UNIVERSITY OF WATERLOO

Secretariat

Senate Graduate and Research Council

Open Session

September 16, 2024

Needles Hall

NH 3318 / Zoom

200 University Avenue West

Waterloo, ON, N2L 3G1

UNIVERSITY OF WATERLOO

Secretariat

2024 09 16 SGRC Meeting Book

2024 09 16 SGRC Meeting Book

Governance Resources

Link to Governance Resources

Open Session

10:30 am	1. Conflict of Interest		
	1.1 Conflict of Interest	Declaration	4
10:35 am	Consent Agenda Motion: To approve or receive for information the items on the consent agenda, listed as items 2-6 below.		
	2. Minutes of June 16, 2024 Meeting		
	2.1 2024-06-17 SGRC Minutes	Decision (SGRC)	5
	3. Research Ethics		
	3.1 CREB & HREB Membership Update [Julie Joza]	Decision (SGRC)	8
	4. Graduate Awards		
	4.1 Graduate Awards [Marianne Simm]		10
	4.1.1 Dean of Engineering Master's Excellence Award (DEMEA) [operating]	Decision (SGRC)	
	4.1.2 Haitham Kamil Graduate Award [trust]	Decision (SGRC)	
	4.1.3 Professor Sofyan Taya Memorial Graduate Scholarship [trust]	Decision (SGRC)	
	4.1.4 Faculty of Engineering Discretionary Graduate Award [operating]	Decision (SGRC)	
	4.1.5 Maks Wulkan Graduate Scholarship [trust]	Information	
	4.1.6 Perimeter Scholars International Award [trust]	Information	
	4.1.7 Women in Mathematics Directed Reading Program Mentorship Award [operating]	Information	
	5. Curricular Submissions		
	5.1 ENV Curricular Report [Phil Bigelow]	Decision (SGRC)	13
	6. RCR Integrity Administrative Guidelines		
	6.1 Research Integrity Guidelines Memo [Ian Milligan]	Information	21

Regular Agenda

	7. Business Arising from the Minutes	Oral/Input	
	7.1 Results of the June 25-28, 2024 E-Vote	Information	22
10:40 am	8. Co-Chairs Remarks	Oral/Information	
11:00 am	9. New Programs		
	9.1 MASc and PhD in Biomedical Engineering [Siva Sivoththaman]	Decision (SEN-R)	24
11:05 am	10. Research Centres and Institutes		
	10.1 Waterloo Centre for Astrophysics (WCA) Renewal [Will Percival]	Decision (SGRC)	
	10.1.1 WCA Progress Report 2024		124
	10.1.2 WCA Renewal Presentation 2024		257
11:10 am	11. 2025 THE Digital Health Conference		
	11.1 THE Health Summit Presentation [Catherine Burns]	Information	264
11:25 am	12. Waterloo Values [Melanie Will]	Oral/Information	
	12.1 Link to Waterloo Values		
	13. Other Business	Oral/Input	
	14. Adjournment	Oral/Input	

Excerpt from Senate Bylaw 1

8. Declarations of conflict of interest

8.01	At the beginning of each meeting of Senate or any of Senate's committees or councils, the chair will call for members to declare any conflicts of interest with regard to any agenda item. For agenda items to be discussed in closed session, the chair will call for declarations of conflict of interest at the beginning of the closed portion of the meeting. Members may nonetheless declare conflicts at any time during a meeting.
8.02	A member shall be considered to have an actual, perceived or potential conflict of interest, when the opportunity exists for the member to use confidential information gained as a member of Senate, or any of Senate's committees or councils, for the personal profit or advantage of any person, or use the authority, knowledge or influence of the Senate, or a committee or council thereof, to further her/his personal, familial or corporate interests or the interests of an employee of the university with whom the member has a marital, familial or sexual relationship.
8.03	Members who declare conflicts of interest shall not enter into debate nor vote upon the specified item upon which they have declared a conflict of interest. The chair will determine whether it is appropriate for said member to remove themselves from the meeting for the duration of debate on the specified item(s).
8.04	Where Senate or a committee or council of Senate is of the opinion that a conflict of interest exists that has not been declared, the body may declare by a resolution carried by two-thirds of its members present at the meeting that a conflict of interest exists and a member thus found to be in conflict shall not enter into debate on the specified item upon which they have declared a conflict of interest. The chair will determine whether it is appropriate for said member to remove themselves from the meeting for the duration of debate on the specified item(s).

University of Waterloo
SENATE GRADUATE & RESEARCH COUNCIL
Minutes of the June 17, 2024 Meeting
[in agenda order]

Present: Sue Ann Campbell, Jeff Casello (co-chair), David Clausi, Robert de Loe, Peter Deadman, Charmaine Dean (co-chair), Mrittika Dreesha, Bernard Duncker, Anna Esselment, Ana Ferrer, Bertrand Guenin, Abhishesh Homagain, Julie Joza, Joseph Meleshko, Marina Mourtzakis, Nicholas Pellegrino, Martin Ross, Marianne Simm, Siva Sivoththaman, Mike Szarka, Tim Weber-Kraljevski (secretary), Kevin White.

Resources/Guests: Elliot Biro, Catherine Burn, Gen Gauthier-Chalifour, Ameen Hussain-Aamir, Maryam Latifpoor-Keparoutis, Alex Lovi, Carrie MacKinnon, Ryan McGuinness, Kate Mercer, Justin Wan, Richard Wikkerink.

Absent: Steven Bednarski, Phil Bigelow *, Alison Hitchens*, Neela Hassan, Ian Milligan* Shirley Tang, Clarence Woudsma. *regrets

Organization of Meeting: Jeff Casello took the chair, and Tim Weber-Kraljevski acted as secretary. The secretary advised that a quorum was present. The agenda was approved without formal motion.

The chair informed members that Council received requests by members of the community under Bylaw 1, section 9.01 to give representations.

Representations
Ameen Hussain-Aamir addressed Council, speaking to sentiments raised by the Muslim community on campus regarding concerns with the University's research partnerships, particularly the partnership with Technion.

Alex Lovi and Elliot Biro addressed Council, speaking to their experience on campus as members of the Jewish community, and to concerns with the recent calls for the University to sever ties with Israeli institutions, specifically with Technion.

The chair thanked those who provided representations.

1. CONFLICT OF INTEREST
No conflicts of interest were declared.

CONSENT AGENDA
The proposed new courses SYDE 620 and SYDE 640 under item 5a. were removed from the consent agenda for discussion, and following concerns raised of possible overlap of courses within the Faculty of Mathematics, Sivoththaman agreed to revise the report from the Faculty of Engineering to remove the approval of the proposed new courses SYDE 620 and SYDE 640.

Council heard a motion to approve or receive for information the items of the consent agenda. Ferrer and Guenin. Carried with one abstention.

2. MINUTES OF THE MAY 6, 2024 MEETING
Council approved the minutes of the meeting as distributed.

3. RESEARCH ETHICS

Council approved the membership update for the Human Research Ethics Board (HREB), as distributed.

4. GRADUATE AWARDS'

Council approved item a. and received items b.-e. for information.

5. CURRICULAR SUBMISSIONS

Council approved item a.-d. on behalf of Senate, as revised.

REGULAR AGENDA

6. BUSINESS ARISING FROM THE MINUTES

The chair informed members that the new Academic Quality Enhancement (AQuE) Committee of Senate was approved by Senate at the May 6, 2024 meeting, and encouraged members interested in being a member of the AQuE Committee to reach out to himself or the secretary.

7. CO-CHAIR'S REMARKS

Dean spoke to the following: protests taken place on campus, Senate's support a taskforce to look at institution agreements, and encouraging members who are interested to participate in the taskforce; and the Bouchard Report from the Advisory Panel on the Federal Research Support System, the plan being developed to restructure the Tri-Agencies, and the efforts within the University to provide feedback within the short timeline that has been allotted to do so, thanking those tasked with undertaking those efforts.

Casello spoke to the following: the increase of the annual support for the Provost's Programs for Black and Indigenous Postdoctoral Scholars and for Interdisciplinary Postdoctoral Scholars from $60,000 to $70,000 in response to recent increases in scholarships by the Tri-Agency; convocation, changes made to address concerns with protests, and thanking those who participated; and thanking Guenin and Bigelow for their service on Council, as their terms as Associate Deans were ending.

8. SGRC AGENDA SUBCOMMITTEE AND SGRC CURRICULUM SUBCOMMITTEE PROPOSAL

Casello spoke to the history of Council restructuring, the concerns of the Associate Deans, Research, and presented the proposal to create two subcommittees of Council. Members discussed: continued concerns of the Associate Deans, Research which they felt the proposal did not address, particularly to have more research focused strategic discussions and to not be involved in approving curricular items; and how large research items are approved by Dean's Council and creating pathways leading to Dean's Council that includes the Research Operations Committee (ROC). Discussion on ROC and the restructuring of Council will be continued at a future meeting.

9. HEALTH FUTURES AND CARE NEXT COALITION

Burns presented on Health Futures, speaking to the vison, core strategy, the community and its focus and collaborations, the connections with the Global Futures Office, and development pathway. Burns also presented on CareNext, speaking to its propose, how it is organized, its three phases, Waterloo's current engagement, and the expected benefits.

Members divided into breakout groups and discussed the following: What health initiatives are members are working on that might advance goals in their Faculty strategic plans, and if they can be tied to the Health Futures vision; how can the CareNext collaboration be a vehicle to advance initiatives in education, research or innovation; and what CoPs are important to develop.

10. OTHER BUSINESS

Dean spoke to Casello's accomplishments as Associate Vice President, Graduate Studies and Postdoctoral Affairs; and thanked him for his service in the role and to Council.

With no further business in the open session, Council moved into confidential session. The only item was the approval of the confidential minutes of the May 6, 2024 meeting, which were approved. There was no other business.

13. ADJOURNMENT

With no further business, the meeting adjourned. The next meeting will be held on Monday, September 16, 2024, 10:00 a.m. to 11:30 a.m. in NH 3318

June 27, 2024

Tim Weber-Kraljevski
Associate University Secretary

Memorandum

To: **Members, Senate Graduate and Research Council (SGRC)**

From: **Julie Joza, Director, Research Ethics**

Date: **August 26, 2024**

Subject: **Membership on Waterloo's Research Ethics Boards**

This memo outlines membership updates that will be taking place on Waterloo's Research Ethics Boards. This update is for consideration and approval by the Senate Graduate and Research Council.

Clinical Research Ethics Board (CREB)

Membership Renewal

Ashraf Sefin, MD, MSc, PhD, CCFP, is renewing for a second term as a clinical physician knowledgeable about clinical trials research. Ashraf's term will continue through to September 30, 2027.

Human Research Ethics Board (HREB)

New Members

David Moscovitch, PhD, Professor, Department of Psychology, provides expertise in clinical psychology. This position on HREB was previously held by Jonathan Oakman whose term is ending. David's term will begin on September 1, 2024, and continue through to August 31, 2025.

Annika Hillebrandt, PhD, Assistant Professor, Department of Psychology will provide expertise in organizational psychology. Annika's position from the Department is currently held by Jonathan Fugelsang who will begin serving as HREB Chair on September 1, 2024. Annika's term will begin on September 1, 2024, and continue through to August 31, 2027.

Clara Colombatto, PhD, Assistant Professor, Department of Psychology will provide expertise in cognitive and social psychology. Clara's term will begin on September 1, 2024, and continue through to August 31, 2027.

Membership Renewal

Douglas Brown, PhD, Professor, Department of Psychology is renewing his term. Douglas's term will continue to August 31, 2027.

Sean Peterson, PhD, Professor, Department of Mechanical and Mechatronics Engineering is renewing his term as a member with expertise in the methods or processes used in engineering/technology research. Sean was a member from October 1, 2020, to September 30, 2023, and had expressed interest in returning following his sabbatical. Shi Cao served in this role for one year. Sean's second term will begin on September 1, 2024, and continue through to August 31, 2027.

Reminder: SGRC members who wish to learn more about the qualifications or academic background and interests of the individual being nominated to the REB are encouraged to contact Julie Joza, Director, Research Ethics at jajoza@uwaterloo.ca. Julie will be pleased to discuss with SGRC members in advance of the meeting the information they may need to help support their decision to recommend the nomination of the individual in becoming a member of the REB. On behalf of the SGRC, the research ethics office retains a copy of each member's CV and expression of interest in being a REB member.

UNIVERSITY OF WATERLOO | Graduate Studies and Postdoctoral Affairs

August 26, 2024

TO: Tim Weber-Kraljevski, Governance Officer

FROM: Heidi Mussar, Associate Director, Graduate Financial Aid & Awards

RE: Agenda items for Senate Graduate & Research Council – September 2024

Items for Approval

a) Dean of Engineering Master's Excellence Award (DEMEA) – operating

The Dean of Engineering Master's Excellence Award, valued at up to $10,000, is available to domestic students who will be registered full time in a master's (MASc) program in the Faculty of Engineering at the University of Waterloo in Fall 2024 or later. A specific award application is not required. Recipients will be selected automatically based on their application for admission to the program, taking into consideration the evaluation criteria of the award. The Faculty of Engineering will select recipients in collaboration with departments as offers of admission are made throughout the year.

The scholarship will be paid in equal instalments across the standard duration of the program, providing they continue to meet the eligibility criteria. In order to continue receiving future instalments, the student must maintain an overall average of 90% in their program.

b) Haitham Kamil Graduate Award – trust

An award valued at $2,000, will be provided annually to a full-time graduate student enrolled in any year of a master's or doctoral program at the University of Waterloo. Selection is based on academic achievement (minimum 70% cumulative average in their current program) combined with involvement in cultural extracurricular activities and contributions to the Iraqi community as determined via their application. Interested students should apply by February 15 using the application found on the Graduate Studies and Postdoctoral Affairs website. This fund is made possible by a donation from Haitham Kamil, a proud alum (MASc'84).

The period of this defined term award will be from 2025 to 2026. The first selection will be made in February 2025 and the last in February 2026. If there are no eligible applicants in a year, the funds may be awarded to an undergraduate student.

c) Professor Sofyan Taya Memorial Graduate Scholarship – trust

A scholarship, valued at $3,000, will be awarded annually to a full-time graduate student enrolled in any research-based master's or doctoral program at the University of Waterloo. Selection is based on academic excellence (80% cumulative average) in their current program combined with demonstrations of leadership and contributions to humanitarian efforts. Interested students should submit an application by October 1 to Graduate Studies and Postdoctoral Affairs. This scholarship is made possible by donations from friends and family of Professor Sofyan Taya, a dedicated researcher, teacher, father and friend taken far too soon.

d) Faculty of Engineering Discretionary Graduate Award – operating

An award created and awarded at the discretion of the Dean of the Faculty of Engineering to support a graduate student for financial assistance for various reasons. Some examples may include:

- Paying for student's tuition as part of a hiring negotiation
- Students who are near to degree completion but for whom other sources of funding are not available, and who are not eligible for bursaries
- Gaps in funding support which may arise from change in supervisor(s)
- Administrative errors/issues
- Funding support offered to facilitate resolutions to complex student cases, particularly in situations where the Faculty/University may have risk exposure

This award will NOT be published in the graduate awards database.

Items for Information

e) Maks Wulkan Graduate Scholarship – trust

This scholarship was originally created in 2020 with a gift of $50,000.
This scholarship is being renewed with a gift of $50,000 with scholarship selection being made in winter 2025. The updated award description is as follows:

A scholarship, valued at up to $50,000, will be provided to one graduate student registered full-time in a doctoral program in the Faculty of Engineering. The scholarship will be paid to the student in equal instalments over the standard program length, as long as they remain registered full time. Selection is based on academic excellence (minimum cumulative average of 80% or equivalent in their current or most recently completed graduate program) combined with an interest in human-factors engineering.
The scholarship will be paid in equal instalments each term for as long as the student is registered full time within time limits of the program (12 terms) and in good academic standing. In the event that a recipient fails to meet the renewal criteria, or completes their degree early, residual funds may be used to offer additional entrance scholarships.

This fund is made possible by a donation from Maks Wulkan, a proud engineering alum (BASc' 97 Electrical) who wants to support graduate students in their research.

f) Perimeter Scholars International Award – trust

Originally established in 2009 to provide students, accepted into the Perimeter Scholars International (PSI) Program, with full financial support for their program. UW would provide tuition scholarships and Perimeter Institute (PI) would provide funding intended to cover expenses related to travel, housing, food, textbooks and reference material, student services fees, and incidental stipends as assessed by PI. Normally, the funding was offered to students for only one year of their program.

The award program is being amended to enhance it by offering a one-year extension. This one-year extension will allow students to complete their course requirements and have two terms to do research in academia and/or internships with partners outside academia under the (co)supervision of an academic supervisor. PSI will have an enrolment target of 35 students. Steady state target will include up to 10 eligible students per year of the 1-year scholarship extension, including the tuition scholarship funded by UW.

g) Women in Mathematics Directed Reading Program Mentorship Award – operating

Originally established in 2022 and amended several times, the Faculty of Mathematics is amending the award effective Fall 2024 with the following changes:

- Division of the Directed Reading Program (DRP) into two distinct tiers:
  - DRP-Reading
  - DRP-Research

The new DRP-Research tier will focus on original research aimed at senior undergraduate mentees. The award value remains the same regardless of which tier the recipient is mentoring under.

- Shortening of the award name to “Women in Mathematics Mentorship Award”

The rest of the criteria remain the same.

FACULTY OF ENVIRONMENT - GRADUATE STUDIES

REPORT TO SENATE GRADUATE & RESEARCH COUNCIL

September 16, 2024

1. **Course revisions for approval**
    a. GEOG
        i. GEMCC 622 – Updating the course description to add a note about possible field trip fees.
        ii. GEOG 656 – Adding GEOG 403 as an anti-requisite as several of the course components are similar.
        iii. GEOG 677 – Updating the course description to add a note about possible field trip fees.

Prior to form submission, review the content revision instructions. For questions about the form submission, contact Trevor Clews, Graduate Studies and Postdoctoral Affairs (GSPA).

Faculty: Environment

Effective date: Term: Fall Year: 2025

Milestone

Note: milestone changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Choose an item.

☐ Inactivate: Choose an item.

☐ Revise: from Choose an item. to Choose an item.

Course

Note: some course changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Complete all course elements below

☐ Inactivate: Complete the following course elements:
Course subject code, Course number, Course ID, Course title

☒ Revise: Complete all course elements below to reflect the proposed change(s) and identify the course elements being revised (*e.g. Course description, Course title*):

Updating the course description to add a note about possible field trip fees.

Course elements (complete as indicated above. Review the glossary of terms for details on course elements)

Course subject code: GEMCC

Course number: 622

Course ID: 014509

Course title (max. 100 characters including spaces): Climate Change, Natural Hazards and Disaster Risk Reduction

Course short title (max. 30 characters including spaces): Climate Change, Natural Hazard

Grading basis: Numerical

Course credit weight: 0.50

Course consent required: Not required

Course description: This course explores the complex links between climate change and natural hazards, and related disasters, including disaster risk reduction as an adaptation strategy. Emphasis is placed on examining these concepts in a developing country context. *eligible for MES (Note: This course may include additional fees

for field trip participation.)

Meet type(s): Seminar Choose an item. Choose an item. Choose an item.

Primary meet type: Seminar

Delivery mode: On-campus

Requisites: N/A

Special topics course: Yes ☐ No ☒

Cross-listed course: Yes ☒ No ☐

Course subject code(s) and number(s) to be cross-listed with and approval status: GEOG 677 (course revision request also submitted by GEOG)

Sections combined/held with:

Rationale for request:

This course contains a field trip component that includes additional fees and instructor plans to continue this in future offerings. The update to the description will provide this information to students so that they take this into consideration during course selection.

Form completed by: Teresa Wilson
Department/School approval date (mm/dd/yy): 04/26/24
Reviewed by GSPA (for GSPA use only) ☒ date (mm/dd/yy): 05/01/24
Faculty approval date (mm/dd/yy): 07/10/24
Senate Graduate & Research Council (SGRC) approval date (mm/dd/yy):

Senate Graduate & Research Council
Graduate Studies Course/Milestone Form

Prior to form submission, review the content revision instructions. For questions about the form submission, contact Trevor Clews, Graduate Studies and Postdoctoral Affairs (GSPA).

Faculty: Environment

Effective date: Term: Fall Year: 2025

Milestone
Note: milestone changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Choose an item.

☐ Inactivate: Choose an item.

☐ Revise: from Choose an item. to Choose an item.

Course
Note: some course changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Complete all course elements below

☐ Inactivate: Complete the following course elements:
Course subject code, Course number, Course ID, Course title

☒ Revise: Complete all course elements below to reflect the proposed change(s) and identify the course elements being revised (*e.g. Course description, Course title*):

Adding GEOG 403 as an anti-requisite as several of the course components are similar.

Course elements (complete as indicated above. Review the glossary of terms for details on course elements)

Course subject code: GEOG

Course number: 656

Course ID: 016420

Course title (max. 100 characters including spaces): Eutrophication: From Process to Water

Quality Management

Course short title (max. 30 characters including spaces): Eutrophication- Water Quality

Grading basis: Numerical

Course credit weight: 0.50

Course consent required: Not required

Course description: Eutrophication, caused by excess nutrients (phosphorus and nitrogen) entering water bodies, results in nuisance and harmful algal blooms, and is a major global threat to water quality and water security. This course explores eutrophication drivers, pressures and impacts on the quality of freshwater systems, from watershed to global scales. Students will learn about the sources and biogeochemical cycling of nutrients along the aquatic (stream-river-lake) continuum, and ecological responses in receiving water bodies. Environmental thresholds for setting water-quality standards and nutrient criteria will be discussed. Students will learn about agricultural beneficial management practices and wastewater management to reduce nutrient inputs to freshwaters. Students will examine the benefits and challenges of sustainable nutrient stewardship in combatting eutrophication, and learn about how this knowledge is used in water-quality management, through international examples.

Meet type(s): Lecture Lab Seminar Choose an item.

Primary meet type: Lecture

Delivery mode: On-campus

Requisites: **Antireq: GEOG 403**

Special topics course: Yes ☐ No ☒

Cross-listed course: Yes ☐ No ☒

Course subject code(s) and number(s) to be cross-listed with and approval status:

Sections combined/held with:

Rationale for request:

Several of the course components have overlap with GEOG 403, so the instructor thinks it is appropriate to add an anti-requisite to that course.

Form completed by: Maria Strack
Department/School approval date (mm/dd/yy): 04/26/24

Reviewed by GSPA (for GSPA use only) ☐ date (mm/dd/yy): 05/01/24
Faculty approval date (mm/dd/yy): 07/10/24
Senate Graduate & Research Council (SGRC) approval date (mm/dd/yy):

Prior to form submission, review the content revision instructions. For questions about the form submission, contact Trevor Clews, Graduate Studies and Postdoctoral Affairs (GSPA).

Faculty: Environment

Effective date: Term: Fall Year: 2025

Milestone

Note: milestone changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Choose an item.

☐ Inactivate: Choose an item.

☐ Revise: from Choose an item. to Choose an item.

Course

Note: some course changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Complete all course elements below

☐ Inactivate: Complete the following course elements:
Course subject code, Course number, Course ID, Course title

☒ Revise: Complete all course elements below to reflect the proposed change(s) and identify the course elements being revised (*e.g. Course description, Course title*):

Updating the course description to add a note about possible field trip fees.

Course elements (complete as indicated above. Review the glossary of terms for details on course elements)

Course subject code: GEOG

Course number: 677

Course ID: 014509

Course title (max. 100 characters including spaces): Climate Change, Natural Hazards and Disaster Risk Reduction

Course short title (max. 30 characters including spaces): Climate Change, Natural Hazard

Grading basis: Numerical

Course credit weight: 0.50

Course consent required: Not required

Course description: This course explores the complex links between climate change and natural hazards, and related disasters, including disaster risk reduction as an adaptation strategy. Emphasis is placed on examining these concepts in a developing country context. *eligible for MES. (Note: This course may include additional fees for field trip participation.)

Meet type(s): Seminar Choose an item. Choose an item. Choose an item.

Primary meet type: Seminar

Delivery mode: On-campus

Requisites: N/A

Special topics course: Yes ☐ No ☒

Cross-listed course: Yes ☒ No ☐

Course subject code(s) and number(s) to be cross-listed with and approval status: GEMCC 622 (course revision request also submitted by GEMCC)

Sections combined/held with:

Rationale for request:

This course contains a field trip component that includes additional fees and the instructor plans to continue this in future offerings. The update to the description will provide this information to students so that they take this into consideration during course selection.

Form completed by: Maria Strack
Department/School approval date (mm/dd/yy): 04/26/24
Reviewed by GSPA (for GSPA use only) ☒ date (mm/dd/yy): 05/01/24
Faculty approval date (mm/dd/yy): 07/10/24
Senate Graduate & Research Council (SGRC) approval date (mm/dd/yy):

MEMORANDUM

To: **Senate Graduate and Research Council**

From: **Ian Milligan, Associate Vice-President, Research Oversight and Analysis**

Date: **September 16, 2024**

Subject: **Updating the Integrity in Research Administrative Guidelines**

- For Information -

The University of Waterloo's "Integrity in Research Administrative Guidelines" (hereafter "Guidelines") have been updated in July 2024 to reflect changes made to the *Tri-Agency Framework on the Responsible Conduct of Research*.

These Guidelines apply to University of Waterloo staff members, graduate and undergraduate students, post-doctoral fellows, and to anyone else not covered by the Memorandum of Agreement (MOA) between the Faculty Association of the University of Waterloo (FAUW) and the University of Waterloo, and who is doing research under the auspices of the university.

It is a requirement to update university guidelines into compliance with this Framework as a condition of receiving Tri-Agency funds. This brings the Guidelines into harmony with the UW/FAUW MOA Article 14 on Research Integrity.

In addition to housekeeping changes, more significant changes include:

- Updating the definition of "falsification" (2.2.2) and "destruction of research data (2.2.3) or records" to reflect new federal language.
- Clarifying the process by which allegations that involve conduct that involved at another university will be addressed (4.1)
- Explicitly allowing for anonymous allegations, noting that such "allegations will be considered if accompanied by sufficient information to enable the assessment of the allegation and the credibility of the facts and evidence on which the allegation is based, without the need for further information from the complainant."

The guidelines are available on the website at https://uwaterloo.ca/research/integrity-research-administrative-guidelines.

From: UW Secretariat Senate
Cc: Tim Weber-Kraljevski
Subject: RE: SGRC E-Vote June 2024 -
Date: Friday, June 28, 2024 4:15:20 PM
Attachments: image001.png
image002.png

Members of the Senate Graduate & Research Council,

Voting has now closed on the e-vote and quorum was achieved. The motion to approve the new courses SYDE 620 and SYDE 640 on behalf of Senate, as presented, carried. Sivoththaman and Dreesha.

Thank you to all who voted,
Tim

Tim Weber-Kraljevski
Associate University Secretary
Secretariat

UNIVERSITY OF WATERLOO

The University of Waterloo acknowledges that much of our work takes place on the traditional territory of the Neutral, Anishinaabeg and Haudenosaunee peoples. Our main campus is situated on the Haldimand Tract, the land granted to the Six Nations that includes six miles on each side of the Grand River. Our active work toward reconciliation takes place across our campuses through research, learning, teaching, and community building, and is centralized within the Office of Indigenous Relations.

From: UW Secretariat Senate <senate@uwaterloo.ca>
Sent: Tuesday, June 25, 2024 3:29 PM
Cc: Tim Weber-Kraljevski <tweber@uwaterloo.ca>
Subject: SGRC E-Vote June 2024 -

Members of the Senate Graduate & Research Council,
At the June 17, 2024 SGRC meeting, the approval of the new courses SYDE 620 and SYDE 640 were removed from the Engineering report that was part of the consent agenda due to concerns raised from the Faculty of Mathematics. The Faculties of Mathematics and Engineering have now connected offline to discuss the concerns and have agreed to put these items forward for approval again as they were presented at the June meeting. They are being brought forward for approval via e-vote to ensure that they can be added to the Fall 2024 calendar.
The material is available at the following link: Engineering June 2024 SGRC E-Vote - SYDE 620 and 640.pdf
MOTION: To approve the new courses SYDE 620 and SYDE 640 on behalf of Senate, as presented.
REQUEST: Please respond to this email indicating your support, or your vote against, or abstention. The first person to respond in support of the motion will be considered the mover, and the second

person to respond will be considered as the seconder.

Kindly reply with your vote **before 12:00 noon on Friday, June 28, 2024**.

For any questions, please contact me directly.

Thank you,

Tim

Tim Weber-Kraljevski
Associate University Secretary
Secretariat
University of Waterloo
3060 Needles Hall – 200 University Ave. West
Waterloo ON N2L 3G1

UNIVERSITY OF WATERLOO

The University of Waterloo acknowledges that much of our work takes place on the traditional territory of the Neutral, Anishinaabeg and Haudenosaunee peoples. Our main campus is situated on the Haldimand Tract, the land granted to the Six Nations that includes six miles on each side of the Grand River. Our active work toward reconciliation takes place across our campuses through research, learning, teaching, and community building, and is centralized within the Office of Indigenous Relations.

UNIVERSITY OF WATERLOO

NEW GRADUATE PROGRAM PROPOSAL*

OF

MASc AND PhD

IN

BIOMEDICAL ENGINEERING

Submitted to the
Ontario Universities Council on Quality Assurance

VOLUME I - PROPOSED BRIEF

NOVEMBER 2023

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1. INTRODUCTION

1.1 Brief Listing of the Program

The Departments of Systems Design Engineering (SYDE), Electrical and Computer Engineering (ECE) and Mechanical and Mechatronics Engineering (MME) seek to establish Doctor of Philosophy (PhD) and research-based Master of Applied Science (MASc) degrees in Biomedical Engineering (BME).

The PhD and MASc programs, which will be four and two years in duration, respectively, include new and existing courses that will engage students in the acquisition of high-level technical knowledge and methods. The program is research-focused on biomedical engineering, with complementary emphases on professional engineering and explicit design practice. In addition to an independent thesis, students will develop professional and transferable skills in modules for milestone-based activities in the proposed Professional Attributes and Competence Enhancement (PACE) Module. The program will include a strong model of engaged thesis advisers forming active interdisciplinary advisory and examination committees.

The initiative builds on several existing research training programs such as, NSERC-CREATE (Global Biomedical Technology Research and Innovation, led by Prof. Catherine Burns), N-GENIUS (Next-Generation Innovations in Ultrasonics, led by Prof Alfred Yu) etc. The graduate education programs will be delivered on campus in Waterloo, Ontario, using online technology and field-based locations, as needed, for optimal student experience. The tuition fees for the programs will be consistent with the fees of the existing graduate programs in the Faculty of Engineering as outlined in the UW Finance fee schedule.

1.2 Method Used for Preparation of the Brief

While the intention to create BME graduate programs stems back to the initiation of the BME undergraduate program more than a decade ago, this version of the proposal was initiated in Winter 2021 after the Dean of the Faculty of Engineering and the Chair of Systems Design Engineering department engaged with the departments of Electrical and Computer Engineering and Mechanical and Mechatronics Engineering.

The intent of those meetings was to present the rationale for a new approach to a graduate program and to seek partnership from the three departments. Following the consultations, the three departments recommended two faculty members each to serve on an interdisciplinary task force. Upon request, department chairs from the Department of Kinesiology and Health Sciences in the Faculty of Health and the School of Optometry and Vision Science in the Faculty of Science also appointed one representative each to the task force. The composition of the task force was based on consultations with students and alumni that showed a preference for a program that is engineering-based and strongly interdisciplinary.

The work of the BME Graduate Program Task Force built on prior analysis of national, graduate-level BME curricula undertaken by SYDE faculty in fall 2020. During the latter half of 2021, a

subset of the Task Force worked on defining curriculum and admissions requirements, with careful consideration of how to engage students with prior degrees that may provide disparate preparation for the graduate program. The Task Force also consulted industry stakeholders, who communicated the importance of transferable skills and motivated the vision for the Professional Attributes and Competence Enhancement (PACE) modules.

To establish the financial model of the program, the SYDE chair worked with staff from the Dean of Engineering office to conceptualize a program involving three departments in an administrative partnership and managed by BME but consist of students training in faculty labs across departments, schools, and faculties. Teaching duties will be shared amongst the partners and costs reimbursed to participating departments.

1.3 Objectives of the Program (QAF 2.1.2.1)

The primary objective of the proposed BME Graduate Program is to produce comprehensively trained and technically outstanding master's and doctoral graduates in biomedical engineering who are prepared to excel and lead in all sectors of society—postsecondary education, industry, not-for-profit, government and more. Our objective is to align the University of Waterloo's research strengths and output with important global challenges in the biomedical sector.

The program aligns with the University of Waterloo Strategic Plan and Strategic Mandate Agreement, as well as these three Signature Commitments described in the Strategic Plan which are: 1. Align our research strengths deliberately with important global challenges, 2. Lead globally and nationally at the interface of society, health and technology, and 3. Be a global powerhouse for commercializing research, developing new enterprises, and supporting business growth.

1) The proposed program strengthens the University's commitment to align research strengths with important global challenges, specifically in the area of health technologies. Developing talent for a complex future and advancing research for global impact are also key to Waterloo's strategic plan themes. Health is an area that is enormously complex, with great need for global education and research; this program's contributions will be at the forefront of biomedical engineering where technology and design contribute to the solution to increasingly complex, real-world challenges. Examples include rehabilitation robotics, tissue engineering, leading edge imaging technologies, and multifaceted systems approach to deal with pandemics (e.g., COVID-19).

2) Leading globally and nationally at the interface of society, health, and technology is something we already do at Waterloo. The program will provide a focal point by contributing directly to this goal. By leveraging Waterloo's research strengths in technology and the social, economic, biological and environmental determinants of health, Waterloo

will lead in securing healthy futures for local and global communities. It is salient to this goal that the proposed BME graduate program will be administratively led by SYDE which is known for its extensive interdisciplinary endeavors. The program will establish a structure within which interdisciplinary learning objectives can be achieved for students seeking the BME credential. Although based in Engineering, the program's proposed partnership structure and interdisciplinary nature exploits existing cross-faculty, interdisciplinary research teams that apply their disciplinary strengths to problems of societal importance. By strengthening existing partnerships, Waterloo can attract more talent at all levels – faculty, researchers, postdoctoral scholars, and graduate students. In this way, the program provides a venue for attracting, developing, and retaining tomorrow's research and industry leaders, including outstanding scholars from around the world.

3) The University of Waterloo has a globally recognized entrepreneurial ecosystem, with many notable alumni founders coming from the Faculty of Engineering. The BME graduate programs have tremendous potential to combine Waterloo's entrepreneurial resources with groundbreaking healthcare technologies that improve quality of life. Several Waterloo faculty members with research interest in biomedical engineering have commercialized their research, are working with an industry partner, and/or started a business venture alongside their research work. There are graduate students currently enrolled in the partner programs developing their own ventures in the biomedical engineering field. For example, a graduate of the first BME undergraduate class and current SYDE PhD student, developed an app to improve the workflow of vaccine clinics. Interest in commercializing research is demonstrated among students in the BME undergraduate program. Capstone design teams often continue to work on their projects beyond the program requirements. In 2022, team Petalos developed a prototype for a novel gastrointestinal modular endoscope that reduces contamination for better clinical outcomes. The team has entered and won several pitch competitions to obtain funding to keep the project going. Advancing to BME graduate program would give interested students the opportunity to continue developing their research training while working towards commercializing their project.

1.4 Admission Requirements (QAF 2.1.2.5)

Admission to the BME graduate program is through direct application, managed by the BME program. While the successful applicant will be registered in the BME program, students will have connection(s) to their advisor's (or advisors') home department(s), where they will conduct their research and be allocated lab and space resources. The admitting advisor must be a BME faculty member. Due to the extensive interdisciplinary nature of BME, students with diverse academic backgrounds are expected to apply, and the admission requirements will take

this into account. The curriculum, guided by the BME Graduate Program Committee, ensures the intended learning outcomes are achieved.
Below is a summary of the admission requirements:

- MASc applicants must have completed a bachelor's degree (or equivalent) in any field of engineering or a related science discipline at a recognized institution with a minimum 80% overall average.
- PhD (regular entry) applicants will have completed a research thesis-based master's degree (or equivalent) in engineering, applied science, or science from a recognized institution with at least an overall 80% average and documented evidence of potential to excel in PhD studies and research.
- For both MASc and PhD applicants, English Language Proficiency (ELP) requirements of the Faculty of Engineering must be met. (Appendix B and C).
- Both MASc and PhD applicants who are deemed by the graduate coordinator, BME graduate program director, Admissions Committee or intended advisor to have an inadequate depth of technical BME background may be directed to take additional foundational courses, to be specified at the time of admission.
- PhD (direct from Honours BME undergraduate entry) applicants require a minimum overall average of 80% in a BME program at the undergraduate level and clear evidence of excellent potential to excel in PhD studies and research. Substantial research experience is expected.

The full description of the admission requirements is in Appendix B for MASc and Appendix C for PhD.

Transfer students from other Waterloo graduate research programs applying to enter the BME graduate program by completing a Change of Program form will be considered on a case-by-case basis by the BME Admissions committee, and must meet the following additional requirements:

- be in good academic standing with their current program;
- have met the BME minimum academic admission requirements above;
- have a research focus on BME, as determined by the BME graduate program director;
- ensure the comprehensive exams and the curriculum requirements will be met; (core, field, two electives, and PACE Modules) by taking additional courses, if required. Exceptions may be granted as described below.

If a student enters the program with substantial BME experience, they may seek recognition for that work in lieu of completing some of the program requirements. Recognition is granted following approval, first by the student's supervisor then by the BME graduate program director who makes the final decision. This exception to waive course requirements will not lower the

total number of courses required.

1.5 Structure

To achieve an MASc or PhD degree in the BME program, students will have successfully completed relevant courses, participated in modules designed to train and enhance professional competencies, attended, and presented at a regular seminar series, and completed a research thesis. These activities ensure the Graduate Level Expectations (GDLE) for both MASc and PhD are met.

For both the MASc and PhD programs, students must successfully complete at least one of the three core courses (BME 601, BME 602, or BME 603) that take a quantitative approach to broad aspects related to human physiology and BME, at least one field-specific course relevant to their research, and at least two electives (Appendix H). Further details on the course requirements, including how they vary between degrees and based on the educational background of the student, can be found in section 4.

Students who have completed the MASc program in BME at Waterloo may apply and continue to the doctoral program. In this situation, students will have already completed the core course requirements (one of BME 601, BME 602, or BME 603), a field-specific course and two electives as part of their master's degree requirements. To satisfy the PhD program requirements, these students must complete a total of four courses including a) one core course requirement (one of BME 601, BME 602 or BME 603 that was not completed as part of the MASc in BME program); b) two additional electives; c) an additional field-specific course if they have switched fields between MASc and PhD. PhD candidates who qualify to enter directly from an Honours undergraduate program must take two core courses, one field-specific course, and four electives to establish an equivalent level of depth.

The program courses are supplemented by the milestone-based[1] PACE Module. In these modules, both MASc and PhD students will receive training in the areas of research design and planning, academic integrity, professional presentation, and scientific writing. PhD students will receive additional training in developing research plans and in writing grant and business proposals.

The program requirements include deadlines for completing milestones (e.g., coursework, research presentation at the regular seminar series, dissertation, and defense) to aid in keeping students on track to complete degrees within the University's expected timeframe. The standard degree lengths are two and four years for MASc and PhD, respectively.

A summary is provided below for different student groups admitted to the program:

[1] Milestones are defined as "non-course degree requirements (e.g., thesis, comprehensives, master's research paper) that a student must complete toward degree progress in order to graduate."

Student admitted from outside of UW		
	MASC admission	PhD admission
Courses:	1 of BME 601, 602, 603	1 of BME 601, 602, 603
	1 Field related course	1 Field related course
	2 Electives	2 Electives
Milestones:	PACE	PACE
		Comprehensive Exam
	Seminar attendance and presentation	Seminar attendance and presentation
	Thesis Defense	Thesis Defense
Student admitted to PhD program having completed UW Masters in BME		
Courses:		1 Additional course from BME 601, 602 or 603 (not taken in Master's program)
		1 Field related course if PhD field differs from Master's
		2 Electives with additional field course; or 3 Electives
Milestones:		As above
Student admitted to PhD program from Honours BME undergraduate program		
Courses:		2 of BME 601, 602, 603
		1 Field related course
		4 electives
Milestones:		As above

The administrative structure and curricular oversight of the BME Graduate programs are described in Section 4.6. The structure includes an administrative department home for program staff, a representative curriculum program committee, an oversight policy committee of core department chairs, and a process for faculty membership in the program from across multiple departments and Faculties.

1.6 Program Content

Biomedical engineering is the application of engineering principles and design concepts to medicine and biology for healthcare purposes. The field seeks to close the gap between engineering and medicine, combining the design and problem-solving skills of engineering with medical and biological sciences to advance healthcare treatment, including diagnosis, monitoring, and therapy.[2]

With the interdisciplinary strengths of faculty from the largest engineering school in Canada, the Waterloo BME graduate program will be at the leading edge of the discipline. Waterloo has deep expertise in five defined research fields (described in section 1.9) that cover the span of BME and represent Waterloo's strengths and societal needs. The proposed curriculum provides

[2] Enderle and Bronzino, Introduction to Biomedical Engineering

for training and instruction in the discipline's state-of-the-art by leaders in said research fields using a combination of the following:

- one core course providing a quantitative engineering approach to human physiology;
- one field-specific course; and
- two electives providing greater depth related to the student's research topic.

A series of experiences described as the Professional Attributes and Competence Enhancement (PACE) Module is a particularly important component to provide professional and transferable skill development that prepares students for careers outside and inside academia. This learning opportunity builds on the University of Waterloo's strong history of partnering with industry to establish relevance and translate research to real-world contexts and potential commercialization.

Consistent with most, if not all, graduate training programs in engineering in Canada, the major research requirement for degree completion is a research thesis examined and approved by an examination committee. The examination will also require an oral defense at both the master's and PhD levels. The thesis research, writing, and overall progress is overseen throughout the program by an advisor and a committee of faculty.

1.7 Mode of Delivery

All graduate courses will be designed and developed by Waterloo faculty, delivered in person on campus, and supported by Waterloo's learning management system (LMS).

Activities related to the PACE Module milestones, such as the regular seminar series and research days, will be conducted in person on campus. The PACE Module milestones will be directed by the BME graduate program director with the support of a new staff member.

Given our recent experiences with the COVID-19 pandemic, we are prepared to deliver training using online teaching tools. In addition to online learning during emergencies and for flipped classroom-style activities, certain components of the program will be enhanced by global advances in online communications that allow us to connect students to research leaders and clinicians globally. For example, virtual site visits to and from distant locations, presentations from higher-profile guest speakers and more extensive interactions with stakeholders and clinicians are all possible with digital technology.

1.8 Assessment of Teaching and Learning (QAF 2.1.2.4)

Assessment of teaching and learning will be conducted at the student and program levels. The BME graduate program will be assessed at the program level by the BME Graduate Program Committee and BME graduate program director. As part of this assessment, the Program Committee will review statistics, such as program performance versus learning objectives, student success rates and teaching evaluations – as provided through both student perception surveys and peer-assessment of teaching. It will identify opportunities to improve performance,

such as enriching course content or teaching. In addition to the information noted above, thesis supervisors, course faculty and the BME Program Committee will note any other student achievements and successes that are relevant to the program.

Performance indicators that will be considered by the BME Program Committee will include:

- Applications to and enrollment within the BME graduate program;
- Student evaluations of PACE Module milestones, core and field courses;
- NSERC and CIHR Scholarships and Graduate Student Awards won by students.
- BME student graduation rates;
- Surveys of alumni;
- Surveys of employers/industry partners; and
- Publications and conference presentations of BME students.

At the student level, there will be the following eight types of activities with assessments:

a) Required core courses, field-specific elective courses, and elective courses: Students will be assigned a grade based on typical assessment methods used in other graduate courses, such as papers, reports, tests, projects, and presentations.
b) Comprehensive background exam (Comprehensive Exam I (Background); PhD students only) at the end of year one.
c) Thesis proposal defense: Typically completed after year two for PhD students (Comprehensive Exam II (Proposal)) and at approximately year one for master's students.
d) End-of-term reports: For both MASc and PhD students, reports include their self-reflection on their own research and professional development, as well as supervisors' evaluation of progress and individual development. Reports are completed online.
e) Annual committee assessment: Completed by the advisory committee outlined below, the assessment evaluates research progress and quality based on an oral presentation. For full-time master's students, the annual assessment is a one-time proposal defense but for part-time master's students, assessments may be conducted annually.
f) Written thesis or dissertation: Explicitly presents the student's individual contribution(s) to the field. For PhD students, the originality of the contribution is also assessed.
g) Oral thesis defense: Evaluated by the committee outlined below.
h) PACE Module milestones completion: See section 4.4 for details.

Refer to Appendix E and Appendix F for the list of methods for assessing student achievement of the intended program learning outcomes and GDLEs.

For the PACE Module milestones, students will be assigned credit/no credit based on whether they complete each component. The components of the module include presenting research proposals and results, drafting research plans, writing mock grants or business proposals, and more. Participation in these activities can also include providing critical, constructive feedback to other students on their work and performance.

For each student, research will be mentored and assessed by an Advisory Committee that is appointed at the end of year 1 for PhD students and during year 1 for Master's students. The Advisory Committee will consist of the members of the Examining Committee except for the PhD external examiner. The Advisory Committee will conduct the comprehensive examinations (if applicable), consider the thesis proposal, evaluate annual research progress and results, and ultimately conduct the thesis defense. At the defense, the written thesis and the performance of the student during the oral defense will be considered.

Annual advisory committee meetings will be required and documented. The first annual committee meeting may include the Comprehensive Exam I (Background) for PhD students. For master's students, the first annual meeting will be the proposal defense.

At the master's level, the composition of the Advisory Committee will consider the required expertise needed to support and evaluate the thesis research. Co-supervision is an option. The Advisory Committee shall be comprised of at least: one tenured or tenure track faculty member from the BME graduate program who will be the student's supervisor(s); an additional tenured or tenure track BME graduate faculty member; and at least one additional examiner who is not a BME faculty member (but may be from a department with BME faculty members) and whose expertise can support the evaluation of the Master's thesis... Consistent with the Faculty of Engineering requirements, a maximum of one committee member with an adjunct appointment or emeritus status is permitted. The University is currently considering changes to the membership of advisory committees, potentially allowing non-voting committee members to provide advice to students as they research. As such changes come into effect they will be adopted as appropriate.

For PhD students, the Examining Committee consists of a minimum of five voting members including the external examiner, with internal members representing at least two different departments or schools. The PhD Examining Committee must follow the Faculty of Engineering requirements and include the following members:

- External examiner (not included in annual meetings, only for the final defense)
- Supervisor or co-supervisors (at least one must be a BME faculty member)
- Internal members (2 BME program faculty members)
- Internal-external member (not a BME faculty member but may be from a department with BME faculty)

Optionally, additional BME program faculty member(s) can be on the committee.

1.9 Fields in a Graduate Program

Both the Master's and PhD programs are composed of the following research fields:

A. Biomaterials, tissue engineering and drug delivery
   - includes regenerative medicine.

B. Biomechanics and rehabilitation
   - includes both solid and fluid biomechanics.

C. Biomedical signals and devices
   - includes EEG, EMG, brain-computer interfaces and neuroscience applications, micro and nano devices.

D. Biomedical imaging technology
   - includes ultrasound, X-ray, MRI, optics, microwave.

E. Biomedical informatics
   - includes AI, big data, population, and health system studies.

This scope has been established by the BME Task Force in consultation with stakeholders. It reflects traditional or typical fields of BME while incorporating Waterloo's globally recognized strengths in biomechanics, medical imaging, and artificial intelligence, as well as addressing growth areas needed to serve societal needs now and into the future.

2. HUMAN RESOURCES

The following sections provide significant evidence that the BME-associated faculty have the established research programs and technical expertise that will sustain the innovation and intellectual activities of a dedicated BME graduate program. Eighty-two percent (82%) of faculty have Approved Doctoral Dissertation Supervisor Status (ADDS) to sole-supervise PhD students. On average, the BME-related faculty have supervised 27 students at the master's, PhD, and PDF levels over their career. To become a faculty member associated with the BME graduate program, an application process will be implemented as described in section 2.1.

The investment in faculty to focus on BME is long-standing across multiple departments, within and beyond engineering, where multiple faculty members in each traditional discipline have focused on biomedical applications. For example, dating back to 1988, graduate students have completed graduate theses with a biomedical focus. BME topics have long been the focus of faculty and graduate student research interest in Engineering. Rapid advances in health and engineering have created significant research interest in the BME field. The quality of faculty and their research output is described in section 2.6.

The investment in biomedical faculty significantly accelerated in 2011 with the creation of Waterloo's interdisciplinary Centre for Bioengineering and Biotechnology (CBB). In 2014, Waterloo established Canada's second BME undergraduate degree program and hired two tenure-track and one lecturer position in that year. Significant investments in BME-focused faculty have continued in the Faculty of Engineering. In SYDE, two BME faculty positions were

filled in 2022 and two remained to be filled and are budgeted for hire in 2024. As the administrative home for both the BME undergraduate and graduate programs, SYDE is financially responsible for these hires and direct costs to the MASc and PhD programs only occur for service teaching. Additionally, other departments at the University of Waterloo have recently hired or are recruiting faculty with BME-related research interests (Appendix G).

Staff human resources are a critical element of the planned program success. Staffing levels are based on existing Engineering graduate programs and leveraging shared human resources with SYDE. A Graduate Program Manager will be hired to jointly support the BME and SYDE Graduate Offices. Their duties will include content and delivery of the PACE Module milestones in partnership with the Director. The BME Graduate Program Coordinator will be hired to support the coordination of the administrative program work including recruiting, admissions, advising, and approvals related courses, theses, defenses, and milestones. As the number of students increases additional staff for these duties will be added. For management, financial assistance, communication, and reception roles, existing SYDE staff will be used for efficiency.

2.1 List of Faculty by Field

Table 1 demonstrates the strength and the significant degree of involvement of the faculty complement participating in each BME field of the graduate program(s). The list includes the faculty from the three administrative partner departments and those who are expected to be involved in thesis supervision. A subset of CVs is provided in Volume II.

- There are 42 full-time associated faculty members, with one lecturer, 9 at the assistant professor level, 9at the associate professor level and 23 at the professor level.
- Currently, there are two vacant positions that are expected to be filled in 2024.
- Membership as a faculty member for the BME graduate program will be for five years automatically renewed for an additional five years. The BME Program Committee will consider faculty applications based on recent research activity, publications, and graduate advising. Eligibility relies on engagement in BME related research.
- Only faculty with Approved Doctoral Dissertation Supervisors (ADDS) can sole-supervise PhD students. Applications will be considered from any department on campus regardless of whether that department is an administrative member of the program. There are several lecturers with directly applicable expertise that might serve as master's advisers or on PhD committees.
- Faculty members in administrative partner departments are not automatically members of the BME Program Committee. BME research is a requirement for membership in the program's advising faculty but licensure as a practicing engineer is not.
- Faculty members can participate in the BME graduate program and committees even if their home faculty or department is not formally participating.
- While cross-appointed professors from outside of Engineering are expected to play a substantial role as co-supervisors, adjunct professors, clinical professors, or emeritus professors are not expected to play a substantial role in student supervision while they may participate by supporting research.

- No faculty members cross-appointed from other universities have been identified at this time, however, we are open to the inclusion of faculty in the future whose contributions would have an impact on the quality of the program through substantive involvement, including clinical faculty.

TABLE 1: Faculty Members from the Core Supporting Departments (ECE, MME, SYDE)[4]

				Research Fields[3]				
Faculty Name	**Rank[2]**	**Dept [1]**	**Supervisory privilege**	**A**	**B**	**C**	**D**	**E**
Eihab Abdel-Rahman	Professor	SYDE	PhD, MASc		x	X		
Arash Arami	Asst. Professor	MME	PhD, MASc		x	X		x
Catherine Burns	Professor	SYDE	PhD, MASc					X
Naveen Chandrashekar	Assoc. Professor	MME	PhD, MASc		X			
David Clausi	Professor	SYDE	PhD, MASc				X	
Duane Cronin	Professor	MME	PhD, MASc	x	X			
Kerstin Dautenhahn	Professor	ECE	PhD, MASc					X
Chris Eliasmith	Professor	SYDE	PhD, MASc		x	X		x
Paul Fieguth	Professor	SYDE	PhD, MASc				X	
Baris Fidan	Professor	MME	PhD, MASc		x	X		x
Maud Gorbet	Professor	SYDE	PhD, MASc	X	x			
Parsin Haji Reza	Assoc. Professor	SYDE	PhD, MASc			x	X	
Jennifer Howcroft	Lecturer	SYDE	MASc only		X	x		x
Karim Karim	Professor	ECE	PhD, MASc				X	
Behrad Khamesee	Professor	MME	PhD, MASc			X		x
HJ Kwon	Assoc. Professor	MME	PhD, MASc				x	X
Fue-Sang Lien	Professor	MME	PhD, MASc		X			x
Ewen MacDonald	Assoc. Professor	SYDE	MASc only			X		
Nima Maftoon	Asst. Professor	SYDE	MASc only		x	X		
Veronika Magdanz	Asst. Professor	SYDE	MASc only	X		x		
Stewart McLachlin	Asst. Professor	MME	PhD, MASc		X	x		
John McPhee	Professor	SYDE	PhD, MASc		X	x		
Sushanta Mitra	Professor	MME	PhD, MASc	x		X		
Kevin Musselman	Assoc. Professor	MME	PhD, MASc	x		X		
Chrystopher Nehaniv	Professor	SYDE	PhD, MASc			x		X
Richard Nuckols	Asst. Professor	SYDE	MASc only		X	x		
Zhao Pan	Asst. Professor	MME	PhD, MASc		X	x		x
Sean Peterson	Professor	MME	PhD, MASc		X			

				Research Fields[3]				
Faculty Name	**Rank[2]**	**Dept [1]**	**Supervisory privilege**	**A**	**B**	**C**	**D**	**E**
Mahla Poudineh	Asst. Professor	ECE	MASc only			X		
Carolyn Ren	Professor	MME	PhD, MASc	x	X	x		
Bryan Tripp	Assoc. Professor	SYDE	PhD, MASc		x	X		x
James Tung	Assoc. Professor	SYDE	MASc only		X	x		x
Mihaela Vlasea	Asst. Professor	MME	PhD, MASc			X		
Thomas Willett	Assoc. Professor	SYDE	PhD, MASc	X	X			
Alexander Wong	Professor	SYDE	PhD, MASc				x	X
Yimin Wu	Asst. Professor	MME	PhD, MASc	x		X		x
Liang-Liang Xie	Professor	ECE	PhD, MASc			x		X
Serhiy Yarusevych	Professor	MME	PhD, MASc		X			
Mustafa Yavuz	Professor	MME	PhD, MASc		X			
John Yeow	Professor	SYDE	PhD, MASc	x		X		x
Alfred Yu	Professor	ECE	PhD, MASc				X	
John Zelek	Assoc. Professor	SYDE	PhD, MASc		x	X		
Totals				9	12	4	7	18

1. This is the home department of the faculty member associated with the program under review.
2. Only those faculty members who are on the Approved Doctoral Dissertation Supervisor (ADDS) list can supervise PhD students.
3. Quality council approved BME fields of study as listed in Section 1.9. (A: Biomaterials, tissue engineering and drug delivery, B: Biomechanics and rehabilitation, C: Biomedical signals and devices, D: Biomedical imaging technology, E: Biomedical informatics), (X: primary research field, x: secondary research field).
4. The faculty member information was collected in Winter 2022

2.2 External Operating Research Funding

Table 2 presents the external and internal research funding by source received by the core faculty, who are listed in Table 1, for the past seven years. Table 2 illustrates that the level of funding is substantial from both public and private sources. The support for graduate students is already established. The level of funding has increased over time from all sources, demonstrating growth and excellence.

TABLE 2

Operating Research Funding[1] ($) by Source and Fiscal Year						
Fiscal Year[2]	**Tri-Agency[a]**	**Public Sector and Non-Profit Funding[a]**	**Private Sector Funding[a]**	**Internal Awards[a,b]**	**Equipment Awards**	**Total**
2015/16	$2,845,040	$1,193,756	$1,257,251	$8,000	$261,580	**$5,565,627**
2016/17	$2,784,518	$1,187,682	$1,402,864	$16,000	$754,801	**$6,145,865**
2017/18	$2,949,103	$1,818,308	$1,495,681	$40,000	$835,133	**$7,138,226**
2018/19	$4,026,755	$4,897,713	$1,419,377	$50,000	$575,194	**$10,969,039**
2019/20	$6,164,613	$5,435,799	$2,374,895	$35,000	$917,999	**$14,928,306**
2020/21	$7,440,206	$4,339,408	$2,524,125	$0	$1,165,232	**$15,468,971**
2021/22	$7,399,306	$3,792,069	$2,885,241	$0	$488,399	**$14,565,015**
Totals	**$33,609,541**	**$22,664,736**	**$13,359,434**	**$149,000**	**$4,998,338**	**$74,781,049**

Notes on Table 2:

This report is composed of 7 fiscal years of data running from 2015/16 to 2021/22

1. Research funding data is reported on the primary investigators identified in Table 1.
2. The fiscal year used when reporting research awards is the fiscal year used by the government. The government fiscal year runs from April 1 until March 31, thus the 2021/22 fiscal year runs from April 1, 2021 until March 31, 2022.

Inclusions and Exclusions

[a] excludes equipment grants.

[b] includes UW-RIF and UW-SSHRC

2.3 Graduate Supervision

Table 3 presents the master's, doctoral, and postdoctoral supervision numbers (current and career-total) by the faculty members that were listed in Table 1, from the three partner departments. The table documents the significant experience of the large faculty group in graduate supervision. Those listed as having only master's privileges are early career professors who are without exception seeking approval to serve as PhD advisers. The lecturer listed may supervise graduate students in the future but is an active teaching champion. One should note that a significant number of current (and past) graduate students are specializing in BME topics within traditional disciplines. Formalization of the new BME program will increase the depth and interdisciplinary endeavors across the members of the program while leading to a healthy growth of the graduate program.

TABLE 3

Completed and Current Numbers[1] of Thesis Supervisions by Faculty Member[2]						
Faculty Name and Rank	**Total Completed Over Career[3]**			**Current[4]**		
	Master's	**PhD**	**PDF**	**Master's**	**PhD**	**PDF**
Eihab Abdel-Rahman - Professor	5	2	0	3	0	1
Arash Arami - Assistant Professor	2	0	0	3	6	2
Catherine Burns - Professor	27	8	5	3	7	0
Naveen Chandrashekar - Associate Professor	12	1	0	2	2	0
David Clausi - Professor	50	24	12	10	5	1
Duane Cronin - Professor	46	10	7	8	8	2
Kerstin Dautenhahn - Professor	5	23	23	4	7	5
Chris Eliasmith - Professor	23	11	3	0	3	1
Paul Fieguth - Professor	21	30	9	2	4	4
Baris Fidan - Professor	4	0	0	1	0	0
Maud Gorbet - Professor	10	3	4	2	4	0
Parsin Haji Reza - Associate Professor	3	1	1	7	4	1
Jennifer Howcroft - Lecturer	0	0	0	0	0	0
Karim Karim - Professor	18	18	5	2	2	0
Behrad Khamesee - Professor	2	0	0	1	0	0
HJ Kwon - Associate Professor	11	6	2	2	2	2
Fue-Sang Lien - Professor	19	16	9	2	6	0
Ewen MacDonald - Associate Professor	29	10	1	1	1	0
Nima Maftoon - Assistant Professor	1	0	1	0	4	0
Veronika Magdanz[5]	0	0	0	0	1	0
Stewart McLachlin - Assistant Professor	3	0	0	4	3	0
John McPhee - Professor	8	2	7	6	7	0
Sushanta Mitra - Professor	0	3	2	0	2	0
Kevin Musselman - Associate Professor	9	4	4	2	6	1
Chrystopher Nehaniv - Professor	2	1	5	0	2	1
Richard Nuckols[5]	0	0	0	0	0	0
Zhao Pan - Assistant Professor	2	0	0	0	0	0
Sean Peterson - Professor	5	1	2	2	2	1
Mahla Poudineh - Assistant Professor	0	0	0	3	2	1
Carolyn Ren - Professor	18	18	8	6	4	4
Bryan Tripp - Associate Professor	5	2	1	4	6	1

Completed and Current Numbers[1] of Thesis Supervisions by Faculty Member[2]						
Faculty Name and Rank	**Total Completed Over Career[3]**			**Current[4]**		
	Master's	**PhD**	**PDF**	**Master's**	**PhD**	**PDF**
James Tung - Associate Professor	5	2	1	3	0	0
Mihaela Vlasea - Assistant Professor	3	2	3	4	4	1
Thomas Willett - Associate Professor	11	1	1	3	4	1
Alex Wong - Professor	23	14	13	10	10	4
Yimin Wu - Assistant Professor	5	2	1	7	5	3
Liang-Liang Xie - Professor	9	3	1	1	9	3
Serhiy Yarusevych - Professor	20	4	3	1	8	0
Mustafa Yavuz - Professor	32	16	10	2	6	4
John Yeow - Professor	4	20	4	2	4	2
Alfred Yu - Professor	9	8	10	6	10	3
John Zelek - Associate Professor	5	2	0	2	0	0
Total	**376**	**217**	**136**	**105**	**132**	**38**

Notes:

1. Numbers self-reported by each faculty member.
2. Faculty members and ranks as specified in Table 1 (from the core supporting departments ECE, MME, and SYDE).
3. Number of thesis supervisions completed thus far over the faculty member's career.
4. Number of current thesis supervisions underway for each faculty member.
5. New faculty members (less than one year on faculty)

2.4 Commitment of Faculty from Other Graduate Programs/Other Institutions

Faculty members from the three Faculties (Engineering, Health, and Science) have participated in the creation of this proposal. In Fall 2022, the proposal was endorsed by faculty vote in the following departments: ECE, MME, and SYDE. There is strong support as well from individual faculty who perform work in BME but whose department may not be formally involved in the administration of the program. Faculty from other programs may apply to be members of the BME program, even if their department is not administratively part of the BME programs.

Within healthcare-related undergraduate and graduate programs across the university, there is an important strategic goal to pursue clinical experiences for students. The University of Waterloo and individual BME faculty members have cultivated relationships and engaged in research collaborations with external organizations in the Kitchener-Waterloo community and beyond so that students may gain access to research facilities as appropriate. Examples within the local area are the Schlegel Research Institute for Aging and Grand River and Saint Mary's Hospitals. Multiple individual faculty members have long-standing research partnerships with McMaster University, University of Toronto, and Western University, that may allow students to gain access to additional resources and facilities.

2.5 Quality of Faculty

The University of Waterloo is consistently ranked among the top universities in the world, thanks in part to the breadth of high-quality research conducted by faculty members. The BME graduate program benefits from incorporating teaching staff from three faculties, whose CVs are compiled in Volume II. To demonstrate the research excellence of the overall BME faculty (those involved with CREATE and those beyond the CREATE programs), a bibliometric overview of the group was performed by the Faculty of Engineering Research Office. BME faculty were sorted into their field of study and their Scopus IDs were used to collect data on their research output. The same metrics and time parameters were applied for each group in the bibliometric database SciVal. Figure 1 shows scholarly output by each of the 5 BME fields listed in Section 1.9 for all publication types. In general, the publication count corresponds to the number of faculty focused on that field. One can observe a slight slowdown in output around 2020 due to the COVID-19 pandemic, followed by a small spike in 2021 as facilities began to reopen and stabilized in 2022.

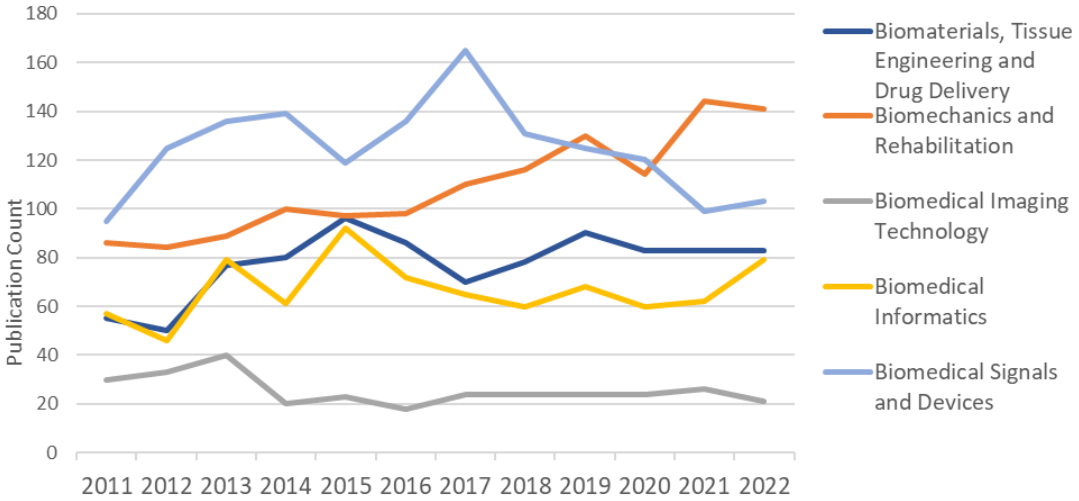


Figure 1. Scholarly Output – All publication types (2011 – 2022) by Research Field

3. PHYSICAL AND FINANCIAL RESOURCES

Due to the long-standing existence of biomedical engineering teaching and research within the traditional engineering departments and their partnerships with cross-campus partners, the new resources needed for this program are not typical. Most of the required faculty resources are already in place, including teaching resources. Additional faculty positions are already approved and will soon be filled.

Support for some of the space and labs used by graduate students will be reallocated within existing groups and compensated using a normalization of new pooled revenue based on the home department of the graduate students' advisers. Operating expenses include student support, staff salaries, faculty salaries/service teaching, program director stipend, student travel and other direct expenses. Financial support to update power and HVAC infrastructure in lab and office facilities is described in section 3.2.

3.1 Library Resources

The University of Waterloo Library purchases and subscribes to numerous resources relevant to BME. Library subscriptions enable access to significant electronic book collections, including Taylor & Francis, Knovel and Springer, and offer access to article indices, such as Scopus and Web of Science. Full text access to many journals is also provided. Given the multidisciplinary nature of BME, resources purchased or licensed to support other faculties and departments at the University expand the breadth of resources available for BME graduate students. These include access to PubMed, Association for Computing Machinery (ACM) Digital Library and publications, Business Source Elite, EconLit, IEEE Xplore Digital Library and publications, and SpringerMaterials. The library's full-text resources are also linked through Google Scholar, which directly connects students to our subscriptions via the search engine.

In response to the COVID-19 pandemic that extended into 2022, the library pivoted to purchasing more electronic content to meet the needs of students while off campus. While electronic procurement was not possible with every title, the library supplemented this by expanding access to print resources through the HathiTrust Digital Library's Emergency Temporary Access Service (ETAS), which permitted special online access for member libraries experiencing unexpected, involuntary or temporary disruptions to normal operations due to the COVID-19 pandemic. Using an ongoing service, students are able to request digitized chapters or articles from a print book in our collection or have print books mailed to their homes or residences provided they are living or staying in Canada.

In addition to the local collection, the University of Waterloo Library partners with other Ontario and Canadian universities to further expand access to information on engineering topics through consortia purchasing at the national and provincial level and through our consortia academic search tool OMNI, which allows users to discover materials from 16 Ontario universities through one search interface.

Should new subject areas emerge within the scope of BME, the library is committed to engaging in discussions to articulate collection needs and assess funding implications. The Liaison Librarian will provide resources during the PACE Module milestones of the proposed program, in particular, to guide students in determining their need for information, locating and evaluating appropriate sources, and properly citing information. The Liaison Librarian is available to answer reference questions via email, telephone, or virtual consultations to support students with their assignments and information needs. Consultations can be booked over email or through the online subject guides for BME at the student's convenience. All are encouraged to make use of the learning, teaching, research support services and expertise the library offers. The Liaison Librarian will interact with the faculty library representatives from the BME graduate program to ensure they are aware of new services.

Representatives from the University of Waterloo Library have prepared a report in Appendix D describing enthusiastic support for the BME graduate programs. Current Library resources and capacity are sufficient to support the programs and there is interest in re-assessing needs should new research areas emerge.

3.2 Laboratory Resources

There are BME-related research spaces and infrastructure spread across ten buildings on the main UW campus, including teaching & individual labs, shared labs, and major research facilities. There are 26 BME research labs in the Faculty of Engineering itself. In addition students will also have access to the 18 Faculty of Health labs that relate to biomechanics, neuroscience and physiology, as well as to resources within the School of Anatomy. The BME researchers and students have access to the analytical facilities in the Faculty of Science such as, the Waterloo Advanced Technology Labs (WATLab); Electron and Confocal Microscopy; Molecular Biology Core Facility; Fusion fluorescence-activated cell sorter (FACS); Mass Spectrometry; Nuclear Magnetic Resonance; X-Ray Diffractometry etc.

In addition, there are several University-administered Research Institutes and Centres that support BME-related research. Examples include:

- Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD)
- Centre for Theoretical Neuroscience
- Centre for Bioengineering and Biotechnology
- Waterloo Centre for Microbial Research
- Waterloo Institute for Nanotechnology (WIN)
- Giga-to-Nanoelectronics (G2N) Centre
- Central Animal Facility (CAF)
- UW RoboHub

Furthermore, BME faculty at Waterloo have laboratory facilities at external partner locations at the Grand River Hospital, Saint Mary's Hospital, and the Schlegel Research Institute for Aging.

3.3 Computer Facilities

All faculty and graduate students are provided with an account on the university computing system. This account provides access to email, internet, and Microsoft Office 365 applications. Students have access to 3D printing and laser cutting resources through the SYDE.

Research groups can apply for advanced research computing (ARC) resources with the Digital Research Alliance of Canada (formerly Compute Canada).

3.4 Space

Faculty will remain in their current faculty and lab offices in their home departments. Administrative staff will be located in SYDE in the Engineering 5 Building (E5). The Faculty of Engineering at Waterloo is already co-located across departments in approximately 10 buildings. This co-location is intended to promote interdisciplinary interactions such as those intended for the BME graduate program.

Faculty have private offices while post-doctoral fellows and graduate students have shared offices. In many engineering departments, graduate students are co-located based on cluster areas.

Due to the distribution of space across many campus buildings, space allocated to the BME graduate program is estimated by the proportion of BME faculty in Engineering by department in approximate Net Assignable Square Meters (NASM).

Table A: BME Associated Engineering Space Allocations (in NASMs)

	Classrooms (m^2)	**Research Labs (m^2)**	**Offices (m^2)**	**Study Space (m^2)**
ECE	64	228	254	26
MME	300	1654	1391	31
SYDE	420	1296	1503	44

3.5 Financial Support

Financial support will be provided to all admitted BME graduate students. Typical support is two years for master's students and four years for PhD students. A fifth year of support may be provided for PhD students pursuing significant lab or field data collection. Sources of support are the following:

1. Graduate Research Studentships (GRS) from faculty supervisors (minimum $26k for PhD, $18k for MASc, per year);
2. Teaching Assistantships (TA) in support of the core BME graduate courses (typically $5850/course if selected, paid on top of the GRS);
3. scholarships are expected in a new Faculty and Department funding modeling for PhD students with faculty GRS support. The current estimate of the Faculty and Department funding is $5,000 per PhD student per year. This will impact student minimum funding from the advisor and TA allocation and duties;
4. international doctoral student award (IDSA) for all eligible students ($15k/year, paid for by the University);
5. international masters award of excellence (IMAE) for select MASc students ($7.5k/year, paid for by the University).

4. CURRICULUM

4.1 The Intellectual Development and the Educational Experience of the Student

We envision positioning and equipping our graduates to innovate and succeed at the intersecting frontiers of engineering and medicine. To achieve this, we have developed a structure that combines a classical thesis-based research degree with courses and innovative professional development modules that ensure graduates have a solid foundation and

expertise for the pursuit of both academic and non-academic careers in biomedical engineering. Supporting this structure is the very large cohort of faculty establishing the program who have significant experience in interdisciplinary research and pedagogy.

The curriculum program is permeated with interdisciplinarity in both experiential and didactic learning and associated assessment methods. The PACE Module milestones, described in detail in section 4.4 includes sessions to orient the students to the program curriculum and build community. The remaining PACE seminars and workshops build professional skills, leading up to the showcase event and their research thesis. To provide hands-on learning opportunities and technical skill development, most courses will include lab experiences. The internal milestones will be tracked by the BME graduate program office and end-of-term reports will be used for assessment. Self-reflection and tracking of activities will be reported by students to their Advisory Committee on a minimum annual basis. Graduate Studies and Postdoctoral Affairs (GSPA) provides travel awards for students to attend external workshops and conferences. Students will be encouraged to take advantage of existing on-campus resources through the Centre for Career Action, Writing and Communications Centre, and the Centre for Teaching Excellence, among others.

4.2 Program Regulations

The admission requirements have been discussed in detail in section 1.4. The program requirements, including course requirements, are listed below. The comprehensive examination and thesis evaluation procedures and annual student assessments are described in section 1.8.

To maintain good standing during coursework, students must maintain a minimum average of 75%. The regulations meet or require a higher standard than the University of Waterloo and the Faculty of Engineering minimum requirements for graduate programs.

Students in both the master's and PhD programs are required to take one course offered by a faculty outside of Engineering. It must be a graduate level course that directly complements the student's research focus.

An Advisory Committee will be formed to evaluate each student's progress throughout the course of the degree. Each student's Advisory Committee must have a minimum of three Waterloo faculty. At least one supervisor and at least one committee member must be on the list of BME faculty members (see section 2.2). For PhD students, at least one supervisor must have Approved Doctoral Dissertation Supervisor (ADDS) status.

The BME graduate program is supportive of the strategic priority to build work-integrated learning (WIL) experiences into curriculum at the graduate level and is open to exploring opportunities in the future. Note, that the PACE modules (Section 4.4) provide opportunity for this type of training, even though there are no co-operative education work terms or field placements integrated into the BME graduate program, at this time.

4.2.1 MASc (thesis-based master's degree)

- Graduate courses: 4 courses (with 0.5 credits each), including 1 core BME course (BME 601, BME 602, BME 603), 1 field-specific course, and 2 elective courses (Appendix H)
    - The field specific course must be selected from the list in Appendix H.
    - The field specific course and the chosen electives must be approved by the supervisor(s).
    - One course shall be taken from outside the Faculty of Engineering.
    - All courses are ideally completed by the end of term 4.
- PACE Module milestones:
    - Seminar series participation, including the student's research seminar presentation, which must be completed by the end of term 5.
    - PACE days participation
    - Annual BME research day participation
- Thesis research milestones: 2 milestones, plus annual committee progress meetings and term reports
    - Proposal defense: Complete by end of term 3
    - Written dissertation and oral thesis defense: Complete by end of term 6

4.2.2 PhD (regular, with master's degree in BME)

- Graduate courses: 4 courses (with 0.5 credits each), including 1 core BME course (BME 601, BME 602, BME 603), 1 field-specific course, and 2 elective courses.
    - The field specific course must be selected from the list in Appendix H.
    - The field specific course and the chosen electives must be approved by the supervisor(s).
    - One course shall be taken from outside the Faculty of Engineering
    - All courses must be completed by the end of term 4.
    - Students who have completed the MASc program in BME at Waterloo may apply and continue to the doctoral program. In this situation, students will have already completed the core course requirements (one of BME 601, BME 602, or BME 603), a field-specific course and two electives as part of their master's degree requirements. To satisfy the PhD program requirements, these students must complete a total of four courses including a) one core course requirement (one of BME 601, BME 602 or BME 603 that was not completed as part of the MASc in BME program); b) two additional electives; c) an additional field-specific course if they have switched fields between MASc and PhD.
- PACE Module milestones:
    - Seminar series participation, including the student's research seminar presentation, which must be completed by end of term 9.
    - PACE days participation
    - Annual BME research day participation

- Thesis research milestones: 3 milestones, plus annual committee progress meetings and term reports
    - PhD Comprehensive Exam I (Background): Complete by end of term 3
    - PhD Comprehensive Exam II (Proposal): Complete by end of term 6
    - Written dissertation (thesis) and oral thesis defense: Complete by end of term 12

4.2.3 PhD (direct entry, with BME Honors undergraduate degree)

- Graduate courses: 7 courses (with 0.5 credits each), including 2 core BME courses (BME 601, BME 602, BME 603), 1 field-specific course, and 4 elective courses.
    - The field specific course must be selected from the list in Appendix H.
    - The field specific course and the chosen electives must be approved by the supervisor(s).
    - One course shall be taken from outside the Faculty of Engineering
    - All courses must be completed by the end of term 5.
- PACE Module milestones:
    - Seminar series participation, including the student's research seminar presentation, must be completed by the end of term 12.
    - PACE days participation
    - Annual BME research day participation
- Thesis research: 3 milestones, plus annual committee progress meetings and term reports
    - PhD Comprehensive Exam I (Background): Complete by end of term 6
    - PhD Comprehensive Exam II (Proposal): Complete by end of term 9
    - Written dissertation (thesis) and oral thesis defense: Complete by end of term 15

4.2.4 PhD (with non-BME equivalent master's degree)

- Graduate courses: 6 courses (with 0.5 credits each), including 1 core BME course (BME 601, BME 602, BME 603), 1 field-specific course, and 4 elective courses.
    - The field specific course must be selected from the list in Appendix H.
    - The field specific course and the chosen electives must be approved by the supervisor(s).
    - One course shall be taken from outside the Faculty of Engineering.
    - All courses must be completed by end of term 5
- PACE Module milestones:
    - Seminar series participation, including the student's research seminar presentation, which must be completed by end of term 12.
    - PACE days participation
    - Annual BME research day participation
- Thesis research: 3 milestones, plus annual committee progress meetings and term reports
    - PhD Comprehensive Exam I (Background): Complete by end of term 4
    - PhD Comprehensive Exam II (Proposal): Complete by end of term 7
    - Written dissertation (thesis) and oral thesis defense: Complete by end of term 15

4.3 Part-time Studies

Full-time study is required for enrolment into BME Graduate programs. At the discretion of the supervisor and program director, and subject to University's regulations, a switch to part-time may be considered for individual cases.

4.4 Curriculum

All incoming graduate students will complete a set of graduate courses to build their intellectual foundations and to prepare them for the effective undertaking of BME research. To satisfy the program's graduate course preparation requirement, each student must complete the following:

- One core BME course with strong emphasis on engineering analysis or design.
- One field-specific course to be chosen based on the student's research field.
- Elective courses (two for MASc and regular PhD, four for direct-entry and non-BME/equivalent master's degree PhD students) to be chosen by the student in consultation with their supervisor. Core and field-specific courses may be taken as electives.
- One course must be taken outside the Faculty of Engineering.

Core BME Course

All incoming students to the BME program, regardless of previous training, will be required to take one of three approved core courses for the BME graduate program. Each course provides an engineering perspective to human biology at the physiological or cellular level and includes a laboratory experience. Students may choose to take the one that best complements the training they already have in order to build out their BME knowledge and skills. Core courses are as follows:

- BME 601 - Physiological Systems and Biomedical Design: Integrates biomedical design with concepts in human biology and physiology from a quantitative, systems perspective. (Taught by SYDE)

- BME 602 – Foundations in Biomechanical Engineering: Provides foundational knowledge in the biomechanics of human physiology, pathology and treatment. (Taught by MME)

- BME 603 - Engineering Analysis of Living Cells: Teaches cell and molecular biology with a focus on mathematical and engineering modeling. (Taught by ECE)

Students may choose to take the other core courses as electives to broaden their foundational knowledge in quantitative human biology. Core courses will not assume that students have an undergraduate background in BME, biomedical science, life physics or variants thereof. Other common BME background knowledge will be covered as part of the PACE Module milestones (e.g., as part of PACE Day events). It is recommended that students with an undergraduate BME background take BME 603.

The context, vision, and general content for the core courses are described below.

BME 601: Physiological Systems and Biomedical Design
This course surveys the anatomy and physiology of the human body at the cellular, organ and whole-body scale, from a systems biology/physiology perspective. Cell biology and some of the physiological systems (e.g., musculoskeletal, cardiovascular, pulmonary, digestive, renal, nervous and sensory, and immune) and their integration/interactions will be introduced from a quantitative systems perspective. Where applicable, common sources of impairments of each system (e.g., pathologies, aging, etc.) will be presented along with implications for diagnostic, therapeutic and rehabilitative technologies (and universal design). Students will be required to perform engineering design that applies their knowledge in biology and physiology that they have gained throughout the course.

BME 602: Foundations in Biomechanical Engineering
This course focuses on equipping students with foundational knowledge in the biomechanics of human physiology, pathology, and treatment. The overarching aim of this course is to develop students' literacy in applying biomechanics principles and modern tools towards understanding the human body. The course will build on existing knowledge in mathematics and physics to develop new expertise and hands-on experience in the biomechanical modeling and analysis of physiological systems.

BME 603: Engineering Analysis of Living Cells
Cell biology has reached a stage where it is in dire need of quantitative understanding. The vast amount of data gathered with the advance of experimental technologies, in the search for a general understanding of the complex cell mechanism at the molecular level, have often made the traditional way of direct interpretation impossible. Therefore, recent years have seen significant efforts made to understand these data with more sophisticated mathematical models, using fundamental physical laws and engineering analytic techniques. This course is an introduction to some of the successful achievements of these approaches, and the exciting potential outcomes of this line of research.

Please see Appendix I for the Senate Graduate & Research Council - Graduate Studies Course/Milestone Forms for these three courses.

Professional Attributes and Competence Enhancement (PACE) Module milestones
All BME MASc and PhD students will be required to complete the PACE Module milestones that focus on professional skills development. See Table B for MASc and Table C for PhD students found below. This module will consist of:

1) Active participation in a bi-weekly seminar series, including giving their own research seminar by the end of their final term (as described in 4.2.1 to 4.2.4);
2) a set of professional education day events known as PACE days; and
3) an annual BME research day event.

Students will be required to complete all three components to meet the PACE Module milestones requirement.

Seminar Series

- Biweekly seminar series with students and internal and external BME speakers (1.5-hour duration).
- Each student must attend a minimum of five seminars per term, except for their final term.
- Each student will be required to present a research seminar by the end of their final term.
- Guest speakers will also be invited to speak at this seminar series.
- Seminar topics may be related to BME research or professional development.

PACE Days for both MASc and PhD students

- Two days at the start of every term (~10 hours of instructional time split over both days) will be dedicated to students' professional development.
- MASc students shall participate in PACE Day events at the start of terms 1, 2 and 3.
    - Total contact time around 30 hours (spread over the first year of study).
    - PACE Day activity topics vary for MASc students (Table B).

Table B: PACE Days Activities for MASc Students

Term	Topic	Remarks
1	Research Design and Planning	• Orientation event • Learn how to draft research project plans with need-oriented problem statements, testable hypotheses, feasible designs, technical solutions etc. • Professionalism in following ethics guidelines and regulatory protocols
2	Professional Presentations	• Learn how to give oral presentations to a range of audiences – laypersons, subject experts, professionals in complementary disciplines.
3	Scientific Writing	• Learn how to effectively communicate in technical English to biomedical professionals and engineers

- PhD students shall participate in PACE Days events at the start of every term, from terms #1 to #5.
    - Total contact time around 50 hours (spread over the first two years of the student's study).
    - PACE Days activity topics for PhD students vary from MASc (Table C).

Table C: PACE Days Activities for PhD Students

Term	Topic	Remarks
1	Research Design and Planning	• For non-holders of the MASC-BME degree from Waterloo
2	Professional Presentations	• For non-holders of the MASC-BME degree from Waterloo
3	Scientific Writing	• For non-holders of the MASC-BME degree from Waterloo
4	Vision Development	• Specific to PhD students • Develop a vision for their career (research & professional goals) and the impact it will make, leading to short- and long-term plans. • Learn how to design hypothesis-driven research programs at the frontiers of BME. • Learn about the importance of including sex and gender as variables in BME research (guided by Tri-Council) • Learn about the importance of equity, diversity and inclusivity considerations and the impact they have on research design and outcomes (guided by Tri-Council)
5	Proposal writing and peer review	• Learn how to write grant proposals and business proposals. • Gain experience in conducting peer reviews and mitigating unconscious bias.

BME Research Day

- An annual event that gives students an opportunity to showcase their progress and research findings while building community among BME graduate students.
- The format of the event will model a research conference or symposium, with higher formality than the biweekly seminar series.
- Students will be expected to submit an abstract and give either an oral or poster presentation.
- The BME Research Day may also include keynote speakers from outside the University.

Administrative note:
The PACE Module Milestones will be developed and managed by the BME Graduate Program Coordinator under the direction of the BME Graduate Program Director.

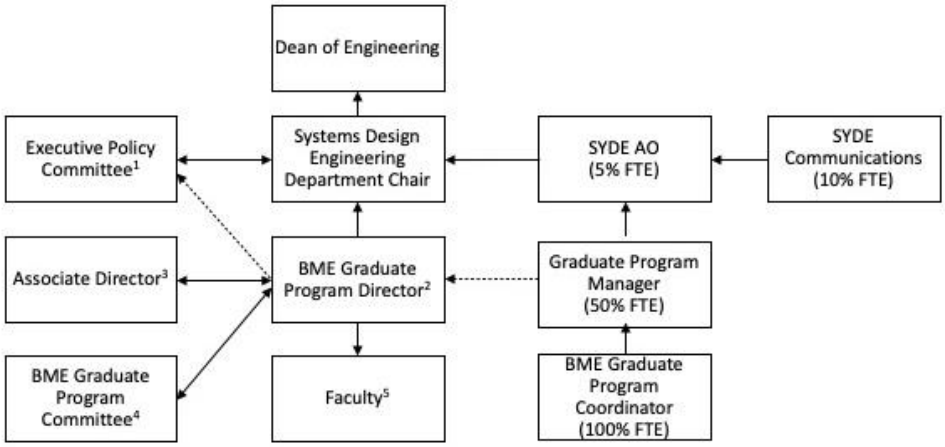
4.5 Collateral and Supporting Departments and Schools

This engineering program is an administrative partnership of three departments in the Faculty of Engineering

- Department of Systems Design Engineering (administrative lead)
- Department of Electrical and Computing Engineering
- Department of Mechanical and Mechatronics Engineering

All individual faculty members, even those in these departments, must apply to the program committees to be associated faculty members that can supervise graduate students in the BME graduate program and supervise graduate students in the program where the coursework and research of graduate students are engineering-based. Other valuable health and science programs exist on campus and complement the work of the BME program faculty and graduate students, while the proposed BME degrees are engineering degrees.

4.6 Organizational Structure



1. Department chairs of partner departments (ECE, MME and SYDE) will serve on the BME Graduate Executive Policy Committee with oversight on policy and resources.
2. Can be a full-time BME faculty member from any partner engineering department.
3. The Director and Associate Director should represent two partner engineering departments.
4. Comprised of 10 faculty members chaired by the Director with oversight of curriculum.
5. Faculty members that wish to supervise graduate students in the BME program will apply to the BME program for membership.

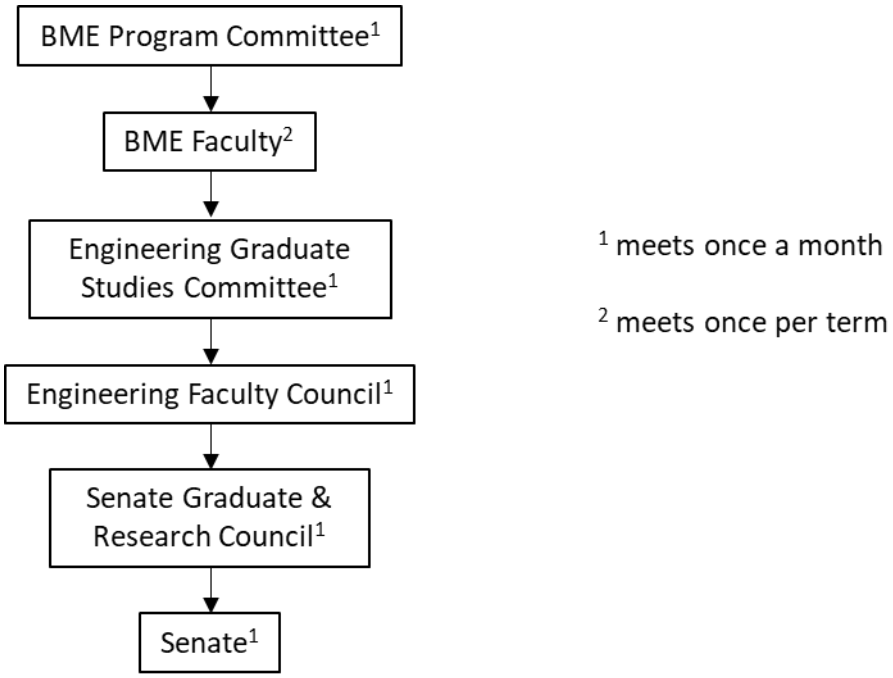
Figure 2: Program Organizational Chart

The organizational arrangements and reporting structures involved in the interdisciplinary, shared program are illustrated in Figure 2. Partner departments in the Faculty of Engineering will be involved in the BME Program Committee, advising, and course instruction. The program will be led by the BME Graduate Program Director who will be a faculty member from any of the partner engineering departments, will report to the chair of SYDE department. The responsibility of the director is to provide strategic direction, including on the curriculum, with the support of the Program Committee. SYDE will function as the administrative home for the program, as it manages the undergraduate program. The arrangement will help minimize costs by sharing some support staff with SYDE. The director or associate director will represent the BME Graduate programs in the Engineering Graduate Studies Committee (EGSC).

The director provides functional supervision to the BME graduate program manager. The director establishes and oversees the components of the PACE Module milestones, while the graduate program manager implements it.

As is the case for all Engineering faculty, partner faculty may apply to the BME Program Membership to serve as graduate advisers. Faculty regardless of home unit are expected to apply for and be approved as faculty advisers in the BME graduate program (see section 4.2). In order to ensure advising faculty members have biomedical engineering expertise, applications to serve as advisers in the programs will be reviewed by the Graduate Program Committee. While this is an engineering program it involves important partnerships with non-engineering units especially in Science and Health. Units with program faculty members may have representations on both the Executive Policy and Program Committees.

The process of BME Graduate Program curricular changes is illustrated in Figure 3.



BME Program Committee: Comprised of 10 faculty members chaired by the Director.

BME Faculty: Approved BME faculty members from any department.

Engineering Graduate Studies Committee: Comprised of graduate associate chairs from the 8 departments/schools in Engineering, 1 faculty member each from the 8 units, BME program director, chaired by the Associate Dean Graduate Studies.

Engineering Faculty Council: Elected legislative body of the Faculty of Engineering

Figure 3: Path of a BME Graduate program curricular change

The first step is that the change will be addressed by the BME Program Committee. This committee will consist of ten members who are appointed for three-year terms by their chairs/directors and will meet monthly. Membership terms will have staggered start and end dates and have an alternate for meeting attendance. Faculty conducting research in all the five research fields must be represented on the committee. There must be at least two members from each of SYDE, MME, and ECE and no partner department may hold a majority on the BME Program Committee. The BME Program Committee will submit approved motions to the collective of BME faculty for vote before motions are submitted to the Engineering Graduate Studies Committee. The BME Graduate Program Director and the BME Undergraduate Program Director will call for a joint BME faculty meeting once per term.

Department Chairs of partner departments (ECE, MME, and SYDE) will serve on the BME Graduate Executive Policy Committee. This committee is called to meet once per term by the SYDE Chair. Meetings are attended by the BME Program Director and Associate Director. The Executive Policy Committee is responsible for budget-related oversight, infrastructure and selection of the program Director and Associate Director.

5. PROJECTED ENROLLMENT

The first intake of new students is planned for 2024 and is expected to be approximately half of the steady-state intake. A modest estimate of the projected enrollment for the master's and PhD programs is given in Table 4a and Table 4b, respectively. The estimates are based on current graduate enrollment in the core supporting departments, the department-based ratios for the current ratio of master's to PhD students, and the ratio of domestic and international students. In steady-state operation the program will attract an increasing number of graduate applicants to BME, contributing to the overall growth of the graduate program.

Table 4a Master's Intake and Enrolment

Projected Student Intake and Enrolment				
Academic Year	**FULL-TIME**			
	Annual Intake[1]		**Total FT Enrolment***	
	Domestic	**International***	**Domestic**	**International****
2024/25	10	5	10	5
2025/26	10	5	20	10
2026/27	10	5	20	10
2027/28	10	5	20	10
2028/29	10	5	20	10

Assuming 100% retention for illustrative purposes

** International fee-paying students

1. Year one intake includes students transferring into a BME graduate program from another Waterloo graduate programs and will be treated on a case-by-case basis.

Table 4b PhD Intake and Enrolment

Projected Student Intake and Enrolment				
Academic Year	**FULL-TIME**			
	Annual Intake[1]		**Total FT Enrolment***	
	Domestic	**International***	**Domestic**	**International****
2024/25	10	8	10	8
2025/26	10	8	20	16
2026/27	10	8	30	24
2027/28	10	8	40	32
2028/29	10	8	40	32

* Assuming 100% retention for illustrative purposes

** International fee-paying students

1. Year one intake includes students transferring into a BME graduate program from another Waterloo graduate programs and will be treated on a case-by-case basis.

It can be anticipated that the first intake may include some current graduate students who are in traditional MASc/PhD discipline programs but would prefer to obtain the BME credential based on their research, course foci, and career goals. Any such student will need to follow the formal Change of Program process and are expected to complete their program on schedule. They will be expected to enroll in the PACE Module milestones and start annual committee meeting requirements upon admission. Course equivalence will be assessed on a case-by-case basis by the BME Graduate Program Director.

6. FINANCIAL PLAN

A financial viability analysis (FVA) investigating the financial parameters and assumptions of the proposed programs was conducted by Institutional Analysis and Planning (IAP) and discussed in detail with the Faculty of Engineering. IAP has not identified significant financial challenges to this proposal moving forward with the proposed enrolment, tuition rate, and costs outlined in the FVA. The financial viability analysis was approved by the Provost on November 23, 2023.

Appendix A NSERC CREATE Programs

This section describes, as examples, two extra-curricular programs developed by Waterloo faculty with the NSERC Collaborative Research and Training Experience (CREATE) program. Both programs provide students with opportunities for skill development in the field of biomedical engineering.

The *Global Biomedical Technology Research and Innovation* program is completing year four of a seven-year training that was designed for 44 graduate students and 48 undergraduate students. The students conduct research in three areas: in-vitro and ex-vivo diagnostics (40%), medical instrumentation (30%), and prosthetics and rehabilitation (30%). To date, the program has included almost equal numbers of doctoral and master's students (19 and 21 respectively). There are four core faculty from SYDE, two from the Department of Electrical and Computer Engineering, one from the Department of Chemical Engineering, two from the Department of Kinesiology and Health Sciences, and one from the School of Optometry and Vision Science.

This program's cross-campus, transdisciplinary partnership mirrors that proposed for the BME graduate program. External partners include hospitals, research institutes, private industry, and universities in other countries. Training sessions for students focused on design (minimum of 21 hours), commercialization (minimum of 14 hours for master's and 28 hours for PhD) and professional soft skills (minimum of seven hours) have informed the PACE Module milestones described in this proposal for the graduate program. Trainees must submit reflection forms after each training session and faculty and students conduct an end-of-term review. Graduates of the CREATE program are also required to have published research papers. The output from the first three years of the program includes 41 articles published in or accepted by refereed journals and 37 conference presentations. The participation in the CREATE program demonstrates that there is strong demand. The new BME graduate program will integrate lessons learned from the first CREATE. The program will be needs first, design focused, which provides for differentiation. The BME Grad Program may utilize the CREATE library of asynchronous video content (>35 hrs and counting) and leverage strong existing partnerships.

Waterloo's second BME NSERC CREATE is complementary to the first. The CREATE *Next-Generation Innovations in Ultrasonics* (N-GENIUS) program, led by Alfred Yu, includes 12 core faculty working across six theme areas: a) Imaging Innovations; b) Diagnostic Application Development; c) AI-Centric Ultrasound Imaging; d) Drug Delivery and Theranostics; e) Simulation and Modeling; and f) Cellular Biophysics of Ultrasound. This work forms the basis of a unique sub-field at Waterloo which will distinguish our BME graduate program. Similar to the first CREATE program, the group spans departments and faculties at Waterloo and boasts external partners, including international partners. Innovative activities for graduate students include orientation, a career training and development session, skill training, entrepreneurship and a "special topics" summer school. By August 2021, the program had 35 trainees: 11 postdoctoral, 11 doctoral, seven master's and six bachelor's. A total of 11 trainees had graduated with approximately half employed and half pursuing further studies.

Appendix B Master of Applied Science (MASc) in Biomedical Engineering

Graduate research fields

- Biomaterials, Tissue Engineering, and Drug Delivery
- Biomechanics and Rehabilitation
- Biomedical Signals and Devices
- Biomedical Imaging Technology
- Biomedical Informatics

Program Information

- Admit term(s)
    - Fall
    - Winter
    - Spring
- Delivery mode
    - On-campus
- Length of program
    - Students are required to complete the program in accordance with the University program time limits.
- Program type
    - Master's
    - Research
- Registration option(s)
    - Full-time
- Study option(s)
    - Thesis

Admission requirements

- Minimum requirements
    - MASc applicants must have completed a bachelor's degree (or equivalent) in any field of engineering or a related science discipline at a recognized institution with a minimum 80% overall average.
    - Applicants who are deemed by the graduate coordinator, BME graduate program director, Admissions Committee or intended advisor to have an inadequate depth of technical BME background may be directed to take additional foundational courses, to be specified at the time of admission.
- Application materials
    - Résumé
    - Supplementary information form
    - Transcript(s)
- References
    - Number of references: two (2)
    - Type of references: Academic. Applicants who completed their degree five or more years before the application date may submit one (1) academic and one (1) professional reference.
- English language proficiency (ELP) (if applicable)

- Minimum Internet-based TOEFL (iBT): 90; writing 25; speaking 25; or
- Minimum IELTS (Academic): 7.0; writing 6.5; speaking 6.5
- See https://uwaterloo.ca/graduate-studies-academic-calendar/general-information-and-regulations/english-language-proficiency

Degree requirements

Thesis option:

- Course Requirements
  - Students must complete the following 4 graduate level courses (0.50 unit weight per course) counting towards degree credit from the University of Waterloo:
    - 1 of the following Biomedical Engineering core courses
      - BME 601
      - BME 602
      - BME 603
    - 1 of the following field-specific courses
      - **Biomaterials, tissue engineering and drug delivery**
        - BME 684 (recoded from SYDE 684): Materials Biocompatibility
        - CHE 601: Theory and Application of Transport Phenomena
        - CHE 602: Chemical Reactor Analysis
        - CHE 612: Interfacial Phenomena
        - CHE 620: Applied Engineering Mathematics
        - CHE 640: Principles of Polymer Science
        - CHE 660: Principles of Biochemical Engineering
        - CHE 663: Bioseparations
        - CHE 760: Special Topics in Biochemical Engineering
        - ECE 601: Foundations of Biology in Engineering
        - BIOL 636: Advanced Immunology
        - KIN 657: Human Neuroanatomy
        - PHARM 609: Advanced Pharmacokinetics
        - PHARM 610: Topics in Drug Development
        - PHARM 617: Formulations
      - **Biomechanics and rehabilitation**
        - BME 550: Sports Engineering
        - BME 551: Biomechanics of Human Movement
        - BME 588, Topic 1: Mechanics of Biomaterials and Tissues
        - ME 662: Advanced Fluid Mechanics
        - ME 663: Computational Fluid Dynamics
        - ME 720: Special Topics in Solid Mechanics Topic 5: Impact Biomechanics

- ME 720: Special Topics in Solid Mechanics Topic 4: Mechanics of Medical Devices
- ME 621: Applied Finite Element Methods
- ME 780: Special Topics in Mechatronics Topic 37: Human Movement Neuromechanics
- SYDE 644: Human Factors Testing
- AMATH 663: Fluid Mechanics
- PHYS 752: Molecular Biophysics
- KIN 601: Skeletal Muscle Physiology: Structure & Function
- KIN 602: Respiratory and Cardiovascular Physiology
- KIN 603: Cardiac and Vascular Smooth Muscle Physiology
- KIN 611: Biomechanics of Human Motion
- KIN 613: Modern Methods in Biomechanical Modeling, Kinematics, and Kinetics
- KIN 620: Ergonomic Aspects of Occupational Musculoskeletal Injuries

- **Biomedical signals and devices**
  - ECE 730: Special Topics in Solid State DevicesTopic 34: Biosensing – Fundamentals and Applications
  - ECE 770: Special Topics in Antenna and Microwave Theory Topic 4: Computational Methods for Engineering Electromagnetics
  - ME 720: Special Topics in Solid Mechanics Topic 4: Mechanics of Medical Devices
  - ME 739: Manufacturing Processes Topics Topic 3: Materials for Nano & Microelectromechanical Systems
  - ME 739: Manufacturing Processes Topics Topic 15: Additive Manufacturing Design
  - ME 765: Special Topics in Fluid Mechanics Topic 22: Microfluidic and MEMS Systems and Applications
  - ME 780: Special Topics in Mechatronics Topic 32: Neural and Rehabilitation Engineering
  - NANO 604: Nanomechanics and Molecular Dynamics Simulations
  - SYDE 750: Topics in Systems Modelling Topic 38: Social Robotics
  - KIN 653: Human Neuroscience Theory
- **Biomedical imaging technology**
  - BME 677 (recoded from SYDE 677): Medical Imaging
  - BME 780 (recoded from SYDE 780): Biomedical Optics

    - ECE 607: Fundamentals of Ultrasonics
    - ECE 613: Image Processing and Visual Communication
    - ECE 675: Radiation & Propagation of Electromagnetic Fields
    - ME 720: Special Topics in Solid Mechanics Topic 20: Acoustics
    - SYDE 671: Advanced Image Processing
    - SYDE 672: Statistical Image Processing
    - SYDE 675: Pattern Recognition
    - PHYS 751: Clinical Applications of Physics in Medicine
- **Biomedical informatics**
    - AMATH 882: Mathematical Cell Biology
    - BIOL 614: Applied Bioinformatics and Genomics
    - HLTH 612: Data Structures and Standards in Health Informatics
    - HLTH 615: Requirements Specification and Analysis in Health Systems
    - HLTH 616: Decision Making and Systems Thinking in Health Informatics
    - HLTH 719: Advanced Research Methods in Health Informatics
    - KIN 613: Modern Methods in Biomechanical Modeling, Kinematics, and Kinetics
- **BME and health electives (general electives that include topics in more than one research fields)**
    - ECE 603: Statistical Signal Processing
    - ECE 608: Quantitative Analysis in Biomedical Engineering
    - SYDE 642: Cognitive Engineering Methods
    - SYDE/ECE 750: Topics in Systems Modelling/Special Topics in Computer Software Topic 37/32: Biology and Computation
    - SYDE/ECE 750: Topics in Systems Modelling/Special Topics in Computer Software Topic 39/33: Embodied Intelligence
    - KIN 601: Skeletal Muscle Physiology: Structure & Function
    - KIN 606: Molecular Basis of Disease
    - KIN 607: Integrative Energy Metabolism in Health and Disease
    - KIN 608: Introduction to Genetics for the Biosciences
    - KIN 612: Instrumentation and Signal Processing in Biophysical Research

        - KIN 646: Physiological and Biochemical Analysis of Nutrition and Health
        - KIN 653: Human Neuroscience Theory
        - KIN 654: Instrumentation in Neuroscience Research

    - 2 elective courses.
  - One of the four courses shall be taken from outside the Faculty of Engineering.
  - All courses must be completed by the end of Term 4.
  - All course selections are arranged by the supervisor(s) in consultation with the student and are subject to the approval of the Director or Associate Director, BME graduate program. Students pursuing one the program's Graduate Research Fields, should inform their supervisor(s) of their chosen field(s) to ensure appropriate course selection.
  - Note: these requirements are in addition to satisfactory completion of any transitional courses that may be specified at the time of admission.
  - Note: The Faculty of Engineering requires that no more than one-half of the courses used for credit toward a graduate degree may be taught by a candidate's supervisor(s). In the case of co-supervision in small research groups, it may be necessary to relax this rule; however, the student's file must contain a statement of formal approval from the BME graduate program director and endorsement from the Associate Dean for Graduate Studies and Postdoctoral Affairs in the Faculty of Engineering.
- Professional Attributes and Competence Enhancement (PACE) Module
  - The PACE module milestone includes the following three components: a Seminar series, PACE days, and Annual BME research day. The requirements for the three components are outlined below:
  - Seminar series including presenting a research seminar:
    - Biweekly seminar series with students and internal and external BME speakers (1.5-hour duration). Guest speakers will also be invited to speak at the seminar series. The topics may be related to BME research, academic integrity, or professional development.
    - Each student must attend a minimum of five seminars per term, except for their final term. It is the student's responsibility to submit their "Seminar Attendance Certificates" attached to their term activity report. BME records should show that the number of seminars a student has attended is at least four times the number of terms the student has been enrolled as a full-time student in the program.
    - Each student will be required to present a research seminar by the end of their final term and as part of the PACE module milestones. BME will contact seminar candidates with scheduling information after they have passed their proposal.
  - PACE Days:

        - Students are required to attend and participate in 2 PACE days at the beginning of terms 1, 2, and 3. PACE days are dedicated to students' professional development and the topics vary each term.
    - Annual BME Research Day – once per year
        - Students are required to attend and present at the Annual BME Research Day. The annual event gives students an opportunity to showcase their progress and research findings while building community among BME graduate students. Students are required to submit an abstract and give either an oral or poster presentation.
- Master's Thesis Proposal
    - Students must develop and defend a thesis proposal that will be examined and approved by their supervisor and committee. The thesis proposal must be completed by the end of term 3.
    -
- Master's Thesis
    - Students may choose to pursue one (1) of the following Graduate Research Fields:
        - Biomaterials, Tissue Engineering, and Drug Delivery
        - Biomechanics and Rehabilitation
        - Biomedical Signals and Devices
        - Biomedical Imaging Technology
        - Biomedical Informatics
    - A Graduate Research Field is a university credential that is recognized on the student's transcript and is intended to reflect that a student has successfully completed research concentrated in the area of the Graduate Research Field. The BME graduate program, represented by the student's supervisor and examining committee, must assess whether a student's completed research warrants the field designation at the time of degree completion.
    - Upon approval of the thesis proposal, students will proceed to the research and writing of the thesis. Students must complete and orally defend the thesis by the end of term 6. The thesis and defence will be evaluated by the student's Advisory Committee. The Advisory Committee shall be comprised of: at least one tenured or tenure track faculty member from the BME graduate program who will normally be the student's supervisor(s); an additional tenured or tenure track BME graduate faculty member; and at least one additional examiner who is not a BME faculty member (but may be from a department with BME faculty members) and whose expertise can support the evaluation of the Master's thesis. Consistent with the Faculty of Engineering requirements, a maximum of one committee member with an adjunct appointment or emeritus status is permitted.

Appendix C Doctor of Philosophy (PhD) in Biomedical Engineering

Graduate research fields

- Biomaterials, Tissue Engineering, and Drug Delivery
- Biomechanics and Rehabilitation
- Biomedical Signals and Devices
- Biomedical Imaging Technology
- Biomedical Informatics

Program information

- Admit term(s)
    - Fall
    - Winter
    - Spring
- Delivery mode
    - On-campus
- Length of program
    - Students are required to complete the program in accordance with the University program time limits.
- Program type
    - Doctoral
    - Research
- Registration option(s)
    - Full-time
- Study option(s)
    - Thesis

Admission requirements

- Minimum requirements
    - PhD (regular entry) applicants who completed a research thesis-based master's degree (or equivalent) in engineering, applied science, or science from a recognized institution with at least an overall 80% average and documented evidence of potential to excel in PhD studies and research.
    - PhD (direct from Honours BME undergraduate entry) applicants require a minimum overall average of 80% in a BME program at the undergraduate level and clear evidence of excellent potential to excel in PhD studies and research. Substantial research experience is expected.
        - Applicants who are deemed by the graduate coordinator, BME graduate program director, Admissions Committee or intended advisor to have an inadequate depth of technical BME background may be directed to take additional foundational courses, to be specified at the time of admission.
- Application materials
    - Résumé
    - Supplementary information form
    - Transcript(s)

- References
    - Number of references: three (3)
    - Type of references: two (2) from academic sources that are able to comment upon academic preparation and research ability.
- English language proficiency (ELP) (if applicable)
    - Minimum Internet-based TOEFL (iBT): 90; writing 25; speaking 25; or
    - Minimum IELTS (Academic): 7.0; writing 6.5; speaking 6.5
    - See https://uwaterloo.ca/graduate-studies-academic-calendar/general-information-and-regulations/english-language-proficiency
    -

Degree requirements

Thesis option:

- Courses
    - Students possessing a recent master's degree in biomedical engineering are required to successfully complete 4 graduate-level courses (with unit weights of 0.50 each), including 1 core biomedical engineering course (BME 601, BME 602, or BME 603), 1 field-specific course from the list below, and 2 elective courses.
        - The field specific course and the chosen electives must be approved by the supervisor(s).
        - One course shall be taken from outside the Faculty of Engineering
        - All courses must be completed by the end of term 4.
        - Students who have completed the MASc program in BME at Waterloo may apply and continue to the doctoral program. In this situation, students will have already completed the core course requirements (one of BME 601, BME 602, or BME 603), a field-specific course and two electives as part of their master's degree requirements. To satisfy the PhD program requirements, these students must complete a total of four courses including a) one core course requirement (one of BME 601, BME 602 or BME 603 that was not completed as part of the MASc in BME program); b) two additional electives; c) an additional field-specific course if they have switched fields between MASc and PhD.
    - Students admitted to the PhD program who possess a master's degree in a discipline outside of biomedical engineering (or equivalent) are required to successfully complete a minimum of 6 graduate-level courses (with a credit weight of 0.50 each) including 1 core biomedical engineering course (BME 601, BME 602, or BME 603), 1 field-specific course from the list below, and 4 elective courses.
        - The field specific course and the chosen electives must be approved by the supervisor(s).

- One course shall be taken from outside the Faculty of Engineering.
- All courses must be completed by end of term 5

- Students admitted directly to the PhD program who posses an honour's undergraduate degree in biomedical engineering are required to complete a minimum of 7 courses (with 0.5 credits each), including 2 core BME courses (BME 601, BME 602, BME 603), 1 field-specific course from the list below, and 4 elective courses.
  - The field specific course and the chosen electives must be approved by the supervisor(s).
  - One course shall be taken from outside the Faculty of Engineering
  - All courses must be completed by the end of term 5.

- Student must select their field-specific course(s) from the following list:
  - **Biomaterials, tissue engineering and drug delivery**
    - BME 684 (recoded from SYDE 684): Materials Biocompatibility
    - CHE 601: Theory and Application of Transport Phenomena
    - CHE 602: Chemical Reactor Analysis
    - CHE 612: Interfacial Phenomena
    - CHE 620: Applied Engineering Mathematics
    - CHE 640: Principles of Polymer Science
    - CHE 660: Principles of Biochemical Engineering
    - CHE 663: Bioseparations
    - CHE 760: Special Topics in Biochemical Engineering
    - ECE 601: Foundations of Biology in Engineering
    - BIOL 636: Advanced Immunology
    - KIN 657: Human Neuroanatomy
    - PHARM 609: Advanced Pharmacokinetics
    - PHARM 610: Topics in Drug Development
    - PHARM 617: Formulations
  - **Biomechanics and rehabilitation**
    - BME 550: Sports Engineering
    - BME 551: Biomechanics of Human Movement
    - BME 588, Topic 1: Mechanics of Biomaterials and Tissues
    - ME 662: Advanced Fluid Mechanics
    - ME 663: Computational Fluid Dynamics
    - ME 720: Special Topics in Solid Mechanics Topic 5: Impact Biomechanics
    - ME 720: Special Topics in Solid Mechanics Topic 4: Mechanics of Medical Devices

- ME 621: Applied Finite Element Methods
- ME 780: Special Topics in Mechatronics Topic 37: Human Movement Neuromechanics
- SYDE 644: Human Factors Testing
- AMATH 663: Fluid Mechanics
- PHYS 752: Molecular Biophysics
- KIN 601: Skeletal Muscle Physiology: Structure & Function
- KIN 602: Respiratory and Cardiovascular Physiology
- KIN 603: Cardiac and Vascular Smooth Muscle Physiology
- KIN 611: Biomechanics of Human Motion
- KIN 613: Modern Methods in Biomechanical Modeling, Kinematics, and Kinetics
- KIN 620: Ergonomic Aspects of Occupational Musculoskeletal Injuries

- **Biomedical signals and devices**
  - ECE 730: Special Topics in Solid State Devices Topic 34: Biosensing – Fundamentals and Applications
  - ECE 770: Special Topics in Antenna and Microwave Theory Topic 4: Computational Methods for Engineering Electromagnetics
  - ME 720: Special Topics in Solid Mechanics Topic 4: Mechanics of Medical Devices
  - ME 739: Manufacturing Processes Topics Topic 3: Materials for Nano & Microelectromechanical Systems
  - ME 739: Manufacturing Processes Topics Topic 15: Additive Manufacturing Design
  - ME 765: Special Topics in Fluid Mechanics Topic 22: Microfluidic and MEMS Systems and Applications
  - ME 780: Special Topics in Mechatronics Topic 32: Neural and Rehabilitation Engineering
  - NANO 604: Nanomechanics and Molecular Dynamics Simulations
  - SYDE 750: Topics in Systems Modelling Topic 38: Social Robotics
  - KIN 653: Human Neuroscience Theory
- **Biomedical imaging technology**
  - BME 677 (recoded from SYDE 677): Medical Imaging
  - BME 780 (recoded from SYDE 780): Biomedical Optics
  - ECE 607: Fundamentals of Ultrasonics
  - ECE 613: Image Processing and Visual Communication

    - ECE 675: Radiation & Propagation of Electromagnetic Fields
    - ME 720: Special Topics in Solid Mechanics Topic 20: Acoustics
    - SYDE 671: Advanced Image Processing
    - SYDE 672: Statistical Image Processing
    - SYDE 675: Pattern Recognition
    - PHYS 751: Clinical Applications of Physics in Medicine
- **Biomedical informatics**
    - AMATH 882: Mathematical Cell Biology
    - BIOL 614: Applied Bioinformatics and Genomics
    - HLTH 612: Data Structures and Standards in Health Informatics
    - HLTH 615: Requirements Specification and Analysis in Health Systems
    - HLTH 616: Decision Making and Systems Thinking in Health Informatics
    - HLTH 719: Advanced Research Methods in Health Informatics
    - KIN 613: Modern Methods in Biomechanical Modeling, Kinematics, and Kinetics
- **BME and health electives (general electives that include topics in more than one research fields)**
    - ECE 603: Statistical Signal Processing
    - ECE 608: Quantitative Analysis in Biomedical Engineering
    - SYDE 642: Cognitive Engineering Methods
    - SYDE/ECE 750: Topics in Systems Modelling/Special Topics in Computer Software Topic 37/32: Biology and Computation
    - SYDE/ECE 750: Topics in Systems Modelling/Special Topics in Computer Software Topic 39/33: Embodied Intelligence
    - KIN 601: Skeletal Muscle Physiology: Structure & Function
    - KIN 606: Molecular Basis of Disease
    - KIN 607: Integrative Energy Metabolism in Health and Disease
    - KIN 608: Introduction to Genetics for the Biosciences
    - KIN 612: Instrumentation and Signal Processing in Biophysical Research
    - KIN 646: Physiological and Biochemical Analysis of Nutrition and Health
    - KIN 653: Human Neuroscience Theory

- KIN 654: Instrumentation in Neuroscience Research

- In every case, a graduate course program is established by the supervisor(s) in consultation with the student and is subject to the approval of the Director of the BME Graduate Program. Candidates may also be required to take additional courses as a result of a comprehensive examination. Students pursuing one of the program's Graduate Research Fields should inform their supervisor(s) of their chosen field(s) to ensure appropriate course selection.
- The Faculty of Engineering requires that no more than one-half of the courses used for credit towards a graduate degree may be taught by the candidate's supervisor(s). In the case of co-supervision in small research groups, it may be necessary to relax this rule, but the student's file must contain a statement of formal approval from the BME graduate program director and endorsement from the Associate Dean for Graduate Studies and Postdoctoral Affairs in the Faculty of Engineering.

- Professional Attributes and Competence Enhancement (PACE) Module
  - The PACE module milestone includes the following three components: a Seminar series, PACE days, and Annual BME research day. The requirements for the three components are outlined below:
  - Seminar series including presenting a research seminar:
    - Biweekly seminar series with students and internal and external BME speakers (1.5-hour duration). Guest speakers will also be invited to speak at the seminar series. The topics may be related to BME research, academic integrity, or professional development.
    - Each student must attend a minimum of five seminars per term, except for their final term. It is the student's responsibility to submit their "Seminar Attendance Certificates" attached to their term activity report. BME records should show that the number of seminars a student has attended is at least four times the number of terms the student has been enrolled as a full-time student in the program.
    - Each student will be required to present a research seminar by the end of their final term and as part of the PACE module milestones. BME will contact seminar candidates with scheduling information after they have passed their comprehensive exam (Parts I and II).
  - PACE days:
    - Students are required to attend and participate in 2 PACE days at the beginning of terms 1, 2, 3, 4 and 5. PACE days are dedicated to students' professional development and the topics vary each term.
  - Annual BME Research Day – once per year
    - Students are required to attend and present at the Annual BME Research Day. The annual event gives students an opportunity to showcase their progress and research findings while building

community among BME graduate students. Students are required to submit an abstract and give either an oral or poster presentation.

- PhD Comprehensive Examination I (Background) and II (Proposal)
    - Students are required to meet the University-level PhD Comprehensive Examination minimum requirements outlined in the "Minimum requirements for the PhD degree" section of the Graduate Studies Academic Calendar (GSAC), with certain noted differences that are specific to the Faculty of Engineering Comprehensive Examination minimum requirements:
        - Comprehensive examination purpose: Consistent with University-level minimum requirements.
        - Timing: Students must follow the Faculty of Engineering completion timelines.
        - Committee: Students must follow the Faculty of Engineering committee composition guidelines which differ from the University-level minimum requirements in both number of committee members and committee makeup.
        - Who Chairs an examination: Students must follow the Faculty of Engineering Chair guidelines whereby the Chair is normally selected from outside of the student's home department.
        - Format / Content: Consistent with University-level minimum requirements but with additional information provided in the Faculty of Engineering Comprehensive Examination minimum requirements.
        - Academic integrity: Consistent with University-level minimum requirements.
    - In addition to the University-level and Faculty-level PhD Comprehensive Examination minimum requirements, PhD students in the Biomedical Engineering graduate program are also required to meet the following requirements:
        - Students must successfully complete (pass) the Comprehensive Background Examination (Comprehensive Exam I (Background)) and the Comprehensive Proposal Examination (Comprehensive Exam II (Proposal) which are conducted by the Department for each candidate.
        - The first exam, the Comprehensive Background Examination, will be held before the end of the third term (fourth term if transferring from an incomplete MASc). The main objective of this examination is to satisfy the Department that the candidate has a broad knowledge of their field and a thorough technical background to pursue their research; the candidate will be questioned on their background preparation.
        - The second exam, the Comprehensive Proposal Examination, will be held no later than the student's sixth term and only after the Background Comprehensive Examination has been successfully completed. The main objective of this examination is to examine and approve the written thesis proposal.

        - The result of these examinations is the identification of an Advisory Committee which has examined and approved the candidate's background and thesis proposal and is willing to assist the supervisor with the subsequent research program.
        - Students who do not complete either Comprehensive Examination by the stated deadline, or fail either exam on their second attempt, will be required to withdraw from the program.
        - It is the supervisor's responsibility to assemble the advisory committee.
- PhD Thesis and Oral Defence
    - Students may choose to pursue one (1) of the following Graduate Research Fields:
        - Biomaterials, Tissue Engineering, and Drug Delivery
        - Biomechanics and Rehabilitation
        - Biomedical Signals and Devices
        - Biomedical Imaging Technology
        - Biomedical Informatics
    - Candidates are expected to attend annual meetings with their Advisory Committee and complete term reports to provide updates on their progress.
    - A Graduate Research Field is a university credential that is recognized on the student's transcript and is intended to reflect that a student has successfully completed research concentrated in the area of the Graduate Research Field. The BME graduate program, represented by the student's supervisor and examining committee, must assess whether a student's completed research warrants the field designation at the time of degree completion.
    - Candidates are expected to maintain continuous registration until the thesis is submitted to Graduate Studies and Postdoctoral Affairs. Under exceptional circumstances, inactive terms or a leave of absence may be requested for a prior specified period with program approval. The role of a supervisor is to assist a candidate in establishing a research problem with an appropriate scope, to suggest alternative general approaches to the solution of a problem and to provide general advice on the structure and content of a thesis. It is imperative that the engineering code of ethics be strictly observed in the supervisor-candidate relationship.
    - The PhD degree in the Faculty of Engineering is awarded to a candidate who has successfully completed a program of advanced study and conducted original research. The program of research and its findings must be presented in the form of a thesis and submitted to the University for public examination prior to its oral defense.
    - The writer of a thesis must demonstrate a critical awareness and understanding of the literature in the research field, exhibit a capability of defining original and useful research problems and a capability of independent thought in solving a research problem. An ability to communicate research results verbally and in writing must be shown. The University of Waterloo allows students to submit theses in English or in French, the latter being governed by certain important constraints. The

principles governing the submission of theses in French are specified in the Graduate Studies Academic Calendar. The oral examination of a thesis will assess the ability of a candidate to communicate orally the results of the research and to defend the contents of the thesis.

- Originality in a thesis may be reflected in a number of ways. A candidate may have posed and solved an important new problem or have formulated an existing problem in a novel and useful way. A candidate may offer new and significant insights into problems examined previously by other researchers. Replications of previous investigations may be acceptable if, and only if, they incorporate [significantly new] elements in the design or execution of an experiment.
- Objective criteria describing what is meant by a significant contribution to knowledge are difficult to specify. One way of gauging a candidate's contribution is to consider the extent to which parts of the thesis might be published in peer-reviewed technical journals with an international stature or as a monograph by an acceptable publisher. The ultimate test of the acceptability of a thesis is the ability of a candidate to satisfy, through an oral examination, to a university-appointed committee of research specialists in the general field of study, that a significant research contribution has been made and communicated adequately.

Appendix D New program report on library support for the proposed graduate (MASc and PhD) program in Biomedical Engineering (August 2022)

1. Level of support summary:

The library provides a high level of support for the undergraduate Biomedical Engineering program and curates a collection to meet the research-intensive needs of existing graduate programs in engineering and science. The library selectively collects clinical information to support research and teaching in the School of Pharmacy, the School of Optometry and Vision Science, and the Faculty of Health that may be of interest to those conducting research in more specialized clinical areas. Access to clinical information not available through library subscriptions is provided through Inter-Library loan services. A liaison librarian works closely with faculty members, researchers, and students in Biomedical Engineering and has a high level of expertise developing creative programming and supporting multidisciplinary research and teaching.

2. Strengths of support provided and recommended opportunities for improvement:

Collections

The library purchases and subscribes to resources relevant to Biomedical Engineering such as Biomaterials, Acta Biomaterialia, Annual Review of Biomedical Engineering, and Nature Biomedical Engineering. Given the multidisciplinary nature of the Biomedical Engineering program, resources purchased or licensed to support other Faculties and departments at the University of Waterloo expand the breadth of resources available to Biomedical Engineering faculty members, researchers, and graduate students. This includes access to the IEEE Xplore Digital Library, SpringerMaterials, Association for Computing Machinery (ACM) Digital Library and publications, Scopus, Web of Science, PubMed, Embase, SPIE, Business Source Elite, and EconLit. The library's full-text resources are linked through Google Scholar, which directly connects students to our subscriptions via the search engine. Library subscriptions provide access to significant electronic book collections including Taylor & Francis, Knovel, and Springer. Current subscriptions provide online access to ASTM, ASME and IEEE standards. Online access to Canadian Standards and Codes is provided through a subscription to the Canadian Standards Association (CSA). Other standards, including ISO standards, are acquired selectively and as budgets permit.

The University of Waterloo Library partners with other Ontario and Canadian universities to further expand access to information through consortial purchasing at the national and provincial level and through our consortial academic search tool OMNI, which allows users to discover materials from 16 Ontario universities through one search interface.

In an ongoing service, faculty members and students can request digitized chapters or articles from a print book in our collection or have print books mailed to their homes or residences provided they are living or staying in Canada.

Should new research areas emerge within the scope of the Biomedical Engineering graduate program, the library is committed to engaging in discussions to articulate collection needs and assess funding implications.

Instruction and Research Support

The Liaison Librarian provides extensive course-based instruction at the undergraduate level in Biomedical Engineering and at the undergraduate and graduate levels in Systems Design Engineering to guide students in determining their need for information, locating, and evaluating appropriate sources, and properly citing information.

The Liaison Librarian is available for 1:1 research consultations and meetings with Lab groups to discuss various types of literature reviews, best resources, research methods, and publishing support, such as identifying predatory journals. All are encouraged to make use of the learning, teaching, research support services, and expertise the library offers.

The Liaison Librarian interacts with the Biomedical Engineering program director to ensure awareness of new services and resources and to provide a line of communication for any issues or recommendations.

3. More information

The library would be happy to meet with the program reviewers to discuss this report and answer their questions. For additional information about University of Waterloo Library and the support it provides for programs, please visit https://uwaterloo.ca/library/about/policies-and-guidelines/support-academic-programs.

4. Report provenance

Report written by Kate Mercer, Liaison Librarian for Systems Design Engineering and Biomedical Engineering, kmercer@uwaterloo.ca
Report reviewed by Jennifer Haas, Head of Davis Library Information Services and Resources, j2haas@uwaterloo.ca
Report approved by Victoria Chu, Associate University Librarian, Learning, Research, and User Services, victoria.chu@uwaterloo.ca

Appendix E - Summary of Learning Outcomes Mapped to Courses and Assessment Methods – MASc Degree

Specific GDLEs and Associated Learning Outcomes	BME 601^ / BME 602^/ BME 603^	Field-specific Course* (1)	Elective Courses+ (2)	Written Dissertation	Oral Thesis Defense	Seminar Series▪	Research Design and Planning▪	Professional Presentations▪	Scientific Writing▪	BME Research Day▪
1. Depth and Breadth of Knowledge										
Interpret, understand, and critically assess state-of-the-art methods, theories, and advances in biomedical engineering	A	A	A	A	A	C	NA	NA	NA	C
2. Research & Scholarship										
Conduct rigorous scientific research to answer questions, while making reasoned judgements and accounting for technical limitations and uncertainties	C	C	C	A	A	NA	C	NA	NA	C
Integrate complex engineering concepts related to the breadth of biomedical engineering, and the underlying and associated sciences	A	A	A	A	A	C	NA	C	C	C
Produce original research related to the design, development, analysis and validation of biomedical solutions/innovations	NA	NA	NA	A	A	C	NA	NA	NA	A
3. Level of Application of Knowledge										
Interpret, critically assess and apply state-of-the-art methods, theories, and advances in biomedical engineering	A	A	A	A	A	A	C	NA	NA	NA
4. Professional Capacity/Autonomy										

Specific GDLEs and Associated Learning Outcomes	BME 601^ / BME 602^/ BME 603^	Field-specific Course* (1)	Elective Courses+ (2)	Written Dissertation	Oral Thesis Defense	Seminar Series▪	Research Design and Planning▪	Professional Presentations▪	Scientific Writing▪	BME Research Day▪
Independently recognize, define and solve complex real-world biomedical needs and associated challenges	C	C	C	A	A	NA	NA	NA	NA	NA
Engage in self-directed professional development and life-long learning	NA	NA	NA	NA	NA	NA	A	NA	NA	C
Ability to recognize, appreciate, consider and apply appropriate ethics, law, regulations, and accountability to biomedical engineering field	C	NA	NA	NA	NA	NA	A	NA	NA	C
Understanding the value of engaging in inter-disciplinary research in biomedical engineering as well as the complexity of knowledge and limitations of different fields	C	NA	NA	C	C	C	A	C	NA	A
5. Level of Communication Skills										
Effectively communicate complex concepts in biomedical engineering to a wide audience ranging from general public to experts in the field biomedical needs and associated challenges (includes GDLE 6 Awareness of Limits of Knowledge)	C	NA	NA	A	A	A	A	A	A	A
6. Awareness of Limits of Knowledge										

Specific GDLEs and Associated Learning Outcomes										
	BME 601^ / BME 602^/ BME 603^	Field-specific Course* (1)	Elective Courses+ (2)	Written Dissertation	Oral Thesis Defense	Seminar Series▪	Research Design and Planning▪	Professional Presentations▪	Scientific Writing▪	BME Research Day▪
Cognizance of the complexity of knowledge and of the potential contributions of other interpretations, methods, and disciplines.	C	C	C	A	A	C	NA	NA	NA	NA

Notes

- Assessed (A) = The outcome is addressed and is formally assessed
- Covered (C) = The outcome is addressed but not assessed
- Not addressed (NA) = The outcome is not addressed
- ^ Required core courses
- * One of 20 courses available
- + Two of 50 courses available
- ▪ Professional Attributes and Competence Enhancement (PACE) Module

Appendix F - Summary of Learning Outcomes Mapped to Courses and Assessment Methods – PhD Degree

Specific GDLEs and Associated Learning Outcomes	BME 601^ / BME 602^/ BME 603^	Field-specific Course* (1)	Elective Courses+ (2)	PhD Comprehensive Exam I (Background)	PhD Comprehensive Exam II (Proposal)	Written Dissertation	Oral Thesis Defense	Seminar Series▪	Research Design and Planning▪	Professional Presentations▪	Scientific Writing▪	Vision Development▪	Proposal Writing▪	BME Research Day▪
1. Depth and Breadth of Knowledge														
Interpret, understand, and critically assess state-of-the-art methods, theories, and advances in biomedical engineering	A	A	A	A	A	A	A	A	C	NA	NA	NA	NA	NA
2. Research & Scholarship														
Conduct rigorous scientific research to answer questions, while making reasoned judgements and accounting for technical limitations and uncertainties	C	C	C	C	C	C	A	A	NA	C	NA	NA	C	C
Integrate complex engineering concepts related to the breadth of biomedical engineering, and the underlying and associated sciences	A	A	A	A	NA	A	A	A	C	NA	C	C	C	C
Produce original research related to the design, development, analysis and validation of biomedical solutions/innovations	NA	NA	NA	NA	NA	A	A	A	C	NA	NA	NA	NA	NA
3. Level of Application of Knowledge														

Apply basic research and development principles and practices relevant to their biomedical engineering specialty	A	A	C	C	NA	A	A	A	NA	NA	NA	NA	NA	NA
Interpret, critically assess and apply state-of-the-art methods, theories, and advances in biomedical engineering	A	A	A	A	A	A	A	A	A	C	NA	NA	C	NA
4. Professional Capacity/Autonomy														
Independently recognize, define and solve complex real-world biomedical needs and associated challenges	C	C	C	C	A	A	A	A	NA	NA	NA	NA	NA	NA
Engage in self-directed professional development and life-long learning	NA	NA	NA	NA	NA	NA	NA	NA	NA	A	NA	NA	A	NA
Ability to recognize, appreciate, consider and apply appropriate ethics, law, regulations, and accountability to biomedical engineering field	C	C	NA	NA	NA	NA	NA	NA	NA	A	NA	NA	A	C
Understanding the value of engaging in inter-disciplinary research in biomedical engineering as well as the complexity of knowledge and limitations of different fields	C	C	NA	NA	C	C	C	C	C	A	C	NA	C	C
5. Level of Communication Skills														
Effectively communicate complex concepts in biomedical engineering to a wide audience ranging from general public to experts in the field biomedical needs and associated challenges	C	C	NA	NA	A	A	A	A	A	A	A	A	A	A
6. Awareness of Limits of Knowledge														
An appreciation of the limitations of their own work and discipline, of the complexity of knowledge, and of the potential contributions of other interpretations, methods, and disciplines.	C	C	C	A	A	A	A	C	C	NA	NA	NA	C	C

Notes

- Assessed (A) = The outcome is addressed and is formally assessed

- Covered (C) = The outcome is addressed but not assessed
- Not addressed (NA) = The outcome is not addressed
- ^ Required core courses
- * One of 20 courses available
- + Two of 50 courses available
- ▪ Professional Attributes and Competence Enhancement (PACE) Modules

Appendix G: Faculty Members beyond the core partnering departments.

In addition to the faculty members in the core supporting departments identified in Table 1, there are faculty members across campus who are conducting research in at least one of the five research fields of the BME Graduate programs. Unless otherwise noted, all faculty members have ADDS status.

Faculty Name	Rank	Home Unit
Stacey Acker	Associate Professor	Kinesiology and Health Sciences
Marc Aucoin	Professor	Chemical Engineering
Hector Budman	Professor	Chemical Engineering
Jack Callaghan	Professor	Kinesiology and Health Sciences
Melanie Campbell	Professor	Physics and Astronomy
Pu Chen	Professor	Chemical Engineering
Perry Chou	Professor	Chemical Engineering
Kristine Dalton	Associate Professor	Optometry and Vision Science
Clark Dickerson	Professor	Kinesiology and Health Sciences
Adil El-Mayah	Professor	Civil and Environmental Engineering
Christian Euler	Assistant Professor	Chemical Engineering
Steve Fischer	Associate Professor	Kinesiology and Health Sciences
Emmanuel Ho	Associate Professor	School of Pharmacy
Chris Hudson	Professor	Optometry and Vision Science
Lyndon Jones	Professor	Optometry and Vision Science
Andrew Laing	Associate Professor	Kinesiology and Health Sciences
Yilan Liu	Assistant Professor	Chemical Engineering
Monica Maly	Associate Professor	Kinesiology and Health Sciences
Christine Moresoli	Professor	Chemical Engineering
Plinio Morita	Associate Professor	School of Public Health Sciences
Elisabeth Prince	Assistant Professor	Chemical Engineering
Hamed Shahsavan	Assistant Professor	Chemical Engineering
Roderick Slavcev	Associate Professor	School of Pharmacy

Michael Tam	Professor	Chemical Engineering
Ting Tsui	Associate Professor	Chemical Engineering
Valerie Ward	Assistant Professor	Chemical Engineering
Stan Woo*	Clinical Professor	Optometry and Vision Science
Evelyn Yim	Associate Professor	Chemical Engineering
Boxin Zhao	Professor	Chemical Engineering

* No supervisory status

Appendix H: Biomedical Engineering Graduate Program Electives

Biomedical Engineering graduate students can meet their elective requirements by taking courses from the Faculties of Engineering, Health, and Science. This list contains eligible elective courses for the 2021/22 academic year in each research field.

- **Biomaterials, tissue engineering and drug delivery (including regenerative medicine)**
  - BME 684 (recoded from SYDE 684): Materials Biocompatibility
  - CHE 601: Theory and Application of Transport Phenomena
  - CHE 602: Chemical Reactor Analysis
  - CHE 612: Interfacial Phenomena
  - CHE 620: Applied Engineering Mathematics
  - CHE 640: Principles of Polymer Science
  - CHE 660: Principles of Biochemical Engineering
  - CHE 663: Bioseparations
  - CHE 760: Special Topics in Biochemical Engineering
  - ECE 601: Foundations of Biology in Engineering
  - BIOL 636: Advanced Immunology
  - KIN 657: Human Neuroanatomy
  - PHARM 609: Advanced Pharmacokinetics
  - PHARM 610: Topics in Drug Development
  - PHARM 617: Formulations

- **Biomechanics and rehabilitation (including both solid and fluid mechanics)**
  - BME 550: Sports Engineering
  - BME 551: Biomechanics of Human Movement
  - BME 588, Topic 1: Mechanics of Biomaterials and Tissues
  - ME 662: Advanced Fluid Mechanics
  - ME 663: Computational Fluid Dynamics
  - ME 720: Special Topics in Solid Mechanics Topic 5: Impact Biomechanics
  - ME 720: Special Topics in Solid Mechanics Topic 4: Mechanics of Medical Devices
  - ME 621: Applied Finite Element Methods
  - ME 780: Special Topics in Mechatronics Topic 37: Human Movement Neuromechanics
  - SYDE 644: Human Factors Testing
  - AMATH 663: Fluid Mechanics
  - PHYS 752: Molecular Biophysics
  - KIN 601: Skeletal Muscle Physiology: Structure & Function
  - KIN 602: Respiratory and Cardiovascular Physiology

- KIN 603: Cardiac and Vascular Smooth Muscle Physiology
- KIN 611: Biomechanics of Human Motion
- KIN 613: Modern Methods in Biomechanical Modeling, Kinematics, and Kinetics
- KIN 620: Ergonomic Aspects of Occupational Musculoskeletal Injuries

- **Biomedical signals and devices (including EEG, EMG, brain-computer interfaces and neuroscience applications, micro and nano devices)**
  - ECE 730: Special Topics in Solid State Devices Topic 34: Biosensing – Fundamentals and Applications
  - ECE 770: Special Topics in Antenna and Microwave Theory Topic 4: Computational Methods for Engineering Electromagnetics
  - ME 720: Special Topics in Solid Mechanics Topic 4: Mechanics of Medical Devices
  - ME 739: Manufacturing Processes Topics Topic 3: Materials for Nano & Microelectromechanical Systems
  - ME 739: Manufacturing Processes Topics Topic 15: Additive Manufacturing Design
  - ME 765: Special Topics in Fluid Mechanics Topic 22: Microfluidic and MEMS Systems and Applications
  - ME 780: Special Topics in Mechatronics Topic 32: Neural and Rehabilitation Engineering
  - NANO 604: Nanomechanics and Molecular Dynamics Simulations
  - SYDE 750: Topics in Systems Modelling Topic 38: Social Robotics
  - KIN 653: Human Neuroscience Theory

- **Biomedical imaging technology (including ultrasound, X-ray, MRI, optics, microwave)**
  - BME 677 (recoded from SYDE 677): Medical Imaging
  - BME 780 (recoded from SYDE 780): Biomedical Optics
  - ECE 607: Fundamentals of Ultrasonics
  - ECE 613: Image Processing and Visual Communication
  - ECE 675: Radiation & Propagation of Electromagnetic Fields
  - ME 720: Special Topics in Solid Mechanics Topic 20: Acoustics
  - SYDE 671: Advanced Image Processing
  - SYDE 672: Statistical Image Processing
  - SYDE 675: Pattern Recognition
  - PHYS 751: Clinical Applications of Physics in Medicine

- **Biomedical informatics (including AI, big data, population and health system studies)**

- AMATH 882: Mathematical Cell Biology
- BIOL 614: Applied Bioinformatics and Genomics
- HLTH 612: Data Structures and Standards in Health Informatics
- HLTH 615: Requirements Specification and Analysis in Health Systems
- HLTH 616: Decision Making and Systems Thinking in Health Informatics
- HLTH 719: Advanced Research Methods in Health Informatics
- KIN 613: Modern Methods in Biomechanical Modeling, Kinematics, and Kinetics

- **BME and health electives (general electives that include topics in more than one research fields)**
  - ECE 603: Statistical Signal Processing
  - ECE 608: Quantitative Analysis in Biomedical Engineering
  - SYDE 642: Cognitive Engineering Methods
  - SYDE/ECE 750: Topics in Systems Modelling/Special Topics in Computer Software Topic 37/32: Biology and Computation
  - SYDE/ECE 750: Topics in Systems Modelling/Special Topics in Computer Software Topic 39/33: Embodied Intelligence
  - KIN 601: Skeletal Muscle Physiology: Structure & Function
  - KIN 606: Molecular Basis of Disease
  - KIN 607: Integrative Energy Metabolism in Health and Disease
  - KIN 608: Introduction to Genetics for the Biosciences
  - KIN 612: Instrumentation and Signal Processing in Biophysical Research
  - KIN 646: Physiological and Biochemical Analysis of Nutrition and Health
  - KIN 653: Human Neuroscience Theory
  - KIN 654: Instrumentation in Neuroscience Research

Appendix I: Senate Graduate & Research Council - Graduate Studies Course/Milestone Forms

The forms to establish BME 601, 602 and 603 are found on the following six pages.

Prior to form submission, review the content revision instructions. For questions about the form submission, contact Trevor Clews, Graduate Studies and Postdoctoral Affairs (GSPA).

Faculty: Engineering

Effective date: Term: Winter Year: 2025

Milestone
Note: milestone changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Choose an item.

☐ Inactivate: Choose an item.

☐ Revise: from Choose an item. to Choose an item.

Course
Note: some course changes also require the completion/submission of the Graduate Studies Program Revision Template.

☒ New: Complete all course elements below

☐ Inactivate: Complete the following course elements:
Course subject code, Course number, Course ID, Course title

☐ Revise: Complete all course elements below to reflect the proposed change(s) and identify the course elements being revised (*e.g. Course description, Course title*):

Course elements (complete as indicated above. Review the glossary of terms for details on course elements)

Course subject code: Choose an item. BME

Course number: 601

Course ID:

Course title (max. 100 characters including spaces): Physiological Systems and Biomedical Design

Course short title (max. 30 characters including spaces): Physiol Systms & Biomed Design

Grading basis: Numerical

Course credit weight: 0.50

Course consent required: Not required

Course description:
This course surveys the anatomy and physiology of the human body at the cellular, organ and whole-body scale, from a systems biology/physiology perspective. Cell biology and some of the physiological systems (e.g., musculoskeletal, cardiovascular, pulmonary, digestive, renal, nervous and sensory, and immune) and their integration/interactions will be introduced from a quantitative systems perspective. Where applicable, common sources of impairments of each system (e.g., pathologies, aging, etc.) will be presented along with implications for diagnostic, therapeutic and rehabilitative technologies (and universal design). Students will be required to perform engineering design that applies their knowledge in biology and physiology that they have gained throughout the course.

Meet type(s): Lecture Choose an item. Choose an item. Choose an item.

Primary meet type: Lecture

Delivery mode: On-campus

Requisites:

Special topics course: Yes ☐ No ☒

Cross-listed course: Yes ☐ No ☒

Course subject code(s) and number(s) to be cross-listed with and approval status: None

Sections combined/held with: None

Rationale for request: Core course in the Biomedical Engineering Graduate Program.

Form completed by:
Department/School approval date (mm/dd/yy): 12/06/23
Reviewed by GSPA (for GSPA use only) ☒ date (mm/dd/yy): 01/16/24
Faculty approval date (mm/dd/yy): 12/04/23
Senate Graduate & Research Council (SGRC) approval date (mm/dd/yy):

Prior to form submission, review the content revision instructions. For questions about the form submission, contact Trevor Clews, Graduate Studies and Postdoctoral Affairs (GSPA).

Faculty: Engineering

Effective date: Term: Winter Year: 2025

Milestone
Note: milestone changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Choose an item.

☐ Inactivate: Choose an item.

☐ Revise: from Choose an item. to Choose an item.

Course
Note: some course changes also require the completion/submission of the Graduate Studies Program Revision Template.

☒ New: Complete all course elements below

☐ Inactivate: Complete the following course elements:
Course subject code, Course number, Course ID, Course title

☐ Revise: Complete all course elements below to reflect the proposed change(s) and identify the course elements being revised (*e.g. Course description, Course title*):

Course elements (complete as indicated above. Review the glossary of terms for details on course elements)

Course subject code: Choose an item. BME

Course number: 602

Course ID:

Course title (max. 100 characters including spaces): Foundations in Biomechanical Engineering

Course short title (max. 30 characters including spaces): Foundations Biomechanical Eng

Grading basis: Numerical

Course credit weight: 0.50

Course consent required: Not required

Course description:
This course focuses on equipping students with foundational knowledge in the biomechanics of human physiology, pathology, and treatment. The overarching aim of this course is to develop students' literacy in applying biomechanics principles and modern tools towards understanding the human body. The course will build on existing knowledge in mathematics and physics to develop new expertise and hands-on experience in the biomechanical modeling and analysis of physiological systems.

Meet type(s): Lecture Choose an item. Choose an item. Choose an item.

Primary meet type: Lecture

Delivery mode: On-campus

Requisites:

Special topics course: Yes ☐ No ☒

Cross-listed course: Yes ☐ No ☒

Course subject code(s) and number(s) to be cross-listed with and approval status: None

Sections combined/held with: None

Rationale for request: Core course in the new Biomedical Engineering Graduate Program.

Form completed by:
Department/School approval date (mm/dd/yy): 12/06/23
Reviewed by GSPA (for GSPA use only) ☒ date (mm/dd/yy): 12/04/23
Faculty approval date (mm/dd/yy): 01/16/24
Senate Graduate & Research Council (SGRC) approval date (mm/dd/yy):

Prior to form submission, review the content revision instructions. For questions about the form submission, contact Trevor Clews, Graduate Studies and Postdoctoral Affairs (GSPA).

Faculty: Engineering

Effective date: Term: Winter Year: 2025

Milestone
Note: milestone changes also require the completion/submission of the Graduate Studies Program Revision Template.

☐ New: Choose an item.

☐ Inactivate: Choose an item.

☐ Revise: from Choose an item. to Choose an item.

Course
Note: some course changes also require the completion/submission of the Graduate Studies Program Revision Template.

☒ New: Complete all course elements below

☐ Inactivate: Complete the following course elements:
Course subject code, Course number, Course ID, Course title

☐ Revise: Complete all course elements below to reflect the proposed change(s) and identify the course elements being revised (*e.g. Course description, Course title*):

Course elements (complete as indicated above. Review the glossary of terms for details on course elements)

Course subject code: Choose an item. BME

Course number: 603

Course ID:

Course title (max. 100 characters including spaces): Engineering Analysis of Living Cells

Course short title (max. 30 characters including spaces): Eng Analysis of Living Cells

Grading basis: Numerical

Course credit weight: 0.50

Course consent required: Not required

Course description:
Cell biology has reached a stage where it is in dire need of quantitative understanding. The vast amount of data gathered with the advance of experimental technologies, in the search for a general understanding of the complex cell mechanism at the molecular level, have often made the traditional way of direct interpretation impossible. Therefore, recent years have seen significant efforts made to understand these data with more sophisticated mathematical models, using fundamental physical laws and engineering analytic techniques. This course is an introduction to some of the successful achievements of these approaches, and the exciting potential outcomes of this line of research.

Meet type(s): Lecture Choose an item. Choose an item. Choose an item.

Primary meet type: Lecture

Delivery mode: On-campus

Requisites:

Special topics course: Yes ☐ No ☒

Cross-listed course: Yes ☐ No ☒

Course subject code(s) and number(s) to be cross-listed with and approval status:

Sections combined/held with: ECE609

Rationale for request: Core course in the new Biomedical Engineering Graduate Program.

Form completed by:
Department/School approval date (mm/dd/yy): 12/06/24
Reviewed by GSPA (for GSPA use only) ☒ date (mm/dd/yy): 01/16/24
Faculty approval date (mm/dd/yy): 12/04/24
Senate Graduate & Research Council (SGRC) approval date (mm/dd/yy):

UNIVERSITY OF
WATERLOO

NEW PROGRAM PROPOSAL*

MASc and PhD

IN

Biomedical Engineering

Submitted to the
Ontario Universities Council on Quality Assurance

VOLUME II – FACULTY CURRICULA VITAE

JANUARY 2024

TABLE OF CONTENTS

Contents

Summary of Faculty Qualifications

This compilation of CVs is provided as evidence of the breadth and depth of biomedical engineering expertise, graduate level training and research being conducted at the University of Waterloo amongst the faculty members of the three partner departments of the proposed programs (Electrical and Computer Engineering, Mechanical and Mechatronics Engineering and Systems Design Engineering). Many faculty members from other departments in the Faculty of Engineering and from other faculties such as the Faculty of Health and Faculty of Science will also contribute to the proposed program at Biomedical Engineering Graduate Program faculty members.

The list includes faculty members of all ranks (lecturers, assistant, associate, and full professors) with expertise spanning the five proposed research areas: Biomaterials, tissue engineering and drug delivery; Biomechanics and rehabilitation; Biomedical signals and devices; Biomedical imaging technology; Biomedical informatics. While many of the faculty members hold PhDs in traditional engineering disciplines, many of these conducted biomedical engineering research during their graduate studies. Five of the listed faculty members hold PhDs in biomedical engineering specifically. Furthermore, several faculty members hold PhDs in associated medical sciences, nanoscience, mathematics, and more.

A survey of the CVs reveals outstanding scholarly records, exemplary pedagogical practices, depth and breadth of expertise in the field of biomedical engineering, and extensive supervisory experience complemented by relevant collaborations, leadership, service, industry experience and entrepreneurship. Furthermore, many of the faculty members receive research funding for their biomedical engineering research from major sources like NSERC, CIHR and many other relevant sources including MITACS, industry, and disease specific and patient advocacy groups.

Curricula Vitae

Ren, Carolyn

Tripp, Bryan

Tung, James

Vlasea, Mihaela

Willett, Thomas

Wong, Alexander

Wu, Yimin

Xie, Liang-Liang

Yarusevych, Serhiy

Yavuz, Mustafa

Yeow, John

Yu, Alfred

Zelek, John

External Reviewers' Report For New Programs

Reviewers' Report on the MASc and PhD Program in Biomedical Engineering at the University of Waterloo.

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EXECUTIVE SUMMARY

The proposed thesis-based graduate program (MASc and PhD) in Biomedical Engineering (BME) is a culmination of over 15 years of careful planning, leveraging existing resources and expertise from the institution's undergraduate BME program. The program will be delivered via a collegial partnership among three core engineering programs, supported by a funding agreement and plans for future expansion of faculty and staff. Addressing an urgent need, it aims to attract and retain high-quality students, projecting an enrollment of over 100 students. This innovative program is a logical addition to the University of Waterloo, offering an "engineering-focused" curriculum with potential ties to commercialization and experiential learning opportunities beyond the thesis area.

The Master's and PhD curricula map closely to well-defined program level learning outcomes that are appropriate for a biomedical engineering graduate degree. The program is designed to give students exposure to the breadth of biomedical engineering through the core courses and seminar series and depth within a field through a rich suite of field-specific courses and thesis research. The innovative PACE module curriculum emphasizes scientific communication, research skills, and professionalism, ensuring adaptability year-to-year. Graduate student support and formative feedback are ensured through regular, structured advisory committee feedback. The reviewers agree with the Provost's description of the program as a "great investment in curricular evolution", and we commend the team for their forward-thinking approach.

1. DETAILS OF THE SITE VISIT

Was the site visit: In person: ☒ Virtual site visit: ☐ Desk Review: ☐

If the review was conducted either virtually or via desk review, was this format agreed to by both external reviewers?

n/a

Was sufficient rationale provided by the Provost/Provost's delegate for an off-site visit?

n/a

1.1 Outline of the Visit

- With whom did you meet?
- What facilities were seen?
- Discuss any other activities relevant to the appraisal.
- Attach or insert site visit schedule

We met with:

1) administrative leadership (e.g., Biomedical Engineering Graduate Program Director; Chairs of the three administrative departments; Associate Deans; Dean of Engineering; Associate Vice-President, Graduate Studies and Postdoctoral Affairs; Vice-President (Academic) and Provost)
2) biomedical engineering faculty
3) library staff
4) professional staff (e.g., Administrative Officer; Academic Services Coordinators; Lab Director)
5) graduate students

We visited various laboratories, including faculty laboratories in engineering (e.g., Tung, Karim, McLachlin, Arami, Willett, Maftoon, Gorbet, Magdanz, Samara), Kinesiology, and Optometry. We also had a tour of the IDEATION Lab and Anatomy Lab.

A copy of the Site Visit Schedule is attached to this report.

1.2 Effectiveness

In order to continuously improve the effectiveness and efficiency of site visits, please comment on the following:

- How effective was the self-study in preparing you for the visit?
- How could the logistics of the visit be improved?

The self-study adequately prepared us for the program visit.

The logistics of the visit were good. We did note that our host experienced some minor challenges with short-term parking while shuttling us across campus; however, this did not

impact our visit.

2. EVALUATION CRITERIA (QAF 5.1.3.1)

2.1 Objectives

For the following Yes/No questions, if 'No', please explain.

- Are the program's objectives clearly described? YES
- Is the degree nomenclature appropriate, given the program's objectives? YES
- Is the program consistent with the University of Waterloo's mission and relevant academic strategic plans? YES

2.2 Program Requirements (QAF 5.1.3.1.2)

NOTE: The Quality Assurance Framework requires a clear distinction between program objectives, program-level learning outcomes, and Degree Level Expectations. Please see the Guidance on Program Objectives and Program-level Learning Outcomes for details on the distinction.

For the following Yes/No questions, if 'No', please explain.

- Are the program's structure and the requirements to meet program objectives and program-level learning outcomes appropriate? YES
- Are the program's structure, requirements and program-level learning outcomes
  - in alignment with the University of Waterloo's Undergraduate or Graduate Degree Level Expectations? YES
  - clear and appropriately communicated? YES
- Is the mode of delivery appropriate in facilitating students' successful completion of the program-level learning outcomes? YES
- What are the ways in which the curriculum addresses the current state of the discipline or area of study? *Please explain.*

Biomedical engineering is still a relatively young discipline, compared to the more traditional engineering areas (e.g., civil, mechanical, electrical, etc.). Biomedical engineering is the application of scientific and engineering principles to medicine and biology; it is broad and is inherently interdisciplinary.

The proposed program is organized with five research fields:

1. Biomaterials, Tissue Engineering, and Drug Delivery
2. Biomechanics and Rehabilitation
3. Biomedical Signals and Devices
4. Biomedical Imaging Technology

5. Biomedical Informatics

The proposed program provides students exposure to the breadth of biomedical engineering through the core courses and seminar series and depth within a field through the field-specific course and thesis research. Allowing for 2 elective courses permits flexibility for students to individualize their course selection appropriate for their research needs and interests. The PACE Modules provide students an excellent opportunity to further develop professional, technical, and research skills. The collaborations with the School of Pharmacy, the School of Optometry and Vision Science, and the Department of Kinesiology and Health Sciences, as well as existing research collaborations with hospitals and medical doctors, including locally (e.g., Grand River Hospital, Saint Mary's Hospital), provide opportunities for interaction with clinical researchers and practitioners. The outstanding Anatomy lab teaching facility provides students with valuable training in human anatomy. There also appears to be good existing collaborations with industry, and support for commercialization efforts.

- Do the program name and credential earned (e.g., BA, MSc, PhD, etc.)
    - reflect the content of the program? YES
    - advance the program's objectives? YES

2.3 Program requirements for graduate programs only (QAF 5.1.3.1.3):

For the following Yes/No questions, if 'No', please explain.

- Is there a clear rationale for the program length that ensures that program requirements can be reasonably completed within the proposed time period? YES
- Is there evidence that graduate students required to take a minimum of two-thirds of the course requirements from among graduate-level courses? YES
- Is there a clear indication of the nature and suitability of the major research requirements for degree completion? YES

2.4 Assessment of teaching and learning (QAF 5.1.3.1.4)

NOTE: Programs should ensure that the plans for monitoring and assessing student achievement provide an assessment of students currently enrolled as well as post-graduation metrics. Please see Guidance on Assessment of Teaching and Learning for further details and examples of measures for assessing teaching and learning that meet the requirements of the Quality Assurance Framework.

For the following Yes/No questions, if 'No', please explain.

- Are the methods used to assess student achievement of the program-level learning outcomes and Degree Level Expectations appropriate and effective? Yes

Please comment on the appropriateness and effectiveness of the plans in place to monitor and assess:

The overall quality of the program;

i. Whether the program is achieving in practice its proposed objectives;
ii. Whether its students are achieving the program-level learning outcomes; and
iii. How the resulting information will be documented and subsequently used to inform continuous program improvement.

The self-study notes, "The primary objective of the proposed BME Graduate Program is to produce comprehensively trained and technically outstanding master's and doctoral graduates in biomedical engineering who are prepared to excel and lead in all sectors of society—postsecondary education, industry, not-for-profit, government and more." The program design appears to meet this objective, with program-level learning outcomes appropriate for a biomedical engineering graduate degree and a mapping of how the program activities intend to achieve these learning outcomes, and where they will be assessed.

Program assessment is the responsibility of the BME Graduate Program Committee and BME Graduate Program Director. Assessment of student learning will be derived from a variety of program activities, including courses, comprehensive exams, proposal defenses, end-of-term reports, annual committee assessments, dissertations, oral defenses, and PACE module milestones. Program-level assessment will occur through analysis of key performance indicators including student, stakeholder, and alumni surveys and student evaluations of courses and instruction. The BME Graduate Program Committee intends to meet monthly, which enables good oversight of the program implementation, program assessment, and the ability to enact curricular changes.

It is noted that this program appears to be quite unique to the University of Waterloo, being perhaps the first program to be an administrative partnership across three departments (i.e., Department of Systems Design Engineering, Department of Electrical and Computing Engineering, and Department of Mechanical and Mechatronics Engineering). Programs that span and are jointly administered can result in additional complexities and challenges; however, the three administrative departments all appear supportive of the proposed program, with a good commitment toward delivering a quality program.

2.5 Admission requirements (QAF 5.1.3.1.5)

For the following Yes/No questions, if 'No', please explain.

- Are admission requirements appropriate, given the program's objectives and program-level learning outcomes? Yes
- Are there any applicable alternative admission requirements, including how the program recognizes prior work or learning experience, and if so, are they appropriate? Yes
- *For undergraduate programs, if applicable,* is there a meaningful path for entry outside of standard 1st year entry (e.g., 2+2 programs or programs that require prior study)? Yes

2.6 Resources (QAF 5.1.3.1.6)

NOTE: Recommendations on issues such as faculty complement, space requirements and/or other elements that are within the purview of the university's internal budgetary decision-making process must be tied directly to issue of program quality or sustainability.

For the following Yes/No questions, if 'No', please explain.

Given the program's class sizes and cohorts as well as its program-level learning outcomes:

a) Is there a sufficient number and quality of core faculty who are competent to teach and/or supervise sufficient to achieve the goals of the program and foster the appropriate academic environment? Yes

b) When adjunct/sessional faculty play a large role in the delivery of the program, is their role suitable? Are plans in place to ensure the sustainability of the program and the quality of student experience and if so, are these suitable? Yes. We note that there does not appear to be any plans for adjunct/sessional faculty to play a large role in the delivery of the program.

c) Is the provision of supervision of experiential learning opportunities adequate? Yes.

d) Comment on the administrative unit's planned use of existing human, physical and financial resources, including implications for other existing programs at the university.

The Department of Systems Design Engineering is serving as the administrative home for the program, as it currently manages the undergraduate BME program. The self-study notes the hiring of BME Graduate Program Coordinator (100% FTE) to support the coordination of the administrative program work including recruiting, admissions, advising, and approvals related courses, theses, defenses, and milestones. This hiring should be completed as soon as the program is launched and taking on new students, as the current staff in the Department of Systems Design Engineering appear to be at their capacity already. We believe that even the additional load, resulting from transfers of existing students from other departments, may pose challenges if this new hire is not yet in place. Contingency plans, including potential administrative support from other departments, should be considered.

The self-study notes the hiring of a Graduate Program Manager (50% FTE) to jointly support the BME and SYDE Graduate Offices, with duties including the content and delivery of the PACE modules. We believe that the program should consider a 100% FTE to appropriately attend to the content and delivery of the PACE modules. The program should also consider this position to be an instructor or contract instructor position.

e) Are there adequate resources available to sustain the quality of scholarship and research activities produced by students, including library support, information technology support, and laboratory access?

Yes, the resources appear adequate. There are plans for additional hires related to the BME graduate program. It is important that such new hires have access to laboratory space and are supported to build up their laboratories.

There are a number of Biomedical Engineering Graduate Program Electives that are not coded as BME graduate courses. The program should ensure that BME students have some level of guaranteed access to these electives; otherwise, graduate electives that are popular may reach capacity, and if they prioritize students in other programs could effectively exclude BME students from these electives.

2.7 Resources for Graduate Programs Only (QAF 5.1.3.1.7):

For the following Yes/No questions, if 'No', please explain.

Given the program's class sizes and cohorts as well as its program-level learning outcomes:

- Does the faculty have the recent research or professional/clinical expertise needed to sustain the program, promote innovation and foster an appropriate intellectual climate?
- Where appropriate, is financial assistance to students sufficient to ensure adequate quality and numbers of students?

Yes, the faculty has the recent research or professional/clinical expertise needed, and financial assistance to students is sufficient.

The program should ensure the internal funding mechanisms do not result in BME students "falling through the cracks". For example, some graduate scholarships (e.g., OGS) are allocated to the departments, and there will be some BME students from the Department of Systems Design Engineering, which is the department that is the administrative home, but there will also be BME students from other departments (e.g., Department of Electrical & Computer Engineering and Department Mechanical and Mechatronics Engineering); perhaps BME should be providing a separate allocation, similar to a department allocation.

International master's students face a high differential tuition fee, and unlike international PhD students, these differential fees are not offset; this is not specific to the BME program and is the practice across the university. There is the International Master's Award of Excellence (IMAE), which offsets the differential tuition fee for some international master's students. The Faculty of Engineering has also established fellowships to financially support its graduate students. The BME program should be provided equitable access to such funding support opportunities. Similarly, the program should ensure that TA allocations are appropriately available and distributed for the BME students.

- Are supervisory loads adequately distributed, given the qualifications and appointment status of the faculty?

Yes, the supervisory loads are adequately distributed. It is noted that the BME program includes faculty members outside of the Faculty of Engineering, who do not have "Engineering Status", which makes them ineligible to sole-supervise BME graduate students; this includes faculty who may have an engineering background including graduate-level training in biomedical engineering. While such faculty are able to co-supervise students (including having a "nominal"

co-supervisor within the Faculty of Engineering), the program should consider a pathway to enable sole-supervision by such faculty members when appropriate.

2.8 Quality and other indicators (QAF 5.1.3.1.8)

Please comment on:

- Quality of the faculty (e.g., qualifications, funding, honours, awards, research, innovation and scholarly record, appropriateness of collective faculty expertise to contribute substantively to the program and commitment to student mentoring).

  NOTE: Please avoid using references to individuals. Instead, aim to assess the ability of the faculty as a whole to deliver the program and focus on the areas of the program(s) that the university has chosen to emphasize, in view of the expertise and scholarly productivity of the faculty.

- Any other evidence that the program and faculty ensure the intellectual quality of the student experience.

The program aligns well with the University's research strength and strategic directions, including a focus on health technologies. While the BME program will be a new program, there is a strong history of BME research already established, including funding, research infrastructure, honours, awards, and publications. There is also a good record of graduate students engaged in BME research; such students have been enrolled in other degree programs (e.g., Systems Design Engineering, Electrical & Computer Engineering, Mechanical & Mechatronics Engineering), which at times can be an awkward fit and the BME program would improve the student experience.

3. ADDITIONAL INSIGHTS

Please comment on:

- Include any additional assessment of the New Program Proposal as a whole, as appropriate.
- Acknowledge any clearly innovative aspects of the proposed program together with recommendations on any essential or otherwise desirable modifications to it.

We believe that the PACE longitudinal curriculum provides an innovative aspect of the program, which can greatly enrich student learning. PACE provides opportunities for experiential learning outside of thesis research, and opportunities to develop professional and leadership skills in a structured manner. There is potential to leverage existing expertise, such as those of the librarians who have delivered guest lectures in graduate courses; integrating this into the PACE curriculum can help ensure all students have such learning opportunities. The self-study indicated a 50% FTE hire for PACE but we believe a 100% FTE hire is required, and consideration should be made to consider an instructor hire (or contractor instructor).

- Any other issues/comments, as applicable.

We believe that building a strong graduate community for BME students is important. This includes the formation of a new BME graduate student association, which engages students as partners in shaping the new program and provides opportunities for "cohort building". This appears to be aligned with the program's intent, and we encourage efforts to ensure that this happens immediately, so that it is a part of the program from the start.

With respect to Tri-Council funding, the Faculty of Engineering is naturally focused on NSERC funding; however, CIHR funding should expand with the BME program. As the University does not have a medical school, the University, and the Faculty of Engineering in particular may have difficulties with CIHR funding without focused support from the research offices (e.g., seed and bridge funding for pilot data that can help CIHR applications, research support staff with CIHR expertise). CIHR funding can have an indirect impact on BME students.

4. SUMMARY AND RECOMMENDATIONS

Provide a brief summary of the review. Please include commentary on any clearly innovative aspects of the proposed program together with recommendations on any essential or otherwise desirable modifications to it, as applicable.

Recommendations that are clear, concise, and actionable are the most helpful. Please include specific steps to be taken on any essential or otherwise desirable modifications to the proposed program.

Please list your recommendations in order of priority:

Based on the self-study and site visit, we believe the proposed program is a well-thought out program that is able to meet its objectives and deliver a quality learning experience for students. The BME graduate program is a natural addition to the existing BME undergraduate program. It builds upon a strong history of BME research activities. The program has the necessary faculty and research infrastructure, as well as a good plan to provide the appropriate professional staff to support the program. It wisely has collaborations outside of the Faculty of Engineering, including the Department of Kinesiology and Health Sciences and the School of Optometry and Vision Science. While the University does not have a medical school, the program plans to leverage existing collaborations with local hospitals, as well as other nearby hospitals (e.g., Toronto and London).

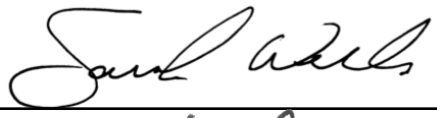
We have 12 recommendations, which we have ordered from highest to lowest priority:

1. **Ensure the new BME Graduate Program Coordinator is hired before new students are recruited.** The program intends to hire a new BME Graduate Program Coordinator, which is necessary as the Graduate Program Coordinators within the Department of Systems Design Engineering are already at capacity. There is also a concern with workload if the number of transfers of existing students into the BME graduate program is large. If the

new BME Graduate Program Coordinator is not in place to handle these transfers, the program should have a contingency plan (e.g., administrative assistance from the other two administrative departments.

2. **Hire a 100% FTE Graduate Program Manager who implements the PACE Modules.** The program proposed to hire a 50% FTE Graduate Program Manager; however, we believe that this should be a 100% FTE given the importance and scope of work for the PACE Modules. In addition, the program should consider hiring an instructor (or contract instructor) for this position.
3. **Increase the term duration for the inaugural BME Program Director.** The Program Director position is proposed to be a 3-year term. While this is reasonable once the program has reached steady-state, we believe that the inaugural BME Program Director should have a long-term (at a minimum, long enough to see the first cohort of students through) given the dynamics when starting up a new program.
4. **Establish a BME graduate student society with the launch of the program.** A BME graduate student society will help engage students in contributing to shaping the program and building the community of BME students. Active encouragement by the program to establish the society, and appropriate supports (e.g., financial support, space), can help ensure the society is present for the launch of the program.
5. **Embed EDIA, information literacy, and team building into the PACE modules.** The PACE modules are described as providing "training in the areas of research design and planning, academic integrity, professional presentation, and scientific writing. PhD students will receive additional training in developing research plans and in writing grant and business proposals." We believe that it is important for the program to include aspects of EDIA, information literacy, and team building in the program. The program could leverage existing programs and expertise at the University, such as librarians who have experience in graduate-level training for information literacy.
6. **Ensure funding allocations for BME students.** Within the Faculty of Engineering, various funding and scholarships are allocated by department (e.g., OGS, IMAE). As BME students will be associated with various departments, there is a danger that they may face inequitable access to funding and scholarships. The program should ensure an equitable allocation process (e.g., a separate allocation to the BME program, similar to a departmental allocation).
7. **Provide BME graduate fellowships.** The Faculty of Engineering has fellowships that help financially support its graduate students. Similar graduate fellowships should be made available for BME graduate students.
8. **Ensure sufficient field-specific courses are offered annually for each of the 5 fields.** The field-specific courses are comprised of courses from multiple departments. Without appropriate coordination, this may result in an academic year with insufficient field-specific courses available in one or more fields. Coordination by the Program Director and Program Committee could avoid this. The program may also consider establishing an introductory graduate course for each field that is delivered annually; this introductory field-specific course may be an existing, modified, or new course.

9. **Establish a plan and process for TA assignments for BME students.** Historically, there has been an alignment between a graduate student's academic program and an undergraduate program within the same department, which simplifies TA assignments; however, the graduate BME students will be associated with multiple departments, while the undergraduate BME program only resides with the Department of Systems Design Engineering. A plan and process should be established to help ensure effective and equitable TA assignments.
10. **Enhance CIHR research support.** The BME program provides greater opportunity for CIHR funding; however, acquiring CIHR funding is challenging without appropriate support (e.g., CIHR knowledge and expertise within the research offices, funding for pilot data).
11. **Consider an exception for "Engineering Status" to allow BME faculty outside of the Faculty of Engineering to sole-supervise graduate students.** The Faculty of Engineering requires "Engineering Status" to sole-supervise graduate students within its programs, which precludes BME faculty, outside of the Faculty of Engineering, who may have an engineering background, including graduate-level training in biomedical engineering. While such faculty are able to co-supervise students (including having a "nominal" co-supervisor within the Faculty of Engineering), the program should consider a pathway to enable sole supervision by such faculty members when appropriate.
12. **Create a plan for DWE Wet Lab Hub infrastructure upgrades.** The DWE Wet Lab Hub is located in the Douglas Wright Engineering Building, which is the oldest building on the University campus. As a result, there are some concerns with the laboratory environment (e.g., temperature control, humidity control, backup power). A plan should be established to upgrade the DWE Wet Lab Hub infrastructure so that it is in line with other BME research laboratories; this may include moving the laboratories into a newer building.

Signature: 

Signature: 

Date: **May 8, 2024**

Biomedical Engineering (MASc and PhD)
Departments of Systems Design Engineering (SYDE), Electrical and Computer Engineering (ECE), and Mechatronics Engineering (MME)
Faculty of Engineering

NEW Academic Program - Site Visit
April 24-25, 2024

Site Visit Team
Dr. Sarah Wells, Dalhousie University, Nova Scotia
Dr. Adrian Chan, Carleton University, Ontario
Dr. Steven Young, associate professor, School of Environment, University of Waterloo

Date (04/24/24)

8:30 – 8:45 a.m.	Transportation from hotel to UW	**Tom Willett** pickup
8:45 – 9:45 a.m.	Breakfast Meeting with Site Visit Team: **Jeff Casello**, Associate Vice-President, Graduate Studies and Postdoctoral Affairs; **Mary Wells**, Dean, Faculty of Engineering; **Tom Willett**, Director, BME Grad Program; **Lisa Aultman-Hall**, Chair, Systems Design Engineering; **Kankar Bhattacharya**, Chair, Electrical & Computer Engineering; **Michael Collins**, Chair, Mechanical and Mechatronics Engineering.	NH 3043
9:45 – 10:15 a.m.	Travel to E5/E7 with **Tom Willett**, situate in 6111	E5-6111
10:15 – 11:15 a.m.	E6/E7/E3 Labs Tour: **Parsin Haji Reza (Ben)**, **James Tung (Alyson)**, **Karim Karim**, **Stewart McLachlin**, **Arash Arami**, RoboHub	**Tom Willett** will give the tour, descending from the 6th floor.
11:15 – 11:30 a.m.	**Break**	E5-6111
11:30 – 12:00 p.m.	Meeting with Associate Deans: **David Clausi,** Associate Dean - Research & External Partnerships; **Siva Sivoththaman**, Associate Dean Graduate Studies and Postdoctoral Affairs	E5-6111
12:00– 1:30 p.m.	**Lunch** with **Mary Wells,** Dean of Engineering	E5-6111
1:30 – 2:45 p.m.	Meeting with Library: **Jennifer Haas**, Head, Information Services and Resources, Davis; **Kate Mercer**, Liaison Librarian	E5-6111
2:45 – 3:15 p.m.	Meeting with BME Grad faculty members: **Bryan Tripp, SYDE; Stewart McLachlin, MME; Veronika Magdanz, SYDE; John McPhee, SYDE; Nima Maftoon, SYDE**	E5-6111

3:15 – 3:30 p.m.	**Break**	E5-6111
3:30 – 4:00 p.m.	Meeting with partner department chairs and director: **Tom Willett**, Director, BME Grad Program; **Lisa Aultman-Hall**, Chair, Systems Design Engineering; **Kankar Bhattacharya**, Chair, Electrical & Computer Engineering; **Michael Collins**, Chair, Mechanical and Mechatronics Engineering.	E5-6111
4:00 – 4:30 p.m.	Meeting with BME Grad faculty members: **Chris Nielsen, ECE; Maud Gorbet, SYDE; Ewen MacDonald, SYDE; Clark Dickerson, KIN** (tentative)	E5-6111
4:30 p.m.	Transportation from UW to hotel	**Tom Willett** drops off at hotel

Date (04/25/24)

8:30 – 8:45 a.m.	Transportation from hotel to UW	**Tom Willett** picks up
8:45 – 9:00 a.m.	**Coffee** at Starbuck's (**Tom Willett**)	BMH/Health
9:00 – 9:30 a.m.	Kinesiology & Anatomy Lab Tour: **Tamara Maciel**, Program Director, School of Anatomy; **Clark Dickerson,** Professor & Canada Research Chair in Shoulder Mechanics; **Tom Willett**	BMH/Health
9:40 – 10:10 a.m.	Tour of Optometry labs/research (Stan Woo, Kelsey Gagnon; still developing); **Tom Willett**	Optometry/CORE
10:20 – 10:50 a.m.	DWE BME space and labs tour: **Tom Willett**, **Nima Maftoon, Maud Gorbet, Veronika Magdanz, Bisan Samara**	DWE 3rd and 2nd floor
10:55 – 11:15 a.m.	IDEATION Lab Tour: **Mahla Poudineh (ECE),** Assistant Professor & Director of IDEATION Lab. Tour will be given by graduate students (Elham, Hesam & Sid); **Tom Willett**	QNC 3622 & 3508
11:15 – 11:30 a.m.	Break and walk over to Needles Hall	
11:30 – 12:00 p.m.	Meeting with **James W.E. Rush**, Vice-President, Academic and Provost	NH 3001
12 – 12:15 p.m.	**Walk over to E5-6111**	
12:15 – 1:00 p.m.	**Lunch** with graduate students	E5-6111
1:00 - 1:30 p.m.	Time for guests to eat their own **catered lunch**	E5-6111
1:30 – 2:00 p.m.	Meeting with Academic Services Coordinators: **Shannel Noseworthy**, Masters students; **Anna Cunningham**, PhD students	E5-6111
2:00 – 2:30 p.m.	Meeting with senior department staff: **Sarah Landy**, Administrative Office; **Eric Kubica**, Lab Director	E5-6111
2:30 – 2:45 p.m.	**Break**	E5-6111
2:45 – 3:15 p.m.	Wrap up with **Tom Willett**, Director, BME Grad Program	E5-6111

3:15 – 4:00 p.m.	Site Visit Team review time and walk to Needles Hall	E5-6111 and **Tom Willett** drive to NH
4:00 – 4:30 p.m.	Exit Meeting with **Jeff Casello**, Associate Vice-President, Graduate Studies and Postdoctoral Affairs	NH 2219 Jeff's Office
4:30 p.m.	Transportation from UW to hotel/airport	**Tom Willett** drop off at hotel

Program Response to External Reviewers' Report **Biomedical Engineering (MASc/PhD)** May 2024

General Commentary
The recommendations fit the program and our plans/aspirations very well. It is impossible currently to fully implement recommendation 3 and 12.

Program Response to External Reviewers' Recommendations

1. **Ensure the new BME Graduate Program Coordinator is hired before new students are recruited.** The program intends to hire a new BME Graduate Program Coordinator, which is necessary as the Graduate Program Coordinators within the Department of Systems Design Engineering are already at capacity. There is also a concern with workload if the number of transfers of existing students into the BME graduate program is large. If the new BME Graduate Program Coordinator is not in place to handle these transfers, the program should have a contingency plan (e.g., administrative assistance from the other two administrative departments.

   Response
   We currently aspire to hire a new BME Graduate Program Coordinator before new students are recruited to the program. The current average number of graduate students per coordinator in the Faculty of Engineering is 100 students. Therefore, hiring this coordinator before the program starts will be consistent with Faculty of Engineering norms based on the estimated steady state enrollment.

2. **Hire a 100% FTE Graduate Program Manager who implements the PACE Modules.** The program proposed to hire a 50% FTE Graduate Program Manager; however, we believe that this should be a 100% FTE given the importance and scope of work for the PACE Modules. In addition, the program should consider hiring an instructor (or contract instructor) for this position

Response

The BME Grad Program agrees with this recommendation. The current plan is to hire a program manager with instructor qualifications/experience on a 100% FTE contract.

4. **Establish a BME graduate student society with the launch of the program.** A BME graduate student society will help engage students in contributing to shaping the program and building the community of BME students. Active encouragement by the program to establish the society, and appropriate supports (e.g., financial support, space), can help ensure the society is present for the launch of the program.

   Response

   This is our intention. Indeed, we have included financial support for this society in our 2024-2025 budget. Once a student body is established, the director and graduate coordinator will work with student representatives to establish the BME Graduate Student Society.

5. **Embed EDIA, information literacy, and team building into the PACE modules.** The PACE modules are described as providing "training in the areas of research design and planning, academic integrity, professional presentation, and scientific writing. PhD students will receive additional training in developing research plans and in writing grant and business proposals." We believe that it is important for the program to include aspects of EDIA, information literacy, and team building in the program. The program could leverage existing programs and expertise at the University, such as librarians who have experience in graduate-level training for information literacy.

   Response

   The BME Grad Program agrees and notes that the resources do indeed already exist on campus. The PACE Graduate Program Manager will be tasked with incorporating these and other subjects into the PACE module as it is developed.

6. **Ensure funding allocations for BME students.** Within the Faculty of Engineering, various funding and scholarships are allocated by department (e.g., OGS, IMAE). As BME students will be associated with various departments, there is a danger that they may face inequitable access to funding and scholarships. The program should ensure an equitable allocation process (e.g., a separate allocation to the BME program, similar to a departmental allocation).

Response

The interim BME director agrees with this recommendation and the inaugural director will ensure that BME graduate students will not be considered 'second class students' within the Faculty of Engineering nor within their home departments, which are determined by the home department of their supervisor.

Note that all thesis/research graduate students at the University of Waterloo receive at least a minimum stipend dictated by their Faculty. In the Faculty of Engineering, the new minimum stipend requirement as of Spring 2024 is $30,000 per year. This does not include what the student may make as a teaching assistant (approximately $7,500 per term).

Nominations for the various provincial and national scholarships are based on academic standing within each home department. All BME graduate students will be associated with home departments, and BME students will be treated as that department's students for this purpose. This is the responsibility of each department's Associate Chair of Graduate Studies. The BME director will monitor this and collect data to protect against inequity.

7. **Provide BME graduate fellowships.** The Faculty of Engineering has fellowships that help financially support its graduate students. Similar graduate fellowships should be made available for BME graduate students.

Response

All graduate students in the Faculty of Engineering are treated the same. Furthermore, according to the new funding model (Spring 2024), fellowships have been replaced by a guaranteed minimum stipend of $30,000.00 per year for PhD students and $18,000 for MASc students.

8. **Ensure sufficient field-specific courses are offered annually for each of the 5 fields.** The field-specific courses are comprised of courses from multiple departments. Without appropriate coordination, this may result in an academic year with insufficient field-specific courses available in one or more fields. Coordination by the Program Director and Program Committee could avoid this. The program may also consider establishing an introductory graduate course for each field that is delivered annually; this introductory field-specific course may be an existing, modified, or new course.

Response

The interim BME Grad Program Director thanks the reviewers for this recommendation and agrees completely. Both the core courses and field specific courses will be coordinated by the Director, members of the Program Committee, and the Graduate Program Coordinator.

Members of the Program Committee from the three partner departments will be tasked with advocating to their home department graduate coordinators to support this.

9. **Establish a plan and process for TA assignments for BME students.** Historically, there has been an alignment between a graduate student's academic program and an undergraduate program within the same department, which simplifies TA assignments; however, the graduate BME students will be associated with multiple departments, while the undergraduate BME program only resides with the Department of Systems Design Engineering. A plan and process should be established to help ensure effective and equitable TA assignments

   Response

   Certainly, it is our intention to establish a plan and process to ensure effective and equitable TA assignments. Furthermore, it is the department's intention to hire BME Graduate students to TA for the BME undergraduate program. Currently, graduate students in the Faculty of Engineering may apply for TAships within their home department and in other departments. The current policy is to hire the best TA(s) for a given course. However, there is currently some uncertainty regarding how this will happen as graduate students are currently organizing towards unionization, which may complicate these processes. A new software system for applications is expected to assist with achieving best TA assignments.

10. **Enhance CIHR research support.** The BME program provides greater opportunity for CIHR funding; however, acquiring CIHR funding is challenging without appropriate support (e.g., CIHR knowledge and expertise within the research offices, funding for pilot data).

    Response

    The Dean of Engineering has made a commitment to advance CIHR funding support in partnership with the Office of Research and the Engineering Research Office. The need for CIHR knowledge and expertise within the Engineering Research Office will be a key consideration in the recruitment of the next Associate Dean of Research in the Faculty of Engineering. The SYDE department chair and BME Grad Director will advocate for the hiring of a grant writer with CIHR expertise and track record.

11. **Consider an exception for "Engineering Status" to allow BME faculty outside of the Faculty of Engineering to sole-supervise graduate students.** The Faculty of Engineering requires "Engineering Status" to sole-supervise graduate students within its programs, which precludes BME faculty, outside of the Faculty of Engineering, who may have an engineering background, including graduate-level

training in biomedical engineering. While such faculty are able to co-supervise students (including having a "nominal" co-supervisor within the Faculty of Engineering), the program should consider a pathway to enable sole supervision by such faculty members when appropriate

Response

The BME Grad Director will pursue a mechanism for exemption to this challenging policy for those who otherwise qualify as full BME Graduate faculty members. The four criteria for BME Graduate Faculty membership are: 1) regular faculty membership status at the University of Waterloo, 2) approved to supervise graduate students within their home faculty (including Approved Doctoral Dissertation Supervisor status when supervising PhD students), 3) demonstrated evidence of expertise in Biomedical Engineering, and 4) evidence of conducting Biomedical Engineering research (past or current).

The BME Grad Director will also seek to establish 'adjunct statuses' for those faculty members within engineering who do not currently qualify for sole supervise, such as adjunct faculty and research professors.

Recommendations Not Selected for Implementation

(Provide a rationale as to why a recommendation was not implemented)

3. **Increase the term duration for the inaugural BME Program Director.** The Program Director position is proposed to be a 3-year term. While this is reasonable once the program has reached steady-state, we believe that the inaugural BME Program Director should have a long-term (at a minimum, long enough to see the first cohort of students through) given the dynamics when starting up a new program.

   Response

   A three-year term for a director is the norm in the Faculty of Engineering. Please note that these terms are renewable.

12. **Create a plan for DWE Wet Lab Hub infrastructure upgrades.** The DWE Wet Lab Hub is located in the Douglas Wright Engineering Building, which is the oldest building on the University campus. As a result, there are some concerns with the laboratory environment (e.g., temperature control, humidity control, backup power). A plan should be established to upgrade the DWE Wet Lab Hub infrastructure so that it is in line with other BME research laboratories; this may include moving the laboratories into a newer building.

Response

The Department of Systems Design Engineering, the home department of the faculty members operating in the DWE Wet Lab Hub, is currently upgrading some research laboratory spaces and graduate student office spaces within this space. Given the age of the building, it is not possible to adequately upgrade the laboratory environment to standard specifications without staggering expense.

The Faculty of Engineering is in the process of planning a new building, currently referred to as Engineering 8. A significant focus of this building will be on health initiatives, and we therefore anticipate that Biomedical Engineering research will feature prominently within this space.

Signature of Approval

	Thomas Willett	June 17th, 2024
Chair/Director	Interim BME Grad Director	Date

Dean's Response to External Reviewers' Report
Biomedical Engineering (MASc/PhD)
May 2024

General Commentary
The External Reviewers' Report on our BME Graduate Program is aligned with our vision and future plans of supporting graduate programs of collaborative nature in key areas. We agree with most of the 12 recommendations, except for #3 and #12 that are rather operational issues and we will take a different approach to address them.

Dean's Response to External Reviewers' Recommendations

1. **Ensure the new BME Graduate Program Coordinator is hired before new students are recruited.** The program intends to hire a new BME Graduate Program Coordinator, which is necessary as the Graduate Program Coordinators within the Department of Systems Design Engineering are already at capacity. There is also a concern with workload if the number of transfers of existing students into the BME graduate program is large. If the new BME Graduate Program Coordinator is not in place to handle these transfers, the program should have a contingency plan (e.g., administrative assistance from the other two administrative departments.

Response
The earliest academic term the program can launch is winter 2025. The BME program is expecting to fill the graduate coordinator position before students enroll.

2. **Hire a 100% FTE Graduate Program Manager who implements the PACE Modules.** The program proposed to hire a 50% FTE Graduate Program Manager; however, we believe that this should be a 100% FTE given the importance and scope of work for the PACE Modules. In addition, the program should consider hiring an instructor (or contract instructor) for this position.

Response

This recommendation is consistent with the BME Program's current plan of hiring a 100% FTE program manager with instructor qualifications and the Faculty will support it.

4. **Establish a BME graduate student society with the launch of the program.** A BME graduate student society will help engage students in contributing to shaping the program and building the community of BME students. Active encouragement by the program to establish the society, and appropriate supports (e.g., financial support, space), can help ensure the society is present for the launch of the program.

Response
The program is intending to establish a BME graduate student society, which will take shape as the student enrollment builds. Financial support for the society has already been budgeted by the program for the first fiscal year.

5. **Embed EDIA, information literacy, and team building into the PACE modules.** The PACE modules are described as providing "training in the areas of research design and planning, academic integrity, professional presentation, and scientific writing. PhD students will receive additional training in developing research plans and in writing grant and business proposals." We believe that it is important for the program to include aspects of EDIA, information literacy, and team building in the program. The program could leverage existing programs and expertise at the University, such as librarians who have experience in graduate-level training for information literacy.

Response
Agreed. As noted in the program's response, the PACE graduate program manager will ensure the inclusion of these topics in the PACE module.

6. **Ensure funding allocations for BME students.** Within the Faculty of Engineering, various funding and scholarships are allocated by department (e.g., OGS, IMAE). As BME students will be associated with various departments, there is a danger that they may face inequitable access to funding and scholarships. The program should ensure an equitable allocation process (e.g., a separate allocation to the BME program, similar to a departmental allocation).

Response
Even though BME graduate program is a stand-alone degree program, the BME students will be affiliated with their faculty supervisor's home department for all practical purposes. As such they will enjoy all scholarship and funding support opportunities as do their fellow students in the department. The BME Program Director and the Faculty of Engineering will ensure that all opportunities are equitably available.

7. **Provide BME graduate fellowships.** The Faculty of Engineering has fellowships that help financially support its graduate students. Similar graduate fellowships should be made available for BME graduate students.

Response
The minimum funding level, $30,000 for PhD and $18,000 for MASc, applies to all students regardless of the home department. The Faculty-funded Engineering Excellence Fellowships (EEF) are being phased out with the implementation of the new funding model where the Faculty contributes to the minimum PhD funding.

8. **Ensure sufficient field-specific courses are offered annually for each of the 5 fields.** The field-specific courses are comprised of courses from multiple departments. Without appropriate coordination, this may result in an academic year with insufficient field-specific courses available in one or more fields. Coordination by the Program Director and Program Committee could avoid this. The program may also consider establishing an introductory graduate course for each field that is delivered annually; this introductory field-specific course may be an existing, modified, or new course.

Response
Agreed. As noted in the program's response, steps will be taken to ensure that sufficient field-specific courses are offered every year.

9. **Establish a plan and process for TA assignments for BME students.** Historically, there has been an alignment between a graduate student's academic program and an undergraduate program within the same department, which simplifies TA assignments; however, the graduate BME students will be associated with multiple departments, while the undergraduate BME program only resides with the Department of Systems Design

Engineering. A plan and process should be established to help ensure effective and equitable TA assignments

Response
TA assignment is an equal opportunity process which also works on the principle of hiring the best for the job. Departments follow established processes for TA allocation based on these principles. While future BME graduate students, regardless of their home department, will naturally be the best TA candidates for the BME undergraduate program, they will also have TA opportunities in other undergrad programs in engineering.

10. **Enhance CIHR research support.** The BME program provides greater opportunity for CIHR funding; however, acquiring CIHR funding is challenging without appropriate support (e.g., CIHR knowledge and expertise within the research offices, funding for pilot data).

Response
The Faculty recognizes that the BME researchers can gain greater recognition and enhanced opportunities to receive CIHR support because of new the graduate program. We commit to providing the necessary support to our faculty by engaging the Office of Research where substantial CIHR support structure exists, and also by adding the CIHR support capability within the Engineering Research Office.

11. **Consider an exception for "Engineering Status" to allow BME faculty outside of the Faculty of Engineering to sole-supervise graduate students.** The Faculty of Engineering requires "Engineering Status" to sole-supervise graduate students within its programs, which precludes BME faculty, outside of the Faculty of Engineering, who may have an engineering background, including graduate-level training in biomedical engineering. While such faculty are able to co-supervise students (including having a "nominal" co-supervisor within the Faculty of Engineering), the program should consider a pathway to enable sole supervision by such faculty members when appropriate

Response
The current practice is that there has to be a co-supervisor from the student's home unit. However, given that BME is an independent and stand-alone degree, the Faculty will explore ways to address the issue of any BME-approved faculty member sole-supervising graduate students in Engineering. On the other hand, given that the supervisor's home department will be considered as that of the student's, the chance for such occurrences is expected to be rare.

Recommendations Not Selected for Implementation
(Provide a rationale as to why a recommendation was not implemented)

3. **Increase the term duration for the inaugural BME Program Director.** The Program Director position is proposed to be a 3-year term. While this is reasonable once the program has reached steady-state, we believe that the inaugural BME Program Director should have a long-term (at a minimum, long enough to see the first cohort of students through) given the dynamics when starting up a new program.

Response
The typical duration of program directorship is 3 years. Sufficient overlaps and staff support is provided to ensure a smooth transition. There have also been instances where the directorship is renewed for another term.

12. **Create a plan for DWE Wet Lab Hub infrastructure upgrades.** The DWE Wet Lab Hub is located in the Douglas Wright Engineering Building, which is the oldest building on the University campus. As a result, there are some concerns with the laboratory environment (e.g., temperature control, humidity control, backup power). A plan should be established to upgrade the DWE Wet Lab Hub infrastructure so that it is in line with other BME research laboratories; this may include moving the laboratories into a newer building.

Response
The Faculty is aware of this issue and is committed to ensuring that the BME researchers have the best infrastructure possible. The building upgrades/renovations will be considered in the context of long-term Faculty- and University- level infrastructure planning, also taking into account the possibility of new buildings in the future, as a potential solution.

Signature of Approval

Mary Wells

June 17, 2024

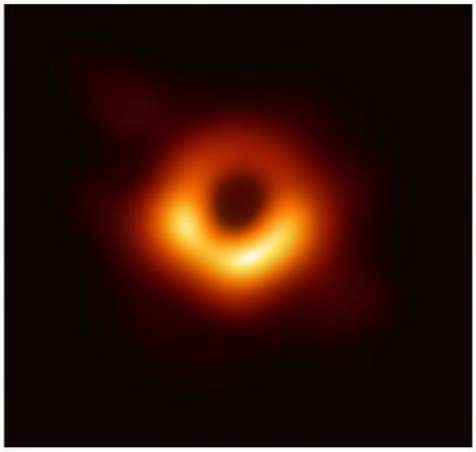
Faculty Dean Date

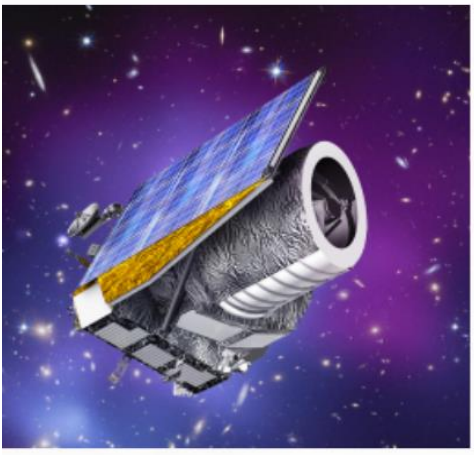
Note: AFIW programs fall under the Faculty of ARTS; however, the Dean does not have fiscal control nor authority over staffing and administration of the program.

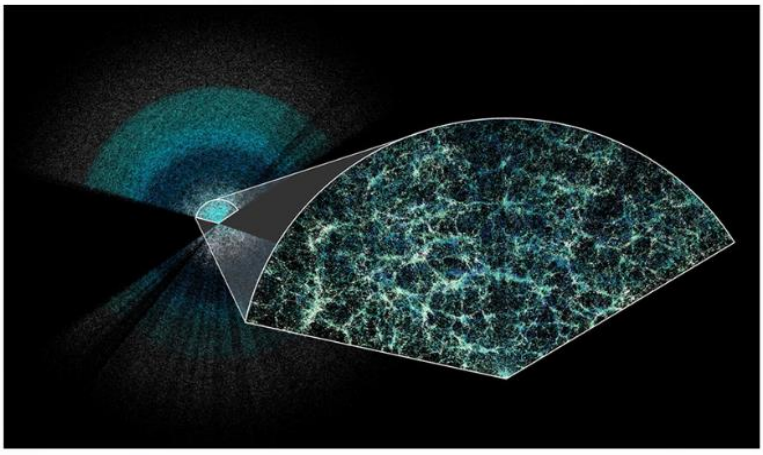
AFIW Administrative Dean/Head (*For AFIW programs only*) Date

WATERLOO CENTRE FOR ASTROPHYSICS

PROGRESS AND RENEWAL REPORT 2018-2024





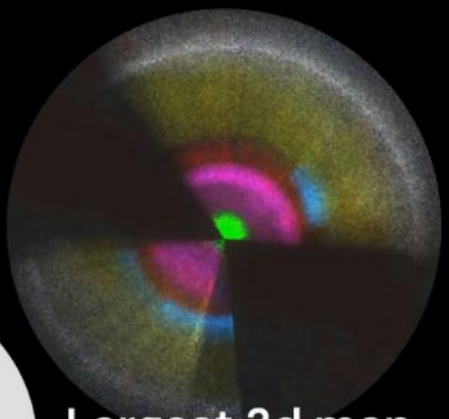


UNIVERSITY OF WATERLOO | WATERLOO CENTRE FOR ASTROPHYSICS

The Waterloo Centre for Astrophysics

... at a glance

102 Grad students
26 Postdocs
11 Faculty



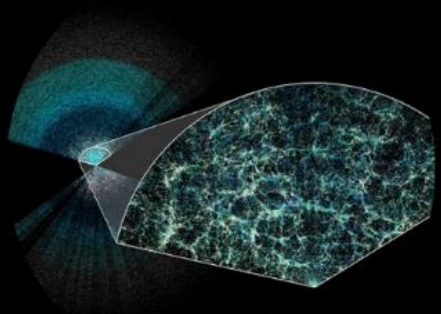
Largest 3d map of the Universe

1/3 of postdocs go into faculty positions

First image of a black hole:
2787 citations

Mapping the Universe with Euclid

506 publications



Looking back 11 billion years with DESI

Outreach to over 6,000 people

200 AstroBubble shows

WATERLOO CENTRE FOR ASTROPHYSICS
WCA

Executive Summary

The strategic plan of the University of Waterloo states that “Scholars and students who want to solve the world’s deepest mysteries will find a home here.” The Waterloo Centre for Astrophysics (WCA) provides those studying astrophysics with a study room within that home. We support and enable high-profile research in astrophysics and utilise our expertise in interdisciplinary directions. We consolidate and support international astrophysics projects, with a critical mass of researchers. The WCA organises astronomy-related events within the University and enables an ambitious outreach programme.

The WCA key initiatives and research interests maintain strong alignment to research directions within the University of Waterloo’s Strategic Plan (2020) and Global Futures initiative: We are creating tomorrow’s research leaders by attracting outstanding, diverse postdoctoral scholars to Waterloo, and supporting undergraduate and graduate students and members of faculty. We are engaged with many international collaborations, enhancing the international reputation of the University. We are exploring interdisciplinary directions where we can use our knowledge in other fields, and where we can bring in the expertise of others to help with astrophysics.

The research undertaken by WCA members has been of exceptional quality. We have contributed to the first direct image of a black hole, an image that has garnered significant attention across the world. Astronomers have also released the largest map of the Universe to date generating significant press coverage. In total, we have published 506 refereed research papers, a significant increase over an equivalent period before the inception of the WCA. The future of research in the fields that we lead is strong, with many experiments coming to fruition over the next five years. These include the XRISM and Euclid satellites launched in 2023, first light of the Rubin telescope in 2024, and continued use of the James-Webb Space Telescope. Exploiting data from these experiments, WCA members will continue to lead high-profile international projects pushing forwards our understanding of the universe.

Through a postdoctoral program including mentoring, we help future academic leaders to develop in the crucial step between graduate study and faculty. Our pool of postdoctoral researchers has now reached steady state, with 16 currently in place. We have used the generous donation by Mike and Ophelia Lazaridis to great effect to fund these positions directly and to leverage and enable further funding. Since July 2022, all postdocs, the director, and administrator are co-located in dedicated, refurbished, office space enhancing collaboration and helping us to build a sense of team within the WCA. The member survey conducted shows that the sense of community is already present, but we are not going to rest - team building will be a priority over the next five years.

The WCA has secured a significant philanthropic donation for outreach work that enabled the purchase of a mobile planetarium and projector that arrived in late 2022. Together with the appointment of an outreach coordinator, a multi-faceted outreach program is underway

designed to support the University and to engage with groups from demographics that are currently underrepresented within the field of astrophysics and science in general. We are focussed on encouraging children within such demographics to consider STEM-based careers.

The WCA is complemented by, and works closely with, the Centre for the Universe at the Perimeter Institute for Theoretical Physics (PI). There are strong synergies between the two: the Centre for the Universe has a theoretical focus, creating models that can be tested by the observational experiments undertaken by the WCA and several WCA members hold joint appointments between the University of Waterloo and PI. Furthermore, the WCA has established ties with other regional centres including the Canadian Institute for Astrophysics (CITA).

The WCA achievements to date have been facilitated by the donation from Mike and Ophelia Lazaridis. This funding source will continue to support the WCA over the next four years, but new avenues for future funding need to be found to continue the momentum that has been built up beyond then. A key goal for the WCA is to explore alternate possible sources of income and resource-sharing.

In Summer 2023, we submitted a renewal request and were approved as a Faculty Centre for 18 months beyond the initial 5 years, limited while the University reviewed its policy on Centres. We now request renewal for a further 5 years, allowing the Centre to continue beyond the tenure of the inaugural director (who has a maximum 10-year term). The WCA has received letters of support from the Dean of Science, and from the chair of Physics and Astronomy supporting the continuation of the WCA as a Faculty Centre for five more years.

We are grateful to the Senate Graduate and Research Council and University of Waterloo Senate for taking the time to review this report, and we look forward to advancing astrophysics research for another five years upon the WCA's successful renewal as a senate-approved research centre.

Sincerely,

Will Percival

Dr Will Percival
Director, Waterloo Centre for Astrophysics
Mike and Ophelia Lazaridis Distinguished Chair in Astrophysics

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Impact of the WCA on Astrophysics in Waterloo

A key aim of the Waterloo Centre for Astrophysics (WCA) is to bring high-quality postdoctoral fellows to Waterloo. The benefits of doing this are numerous and include engendering innovative research opportunities, collaboration, a high research output and better mentorship of students. The WCA has been successful in this goal and the impact has been strongly felt in terms of the reputation of Astrophysics at Waterloo, the quality of our training of early career researchers, and in our successes in outreach.

Reputation of Astrophysics at Waterloo

In 2023, the University of Waterloo was rated #1 in Canada for Physics (Academic ranking of World Universities) and the #1 comprehensive research University in Canada (Research Infosource), and the WCA has played a part in that success. The WCA is globally recognised for the major contributions it makes to international scientific collaborations. WCA members have been instrumental in the publication of high impact results, such as: the first image of a black hole; the largest 3d map of the Universe; and the first cosmological results from the Dark Energy Spectroscopic Instrument, allowing us to look back at the Universe 11 billion years ago. WCA members have leadership roles in the Euclid satellite, which was launched on July 1, 2023, to major press interest and will map the Universe at higher resolution than ever before.

The impact of the WCA postdoctoral fellows on the research output of the WCA is seen in the number of refereed publications produced by the WCA. The publication rate of the group has doubled since the formation of the WCA. In six years, the WCA has produced 506 publications, 49 of which have been cited more than 100 times (see Publications). In addition to the increase in the total number of publications produced by the group, we also see a steady increase in the productivity of the faculty members since the formation of the WCA, even though the number of faculty members of the WCA has decreased.

Another indicator that the WCA is successfully raising the profile of Astrophysics at Waterloo is that more people want to come to Waterloo to do Astrophysics! Undergraduate numbers in the Astrophysics program have steadily climbed to the extent that it is the most popular program in Physics. Feedback from the latest round of postdoc hiring shows that a postdoctoral fellowship at the WCA is now considered a prestigious position and we are now attracting candidates of Hubble Fellowship or Harvard quality.

Early career training

In 2018, prior to the formation of the WCA, the astrophysics group at the University of Waterloo consisted of 12 faculty, 2 postdoctoral fellows and some 30 graduate students. Today, the WCA numbers over 60 people, including 16 postdoctoral fellows and 38 graduate students. This is the result of a dedicated effort to grow the group and increase the number of early career researchers at Waterloo.

In addition to the usual academic mentoring provided to both postdoctoral fellows and graduate students, we introduced an additional mentor with a "non-academic mentoring scheme" for the postdocs (more detail in Mentoring and promoting early career researchers). As numbers in the WCA grew, our early-career researchers supported each other and increased their mentoring networks. Several initiatives to support research, quality of research and well-being of researchers have grown organically from conversations within the group; these include non-academic mentoring of graduate students by postdocs and regular journal clubs aimed at addressing areas as identified as requiring attention (see, Creating a WCA community).

The supportive, inclusive and proactive atmosphere in the WCA attracts prospective postdoctoral fellows and graduate students and is conducive to good outcomes for our early career researchers. Twenty-six postdocs (past and current) have been members of the WCA since its inception. Of the ten postdocs who have already moved on, 3 moved into a faculty position or onto a faculty path, 4 went to a further postdoc position, and 2 have gone into data science. Sixty-four graduate students have earned their MSc or PhD with the WCA. Twenty-nine of them (45%) have continued to the next level of academia, 18 (29%) have moved into industry in the form of data science, software engineering, finance or education, we have no data for the final 17 former graduate students, some of whom are very recent post-graduates.

Outreach successes

Outreach, specifically outreach geared towards people who are traditionally under-represented in Physics and Astronomy, has always been an aim of the WCA. Our outreach efforts include faculty giving public talks in collaboration with Advancement and more informal talks aimed at a broader public and organized by our Outreach Coordinator. One series of talks are held monthly at the Kitchener Public Library and the other, Astronomy on Tap, are held bi-monthly at the Crazy Kanuck in Kitchener. Both series are immensely popular; they always fill the room and draw a mix of regulars and new people each time. Over 1,000 people have attended our Kitchener Public Library and Astronomy on Tap talks since they began in May 2023.

We have worked hard to enhance our presence on social media and have made use of Instagram to reach out to the younger adult audience. We have gained 572 followers over the past 15 months. We use social media to promote WCA outreach and group events and to educate light-heartedly. We collaborated with the Faculty of Science communications team to make a reel about the total solar eclipse in April 2024, which was viewed over 30,000 times.

However, the centerpiece of our outreach program is our inflatable planetarium, the AstroBubble. We have teamed up with the Ontario Postsecondary Access and Inclusion Program (OPAIP) to take the AstroBubble into high schools in communities which historically have not accessed postsecondary education (PSE), which include students who identify as Black, Indigenous, marginalized or racialized, first-generation, newcomers, low-income, 2SLGBTQIA+, and students with disabilities. In addition, we organise AstroBubble events for girl groups, such as the Girl Guides, the Canadian Association of Girls in Science (CAGIS) and PhysiX: Girls Matter. The AstroBubble has been a popular addition to campus events such as Science Open House and

Physics Lab Days. We began our AstroBubble program in November 2022 and, to date, have held 200 AstroBubble shows for 4719 children or families. It is worth noting that we used the first six months as a small-scale pilot scheme while we established ourselves. We ran shows for 744 children and families during the 2022-2023 school year. For the 2023-2024 school year that number increases to 3975, which equates to 20 children being enthused by the AstroBubble for each day of the instructional year!

Alignment with University of Waterloo aims and goals

The WCA recognizes the importance of aligning with the aims and goals of the University of Waterloo and we refer to University planning documents when looking to chart our own future. We find a natural concordance between the university's intents and aspirations and the WCA's and will draw examples from the "Global Futures 2024" and "University of Waterloo Strategic Plan 2020-2025" documents to illustrate.

Global Futures 2024

The Global Futures 2024 document lists six pathways towards the future for the University of Waterloo: societal, technological, economic, sustainable, health, and fundamental research and scholarship. The work done at the WCA aligns with the fundamental research and scholarship, technological, and societal futures.

Fundamental Research and Scholarship

The Fundamental Research and Scholarship section of the Global Futures 2024 document begins "*Our vision for Waterloo's global futures is fueled by a relentless commitment to fundamental research and scholarship*." and then quotes from the "Waterloo at 100" document, "*A spirit of curiosity and commitment to excellence in fundamental research and scholarship advances our understanding of ourselves, our planet and the cosmos and enables the ongoing development of technologies, innovations and applications we cannot imagine today*."

The article that immediately followed this describes how the work done in the WCA supports this vision and why such fundamental science is important for humanity's future. Studying unanswered and unknown questions – the fundamental research undertaken at the WCA - is a driver of long-term progress for society in terms of health, sustainability, technology, economy and more. Fundamental research provides unexpected discoveries and real-world applications.

The work done at the WCA, which aims to understand how the Universe formed and evolved, is about as fundamental as it gets! At a time where there is also an emphasis on interdisciplinary work as a route to major breakthroughs and societally significant findings, it is worth noting that astrophysics (a merging of the fields of Astronomy and Physics) is inherently interdisciplinary. Terms such as "astro-statistics", "astro-chemistry" and "astro-biology" already abound in the field.

Technological Futures

The Technological Futures asks how the University of Waterloo will, "*lead the next technological transformation to ensure a safe and human-centred digital future?"* Astronomical projects and instruments generate vast amounts of data, and machine learning, with a focus on data mining, is fast becoming an essential aspect of modern astronomy. WCA astronomers using data from modern surveys are at the forefront of the development of machine learning tools and quality assurance of the results.

Space technology, whether communications satellites or satellite observatories, is well-known for developing technologies that lead to use in everyday life. Some examples include microprocessors, crash helmets, emergency blankets, the dimples in golf balls, and household smoke detectors. The development of space technology is often led by the development of scientific missions including satellite observatories, which have exacting and difficult-to-meet requirements that push technological progress. Thus, by driving these missions, WCA members drive the technological developments.

Societal Futures

The Societal Futures section asks, "*How* do *we promote knowledge and research to positively advance society's future and ensure communities and everyone within them thrive?"* and asks if there is a crisis in trust [in scientists]. Education is key to re-building trust in science and scientists and outreach is an essential part of that education. Astronomy inspires wonder and curiosity and that can ignite an interest in STEM subjects.

The WCA's outreach program (see, *Outreach Activities*) reaches thousands of children and their families each year. Our inflatable planetarium awakens children's interests in Astronomy and we use our seminar series with Kitchener Public Library and Astronomy on Tap to inform the public in an accessible way about the research done by the WCA. Our outreach program is available for all but targeted towards the portion of the population that has traditionally been under-represented in the sciences, aligning with the university's goals towards inclusivity and belonging.

Strategic Plan 2020-2025

The University of Waterloo's Strategic plan states that Waterloo is "committed to fundamental research as well as collaboration across research disciplines" and that Waterloo will build on three themes for impact: Developing talent for a complex future, advancing research for global impact, strengthening sustainable and diverse communities. The WCA supports all three of these themes. We train early career researchers to do fundamental research in astrophysics. The interdisciplinary nature of our research means that our early career researchers leave the WCA ready to move onto the next step in academia or with the skill set to pivot towards roles in industry, especially data science, software engineering, teaching and finance. Our focus on training (mostly international) young scientists necessitates a people-centered approach that is inclusive and supportive. We have developed mentoring schemes to help everyone achieve their best. The WCA's outreach program is focused on peoples who have traditionally been under-

represented in Astronomy and the Sciences, and we have worked hard to build connections so that everybody can see a place for themselves in STEM roles. The WCA looks forward to moving into the future envisioned by the University of Waterloo.

Waterloo Centre for Astrophysics (WCA) establishment and goals

The Waterloo Centre for Astrophysics (WCA) is a strategic investment that synergizes the world-leading research and training in astrophysics and related areas. Although much progress has been made in the fields of astrophysics and cosmology over the past decade, many fundamental questions remain: the physics driving the current accelerated expansion of the Universe is unknown; the physics driving the period of acceleration in the early Universe, often termed inflation, is unknown; the physics driving galaxy formation and evolution is still not fully understood.

The WCA provides an environment for astrophysicists to ask and answer such fundamental questions about the Universe in which we live. By using the Universe as a laboratory, members design and analyse experiments testing physical processes that are impossible to replicate on Earth. Research into phenomena including black holes, distant galaxies, and the energy-density components of the universe, push the boundaries of human knowledge. Research is an integral and intensive area at the University of Waterloo and the international reputation of the WCA helps the university to be recognized worldwide.

Mission Statement

The Waterloo Centre for Astrophysics looks to the cosmos to solve the greatest mysteries of the universe. World-class researchers and students come here in an atmosphere of curiosity, creativity, and collaboration; exploring our cosmic origin to truly understand the physical processes at work in the Universe. From black holes to cosmology, we aim to understand what lies beyond the Earth. The possibilities for new discoveries are limitless.

History

The Waterloo Centre for Astrophysics (WCA) is an initiative conceived by members of the faculty specialising in astrophysics to build upon the generous donation by Mike Lazaridis, which enabled a Distinguished Research Chair in Astrophysics, held by the inaugural WCA Director, Will Percival. The WCA was approved by the University of Waterloo Senate at their November 19th meeting in 2018. Prior to this, the proposal was reviewed at a dedicated Physics and Astronomy department meeting (August 27, 2018), by the Science Faculty Council (September 12, 2018), the Research Leaders Council (September 17, 2018), and by the Senate Graduate and Research Council (October 1, 2018).

After approval by the Senate, we were able to use the WCA name for the first time. Following this, we formed the governing board, worked with Creative Services to design a logo, and created

a brochure to advertise the new Centre. We also created the web page and started a series of short videos describing work by WCA members. To help with the administation of the WCA, Donna Hayes joined as the admin assistant (4/2019-9/2021), and we have subsequently been supported by Lindsay Sine (10/2021-11/2022) and Carolyn McCoey (11/2022-present).

A major focus of the WCA has been building a critical mass of postdoctoral fellows. When the WCA was formed, there were two postdocs in astronomy working in the Physics and Astronomy department. In September 2019 we were able to bring in two WCA Fellows, and one more followed in October 2020. In 2020 we also began to see the leverage provided by the new WCA in that we were also joined by an AMTD Fellow. We welcomed four new postdocs in 2021, supported by the WCA and by additional funding from several research grants. 2022 saw the arrival of five postdocs including two WCA LSST Fellows, working on the Rubin observatory (which will undertake the Legacy Survey of Space and Time, LSST) supported by the University research office and faculty, allowing the WCA to join this project. In 2023, we had a further eight accepted postdoc offers, including a Banting Fellow and a CITA National Fellow.

In July 2022 the WCA moved into refurbished office space in the physics and astronomy building, with the renovation funded by the Faculty of Science. The new space is described in more detail in Accommodations for the WCA, and allows all the postdocs to be co-located, together with the Director, admin support, and a small number of our graduate students.

Another milestone happened in October 2022 when the WCA took delivery of our mobile planetarium, paid for by a philanthropic donation. Together with the hire of our new outreach coordinator, Roan Haggar, this has enabled us to instigate an outreach program aimed at children, particularly those from groups that do not traditionally follow a STEM career path. Astronomy and astrophysics are particularly well suited to engaging children in science. More details about our outreach activity can be found in Outreach Activities.

Throughout the whole history of the WCA we have been doing excellent science, and much of this document is dedicated to that.

Key aims and goals (copied from the original proposal)

The key aims and goals of the WCA were listed in the original proposal and are to facilitate and conduct ground-breaking research, training, and outreach in Cosmology and Astrophysics at the University of Waterloo. The WCA will foster new and exciting discoveries about the nature of the Cosmos and establish the University of Waterloo as a world leader in observational astrophysics and cosmology, and the detailed testing of theoretical models of the Universe.

1. **Research**: The WCA will stimulate fundamental research in Astrophysics and Cosmology, catalyze and foster national and international collaborations.
2. **Training**: The WCA will add to the graduate and postdoctoral training and mentorship undertaken in the Department of Physics and Astronomy, leading to the successful entry

of the trained highly qualified personnel into a career in astrophysics, cosmology and industry.

3. **Partnership**: The WCA seeks to partner with regional and international centres of excellence in astrophysics in order to promote synergies and further WCA missions.
4. **Dissemination**: The WCA will facilitate dissemination of astrophysical sciences by hosting topical conferences and focused workshops, as well as by developing and maintaining an active visitor program.
5. **Outreach**: The WCA will engage the broader academic community at UW, as well as the general public, via physical and virtual platforms, in order to promote the significance of fundamental research and share the excitement of the science done by WCA members. In particular, it will strive to engage and recruit women, underrepresented minorities, and indigenous communities in its scientific and outreach activities.

Progress against goals – years 1-6

We revisit these goals and list the ways that we have met them below. While we have made good progress for all, there is more we can, and want, to do.

1. **Research:** The research conducted by WCA members over the last 6 years has been spectacular. Members have contributed to the collaboration that made the first direct image of a black hole - an image that has garnered significant attention across the world. Members have also led the release the largest map of the Universe to date and been involved in many cutting-edge experiments. The long list of international experiments including WCA members is available in Projects and Facilities. To see the impact that the WCA has had on the scientific output in astrophysics coming from the University of Waterloo, please see *Figure 9* (which we're very proud of).
2. **Training:** We enhance the training of undergraduate and graduate students by providing a research atmosphere within the WCA. Our postdoctoral researchers often join the supervisory teams for students providing additional practical support. The primary change since the instigation of the WCA has been the number of postdoctoral researchers working in astrophysics. We provide support and mentoring for these researchers, and this has helped three of the cohort secure permanent academic positions, while the others have moved to either further postdoctoral positions or positions in industry. The list of graduate students and postdoctoral researchers directly or indirectly supported by the WCA is given in Membership.
3. **Partnership:** We have a strong partnership with the Perimeter Institute for Theoretical Physics (PI) with many faculty (Afshordi, Broderick, Percival) jointly appointed. We have also hired two joint postdoctoral researchers (Krolewski 2019-22, Ennis 2022-25) and held two joint conferences (2/2022, 7/2024). PI has also research initiatives on the Event Horizon Telescope and the Dark Energy Spectroscopic Instrument, tying in with research at the WCA including many of the same scientists. A representative of PI serves on the governing board. We also have built a strong relationship with the Canadian Institute for

Theoretical Astrophysics (CITA), with Taylor (2016-20, chair 2018-20) and Percival (2022-25) serving on the CITA governing board. Krolewski recently accepted a CITA National Fellowship at the WCA which will further strengthen this link. WCA members work with many national and international colleagues on research projects and on several experiments.

4. **Dissemination:** Despite the impact of Covid and associated lockdowns, we have hosted several conferences and meetings over the last 6 years. The largest of these was the Canadian Astronomical Society (CASCA) annual general meeting in 2022. More details of this and other meetings can be found in WCA Supported events. To encourage collaborations between WCA members and external groups we have recently appointed several Associate Members, and we hope to encourage them to be frequent visitors to the WCA.
5. **Outreach:** We are very pleased with our outreach program. Astronomy is a subject with the ability to captivate children and adults as we explain the wonders of the Universe. Thanks to a generous donation, in 2022 we were able to purchase an inflatable planetarium and digital projector to put on shows and play full dome (360 degree) movies. Our outreach program uses this facility to share the science done by WCA members, to support advancement, to engage and recruit women into astrophysics. More details about our outreach program can be found in Outreach Successes

Objectives for the next five years

Practically, the main goals of the WCA continue with increased focus. The success of the Centre lies in its ability to attract further funding and resources, ensuring its sustainability, and to continue its ability to support research. We include putting this in place as an additional objective for the next five years.

1. **Research:** The WCA will stimulate fundamental research in Astrophysics and Cosmology, catalyze and foster national and international collaborations. In particular, we will exploit surveys and facilities taking data over the next five years including DESI, EHT, Euclid, JWST, Rubin, XRISM. We will also prepare for the next generation of facilities including ngEHT, MSE & TMT.
2. **Training:** The WCA will continue to enhance the training of highly qualified personnel seeking a career in astrophysics, cosmology and industry. Our successful postdoctoral fellowship program will continue, and we will increasingly leverage existing funding to provide further sources of revenue.
3. **Partnership:** We will continue to partner with regional and international centres of excellence in astrophysics to promote synergies.
4. **Dissemination:** The WCA will facilitate dissemination of astrophysical sciences by hosting topical conferences and focused workshops, as well as by developing and maintaining an active visitor program.
5. **Outreach:** The planetarium offers an amazing opportunity to advertise the centre, and to engage with the local community. We will exploit this by expanding on our regular

program of visits to local schools as well as youth groups. Here we will increase. the focus on groups that are underrepresented in physics. Alongside this, we will support initiatives based on visits made to campus including those from Advancement.

6. **Sustainability:** The funding used to initiate the WCA was from a donation, providing a generous research budget for ten years. At the end of this renewal period, we will come to the end of that funding, and the sustainability of the WCA will be dependent on finding and securing additional sources of funding.

Research Accomplishment

Core Research

Members of the WCA are studying problems amongst the most fundamental in physics:

- The origin and fate of the Universe
- The nature of dark matter
- Black hole dynamics and thermodynamics
- Gravitational waves and gravitational lenses
- The properties of stars and interstellar matter
- The formation of galaxies, stars and solar systems
- The unification of General Relativity and quantum mechanics

Interdisciplinary Research

A significant amount of scientific advancement comes from the adoption of methodologies developed for other applications, fields or experiments. Thus, it is important to promote dialogue between different fields and sub-fields, both within astrophysics and with outside areas. In many ways, astronomy is the archetypal Big Data science, with future experiments such as the Large Synoptic Survey Telescope predicted to produce 20TB of data per night. Artificial Intelligence techniques, specifically machine learning and the sub-class of deep learning algorithms, have the potential to transform astronomical data analysis, using the new data sets.

Significant science from the next generation of astronomical experiments will result from the cross-correlation of different data. Examples include multi-wavelength studies where sources are observed in multiple bands, or the follow-up of one type of object discovered in one survey with a different instrument, or the analysis of the same objects in a different data set. In survey science, the statistical cross-correlation of populations can highlight physical processes (e.g., Integrated Sachs-Wolfe and Sunyaev-Zel'dovich measurements from the cross-correlation of Cosmic Microwave Background and intervening large-scales structure). They can also beat down systematics effects and remove foreground contamination: if these are different in two experiments, then they cancel in cross-correlation measurements.

Over the last six years, members of the WCA have successfully obtained grants to support interdisciplinary research linking the WCA with the department of statistics and actuarial science, the department of philosophy and the department of applied maths.

Projects and Facilities

Much of the experimental research in the WCA results from international collaborations using international facilities. Typically, faculty participate in the planning and development of these facilities, and subsequently help to lead the collaborations of scientists undertaking the experiments. We list here the primary experiments that WCA members are involved in:

4MOST

The 4MOST Hemisphere Survey of the Nearby Universe (4HS) is an accepted ESO public survey to conduct a massive spectroscopic survey of the southern sky, obtaining spectroscopic redshifts up to 7.2 million galaxies. This will be achieved with very high (>95%) and unbiased completeness over 21,000 square degrees, and with a particular focus on the nearby Universe ($z < 0.15$). **Hudson** and **Percival** were co-Is on the 4HS proposal and are members of the scientific collaboration. They will use 4MOST to investigate the large-scale structure of the Universe.

CASTOR

The Cosmological Advanced Survey Telescope for Optical and UV Research is a proposed space telescope being developed by the Canadian Space Agency, Canadian industry and international partners. An innovative optical design allows this telescope to deliver images comparable in resolution to those of the Hubble Space Telescope, but over a field that is two orders of magnitude larger, and simultaneously in three wavelength channels spanning the UV/optical (0.15–0.55 µm). Participation in this mission will allow WCA members to make groundbreaking discoveries in a wide range of topics including galaxy formation, black hole growth and extrasolar planet atmospheres.

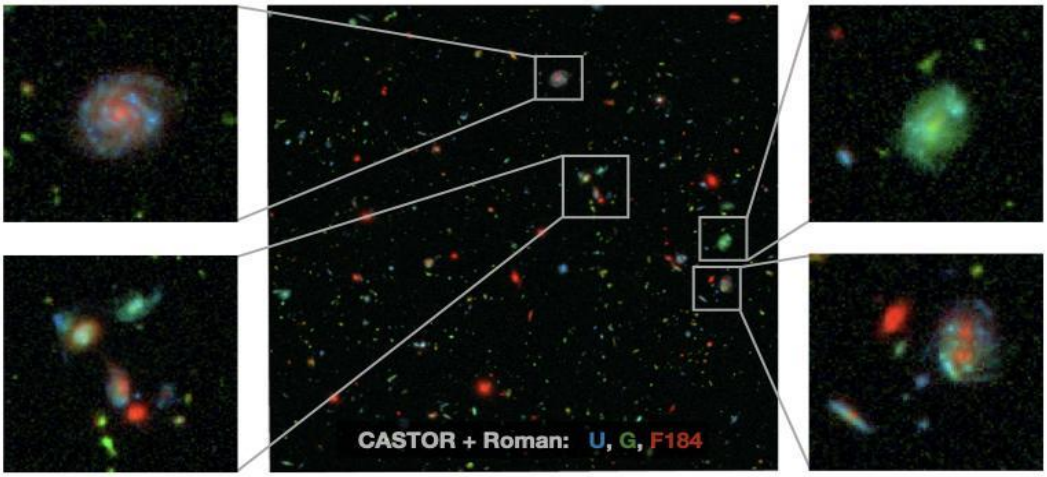


Figure 1: A simulation of the Hubble Ultra Deep Field (UDF) in filters from CASTOR (U, G) and Roman (F184). This image shows a ~1.5'×1.5' field, or just ~0.06% of the area that will be covered by the CASTOR Ultra-Deep Survey. While Roman's IR imaging (red) is sensitive to existing stellar mass, CASTOR picks out regions of ongoing star formation. With comparable spatial resolution from the ultraviolet to the near-infrared it will be possible to map stellar populations and other physical parameters across galaxies, out to cosmic noon (z=2.5).

CASTOR recently completed a Phase 0 study for the CSA. **Balogh** was the lead of the "Galaxies and Evolution of Cosmic Star Formation" Science Working Group (SWG) for this study, and two of his students (**Cam Morgan** and **Cam Lawlor-Forsyth**) contributed work to the science case.

Dark Energy Spectroscopic Instrument (DESI)

The Dark Energy Spectroscopic Instrument (DESI) allows astronomers to undertake a spectroscopic galaxy survey 20 times faster than was previously possible. DESI started survey operations on May 17, 2021 and is studying Dark Energy at a level not previously available. The start of the survey was accompanied by a press release from the WCA looking ahead to the science to come. The first cosmological results were released on April 4, 2024 accompanied by another news item. The results show tantalizing hints of deviations from the standard LCDM model, and resulted in over 1000 news articles around the world. From September 2024, Will **Percival** will become co-Spokesperson for this project for a period of 2 years, in charge of coordinating all science coming from this project, with possible renewal for another 2-year term. The WCA-DESI group includes associate member, Dustin **Lang**, 4 WCA postdocs and 4 graduate students, and forms a key institute contributing to this project.

Extended Baryon Oscillation Spectroscopic Survey (eBOSS)

The eBOSS project used the Sloan telescope to observe galaxies and quasars at a range of distances (redshifts) left completely unexplored by other three-dimensional maps of large-scale structure in the Universe. In filling this gap, eBOSS created the largest volume survey of the Universe to date, publicly released in July 2020. This region corresponds to the epoch when the Universe was transitioning from deceleration because of gravity, to the current epoch of acceleration due to Dark Energy. Will **Percival** was Survey Scientist for the project and several students and postdocs working in the WCA led science projects using these data. Further details about the announcement of the final results and the accompanying press interest can be found in Astrophysicists release largest 3D map of the Universe ever created in the Research Highlights section of this report.

Event Horizon Telescope (EHT)

WCA member Avery **Broderick** is a founding member of the Event Horizon Telescope (EHT) Collaboration, which is responsible for constructing, operating, and interpreting observations from a global array of high-frequency radio telescopes that together comprise the highest resolution telescope in history. The aim of the EHT is to achieve a long-standing goal in astrophysics to directly observe the immediate environment of black holes with angular resolution comparable to the event horizon. **Broderick** now sits of the Board of the EHT and plays a central role in the science extraction.

Euclid

The cosmology-focussed satellite mission Euclid successfully launched from Cape Canaveral July 1st, 2023. The launch was accompanied by a press release with significant public interest, with WCA members **Percival** and **Hudson** called upon to undertake several interviews. Early observation data has been released twice within the year since launch, with further press interest. The latest press release (May 23, 2024) led to a 2-page spread in the Globe and Mail and a CBC science article in which both **Percival** and **Hudson** were featured.

Figure 2: Will Percival at the Euclid launch site. The primed launch vehicle is visible in the background.

The scientific work on the 6-year project continues, and the 15,000deg^2 survey including both imaging and spectroscopy to be provided by Euclid, will be a game-changer in many fields of astronomy. Within the Euclid consortium, Mike **Hudson** serves as the Canadian Euclid Consortium Board representative, and Will **Percival** serves as a co-lead of the Galaxy Clustering science working group, and is one of four Science Coordinators for the consortium, with various other roles. Together with Euclid Consortium members Michael **Balogh**, and James **Taylor** and two WCA Euclid Fellows, Marco **Bonici** and Pierre **Burger,** they ensure that the WCA remains at the heart of the Euclid science.

Fred Young Submillimeter Telescope (FYST)

The CCAT-prime collaboration is building the Fred Young Submillimeter Telescope (FYST), a 6-meter aperture submillimeter wavelength telescope designed for very wide field observing. Construction is expected to be completed in 2024, following extensive delays due to Covid-19, and first light is expected in 2025. FYST will be used for several large-area surveys with a mapping speed unchallenged by any current or near-future facilities in the 150 to 1500 GHz telluric window. With FYST, we will be poised to make new discoveries and grow our emerging leadership in key areas of observational cosmology and fundamental physics as well as studies of the magnetic structure of our Milky Way galaxy. The rapid cadence surveys that were science goals since the start of this project will also permit a new, exciting, and unique science goal: a search for rapid submillimeter-wave transients.

Figure 3: Computer rendering of FYST

The Canadian Team for CCAT-prime is led by WCA associate member Mike **Fich** and includes researchers at twelve other Canadian universities. All of the Canadian funding proposals have been successful: the Canada Foundation for Innovation (CFI) approved an Innovation Fund 2020 grant to support CCAT-prime and the Provinces of Ontario, Alberta, and BC have provided additional funds to match the CFI funding for a total of $9.4M. Approximately 2/3 of these funds are being used for construction at the site of the observatory including roads, power, buildings, and the assembly of FYST itself. Other major expenses include the central camera module for the main FYST instrument (Prime-Cam) and software both for the observatory and for Prime-Cam data reduction.

JWST

The James Webb Space Telescope (JWST), which launched on December 25, 2021, is the long-anticipated successor to the Hubble Space Telescope. Optimized for near-infrared observations, with a dazzling array of instrumentation, JWST will make fundamental new discoveries about the very early Universe, the assembly of galaxies, the birth of stars and planets, and the origins of life. Through the involvement of the Canadian Space Agency, Canadian astronomers have access to 5% of time for PI-driven projects on this extraordinary facility. WCA member Brian **McNamara**, has successfully applied for observing time in every JWST observing cycle, with time awarded for "Resolving the Cooling Flow at the Center of the Phoenix Cluster" (2022), "A Galaxy-Scale Fountain of Multiphase Gas Pumped by a Black Hole: The power of JWST combined with ALMA, MUSE, Chandra, and HST" (2023), "Feeding the Black-Holes : From cooling filaments to H2 accretion disk" (2024) and, "Mapping a Black Hole Accretion Flow with JWST/NIRSpec (2024). The time awarded for the two 2024 projects totals 10% of the allocated Canadian time.

Nancy Grace Roman Telescope

Figure 4: Artist's impression of the Nancy Grace Roman telescope in front of a fictional background

The NASA-led Nancy Grace Roman telescope is scheduled for launch in 2026. It consists of a 2.4m telescope, wide-field IR instrument operating in the 0.48 - 2.0 micron range and an exoplanet imaging coronagraph instrument operating in the 400 - 1000nm range. With a wide field of view of 0.28 sq deg, Roman will provide unique opportunities for cosmology, exoplanet studies and a wide range of astrophysics from its near-IR surveys. The instrument also allows grism-based spectroscopy, that will enable a galaxy redshift survey over 2000deg^2 covering the redshift range $1<z<3$. This is highly complementary to the Euclid survey, covering a smaller area with a denser and higher redshift sample. Will **Percival** is the only non-US member of the Roman Galaxy Redshift Survey Project Infrastructure Team, led by Yun Wang (Caltech).

ngEHT

Building on the success of the original Event Horizon Telescope (EHT) and the first black hole picture ever, the next generation EHT (ngEHT) will modernize existing instrumentation and expand the geographical footprint of the array with roughly 10 new dishes. The ngEHT will use the same technique of very long baseline interferometry (VLBI) adopted by the EHT to unite the array of dishes spread across numerous continents into a single virtual telescope. Taking advantage of an additional observing frequency and modern high-speed data transfer protocols, data from this array will be used to form images and movies through advanced data processing algorithms. This cutting-edge technology will enable revolutionary science. The ngEHT will capture movies of black holes and better black hole pictures than ever before. It will test Einstein's general theory of relativity at the event horizon, and uncover the nature of the magnetic field, the unseen force that shapes the surroundings of black holes. It will also discover the origin of black hole jets, the immense beams of particles that defy a black hole's gravity. Avery **Broderick** is one of the key scientists driving this project forward.

Thirty Meter Telescope (TMT)

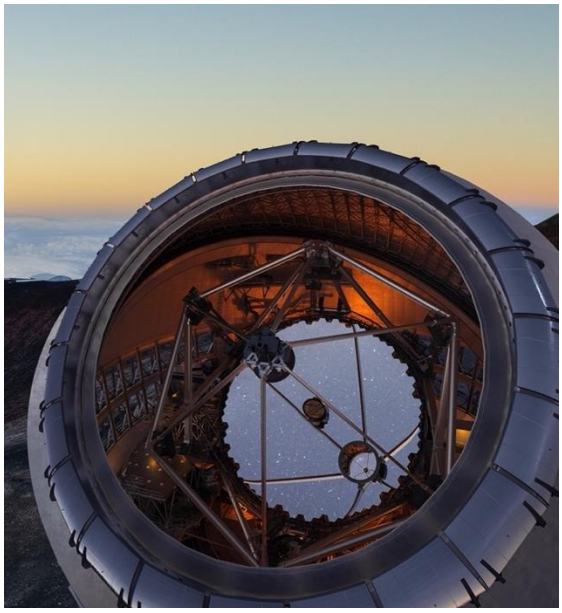


Figure 5: The 30-m primary mirror is seen through the opening in the Calotte dome, a unique design by Empire Dynamic Structures Ltd., a Canadian company based in Burnaby , BC.

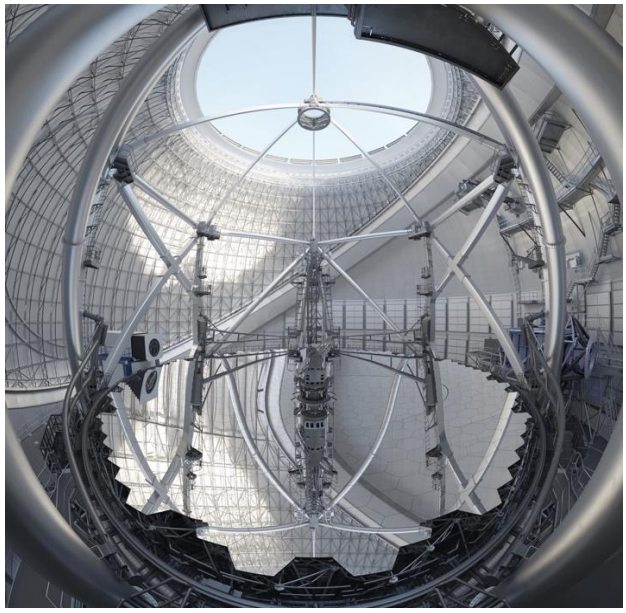


Figure 5: A view of the segmented primary mirror and the thin, lightweight "spider" structure supporting the secondary mirror above it. Two of the first light instruments can be seen on the Nasmyth platform.

Canada's Long Range Plan for astronomy identified participation in a 30-m class telescope as the top priority for ground-based infrastructure. With a primary mirror area about ten times larger than the largest telescopes that exist today, these facilities will provide the most transformational leap in capability that has been seen for decades. With an advanced adaptive optics system (being designed and built in Canada), TMT will provide an improvement in sensitivity of up to a factor 100 for some applications. At the forefront of the many exciting science applications is the possibility to detect signs of life on extrasolar planets. WCA member Michael **Balogh** is one of three Canadian representatives on the Board of Directors, and a member of the science team for one of the first-light TMT instruments, the Wide Field Optical Spectrograph (WFOS). The innovative design of this instrument will make it the most sensitive spectrograph ever built. First light for the TMT is now anticipated for the late 2030s.

UNIONS

The Ultraviolet Near Infrared Northern Survey (UNIONS) is a panchromatic imaging survey of the northern sky at declinations greater than +30 degrees (5,000 square degrees). **Hudson** led a successful large "Subaru Intensive" proposal to fill in the missing g-band from Subaru Telescope and is PI of a component of UNIONS, the Waterloo Hawaii IfA g-band Survey (WHIGS).

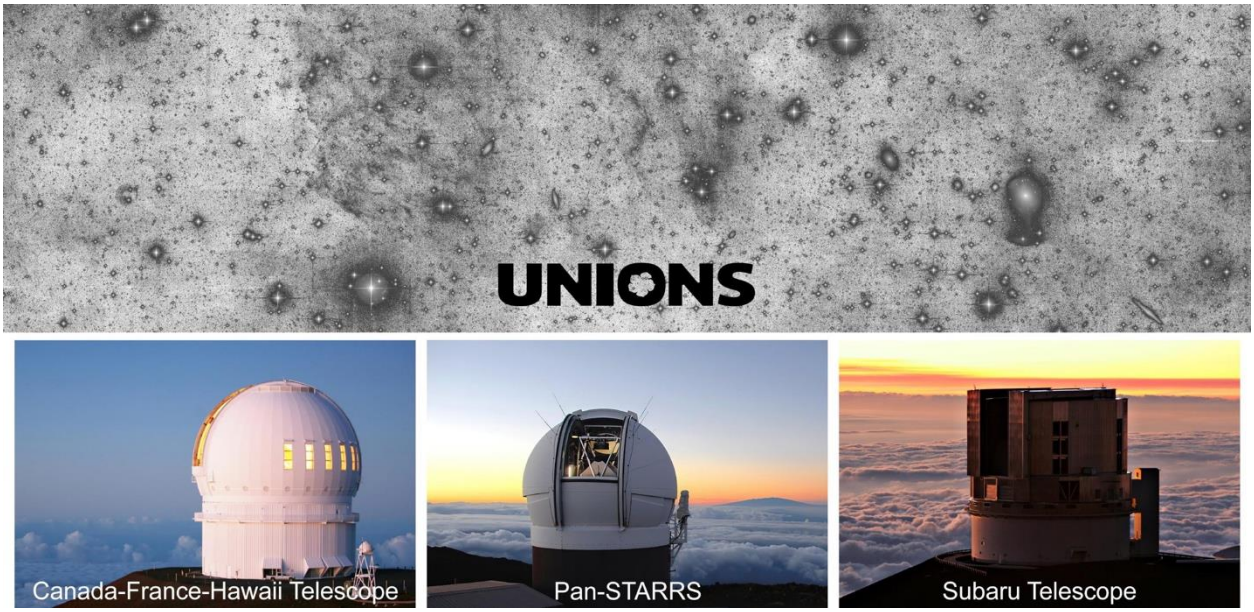


Figure 6: Observatories involved in UNIONS. Credit: UNIONS (https://www.skysurvey.cc)

The survey is roughly halfway to meeting its goal of covering 5000 square degrees. The UNION weak gravitational lensing team is led by **Hudson** and includes his Ph.D. students (**Spitzer**, **Robison**, **Martin**, and **Srinivasan**). The team has recently produced a preliminary 1,700 square degree galaxy shape catalogue that is ideal for weak-lensing studies. Some early lensing papers have been published (including one led by WCA student, Bailey **Robison**), but most of the first round of weak lensing papers is expected in late 2024, and we expect this to be a research highlight in our next renewal proposal!

Vera C. Rubin Observatory

The Vera C. Rubin Observatory on Cerro Pachon, in Chile, is on track for a start of survey operations toward the end of 2025 (*Figure 7* shows the nearly completed exterior in July 2021). This US-led telescope will conduct a ten-year Legacy Survey of Space and Time (LSST). Revisiting each location on the sky multiple times over the course of the survey will provide not only very deep multicolour imaging of the entire Southern Sky, but also the ability to chart changing events on a range of timescales from days to years. This exploration of time domain astronomy opens up many opportunities for new discovery. Thanks in part to support from the University of Waterloo, the Faculty of Science, and the WCA, Waterloo is hosting several Canadian Rubin fellowships, which will contribute both to the software architecture and science of the project. The first fellows, Liza **Sazanova** and Jack **Elvin-Poole**, arrived in Waterloo in Fall, 2022. In return for their technical support to the project, several WCA members (**Percival**, **Hudson**, **Balogh**) are expected to have full Data Rights at first light.


Figure 7: Vera C. Rubin Observatory in July 2021

XRISM

The X-Ray Imaging and Spectroscopy Mission (XRISM) is an earth-orbiting X-ray observatory developed jointly by JAXA, NASA, ESA, and the Canadian Space Agency. Its prime camera, Resolve, provides non-dispersive spectroscopy with approximately 5 eV energy resolution in the 0.3-12 keV bandpass. XRISM is the successor to Hitomi, which yielded an unprecedented study of the dynamics of the X-ray atmosphere of the Perseus cluster. XRISM will study the X-ray atmospheres of galaxy clusters, young stars, and the gaseous environments of accreting black holes after it is launched in 2023.

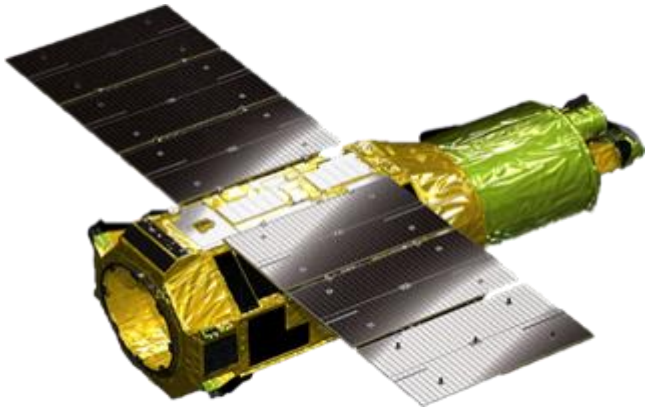


Figure 8: Computer rendering of the XRISM observatory.

WCA member Brian **McNamara** serves on NASA's Resolve Instrument Team and is principal investigator for the agreement between NASA and the Canadian Space Agency entitled, X-ray Calibration for the NASA Resolve Instrument at the Canadian Light Source Synchrotron (CLS) Facility. This program supported facility upgrades and operation of the Canadian Light Source. Led by scientists from Goddard Space Flight Center and Lawrence Livermore National Laboratory, **McNamara**'s team is performing Resolve filter transmission studies to calibrate the instrument. **McNamara** serves on the XRISM Science Team. His research team will use Resolve to perform detailed spectroscopic studies of the hot atmospheres of galaxies, clusters of galaxies, and accreting black holes.

Publications

The formation of WCA has significantly increased the number of publications from the Astronomy group at Waterloo. To quantify this, we used the Smithsonian/NASA Astrophysics Data System (ADS) to search for articles published by WCA astronomers over the time period 2010-2023 (data for 2024 is incomplete), to establish a baseline publication rate prior to the establishment of the WCA in November 2018 and to measure the activity of researchers within the WCA after formation. We limited our search to publications in the astronomy collection and affiliated with the University of Waterloo by the faculty and postdoc members (past and present) of the WCA, while they were based in Waterloo. That search was then refined to include only refereed articles. This approach does not include any articles written by WCA graduate students that were not co-authored with WCA faculty or postdocs. While we are aware that such articles exist, they are limited in number.

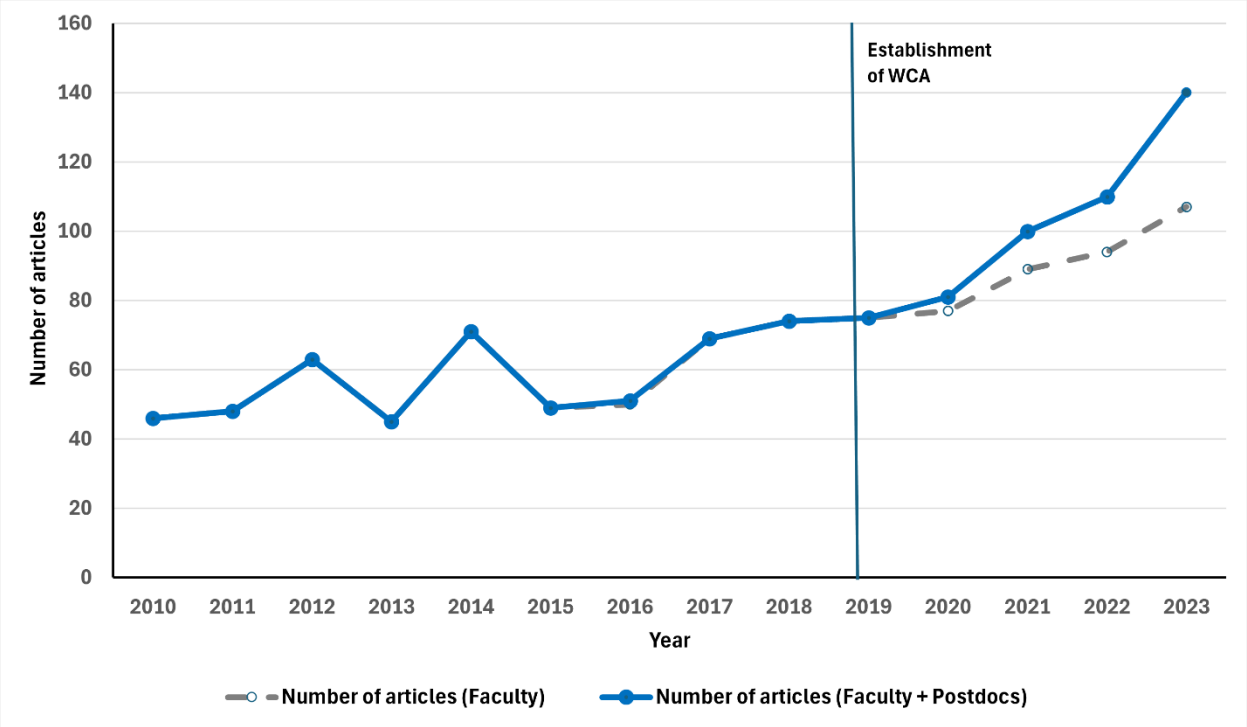


Figure 9: Number of refereed publications per year co-authored by WCA members.

The total number of refereed publications from WCA Faculty and postdocs, while affiliated with the University of Waterloo, over the fourteen-year period of 2010-2023 is 1022. 506 (49.5%) of those refereed publications were published in the five years 2019-2023 since the formation of the WCA. A listing of all WCA-affiliated papers is given in Appendix D: WCA Publications. We plot the number of refereed publications from WCA members in *Figure 9*. The dashed grey line indicates the number of publications from WCA faculty members, while the blue line shows the number of publications from WCA faculty **and** Postdoctoral fellows. The establishment of the WCA is marked by the grey vertical line. The plot shows that the publication rate of the astronomy group at the University of Waterloo has increased by a factor of more than 2 and continues to rise. The difference between the blue line and the grey dashed line indicates the number of papers written by postdocs that are not co-authored with WCA faculty and this is an indication of the extent to which our postdocs are making connections and collaborating with researchers outside of the WCA. The difference between the two lines in 2016 is due to a paper written by WCA former postdoc **Simovic**, as a graduate student, with David Kubizňák (Perimeter Institute).

Impactful Publications

At the time of writing (June, 2024), forty-nine papers published by the WCA within the last 6 years have over 100 citations. The journal reference, title and current number of citations are listed in *Table 1* below.

What stands out from this list are the series of papers by the Event Horizon Telescope (EHT) team since the end of 2018, 38 in total, which have received 10,624 citations to date. Avery **Broderick** and his team have made significant contributions to this body of work. "First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole" (2019 ApJ, 875L, 1) co-authored by WCA members **Broderick**, **Georgiev**, **Jeter**, **Ni** and **Tiede** is the most highly cited paper published by the WCA. It has received 2787 citations to date. (The most highly cited paper written prior to the establishment of the WCA is "P-V criticality of charged AdS black holes" (Kubizňák & **Mann**, 2012, JHEP, 07, 033), which has received 982 citations to date.).

The list also includes a set of highly cited papers focussed on cosmology, including papers presenting data from the Sloan Digital Sky Survey (SDSS). Will **Percival** and his team have worked for many years on this project, with **Percival** most recently serving as Survey Scientist for the fourth SDSS-IV and holding various management positions for prior stages of this project. The results from SDSS-IV including cosmological measurements from Baryon Acoustic Oscillation (BAO) and Redshift Space Distortion (RSD) were summarised in "The Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: Cosmological Implications from two Decades of Spectroscopic Surveys at the Apache Point observatory" (2021 PRD, 103, 083533) co-authored by WCA members **Chapman**, **Mohammad** and **Percival**. It has received 846 citations to date.

There are several additional highly cited papers by WCA members, including theoretical papers on black holes and cosmological simulations. There are also a series of white papers resulting from a US based future plan, which review the current state of cosmology and rank the desires for the future. Looking ahead, we can also see good traction for a paper summarising the cosmological measurements to be made from the Euclid satellite.

Table 1: WCA papers receiving more than 100 citations, as of June 2024.

Journal reference	Title	Citations
2019 ApJL ,875, L1	First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole	2787
2019 ApJL ,875, L6	First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole	1089
2019 ApJL,875,L5	First M87 Event Horizon Telescope Results. V. Physical Origin of the Asymmetric Ring	1017
2020 ApJS, 249, 3	The 16th Data Release of the Sloan Digital Sky Surveys: First Release from the APOGEE-2 Southern Survey and Full Release of eBOSS Spectra	1012
2019 ApJL, 875, L4	First M87 Event Horizon Telescope Results. IV. Imaging the Central Supermassive Black Hole	997

2021 PhRvD, 103h, 3533A	Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: Cosmological implications from two decades of spectroscopic surveys at the Apache Point Observatory	846
2022 ApJL, 930, L12	First Sagittarius A* Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole in the Center of the Milky Way	756
2019 ApJL, 875, L2	First M87 Event Horizon Telescope Results. II. Array and Instrumentation	729
2022 JHEAp, 34, 49	Cosmology intertwined: A review of the particle physics astrophysics and cosmology associated with the cosmological tensions and anomalies	665
2019 ApJL, 875, L3	First M87 Event Horizon Telescope Results. III. Data Processing and Calibration	639
2022 ApJS, 259, 35	The Seventeenth Data Release of the Sloan Digital Sky Surveys: Complete Release of MaNGA MaStar and APOGEE-2 Data	585
2021 ApJL, 910, L13	First M87 Event Horizon Telescope Results. VIII. Magnetic Field Structure near The Event Horizon	395
2021 APh, 131, 102605	Cosmology Intertwined II: The hubble constant tension	367
2019 ApJS, 240, 23	The Fifteenth Data Release of the Sloan Digital Sky Surveys: First Release of MaNGA-derived Quantities Data Visualization Tools and Stellar Library	334
2020 ApJS, 250, 8	The Sloan Digital Sky Survey Quasar Catalog: Sixteenth Data Release	317
2022 ApJL, 930, L17	First Sagittarius A* Event Horizon Telescope Results. VI. Testing the Black Hole Metric	313
2020 A&A, 642, A191	Euclid preparation. VII. Forecast validation for Euclid cosmological probes	294
2021 APh, 131, 102604	Cosmology Intertwined III: fs_8 and S_8	279
2021 ApJL, 910, L12	First M87 Event Horizon Telescope Results. VII. Polarization of the Ring	277
2020 ApJ, 901, 153	The Completed SDSS-IV Extended Baryon Oscillation Spectroscopic Survey: Baryon Acoustic Oscillations with Ly-alpha Forests	264
2022 ApJL, 930, L16	First Sagittarius A* Event Horizon Telescope Results. V. Testing Astrophysical Models of the Galactic Center Black Hole	262
2022 A&A, 662, A112	Euclid preparation. I. The Euclid Wide Survey	245
2020 ApJS, 250, 2	The Quijote Simulations	238
2020 JHEP, 2020, 27	On taking the D®4 limit of Gauss-Bonnet gravity: theory and solutions	224
2019 ApJS, 243, 26	The Event Horizon General Relativistic Magnetohydrodynamic Code Comparison Project	224
2021 MNRAS, 500, 736	The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: measurement of the BAO and growth rate of structure of the luminous red galaxy sample from the anisotropic correlation function between redshifts 0.6 and 1	222
2019 A&A, 629, A86	Baryon acoustic oscillations from the cross-correlation of Ly-alpha absorption and quasars in eBOSS DR14	220

2021 MNRAS, 500, 1201	The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: BAO and RSD measurements from anisotropic clustering analysis of the quasar sample in configuration space between redshift 0.8 and 2.2	213
2019 A&A, 629, A85	Baryon acoustic oscillations at z = 2.34 from the correlations of Ly-alpha absorption in eBOSS DR14	209
2022 ApJL, 930, L14	First Sagittarius A* Event Horizon Telescope Results. III. Imaging of the Galactic Center Supermassive Black Hole	208
2020 MNRAS, 499, 210	The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: BAO and RSD measurements from the anisotropic power spectrum of the quasar sample between redshift 0.8 and 2.2	191
2020 MNRAS, 498, 2492	The Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: measurement of the BAO and growth rate of structure of the luminous red galaxy sample from the anisotropic power spectrum between redshifts 0.6 and 1.0	190
2022 AJ, 164, 207	Overview of the Instrumentation for the Dark Energy Spectroscopic Instrument	185
2022 ApJL, 930, L13	First Sagittarius A* Event Horizon Telescope Results. II. EHT and Multiwavelength Observations and Calibration	183
2021 PhRvD, 103, 104047	Constraints on black-hole charges with the 2017 EHT observations of M87*	177
2022 ApJL, 930, L15	First Sagittarius A* Event Horizon Telescope Results. IV. Variability Morphology and Black Hole Mass	176
2021 MNRAS, 501, 5616	The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: measurement of the BAO and growth rate of structure of the emission line galaxy sample from the anisotropic power spectrum between redshift 0.6 and 1.1	175
2022 ApJL, 936, L14	The JWST Early Release Observations	166
2019 PhRvL 123, 071103	Repulsive Interactions and Universal Properties of Charged Anti-de Sitter Black Hole Microstructures	166
2020 MNRAS, 498, 2354	The Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: Large-scale structure catalogues for cosmological analysis	138
2019 PhRvD, 99, 044015	Shadow and deflection angle of rotating black holes in perfect fluid dark matter with a cosmological constant	133
2019 JCAP, 2019, 030	Curvature radius and Kerr black hole shadow	133
2023 AJ, 165, 253	The DESI Bright Galaxy Survey: Final Target Selection Design and Validation	115
2020 MNRAS, 499, 5527	The completed SDSS-IV extended baryon oscillation spectroscopic survey: growth rate of structure measurement from anisotropic clustering analysis in configuration space between redshift 0.6 and 1.1 for the emission-line galaxy sample	114
2019 PhRvD, 100, 124033	Ruppeiner geometry phase transitions and the microstructure of charged AdS black holes	114

2019 ApJ, 878, 18	The Next Generation Virgo Cluster Survey. XXIII. Fundamentals of Nuclear Star Clusters over Seven Decades in Galaxy Mass	107
2021 MNRAS, 500, 3254	The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: large-scale structure catalogues and measurement of the isotropic BAO between redshift 0.6 and 1.1 for the Emission Line Galaxy Sample	103
2021 A&A, 648, A24	Water in star-forming regions: physics and chemistry from clouds to disks as probed by Herschel spectroscopy	102
2021 MNRAS, 503, 1149	The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: 1000 multi-tracer mock catalogues with redshift evolution and systematics for galaxies and quasars of the final data release	101

Research Highlights

Results from the EHT: The first ever images of black holes

On April 10th 2019, the (EHT) collaboration reported the first ever image of a black hole. They used eight interconnected ground-based radio telescopes spread over four continents, working together using a technique called very-long-baseline interferometry (VLBI). VLBI allowed the EHT to achieve an astounding resolution of 10 to 20 micro-arcseconds — equivalent to reading a newspaper in New York from a sidewalk café in Paris. With these new cluster of powerful instruments, they obtained images of the supermassive black hole M87, the first ever image of a black hole. WCA member Avery **Broderick** participated in the creation and interpretation of these images.

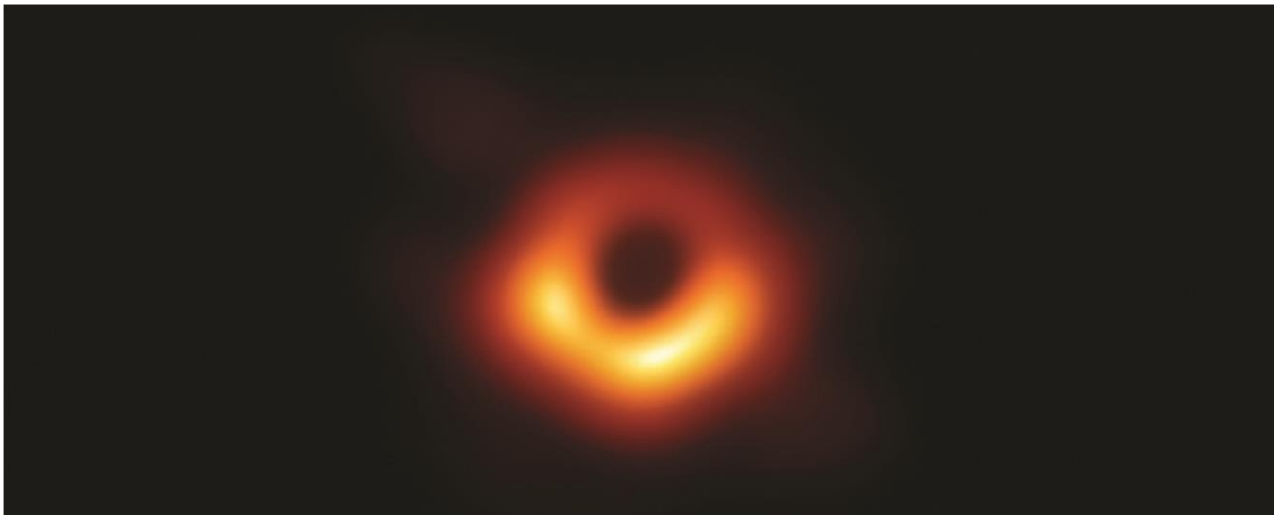


Figure 10: The shadow at the centre of M87; the first image of a black hole

“This is a landmark in astronomy, an unprecedented scientific feat accomplished by more than 200 scientists”, said EHT project director Sheperd S. Doeleman of the Center for Astrophysics | Harvard & Smithsonian. “This remarkable result has given humanity its first glimpse of the

shadow of a supermassive black hole." **Broderick** was one of the four members of the EHT selected to present the first image of a black hole at the EHT press conference in April 2019. The European Southern Observatory estimated that the EHT's image of M87 has been seen by more than half of humanity, emphasizing the profound societal impact that science can have.

Following the release of the first images of M87, the EHT Collaboration has overseen the development of ground-breaking advances in imaging techniques, retrospective studies of M87's "wobble", and observations of the quasar 3C 279. The EHT stations also record the polarization of the incident astronomical radio waves, which carry information about magnetic fields in EHT sources. In March 2021, the EHT published the first horizon-resolving polarization maps of M87, proving the existence of large-scale ordered magnetic fields wrapped about the black hole. These fields have long been implicated in the launching and acceleration of jets, the lightspeed outflows observed to emanate from active galactic nuclei.

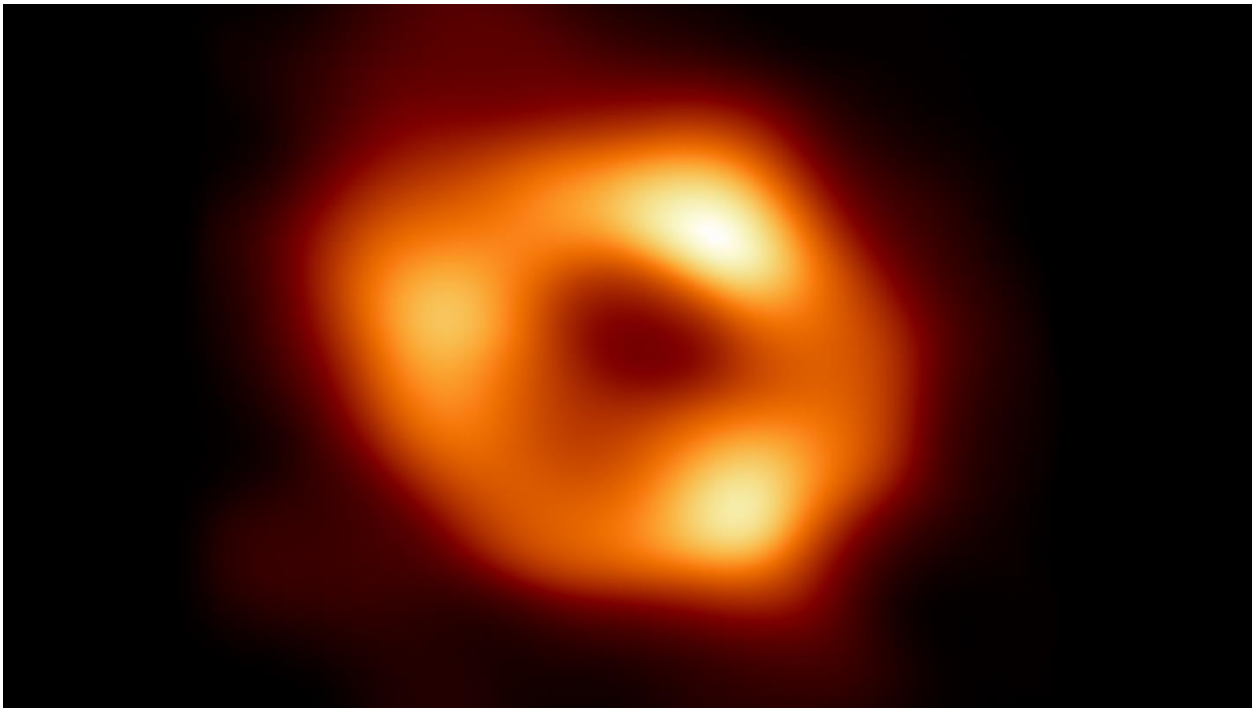
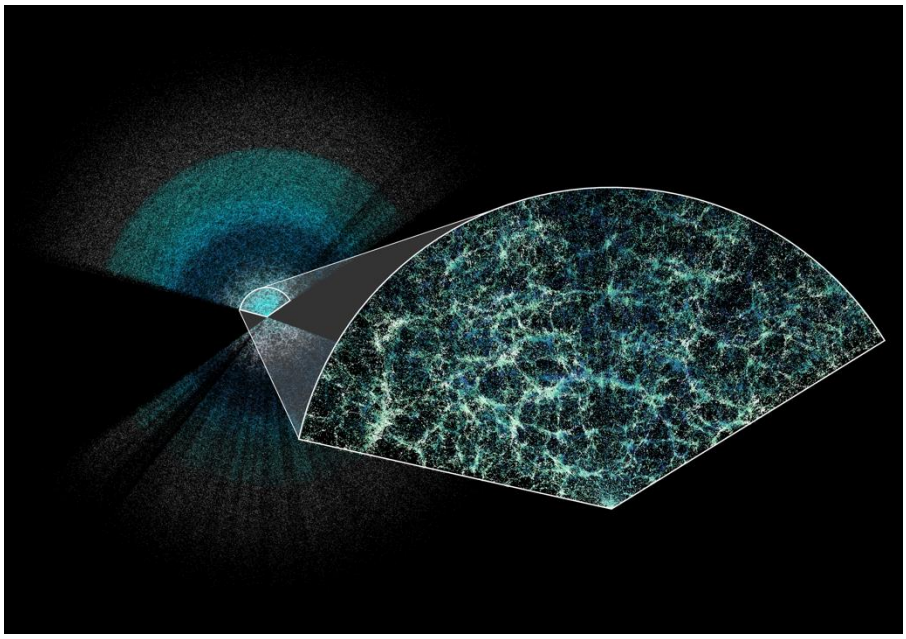


Figure 11: EHT image of time-averaged emission from Sagittarius A over a single night*

In May 2022, the EHT reported the first images of the second horizon-science target: the supermassive black hole at the centre of the Milky Way, Sagittarius A* (Sgr A*). Doing so was the culmination of many fundamental developments in radio astronomy, the most important of which was addressing Sgr A*'s extreme variability; Sgr A* would evolve on timescales of minutes while EHT images are synthesized from observations that extend over many hours. Characterizing the structural variability in Sgr A* probed a crucial process for driving accretion, turbulence, and placed our best theoretical models on a firm empirical foundation. The image releases of the black holes in the centre of M87 and SgrA* were reported in the UWaterloo news articles, "First image of black hole captured" and "Finding our galactic centre".

First cosmology results from the Dark Energy Spectroscopic Instrument (DESI)



On April 4 2024, DESI released cosmological results made using the Baryon Acoustic Oscillation technique, a technique developed by Will **Percival** over the last 25 years. The 3D map produced by DESI can see 11 billion years into the past and provides information on how the universe has grown and evolved. This map uses galaxies and gas clouds, observed by DESI during its first year of operation, as tracers of cosmic expansion throughout history and provides the most precise measurements we've ever seen of how the universe as expanded. **Percival** and WCA postdocs Alex **Krolewski,** Enrique **Paillas** and Hanyu **Zhang** played an integral role in creating this new map along with collaborators from over 70 institutions around the world. Over 1000 press articles were written about these results world-wide. DESI is managed by the US Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab). The Waterloo team is led by Will Percival, who will serve a 2-year term as co-Spokesperson of the project from Sept 1, 2024.

Astrophysicists release largest 3D map of the Universe ever created

In July 2020, the eBOSS (extended Baryon Oscillation Spectroscopic Survey) team formally announced its final measurements. eBOSS was a dedicated galaxy redshift survey produced as part of the Sloan Digital Sky Survey (SDSS), and represents the culmination of 20 years of development, that has produced a series of galaxy surveys that now span a period of 11 billion years of cosmic history. Combining observations from eBOSS with studies of the universe in its infancy from the CMB reveals cracks in the standard cosmological model. In particular, the eBOSS team's measurement of the current rate of expansion of the universe (the "Hubble Constant") is about 10 percent lower than the value found from distances to nearby galaxies.

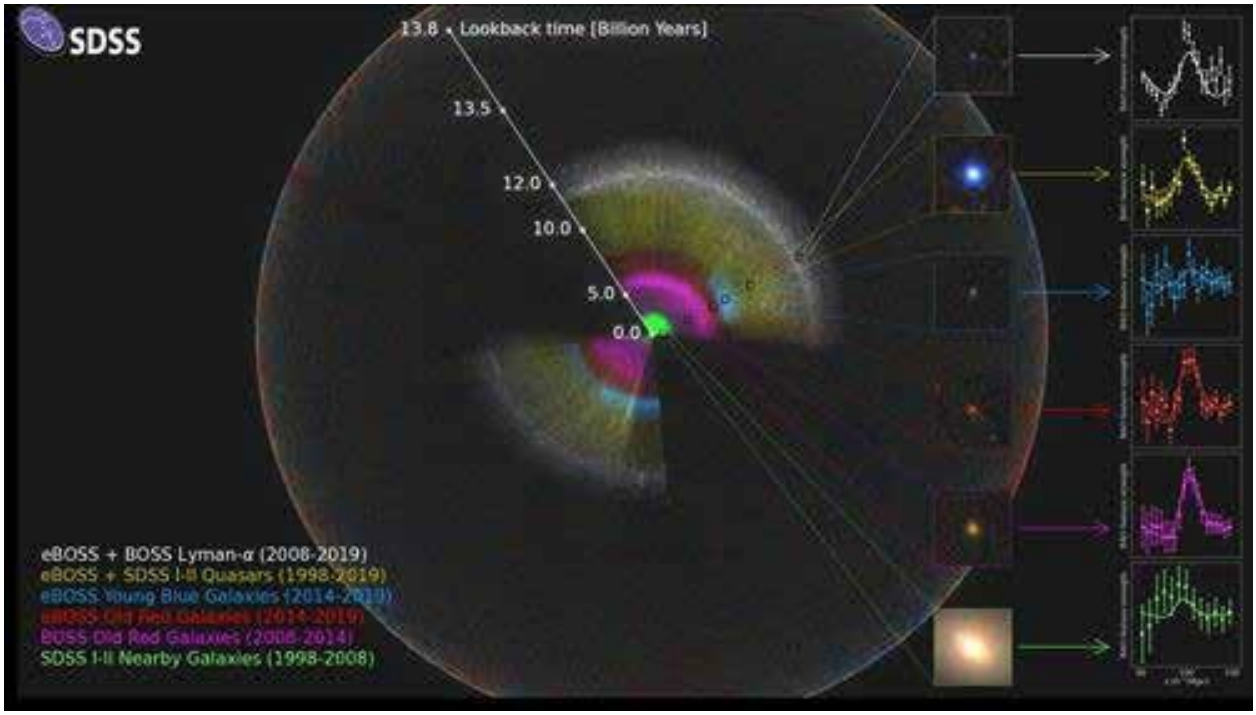


Figure 12: The SDSS galaxy surveys (coloured points) located in the observable universe (surrounding sphere) defined by the Cosmic Microwave Background. The plots on the rights show the Baryon Acoustic Oscillation measurements in each sub-sample at a different redshift. The scale of the "bump" in these plots acts a standard ruler allowing the expansion of the Universe to be robustly measured. [Image credit: Anand Raichoor (EPFL), Ashley Ross (Ohio State University)]

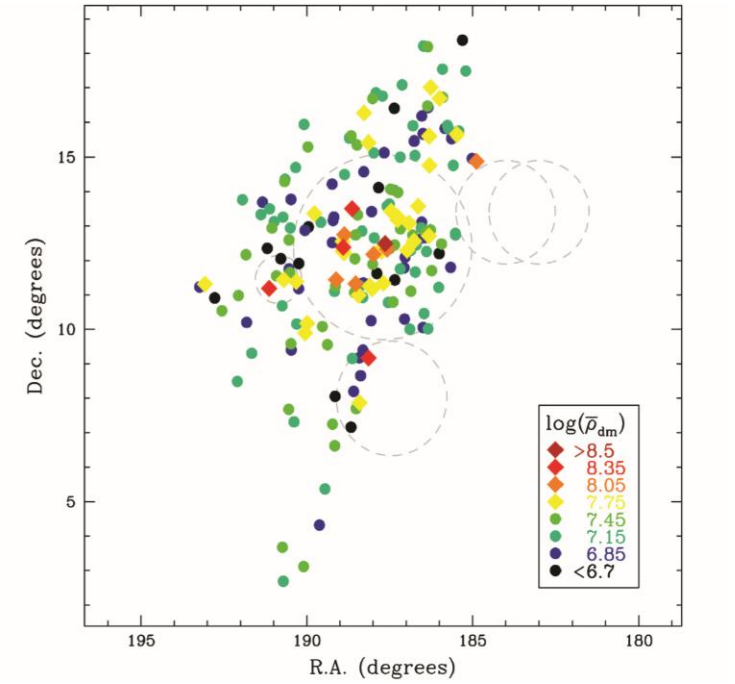
Within the eBOSS team, individual groups at universities around the world focused on different aspects of the analysis. To create the part of the map dating back six billion years, the team used large, red galaxies. Farther out, they used younger, blue galaxies. Finally, to map the universe eleven billion years in the past and more, they used quasars, which are bright galaxies lit up by material falling onto a central supermassive black hole. Each of these samples required careful analysis to remove contaminants and reveal the patterns of the universe. Faizan **Mohammad**, a postdoctoral researcher at the WCA, led one such analysis. "The hardware used to make the observations itself leaves an imprint on the map," said Mohammad. "It has been a lot of hard work to understand this imprint and remove it from the data, enabling robust measurements to be made about the universe." eBOSS, and SDSS more generally, leaves the puzzle of dark energy, and the mismatch of local and early universe expansion rate, as a legacy to future projects – such as the Dark Energy Spectroscopic Instrument (DESI) and Euclid, a European Space Agency satellite mission.

23 papers were published on arXiv together on July 20 2022, and a press release was sent out describing the work aimed at news outlets across the world. As Survey Scientist for the latest SDSS survey Will **Percival** played a big part in the coordination of these results, and the press interest that followed. In particular, he gave three interviews on primetime Canadian TV networks (including the CBC National) describing the research, and a similar number of radio

interviews. The press release was picked up by many news outlets (CNN, CBC, …) across the world and news articles were written about this work. In addition, four YouTube videos were released describing the work and providing a "fly-through" of the Universe, including two produced by the Perimeter Institute. Collective views currently stand at over one million for these videos.

Observing the build-up of structure

The standard model for cosmology predicts that the large structures we see around us in the universe - galaxies or groups and clusters of galaxies - should have assembled "hierarchically", from smaller pieces that formed earlier. While local structures such as the Virgo cluster certainly seem irregular, direct evidence for their hierarchical assembly from older components was lacking. In a recent publication, James **Taylor** demonstrated that galaxies in the central regions of the cluster have higher dark matter densities than those on the edges of the cluster. This is the first direct evidence that these objects formed earlier, at a time when the background density of the universe was higher, and thus dark matter halos were denser.



In the figure to the left, points represent individual galaxies whose mass distributions were determined by the SHIVir survey (Ouellette et al. 2017). The colour scale indicates average dark matter density within the optical extent of the galaxy. The dashed circles outline the main structural components of the cluster (note that SHIVir only covers the upper left half of the field). Galaxies with high dark matter densities (yellow, orange and red symbols) tend to reside at the centres of the structural components, showing that these regions formed earlier, whereas lower-density objects (green and blue symbols) are more widely dispersed.

The GOGREEN survey

The Gemini Observations of Galaxies in Rich Early ENvironments (GOGREEN) survey is a spectroscopic and imaging survey of 21 galaxy clusters in the redshift range $1 < z < 1.5$. The systems span a wide range of mass, from groups of only a few galaxies up to the most massive clusters at those early epochs. WCA member Michael **Balogh** is the Project Lead and was Principal Investigator on the initial proposal for the inaugural round of Large and Long Programs on the Gemini telescopes in 2014. Ultimately, the Gemini program observed over 500 hours of spectroscopy from 2014-2019, in the largest ever allocation of time to a single program at that

observatory. In addition to the spectroscopy, deep multiwavelength imaging over the full optical/near-infrared spectrum was obtained from over 100 hours of integration on 4m- and 8m-class facilities around the world. Imaging with the *Hubble Space Telescope* was also obtained on all clusters.

The power of these data are illustrated in *Figure 13*. GOGREEN and the earlier GCLASS project provide a premier sample of galaxy clusters, reflecting the Universe as it was more than 7 billion years ago (top left). For each cluster, the highly complete spectroscopy allows the identification of cluster members over the full extent of the virialized system (right panel). Each galaxy has high precision photometry over the full optical/NIR spectrum as well as medium resolution spectroscopy from Gemini (lower left).

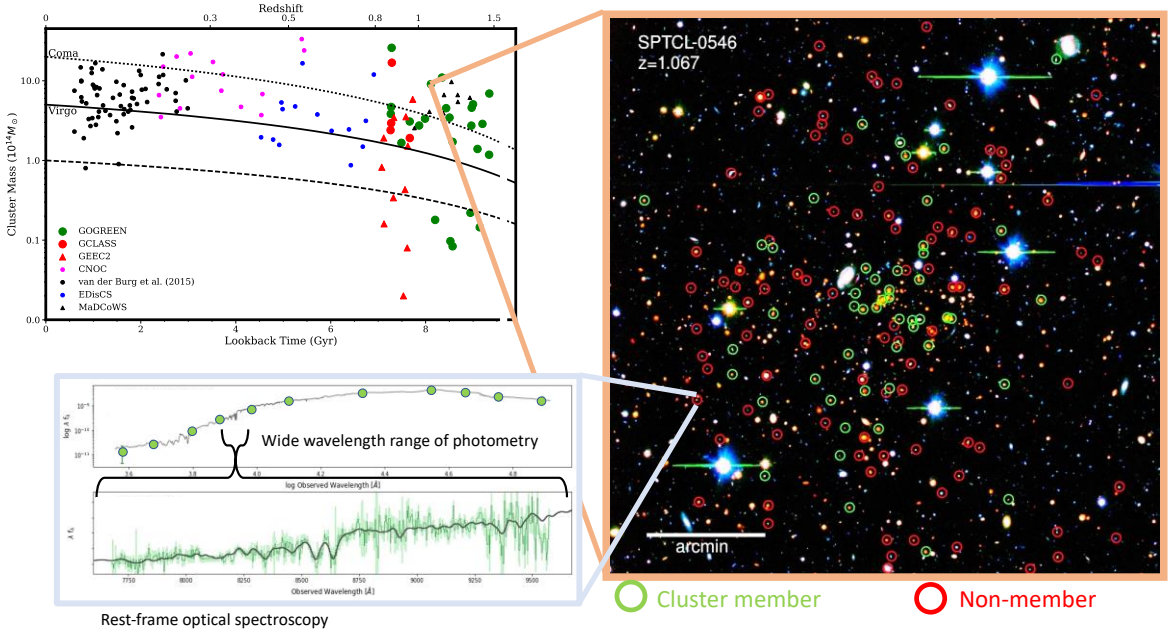


Figure 13: The top left panel shows several existing galaxy cluster surveys, as a function of cluster mass and redshift. GOGREEN and GCLASS clusters are represented by green and red circles; these are the best studied clusters at this redshift. Each cluster has Gemini spectroscopy over its full extent, which allows us to distinguish cluster members from the foreground and background (right panel). For ever cluster member the full spectral energy distribution is available from high precision photometry and moderate resolution spectroscopy (bottom left), from which stellar population parameters can be measured.

At the time of writing, GOGREEN has resulted in 15 refereed publications, that have been collectively cited over 200 times, including papers led by MSc students Guillaume **Hewitt,** Karen **McNab** and PhD students Kristi **Webb** and Andrew **Reeves.**

Testing Einstein's theory of gravity

Finding competitors to Einstein's theory of gravity is now quite commonplace. There are many ways of generalizing his original idea that gravity is manifest as spacetime curvature. One new competitor — known as Einstein Cubic Gravity — has recently been shown to be of particular interest. It modifies Einstein's theory by adding a combination of terms cubic in curvature to the usual linear term in such a way that the thermodynamics of black holes is uniquely determined and that gravitational waves at large distances have behaviour identical to that in Einstein gravity.

These two features make the theory an interesting competitor that can be tested by further observation. Last year, Robert **Mann** and PhD student Mohammad **Poshteh,** showed that gravitational lensing effects due to black holes in Einstein Cubic Gravity differ in a small but distinct way from their counterparts in Einstein's theory of general relativity. This means that Einstein Cubic Gravity can be tested by observation (Poshteh & Mann, Phys. Rev. D 99, 024035, 2019)

Understanding the early universe

The physics of the early universe is what determines how our cosmos looks like today. In the last couple of decades, the inflationary paradigm has gradually become the widely accepted theory to describe the initial conditions of the Universe. Ghazal **Geshnizjani** has been testing the validity of the effective field theory and semi-classical gravity assumptions that are used in inflation and their consistency with current theoretical candidates to describe quantum gravity (Babic et al. 2020 as well as past and ongoing project with **Hyungjin Kim**). She has found a bounce solution within a modified theory of gravity called cuscuton that can potentially resolve the Big Bang singularity problem. With her student **Leo Kim**, they showed that in a cuscuton bounce scenario scale-invariant entropy modes can be generated (Kim and GG 2020). As far as they are aware this is the first time that such a self-consistent mathematical solution has been found.

A novel predictive framework for the novel Coronovirus

It would be hard to exaggerate the impact that COVID-19 pandemic outbreak, caused by the rapid spread of the SARS–CoV-2 coronavirus, has had on human civilization. Cascading effects from the impact of the pandemic on national healthcare systems, as well as the shutdown of a large fraction of global socioeconomic activity can further impact the health and livelihood of the world population and lead to secondary fatalities, as well as shortening and/or deterioration of lives. Therefore, it is of paramount importance to understand the true dynamics and efficiency of mitigation strategies, so that a proper, transparent, and balanced response can be designed and adopted by local governments across the world.

In a truly interdisciplinary effort, **Afshordi** and his collaborators (Afshordi et al, Mathematics of Public Health, 2020) offer a new data-driven way of attacking this problem via a dynamical causal model informed by their unusual array of backgrounds in cosmology, quantum mechanics, and mathematical modeling. They have developed a physical model for the growth of the disease based on the collision of infected and susceptible populations in a community, with a cross-section+stochastic incubation of the virus. They then calibrate the cross-section and incubation, in terms of population demographics of the county, its Google social mobility, search trends, and weather, by comparing the model to the actual growth rates of COVID in all US counties. This leads to a powerful model that can be used to predict the growth/decay of pandemic in all local communities, through their online dashboard: https://wolfr.am/COVID19Dash . They hope this framework can be scaled up to more regions/data and be used to inform smart region-specific policies to suppress and/or mitigate the pandemic and its adverse effects, and ultimately, save lives. This work was featured in a University of Waterloo news item.

A New Cosmological Test based on the Structure of Galaxy Clusters

Not all is well in cosmology, and there is tension between measurements of the amplitude of fluctuations in the large-scale distribution of matter, made using different data. Fluctuations in the distribution of matter can be measured directly in the local universe by counting galaxy clusters, which correspond to peaks in the matter distribution. In a paper published in the Monthly Notices of the Royal Astronomical Society, James **Taylor** and PhD student Yuba **Amoura** (Amoura Y., et al. , 2021, MNRAS, 508, 100), considered the problem of distinguishing between models where fluctuations start large and grow slowly, versus models where they start small and grow quickly. One key difference is in the age of structures; in the high-growth case, structures such as galaxy clusters should have formed more recently, and thus be more diffuse, irregular, and disturbed. Using both analytic theory and numerical simulations, Amoura and collaborators show that age (or assembly time) varies almost orthogonally to abundance in the space of cosmological model parameters, such that separate measurements of age and abundance might reduce the uncertainties in these parameters by a factor of 10 or more. They are now developing a practical pipeline for this test, in collaboration with members of the Euclid Cluster Science Working Group.

Research Grants

WCA faculty members are active in seeking funding to support their research and enjoy success. Faculty are regularly awarded grants from the Natural Sciences and Engineering Research Council of Canada (NSERC) and Canadian Space Agency (CSA). We also take advantage of other opportunities, including interdisciplinary grants, such as the New Frontiers in Research Fund, and grants targeted towards supporting junior researchers, such as the NSERC NOVA grants**. In 2022 and 2023, our income from research grants and awards running over multiple years was approximately $1.4M and $1.3M CAD, respectively.** While we expect fluctuations in this amount per year, we do not see these years as atypical.

We also have also received a number of one-off sources of funding: Avery Broderick has been supported by the Dean of Science and Perimeter Institute to set up the Horizon AstroPhysics Initiative (HAPI), a joint venture by the University of Waterloo and Perimeter Institute to support and accelerate the continued exploitation of EHT/ngEHT observations of the near-horizon region of M87* and Sgr A* to inform the nature and astronomical impact of black holes and prepare for future space-based experiments. Mike Fich (now Associate WCA member) was PI for the CFI award covering the Fred Young Submillimeter Telescope (FYST) in 2022. Ghazal Geshniziani (now Associate WCA member) was co-investigator for an award from the Fields Institute for Research in Mathematical Sciences to organise a Thematic Program on Nonsmooth Riemannian and Lorentzian Geometry. This brought together a diverse group of scientists together to work on this topic with a series of visits, conferences and the support of postdoctoral fellows. WCA Postdoctoral Fellows are also encouraged to seek funding. We currently number a Banting Fellow and a CITA National fellow among postdoctoral fellows and have previously had a postdoctoral fellow funded by an AMTD award.

The WCA continues to obtain significant computing resources through the Digital Research Alliance of Canada (formerly Compute Canada in 2024. For the year 2022, the same organisation awarded WCA members Percival, Broderick and Taylor over 4,000 cpu years of computing time so that **the WCA accounted for 36% of the allocation awarded to PIs based at the University of Waterloo**. The equivalent value, as calculated by the Digital Alliance is over $600k / year. Approximately the same level of support has continued with simpler fast-track proposals in the subsequent two years.

WCA Supported events

WCA Launch Event

The launch event for the WCA happened on the same day as our first Governing Board meeting, 4 October 2019, and consisted of three parts: a scientific meeting during the day and early afternoon; a formal inauguration including a speech by the president of the University; and a public talk by Christine Jones Forman on “Black Holes, Dark Matter and Dark Energy: Exploring the Invisible Universe” in the early evening.

CFU-WCA Conference

We held a joint meeting between the Perimeter Institute Centre for the Universe (CFU) and the Waterloo Centre for Astrophysics on February 21st, 2020. Theory talks were given at the University of Waterloo in the morning, with lunch provided, followed by observational talks at Perimeter in the afternoon and a joint dinner event. The meeting went well, with a series of excellent interesting talks, leading to significant discussion. The interactions led to several collaborations between CFU and WCA members.

CCAT Prime collaboration meeting

The CCAT-prime telescope collaboration was scheduled to hold its first “Collaboration Meeting” April 7 and April 8, 2020. The COVID-19 pandemic meant that we switched formats to an on-line four-day, five hours/day format: initially there were 41 people planning to attend the in-person meeting but by the end 103 people had joined the on-line meeting. The meeting helped to optimise the survey strategy for the project.

GOGREEN

In August 2020, the WCA hosted the annual workshop of the GOGREEN collaboration, led by WCA faculty member, Michael Balogh. The workshop coincided with the first major public data release from the survey. To announce and celebrate this milestone, the first two days of the conference were opened to people outside the collaboration and over 80 people attended. The meeting featured many talks from students and postdocs, including WCA members Karen McNab (MSc), Andrew Reeves (PhD) and Kristi Webb (PhD).

CASCA 2022

From May 16-20, 2022 we hosted the Canadian Astronomical Society (CASCA) Annual General Meeting “Canadian Astronomy in the Roaring 2020’s” / "L'astronomie canadienne dans les années 2020". Unfortunately, because of Covid restrictions we had to take the decision to hold the meeting online, rather than in-person. We had 468 participants and participants were able to use the Whova platform to facilitate session streaming, networking, and access to materials. Attached to the conference, we held an in-person outreach talk, with Prof Katie Mack discussing how the Universe will end “Physics at the end of the Universe”.

Quantum Spacetime in the Cosmos: From Conception to Reality

Afshordi’s University of Waterloo Trailblazer Grant was used to host an interdisciplinary conference exploring the inconsistencies between Einstein’s theory of relativity and Quantum Mechanics. The WCA was a sponsor for the conference, which was held at the Perimeter Institute on May 8-12, 2023.

Understanding feedback in galaxies and clusters

During the week May 27-30, 2024, we hosted a conference to celebrate WCA member Brian McNamara’s 65th birthday. With 24 invited speakers and numerous events, this was a great success, with many anecdotes about Brian’s career aired. Dr Helen Russell, a former Waterloo postdoc who is now faculty at the University of Nottingham in the UK, gave a public talk: “Black Hole Feedback”.

50 Years of Horndeski Gravity: Exploring Modified Gravity

50 years ago, Gregory Horndeski's undertook pioneering work within the Waterloo Mathematical Physics Community considering ways to expand on Einstein’s theory of Gravity. After leaving Waterloo to pursue a successful career as an artist, he returned to attend a conference in his honor, July 15-19, 2024. On July 16, we collaborated with Advancement to host a public talk “The Gravity of Tinkering with Einstein” by Waterloo alumni, Cliff Burgess.

Outreach Activities

From its inception, it has been the intent to use the WCA as a base to engage with the general public and the broader academic community, and to share the excitement of the science done by WCA members. Astronomy naturally lends itself to outreach efforts and we will use this to enhance our impact.

Involving Advancement

The need to raise funds to help us deliver exceptional, informative and entertaining events was recognised early on. WCA members worked closely with the advancement team. On November 22, 2018, WCA members Will Percival and Brian McNamara attended the Canadian Council for the Advancement of Education (CCAE) course “Development for Deans with Lorna Somers”. This

provided insight into the work of Advancement, and Advancement techniques. We also took the opportunity of both Percival and Broderick attending a conference on “Testing Gravity” in Vancouver in January 2019, to organise a public talk by Broderick “Images from the Edge of Spacetime: Resolving Black Holes” for Waterloo Alumni in the California region, and several meet-and-greet events for both Broderick and Percival in Vancouver. These efforts have proved successful and the WCA is the beneficiary of donations totalling $63,991.75. This includes two philanthropic donations of $50,000 and $6,000, which have been used to purchase our inflatable planetarium.

Planetarium

We took delivery of our inflatable planetarium at the end of October 2022. An inflatable dome means that a specialized building is not required to host planetarium shows and, most importantly, we can take our planetarium on tour. Our planetarium has a 6m diameter inflatable dome and digital projector from Digitalis, which is large enough to easily fit a class of thirty school

Figure 14: WCA planetarium. The 6m dome inflatable dome (left) deflates to an easily transportable size (right). Small telescopes we can use for outreach can be seen in storage behind the projector and deflated dome.

children, teachers and planetarium presenters but, once deflated, is easily transportable. As well as live shows we can also play movies in the appropriate 360degree format, including one released in March 2023 covering the DESI project described in *Dark Energy Spectroscopic Instrument (DESI).* We have used the planetarium on campus for school visits and other events as well as taking it to schools and youth groups. The dome can be used indoors only.

Outreach coordinator

Recognising the need to have a specific person in charge of coordinating outreach activities, the WCA created the position of Outreach Coordinator in 2022. The outreach coordinator is responsible for creating outreach initiatives and coordinating our group of graduate student and postdoctoral outreach volunteers to run outreach events. Currently, the role is filled by Postdoctoral Fellow, **Roan Haggar**, who spends half of his time on research and half on outreach.

Roan is driven to make astronomy accessible to as many people as possible and is keen to reach people in the wider Kitchener-Waterloo community.

Regular outreach events

Over the past 18 months, Roan has set up a popular and effective outreach program. The inflatable planetarium in the star of the show but we also run two different regular seminar series and have become regular contributors to annual on-campus efforts.

Astrobubble: planetarium tours and visits

The planetarium is advertised as the *AstroBubble*, named to appeal to children and educators. The content of the planetarium shows has focused on planets, stars and constellations that can be seen in the night sky, to encourage students to develop an interest in looking at the night sky themselves. Additionally, we discuss the cultural significance of the night sky and the history of observational astronomy. The content and length of AstroBubble shows are tailored to the age of the group we are seeing.

We have teamed up with **Becca Tanouye**, who coordinates with the Ontario Postsecondary Access and Inclusion Program (OPAIP) for the University of Waterloo. Becca helps us to coordinate taking the AstroBubble into high schools in communities which historically have not accessed postsecondary education (PSE), which include students who identify as Black, Indigenous, marginalized or racialized, first-generation, newcomers, low-income, 2SLGBTQIA+, and students with disabilities. We also take the AstroBubble into elementary and high schools on request.

Although we focus on taking the AstroBubble into schools, we have also undertaken a small number of visits to youth groups and classes, but mainly rely on these groups visiting campus for planetarium shows. Girl groups we have made presentation to include the Girl Guides and the Canadian Association of Girls in Science. On campus, the AstroBubble has become a highly popular addition for Physics Lab Days, PhysiX: Girls Matter, Science Open House and alumni weekends.

We began running AstroBubble shows in November 2022. Since then, we have run 200 AstroBubble shows for a total of 4719 school children and their families. In the school year of 2022-2023, when we were still establishing the program, we ran 36 shows for 744 children and families. We consider the 2023-2024 school year to be more typical and ran 164 shows for 3975 children and families. When one considers that the school year contains a minimum of 194 instructional days, this means that we have seen an average of 20 school children (a small class) per instructional day!

Figure 15: Collage of images from planetarium shows in 2022.

Public talks

The WCA has given many public talks since its inception. Before 2023, these were one-off events. For example, in 2018, Will Percival spoke on “Mapping the Universe”, while in 2019, Mike Hudson gave a lecture on “Cosmic Mirages: seeing dark matter with gravitational lenses”. Both were sold out. The WCA also hosted a special public talk from Avery Broderick to coincide with the EHT image release in 2019. Katie Mack gave a public presentations and book signing at part of the CASCA AGM (see *CASCA 2022* above). WCA ATMD Fellow, Alex Krolewski, gave a public talk “An evening among the galaxies: gravitational lensing and dark energy" on January 26 2023. Most recently, on April 24th 2024, Avery Broderick gave a public talk “Resolving the lives of black holes: experimental strong gravity” to celebrate the release of the first images of polarised light from

Sgr A*, the black hole at the centre of our galaxy. This was the first of a planned series of talks co-organised with advancement, designed to appeal to Alumni.

WCA-Kitchener Public Library seminar series

In 2023, to draw in a more diverse audience than usually attends public talks held on the University campus, Roan approached the Kitchener Public Library (KPL) and we now jointly hold a series of monthly public astronomy talks. The talks are advertised over existing mailing lists maintained by science outreach and the Gustav Bakos Observatory but, to reach out more broadly, we also take advantage of the KPL's event advertising and the event pages of the Cities of Kitchener and Waterloo. The public lecture series at KPL began in May 2023 and to date, we have held 11 events at KPL that have been attended by 755 people.

Astronomy on Tap

"Astronomy on Tap" happens approximately every 2 months at the Crazy Canuck bar in Kitchener, where we engage in informal discussions about astronomy with interested patrons. This attracts a very different audience than would, for example, come to a public talk held at the University. The venue is smaller than the library and the seven events we have held to date have been attended by 348 people.

Perseid meteor shower

Since August of the International Year of Astronomy (2009), the Astronomy group runs an event, jointly with the Kitchener-Waterloo branch of the Royal Astronomical Society of Canada, timed to coincide with the Perseids meteor shower. This annual activity is a popular event in the WCA outreach calendar. Last year, 350 people attended, despite cloudy skies!

Social Media

We have worked hard to reach more people through social media. One of our postdoctoral fellows, **Ana Ennis**, volunteered to take on this role. She created an Instagram account in March 2023, which now has just under 600 followers. She worked with the Admin to ensure that UWaterloo branding and best social media practices were followed. Ana and WCA members have worked together to create content to advertise WCA events and research, and to educate about the background science to the research done at the WCA. The WCA has collaborated with Science Communications and University Relations to coordinate promotions of press releases and to generate social media content. The reels describing the AstroBubble and discussing the total eclipse in April 2024 were especially popular, with the eclipse reel being view over 30,000 times in the first week.

Creating a WCA community

Facilitating and conducting ground-breaking research and the training of early career scientists are key aims of the WCA. To achieve these aims, it is important to establish an environment and sense of community in which collaborations can be established and thrive and in which WCA group members can support each other in their work. This is especially important for the WCA funded postdoctoral fellows, who are not bound to one supervisor but are free to develop ideas and projects with any researcher they synergize with, irrespective of their affiliation.

Accommodations for the WCA

It is natural that the physical footprint of the WCA be within the Department of Physics and Astronomy on the UW campus. Our long-term goal is that the WCA will be accommodated in the top floor of the proposed new Physics building on the University of Waterloo campus. In the meantime, unused lab-space close to existing astronomy graduate student and faculty offices on the second floor of the Physics building has been renovated to provide a space for the WCA. Contractors started the renovations for the new Waterloo Centre for Astrophysics space on November 15, 2021 and work was completed in July 2022.

Figure 16: Reception office door showcasing the WCA logo.

The WCA offices house the Director, the Administrative Assistant, the WCA postdoctoral fellows and some graduate students. We also have a visitor office (soon to be filled by a new faculty member) and a small meeting room. Our office space is currently full, and we will be expanding into lab space across the hallway.

Regular WCA events

We have regular series of seminars, journal clubs, discussion groups and daily paper reviews (with morning coffee). Everybody in the group is encouraged to attend these events. Seminars are usually given by external speakers and visitors often lead the discussion in journals clubs. Faculty hold group meetings for just their grad students and postdocs but there are discussion groups based on common themes of interest that are more broadly attended.

Several journal clubs arose in response to identified need or interest and it is worth noting that these were conceived of and run by the postdocs. “Retro-journal club” gives an opportunity to review classic papers in the field, *without* faculty present so that graduate students feel comfortable admitting they do not understand something. A statistics book club ran for a while so that a number of postdocs and grad students wishing to improve their understanding of statistics could work together. EDI coffee time gives an opportunity to review papers about EDI issues and to discuss how we can work in a more inclusive way. EDI coffee times are also used

to discuss techniques to improve well-being and best work practices. For example, the WCA graduate student-supervisor agreement was discussed and written during EDI coffee.

Once a year, the WCA holds a jamboree in which everybody presents a slide and talks for one or two minutes about their research. This helps everybody in the WCA keep track of what everybody is doing and is also good practice for interviews for the students and postdocs.

Informal community building

While journal clubs and coffee times help set-up a good working relationship, if it also important for team-building to meet informally too. On a day-to-day basis, the WCA kitchenette is an informal hub for making and growing connections, and a visit to the Grad House on Friday evenings is a long-standing tradition. However, the faculty are less likely to be involved in these get-togethers. To engage more of the group, we held: a Winter party in December 2023; Pride Month Potlucks in June 2023 and 2024; and group BBQs in September 2023 and May 2024.

Mentoring and promoting early career researchers

Postdoctoral Fellows are assigned a member of the faculty who is not their supervisor to be a "non-academic" mentor after they join the WCA. The mentors meet with their assigned postdoc at least once a year to discuss progress, career plans and any issues of concern. The mentors provide a different viewpoint and set of experiences than the postdocs academic supervisor but are also a resource in the case that there are any issues between the postdoc and their academic supervisor. The postdocs felt this was valuable enough that the graduate students should have access to a similar scheme. The Grad student non-academic mentoring scheme was established and is popular with the students. Graduate students may also turn to their committee and the graduate officer for advice.

In Winter 2022, we organised a graduate-level reading course where lectures and assignments were split between four of our postdoctoral fellows. This was well received by the postdocs, giving them valuable teaching experience, and by the graduate students. This was repeated in 2024, with an astro-statistics course (after the Statistics book club felt they had been successful in teaching themselves statistics). We plan to expand upon this by having the postdocs also run a short series of seminars for the graduate students on various skills such as: writing CVs, being interviewed, writing proposals, conducting literature searches and reviews and writing papers. Now that we have a good-sized number of postdocs in the group, advice on applying for faculty positions and next steps in their career that has previously been passed on an as-needed basis has been formalized into a workshop given by the faculty.

This year, we held the inaugural WCA graduate student paper prize. Nominations were sought for papers submitted by graduate students affiliated with the WCA between July 1, 2022, and June 30, 2023. The nominated papers were considered by a panel of faculty and postdocs and evaluated on their importance to their field, originality of conception, difficulty of execution, clarity of exposition, and public availability of data/code utilized. Drs. Mike Chapman and Chunchong (Rufus) Xi received their cash prize and their certificates on June 14th for their papers

“Isolating the linear signal when making redshift space distortion measurements" (Chapman) and "Probing Accretion Turbulence in the Galactic Center with EHT Polarimetry”, (Ni).

Postdocs and students have a voice in the WCA executive. Postdoc and graduate student representatives meet regularly with their cohorts and bring feedback, questions, concerns, and requests to the WCA monthly meetings. In addition to providing representation independent of academic supervisors, this gives our early researchers some insight into how academic groups are run and gives the representatives themselves the experience of attending and participating in what are traditionally faculty meetings. Following feedback received from the WCA Membership survey, we introduced postdoc and graduate student deputy representatives to serve as back-up.

Membership

Overview and conditions for membership

The WCA currently consists of 11 faculty members, 16 Postdoctoral Fellows, 38 Graduate Students (22 PhD, 16 MSc), and 8 associate members. Past members include 64 Graduate Students and 10 Postdocs. In total, 102 Graduate Students have been affiliated with the WCA since its inception.

Conditions for membership of the WCA are laid out in our constitution and are as described below.

Regular Faculty, Student and Postdoctoral Members

Regular Faculty Members of the WCA are faculty members at the University of Waterloo whose research interests overlap with the mission of the WCA. Membership whether granted by the Board, or granted for the initial complement of Members when the proposal to establish the Centre was approved by the University of Waterloo Senate, will be for a period of 3 years. Reappointment will require application to the Director within the 3rd year and approval by the Board. Regular Student and Postdoctoral membership may be granted by

Code of conduct

The Waterloo Centre for Astrophysics (WCA) at the University of Waterloo is committed to creating and maintaining an environment that is free from unlawful harassment, violence and/or discrimination. WCA supports a zero-tolerance policy with regards to workplace harassment, violence and/or discrimination. We will not tolerate or condone behaviour that is contrary to the Human Rights Code or other Canadian provincial or federal legislation anywhere in its workplace or any activities on or off the Campuses of the University of Waterloo which could reasonably be associated with the workplace.

Harassment, discrimination, or the abuse of supervisory authority will not be allowed for any activity connected with the WCA. UW policies will be used to define unacceptable behavior including the Conflict-of-Interest Policy #69, Ethical Behavior policy #33, and Prevention and Response to Sexual Violence Policy #42.

the Director upon recommendation of the mentor or advisor. Regular student and postdoctoral members will be reviewed annually by the Board. Regular Faculty, Student and Postdoctoral Members are expected to be primarily “in residence” at the University of Waterloo.

Associate Members
Scientists with primary appointments outside the University of Waterloo, or who are retired WCA Regular Faculty Members, may seek to become Associate Members of the WCA. Membership will be subject to the same criteria as Regular Members. Associate Members will have access to shared desk space during the time they spend within the WCA.

Membership Privileges and Responsibilities
Regular Faculty, Student, Postdoctoral and Associate Members will be able to use WCA facilities and funds to conduct and disseminate their research, within the framework described in the constitution, and established by the Director. In return, all Members will be expected to acknowledge their WCA affiliation and/or funding, and to play an active role within the WCA.

Current Membership

Faculty

Name	Position	Department
Niayesh Afshordi	Professor	Physics and Astronomy, Perimeter Institute
Michael Balogh	Professor	Physics and Astronomy
Avery Broderick	Associate Professor	Physics and Astronomy, Perimeter Institute
Richard Epp	Continuing Lecturer	Physics and Astronomy
Mike Hudson	Professor	Physics and Astronomy
Achim Kempf	Professor; Canada Research Chair in the Physics of Information	Physics and Astronomy
Robert Mann	University Professor	Physics and Astronomy
Eduardo Martin-Martinez	Associate Professor	Physics and Astronomy, Applied Mathematics
Brian McNamara	Professor; Department Chair; University Research Chair in Astrophysics	Physics and Astronomy
Will Percival	Professor; Distinguished Research Chair in Astrophysics; Director, Waterloo Centre for Astrophysics	Physics and Astronomy
James Taylor	Associate Professor	Physics and Astronomy

Table 2: Current faculty members of WCA

Postdoctoral Fellows

Name	Years	Funding
Alex Krolewski	2020-2023 2023-2026	AMTD fellow (support from PI) CITA National Fellow (support from WCA)

Enrique Paillas	2021-2024	Supported by Percival
Tom Rose	2021-2024	50% WCA Fellow, 50% supported by McNamara
Ana Ennis	2022-2025	Joint WCA/PI position (Funding: 33% WCA, 67% PI)
Liza Sazonova	2022-2025	LSST fellow, supported by UW central funding
Roan Haggar	2022-2025	50% WCA Fellow, 50% outreach coordinator
Jack Elvin-Poole	2022-2025	LSST fellow, supported by UW central funding
Jerome Quintin	2022-2025	Mathematics Prestigious Postdoctoral Fellowship
Hanyu Zhang	2023-2026	Supported by Percival
Marco Bonici	2023-2027	Supported by Percival
Amber Hollinger	2023-2024	Supported by Hudson
Pierre Burger	2023-2025	50% WCA Fellow, 50% supported by Hudson
Lammim Ahad	2023-2026	WCA Fellow
Ian Roberts	2023-2026	Banting Fellow (WCA for final year)
Ashley Bemis	2024-2026	WCA Fellow (support from office of Dean of Science)
Shokoufeh Faraji	2024-2026	50% WCA Fellow, 50% supported by Afshordi and Broderick

Table 3: Current Postdoctoral Fellow members of WCA (arranged in order of arrival).

PhD Students

Student	Supervisor
Dyuman Bhattcharya	Mann
Alice Chen	Afshordi
Sofia Chiarenza	Percival
Conner Dailey	Afshordi
Amirhosein Dehghanizade	Geshnizjani
Tristan Fraser	Percival
Batia Friedman-Shaw	Percival
Michael Gammon	Mann
Marie-Joelle Gingras	McNamara
Hans Hopkins	Percival, Lang
Dorsa Sadat Hosseini	Geshnizjani
Brayden Hull	Geshnizjani, Mann
Cameron Lawlor-Forsyth	Balogh
Muzi Li	McNamara
Adrian Lopez	Mann
Hunter Martin	Hudson
Elly (officially Ali) Moghtaderi	Geshnizjani
Cameron Morgan	Balogh
Everett Patterson	Mann
Maria Rosa Preciado Rivas	Mann
Krishan Saraswat	Afshordi
Cendikiawan Suryaatmadja	Mann

Table 4: Current PhD student members of WCA

Masters Students

Student	Supervisor
Martine Campbell	Hudson
Taylor Cey	Mann

Jedri de Luna	Taylor
Neo Dizdar	McNamara
Jordan Ducatel	Hudson, Balogh
Katherine Frazer	Taylor
Guillaume Hewitt	Balogh
Mengqi Lu	Mann
Justin Marchioni	Taylor
Julian Meunier	McNamara
James Morawetz	Percival
Alan Nguyen	Percival
Kiana Salehi	Broderick
Greg Schreiner	Percival
Jiayue Yang	Afshordi, Mann
Zhiren (Joseph) Wang	Broderick

Table 5: Current MSc members of WCA

Associate Members

Name	Position	Department
Alison Coil	Professor; Ingrid and Joseph W. Hibben Chair	Center for Astrophysics and Space Sciences, University of California, San Diego
Neal Dalal	Research Faculty	Perimeter Institute
Michel Fich	Professor Emeritus	Physics and Astronomy, University of Waterloo
Ghazal Geshnizjani	Teaching Faculty (Research Track) Adjunct Associate Professor	Perimeter Institute Applied Mathematics
Gretchen Harris	Professor Emeritus	Physics and Astronomy, University of Waterloo
Dustin Lang	Computational Scientist	Perimeter Institute
Katherine Mack	Hawking Chair in Cosmology and Science Communication	Perimeter Institute
Zhongxu Zhai	Associate Professor	Shanghai Jiao Tong University

Table 6: Associate members of the WCA

Past Membership

Postdoctoral Fellows

Name	Dates	Went to...
Simone Paradiso	2023-2024	Postdoc, INAF (Astrophysics national institute), Italy
Shahab Joudaki	2021-2023	Dennis Sciama Research Fellowship, University of Portsmouth
Elena Massara	2019-2023	Moving to Data Science
Alexa Villaume	2020-2023	
Zhongxu Zhai	2021-2022	Faculty, Shanghai Jiao Tong University, China, WCA Associate
Fil Simovic	2021-2022	Research Fellow, Macquarie University, Australia
Laura Henderson	2021-2022	Research Fellow, University of Queensland, Australia
Go Ogiya	2019-2021	Faculty, Zhejiang University, China
Andrej Obuljen	2018-2021	Research Fellow, University of Zurich, Switzerland
Faizan Mohammed	2018-2021	Senior data scientist, BC Ferries

Table 7: Former WCA Postdoctoral Fellows

Graduate Students

Name	Date	Degree	Supervisor	New position
Chunchong (Rufus) Ni	2020-2024	Ph.D	Broderick	
Adit Edward	2021-2024	MSc	Balogh	
Siddhardha Penmetsa	2021-2023	Msc	Percival	NEquest AI
Suraj Srinivasan	2019-2023	Ph.D	Hudson	
Boris Georgiev	2018-2023	Ph.D	Broderick	Postdoctoral Fellow, Steward Observatory, University of Arizona
Mike Chapman	2018-2023	Ph.D	Percival	
Andrew Reeves	2019-2023	Ph.D	Hudson	Organizer/Software Developer for CUPE
Manar Naeem	2021-2023	MSc	Mann	
Jack Davis	2018-2023	Ph.D	Mann	Postdoctoral Fellow, India, Paris
Erickson Tjoa	2019-2023	Ph.D	Mann	Postdoctoral researcher at the Max Planck Institute for Quantum Optics, Germany
Ken Yoshimura	2019-2023	Ph.D	Mann	Assistant Professor, Kyushu University, Japan
Alex Woodfinden	2019-2023	Ph.D	Percival	Junior Quant Trader at Akuna Capital
Yuba Amoura	2019-2023	Ph.D	Taylor	
Kristi Webb	2017-2023	Ph.D	Balogh	Environment Canada as part of Canada Centre for Climate modelling and analysis (CCCma).
Amit Anand	2021-2023	M.Sc	Ghose/Mann	Graduate Teaching Assistant, University of Waterloo
Zhiren (Joseph) Wang	2021-2023	M.Sc	Broderick	
Setareh Foroozan	2020-2023	Ph.D	Taylor/Percival	Software engineer/Computational Scientist for Aurora Solar
Nick De Marchi	2019-2023	M.Sc	Percival	Data Scientist at Altas Partners
Maxence Corman	2019-2023	Ph.D	East/Afshordi	
Finnian Padraig Stott Gray	2018-2023	Ph.D	Kubiznak/Mann	Postdoc at University of Vienna
Prathamesh Tamhane	2017-2022	Ph.D.	McNamara	Postdoctoral Researcher, Univesrity of Alabama in Huntsville
Ahmed Shalabi	2021-2022	M.Sc	Mann	
Cemile Senem Arabaci	2020-2022	M.Sc	Mann	
Chloe Cheng	2020-2022	M.Sc	Balogh	PhD candidate at Leiden Observatory
Margie Christ	2020-2022	M.Sc	Ghose/Mann	

Barbara Soda	2019-2022	Ph.D	Kempf/Hardy	Postdoctoral Fellow at Perimeter Institute
Soham Mukherjee	2017-2022	Ph.D	Schnetter/ Broderick	Data Scientist at Shopify
Isaac Spitzer	2016-2022	Ph.D	Hudson	Staff at Space Telescope Science Institute
Chengyu Xi	2014-2022	Ph.D	Taylor	
Hamidreza Ramezani-Gol-Afshani	2021-	M.Sc	Afshordi	
Bailey Alexander Robison	2019-2021	M.Sc	Hudson	Royal Bank of Canada
Leo Kim	2019-2021	MMath	Geshnizjani	PhD student at Queens University
Mayar Tharwat Mohamed	2019-2021	M.Sc	Ghose/Mann	Electronic Specialist at Yasuke Audioworks
Karen McNab	2018-2021	M.Sc	Balogh	
Allison Sachs	2018-2021	Ph.D	Mann/Kempf	Returned to US
Wan Cong	2018-2021	Ph.D	Kubiznak/Mann	Postdoc at the University of Vienna
Fiona McCarthy	2017-2021	Ph.D	Kubiznak/Mann	Postdoctoral Researcher and Simons Foundation
Matthew Robbins	2017-2021	Ph.D	Mann/Afshordi	Sessional Instructor, Dept Physics and Astronomy, University of Waterloo
Nitica Sakharwade	2017-2021	Ph.D	Hardy/Kempf	Postdoctoral Fellow at University Gdansk, Poland
Paul Tiede	2017-2021	Ph.D	Broderick	Postdoctoral Fellow Centre for Astrophysics | Havard & Smithsonian
Abdulrahim Al Balushi	2017-2021	Ph.D	Mann	
Juan Ignacio Cayuso	2017-2021	Ph.D	Johnson/Afshordi	SSr Data Scientist, Mercado Libre
Utkarsh Giri	2016-2021	Ph.D	Afshordi	Research Associate, University of Wisconsin-Madison
Masoud Rafiei Ravandi	2016-2021	Ph.D	Broderick/Smith	Postdoctoral Researcher at McGill University
Pablo Bosch Gomez	2015-2021	Ph.D	Lehner/McNamara	Postdoctoral Researcher, University of Amsterdam (GRAPPA & IHEF)
Hyung Jin Kim (Tony)	2015-2021	MMath + PhD	Geshnizjani	Software engineer at Comparative
Marcus Edwards	2018-2020	M.Sc	Mann	Ph.D in Quantum Science and Technology Lab at University of British Columbia
Samantha Hergott	2018-2020	M.Sc	Afshordi	Ph.D at York University

Tianyi Yang	2018-2020	M.Sc	Afshordi/Hudson	Postdoctoral Fellow at University of Arizona
Daniel Grimmer	2017-2020	Ph.D	Mann/Martin-Martinez	MSt in Philosophy of Physics at Oxford University
Nayeli Azucena Rodriguez Briones	2016-2020	Ph.D	Laflamme/Kempf	Miller Postdoctoral Fellow at Berkley
Supranta Sarma Boruah	2016-2020	MMath + PhD	Geshnizjani/Hudson	Postdoctoral Fellow at University of Arizona
Qingwen Wang	2016-2020	Ph.D	Afshordi	Senior Quantitative Analyst
Britt Jeter	2015-2020	Ph.D	Broderick/ McNamara	Postdoctoral Fellow, Academia Sinica, Institute for Astronomy and Astrophysics
Marvy Onuma-Kalu	2012-2020	M.Sc and Ph.D	Mann	Business Analyst Trainee at Udacity
Connor Gordon Martz	2017-2019	M.Sc	McNamara	In-house STEM Editor at Scribendi Inc
Nicole Drakos	2015-2019	Ph.D	Taylor	Postdoctoral Scholar at University College Santa Cruz
Meenu Kumari	2014-2019	Ph.D	Ghose/Mann	Postdoctoral researcher at Perimeter Institute
Saoussen Mbarek	2014-2019	Ph.D	Mann	Data Scientist at Videns Analytics
Keith Kai-Chung Ng	2014-2019	Ph.D	Mann	Research Fellow at Nanyang Technological University, Singapore
Faerlin Pulido	2019-		McNamara	
Alexander Roman	2019-	Ph.D	Smith/Afshordi	
Haomiao Jiang	2017-2019	M.Sc	Mann	PhD candidate, Yunnan University, China

Table 8: Former WCA Graduate students

Membership survey

In February 2023, we surveyed our members to obtain feedback about the WCA. We were also asked by our governing board at the last meeting to obtain demographic information about our members. We undertook a combined survey. We wished to ensure that the survey was appropriate and in accordance with guidelines around collecting demographics. The survey was compiled with assistance from Karen Cummings (Chair of the Physics and Astronomy EDI committee) and Savannah Sloat (Manager, Science Indigenous Initiatives, Faculty of Science), who both have expertise and experience in conducting such surveys. The WCA is a relatively small group so, to ensure the anonymity of the respondents, the survey responses were collected by Savannah, who compiled an executive summary for us, and provided the anonymized survey

results and qualitative comments. The survey results are given in Appendix C: WCA Membership survey responses we have kept the qualitative results private to maintain anonymity.

Waterloo Centre for Astrophysics (WCA) 2023 Membership Survey Results Summary

Overview

This survey was conducted to gather insights from members of the WCA concerning its operation and to provide a demographic review. The survey was conducted online through Microsoft Forms for ease of access and integration with Outlook, and members were given 14 days to respond. The survey closed with a total of 36 respondents, which represents 47% of the membership of the WCA. Respondents who self-identified as students represented 50% of the total submitted responses. 34% of respondents stated they had been members of the WCA for 4+ years, and 29% of respondents stated they had been members for 1 year or less.

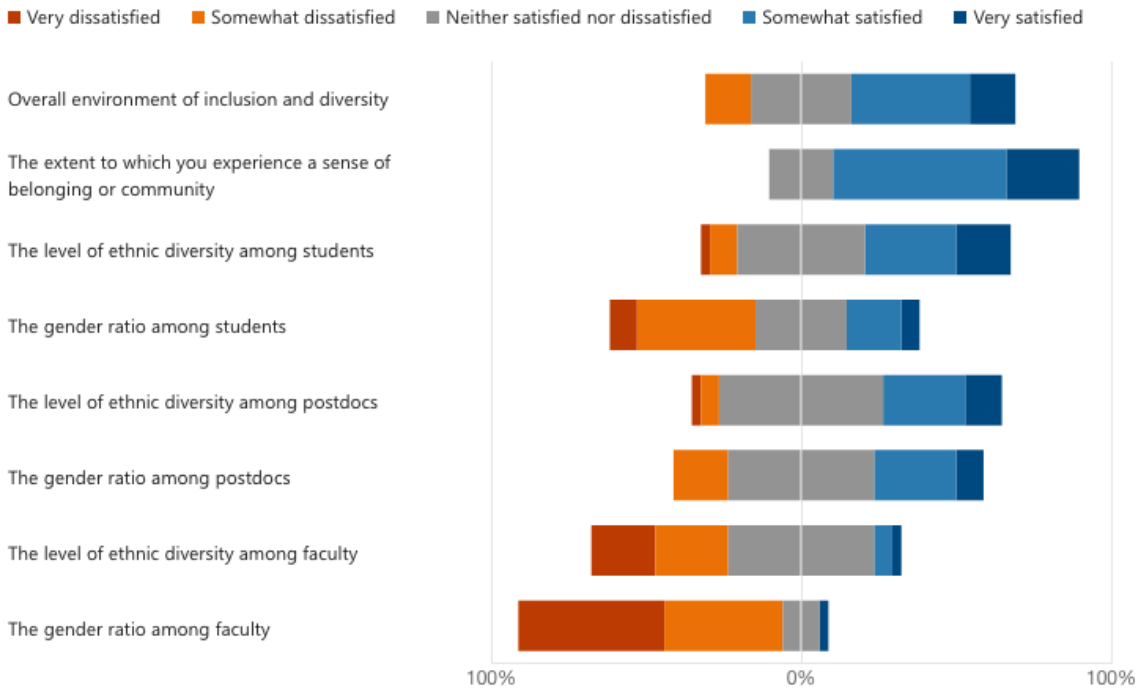
WCA Engagement

When asked why they joined the University of Waterloo and the WCA, 58% of respondents identified the research reputation of their supervisor/mentor, and 50% identified the research reputation in astrophysics and the reputation of the University of Waterloo overall. Regarding the WCA Seminar Program, 86% of respondents identified that it was beneficial to them. Qualitative feedback suggested seminars always be held in person to garner more engagement, and several respondents suggested that the diversity of speakers (both the identity of speakers and the research areas) could be expanded. One respondent suggested encouraging supervisors and their students to compile lists of potential speakers at the start of each year. Additionally, 74% of respondents find the Journal Clubs/Topical Meetings beneficial. Suggestions for improving these meetings included making them more discussion-focused and determining a consistent format for presentations. The Retro Journal Club garnered positive feedback from multiple participants.

When asked what they would like to see for future engagement, numerous respondents identified community-building and social events as something they would engage with. It was noted that it can be difficult to navigate the WCA administratively due to staff turnover and having social opportunities would promote networking. The development of a student mentorship program within the WCA was brought up by several respondents who felt it would be valuable for engagement and navigating the academic climate. It was noted that a true mentorship program is distinct from the student committee which currently exists. Equity, diversity, and inclusion training for staff and faculty was also suggested.

General Climate of the WCA

Overall, 79.4% of members identified being either somewhat satisfied or very satisfied with their personal sense of belonging within the WCA: the remaining 20.6% were neither satisfied nor dissatisfied. No respondents were dissatisfied. The data demonstrated a clear concern with the gender ratio and ethnic diversity ratio among members. 47.1% of respondents were strongly dissatisfied with the gender ratio among faculty, and 20.6% were strongly dissatisfied with the ethnic diversity among faculty. The chart below shows the responses for all questions related to ethnic and gender diversity in the WCA:



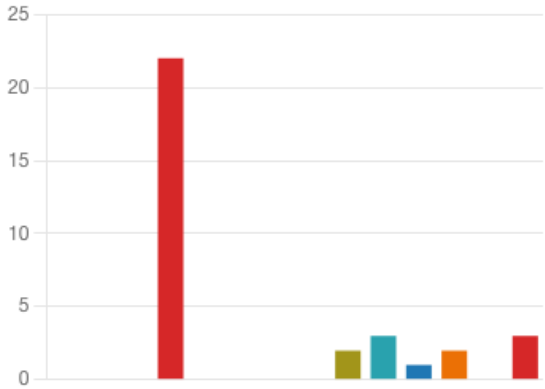
When asked about perceptions of the membership's commitment to diversity, equity, and inclusion, respondents identified students and postdocs to be the most committed, and the perception on faculty commitment to diversity, equity, and inclusion was largely neutral (41.2%). In their qualitative responses, several respondents identified inclusion to be a clear concern in relation to gender diversity of the membership. A few respondents noted that the climate of inclusion and belonging is welcoming between graduate students and postdocs, but this is not reflected in relationships with staff and faculty. One respondent felt staff and faculty do not wish to engage with feedback from graduate students and postdocs.

Demographic Information

Of the 36 respondents, 25 self-identified as men, 9 self-identified as women, 1 person self-identified as transgender/transitioning, and 1 respondent chose not to identify. 17% of respondents self-identified as 2SLGBT+, and 15% of respondents self-identified having a disability.

Regarding ethnic diversity, 61% of all respondents self-identified as European. 3 respondents self-identified as South Asian, 2 respondents self-identified as West Asian 1, respondent self-identified as Southeast Asian, and 2 respondents identified as Latin American. 3 respondents self-identified as "Other" but did not state their identity, and 3 respondents chose not to self-identify. The survey used the ethnic origin list used for the Canadian Census. The results of the ethnic self-identification are reflected in the chart below:

Arab	0
Black	0
Chinese	0
European	22
Filipino	0
Indigenous (eg., First Nations, In...	0
Japanese	0
Korean	0
Latin American	2
South Asian (e.g., East Indian, Pa...	3
Southeast Asian (e.g., Cambodia...	1
West Asian (e.g., Afghan, Iranian...	2
Prefer not to say	0
Other	3



Reflection on survey results

Reflection 1: Astroseminars and journal clubs and journal clubs are popular and helpful.
The majority of our members find our astroseminars and journal clubs to be helpful. The new "Retro Journal Club" organized by Canada Rubin Postdoctoral Fellow, Liza Sazanova, warrants a special mention for the number of positive comments it received. The seminar and journal club experiences are important enough to our members that the demand for more in-person seminars and ways to further improve journal clubs were a major theme in the qualitative responses.

Action: There was a very clear demand for a return to in-person seminars. The seminar series had to switch to an on-line format during the pandemic, and we are now running a hybrid approach with some speakers in person and some remote. In the 2023 Winter term, just under half of the speakers visited and spoke in person and this has increased to over 75% of speakers giving an in-person seminar in the last term. Remote attendance is now limited to personal choice of the speaker or due to budgetary constraints for more geographically distant seminar invitees.

It is pleasing to see so many detailed qualitative responses about the journal clubs. They are an important way to engage with and train the early researchers within the group. The qualitative feedback on journal clubs from the survey was discussed during the March 2023 WCA executive meeting and recommendations were implemented by the Astro Journal Club organizer.

Reflection 2: Our members enjoy being in the WCA but we are not satisfied that our code of conduct is being fully lived up to. We need to offer more student support.

The majority of members are happy with the environment in the WCA and almost 80% are satisfied with their sense of belonging in the WCA. However, seven people reported that they experienced or witnessed harassing or discriminatory behaviour in the WCA. This is disappointing and distressing and something we take with utmost seriousness. The director immediately sought guidance on how to respond to this and followed up with an email to the group reminding everyone of our code of conduct and offering resources. As the survey is anonymous, we cannot directly follow up with individuals, but members were encouraged to report any issues and offered guidance on how to do this. One person indicated that they wished to be contacted regarding the survey and Savannah contacted them and followed up.

There were several comments from the survey that indicated that improvements could be made regarding student-faculty relations and student engagement. Several comments noted that mental health support and resources would be helpful for students and that training for faculty in supporting students in crisis would be beneficial.

Action: This matter was discussed in detail at the March 2023 WCA executive meeting and the following actions were taken:

- We encouraged all members of the group to make formal complaints about inappropriate behaviour.
- We updated our website to include sections for resources for graduate students and postdocs, focussing on information about resources they can utilise and actions they can take in the case of harassment or discriminatory behaviour. We included links to the GSPA Wellness and resource pages and the Human Rights, Equity, and Inclusion Office. We posted a similar paper list on the bulletin board in the WCA welcome area.
- We formulated and circulated an email containing resources for faculty, including information about courses for helping students in crisis. This information was also posted on our website in a resources section called for faculty. The faculty felt this would be a good topic for a teaching retreat and have raised this a suggestion with the Physics and Astronomy department.
- These survey comments have been passed on to the Chair of the Department of Physics and Astronomy, as it hosts most of the students within the WCA and enrolled in the department graduate programme.

Reflection 3: There was a repeated and clear dissatisfaction with the gender imbalance among the faculty.

Action: The WCA has some control over the demographics of postdoctoral members, and we have put in place hiring practices aimed to hire a balanced cohort. There were fewer concerns raised by WCA members about gender balance for our postdocs. We have no control over the demographic distribution of faculty members in Waterloo with interests in astronomy as this is handled by individual departments. Since the inception of the WCA there have been no new

faculty hired by the University with interests in astrophysics. We have provided the Physics and Astronomy department with these survey results.

Reflection 4: WCA members are happy with how the WCA is being managed.
However, several members selected the "not applicable" option, indicating some lack of engagement.

Action: We will continue with the same management structure and style of the WCA.
In the qualitative responses to the survey, there was one suggestion to have deputies for the graduate and postdoc representatives on the WCA executive. This idea has the potential to further increase engagement of young researchers in the group and was suggested to the postdoc and graduate student representatives at the March 2023 WCA executive meeting. The suggestion was discussed privately among the graduate student and postdoc cohorts and implemented in April 2023. From April 2023, we started to circulate the WCA Monthly meeting agenda and minutes to all WCA members, rather than only the executive.
Engaging all members of the WCA will happen more naturally once we are all located in the same space in the planned new Physics building and we will continue to advocate for this project.

Reflection 5: There is a desire for opportunities for social interaction.
Several of the qualitative responses as to how the WCA could be improved mentioned social events.

Action: Social interactions obviously came to a halt during the pandemic, and we needed to do more to revitalise this. We have had two Pride month potlucks, a Winter party and two group BBQs since March 2023

Governance

The constitution of the WCA outlines the way that the WCA is governed. The oversight and financial responsibility of the Centre rests with the University of Waterloo, through the Dean of the Faculty of Science as described in UW Policy #44. The operations are to be supervised and conducted by the WCA Director, assisted by an administrative assistant, subject to the WCA constitution.

There will be a single Governing Board (hereafter referred to as the Board), composed of:

1. Dean of Science or a delegate (Chair)
2. Director of the WCA
3. Chair of Physics and Astronomy or a delegate*
4. Two representatives from the Regular Membership
5. Director of Centre for the Universe at PI or a delegate
6. One member of high standing selected from the Canadian astrophysics community
7. One member of high standing selected from the international astrophysics community

* If the chair of Physics and Astronomy is also a WCA member, they will nominate an additional non-WCA member of the Physics and Astronomy Faculty to join the Board for the term of their position.

This Governing Board has the authority to execute and monitor the affairs of the WCA, subject to all applicable University policies, procedures and guidelines, as described in UW Policy #44. The operation of the Governing Board is described in the WCA constitution (see Appendix B: WCA Constitution).

Organizational Chart

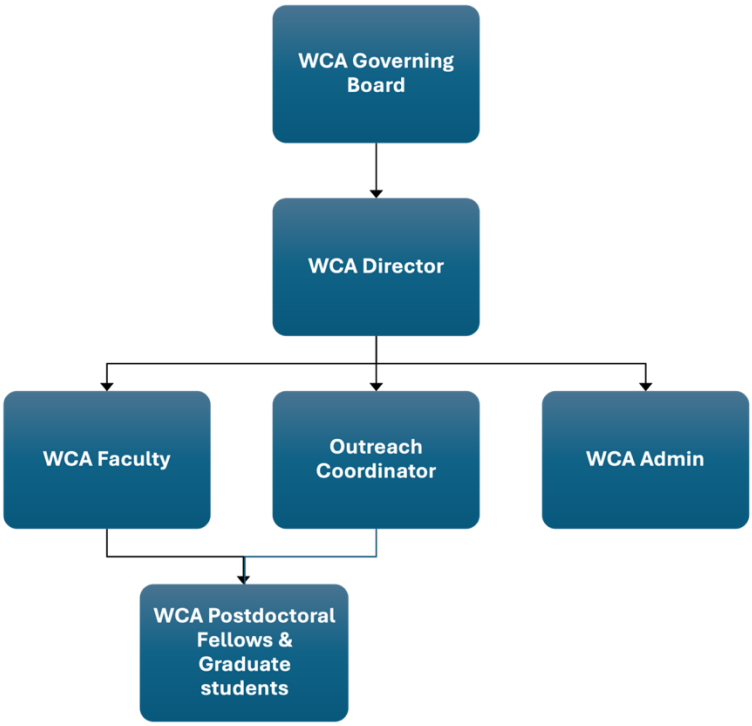


Figure 17: Organisational diagram for the WCA

The WCA reports annually to the Board of Governors, which provides feedback and direction to the WCA, through the Director. The faculty direct Postdoctoral fellows on research matters, while the Outreach Coordinator organises outreach activities with volunteers from the WCA, primarily drawn from the pool of Postdoctoral fellows and graduate students. This organizational structure is illustrated in the diagram below. On a day-to-day basis, the WCA enjoys a high level of interaction and cooperation between all the members. Everybody has a voice and the potential to suggest and implement new ideas.

Board of governors

The board of governors has met annually since the formation of the WCA. The most recent meeting was an in-person meeting in November 21-22, 2023. The Board met with various groups of WCA members and had several discussions about the WCA with the director. A summary report from

the Board is attached at the end of this document (see Appendix A: Letters of support from Dean of Science, Department of Physics and Astronomy Chair and WCA Governing Board).

WCA Governing Board			Date served
Sara Ellison	Professor, Physics and Astronomy, University of Victoria	Board Member	December 2022 - present
Christine Jones Forman	Senior Astrophysicist and Lecturer, Harvard-Smithsonian Center for Astrophysics	Board Member	November 2018 - present
Chris Houser	Dean of Science, University of Waterloo	Board Chair	July 2023 - present
Katie Mack	Hawking Chair in Cosmology and Science Communication Perimeter Institute for Theoretical Physics	Board Member	December 2022 - present
Steve MacLean	Committee Member, Quantum Valley Investments, CSA Astronaut	Board Member	November 2018 - present
Brian McNamara	Professor; Department Chair; University Research Chair in Astrophysics, University of Waterloo	Board Member	November 2018 - present
Will Percival	Professor; Distinguished Research Chair in Astrophysics; Director, Waterloo Centre for Astrophysics, University of Waterloo	Board Member	November 2018 - present
Crystal Senko	Assistant Professor; Canada Research Chair Institute of Quantum Computing, University of Waterloo	Board Member	November 2018 - present
James Taylor	Associate Professor, Physics and Astronomy, University of Waterloo	Board Member	December 2022 - present
Mike Hudson	Professor, Physics and Astronomy, University of Waterloo	Board Member	November 2018 – December 2022
Bob Lemieux	Dean of Science, University of Waterloo	Board Chair	November 2018 – July 2023
Neal Turok	Perimeter Research Chair (visiting) & Director Emeritus	Board Member	November 2018-December 2022
Scott Tremaine	Professor Emeritus, Princeton University	Board Member	November 2018 – December 2022

Table 9: Members of the WCA Board of Governors, from the inception of the WCA

WCA Executive Monthly Meetings

The WCA holds meetings on the third Friday of every month. The list of members regularly invited include the WCA faculty, the Outreach Coordinator, the Postdoc representative, the Postdoc deputy, the Graduate Student representative, the Graduate Student deputy, the EDI representative and the WCA administrative assistant. Standing agenda items include student, postdoc, and outreach reports. We typically have wide ranging discussions on a variety of topics, helping to form the policies of the WCA and enact changes.

Administration

Director

The director leads the activities within the centre, working towards the goals described in the mission statement in Section 2.1 of the constitution. Procedures for the appointment and possible pre-emptory removal of the Director of the WCA shall follow that described in UW policy #40, except as modified by policy #44, which states that the first term of office for the Director will be five years, renewable for up to five years, to a maximum of ten years.

Staff

The administrative assistant manages the WCA's finances and operations, provides organizational and logistical support, and serves as the initial point of contact between the WCA and internal/external individuals and organizations. They help manage the visitors and meetings programs, and with the hiring of WCA postdoctoral researchers.

Standing and Ad Hoc Committees

Standing and Ad Hoc Committees may be established by the Director to provide advice on policy and operational matters. A typical example of such a committee is for the WCA Postdoctoral Fellow recruitment using Centre funding.

Financials

	2018-2019	2019-2020	2020-2021	2021-2022	2022 - 2023	2023-2024	2024-2025	2025-2026	2026-2027	2027-2028	2028-2029	2029-2030
Expenses												
Admin salary	23.1	77.0	62.9	61.0	36.0	36.9	38.4	39.9	41.5	43.2	45.0	45.0
Postdoc salary	1.2	146.0	224.4	240.2	214.8	400.3	360.0	388.4	347.2	435.9	263.5	88.7
Postdoc expenses	1.5	6.0	8.6	14.7	14.5	65.5	59.5	67.7	60.0	75.0	45.0	15.0
Visitors program	2.8	2.8	1.1	0.0	1.1	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Operating	6.7	13.0	0.6	4.1	2.8	15.0	15.0	15.0	15.0	15.0	10.0	10.0
Outreach	0.0	0.0	0.0	51.5	1.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Total expenses	**35.3**	**244.8**	**297.6**	**371.5**	**271.0**	**551.7**	**506.9**	**545.0**	**497.7**	**603.1**	**397.5**	**192.7**
Income												
Lazaridis donation	504.2	500.0	500.0	500.0	500.0	350.0	350.0	250.0	250.0	250.0	0.0	0.0
Dean	0.0	50.0	50.0	50.0	50.0	50.0	75.0	75.0	75.0	75.0	75.0	0.0
Advancement	0.0	0.0	0.0	56.5	6.5	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total income	**504.2**	**550.0**	**550.0**	**606.5**	**556.5**	**410.0**	**435.0**	**335.0**	**335.0**	**335.0**	**85.0**	**10.0**
Cumulative total	468.9	774.1	1026.5	1261.5	1547.0	1405.3	1333.4	1123.4	960.7	692.7	380.2	197.5

Table 10: WCA budget, actual expenditures up to 2022-2023 and projected values thereafter. Values are in units of $1,000.

The table above shows the actual income and spend by the WCA each financial year (November 1 – October 31) up to the financial year 2022-23, with anticipated spending in the years to follow. The Dean of the Science faculty provided $50k/year support from faculty funds for the first six years of operations and has confirmed $75k/year support from faculty funds over the next five years (see Appendix A: Letters of support from Dean of Science, Department of Physics and Astronomy Chair and WCA Governing Board). The WCA has been fortunate to receive some generous donations and one particularly large donation in 2021 allowed us to purchase our inflatable planetarium. It is anticipated that Advancement should be able to generate $10k/year for the WCA while also attempting to find another multi-million dollar donation to maintain the operation of the WCA. The remaining support is allocated from money transferred from research funding allocated to Professor Percival as part of the donation that led to him being hired in Waterloo.

After the retirement of our initial admin lead in August 2021, we decided to rehire at a part-time level of 20 hours/week, explaining the reduction in salary from 2022. Our primary expense is to hire and support postdoctoral researchers, and we have been adaptable in how we allocate this money to attract the most high-quality researchers into the WCA.

(Per year)	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023	2023-2024	2024-2025	2025-2026	2026-2027	2027-2028	2028-2029	2029-2030
New PDFs	2	2	3	5	6	8	0	3	3	1	0	0
New WCA PDFs	0	2	1	1	1.3	3	0	3	2	1	0	0
Total PDFs	2	4	7	9	12	17	13	8	7	7	4	1
Total WCA PDFs	0	2	3	3	2.8	4.8	4.3	4.6	4	5	3	1

The table above gives the number of postdoctoral fellows hired in a particular year, the cost to the WCA of the new hires (in equivalent postdoc costs), the total number of WCA postdocs in place, and total cost to the WCA budget of those postdocs. The same information is illustrated graphically in *Figure 18* below.

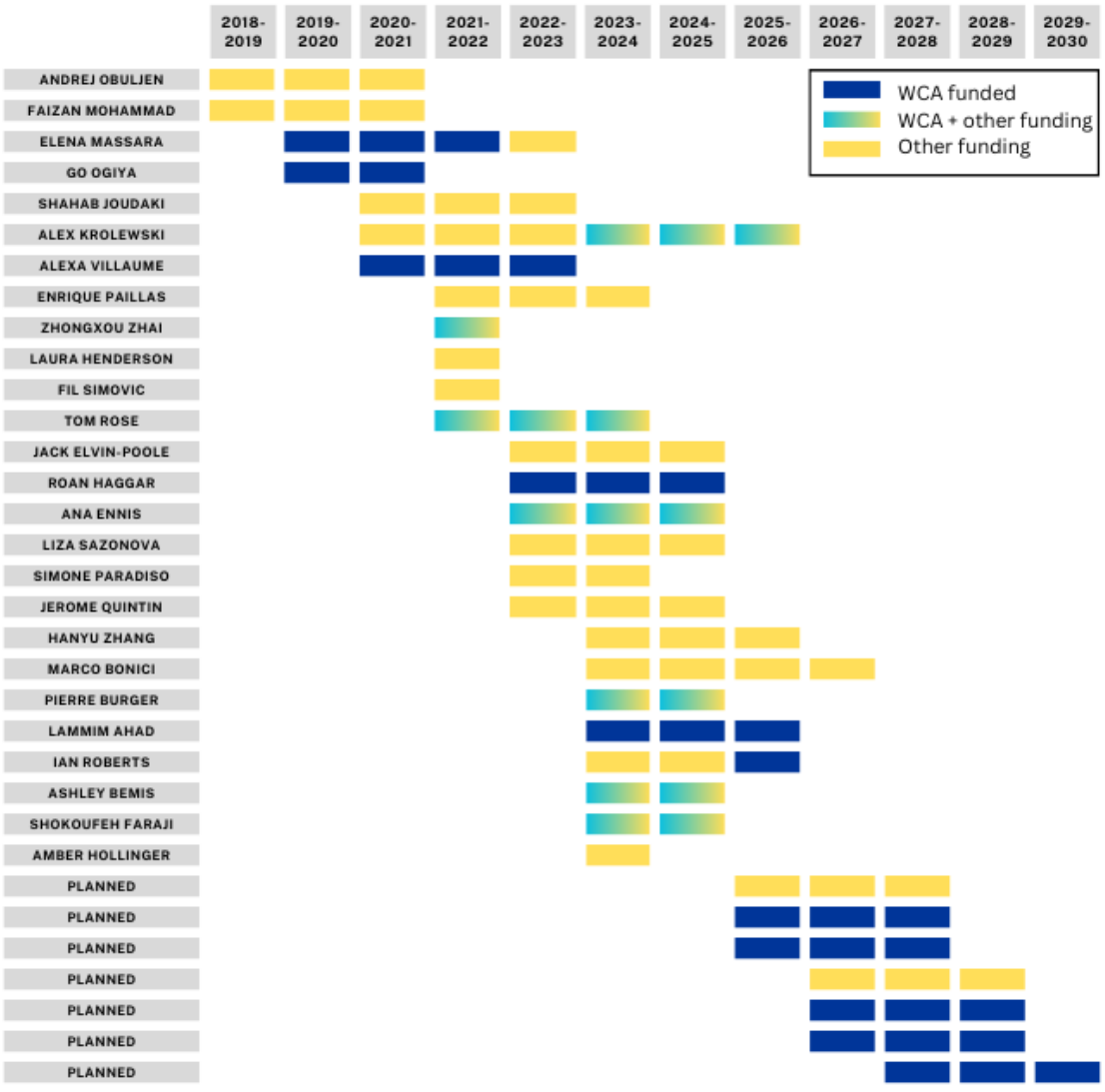


Figure 18: WCA postdoc funding timeline from 2018. Postdocs funded with WCA funds are shown in blue, other funds in yellow.

Two postdoctoral fellows left their positions early to take up faculty positions, and we host multiple postdoctoral researchers' part-supported by the WCA, complicating the picture. For example, in the year 2021-22, two new postdocs started, each 50% funded by the WCA, so the total cost was one. They (along two new postdocs supported by faculty grants) joined four existing postdocs, two of whom were supported by the WCA so the total cost to the WCA for that year was equivalent to three postdocs. Nine postdocs accepted new positions within the WCA in 2023-2024, bringing our numbers up to 17 postdoctoral researchers in total. The cost to the WCA is equivalent to 4.8 postdocs, thanks to grants to individual faculty, a Banting Fellowship and a CITA National fellowship.

Conclusions

The first six years of the WCA have been successful and eventful. The research accomplishments of core members, as well as our strong reputation attracting national and international attention, show we have made substantive, high-impact scientific progress in several sub-fields of astrophysics. Our contributions to the imaging of the Black Hole by the Event Horizon Team and the largest 3D map of the Universe by the eBOSS team are strong highlights. The trend in the numbers of refereed scientific publications coming from WCA members and the exciting new projects highlighted in this report suggest that the future will also be strong.

Our postdoc hiring has been incredibly successful, and we now have an excellent team of researchers in place. It is particularly nice to see that the WCA funding is being used to leverage additional funds both from outside the University – from the Perimeter Institute, CITA and Banting, as well as research grants where WCA members are lead investigators. Our ambitious meetings, visitor and outreach programmes were delayed by Covid travel restrictions but, nevertheless, we have achieved a great deal and there are strong signs of them getting back on track, with two major conferences hosted at the University this year. The outreach highlight is clearly our new mobile planetarium. Feedback from the events that we have done so far has been excellent – we have a long list of interested schools.

Looking forwards, WCA members have raised some points in the membership survey that need to be addressed. While some are outside the control of the WCA, there is still clearly work that we can do to improve the environment within the WCA. We will work to engage more with our student and postdoc communities and strengthen the link to the executive. We will also work to ensure that **every** member of the WCA feels respected and valued.

In its strategic plan, the University of Waterloo has emphasised the importance of disciplinary and interdisciplinary strengths, and we align well with both. We will continue to explore ways in which we can apply the techniques used in astronomy to other fields, and likewise explore how we can use knowledge from those field to help with astrophysical problems. We will apply similar principles outside of direct research and will leverage the attraction of astronomy to potential new researchers to help to train the next generation of diverse scientists.

Acknowledgements

We would like to acknowledge and thank Savannah Sloat (Manager, Science Indigenous Initiatives, Faculty of Science) and Karen Cummings (Chair of the Physics and Astronomy EDI committee) for their assistance with the WCA membership survey.

We would also like the thank and acknowledge Anja Drygala (Financial Officer, Physics and Astronomy), Maya El-Baltaji (Physics Operations Coordinator) and Holly Haig-Brown (Graduate Program Manager, Physics and Astronomy), who compiled and provided information on grants and graduate student membership, respectively.

This report was written by WCA members and compiled by the Administrative Assistant, Carolyn McCoey, and by Director Will Percival.

Waterloo Centre for Astrophysics … at a glance: credits
First image of a black hole: Event Horizon Telescope Consortium
First 3D map of the Universe: A Raichoor (EPFL)/A. Ross (Ohio State University)/SDSS Consortium
NGC 6744: ESA/Euclid Consortium/NASA
DESI Slice: Claire Lammam, DESI Collaboration

Appendix A: Letters of support from Dean of Science, Department of Physics and Astronomy Chair and WCA Governing Board

UNIVERSITY OF WATERLOO

FACULTY OF SCIENCE | Office of the Dean
519-888-4567, ext. 46550
chouser@uwaterloo.ca | uwaterloo.ca

May 23, 2024

Dr. Charmaine Dean
Vice-President-Research & International Univcersity of Waterloo

The **Waterloo Centre for Astrophysics** (WCA) is one of the premier research centres at the University of Waterloo, and just in the last year alone, it has been one of the lead organizations in the release of the first polarised image of a black hole, the release of the first cosmology results from DESI, and the first images from Euclid. **The Faculty of Science is strong support of the WCA application for a five-year renewal as a university recognized research centre.**

The primary focus of the WCA is to enhance the profile of the University of Waterloo through astrophysics research, scholarship and outreach. The WCA was formed in 2019 through a bequest by Mike Lazaridis which enabled us to hire the inaugural director, Dr. Will Percival. Through this generous gift, the world-class researchers and students of the WCA have become a world-leading astrophysics center that is attracting top postdoctoral students and visiting scholars to the University of Waterloo to tackle cutting-edge problems in astrophysics. As part of its commitment to knowledge translation, the WCA has made outreach to the community a key priority, and in 2023 alone it hosted 12 public events, presented at 14 schools, and excited 1,727 future scientists through its Astro-Bubble shows.

To support the growth and reputation of the WCA, a newly renovated space was opened in the Physics Building in 2022. During the first 5 years of the WCA, the center was provided $50k/year by the Faculty of Science, and with the successful renewal of the WCA for another 5 years, the Faculty of Science is committed to annual support of $75K, in addition to the in-kind support we are providing through the restructured Offices of Science Communication and Advancement. The Science Advancement Office has also made the WCA a campaign priority for the Faculty of Science to ensure that the Centre is financially sustainable once the Lazaridis funding comes to an end in 5 years. Having the WCA recognized as an institutional centre will ensure the success of the Advancement Office in raising the external donor and foundation support to ensure that the University of Waterloo remains at the forefront of astrophysics research globally.

I am excited to support the WCA application for renewal and believe that the WCA will continue to be a world leading research centre that boosts the reputation of the University of Waterloo for the next 5 years and beyond.

Sincerely,

Dr. Chris Houser
Dean, Faculty of Science
Professor, Department of Earth and Environmental Science
University of Waterloo

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June 13, 2024

Professor Charmaine Dean
Vice President, Research & International
University of Waterloo

Dear Charmaine,

On behalf of the Department of Physics & Astronomy, it is my pleasure to express strong support for the five-year renewal of the Waterloo Centre for Astrophysics (WCA). Guided by the strong leadership of Professor Will Percival, the WCA has significantly enhanced the research profile in astrophysics at the University of Waterloo. Waterloo is now recognized around the world as a premier institution for research and education in astrophysics. This recognition has been propelled by a 50% increase in refereed publications emerging from Waterloo astrophysics since the WCA was founded nearly five years ago. The rise in research productivity is a direct consequence of financial support provided by the University and private donations financing many outstanding postdoctoral fellows and outreach activities. The Department's rising profile has propelled it deeply into the top 100 Physics departments world-wide in the QS rankings. Physics & Astronomy is among a handful of world-recognized programs at Waterloo which has enhanced the University's profile and thus is worthy of continuing support.

Accompanying the development of the WCA, the Department of Physics & Astronomy has experienced a three-fold rise in undergraduate majors and a two-fold rise in graduate student enrolment over the past decade. A significant fraction of our undergraduate students are attracted to the Physics & Astronomy program, while the increasing numbers and quality of graduate applications are surely driven by the strong reputation of Waterloo astrophysics faculty. As a senior member of the Centre, I can express personally the enormous value the new WCA space and accompanying resources bring to scholarly life in the department.

I am delighted to support this application for renewal of the Waterloo Centre for Astrophysics.

With warm regards,

Brian R. McNamara
Professor & Chair
Department of Physics & Astronomy
University of Waterloo

UNIVERSITY OF WATERLOO

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April 16, 2024

The Waterloo Centre for Astrophysics (WCA) Board met in-person at the WCA November 21-22, 2023. Board Members include Professor Sara Ellison (U. Victoria), Dr. Christine Jones (Harvard-Smithsonian Center for Astrophysics), Dr. Katie Mack (Perimeter Institute), Dr. Steve MacLean (Infinite Potential Group), Professor Crystal Senko (U. Waterloo/Institute of Quantum Computing), Professor James Taylor (U. Waterloo/WCA), Professor Brian McNamara (U. Waterloo/WCA), Professor Will Percival (U. Waterloo/WCA), and Professor Chris Houser (Dean of Science, Chair). The board received presentations from the WCA director on the state of the Centre, its achievements over its five-year history, and challenges the Centre is facing. The Committee was briefed by Professor Bernie Dunker (Office of Research) regarding changes to the university's Centers and Institutes policy, and how these new policies may affect the WCA. The committee was briefed on WCA's extensive outreach activities regarding achievements, challenges and plans for expansion by the Outreach Team, Roan Haggar, Ana Ennis and Carolyn McCoey. Over the course of two days, the Board then met with WCA faculty, graduate students and postdoctoral fellows. (WCA-affiliated board members were excused during meetings with students and fellows.) The Board also reserved time in the schedule to discuss and present its key findings, and to attend a research seminar. A dinner was provided on the evening of day one. The Committee adjourned at 4:00 pm on day two. In what follows, we, the members of the Board, will summarize our findings and conclusions.

The inauguration of the WCA has transformed the atmosphere in astrophysics at Waterloo, primarily through recruitment of high-quality postdoctoral fellows. As full-time researchers with graduate training and some research experience, postdocs are engines of research progress, and provide a bridge between students and faculty. Since its foundation, the Centre has supported a total of 22 postdoctoral fellows, as of November 2023. A total of 8.3 have been supported fully from WCA funds. The remaining postdocs were leveraged by using third-party funds including Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grants, University of Waterloo funds, and International Fellowships. Increasing postdoctoral fellow numbers across the country is a priority in the Canadian Astronomical Society's Long Range Plan 2020 (LRP2020), in order to develop Canadian highly qualified personnel (HQP) capacity, sustainability, and continuity in astrophysics. The WCA currently has one of the largest populations of early career researchers in Canada. The first crop of nine postdoctoral fellow graduates have demonstrated the beginning of a legacy for WCA, with three accepting faculty appointments, three entering data science careers, and three appointed elsewhere as

research fellows. Since the founding of the Centre, the publication rate in astrophysics at Waterloo has increased by 50%, and there has been a general broadening into new areas of research, as postdoctoral fellows bring new ideas and new points of view into the group.

Along with this infusion of young talent, the WCA has created a vibrant atmosphere around daily activities including seminars, journal clubs, EDI (equity, diversity and inclusivity) initiatives, mentoring programs, and outreach events or team-building events. Contact and exchanges between faculty, postdocs and graduate students have benefitted all three groups, supporting faculty in their training of graduate students, giving postdocs direct experience in mentorship and project supervision, and providing the graduate students with living examples of what careers in research can be like.

The research areas in which the WCA is now involved are among the most impactful in international astronomy. These fields span a range of topics in extragalactic astronomy and cosmology, with an excellent balance of diversity (ranging from black hole physics to galaxy evolution) and complementarity. Notably, the WCA holds leadership positions in major international missions, collaborations and surveys spanning the entire electromagnetic spectrum, both on the ground (e.g. UNIONS, DESI and the Event Horizon Telescope) and in space (e.g. Euclid and XRISM). The highly visible involvement of WCA astronomers in these projects brings international prestige and recognition to Waterloo, and economic prosperity to Canada through contracts and employment. The WCA is also strategically positioned for the next generation of facilities. The LRP2020 identifies the Thirty Metre Telescope (TMT) and the Cosmological Advanced Survey Telescope for Optical and UV research (CASTOR) as the primary ground- and space-based missions, respectively, for the next generation. WCA faculty are actively involved in the planning and science advising for both of these projects. These early leadership roles ensure a future legacy for WCA students and postdoctoral fellows, providing critical training in data analysis, statistics, machine learning, and applied data science, skills that drive Canada's economic development in both the academic and industrial sectors. WCA is therefore ideally placed to deliver excellence at the forefront of astrophysical research in the coming decades.

Concomitant with its fundamental science research, astronomy has a reputation for pushing the boundaries of technology and improving everyday life. Critical technologies developed for astronomy have, for example, enabled Wi-Fi and sensitive detectors for medical imaging, environmental monitoring, and remote sensing. In addition to these spin-offs, the multifaceted training required by astronomy is of strategic importance to Canada's knowledge-based economy as it pertains to the government, business and financial sectors experiencing pressing HQP needs. The WCA encourages the education

and training of the highly skilled individuals that these communities are looking for. This training is based on developing digital skills, including the management and analysis of massive data sets, as well as scientific software and web development. The Canadian Space Agency (CSA) recognizes the importance of this skill set and has recently given a grant to the WCA supporting their lead role on Euclid, the Dark Energy Satellite. The CSA grant enables a group of early-career researchers to work at the heart of the consortium of scientists working on this Dark Energy Satellite, and to simultaneously train the key skills required for several future career directions.

A further strength of the WCA is its significant impact via public engagement alongside research output. Due to highly strategic use of resources, including funding a postdoctoral researcher to spend half his contracted time coordinating the outreach program, the WCA has managed to create an outreach program focused on maximizing benefit for key groups of beneficiaries. The program includes several major efforts. Regular in-person presentations at the Kitchener Public Library and "Astronomy On Tap" events at a local pub reach complementary audiences across a wide range of age, background, and socioeconomic demographic categories. Social media content (primarily via Twitter and Instagram) is tailored to followers to share relevant local information and brief insights into WCA research areas. The most innovative outreach effort involves the "Astro Bubble," an inflatable planetarium regularly taken to schools, University of Waterloo events, and other venues in which small groups of young people can participate in a unique experience of a simulated night sky with an opportunity for learning and engagement. Importantly, the WCA has connected with a range of organizations serving communities that are traditionally underrepresented in science (such as women and indigenous communities) to focus outreach efforts where they will be most impactful. The Centre's budget is set up to continue to fund a partial postdoc to coordinate the outreach program. Additionally, graduate students are being included in outreach activities to ensure continuity of programming.

We consider these efforts in outreach to be a major asset for the university and the local community. Astronomy has a unique ability to engage young people and non-scientists. Continuing the WCA's outreach program in this area will positively benefit the university and the community, and will serve to inspire and recruit future generations of scientists and STEM professionals.

The WCA growth has paralleled the large undergraduate growth in the Physics & Astronomy (P&A) program, which hosts a large international population. This program provides an alternative to the standard physics degree, including a significant number of specialized courses in astronomy and astrophysics. The program has grown from roughly

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30 students in 2013, the year it began, to more than 300 students. P&A has become the largest program in the department. With approximately 800 undergraduate majors in four programs, the department is among the largest in North America. While the student population in Physics & Astronomy continues to rise, the faculty complement has not grown proportionally, resulting in an unacceptably large ratio of students to faculty.

Overall, the board is delighted to highlight the resounding success of the WCA in invigorating this key research domain within the Department of Physics and Astronomy. The Centre's dynamic research environment has not only propelled ground-breaking discoveries, but has also fostered an atmosphere of intellectual vitality, supported by vibrant journal clubs, mentoring initiatives, and outreach activities.

While we celebrate these accomplishments, it is important to acknowledge the imminent challenge posed by the large student-to-faculty ratio. The board emphasizes the urgency of strategic planning for faculty hires, to ensure a seamless transition through upcoming retirements and sustained impact of the astrophysics initiatives. Additionally, the committee underscores the importance of cultivating diversity within the faculty, recognizing that inclusivity is key to nurturing a rich and multifaceted academic community.

We look forward to the continued success of the Centre and its influence on the Department of Physics and Astronomy, the university, and the broader scientific community. Notably, the board applauds the WCA's role in shaping the trajectories of numerous postdocs who have gone on to achieve remarkable success in their subsequent careers, a testament to the enduring impact of the vibrant and collaborative research culture established by WCA.

On behalf of the Waterloo Centre for Astrophysics Governing Board,

Chris Houser,
Dean of Science, University of Waterloo

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Appendix B: WCA Constitution

1 Constitution

1.1 Aims of the WCA

To facilitate and conduct ground-breaking research, training, and outreach in Cosmology and Astrophysics at the University of Waterloo. The WCA will foster new and exciting discoveries about the nature of the Cosmos and establish the University of Waterloo as a world leader in observational astrophysics and cosmology and the detailed testing of theoretical models of the Universe.

1. **Research:** The WCA will stimulate fundamental research in Astrophysics and Cosmology, catalyze and foster national and international collaborations.
2. **Innovation:** The WCA will support and exploit innovative and ground-breaking methods, techniques, and data.
3. **Training:** The WCA will add to the graduate and postdoctoral training and mentorship undertaken at the University of Waterloo, leading to the successful entry of highly trained qualified personnel into a career in astrophysics, cosmology and industry.
4. **Partnership:** The WCA seeks to partner with regional and international centres of excellence in astrophysics in order to promote synergies and further WCA missions.
5. **Dissemination:** The WCA will facilitate dissemination of astrophysical sciences by hosting topical conferences and focused workshops, as well as by developing and maintaining an active visitor program.
6. **Outreach:** The WCA will engage the broader academic community at UW, as well as the general public, via physical and virtual platforms, in order to promote the significance of fundamental research and share the excitement of the science done by WCA members. In particular, it will strive to engage and recruit women, underrepresented minorities, and members of indigenous communities in its scientific and outreach activities.

1.2 Membership

1.2.1 Regular Faculty, Student and Postdoctoral Members

Regular Faculty Members of the WCA are faculty members at the University of Waterloo whose research interests overlap with the mission of the WCA. Membership whether granted by the Board, or granted for the initial complement of Members when the proposal to establish the Centre was approved by the University of Waterloo Senate, will be for a period of 3 years. Reappointment will require application to the Director within the 3rd year and approval by the Board. Regular Student and Postdoctoral membership may be granted by the Director upon recommendation of the mentor or advisor. Regular student and postdoctoral members will be reviewed annually by the Board. Regular Faculty, Student and Postdoctoral Members are expected to be primarily “in residence” at the University of Waterloo.

1.2.2 Associate Members

Scientists with primary appointments outside the University of Waterloo, or who are retired WCA Regular Faculty Members, may seek to become Associate Members of the WCA. Membership will be subject to

the same criteria as Regular Members. Associate Members will have access to shared desk space during the time they spend within the WCA.

1.2.3 Membership Privileges and Responsibilities

Regular Faculty, Student, Postdoctoral and Associate Members will be able to use WCA facilities and funds to conduct and disseminate their research, within the framework described in this document, and established by the Director. In return, all Members will be expected to acknowledge their WCA affiliation and/or funding, and to play an active role within the WCA.

1.3 Governance

The oversight and financial responsibility of the Centre will rest with the University of Waterloo, through the Dean of the Faculty of Science as described in UW Policy #44. The operations are to be supervised and conducted by the WCA Director, assisted by an administrative assistant, subject to this constitution.

There will be a single Governing Board (hereafter referred to as the Board), composed of:

1. Dean of Science or a delegate (Chair)
2. Director of the WCA
3. Chair of Physics and Astronomy
4. Non-WCA member of the Physics and Astronomy faculty*
5. One or two representatives from the Regular Membership+
6. Director of *Centre for the Universe* at PI or a delegate
7. One member of high standing selected from the Canadian astrophysics community
8. One member of high standing selected from the international astrophysics community
9. One member of the non-academic Physics community (e.g. physicist working in industry, government agency, private research lab, etc.)

* Only included if the chair of Physics and Astronomy is a WCA member. In this case, he/she will nominate an additional non-WCA member of the Physics and Astronomy Faculty to join the Board for the term of their position.
+ One representative will be selected if the chair of Physics and Astronomy is a WCA member, otherwise two representatives will be selected.

This Governing Board has the authority to execute and monitor the affairs of the Research Centre, subject to all applicable University policies, procedures and guidelines. As described in UW Policy #44, this includes the ability to:

Enact rules and regulations for membership of the Governing Board and the conduct of its affairs; Recommend appointment of the Director and other leaders to the Dean; Recommend appointment and removal of staff to the Dean;

Appoint and remove Members, and establish categories of membership and associated fees; Plan and implement the Centre's development; Establish processes to manage and monitor the Research Centre's financial affairs; Establish and enforce

rules and regulations governing the Research Centre's activities, provided such rules and regulations are consistent with University policies, procedures and guidelines; and

Establish such committees as it deems necessary to discharge its responsibilities; this may include establishing advisory bodies comprised primarily of external Members for the purpose of providing strategic or scientific advice to the Governing Board or the Director.

On the Board, the external members and the representatives of Regular Membership will serve a 3-year term, with possible renewal for a single additional term. Renewal and selection of external members will be undertaken by the Dean in consultation with the Director. A call will be put out for new representatives of the Regular Membership when they are required. If there are more applicants than positions available, the Director of the WCA will organize an election, where Regular Members have a single transferable vote on their representatives.

The WCA Director will prepare a progress report including budget and a review of activity, membership and the development of the WCA for the Board every two years. After receipt of this report, the Board will meet, typically in-person, to review its contents and will meet with the director, faculty, postdocs, students, staff and others as deemed necessary. It will produce a brief summary detailing any specific issues or concerns. The Board will meet a year after its review, typically online, to hear a progress report. The Director and Members on the Board will absent themselves when their appointments are being discussed. The Board may meet at other times, in person or remotely, if requested by the Director or the Dean of Science. At the discretion of the Chair, the Board may conduct business and vote by e-mail. In order to be quorate, 7 or more members of the Board must attend (either in person or remotely) a board meeting. Following University of Waterloo policy #44, at least (50%+1) of Board members present at any meeting must be Regular Faculty Members of UW.

Board meetings will be announced to all the WCA members in sufficient time for them to propose agenda items. The final agenda will be circulated to all the WCA members, indicating all decision items and background material. After each meeting, the minutes will be circulated to all members.

Only the Board may propose amendments to this Constitution. After proposal by the Board, these changes will be put to a vote: a two-thirds majority of the WCA Regular Faculty Membership is required to ratify amendments to the constitution.

1.4 Positions and Committees

1.4.1 Director

The director will lead the activities within the Centre, working towards the goals described in the aims statement above. Procedures for the appointment and possible preemptory removal of the Director of the WCA shall follow that described in UW policy #40, except as modified by policy #44, which states that the first term of office for the Director will be five years, renewable for up to five years, to a maximum of ten years.

1.4.2 Administrative Assistant

An administrative assistant will manage the Institute's finances and operations, provide organizational and logistical support, and serve as the initial point of contact between the WCA and internal/external individuals and organizations. They will help manage the visitors and meetings programs, and with the hiring of WCA postdoctoral researchers.

1.4.3 Standing and Ad Hoc Committees

Standing and Ad Hoc Committees will be established by the Director to provide advice on policy and operational matters. A typical example of such a committee is for the WCA Postdoctoral Fellow recruitment using Centre funding.

1.5 Gender balance and support of minorities

Having a diverse workforce has been shown to provide a more robust, flexible, and successful work environment. In particular, given the under-representation of female scientists within the discipline of physics, the WCA would take progressive steps to develop a gender balance and become a leader for other astrophysics groups, centres and institutes within Canada and around the world. Similarly, the WCA is committed to increasing the representation from all equity-seeking groups thereby creating a diverse workforce that truly represents the diversity within Canada.

In order to support these efforts, the WCA will educate its membership through equity-related training and information sessions. This is especially important for those members who will be engaged in recruiting, selection and hiring new members of the Centre. In addition, these educational initiatives will be aimed at creating and maintaining work environments that are welcoming, inclusive and respectful of all members and the diversity they bring to the Centre.

When recruiting and hiring postdoctoral fellows, the WCA will strongly encourage applications from candidates that would help to provide equity across all groups. In particular, every member of the Centre will encourage and facilitate applications from qualified candidates from all of the equity-seeking groups.

The WCA will also undertake, through outreach activities, to promote physics and astronomy as both an area of study and a career. In doing so, the WCA hopes to increase the participation of women, visible minorities and indigenous communities in the field of physics and astronomy in Canada.

1.6 Statement on conduct and behaviour

The WCA will be proud to provide an environment where all staff, regardless of gender, race, sexual orientation, age, religious belief and disability can work towards the mission statement in Section 2.2.

Harassment, discrimination, or the abuse of supervisory authority will not be allowed for any activity connected with the WCA. UW policies will be used to define unacceptable behavior including the Conflict of Interest Policy #69, Ethical Behavior policy #33, and Prevention and Response to Sexual Violence Policy #42. Training and open discussion will be used to encourage the welcoming, inclusive and respectful workplace desired (See Sec 2.5).

Use of Waterloo computing and network resources by WCA members will follow standard UW guidelines. This includes following the Use of Proprietary Software Policy #64.

Any issues covered by UW policies will be handled using the standard UW procedures, and all WCA members will be expected to fully cooperate with any inquiries. If a concern is directed towards a non-UW member and consequently the formal UW procedure cannot be applied, the Director and Board (excluding any members or the Director if conflicted) will investigate, following the UW procedure as closely as possible. Possible outcomes include the loss of privileges and/or expulsion from the Centre.

All external members will be made aware of the UW policies, and this constitution upon joining the WCA.

2 Criteria for the membership review of potential regular full and associate members

This section gives the criteria to be used by the Board to decide on WCA membership for regular and associate faculty members. This does not include Student or Postdoc members, for whom membership is granted by the Director upon recommendation of the mentor or advisor.

2.1 Excellence of research scientist

Evidence of research excellence, including recent refereed publications, invited talks and other research activity. Strong positive and upstanding reputation within the field of astrophysics as judged from a submitted CV and by potential follow-up by Board members.

2.2 Fit to the research aims of the WCA

Recent research activity within areas deemed to be important for the future development of the WCA. Strong potential for future positive contributions to the research of other members of the WCA. Initial priority research directions include undertaking and supporting experimental activity, particularly astronomical observations, and survey analysis.

2.3 Diversity of WCA

Either directly or indirectly helps with the aim of the WCA to embrace diversity and provide equity between all equity-seeking groups. Shows a strong commitment to support the aims of the WCA in this regard.

2.4 Commitment to the WCA

Shows commitment to the future development and to winning support for the growth of the WCA: in particular is likely to spend a significant amount of time at the WCA working with WCA members, or will provide equivalent support.

Appendix C: WCA Membership survey responses

WCA Membership Survey

36	10:48	Closed
Responses	Average time to complete	Status

1. What is your current status:

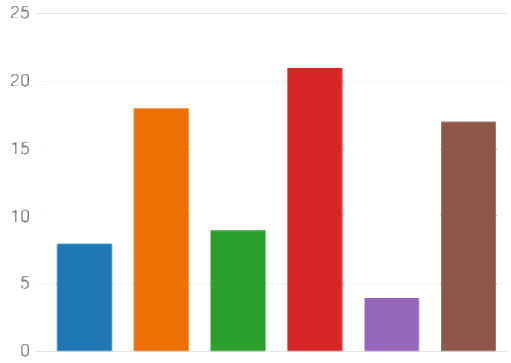
Student	18
Postdoc or staff	11
Faculty	6
Other	0

2. For how many years have you been a member of the WCA (students and postdocs working in astrophysics are all members of the WCA from when they start):

Less than 1 year	10
1 year	2
2 years	4
3 years	7
4 or more years	12

3. Why did you decide to come to the University of Waterloo and become a member of the WCA? Choose all that apply.

Close to my home	8
Research reputation in astrophy..	18
Research reputation in my sub-f...	9
Reputation of my supervisor/me...	21
Teaching reputation at the unive..	4
University reputation overall	17



4. Do you find the WCA seminar program to be beneficial?

Yes	31
No	2
Not applicable	2

5. Do you have any suggestions for improvement of the WCA seminar program?

15
Responses

Latest Responses

6. Do you find the journal clubs/topical meetings to be beneficial?

Yes	26
No	3
Not applicable	6

7. Do you have any suggestions for improvements to the journal clubs/topical meetings?

12
Responses

Latest Responses

8. The WCA holds monthly management meetings with faculty, and students and postdocs representatives. There is also a governing board with annual reviews. Do you feel that your views are adequately represented at these meetings?

Yes	17
No	4
Not applicable	11

9. Would you like to see any changes to the way the WCA is managed?

11
Responses

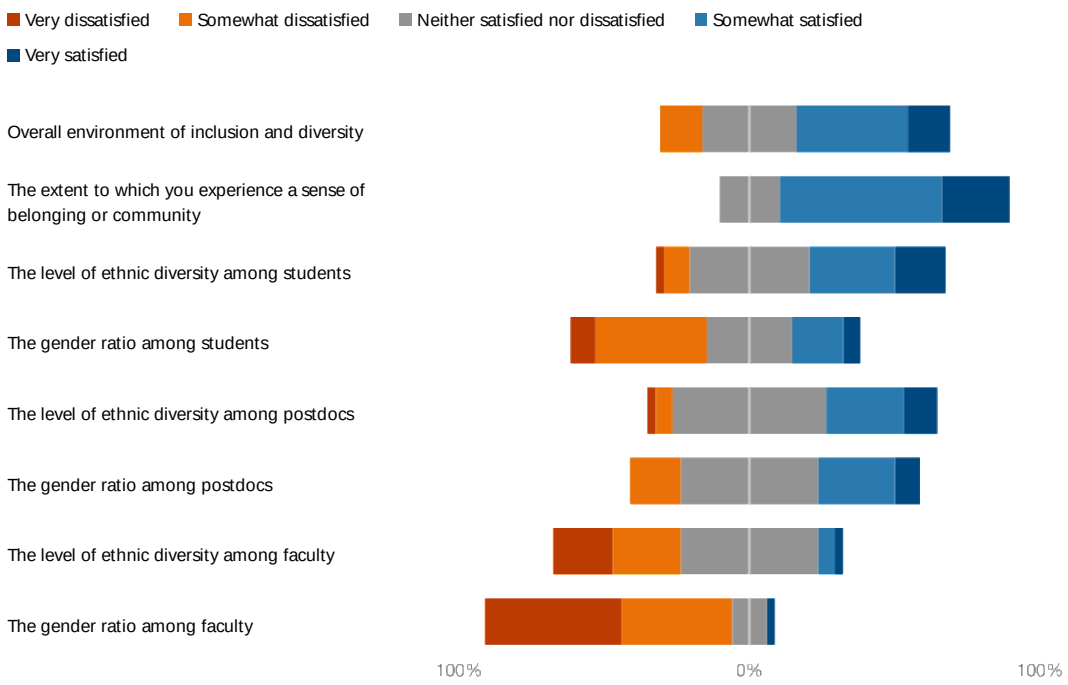
Latest Responses
"More active participation from students"

10. Going forward, is there anything that the WCA is not doing that you would like to see happen?

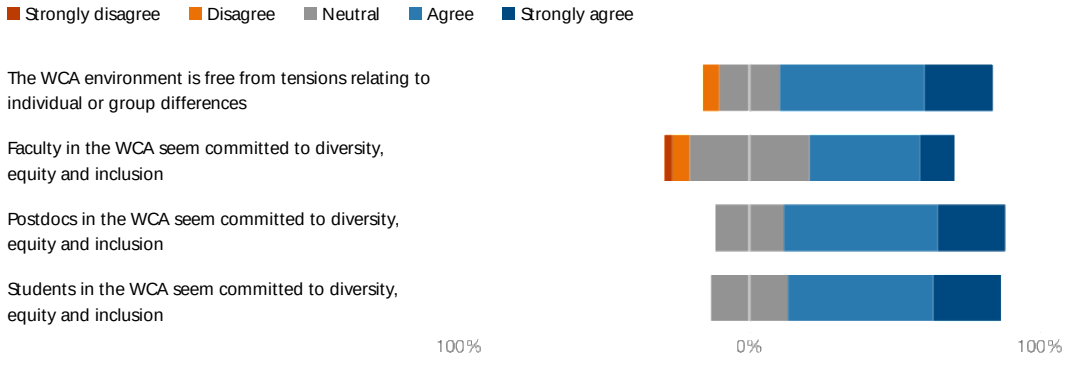
17
Responses

Latest Responses
"More in person seminars"

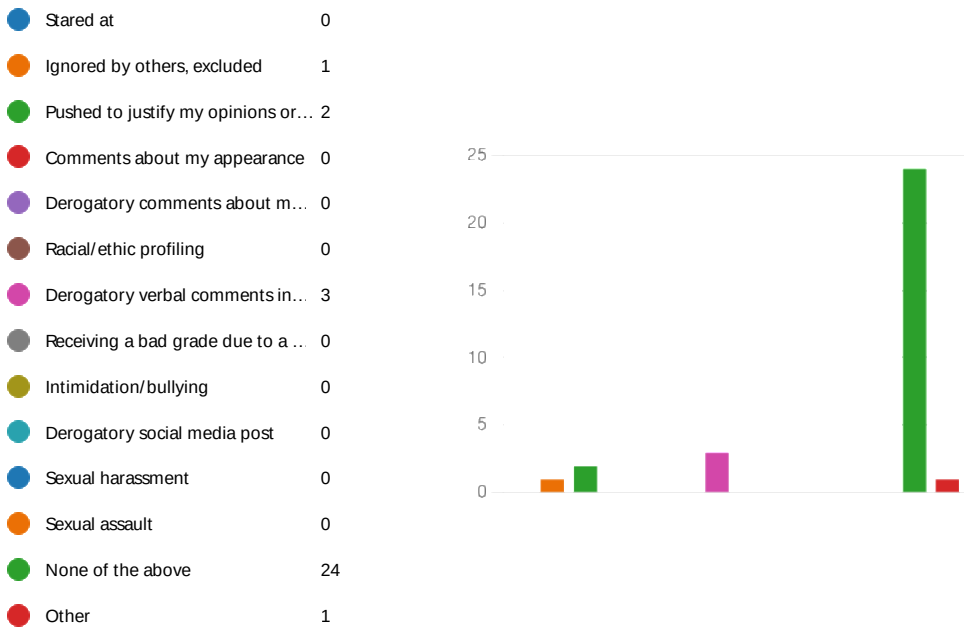
11. Please indicate your level of satisfaction with the WCA in the following regards (very dissatisfied - very satisfied):



12. Please indicate your level of agreement with each of the following statements at the WCA (strongly disagree - strongly agree):



13. Which of the following forms of discrimination or harassment have you experienced and/or observed within the WCA? Please choose all that apply. If you select "other" please describe.



14. Is there anything more you would like to say about the general climate within the WCA? (Leave blank if no.)

7
Responses

Latest Responses

15. If you would like someone to get in touch with you about this part of the survey please leave your email below. (Leave blank if not.)

1
Responses

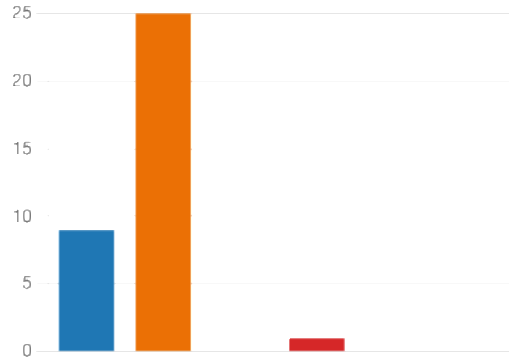
Latest Responses

16. What is your current status

Student	18
Postdoc or staff	11
Faculty	6
Other	0

17. What is your self-identified gender?

Woman	9
Man	25
Non-binary/Gender fluid	0
Transgender/Transitioning	1
Prefer not to say	0
Other	0



18. Do you self-identify as part of the 2SLGBTQ+ community? For definitions of these identities please visit: https://ok2bme.ca/resources/kids-teens/what-does-lgbtq-mean/

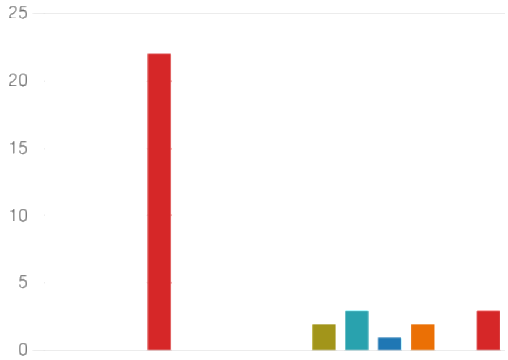
Yes	6
No	29
Prefer not to say	0

19. Do you self-identify as a person with a disability? “Disability” covers a broad range and degree of conditions, some visible and some not visible.

Yes	5
No	30
Prefer not to say	0

20. With which of the following ethnic groups do you self-identify? (select all that apply). This list is based on the ethnic origin data of the Canadian Census.

Arab	0
Black	0
Chinese	0
European	22
Filipino	0
Indigenous (eg., First Nations, In…	0
Japanese	0
Korean	0
Latin American	2
South Asian (e.g., East Indian, Pa…	3
Southeast Asian (e.g., Cambodia…	1
West Asian (e.g., Afghan, Iranian…	2
Prefer not to say	0
Other	3



Appendix D: WCA Publications

Referred publications of WCA faculty and postdocs from start of WCA (11-2018) to June 2024. For postdocs and retired faculty, the list is limited to publications while based in Waterloo.

Niayesh Afshordi:

Mylova, Maria & Afshordi, Niayesh 2024 Effective cuscuton theory JHEP 2024 144

Wen, Robin Y., Hergt, Lukas T., Afshordi, Niayesh, & Scott, Douglas 2024 A cosmic glitch in gravity JCAP 2024 045

Dey, Ramit, Micchi, Luís Felipe Longo, Mukherjee, Suvodip, & Afshordi, Niayesh 2024 Spectrogram correlated stacking: A novel time-frequency domain analysis of the stochastic gravitational wave background PhRvD 109 023029

Wu, Di, Gao, Pengyuan, Ren, Jing, & Afshordi, Niayesh 2023 Model-independent search for the quasinormal modes of gravitational wave echoes PhRvD 108 124006

Dailey, Conner, Afshordi, Niayesh, & Schnetter, Erik 2023 Reflecting boundary conditions in numerical relativity as a model for black hole echoes CQGra 40 195007

Abedi, Jahed, Longo Micchi, Luís Felipe, & Afshordi, Niayesh 2023 GW190521: Search for echoes due to stimulated Hawking radiation from black holes PhRvD 108 044047

Oshita, Naritaka & Afshordi, Niayesh 2023 From entropy to echoes: Counting the quasi-normal modes and the quantum limit of silence PhLB 841 137901

Chen, Alice Y. & Afshordi, Niayesh 2023 Outskirts of dark matter haloes PhRvD 107 103526

Borissova, Johanna N., Held, Aaron, & Afshordi, Niayesh 2023 Scale-invariance at the core of quantum black holes CQGra 40 075011

Robbins, Matthew P. G., Afshordi, Niayesh, Jamison, Alan O., & Mann, Robert B. 2022 Detection of gravitational waves using parametric resonance in Bose-Einstein condensates CQGra 39 175009

Mylova, Maria, Moschou, Marianthi, Afshordi, Niayesh, & Magueijo, João 2022 Non-Gaussian signatures of a thermal Big Bang JCAP 2022 005

Saraswat, Krishan & Afshordi, Niayesh 2022 Spacing statistics of energy spectra: random matrices, black hole thermalization, and echoes JHEP 2022 17

Afshordi N., Magueijo J., 2022, Lower bound on the cosmological constant from the classicality of the early Universe, PhRvD, 106, 123518.

Arun K. G., Belgacem E., Benkel R., Bernard L., Berti E., Bertone G., Besancon M., et al., 2022, New horizons for fundamental physics with LISA, LRR, 25, 4.

Yang T., Hudson M. J., Afshordi N., 2022, A universal profile for stacked filaments from cold dark matter simulations, MNRAS, 516, 6041.

Robbins M. P. G., Afshordi N., Jamison A. O., Mann R. B., 2022, Detection of gravitational waves using parametric resonance in Bose-Einstein condensates, CQGra, 39, 175009.

Mylova M., Moschou M., Afshordi N., Magueijo J., 2022, Non-Gaussian signatures of a thermal Big Bang, JCAP, 2022, 005.

Abolfath R., Baikalov A., Bartzsch S., Afshordi N., Mohan R., 2022, The effect of non-ionizing excitations on the diffusion of ion species and inter-track correlations in FLASH ultra-high dose rate radiotherapy, PMB, 67, 105005.

Saraswat K., Afshordi N., 2022, Spacing statistics of energy spectra: random matrices, black hole thermalization, and echoes, JHEP, 2022, 17.

Chua W. Z., Afshordi N., 2021, Electromagnetic albedo of Quantum Black Holes, JHEP, 2021, 6.

Oshita N., Afshordi N., Mukohyama S., 2021, Lifshitz scaling, ringing black holes, and superradiance, JCAP, 2021, 005.

Longo Micchi L. F., Afshordi N., Chirenti C., 2021, How loud are echoes from exotic compact objects?, PhRvD, 103, 044028.

Saraswat K., Afshordi N., 2021, Extracting Hawking radiation near the horizon of AdS black holes, JHEP, 2021, 77.

Adshead P., Afshordi N., Dimastrogiovanni E., Fasiello M., Lim E. A., Tasinato G., 2021, Multimessenger cosmology: Correlating cosmic microwave background and stochastic gravitational wave background measurements, PhRvD, 103, 023532.

Dey R., Afshordi N., 2020, Echoes in the Kerr/CFT correspondence, PhRvD, 102, 126006.

Yang T., Hudson M. J., Afshordi N., 2020, How dark are filaments in the cosmic web?, MNRAS, 498, 3158.

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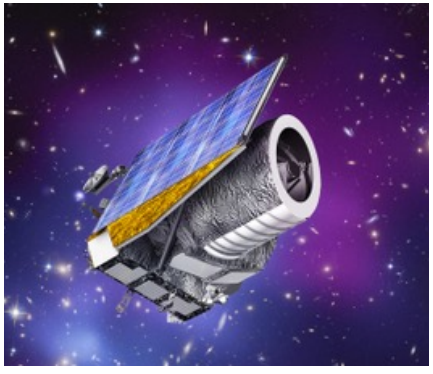
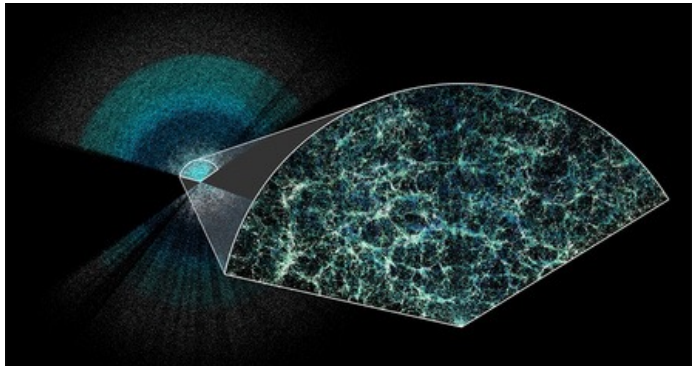
WATERLOO CENTRE FOR ASTROPHYSICS

PROGRESS AND RENEWAL REPORT 2018-2024





Presentation to the Senate Graduate and Research Council September 16, 2024

UNIVERSITY OF WATERLOO | WATERLOO CENTRE FOR ASTROPHYSICS

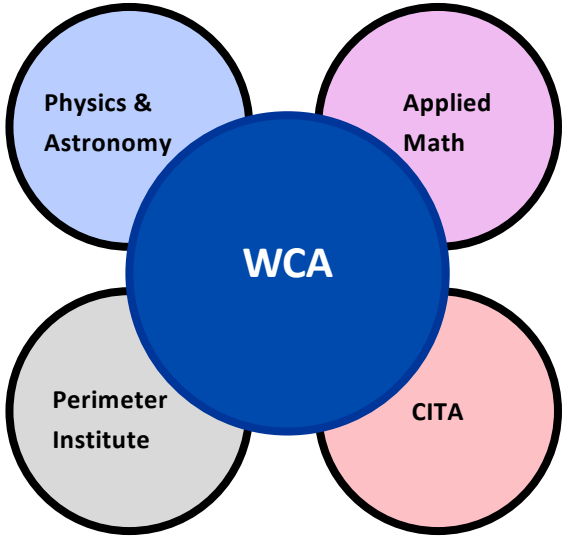
Within the last six years, the WCA has:

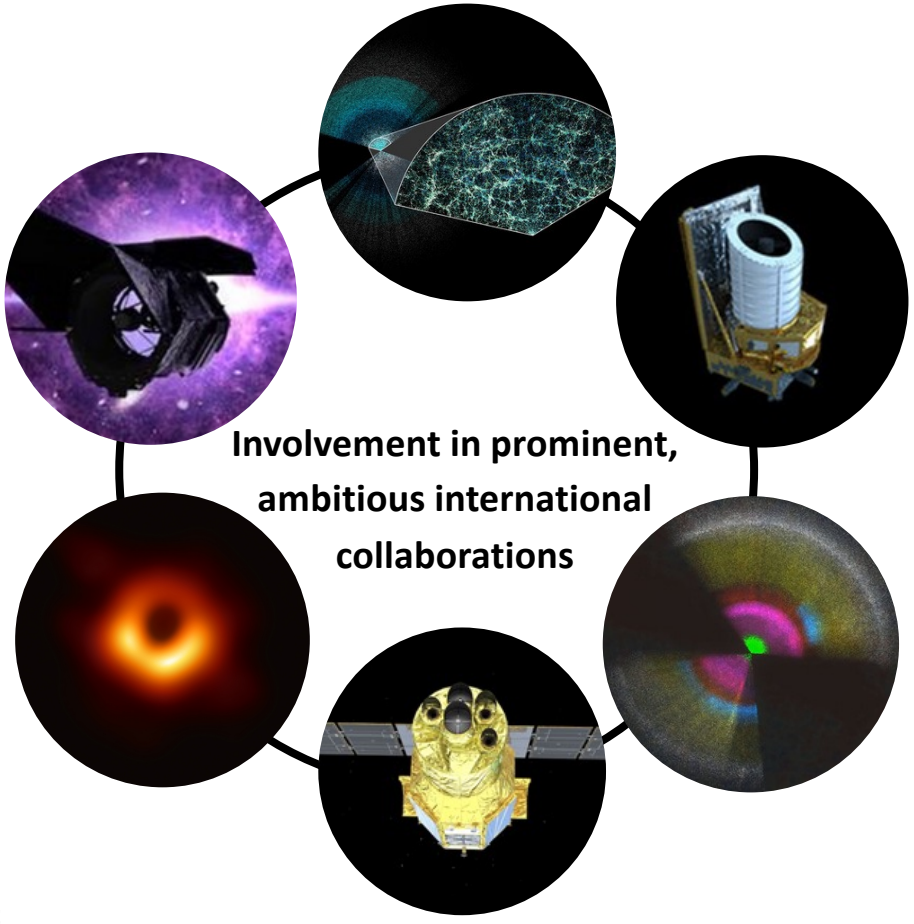
- Enhanced the reputation of astronomy in Waterloo,
- Built a community spirit within the group of astronomers,
- Enhanced connections within and outside of the University.
- Trained 128 early career researchers,
- Developed an ambitious and successful outreach program,

WATERLOO CENTRE FOR ASTROPHYSICS

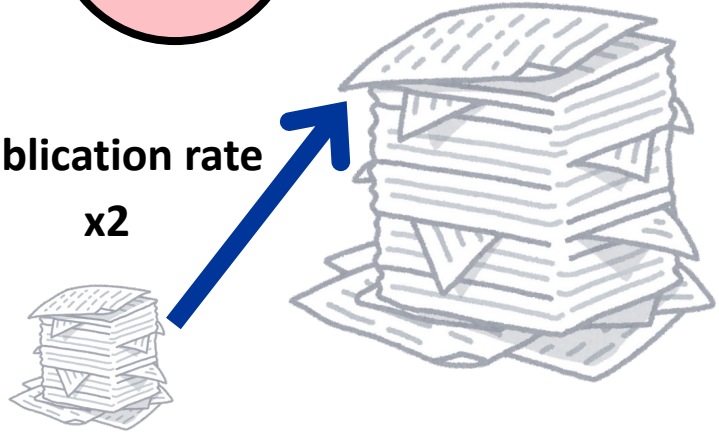
Advancing Astronomy at Waterloo

We have created a thriving community of Astrophysicists doing world-class research





Involvement in prominent, ambitious international collaborations



Publication rate x2

Increased uptake in Physics & Astronomy courses

WATERLOO CENTRE FOR ASTROPHYSICS

Training Early Career Researchers

WCA has brought 26 postdocs and over 100 grad students to Waterloo

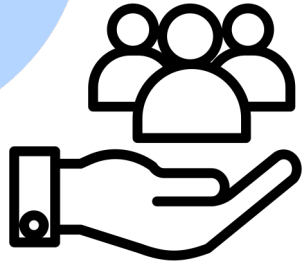
60% go on to the next stage in academia

16 postdocs currently

1/3 of postdocs have gone directly into faculty positions

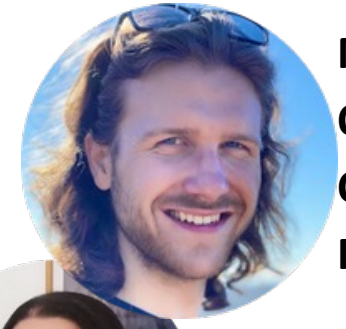
We have established mentorship programs (beyond academic supervision) for WCA Grad students and Postdocs

Inclusion, belonging, support, peer-to-peer mentoring



Outreach Program

Outreach is done by graduate students, postdocs and faculty.



Managed by Outreach Coordinator, Roan Haggar.

Social Media handled by Ana Ennis.

A generous donation allowed us to purchase an inflatable planetarium, the *AstroBubble*, in 2022.

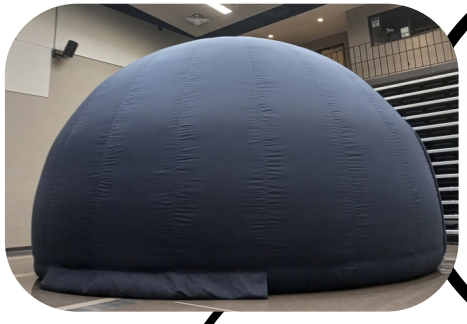
We have joined in the Ontario Postsecondary Accessand Inclusion Program (OPAIP) to take the AstroBubble into schools.

20 children per school day in 2023-2024

200 AstroBubble shows

18 Public talks and 2 Perseid events

Outreach to > 6,000 people



Kitchener Public Library

ASTRONOMY SERIES

WATERLOO CENTRE FOR ASTROPHYSICS

Astronomy on Tap Kitchener-Waterloo

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Future Directions for WCA

- The WCA will continue to do world-class astrophysical research,
- We will continue to bring high-quality early career researchers to Waterloo,
- We will expand the WCA's outreach program to encourage more under-represented minorities find their place in STEM fields,
- We will work to secure future funding.

WATERLOO CENTRE FOR ASTROPHYSICS

The Waterloo Centre for Astrophysics

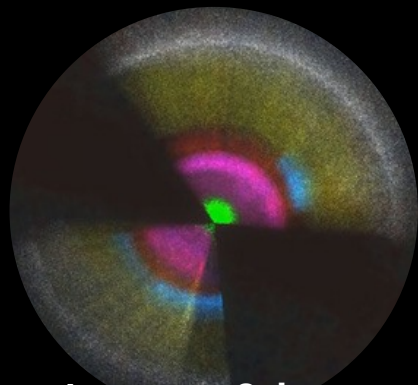
... at a glance

First image of a black hole:
2787 citations

102 Grad students
26 Postdocs
11 Faculty

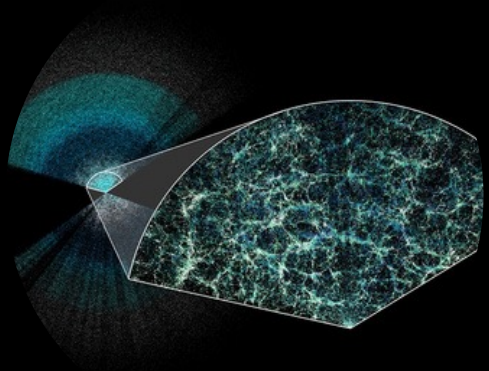
1/3 of postdocs go into faculty positions

Mapping the Universe with Euclid



Largest 3d map of the Universe

506 publications



Looking back 11 billion years with DESI

Outreach to over 6,000 people

200 AstroBubble shows

TIMES HIGHER EDUCATION

Digital Health Summit
April 10 & 11, 2025

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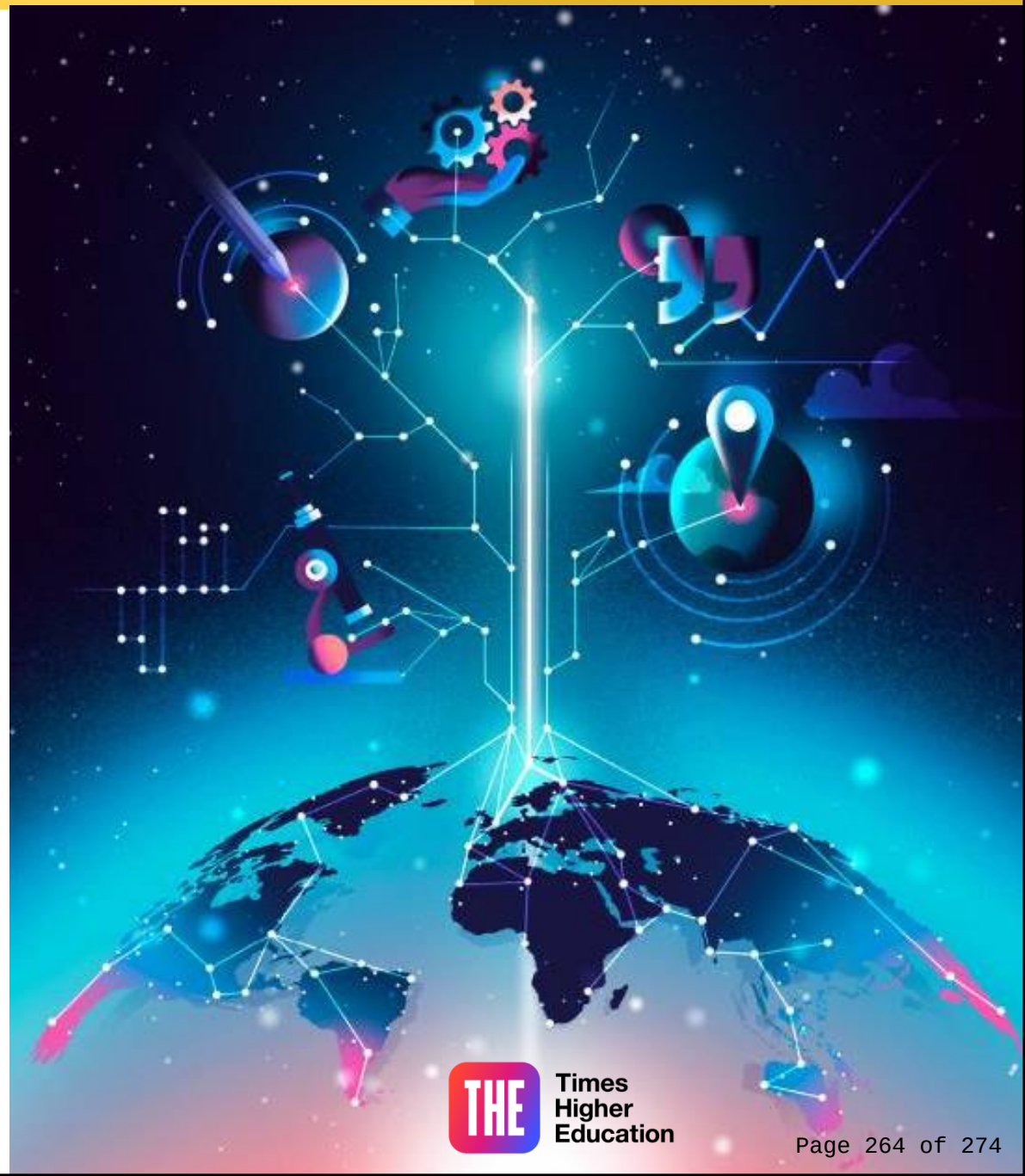

Event overview

- **Delegates** (estimate) 200-250 registrants
  - 40-50% from outside of North America

- **Event Structure**: 2 days with keynotes, panels, and programming that will include a pitch competition, reception, and tours

- **Venue:** we are expecting to showcase our best campus spaces, including Engineering 7, the Mike & Ophelia Lazaridis Quantum-Nano Center, and the Innovation Arena .

- **Community engagement:** We are engaging regional partners to participate as sponsors, presenters, and tour hosts

- **Associated Programming:** This is an opportunity for associated events to engage those visiting for the summit

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Digital Health 2023: Shaping a healthier future through innovation, entrepreneurship and partnerships

Themes:

- Ethics and health care equity
- Collaboration and commercialization
- AI and health technologies

Speakers to include UWaterloo faculty and alumni, Velocity startups, and academic and corporate leaders from across North America. The World Health Organization is expected to participate.

The opportunity for Waterloo

- The summit is an opportunity for us to showcase **thought leadership** and Waterloo's **distinct point of view** on Health Tech issues, including…

	Focus on the **intersection of health, technology and society** (i.e. not just 'tech')
Region of Waterloo	Demonstrate our **impact our community** and Waterloo region (i.e. a local focus)
	Set the stage for **collaboration** between Academia, Industry and Policy-Makers
	Showcase a wide-range of topics including **Health Policy** (social issues relating to tobacco, aging, etc.), **Health Technologies** (e.g. health devices, new tech, AI, robotics), **Health Interventions**, **Health Data**, **Public health**, and much more

- We will leverage event models used for Waterloo Innovation Summit (Oct 2019) and the Royal Society of Canada (Nov 2023) both featuring Health Tech
- Alignment to Global Futures and Waterloo at 100

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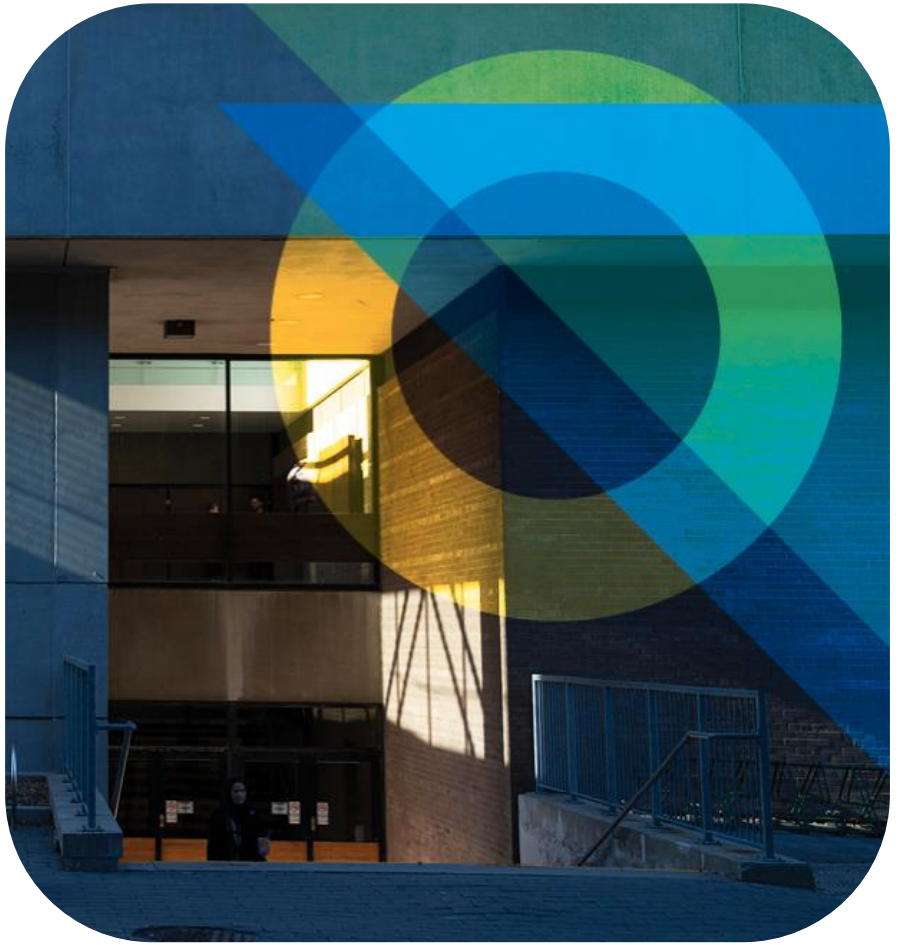
Objectives

Hosting the 2025 Times Higher Education Digital Health Summit will yield the following benefits:

- Reaching a global audience
- Targeted engagement with academic leaders, researchers, innovators in health tech
- Expanding Waterloo brand exposure
- Possible rankings ”halo” effect
- Waterloo/THE relationship development



Context

- The **Times Higher Education World University Rankings** is one of the most highly regarded university rankings worldwide (alongside the QS Rankings and the Shanghai Ranking)
- These rankings shape and influence university perceptions among **international audiences** (prospective students, university leaders, etc.)
- University of Waterloo's current THE rankings are…
  - **201-250th** World University Rankings 2023
  - **55th** Impact Rankings 2023
  - **Top 10** research on ending poverty & world hunger (Impact Rankings 2023)
  - **Top 50** sustainable cities & communities (Impact Rankings 2023)
- Waterloo's 2022 Reputation Research (conducted by Leger and University Relations) reveals that **University Rankings are the top influential source** on perceptions of Canadian universities (across all key audiences)

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Reputational enhancement

Reaching Global Audiences

- Reputation Enhancement on a global stage via THE's global network (175K members, 3.5K institutions)

International Brand Exposure / Media Coverage

- THE will lead an extensive marketing campaign 12 months leading to the event, **valued at $135,000**
  - **Print adverts** in the THE Magazine, **targeted emails** to higher education contacts and **editorial content** commissioned by THE's editors (in partnership with Waterloo), plus a **strong digital footprint** and global reach (30M unique web users per year)

Potential Rankings "Halo" Effect

- While THE rankings are not a primary motivator for this event; the potential for reputational "*boost*" from the above activities presents a potential opportunity to rise in rankings

Waterloo-Region Community-Building & Showcase

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Inaugural event at Stan

- In February 2024, **THE hosted its first Digital Health Summit** in partnership with the Stanford Healthcare Innovation Lab

- UWaterloo representatives attended this event, and Catherine Burns moderated a panel.

- At the conclusion of the Summit, Nenone Donaldson announced the UWaterloo event and a teaser video was launched.

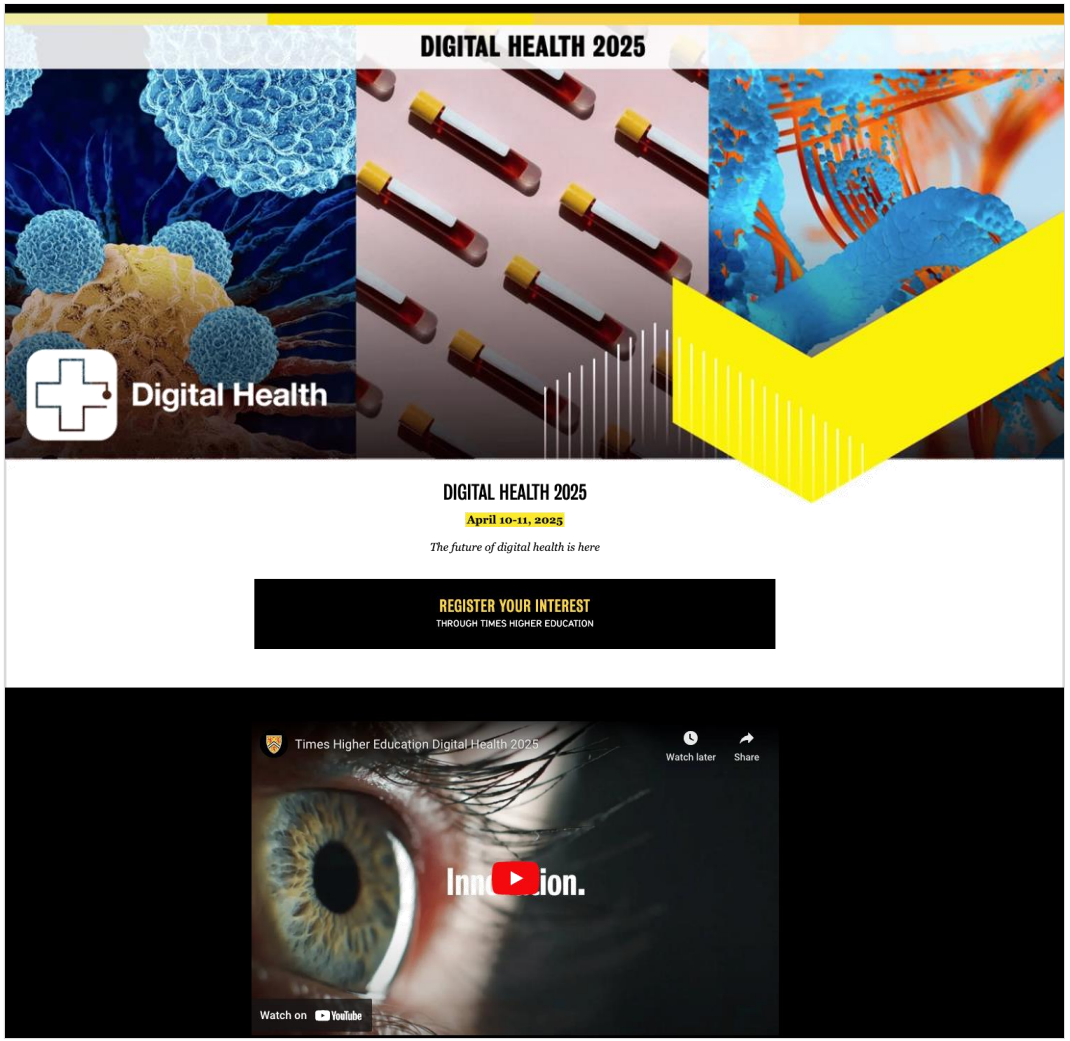
PRELIMINARY MARKETING & TIMELINES

- The public-facing **website** for the Digital Health 2025 event has been developed and was launched on February 26

  https://uwaterloo.ca/digital-health

- **Program** to be confirmed by late 2024

- **Tickets** for the April 2025 event are expected to go live in early 2025



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INTERDEPARTMENTAL PLANNING TEAM

Membership

- Kelly McManus & Michael Dorr (co-chairs)
- Event program and logistics: Alyssa Doyle
- Content:
  - Catherine Burns, AVP Health Initiatives
  - Adrien Cote, Velocity
  - Amy Carroll-Dee, Office of Research
- Marketing: Bryan Coren
- Communications: Stephanie Longeway
- Sponsorship: Bridget McMahon
- Government relations and community partner engagement: Kerri Behling

The expectation is that leads will be engaged with their home units to share updates and solicit feedback from their colleagues.

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Canada’s Innovation University