GOGREEN Galaxy Groups

And The Role of Halo Mass in the Quenching of Star Formation

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Image credit: Adam Block, UA

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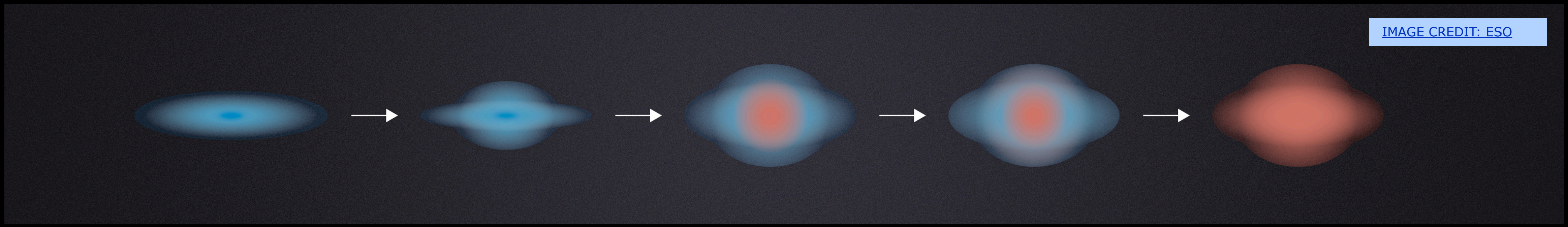
GOGREEN

Reminder:

“Quenching” of star formation in galaxies

Dictionary definition: to *extinguish*, *stifle*, or *suppress*



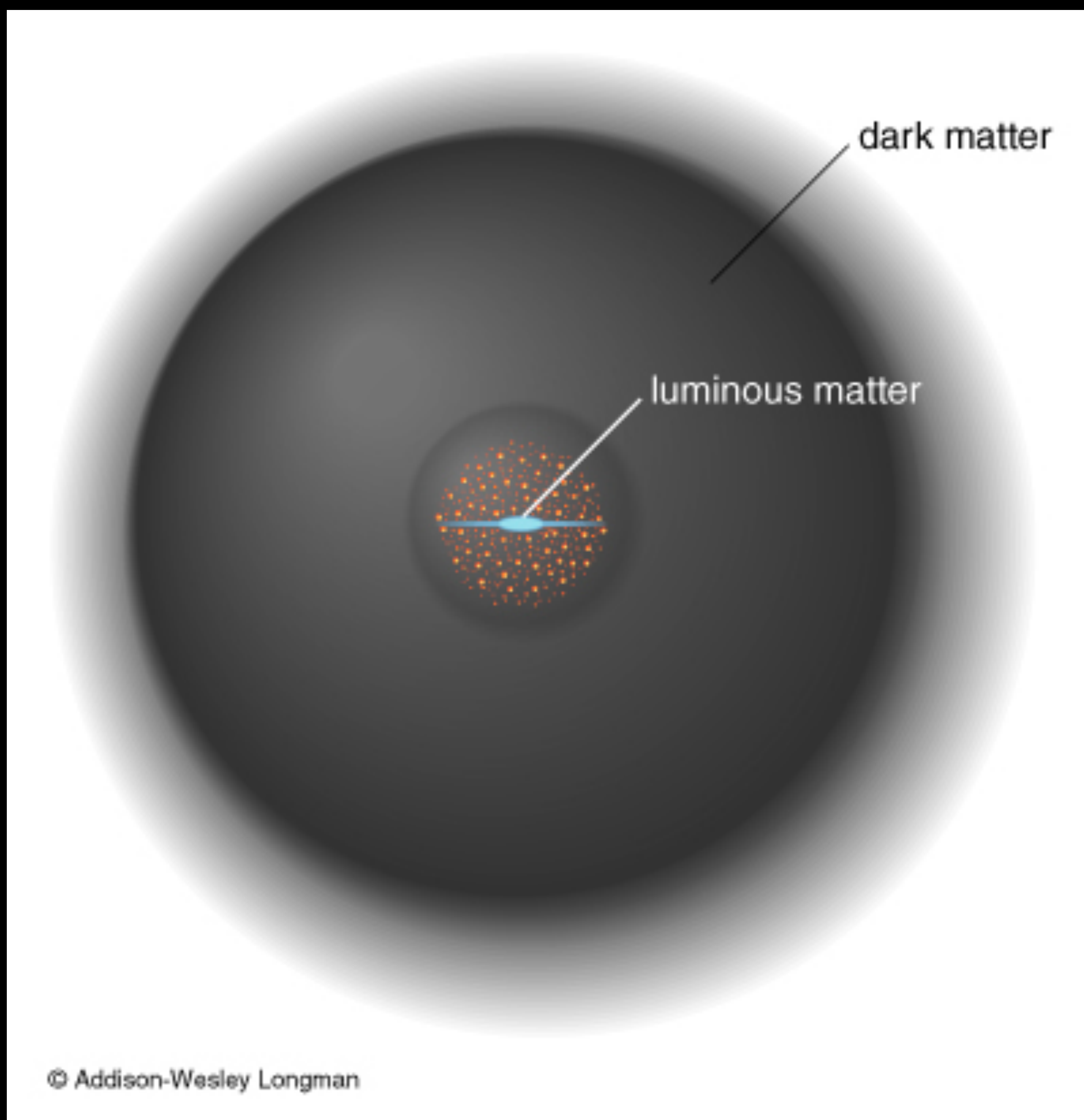
Star-forming **Quiescent/quenched**

Intro: 2 key concepts

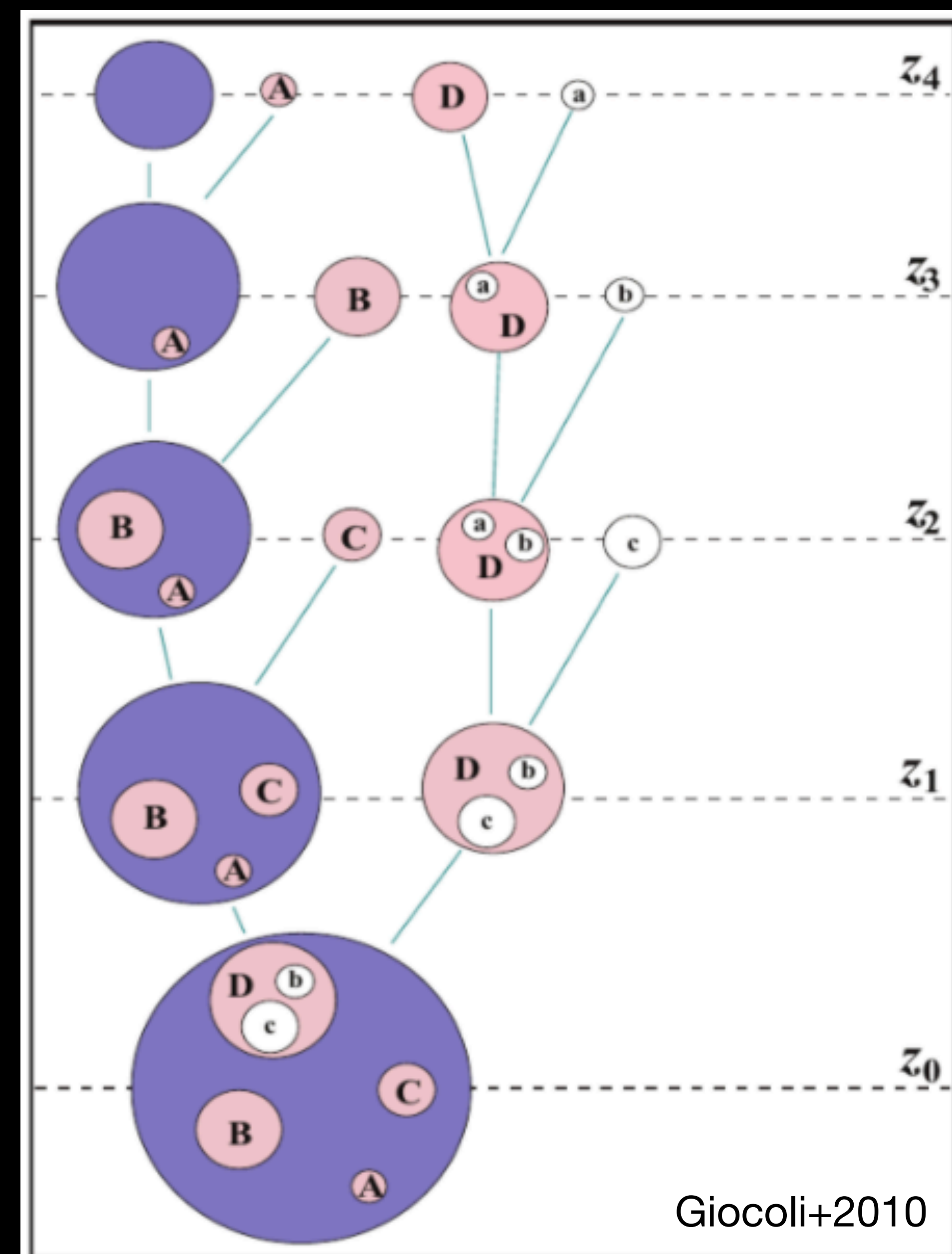
1. **Dark matter halos and how a cluster is made**
2. **“Central” vs “satellite” galaxies**

Key concept #1:

Dark matter halos and how a cluster is made



Galaxies reside in dark matter halos



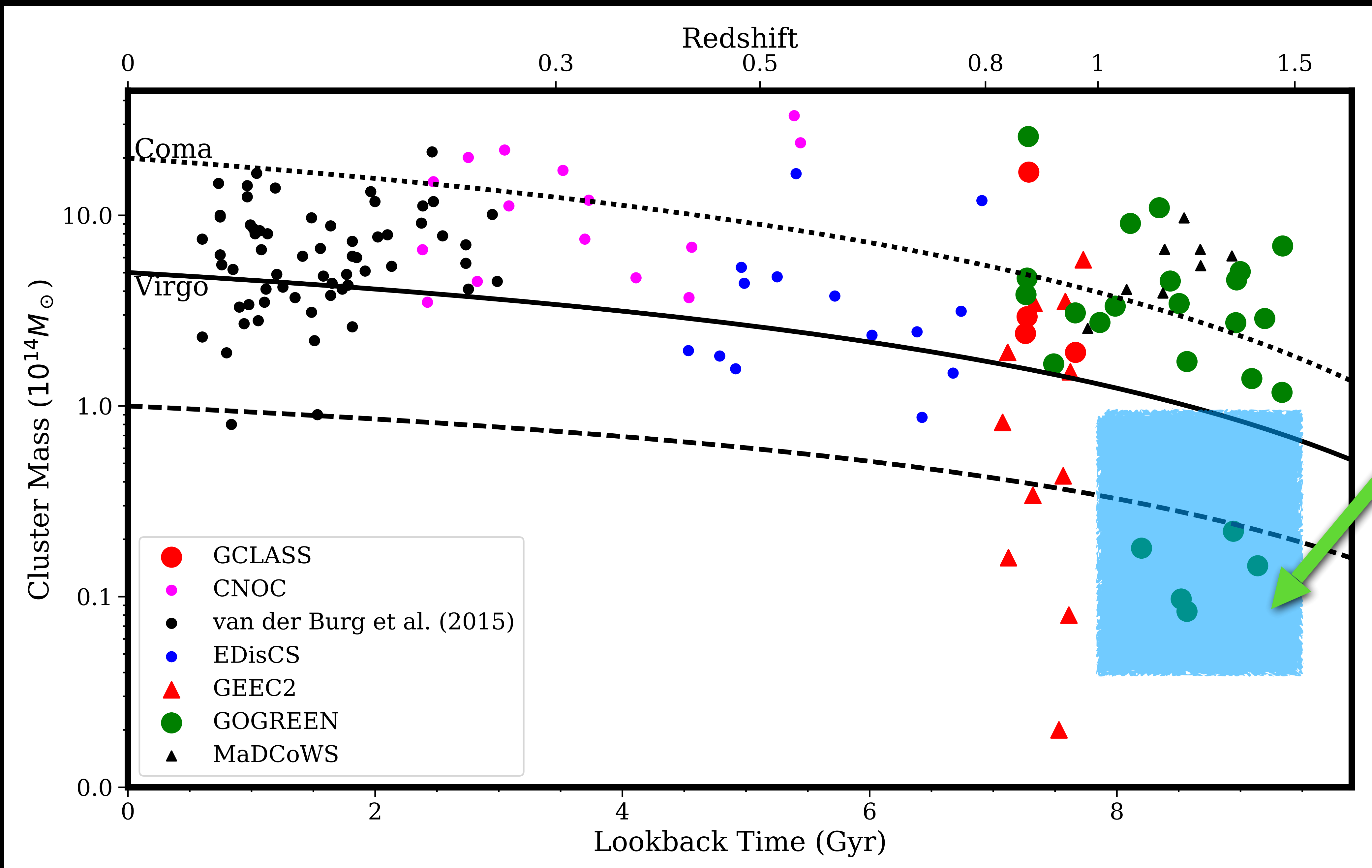
Dark matter halo merger history tree

Redshift

Towards present time ↓

Halo mass ranges in this work

What we mean by “groups” of galaxies



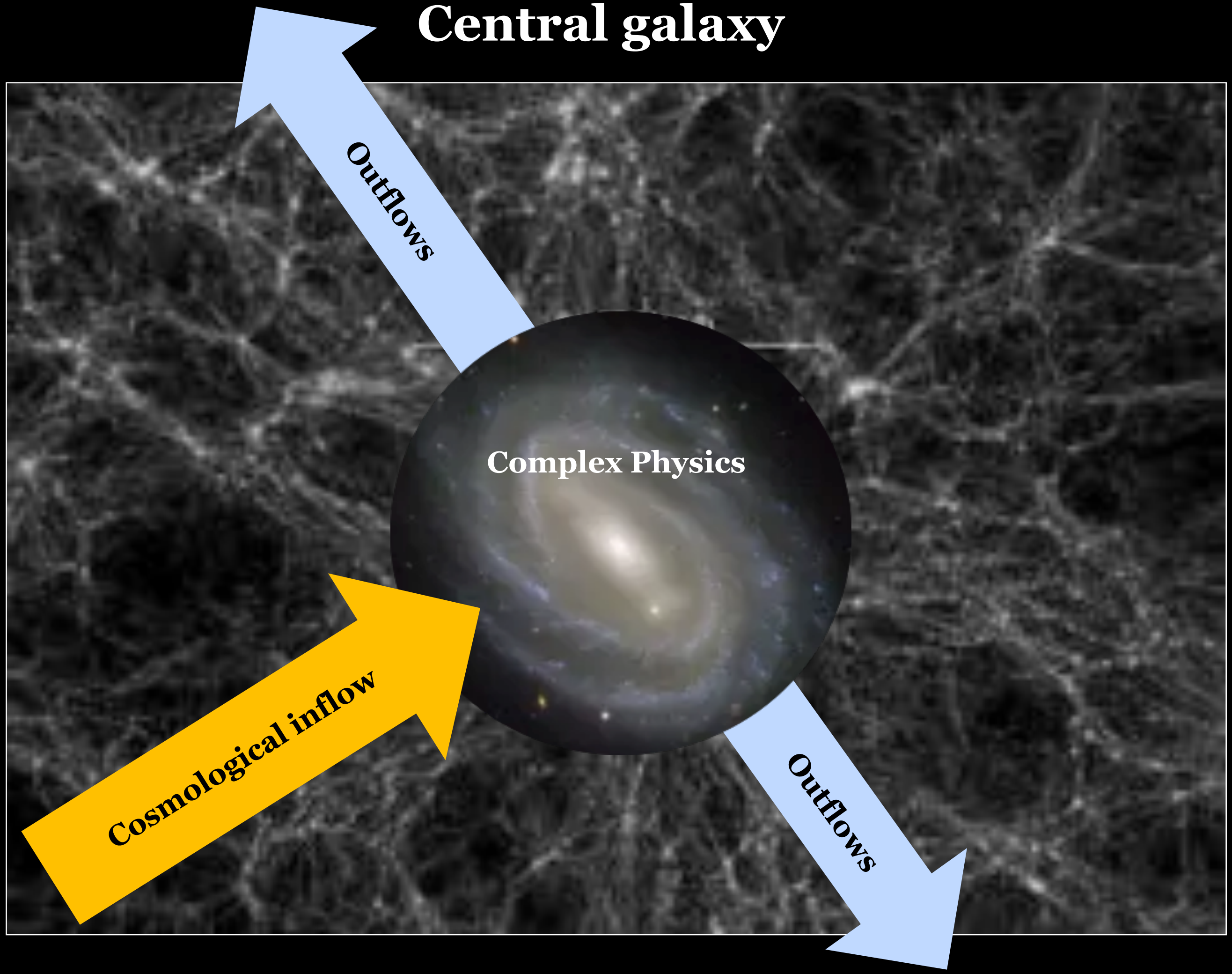
- “Groups” in GOGREEN are gravitationally bound collections of galaxies with halo masses $M_{200c} < 10^{14} M_\odot$
- This study: 20 groups total (span the blue region)
- **Groups at 1<z<1.5** in COSMOS/SXDF survey regions, with halo masses estimated based on x-ray fluxes

Towards present time

Key concept #2:

"Central" vs "satellite" galaxies

Central galaxy



Satellite galaxy

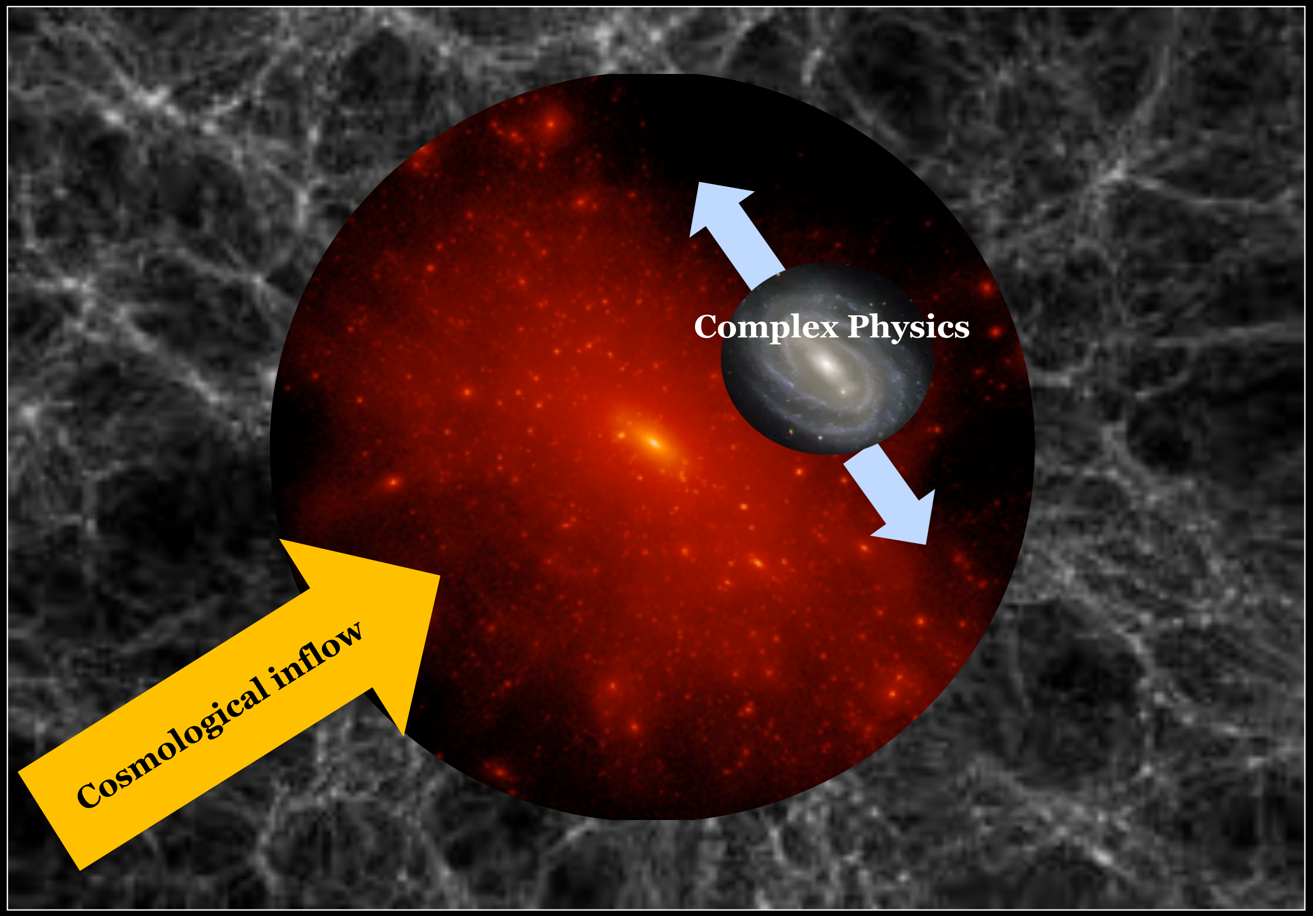


IMAGE CREDIT: Michael Balogh

This work and how it fits into GOGREEN

Gemini Observations of Galaxies in Rich Early ENvironments

Project goal: to constrain or understand how quenching processes in galaxies depend on their group/cluster halo mass at 1<z<1.5, by making use of our GOGREEN cluster measurements and 1<z<1.5 group measurements (explicitly analyzed in this work).

Fits into the core GOGREEN science goals:

- Environmental-quenching of low mass galaxies
- Hierarchical assembly of baryons

Unique feature of GOGREEN:

- Wide range of halo masses at GOGREEN redshifts, 1<z<1.5
- Depth of observations to lower stellar mass galaxies at 1<z<1.5

Method

Background subtraction

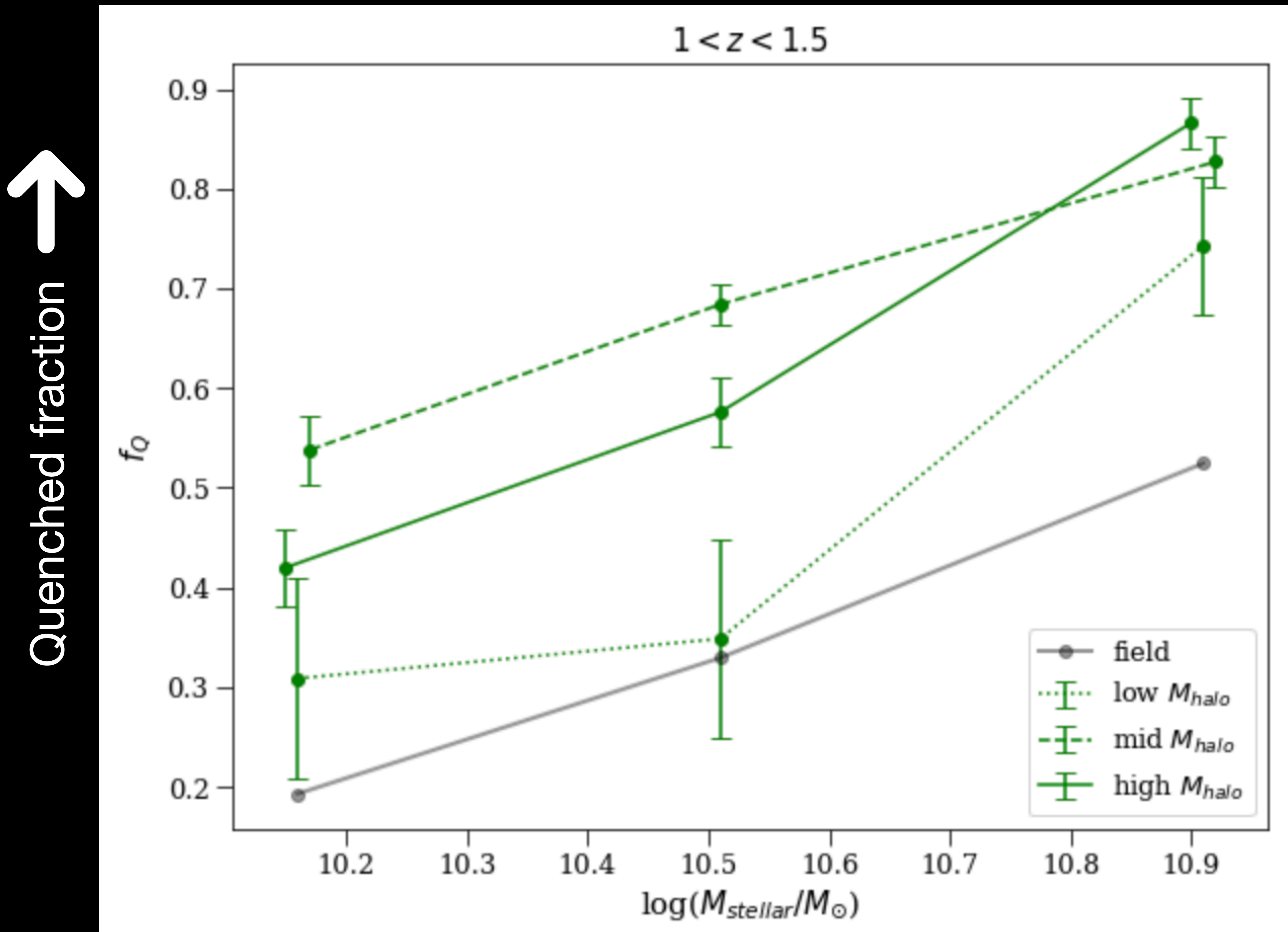
- **3 survey regions on the sky**:
  - COSMOS field
    - UltraVISTA DR1
    - UltraVISTA DR3 (ultra-deep stripes)
  - SPLASH SXDF

- **Method:** $N_G = N_C - N_{\mathrm{field}} \left(\frac{A_C}{A_{\mathrm{field}}} \right)$
  - Sum over all groups
  - Quiescent / star-forming color cut using rest-frame U-V vs V-J
  - $z = z_{group} \pm dz$ photometric redshift cut
  - Simple background subtraction to compute stellar mass functions
  - For a given stellar mass bin, error bars are simple Poisson, ie: sqrt(N_C) (field contribution to the error was very negligible)
  - Other details of course, but these are the essential points

Results

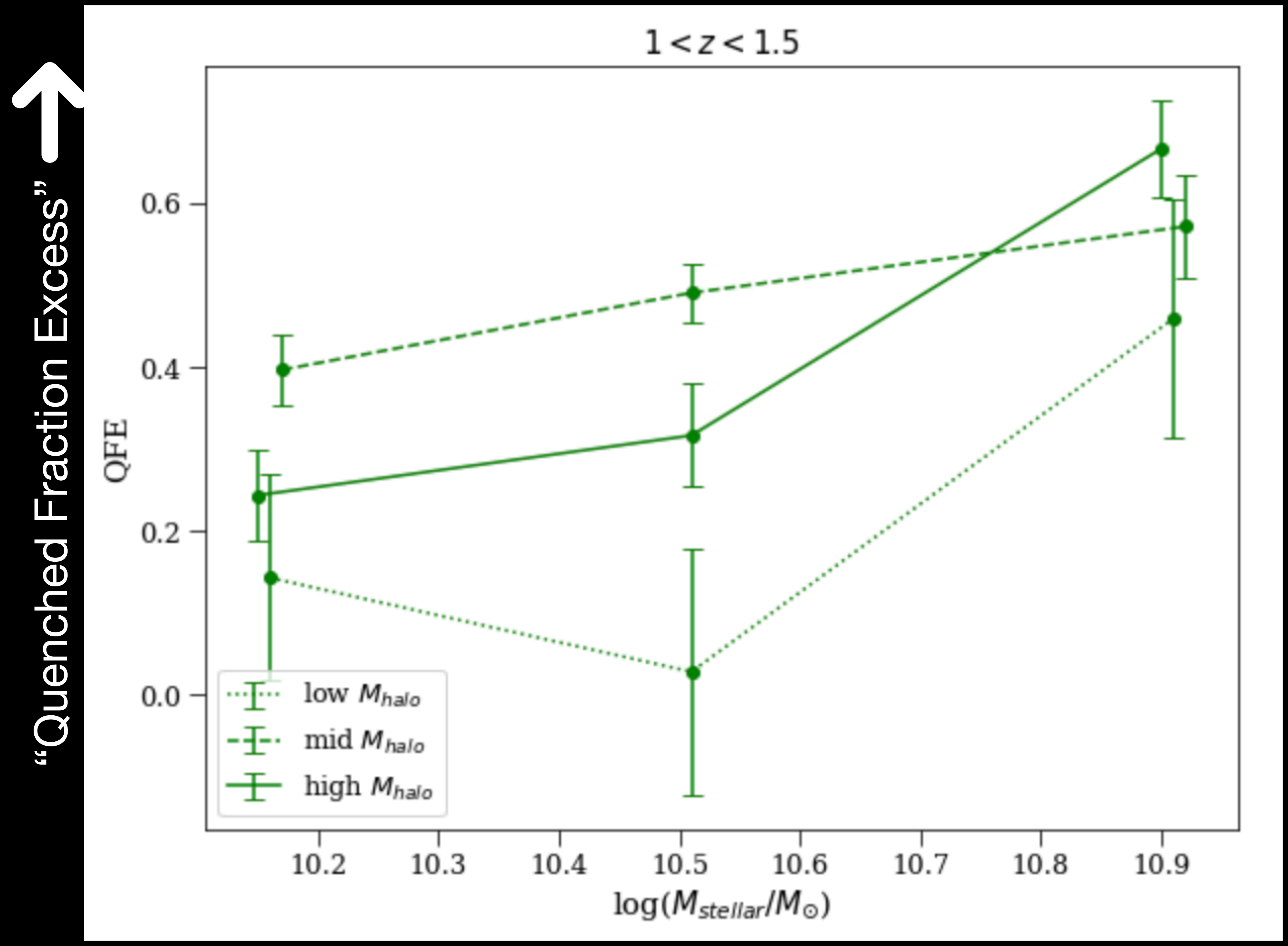
Results

Quenching Dependence on Stellar and Halo Mass



Results

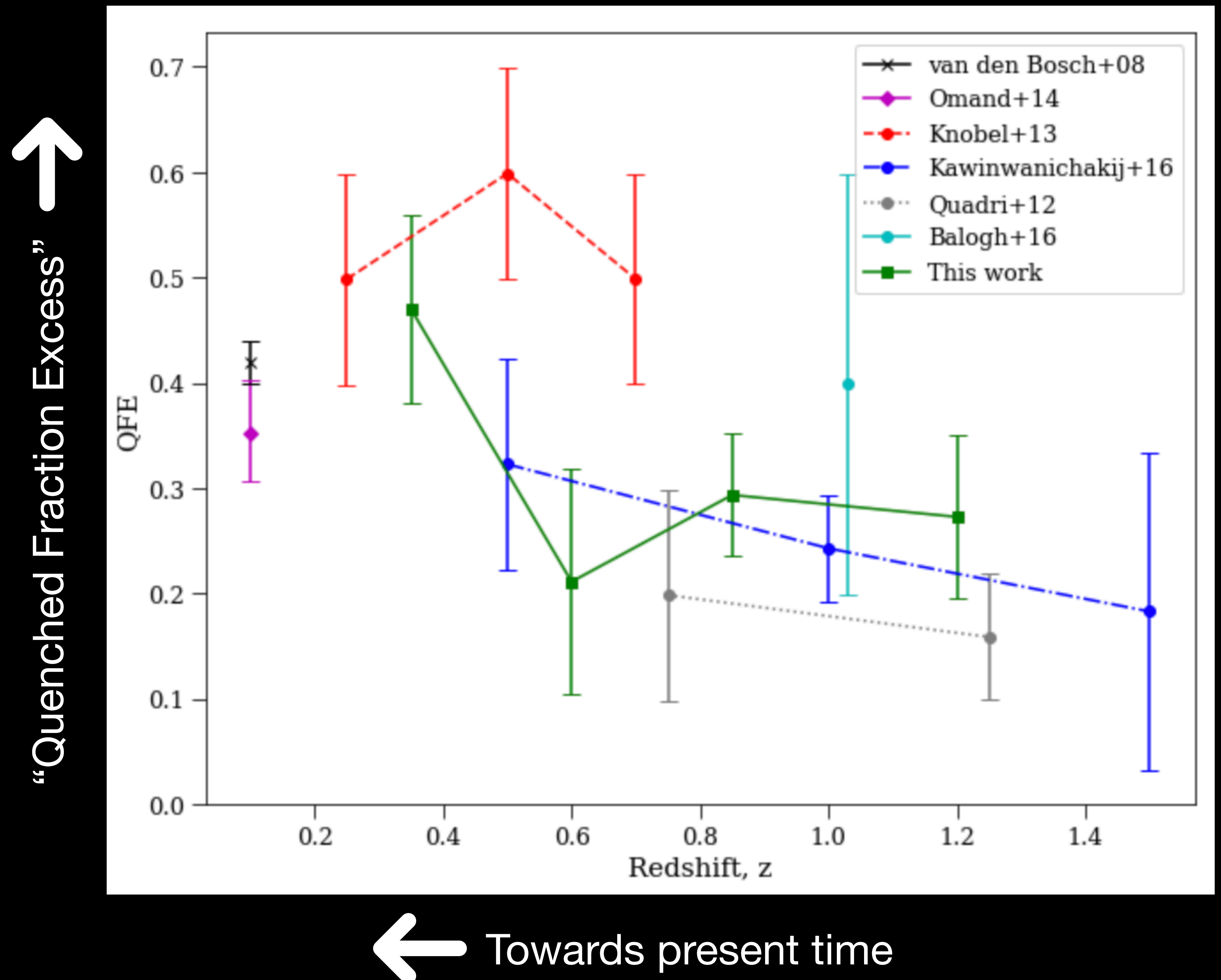
“Quenched Fraction Excess” and Dependence on Halo Mass



$$QFE = \frac{f_{Q,cluster} - f_{Q,field}}{(1 - f_{Q,field})}$$

Results in context

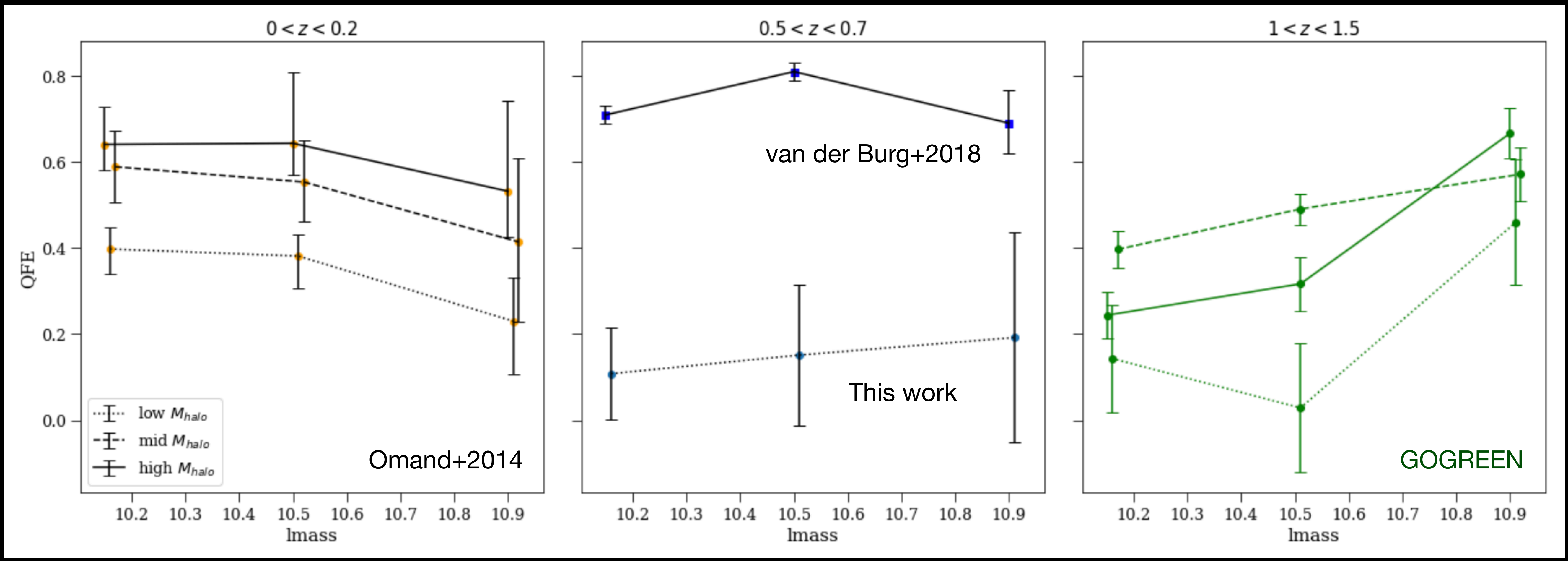
QFE in groups - evolution with redshift



- Our work is for all galaxies with log(Mstellar)>10
- Appears to be a general decreasing trend of QFE towards higher redshift

Results+literature comparison

A quick look into redshift evolution

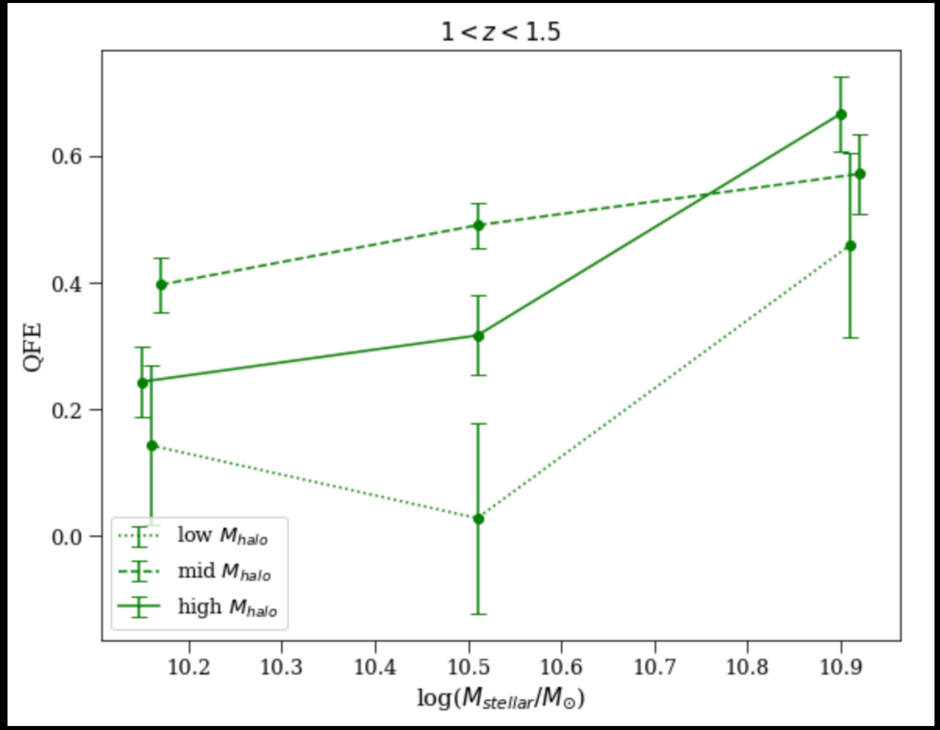


$$QFE = \frac{f_{Q,cluster} - f_{Q,field}}{(1 - f_{Q,field})}$$

- No clear redshift evolution
- Enhanced Quenched Fraction Excess for groups/clusters at all redshifts
- Clusters more enhanced QFE overall than groups at all redshifts
- Exact halo dependence unclear

Results

What does this mean?



- Environment-related processes are commonly observed in the most massive clusters (tidal stripping, jelly-fish galaxies, etc); quenching toy models indicate long quenching timescales in the literature at low redshifts
    - The excess of quenching observed even in early modest structures (groups) at GOGREEN redshifts indicate the quenching timescales are shorter
    - Quenching/galaxy formation mechanisms in the early universe in need of further study
- Accretion histories of groups/clusters are different but also theoretically well-understood
    - ⇒We can then combine our observational quenching constraints with toy accretion models to constrain timescales associated with quenching

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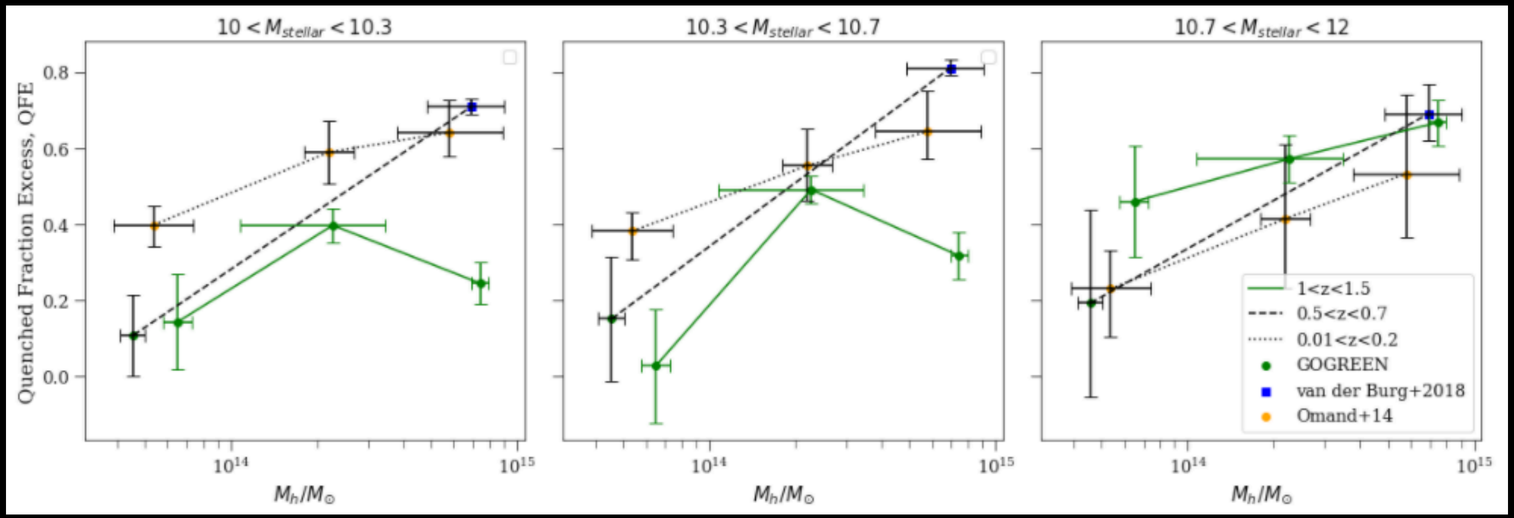
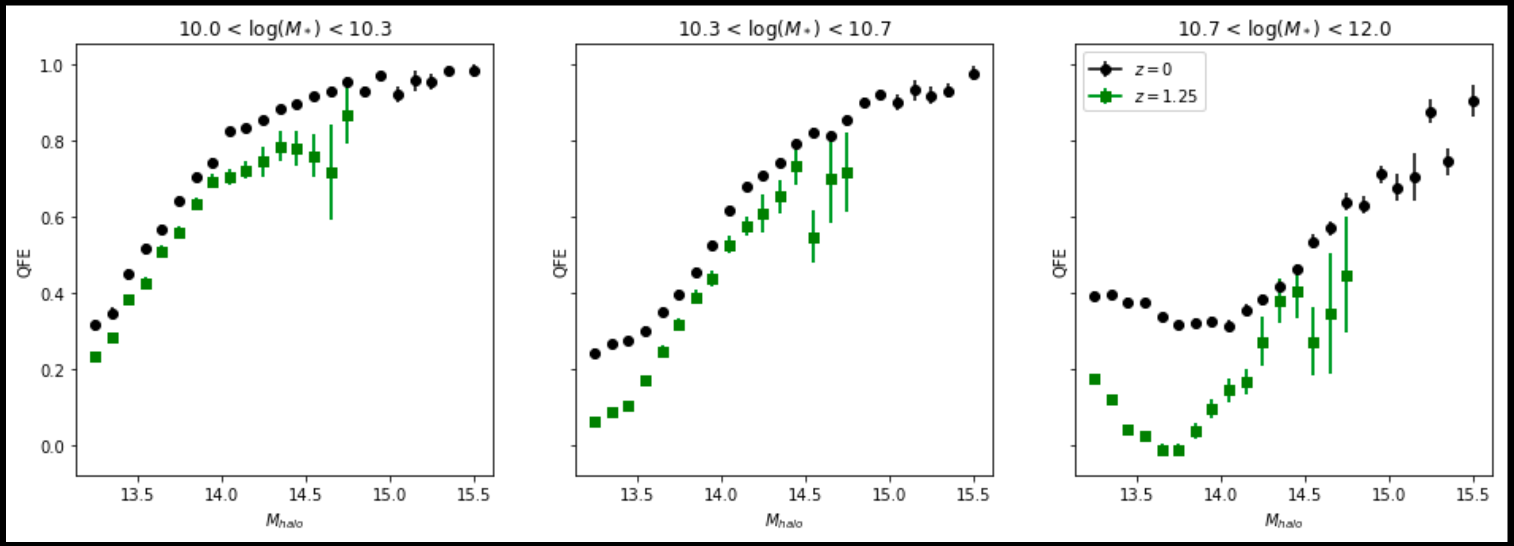
Backup/extra slides

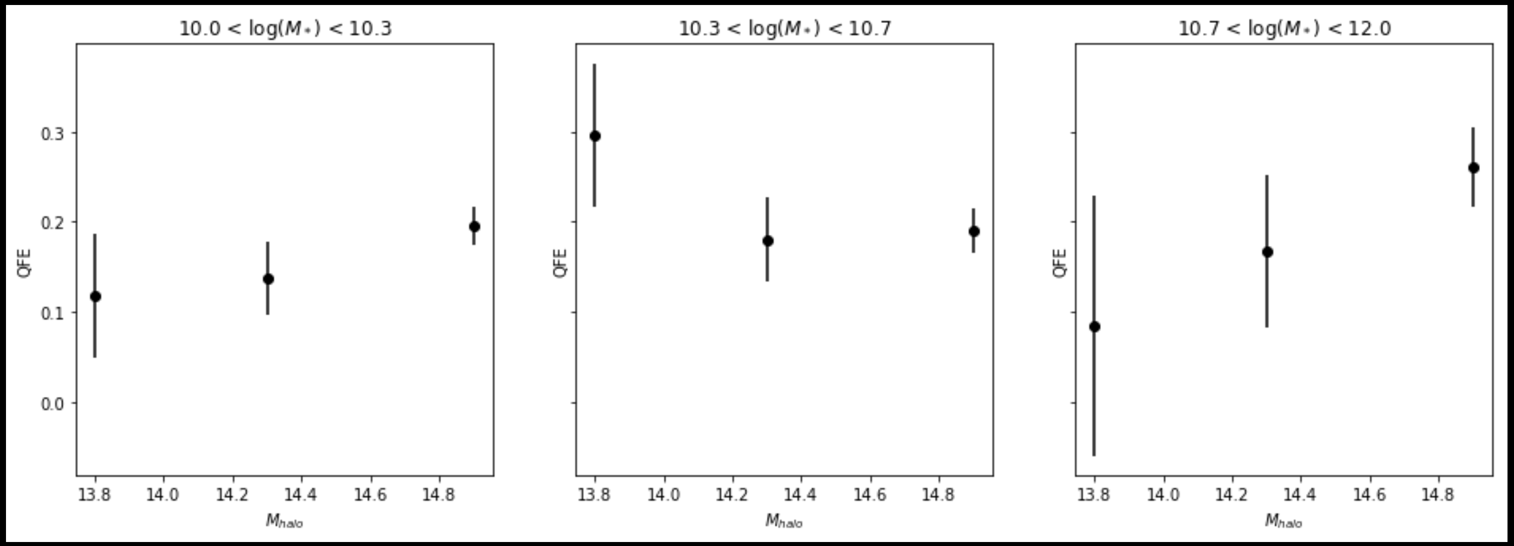
Results + Simulation Comparison



The data:
QFE higher in clusters than groups; unclear halo mass trend

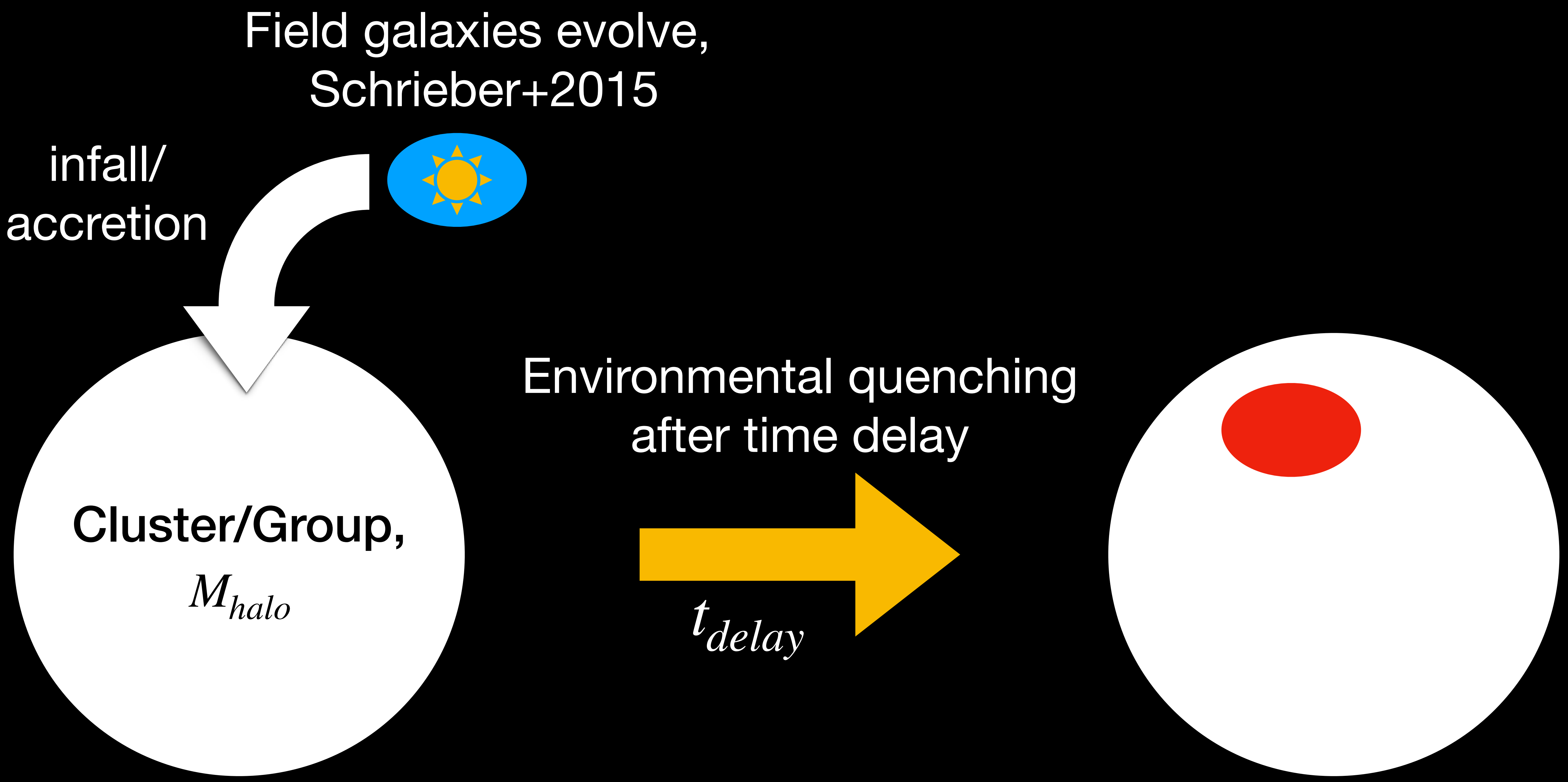


BAHAMAS hydro simulation:
captures QFE > in clusters than groups, but not stellar mass trend



GAEA SAM model: appears to capture stellar mass trend but not halo mass trend

Toy model: Accretion+quenching



Two accretion models:

What they are and how they differ

From central to first time
as a satellite,
McGee+2009 formalism

Accreted onto main cluster progenitor

Const rate of accretion, plus cluster head-start

dN/dt prop dM/dt

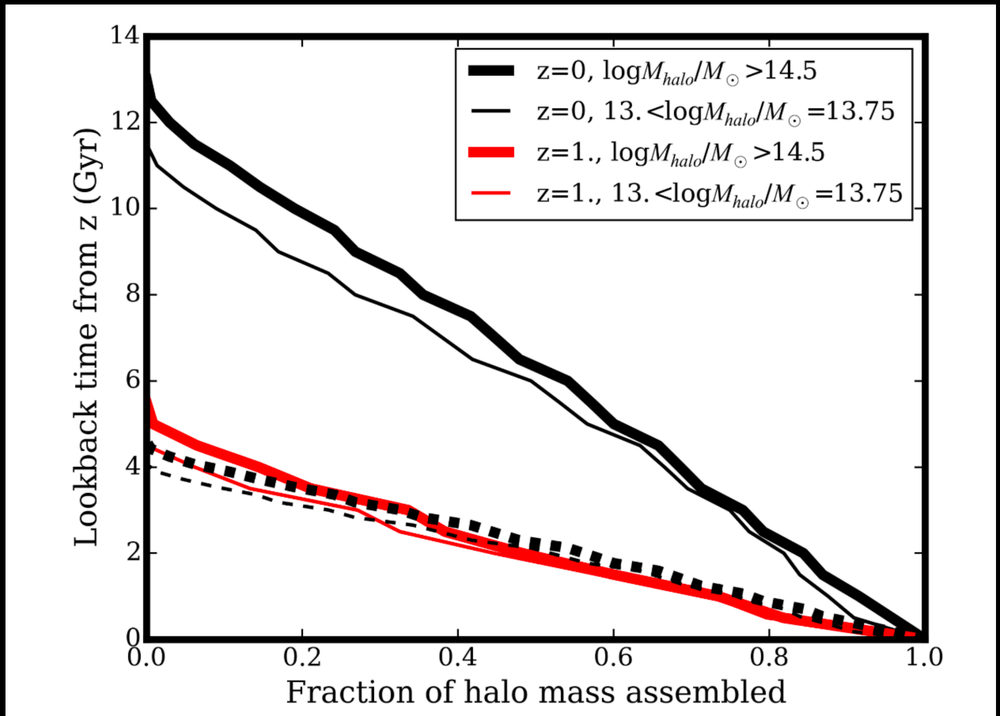
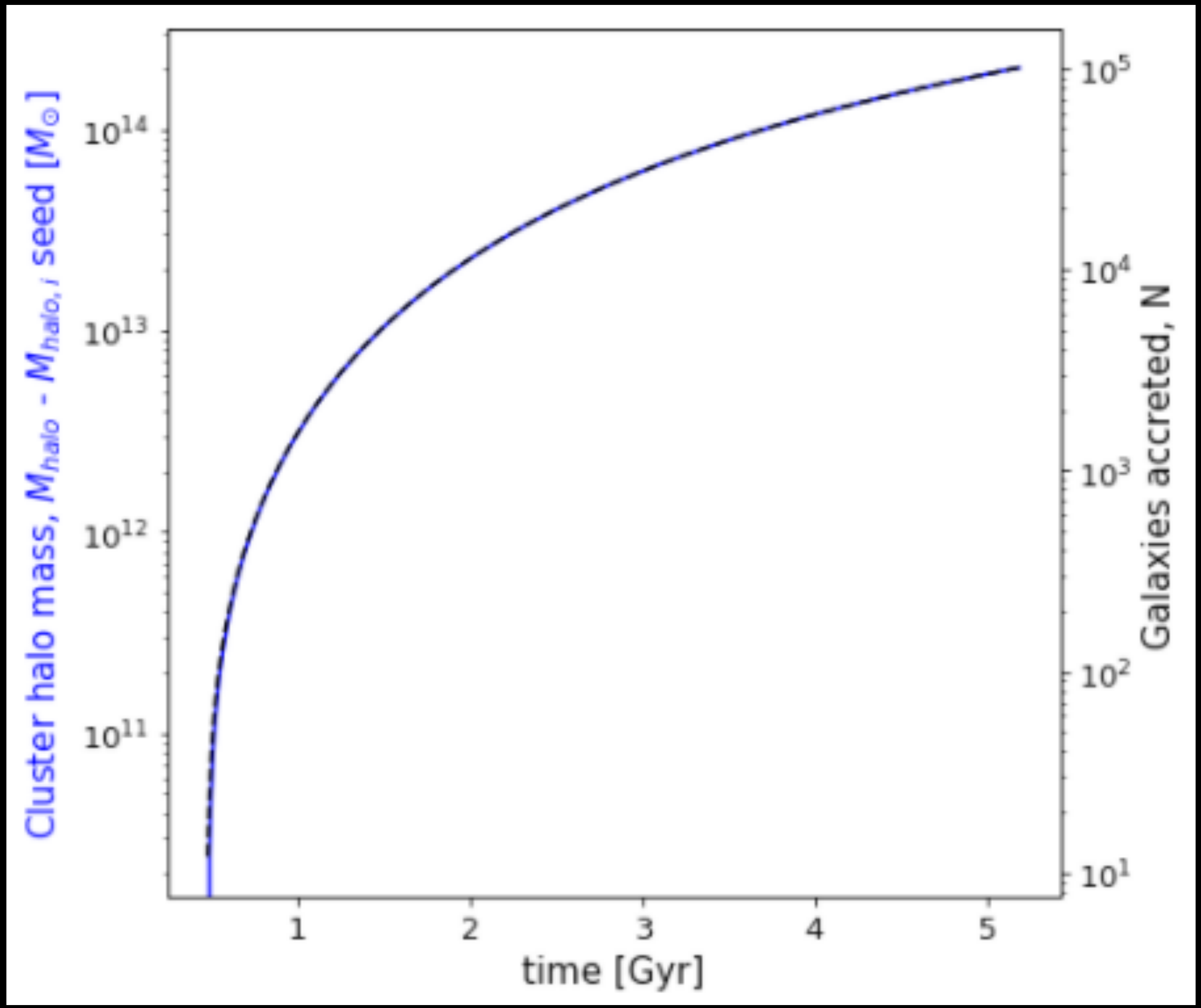


Figure 5. The time since a galaxy in a halo of a given mass, observed at a given epoch, was first found as a satellite is shown using the formalism of McGee et al. (2009). The black dotted lines show the $z = 0$ curves with the corresponding times rescaled by a factor $(1 + z)^{-3/2}$. This shows that the average accretion rate of haloes of a given mass evolves like the dynamical time.



Balogh+2016

Bouché+2010

Example quenching time-delay constraints

Comparing accretion histories