Comparing ages and star formation histories of quiescent galaxies in GOGREEN between field and cluster environments

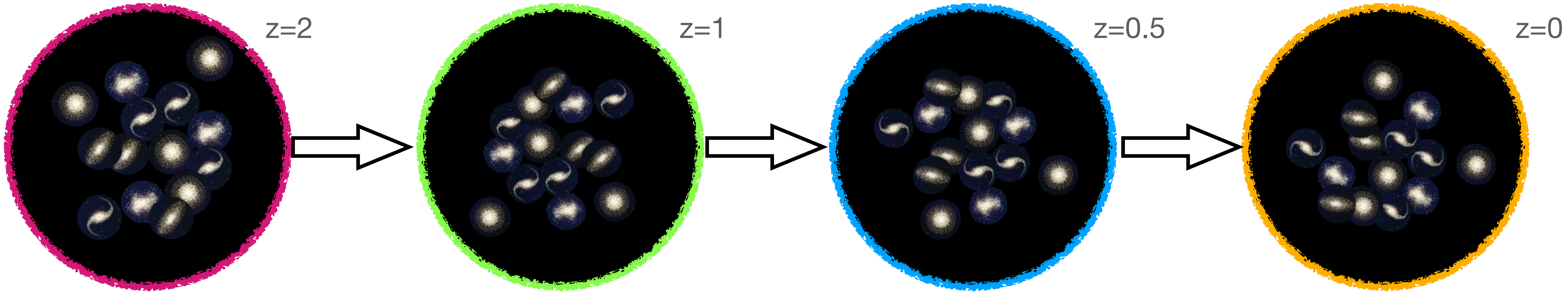
Kristi Webb + GOGREENers, Aug 24 2020, GOGREEN conference

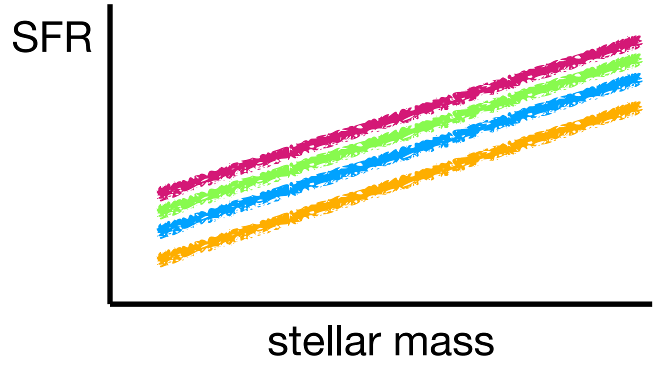
UNIVERSITY OF WATERLOO

GOGREEN

WATERLOO CENTRE FOR ASTROPHYSICS

Idea: Trace the formation and evolution of a galaxy from their stellar populations





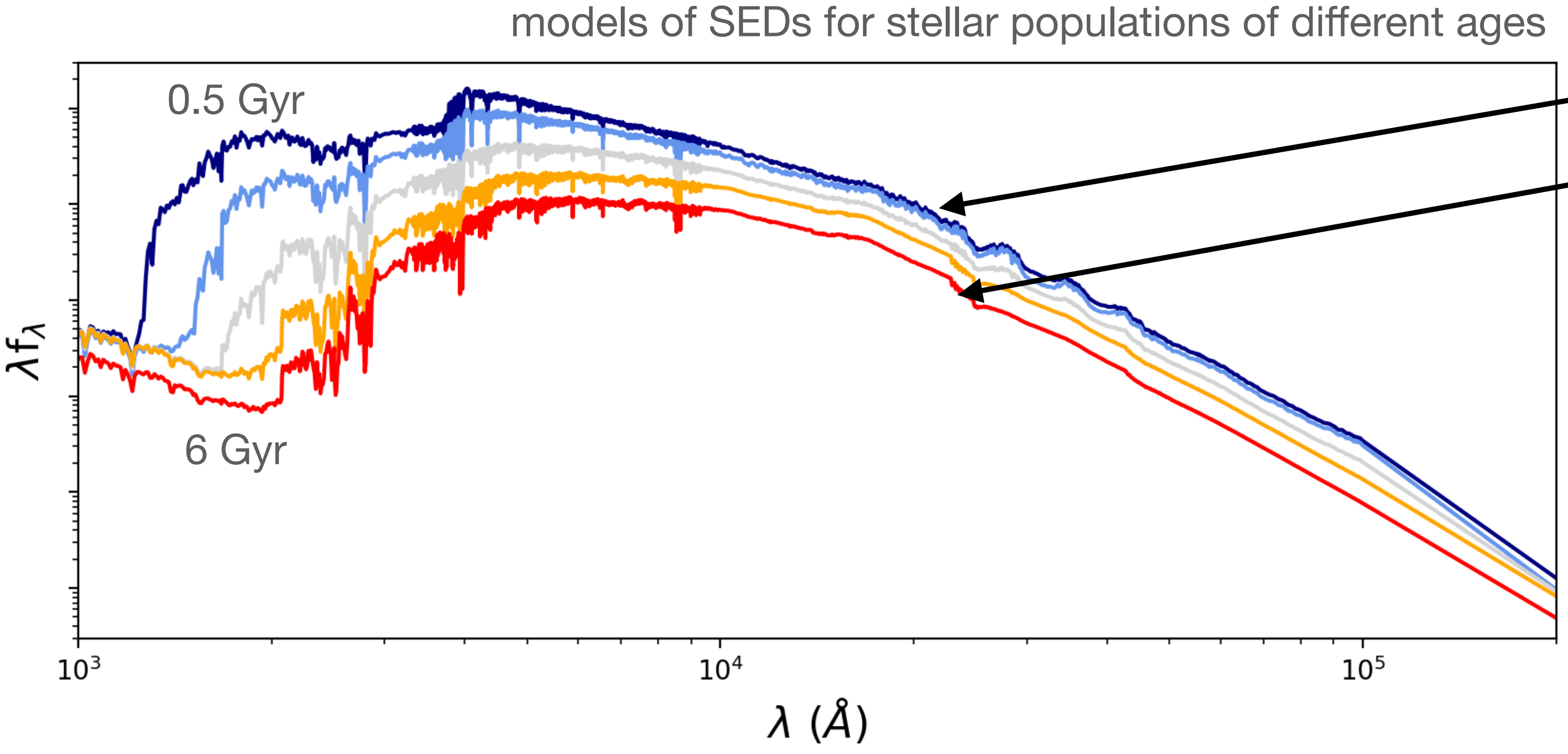
“Instantaneous” measures of galaxy properties **compared across different redshifts**

- stellar mass functions
- star formation rates
- galaxy ages (eg, fundamental plane), chemical enrichment, etc

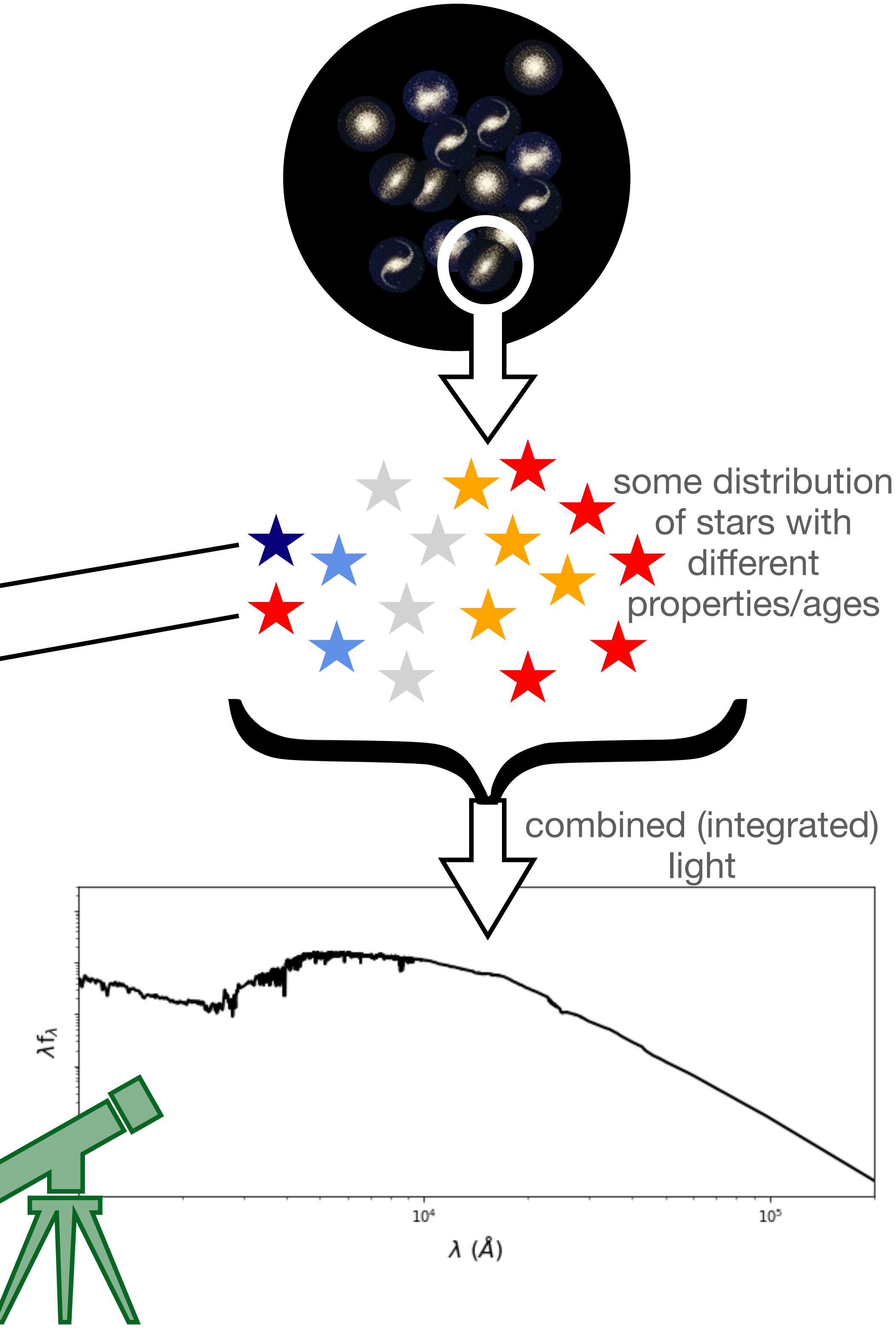
Assume that the higher-redshift galaxies are the **progenitors** of later galaxies

Idea: Trace the formation and evolution of a galaxy from their stellar populations

Reconstruct the **star formation histories** from the contribution of stars of different ages to the **integrated luminosity**



models of SEDs for stellar populations of different ages

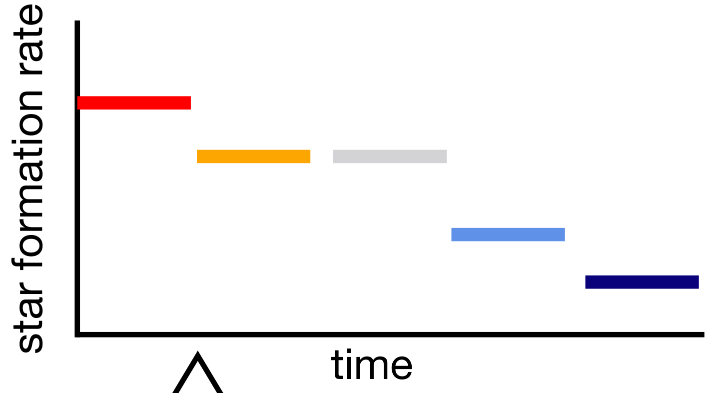


some distribution of stars with different properties/ages

combined (integrated) light

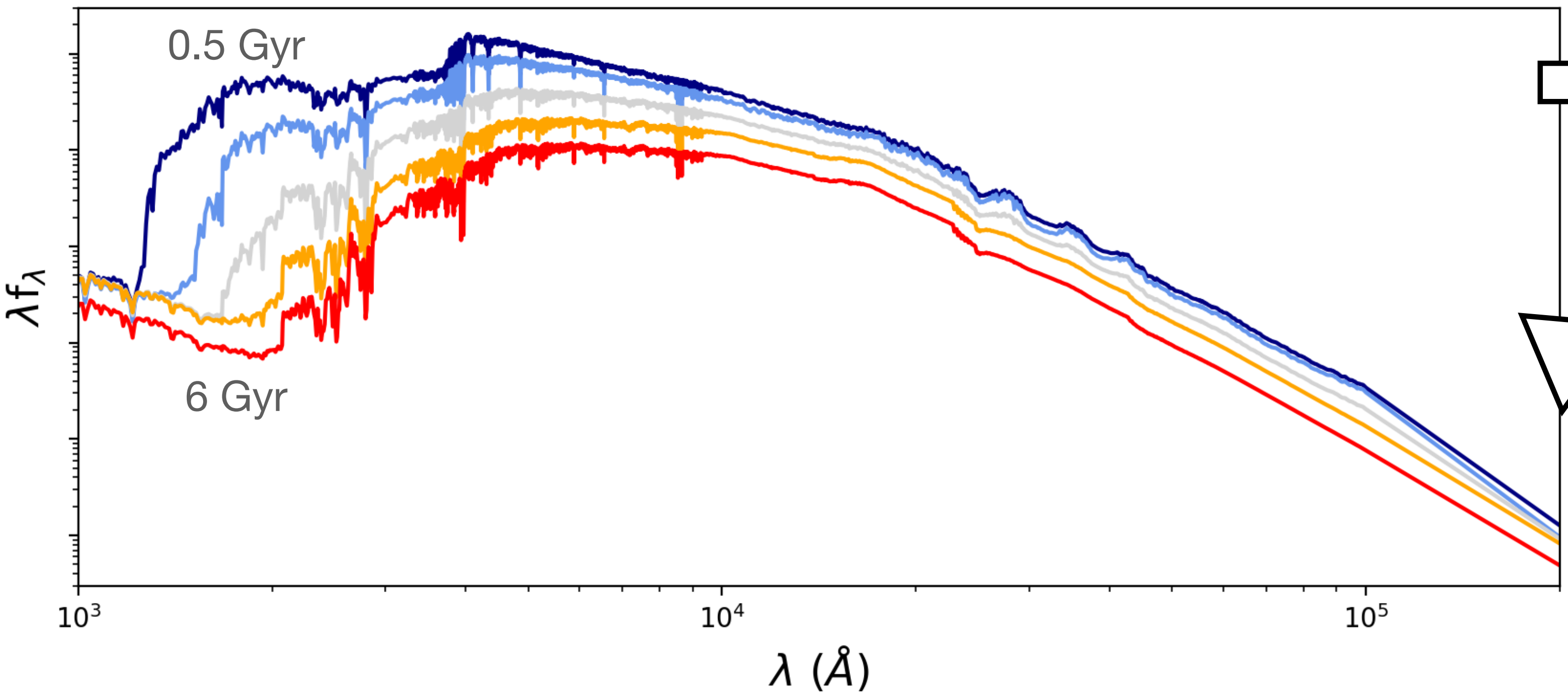
Idea: Trace the formation and evolution of a galaxy from their stellar populations

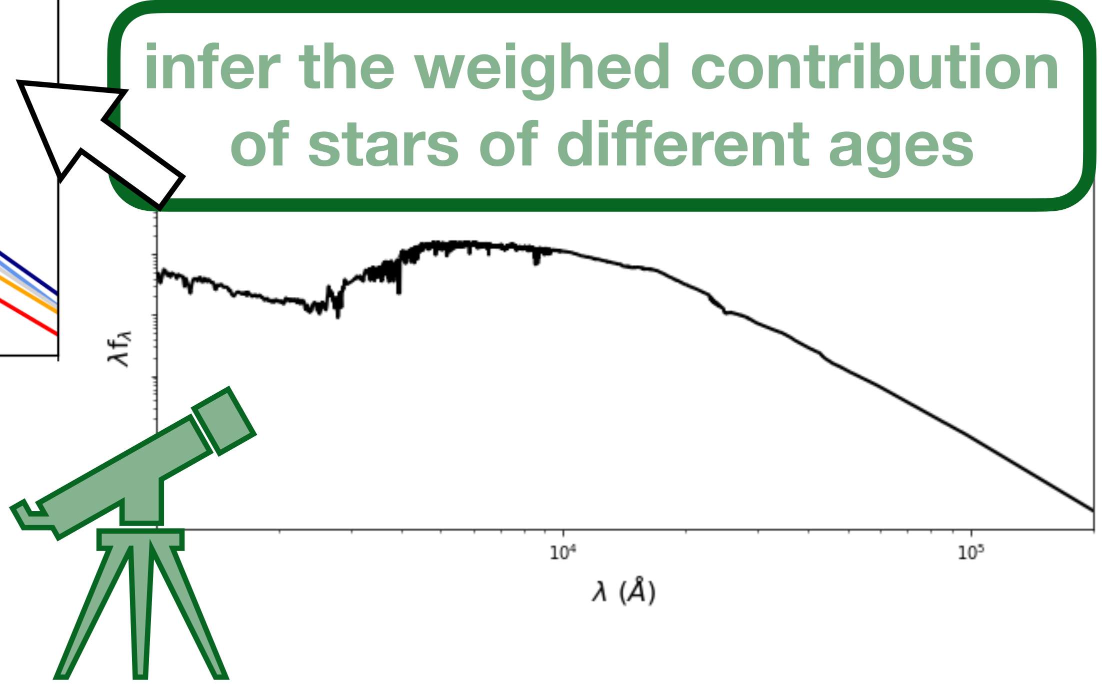
Reconstruct the **star formation histories** from the contribution of stars of different ages to the integrated luminosity



some distribution of stars with different properties/ages

models of SEDs for stellar populations of different ages



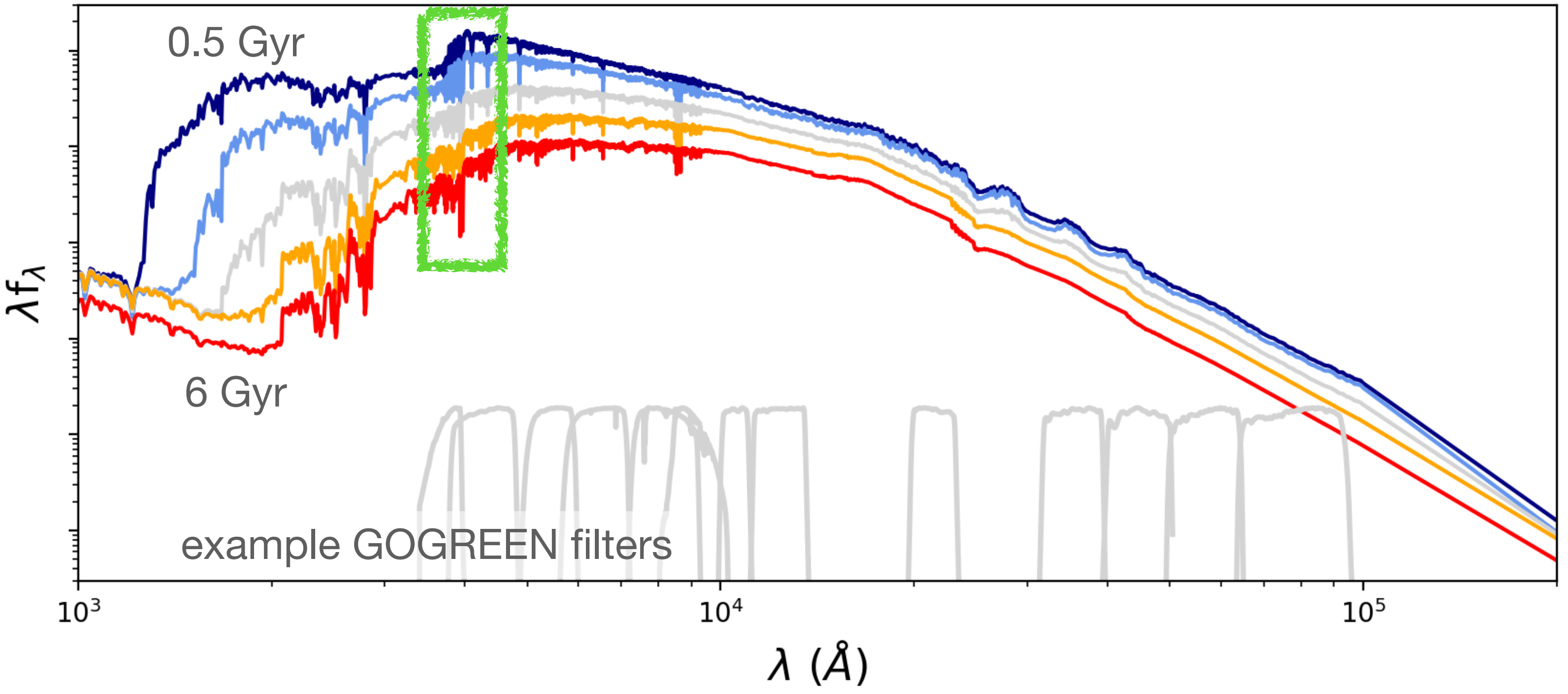


infer the weighed contribution of stars of different ages

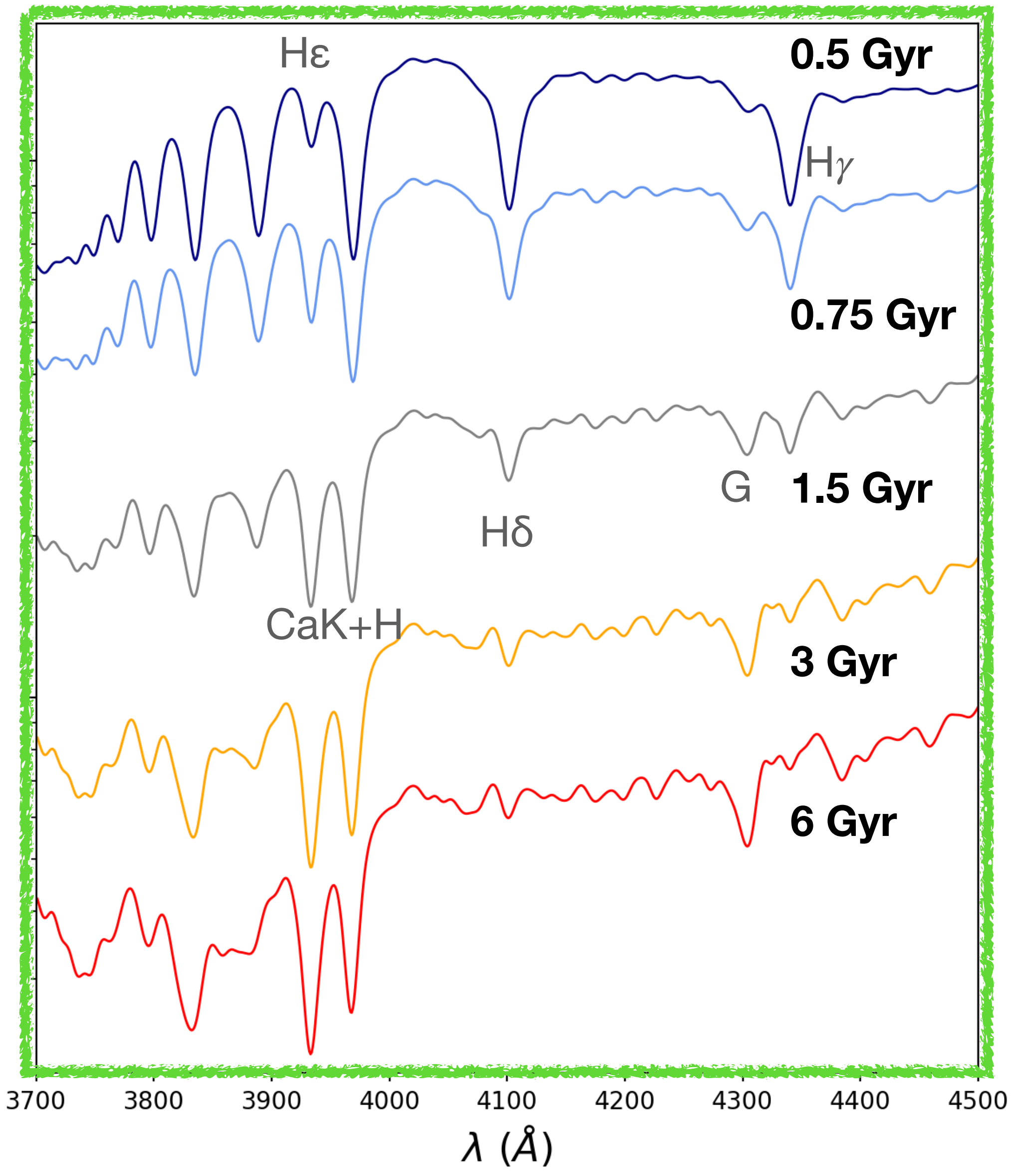
Idea: Trace the formation and evolution of a galaxy from their stellar populations

Reconstruct the **star formation histories** from the contribution of stars of different ages to the integrated luminosity

models of SEDs for stellar populations of different ages

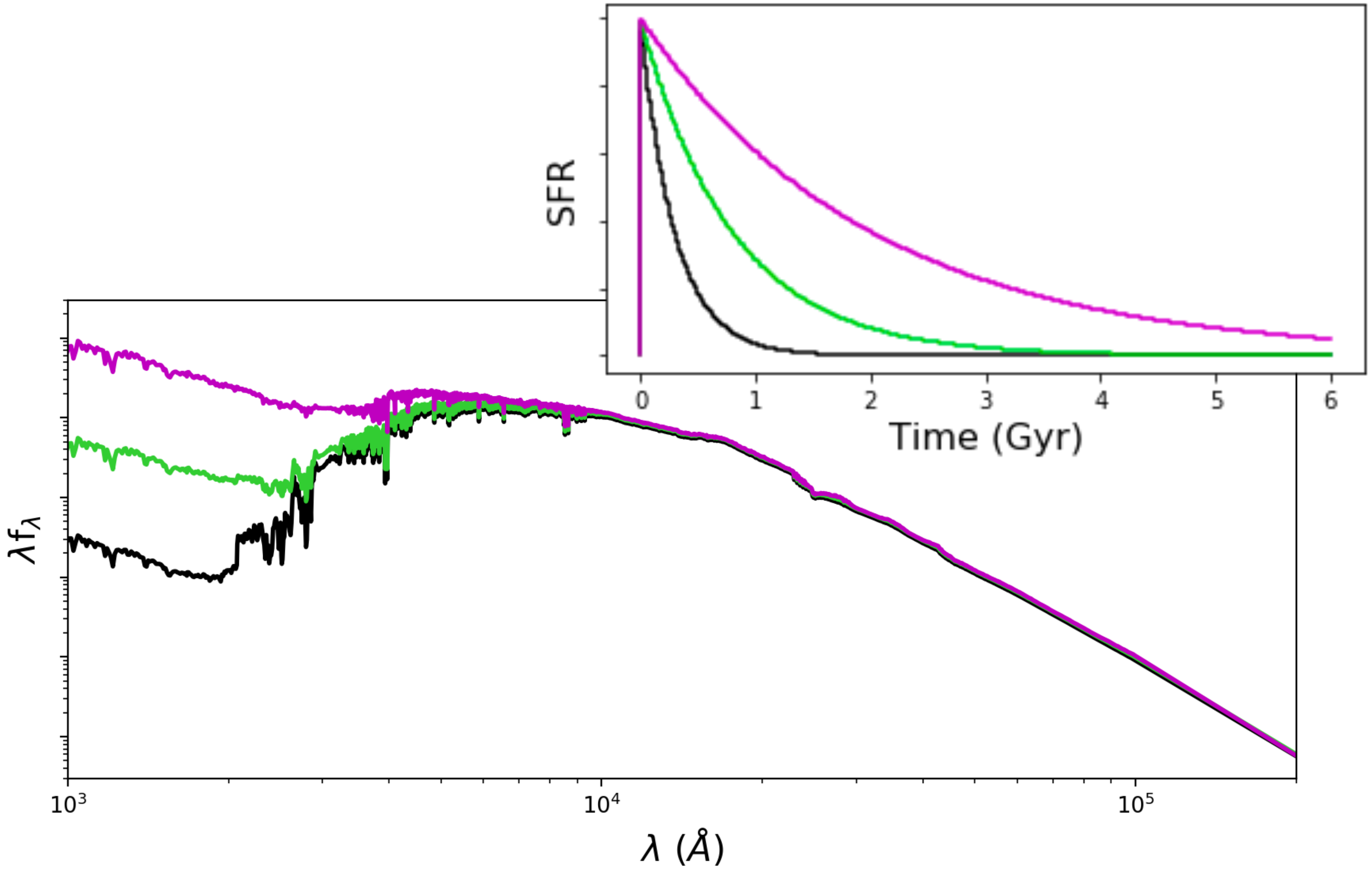


SEDs of SSPs of different ages
emission lines not shown



Idea: Trace the formation and evolution of a galaxy from their stellar populations

Reconstruct the star formation histories from the contribution of stars of different ages to the integrated luminosity

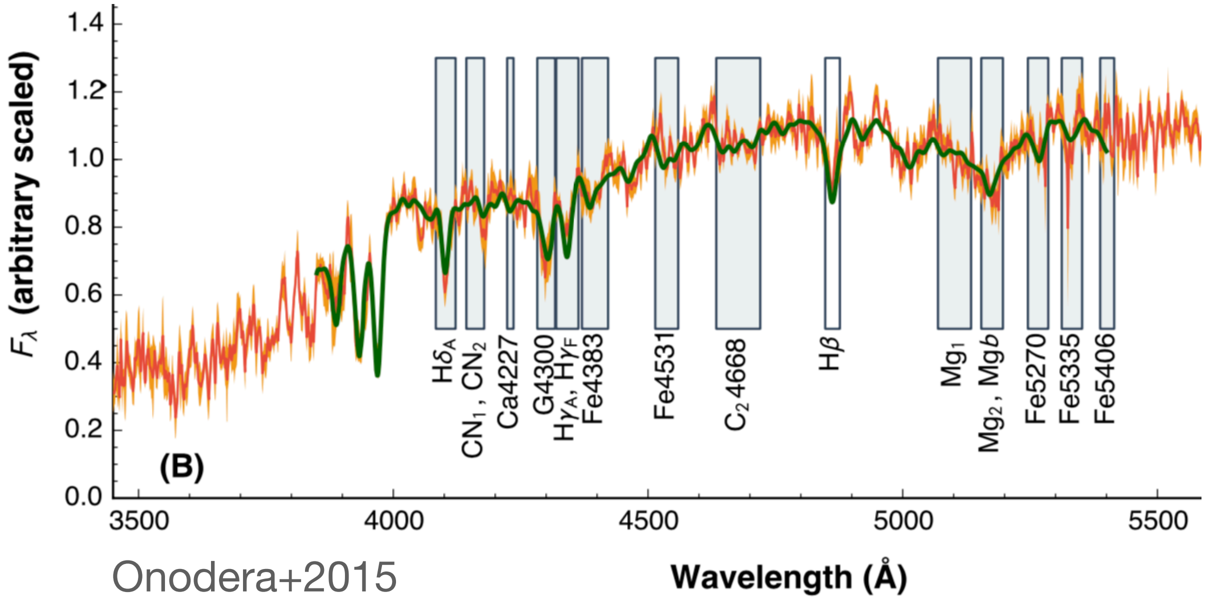


This is difficult for a few reasons:

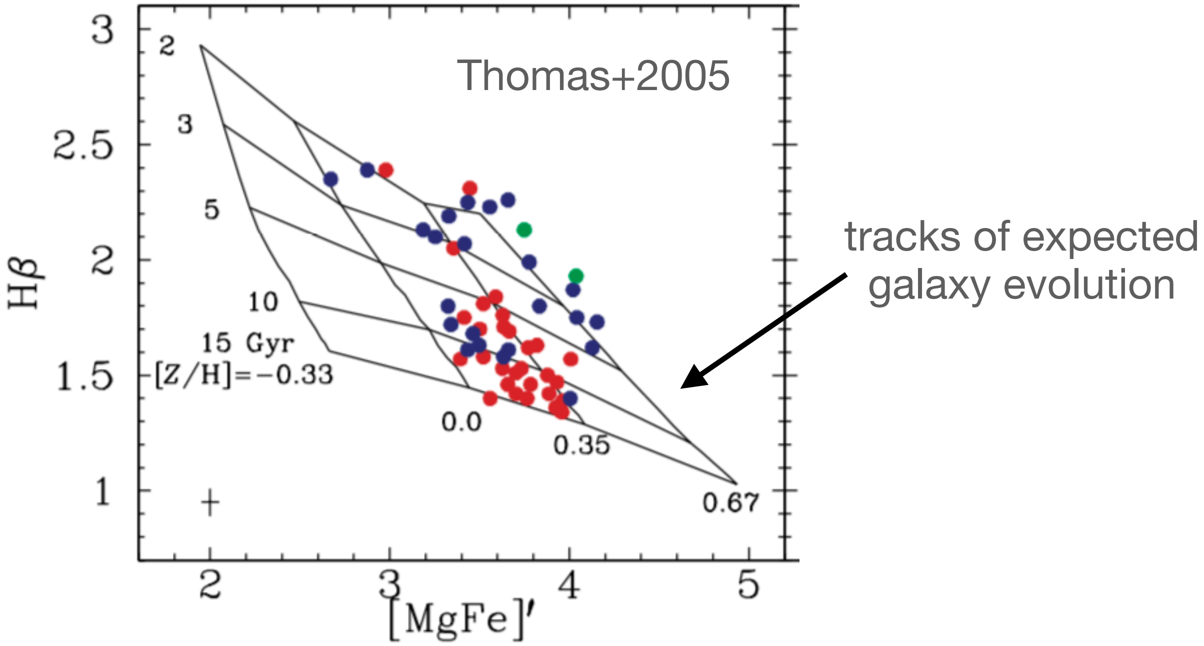
- stars older than 5 Gyr have similar SEDs
- young stars outshine older stars
- degeneracies between galaxy properties (dust, age, metallicity)
- biases from expected shape of the SFH (see eg, Carnall+2019, Leja+2019)

Idea: Trace the formation and evolution of a galaxy from their stellar populations

Historically these issues have been avoided by measuring high S/N spectral features (eg LICK indices).



Onodera+2015



Thomas+2005

tracks of expected galaxy evolution

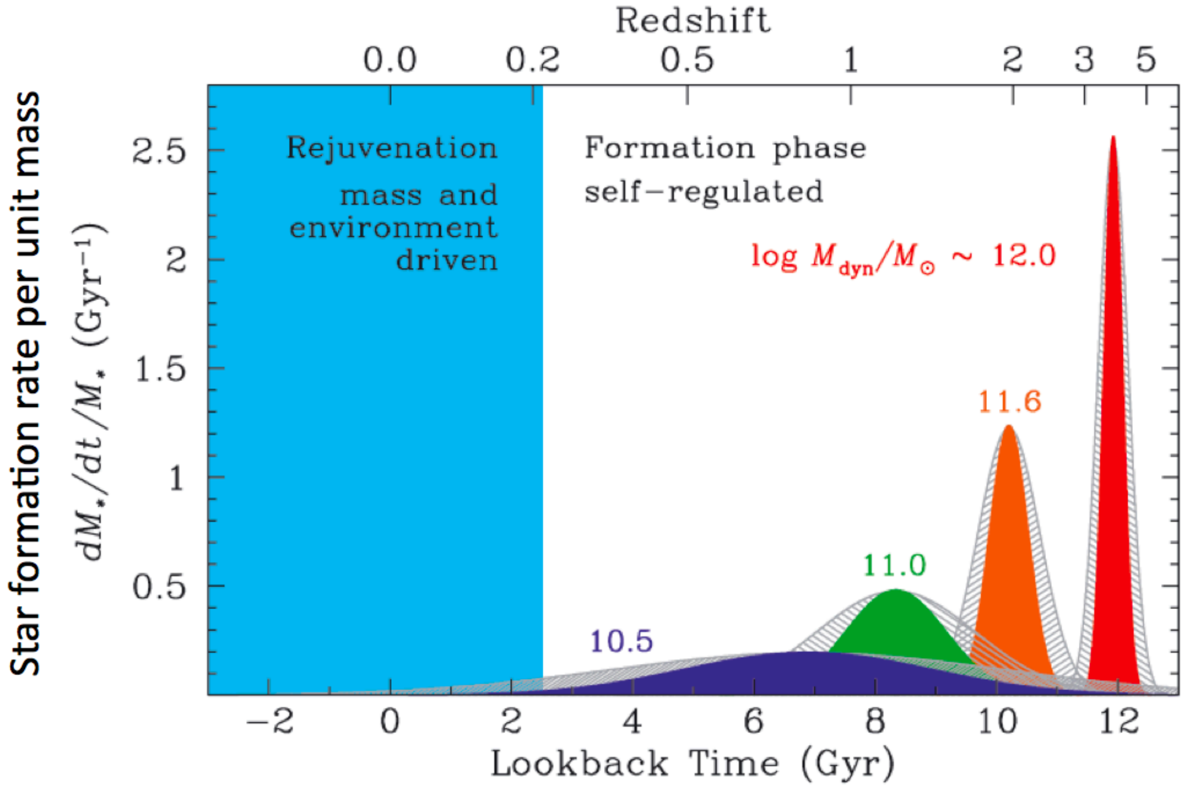
This is challenging at high-z where S/N is lower, but age estimates are more precise (<5 Gyr)

➔ SFH-fitting is better suited

and SFH-fitting techniques have significantly improved

Consensus of z<1 observations:

Thomas+2010



Mass-dependent evolution:

SFRs of massive galaxies peaked at earlier times than lower mass galaxies, and therefore form their stellar mass earlier

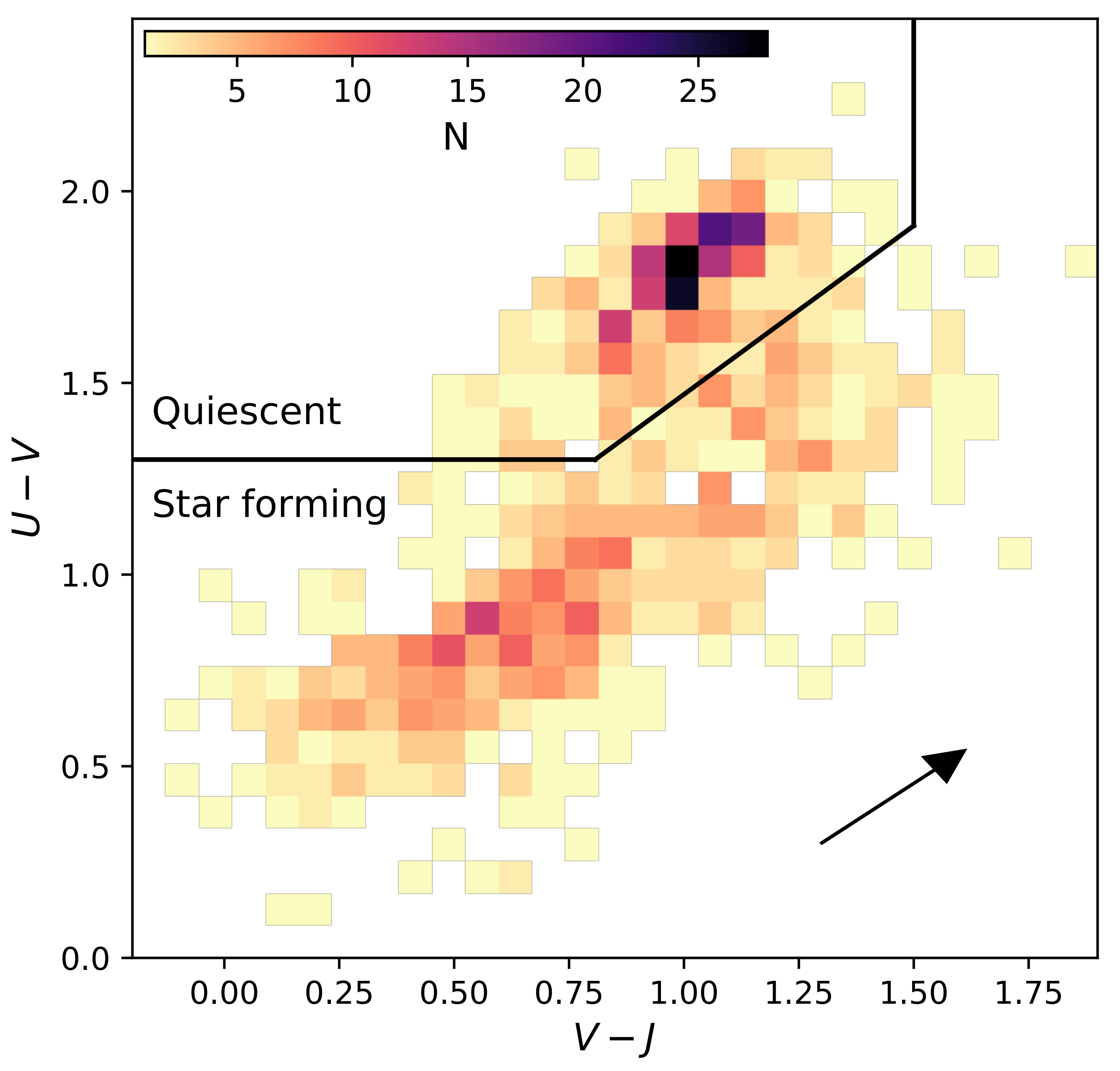
Massive early-type galaxies in clusters are older than comparable galaxies in the field

z ~ 0 : age difference ~2 Gyr … partially due to late star formation (rejuvenation/frosting)
z ~ 1 : age difference < 0.5 Gyr ± 0.5 Gyr

Comparisons are typically between few, very massive galaxies, using either few absorption line indices or based on photometric SEDs

Better age comparison with GOGREEN

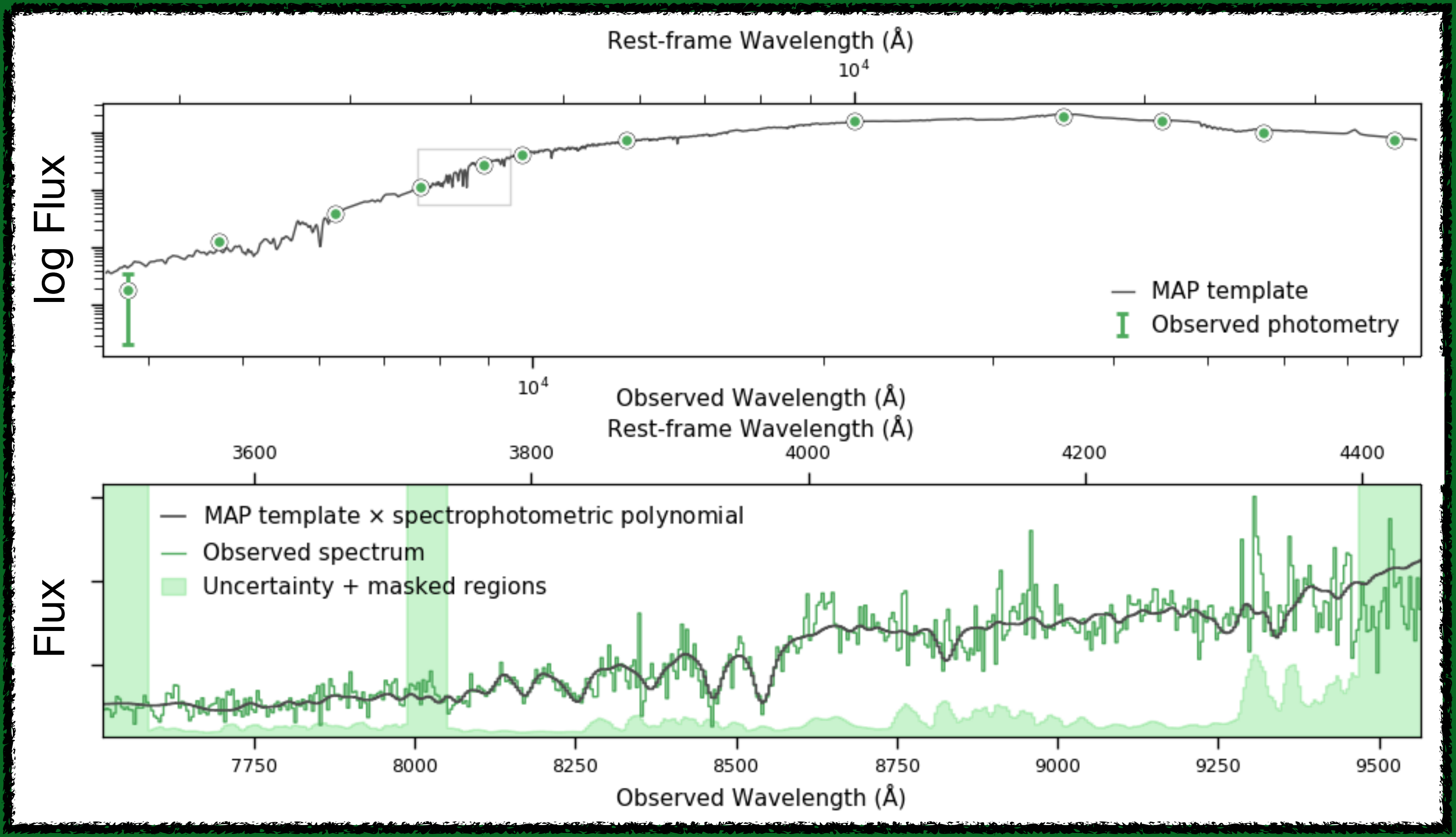
From the GOGREEN spectroscopic sample we identify galaxies which are quiescent based on their rest-frame *UVJ* colours



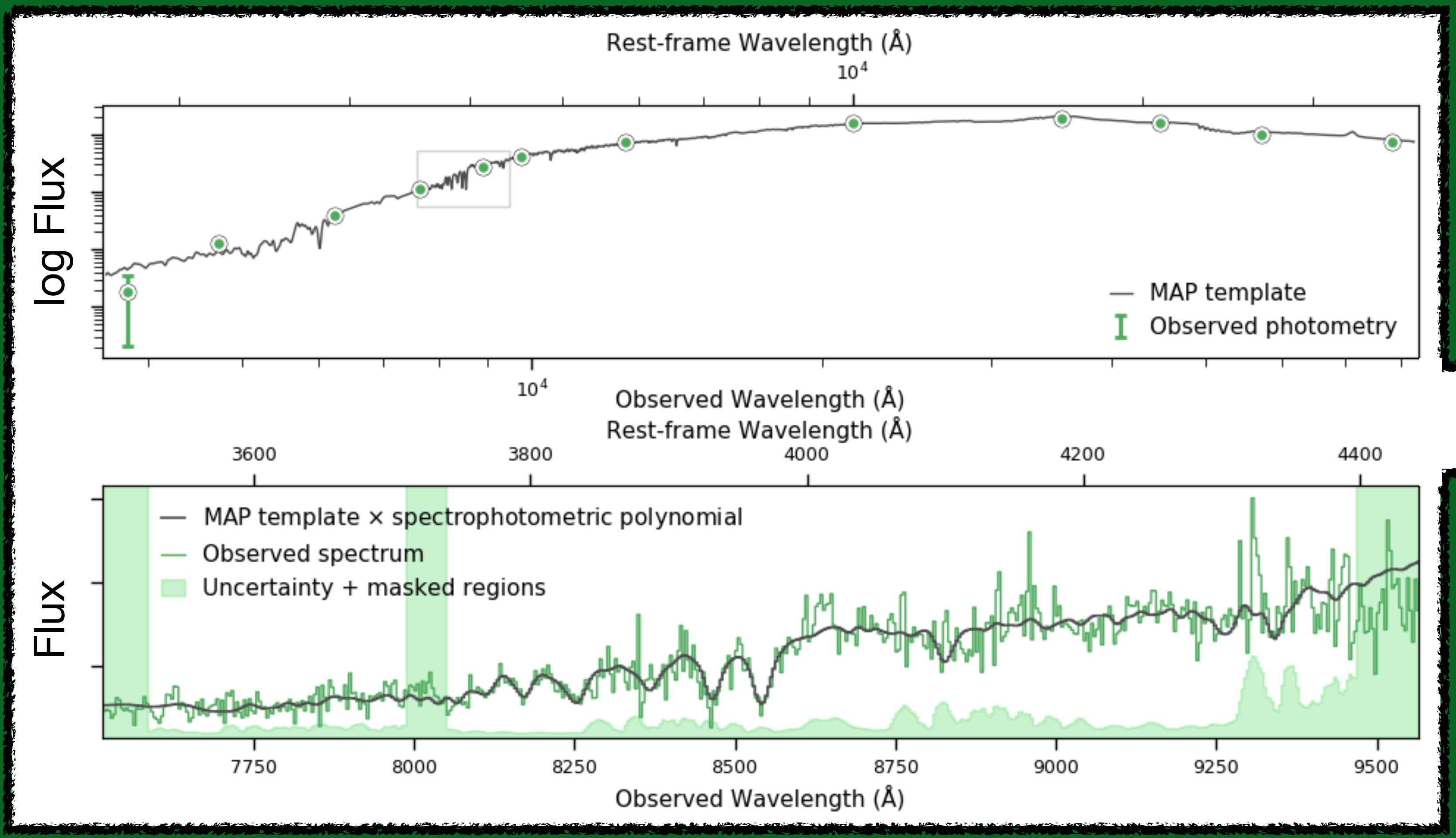
GOGREEN galaxies with spectroscopy,
robust $1 < z < 1.5$ redshifts,
and *UVJ*-quiescent:

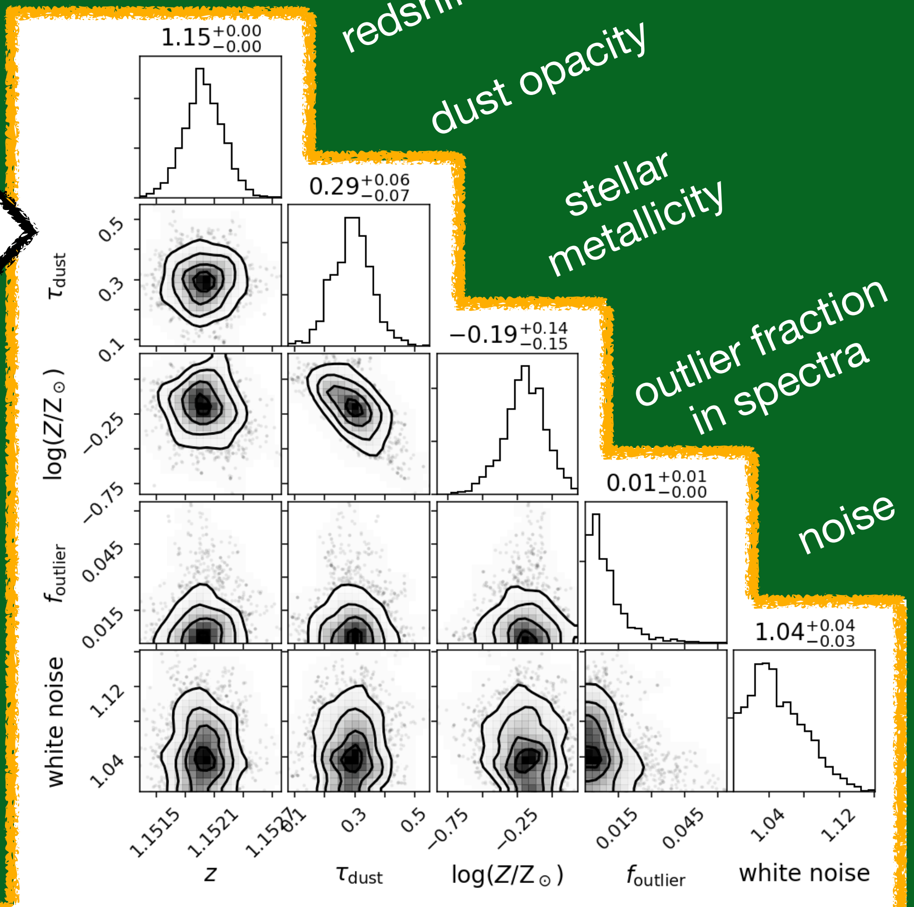
224 cluster galaxies

110 field galaxies



Fit wide-band photometry and rest-frame optical spectroscopy simultaneously to model SEDs of different SFHs





redshift

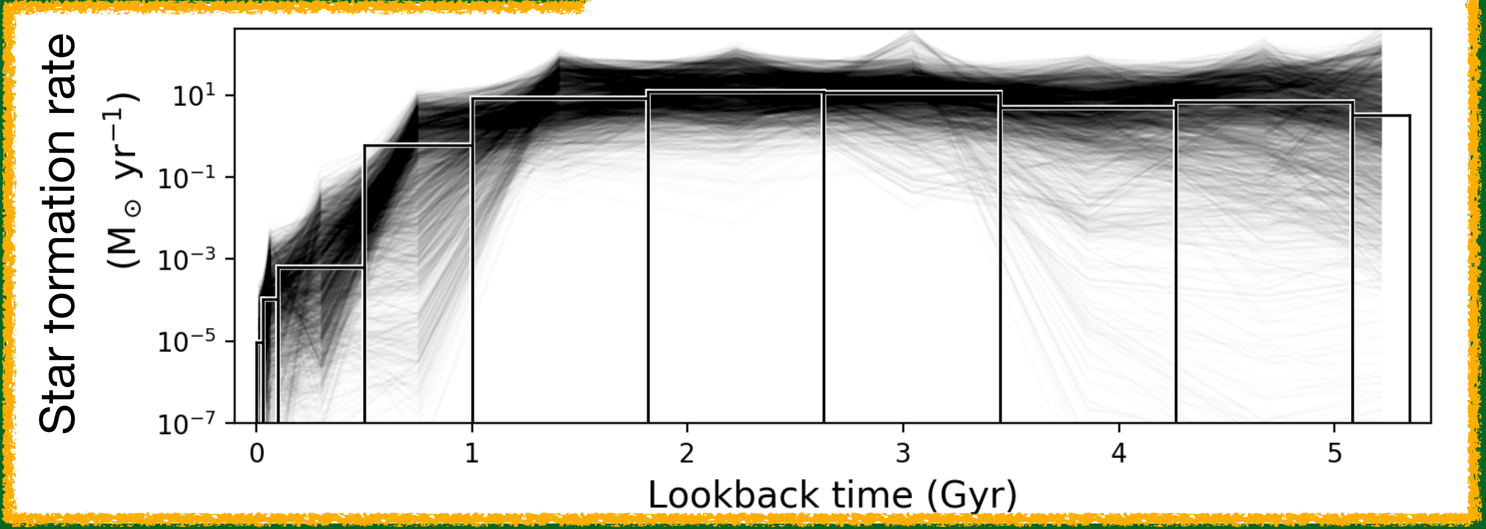
dust opacity

stellar metallicity

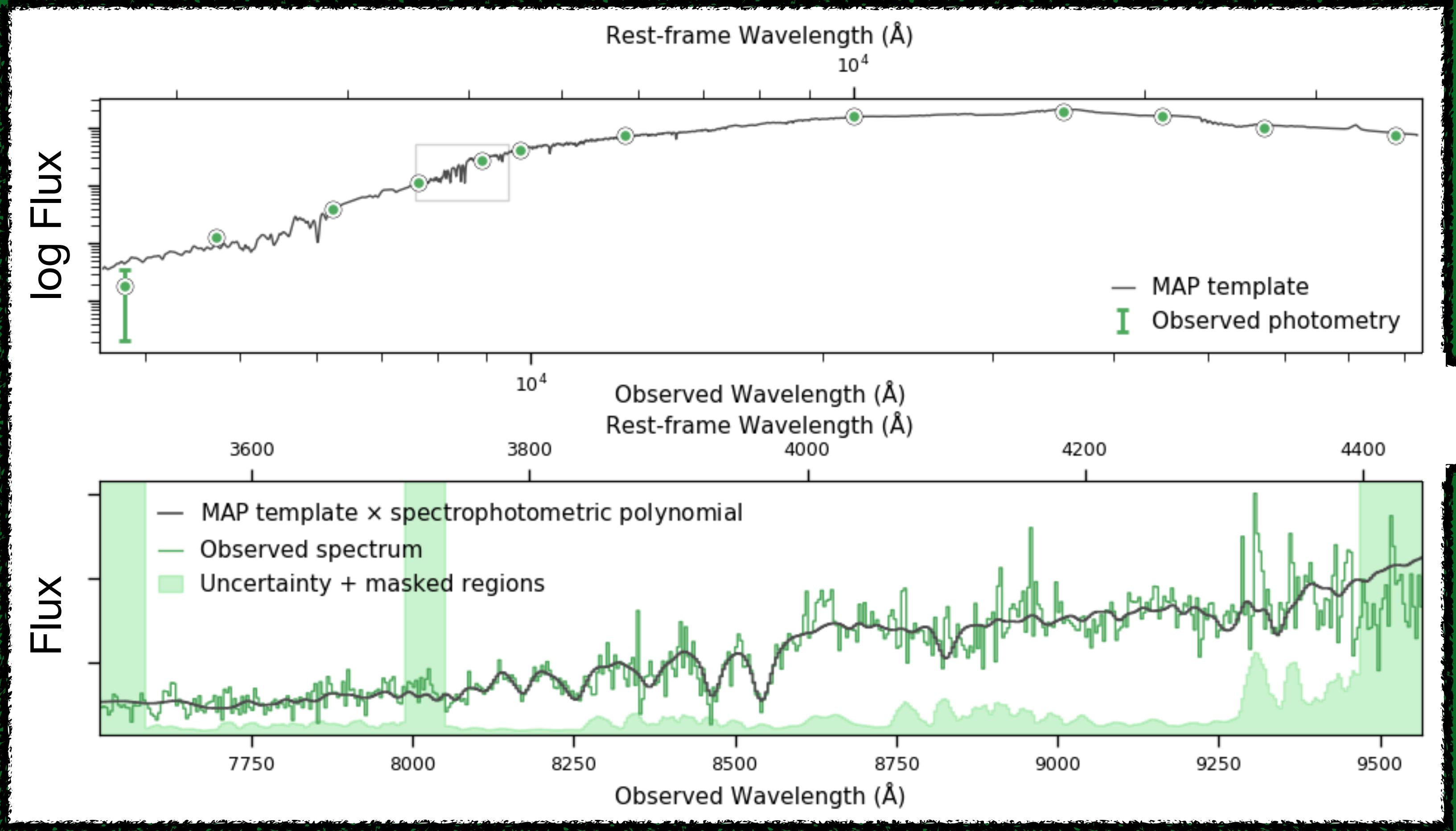
outlier fraction in spectra

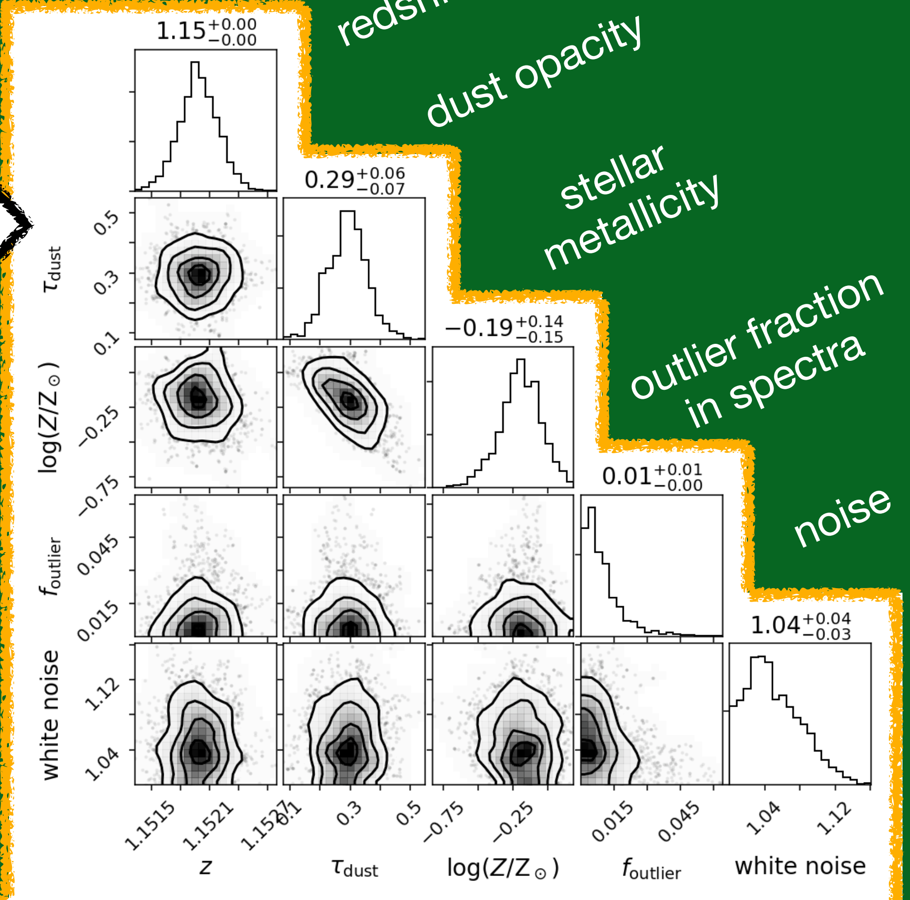
noise

We use MCMC to build posteriors for the SFH parameters, and several parameters which control for shape distortions and systematic biases in the data



Fitting done with the *Prospector* code, Leja+2017, Johnson+2019





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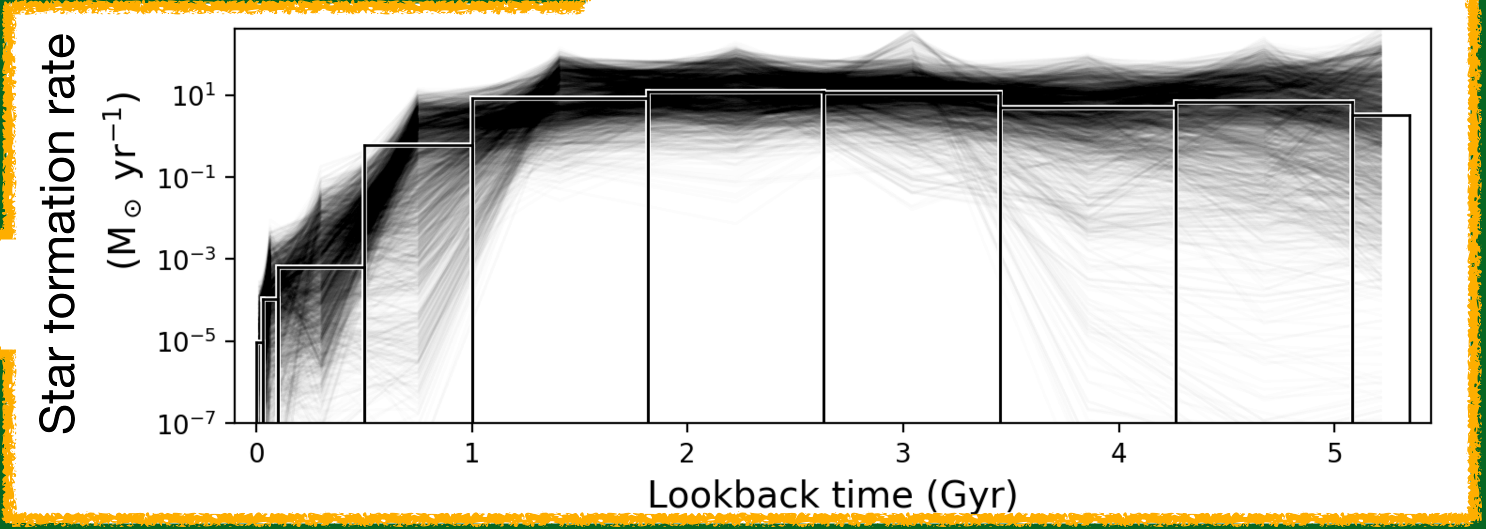
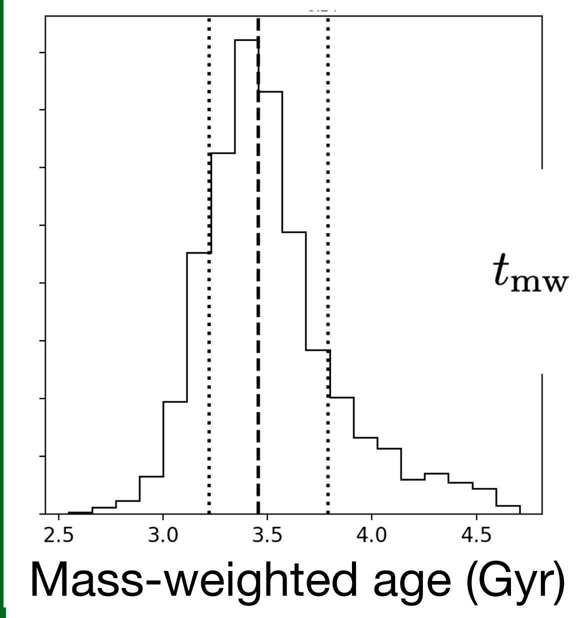
From the **non-parametric** SFH model, we calculate the mass-weighted age posterior



$$t_{\rm mw} = \frac{\int_{t_{\rm obs}}^{0} t\ \mathrm{SFR}(t)\,\mathrm{d}t}{\int_{t_{\rm obs}}^{0} \mathrm{SFR}(t)\,\mathrm{d}t}$$



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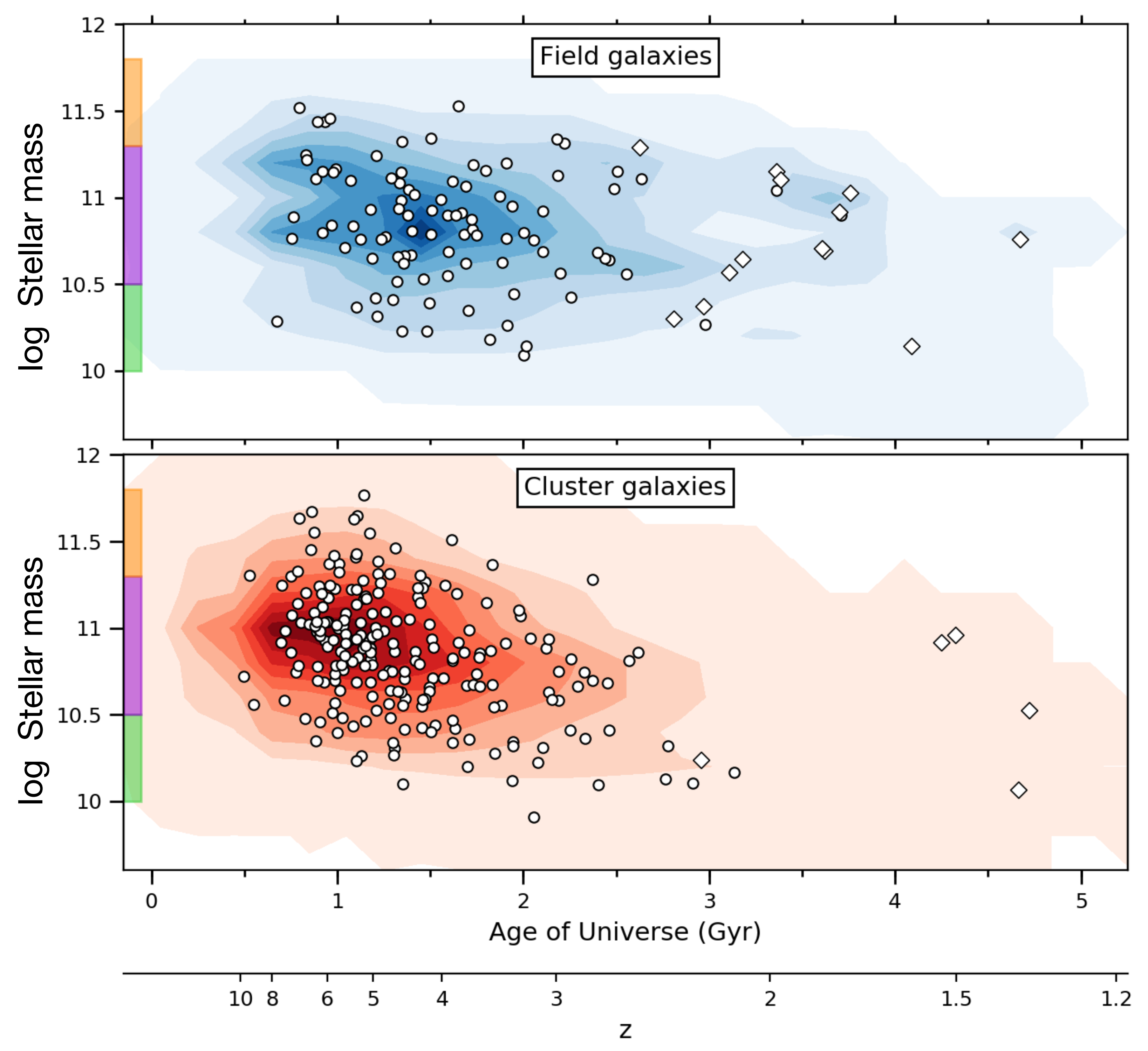


Ages primarily between $2 < z < 8$

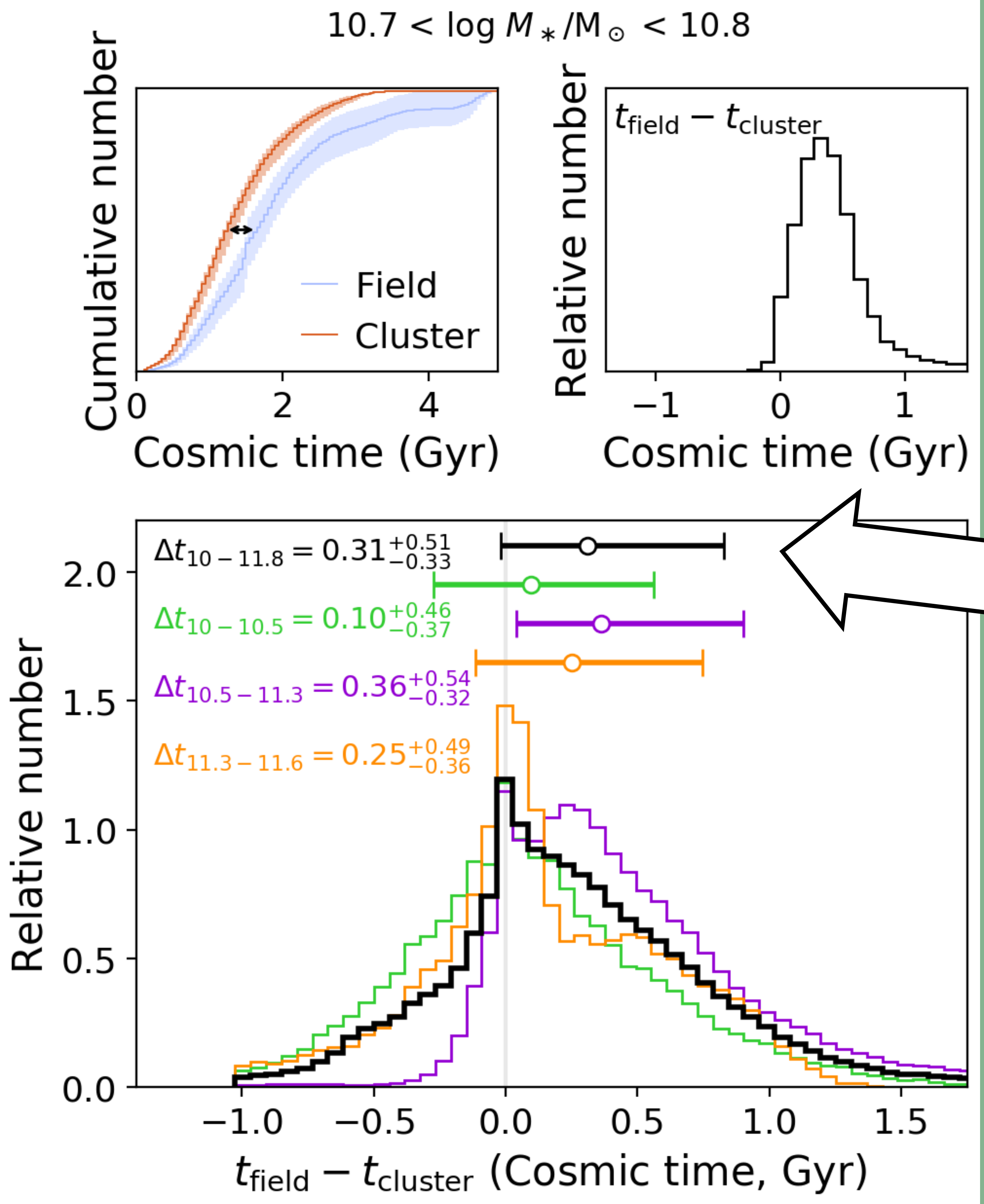
Mass-weighted age

in units of cosmic time, so $t_{univ}(z_{obs})$-t_{mw}

vs stellar mass

Contours show the combined posteriors from all of the **quiescent** galaxies, and white circles/diamonds indicate the 50th percentiles of individual posteriors

Diamonds indicate galaxies which have had more than 10 per cent of their stellar mass formed within the last 1 Gyr



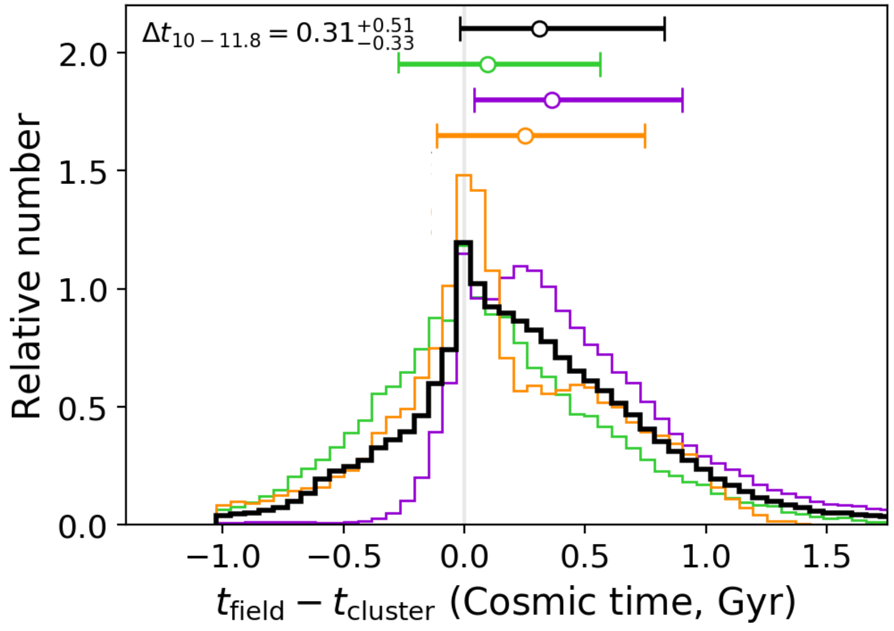
To calculate the *difference* in age distributions, we measure the offset between the cumulative distributions

Across the full mass range of our sample, the difference in mass-weighted ages is $0.31_{-0.33}^{+0.51}$ Gyr.

This is largely dominated by galaxies with masses $10^{10.5}$—$10^{11.3}$ M$_\odot$.

What does this imply for the star formation histories of field and cluster galaxies?

Cluster galaxies 0-0.5 Gyr *older* than field galaxies



Fiducial model:
Environmental quenching occurs after a galaxy falls into a cluster

Without pre-processing, *field* galaxies are older than cluster galaxies

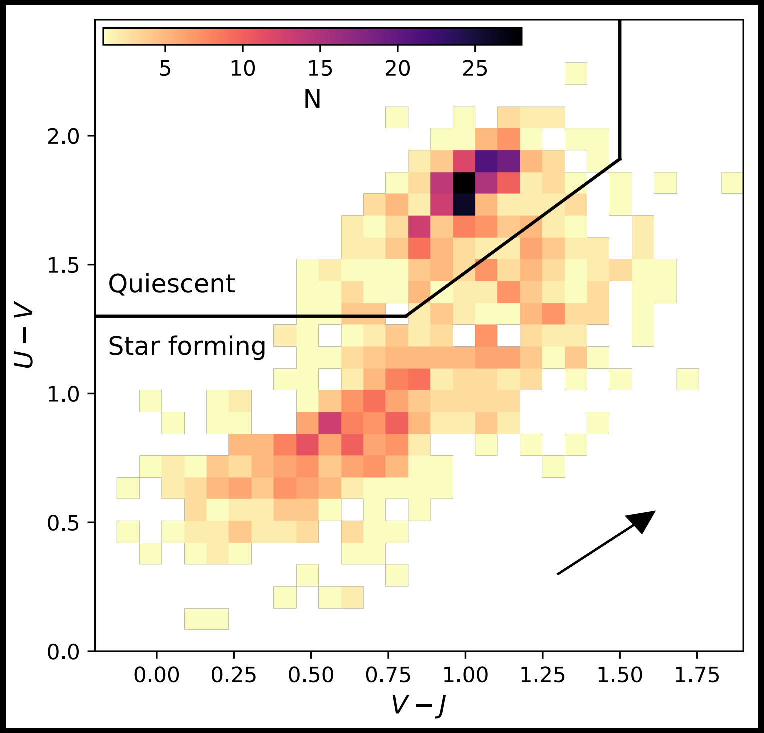
Head-start model:
No significant environmental quenching, galaxies in clusters just formed earlier

Difference in quenched fractions predicts $\Delta t_{\rm form}$ ~ 1.75 Gyr

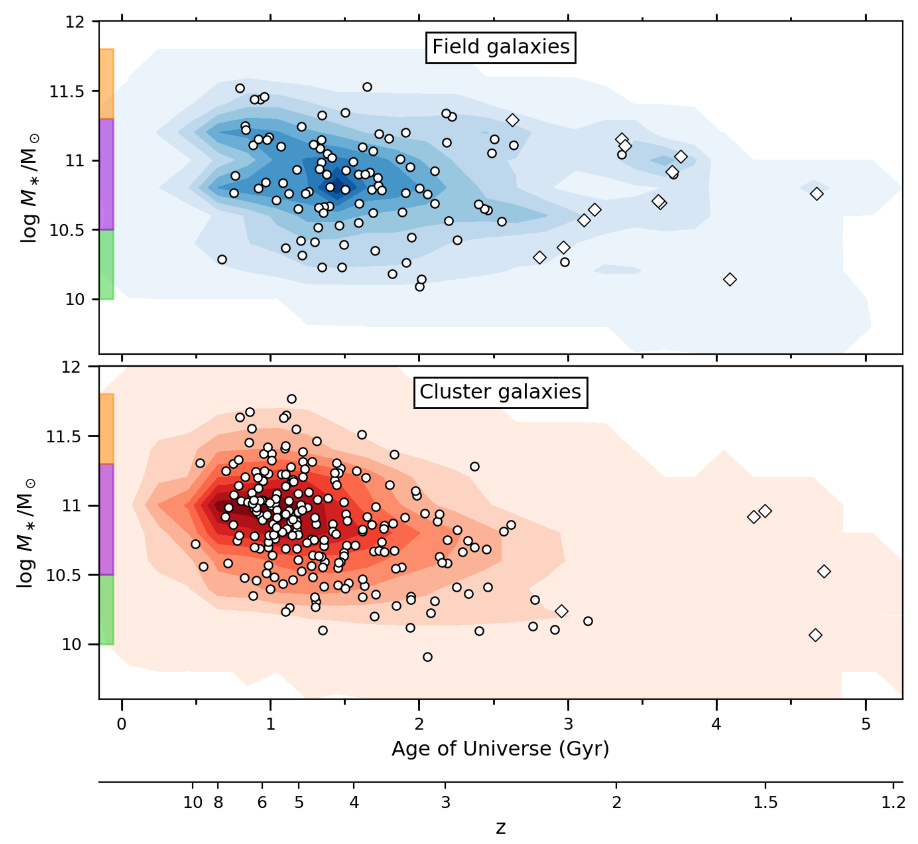
(or 1 Gyr in Remco's model)

Ages predict $\Delta t_{\rm form} < 0.75$ Gyr

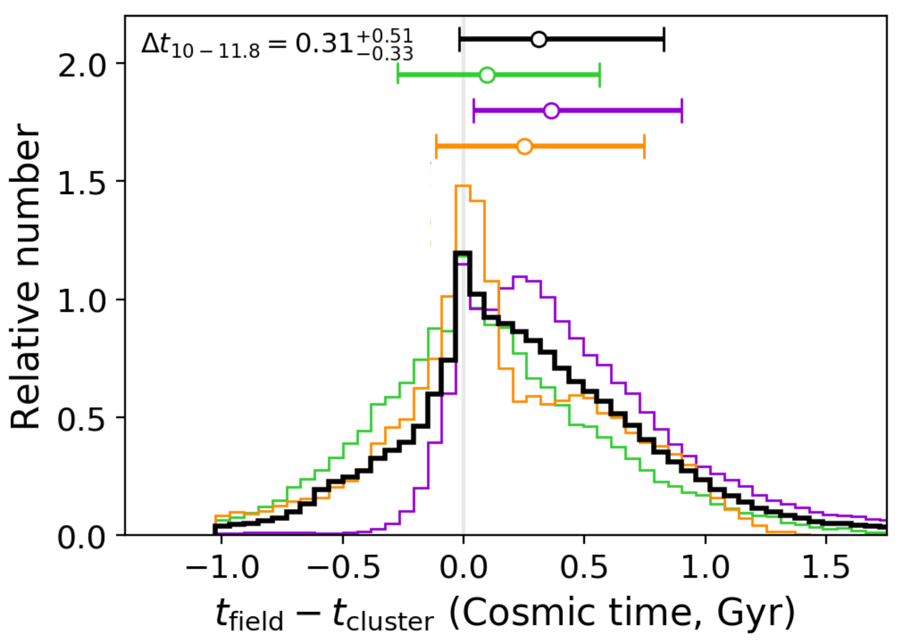
Thank you



Kristi Webb + GOGREENers



UVJ-quiescent cluster galaxies are ~0.3 Gyr *older* than field galaxies



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The following slides are supplementary

Supplementary information

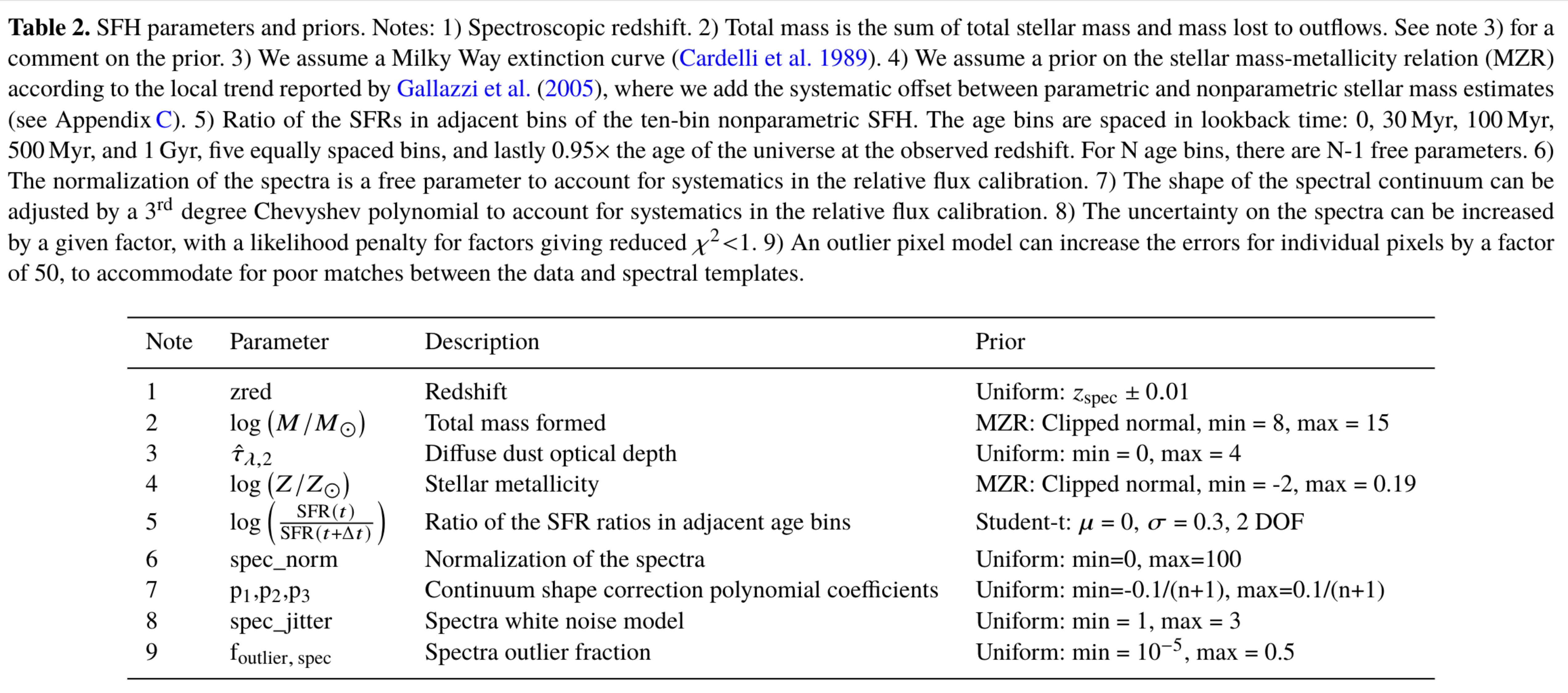

Table 2. SFH parameters and priors. Notes: 1) Spectroscopic redshift. 2) Total mass is the sum of total stellar mass and mass lost to outflows. See note 3) for a comment on the prior. 3) We assume a Milky Way extinction curve (Cardelli et al. 1989). 4) We assume a prior on the stellar mass-metallicity relation (MZR) according to the local trend reported by Gallazzi et al. (2005), where we add the systematic offset between parametric and nonparametric stellar mass estimates (see Appendix C). 5) Ratio of the SFRs in adjacent bins of the ten-bin nonparametric SFH. The age bins are spaced in lookback time: 0, 30 Myr, 100 Myr, 500 Myr, and 1 Gyr, five equally spaced bins, and lastly 0.95× the age of the universe at the observed redshift. For N age bins, there are N-1 free parameters. 6) The normalization of the spectra is a free parameter to account for systematics in the relative flux calibration. 7) The shape of the spectral continuum can be adjusted by a 3rd degree Chevyshev polynomial to account for systematics in the relative flux calibration. 8) The uncertainty on the spectra can be increased by a given factor, with a likelihood penalty for factors giving reduced $\chi^2 < 1$. 9) An outlier pixel model can increase the errors for individual pixels by a factor of 50, to accommodate for poor matches between the data and spectral templates.

Note	Parameter	Description	Prior
1	zred	Redshift	Uniform: $z_{\rm spec} \pm 0.01$
2	$\log\left(M/M_\odot\right)$	Total mass formed	MZR: Clipped normal, min = 8, max = 15
3	$\hat{\tau}_{\lambda,2}$	Diffuse dust optical depth	Uniform: min = 0, max = 4
4	$\log\left(Z/Z_\odot\right)$	Stellar metallicity	MZR: Clipped normal, min = -2, max = 0.19
5	$\log\left(\frac{\rm SFR(t)}{\rm SFR(t+\Delta t)}\right)$	Ratio of the SFR ratios in adjacent age bins	Student-t: $\mu = 0$, $\sigma = 0.3$, 2 DOF
6	spec_norm	Normalization of the spectra	Uniform: min=0, max=100
7	$\rm p_1,p_2,p_3$	Continuum shape correction polynomial coefficients	Uniform: min=-0.1/(n+1), max=0.1/(n+1)
8	spec_jitter	Spectra white noise model	Uniform: min = 1, max = 3
9	$\rm f_{outlier,\,spec}$	Spectra outlier fraction	Uniform: min = 10^{-5}, max = 0.5