WHAT CAN CLUSTER GALAXIES CAN TELL US ABOUT THEIR HOST ENVIRONMENTS?

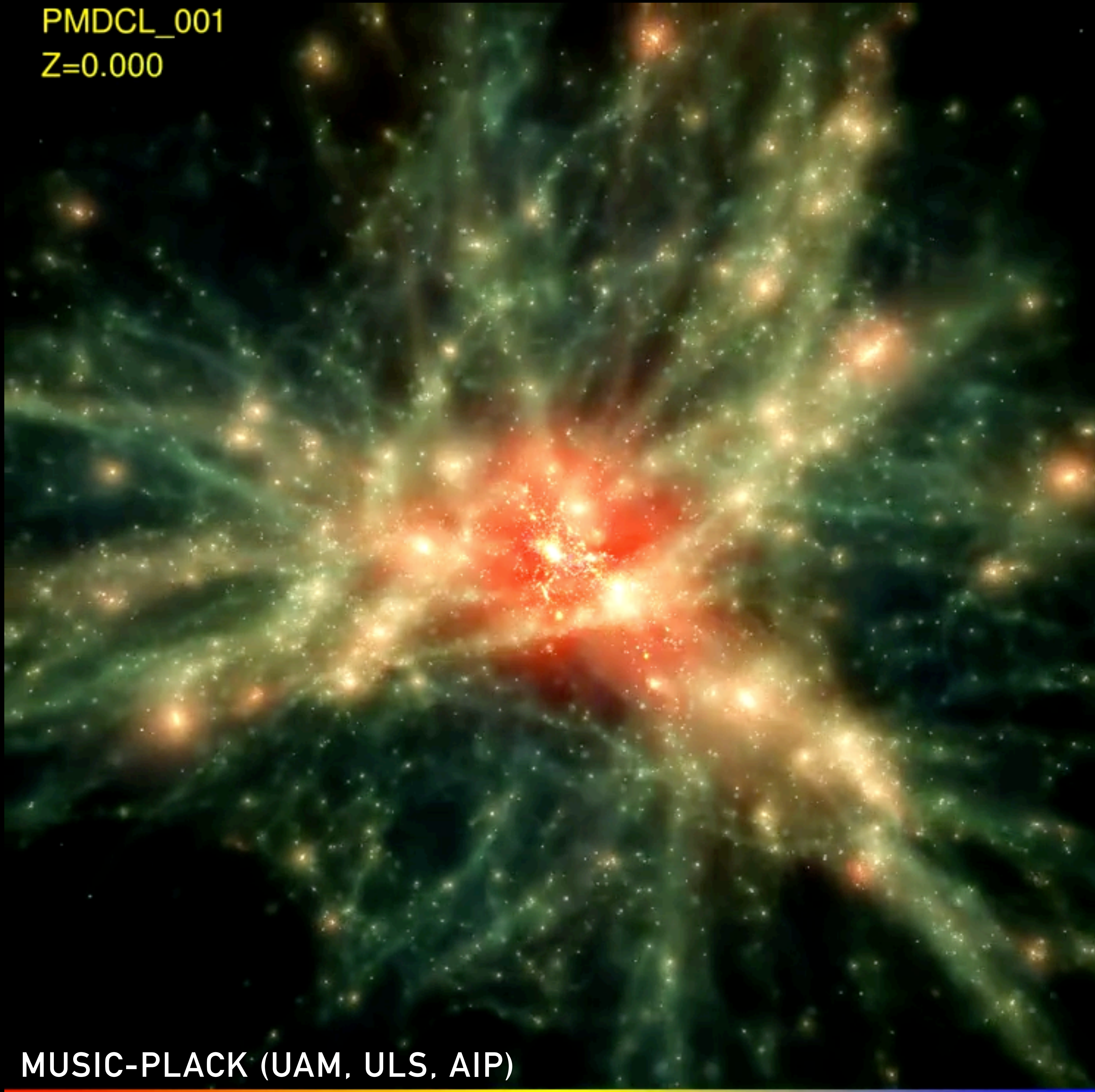
esa

LYNDSAY OLD - RESEARCH FELLOW @ ESAC

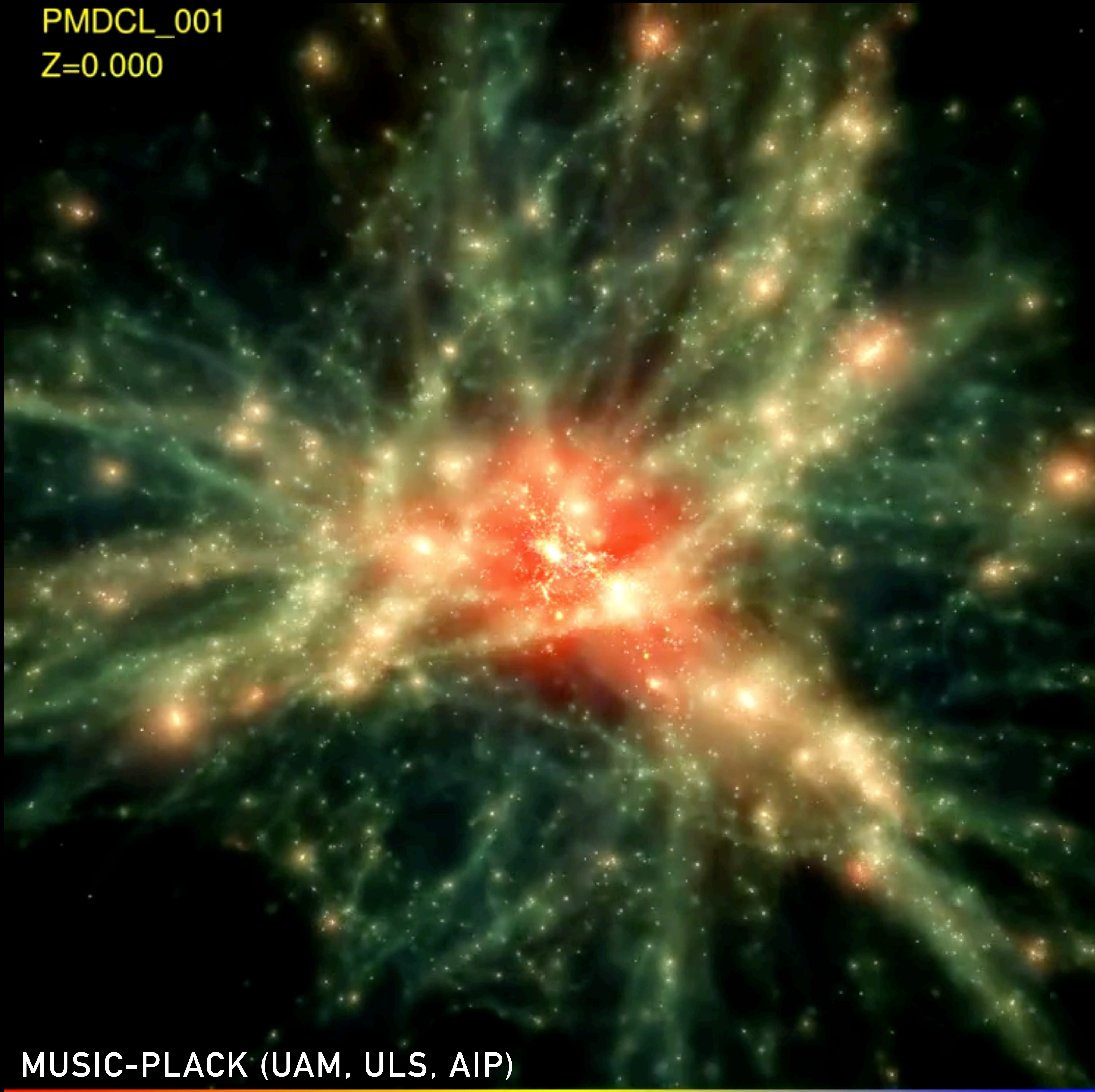
IMAGE: MUSIC-PLACK (UAM, ULS, AIP)

ESAC 17TH JANUARY 2019

Radek Wojtak, Gary Mamon, Frazer Pearce, Meghan Gray + Galaxy Cluster Mass Reconstruction Project team
Michael Balogh, Howard Yee, Irene Pintos-Castro, Adam Muzzin, Greg Rudnick, Remco van der Burg + the GOGREEN team



MUSIC-PLACK (UAM, ULS, AIP)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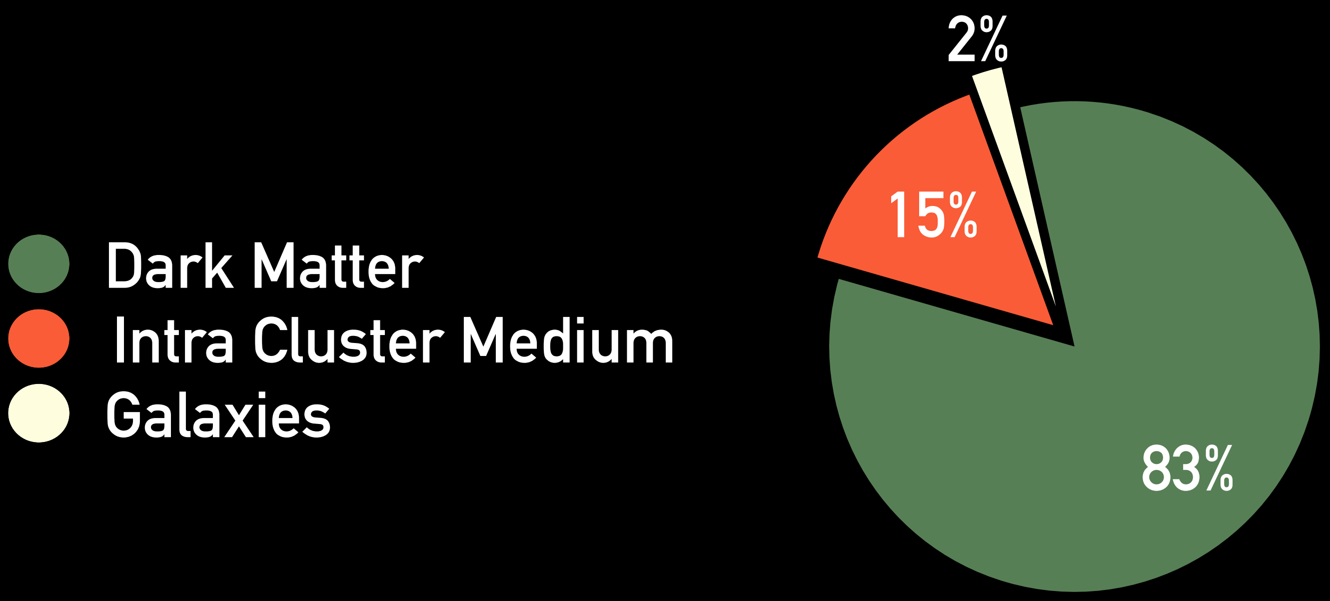
MUSIC-PLACK (UAM, ULS, AIP)

GALAXY CLUSTER BASICS



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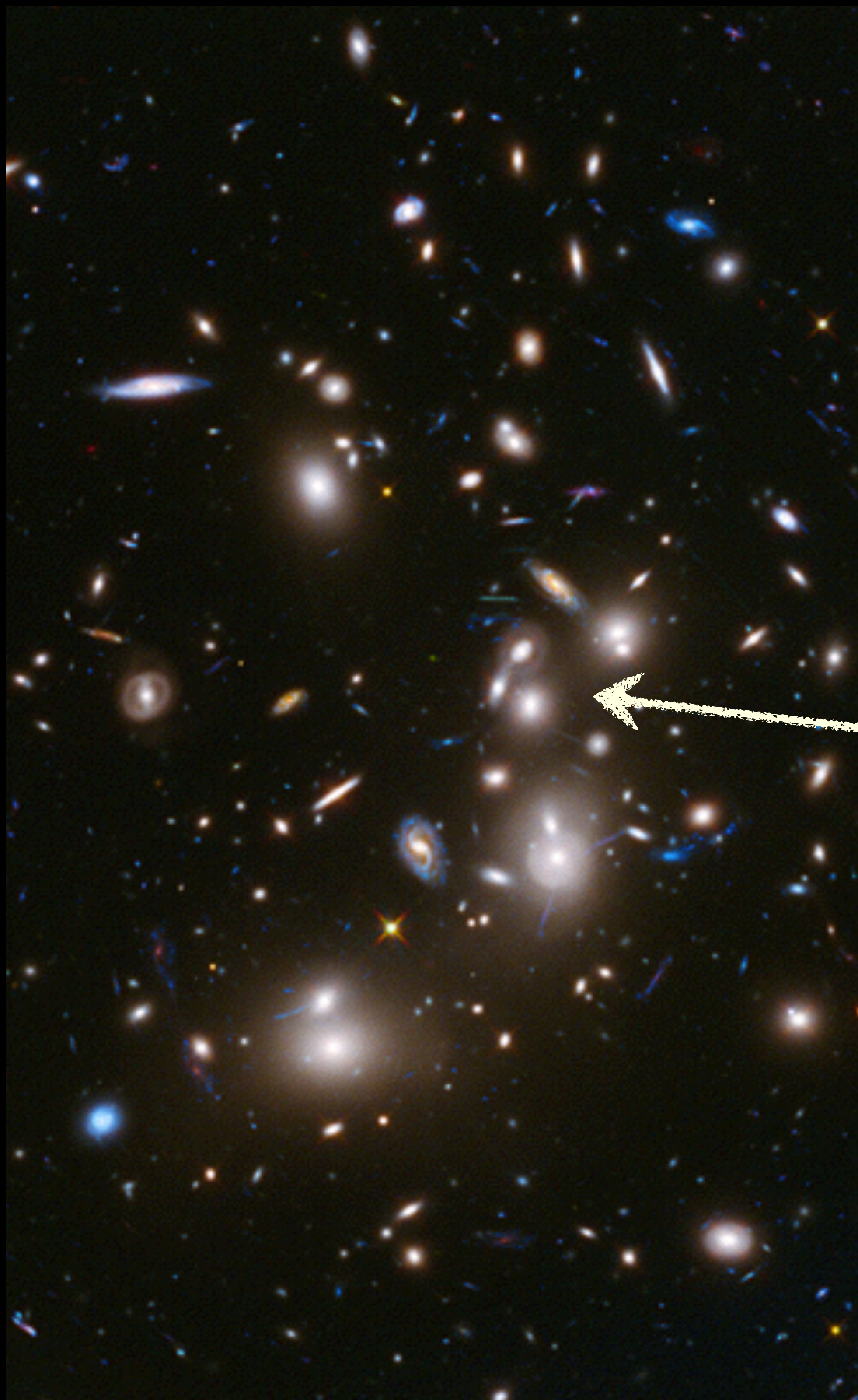
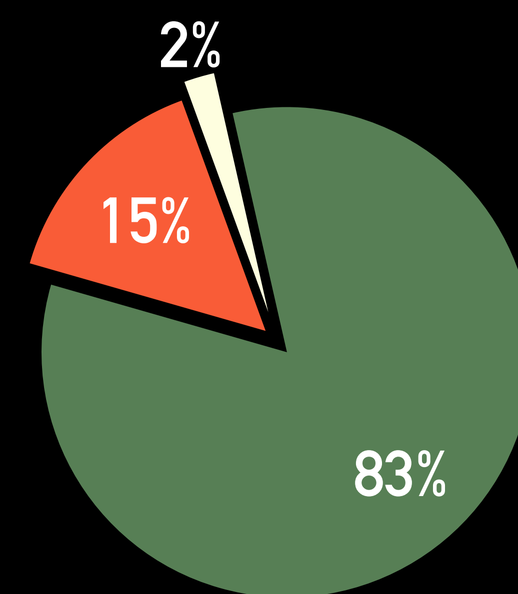


NASA/ESA Hubble Frontier Field Abell 2744

- Dark Matter
- Intra Cluster Medium
- Galaxies



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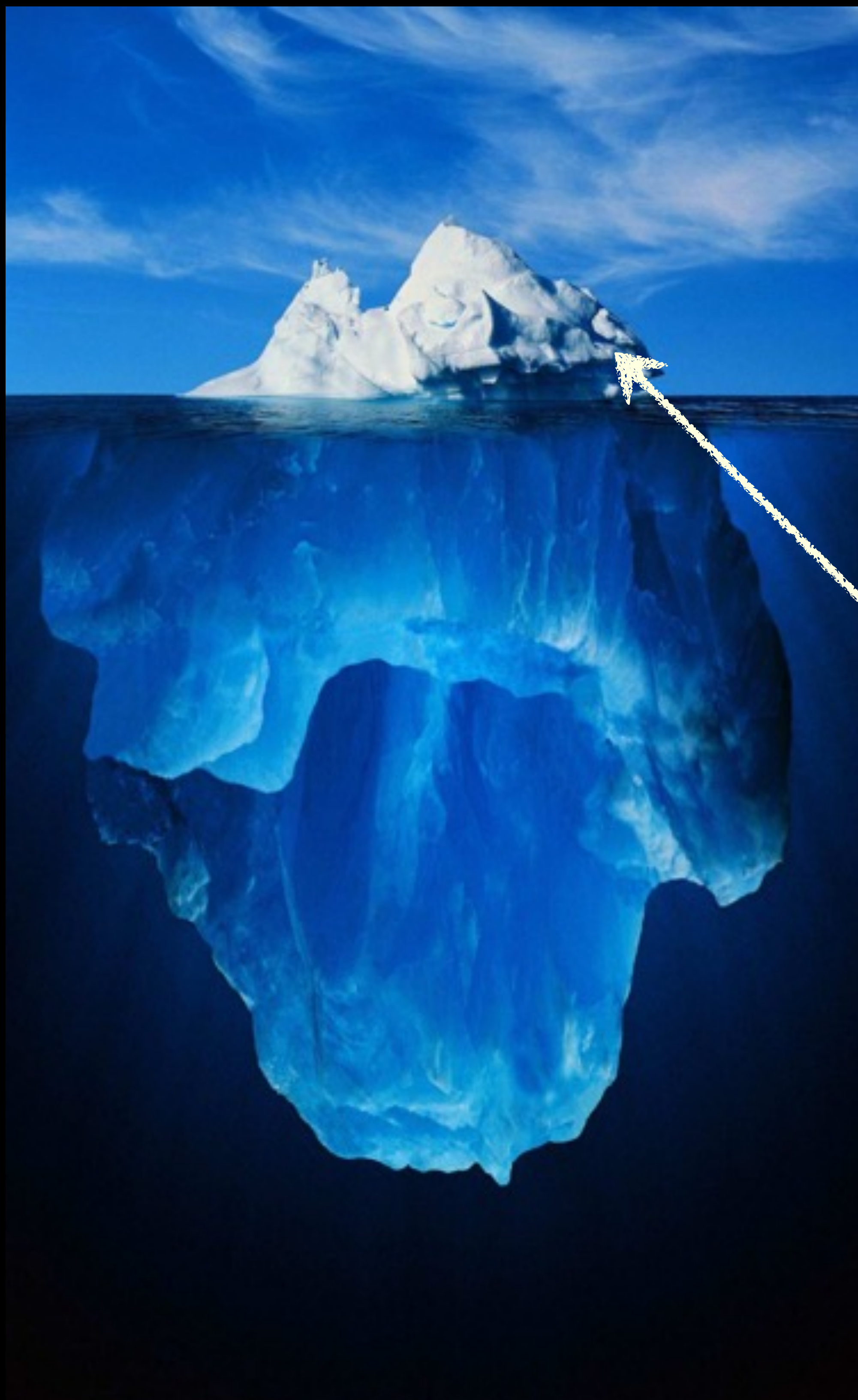
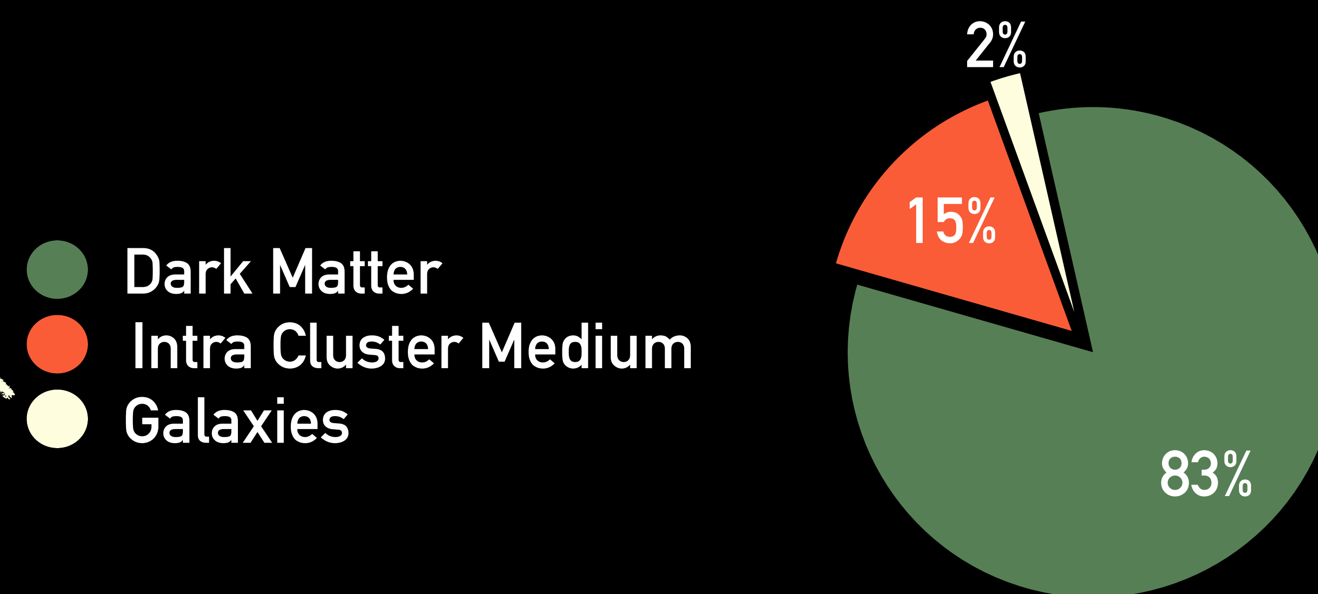
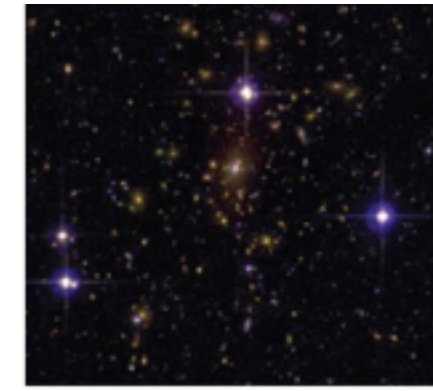




OBSERVING GALAXY CLUSTERS

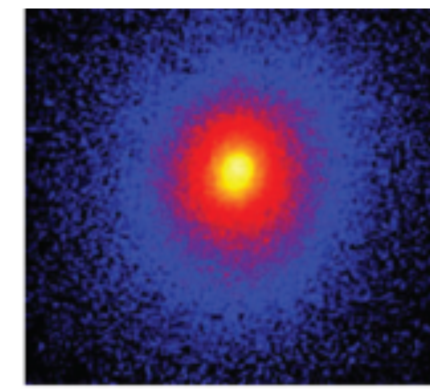
- Optical & infrared: over densities, red sequence

(e.g., Abell 1958, Gladders & Yee 2000)



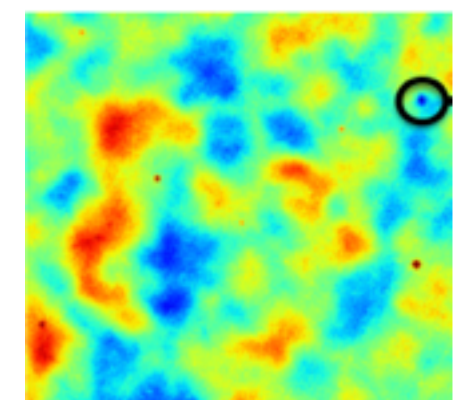
- X-ray bright: $L_X \sim 10^{43}$-10^{45} erg s^{-1}

(e.g., Forman et al. 1972, Vikhlinin et al. 2009).



- Sunyaev-Zeldovich effect

(e.g., Sunyaev & Zeldovich 1972, Hasselfield et al. 2013).

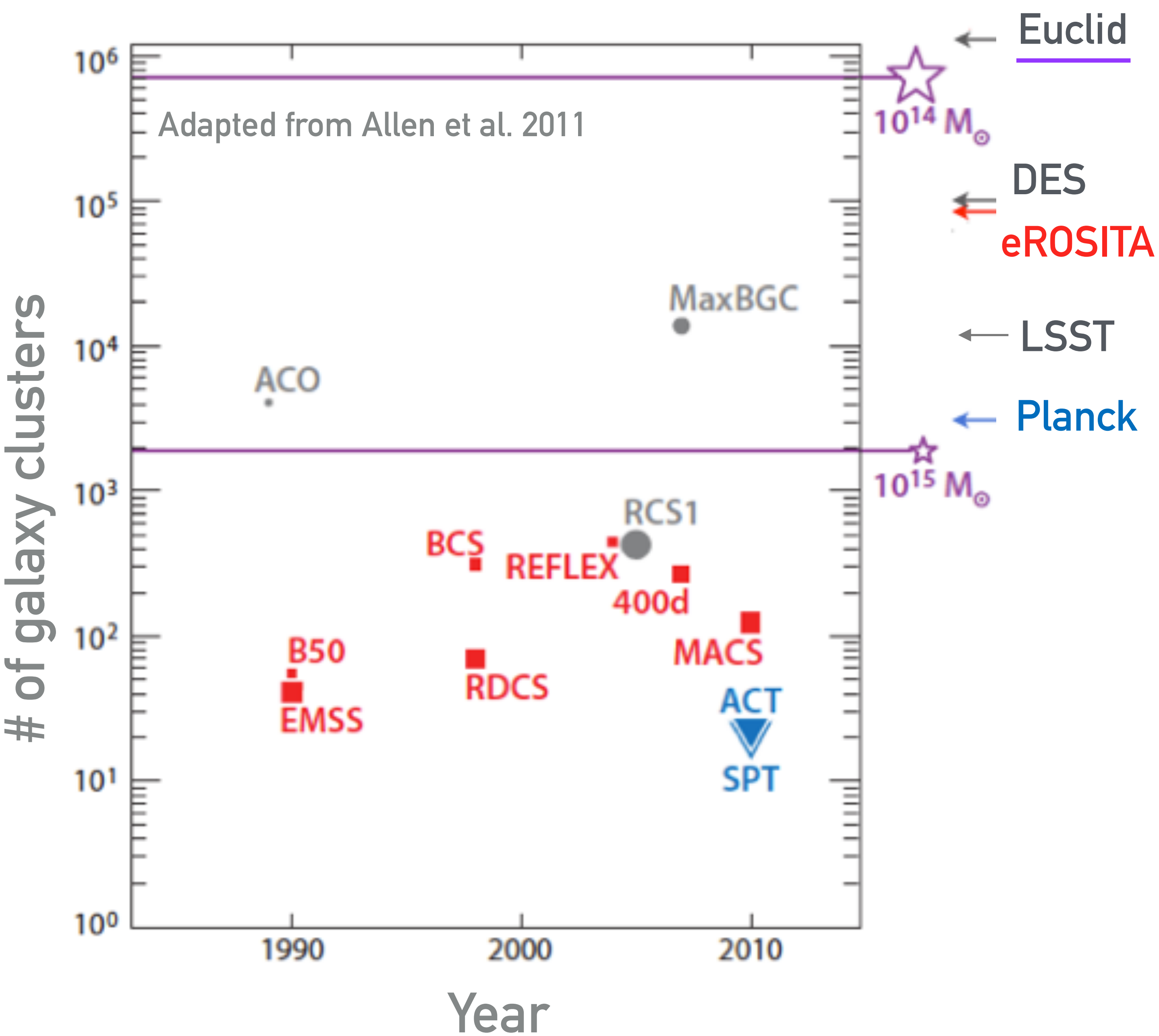


- Gravitational lensing

(e.g., Bartlemann et. al., 2010, Applegate et al. 2012).

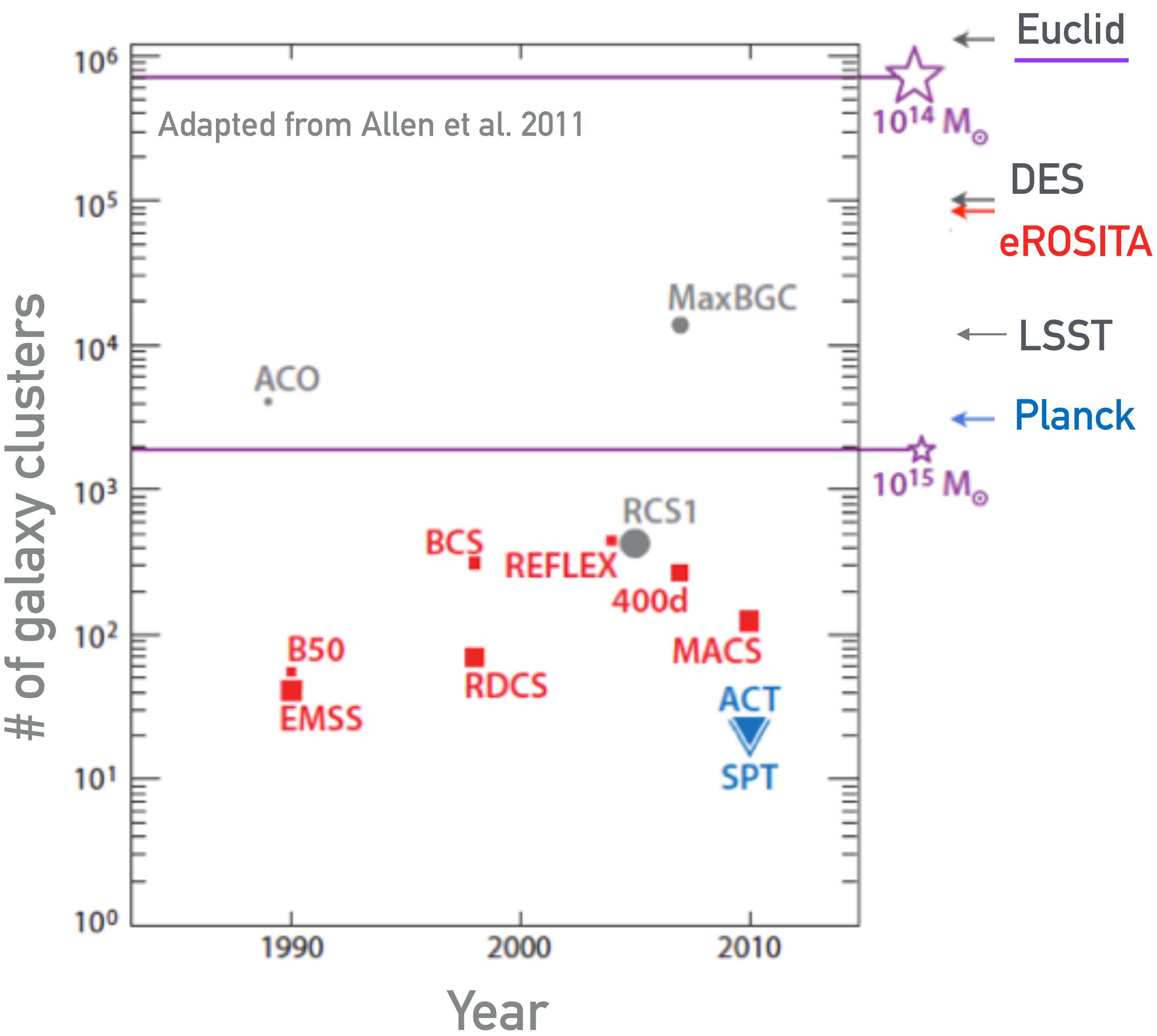
Allen, Evrard & Mantz (2011),
NASA/ESA: SDSS J1038+4849

GALAXY CLUSTERS AS COSMOLOGY TOOLS 2018+



Adapted from Allen et. al 2011

GALAXY CLUSTERS AS COSMOLOGY TOOLS 2018+



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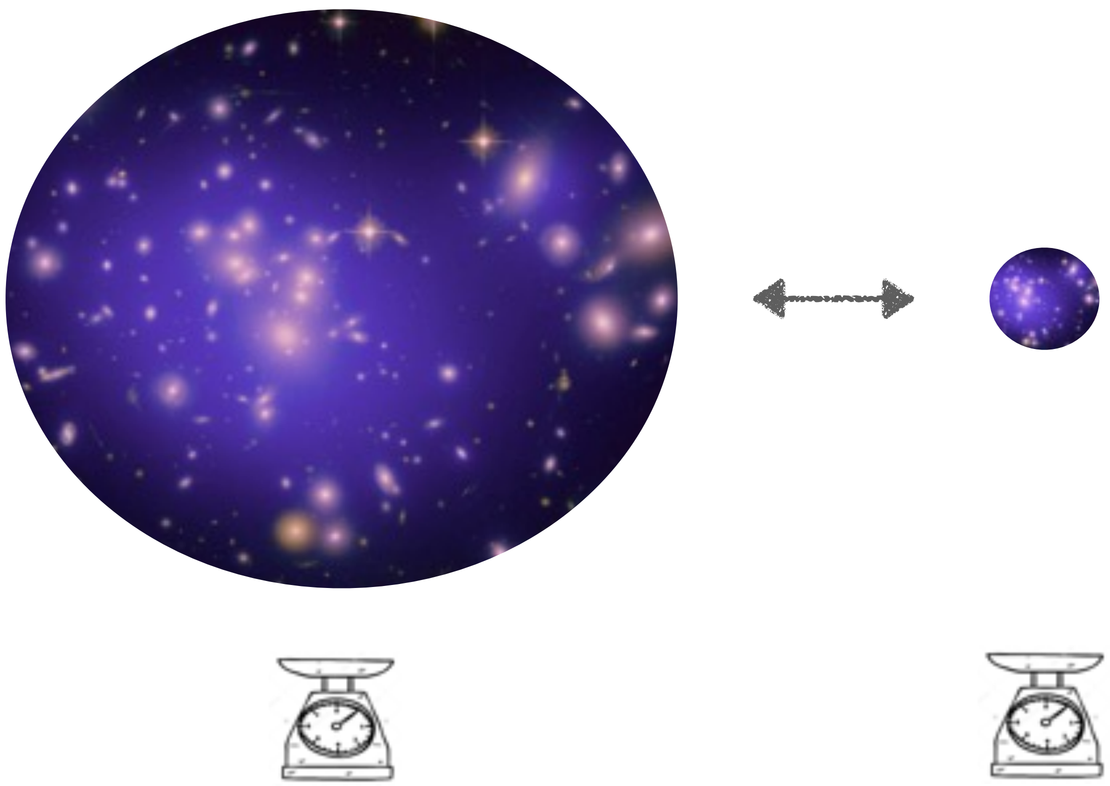
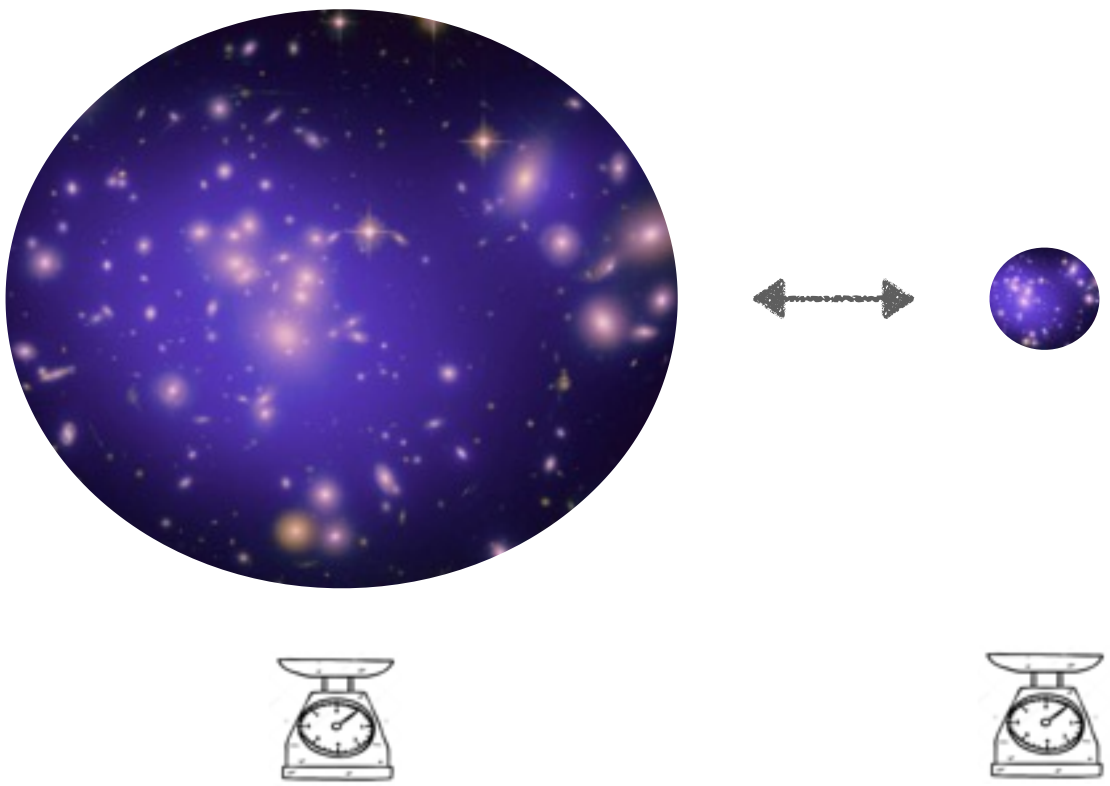
> 'Galaxy clusters could emerge as the **most powerful cosmological probe if** the masses of the clusters can be accurately measured'
>
> \- Cosmic Visions Report (2016)

GALAXY CLUSTERS AS COSMOLOGY TOOLS 2018+



‘GALAXY-BASED’ CLUSTER MASS ESTIMATION



Any technique that uses galaxy properties as a mass proxy

e.g., positions, velocities, colours & luminosities

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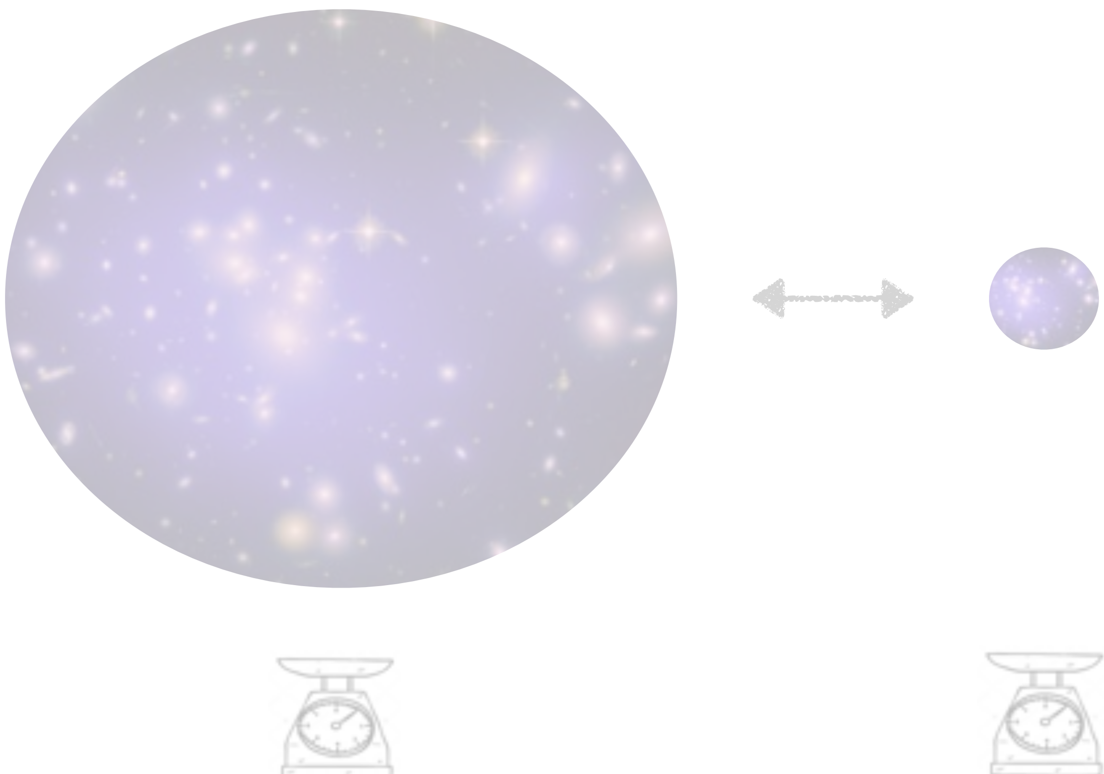
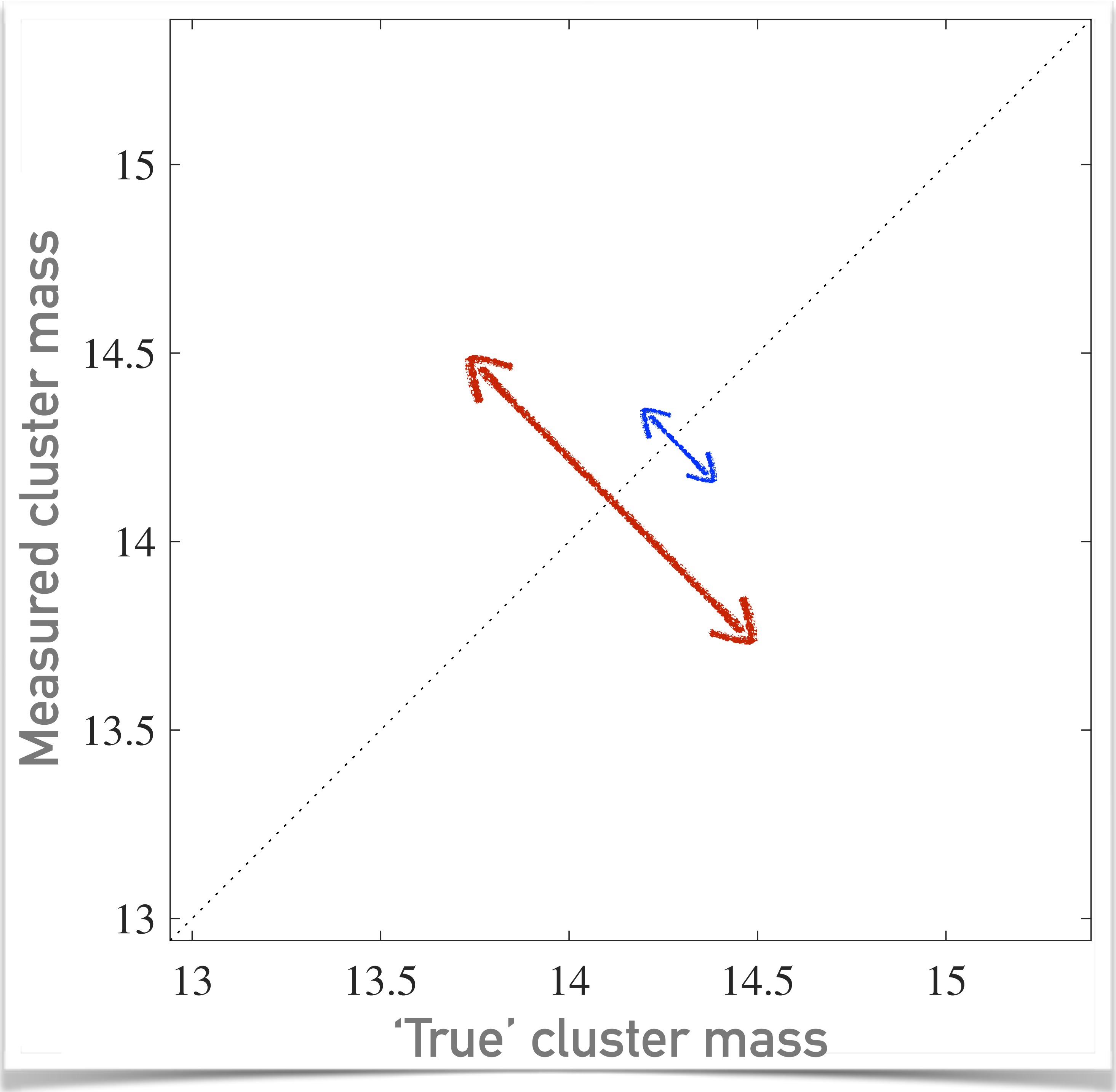


Any technique that uses galaxy properties as a mass proxy

e.g., positions, velocities, colours & luminosities

- Independent proxy to SZ, X-ray, lensing
- Relatively $
- Critical for detecting lower mass clusters (bulk of mass function!)
- Extended galaxy distribution: clusters can be probed out to large radii
- 2-for-1: dynamical analysis provides information on virialisation state

HOW WELL CAN WE MEASURE HOW MUCH CLUSTERS WEIGH?



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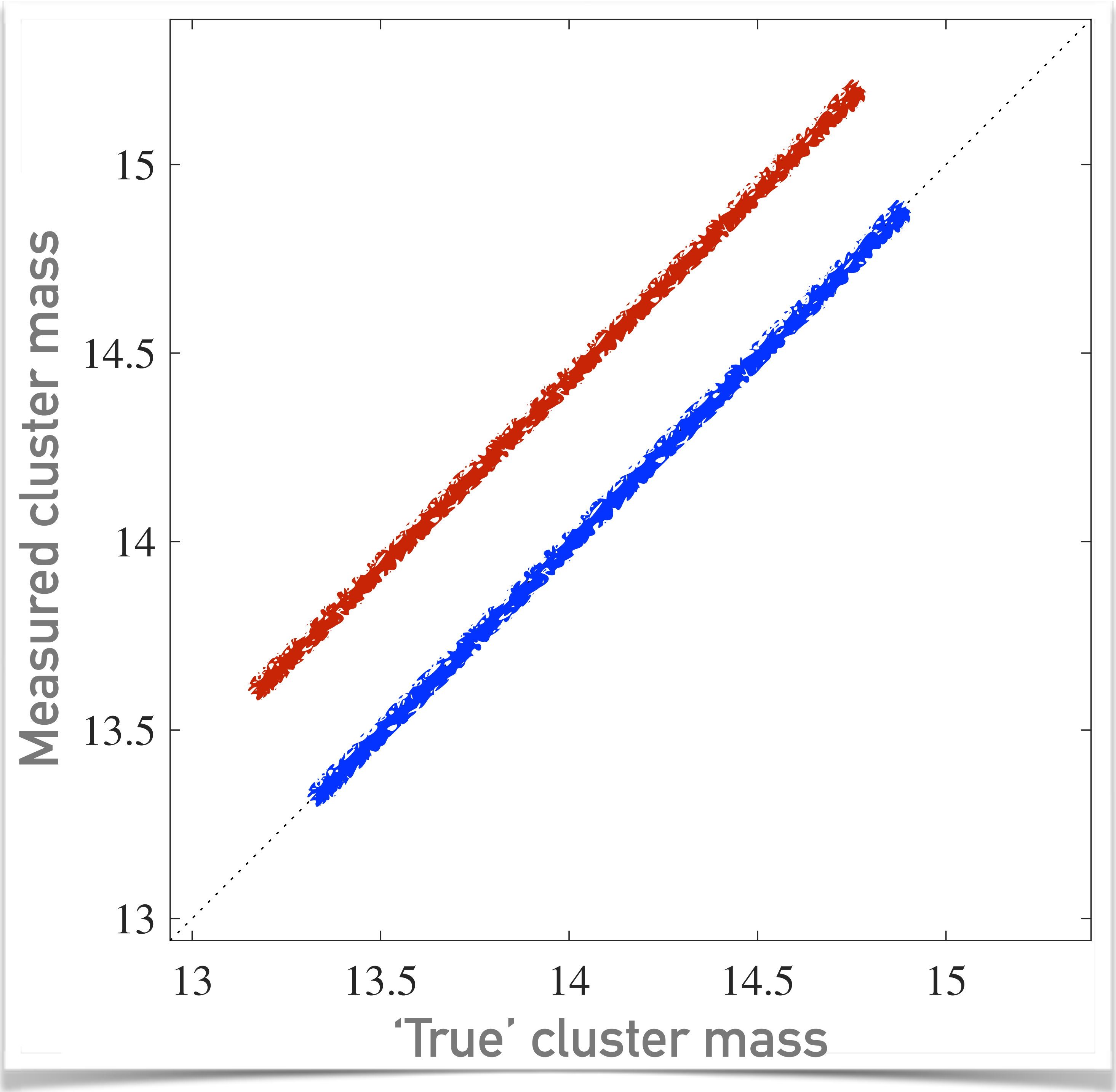

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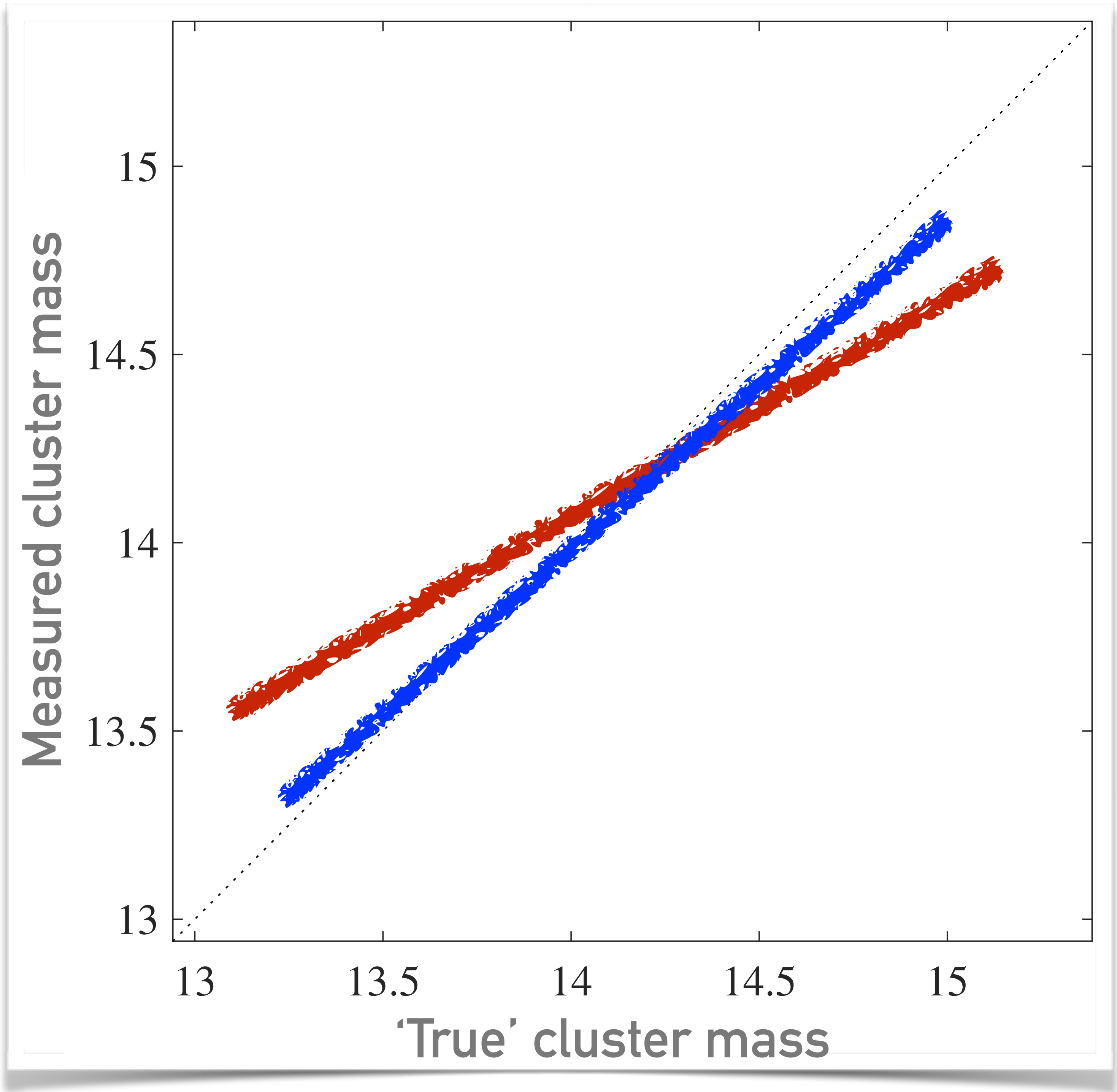

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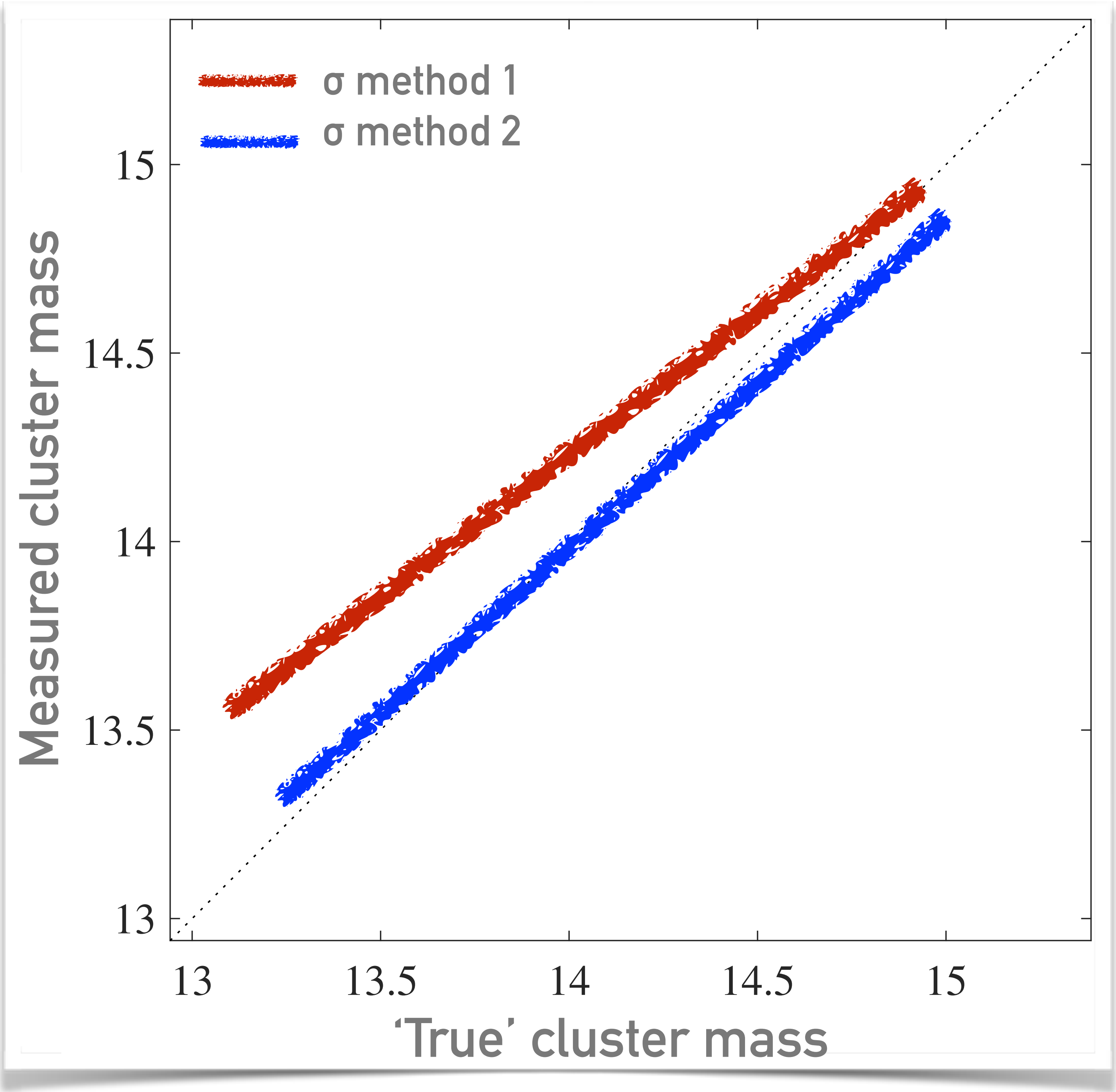

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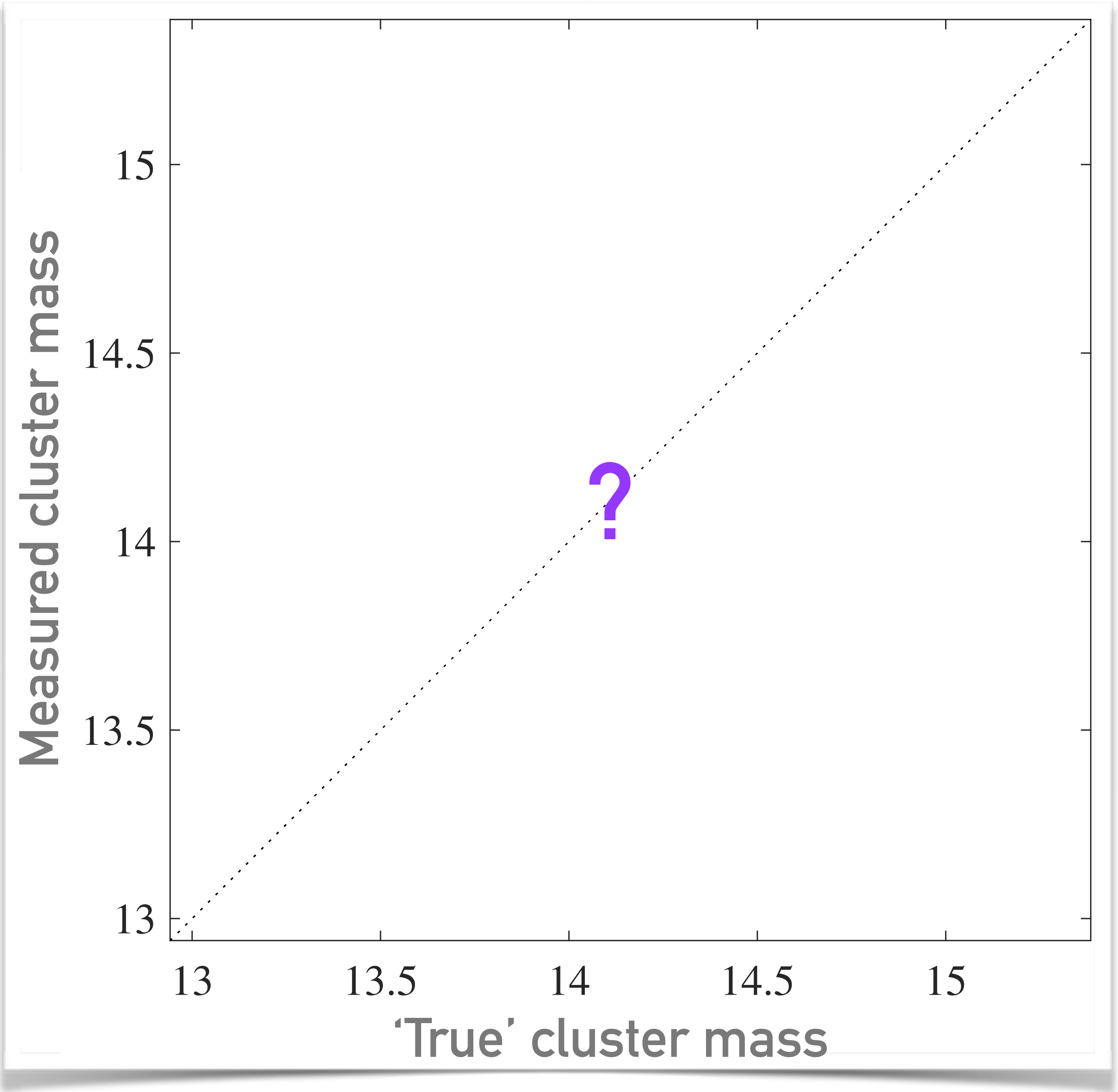
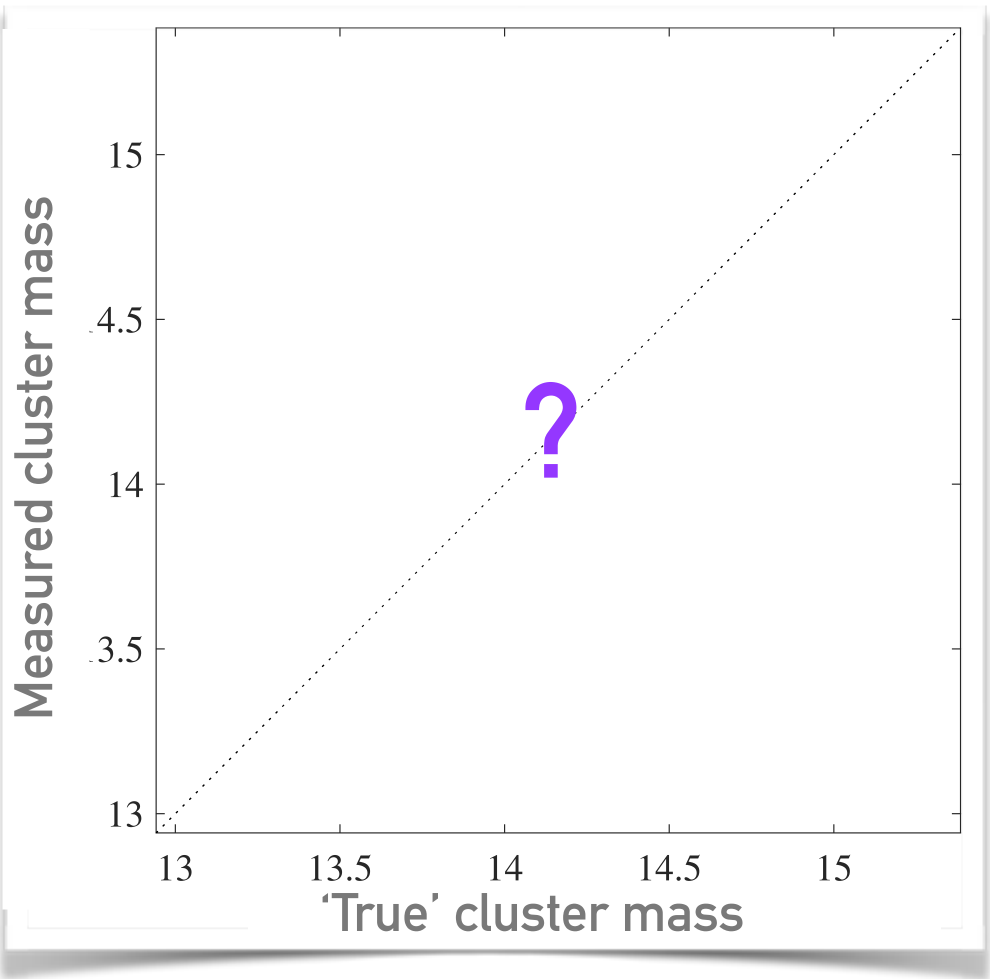


THE GALAXY CLUSTER MASS RECONSTRUCTION PROJECT



→ First systematic, homogenous study of 25 cluster mass estimation techniques

GCMRP goals:

1. Scatter, bias and completeness
2. Impact of uncertainties on cluster-cosmology
3. Methods consistent?
4. Best application of techniques to upcoming data-sets

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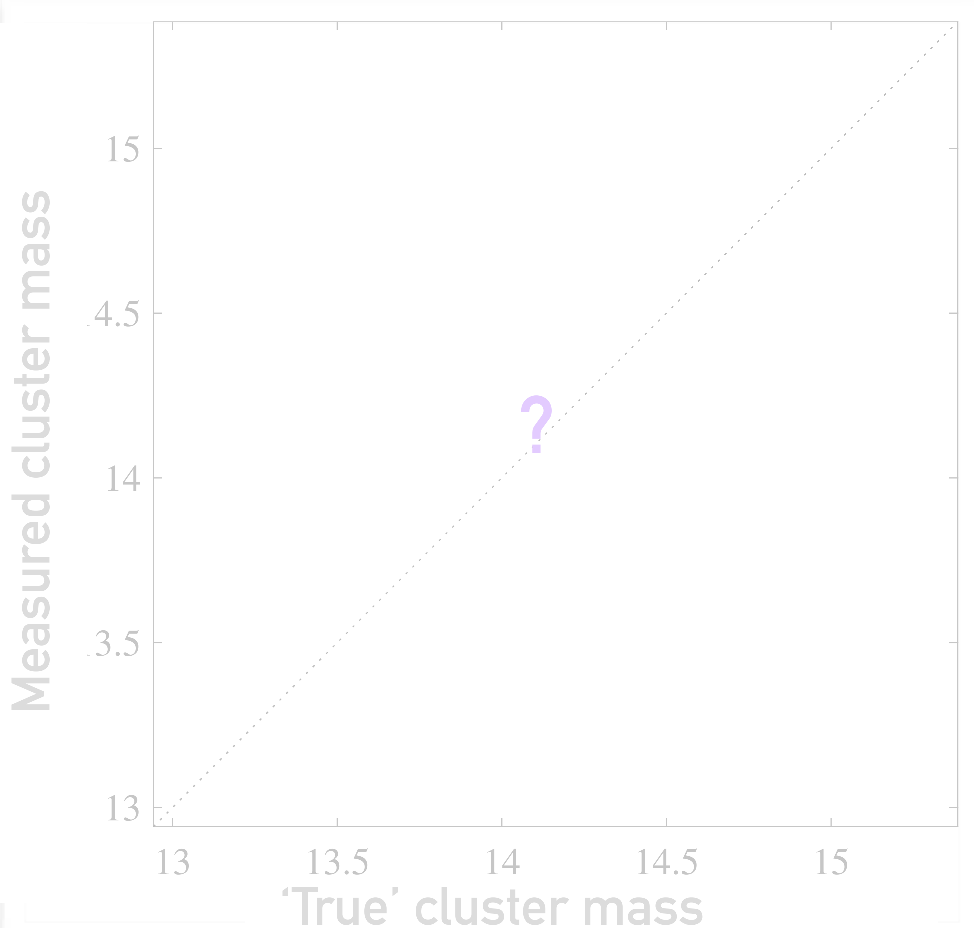

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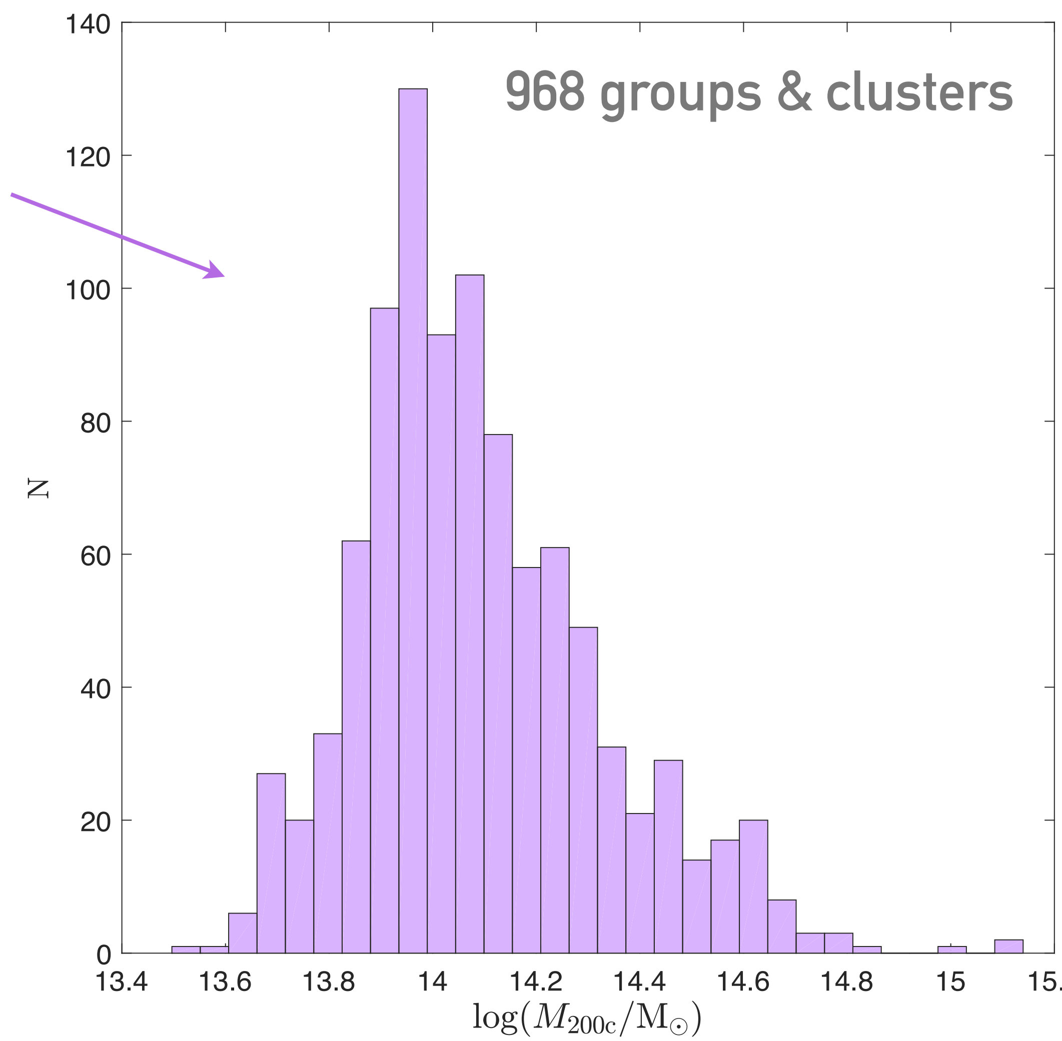
Co-authors: Radek Wojtak, Gary Mamon, Frazer Pearce, Meghan Gray, Ramin Skibba, Darren Croton, Alex Saro, Tiit Sepp, Cristobal Sifón, Elmo Tempel, Peter Behroozi, Reinaldo de Carvahlo, Andrea Biviano, Juan Muñoz-Cuartas, Eduardo Rozo, Eli Rykoff, Daniel Gifford, Anja von der Linden, Mike Merrifield, Volker Müller, Chris Power, Stuart Muldrew, Yang Wang, Richard Pearson & Trevor Ponman.

THE GALAXY CLUSTER MASS RECONSTRUCTION PROJECT

DM only → Add galaxies - SAM & HOD models → 3 mock group/ cluster catalogues

D. Croton, R. Skibba

577 clusters with log M_{200c} > 14 M_{solar}



THE GALAXY CLUSTER MASS RECONSTRUCTION PROJECT

DM only

Add galaxies - SAM & HOD models

3 mock group/ cluster catalogues

Blind test at 3 day workshop: give participants galaxy catalogues

Participants return membership & cluster parameters

For the 968 systems:

- M_{200c}
- Velocity dispersion
- Radius
- Galaxy membership

THE MASS MEASUREMENT TECHNIQUES

~~Step 1 = cluster finding~~ → Step 2 = members → Step 3 = mass

Method	Initial Galaxy Selection	Mass Estimation	Type of data required	Reference
PCN	Phase space	Richness	Spectroscopy	Pearson et al. (2015)
PFN*	FOF	Richness	Spectroscopy	Pearson et al. (2015)
NUM	Phase space	Richness	Spectroscopy	Mamon et al. (in prep.)
ESC	Phase space	Phase space	Spectroscopy	Gifford & Miller (2013)
MPO	Phase space	Phase space	Multi-band photometry, spectroscopy	Mamon et al. (2013)
MP1	Phase space	Phase space	Spectroscopy	Mamon et al. (2013)
RW	Phase space	Phase space	Spectroscopy	Wojtak et al. (2009)
TAR*	FOF	Phase space	Spectroscopy	Tempel et al. (2014)
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PFO*	FOF	Radius	Spectroscopy	Pearson et al. (2015)
PCR	Phase space	Radius	Spectroscopy	Pearson et al. (2015)
PFR*	FOF	Radius	Spectroscopy	Pearson et al. (2015)
MVM*	FOF	Abundance matching	Spectroscopy	Muñoz-Cuartas & Müller (2012)
AS1	Red Sequence	Velocity dispersion	Spectroscopy	Saro et al. (2013)
AS2	Red Sequence	Velocity dispersion	Spectroscopy	Saro et al. (2013)
AvL	Phase space	Velocity dispersion	Spectroscopy	von der Linden et al. (2007)
CLE	Phase space	Velocity dispersion	Spectroscopy	Mamon et al. (2013)
CLN	Phase space	Velocity dispersion	Spectroscopy	Mamon et al. (2013)
SG1	Phase space	Velocity dispersion	Spectroscopy	Sifón et al. (2013)
SG2	Phase space	Velocity dispersion	Spectroscopy	Sifón et al. (2013)
SG3	Phase space	Velocity dispersion	Spectroscopy	Lopes et al. (2009)
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THE MASS MEASUREMENT TECHNIQUES

Step 2 = members

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Friends-Of-Friends algorithm

Phase space: within a certain distance and velocity from cluster centre

Red sequence: selecting galaxies of a certain colour

THE MASS MEASUREMENT TECHNIQUES

Step 3 = mass

Method	Initial Galaxy Selection	Mass Estimation	Type of data required	Reference
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Number of galaxies above a given luminosity threshold

Positions & velocities of galaxies e.g., caustics

RMS radius/ DM profile fitted to obtain radius.

Matching using theoretical halo mass function & cluster r-band luminosity function

$$M \propto \sigma^3$$

GCMRP MASS RECONSTRUCTION ANALYSIS

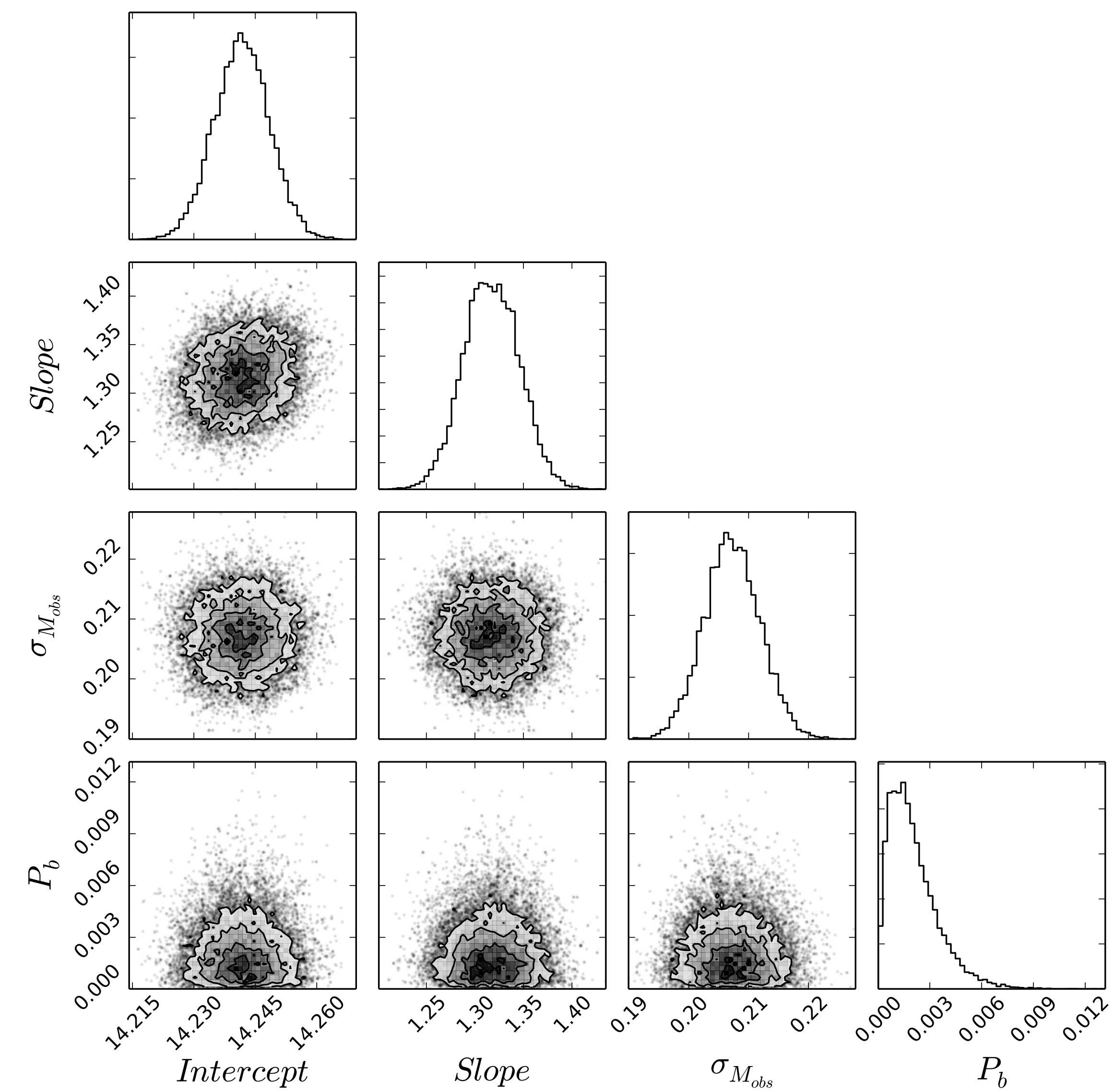
- We perform a likelihood fitting analysis assuming a model where there is a linear relationship between log $M_{200,rec}$ and log $M_{200,true}$ log and residual offsets in the recovered mass are drawn from a normal distribution.

- We use the parallel-tempered MCMC sampler emcee (Foreman & Mackay 2013) to efficiently sample the parameter space

- RMS: encompasses both scatter and bias and, hence, delivers the overall uncertainty

- Scatter in the recovered mass, σ_{MRec} , delivers a measure of the intrinsic scatter

- Bias (at pivot mass)



GCMRP: HIGHLIGHTS

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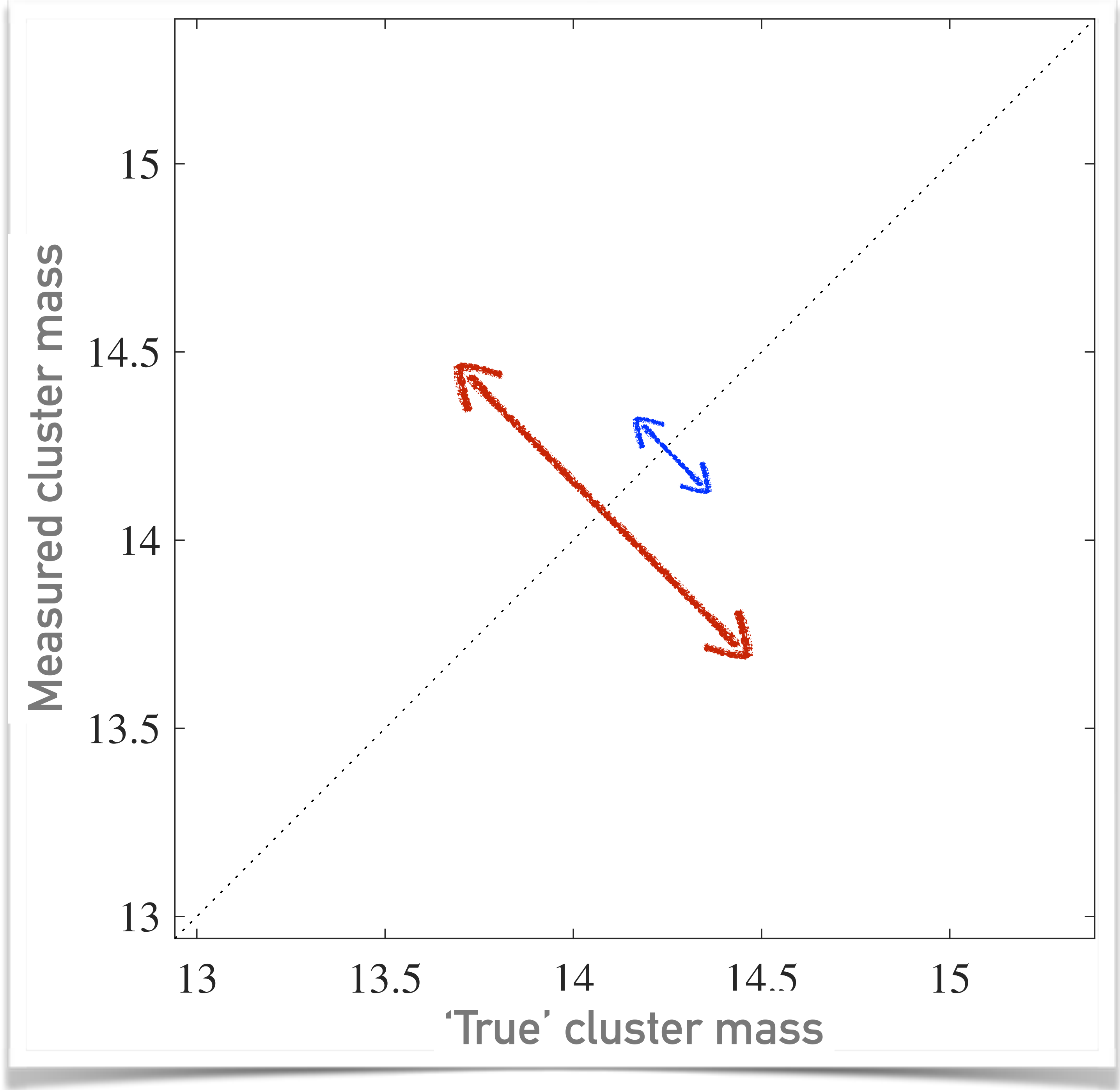
- RMS in mass is higher than expected, factor of ~2-12, & mass dependant!



Old et al. 2014, Old et al. 2015 (1403.4610, 1502.07347)

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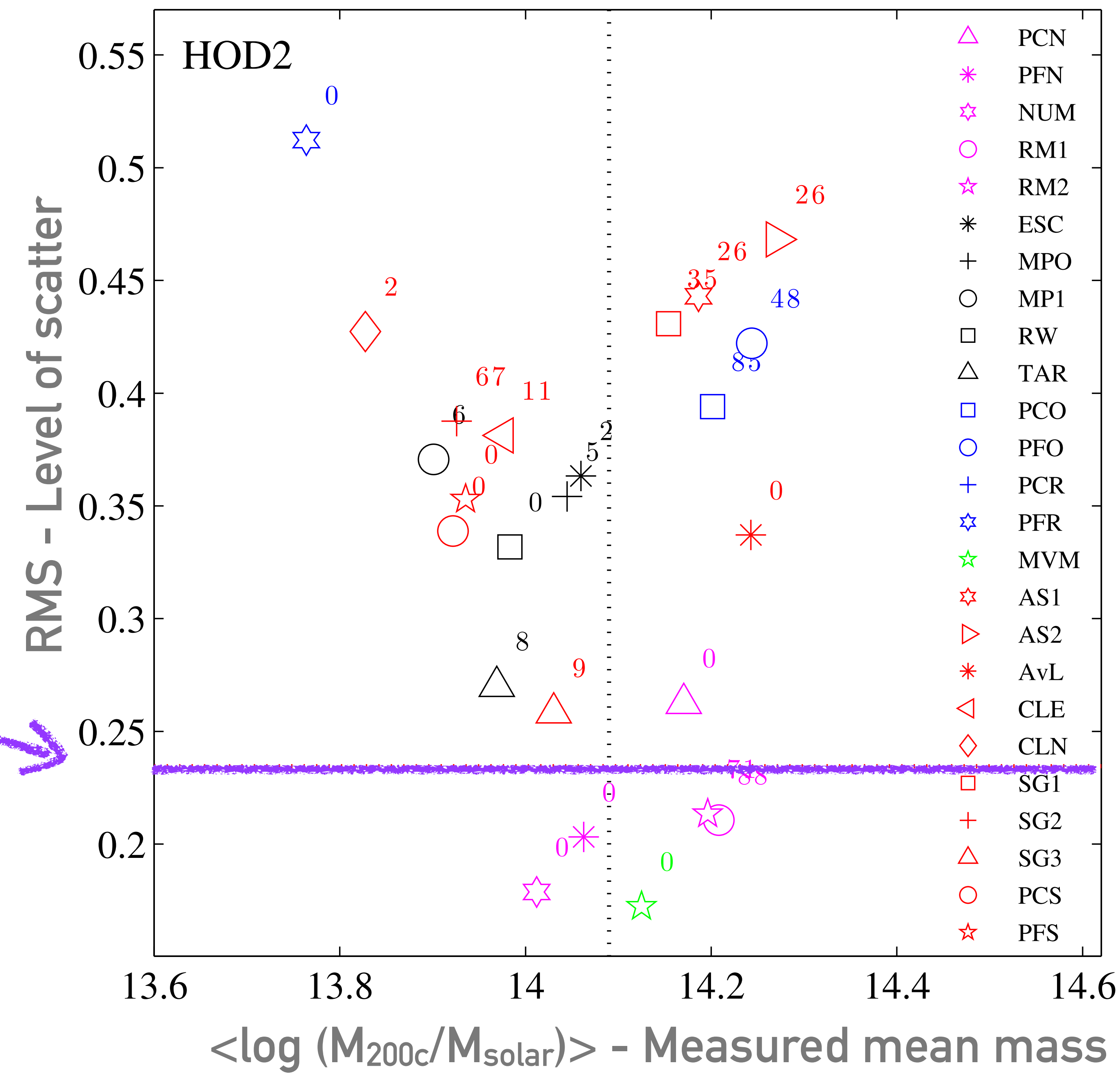
Scatter if we assume all 968 clusters have the same mass!



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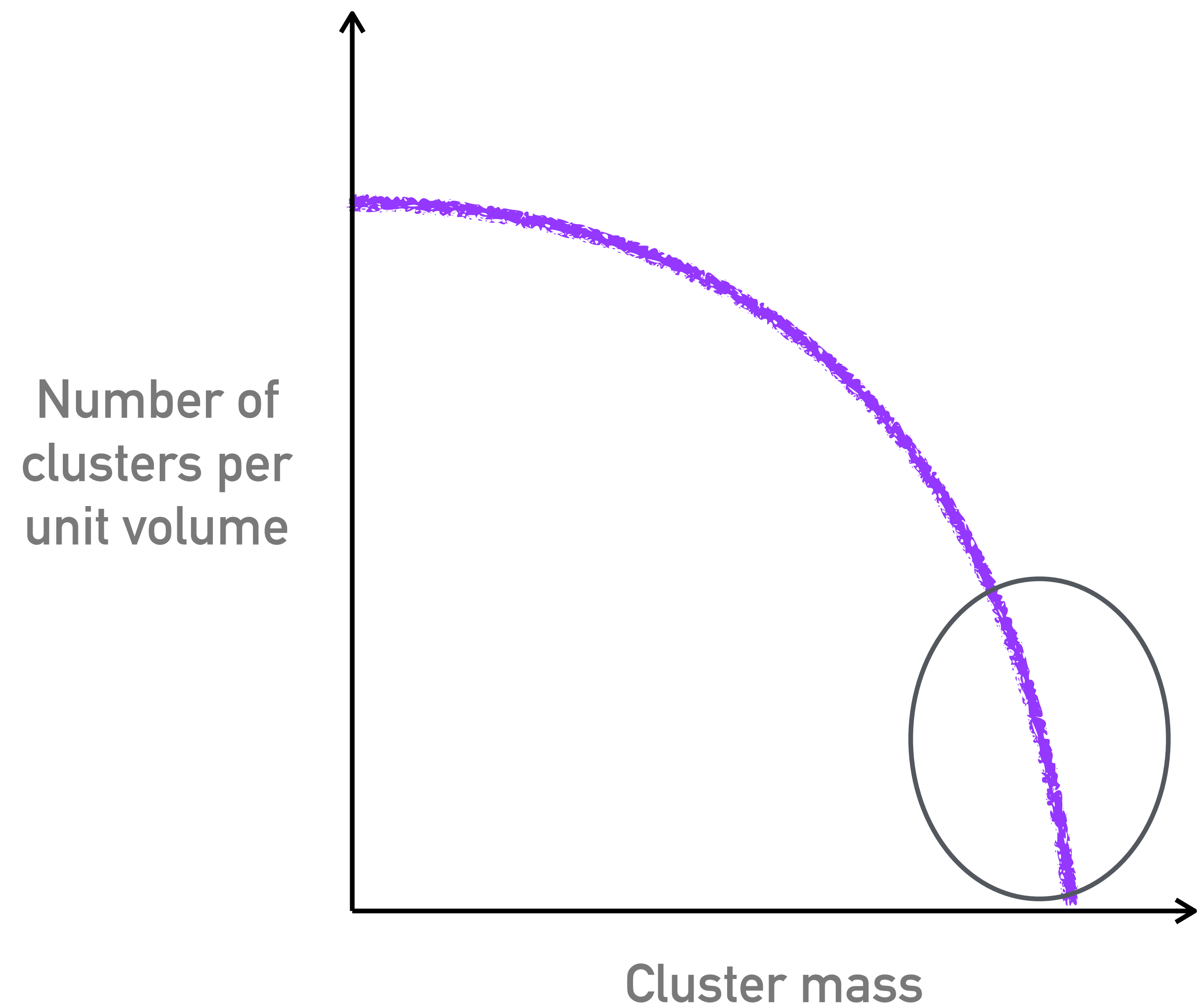

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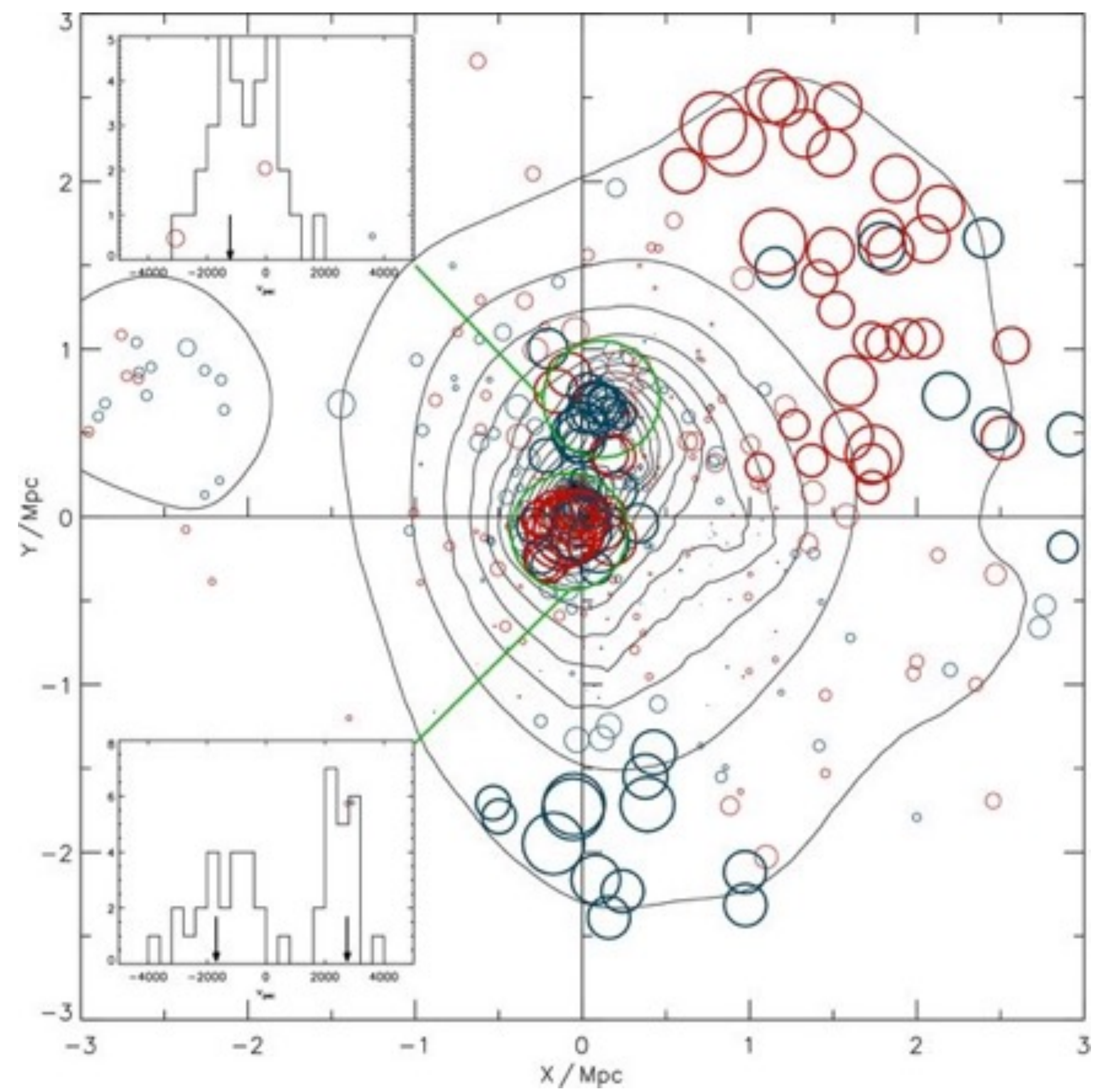

Owers et al., 2011, Abell 2744

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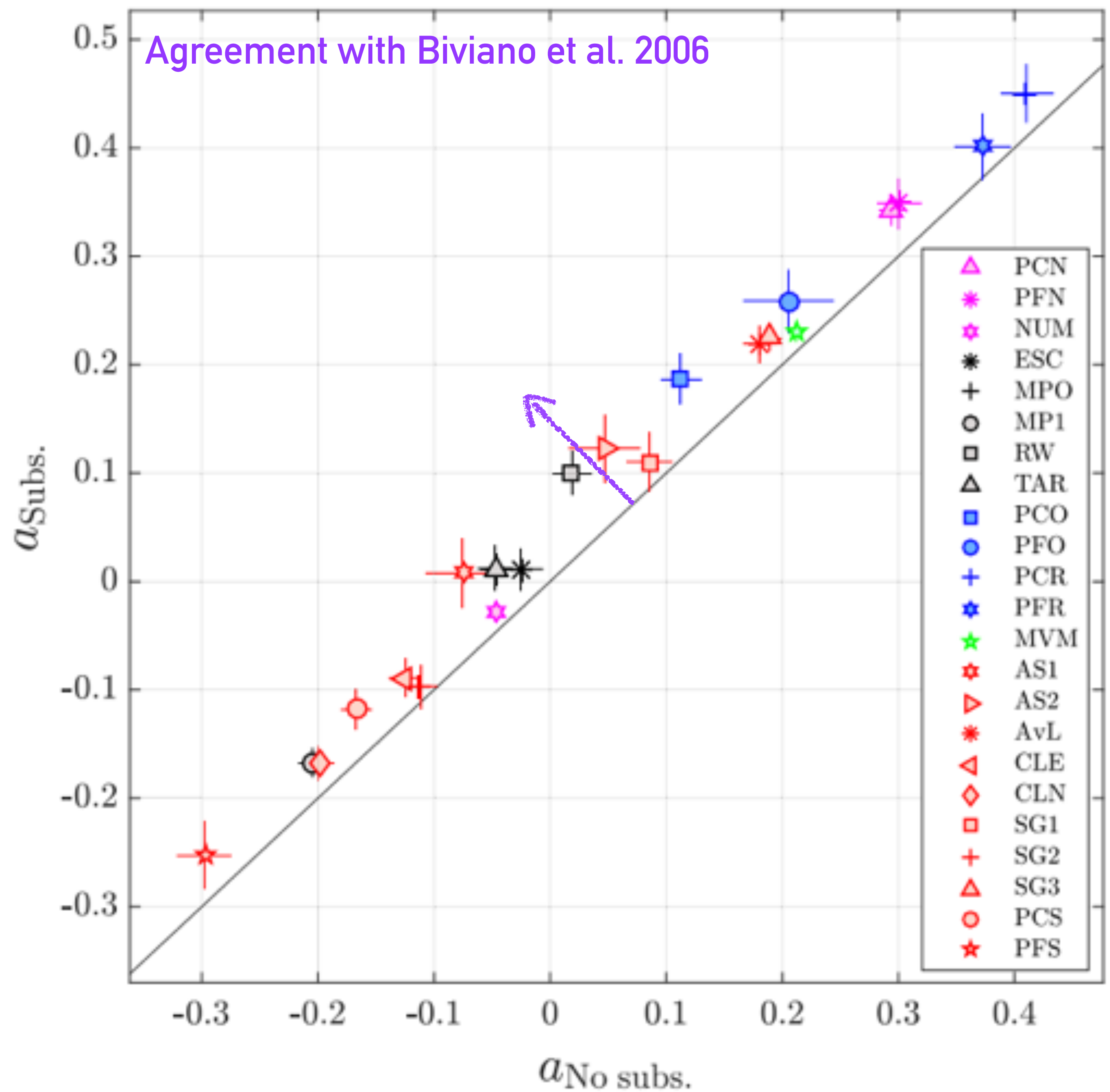

Old et al. 2017 (1709.10108)

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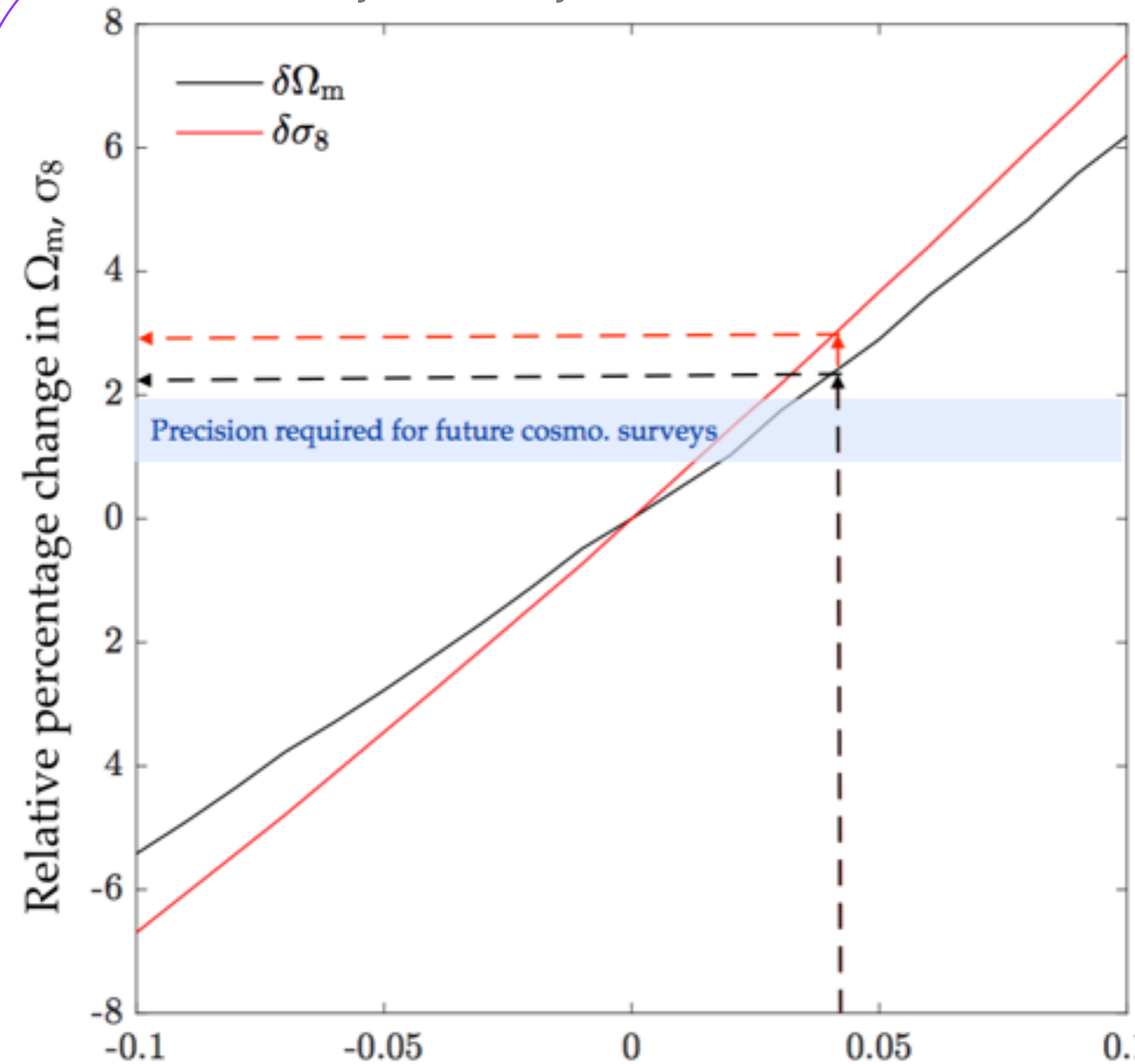
% change in cosmological model parameters due to dynamically disturbed clusters

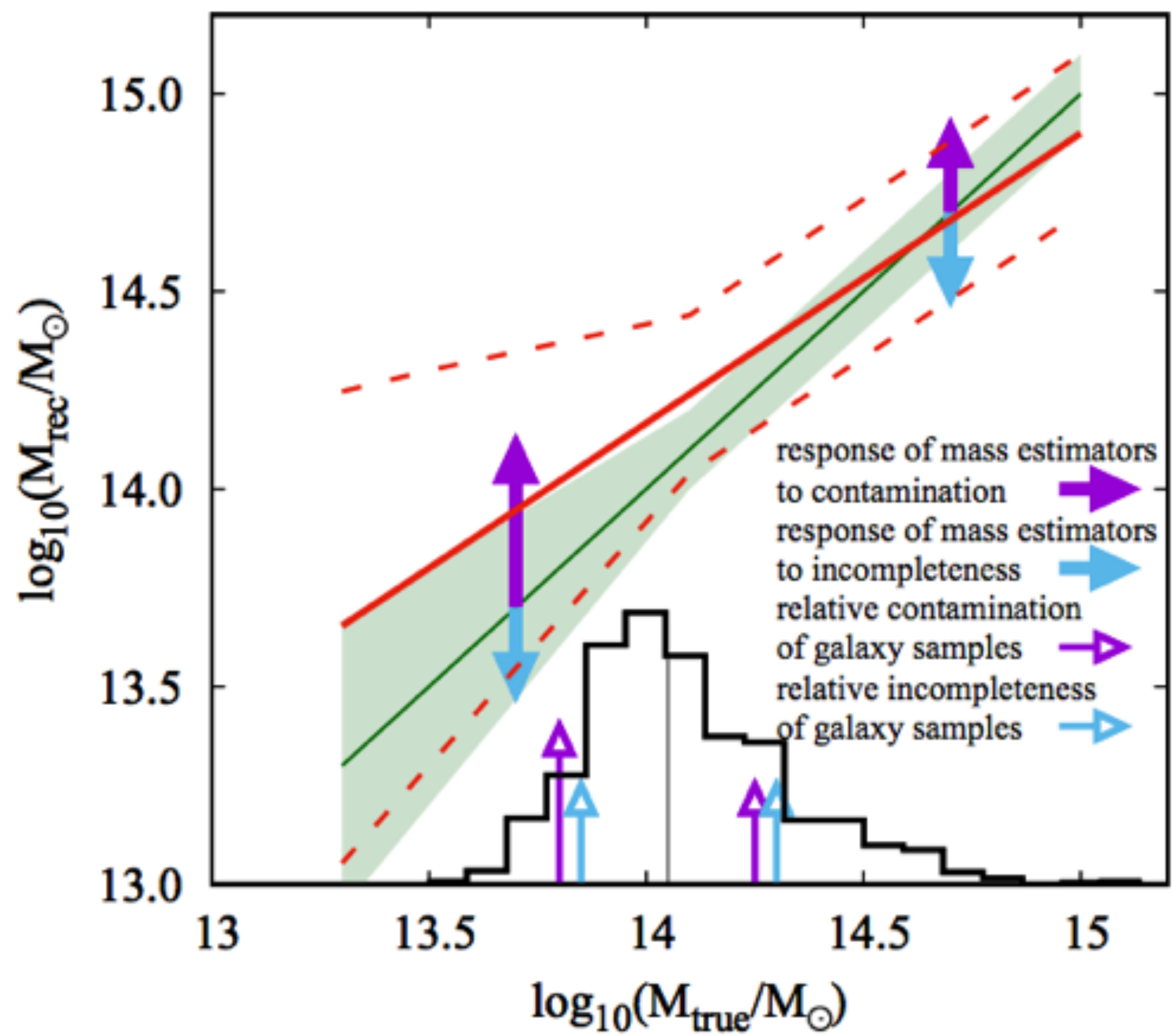


Bias in mass (dex)

Old et al. 2017 (1709.10108)

GCMRP: HIGHLIGHTS

- Contamination and incompleteness give rise to overestimation & underestimation of measured masses respectively
- Kinematic methods more sensitive to incompleteness



Wojtak et al. 2018 (1806.03199)

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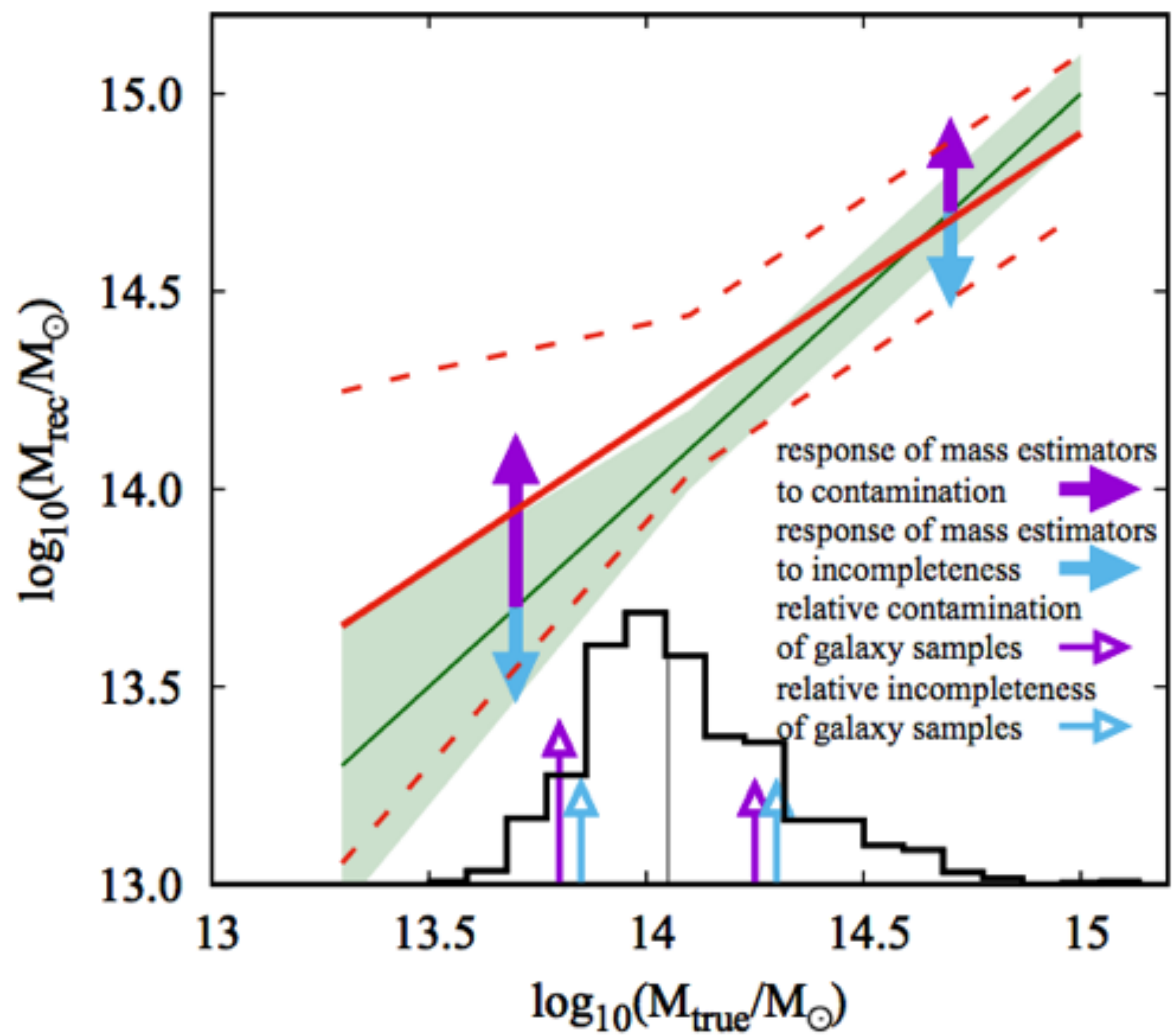
- M_{rec} – M_{true} relation flattens due to a mass-dependent selection of cluster members & mass-dependent response of estimators to imperfect membership.
- Flattening results in suppression in mass function at low masses & amplification at high masses… Ω_m biased down by ~10% and σ_8 biased up by ~ 7%



Wojtak et al. 2018 (1806.03199)

GCMRP: FUTURE

Data set still unblinded — available for testing new cluster mass estimation techniques!

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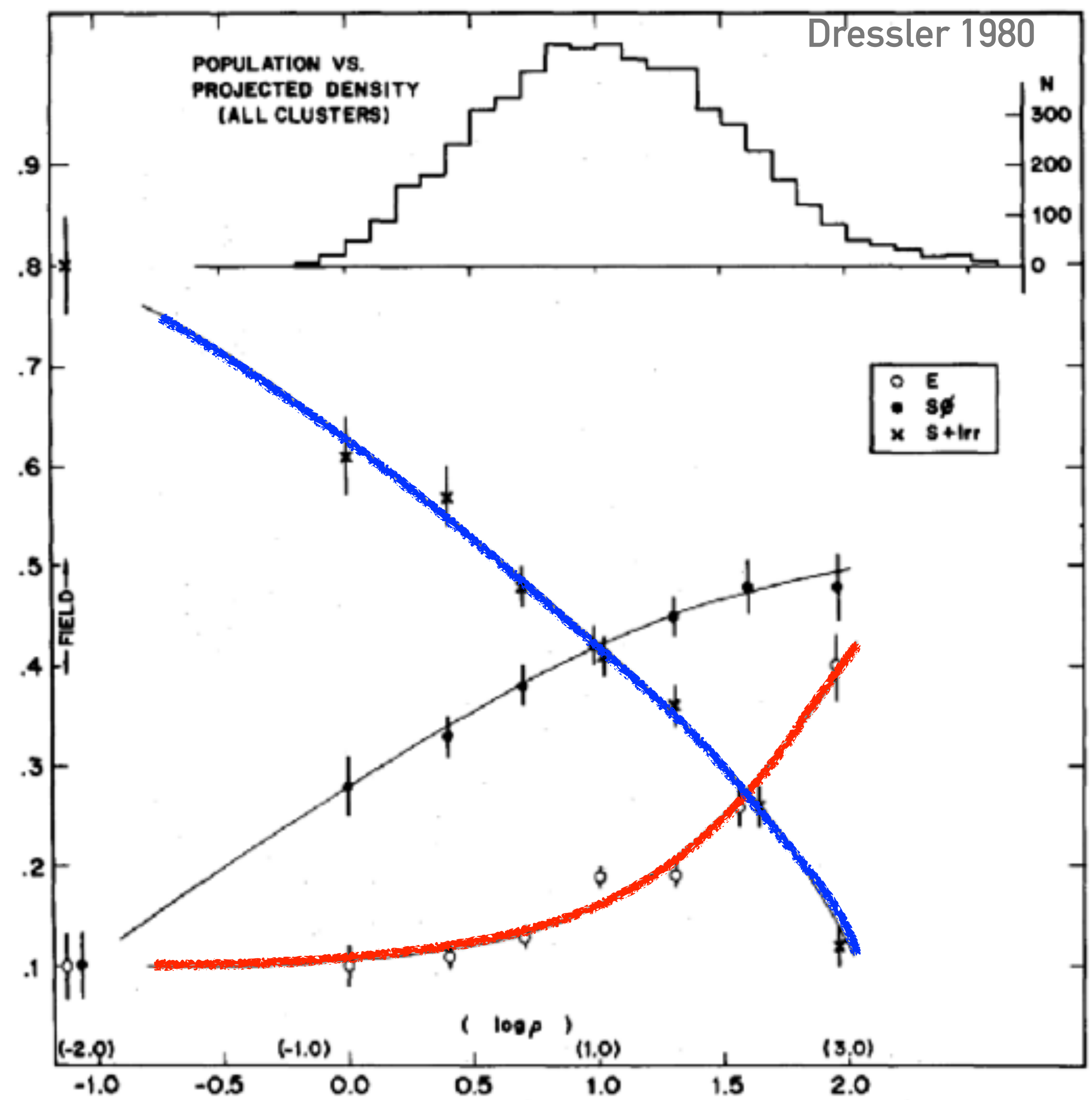
Wojtak et al. 2018 (1806.03199)

GALAXY CLUSTER COSMOLOGY → GALAXY EVOLUTION

At low redshift

Fraction of galaxy population



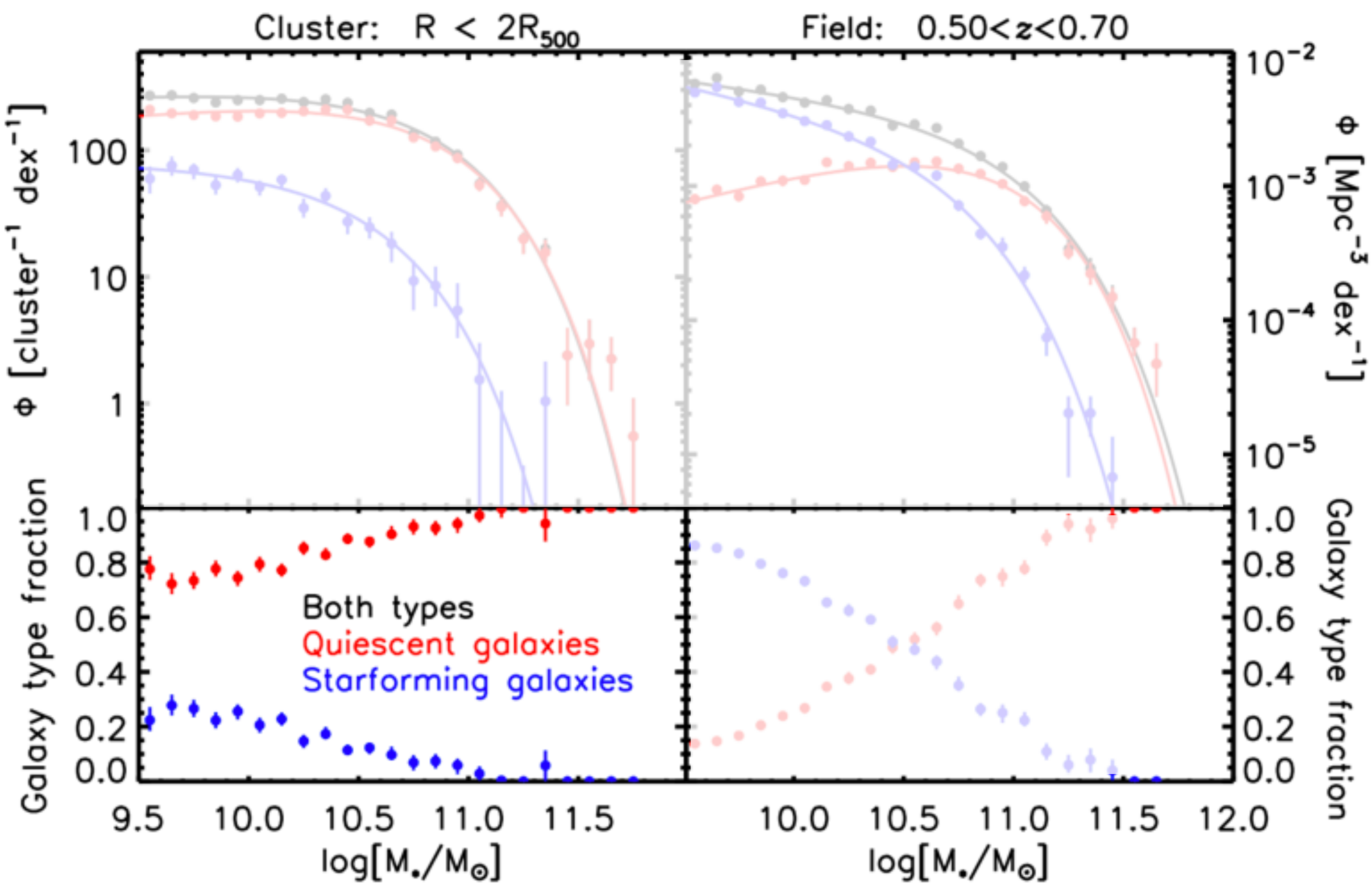
Spirals, Irregulars

Ellipticals

Field Environment Cluster

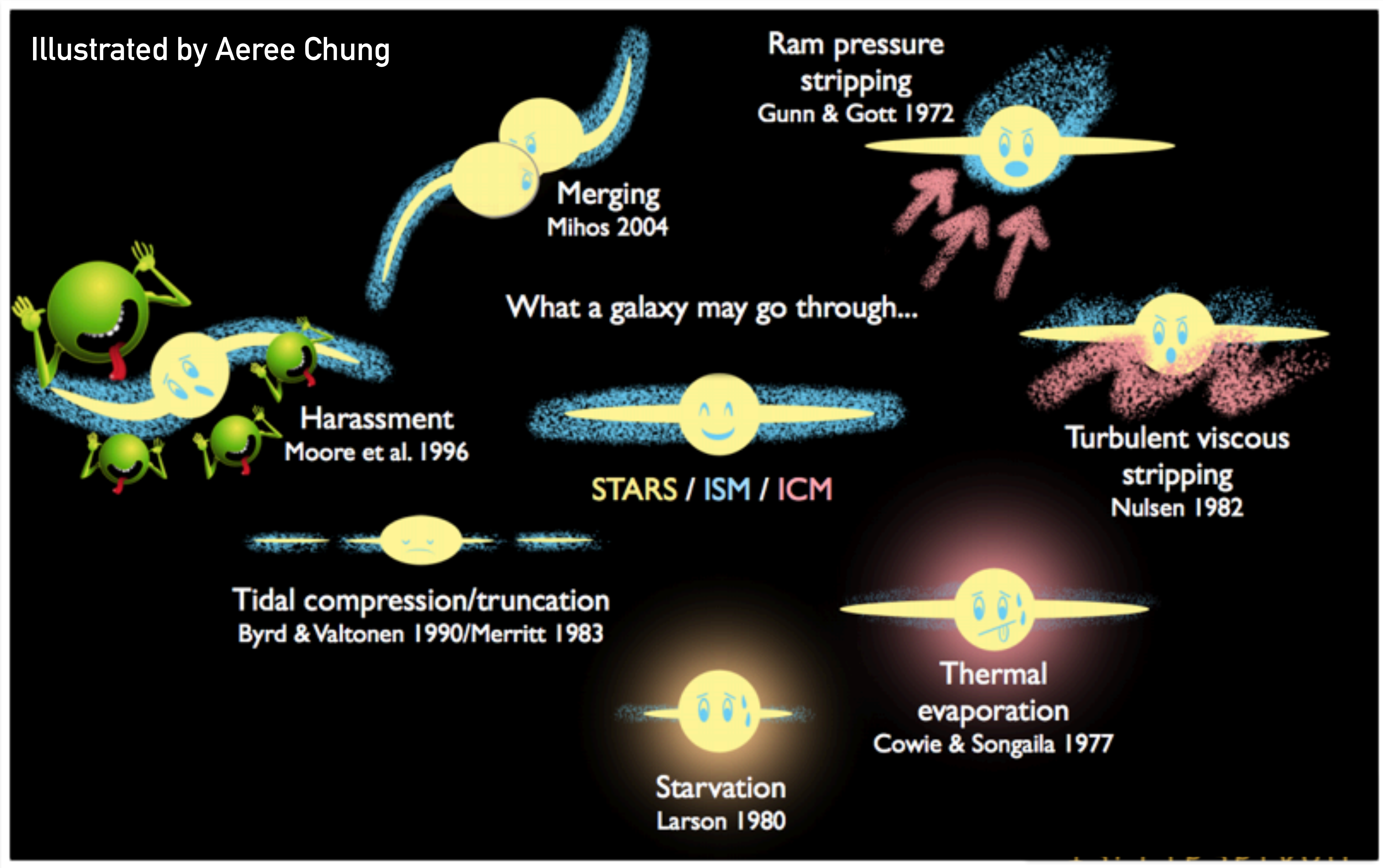
See also: Oemler 1974, Balogh et al. 20014, Hogg et al. 2004, Blanton et al. 2005

At intermediate redshifts



Planck clusters, z~0.6, ~ Universe was ~8 Gyr old : van der Burg et al. 2018

WHAT PROCESSES GOVERN THE LIFE & DEATH OF GALAXIES?



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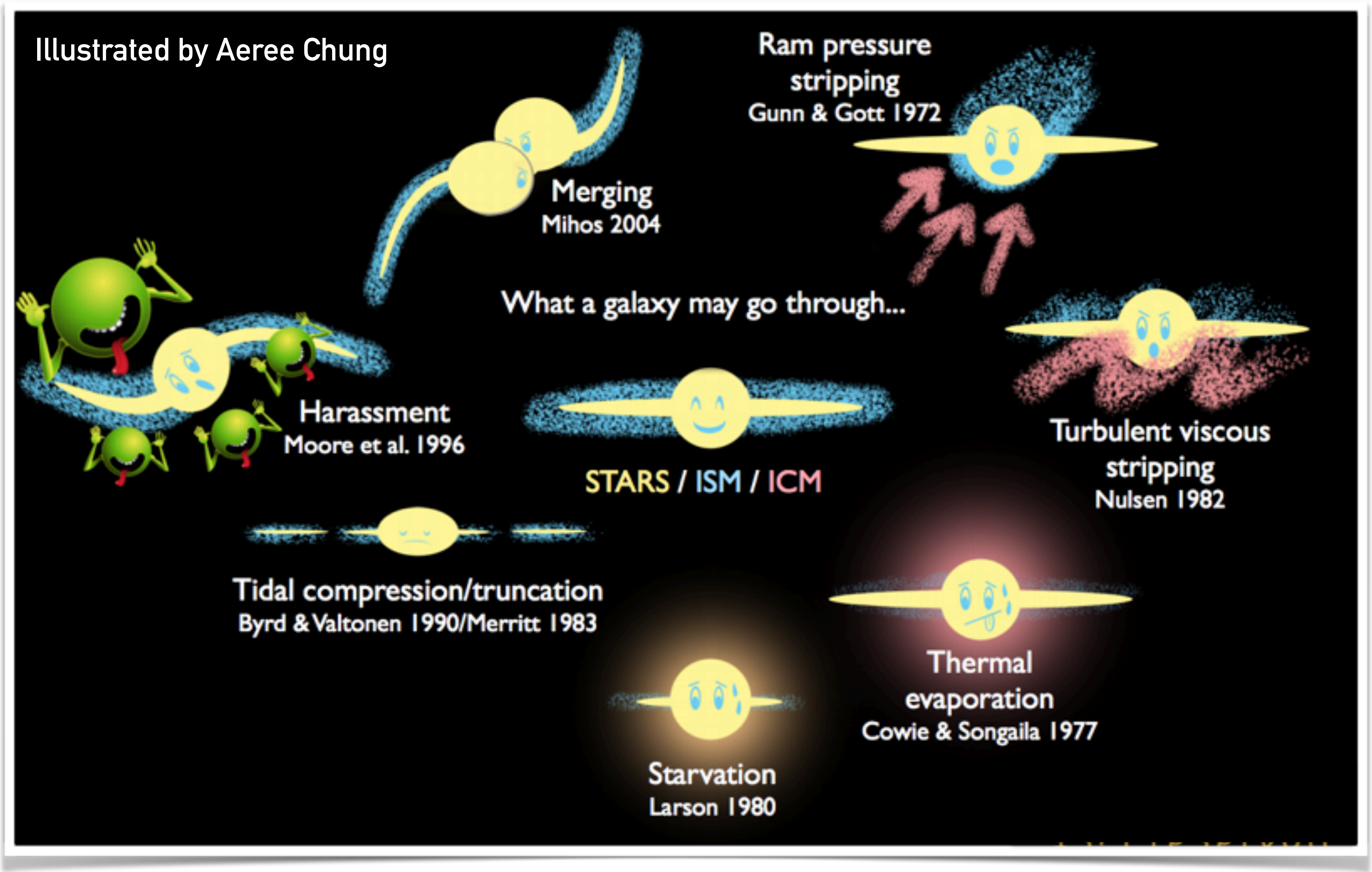
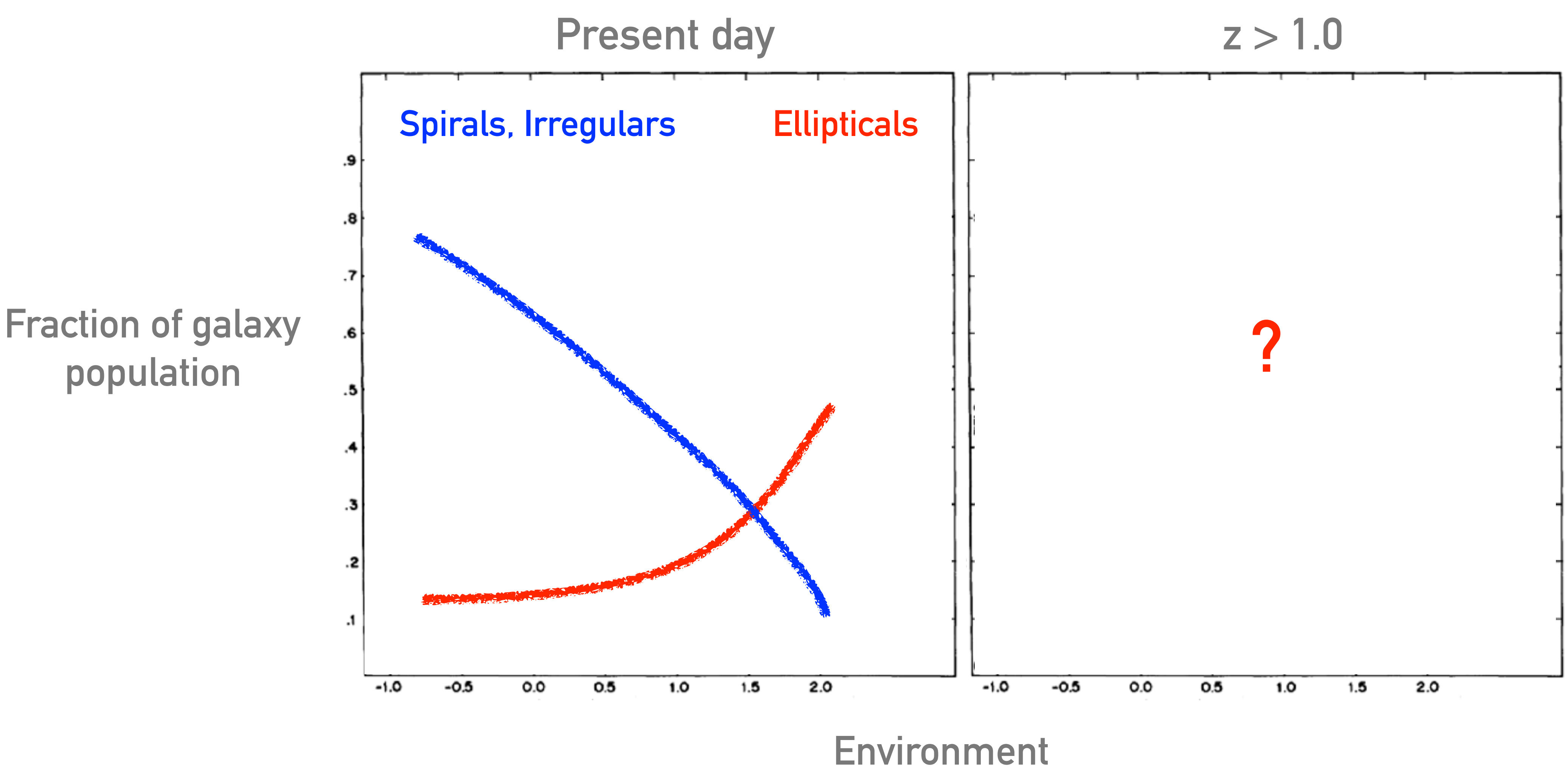


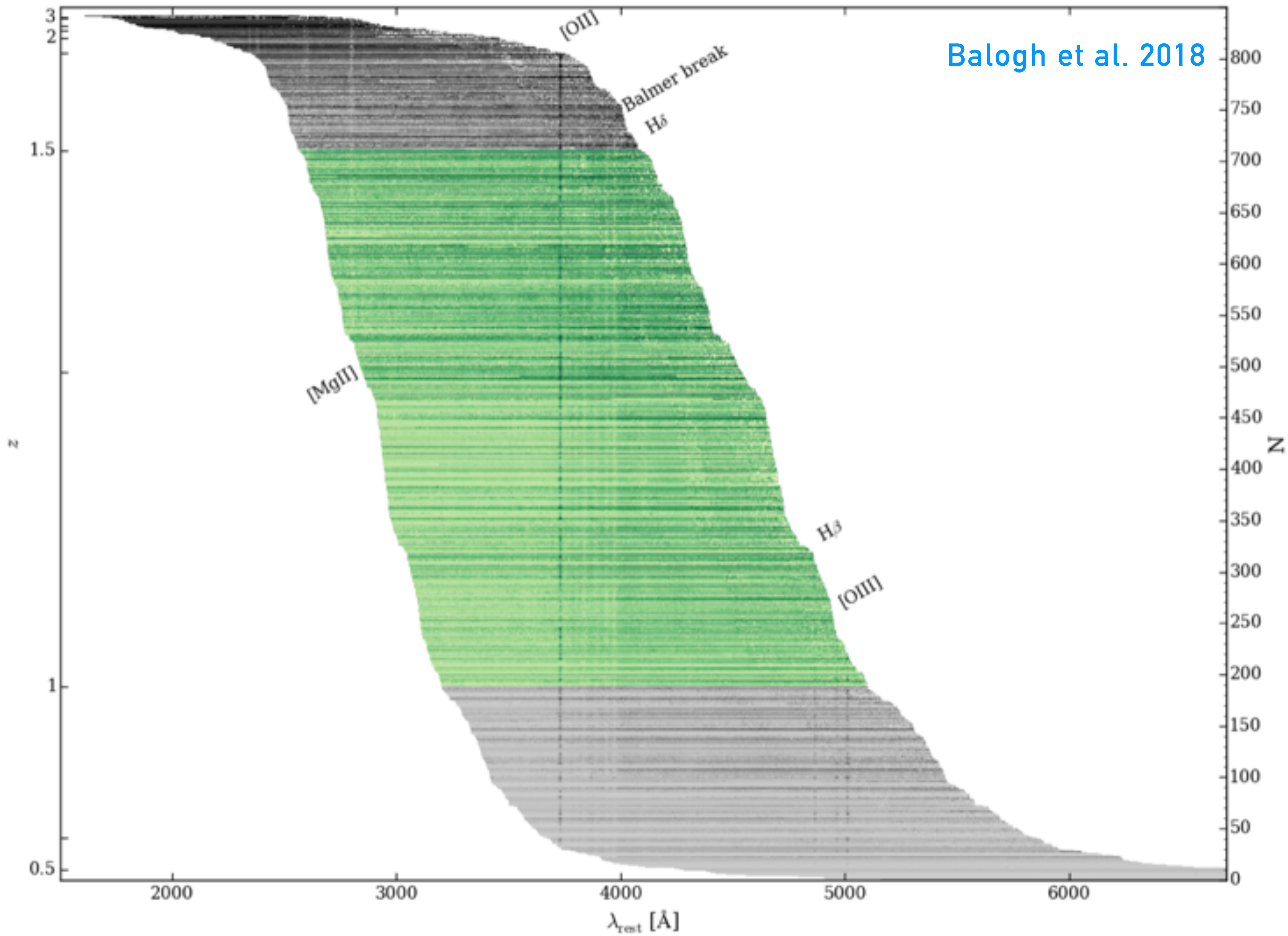
These mechanisms act on different timescales & are location dependent!

WHAT ABOUT AT HIGHER REDSHIFTS?

- At $z > 1$, Universe was ~eight times denser. Expect that gas accretion rates, star-formation rates (SFRs) were much higher than the present day.
- Properties of typical galaxies in $z > 1$ clusters are almost completely unknown!



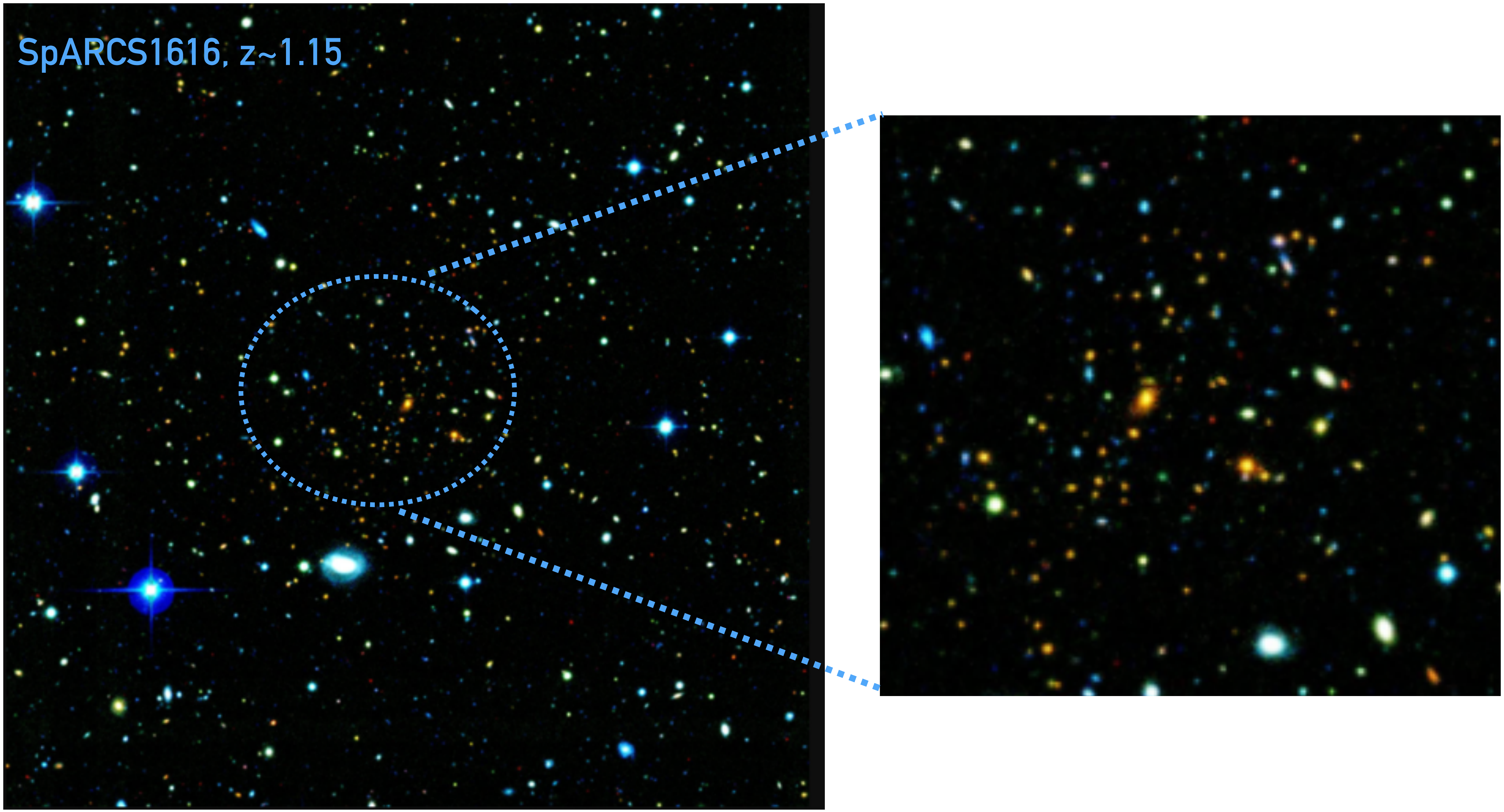
Gemini Observations of Galaxies in Rich Early ENvironments survey (GOGREEN)



~440 hrs Gemini MOS of galaxies in 21 groups + clusters at 1 < z < 1.5 (PI: Balogh, GCLASS, SpARCS)

THE GOGREEN SURVEY

→ Deep imaging multi-band imaging: Subaru, VIMOS, CFHT, MMT, Magellan, HAWK-I, HST

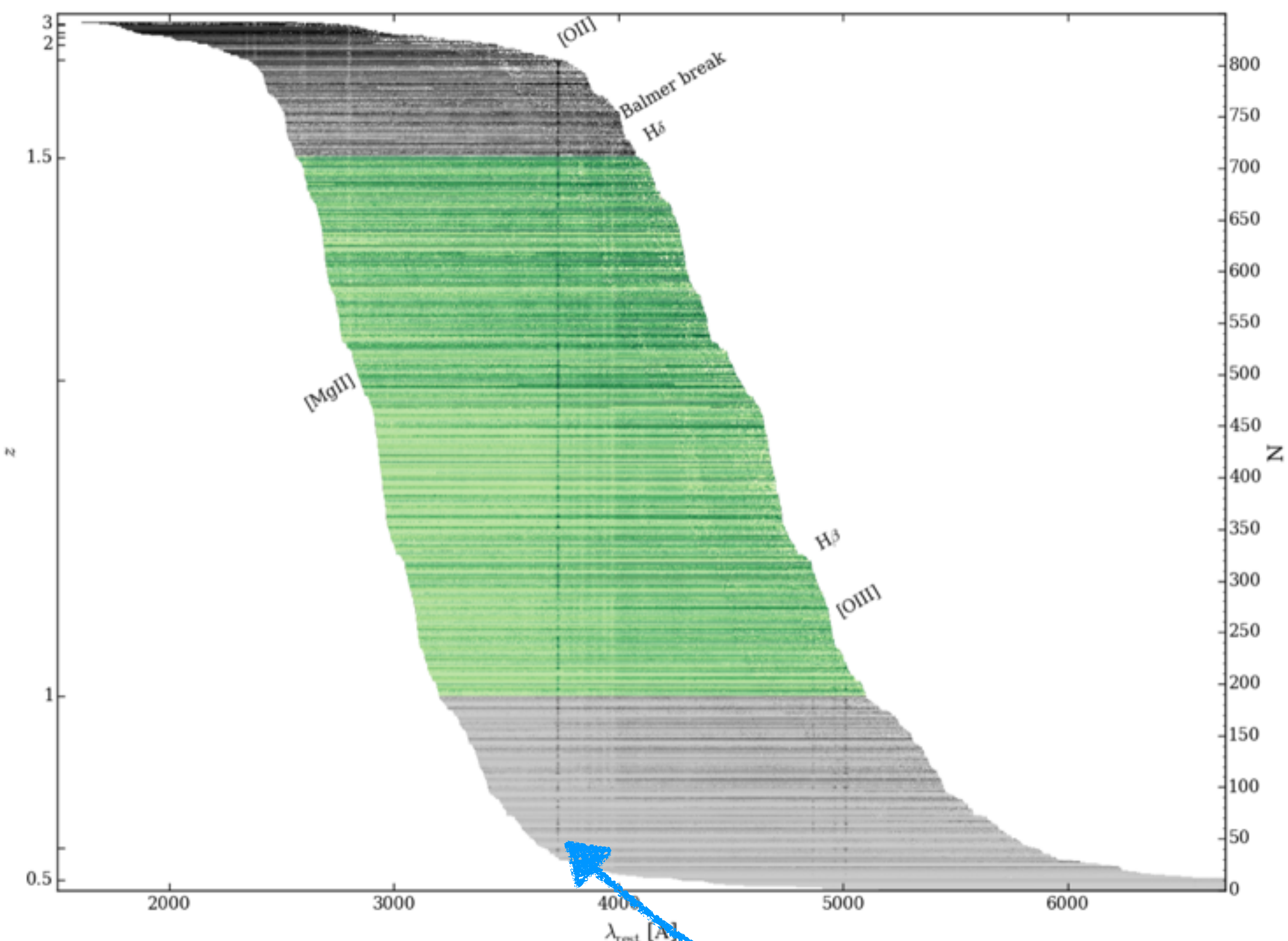


→ Deep imaging multi-band imaging: Subaru, VIMOS, CFHT, MMT, Magellan, HAWK-I, HST

- How is Star Formation (SF) distributed in these clusters?
- Is there difference in SF between cluster and field?
- Is there a difference in SF properties at z=0 & z=1?

THE GOGREEN SURVEY

→ Deep imaging multi-band imaging: Subaru, VIMOS, CFHT (PI: Old), MMT, Magellan, HAWK-I

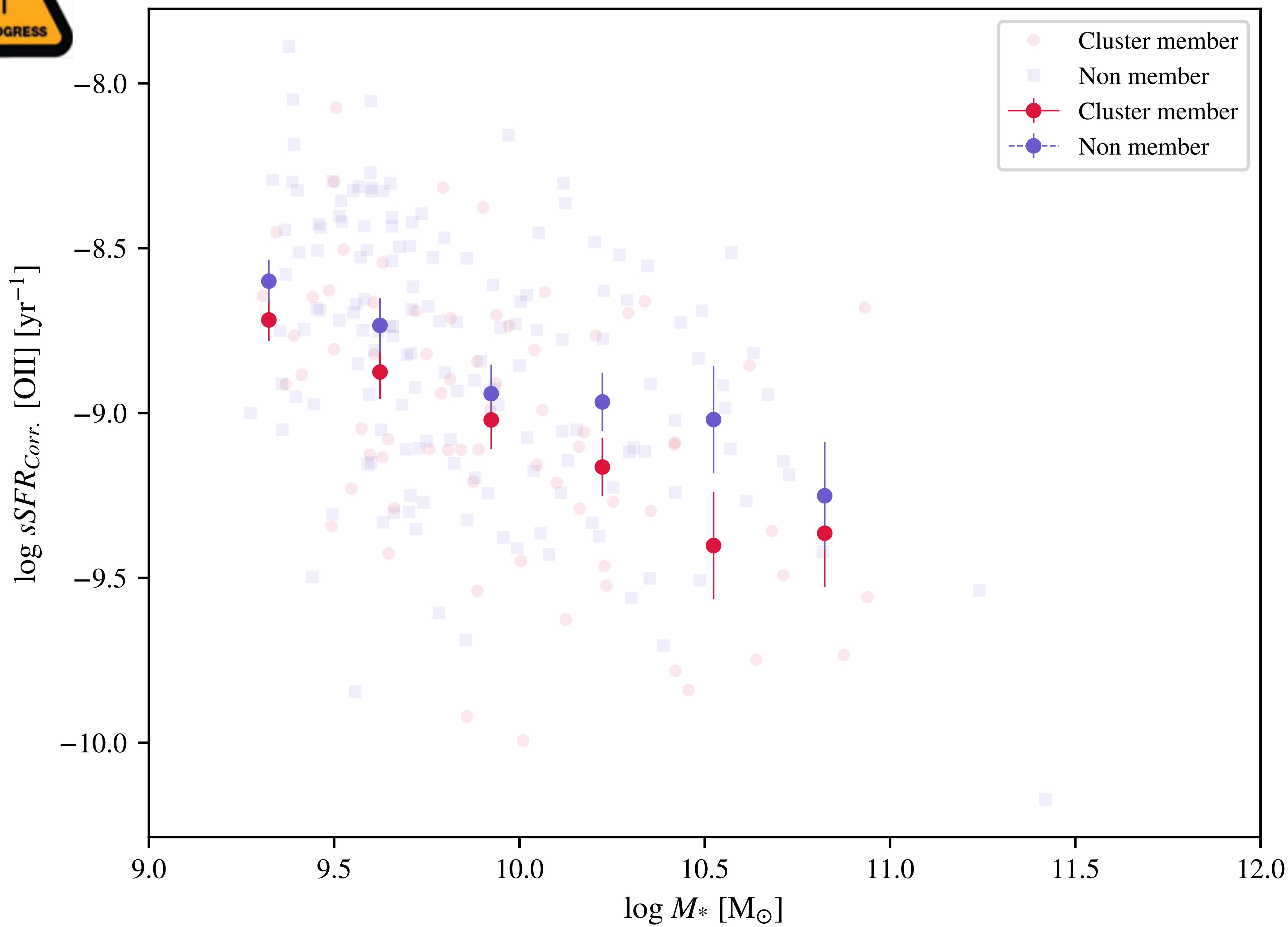


- How is Star Formation (SF) distributed in these clusters?
- Is there difference in SF between cluster and field?
- Is there a difference in SF properties at z=0 & z=1?

E.g., using [OII] emission as SFR proxy

THE GOGREEN SURVEY - SPECIFIC SFR

Following Gilbank et al., 2010: empirically corrected SFR from [OII] luminosity



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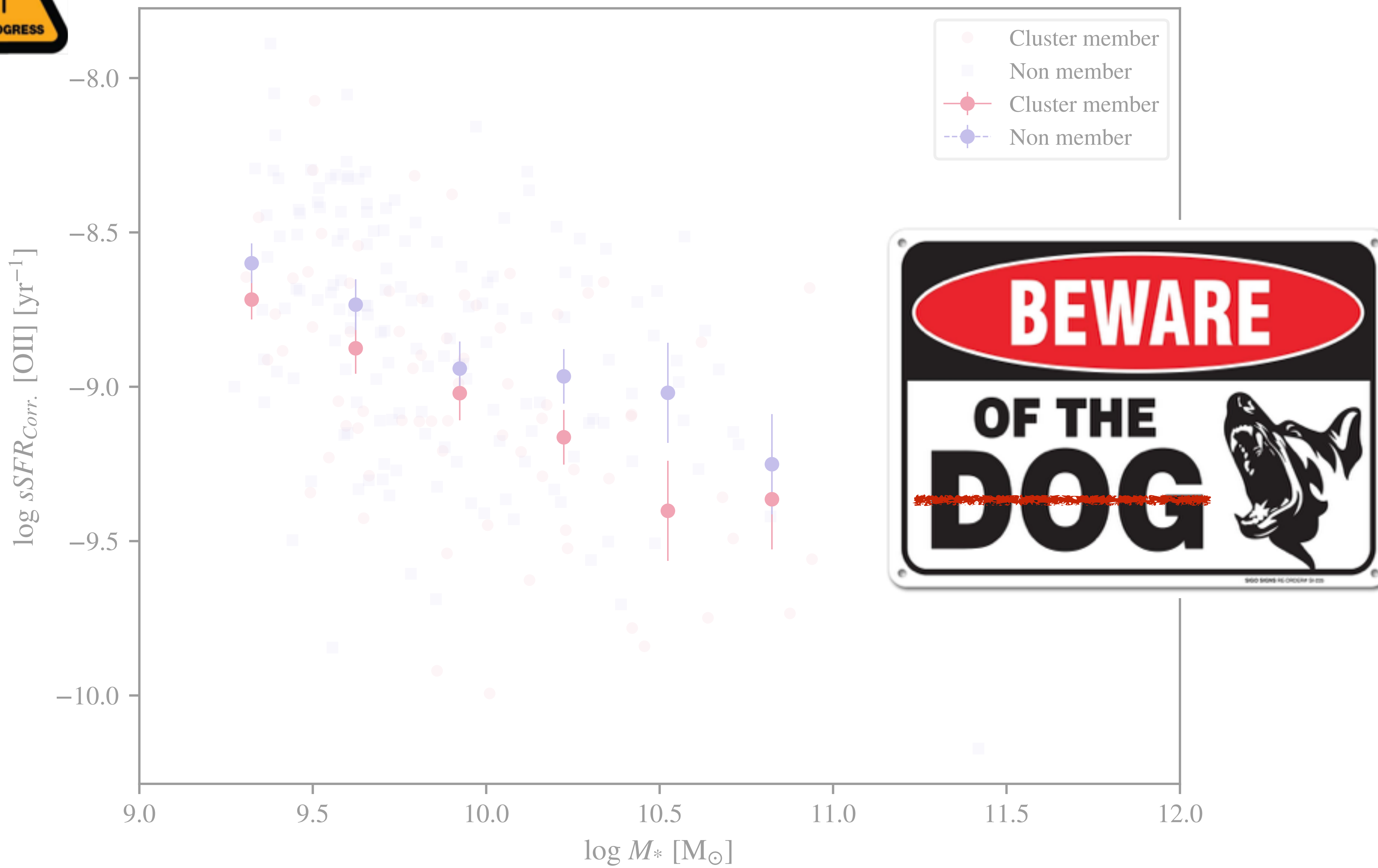
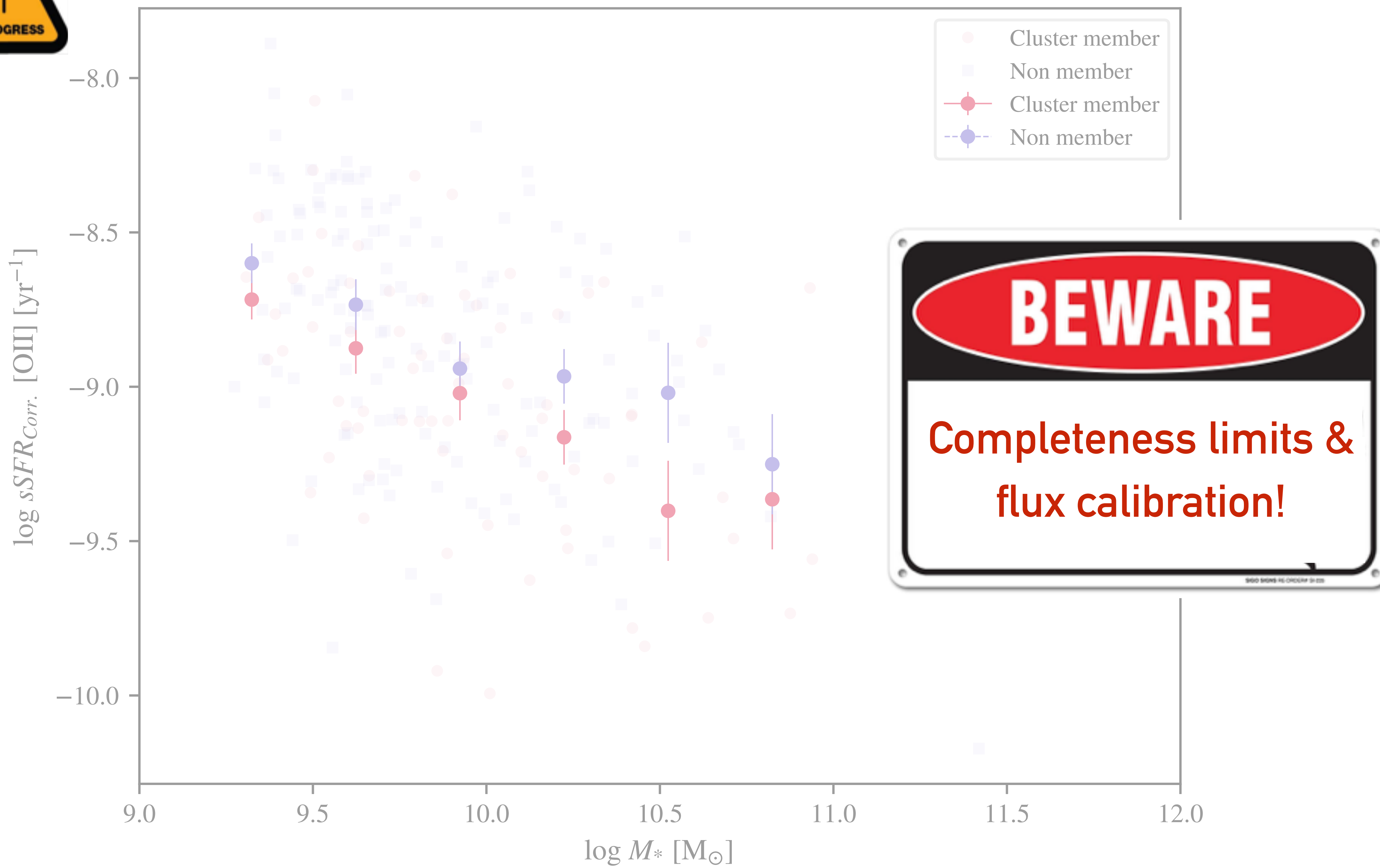


THE GOGREEN SURVEY - SPECIFIC SFR

Following Gilbank et al., 2010: empirically corrected SFR from [OII] luminosity



THE GOGREEN SURVEY - FUTURE

→ Watch out for the following GOGREEN early science results!

I. Buildup of the red sequence in massive clusters (J. Chan, UC Riverside)

II. Environment-dependent ages of quiescent galaxies at $1<z<1.5$ (K. Webb, U. Waterloo)

III. The environmental dependence of the star forming main sequence at $1<z<1.5$ (L. Old)

IV. The quiescent galaxy population of $1<z<1.5$ groups (A. Reeves, U. Waterloo)

V. First Data Release (M. Balogh, U. Waterloo)

VI. + HST morphology!

Thanks Gemini!