Impact of environment beyond quenching

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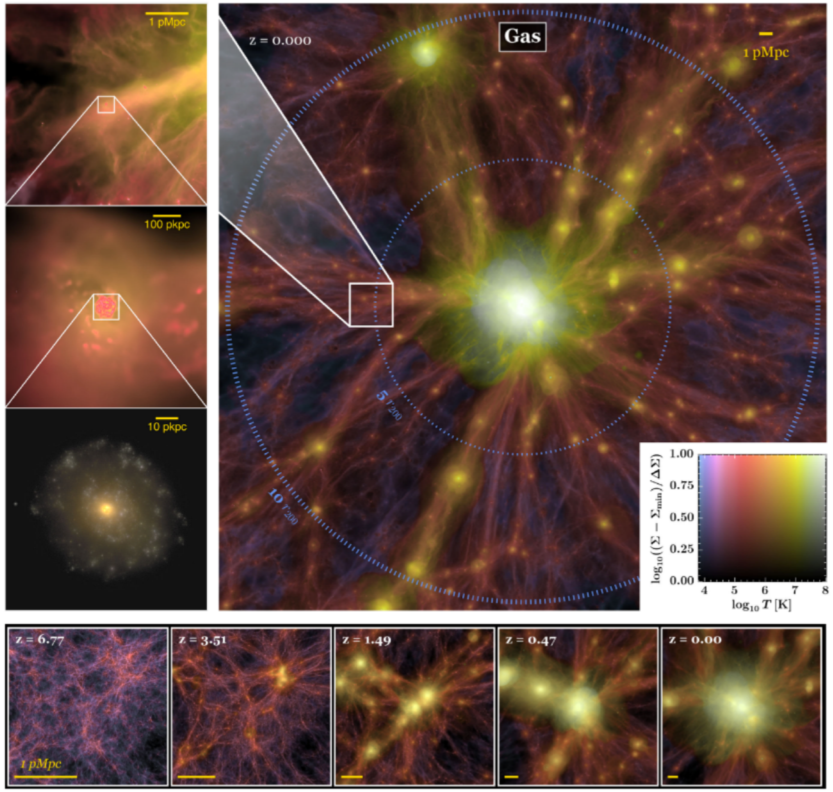
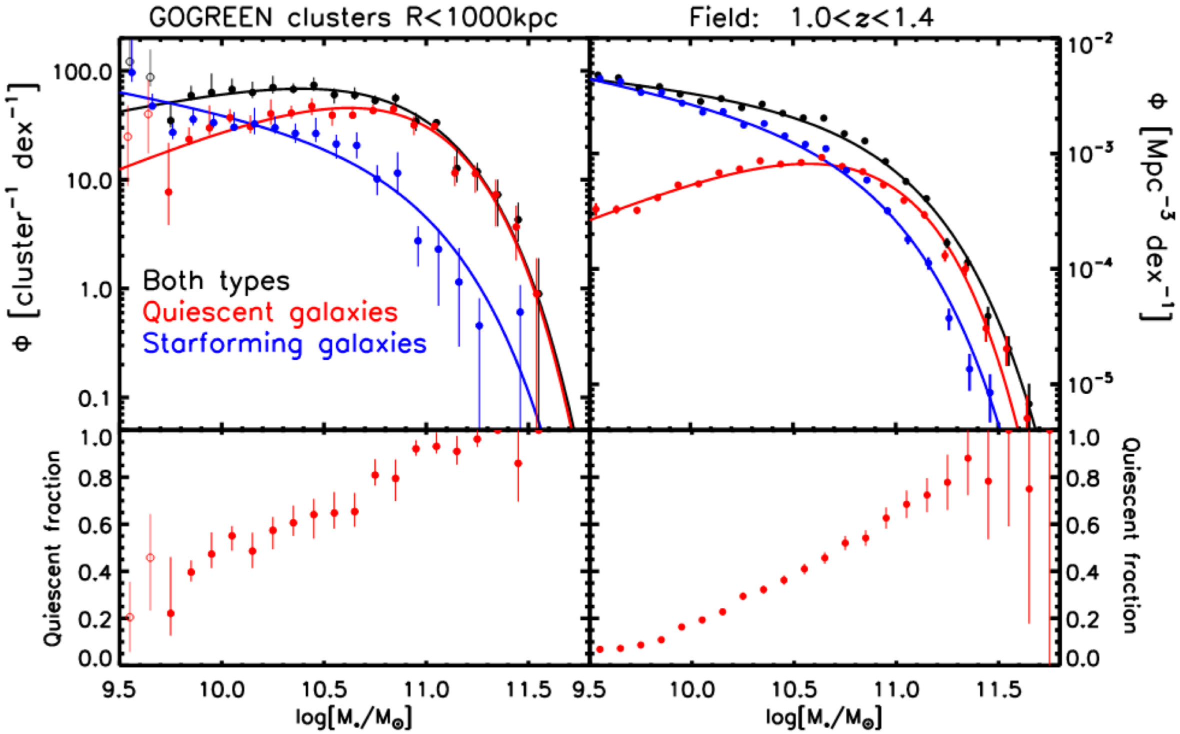
Rapid quenching and rejuvenating galaxies
Cressida Cleland & SM
arXiv: 2006.16307

Bringing together theory and observations



(Bahe et al. 2017)



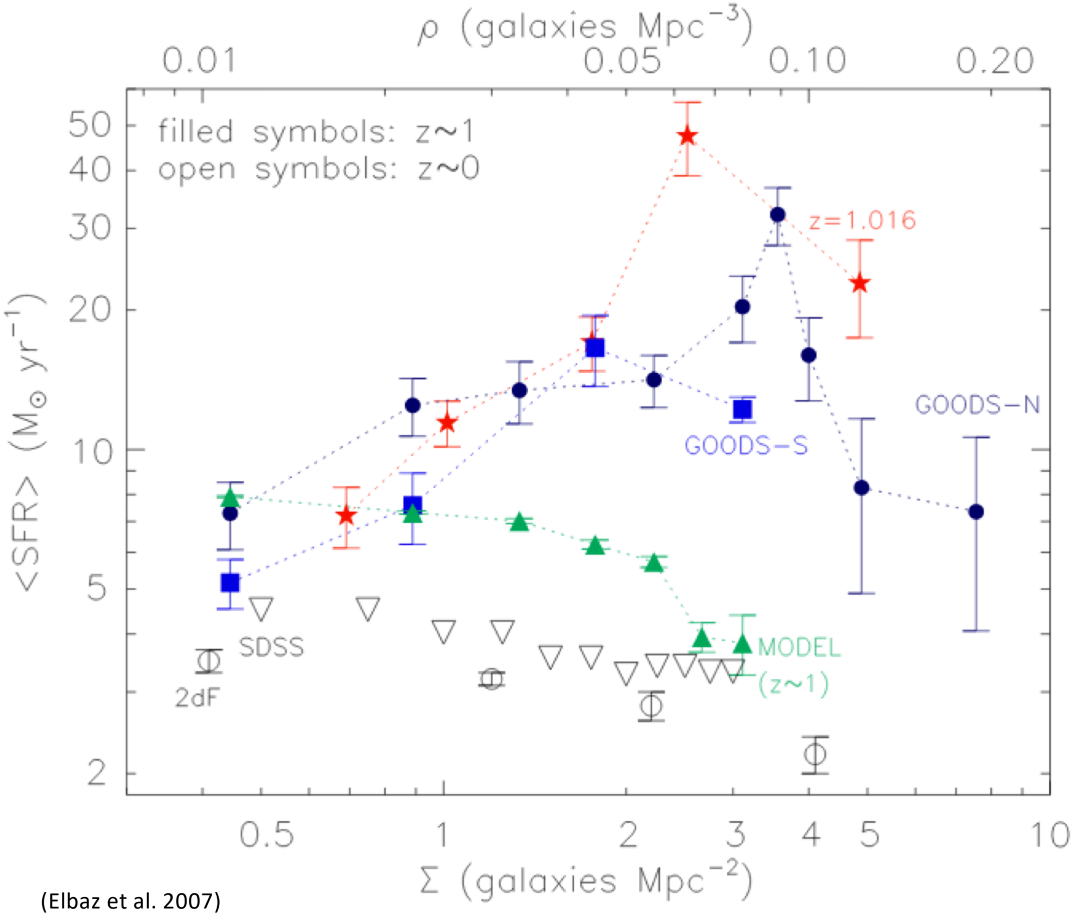
(van der Burg et al. 2020)

Points to enhanced/early evolution of galaxies in protoclusters?

Impact of environment beyond quenching

- ‘Enhancement’ of star formation
- Stellar mass/halo mass relations
- Stellar age distributions
- Gas content
- Black holes – content and ‘enhancement’
- Morphologies – shape and size
- Kinematics, abundances, etc.
- Rejuvenation of star formation
- Stellar mass function/fractions
- Diffuse intracluster light
- Hot gas properties, cluster masses, etc, etc.

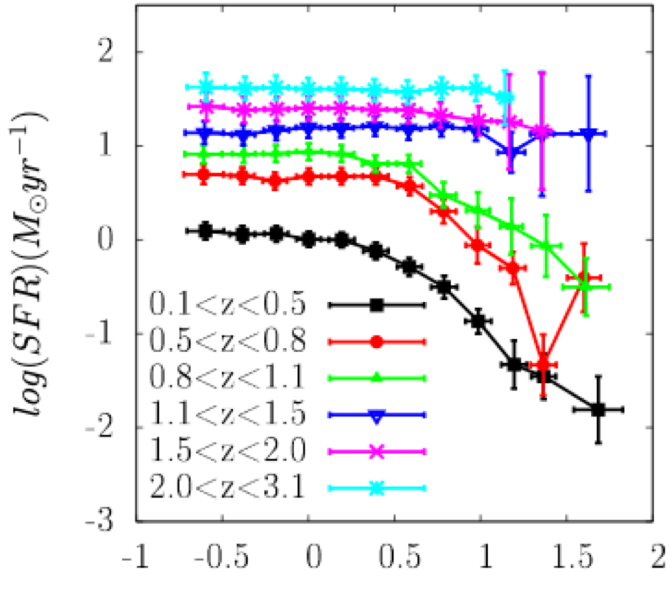
'Enhancement' (or reversal) of star formation



(Elbaz et al. 2007)

Elbaz et al. (2007) claimed that at z ~ 1, the star formation rate per galaxy increased at with galaxy density.

The 'reversal' (or not) of the star formation-density relation with redshift has been one of the most debated topics in this field.



(Darvish et al. 2016)

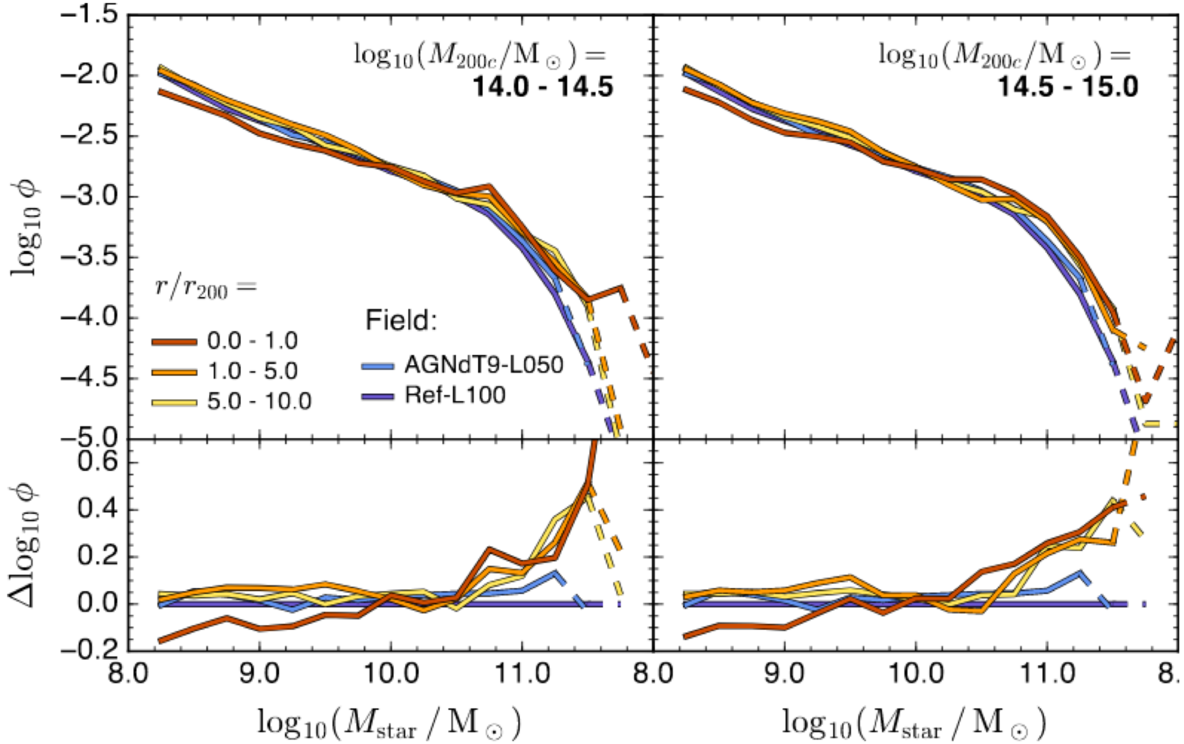
Reversal might be required for enhanced/early evolution of galaxies

Is the reversal (in itself) interesting?

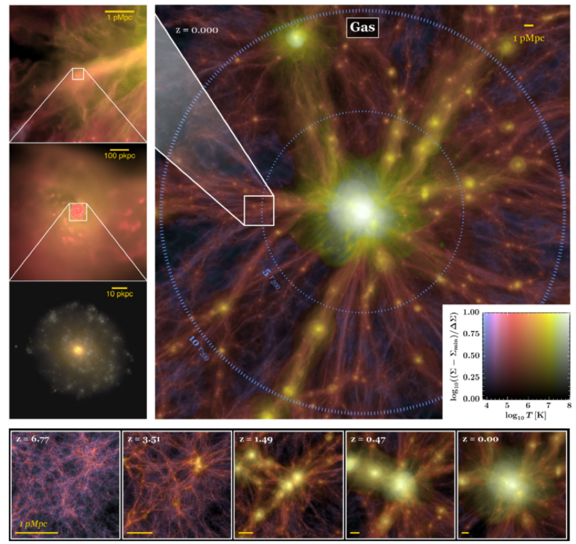
Imprints on stellar-halo relation/concentration

Hydrangea clusters (Bahe et al. 2017)

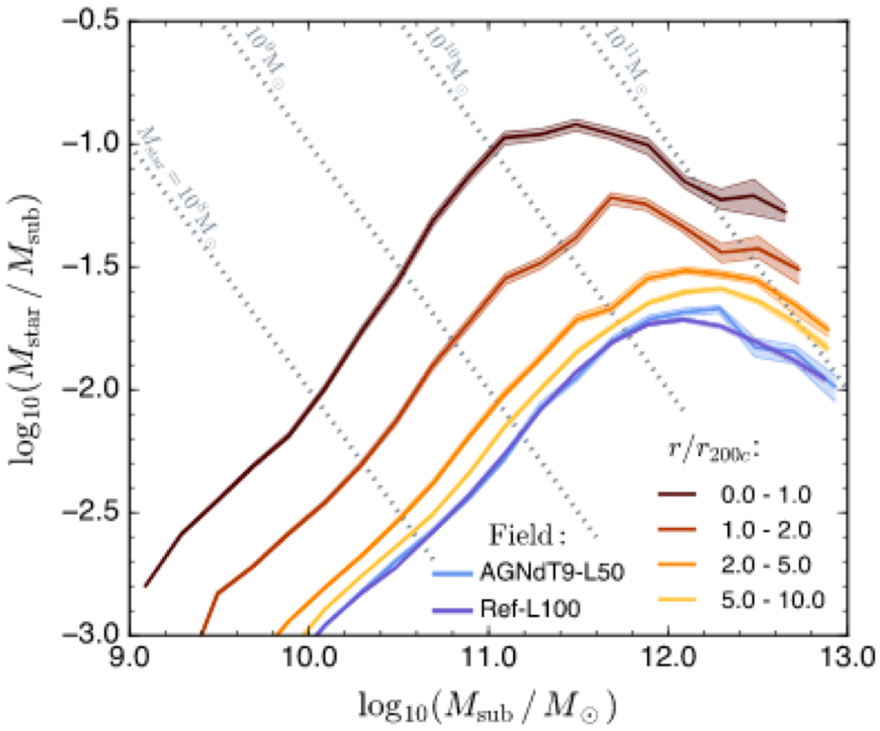
An excess of massive (>10^(10) Msun) galaxies was found on the outskirts of clusters in these simulations.



(Bahe et al. 2017)



Imprints on stellar-halo relation/concentration

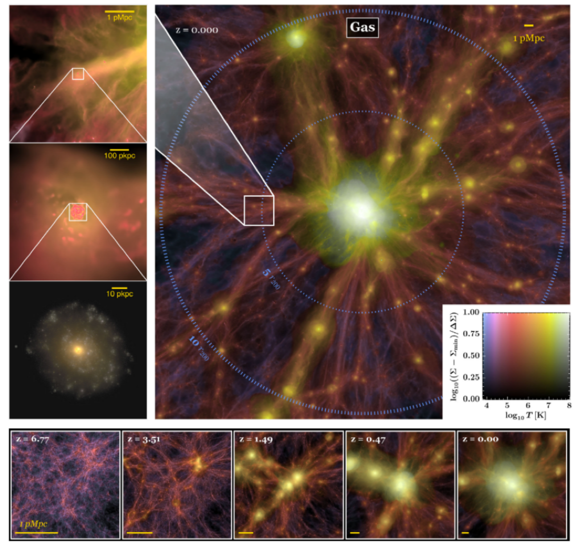


(Bahe et al. 2017)

Hydrangea clusters (Bahe et al. 2017)

An excess of massive (>10^(10) Msun) galaxies was found on the outskirts of clusters in these simulations.

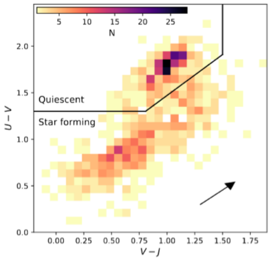
But it was not because of an excess of massive subhalos – a different stellar mass – halo mass relation exists. Seems to be due to an excess of star formation in protocluster environments. ('reversal')

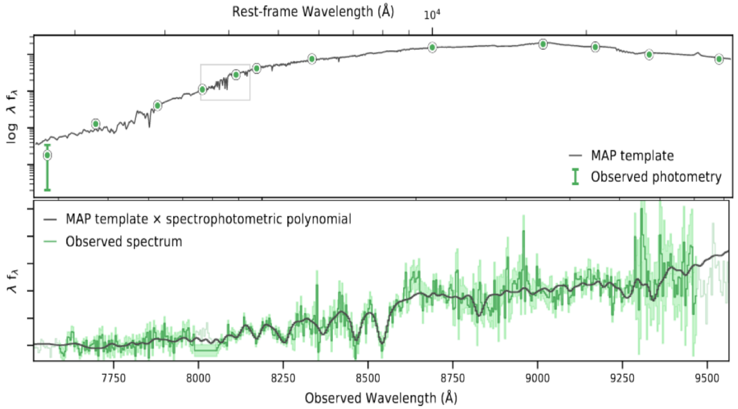


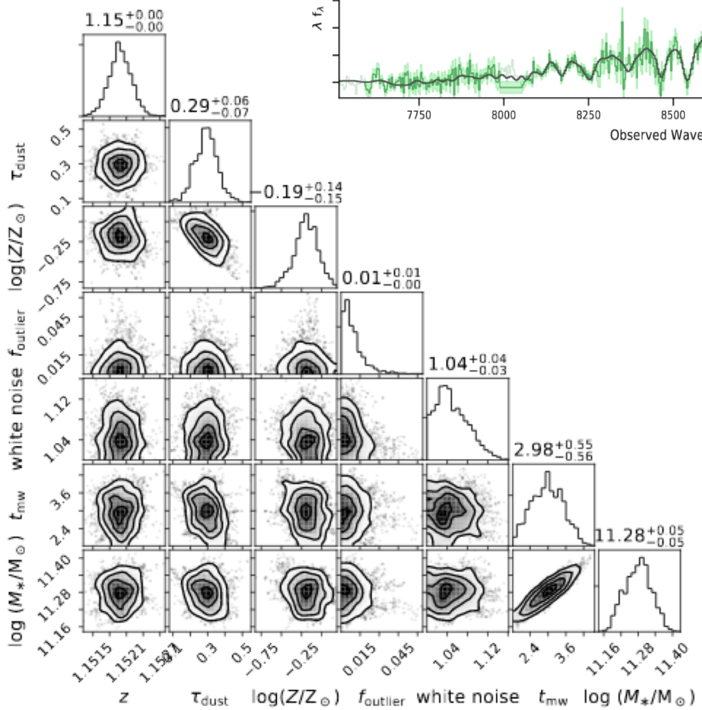
Suggests early enhancement of star formation in protocluster environments

Would we have come to the correct interpretation if seen in observations?

Stellar age distributions



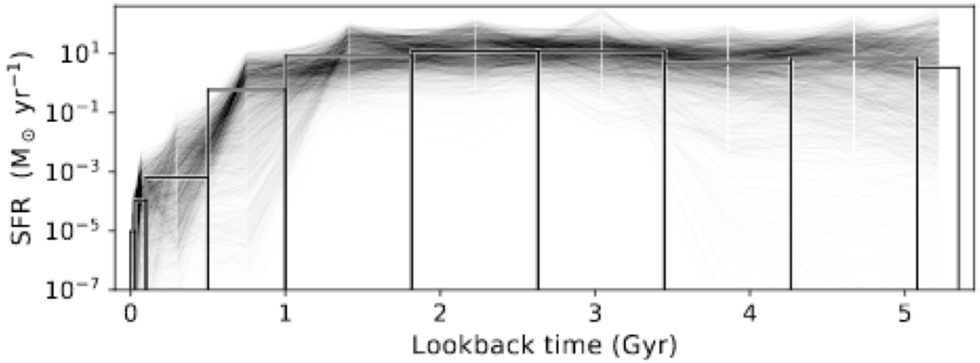




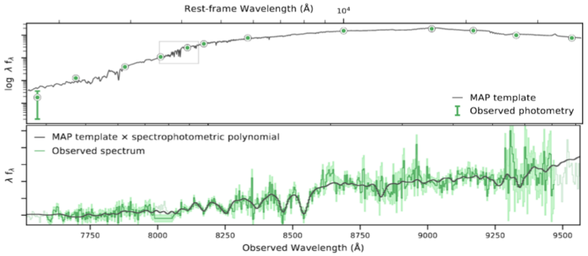
(Webb et al. *in prep*)

GOGREEN cluster survey at z = 1 – 1.5
Results from Old, Chan, van der Burg previously.
Kristi Webb (Waterloo) work on stellar ages of quiescent galaxies.

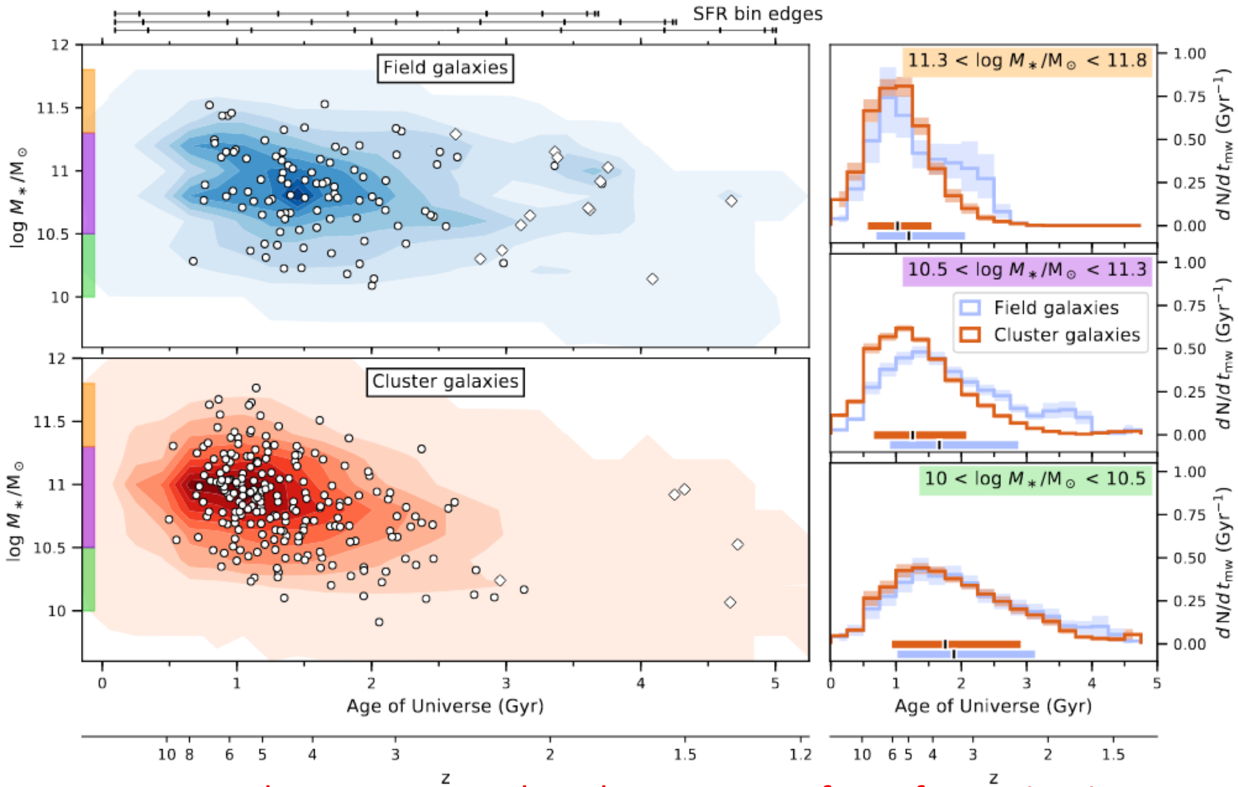
Detailed stellar population (spectra and photometry) to constrain ages/star formation histories of 350 field/cluster galaxies at 1 < z < 1.5



Stellar age distributions



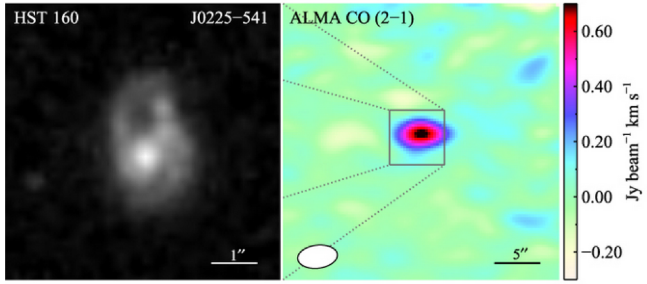
Detailed stellar population (spectra and photometry) to constrain ages. On average, relatively small age difference of 0.31 Gyrs between cluster and field galaxies overall.



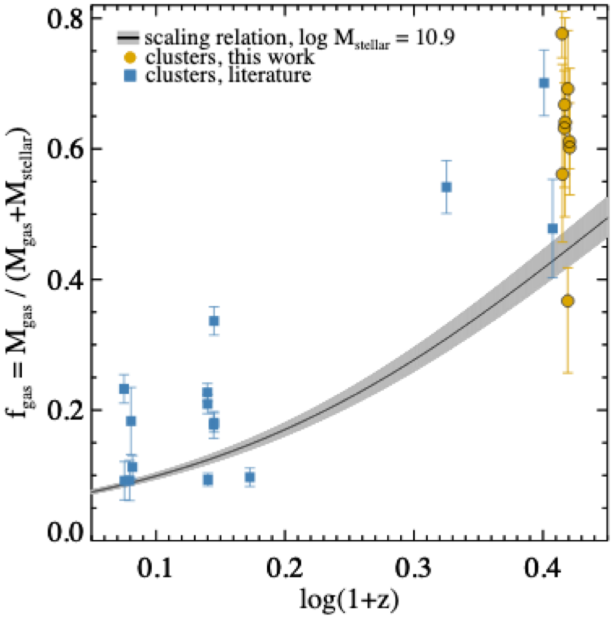
(Webb et al. *in prep*)

Maybe suggests early enhancement of star formation in protocluster environments

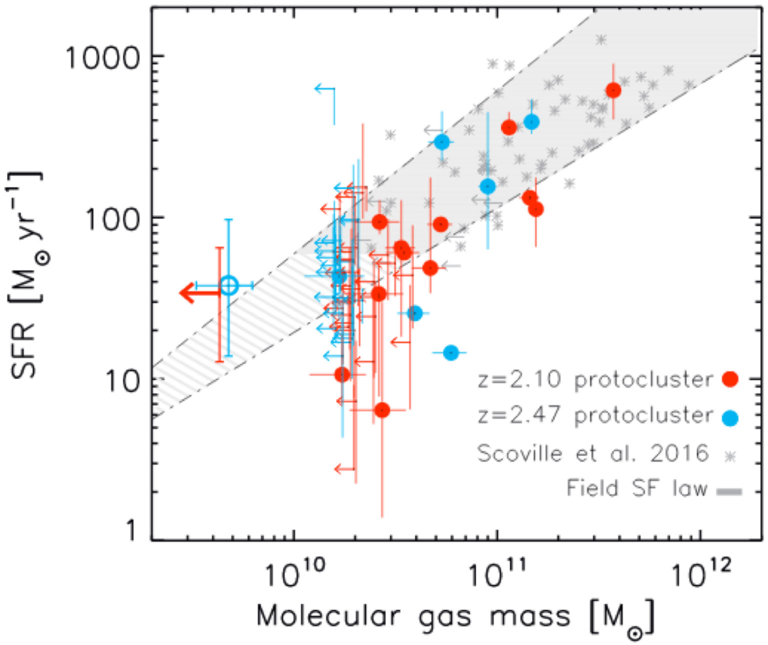
Gas fractions/mass



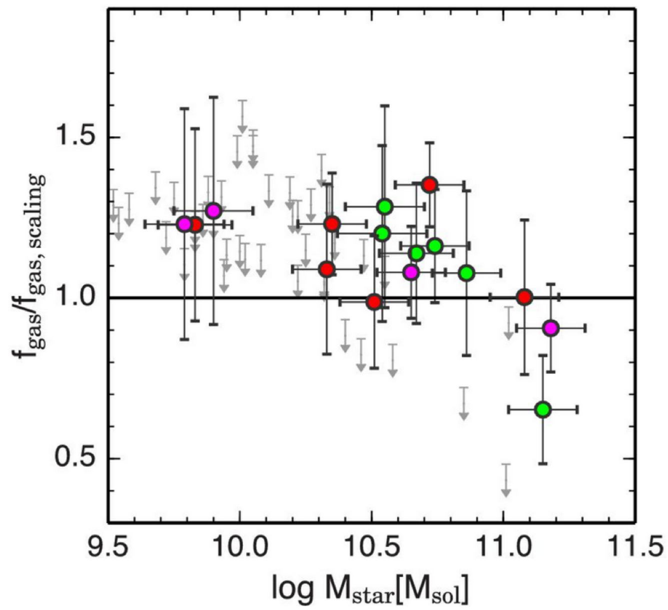
(Noble et al. 2017)



(Noble et al. 2017)



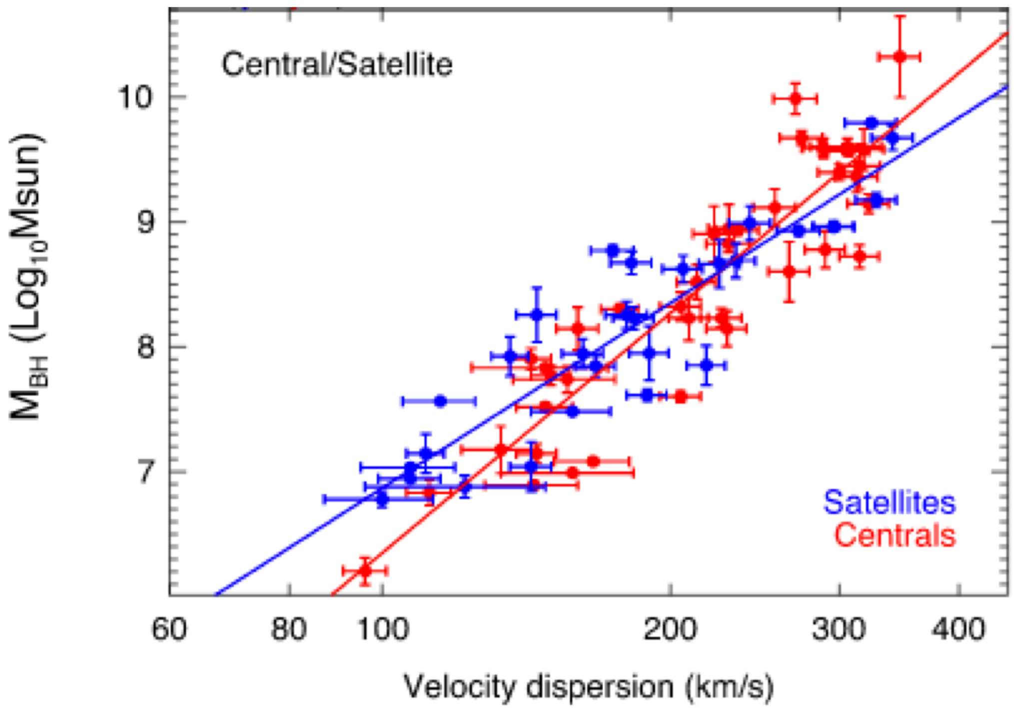
(Zavala et al. 2019)



(Tadaki et al. 2019)

Large samples clearly the next important step forward

AGN – Enhanced BH growth/tidal stripping?



(McGee 2013)

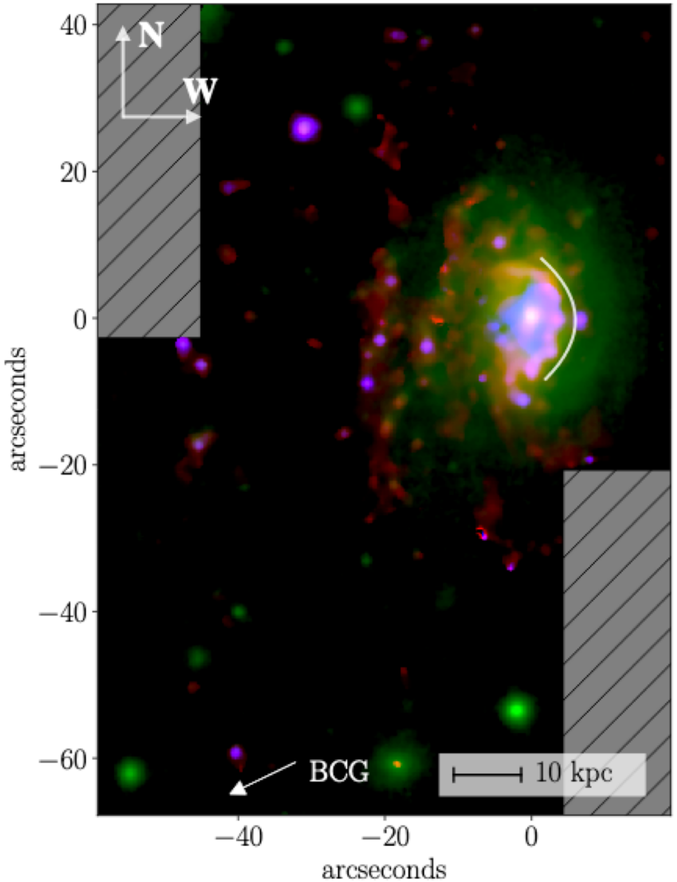
Directly measured black hole masses vs velocity dispersion broken up by ‘environmental’ parameters

‘central’ slope ~ 6.4 +/- 0.5
‘satellite’ slope ~ 4.9 +/- 0.5

Similar differences for other environmental parameters

At the time, “we suggest that gas-rich, low-mass galaxies undergo a period of rapid black hole growth in the process of becoming satellites”

Ram pressure linked AGN emission?



(Bellhouse et al. 2019, 2018)

GASP survey (PI B. Poggianti) – MUSE follow-up of 100 ‘jellyfish’ / ram pressure stripped galaxies

A wide range of papers on star formation, gas, metallicity, etc in these galaxies. (See Marco’s talk this morning)

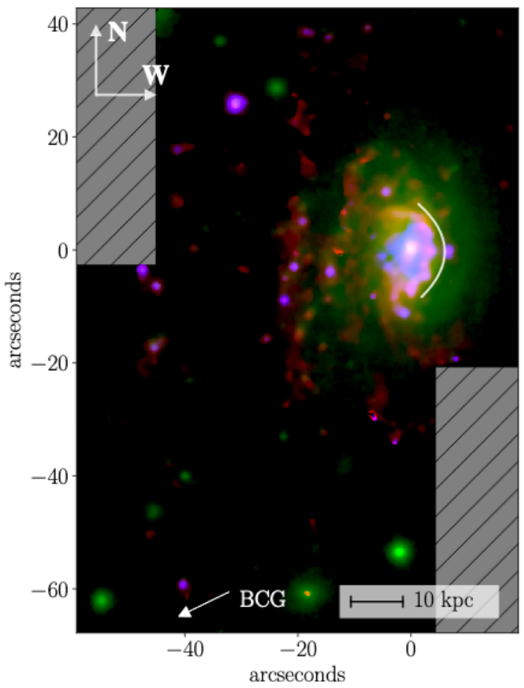
An examination of the most strongly stripped galaxies (Halpha tail at least as long as the galaxy stellar disc diameter)

Ram pressure linked AGN emission?

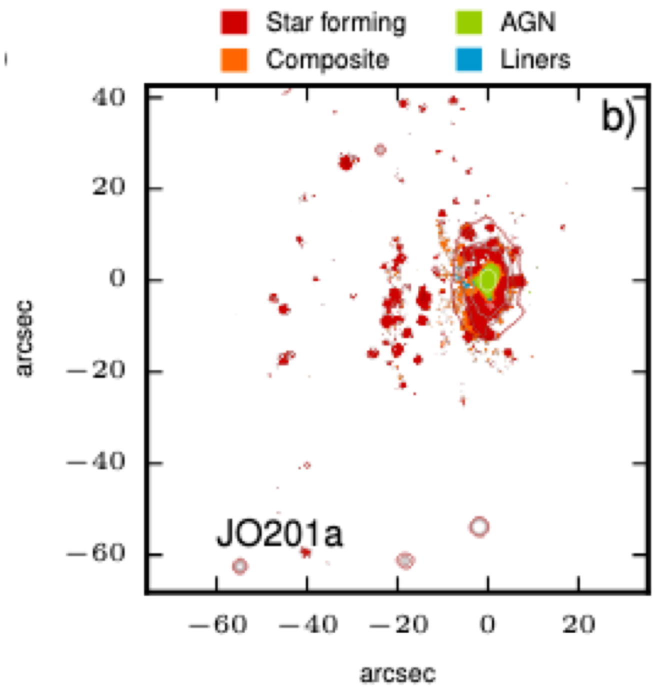
GASP survey (PI B. Poggianti) – MUSE follow-up of 100 ‘jellyfish’ / ram pressure stripped galaxies

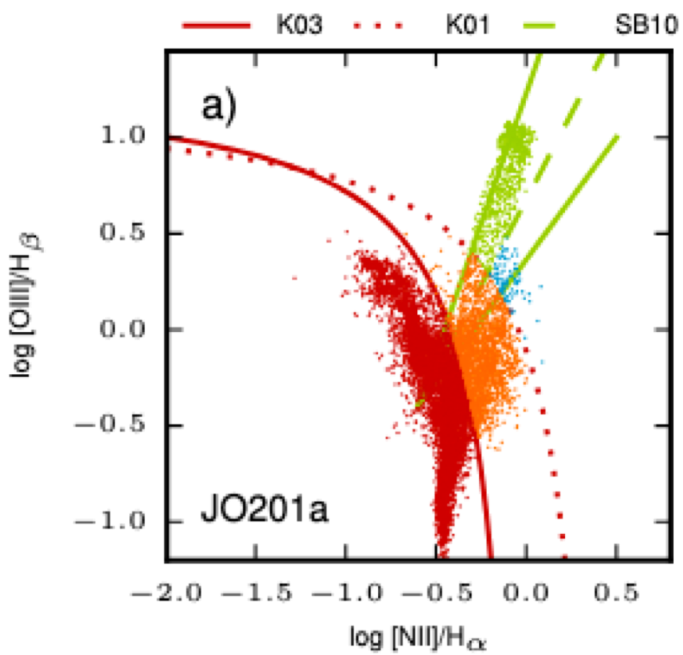
An examination of the most strongly stripped galaxies (Halpha tail at least as long as the galaxy stellar disc diameter) - 6 out of 7 had strong AGN emission

~ 3 percent expected from stellar mass matched galaxies not being stripped



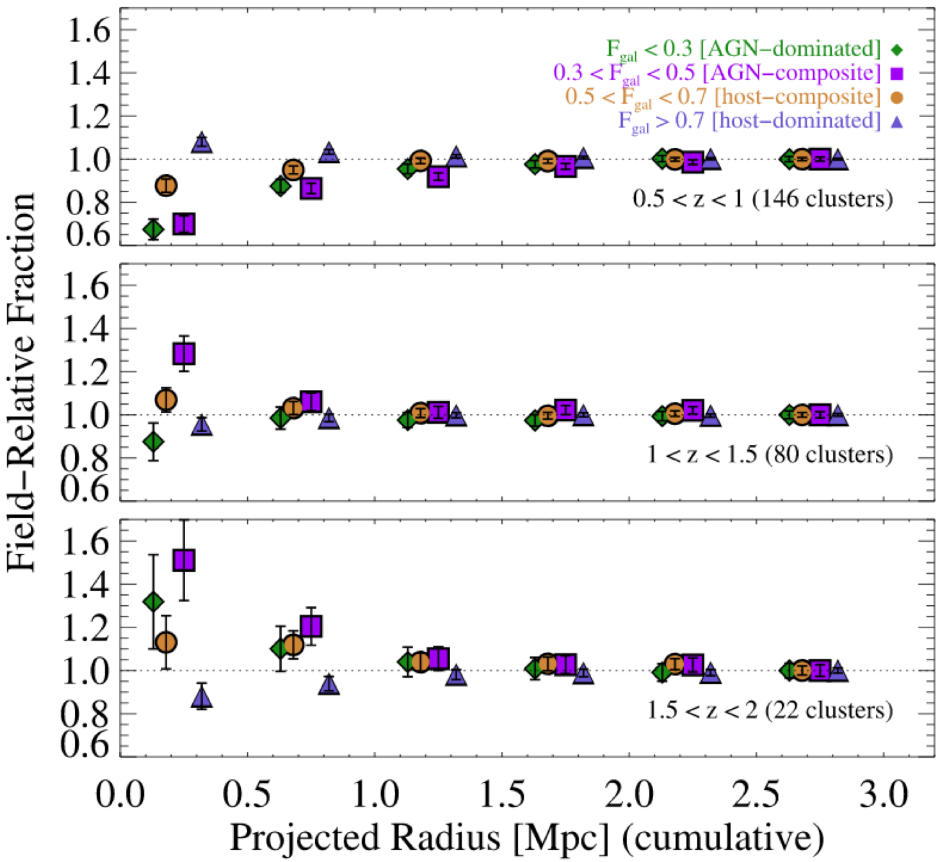
(Bellhouse et al. 2019, 2018)





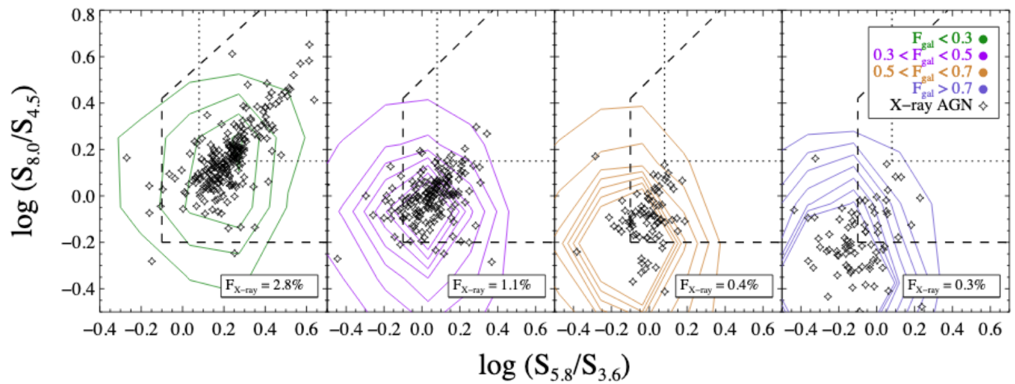
(Poggianti et al. 2017)

Cluster observations at high redshift



IRAC shallow and distant cluster survey

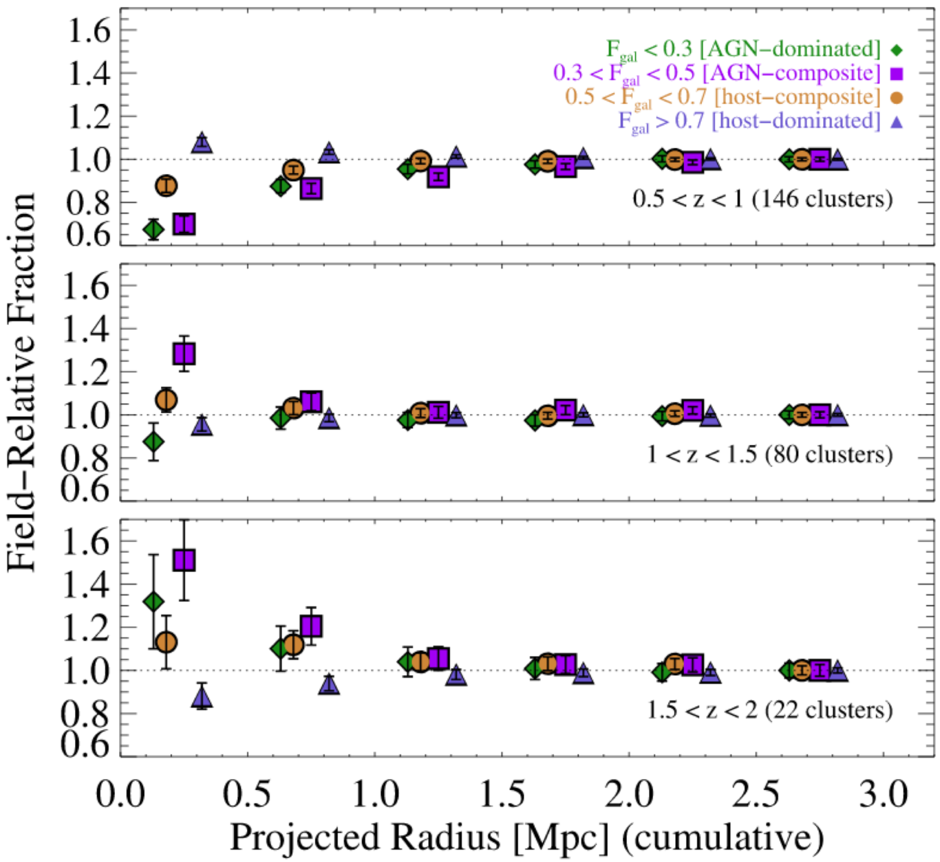
Used deep Herschel/PACS imaging together with other multi-wavelength imaging to constrain the AGN fraction through SED fitting.



Radial profile (relative to field) of ‘AGN-dominated’ / AGN-composite galaxies. – Excess seen certainly at z > 1.5

(Alberts et al. 2016)

Cluster observations at high redshift



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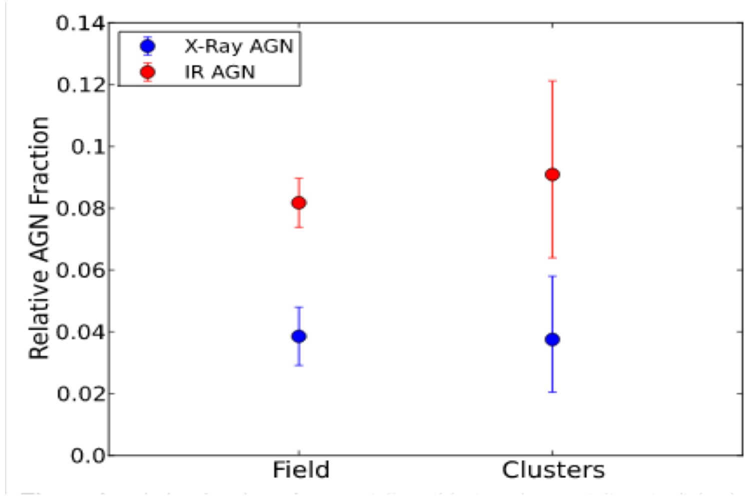
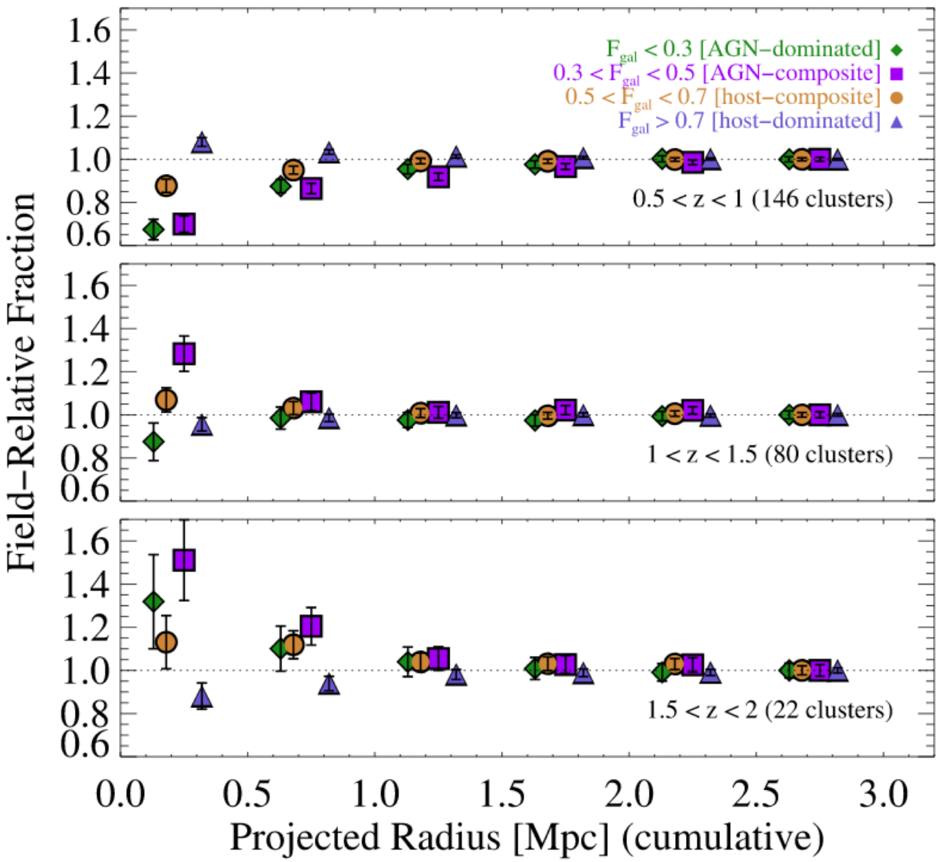
Similar levels seen In z = 1.2 clusters:



(Martini et al. 2013)

Cluster observations at high redshift



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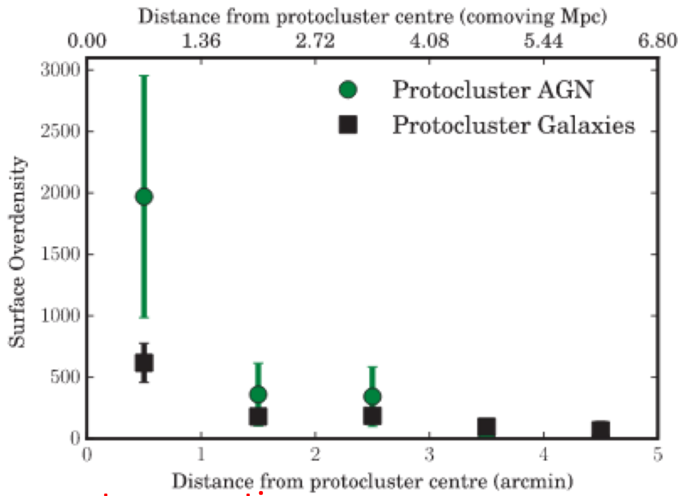
Enhanced levels in z = 1.6 protocluster/cluster (Krishnan et al. 2017)

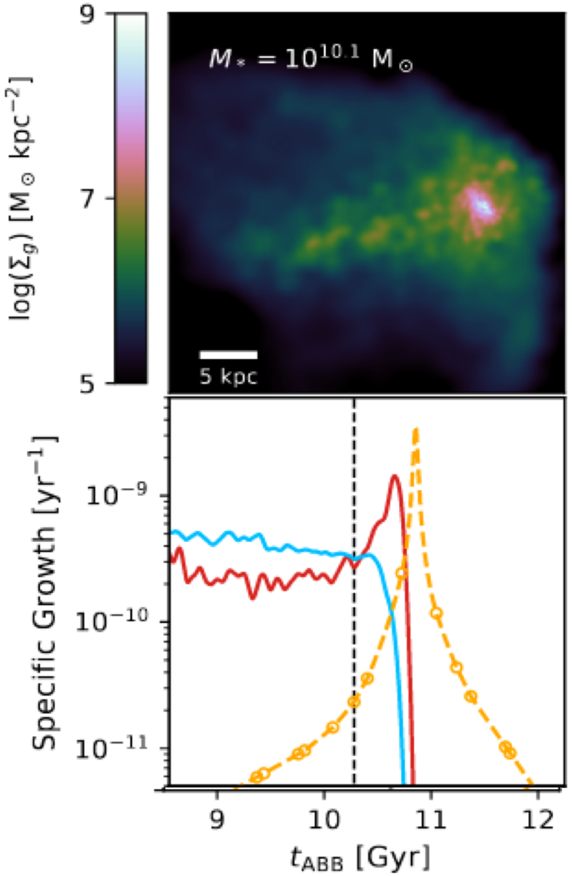


(Krishnan et al. 2017)

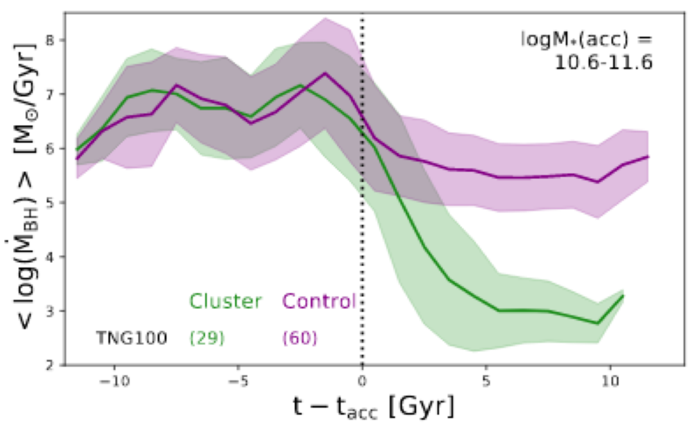
Observationally, seems clear that there is some AGN-environment connection

Simulations of the environmental BH effect

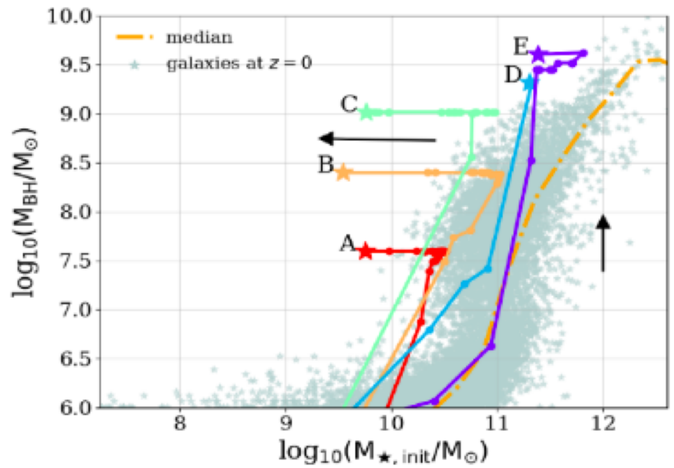
An interesting problem for cosmological simulations – although often tests the limits of the subgrid implementation



(Ricarte et al. 2020)



(Joshi et al. 2020)



(van Son, L et al. 2019)

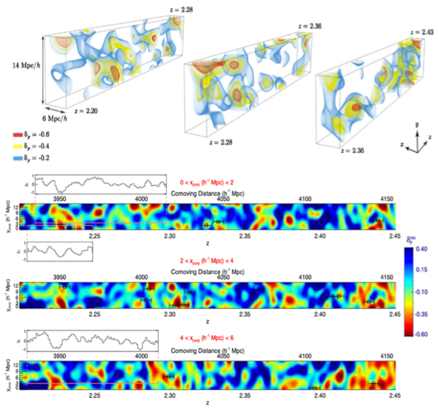
ROMULUS C – ~10^10 Msun have enhanced BH accretion near pericenter, suppressed at lower mass (Ricarte et al. 2020)

IllustrisTNG – cluster disk galaxies have reduced BH accretion after accretion into the cluster (Joshi et al. 2020)

Hydrangea/Eagle – overly massive black holes in cluster galaxies largely caused by tidal stripping of stellar material (van Son et al. 2019)

Conclusions – The future

- Several lines of evidence pointing to possibility of early evolution of cluster galaxies at z = 1-2
- Interesting picture of gas fractions, etc at high z emerging, will be really useful to get larger samples
- Black hole – environment connection an important emerging trend.
- Future at these redshifts are difficult – when will we get large samples of gas profiles (temperature/density),



Could map IGM on 100 kpc with spectroscopy of g=26 mag sources.

(Lee et al. 2014)

- Important to make like-for-like comparison of simulations and observations
    - Avoids observational arguments that are not the physics (reversal of star formation density)
    - Can learn the physics
    - The things we are spending time doing might not be the most important to learn the physics (It would be surprising if it was)
- Concentrated collaboration/effort to develop 'open-science' tools to facilitate these comparisons – morphology, metallicity, etc.