Dissecting z~1 Galaxy Clusters:
Studying Star Formation from the Outskirts to the Core

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How does Environment Influence Galaxy Evolution?

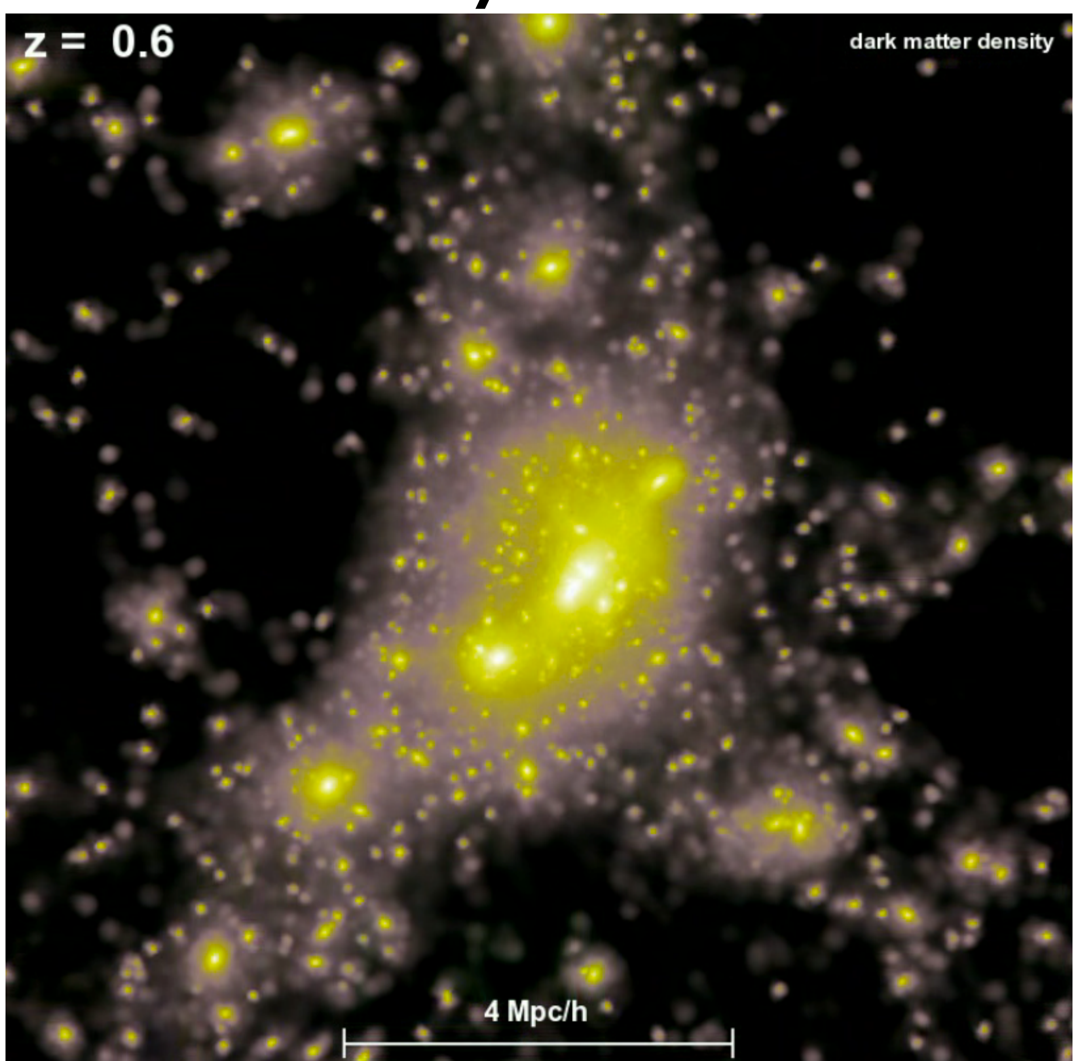
Hierarchical Structure Formation

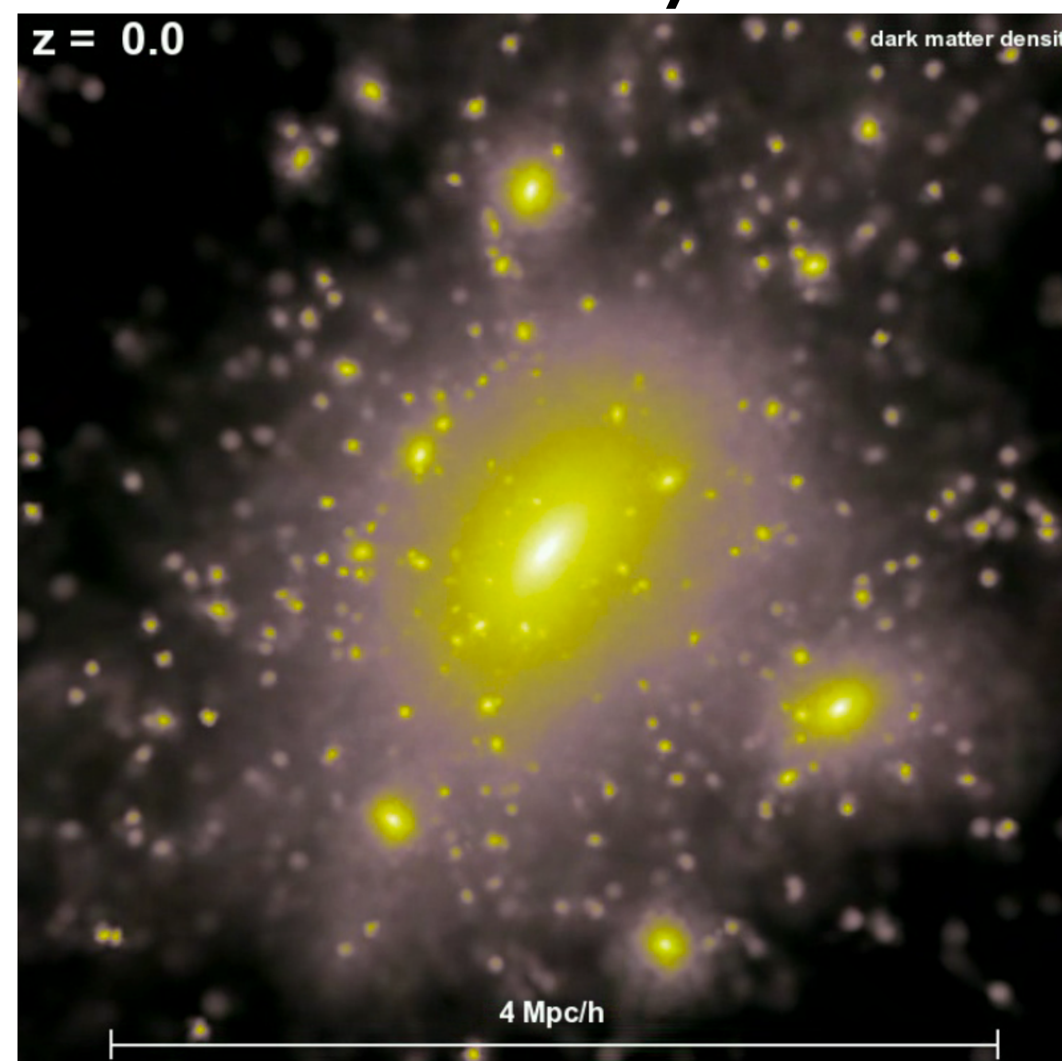
Distinct Galaxy Populations within Clusters

galaxies accreted at early times

vs

galaxies accreted recently





Credit: Volker Springel - MPIA

How does cluster environment shape galaxy evolution at z>1?

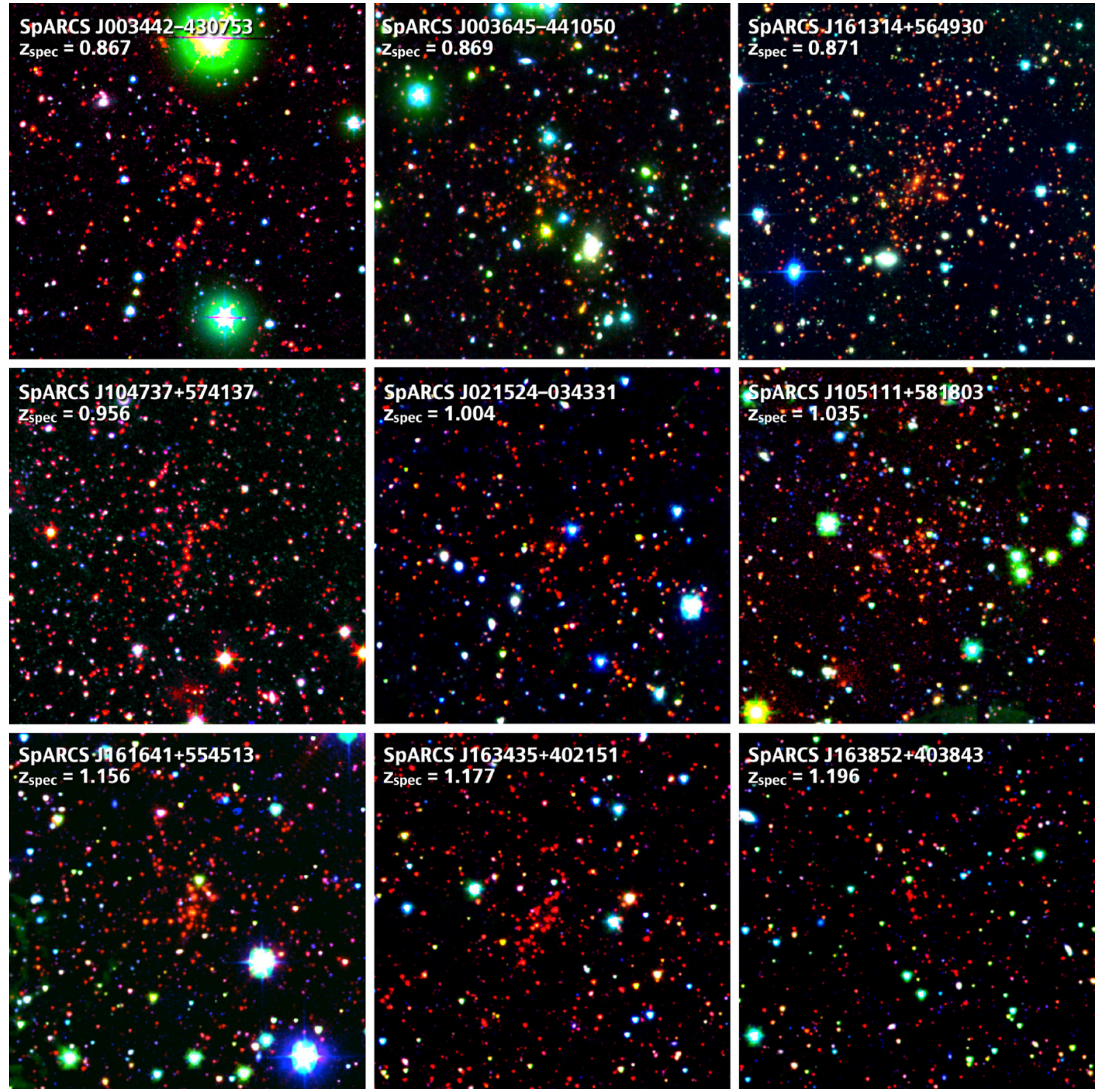
How we accomplish this

- develop a dynamical definition for environment
  → accretion histories can isolate dynamically distinct galaxy populations

- a homogenous sample of high-z clusters, with spectroscopy
  → SpARCS/GCLASS
  → see Gillian Wilson's talk today!

SpARCS Cluster Survey/GCLASS

- Cluster Red-sequence Method
- >200 massive infrared-selected cluster candidates
- 42 sq. deg. survey with z' (0.9um) band imaging
- GCLASS: 10 spectroscopically confirmed clusters from $0.86 < z < 1.34$ with ~500 members above 2e9 $M_\odot$



Muzzin et al 2012

SpARCS Cluster Survey/GCLASS

Mid/Far-Infrared

- $z = 0.871$
- 85 spectroscopic cluster members
- MIPS - 24um imaging

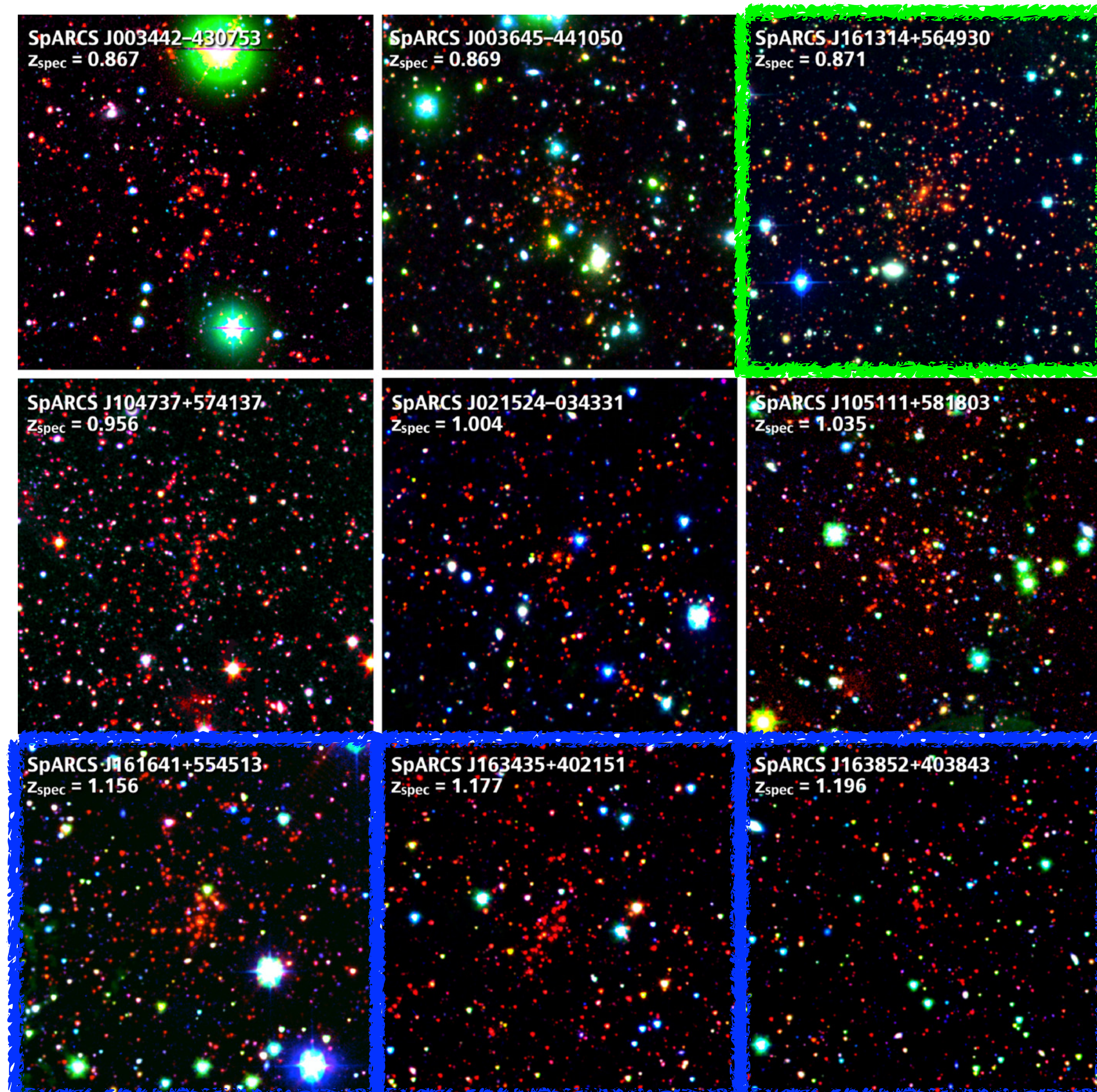
$$M_{200} = 2.6 \times 10^{15}\, M_{\odot}$$

Noble et al 2013

- $z \sim 1.2$
- 123 spectroscopic cluster members → stacking
- Herschel-100/160/250/350/500um imaging

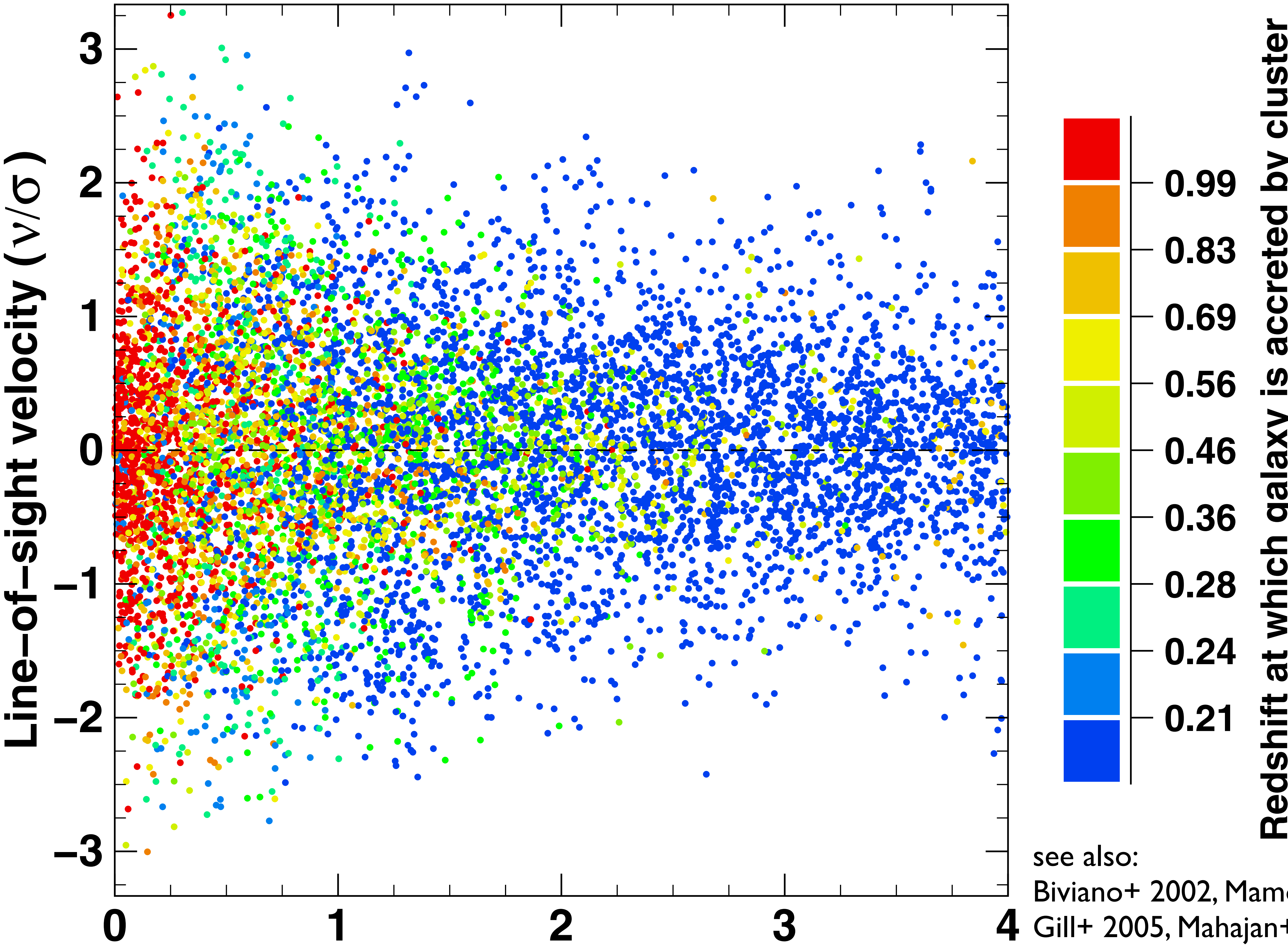
$$M_{200} = 1 - 4 \times 10^{14}\, M_{\odot}$$

Noble et al 2016



Muzzin et al 2012

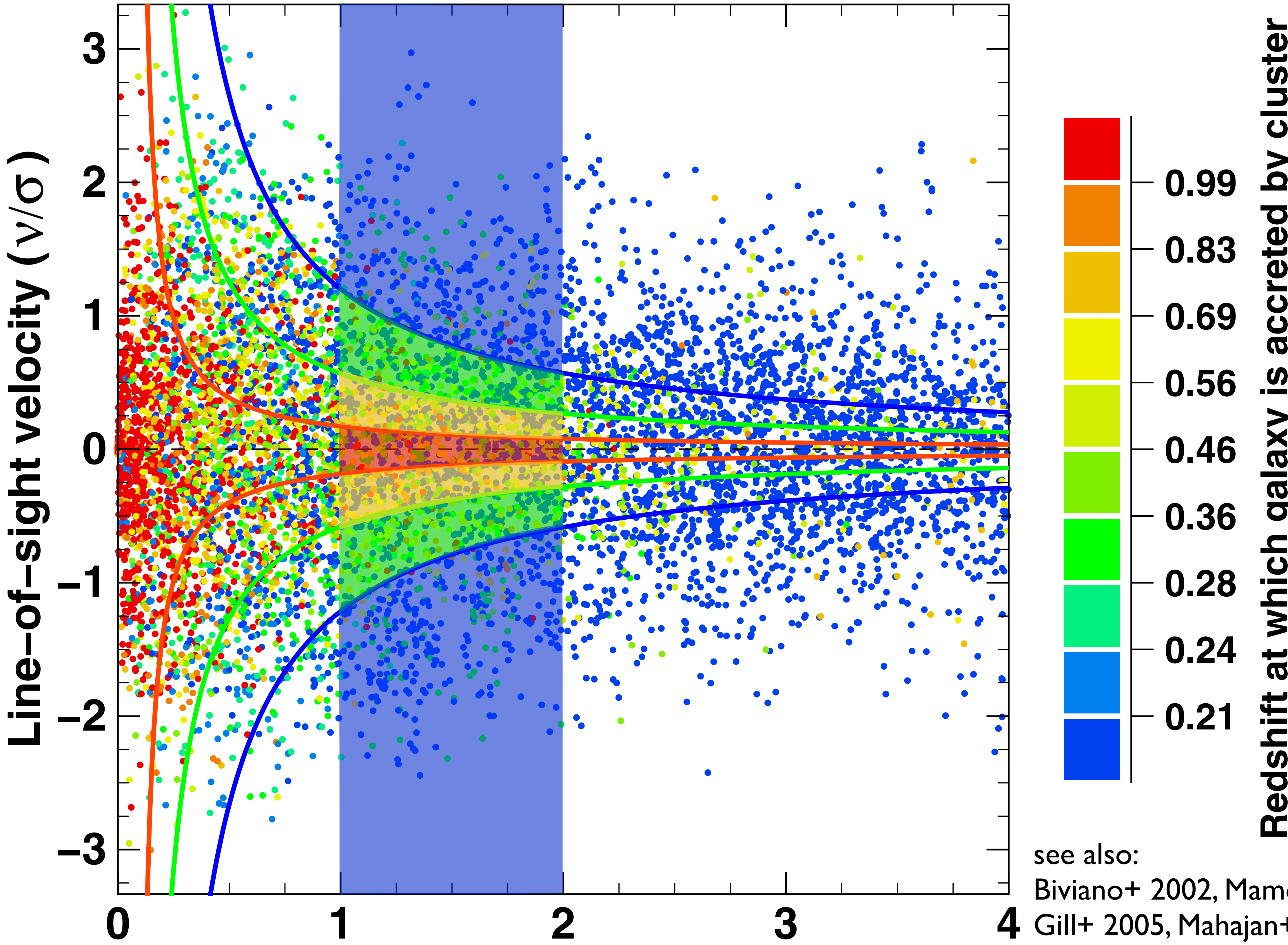
Isolating Accretion Histories with Simulations



Haines et al 2012

see also:
Biviano+ 2002, Mamon+ 2004, Gill+ 2005, Mahajan+ 2011, Oman+ 2013, Oman+ 2016, **Matt Ower's talk today!**

Isolating Accretion Histories with Simulations



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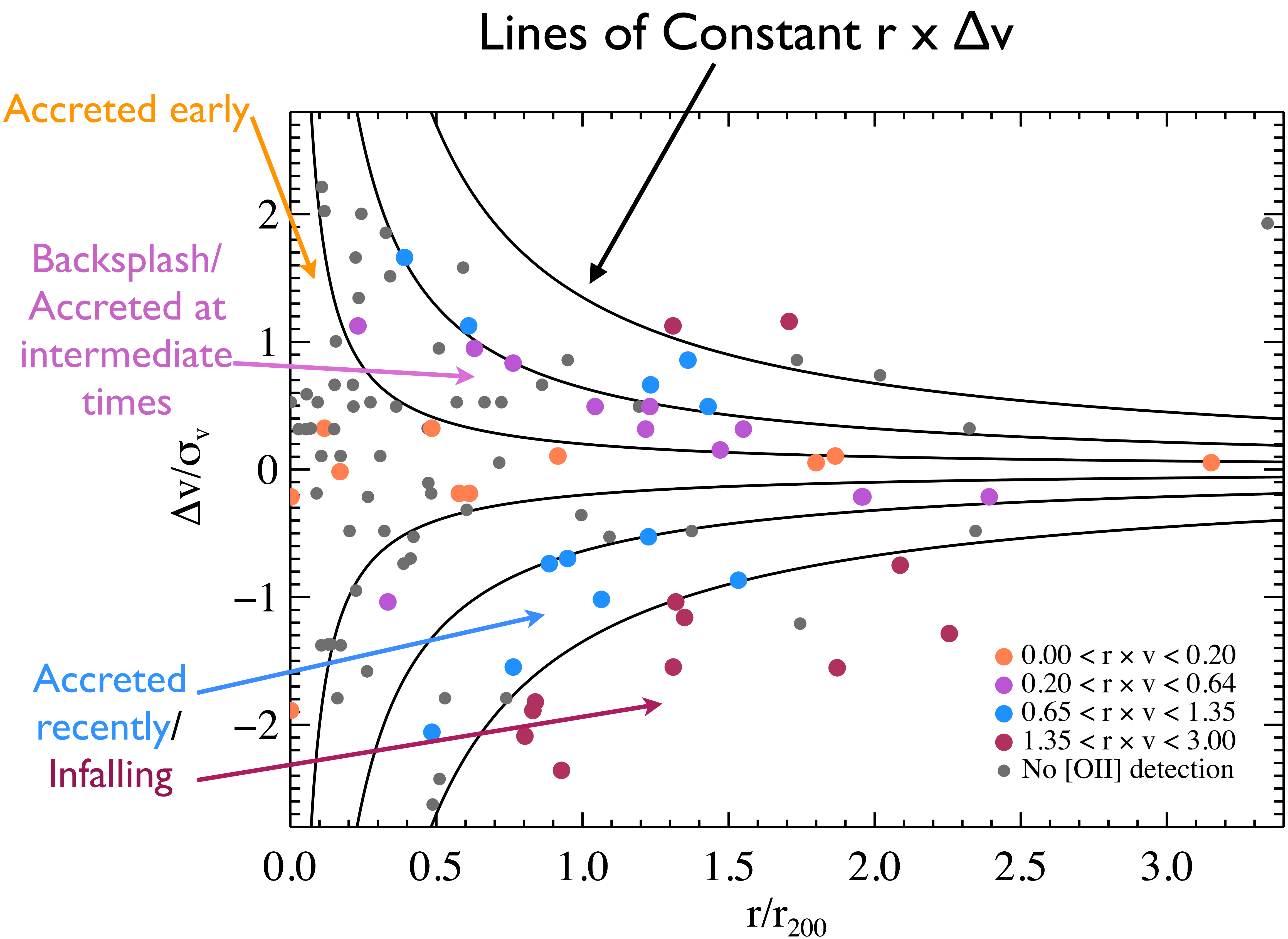
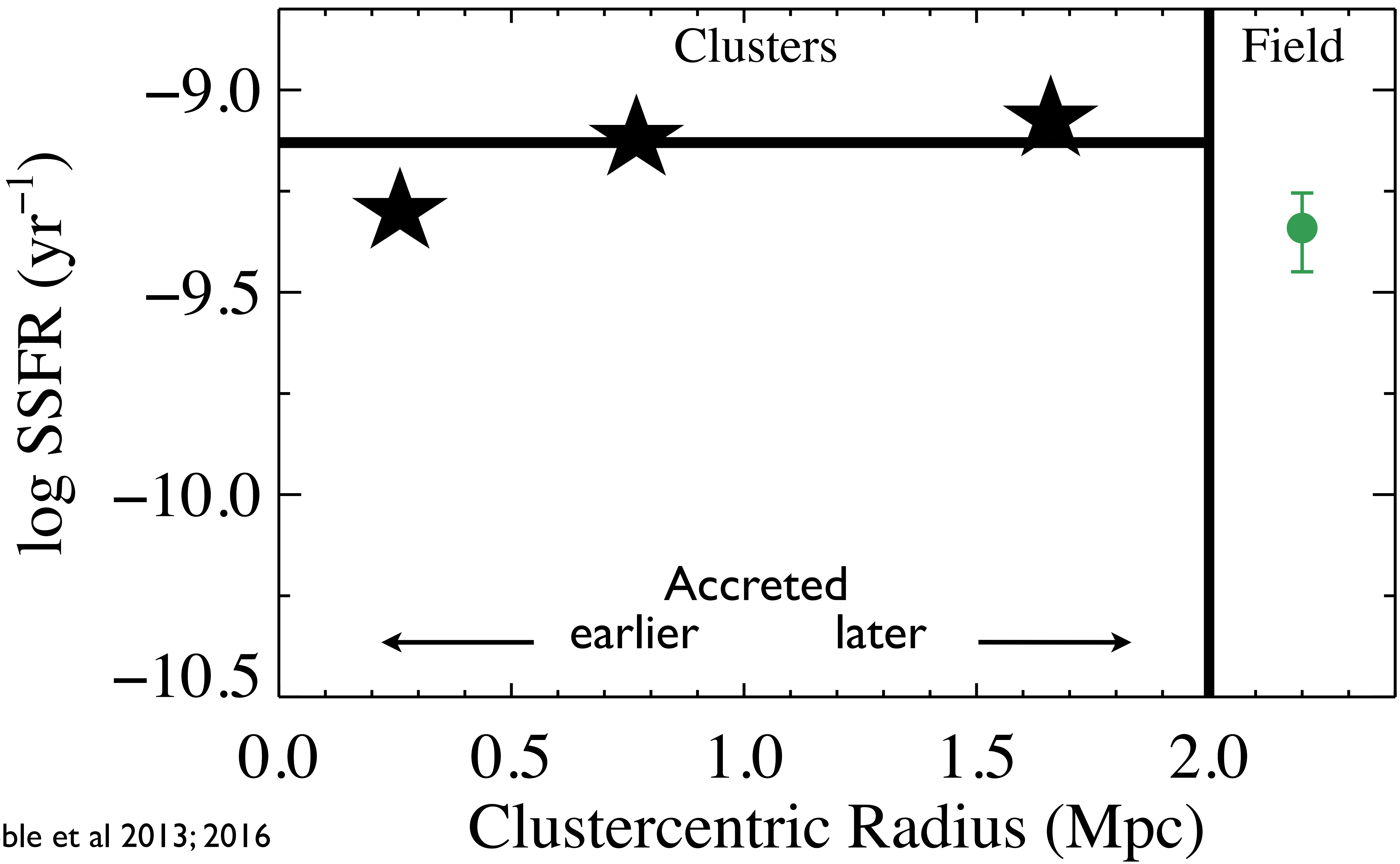
Isolating Accretion Histories in Phase-Space



Noble et al 2013; 2016

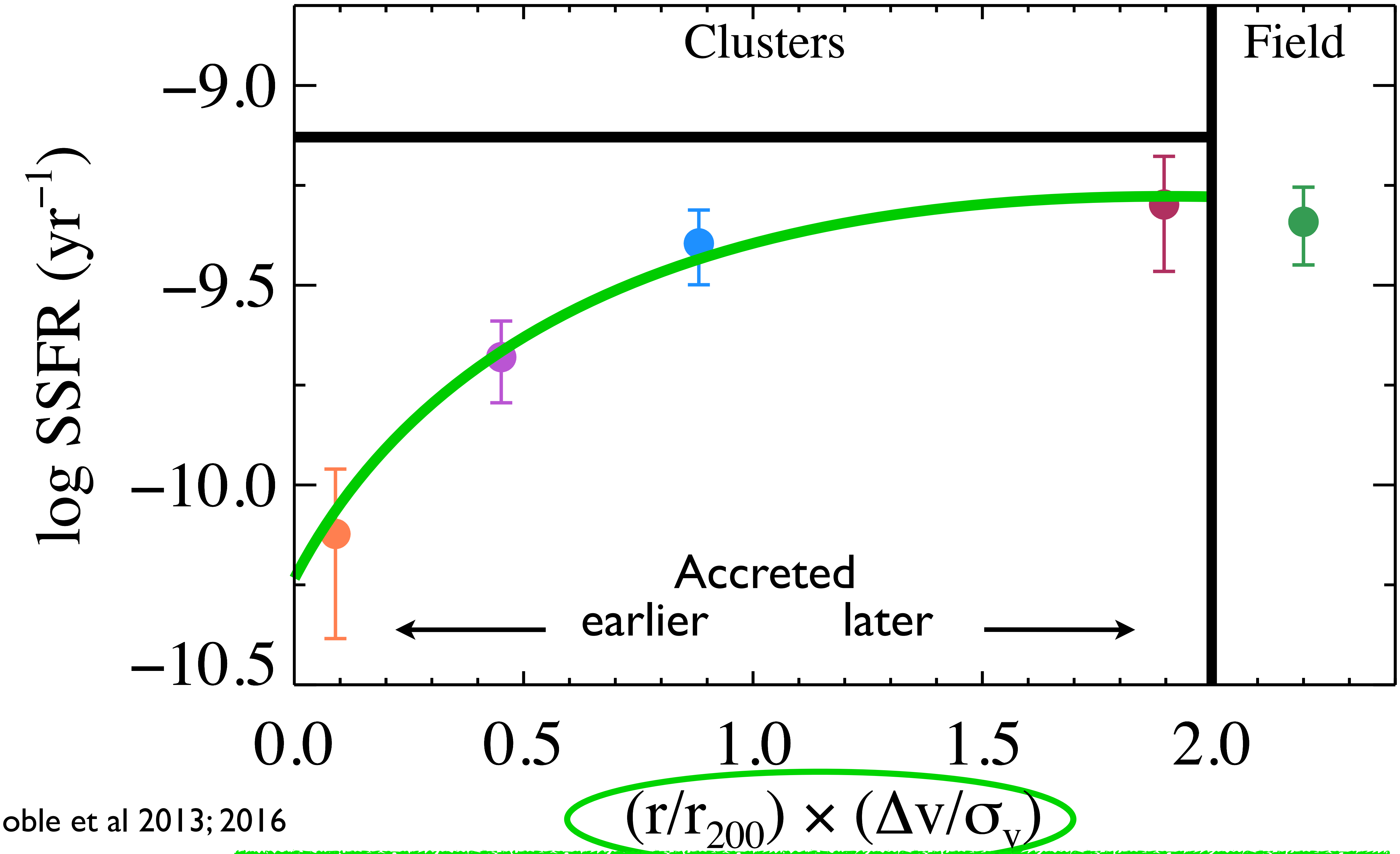
Specific SFR versus radius at z~1



Noble et al 2013; 2016

Flat trend with radius

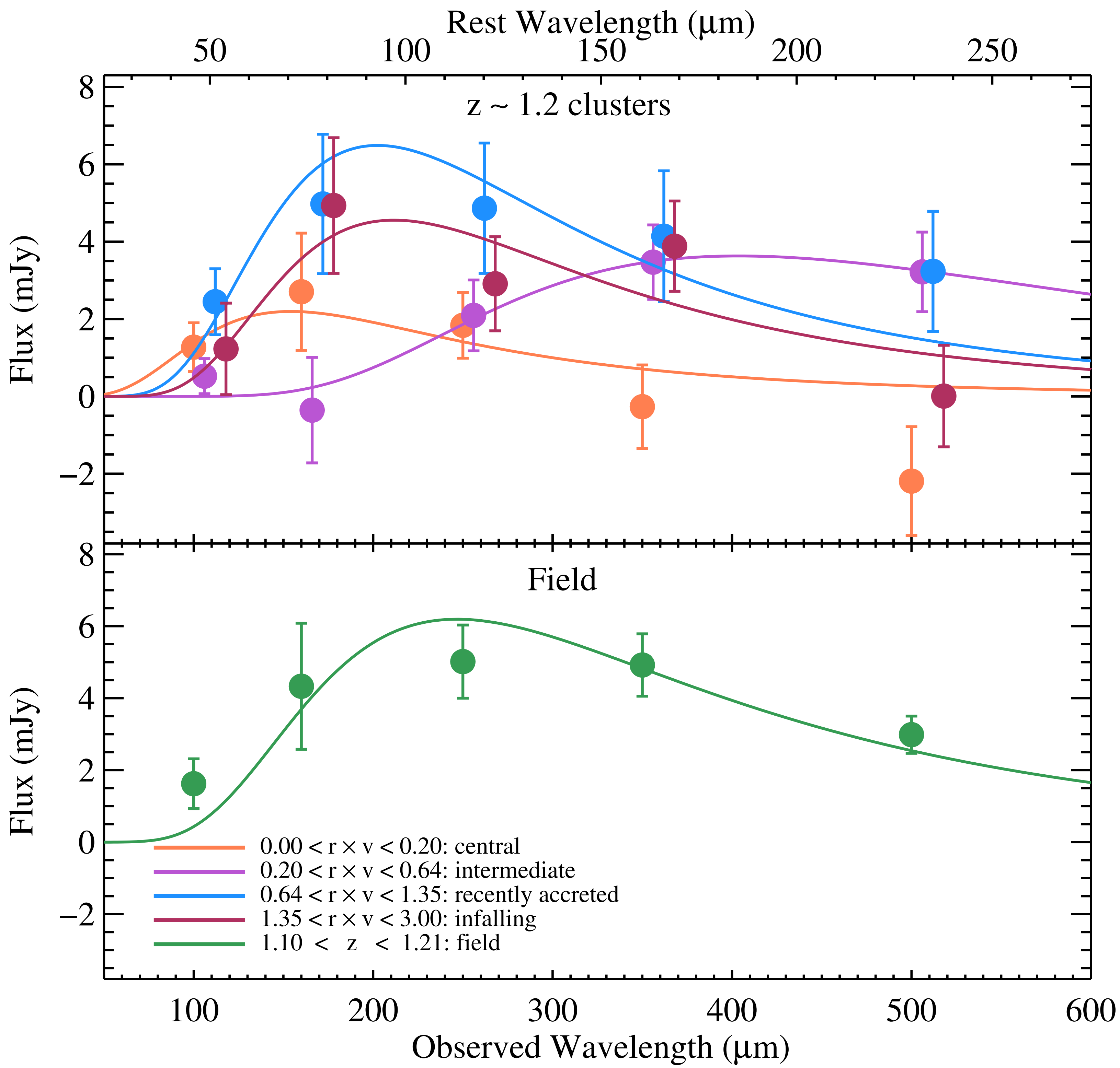
Specific SFR versus r x Δv at z~1



Noble et al 2013; 2016

An accretion-based definition of environment yields a ~1 dex depression of SSFR at low values of r x Δv

Stacked SEDs of z~1.2 Star-Forming Cluster Galaxies in Phase Space



Increasing $r \times \Delta v$

Accreted early

Intermediate

Accreted recently

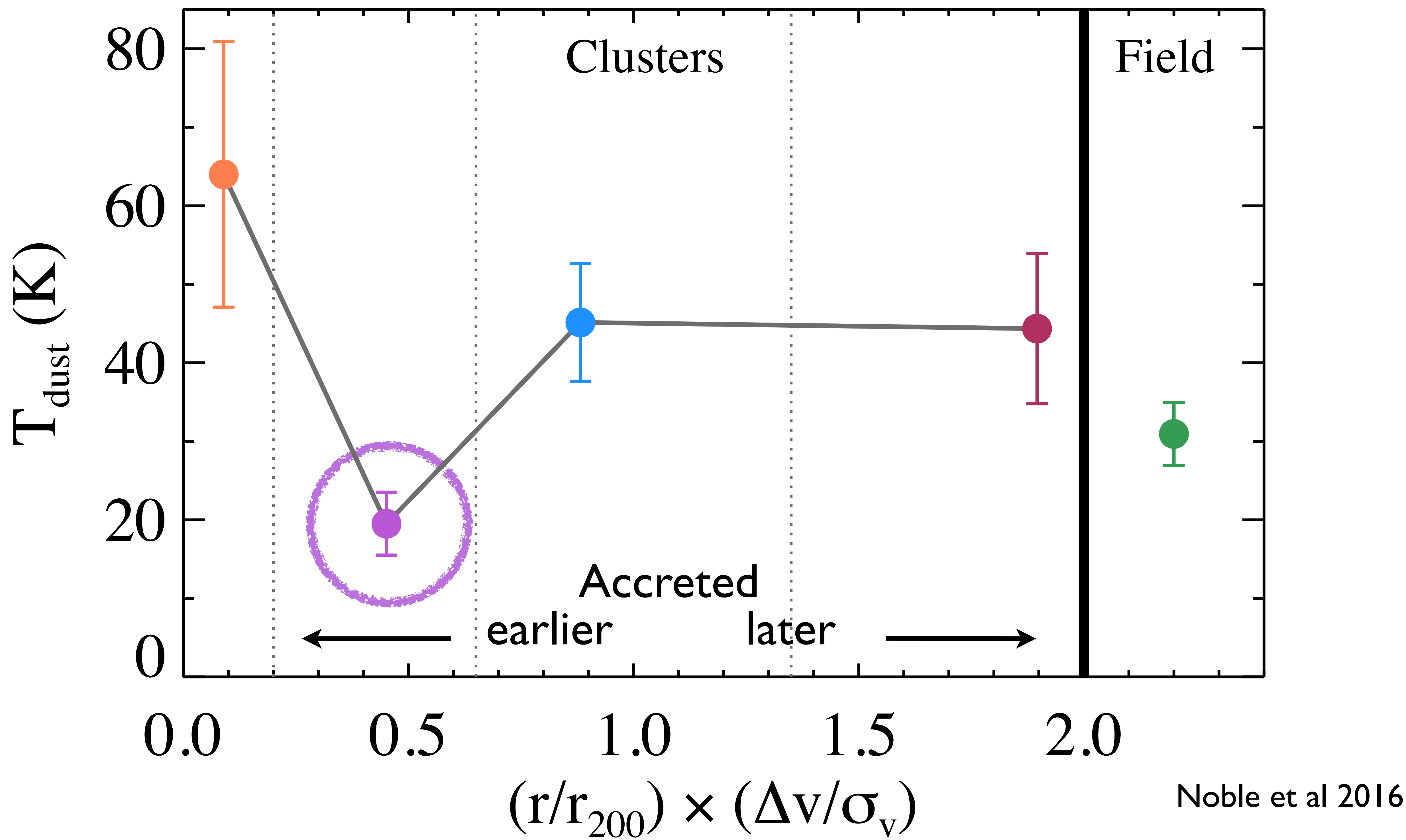
Infalling

Field

Intermediate population peaks at longer wavelengths

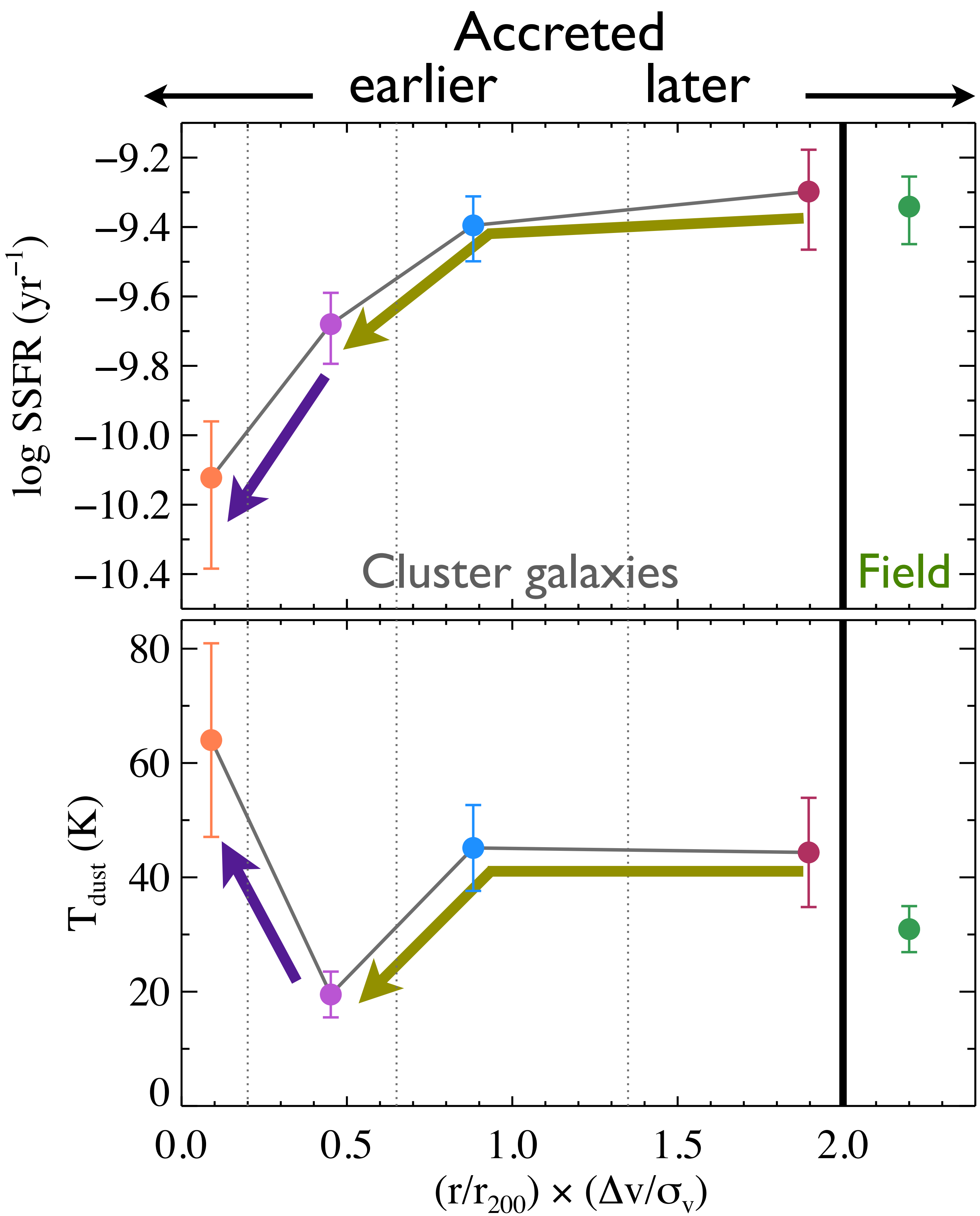
Noble et al 2016

Dust Temperature versus r x Δv



The intermediate phase-space bin has a ~4σ drop in dust temperature compared to infalling and earliest accreted bins

A Possible Quenching Model?



delayed decline in SSFR and removal of warm dust

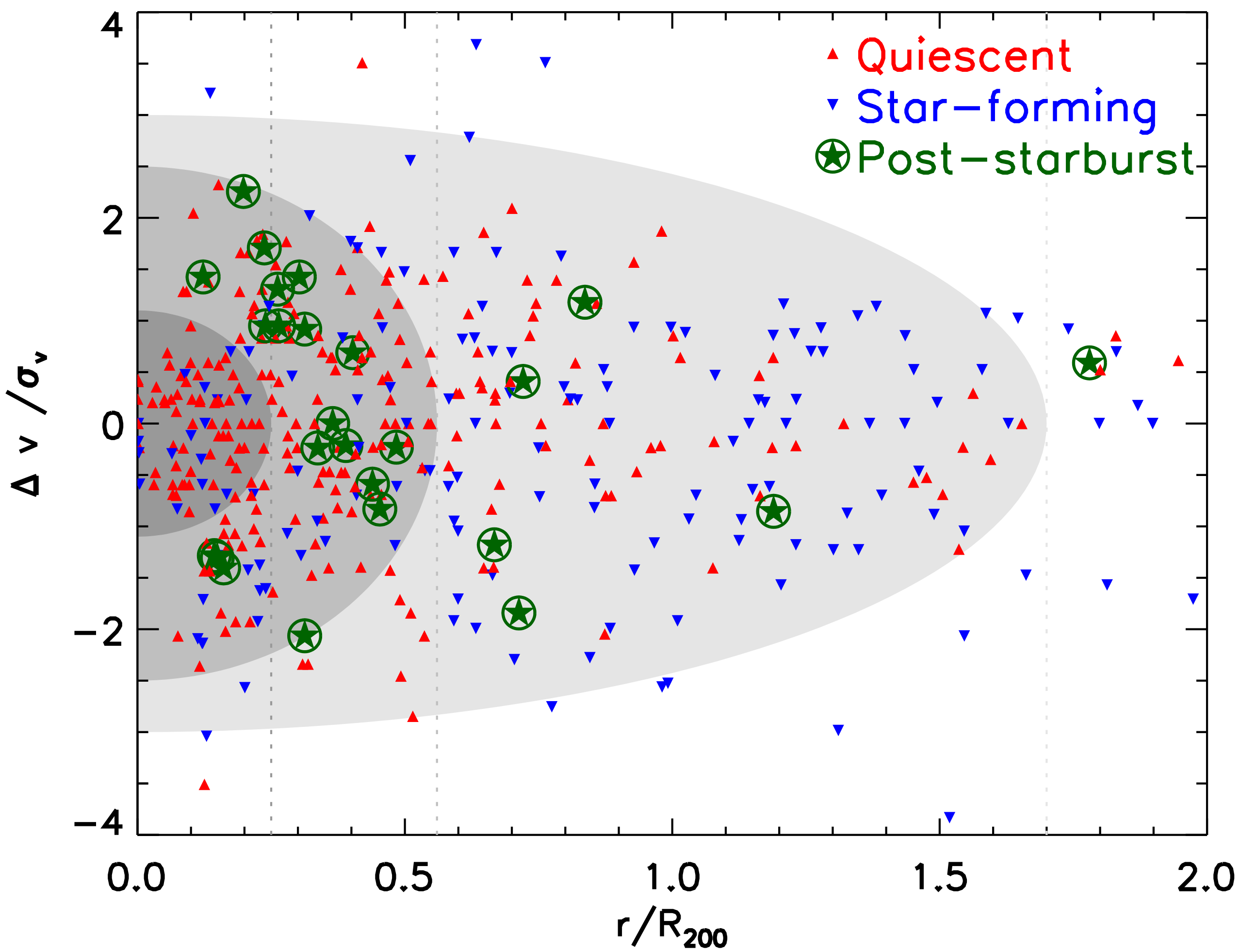
reheating of dust from residual star formation

Ram-pressure stripping?
(r x Δv < 1.0)

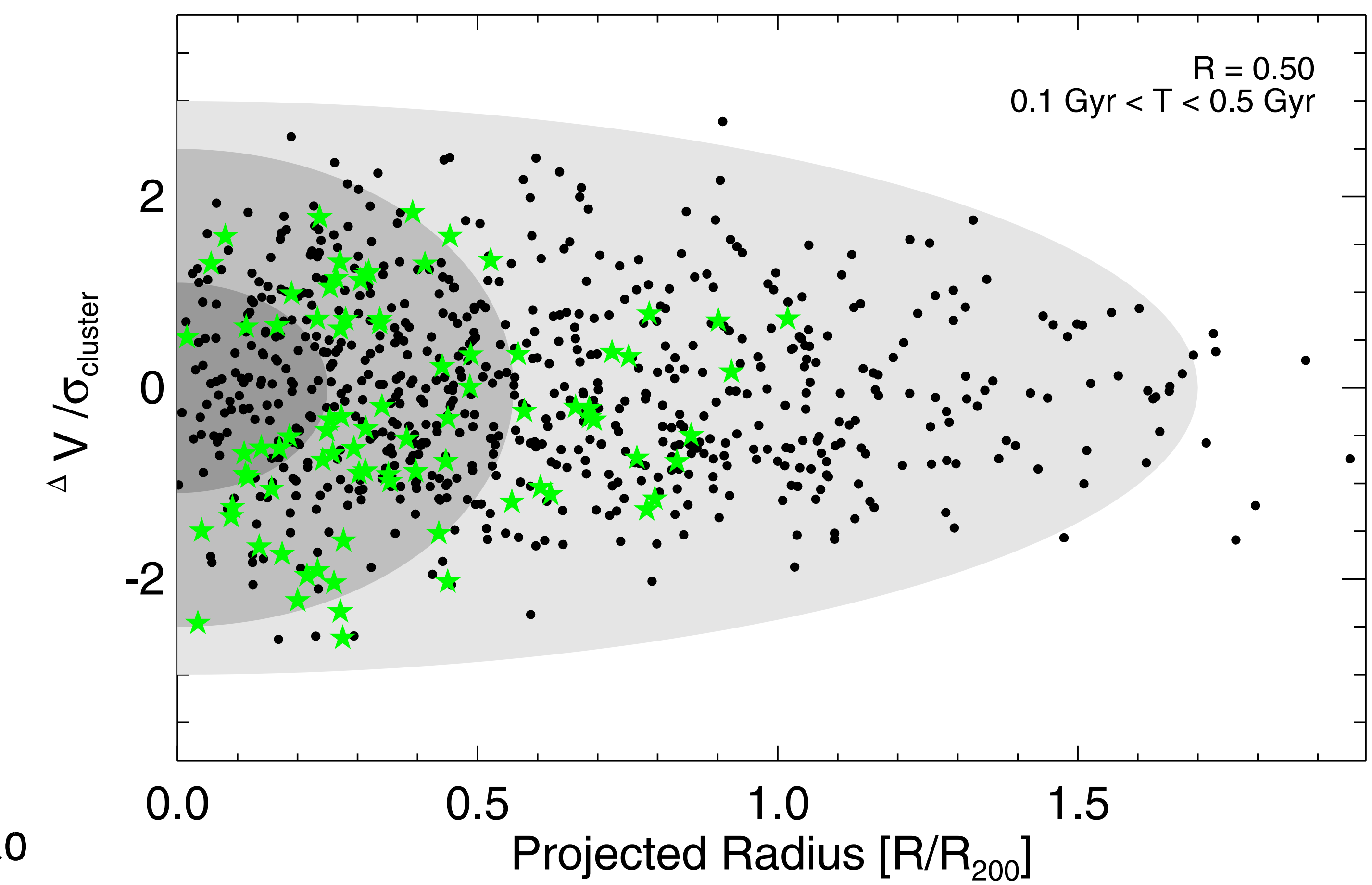
Noble et al 2016

Phase Space of Post-Starbursts

Real Observations



DM Simulations



Muzzin et al 2014

Sims reproduce coherent ring structure of post-starburst galaxies when galaxies quench on short timescales <0.5 Gyr after first passage of $0.5R_{200}$

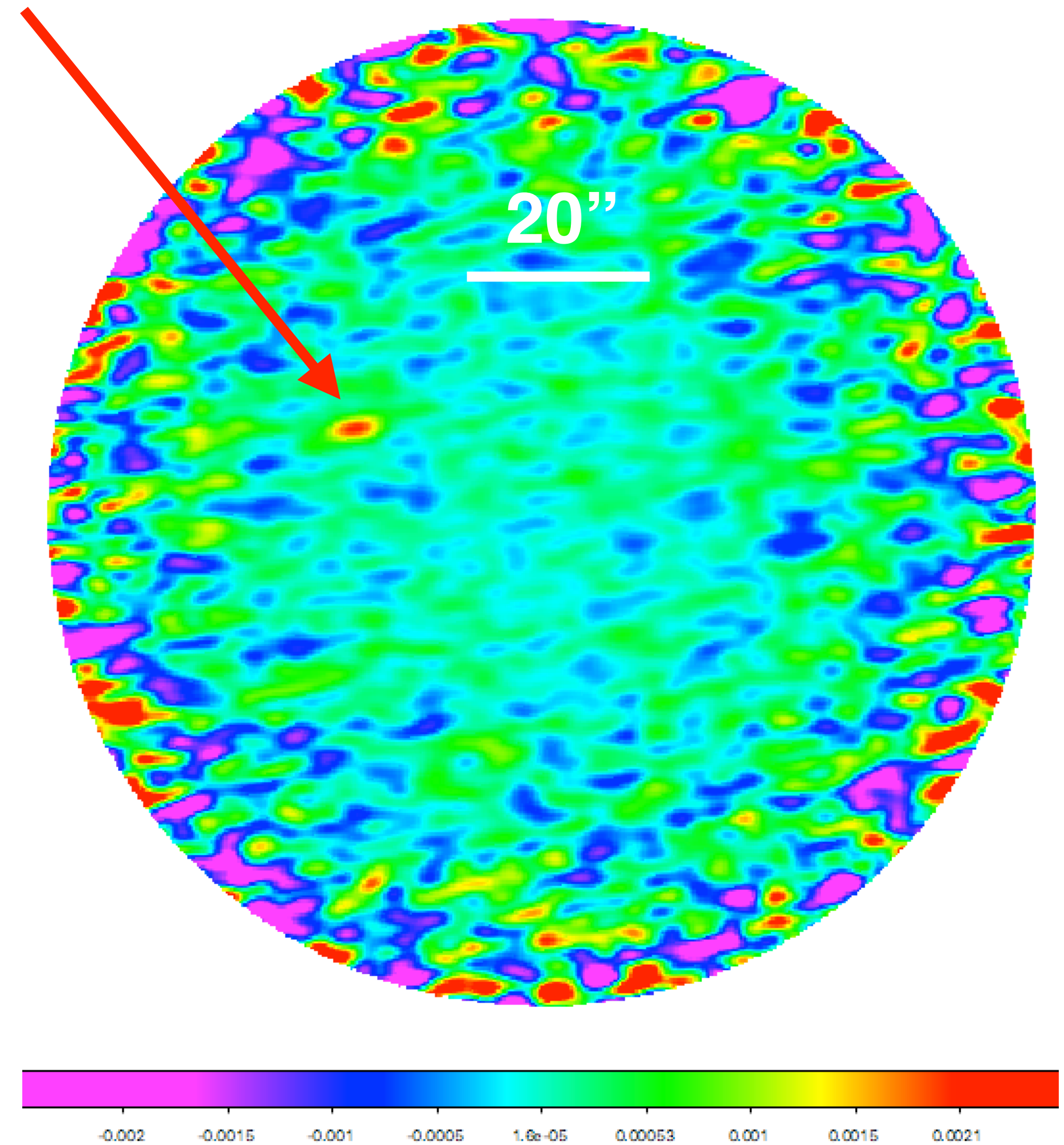
see also:
Jaffe+ 2015, Oman+ 2016,
Matt Ower's talk today!

ALMA Teaser:
Molecular Gas in z~1.6 Cluster Galaxies

13 hours of Band 3 ALMA Cycle 3 time for 3 z~1.6 SpARCS clusters to detect CO 2-1

- What regulates star formation in z>1 cluster galaxies?
- Place constraints on star formation rate efficiencies and quenching timescales
- First look: ~>8 detections at z~1.6

CO 2-1 detection in z~1.6 cluster galaxy!



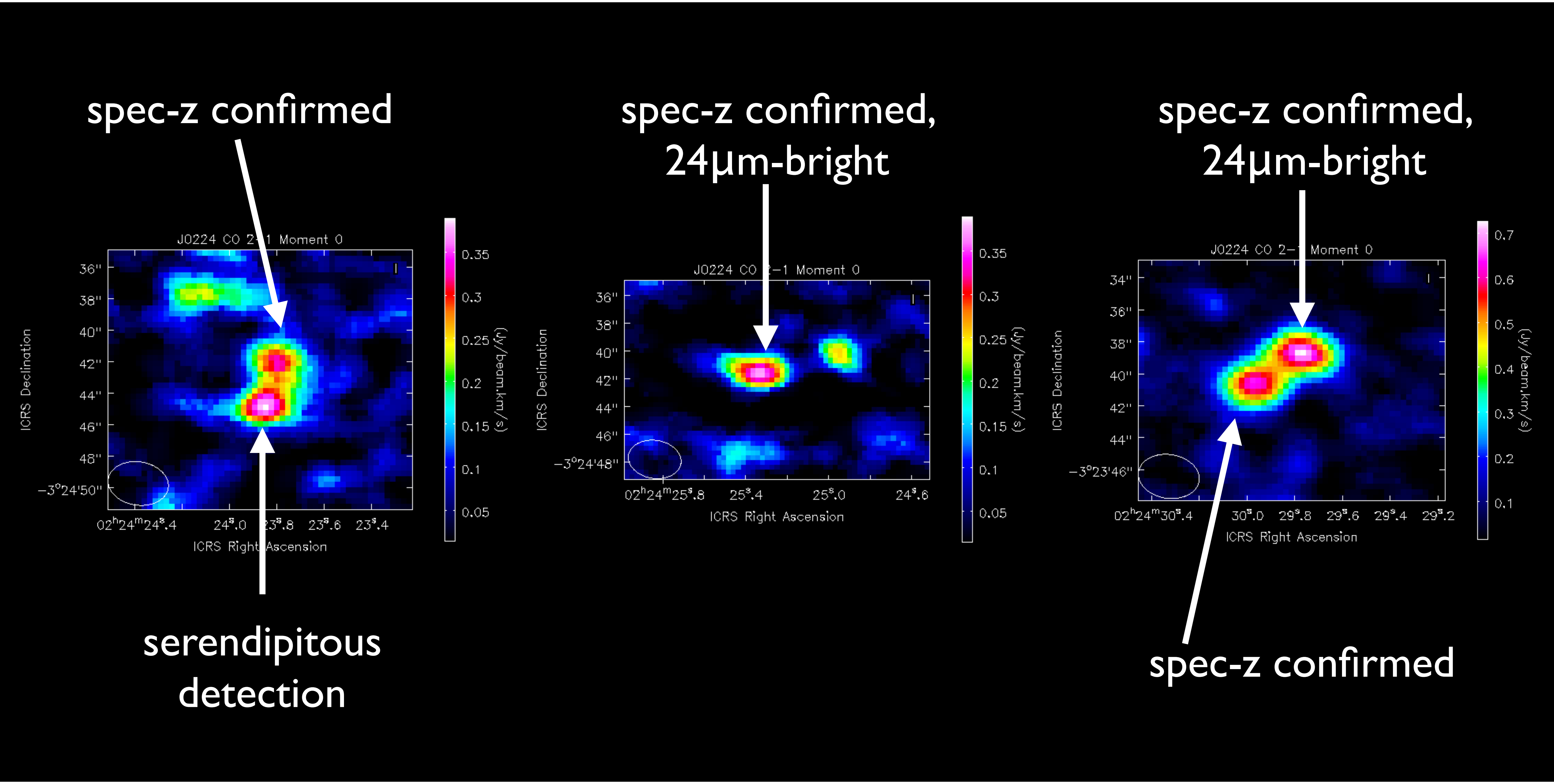
88.23 GHz, 100 km/s channel

beam ~ 4.4” x 2.2”

Noble et al in prep

ALMA Teaser:
Molecular Gas in z~1.6 Cluster Galaxies

CO 2-1 Integrated Intensity (Moment 0) Maps



Noble et al in prep

Conclusions

- lines of constant ($r \times \Delta v$) trace accretion histories of cluster galaxies

- we see a decline in the specific SFR of cluster star-forming galaxies towards low $r \times \Delta v$ moving from recently accreted to earliest accreted galaxies

- we see a drop in the dust temperature for galaxies in the intermediate phase-space bin

- everything but the coldest dust might be stripped at $r \times \Delta v < 1.0$

  $\longrightarrow$ ram-pressure stripping?

- stay tuned for new CO 2-1 ALMA results in z~1.6 galaxy clusters!