The Phase-Space of z~1 Clusters: A View from *Spitzer* and *Herschel*

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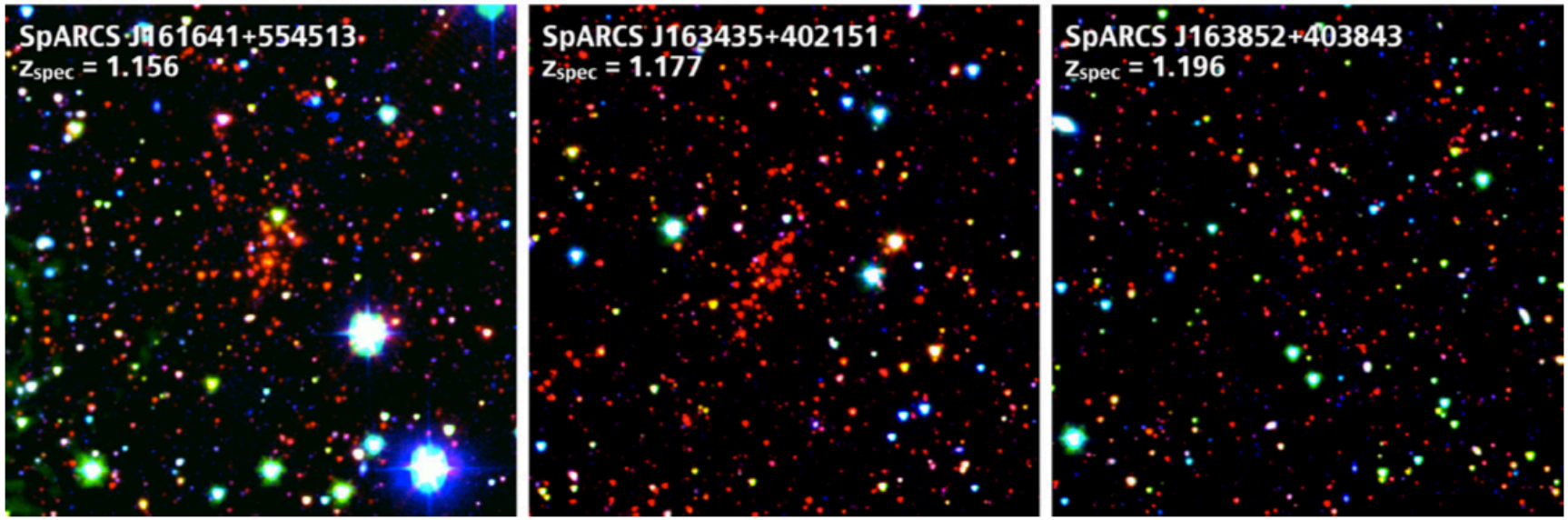
Tracy Webb, Howard Yee, Adam Muzzin, Gillian Wilson,
and the SpARCS Collaboration



How does Environment Influence Galaxy Evolution?

Hierarchical Structure Formation

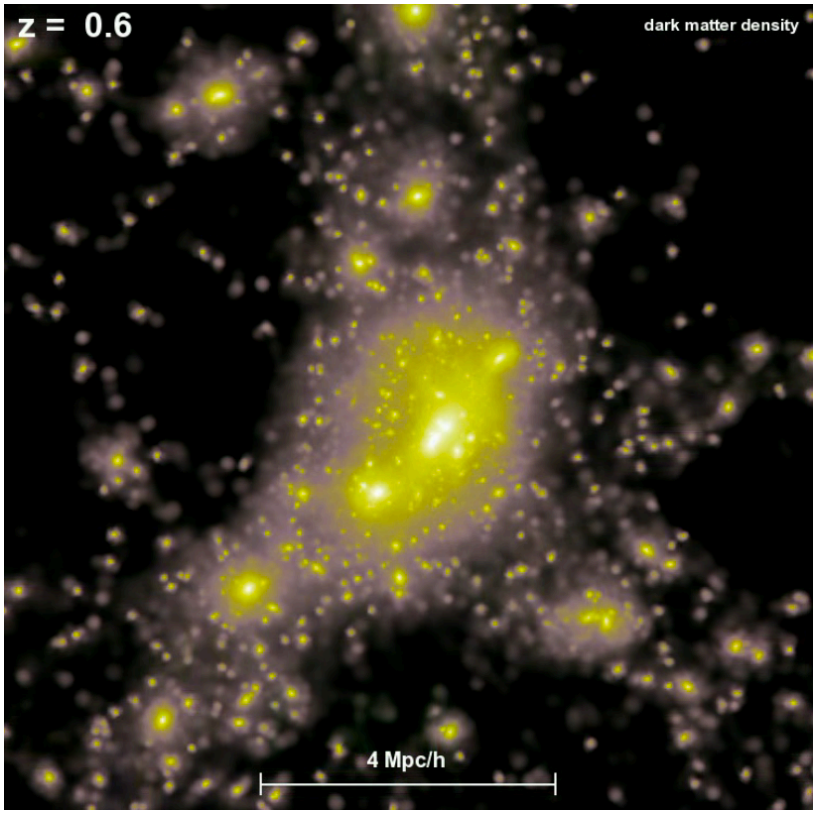
↓

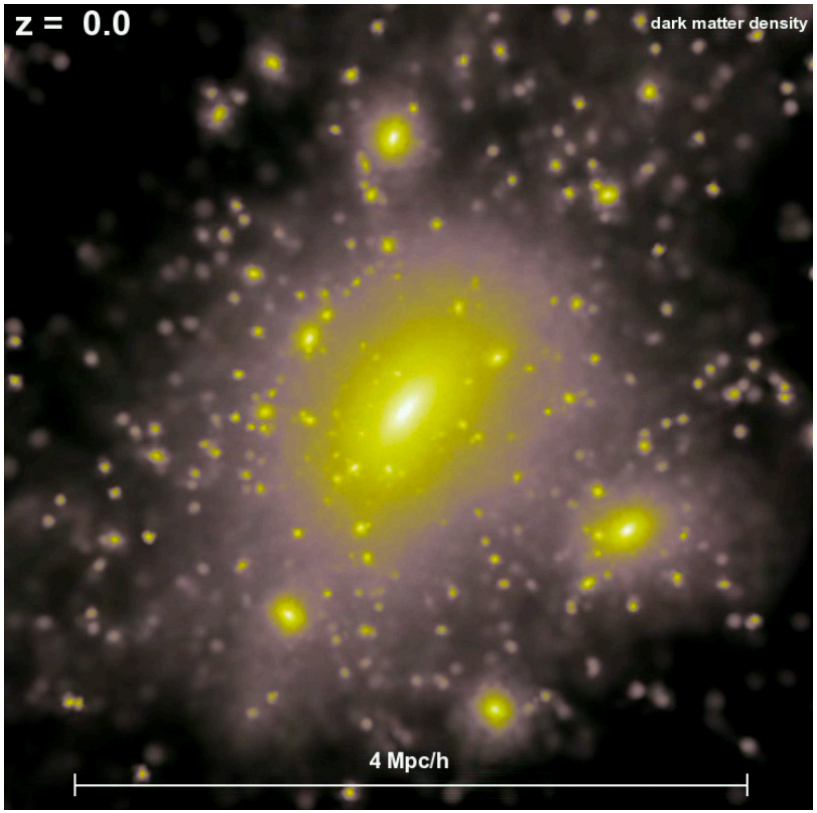
Distinct Galaxy Populations within Clusters

galaxies accreted at early times

vs

galaxies accreted recently

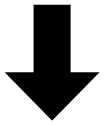


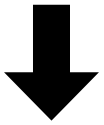


Credit: Volker Springel - MPIA

Stellar Mass/Environment Covariance

Nature vs Nurture





	Mass	Environment
Fraction of star-forming galaxies	✓	✓
SFR per unit mass (SSFR)	✓	✗
Age of star-forming galaxies	✓	✗

e.g., Kauffmann+ 2004
Peng+ 2010
Muzzin+ 2012
Wetzel+ 2012

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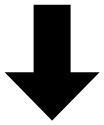

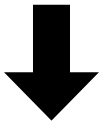

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Rapid Quenching of Star Formation?

e.g., Kauffmann+ 2004
Peng+ 2010
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Stellar Mass/Environment Covariance

Nature vs Nurture

	Mass	Environment
Fraction of star-forming galaxies	✓	✓
SFR per unit mass		✗ ?
Age of star-forming galaxies	✓	✗ ?

How well do we understand "environment"?

e.g., Kauffmann+ 2004
Peng+ 2010
Muzzin+ 2012
Wetzel+ 2012

The Next Step

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

How we accomplish this

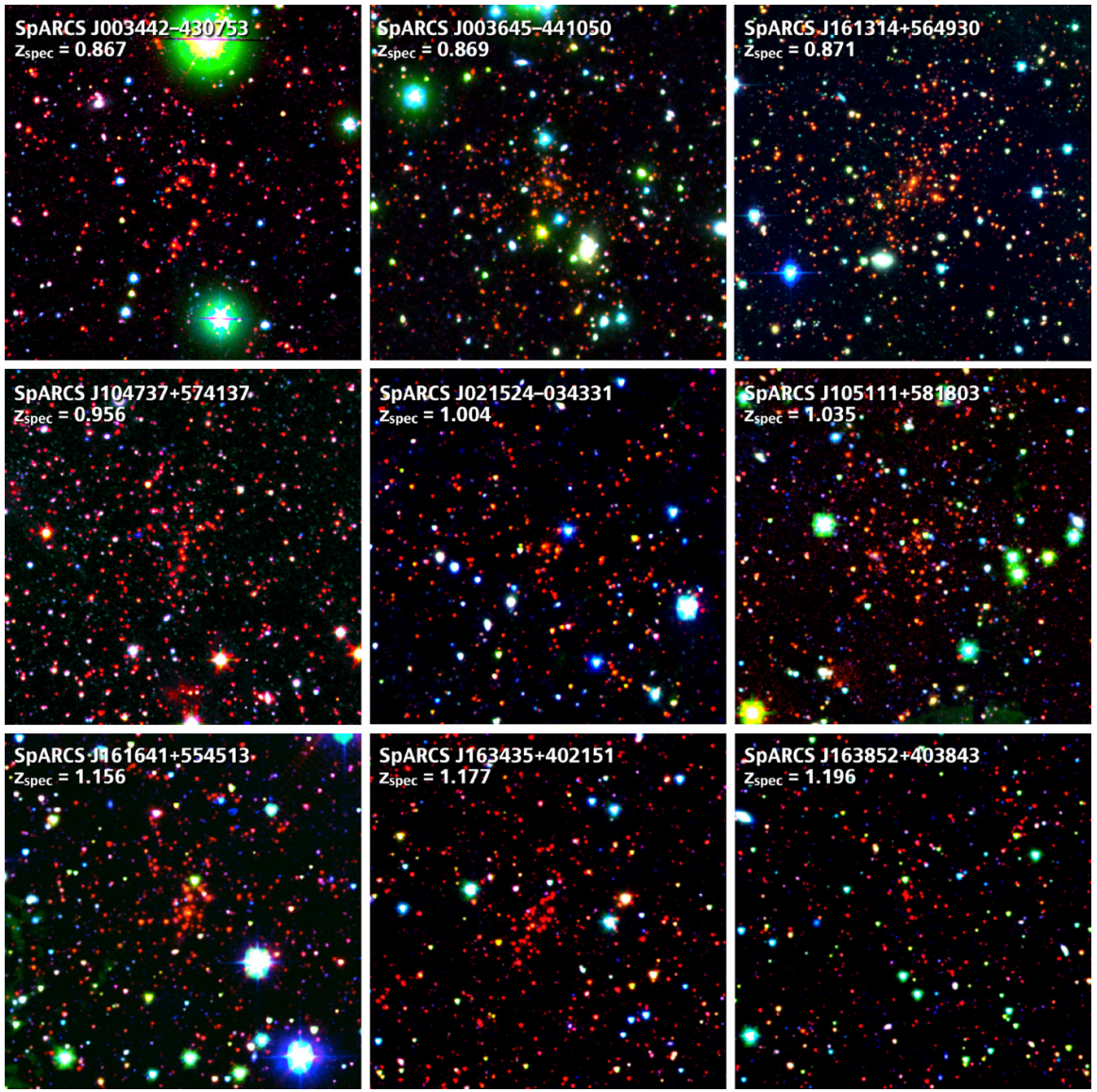
- a homogenous sample of high-z clusters, with spectroscopy
  → SpARCS/GCLASS

- accurate star formation rates
  → 24um-Spitzer, 100/160/250/350/500um-Herschel

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

SpARCS Cluster Survey/GCLASS

- >200 massive infrared-selected cluster candidates
- 42 sq. deg. survey with deep z' band imaging
- GCLASS: 10 spectroscopically confirmed clusters from 0.86 < z < 1.34 with ~500 members above 2e9 M⊙



Muzzin et al 2012

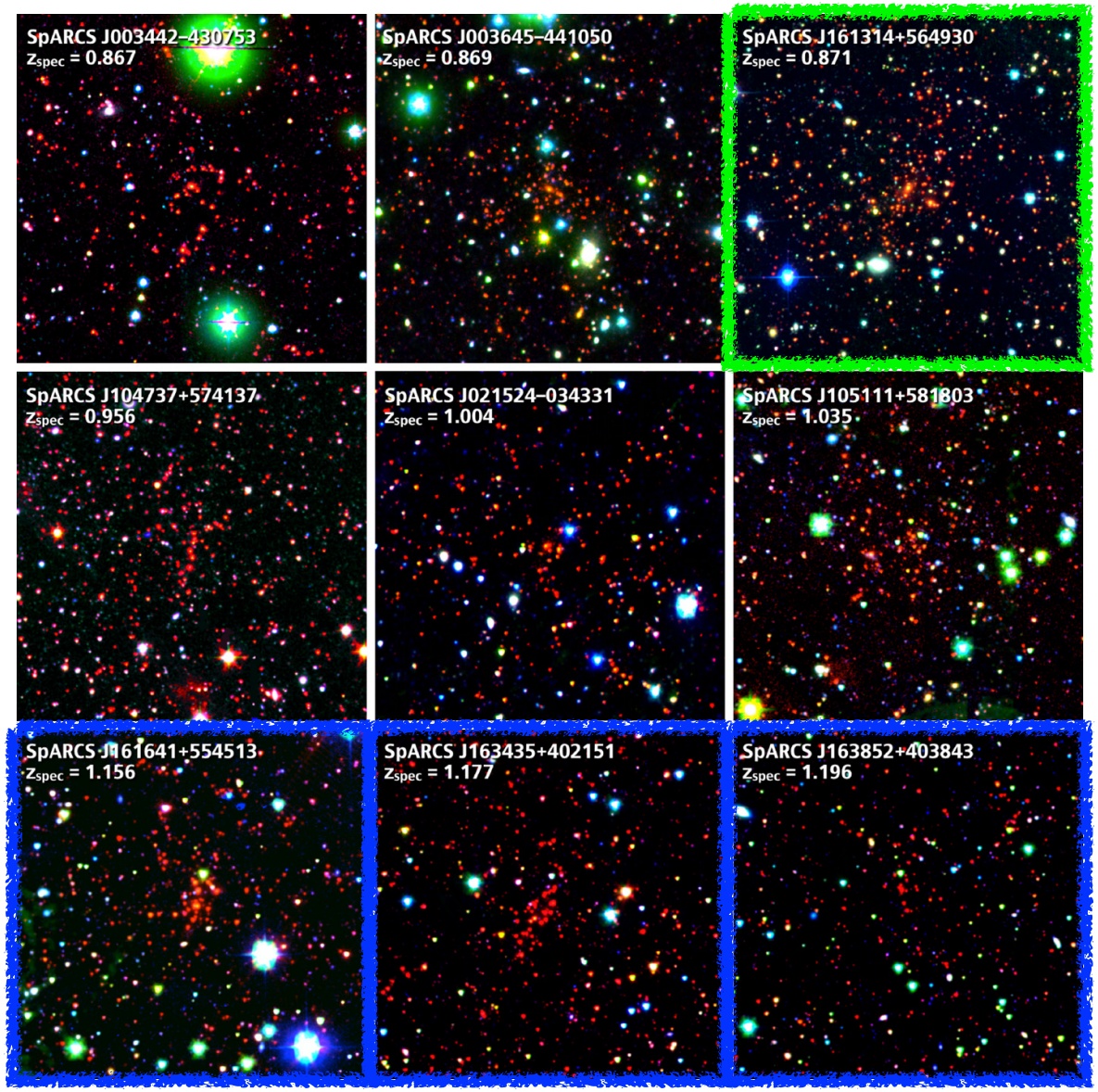
SpARCS Cluster Survey/GCLASS

- z = 0.871
- 85 spectroscopic cluster members
- 24um imaging
- $M_{200} = 2.6 \times 10^{15}\, M_{\odot}$

Noble et al 2013

- z ~ 1.2
- 123 spectroscopic cluster members → stacking
- 100/160/250/350/500um imaging
- $M_{200} = 1 - 4 \times 10^{14}\, M_{\odot}$

Noble et al in prep



Muzzin et al 2012

Results: z=0.871 Star-Forming Cluster Galaxies

MIPS cluster members

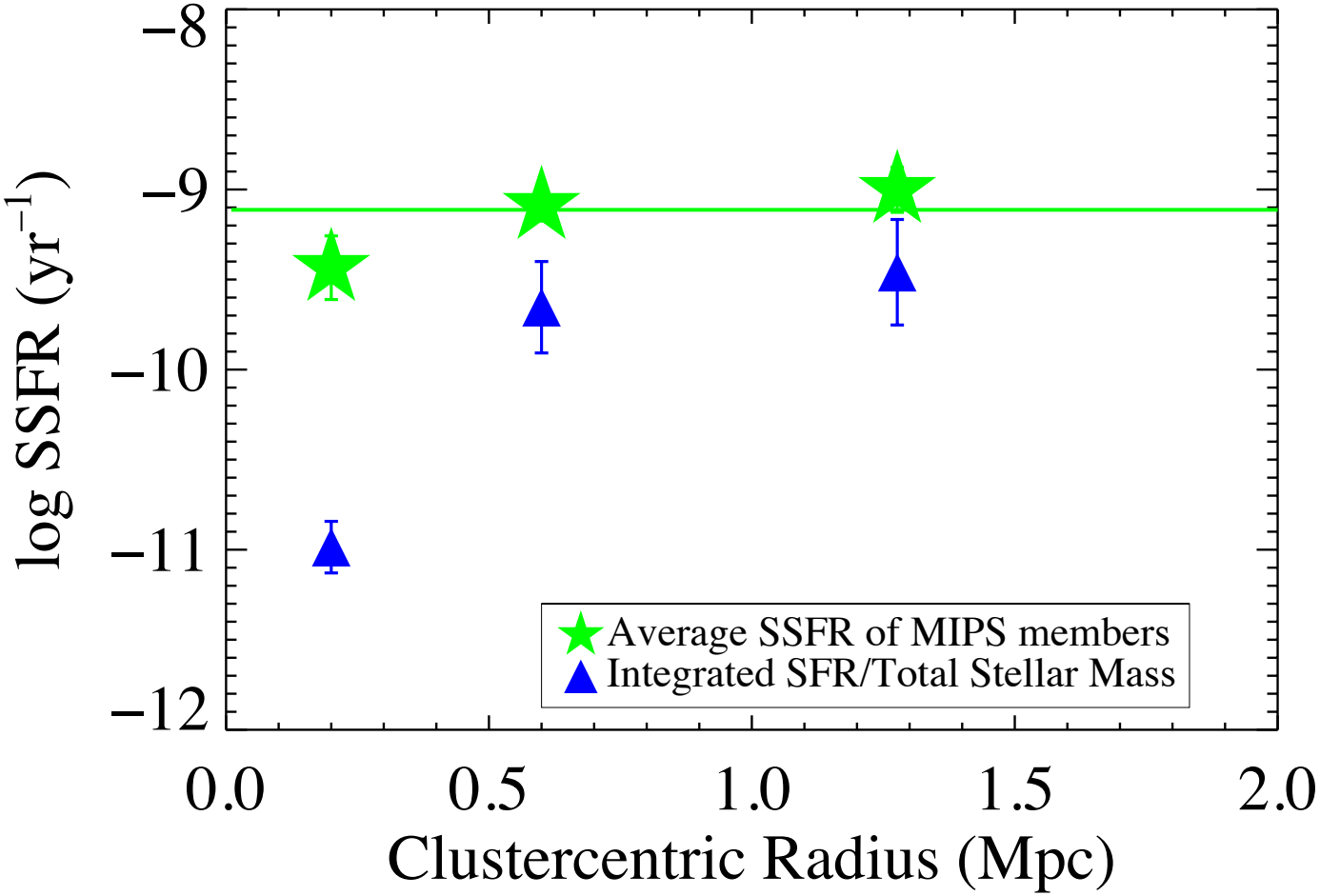
↕

star-forming galaxies

Integrated SFR per total stellar mass of all cluster members increases with radius, but...

SSFR of star-forming galaxies is flat with radius

↳rapid quenching?



Noble et al 2013

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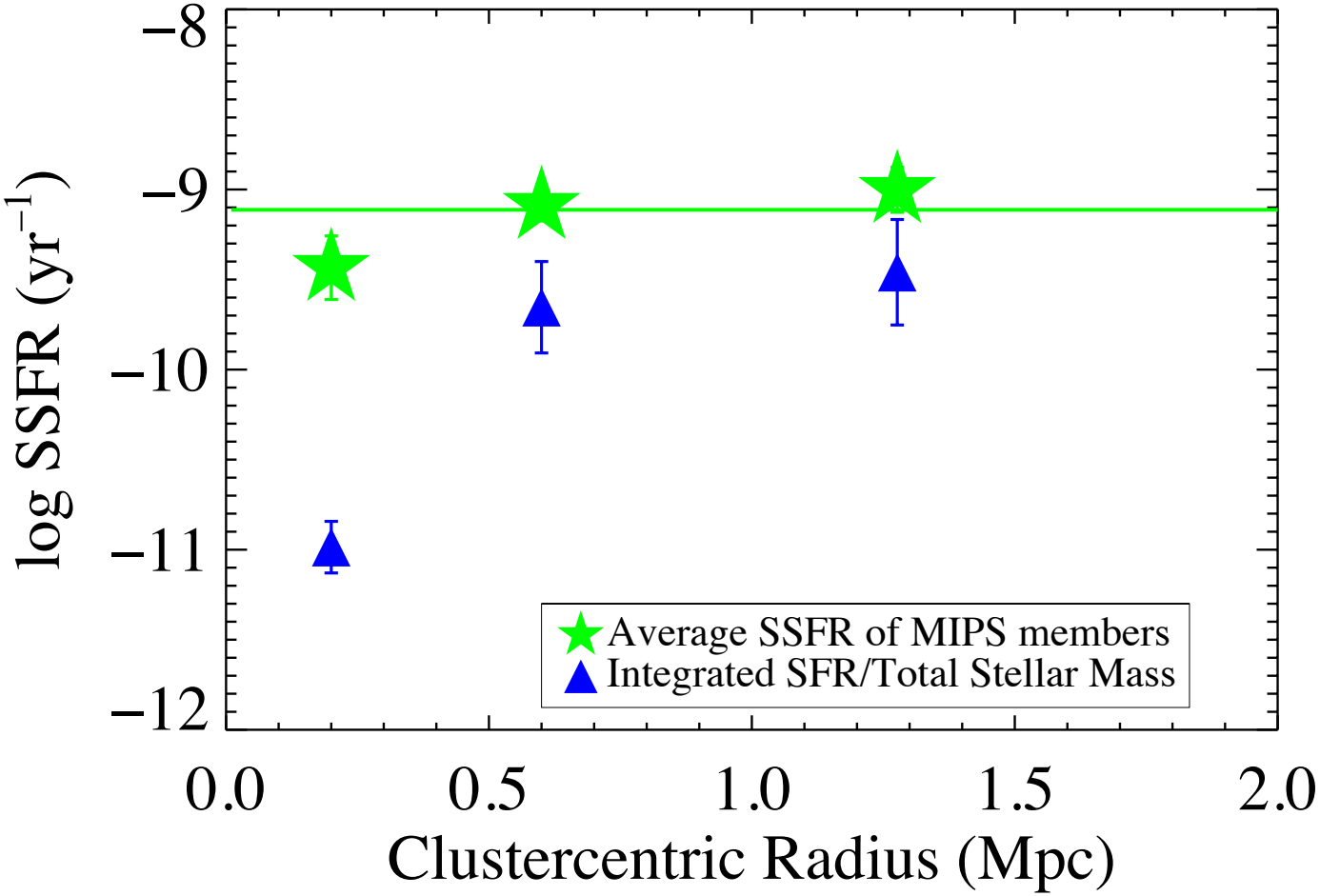
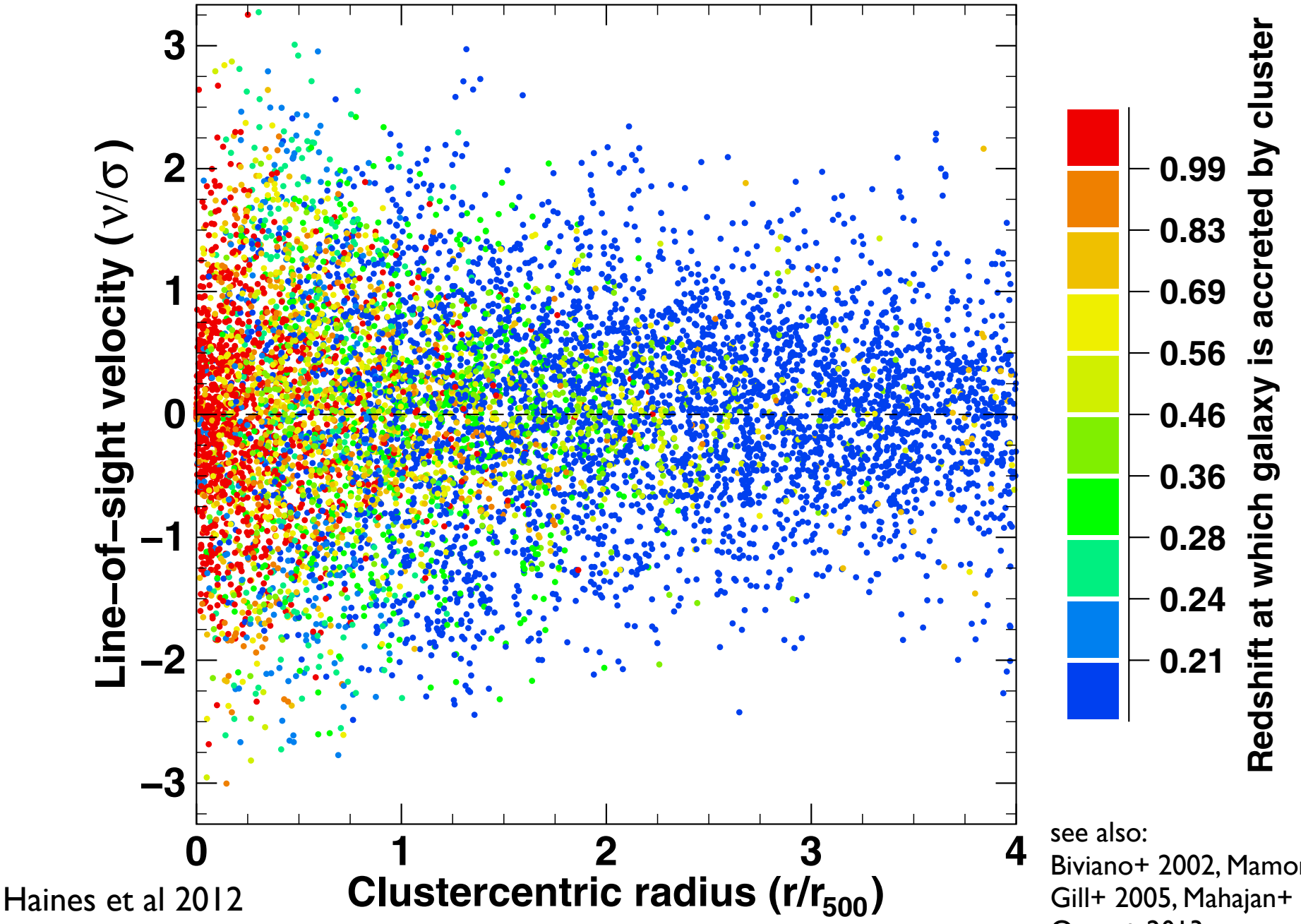


Noble et al 2013

Are we truly sampling star-forming galaxies in distinct environments?

Isolating Accretion Histories with Simulations



Haines et al 2012

see also:
Biviano+ 2002, Mamon+ 2004,
Gill+ 2005, Mahajan+ 2011,
Oman+ 2013

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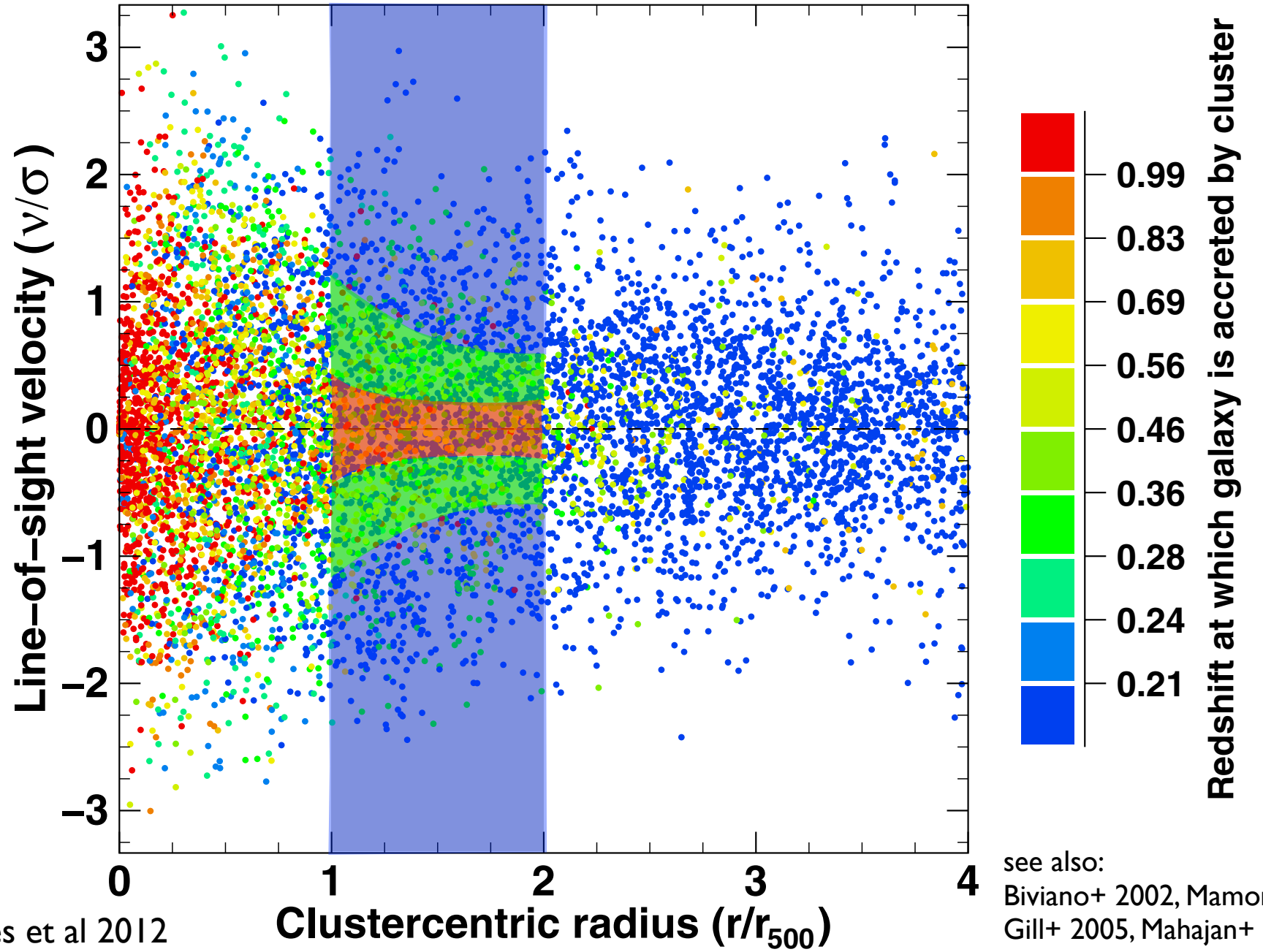

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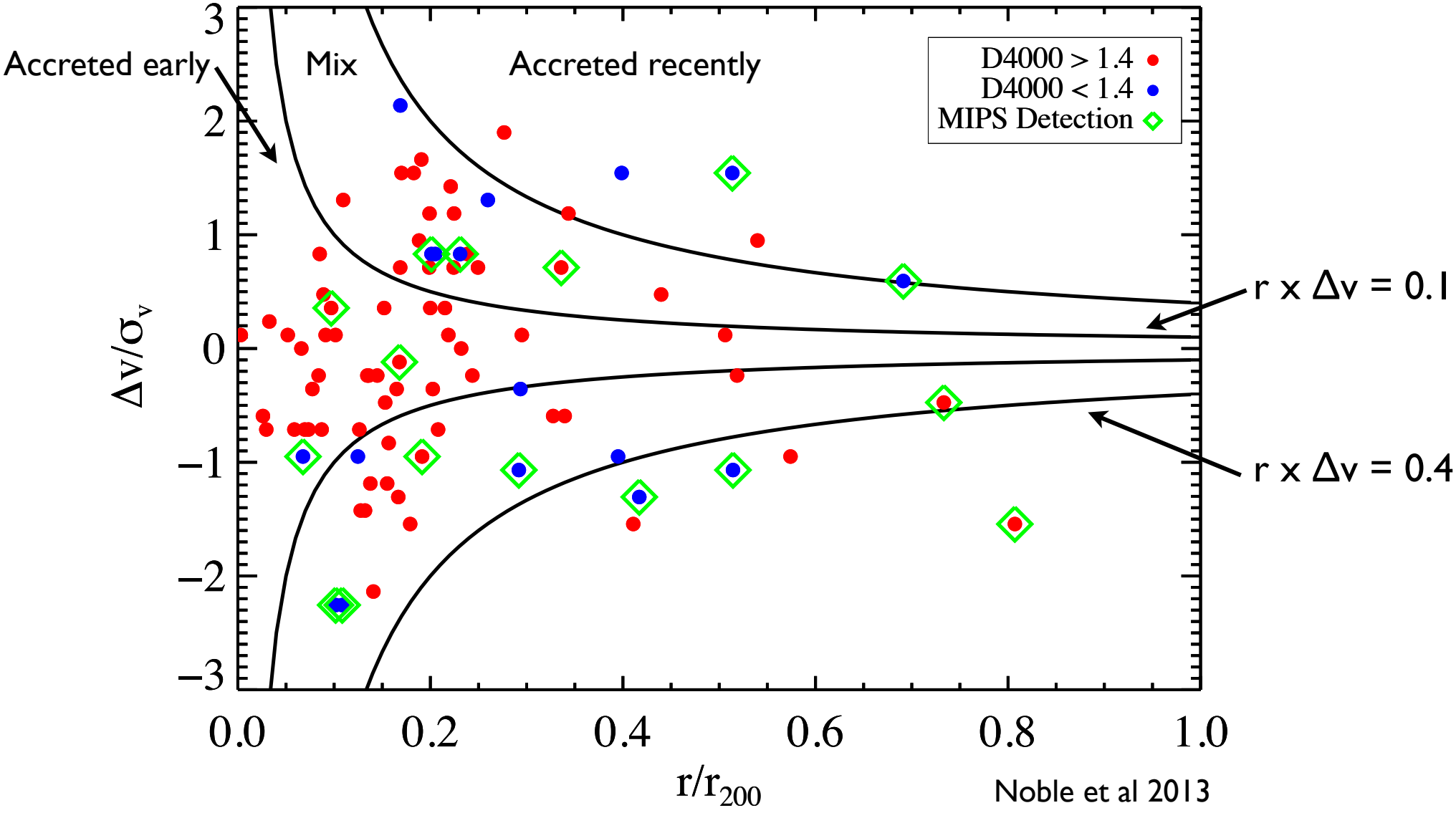
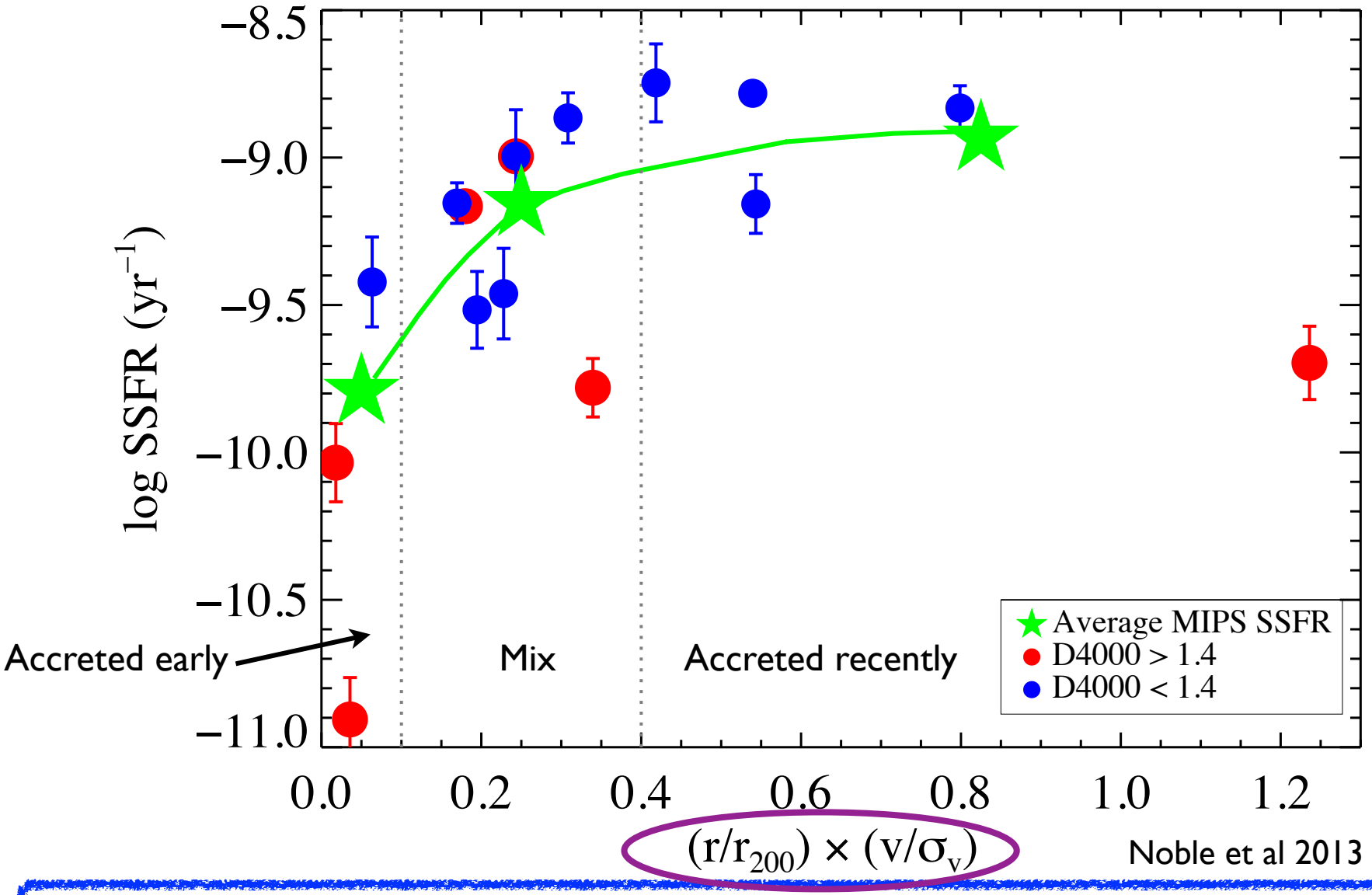
Isolating Accretion Histories in Phase-Space



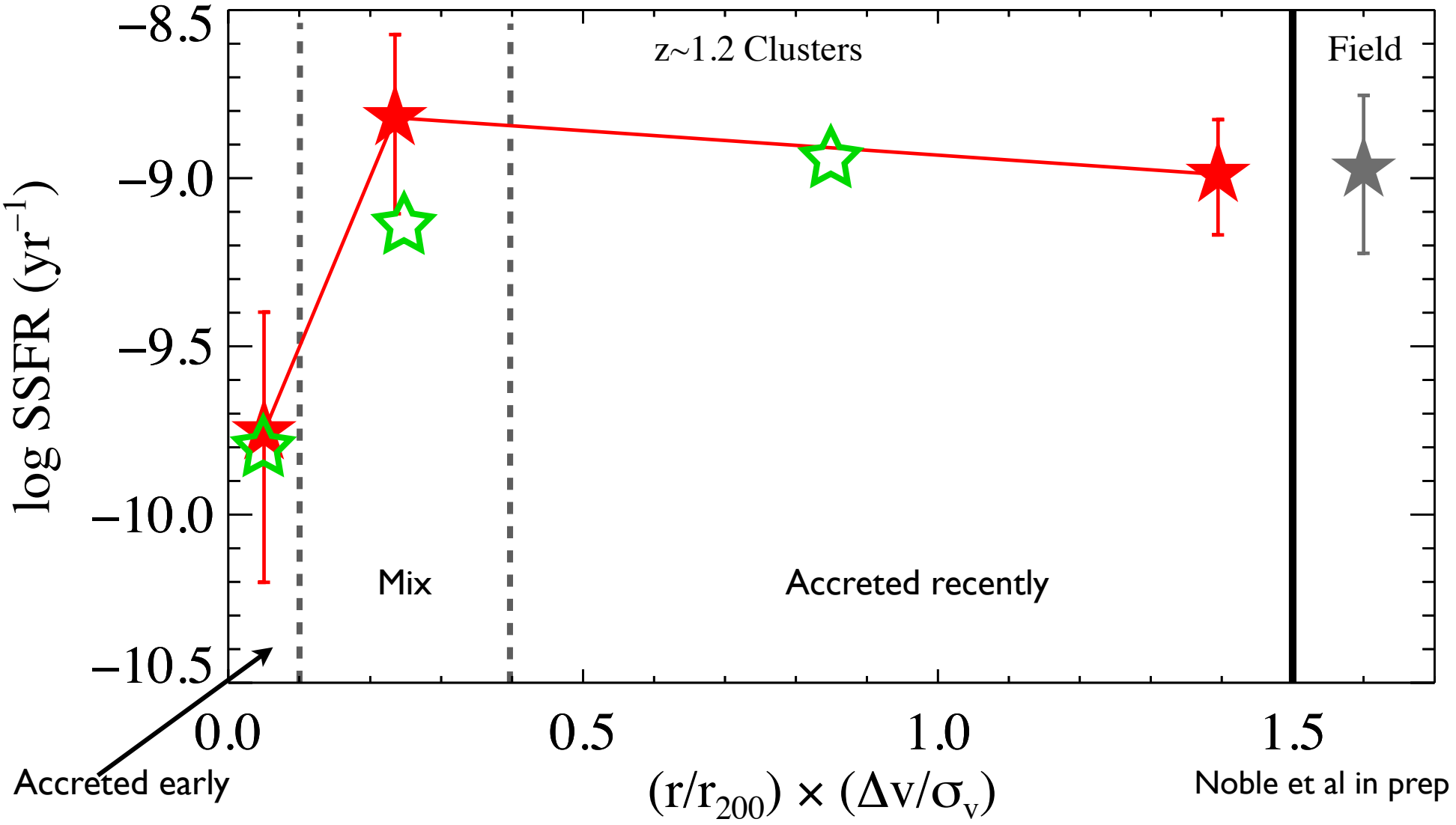
Caustic profiles kinematically isolate different accretion histories

Specific SFR versus r x Δv at z=0.871



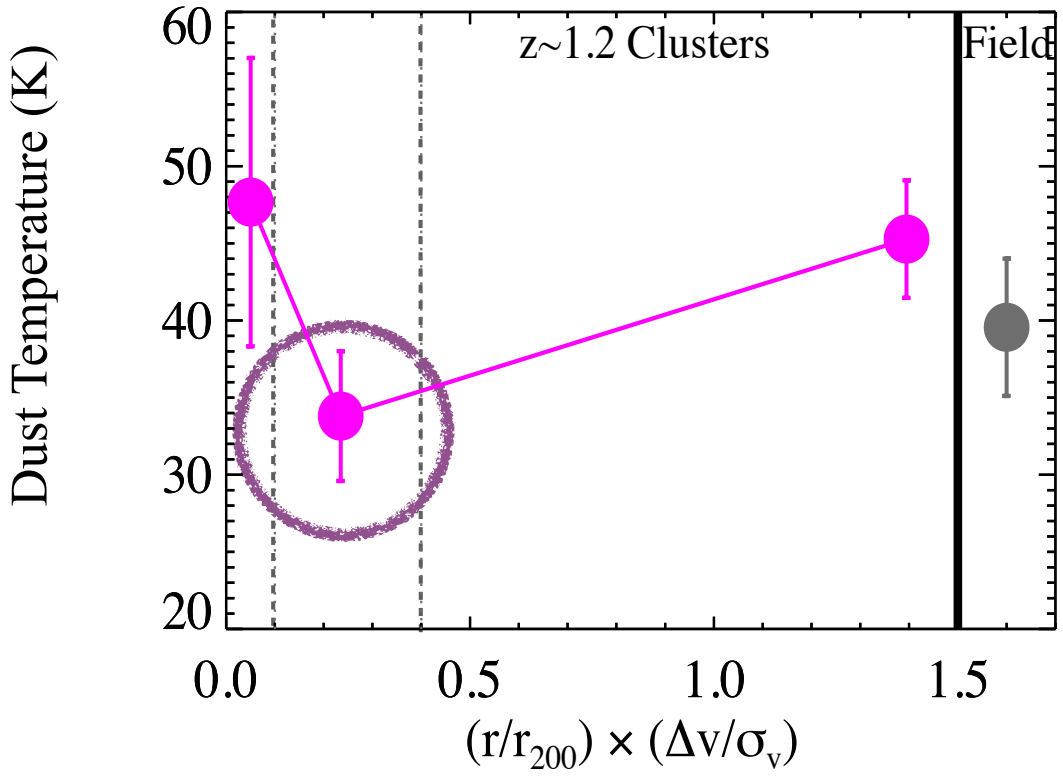
Conclusion: An accretion-based definition of environment yields a ~1 dex depression of SSFR at low values of r x Δv

Stacked Specific SFR versus r x Δv at z~1.2



same depression of SSFR at low values of r x Δv (early accretion) with larger sample and MIPS sample

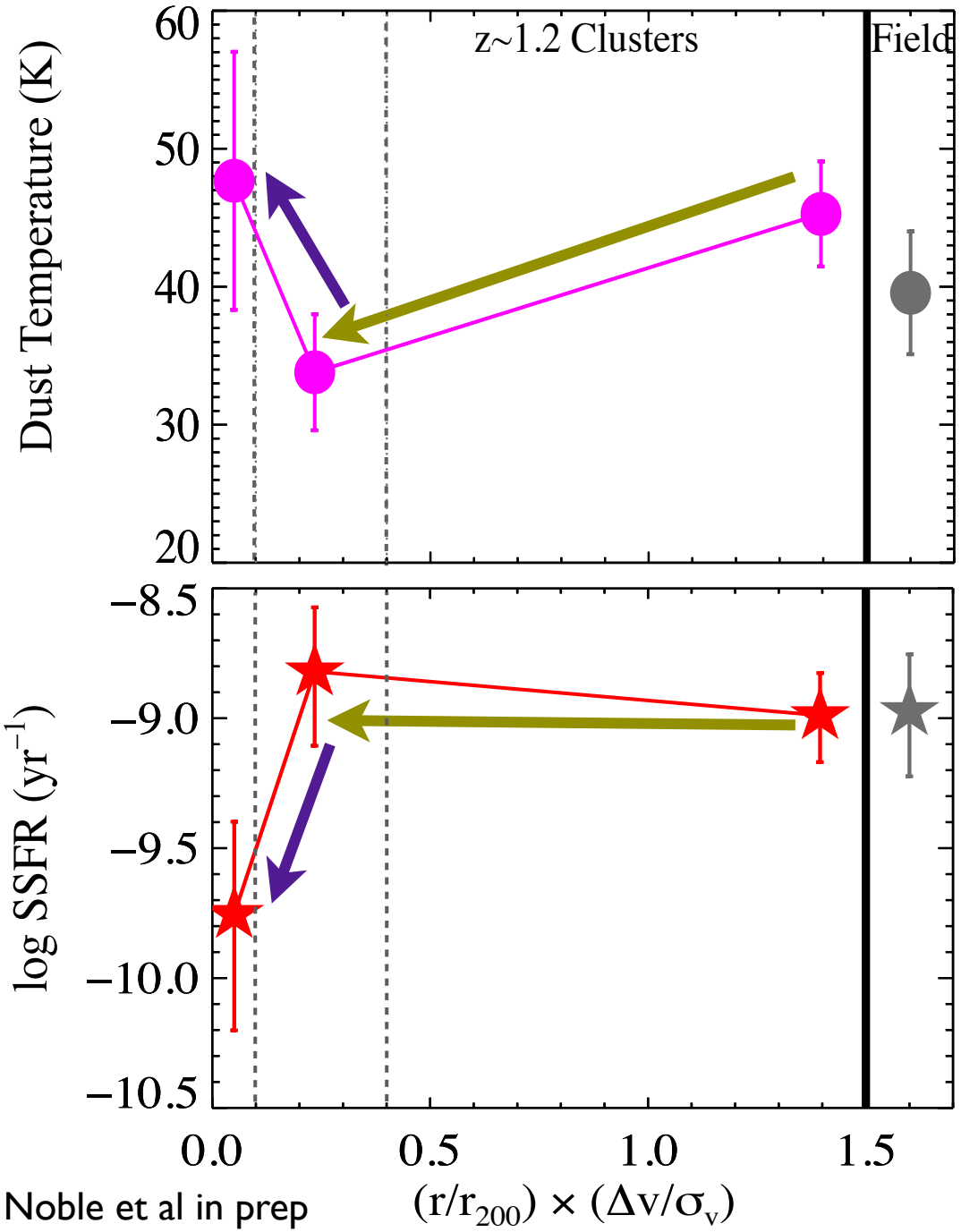
Dust Temperature versus r x Δv



Intermediate phase-space bin has coolest dust temperature

Noble et al in prep

A Possible Quenching Model?



Noble et al in prep

Strangulation

removal of warm gas/dust; gradual or no decline in SFR

Ram-pressure stripping

removal of cold atomic disk gas; delayed then rapid quenching of star formation

Conclusions

- a dynamical definition for environment based on phase-space trumpet profiles ($r \times \Delta v$) offers a unique snapshot of distinct galaxy populations that have been accreted at different periods of cluster formation

- we see a decline in the specific SFR of cluster star-forming galaxies with caustic environment - moving from regions of recently accreted galaxies to earliest accreted galaxies

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

- we suggest one plausible quenching model with combination of strangulation and ram-pressure stripping