Probing the End of Star Formation in Distant Group and Cluster Galaxies

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The EDisCS collaboration

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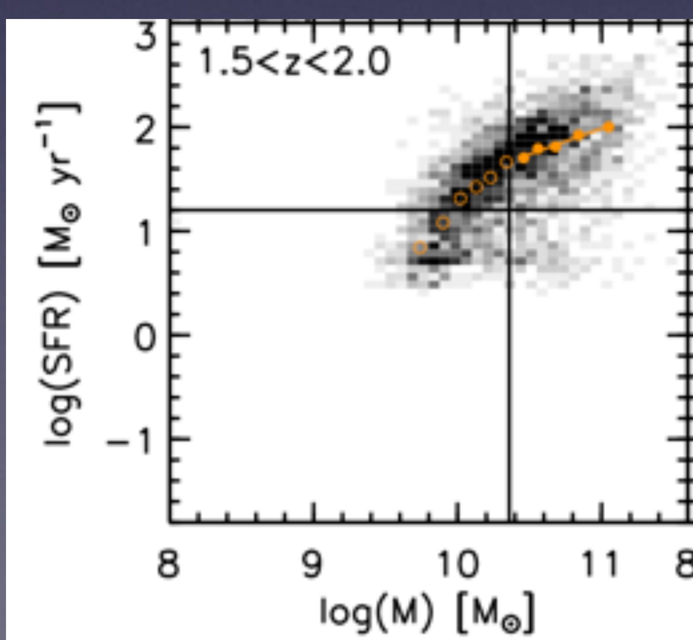
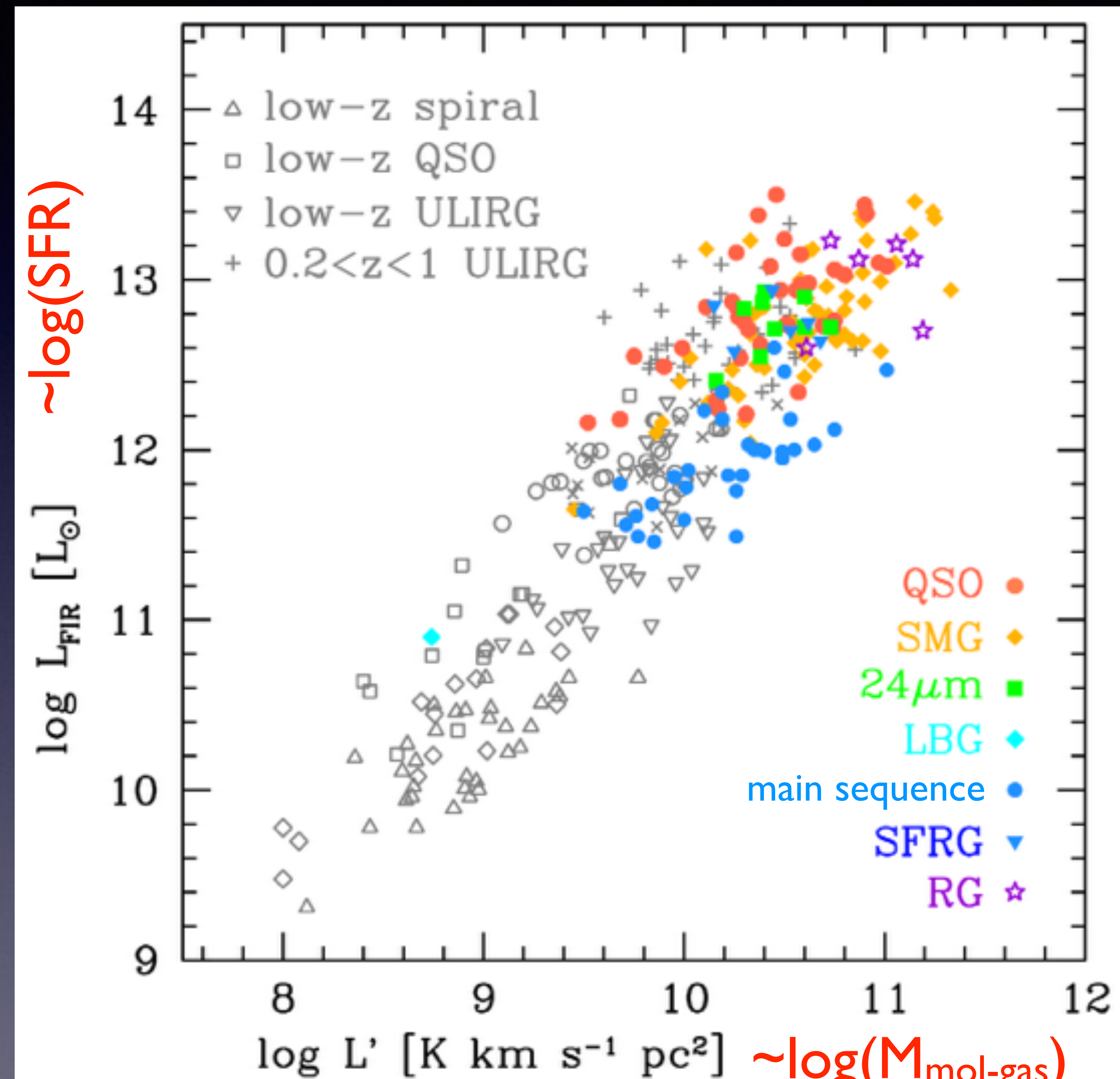
Molecular Gas Supply as a Driver of Star Formation

- SFR is correlated with $M_{mol\text{-}gas}$.
- Typical main-sequence galaxies have short gas consumption timescales (0.7 Gyr).
- Implies continuous gas accretion. (Daddi et al. 2008; Aravena et al. 2010; Tacconi et al. 2010; Tacconi et al. 2013)



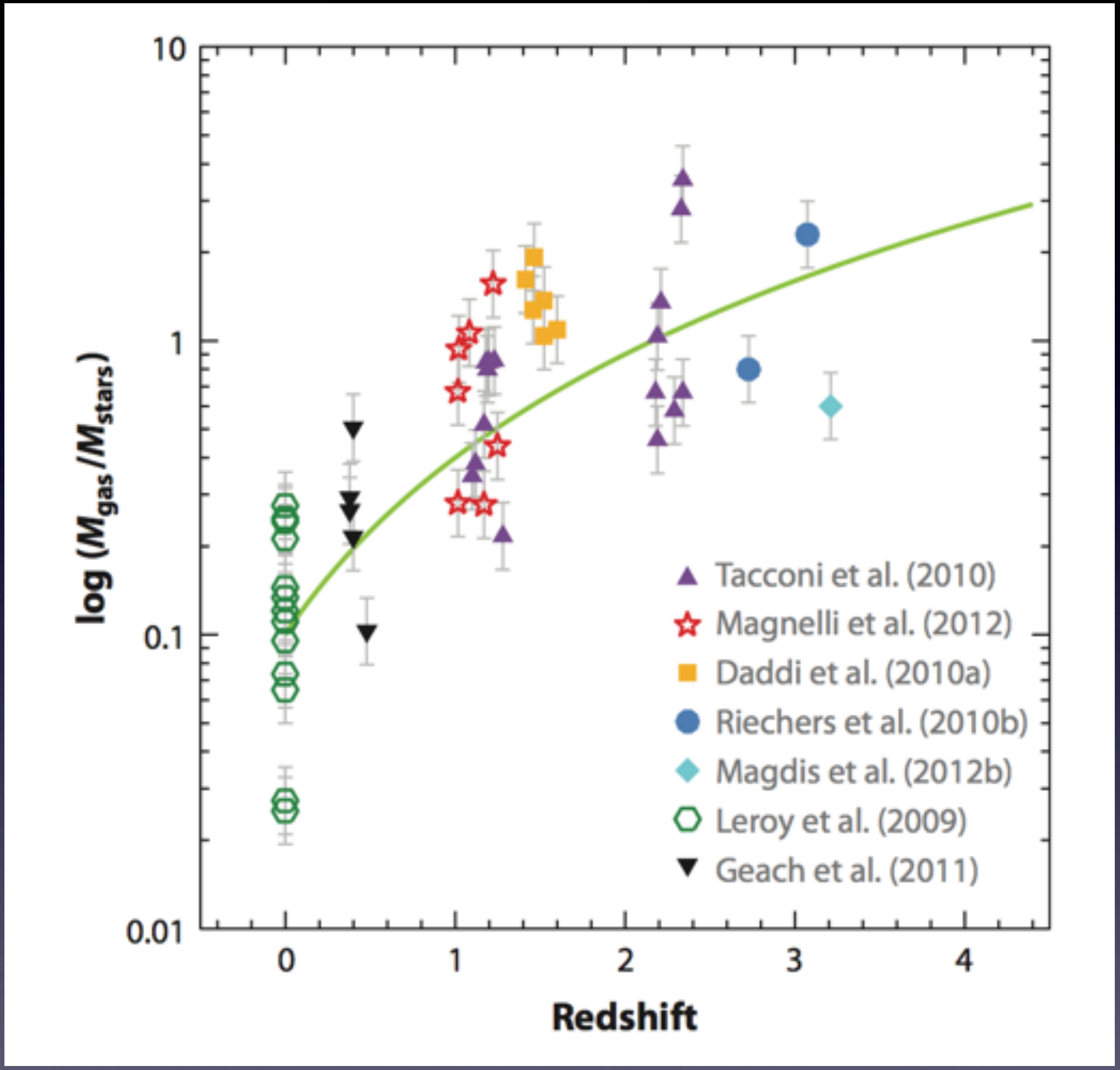
Whitaker et al. (2012)



Carilli & Walter 2013 ARAA

What drives the overall decline in SFRs with time

- The decline in SFR is mirrored by a decline in gas supply
- Massive galaxies in high-z dense environments may evolve more rapidly (Fassbender et al. 2014; Huertas-Company et al. 2013; Papovich et al. 2012; Rudnick et al. 2012; Lotz et al 2014)
- Almost no CO observations of high-z dense environments.



- What is SFR-M_{gas} relation in dense environments?
- How does environment regulate the gas supply?

Carilli & Walter 2013 ARAA

A z=1.62 cluster as an ideal CO target

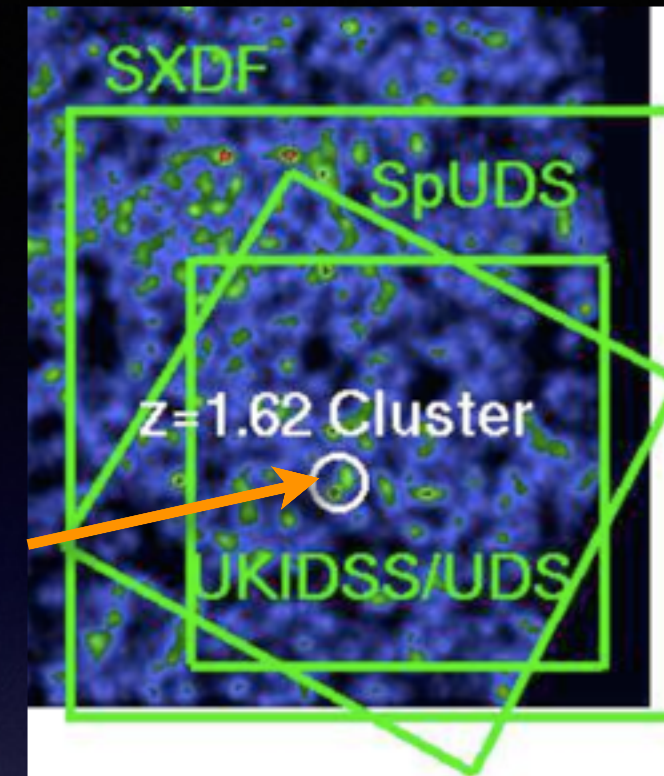
- many (>30) spectroscopically confirmed members
  - Papovich, et al. + Rudnick 2010; Tanaka et al. (2010); Momcheva in prep.

- subsequently diffuse x-ray emission marginally detected
- $M \sim 10^{14}$Msol
  - Pierre et al. 2011

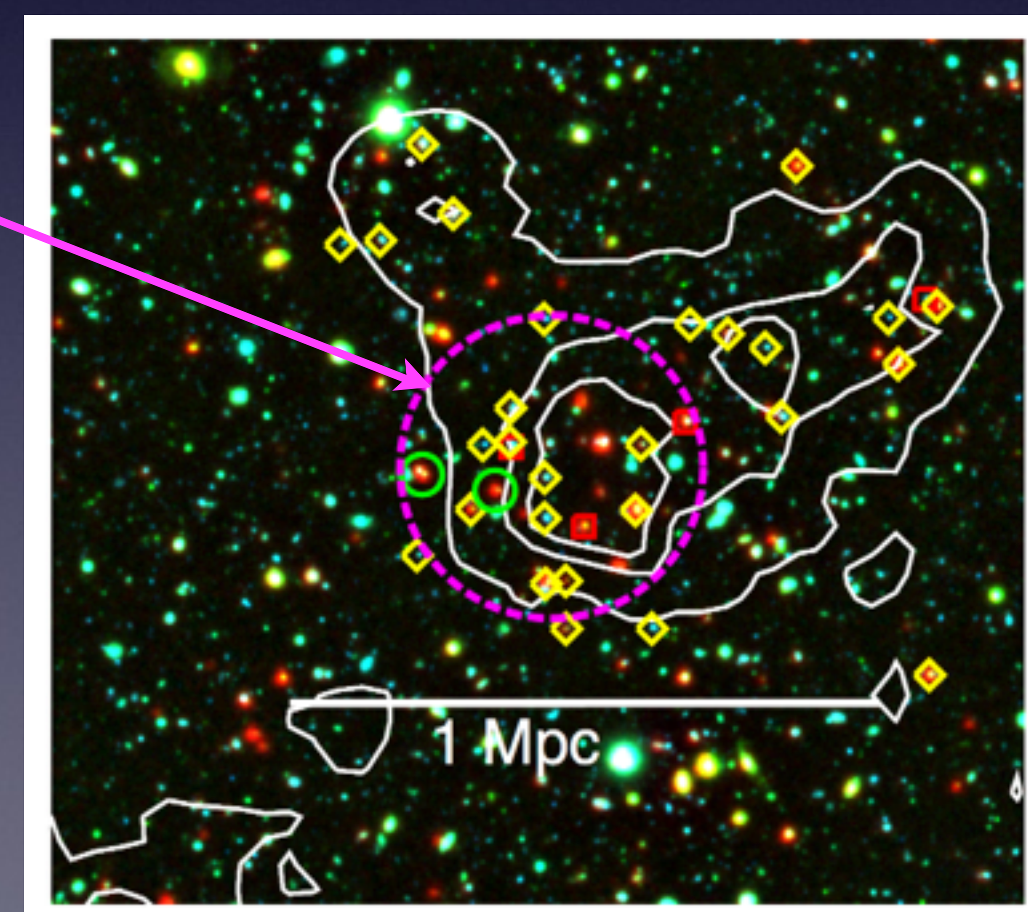
- Star-forming galaxies in the cluster core
  - Tran et al. 2010; Santos et al. 2014

- Deepest ever JVLA image taken in CO. 45h on source

Papovich 2010; Papovich et al. + Rudnick 2012



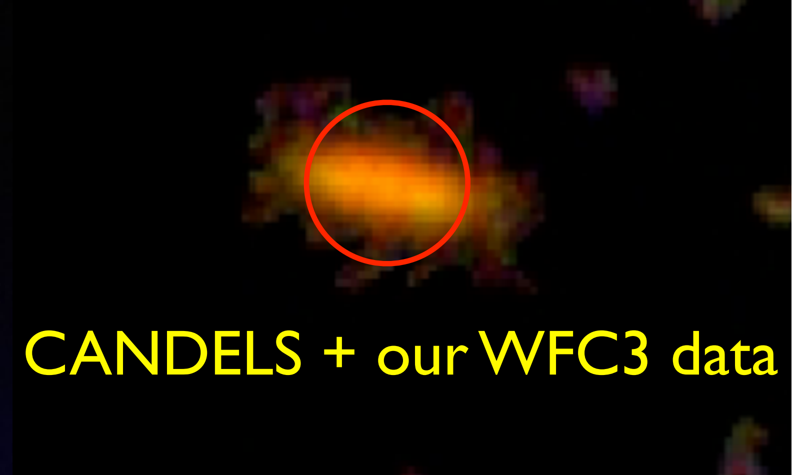
JVLA field of view



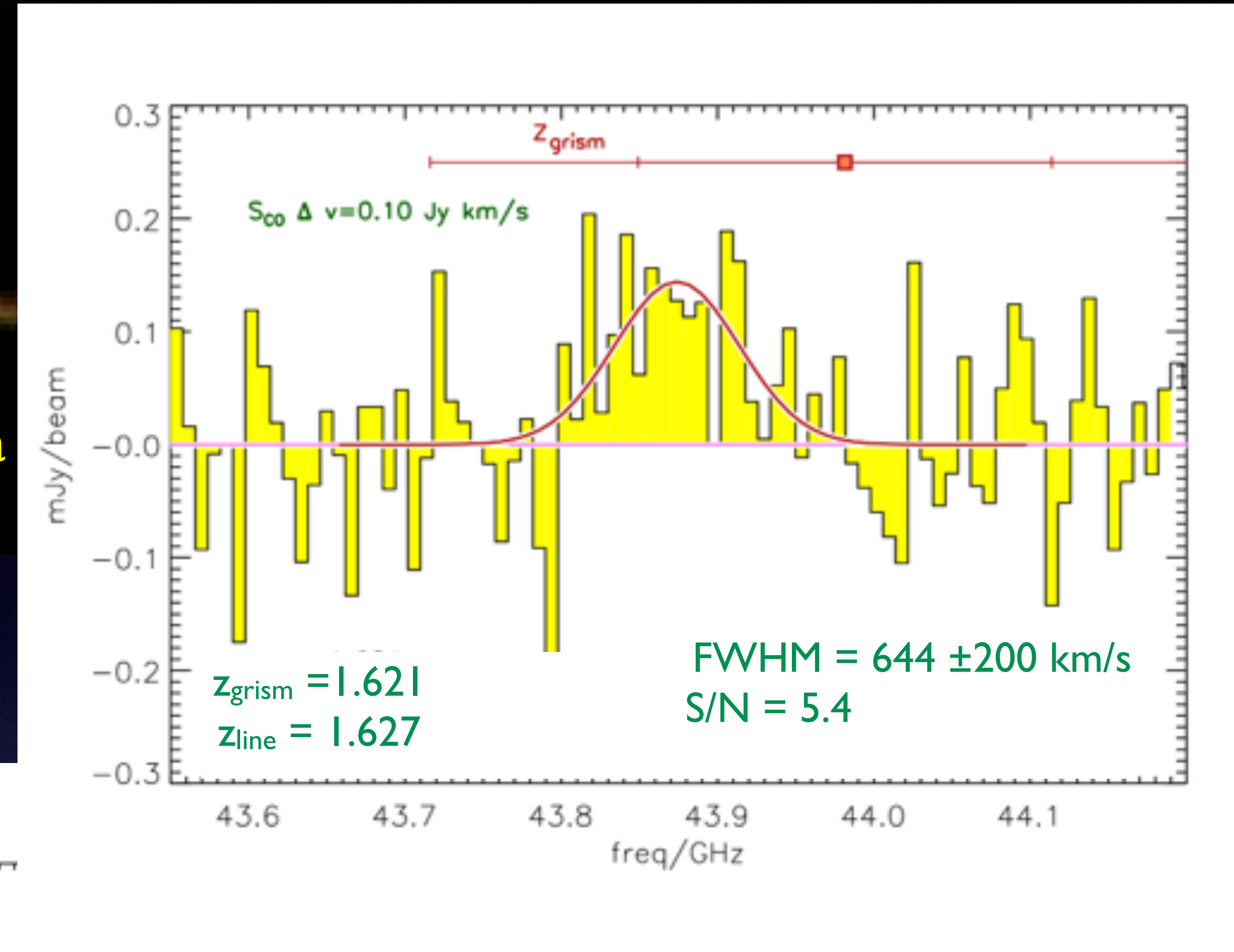
CO detection

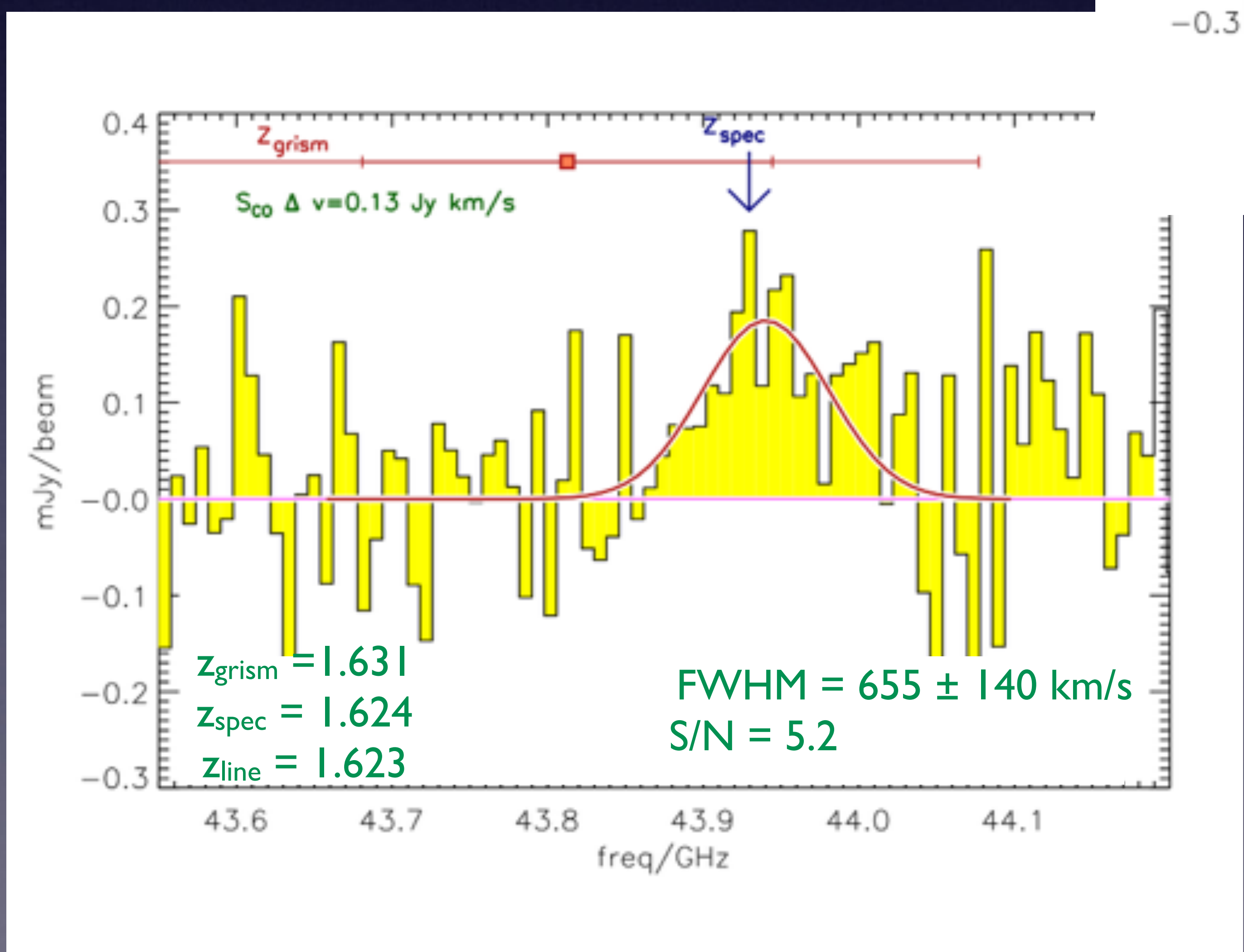
spec member

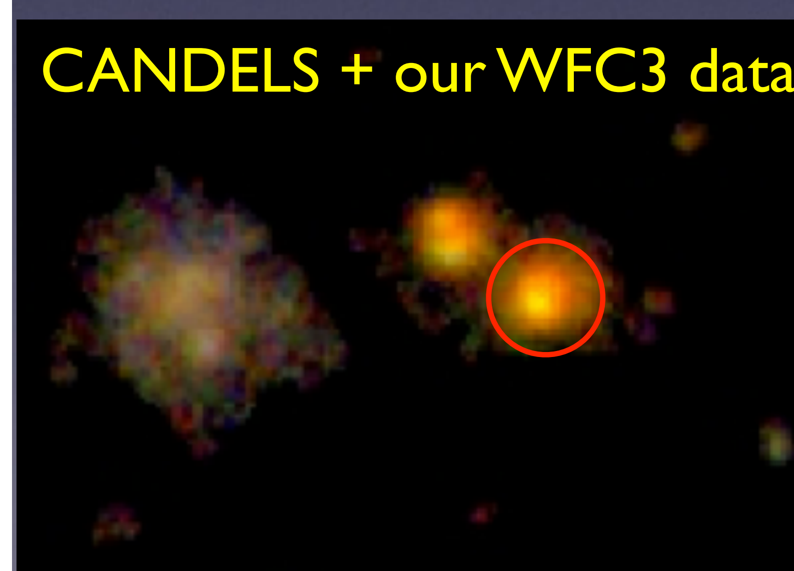
CO Detections



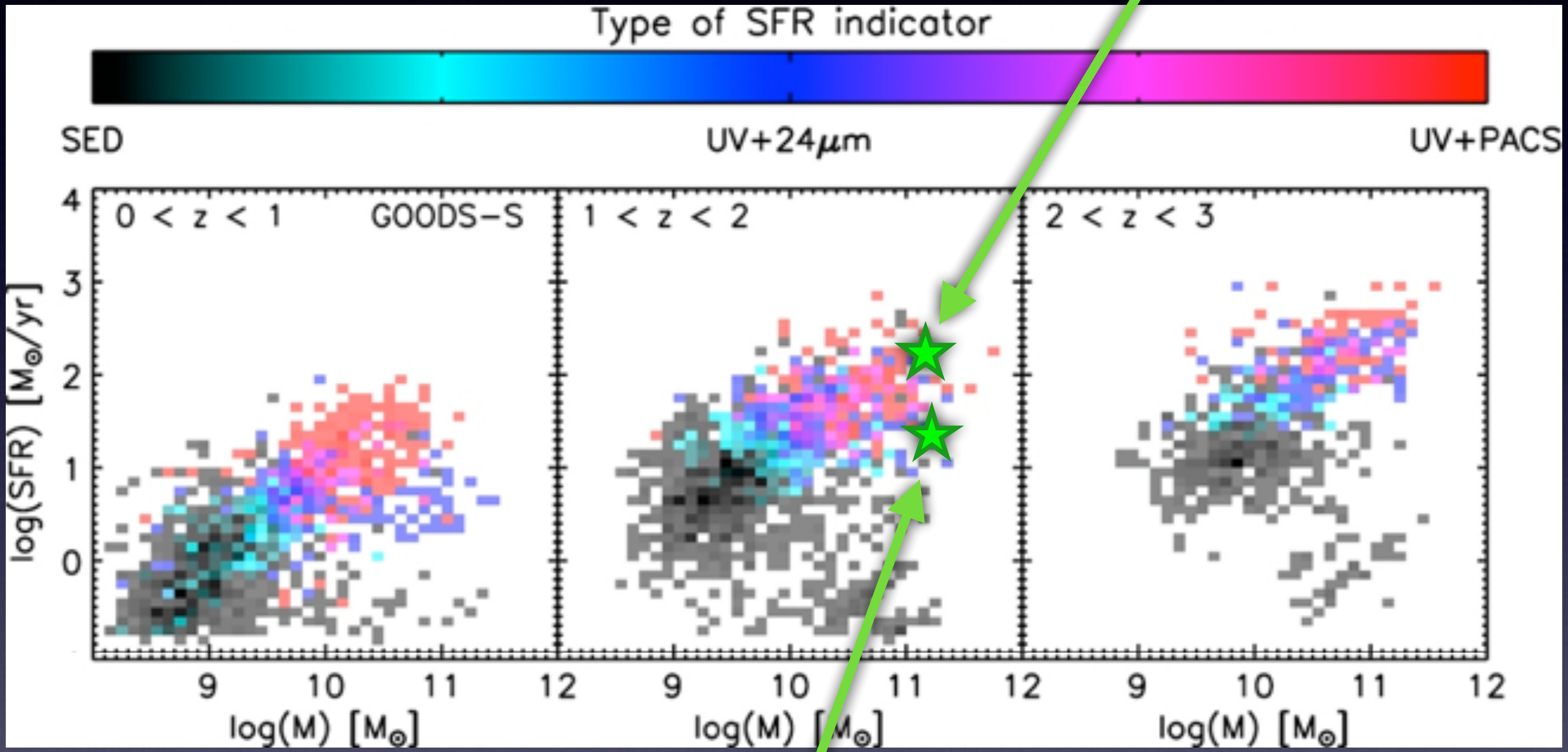
$\sigma_{CO} \approx 275$ km/s





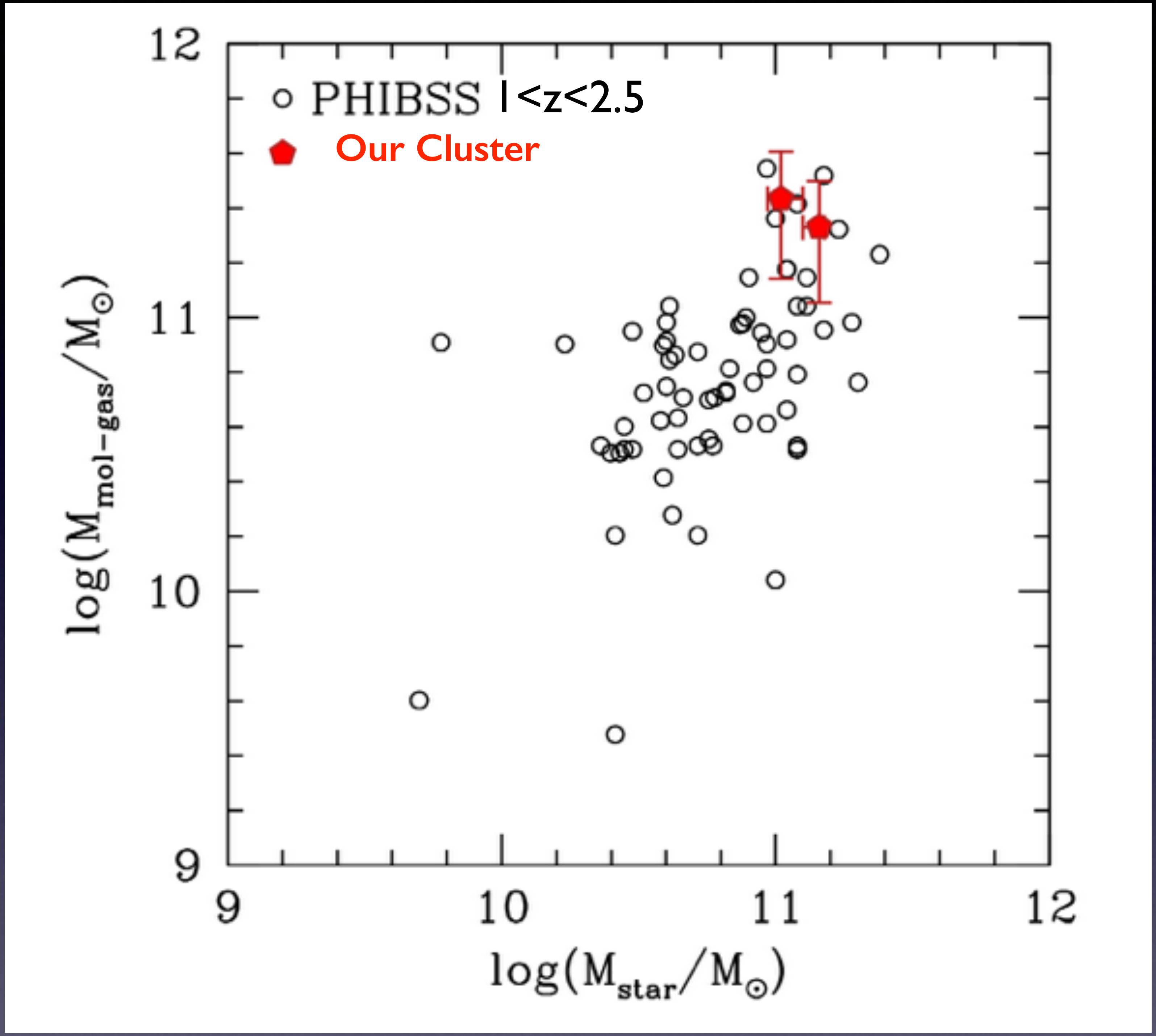


- Galaxies are on/below star formation main sequence



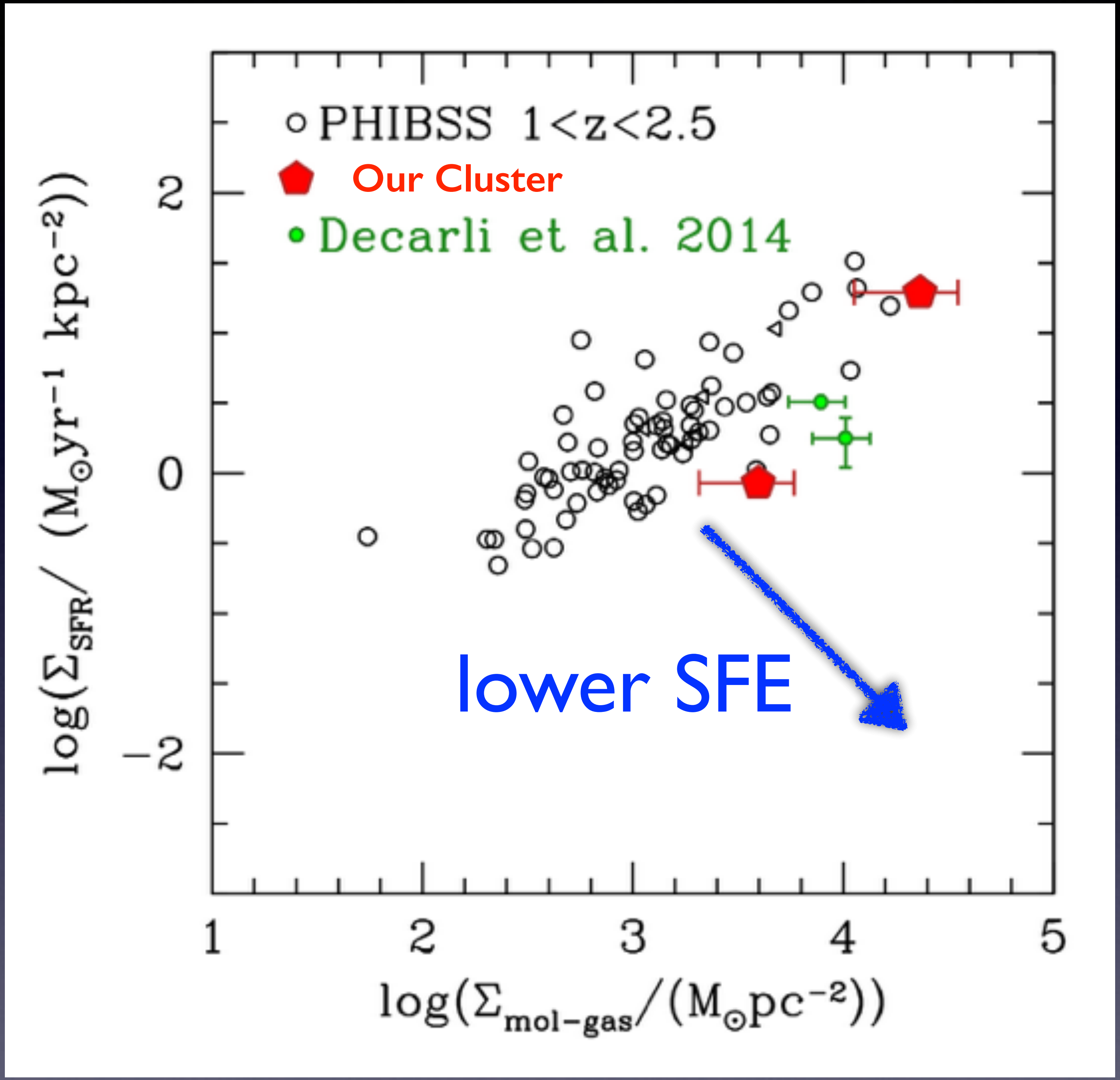
wuyts et al. (2011)

- galaxies are among the most massive
- galaxies are among the most gas rich
- $M_{gas} / (M_{gas}+M_{star}) = 0.6\text{-}0.7$
- $M_{gas}/M_{star} = 1.5\text{-}2.5$

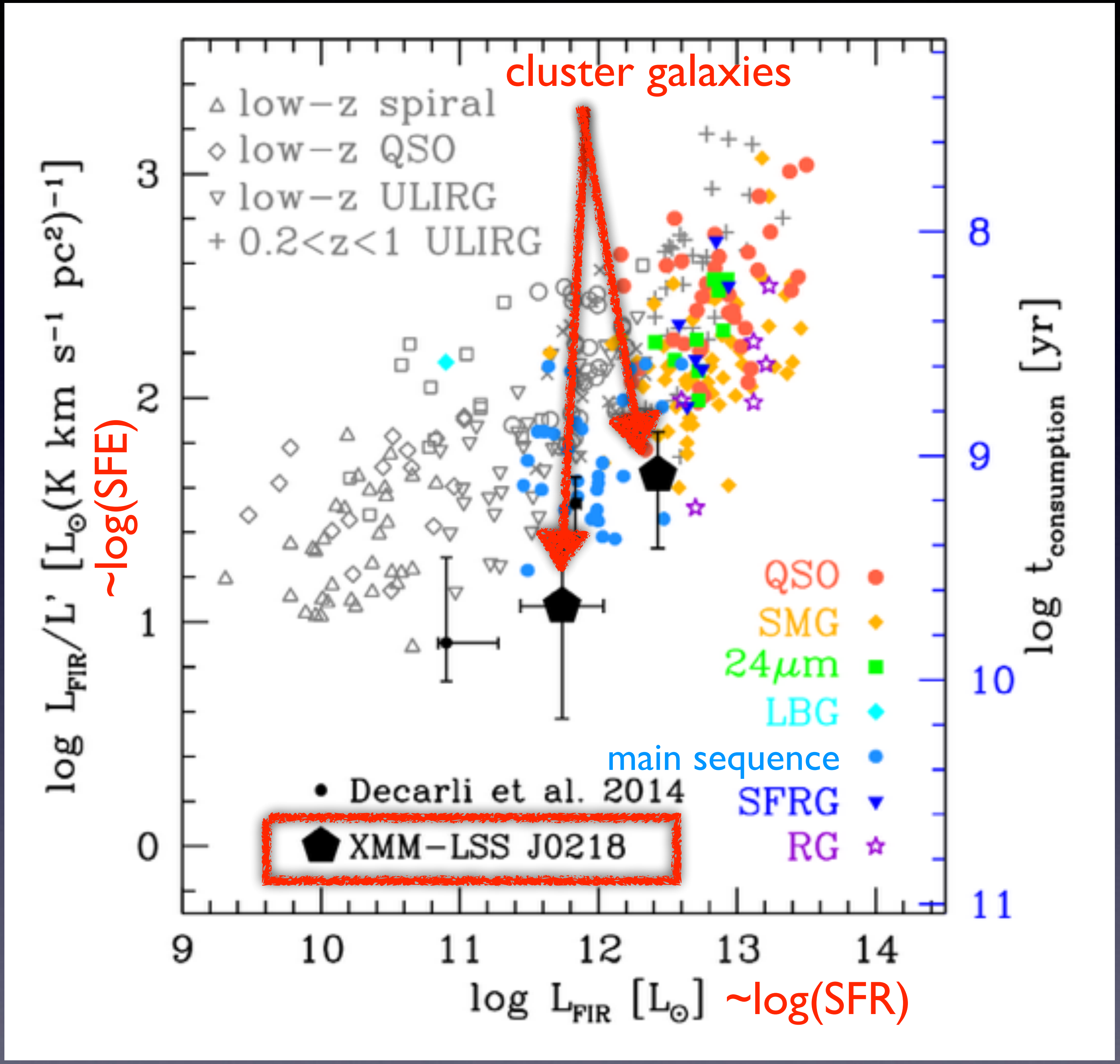


- What is preventing the CO from forming stars?
  - Are the physical conditions of the gas different?
  - Is the stability of gas different?

- Deep blind CO surveys and spatially resolved studies are needed to answer this question.



- Field galaxies have ~0.7 Gyr gas consumption timescales and require replenishment. (Daddi et al. 2008; Aravena et al. 2010; Tacconi et al. 2010; Tacconi et al. 2013)
- Cluster galaxies have long gas consumption timescales (1-4Gyr), assuming constant SFR.
- 80% of 10^{11} M_{sol} galaxies in z~1 clusters are passive.
- No additional gas accretion is allowed over 2 Gyr to z~1
- **Potential sign of high-z environmental truncation of gas accretion**



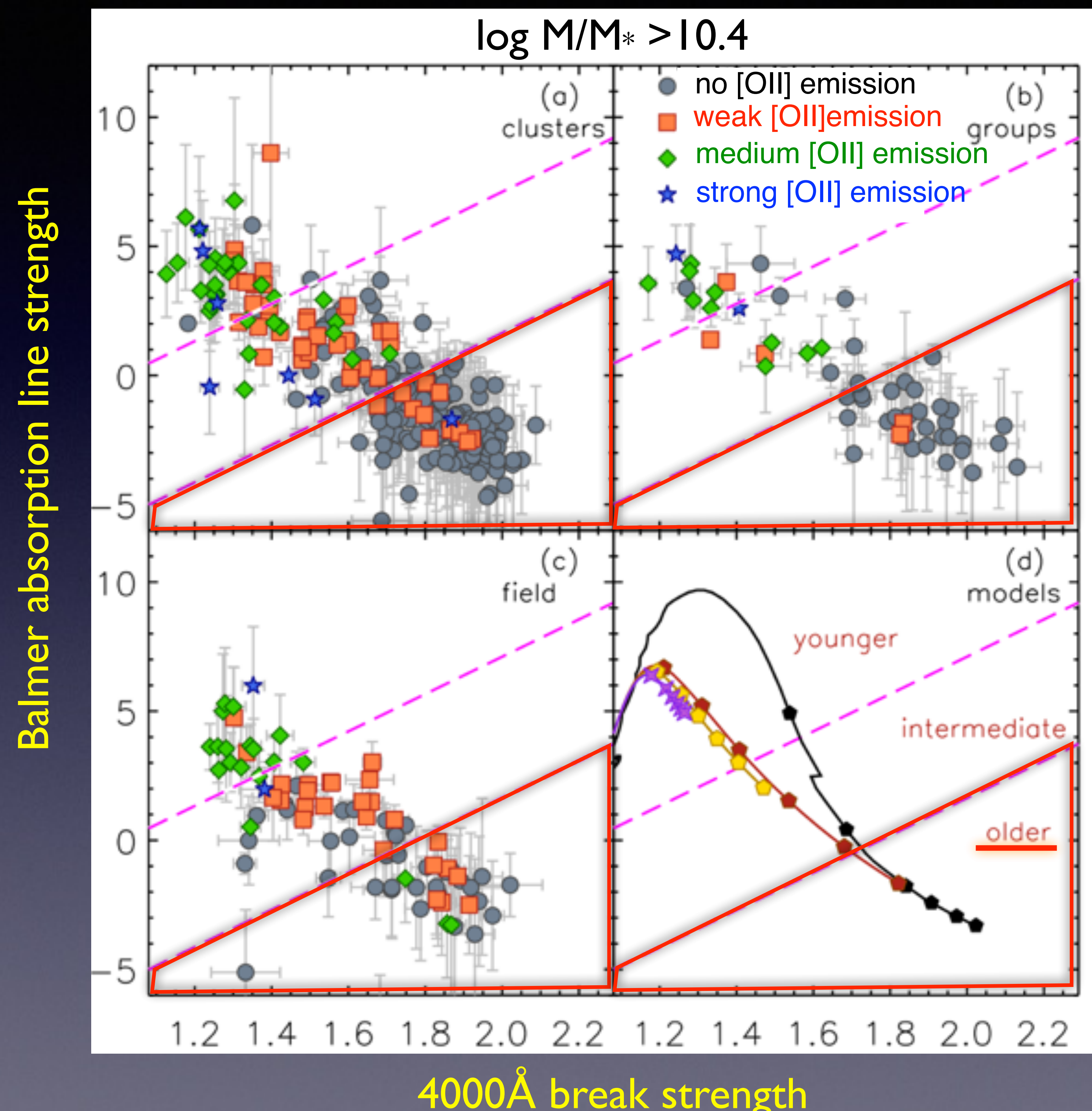
Fighting zombies: how to keep dead galaxies dead

- The universe is filled with gas. How do we keep dead galaxies from getting new gas and forming stars again?
- Mass loss will rejuvenate internal gas supply
  - M_{return} ~0.5*M_{star} for Chabrier IMF
- Quiescent fraction is much higher in dense environments. Can we track down why?

With:
John Moustakas
Pascale Jablonka
&
EDisCS collaboration

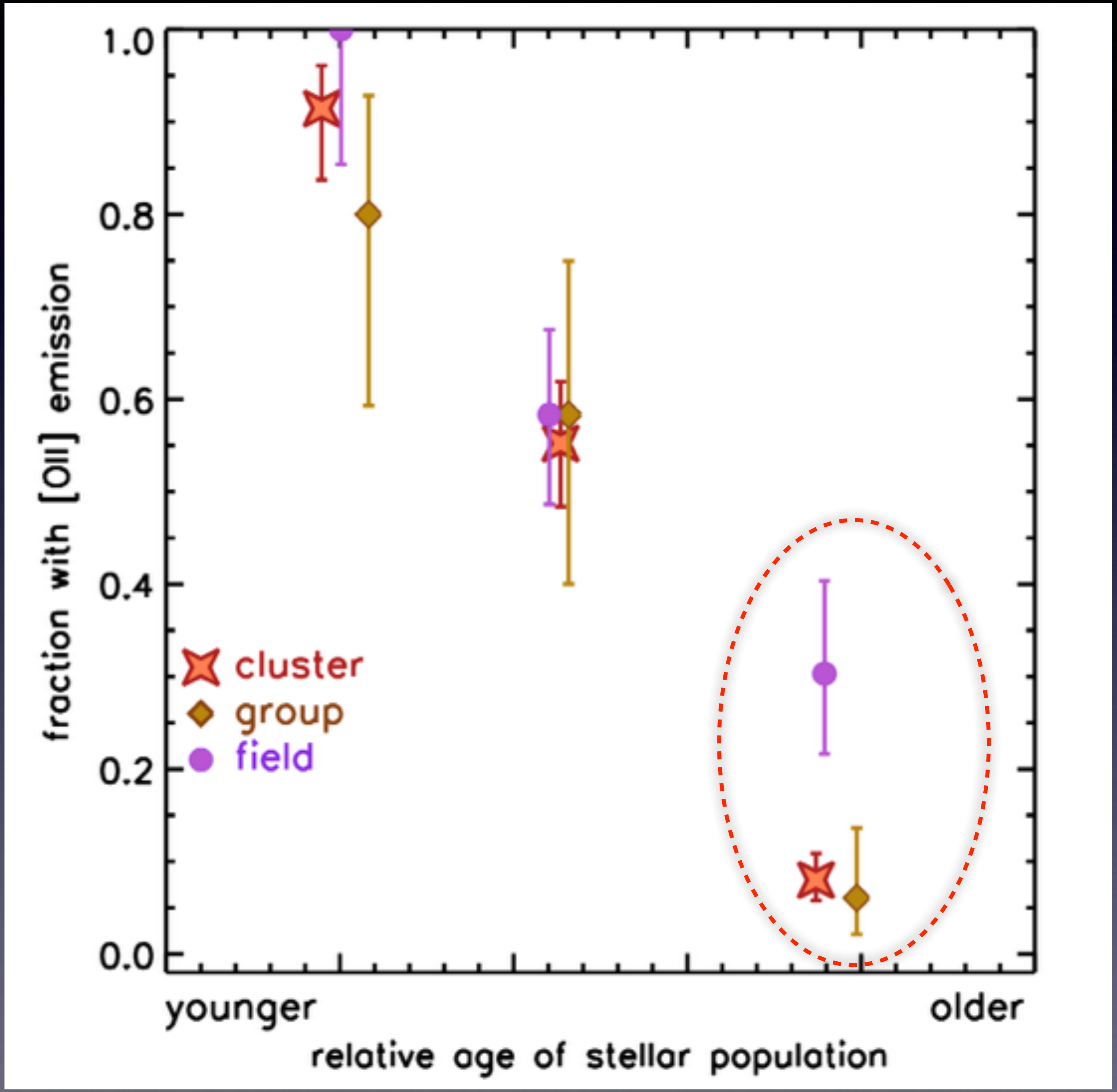
Isolating the environment where gas accretion is shut off

- Use spectral indices to determine relative stellar ages of galaxies
- "Older" galaxies have less than 2% of stellar mass formed in last Gyr.
- There is weak emission in "older" galaxies
- Not star formation: Likely diffuse and heated by pAGB stars → stellar mass loss + accretion



Rudnick et al. in prep.

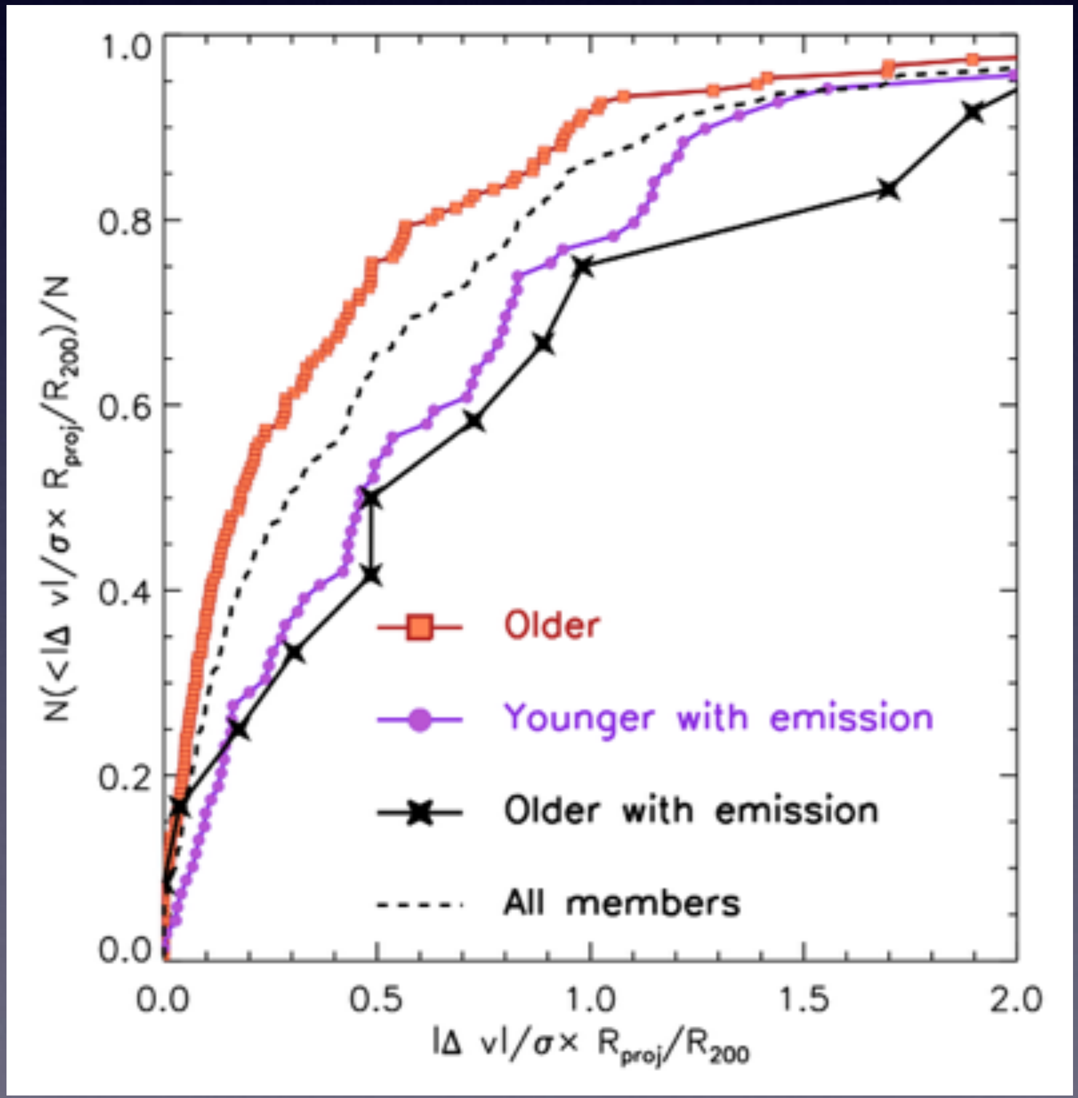
- Old galaxies in groups and clusters have lower emission than in the field
- Emission fraction in younger galaxies is the same in every environment

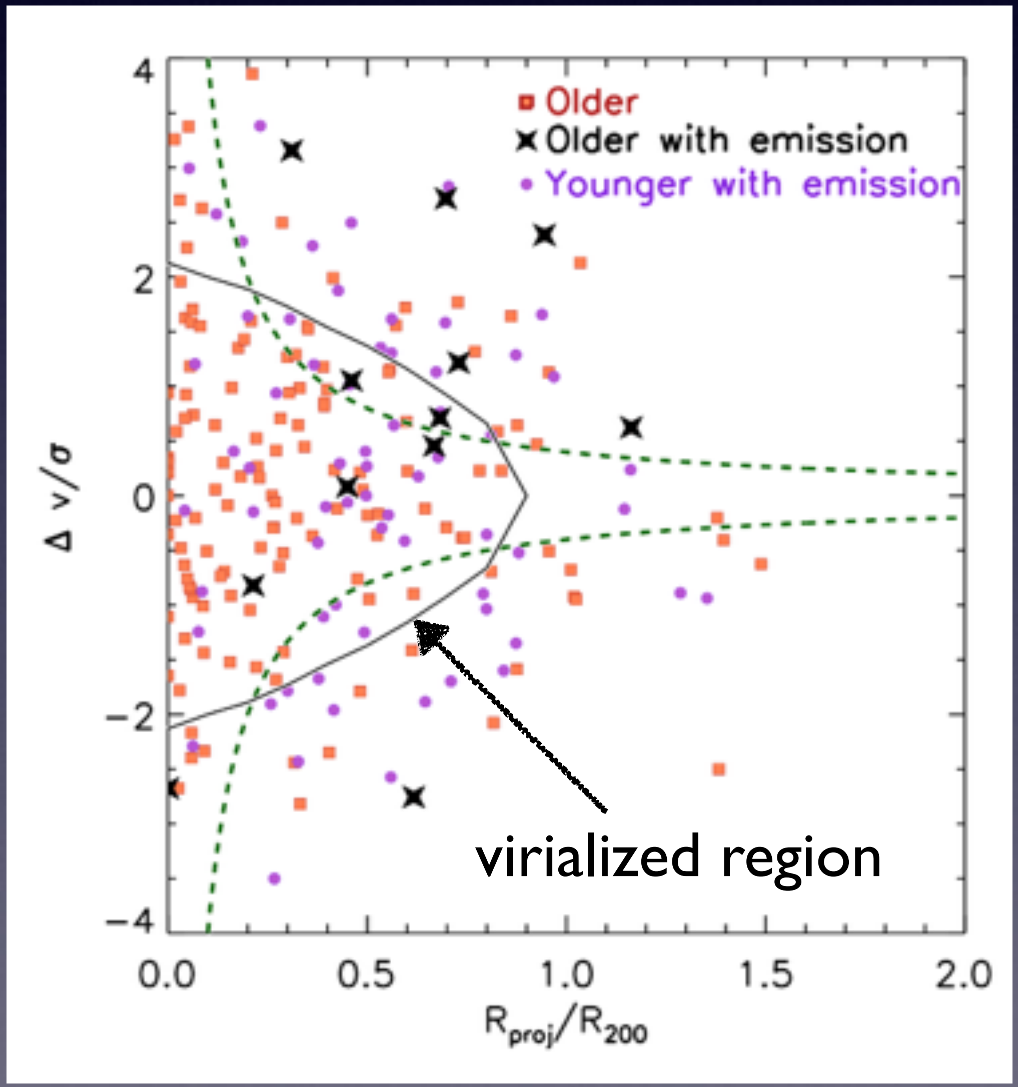


Rudnick et al. in prep.

- Galaxies in the field experience mass loss and gas accretion
- Gas is absent in groups + clusters ⟹ decoupling of accretion from cosmic web
- Gas is absent in cluster cores ⟹ additional ram pressure stripping
- These processes affect the gas, but they don’t necessarily shut off star formation

Stack of All EDisCS clusters





Mahajan+ 2011, Haines+2012, Oman+2013; Noble+ 2013

Rudnick et al. in prep.

Summary

- CO observations of z>1.5 clusters are telling us about the demise of the massive cluster population.
  - Clusters are preventing gas accretion at z>1.5
  - Need more deep CO observations in high-z dense environments.
- The group and cluster environment cut off gas accretion in old galaxies.
- Clusters exhibit addition stripping processes that can trim hot gas reservoirs from massive galaxies.