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Molecular Gas and the Last Gasp of Star Formation in High Redshift Cluster Galaxies

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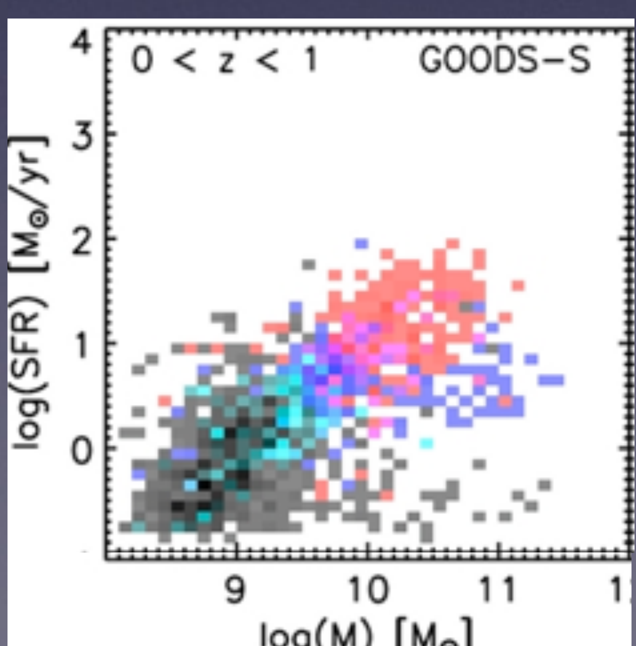
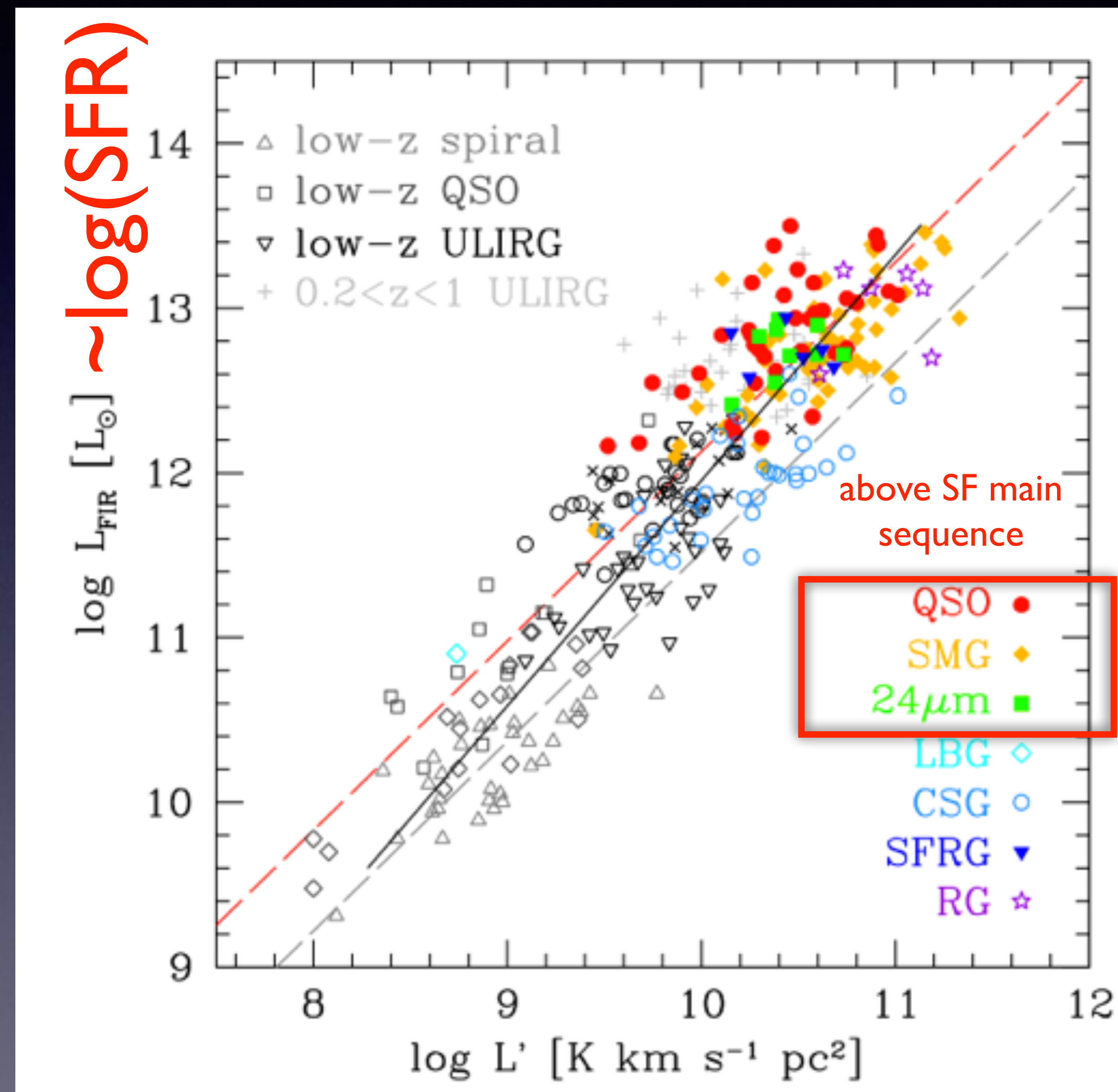
The supply-side economics of regulating star formation

Molecular Gas Supply as a Driver of Star Formation

- SFR is correlated with $M_{mol\text{-}gas}$.
- Galaxies on the star formation main sequence at z>1 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)



wuyts et al. (2011)

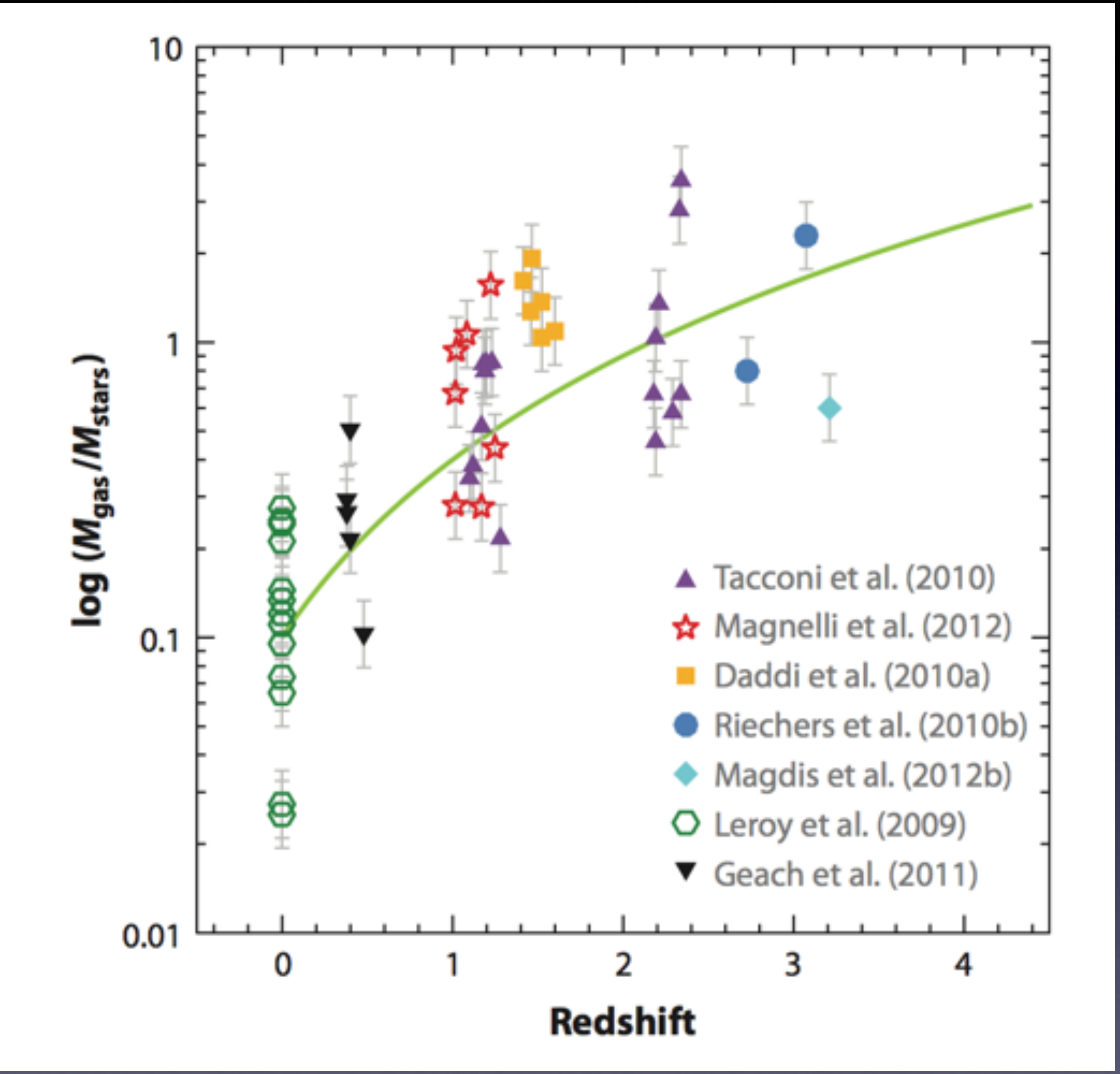


$=\log(M_{mol\text{-}gas}/\alpha)$

Carilli & Walter 2013 ARAA

What drives the overall decline in SFRs with time

- The decline in SFR is mirrored by a decline in M_{gas}/M_{star}
- What governs star formation at high redshift
- 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)
- Obstacles include:
  - There are few CO(1-) gas mass measurements at z>1
  - Few blind CO studies
  - There are no tests of molecular gas abundances in dense environments.

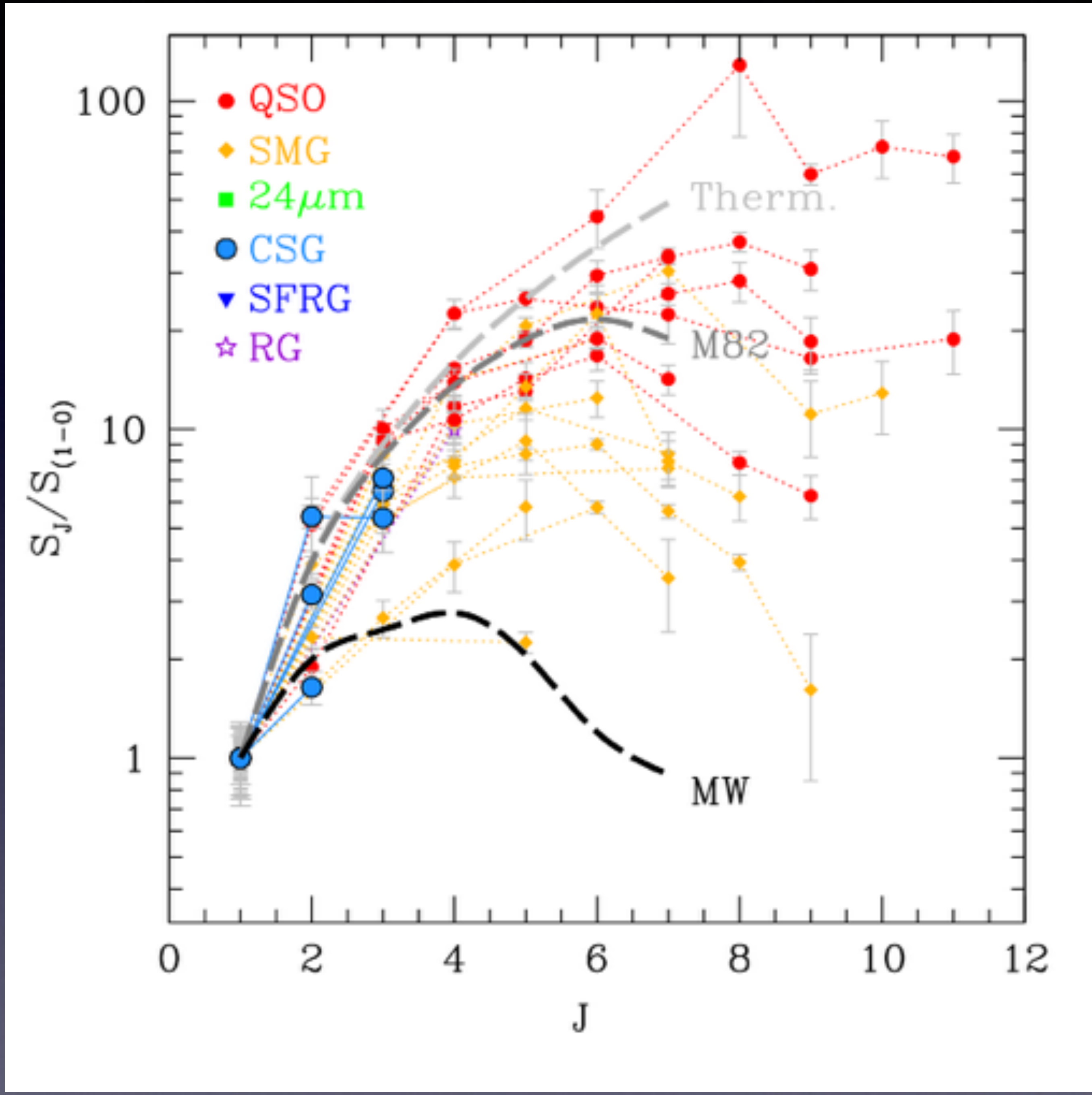


- Are we missing galaxies with interesting properties
- How does supply-side regulation work in urban environments?

Carilli & Walter 2013 ARAA

Robustly measuring the molecular gas

- We would like to study molecular gas to get
  - baryon budgets, mass fractions
  - gas consumption times
  - physical gas conditions
  - effect of environment
- Use CO as tracer of H_2
- $M(H_2) = L_{CO}/\alpha$
- Uncertain excitation makes conversion of CO luminosity to gas mass uncertain.
- CO(J=1→0) has minimal excitation corrections
- JVLA is uniquely capable



Carilli & Walter 2013 ARAA

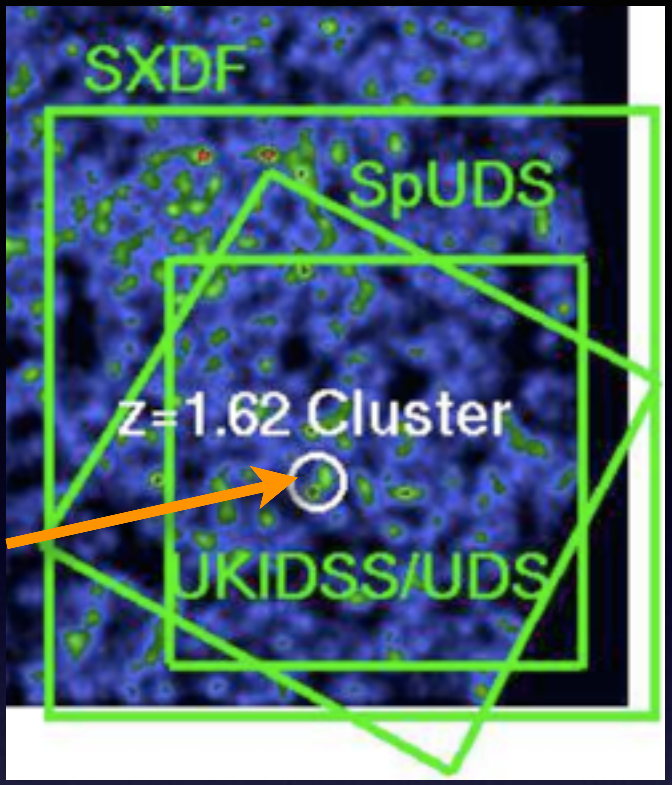
A z=1.62 cluster as an ideal CO target

- many (>30) spectroscopically confirmed members WFC3 Grism
  - Papovich, et al. + Rudnick 2010; Tanaka et al. (2010); Momcheva in prep.

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

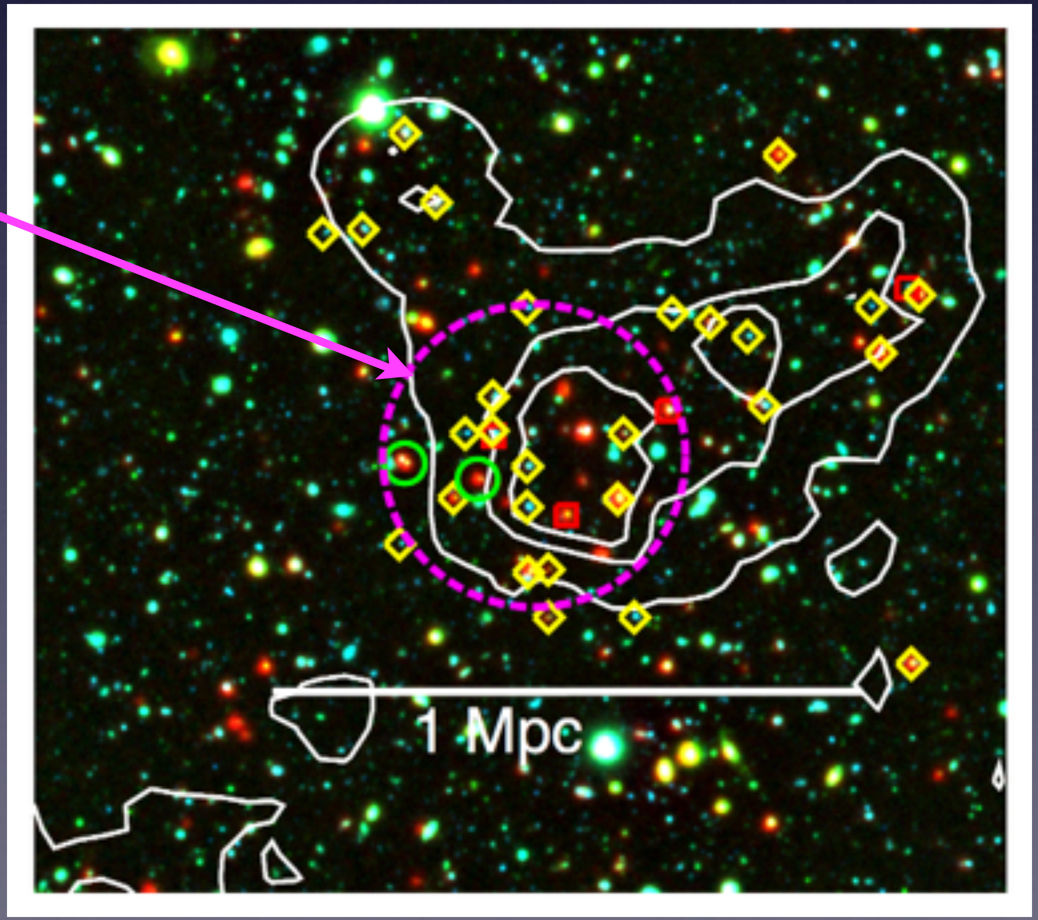
- Many star-forming galaxies in the cluster core
  - Tran et al. 2010; Santos et al. 2014

- Deepest ever VLA image taken in CO. 45h on source + 60h on source in 2014B



Papovich 2010; Papovich et al. + Rudnick 2012

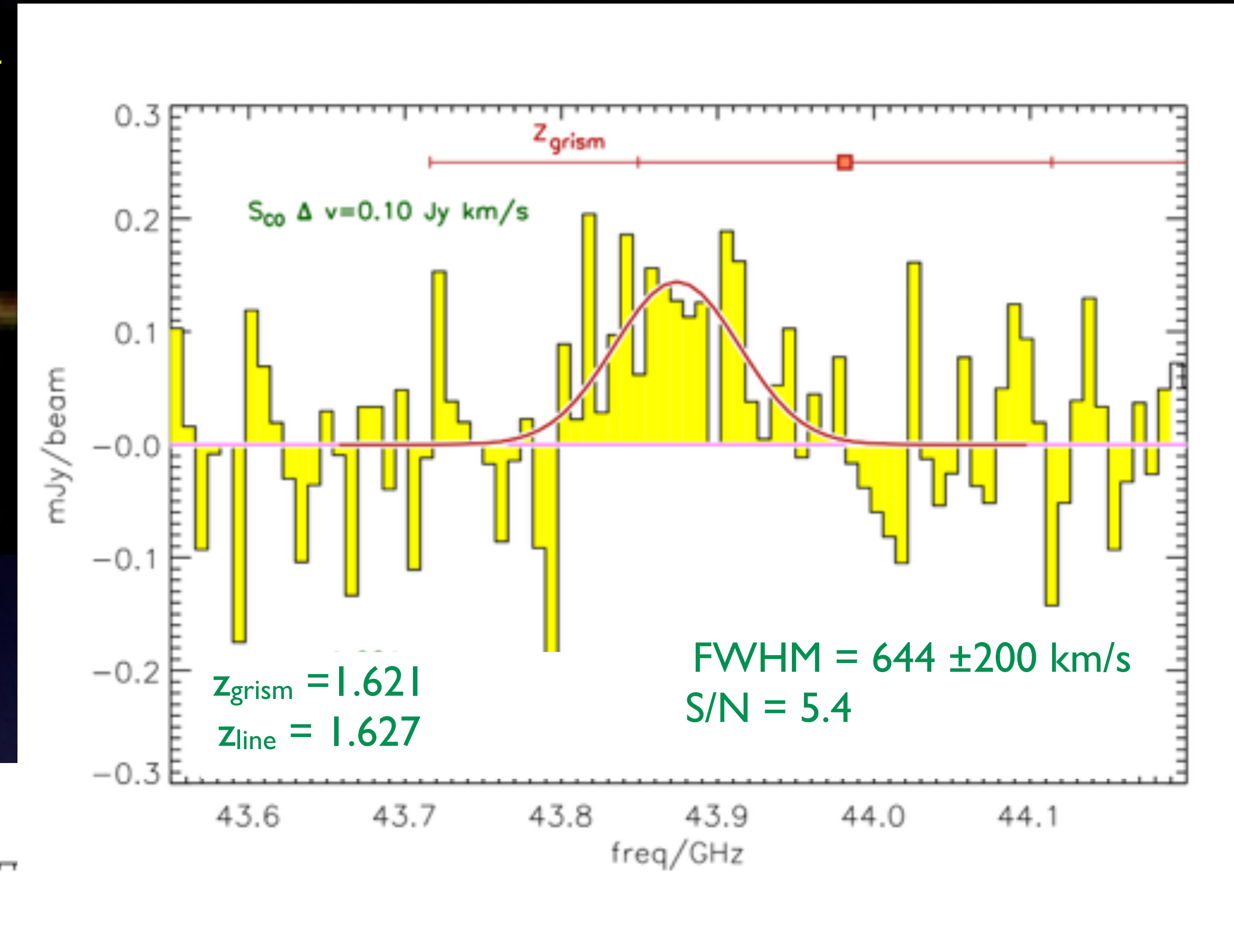
EVLA field of view



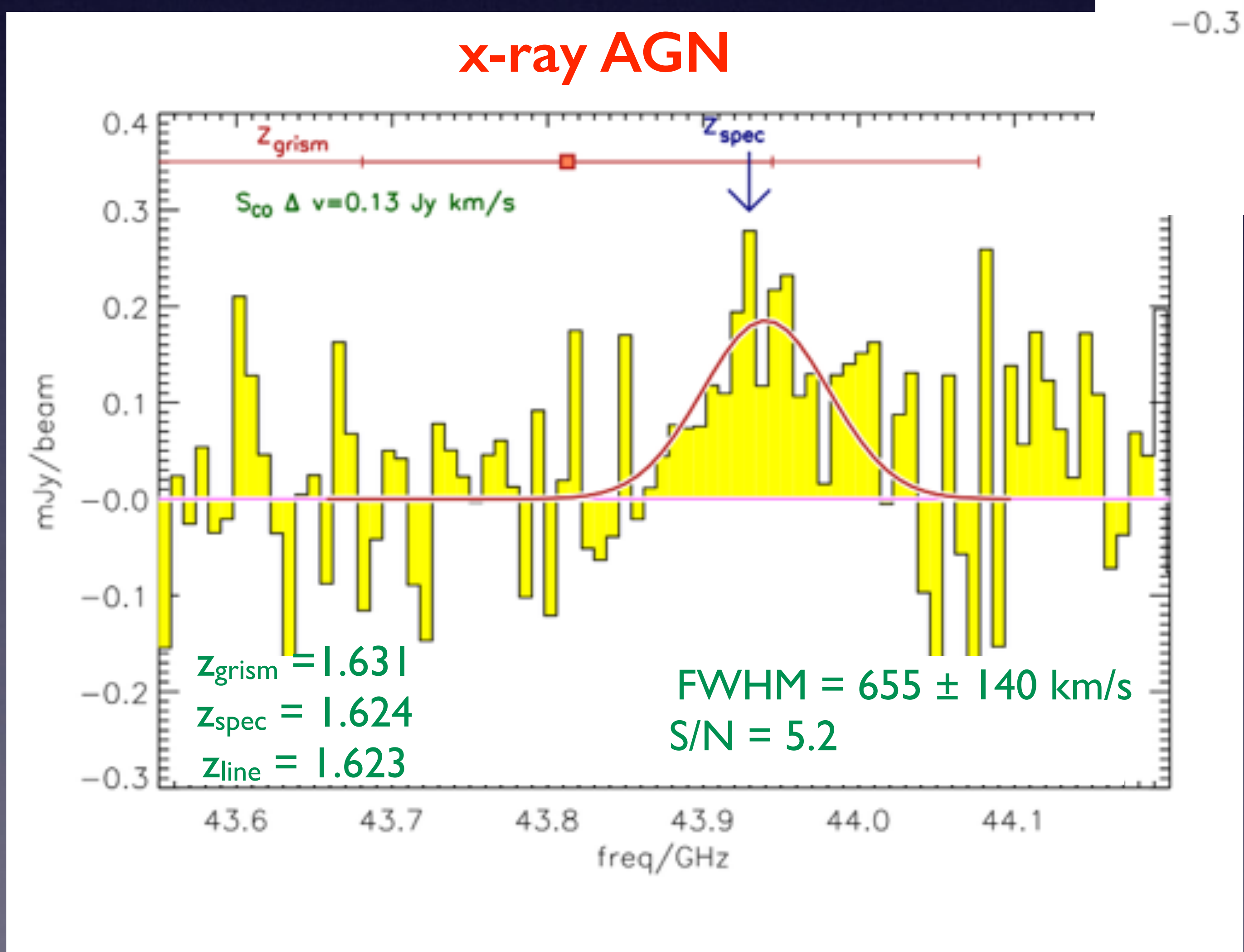
CO detection

spec member

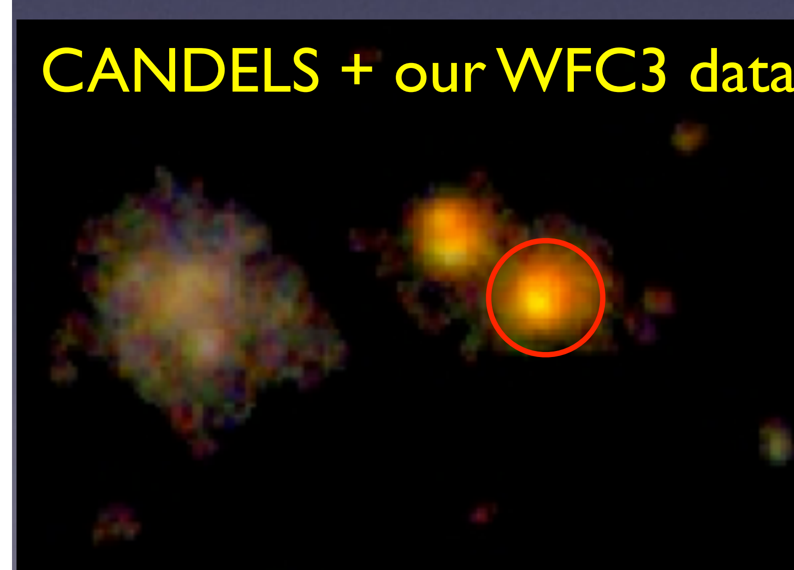
non-member



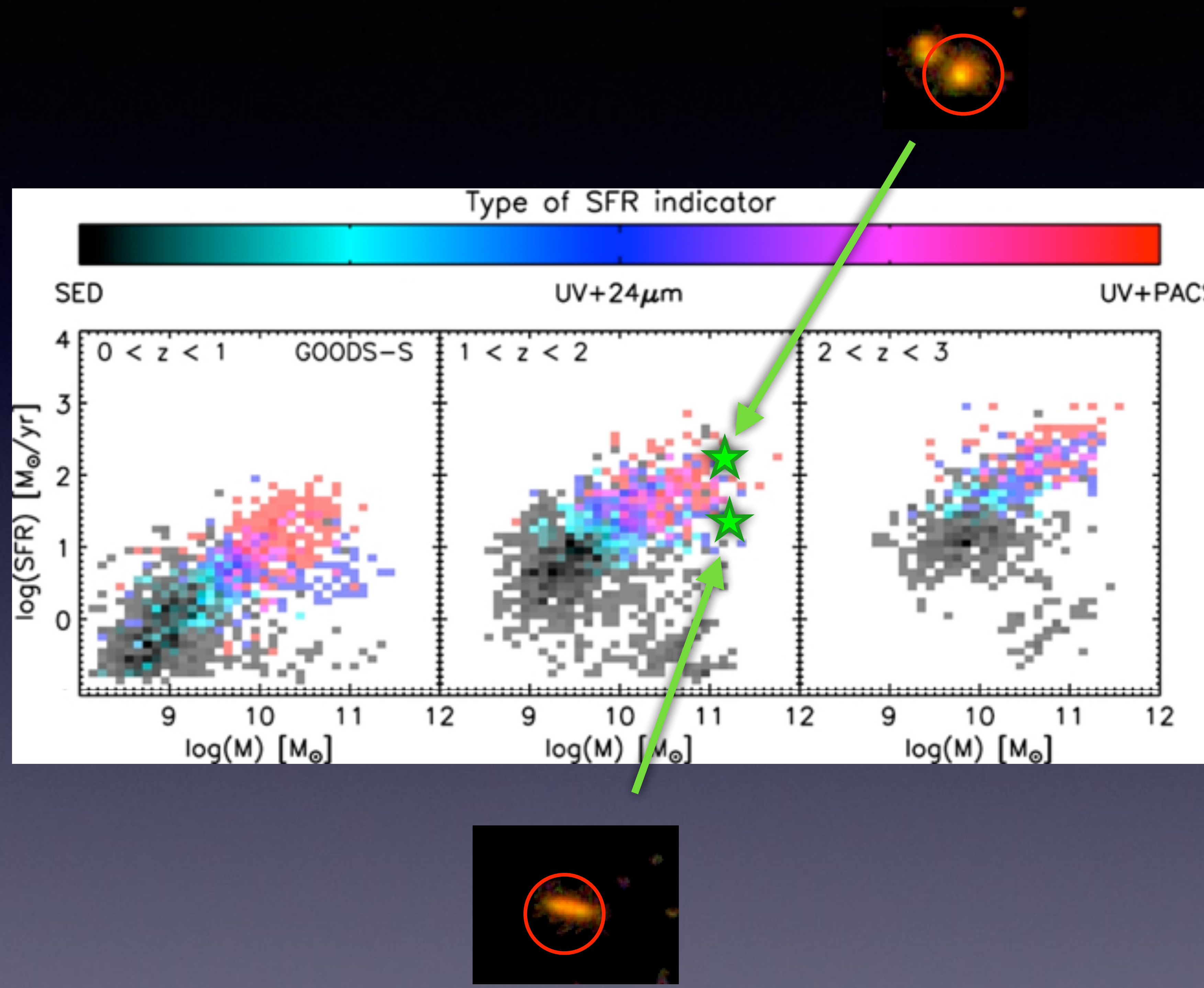
$\sigma_{CO} \approx 275$ km/s



$m_{star} \sim m_{dyn}$ for both galaxies

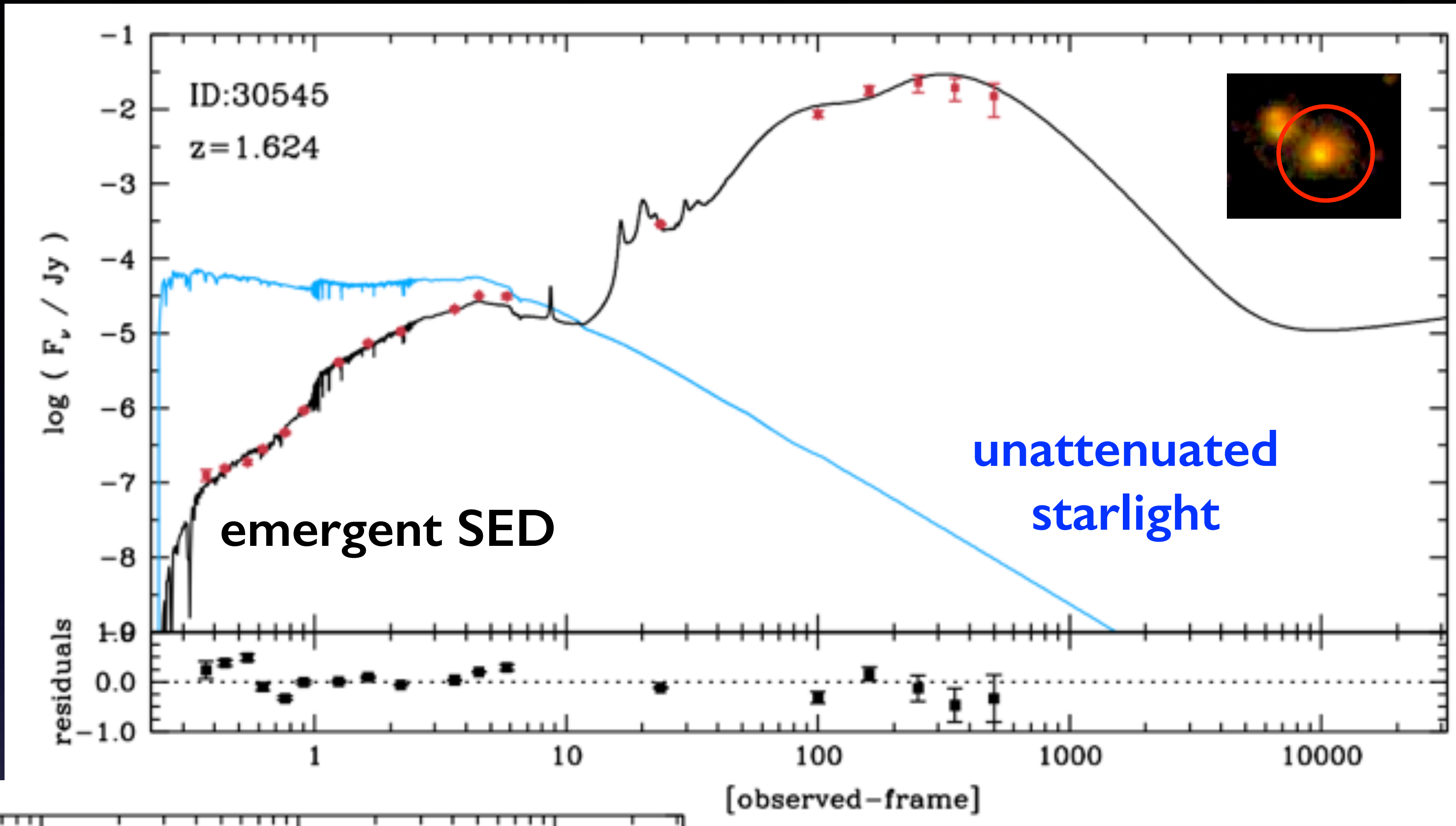


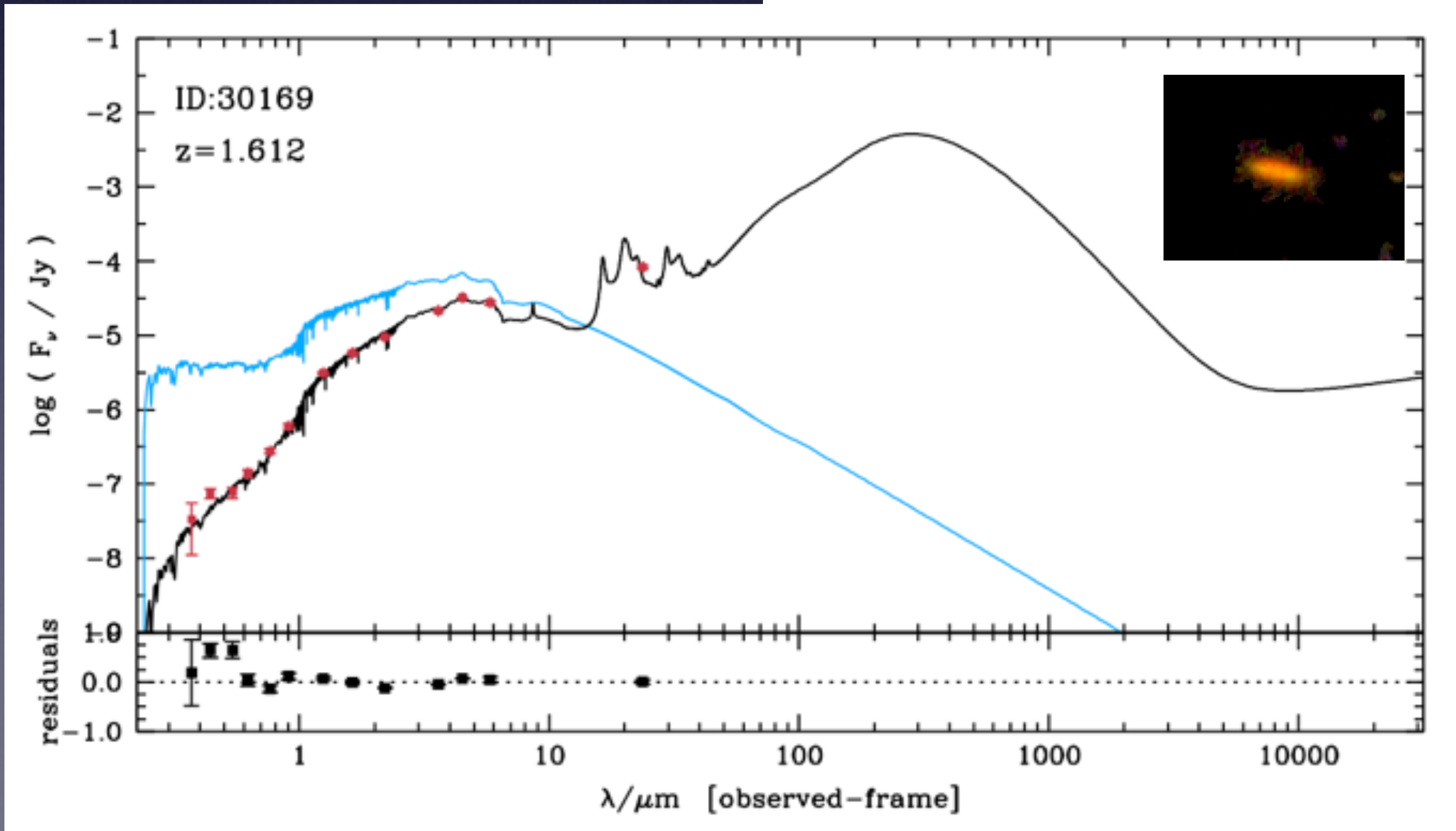
- Galaxies are on/below star formation main sequence



wuyts et al. (2011)

- Fit using MAGPHYS (da Cunha et al. 2008)
- Highly obscured galaxies





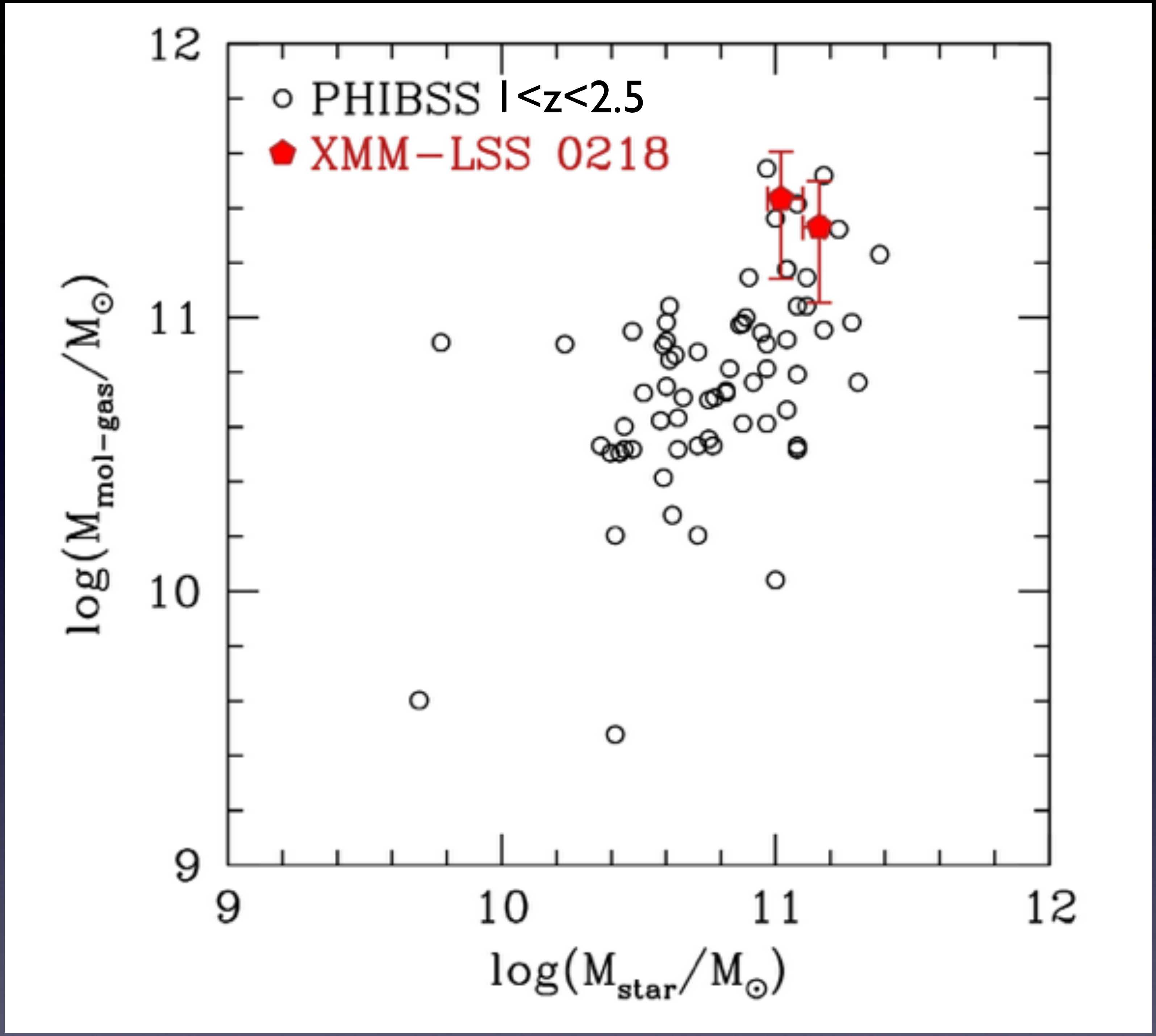
Dynamical constraints favor MW-like α_{CO}

Our galaxies are massive and have large reservoirs of molecular gas.

$M_{gas} / (M_{gas}+M_{star}) = 0.6\text{-}0.7$

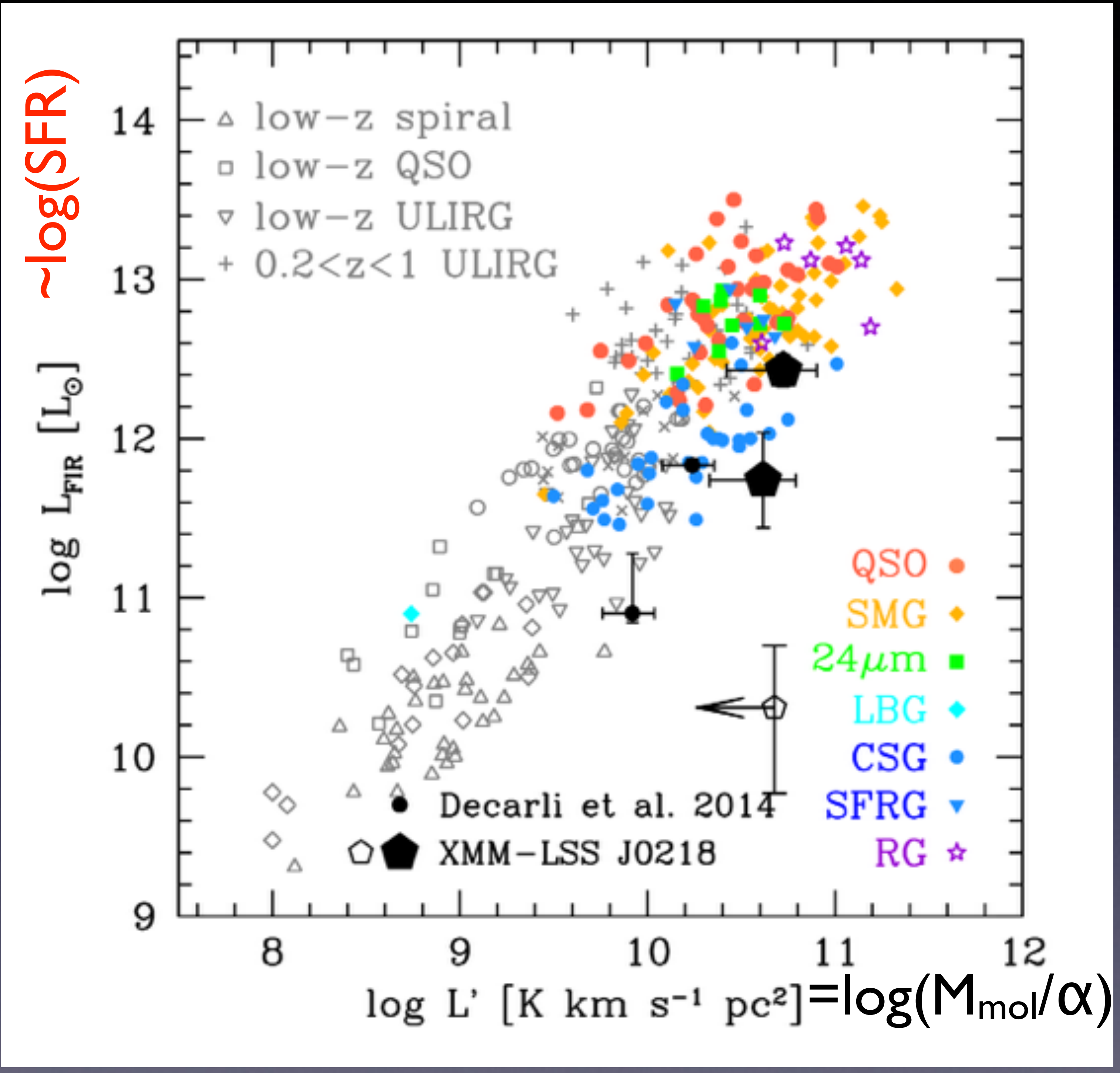
$M_{gas}/M_{star} = 1.5\text{-}2.5$

At the high end of gas fractions for equivalently massive galaxies

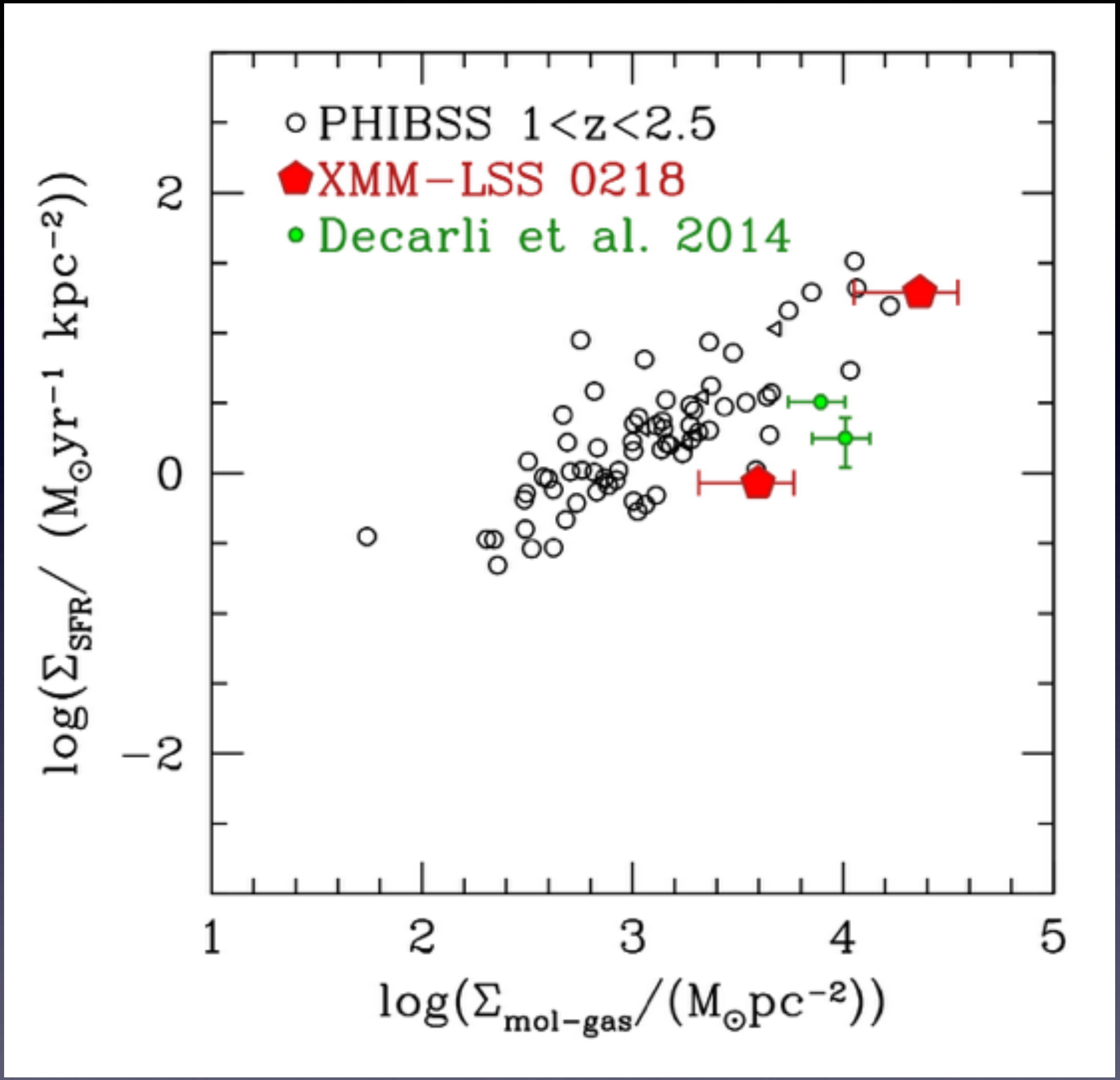


Adapted from Carilli & Walter 2013 ARAA

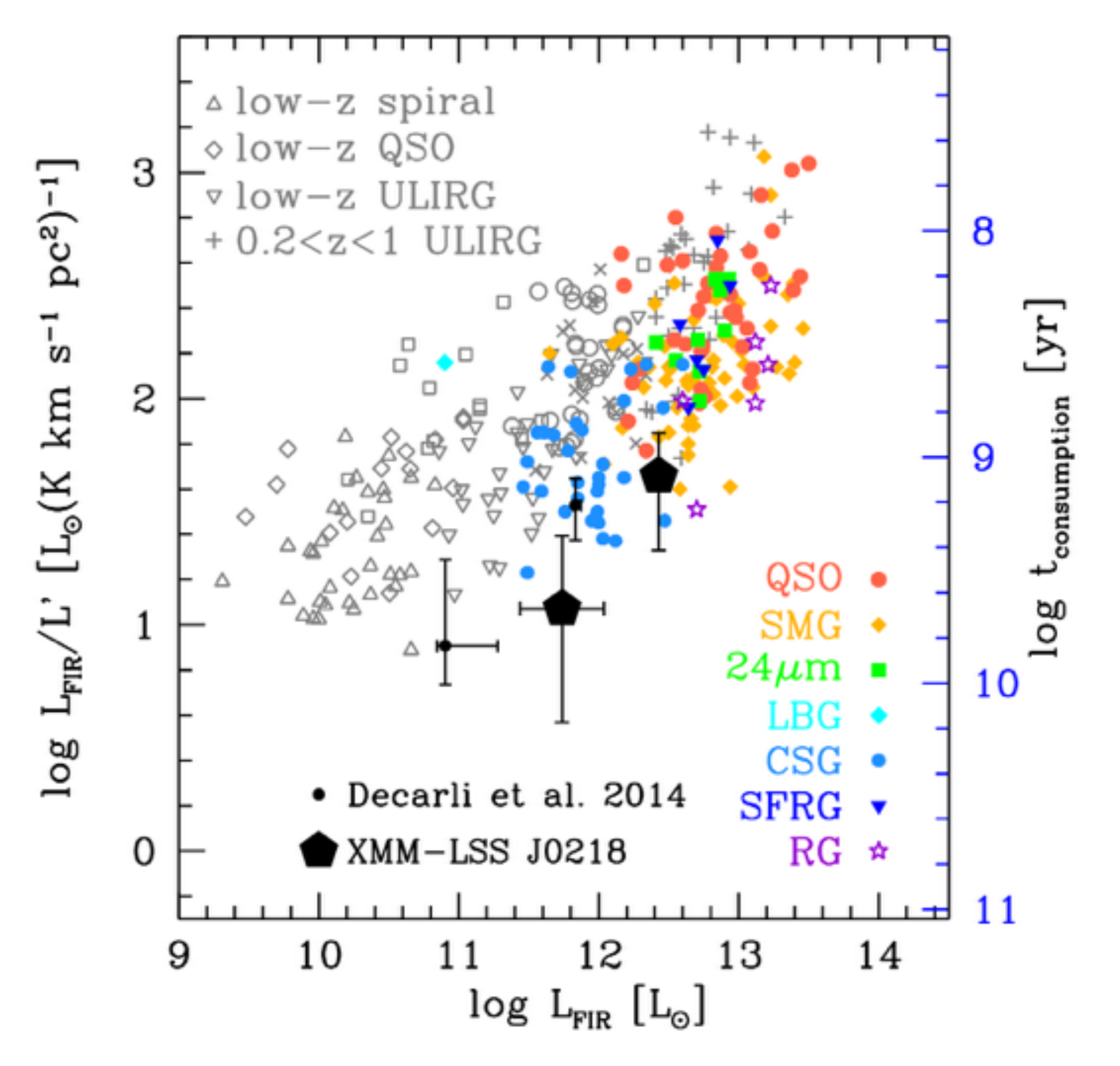
- low SFR for amount of CO gas compared to targeted surveys



- low SFR for amount of CO gas compared to targeted surveys
- 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)
- our 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
- Is this a sign of an environmental truncation of gas accretion?



Summary

- 2 secure CO(1-0) detections in a z=1.62 galaxy cluster
- 50% increase in all high-redshift CO(1-0) detections.
- High stellar mass, high gas fractions, but low star formation efficiency.
  - What keeps the gas from forming stars?
- No additional accretion allowed.
  - Is this a sign of the truncation of accretion?
- Highlights importance of blind CO surveys (e.g. Decarli et al. 2014) and deep surveys in dense high-redshift environments.