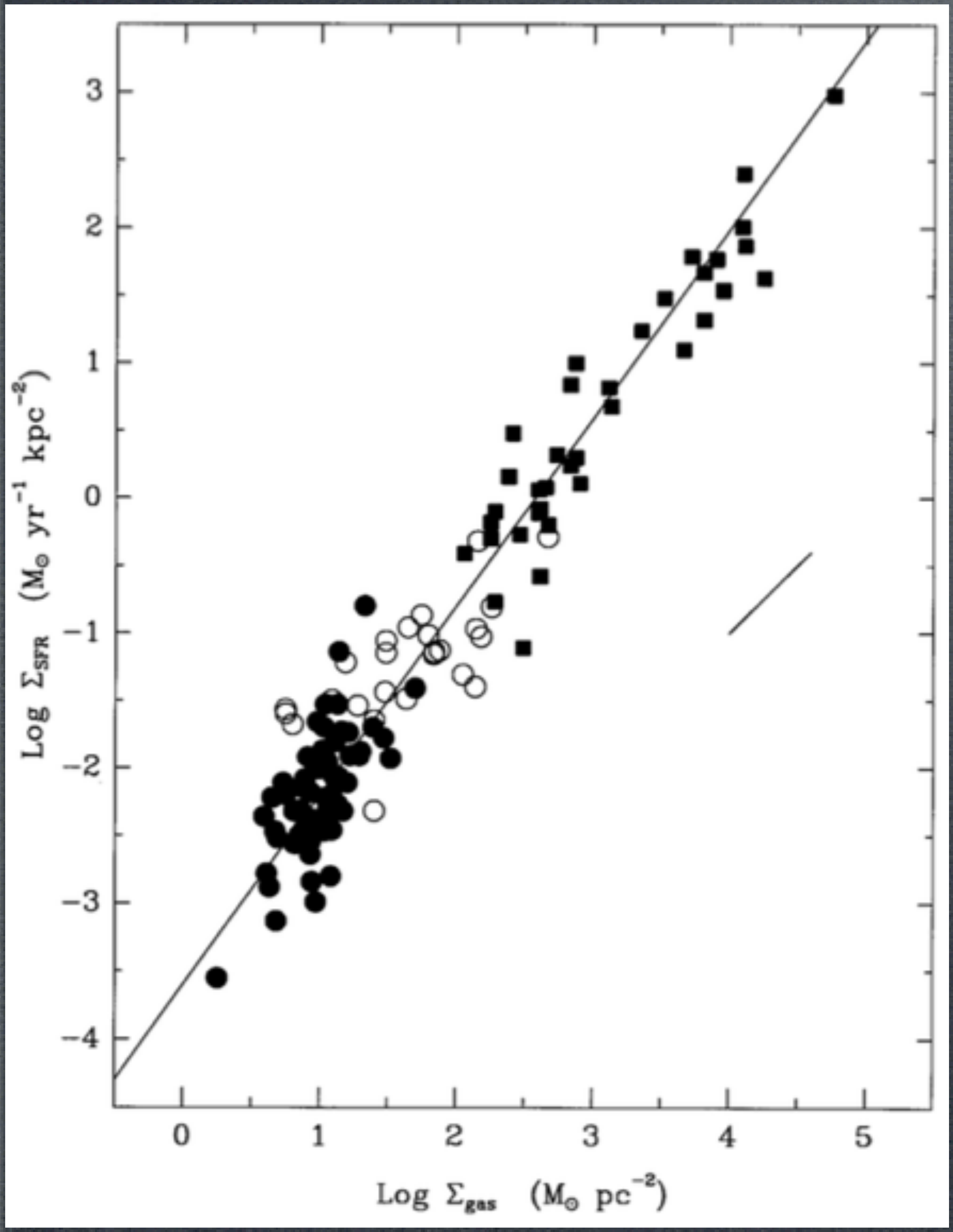
The gas at dawn: Star formation efficiency at z~3

Brent Groves (ANU)
Eva Schinnerer (MPIA), Mark Sargent (Sussex),
COSMOS-ALMA team

Australian Government
Australian Research Council

Australian National University

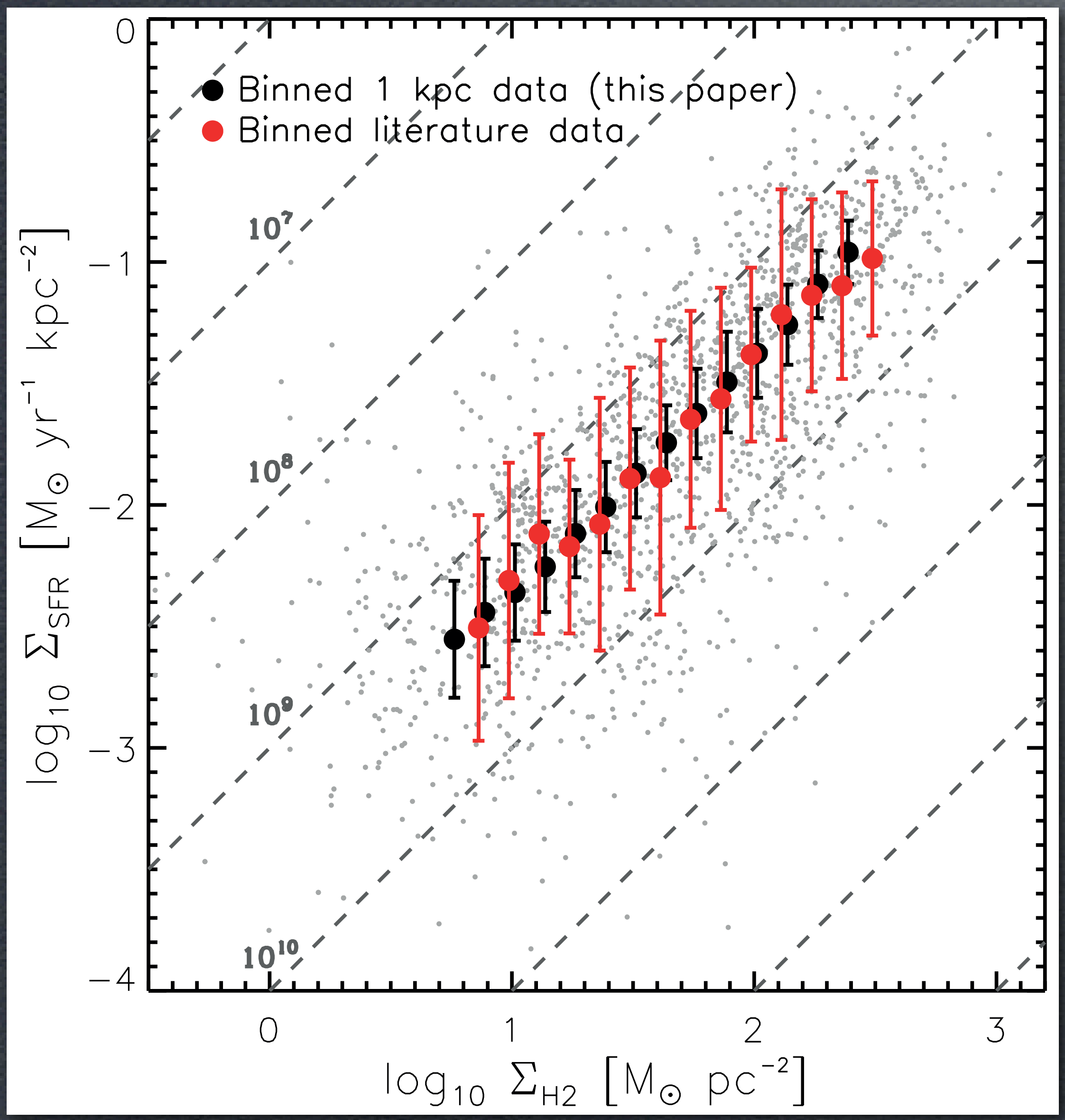
A constant efficiency for gas to stars?



- In the local universe we see a strong relation between gas and star: KS law

Kennicutt et al. (1998)

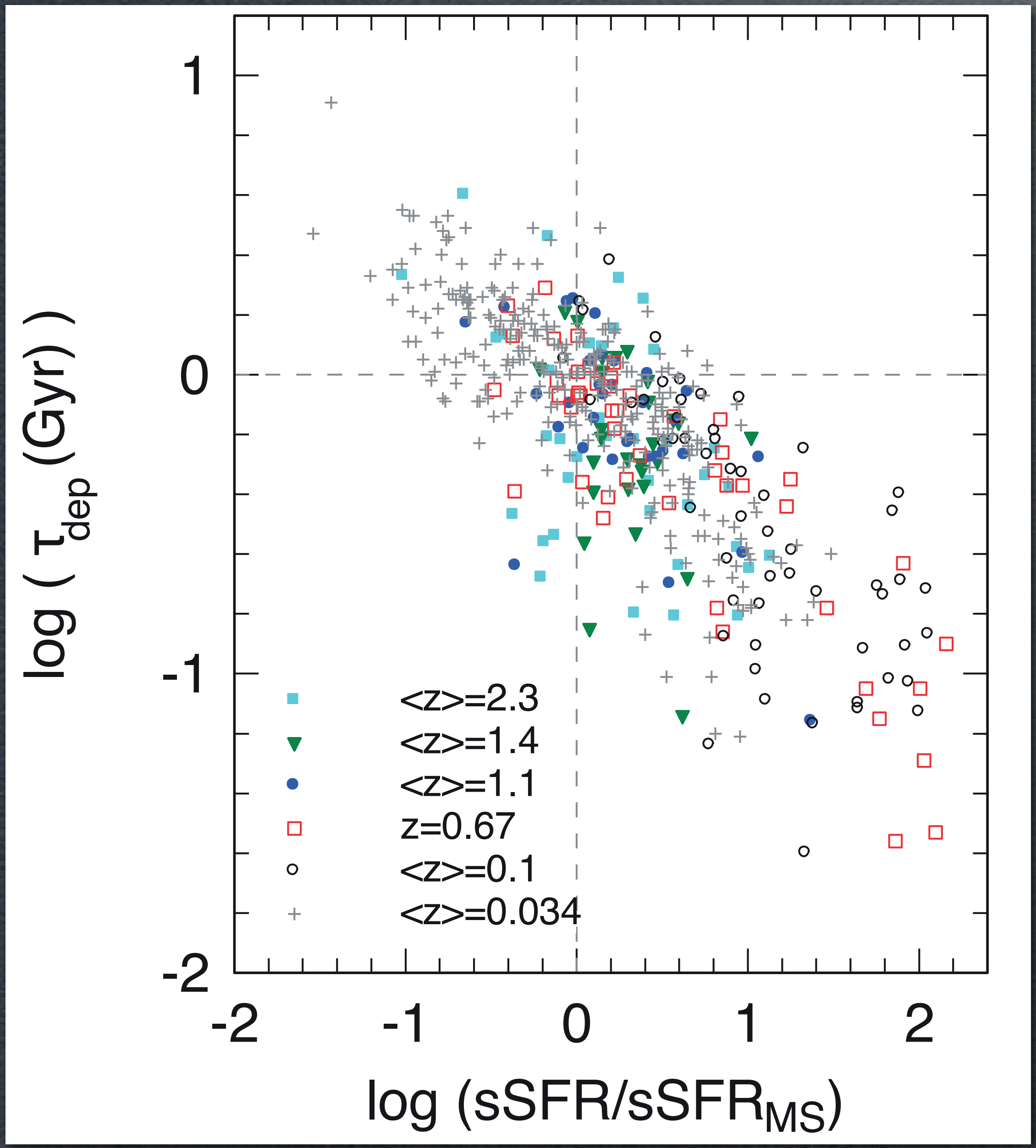
A constant efficiency for gas to stars?



Bigiel et al. (2011)

- In the local universe we see a strong relation between gas and stars: KS law
- On kpc scales see constant relation
  - $\tau_{dep} = 1/SFE = \Sigma_{gas}/\Sigma_{SFR}$

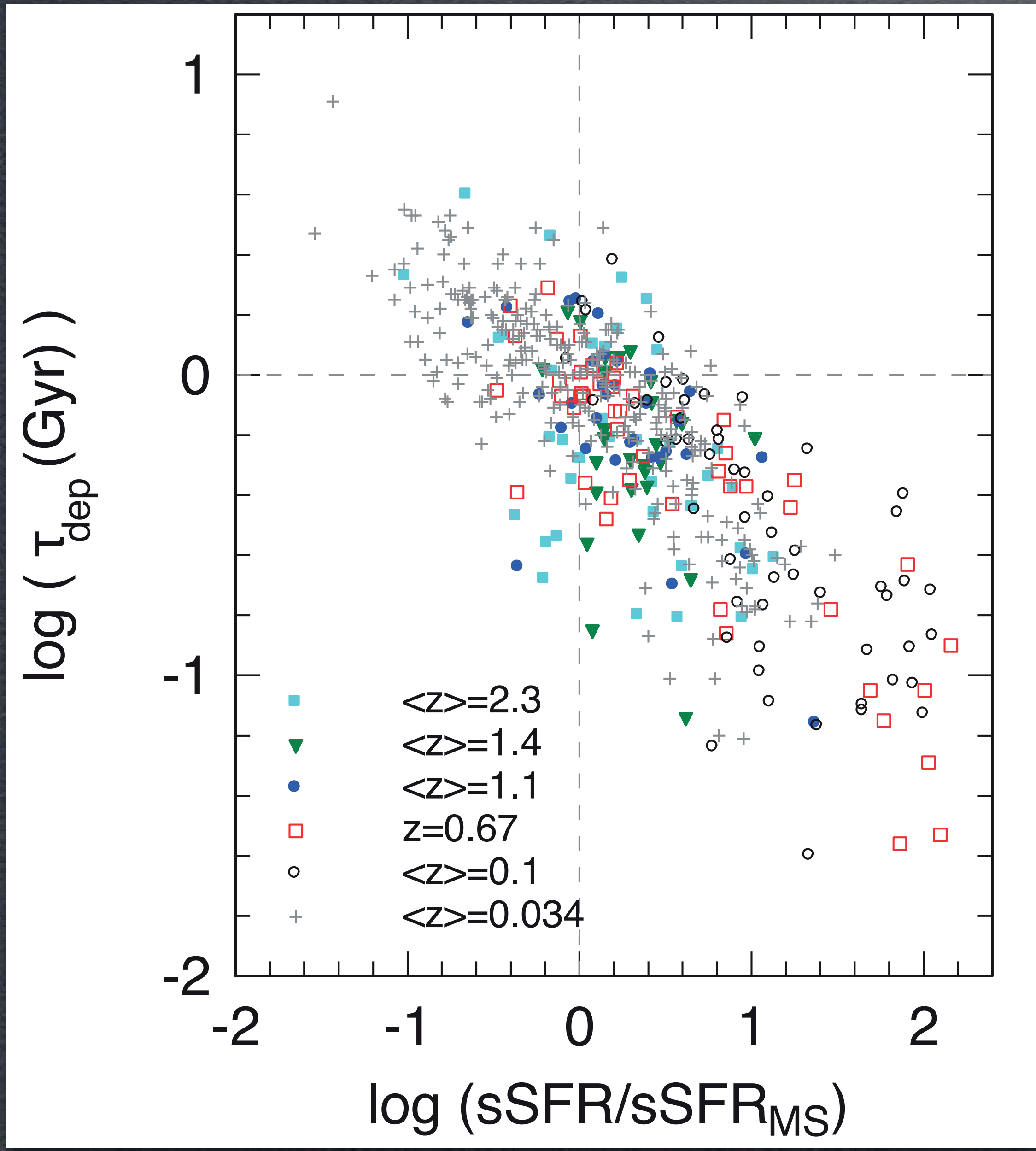
A constant efficiency for gas to stars?



Genzel et al. (2011)

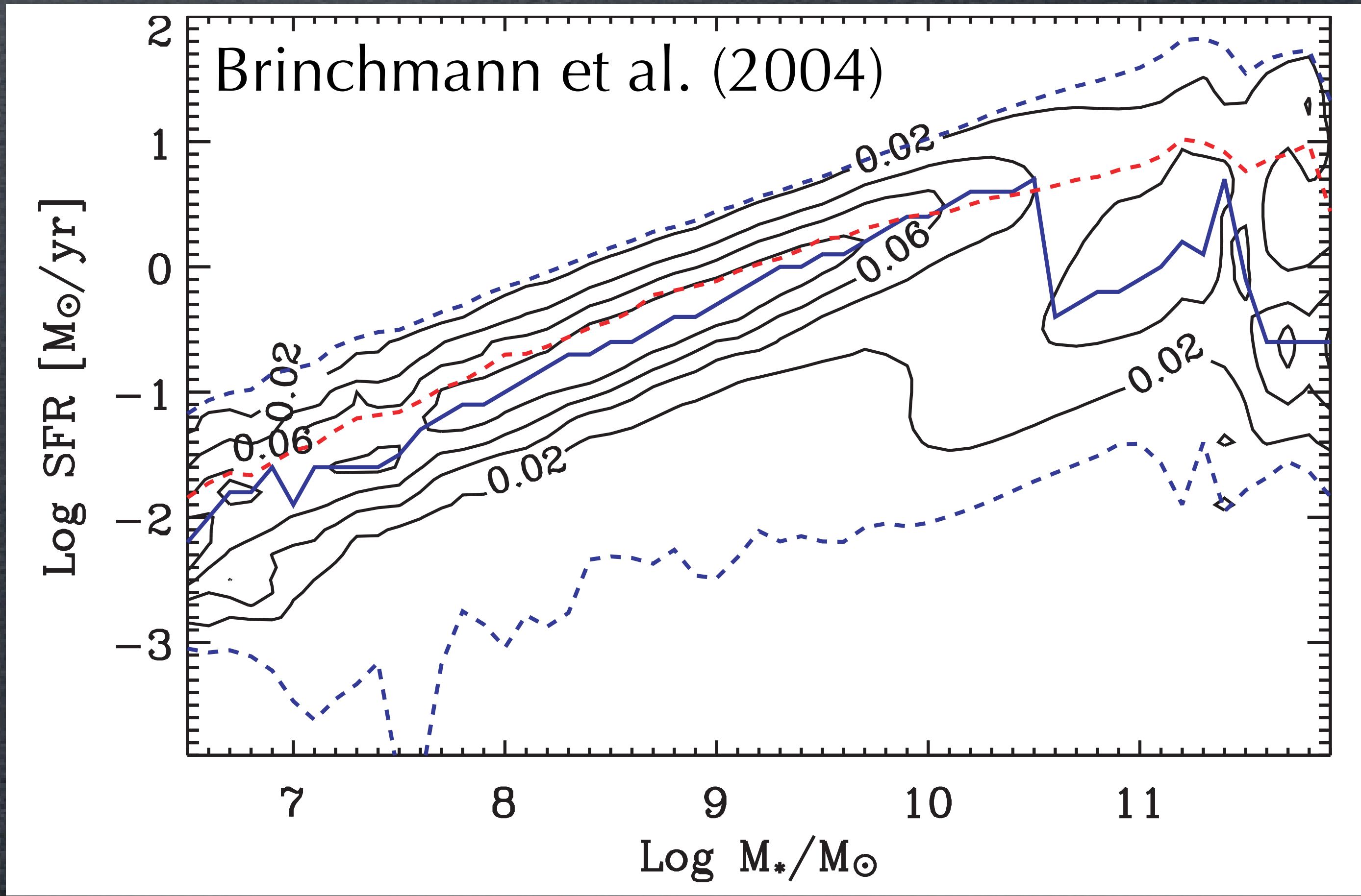
- In the local universe we see a relation between gas and stars: KS law
- On kpc scales see constant relation
  - $\tau_{dep} = 1/SFE = \Sigma_{gas}/\Sigma_{SFR}$
- But see possible variation with starbursts i.e. sSFR (=SFR/M*) = offset from the Main Sequence

A constant efficiency for gas to stars?



Genzel et al. (2011)

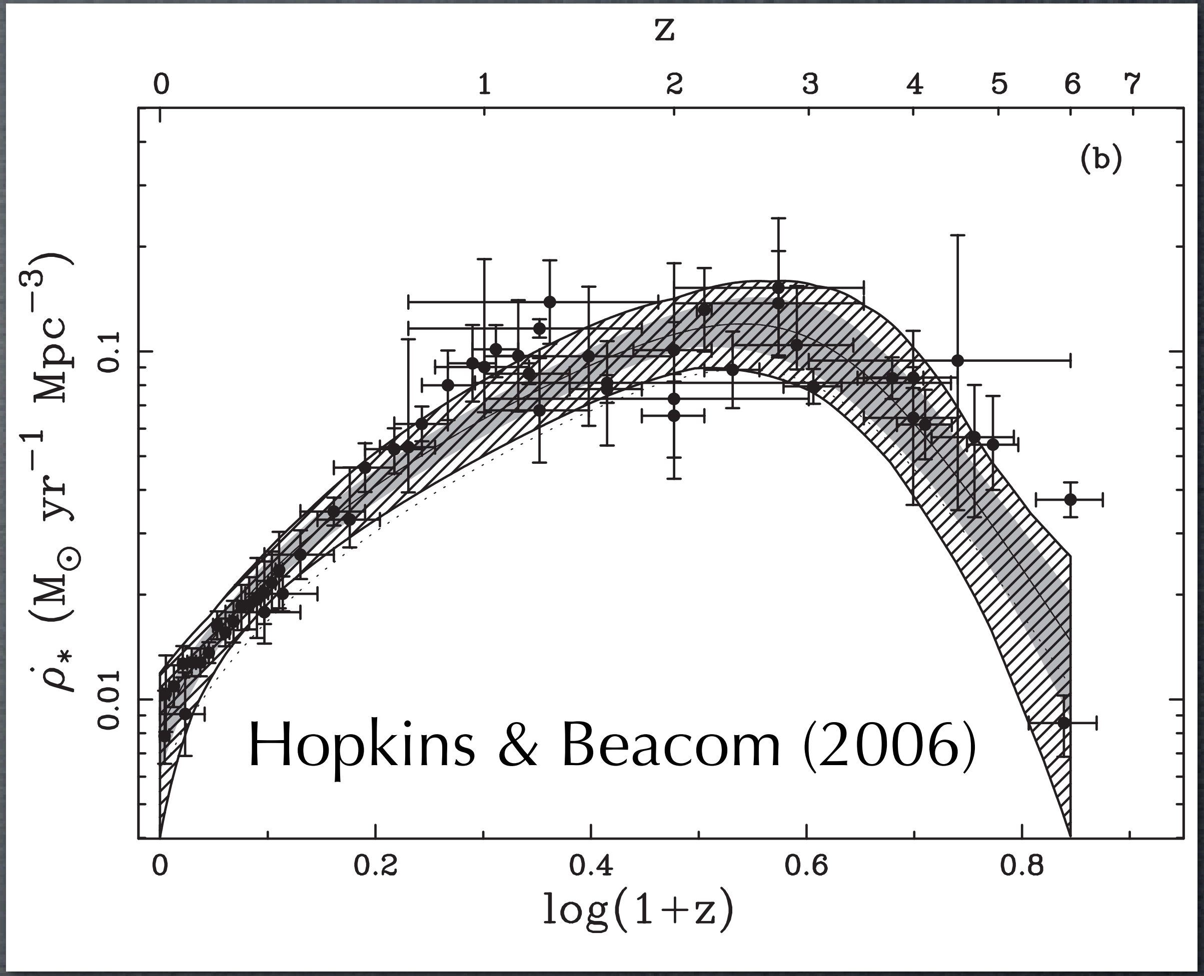
- In the local universe we see a relation between gas and stars: KS law
- On kpc scales see constant relation
  - $\tau_{dep} = 1/SFE = \Sigma_{gas}/\Sigma_{SFR}$
- But see possible variation with starbursts i.e. sSFR (=SFR/M*) = offset from the Main Sequence



Brent

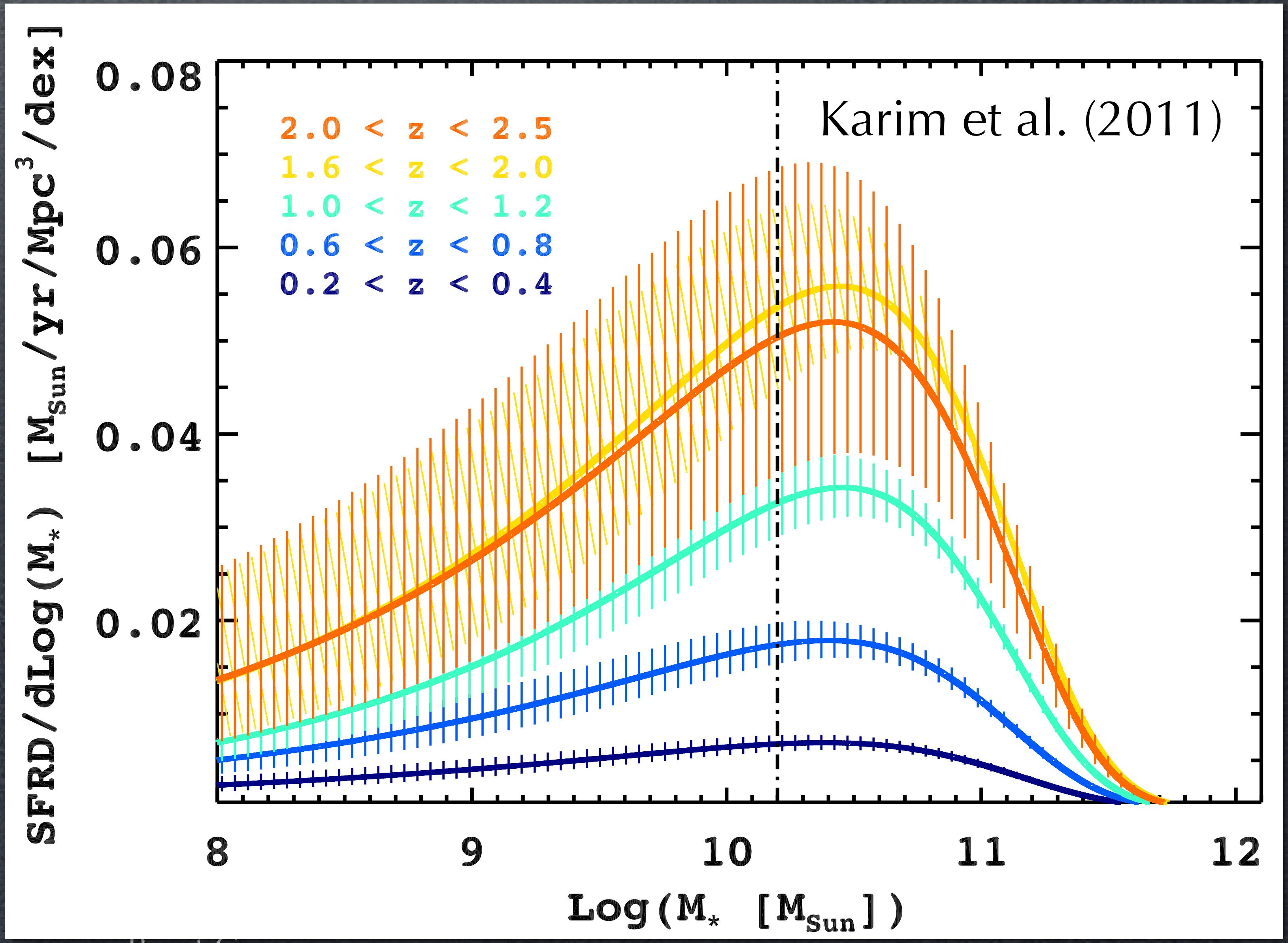
Galaxies growing: more food or faster ?

- SFR density has increased out to z=2 - 3



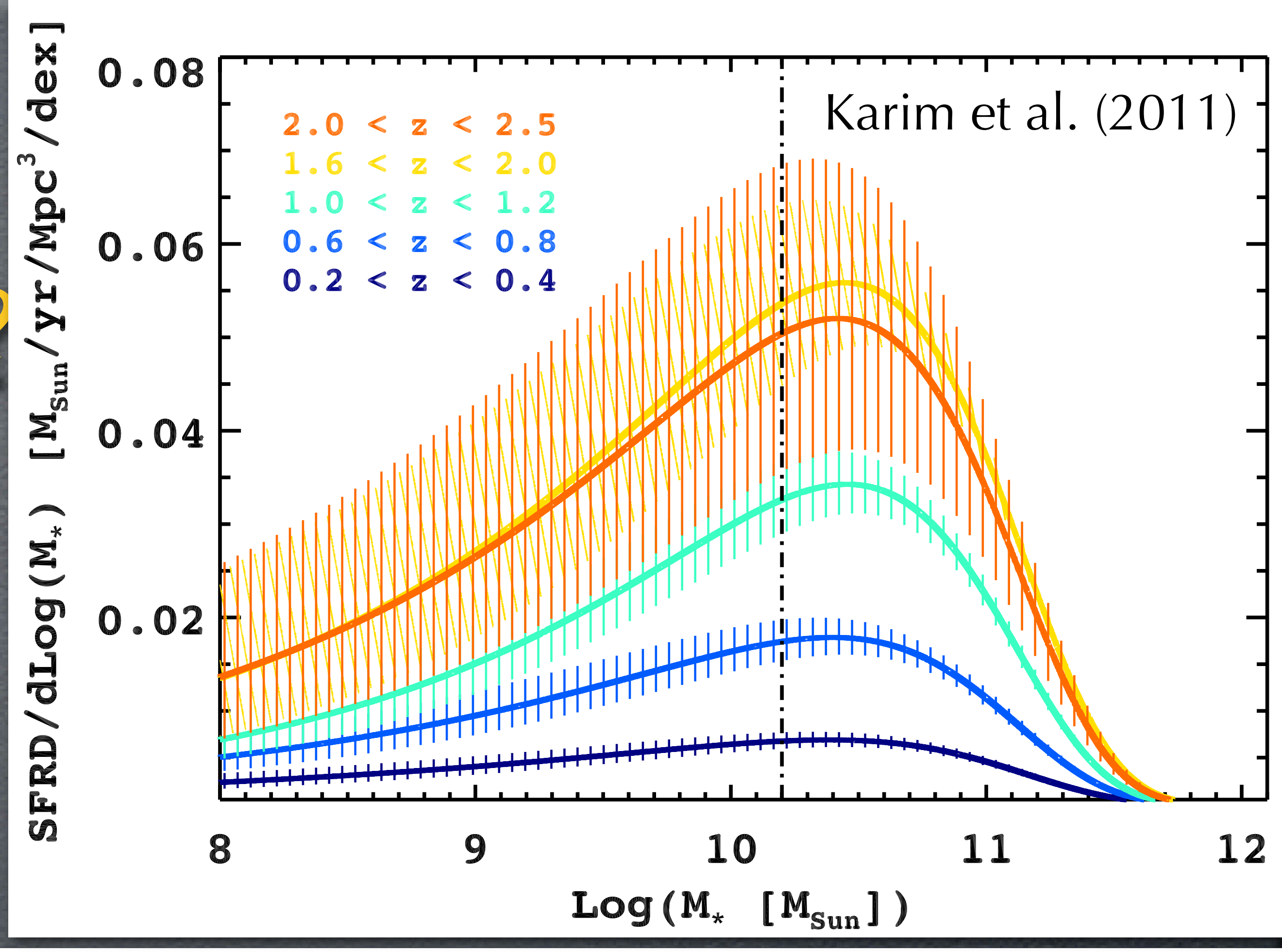
Galaxies growing: more food or faster ?

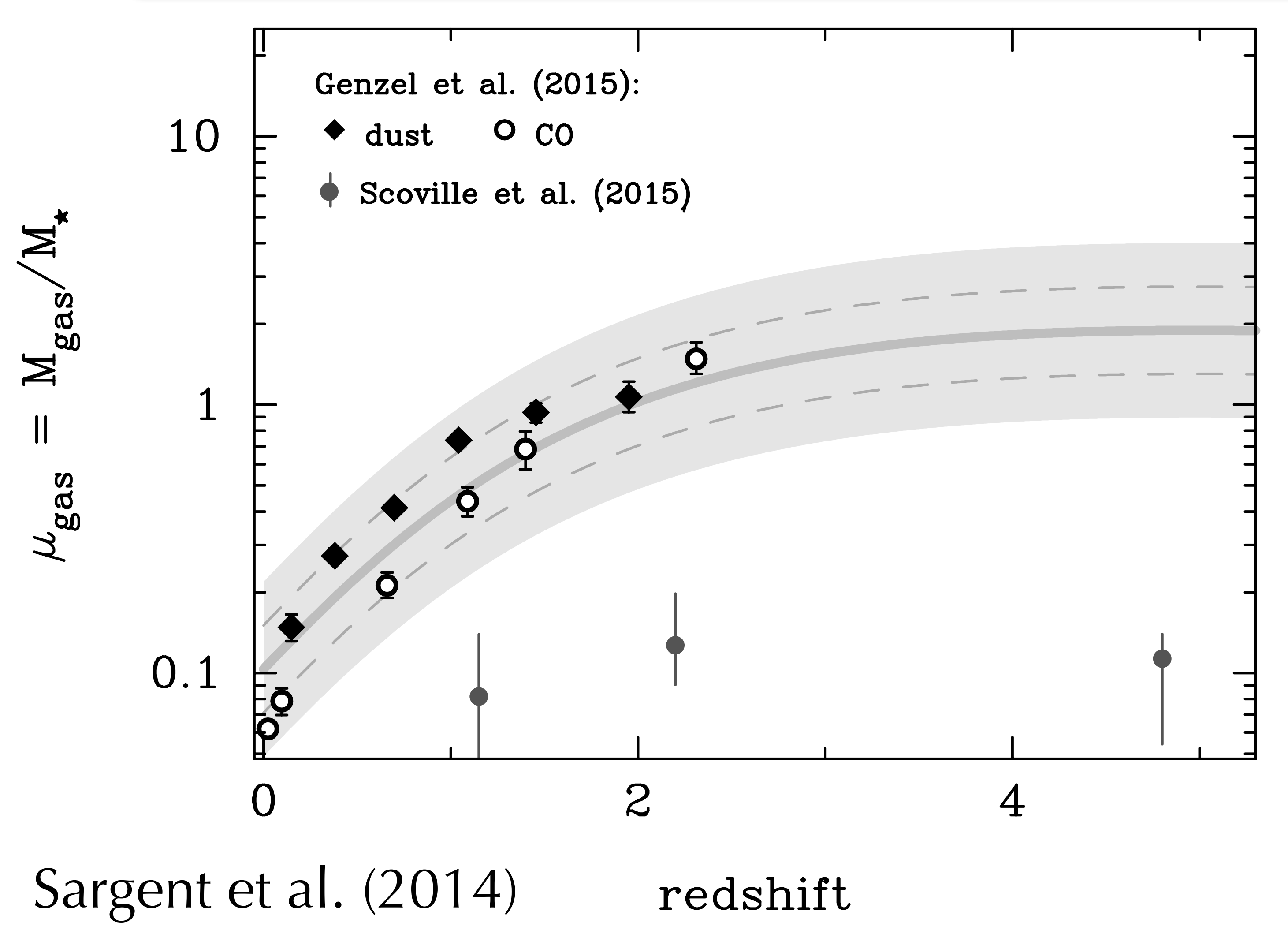
- SFR density has increased out to z=2 - 3
- As has the SFR per galaxy



Galaxies growing: more food or faster ?

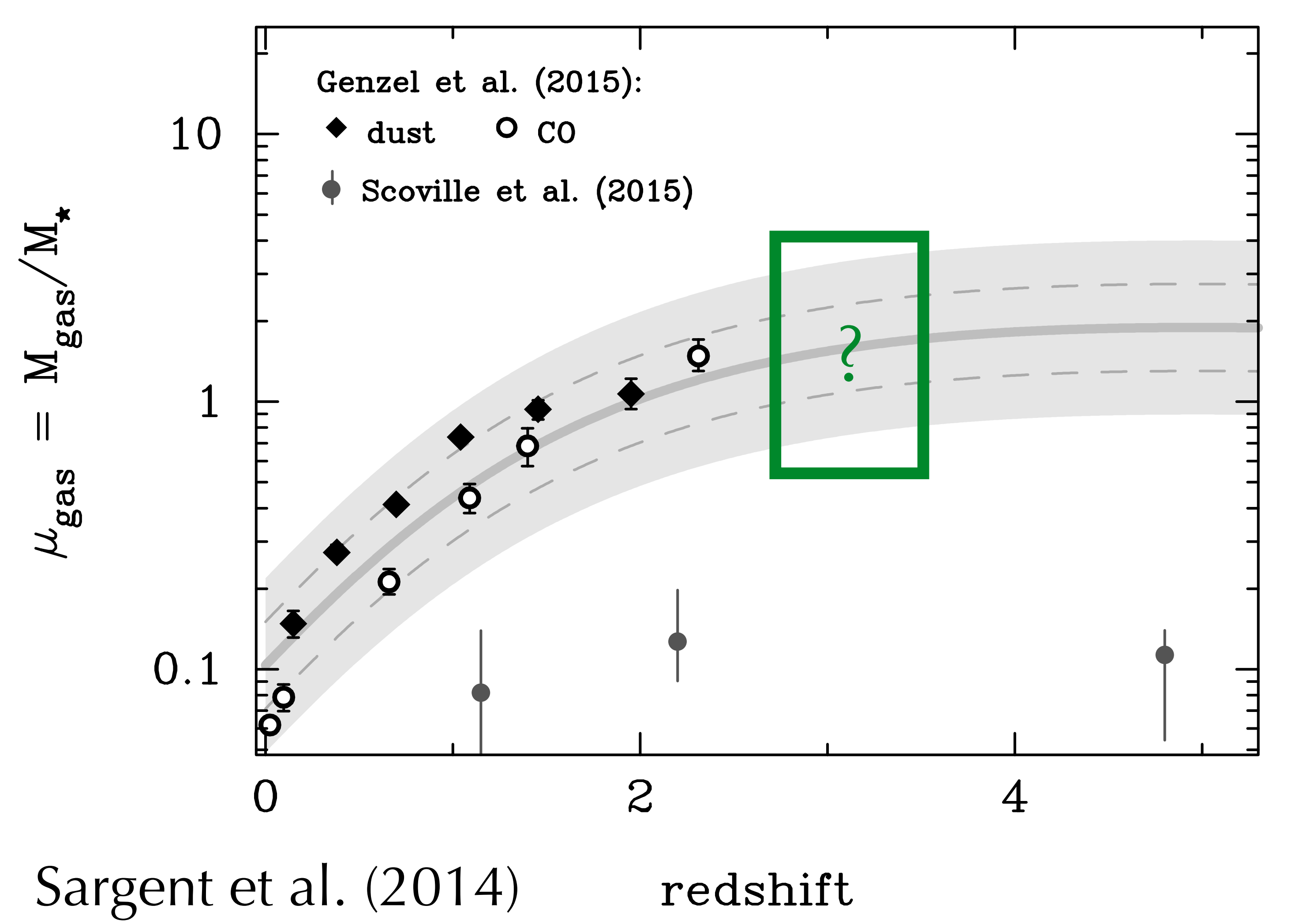
- SFR density has increased out to z=2 - 3
- As has the SFR per galaxy
- How much of this is because galaxies have more gas?
- And how much is because stars form more efficiently (τ_{dep} is smaller)?





Galaxies growing: more food or faster ?

- How much of this is because galaxies have more gas?
- And how much is because stars form more efficiently (τ_{dep} is smaller)?

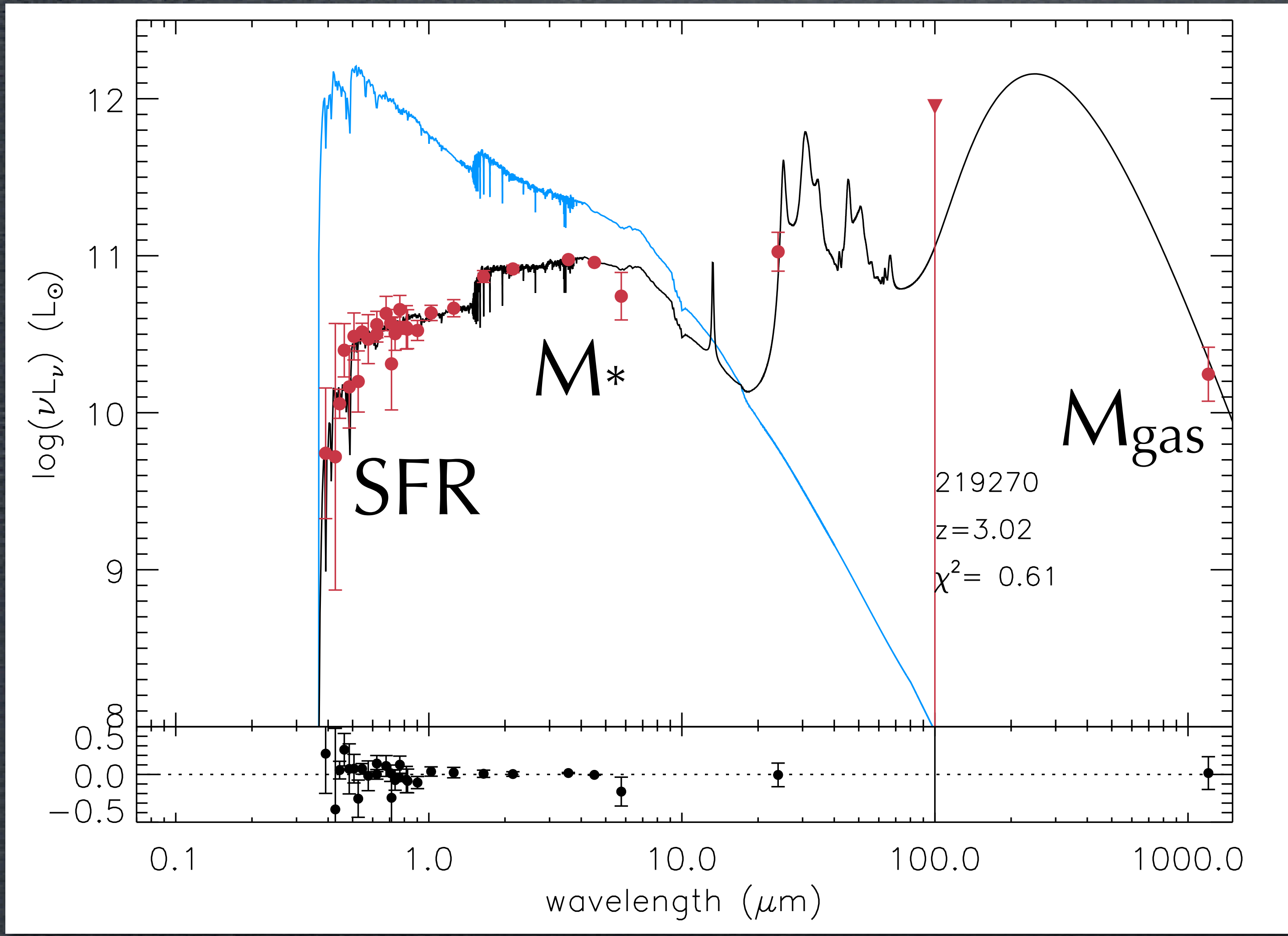


Sargent et al. (2014)

We need to reliably measure the stellar and gas mass and SFR at z = 3 - 4 to answer this

Reliable measures

- To reliably measure at high redshift:
  - stellar mass - good rest-frame optical-NIR SED
  - SFR - rest-frame UV+IR data
  - gas mass - difficult to observe CO for a large sample so why not use dust continuum?

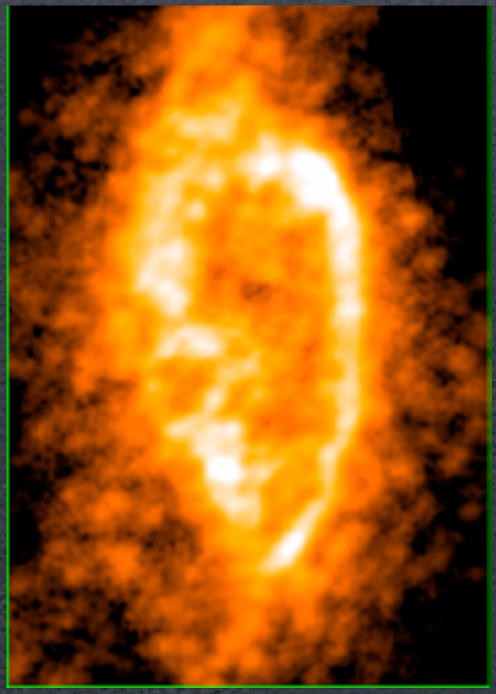


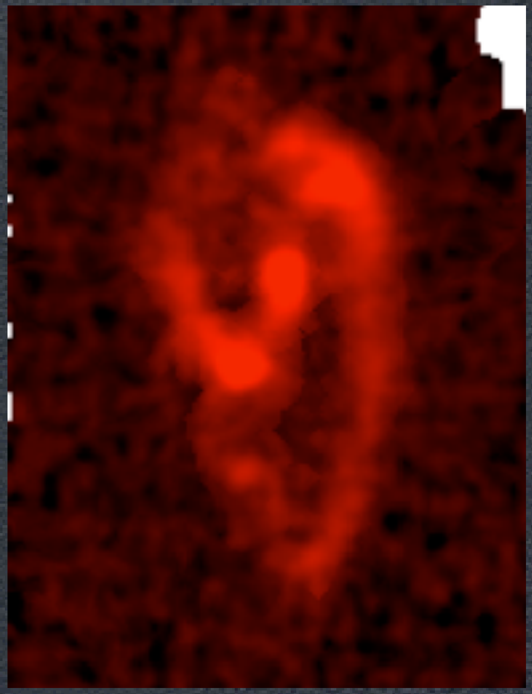
36 Nearby Galaxies

Key Insights into Nearby Galaxies: a Far-Infrared Survey with Herschel

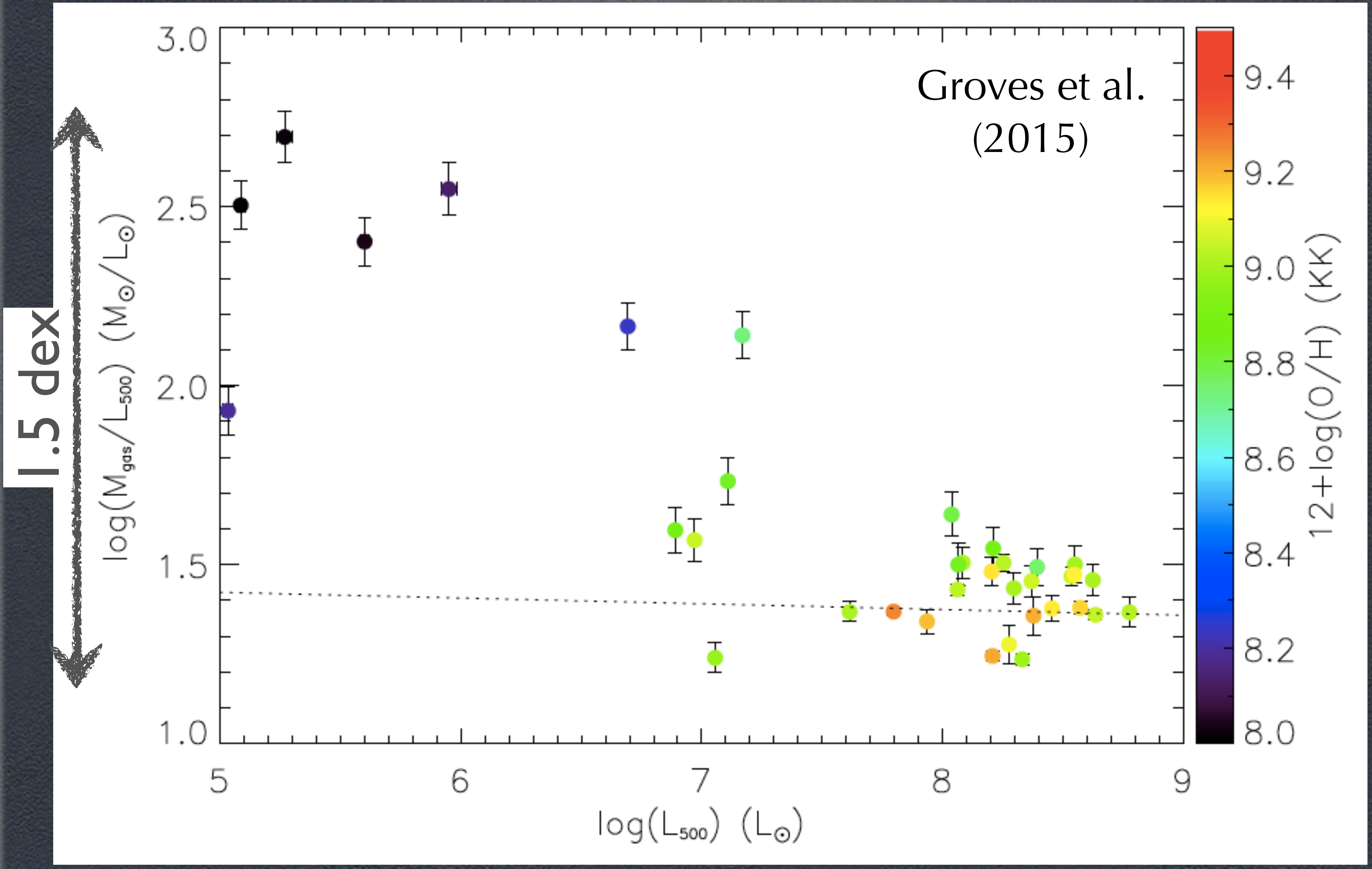
The HI Nearby Galaxy Survey

HERACLES: The HERA CO Line Extragalactic Survey

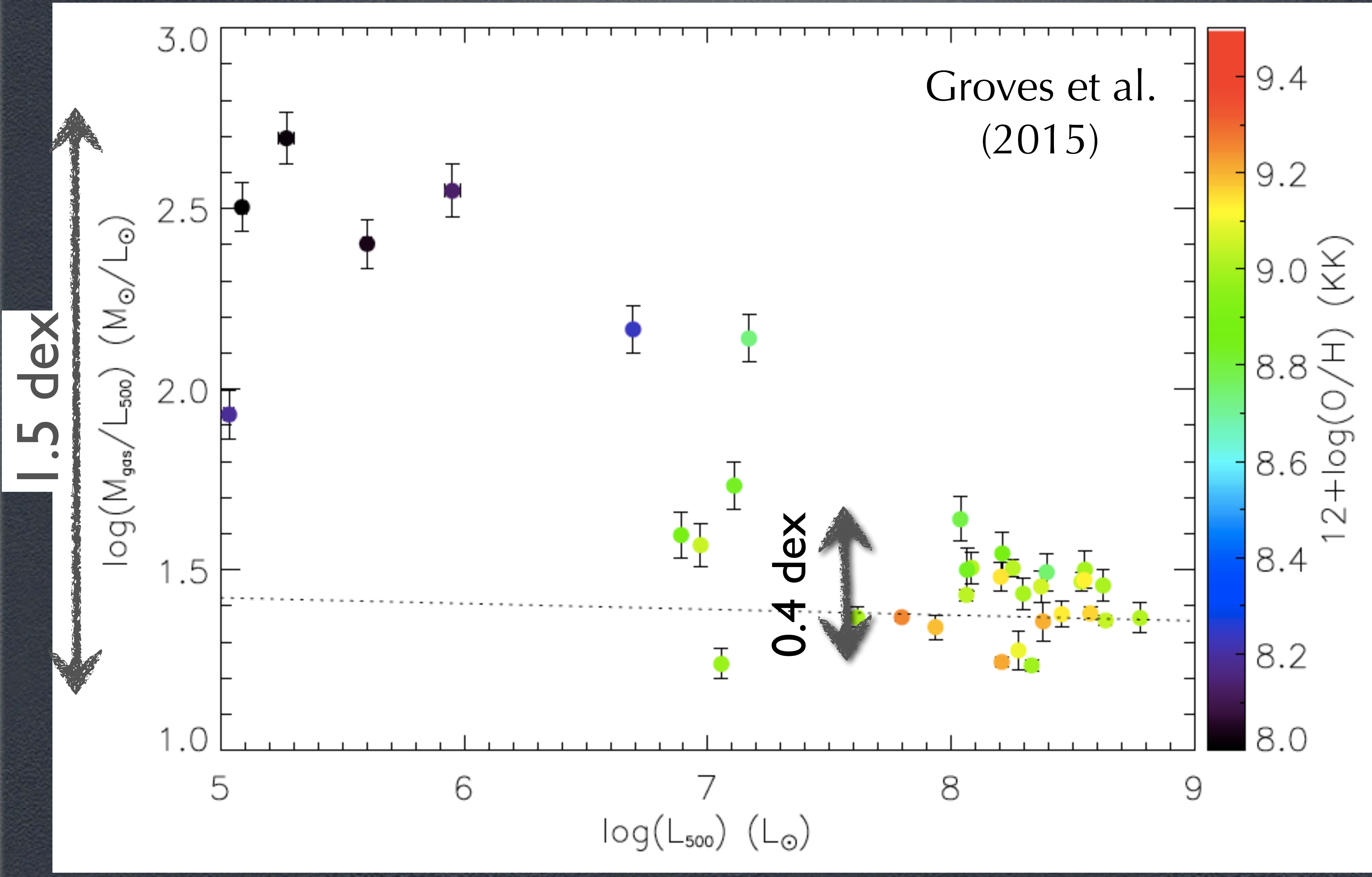




Sub-mm vs Gas mass



Sub-mm vs Gas mass

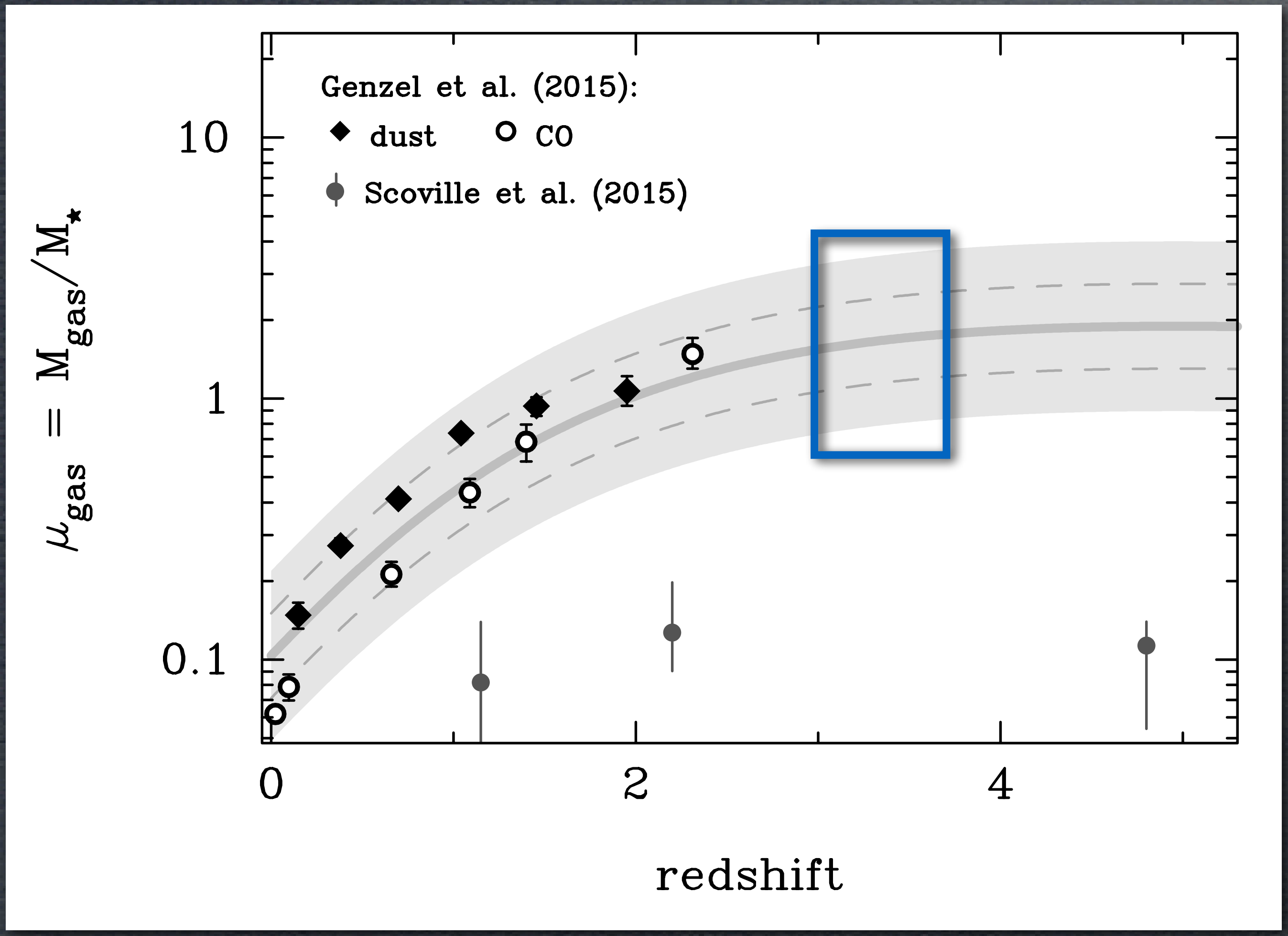


Simple Estimator

$$\mathrm{M_{gas}}[\mathrm{M_\odot}] = 28.5 L_{500}[L_\odot]$$

- Dust Emission at long wavelengths can determine gas mass in massive galaxies (>$10^9 M_\odot$) to ~30%
- can also use 250μm, but with greater dispersion

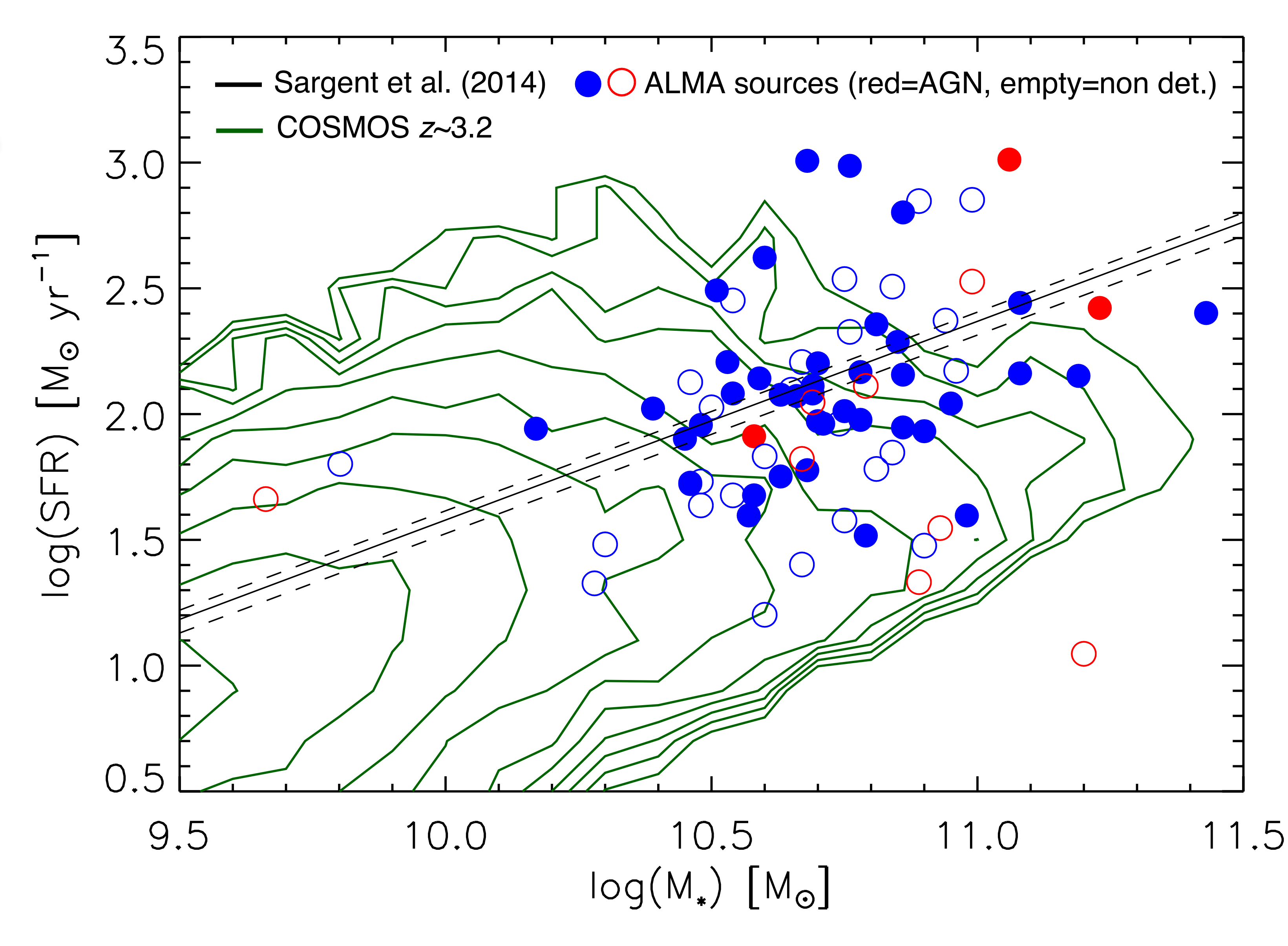
Measuring gas at z~3 with ALMA



- A sample of Massive main-sequence galaxies at z>3 to help answer question:
- Is the increase in ρ_{SFR} with *z* more gas or more efficient star formation?

z~3-4 Massive LBGs with ALMA

- From COSMOS photo-z catalog selected 86 galaxies sampling main sequence 2.8 < z < 3.6
- Cycle-2 proposal (PI Schinnerer) with Band 7 (~240 GHz)
- Measure dust continuum to determine gas mass



Schinnerer, BG et al (2016)

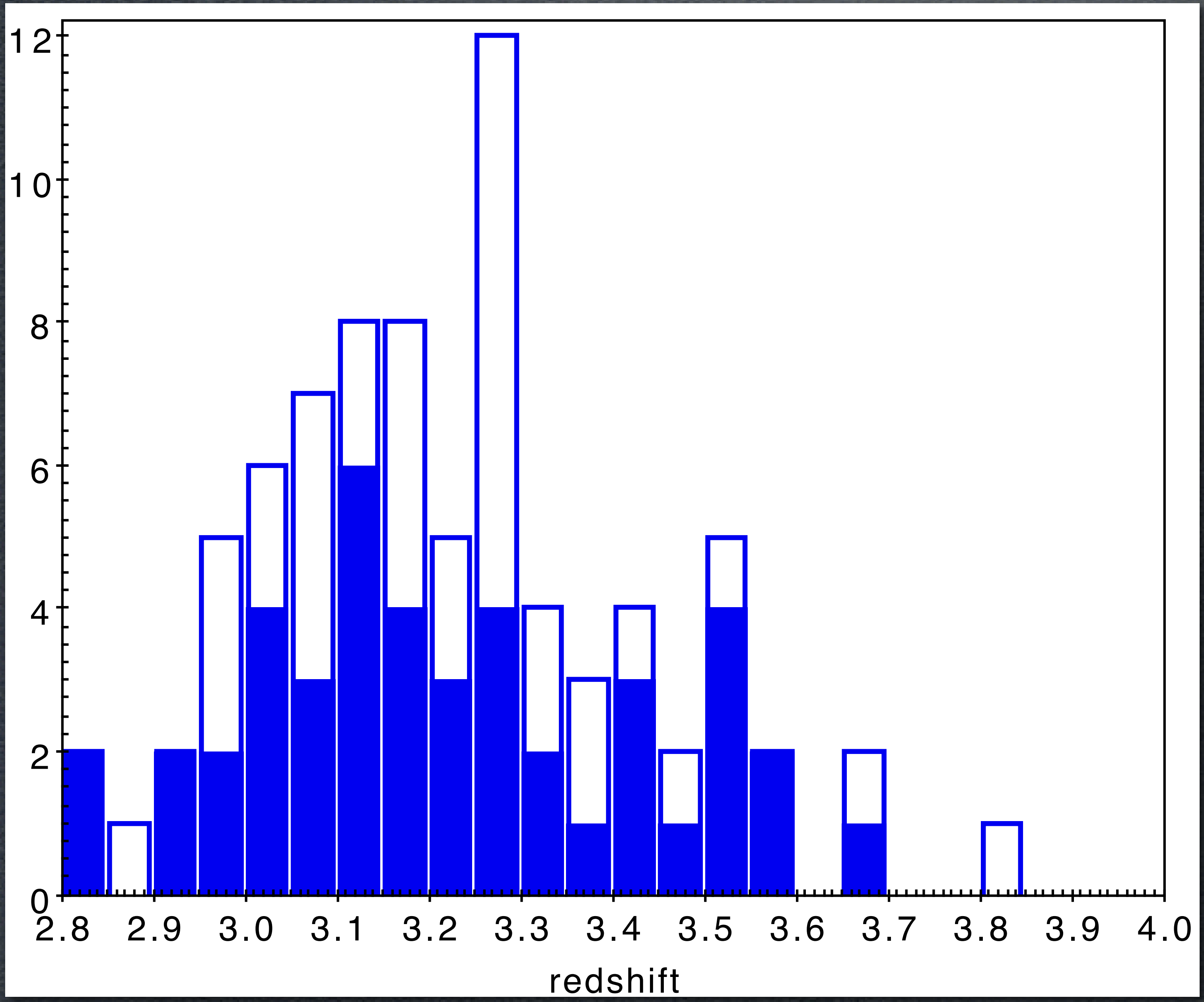
ALMA observations

240 GHz continuum

rms ~ 65 - 70 μJy/beam

beam of 0.7”x0.5”

55% detection rate (47/86) using 3σ detection limit



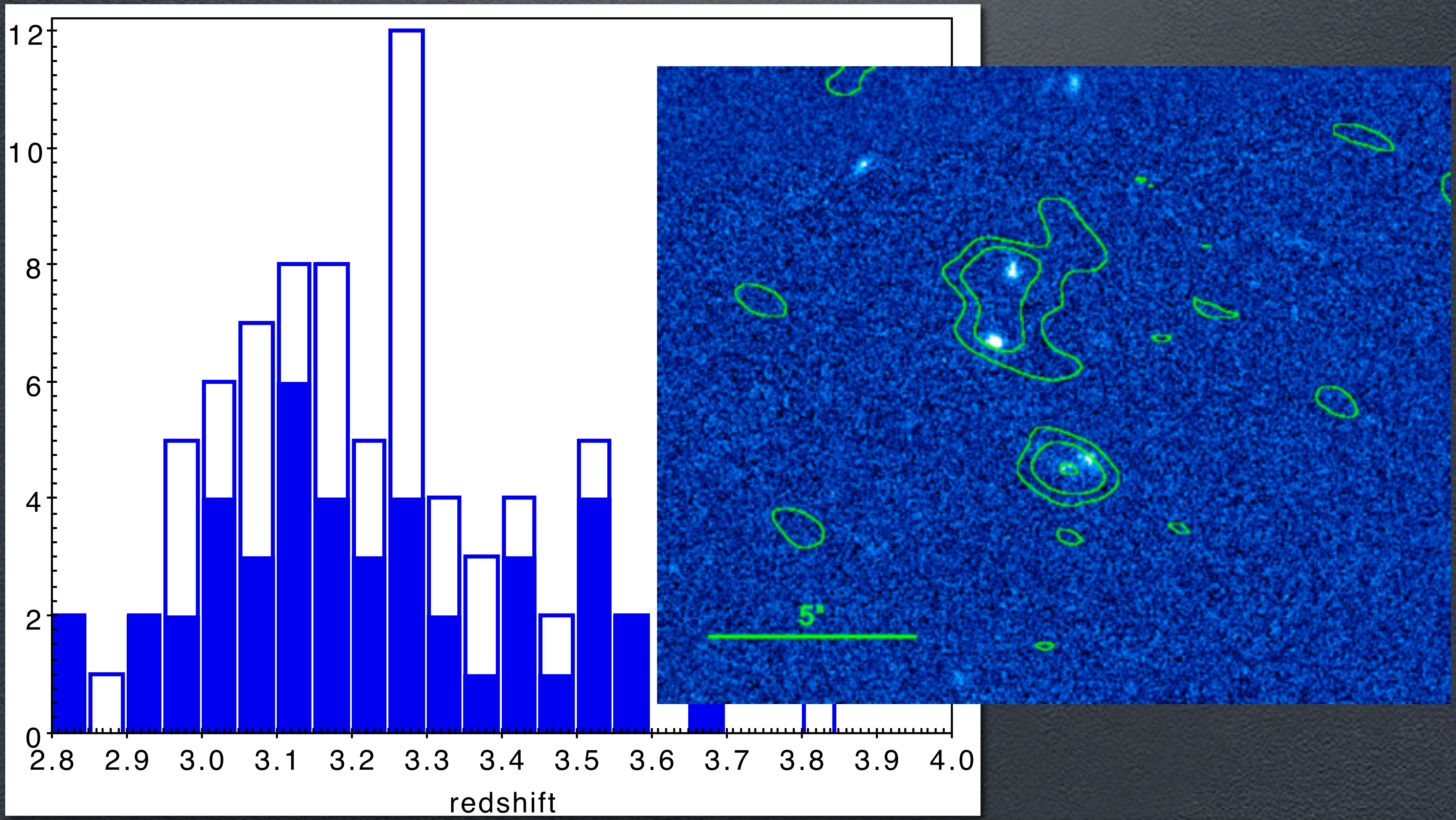
ALMA observations

240 GHz continuum

rms ~ 65 - 70 μJy/beam

beam of 0.7”x0.5”

55% detection rate (47/86) using 3σ detection limit

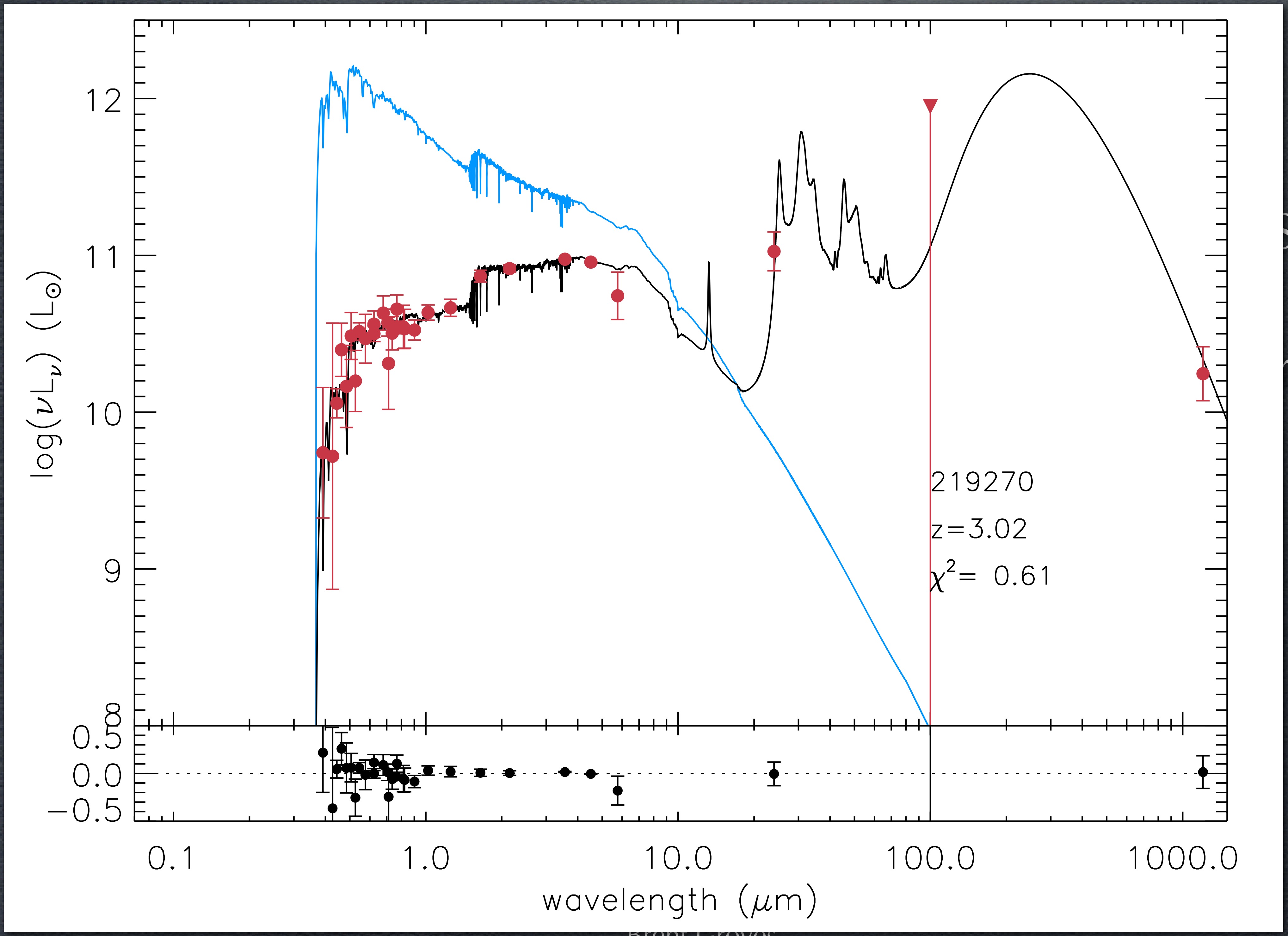


High-z Main sequence gas

- Detect 45/86 sources (2 low-z interlopers)
- Mostly photo-z (Laigle et al. in prep.)
    - 22 of our detections have secure spec-z (VUDS, zCOSMOS)
- $M_\star$ - based on SED fit using SUBARU data (MAGPHYS)
- SFR - UV+IR based on SED fit (MAGPYS)
- S_{240GHz} - based on Gaussian fit (extraction software - Karim et al. 2012)
- M_{gas} - Groves et al. (2015) prescription (for 250/350μm rest-frame)
- Main Sequence - definition of Sargent et al. (2014)

High-z Main sequence gas

- Detect 45/86 sources (2 low-z interlopers)

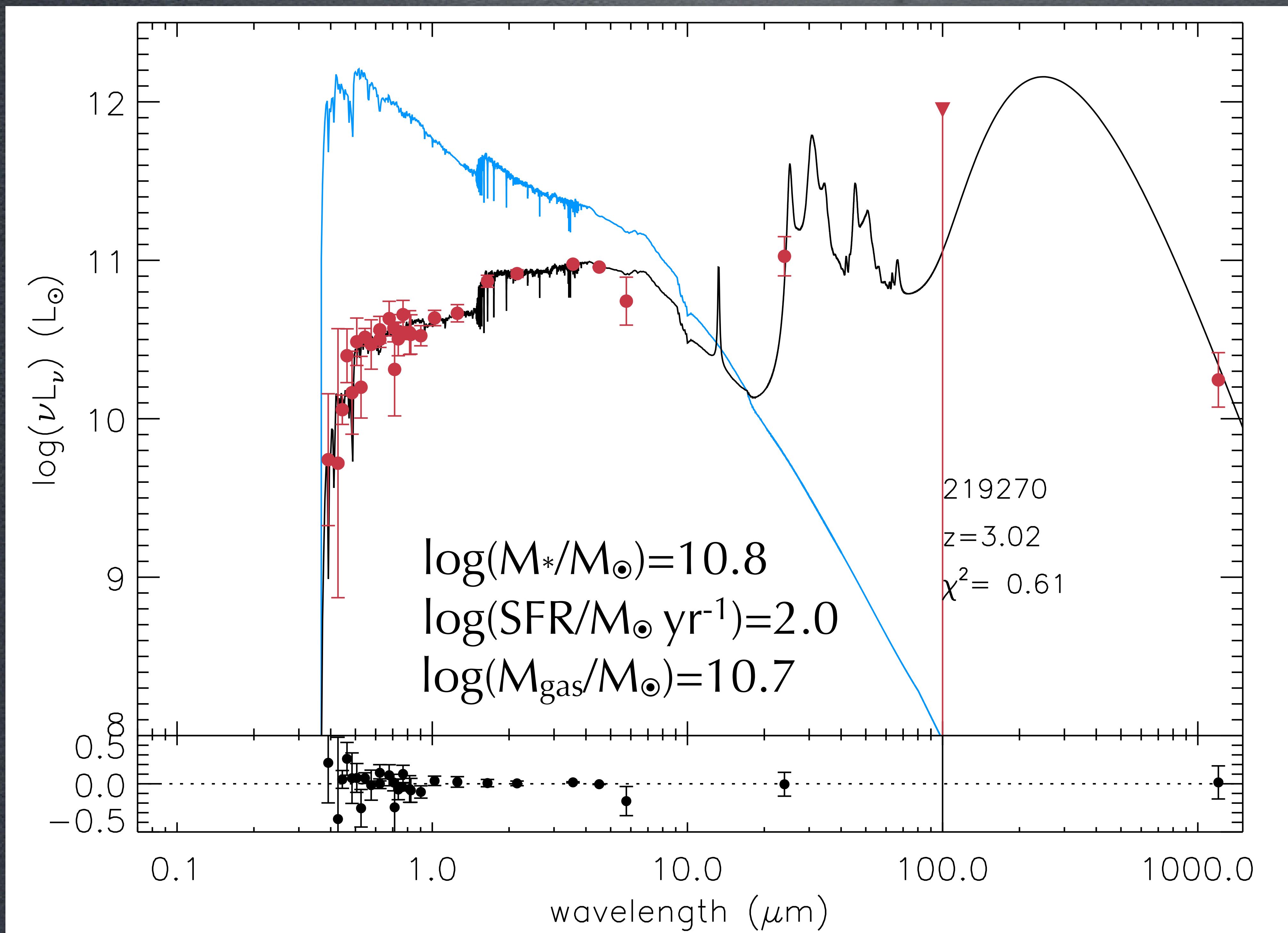


S)

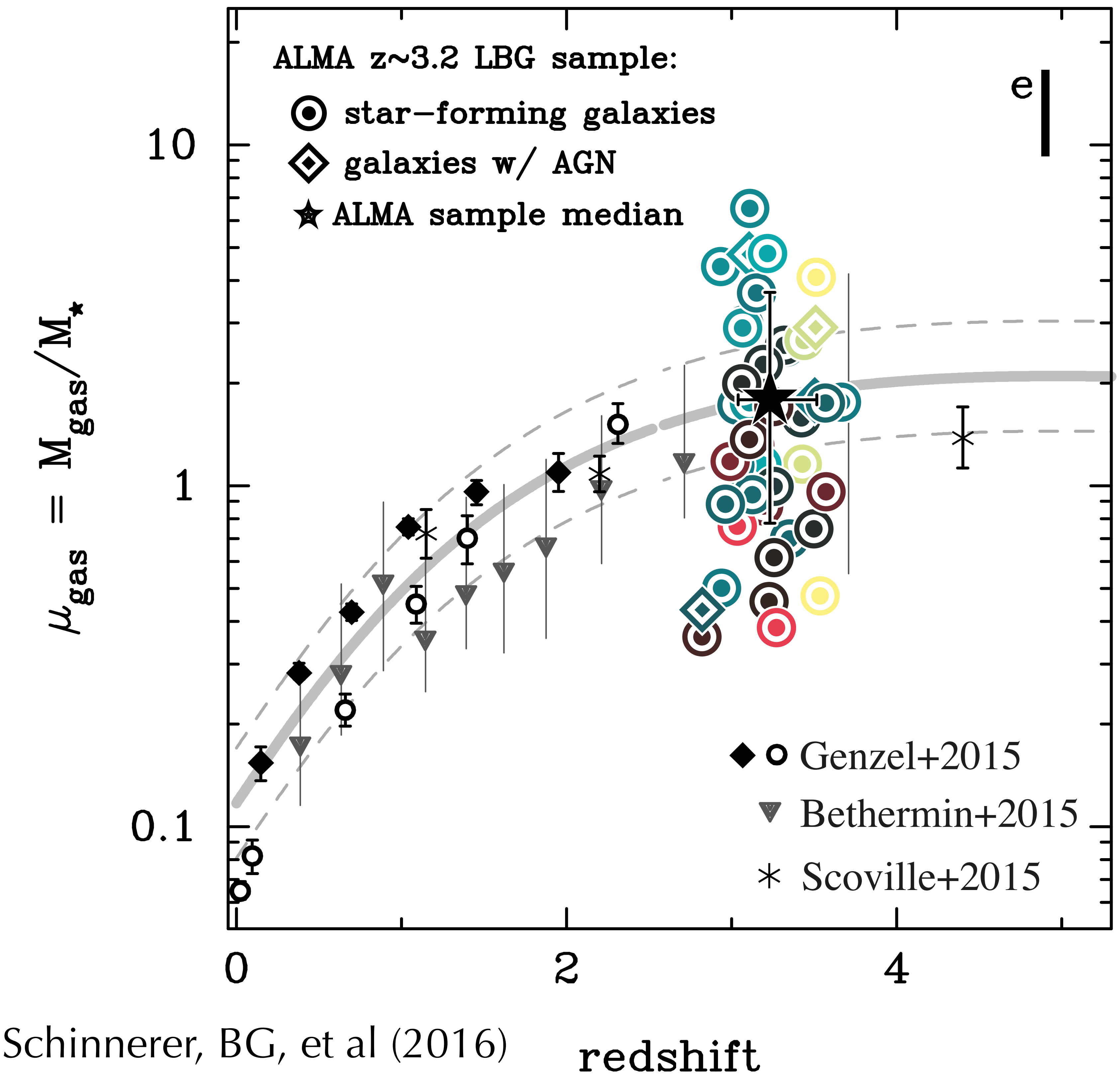
rim

High-z Main sequence gas

- Detect 45/86 sources (2 low-z interlopers)

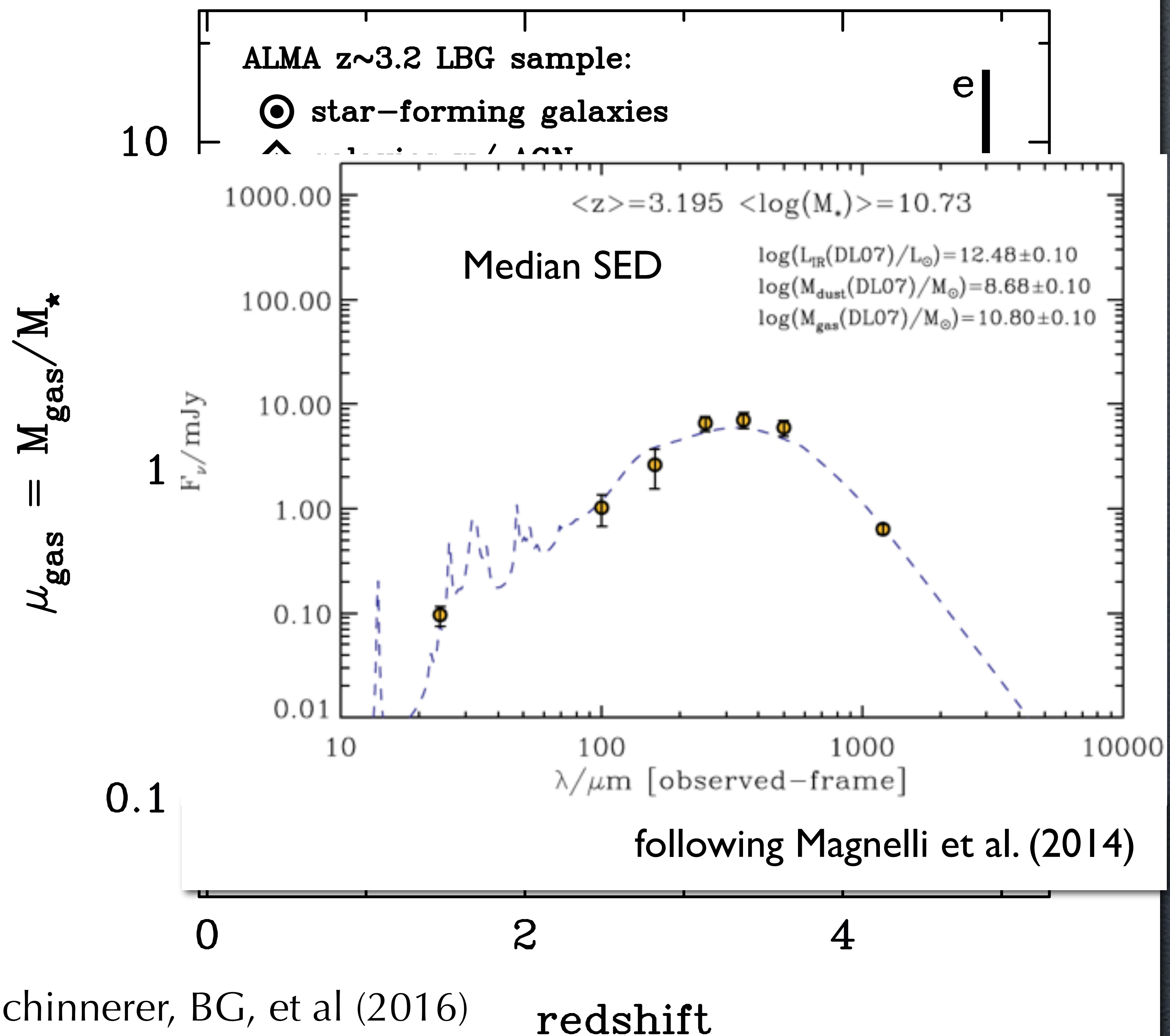


Gas content!



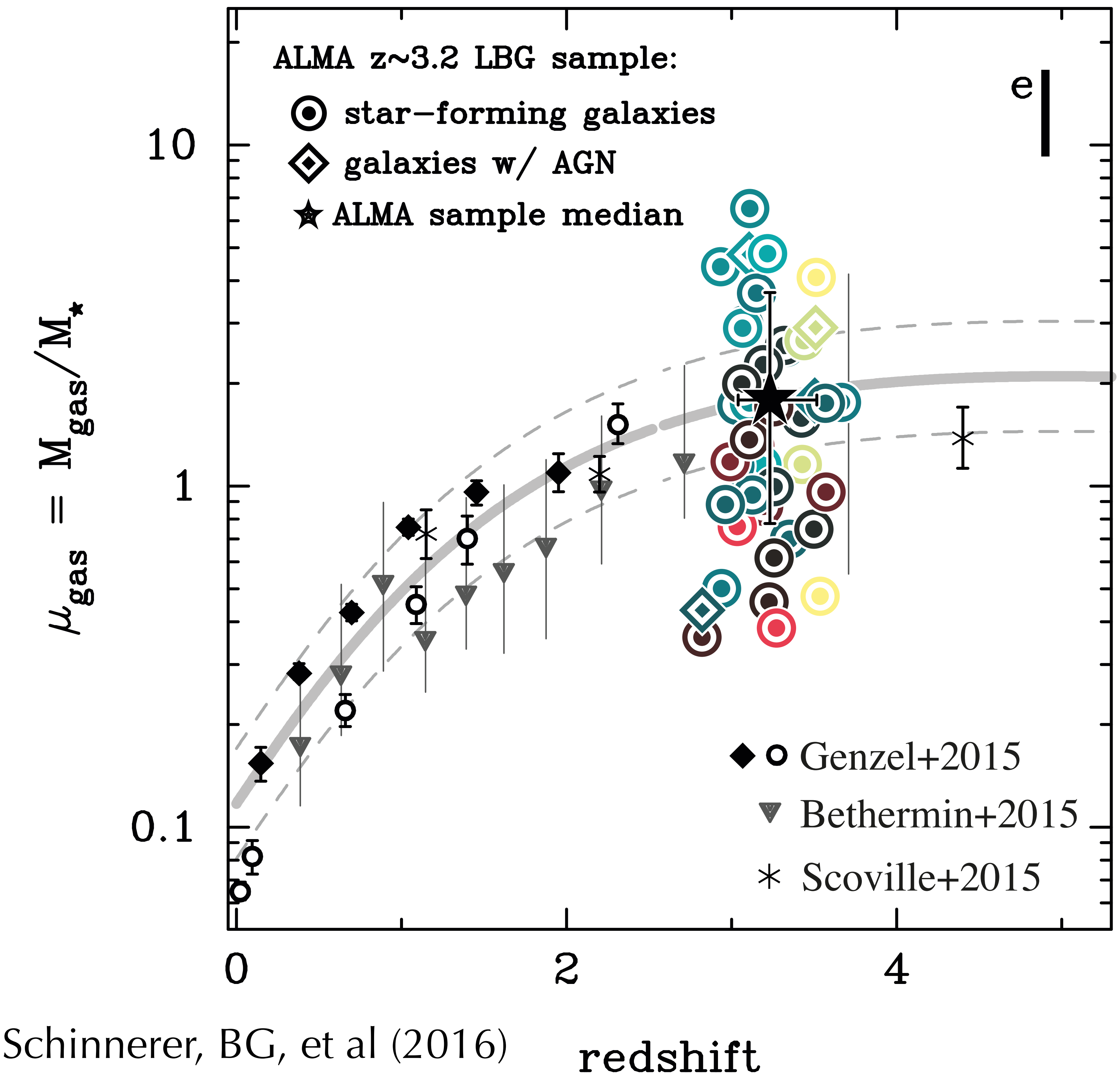
Schinnerer, BG, et al (2016)

Gas content!



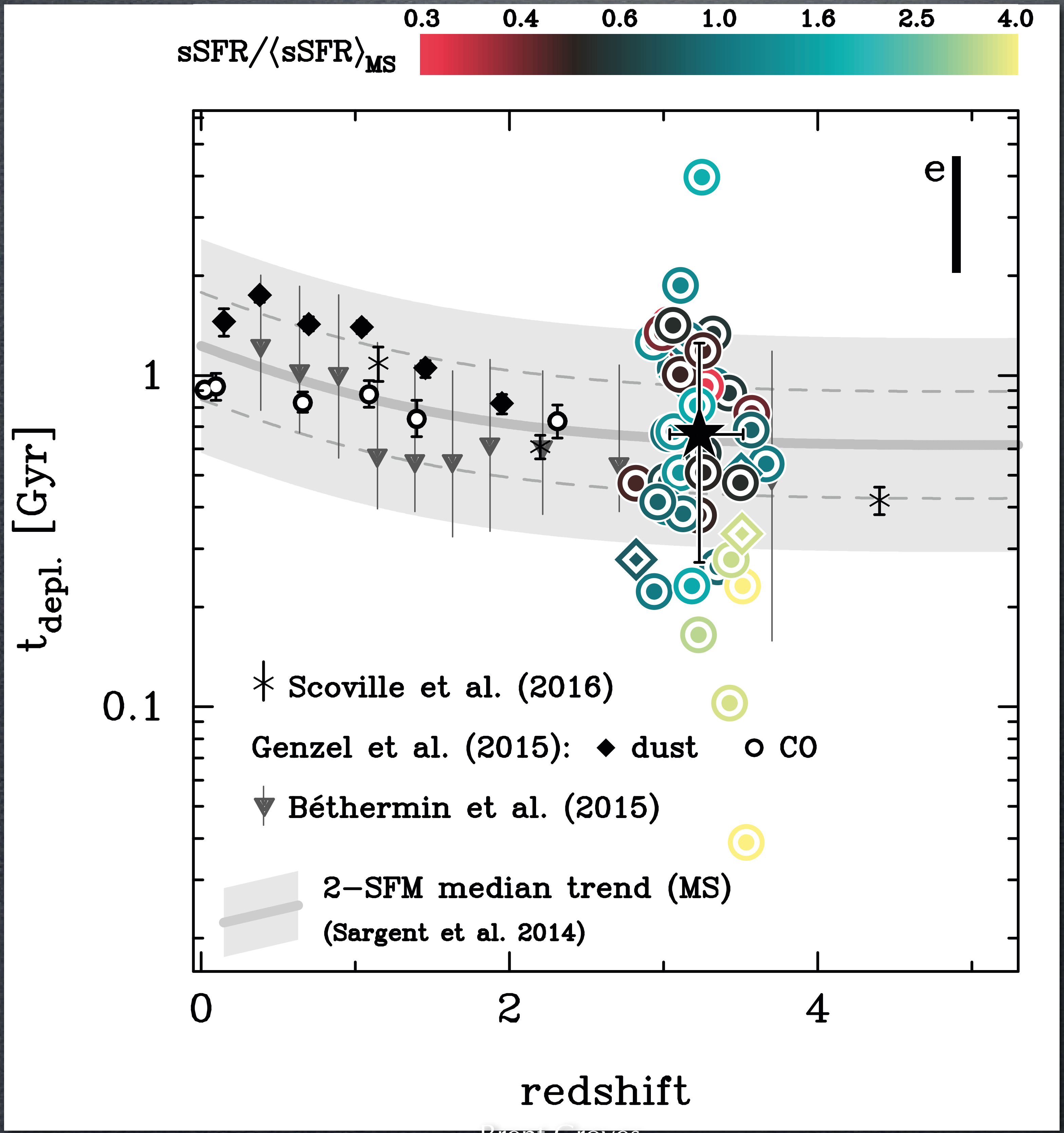
Schinnerer, BG, et al (2016)

Gas content!



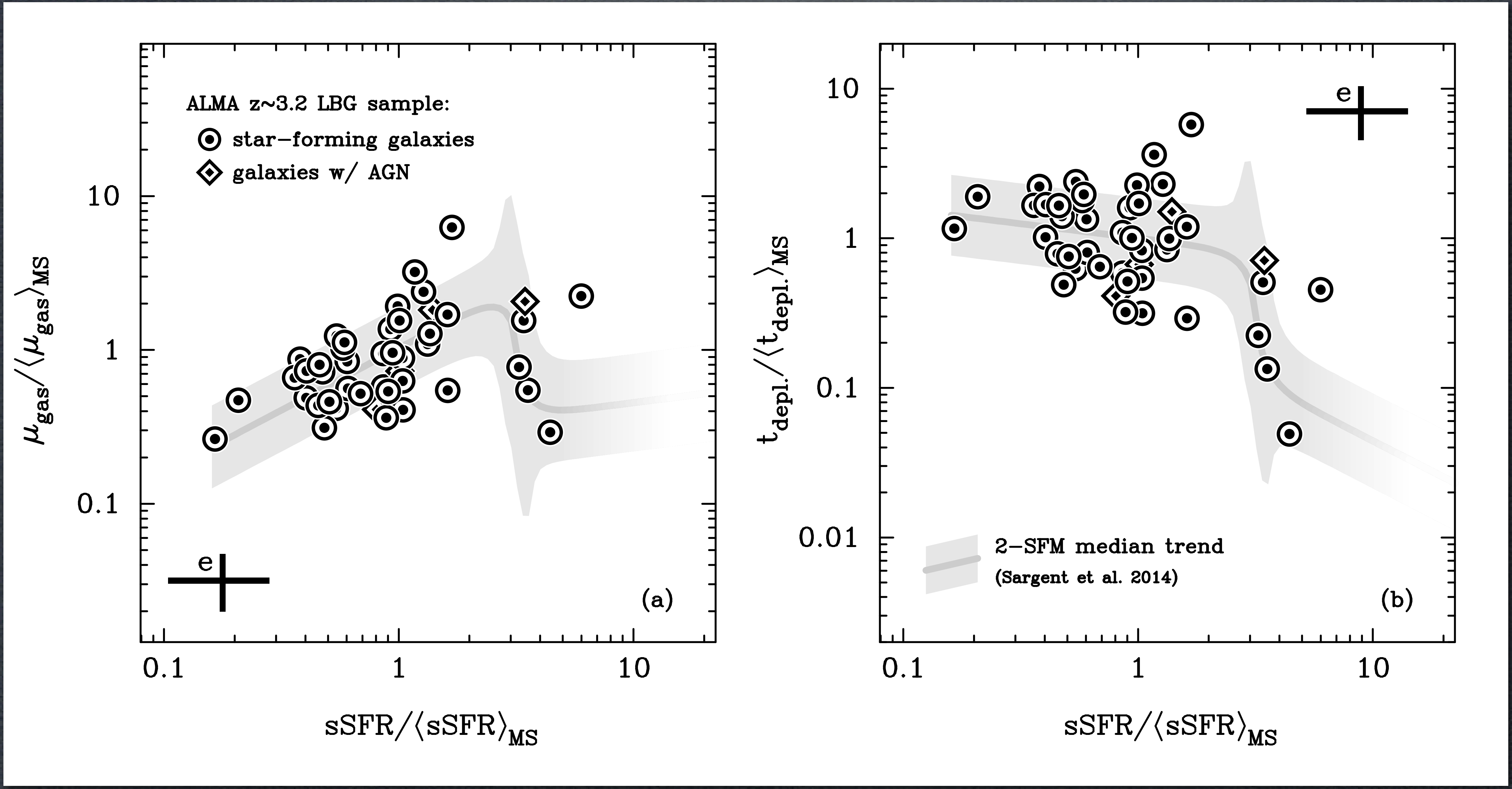
Schinnerer, BG, et al (2016)

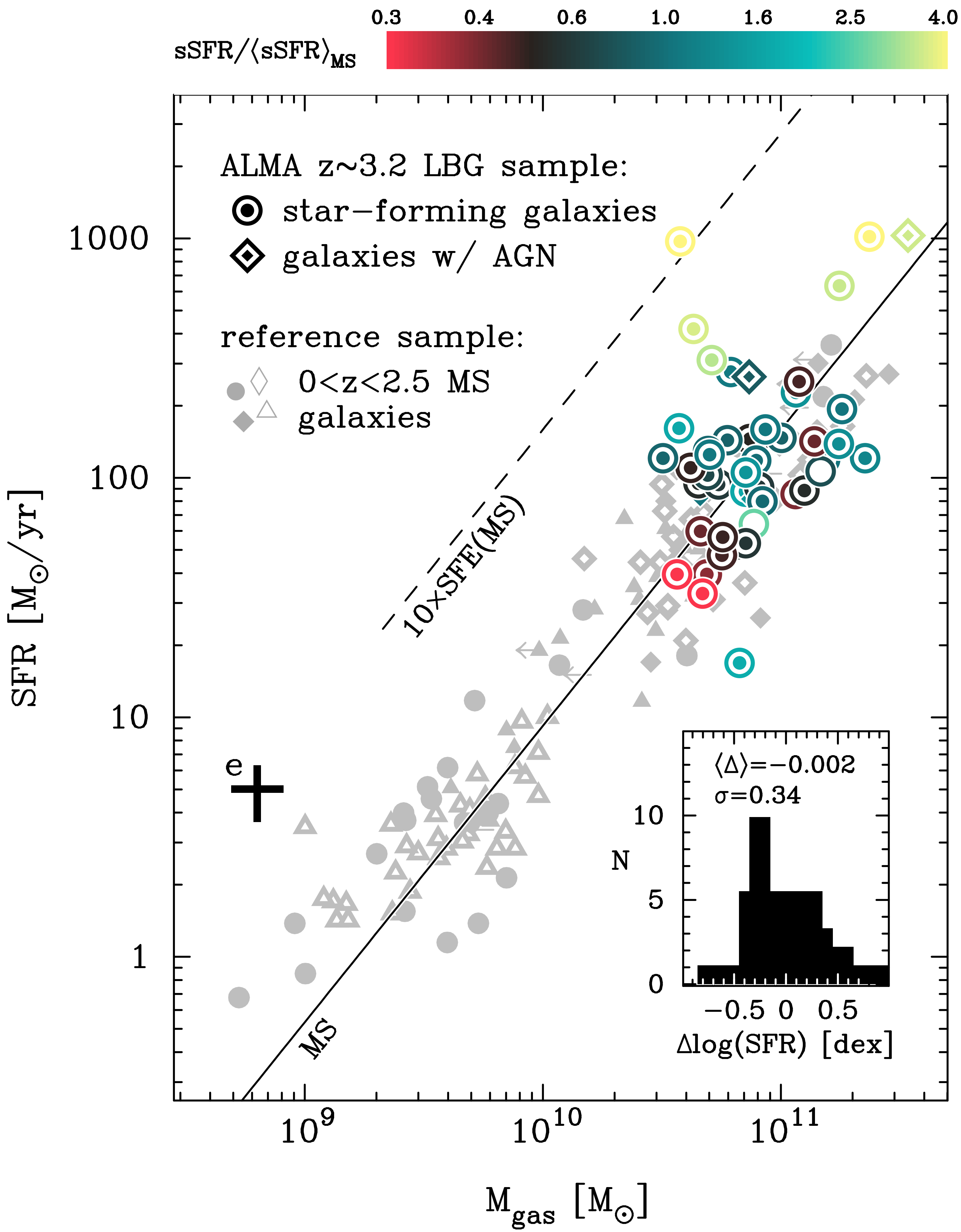
Results - gas depletion time



sSFR vs gas

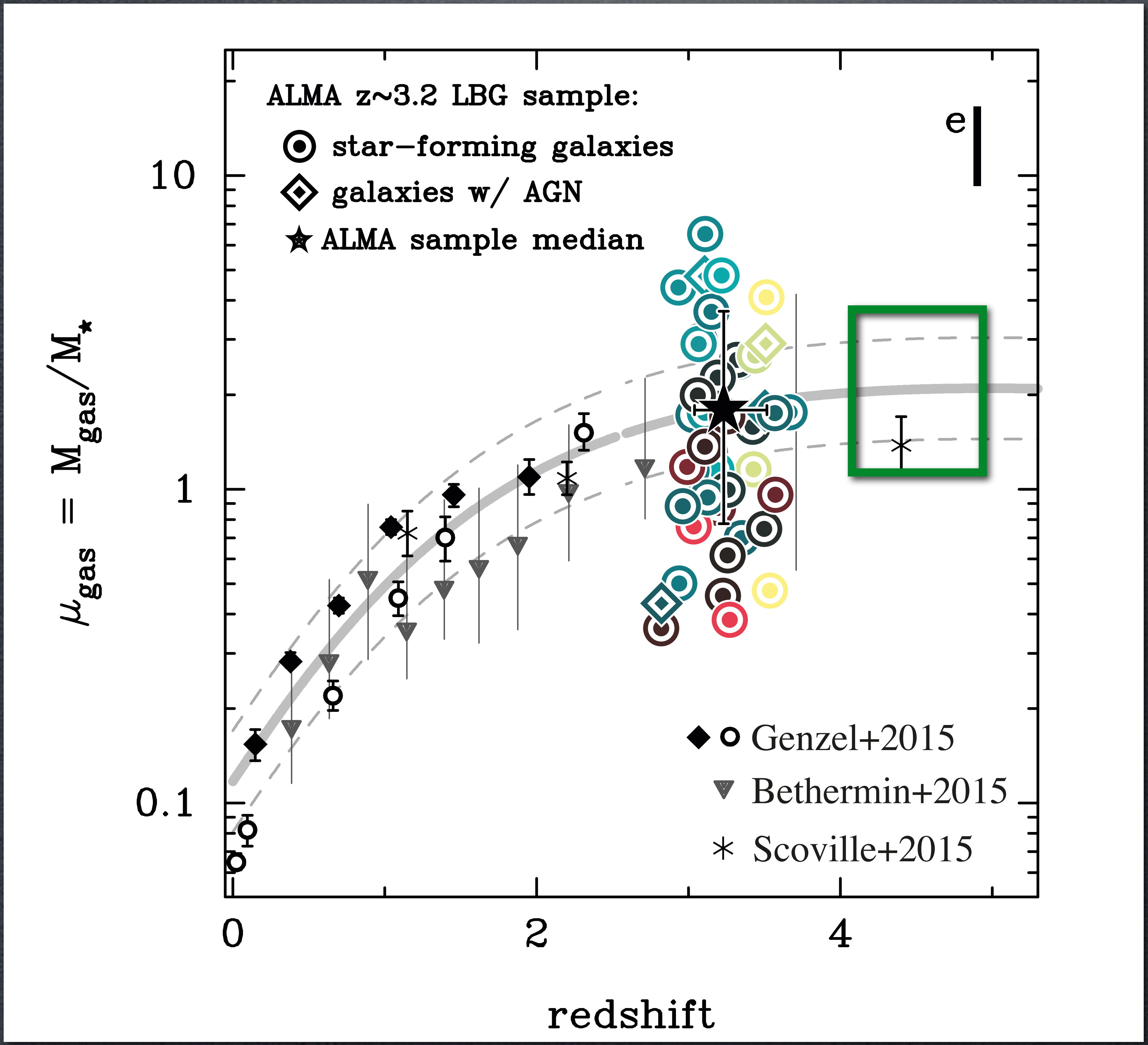
- Variation with sSFR is seen
- Too much scatter/uncertainty to be definite





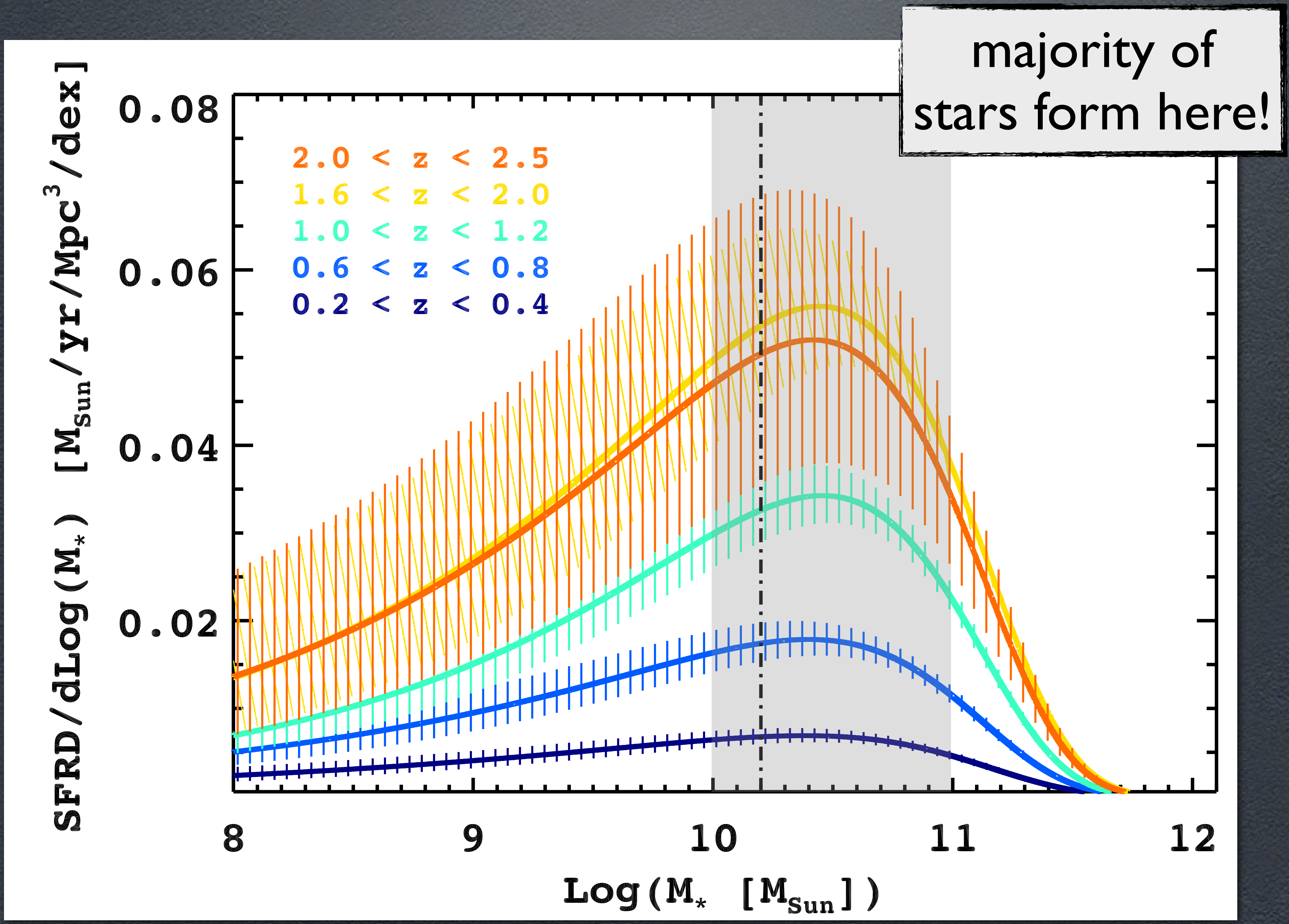
KS at z ~3.2

- Our ALMA observations support predictions of Genzel and Sargent
- Most of the increase in SFR due to increased M_{gas}, with a smaller contribution by Star formation efficiency
- Do see trends with sSFR, but scatter is large



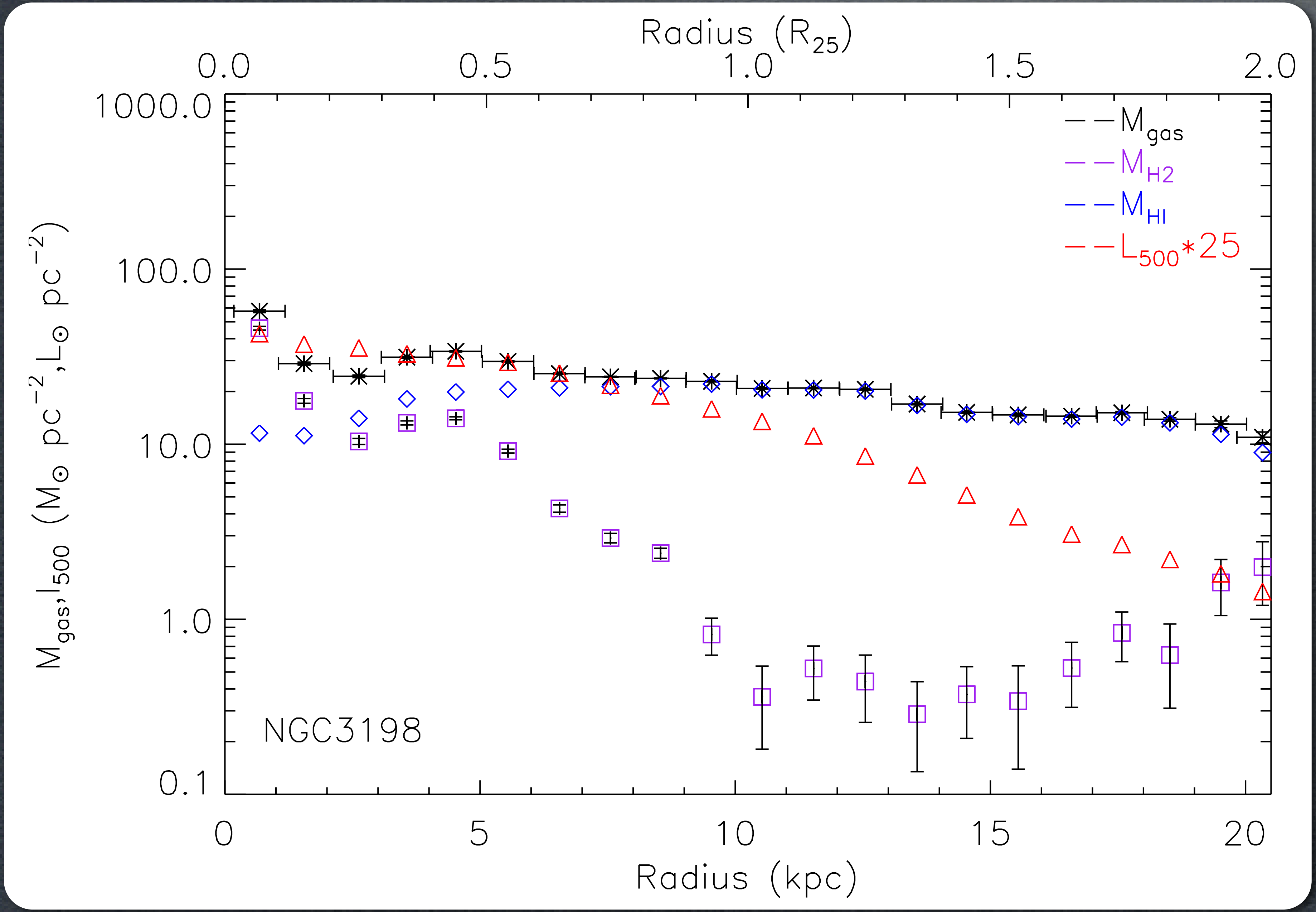
Brent Groves

Why massive main sequence galaxies?



Karim et al. (2011)

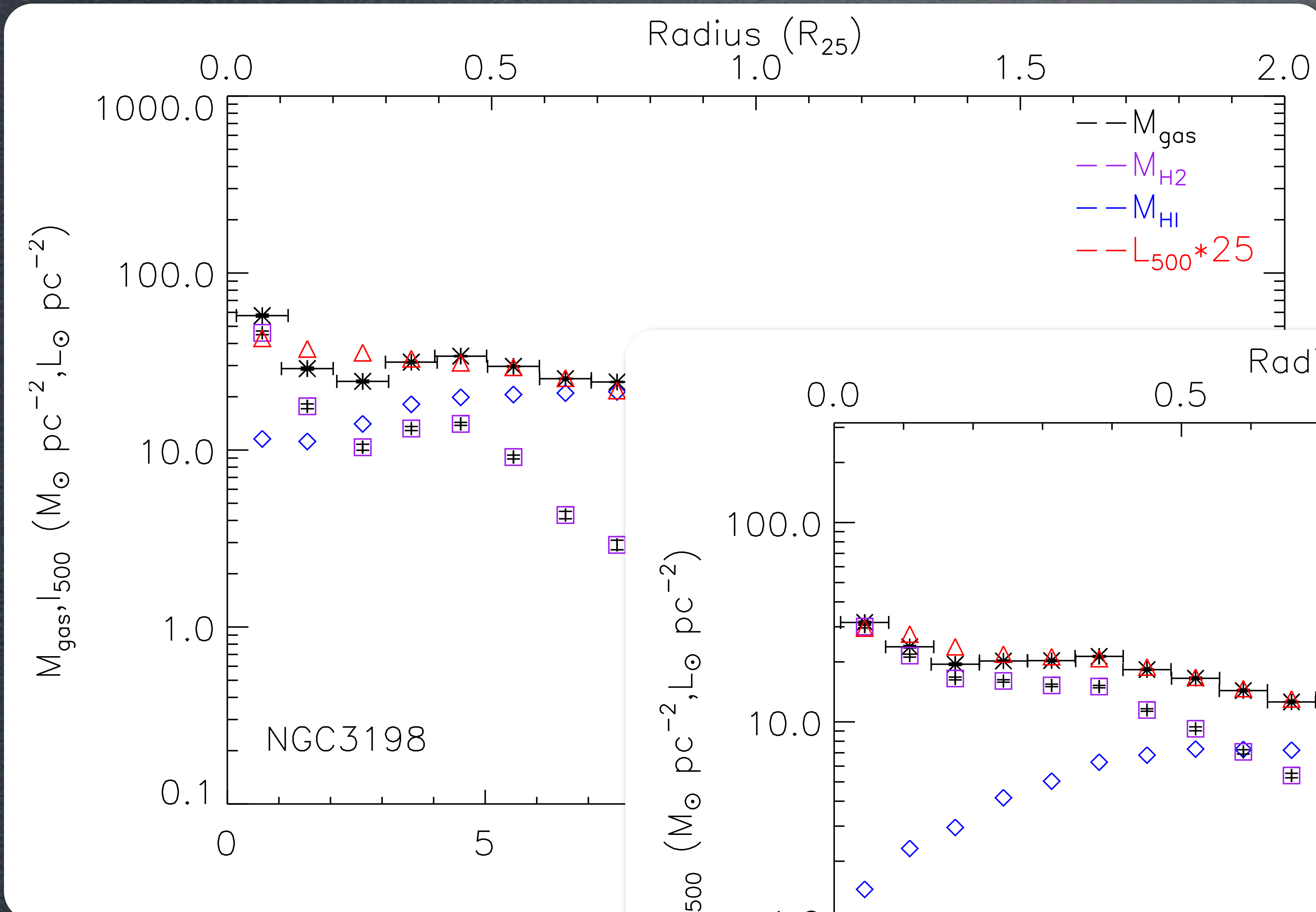
Extended Emission

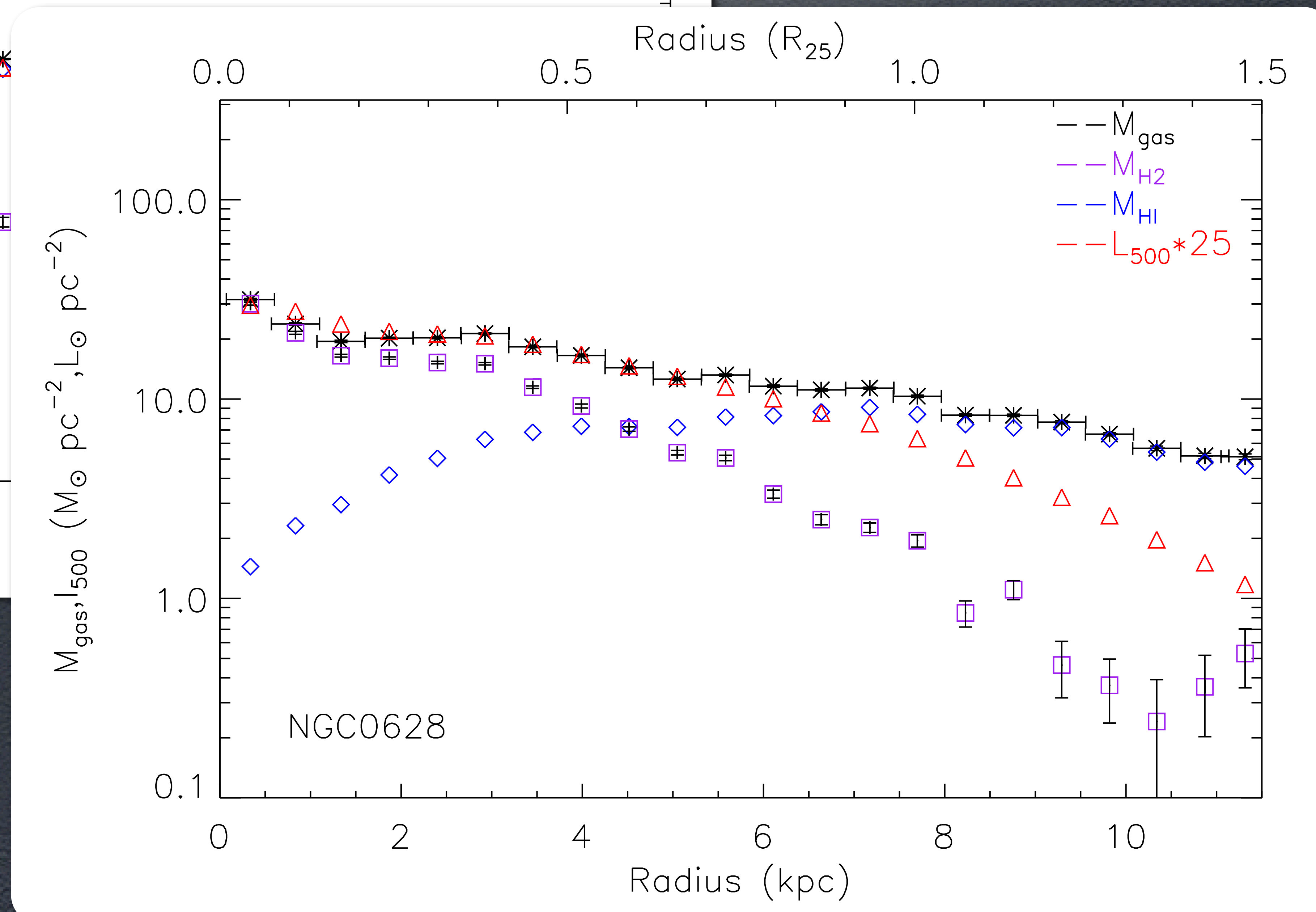


Schruba et al. (2011)
Gas data

Groves et al.
(2014)

Extended Emission



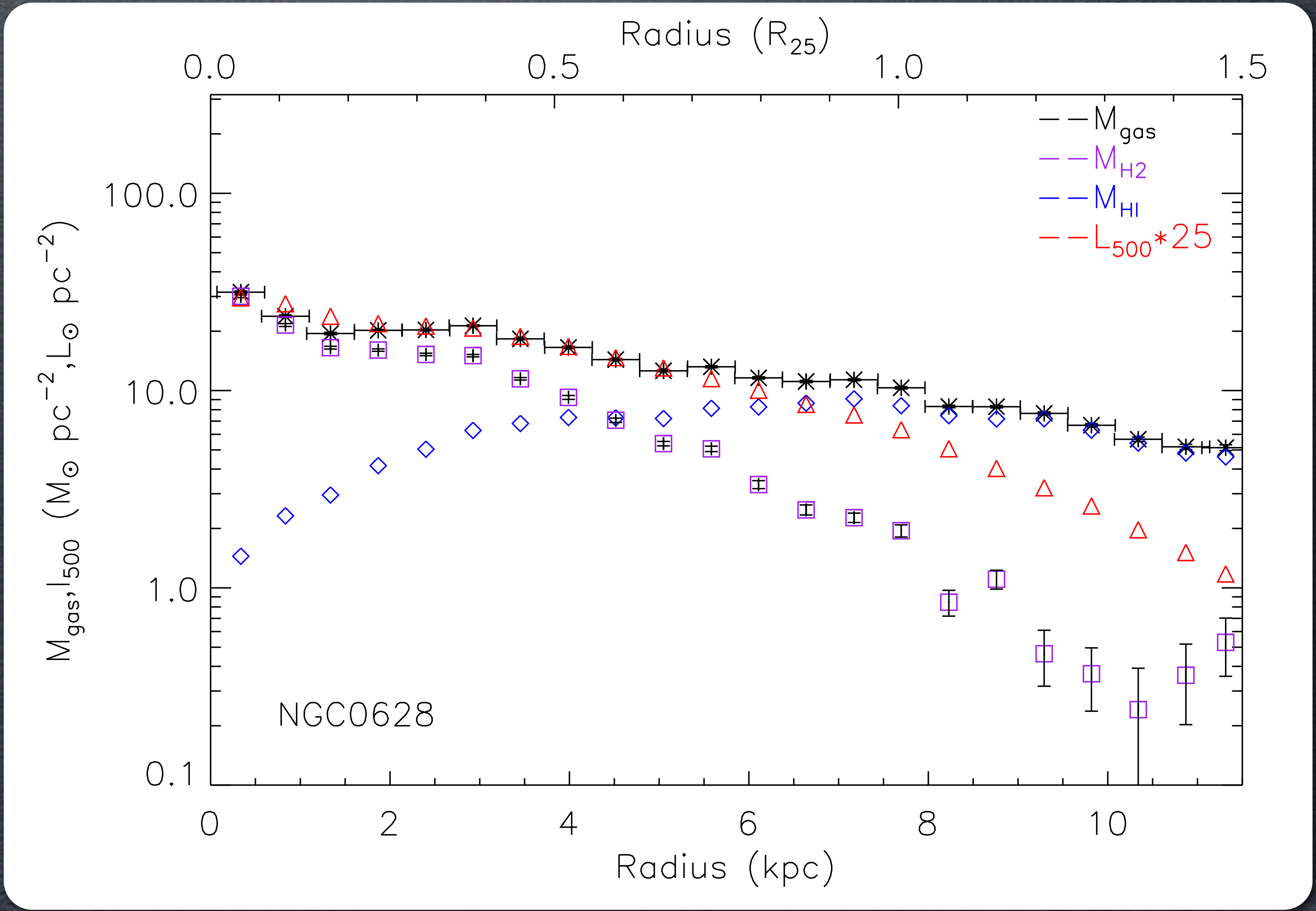


Schruba et al. (2011)
Gas data

Groves et al. (2014)

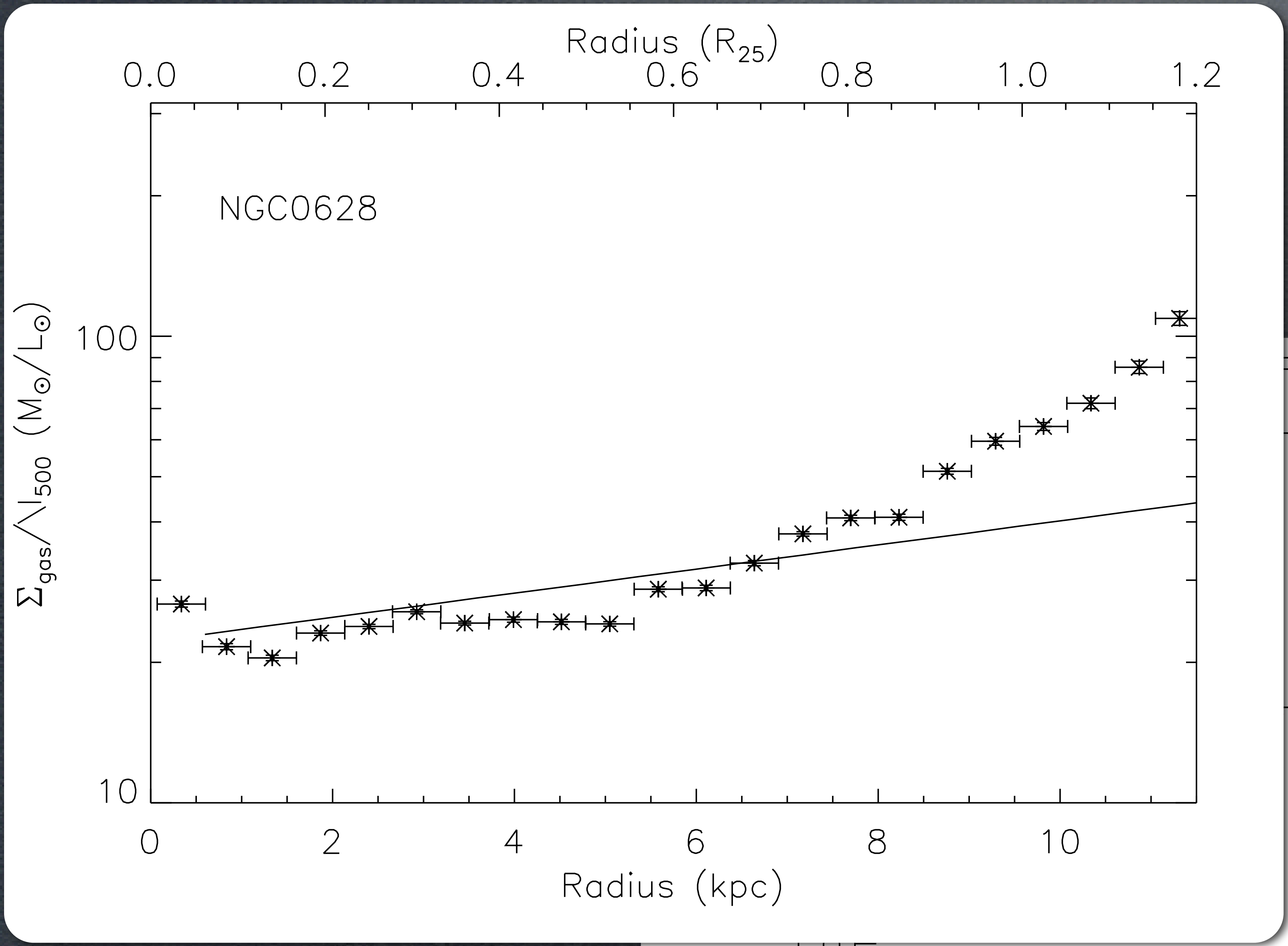
Extended Emission

Moustakas et al. (2009)
Metal gradients

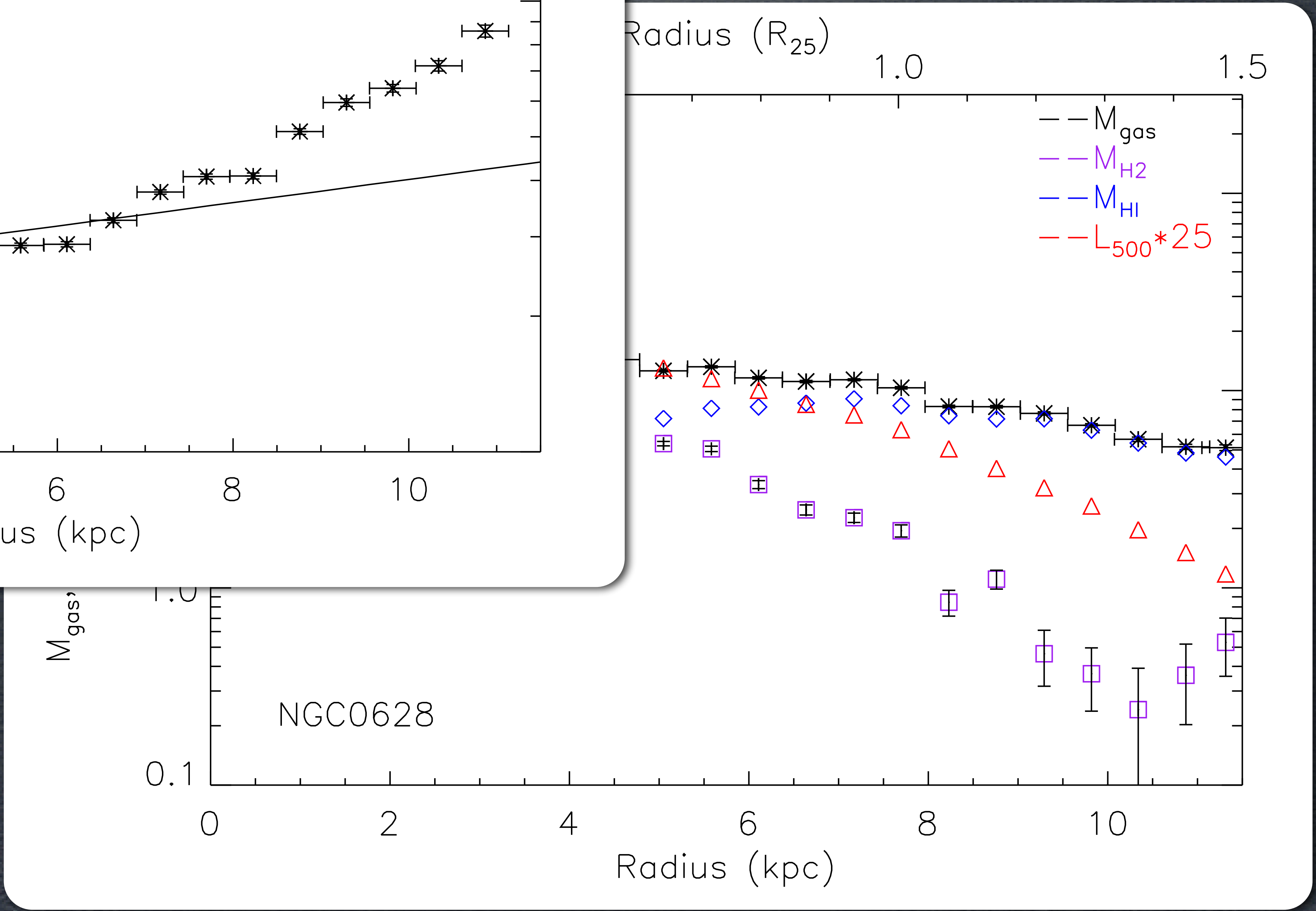


Groves et al. (2014)

Extended Emission



Moustakas et al. (2009)
Metal gradients



Groves et al. (2014)