Dust and Gas in high-z galaxies as seen by Herschel (and beyond)

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& the PEP, HerMES, GOODS-H, etc. Teams

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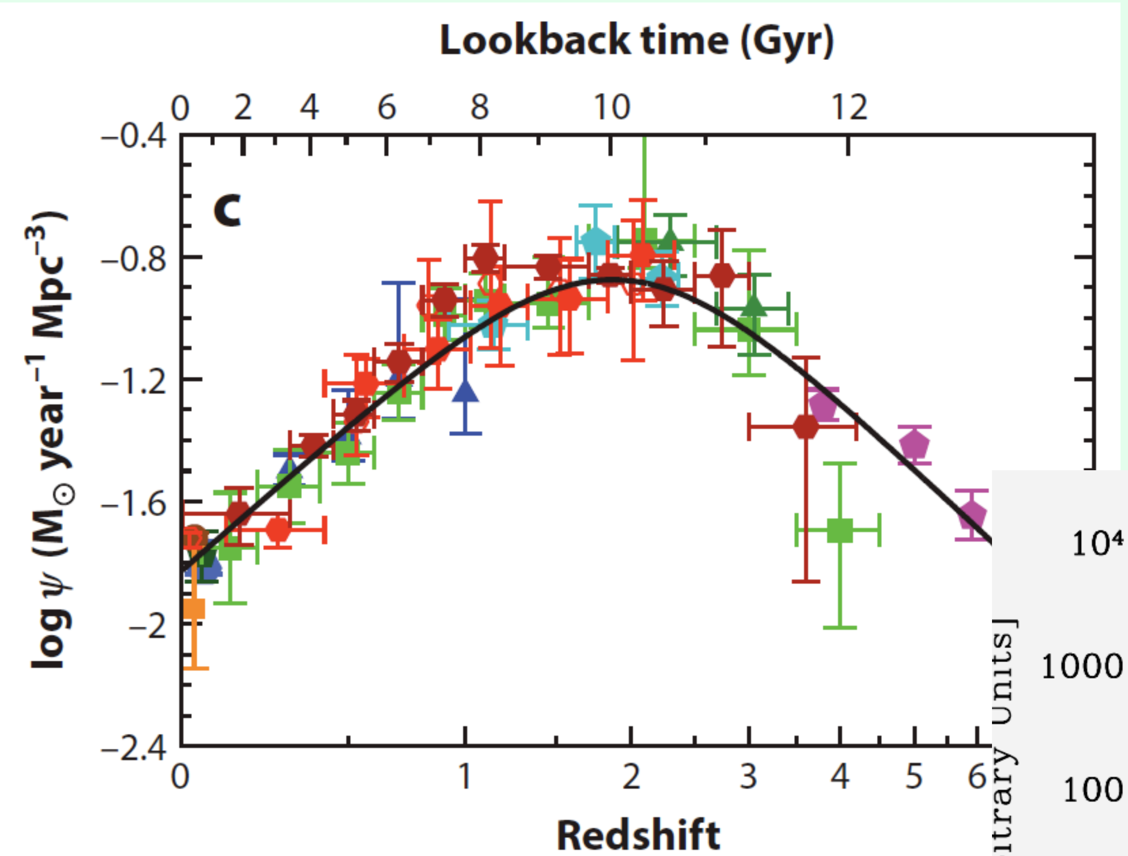
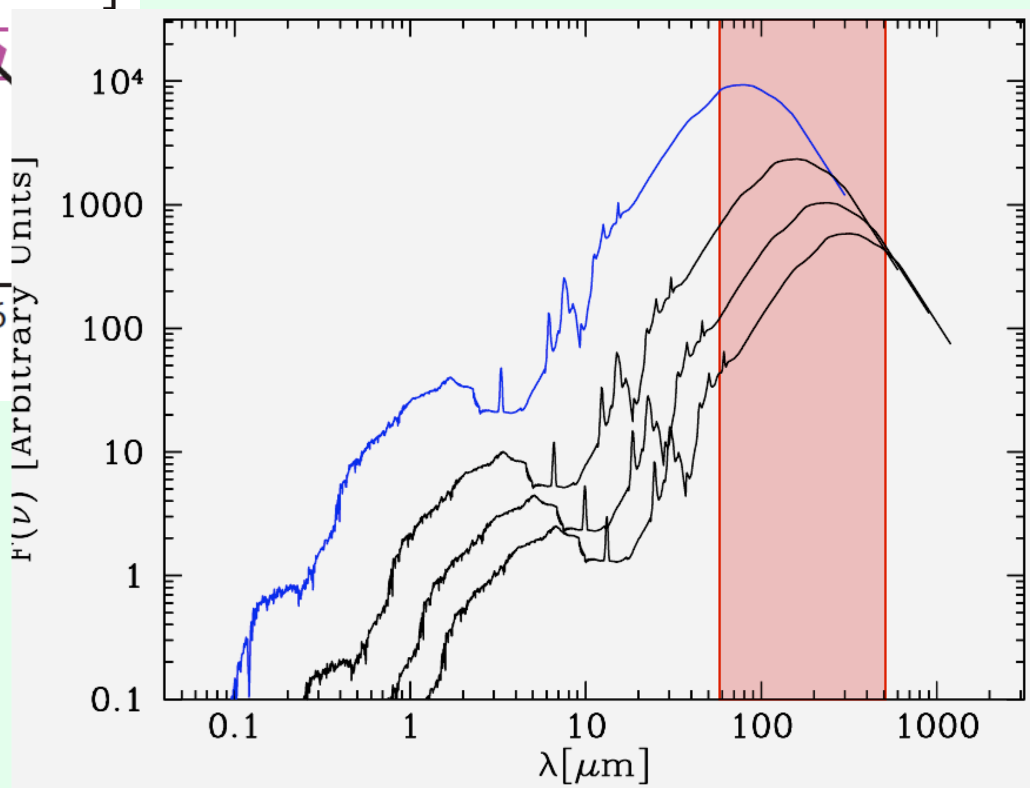
Overview

- ✓ Far-IR observations and Herschel basic results
- ✓ The Gas Mass Function
- ✓ Deriving Gas (dust) masses
- ✓ Scaling relations
- ✓ Uncertainties (Herschel, ALMA or ALMA+Herschel)

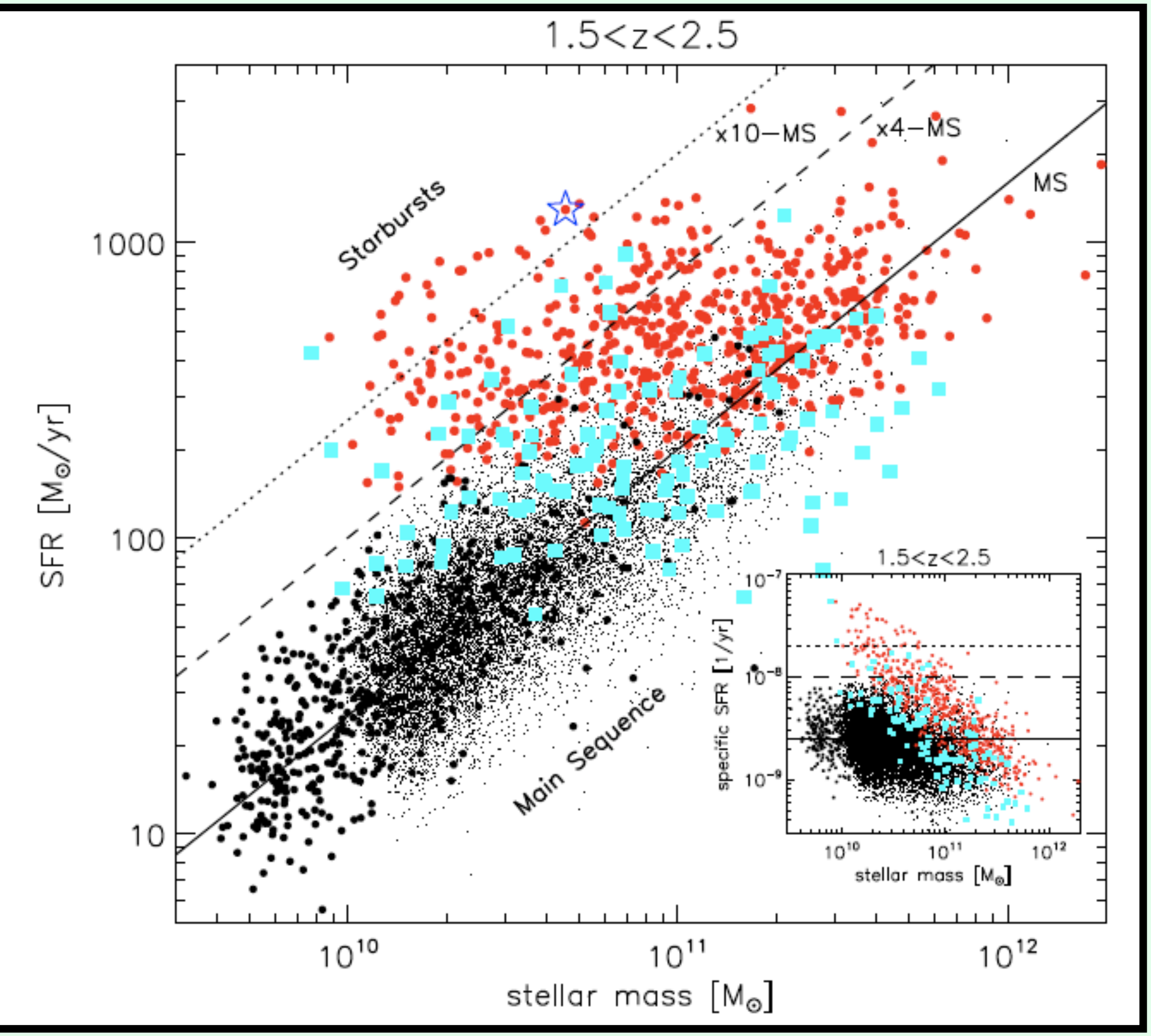
The FIR and Herschel, because…





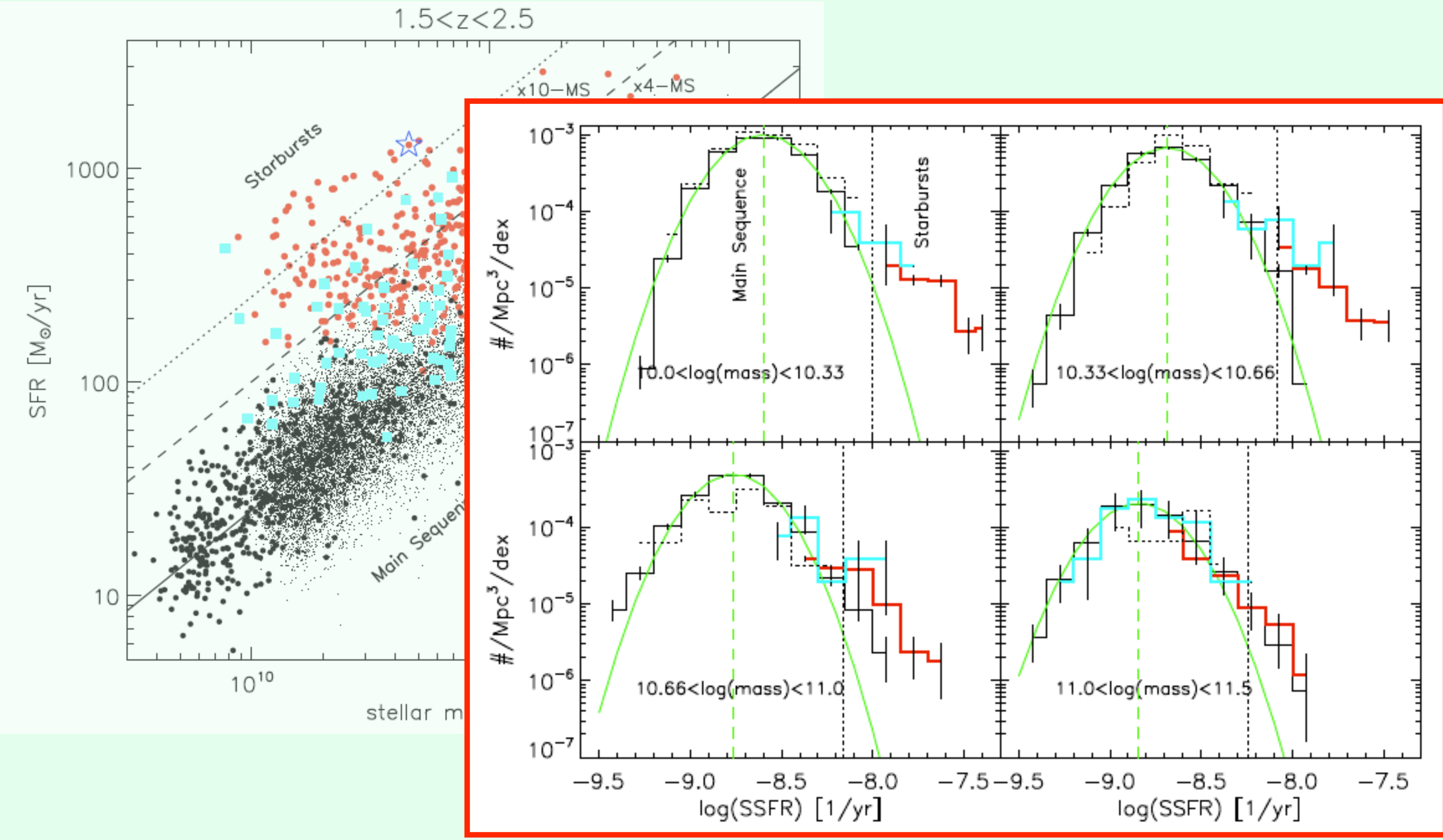
Madau & Dickinson (2014),
Lutz (2014), Berta et al. (2013a)

The lesser role of "starbursts"



Rodighiero et al. (2011), Sargent et al. (2012, 2013)

The lesser role of "starbursts"



Rodighiero et al. (2011), Sargent et al. (2012, 2013)

Deriving gas masses

We would now like to go a step further and study the fuel of star formation.

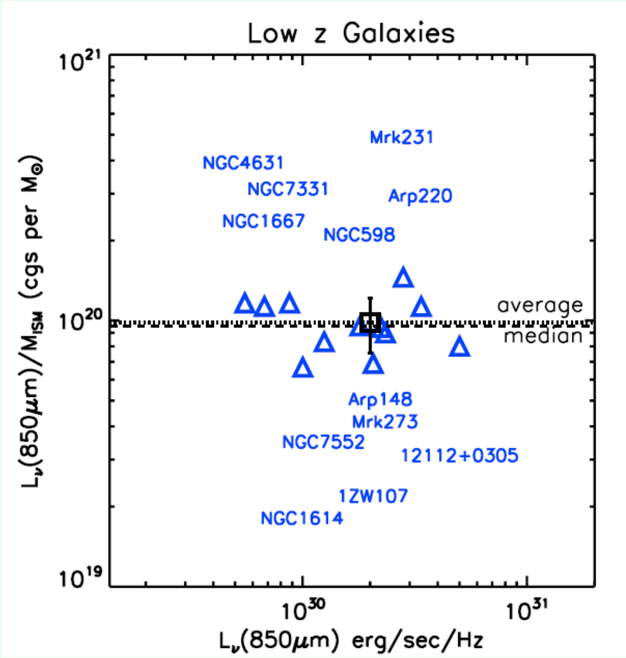
1. CO tracer -> Alpha(CO) ; still limited to small samples at z>0 and still time expensive

2. Derive M(gas) from t(depl) using KS scaling

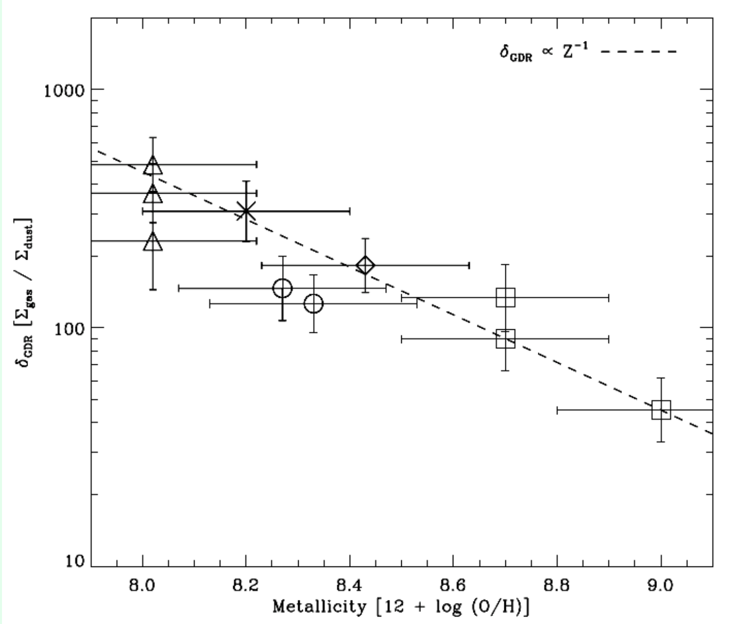
3. Use scalings of other accessible quantities into M(gas) -> M(star), sSFR, … ???

Deriving gas masses

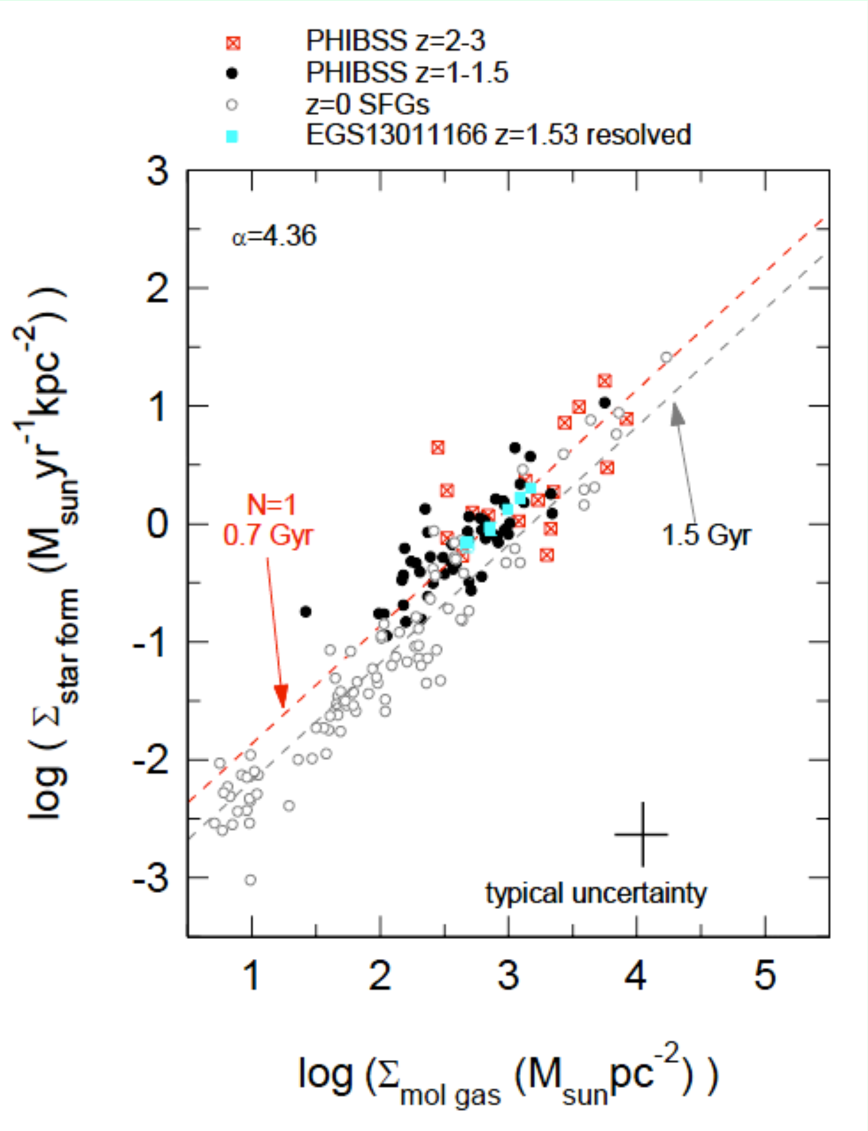
4. Scaling sub-mm fluxes (e.g. Scoville et al. 2014, Eales et al. 2012)

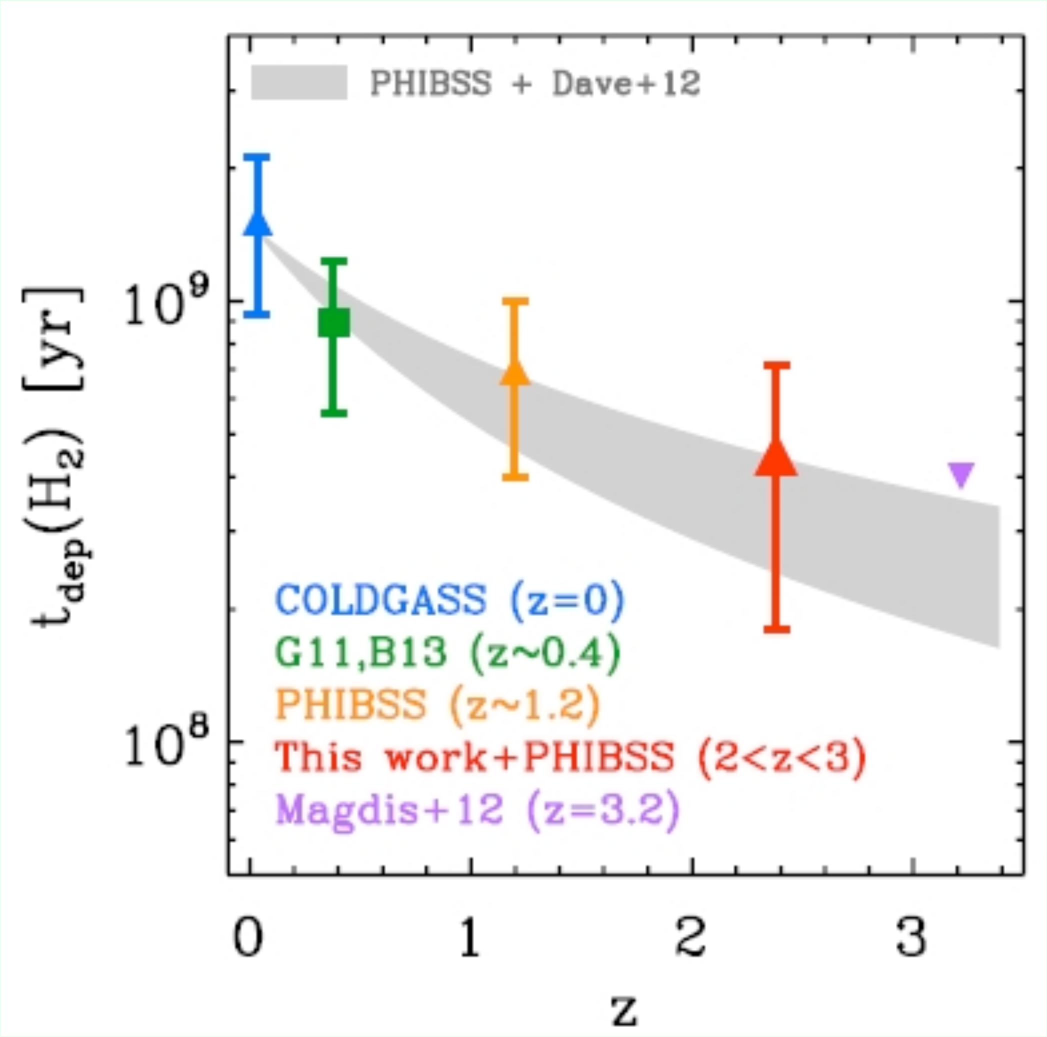


5. derive M(gas) from M(dust, SED), e.g. via gas/dust scaling with metallicity (e.g. Leroy et al 2011, Magdis et al. 2012, Santini et al. 2014, Remy-Ruyer et al. 2013, Genzel et al. 2015)



The fuel of star formation





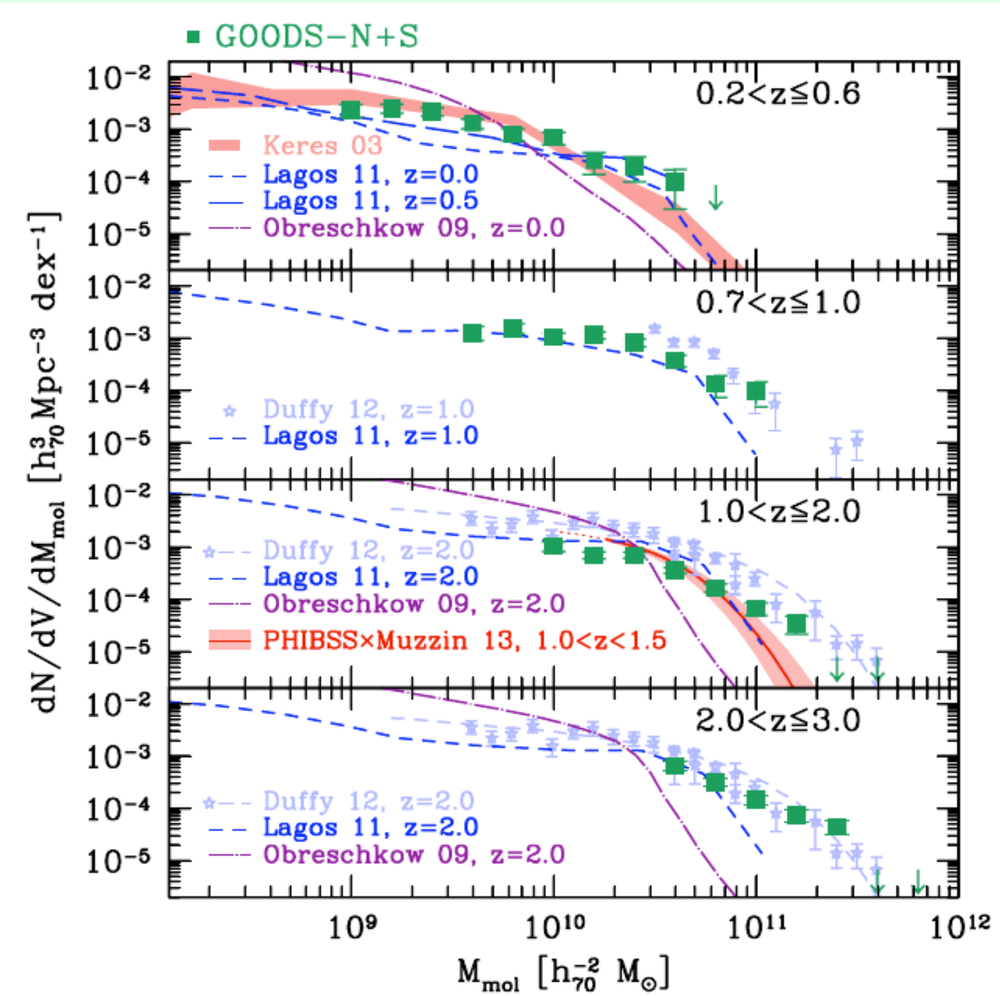
$$t_{depl} = M_{mol\ gas}/SFR = 1.5 \times (1+z)^{-1}\ \mathrm{Gyr}$$

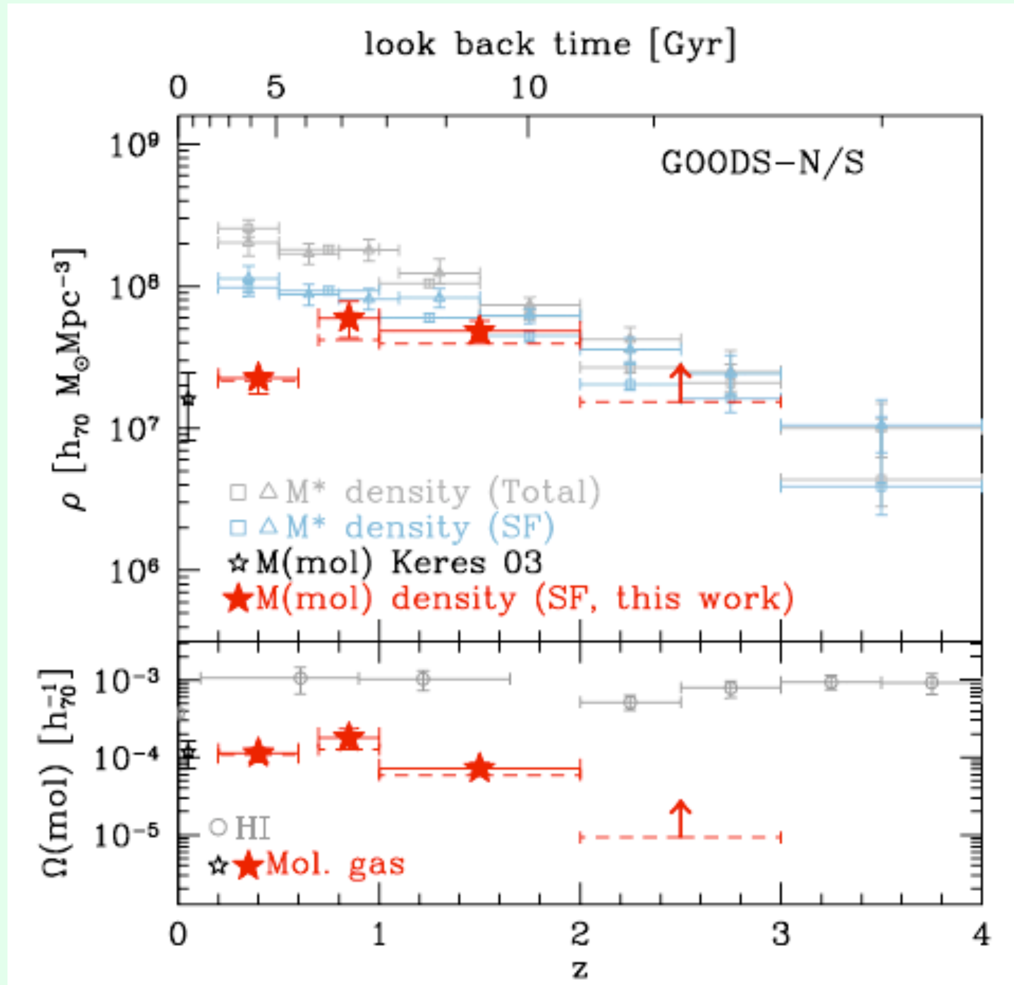
(e.g. Tacconi et al. 2013, Saintonge et al. 2011,2012, Genzel et al. 2015)

The M(mol) Mass Function

1/V(access)

STY

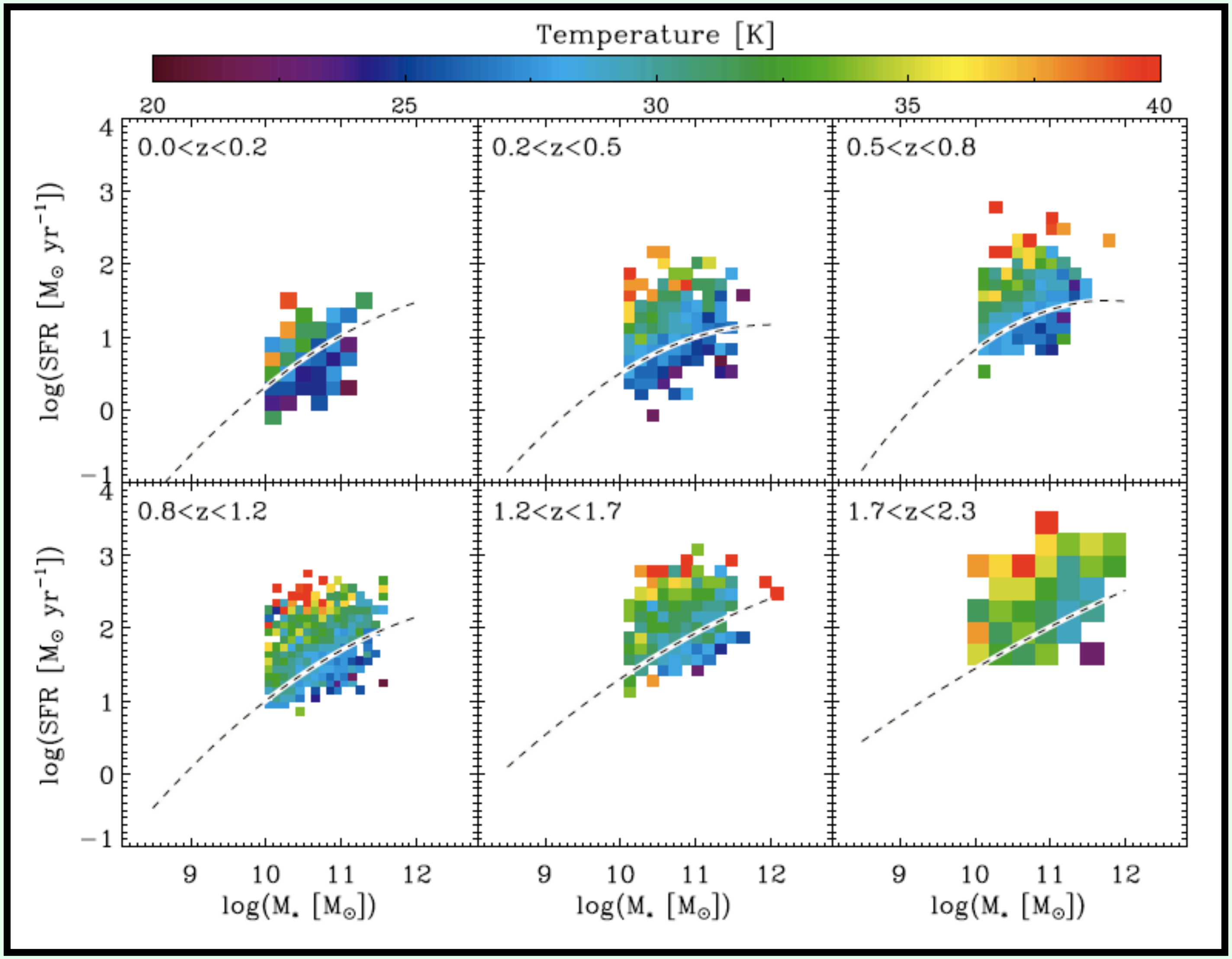




~700 “Main Sequence” galaxies

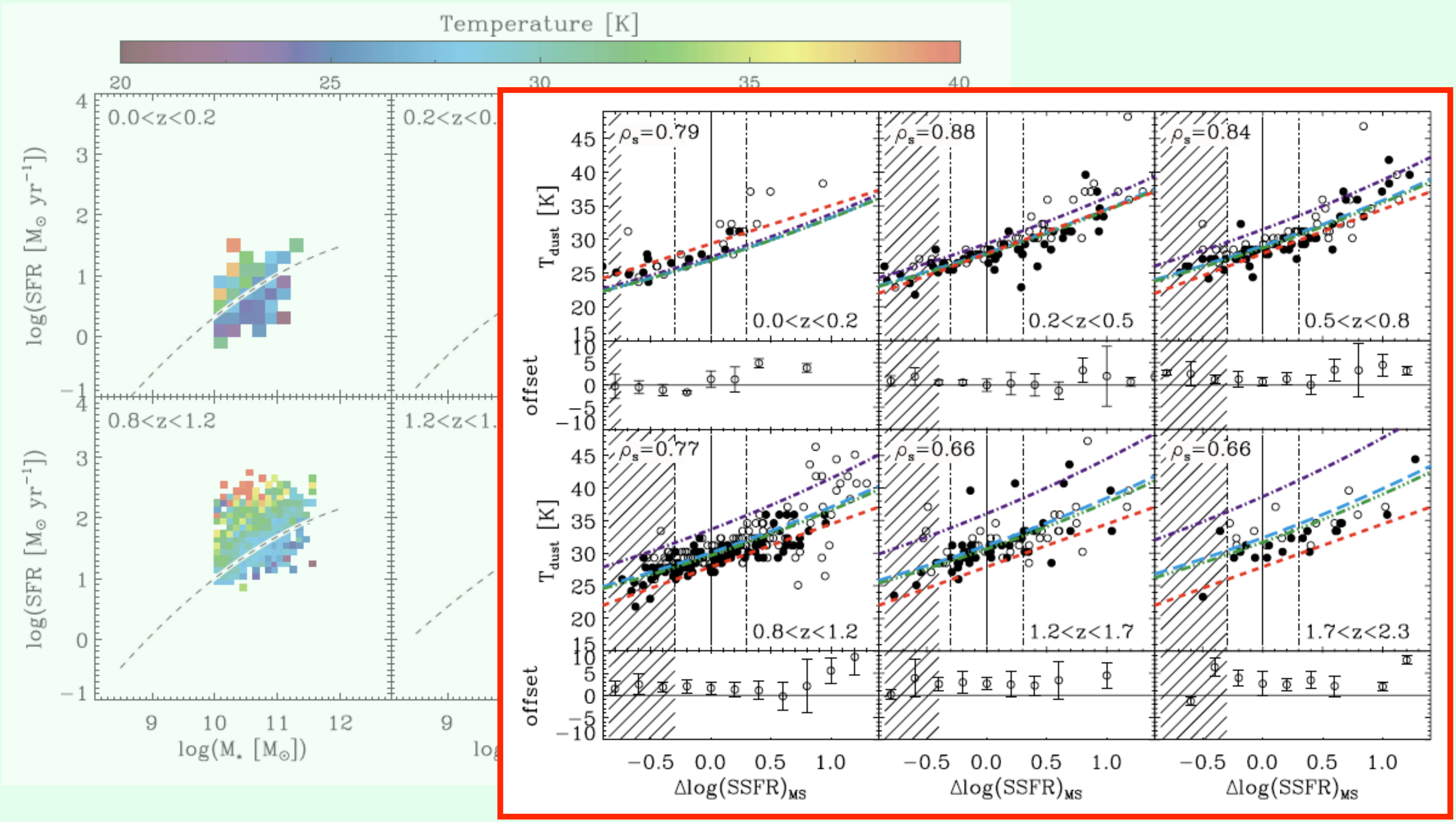
Berta et al. (2013b), see also Sargent et al. (2013)

Dust Properties along/across the "Main Sequence"



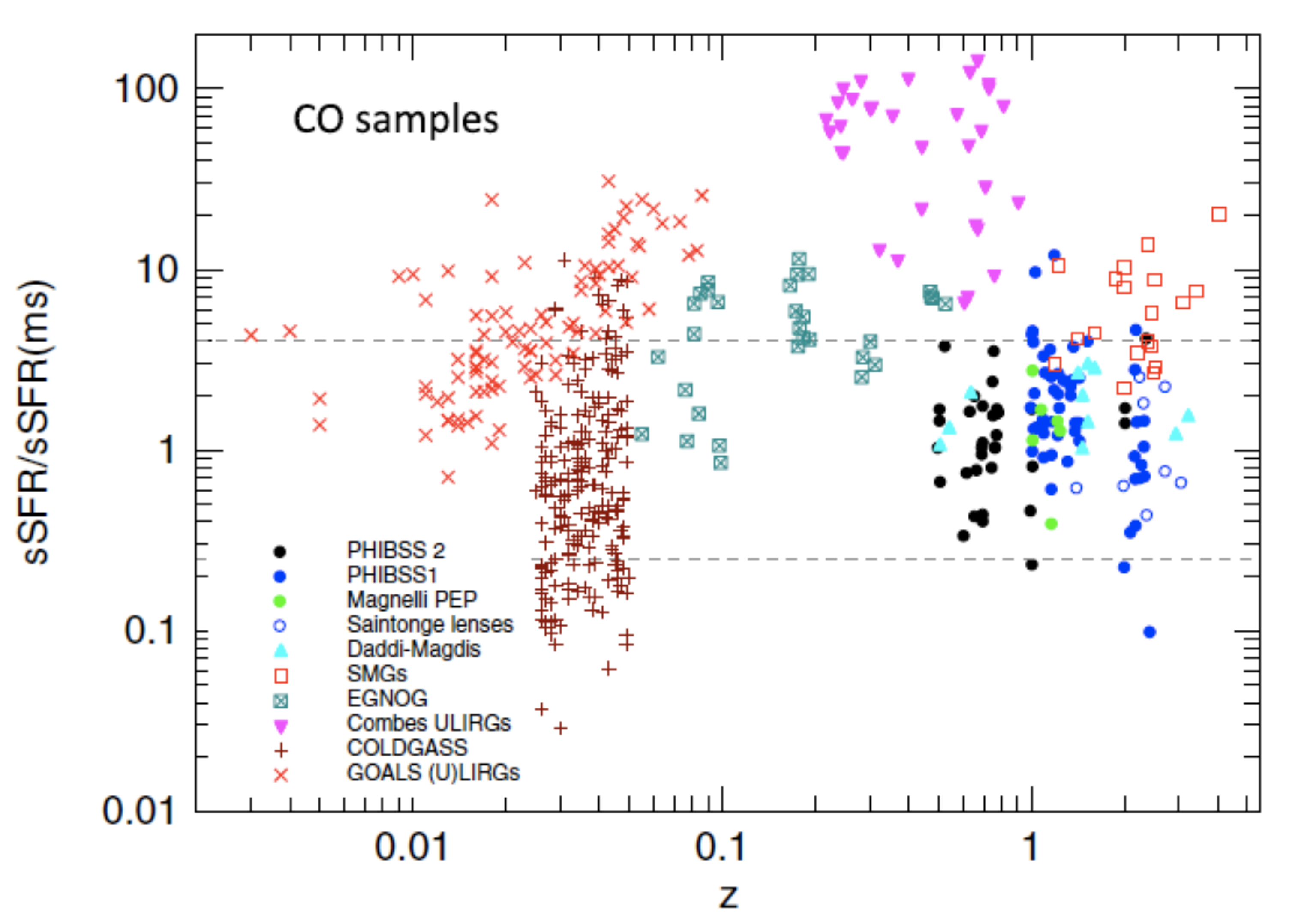
Magnelli et al.(2014); Using DH02 + associated T(Dust)

Dust Properties along/across the "Main Sequence"



Magnelli et al.(2014), see also Genzel et al.(2015)

Gas Masses along/across the "Main Sequence"

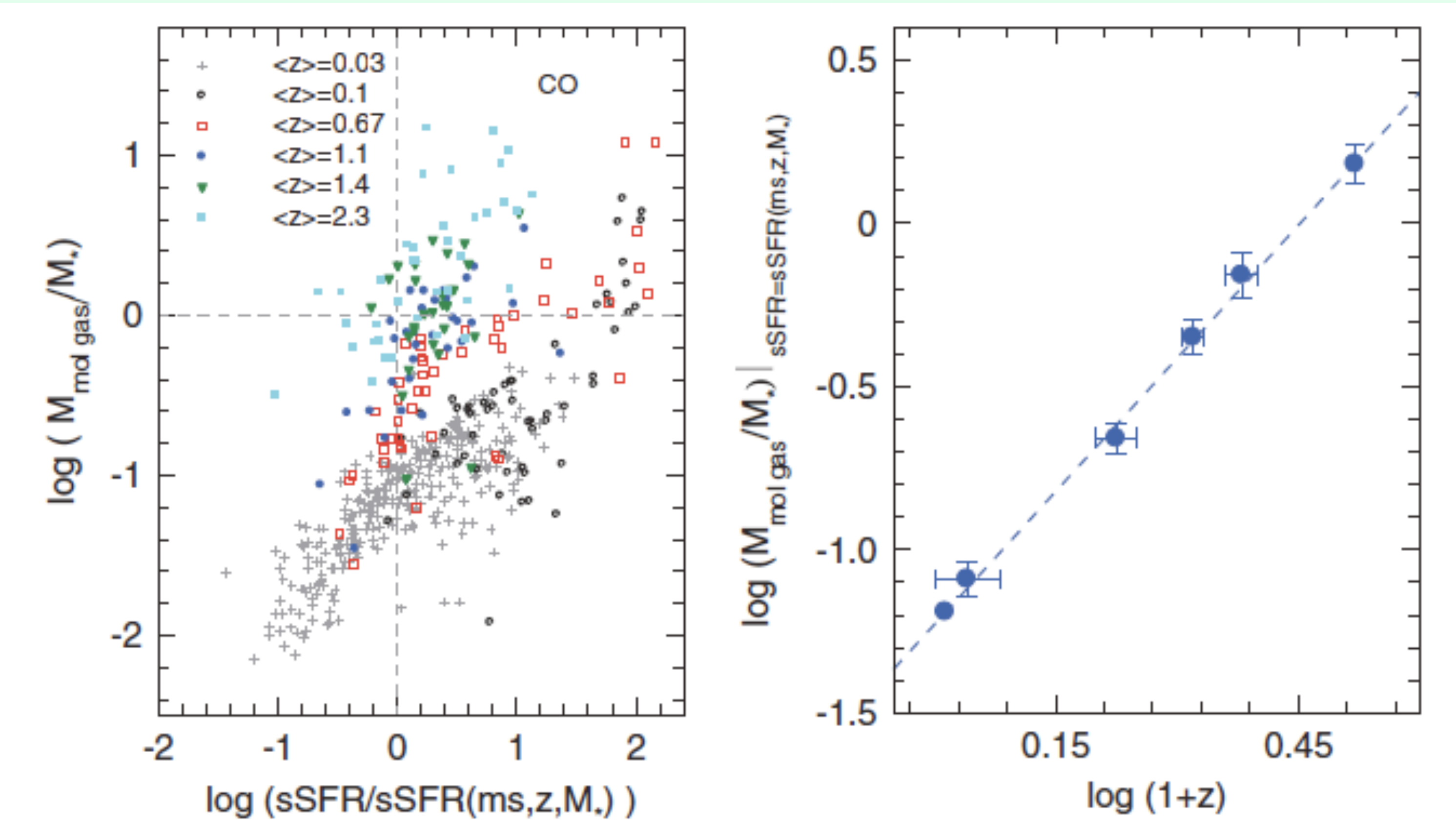


~500 sources

Genzel et al.(2015)

Gas Masses along/across the "Main Sequence"

CO-based



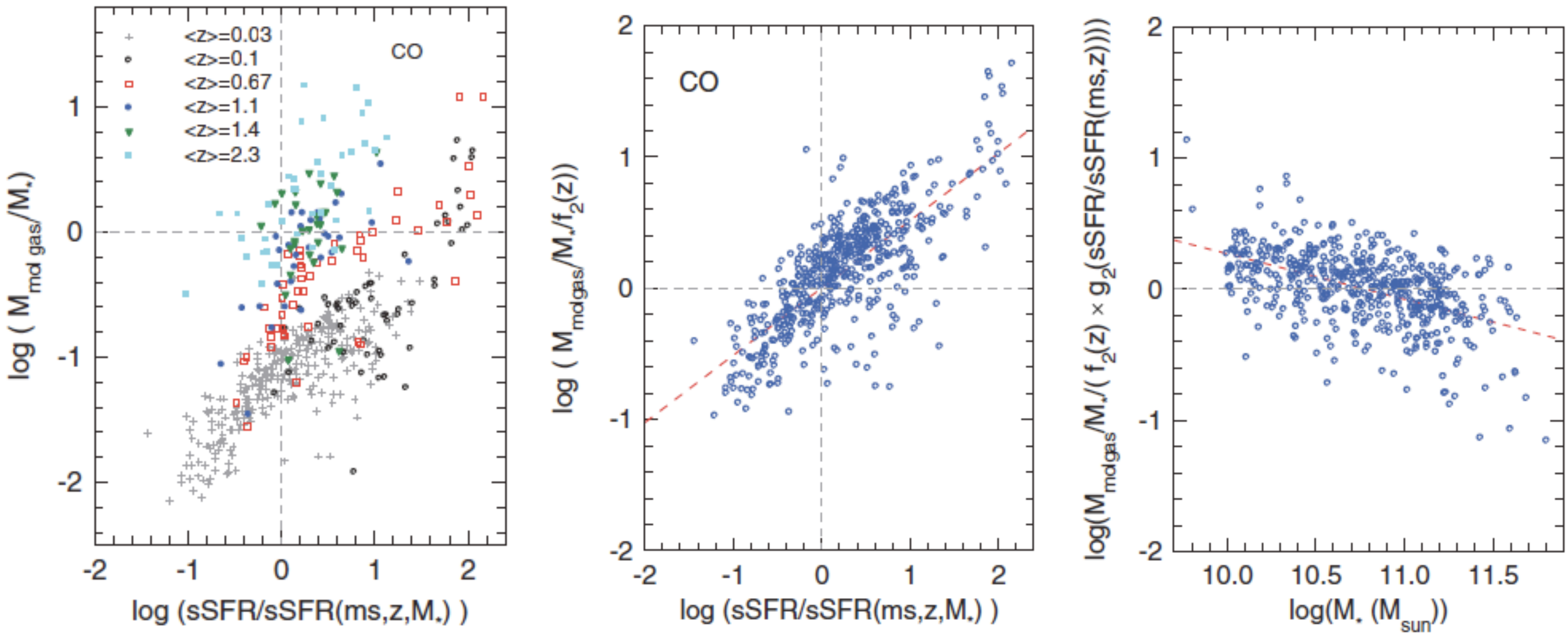
$$
\log(M_{\rm mol\ gas}/M_*(z,\,{\rm sSFR},\,M_*)|_{\alpha=\alpha_{0J}}) = \log(f_2(z)|_{sSFR=sSFR({\rm ms},z,M_*)}) + \log(g_2({\rm sSFR}/{\rm sSFR}({\rm ms},\,z,\,M_*))) + \log(h_2(M_*))
$$

Genzel et al.(2015)

Using MW conversion factor

Gas Masses along/across the "Main Sequence"

CO-based

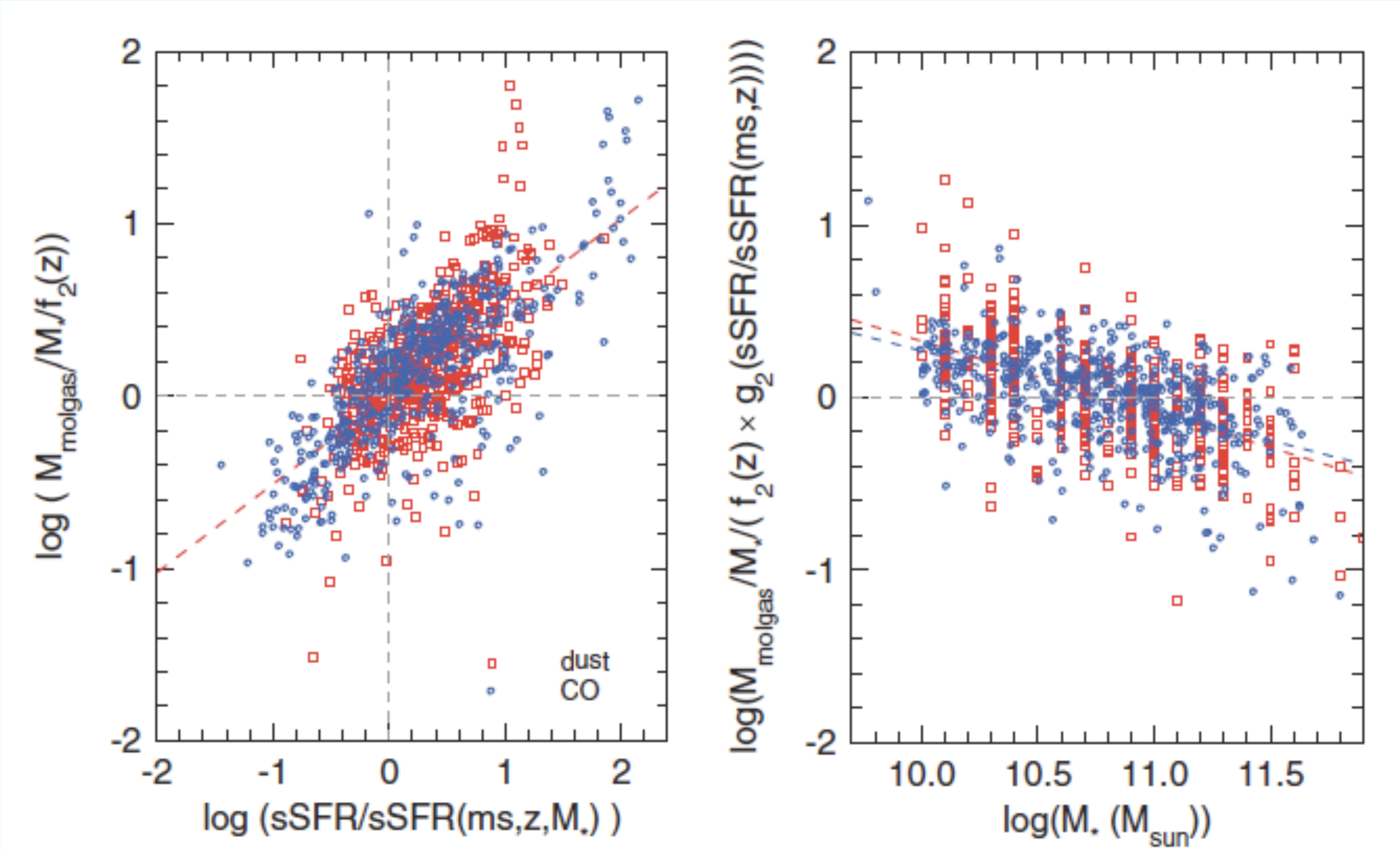


$$\log(M_{\mathrm{mol\ gas}}/M_*(z,\mathrm{sSFR},M_*)|_{\alpha=\alpha_{0J}})$$
$$=\log(f_2(z)|_{sSFR=sSFR(\mathrm{ms},z,M_*)})$$
$$+\log(g_2(\mathrm{sSFR}/\mathrm{sSFR}(\mathrm{ms},z,M_*)))+\log(h_2(M_*))$$

Genzel et al.(2015)

Gas Masses along/across the "Main Sequence"

Dust-based



Agreement to better than 50%!

Genzel et al.(2015)

Testing sub-mm single-band M(gas)

MBB simulation

INPUT:

- Magnelli et al. (2014) T(dust) vs z-M*-sSFR
- Genzel et al. (2015) M(gas) vs z-M*-sSFR
- Modified Black Body

OUTPUT:

- M(gas) based on Scoville et al. (2014) scaling of sub-mm flux

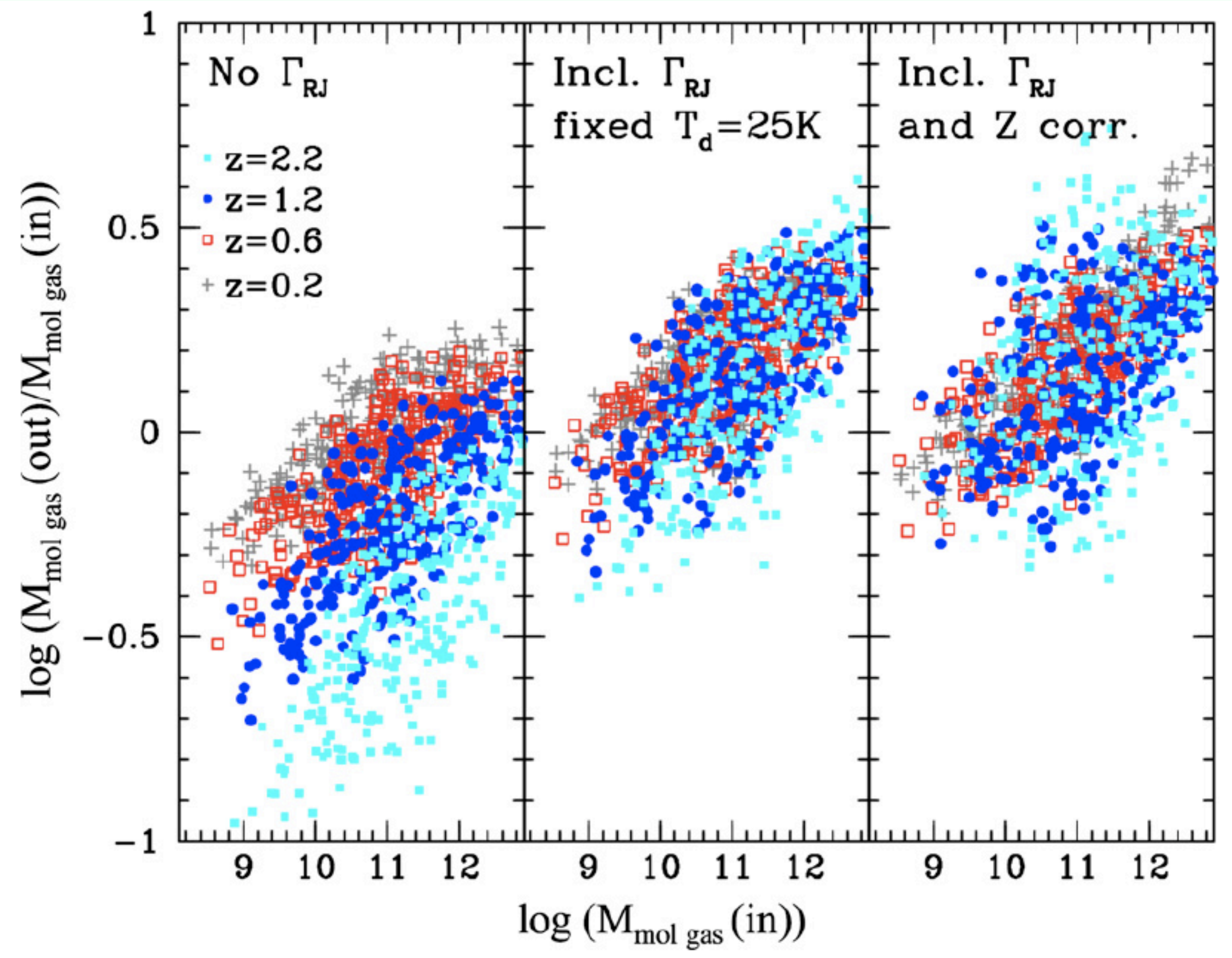
$$\alpha_{850\,\mu\mathrm{m}} = \frac{L_{\nu_{850\,\mu\mathrm{m}}}}{M_{\mathrm{ISM}}} = 4\pi\,\kappa_{\mathrm{ISM}}(\nu_{850\,\mu\mathrm{m}})B_{\nu}(T_d)$$
$$= 0.79 \times 10^{20}\ \mathrm{erg\,s^{-1}\,Hz^{-1}}\ M_{\odot}{}^{-1}, \qquad (9)$$

(Valid for T(d)=25 K and Planck-based kappa(ISM))

Genzel et al. (2015)

Testing ALMA single-band M(gas)

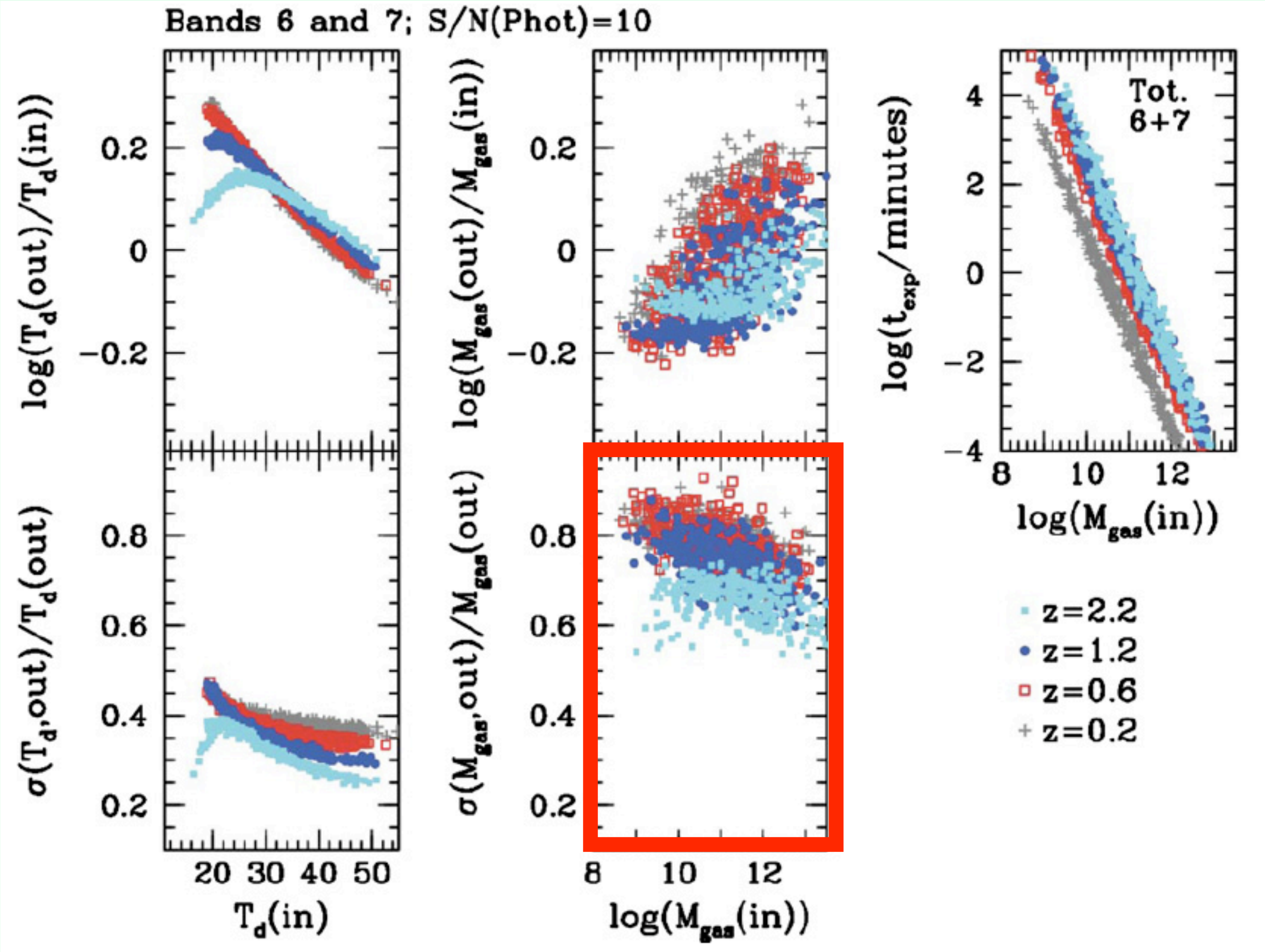
MBB simulation



Genzel et al. (2015)

Switching to two ALMA bands (6+7)

MBB simulation

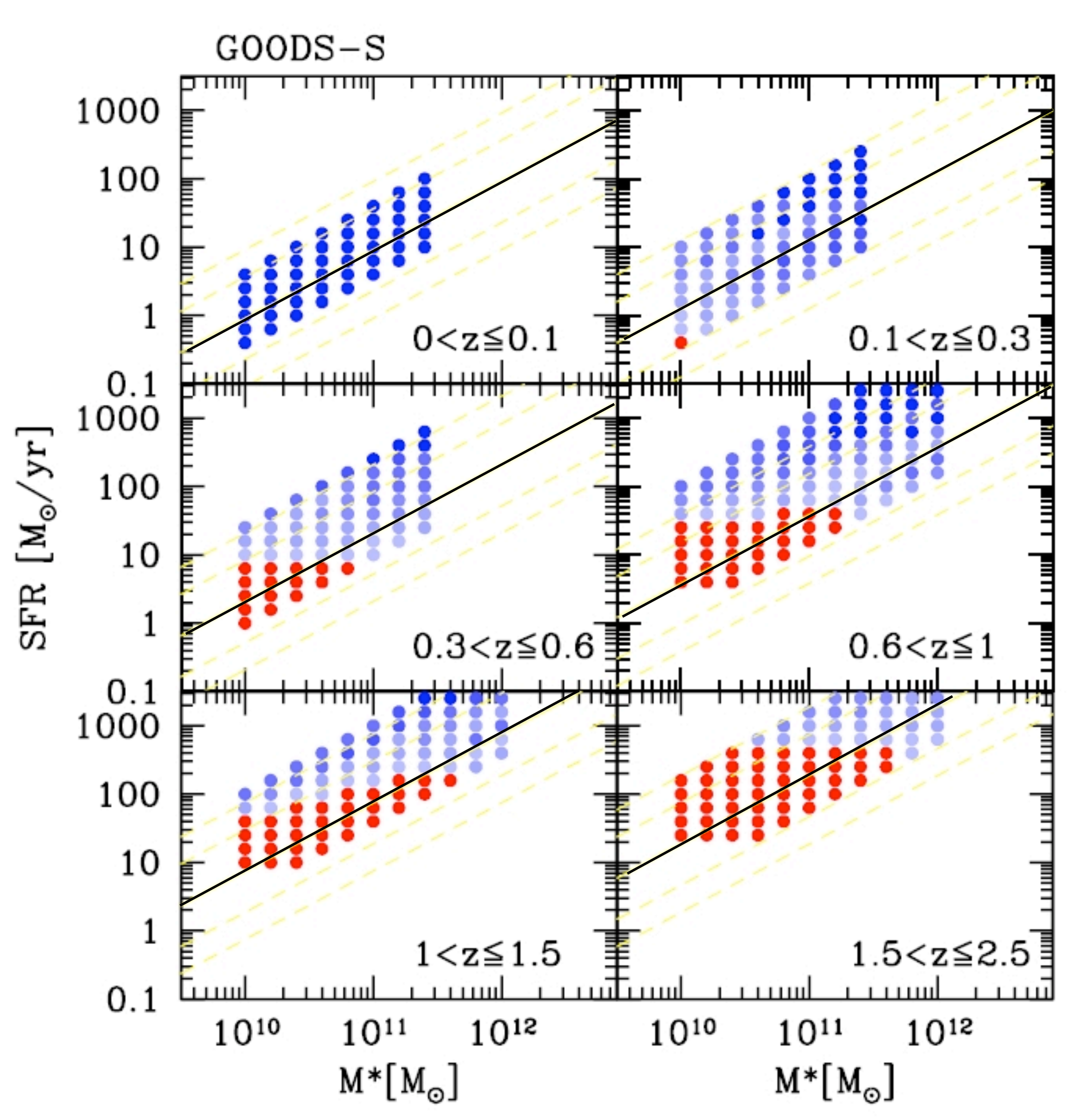


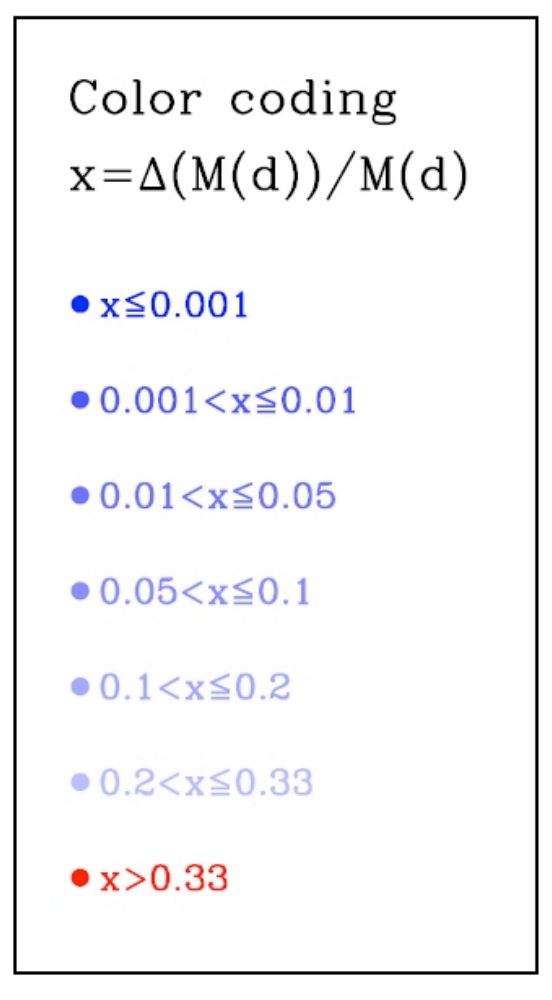
(Time expensive)

Genzel et al. (2015)

Herschel handles dust masses

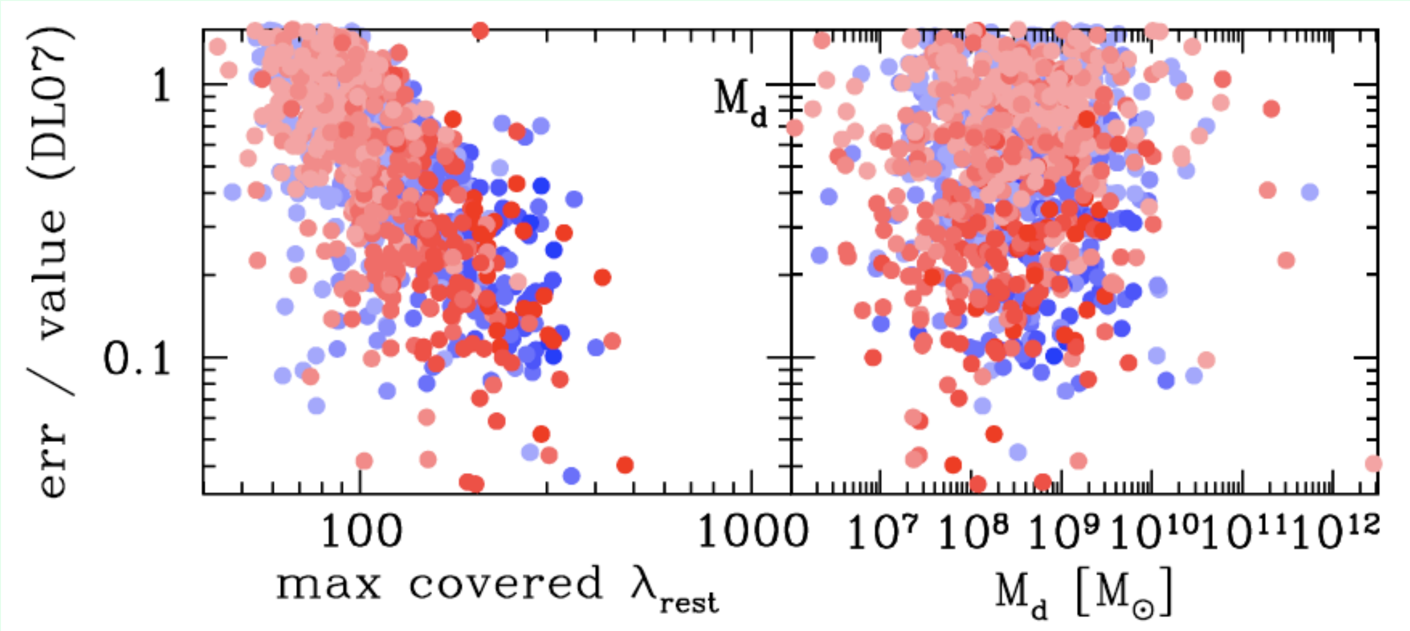
DL07 Simulation,
sampling the M*-SFR space with PEP/HerMES noise





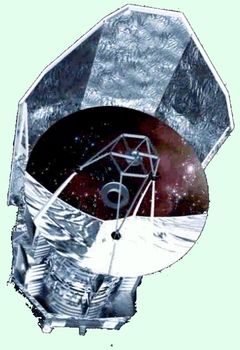
Berta et al. (in prep)

Studying our ignorance in deriving dust masses

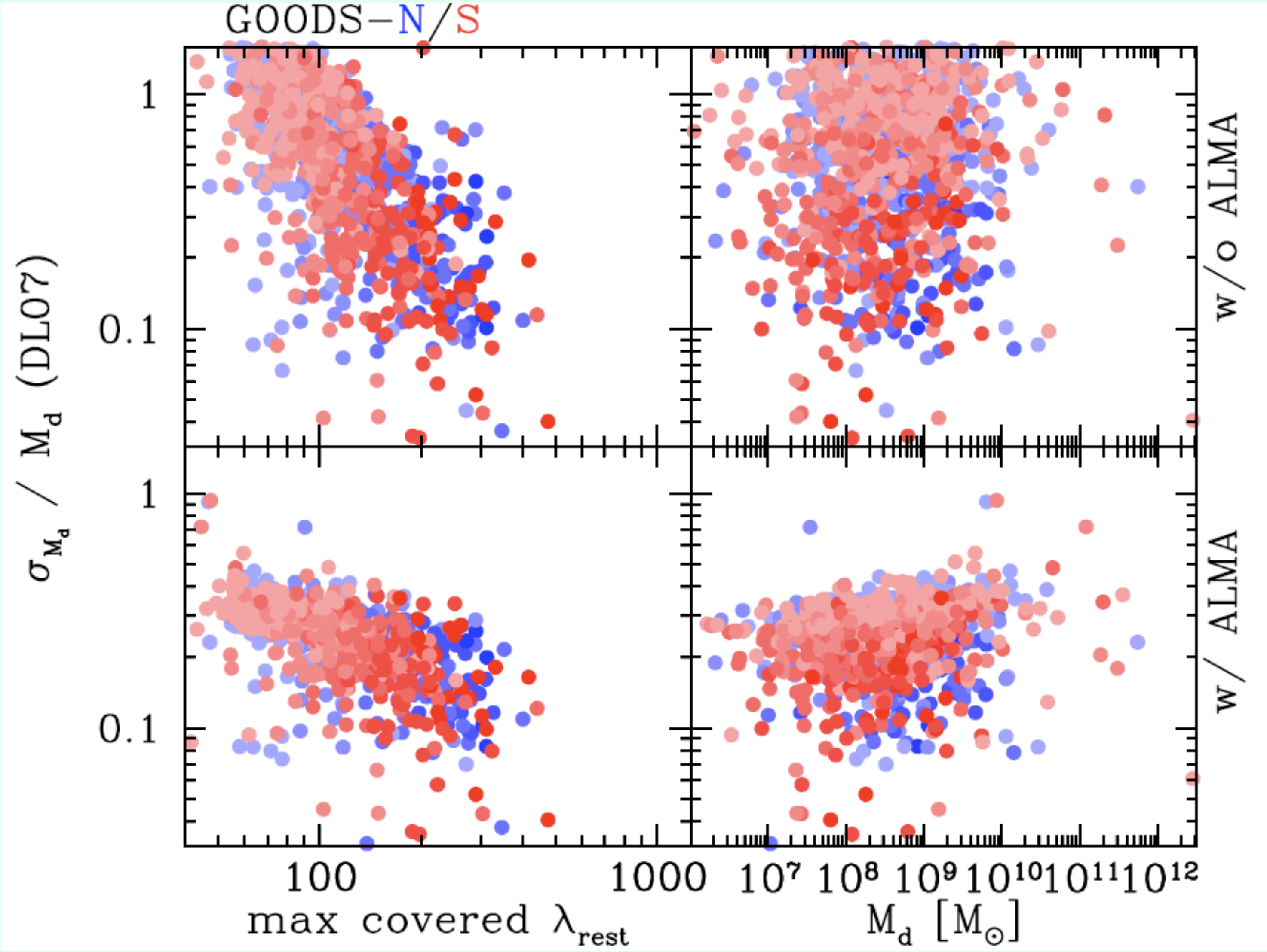


Berta et al. (in prep.)

Based on DL07 fitting



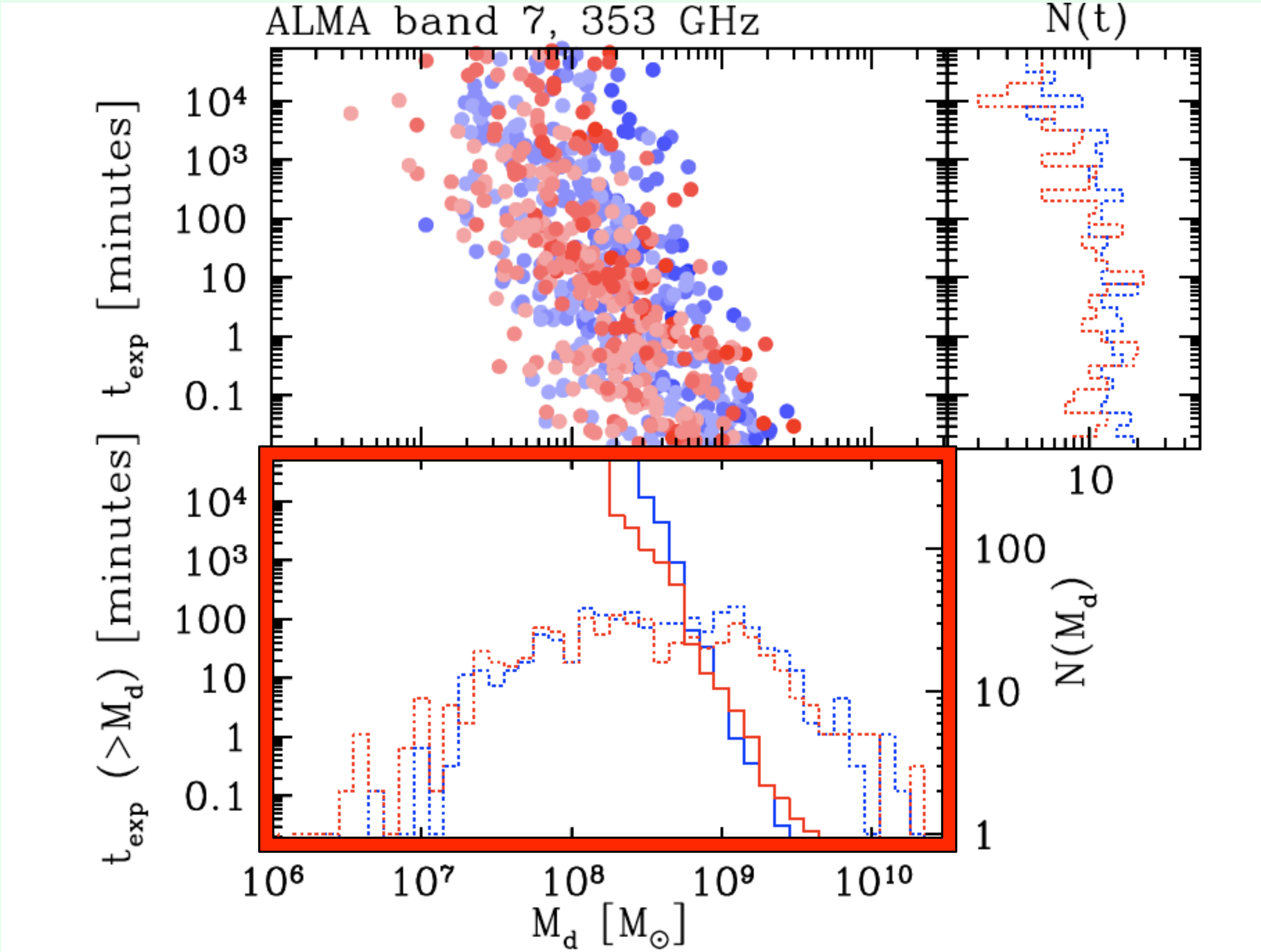
Herschel + ALMA !



[gives an exposure time for ALMA]

Berta et al. (in prep.) Based on DL07 fitting

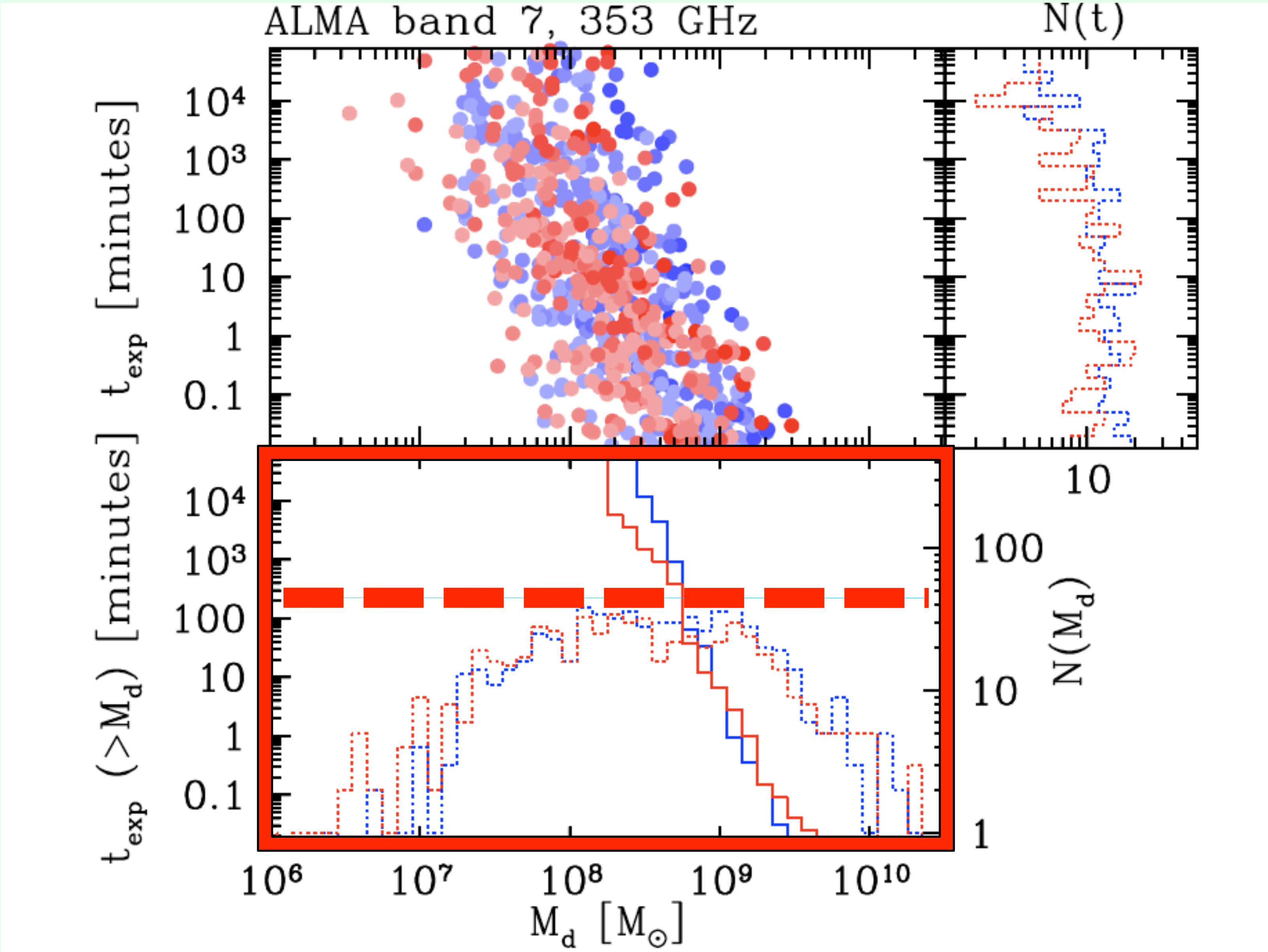
Herschel + ALMA !



34 antennas allow to observe all PACS/Herschel detected sources in GOODS-S down to M(gas)>1e10.5 Msun in few tens of hours (modulo overheads)

Berta et al. (in prep.)

Herschel + ALMA !



34 antennas allow to observe all PACS/Herschel detected sources in GOODS-S down to M(gas)>1e10.5 Msun in few tens of hours (modulo overheads)

Berta et al. (in prep.)

Take home messages

- ✓ We have derived the first (and only) determination of the gas mass function at z>0 scaling Herschel-based SFR with t(depl).

- ✓ CO-based and dust-based determinations of M(gas) agree to better than 50% (for massive SFG with nearly-solar Z on the MS).

- ✓ ALMA-only and Herschel-only estimates of gas (dust) masses are affected by large uncertainties and possibly systematics.

- ✓ A combined ALMA+Herschel approach allows to measure dust (gas) masses with SN>3.

- ✓ ALMA requires few tens of hours (on source, e.g. band 7) to target all GOODS-S PACS-detected sources down to M(gas)~1e10.5 up to z~2.