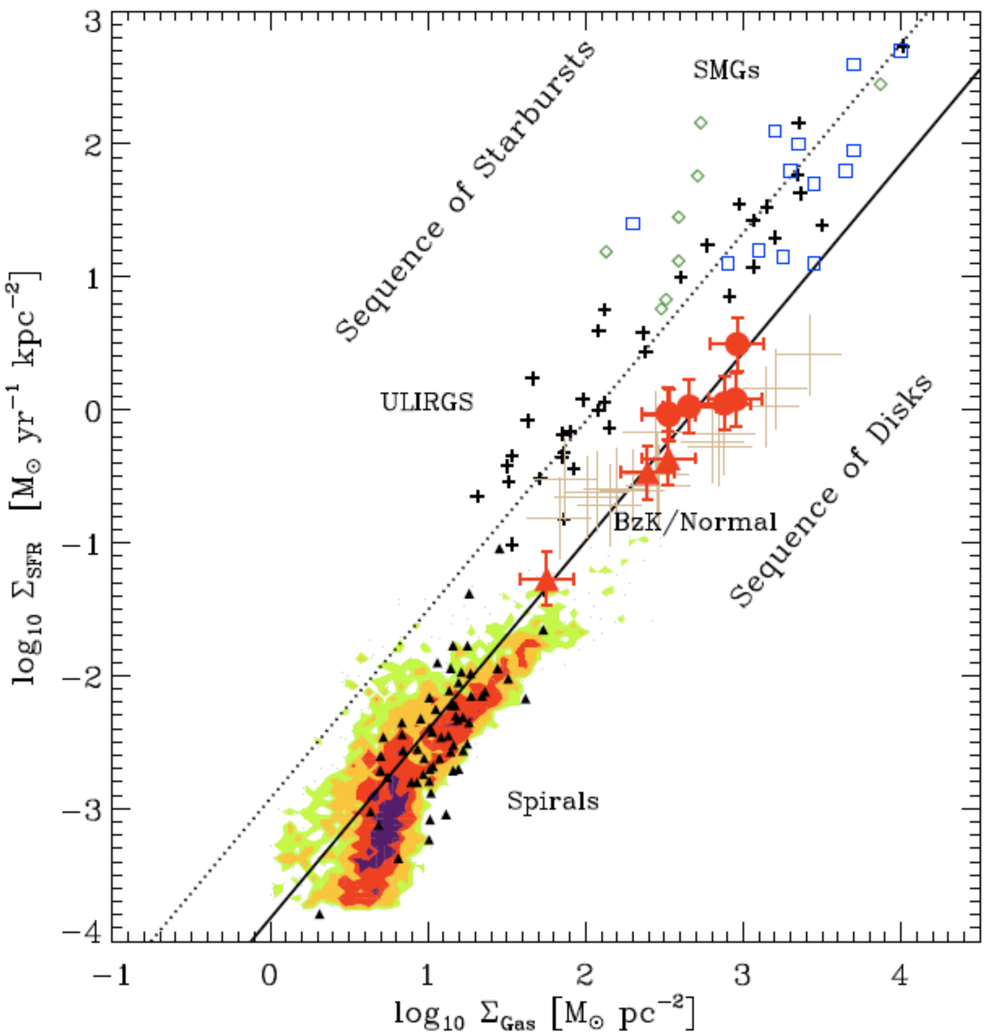
Unveiling different star formation modes in the distant Universe

E. Daddi (CEA Saclay)

Herschel-GOODS: Magdis et al 2011 ApJ 739 L40
PEP: Rodighiero et al. 2011 ApJ 740 L15

Failure of classical Kennicutt law
to account for z~1.5-2 normal galaxies

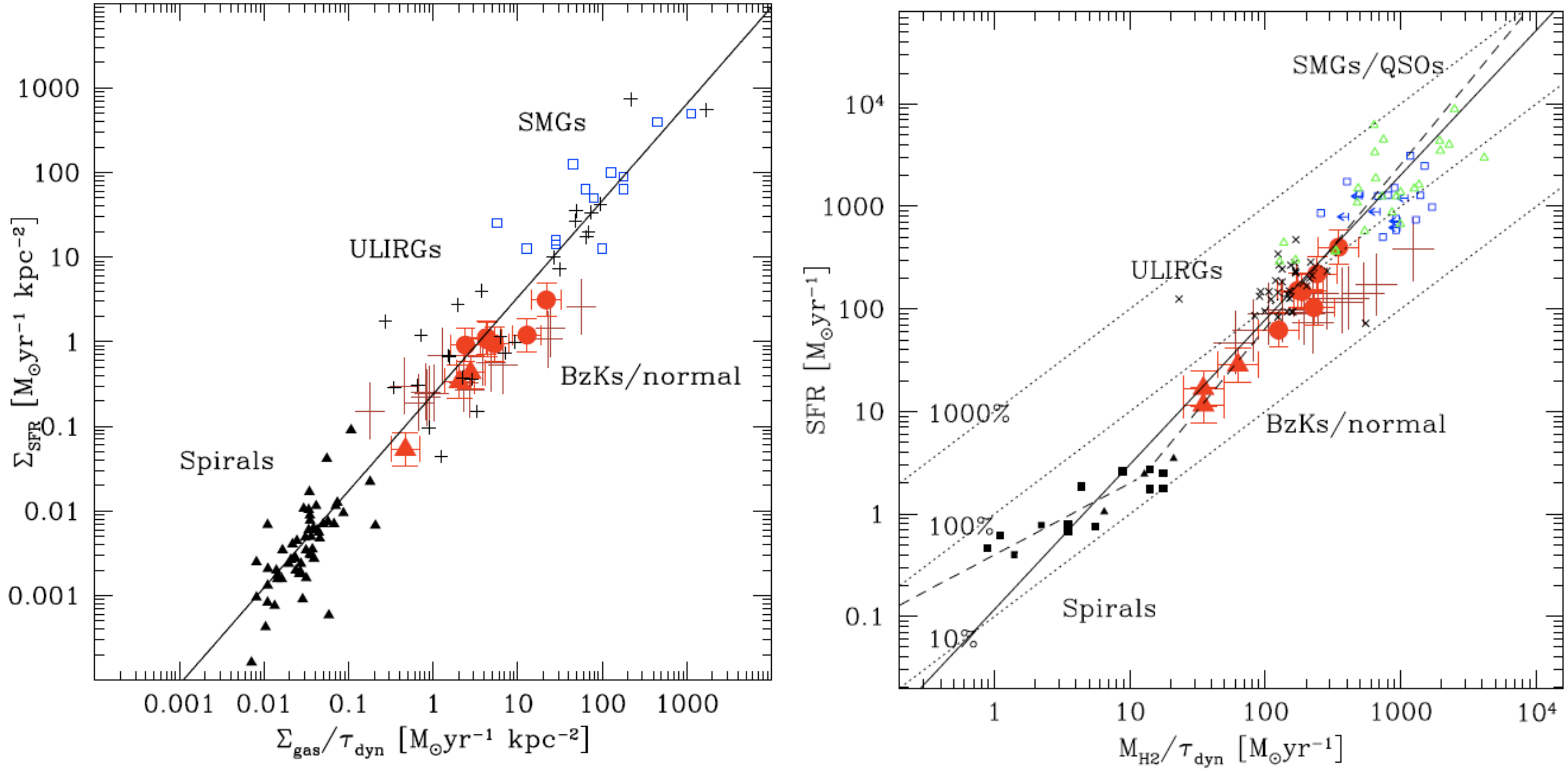


Normal (main sequence)
Galaxies behave very
Differently from SBs

BzKs have ~10 times lower
Sigma_SFR than
ULIRGs/SMGs

Daddi et al 2010b
see also Genzel et al 2010

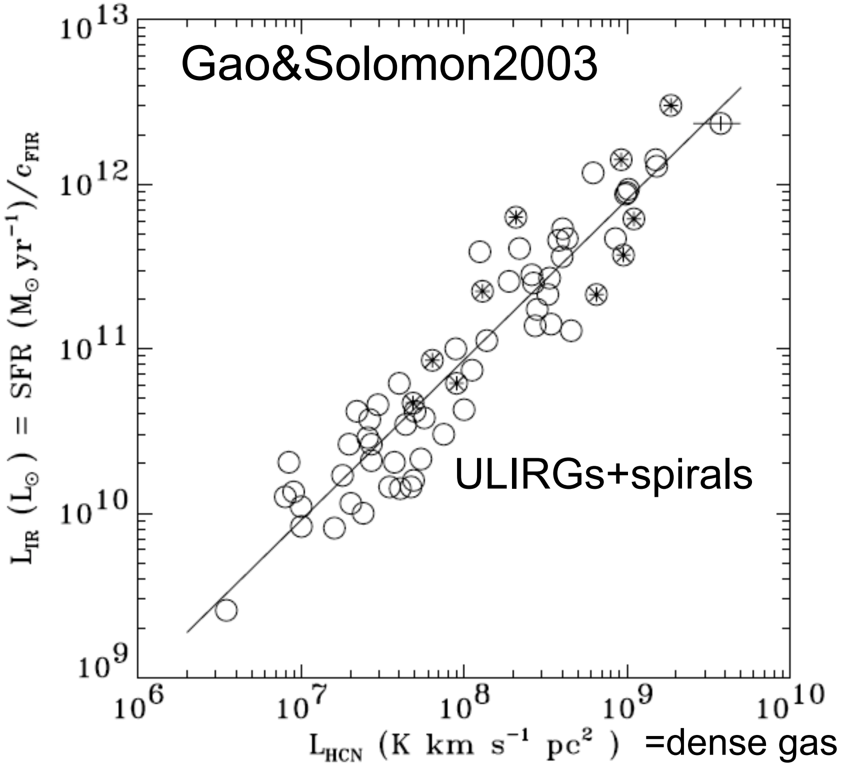
When considering the dynamical (rotation time)
Silk 97; Elmegreen 2002; Krumholz et al 2009; K98

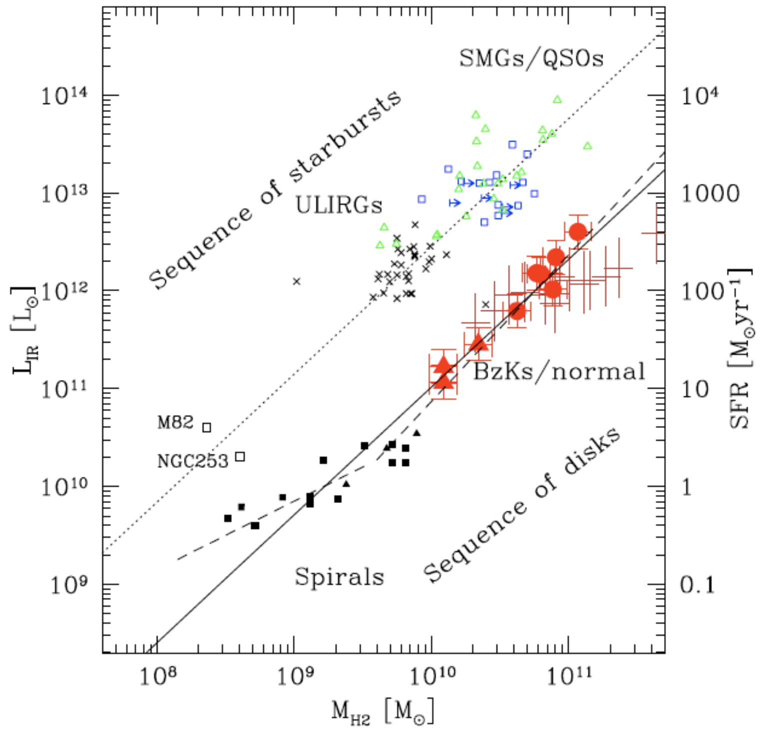


Both disks/starbursts fall back to a single law
→ tau_gas vs tau_dyn relation is unique

Krumholz et al → volumetric SF law must be used, including free fall time

The different ‘modes’ seem to relate to dense gas fraction (Daddi et al 2010b)





Bimodal trend for total H_2, single linear trend for most dense H_2

→Different behaviour for the fraction of dense gas in disks/SBs

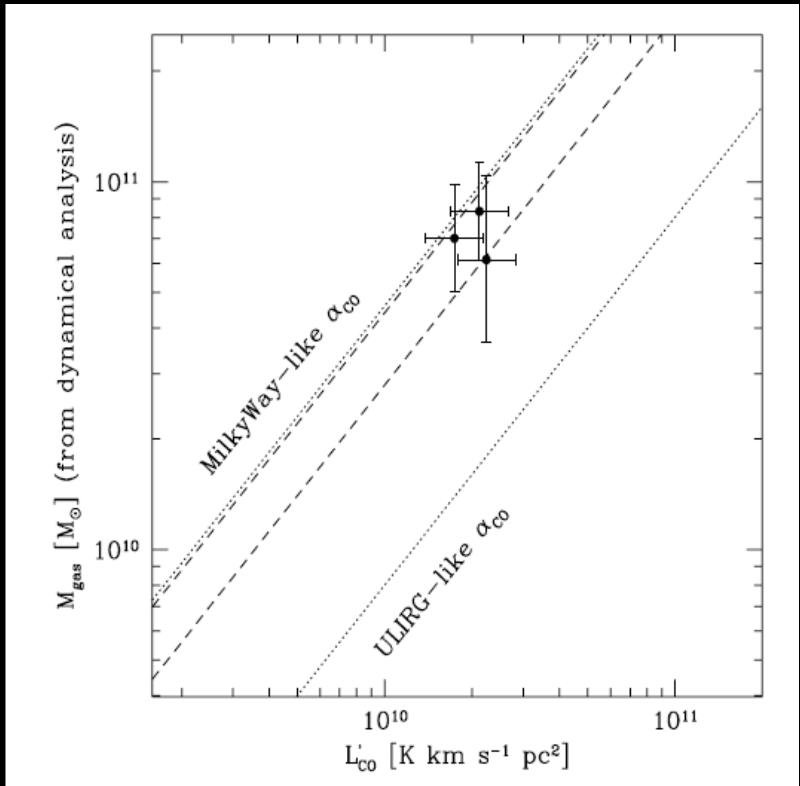
→ playing with IMF would leave at least 1 bimodality

Two important problems:

1) CO to H_2 conversion factors at high z. What they are ?
Different in SBs and MS galaxies ?
<u>This is totally fundamental for physical interpretation</u>
(are we fooling ourselves in believing z~2 galaxies are 50% gas)

2) Are SMGs all SBs (Engel/Tacconi et al) ? Or ~none (Dunlop et al) ?
Can we find starbursts at high-z to study this bimodality ?

High α_{CO} conversion factor (3.6 +- 0.8)
(assuming 25% of dark matter)



To get back to '0.8' (ULIRGs value)

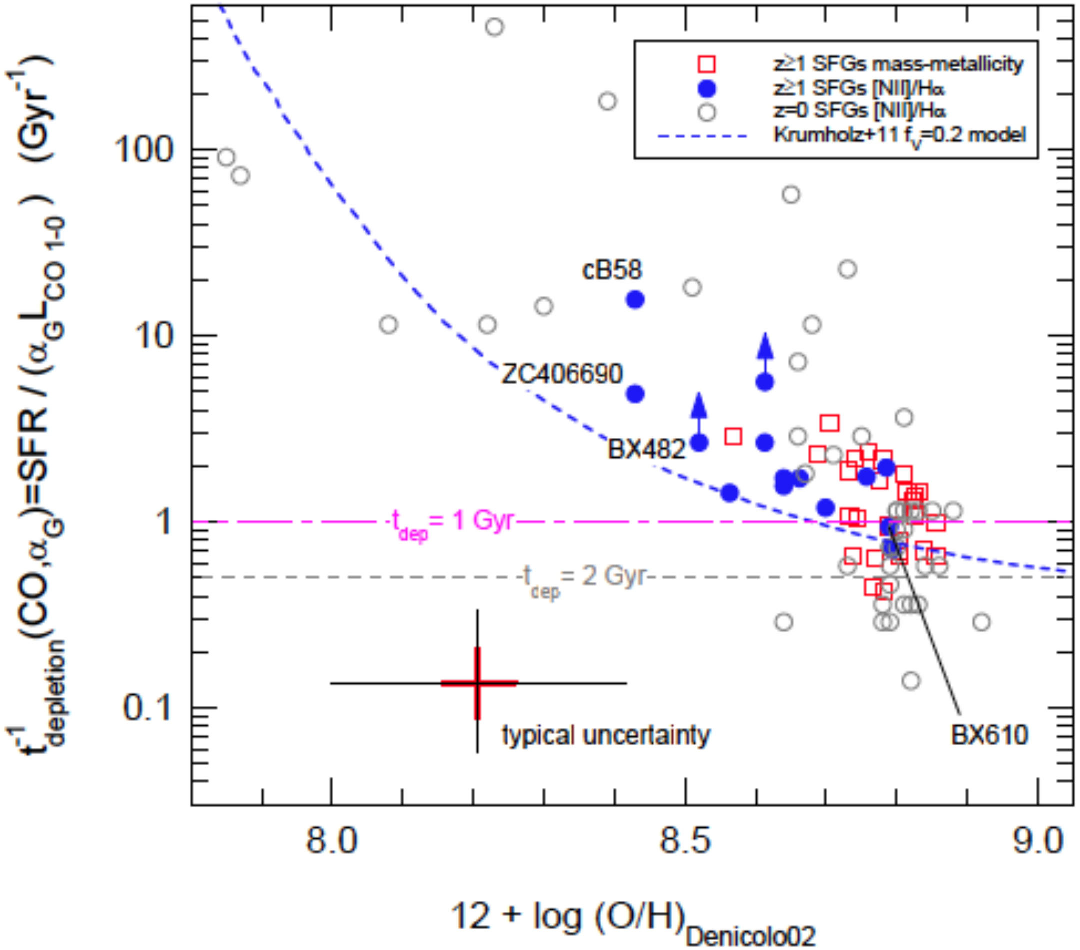
- Dark matter ~60%
- M_{stars} x3 larger
- 'Bournaud' factor down to 0.7 (1.3) (i.e., velocity overest.)

Daddi et al 2010

Based on Bournaud et al 2007 clumpy disk models
See also Narayanan et al results from theory

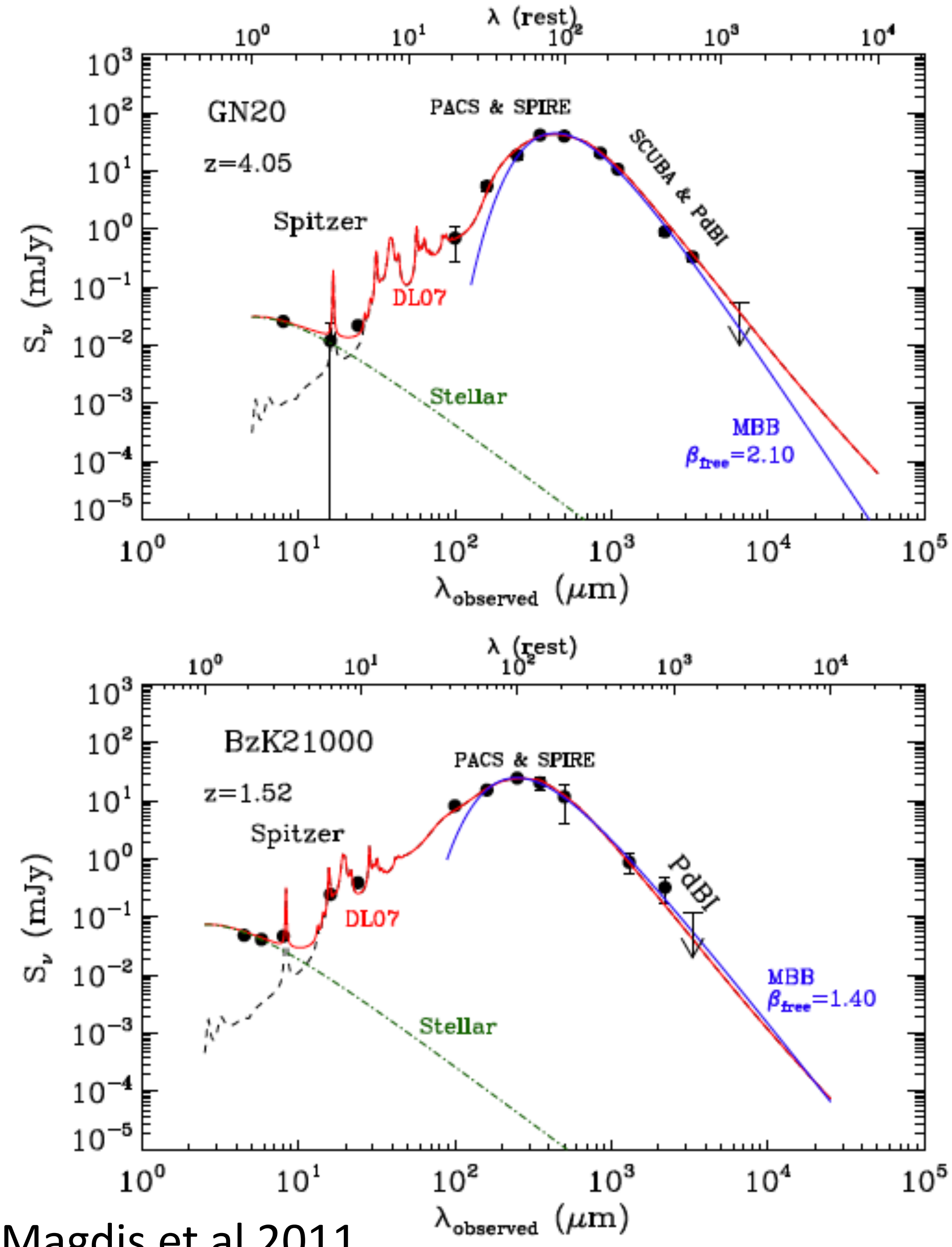
SFR/L'CO scales with metallicity as in local galaxies

Genzel et al 2011



Supports idea that alpha_CO Scales with metallicity as in Local galaxies.

But tells nothing about the normalization



Magdis et al 2011

A way to constrain a_CO in the local Universe is through Mdust measurement (and prior knowledge of what Dust/Gas should be)

We had lots of IRAM observations to look at multiple CO transitions, and continuum as a byproduct (hard and expensive to get)

→ This will change dramatically with ALMA

Modeling approach:

- Full suite of Draine and Lee 2007 Models
- MBB with free T and beta

Notice the quality of the HGOODS photometry: beating confusion at 250um

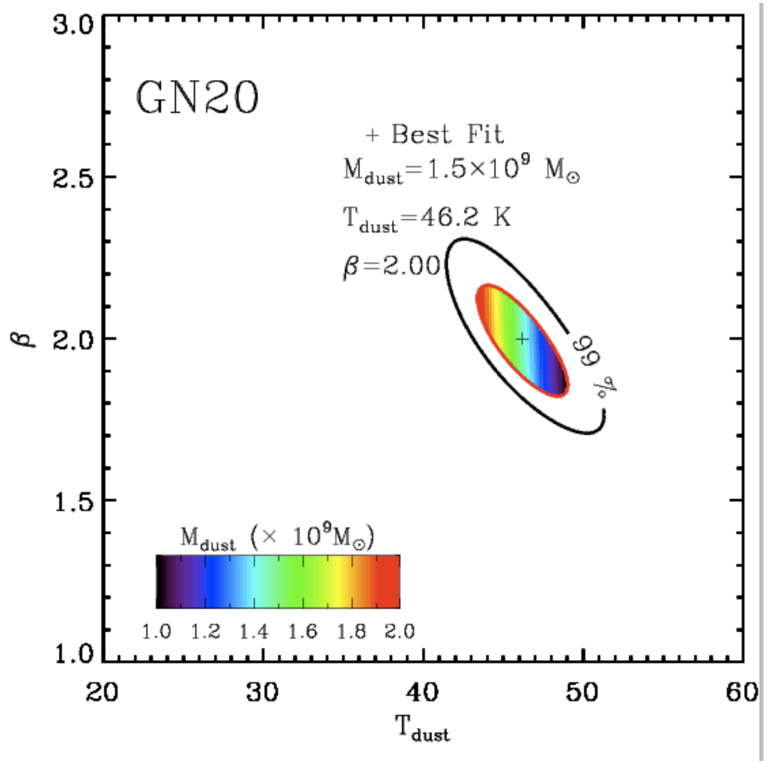
Table 1
Summary of *Herschel* and (sub)mm Data

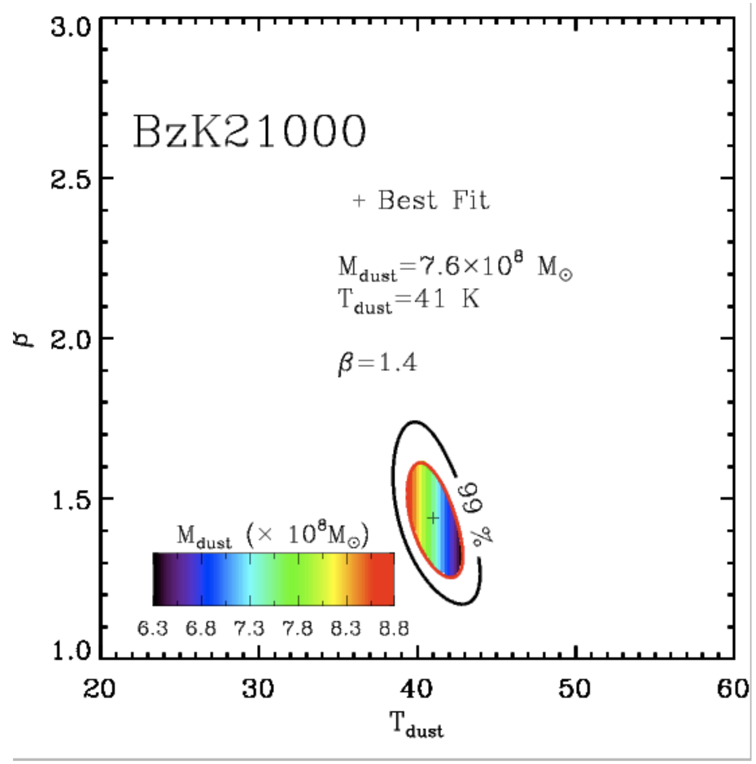
λ (μm)	GN20 (mJy)	BzK-21000 (mJy)
100	0.7 ± 0.4[1]	8.1 ± 0.6[1]
160	5.4 ± 1.0[1]	15.1 ± 1.4[1]
250	18.6 ± 2.7[1]	24.4 ± 1.5[1]
350	41.3 ± 5.2[1]	20.1 ± 4.7[1]
500	39.7 ± 6.1[1]	11.6 ± 7.4[1]
850	20.3 ± 2.0[2]	...
1100	10.7 ± 1.0[3]	...
1300	...	0.87 ± 0.32[4]
2200	0.90 ± 0.15[5]	0.32 ± 0.15[6]
3300	0.33 ± 0.06[7]	0.04 ± 0.06[7]
6600	-0.01 ± 0.018[8]	...

Magdis et al 2011

Parameter constraints from MBB models

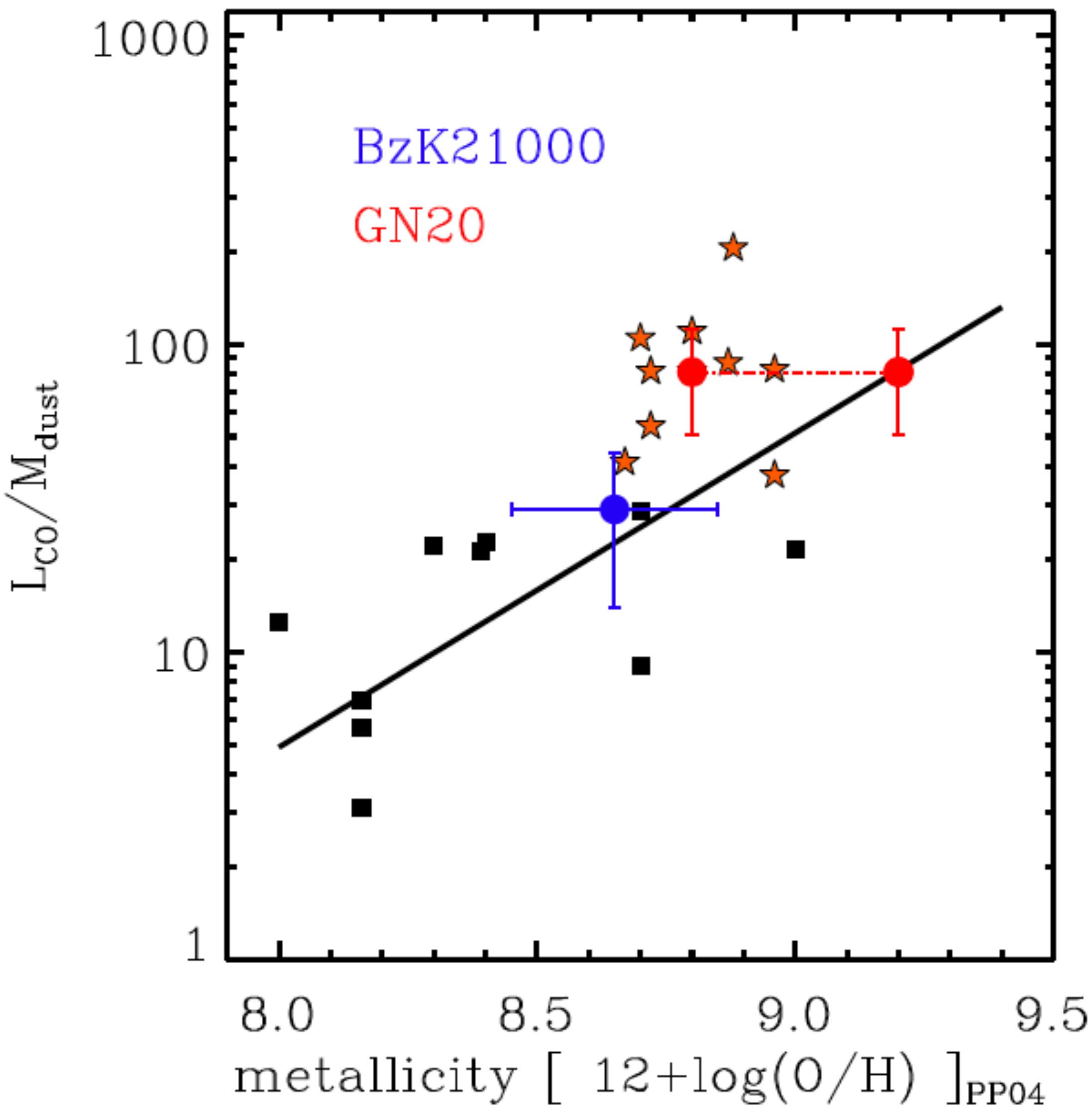
Magdis et al 2011





<u>Different beta for MS vs starbursts</u> ? Consistent with Elbaz et al 2011

Got Mdust → compare to other observables

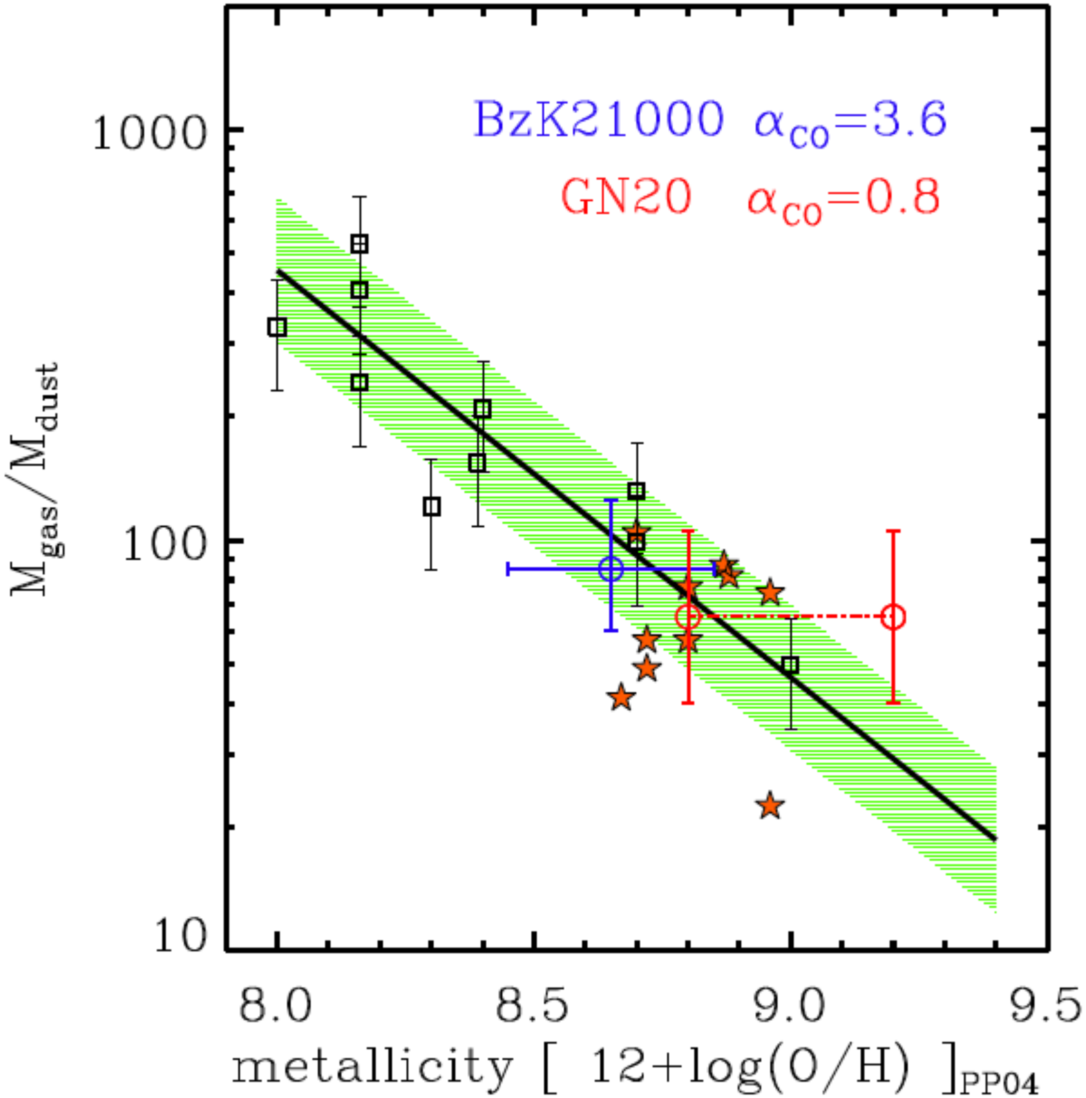


LCO/Mdust segregates
As in local galaxies

LIR/Mdust does the same

Magdis et al 2011

Using the standard assumption for alpha_CO → they lie on the G/D relation

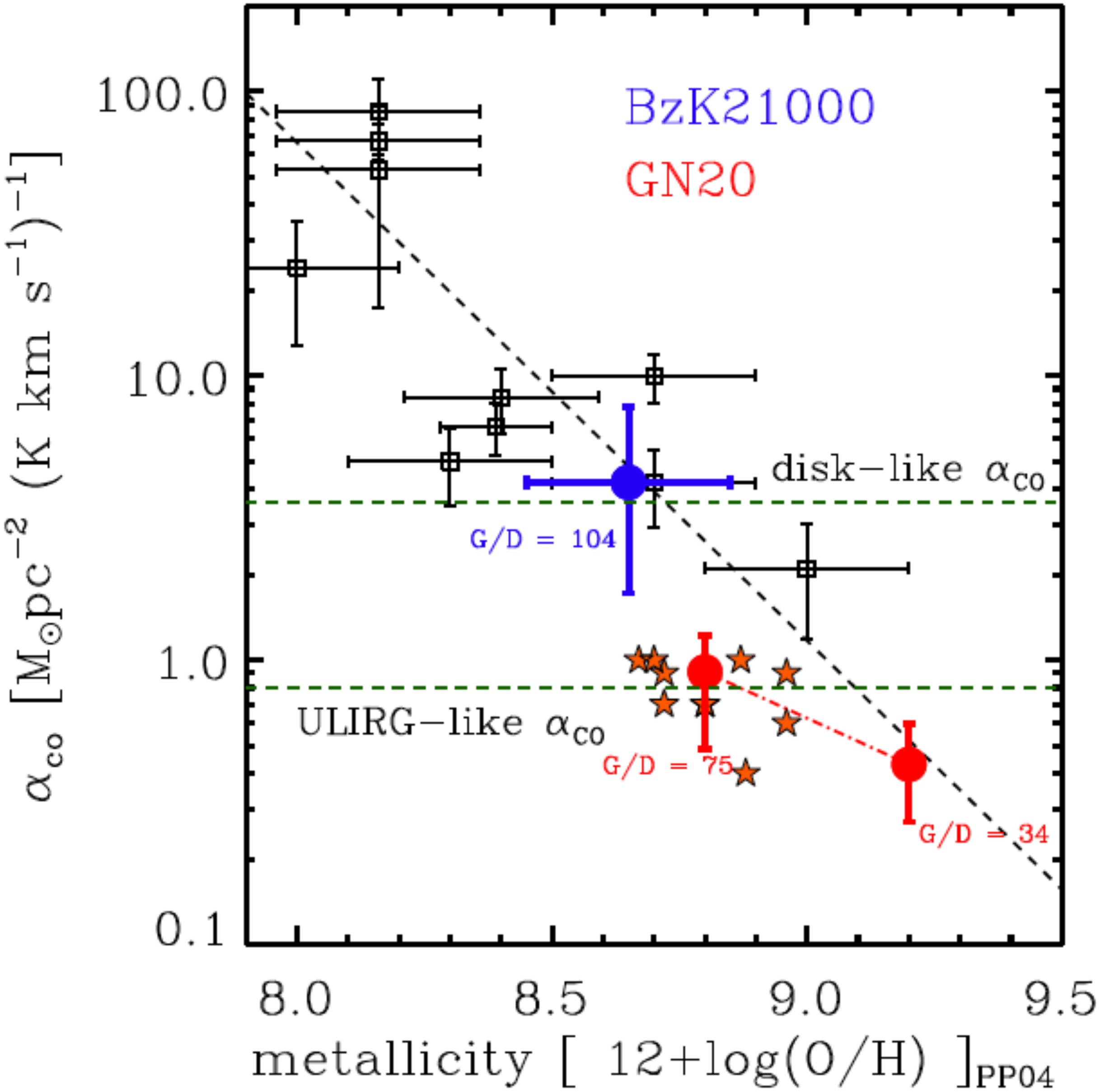


Local group spirals
(Leroy et al 2010)

ULIRGs
(Downes and Solomon 1998)

Magdis et al 2011

Trusting the G/D trend → get estimates for alpha_CO



Notice that it is very hard
To overestimate much Mgas
Hence alpha_CO
Because G/D > 1/Z

And the local relation has
G/D~2/Z

GN20 vs BzK21000 → normal vs starburst

Systematic difference in Mdust/LCO, Mdust/LIR
(similar Mdust/Mstar as expected, see da Cunha et al 2010)

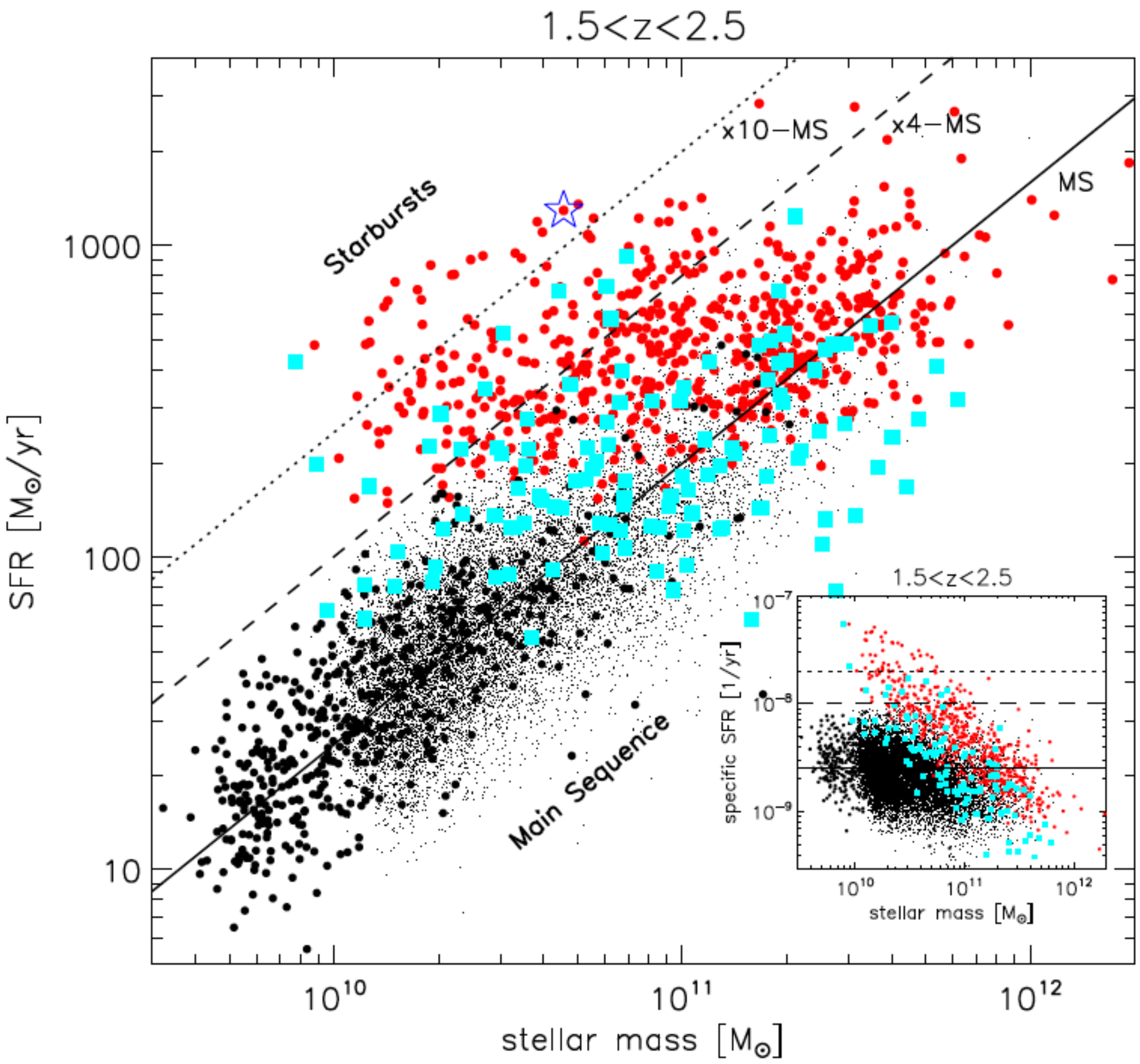
→ High sSFR in GN20 because SFR has been 'enhanced' (merger ?)

From D/G ratios trends → get alpha_CO much different in the two
→ Higher SFE=SFR/Mgas in GN20 by 5-10 (and prop shorter t_gas)
→ Confirm the much different locations in the KS plane

Of course, we would like to do this with >>2 galaxies

A few more are becoming available (IRAM/EVLA?).
Alma will probably change this field too

What is the statistical importance of SB galaxies ? Typical answer: ~50%



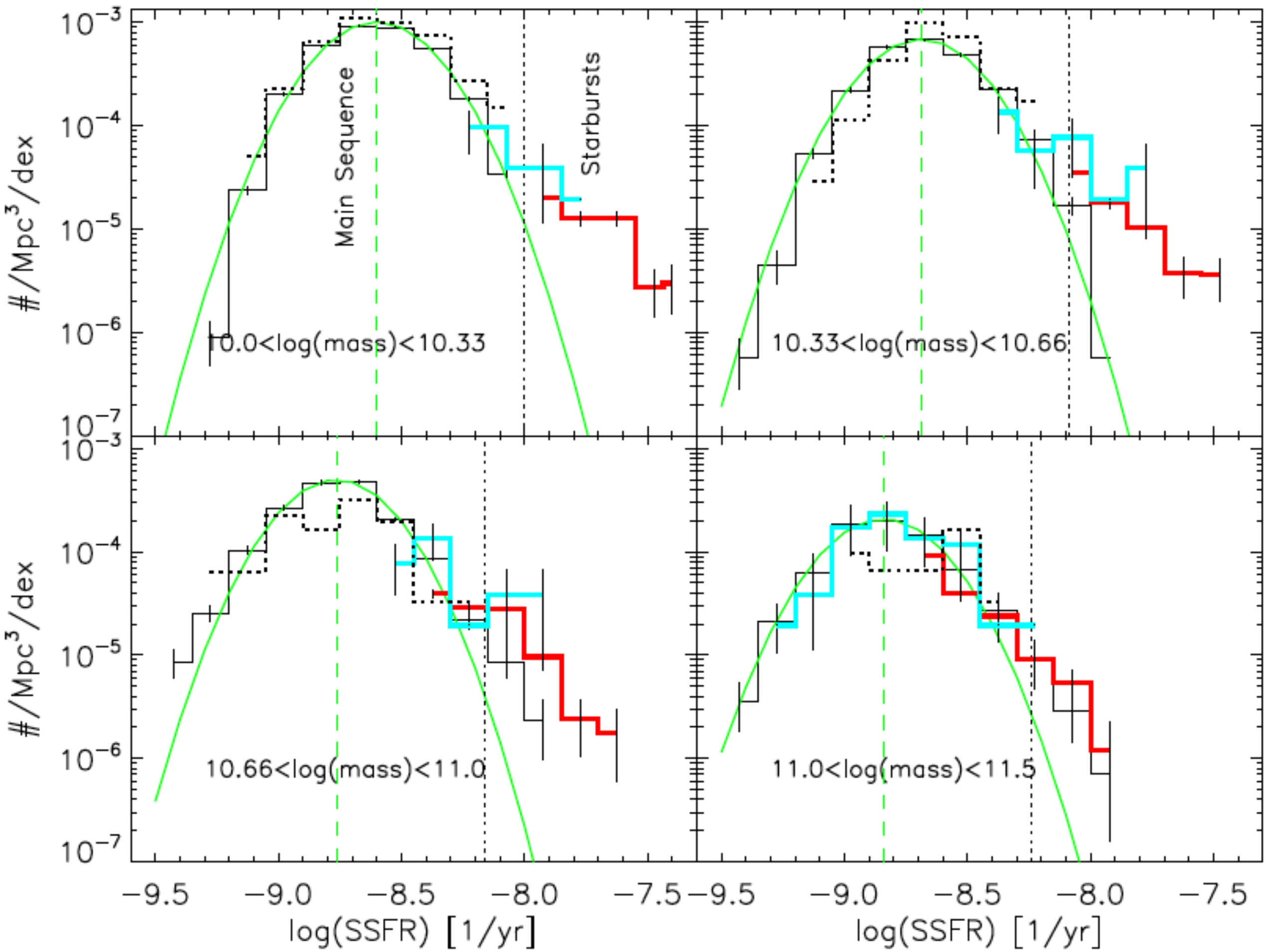
COSMOS PACS data
From PEP
(and also GOODS-S)

Near-IR galaxies
From BzK samples,
UV-corrected SFRs

Rodighiero et al. 2011

(beware, Salpeter IMF
Here)

No main sequence see if using Herschel data alone (SFR-selection)



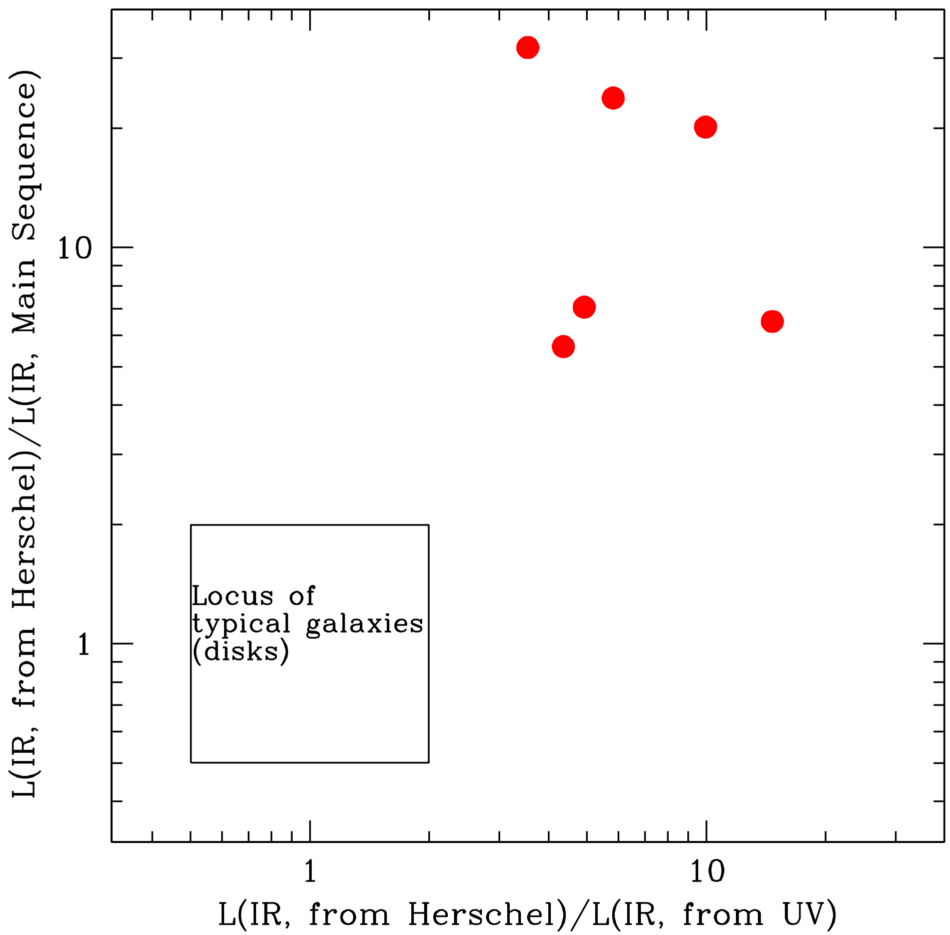
Notice very good agreement between UV and Herschel at the high mass bin

Threshold between MS and SB is objectively defined: 0.6 dex (2.5 sigma of the distribution)
Notice that SBs will be present also below the threshold, but becoming overwhelmed by Normal galaxies. Also, they would be objects with minor modification of their SFRs

SB: objects with SFR enhanced on average by x4 over what they should heve, given M*

MS outliers: are they mergers ?

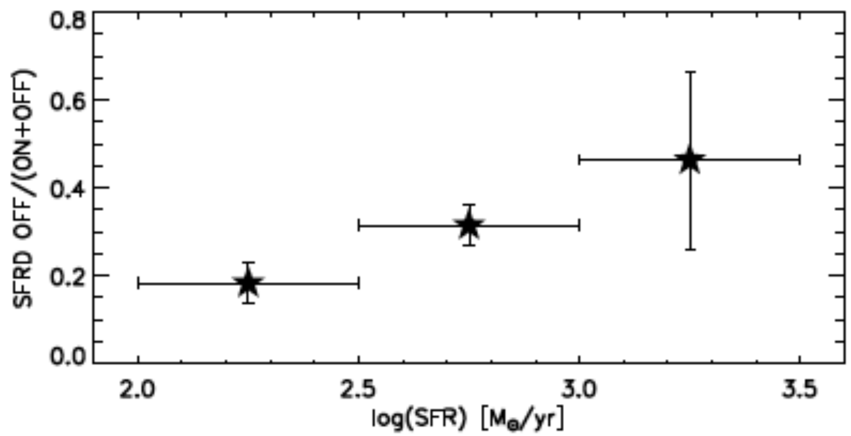
HGOODS objects with sSFR x4 excess and measured zspec



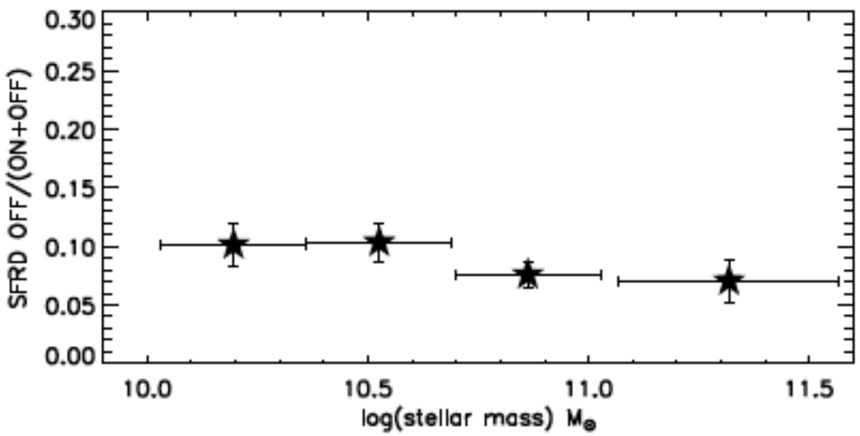
For all cases the UV SFR fails (optically thick)

UV underestimate similar to excess sSFR

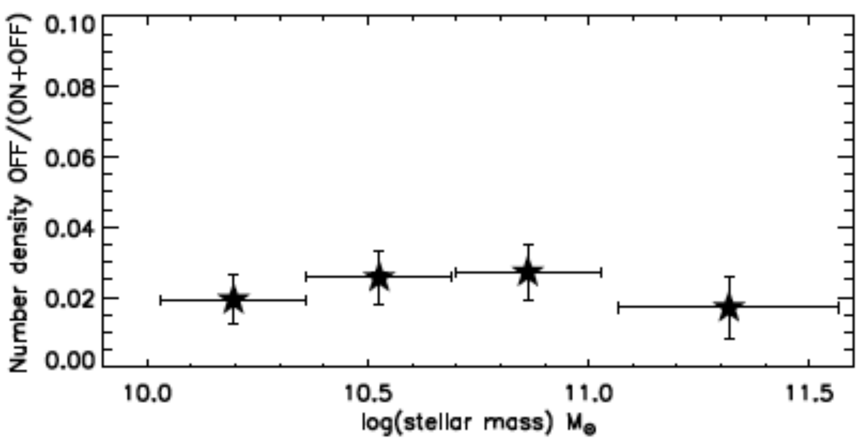
Most likely they are indeed 'Dense' mergers



FIR selection (dust)
→ SMGs/Herschel galaxies are mixed bags (might explain similarities sometimes found with BzKs e.g. in excitation, SFE)
→ Need different approach tu build appropriate sample of starbursts



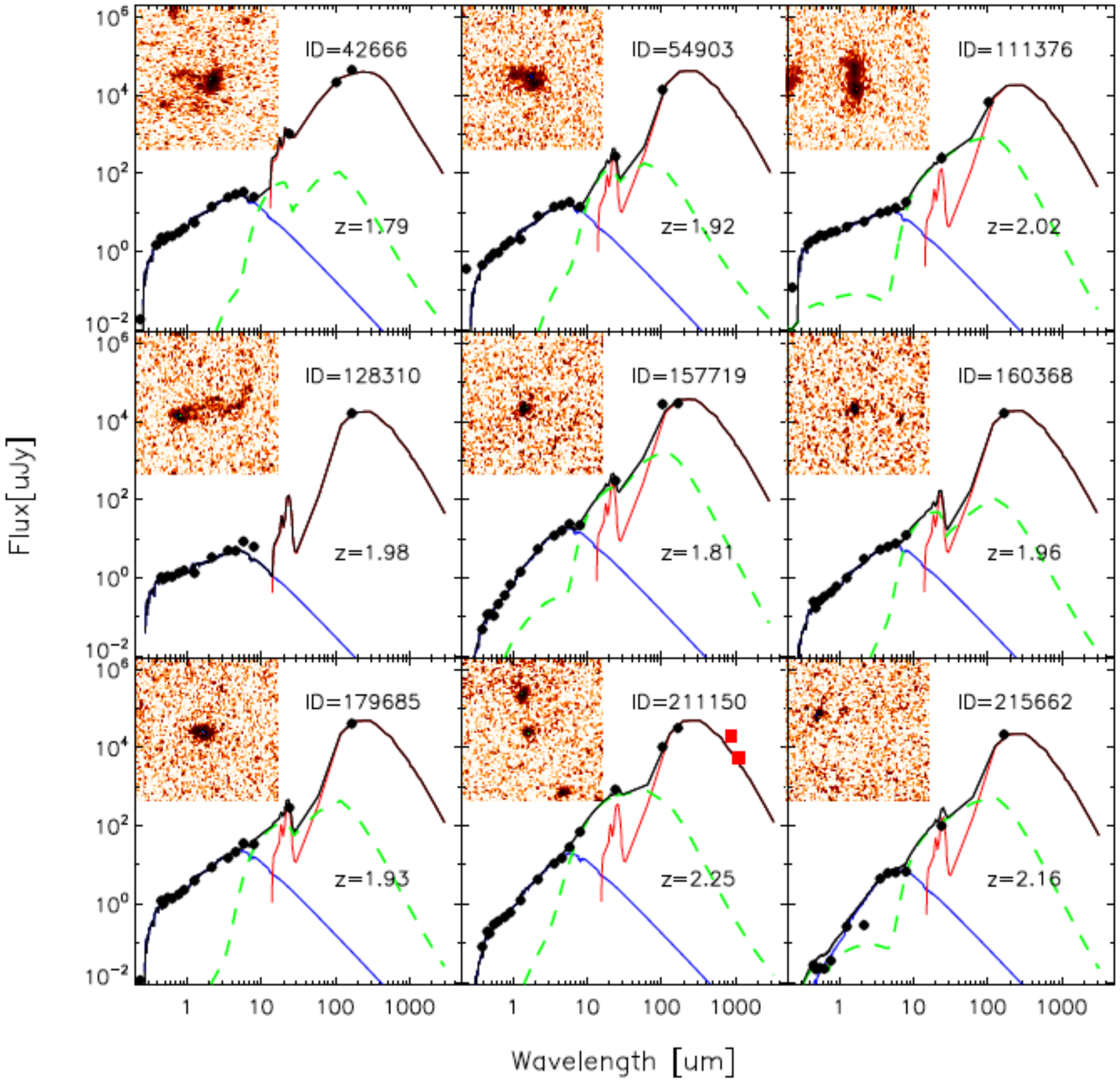
SFRD contribution of SBs only ~10% (mergers not so important for star form.)



Near-IR selection (stars)
→ You must be very (un)lucky to pick up a SBs there (2% chance)

SB duty cycle ~20Myr
Much shorter than ~200Myr typical merger duration (refer only to SFR nnhancement >4)

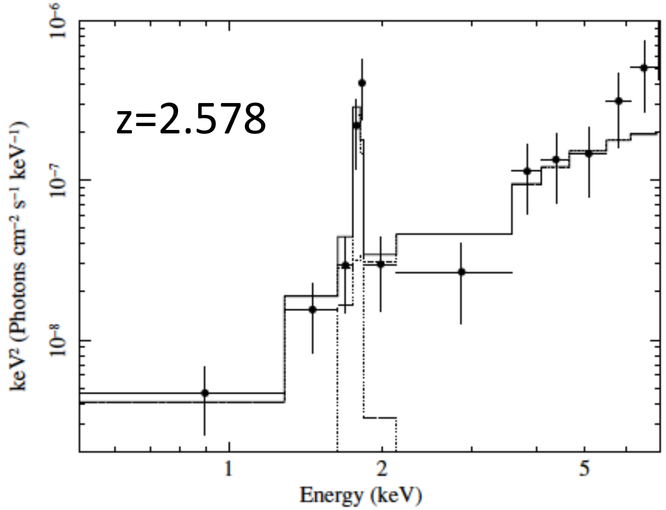
Connection between SBs and obscured AGN activities ?



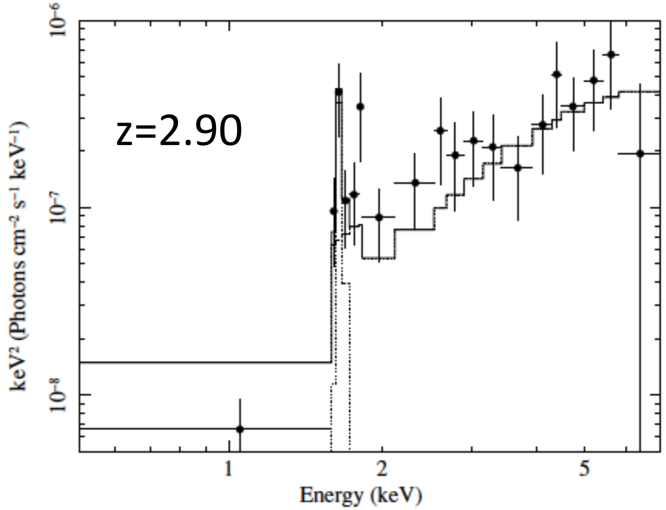
Vast majority of off-MS
Require powerful AGN
Components to reproduce
Their FIR SEDs

Very little evidence for X-rays
→ High obscuration

Two BzK galaxies with FeK emission in the X-ray from Chandra (Feruglio et al. 2011)
Best case of individual Compton thick AGN at high redshift to date



BzK8608 z=2.9



sSFR is high: off MS galaxies

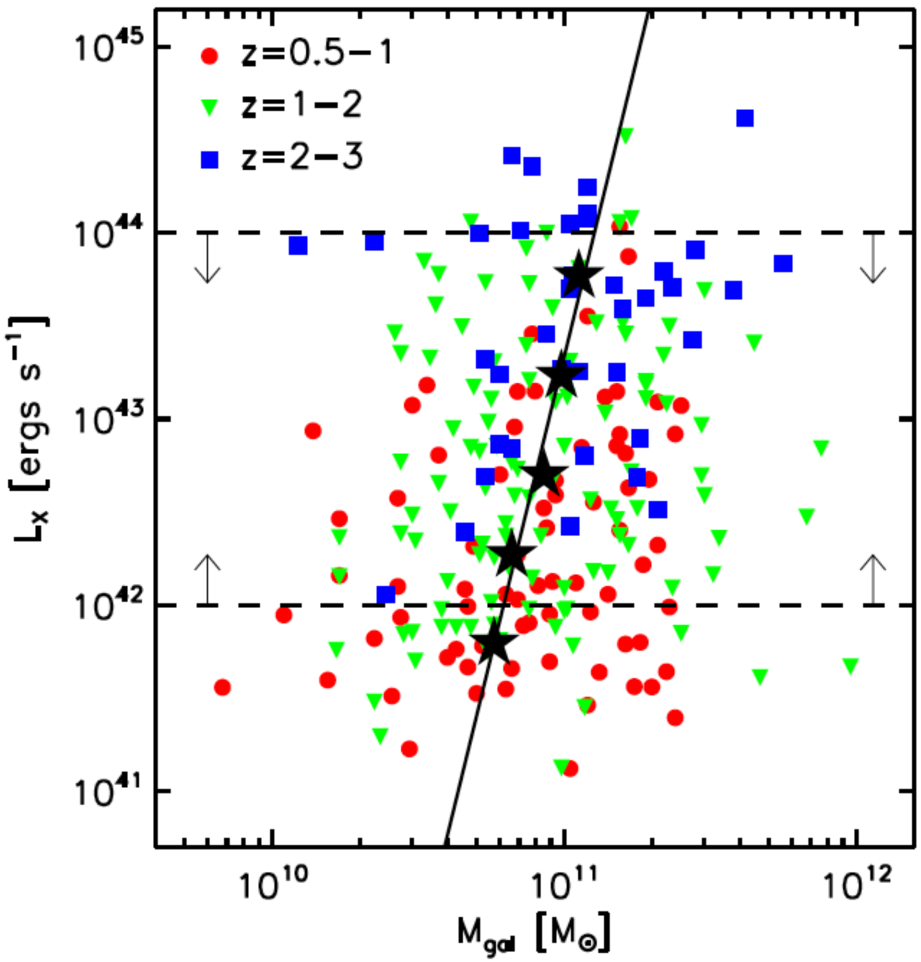
2 complementary ways to look at the
Same thing:

SBs have obscured AGNs lurking inside,
and most obscured AGNs tend to be in SB

Fits well in the BH-merger connection
Scenario (e.g., Sanders et al 1988, Hopkins
Et al 2005)

Mullaney et al. 2011

Very weak correlation between Lx and Mstar for X-ray AGNs



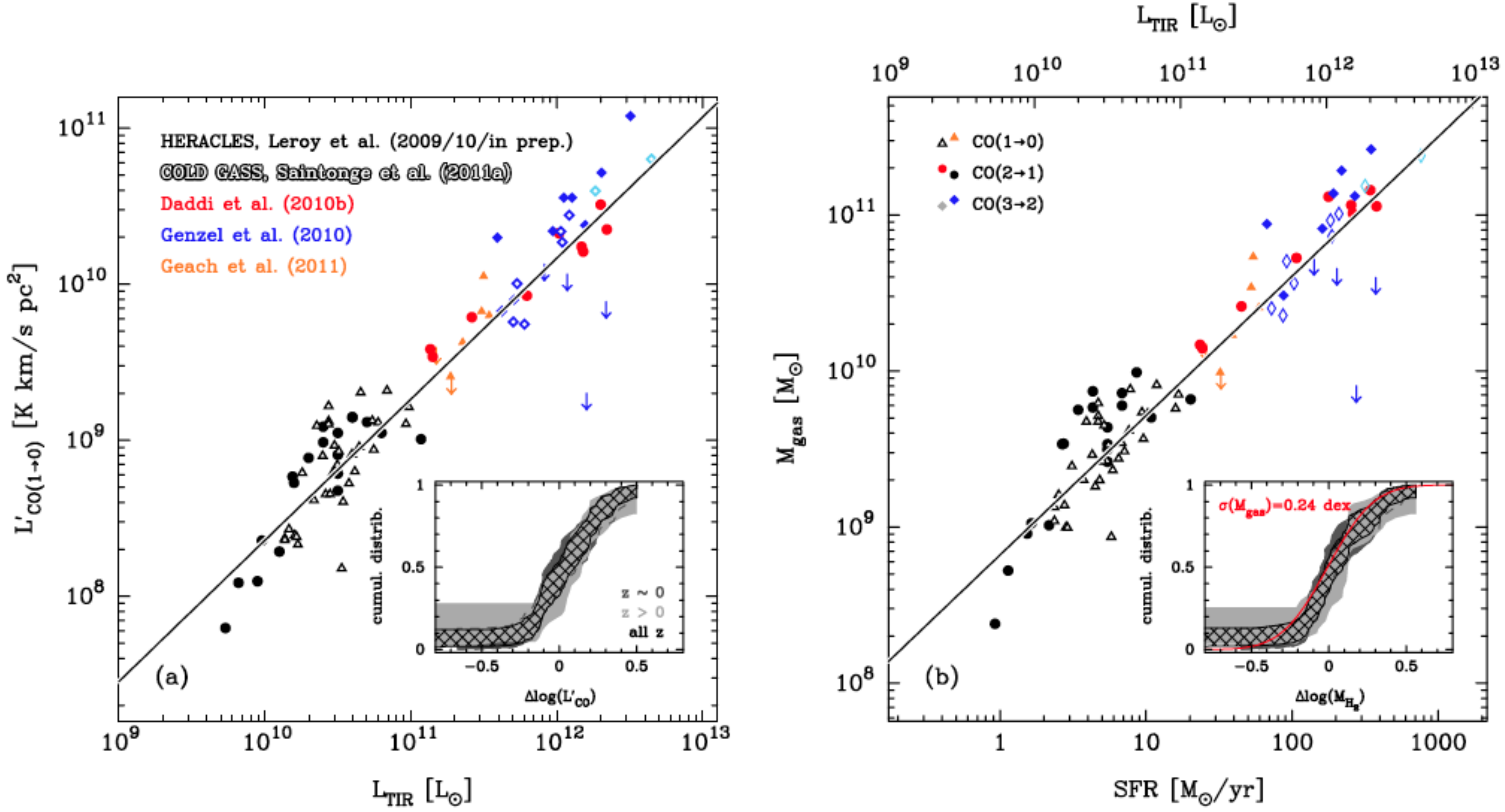
Consistent with poor dependence of AGN clustering with Lx

But problematic:

Lx → BH accretion rate ?
Mstar → M_BH ?

And the 2 things don't talk to each other ?

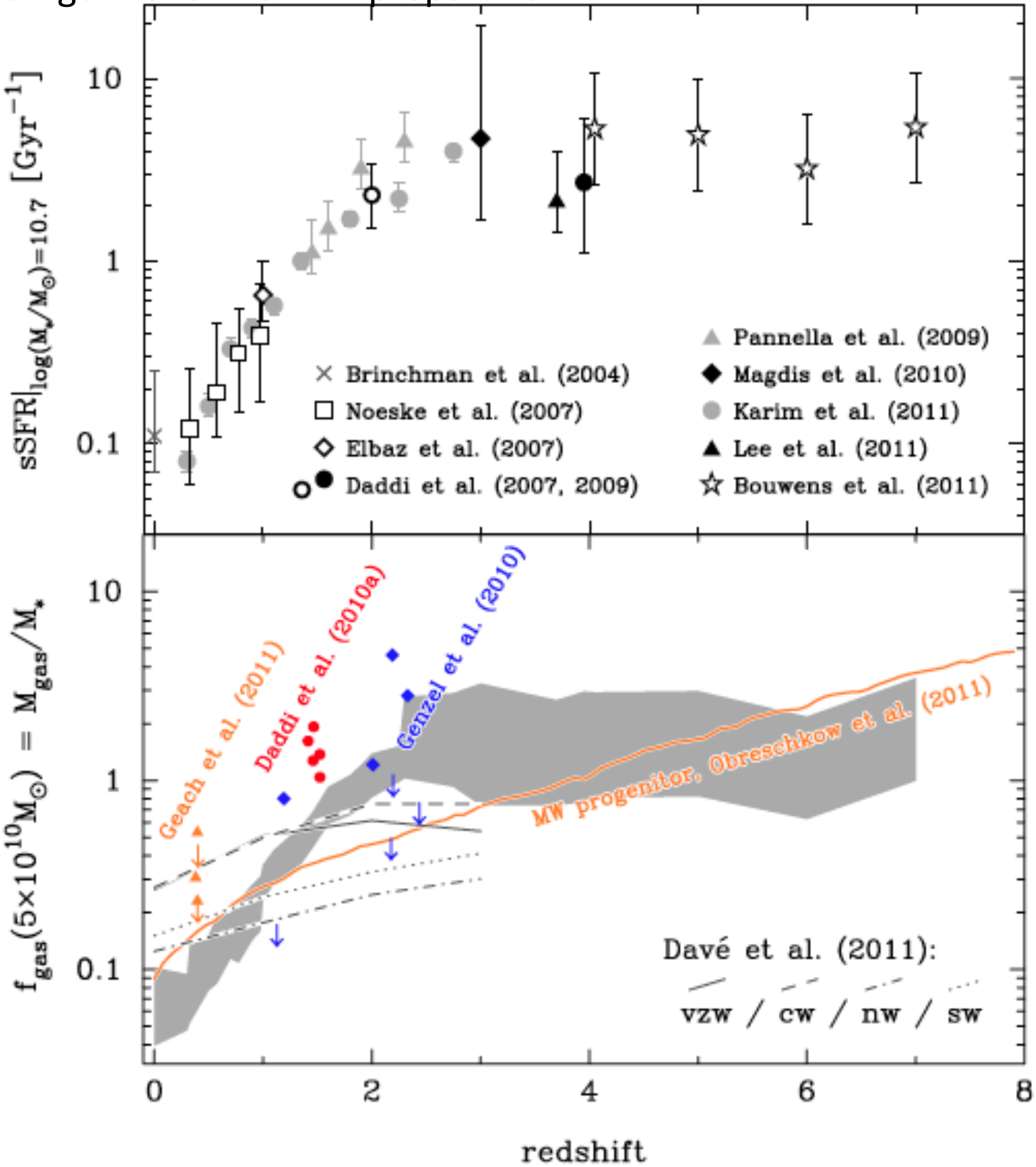
Sargent et al. 2011 in preparation



Remarkable correlation between SFR and L'CO/Mgas (0.2 dex scatter)

Slightly non linear, log slope of ~1.1--1.2

Sargent et al. 2011 in preparation



Rise of sSFR from z=0 to 2
And then plateau to z~8 ?

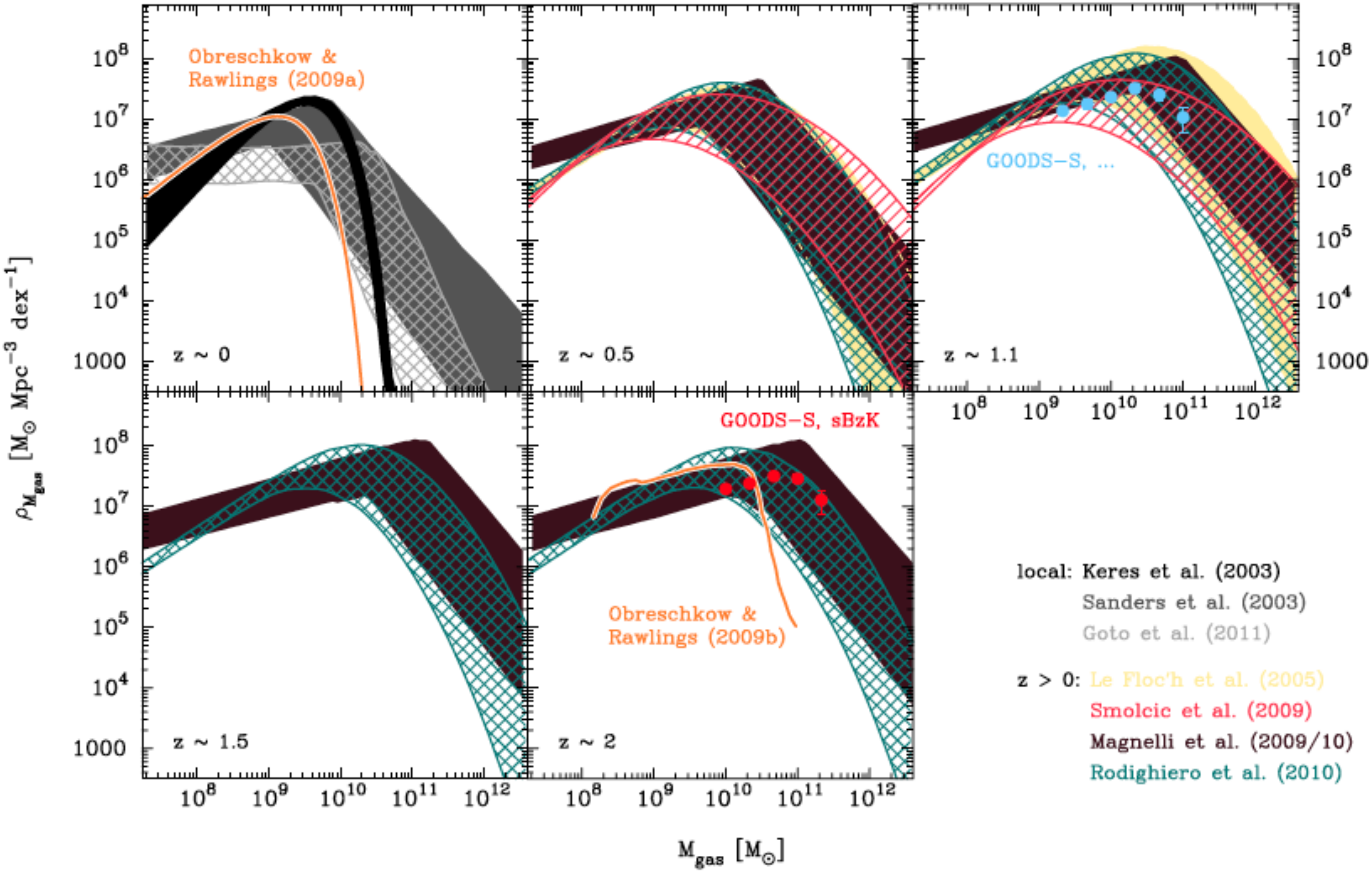
→ Maps directly in the
Evolution of the gas fraction
(or M_H2/Mstar)

Constant ~50% gas fraction
To z=8 ???

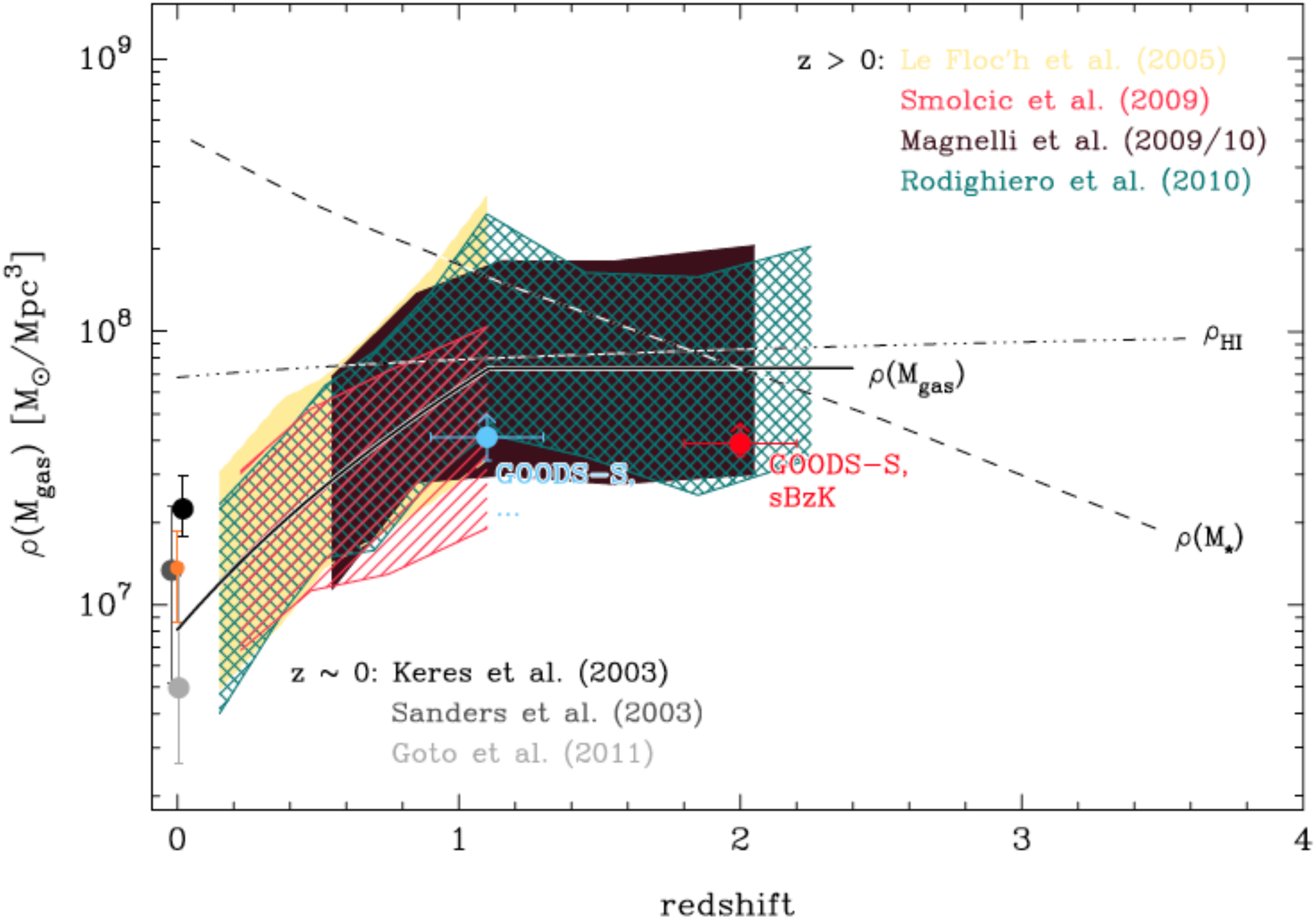
Problem for models, where
Gas accretion rates rise fast
from z=2 to z=8
(e.g., Krumholz & Dekel 2011,
Dave et al 2011)

Very interesting z>>2
observing frontier, we need
direct measurements

Sargent et al. 2011 in preparation



Sargent et al. 2011 in preparation



Conclusions:

- When observing IR galaxies it is crucial to know if you are observing
a normal galaxy or a merger/starburst, to interpret the observables in term of physical properties

- SMGs and/or luminous Herschel galaxies are mixed bags of disks/SBs
- Near-IR/optical galaxies are almost all main sequence

- Herschel+mm (IRAM/ALMA) very powerful Mdust machine
- Mdust, T/beta, alpha_CO seem to believe as reasonably expected
(differences substantial between MS and SBs)
- Very little SFRD in the MS outliers ~10% (not an important mode
for the built up of stars)

- Mgas extrapolations: big rise of cosmic H2 density to z=1, flat afterwards
(problematic for gas accretion understanding, need confirmation)

Reliable normal galaxy vs starbursts indicators:

- sSFR vs z (main sequence vs outliers)
- SFR/Mgas (hard to directly measure!)
- IR8 (sed shape)
- UV optical thickness

Promising indicators

- Mdust/LIR ?
- Beta (far-IR/submm SED shape) ?
- Morphology ?
- Compactness/sizes ?
- CO excitation ratios ?
- LIR/LCO ?