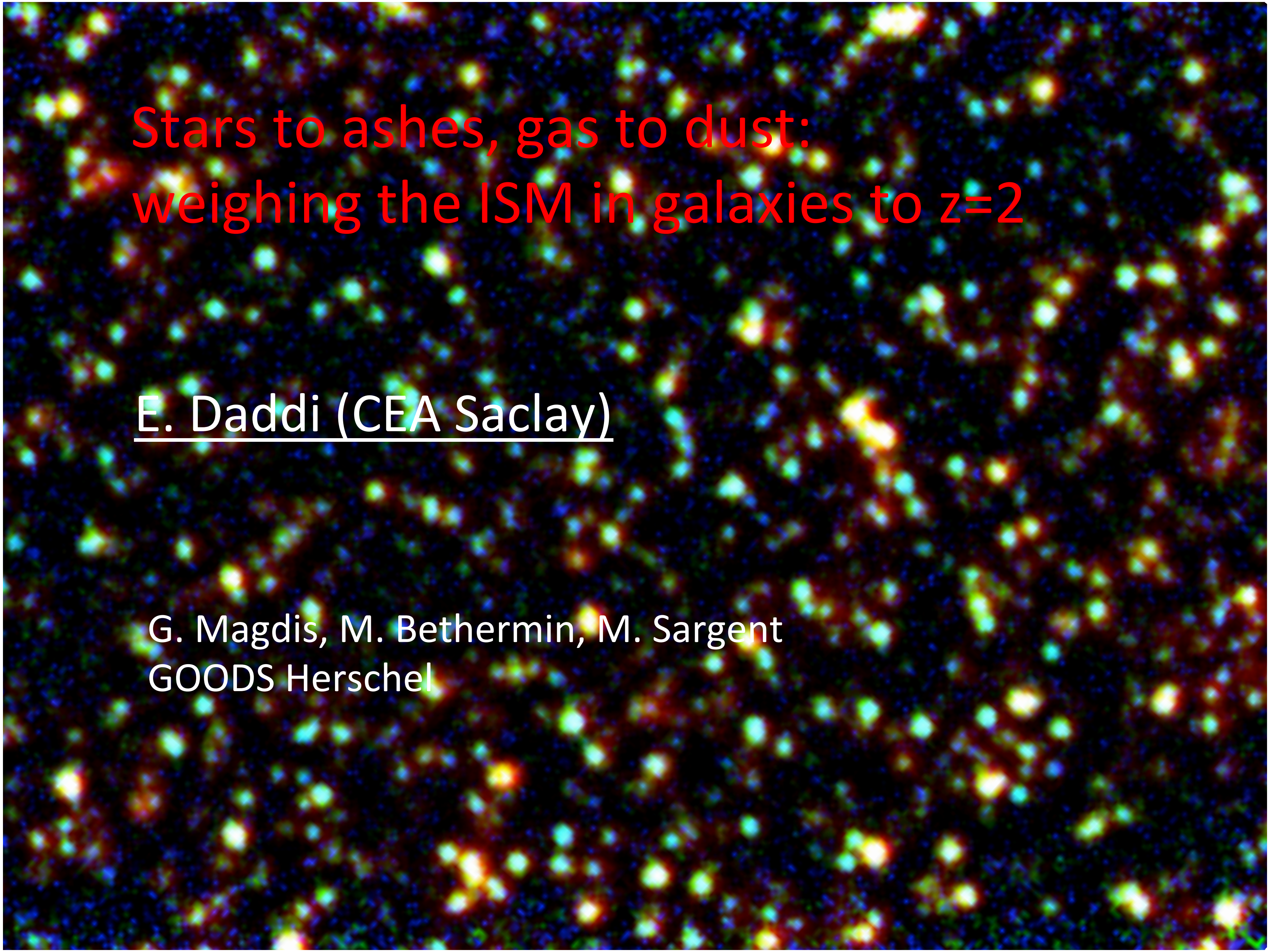


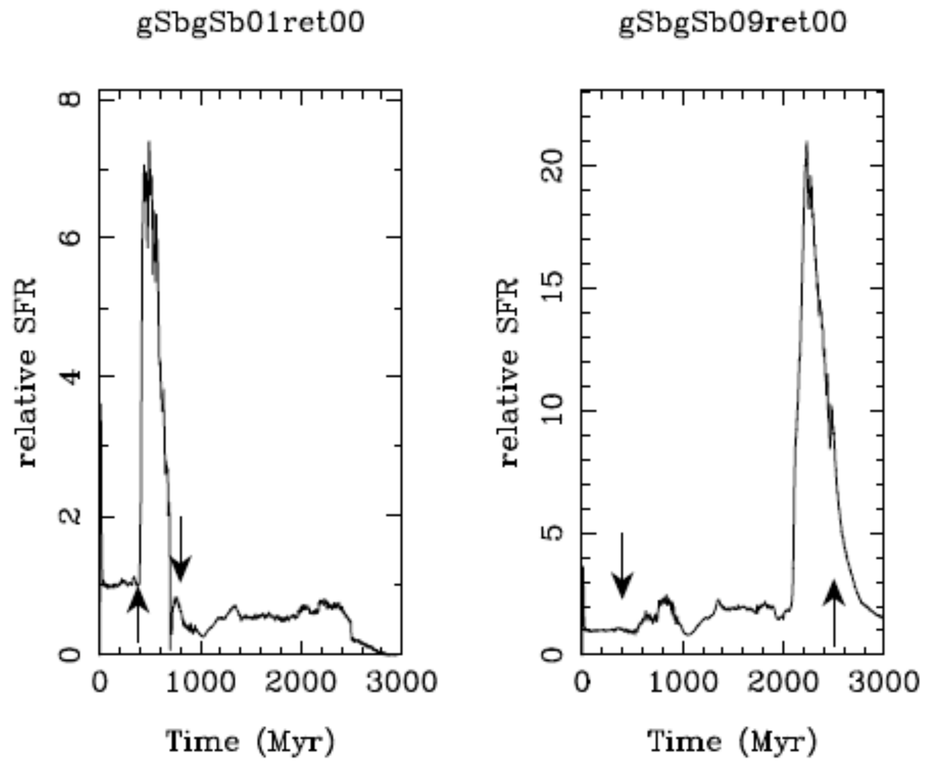
Stars to ashes, gas to dust: weighing the ISM in galaxies to z=2

E. Daddi (CEA Saclay)

G. Magdis, M. Bethermin, M. Sargent
GOODS Herschel

Framework: there are 2 'major' SF modes for galaxy buildup: a 'secular'/' normal' and a 'starburst'

Definition (operational): starburst are the 'excess SFR'
high-gas-density phase that *can* happen during mergers (or other events)



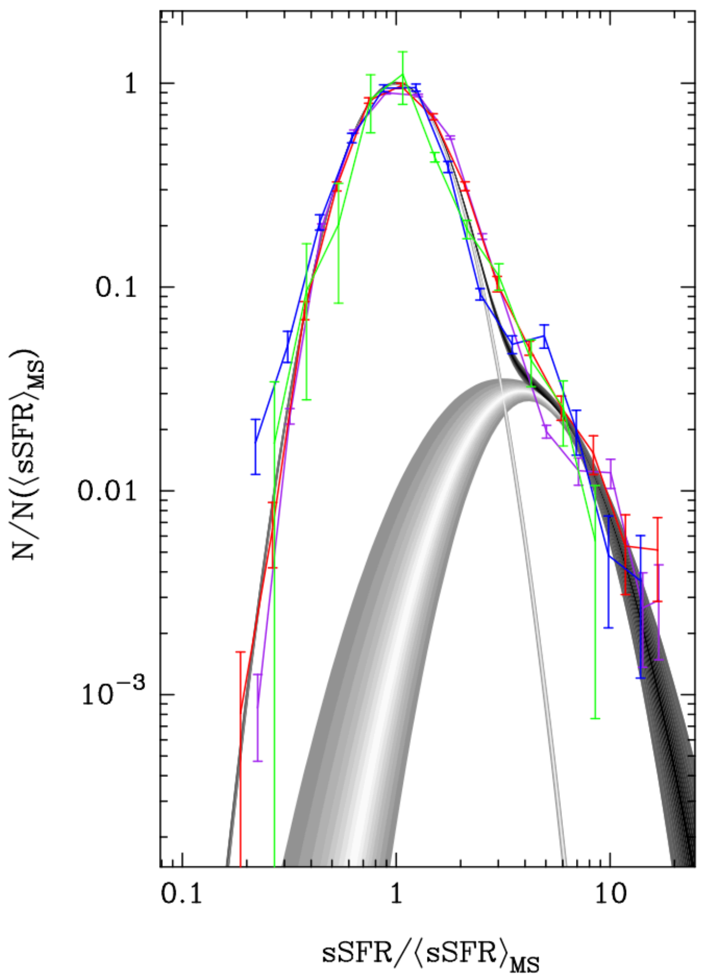
Di Matteo et al 2008
Martig & Bournaud 2008
(Mihos & Hernquist 90's)

SFR can be enhanced rapidly while
M* and Mgas unaffected
→ sSFR = SFR/M* excess
→ SFE = SFR/Mgas excess
Because of the tightness of the MS,
hope to use this as selection tool

- But does not happen in all mergers → presence of merger doesn't mean SF is affected
(crucial point; to be kept in mind with morphological/kinematics analyses)
- Even in mergers excess phase is short → rare population
(dominate high L tail because of exponential shape of MF)

(Main sequence + starburst) decomposition

Sargent et al 2012



Why double gaussian ?
Merger as a Transfer function
(in any case, left side of both gaussians has little impact)

Main Gaussian shifts with z but FWHM~const
SB contrib less constrained (but is a 'correction')

→ **Two SF mode paradigm**

SB/merger gaussian contributes only
10-15% of SFRD at z=2
~2-4% in number

And likely somewhat lower z=0

Histogram based on Rodighiero et al 2011
Herschel work

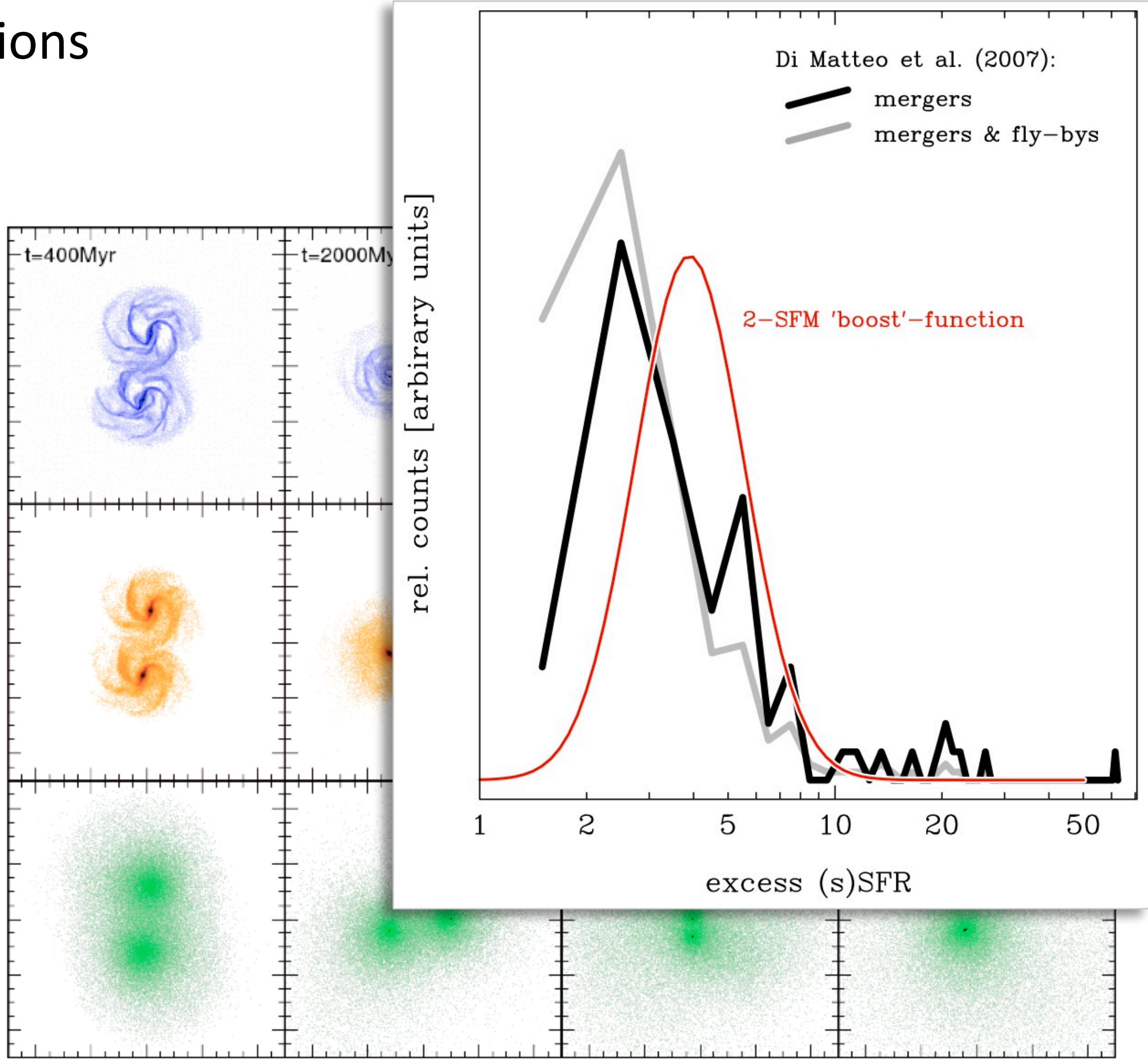
Merger-simulations

Di Matteo+ ’07:
retrograde merger
of 2 Sbc galaxies

gas ➽

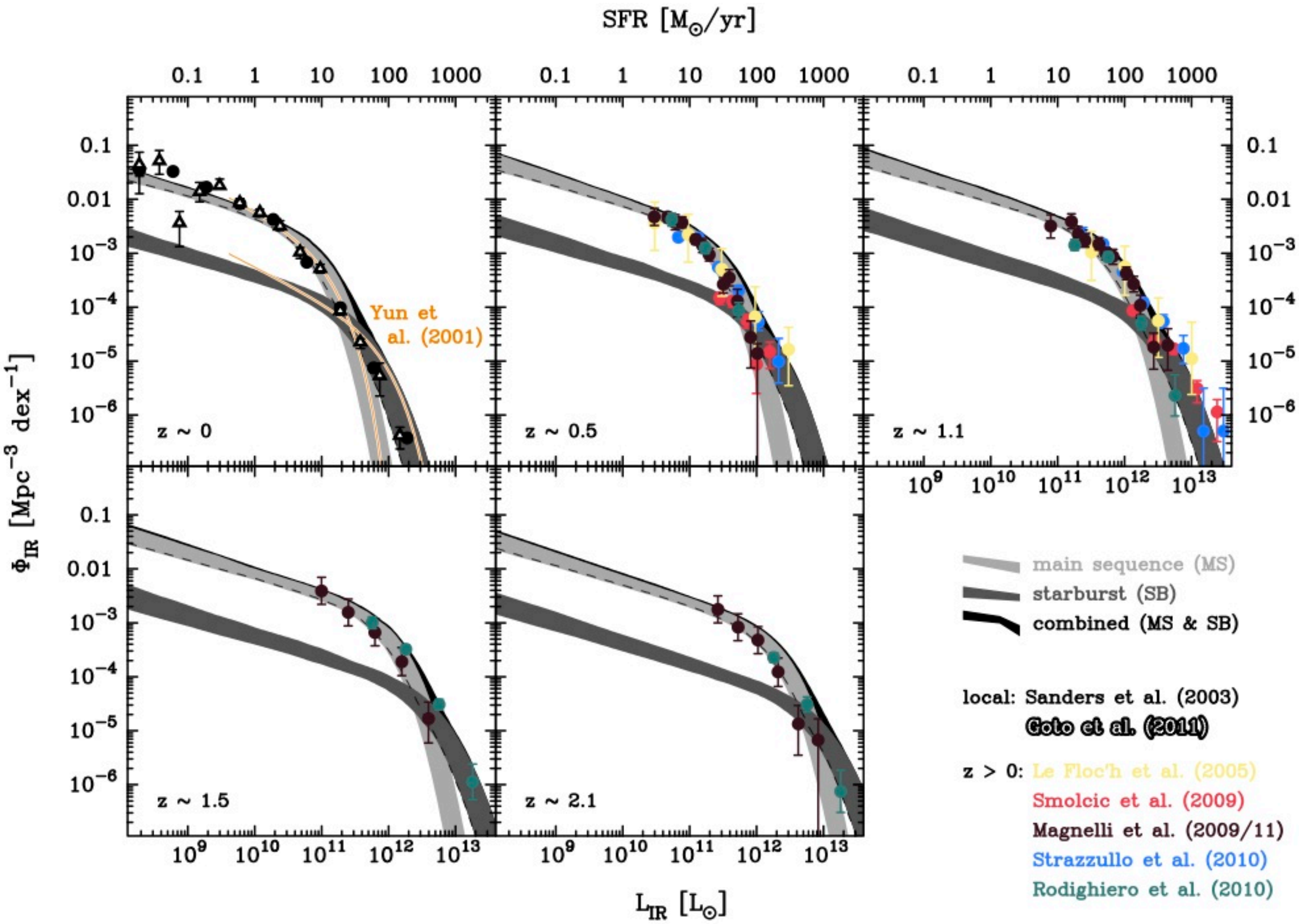
stars ➽

dark matter ➽

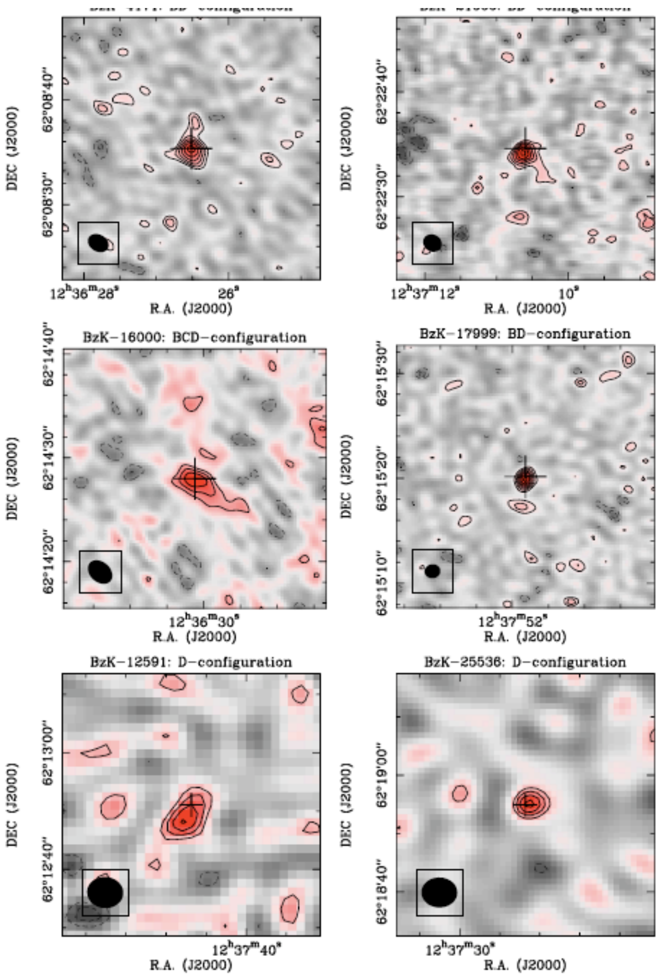


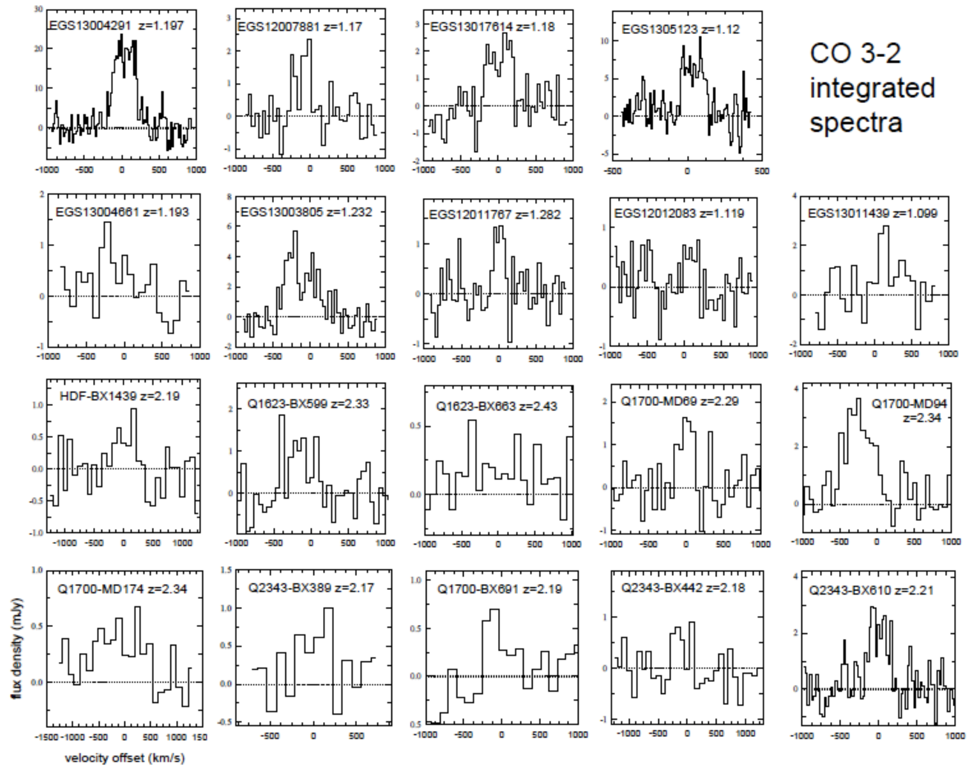
Sargent et al 2012

IR luminosity function: prediction vs. observations



Since 2008: routine detection of CO emission lines inside normal (massive) galaxies (near-IR selected, UV/optically selected), opened up the way to study their gas content over 0.5<z<2.5

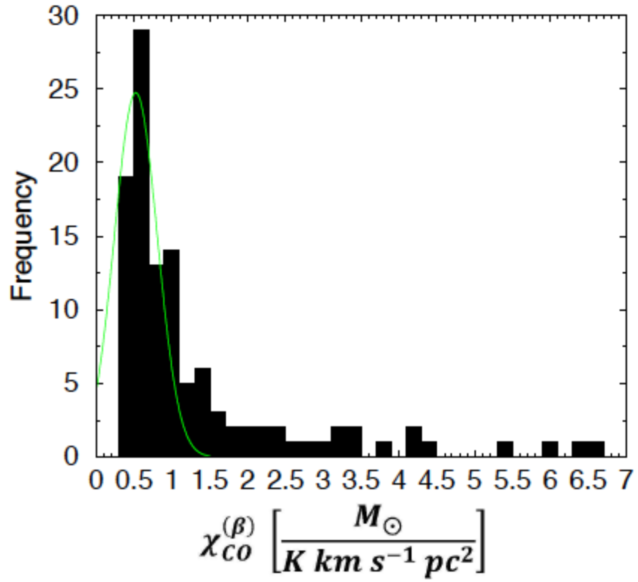




Daddi et al 2008; 2010; Tacconi et al 2010; Geach et al 2011; Combes et al 2012; etc

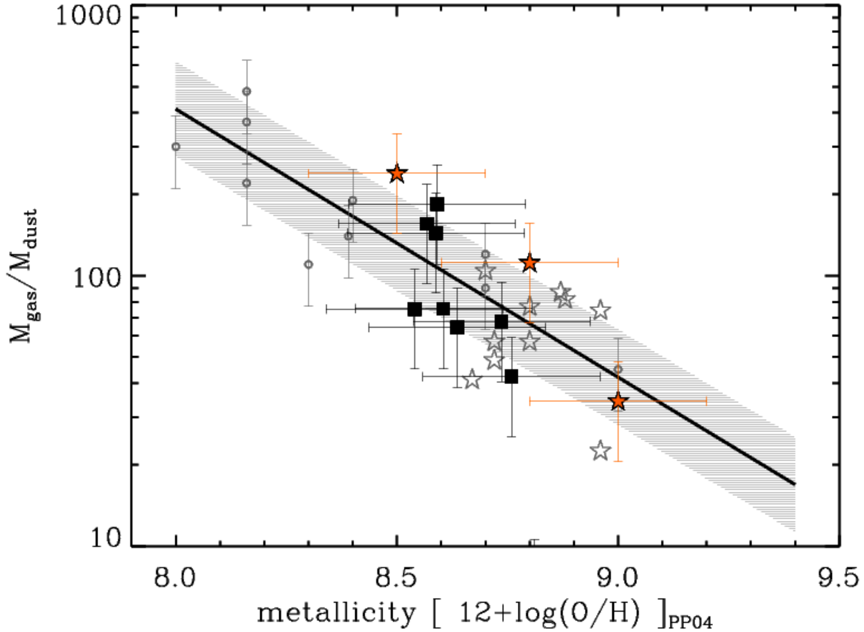
CO to H2 conversion factor,
(or how much gas ? → M/L ratios for CO)

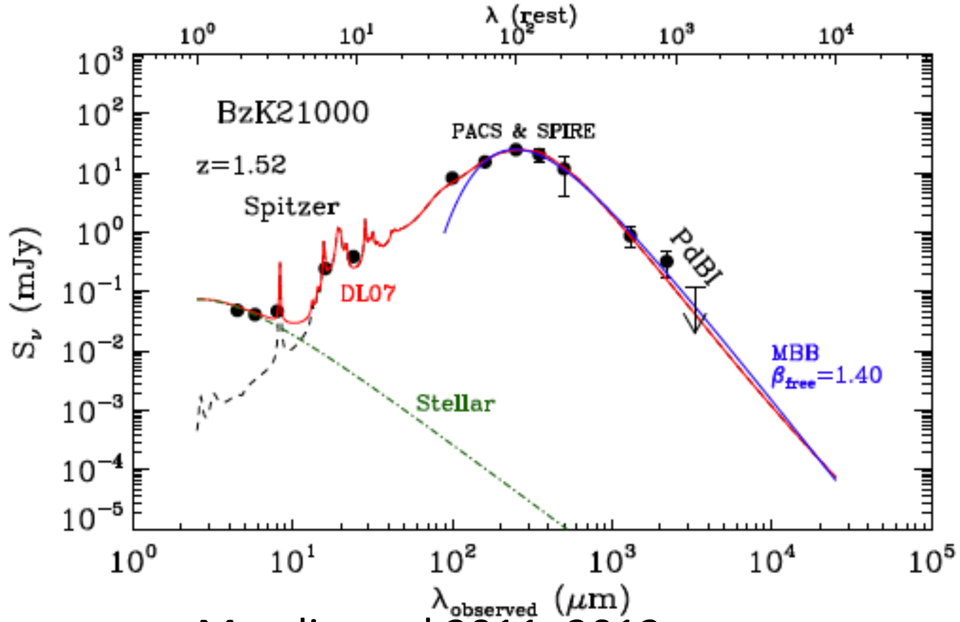
Massive z~2 galaxies are LIRGs/ULIRGs



z=0 LIRGs/ULIRGs
Papadopoulos et al 2012

A powerful way to constrain Mgas is through Mdust, as Mdust ~ 0.5*Z*Mgas





Data from Leroy et al 2010; daCunha et al 2010
Magdis et al 2012 → agree with high aCO values
For MS galaxies

Magdis et al 2011; 2012
(Draine and Li 2007 models)

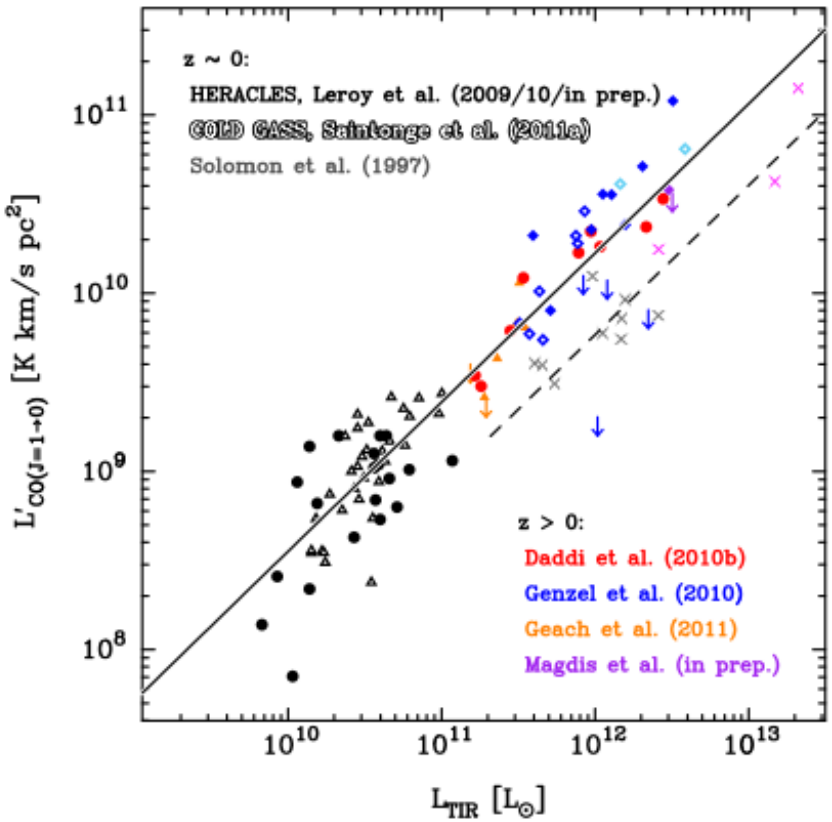
<U> ~ LIR/Mdust ~ $T^{4+\beta}$ ~ SFR/(Z*Mgas) ~ SFE/Z

From the IR SED shape, modulo metallicity, one can get to SFE!

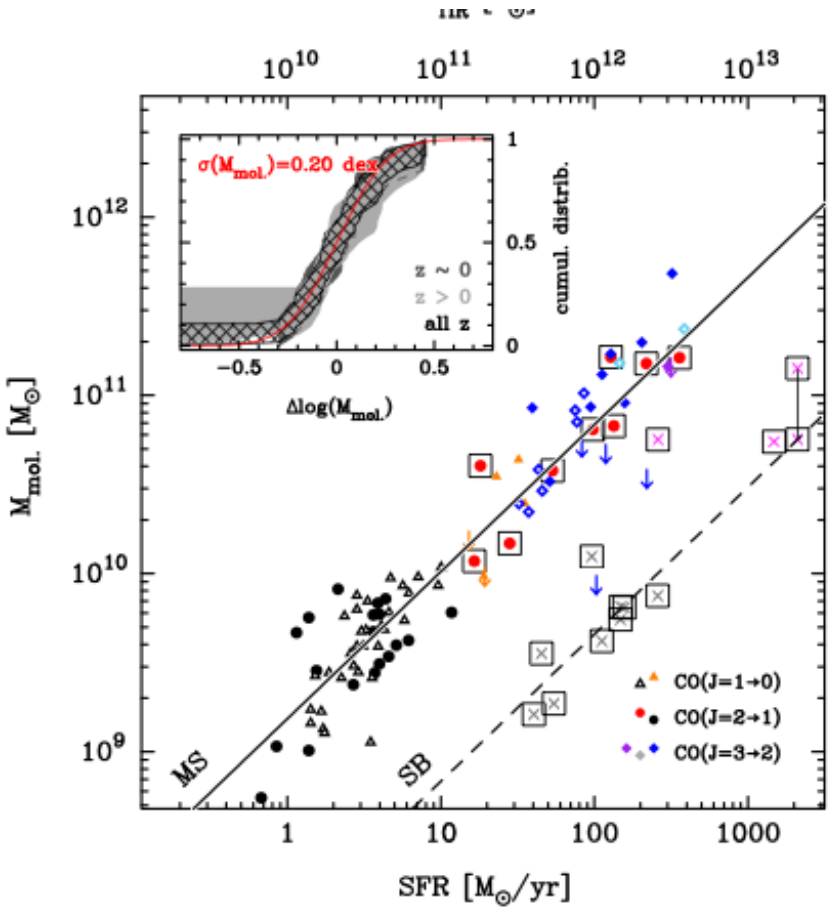
In fact U(z=0 ULIRGs)/U(massive spirals) ~ 10 just like SFE

→ Confirm aco and thus exploitation of CO observations
→ Get Mgas independently on CO/ALMA whatever, and on gigantic samples

Tight correlations of LIR/SFR with CO and Mgas
(Daddi et al 2008; 2010ab; Tacconi et al 2010; Genzel et al 2010)
Sargent et al 2012, in preparation)



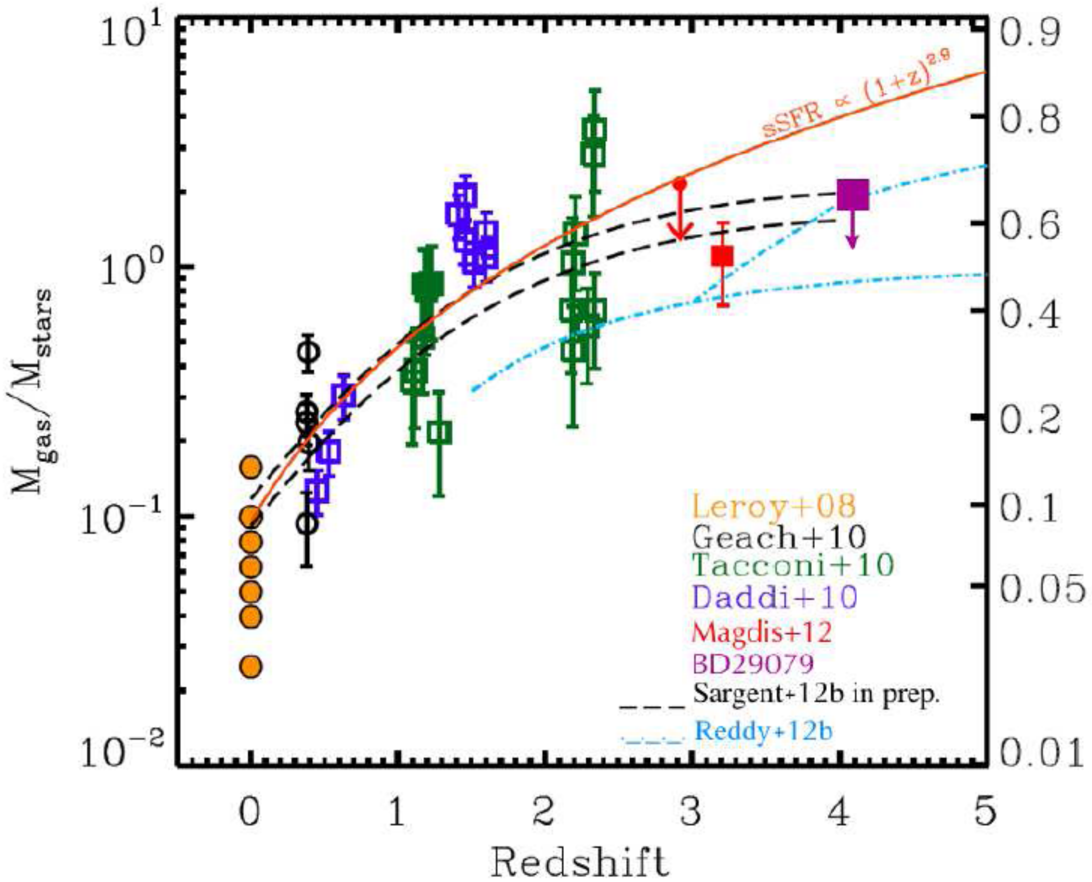
X3 offset from *observables only*

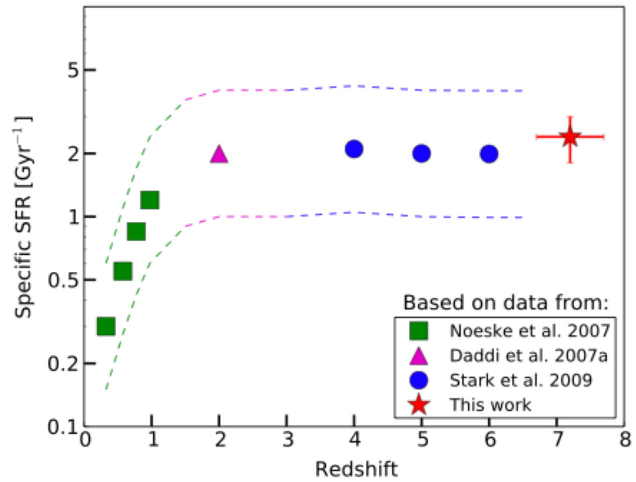


X10 offset, dense gas fraction

Doubling time for MS galaxies >~0.5Gyr, gas accretion rate high
Duty cycle high, MS narrow

Gas fractions in MS galaxies rising sharply from z=0 to 2 from 5% to 50%
(Daddi et al 2008; 2010; Tacconi et al 2010; Geach et al 2011; etc)





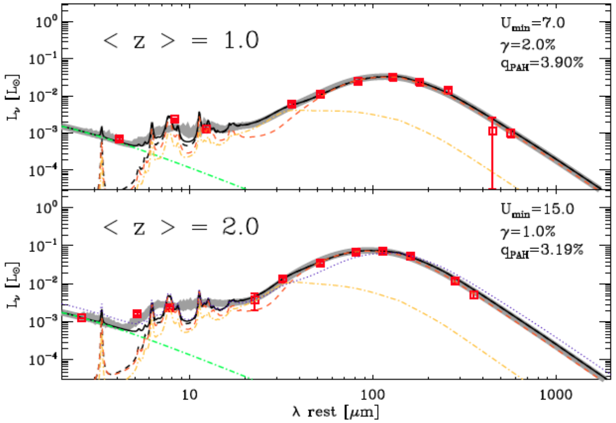
Fgas increase fully explains the sSFR increase of MS

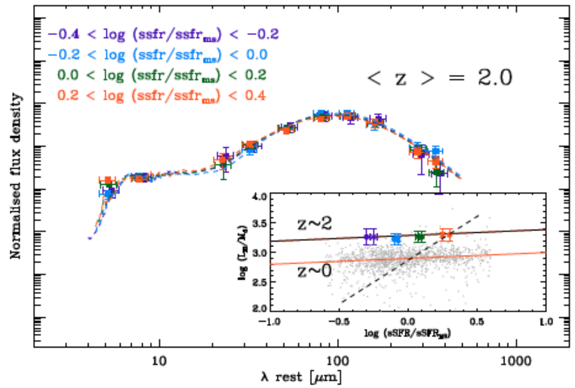
z>=2 massive galaxies are gas dominated, very different beasts from z=0 spirals

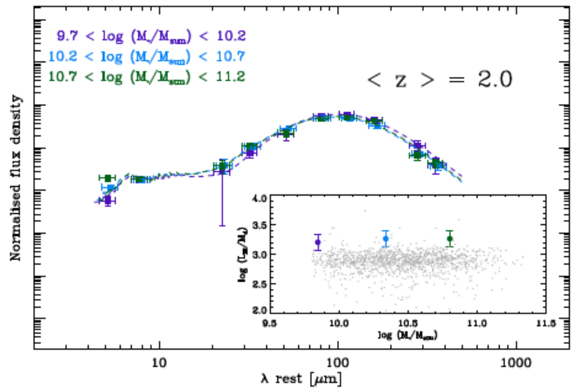
Magdis et al 2012b; Tan et al 2012 in prep

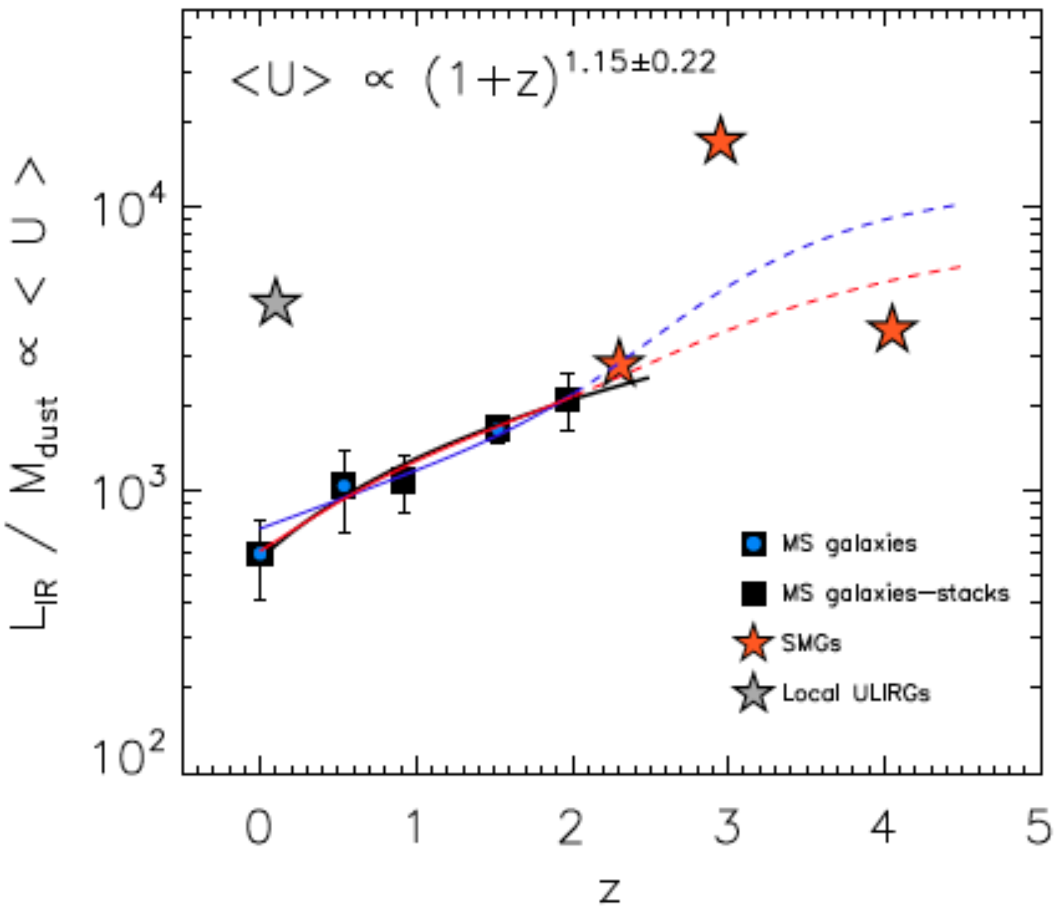
SEDs, Mdust … and Mgas (Magdis et al 2012)
Spitzer+Herschel(PACS/SPIRE)+Laboca+AzTEC

U ~ LIR/Md ~ SFE/Z







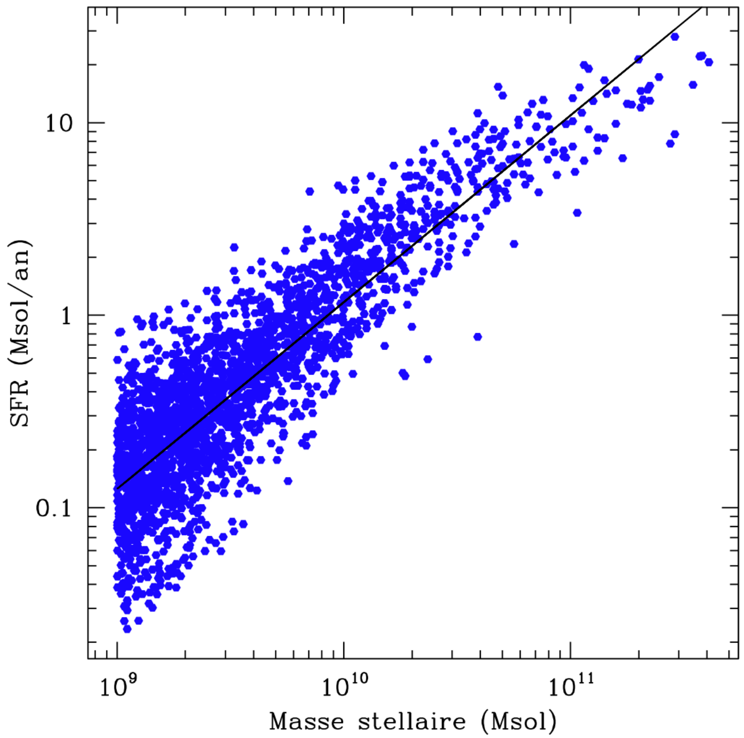


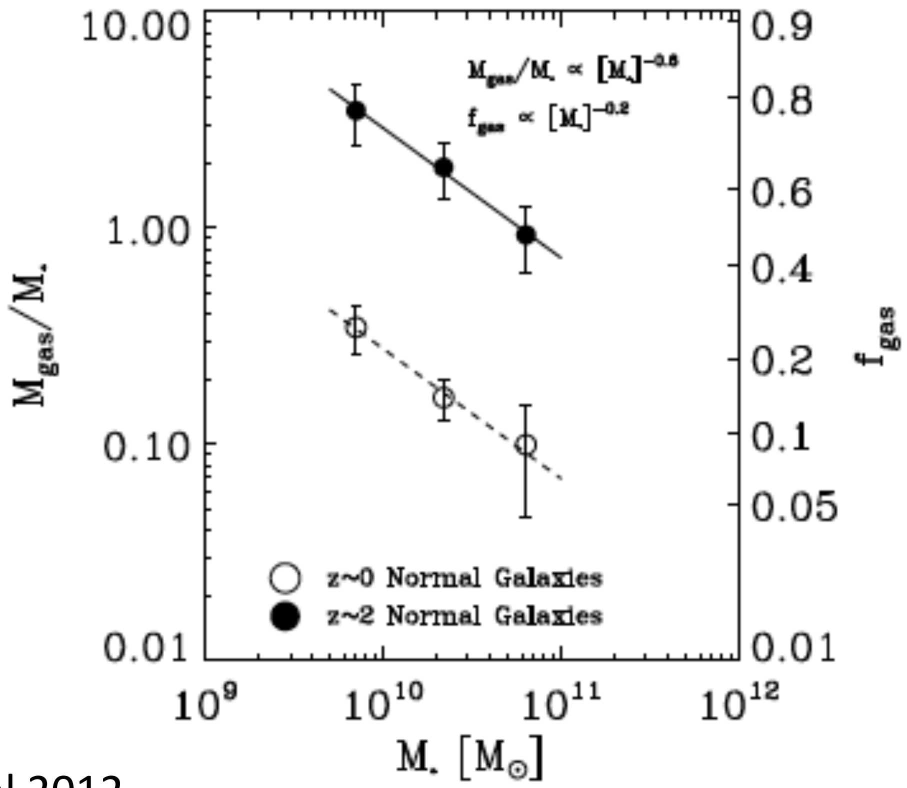
z~2 MS galaxies are warmer than z=0 MS galaxies
But they can be ULIRGs, colder than z=0 ULIRGs
→ If you do cosmic evolution of "something" need to care what you are looking at (notice SBs are more luminous)

But fgas is not a single number quantity at a given z

As the SFR and M* rise along the MS, the gas fraction decreases (Magdis et al 2012)

Simple consequence of SF law slope, MS slopes<1

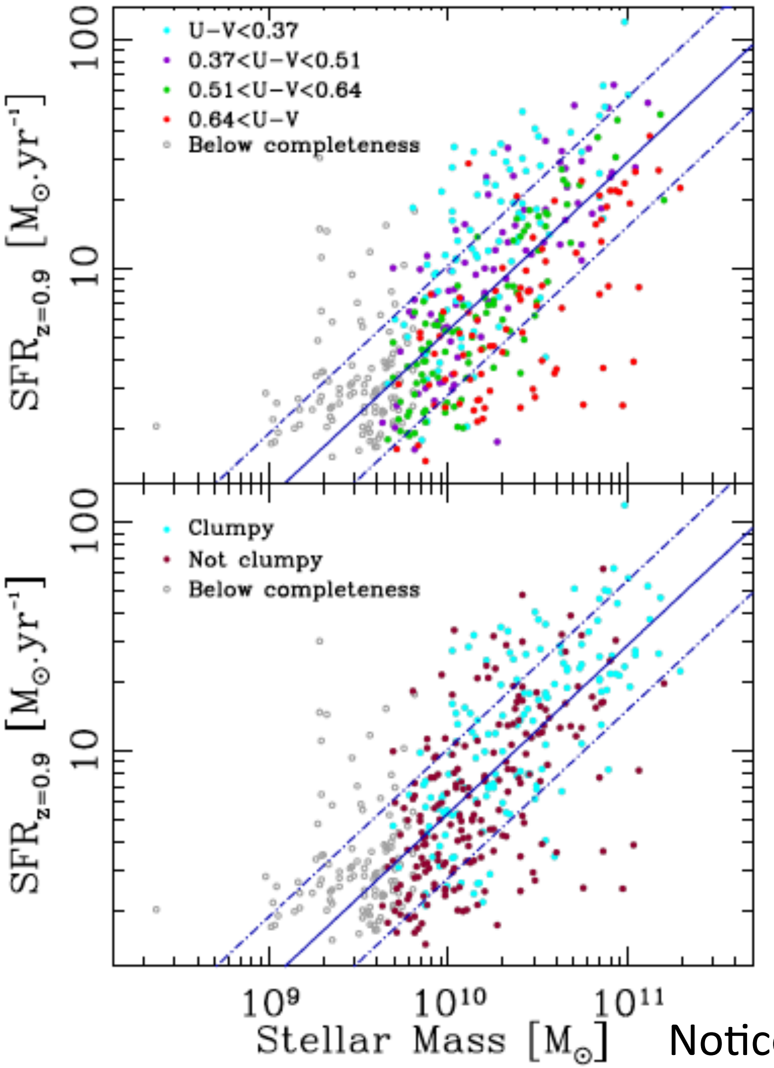




Magdis et al 2012

The bathtub is loosing water…

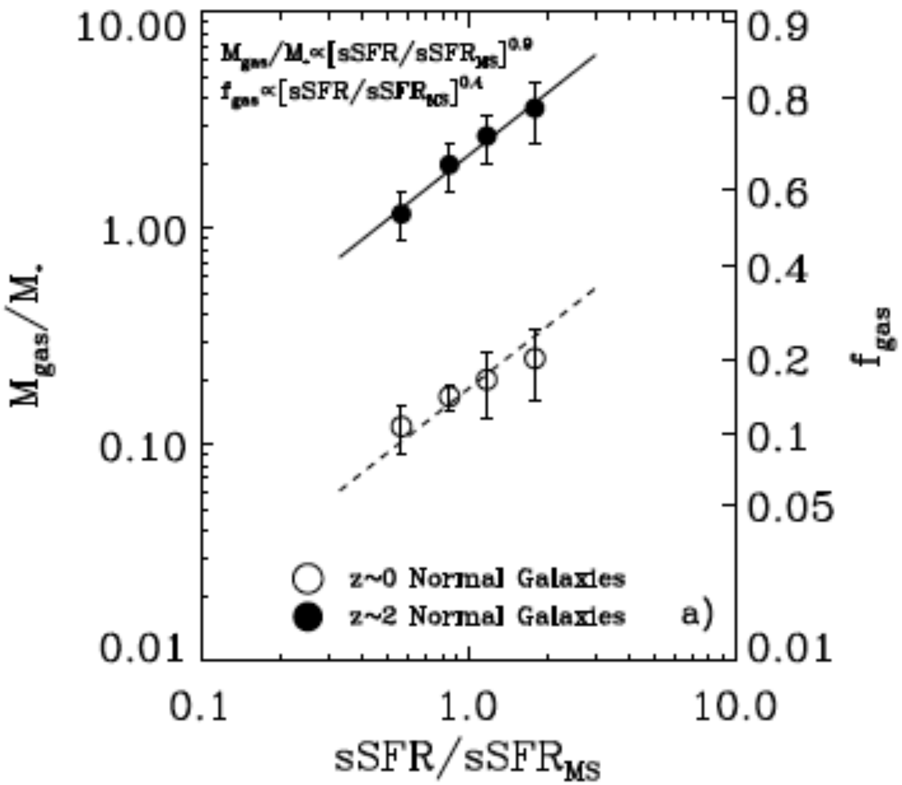
Salmi et al 2012



Why the MS is thick ?

1) Fgas driven ?
2) SFE driven ?

→ Fgas is the answer (Magdis et al 2012)

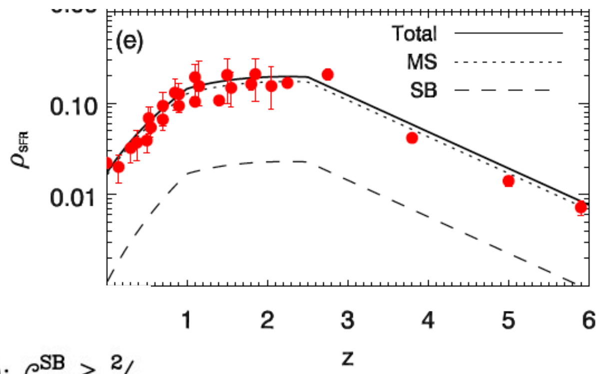


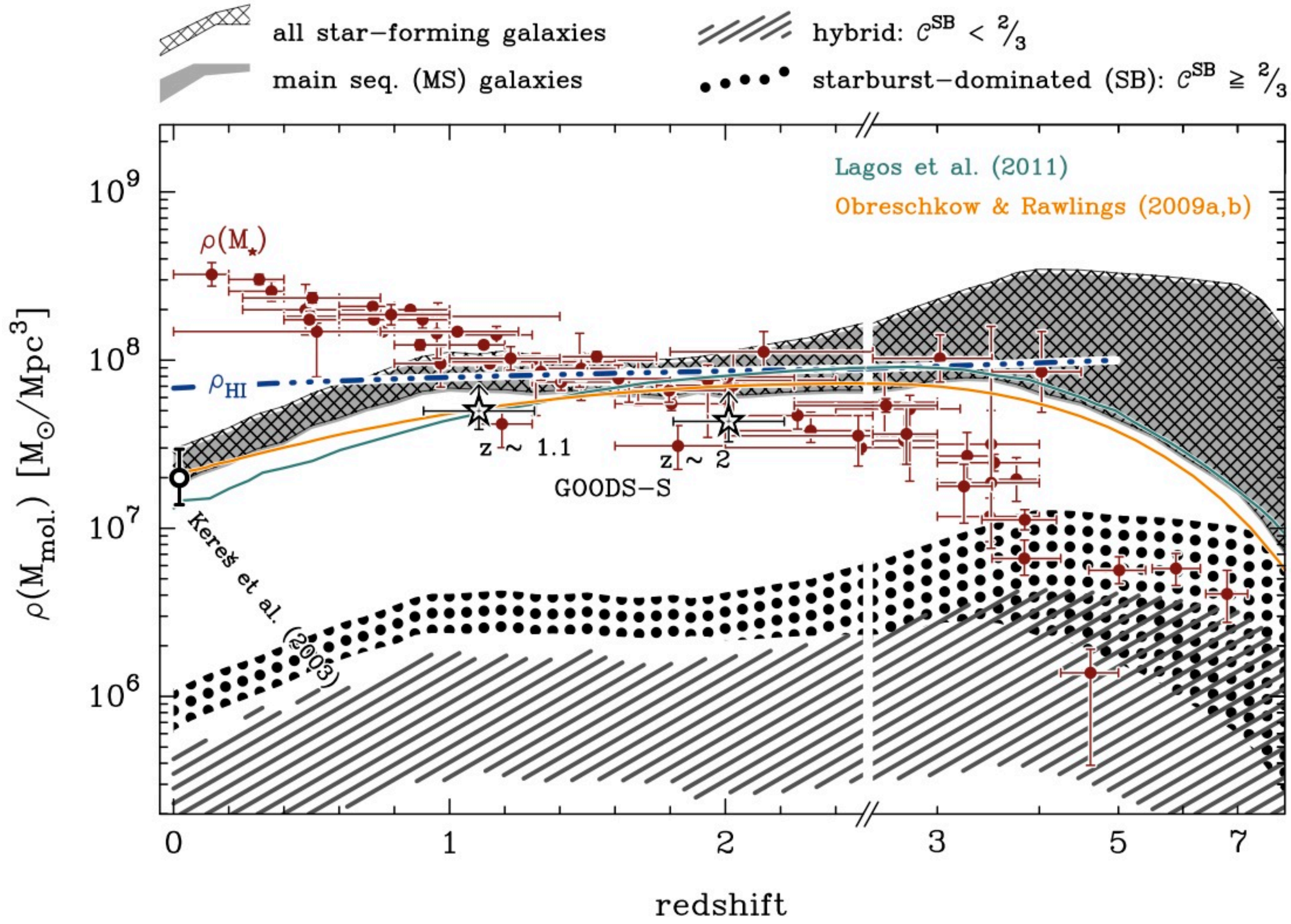
Notice that SFR feels f_dense, not fgas (e.g., Daddi+2010)

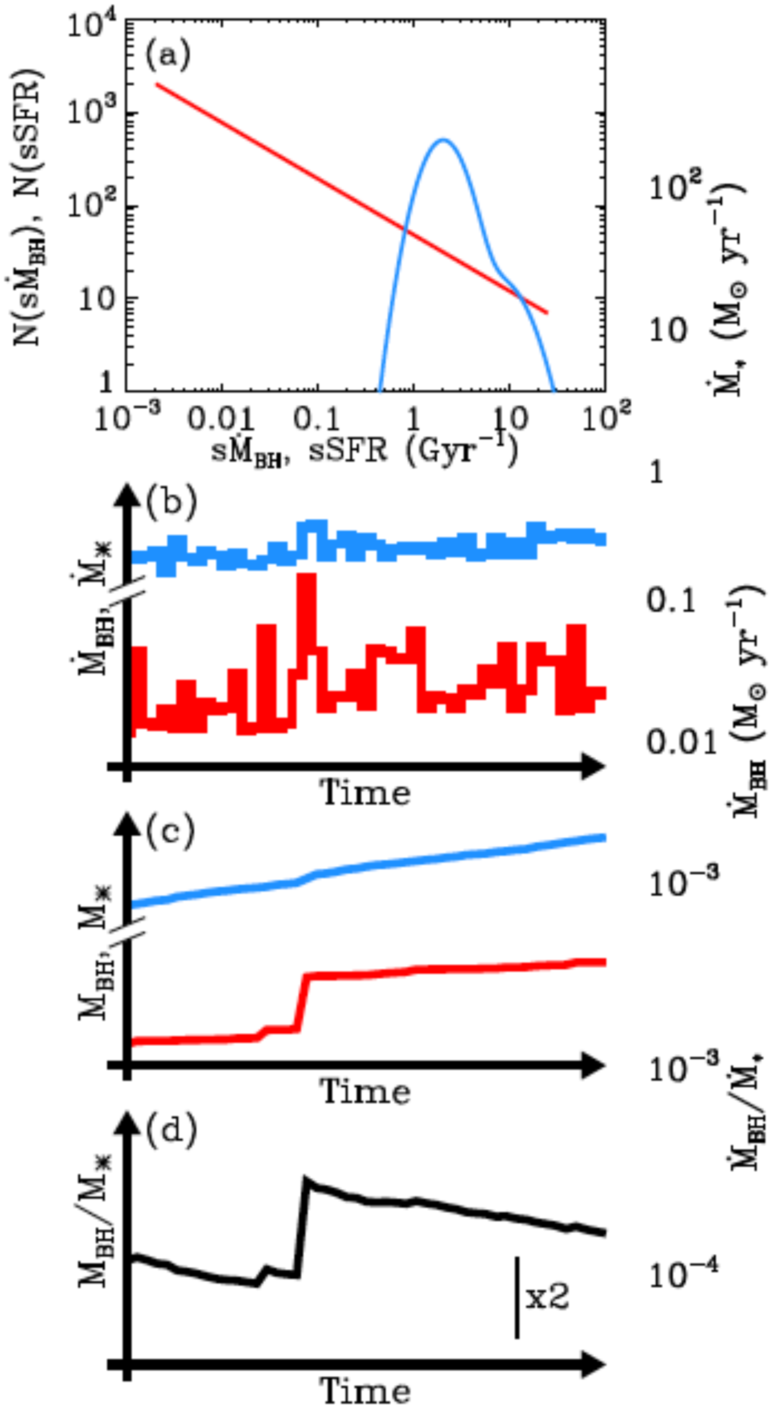
→ Must mean fluctuations are long lived >10^8yrs

(also time needed to reflect color variations)

Cosmic evolution of H_2-reservoirs (Sargent et al 2012 in prep)







AGN evolution

Doing ensemble averages (→ time averages)
The picture clears up for AGNs

Mullaney et al 2012b

Strongly suggest that BH and galaxy do grow
Together, and MBH/Mgalaxy is ~constant at the
Same ratio of today through formation epoch

←
There is a Main Sequence also for AGNs!
(when eliminating short-time fluctuations)

Level is ~ Magorrian

Gas reservoir regulating both SFR/AGN activity

How is environment affecting SF ?

Statistical properties of scaling laws (MS, Mgas-LIR)

Evolutionary trends (fgas vs z, U vs z)

SF mode impact (fraction of SBs, thickness of MS)

Maybe we should look for special times (cluster formation) when the enviroment did affect SF ?

Is cluster formation just accelerated galaxy formation ?

Dense environment at early times did favor SF instead of reducing it ?

How over-densities of SF galaxies relate to clusters ?