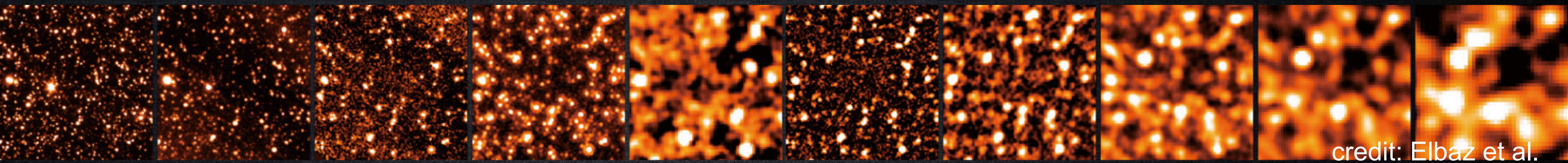


credit: Elbaz et al. 2011

A Highly Deconfused Mid-far-IR to Submm Catalog in GOODS-N
II. Towards the first results…

Emanuele Daddi, Daizhong Liu, M. Bethermin, G. Magdis, M. Sargent, F. Valentino, A. Zanella, G. Rodighiero, M. Brusa, J. Mullaney, M. Dickinson, F. Owen
& GOODS team etc

Jan 29th 2015

Peculiarity of our GOODS-N IR catalogue:

- 24um+VLA priors
- Progressive identification of desperately faint galaxies, removed from prior fitting (band by band), using redshift and SED information
- Associate 'quasi Gaussian' errors to each measurements

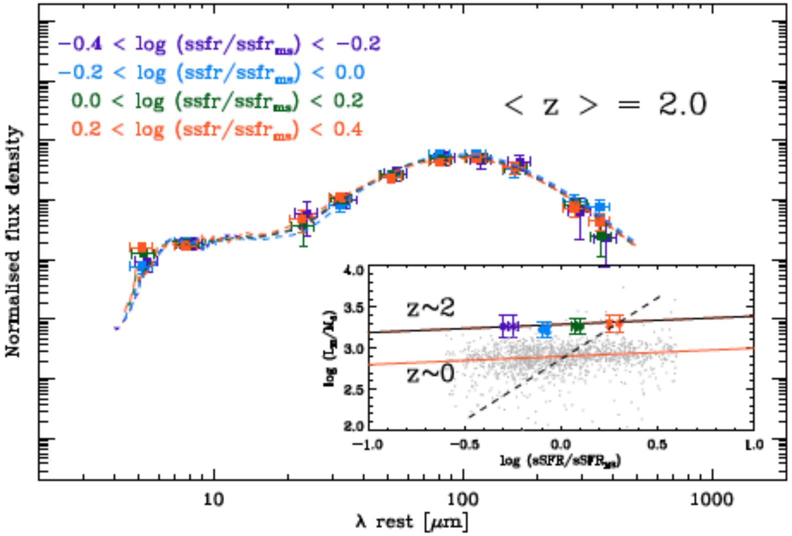
Outline:

A) Learning about ISM galaxy properties and evolution: gas, dust content and their physical properties

B) The concurrent growth of stars and BHs in the starburst/merging phases

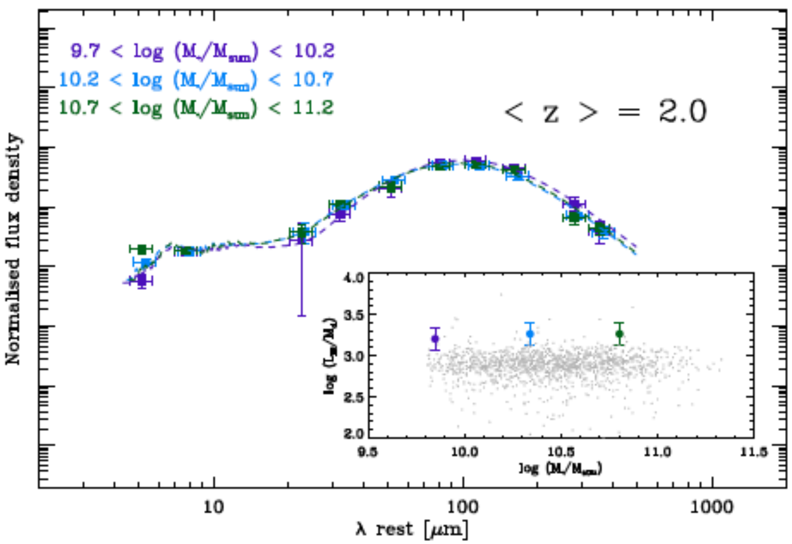
From multiwavelength FIR observations of high-z galaxies to the properties of their ISM
Fitting Draine & Li 2007 dust models

(ideas first tried in Magdis et al 2011; 2012; many others afterwards)



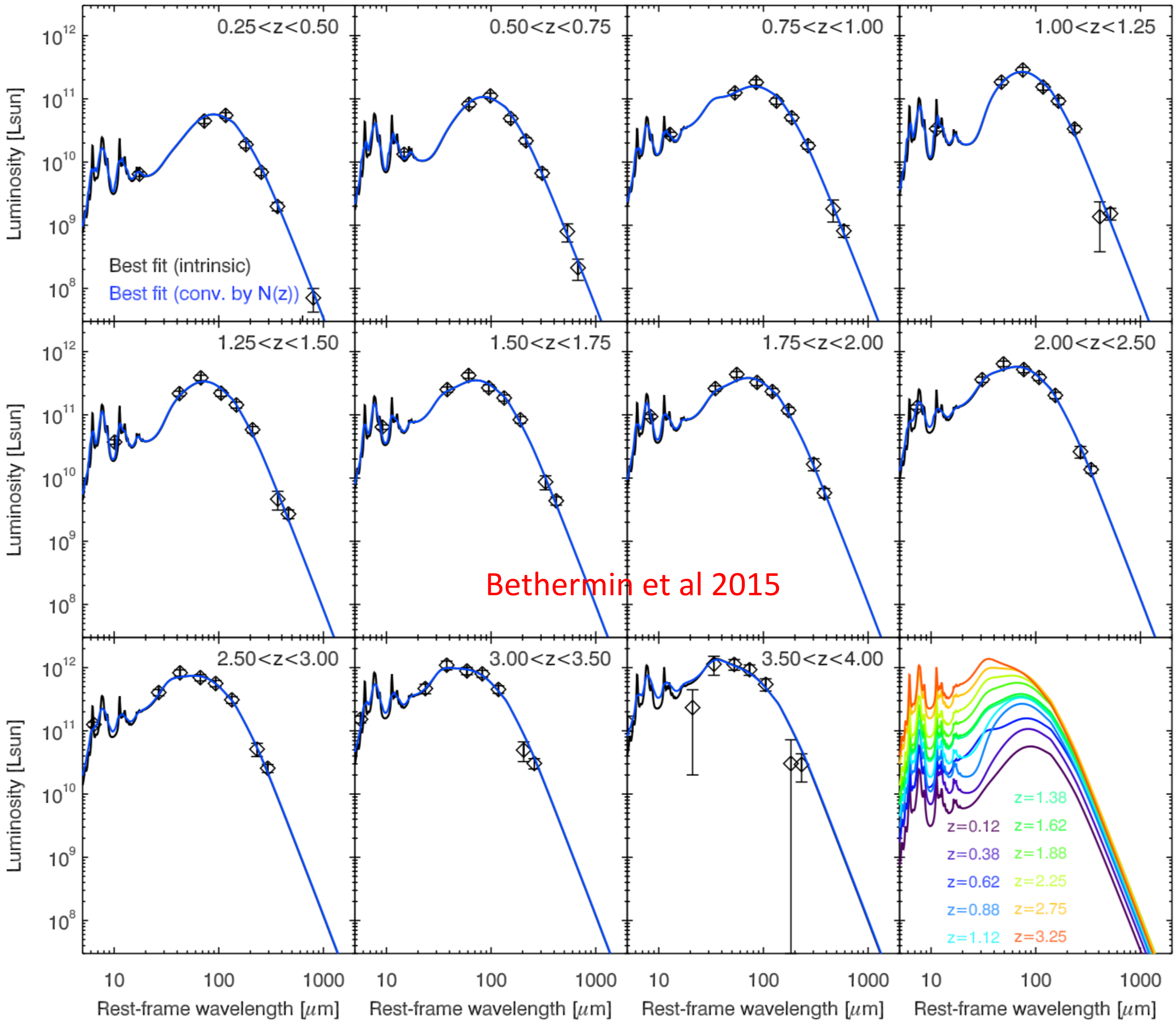
LIR → SFR bolometric (100Myr timescale)

Mdust → Mgas
(assuming Mdust ~ Mgas*Z; massive galaxies)

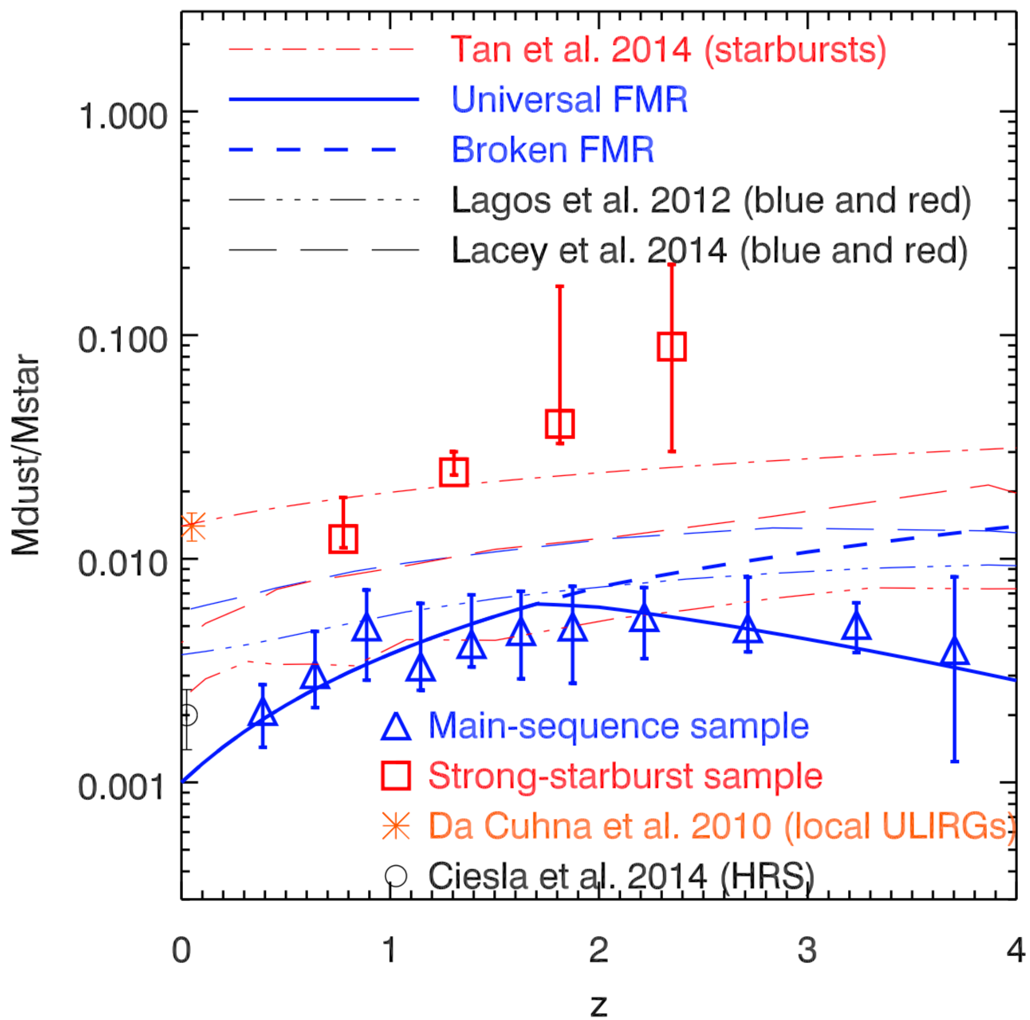


LIR/Mdust ~ <U> ~ SFR/(Mgas*Z) ~ SFE/Z
Weakly dependent on sSFR and Mass above 10^10

<U> is proportional to T^{4+beta}~5.5
Intensity of the radiation field
→ Peak lambda of the SED


0.25<z<0.50
0.50<z<0.75
0.75<z<1.00
1.00<z<1.25
1.25<z<1.50
1.50<z<1.75
1.75<z<2.00
2.00<z<2.50
2.50<z<3.00
3.00<z<3.50
3.50<z<4.00
Best fit (intrinsic)
Best fit (conv. by N(z))
Luminosity [Lsun]
Rest-frame wavelength [μm]
z=0.12
z=0.38
z=0.62
z=0.88
z=1.12
z=1.38
z=1.62
z=1.88
z=2.25
z=2.75
z=3.25
Bethermin et al 2015

Dust masses ← → Metallicity evolution

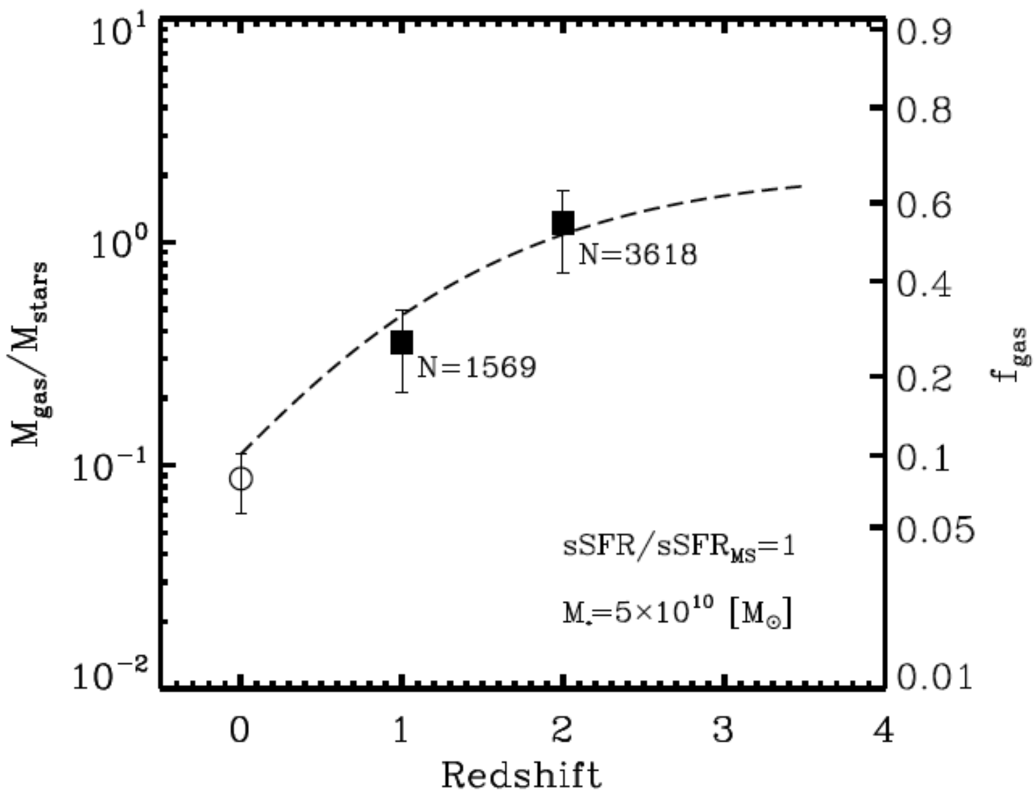


Factor of ~3 rise of Mdust/M*
From z=0 to 2—3

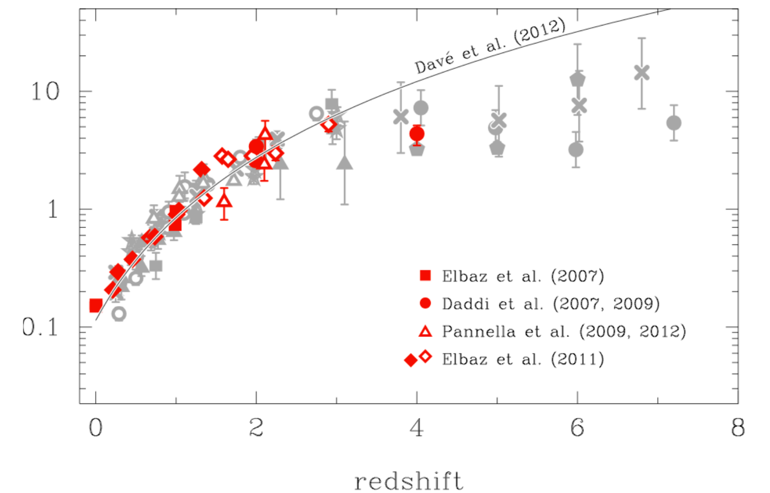
Driven by x10 Mgas increase, diluted by metallicity decrease

Bethermin et al 2015

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)



Magdis et al 2012b



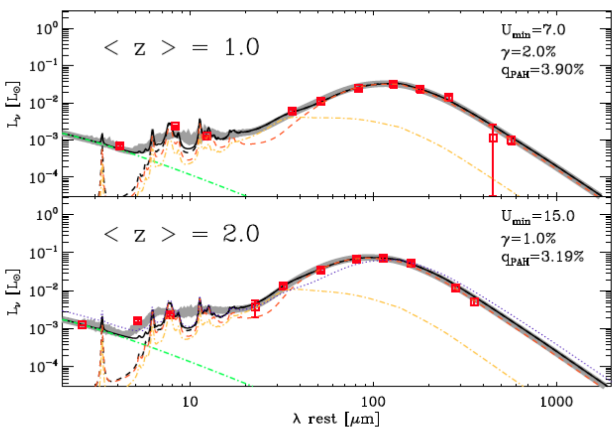
Fgas increase fully explains
the sSFR increase of MS
No need to alter the IMF, or invoke
anomalous SFE to account for the
high SFRs z~2

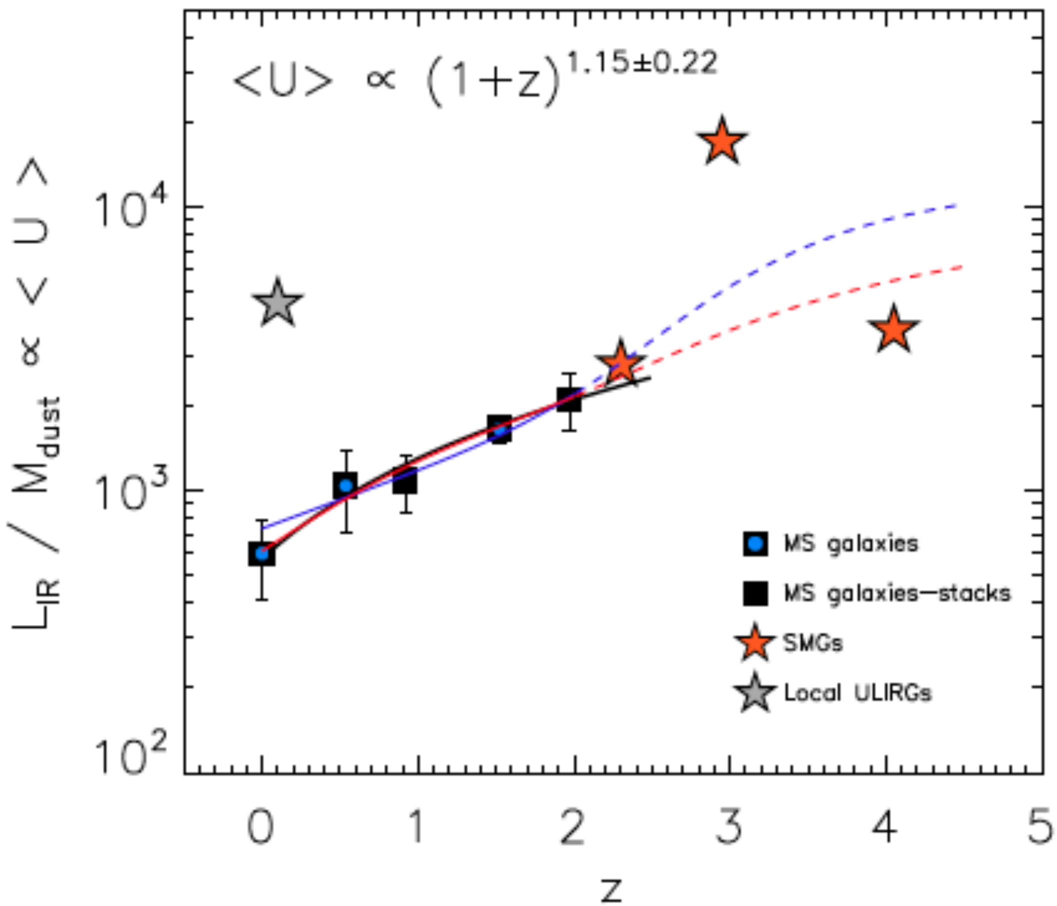
z>=2 massive galaxies are gas
dominated, very different
beasts from z=0 spirals

Gas from Dust

U ~ LIR/Mdust ~ SFE/Z
Mdust ~ 0.5 Z Mgas

Magdis et al 2011; 2012
See also Magnelli et al 2012, 2013,
Santini et al 2013; Scoville et al 2014
Genzel et al 2014,
Bethermin et al 2015 etc





From z=0 to z=3 average T increase by x1.5 (e.g., 25K → 40K)

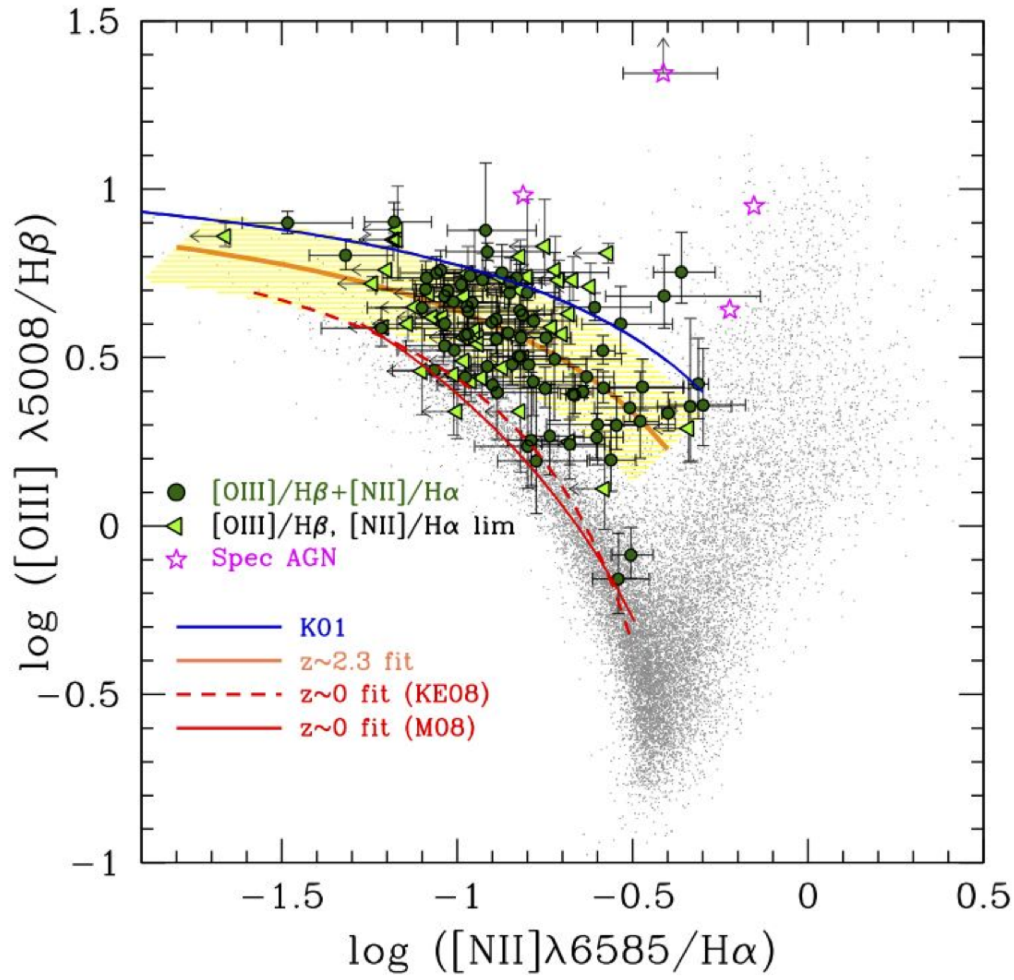
z~2 MS galaxies are warmer than z=0 MS galaxies
But they can be (U)LIRGs, colder than z=0 (U)LIRGs
→ If you do cosmic evolution of "something" need to care what you are looking at (notice SBs are more luminous)

Evolving ISM: emission line ratios

Strong rise of [OIII]/Hbeta ratios (Steidel et al 2014)

→ Higher Teff of ionizing radiation field

Agrees with rise in <U> (bolometric indicator) From Magdis et al 2012



And x2 lower metallicity at z=2

Evolving ISM: emission line ratios, environment

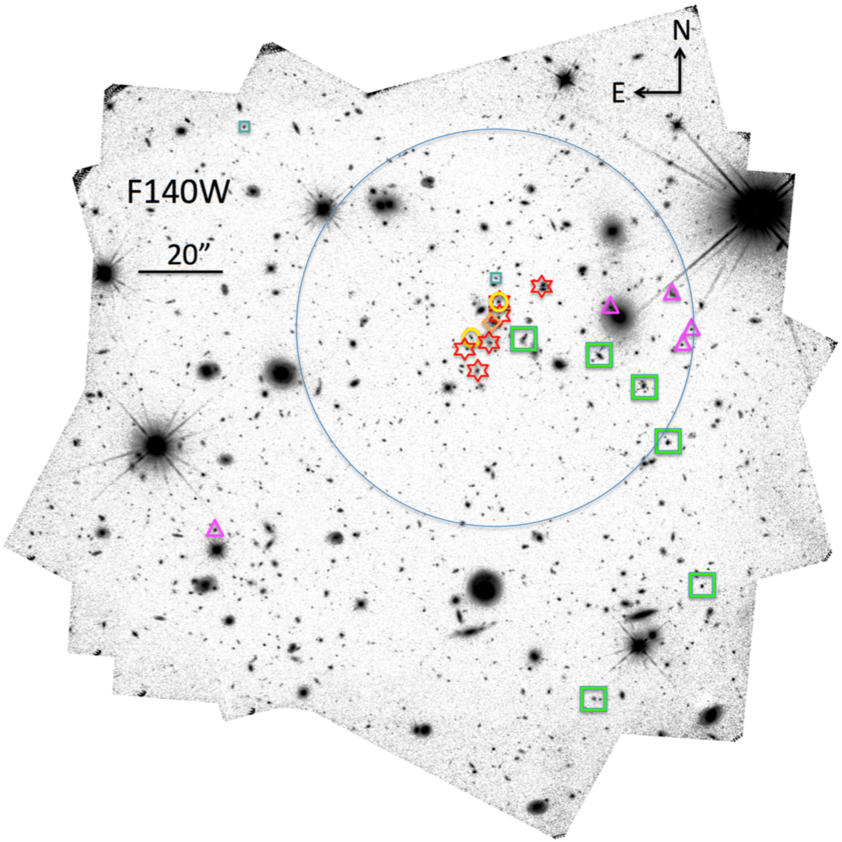
Evidence for metal deficit in cluster SF galaxies

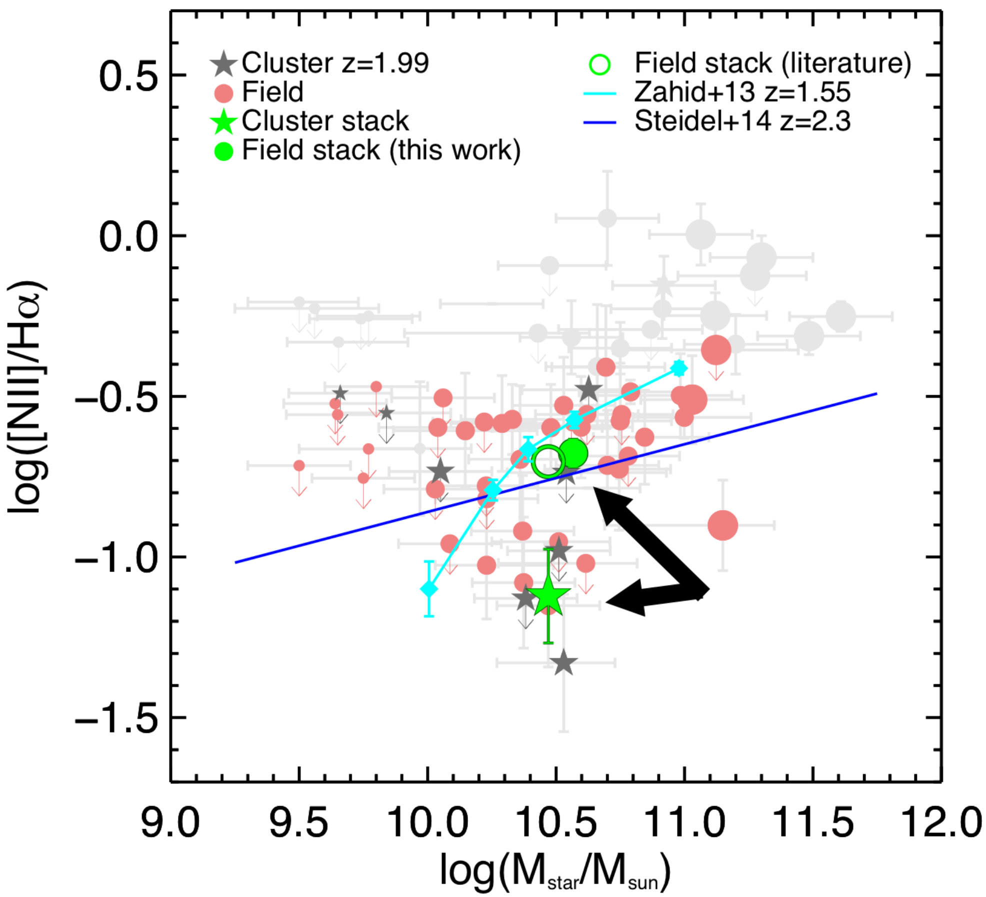
Valentino et al 2015, in press

10<logM<11 galaxies stacking

<z>=2 Field

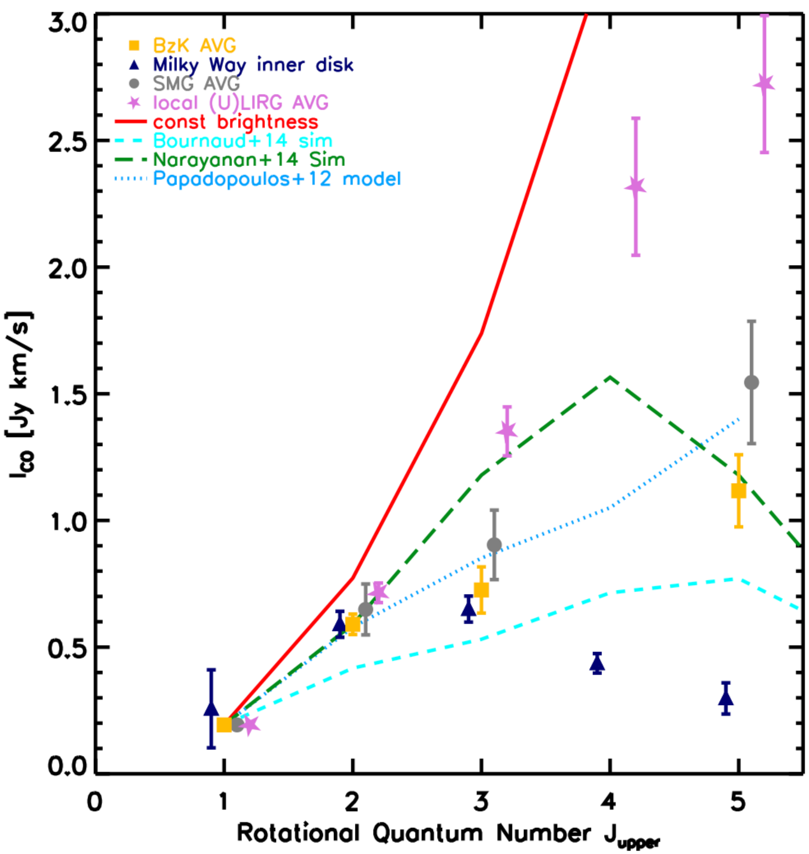
vs z=2.00 Cluster (Gobat et al+11; 13)

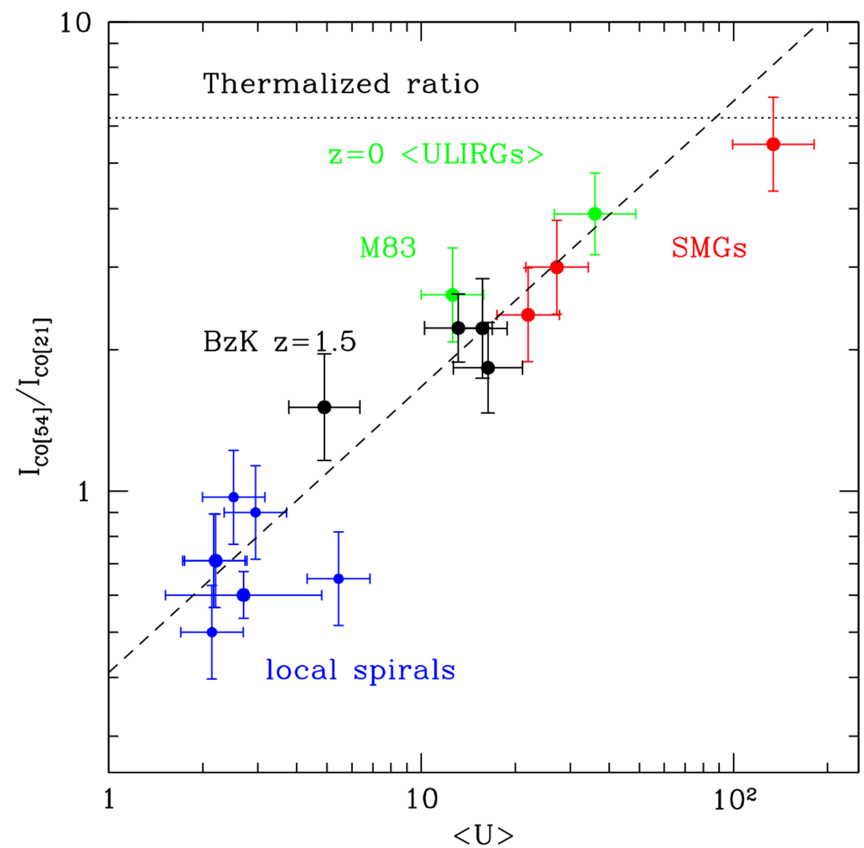




The average CO SLED of z=1.5 MS galaxies requires an additional denser/warmer component over cold MW-like gas
Much less excited than average (U)LIRGs

The ratio of warm/cold CO emission over galaxy populations (spirals, (U)LIRGs, BzK galaxies z=1.5, SMGs) is regulated by the radiation field intensity <U>

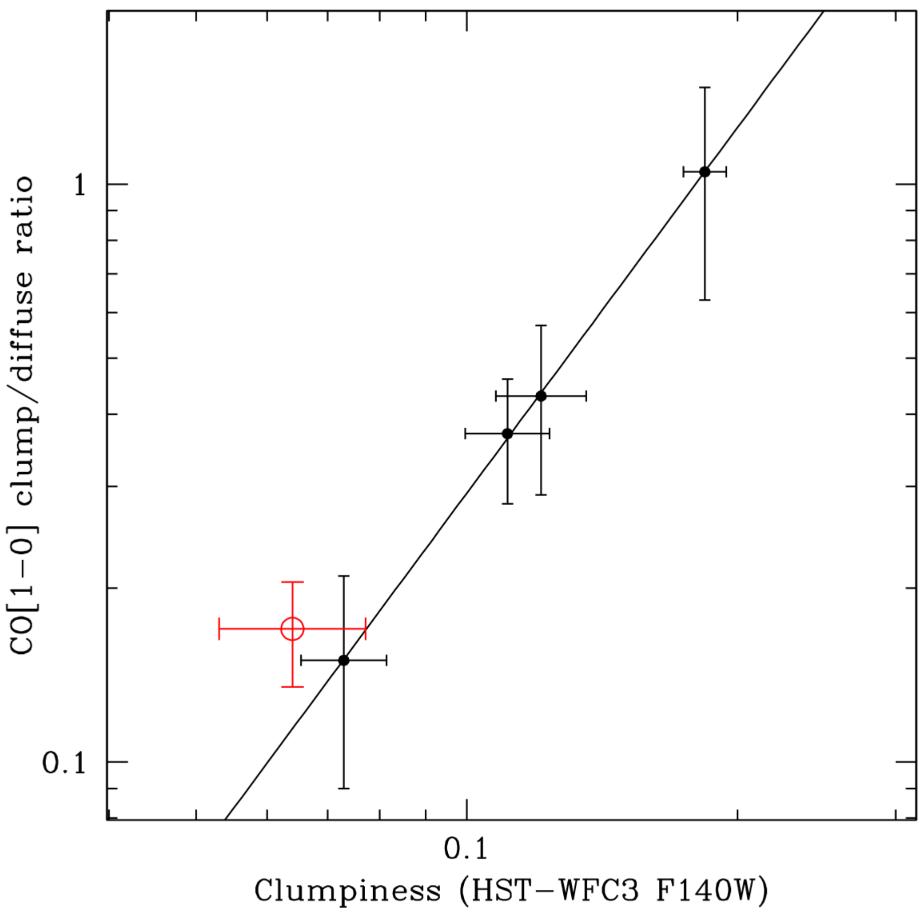


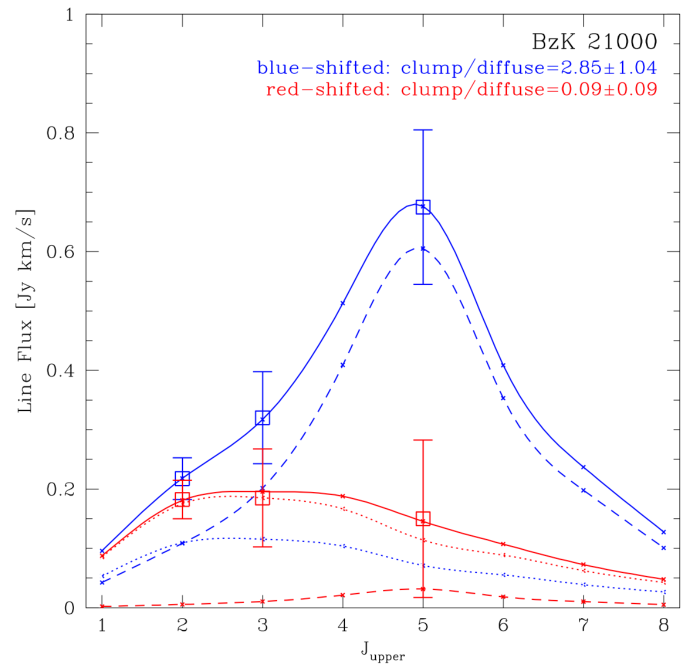


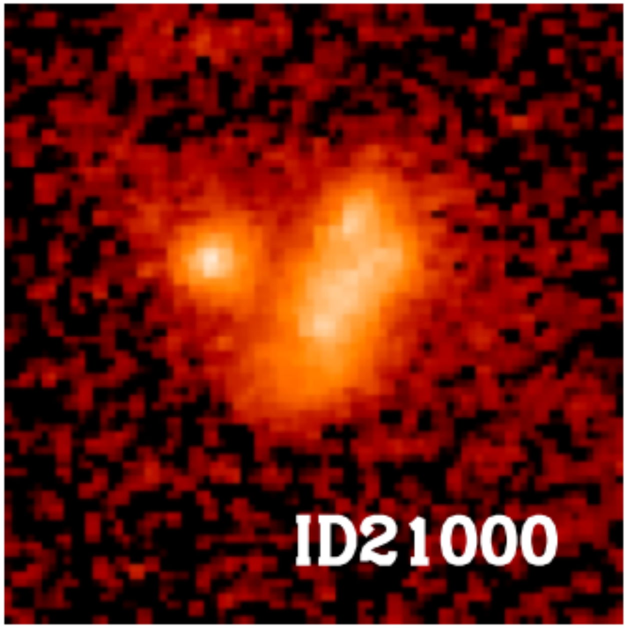
Only 4 galaxies, but lots of data (overall, >200h PdBI and >200h (J)VLA)

Daddi et al 2015 A&A in press

The data support the claim from Bournaud 2014 models, clumps seem connected to the high-J CO







Violent instability inside gas rich z=2 disk galaxy: caught in action

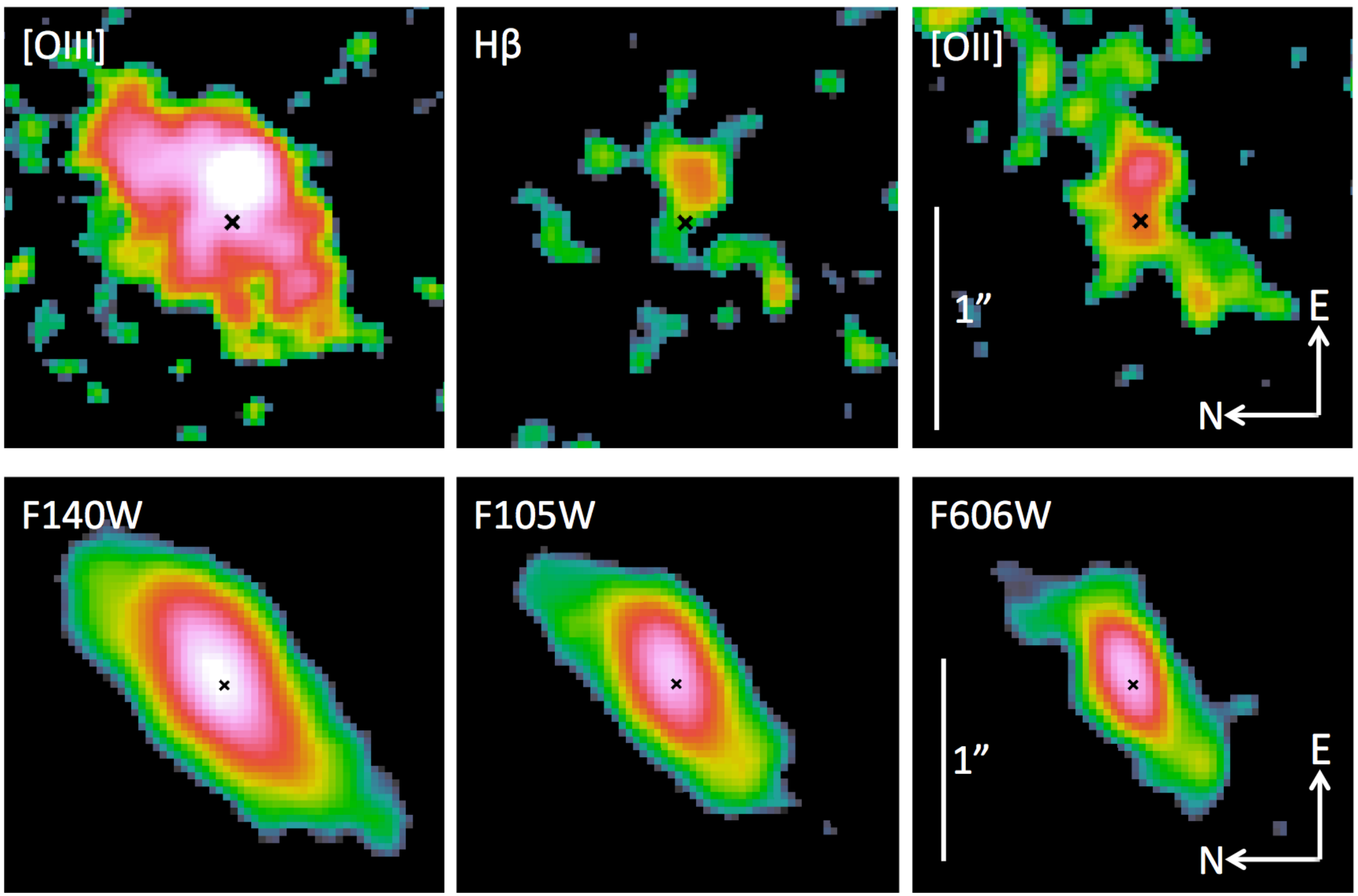
(Zanella et al 2015; submitted)

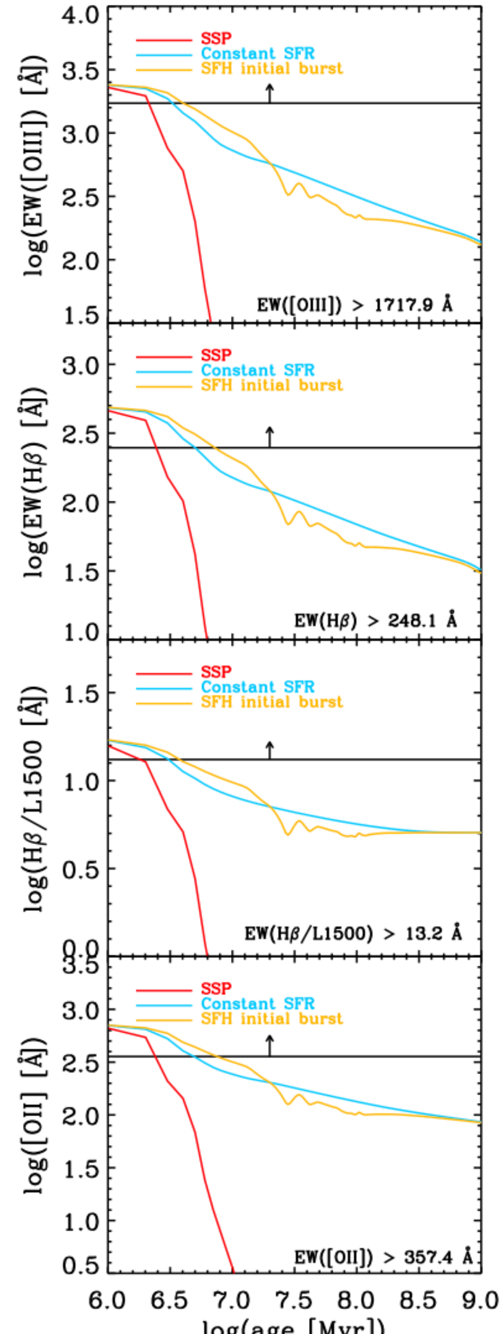
From an ultradeep 16 orbit G141 WFC3 grism survey

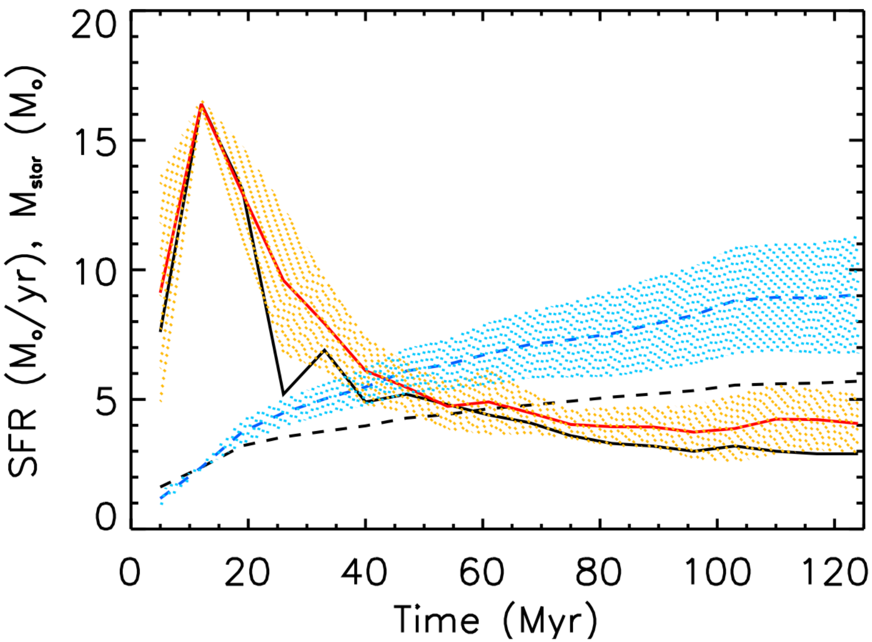
68 galaxies in the em-line sample, brightest case found

SFR~25—30 (half the total SFR of the galaxy)

Radius < 500pc (unresolved) (galaxy is ~15 kpc wide)



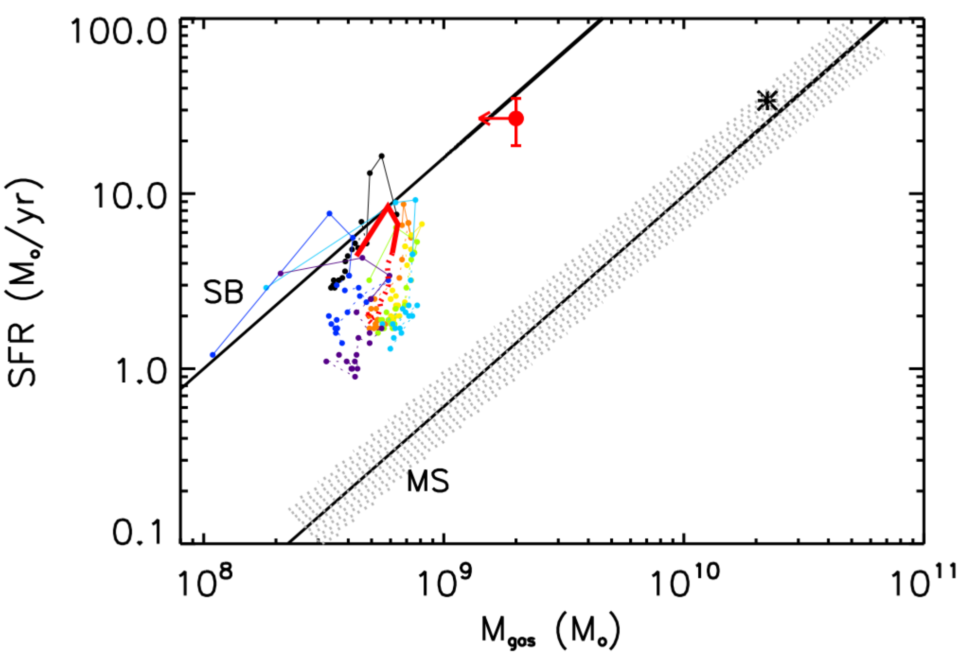




We assume Jeans-Mass clump upper
Limit 2—3x10^9Msun

→ FF time ~ 10Myr, of same order of age
(first time we observe this phase)

→ Excess SFR x3—5 compared to
Same mass clumps at late ages (burst
At formation)



→high SFE typical of SB,
but SFE/Tdyn consistent with universal trend

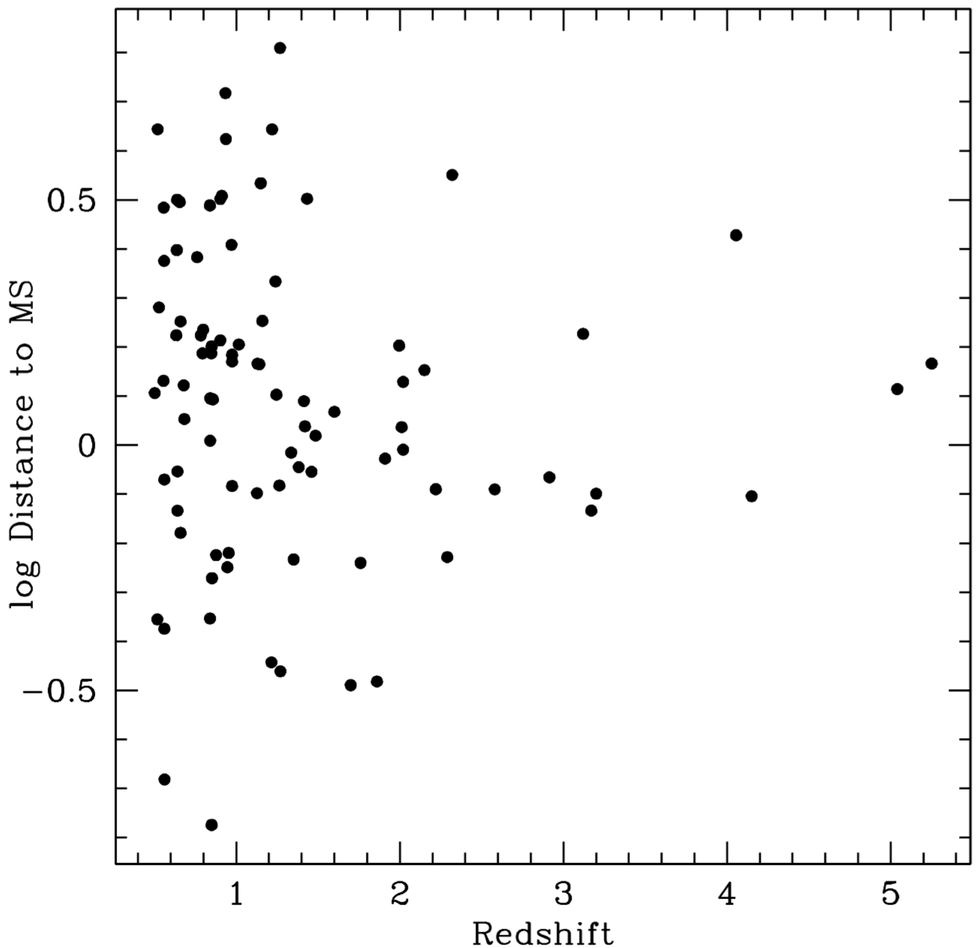
→ Massive clumps drive the rise of SFE
In MS galaxies/disks from z=0 to 2
(in addition to contribute to the rise
Of U and CO excitation)

→ Consistent with long lifetimes of clumps

Zanella et al 2015 submitted

100 galaxies in GOODS-N with <U> estimated to better than 0.2dex (0.1dex average)
→ gas estimates from dust (and more, we also have consistently SFR, hence SFE from U/Tdust) mostly for MS galaxies <z>=1.3

Compare to ~200 galaxies with CO detection



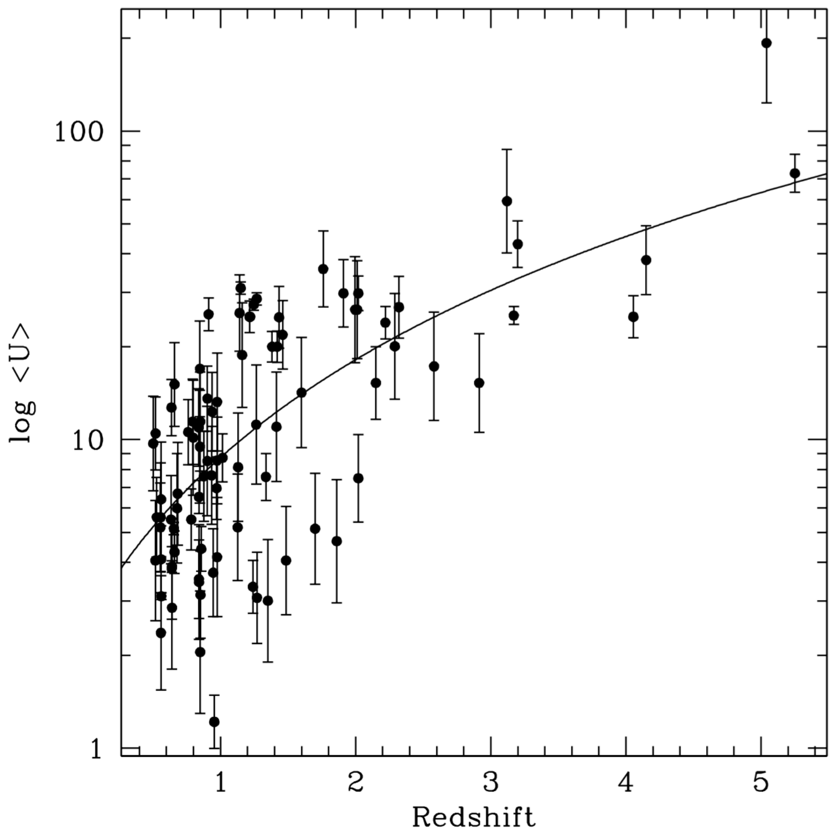
U (→ SFE) depends on galaxy properties ?
KS location dispersion

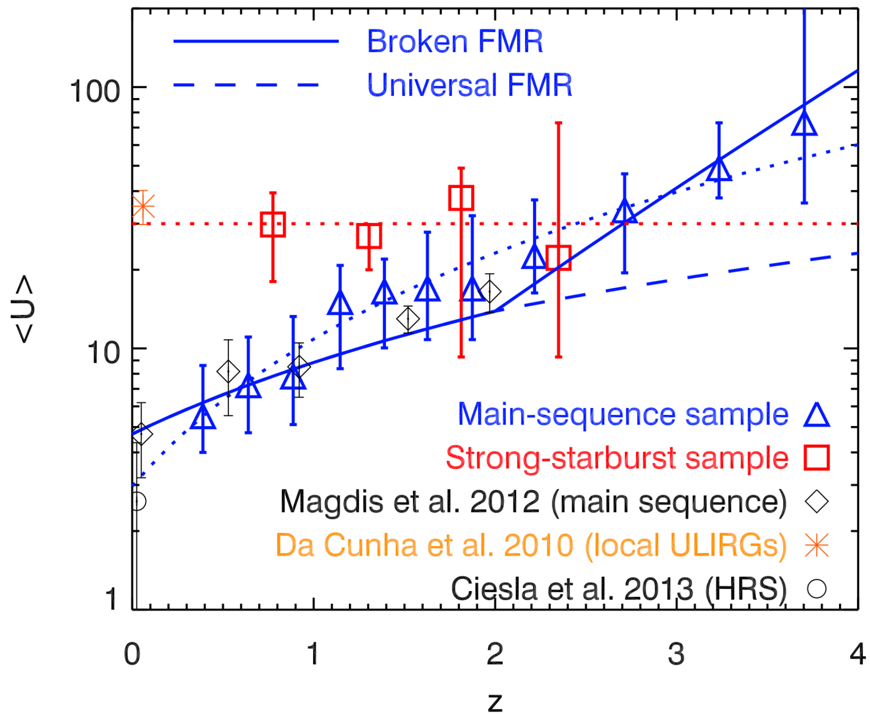
Dust masses over M* evolution and dispersion (related to scatter of gas fractions, metallicity)

PRELIMINARY!!

Redshift evolution of <U>

Bethermin trend scaled down by 0.07dex → modest bias for colder sources





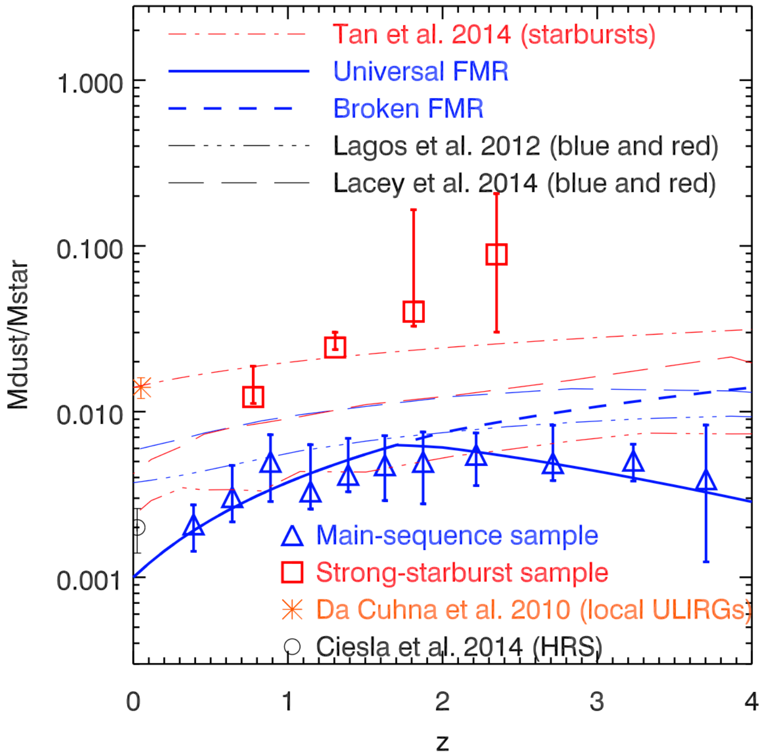
Dispersion of <U> individual galaxies → modeling of IR counts, background power spectrum

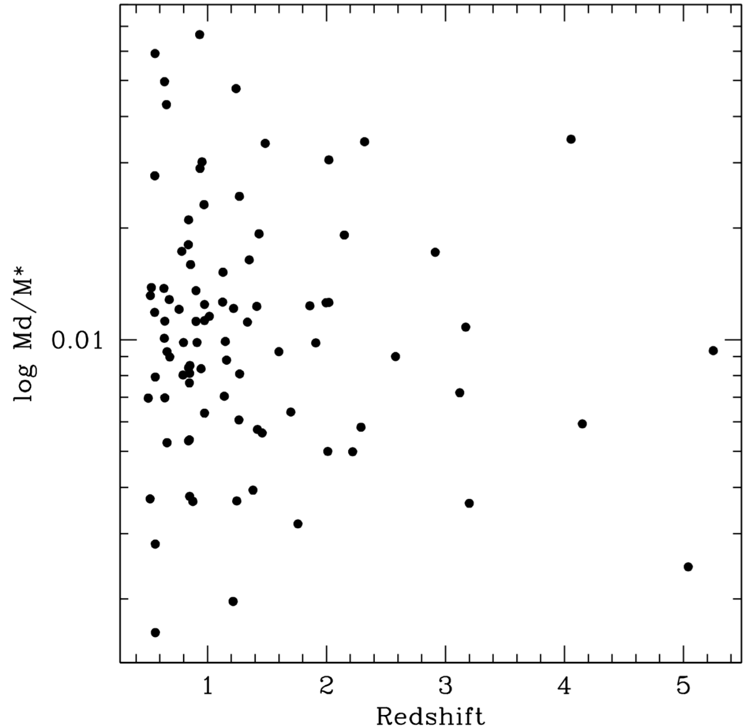
0.25dex in U → factor 1.8 (after accounting for measurement errors)

→ 10% variation in temperature (e.g., 30 +- 3 K)

Derivation of dust masses for individual galaxies z~1 to 3—5

Possible ‘cold’ bias respect to Bethermin+2015 seen also here





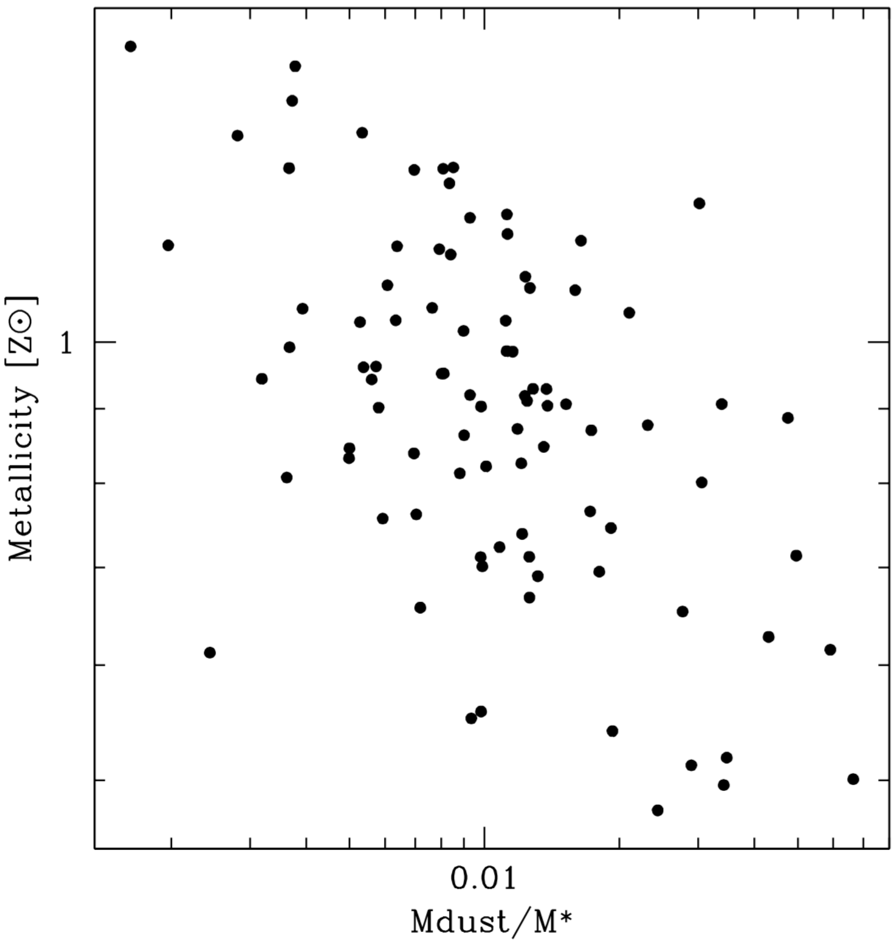
Scatter of factor of 2 in Mdust/M* in this sample

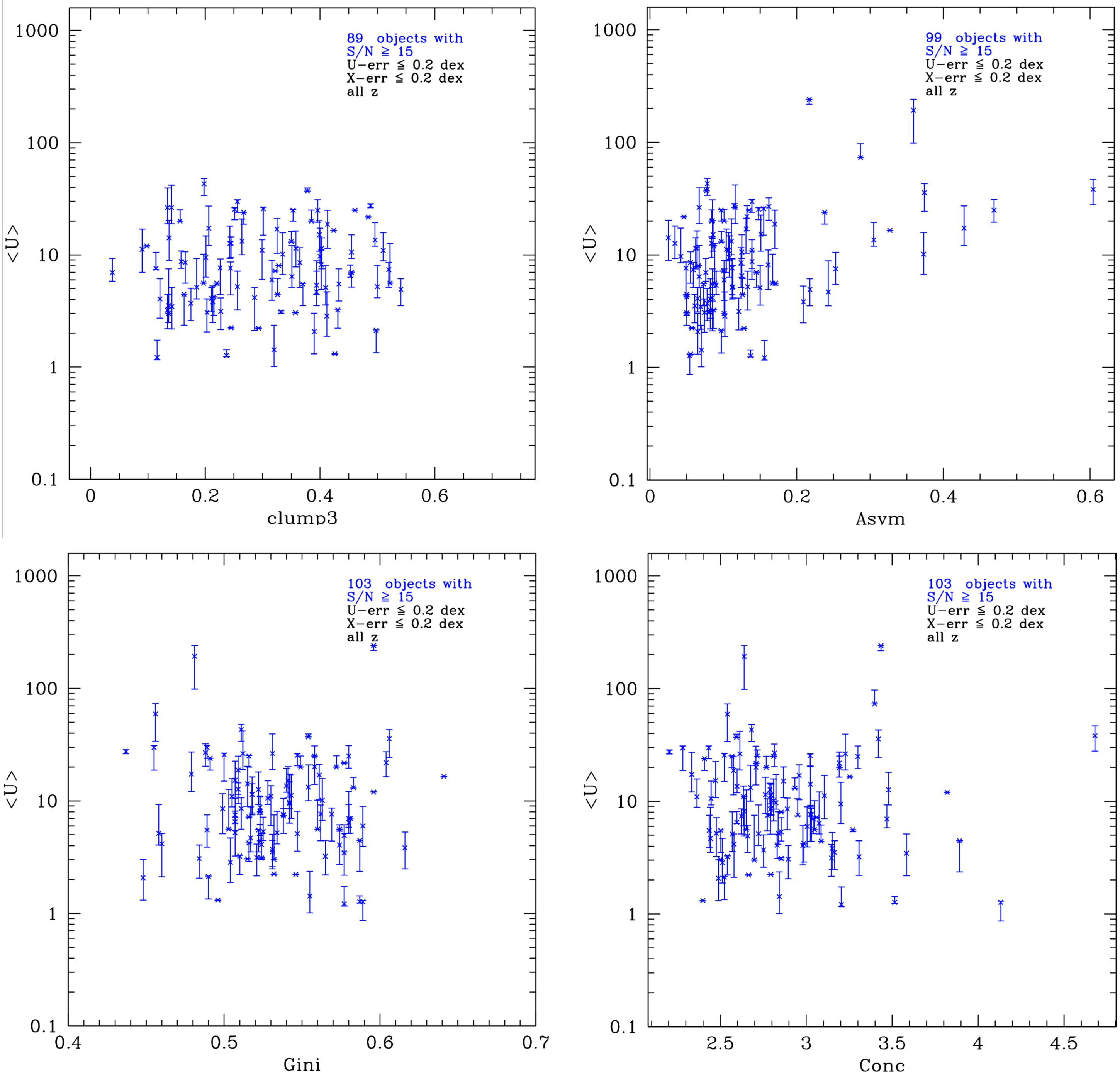
Real variation of metallicities at fixed redshift ? Or metal fraction in dust ?

Intrinsic scatter of M-metallicity relation is though to be <0.1dex

Strangely anti-correlated with metallicities inferred from FMR (SFR, M*)

We don't understand this… seems to tell low fraction of metals in dust corresponds to a higher one in the gas





Does <U> knows
about morphological
properties of galaxies ?
Clumpiness ?
Compactness ?

Only a weak trend
With asymmetry

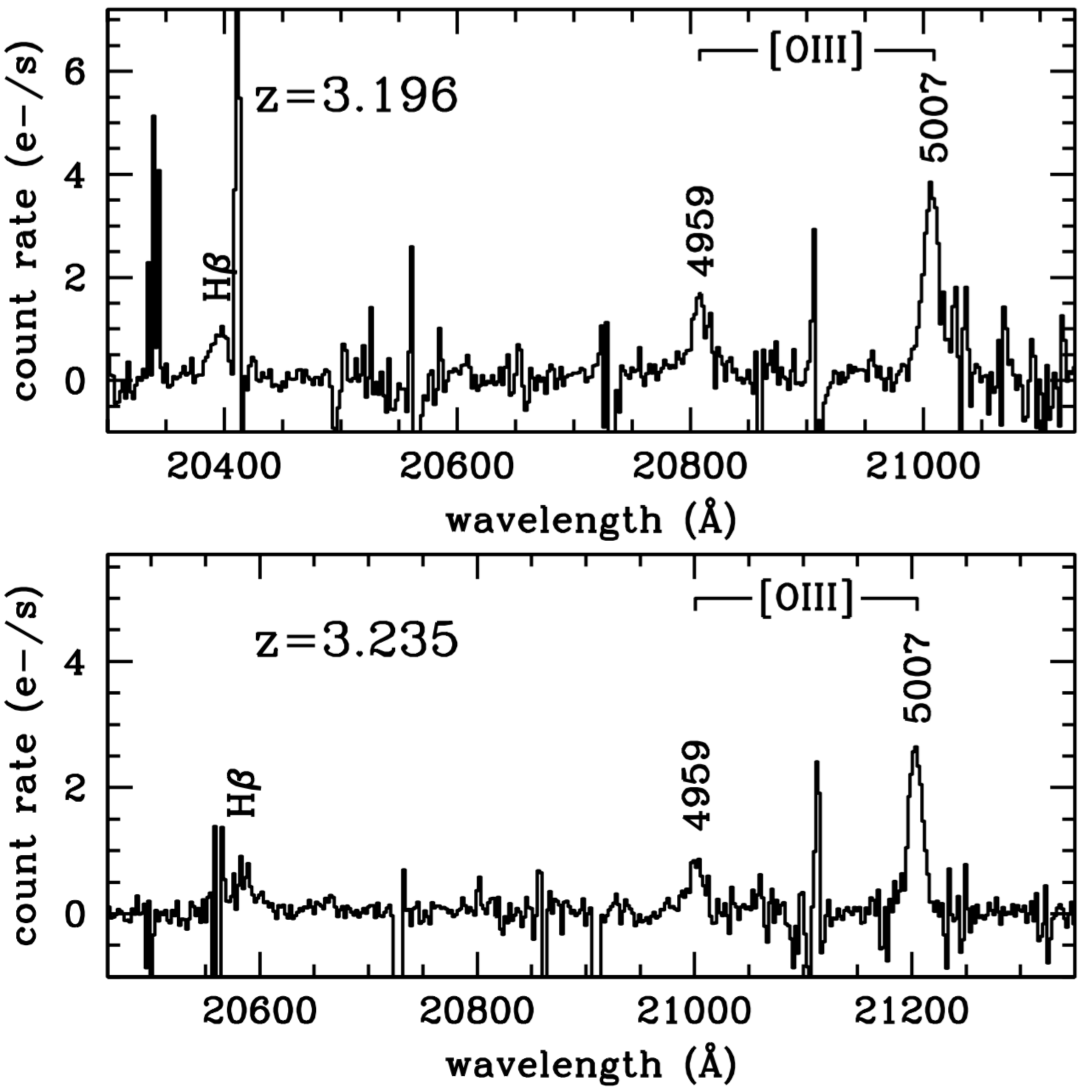
Not much more,
Surprisingly!

Maybe effects hidden
By range in z, M*, etc

To be investigated

Substantial sample of z>3 IR-detected galaxy candidates: ~55 objects

Follow-up program with MOSFIRE, lead by M. Dickinson



We have a handful redshift confirmations so far, more time allocated, this is tough!

A new look at the M*/BH relative growth
Rodighiero, Brusa, ED et al 2015
COSMOS field, 20000+ galaxies

(building on Mullaney, ED, et al 2012)

MS, below-MS, SBs (Herschel)

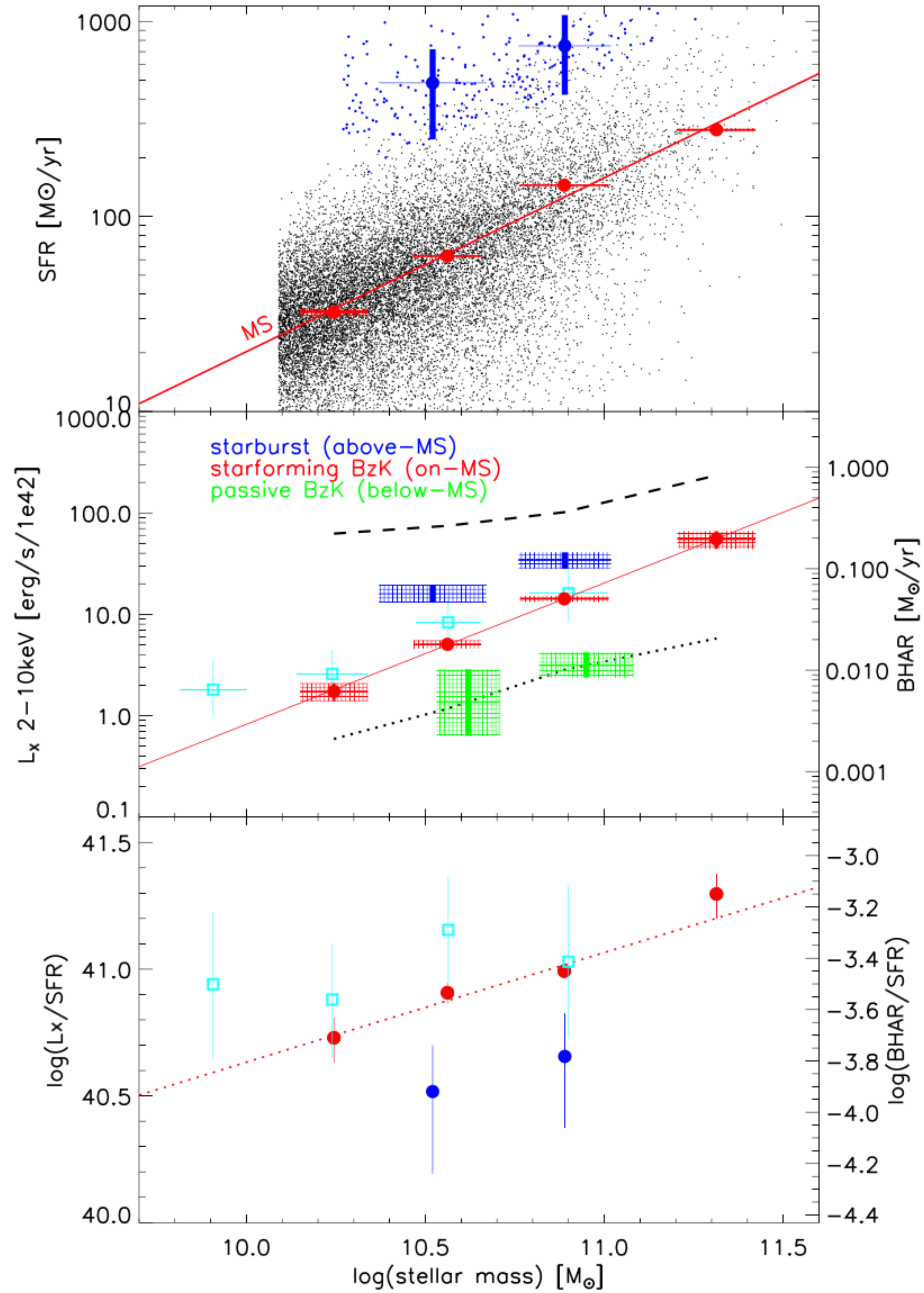
Goal: understand MBH/M* relation
examining relative growth rates SFR/Lx
(derivatives)

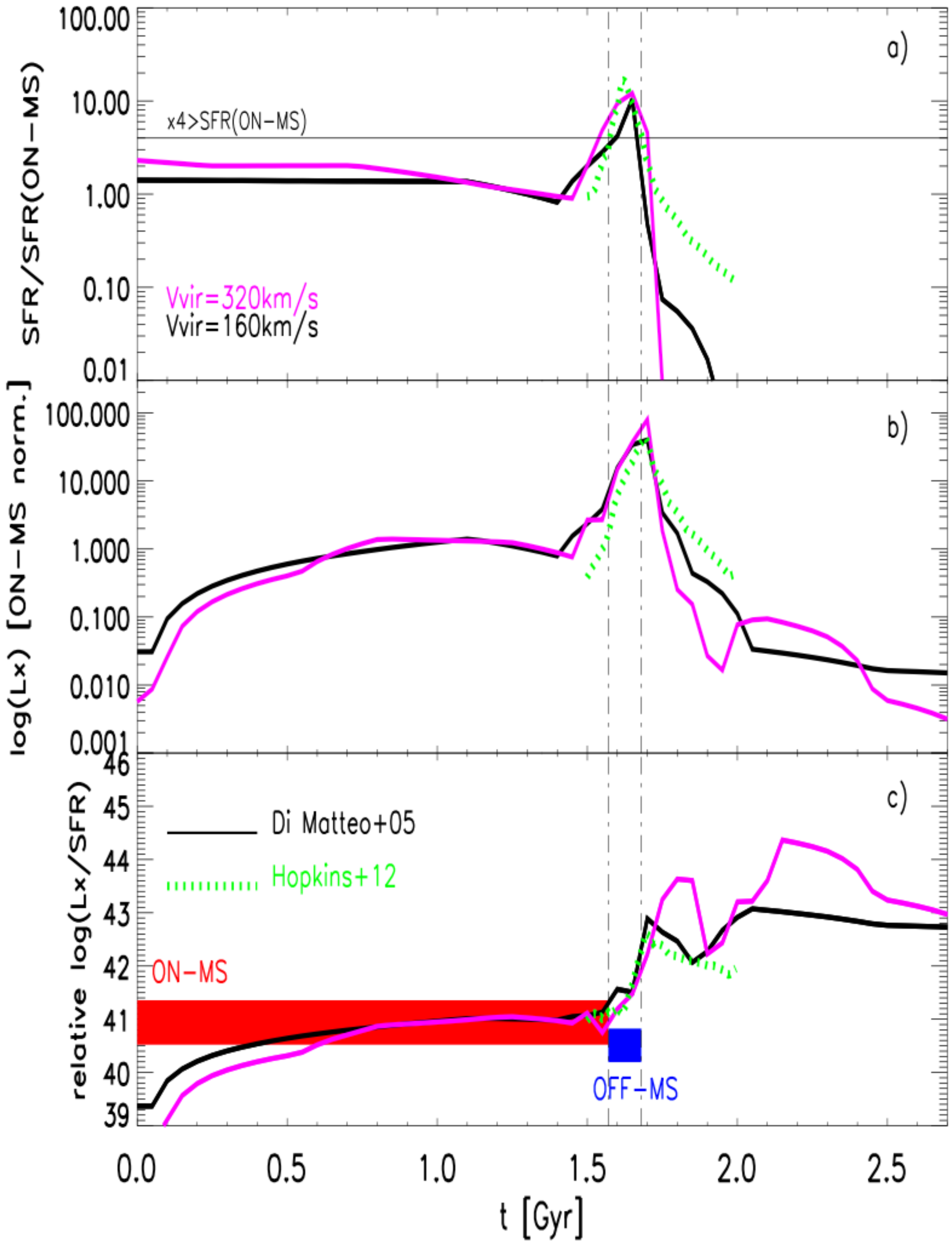
Results:
BH density in SBs (~6%) passive (~11%)

Nonlinear Lx/SFR trend in MS detected
(big BHs grows faster relative to stars)

Problem1: ratio ~0.5e-3
vs MBH/M* ~2—5 e-3 preferred today
(similar to X-ray density integral issue)

Problem2: Lx/SFR lower in SBs!





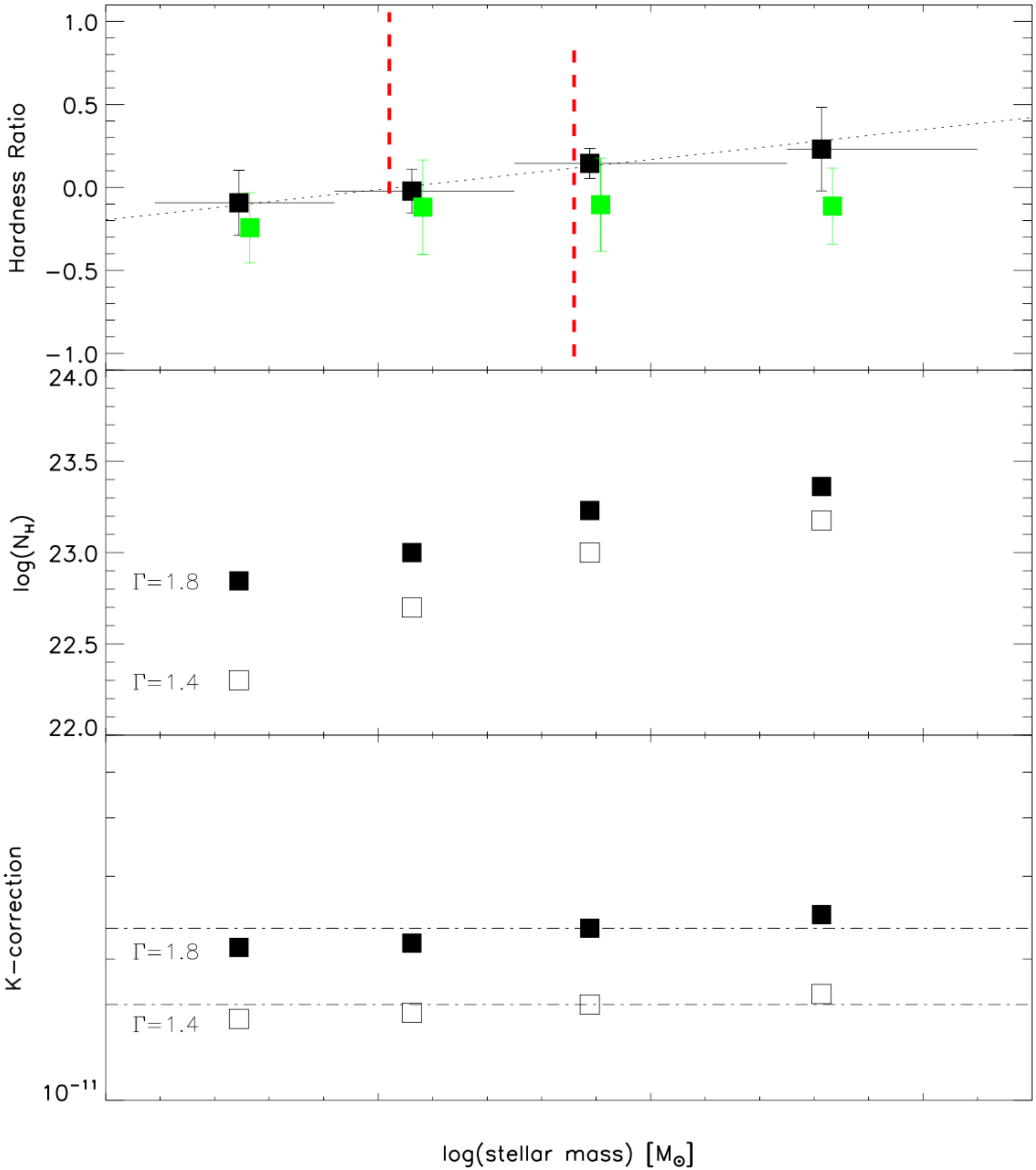
Lx/SFR lower in SBs!

A problem for merging driven BH triggering ? (ULIRG/QSO connection)

Models: di Matteo et al 2005; Hopkins et al 2012

Predict ~3—5 more BH growth than SFR during SB phase

<u>We observe x2 smaller!</u>



Limitations:

1) Obscuration ?
(we see little)

2) Bolometric corrections ?
(we use 22.5 Bol/Lx)

3) Efficiencies ?
(we use 10%)

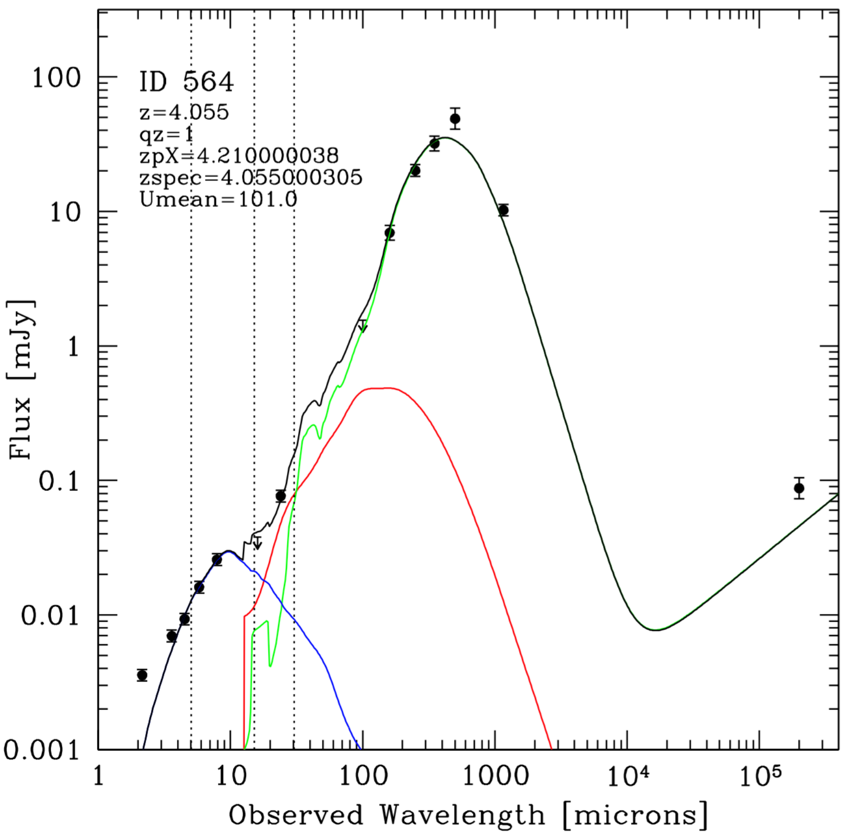
Point 1 and 2 can be improved from the IR

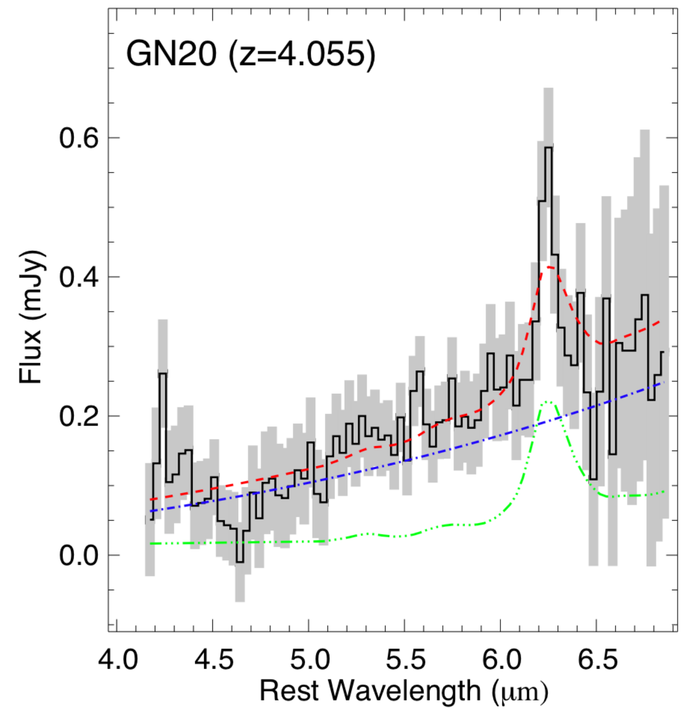
56 SBs in our sample 0.5<z<4 → try estimate BH rates from mid-IR torus detection

Fitting with SB template (Magdis+2012) and AGN torus templates (Mullaney+11)

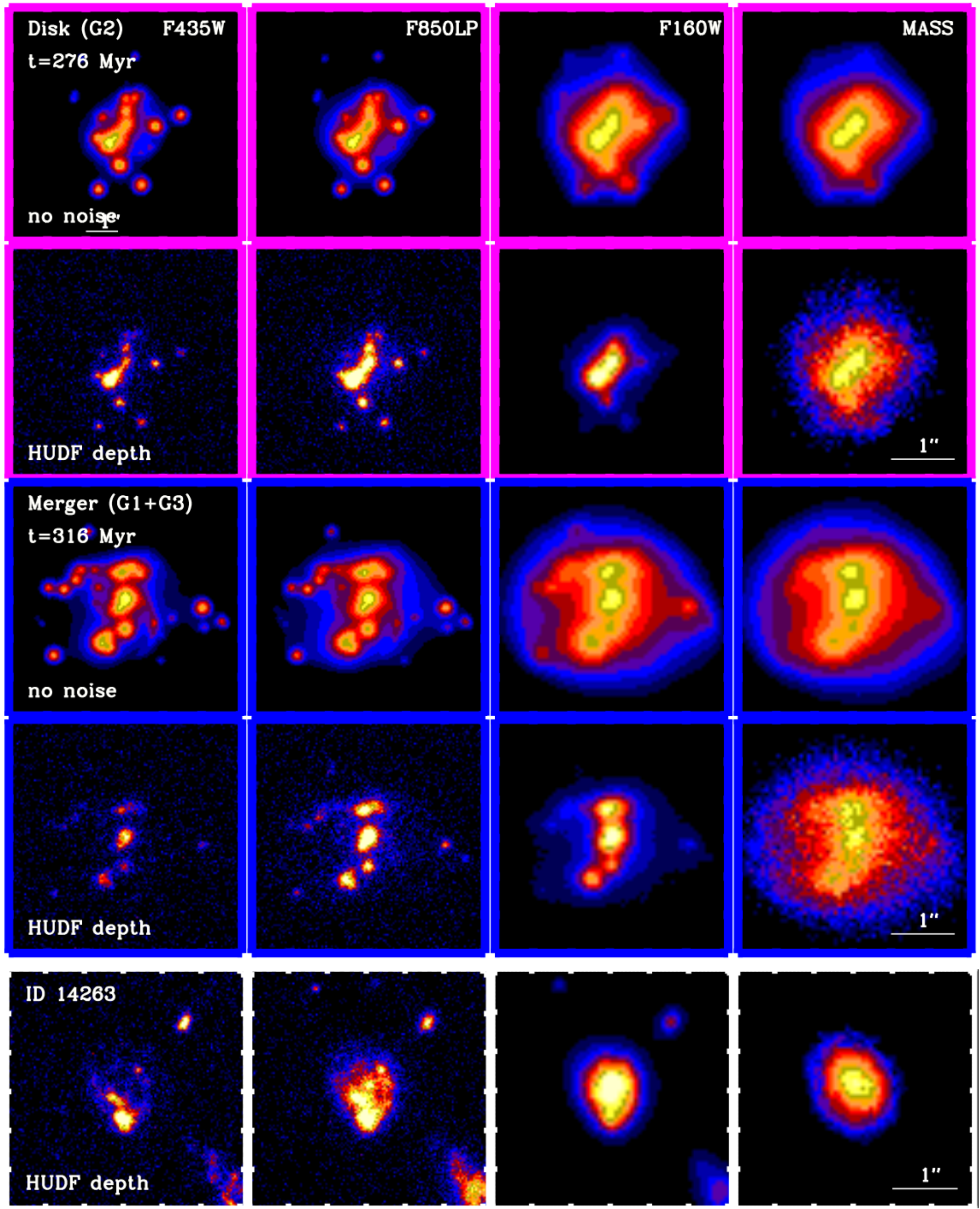
Determine acceptable fit from Δchi2 variations (Avni et al) for 2 interesting parameters (AGN and galaxy bolometric luminosity)

95% confidence threshold to accept AGN component



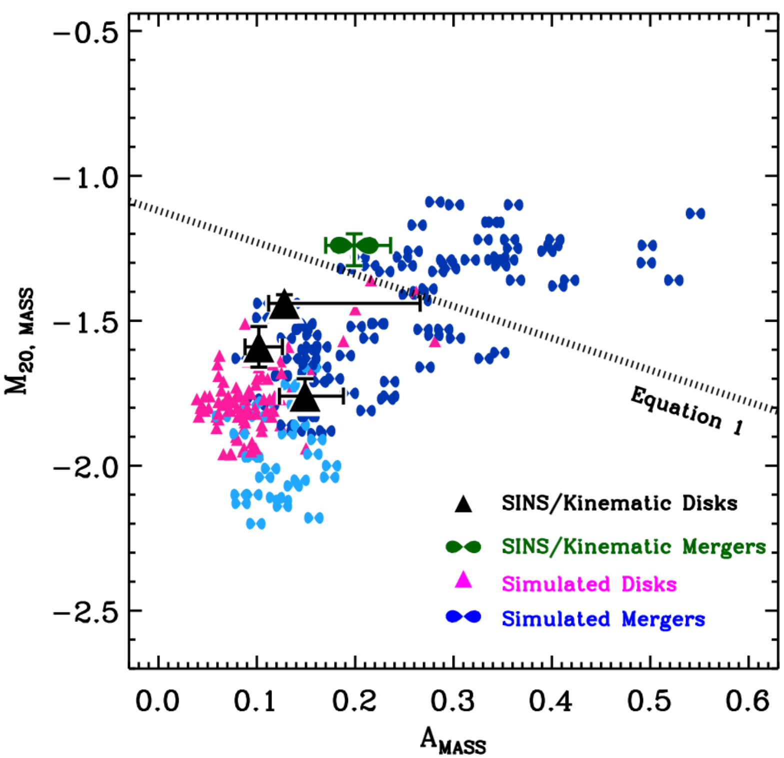


Encouraging results from GN20 IRS properties (Riechers+2014), by construction!



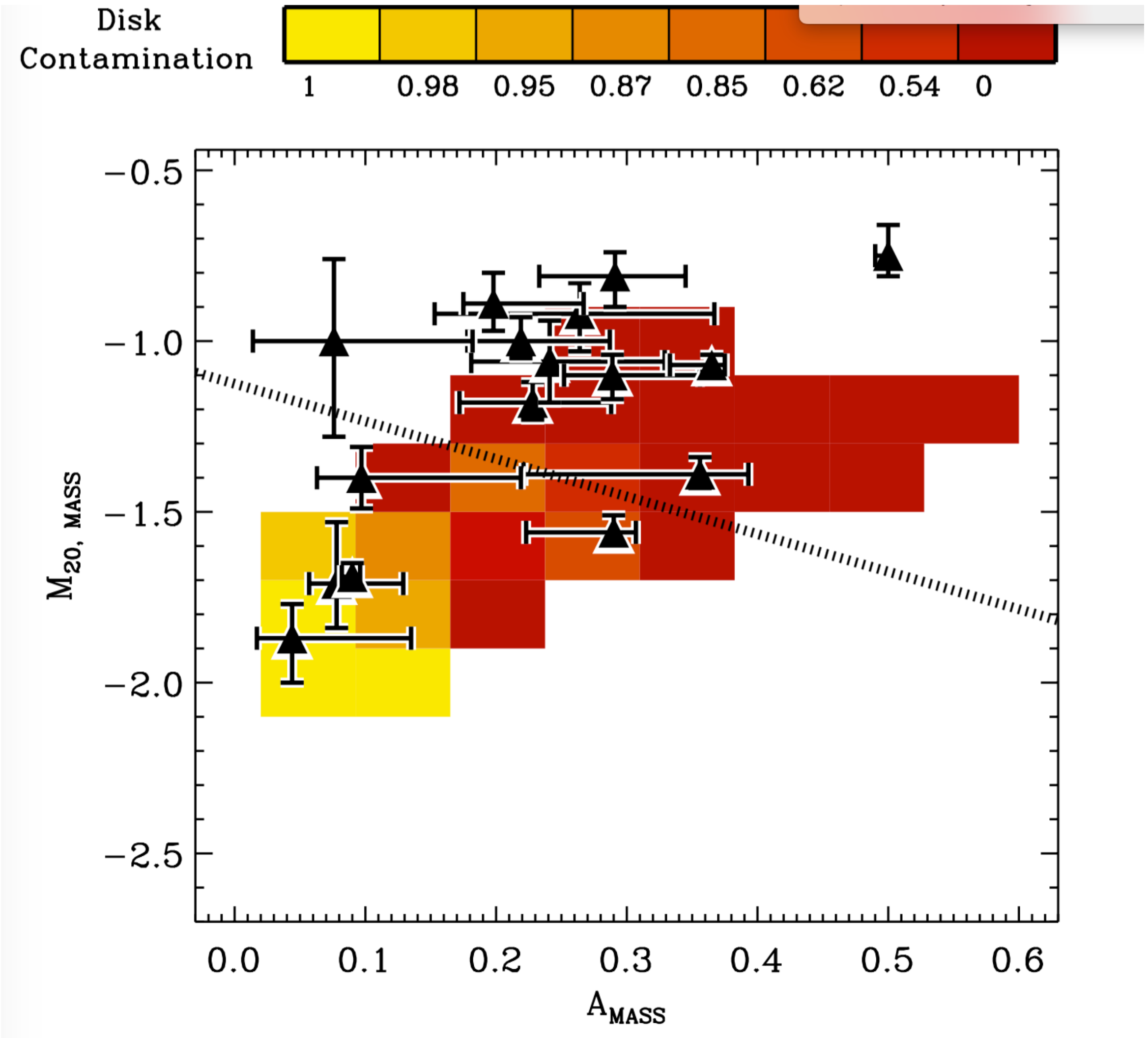
A new methods to identify mergers based on stellar mass maps derived from HST imaging

A. Cibinel et al 2015 submitted



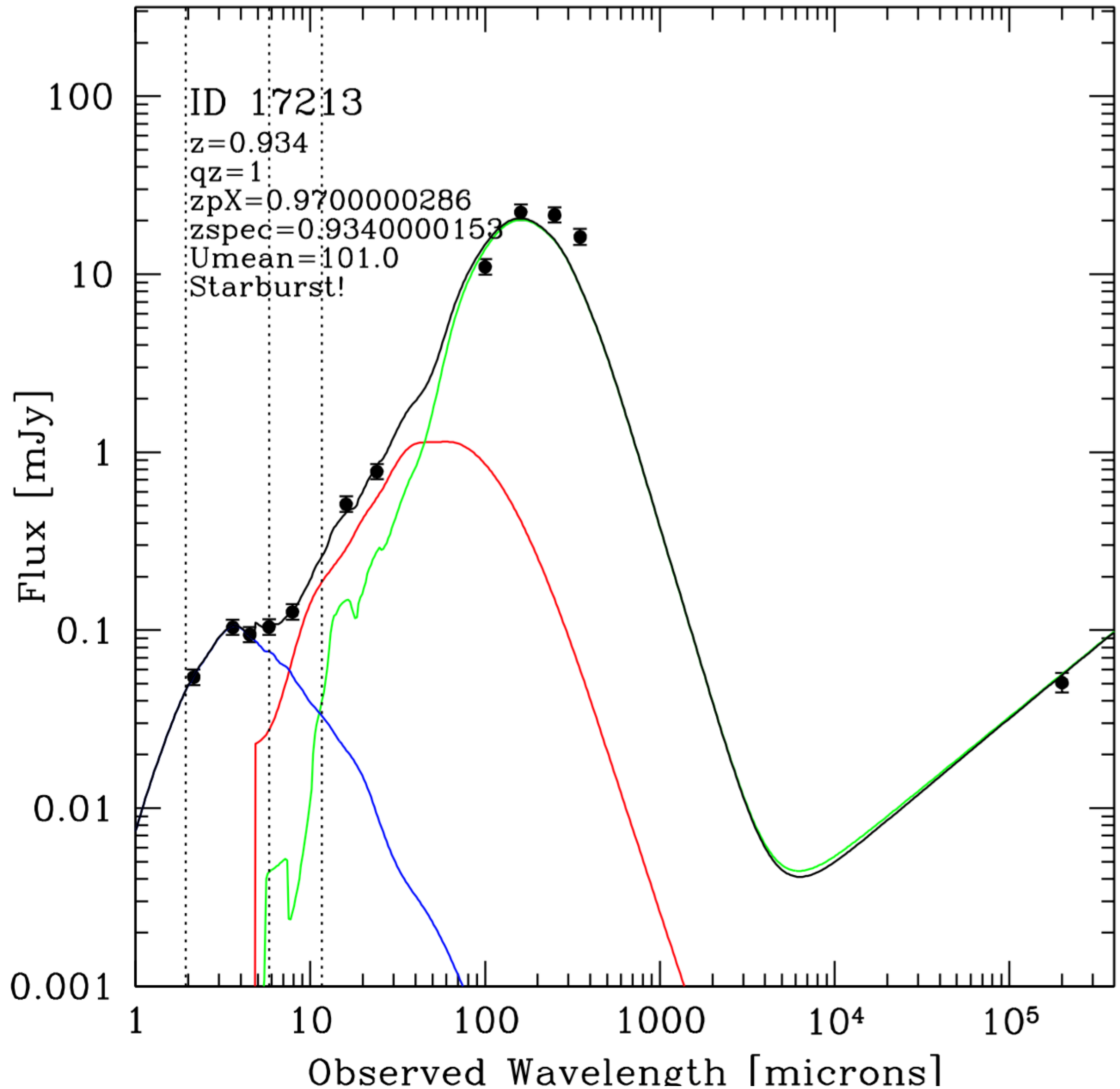
Based on Bournaud et al simulations

15 SBs with >.8 dex excess over the MS (most extreme sample)
Analysis by Anna Cibinel



Very large contribution of merging systems

Considering interactions, it could reach almost full sample



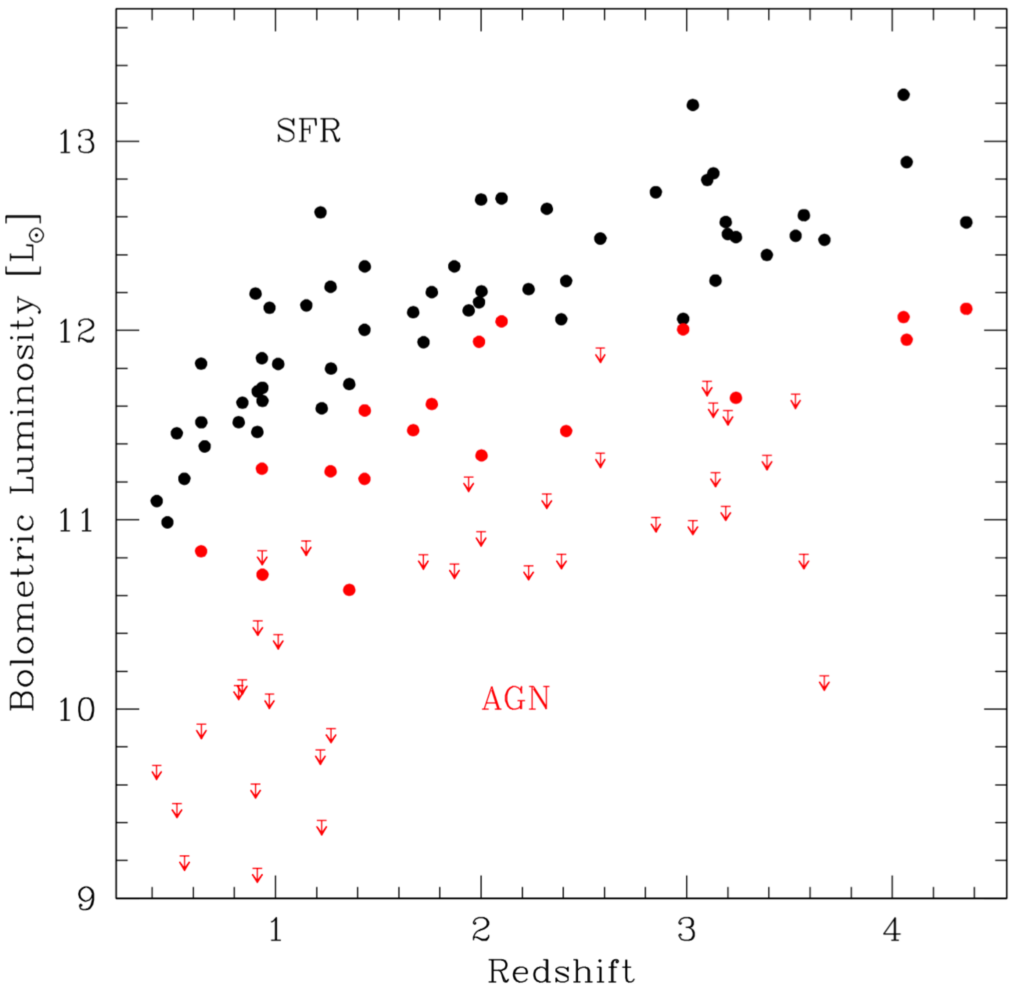
The only source that would have been seen in the X-ray in COSMOS is also our most significant torus detection

Soft ~ Hard 2e-15 cgs flux (HR~0)
Little X-ray obscuration

But Lbol from mid-IR 5x Lbol from X

Different bolometric correction ?
~20 → ~100
Plausible for brightest sources

From the analysis of the 56 SB galaxies, taken at face value…



Detection fraction:

33% at >0.6dex from MS
50% at >0.8dex from MS

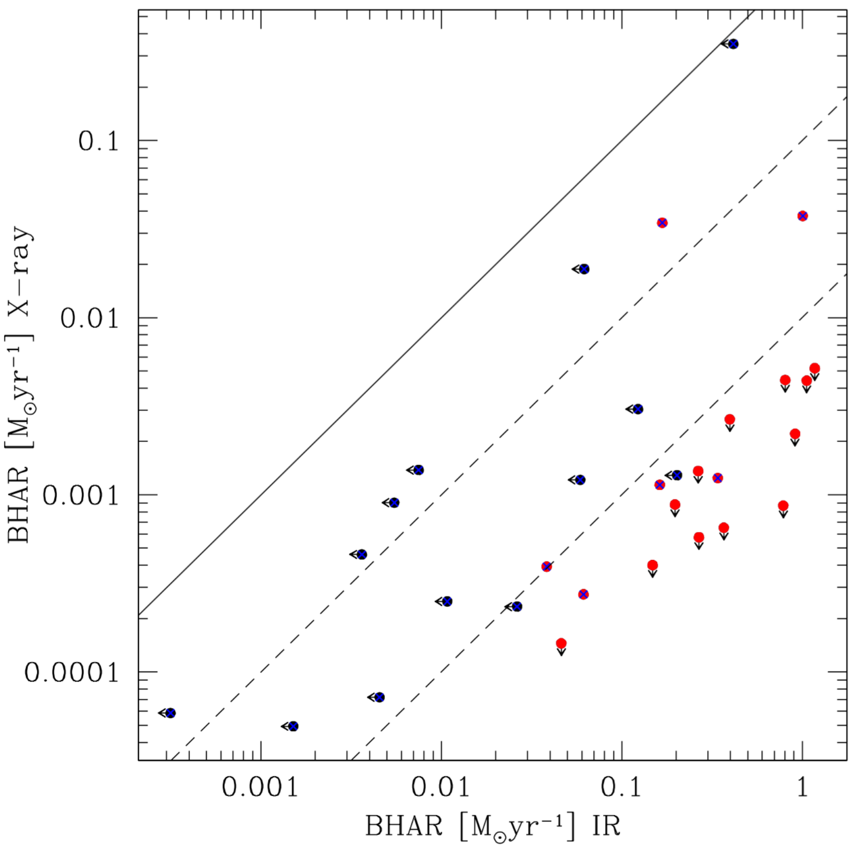
34% in X-rays (2Ms Chandra)

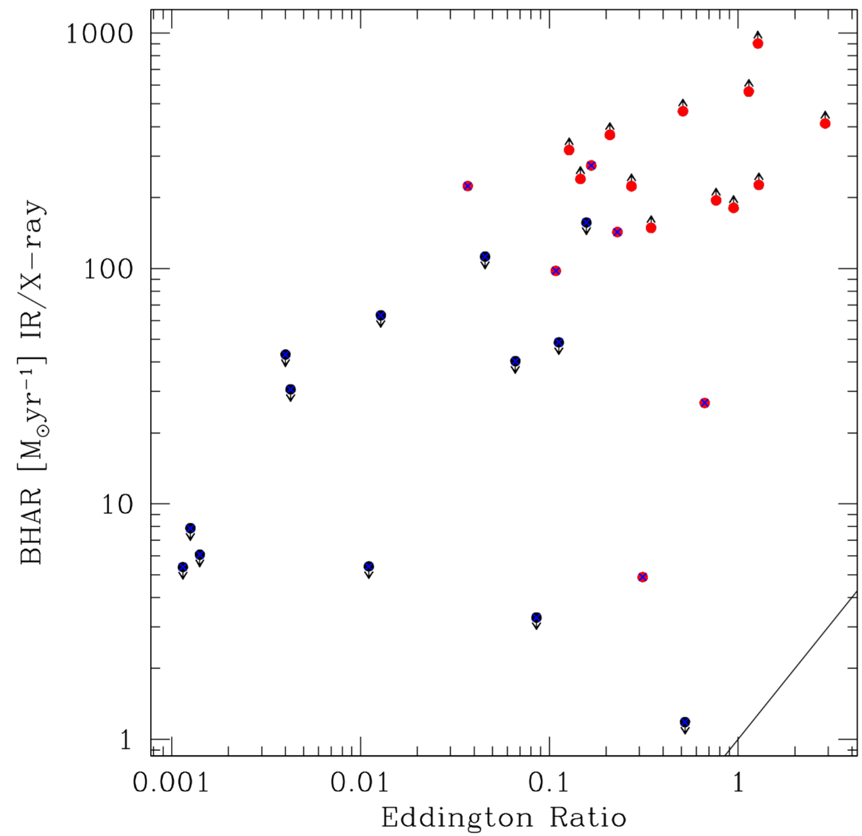
Typical Lbol from torus:
15% of SFRs (only detections)

Torus candidates: heavily obscured in X (and/or with very high bolometric corrections)

And high Eddington ratios: 0.1—1 (reaching close to the maximum expected luminosity)

If true, implies lots more AGN accretion activity than seen in X-rays… but





The average log(BHAR/SFR) from our Starburst sample is -3.1 +- 0.2dex
Only X3 higher than X-rays of Rodighiero et al (2015)
Because most X-ray signal comes from rare very luminous sources (we have 1)
And ratio is still low respect to what we could expect
If something wrong, most likely we overestimate <BHAR> from IR (spurious detections?)

Not clear if we could find a much bigger IR number if going wider also in IR
Otherwise maybe the energy conversion efficiency is <<0.1
(need lots more BH mass accreted for the same AGN light emitted)