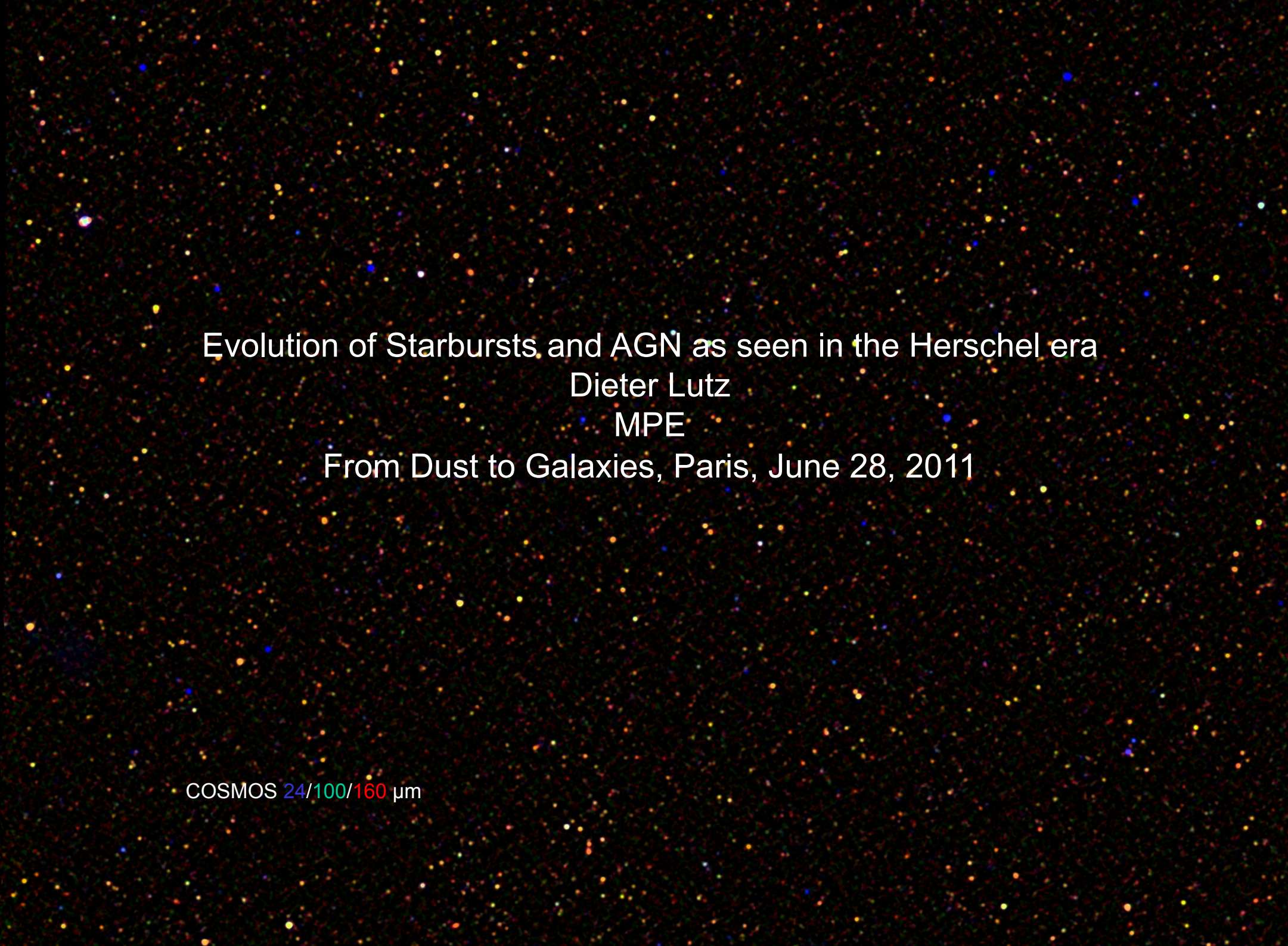
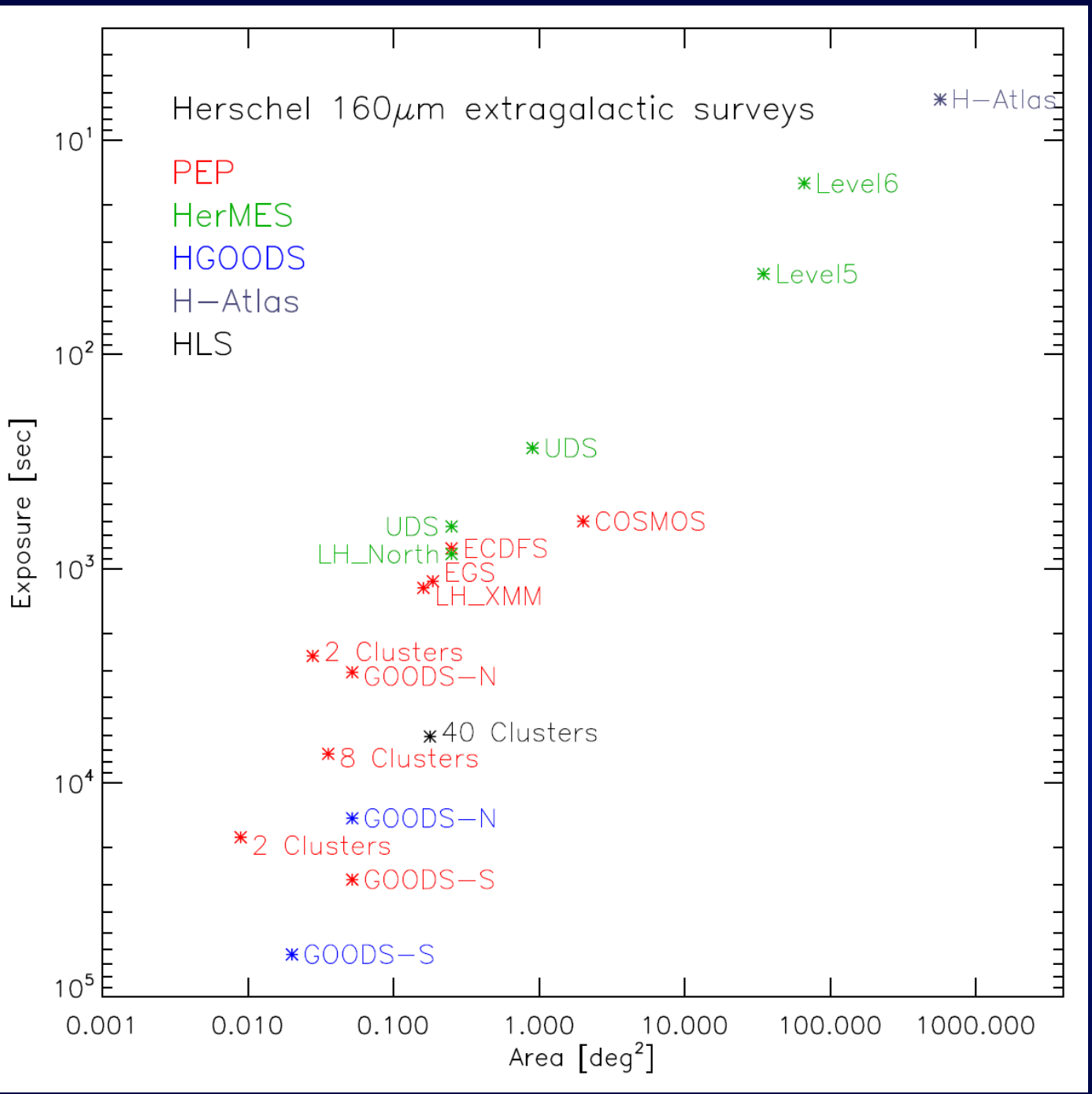
Evolution of Starbursts and AGN as seen in the Herschel era

Dieter Lutz
MPE

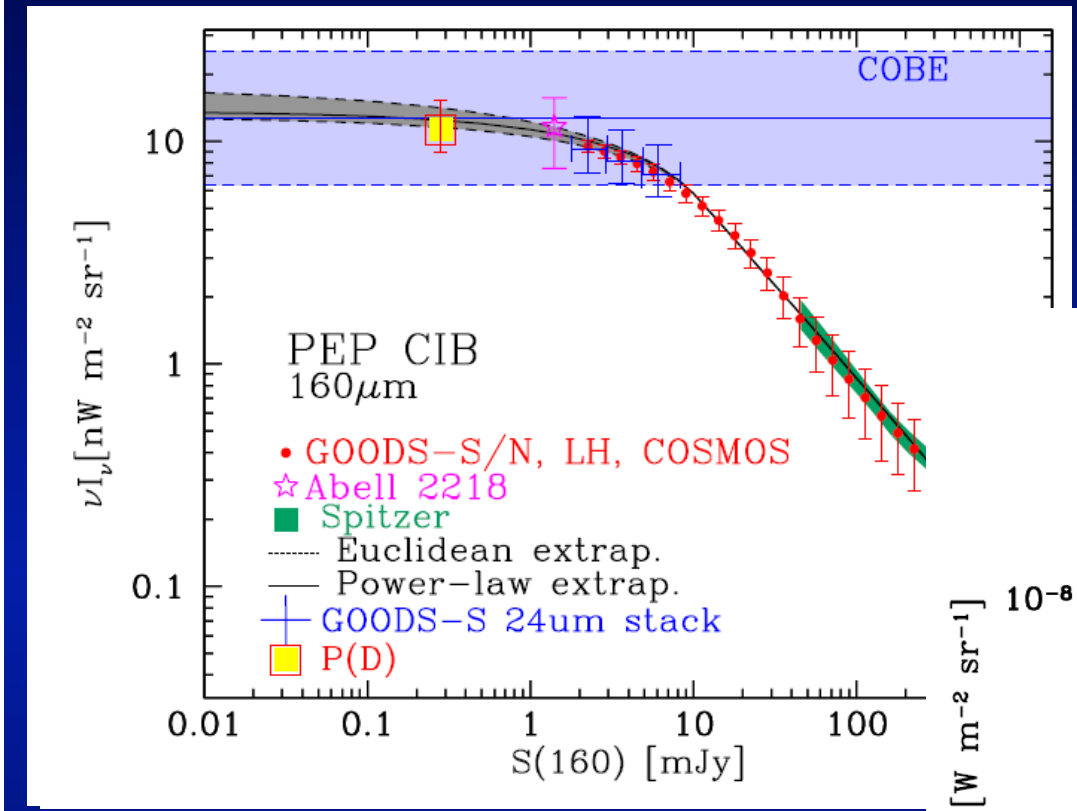
From Dust to Galaxies, Paris, June 28, 2011



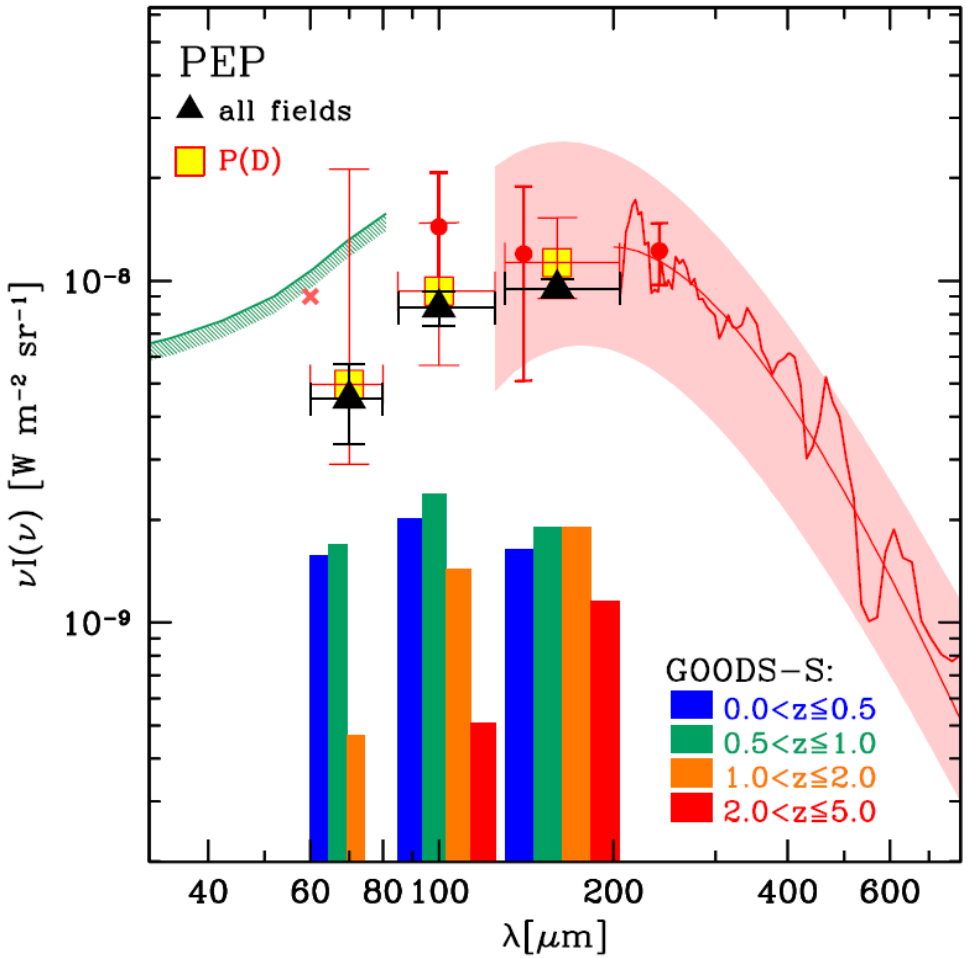


Leo Metcalfe
Marco Mignoli
Hagai Netzer
Raanan Nordon
Koryo Okumura
Ana Perez
Ismael Perez Fournon
Albrecht Poglitsch
Paola Popesso
Lucia Pozzetti
Francesca Pozzi
Laurie Riguccini
Giulia Rodighiero
Jose Miguel Rodriguez
David Rosario
Amelie Saintonge
Fadia Salmi
Mara Salvato
Miguel Sanchez
Paola Santini
Joana Santos
Li Shao
Eckhard Sturm
Linda Tacconi
Margherita Talia
Silvia Tomassin
Ivan Valtchanov
Michael Wetzstein
Eckhard Wieprecht
Stijn Wuyts

Resolving and slicing the CIB



Berta+ 2010, 2011

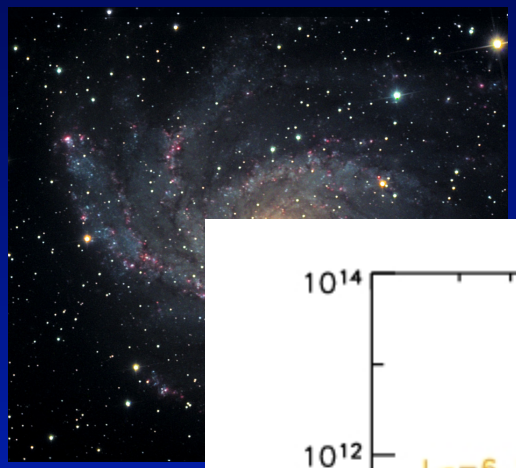


10x deeper than Spitzer

Resolved into individual sources:
(~35% @ 70μm)
~58% @ 100μm
~74% @ 160μm

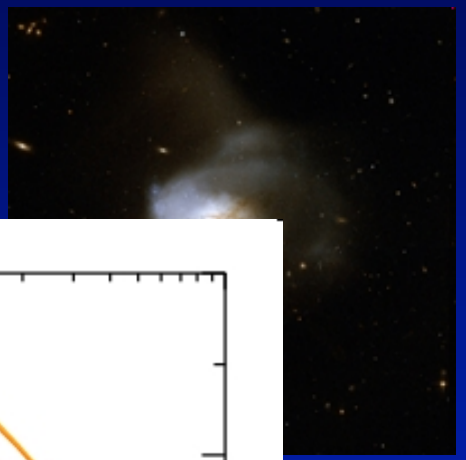
Conventional (local) wisdom on infrared galaxies and star formation

Normal galaxy



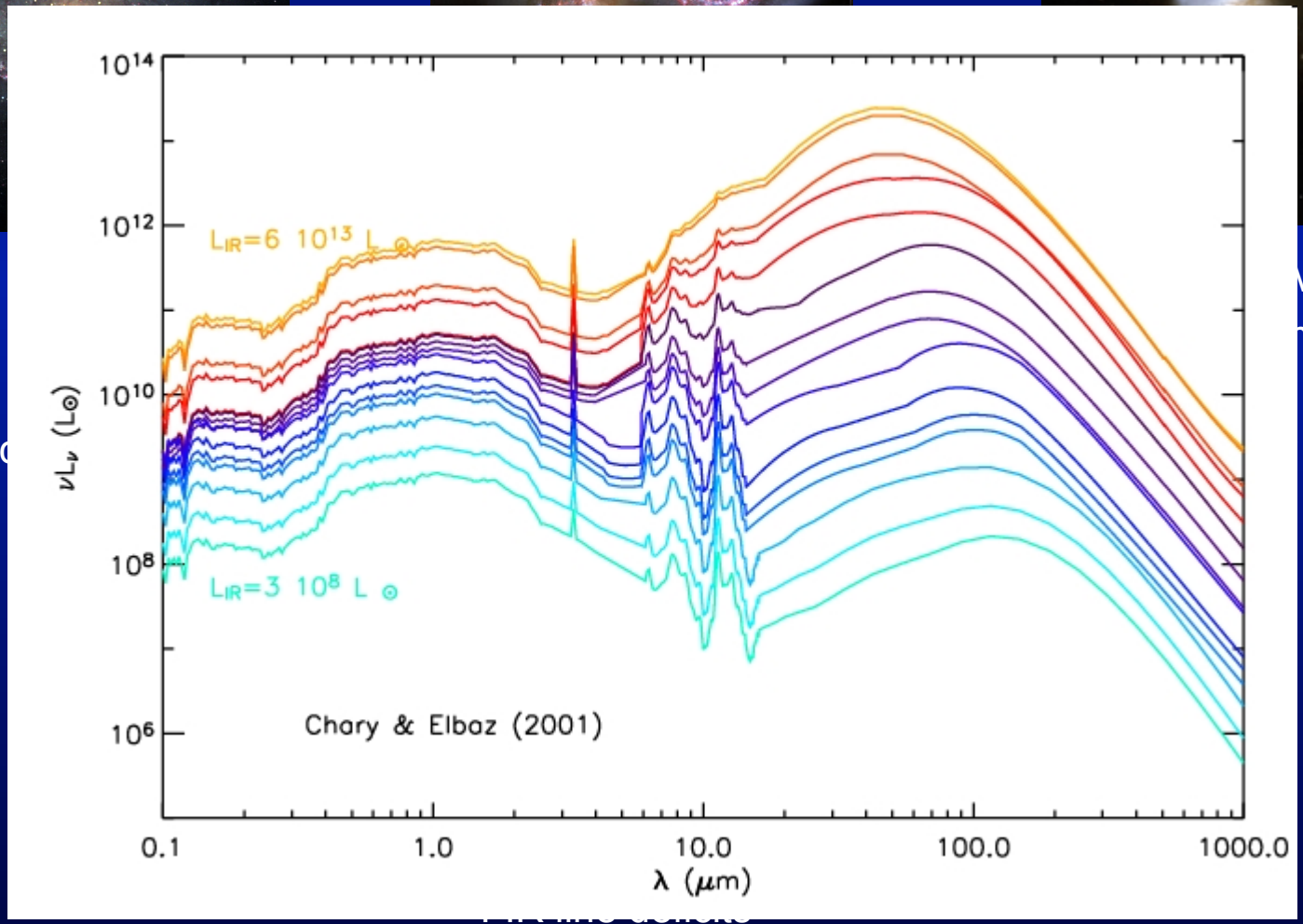
LIRG

ULIRG



2 M_{Sun}/yr
disk
low
several kpc
on
cool
high

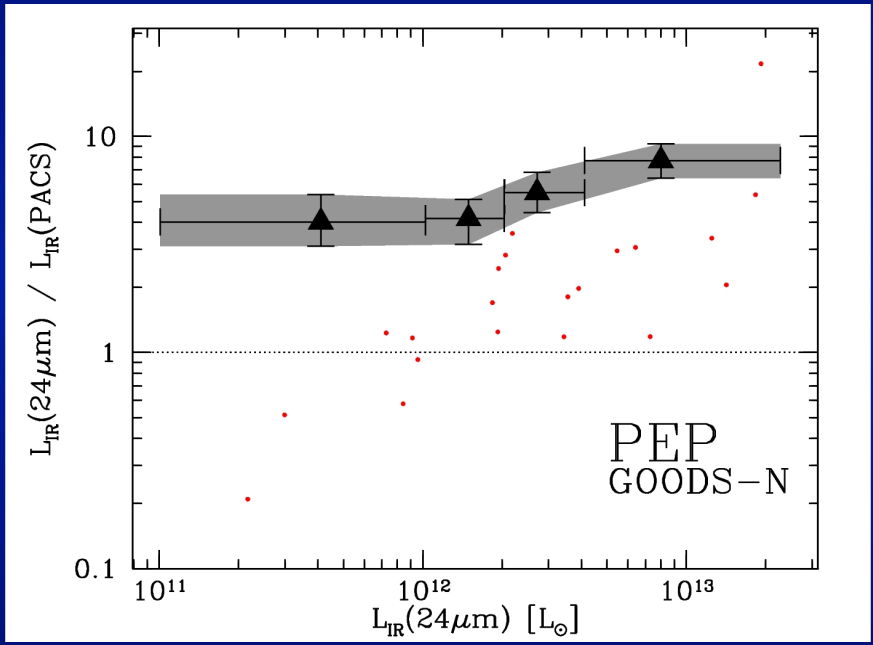
M_{Sun}/yr
merger
high
100pc
above
warm
low

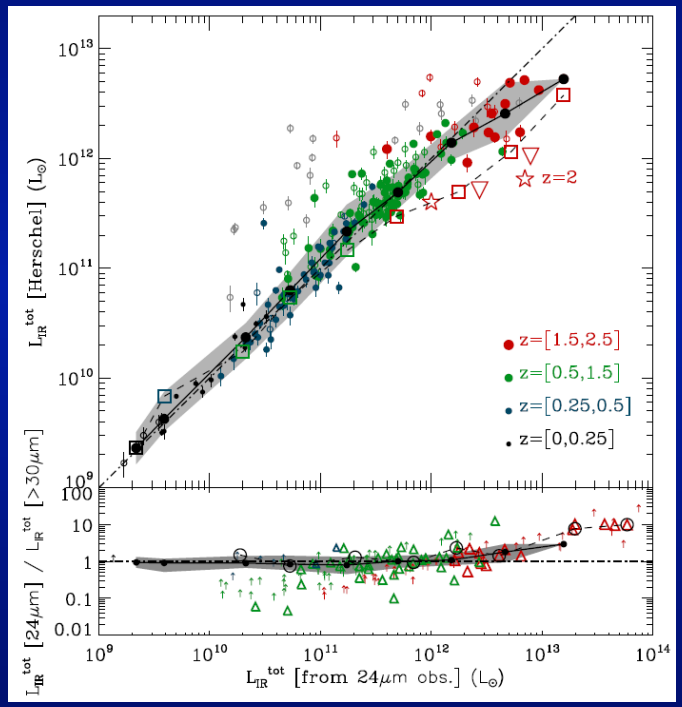


The IR ‘excess’ – overpredicted SFR from 24μm at z~2

Spitzer indications for SFR overestimate using 24μm and local SED template families :
Papovich+ 07, Daddi+ 07

Change of SEDs’ PAH/IR at given L, or mid-IR contribution by (obscured) AGN?



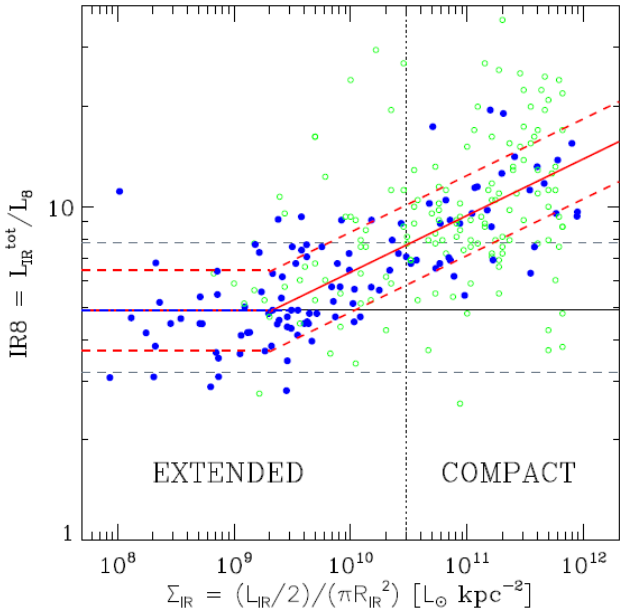


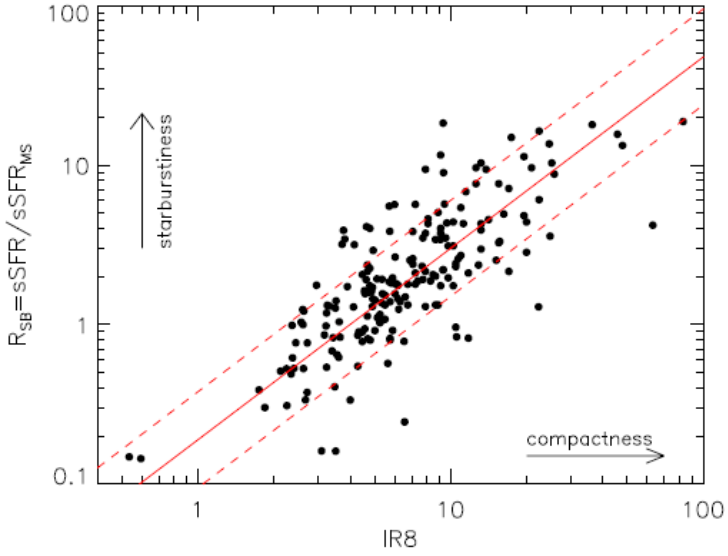
Strongly seen in Herschel Science Demonstration Data: Nordon+ 10, Elbaz+10

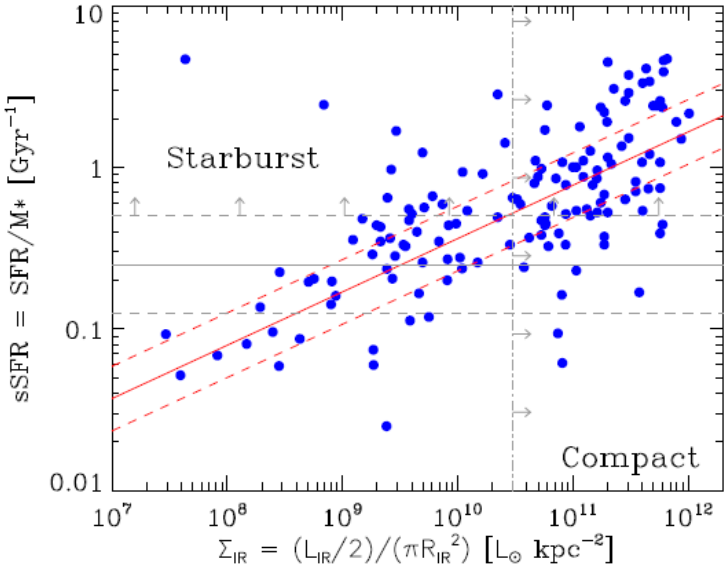
… and again in the deepest current Herschel data (Elbaz+11, Nordon+11)

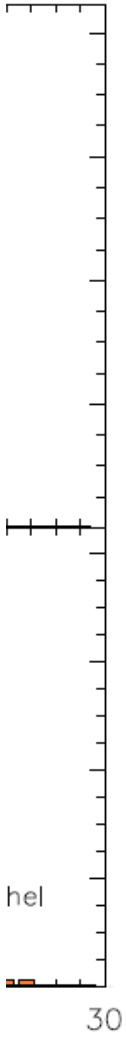
The role of the ‘main sequence’ of star-forming galaxies

Local galaxies







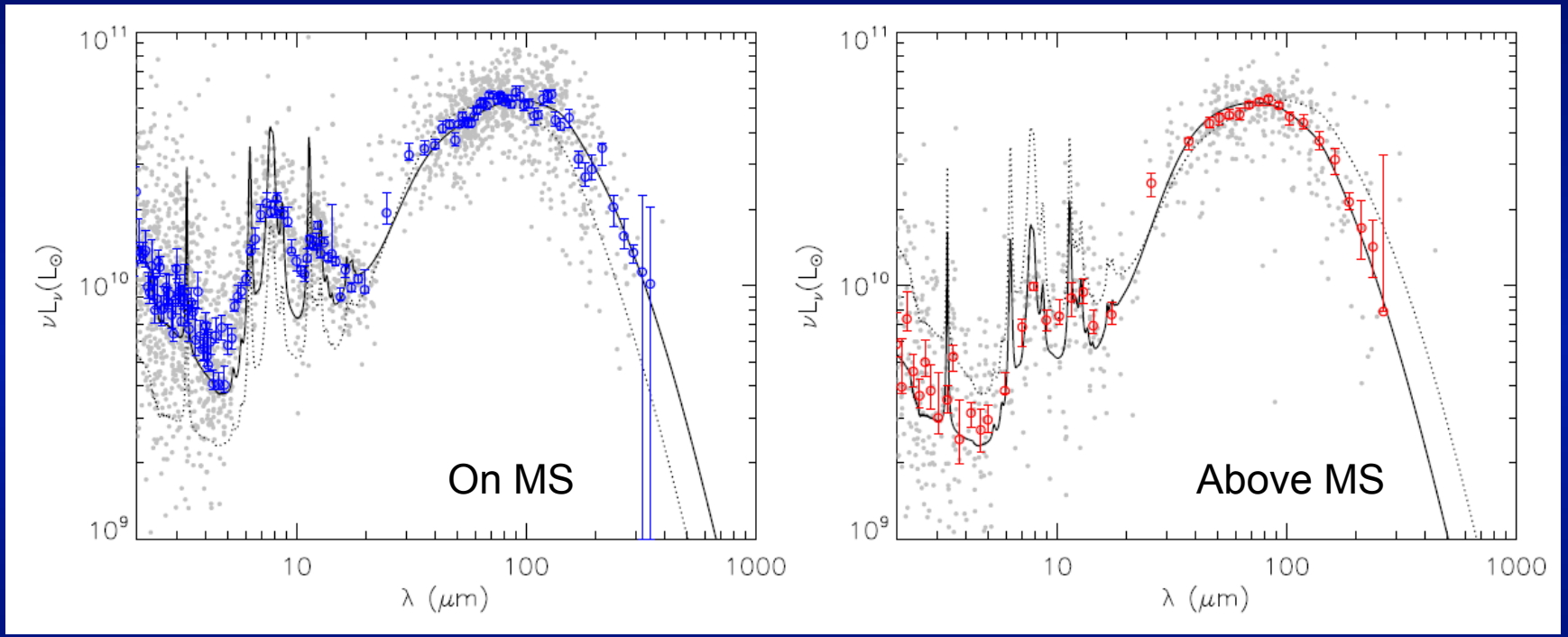


IR8 = L_{IR}^{tot}/L_8

L_{IR}^{tot} ($L_\odot$)

Elba

Average SEDs for high-z galaxies on and above MS

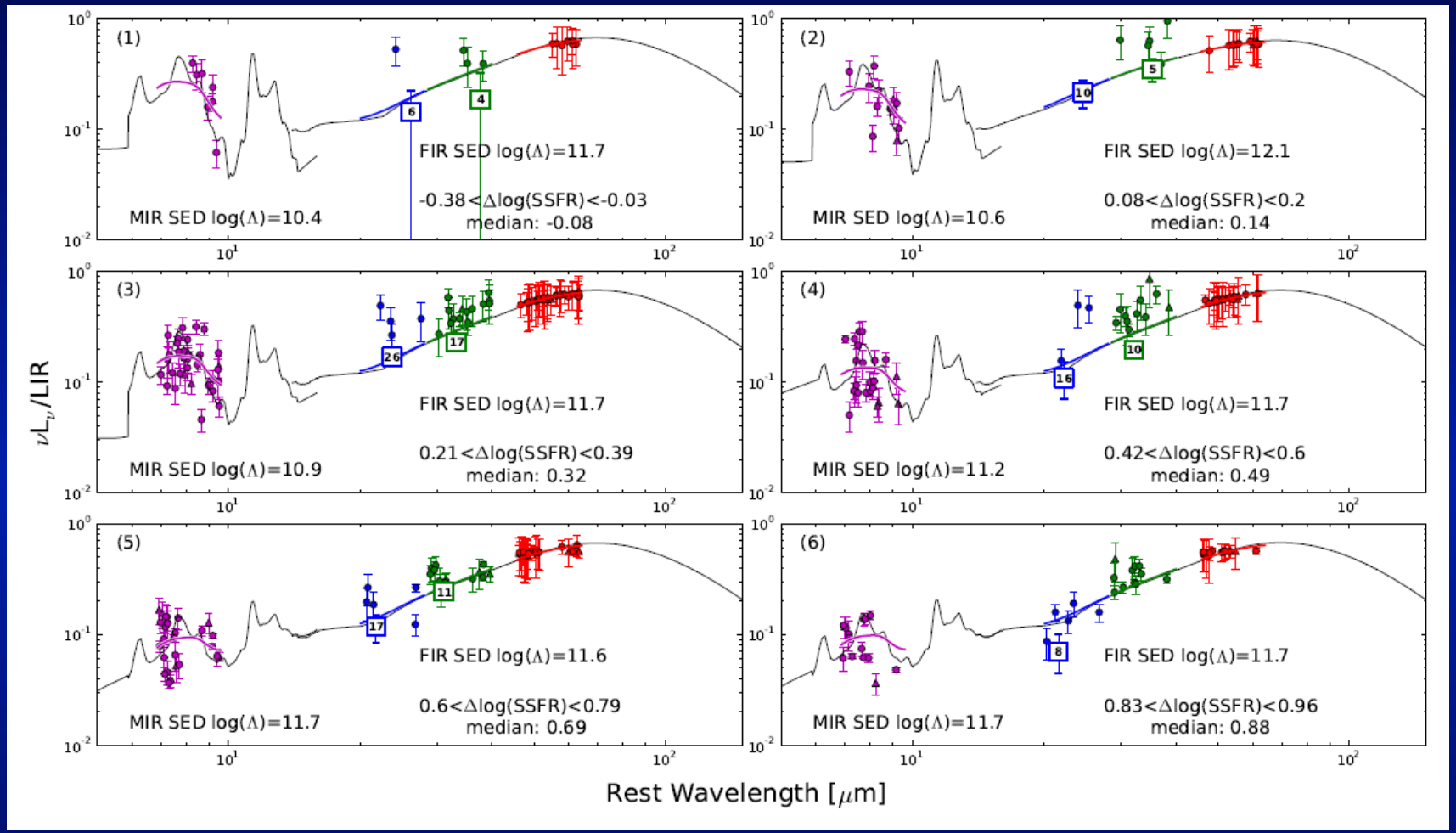


High PAH/FIR, cold FIR

Low PAH/FIR, warm FIR

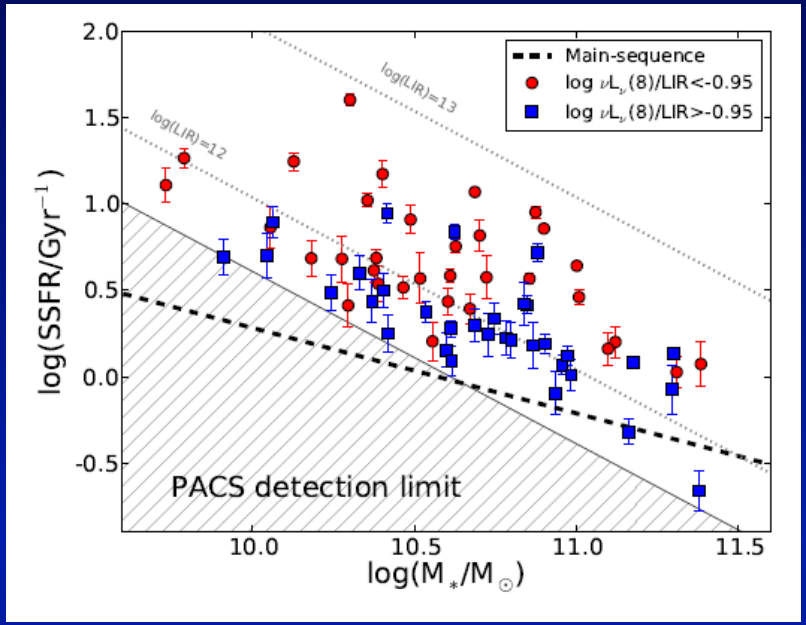
Elbaz+11 1105.2537 (GOODS-Herschel KP)

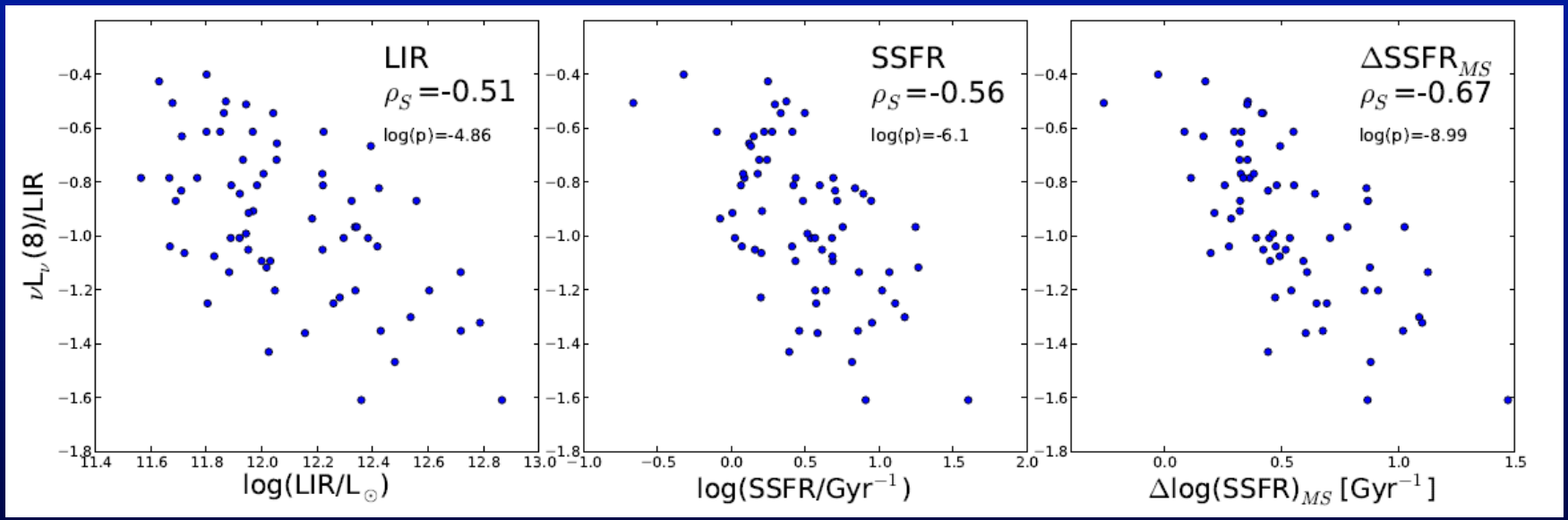
Reconstructing average mid-to FIR SEDs of z~1-2 FIR detected galaxies



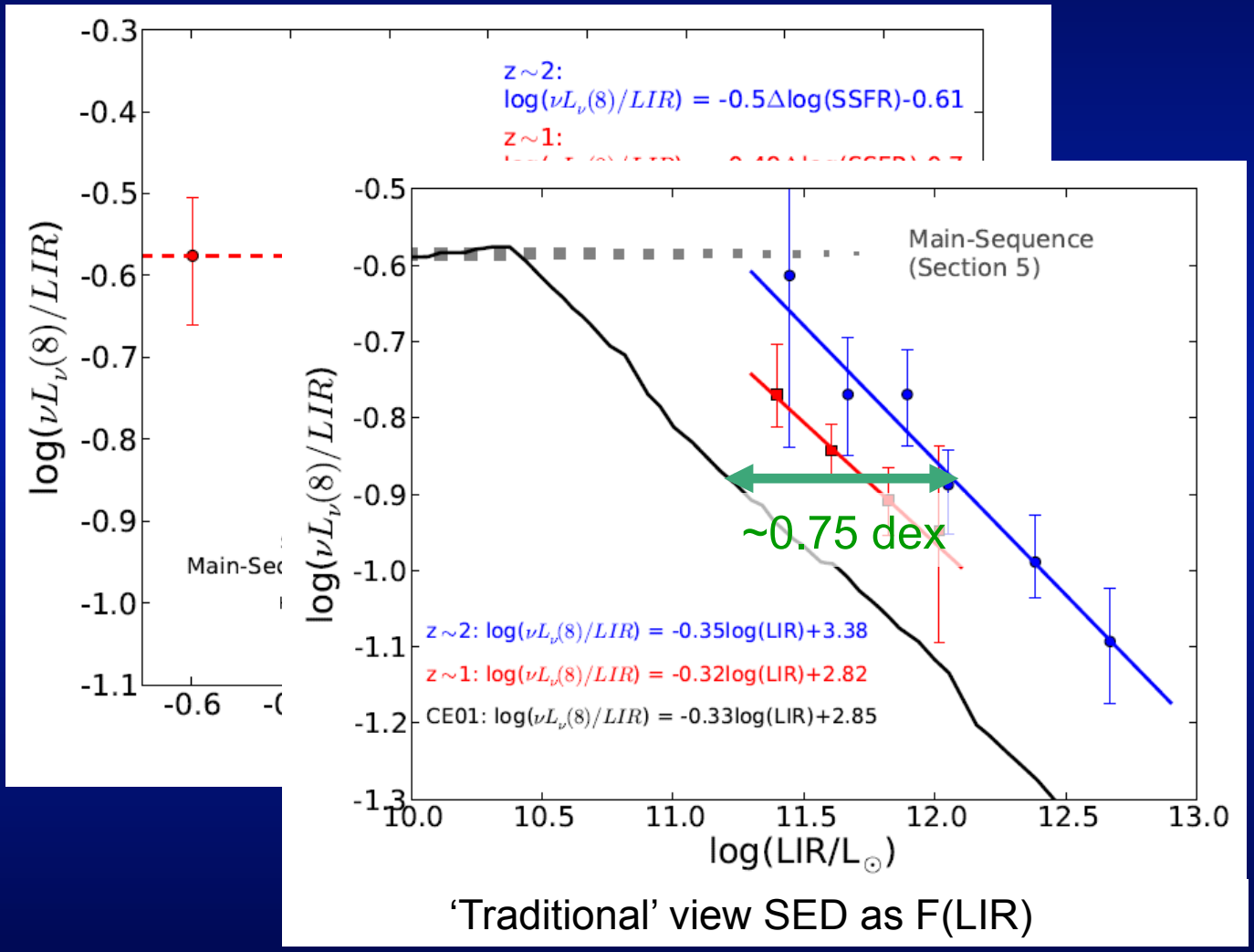
SEDs and νLν(8)/IR from combination of Herschel/PEP with deep Spitzer MIPS/IRS peakup imaging
Nordon+ 1106.1186

But what is the physical quantity best correlating with νLν(8)/IR?





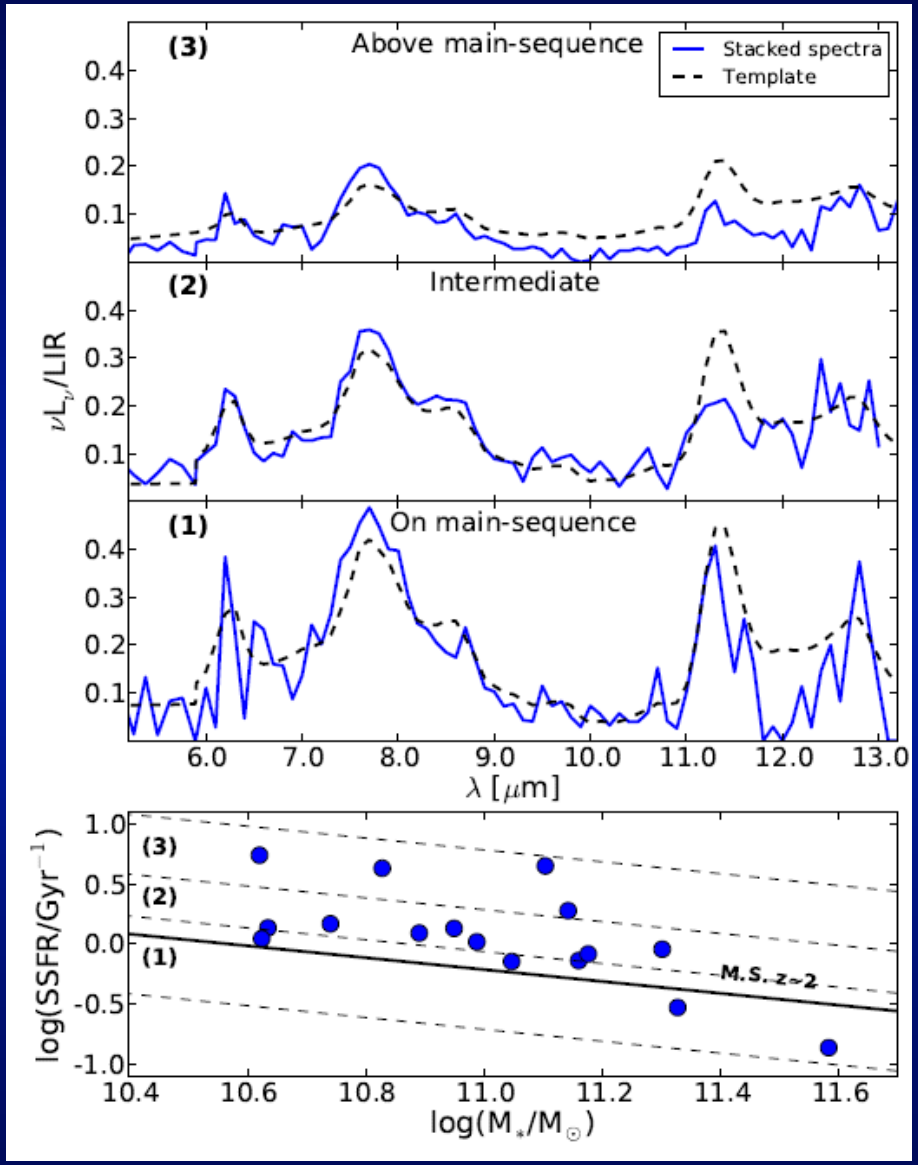
Consistent relation between νLν(8)/IR and offset from main sequence



'Traditional' view SED as F(LIR)

Nordon+11 1106.1186

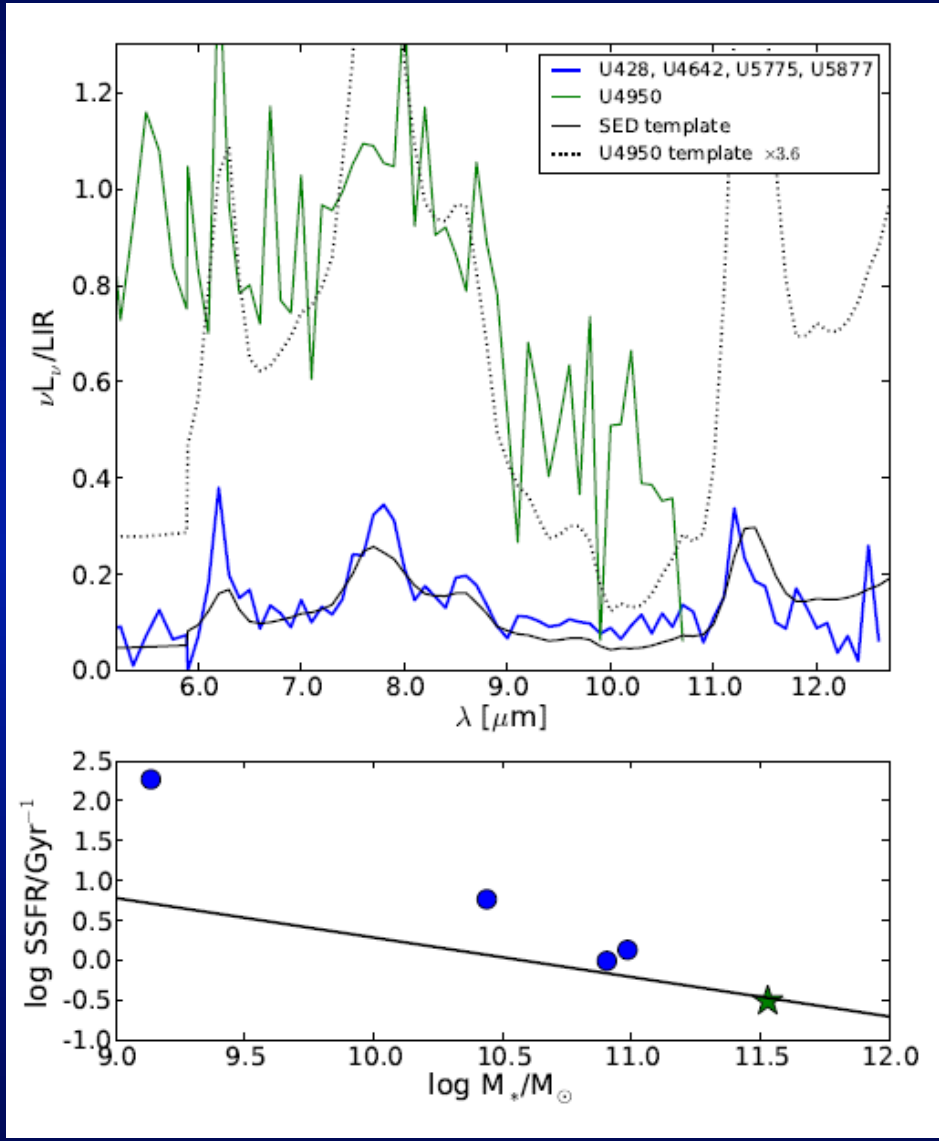
IRS spectra: influence of AGN is minor



Using IRS spectra from Fadda+10

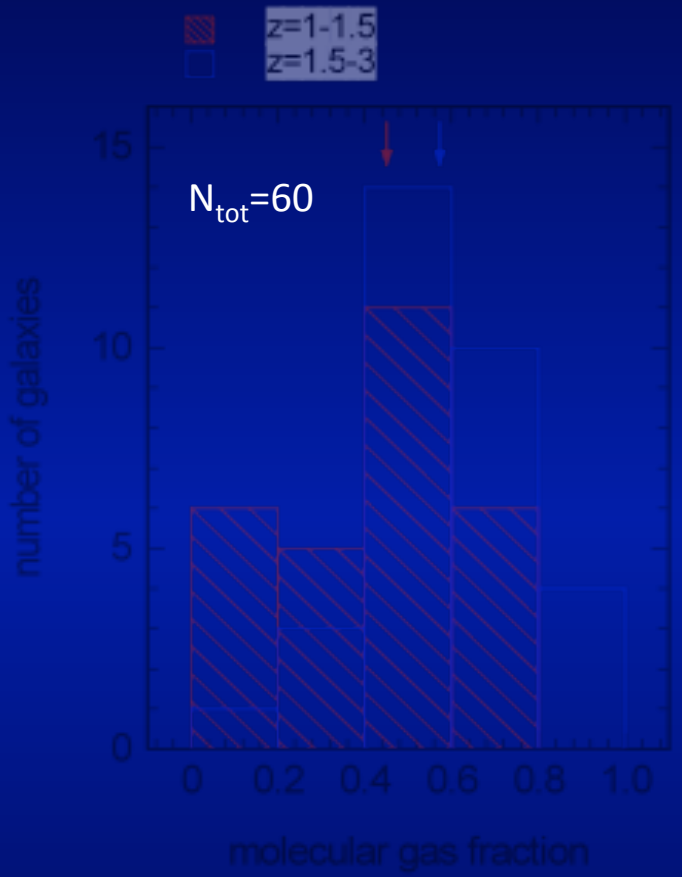
Nordon+11 1106.1186

… even most AGN hosts follow these scalings



Nordon+11 1106.1186

High molecular gas fractions in z~1-3 star forming galaxies

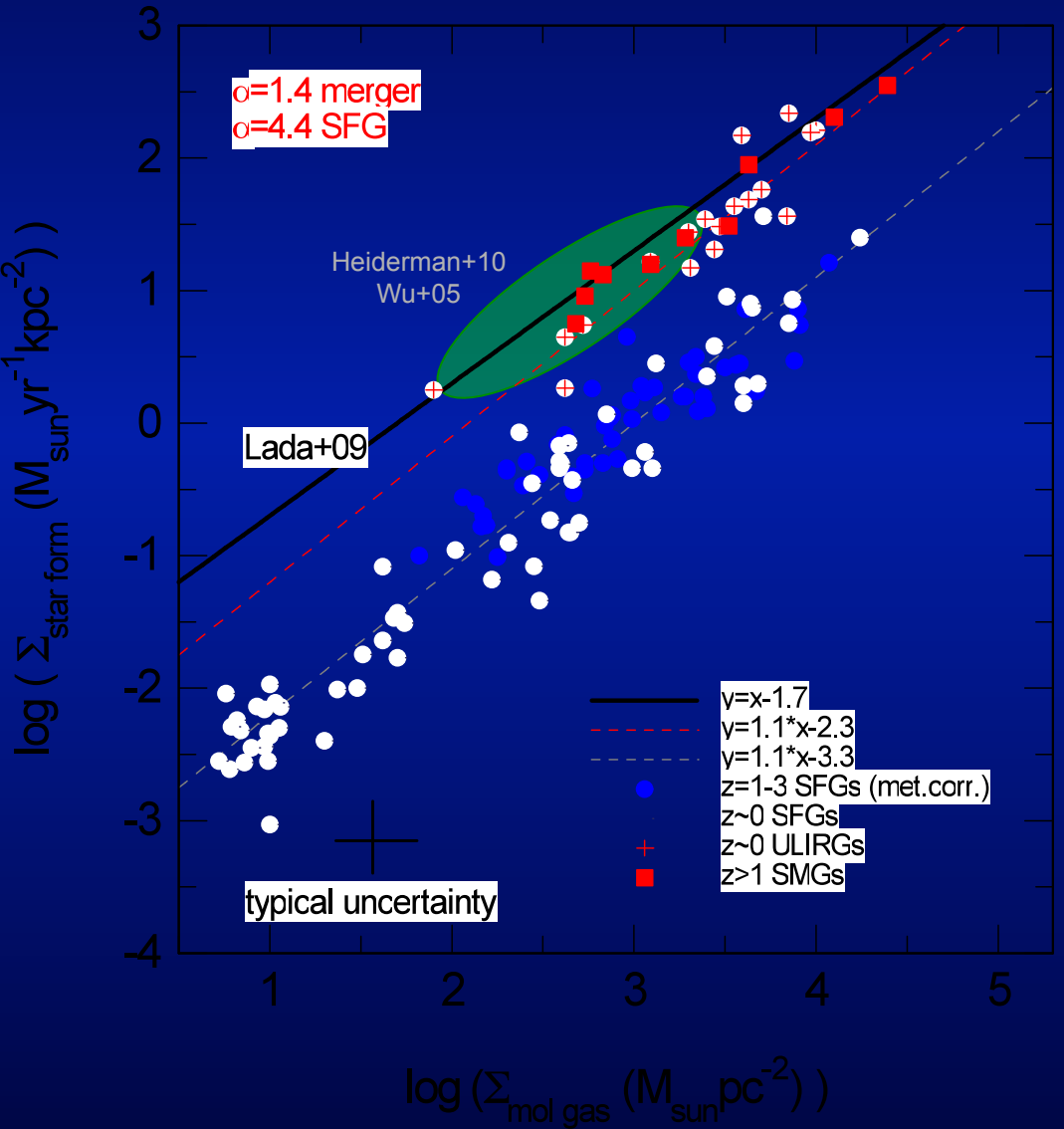


Mean $f_{mol\text{-}gas}$:
@z~1 = 0.45±0.04
@z~2 = 0.56±0.04

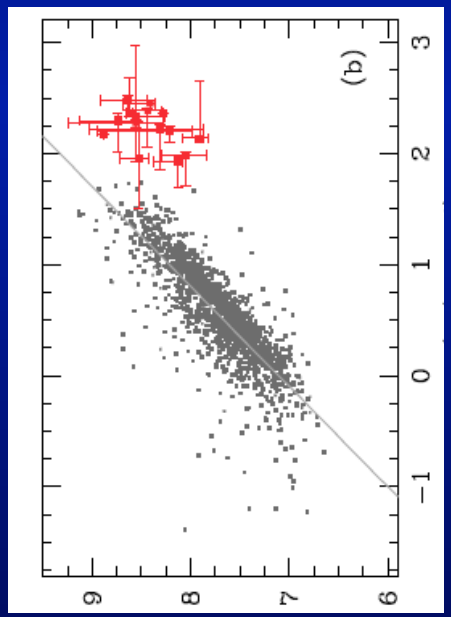
$f_{mol\text{-}gas} = M_{gas}/(M_{gas}+M_*)$

CO: Tacconi+2008, 2010, in prep; Genzel+2010, 2011, Combes+in prep; Daddi +2008, 2010, Baker+2004, Coppin+2007
Models: Davé+2011

Galaxies on and above MS: Two modes of star formation in the KS-relation?

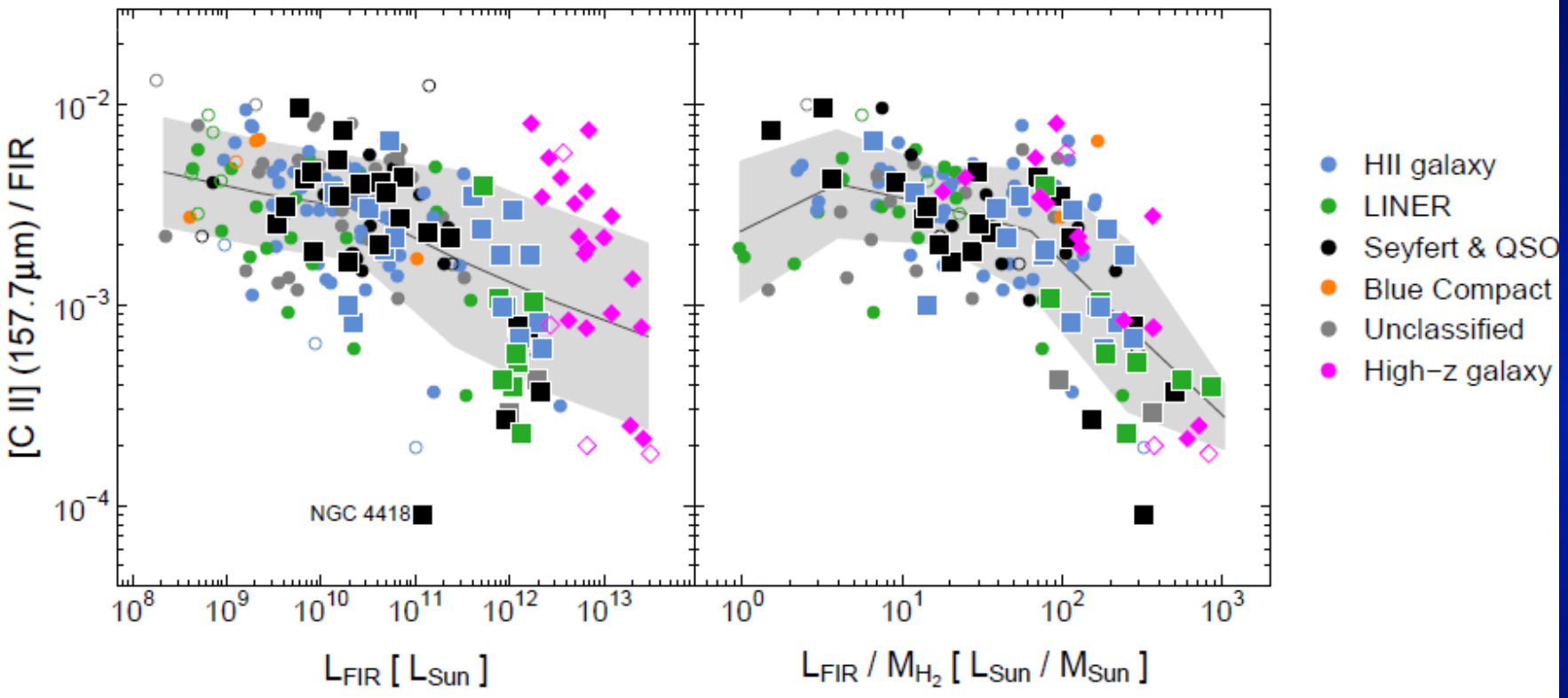


Genzel+ 10, Daddi+10



da Cunha+10
ULIRGs vs SDSS/IRAS

Galaxies on and above MS: CII deficit



[Graciá-Carpio et al. 2011, ApJ 728: L7]

[Brauher et al. 2008, ApJS 178: 280]

[Luhman et al. 2003, ApJ 594: 758]

[Ivison et al. 2010, A&A 518: L35]

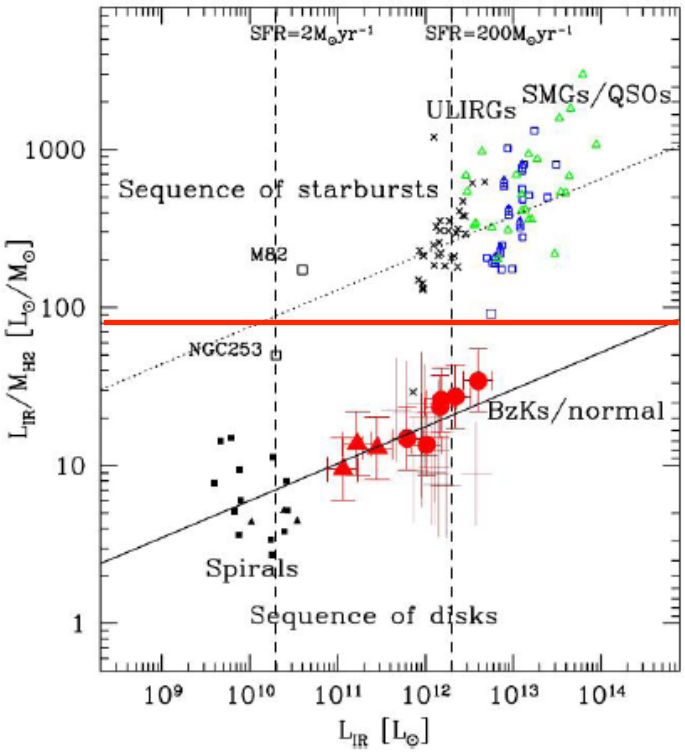
[Stacey et al. 2010, ApJ 724: 957]

[Hailey-Dunsheath et al. 2010, ApJ 714: L162]

[Maiolino et al. 2009, A&A 500: L1]

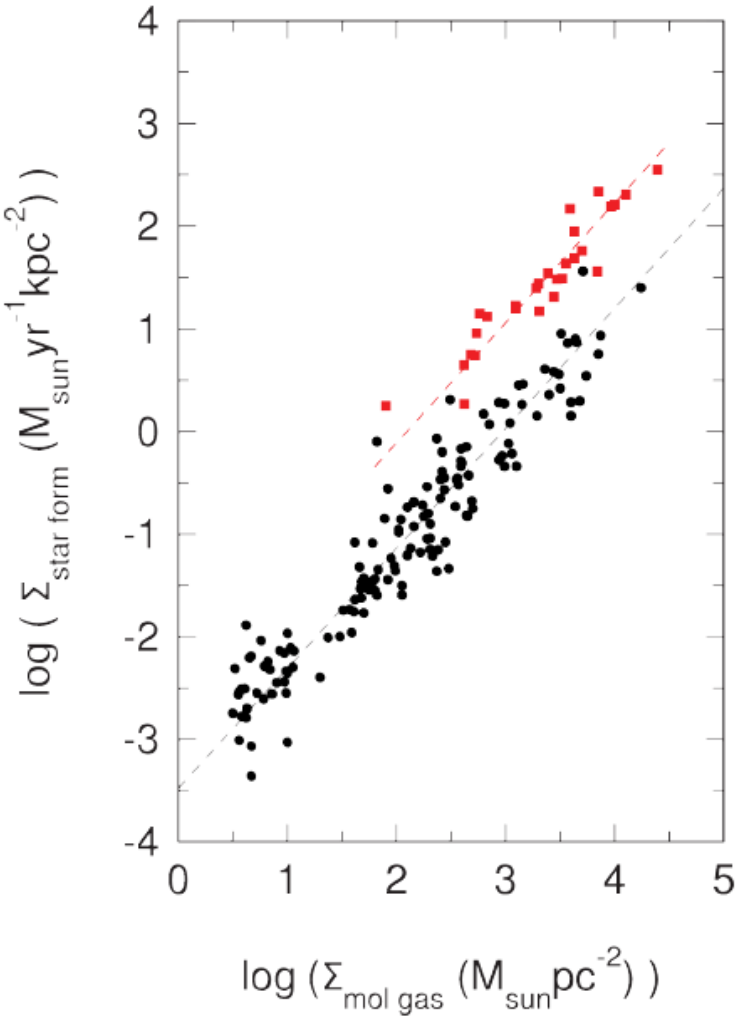
[Walter et al. 2009, Nature 457: 699]

Galaxies on and above MS: General FIR line deficits



[Genzel et al. 2010, MNRAS 407: 2091]

[Daddi et al. 2010, ApJ 714: L118]

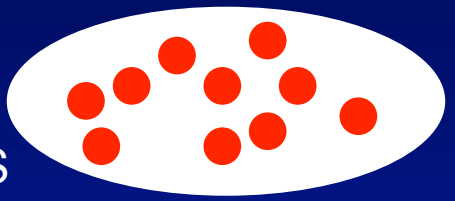


A toy view

Local KS on cloud scale:

$$\dot{\rho}_* \propto \epsilon \rho_c{}^{\alpha} \qquad \frac{\dot{\rho}_*}{\rho_g}\tau_{ff} = \epsilon$$

Changing mode, cloud conditions, Merger, above MS



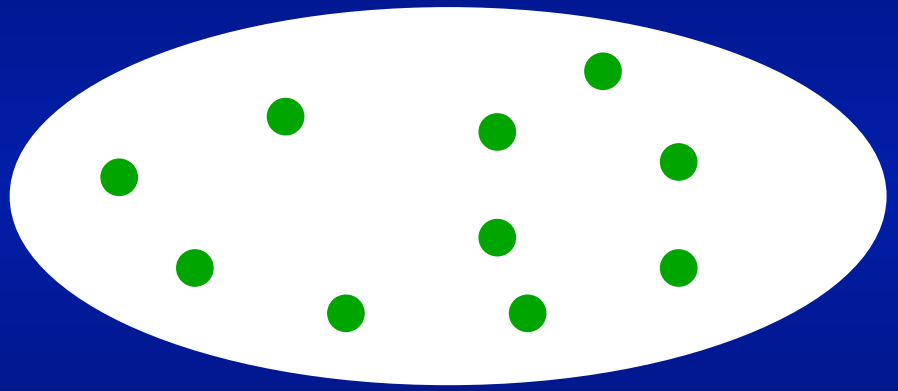
Main sequence galaxy with distributed such ~identical clouds:

$$\frac{\dot{M}_*}{M_*} \propto \left(\frac{M_g}{M_*}\right)\left(\epsilon \rho_c^{\alpha-1}\right)$$

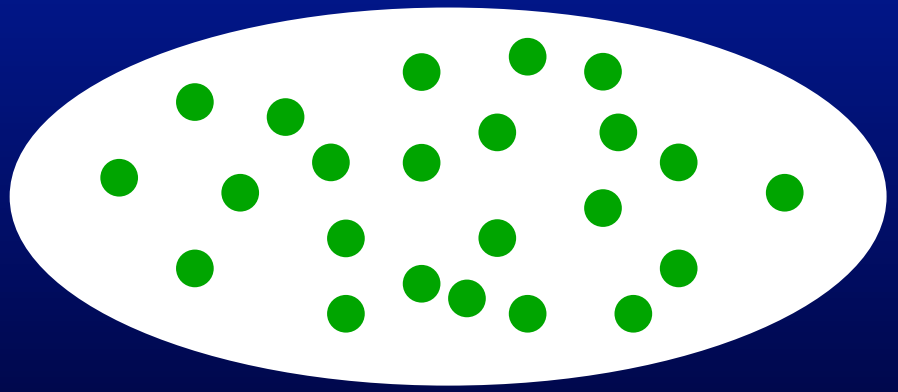
SSFR

Gas fraction

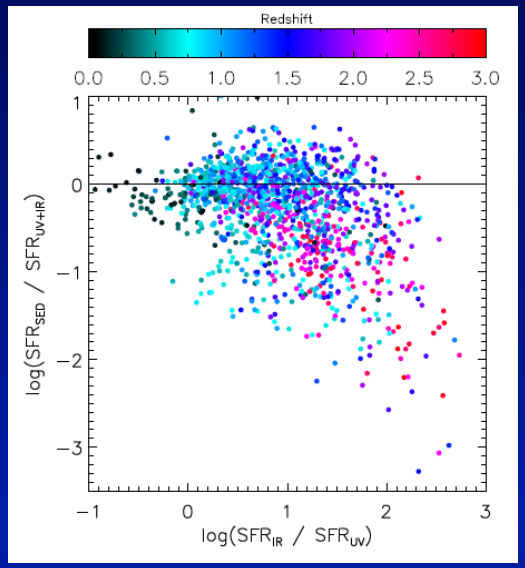
Local conditions

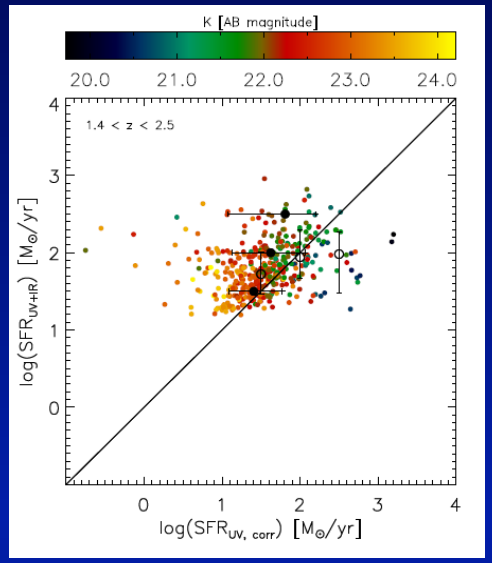


Rising gas fraction, filling factor, SSFR, MS with redshift

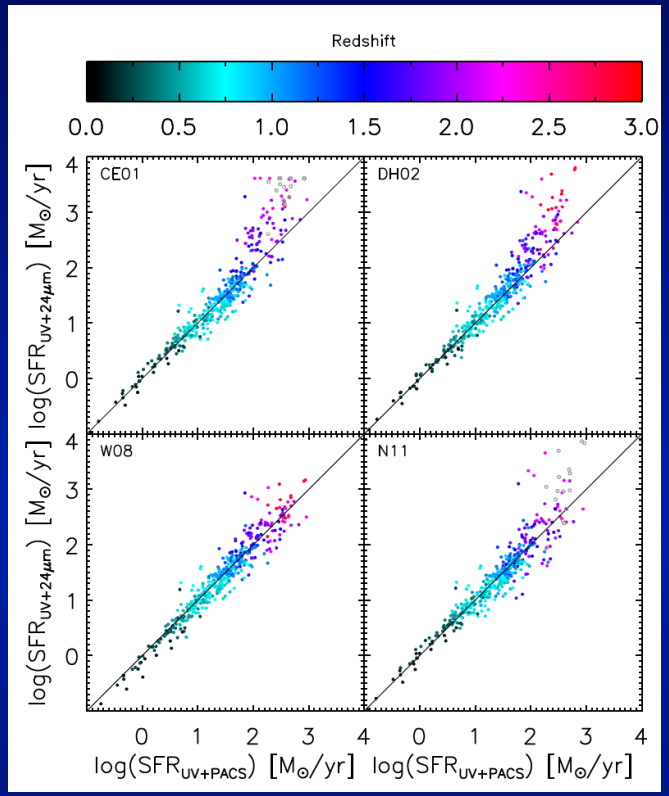


Combining UV SED – mid-IR – far-IR star formation indicators





SED fitting misses SFR for highly dusty and star forming systems



Biases in 24μm based SFRs taken out

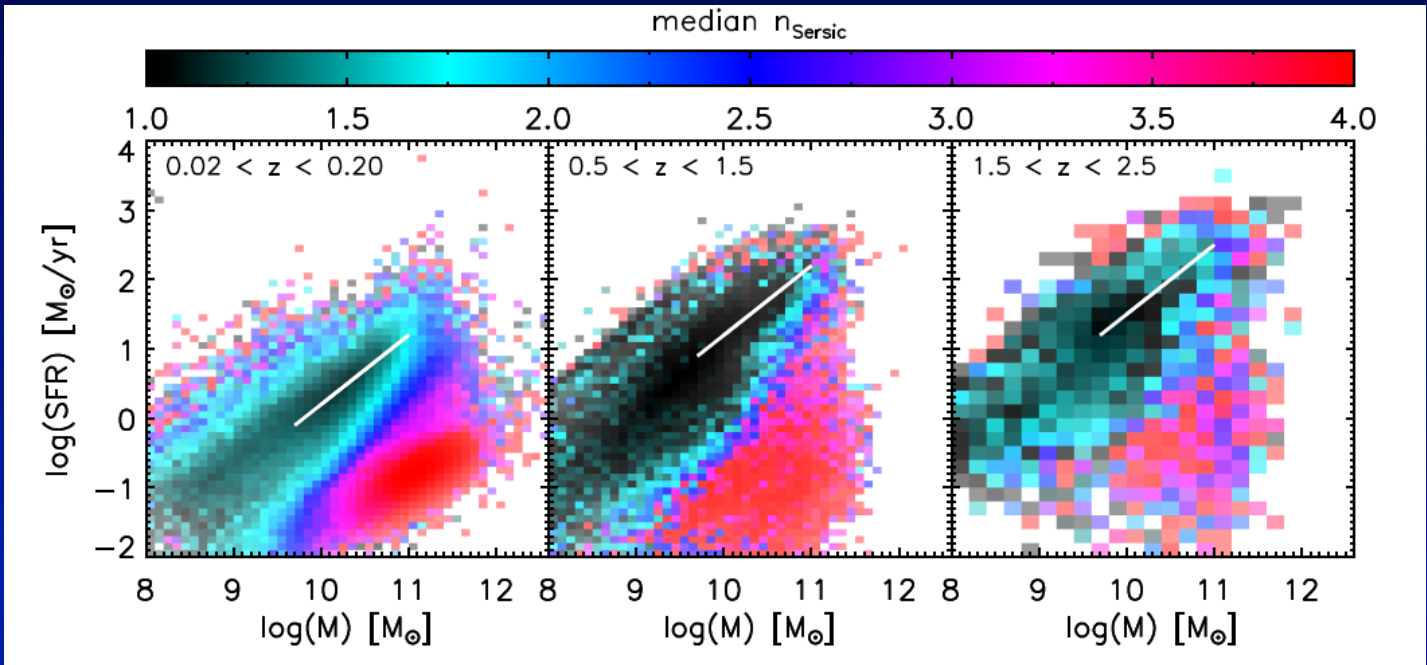
Continuous and consistent hierarchy of SF indicators

- PACS+UV
- 24μm+UV
- SED fitting

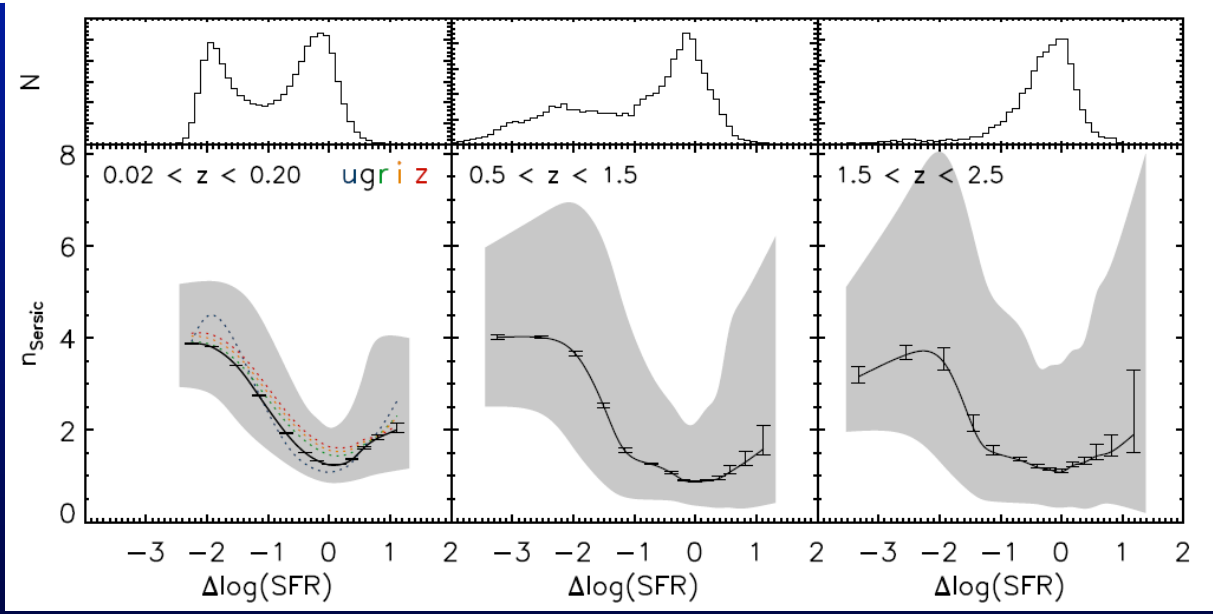
(avoiding age underestimates)

Wuyts+ 11 arXiv.

Morphologies on and off the main sequence

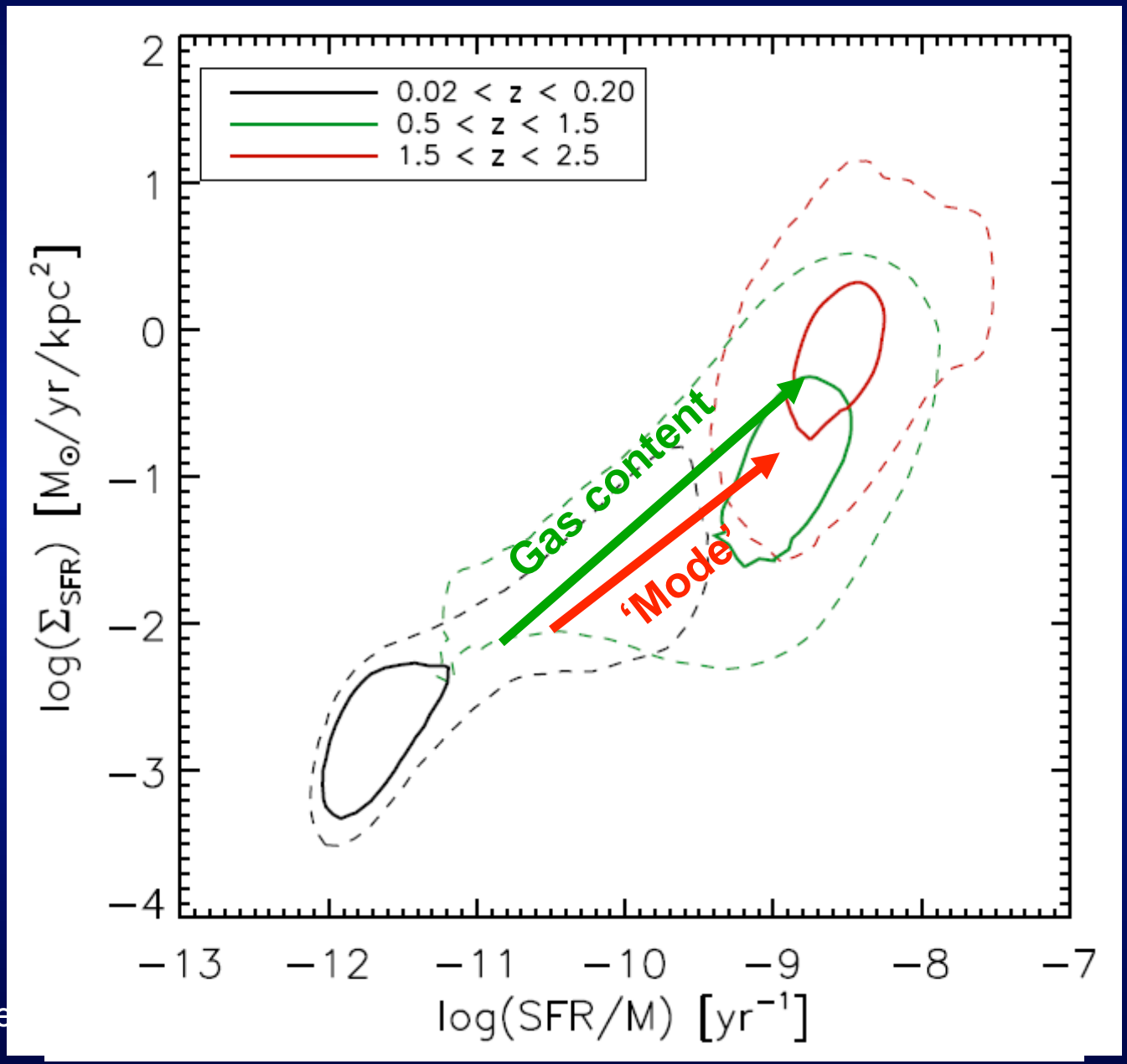


z=0 N~640000
z=1 N~97000
z=2 N~24500



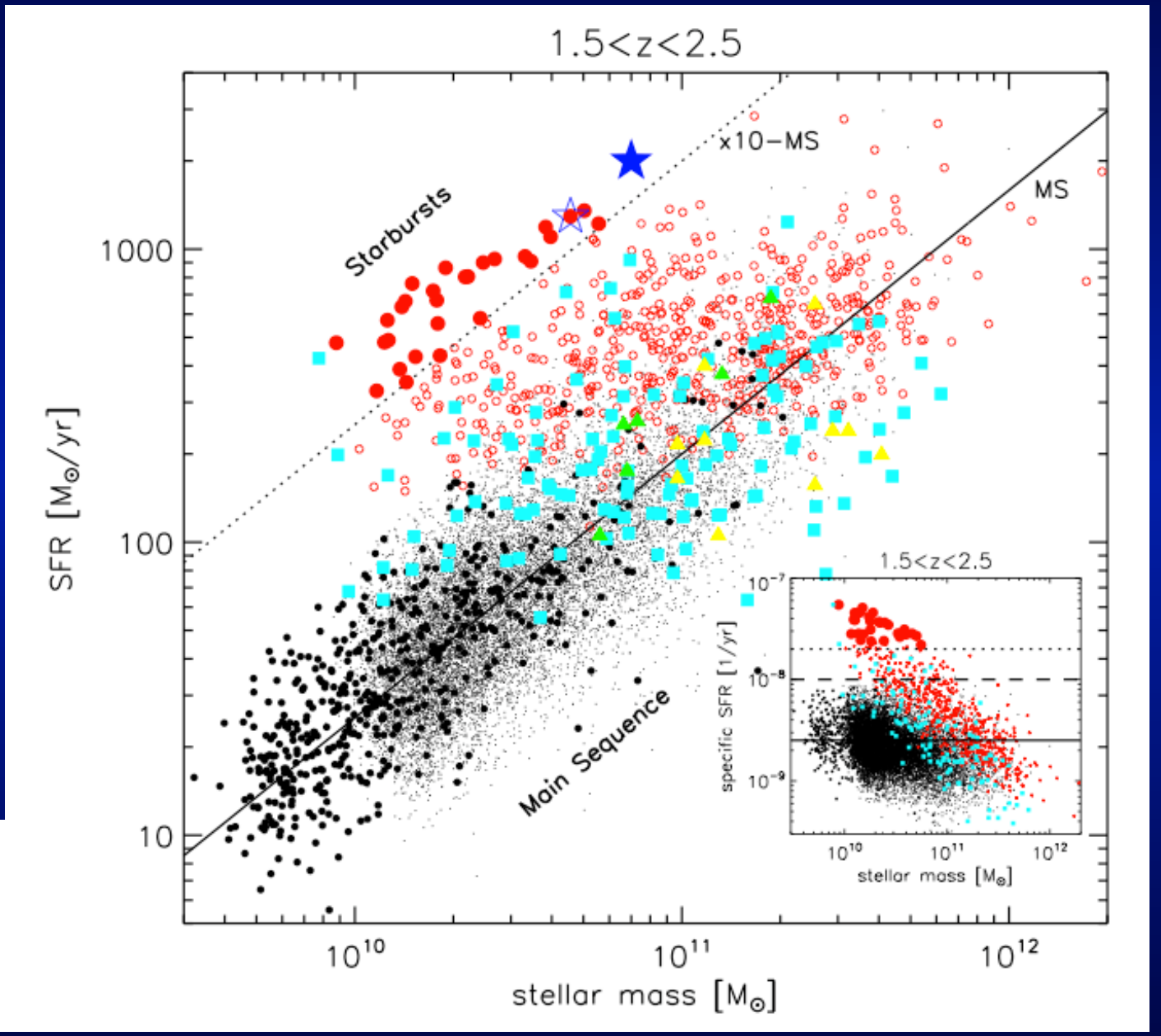
Wuyts+ in prep.

Sizes and star formation surface densities



Wuyts+ in pre

What is the importance of above-MS star formation?



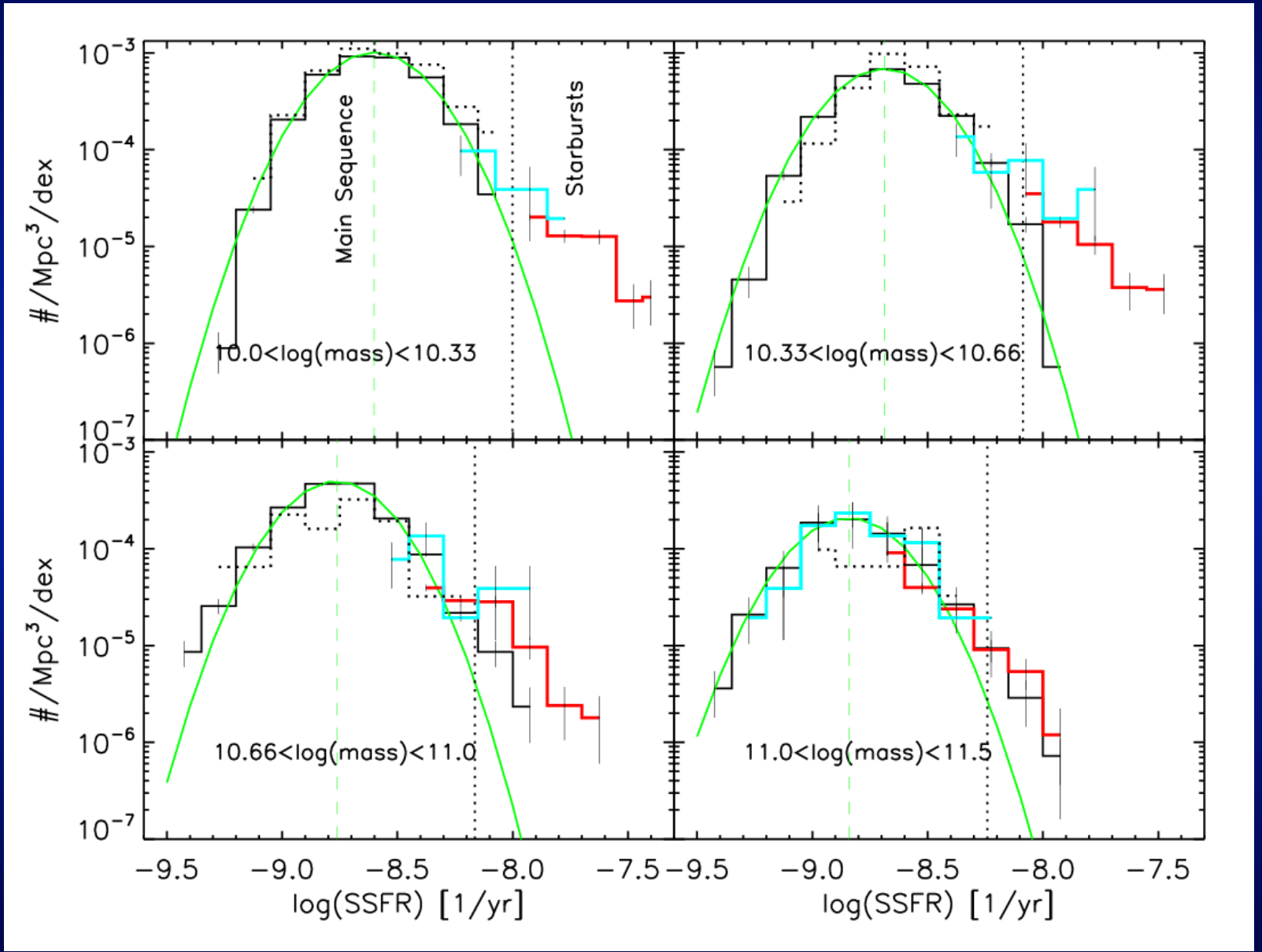
Rodighiero+
in prep

PACS-shallow

PACS-deep

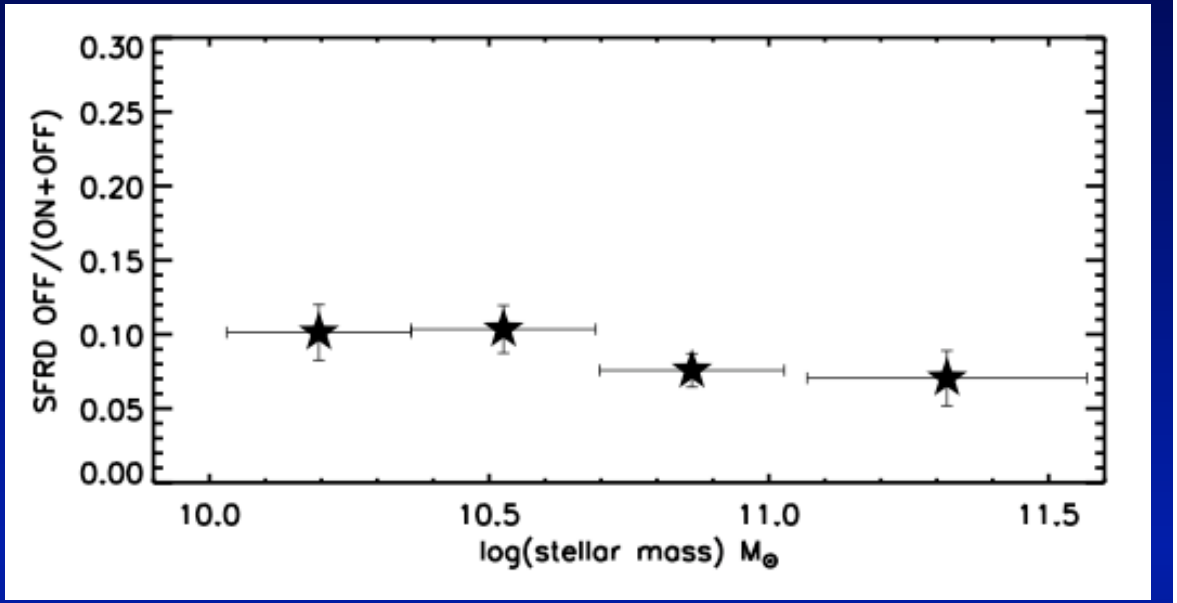
BzK

What is the importance of above-MS star formation?

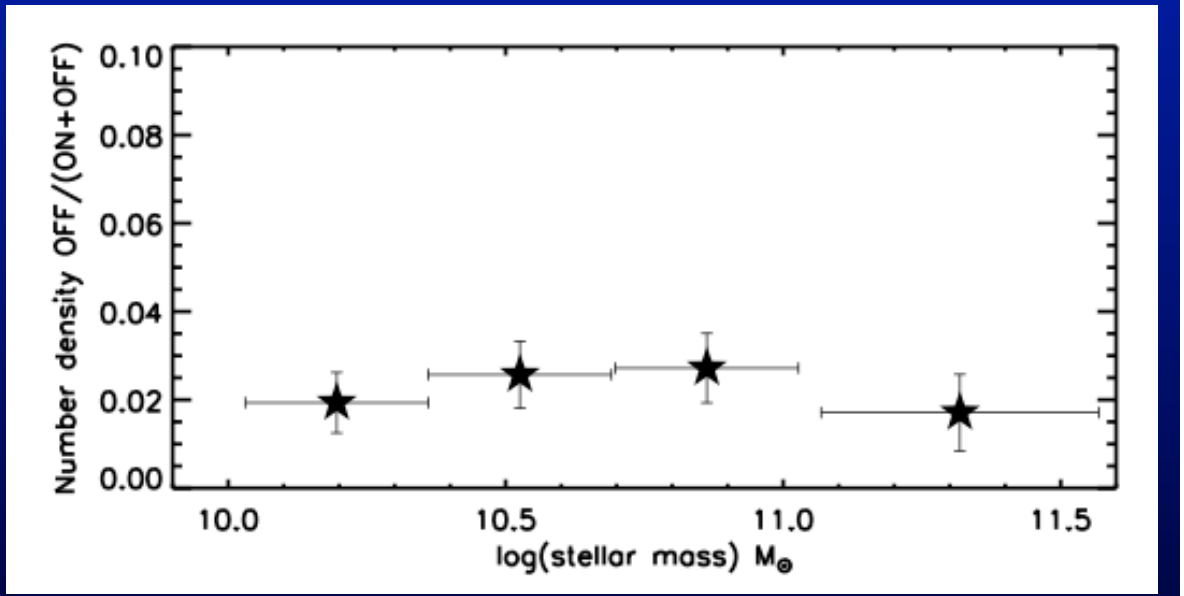


Objects >4x above main sequence

~10% of SF density



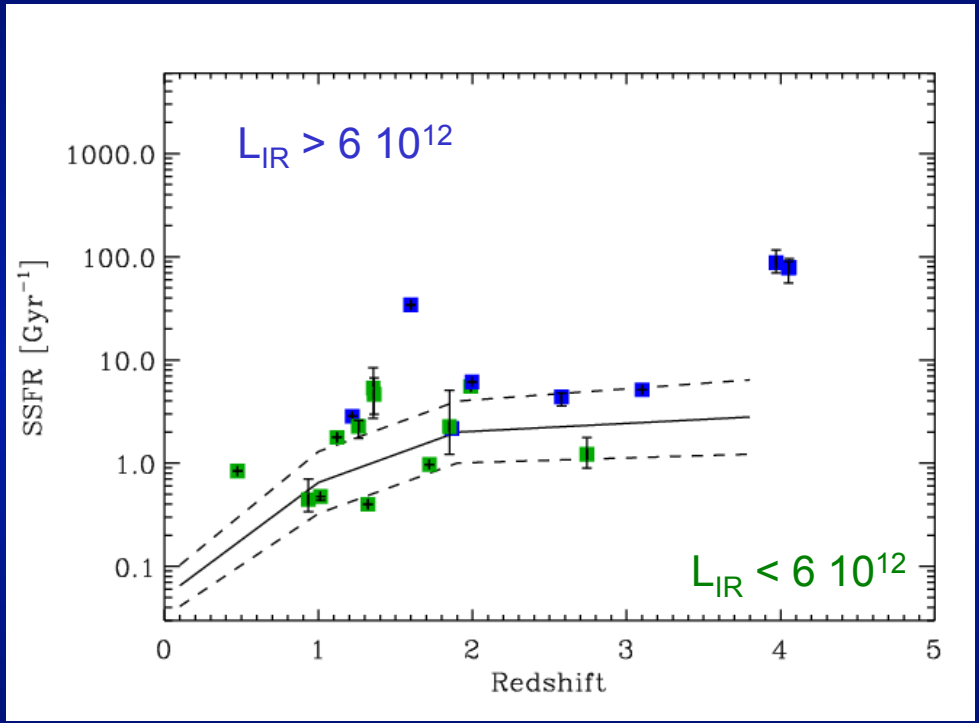
~2% of number density



On average, each galaxy ~20Myr in this phase - short wrt period of elevated SFR in major mergers

Not all galaxies going through major merger in 1.5<z<2.5

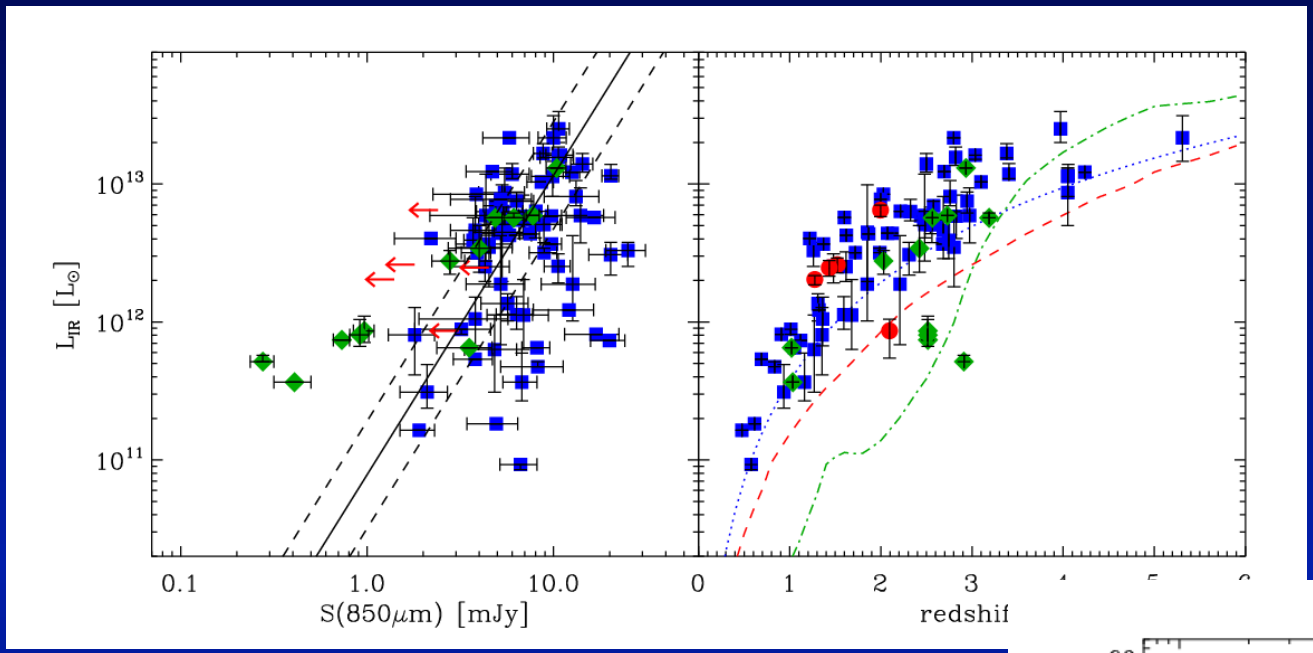
Properties of the most luminous objects: The case of SMGs



~20% of sample

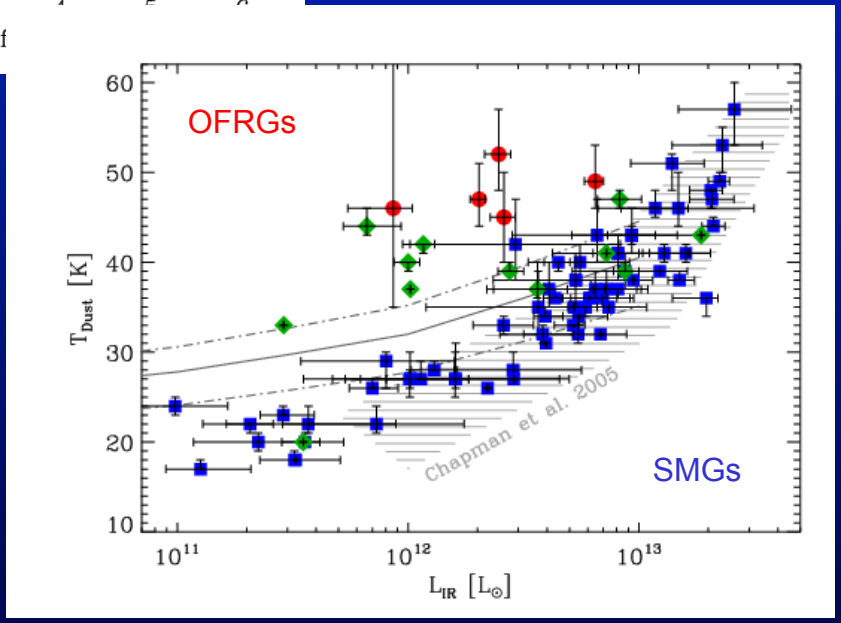
Magnelli et al. in prep.

The most luminous star forming galaxies



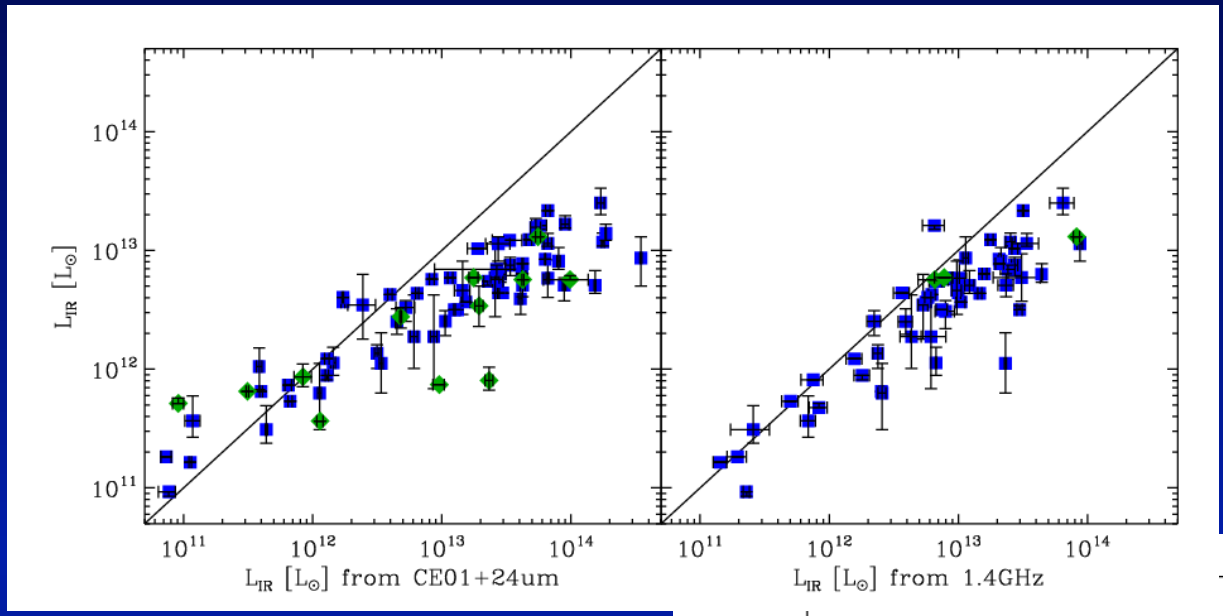
Star formation rates
~1000M_{Sun}/yr

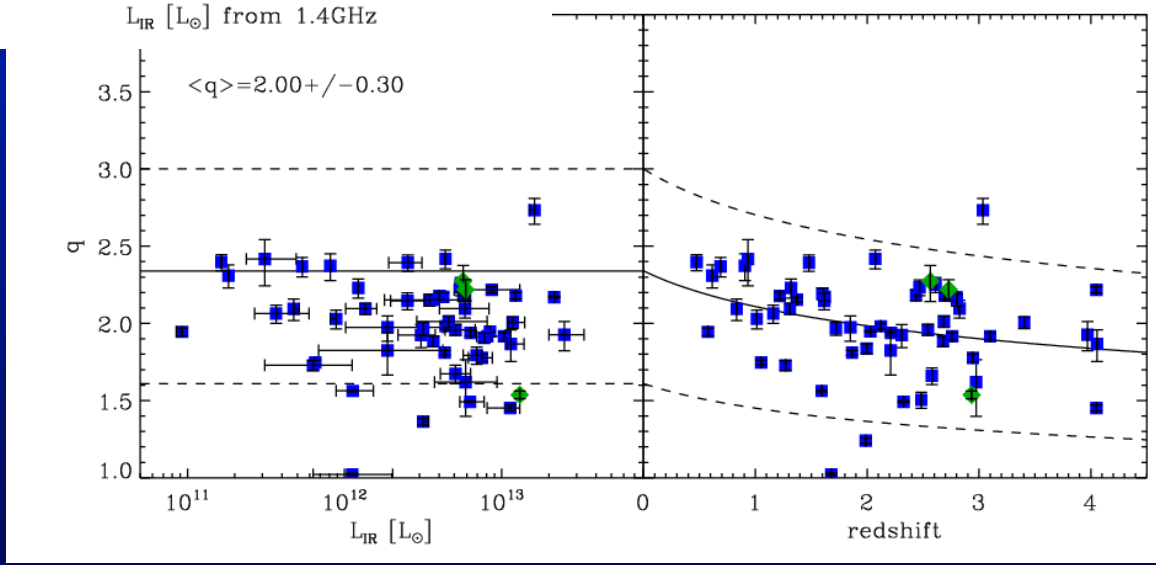
.. Note selection effects



Magnelli et al. 2010 and in prep., see also Chapman et al. 2010

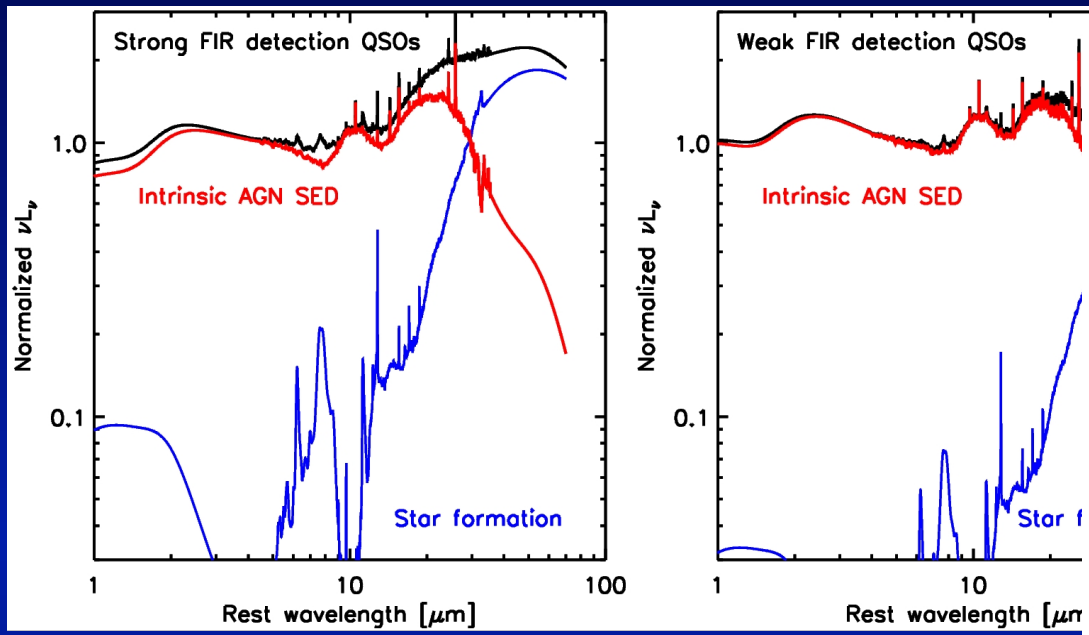
24μm and radio-based star formation rates vs. Herschel





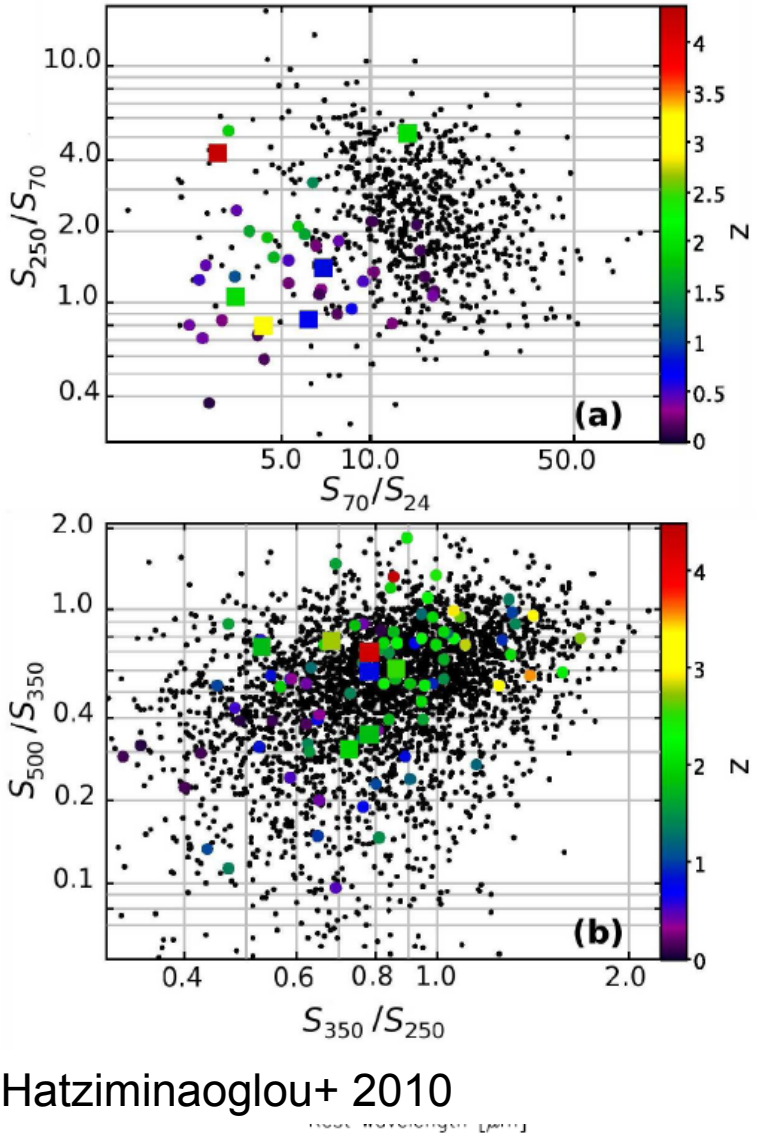
Magnelli et al. 2010 and in prep., Ivison et al. 2010

Using Herschel to study AGN host star formation



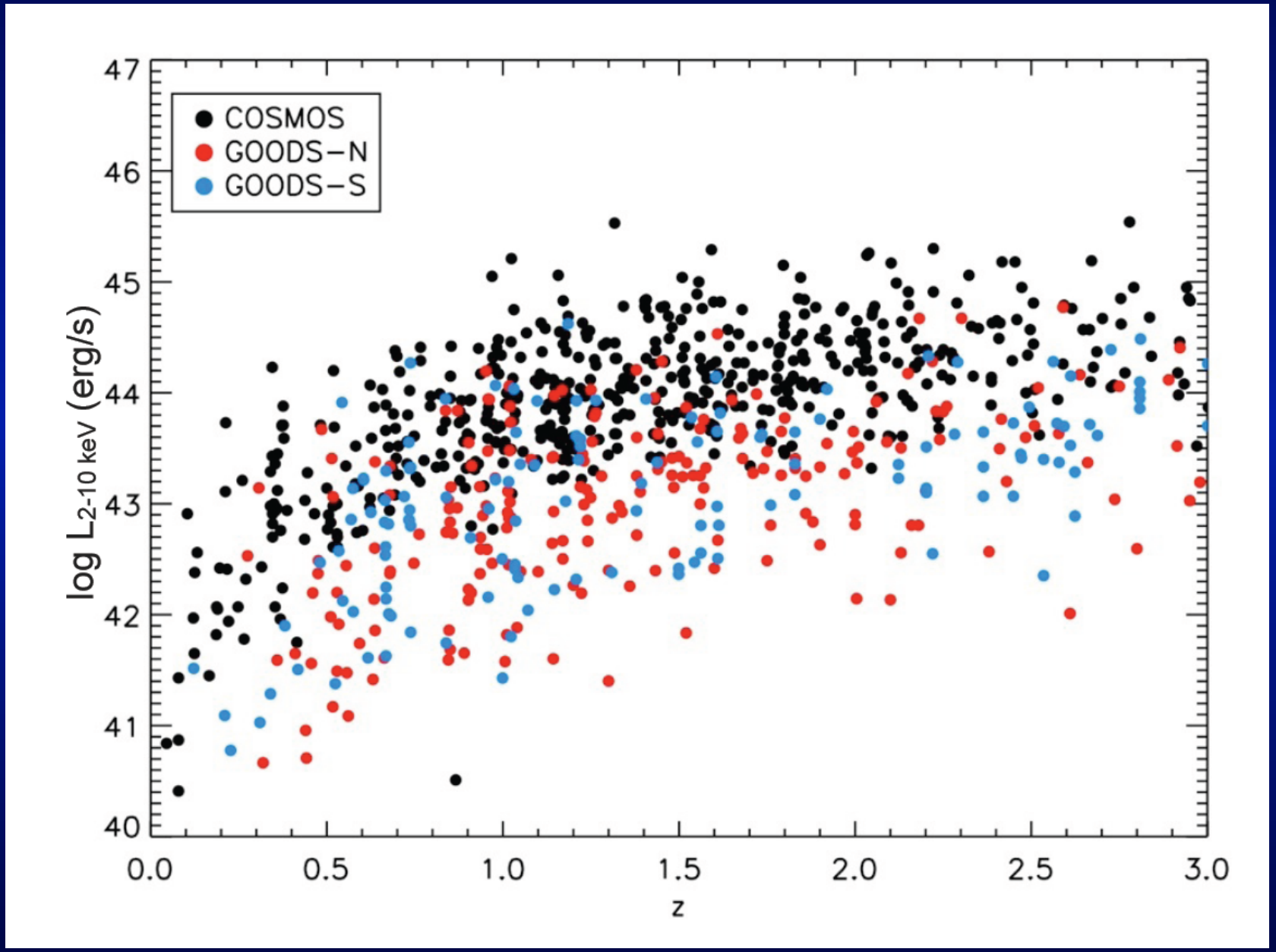
QSO SEDs from Netzer+07

FIR is SF indicator down to L(FIR)~0.1 L(BOL,AGN)

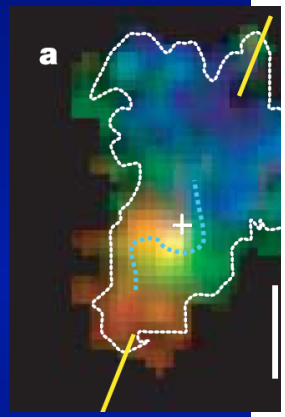


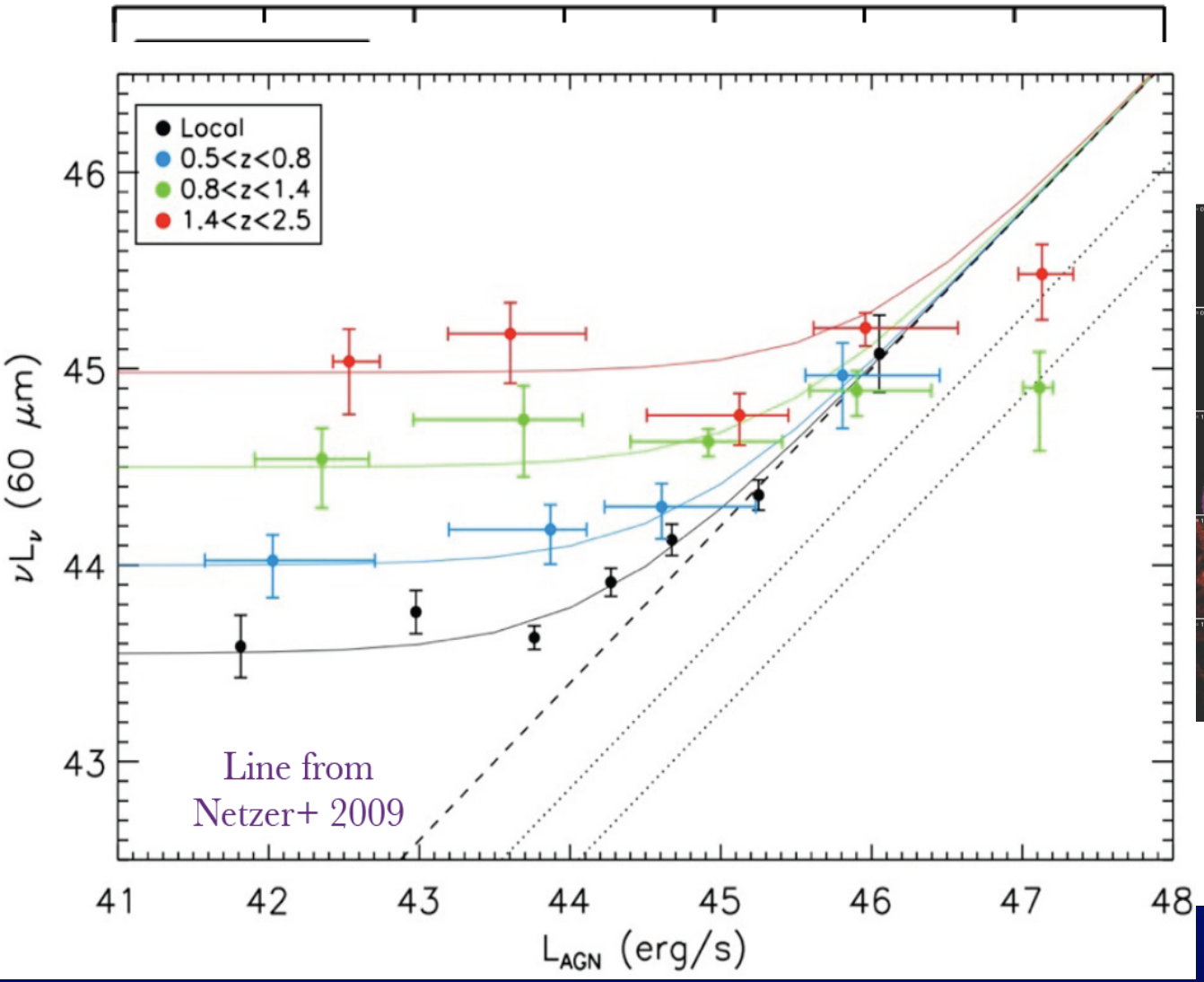
Hatziminaoglou+ 2010

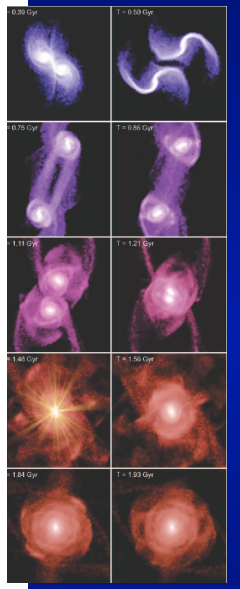
AGN over a wide L,z range



AGN / host coevolution: Merger vs. secular



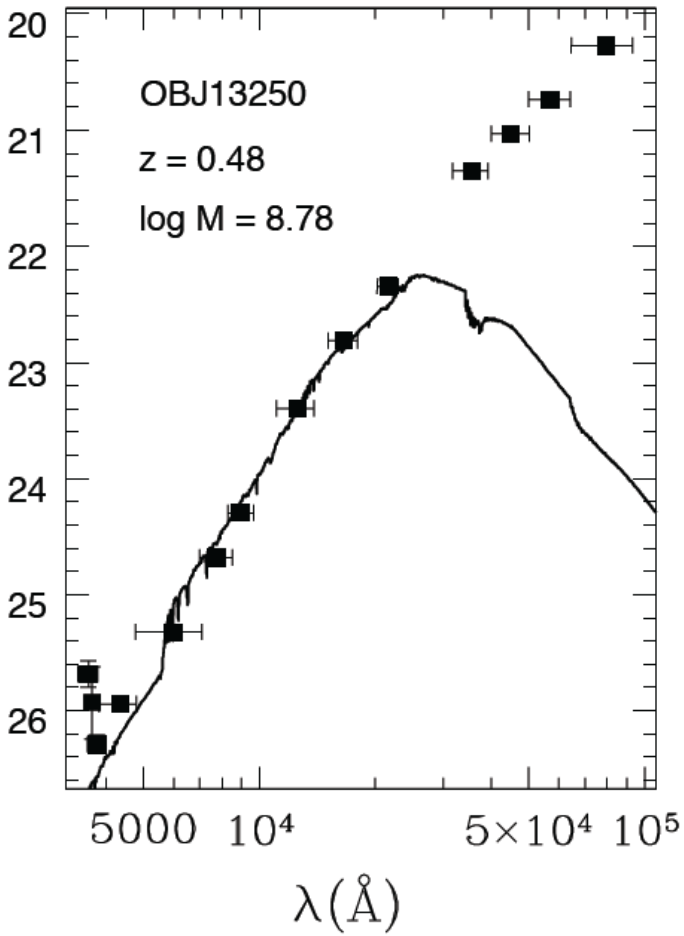


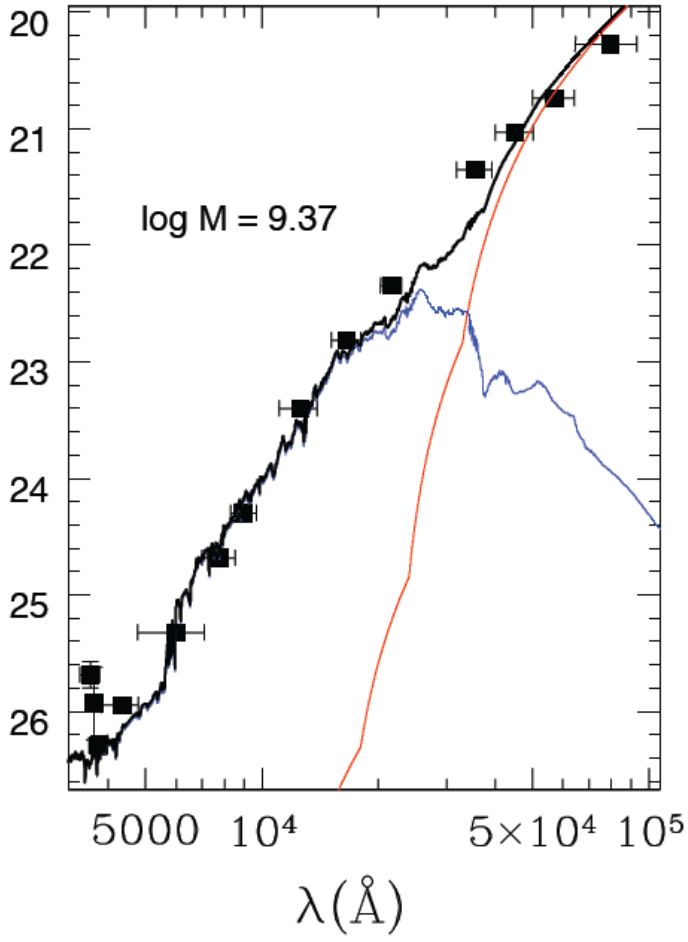


Shao et al. 2010, Rosario et al. in prep.

(see also Lutz et al. 2010 submm results, Mullaney et al. 2010 Spitzer, Mullaney+ 2011 GOODS-Herschel)

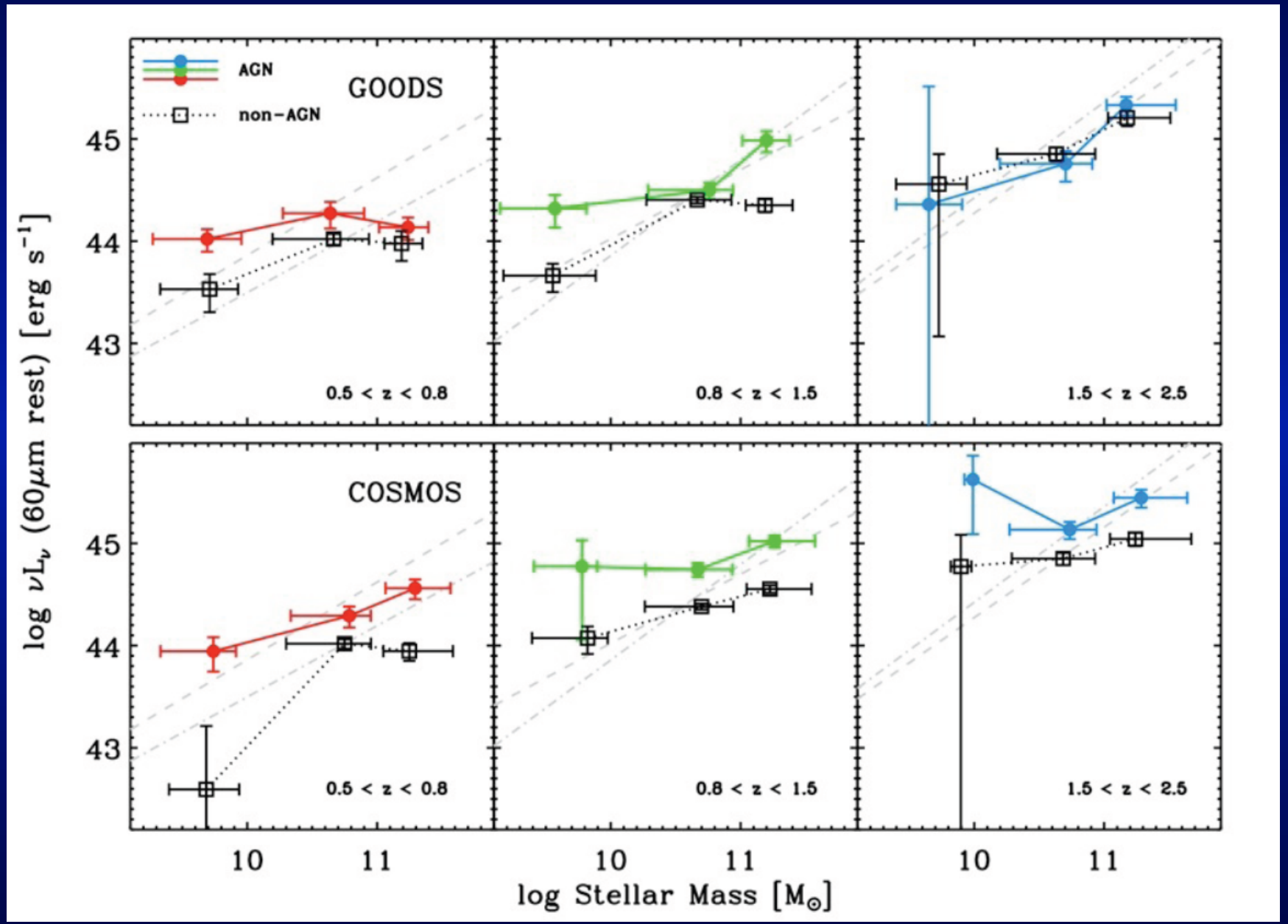
Comparing (S)SFR in mass-matched AGN and inactive galaxies



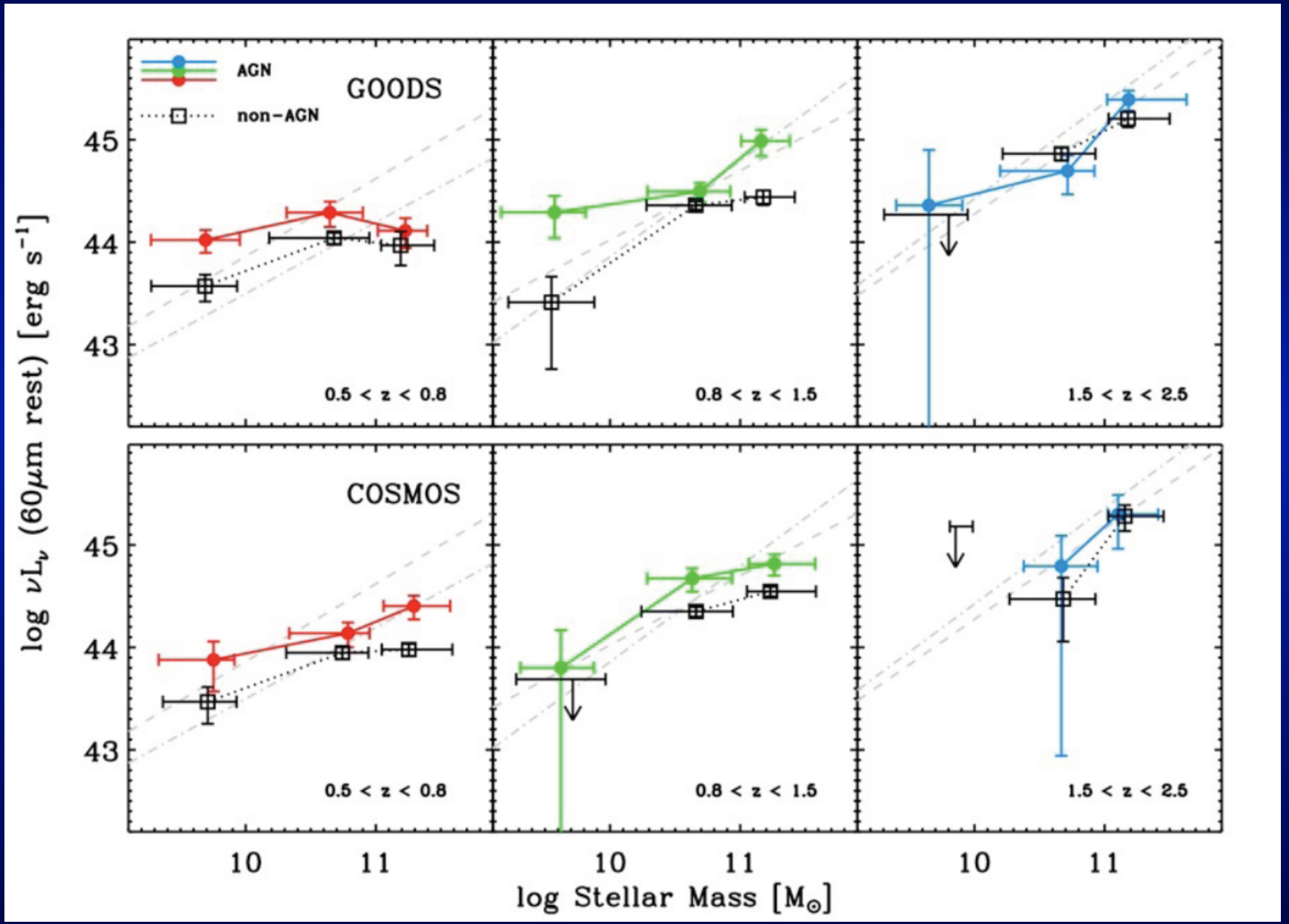


Santini+ in preparation

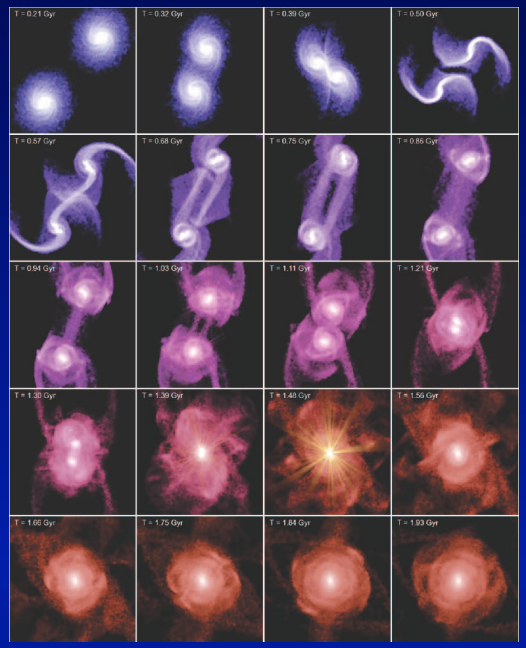
Star formation in active vs. nonactive galaxies



Only moderate luminosity AGN ($L_X < 10^{44.5}$)



AGN feedback?



Sanders+88, Fabian 99, Di Matteo+ 05, Hopkins+06,....

- merger → ULIRG → QSO → elliptical
- quenching of star formation
- BH-spheroid mass relation
- blue cloud vs. red sequence
- Galaxy vs. Halo mass function

Herschel OH spectra of ULIRGs - evidence for AGN feedback and quenching

P-Cyg
blue-
and r

Terminal velocity (obs): ~1.200 km/s

R_{out} (model) ~1.5 kpc

Outflow rate (dM/dt): ~1.200 $M_\odot$/yr

SFR: ~100 $M_\odot$/yr

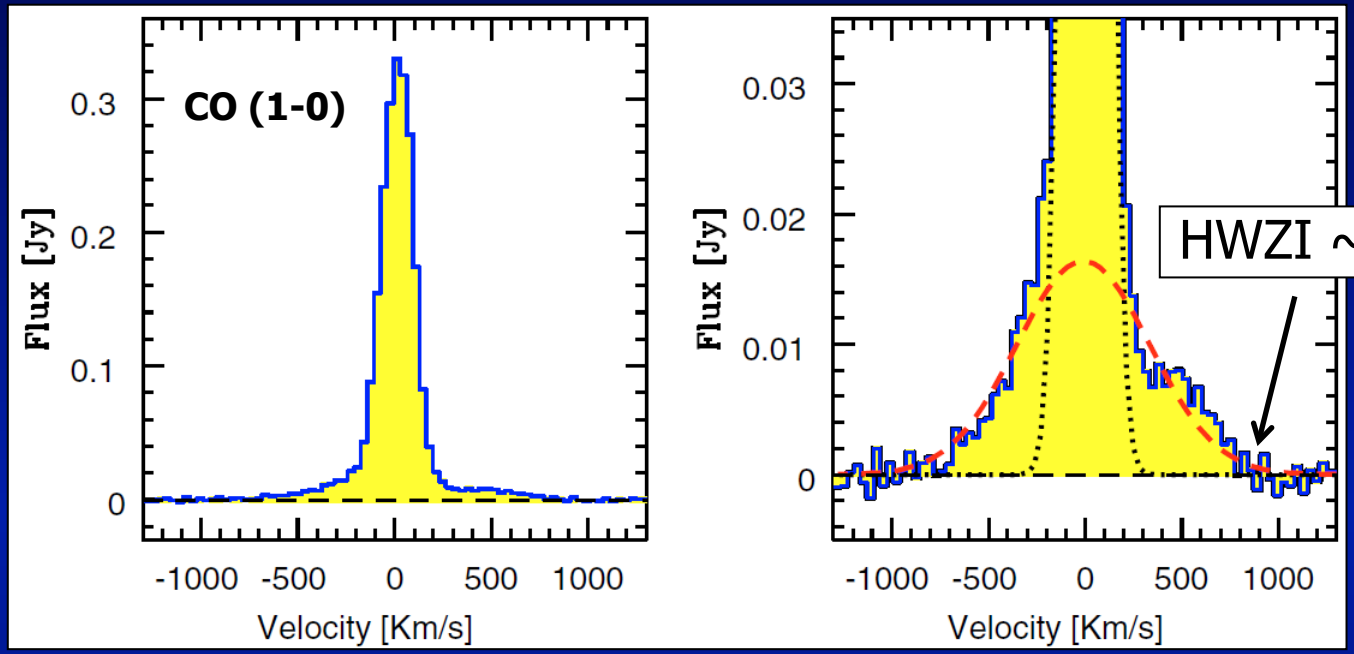
Gas mass (from CO): 4.2 x 10^9 $M_\odot$

Depletion time scale (M_{gas}/M): ~4 x 10^6 yr

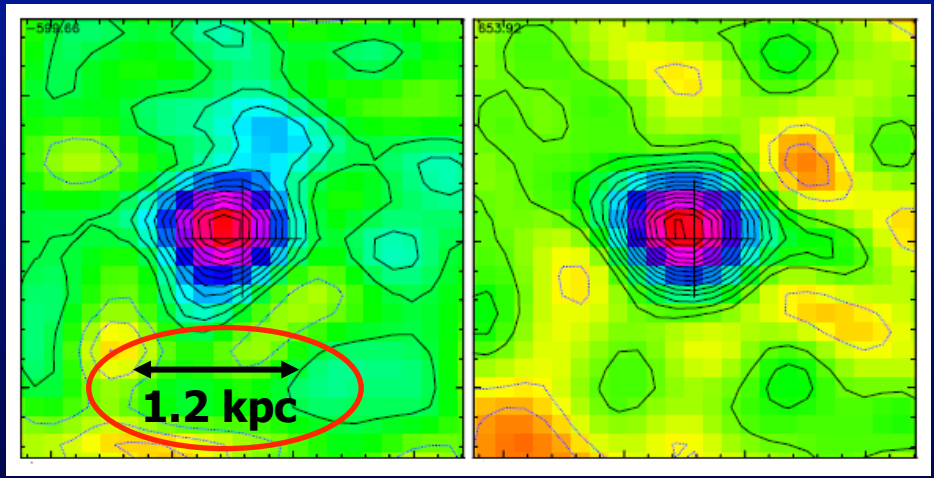
Mechanical energy: ≥ 10^{56} ergs

Mechanical luminosity: ≥ 1% L_{IR}

Mrk 231 – CO Outflow



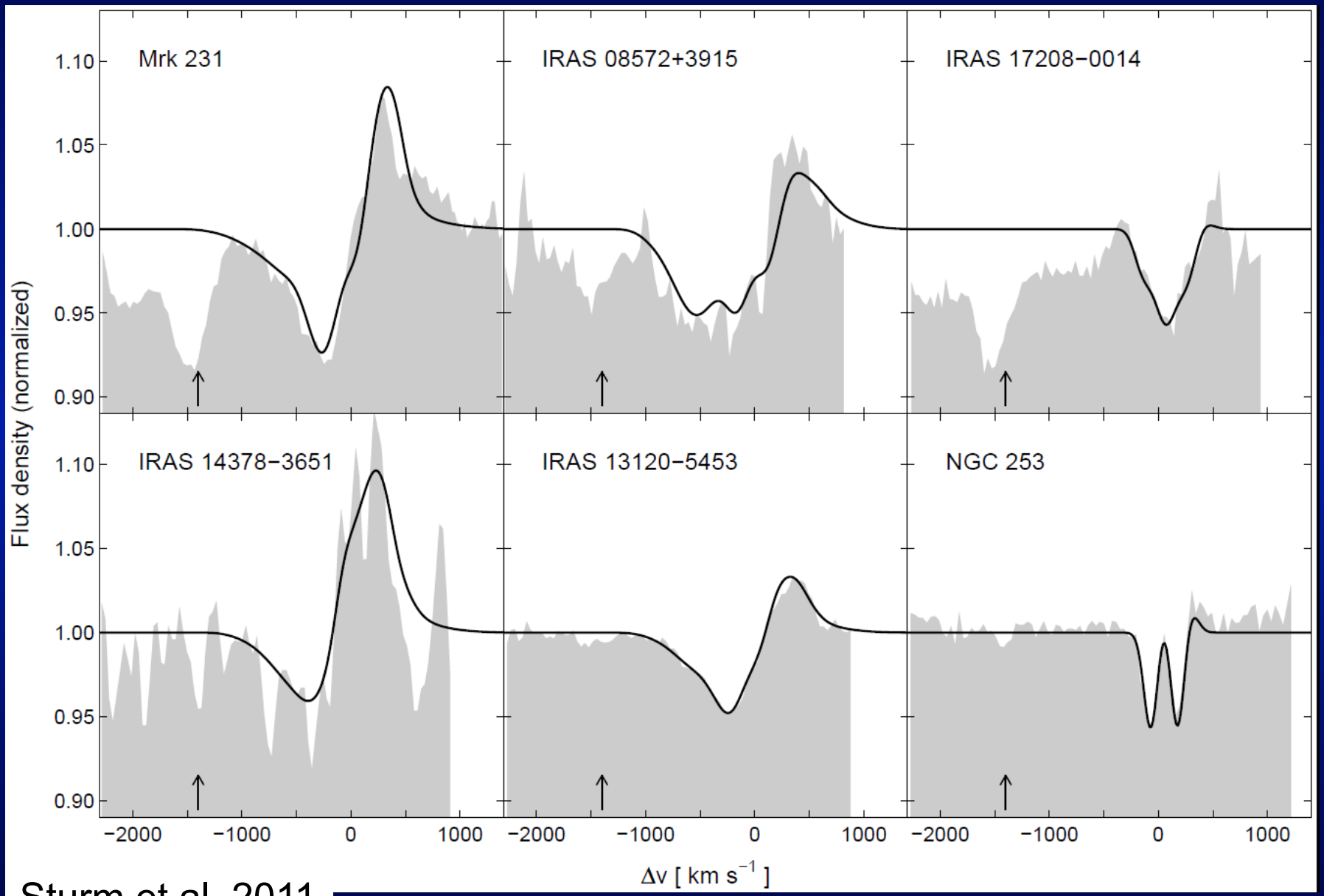
Feruglio+2010



outflow mass of 5.8×10^8 $M_\odot$

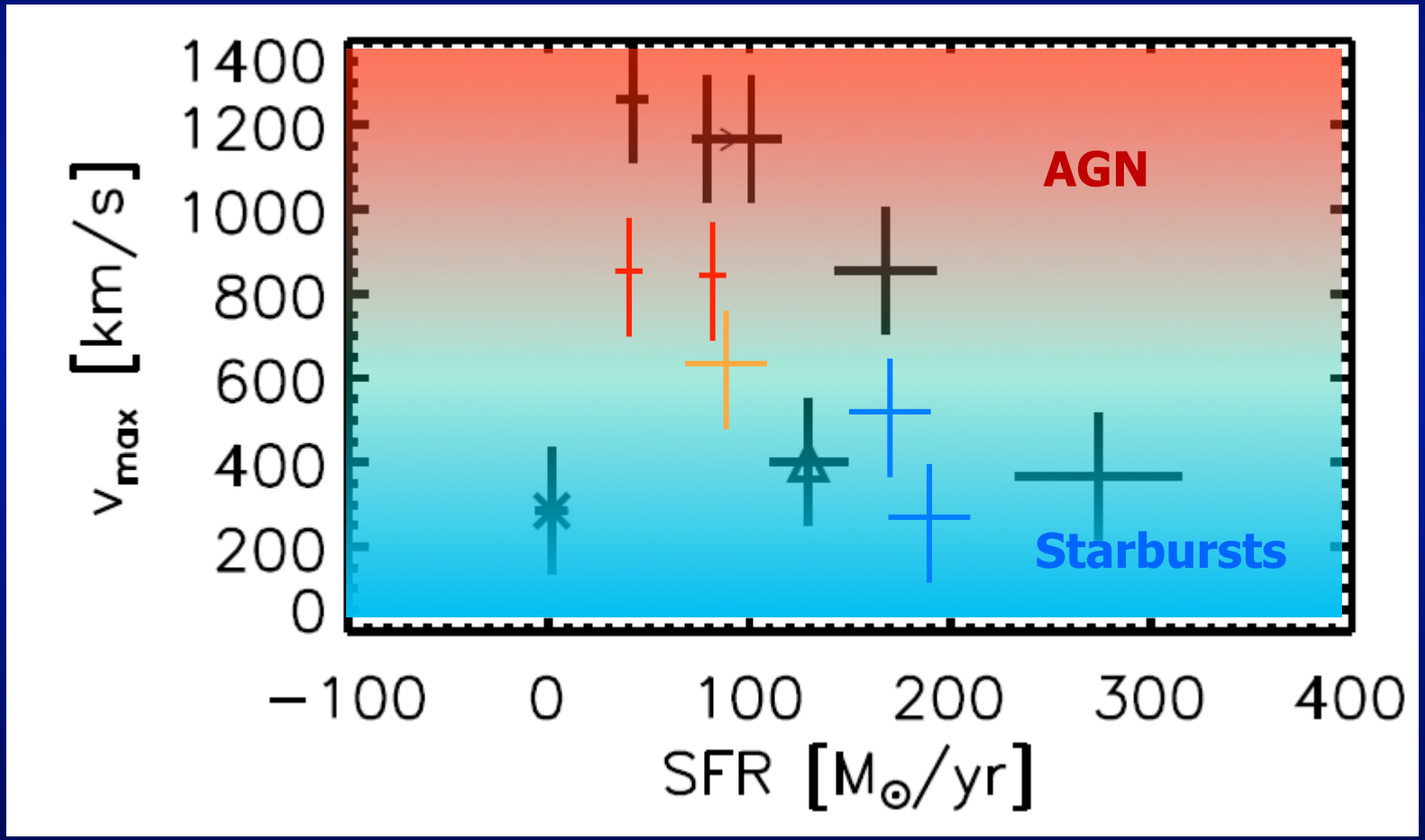
outflow rate of ~700 $M_\odot$/yr

Is Mrk 231 a bizarre single case? No!



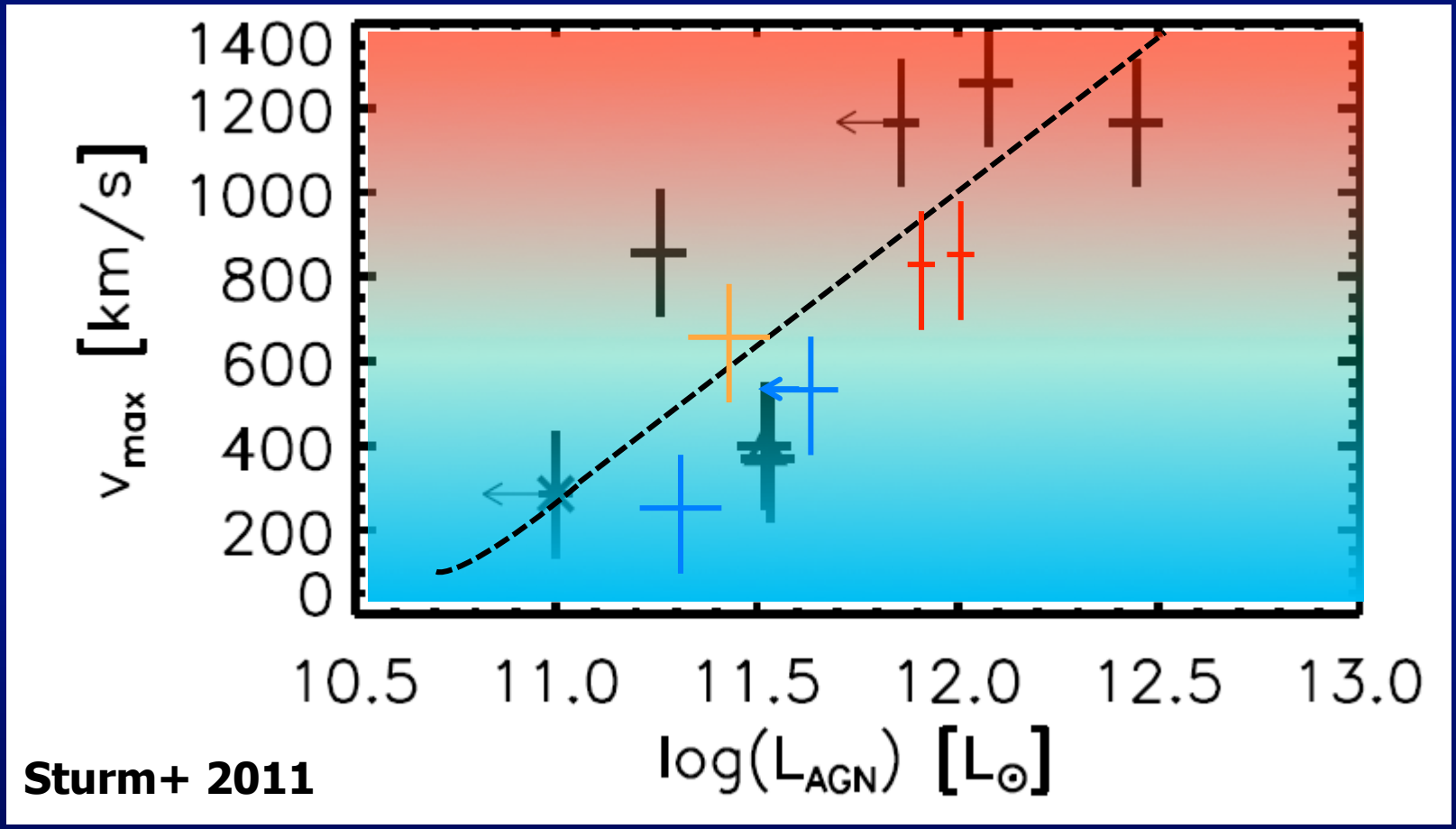
Sturm et al. 2011

Is star formation rather than AGN the driver of the outflows?



Sturm+ 2011

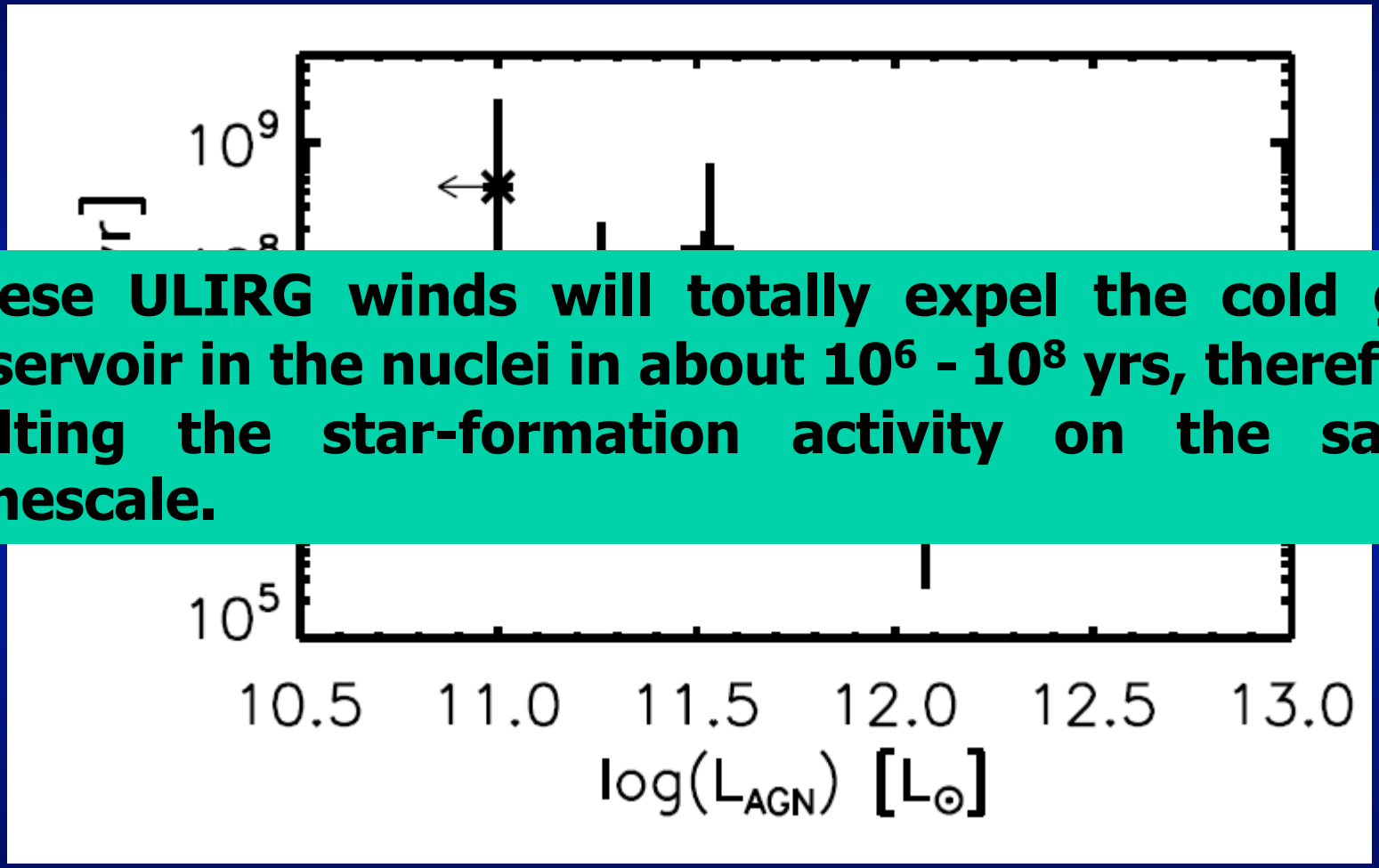
Is star formation rather than AGN driving the outflows?



Sturm+ 2011

SNe driven → v(outflow) $\lesssim$ 500 km/s (e.g. Martin 2005, Thacker+ 2006)

Does the outflow carry enough gas to actually quench star formation?



These ULIRG winds will totally expel the cold gas reservoir in the nuclei in about 10^6 - 10^8 yrs, therefore halting the star-formation activity on the same timescale.

Sturm+ 2011

Summary

- Herschel is correcting previous mid-IR based star formation rate estimates
- Infrared SED properties are more naturally explained in relation to the redshift-dependent main sequence than in the traditional way as a function of IR luminosity.
  This agrees with similar trends in FIR line deficits and star formation laws, among others.
- Out to z~2, relations between morphology and position on/above main sequence are in place
- At z~2, galaxies above main sequence contribute ~10% in SFRD and ~2% in number
- Herschel characterizes submm galaxies and substantiates huge SFRs, consistent with major mergers
- Most z~1-2 AGN hosts seem to follow a secular evolution, with the possible exception of the most luminous objects
- Massive molecular outflows driven by AGN are detected via OH spectroscopy of ULIRGs, tracing AGN feedback/quenching