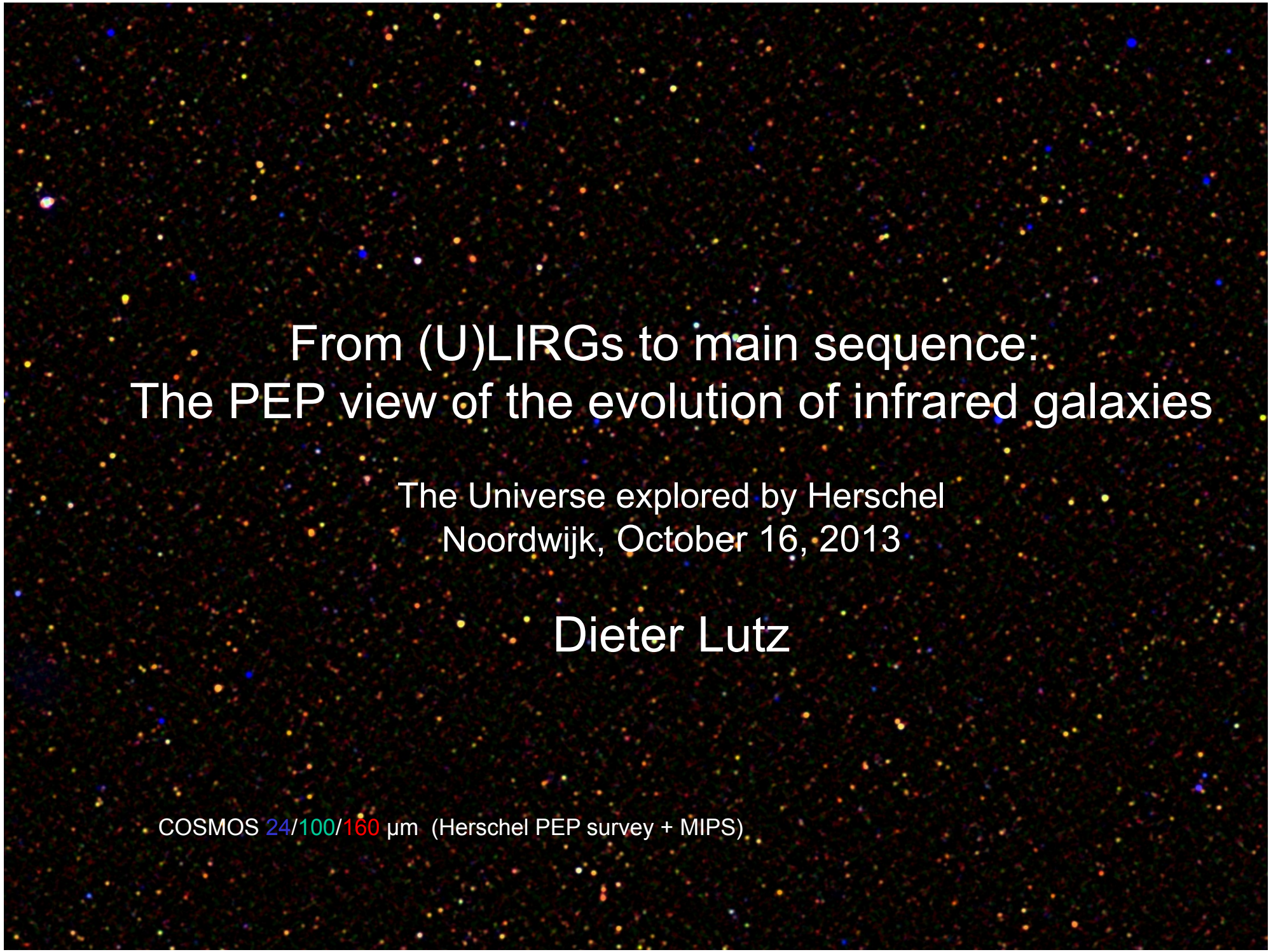


From (U)LIRGs to main sequence: The PEP view of the evolution of infrared galaxies

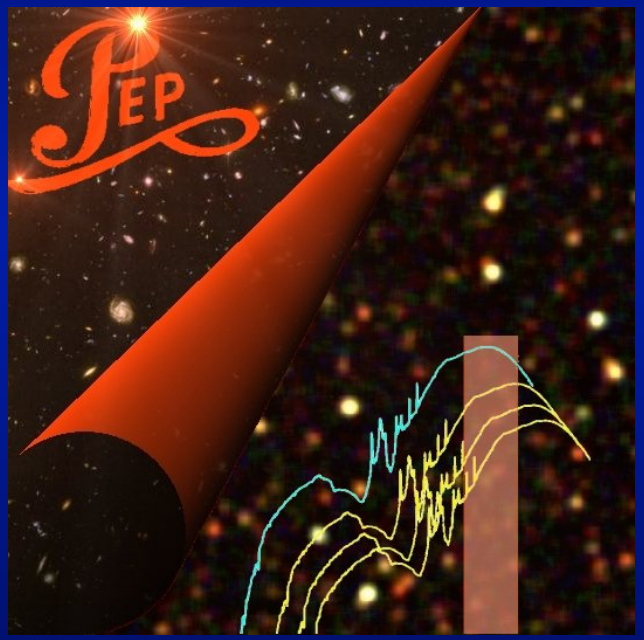
The Universe explored by Herschel
Noordwijk, October 16, 2013

Dieter Lutz

COSMOS 24/100/160 μm (Herschel PEP survey + MIPS)

PACS Evolutionary Probe (PEP) GT survey: GOODS, COSMOS, EGS, ECDFS….

All images and catalogs publicly released since March 2013
at http://www.mpe.mpg.de/ir/Research/PEP/public_data_releases.php



… and collaborations with
HerMES and GOODS-Herschel

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Bruno Altieri
Paola Andreani
Herve Aussel
Stefano Berta
Angel Bongiovanni
Margherita Bonzini
Damien Le Borgne
Drew Brisbin
Marcella Brusa
Hector Castaneda
Antonio Cava
Jordi Cepa
Andrea Cimatti
Emanuele Daddi
Helmut Dannerbauer
Helena Dominguez-Sanchez
David Elbaz
Emeric Le Floc'h
Natascha Förster Schreiber
Reinhard Genzel
Ignacio Gonzalez
Gianluigi Granato
Andrea Grazian
Carlotta Gruppioni
Martin Harwit
Ho-Seong Hwang
Georgios Magdis
Manuela Magliocchetti
Benjamin Magnelli
Roberto Maiolino
Leo Metcalfe
Marco Mignoli
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Paola Popesso
Lucia Pozzetti
Francesca Pozzi
Laurie Riguccini
Giulia Rodighiero
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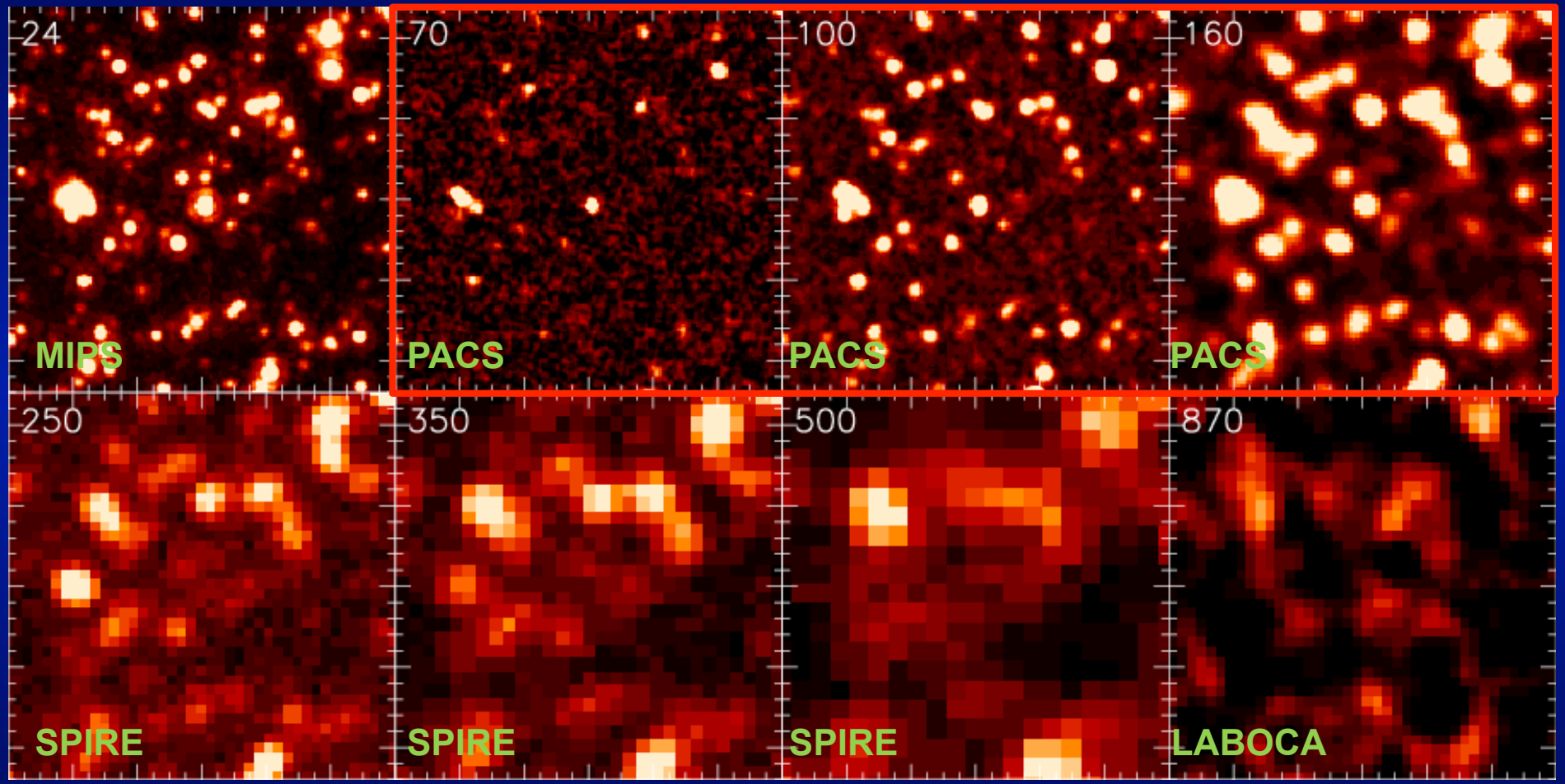
David Rosario
Amelie Saintonge
Fadia Salmi
Mara Salvato
Miguel Sanchez
Paola Santini
Joana Santos
Li Shao
Eckhard Sturm
Linda Tacconi
Margherita Talia
Silvia Tomassin
Ivan Valtchanov
Michael Wetzstein
Eckhard Wieprecht
Stijn Wuyts

Main goals:

- Resolve the cosmic infrared background
- Determine the cosmic evolution of dusty star formation and of the infrared luminosity function.
- Determine the role of AGN and their co-evolution with galaxies.
- Determine the infrared emission and energetics of known galaxy populations.
- Elucidate the relation of far-infrared emission and environment.

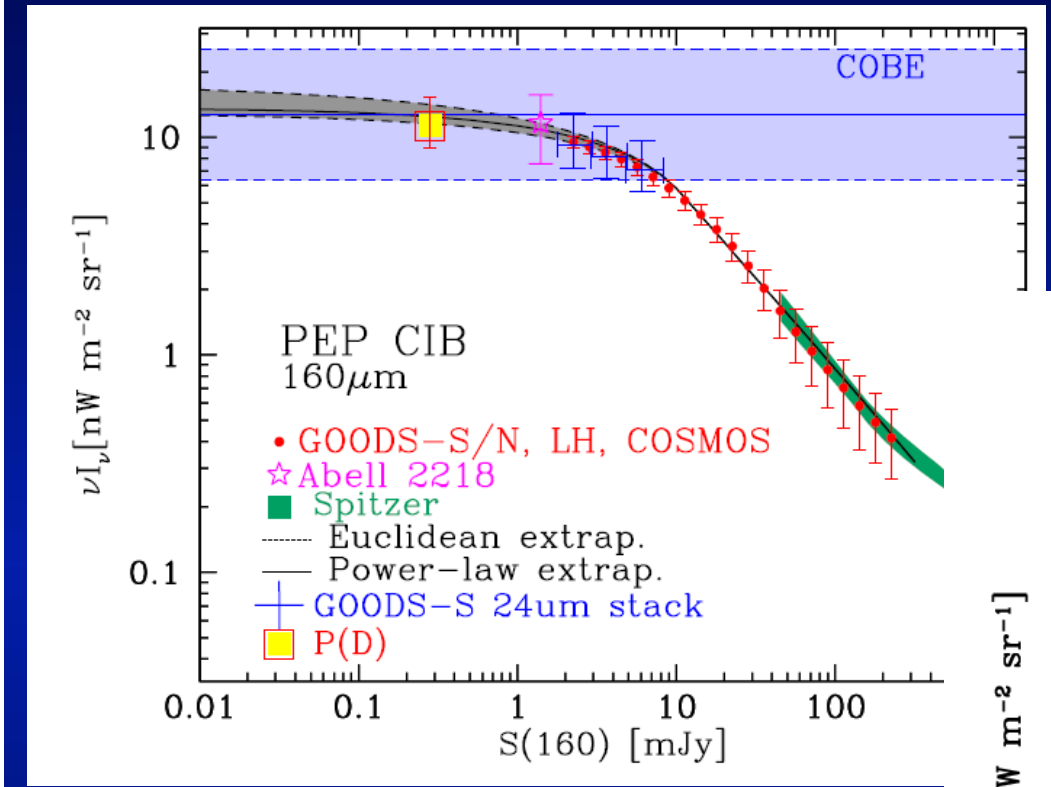
More than 50 refereed team publications since 2010

Current deep far-infrared data (4'x4' cutout in UDF region)



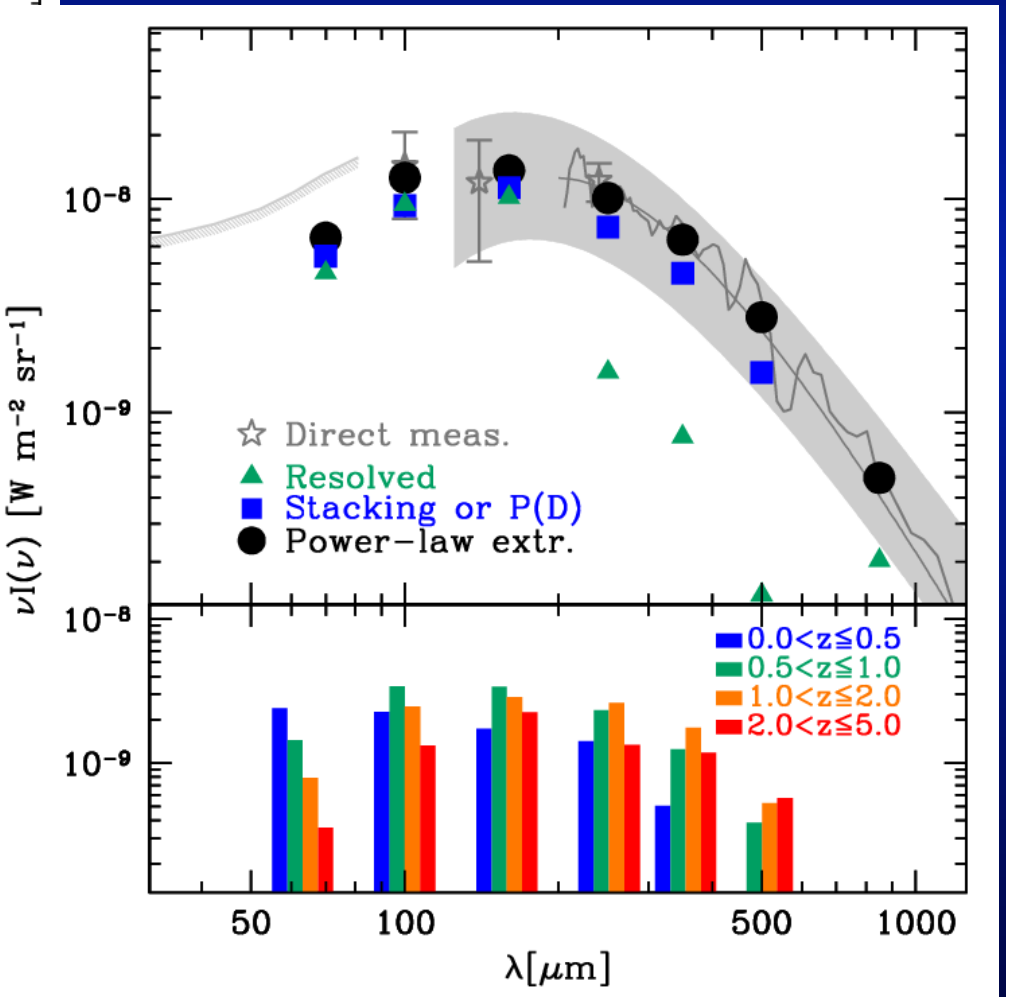
GOODS, PEP, HerMES, LESS

Herschel resolves the majority of the Cosmic Infrared Background



Berta+10,11, Magnelli+13

SPIRE: Oliver+10, Clements+10, Bethermin+12…

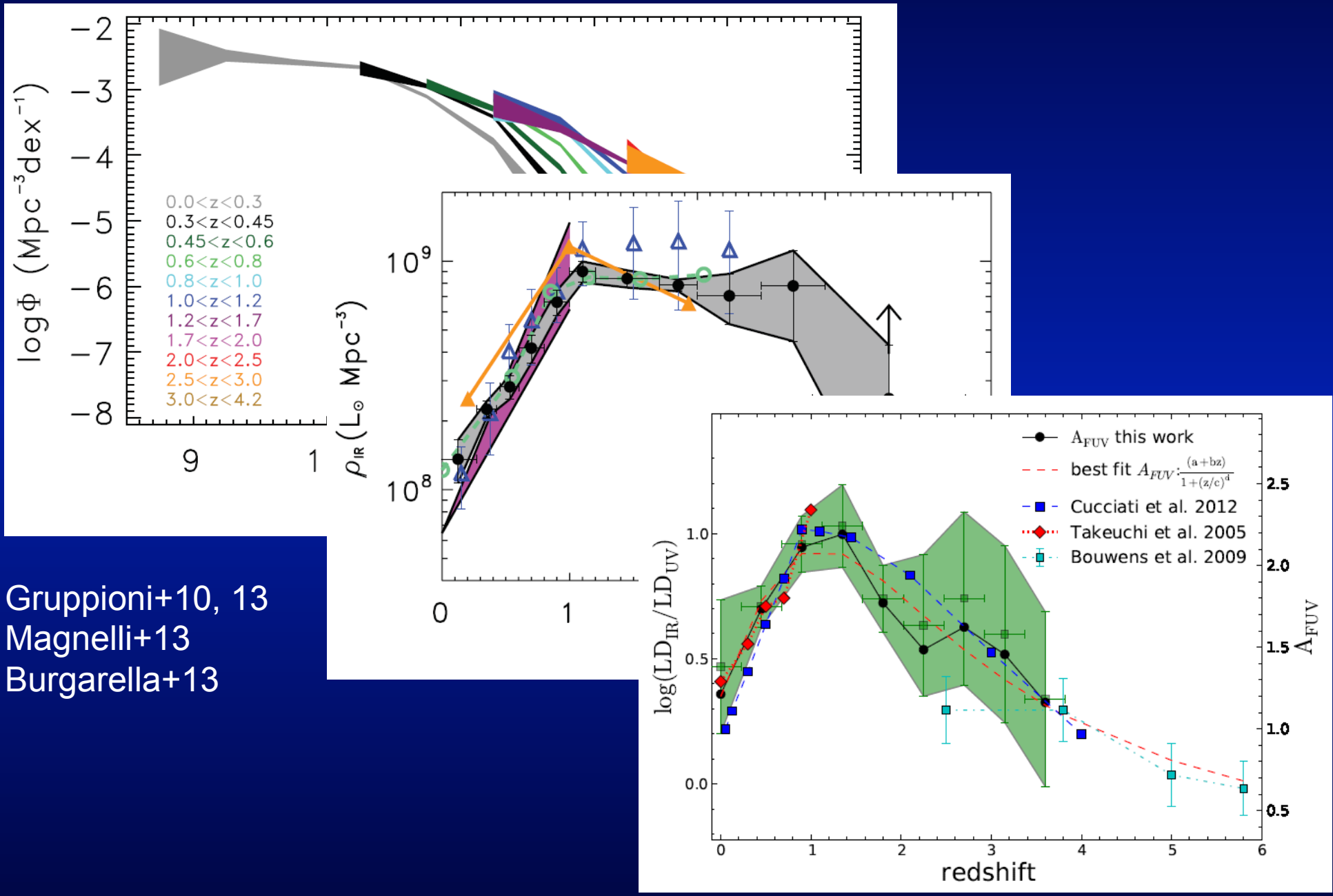


Resolved into individually detected sources:

~75% @ 100μm and 160μm

No evidence for a truly diffuse extragalactic background, COBE measurements accounted for

True IR luminosity functions out to z>2



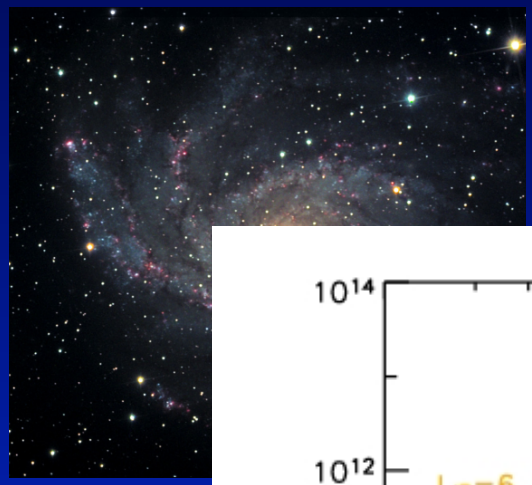
Gruppioni+10, 13
Magnelli+13
Burgarella+13

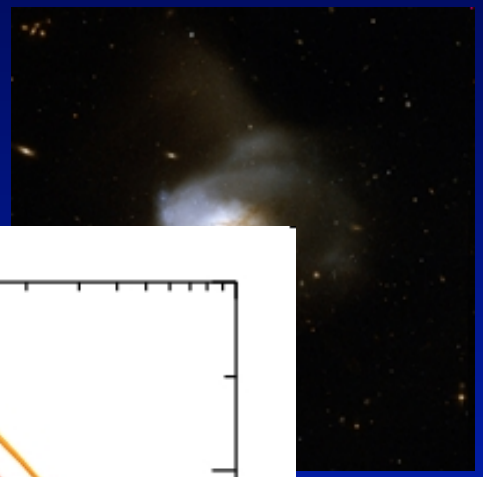
How we looked at (local) infrared galaxies some years ago….

Normal galaxy

LIRG

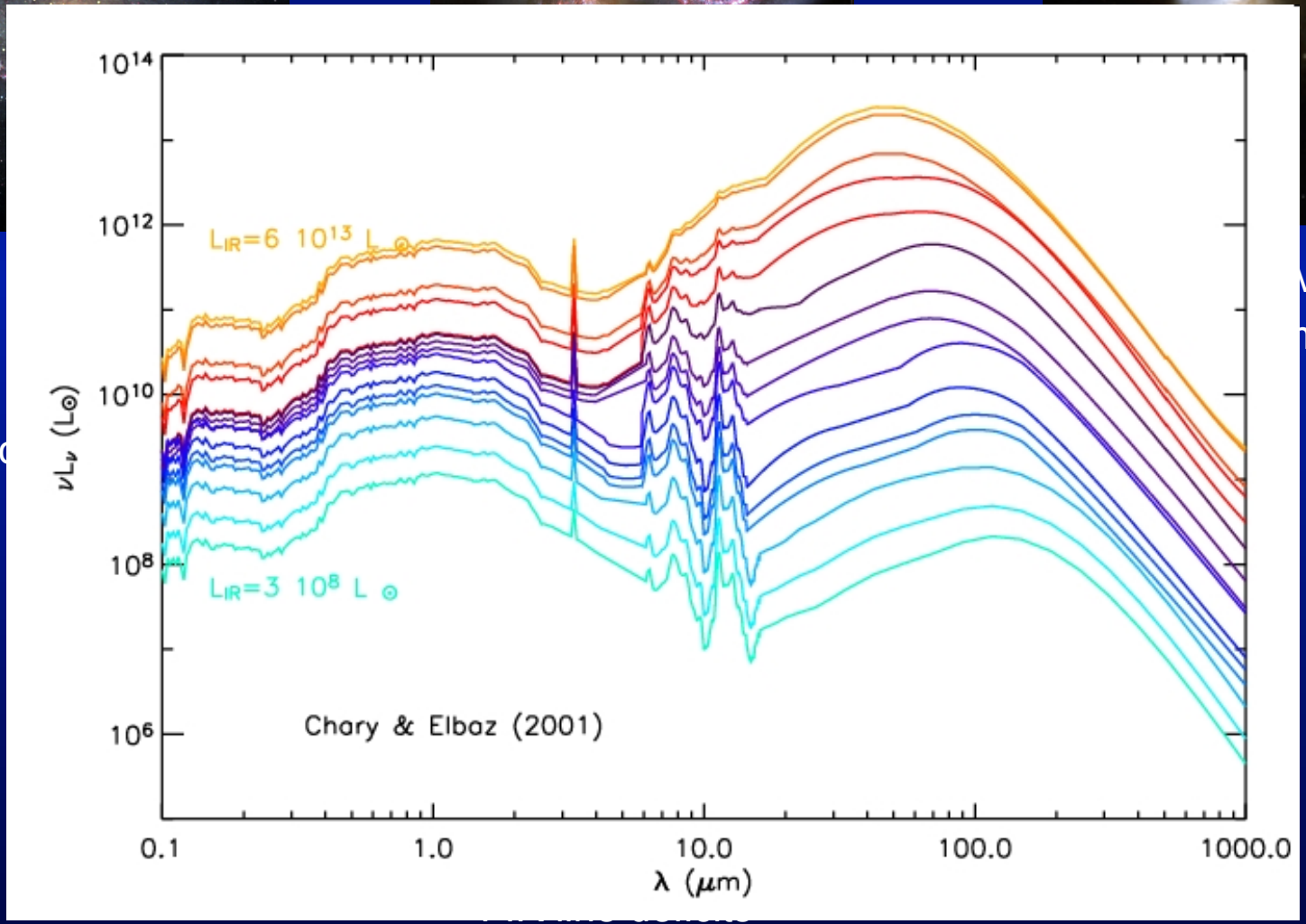
ULIRG

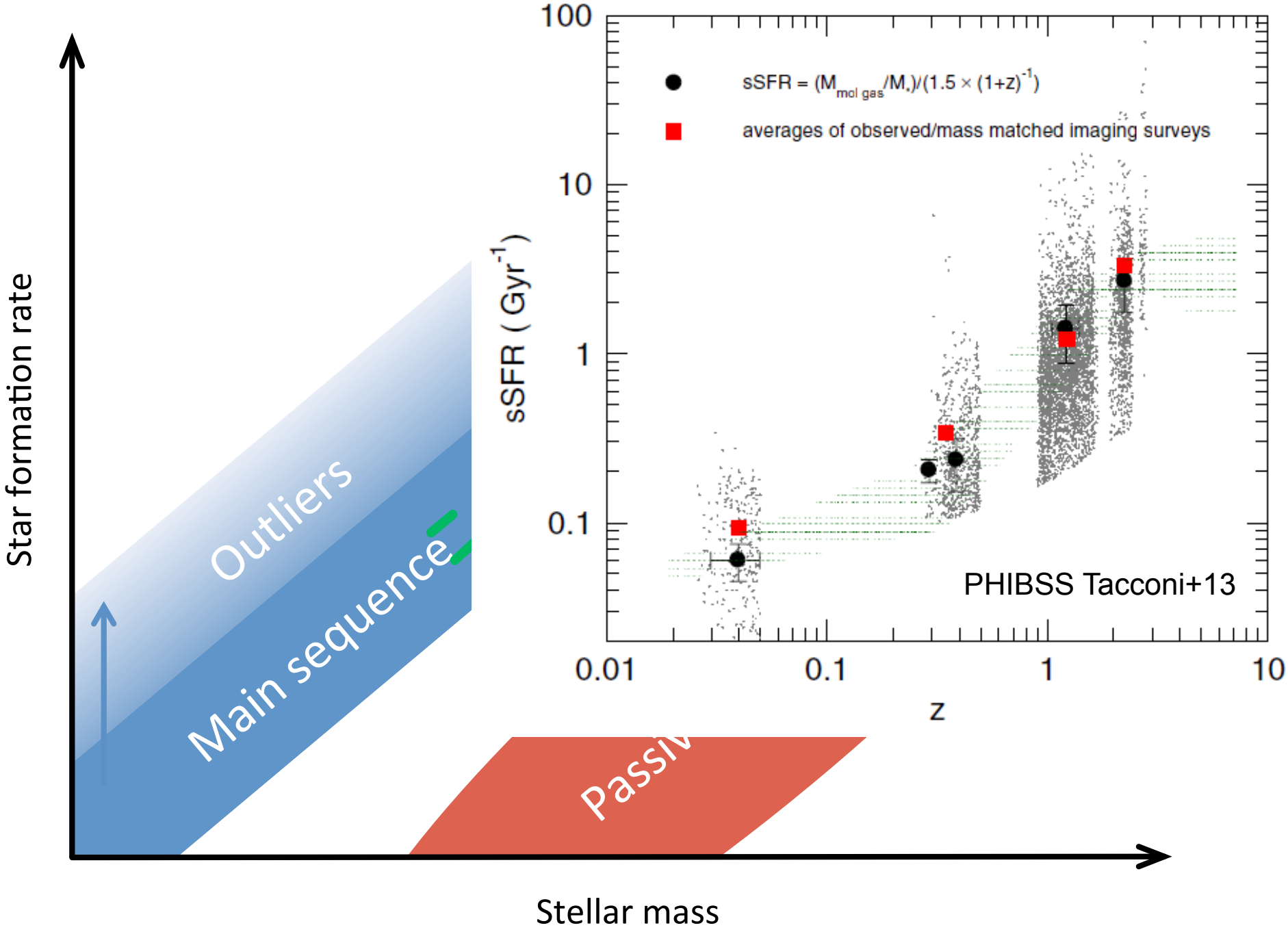




2 M_{Sun}/yr
disk
low
several kpc
on
cool
high

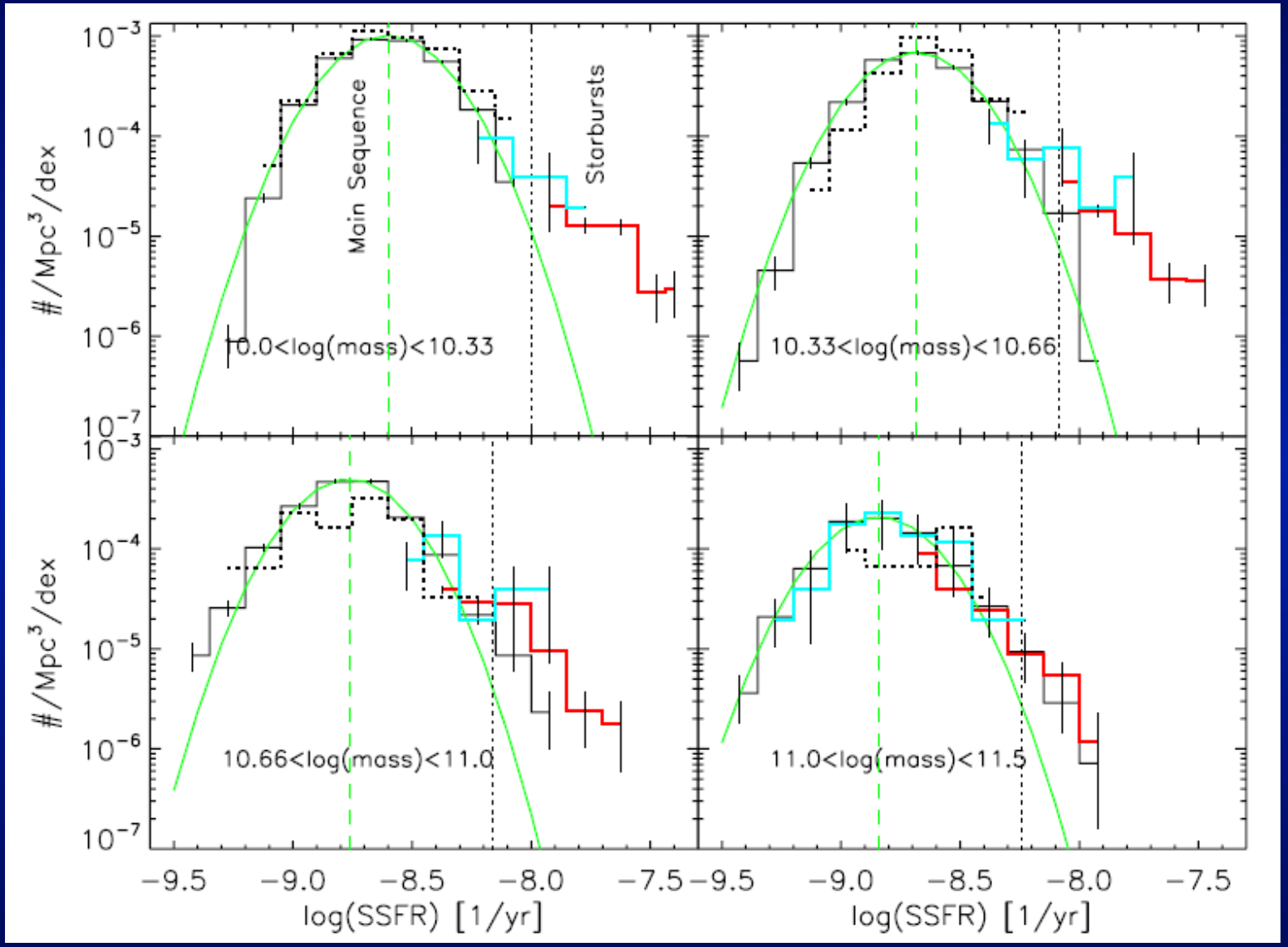
M_{Sun}/yr
merger
high
100pc
above
warm
low





e.g. Brinchmann+04, Noeske+07, Elbaz+07, Daddi+07, Rodighiero+10, Whitaker+12

The lesser role of z~2 starbursts



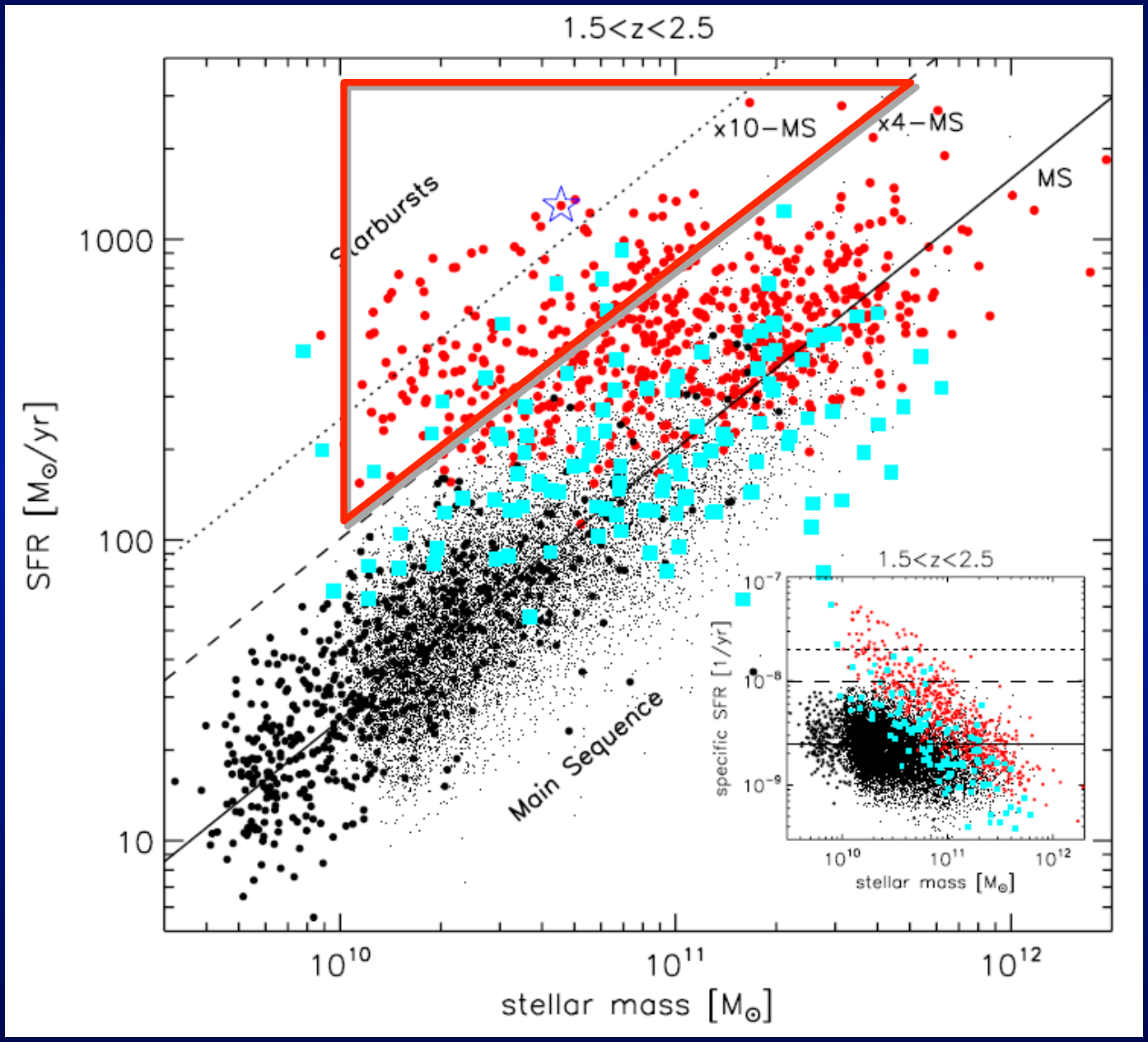
Rodighiero+ 11, Sargent+12

The lesser role of z~2 starbursts

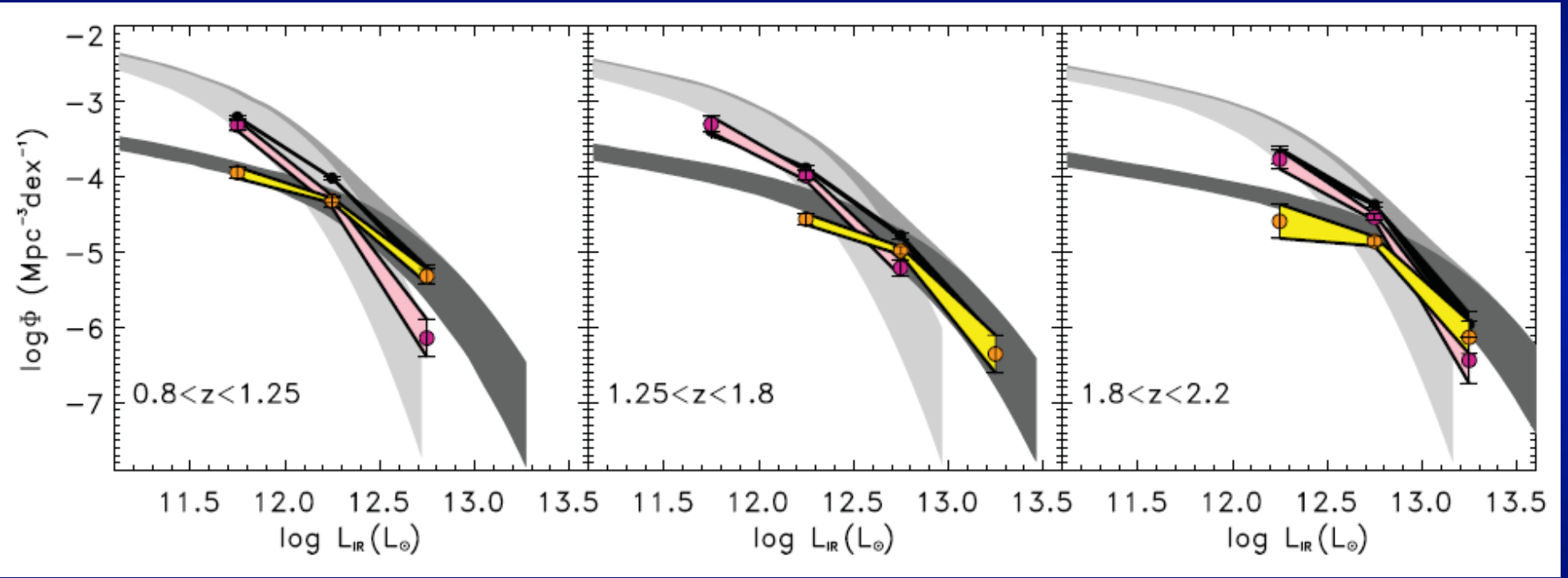
Starbursts:
2% of z~2 massive galaxies
10% of SFR from z~2 massive galaxies

All the Rest is on main sequence

Rodighiero+ 2011

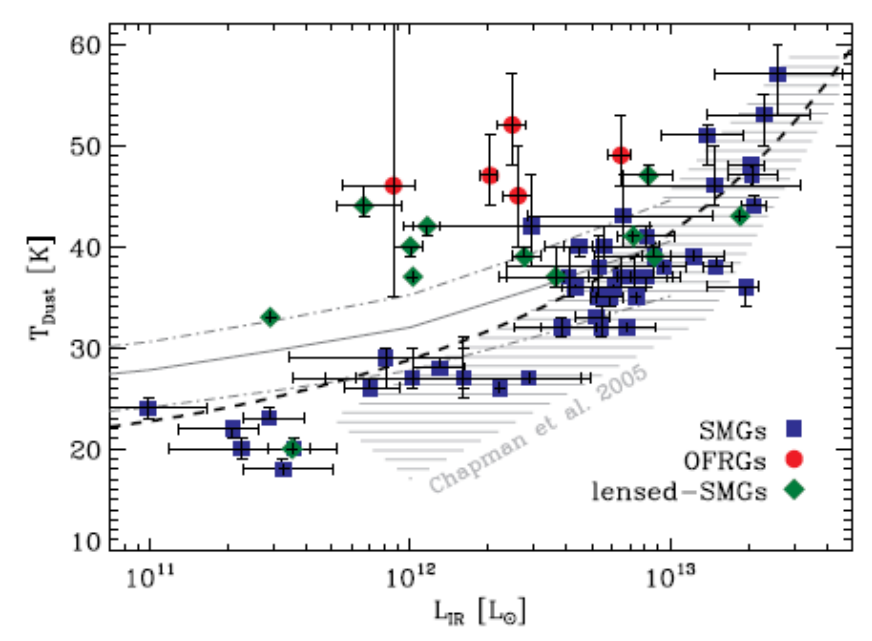


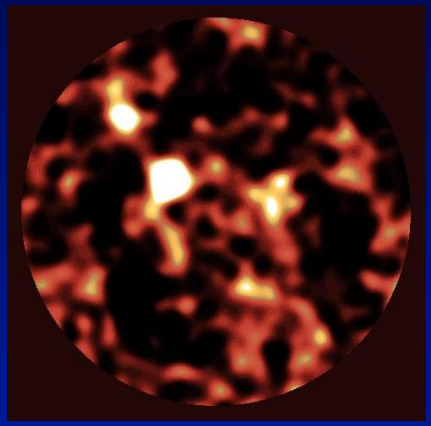
Main sequence galaxies dominate LF except highest end



Gruppioni+13
(and models by Sargent+12)

Classical 850μm selected SMGs are a mixed group!

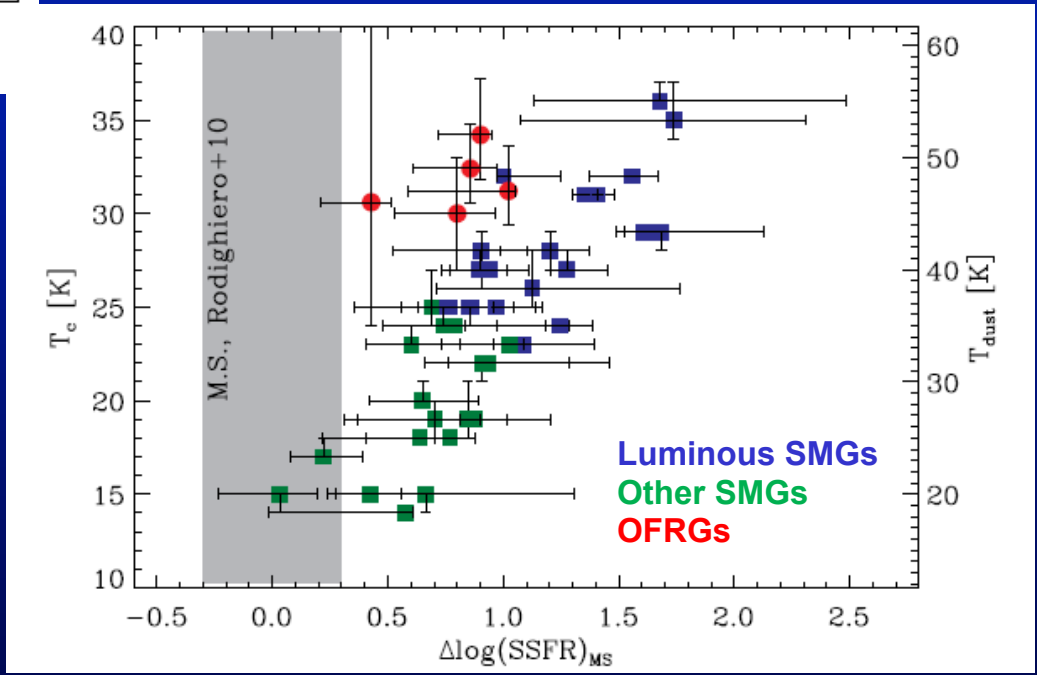




Hughes+98 Scuba 850μm

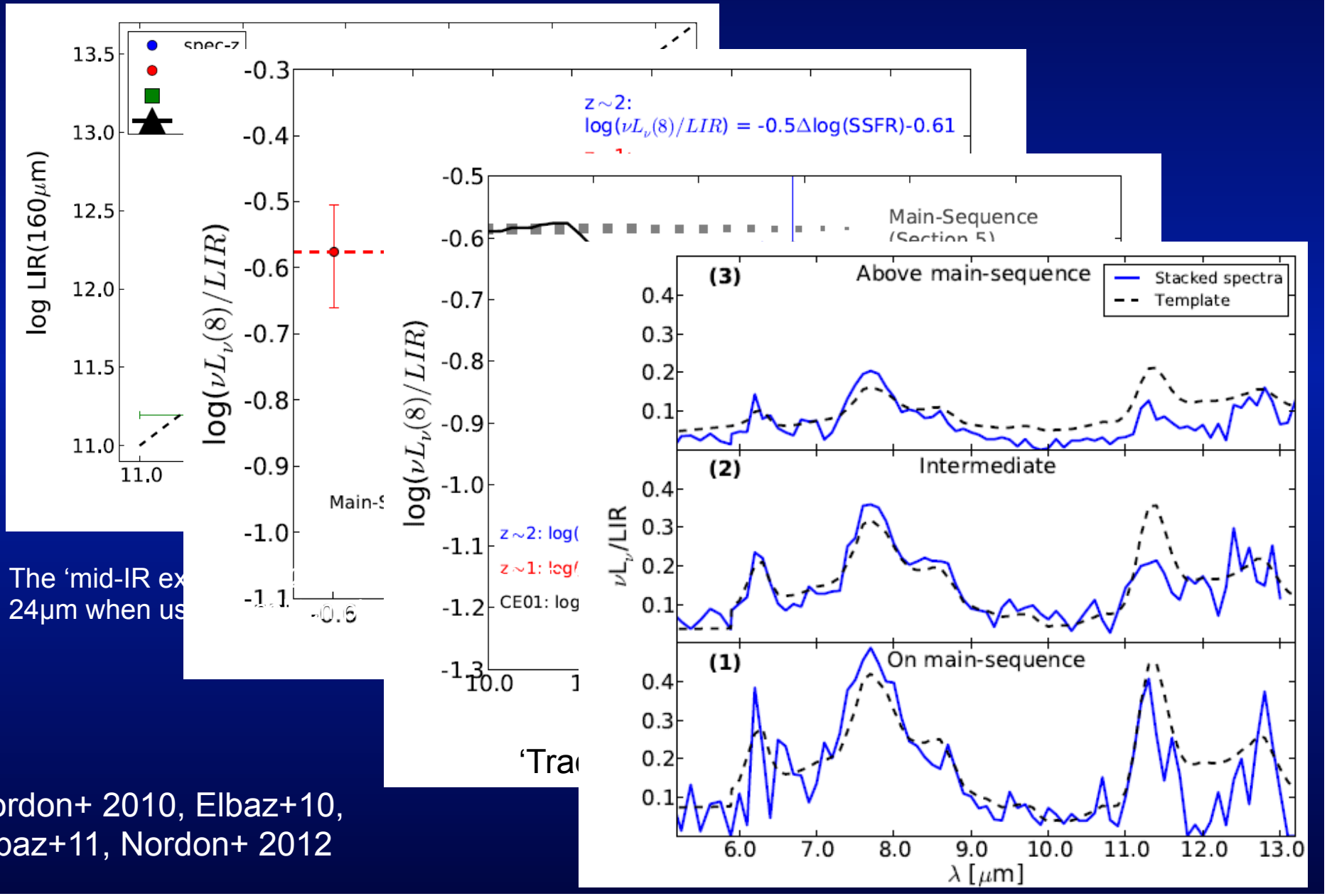
Star formation rates up to ~1000M_{Sun}/yr at z~2

.. Note SMG selection effects



Magnelli+ 2010 and 2012, see also Chapman+ 2010

Relation to main sequence: $\nu L\nu(8\mu m)$ / L_{IR}

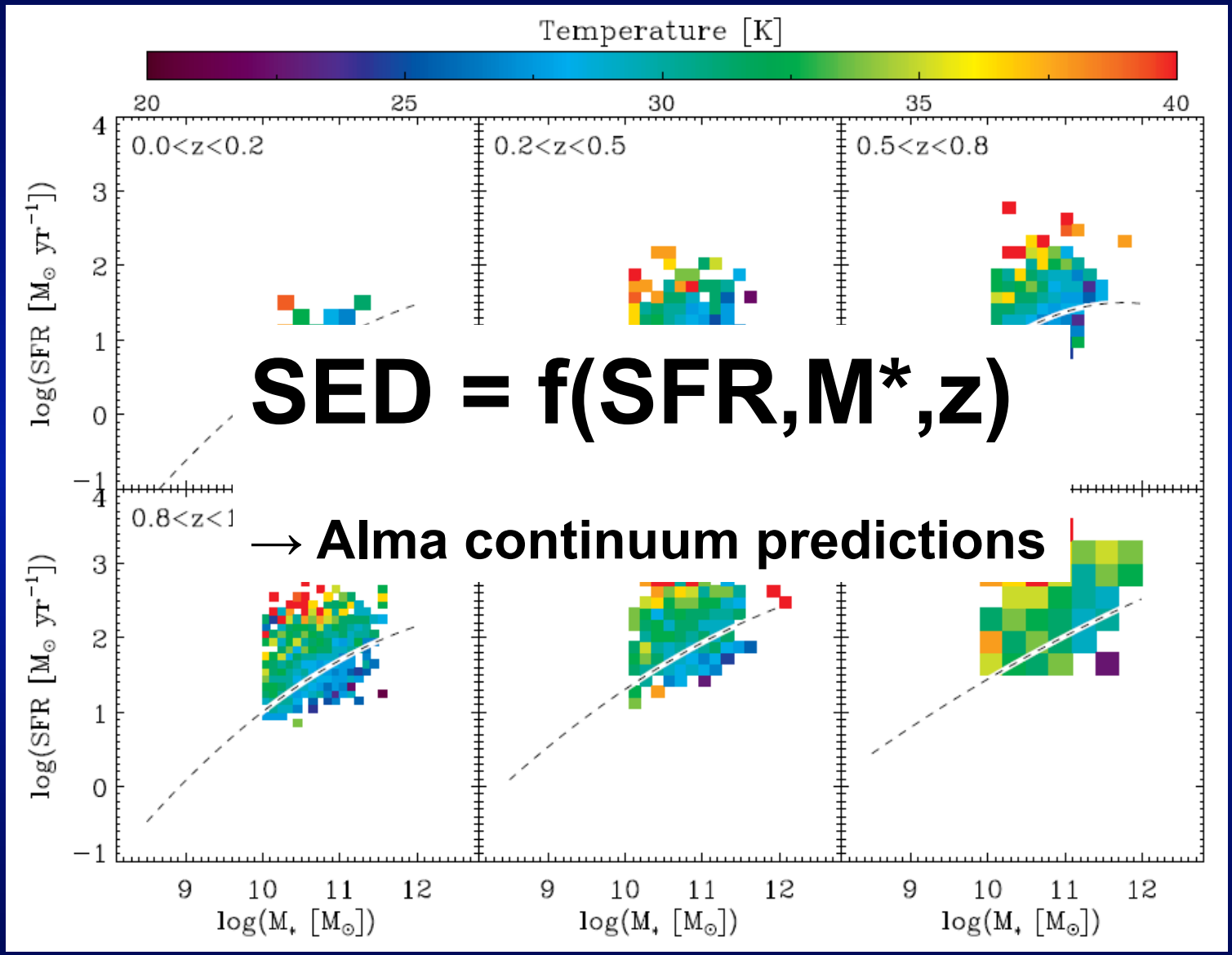


The 'mid-IR ex
24μm when us

'Trac

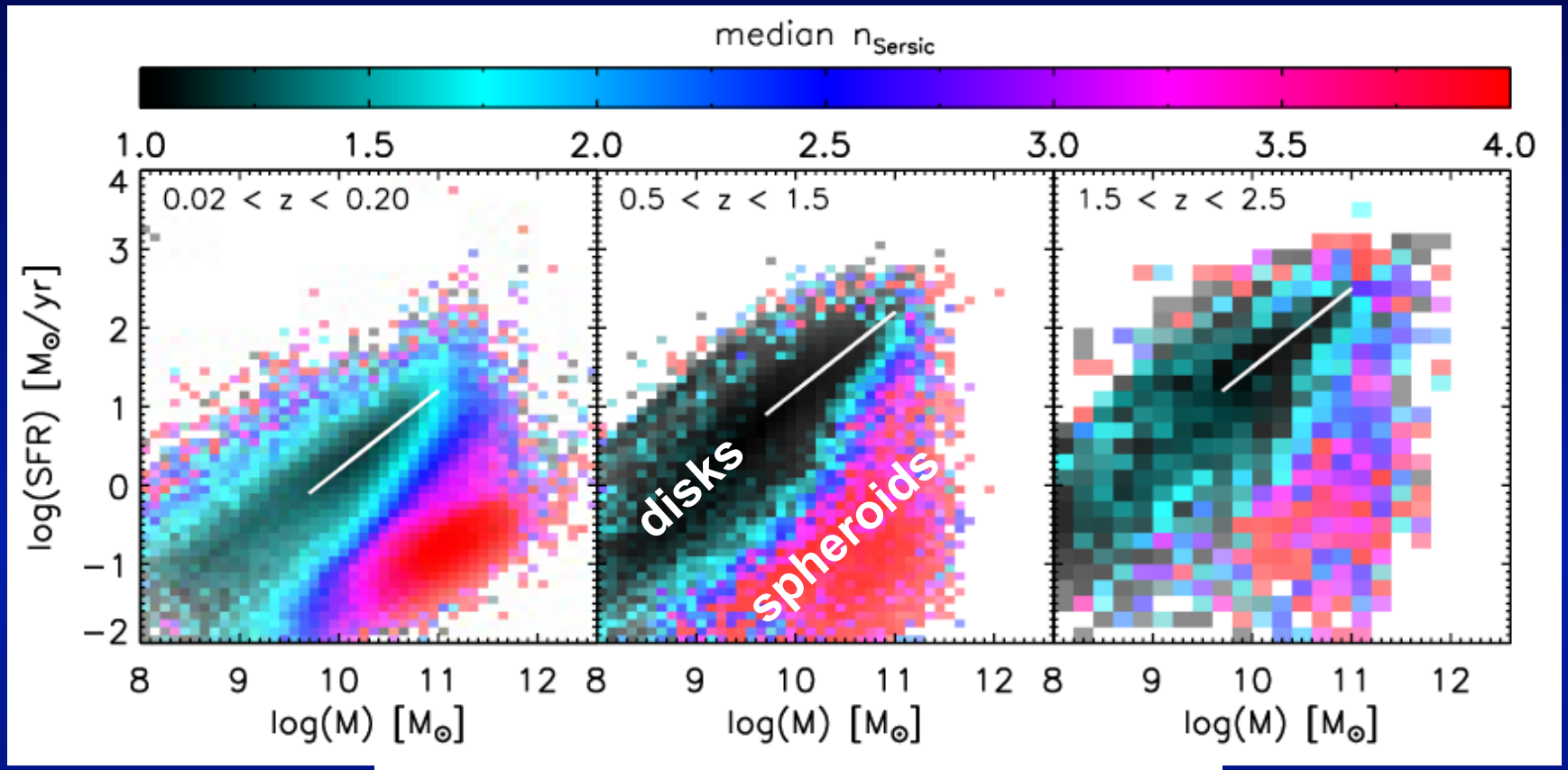
Nordon+ 2010, Elbaz+10,
Elbaz+11, Nordon+ 2012

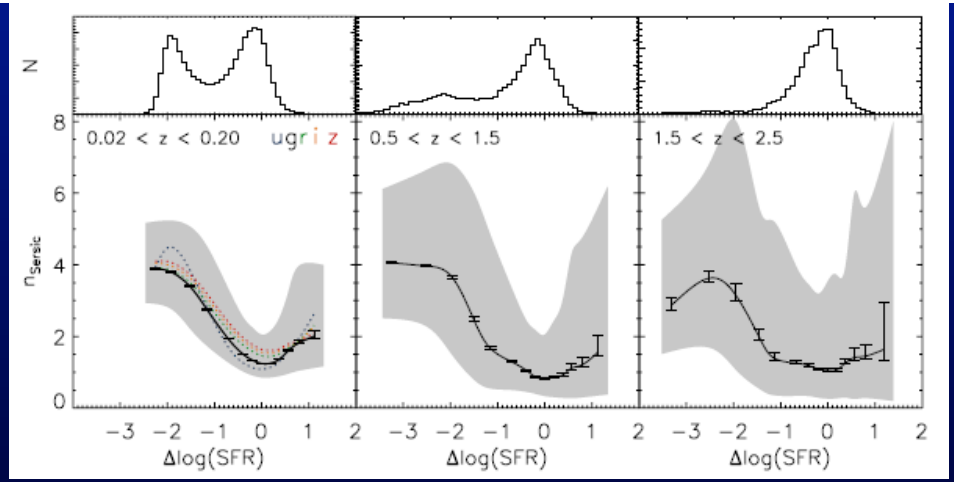
Relation to main sequence: Far-infrared SEDs



T_{Dust} increases with MS offset & SSFR [also with decreasing metallicity]
Magnelli+ submitted

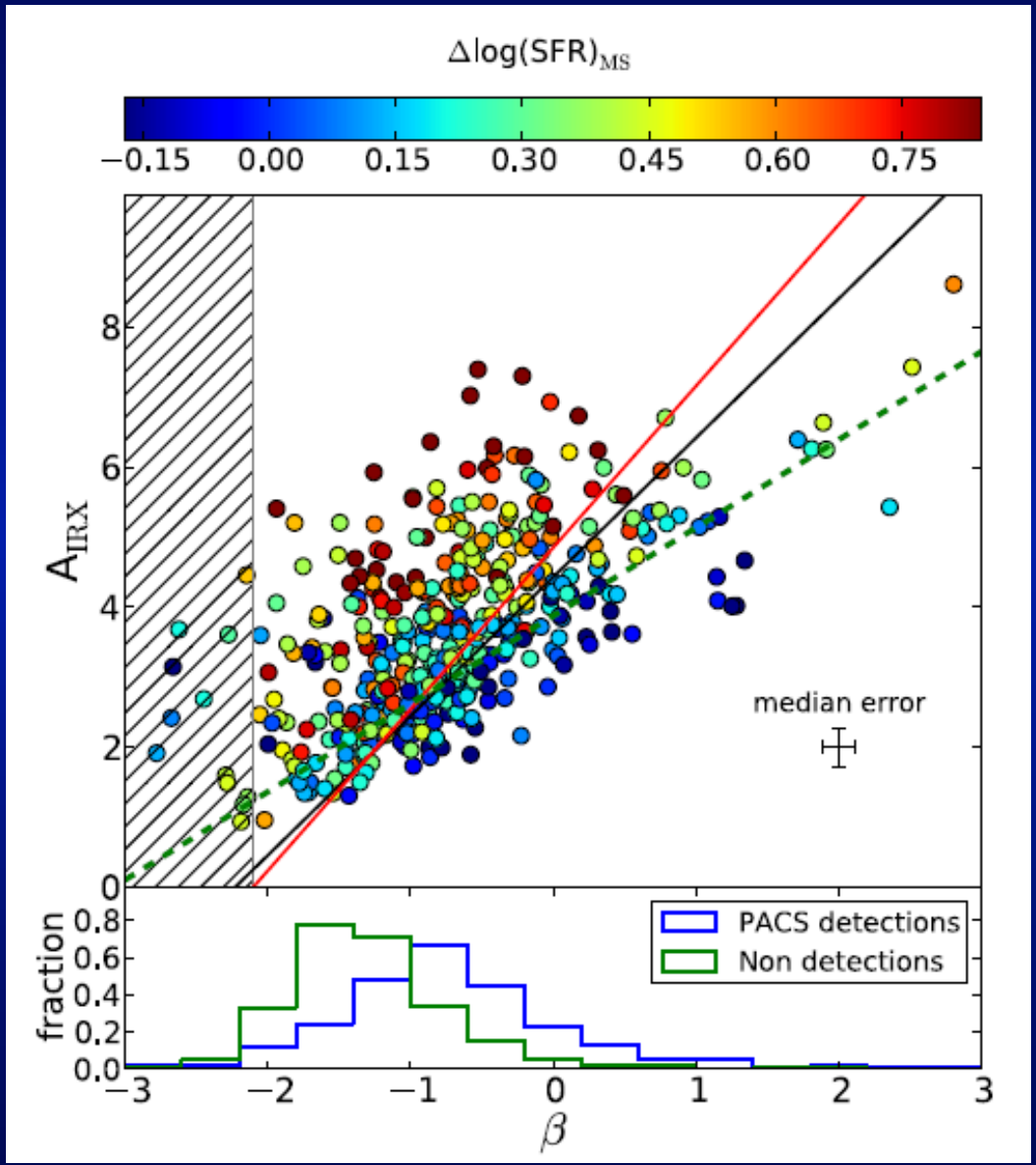
A morphological `main sequence'





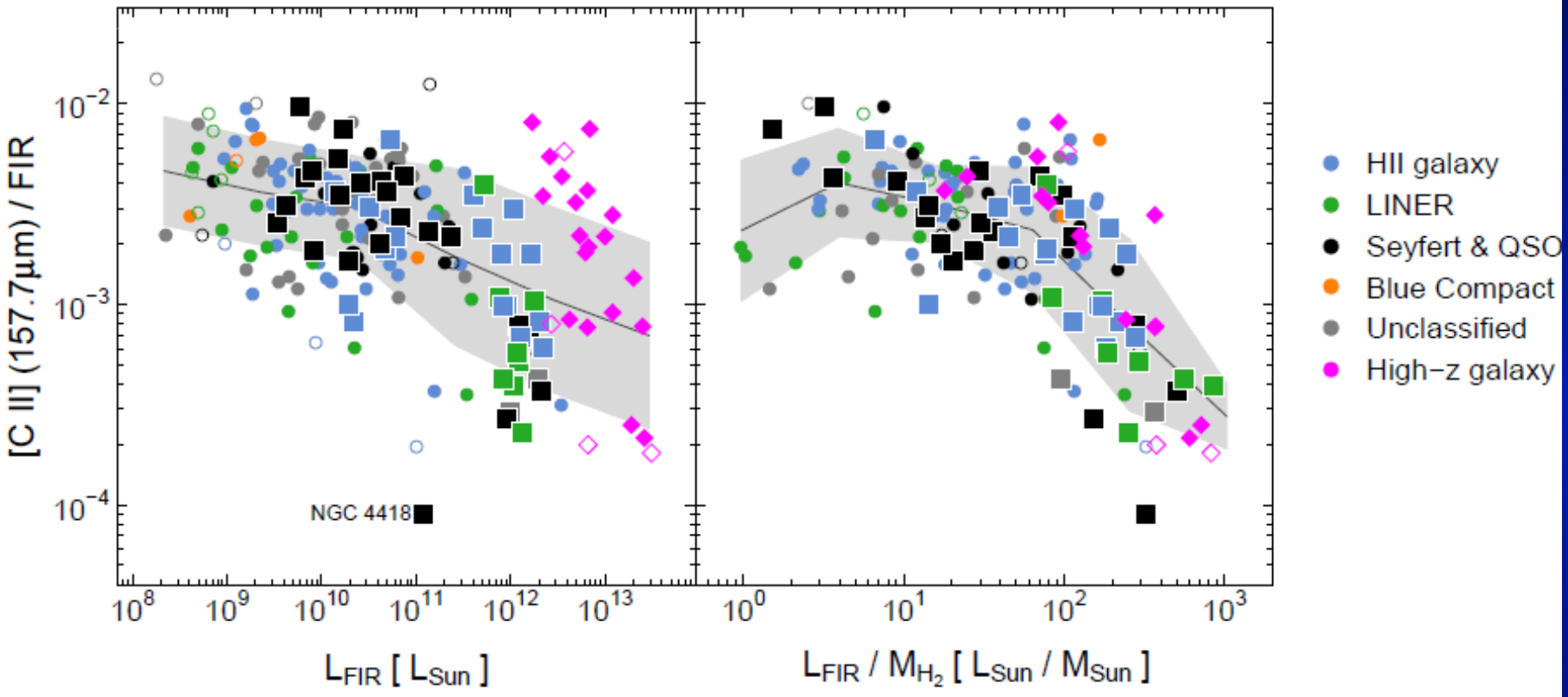
Wuyts+ 2011.

Relation to main sequence: UV obscuration properties



Nordon+13

Relation to main sequence: The ‘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]

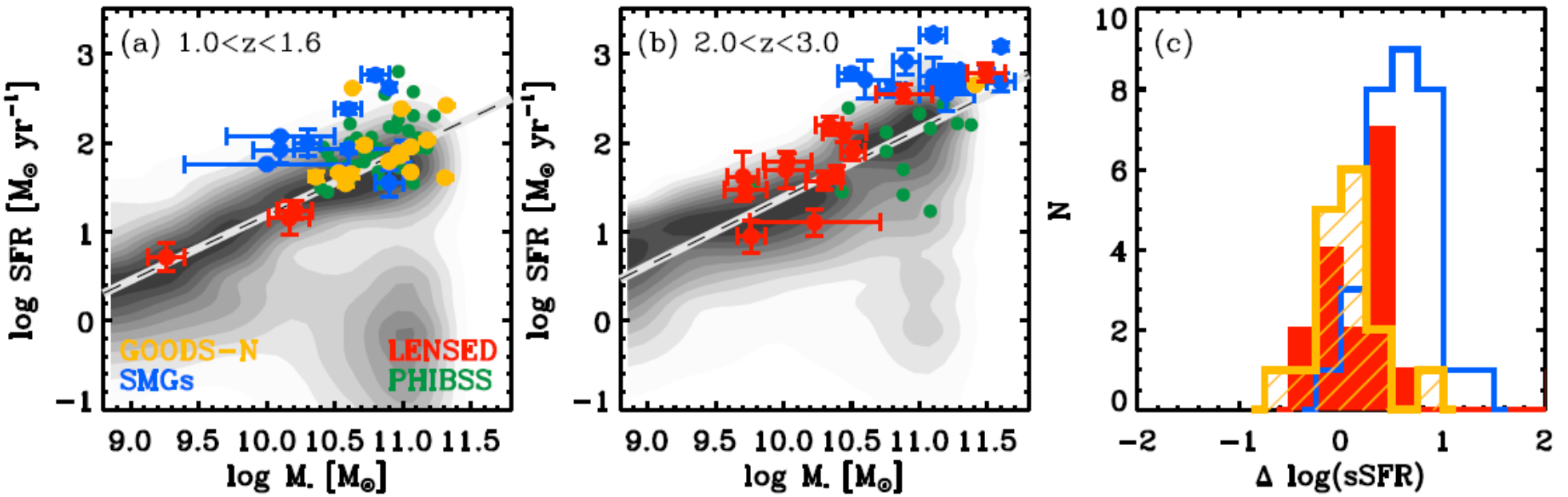
[Stacey et al. 2010, ApJ 724: 957]

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

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

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

A Herschel and IRAM CO lensed sample

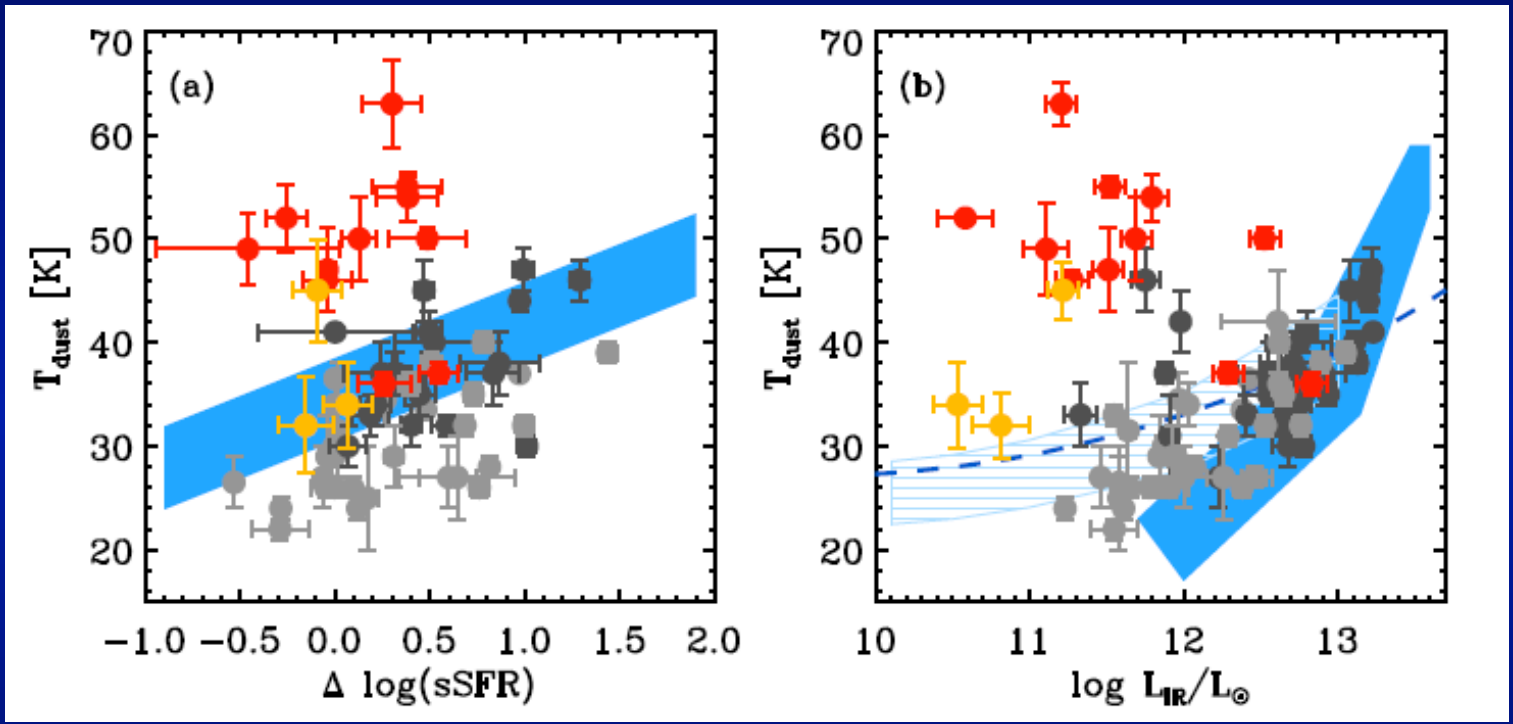


Saintonge+13: 17 lensed galaxies, z=1.4-3.1

- Full PACS-SPIRE photometric coverage
- CO data for 10 galaxies (8 detections)
- Good ancillary data (e.g. direct metallicities for 13)

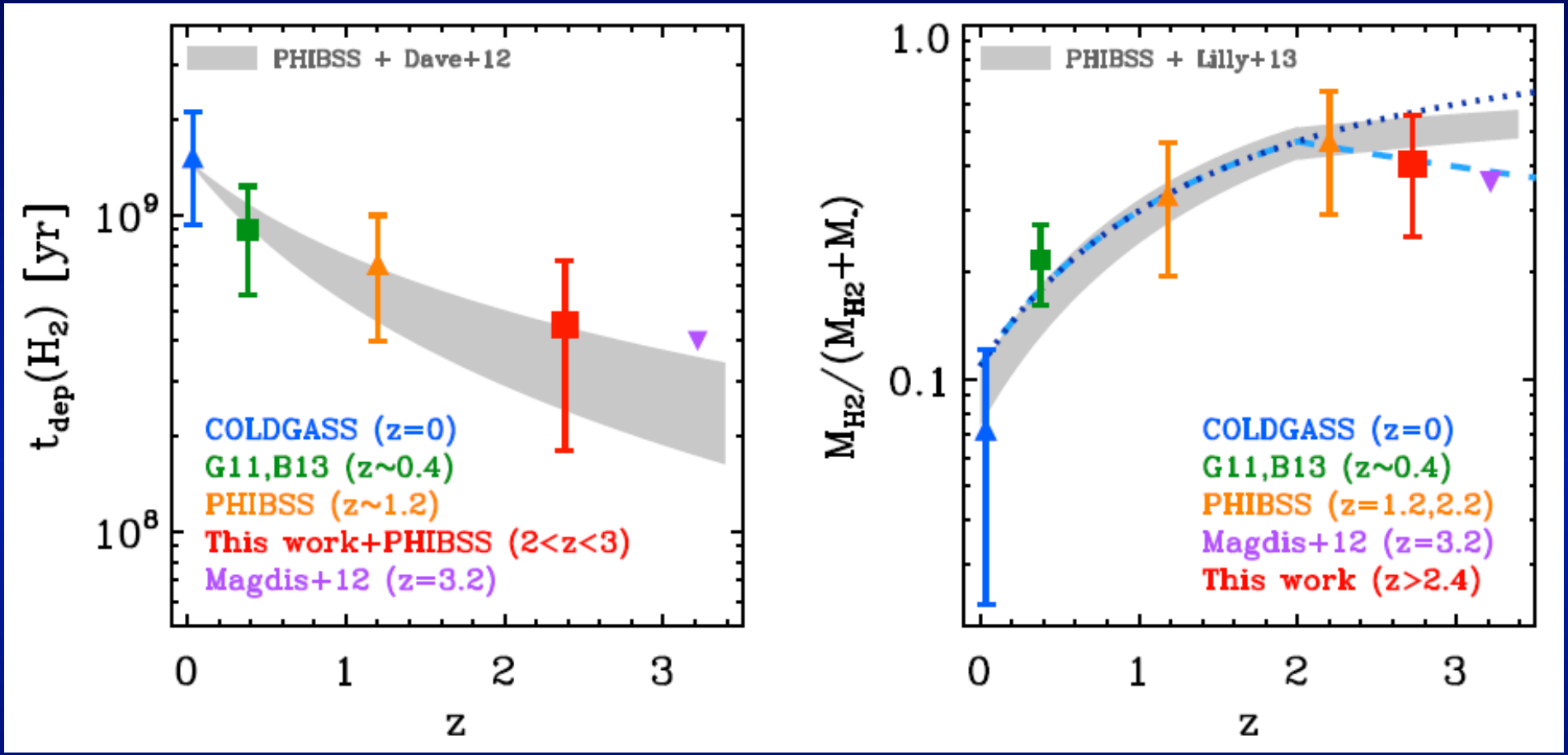
Probe M*~1e10 near-main sequence galaxies individually – without stacking

On main sequence, but warm dust temperatures



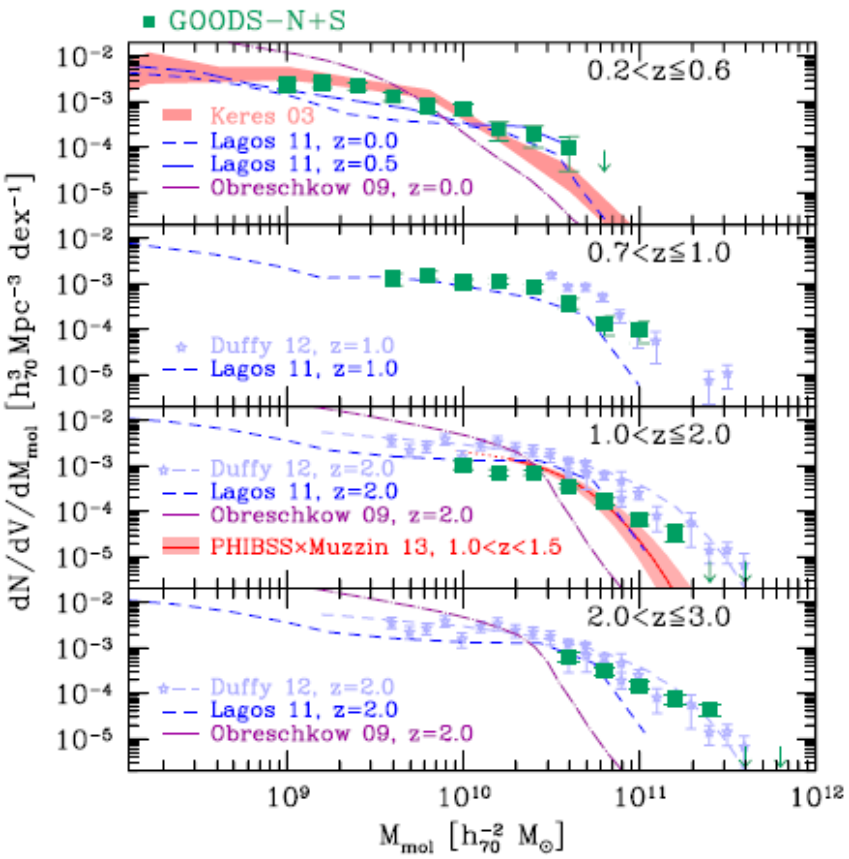
Consistent with high SFE=SFR/
Mgas and low metallicity!

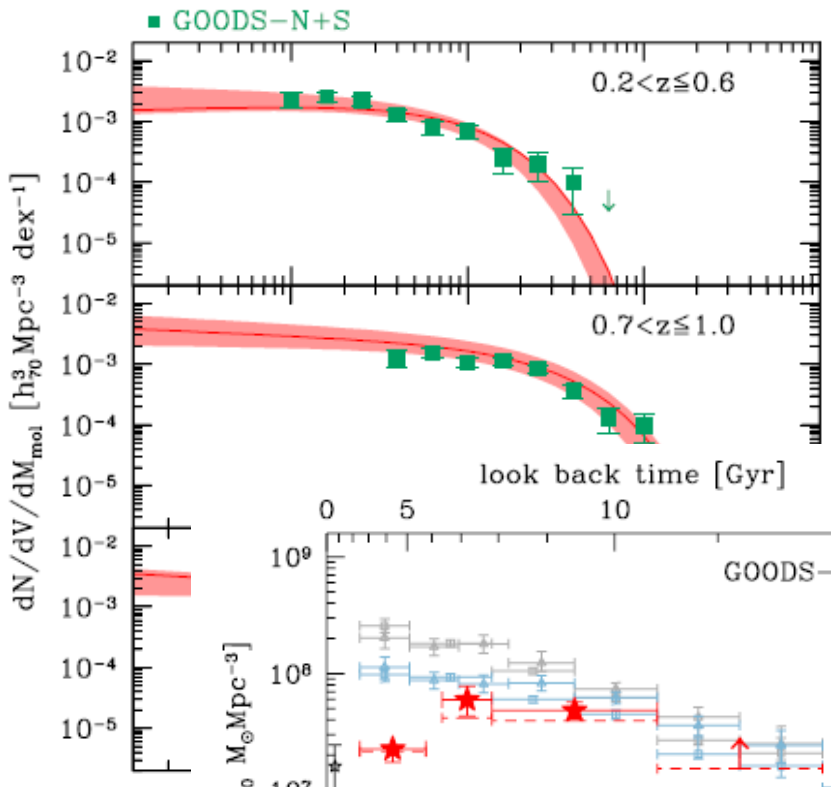
Evolution of gas depletion time and gas fractions

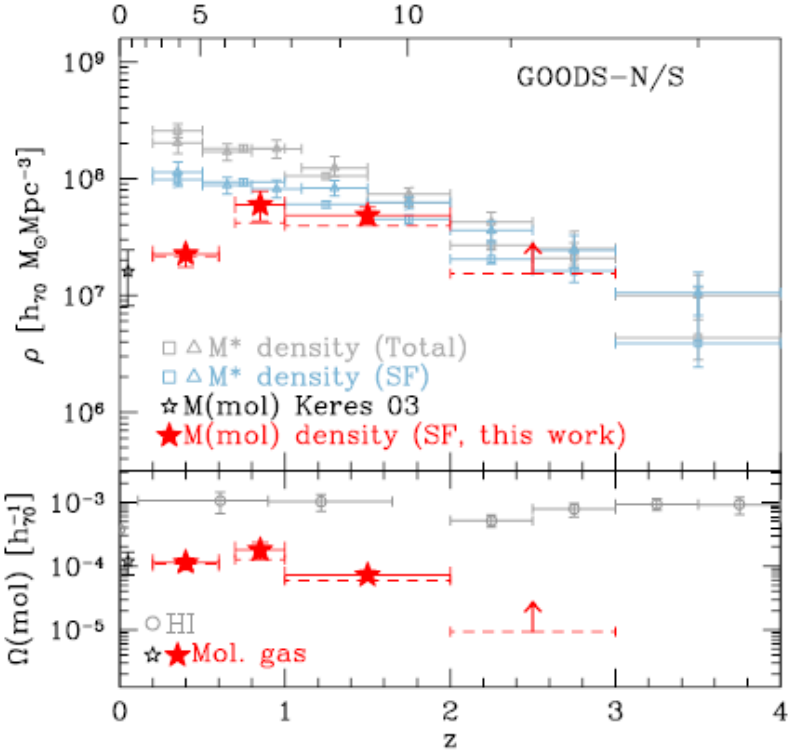


- Agrees with $t_{dep} \sim (1+z)^{-1}$ (PHIBSS, Tacconi+13) out to z>2
- Gas fractions may level off at z>2, in agreement with equilibrium model for a situation where SSFR increase slows down at z>2

Molecular gas mass functions since z~3







Berta+ 13: CO mass function using Herschel data and

- Specific attenuation method of Nordon+13
- PHIBSS depletion time scaling $t_{Dep} \sim (1+z)^{-1}$ (Tacconi+13)

Summary

- Herschel has resolved the cosmic infrared background near its peak, and determined the contribution of different epochs to the CIB and star formation density.

- Infrared SEDs and ISM properties of z=0-2 infrared galaxies are best described in relation to the evolving main sequence of star forming galaxies. Most star formation happens near the main sequence.

- Cold gas content is a main factor in driving theevolution of the main sequence, in the equilibrium of inflow, star formation and metal enrichment, outflow. Herschel dust-based surveys add statistics to CO-based characterisations, and quantify the comoving density of cold gas

Related talks: Burgarella, Rosario

Related posters: Berta, Dominguez Sanchez, Gruppioni, Magliocchetti, Magnelli, Symeonidis, Vaccari, Xu