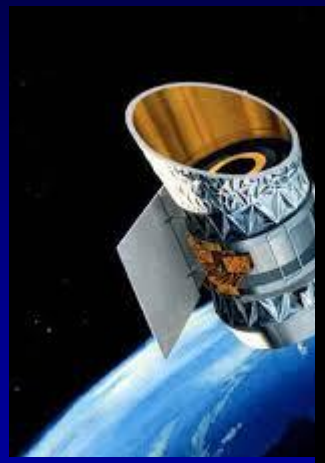
Herschel extragalactic deep surveys: Results and legacy

Herschel 10 years after launch
ESAC Villafranca, May 13, 2019

Dieter Lutz

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

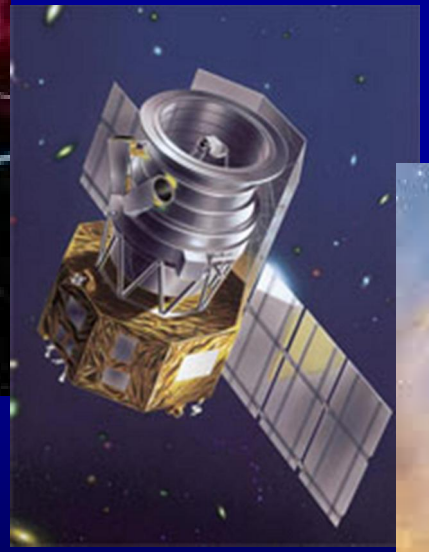
A success story of far-infrared surveys of galaxy evolution



IRAS

ISO

Spitzer

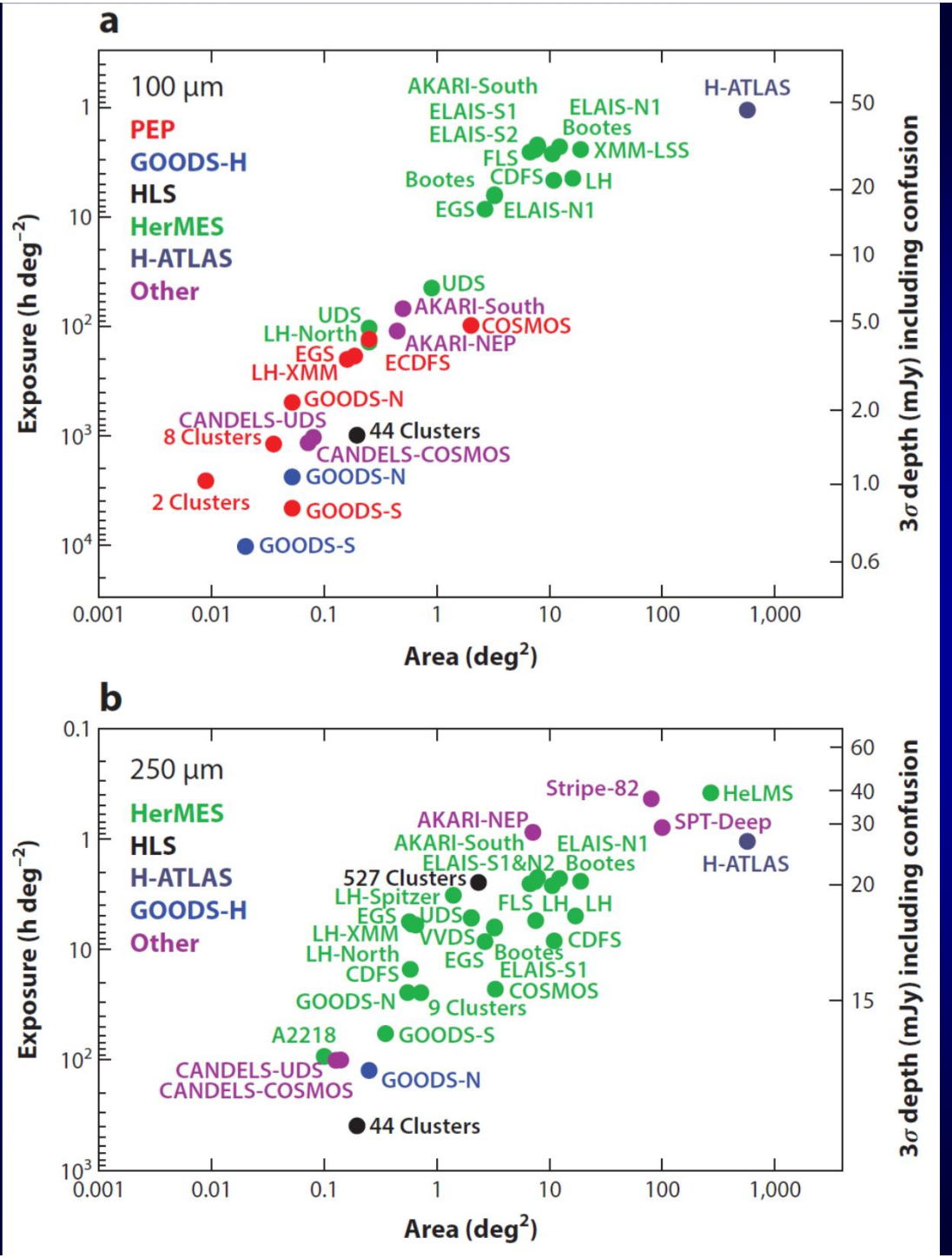


Akari

Herschel

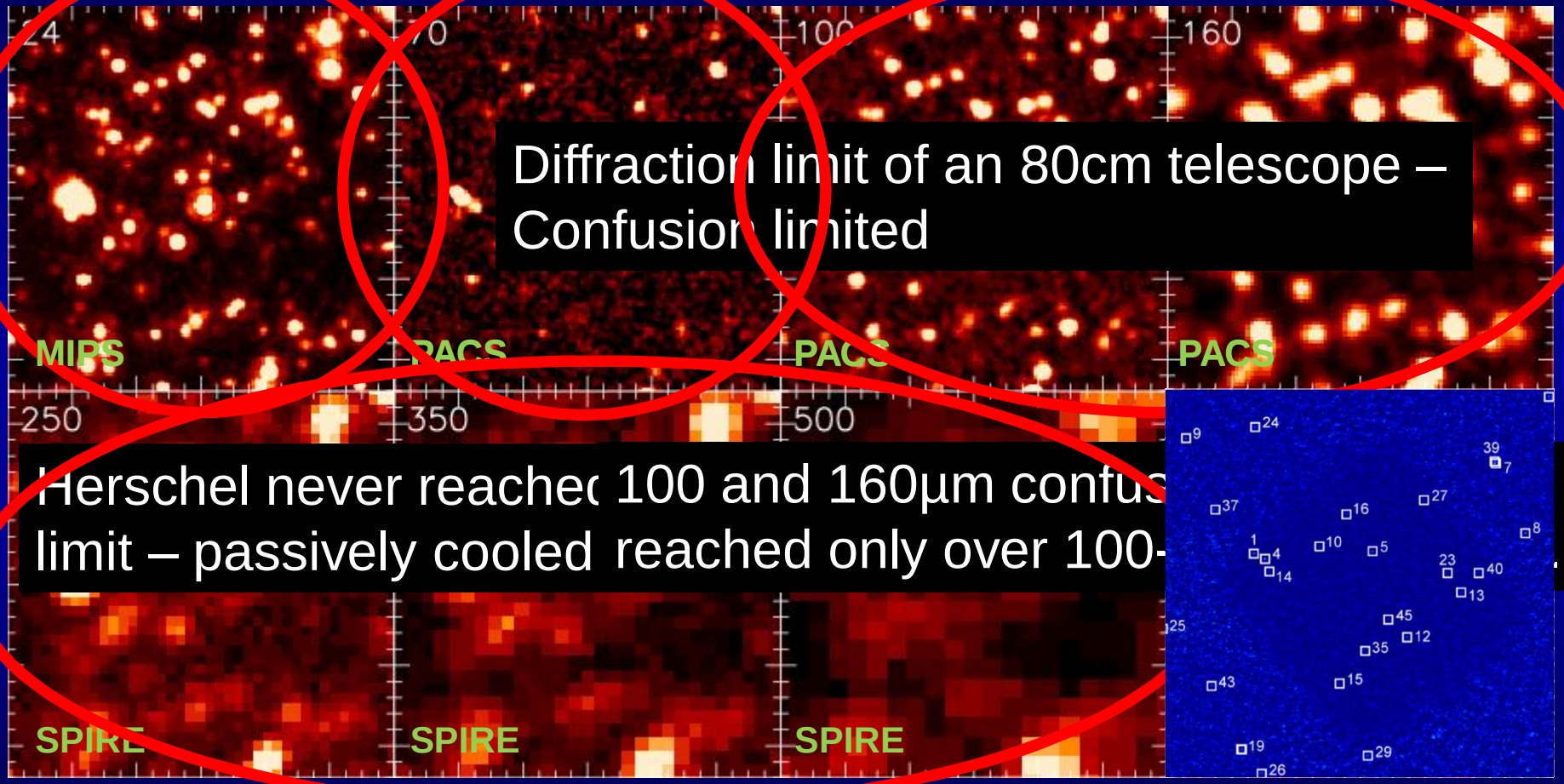
Post-Herschel review: Lutz ARA&A 52, 373 (2014)

- Herschel resolves the cosmic infrared background
- Infrared SEDs and the roles of ‘main sequence’ steady evolution and of mergers in the galaxy population out to z~2
- Dust as a tracer of gas, gas scaling relations
- Herschel and AGN / host coevolution
- Bright / lensed dusty star forming galaxies as laboratories for detailed study
- Herschel surveys in the ALMA era



Lutz 14
ARA&A 52, 373

Current deep infrared/submm data (4'x4' cutout in UDF region)



Diffraction limit of an 80cm telescope – Confusion limited

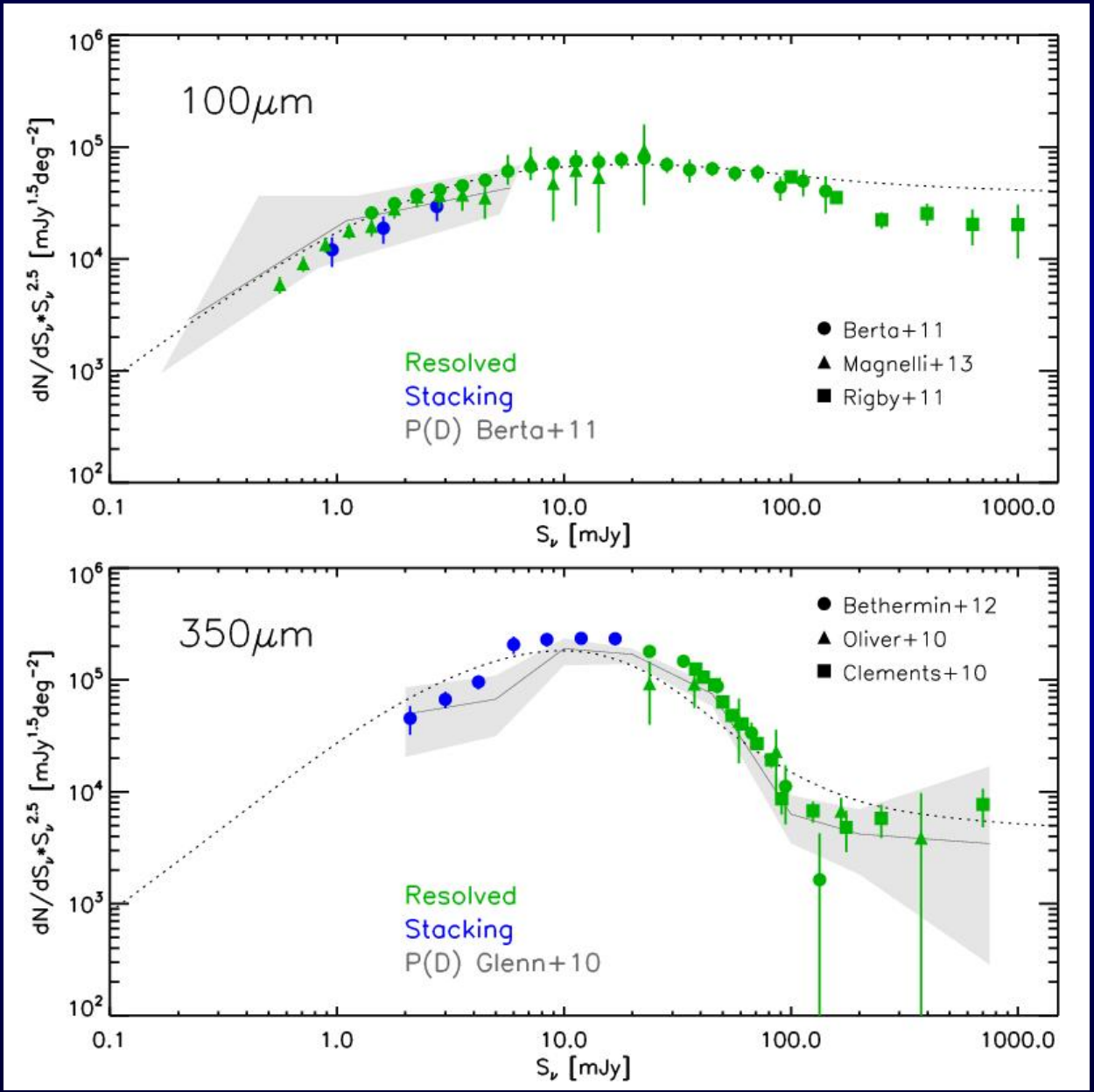
Herschel never reached 100 and 160μm confusion limit – passively cooled reached only over 100-

ALMA 1.2 mm: Asagao

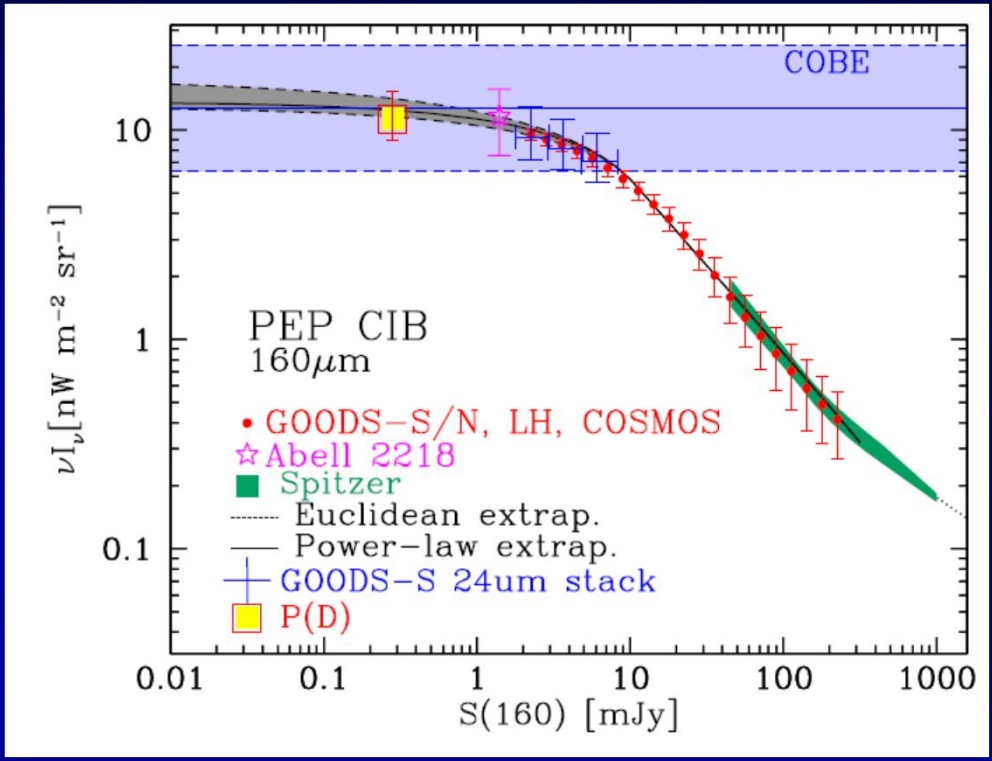
GOODS, PEP, HerMES, LESS

250 to 500μm confusion reached over large areas, but limited depth.

Counts


100μm
Resolved
Stacking
P(D) Berta+11
Berta+11
Magnelli+13
Rigby+11
dN/dS$_\nu$*S$_\nu^{2.5}$ [mJy$^{1.5}$deg^{-2}]
S$_\nu$ [mJy]
350μm
Resolved
Stacking
P(D) Glenn+10
Bethermin+12
Oliver+10
Clements+10
dN/dS$_\nu$*S$_\nu^{2.5}$ [mJy$^{1.5}$deg^{-2}]
S$_\nu$ [mJy]

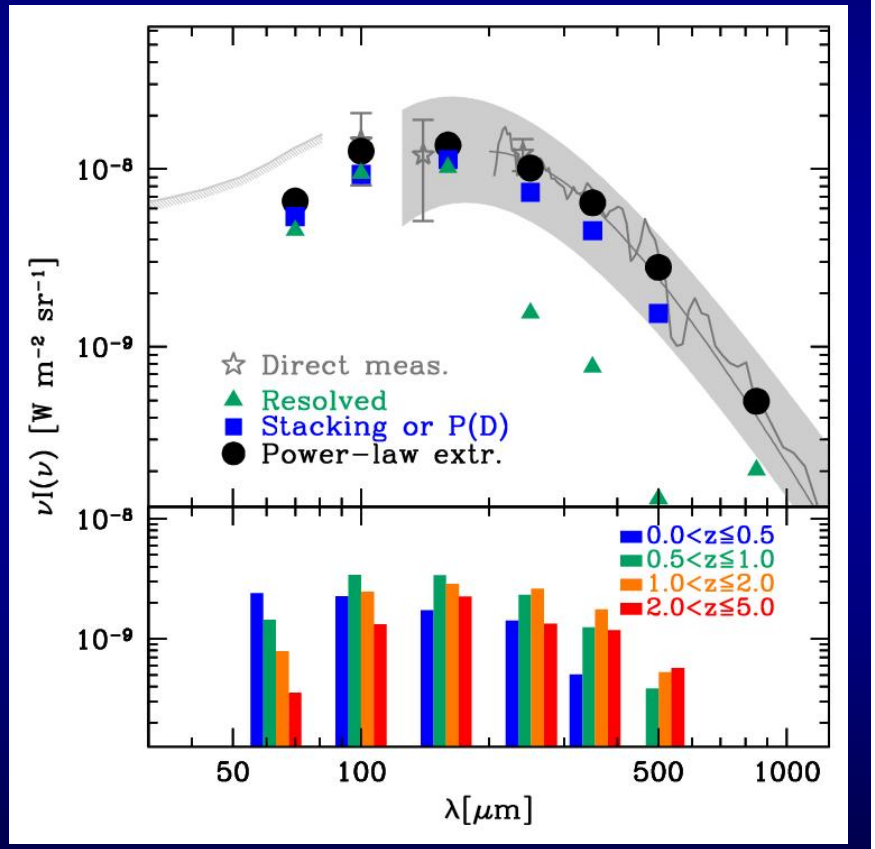
Herschel resolves the majority of the Cosmic Infrared Background



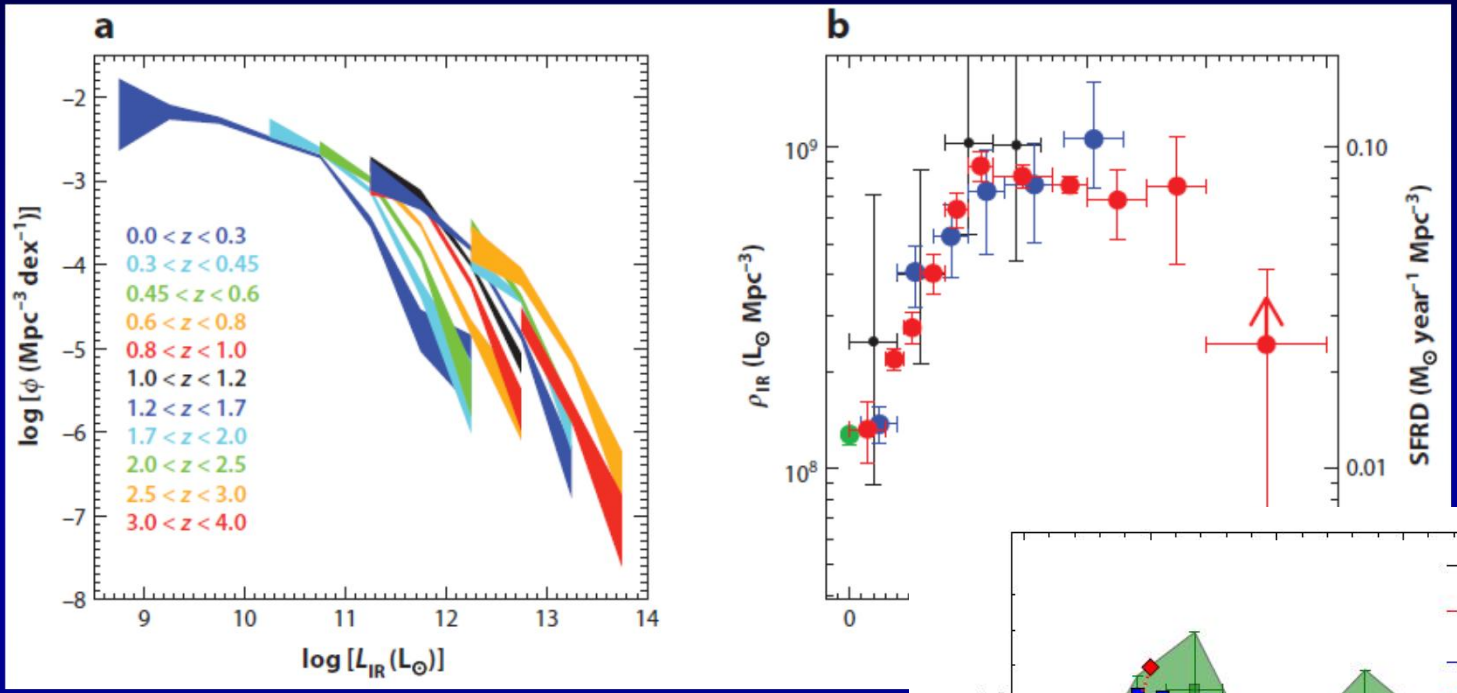
Resolved into individually detected sources:
(~35% @ 70μm)
~75% @ 100μm and 160μm
~15% - 6% @ 250 - 500μm

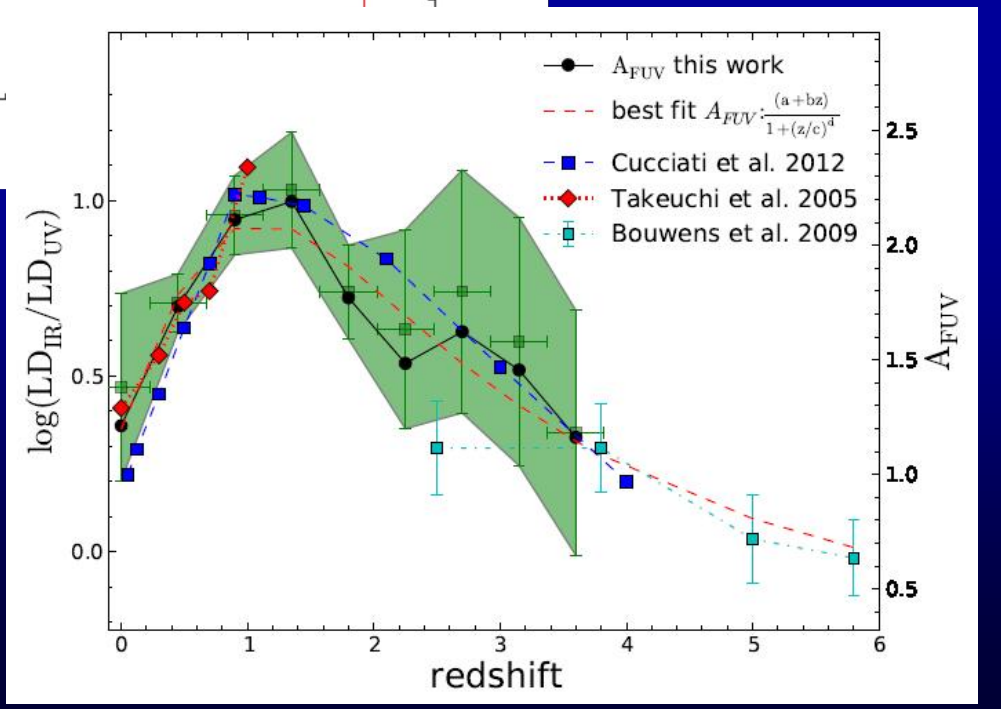
No evidence for a truly diffuse extragalactic background, COBE measurements are accounted for

Berta+10,11, Magnelli+13, Oliver+10, Clements+10, Bethermin+12…



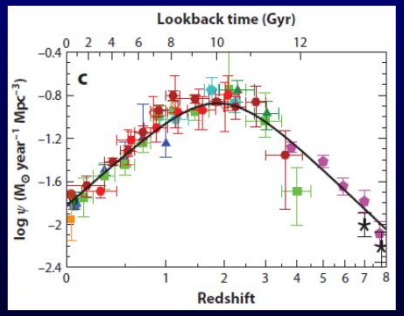
True IR luminosity functions out to z>2





Gruppioni+10, 13
Magnelli+13
Casey+12
Burgarella+13

→ Madau & Dickinson 14

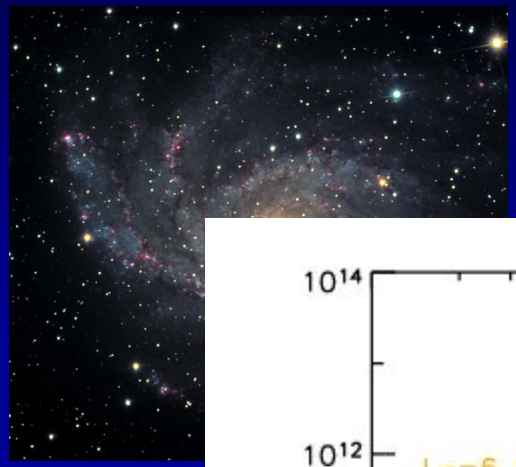


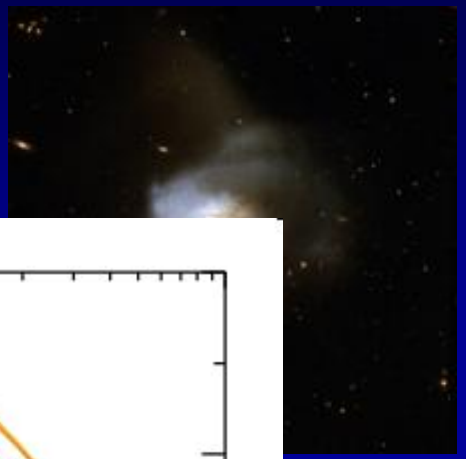
How we looked at (local) infrared galaxies some years ago….

Normal galaxy

LIRG

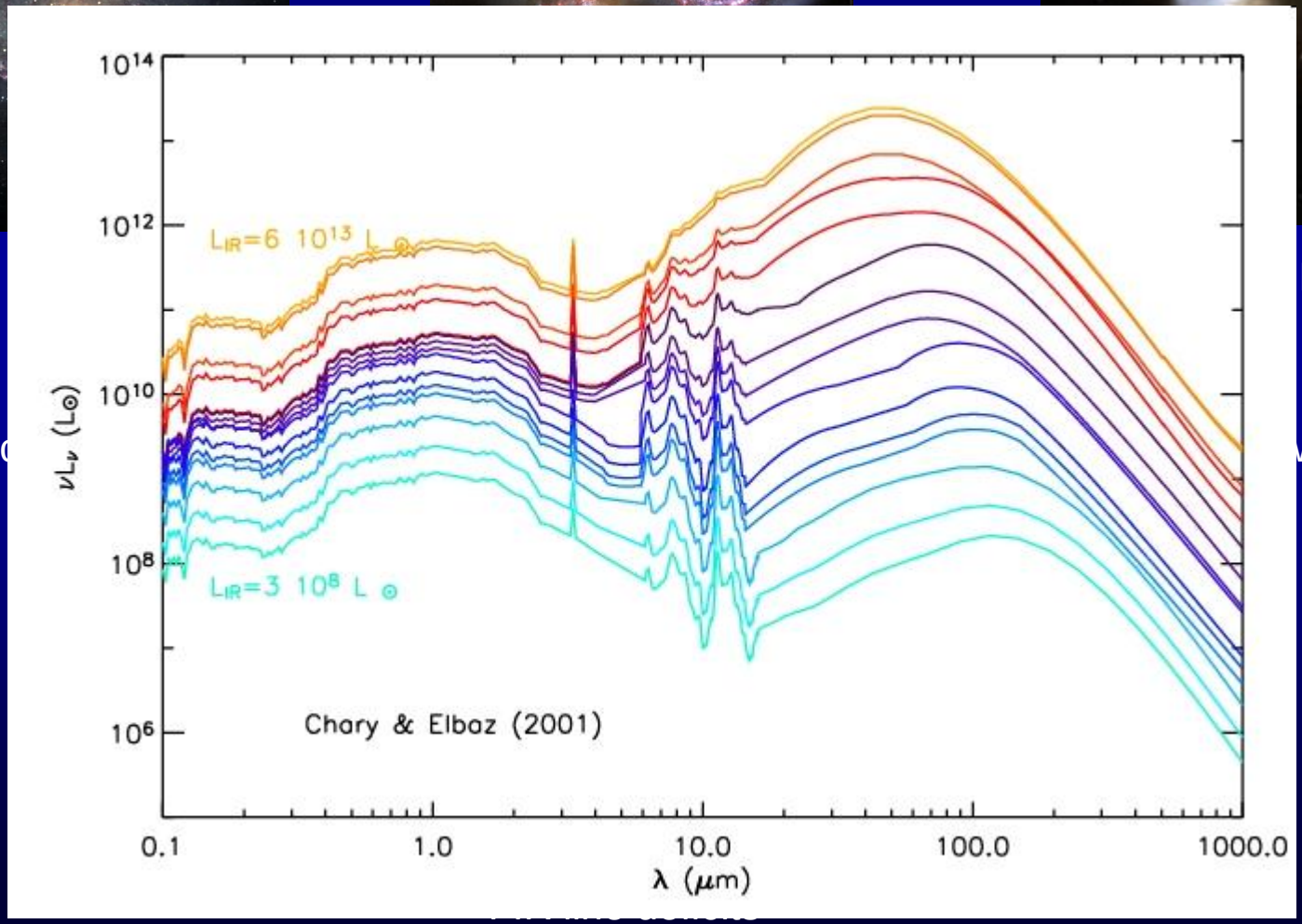
ULIRG



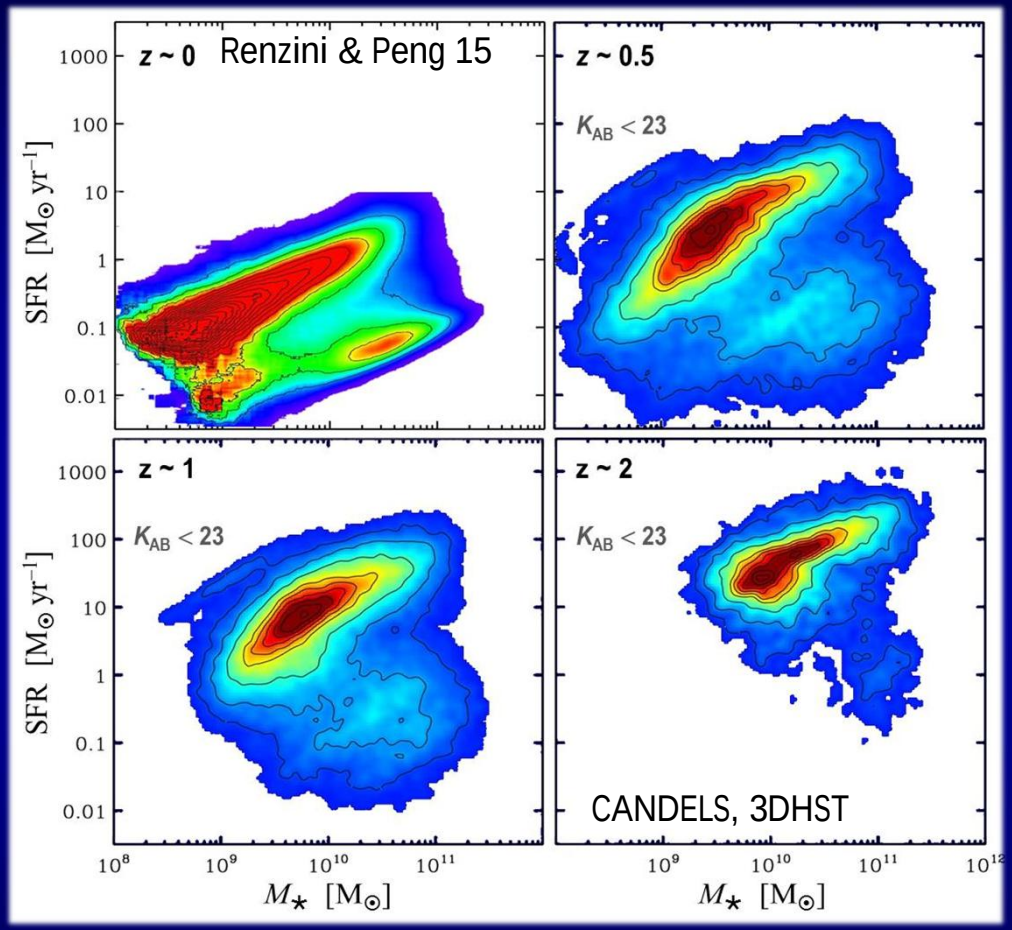


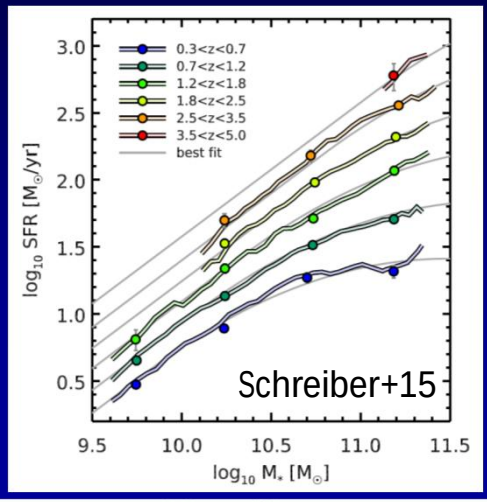
2 M_{Sun}/yr
disk
low
several kpc
on
cool
high

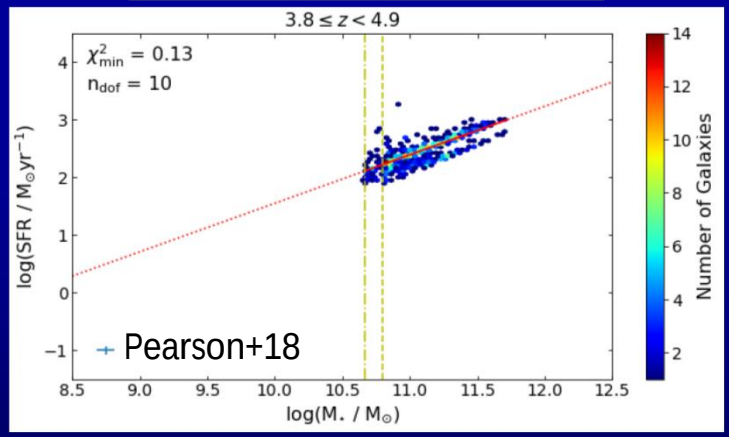
M_{Sun}/yr
merger
high
v 100pc
above
warm
low



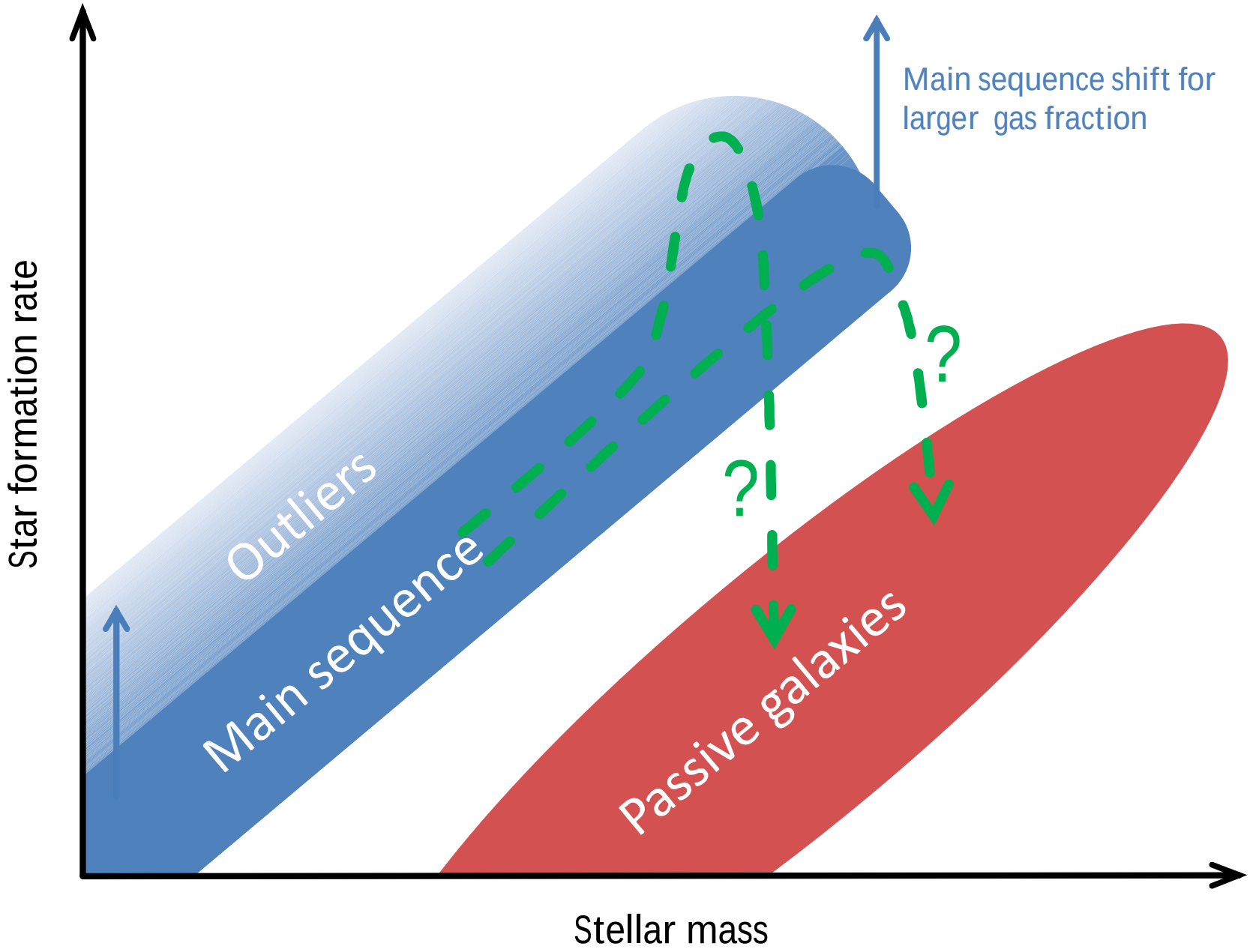
The ‘star forming sequence’ / ‘main sequence’





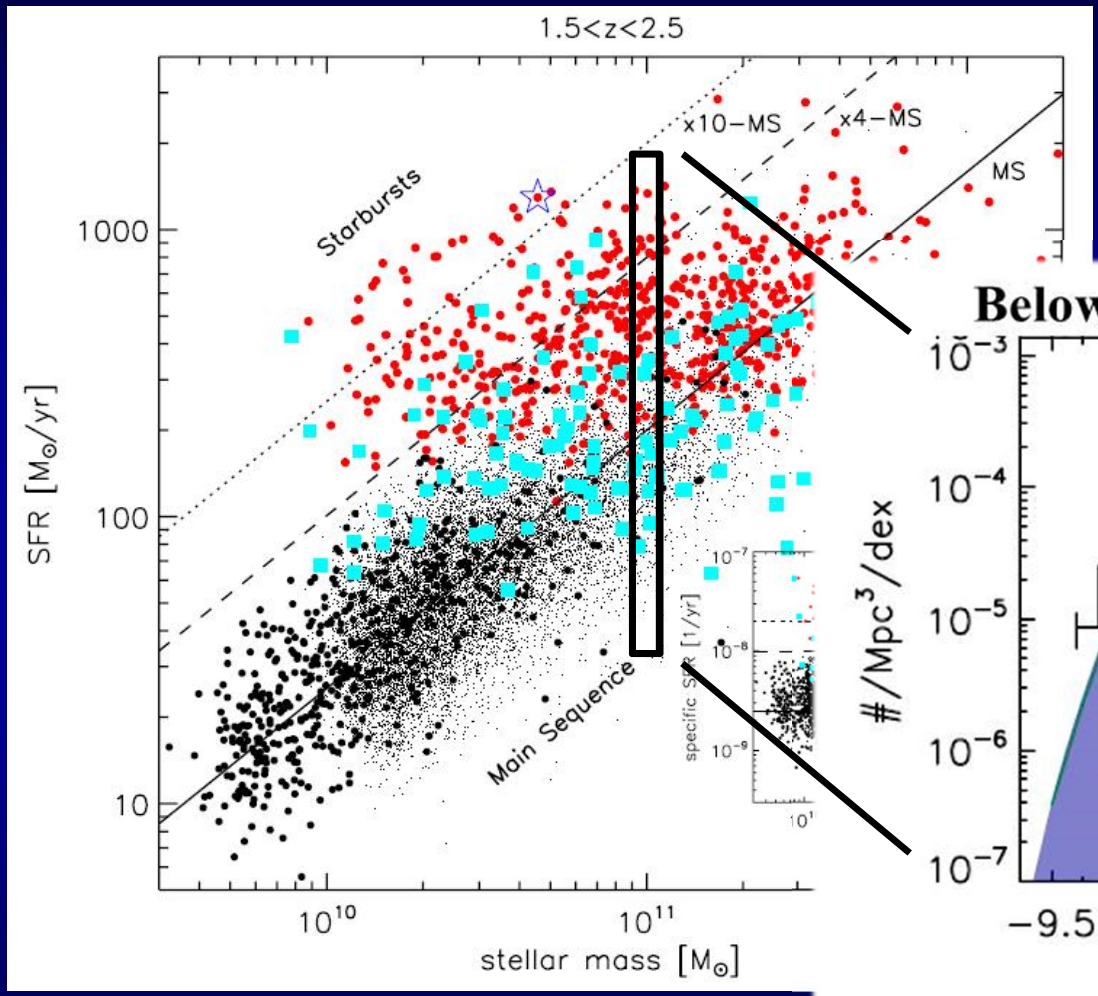


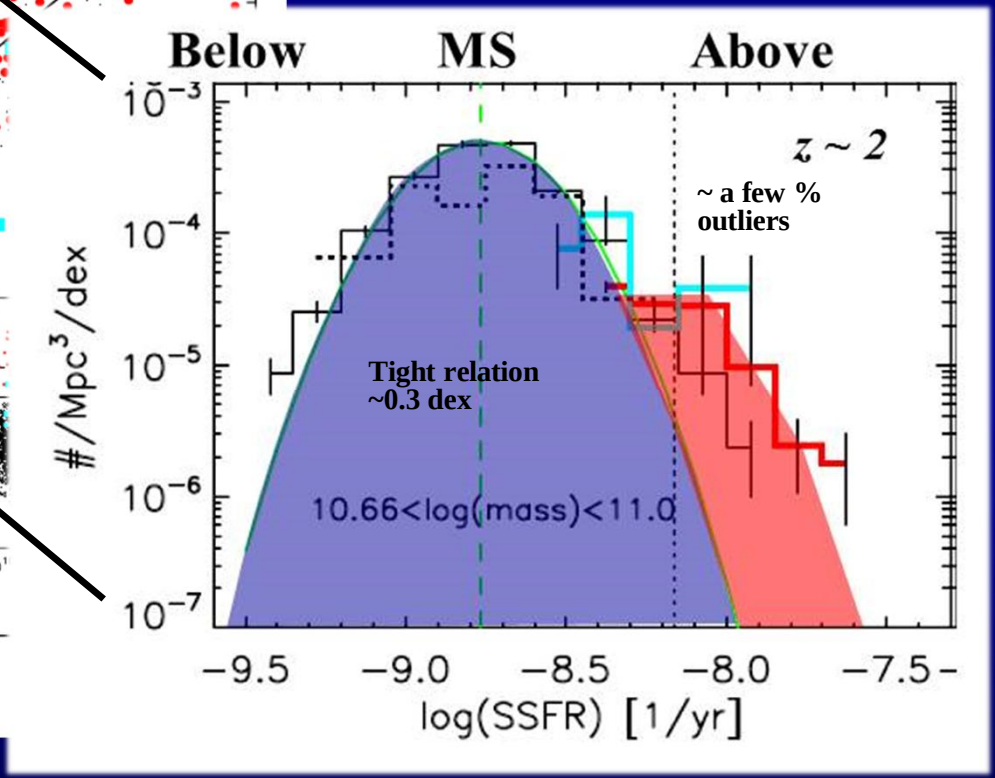
Brinchmann+04, Noeske+07, Schiminovich+07, Daddi+07, Elbaz+07, Peng+10, Rodighiero+10,11,14, Whitaker+12,14, Salmi+12, Speagle+14, Renzini & Peng 15, Schreiber+15, Pearson+18 etc. etc.



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

The lesser role of z~2 starbursts

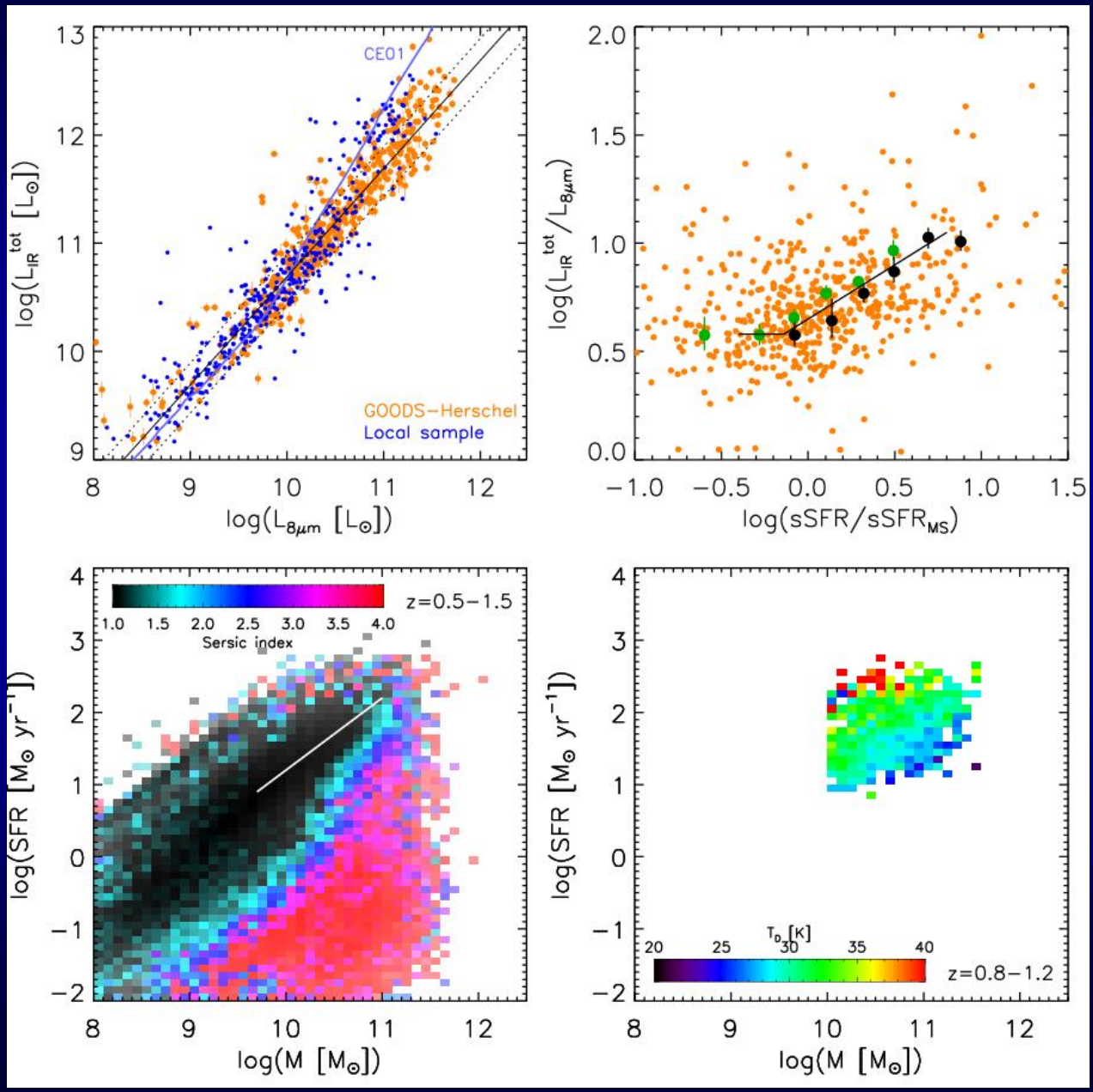




Rodighiero+11,
Sargent+12,14
Schreiber+15

Rodighiero+11

Relating properties to main sequence rather than L_{IR}



Elbaz+11

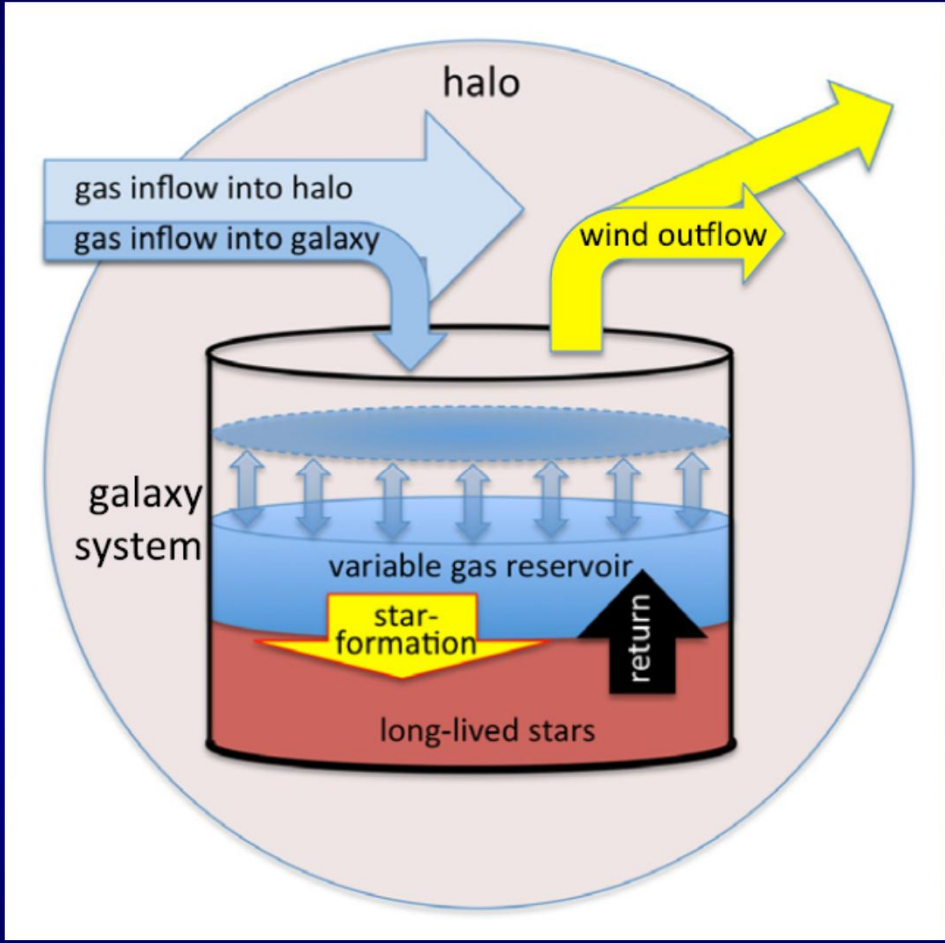
Key for MIR-based star formation rates!

Elbaz+11, Nordon+12

Wuyts+11

Magnelli+14

The equilibrium / regulator / bathtub model



$$\frac{\mathrm{d}M_{\mathrm{gas}}}{\mathrm{d}t} = \Phi - (1-R)\cdot \mathrm{SFR} - \Psi$$

$$= \Phi - (1-R+\lambda)\varepsilon M_{\mathrm{gas}}.$$

Inflow rate

$$\Phi = f_{\mathrm{gal}} f_{\mathrm{b}} \frac{\mathrm{d}M_{\mathrm{halo}}}{\mathrm{d}t},$$

dMhalo/dt:
$\sim M_{\mathrm{halo}}^{1.1}$
$\sim (1+z)^{2.3}$

Star formation efficiency | depletion time

$$\mathrm{SFR} = \varepsilon M_{\mathrm{gas}}.$$

$t_{\mathrm{dep}} = 1/\varepsilon$

Outflow rate

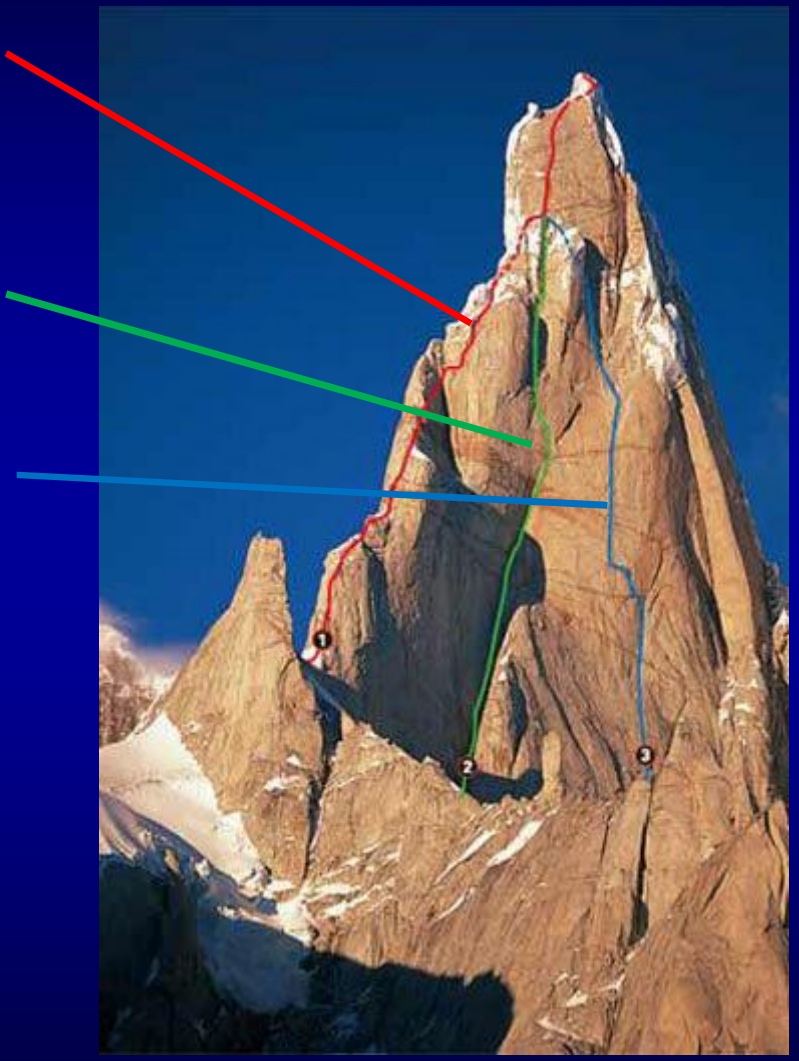
$$\Psi = \lambda \cdot \mathrm{SFR},$$

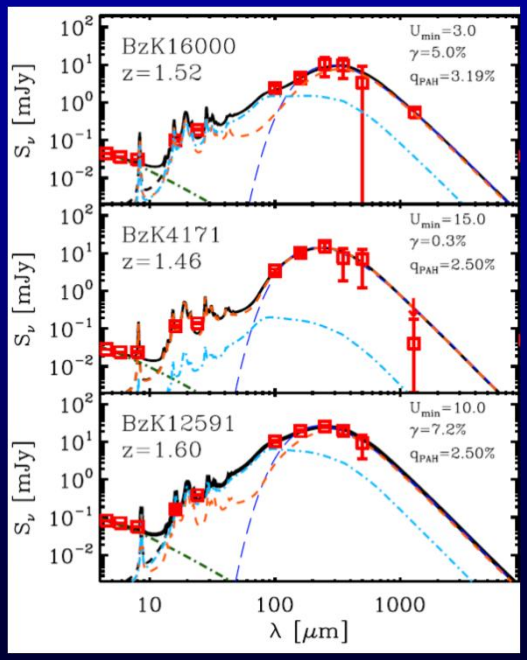
λ: Mass loading

e.g., Bouche+10, Lilly+13, Peng & Maiolino 14

Common routes to high-z gas masses

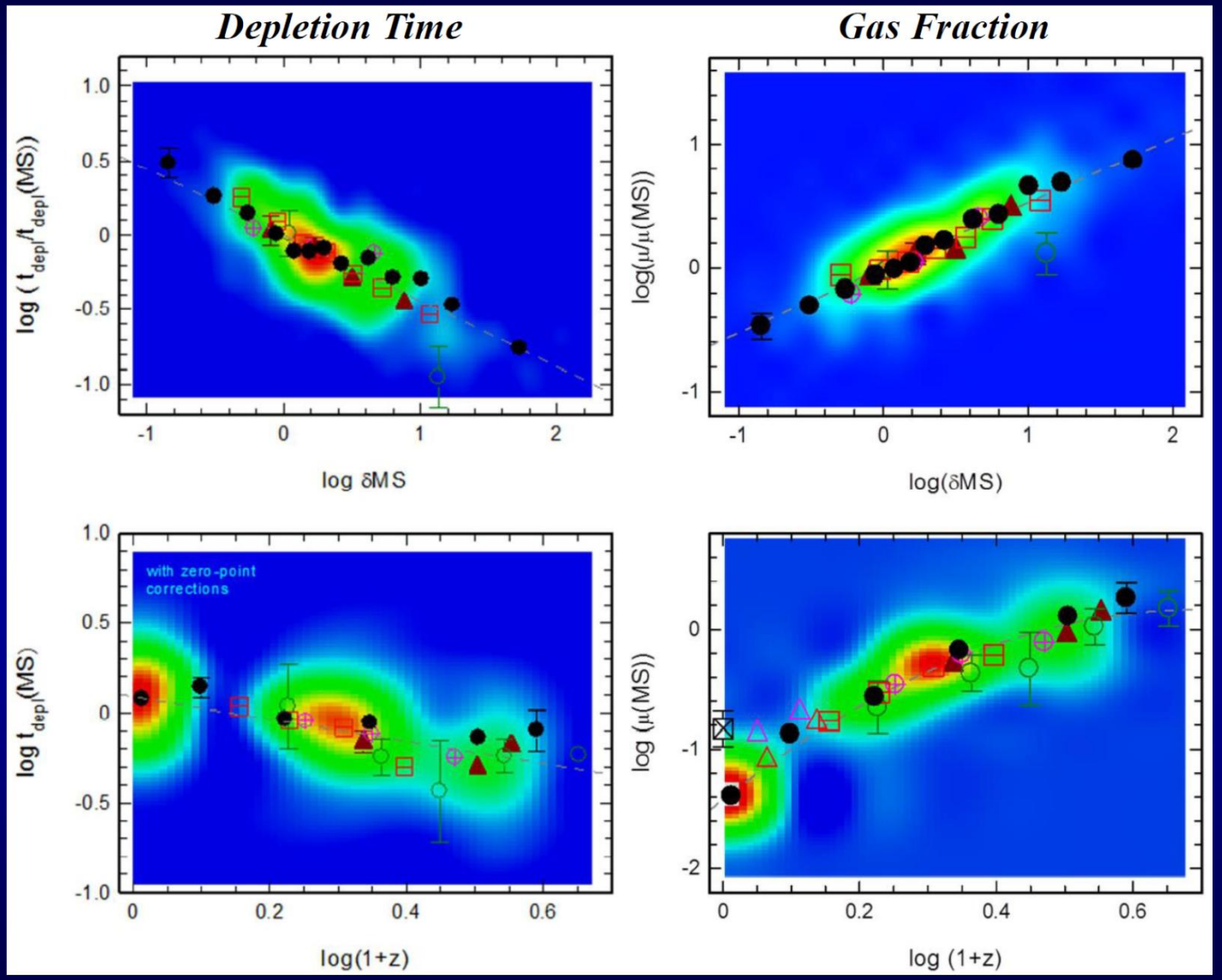
- Molecular gas mass from CO lines - ALMA, NOEMA
- Gas mass from dust mass and gas-to-dust ratio:
  - Dust mass from fitting models to SEDs around and beyond the SED peak - Herschel
  - Dust mass from single band photometry on Rayleigh-Jeans tail – ALMA, NOEMA





Magdis+12

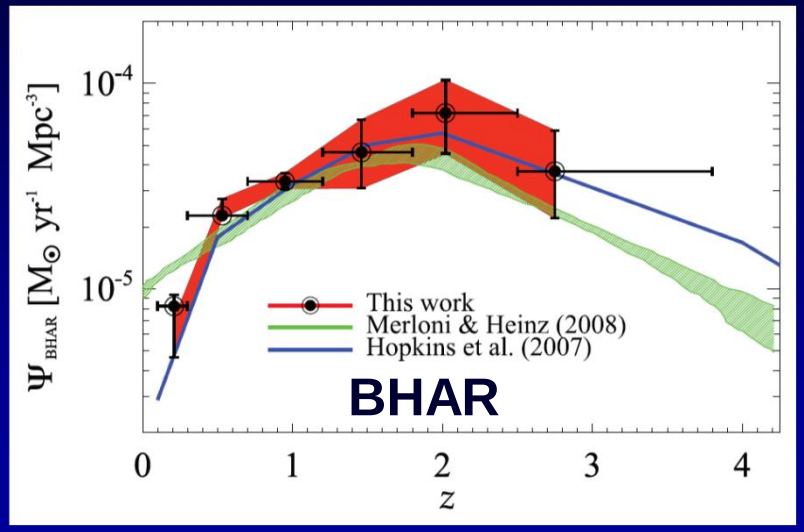
Towards convergence, using all three methods



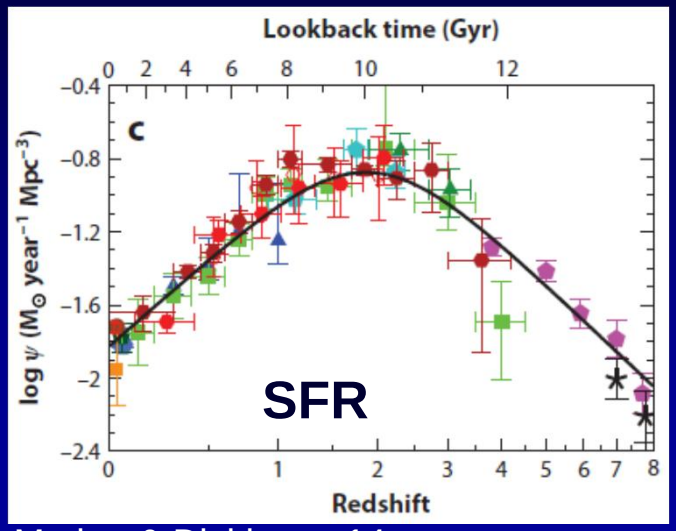
Tacconi+18

Daddi+10, Genzel+10,12, 15, Tacconi+10,13,18, Magdis+11,12, Saintonge+11, Eales+12, Magnelli+12, Scoville+12,14,16,17, Santini+14, Sargent+14,15, Bethermin+15, Berta+16 etc.

AGN / galaxy coevolution



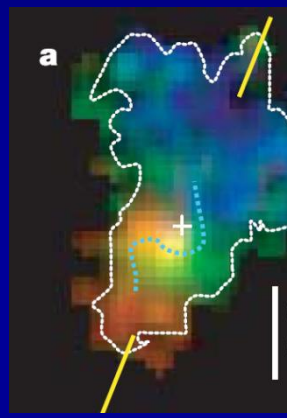
Delvecchio+14

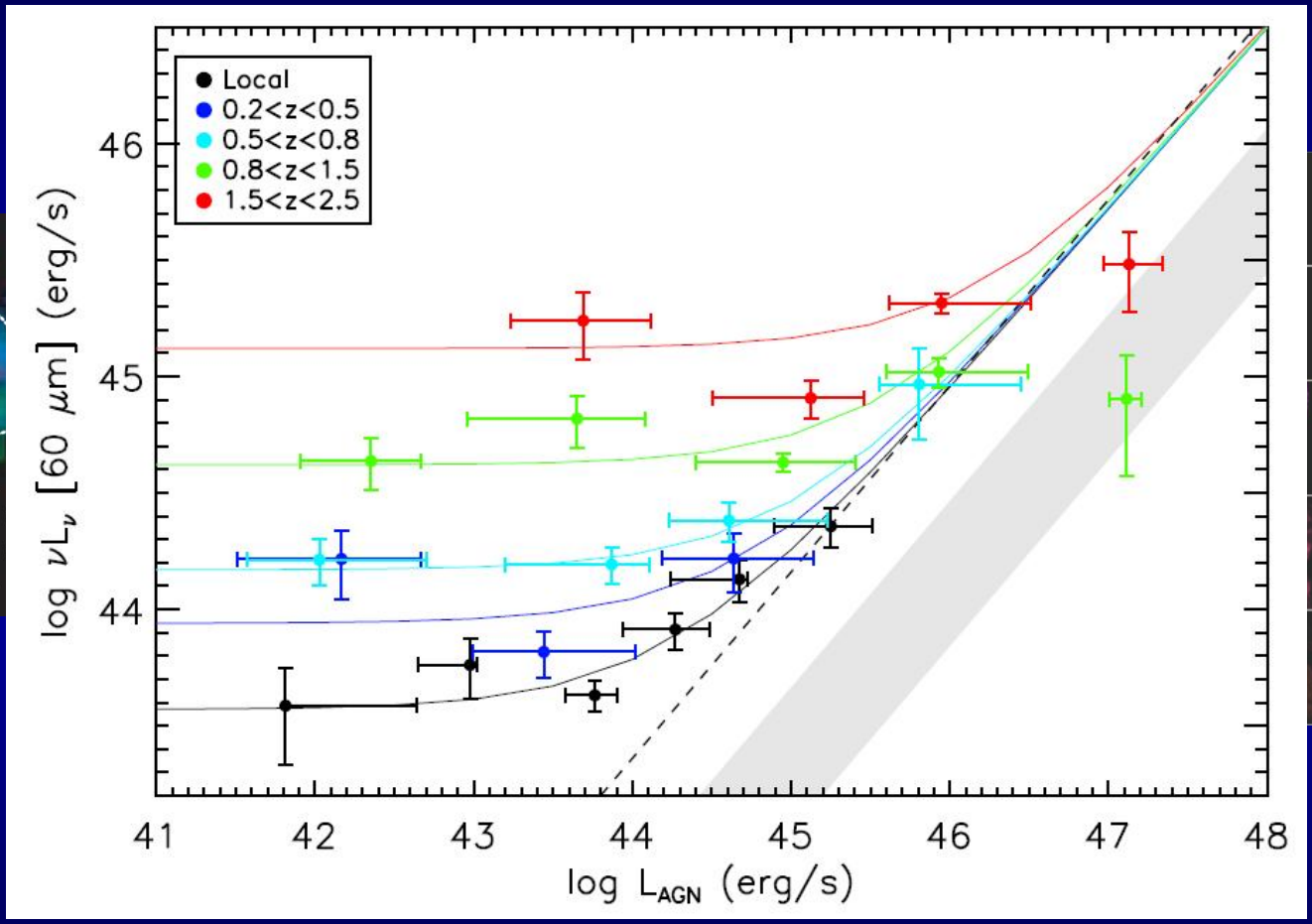


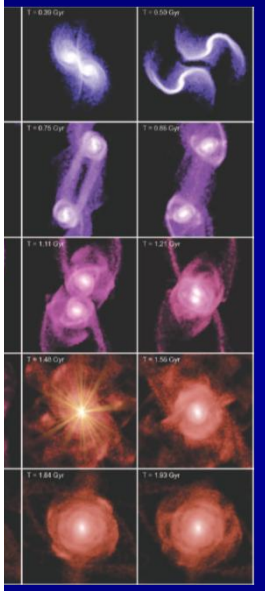
Madau & Dickinson 14

- Is there correlation between accretion rate and star formation rate? … would indicate a causal (feeding) link and some level of synchronisation
- What are the controlling mechanisms?
  - Mergers?
  - ‘Secular’ disk instabilties and clumps / bars / nuclear spiral structures/ stellar winds ?
- What is the role of AGN in quenching star formation?

Perspective 1: SFR of AGN hosts





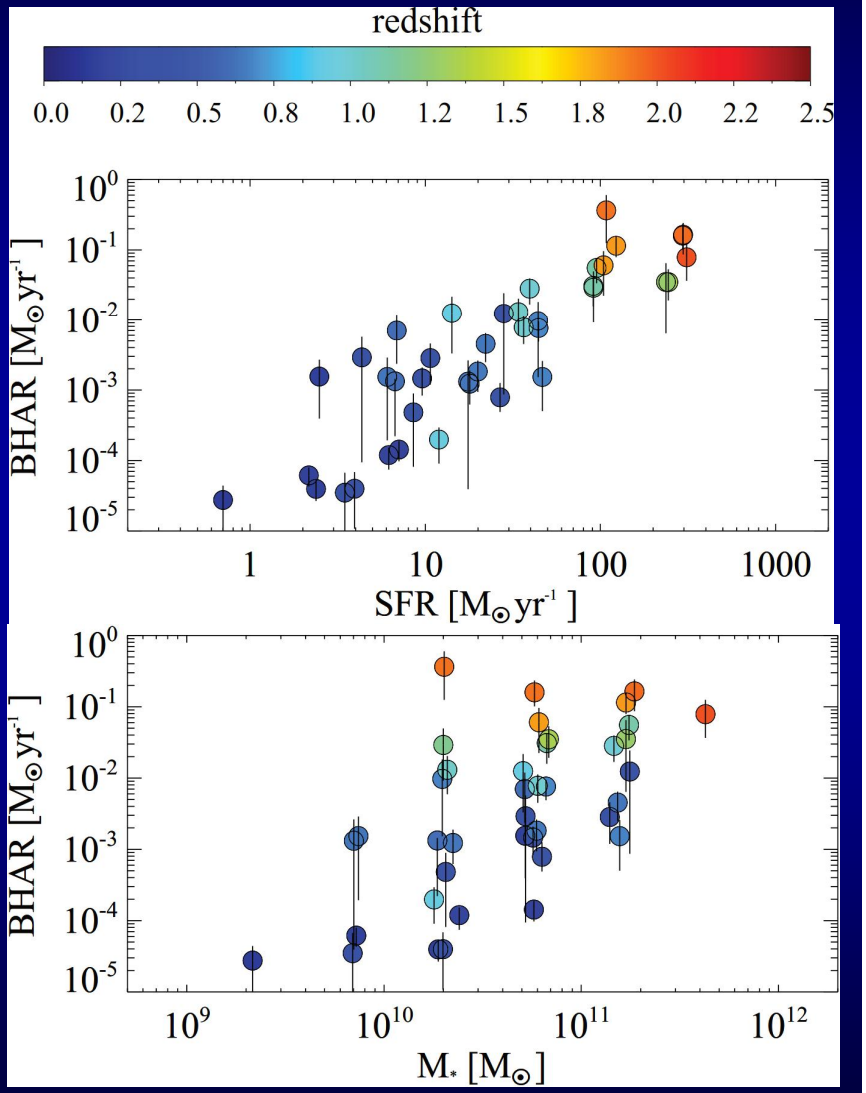


Rosario+ 2012
(see also Lutz+10, Shao+10, Mullaney+12,15, Rovilos+12, Page+12, Harrison+12, Stanley+15,18, Suh+19)

Perspective 2: Averaged BHAR of populations

AVERAGE accretion rate correlates well with SFR (even better than with stellar mass)

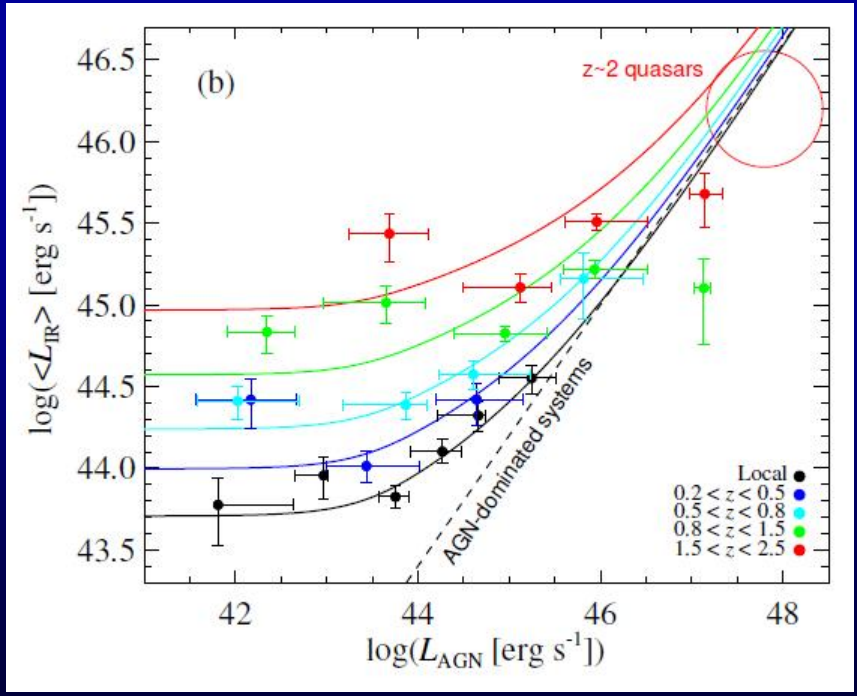
Rafferty+11, Mullaney+12, Chen+13, Delvecchio+15



Delvecchio+15

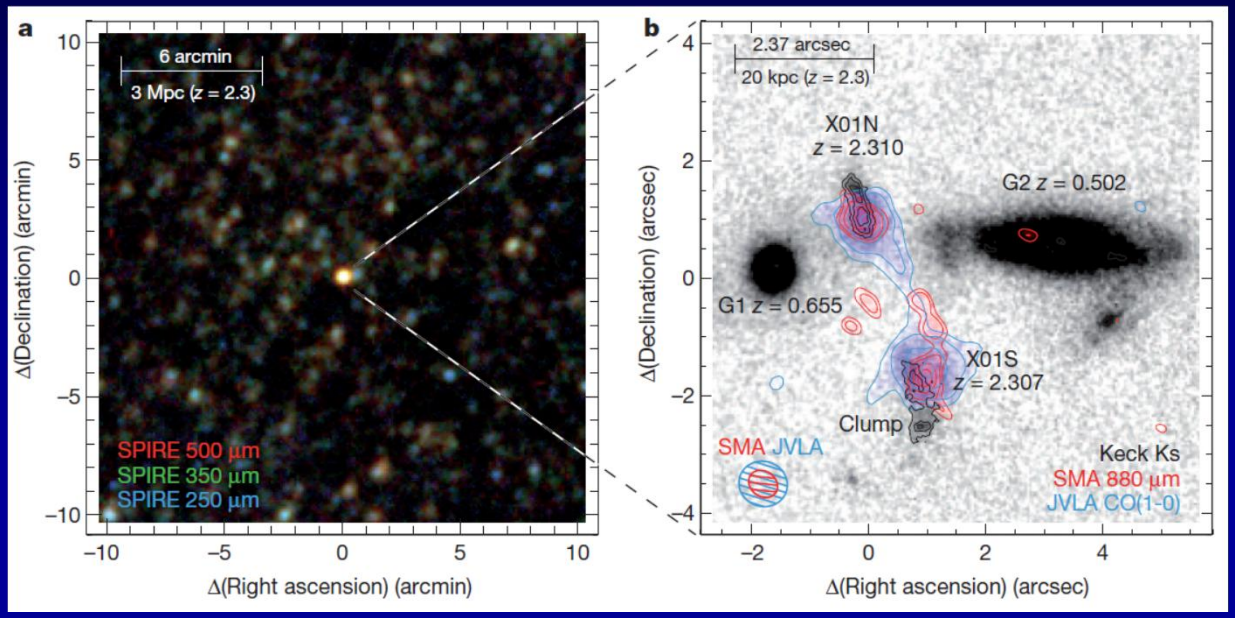
AGN hosts: summary

- AGN at z<~2 are typically hosted by normal ‘main sequence’ type star forming galaxies
- Star formation and accretion are in a broad sense fed by the same gas reservoir BUT detailed mechanisms are not well constrained
- Rapid variability of accretion has an important role in shaping the observed relations ‘unsynchronized coevolution’

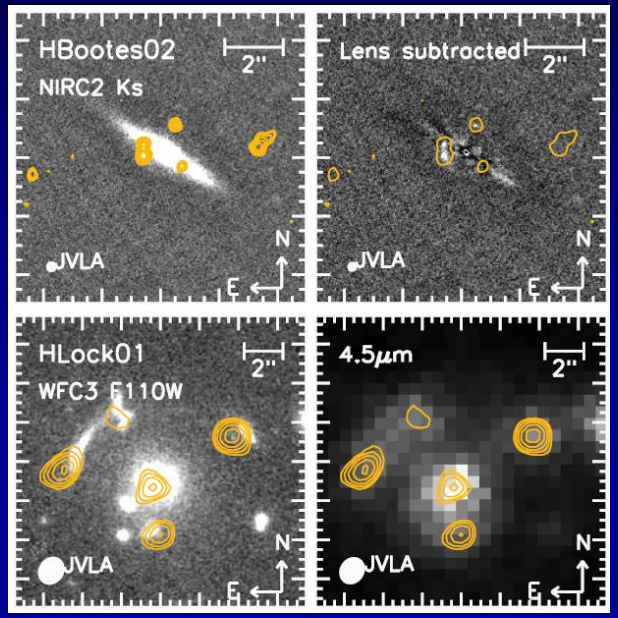


Hickox+14

Search for bright very high z sources



Fu+13



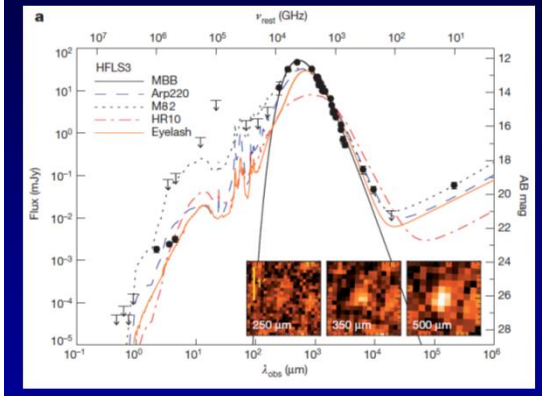
Wardlow+13

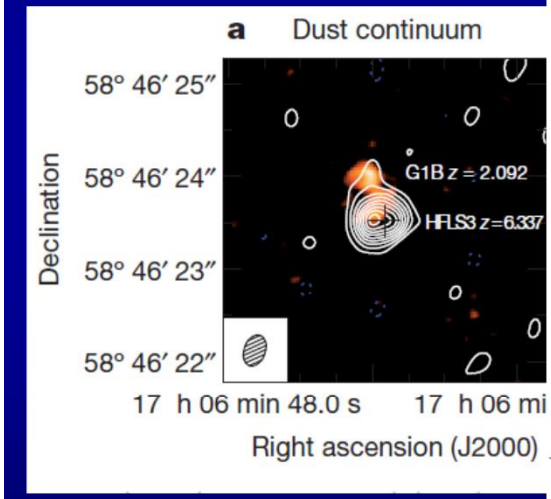
- Bright and bright/red point sources in large area SPIRE surveys efficiently pick high-z sources
- Mostly lensed starbursts, but also very luminous non-lensed galaxies

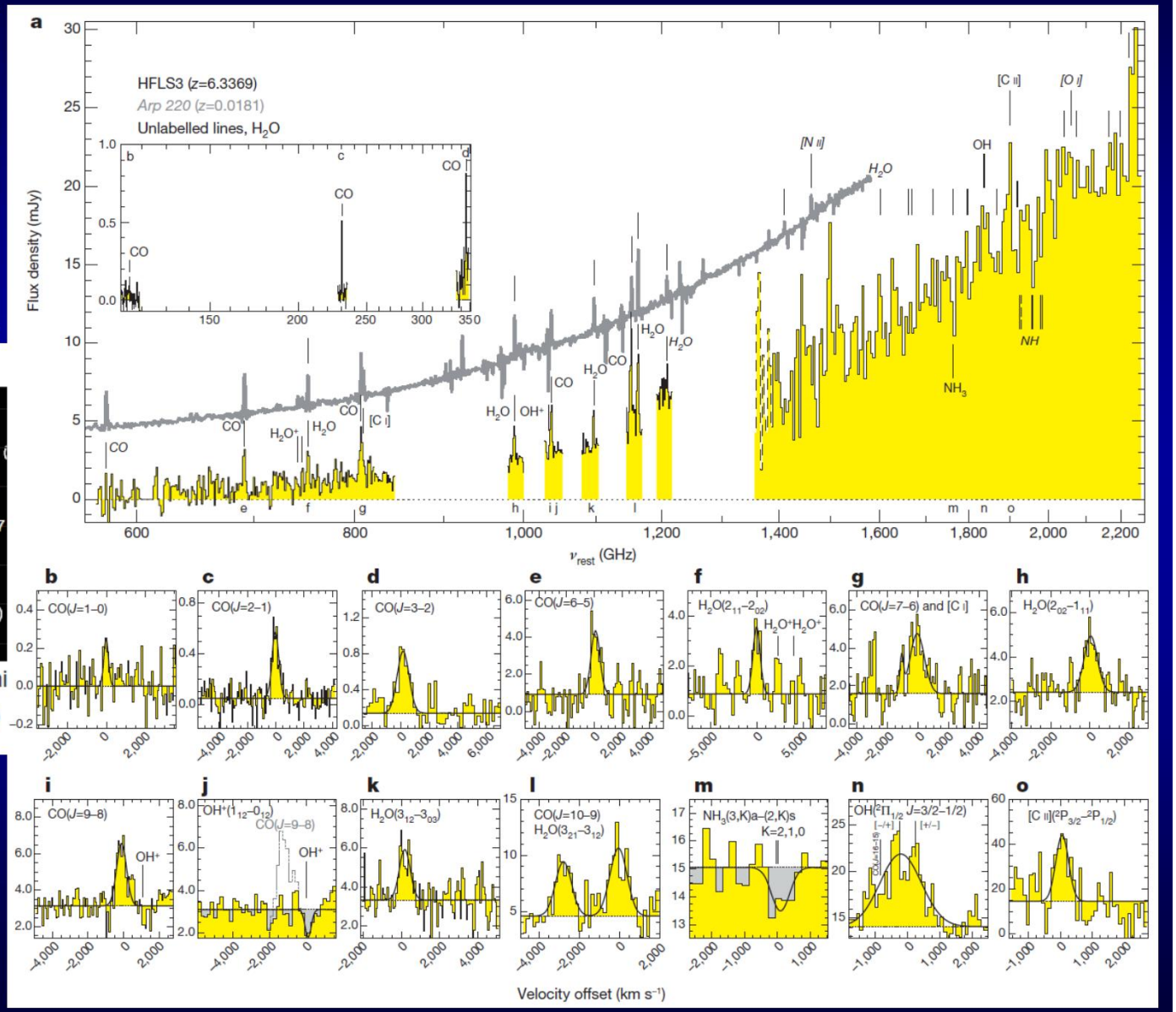
- Similar: Planck, ground-based SZ telescopes like SPT

Negrello+10,14,17, Bussmann+12,13, Gonzelz-Nuevo+12, Fu+13, Riechers+13,17, Wardlow+13, Calanog+14, Dowell+14, Nayyeri+16, Oteo+16,17, Bakx+18 and many more

Success







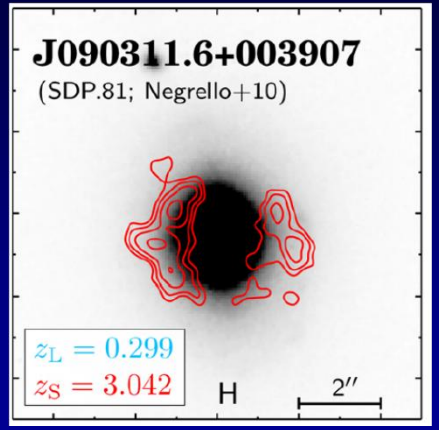
Riechers+13

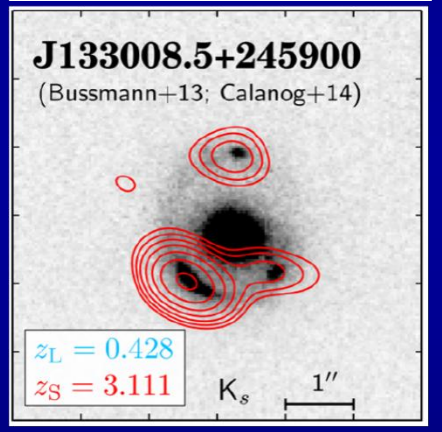
HFLS3 z=6.3
2000 M_{sun}/yr

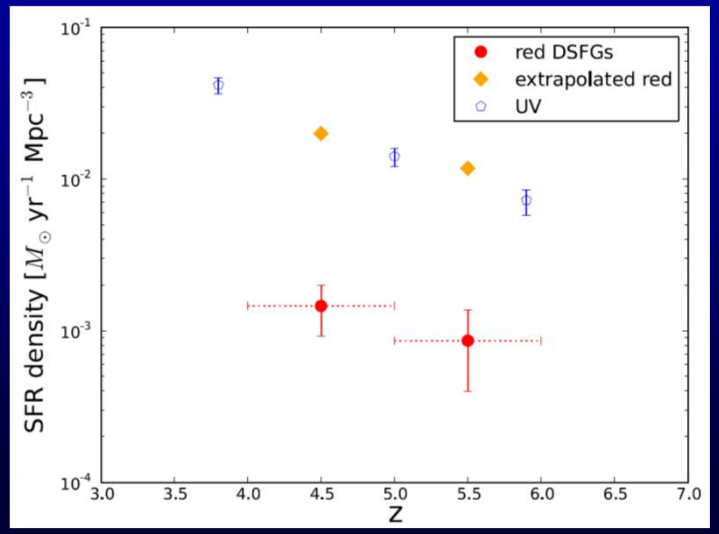
Challenges

- Need for lensing models, and for ancillary data that are good enough to constrain them
- Rest UV/optical/NIR sometimes poorly constrained
- Already intrinsically extreme objects
- Lensing bias

→ Tendency to stay disconnected from other galaxy evolution studies

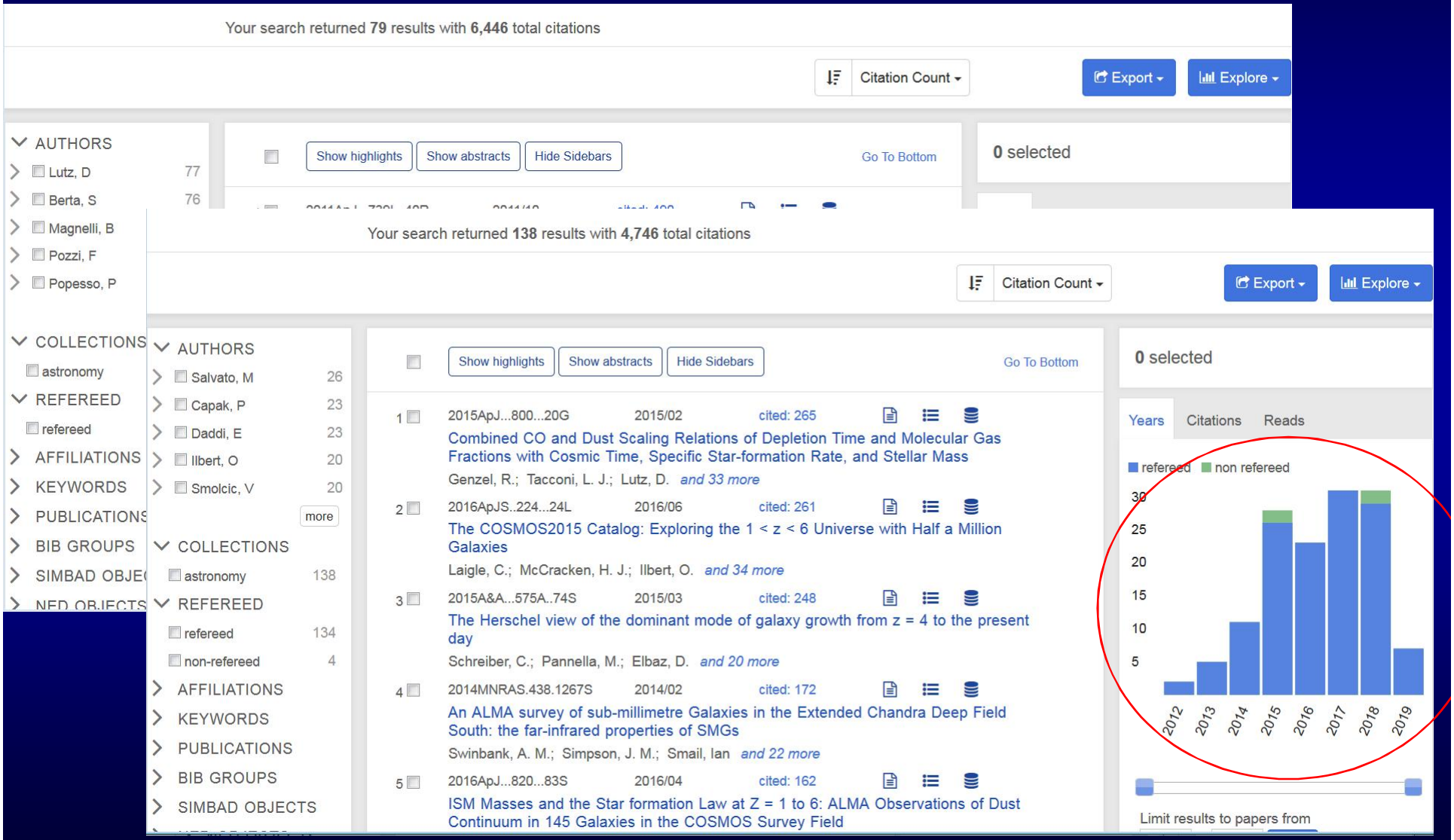




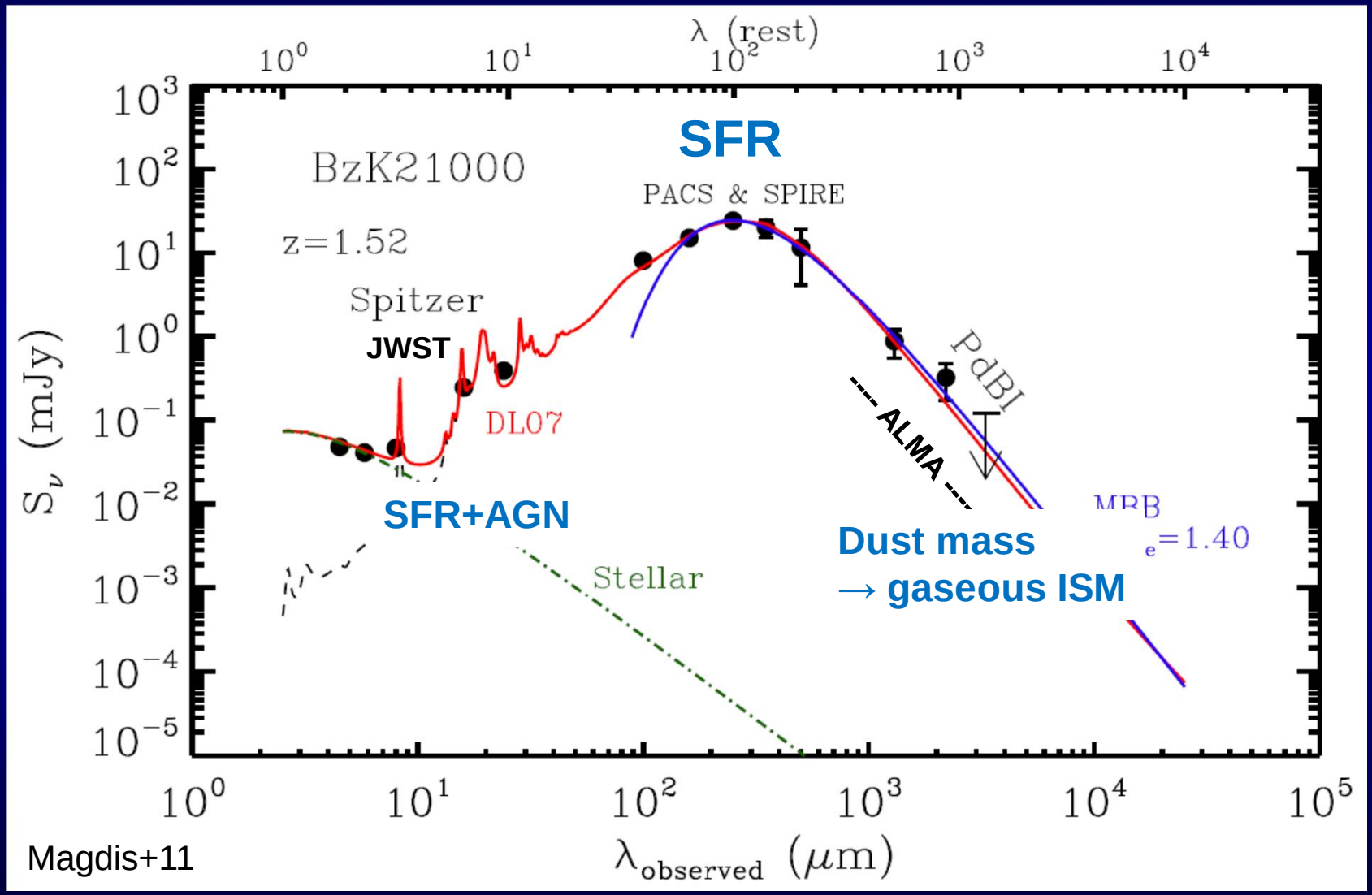


Dowell+14

Herschel surveys 2019: An example



Herschel FIR-based SFR: ‘gold standard’ for many galaxies, until superseded by SPICA / Origins Space Telescope / …



Magdis+11

Not the end