

Probing the evolution of star forming and starburst galaxies at cosmological distances

A blobologist's take on galaxy evolution

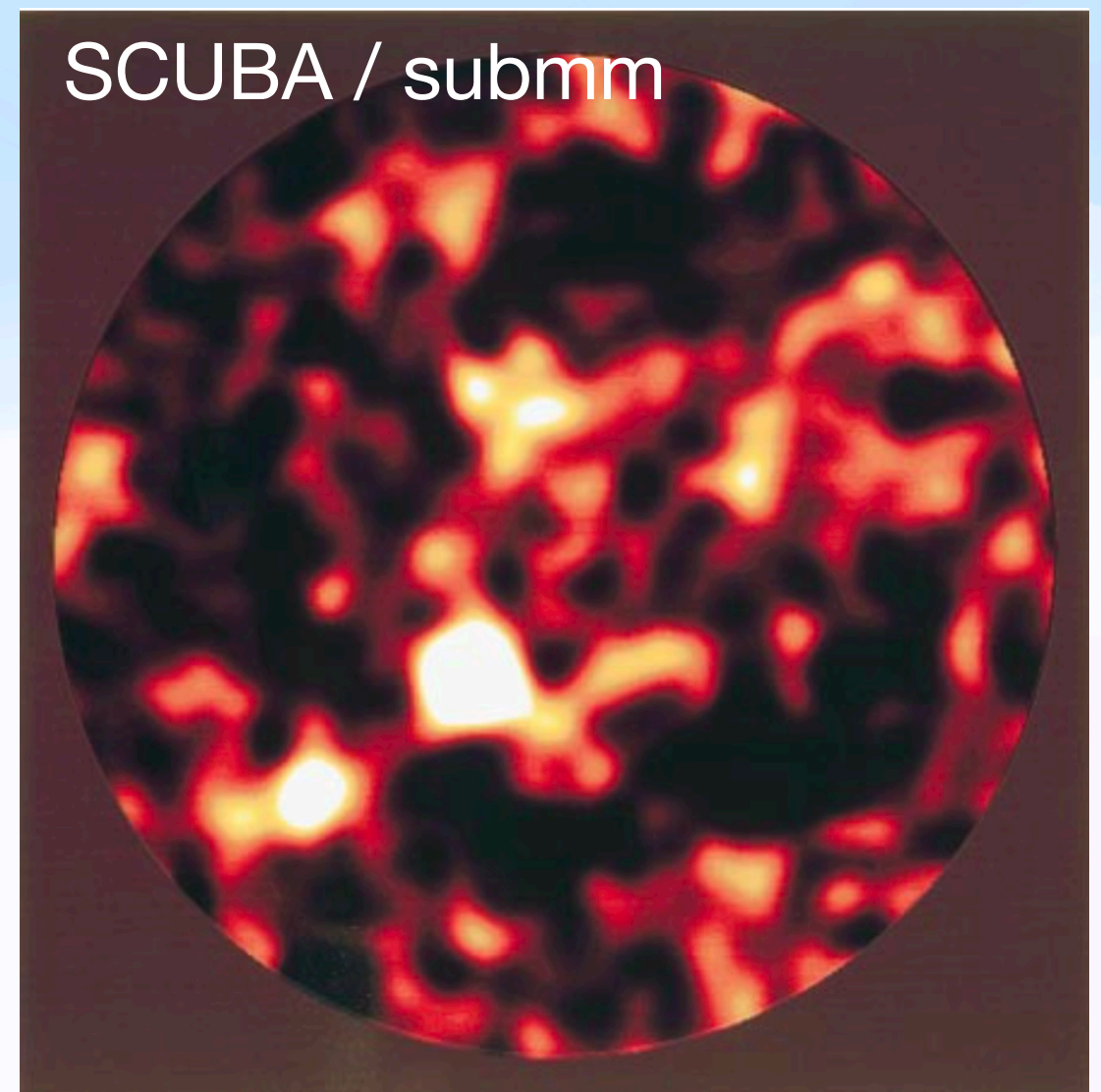
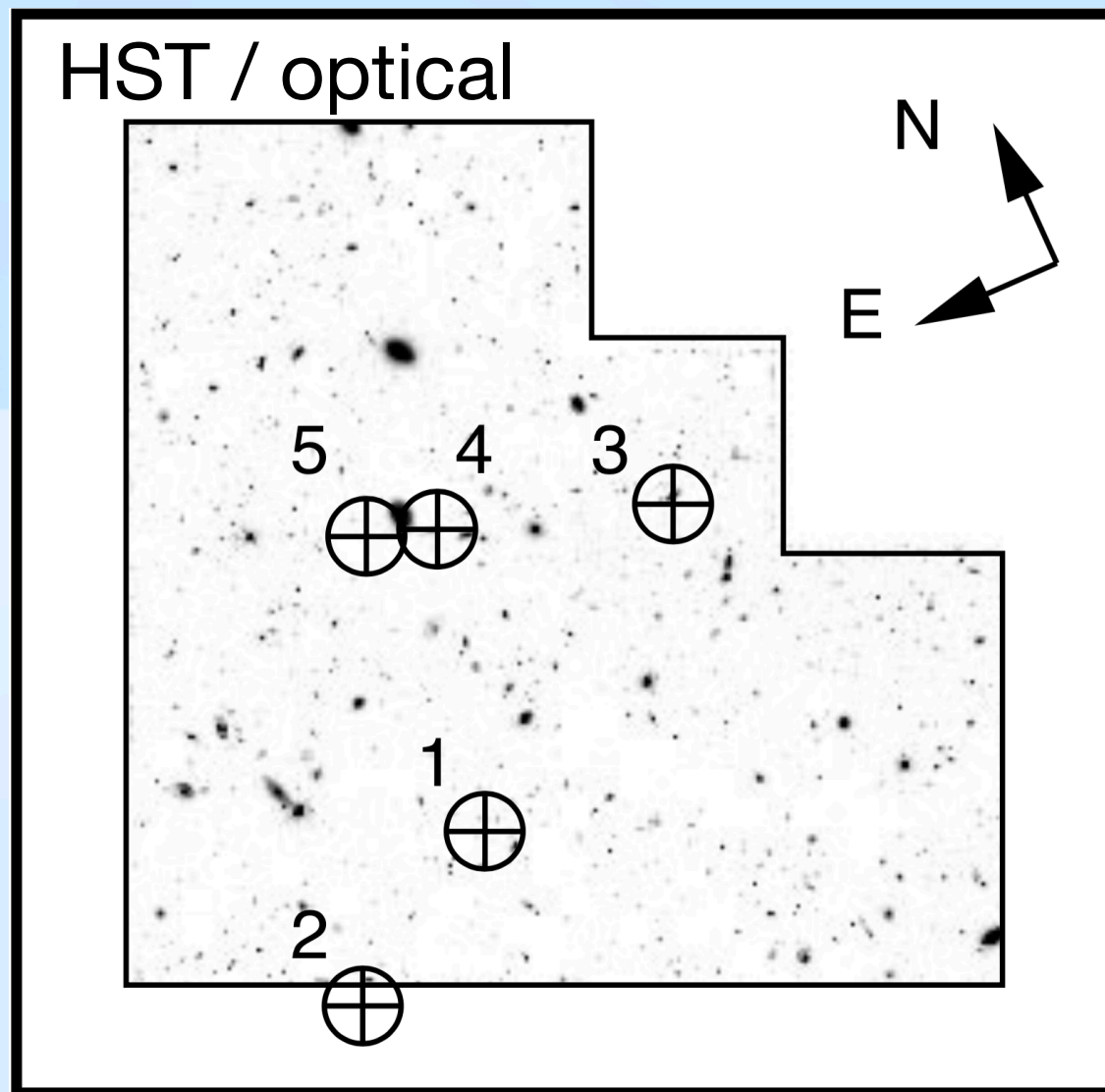
Tom Bakx – Chalmers – FIR Leiden 2025



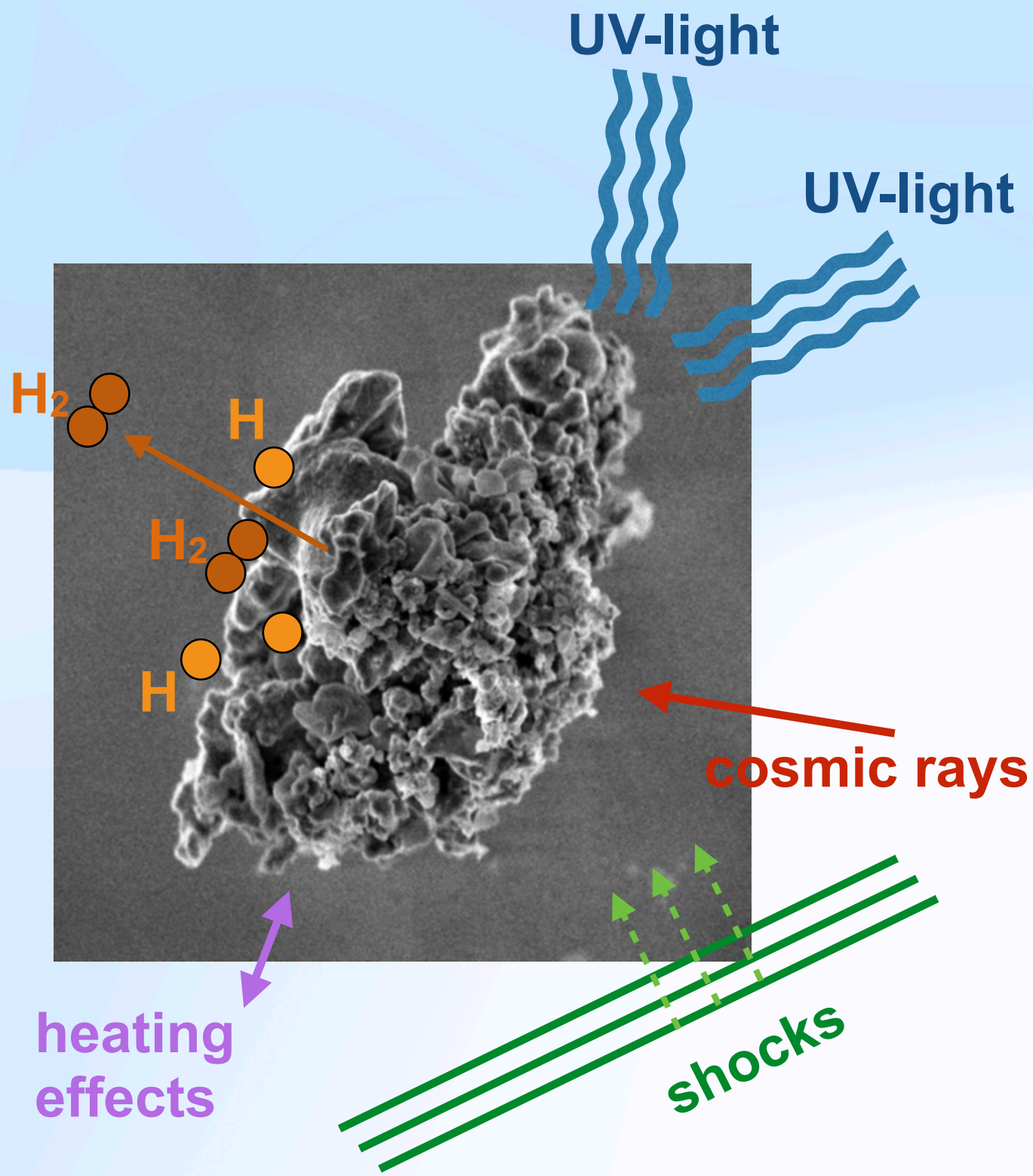
Complementary views of the Universe

Smail et al. 1997

Hughes et al. 1998



Dust — what is it good for?



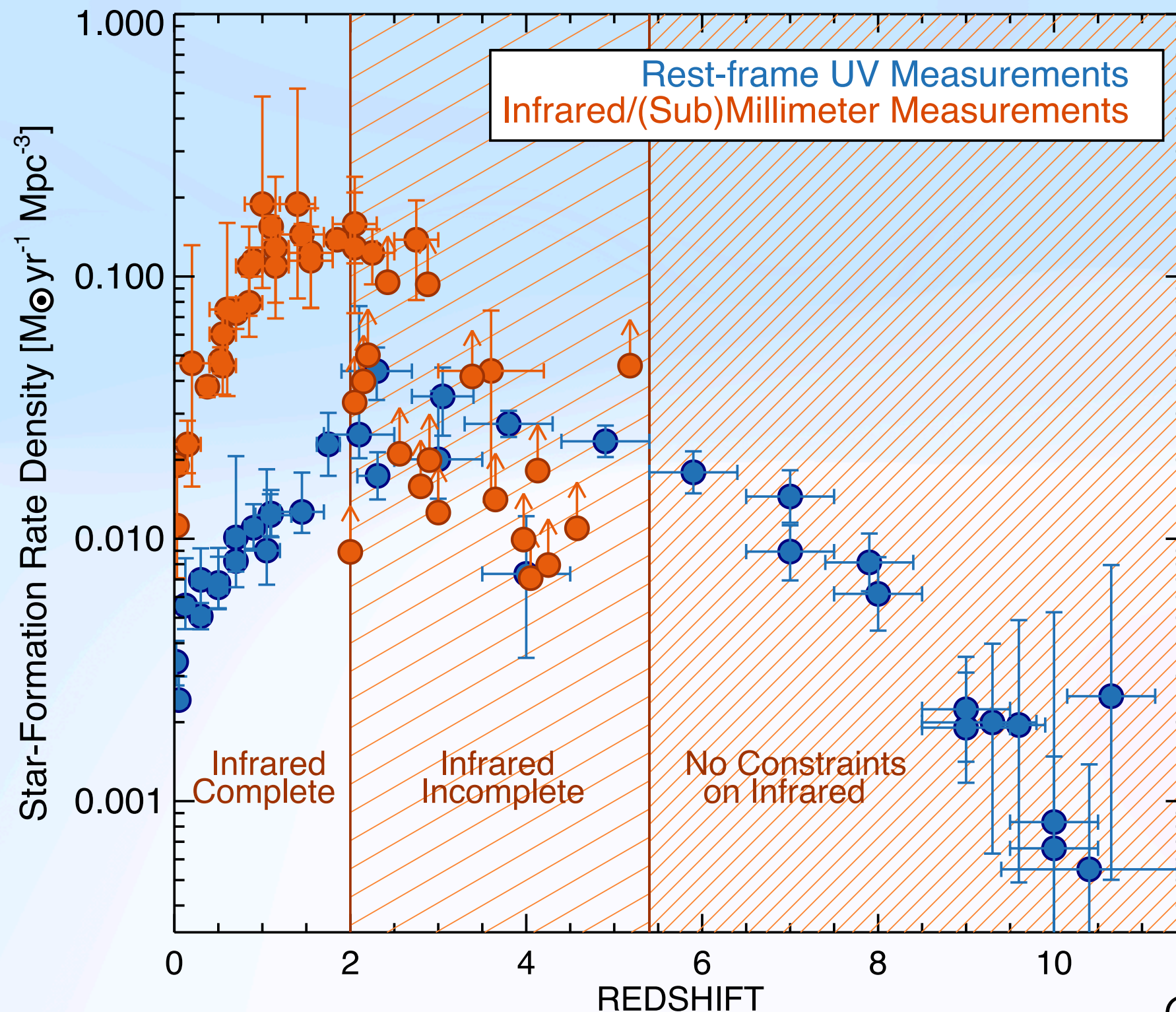
... H₂ formation

... heating and cooling of ISM

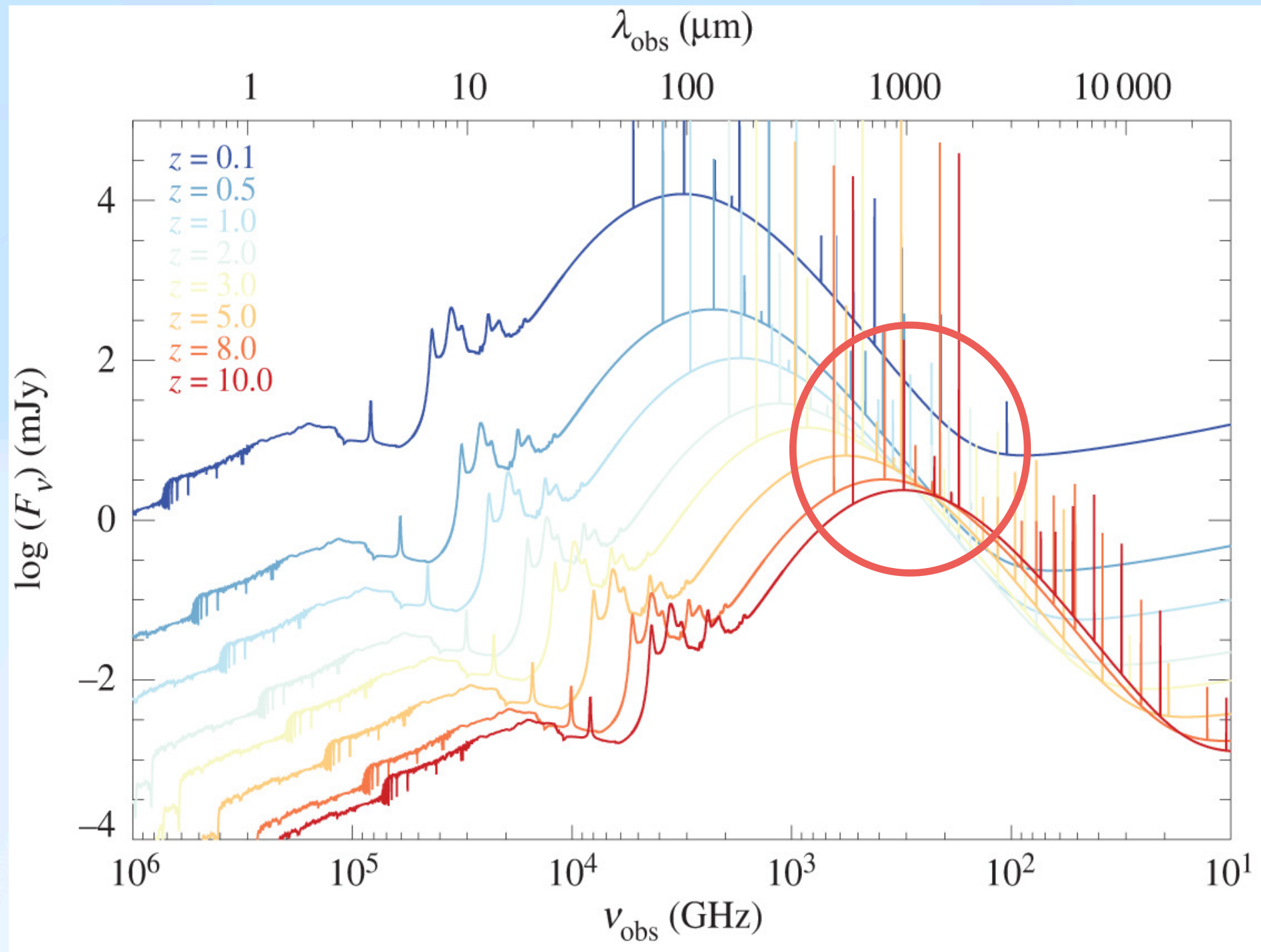
... home to metals

...

Even pre-JWST, (sub)mm observations are playing catch-up...



... despite the benefit of K-correction

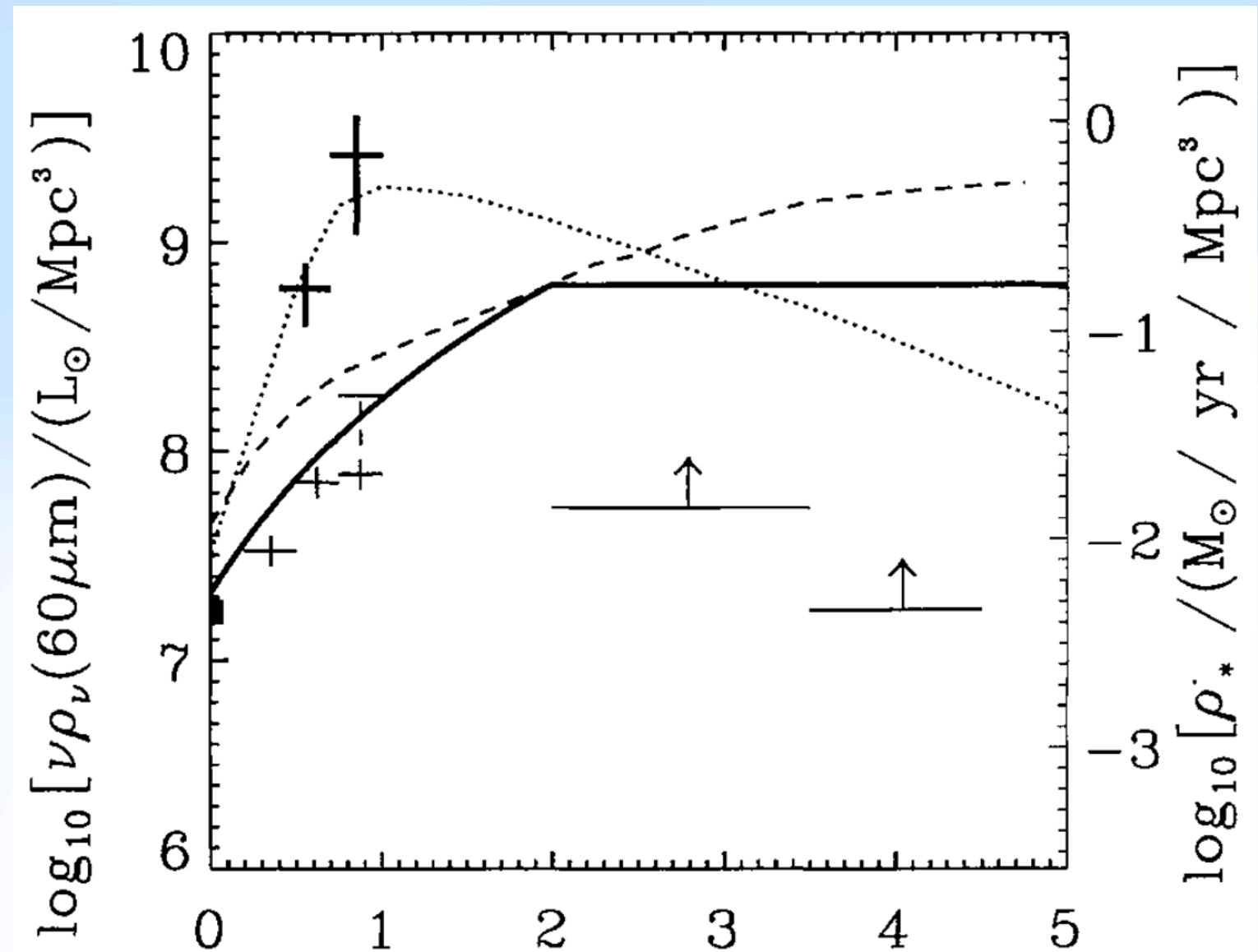


From review by Hodge & da Cunha (2020)

Unique parameter spaces lay open for future infrared/submm space telescopes:

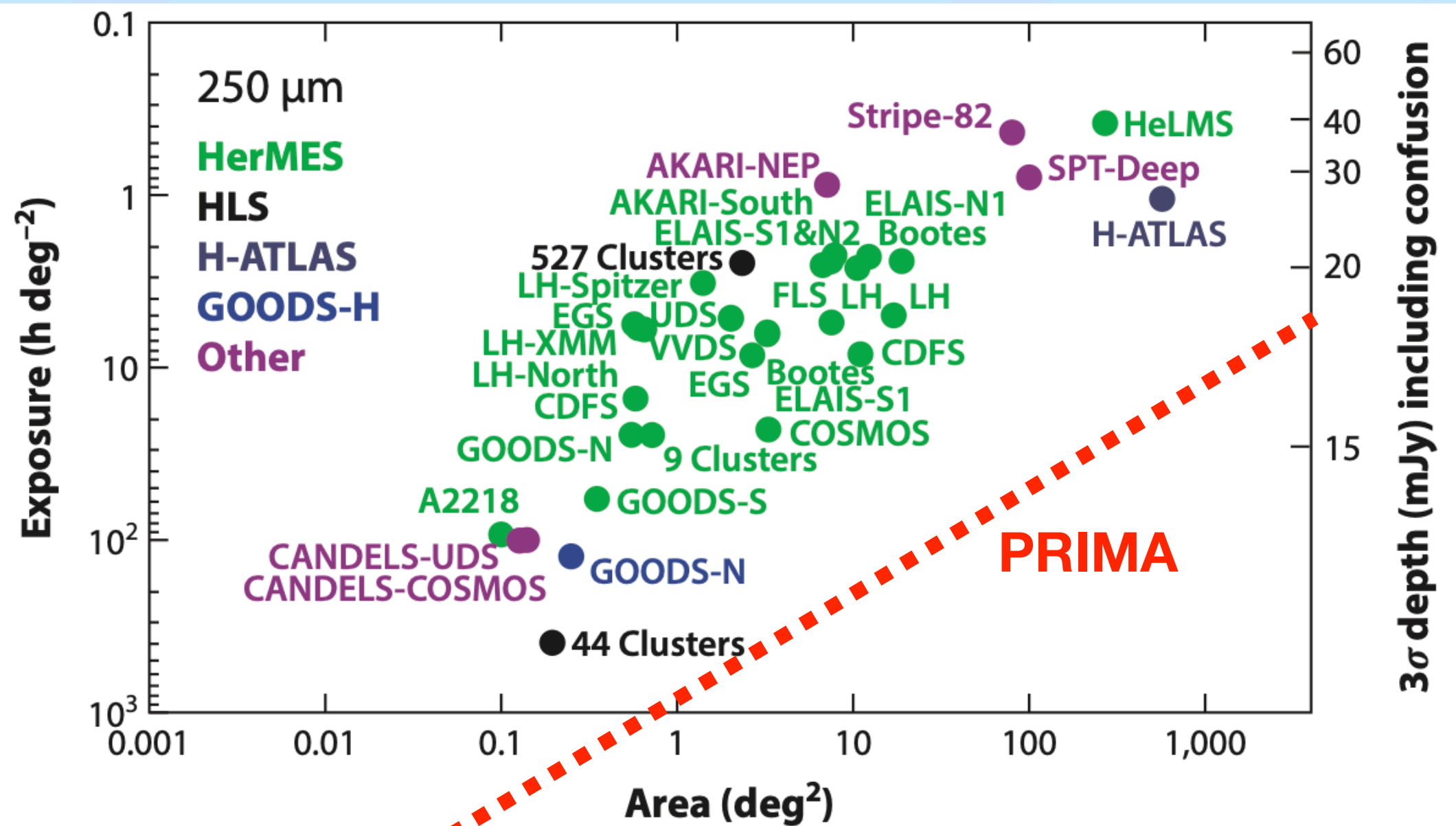
- 1. Identification of new populations**
- 2. Characterization of galaxies in unexplored wavelengths**

Single-dish telescopes catalog dust in distant galaxies

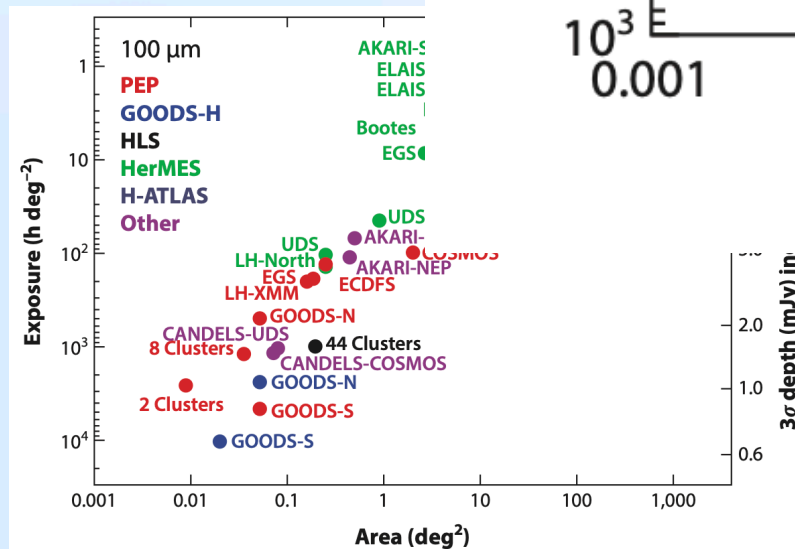


Sanders+1990; Lawrence^z+1996;
Rowan-Robinson+1997

Space missions are unique survey telescopes that reveal the 100 - 500 μ m Universe

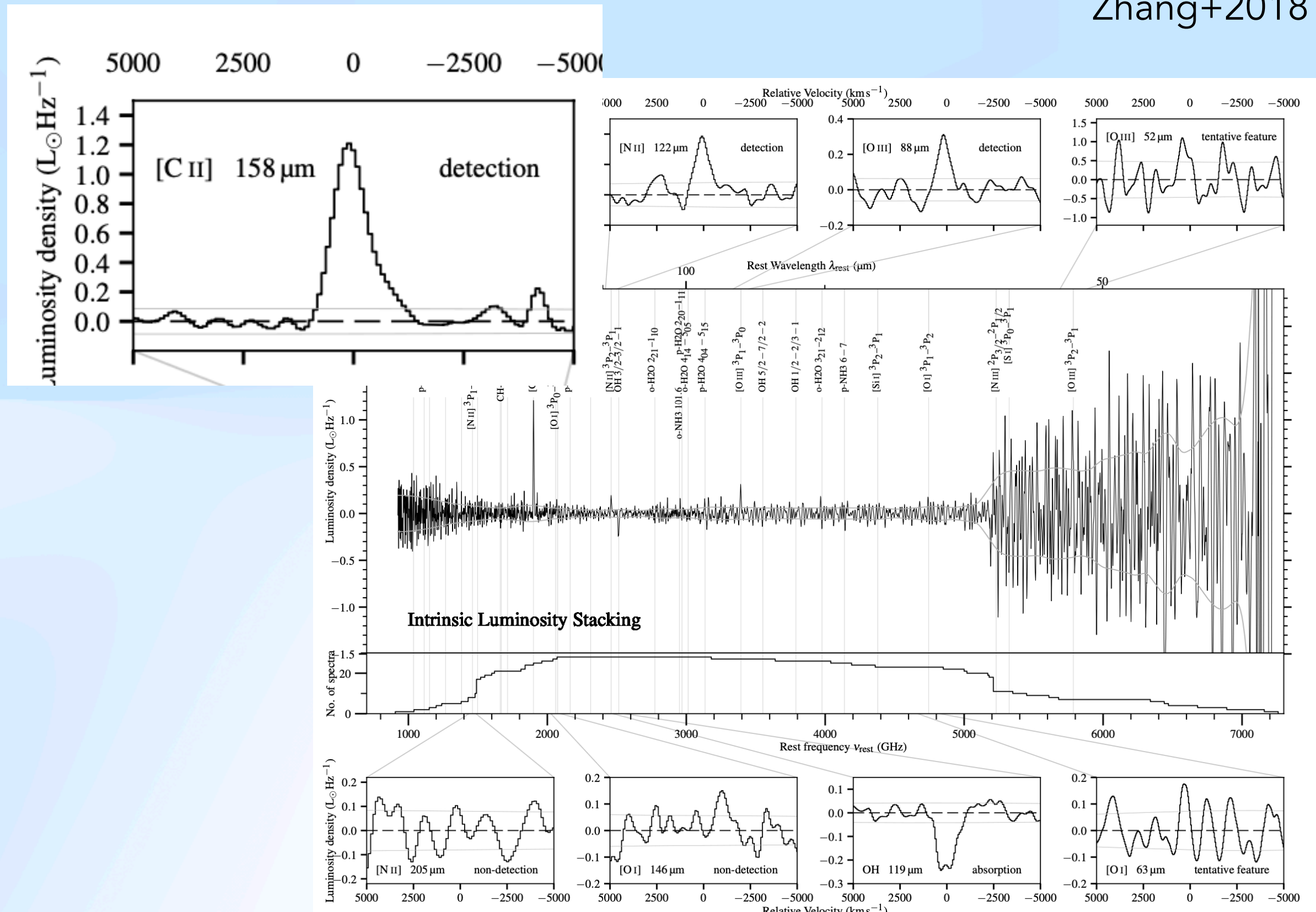


Lutz 2014 (!)

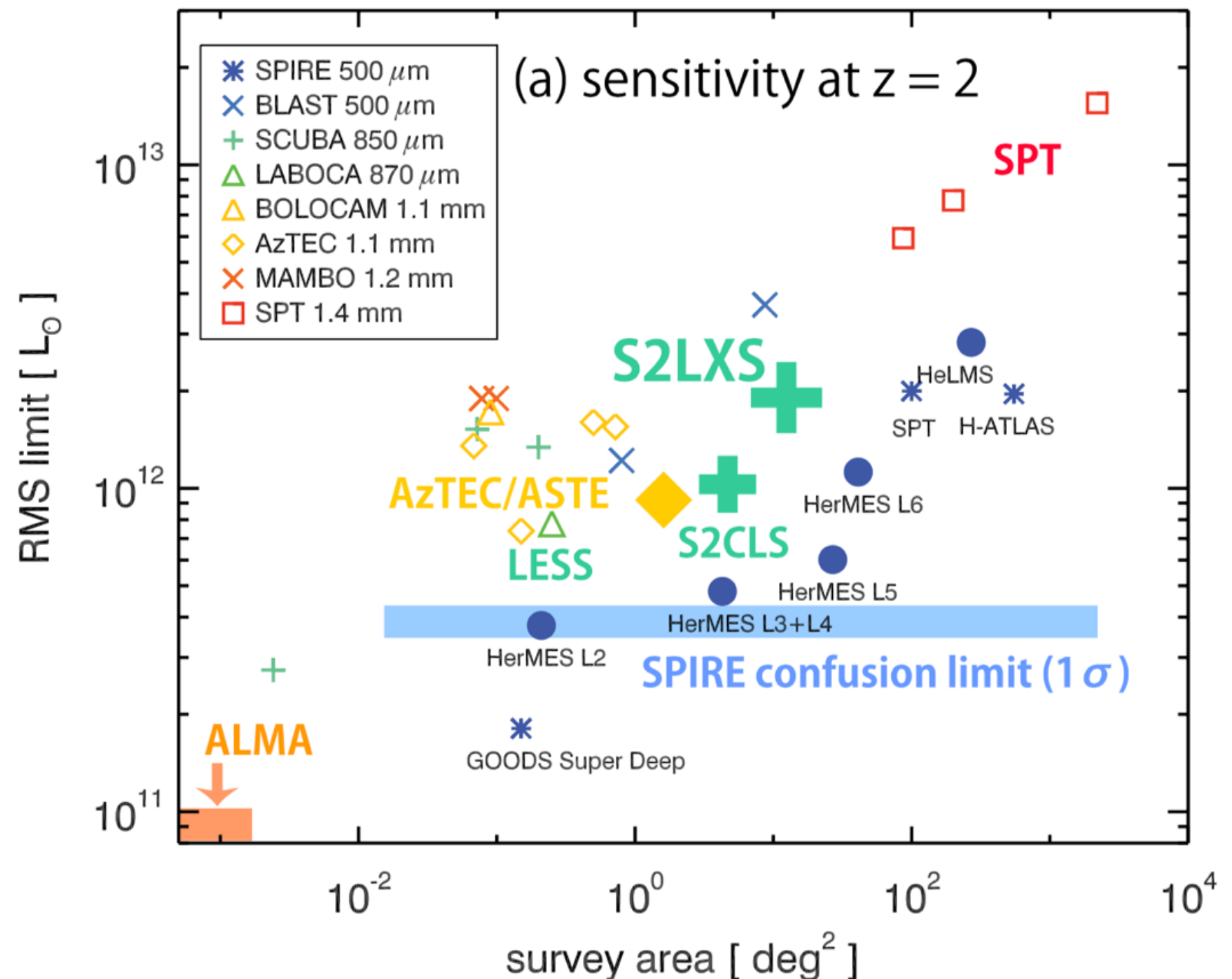


Space missions are unique probes for spectroscopic studies

Zhang+2018



Ground-based telescopes offer larger dishes for a complementary view of the early Universe



Ground-based telescopes enable rapid development of (sub)mm instrumentation

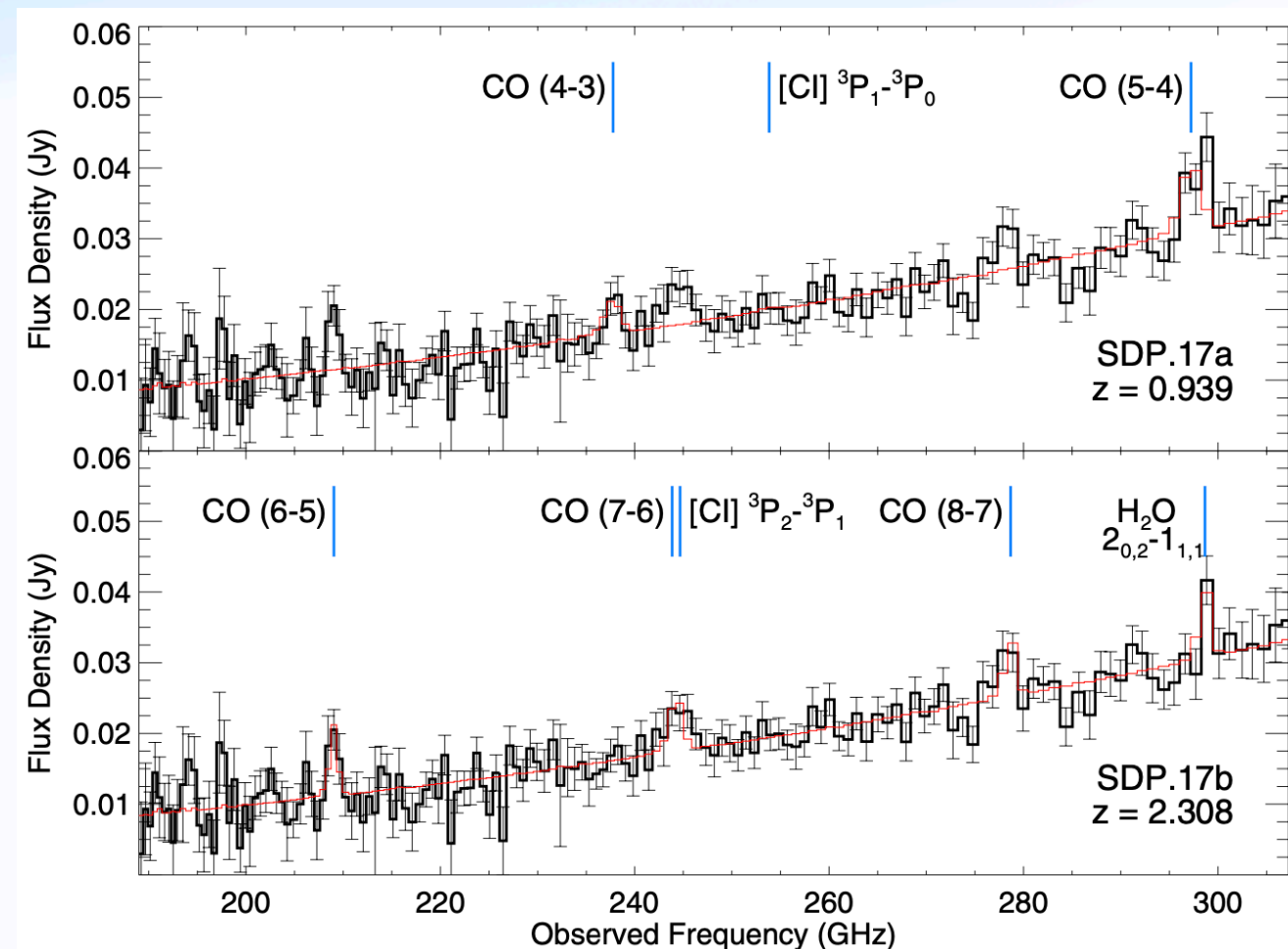
Large-area mappers: AMKID / ToITEC / NIKA (2)

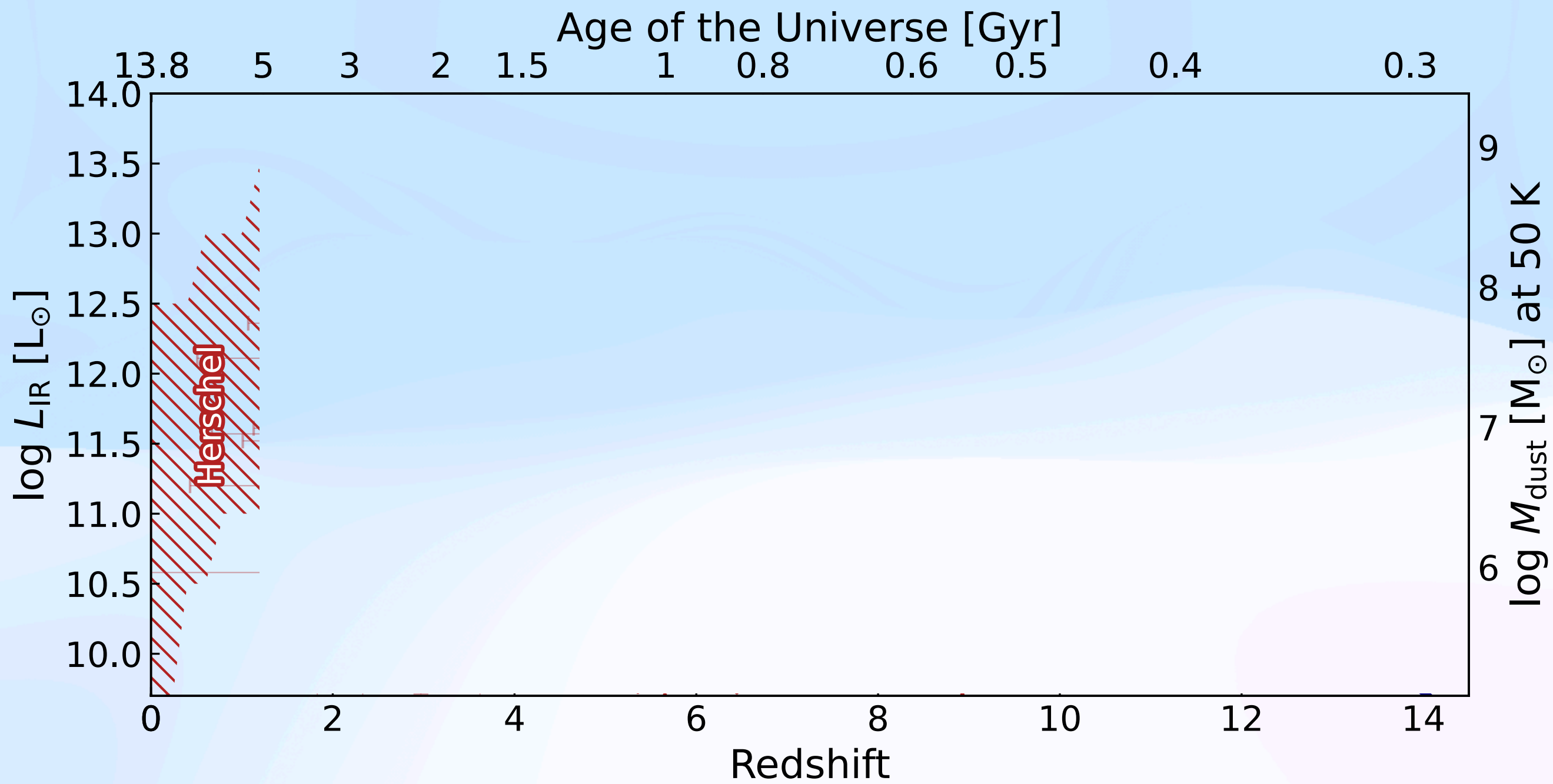


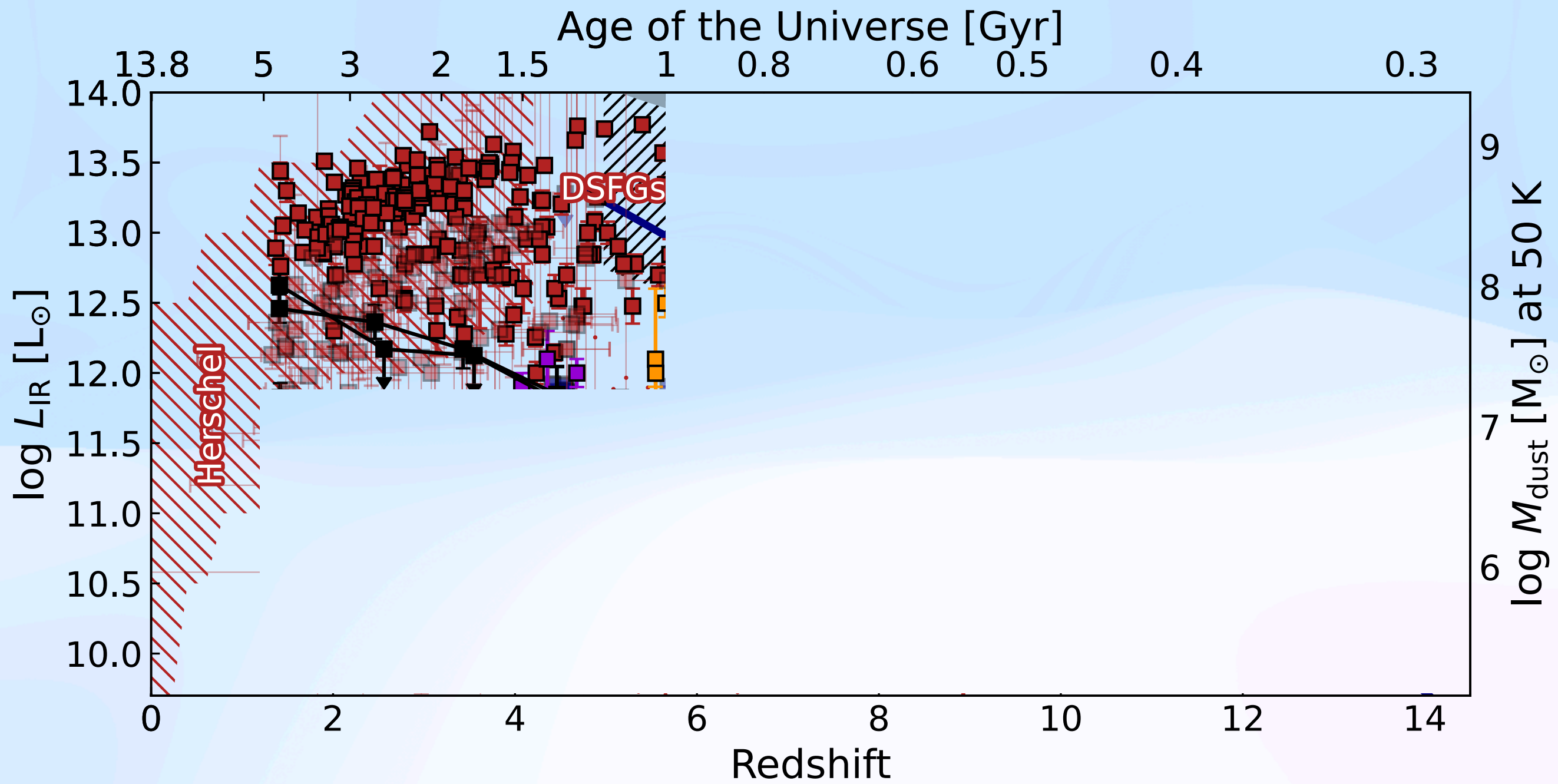
Spectroscopic instruments
(z-spec, Zpectrometer,
DESHIMA, superspec...)

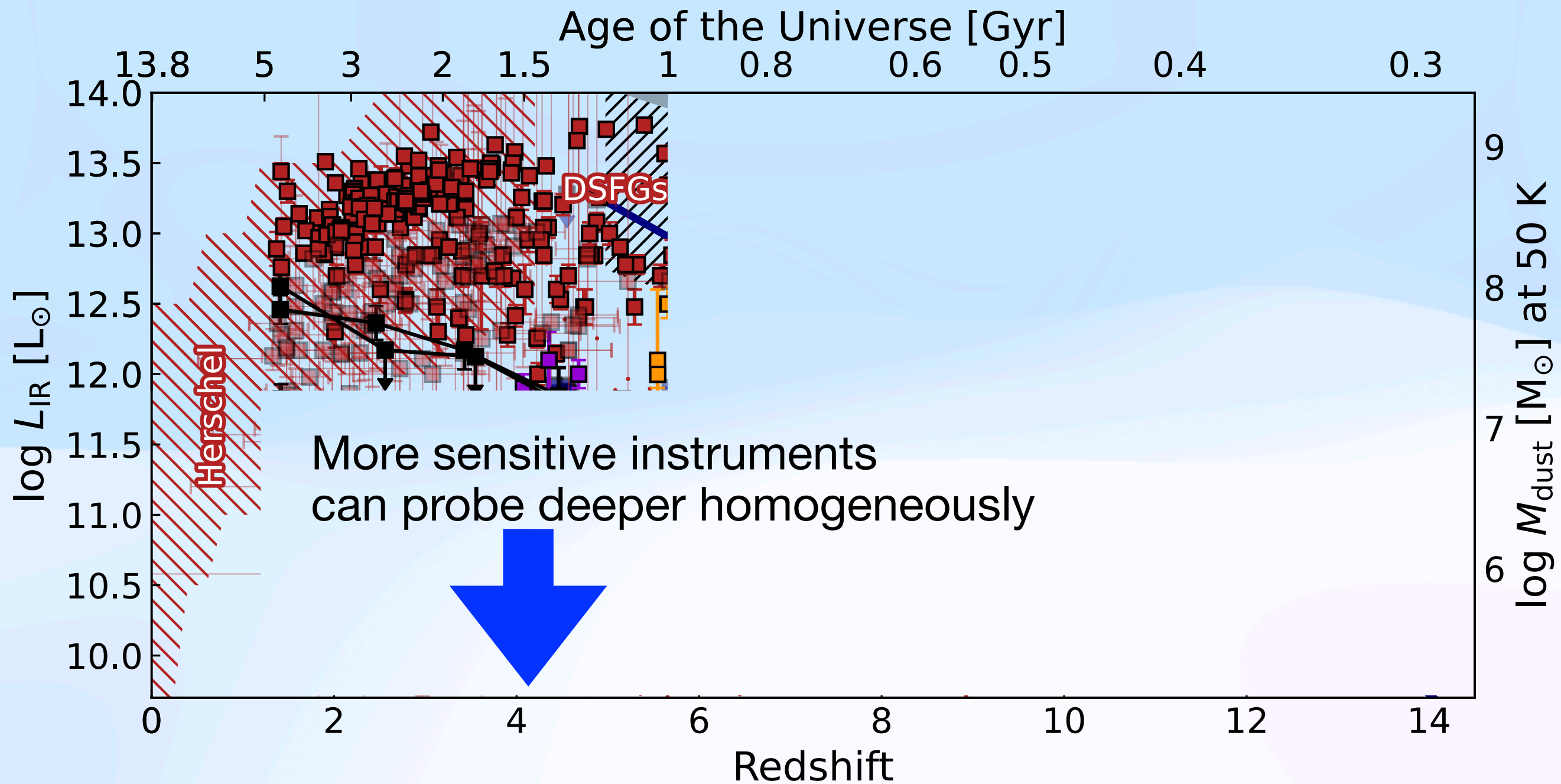
Somewhere in
between: **TIFUUN**

see talk by A. Endo









Fundamental challenges of single-dish observations

Limited angular resolution - especially in space

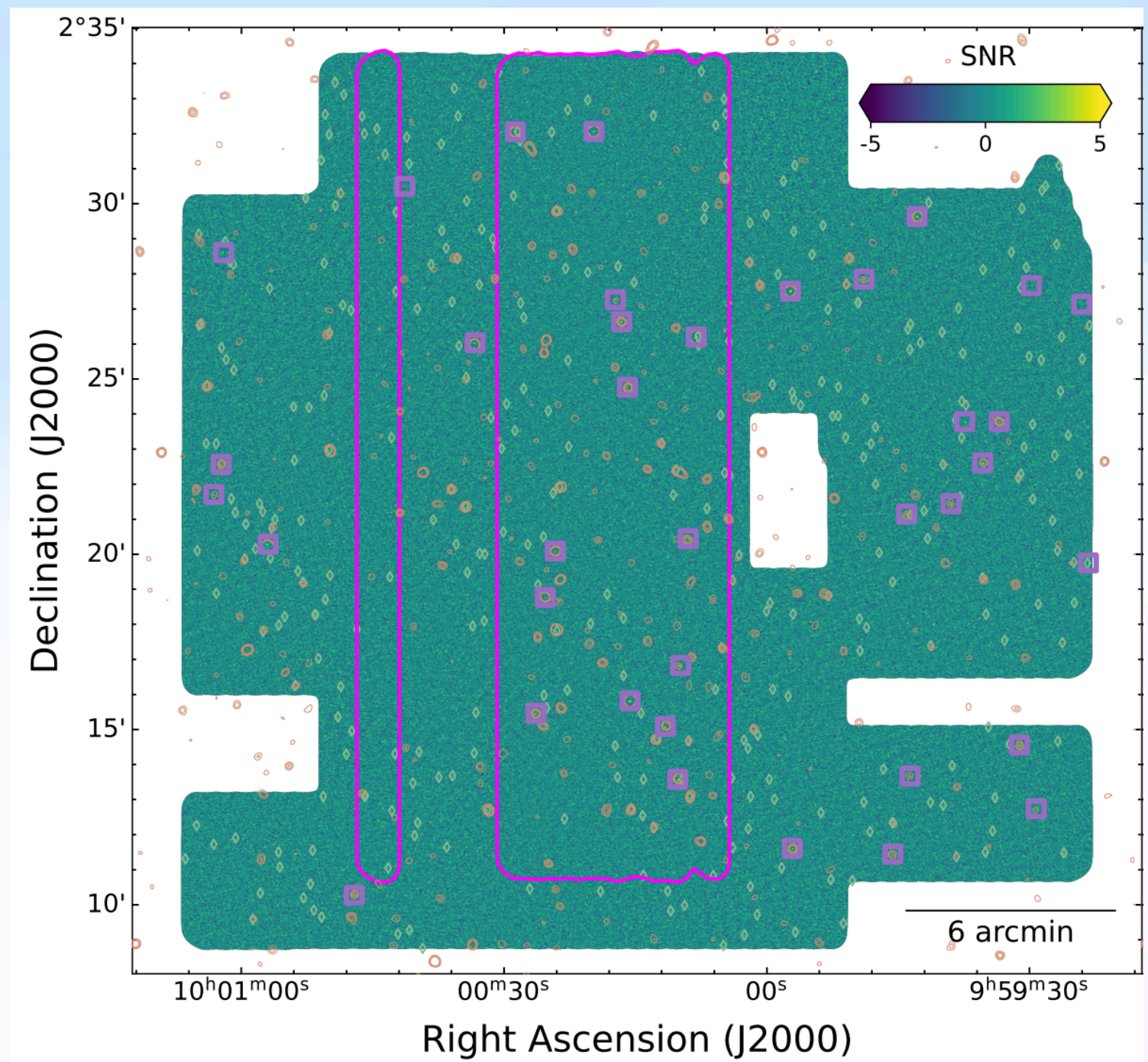
Source confusion (up to ~15 m. dishes)

Limited atmospheric windows - especially from earth

Limited sensitivity due to

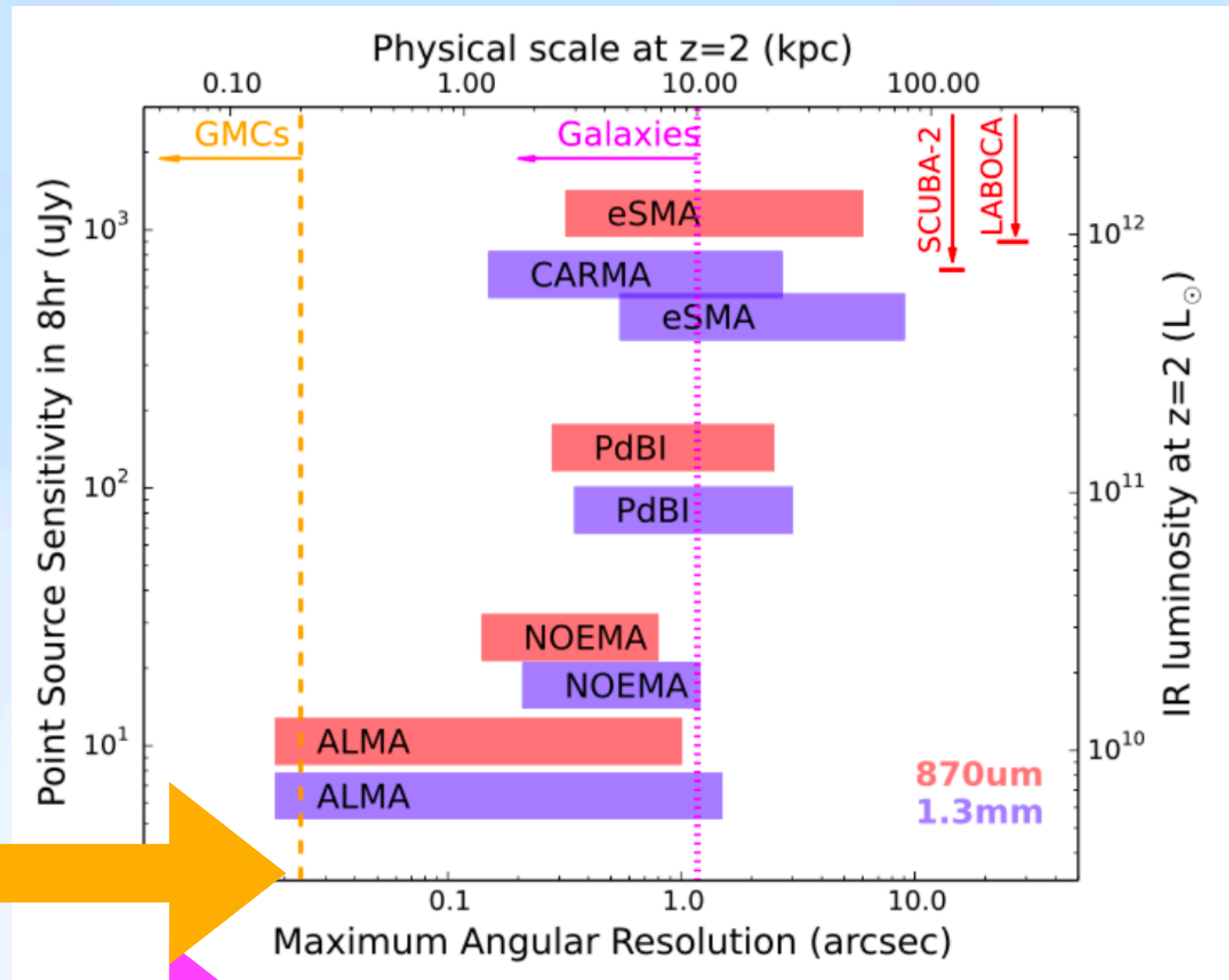
- collecting area for space telescopes
- bright atmosphere for ground-based telescopes

Interferometers can deeply probe space through single-pixel receivers



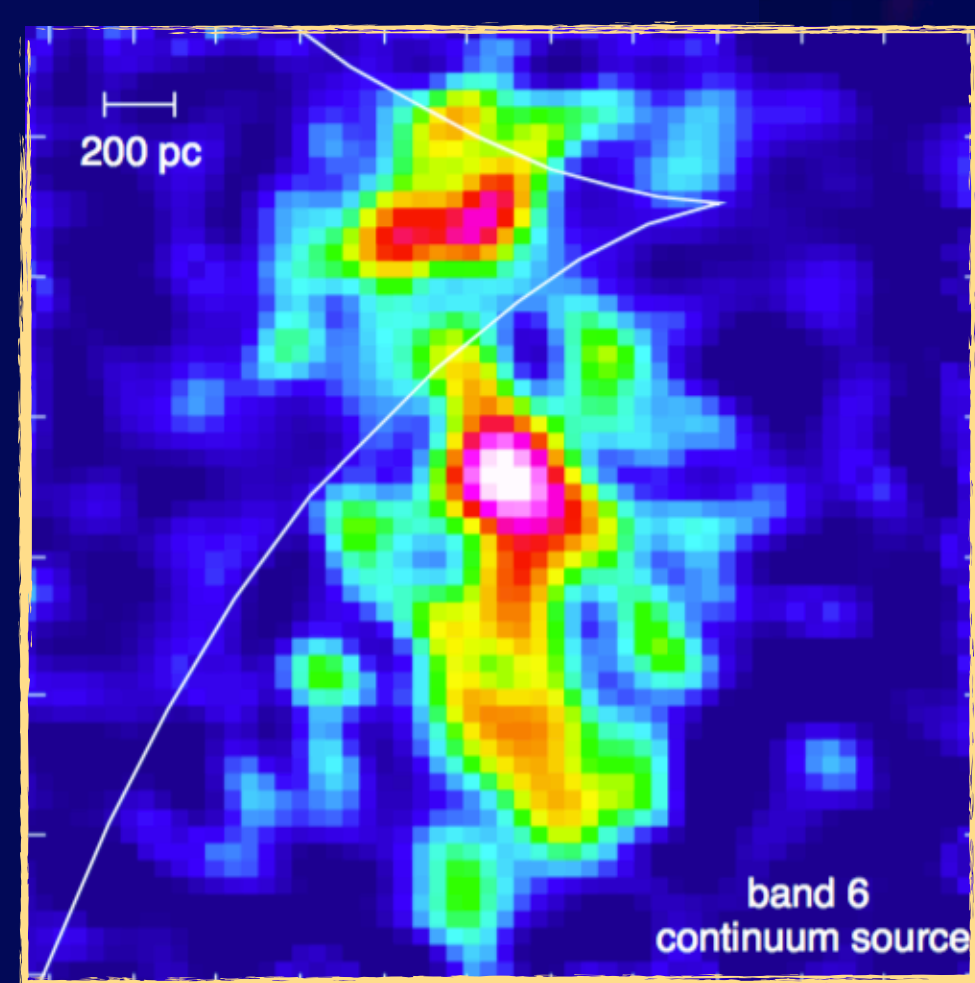
Long+2024; Zavala+2021

Individual observations can probe GMC-scale environments



WSU

ALMA 2040...

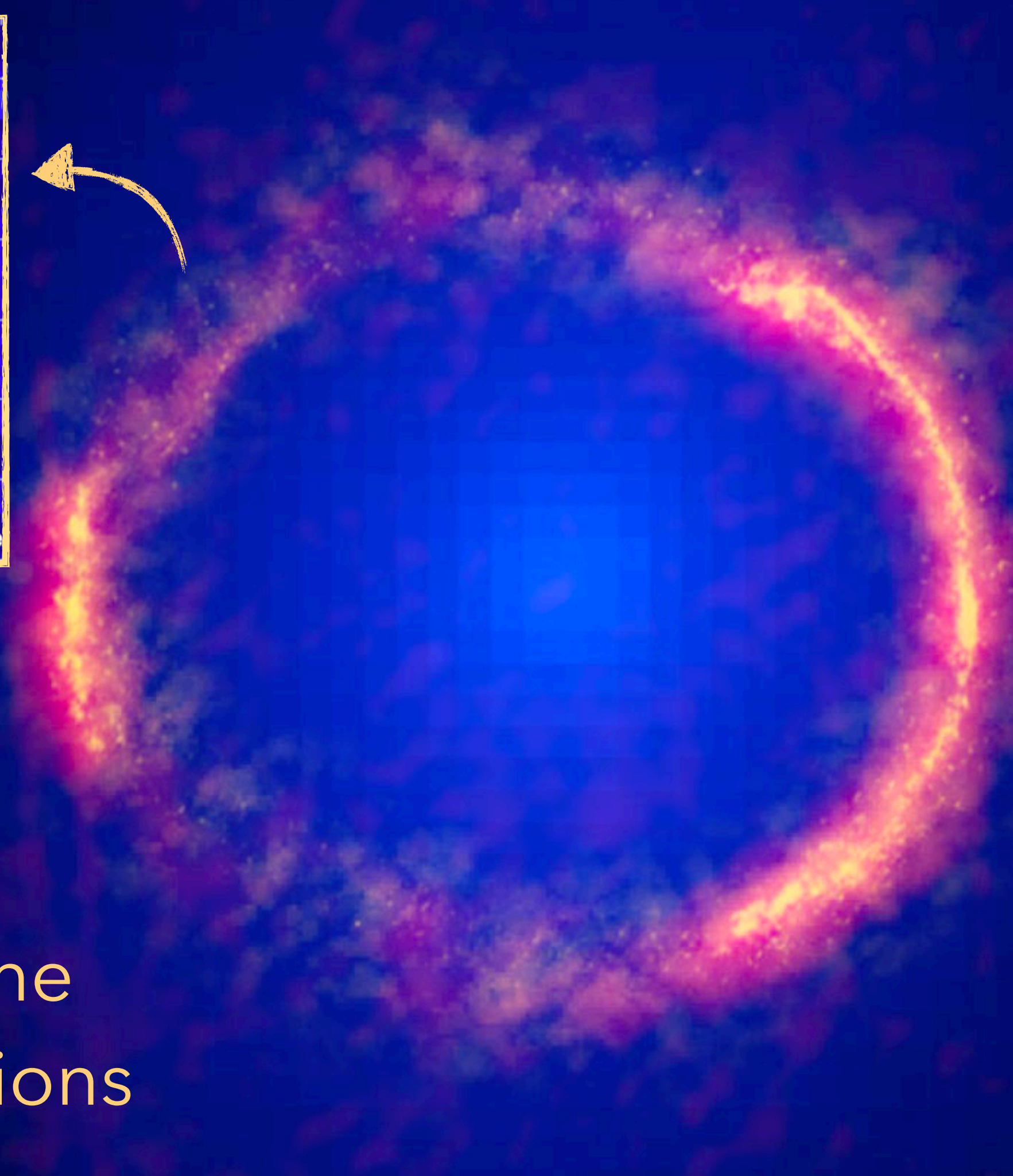


Dye et al. 2015

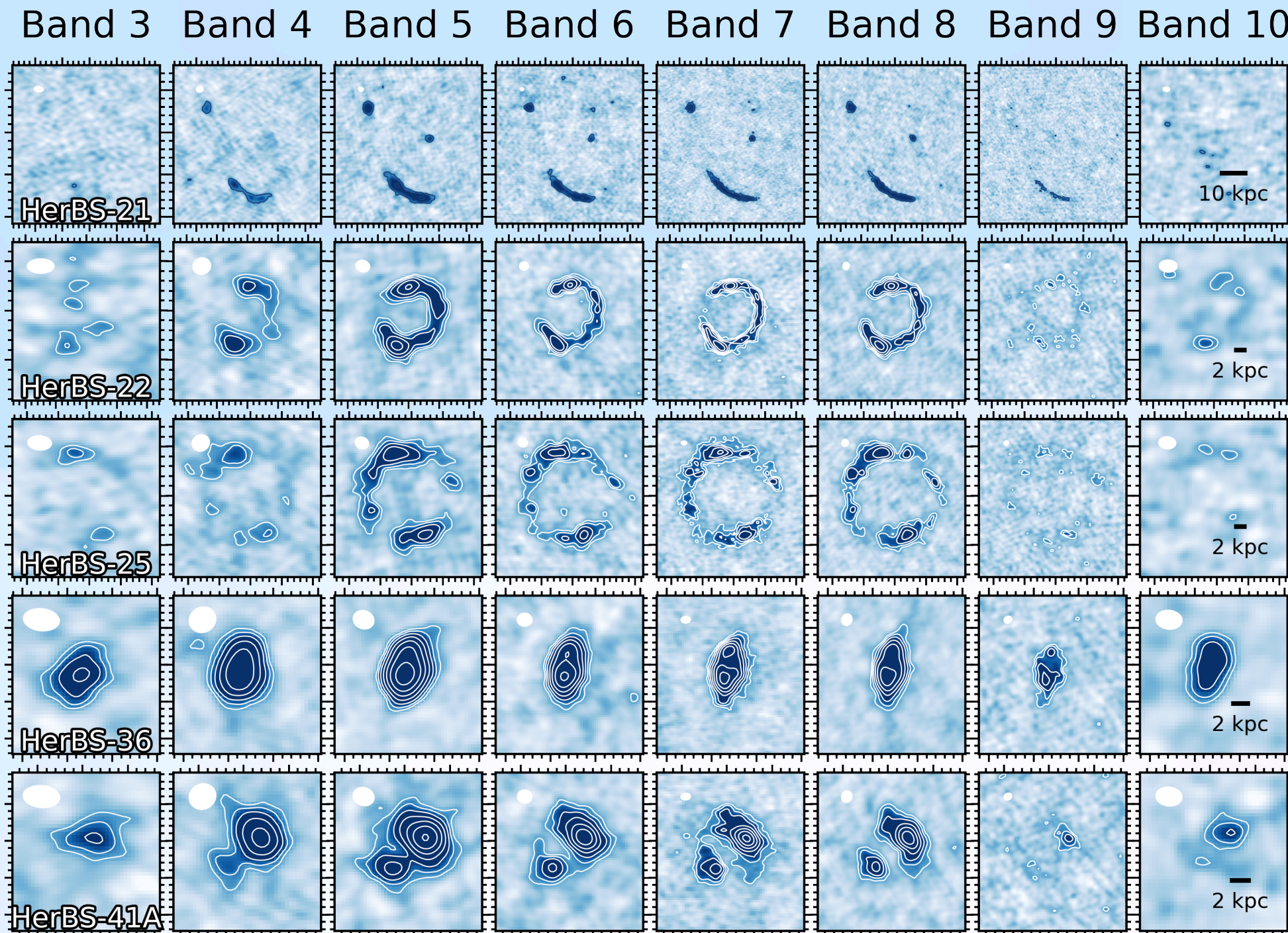
Tamura et al. 2015

Rybak et al. 2015

Gas supply at the
highest resolutions

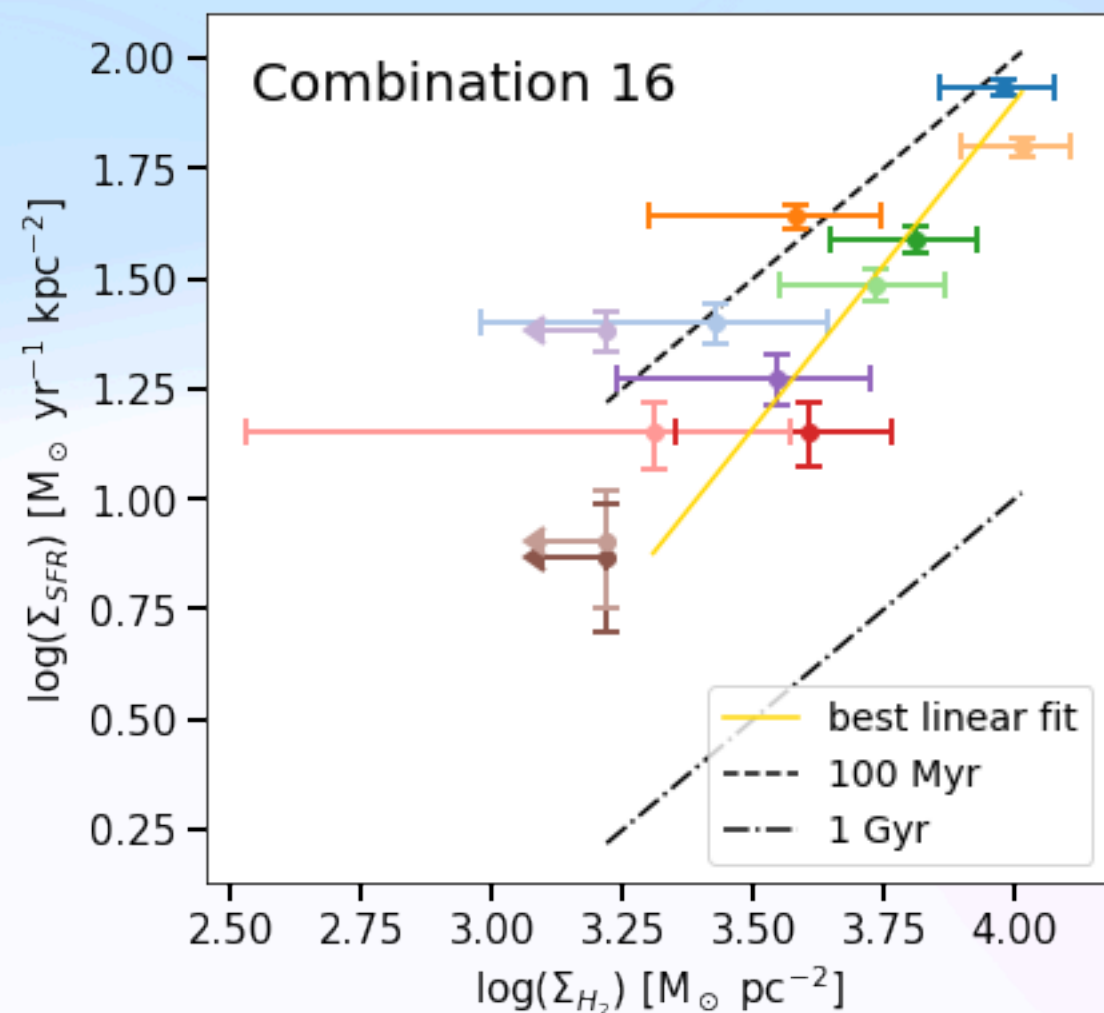
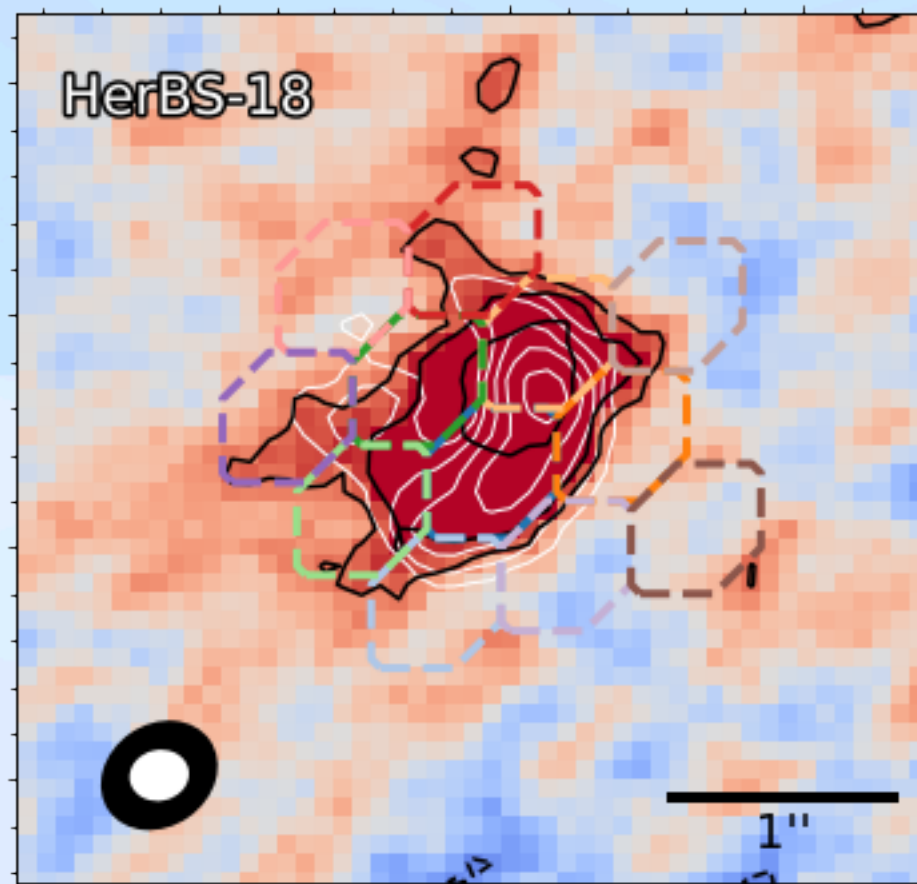


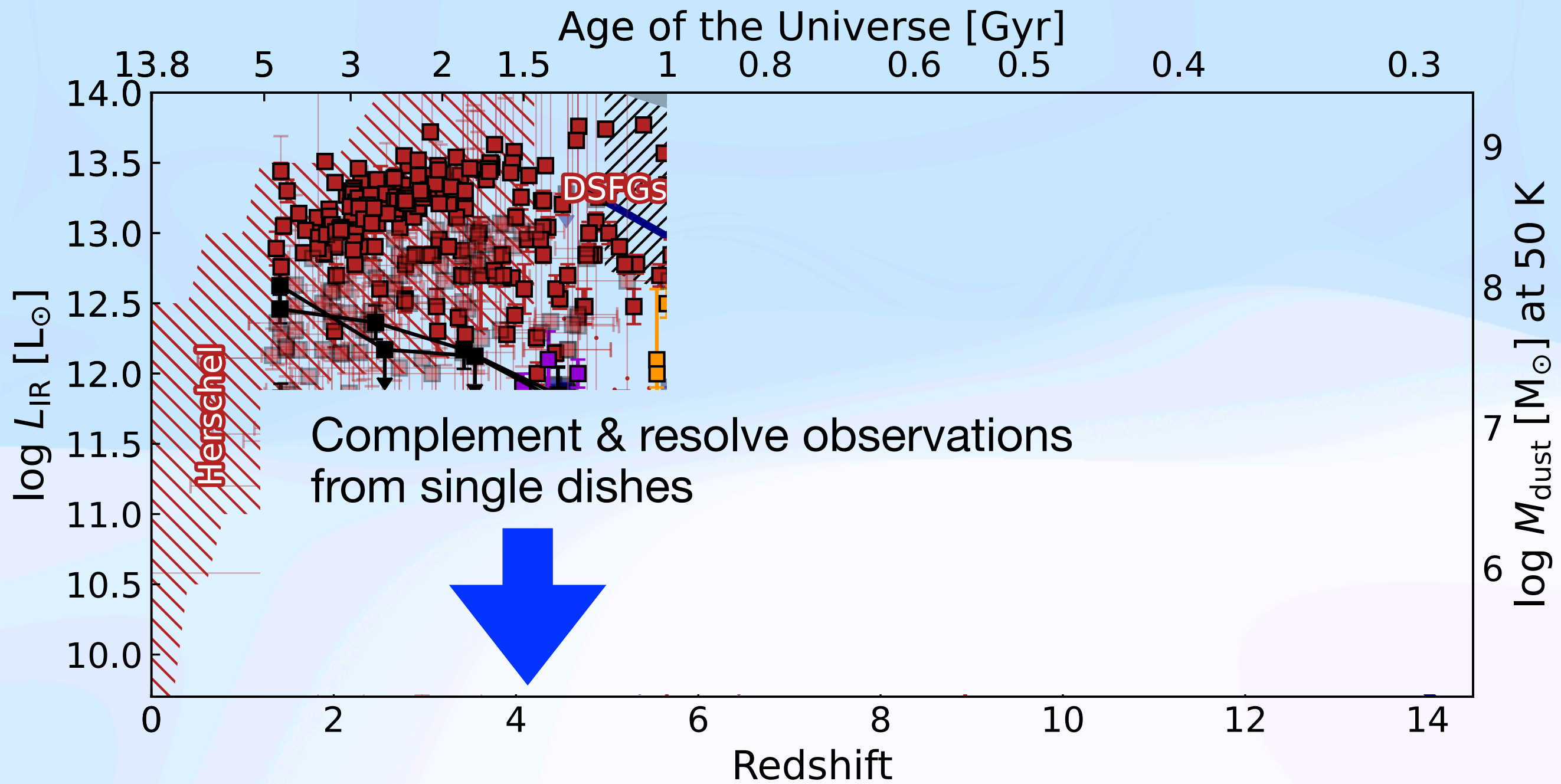
Rapid continuum characterisation of unresolved objects at 0.1''



A subsample of 5/21 ANGELS sources (Bakx+24) with Band 3 - 10 data

Spectroscopic follow-up can reveal the detailed ISM physics

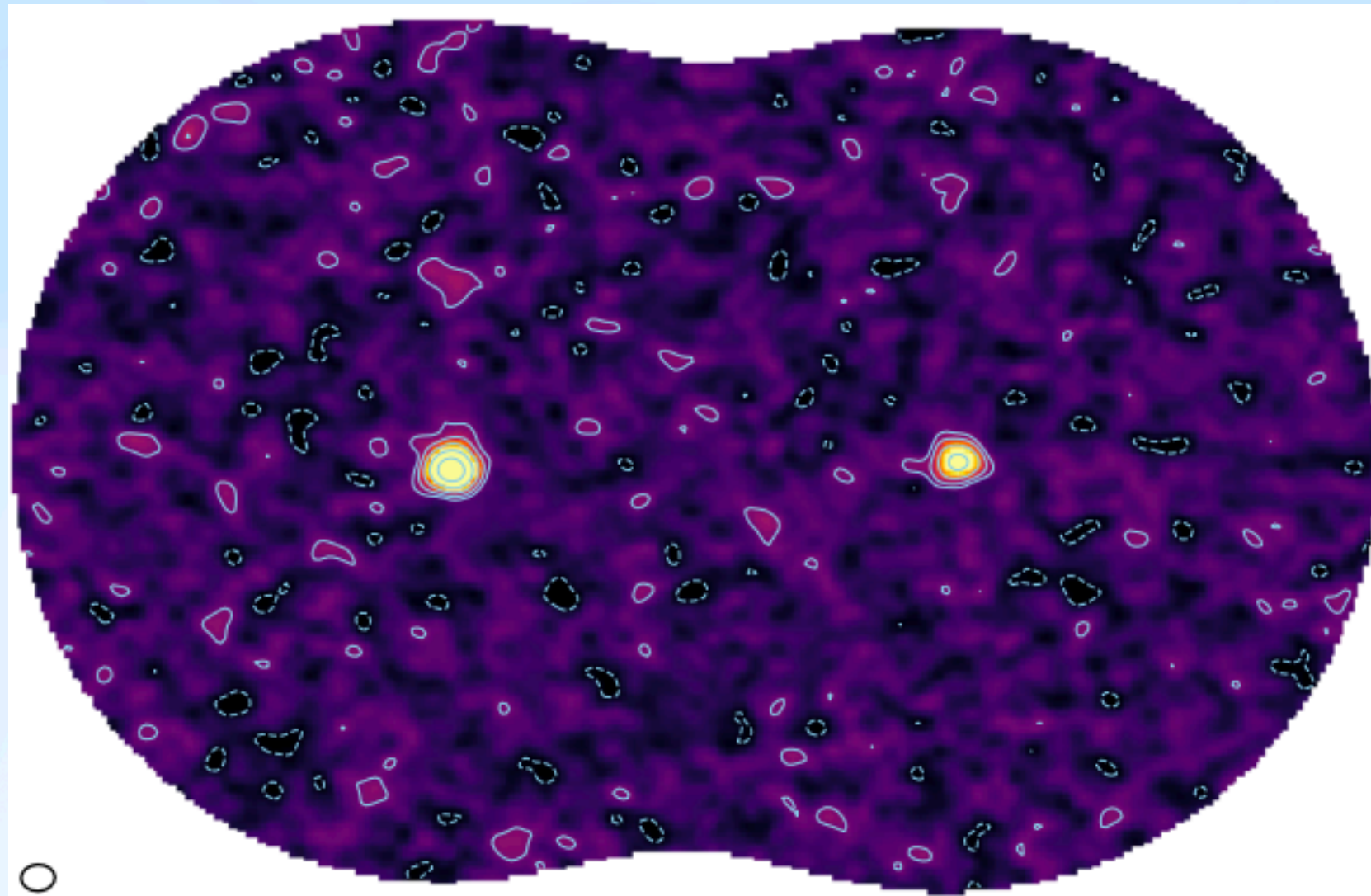




Emission-line galaxies offer an alternative selection

Decarli et al. 2024

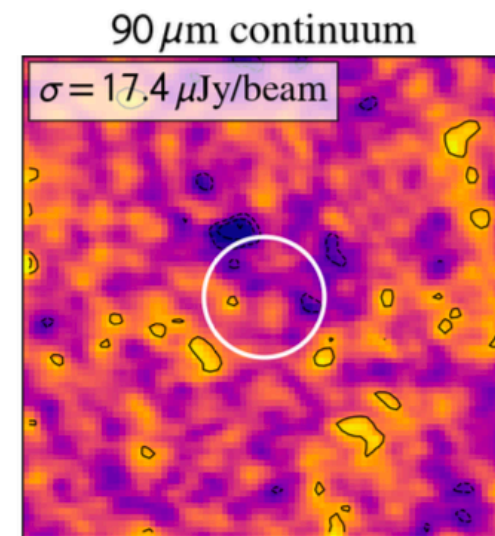
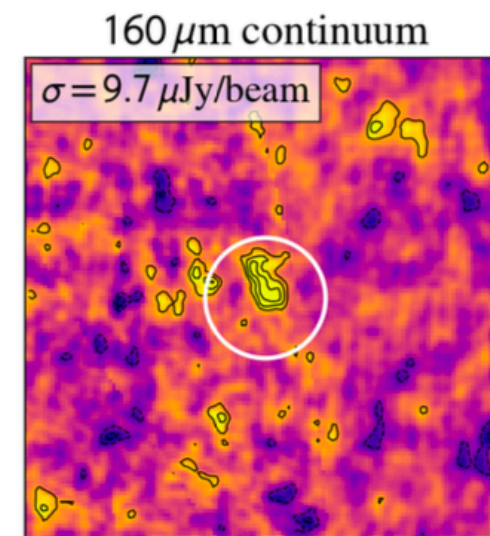
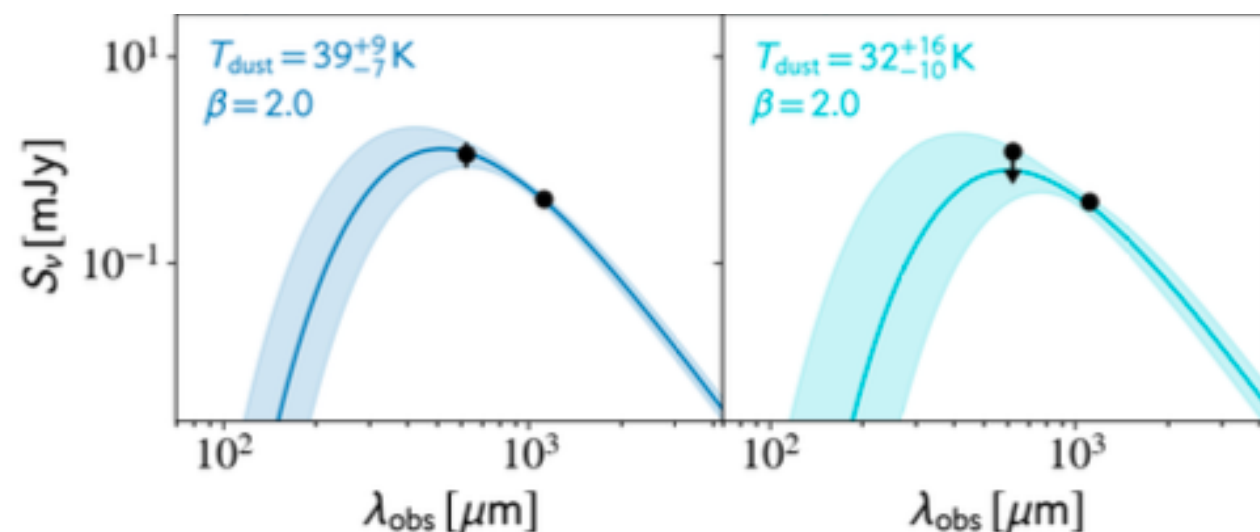
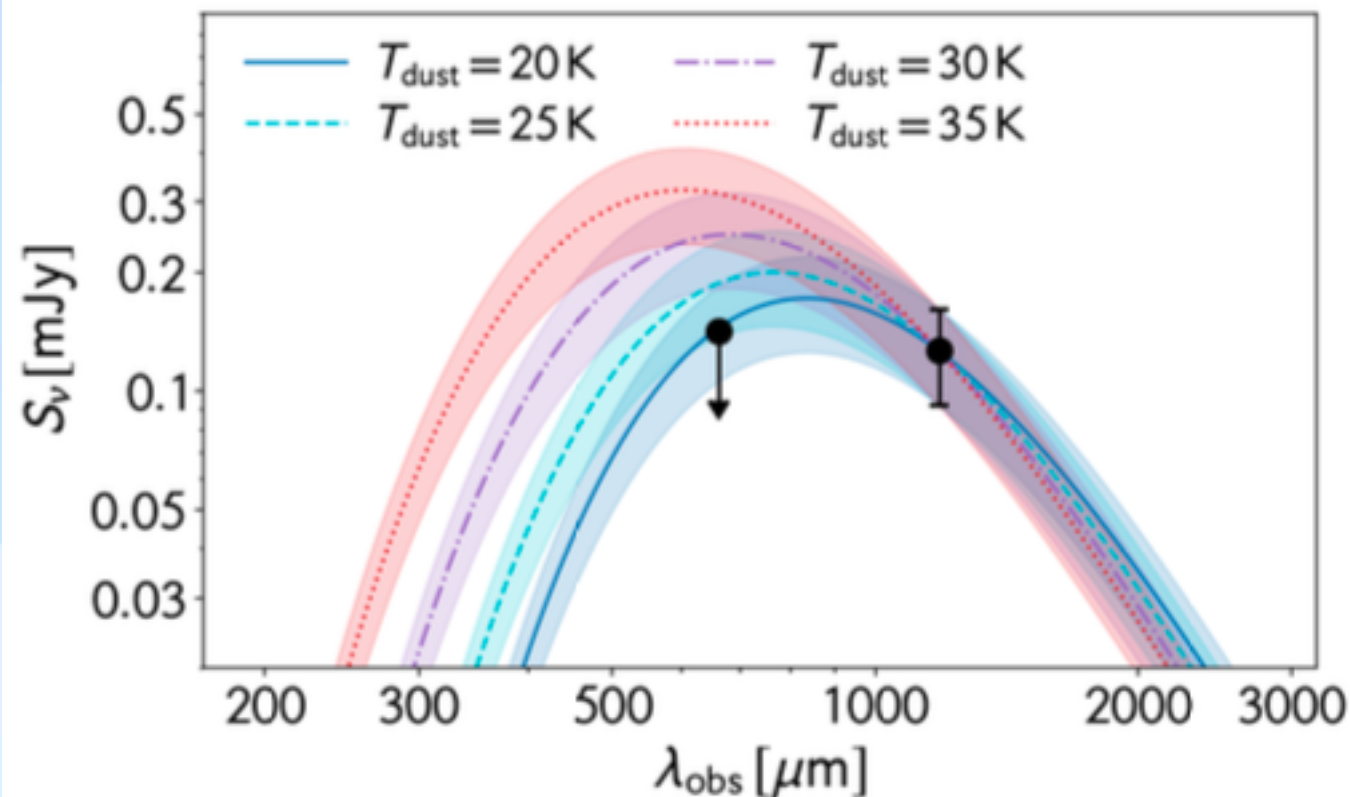
QSO



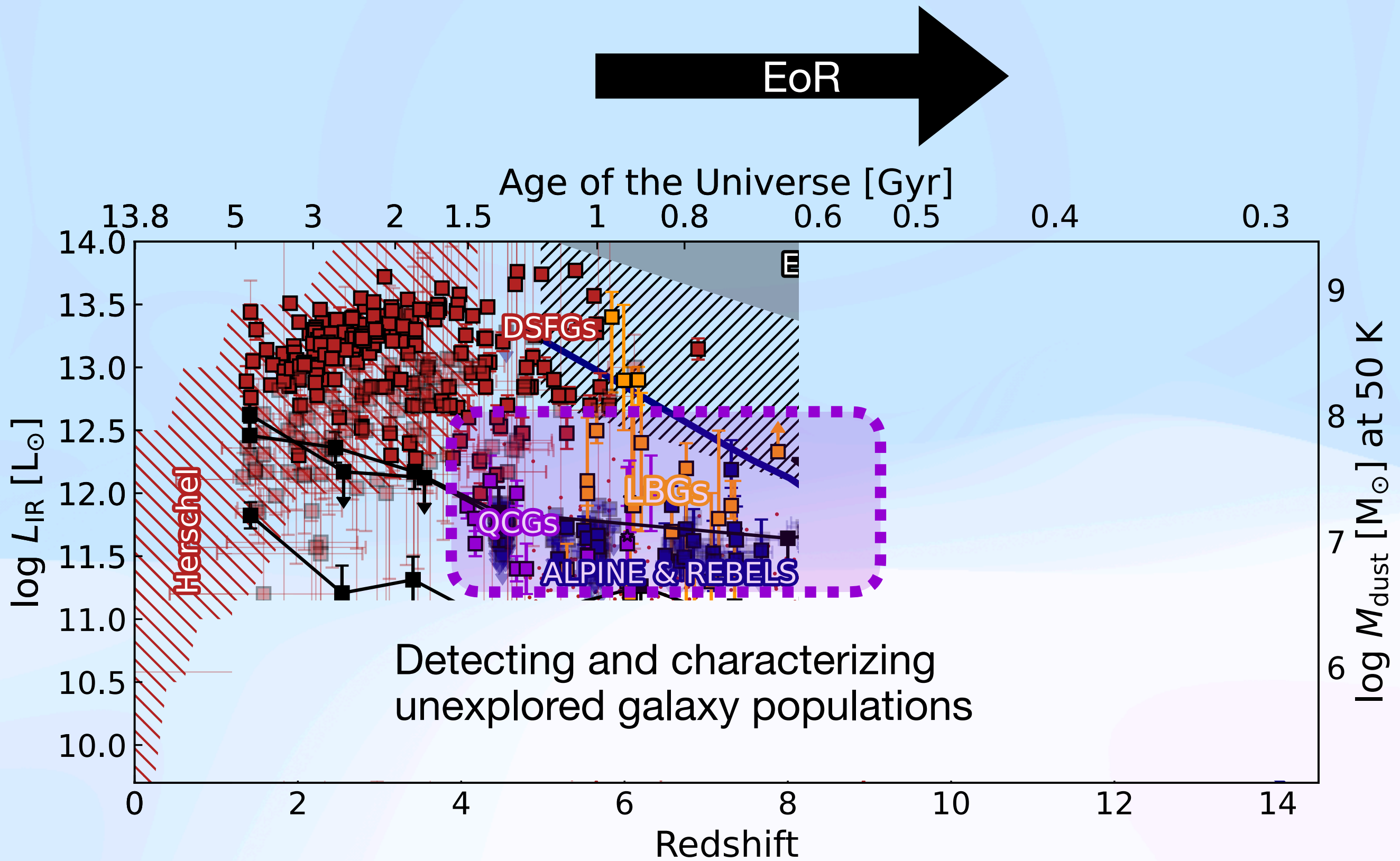
SMG

Follow-up of 13 emission-line galaxies find cold and ubiquitous dust

Bakx et al. 2024

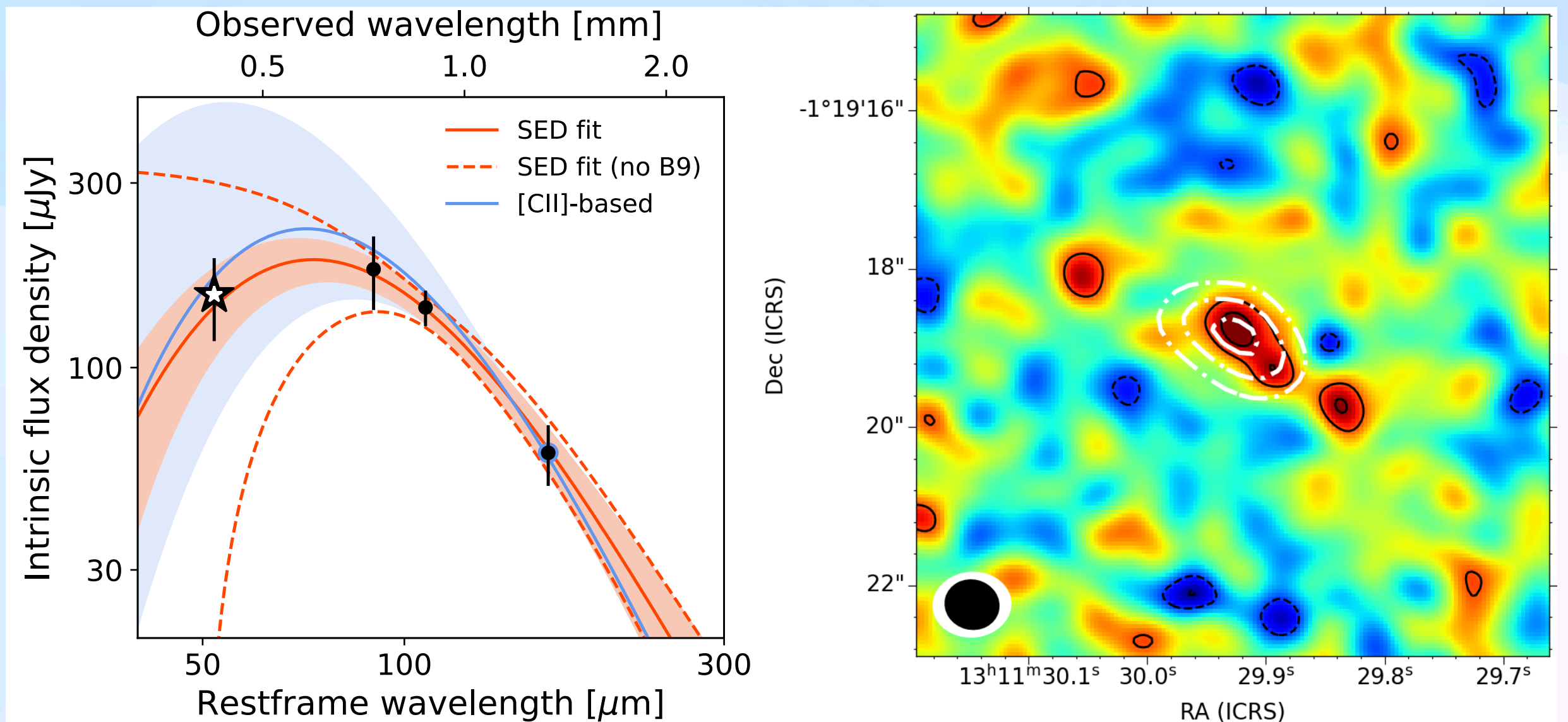


See also: van Leeuwen+2024



A first direct measurement of the dust temperature at $z > 7$

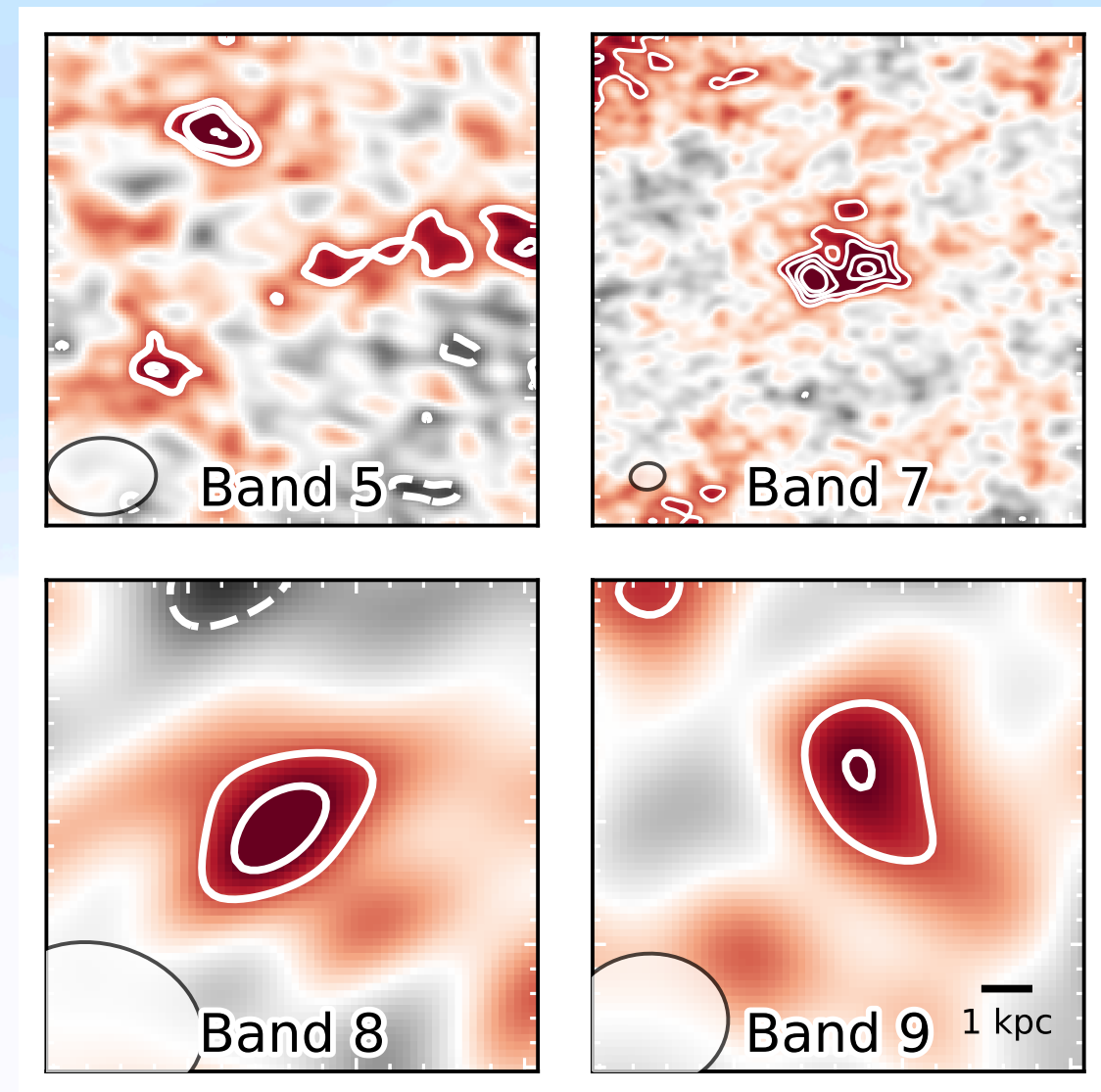
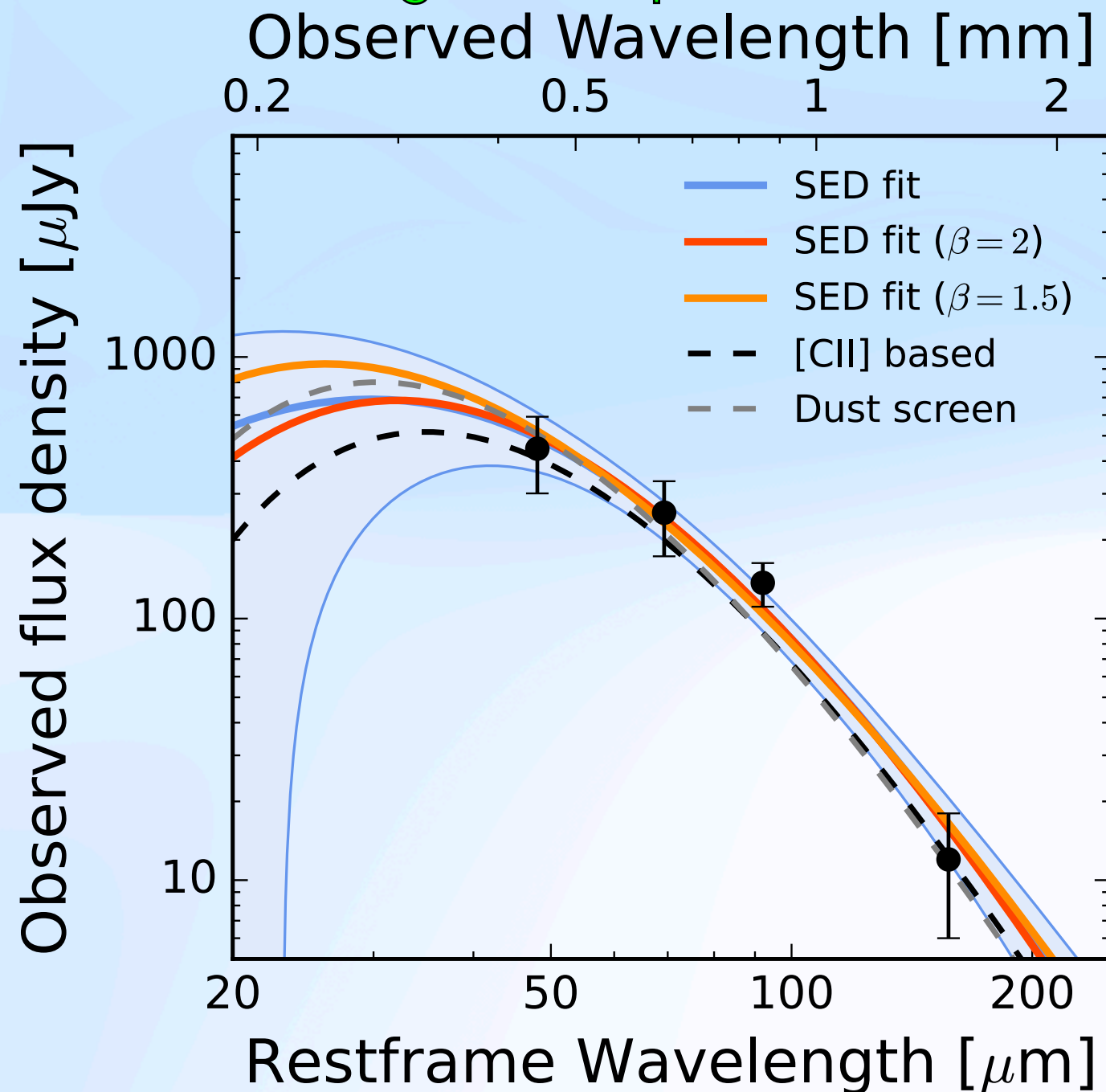
Bakx et al. 21



Galaxy A1689-zD1, also see Watson+ 2015, Knudsen+ 2017

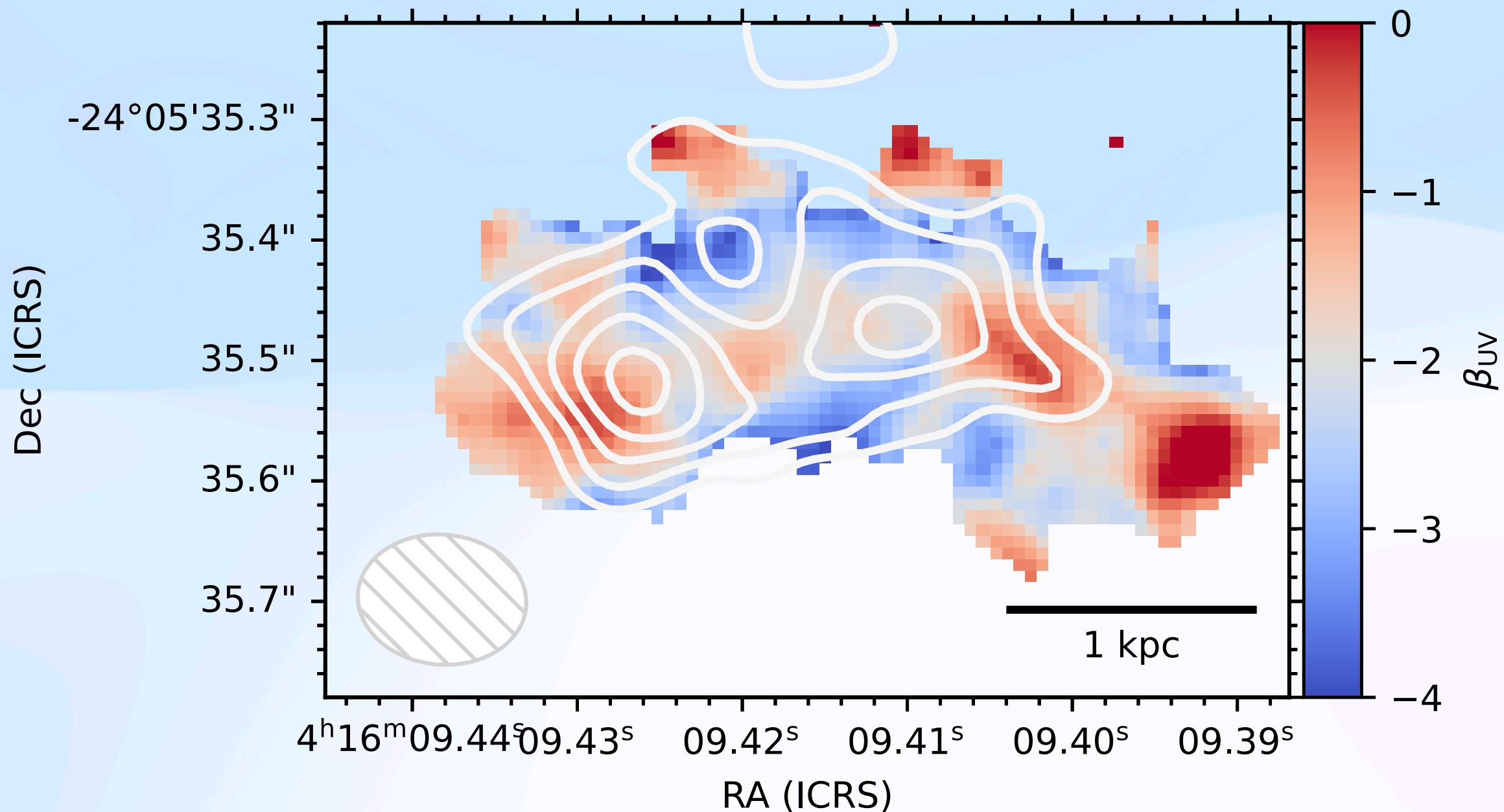
The most distant dust detection confirms a ULIRG at 600 Myr

Waarschuwing: Temperatuur

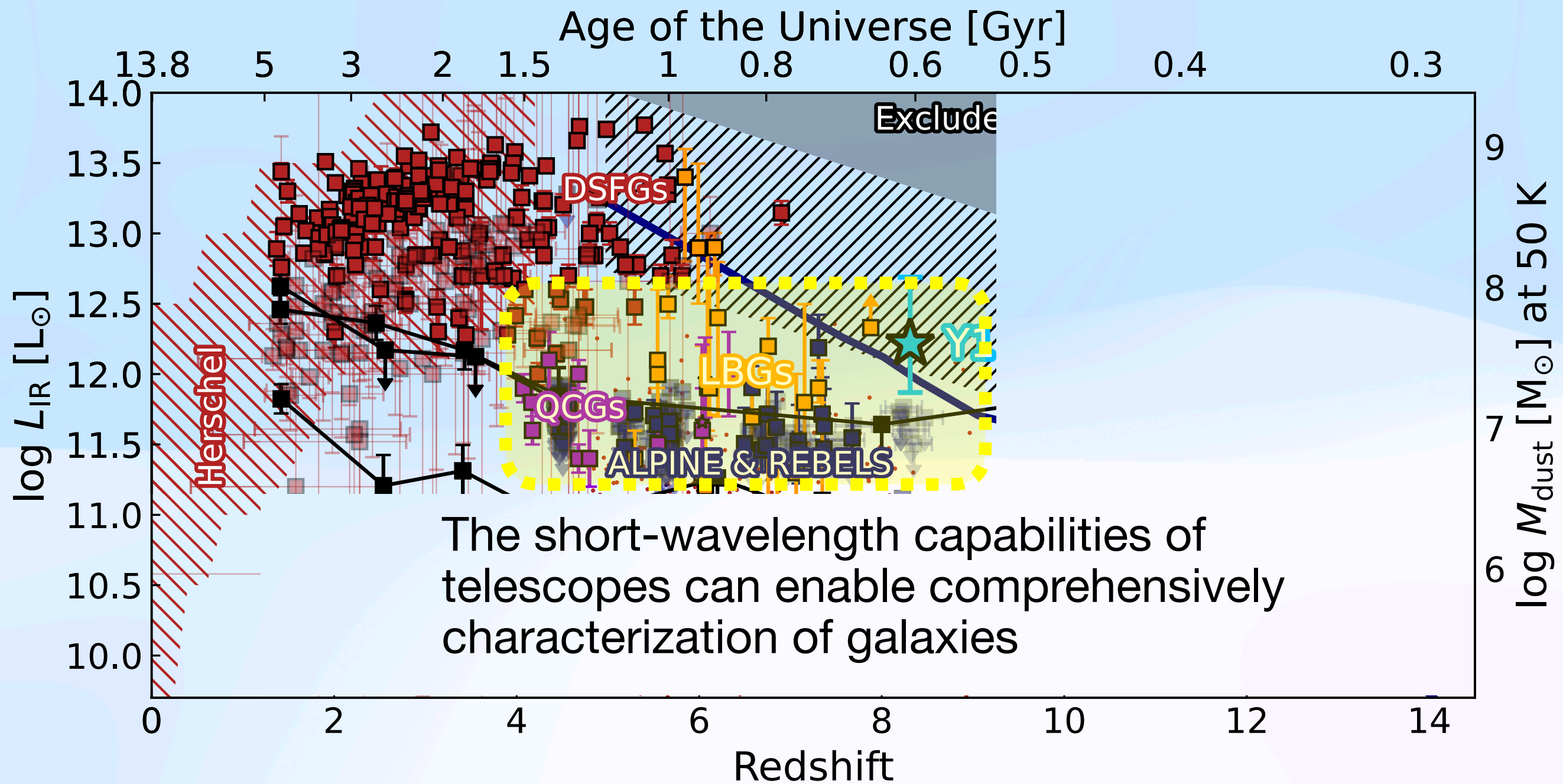


Bakx et al. 20, +subm; in prep.;
Tamura et al. 19, 23

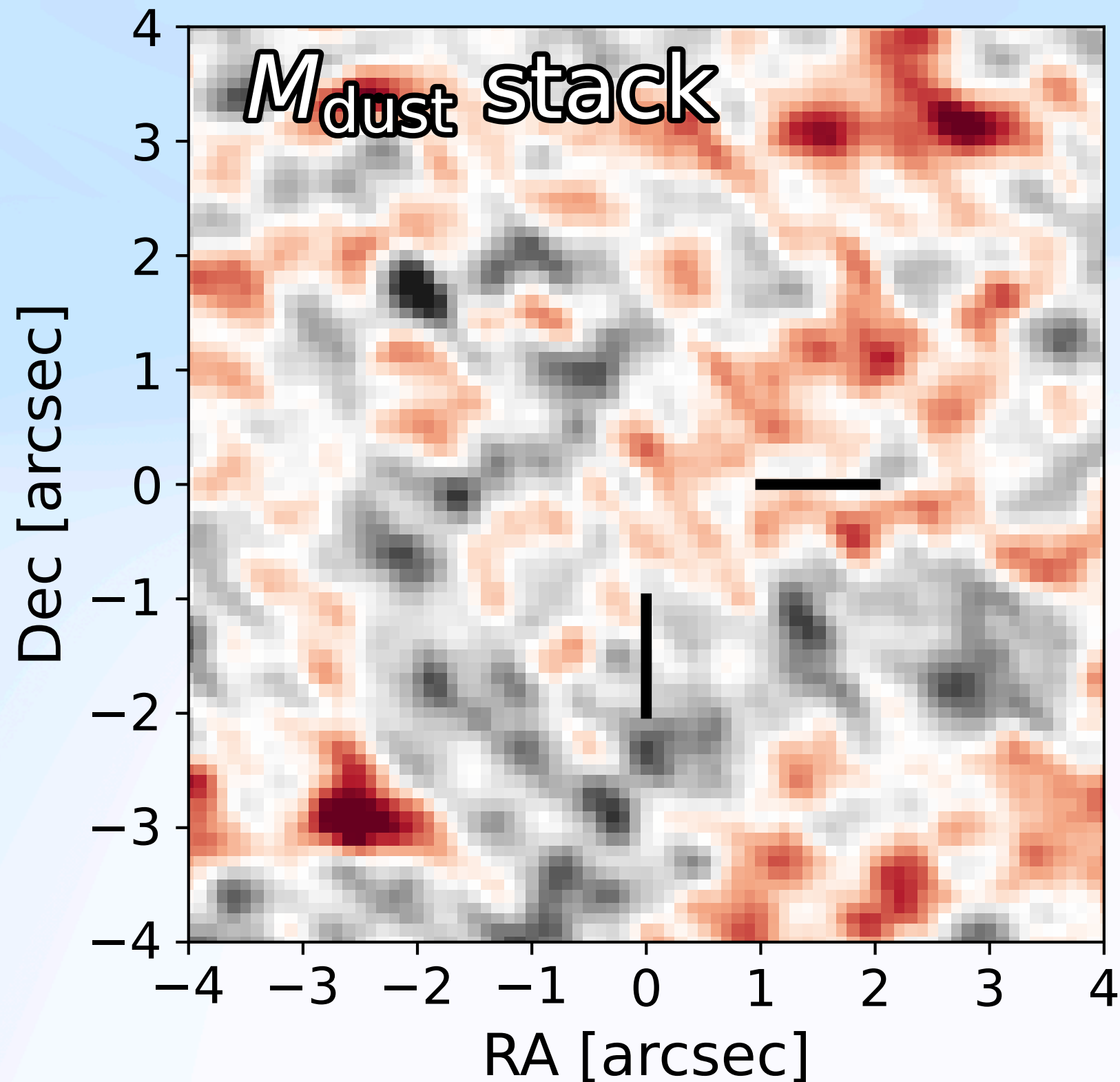
Deep JWST imaging shows a complicated source



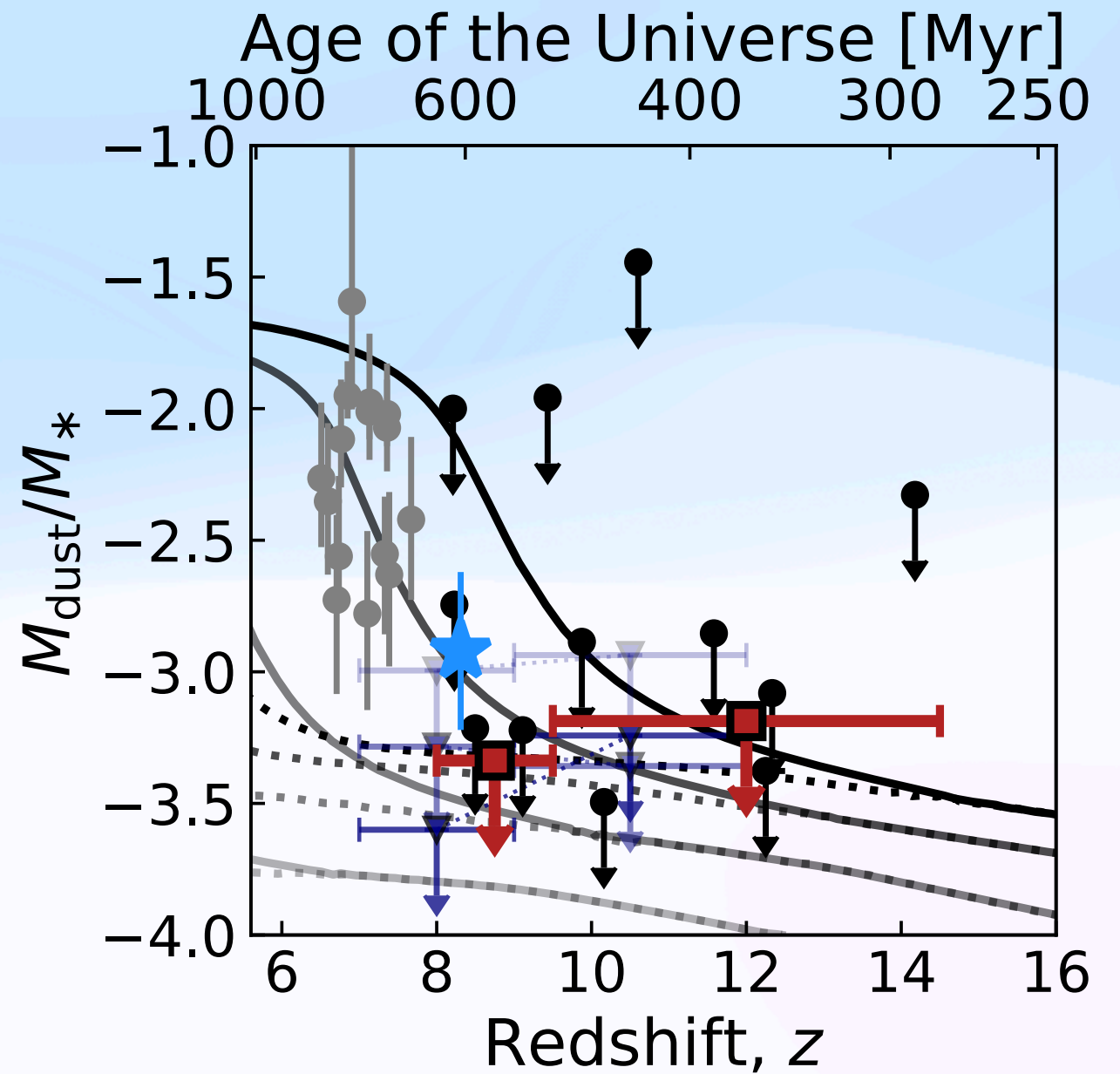
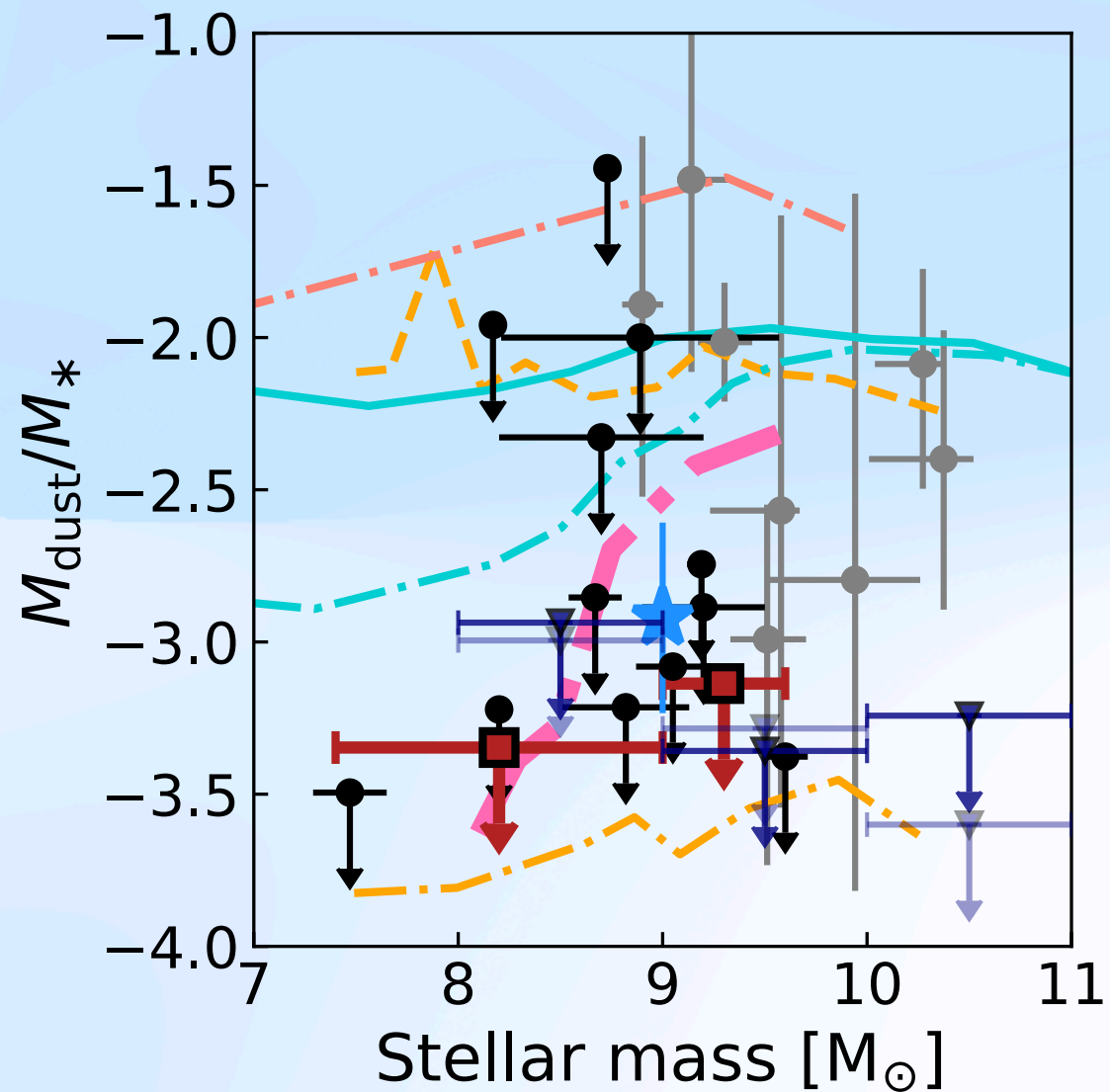
Bakx et al. 20, subm; in prep.;
Tamura et al. 19, 23; Harshan+24

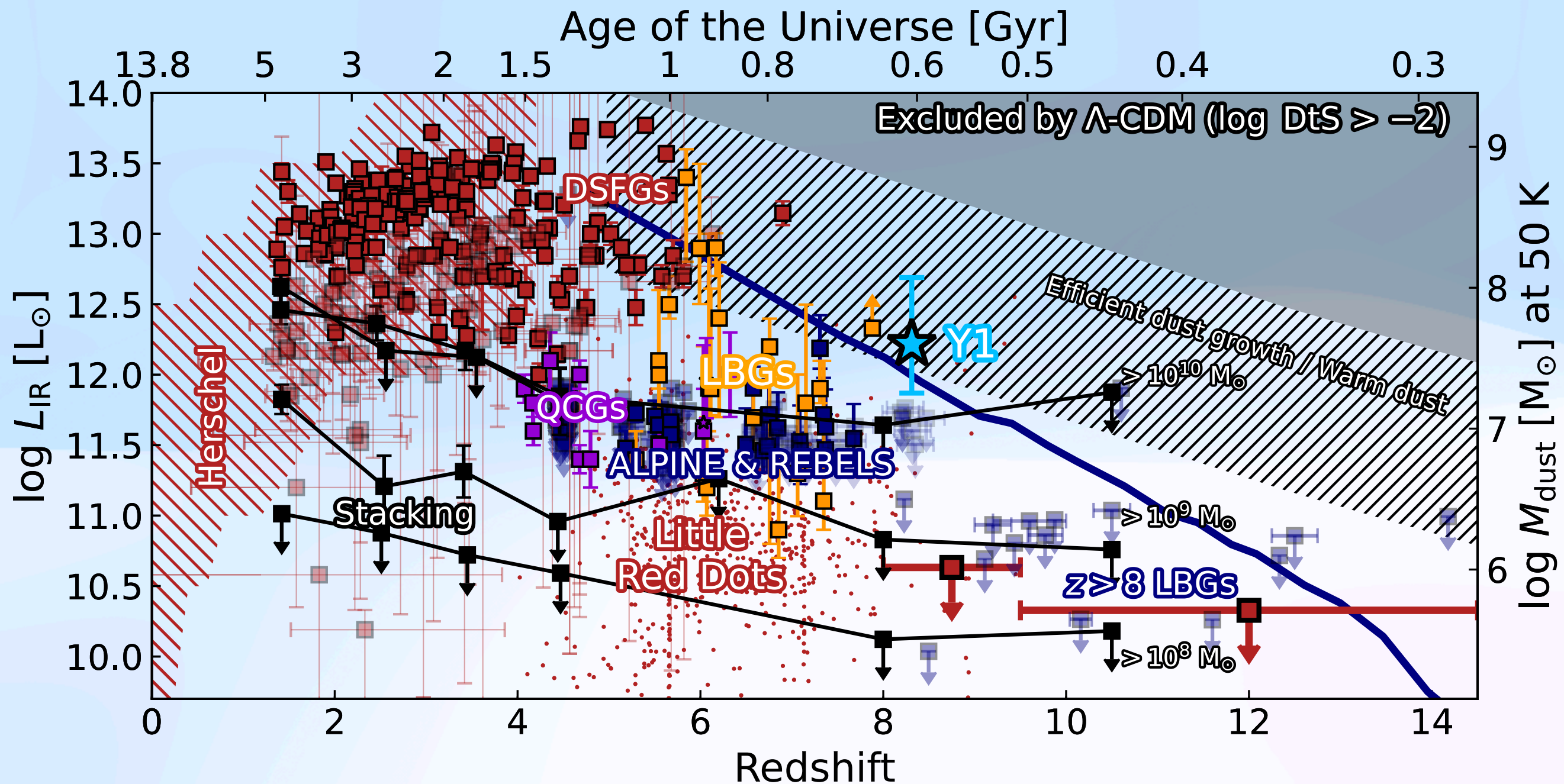


Two hundred hours of interferometer time finds no dust



Pushing strong limits in dust production





Large-area deep single-dish surveys offer unique stacking potential

Fundamental challenges of interferometric observations

Limited Field of View - especially Maximum Resolvable Scale

Low mapping speeds that favour pencil-beam surveys

To-date modest spectral windows (see NOEMA, WSU, ALMA2040)

Limited atmospheric windows - until the Space Array
(see E. Villard's talk)

Polarization observations require long observations

Unique parameter spaces lay open for future infrared/submm space telescopes:

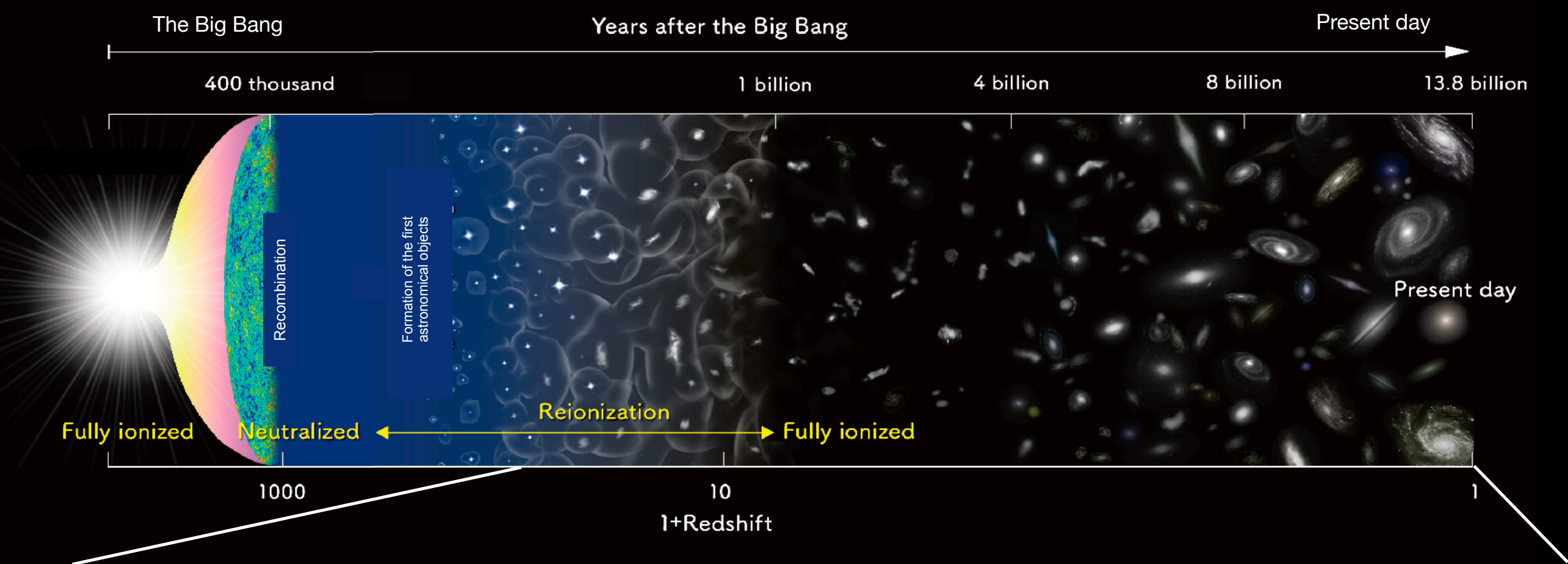
1. Identification of new populations:
 - Mapping can identify new populations of warm dust
 - Spectroscopic capabilities find redshifts fast
2. Characterization of unexplored wavelengths (40 - 250 μ m)
 - FIR fine-structure lines for galaxies at cosmic noon
 - Cool mirrors enable more 'normal' galaxies

Probing the evolution of star forming and starburst galaxies at cosmological distances

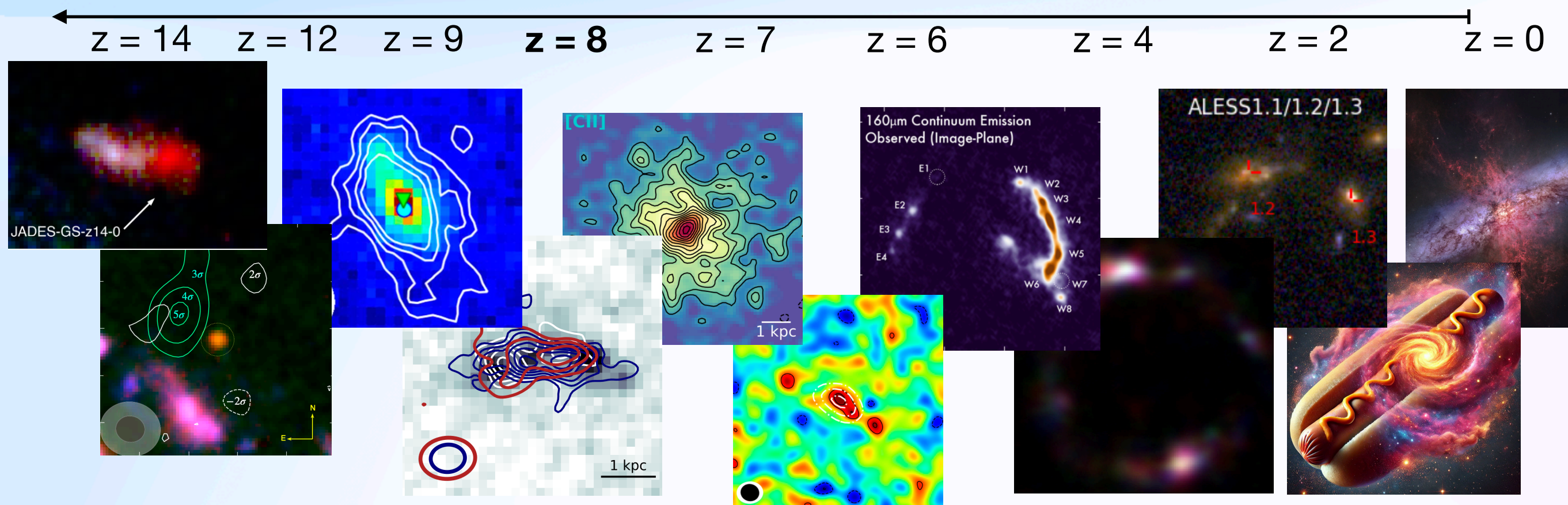
A blobologist's take on galaxy evolution

Tom Bakx – Chalmers UoT – FIR Leiden 2025





Dusty outflows? AGN systems? Hot dust? Regular disks? Lenses? Multiples?



Carniani et al. 24a, 24b, Bakx et al. 20, 21, 23, 24, in prep., Rowlands et al. 24, Spilker et al. 23, Hodge et al. 24