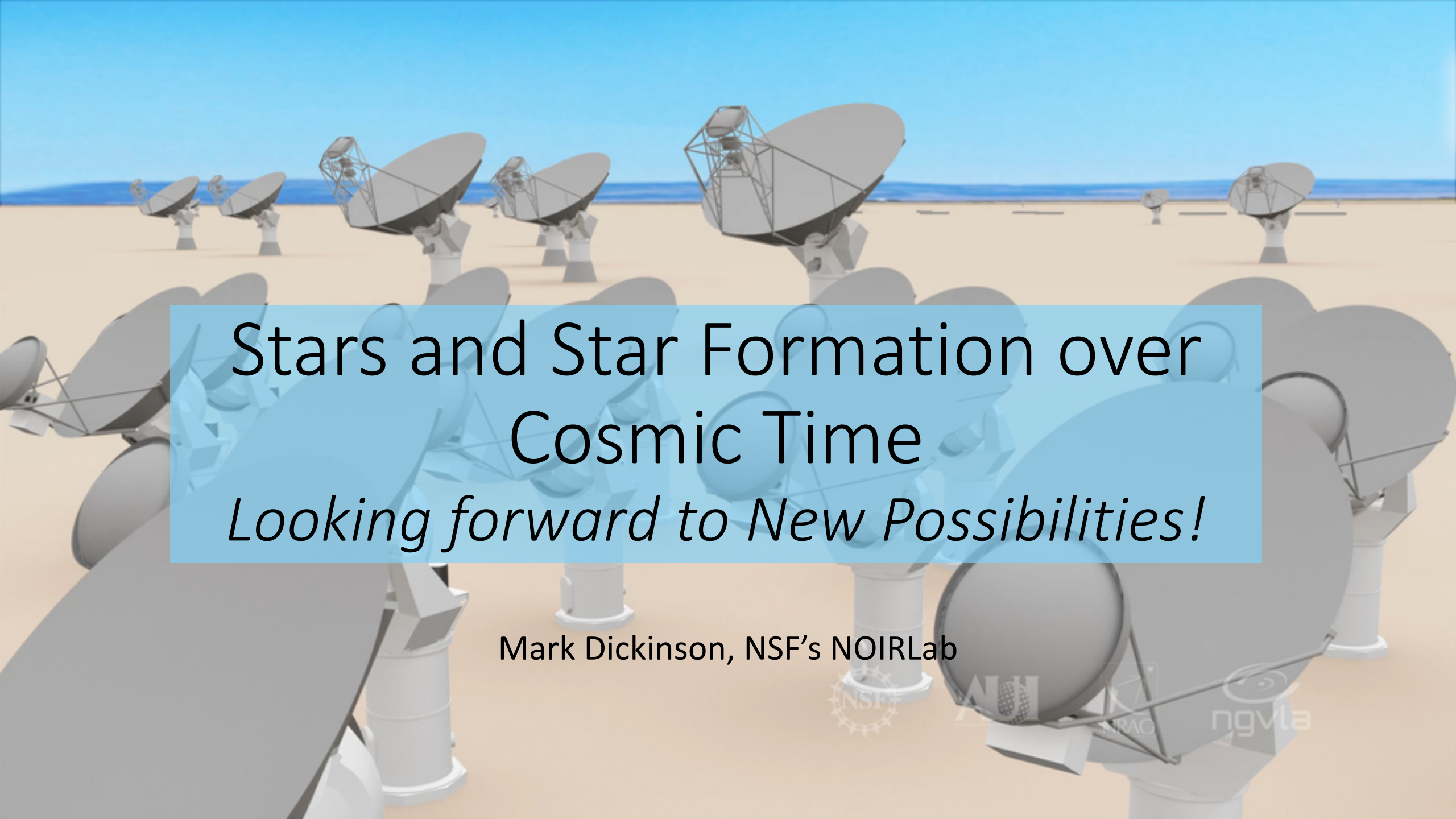


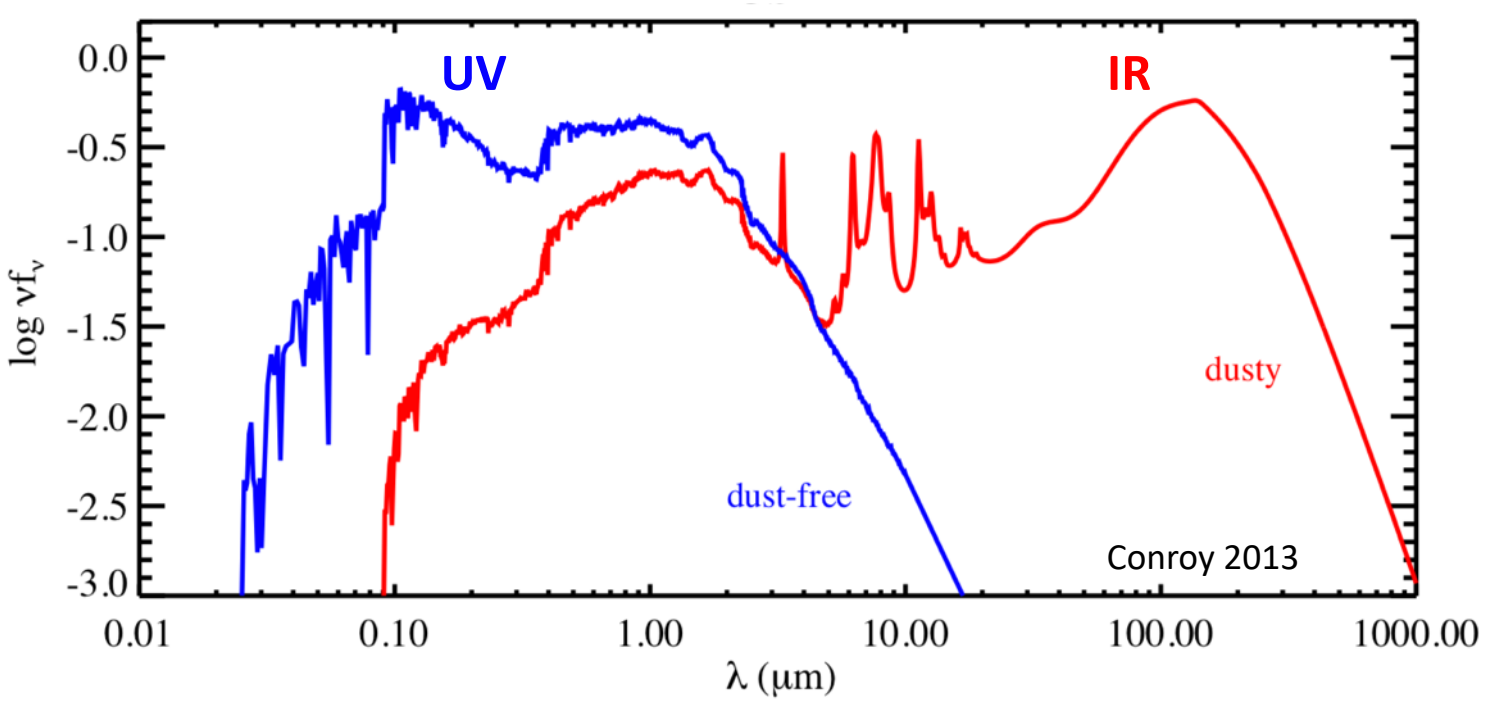
Stars and Star Formation over Cosmic Time

Looking forward to New Possibilities!

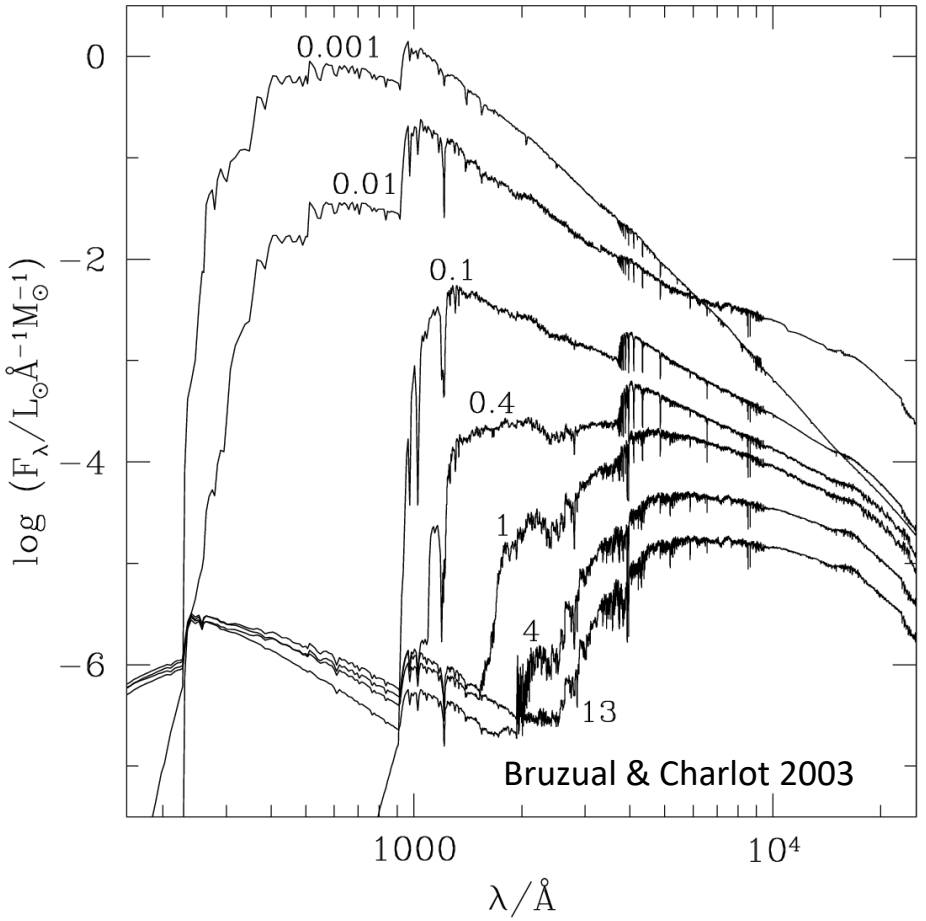
Mark Dickinson, NSF's NOIRLab

Measuring stars and star formation

Star Formation

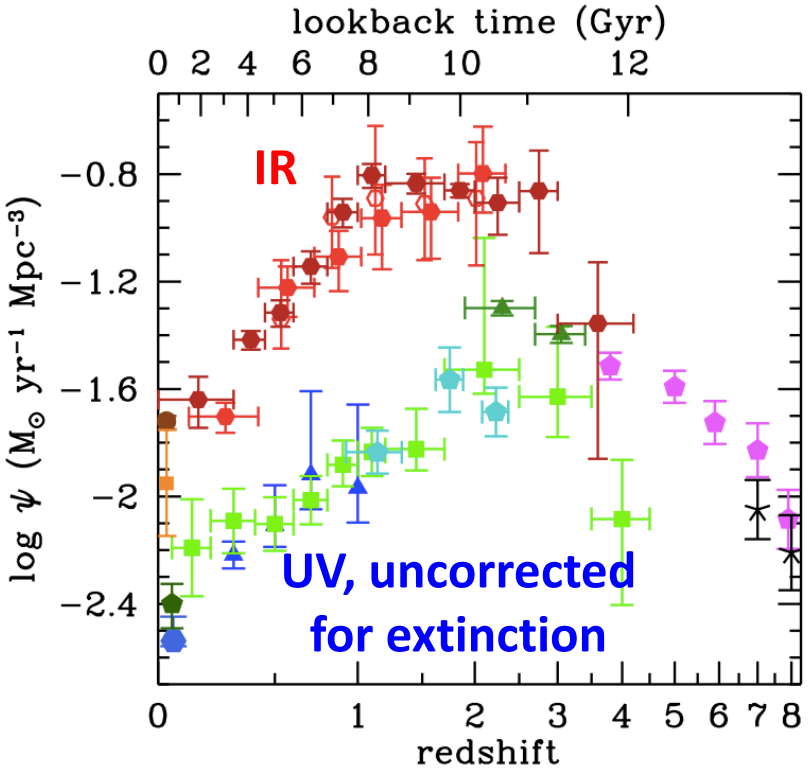


Stellar Populations & Masses

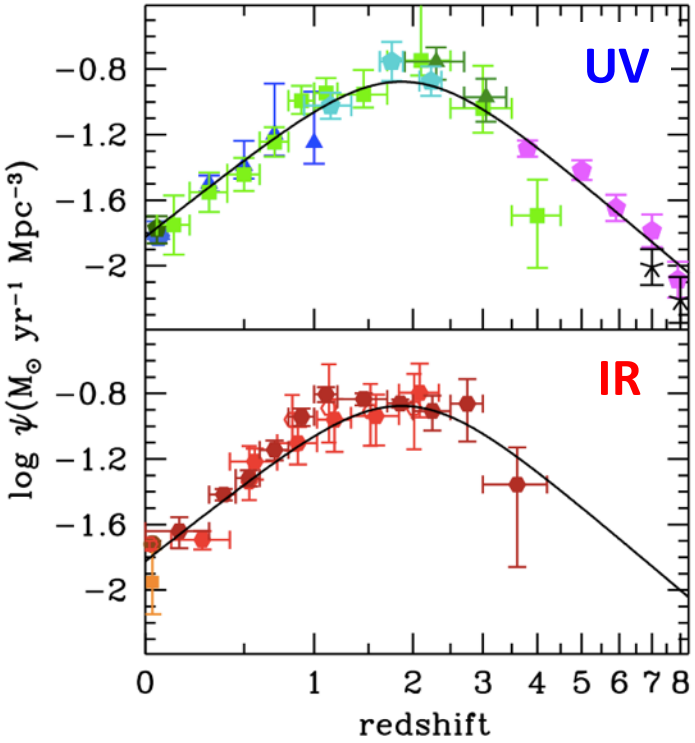


Evolution of global quantities

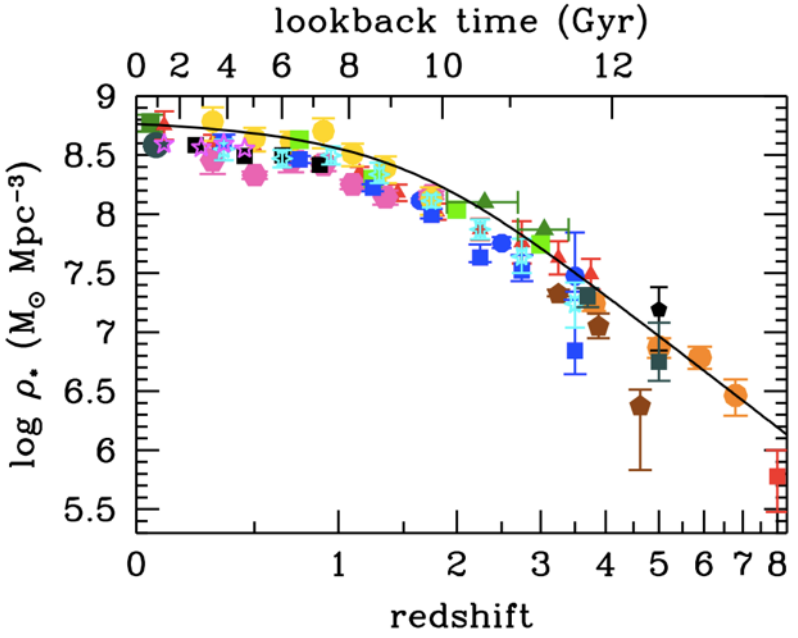
Star Formation Rate Density



Star Formation Rate Density



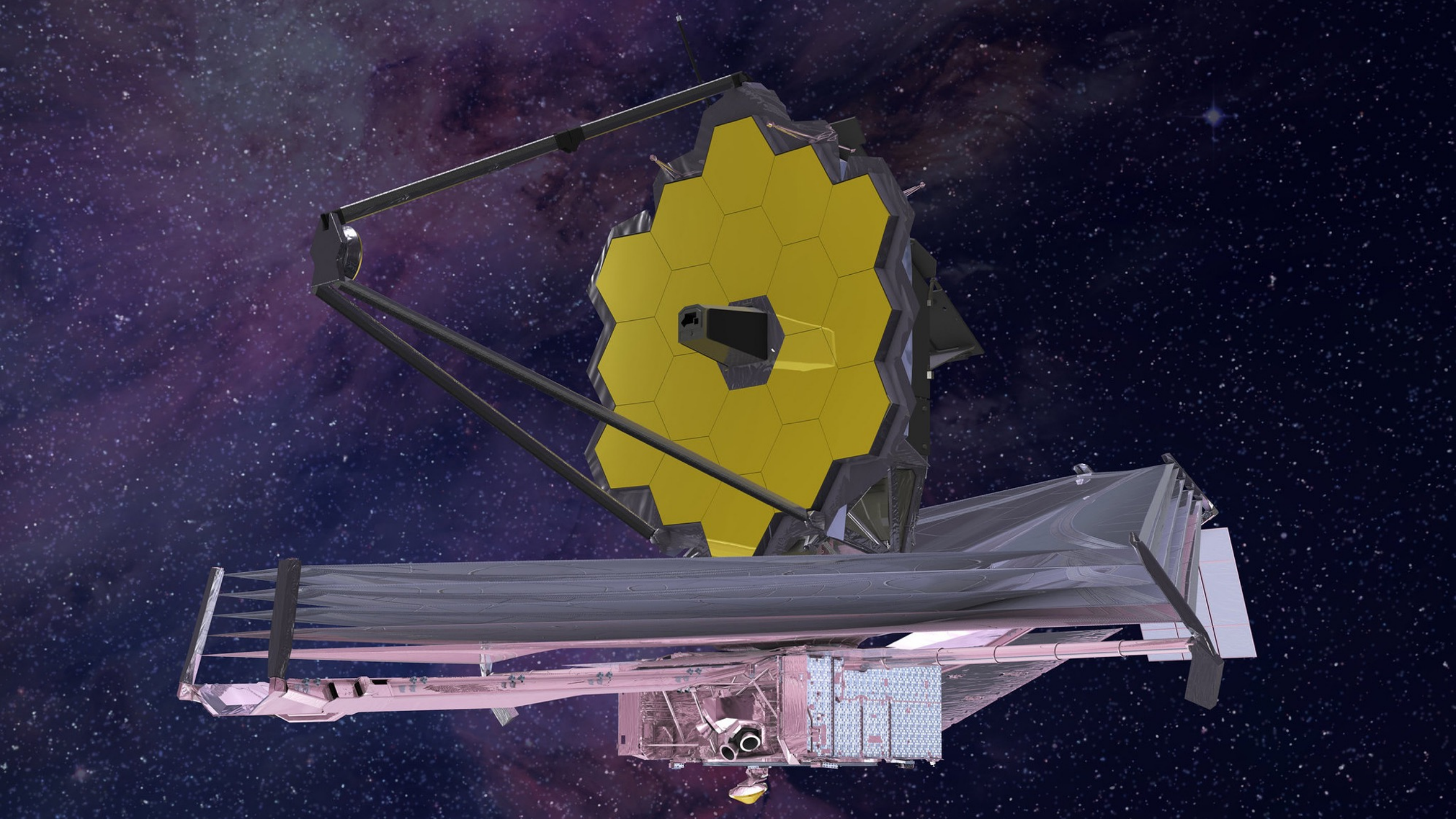
Stellar Mass Density



Madau + Dickinson 2014

Some open questions

- How did galaxies form and grow during the first cosmic Gyr?
- How did galaxies reionize the intergalactic medium?
- What processes regulated and quenched star formation, and when?
- How did galaxies and supermassive black holes grow together?
- How does the cosmic ‘baryon cycle’ connect galaxies to their circum-galactic and inter-galactic environments?
- How does environment affect star formation and quenching over cosmic time?
- How does the internal structure of galaxies grow, mature and evolve?
- … ?



JSWT: Discovery, Confirmation, Characterization

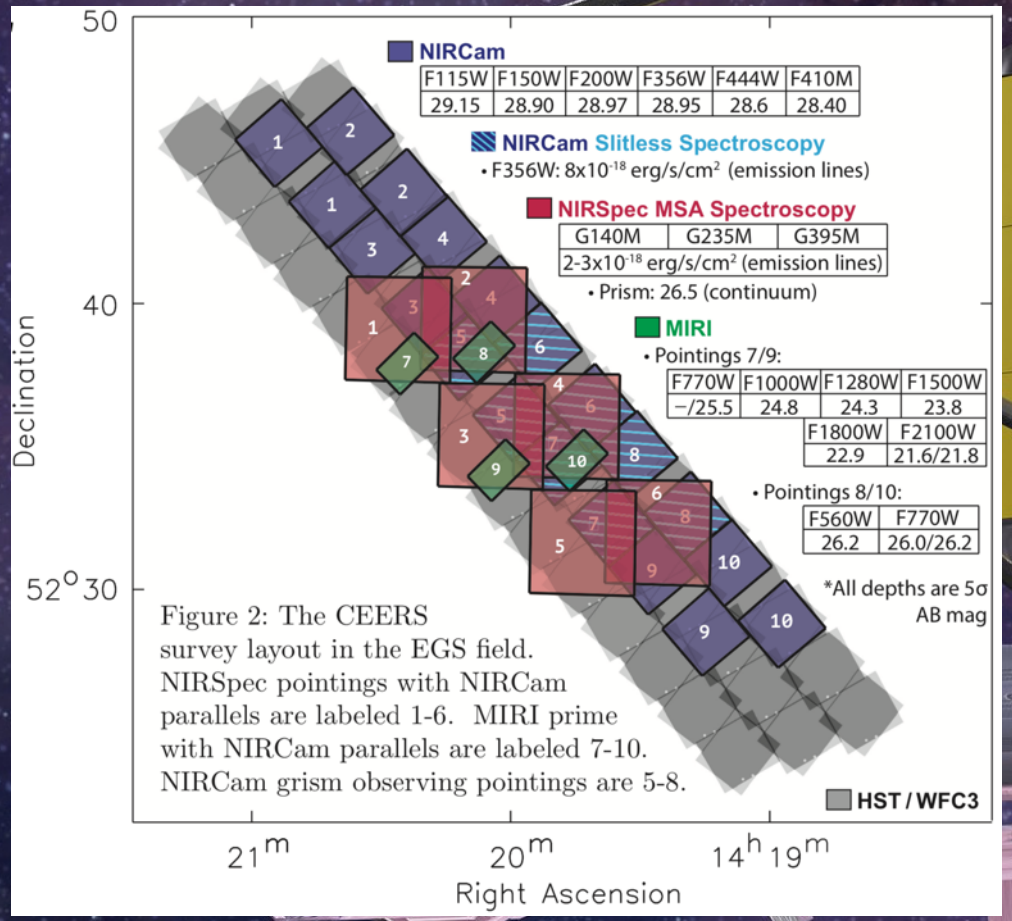
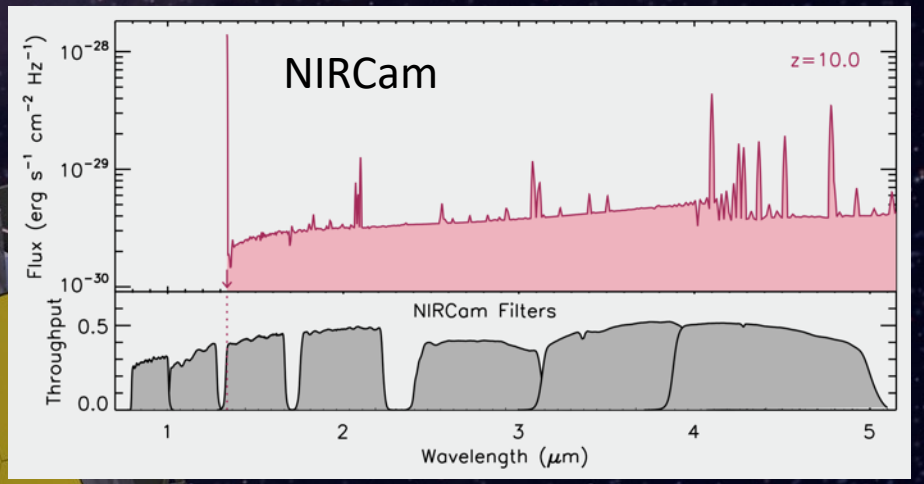
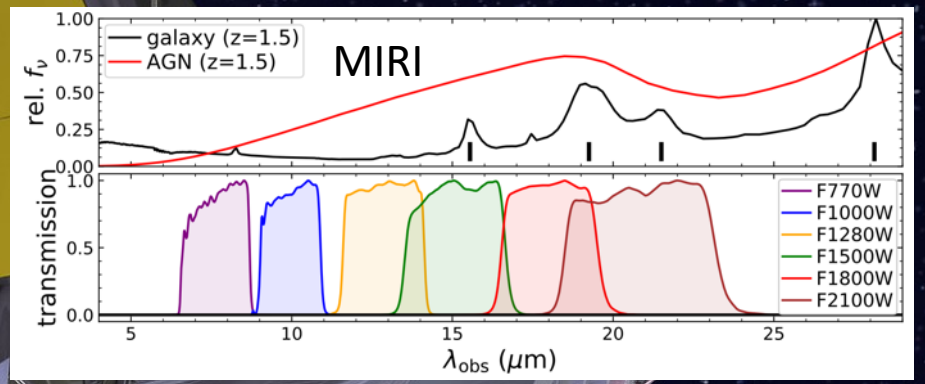
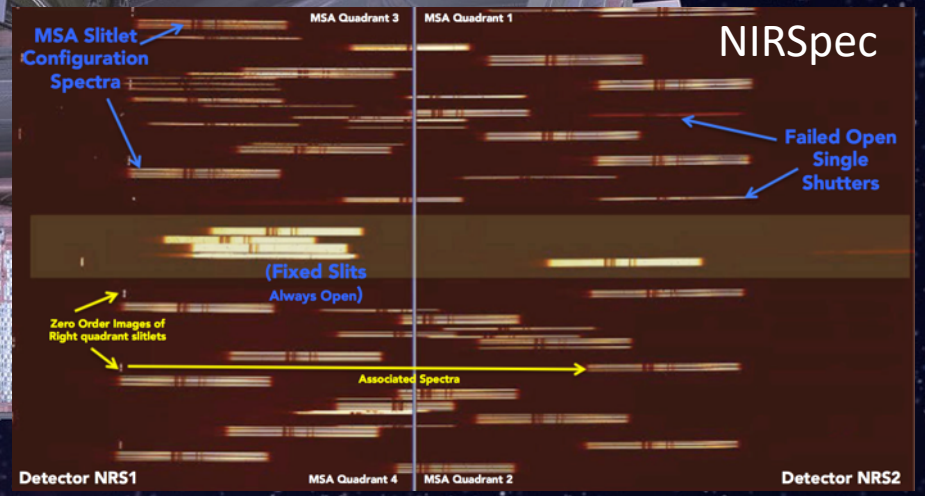


Figure 2: The CEERS survey layout in the EGS field. NIRSpec pointings with NIRCam parallels are labeled 1-6. MIRI prime with NIRCam parallels are labeled 7-10. NIRCam grism observing pointings are 5-8.



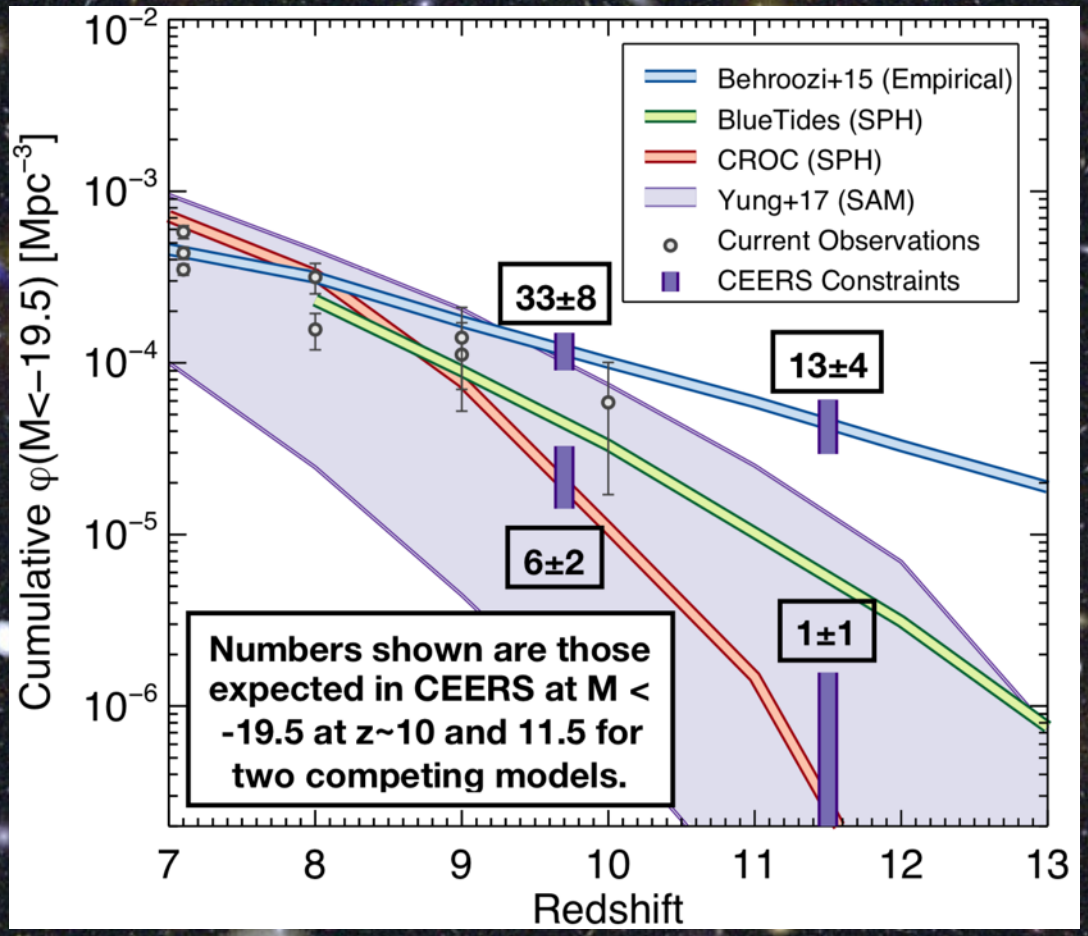


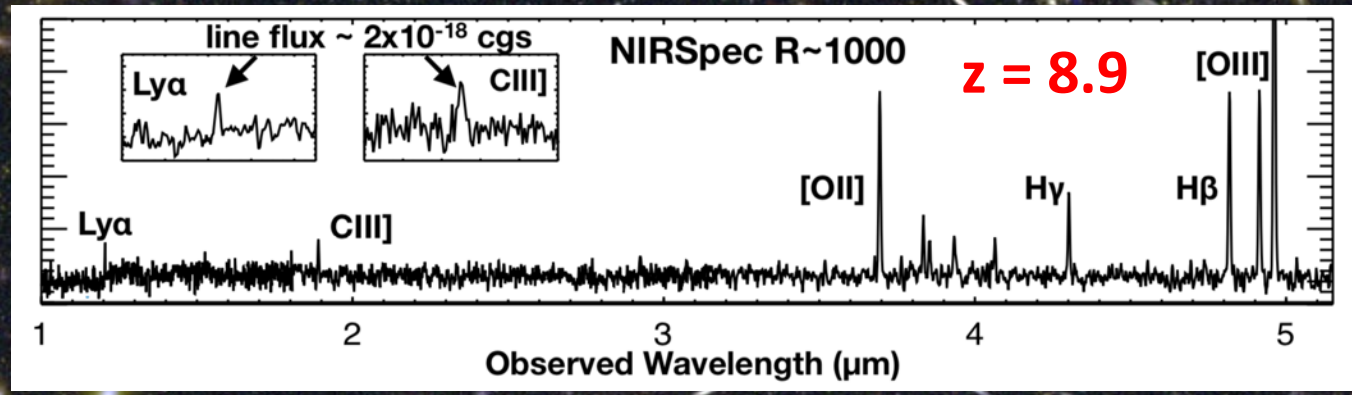


CEERS: Cosmic Evolution Early Release Survey

PI: Steven Finkelstein (UT Austin)

Surveying the epoch of reionization with JWST



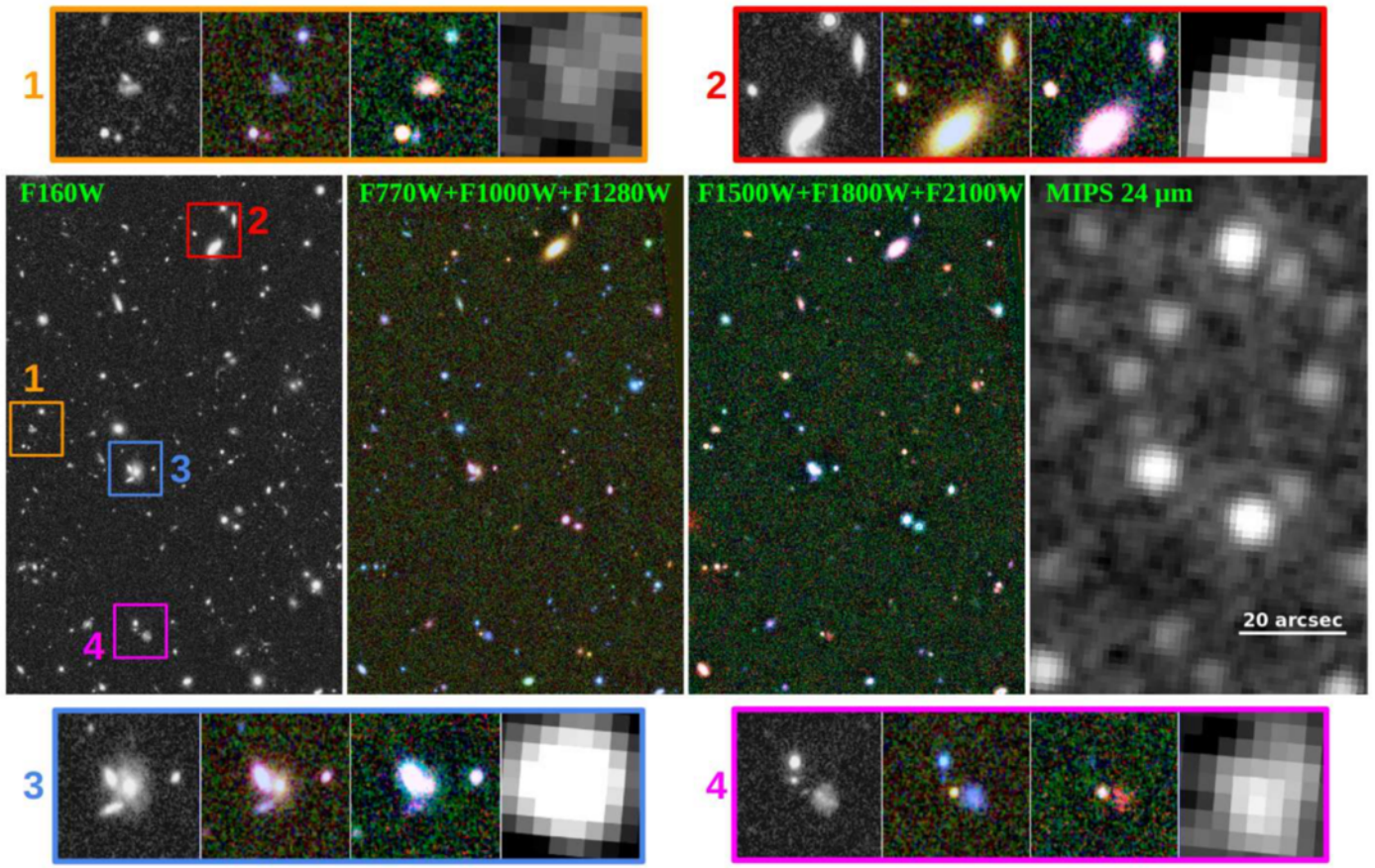


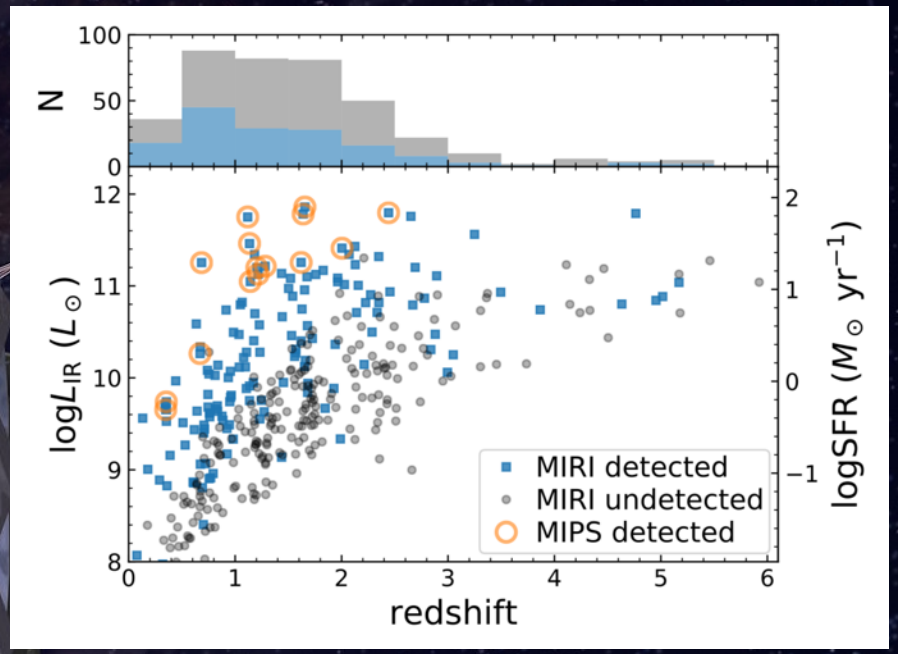
JWST will

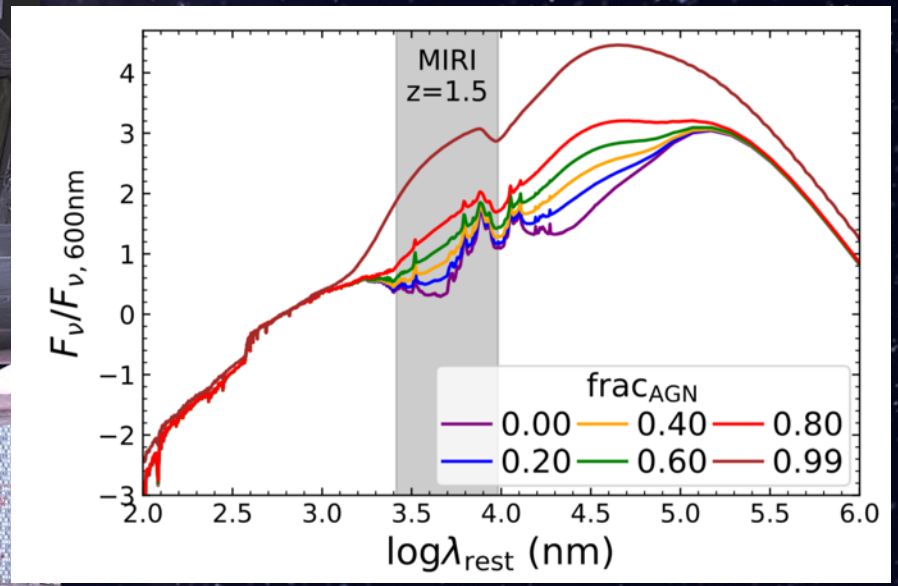
- discover galaxies at z > 8 in large numbers,
- measure their spectroscopic redshifts,
- analyze their stellar populations, star formation rates, and ISM conditions, and
- quantify their abundance and its evolution

Resolving dusty high-z galaxies with JWST/MIRI

G. Yang et al. 2021

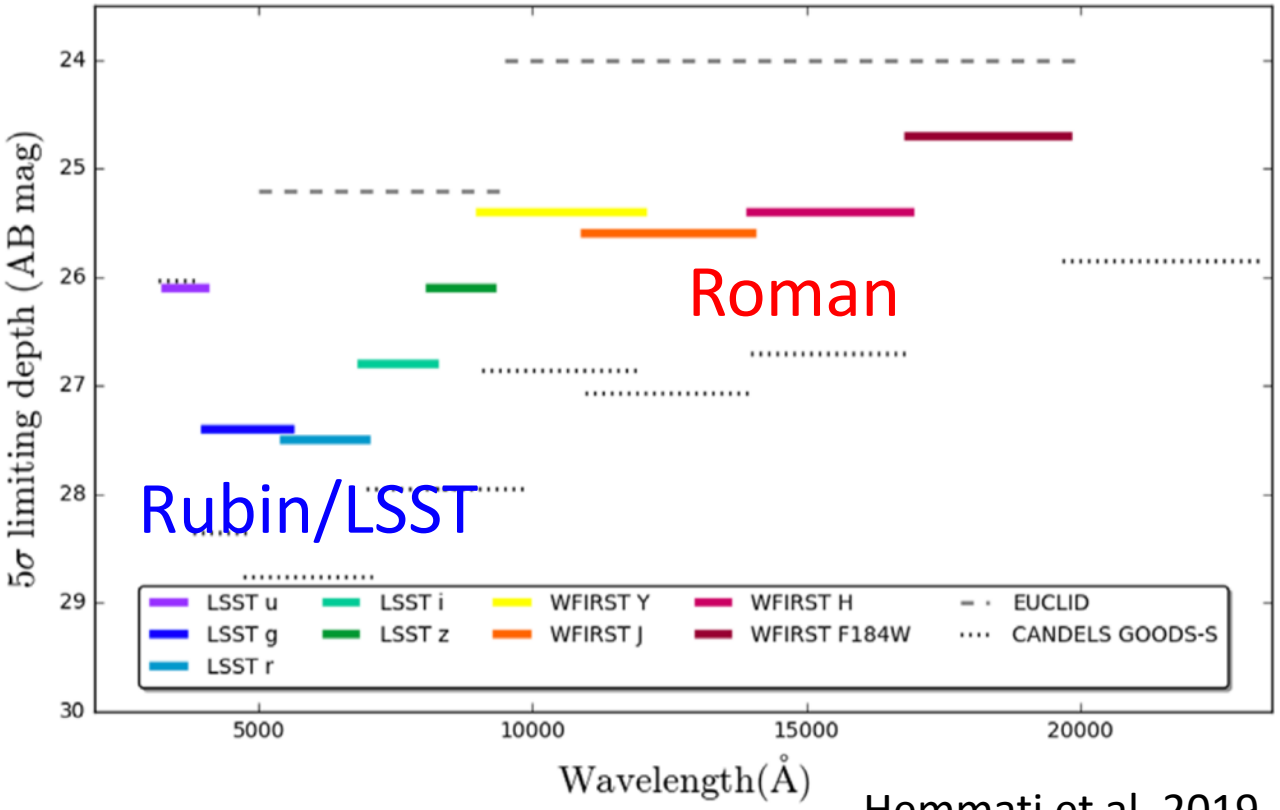




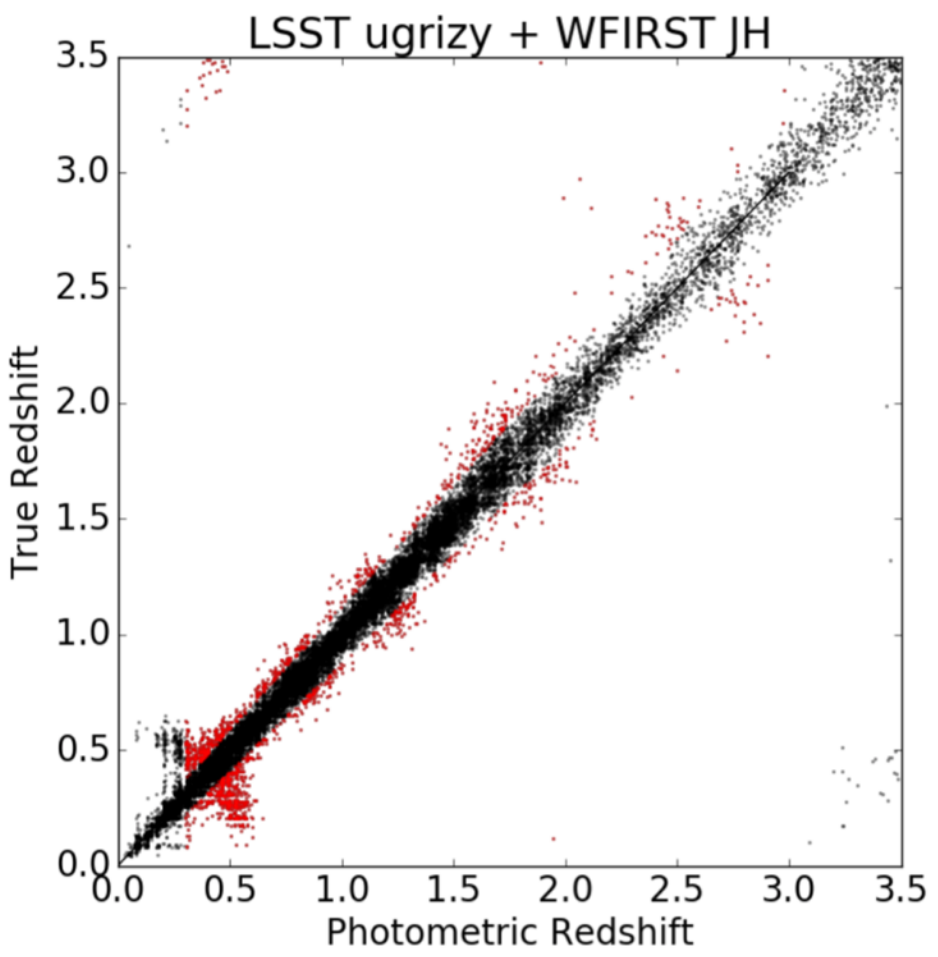


Rubin, Euclid, Roman

Rubin/LSST main survey: 18,000 deg^2, 0.34 – 1.0 μm
Euclid main survey: 15,000 deg^2, 0.5 – 1.85 μm
Roman High-Latitude Survey: 2,200 deg^2, 0.5 – 2.3 μm



Hemmati et al. 2019



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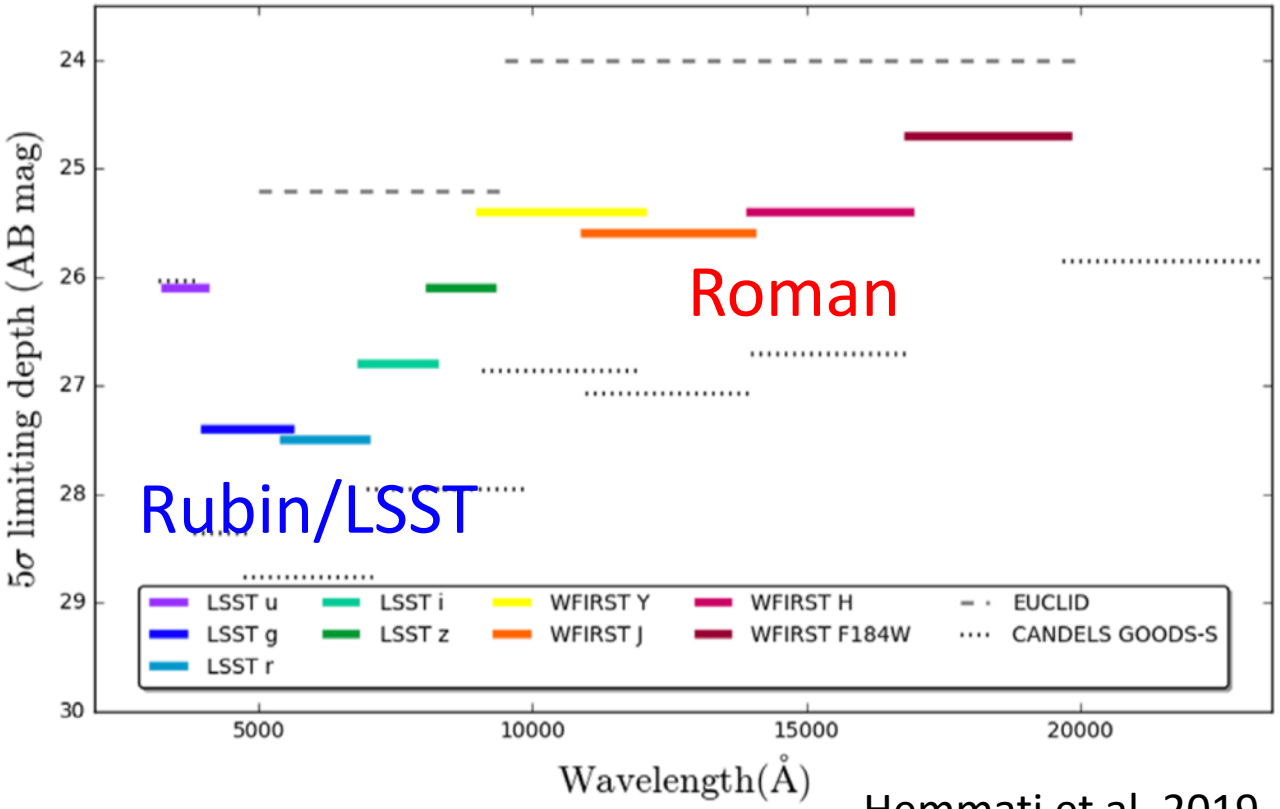
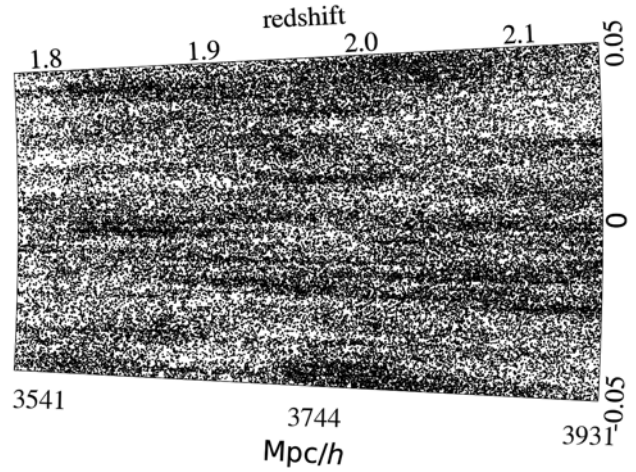
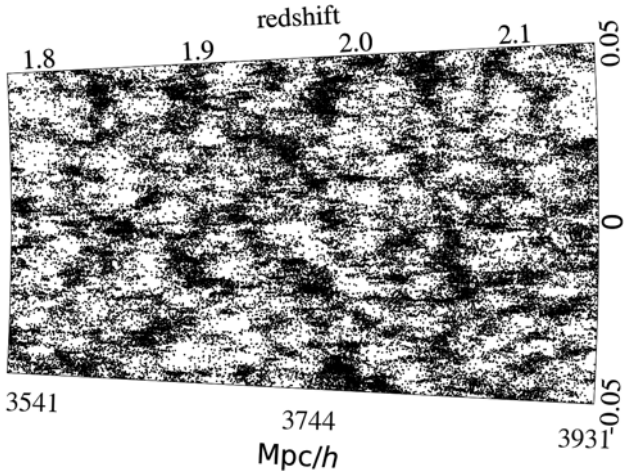


Hemmati et al. 2019

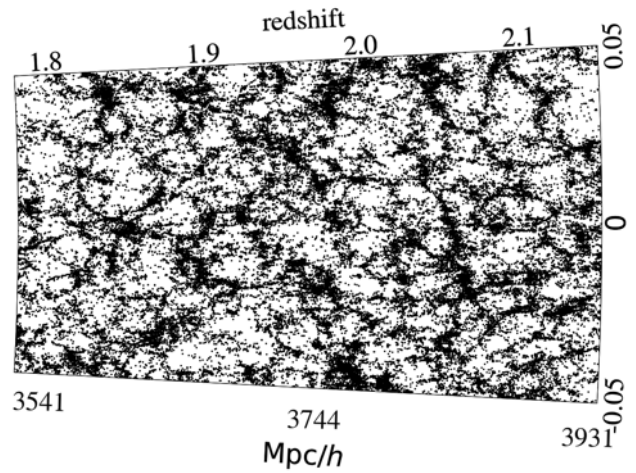
$\sigma(z)/(1+z) = 10^{-2}$
Photo-z (best)



$\sigma(z)/(1+z) = 10^{-3}$
Grism z



$\sigma(z)/(1+z) = 10^{-4}$
Slit spectroscopy



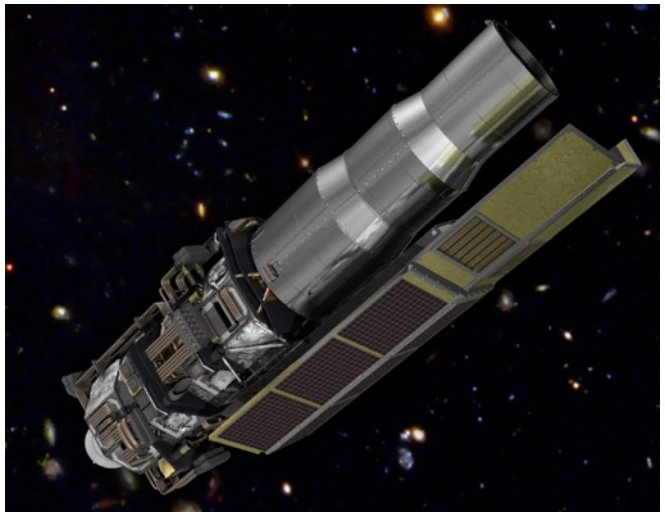
ATLAS Probe

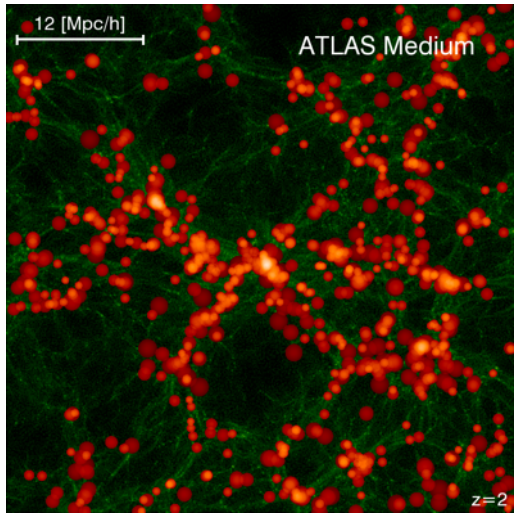
Astrophysics Telescope for Large Area Spectroscopy

http://atlas-probe.ipac.caltech.edu

- 1.5m aperture telescope with 0.4 deg^2 FoV
- R = 1000 slit spectroscopy over 1-4µm
- Slit selectors: Digital Micro-mirror Devices
- Takes 6,000 spectra simultaneously
- Launch Ready Date: < 2030
- Cost fits within the NASA probe-class envelope

¶ Map the cosmic web to shed light on the physics of galaxy evolution.
¶ Trace large scale structure densely to illuminate the nature of dark energy.
¶ Probe the Milky Way's dust-shrouded regions, reaching the far side of the Galaxy.
¶ Explore asteroids and other objects in the outer Solar System.

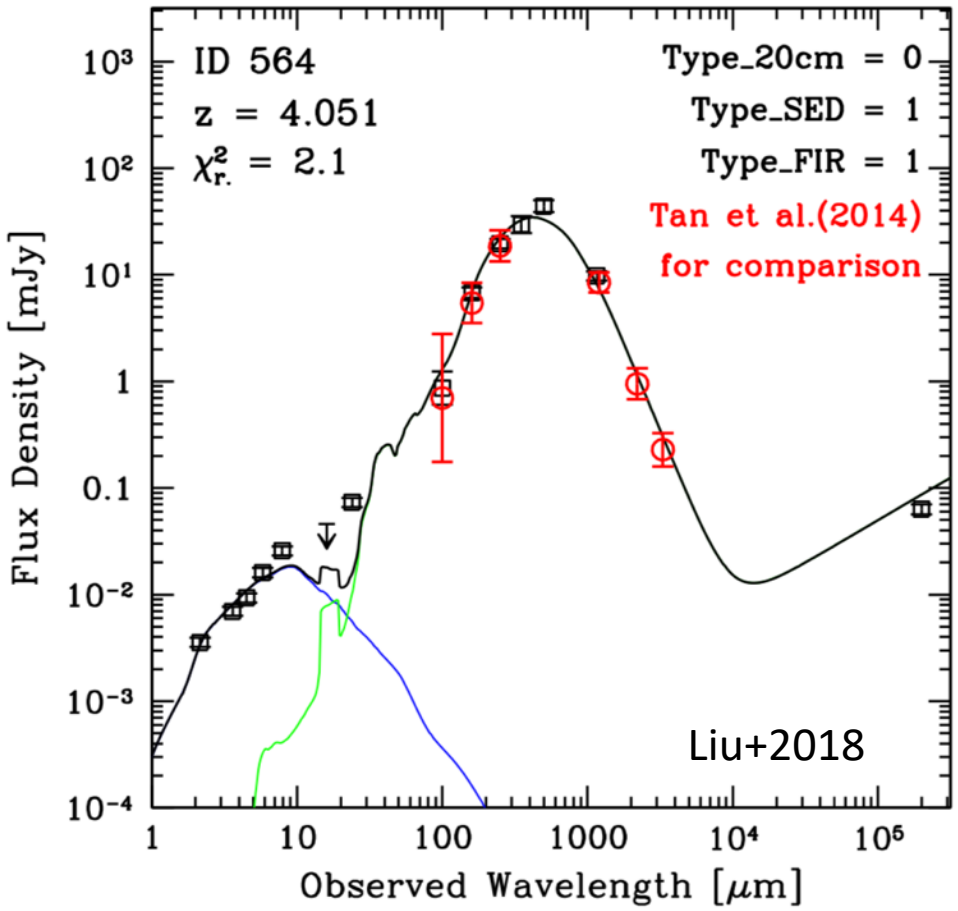


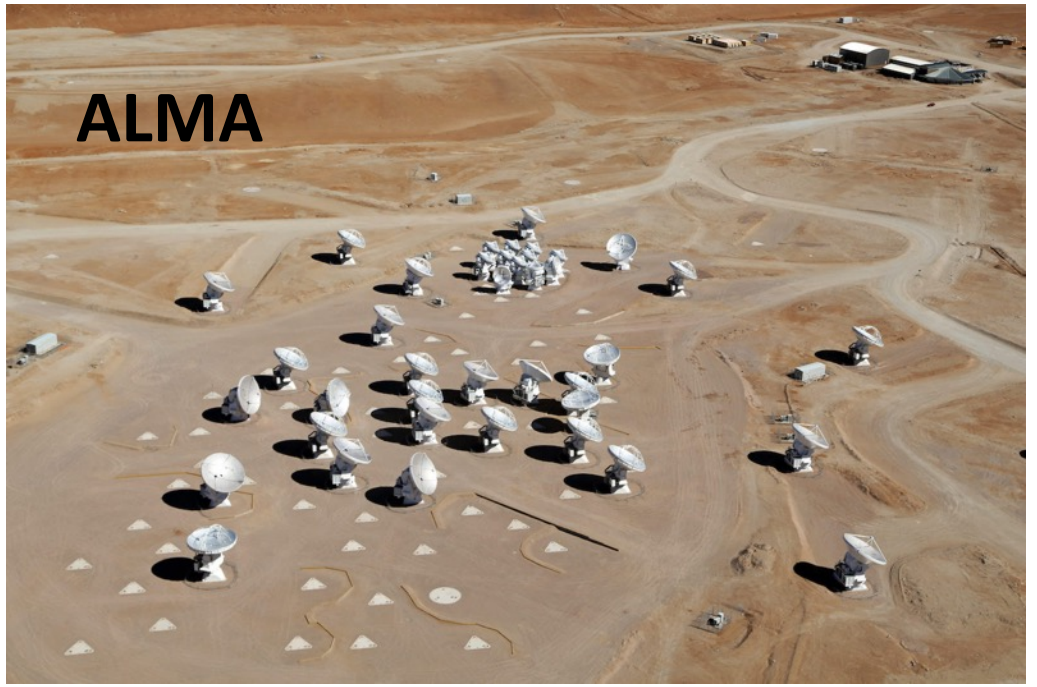


ATLAS Survey	Area (deg^2)	Line Flux Depth (erg/s/cm^2)	Continuum Depth (AB mag)	N_{gal}
Wide	2000	5e-18 (5σ)	23 (3σ)	183M
Medium	100	1.2e-18 (5σ)	24.5 (3σ)	17M
Deep	1	4.6e-19 (5σ)	25.5 (3σ)	.31M

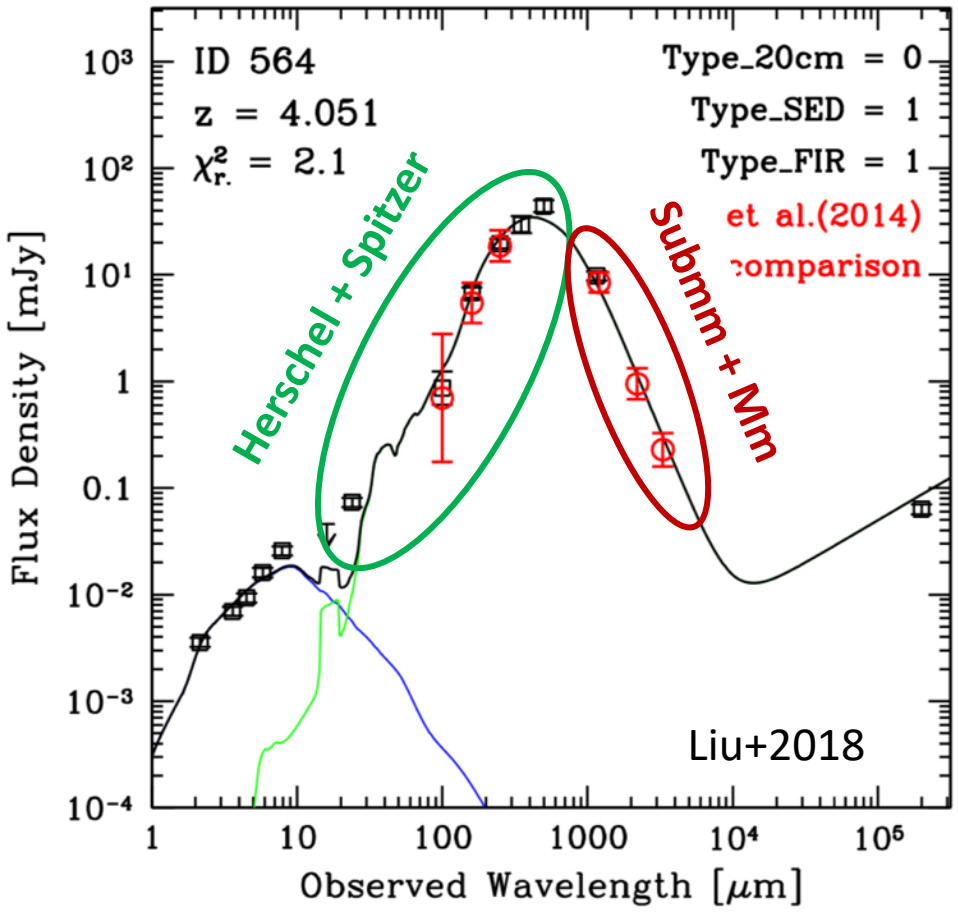
PI: Yun Wang (Caltech/IPAC)
Instrument PI: Massimo Robberto (STSci & JHU)
Science Leads: Mark Dickinson (NOAO),
Lynne Hillenbrand (Caltech)
Primary Partner: JPL

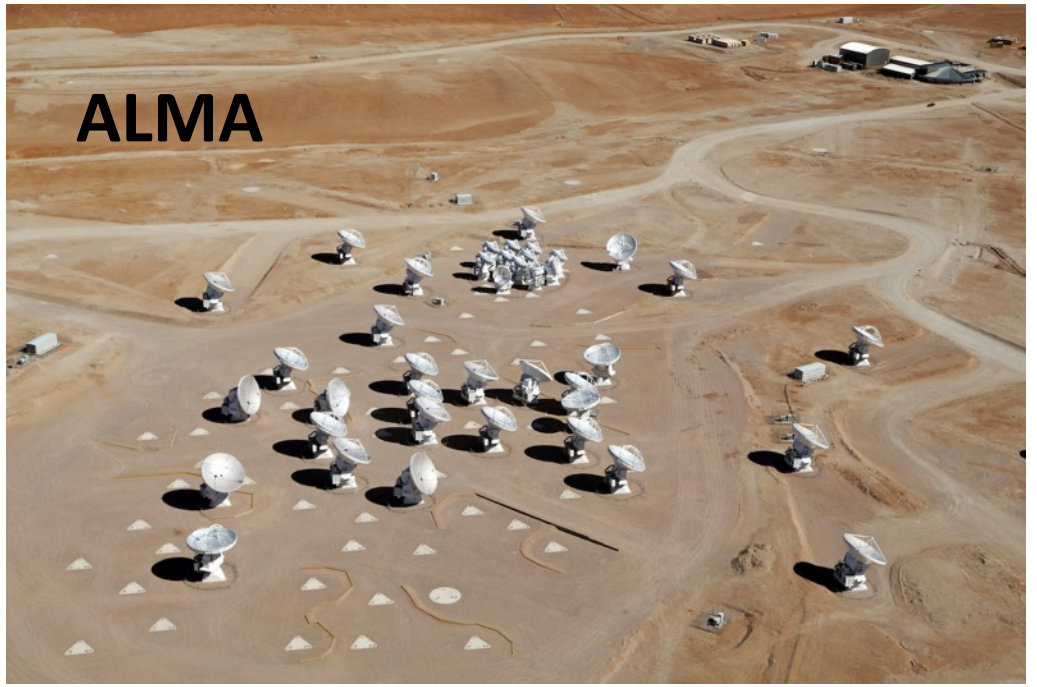
Star formation in the Far-Infrared



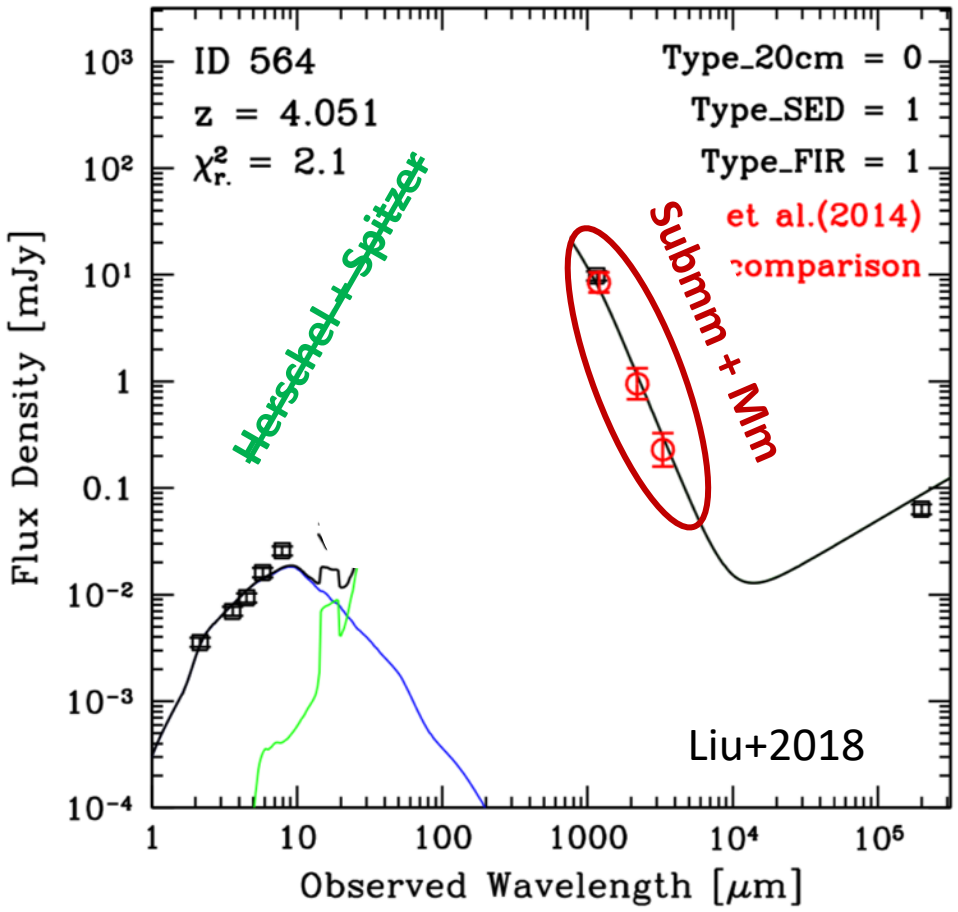


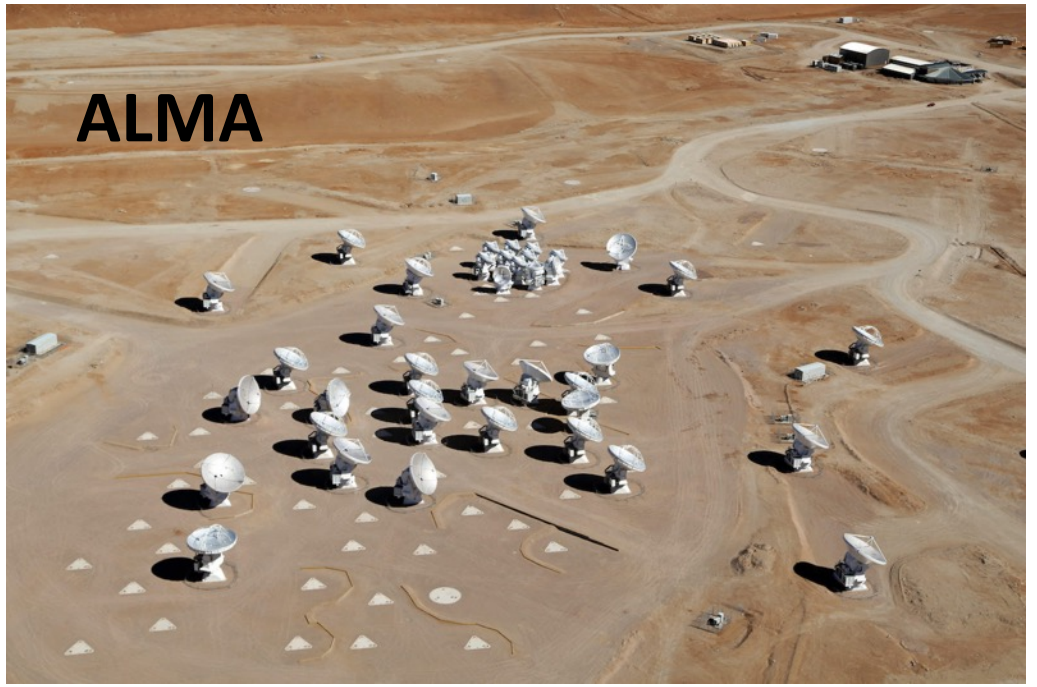
Star formation in the Far-Infrared



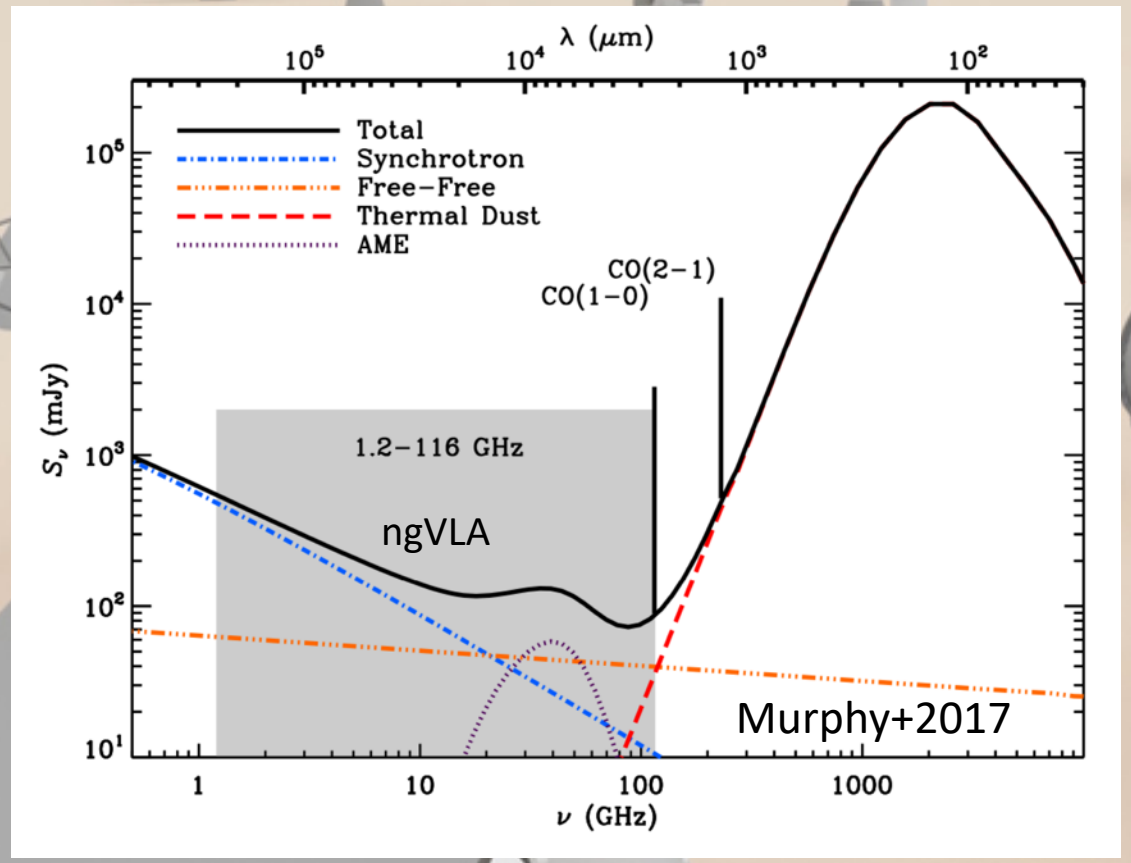


Star formation in the Far-Infrared

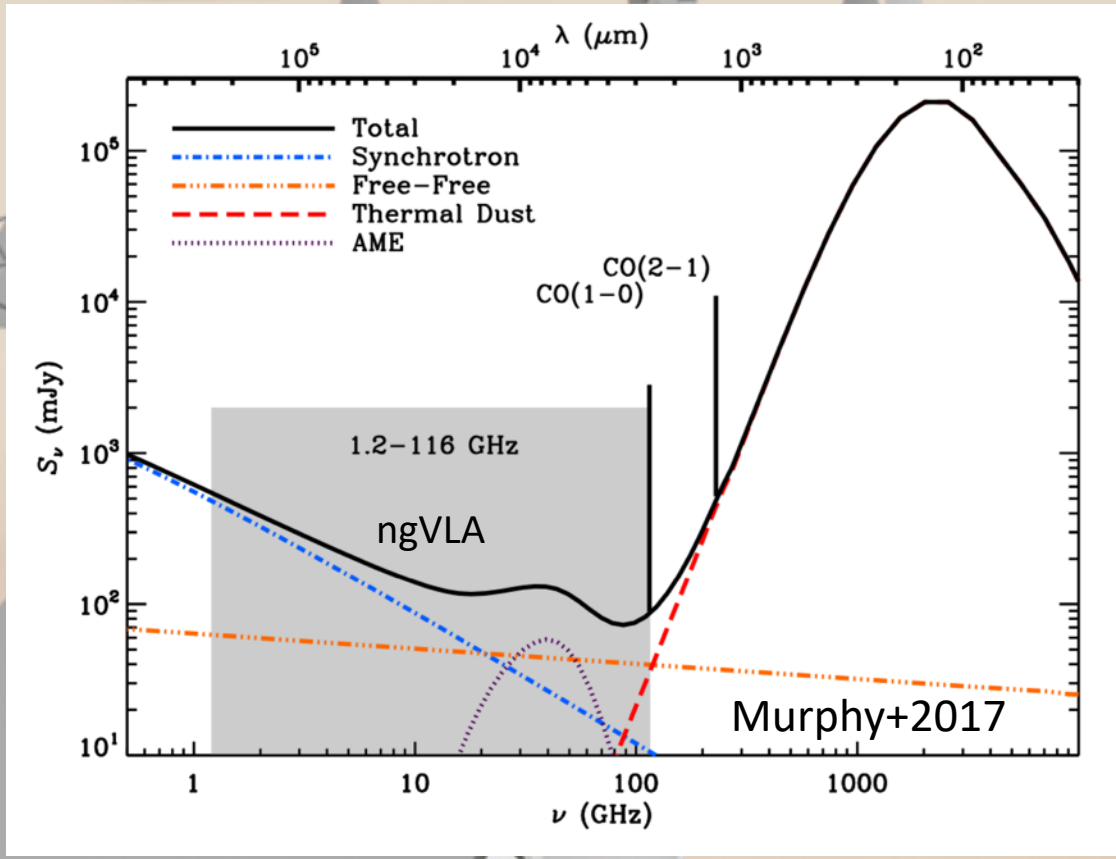


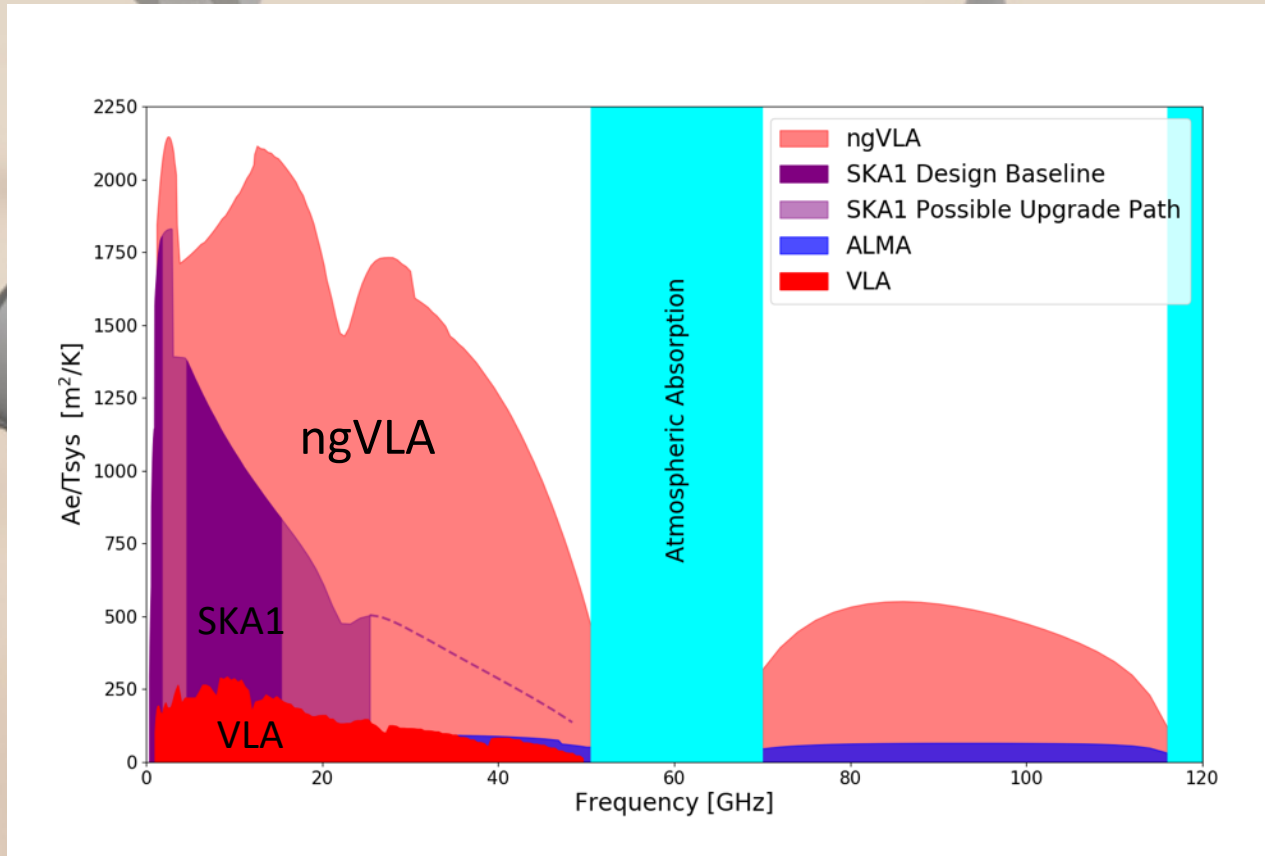


Radio thermal continuum: A new probe of high-redshift star formation

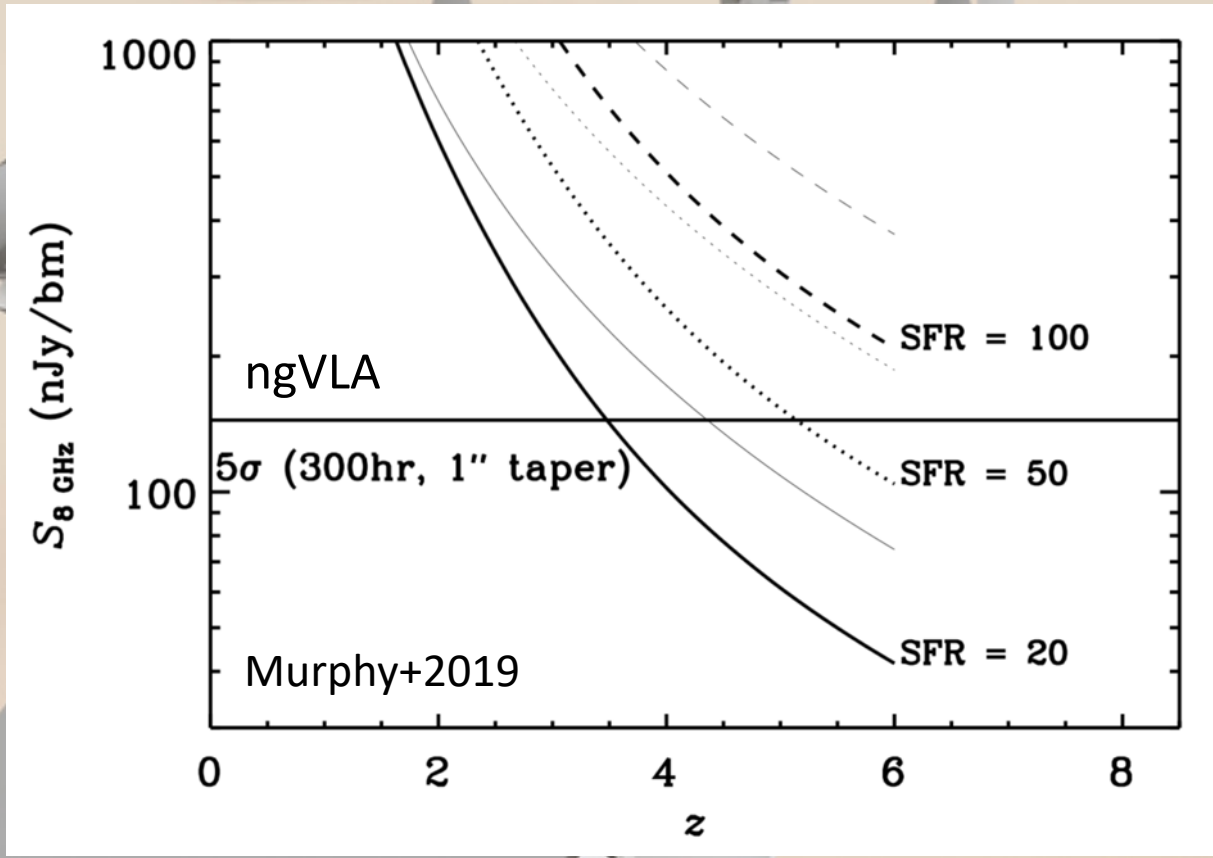


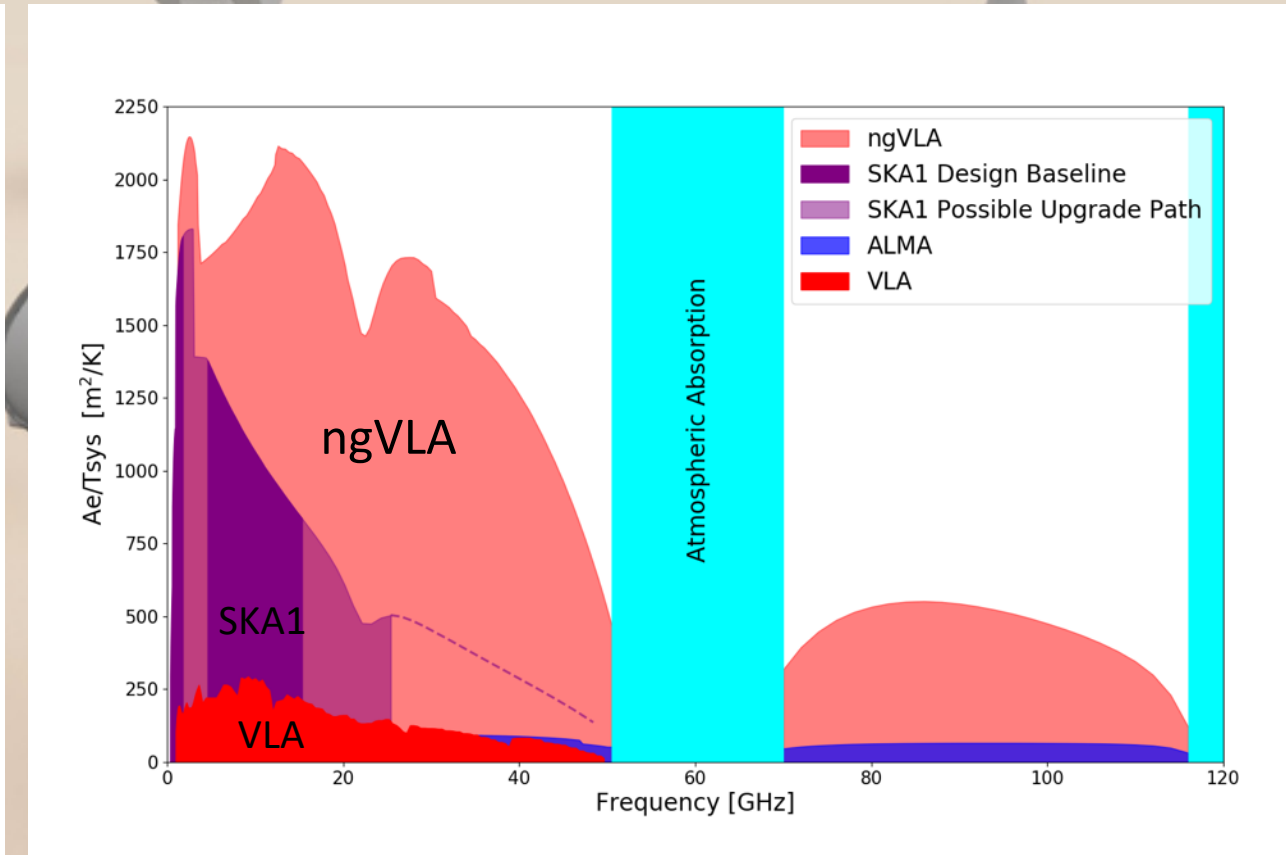
Radio thermal continuum: A new probe of high-redshift star formation





Radio thermal continuum: A new probe of high-redshift star formation

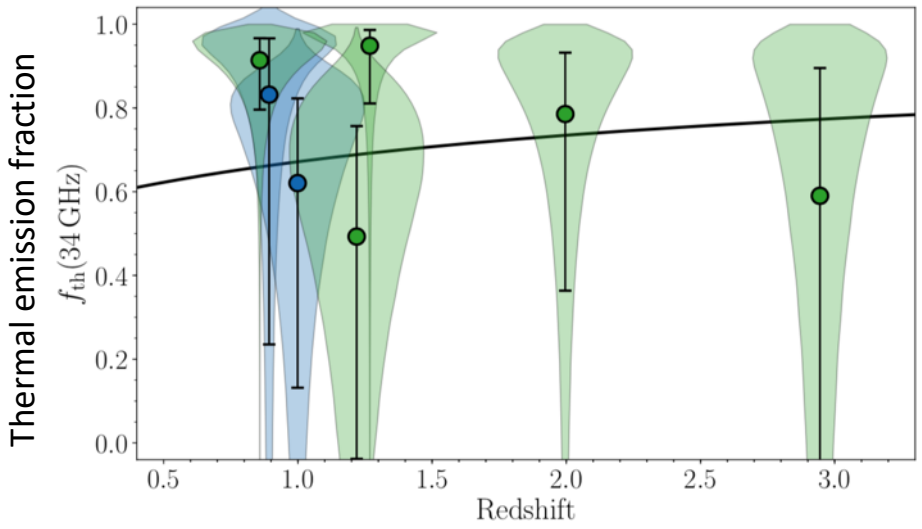


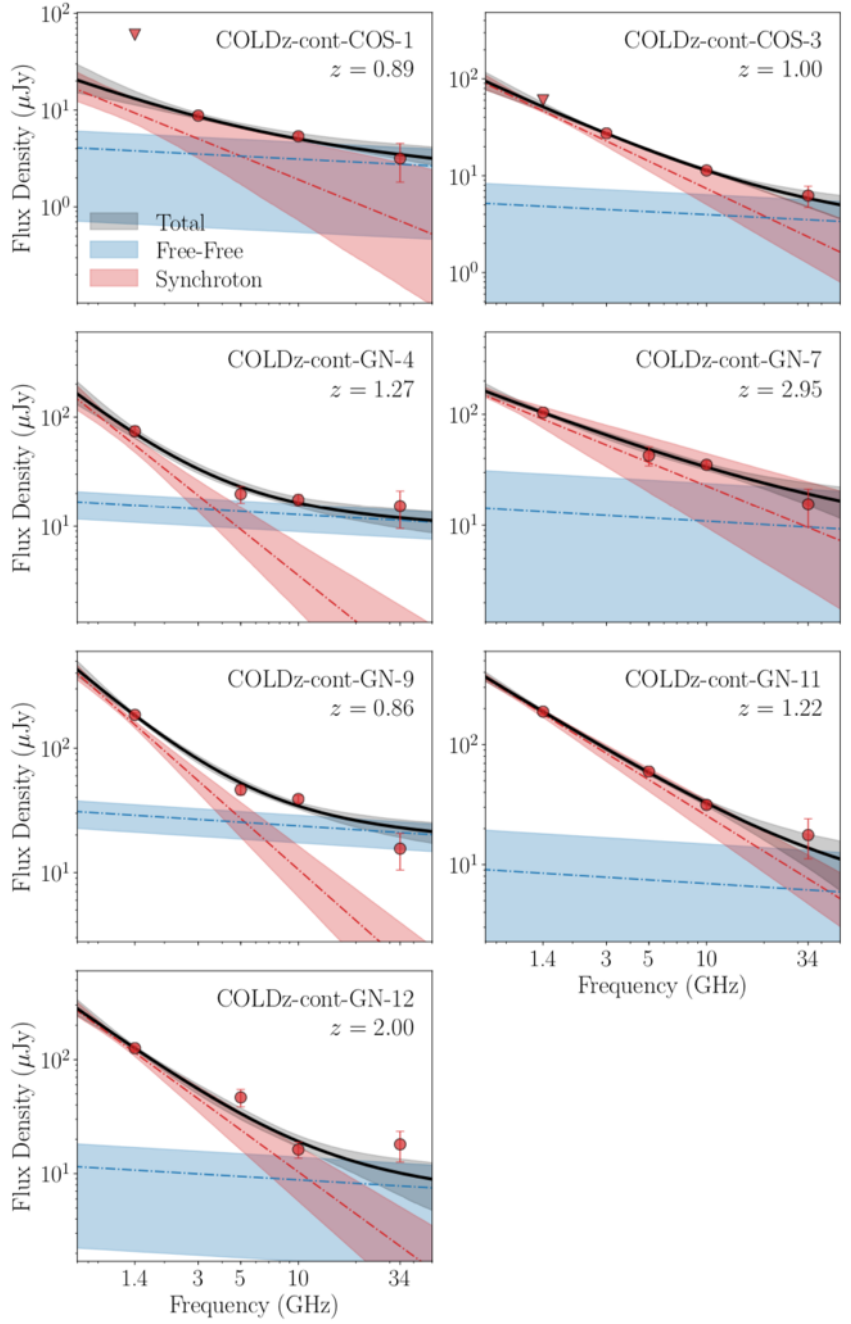


Radio thermal continuum

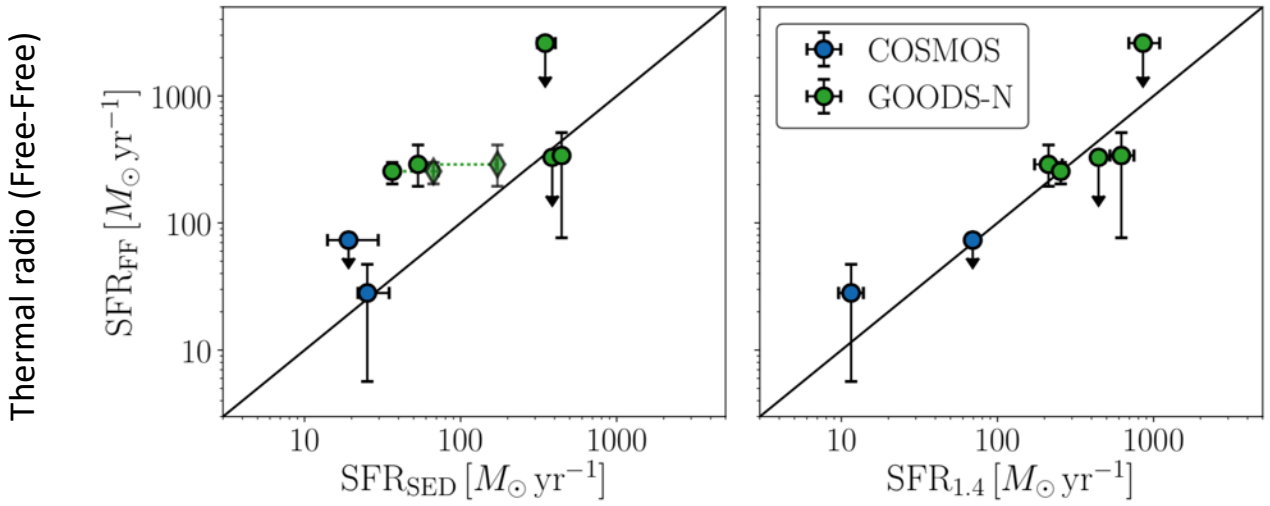
H. Algera+2021, COLDz survey at 34 GHz

GOODS-N: 50 arcmin^2, σ = 5.3 μJy/beam
COSMOS: 10 arcmin^2, σ = 1.3 μJy/beam





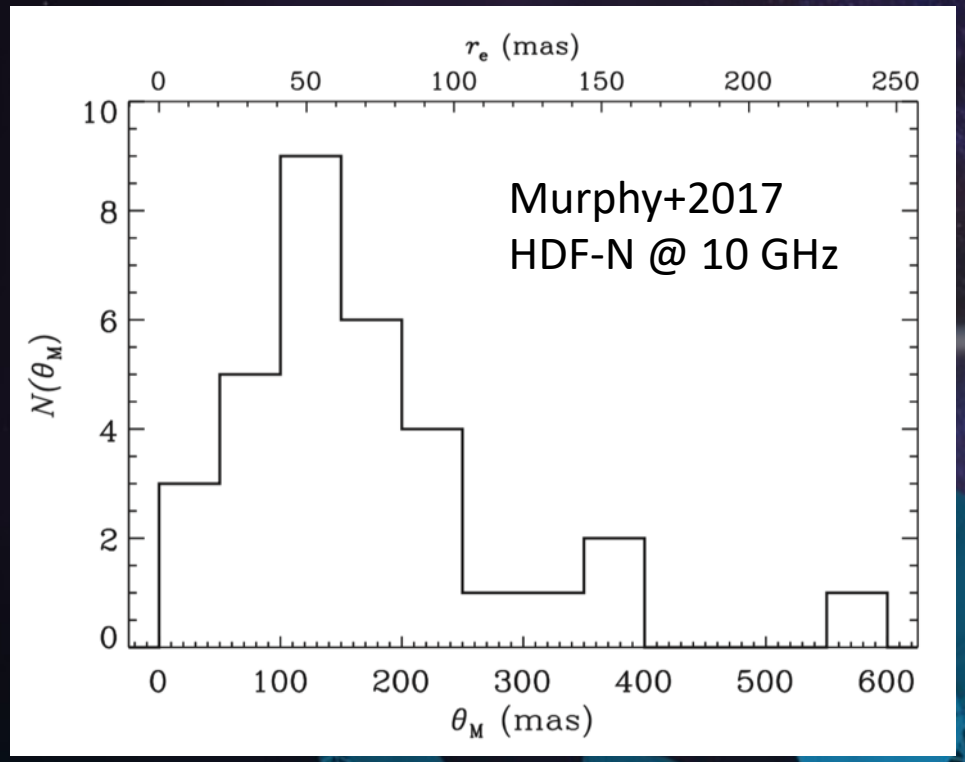
Star Formation Rate Comparison

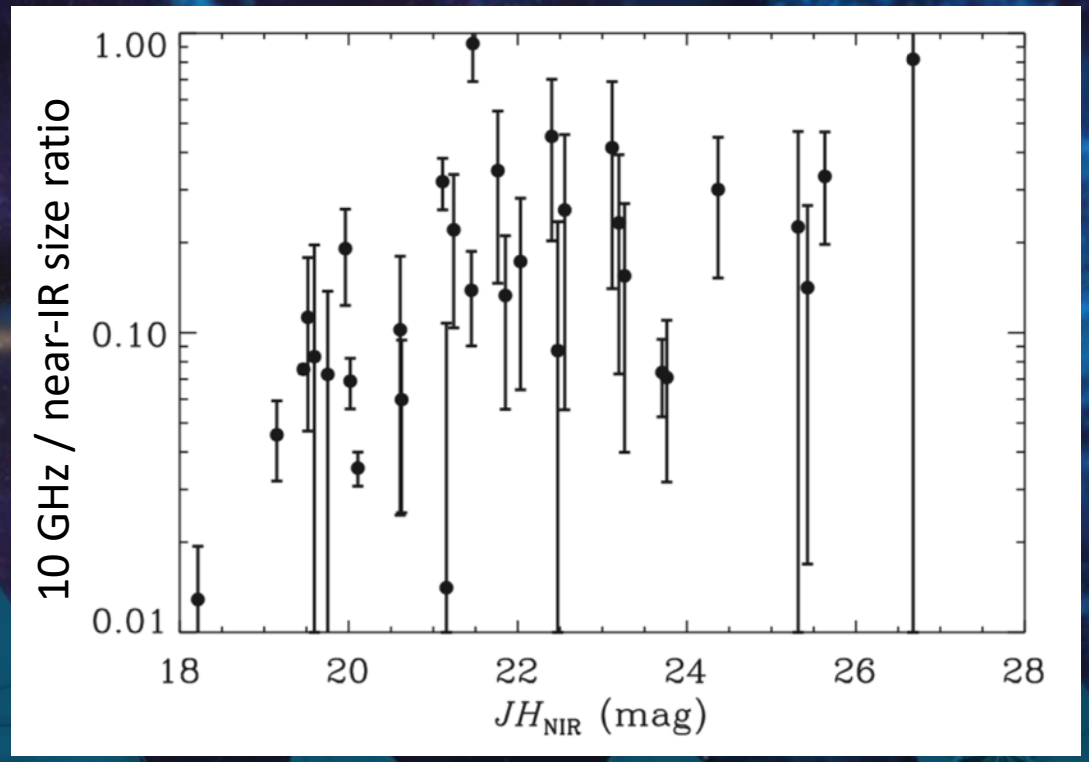


Optical-IR SED modeling

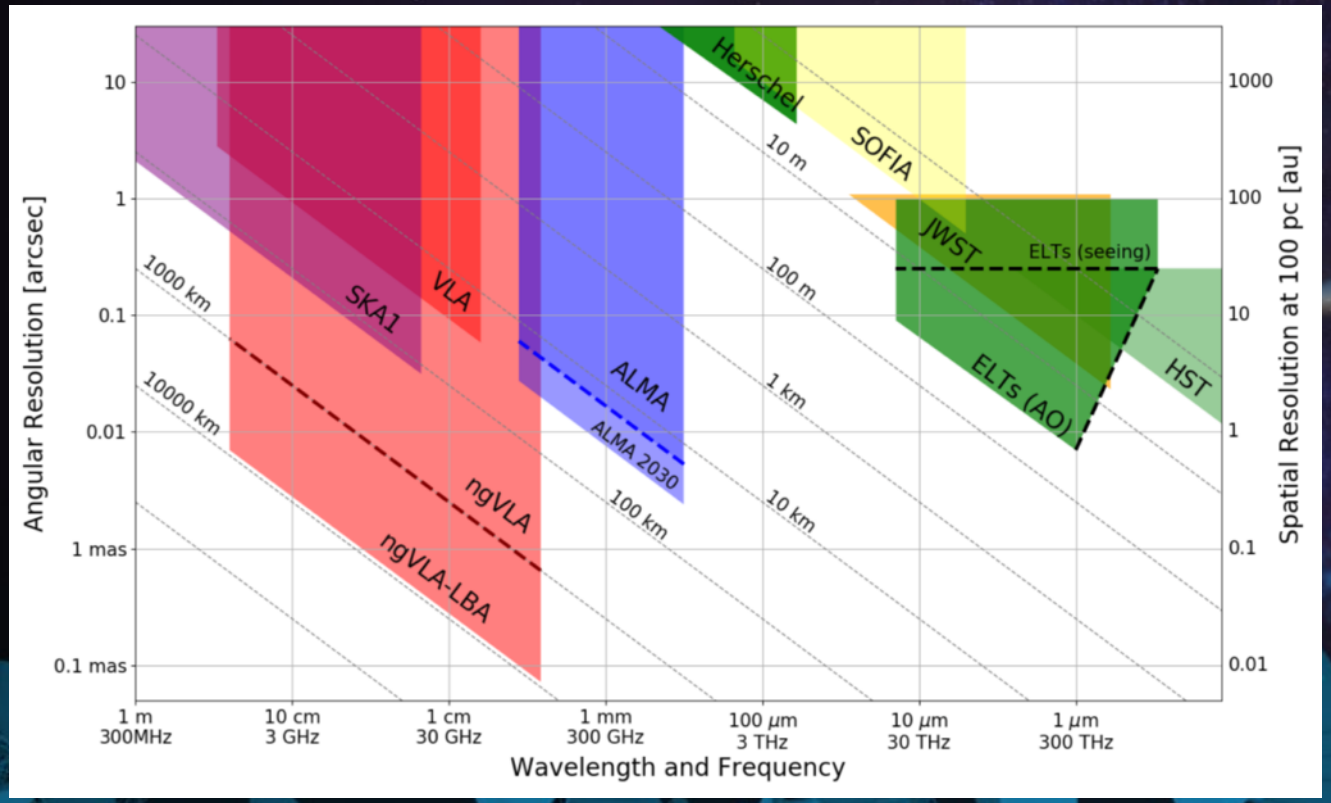
Non-thermal radio (synchrotron)

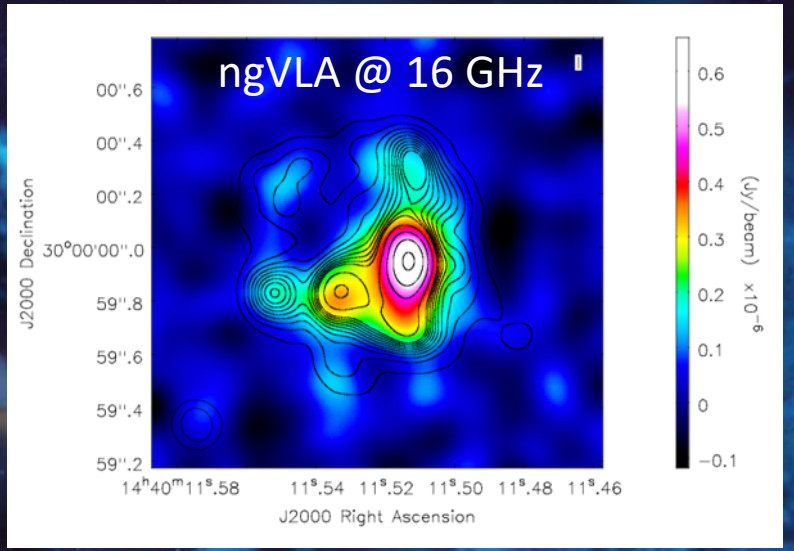
Resolving high-z star formation & galaxy physics

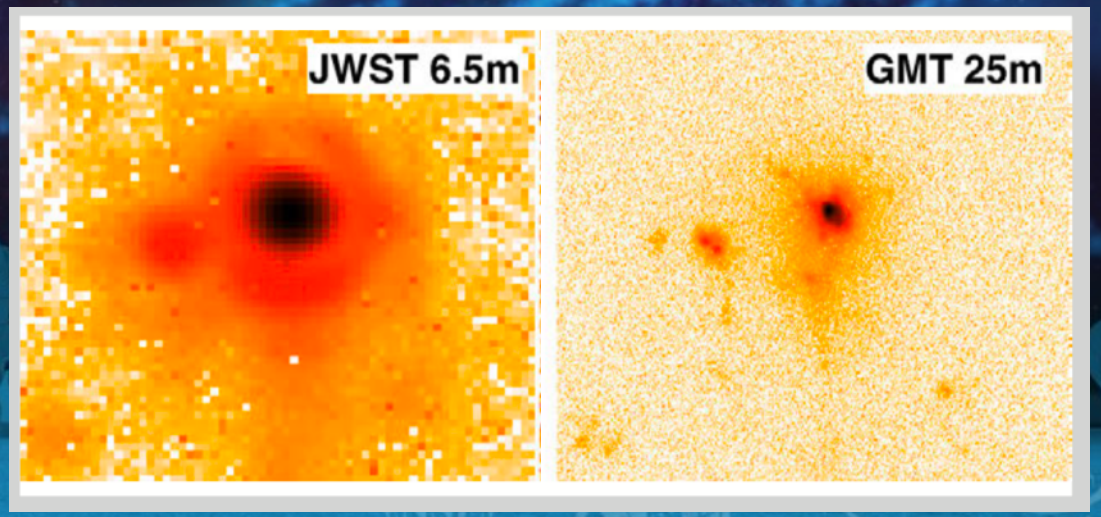




Resolving high-z star formation & galaxy physics







Summary

New capabilities will be powerful tools to study stars and star formation over cosmic time, including:

- JWST:
  - Surveying galaxies in the epoch of reionization
  - Resolving dusty galaxies and diagnosing star formation and AGN activity
- Rubin, Euclid, Roman, ATLAS Probe:
  - Vast numbers will enable precision studies of high-z galaxy evolution in the context of the cosmic web of large scale structure
- ngVLA and the US ELT Program
  - Thermal radio continuum as a new, direct measure of star formation
  - High angular resolution to study the internal physics of galaxy evolution