PRIMA

The PRobe far-Infrared Mission for Astrophysics

Mission Concept, Science, and Technology of the PRIMA Astrophysics Probe

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BAE SYSTEMS
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SRON
NG
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Stepping Back: Far-IR Detector Technological Readiness

Sensitivities of far-IR detectors have doubled approx. every two years for 75 years!

Probe region of interest

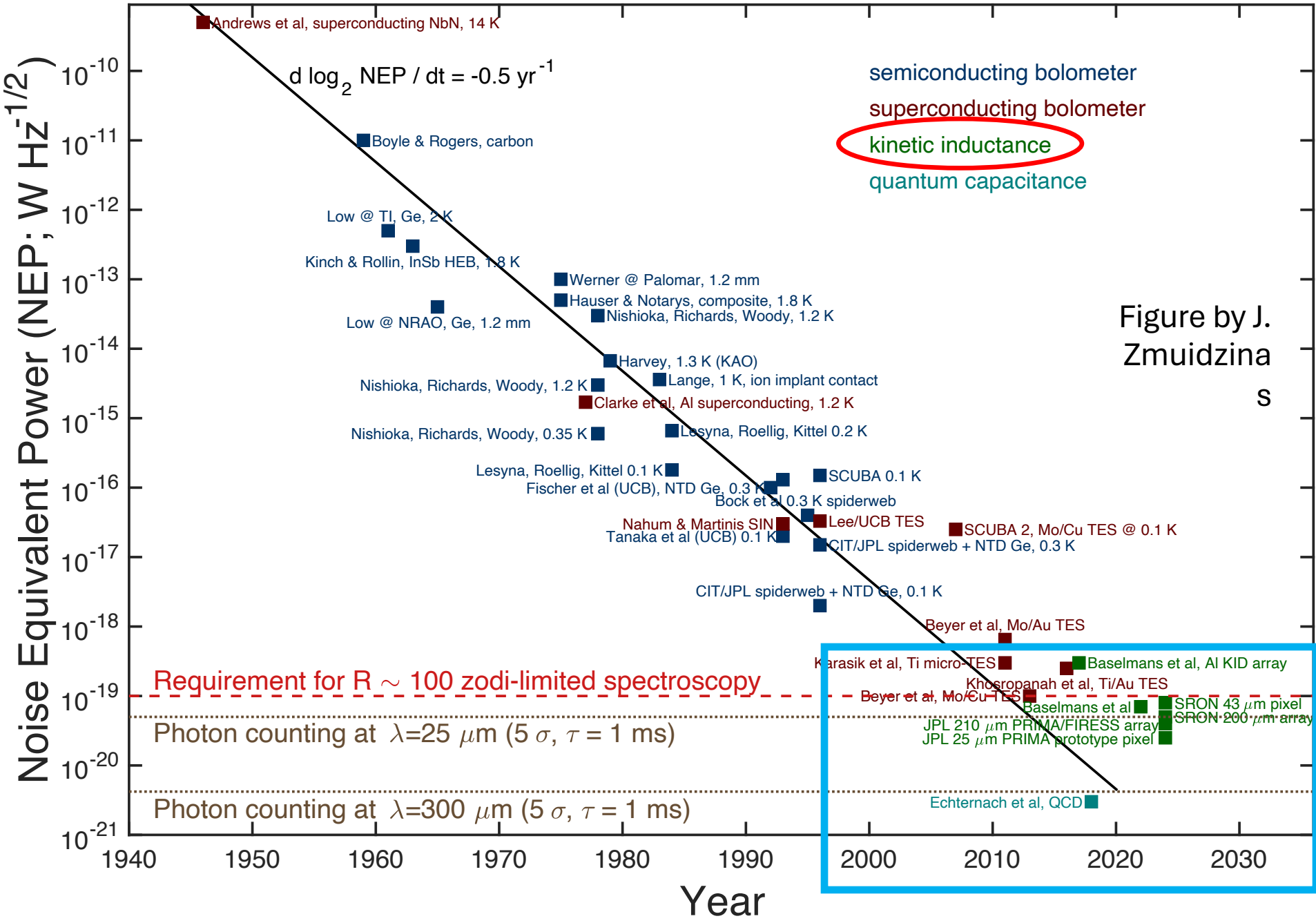


Figure by J. Zmuidzinas

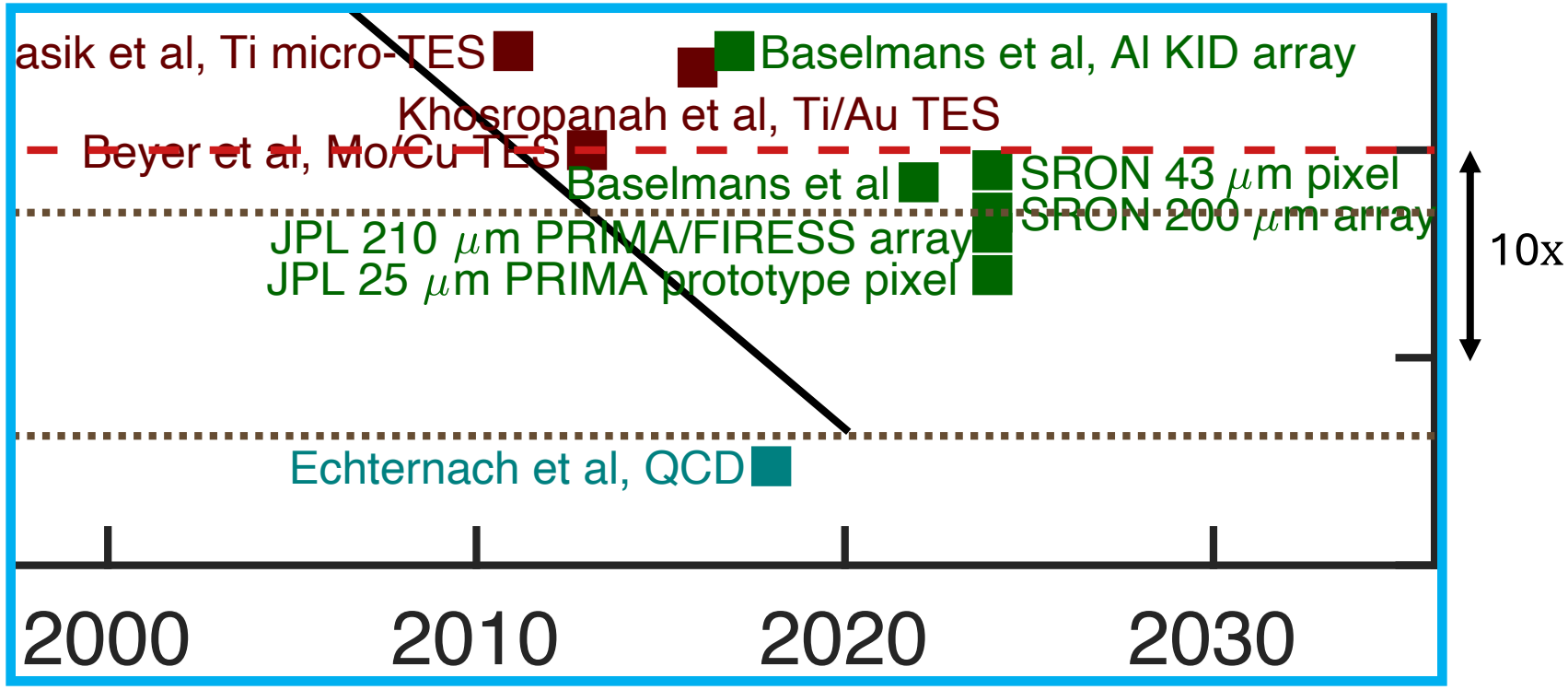
The timing is perfect for a background-limited Far-IR Observatory

Our JPL / Goddard / SRON collaboration has demonstrated kinetic inductance detector (KID) sensitivities exceeding PRIMA's requirements spanning PRIMA's wavelengths

PRIMA R = 10 imaging requirement

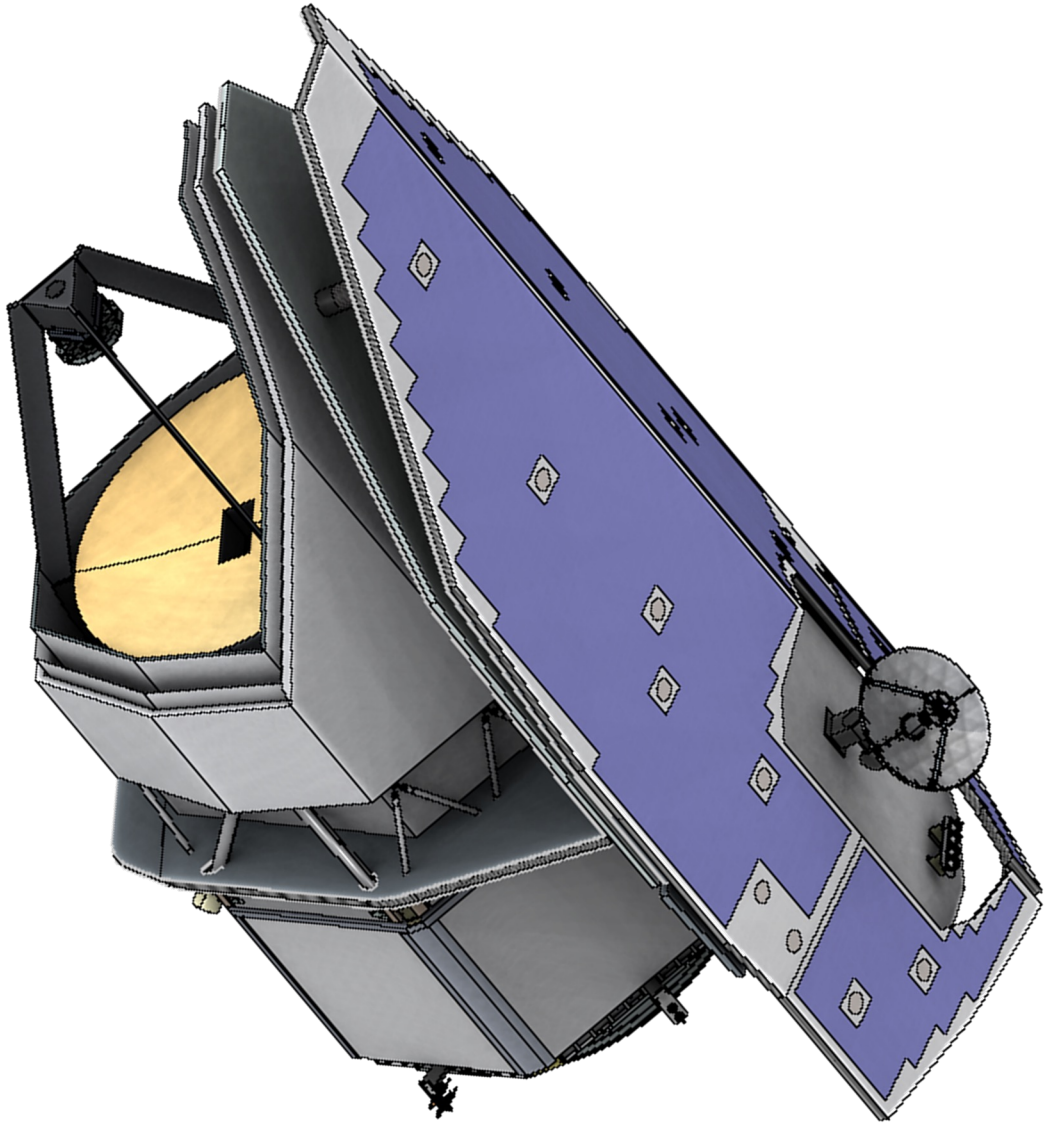
PRIMA R = 100 spectroscopy ~~requirement~~

Demonstrated performance (lower on this plot is better!)



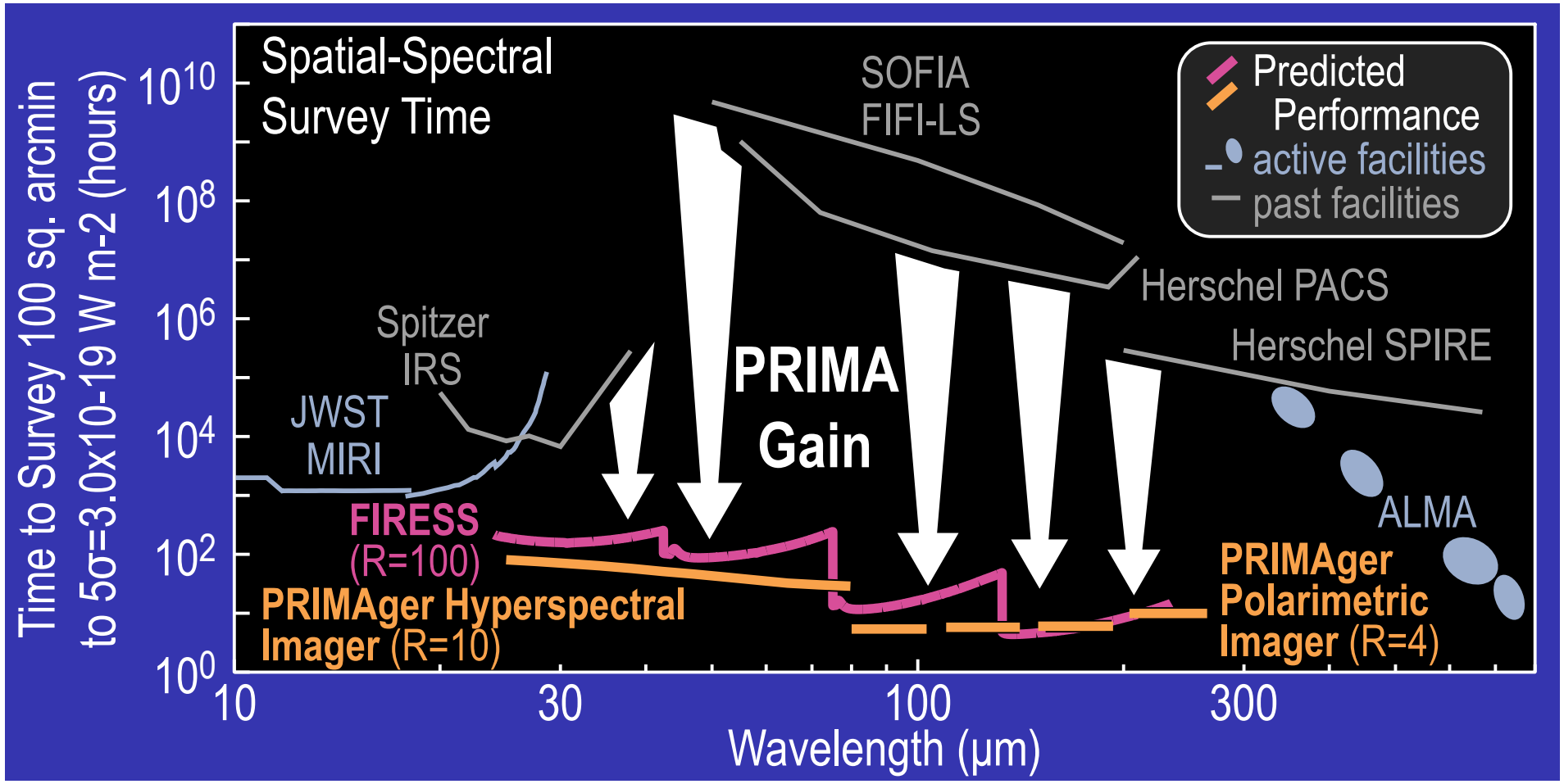
What is PRIMA?

Telescope	1.8-m, all aluminum, 4.5 Kelvin
PRIMAger Imager & polarimeter	R = 10 hyperspectral imaging 25-80 μm R= 4 imaging & polarimetry 91-261 μm
FIRESS Spectrometer	R > 85 spectroscopy 24-235 μm High-Res mode R = 4,400 x ($\lambda/112\mu$m)
Detectors	100 mK KID arrays (~11k total)
Data	IPAC
Orbit	Earth-Sun L2
Launch	2032
Observations	75% GO, 25% PI (→ GI)

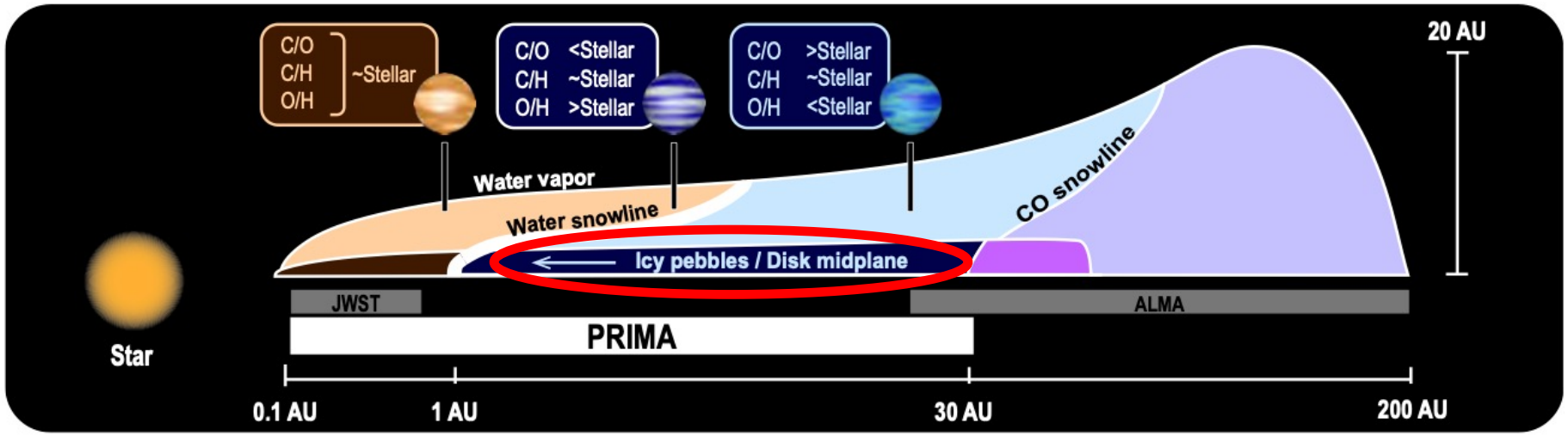


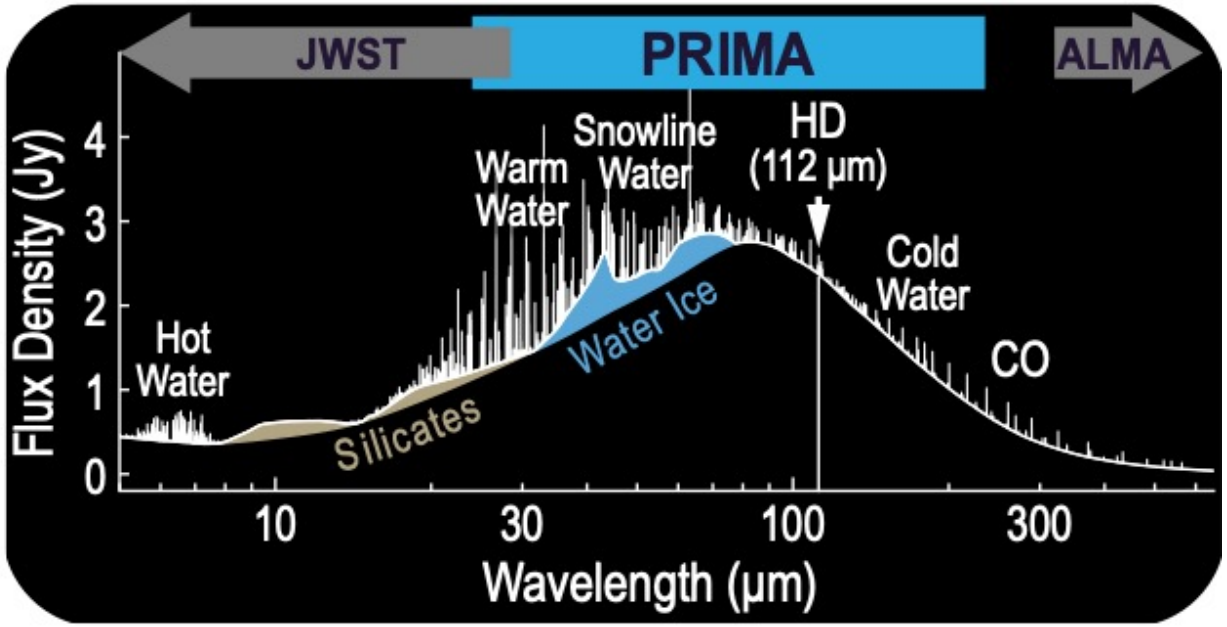
Large Gains and New Capabilities from Sensitive KID Arrays

- Extended-source and ”blind” spectral mapping
- Extensive polarimetric mapping
- Deep all-sky far-IR survey



Background: Protoplanetary Disk Structure and Spectra



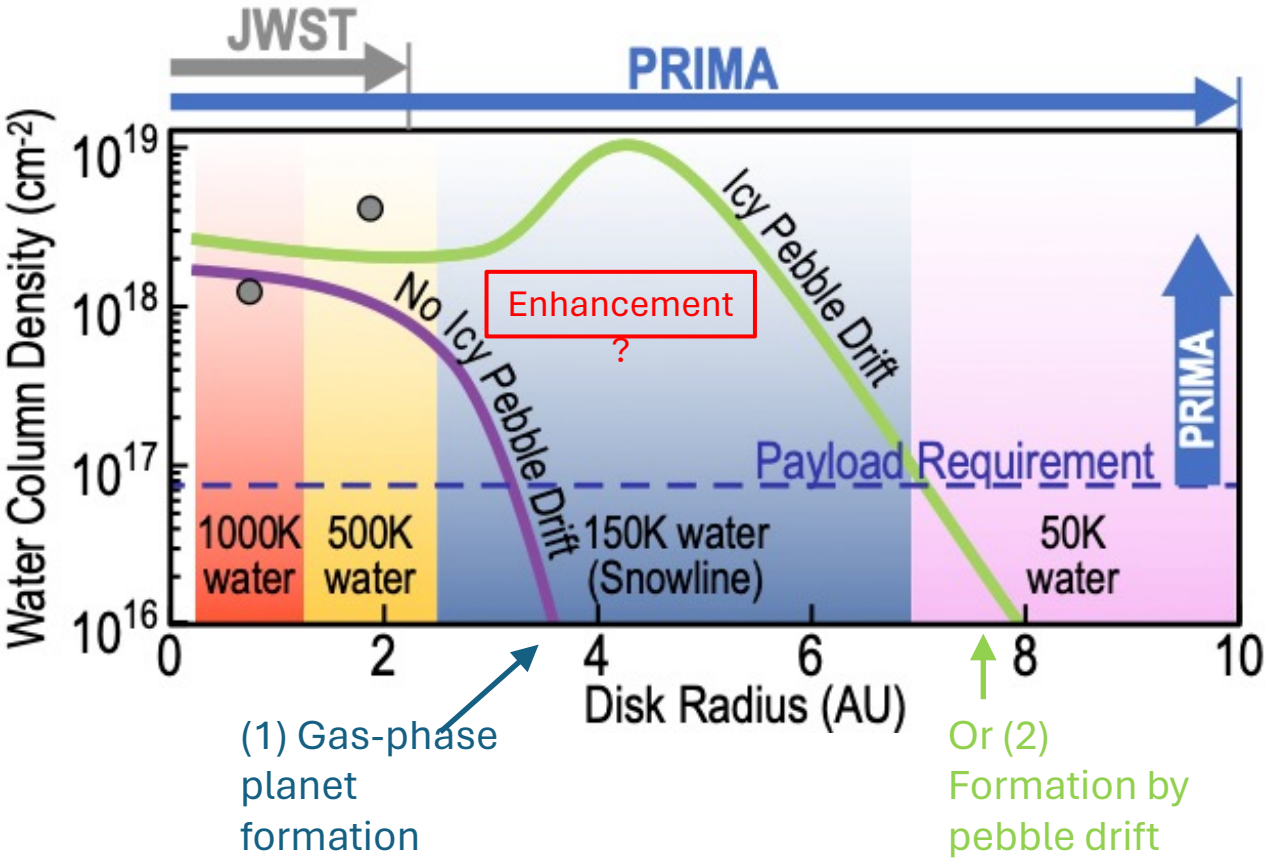


Unknowns and uncertainties

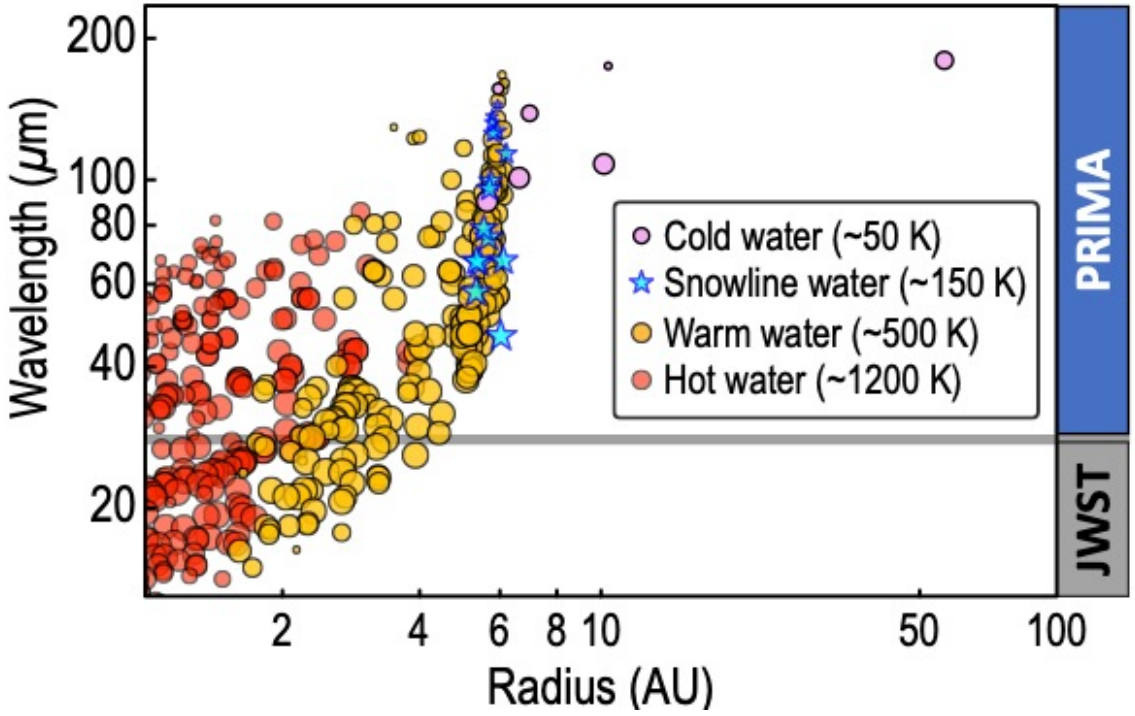
- Disk C and O abundances and whether they map to stellar metallicities
- Disk masses uncertain to an order of magnitude due to CO depletion → HD
- Water vapor content and

Protoplanetary Disks: Is there enough water mass to drive the formation of planetesimals near the water snowline?

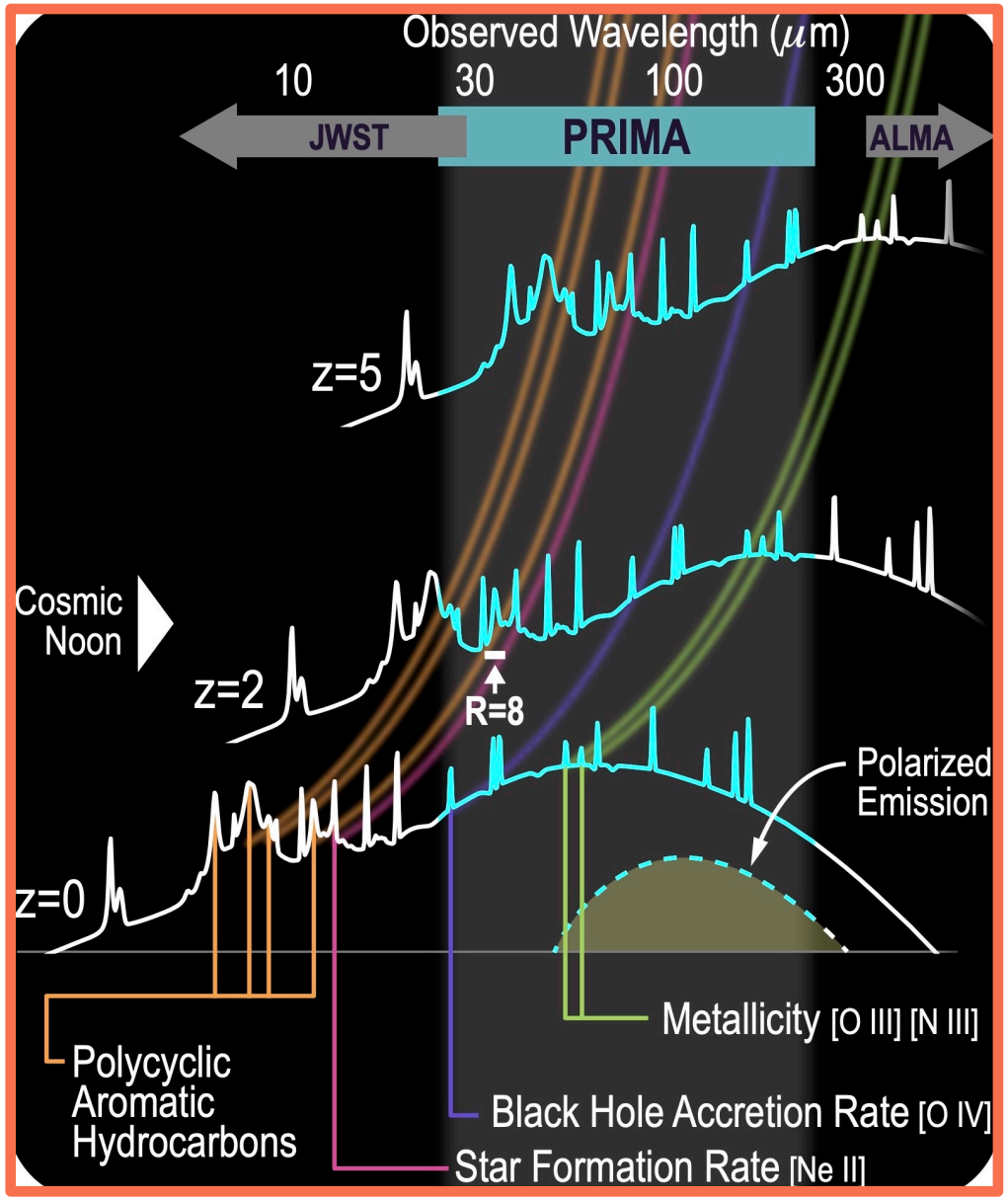
Water likely dominates the solid disk mass outside the snow line and coagulates via ice pebble drift to form planetesimals. PRIMA measures $N_{H2O}(T)$ to test models.



PRIMA FIRESS FTM will measure the level of water enhancement in 200 disks of various ages and masses (point size ∝ line flux).



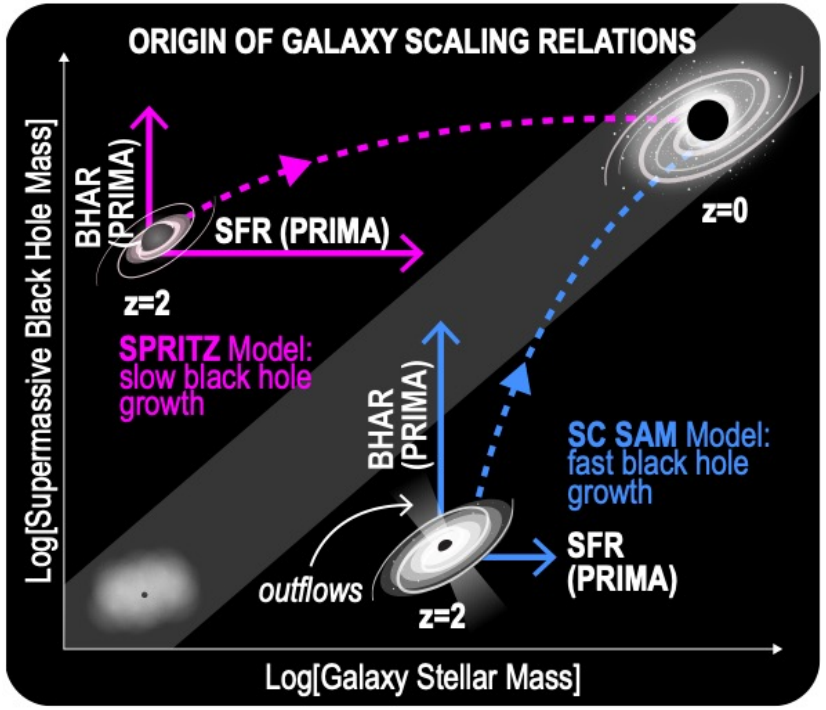
Background: Far-IR and Rest-frame Mid-IR Galaxy Spectra

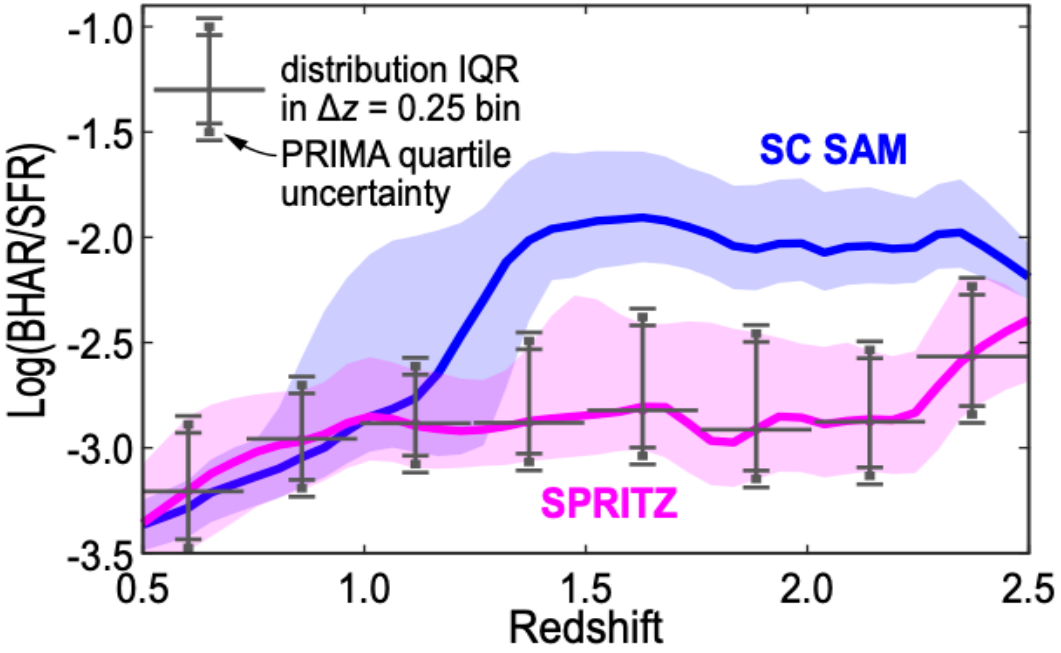


Galaxy Evolution: What is the scaling relation between black-hole accretion rate and star-formation rate in luminous galaxies since the peak epoch (z ~ 2)?

How to measure the SFRs and obscured SMBH luminosities simultaneously in galaxies?

⇒ Redshifted mid-IR and far-IR spectral energy distributions (SEDs) and atomic fine-structure lines.





2 example histories

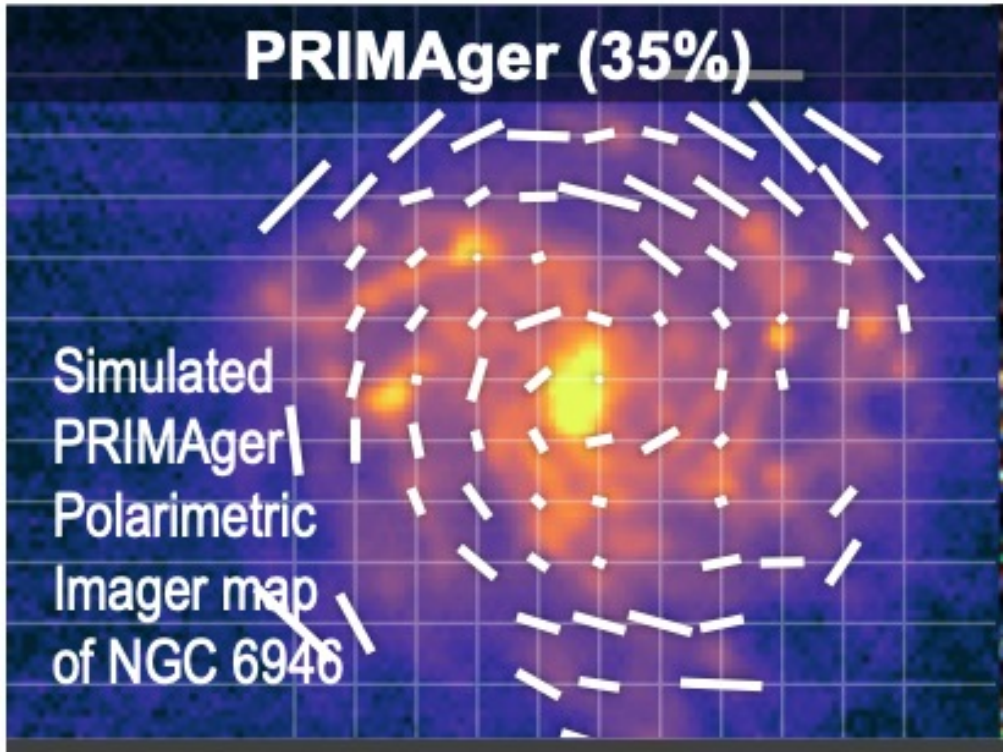
Santa Cruz Semi-analytic model: more black hole growth at cosmic noon.

SPRITZ – star-formation based model linked to Spitzer, Herschel datasets (Bisigello et al. 2021).

- BHAR / SFR extracted from SED using CIGALE framework (Boquien+ 2019, Bisigello+ 2024)
- Will detect 42k galaxies in 1 sq deg (Donnellan+ 2024)
- Spectroscopic sub-samples of 160 z = 1.0-2.5 galaxies using [O IV] and [Ne II] (rest frame 26 & 12.8 μm)

In addition: PRIMA's FTM will measure cool mass outflow rates of 50 z = 1-2 galaxies with OH (R = 900 @ 84 μm) absorption to test if they are consistent with quenching.

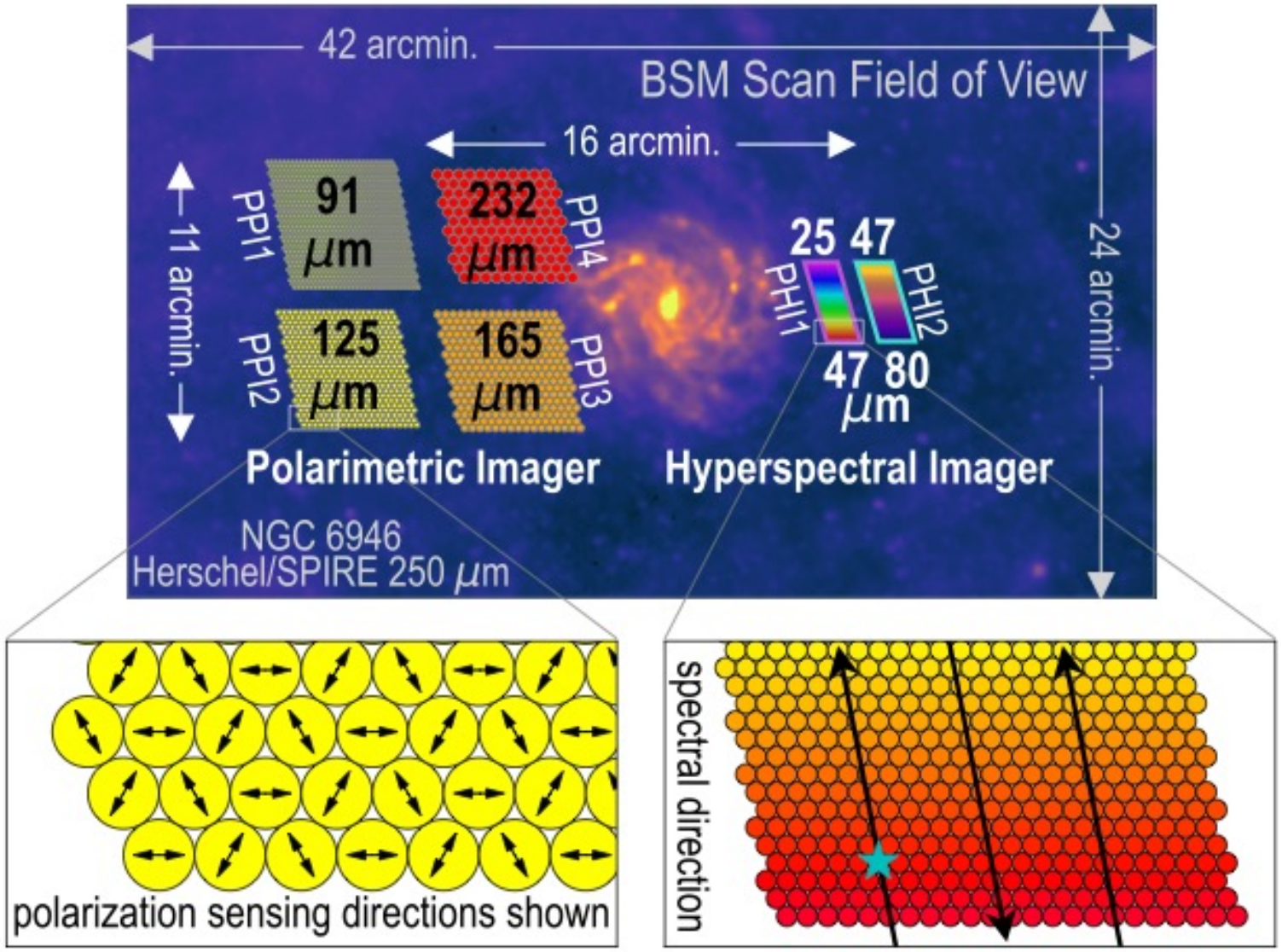
GO Science: Polarimetry and Magnetic Fields in Galaxies



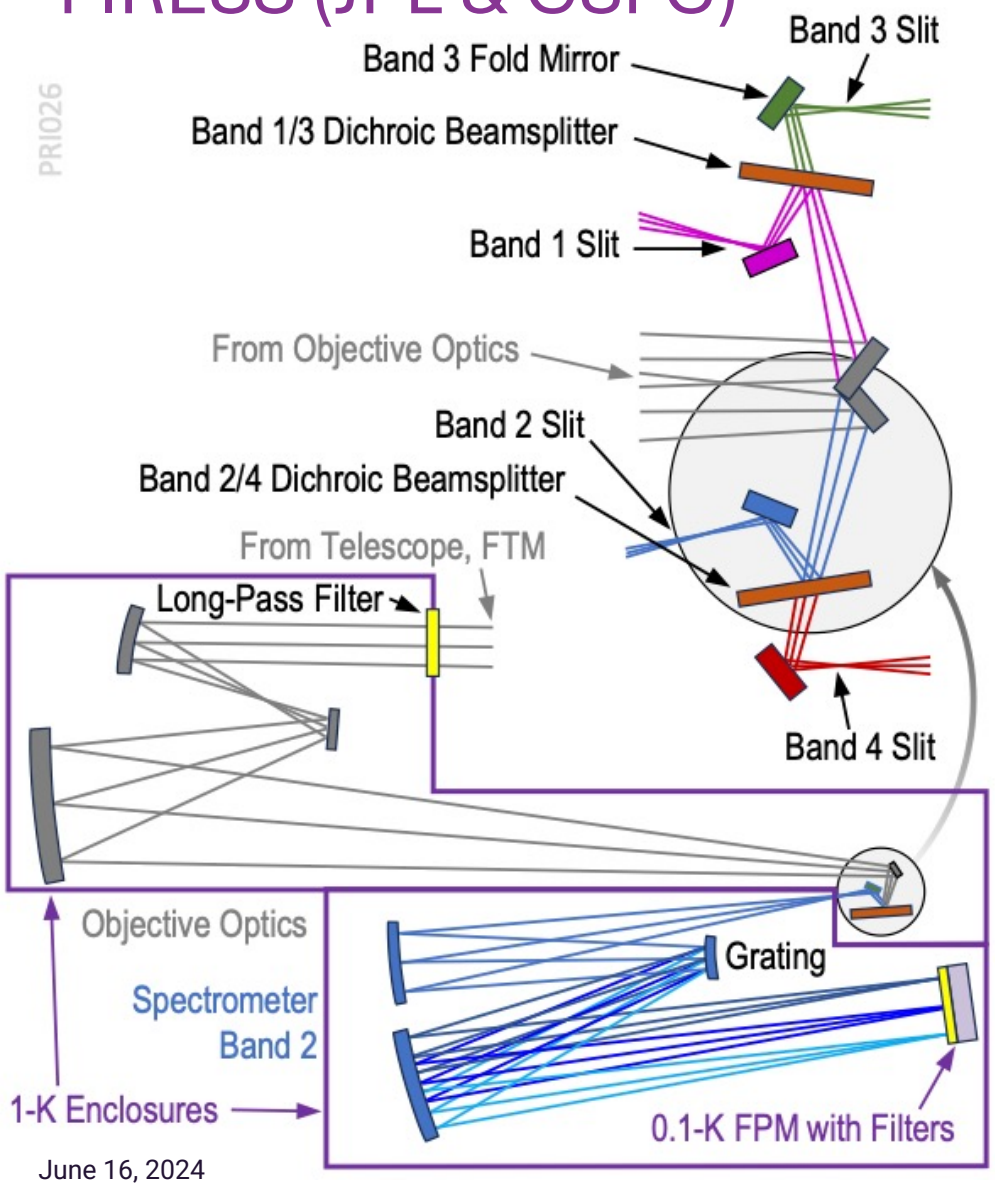
- Simulations of polarimetric capability: Dowell+ 2024
- Magnetic fields (Lopez-Rodriguez; Louvet; Paré; Pattle)
  - Galactic clouds: The role of magnetic fields in cloud dynamics
  - Nearby, resolved galaxies: Do molecular cloud fields generally align with and reflect radio (cosmic ray) derived fields on larger scales?
  - High redshift galaxies: confusion mitigation and large-scale structure (Bethermin+ 2024)

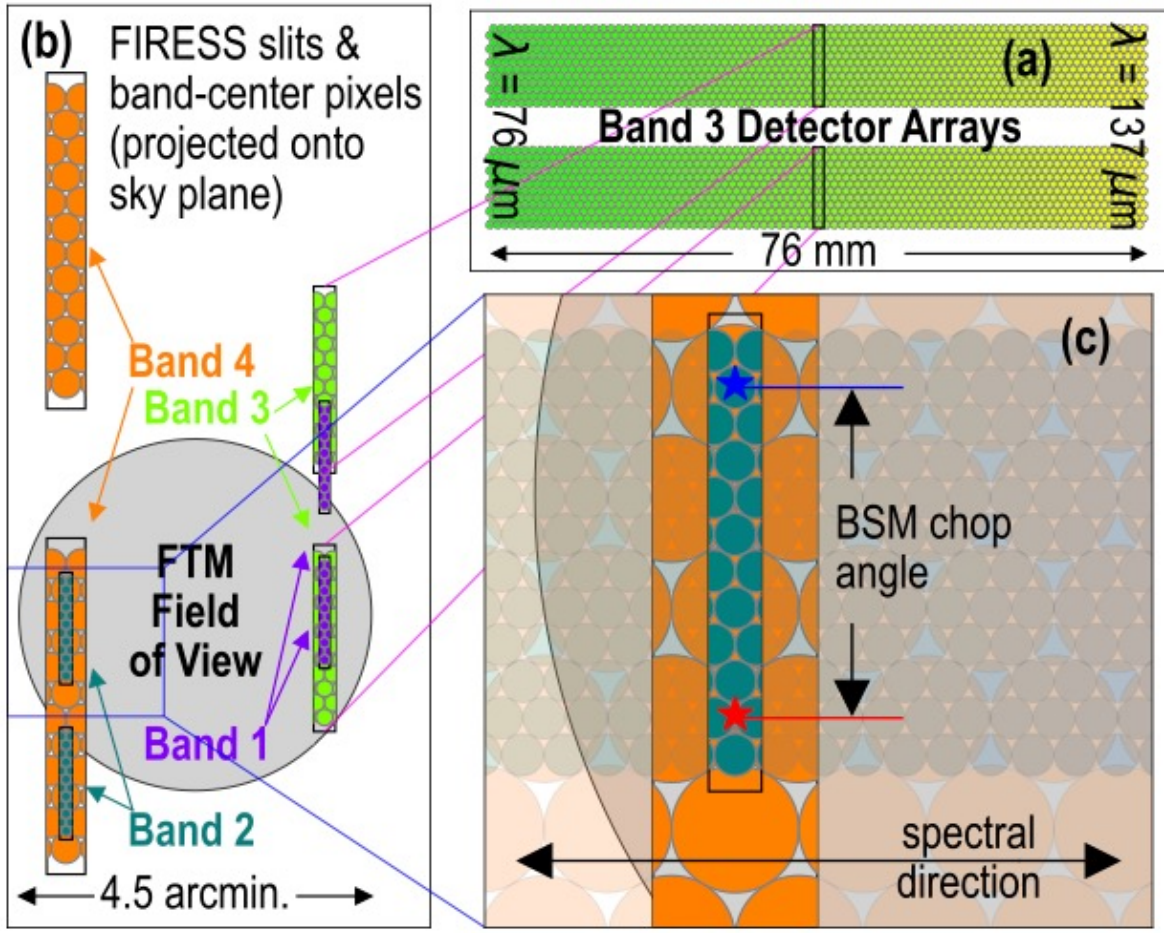
In *PI science*, PRIMA will test dust models with far-IR polarimetry.

PRIMAger (LAM)



FIRESS (JPL & GSFC)

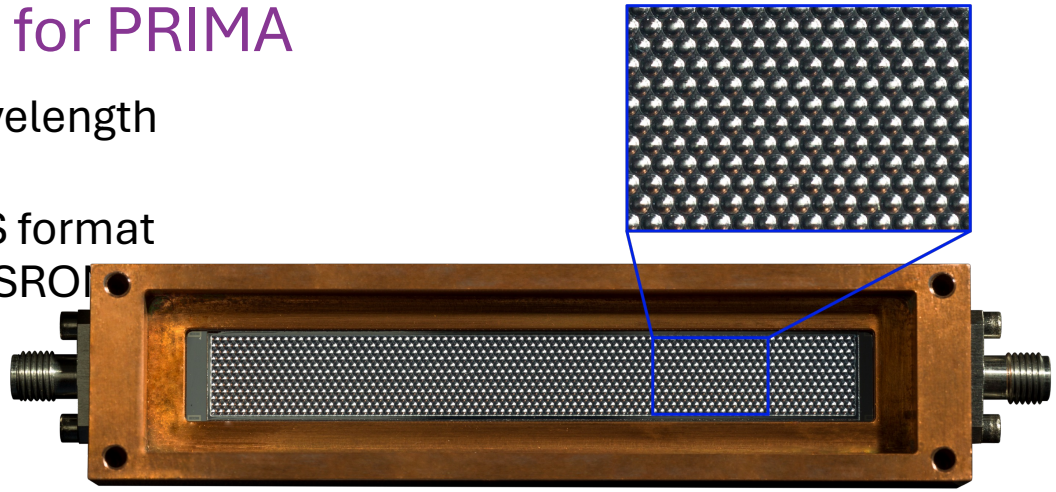


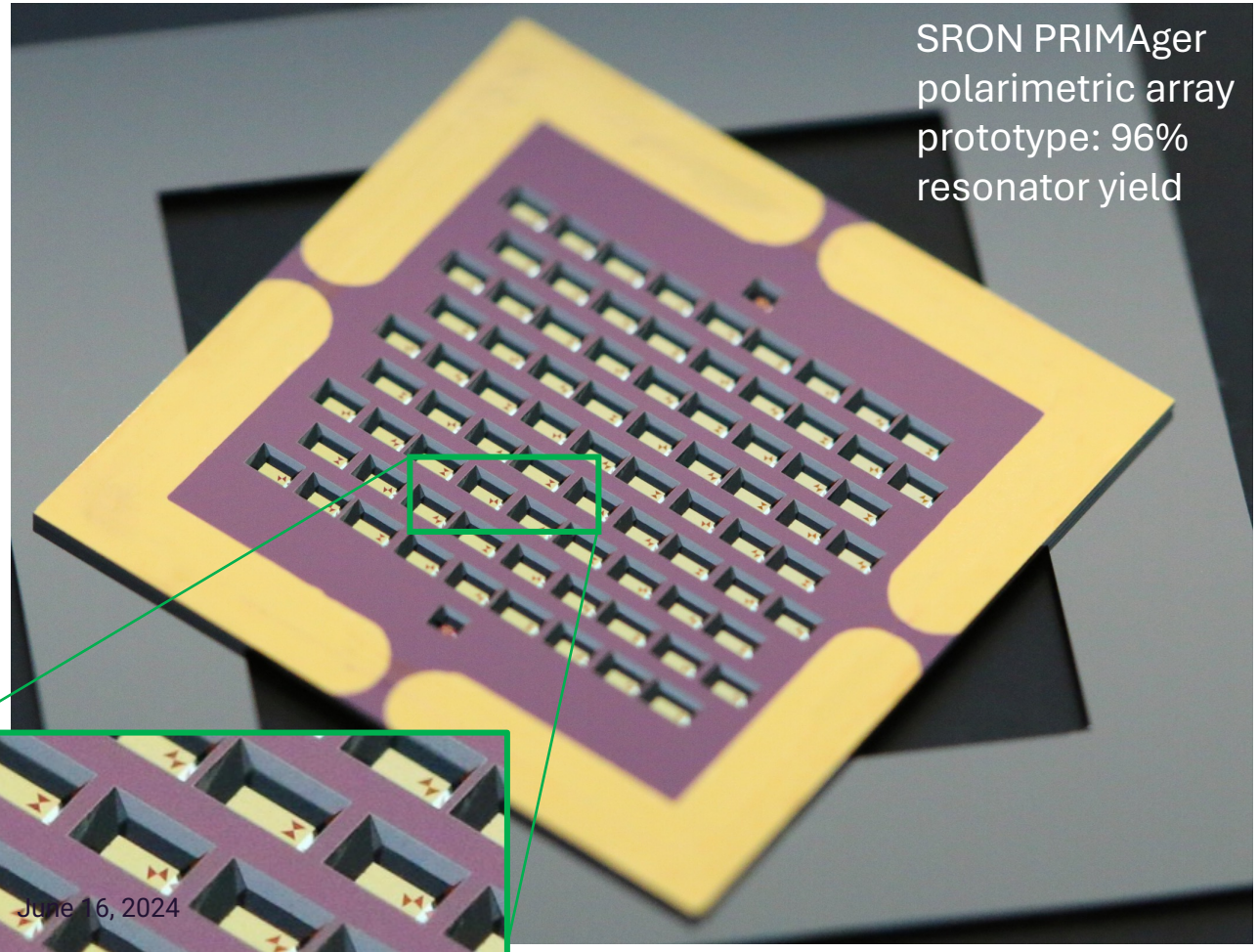


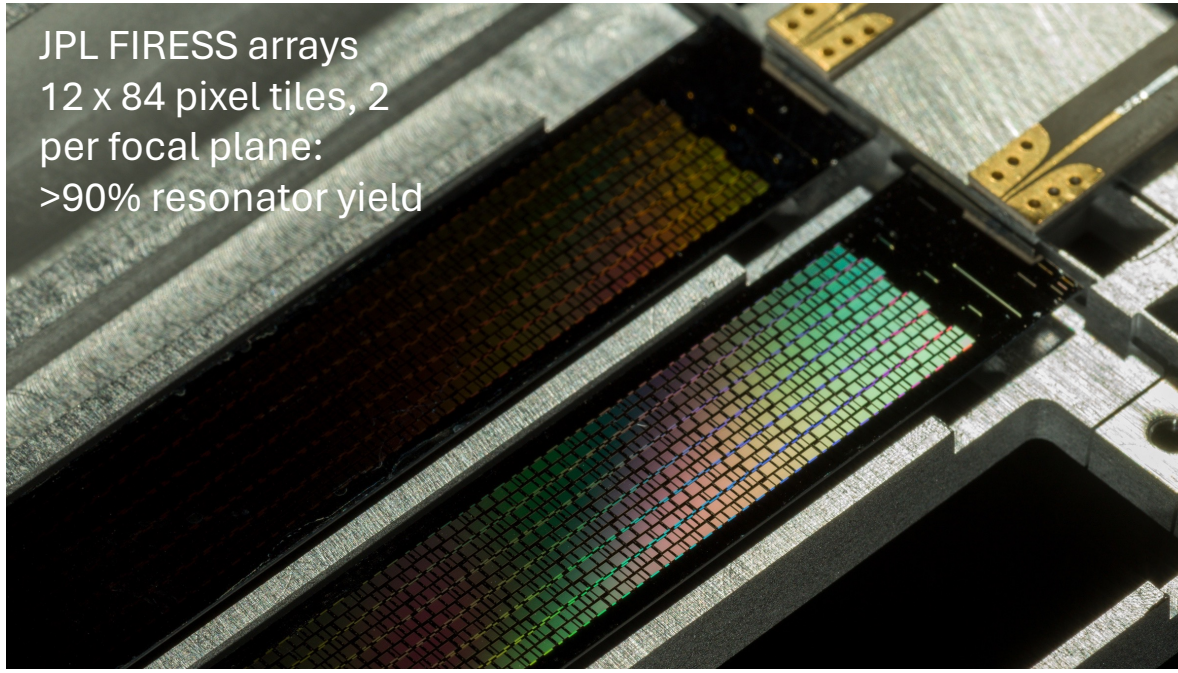
- 4 slit-fed grating modules, each 24 x 84 pixels
- Bands 1 and 3 overlap, Bands 2 and 4 overlap.
- High-res mode with FTM couples all bands when engaged.

KID Detectors: JPL / GSFC / SRON Collaboration for PRIMA

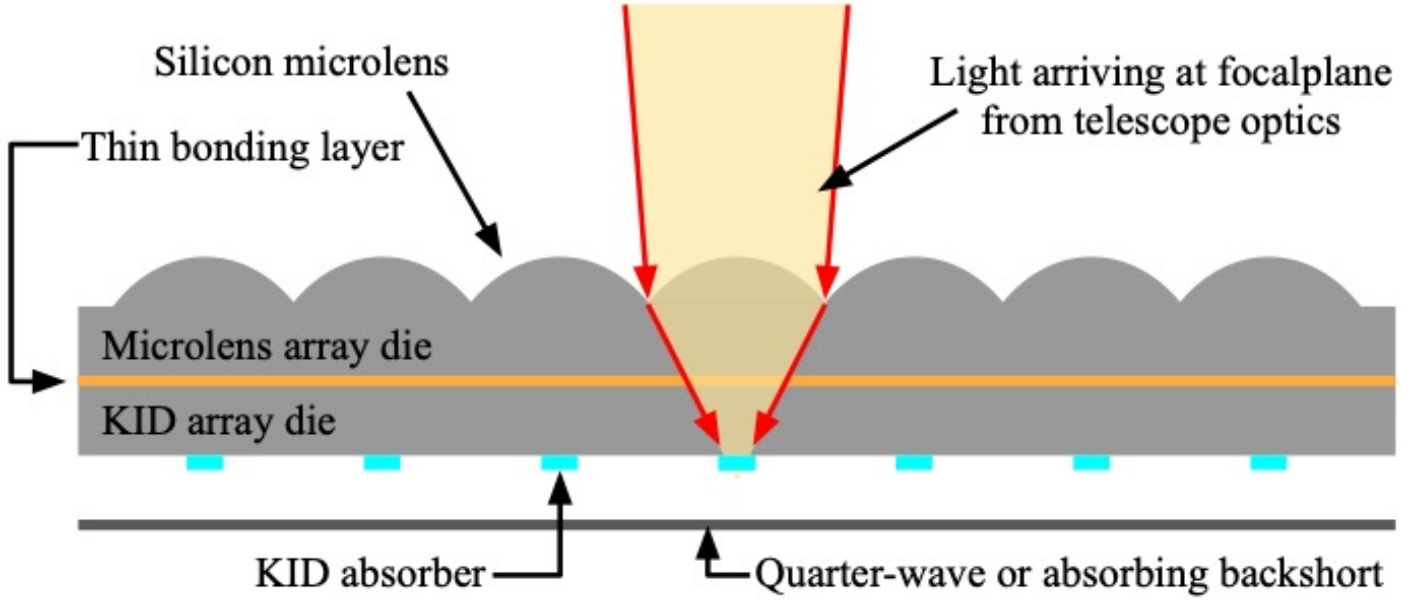
- Sensitivity exceeds performance requirements over full wavelength range.
- Demonstrated detector/lenslet hybridized arrays with full FIRESS format (84x12, 900-μm pixel pitch). PRIMAger prototypes in place from SRO

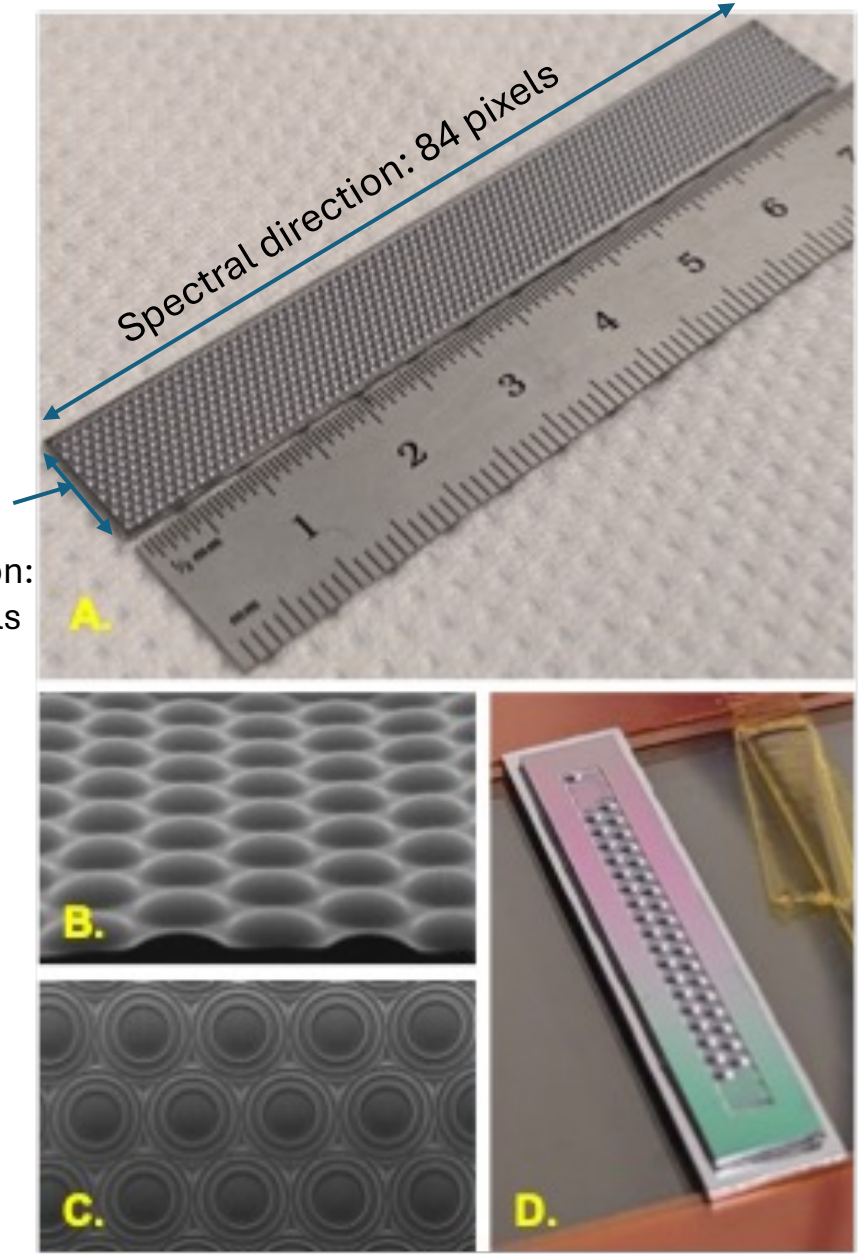






Microlens Arrays & Hybridization





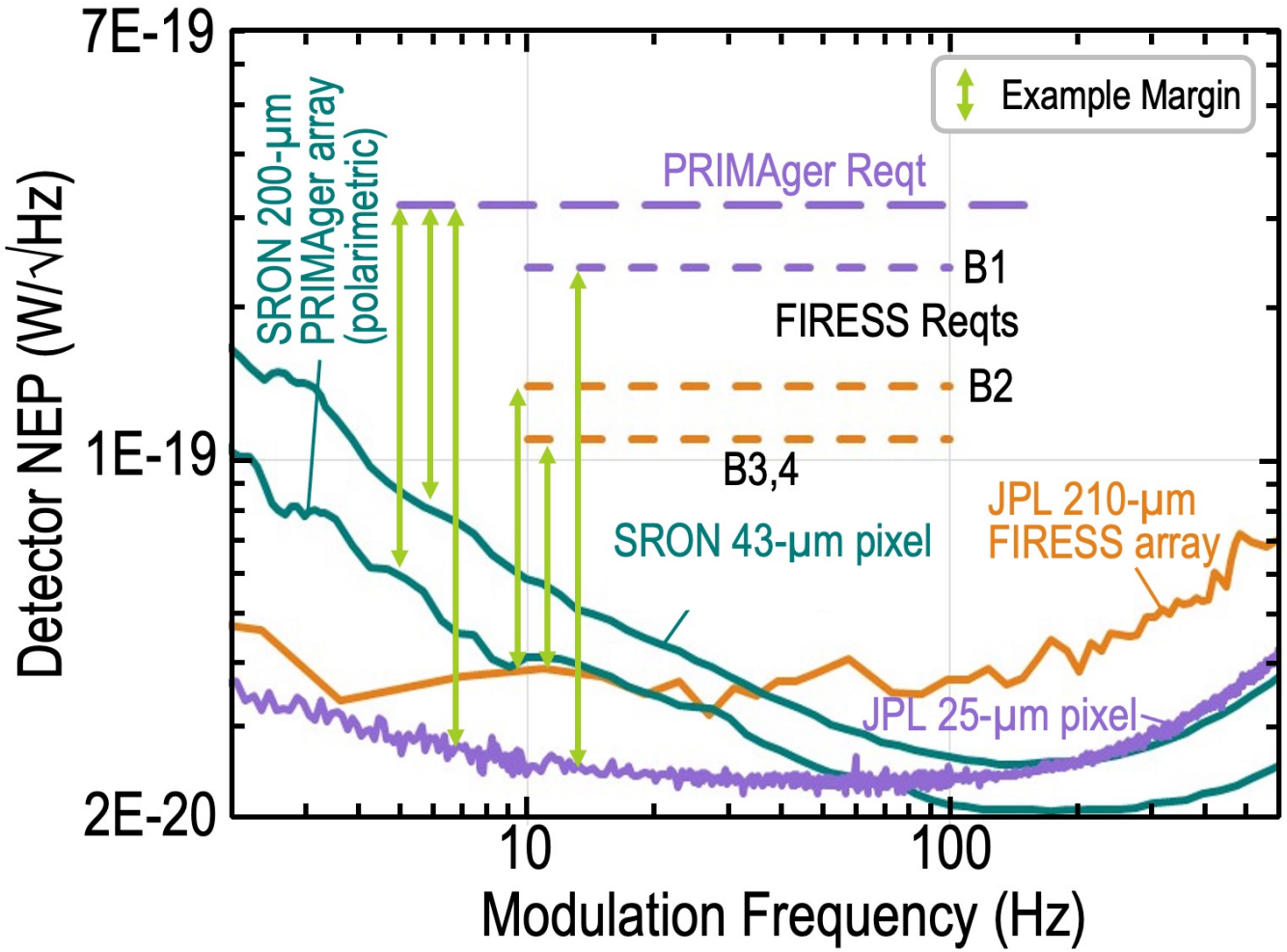
GSFC greyscale-etched microlens arrays & hybridization technique.

Accuracy across the bulk of each lens is ~ 2 μm!

Cothard et al. (2024)

KID Sensitivities

Significant margin for both instruments, spanning the wavelengths



25 μm result: Day+ 2024

Extra Slides

Who is PRIMA?

An international team of astrophysics and technology experts

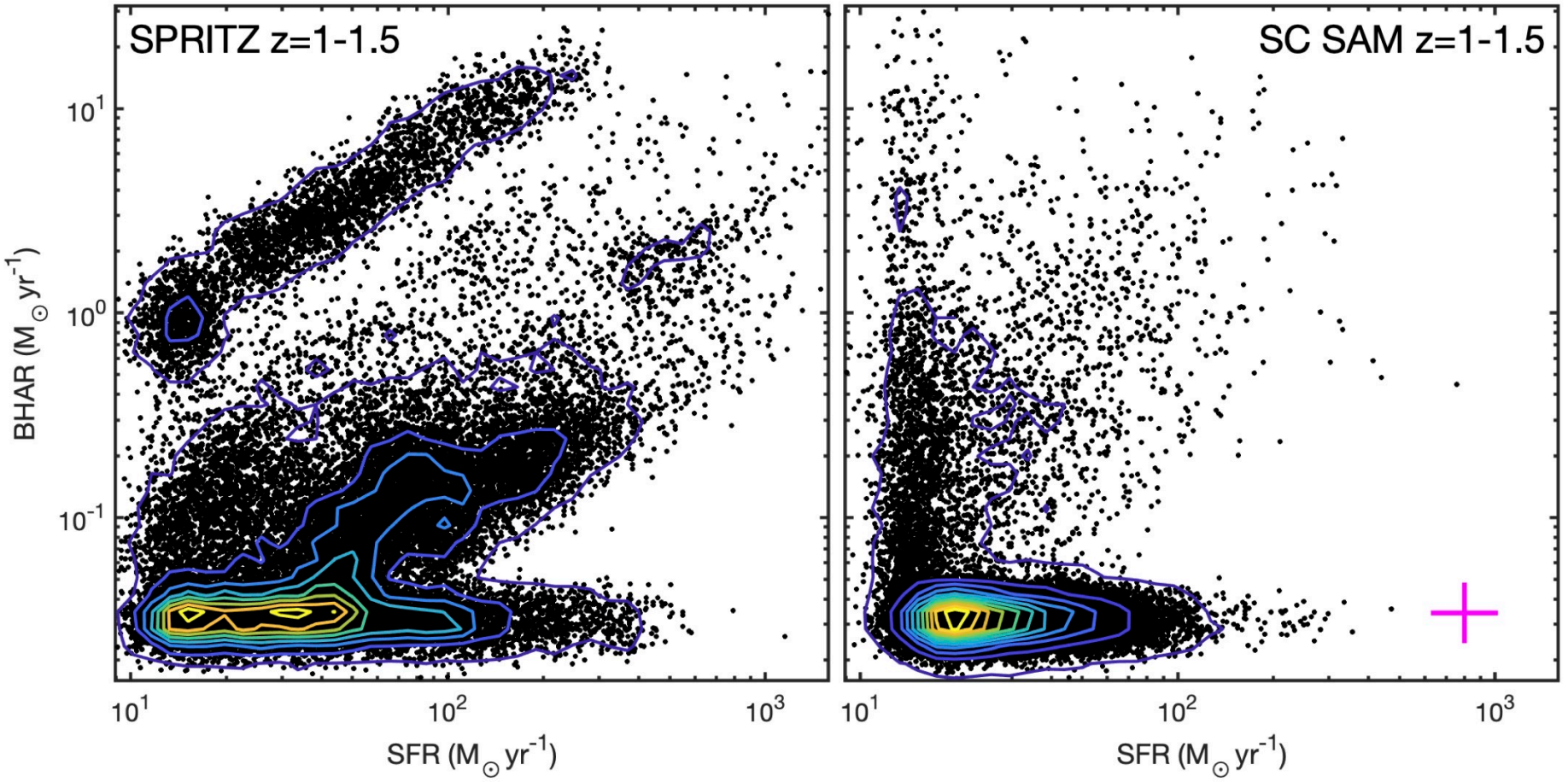
Co-I shown, plus a strong corps of engineers at JPL, GSFC, & BAE Systems

Partner Institutions

JPL
GSFC
BAE Systems (prev. Ball)
ASI / INAF
Cardiff
IPAC
LAM
MPIA
SRON

BHAR and SFR for Two Models

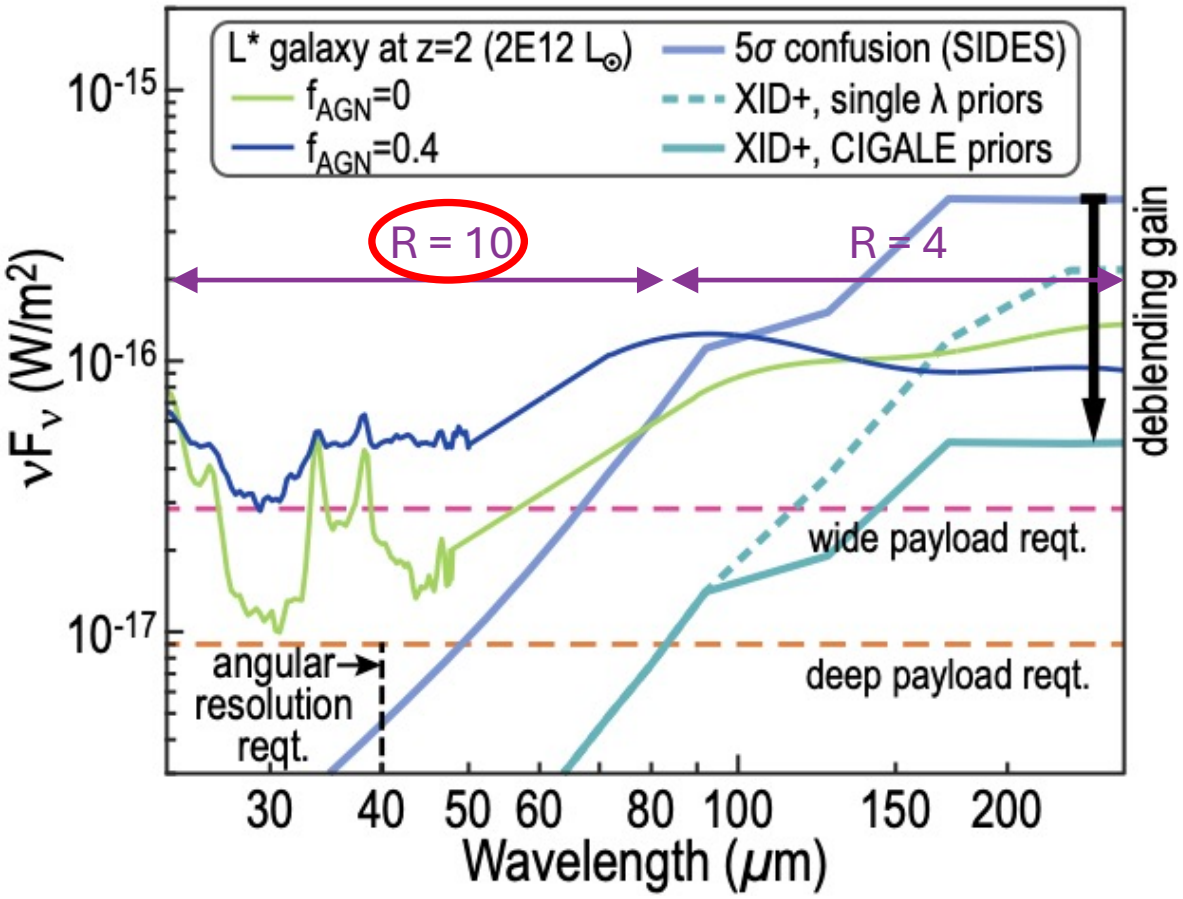
Model predictions vary considerably and new data are needed to test them.



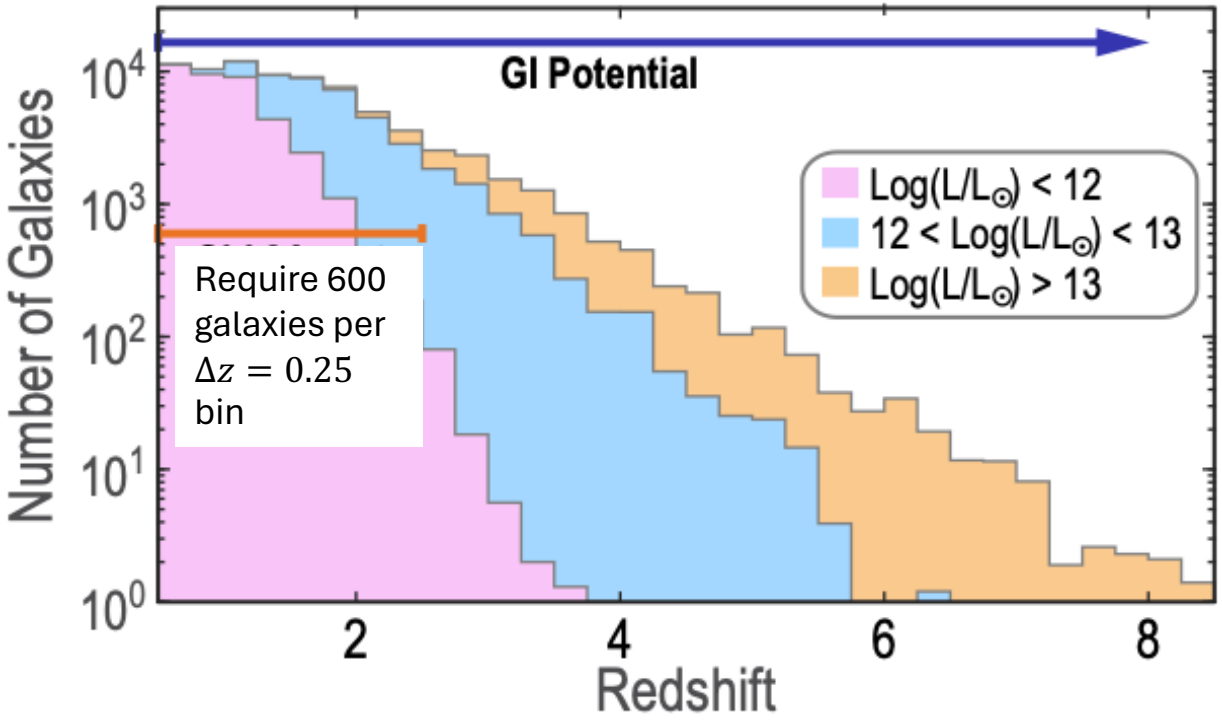
- 10 sq deg, 1500 hrs
- SPRITZ models are empirical and have a large number of coevolving galaxies
- SC models are semi-analytical, black holes form early and quench star formation
- Cross denotes typical error bars

From Bisigello+ 2024

Mitigation of Confusion: Spectrally densely sampled, R = 10 rest-frame mid-IR spectra – excellent short-wave positional priors



1 and 10 sq deg surveys

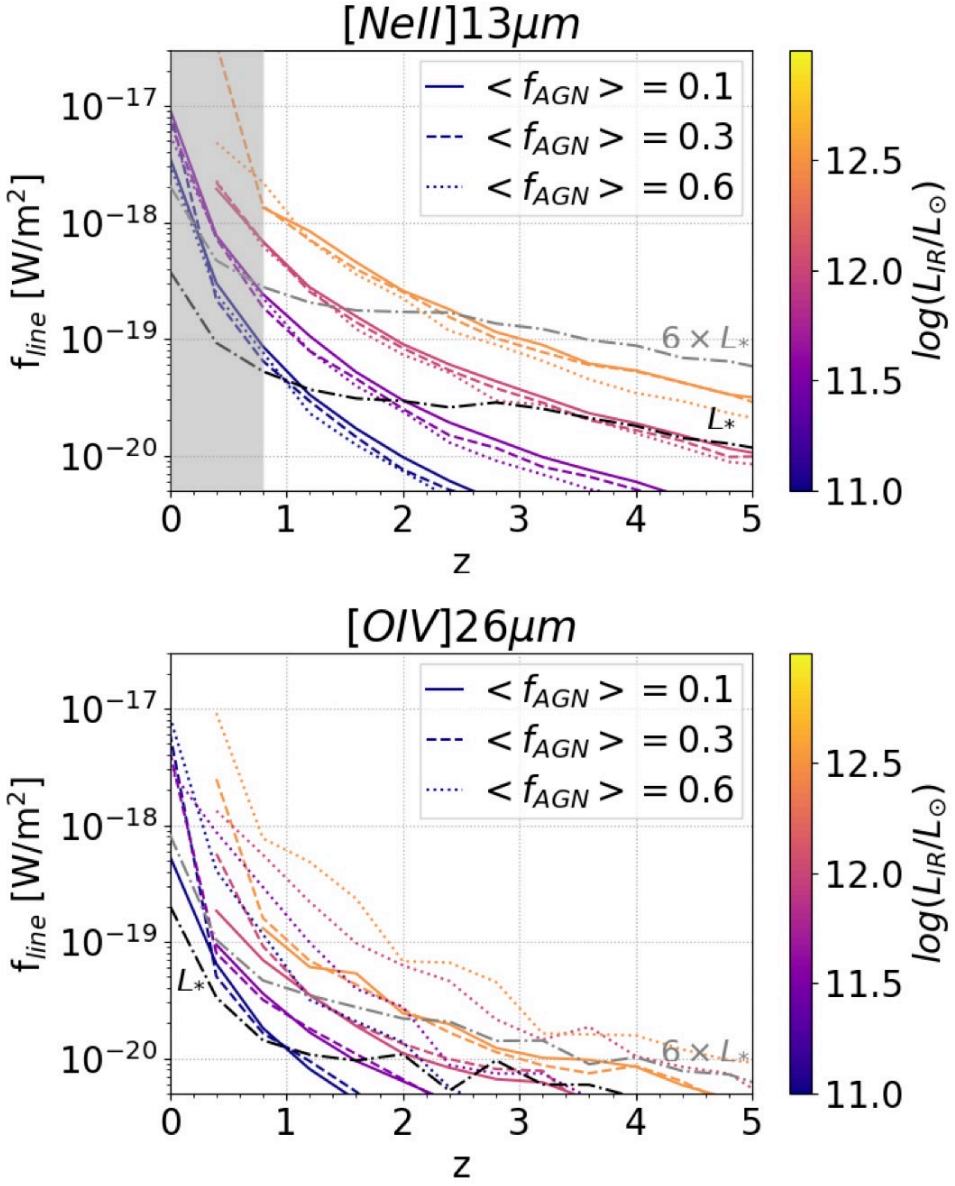


Bethermin+ 2024
Donnellan+ 2024

[Ne II] and [O IV] Detectability

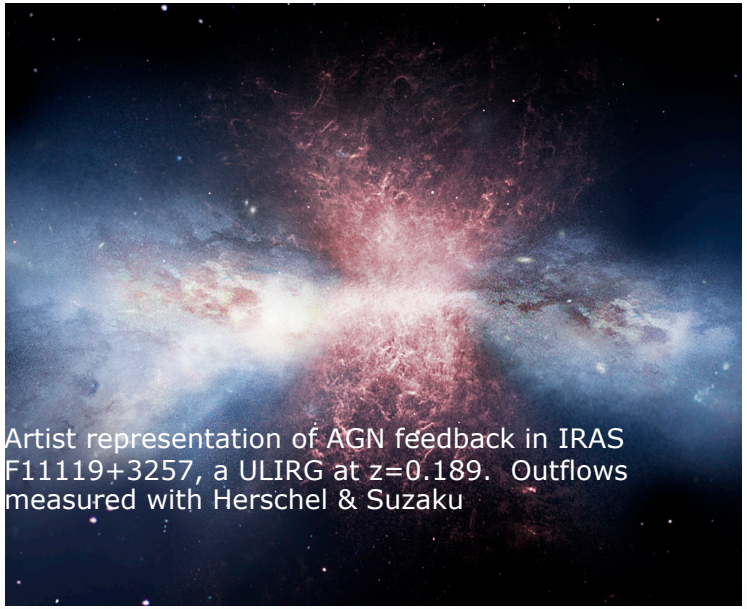
- PRIMA wavelength coverage starts where JWST stops
- Dashed lines show L* and 6 x L*
- L* galaxies with significant AGN will be detectable up to cosmic noon, above L* to high redshifts

From Bisigello+ 2024



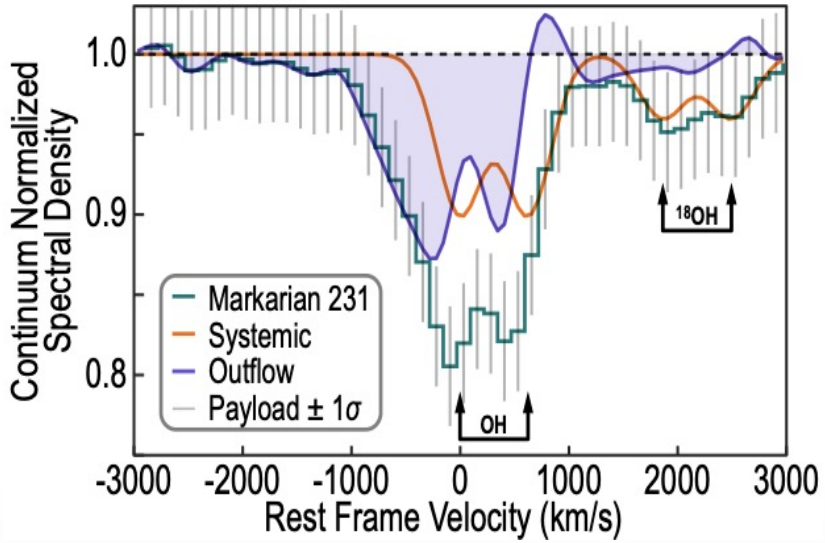
Evolution of Galactic Ecosystems: Can outflows quench z = 1-2 star formation?

Models



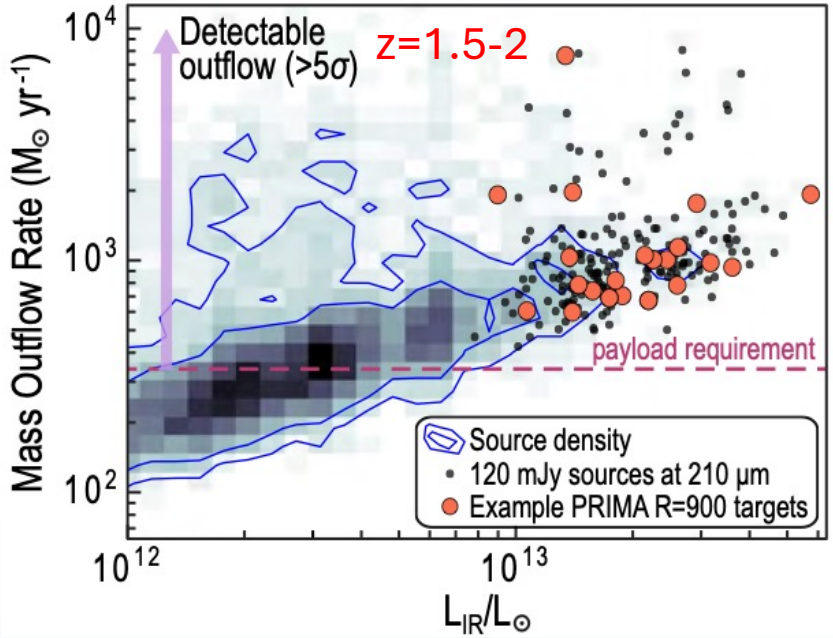
- Models require winds ejecting gas to quench star formation in massive galaxies
- Need velocities and mass outflow rates to test models
- Cool component (T<10,000K) dominates the mass

Method



- OH doublet absorption features (here 84 μm @ z=1.5; also 61, 71, 79 μm) with the FIRESS FTM tuned to R=900
- Fit components to measure outlflow velocity and mass
- Shown: 850 M_{sun} / yr @ 13σ

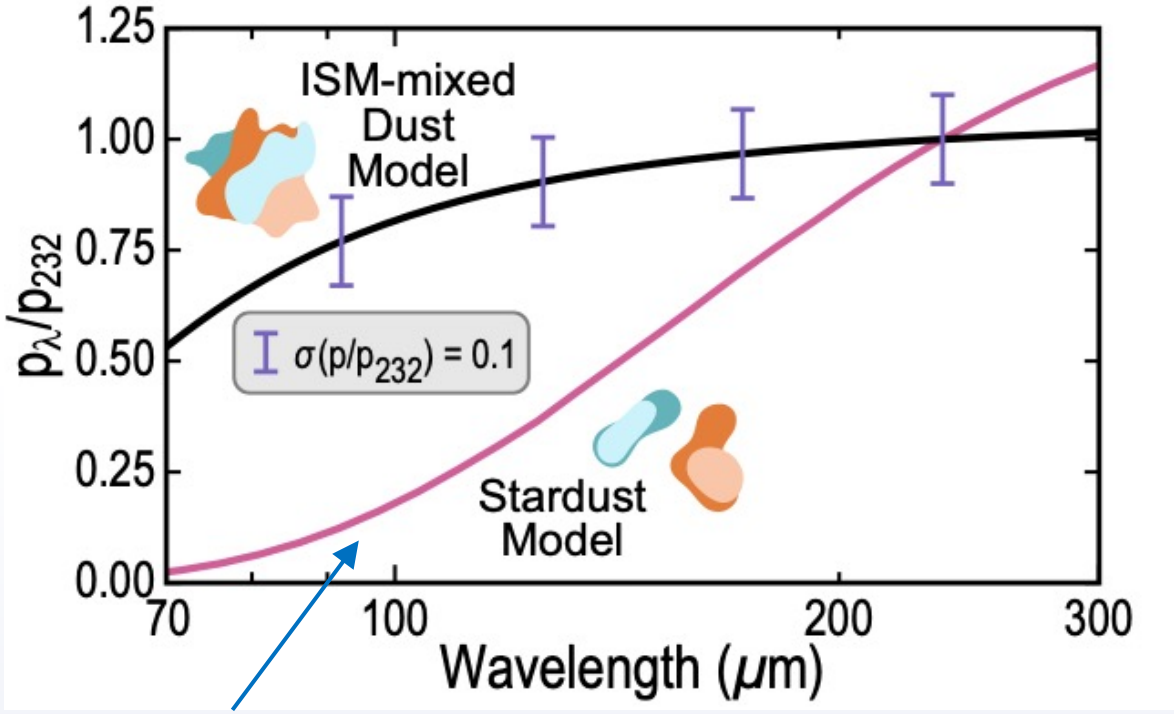
Survey



- Contours: Illustris TNG outflow model on PRIMA SPRITZ populations
- Requirement: detect 340 $M_\odot$ / yr (all HLIRGs should have this)
- Survey: 25 galaxies each in redshift bins z = 1-1.5 and z = 1.5-20

Interstellar Dust Grain Structure and Composition

How does the structure of interstellar dust change across environments in the local universe?

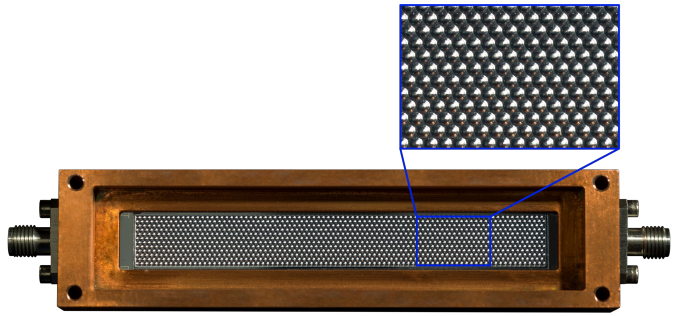


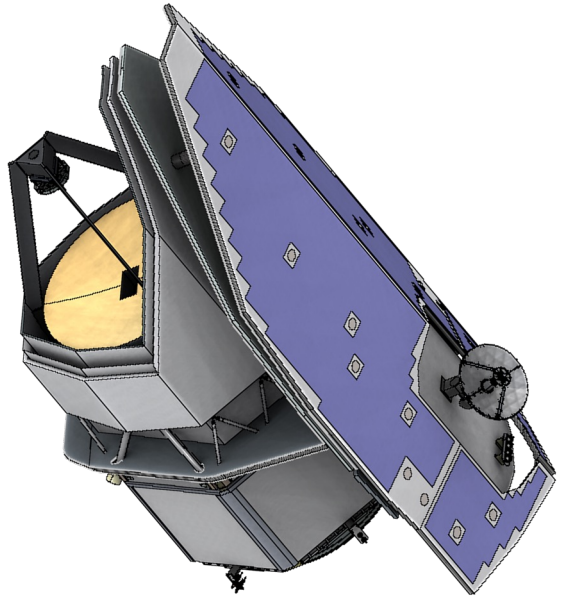
Warm, C-rich grains warmer than silicates and unpolarized

- Polarization:
  - Pristine stardust from C-rich AGB stars does not produce polarized emission.
  - Composite grains aggregating stardust with ISM-grown grains does.
- Test: Are ISM grain growth rates suppressed in low-metallicity galaxies/environments (→ low pol)?
- Survey: 91-232 μm polarization imaging of 31 local galaxies

Simple Take-Away Points

- The Far-IR provides unique probes of the cool ISM.
- PRIMA is poised to measure the coevolution of galaxies and their black holes, the buildup of dust and metals in the universe, and abundances in protoplanetary disks (PI science) and provide a broadly capable observatory for exciting GO science (*75% of the observing time*).
- With exciting results over the last several years, the detector technology is in hand.
- We have a mature design and are ready to proceed to Step 2!





Please consider how far-IR observations can address *your* science and talk to the PRIMA team!

https://prima.ipac.caltech.edu