Building on SOFIA'S Legacy, future far-infrared astronomy opportunities

SOFIA meeting – Stuttgart

Margaret Meixner

Jet Propulsion Lab, California Institute of Technology

Building on SOFIA’S Legacy, future far-infrared astronomy opportunities

- Landscape of far-infrared astronomy
- NASA Probe proposals
- PRIMA
- SALTUS
- Origins Space Telescope Study –Large NASA mission
- Summary

Far-Infrared Astronomy Historically

Learjet Observatory (late 1960s and 1970s) removable 12-inch (30.4cm) telescope

NASA Ames U2 (early 1970s)

IRAS Infrared Astron. Sat. (1983)
57cm telescope
scanning
12µm, 25µm, 60µm, 100µm

ISO Infrared Space Obs.
(1995-1998)
60cm telescope
2.5-240µm

Spitzer
(2003-2009)
(Warm mission - 2020)
70cm telescope
3-180µm

today

Astro2020: Far-IR important

cold

Spitzer

Akari
(2006-2011)
67cm telescope
1.7-180µm

c

Akari

Far-IR Flagship Origins?

Ames U2

IRAS

ISO

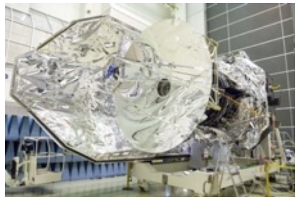
IRTS

MSX

Kuiper Airborne Observatory (1974-1995)
91cm telescope

Herschel
(2009-2013)
350cm telescope
50-500µm

Herschel



The **Convair 990** “Galileo” (1965-1973)

Learjet

Convair 990

Kuiper Airborne

SOFIA

SOFIA (2014-pres)
270cm Telescope

Far-IR Probe?

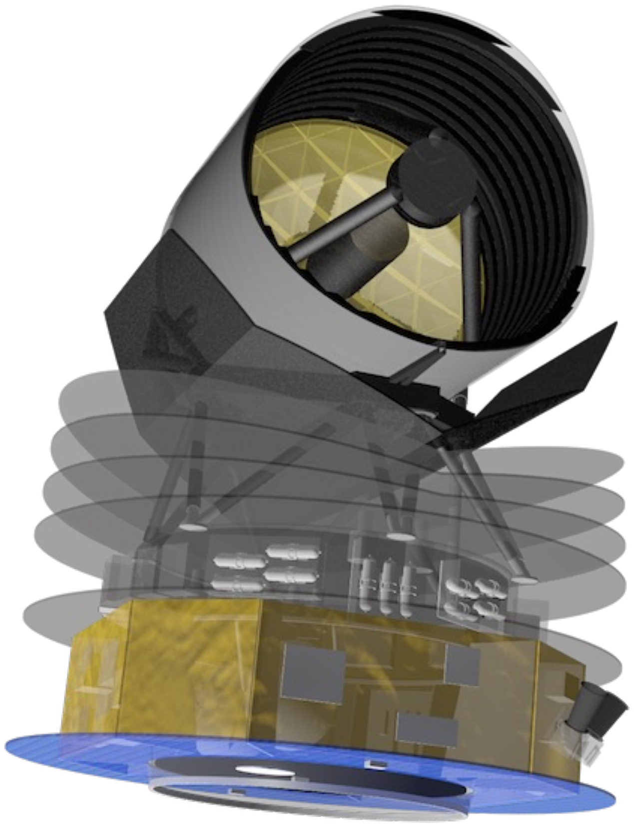
1960 1970 1980 1990 2000 2010 2020 2030 2040

Credit: Schulz

SPICA

- **ESA/JAXA mission**
- **2.5-m telescope**
- **T < 8 K**
- **l = 12 – 350 µm**
- **Instrumentation**
  - **MIR imaging/spectroscopy**
  - **FIR spectroscopy, imaging and polarimetry**

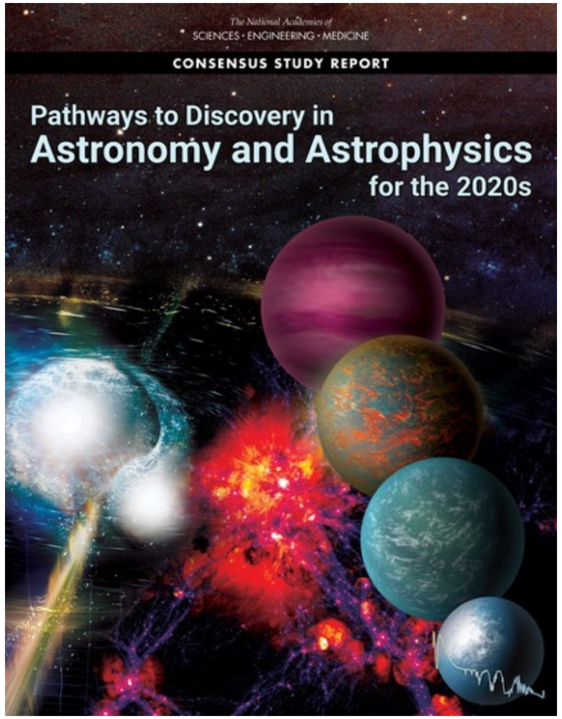
Cancelled during Phase-A study



Credit: Griffin

Astro2020 Decadal Survey Recommendations Concerning the Far Infrared

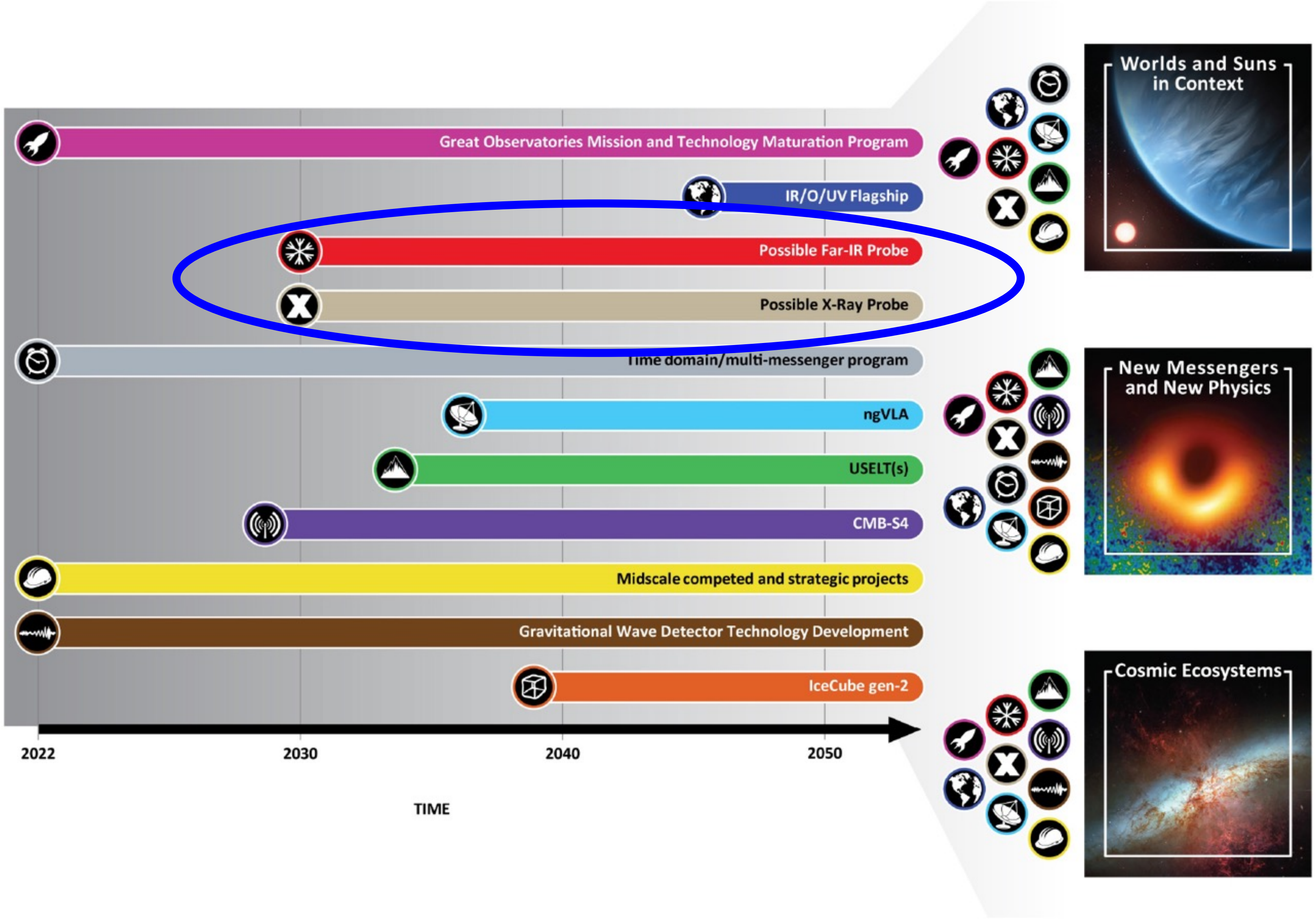
- **FIR Probe mission**
  - **Extremely timely and compelling**
  - **Gap in worldwide capabilities following SPICA cancellation**
  - **New technologies → major advances over Herschel**
  - **Formation and buildup of galaxies, dust aqnd metals**
  - **Planet formation**
  - **Co-evolution of galaxies and black holes**



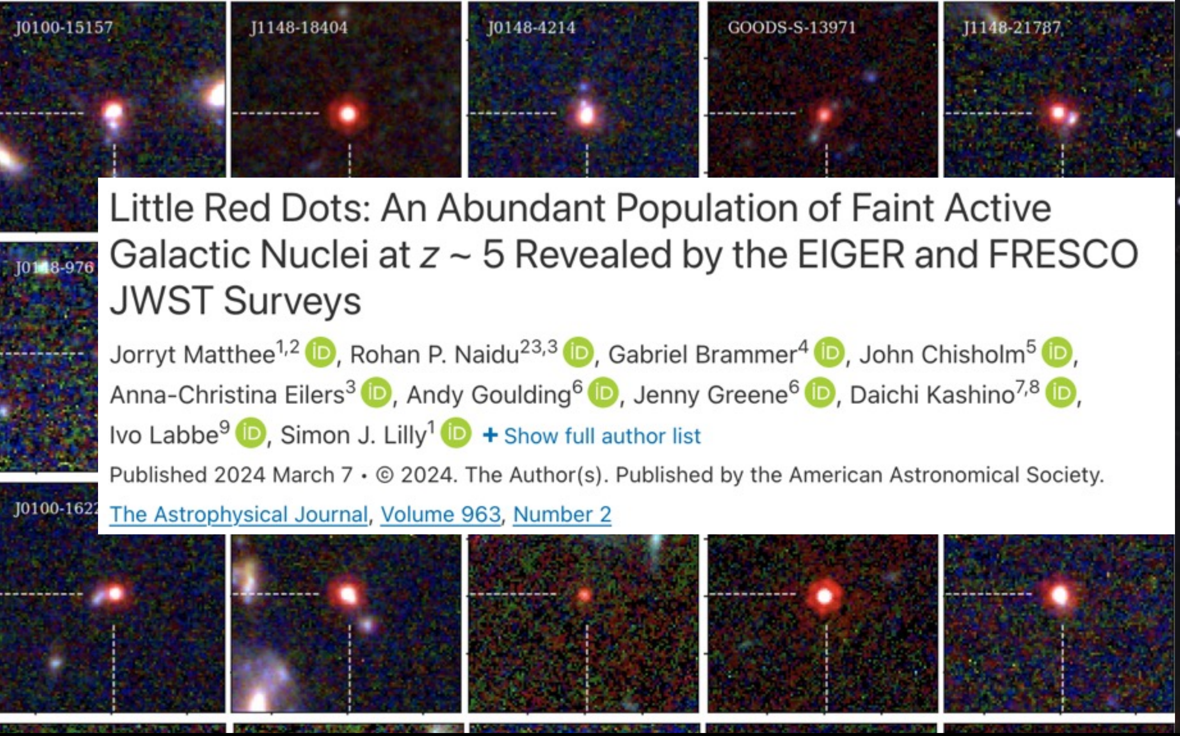
- **Origins-scale mission?**
  - **Five years after start of technology maturation programme for HWO, the same process should start for large FIR and X-ray missions**

Credit: Griffin

Decadal Survey Recommended Programme



Credit: Griffin



Little Red Dots: An Abundant Population of Faint Active Galactic Nuclei at $z \sim 5$ Revealed by the EIGER and FRESCO JWST Surveys

Jorryt Matthee[1,2], Rohan P. Naidu[23,3], Gabriel Brammer[4], John Chisholm[5], Anna-Christina Eilers[3], Andy Goulding[6], Jenny Greene[6], Daichi Kashino[7,8], Ivo Labbe[9], Simon J. Lilly[1] + Show full author list

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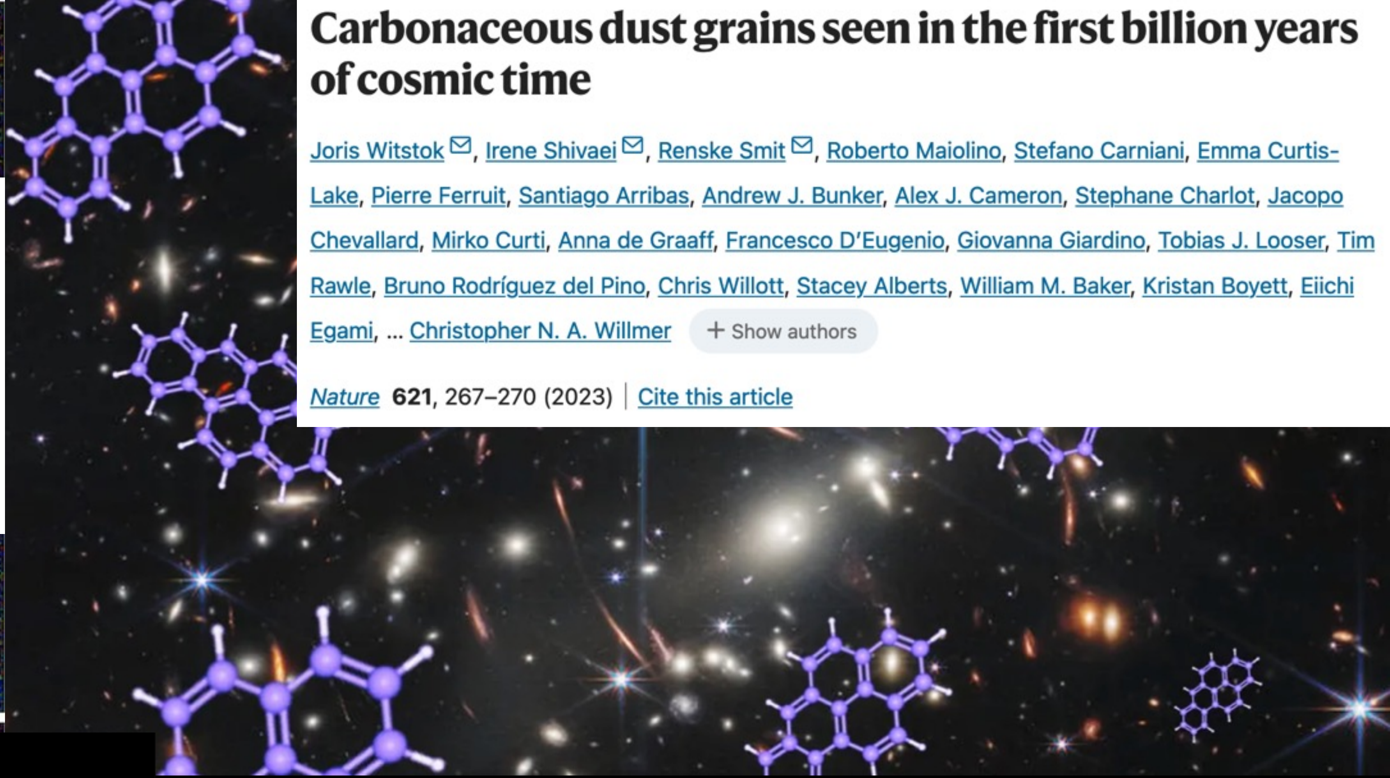
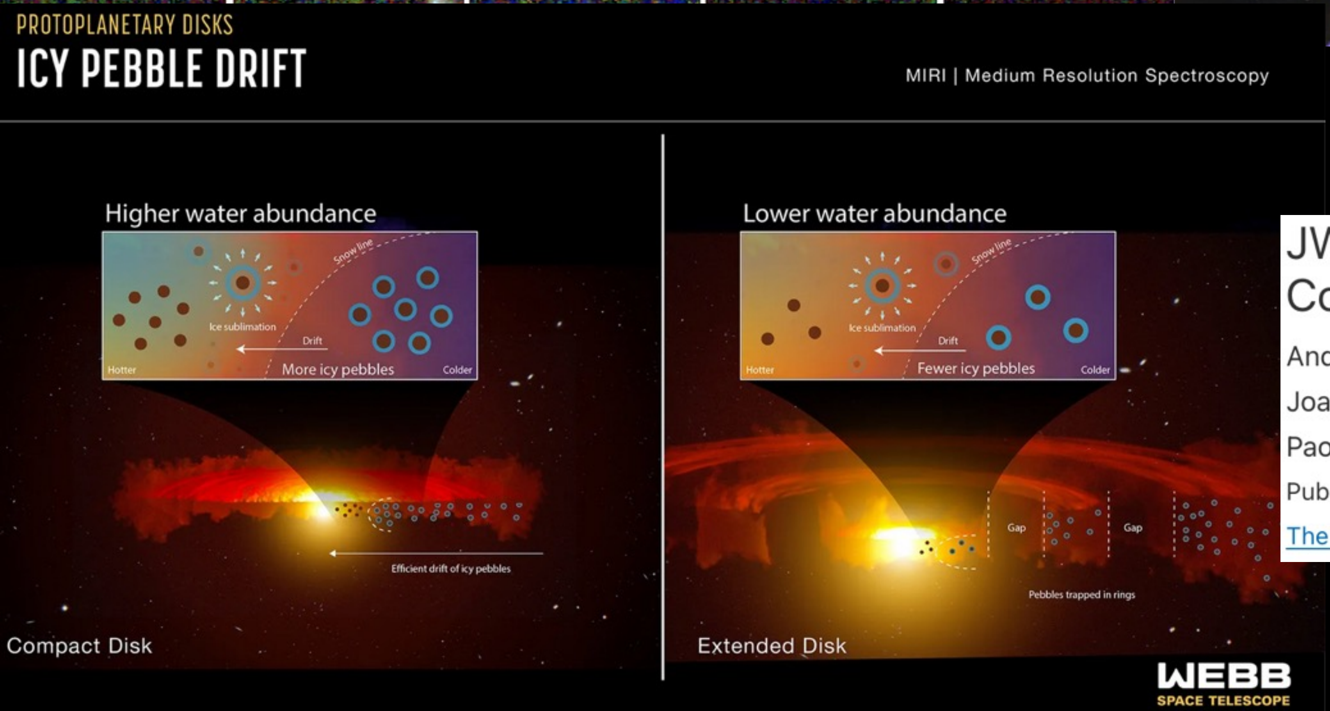


Carbonaceous dust grains seen in the first billion years of cosmic time

Joris Witstok, Irene Shivaei, Renske Smit, Roberto Maiolino, Stefano Carniani, Emma Curtis-Lake, Pierre Ferruit, Santiago Arribas, Andrew J. Bunker, Alex J. Cameron, Stephane Charlot, Jacopo Chevallard, Mirko Curti, Anna de Graaff, Francesco D'Eugenio, Giovanna Giardino, Tobias J. Looser, Tim Rawle, Bruno Rodríguez del Pino, Chris Willott, Stacey Alberts, William M. Baker, Kristan Boyett, Eiichi Egami, ... Christopher N. A. Willmer + Show authors

Nature **621**, 267–270 (2023) | Cite this article



JWST Reveals Excess Cool Water near the Snow Line in Compact Disks, Consistent with Pebble Drift

Andrea Banzatti[1], Klaus M. Pontoppidan[2], John S. Carr[3], Evan Jellison[1], Ilaria Pascucci[4], Joan R. Najita[5], Carlos E. Muñoz-Romero[7], Karin I. Öberg[6], Anusha Kalyaan[1], Paola Pinilla[7] + Show full author list

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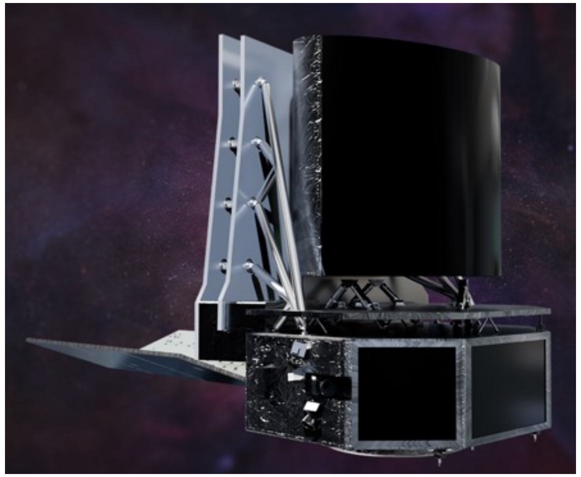
The Astrophysical Journal Letters, Volume 957, Number 2

Astrophysics Probe Explorer (APEX) Proposal Call

- **PI-led mission**
- **$1B cost cap**
- **Additional international contributions welcome**
- **Selection of missions for Phase-A study Q4 2024**
- **Phase-A study reports Q4 2025**
- **Selection of one mission Q2 2026**
- **Launch readiness no later than Mid-2032**
- **Three FIR Probe proposals and five X-ray proposals submitted in Nov. 2023**

Credit: Griffin

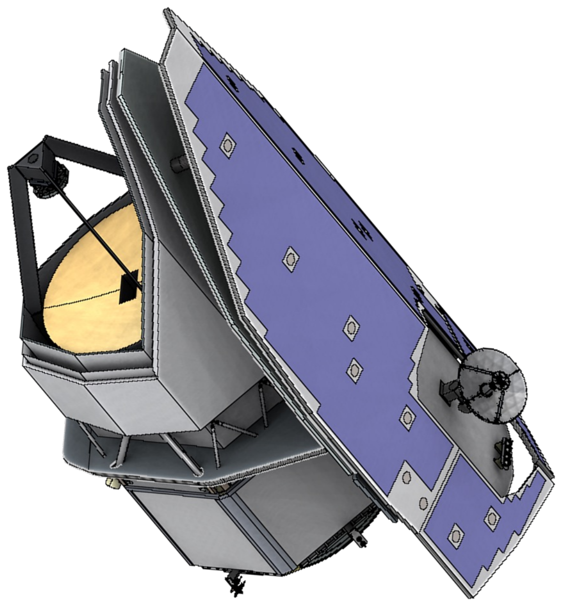
Far-InfraRed Spectroscopy Space Telescope (FIRSST)



- Key science objectives
  - Fingerprinting planetary reservoirs
  - Tracing water to rocky planets
  - Unveiling the drivers of galaxy growth
- 1.8-m primary cooled to < 8 K (CBE 4.7 K)
- Instruments
  - DDSI
    - R = 100 35 – 260 μm
    - R = 20,000 156 – 180 μm (CII and H_2O)
    - R ~ 100,000 two 10% BW channels for HD, OH, OI
    - MKID detectors
  - HSI
    - R = $10^6 – 10^7$
    - 3 bands 150 – 200; 240 – 340 ; 380 – 600 μm
    - HEB and SIS mixers
    - 5 pixels dual polarisation arrays in each band
- 5-year mission
- 75% GO time
- PI: Cooray

Credit: Griffin

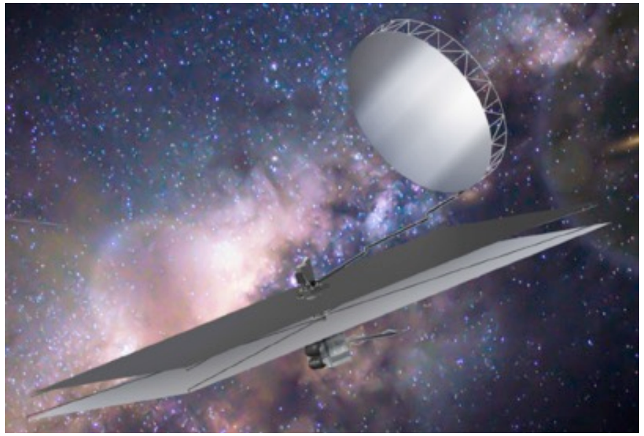
Probe far-Infrared Mission for Astrophysics (PRIMA)



Credit: Griffin

- **Key science objectives**
  - **Origins of planetary atmospheres**
  - **Evolution of galactic ecosystems**
  - **Buildup of dust and metals**
- **1.8-m primary cooled to 4.5 K**
- **Instruments**
  - **FIRESS**
    - **R > 85 24 – 235 μm**
    - **R = 4400(112 μm/λ) 24 – 235 μm**
    - **100-mK MKID detectors**
  - **PRIMAger**
    - **R ~ 10 25 – 80 μm hyperspectral imaging**
    - **Imaging 80 – 261 μm; 4 bands photometry/polarimetry**
    - **100-mK MKID detectors**
- **5-year mission**
- **75% GO time**
- **PI: Glenn (Deputy-PI: Meixner)**

Single Aperture Large Telescope for Universe Studies (SALTUS)



- **Key science objectives**
  - **Galaxy and BH co-evolution and metal production**
  - **Structure of PPDs and water trail from PPDs to planets**
- **14-m inflatable primary cooled to < 45 K**
- **Instruments**
  - **SAFARI-Lite**
    - **R = 300 34 – 230 μm**
    - **100-mK MKID detectors**
  - **HiRX**
    - **$R = 10^5 – 10^7$ 56 – 660 μm in 4 bands**
    - **HEB and SIS mixers**
- **5-year mission**
- **70% GO time**
- **PI: Walker**

Credit: Griffin

PRobe far-Infrared Mission for Astrophysics (PRIMA)

Who is PRIMA?

An international team of astrophysics and technology experts

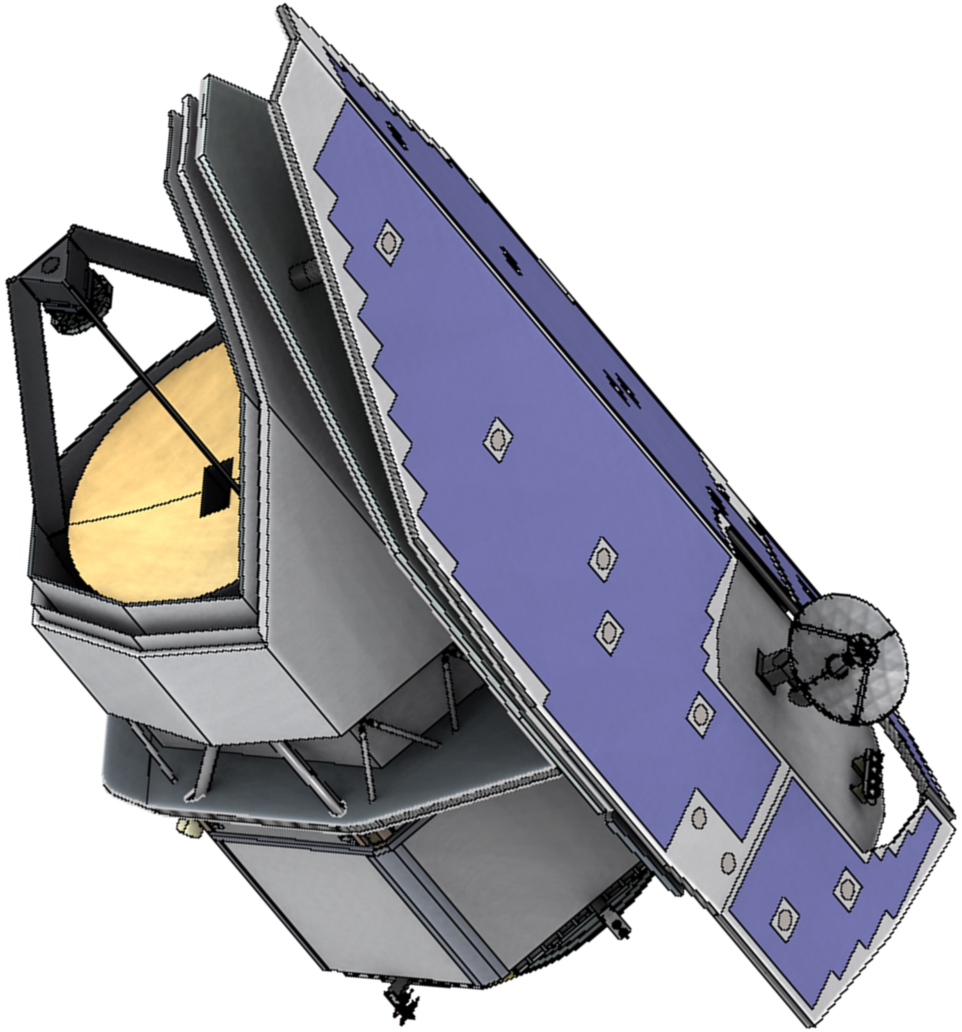
Co-I shown, plus a strong corps of engineers and scientists at JPL, GSFC, & BAE Systems

<u>Partner Institutions</u>

JPL
GSFC
BAE Systems
ASI / INAF
Cardiff
IPAC
LAM
MPIA
SRON

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)

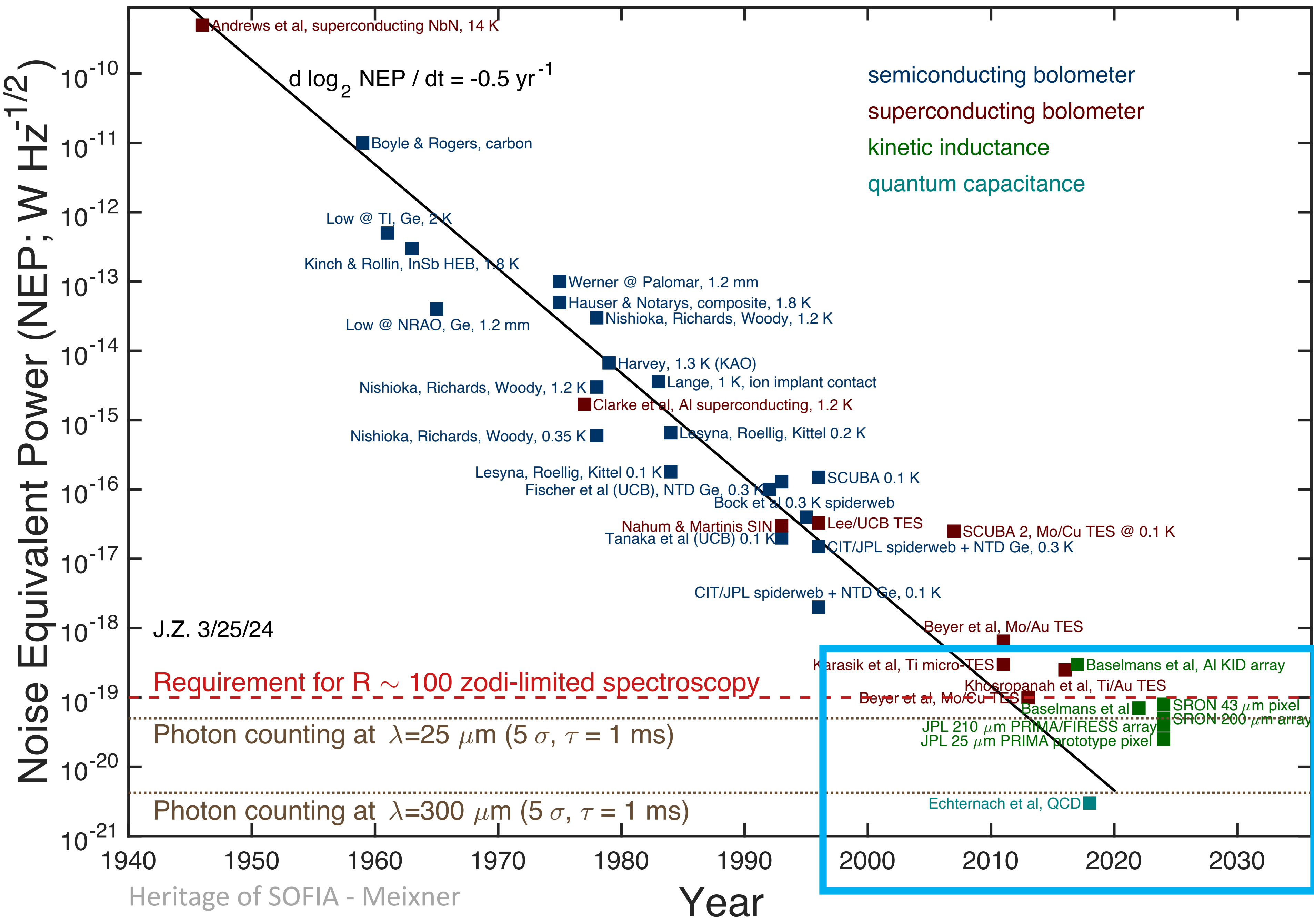


PRIMA Team

Stepping Back: FIR Detector Technological Readiness

Sensitivities of far-IR detectors have doubled every two years for 75 years and *exceed PRIMA requirements*

Probe region of interest



Heritage of SOFIA - Meixner

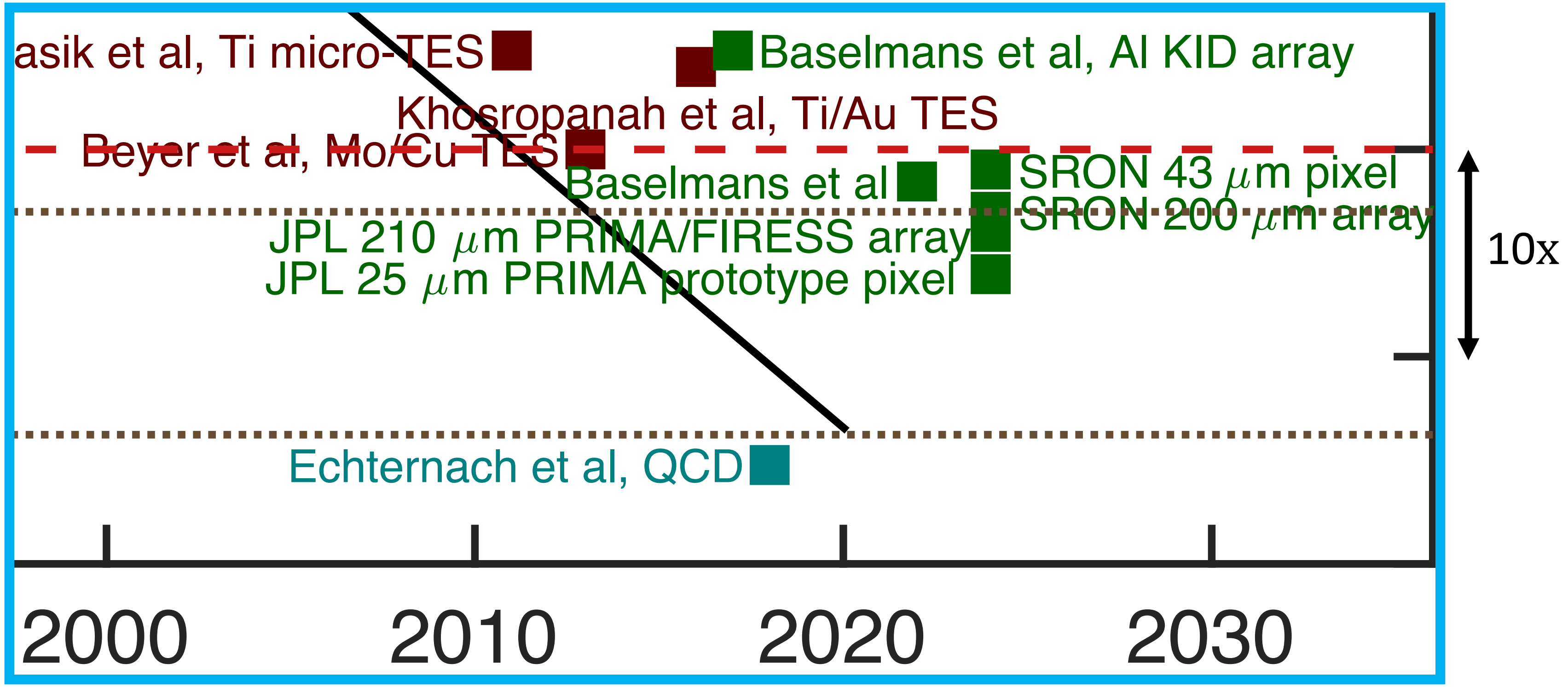
The timing is perfect for a background-limited Far-IR Observatory

Our JPL / Goddard / SRON collaboration has demonstrated 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!)



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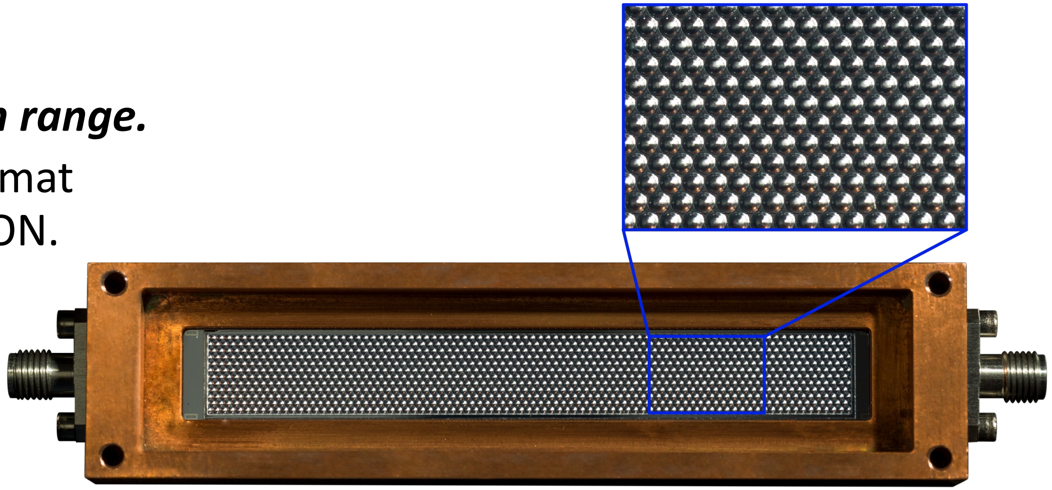
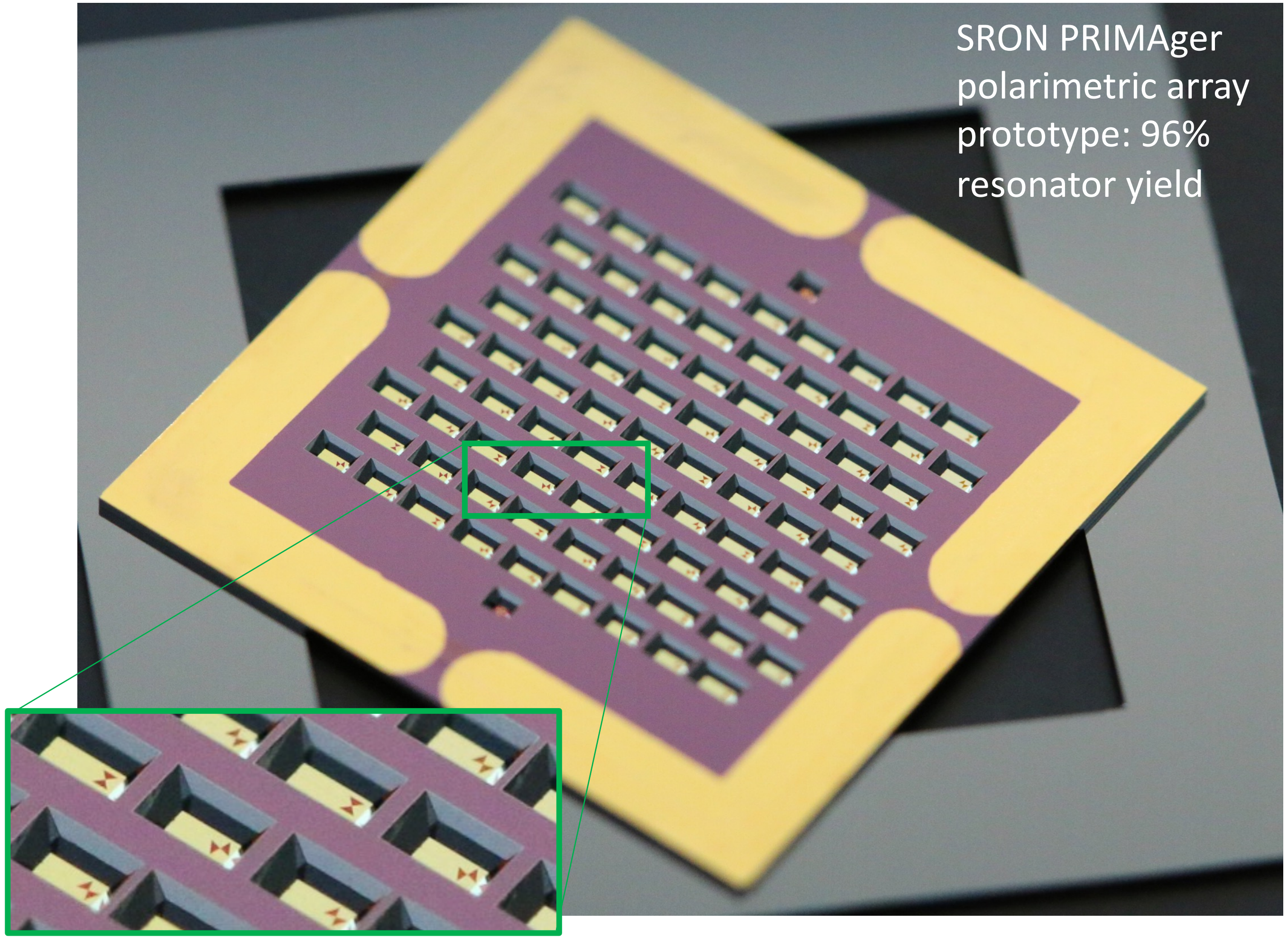
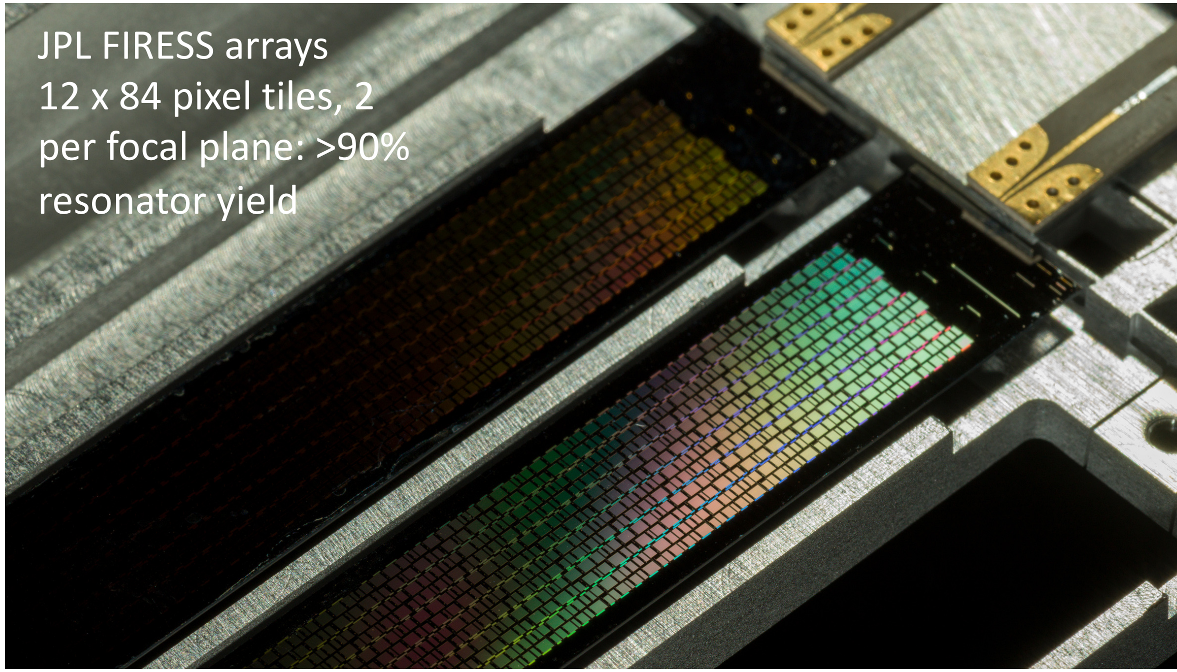
KID Detectors: JPL / GSFC / SRON Collaboration for PRIMA

- ***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 SRON.







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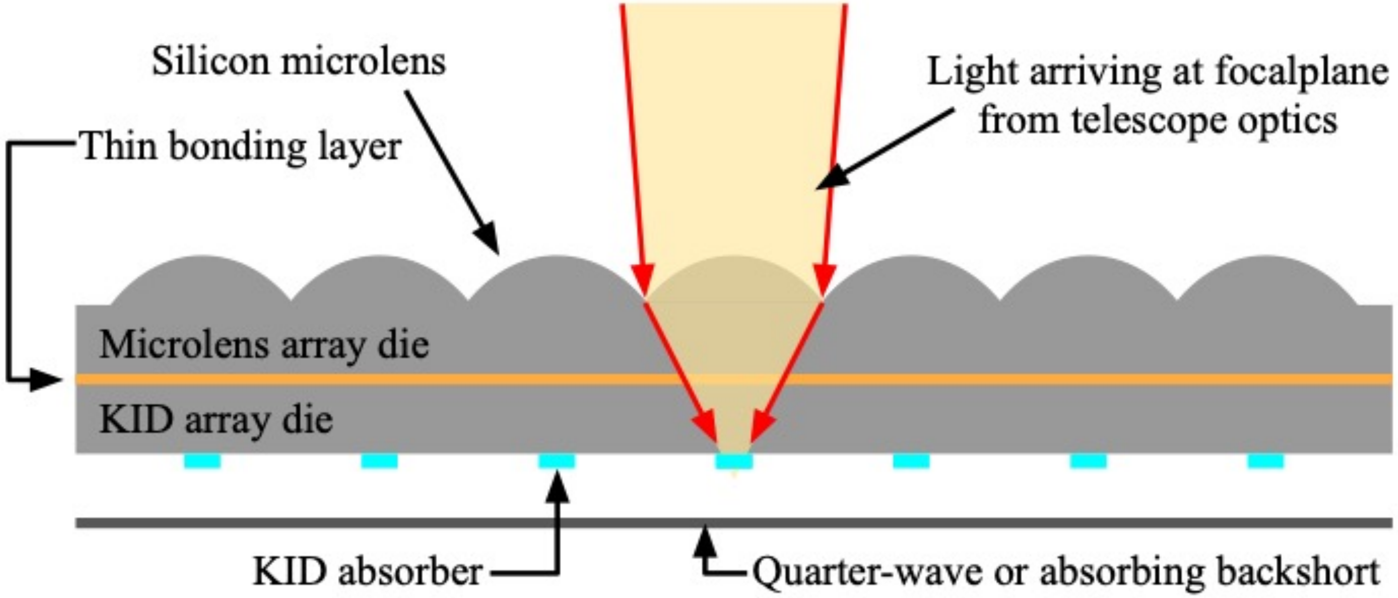
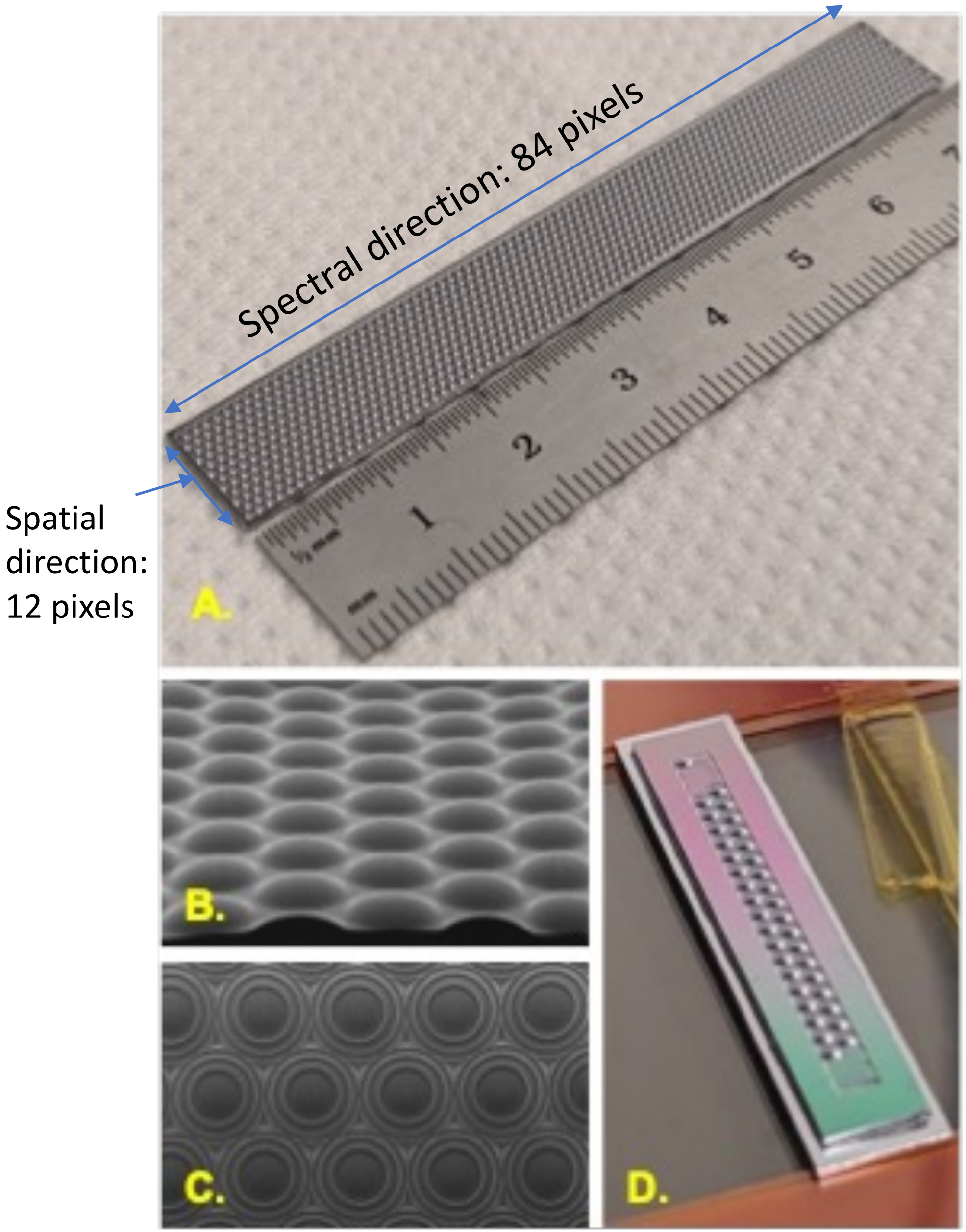
Microlens Arrays & Hybridization



Goddard team has developed greyscale-etched microlens arrays & hybridization technique.

Accuracy across the bulk of each lens is better than 2 microns.

Cothard et al. (2024)



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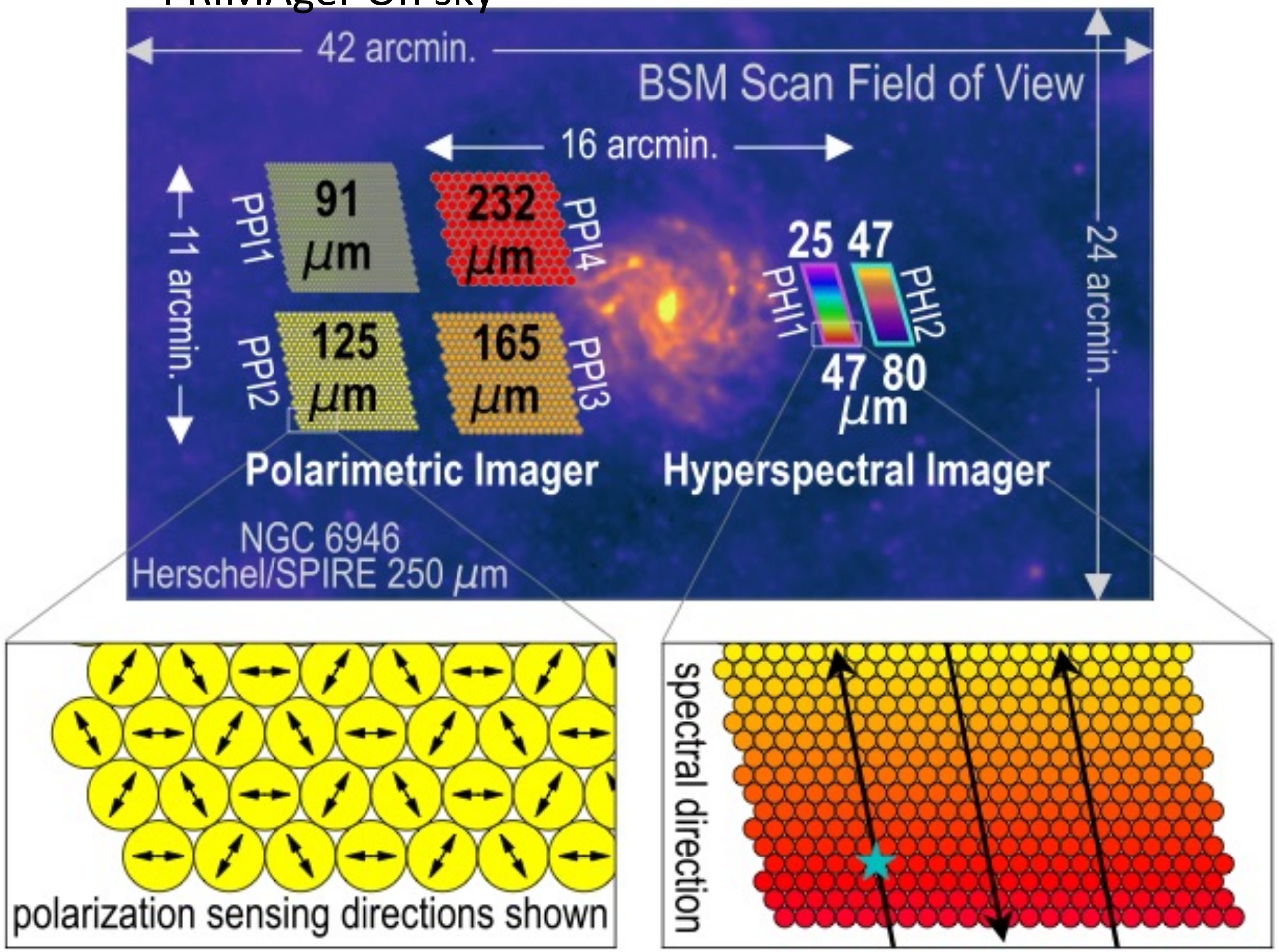
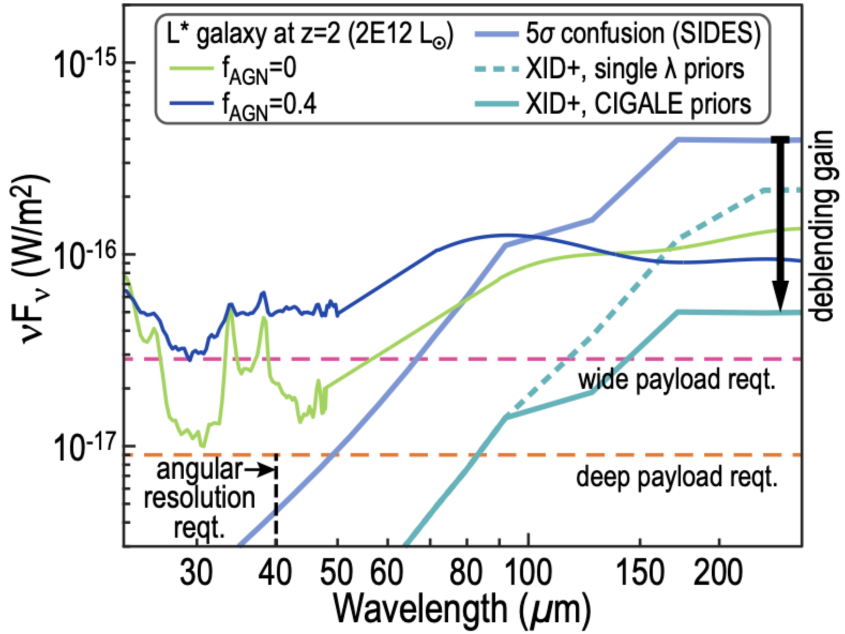
PRIMAger: hyperspectral Imager and Polarimeter

PRIMAger On sky

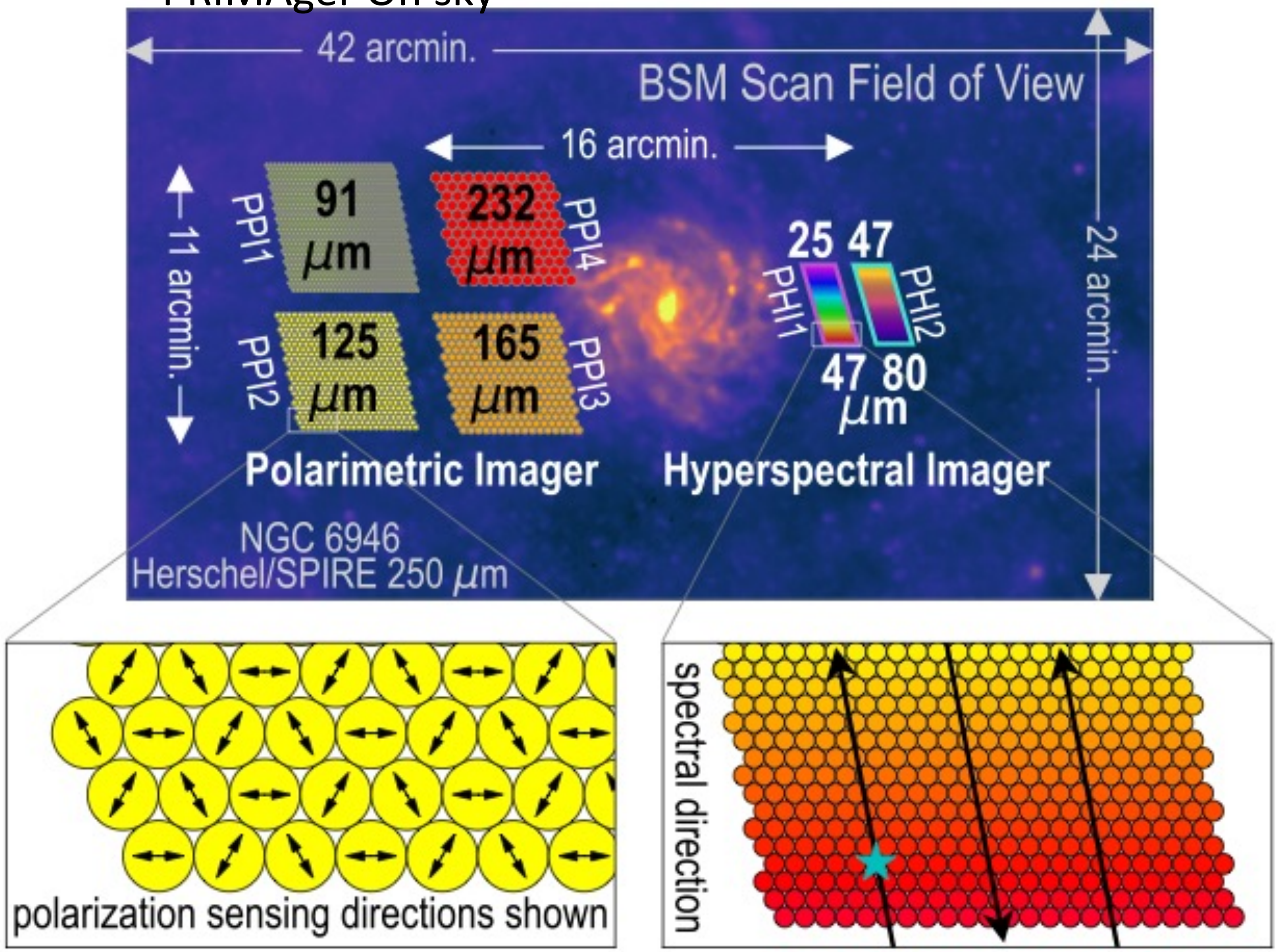


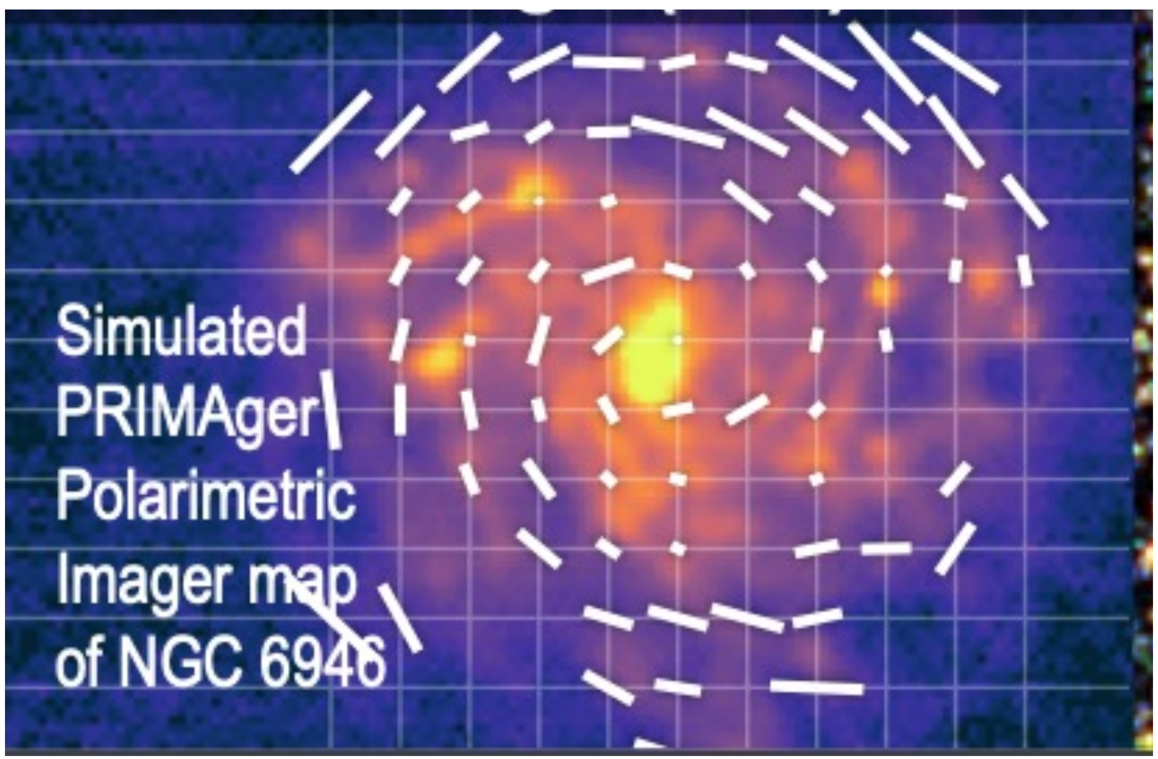


- 2 hyperspectral focal planes using linear variable filters with continuous R=10 coverage.
- 4 single-band polarimetric focal planes
- Whole instrument read out simultaneously.

PRIMAger: hyperspectral Imager and Polarimeter

PRIMAger On sky

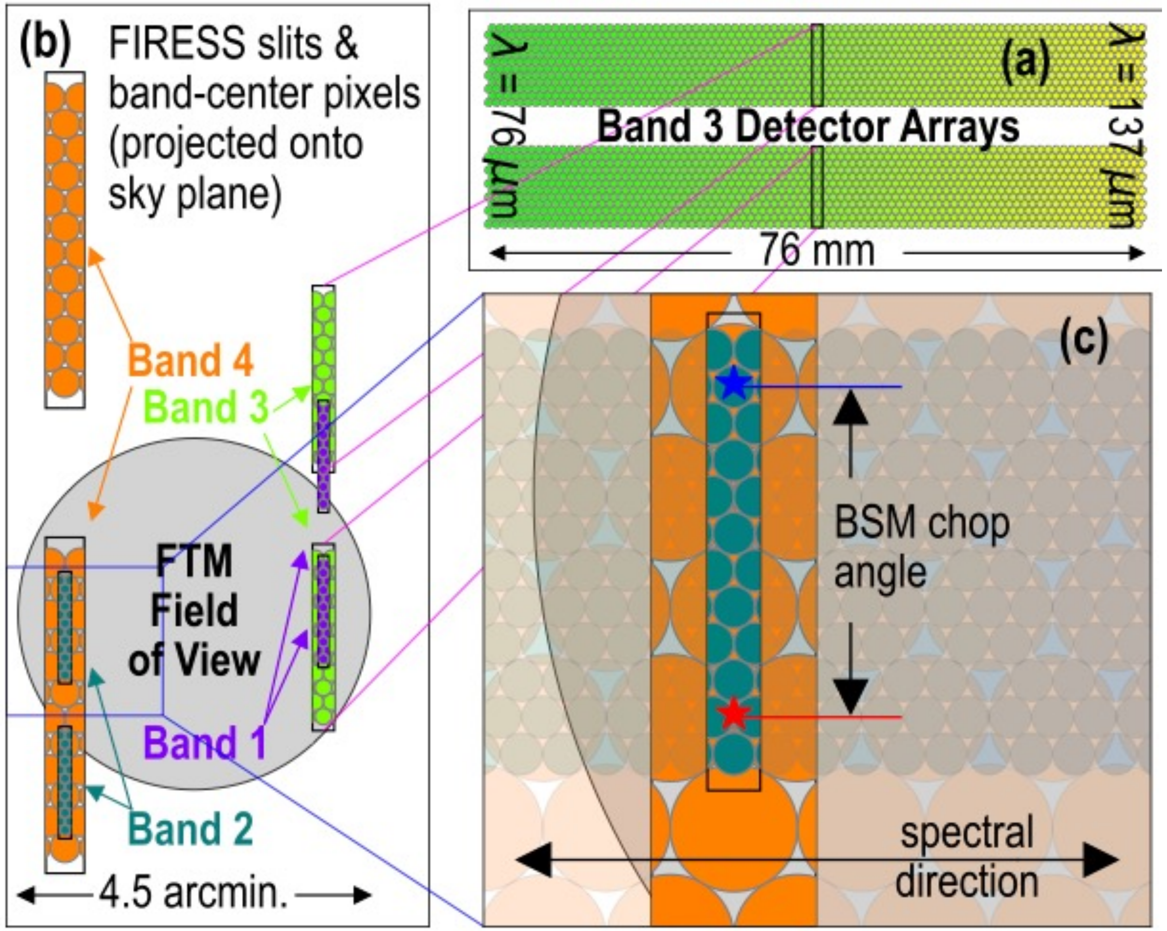


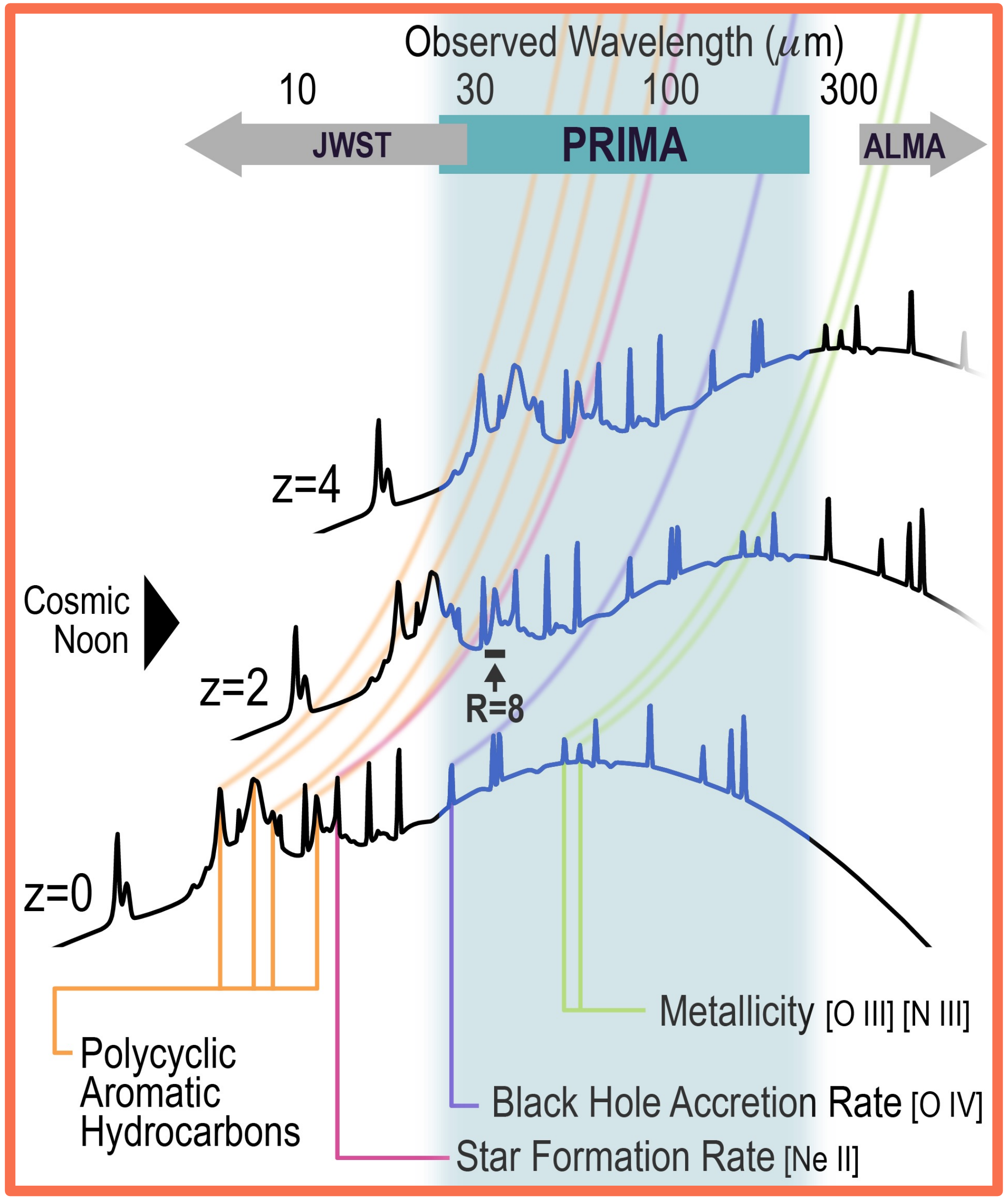


- 2 hyperspectral focal planes using linear variable filters with continuous R=10 coverage.
- 4 single-band polarimetric focal planes
- Whole instrument read out simultaneously.

Heritage of SOFIA - Meixner

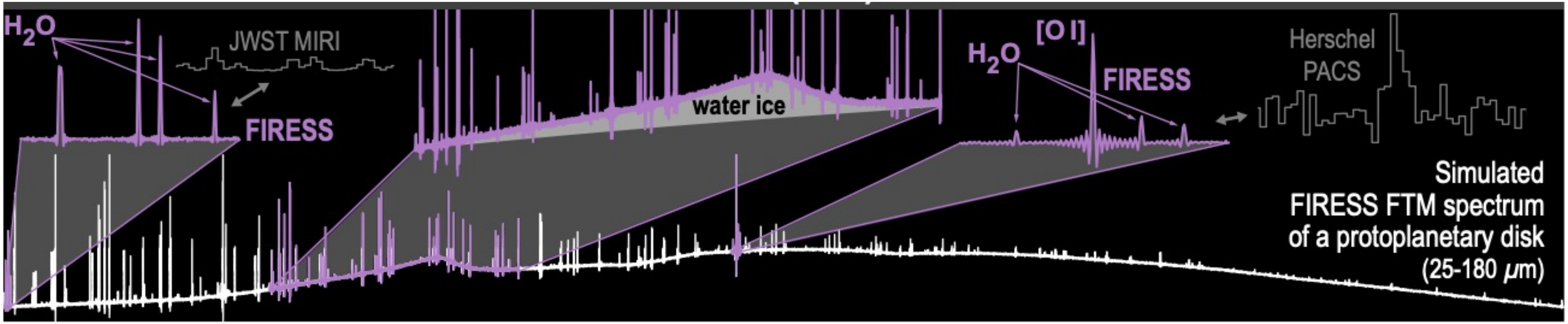
FIRESS: Spectrometer





- 4 slit-fed grating modules, each 24 x 84 pixels w/ gap.
- Bands 1 and 3 overlap, Bands 2 and 4 overlap.
- 2 pointings for full spectrum, though all 4 bands read out.
- High-res mode couples all bands when engaged

FIRESS high-res FTM module

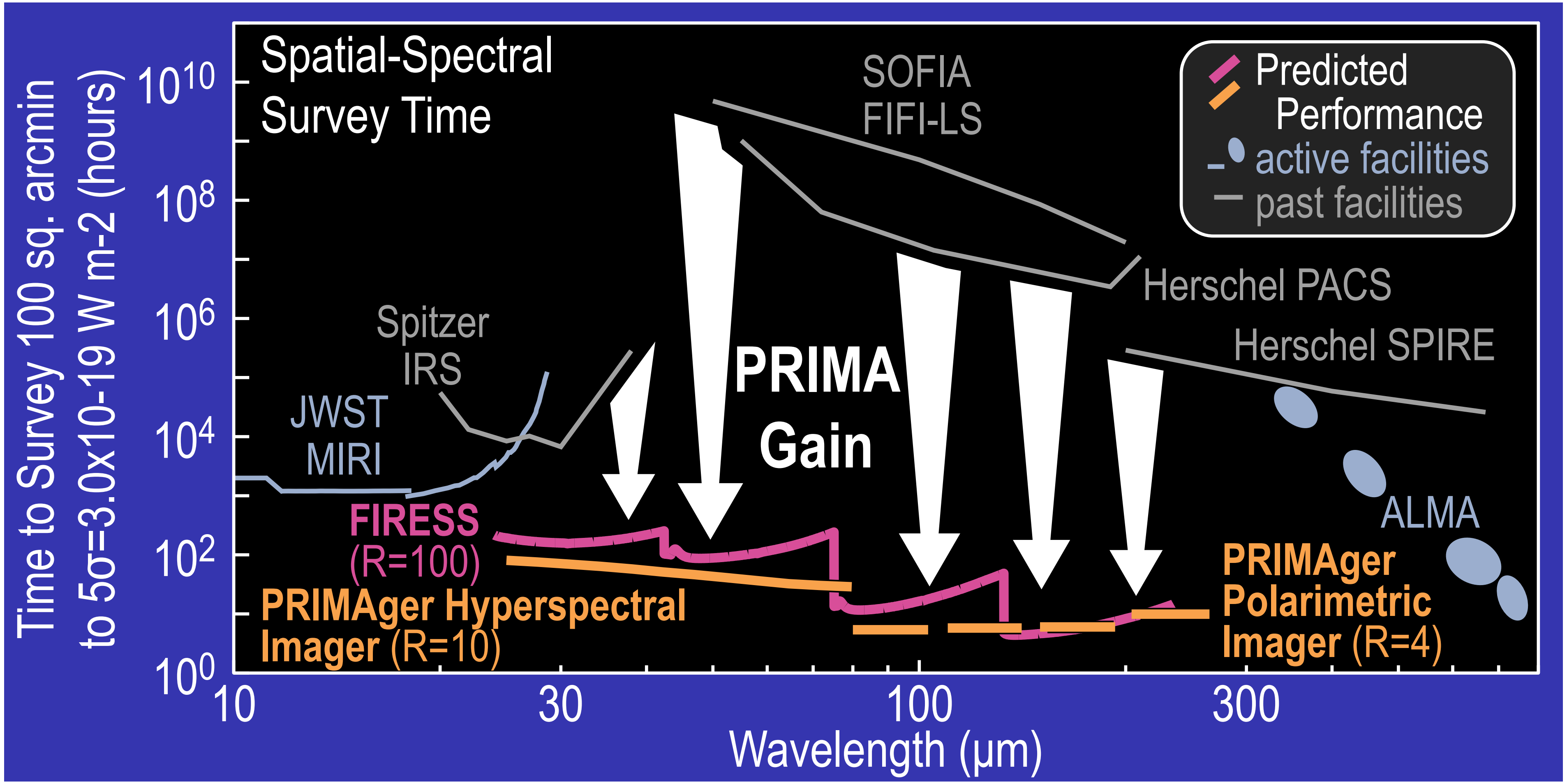


- When engaged, picks off light from telescope in collimated space
- Serves the full band simultaneously (2 pointings required for a source)
- Path length can be tuned, provides up to R=4,400 at 112 microns
- R scales as 1/lambda.   So can resolve water lines in Band 1.

Heritage: Herschel SPIRE FTS also 4.5 K imaging FTS.
(Griffin et al.)
Same Canadian team developing the low-power-dissipation scan mechanism.

Large Gains and New Capabilities from Per-Pixel Sensitivity Gains & Kilopixel Arrays

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



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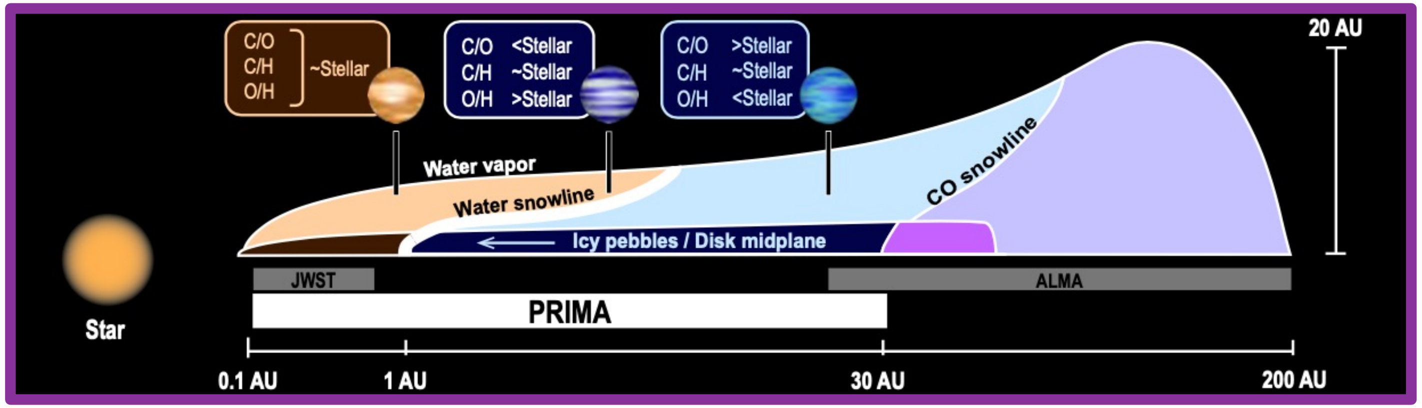
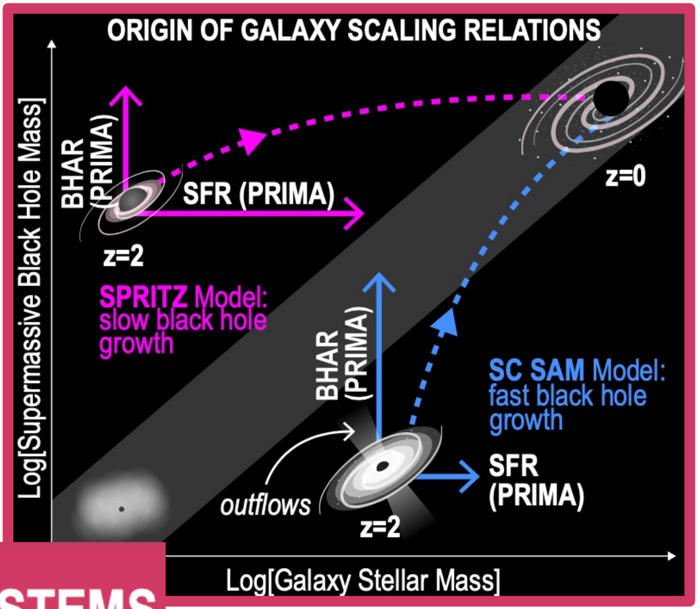
Astro2020 Decadal Survey Section 7.5.3.3 :

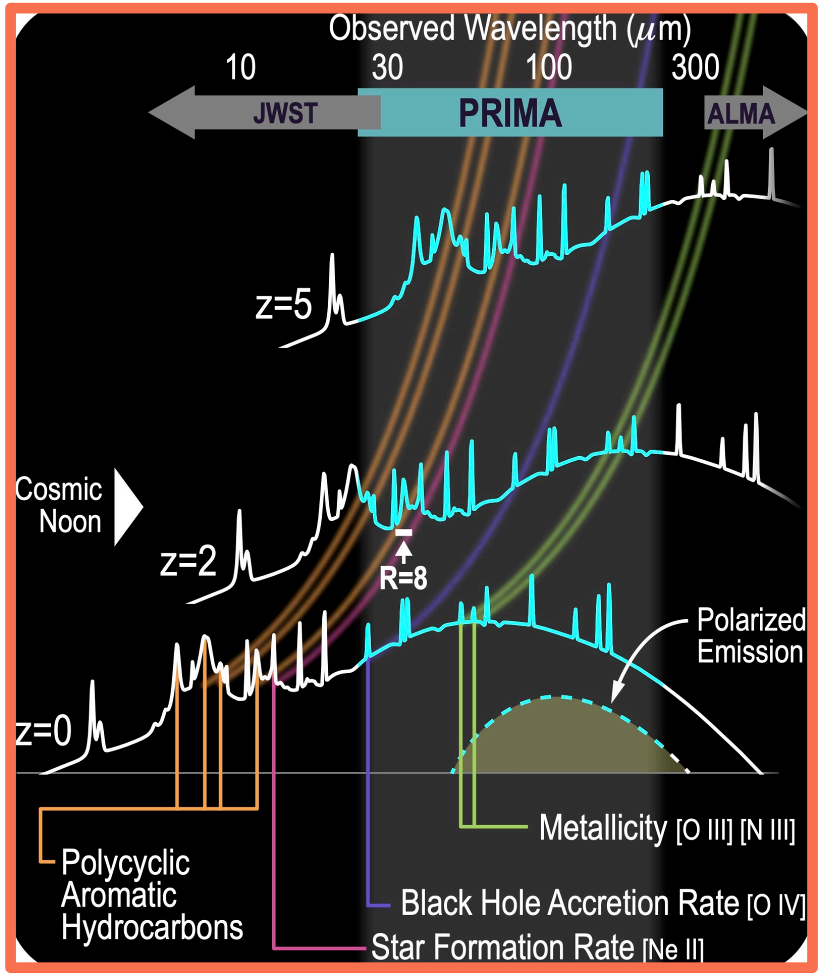
and a probe scale mission is an extremely timely and compelling opportunity to do so. These scientific areas include tracing the astrochemical signatures of planet formation (within and outside of our own Solar System), measuring the formation and buildup of galaxies, heavy elements, and interstellar dust from the first galaxies to today, and probing the co-evolution of galaxies and their supermassive black holes across cosmic time. These goals are all central to the broader scientific themes of the survey. The



ORIGINS OF PLANETARY ATMOSPHERES

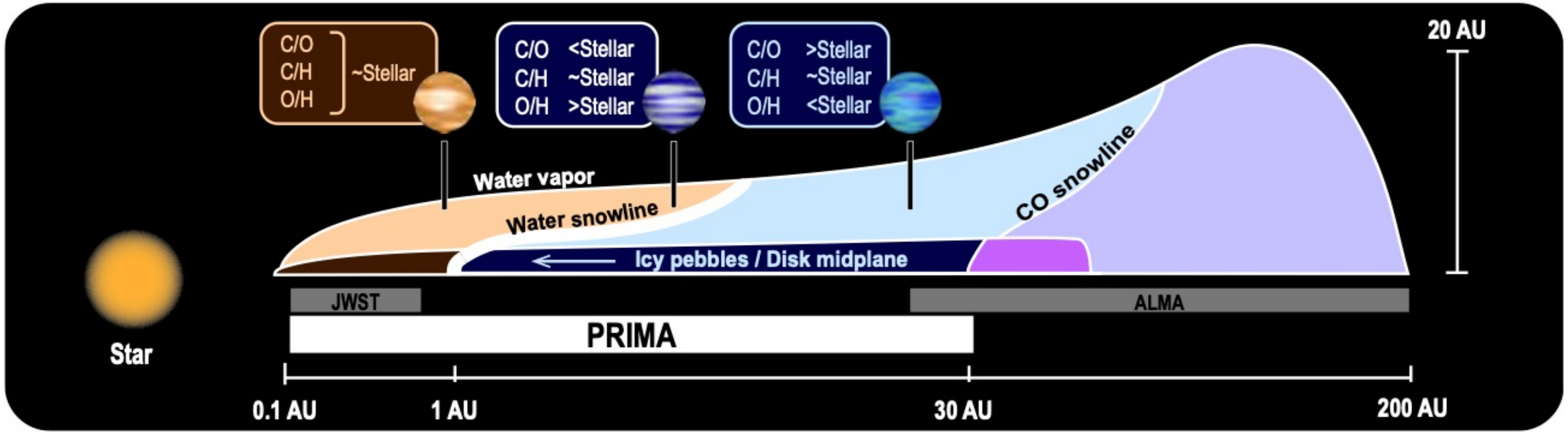


EVOLUTION OF GALACTIC ECOSYSTEMS



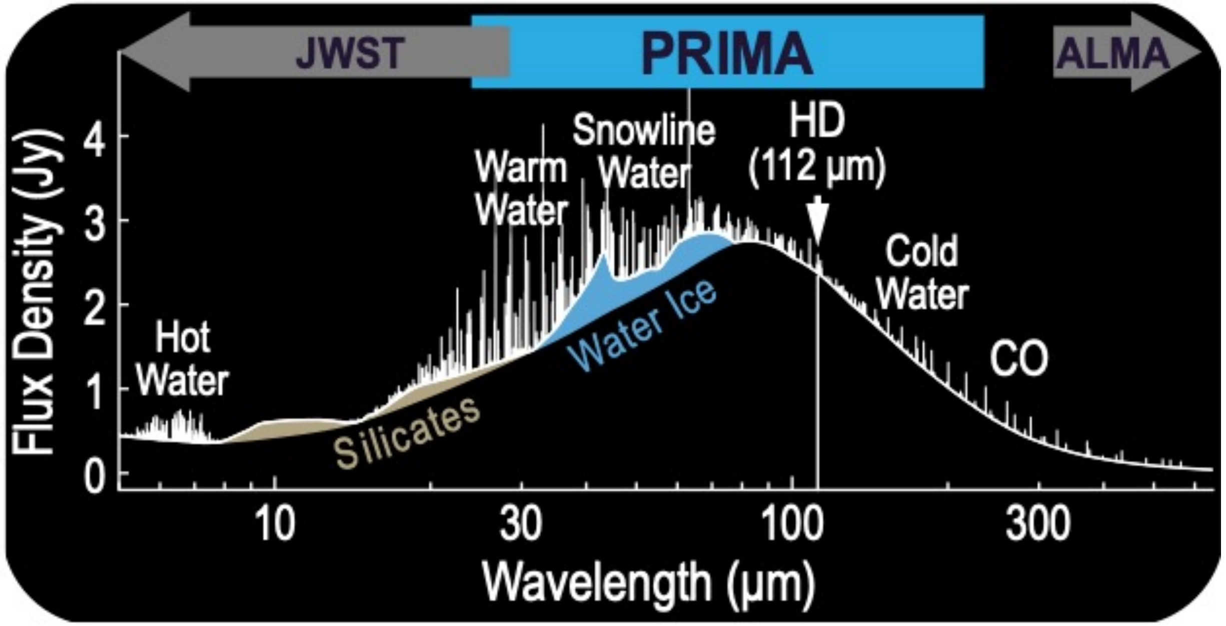
BUILDUP OF DUST AND METALS

Background: Protoplanetary Disk Structure and Spectra



Unknowns and uncertainties

- Disk masses
- Elemental abundances
- Water vapor content and distribution



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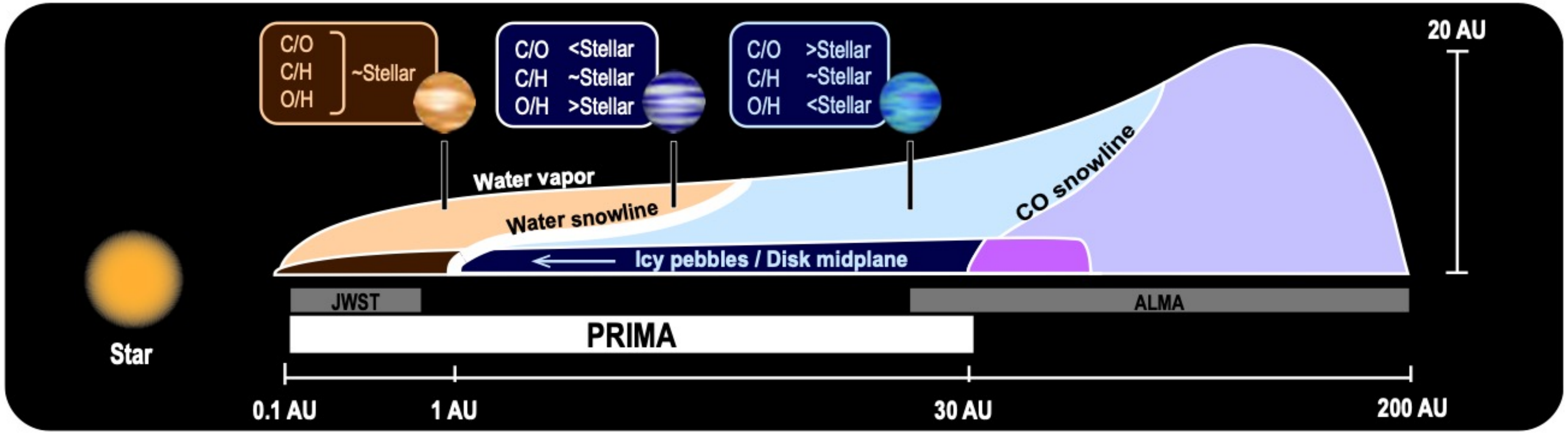
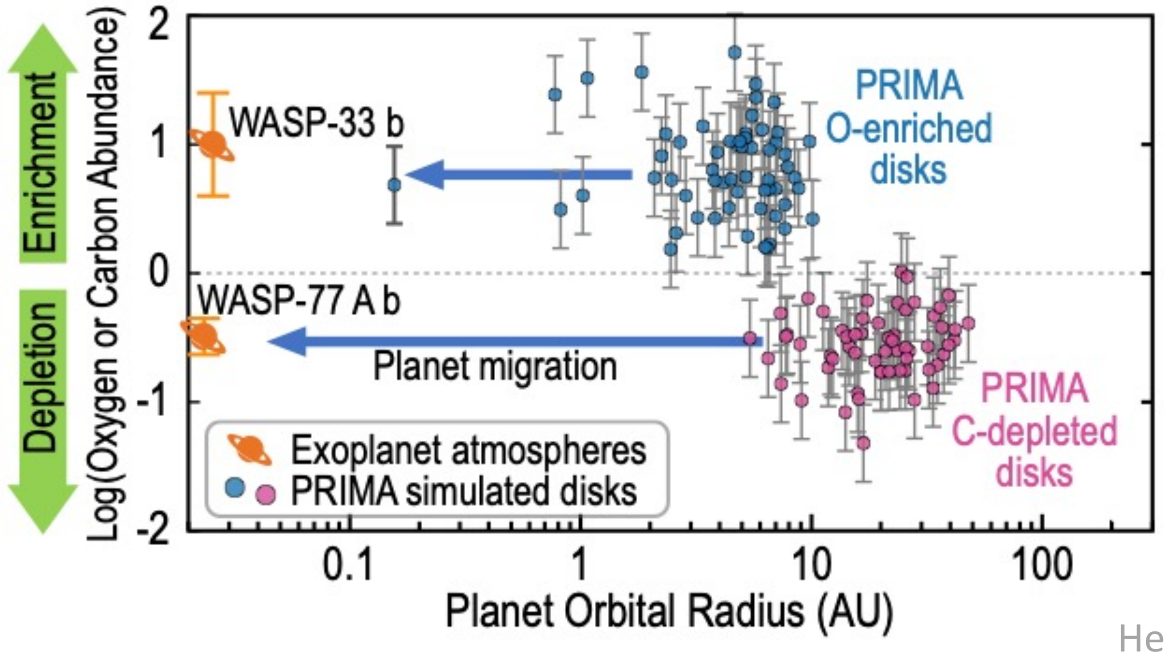
Linking exoplanet atmospheric abundances to their disk origins: Do protoplanetary disks have non-solar carbon and oxygen abundances where most planets form?





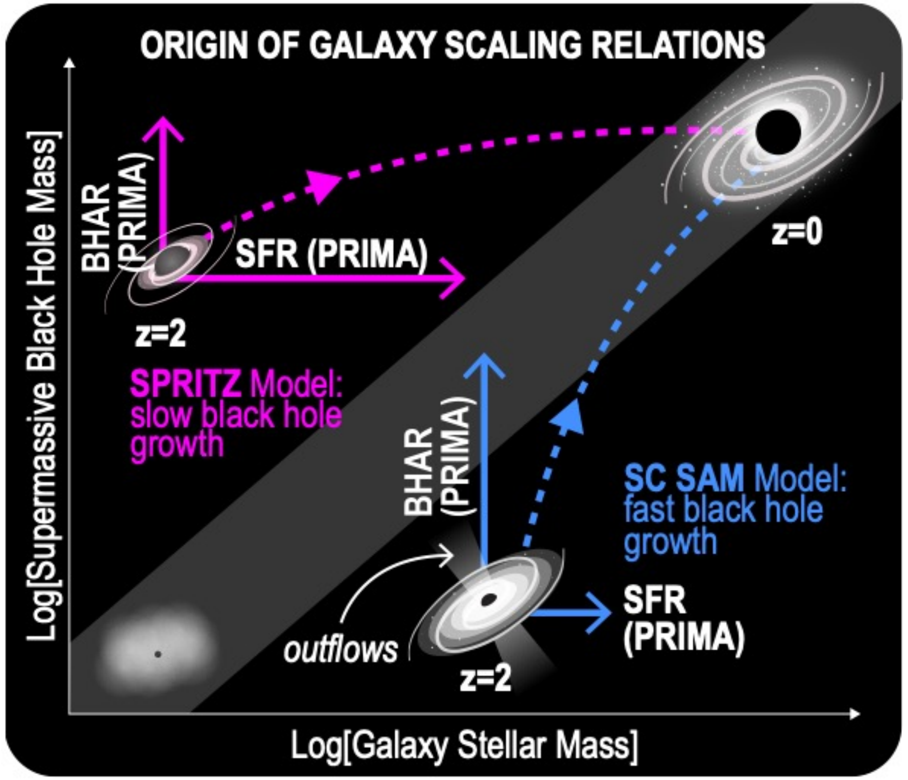
- H_2 mass derived from HD (112 μm), temperatures from existing ALMA CO or CI
- Oxygen derived from water (PRIMA) and carbon from existing CO ALMA observations
- 200 disks of various ages

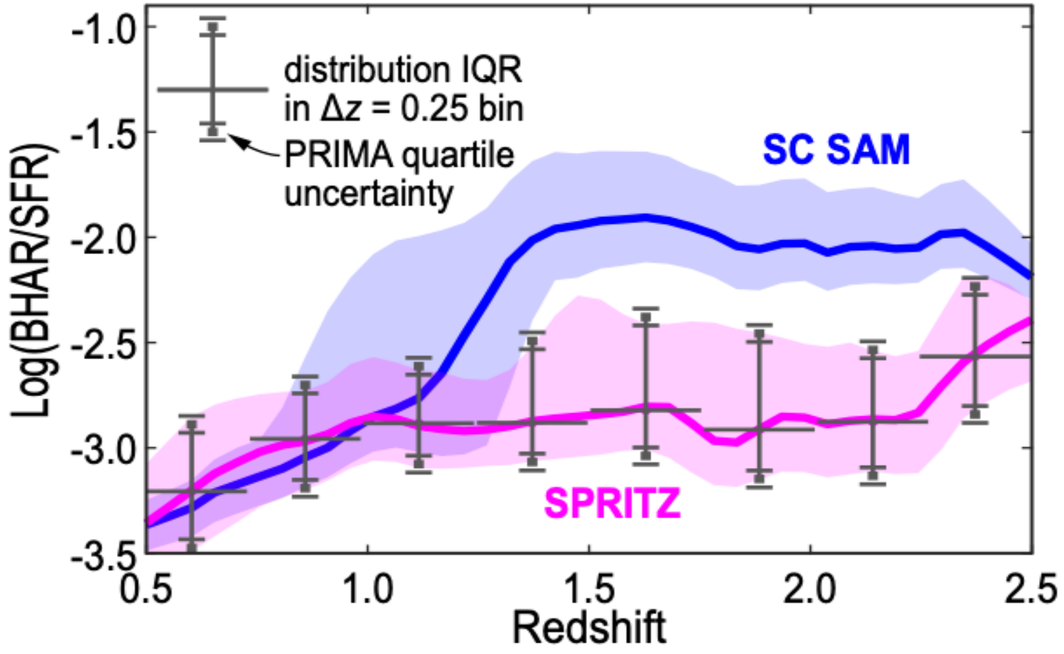
PRIMA's disk survey simulated as two sub-samples with expected error bars. Few measured disks have $\pm$1 dex or more uncertainty.

Galaxy Evolution: What is the scaling relation between black-hole accretion rate and star-formation rate in luminous galaxies since the peak epoch (z = 0.5-2.5)?

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

⇒ Redshifted mid-IR and far-IR spectral energy distributions 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 et al., 2019)
- Verified with spectroscopic sub-samples of 160 z = 1.0-2.5 galaxies using [O IV] and [Ne II] (rest frame 26 & 12.8 μm)

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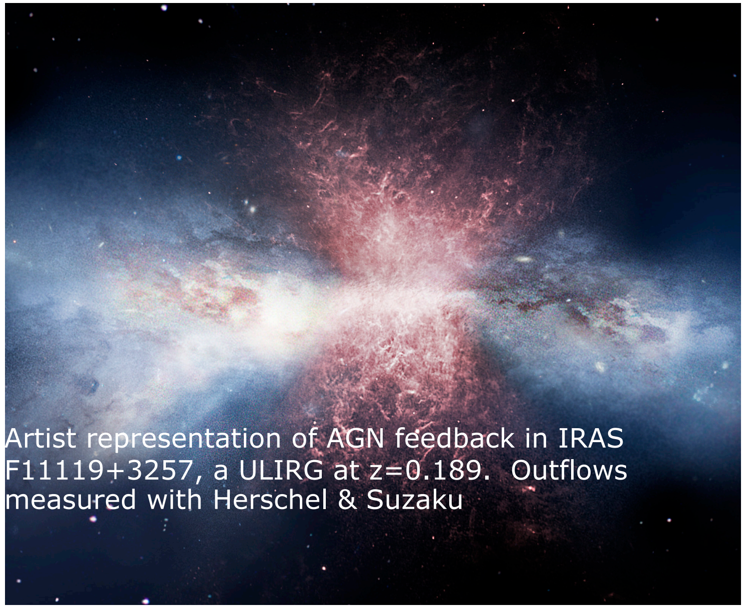
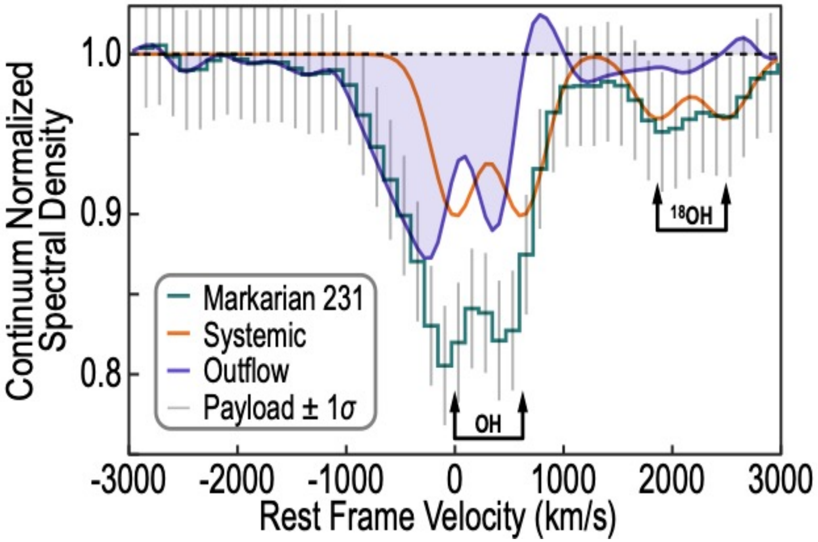
Evolution of Galactic Ecosystems: Can outflows quench z = 1-2 star formation?

Models



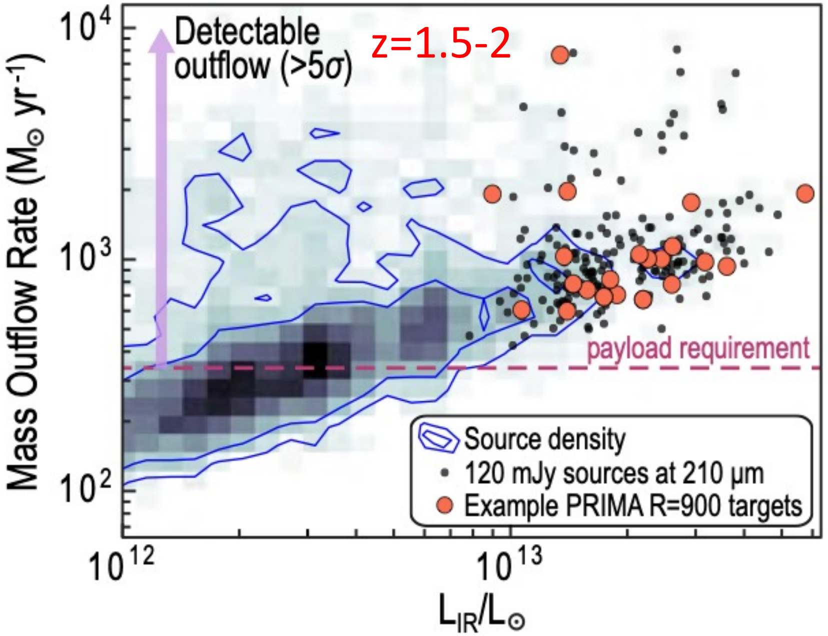
- Models require winds ejecting gas to quench star formation in massive galaxies
- Need velocities and mass outflow rates to test models
- Cool component (T<10,000K) dominates the mass

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

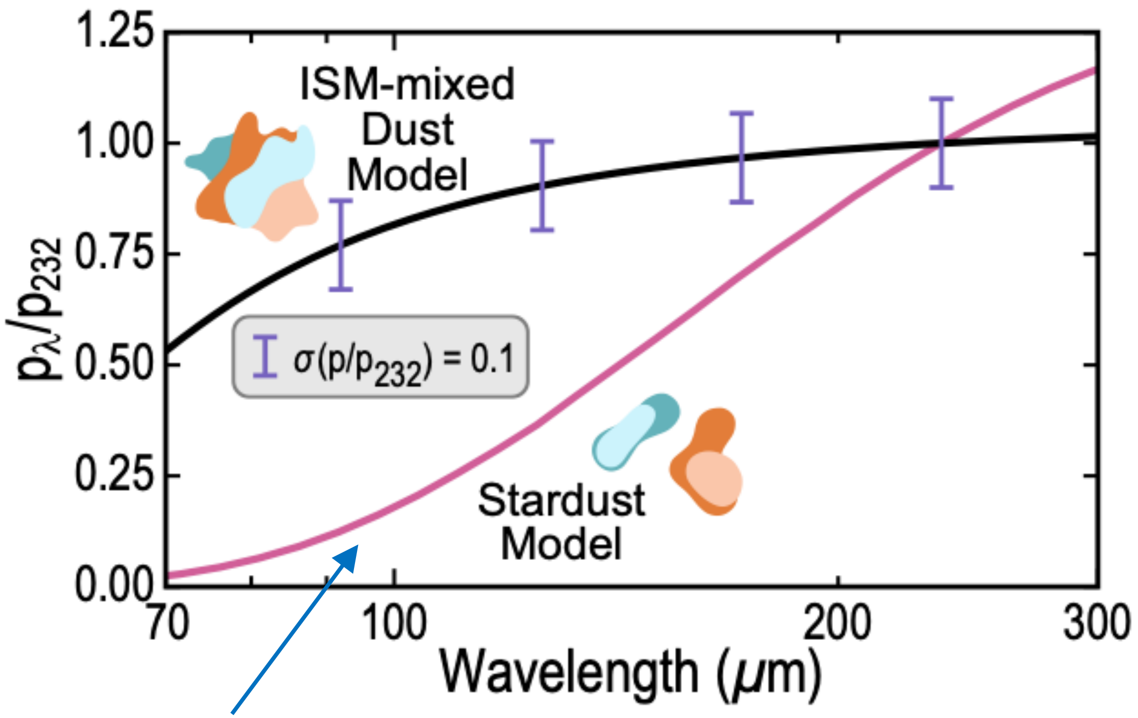
Survey



- Contours: Illustris TNG outflow model on PRIMA SPRITZ populations
- Requirement: detect 340 $M_{\odot}$ / yr (all HLIRGs should have this)
- Survey: 16 galaxies each in 2 redshift bins

Interstellar Dust Grain Structure and Composition

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

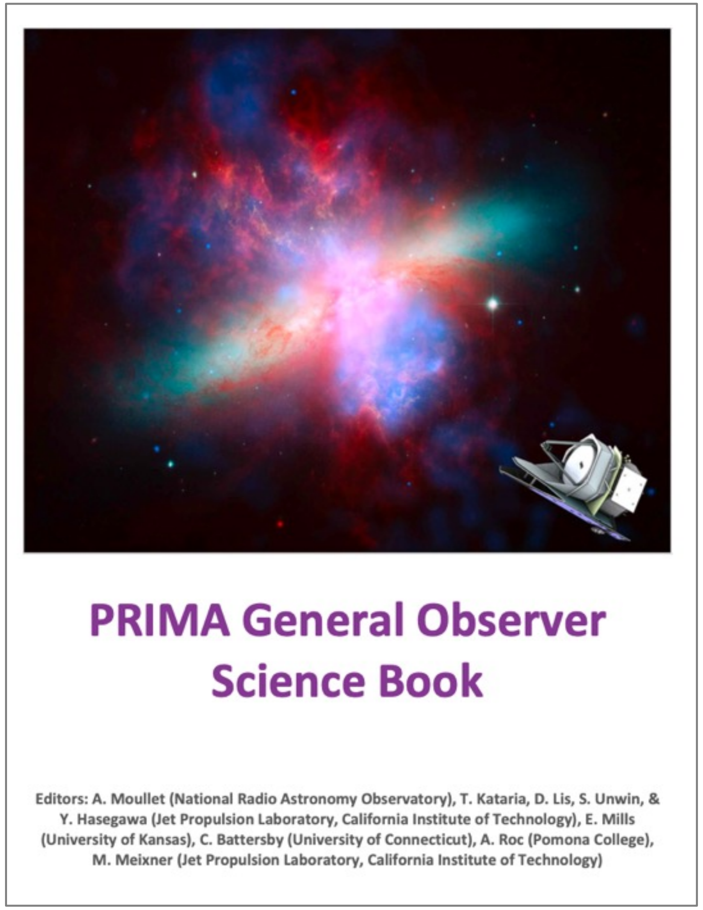


Warm, C-rich grains unpolarized

- 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?
- Survey: 91-232 μm polarization imaging of 31 local galaxies

GO Science – 75% of observing time

See the inspiring GO Science Book at **https://arxiv.org/abs/2310.20572**
76 cases ranging from comets to cosmology!



PRIMA was developed with the community through a series of workshops (>200 participants) culminating in the "PRIMA GO book" (76 cases from 215 unique co-authors requesting ~21,000 hours evenly split over both PRIMA instruments)

75% of PRIMA time will be GO: determined by the community

PRIMA GO book science areas

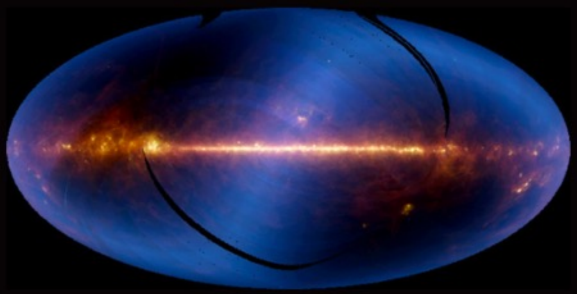
Astro 2020 science panel	# PRIMA GO cases
Compact Objects and Energetic Phenomena	9
Cosmology	3
Galaxies	31
ExoAstroSolar	3
ISM & Star/Planet Formation	25
Stars, the Sun, and Stellar Populations	5

Including numerous **time domain** cases: young stellar object accretion, transient follow-up, high energy compact object mergers. PRIMA will provide a substantial timeline and agile observatory to expand this important window on the universe.

In 1200 hours: PRIMA can measure the D/H isotopic ratio of water in a statistically-significant sample of solar system comets - a key constraint to the origin of water on Earth

In 100 hours: PRIMA can map magnetic fields in the diffuse gas in many local galaxies, revealing their role in how star-forming clouds are born

In 5000 hours: PRIMA can survey the entire sky to a sensitivity 100x deeper than IRAS and Akari that would engender a legacy of discovery



Background image: Simulated PRIMAger hyperspectral dataset (1 deg across)

- **PRIMA addresses all 3 science goals for a far-IR Probe from the Decadal:**
  - Tracing the astrochemical signatures of planet formation
  - Probing the co-evolution of galaxies and their supermassive black holes across cosmic time
  - Measuring the formation and buildup of galaxies, heavy elements, and interstellar dust from the first galaxies to today

- **The technology is in hand to implement PRIMA**
  - The Kinetic Inductance Detectors (KIDS) have exceeded our baseline sensitivity requirements across the far-infrared spectrum and are 100 times more sensitive than prior far-IR observatories.
  - We have fabricated kilo-pixel subarrays for PRIMA which will be incorporated into focal planes which provide unprecedented spectral mapping speeds – some 100,000 times faster than prior far-IR observatories.

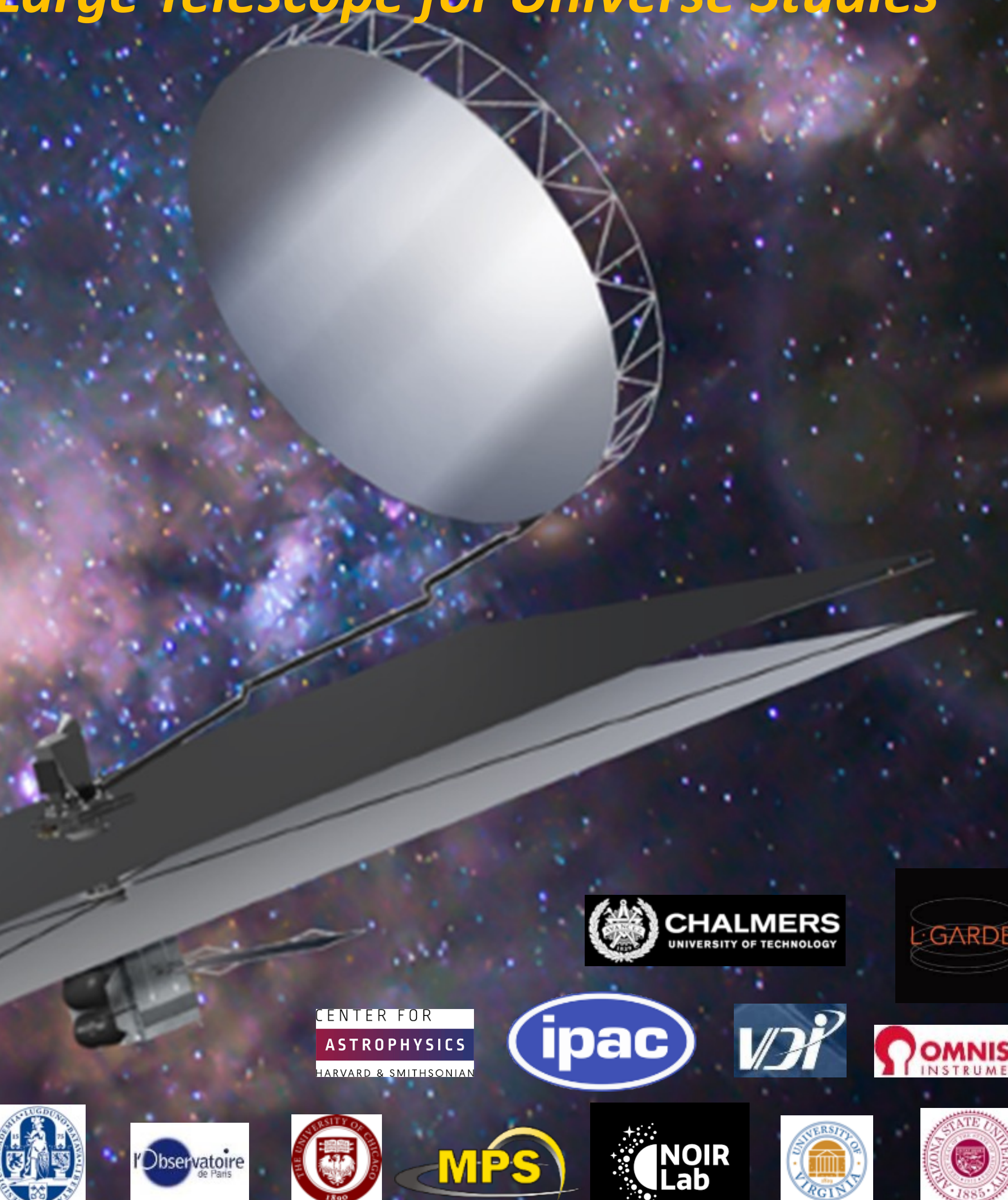
- **PRIMA has broad science grasp with large community interest**
  - GO science book featuring 76 cases from comets to cosmology. These are impossible without a cold far-IR space telescope.

https://prima.ipac.caltech.edu

PRIMA Team

SALTUS: *Single Aperture Large Telescope for Universe Studies*

- 14m Reflector
- $\leq$ 45K Optics
- Coherent & Incoherent Spectroscopy/Imaging
- ~30 to 660 µm
- >5 yrs Baseline Mission
- >3.5 yrs of Guest Observations



Addresses many Science Objectives within the Astro 2020 Decadal

SALTUS Team

Far-IR Space Observatories

IRAS 1983

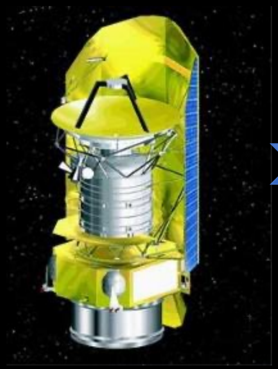
0.57m
2º K
~0.8 yr

ISO
SWAS

26yr

Odin
Spitzer
AKARI

Herschel 2009



3.5m
~80º K
3 yr

22yr

SALTUS 2031

14m
~45K
>5 yr

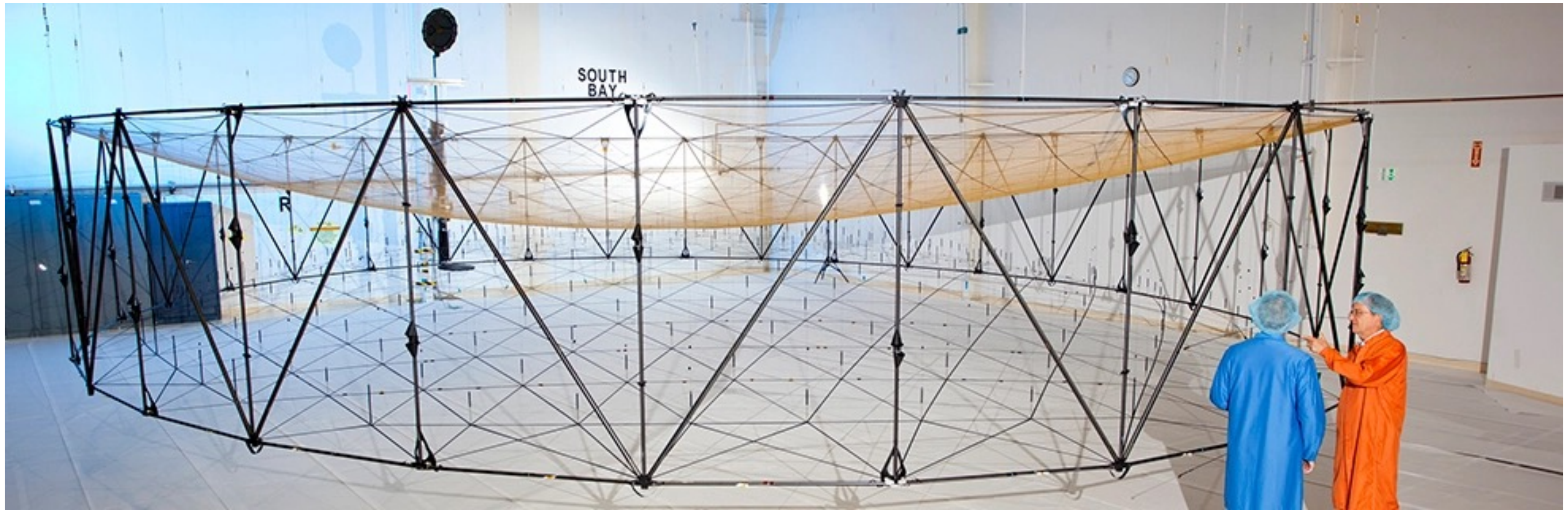
$0.199 B

$0.776 B

$1 B
How?

Paradigm Shift in realizing far-IR space apertures

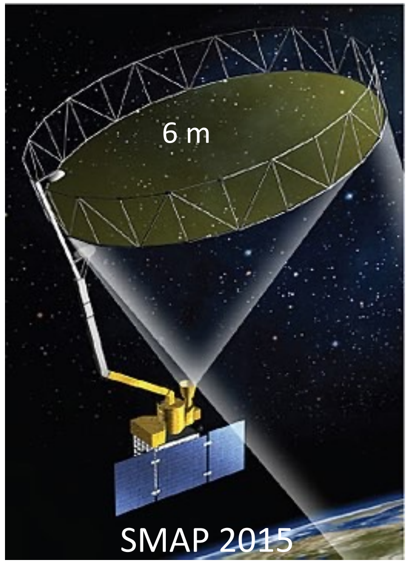
SALTUS Truss



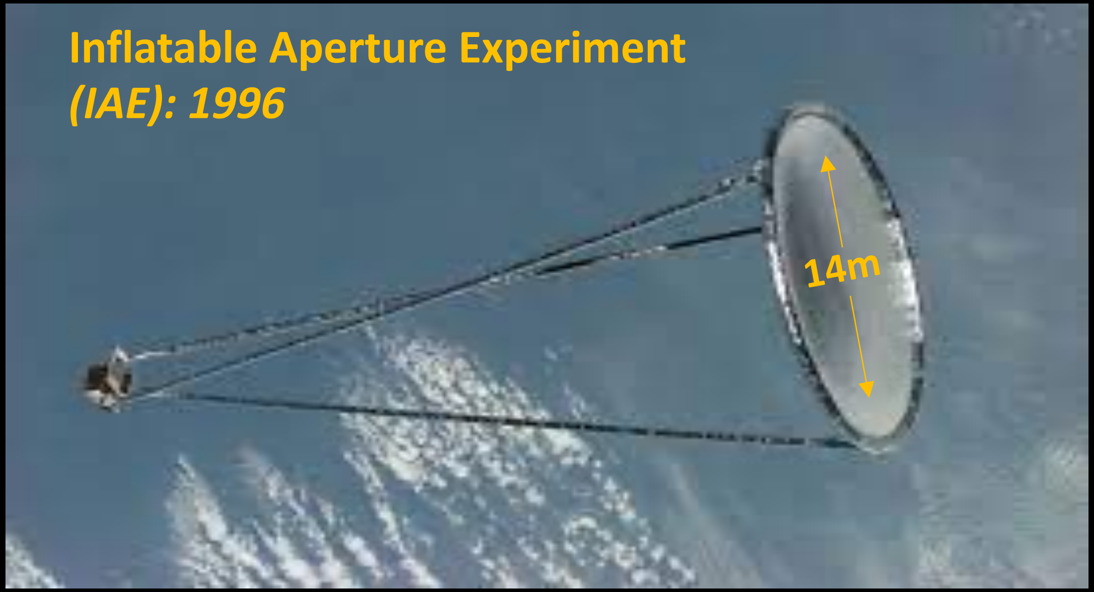
Space Rated 25 m version available

AstroMesh® Reflector Technology

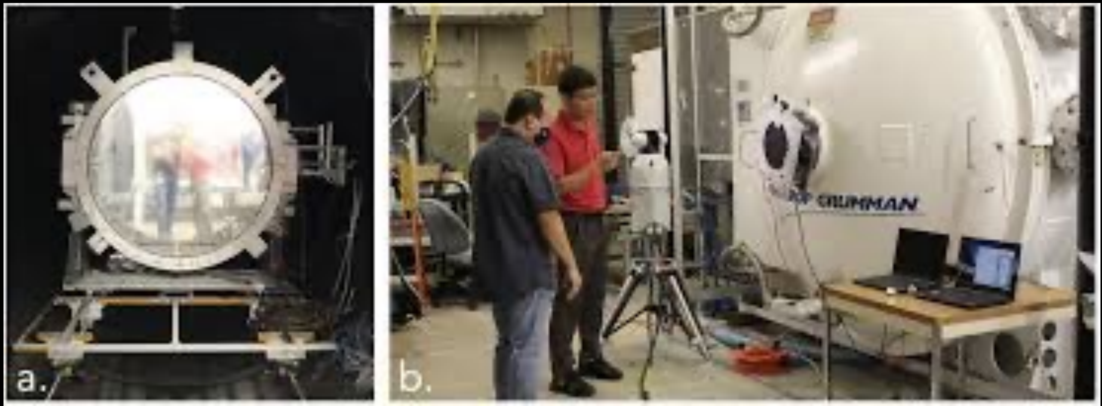
100% On-Orbit Success – No Failures – No Anomalies



SALTUS Team



2021



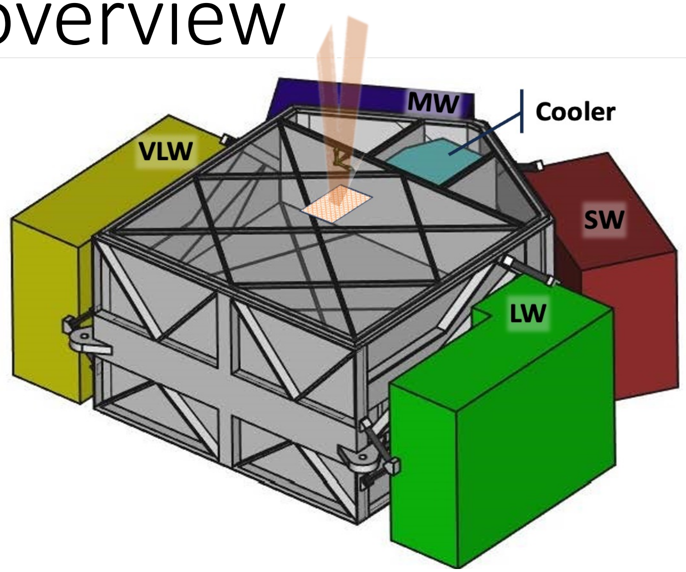
25 years of Advancement

- *Surface Measurement of a Large Inflatable Reflector in Cryogenic Vacuum* (Quach, et. al. 2021; Special Session, Proceedings SPIE, 24 August 2021, >100 pages)
- Constructing Highly Accurate Inflatable Parabolic Dish Reflector Antennas and Solar Concentrators, A. Palisoc, et al, AIAA 2024-2435

The **SAFARI-lite** instrument - overview

Far-IR grating spectrometer – 5K focal plane unit

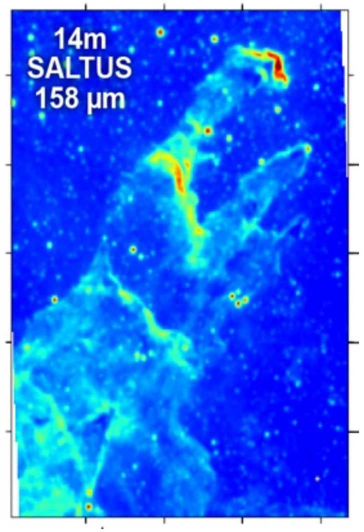
- 4 bands in the 35-240 μm domain, co-aligned on sky
  - *Instantaneous contiguous* coverage
- Interlaced KID arrays provide R~300 after processing
  - ~180 pixels in spectral direction, 6 pixels in spatial direction
- Warm electronics in service module
  - Power, monitoring and control, detector control and read-out



- A *14 meter* telescope with *sensitive KIDs*:

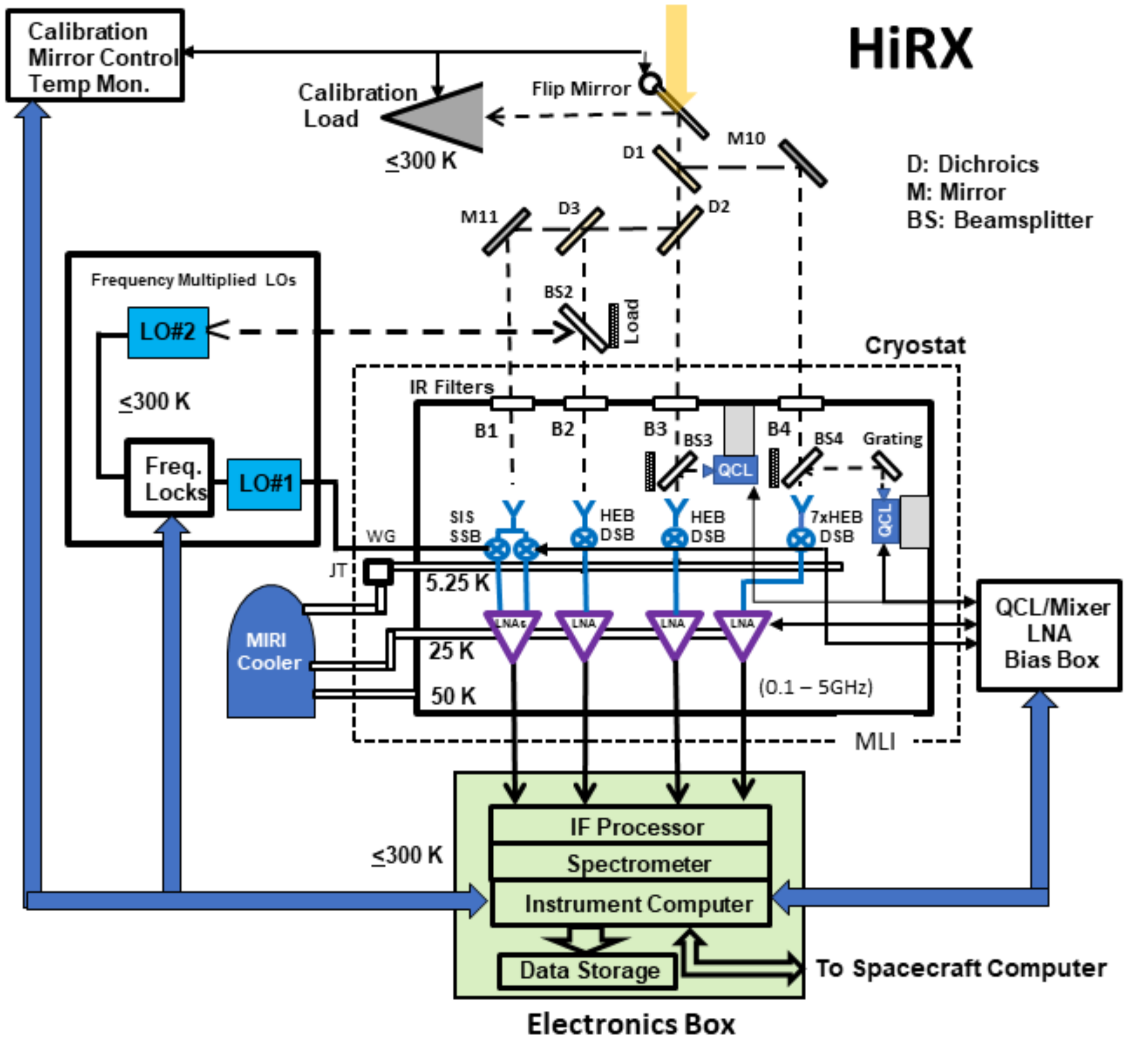
Unprecedented FIR spectroscopic sensitivity at ~10^{-20} W/m² 5σ/1hr !

A new domain:
*SALTUS/SAFAR-lite will provide the capability to do **CII mapping** of the 'Pillars of creation' at **JWST resolution***



	SW	MW	LW	VLW
Band center / μm	45	72	115	185
Wavelength range / μm	34-56	54-89	87-143	140-230
Band center beam FWHM	0.66”	1.1”	1.7”	2.7”
Point source spectroscopy – R300 (5σ-1hr)				
Limiting flux / $\times10^{-20}$ Wm^{-2}	0.5	1	2	2
Limiting flux density / μJy	20	75	250	400
Mapping spectroscopy 1 arcmin2 – R300 (5σ-1hr)				
Limiting flux / $\times10^{-20}$ Wm^{-2}	5	5	6	4
Limiting flux density / mJy	2	4	7	7
Photometric mapping 1 arcmin^2 – R1 (5σ-1hr)				
Limiting flux density / μJy	170	330	670	670
Confusion limit / μJy	<0.1	0.6	12	60
Saturation flux density / Jy	15	25	40	50

SALTUS Team



Heritage from GUSTO, GREAT

Beam/Band	HiRX Bands					
	B1	B2L	B2M	B2H	B3	B4
Ω (")	10.4	4.8	3.6	2.4	2	1
λ (µm)	590	272	204	136	112	60

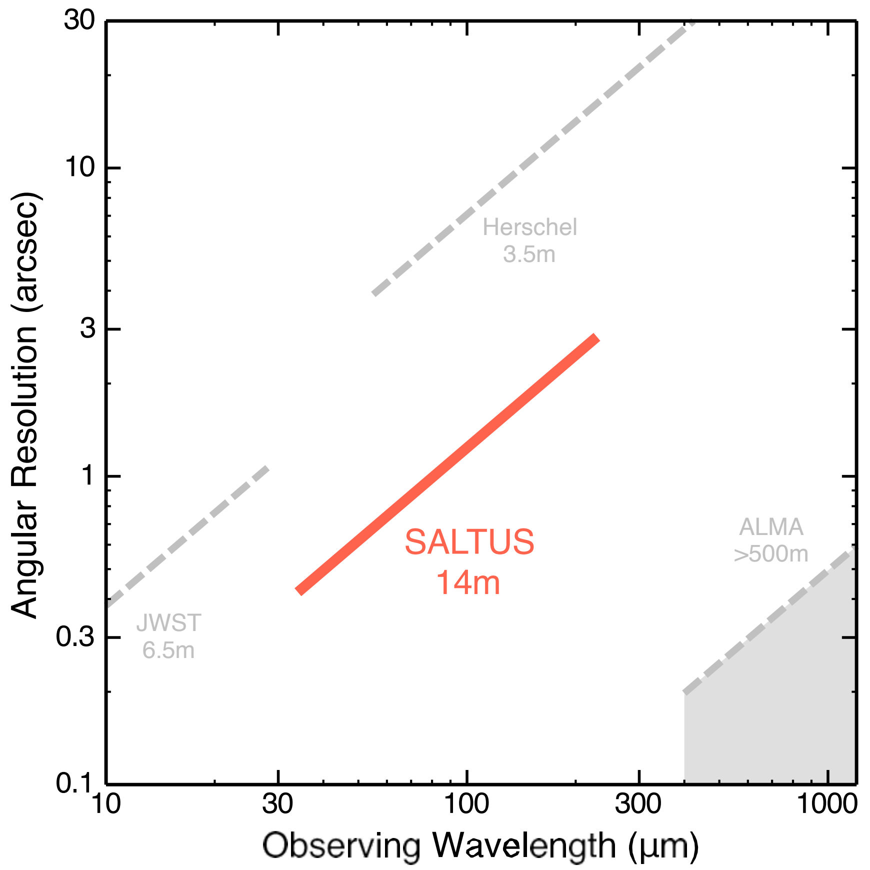
Bands Observed Simultaneously

SALTUS Team

High Spatial Resolution

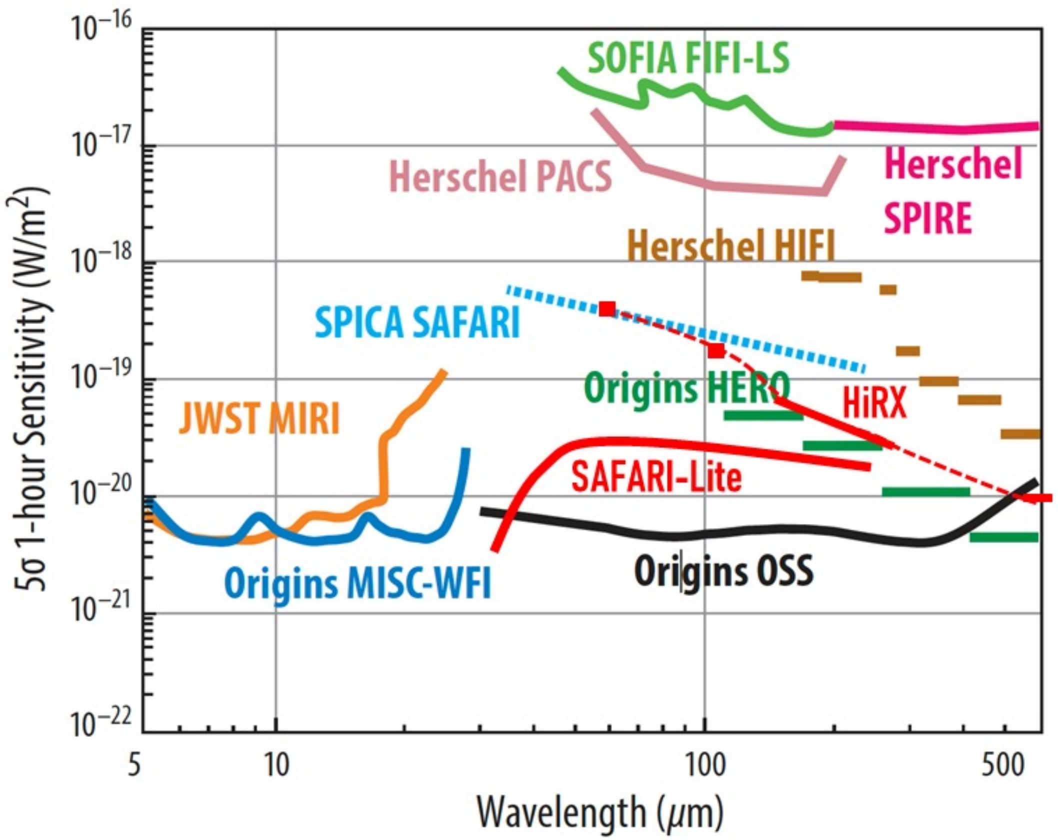
- SALTUS reaches JWST/MIRI-like resolution in the far-IR

  - Sensitive far-IR mapping on ~5arcmin scales at ~1arcsec resolution
  - No confusion! No de-blending! No cross-matching!



SALTUS Team

Large Aperture Provides High Sensitivity



Instruments

SALTUS Far-IR Spectrometer (SAFARI-Lite)

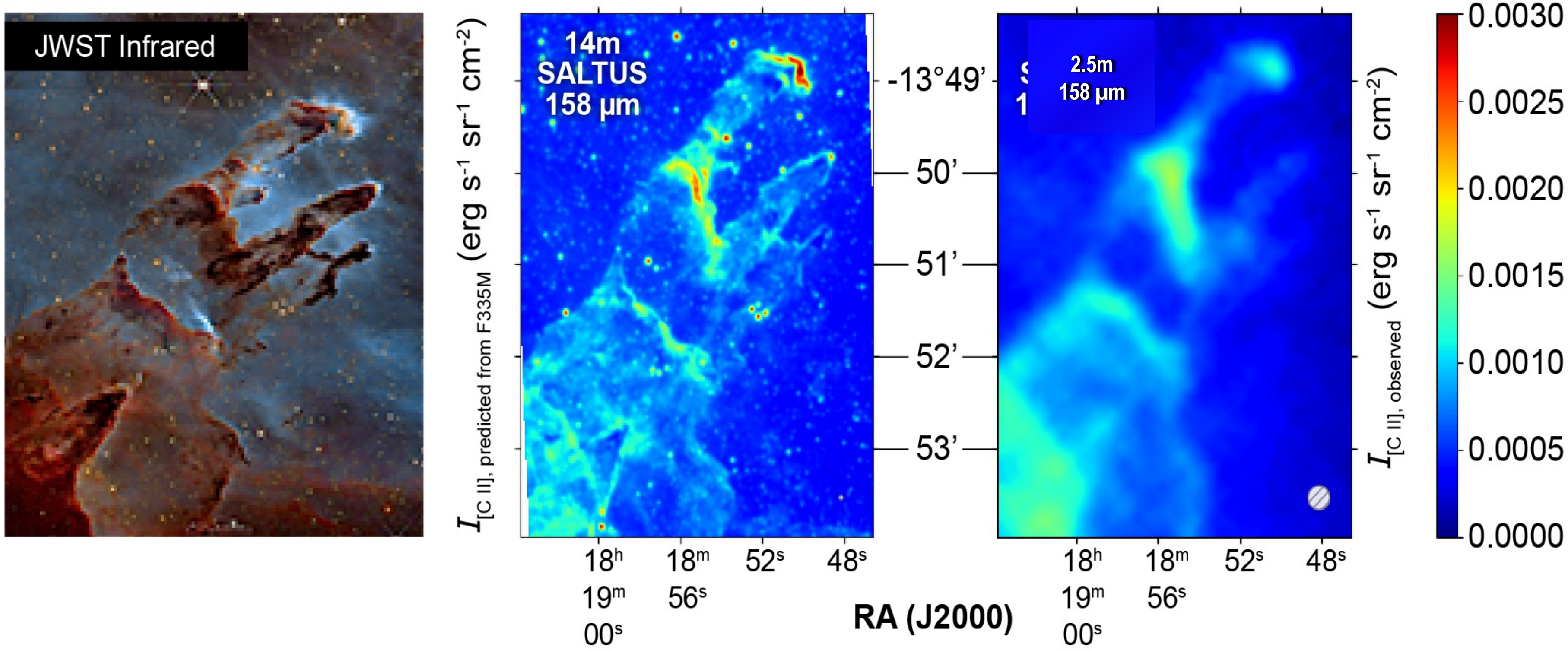
- 34 to 230 µm (4 Bands)
- Instantaneous coverage
- ~180 pixel KID arrays, spectroscopic
- R = 300
- *Existing technology*

SALTUS High Resolution Receiver (HiRX)

- 56 to 300 µm
  4 Bands HEB mixers
- 520 to 660 µm
  Dual Polarization SIS
- R = ~$10^{6\text{-}7}$
- *GUSTO Heritage, GREAT*

SALTUS Team

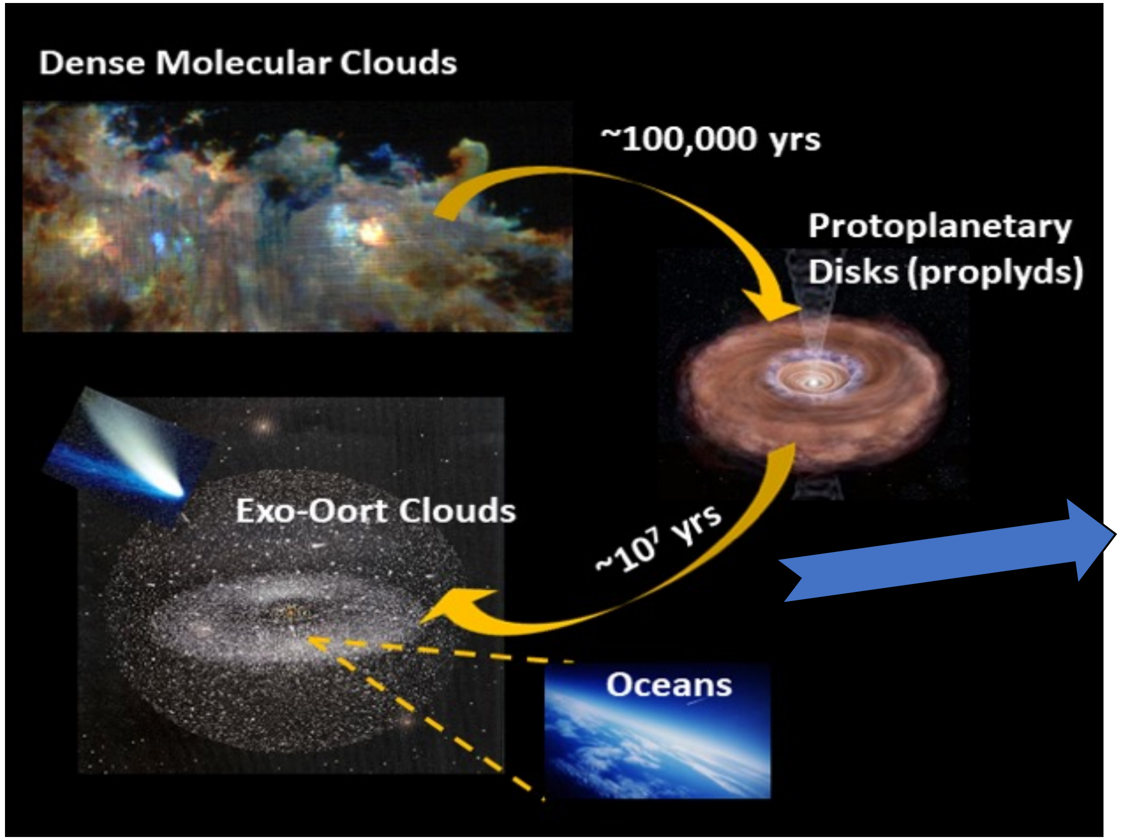
Large Aperture Provides High Angular Resolution



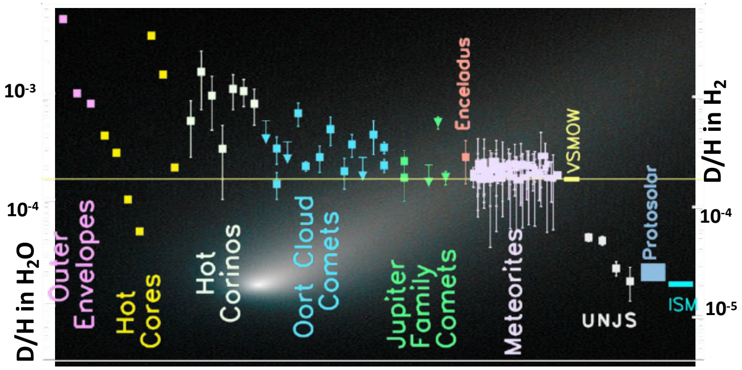
Simulated *SALTUS* image at 2.5" angular resolution (middle) of the [CII] 158µm emission in NGC 6611 (Pillars of Creation) is similar to the *JWST* image (left) and compared to a 2.5m reflecting telescope-created map (right). SAFARI-Lite can map this 10 arcmin^2 region in 10 hours and simultaneously provide maps in all diagnostic lines of photo-dissociation regions (PDRs) and HII regions in our galaxy and the local group, probing the physical environment produced by radiation feedback of massive stars and its link to stellar clusters and its molecular core.

SALTUS Team

SALTUS follows the Water Trail from Molecular Clouds to Oceans



Measure D/H in solar system objects to investigate the fractionation of water at low temperatures.



SALTUS is designed to probe the water trail using low lying rotational H_2O lines that probe cold gas with HiRX and the icy grain reservoir through their phonon modes in emission with SAFARI-Lite

SALTUS Team

1) Trace Formation and Evolution of Planetary Systems

How does habitability develop during planet formation?

Distribution of mass and C/N/O in 1000 protoplanetary disks

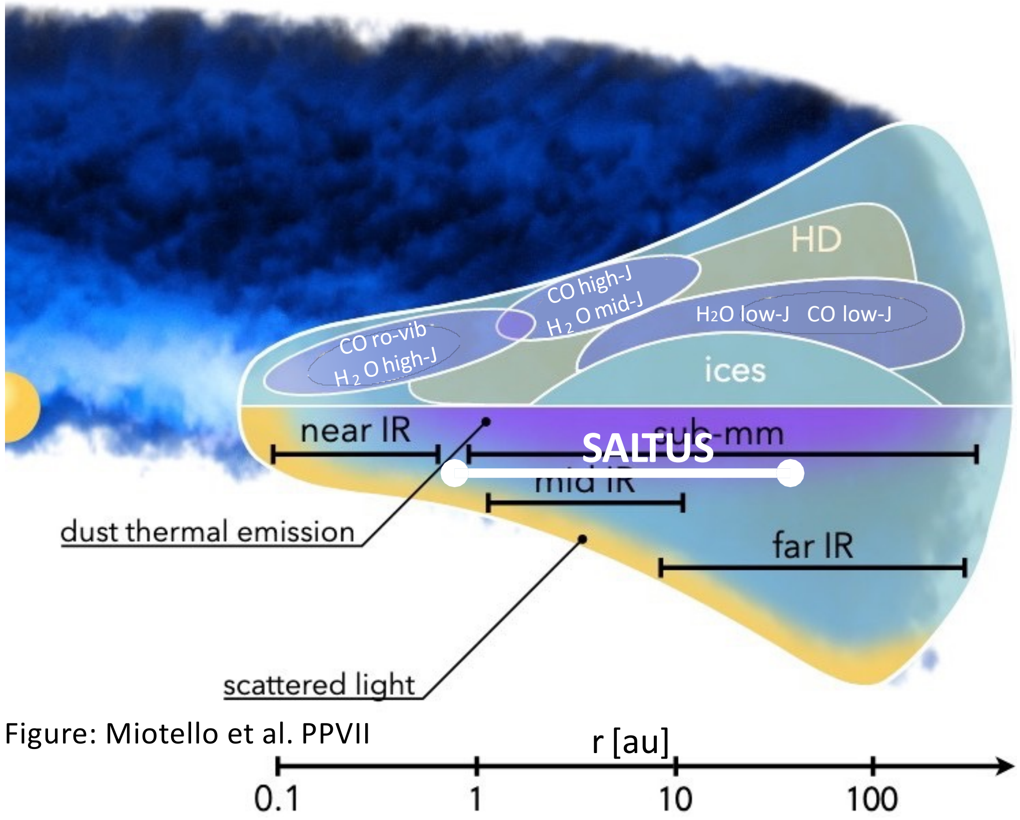
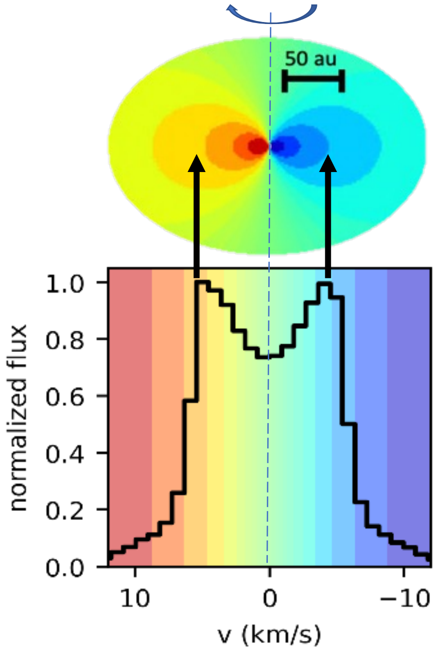


Figure: Miotello et al. PPVII

- What is the mass?: Target HD
- Where is O?: Target H_2O vapor & ice
- Where is N?: Target NH_3
- Where is C?: Target High J CO



Heterodyne Spectroscopy
Heritage of SOFIA - Meixner

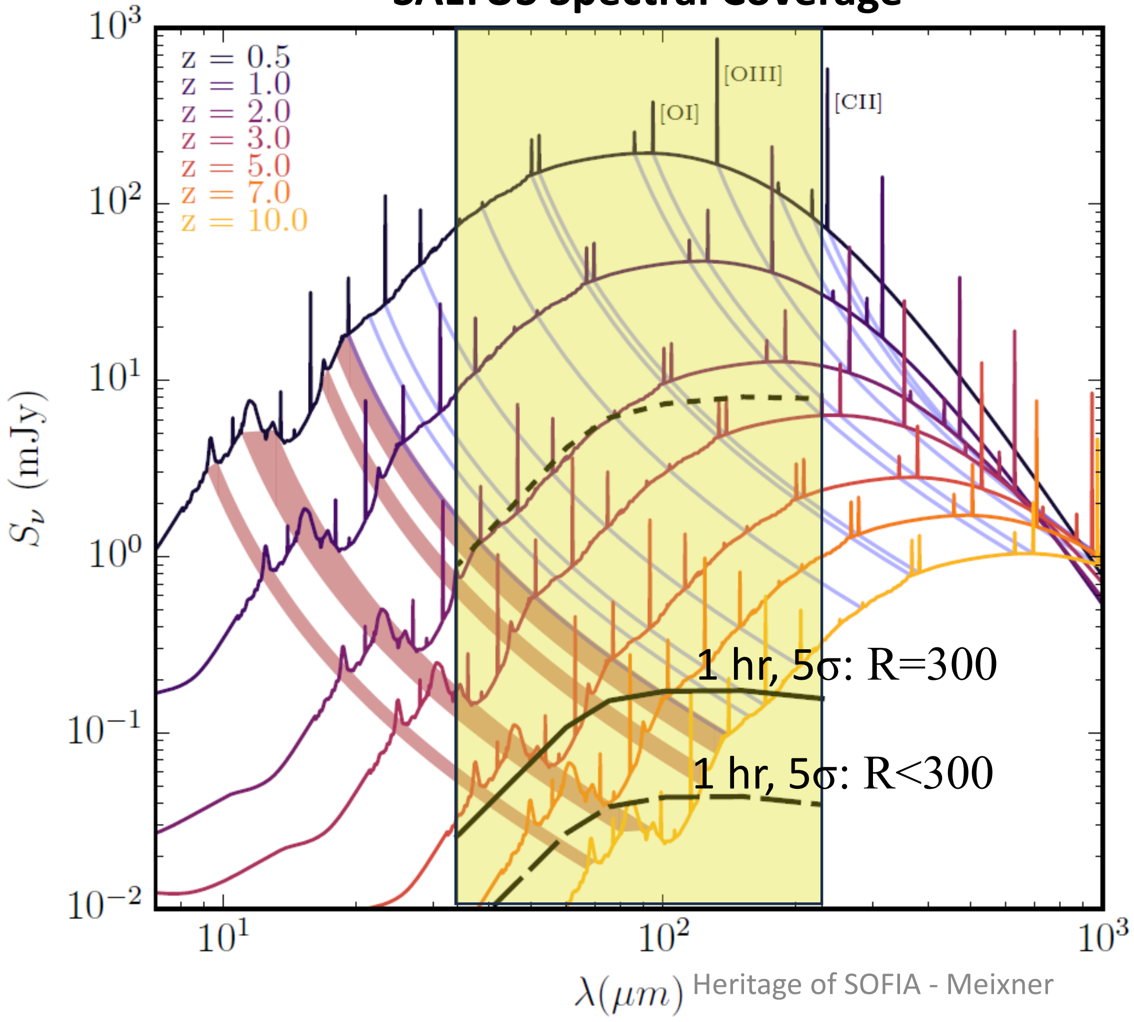
Doppler Tomography of HD and H_2O Disk Spectra R~10^6

SALTUS Team

2) Trace Galaxy Evolution

SALTUS will ***spatially resolve*** and measure the peak of the IR SED of Star Forming Galaxies **in addition** to spectral lines

SALTUS Spectral Coverage



Heritage of SOFIA - Meixner

Spectral Energy Distribution (SED) of $3x10^{12}$ $L_\odot$ star forming galaxy with redshift.

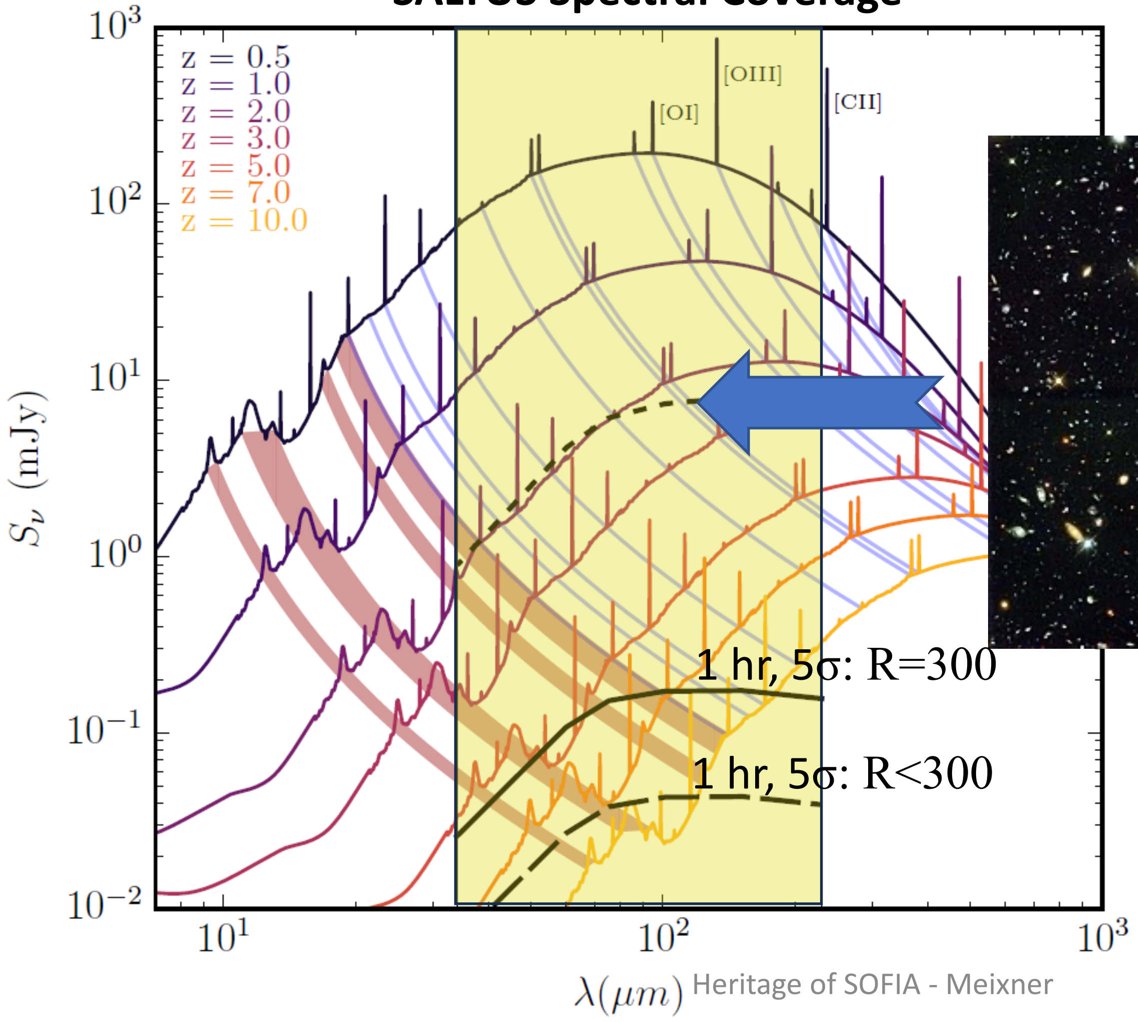
- Spectral lines and PAH features traced through redshift
- Out to z ~3, SAFARI-Lite probes the peak of the dust continuum and the bulk of the dust emission.
- Beyond z ~3, SAFARI-Lite takes over from *JWST*/MIRI

SALTUS Team

2) Trace Galaxy Evolution

SALTUS will ***spatially resolve*** and measure the peak of the IR SED of Star Forming Galaxies **in addition** to spectral lines

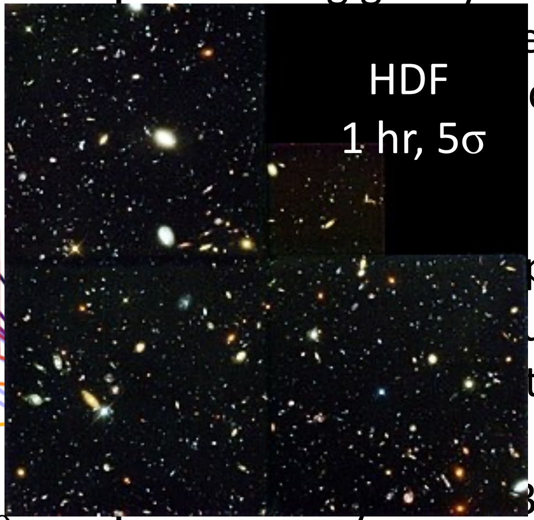
SALTUS Spectral Coverage



Spectral Energy Distribution (SED) of 3x10[12] $L_\odot$ star forming galaxy with redshift.

es and PAH

ced through



SAFARI-Lite

peak of the

uum and

the dust

, SAFARI-Lite takes over from *JWST*/MIRI

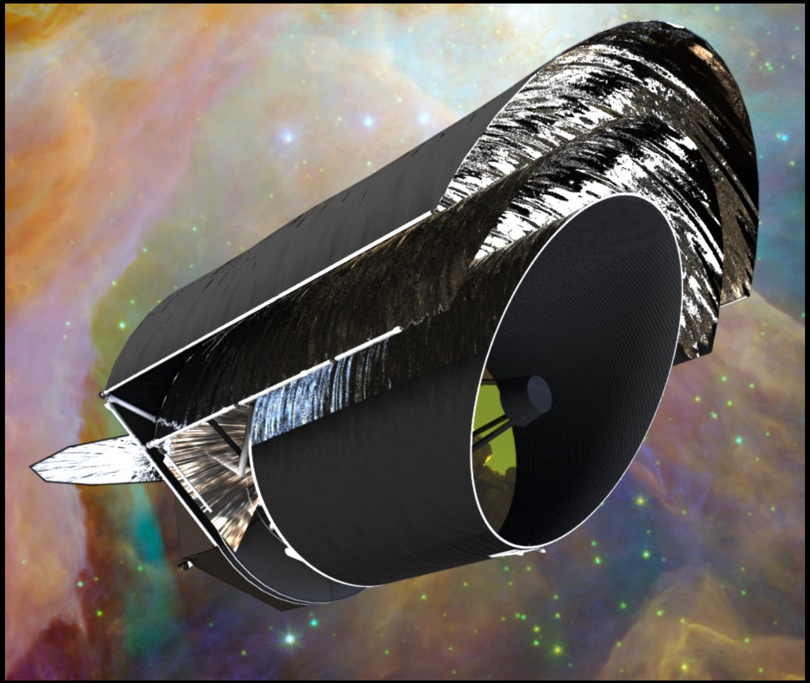
SALTUS Team

Origins Space Telescope: Part of Great Observatories

an ASTRO2020 Decadal large mission study involving Europe and Japan

Final Report and JATIS special section: https://asd.gsfc.nasa.gov/firs/docs/

- ★ x1000 more sensitive than anything before
- ★ 5.9m aperture non-deployed cold aperture (4.5K)
- ★ Low-risk development, testing, and deployment
- ★ 3 orders of magnitude in wavelength coverage: 2.8-588 µm



https://origins.ipac.caltech.edu

https://asd.gsfc.nasa.gov/firs/

ORIGINS
Space Telescope

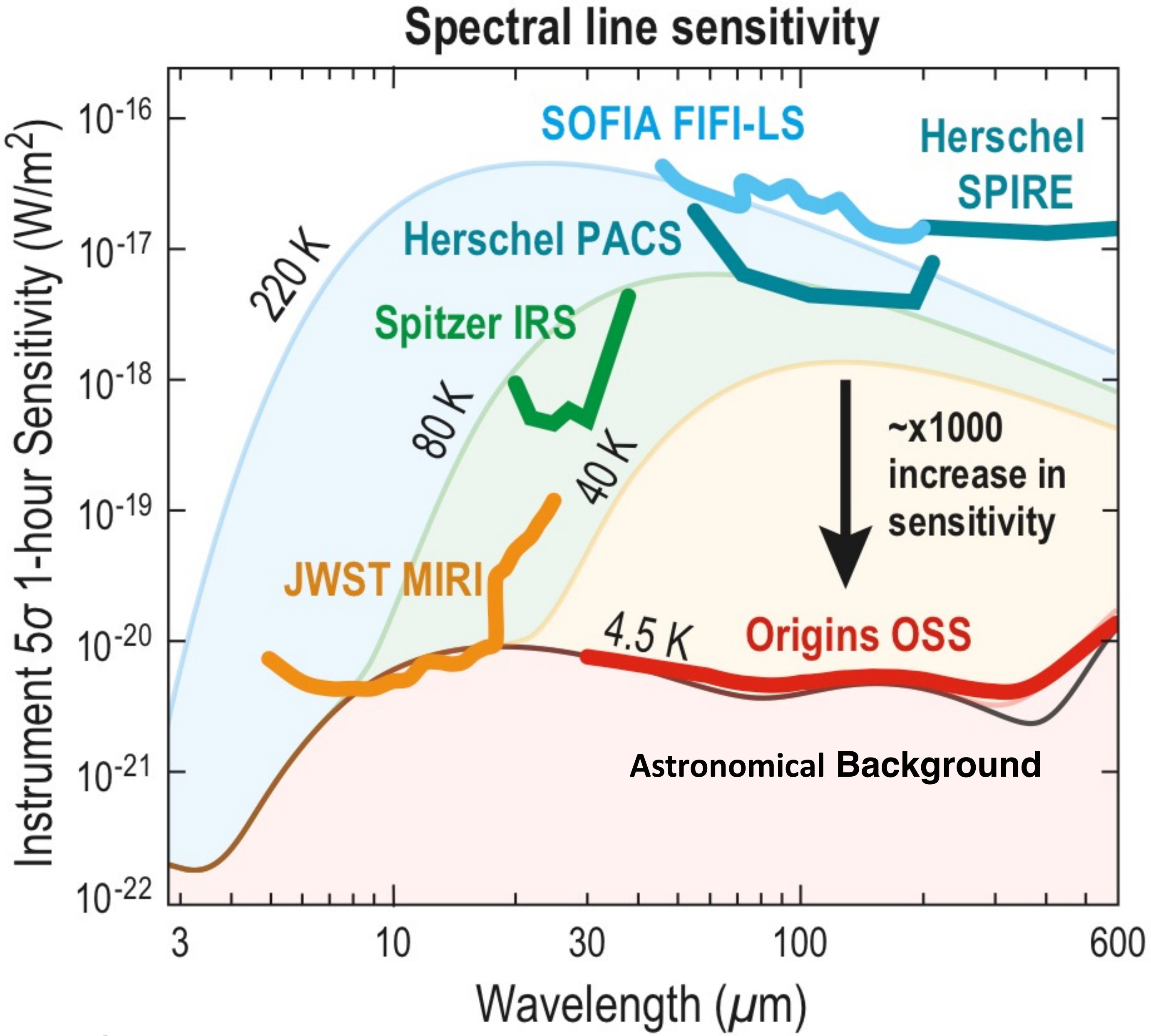
How does the universe work?

How did we get here?

Are we alone?

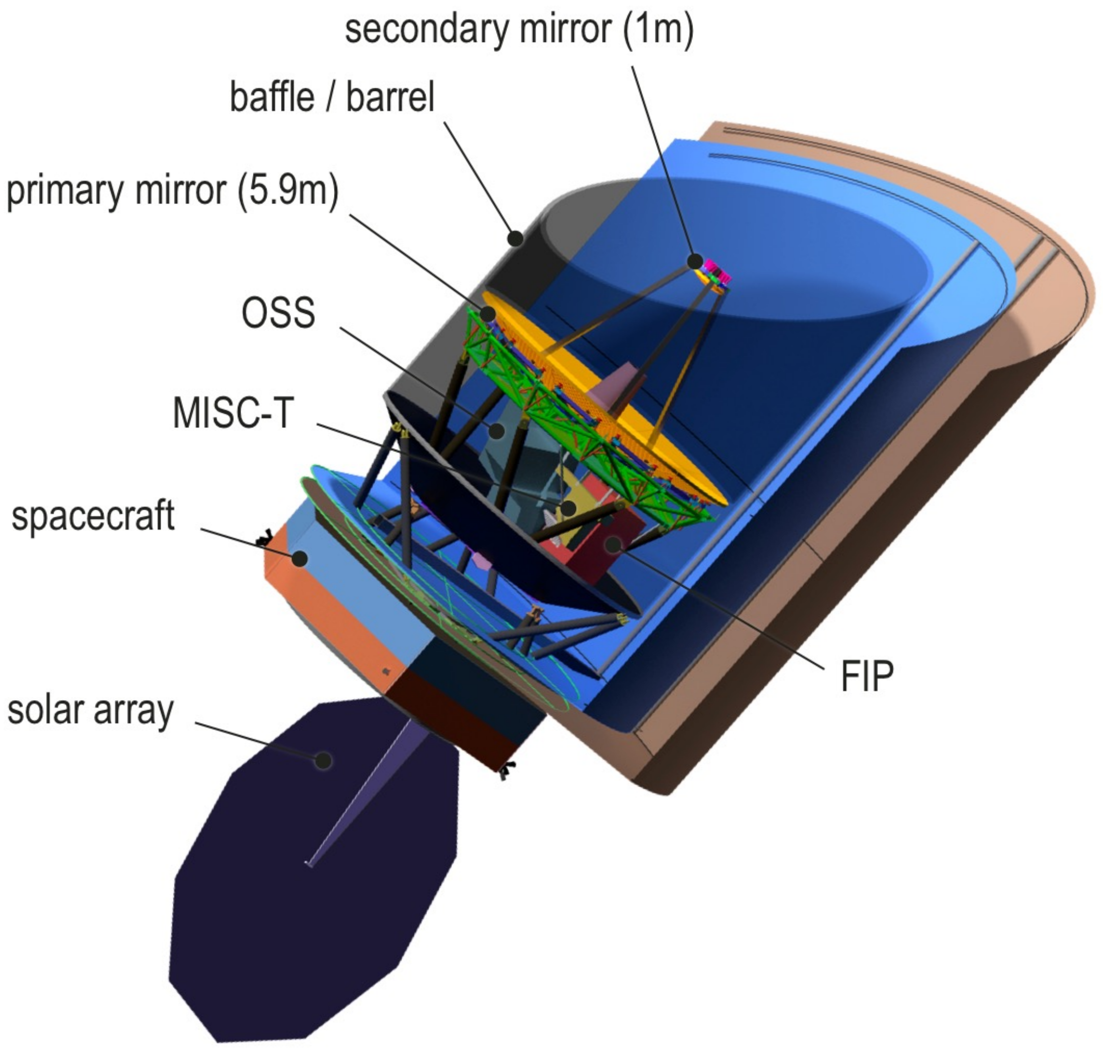
Discovery of new phenomena

Why does Origins need to be 4.5 K?



Heritage of SOFIA - Meixner

Origins:
Spitzer-like low-risk design



Wavelength coverage: 2.8-588 µm

Telescope:

- diameter: 5.9 m
- area: 25 m^2 (=JWST area)
- diffraction-limit: 30 µm
- temperature: 4.5 K

Cooling: long life cryo-coolers

Agile Observatory for surveys: 60” per second

Launch Vehicle:

Large, SLS Block 1, Space-X BFR

Mission: 10 year propellant, serviceable

Orbit: Sun-Earth L2

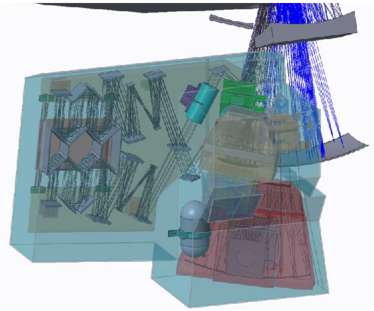
Origins Three Instruments

OSS: Origins Survey Spectrometer

-25-588 µm R~300, survey mapping

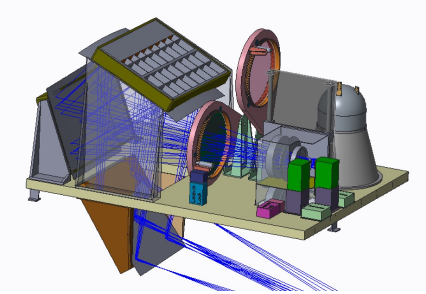
-25-588 µm R~43,000, spectral surveys

-100-200 µm R~325,000, kinematics



infrared Imager

Polarimeter



vey mapping

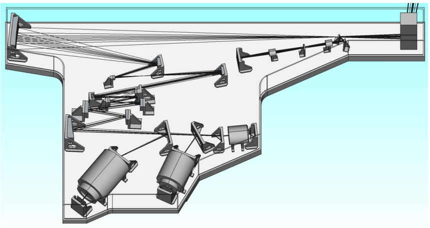
/FWHM

polarimetry

- 50 or 250 µm, Large area

-1.75” @ 50 8.75” @ 200

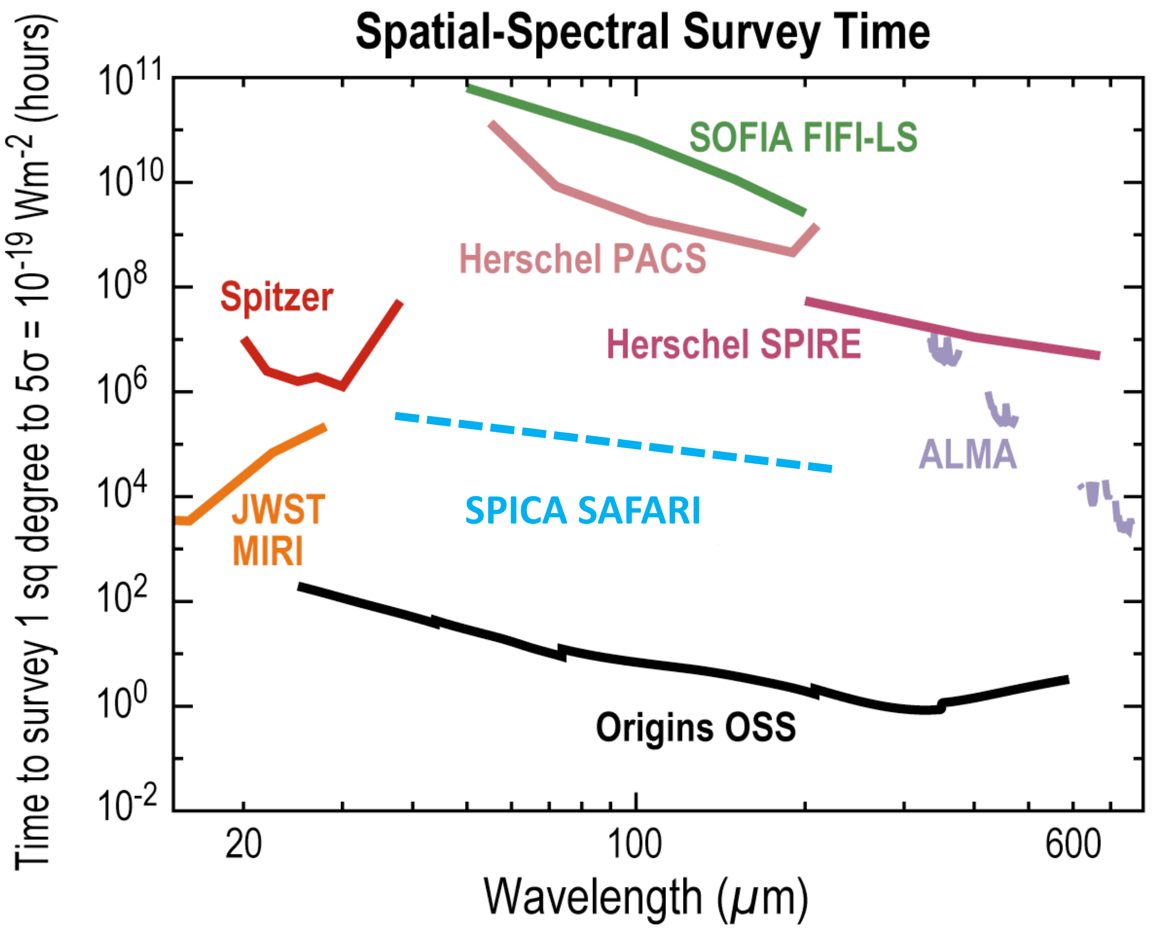
- 50 or 250 µm,

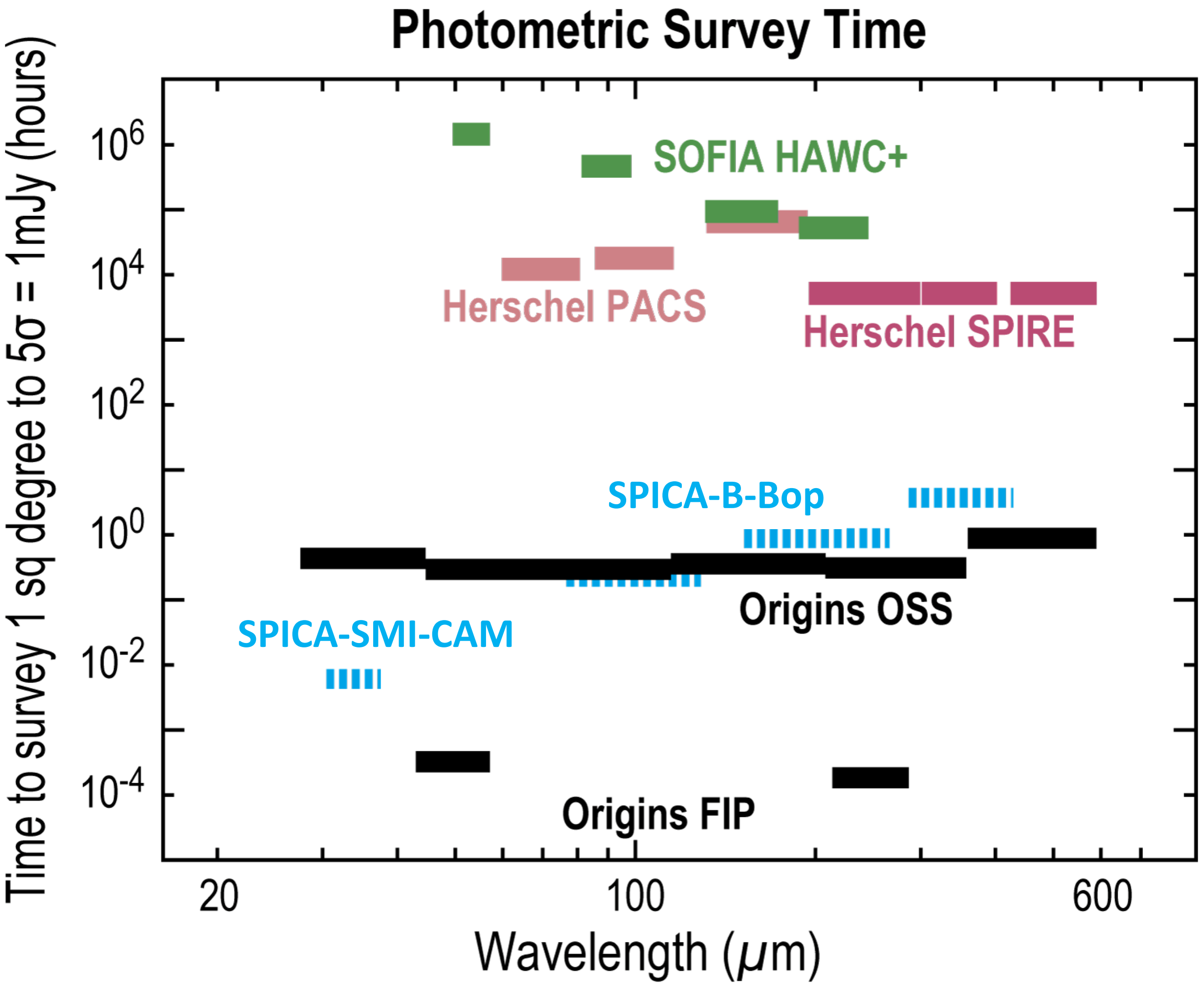


MISC-T: Mid-Infrared Spectrometer Camera Transit

-Ultra-Stable Transit Spectroscopy

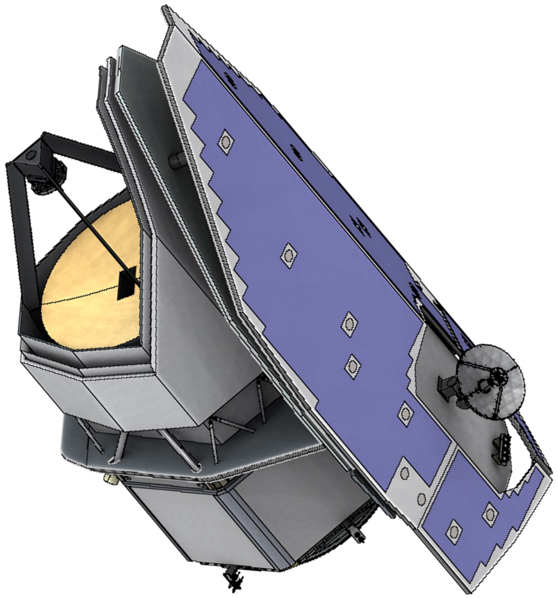
-2.8-20 µm R~50-295


Spatial-Spectral Survey Time
Time to survey 1 sq degree to 5σ = 10-19 Wm-2 (hours)
10^11
10^10
10^8
10^6
10^4
10^2
10^0
10^-2
20
100
600
Wavelength (μm)
SOFIA FIFI-LS
Herschel PACS
Spitzer
Herschel SPIRE
ALMA
JWST
MIRI
SPICA SAFARI
Origins OSS

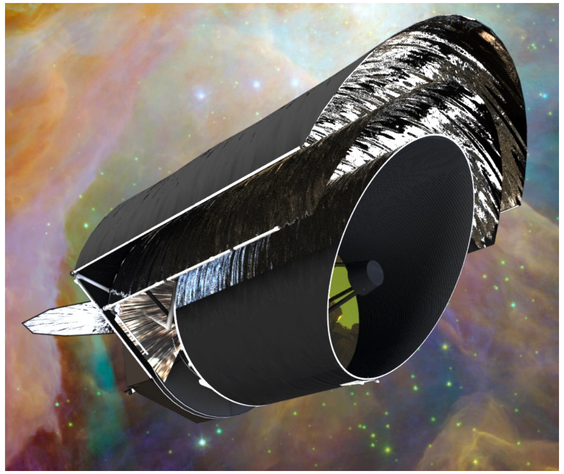

Photometric Survey Time
Time to survey 1 sq degree to 5σ = 1mJy (hours)
10^6
10^4
10^2
10^0
10^-2
10^-4
20
100
600
Wavelength (μm)
SOFIA HAWC+
Herschel PACS
Herschel SPIRE
SPICA-B-Bop
SPICA-SMI-CAM
Origins OSS
Origins FIP

Summary

- The Far-IR provides access to the majority of radiation from the baryonic Universe, origins of things
- Far-IR observations address >70% of the Astro2020 questions
- Probe opportunity is key for sustaining and building far-IR expertise in the astronomy community.
- Significant advances in technology in detectors and cryo-cooling enables powerful probe or large missions.
- Longer range, large great observatory: Origins
- Future is bright with opportunity, but we have a >10 year gap
- Secruing a far-IR probe requires recognition outside the IR community in order to compete with X-ray. **Please talk to your colleagues!**



https://prima.ipac.caltech.edu

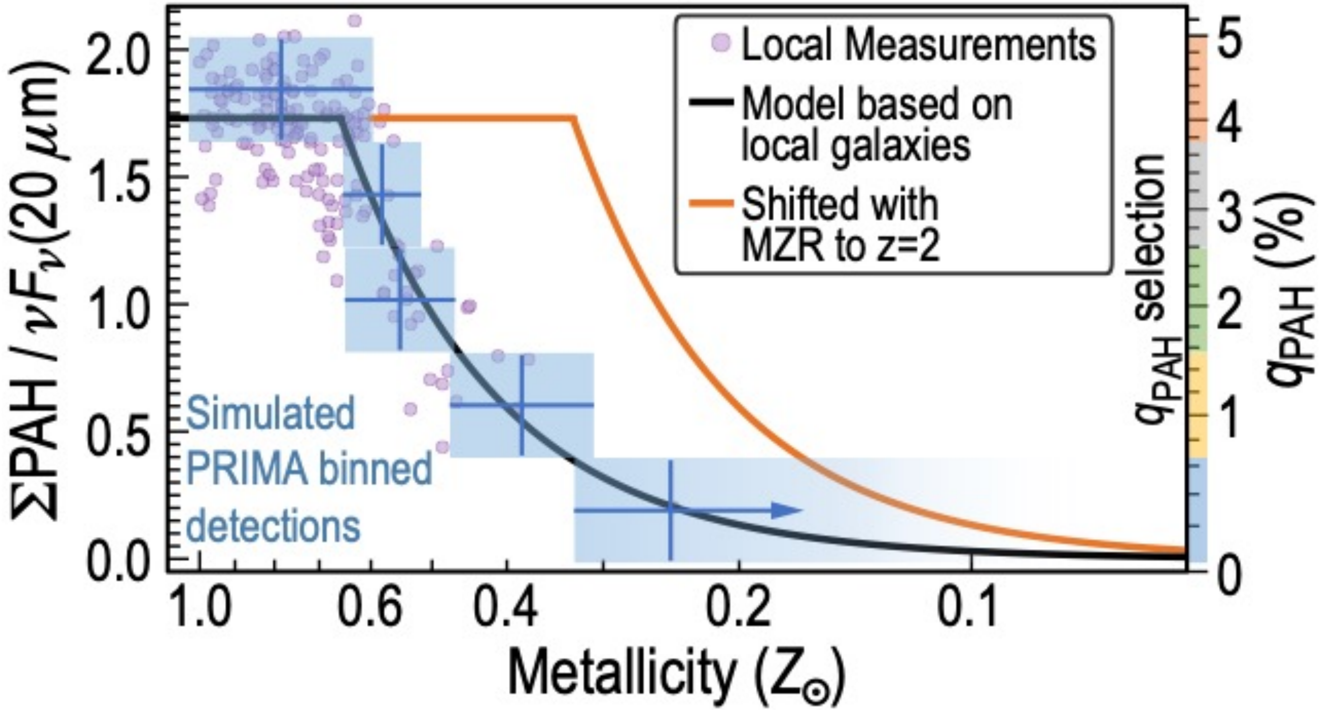


https://asd.gsfc.nasa.gov/firs/

Backups

The Rise of Dust and Metals: Has the relationship between PAHs and metals evolved since cosmic noon?

In the local universe, there a reduction in PAH emission with reduced metallicity.



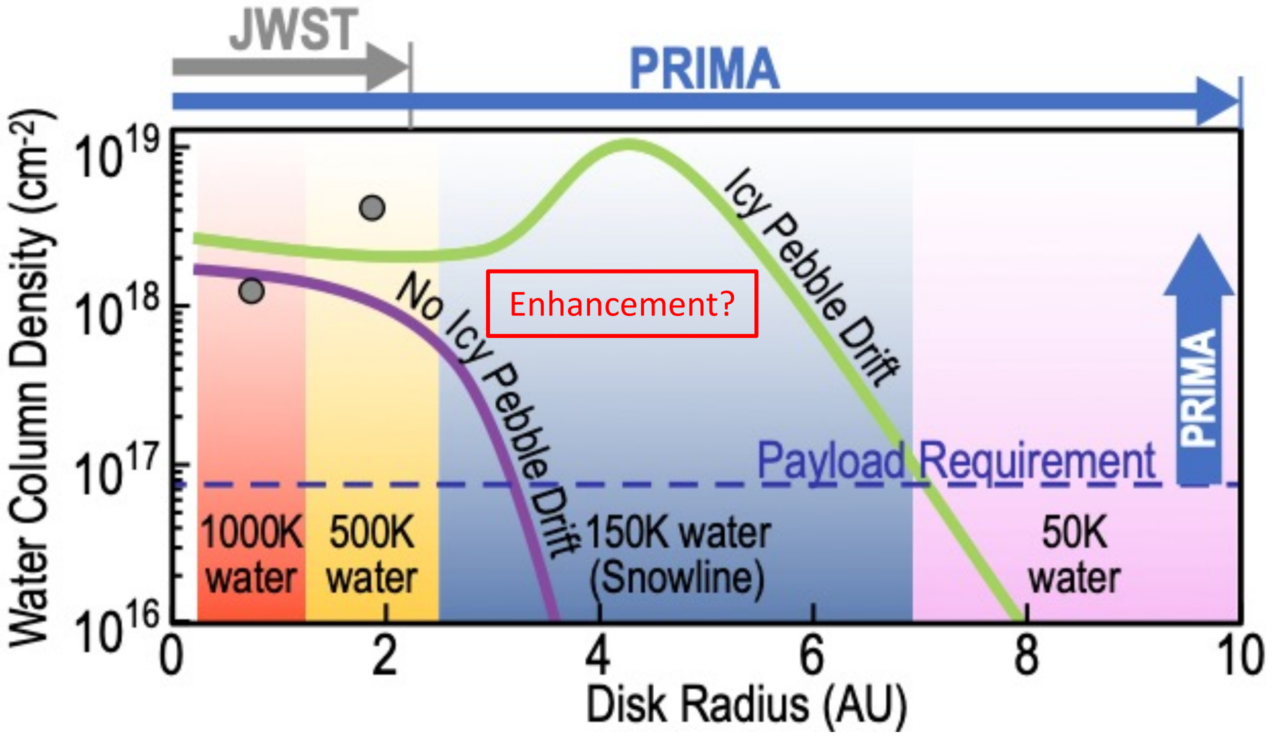
For 100 $1.75 \leq z \leq 2.25$ galaxies in 5 q_{PAH} bins, PRIMA will measure

- Gas-phase abundances of O and N via [O III], [NIII]
- q_{PAH} from rest-frame 11.3 and 12.7 μm bands

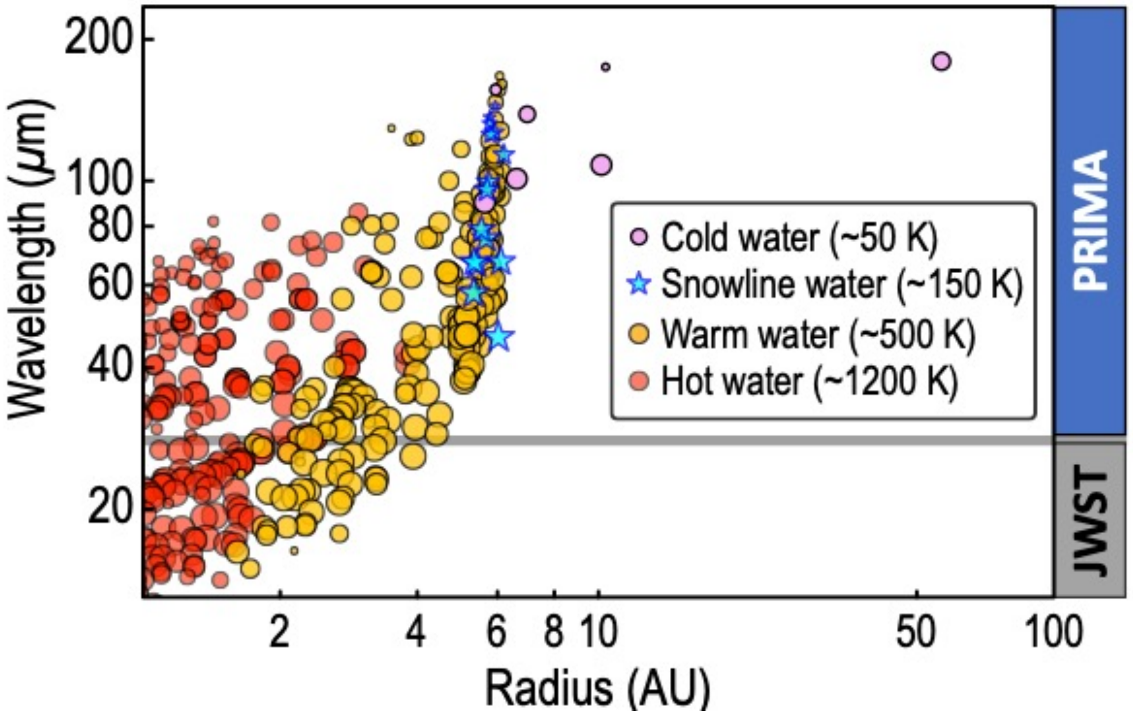
PRIMA Team

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.

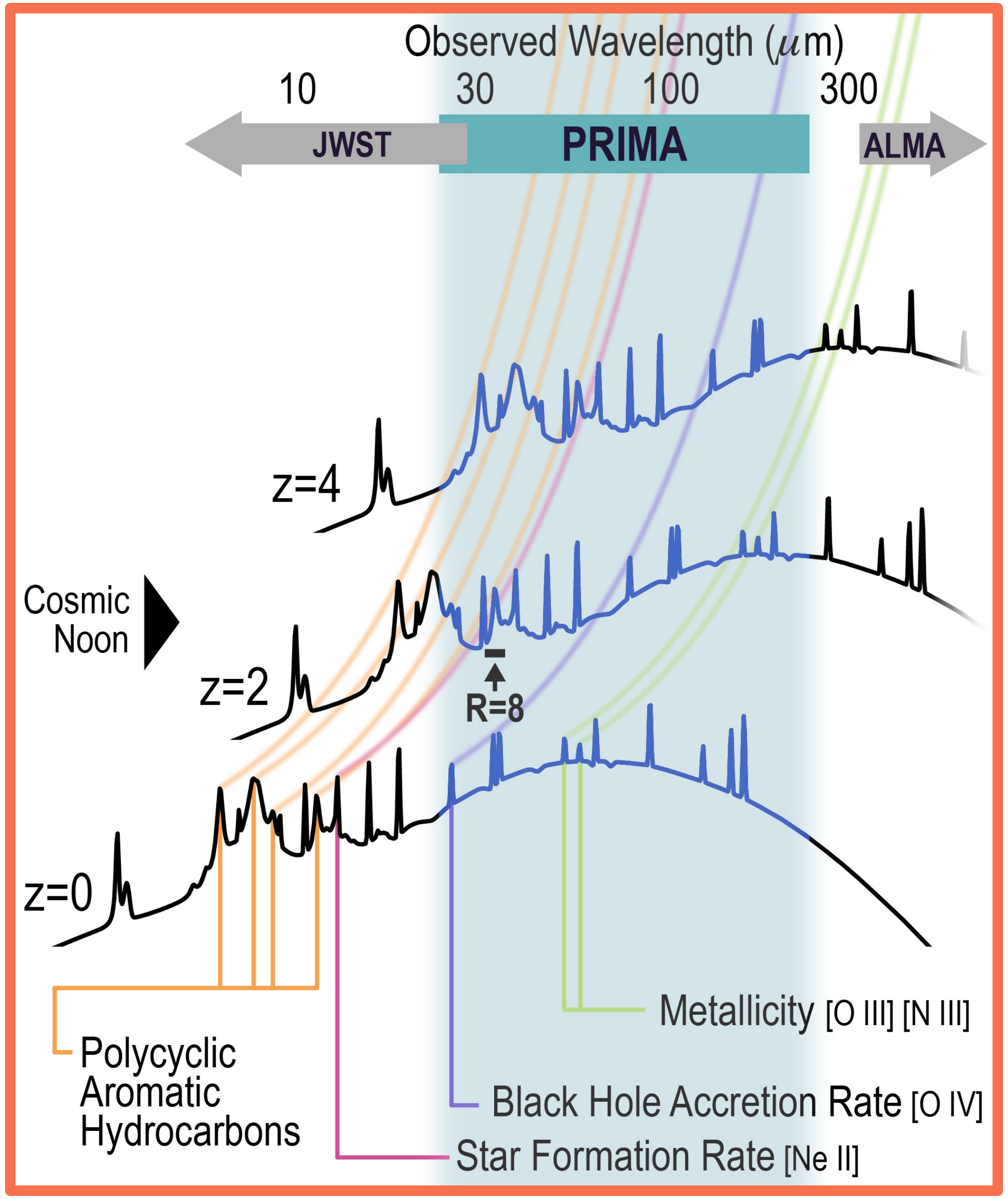


PRIMA FIRESS FTM will measure the level of water enhancement in 200 disks via temperature-sensitive spectral line energy distributions.



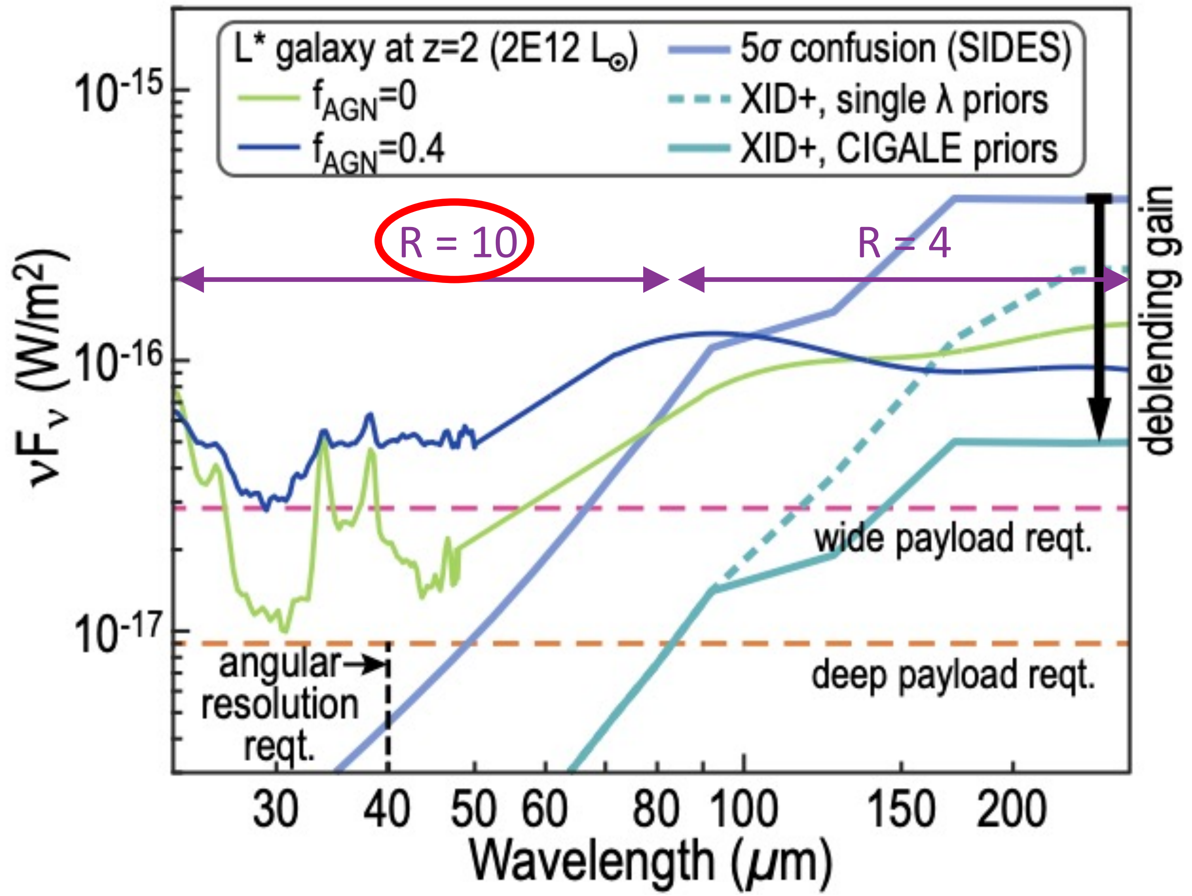
PRIMA Team

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

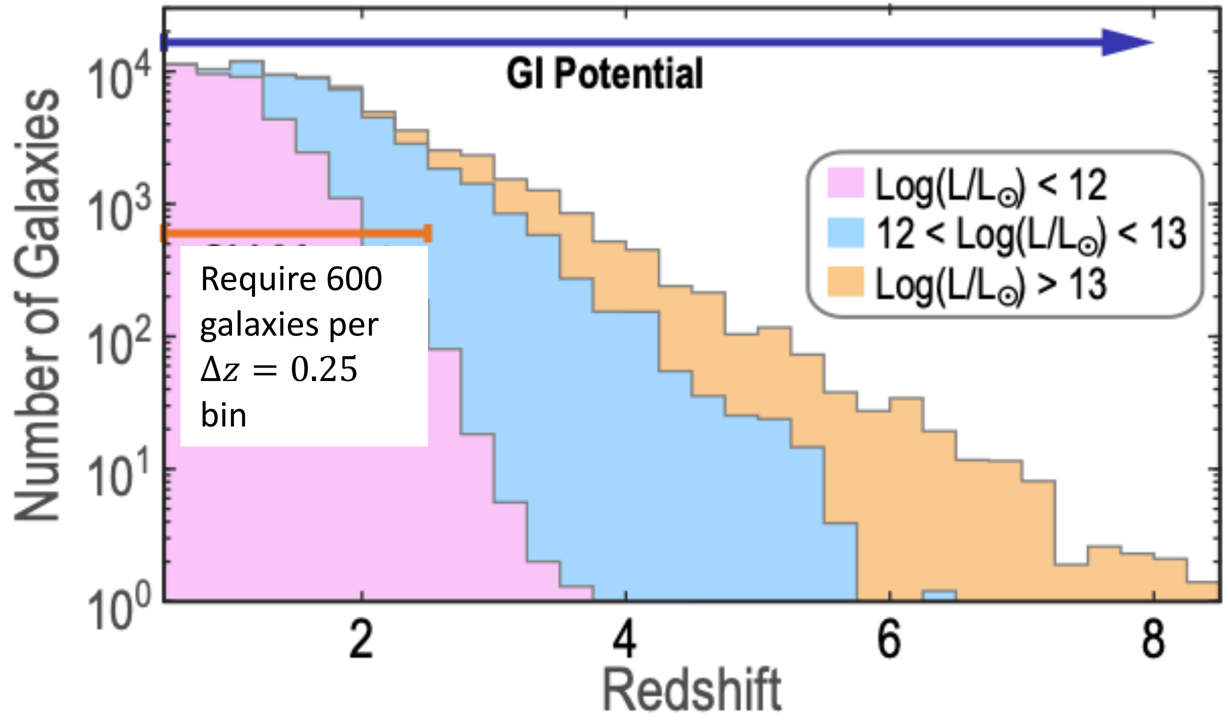


PRIMA Team

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



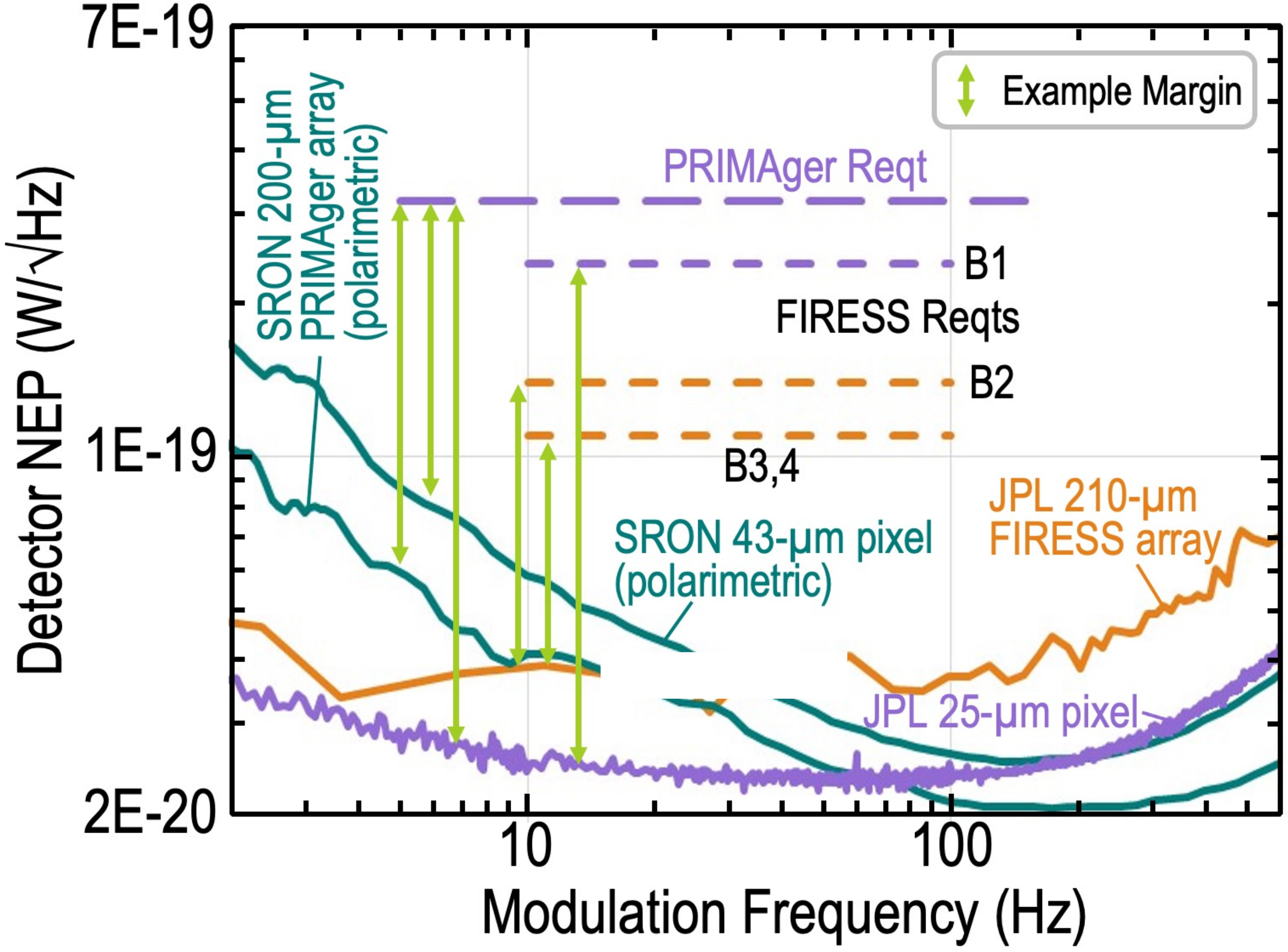
1 and 10 sq deg surveys



PRIMA Team

KID Sensitivities

Significant margin for both instruments, spanning the wavelengths



Day et al. (2024)