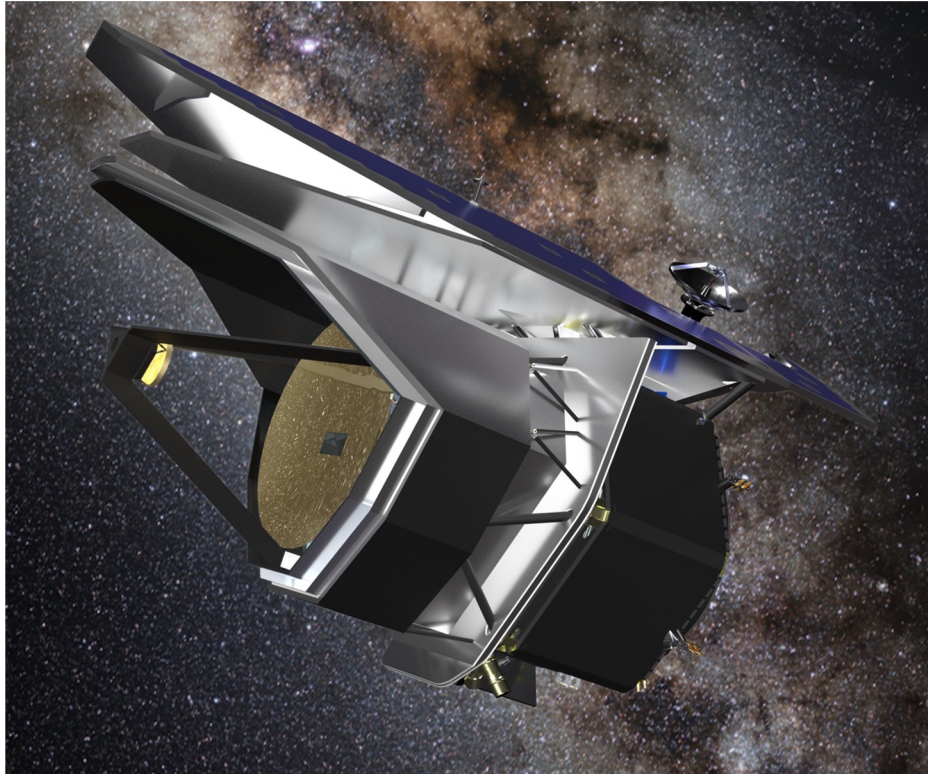




The PProbe far-Infrared Mission for Astrophysics



Matt Bradford, Project Scientist, JPL

On behalf of the PRIMA team

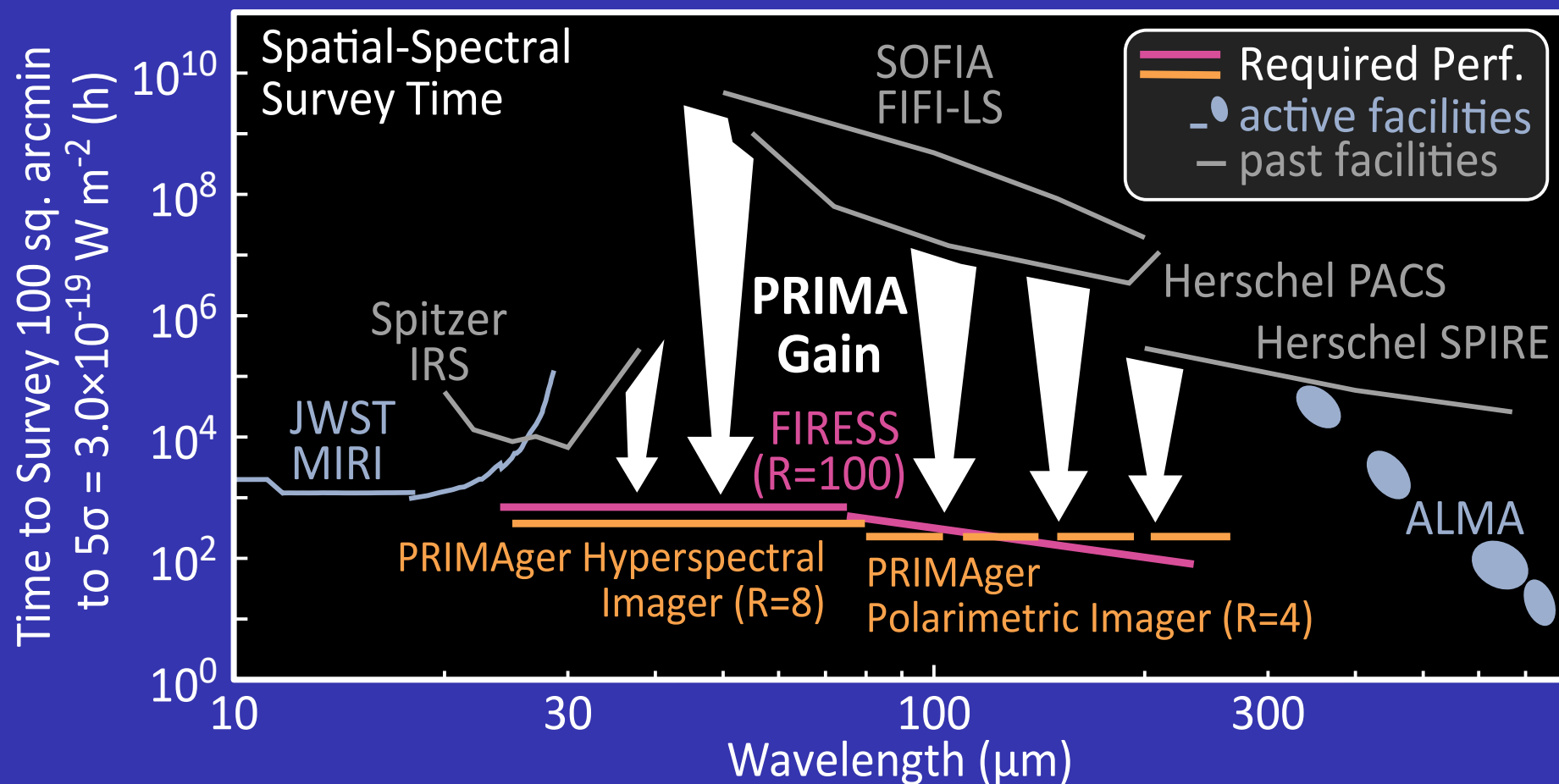
More Info:

Special Session Wednesday 2-3:30 Room 224 B

<https://prima.ipac.caltech.edu/>



PRIMA sensitivity leap provided cold telescope and improved detectors



Flagship class science for a Probe price point



ORIGINS OF PLANETARY
ATMOSPHERES



EVOLUTION OF GALACTIC
ECOSYSTEMS

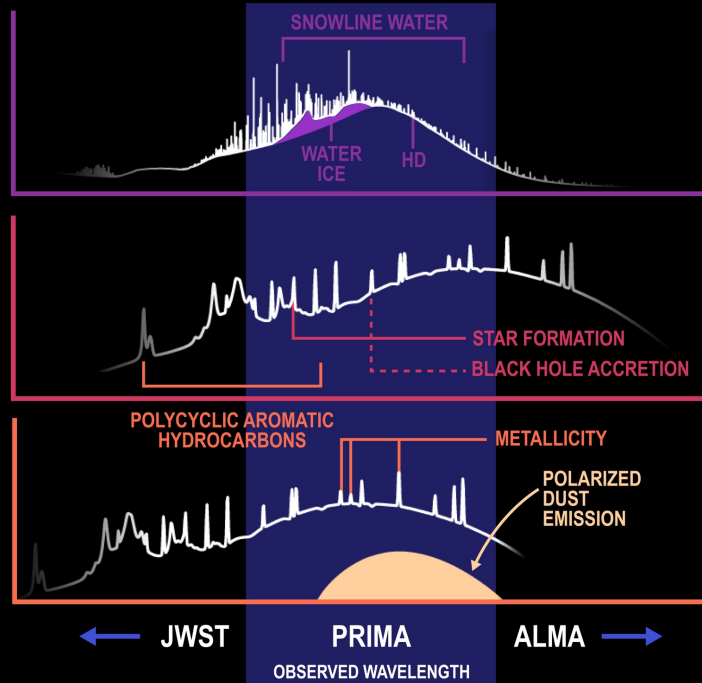


BUILDUP OF DUST
AND METALS

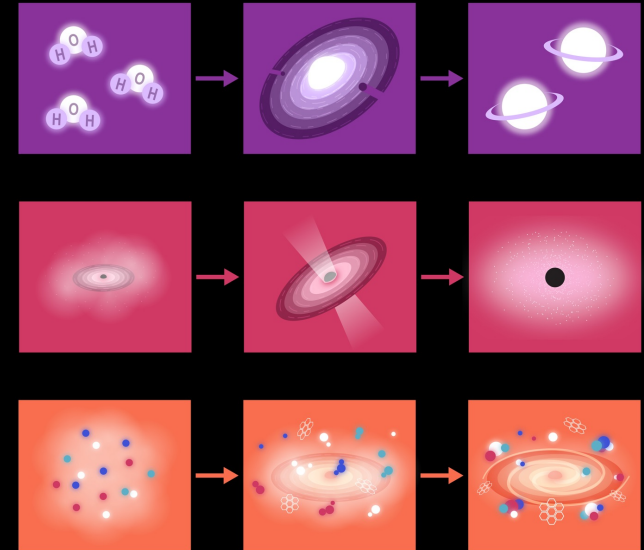


GENERAL OBSERVER
AND GUEST
INVESTIGATOR
POTENTIAL

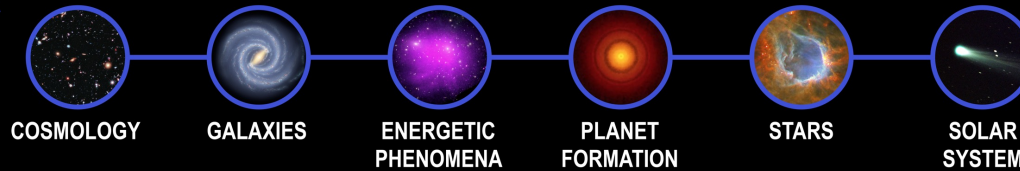
SPECTRAL MEASUREMENT



EVOLUTION



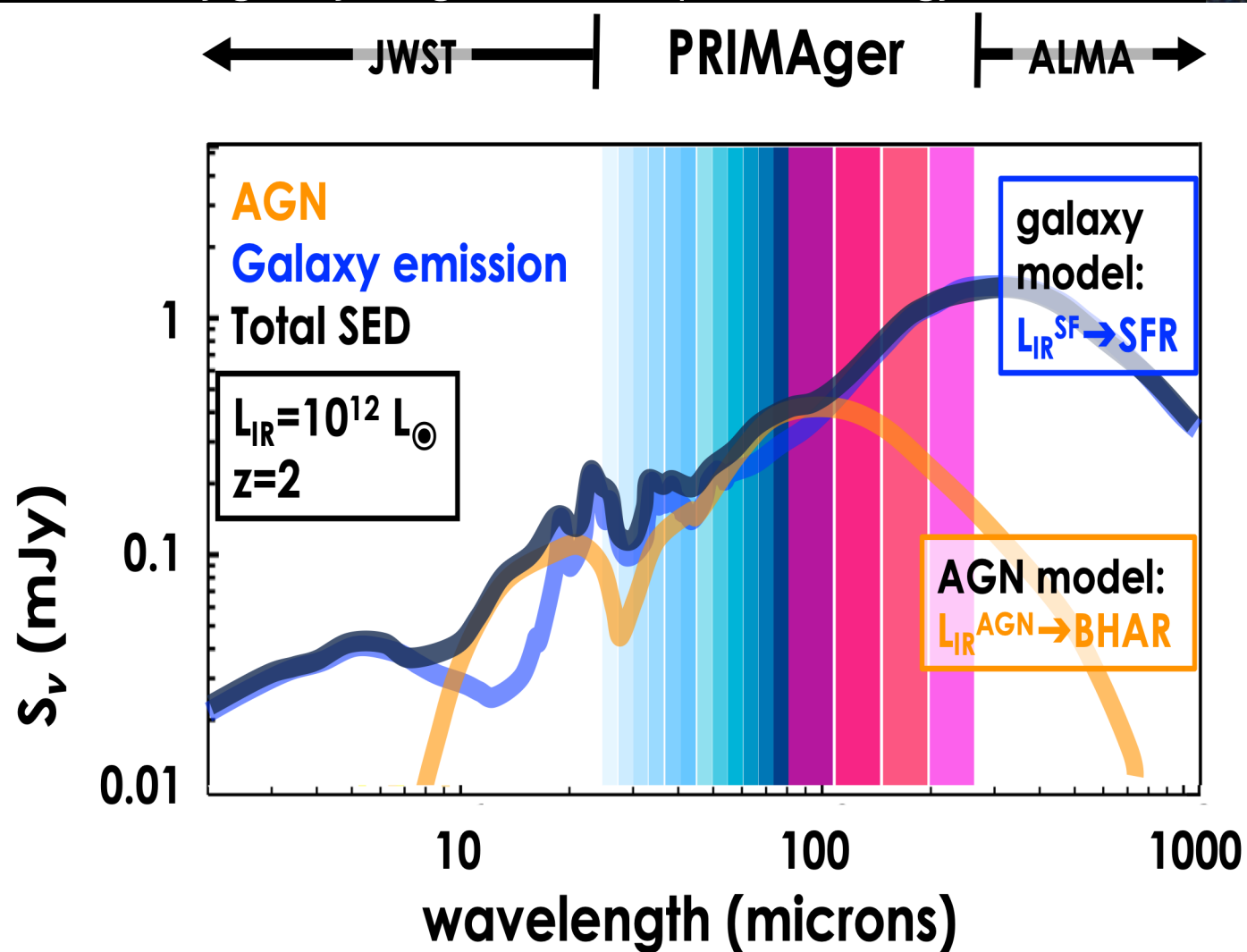
PRIMA uses the power of the far-infrared to see into the heart of dusty and obscured sources across cosmic time.



PRIMA's powerful and flexible capabilities enable general observer (GO) programs.

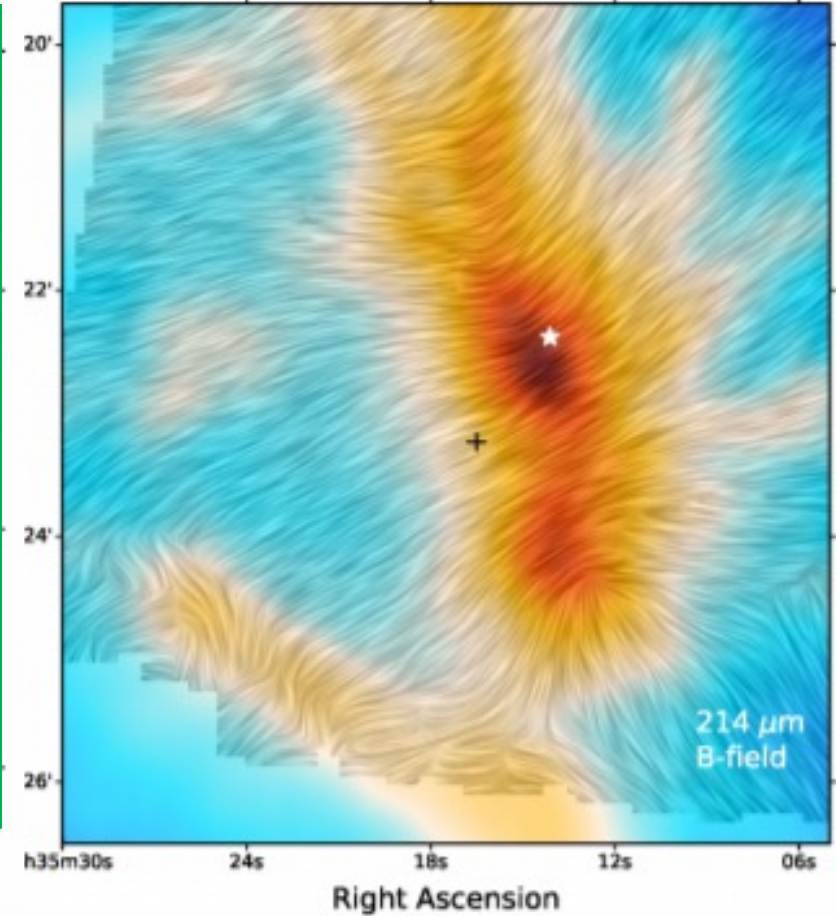
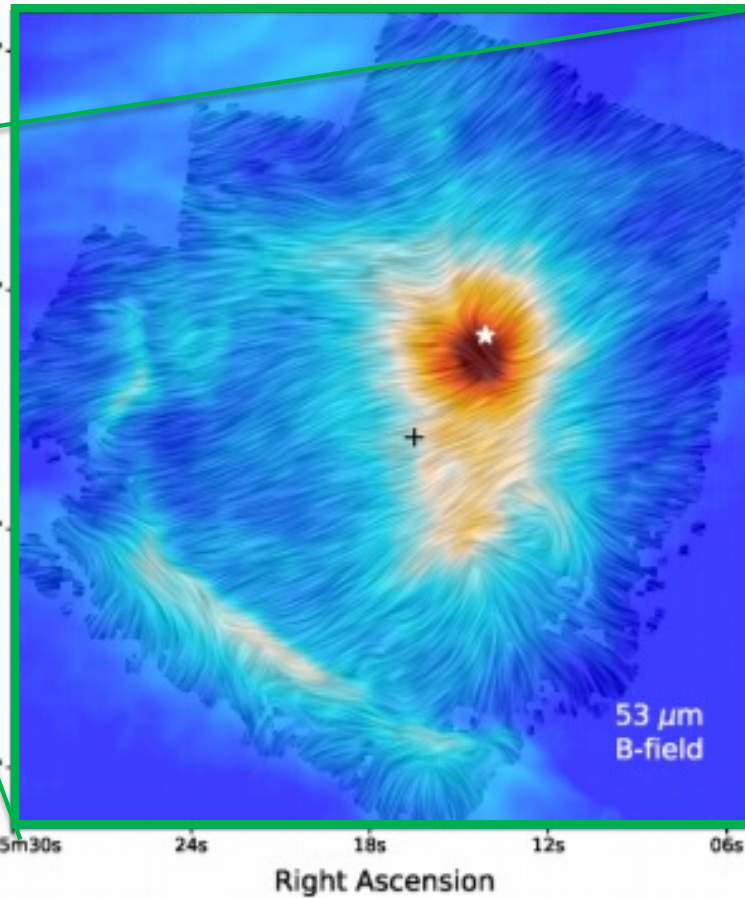
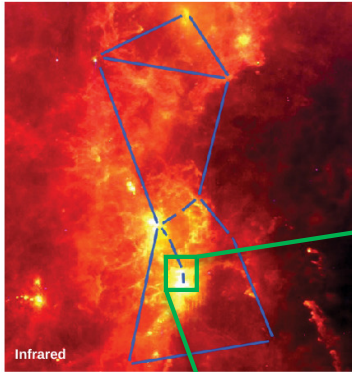
GO and GI community science will address >70% of Astro2020 decadal questions.

3D Hyperspectral surveys: for every galaxy we get a full IR spectral energy distribution



Simulated PRIMAgger 3-color image

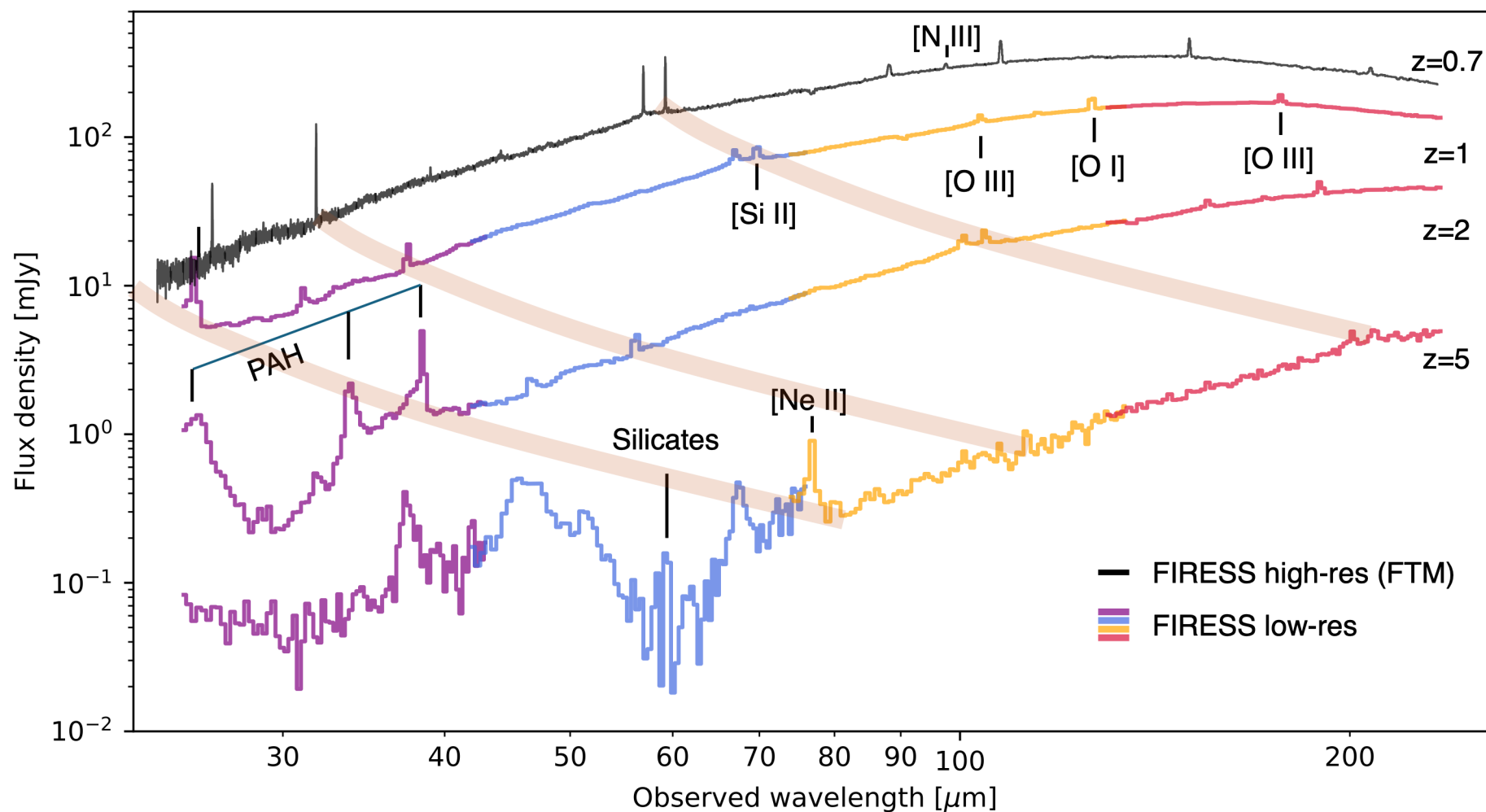
Far-IR Polarimetry with PRiMA: Tens of thousands of times faster than SOFIA



Magnetic field lines
in the Orion star
forming region.

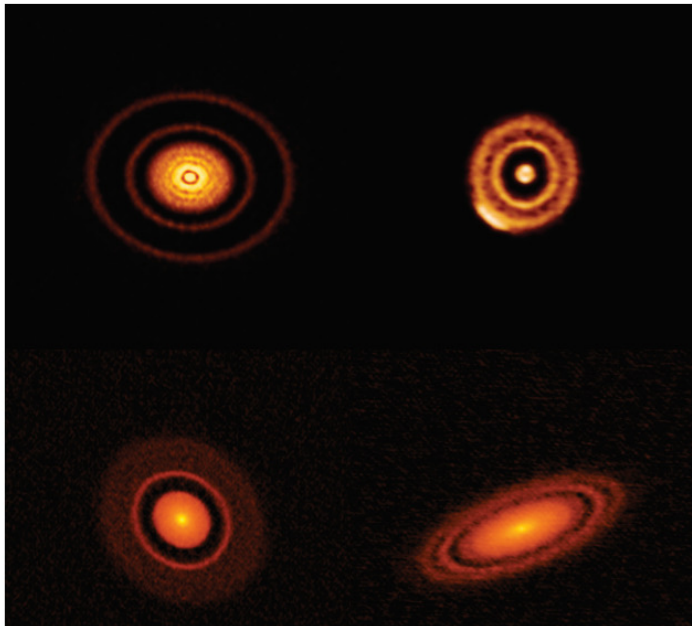
Obtained with
SOFIA HAWC+
D. Chuss et al.
2019

FIRESS Full-band spectra



PI Theme 1: Origin of Planetary Atmospheres: Measure Disk Masses to Fix Abundances

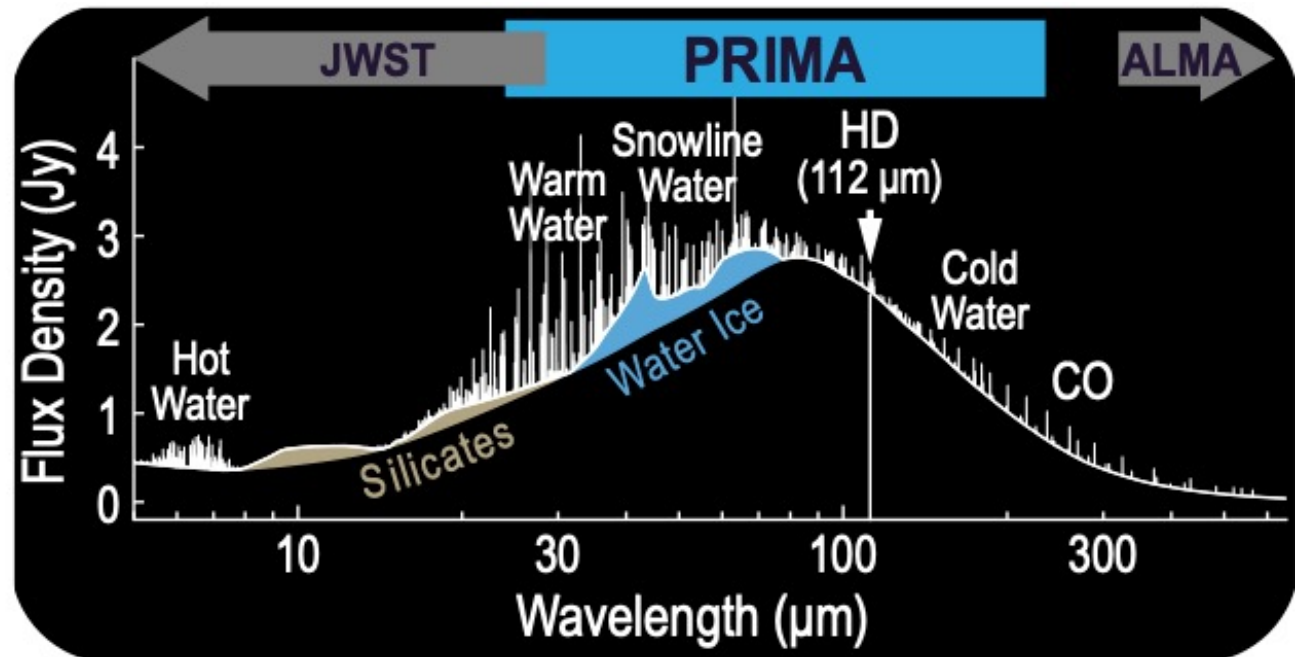
ALMA has produced images of disks, confirming some basic aspects of planet formation.



S. Andrews et al.;
NRAO/AUI/NSF, S. Dagnello

But disk mass (thus basic elemental abundances) and water content and distribution remain uncertain by orders of magnitude. CO and dust are not good mass tracers in disks.

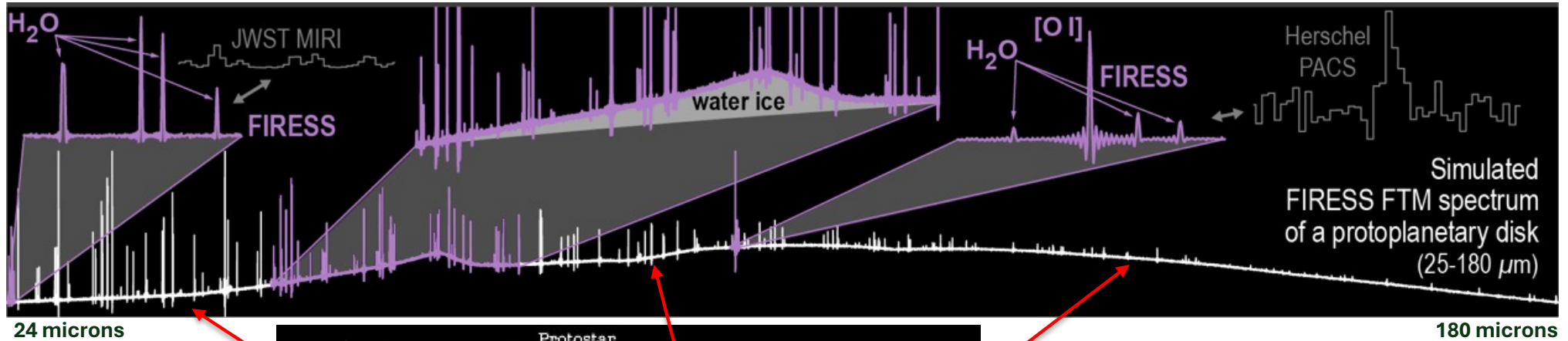
PRIMA will survey 200 disks with full band spectra, providing the HD 1-0 transition as well as hundreds of water lines.





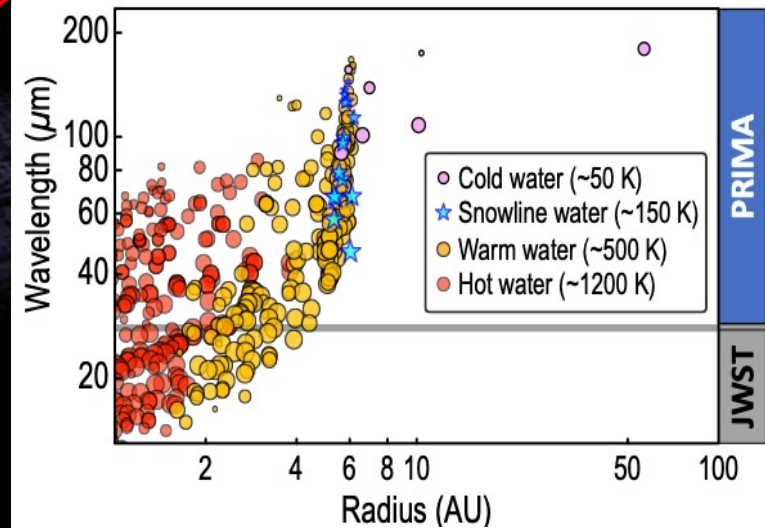
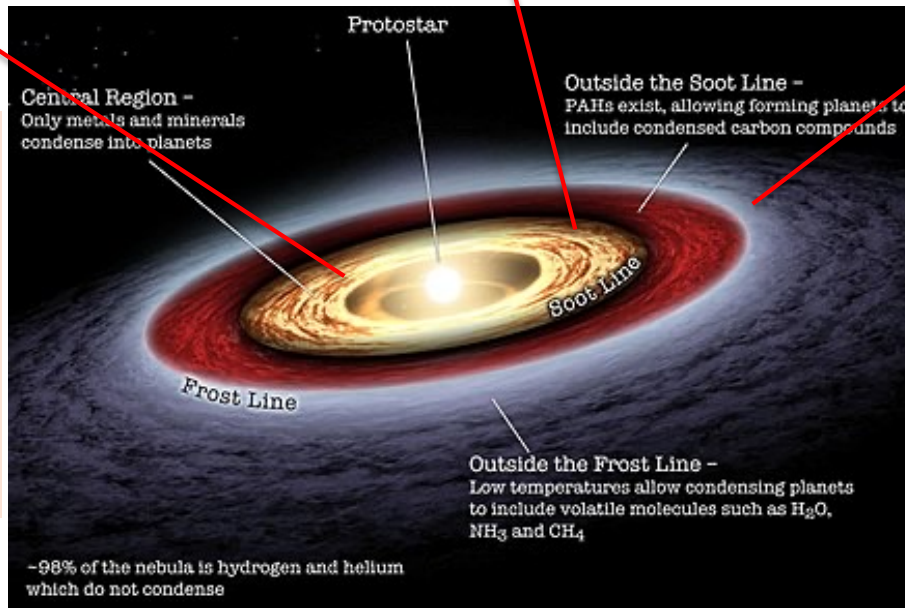
PRIMA

The PRobe far-Infrared
Mission for Astrophysics



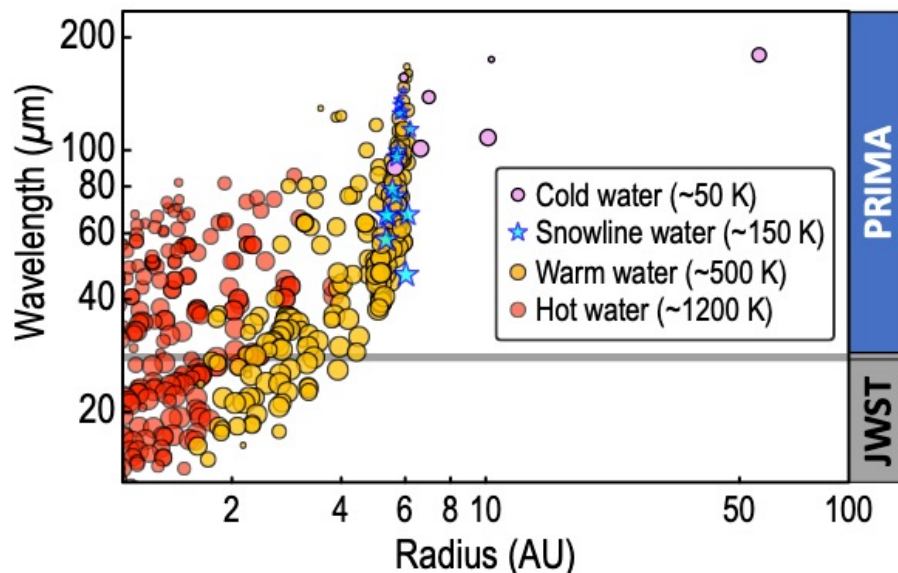
PRIMA Disk Observations

- 200 PP Disks
- 0.5-2.0 M_{sun}
- 24-235 micron
- R=2,000-20,000

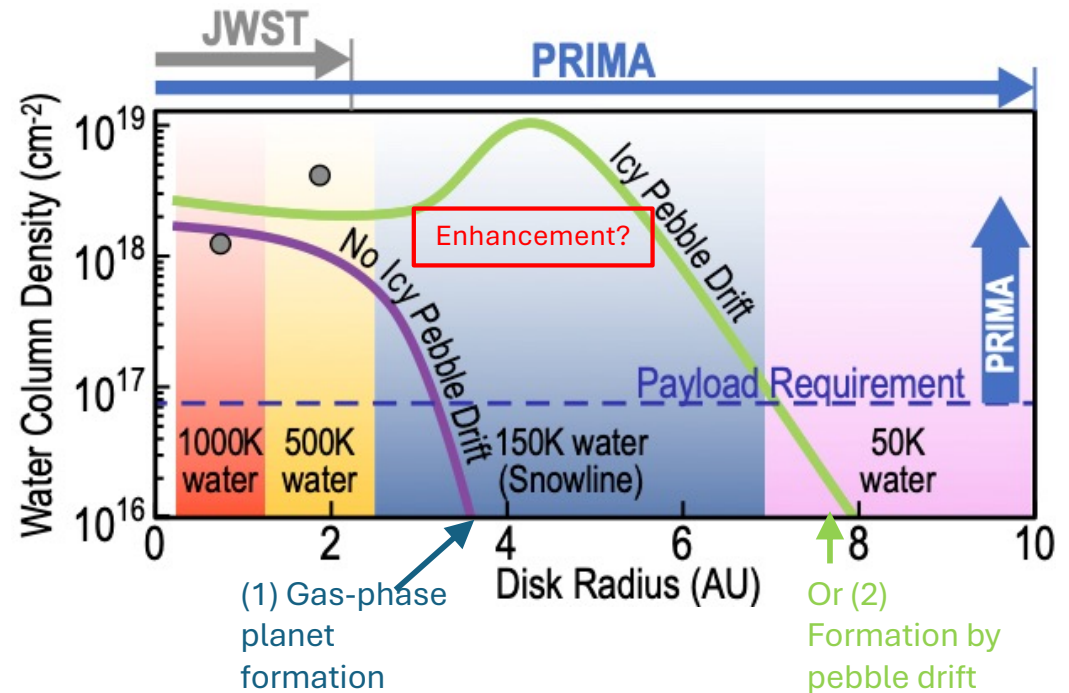


Theme 1 (continued): Is there enough water mass to drive the formation of planetesimals near the water snowline?

PRIMA will measure the level of water enhancement in 200 disks of various ages and masses (point size $\propto$ line flux).

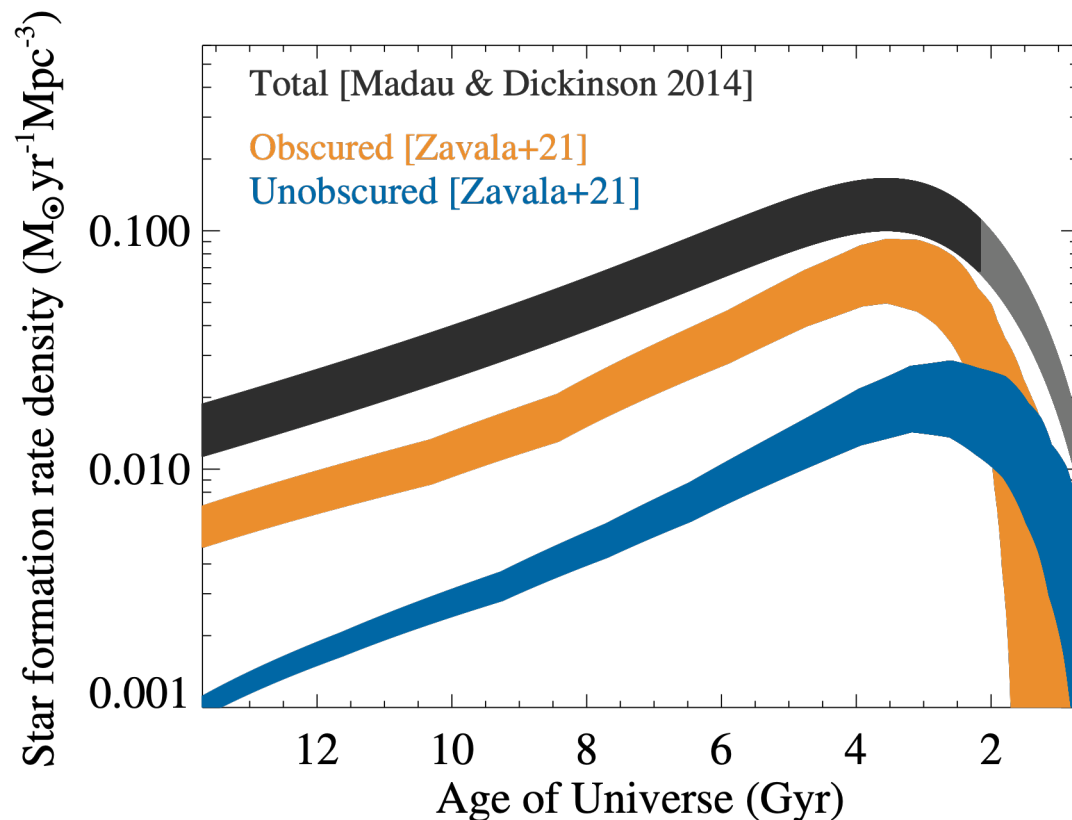
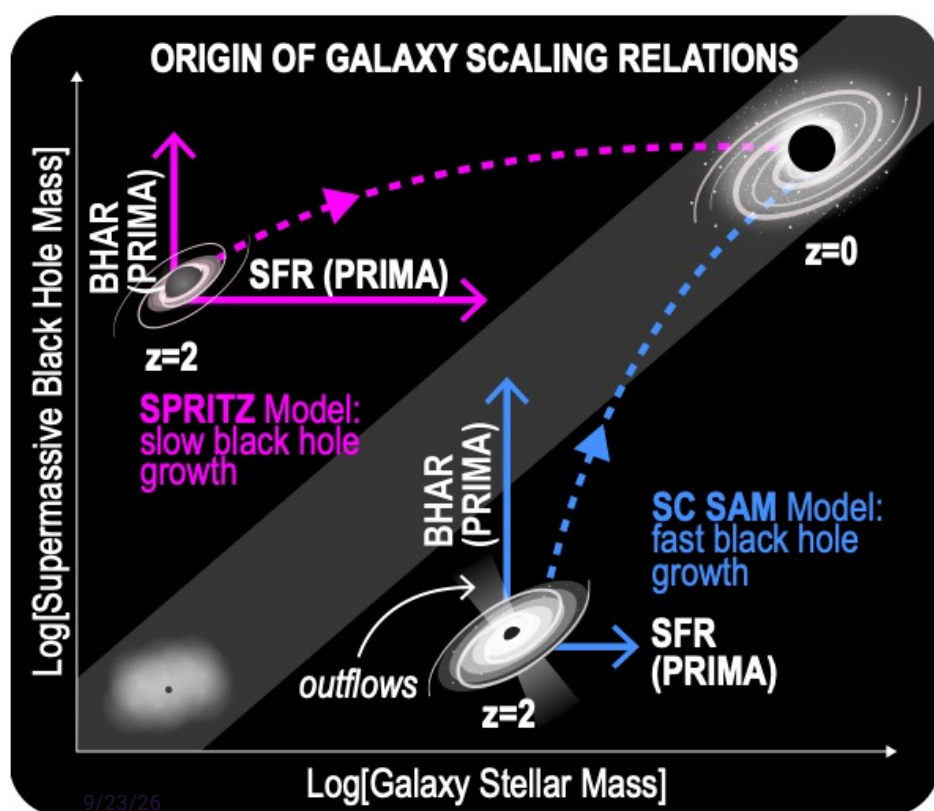


Water likely dominates the solid disk mass outside the snow line and coagulates via ice pebble drift to form planetesimals. PRIMA measures $N_{\text{H}_2\text{O}}(T)$ to test models.



PI Theme 2: What is the scaling relation between black-hole accretion rate and star-formation rate in luminous galaxies since the peak epoch ($z \sim 2$)?

PRIMA will measure dusty SFRs and obscured SMBH luminosities with redshifted mid- to far-IR spectral energy distributions (SEDs) and atomic fine-structure lines.



Themes 2 and 3: First step is blind hyperspectral surveys in 1 and 10 sq degrees

Expect on order 100,000 galaxies
blindly detected in the 2-tiered survey

$z=2$ galaxies

30

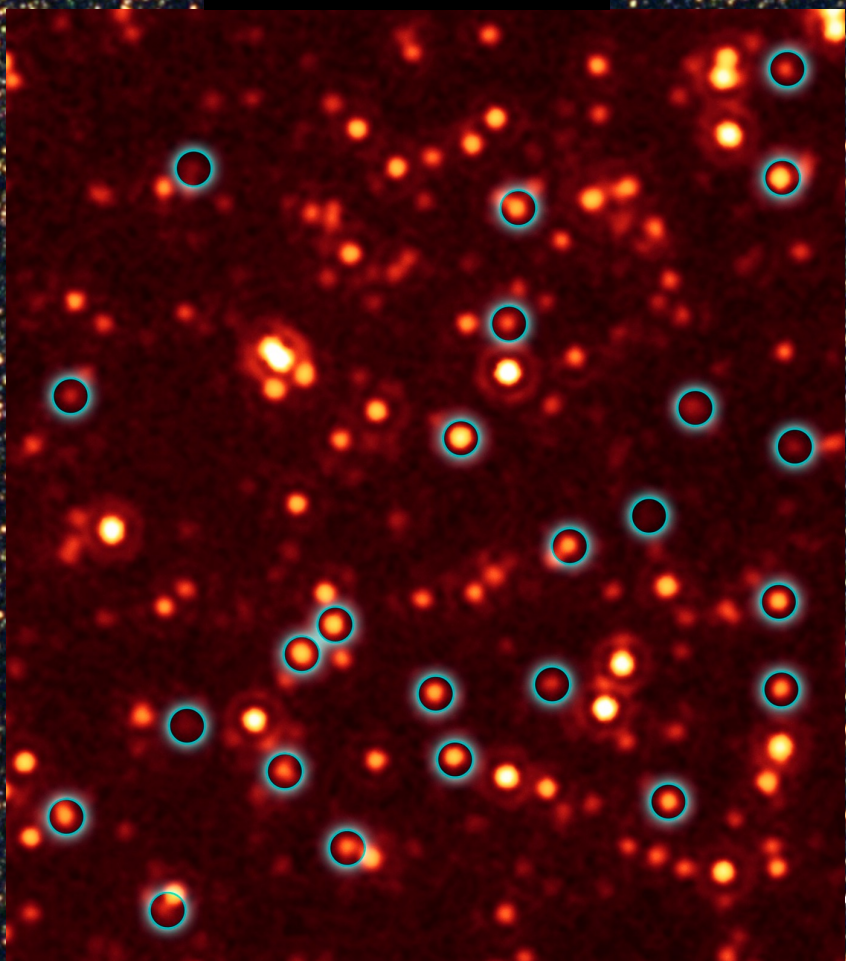
200

1 deg

Simulated PRIMAgger 3-color image from SIDES (Bethemin+24)

Themes 2 and 3: First step is blind hyperspectral surveys in 1 and 10 sq degrees

Spitzer MIPS 24 micron



Expect on order 100,000 galaxies
blindly detected in the 2-tiered survey

Beamsize with PRIMA at 55-60 microns
is comparable to Spitzer at 24 microns.
Unconfused and resolves most of the
light.

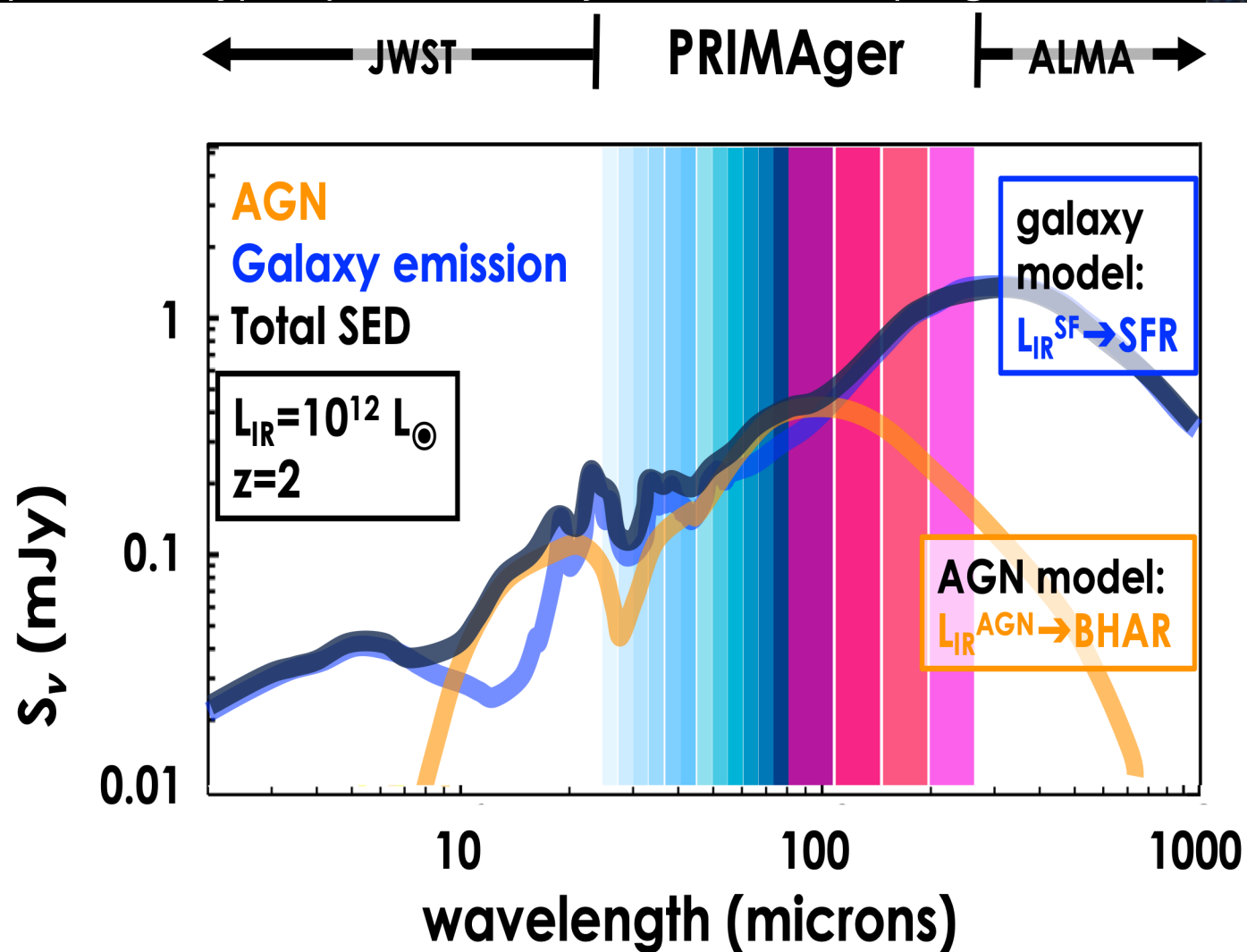
Flux recovery utilizes positional priors
from shortest wavelengths. Donnellan
et al. 2024, 2025

Can also use near-IR priors from Euclid.

1 deg

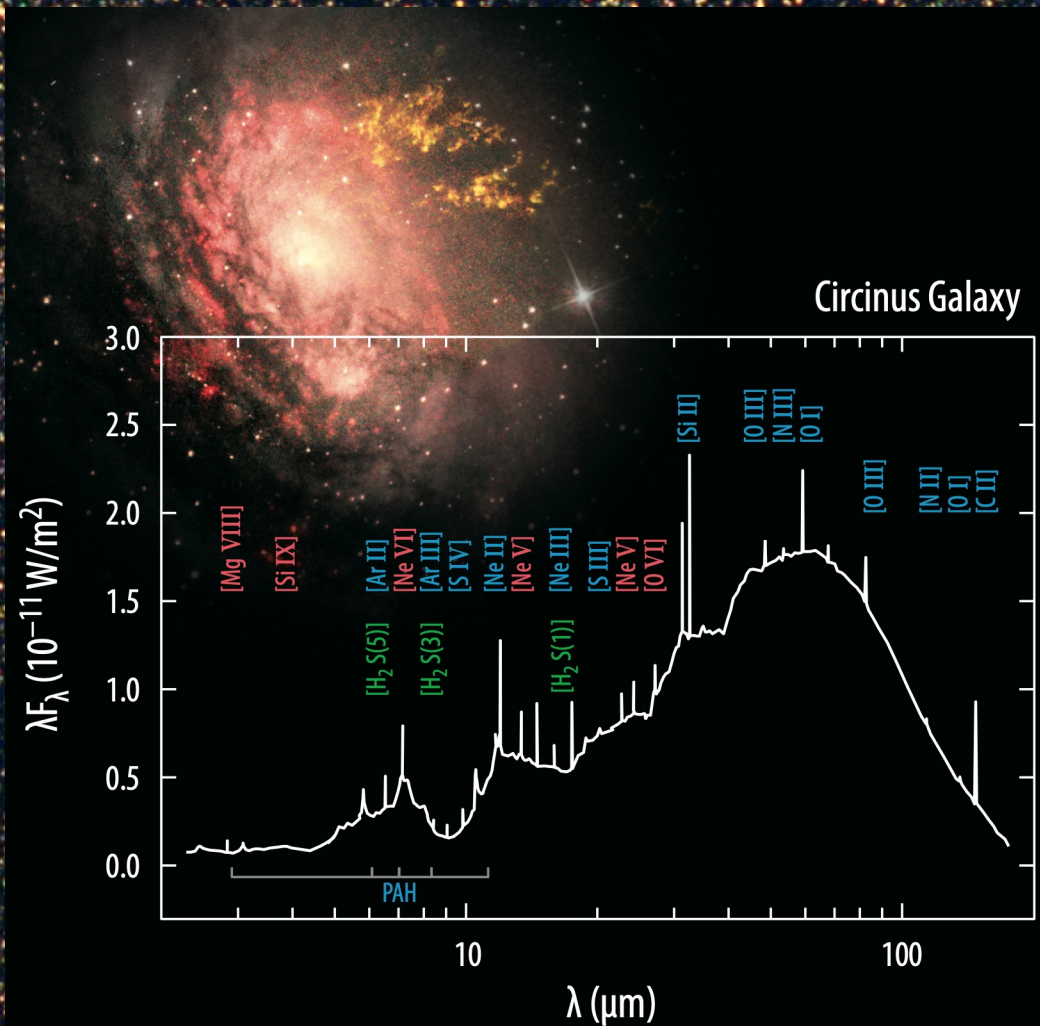
Simulated PRIMAGER 3-color image from SIDES (Bethérmin+24)

Theme 2: First step is blind hyperspectral surveys in 1 and 10 sq degrees



Simulated PRIMAgger 3-color image

Selected galaxies have detailed spectra



Outflows and feedback

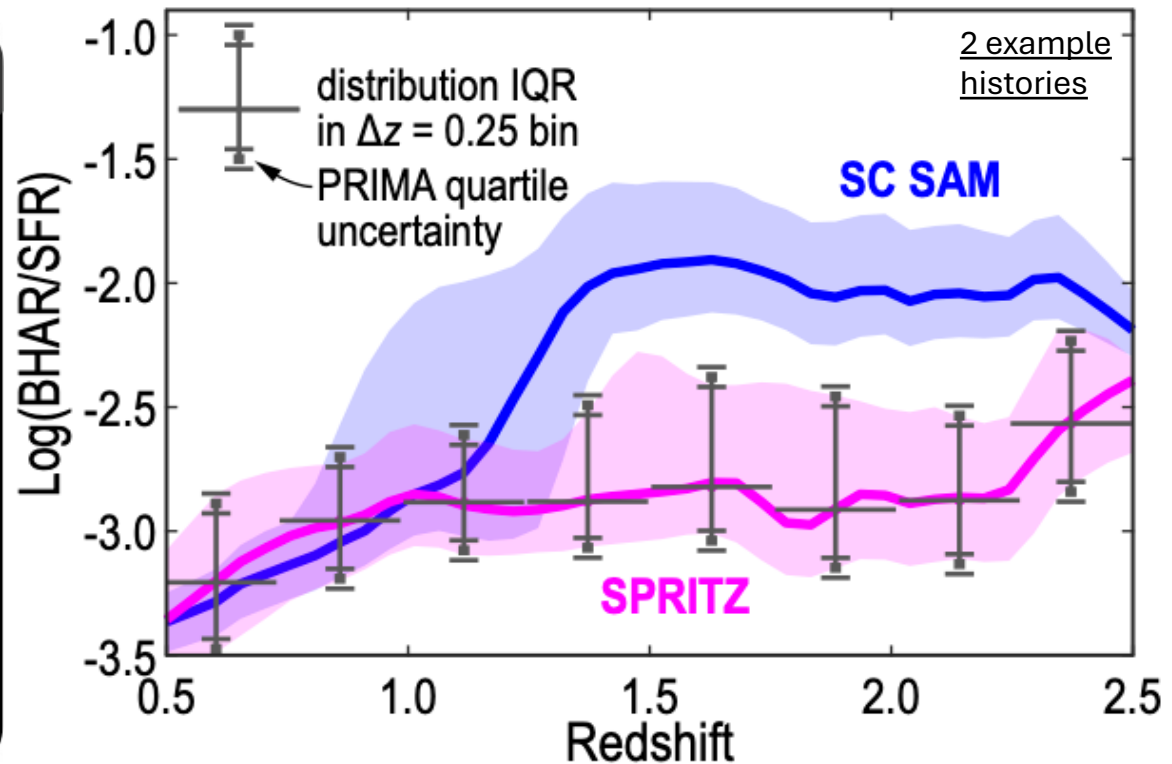
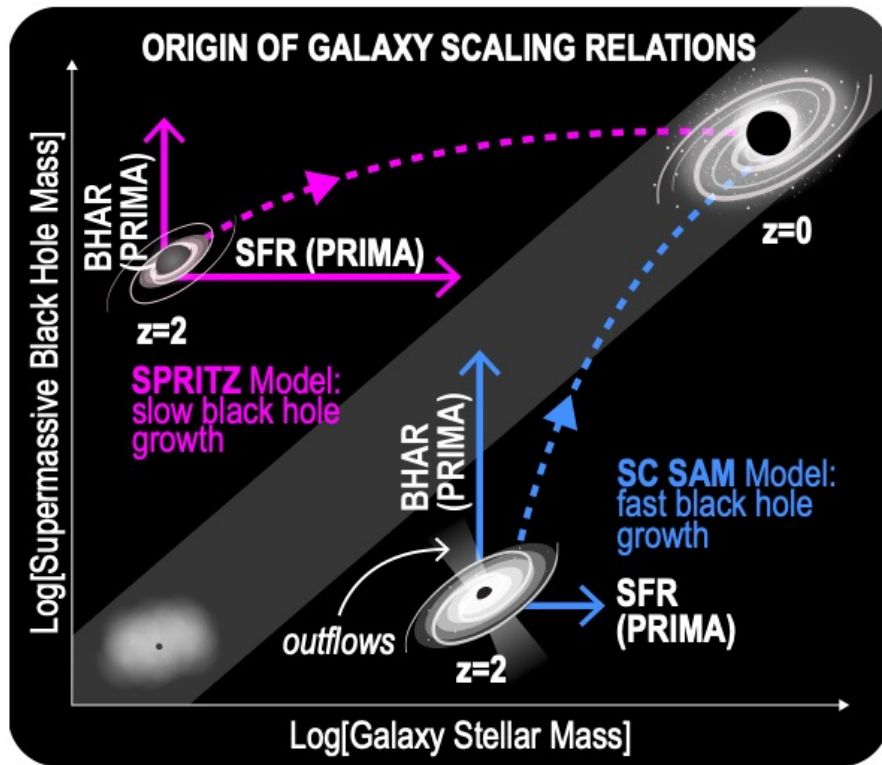
Atomic & ionized gas

Elemental abundances

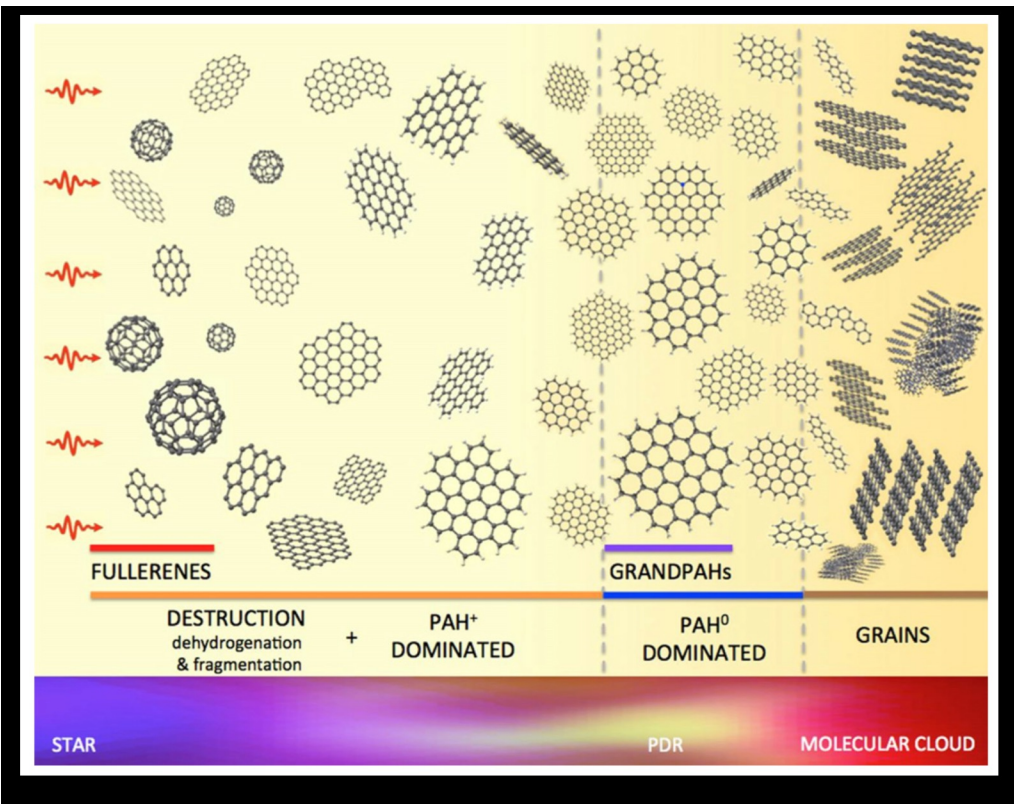
Supermassive black hole growth

PI Theme 2: What is the scaling relation between black-hole accretion rate and star-formation rate in luminous galaxies since the peak epoch ($z \sim 2$)?

PRIMA will measure dusty SFRs and obscured SMBH luminosities with redshifted mid- to far-IR spectral energy distributions (SEDs) and atomic fine-structure lines.



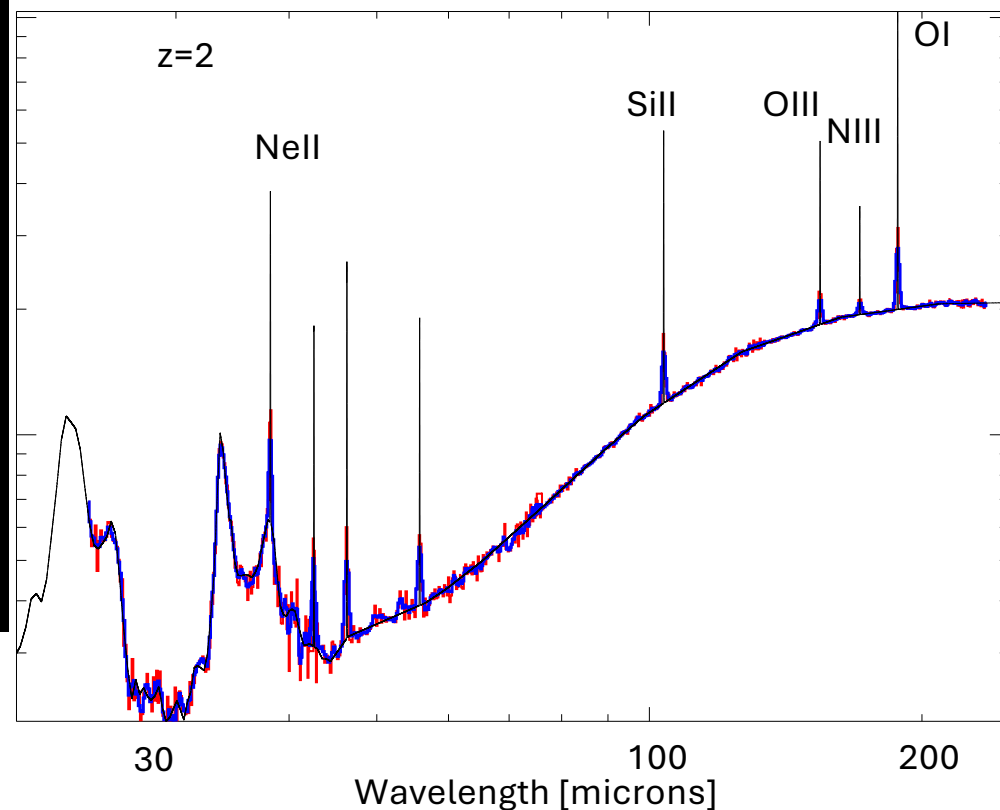
PI Theme 3: Buildup of dust and metals, their relationship and composition



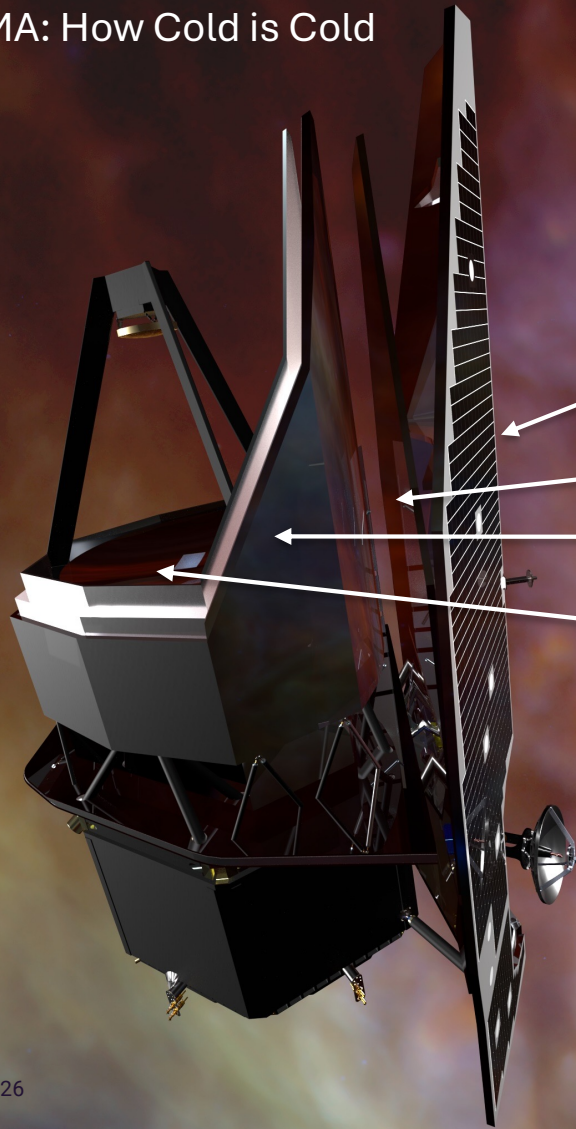
Grain composition (pristine stardust vs mixed ISM dust) measured with polarimetry locally

9/23/26

PRIMA will conduct a census of small grains and gas phase abundances in active galaxies since cosmic noon.



PRIMA: How Cold is Cold



5800 K surface of sun

310 K July in Pasadena
300 K warm spacecraft
235 K Antarctic winter

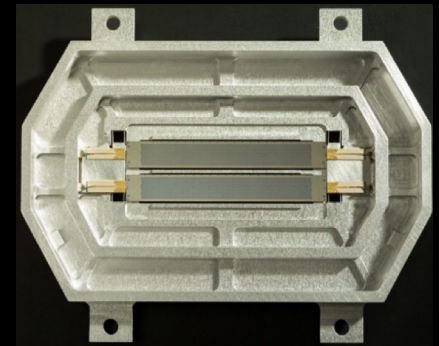
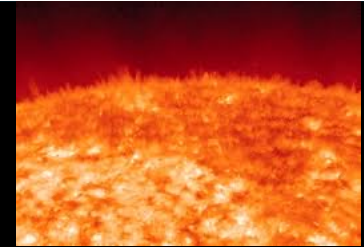
45 K radiative cooled stage

18 K active intercept

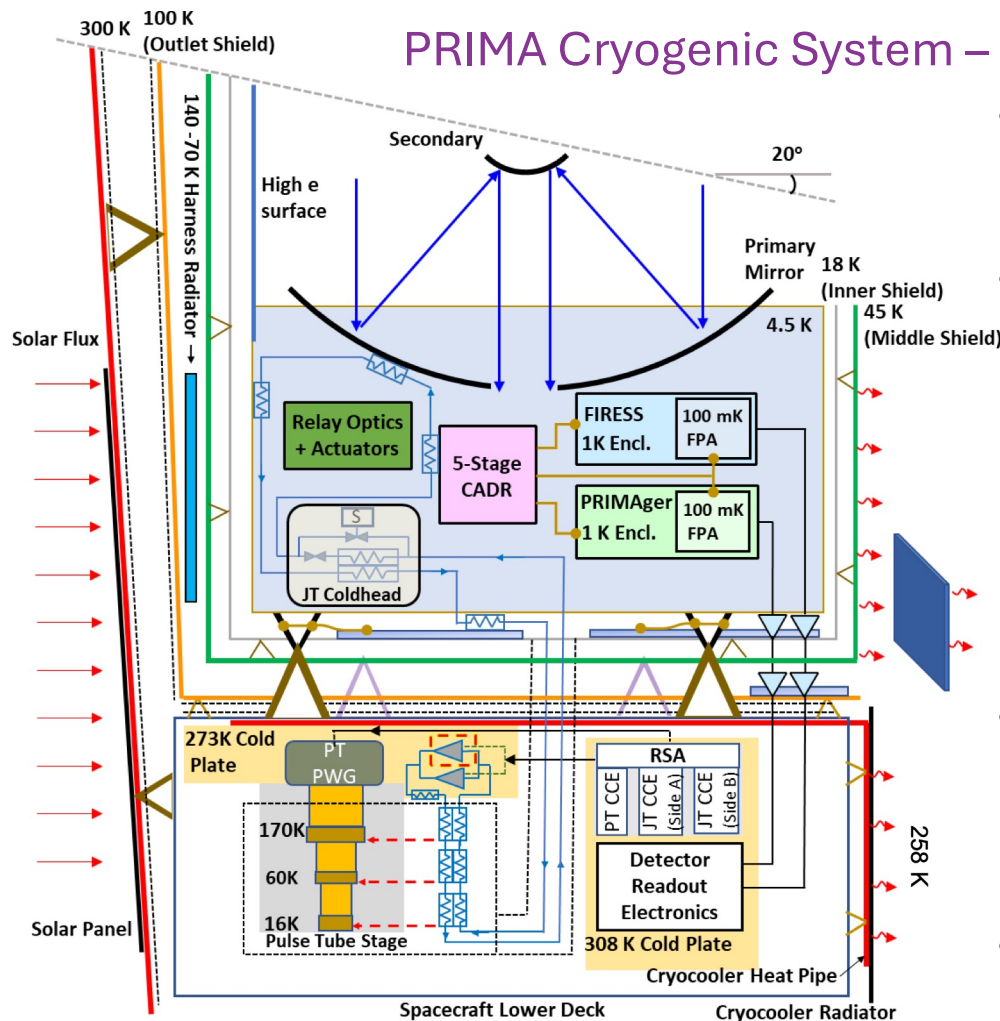
4.5 K telescope
2.7 K deep space

1 K instrument optics

0.1 K detectors



PRIMA Cryogenic System – see Weibo Chen et al. 2023



- Passive cooling with sunshades and radiators create payload environmental temperature at 45 K.
- MIRI flight spare cooler using ^3He as working fluid (TRL 9) provides lift at 18 K and 4.5 K.
 - 4.5 K stage cools telescope, struts, inner shield, reimaging optics, steering mirrors, FIRESS FTM. 50 mW capacity
 - 4.5 K stage backs 1 K / 0.1 K ADR cooler.
 - Amplifiers at 18 K to increase pixel count.
 - Cooler requires 410 W at bus.
- 1 K / 0.1 K continuous adiabatic demagnetization refrigerator (DiPirro poster Monday 5-7)
 - Cools instrument enclosures to 1 K
 - Cools focal plane arrays to 100 mK
- >100% margin at all stages.

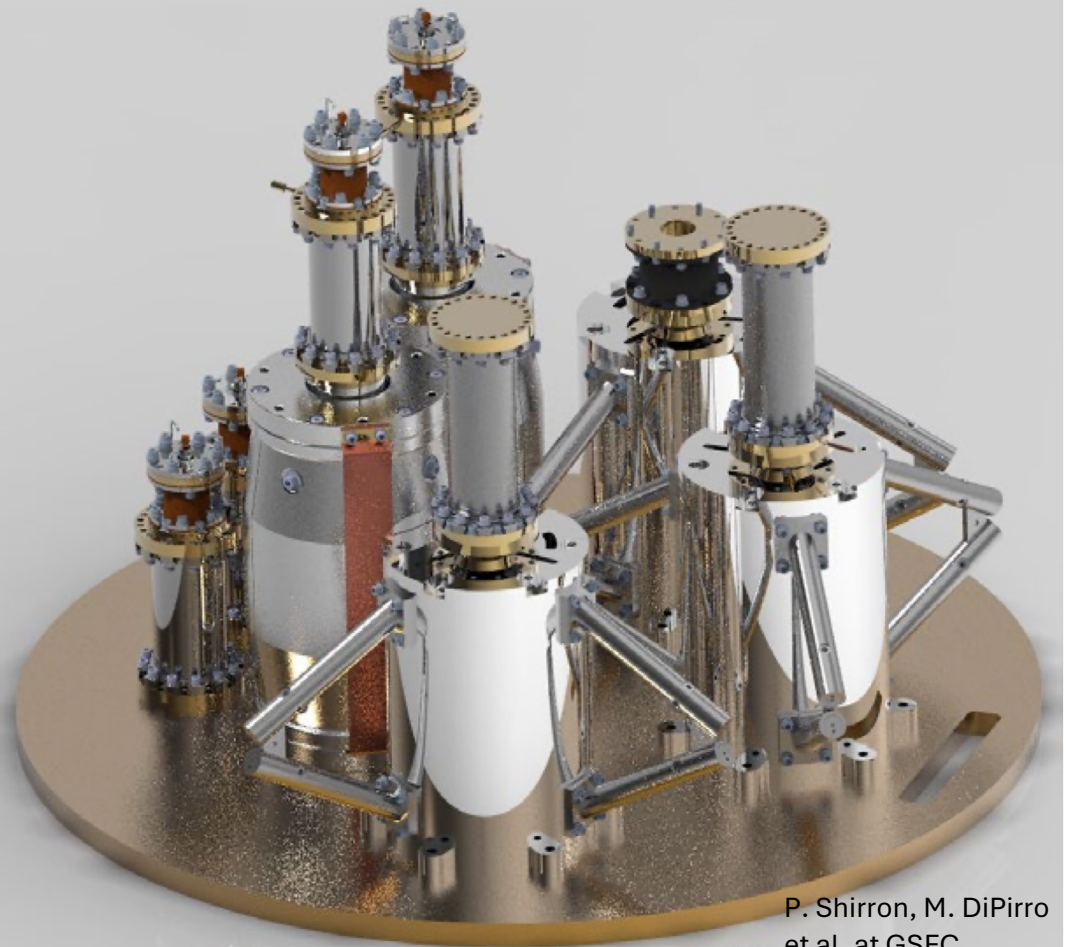
Facility cooler is MIRI flight spare



Uses ^3He instead of ^4He to reach 4.5 K

1/23/26

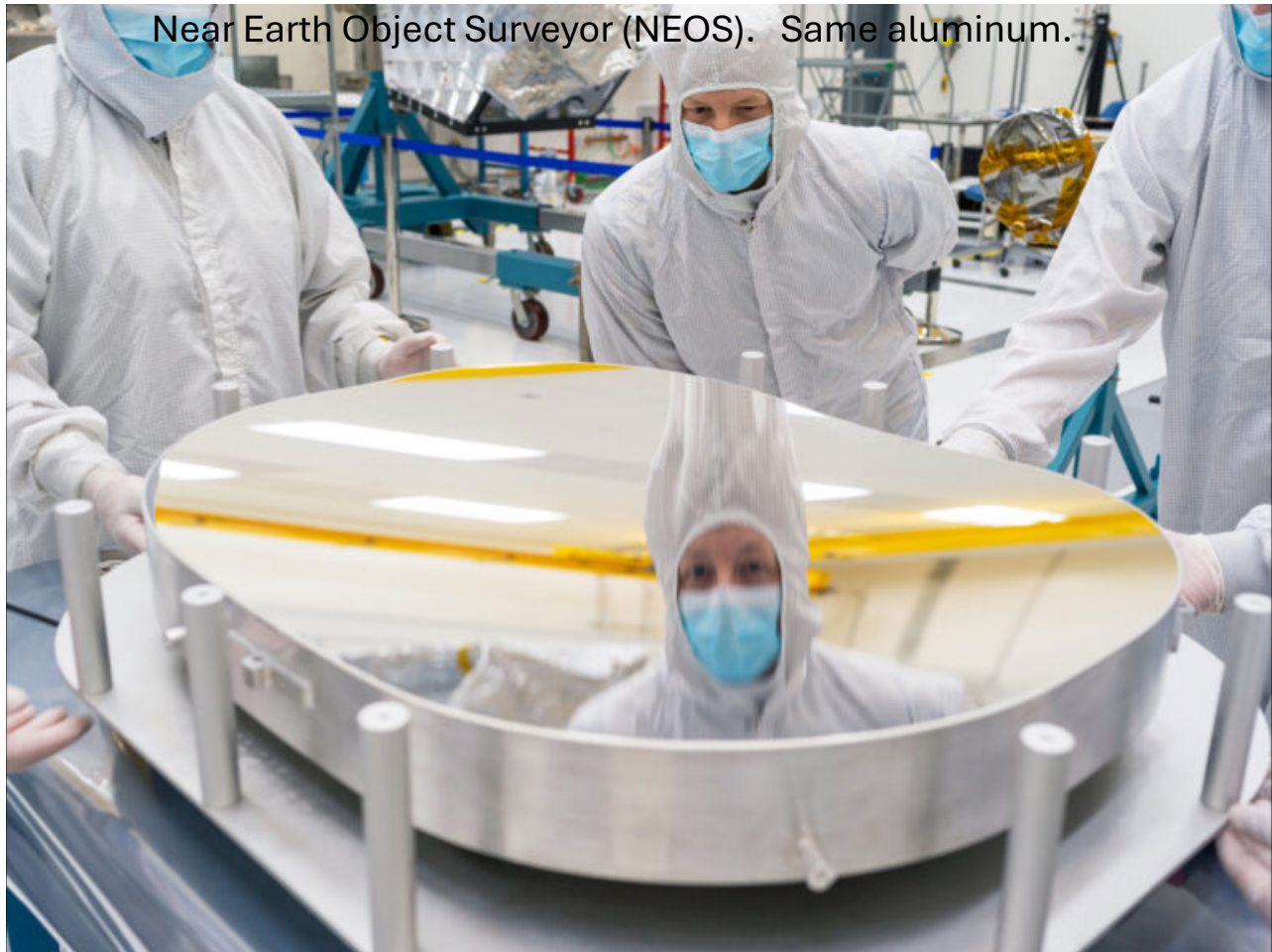
Cooling the 1 K instruments and 0.1 K detector arrays uses magnetic refrigerator built at GSFC.

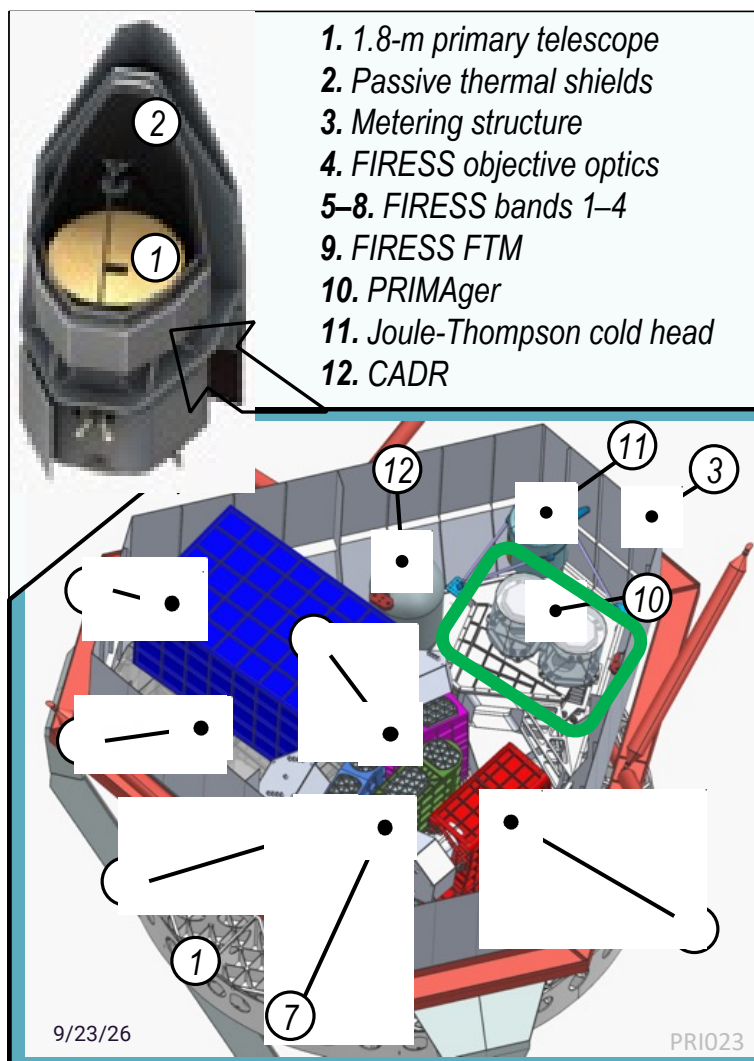


P. Shirron, M. DiPirro
et al. at GSFC

PRIMA Telescope

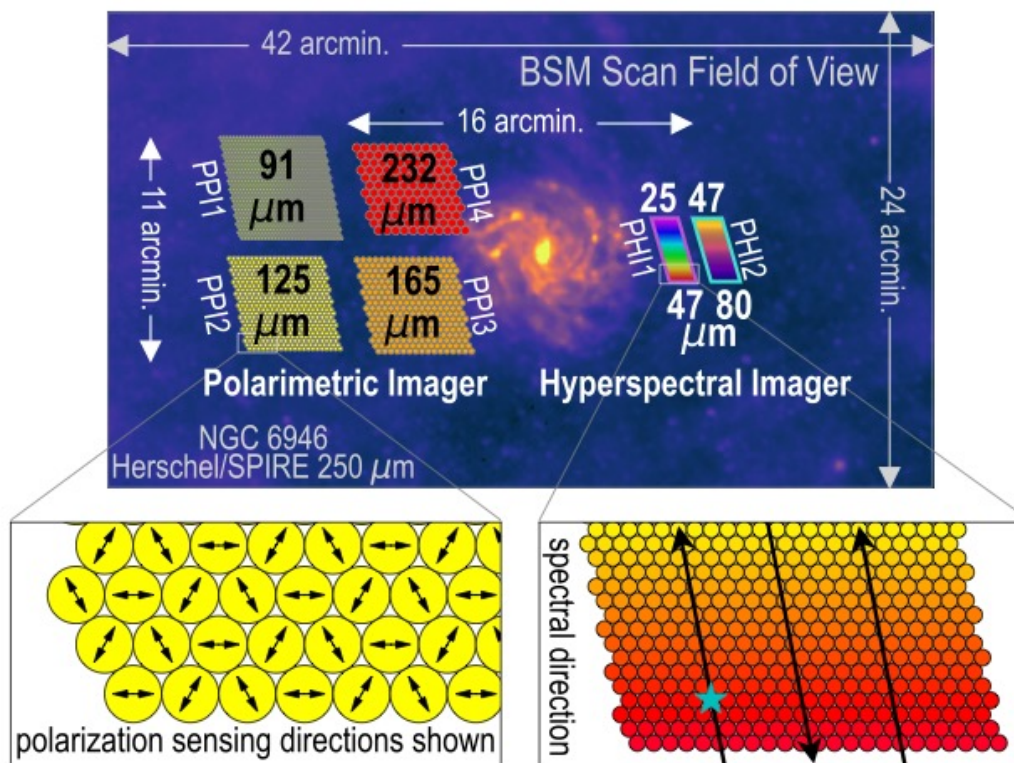
- 1.8 meter all aluminum monolith for primary mirror
- Cooled to 4.5 K
- Diffraction limited at 28 microns (10x looser than demonstrated with SPHEREx)
- Uses same vendors and processes as SPHEREx, NEOS aluminum, with diamond turning and test at Marshall.





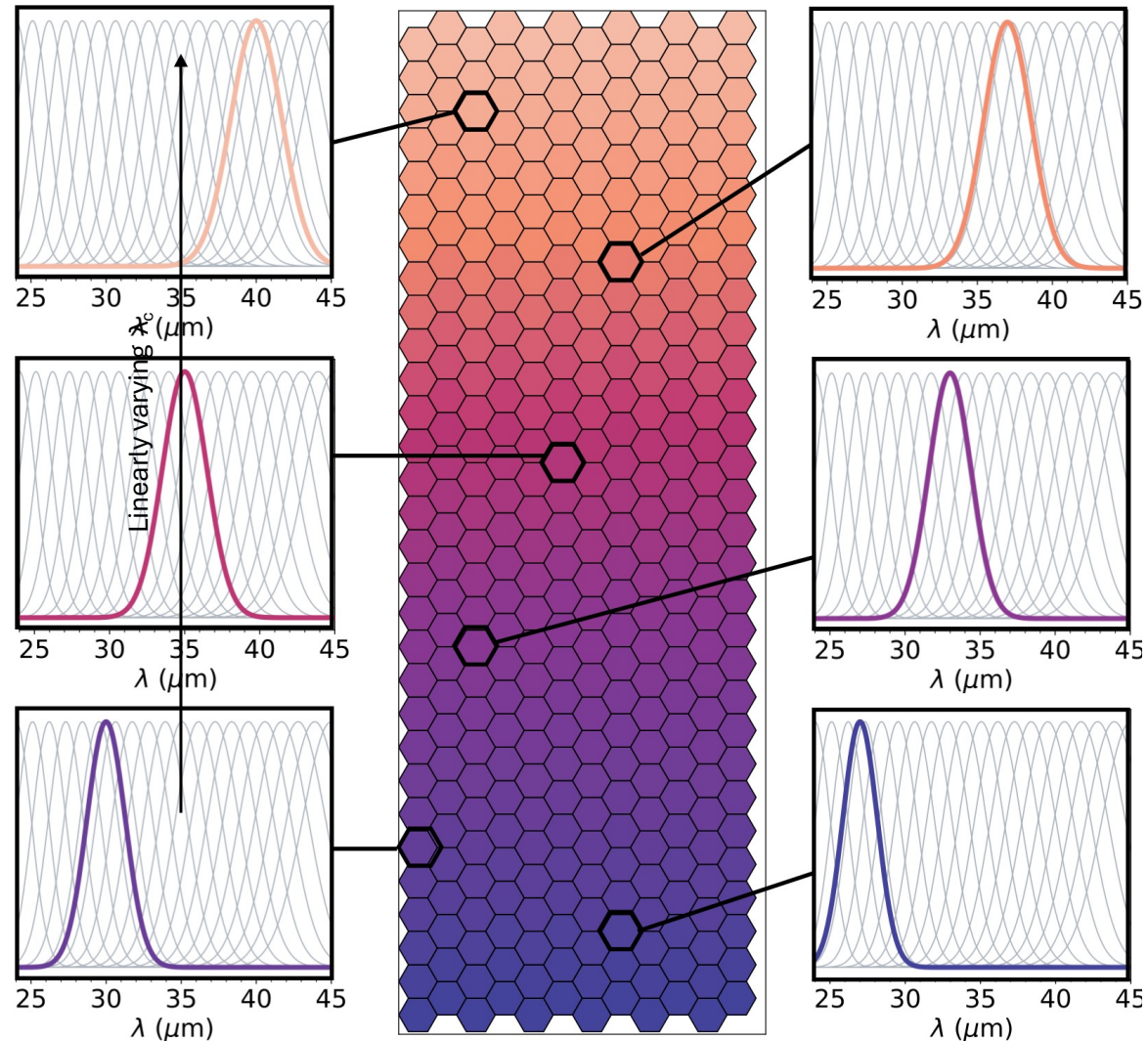
PRIMAgger (French / Dutch contribution)

- Two R=10 Hyperspectral focal planes using linear variable filters: (24 – 80 μm)
- Four R=4 polarimetric imaging arrays: (80 – 235 μm)
- 3993 total pixels

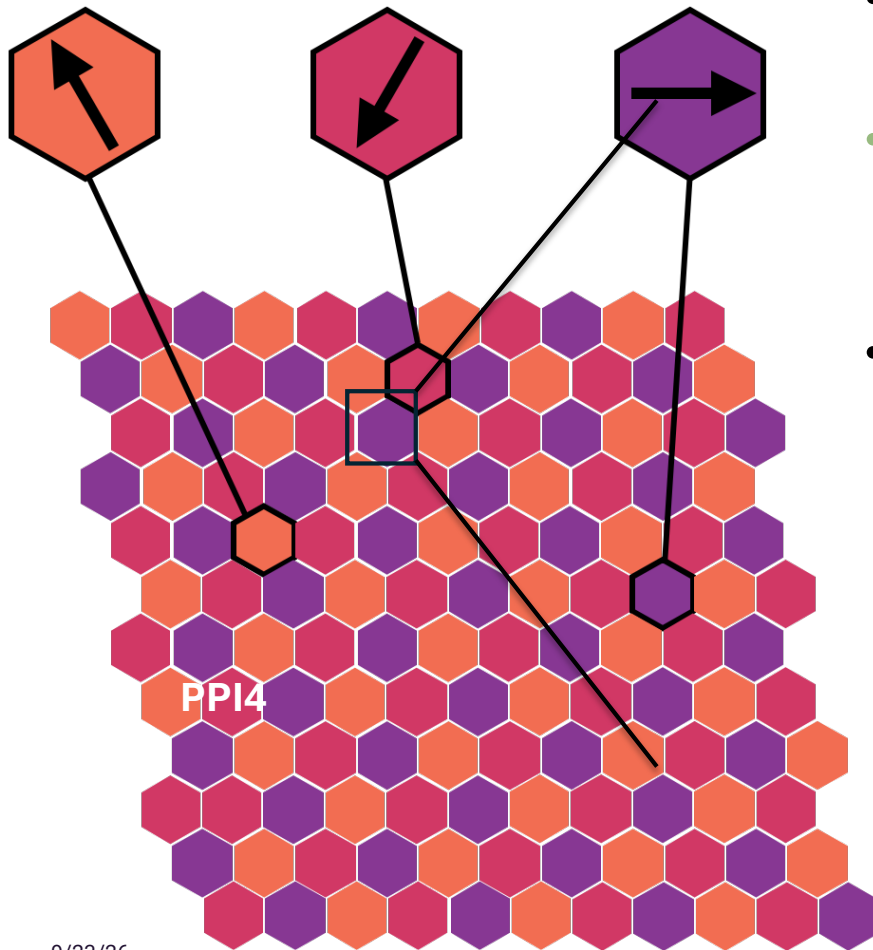


PRIMAger Hyperspectral Imager

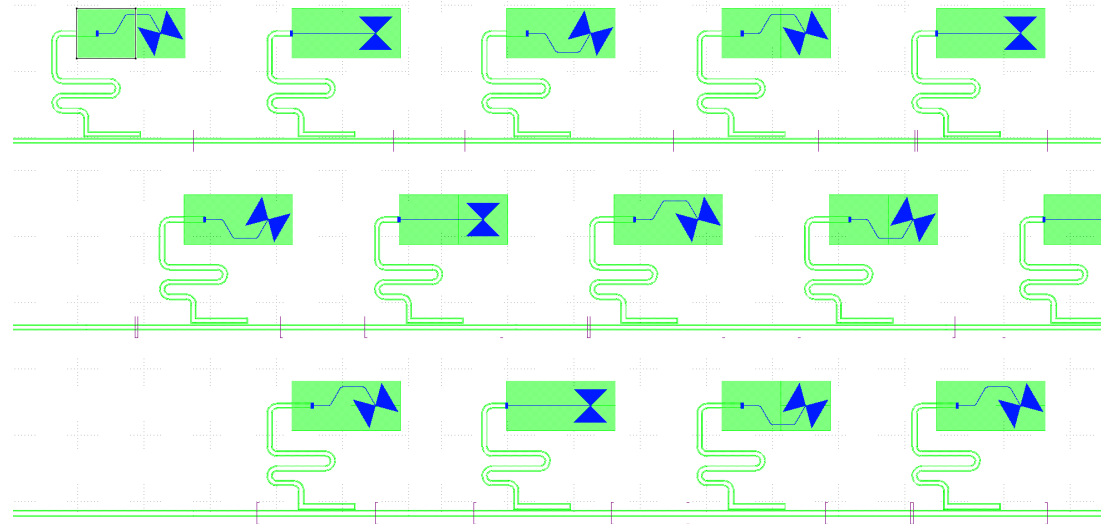
- **PHI** has two arrays (PHI1 & PHI2) of **absorber-coupled KIDs** (24-84 microns).
- **R=10** using **Linear Variable Filter** (LVF): spectral response varies linearly along one axis.
- LVFs use **resonant metal-mesh structures**.



PRIMAger Polarimetric Imager

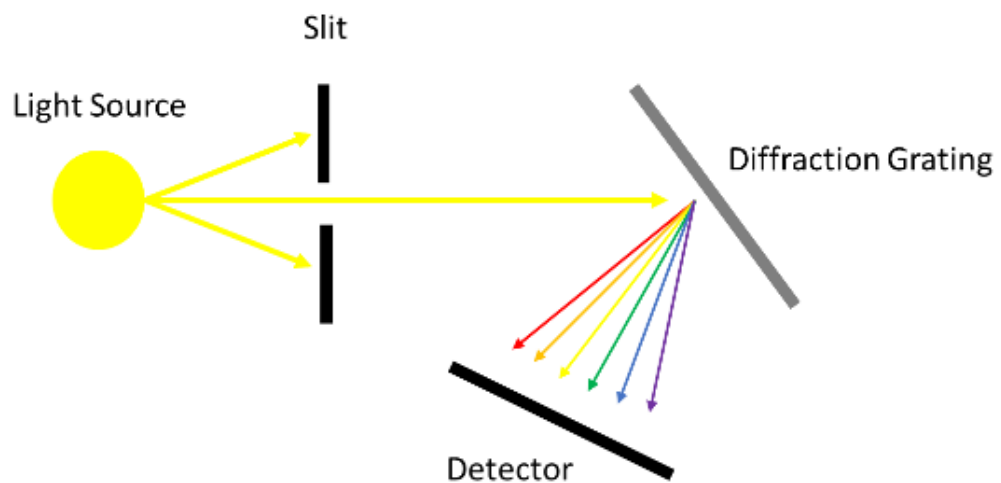


- Polarization selectivity achieved by **orientation of each pixel's antenna**.
- 4 broad-band filters at **91, 126, 172, and 232** microns, ~2000 pixels total.
- Polarimetric KID design... Real prototype device at SRON booth



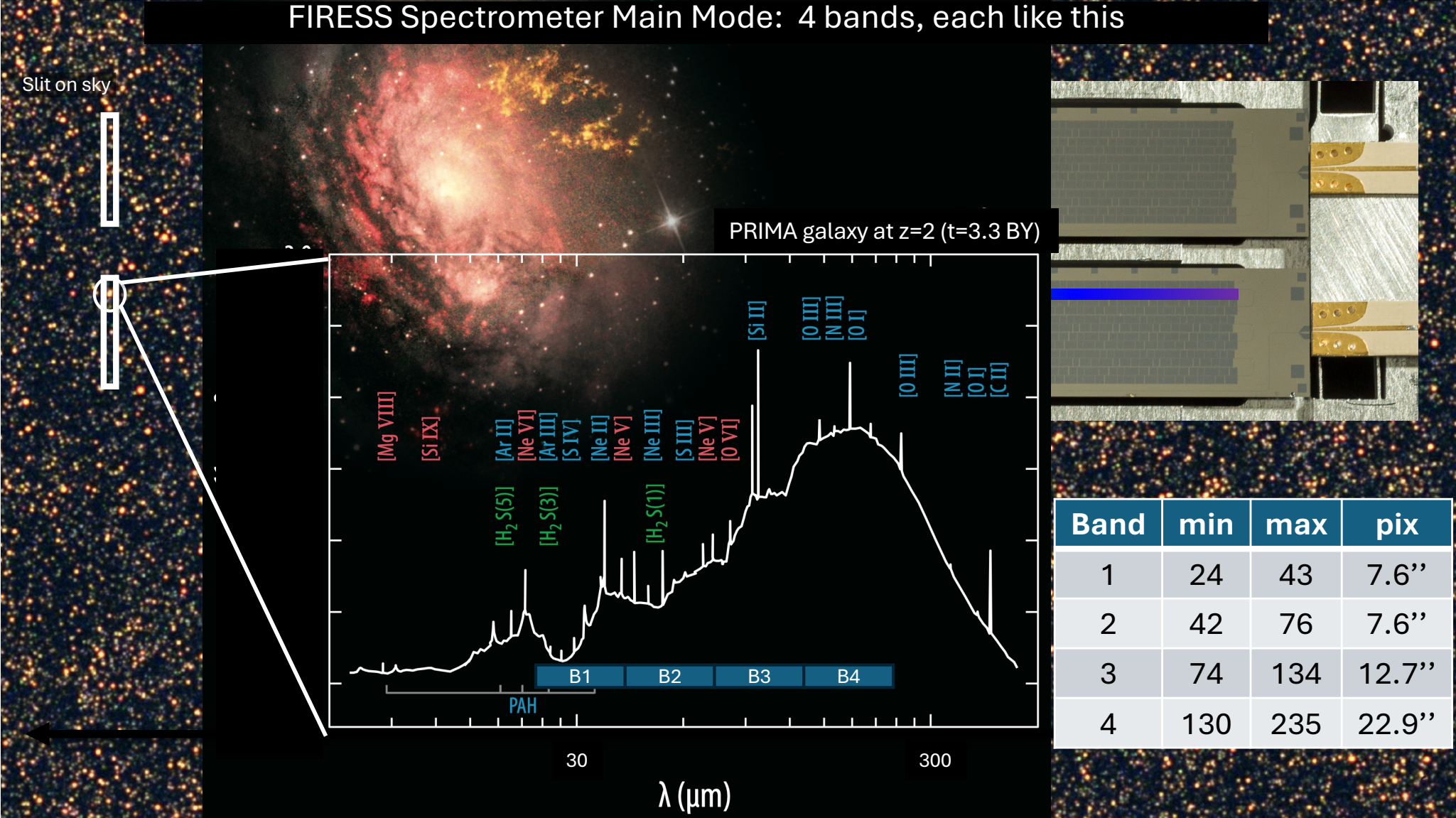
FIRESS Spectrometer Main Mode: 4 bands, each like this

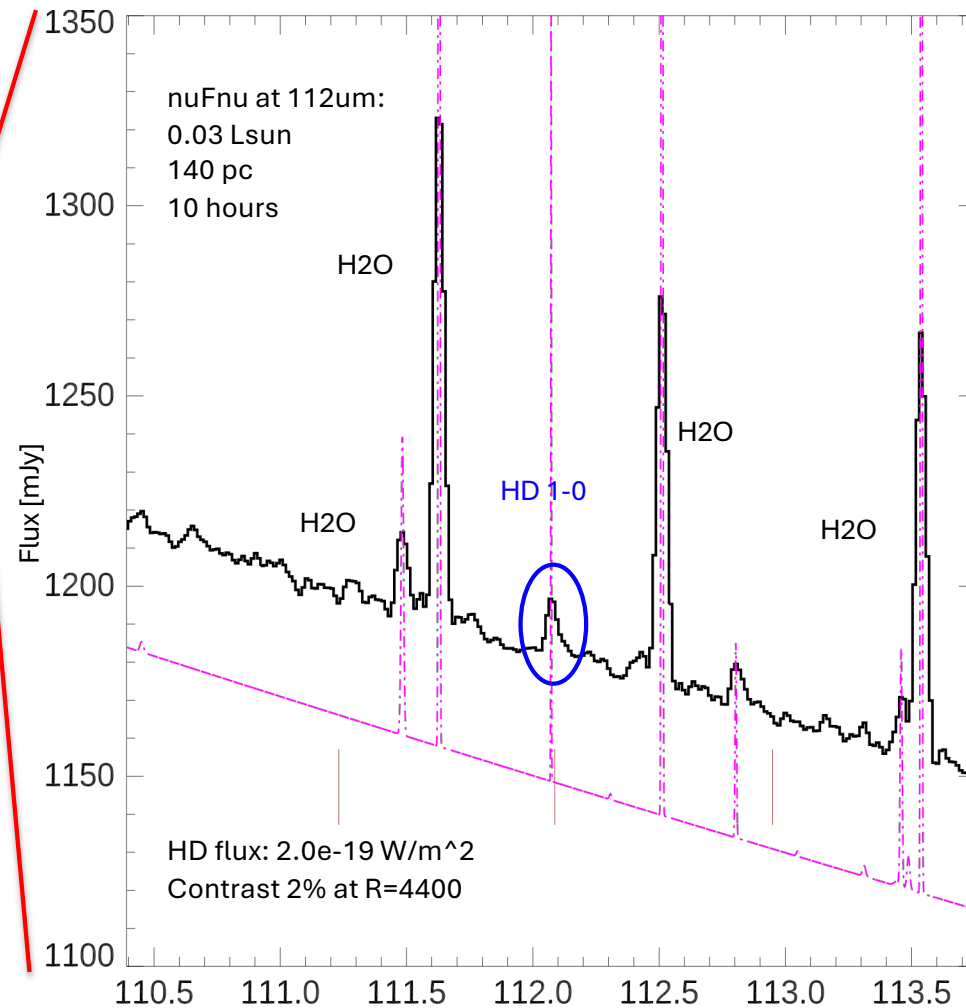
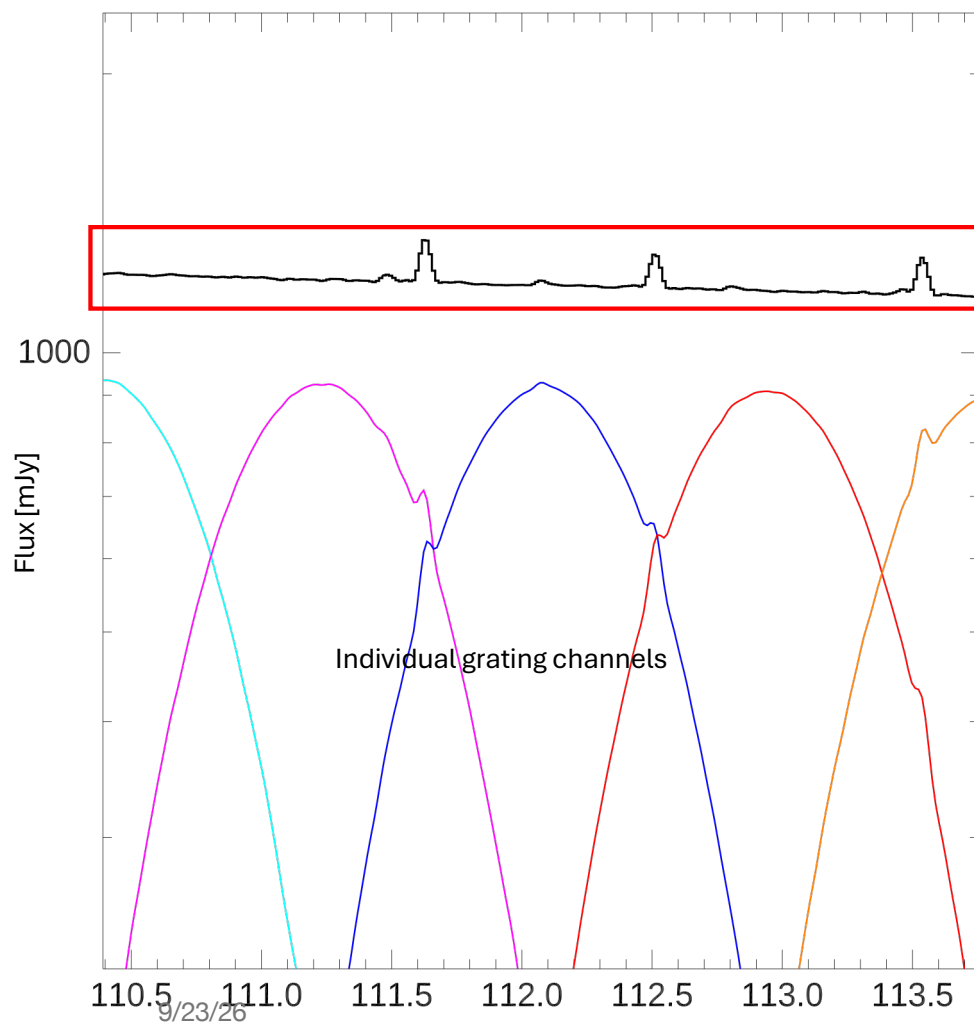
Slit on sky



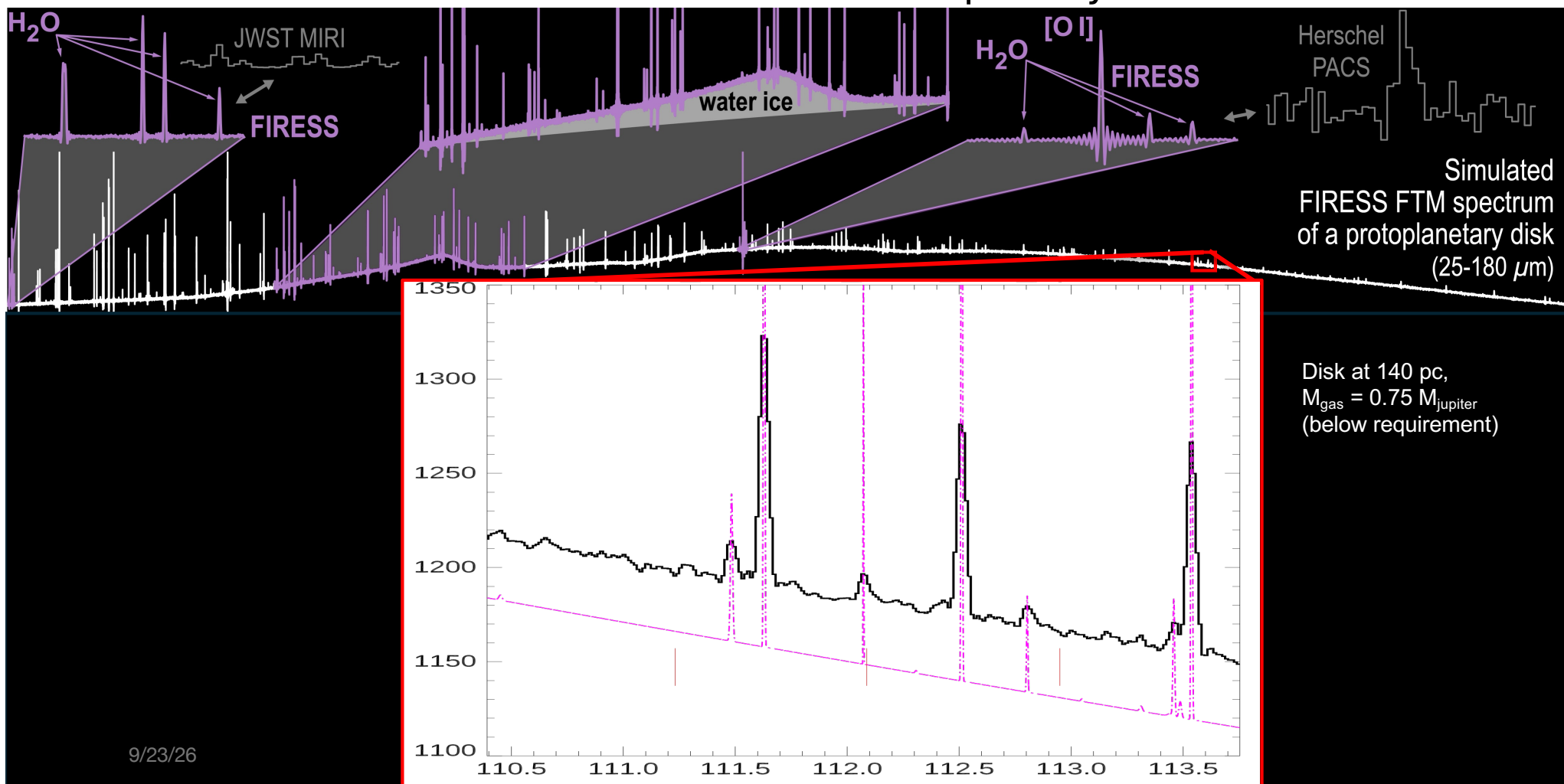
Band	min	max	pix
1	24 μm	43 μm	7.6''
2	42 μm	76 μm	7.6''
3	74 μm	134 μm	12.7''
4	130 μm	235 μm	22.9''

FIRESS Spectrometer Main Mode: 4 bands, each like this





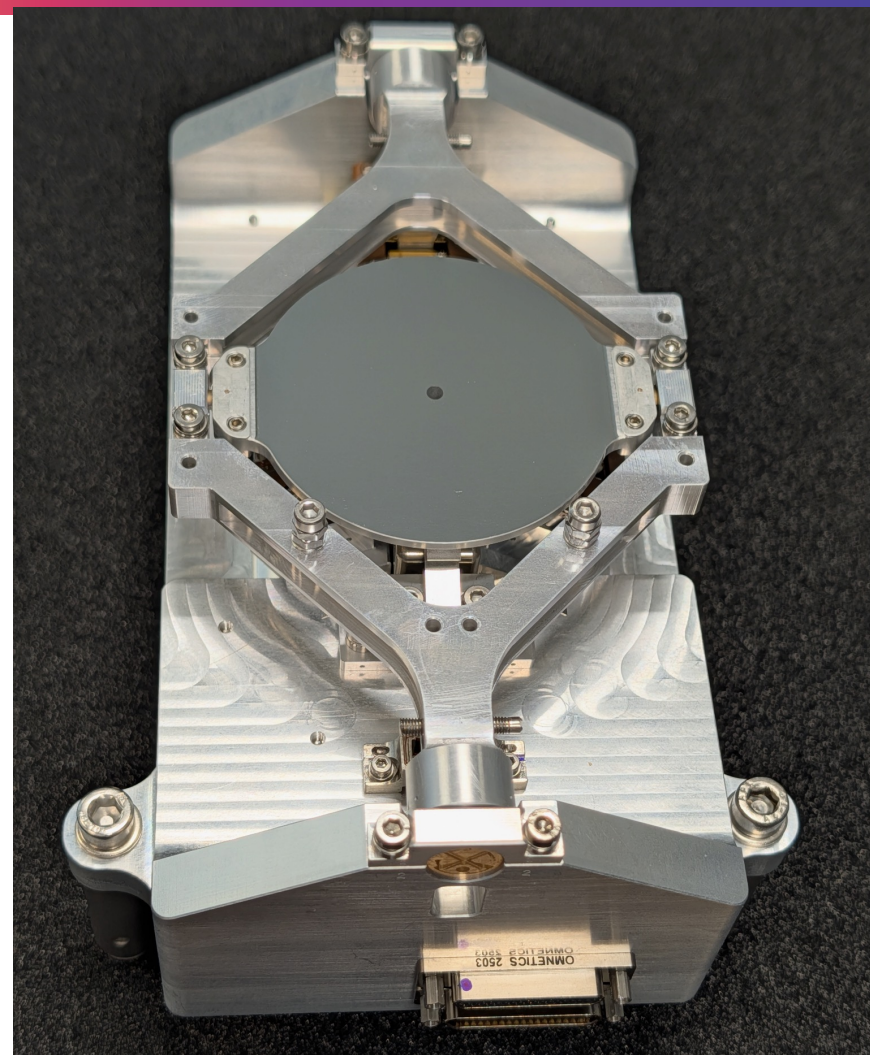
FIRESS FTM Full Band Capability



Observing Modes and Modulation

- Either PRIMAgar or FIRESS operates at any given time (they share readout electronics).
- All detectors for either instrument instrument are read out when operating.
- Both FIRESS and PRIMAgar have their own beam steering mirror (BSM) at a telescope pupil which provides up to +/- 17 arcmin steering in both dimensions.
- Science sample rate limited by downlink to 200 Hz for FIRESS, 350 Hz for PRIMAgar.

Mode	Modulation Method	Modulation Freqs
Scan mapping	Observatory scan and/or BSM scan, raster or Lissajous in 2D with BSM	1 to 100 Hz λ dependent (175 for PRIMAgar)
Point source spectroscopy	BSM chop at 10 Hz along slit direction.	5 Hz + harmonics
High-res spectroscopy	FTS scan	5 to 600 Hz λ dependent



Detector System Approach

Top Level Attributes for Science

- **Span 25 to 235 microns**
- **NEP below $1\text{e-}19 \text{ W Hz}^{-1/2}$ at 10 Hz.**
(Demonstrated at SRON and JPL with different designs.)
- **Response time <1.5 ms to remove cosmic rays.**
- **At least 2000 pixels per array to achieve high mapping speed and redundancy in spectrometer** (difficult with TES)
- **Dynamic range of at least 10,000** (difficult with QCD)

Engineering Constraints

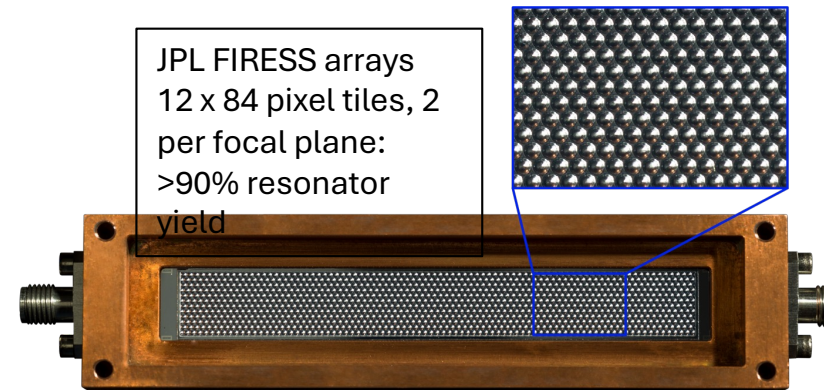
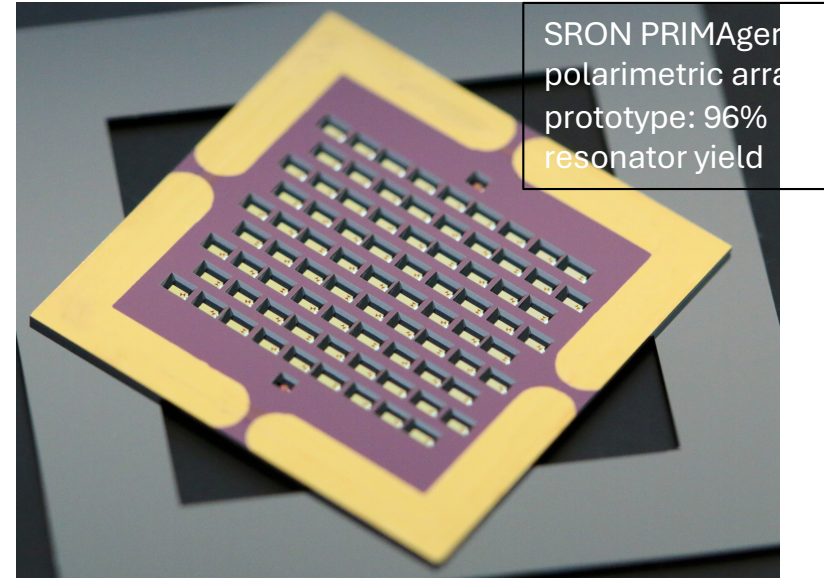
- **Operation at 100 mK** (Difficult with TES)
- **8 readout circuits in full instrument**

Imposed Performance Requirements

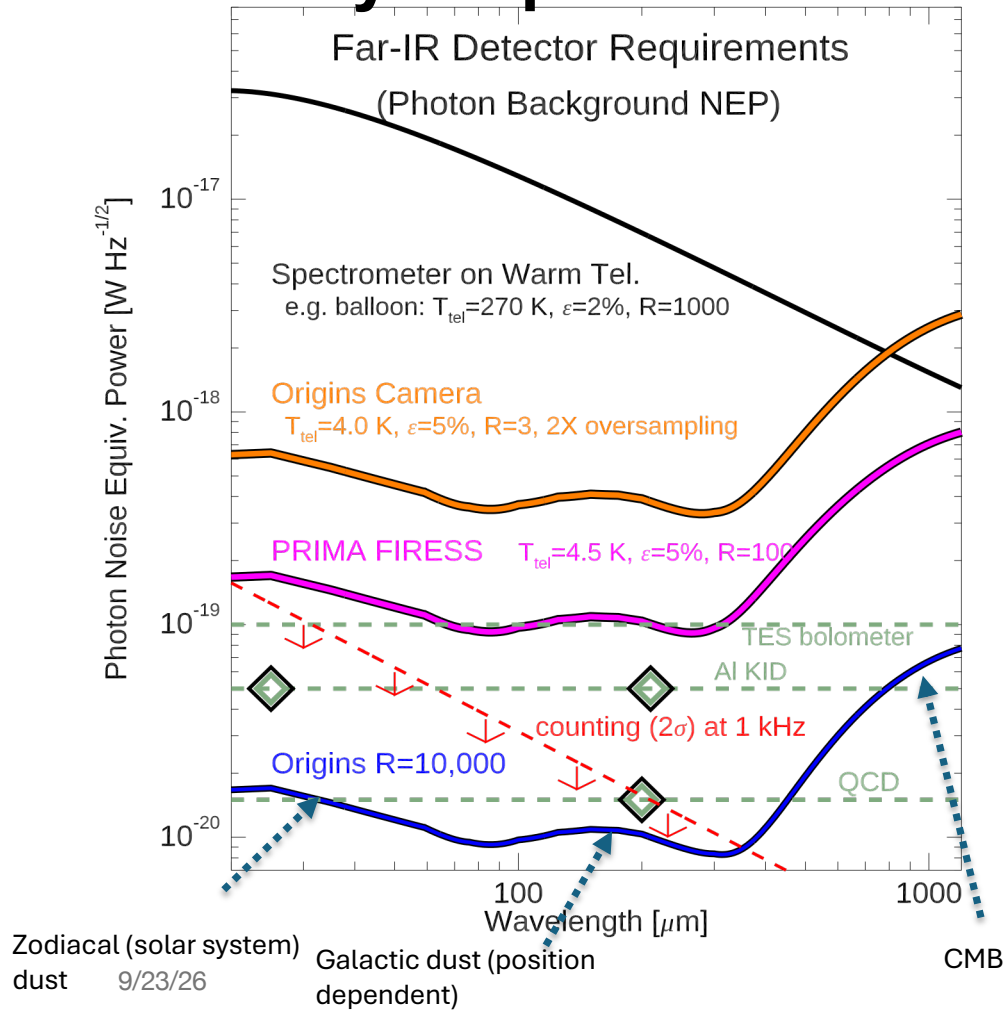
- **Yield of 80%** (expect >95%)
- **Cosmic ray duty cycle > 90%** (expect >95%)

Design Choices

- **Readout frequencies 0.4-2.4 GHz for 1008 pixels.**
 - 2.6 octaves gives good separation
 - 2 GHz information bandwidth tractable with electronics
- **1st amplifier at 18 K stage.**



Sensitivity Requirements in the Far-IR



Noise Equivalent Power (NEP) is our metric.

Units are $\text{W} / \sqrt{\text{Hz}}$

Power that provide a SNR of 1 in 1 second.

Fundamental limits are fluctuations in the arrival rates of photons

$$\text{NEP}_{\gamma}^2 = 2h\nu P_{\text{abs}} \left(1 + n_0 + \frac{2\Delta_0}{h\nu\eta_{\text{pb}}} \right)$$

Shot noise ($\sqrt{P}$) for most of the mid and far-IR.

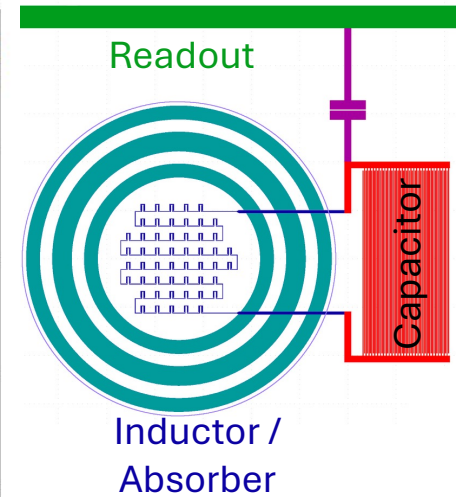
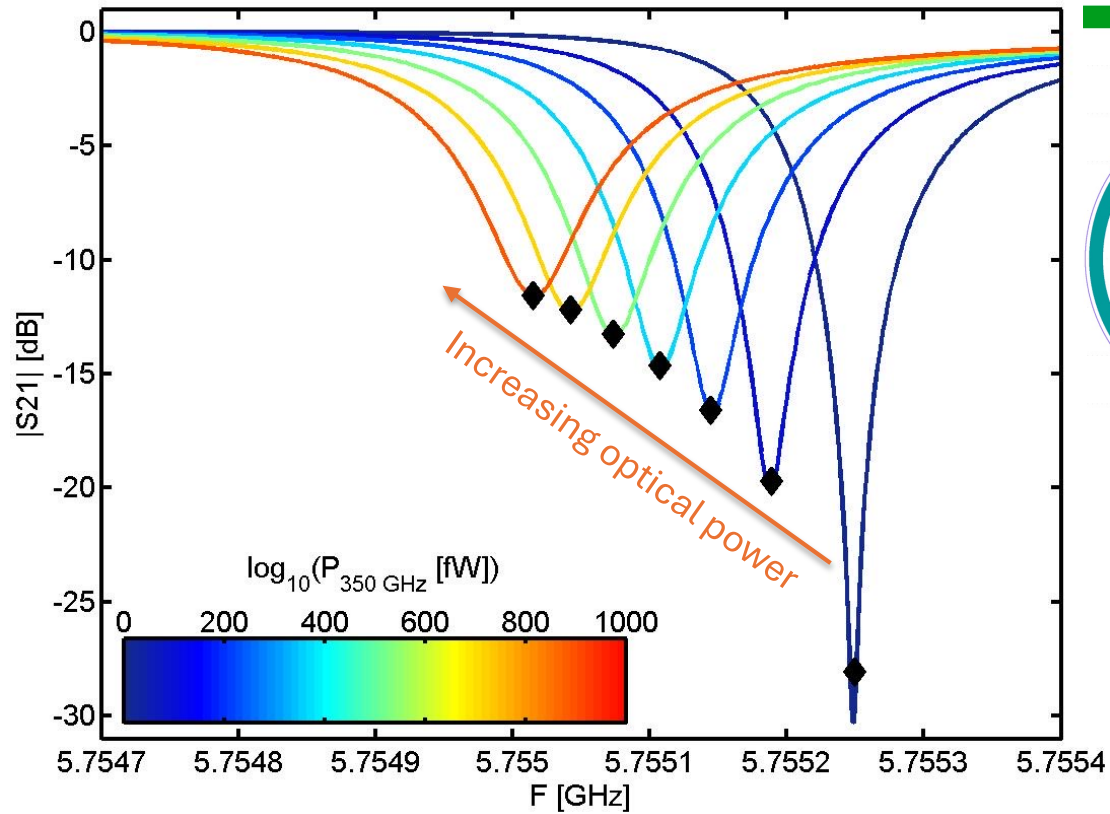
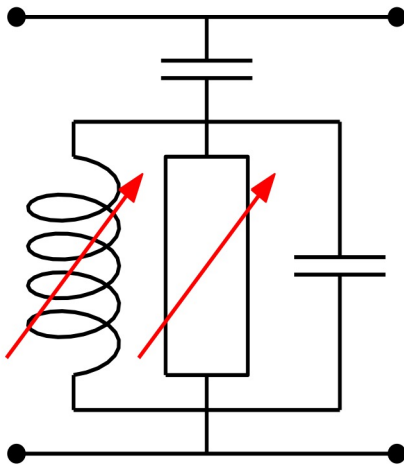
[Wave noise (noise scales as P) for long wavelengths, high backgrounds. CMB beyond about 2 mm.]

Kinetic Inductance Detector – operational principle

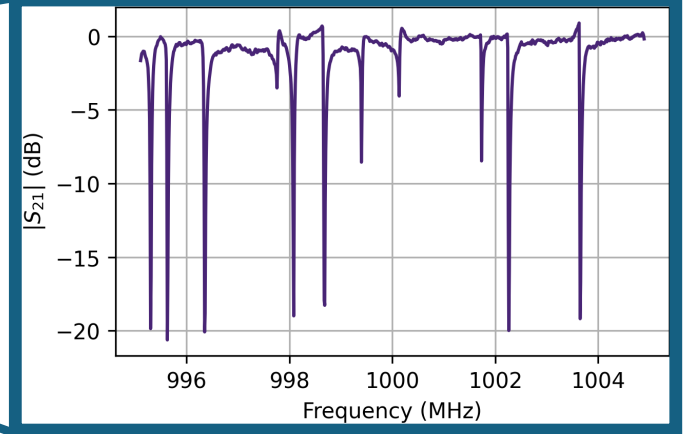
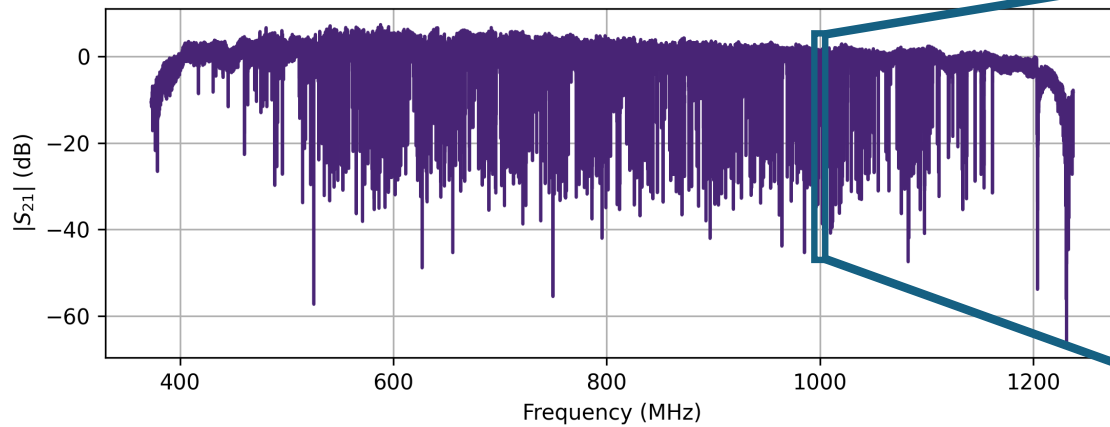
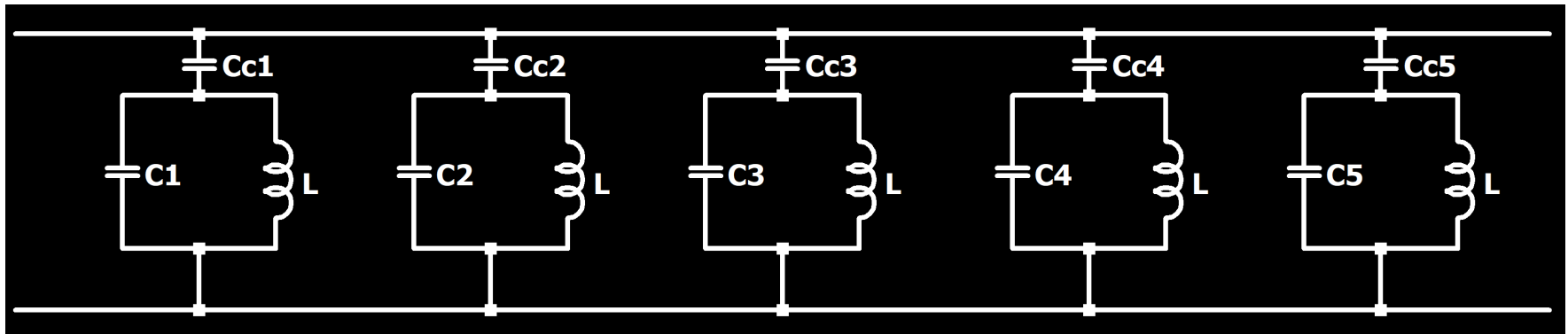
Superconducting resonator

$Q \sim 10^4 - 10^6$

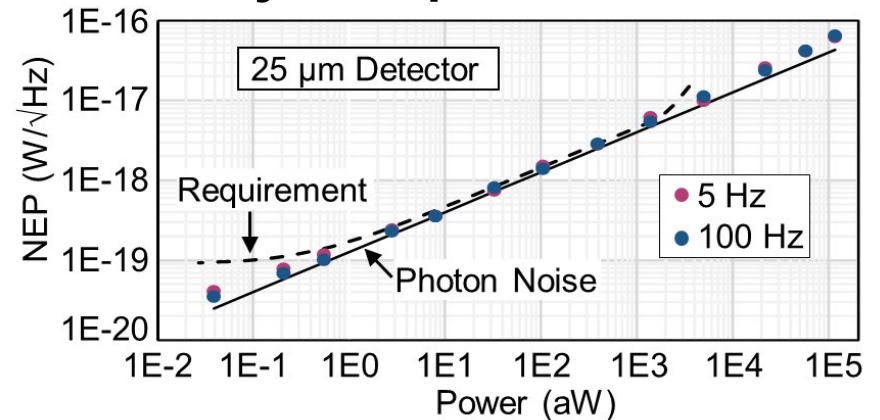
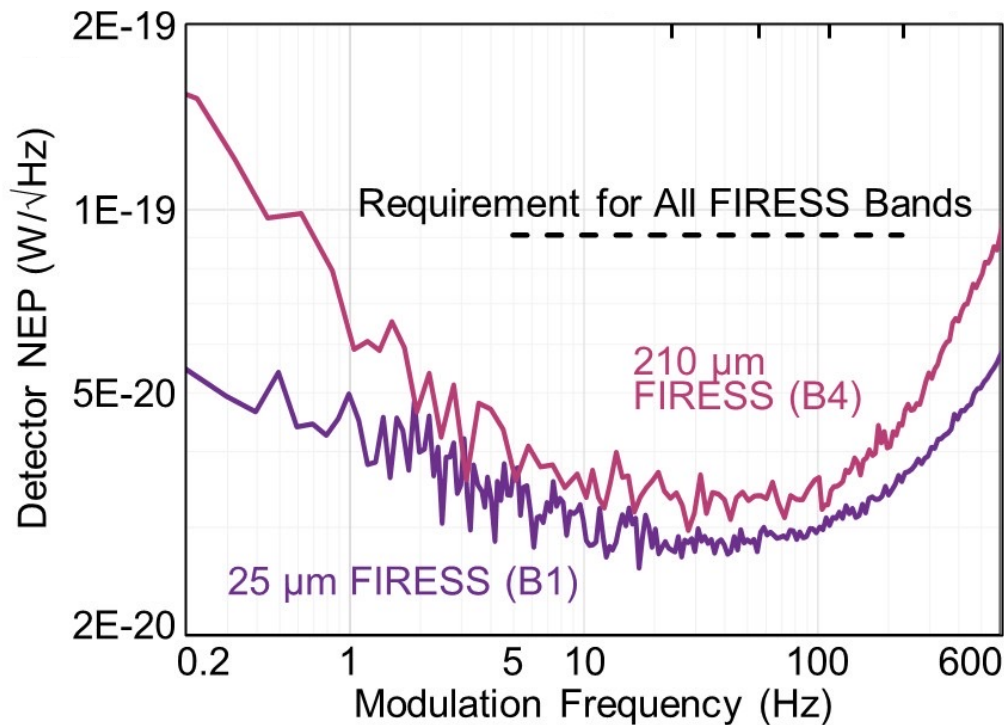
$F_{res} \sim 0.1 - 10 \text{ GHz}$



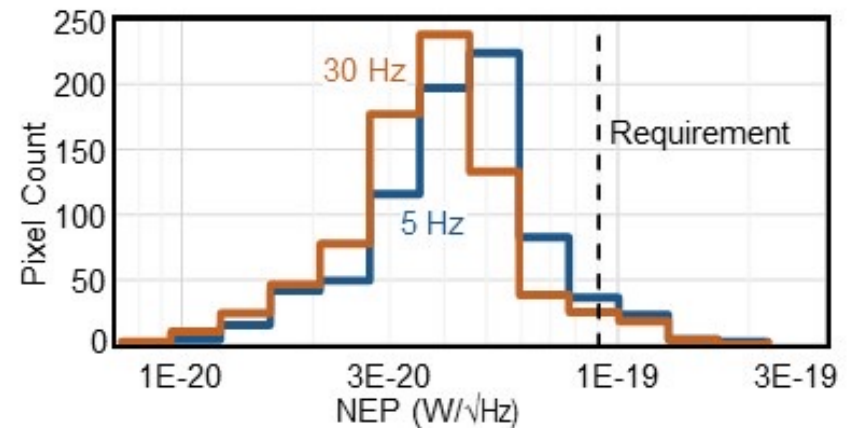
KIDs are resonators: inherently multiplexable



PRIMA arrays meeting sensitivity requirements

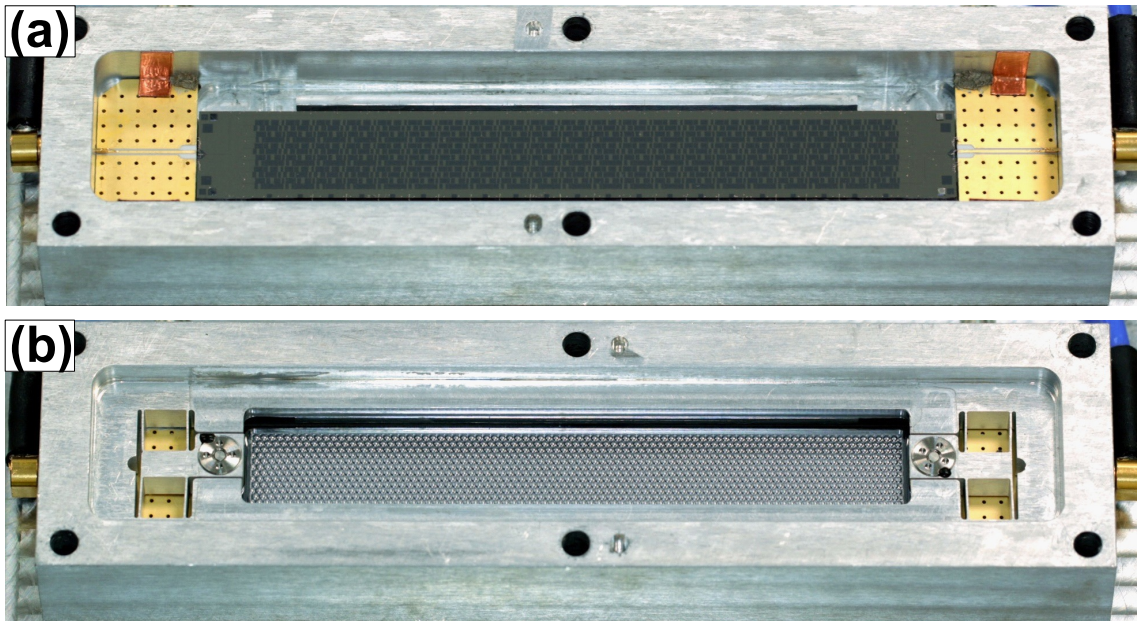


FIRESS KIDs are nearly photon noise (background) limited over a wide range of power, and meet the PRIMA requirements.

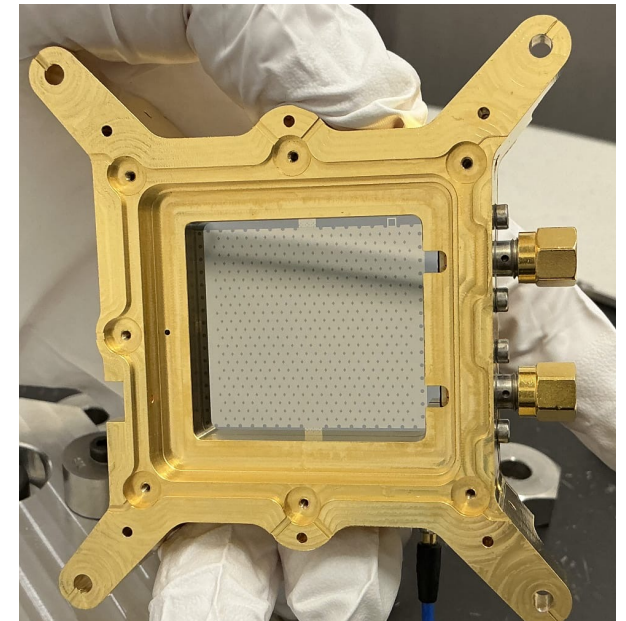


More Info – see Elijah Kane FIRESS KID talk this afternoon:
2:40-2:50PM Room 230

PRIMA KID arrays preparing for flight.



FIRESS KID hybrid array mounted in a flight-like mount with flexures for dynamics testing.
a) Detector side. b) Lenslet side.



PRIMAGER PHI KID hybrid array mounted in a flight-like mount for dynamics testing

75% of PRIMA's time is dedicated to General Observer Science

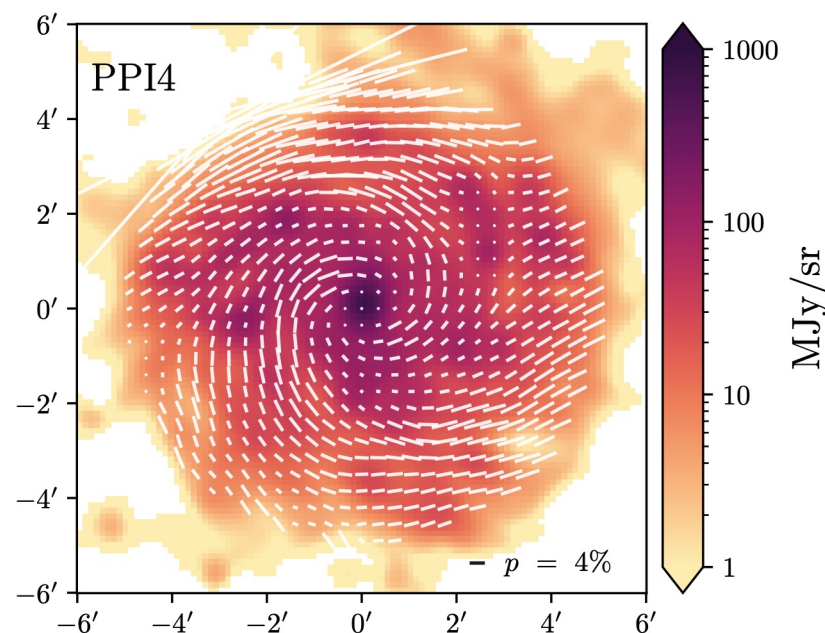
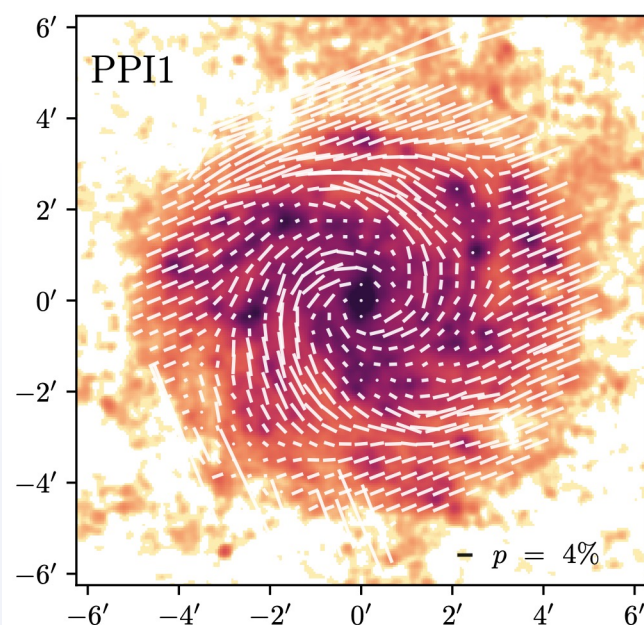
PI surveys define mission requirements- the goal is to create a powerful and flexible set of observatory capabilities that enables a rich program of community science.

The PRIMA team wants this to be YOUR observatory. You can help the PRIMA team by starting early to define the science you would perform with PRIMA. This helps ensure that your scientific needs can be met with this observatory and demonstrates the community's need for this facility!

All PI data will be public after initial validation- In addition to GO cases, we welcome examples of GI use cases that demonstrate the rich potential of the PI surveys.

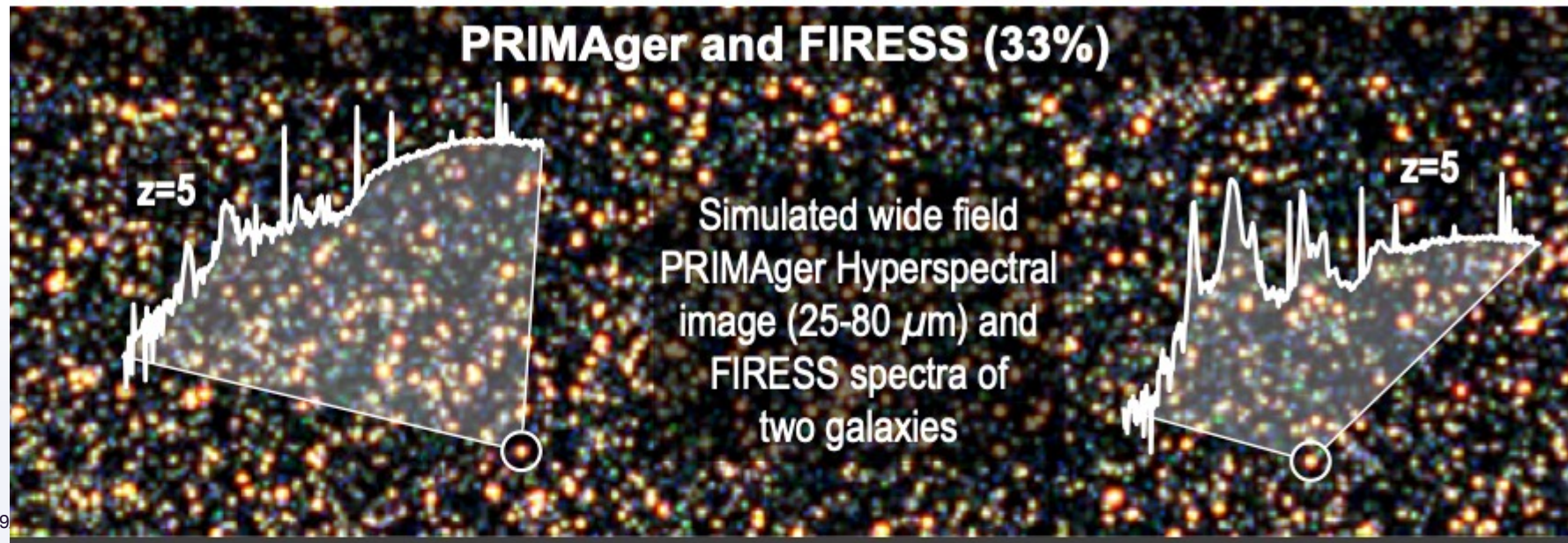
GO Opportunities: 75% of 5 years (likely more if longer-lived)

- Sensitivities available on fact sheet and web page.
- Instantaneous field of regard currently 26% of the sky.
 - Larger FoR possible. Have margins in thermal lift and mass so can increase sunshade area.
- Agile. Can slew and anywhere in field of regard in 12 minutes, no constraints on changing instruments
- GO book published late 2023 and now volume 2 in 2025.
- Many papers for JATIS special issue.



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- Many papers for JATIS special issue.



PRIMA team

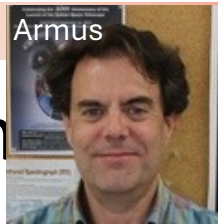
*An international team of
astro/ technology experts*

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

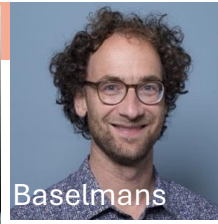
Partner Institutions

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

+ science affiliates
+ *many* community science
working group members!!



Armus



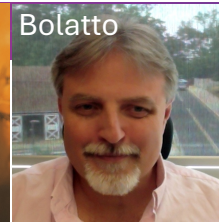
Baselmans



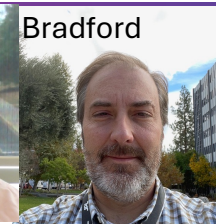
Battersby



Bergin



Bolatto



Bradford



Burgarella



Ciesla



Cleaves



Dowell



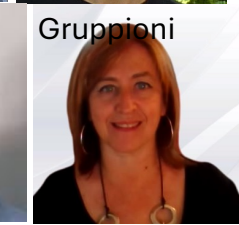
Essinger-
Hileman



Glenn



Di Giorgio



Gruppioni



Henning



Hensley



Inami



Jellema



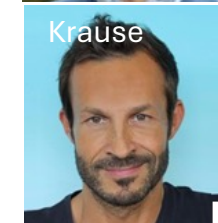
Jeong



Kataria



Kogut



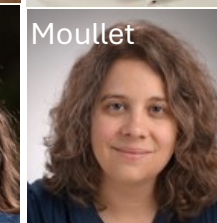
Krause



Meixner



Mills



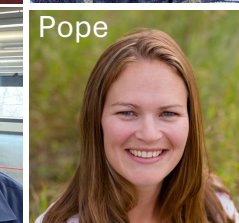
Moullet



Oliver



Pontoppidan



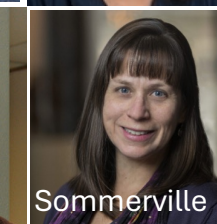
Pope



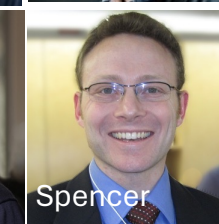
Sauvage



Smith



Sommerville



Spencer



Staguhn

Thank you

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