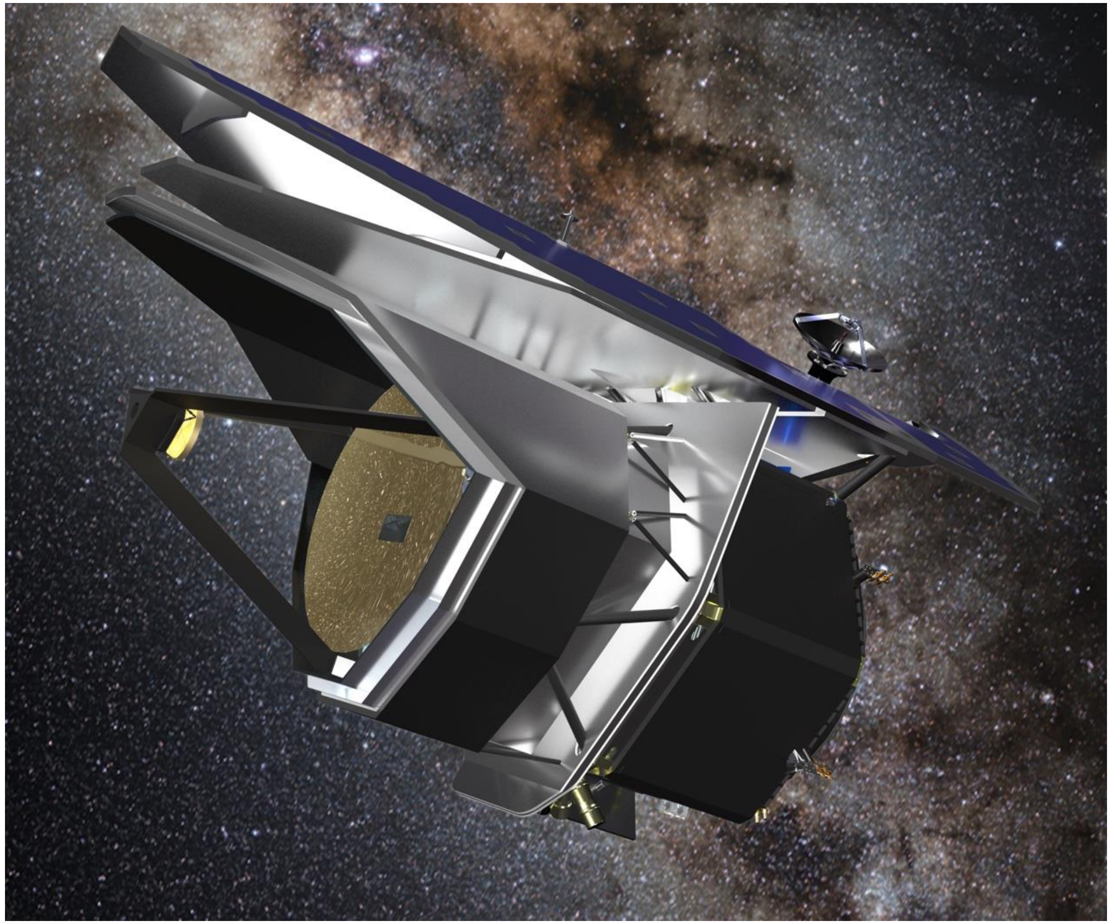
PRIMA
The PRobe far-Infrared Mission for Astrophysics



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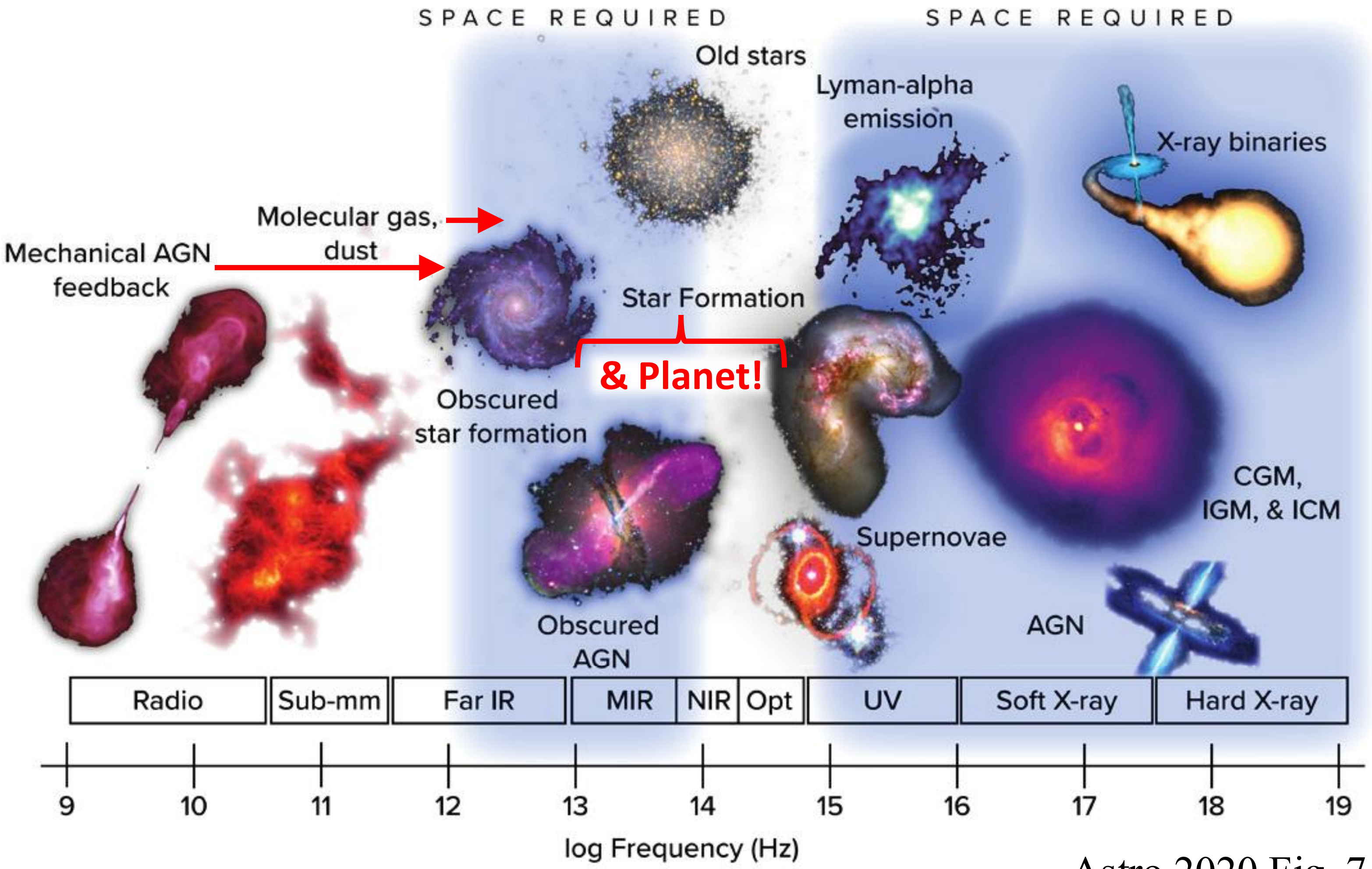
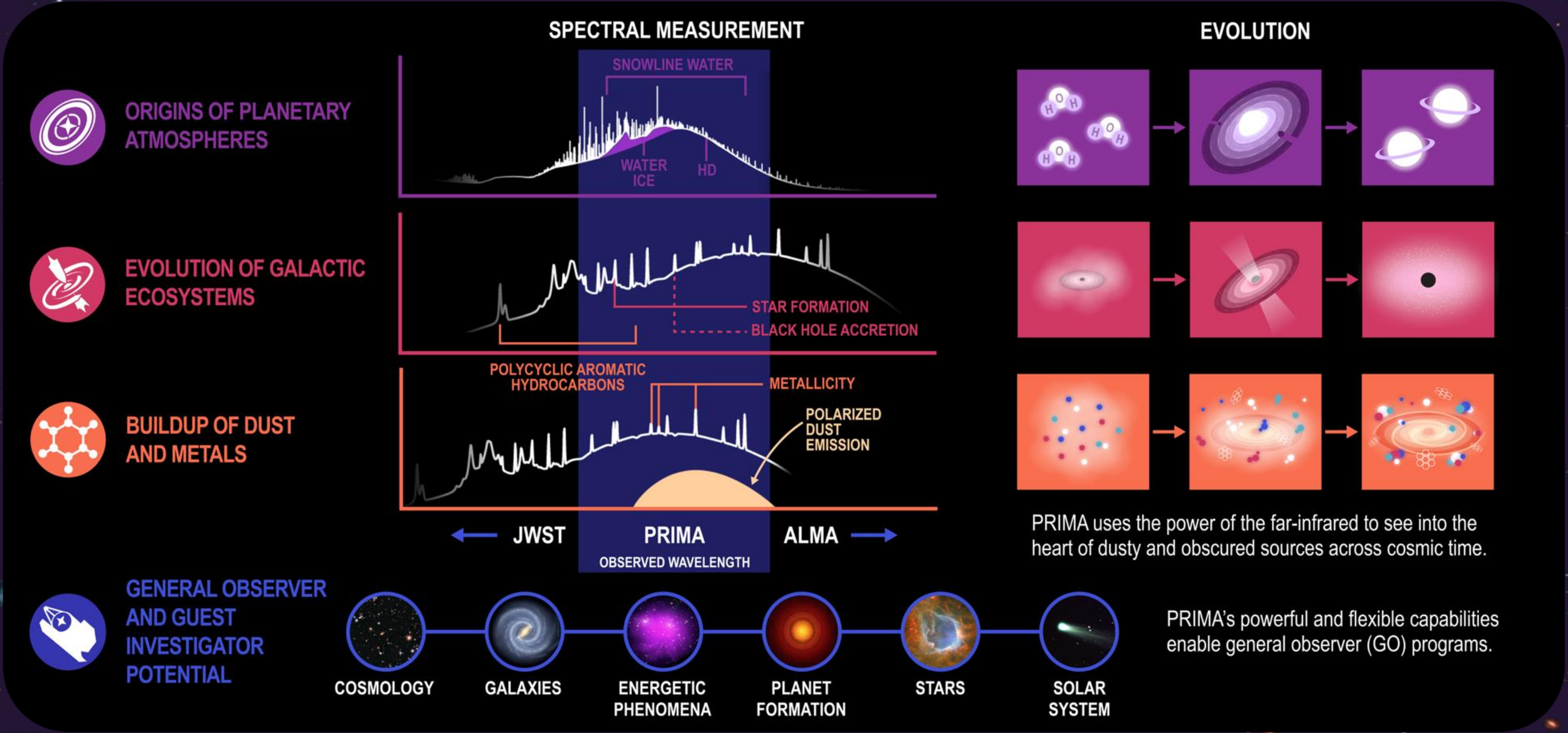
Astrophysics Probed with Far-IR Observations

- Uniqueness: Dust-obscured star formation *and* AGN; protoplanetary disk masses & chemical abundances
- Complementarity: Cooler gas than JWST can access (e.g., < 150 K H_2O in protoplanetary disks)



Astro 2020 Fig. 7.1

PRIMA is flagship-class science for a Probe price

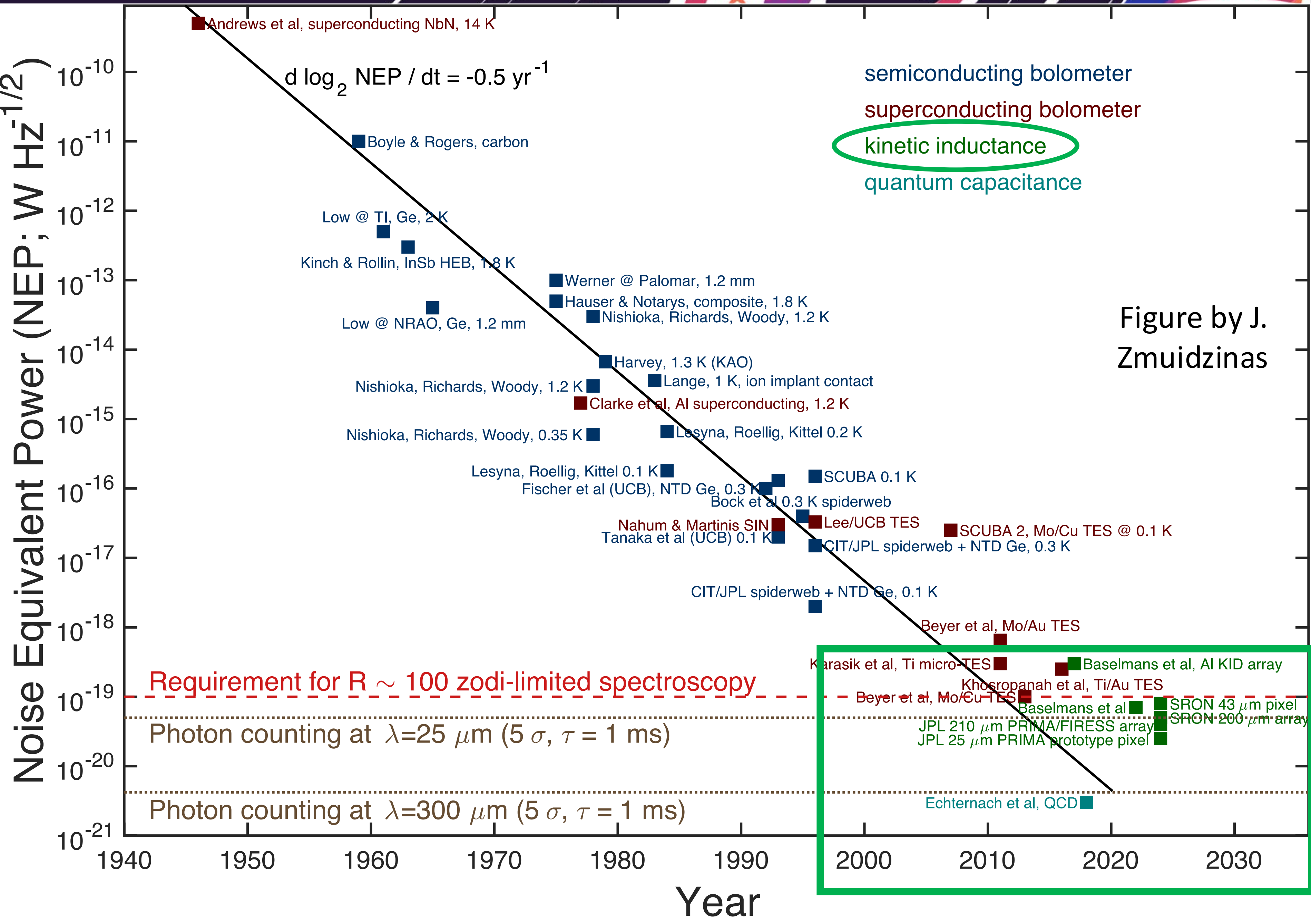


Why Now?

→ Far-IR Detector Technological Readiness

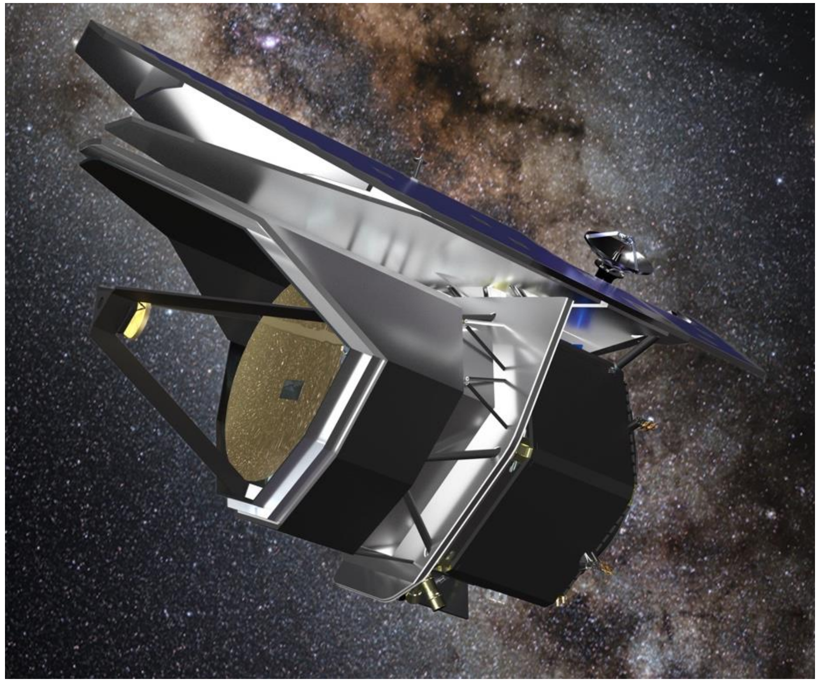
Sensitivities of far-IR detectors have doubled approx. every two years for 75 years!

Probe region of interest



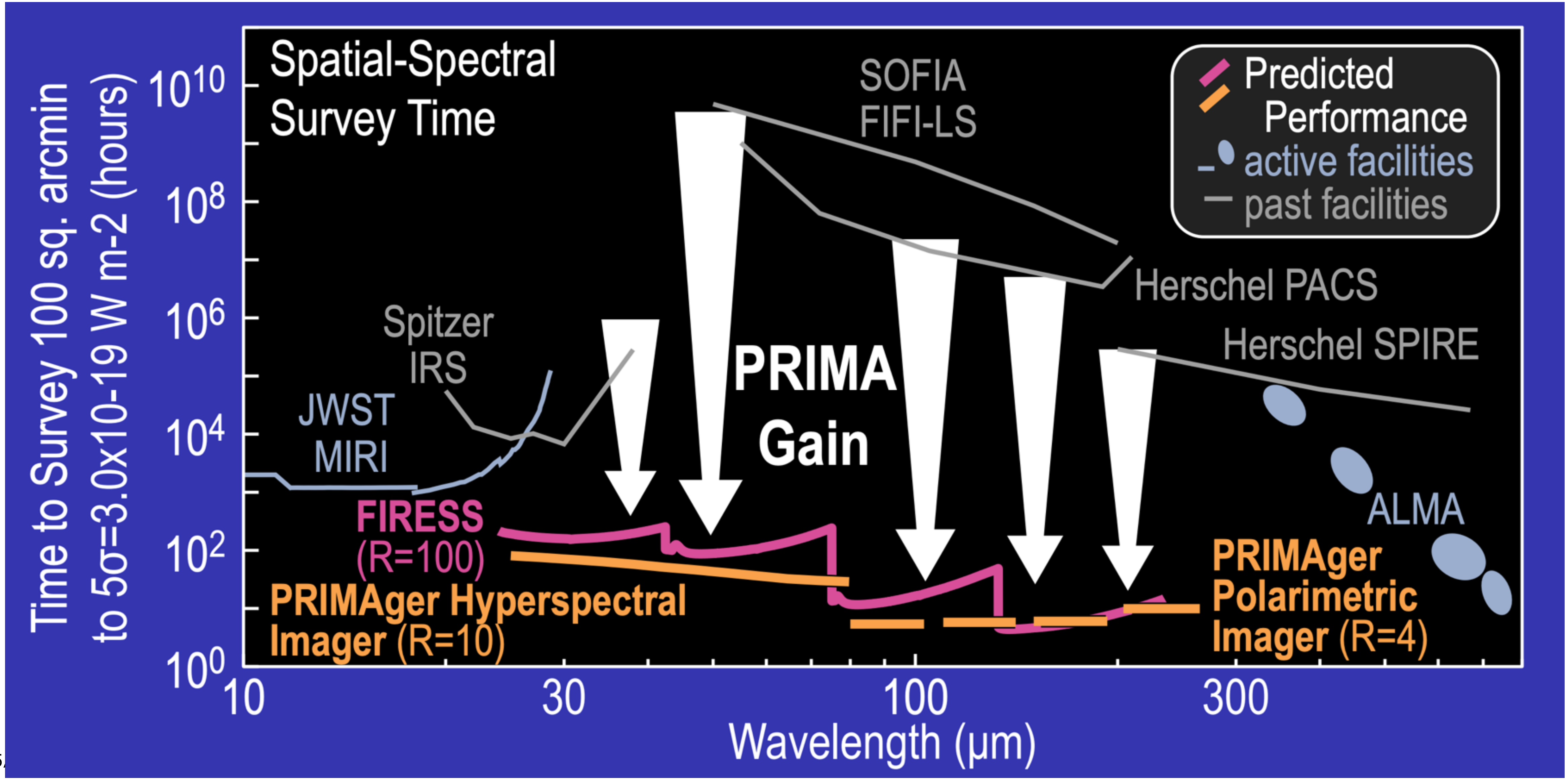
PRIMA

- *25% is for Principal Investigator science*
- *75% of observing time is for Guest Observers*
- *PI data will be available quickly for Guest Investigator science*

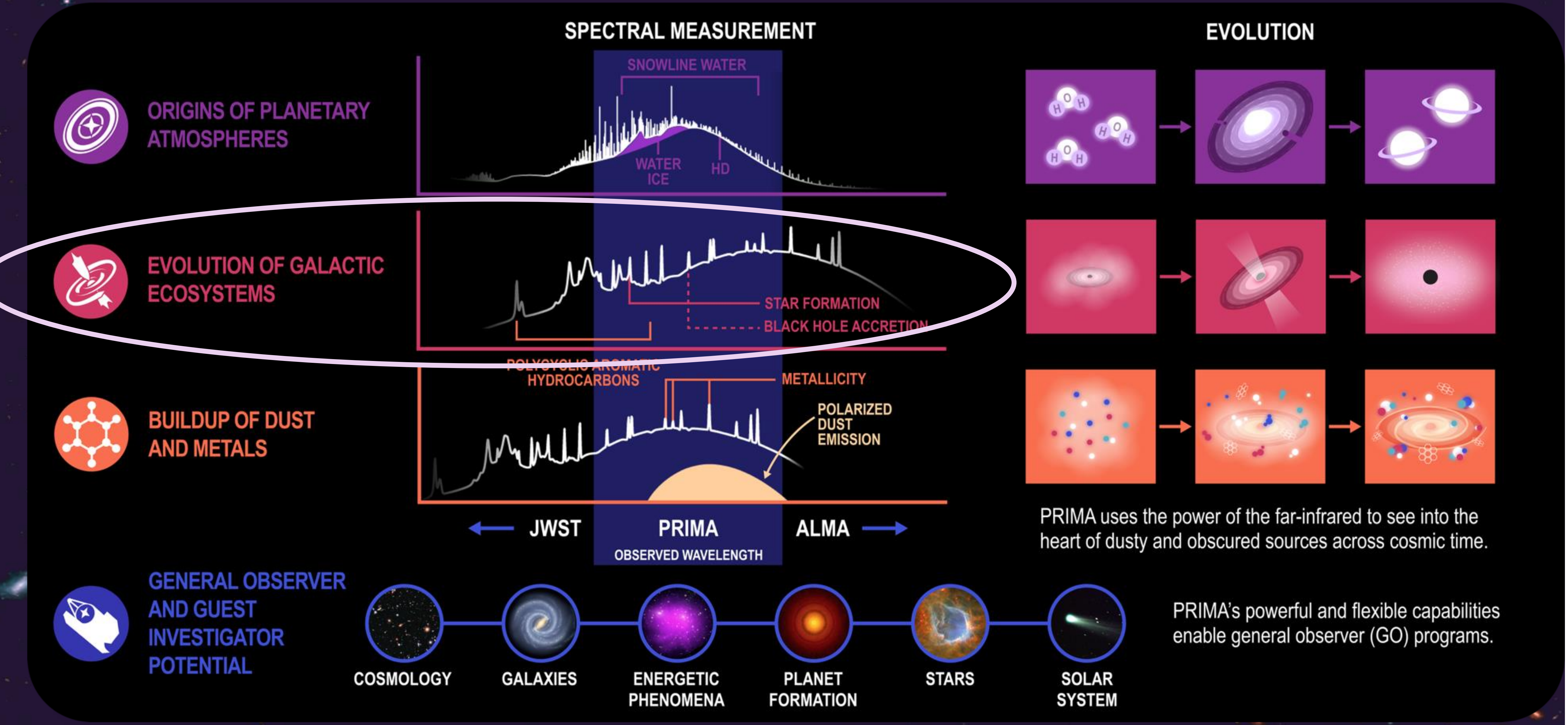


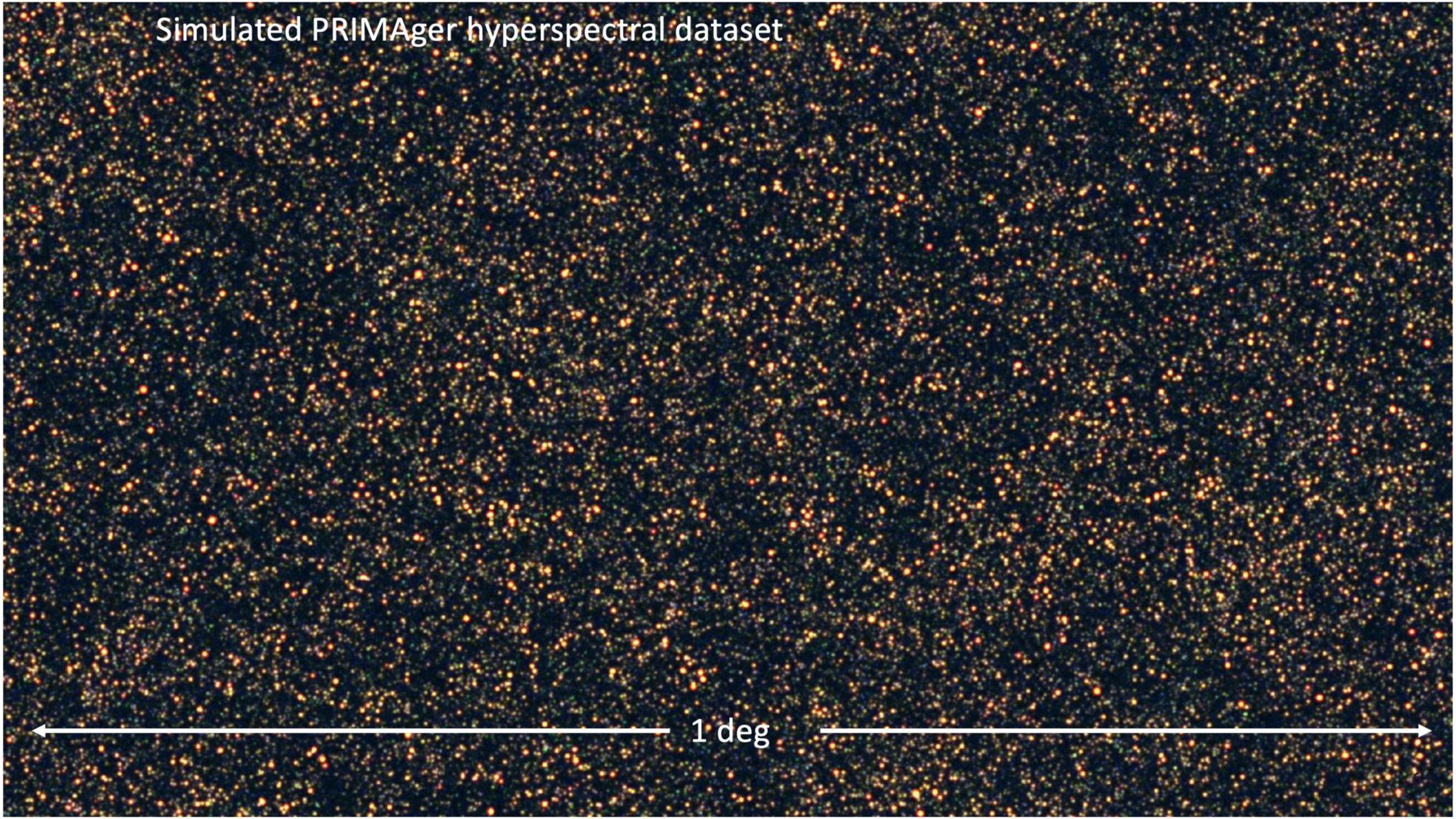
Telescope	1.8-m, all aluminum, 4.5 Kelvin
PRIMAger Imager & polarimeter	R = 10 hyperspectral imaging 25-80 μm R= 4 imaging & polarimetry 91-261 μm
FIRESS Spectrometer	R > 85 spectroscopy 24-235 μm High-Res mode R = 4,400 x $(\lambda/112\mu m)^{-1}$
Detectors	100 mK KID arrays (~11k total)
Data	IPAC
Orbit	Earth-Sun L2
Launch	2032
Observations	75% GO, 25% PI (→ GI)

75% time for General Observer science



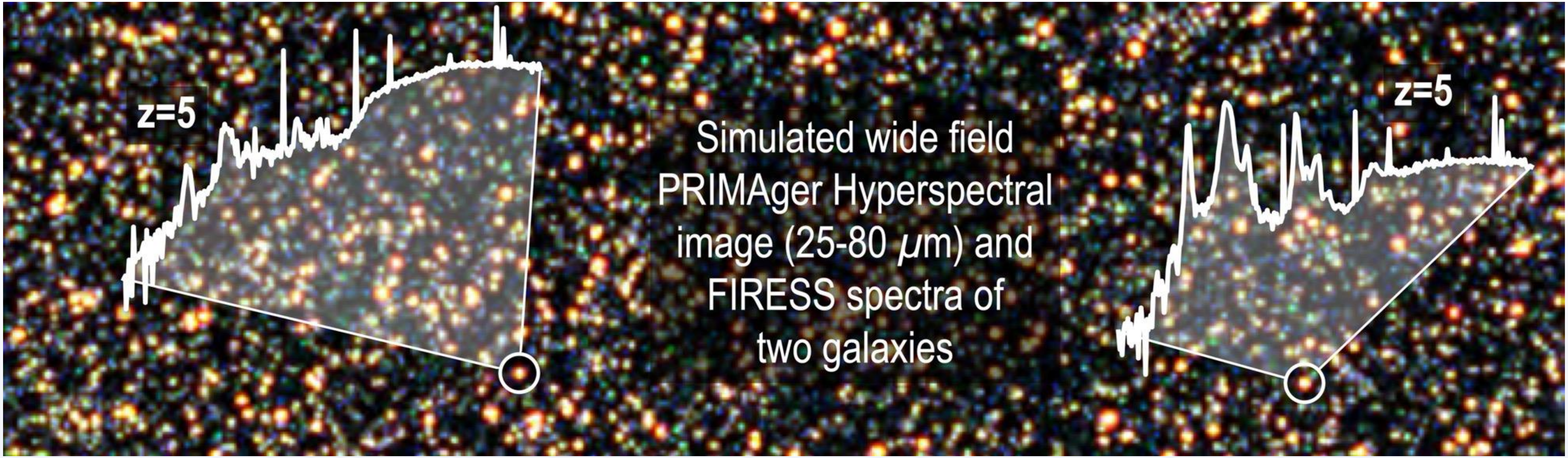
PRIMA is flagship-class science for a Probe price




Simulated PRIMAger hyperspectral dataset
1 deg

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

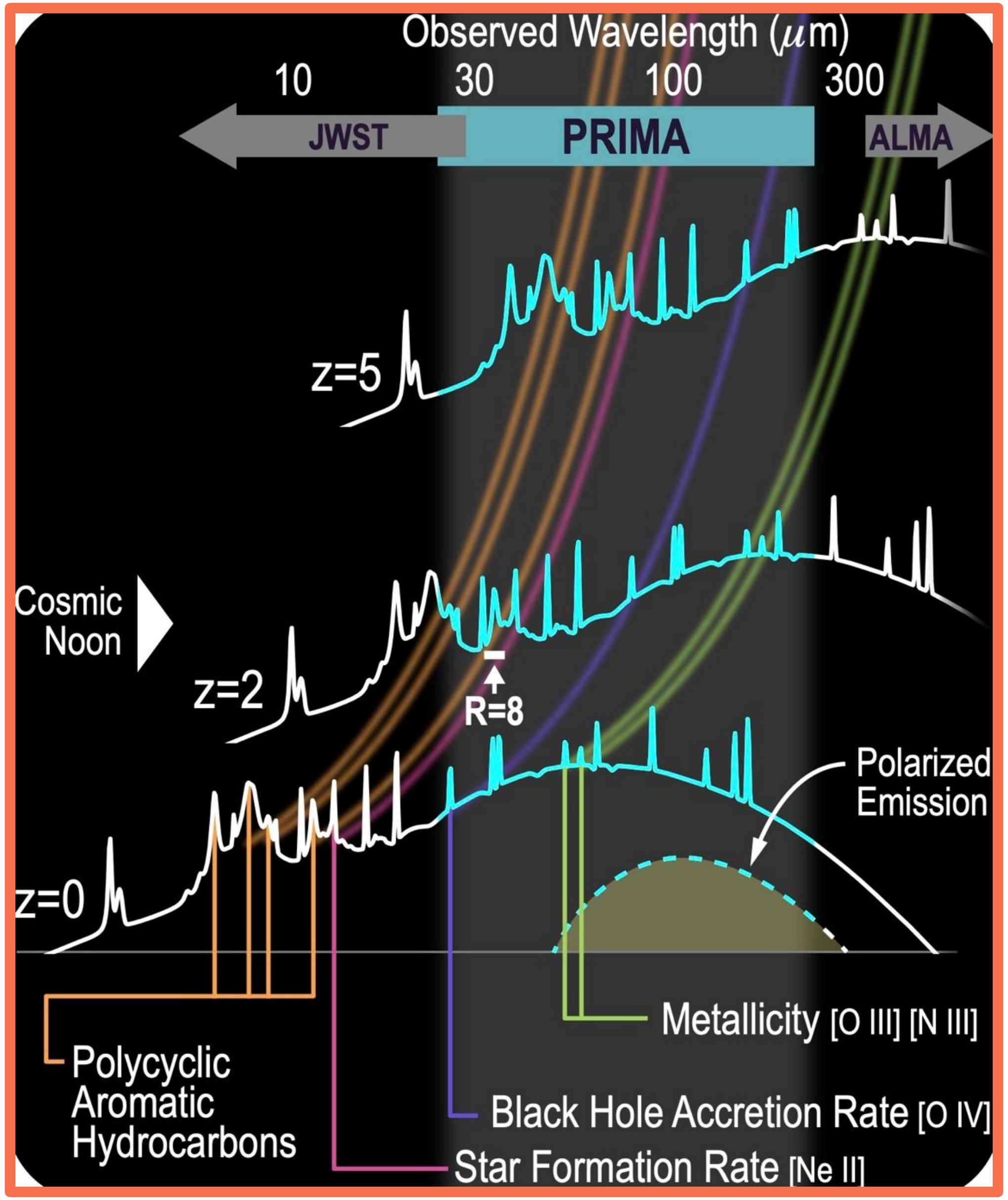
- Sensitivities available on fact sheet and web page.
- Instantaneous field of regard currently 26% of the sky.
- Agile. Can slew and anywhere in field of regard in 12 minutes, no constraints on changing instruments
- **GO book a set of example fiducial cases. Make your own.**



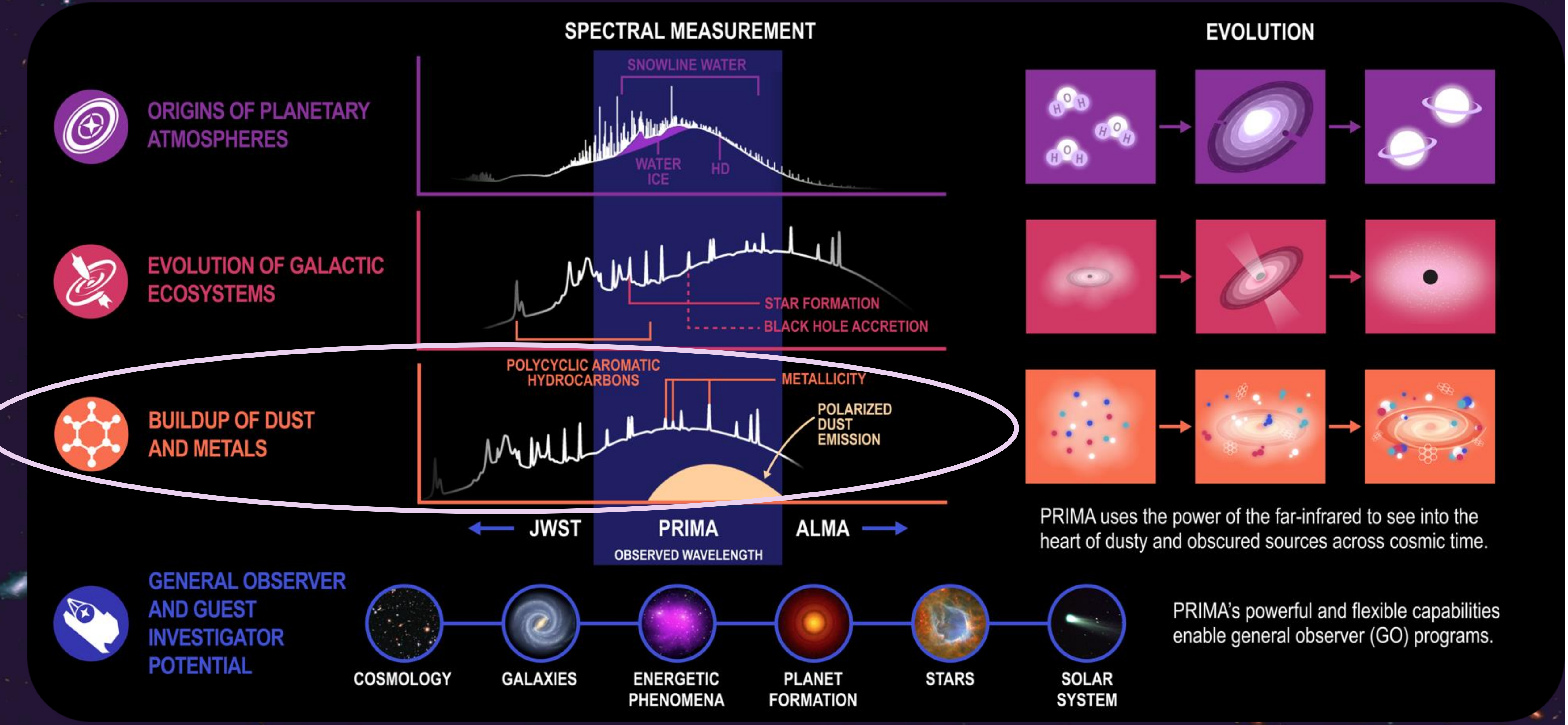
prima.ipac.caltech.edu

Background: Mid- and Far-IR Galaxy Spectra

- Simultaneous black hole accretion rates and star formation rates
- Metallicities
- PAHs

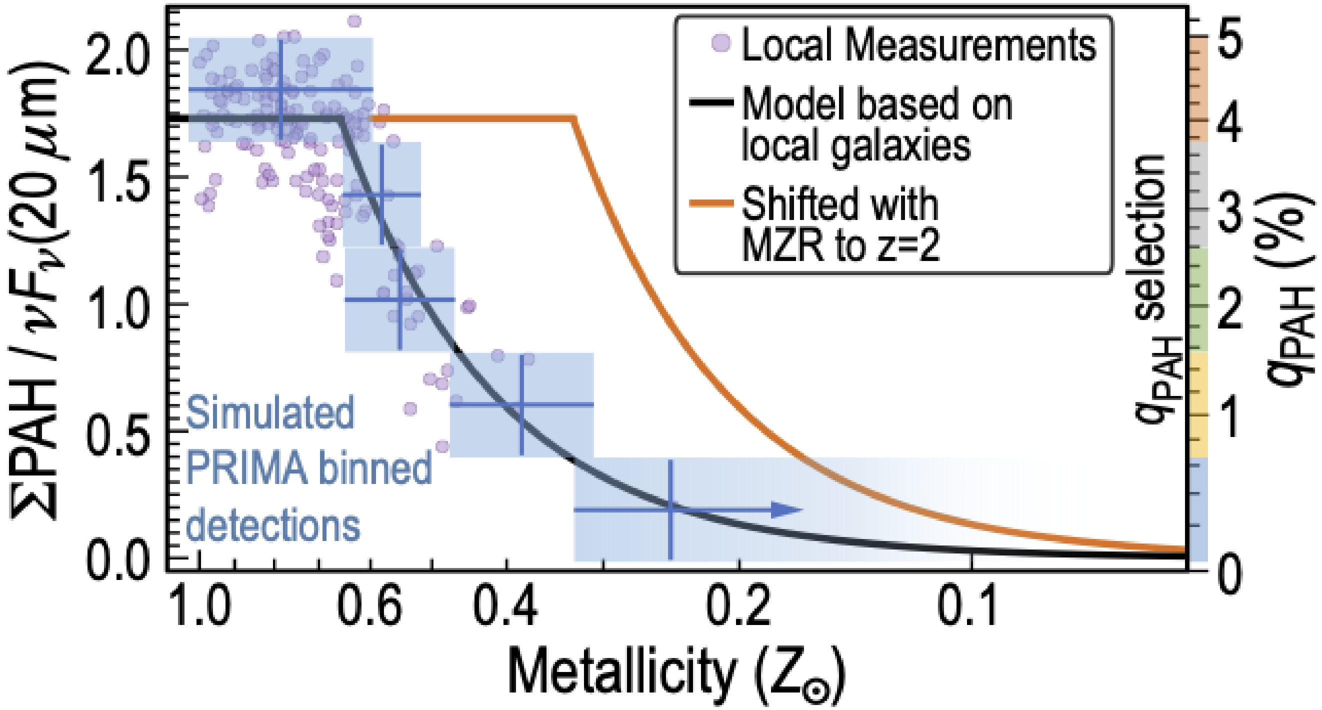


PRIMA is flagship-class science for a Probe price



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

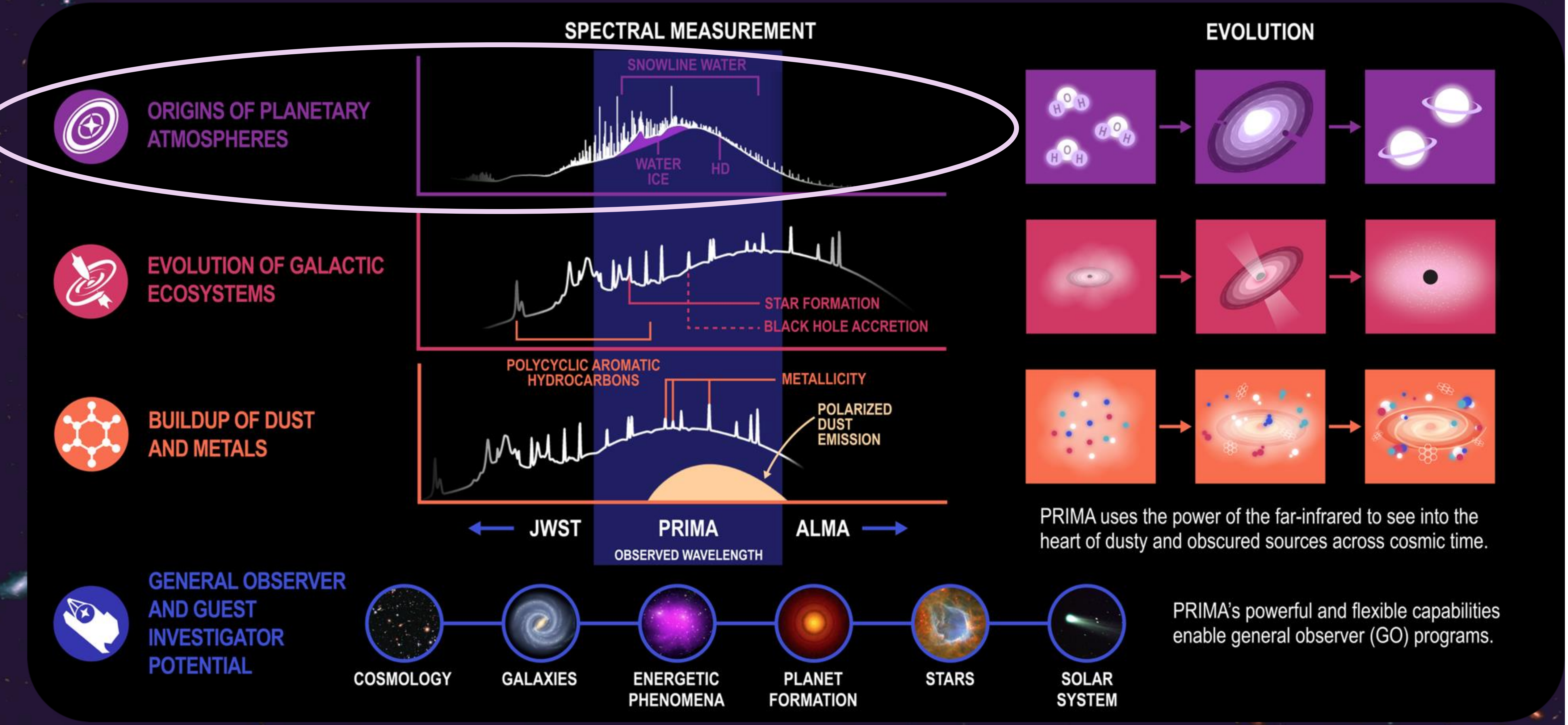
In the local universe, there a reduction in PAH emission with reduced metallicity.

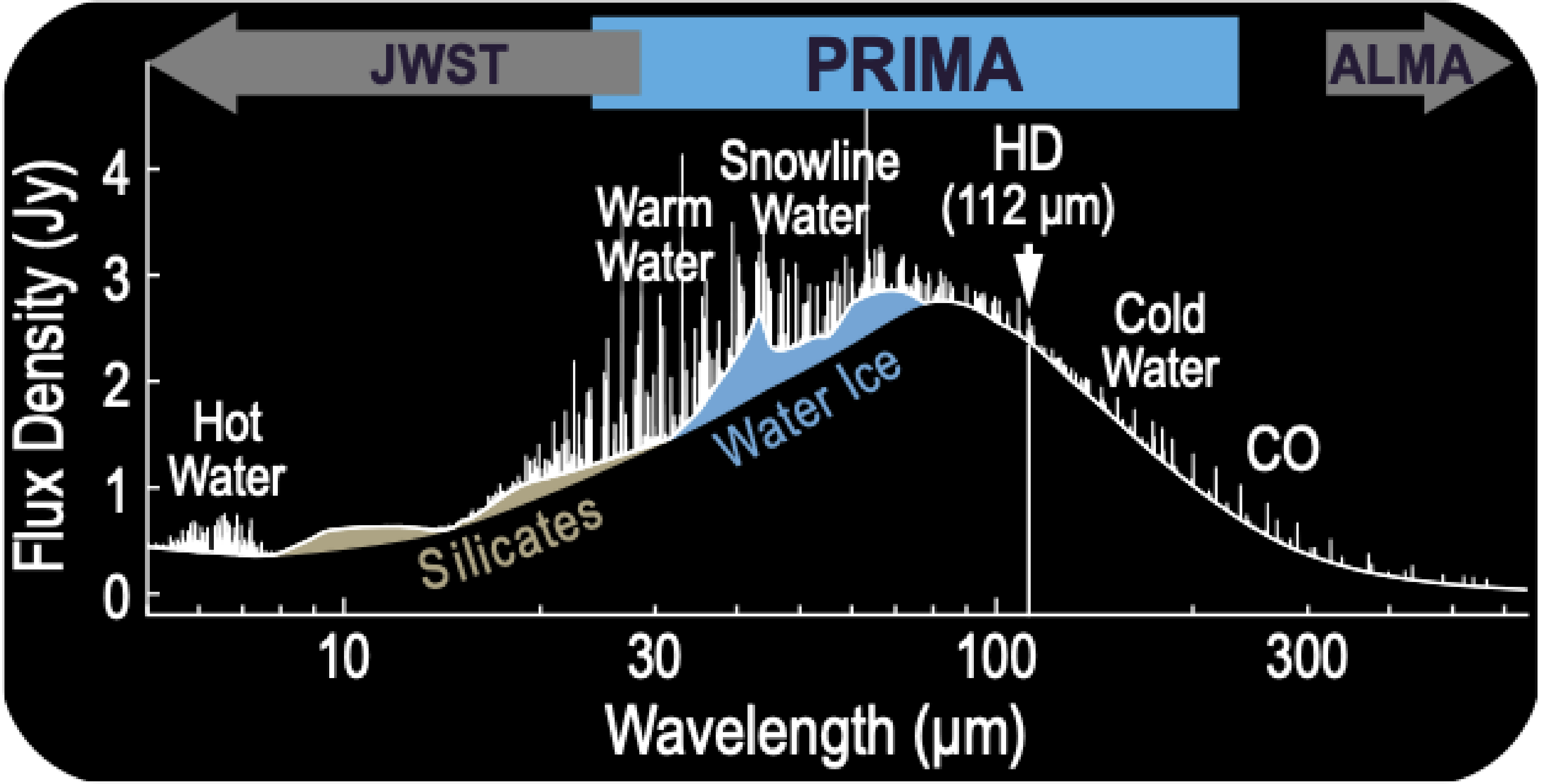


For 100 $1.75 \leq z \leq 2.25$ galaxies in 5 q_{PAH} bins, PRIMA will measure

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

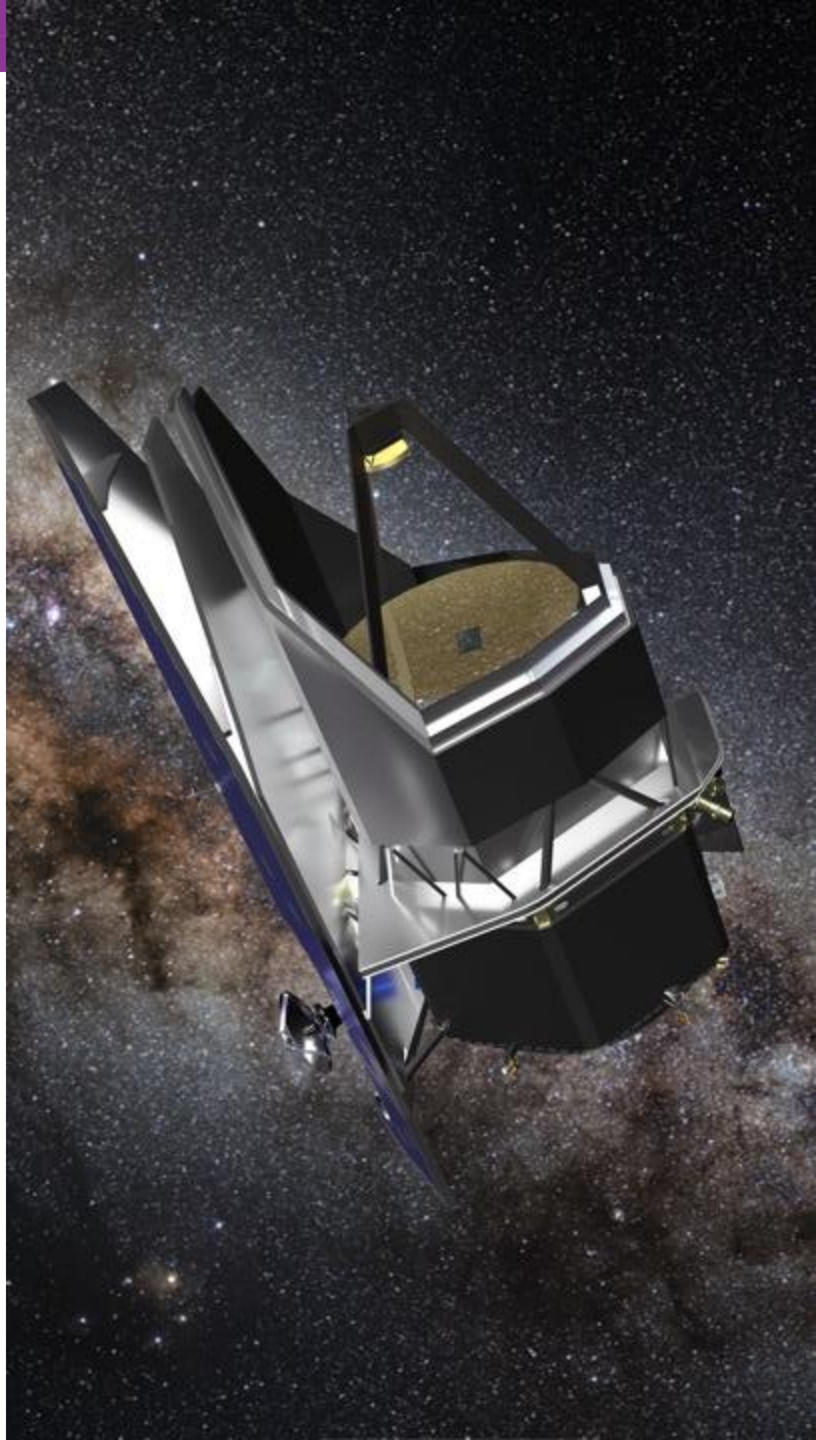
PRIMA is flagship-class science for a Probe price

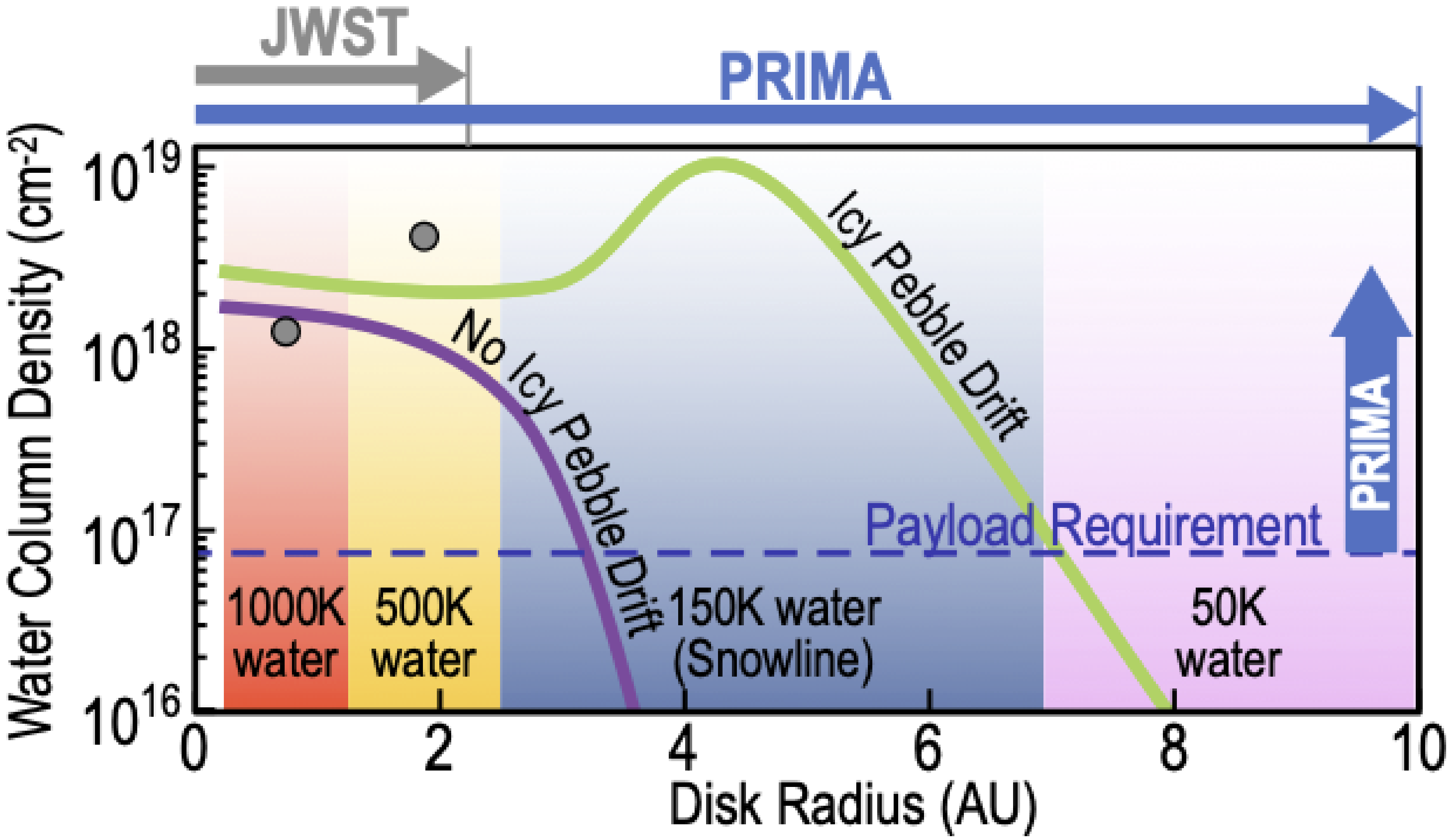




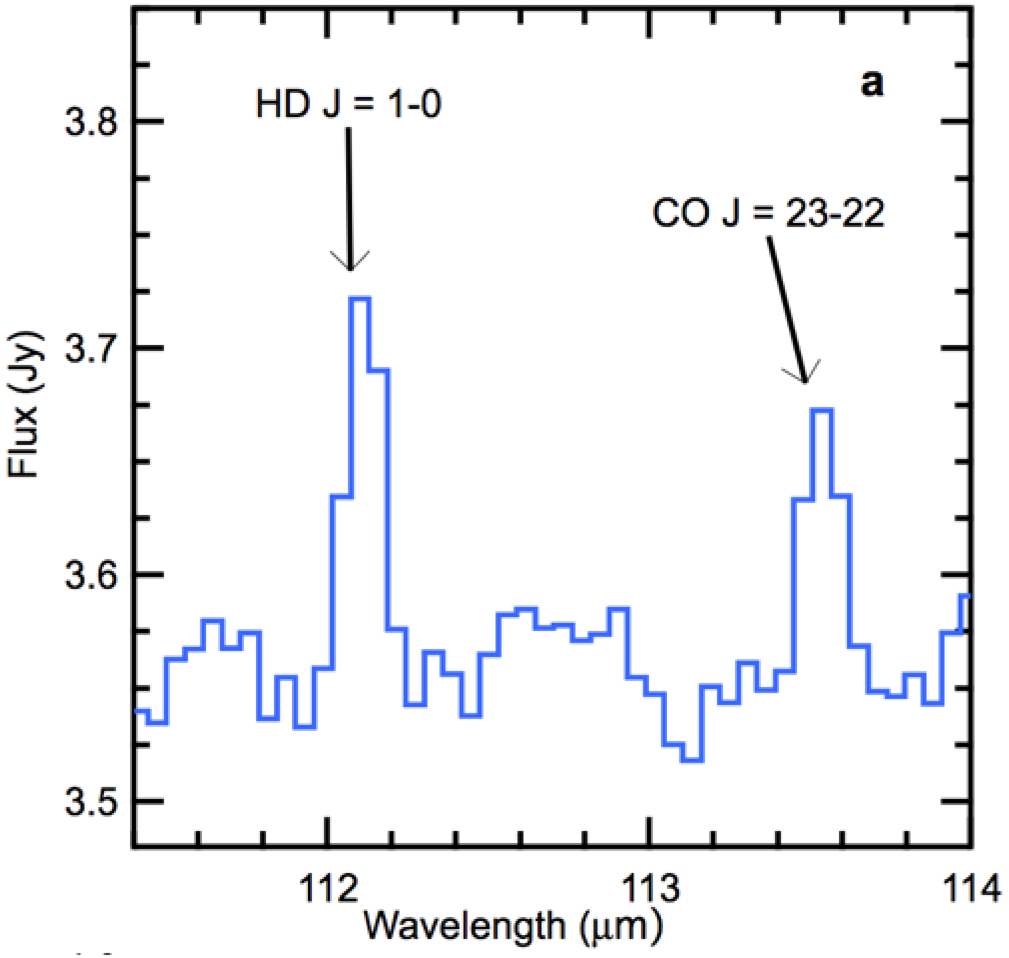
Unique disk tracers accessed by PRIMA

- HD (1-0 and 2-1)
- H_2O gas (Eupper 50-1000 K)
- $H_2{}^{18}O$ + HDO
- H_2O ice (43 micron)
- NH_3 gas
- 63 micron [OI]
- H_2 S(0)
- CO (J>11)
- OH gas
- HF

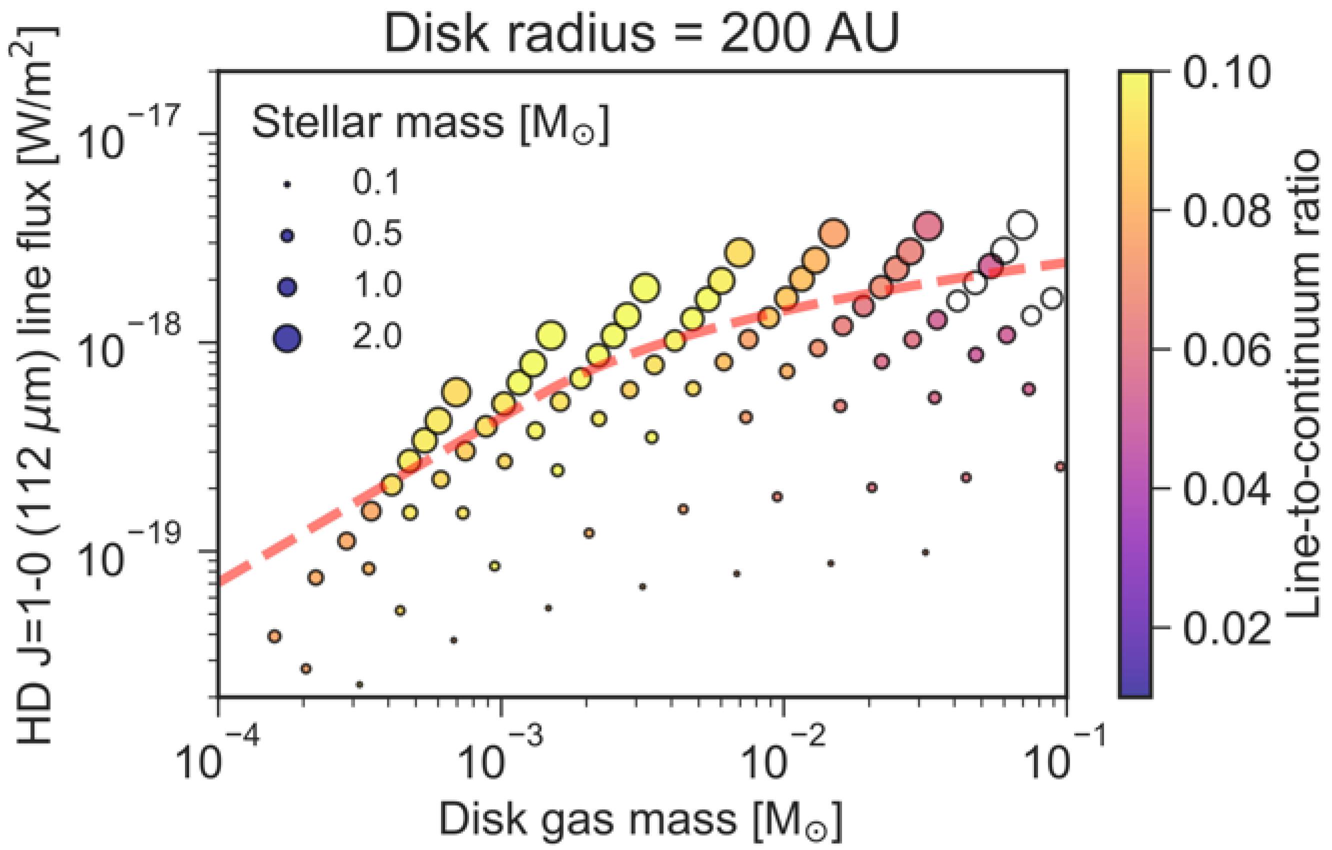


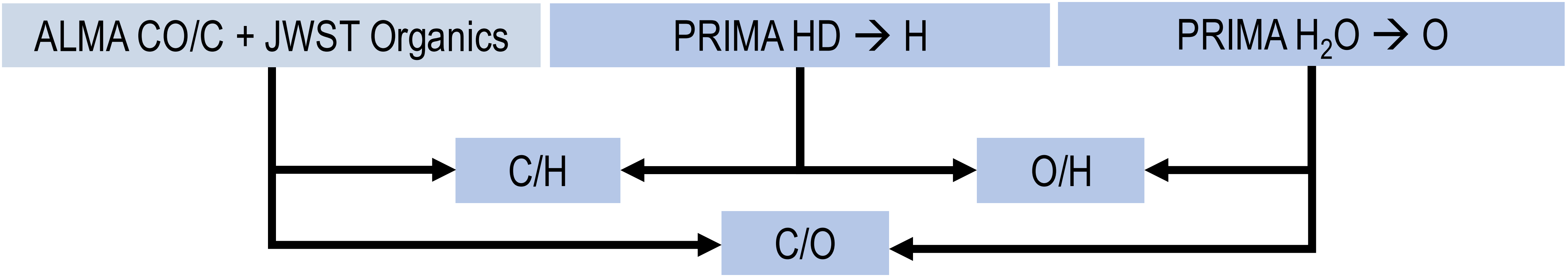

JWST
PRIMA
Water Column Density (cm-2)
10^19
10^18
10^17
10^16
No Icy Pebble Drift
Icy Pebble Drift
Payload Requirement
PRIMA
1000K water
500K water
150K water (Snowline)
50K water
0
2
4
6
8
10
Disk Radius (AU)

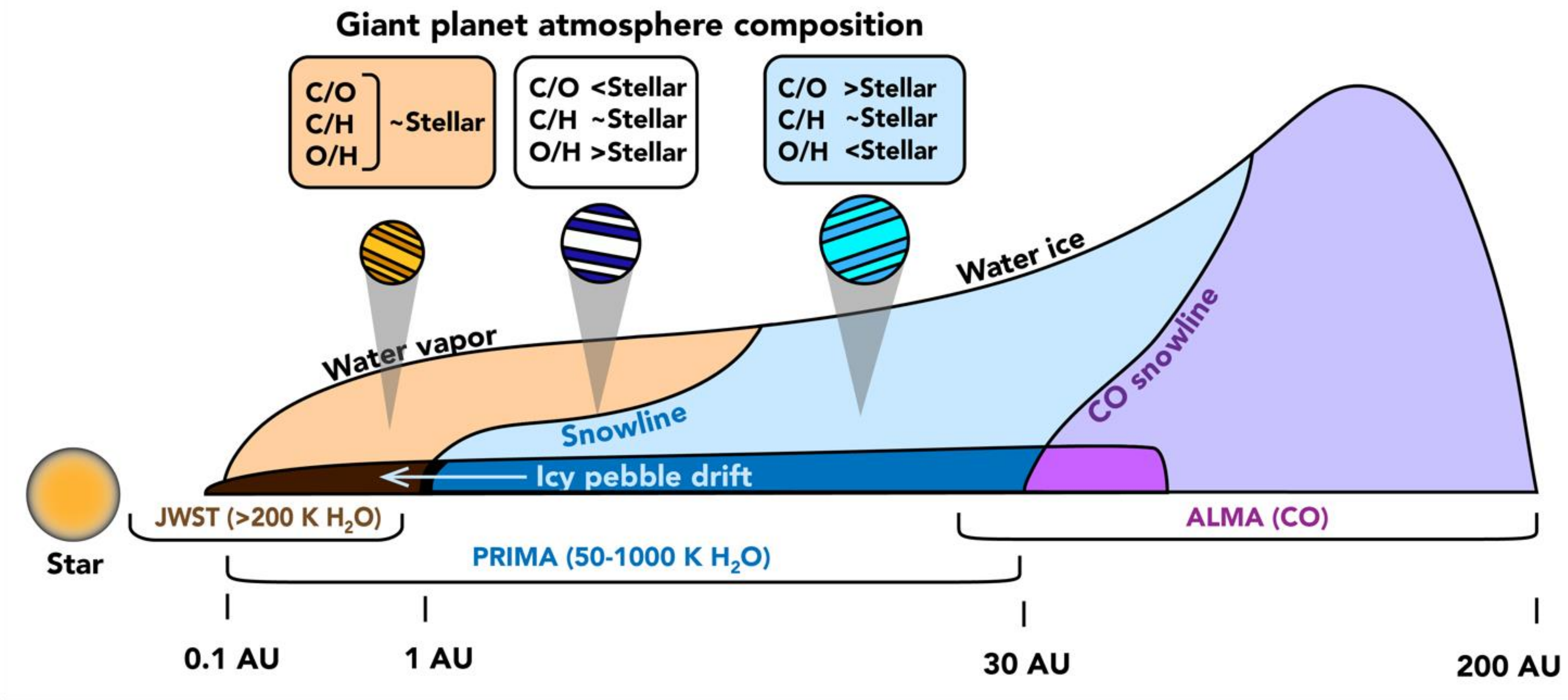
Total disk gas masses are uncertain – HD best mass tracer

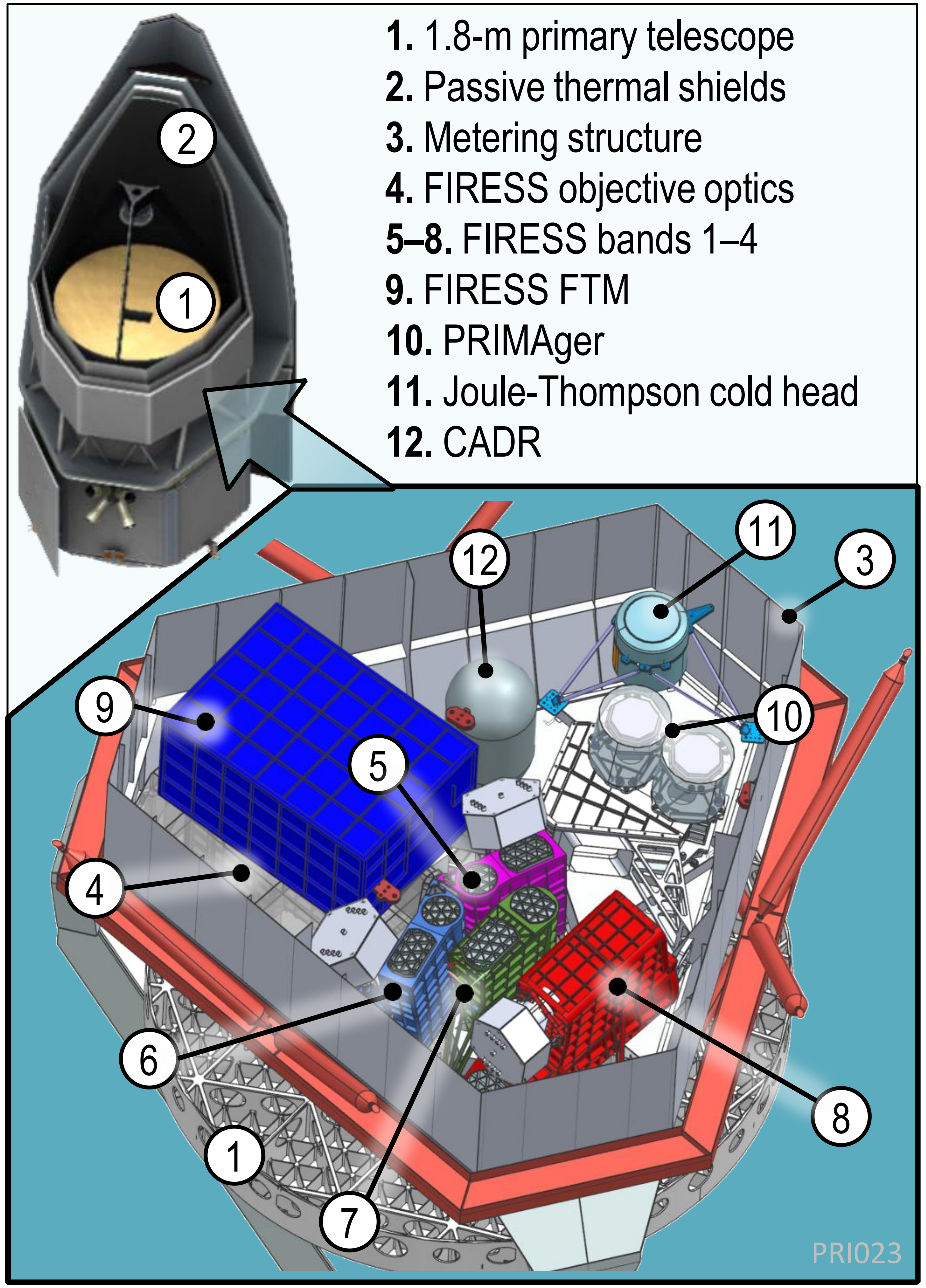


Herschel-PACS / Bergin+ 2013




ALMA CO/C + JWST Organics
PRIMA HD → H
PRIMA H_2O → O
C/H
O/H
C/O


Giant planet atmosphere composition
C/O
C/H
O/H
~Stellar
C/O <Stellar
C/H ~Stellar
O/H >Stellar
C/O >Stellar
C/H ~Stellar
O/H <Stellar
Water ice
Water vapor
CO snowline
Snowline
Icy pebble drift
Star
JWST (>200 K H_2O)
ALMA (CO)
PRIMA (50-1000 K H_2O)
0.1 AU
1 AU
30 AU
200 AU

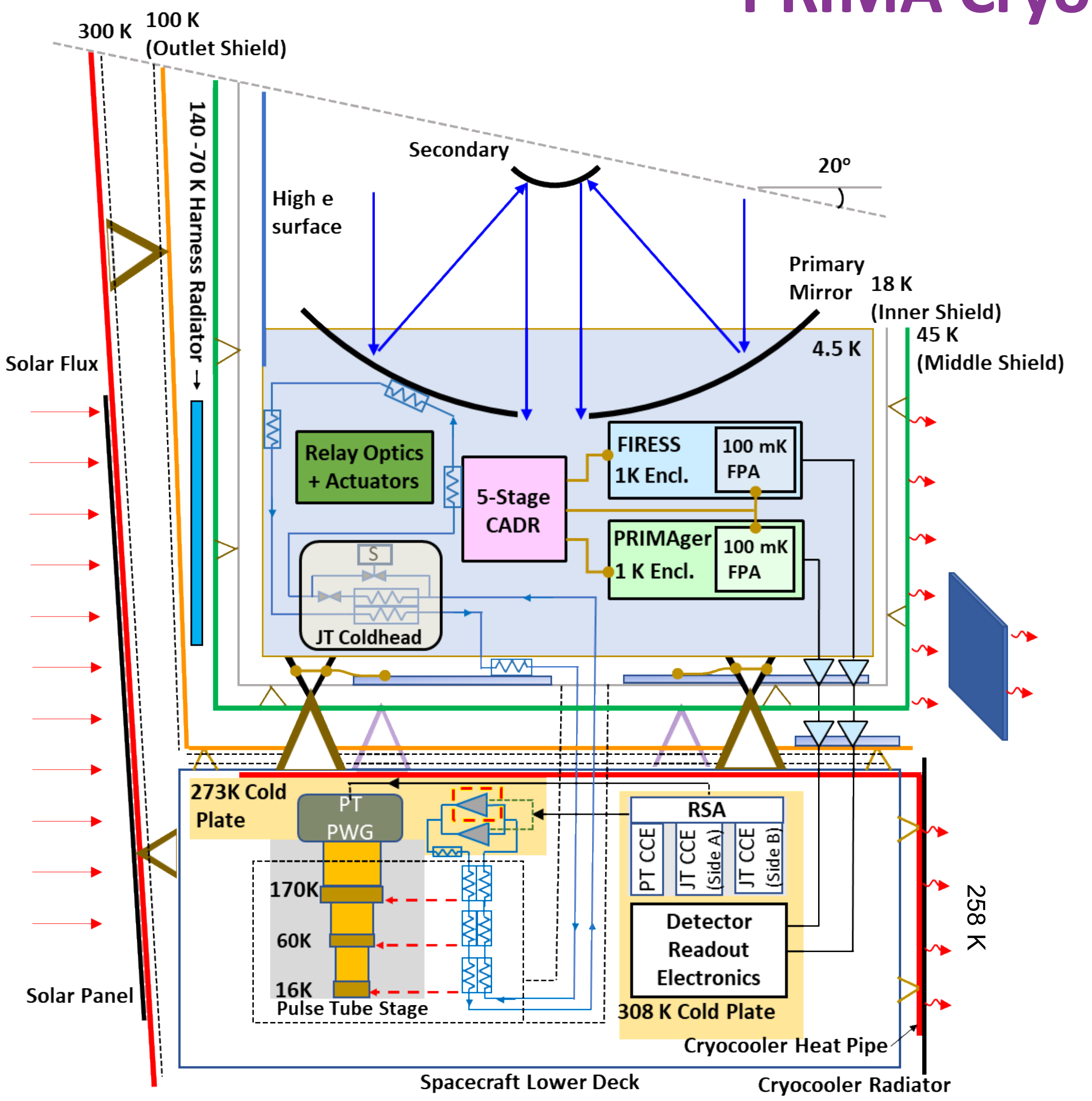


Payload Overview

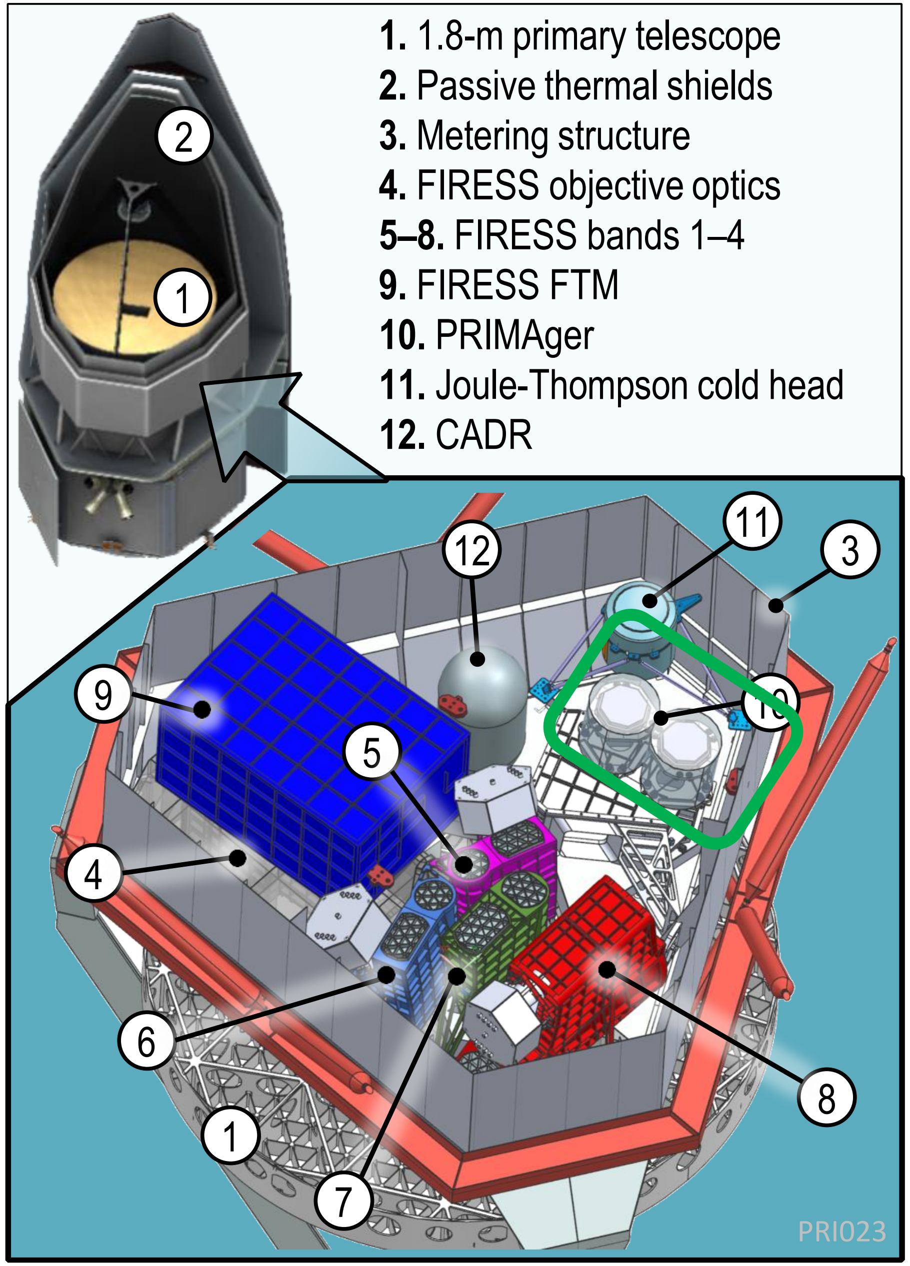
PRIMA Telescope

- 1.8 meter all aluminum primary mirror
  - Aluminum has lots of heritage with very low CTE below ~50 K
- Afocal Korsch three-mirror anastigmat (like JWST)
- Actively cooled to 4.5 K
- Diffraction limited >28 micron
- Two science instruments in prime focus
  - PRIMAger and FIRESS
- ~10,000 Microwave Kinetic Inductance Detectors (MKIDs)

PRIMA Cryogenic System

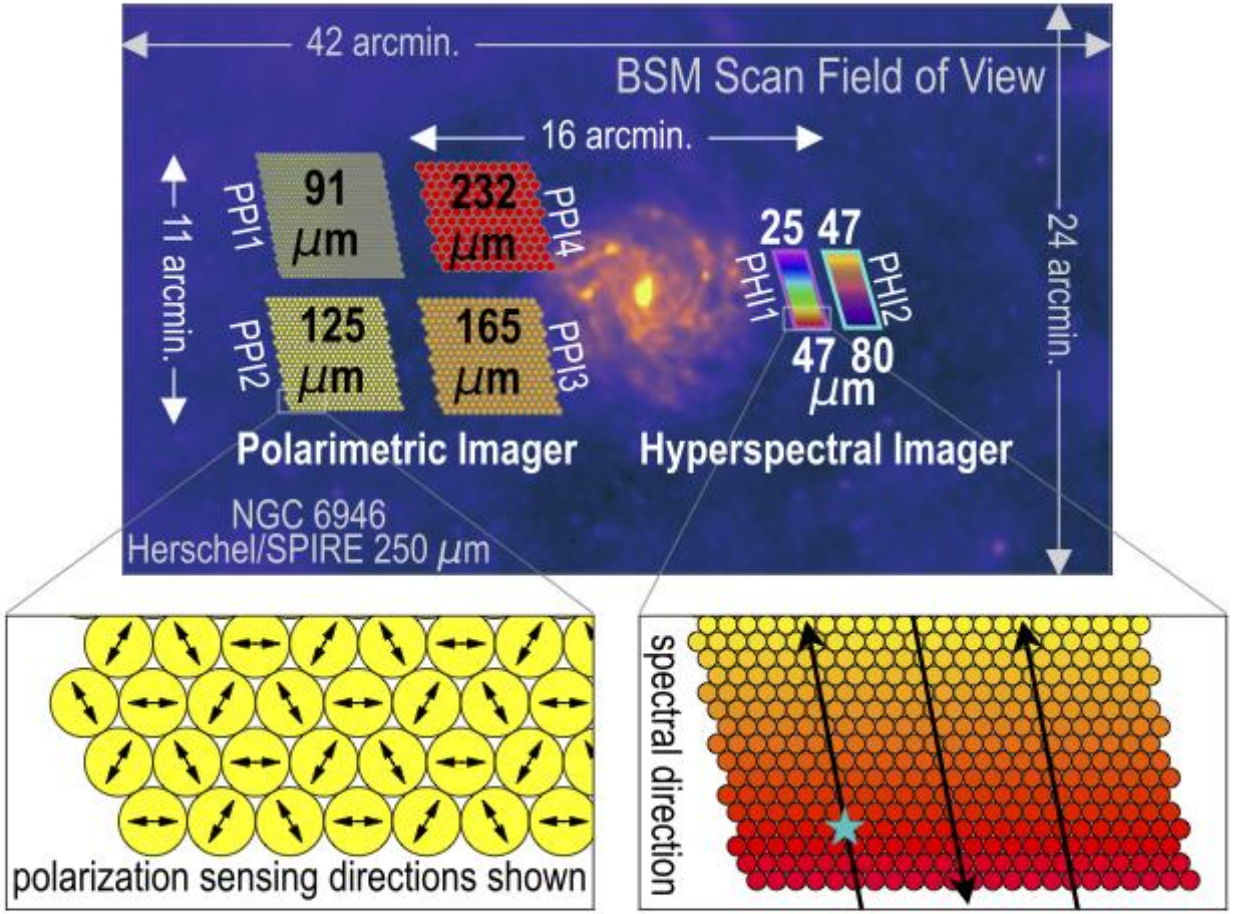


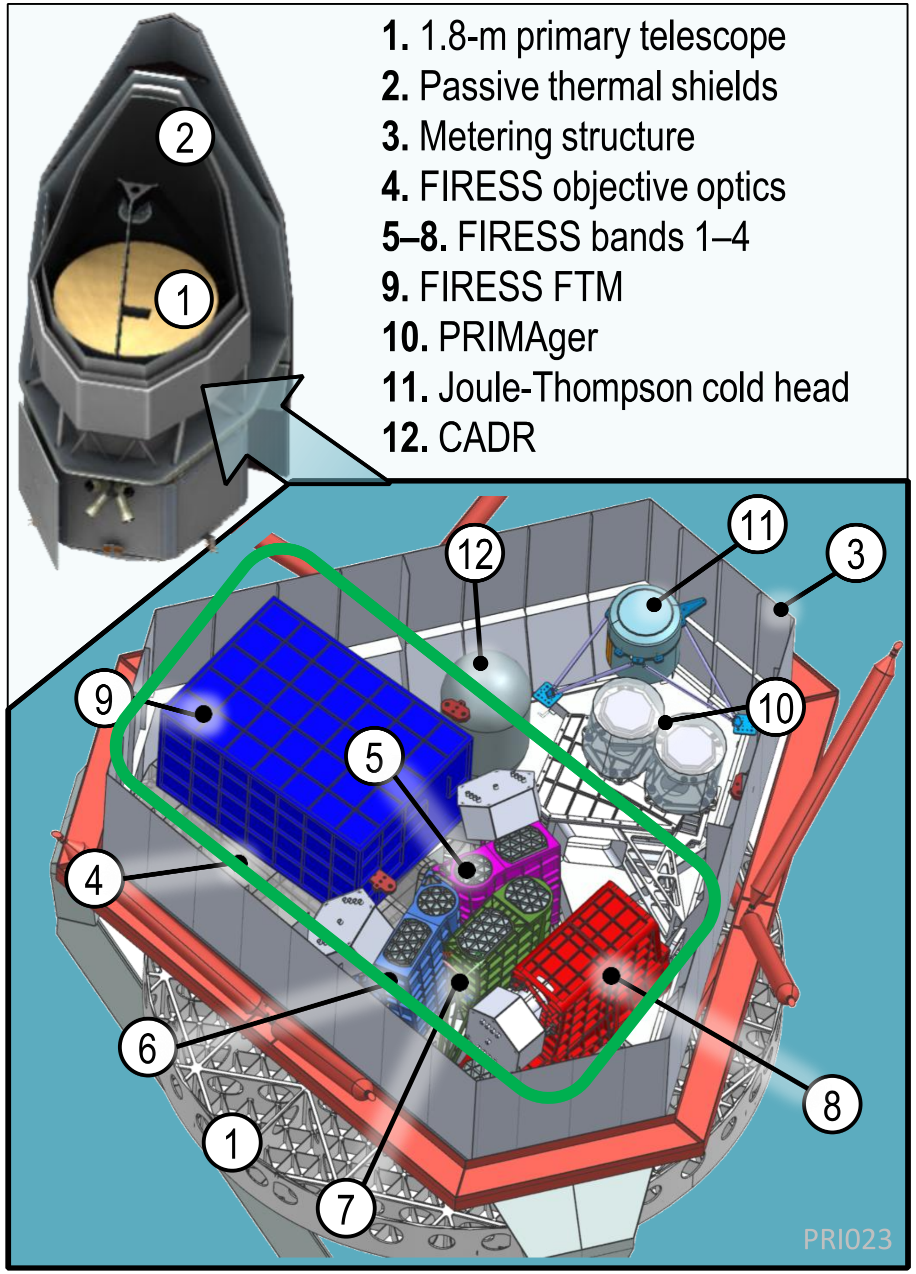
- Passive cooling with sunshades and radiators create payload environmental temperature at 45 K.
- MIRI flight spare cooler using ^{3}He as working fluid provides lift at 18 K and 4.5 K.
  - 4.5 K stage cools telescope, struts, inner shield, reimaging optics, steering mirrors, FIRESS FTM.
  - 4.5 K stage backs 1 K / 0.1 K ADR cooler.
- 1 K / 0.1 K continuous adiabatic demagnetization refrigerator (DiPirro @ GSFC lead)
  - Cools instrument enclosures to 1 K
  - Cools focal plane arrays to 100 mK



PRIMAger

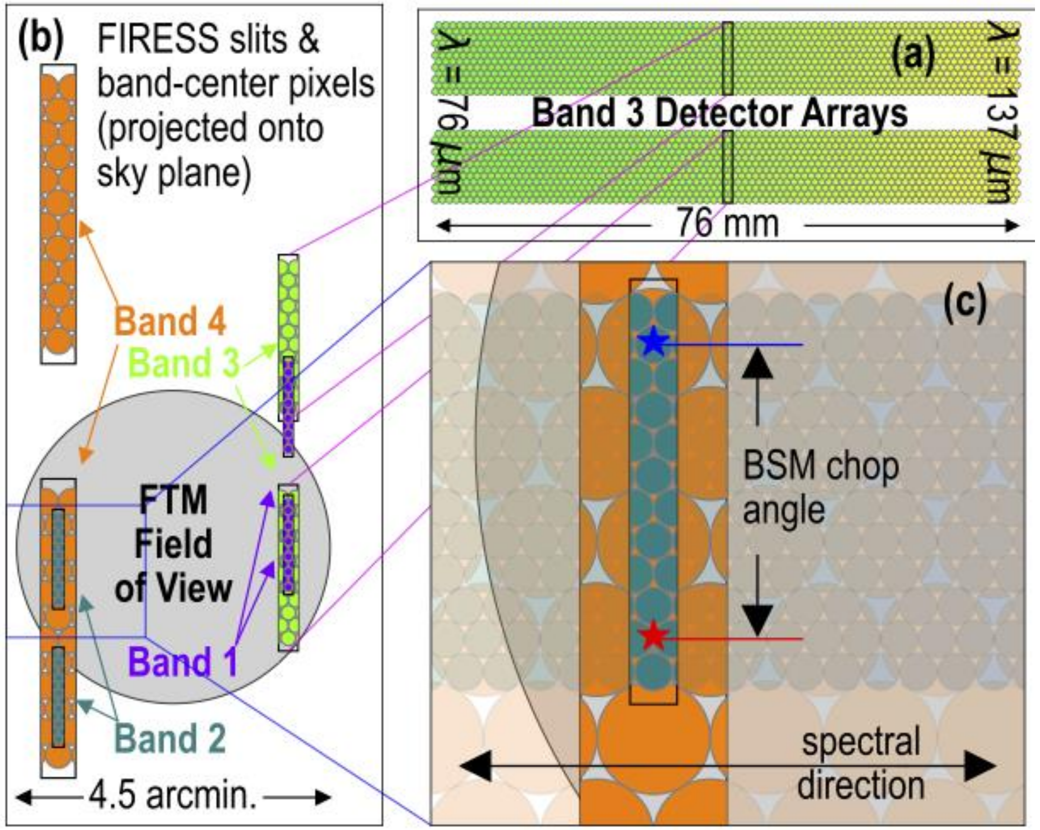
- Two R=10 Hyperspectral focal planes using linear variable filters: (24 – 80 μm)
- Four R=4 polarimetric imaging arrays: (80 – 235 μm)
- 3993 total pixels





FIRESS

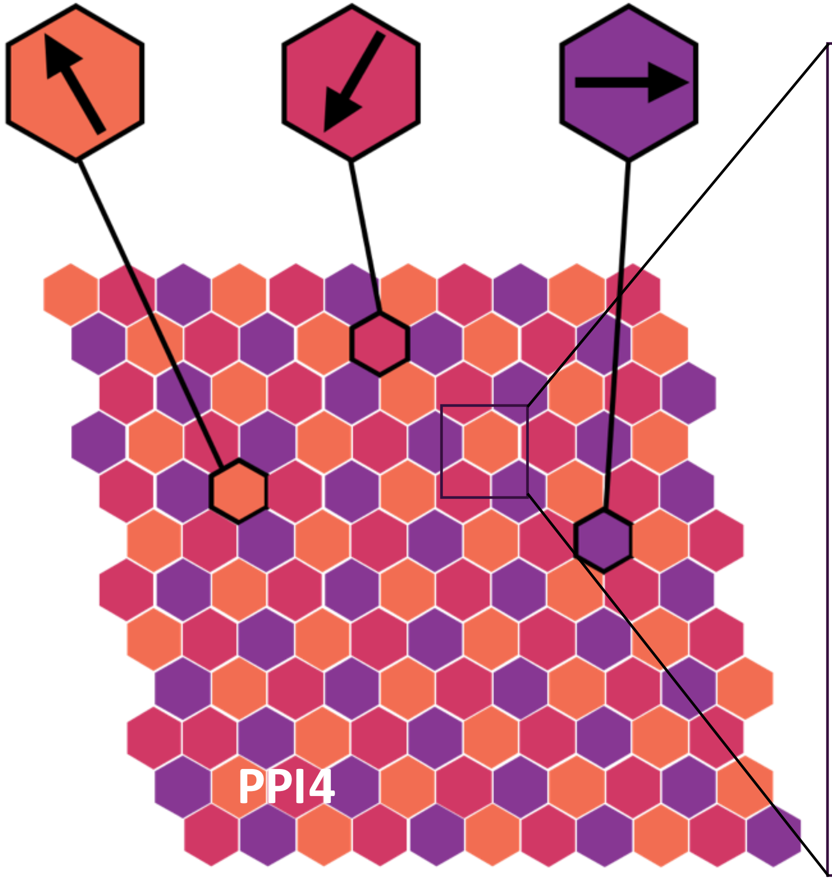
- **Low-res spectroscopy:** R~100 at 25 – 235 μm in 4 bands.
  - 24 spatial x 84 spectral pixels per band.
- **High-res spectroscopy**: R=4,400 * (112 mu/lambda) Fourier Transform Module (FTM) full-band coverage.



KEY POINTS

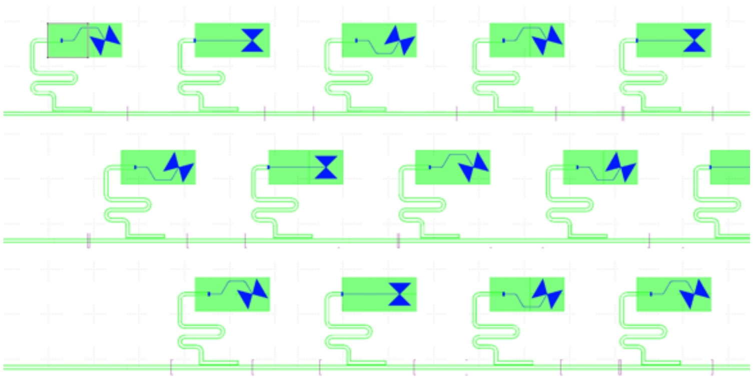
- PRIMA in phase A in competition with an X-ray mission (AXIS)
- Phase A study due in December 2025
- Selection in 2026
- Launch no later than 2032 (current NASA schedule)
- 75% of science available for GO – will be a facility observatory!

PRIMAger Polarimetric imager (PPI)



3 type of pixels,
each sensitive
to 1 angle of polarization

Polarization selectivity achieved by **orientation of MKID antenna**.
Pixel type distribution in focal plane can further be adjusted.

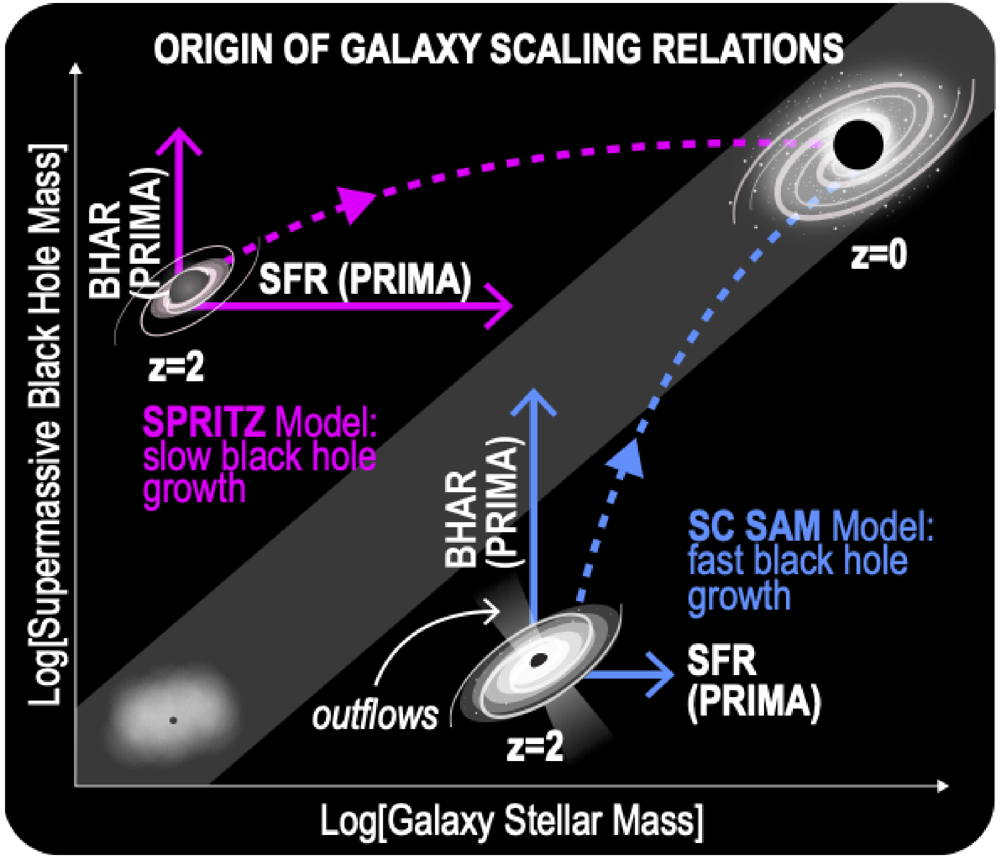


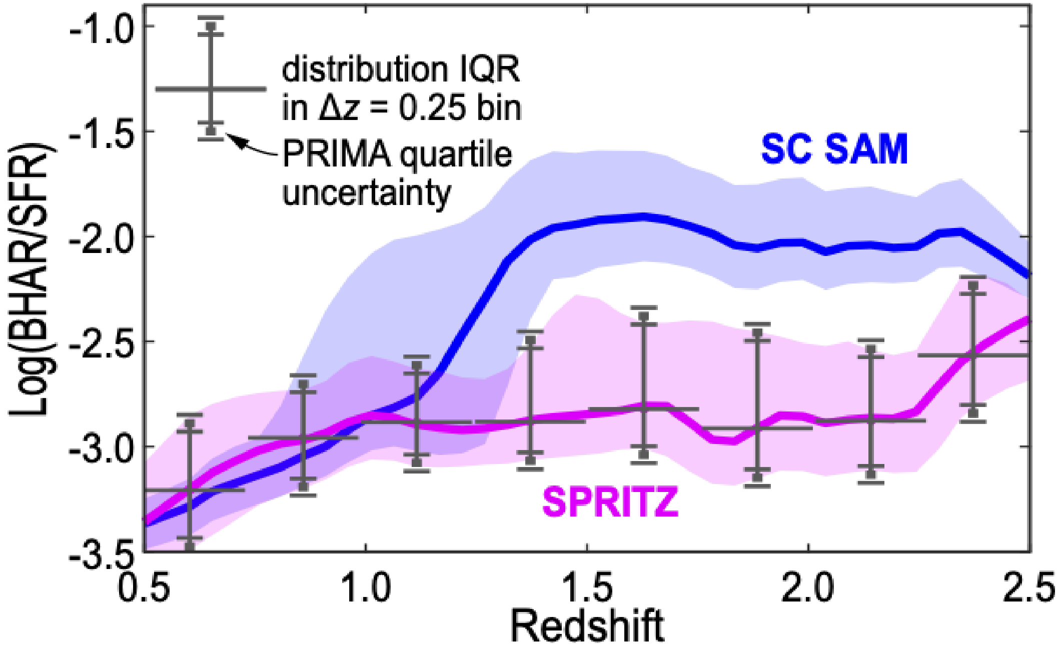
4 monochromatic broad-band filters (R=4) at 91, 126, 172, and 232 microns.

~2000 pixels and beam sizes near diffraction limit.

Common f/9 optical path

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





<u>2 example histories</u>

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).

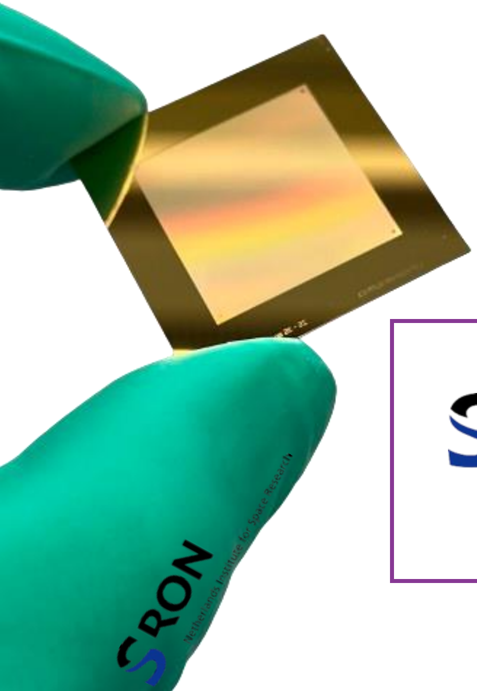
- 42k galaxies in 1 sq deg (Donnellan+ 2024)
- Spectroscopic sub-samples of 160 z = 1.0-2.5 galaxies using [O IV] and [Ne II] (rest frame 26 & 12.8 μm)
- Measure cool mass outflow rates of 50 z = 1-2 galaxies with OH (R = 900 @ 84 μm) absorption to test if they are consistent with quenching

PRIMAger hyperspectral imager (PHI)

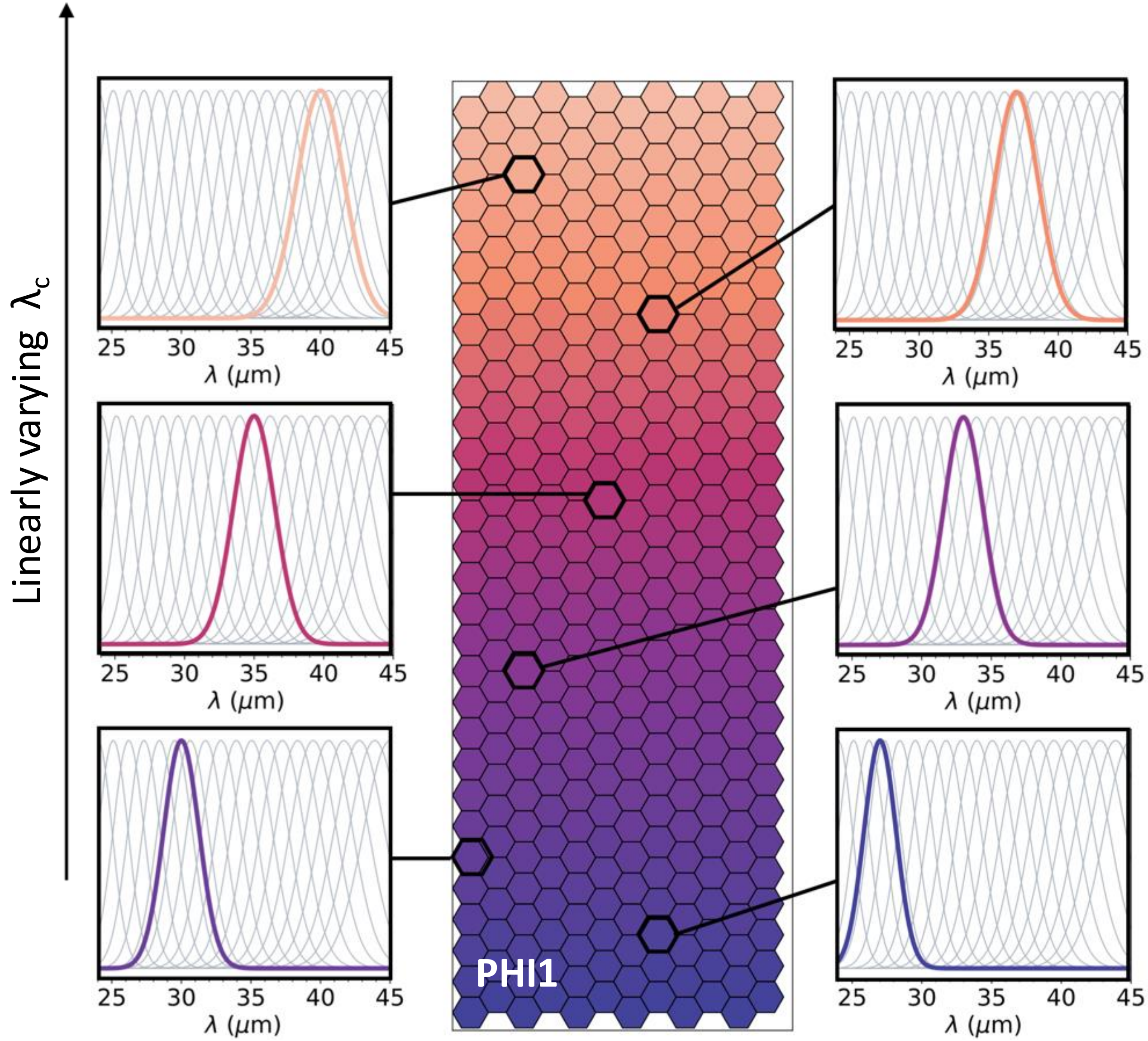
PHI has two arrays (PHI1 & PHI2) of **absorber-coupled KIDs** (**24-84** microns).

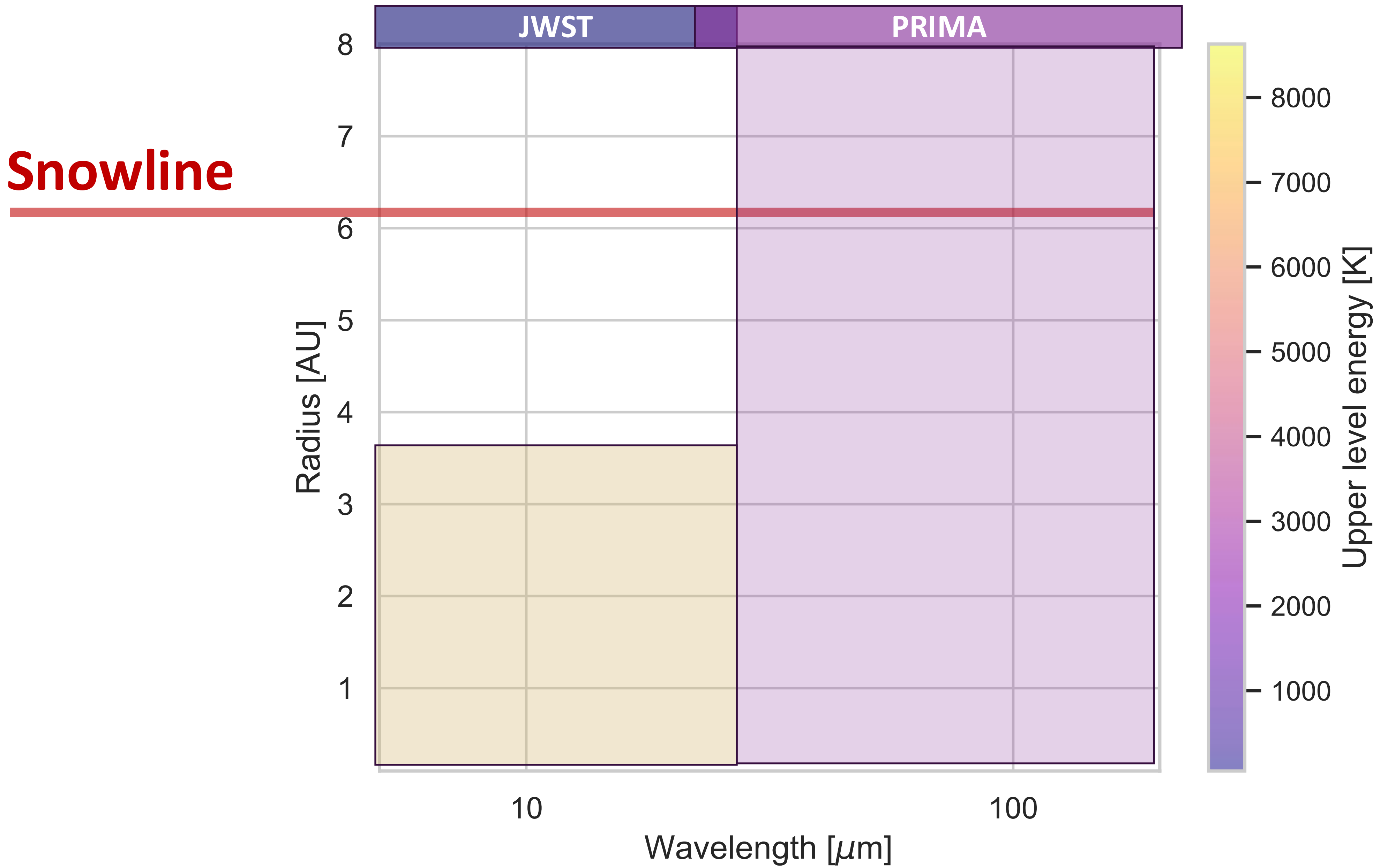
R=10 using **Linear Variable Filter** (LVF): spectral response varies linearly along one axis.

LVFs use **resonant metal-mesh structures**.



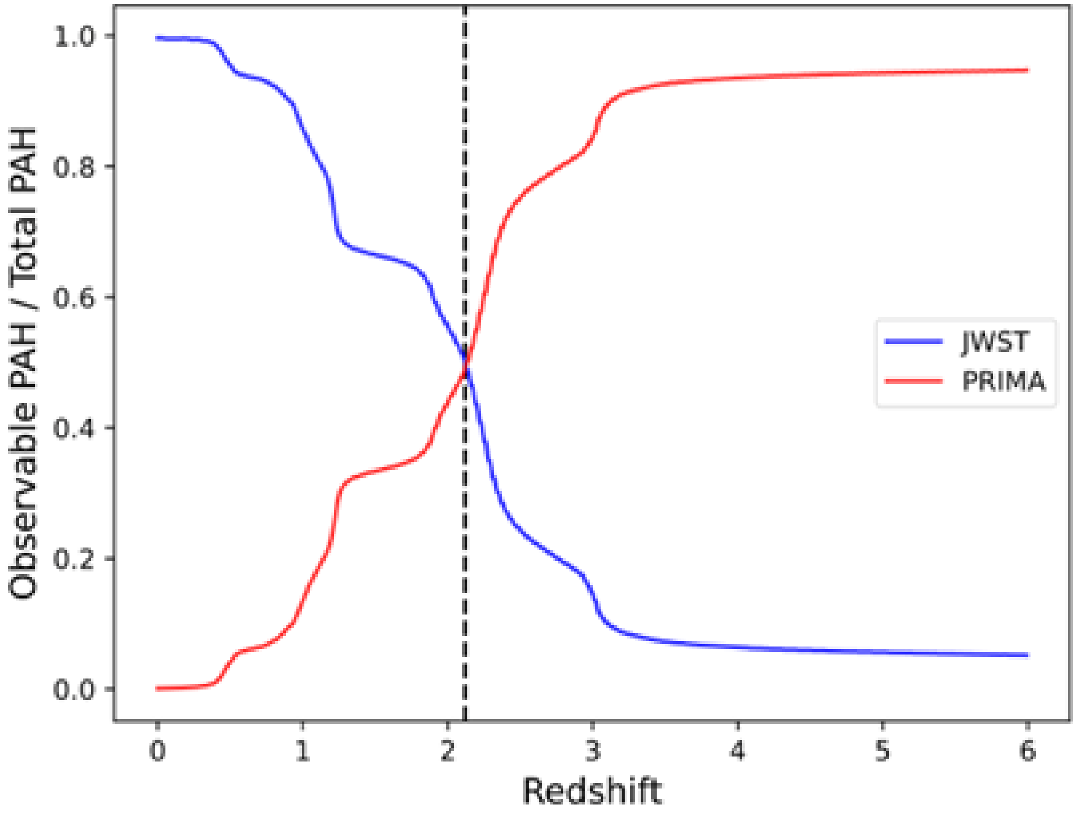
SRON Netherlands Institute for Space Research and Cardiff University Prifysgol Caerdydd are building prototypes.

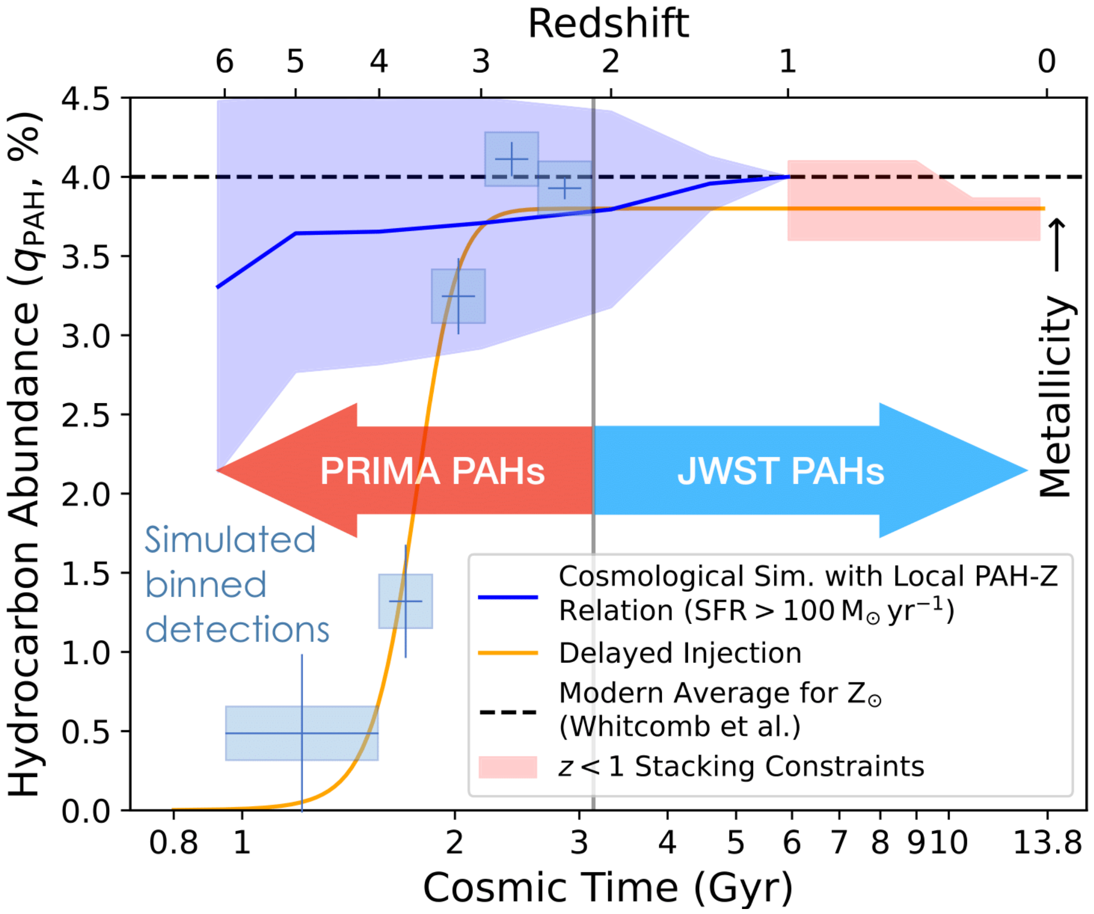



Snowline
JWST
PRIMA
Radius [AU]
1
2
3
4
5
6
7
8
10
100
Wavelength [μm]
1000
2000
3000
4000
5000
6000
7000
8000
Upper level energy [K]

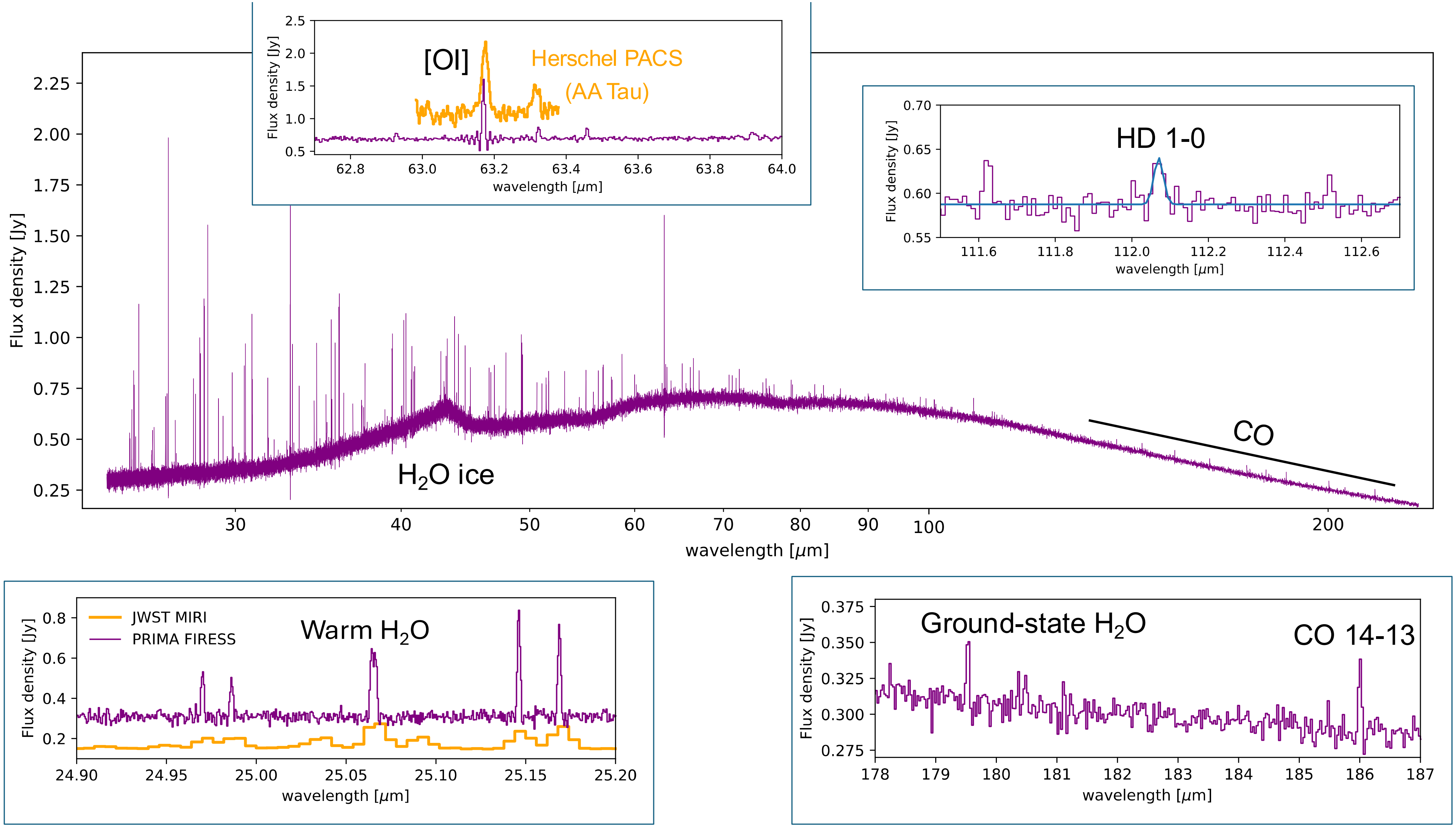
GO Science: High-z PAHs

An exciting and unique opportunity to observe hydrocarbons in the early universe, complementary to JWST (Donnelly et al., PRIMA GO Science Book)



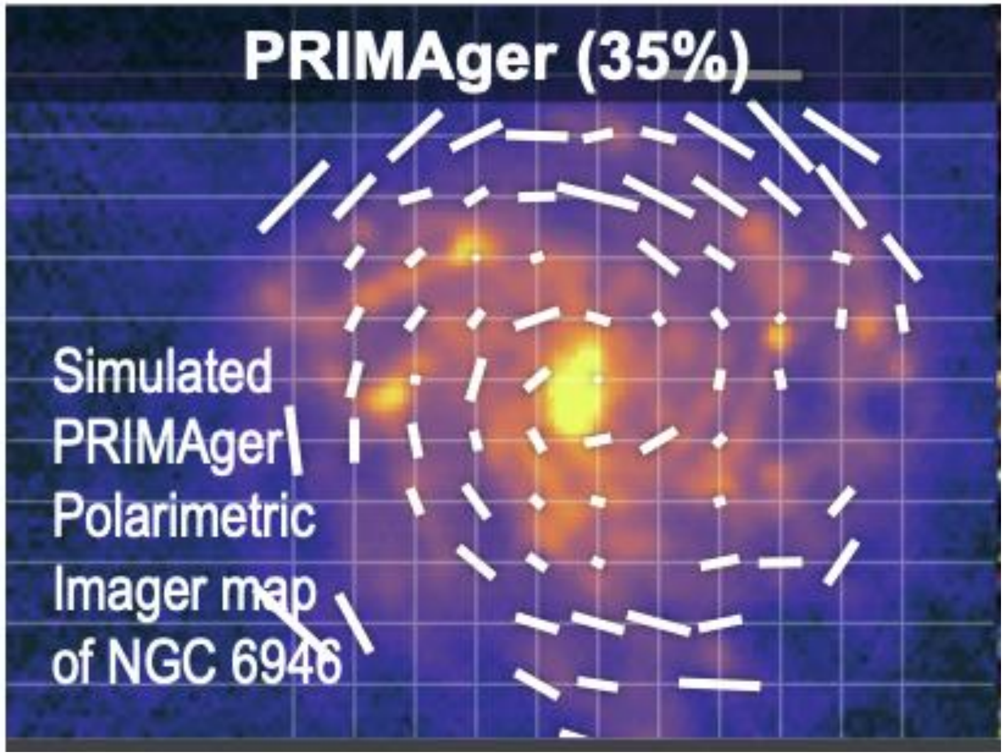


Simulated observation of a typical protoplanetary disk with PRIMA-FIRESS



GO Science: Polarimetry and Magnetic Fields in Galaxies

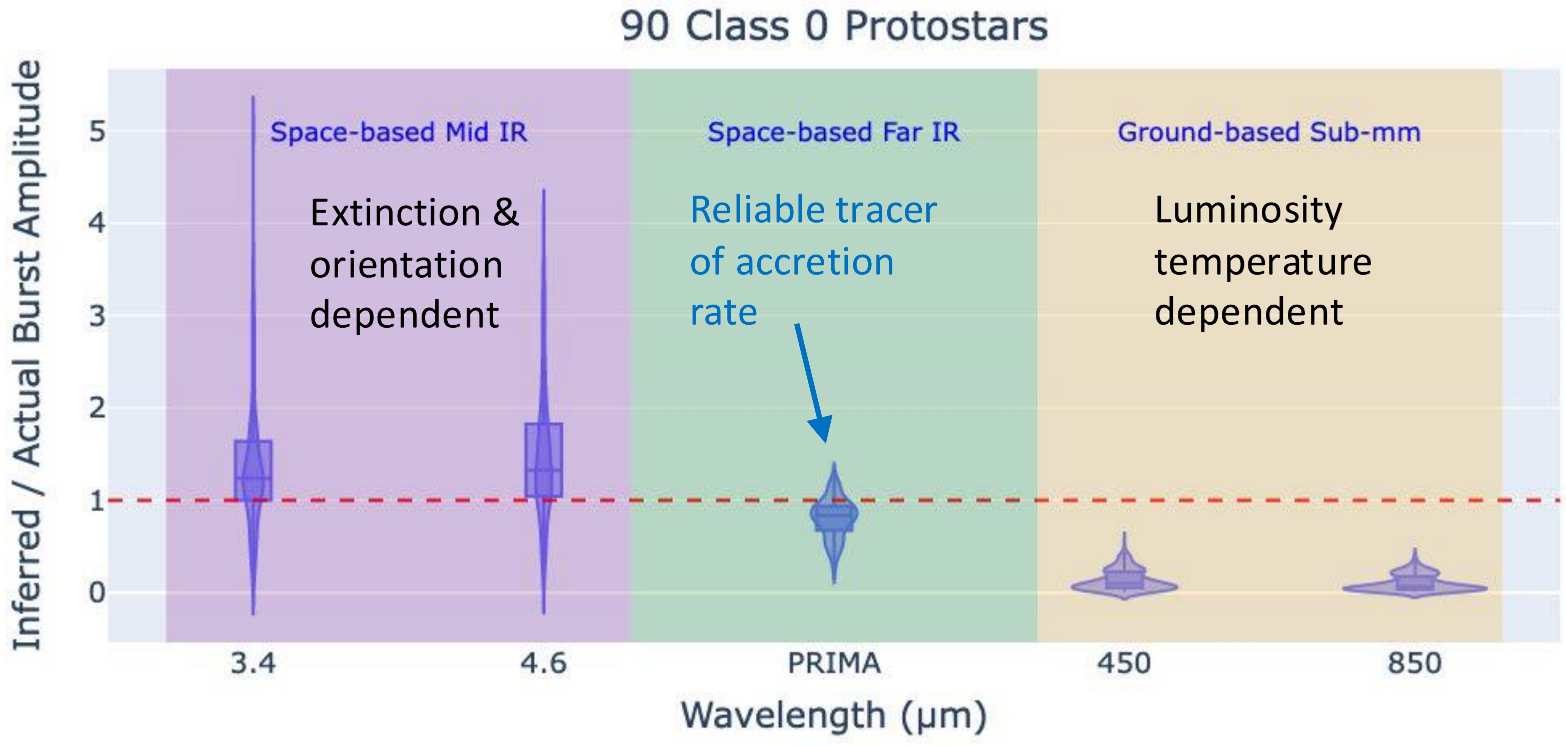
(In PI science, PRIMA will test dust models with far-IR polarimetry.)



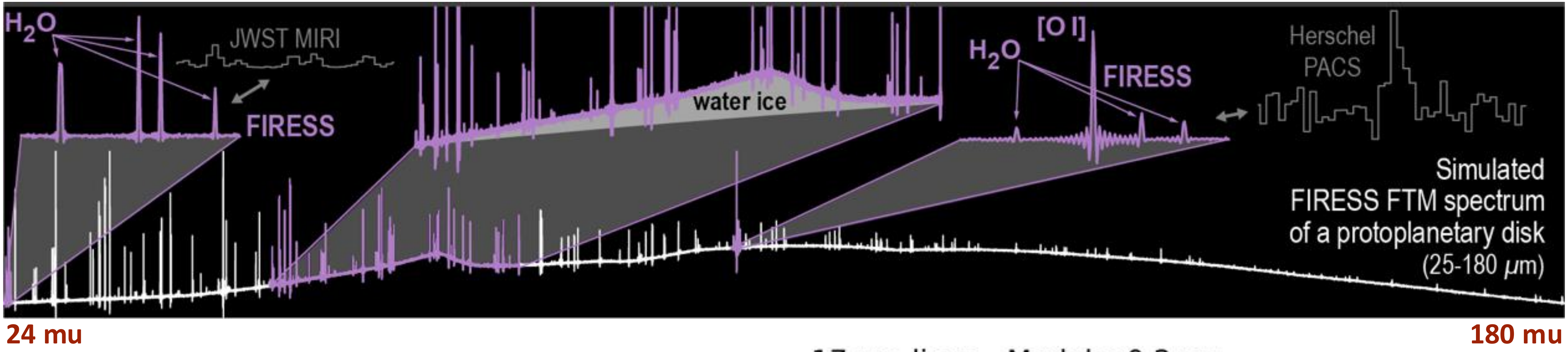
- Simulations of polarimetric capability: Dowell+ 2024
- Magnetic fields (Lopez-Rodriguez; Louvet; Paré; Pattle)
  - Galactic clouds: The role of magnetic fields in cloud dynamics
  - Nearby, resolved galaxies: Do molecular cloud fields generally align with and reflect radio (cosmic ray) derived fields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

GO Science: How do stars get their mass?

- Mass: *The* fundamental property of stars, but we do not know how they accrete their mass. Quiescent or episodic?
- Far-IR: Only wavelength for which luminosity correlates tightly with accretion rate.
- Test: >50% of mass is derived from rare events?
- Survey: 2000 protostars with cadences of 2 wks to 5 yrs (& back to Herschel)
- Archival value: Huge, plus polarimetry!

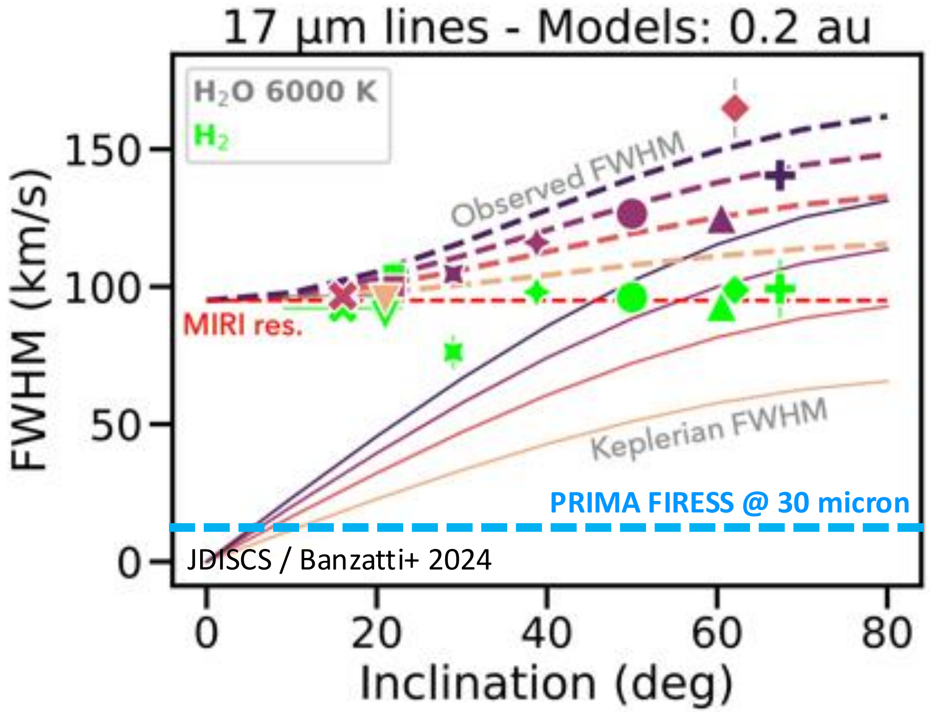


Battersby, et al., (2023, PRIMA GO Science Book)



PRIMA
Disk Observations

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



GO Opportunities: Survey Potential with PRIMA