PRIMA The PRobe far-Infrared Mission for Astrophysics

Probe far-Infrared Mission for Astrophysics (PRIMA)

Bally Fest 2025

Margaret Meixner, Deputy PI, Jet Propulsion Laboratory (JPL)/ California Institute of Technology (Caltech)

on behalf of the PRIMA team, including
Jason Glenn, Principal Investigator, GSFC
Matt Bradford, Project Scientist, JPL/Caltech
Klaus Pontoppidan, Deputy PS, JPL/Caltech
Alexandra Pope, Science Lead, UMass
Tiffany Kataria, Deputy Science Lead, JPL/Caltech
Alberto Bolatto, UMD, College Park
and whole PRIMA team

Full list of co-Is:

Jet Propulsion Laboratory California Institute of Technology · NASA Goddard Space Flight Center · BAE SYSTEMS · ipac · cnes · asi agenzia spaziale italiana · DLR · SRON · NG · NASA Marshall Space Flight Center

Thank You !

PRIMA Team
Astrophysics and technology experts
9/24 are international.

Co-I shown, plus:

Science affiliates.

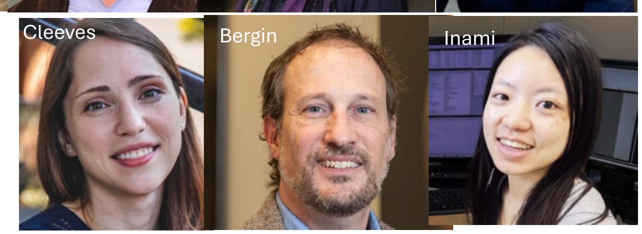
A strong corps of engineers at JPL, GSFC, & BAE Systems

Partner Institutions

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

PI: Jason Glenn
dPI: Margaret Meixner

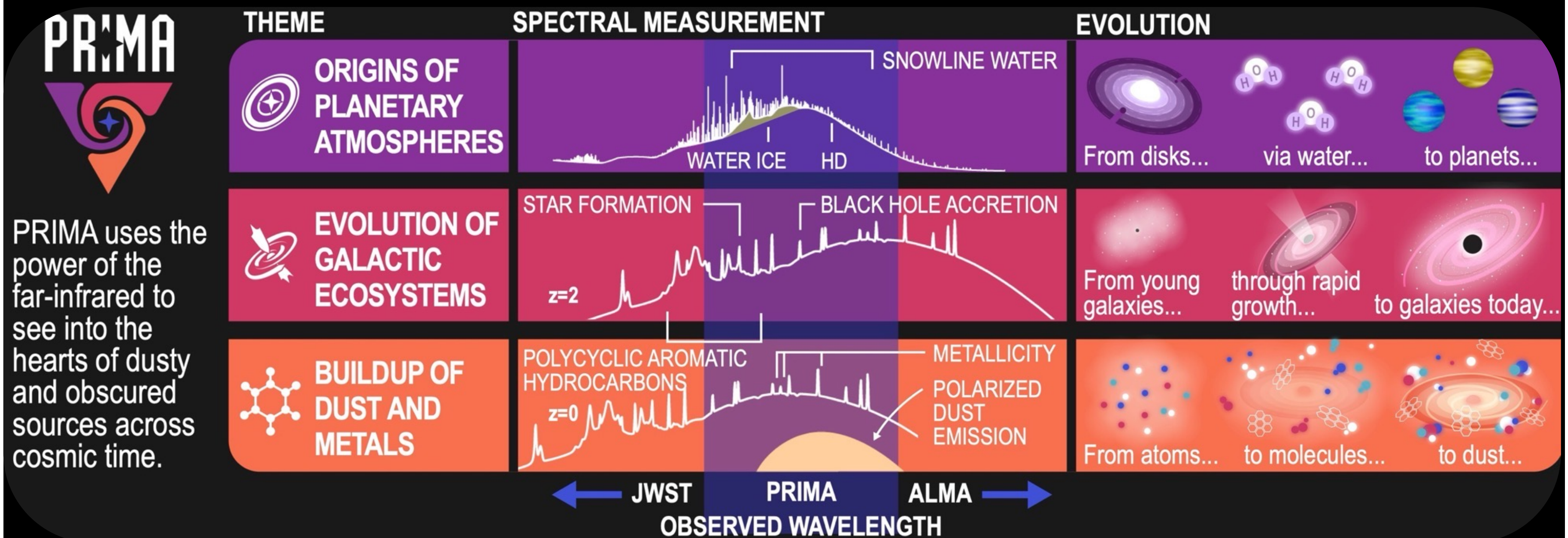
PS: Matt Bradford
dPS: Klaus Pontoppidan



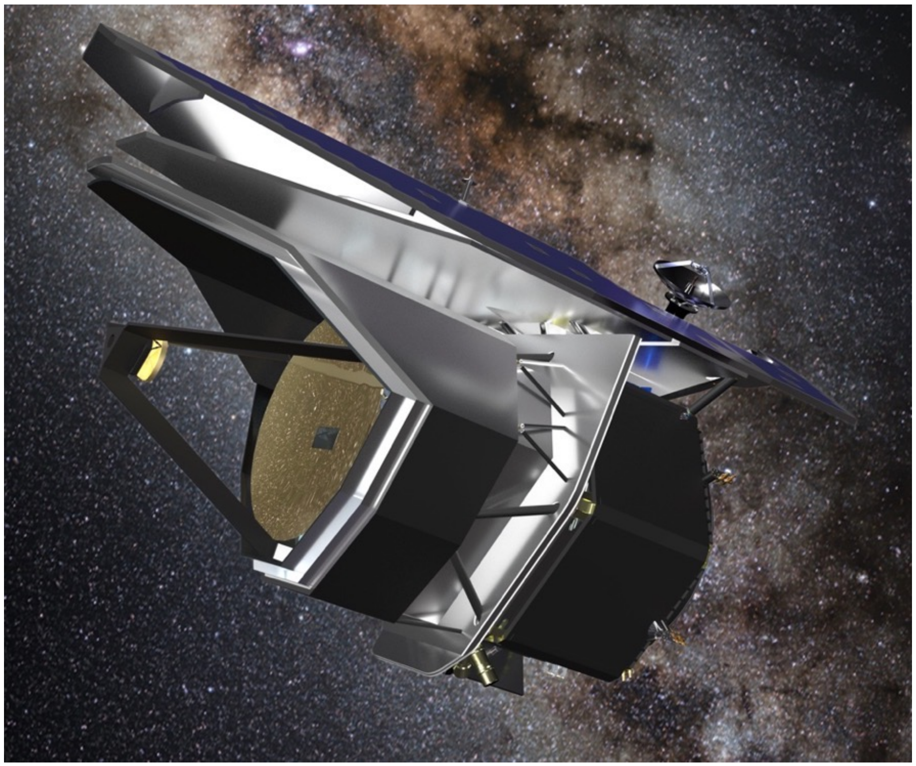
JPL Jet Propulsion Laboratory California Institute of Technology · NASA Goddard Space Flight Center · BAE SYSTEMS · ipac · cnes · asi agenzia spaziale italiana · DLR · SRON · NG · NASA Marshall Space Flight Center

Astro2020 Decadal Survey Section 7.5.3.3 :

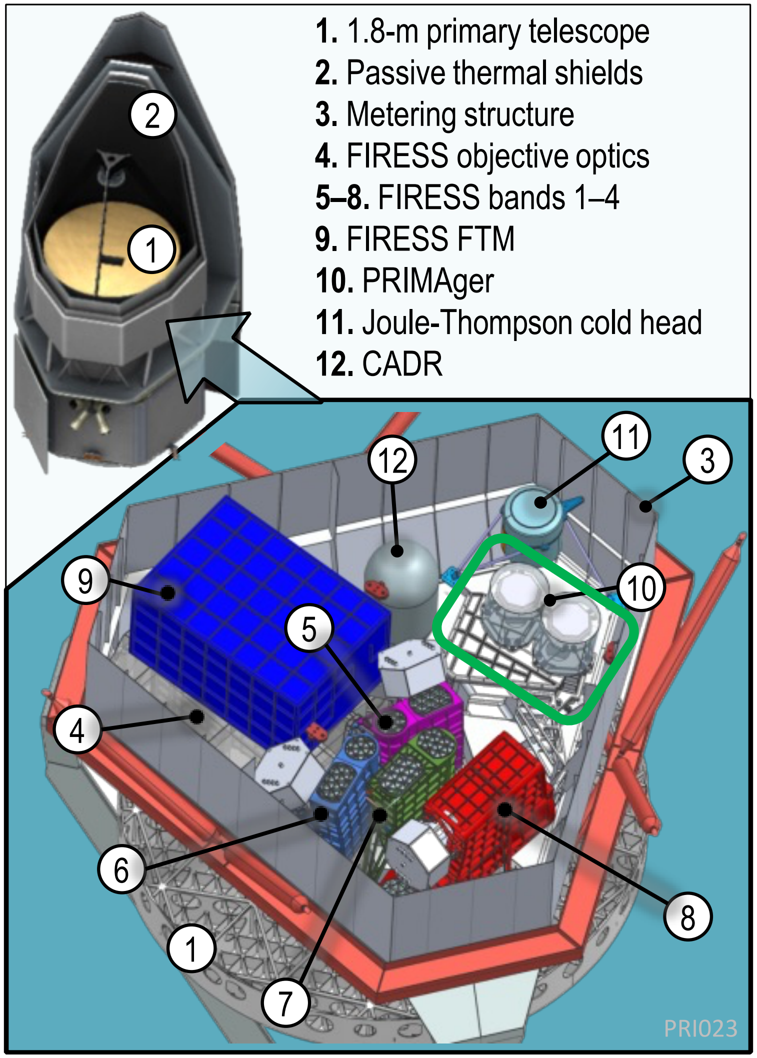
and a probe scale mission is an extremely timely and compelling opportunity to do so. These scientific areas include tracing the astrochemical signatures of planet formation (within and outside of our own Solar System), measuring the formation and buildup of galaxies, heavy elements, and interstellar 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



PRIMA

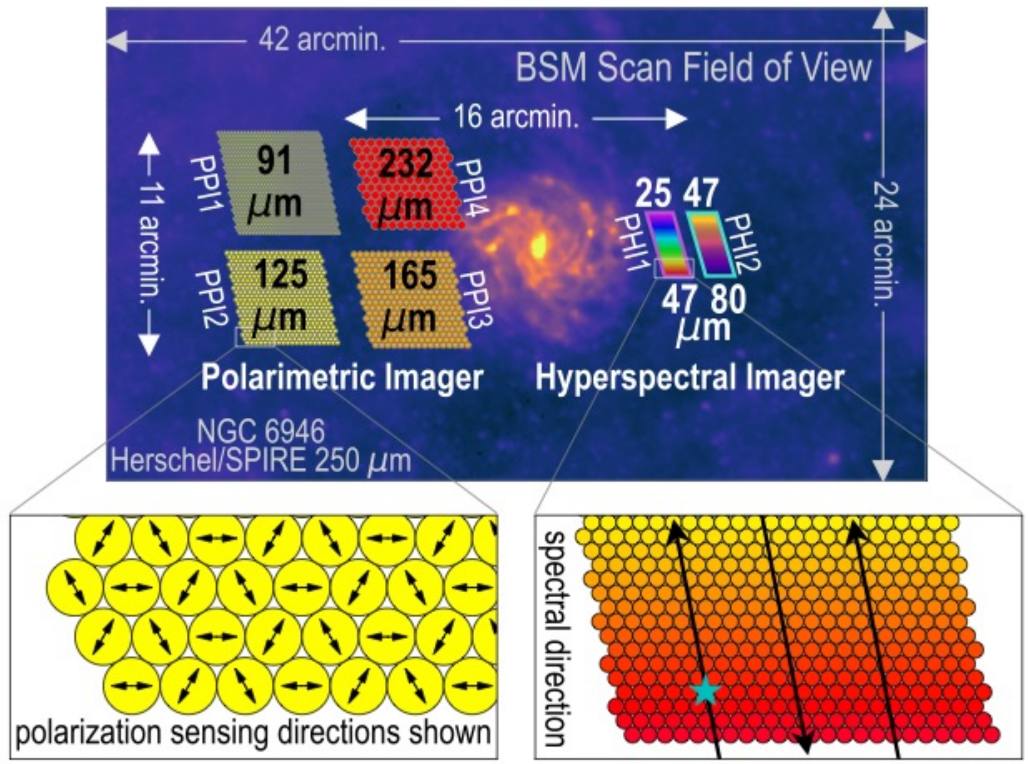


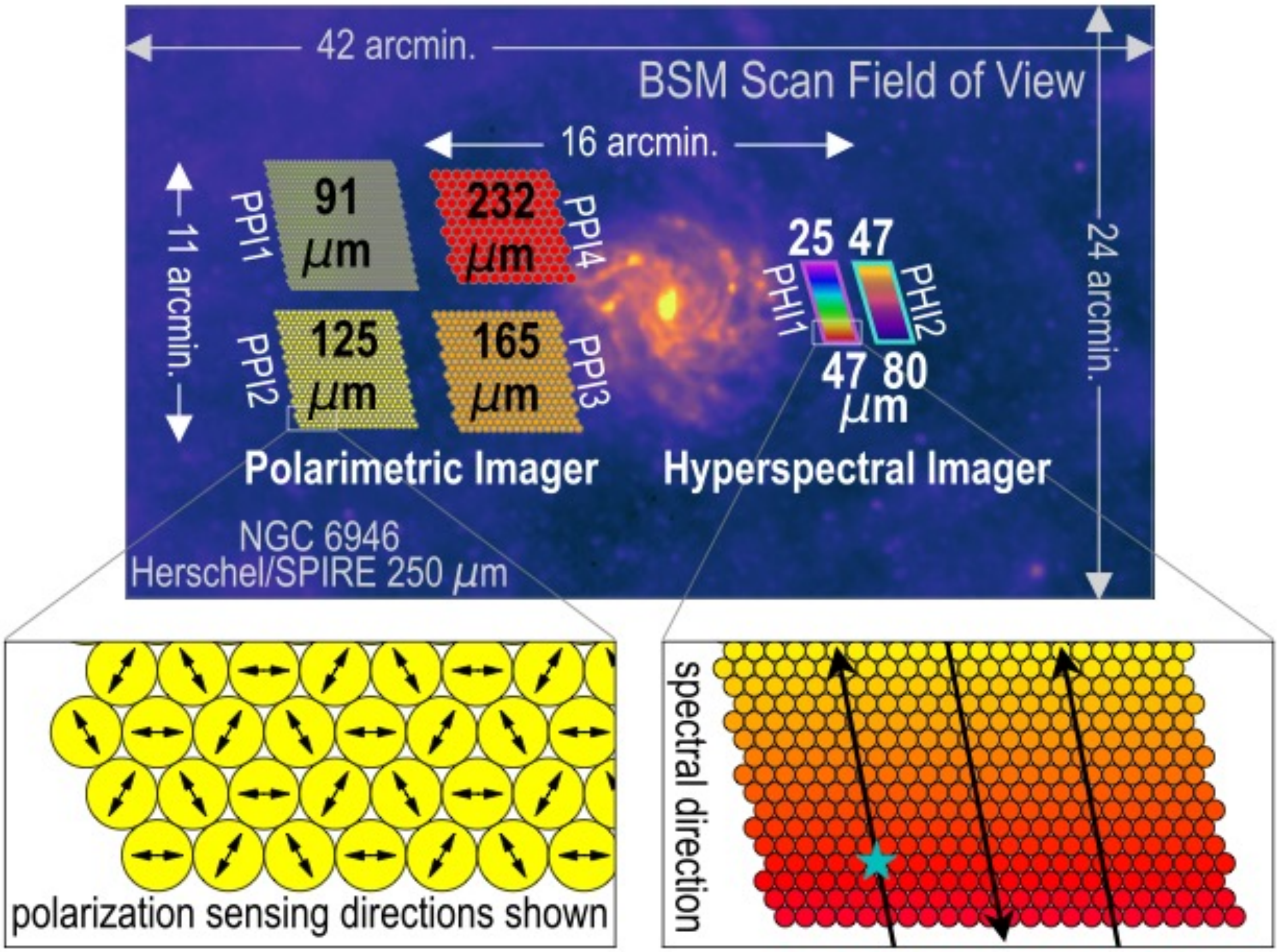
Telescope	1.8-m, all aluminum, 4.5 Kelvin
PRIMAger Imager & polarimeter	R = 10 hyperspectral imaging 25-80 μm R= 4 imaging & polarimetry 91-261 μm
FIRESS Spectrometer	R > 85 spectroscopy 24-235 μm High-Res mode R = 4,400 x (112μm/λ)
Detectors	100 mK KID arrays (~12k total)
Data	IPAC
Orbit	Earth-Sun L2
Launch	2031
Observations	75% GO, 25% PI (→ GI)



PRIMAger (French / Dutch contribution)

- Two R=10 Hyperspectral focal planes using linear variable filters: (24 – 80 μm, PHI1/PHI2)
- Four R=4 polarimetric imaging arrays: (80 – 235 μm, PPI1-4)
- 3993 total pixels

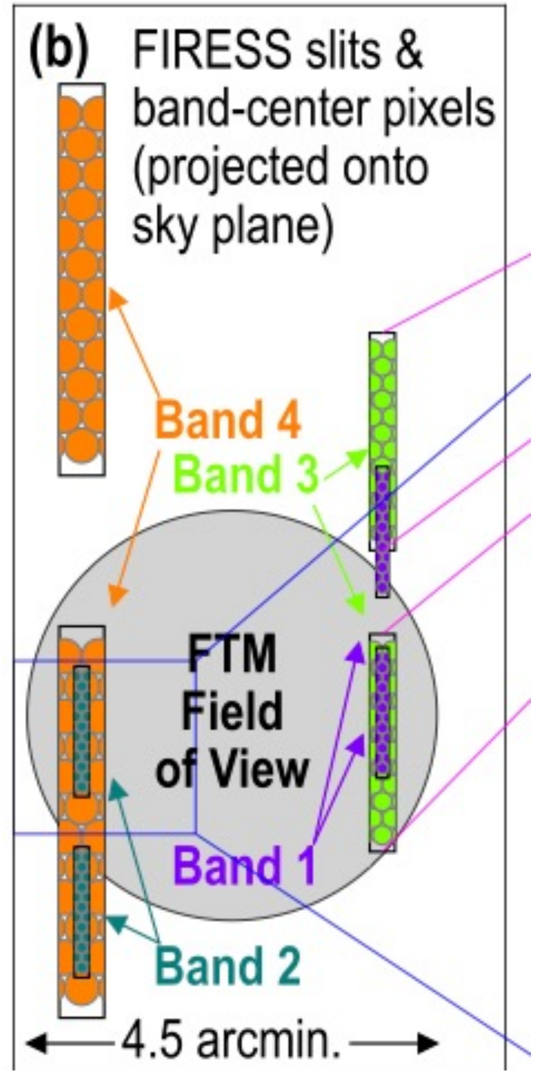


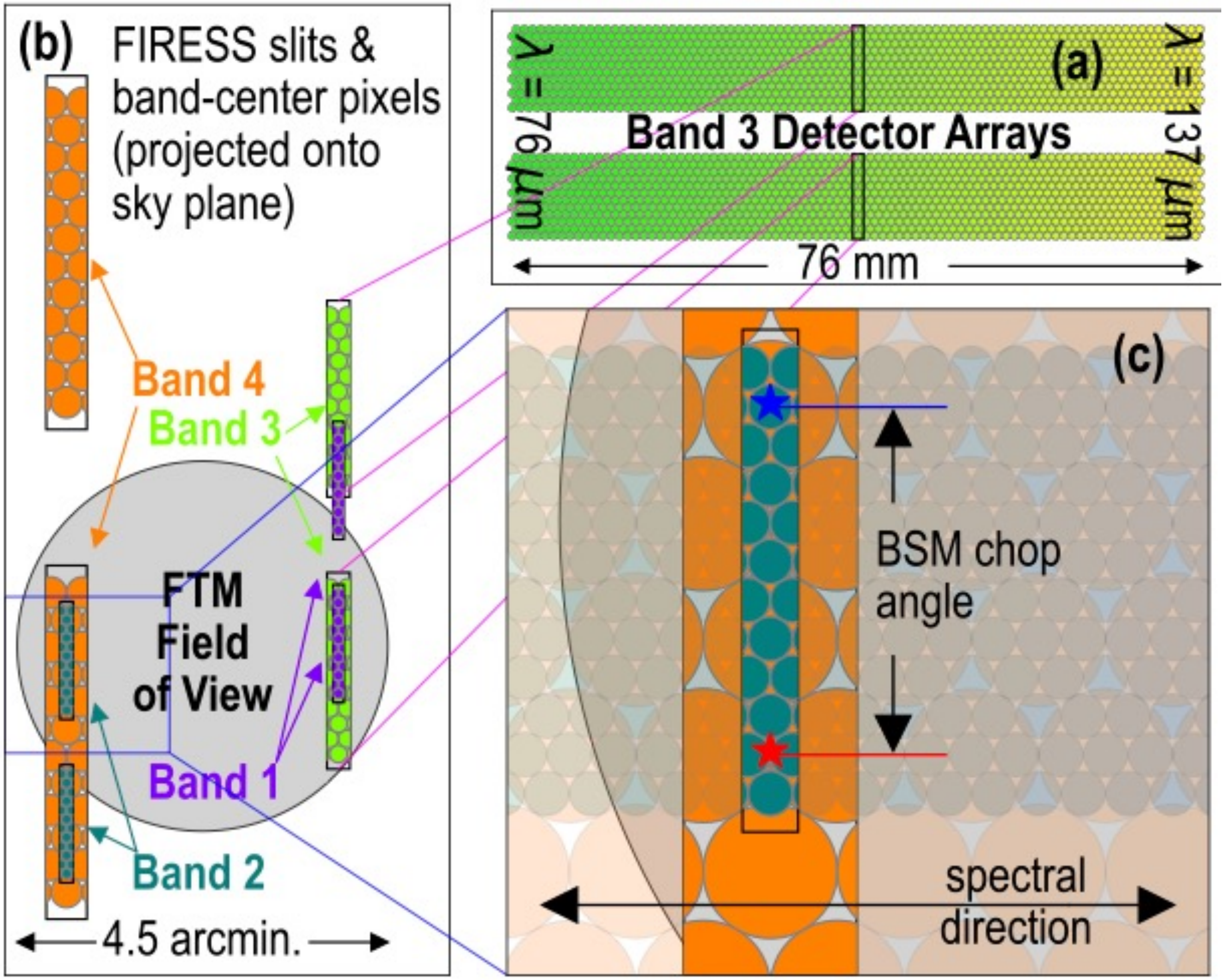

42 arcmin.
BSM Scan Field of View
16 arcmin.
11 arcmin.
24 arcmin.
PPI1
91 μm
232 μm
PPI4
PPI2
125 μm
165 μm
PPI3
25 47
PHI1
PHI2
47 80 μm
Polarimetric Imager
Hyperspectral Imager
NGC 6946
Herschel/SPIRE 250 μm
polarization sensing directions shown
spectral direction

FIRESS (JPL)

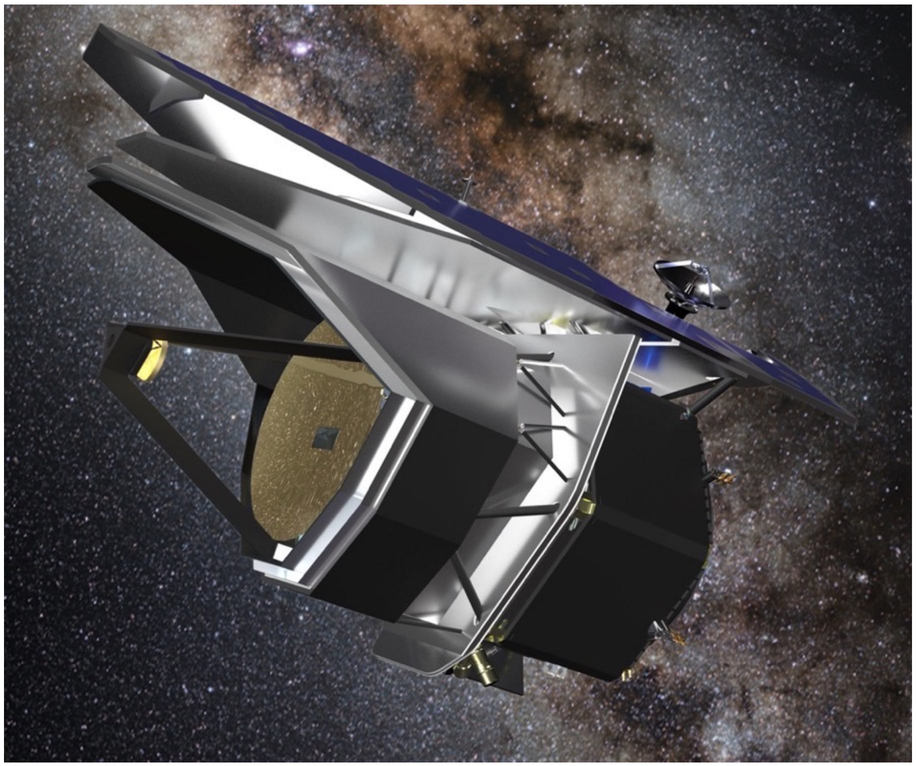
- 4 slit-fed grating modules giving R ~ 100, greater than 85 everywhere (including sampling and grating intrinsic R)
- 2 pointings for full spectrum of a source, though all 4 bands read out.
- High-res mode (with Fourier Transform module) providing $R = 4{,}400 \times (112\mu m/\lambda)$

Parameter	Band 1	Band 2	Band 3	Band 4
Spectral range (μm)	24–43	42–76	74–134	130–235
Spectral sampling (μm)	0.23	0.41	0.73	1.29
Resolving power	95-150	85-120	90-125	95-130
Array format per band	24 spatial ×84 spectral pix, 900-μm pitch			
Pix size on sky (arcsec)	7.6		12.7	22.9
Pix pitch ratio to B1,2	-		5:3	3:1




(b) FIRESS slits & band-center pixels (projected onto sky plane)
Band 4
Band 3
FTM Field of View
Band 1
Band 2
4.5 arcmin.
(a)
Band 3 Detector Arrays
λ = 76 μm
λ = 137 μm
76 mm
(c)
BSM chop angle
spectral direction

PRIMA



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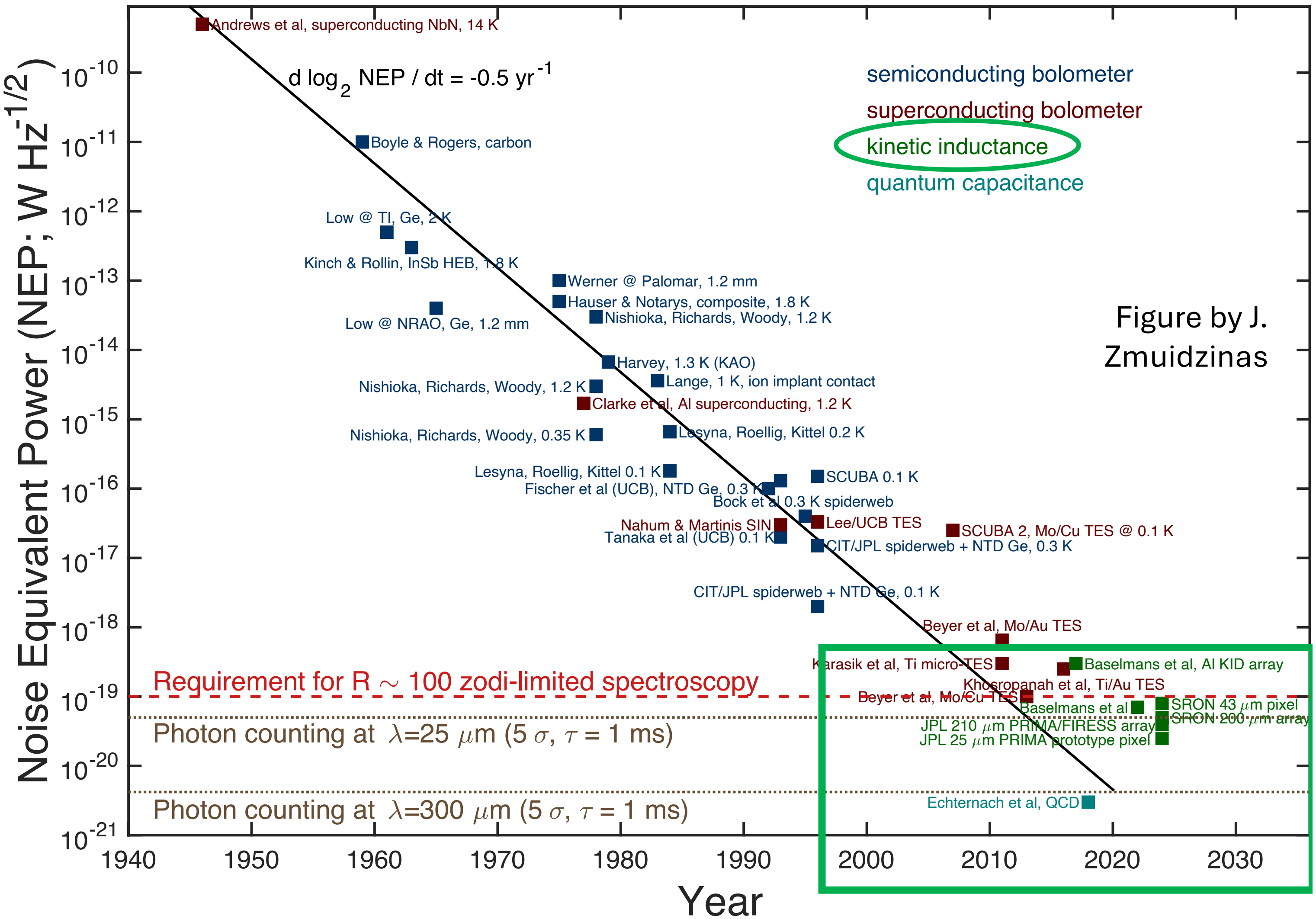
Why Now?

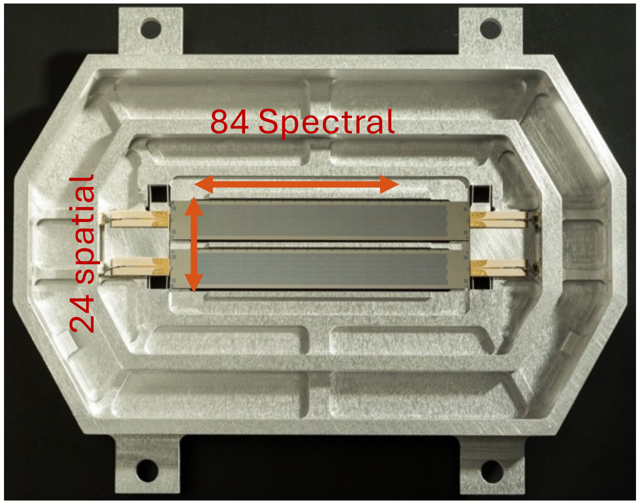
→ Far-IR Detector Technology

Sensitivities of far-IR detectors have doubled every ~2 years for 75 years!

PRIMA detectors exceed performance requirements over the full wavelength range.

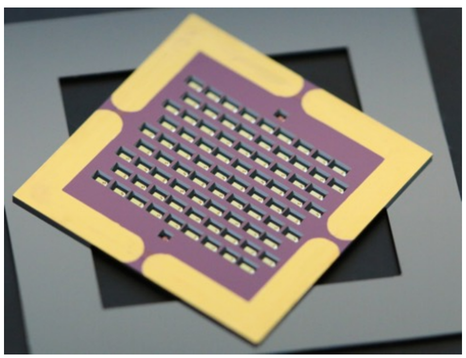


KIDs: Culmination of 2 Decades of Technology Investment

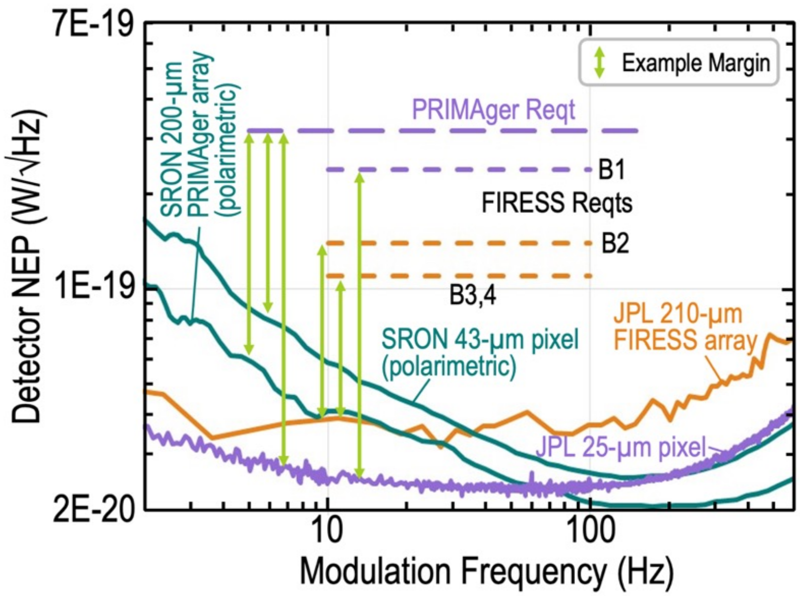


JPL FIRESS prototype KID arrays with GSFC microlenses

SRON polarimetric KIDs (derived from SPACEKIDs effort for SPICA)

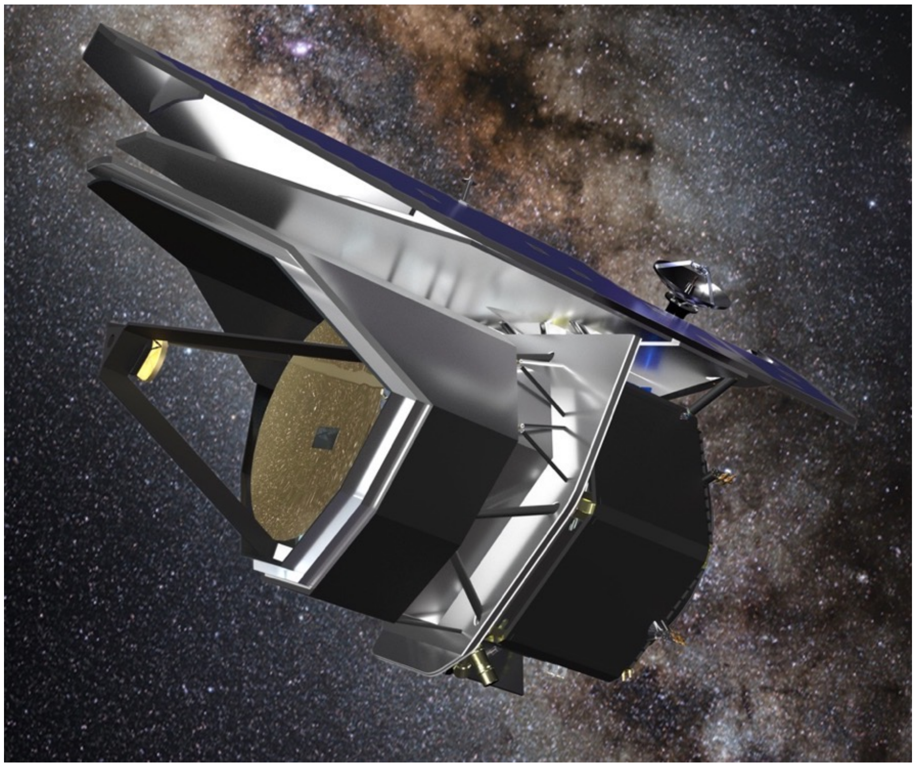


Prototype KIDs meet PRIMA requirements



25 μm result: Day+ 2024, Phys Rev X

PRIMA



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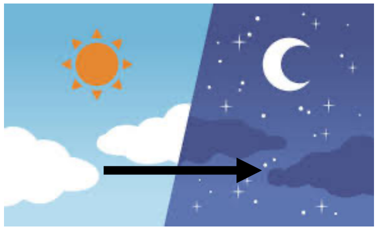
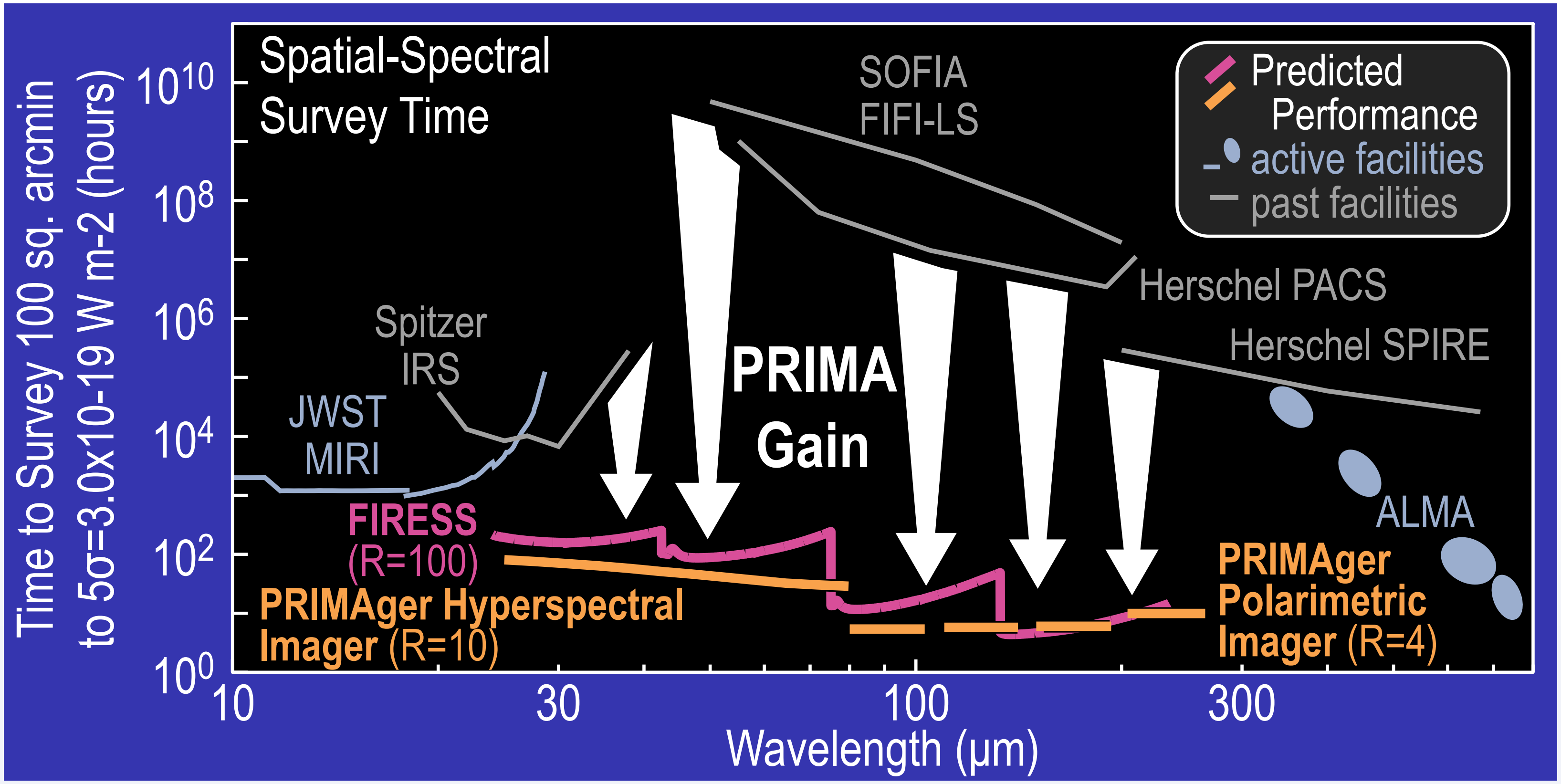
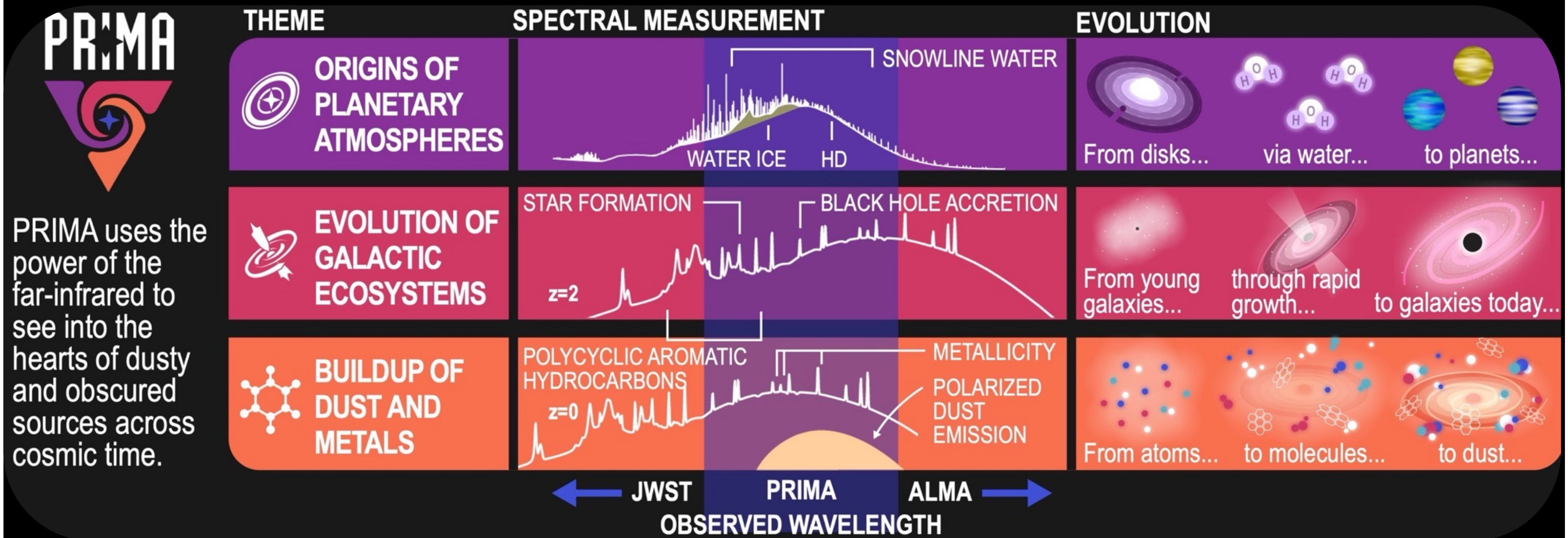
PRIMA makes massive gains in sensitivity



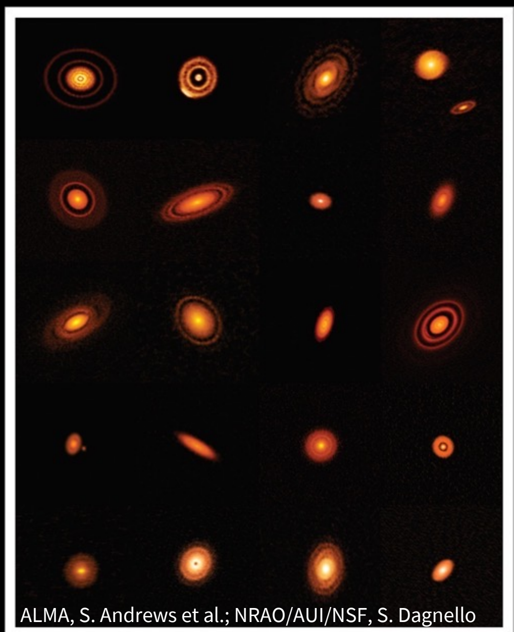


PRIMA PI science

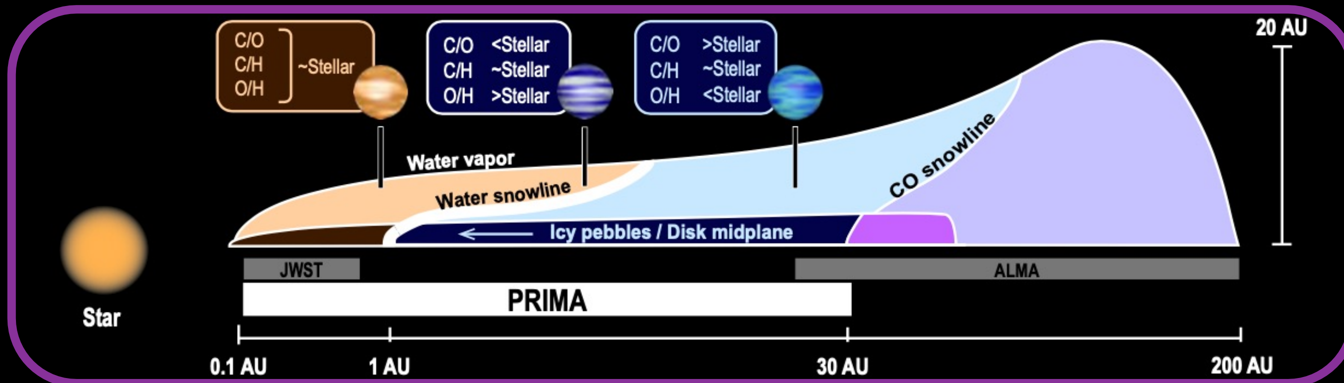


ORIGINS OF PLANETARY ATMOSPHERES

Protoplanetary disk structure is linked to the formation of exoplanets

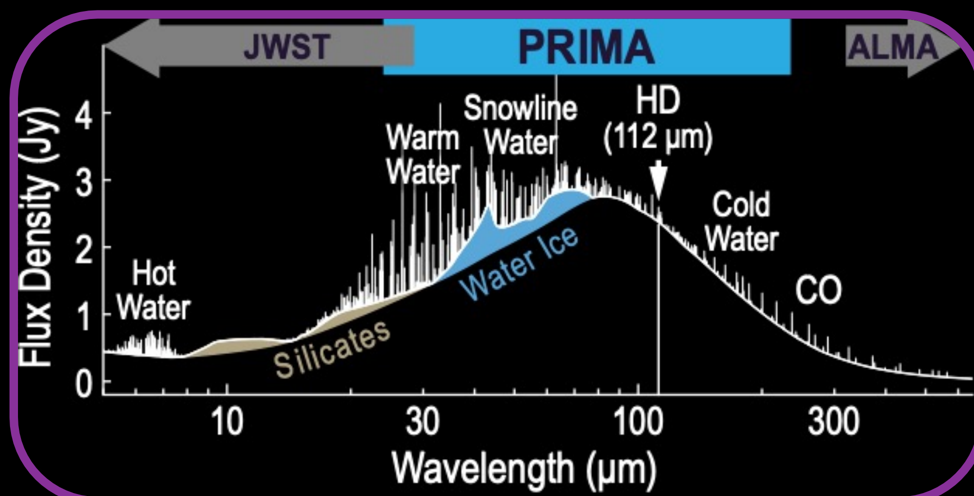


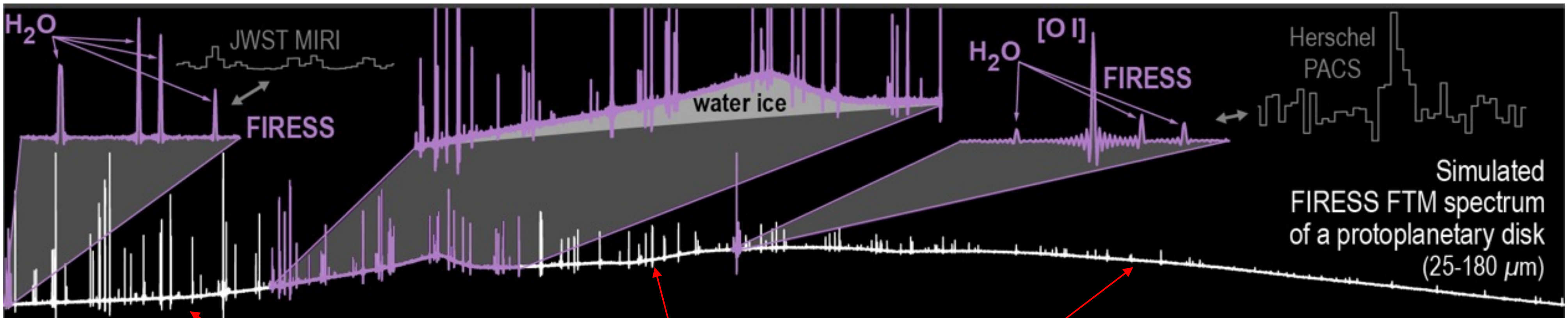
ALMA, S. Andrews et al.; NRAO/AUI/NSF, S. Dagnello



Unknowns and uncertainties

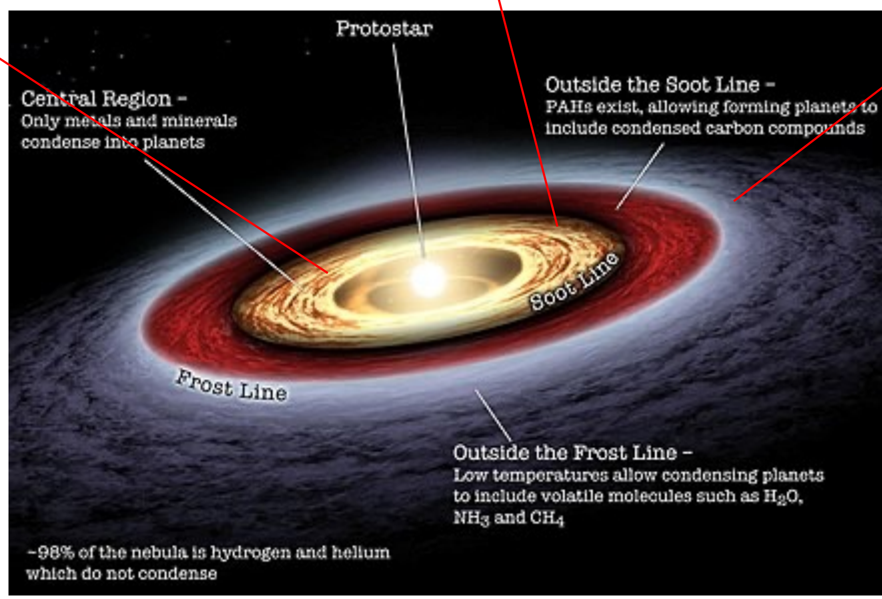
- Disk masses
- Elemental abundances
- Water vapor content and distribution

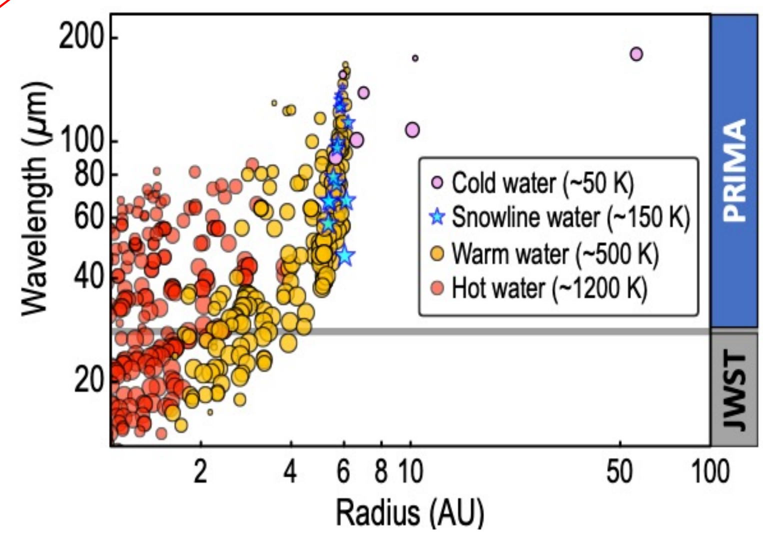




24 mu

180 mu



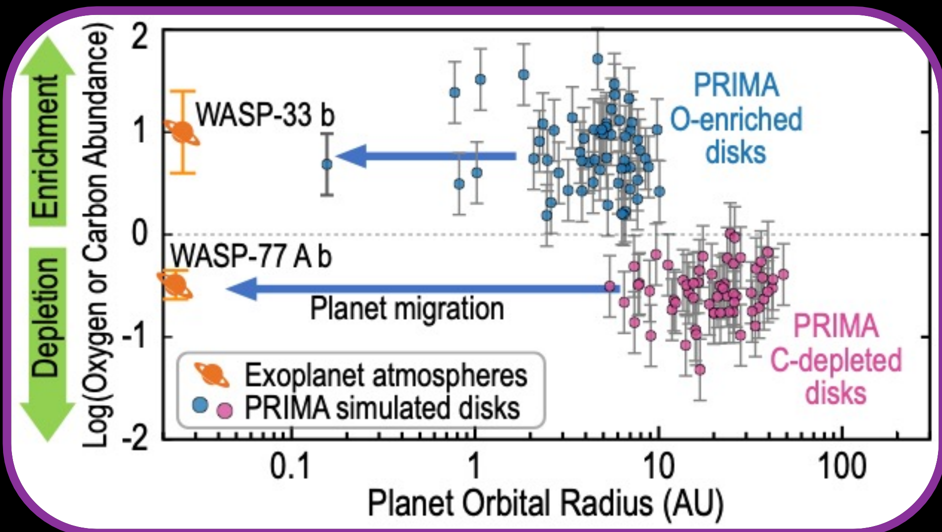


PRIMA
Disk Observations

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

ORIGINS OF PLANETARY ATMOSPHERES

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



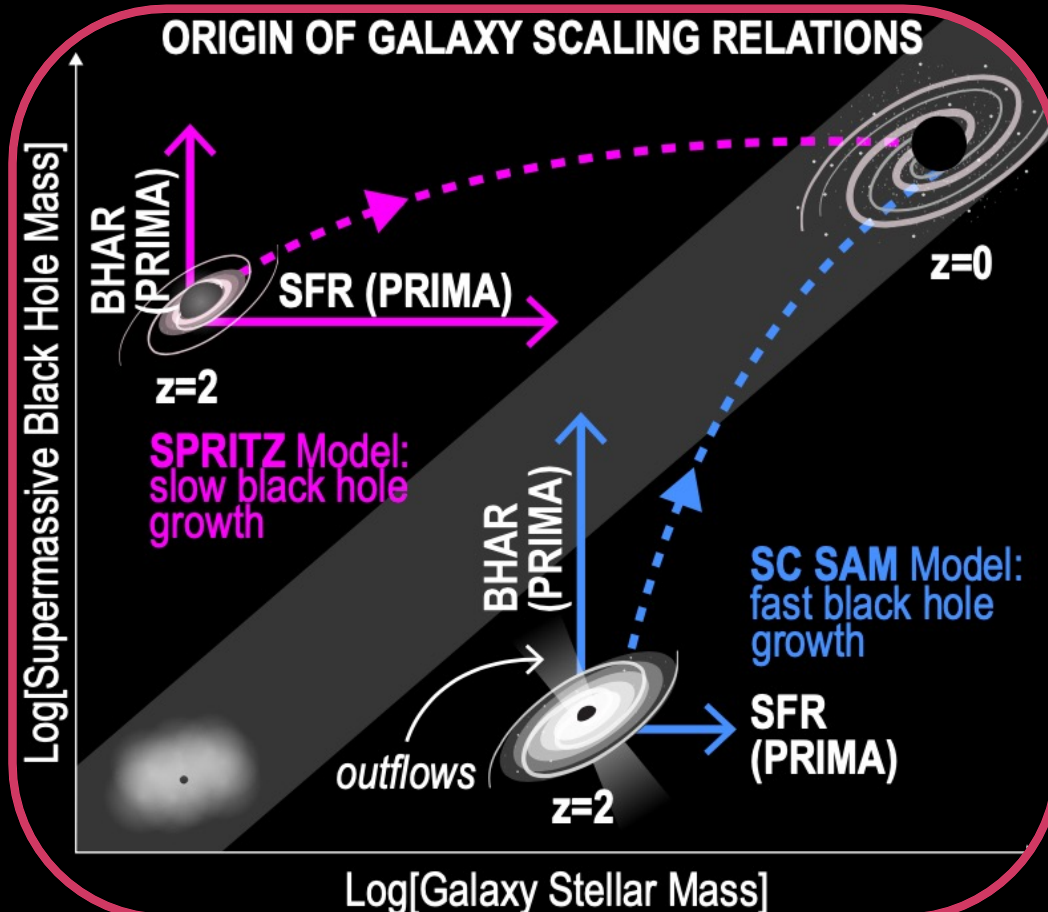
PRIMA's disk survey simulated as two sub-samples with expected error bars.

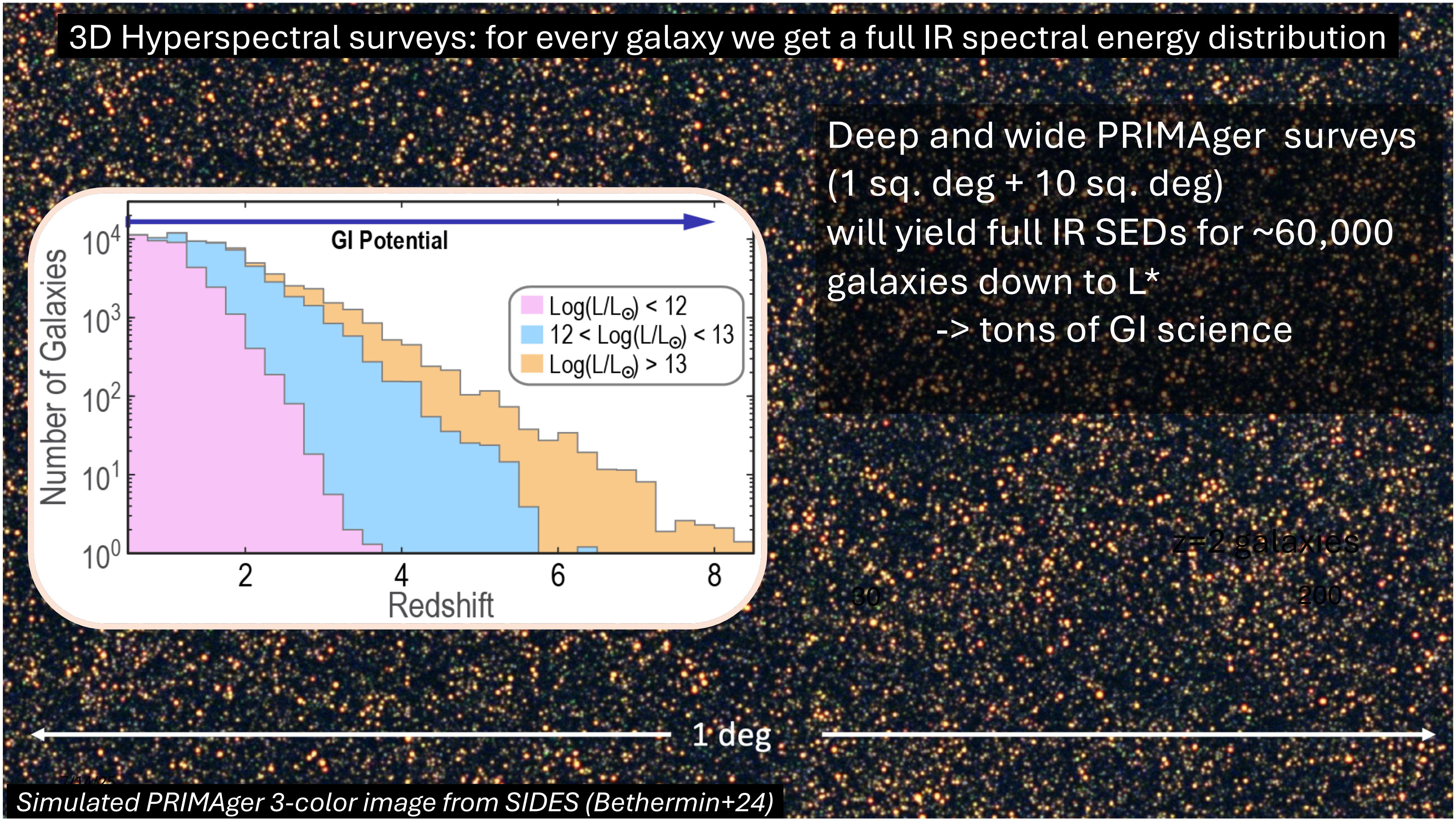
- H_2 mass derived from HD (112 μm), temperatures from existing ALMA CO or CI
- Oxygen derived from water (PRIMA) and carbon from existing CO ALMA observations
- 200 disks of various ages

EVOLUTION OF GALACTIC ECOSYSTEMS

How do supermassive black holes and their host galaxies coevolve?

PRIMA will measure the black-hole accretion rates and star-formation rates in luminous galaxies since the peak epoch to map their pathway onto the local M_{star}-M_{BH} relation



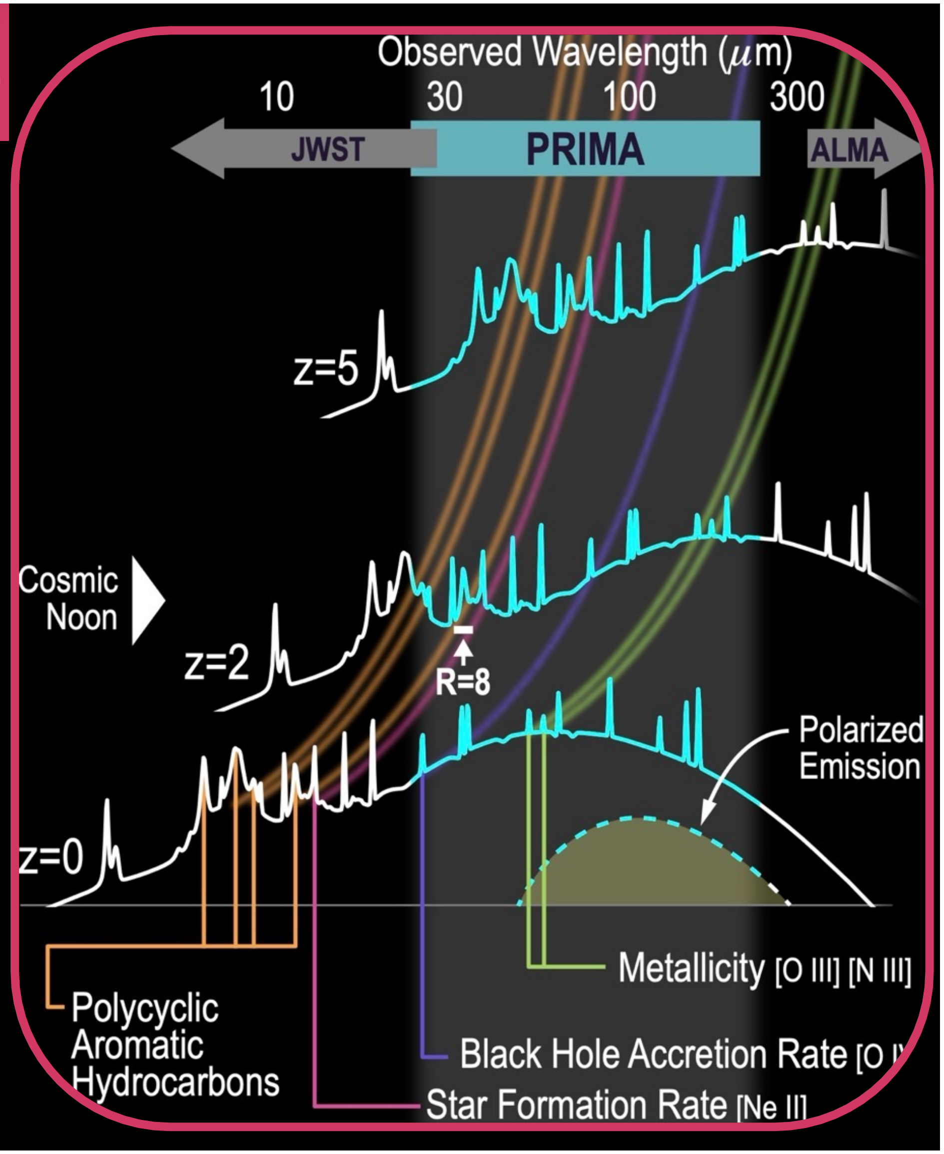

3D Hyperspectral surveys: for every galaxy we get a full IR spectral energy distribution
Deep and wide PRIMAger surveys
(1 sq. deg + 10 sq. deg)
will yield full IR SEDs for ~60,000
galaxies down to L*
-> tons of GI science
GI Potential
Number of Galaxies
10^4
10^3
10^2
10^1
10^0
2
4
6
8
Redshift
$\mathrm{Log}(L/L_\odot) < 12$
$12 < \mathrm{Log}(L/L_\odot) < 13$
$\mathrm{Log}(L/L_\odot) > 13$
z=2 galaxies
30
200
1 deg
Simulated PRIMAger 3-color image from SIDES (Bethermin+24)

EVOLUTION OF GALACTIC ECOSYSTEMS

Mid-infrared spectra provide unique signatures of:

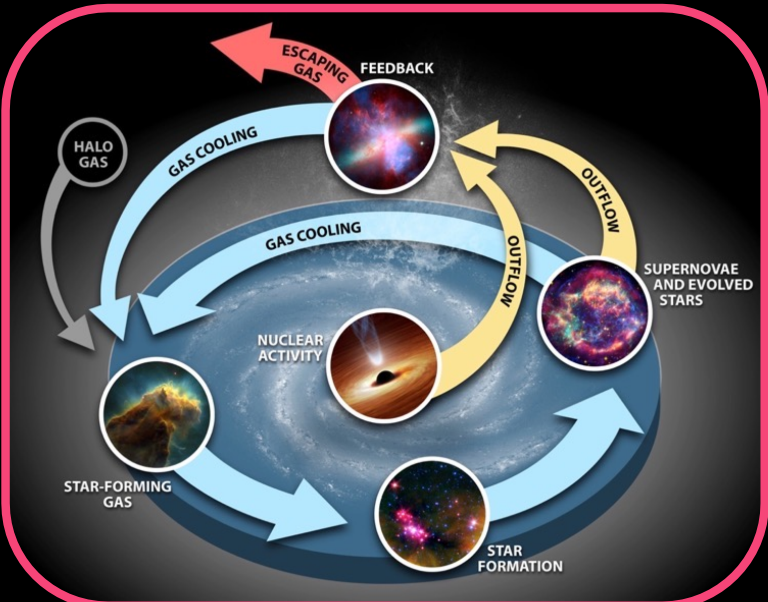
- black hole accretion rate (BHAR)
- star formation rate (SFR)

which shift into the far-IR with redshift

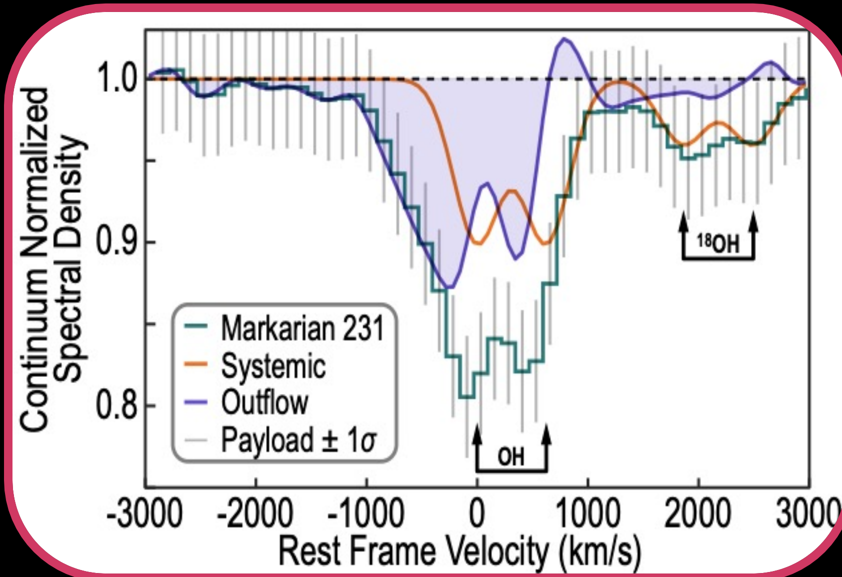


EVOLUTION OF GALACTIC ECOSYSTEMS

What is the role of outflows?



Outflows could be the link between star formation and black hole accretion



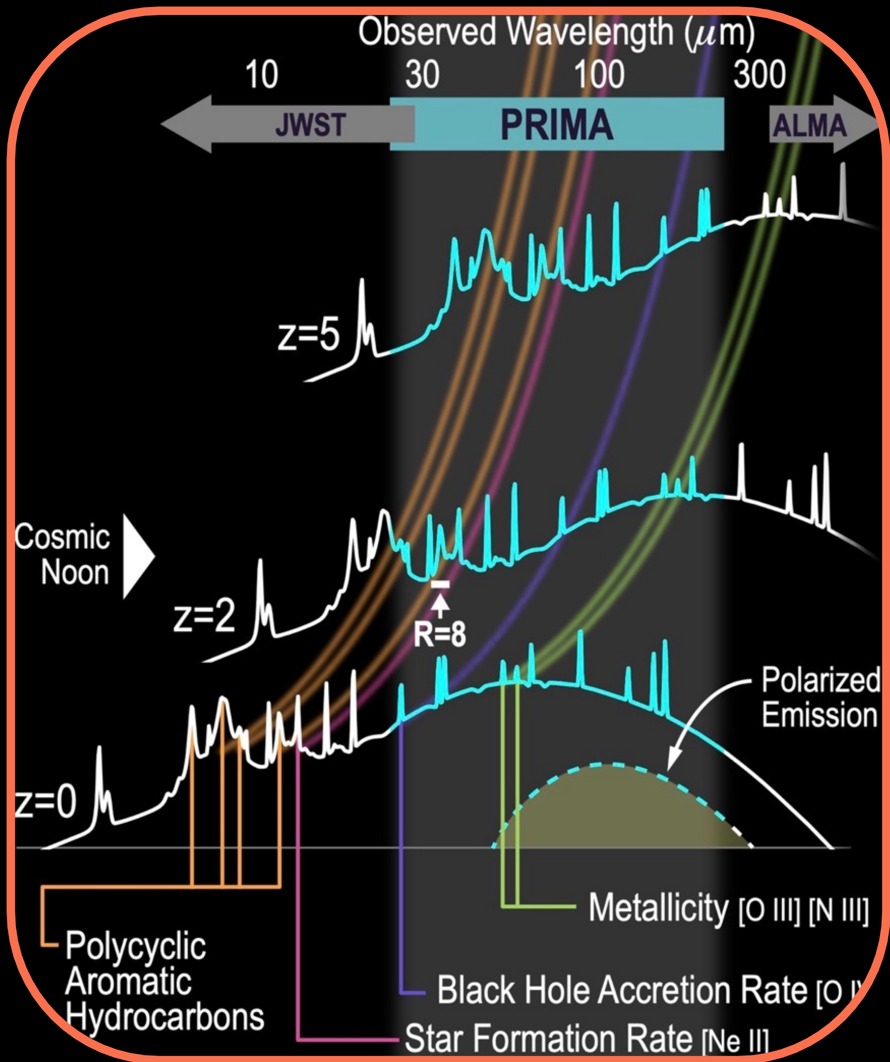
PRIMA/FIRESS high res: OH doublet absorption features (here 84 μm @ z=1.5; also 61, 71, 79 μm)

-> measure outflow velocity and mass

BUILDUP OF DUST AND METALS

Mid-infrared spectra provide crucial diagnostics of:

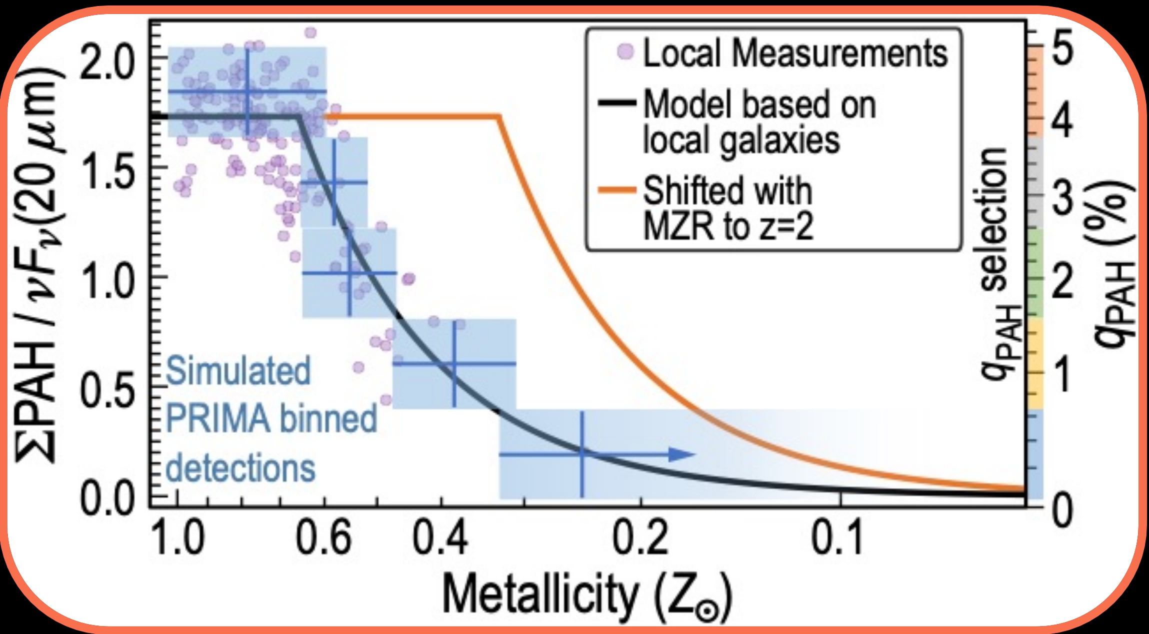
- dust properties (polarized emission)
- metallicity (FIR fine structure lines and PAHs)



BUILDUP OF DUST AND METALS

Has the relationship between PAHs and metals evolved since cosmic noon?

In the local universe, there a decrease in PAH emission at lower metallicities.



PRIMA/FIRESS will observe 100 z=2 galaxies to measure:

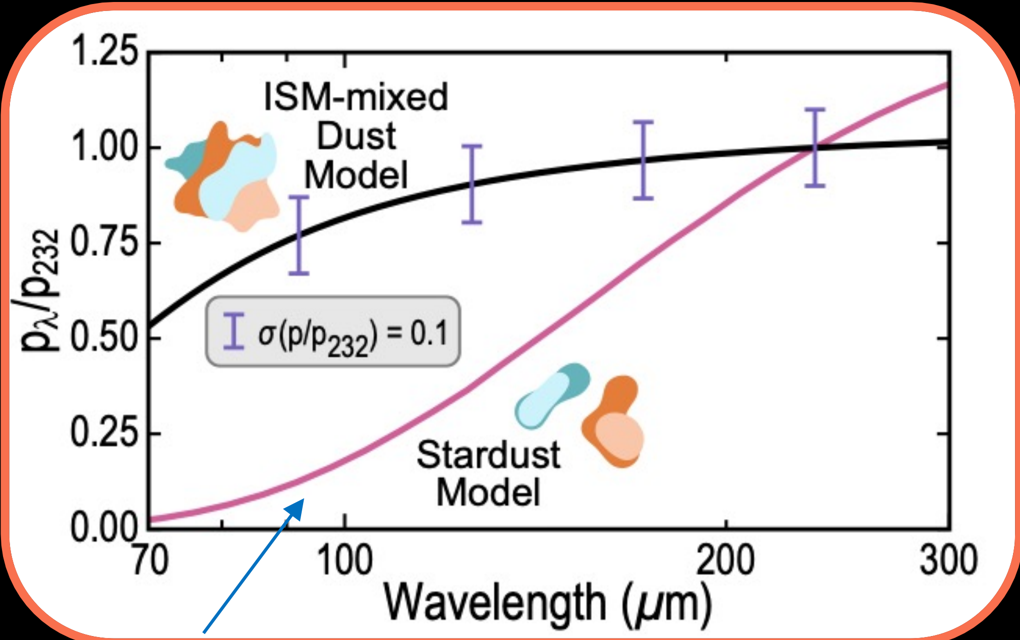
- Gas-phase abundances of O and N via [O III], [NIII]
- q_{PAH} from rest-frame 11.3 and 12.7 μm bands

See Whitcomb et al. 2024

BUILDUP OF DUST AND METALS

Interstellar Dust Grain Growth

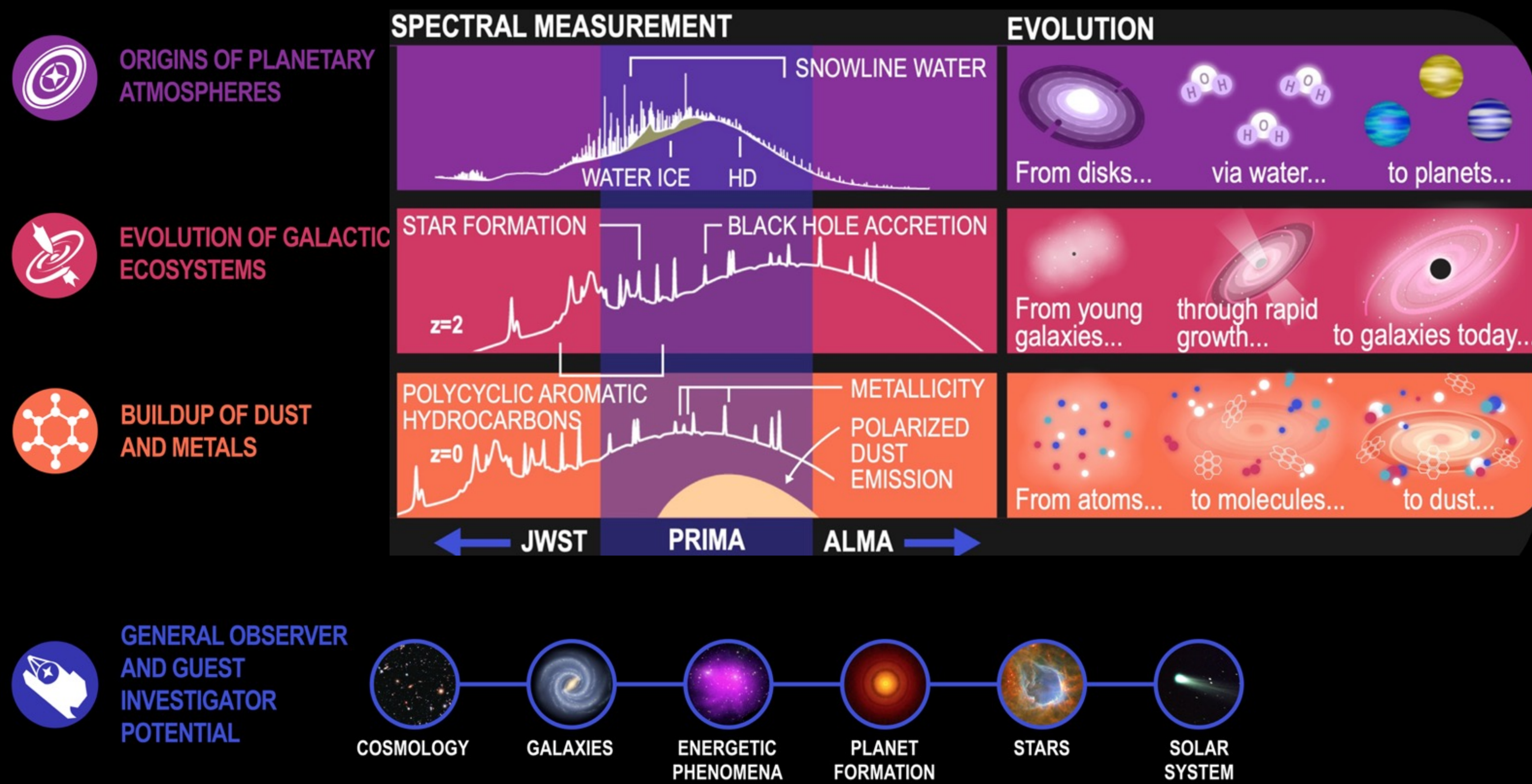
How does the structure of interstellar dust change across environments in the local universe?



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.
- PRIMA will test if ISM grain growth rates are suppressed in low-metallicity galaxies/environments by imaging 31 local galaxies from 91-232 μm with polarization

PRIMA addresses Astro2020's 3 science goals for a far-IR probe <u>and</u> opens vast discovery space for the community



PRIMA is designed primarily as community resource

- **75% of observing time for general observer (GO) programs** -> ~ 32,000h over 5 years
- PI surveys producing high-impact legacy datasets for archival research (Guest Investigator [GI] science)
- Archive with access to all science and calibration data, software

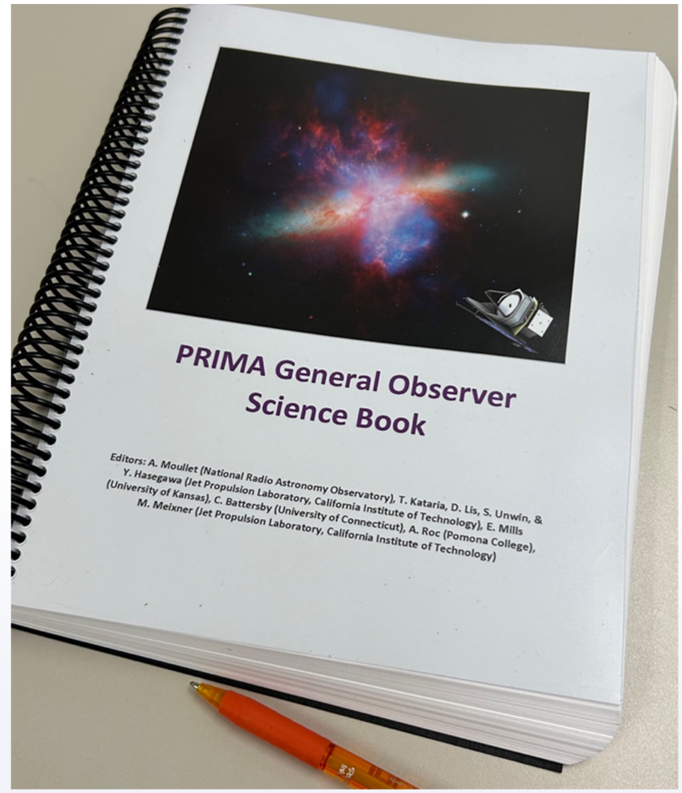
Astro2020 Science Panel	Astro2020 Questions addressed	# GO Science Book cases
Compact Objects and Energetic Phenomena (Appx. B)	B-Q2, B-Q3, B-Q4, B-DA	9
Cosmology (Appx. C)	C-Q2, C-Q3, C-Q4	3
Galaxies (Appx. D)	D-Q1, D-Q2, D-Q3, D-Q4, D-DA	31
ExoAstroSolar (Appx. E)	E-Q1, E-Q2, E-Q3	3
ISM & Star/Planet Formation (Appx. F)	F-Q1, F-Q2, F-Q3, F-Q4	25
Stars, the Sun, and Stellar Populations (Appx. G)	G-Q1, G-Q2, G-DA	5

Most of PRIMA's scientific impact will come from community-led studies (GO, GI). Based on PRIMA GO Science Book, Vol 1, GO program can address >70% of Astro2020 science questions

To develop a concept that is most responsive to community needs, PRIMA continues to solicit community engagement in phase A

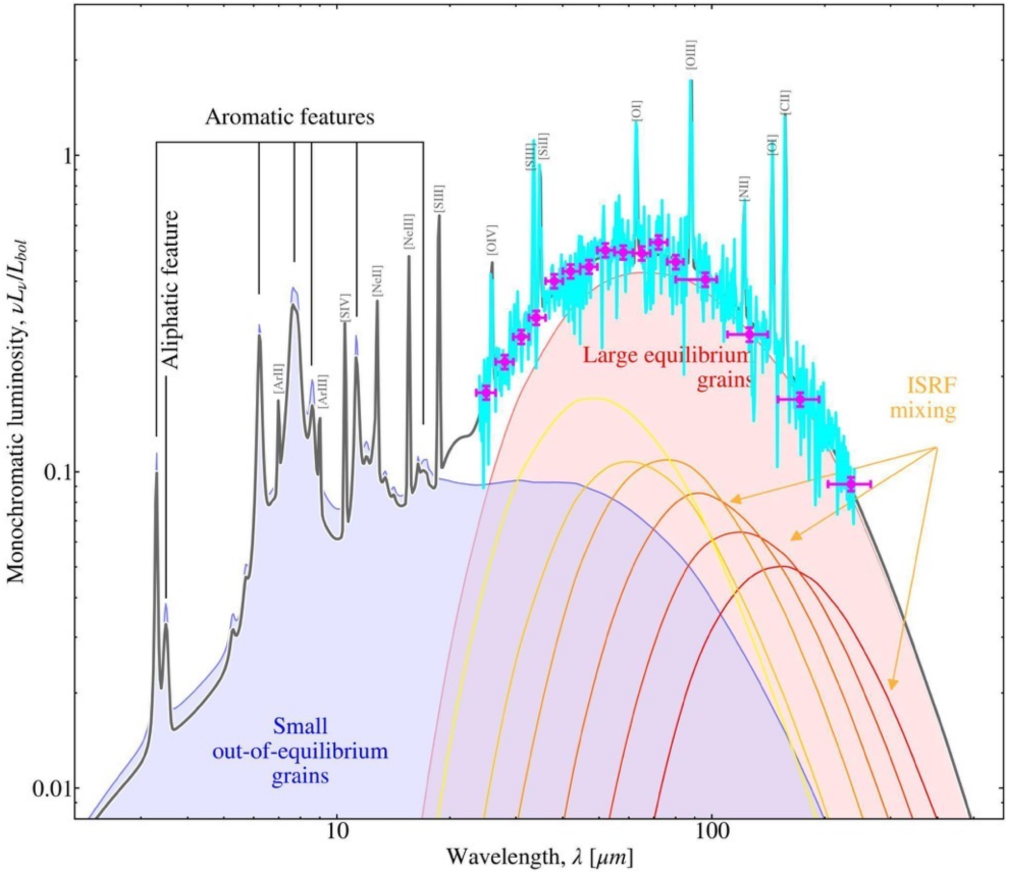
PRIMA GO Science Book Volume 1

- Volume 1 published on ArXiv in November 2023 (arXiv:2310.20572)
- Collection of 76 community-contributed cases, spanning scientific areas from comets to high-z polarimetry
- Volume 1 totals about ~21,000 h of observations, or **about 65% of the expected time available for GO observations.**
- Approximately use requests for PRIMAger (35% of cases), FIRESS (32%) or both instruments (32%).

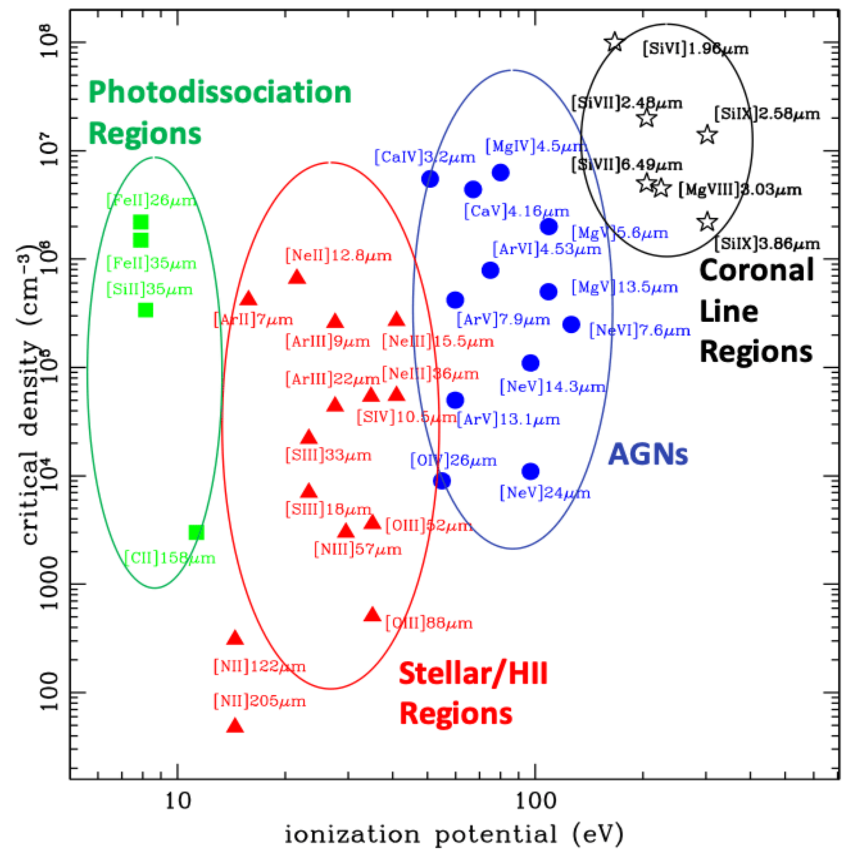


Thank you to all case writers!

Milky Way and Nearby Galaxy Studies: Photodissociation Regions and Dust

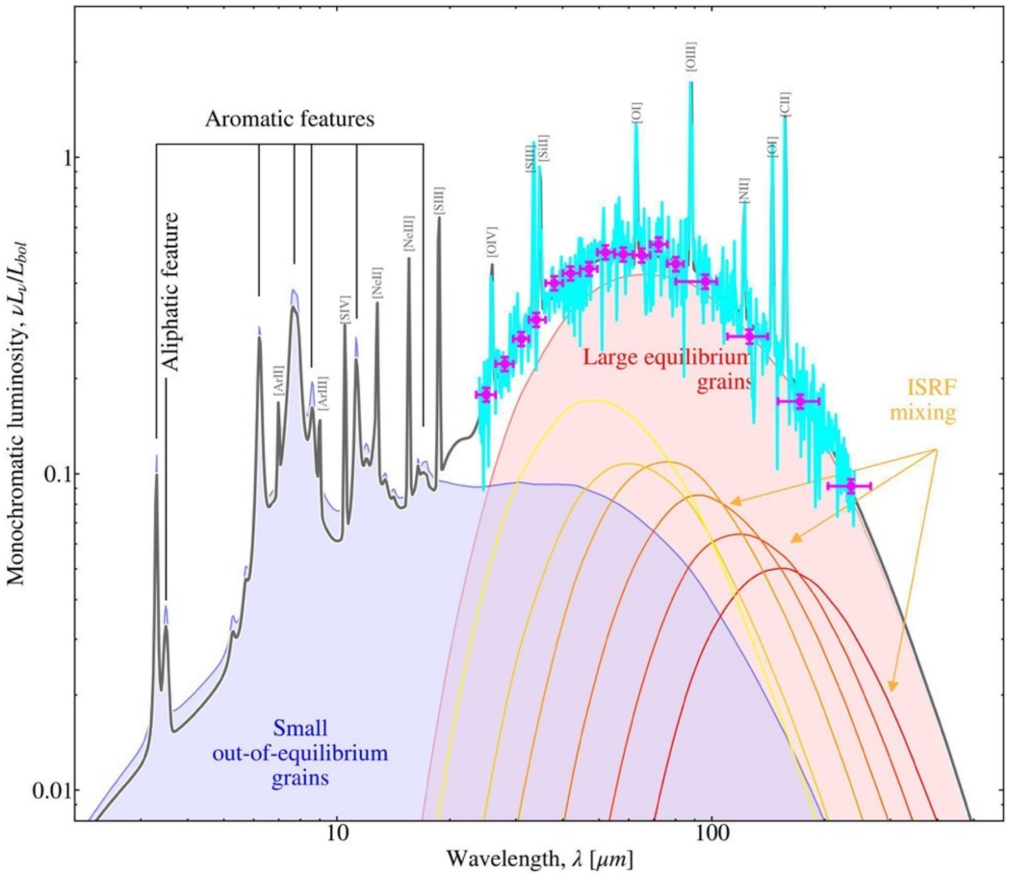


Galliano et al., 2023, PRIMA GO Book Vol. 1



Spinoglio et al. (2019)

Milky Way and Nearby Galaxy Studies: Photodissociation Regions and Dust

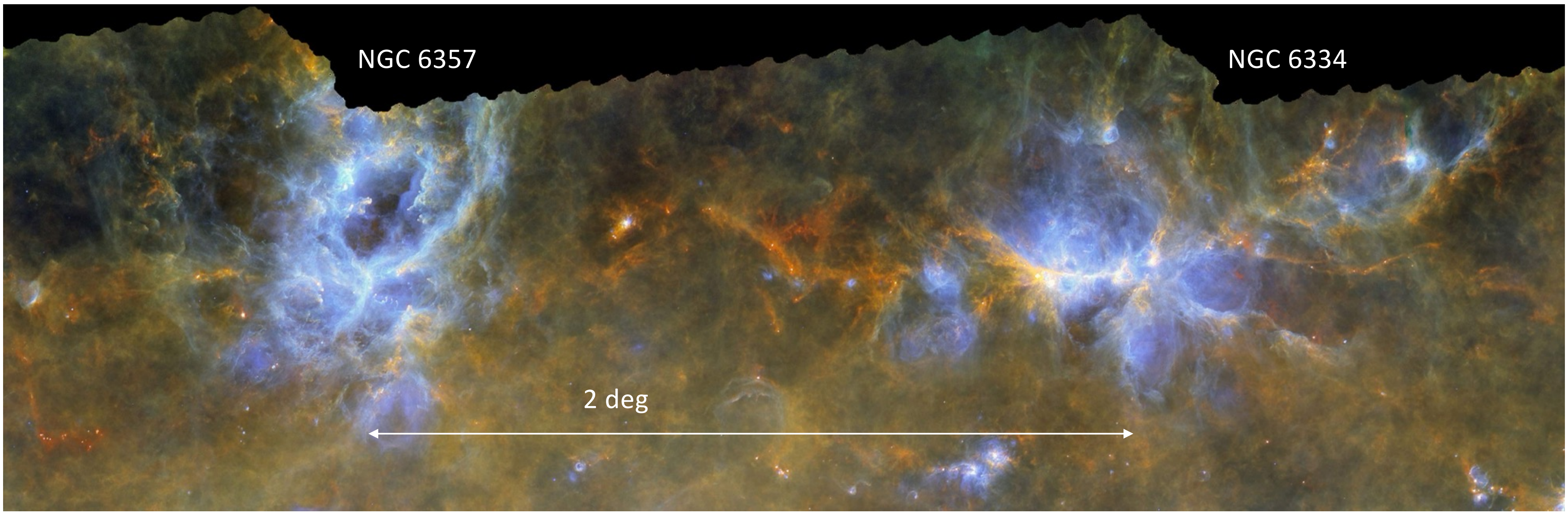


Galliano et al., 2023, PRIMA GO Book Vol. 1

- Far-infrared spectral line suite has a miriad of spectral line diagnostics to study the effects of Stellar and Galactic outflow feeback
- Continuum covers the peak of the dust SED
- FIRESS spectral mapping of
  - nearby galaxies (Galliano #47, Sutter et al. #62, Jacob #53,)
  - Circumgalactic medium (Bartlett #12, Tarantino #38)
  - MW interstellar medium (Goldsmith #50, Onaka #58,)
  - Feedback from high mass stars (Zavagno #67)
  - Galactic Center (Hatchfield #52)

Mapping of Milky Way Interstellar Medium

Herschel HiGal example

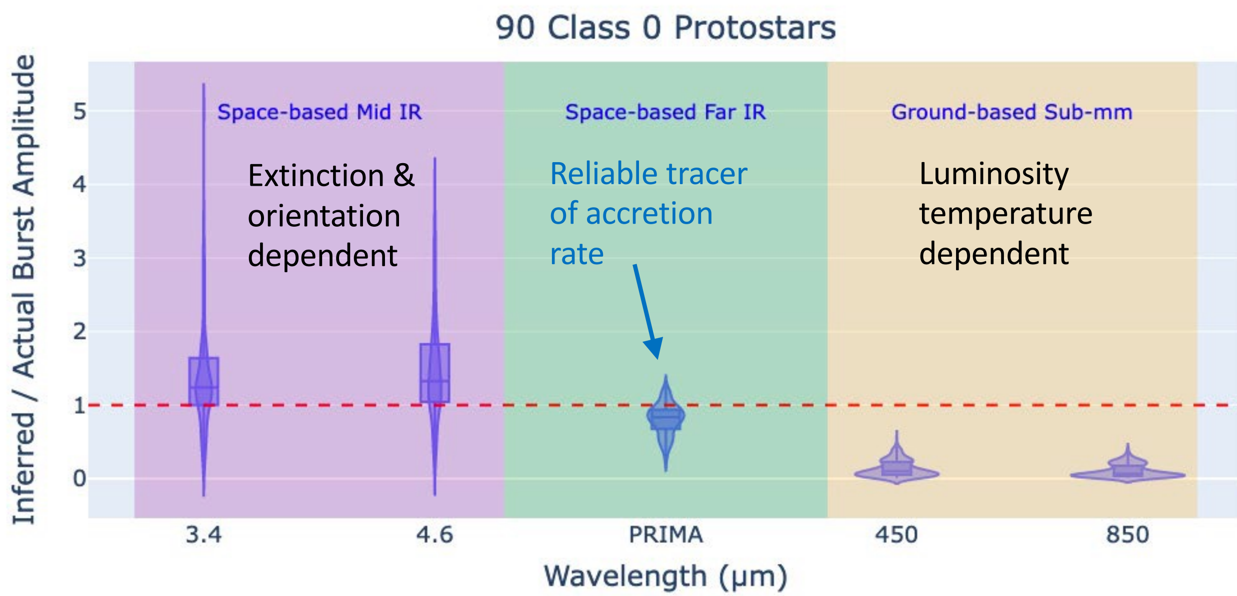


Molinari et al. ~2011

PRIMA FIRESS low res in 6 seconds: 7 mK x 30 km/s (5 sigma) (better in fainter regions.)
Can map CII and other bright fine structure transitions in sizeable regions of the Milky Way.

GO Science: How do stars get their mass?

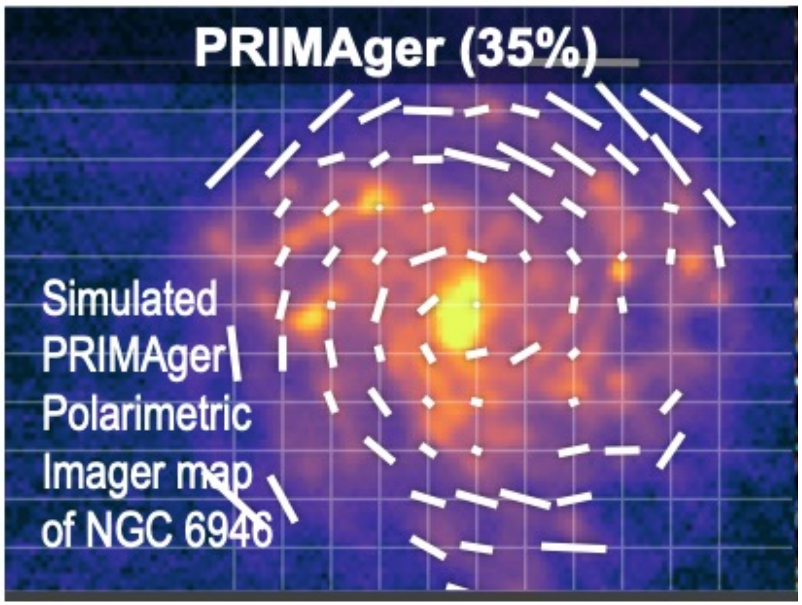
- Mass: *The* fundamental property of stars, but we do not know how they accrete their mass. Quiescent or episodic?
- Far-IR: Only wavelength for which luminosity correlates tightly with accretion rate.
- Test: >50% of mass is derived from rare events?
- Survey: 2000 protostars with cadences of 2 wks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



Battersby, et al., (#43, 2023, PRIMA GO Science Book)

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 #55; Louvet #56; Paré #59; Pattle #60)
  - 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 Book Volume 2 is now in preparation

Any member of the international astronomy community is encouraged to develop and submit a case for Volume 2. A great way to **contribute to the scientific development of the PRIMA concept, and be an active part of the PRIMA community**

- **Submission deadline (through Google form): May 31, 2025**
- Expected publication late Summer 2025
- Includes new and revised cases

Google Form for GO cases submissions

We are here to support contributors
Main contacts: Arielle Moullet (amoullet@nrao.edu), Denis Burgarella (denis.burgarella@lam.fr)
A team of editors + PRIMA team is available for general support

Are you considering submitting a new GO case? How to get started

	PRIMA Hyperspectral Imager	
Parameter	PHI1	PHI2
Wavelength (μm)	24-45	45-84
Spectral resolving power	10	10
Polarimetry	-	-
Band center FWHM (")	4.1	7.4
Pixel size (")	4.1	7.4
Pixel count	63×23	33×14
Field of view	3.6'×1.5'	3.6'×1.7'

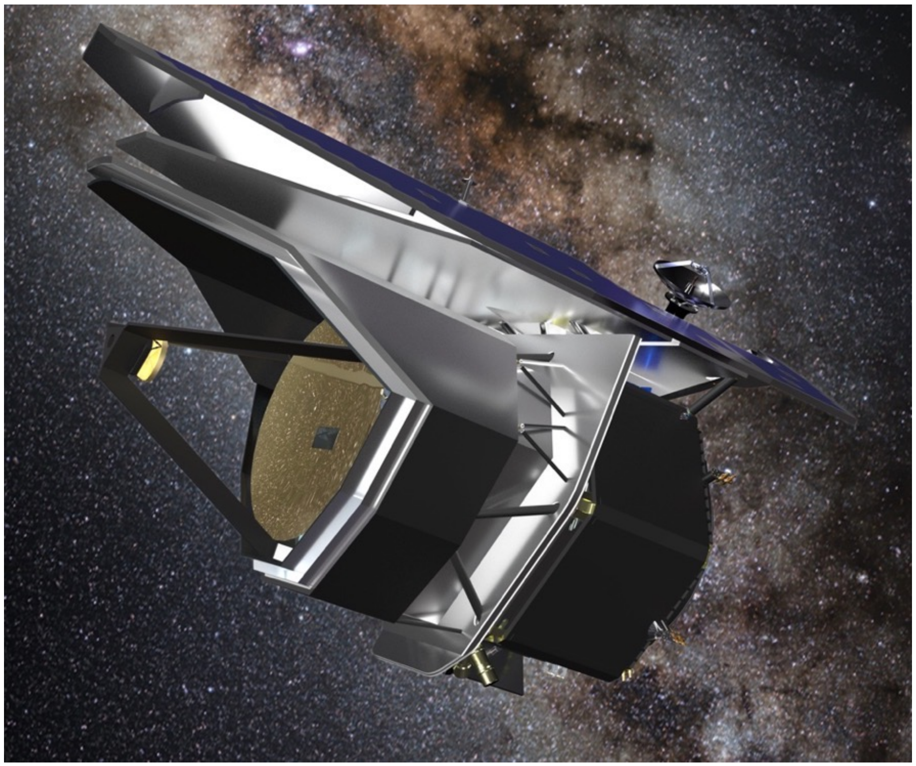
General guidelines:

- All observing modes available
- We are soliciting GO program observations up to 1000s of hours
- Contributions are ~3-8 pages, based on provided template

References

- GO Science Book Volume 1
- Instrument page/Fact Sheet/**Exposure Time Calculator**
- Upcoming PRIMA JATIS special section
- Science page for information on PI science. **Please reach out to editors if you think your idea is based on PI survey observations. We welcome archival (Guest investigator/GI) cases**

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 (112μm/λ)
Detectors	100 mK KID arrays (~12k total)
Data	IPAC
Orbit	Earth-Sun L2
Launch	2031
Observations	75% GO, 25% PI (→ GI)