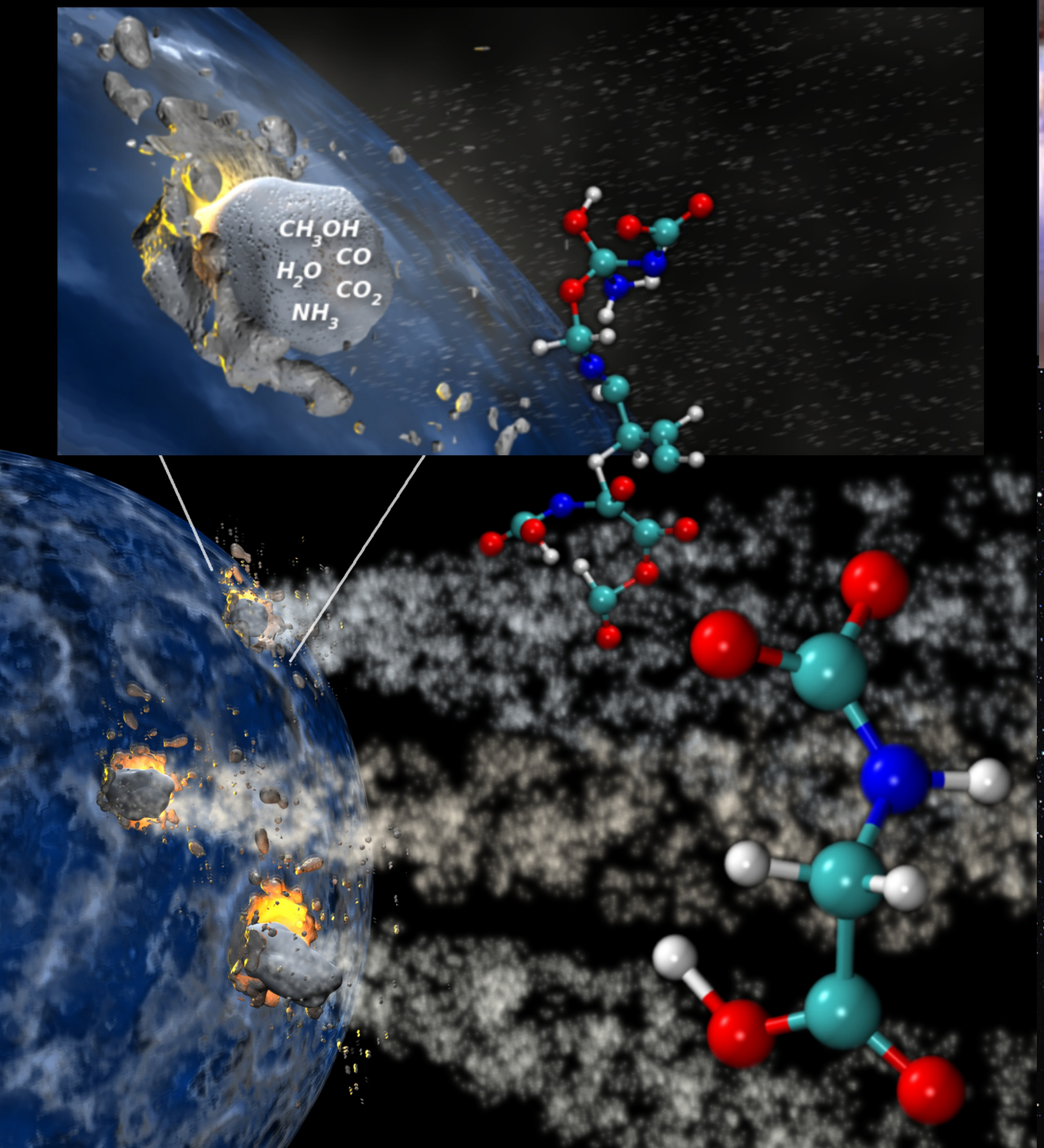
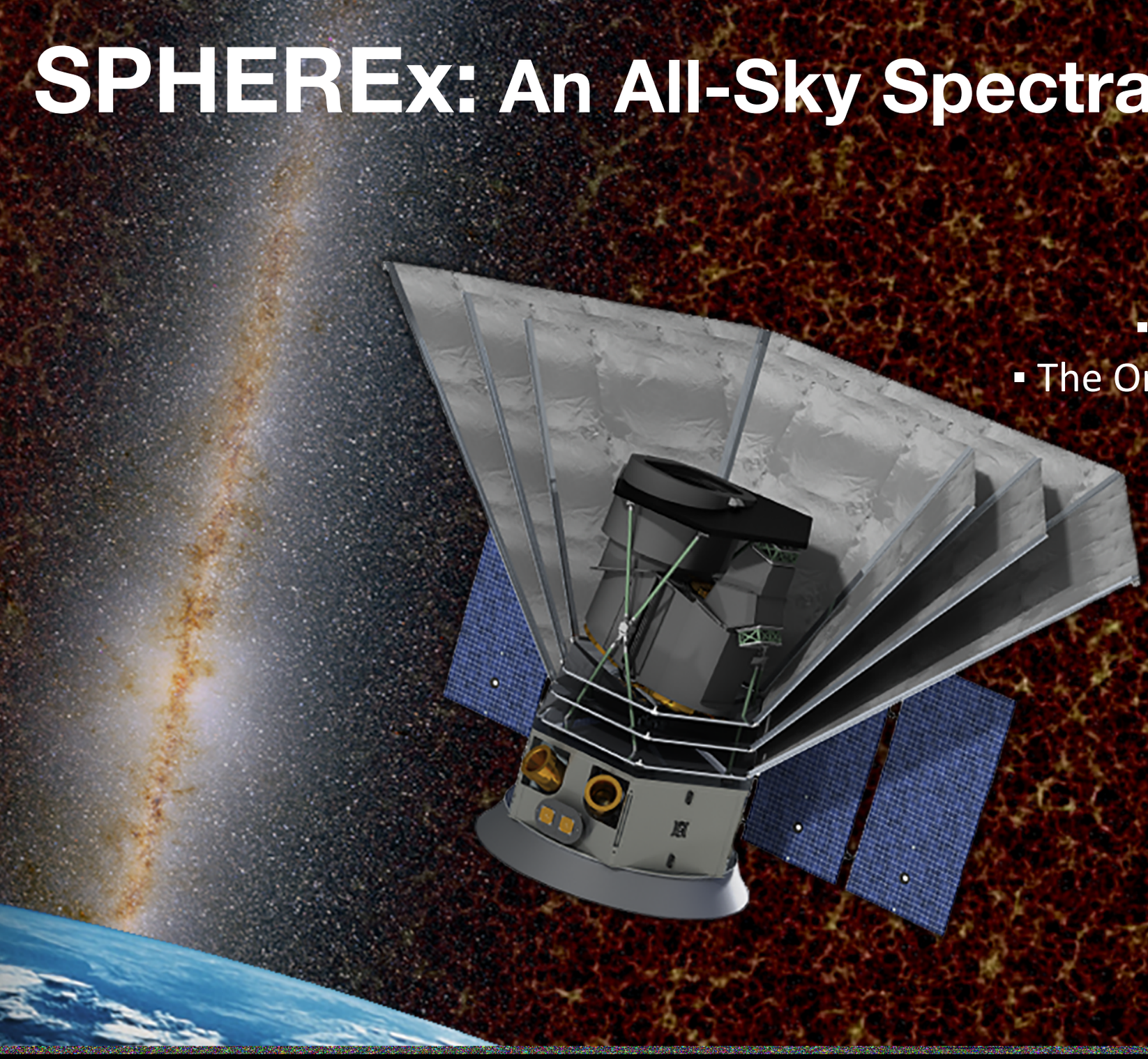
SPHEREx Ice Studies

Gary Melnick

Center for Astrophysics | Harvard & Smithsonian



SPHEREx: An All-Sky Spectral Survey



Designed to Explore

- The Origin of the Universe
- The Origin and History of Galaxies
- The Origin of Water in Planetary Systems

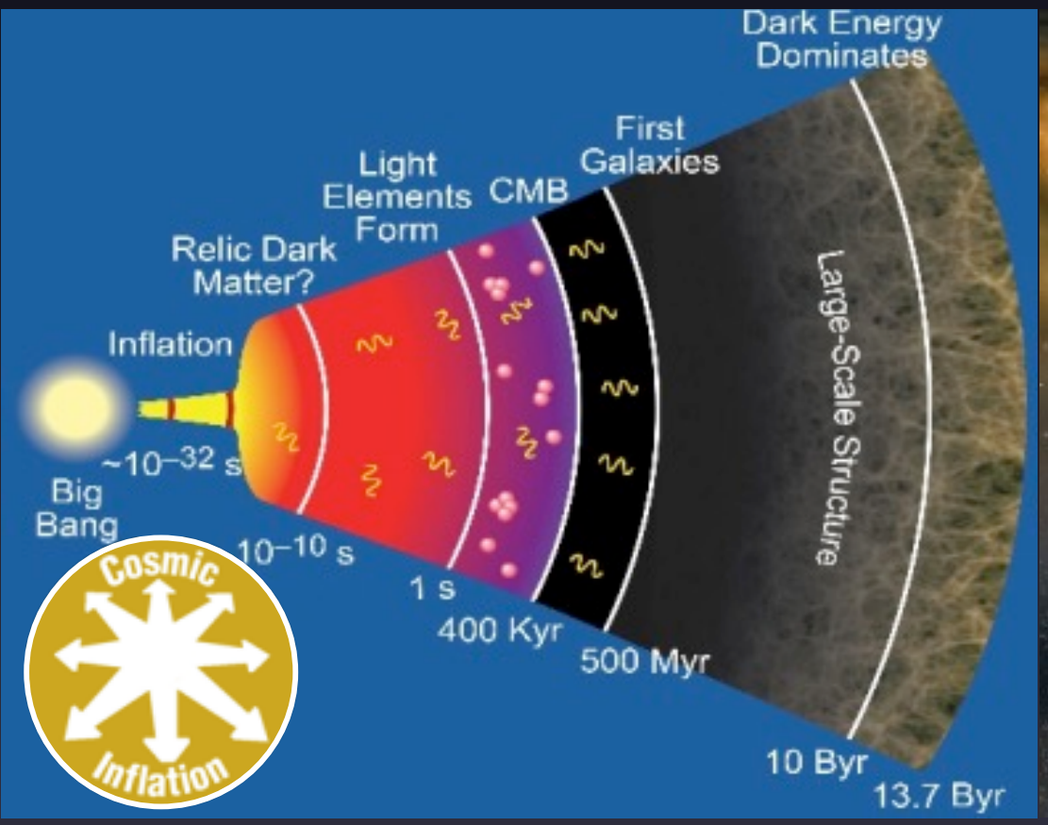
The First All-Sky Near-IR Spectral Survey

A Rich Legacy Archive for the Astronomy Community with 100s of Millions of Stars and Galaxies

Low-Risk Implementation

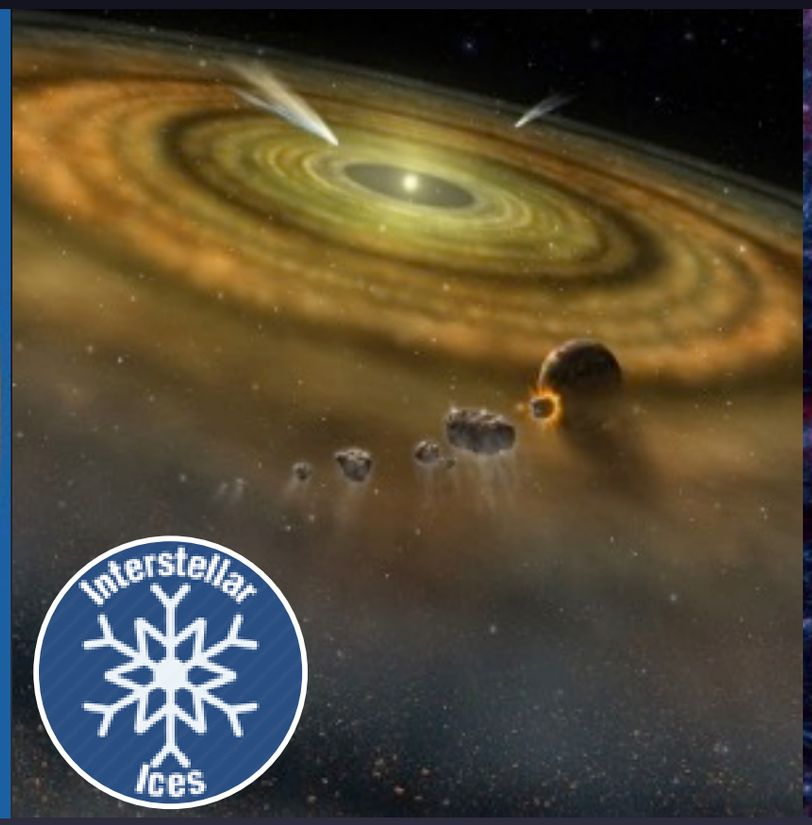
- Single Observing Mode
- No Moving Parts

SPHEREx: Major Science Themes



Probe the earliest epochs in the Universe's history

Jamie Bock, PI
Olivier Dore
Caltech



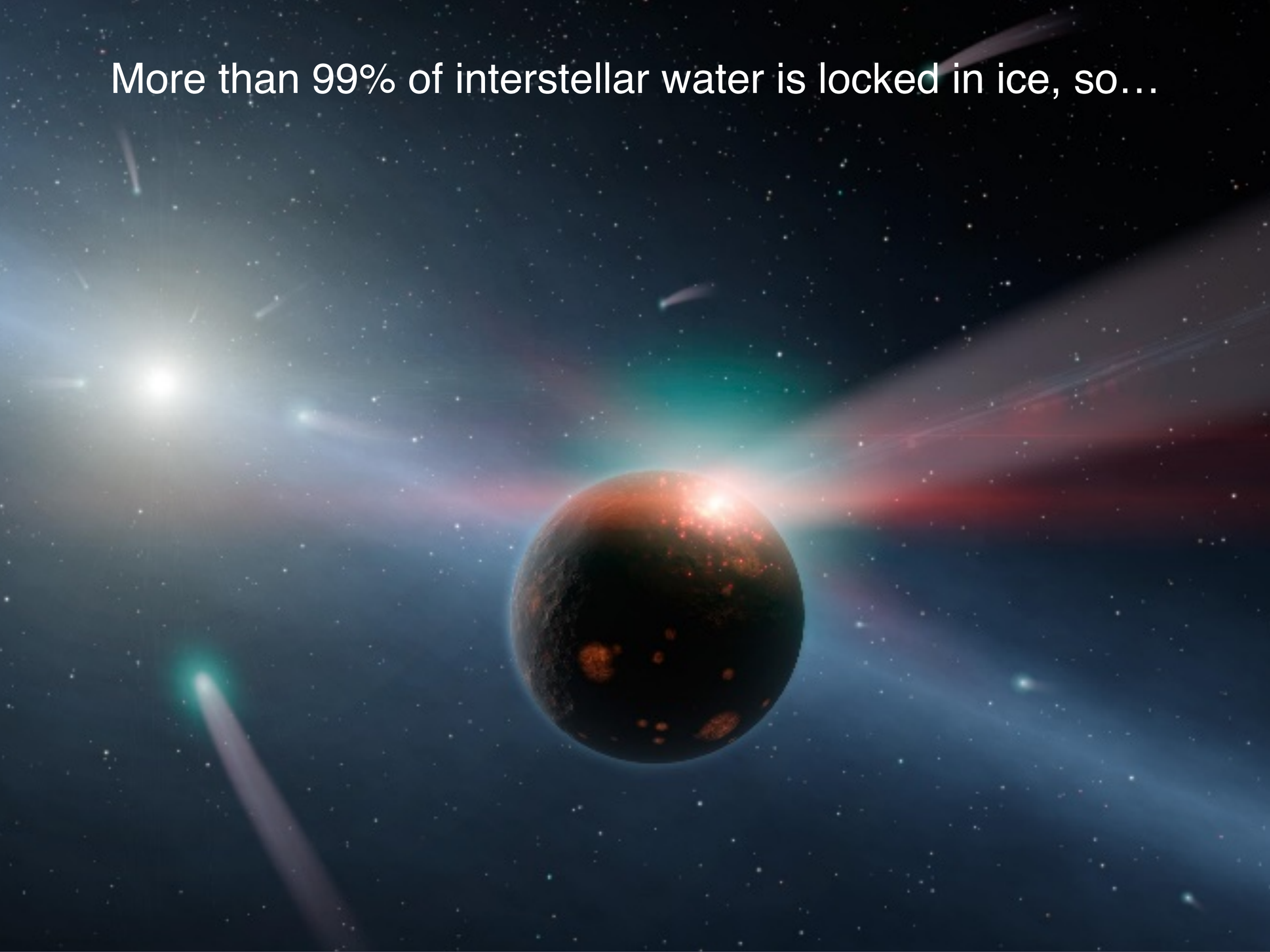
Survey the ice content throughout the Milky Way

Gary Melnick
Harvard & Smithsonian

Measure the history of light production and constrain galaxy formation

Asantha Cooray
UC, Irvine

More than 99% of interstellar water is locked in ice, so…



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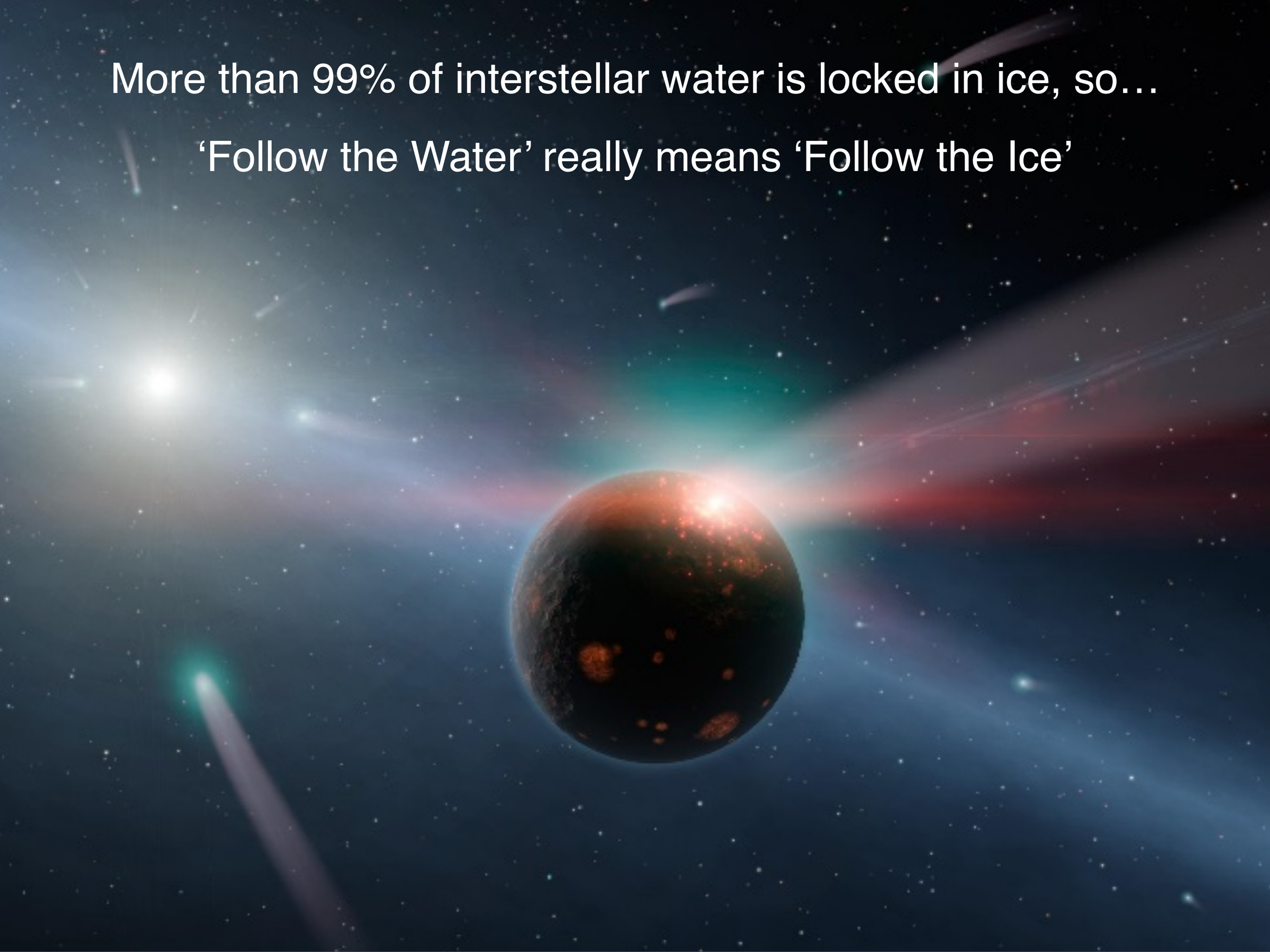
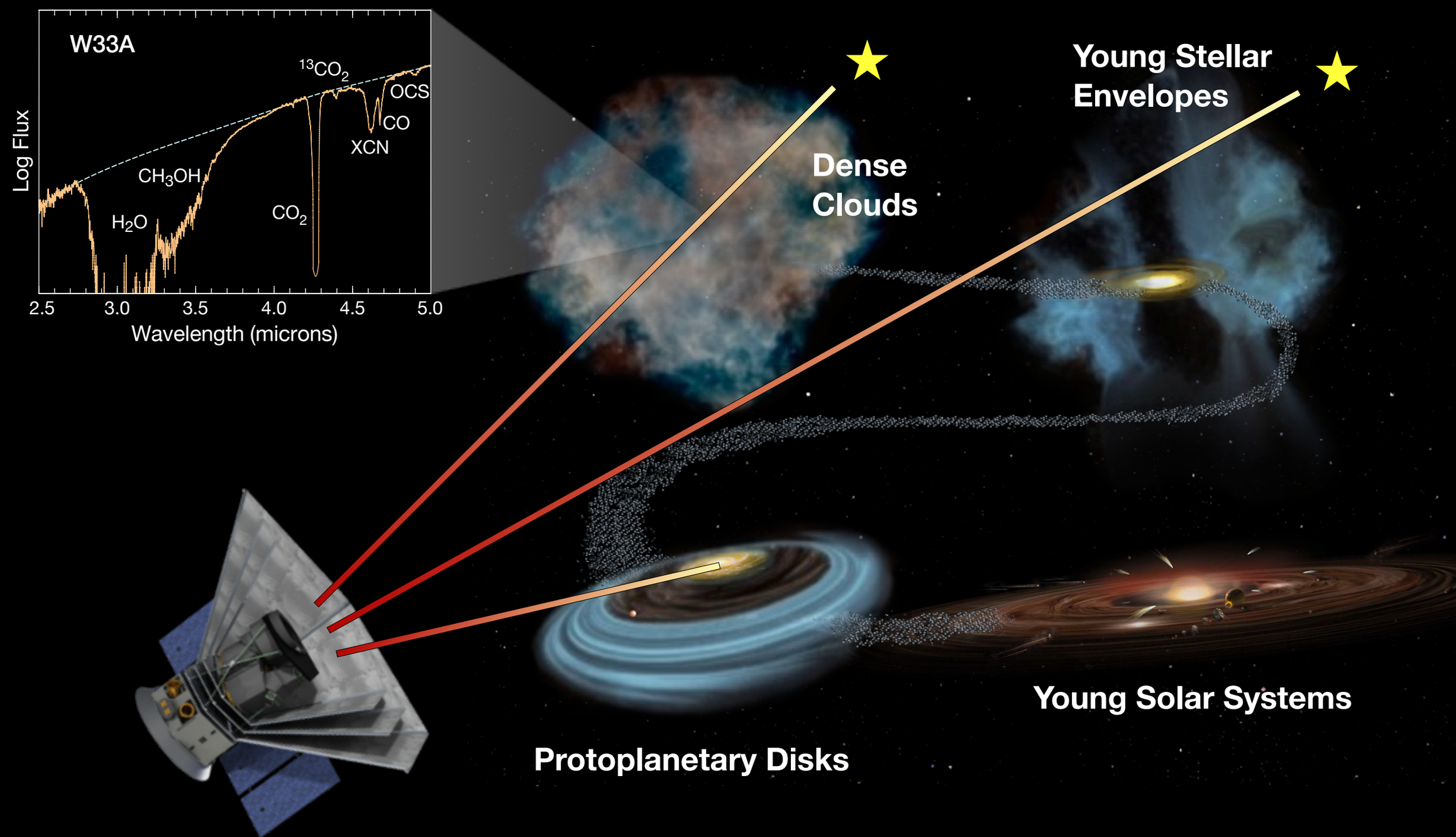
‘Follow the Water’ really means ‘Follow the Ice’



SPHEREx Will Survey Ices in All Phases of Star Formation via Absorption Spectroscopy



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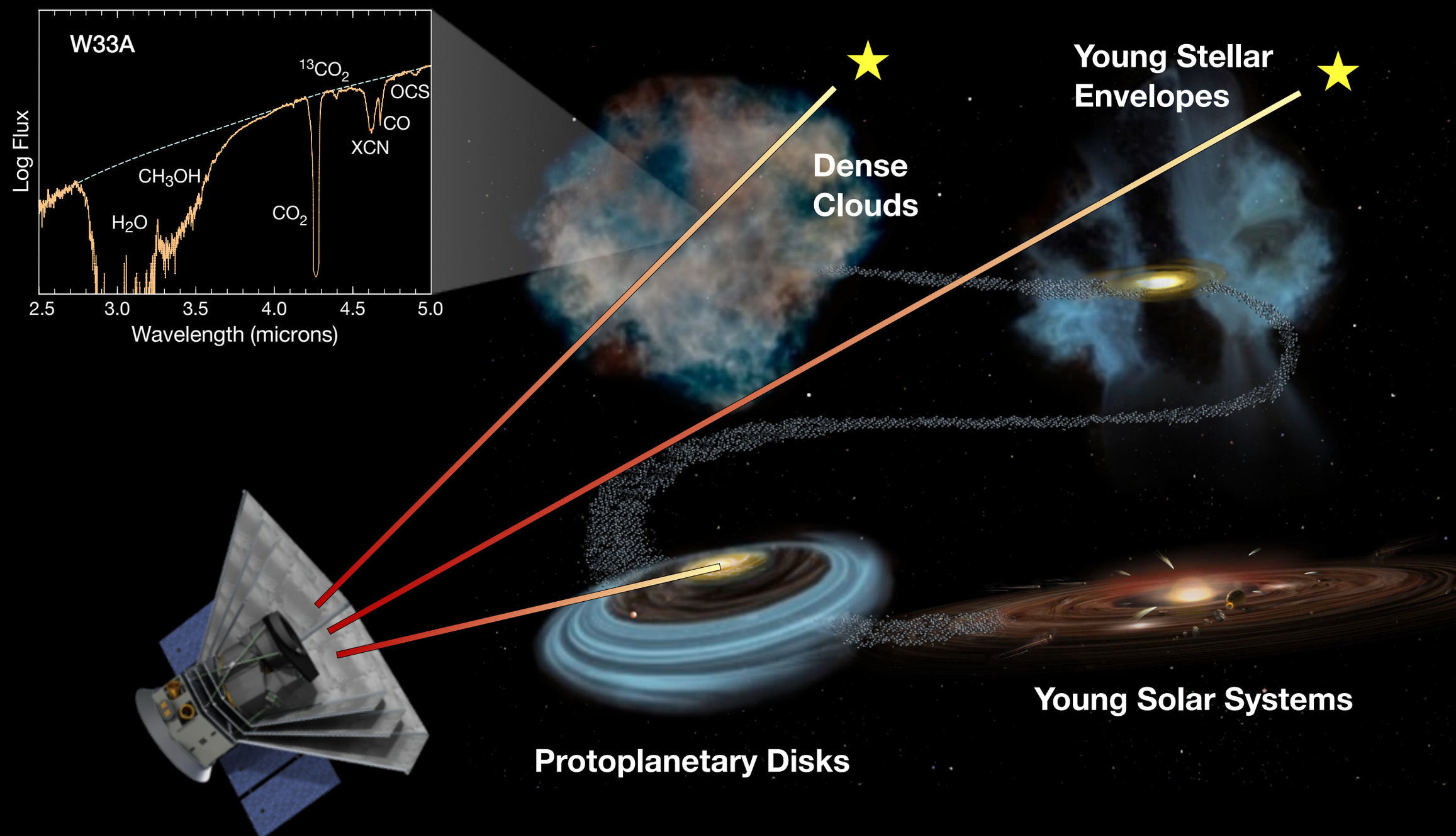
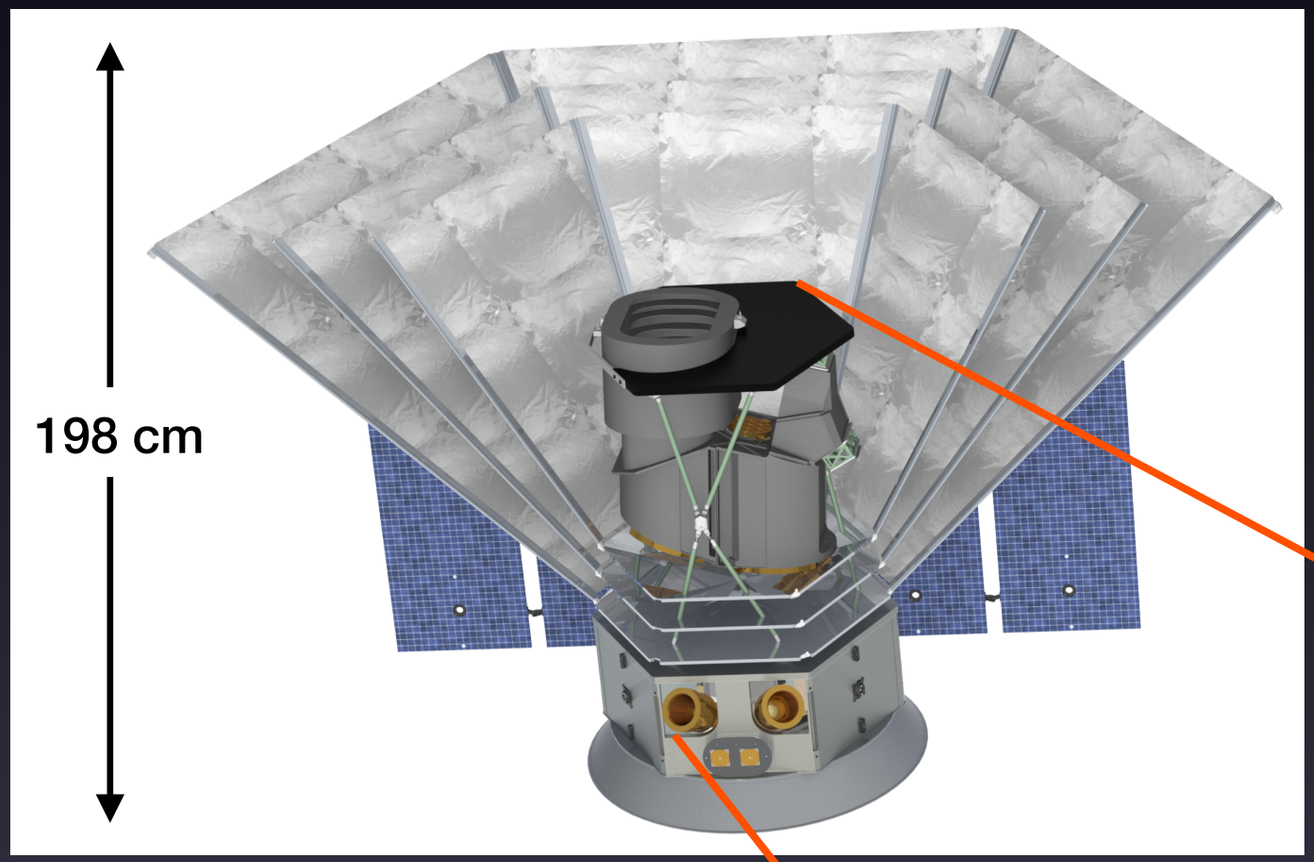
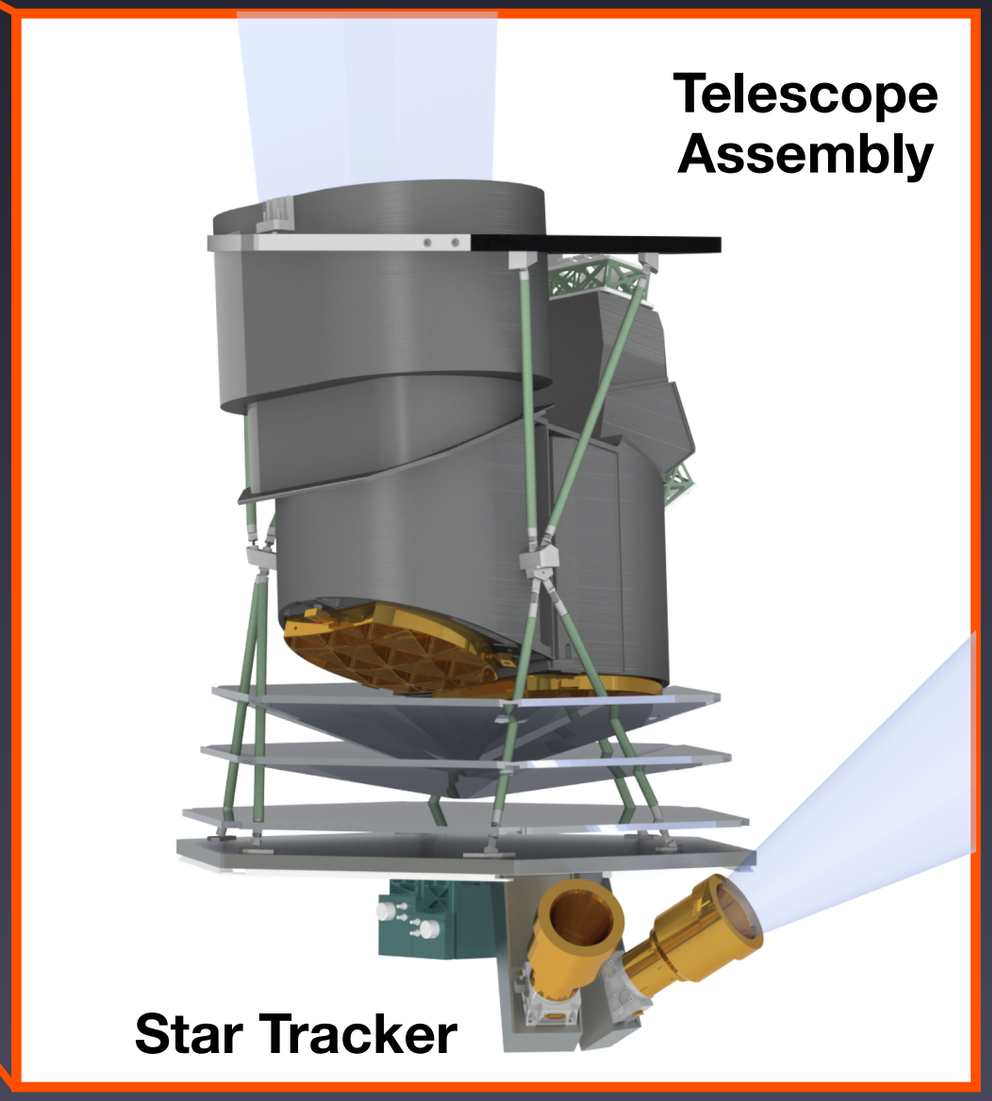


SPHEREx will measure ice column densities toward >> 20,000 sources and determine how water and biogenic ices evolve from molecular clouds to young stars to protoplanetary disks

SPHEREx: Top-Level Summary



- 20-cm telescope effective diameter
- 0.75 – 5.0 μm wavelength range
- Passively cooled, background limited
- $\lambda/\Delta\lambda$ = 35 – 130 resolving power
- 3.5° x 11.3° field of view
- 6.2″ pixel size (13.9 billion spectra)



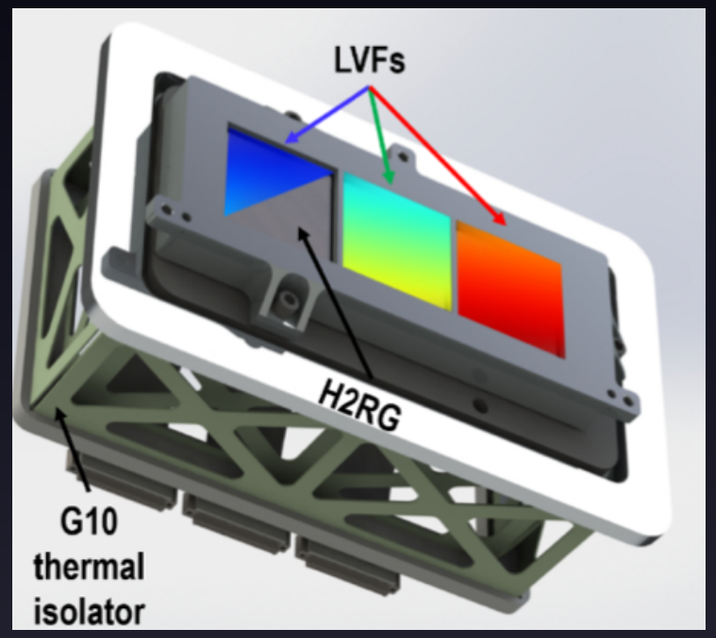
Sensitivity

Point: 18.4 AB mag (5σ @ 2 μm)

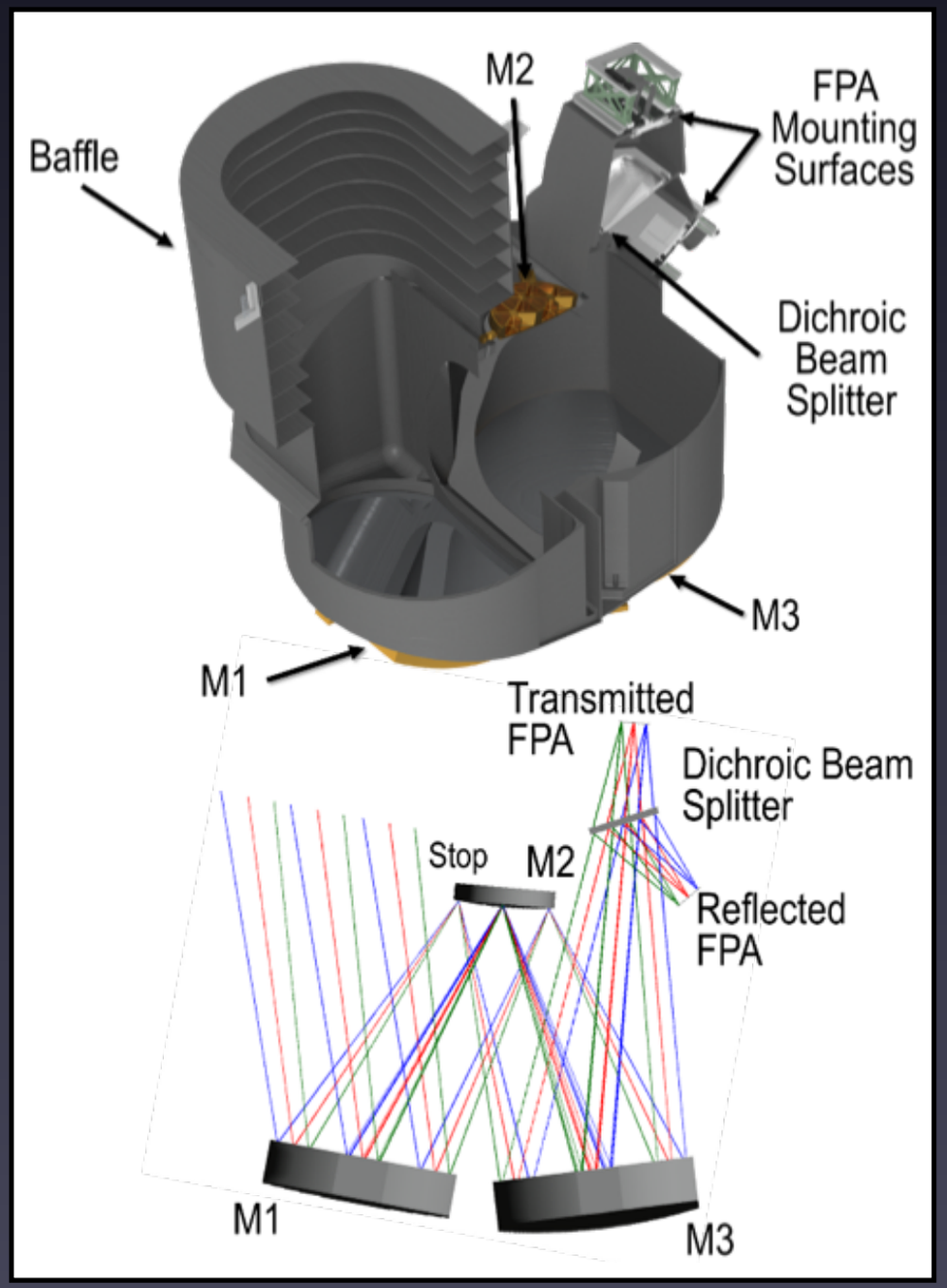
Surface: 4.5 kJy/sr (1σ @ 1.1 μm)

- High S/N spectrum for every 2MASS source (~ 4 mag deeper than 2MASS)
- Solid detection of faintest WISE sources

SPHEREx's 28-gm spectrometers



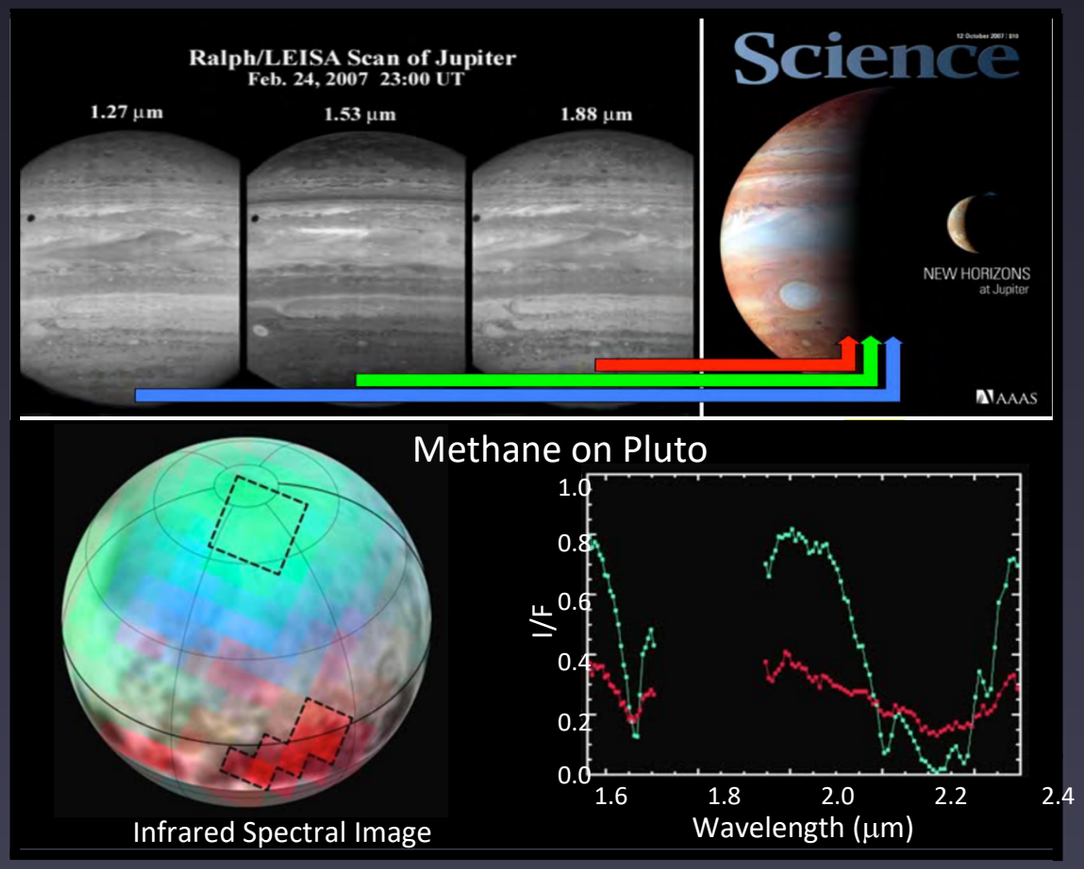
3-Mirror Astigmat



Used on:

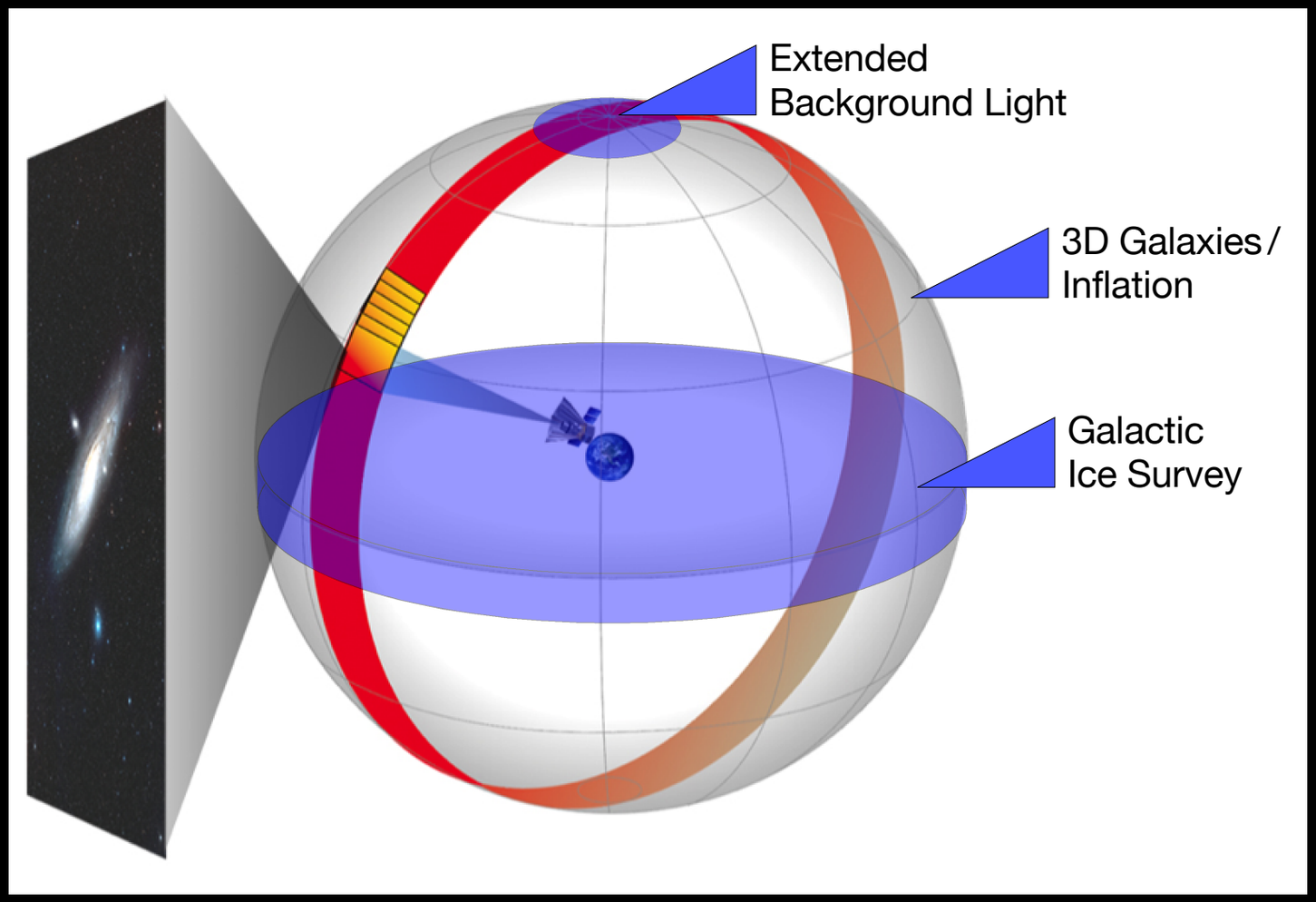
- ISOCAM
- HST-WFPC2
- New Horizon
  - LEISA
- OSIRIX-Rex

High-Throughput LVF Spectrometer



Spectra obtained by stepping source over the FOV in multiple images: ***no moving parts***

SPHEREx will conduct an all-sky spectroscopic survey between 0.75 – 5.0 μm



- Sun synchronous low-Earth orbit

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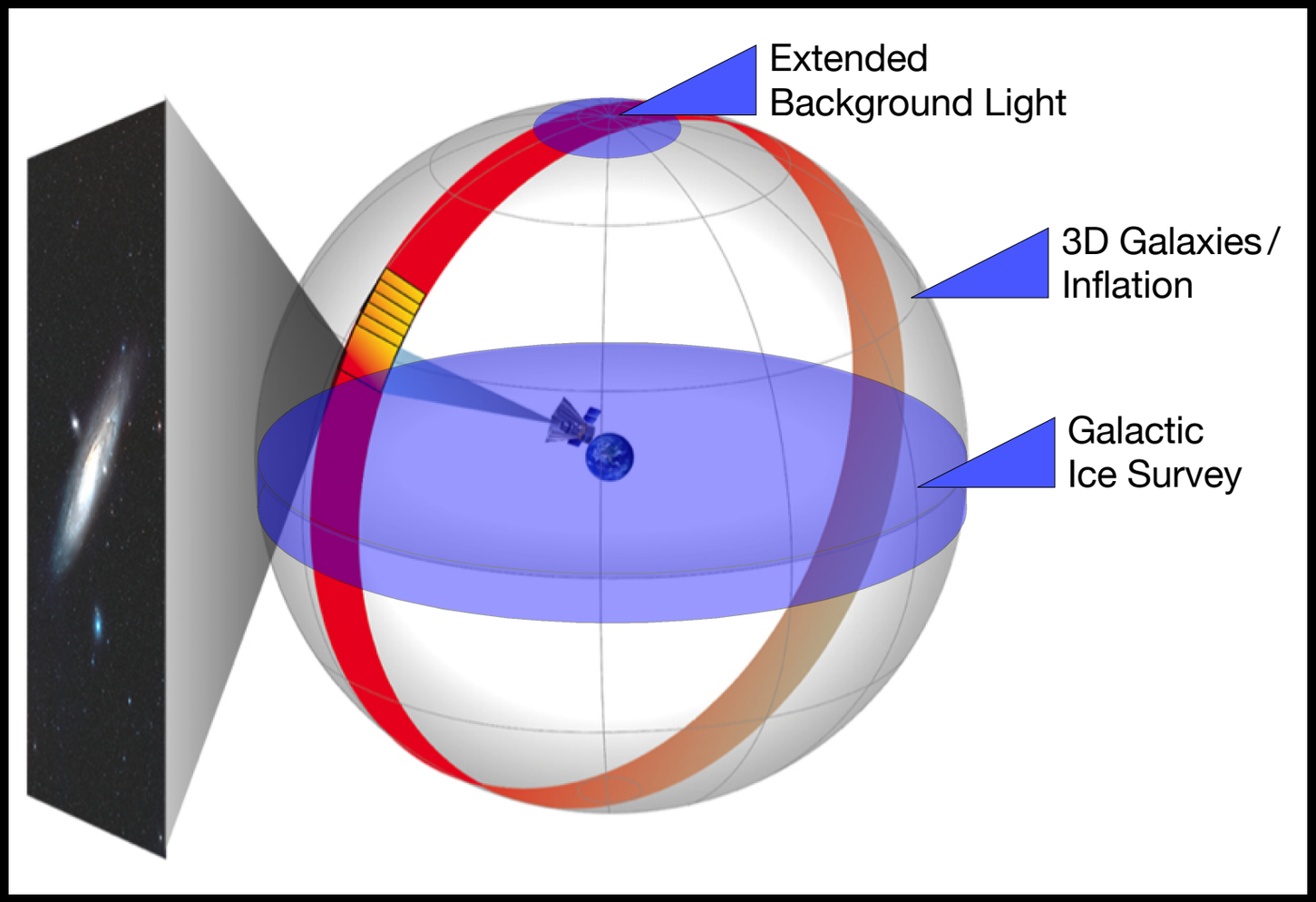

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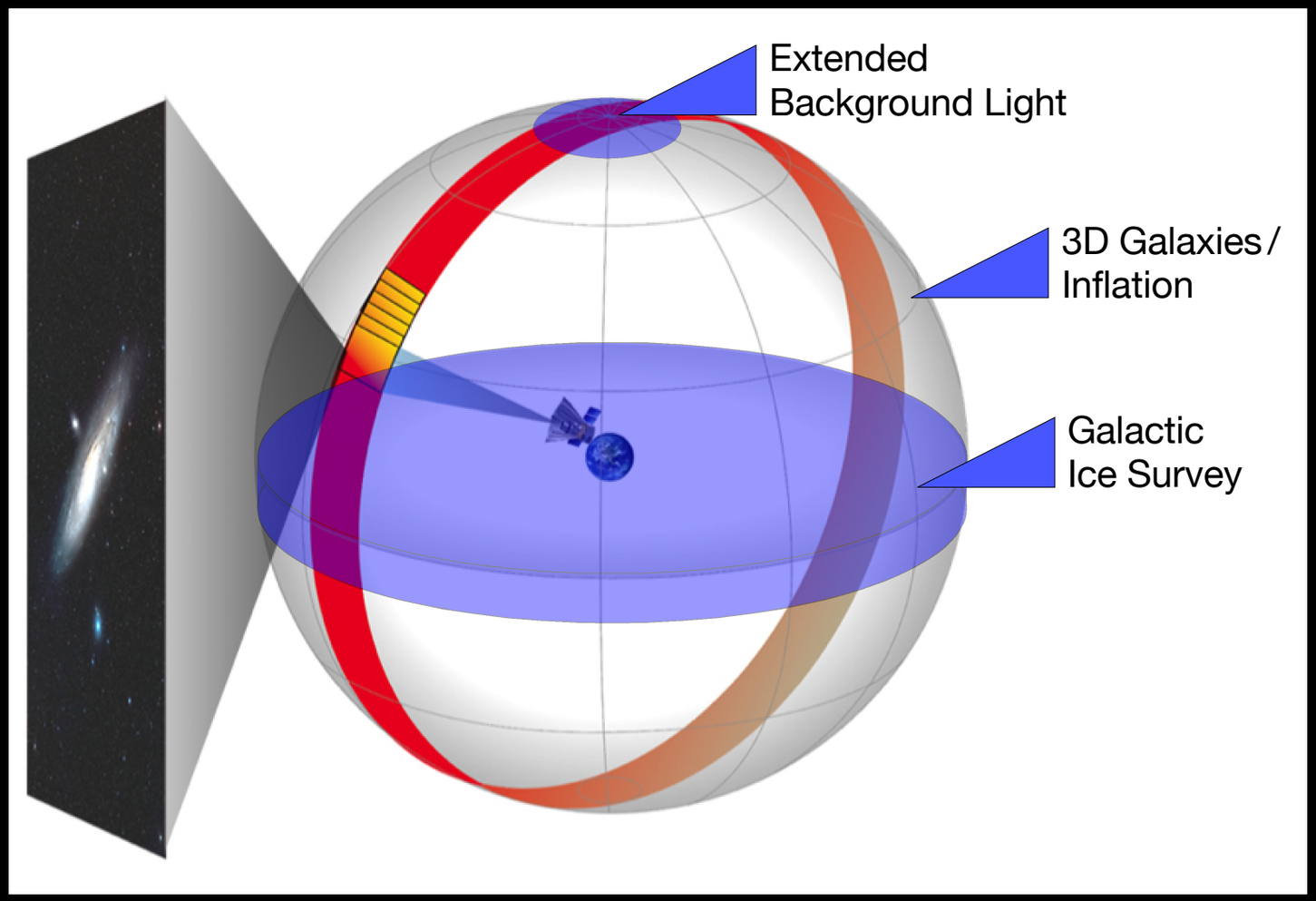

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- Six 2k x 2k H2RG detectors

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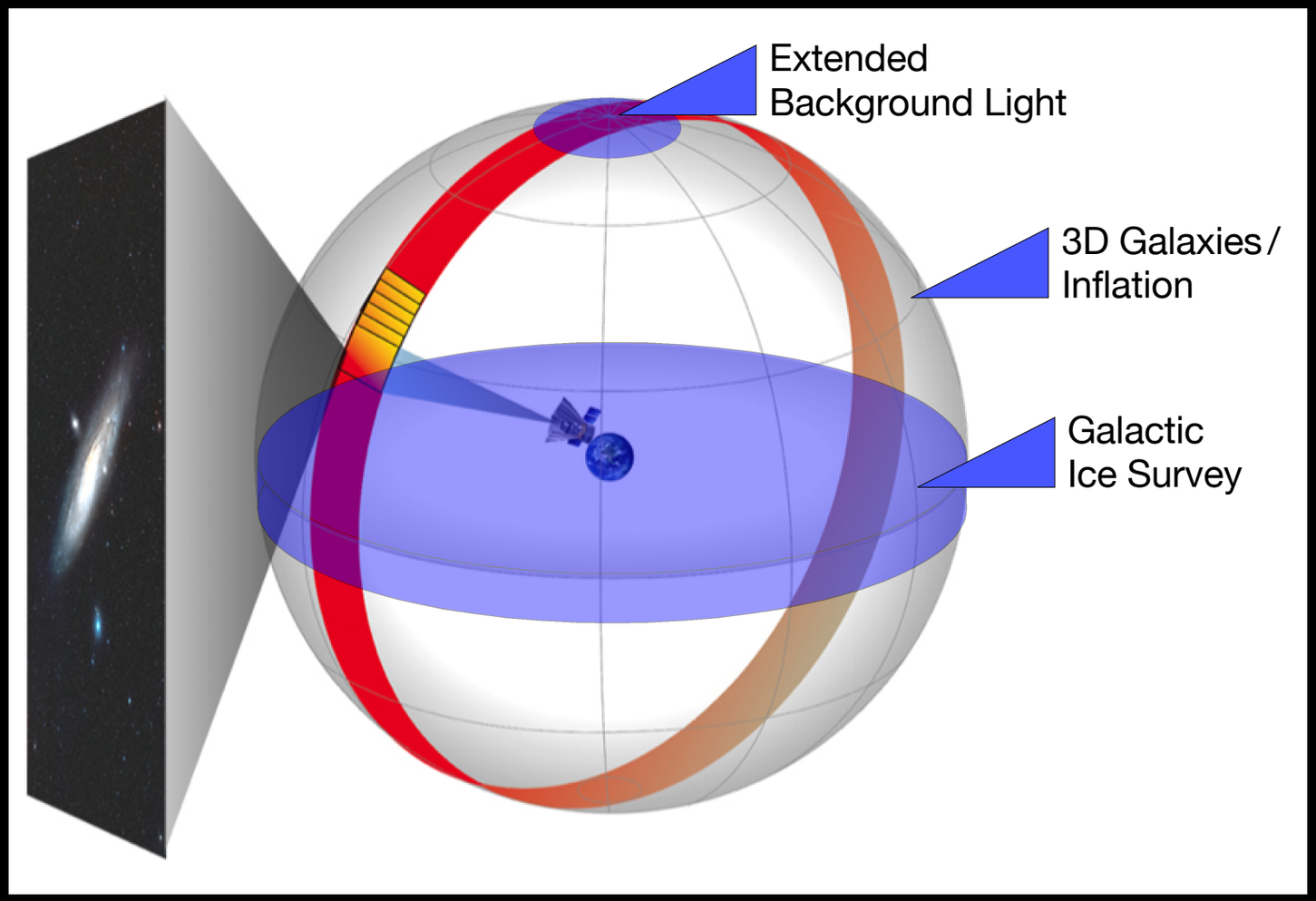

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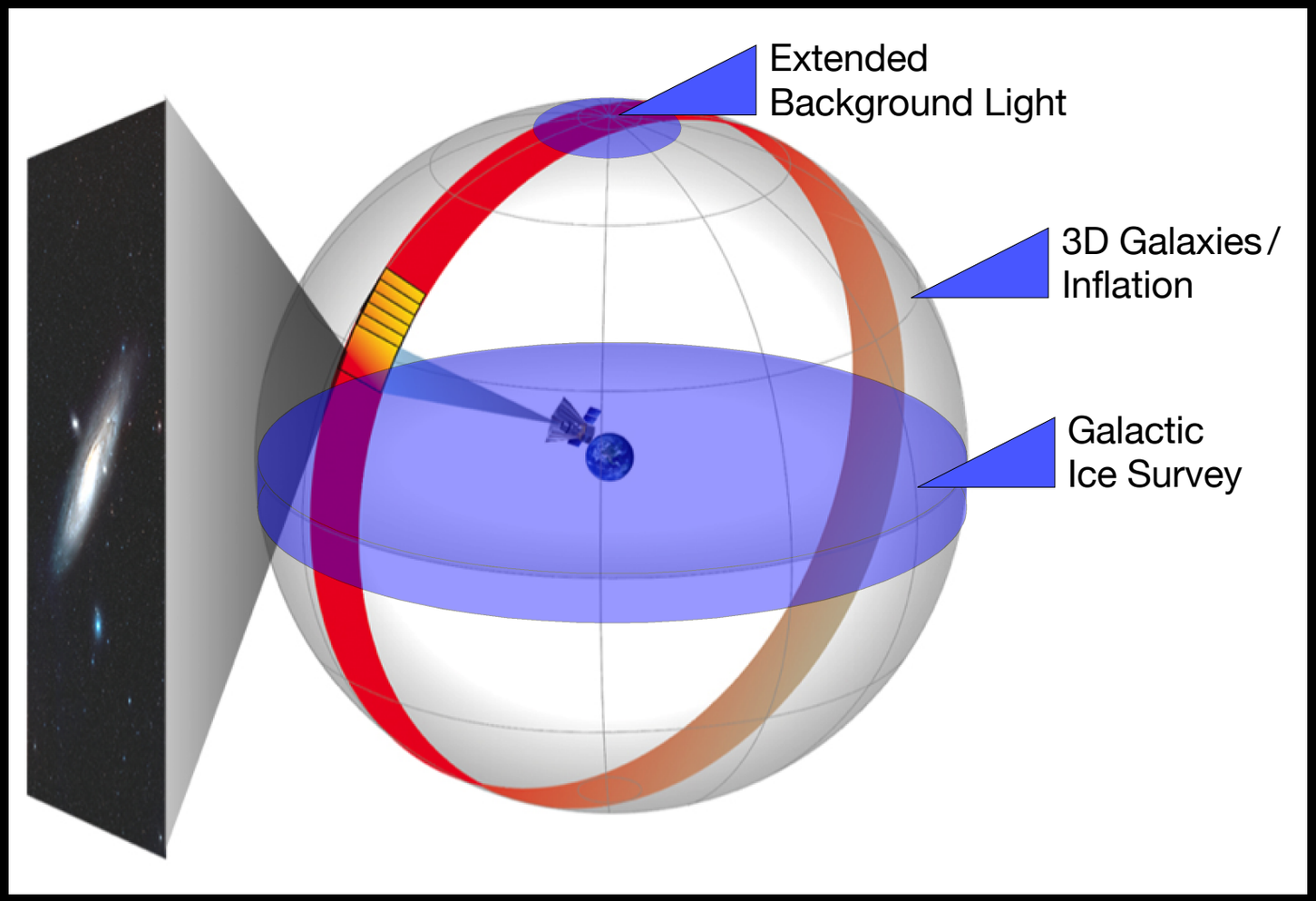

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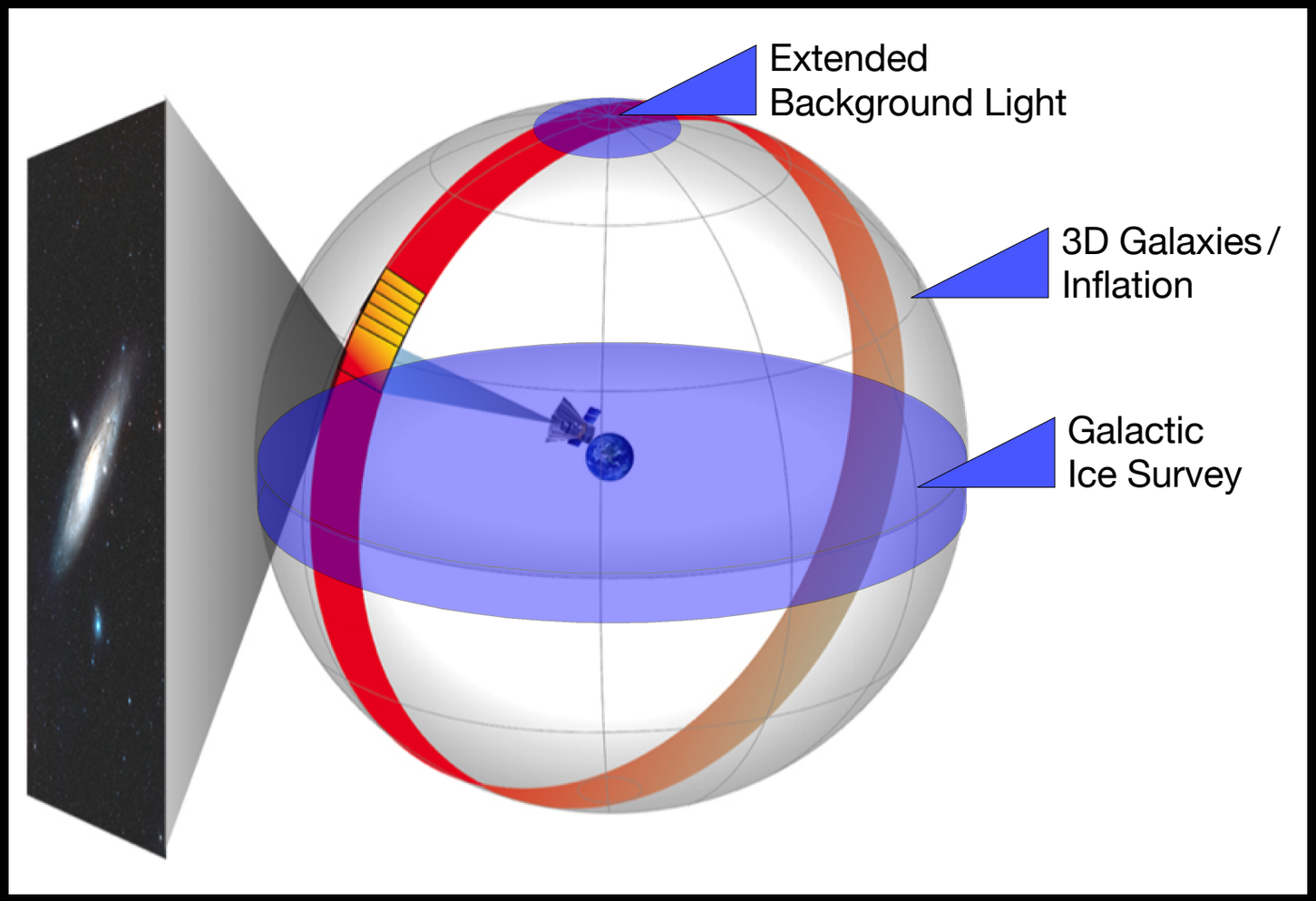
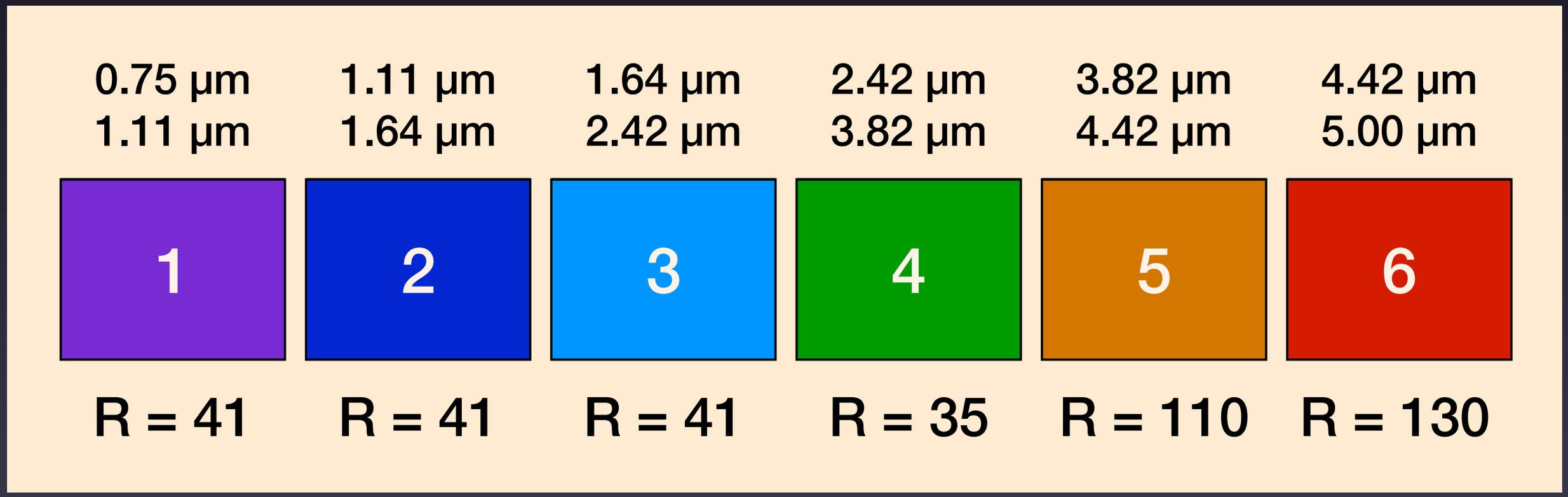


- Sun synchronous low-Earth orbit
  - *Build-up spectra over successive orbits*
- Six 2k x 2k H2RG detectors
- Passively-cooled to < 80 K (detectors to < 55 K)
- Baseline 2-year mission
  - *4 independent all-sky surveys*
  - *13.7 billion positions per survey, each with spectra*
  - *No expendables*

SPHEREx Operates in 6 Spectral Bands Between 0.75 – 5 μm



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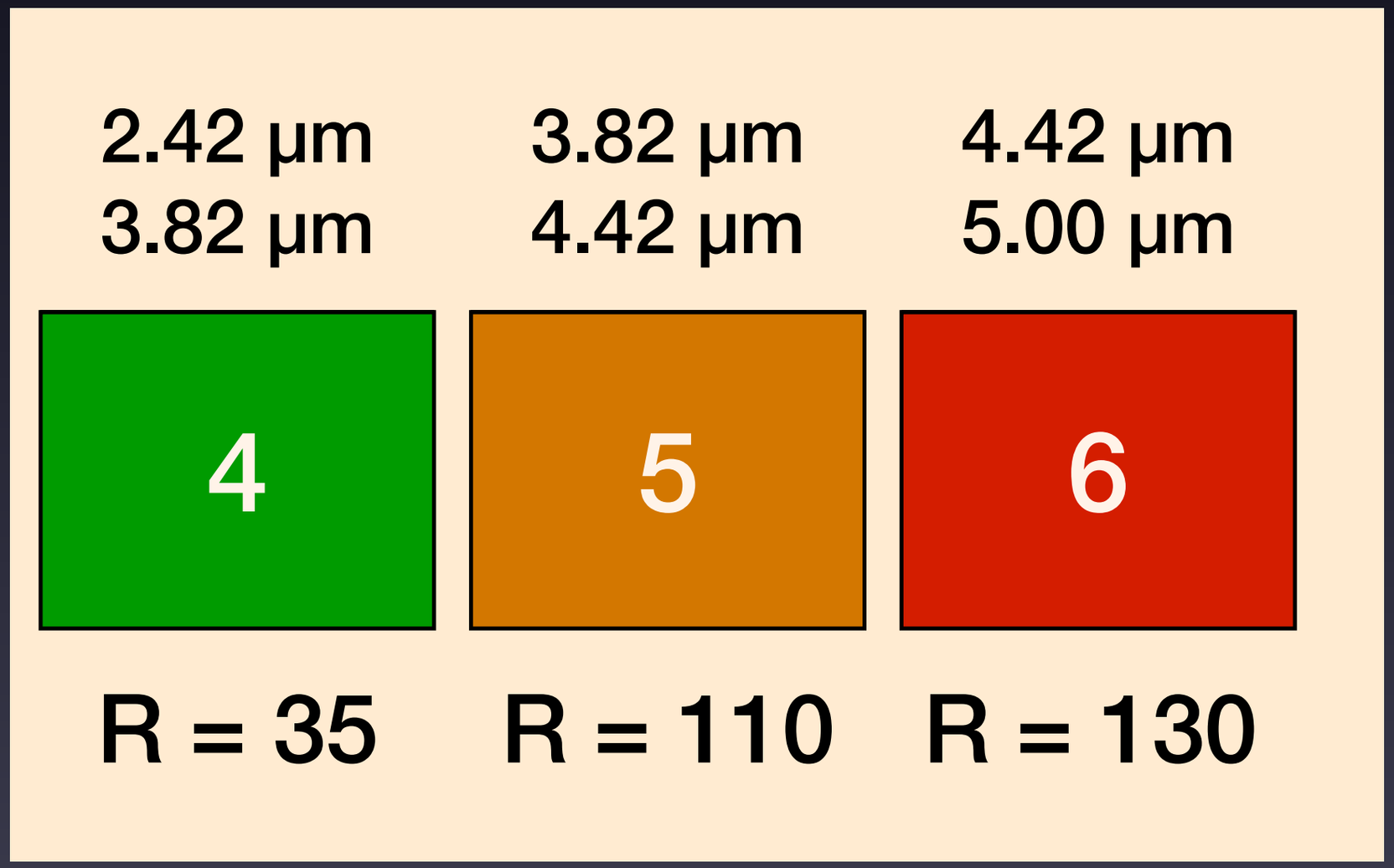

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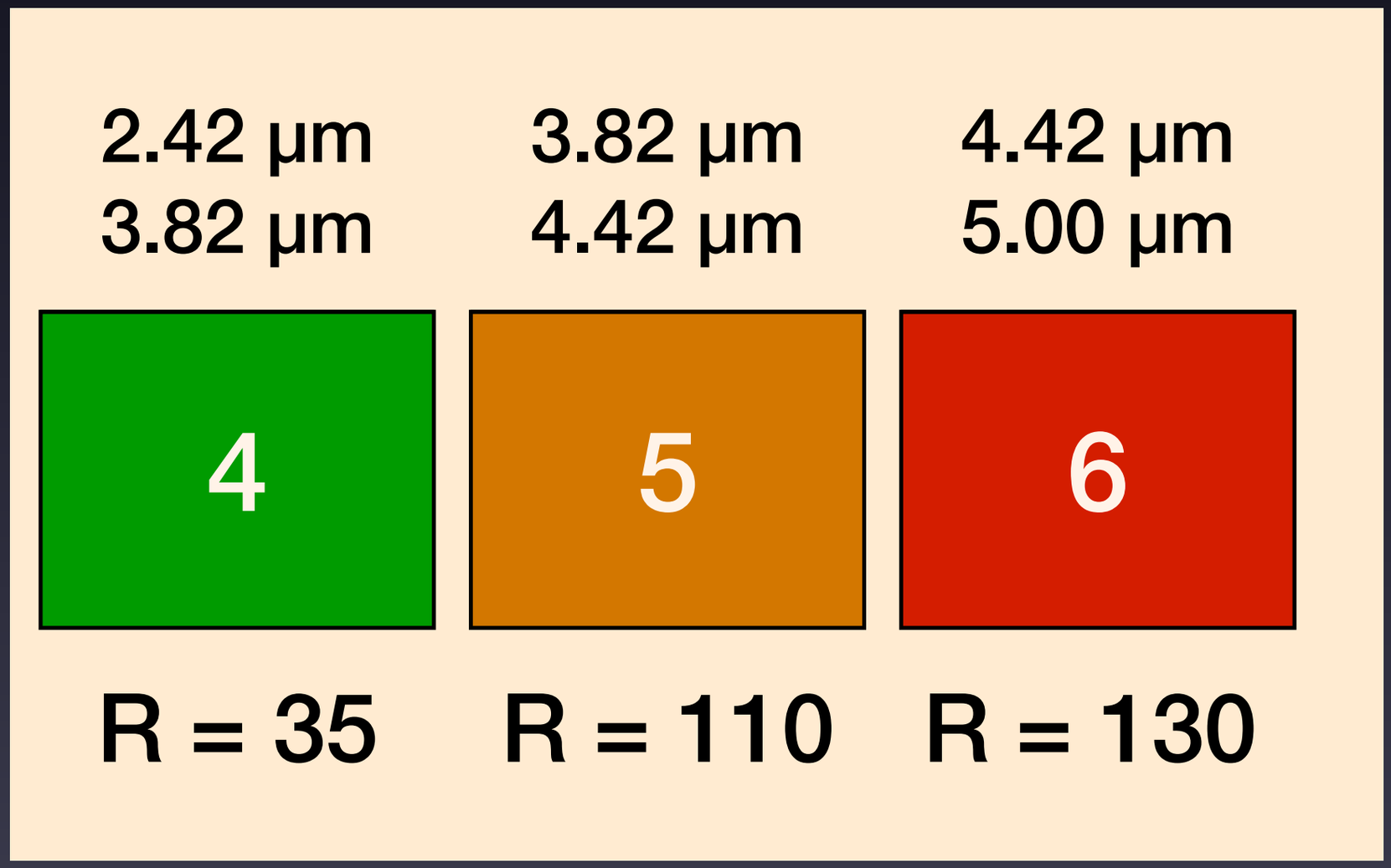
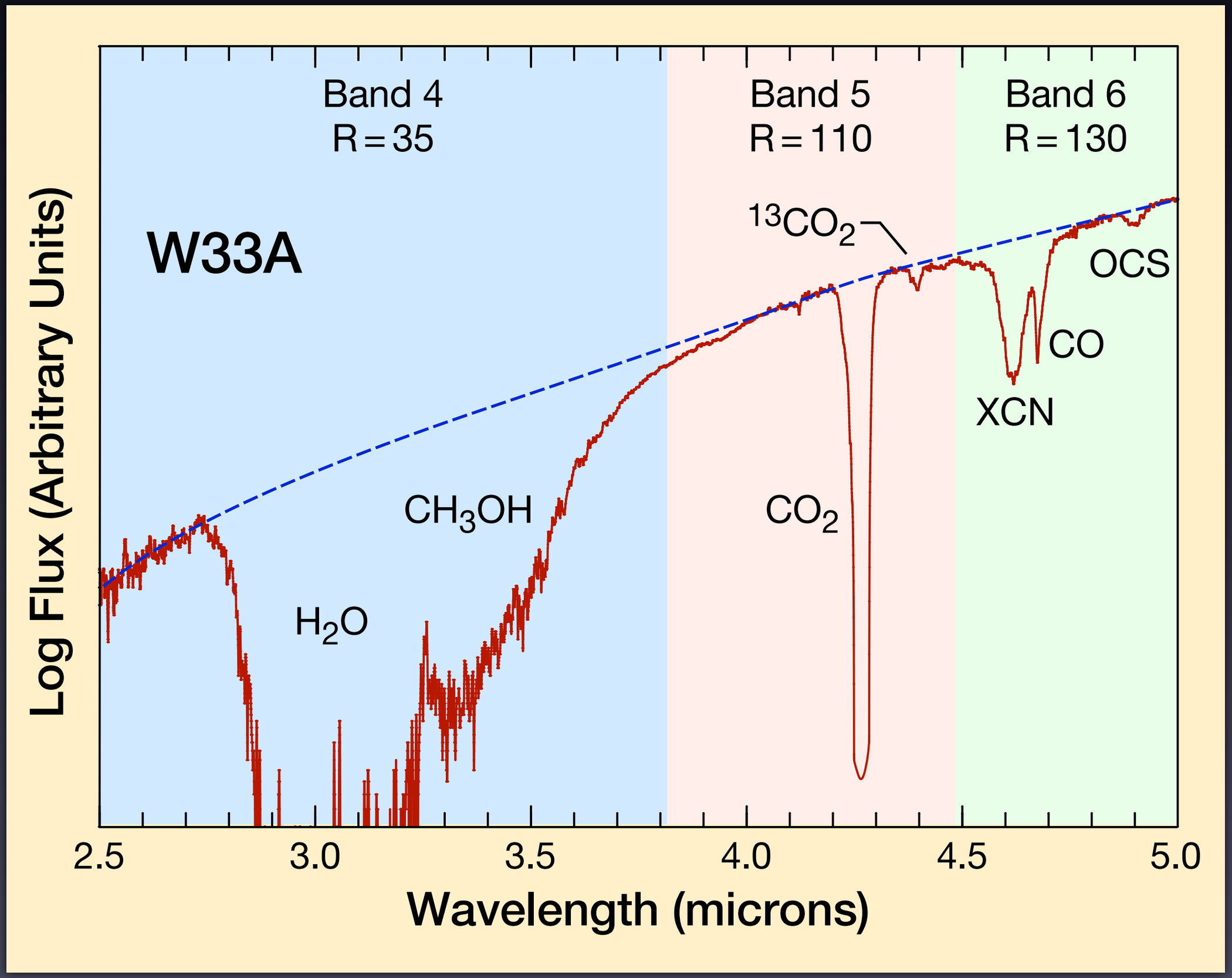


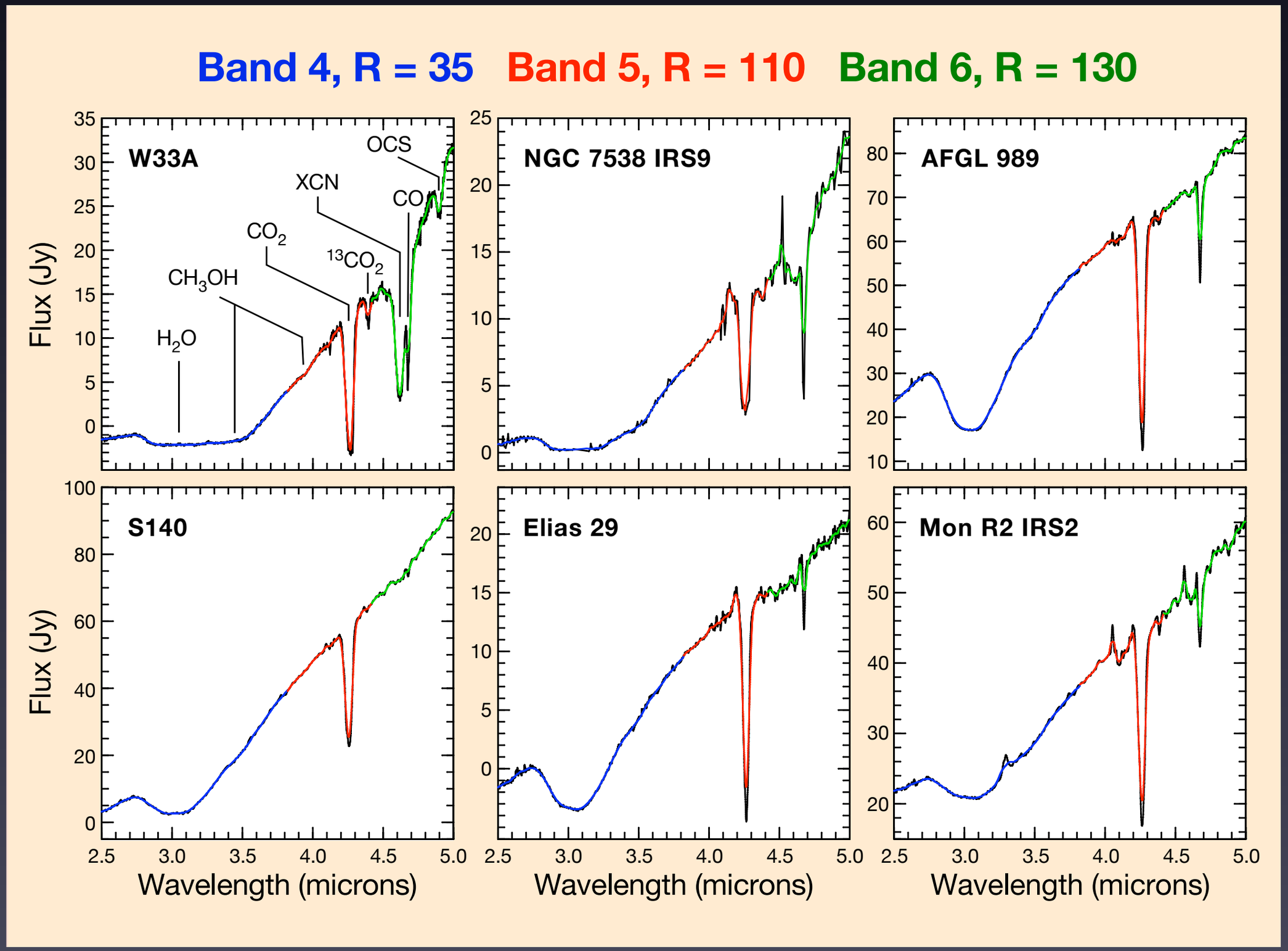
This is where the gold is buried (for ices)

The 2.5-5 μm range is particularly rich in ice features



SPHEREx is designed to permit spectral isolation of ice features

ISO absorption spectra toward Galactic star forming regions in black, obtained with R > 700



In order to understand the relation between the measured ice composition and such factors as…

- Cloud density
- Internal temperature variations
- Starless cores or clouds with embedded sources
- External far-ultraviolet flux
- External x-ray flux
- Elemental abundances (e.g., Galactic C/O gradient)
- Gas-phase molecular composition
- Cosmic-ray ionization rate
- Cloud age (if possible to estimate)
- Other?

a large sample of spectra is needed.

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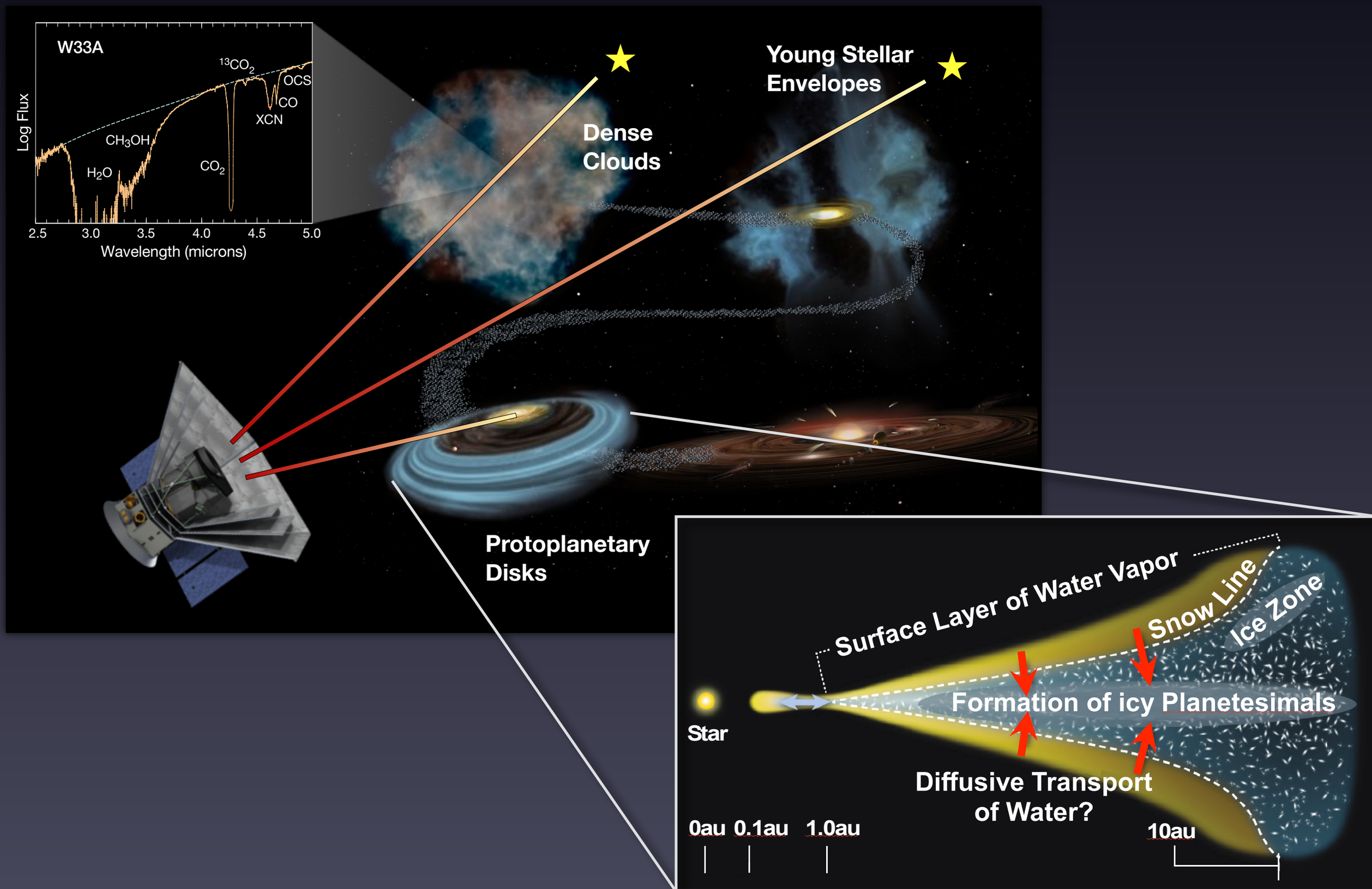
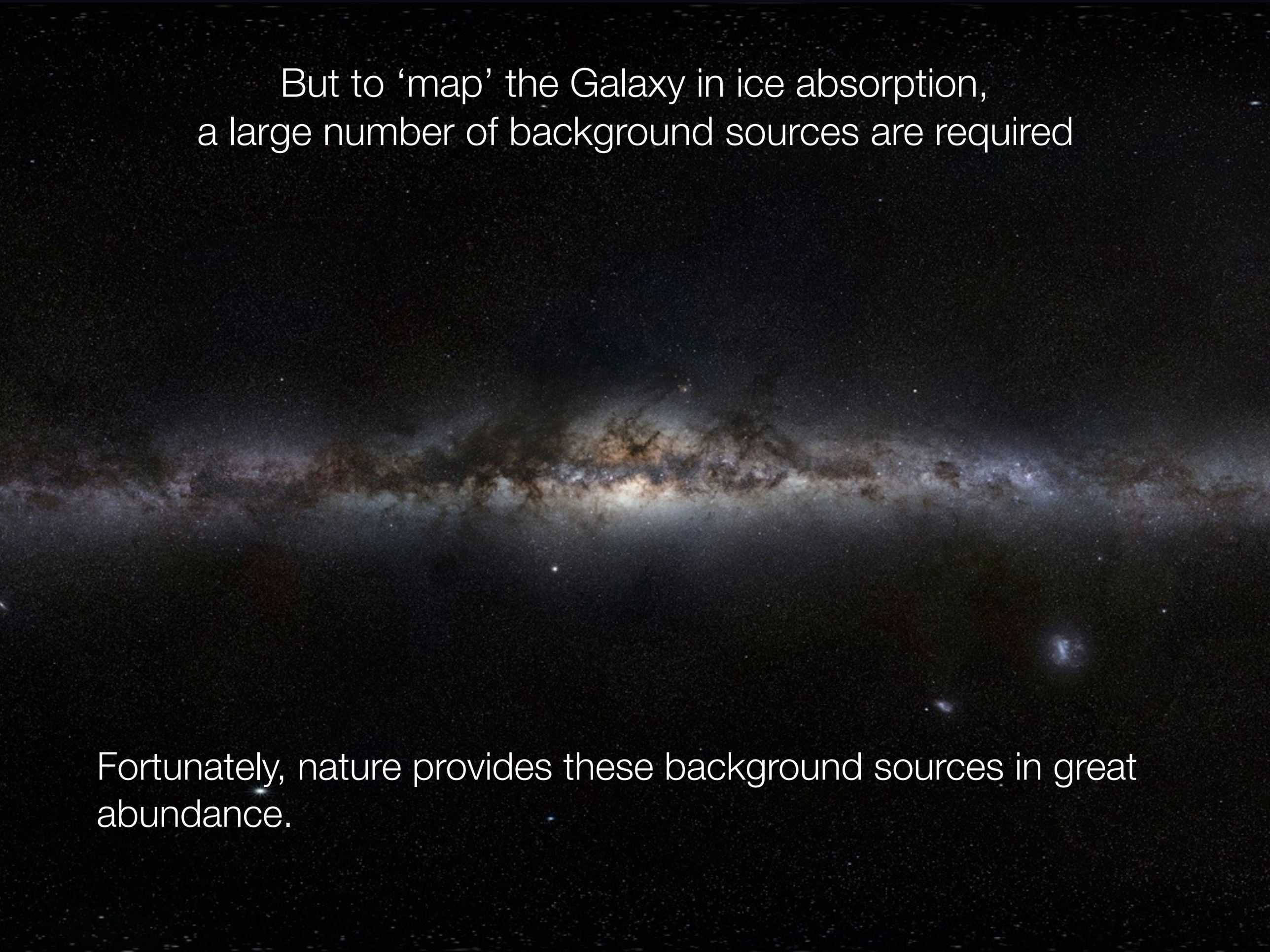
Unfortunately, ISO, Spitzer, and AKARI have only published spectra toward a total of ~ 200 lines of sight…

…too few to enable the type of statistically significant studies needed to relate cloud properties to ice composition and distribution.

SPHEREx will increase the number of high-quality ice absorption spectra by at least 100-fold (and likely > 1,000 fold)



But to ‘map’ the Galaxy in ice absorption,
a large number of background sources are required


But to ‘map’ the Galaxy in ice absorption,
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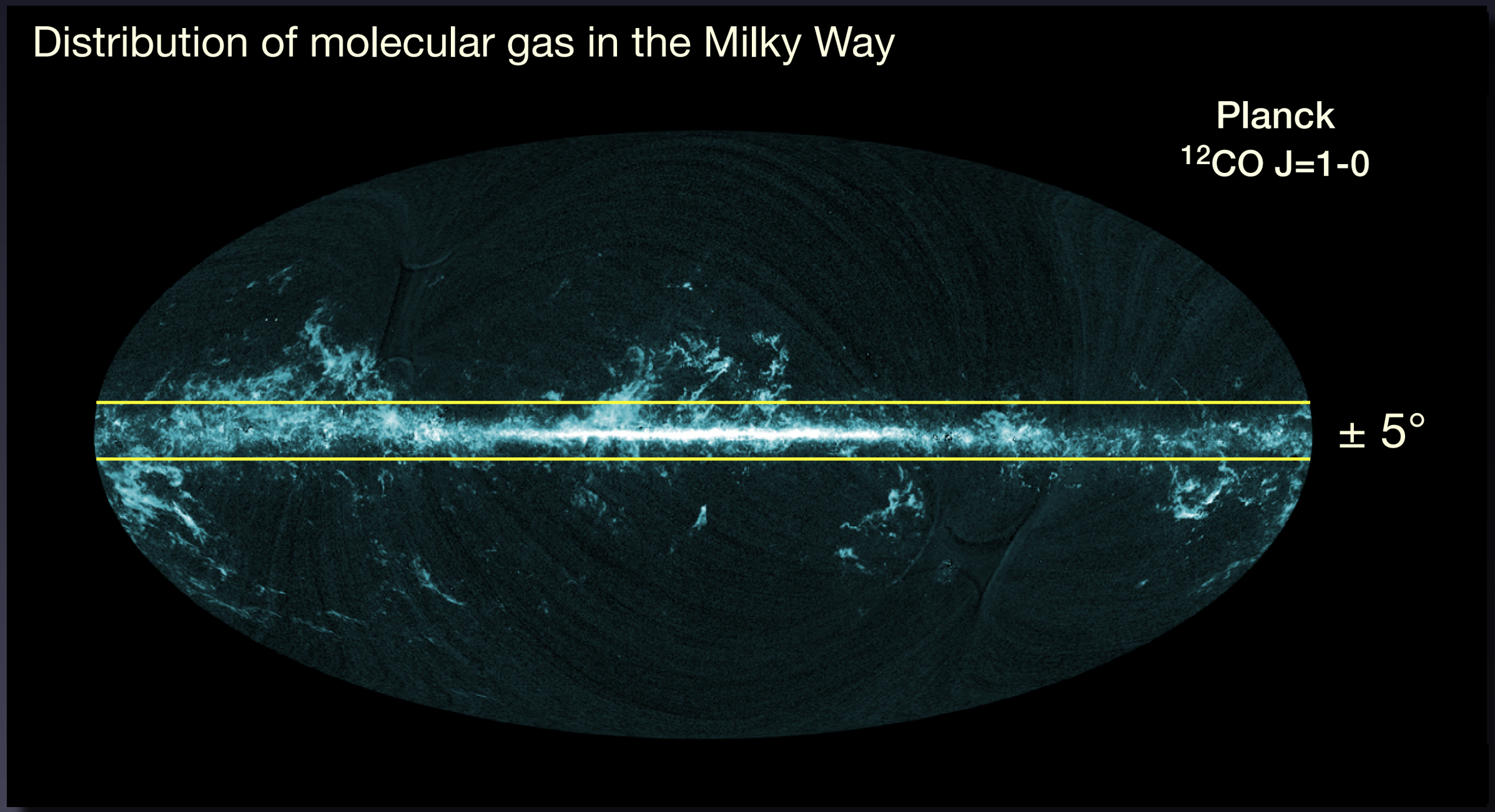
Fortunately, nature provides these background sources in great abundance.

Between

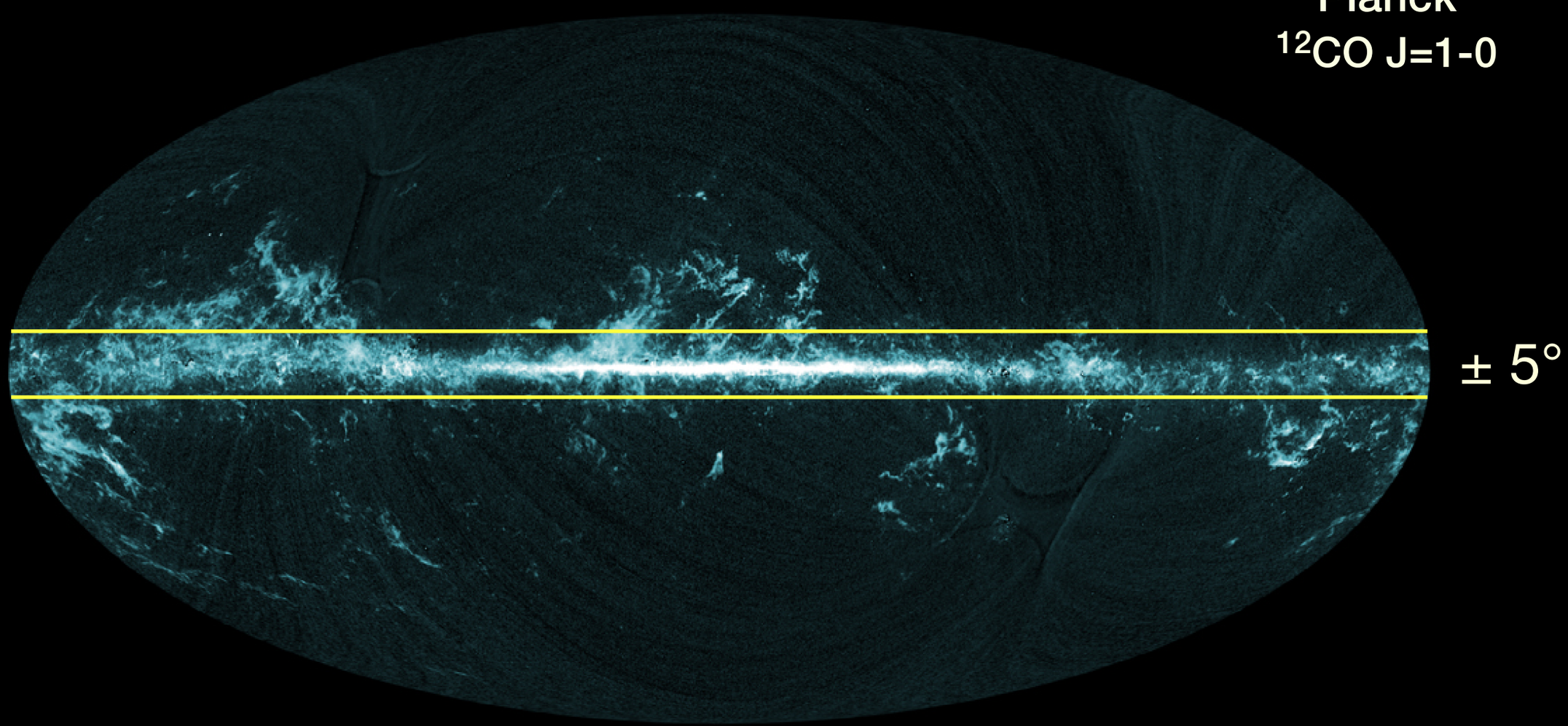
$-180° \leq \ell_{II} \leq +180°$

$-5° \leq b_{II} \leq +5°$



Between	there are...
$-180° \leq \ell_{II} \leq +180°$	$> 4 \times 10^7$ 3.4 μm WISE point sources > 1 mJy
$-5° \leq \ell_{II} \leq +5°$	$> 3 \times 10^7$ 4.6 μm WISE point sources > 1 mJy

Distribution of molecular gas in the Milky Way



To be considered a ‘good’ background source, 3 criteria must be met:

1) To ensure a background source is spatially isolated (i.e., no confusion), there can be no other WISE source within ± 6.2 arcsec with more than 1% of its flux density.

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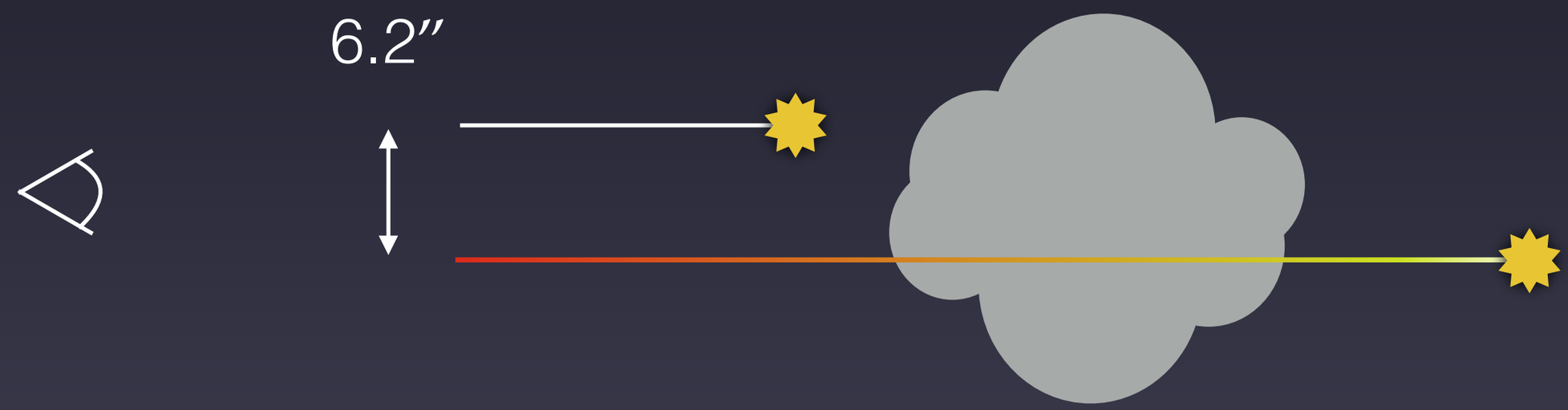

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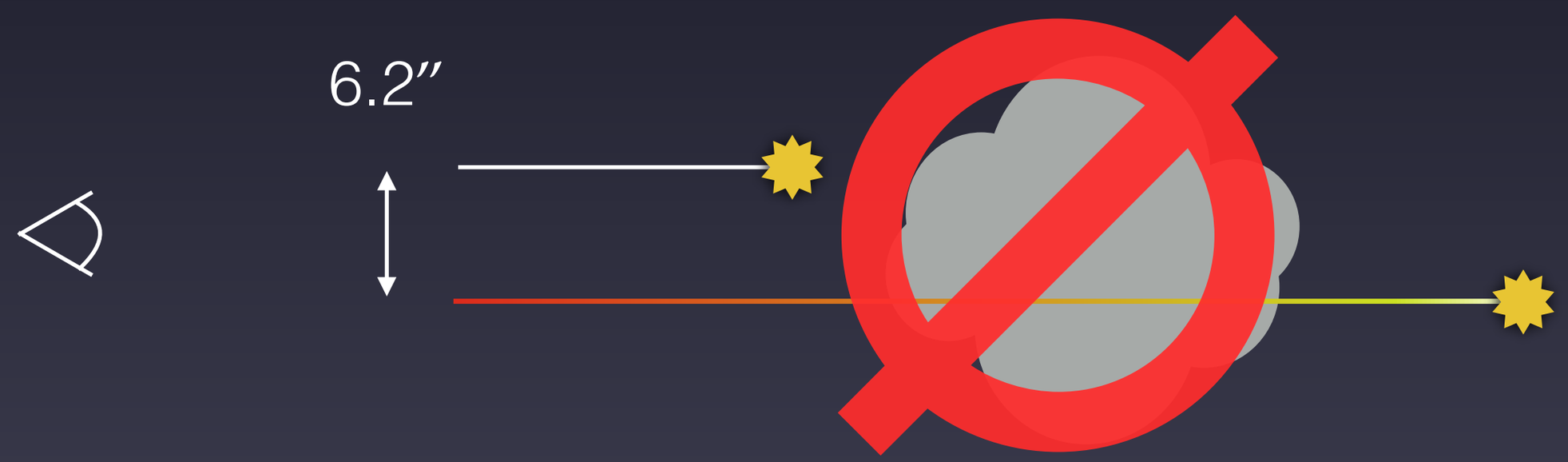

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1) To ensure a background source is spatially isolated (i.e., no confusion), there can be no other WISE source within ± 6.2 arcsec with more than 1% of its flux density.

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   — Use is made of 2MASS H- and K-band data + WISE 3.4 μm (W1) and WISE 4.6 μm (W2) data.

   (Intervening extinction is inferred if: H-W2 > 1.55 and K-W1 < 0.7)

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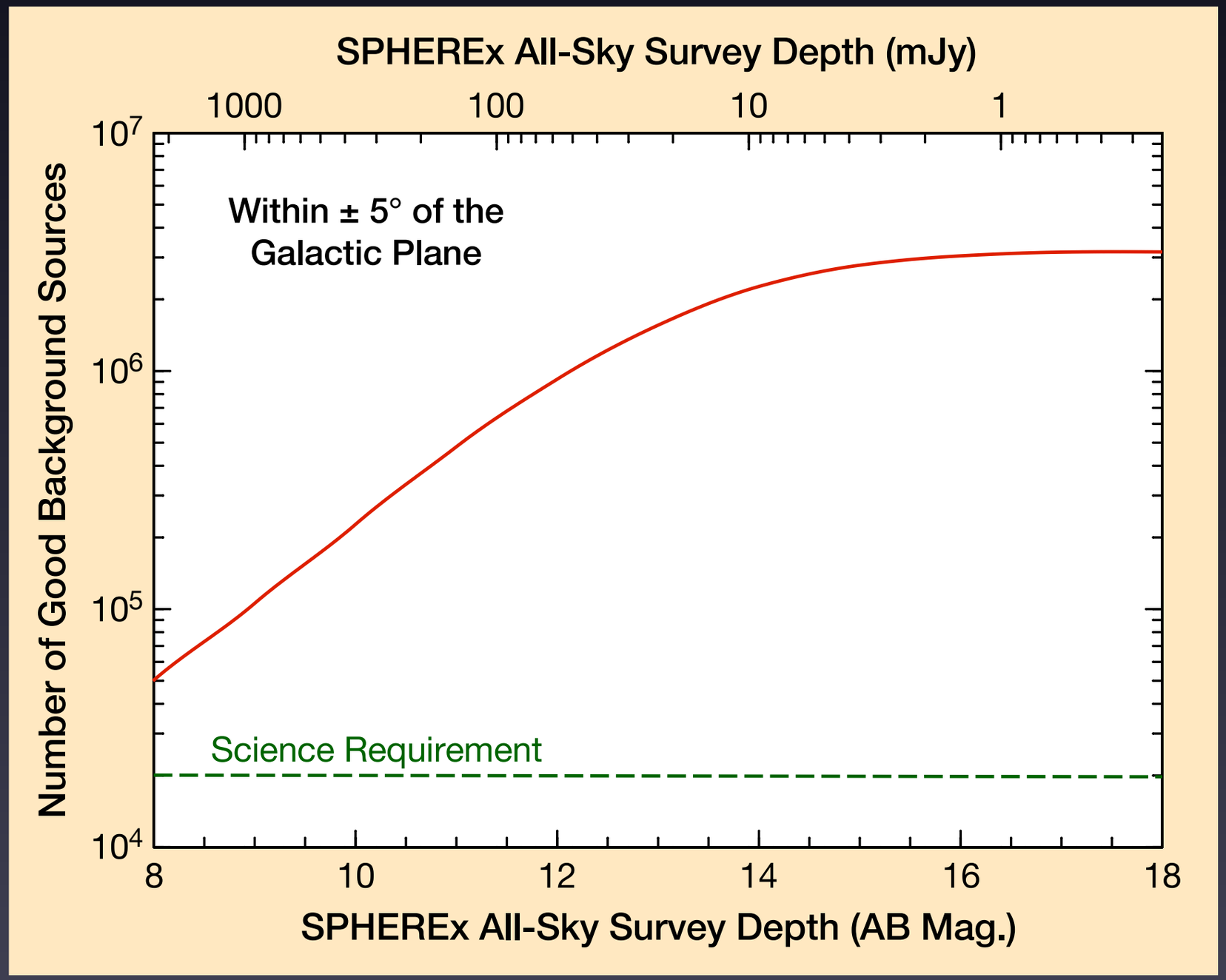
3) The catalogued flux density of the background point source would result in a signal-to-noise ratio ≥ 100 per SPHEREx spectral resolution element ($\Delta\lambda$).

With its expected and worst case sensitivity, SPHEREx easily meets the Level 1 Requirement of 20,000 high-quality ice absorption spectra



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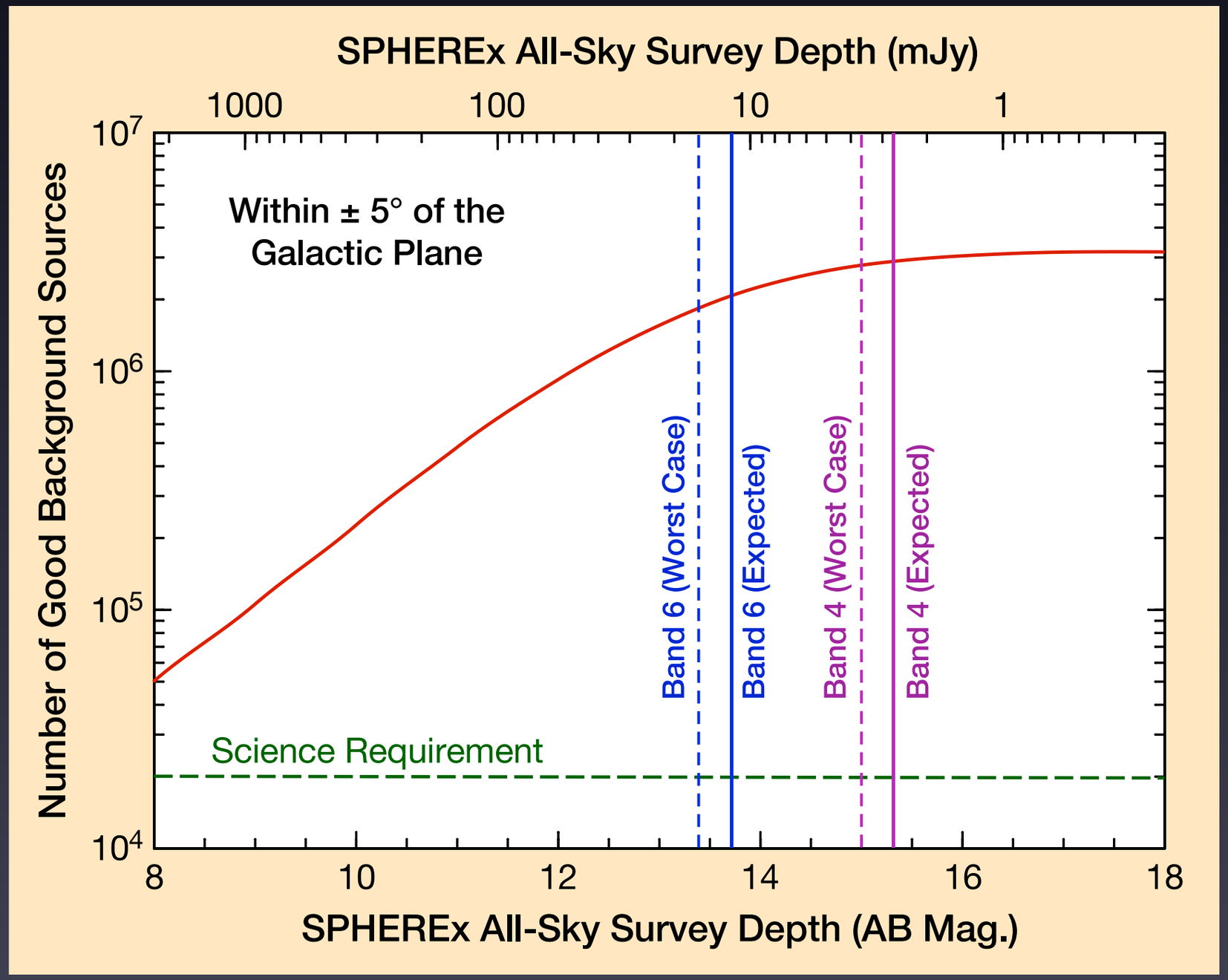

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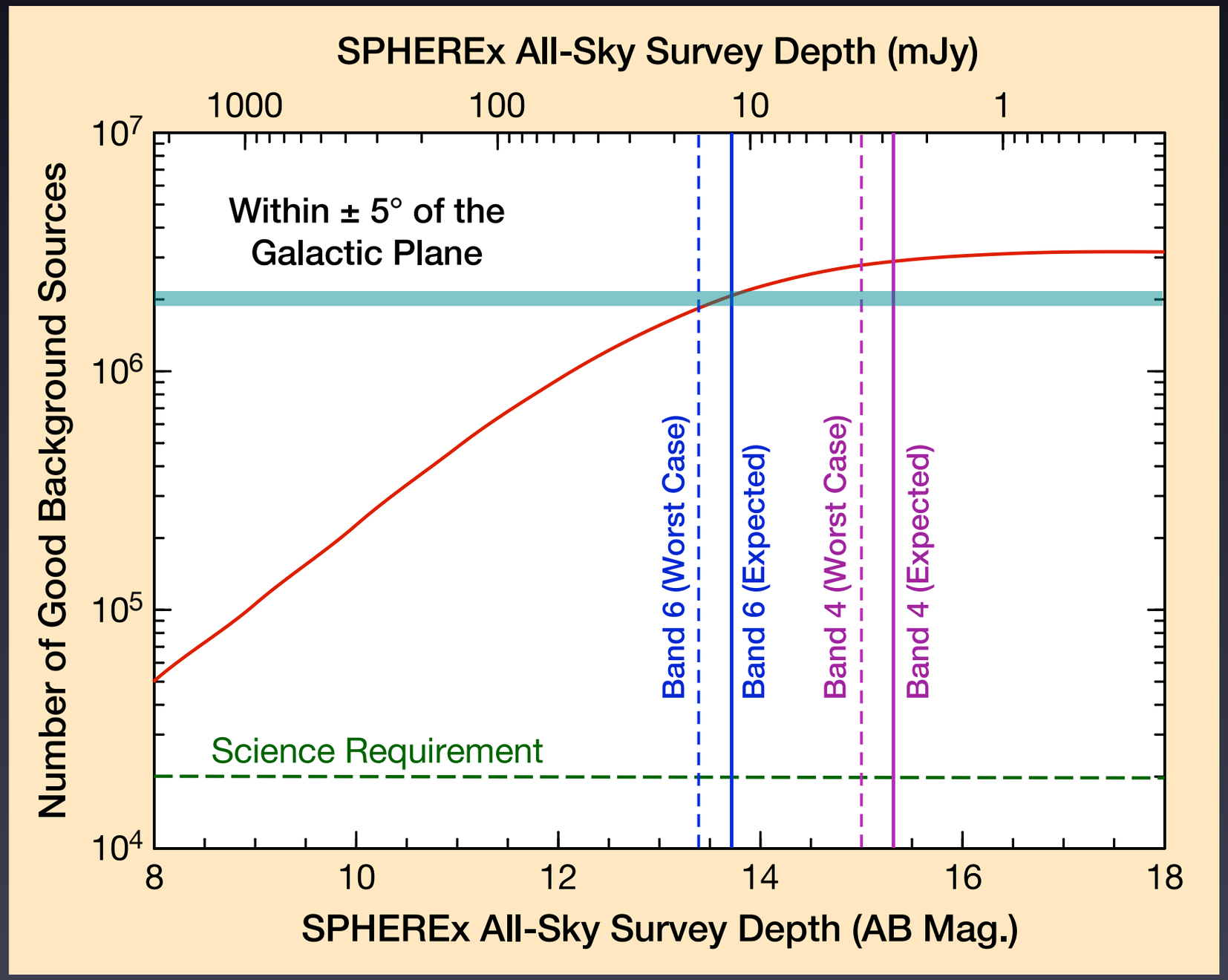
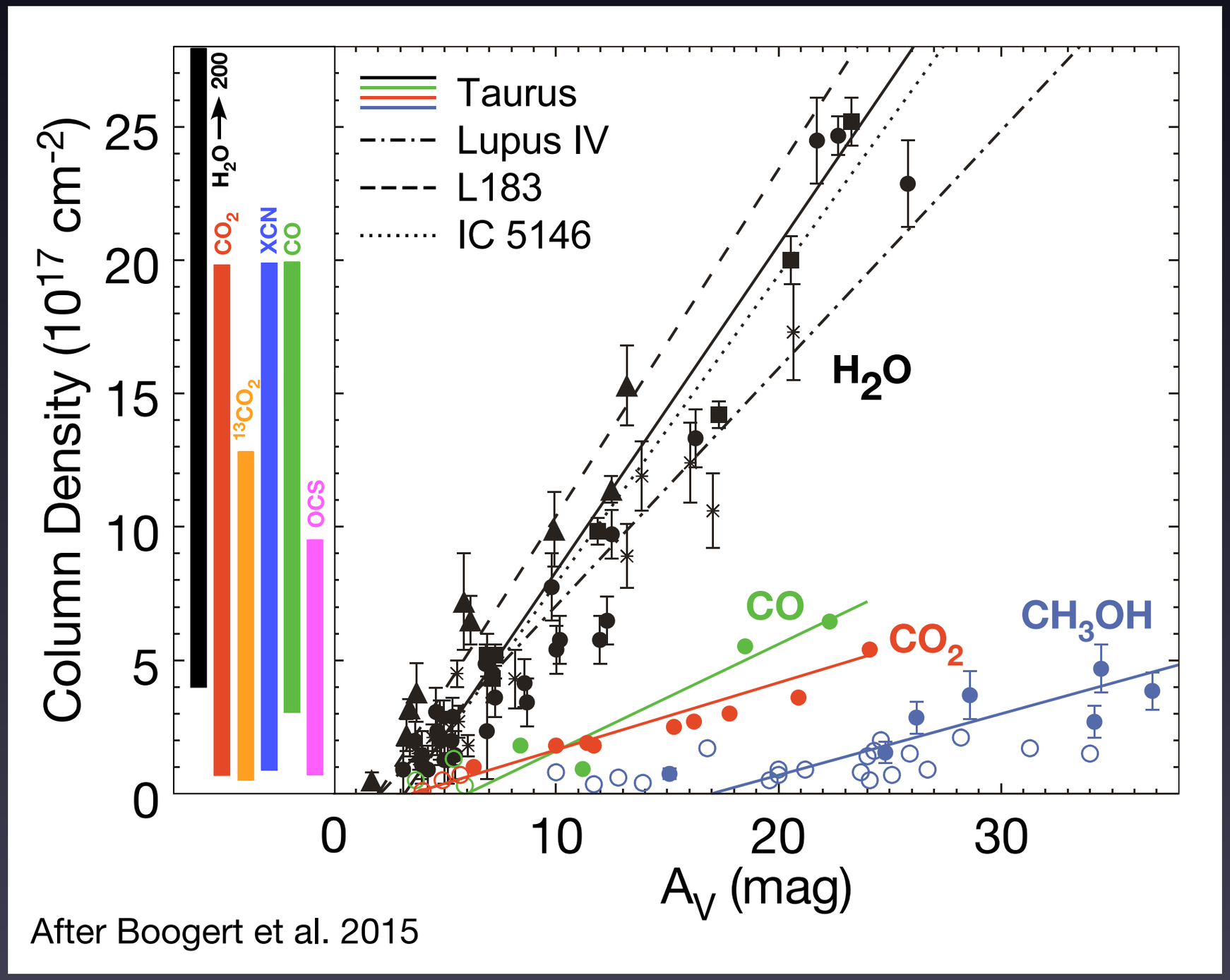


Between ±5°, there are > 2 x 10^6 good lines of sight, or ~ 10,000 x the current number of ice absorption spectra

SPHEREx will be a game changer for the study of ices by…



After Boogert et al. 2015

… revealing the relation between ice column density and A_V within molecular clouds

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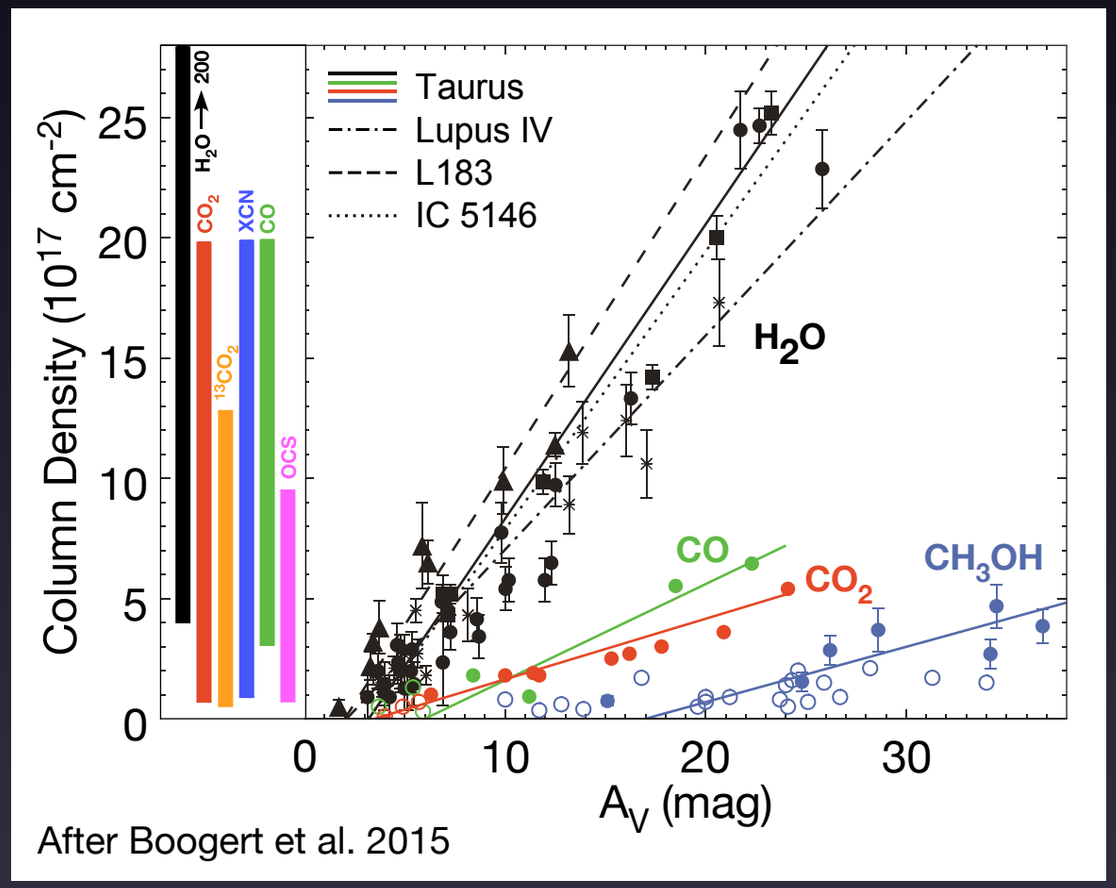

After Boogert et al. 2015

By sampling orders of magnitude more lines of sight, SPHEREx will add significantly to our knowledge of both the depths at which ices form, and their relative abundances as a function of cloud depth.

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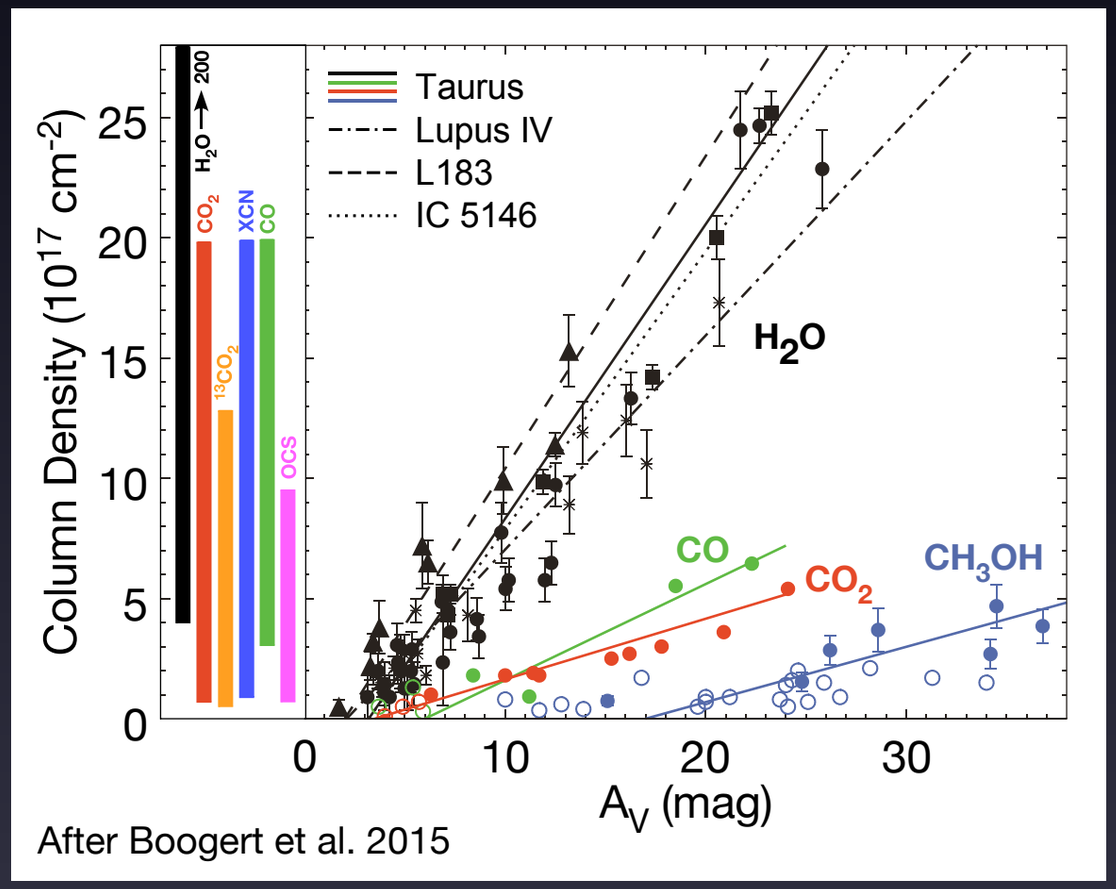

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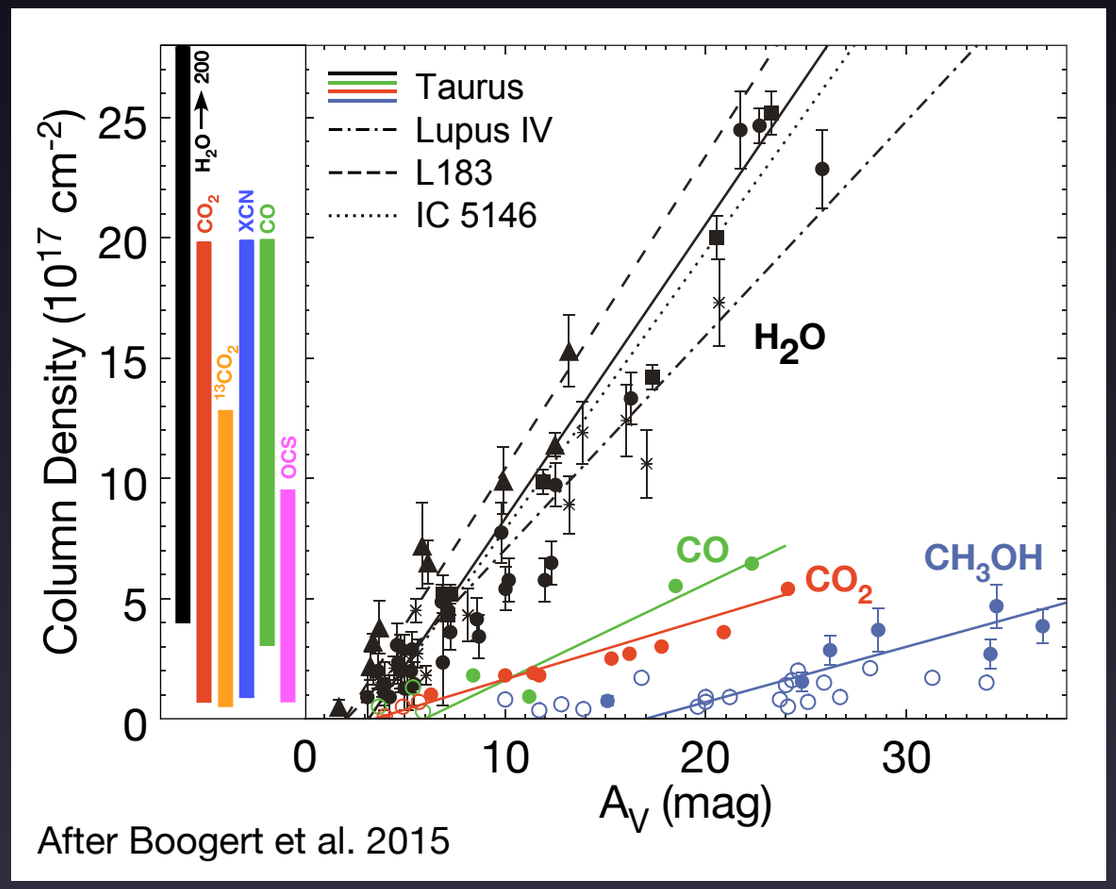

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SPHEREx and JWST will be operational at the same time

⇒ SPHEREx can provide a target list of interesting sources for JWST follow-up.

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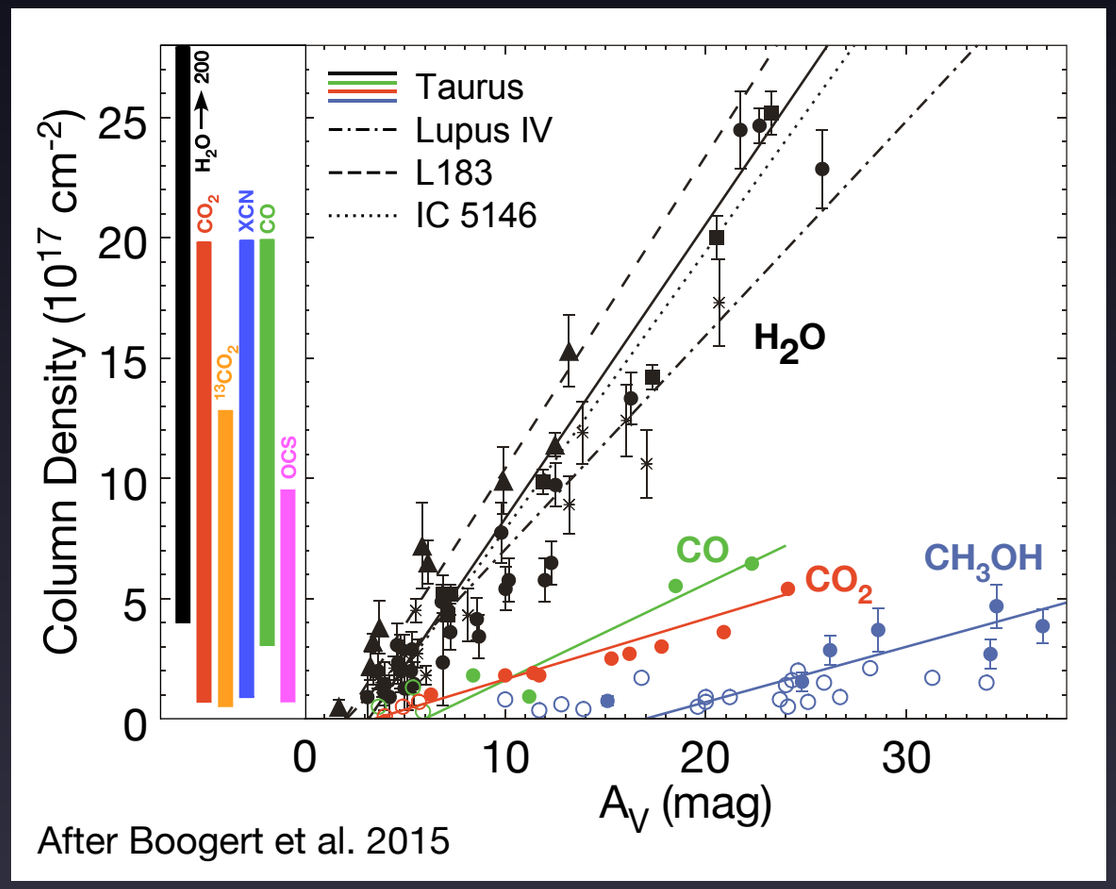

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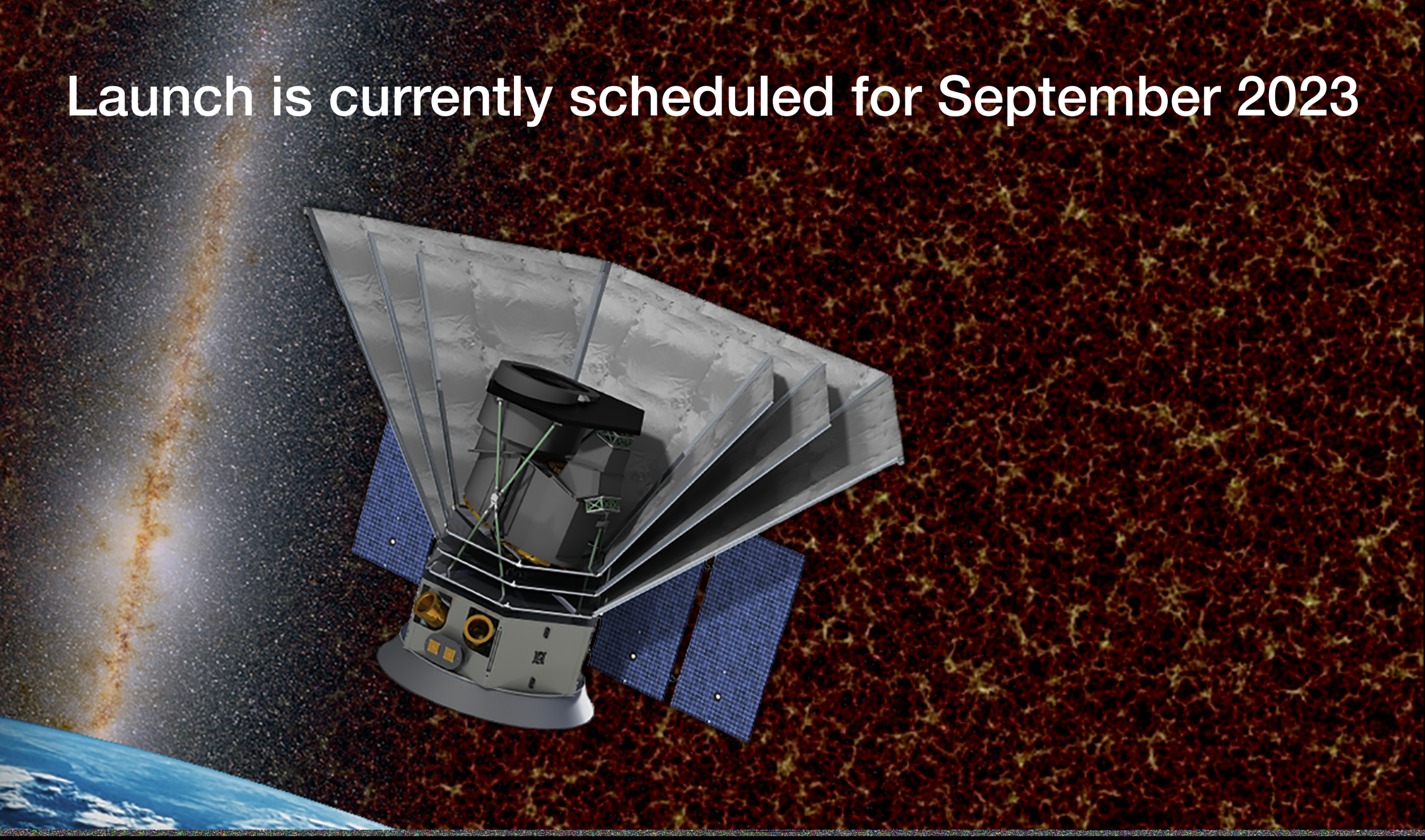
SPHEREx and JWST will be operational at the same time
⇒ SPHEREx can provide a target list of interesting sources for JWST follow-up.

— JWST is not a survey telescope and, thus, cannot produce the extensive and unbiased catalog of spectra possible with SPHEREx.

— However, JWST's ability to cover 0.6 – 28 μm (0.6–5 μm, R ≥ 1000 with NIRSpec; 4.6–28.6 μm, R~3000 with MIRI) can provide valuable follow up of select SPHEREx results.

Launch is currently scheduled for September 2023




End

The 2.5-5 μm range is particularly rich in ice features

Ice Features Between 2.9 and 4.9 μm

TABLE 1. Solid State Transitions: $2.96\,\mu\text{m} \leq \lambda \leq 5\,\mu\text{m}$

Molecule	λ (μm)	$\Delta\nu$ (cm^{-1})	Vibration Mode	A (10^{-17} cm molecule^{-1})
NH_3	2.96	45	–N–H stretch	1.1
H_2O	3.05	335	O–H stretch	20
$–CH_2–$, $–CH_3$ ...	3.47	~ 10	C–H stretch	$\sim 0.1 - 0.4$
CH_3OH	3.53	30	C–H stretch	0.76
CH_3OH	3.95	115.3	C–H stretch	0.51
H_2S	3.95	45	S–H stretch	2.9
CO_2	4.27	18	C–O stretch	7.6
$^{13}CO_2$	4.38	12.9	^{13}C–O stretch	7.8
H_2O	4.5	700	$3\nu_L$ and/or $\nu_2 + \nu_L$	1.0
"XCN"	4.62	29.1	CN stretch	~ 5
CO	4.67	9.71	^{12}CO stretch	1.1
^{13}CO	4.78		^{13}CO stretch	1.3
OCS	4.91	19.6	C–S stretch	17

After Gibb et al. 2004, *ApJ Suppl. Series*, 151, 35 (see their Table 2, p. 38).