Detector Technologies and Performance Requirements for Future Mid-Infrared Space Missions

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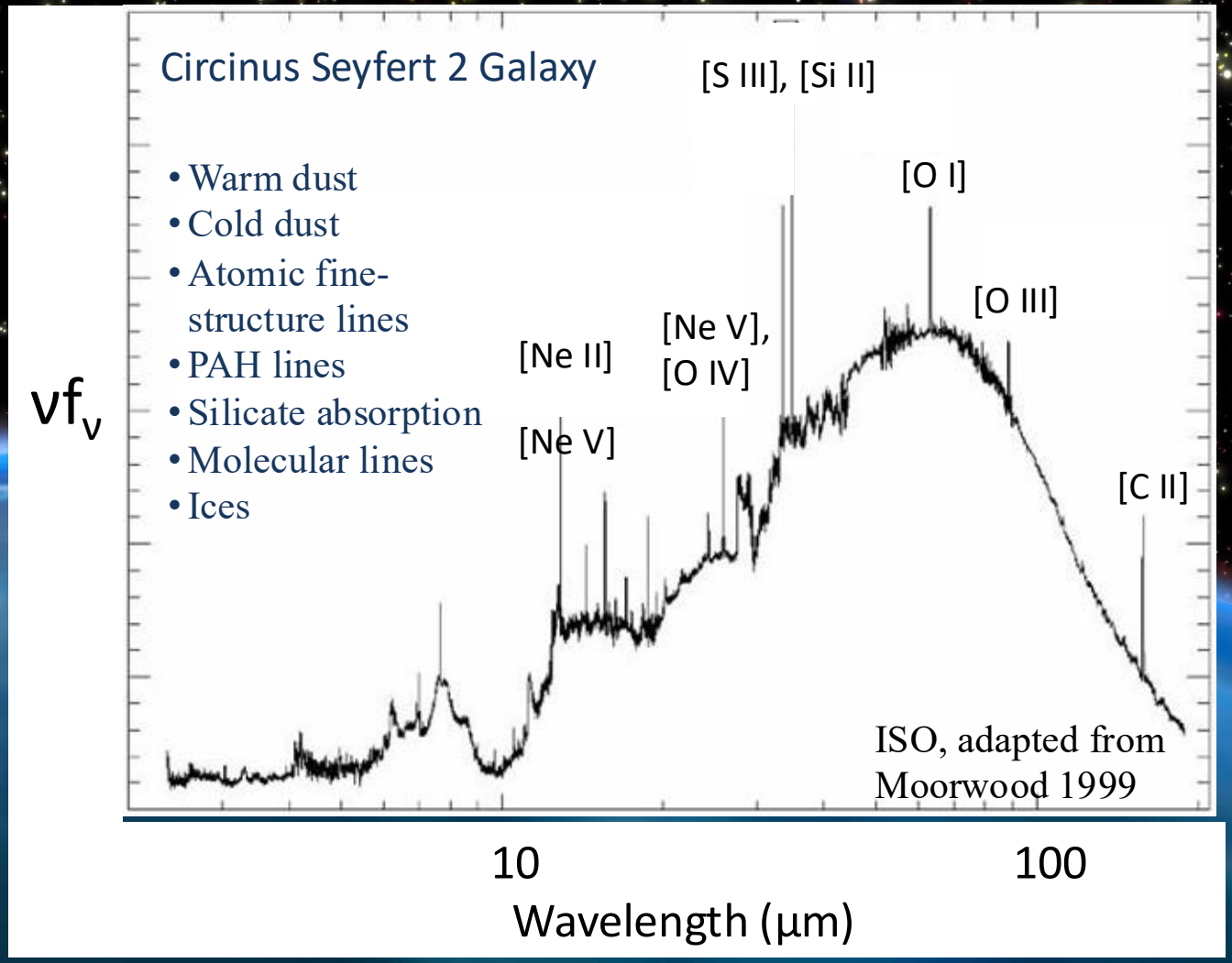
Exploring the Cosmos Through MIR Spectroscopy

MIR covers major science goals from origin of molecular clouds to exo-planet characterization

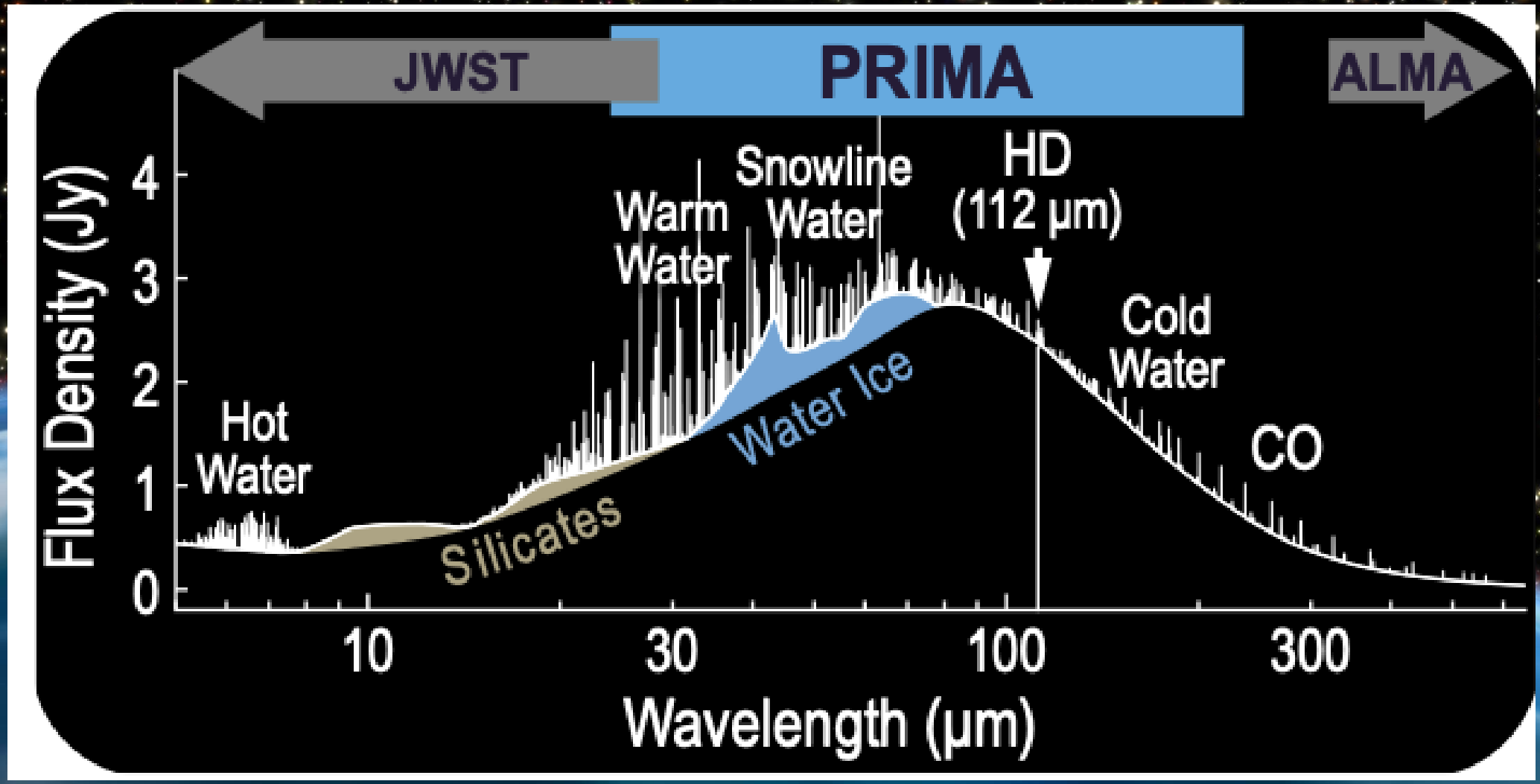
Exploring the Cosmos Through MIR Spectroscopy

Mid- to Far-IR Spectra of Galaxies



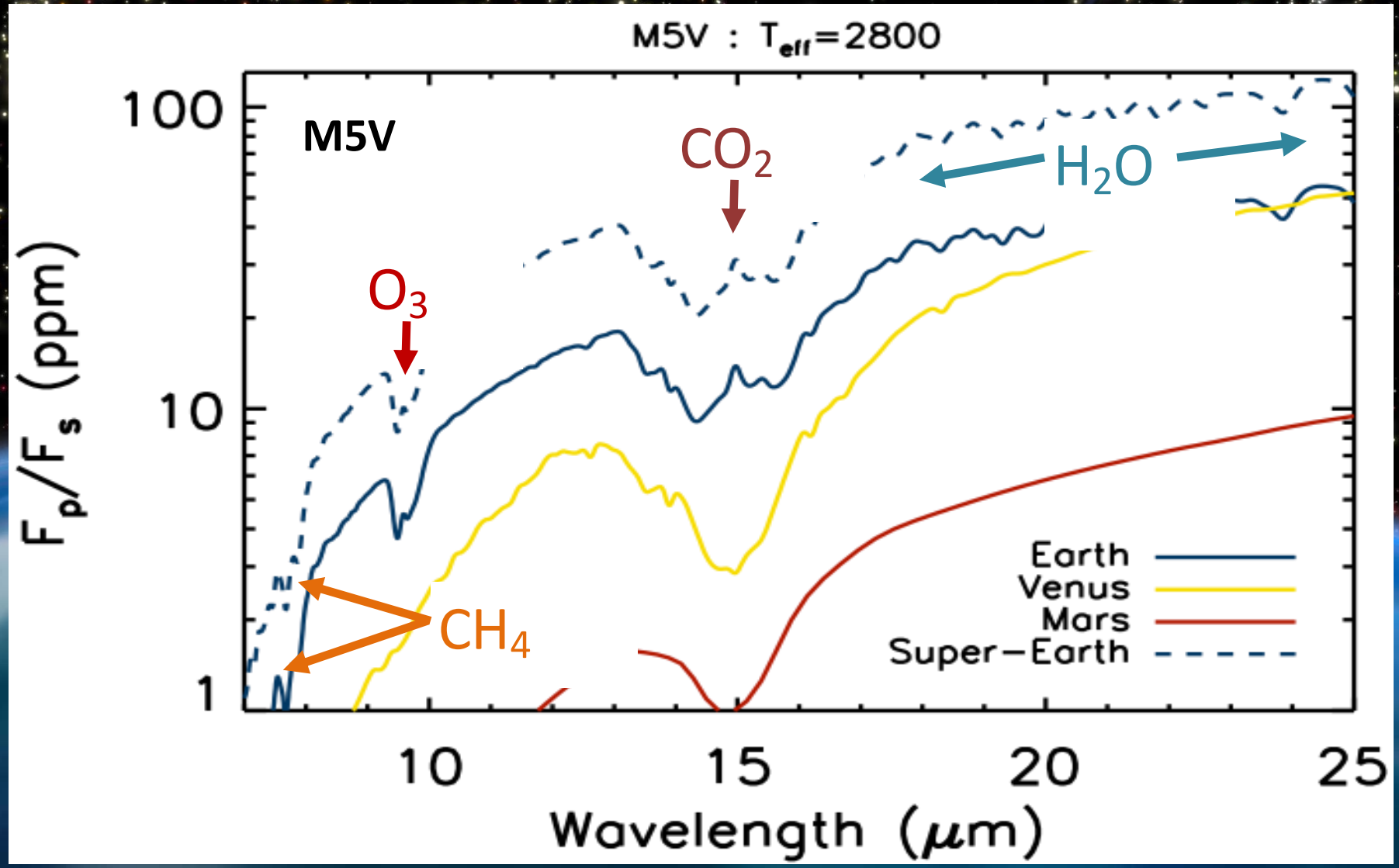
Exploring the Cosmos Through MIR Spectroscopy

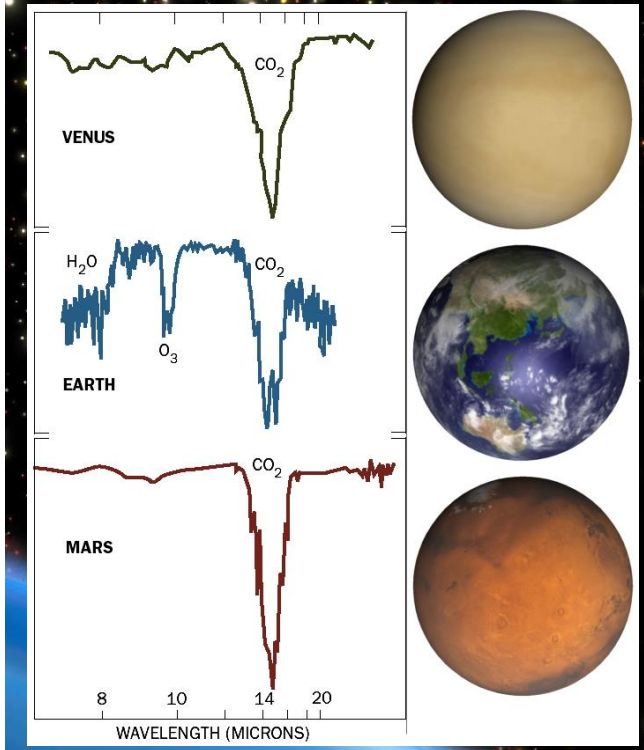
Protoplanetary Disks



Exploring the Cosmos Through MIR Spectroscopy

Exo-Planet Atmospheres





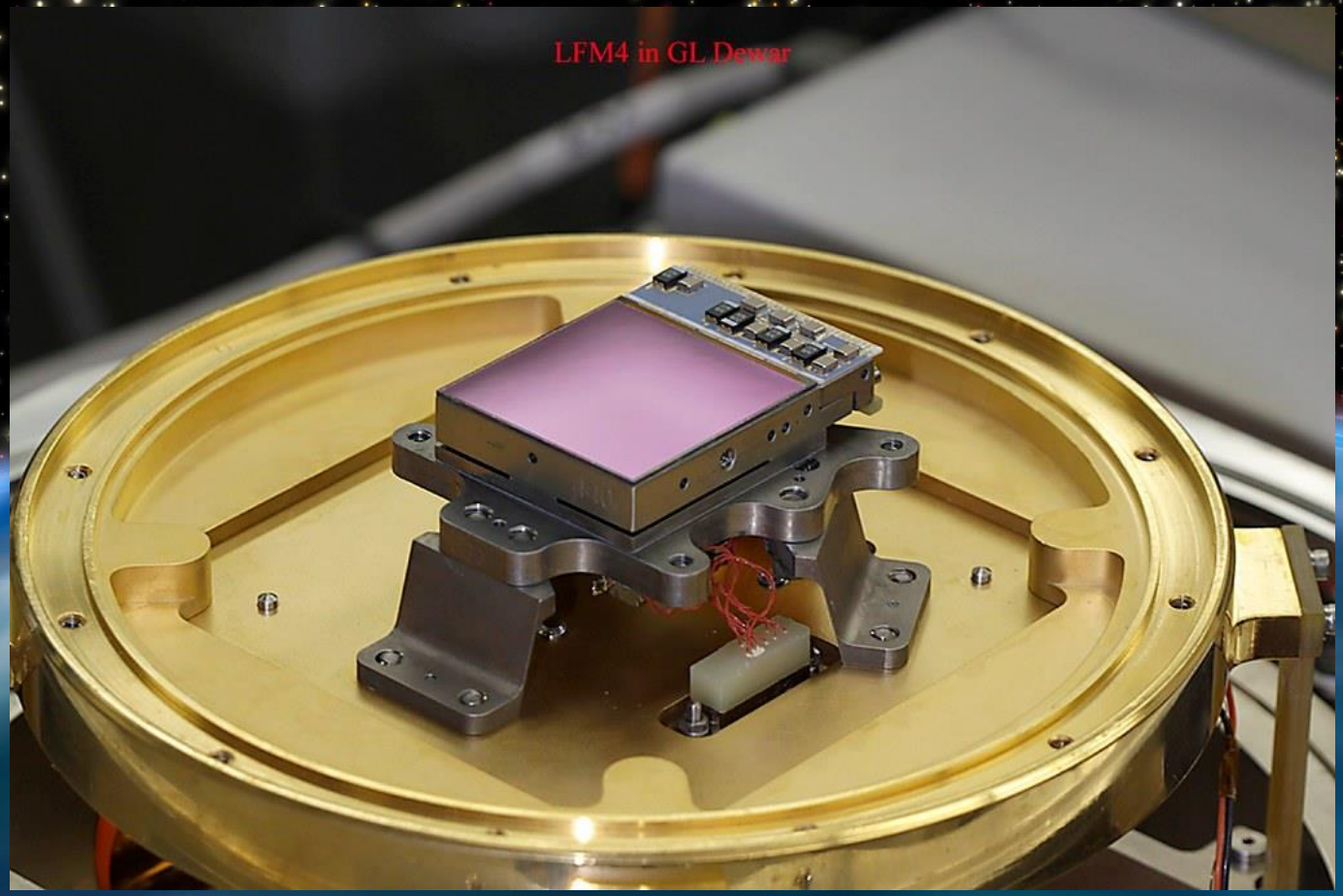
MIR Detector Technologies

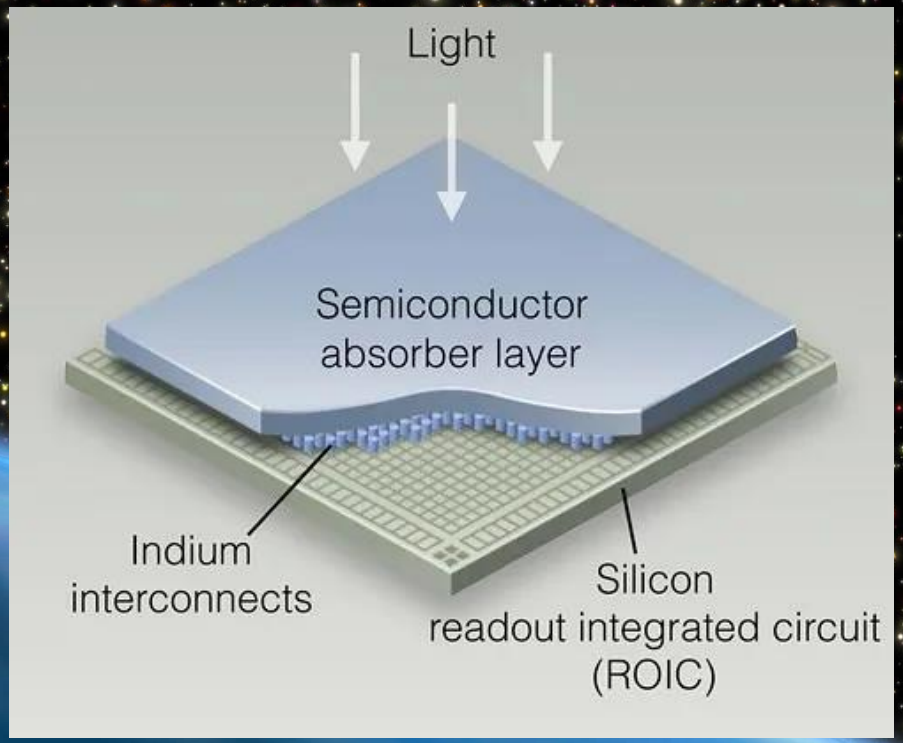
There is a significant number of MIR-capable detector technologies available, in the following we discuss the 3 strongest candidate technologies

Other notable technologies are:

- Arsenic Doped Silicon (Si:As) Detectors
- Superconducting Nano Wire Detectors
- Quantum Capacitance Detectors

HgCdTe Detectors

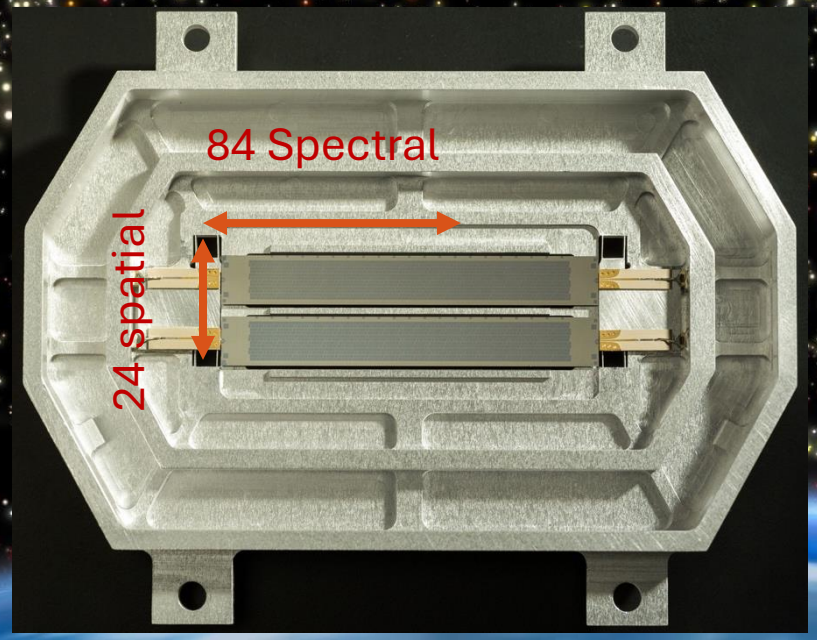




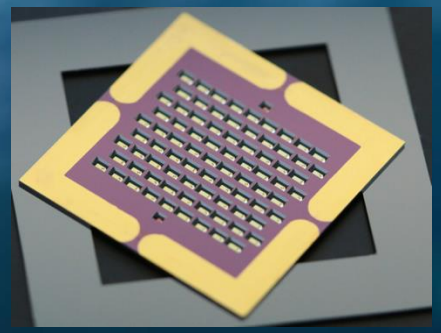
Note:

- Current long wavelength limit:16.7 μm
- S/N during signal accumulation scales as $t^{2/3}$

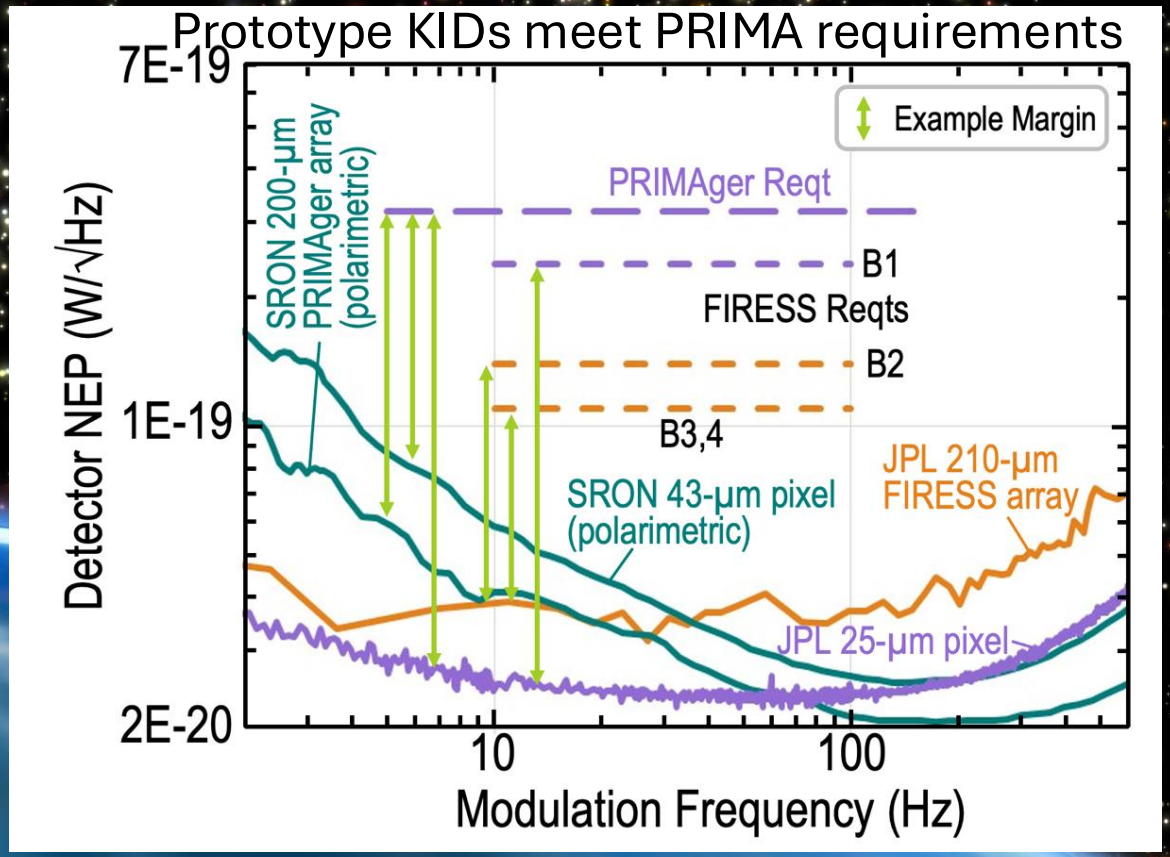
KIDs: Culmination of 2 Decades of Technology Investment



JPL FIRESS prototype KID arrays with GSFC microlenses

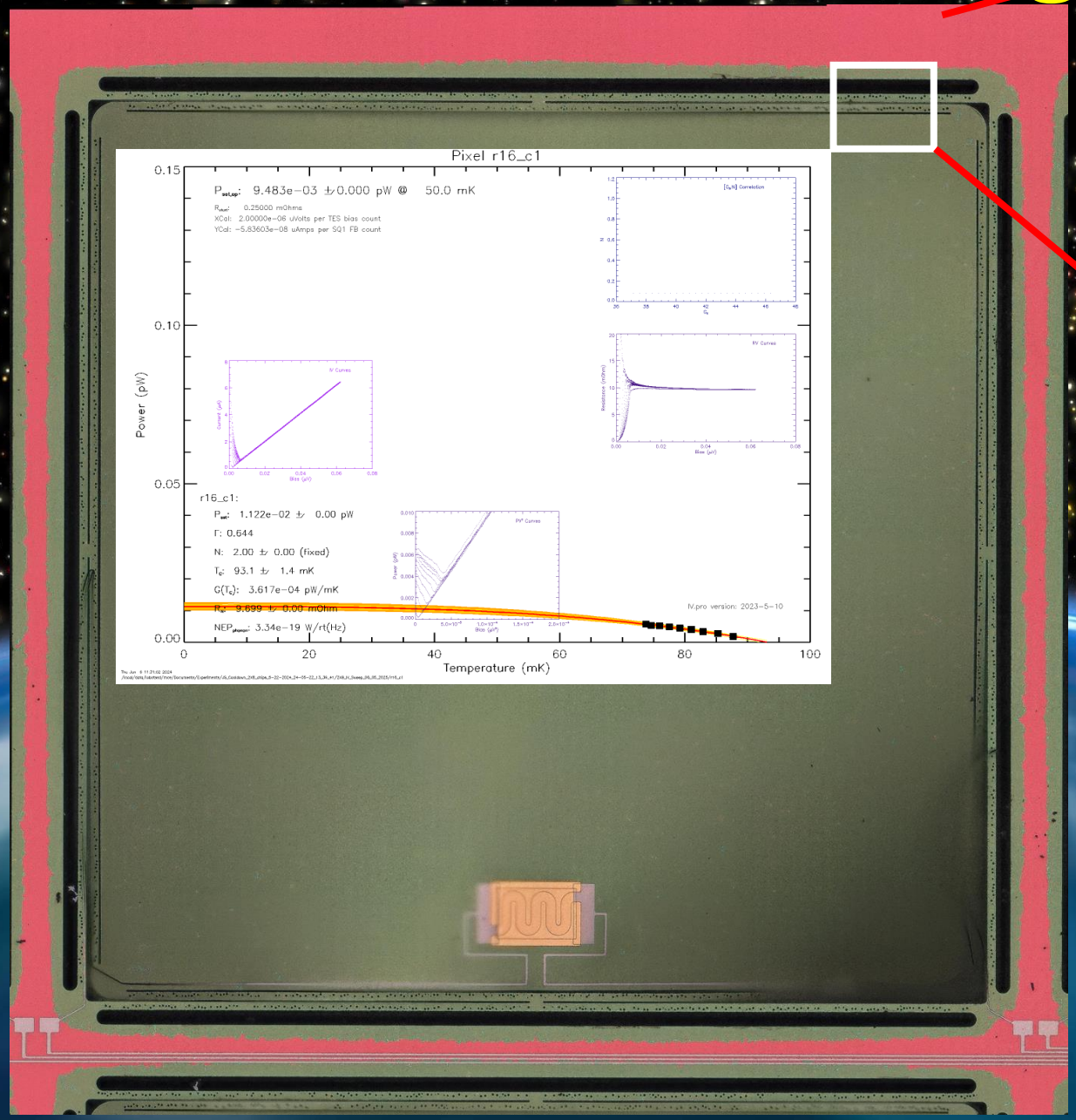


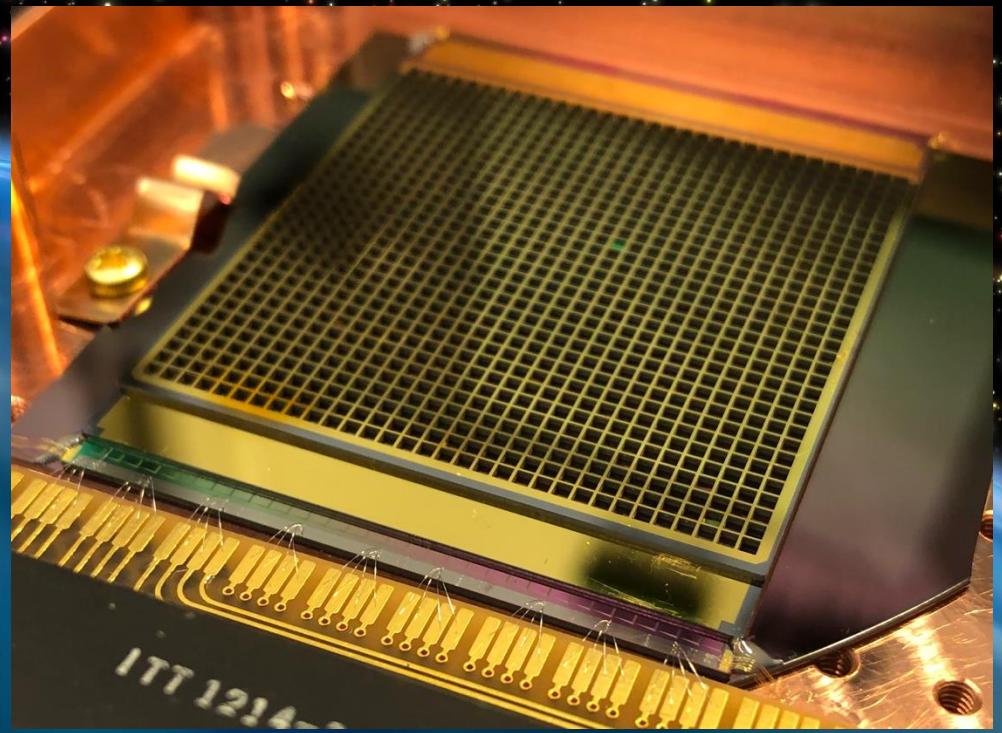
SRON polarimetric KIDs (derived from SPACEKIDs effort for SPICA)



25 μm result: Day+ 2024, Phys Rev X

Transition Edge Sensors

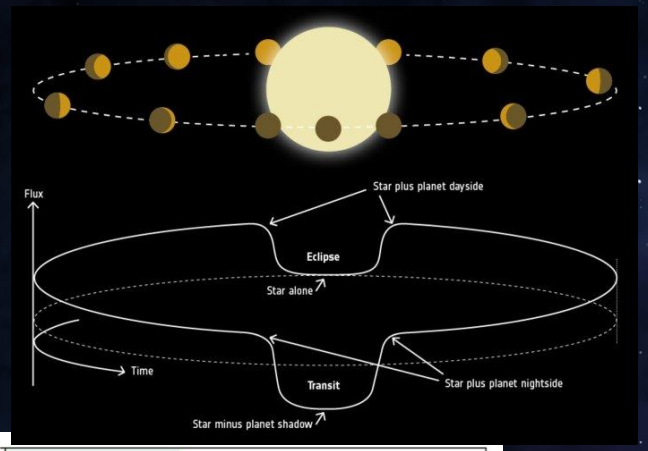


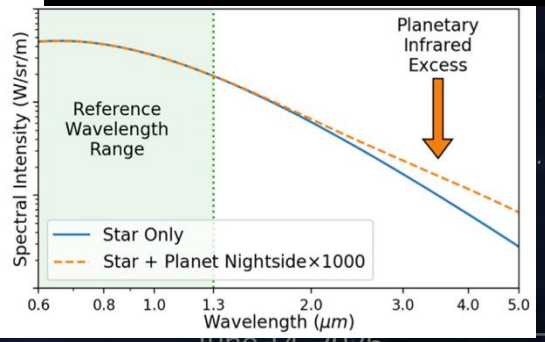


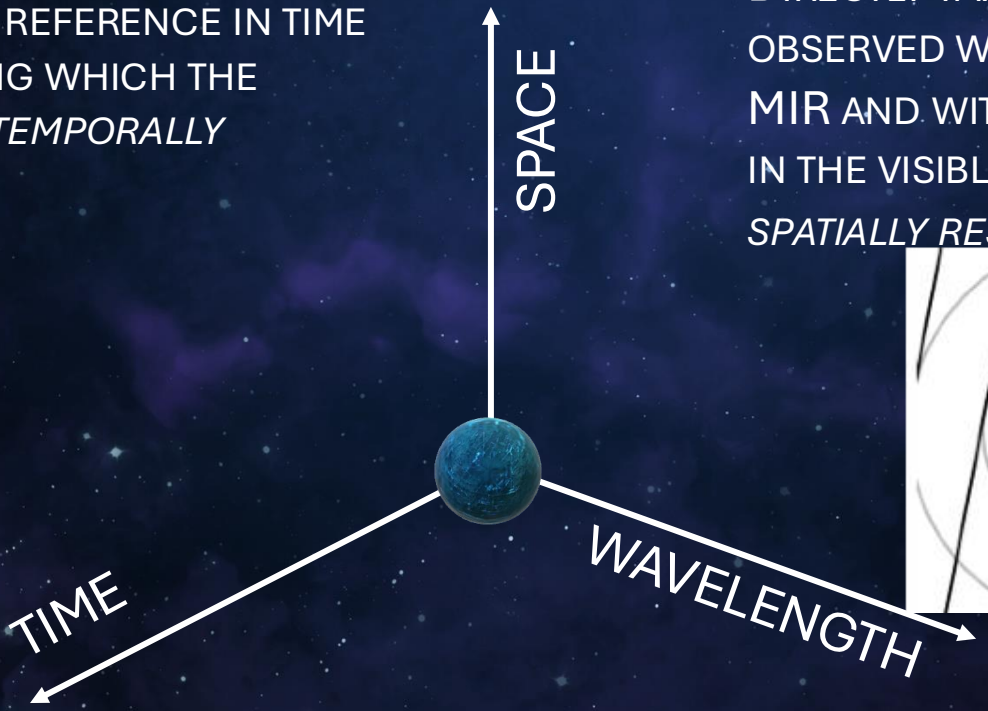
How to Observe Habitable Zone Exo-Planets

(and how it applies to exoplanet characterization)

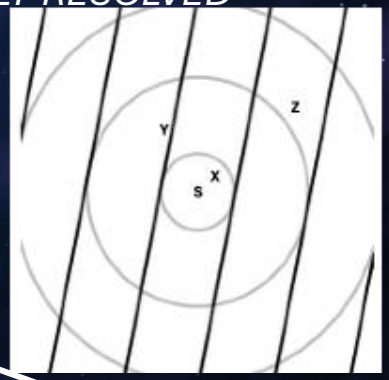
- Transiting planets have a reference in time (secondary eclipse) during which the planet's flux is blocked (*temporally resolved*)

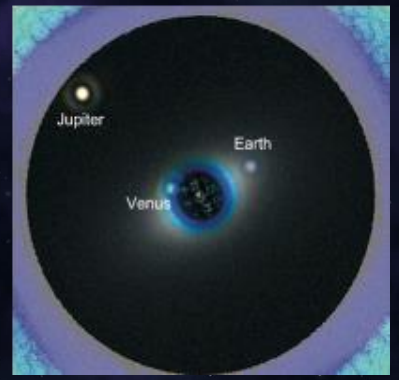






- Directly-imaged exoplanets can be observed with an Interferometer in the MIR and with a coronagraph or starshade in the visible/NIR to observe the planets *spatially resolved*





- Stevenson (2020) proposed that sufficiently broad wavelength coverage will allow the planet and star to be *spectroscopically resolved*

Image credit: Slide is a modified version of figure from K. Sevenson

MIRECLE: MIR-Exo-Planet Mission

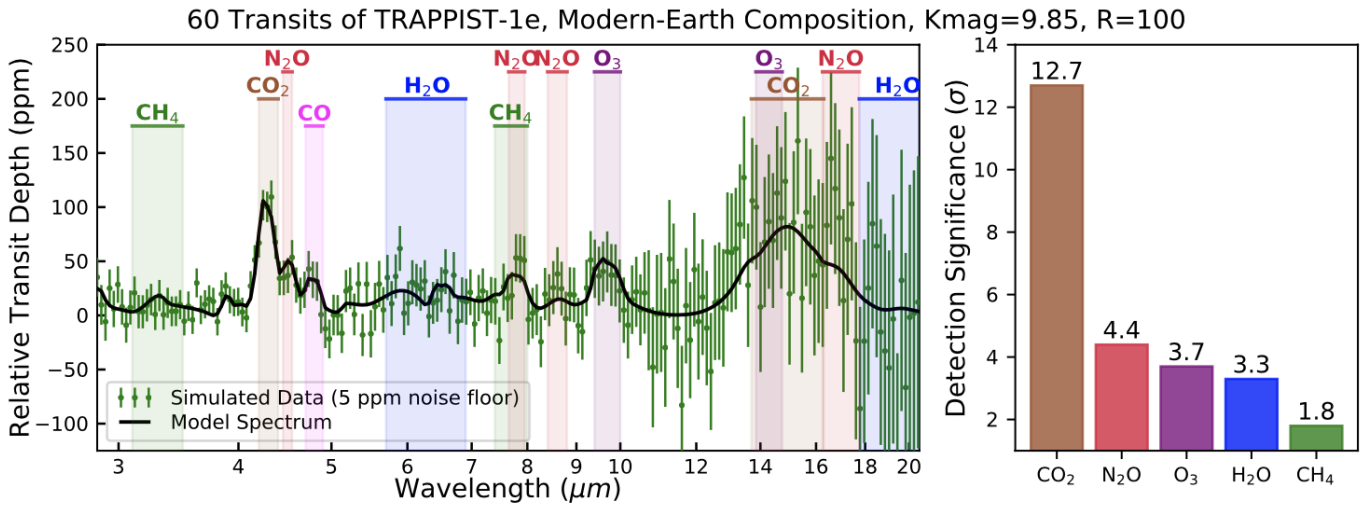


Figure 1: **A mid-infrared mission expressly designed with simultaneous, broad-wavelength coverage and a low (~5 ppm) noise floor would be primed to detect key bio-indicator and biosignature gases in the atmospheres of terrestrial planets in the habitable zones of M dwarfs.**

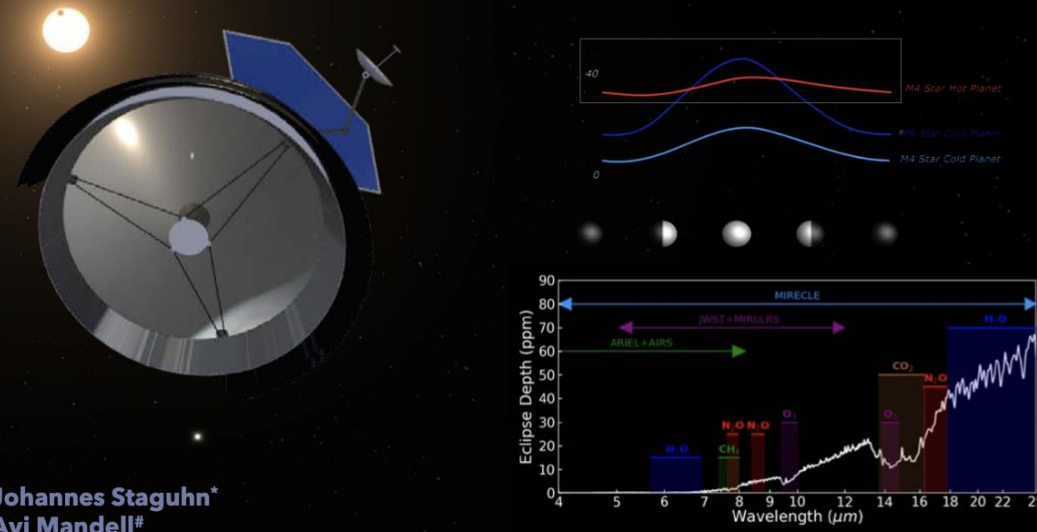
From Kataria et al., 2020 Decadal White Paper

Staguhn et al,
Decadal White Paper.
2019arXiv190802356S

MIRECLE

Mid InfraRed Exoplanet CLimate Explorer

EXPLORING M-EARTHS WITH ULTRA-STABLE MID-IR TRANSIT AND PHASE-CURVE SPECTROSCOPY



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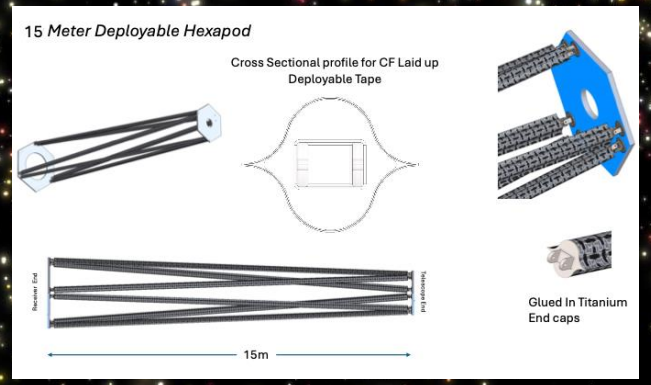
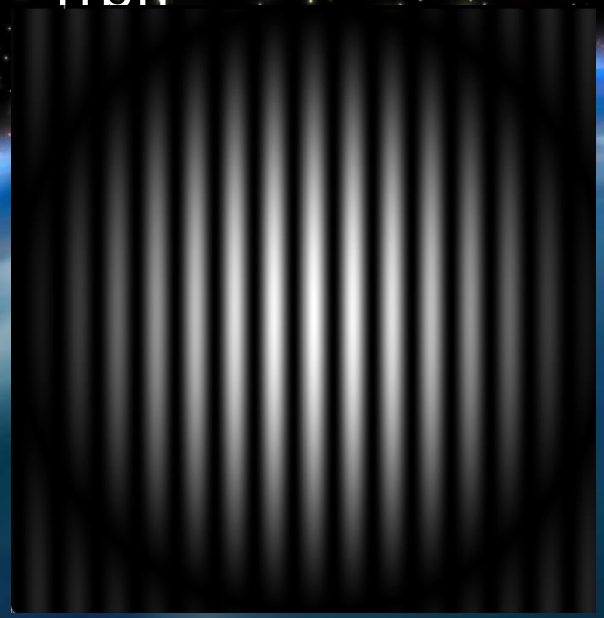
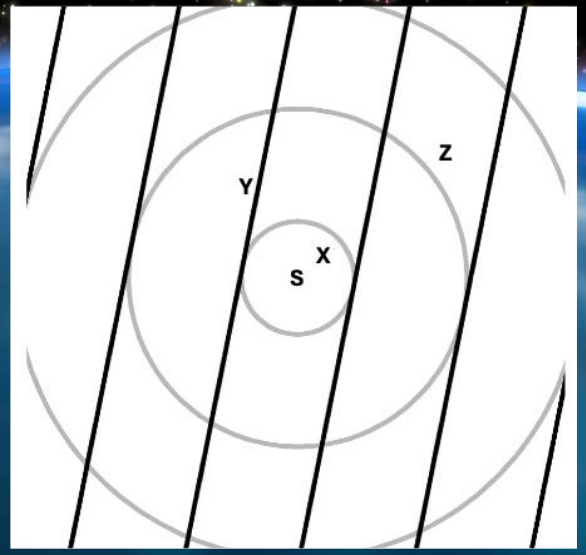
Background image credit: NASA Ames/JPL-Caltech/T

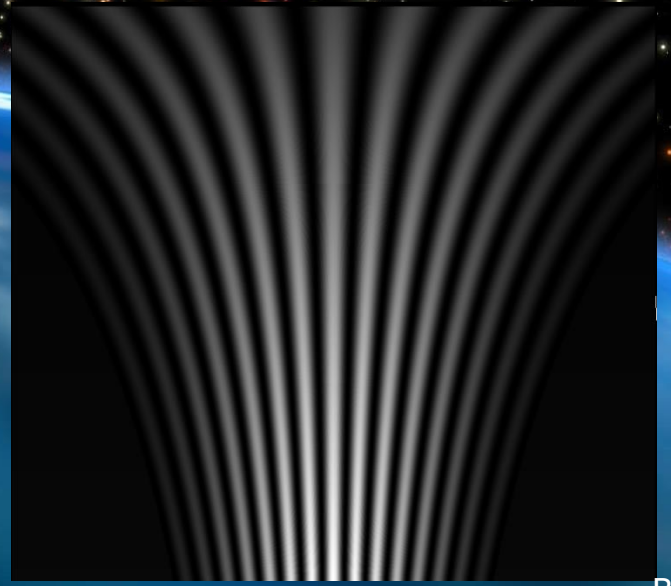
Space InfraRed Two-element Exoplanet Nuller AdASTRA Concept SIRTEN

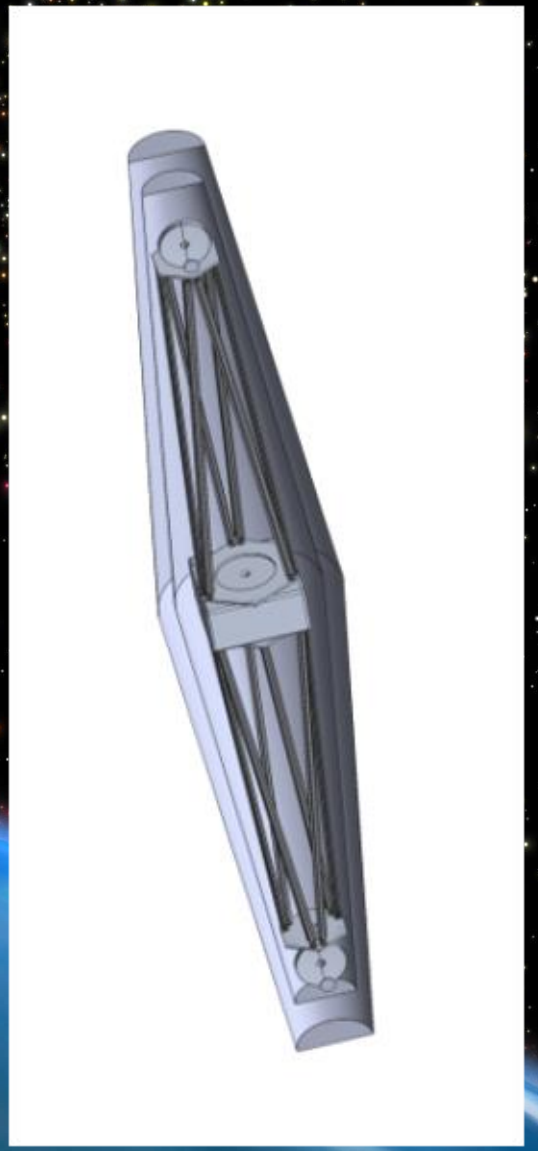
- Identification and Characterization of Exo-planet atmospheres around F, G, and K- stars
- Single Bracewell Nulling Interferometer will rotate around its central axis at 1rph





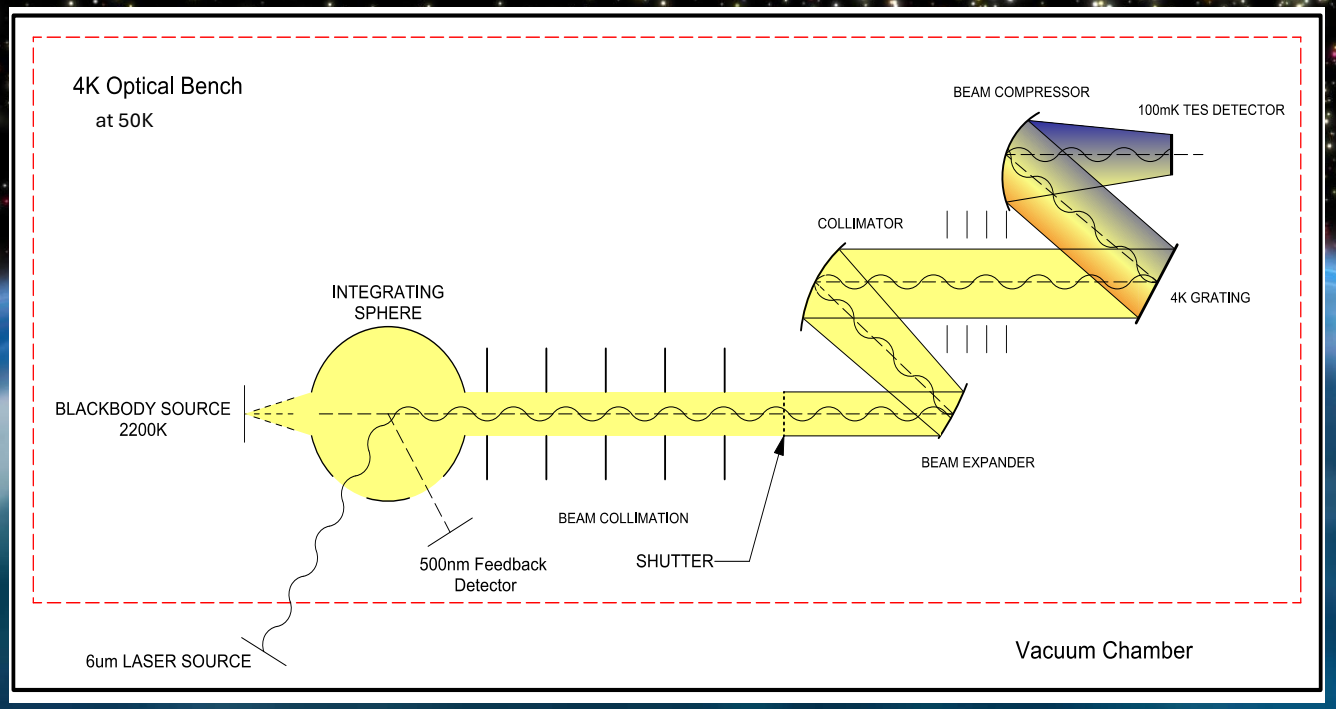


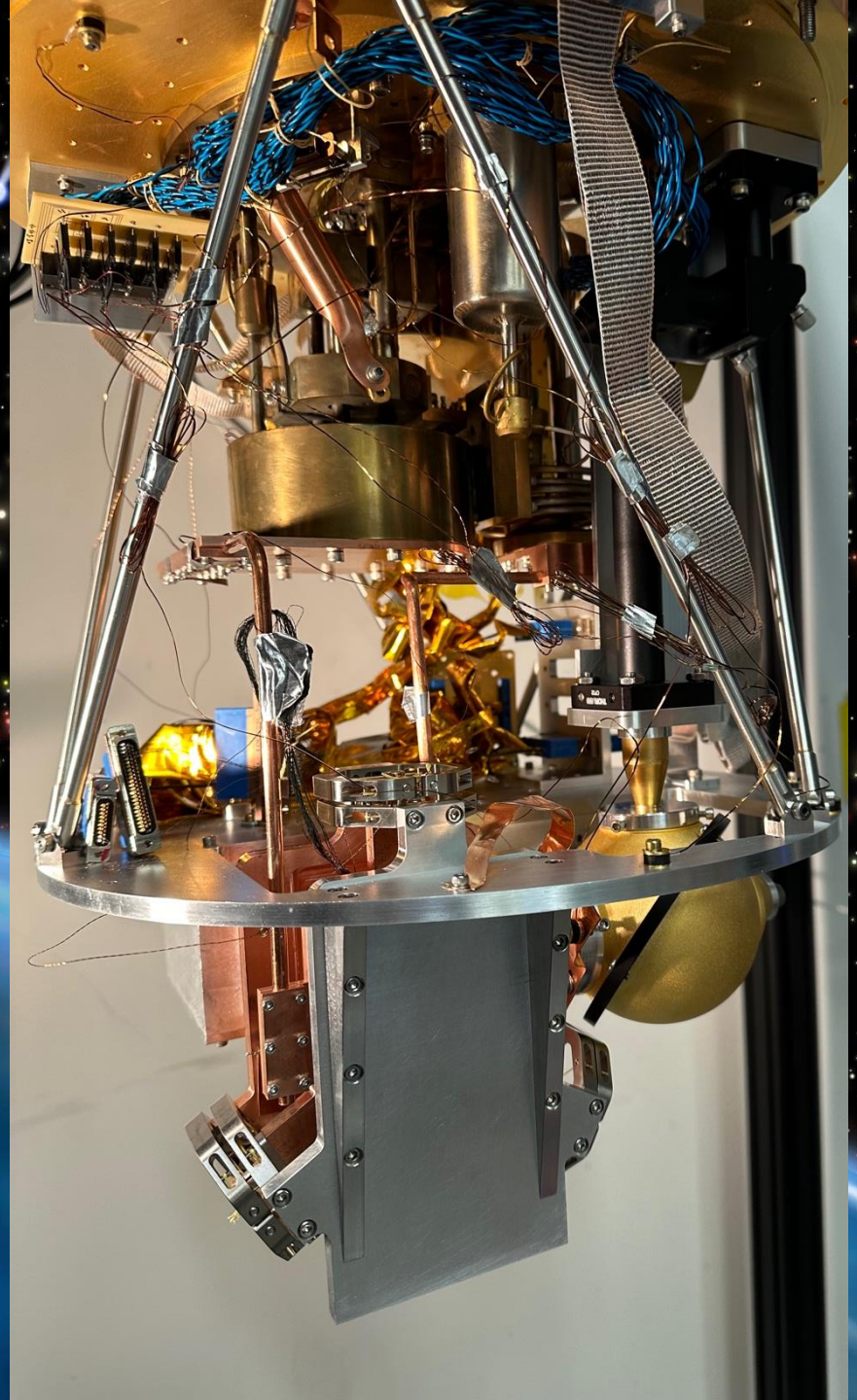




Booms potentially made of rollable, pre- shaped carbon sheets, see Fernandez, 2017

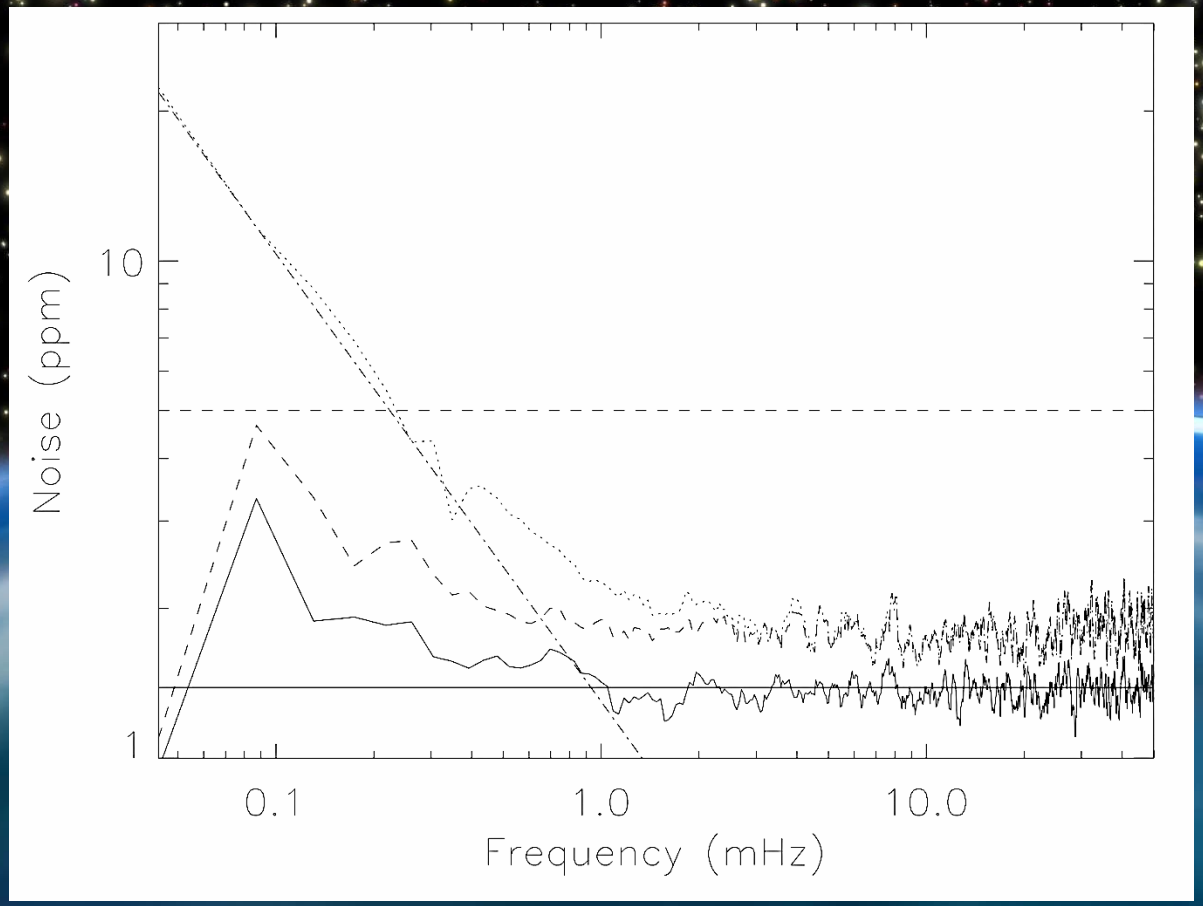
1/f noise is Key to Exo-Planet Observations: an Ultra-Stable MIR Spectroscopy with TES Detectors



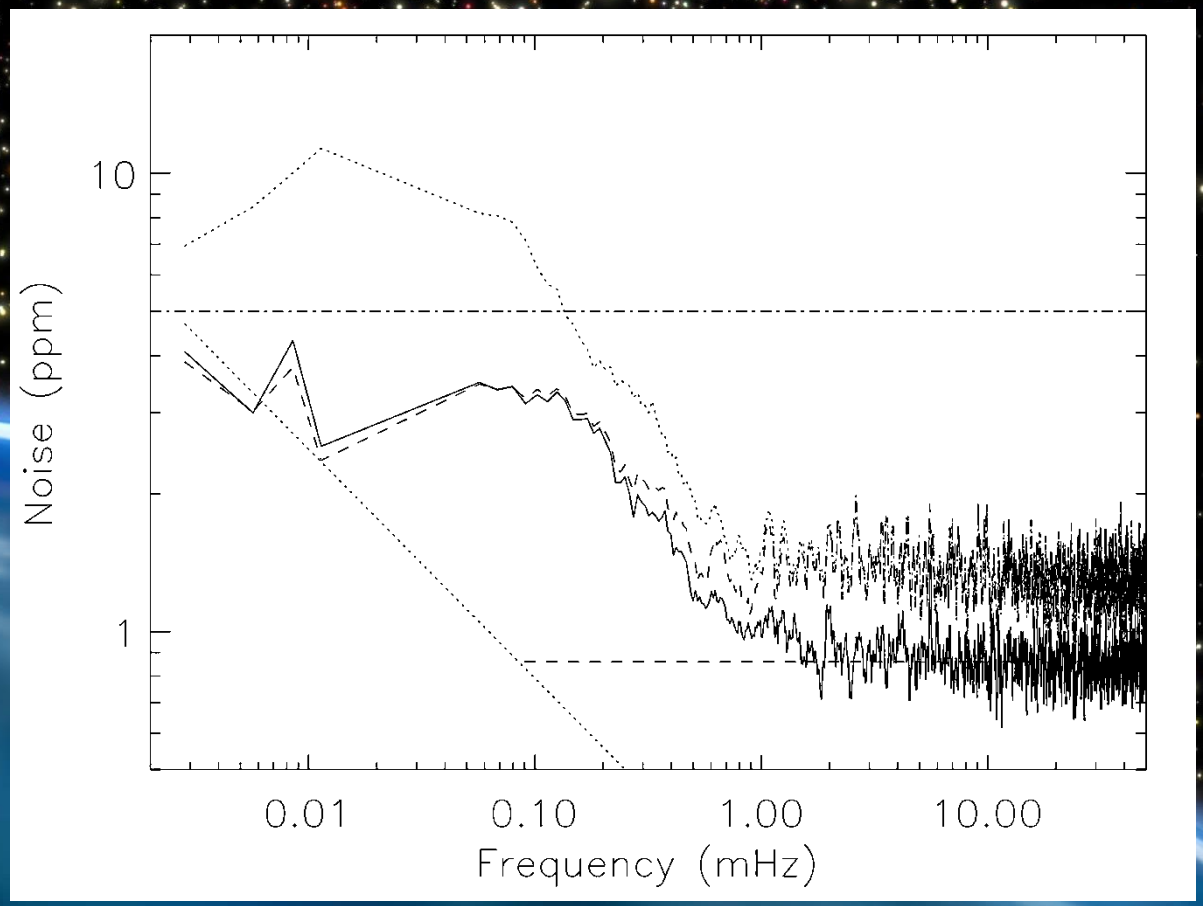


MIRASET achieves < 5 ppm noise floor over 4 days (down to ~ 1 μHz)

6hours



4-days (4x 6hours)



Fixsen, D. J., et al. 2025, Review of Scientific Instruments, 96

Superconducting

KIDs

Pros:

- fast (< ms)
- Very low NEPs
- Large Dynamic Range

Cons:

- Sub-K cooling requirements
- Poor 1/f stability
- High cosmic ray cross-sections
- Current designs have low point source coupling efficiencies
- Limited number of array pixels (kilopixel arrays)

TES

Pros:

- Very stable (excellent 1/f),
- Demonstrated in ultra-stable MIR spectrometer
- Very good point source coupling efficiencies at at all wavelengths

Cons:

- Sub-K cooling requirements
- Still room for improvement for sensitivity
- Limited number of array pixels (kilopixel arrays)

Semiconductor

HgCdTe Detectors

Pros:

- Operate at >> 1 K

  ($T[K] < 400/\lambda[\mu m]$)
- Large Pixel numbers (mega pixel arrays)
- Can count photons over long integration times (minutes)
- Low cosmic ray cross-sections

Cons:

- Slow
- Limited wavelength coverage (currently 16.7 um cutoff)

Summary

- Superconducting detectors, as well as HgCdTe-based arrays are good options for MIR Spectroscopic Space Missions
- HgCdTe require significant less cooling and provide large pixel numbers (megapixels). However, they currently have a cutoff wavelength of 16.7 μm and require large readout times (minutes) to achieve photon-counting sensitivities
- Superconducting detectors will be the choice where fast, low noise readout is required (fast sky mapping, fast spectrometer modulation, etc....)
- Exo-Planet instrumentation will require an ultra stable spectrometer design, such as MIRASET.