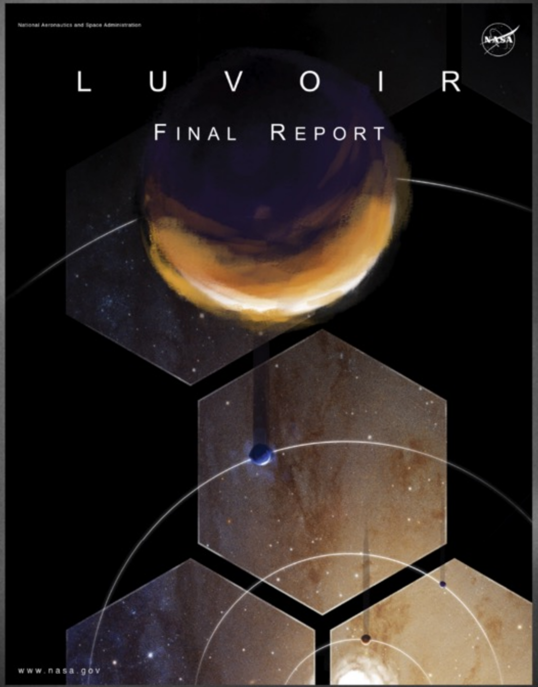
Future Flagships for Disks and Young Planets

Aki Roberge

NASA Goddard Space Flight Center

Sagan Summer Workshop
July 23, 2021

a NEW EPOCH *of* DISCOVERY



www.GREATOBSERVATORIES.org

Wavelength Range Comparison

LUVOIR

HABEX

LUVOIR ARCHITECTURES

Two LUVOIR designs

Total wavelength range: 100 nm – 2.5 μm

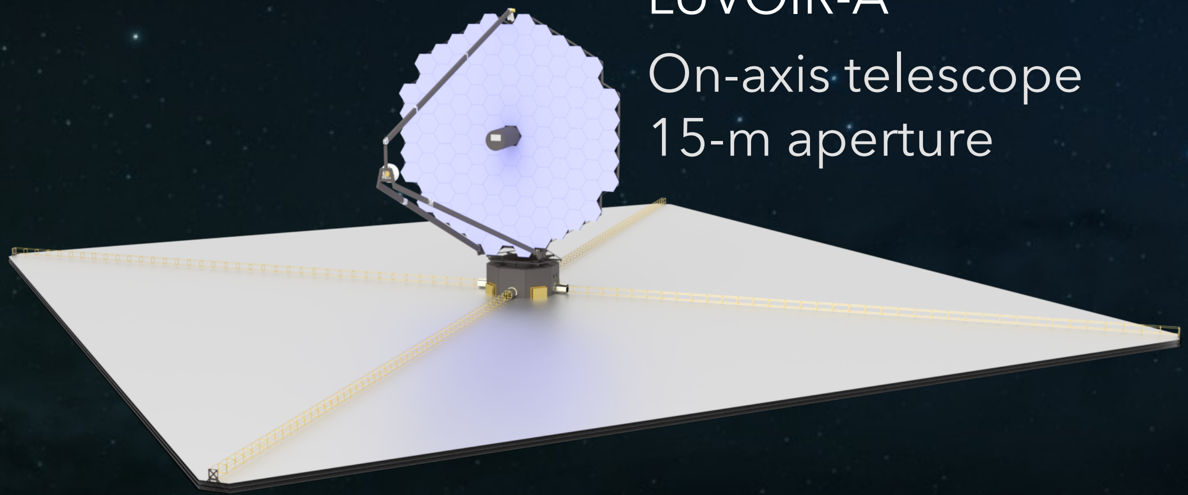
Four instruments (discussed in next slides)

Launch date ~ late-2030s

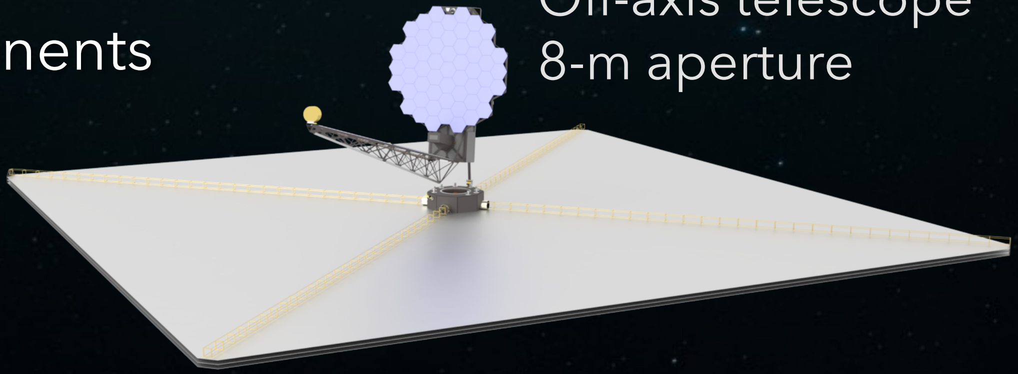
Serviceable and upgradable

5-year prime mission duration, 10 years of consumables

25-year lifetime goal for non-serviceable components



LUVOIR-A
On-axis telescope
15-m aperture



LUVOIR-B
Off-axis telescope
8-m aperture

LUVOIR-A deployment and pointing sequence

Watch LUVOIR-B video at https://www.luvoirtelescope.org/design

The LUVOIR instruments

Observational challenge

Faint planets next to bright stars

Extreme Coronagraph for LIving Planetary Systems (ECLIPS)

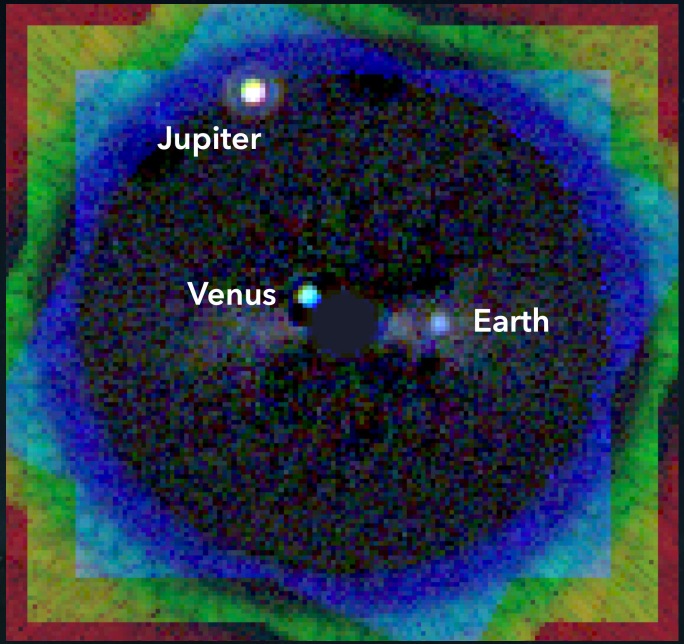
Contrast ~ 10^{-10}

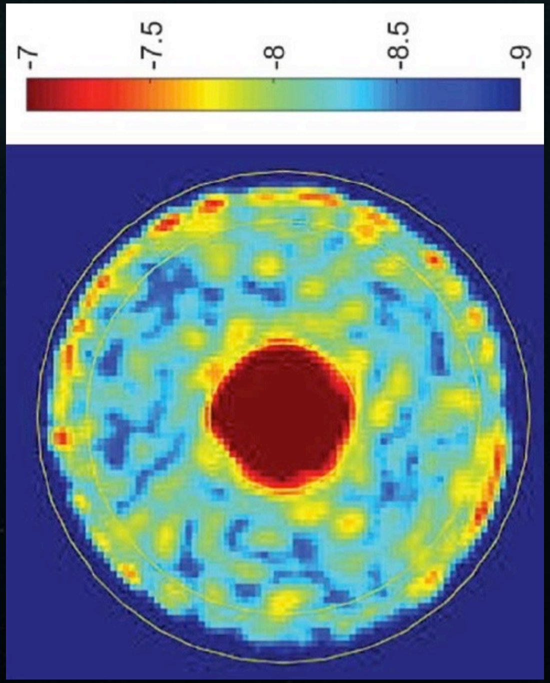
Bandpass: 0.2 μm to 2.0 μm

Broad-band imaging

Imaging spectroscopy: Vis R=140, NIR R=70 & 200

Tech development via Roman Space Telescope Coronagraph Instrument





Roman Hybrid Lyot Coronagraph

The LUVOIR instruments

Observational challenge

Very cold to very hot gases

LUVOIR UV Multi-Object Spectrograph (LUMOS)

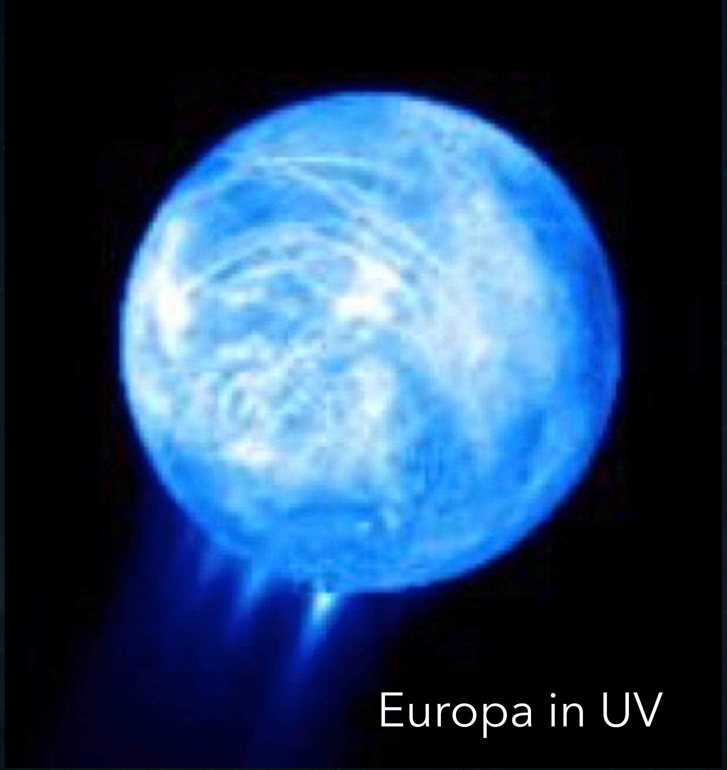
Bandpass: 100 nm to 1000 nm

R = 500 – 56,000

Up to 840 simultaneous spectra

FUV imaging channel

Heritage from STIS, COS, & NIRSPEC



Europa in UV

HST COS UV instrument

The LUVOIR instruments

Observational challenge

Imaging the ultra-faint and very small at high resolution

High-Definition Imager (HDI)

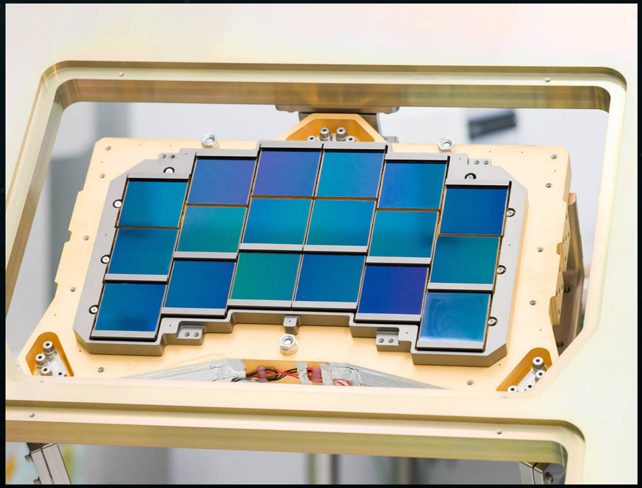
2 x 3 arcmin field-of-view

Bandpass: 0.2 μm to 2.5 μm

Large suite of filters & grisms

Micro-arcsec astrometry capability

Heritage from HST WFC3 & Roman WFI



Roman WFI focal plane

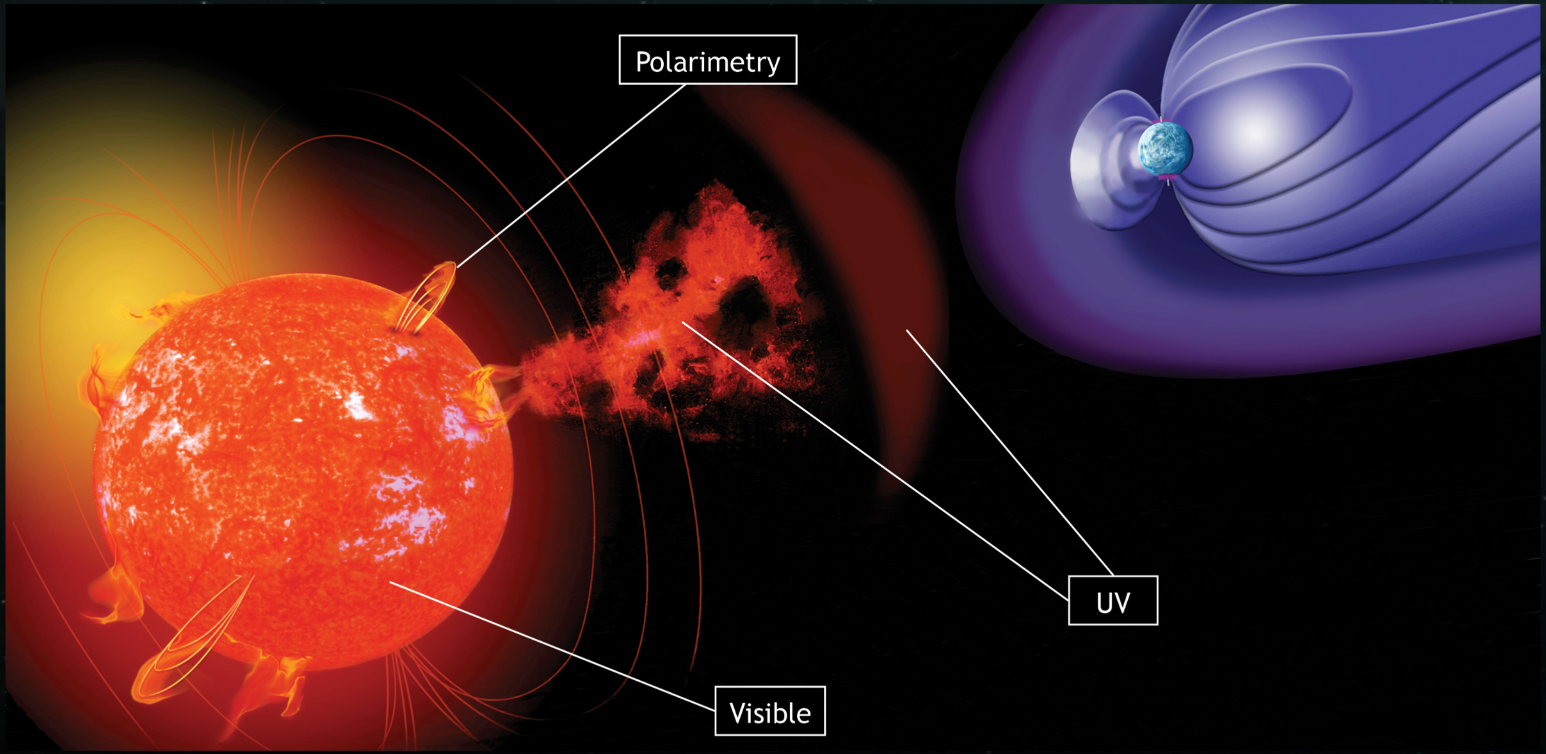
POLLUX – EUROPEAN CONTRIBUTION TO LUVOIR

CNES CENTRE NATIONAL D'ETUDES SPATIALES

UV spectropolarimeter (100 – 400 nm)

Circular + linear polarization

High resolution point-source spectroscopy (R ~ 120,000)



- Star-exoplanet interactions
- Fundamental physics & cosmology
- ISM and CGM
- Stellar magnetic fields
- Active galactic nuclei
- Solar System

HabEx

PREFERRED ARCHITECTURE

4-m off-axis monolith primary mirror

Total wavelength range: 115 nm – 1.8 μm

Four instruments:

- Coronagraph Instrument → similar to LUVOIR ECLIPS
- UV Spectrograph (UVS) → similar to LUVOIR LUMOS
- HabEx Workhorse Camera (HWC) → similar to LUVOIR HDI
- Starshade Instrument → unique to HabEx

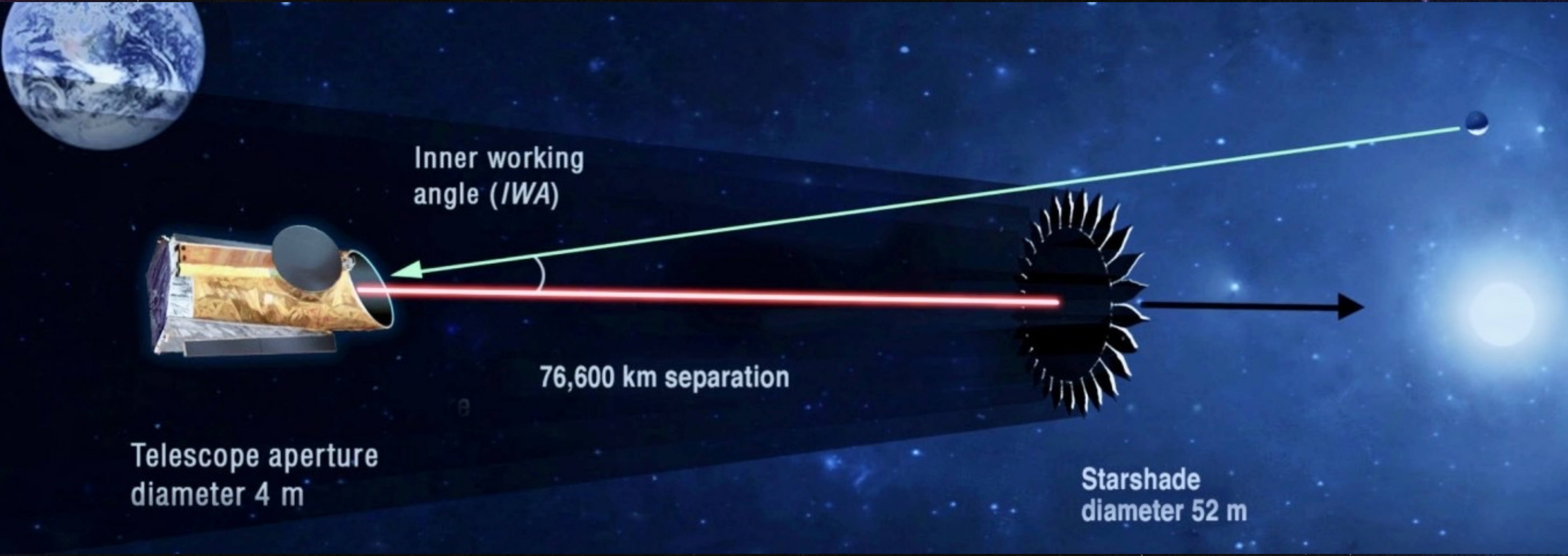
Launch date ~ mid-2030s

Serviceable

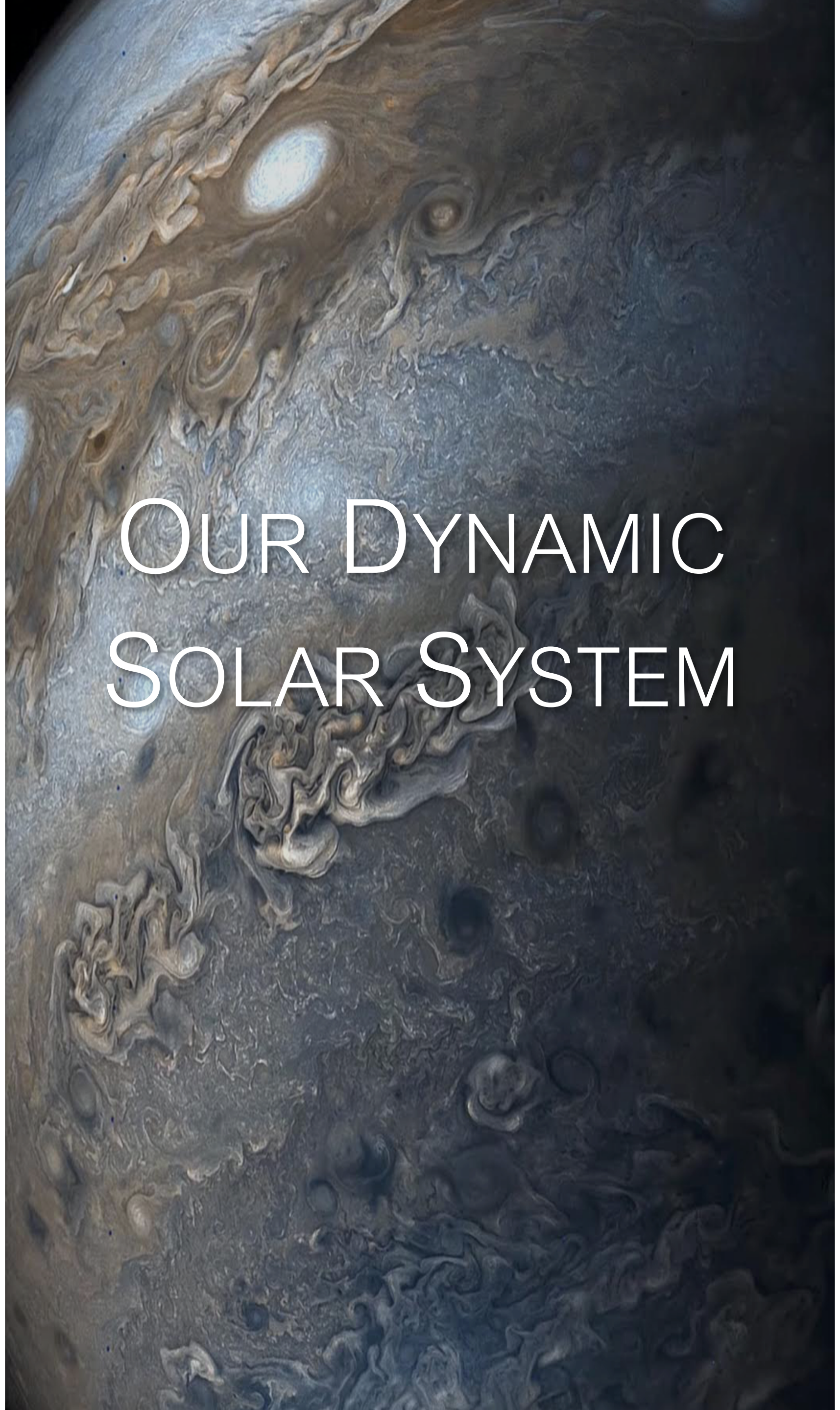
5-year prime mission duration, 10 years of propellant

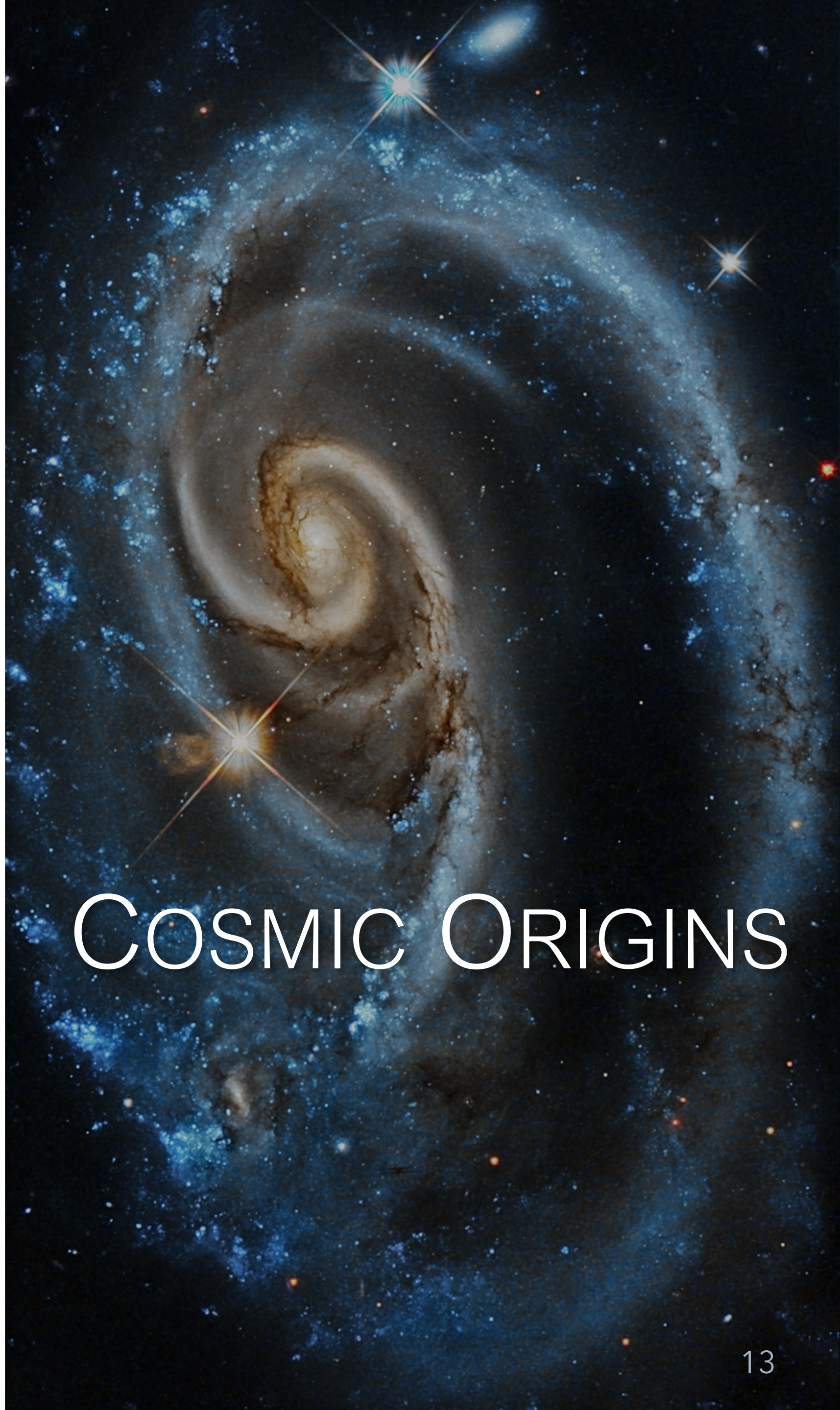
Also studied 8 other architectures with smaller apertures

STARSHADE


Inner working angle (*IWA*)
76,600 km separation
Telescope aperture diameter 4 m
Starshade diameter 52 m


Exotic Worlds
The Search for Life

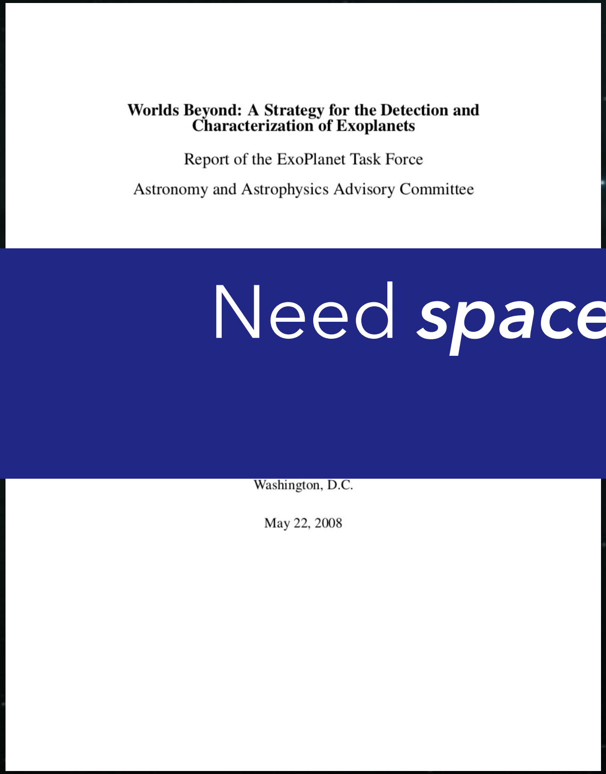

Our Dynamic Solar System


Cosmic Origins

Designing a well-posed search for life experiment

Finding Earth-like planets & life would be a momentous achievement

2008


Worlds Beyond: A Strategy for the Detection and Characterization of Exoplanets

Report of the ExoPlanet Task Force

Astronomy and Astrophysics Advisory Committee

Washington, D.C.

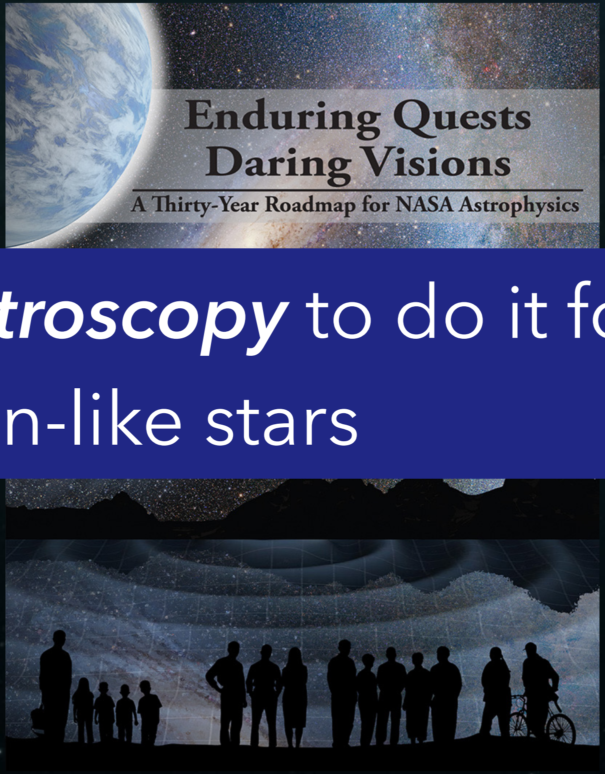
May 22, 2008

AAAC Exoplanet Task Force

2010

NAS Astro2010 Decadal

2013



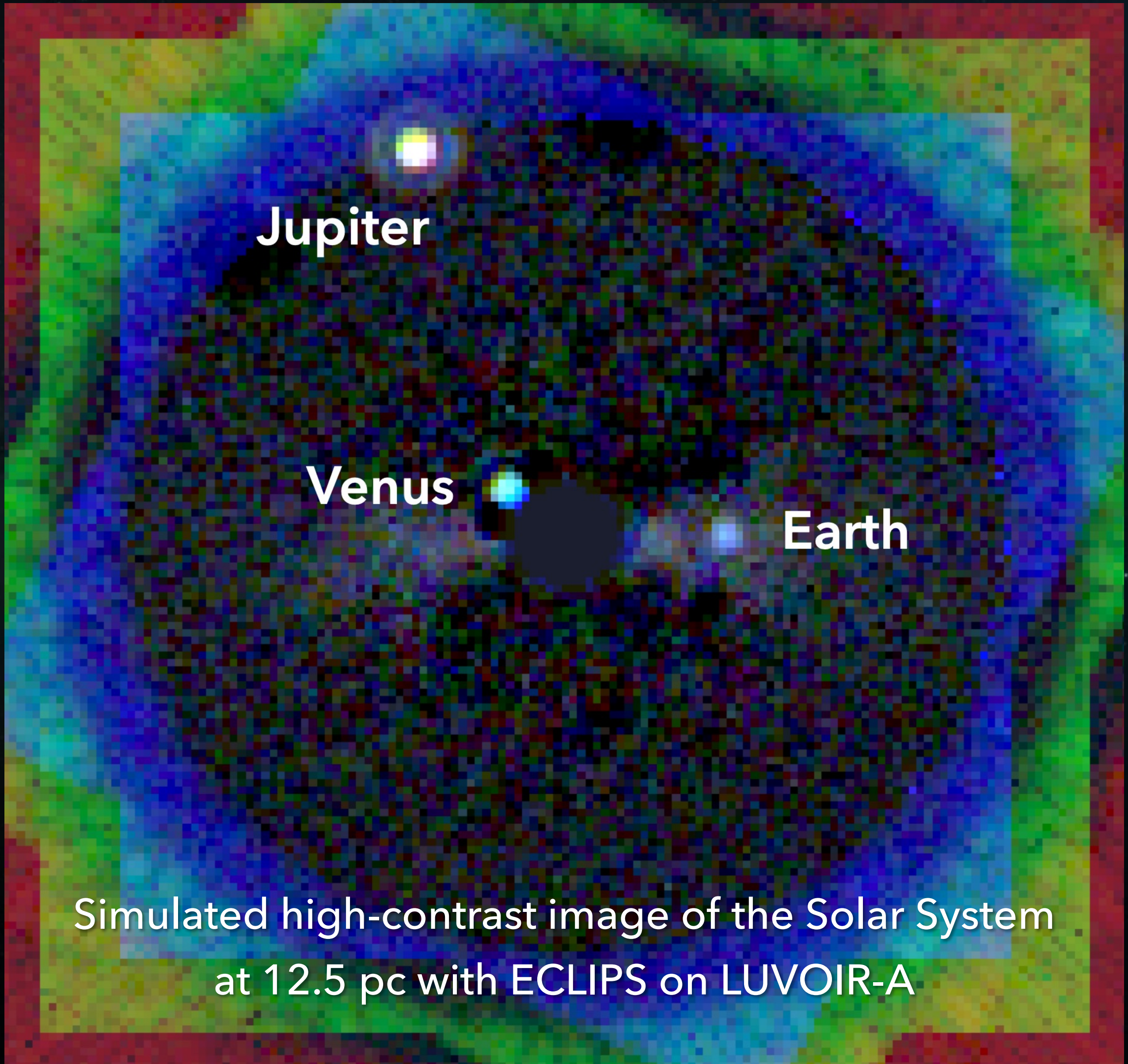
NASA Astro Roadmap

2018

NAS Consensus Study

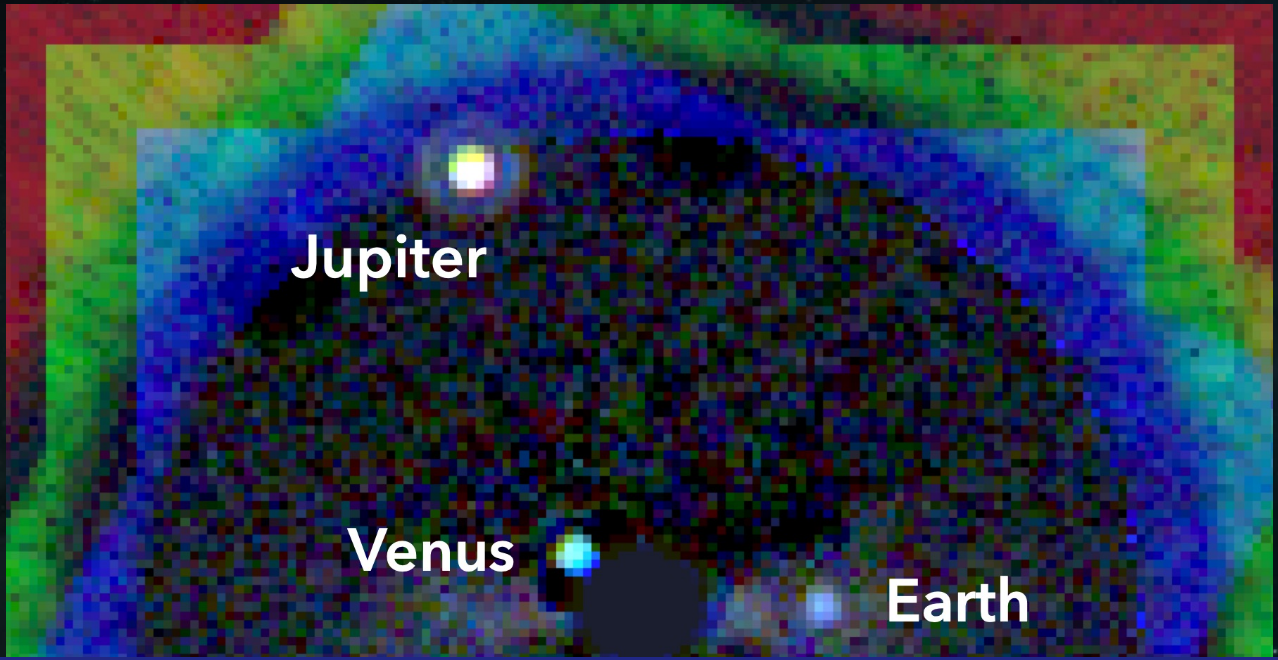
Need ***space-based direct spectroscopy*** to do it for exoplanets around Sun-like stars

The habitable planet survey observations



Simulated high-contrast image of the Solar System at 12.5 pc with ECLIPS on LUVOIR-A

THE HABITABLE PLANET SURVEY OBSERVATIONS

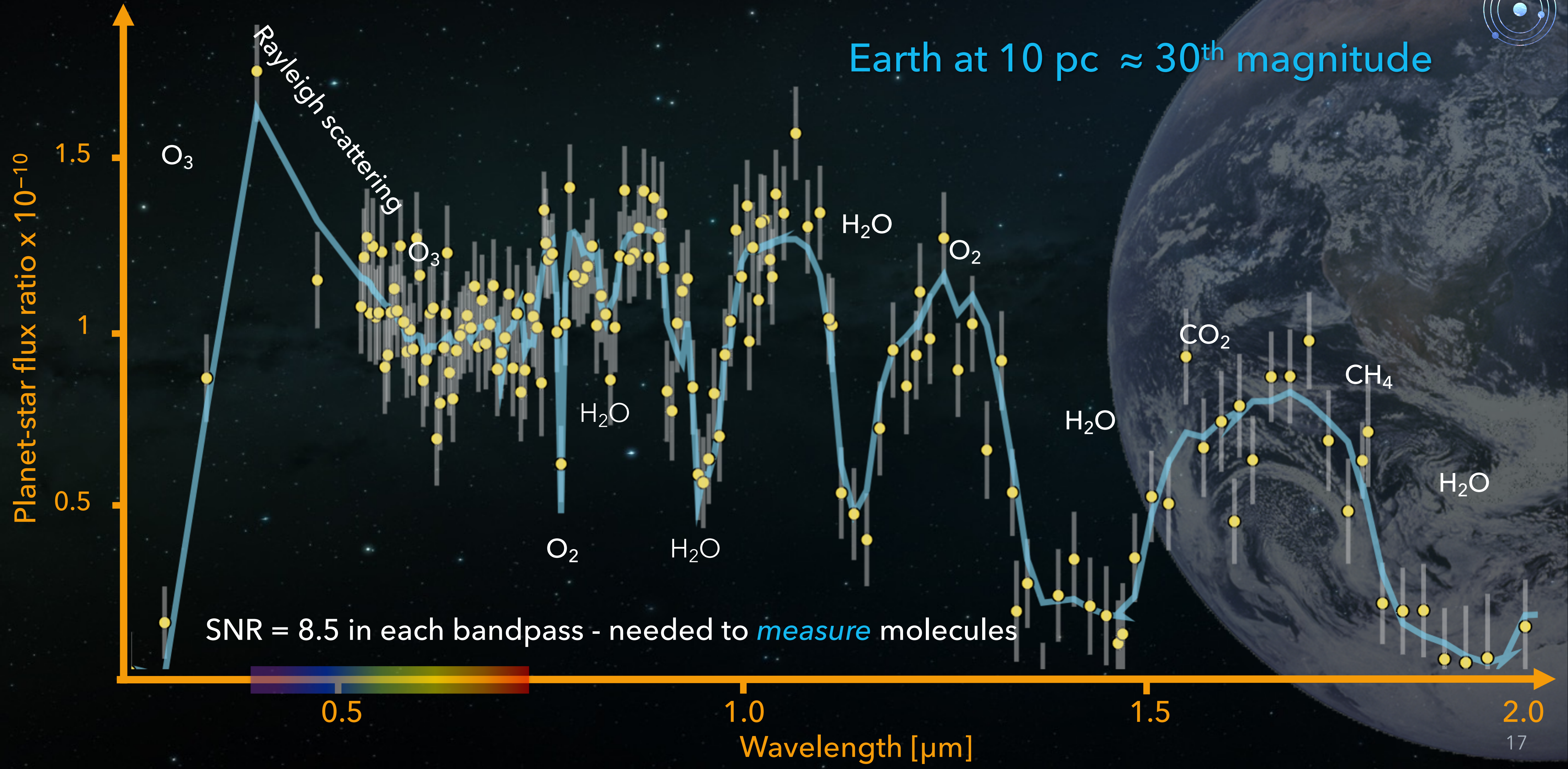


Hundreds of stars with LUVOIR, dozens with HabEx

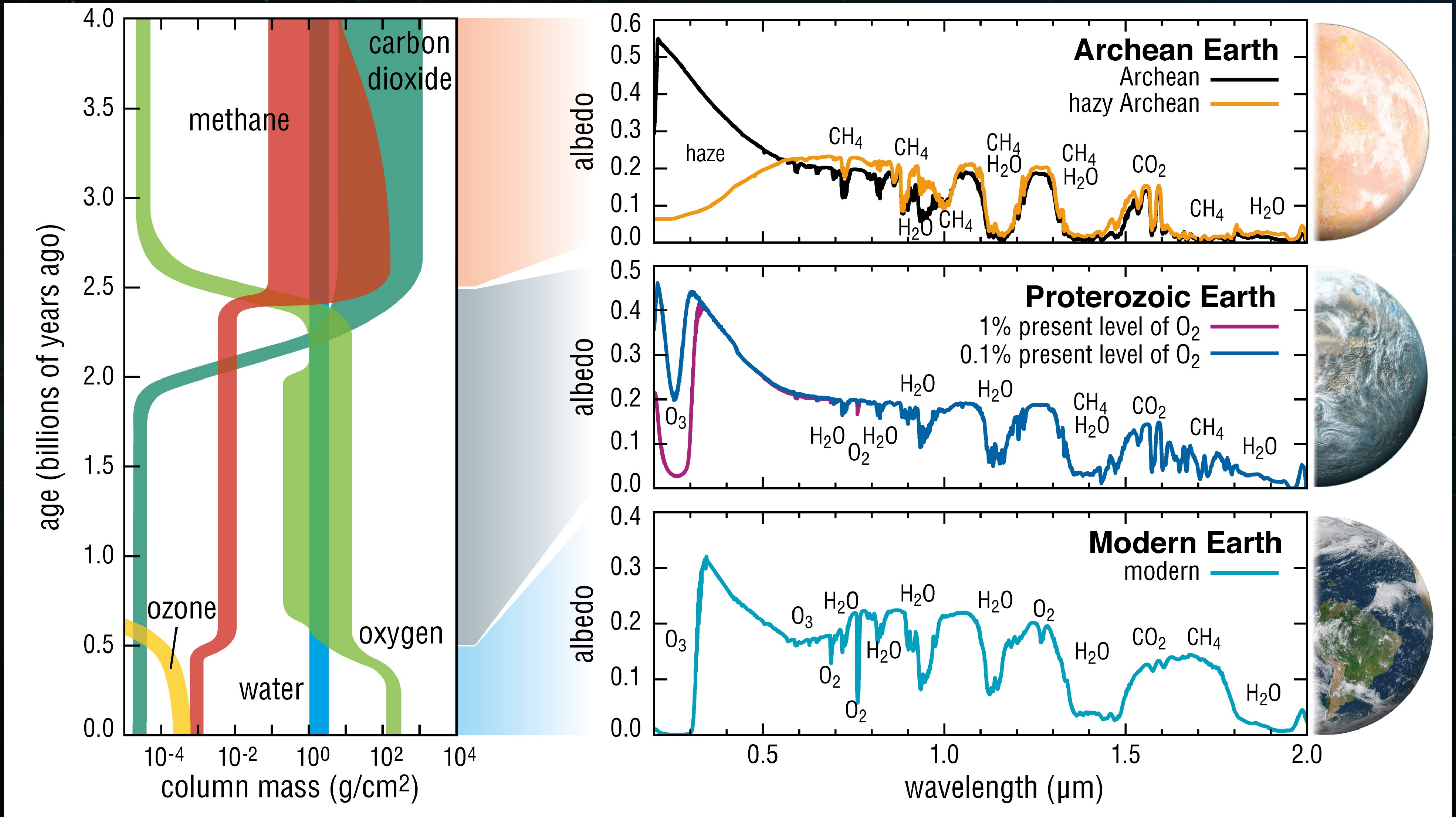
Preliminary characterization for every habitable planet candidate

Detailed follow-up of promising candidates

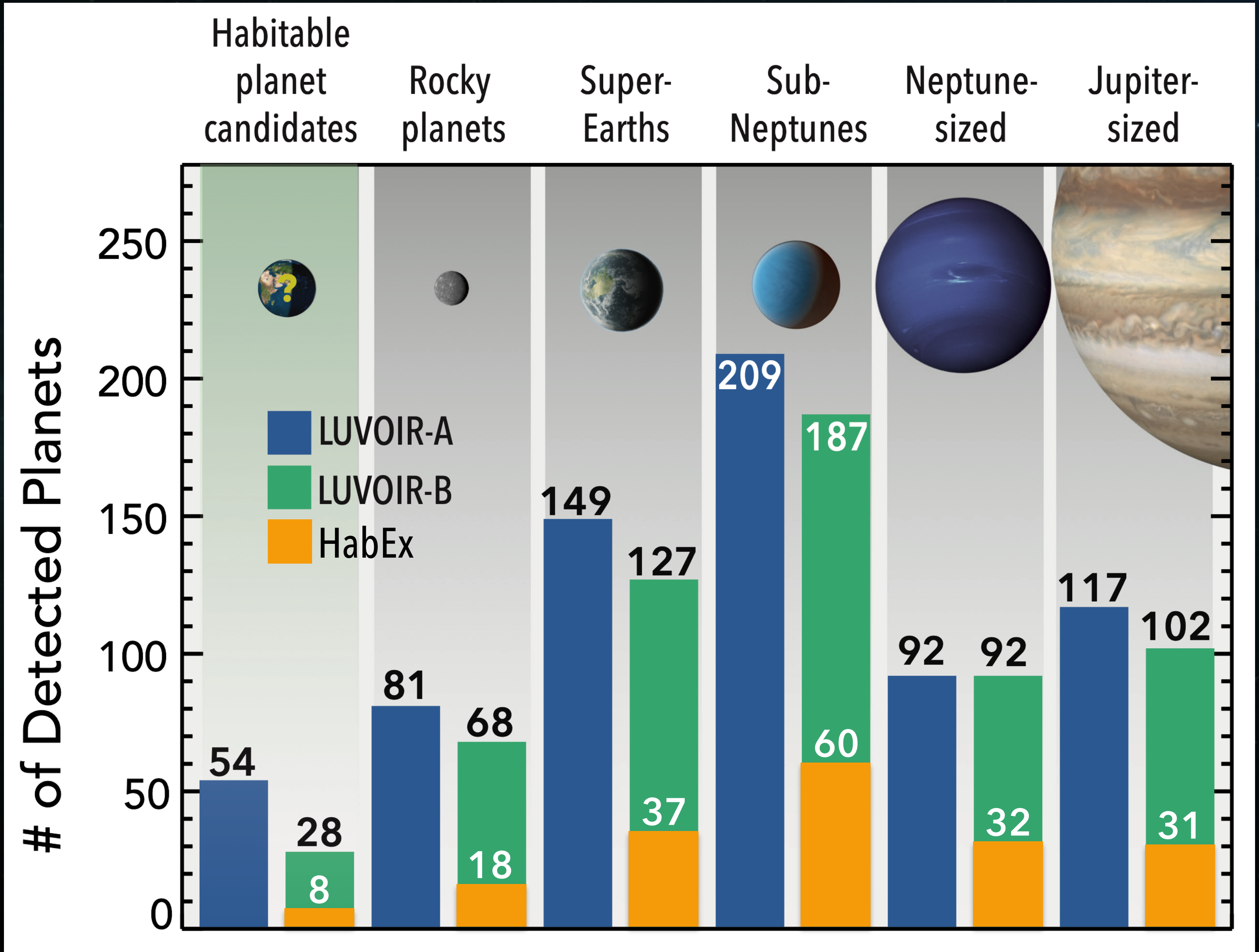
What would an inhabited exoplanet look like?



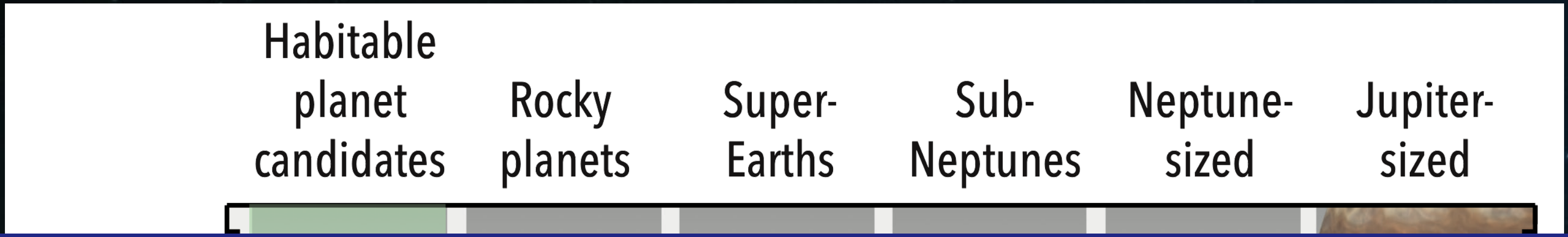
Three inhabited planets: the Earth through time



NOT ONLY HABITABLE PLANET CANDIDATES



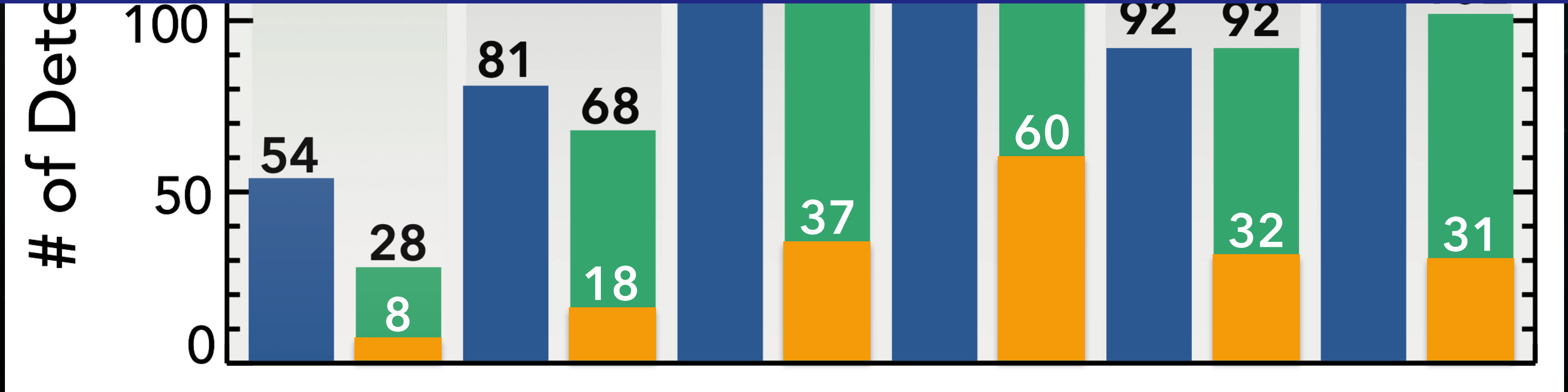
Not only habitable planet candidates



Estimated yields of other types of exoplanets found in hab. planet survey

LUVOIR-A ~ 648, LUVOIR-B ~ 576
HabEx ~ 178

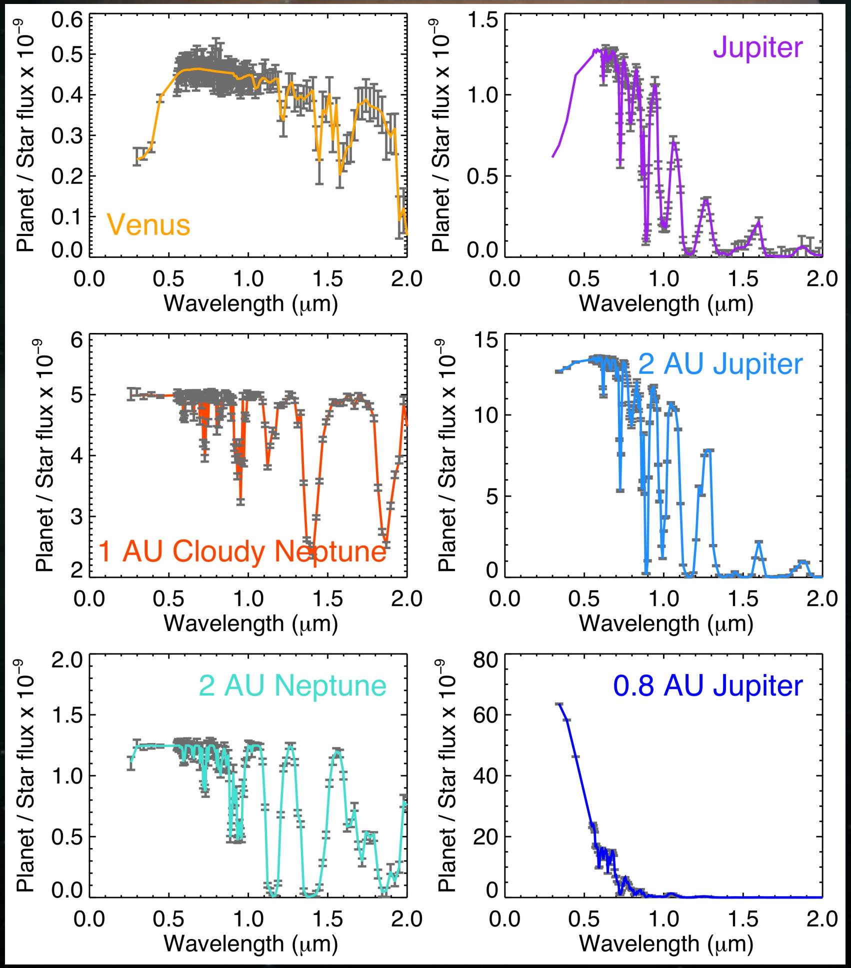
These planets will inevitably have a range of ages



Comparative exoplanetology

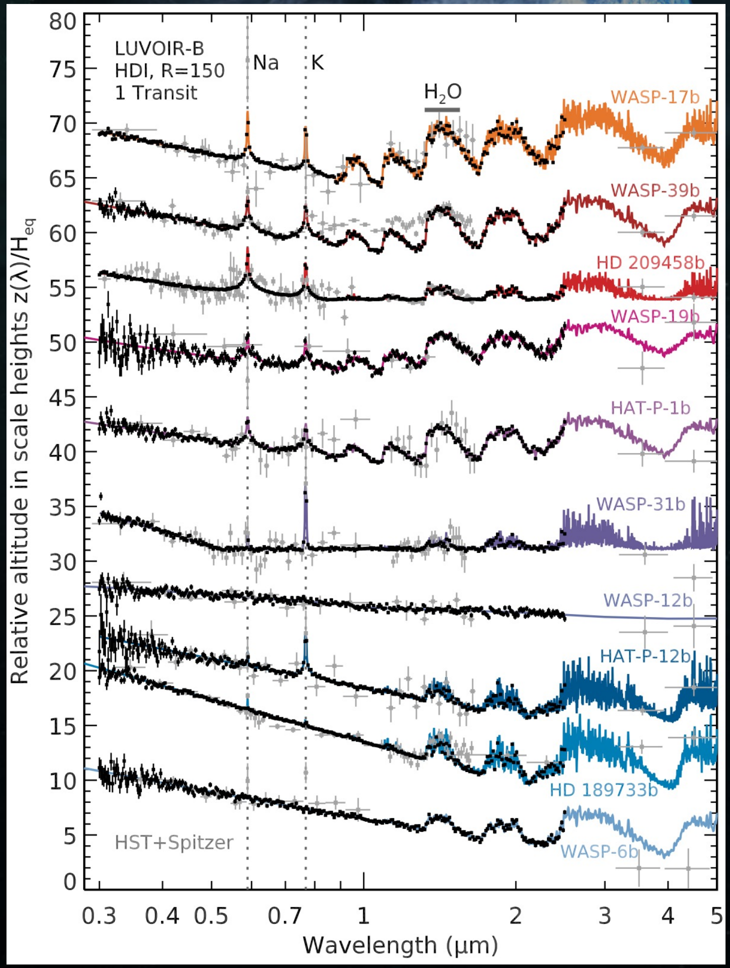
Cold to warm planets

NUV / optical / NIR direct spectroscopy



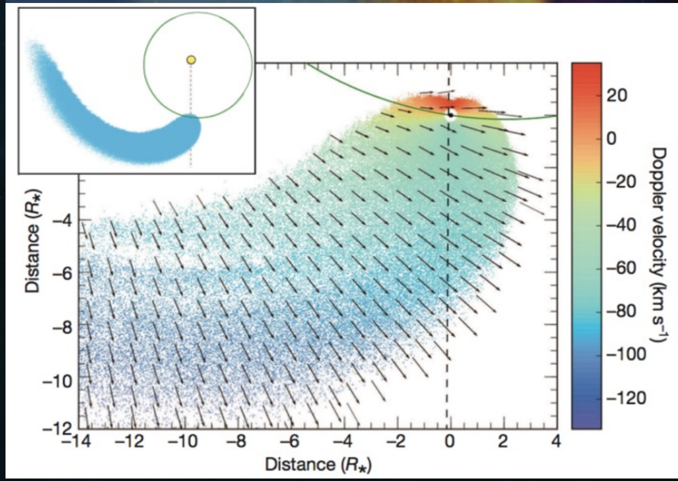
Warm to hot planets

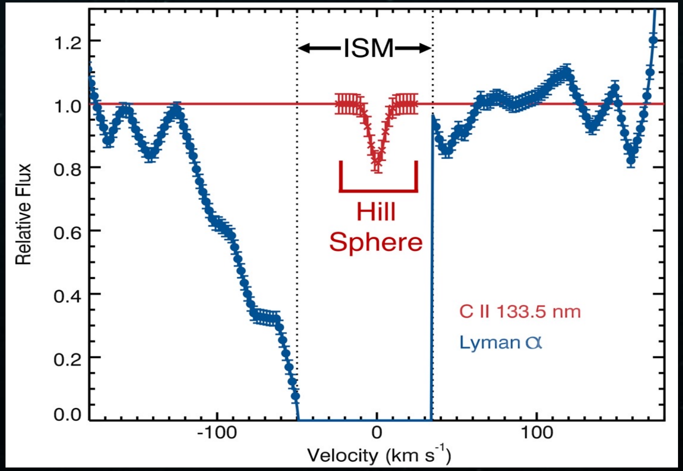
Optical / NIR transit spectroscopy



Atmospheric escape

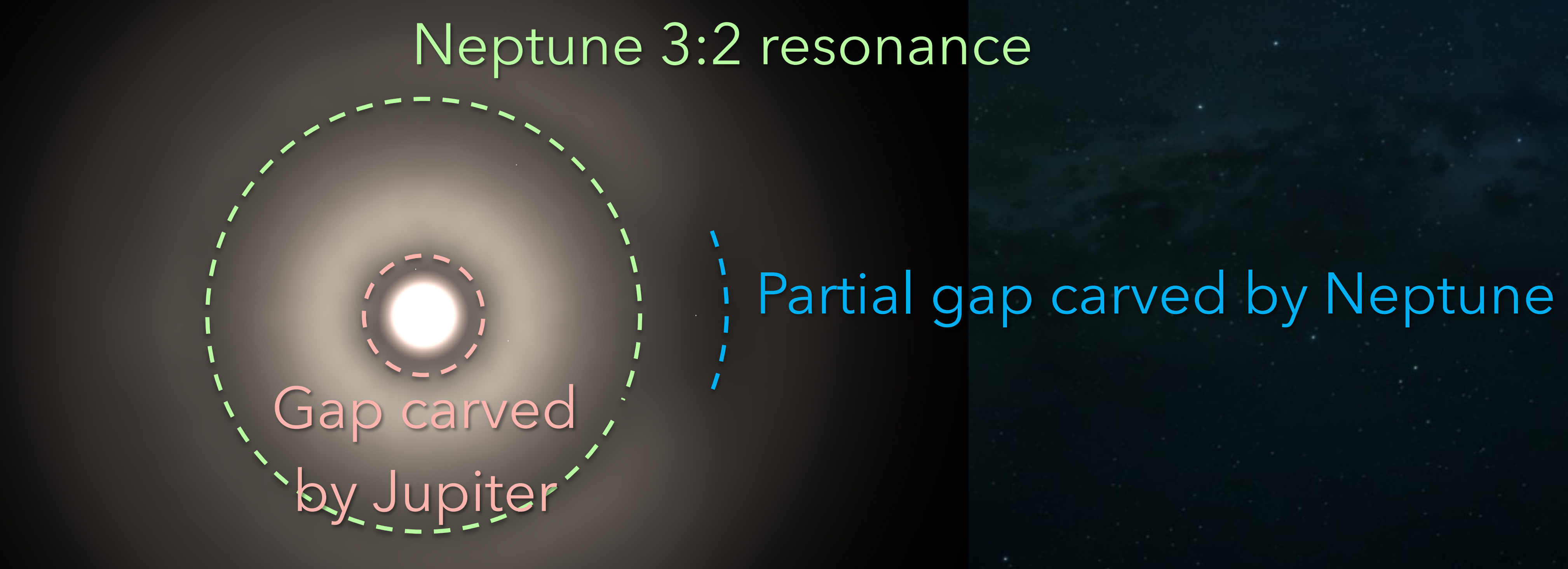
FUV transit spectroscopy





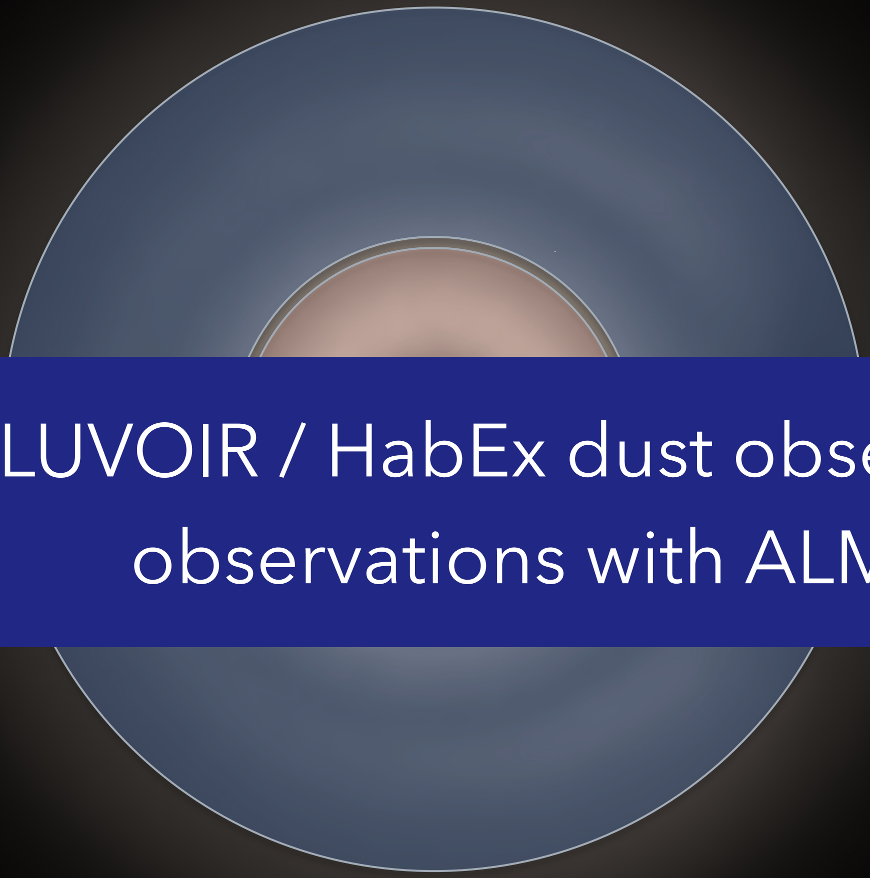
THE DYNAMICAL HISTORIES OF PLANETARY SYSTEMS

Planets + dust from planetesimal belts = complete system architecture



Solar System, with planets and interplanetary dust

The Dynamical Histories of Planetary Systems



First high-resolution images of warm interplanetary dust from high-contrast imaging

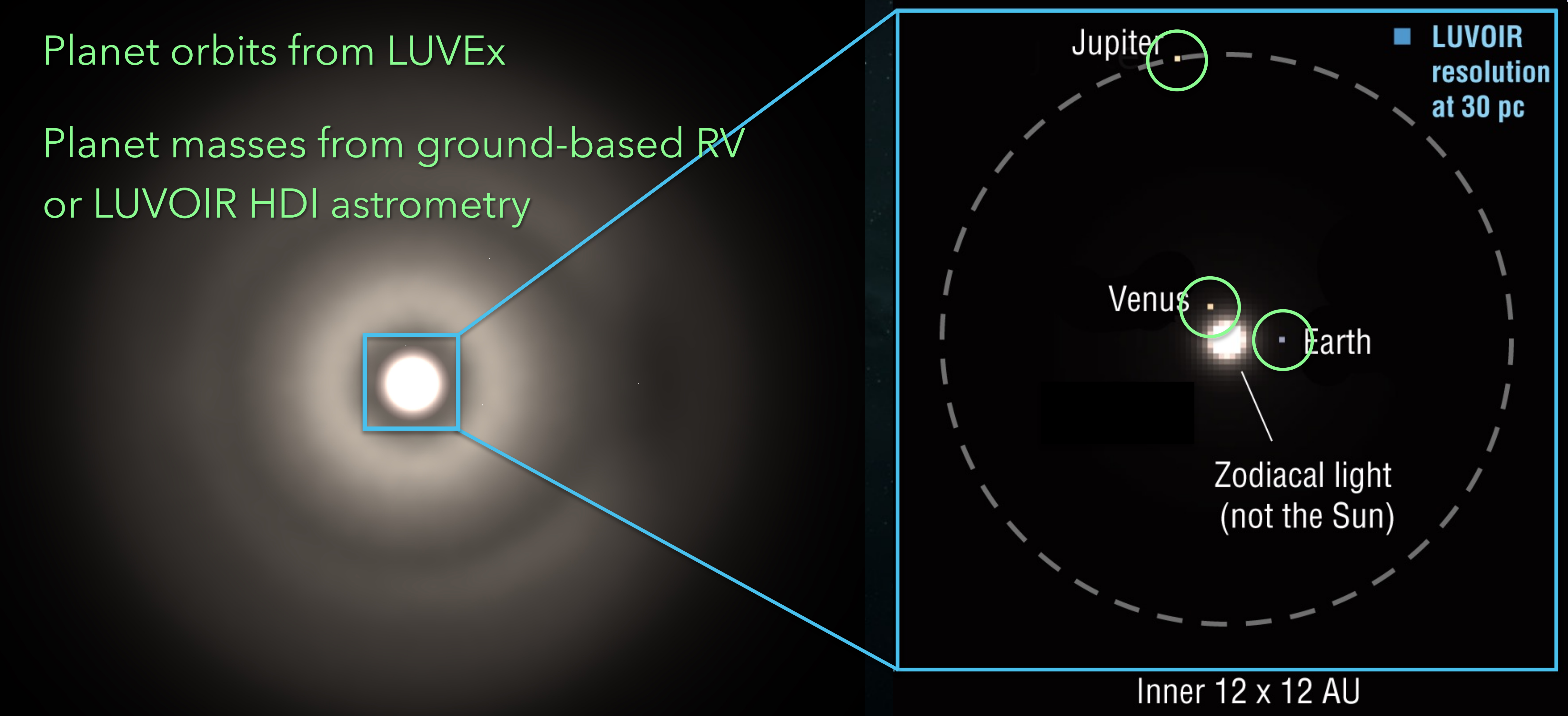
LUVOIR / HabEx dust observations will complement and extend observations with ALMA & other ground-based facilities

Cold interplanetary dust from ALMA

THE DYNAMICAL HISTORIES OF PLANETARY SYSTEMS

Planet orbits from LUVEx

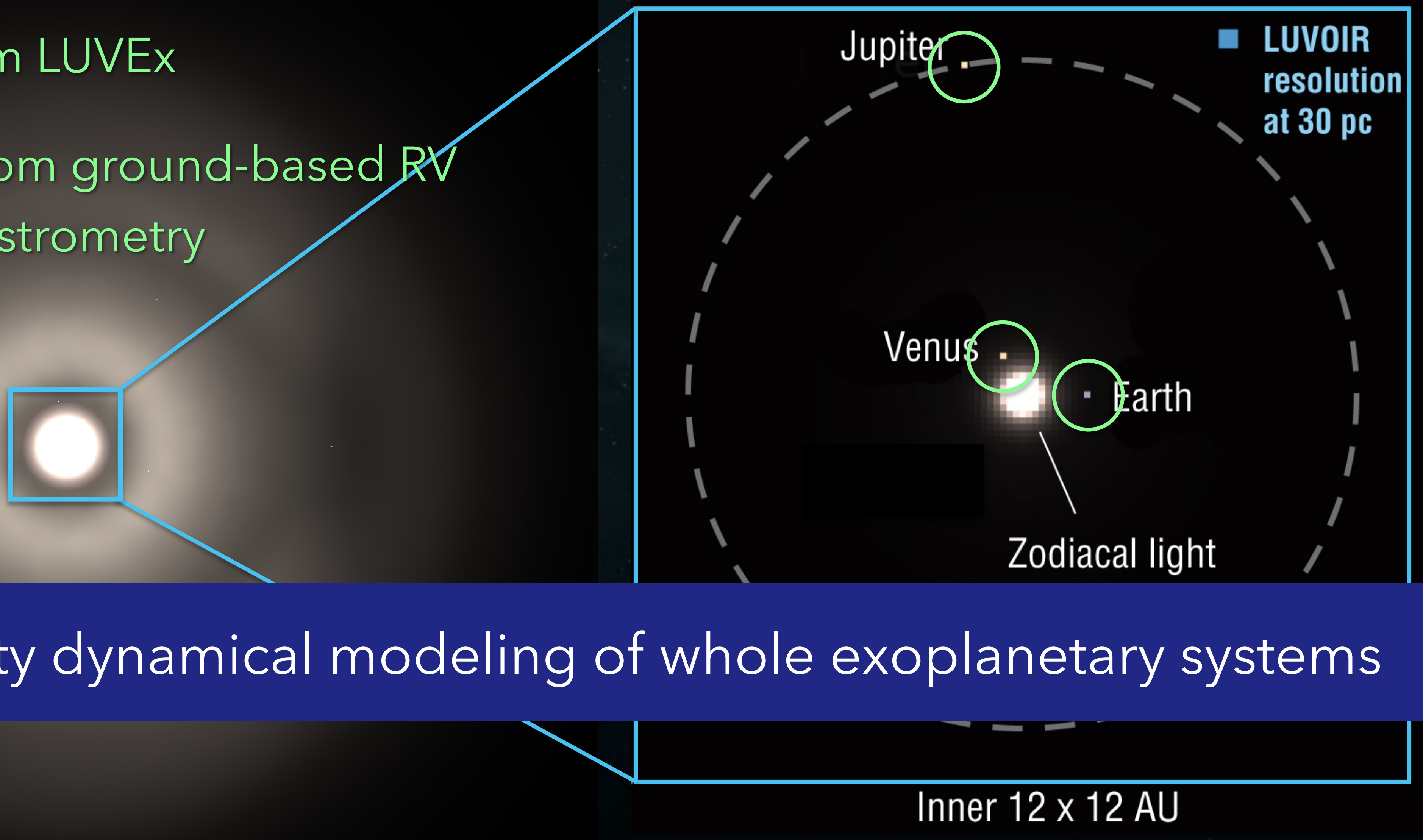
Planet masses from ground-based RV or LUVOIR HDI astrometry



The Dynamical Histories of Planetary Systems

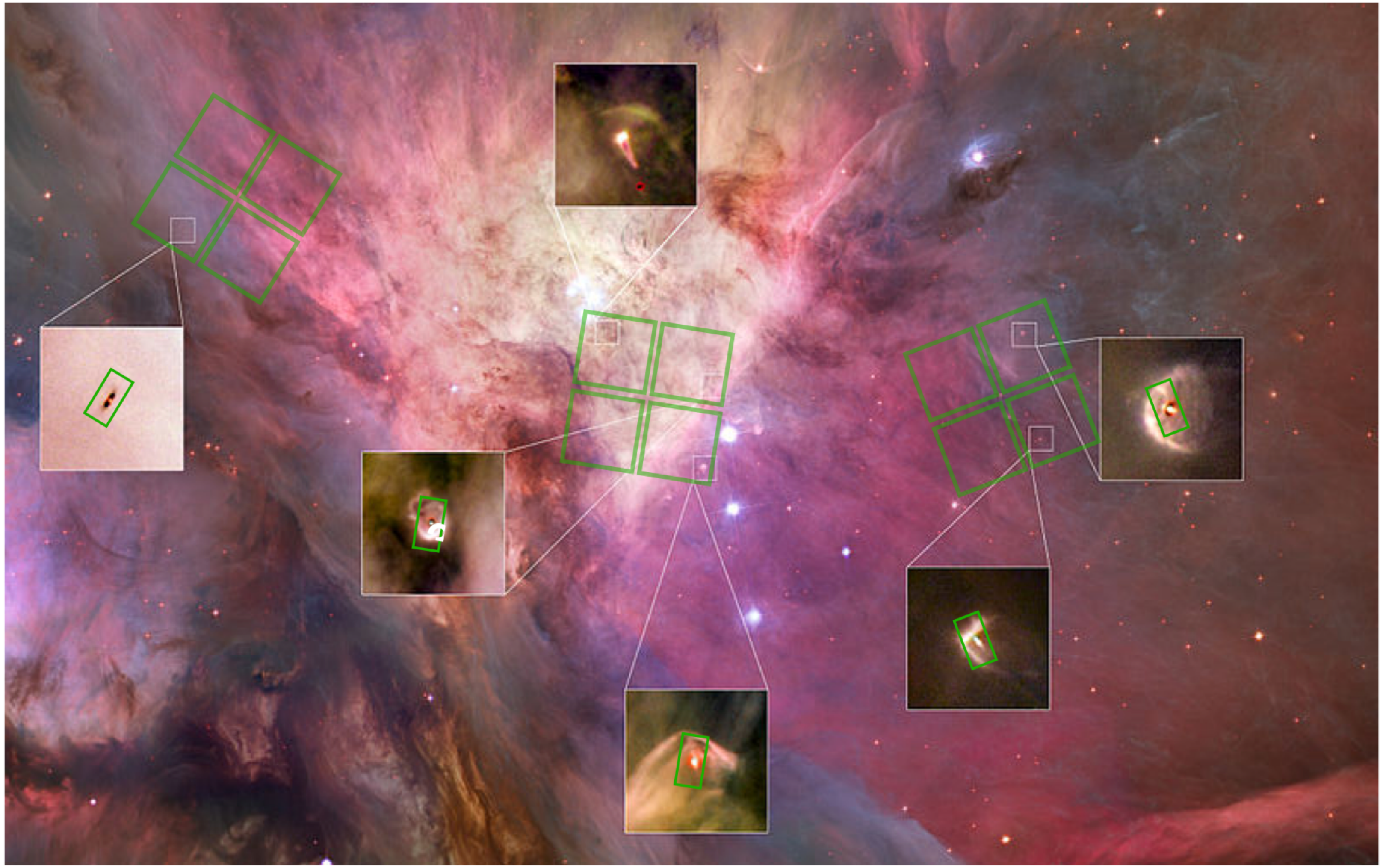
Planet orbits from LUVEx

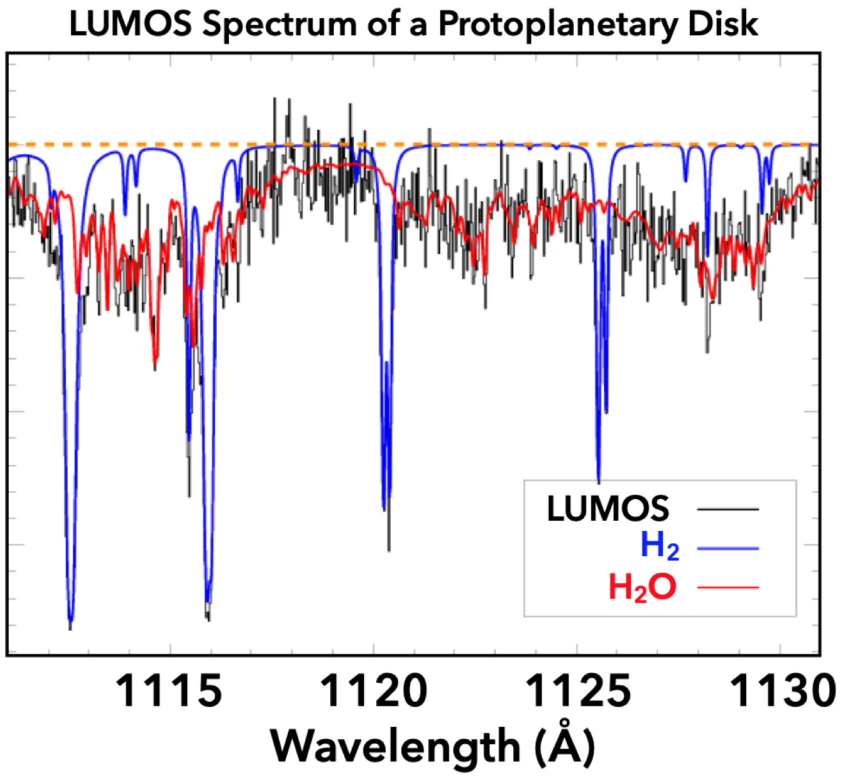
Planet masses from ground-based RV or LUVOIR HDI astrometry



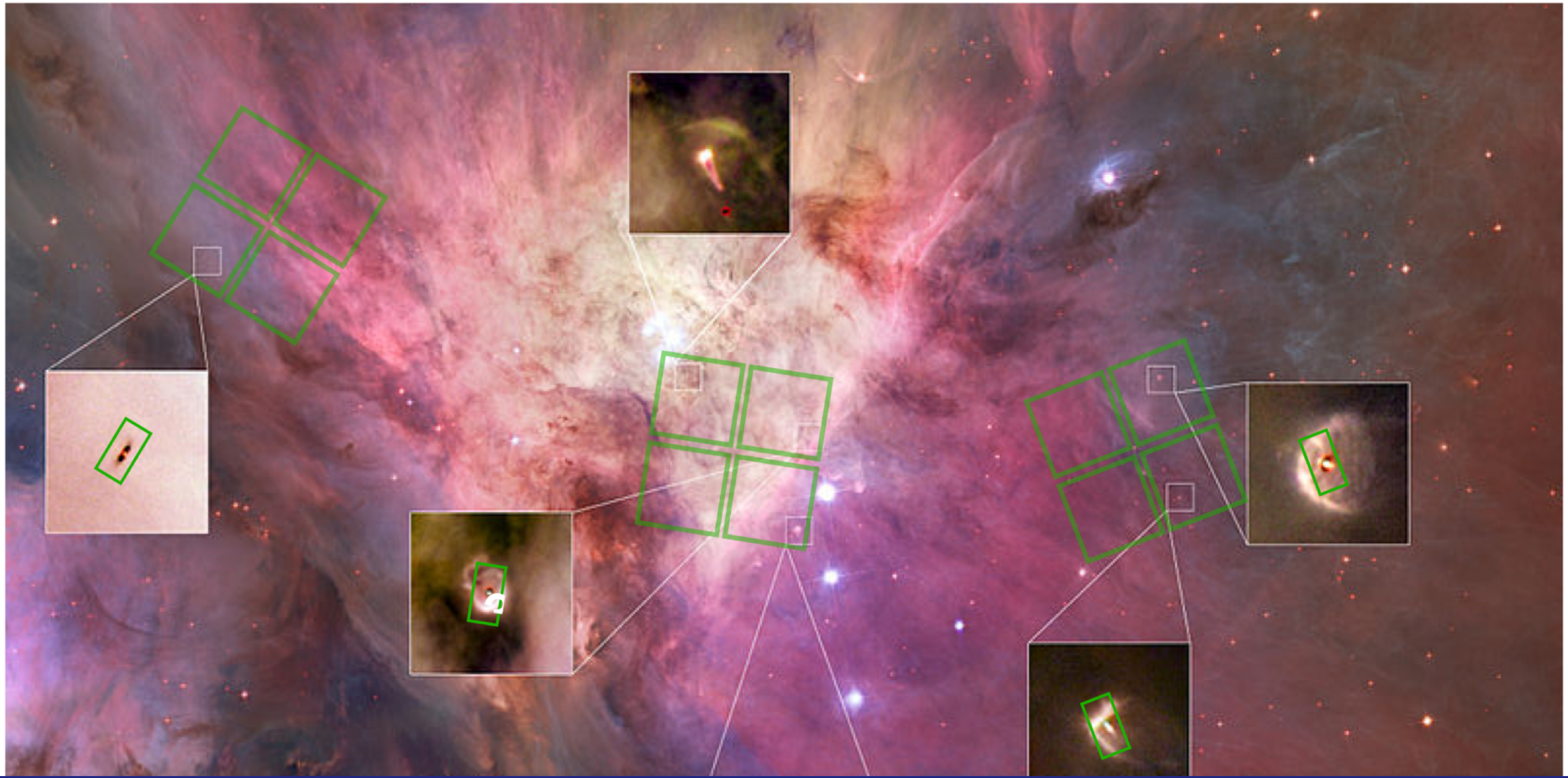
High-fidelity dynamical modeling of whole exoplanetary systems

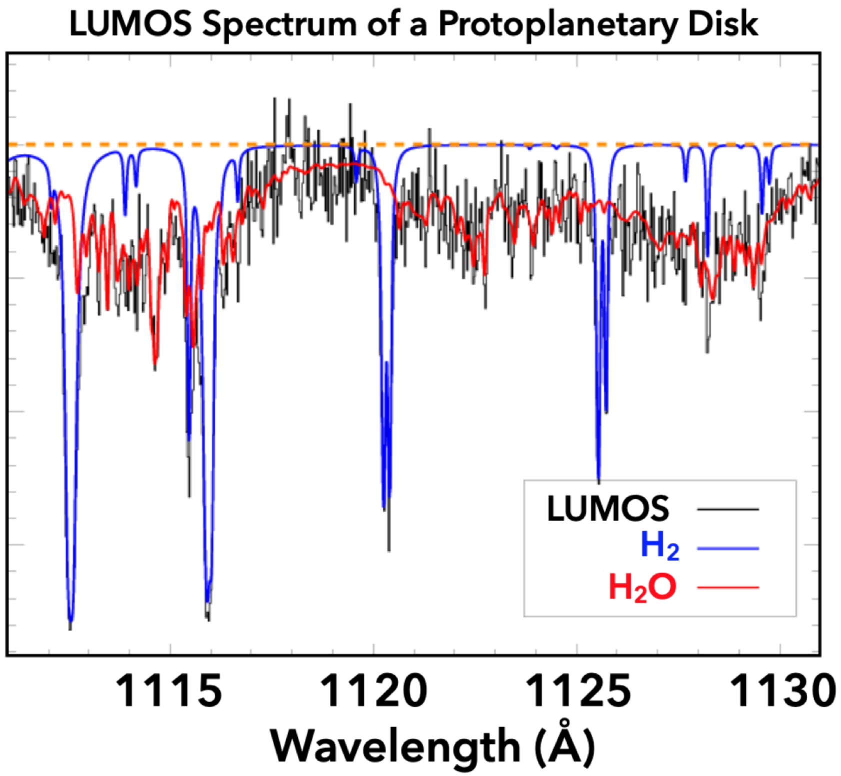
The power of multi-object spectroscopy





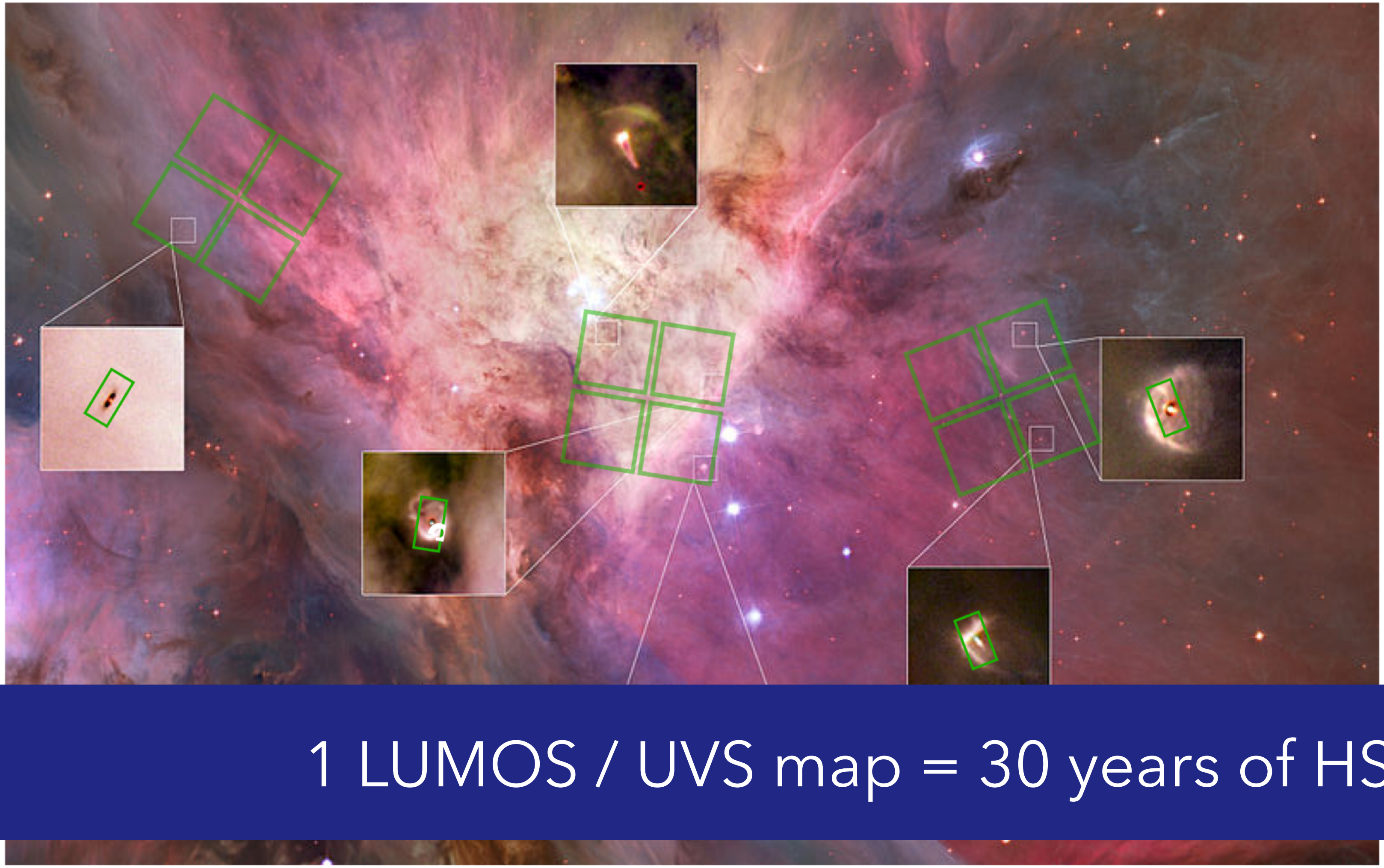
THE POWER OF MULTI-OBJECT SPECTROSCOPY

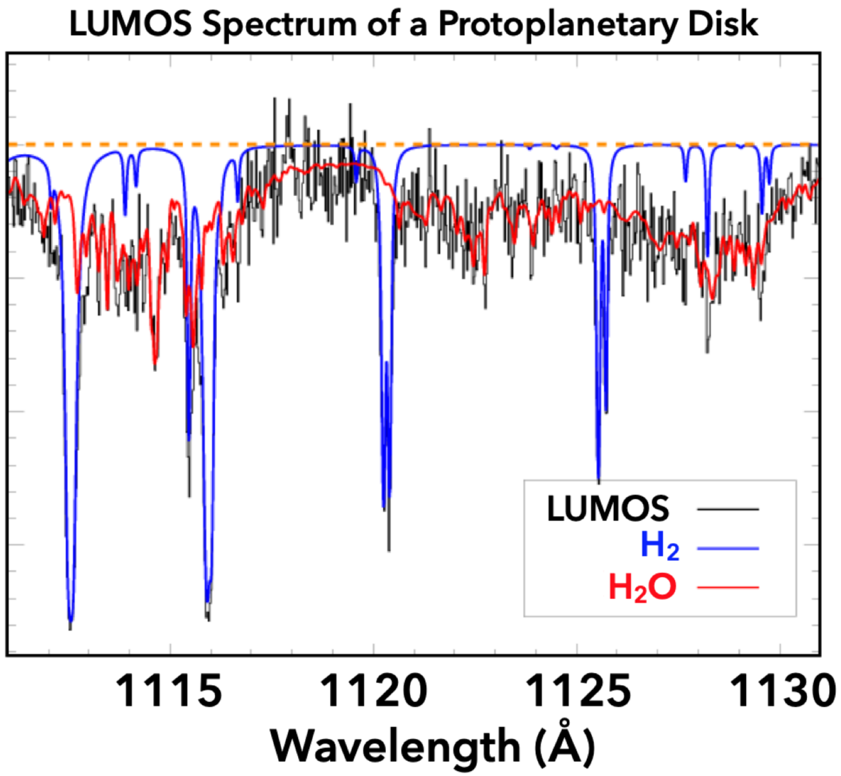




LUVOIR / HabEx can measure H_2 and water in hundreds of simultaneous protoplanetary disk FUV spectra

THE POWER OF MULTI-OBJECT SPECTROSCOPY





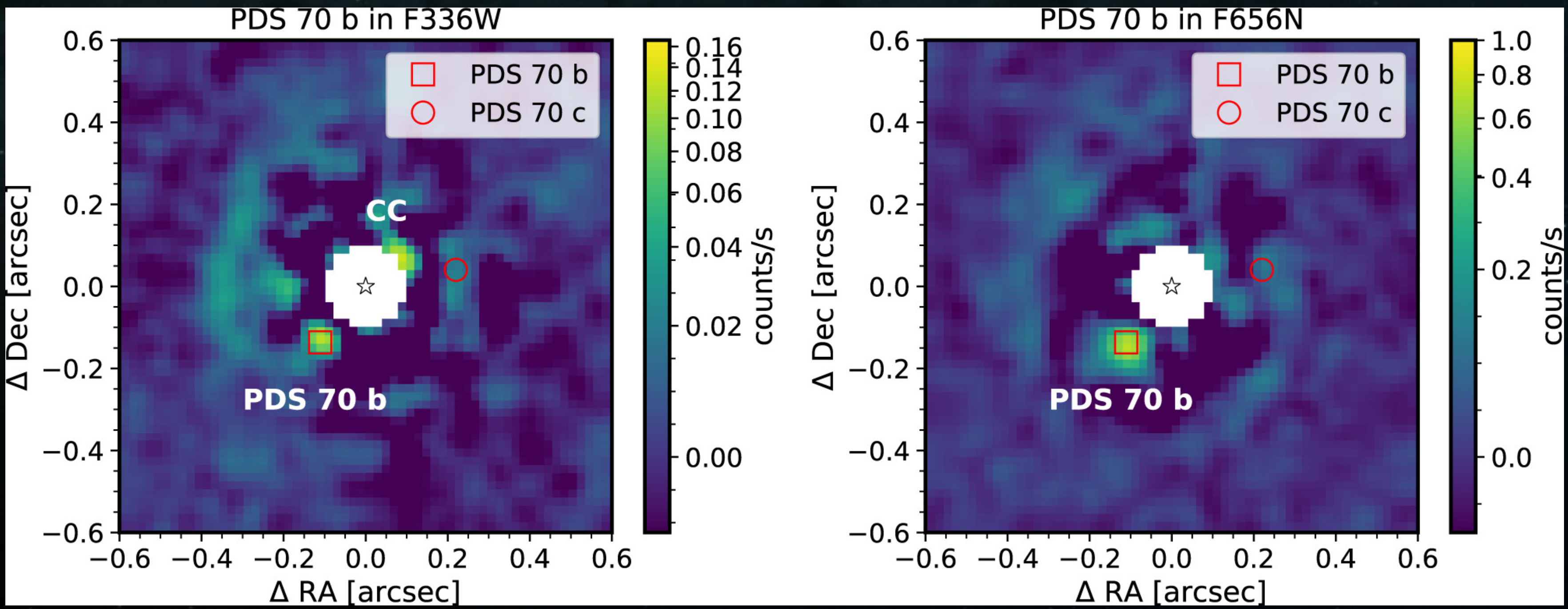
1 LUMOS / UVS map = 30 years of HST observations

OTHER LUVOIR / HABEX PLANET FORMATION SCIENCE

Accreting young planets embedded in protoplanetary disks

- Bright in optical Hα emission and in UV hydrogen continuum emission
- UV continuum better for measuring accretion rates

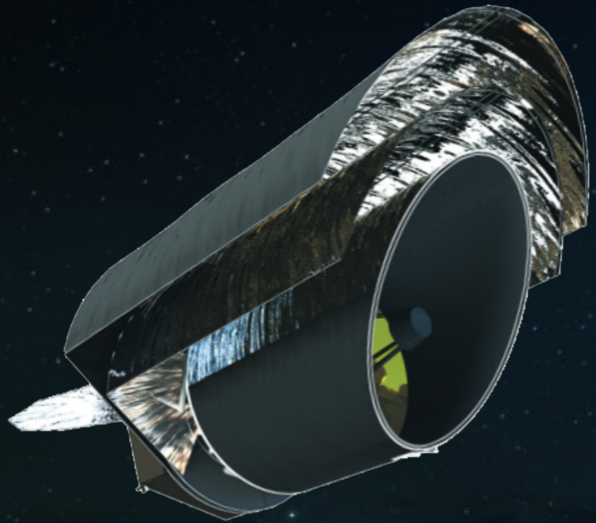
Hubble – UV continuum   Hubble – Hα



Zhou et al. 2021

O R I G I N S

ORIGINS ARCHITECTURE



5.9-m on-axis segmented primary mirror

Total wavelength range: 2.8 μm – 588 μm

Telescope operating temperature = 4.5 K

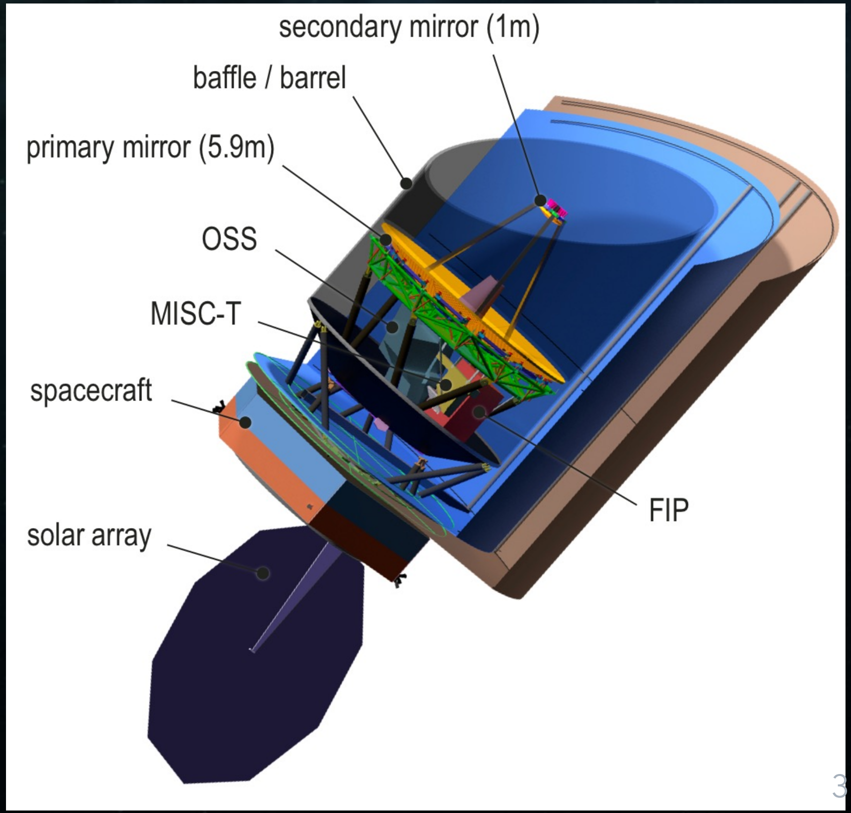
(Webb temperature = 50 K)

Three instruments (discussed in next slide)

Launch date ~ mid-2030s

Serviceable

5-year prime mission duration, 10 years of propellant



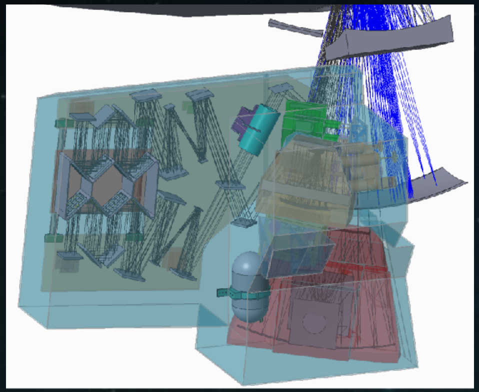
ORIGINS INSTRUMENTS

Origins Survey Spectrometer (OSS)

Survey mapping: 25 – 588 μm, R ~ 300

Spectral surveys: 25 – 588 μm, R ~ 43,000

Kinematics: 100 – 200 μm, R ~ 325,000

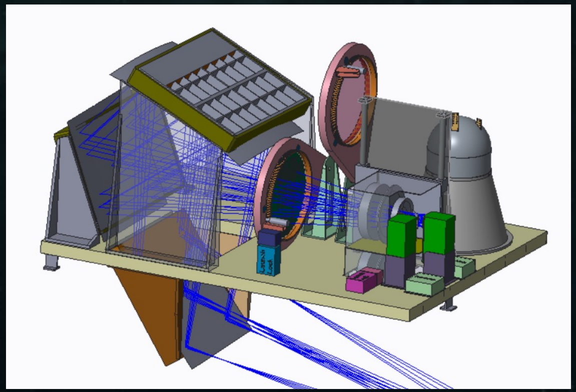


Far-infrared Imager Polarimeter (FIP)

Large area survey mapping: 50 or 250 μm

PSF FWHM: 1.75″ at 50 μm, 8.75″ at 250 μm

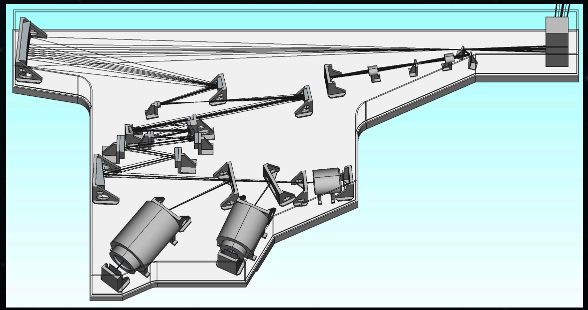
Polarimetry at 50 or 250 μm



Mid-Infrared Spectrometer Camera Transit Spectrometer (MISC-T)

Ultra-stable transit spectroscopy: 2.8 – 10.5 μm, R ~ 50 – 100

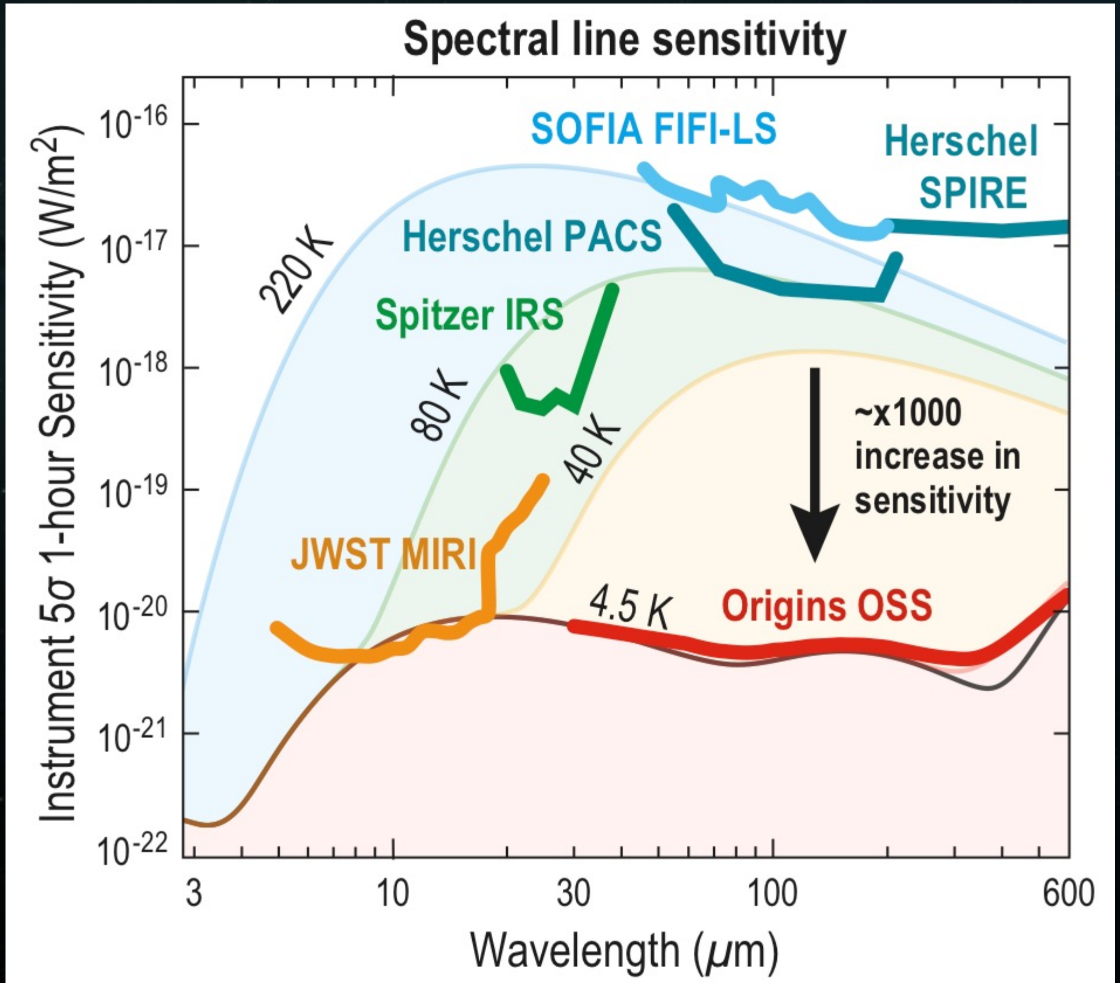
10.5 – 20 μm, R ~ 165 – 295



Origins sensitivity

Greater sensitivity than Webb at wavelengths ≳ 18 μm

1000x more sensitive than previous far-IR observatories



ORIGINS SCIENCE THEMES

How does the universe work?

How do galaxies form stars, make metals and grow central supermassive black holes?

How did we get here?

How do the conditions for habitability develop during the process of planet formation?

Are we alone?

How common are life bearing planets around M-dwarf stars?

ORIGINS SCIENCE THEMES

How does the universe work?

How do galaxies form stars, make metals and grow central supermassive black holes?

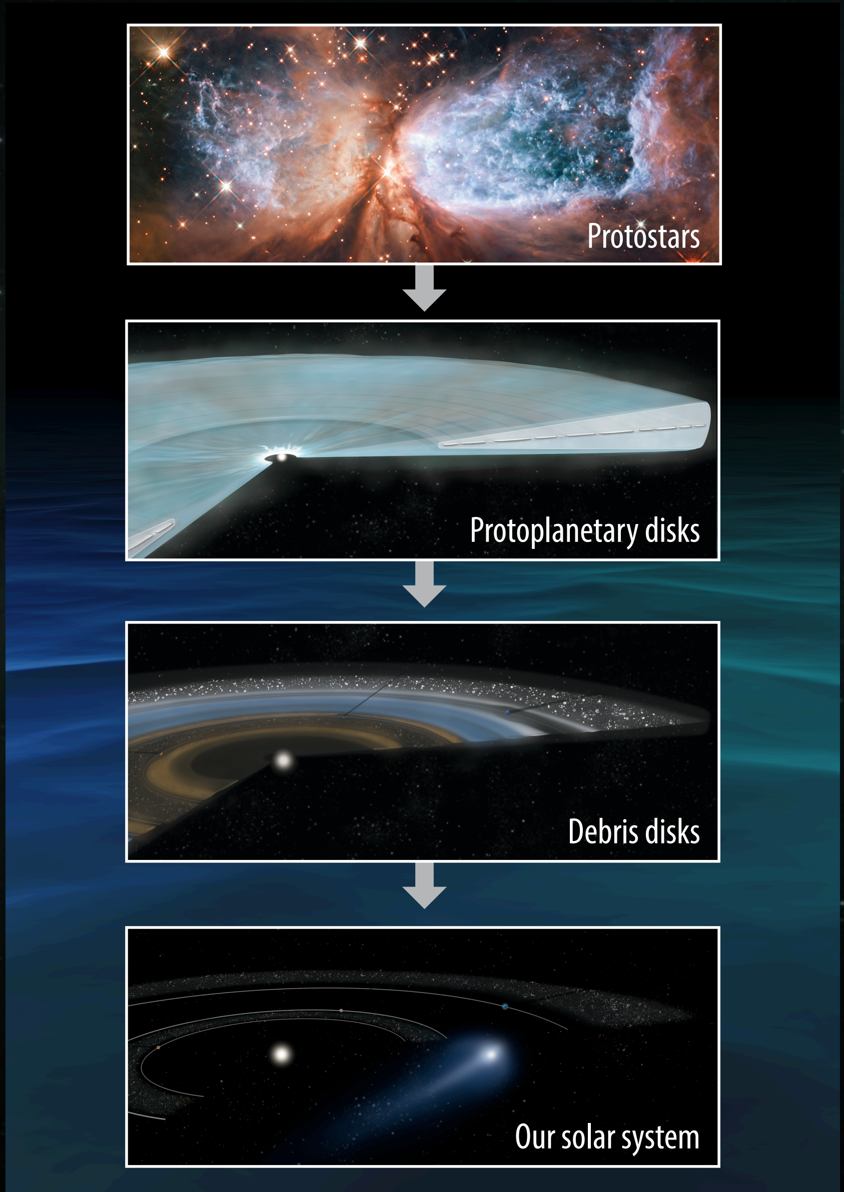
How did we get here?

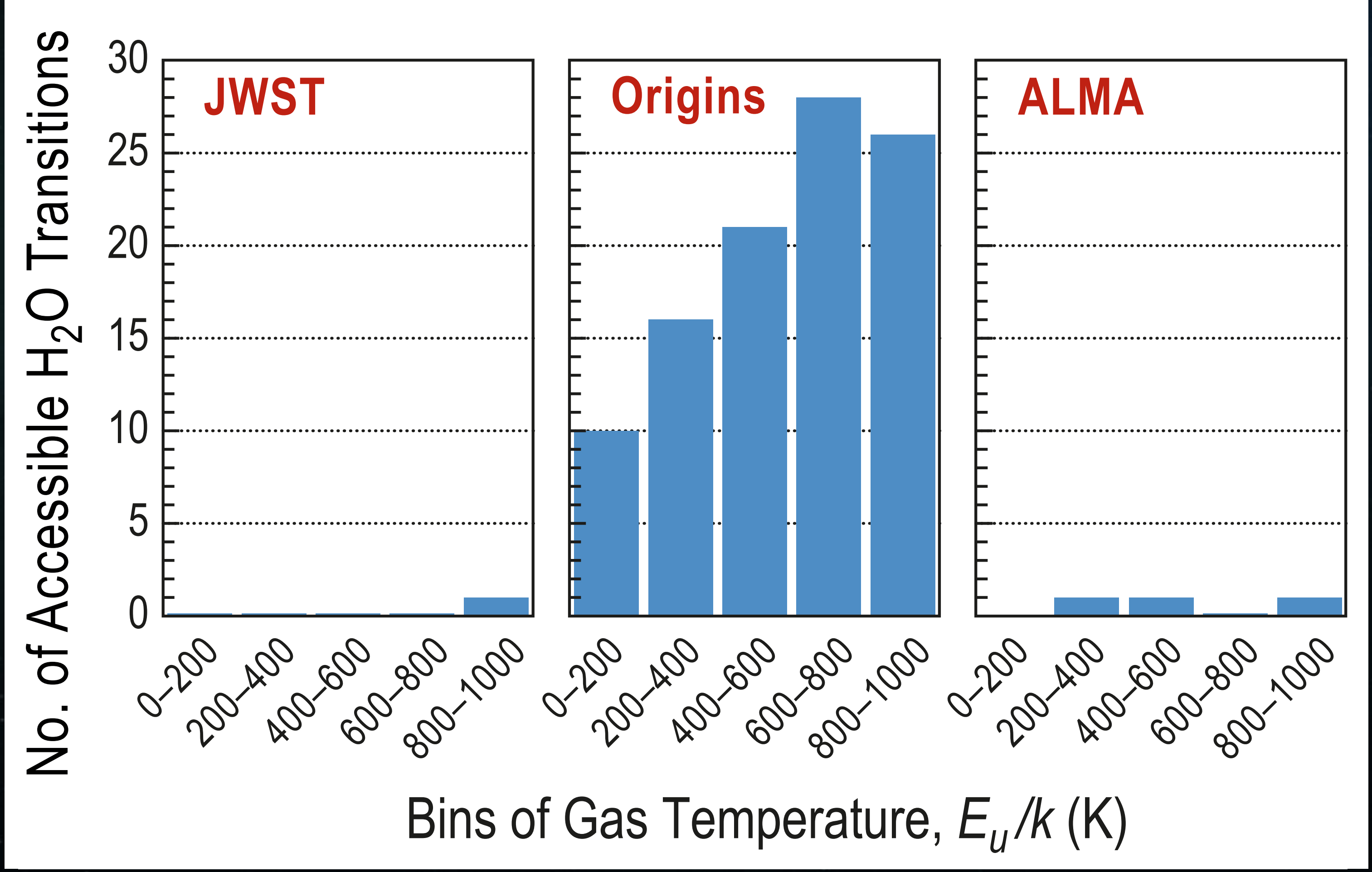
How do the conditions for habitability develop during the process of planet formation?

Are we alone?

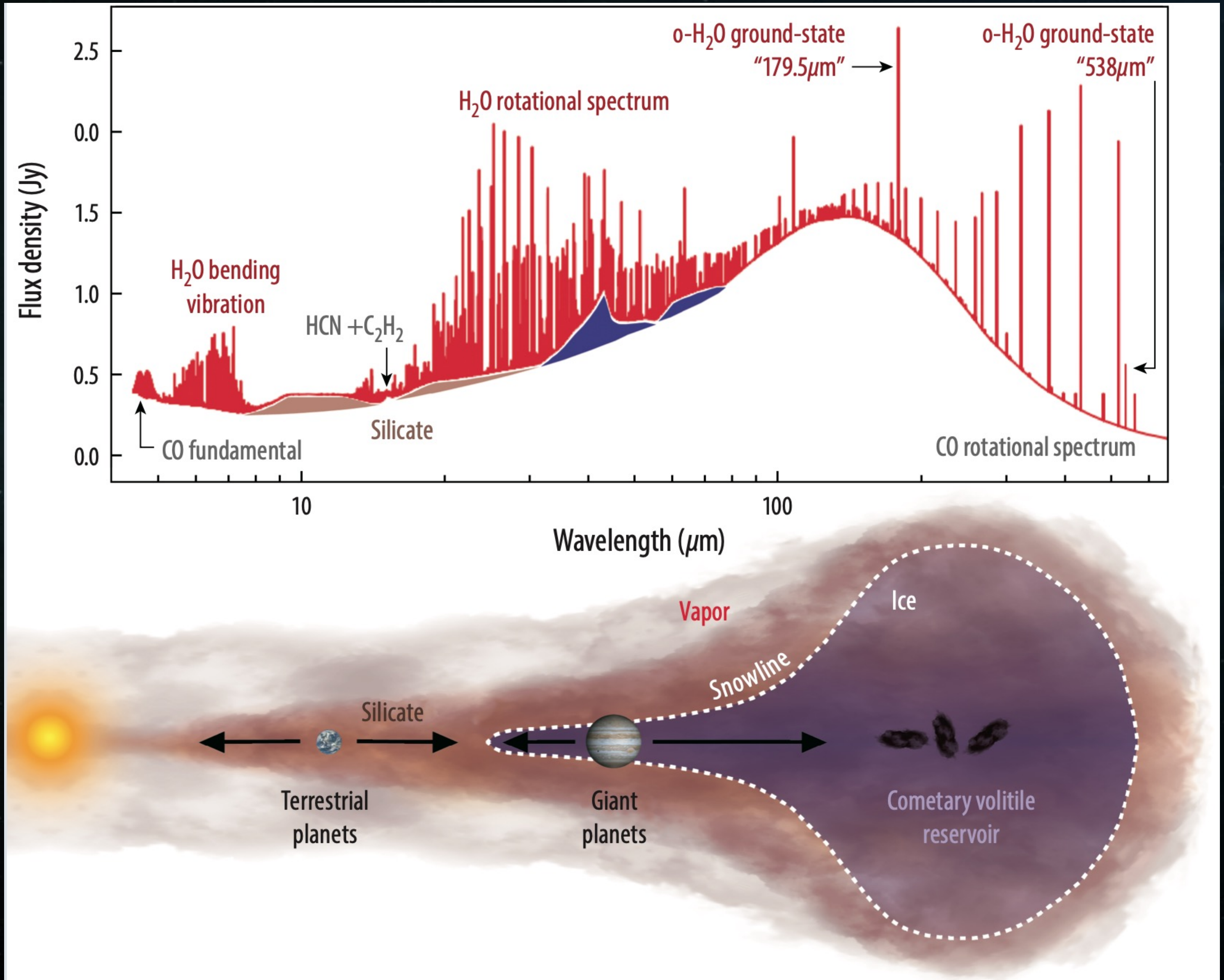
How common are life bearing planets around M-dwarf stars?

WATER'S ROLE IN PLANET FORMATION

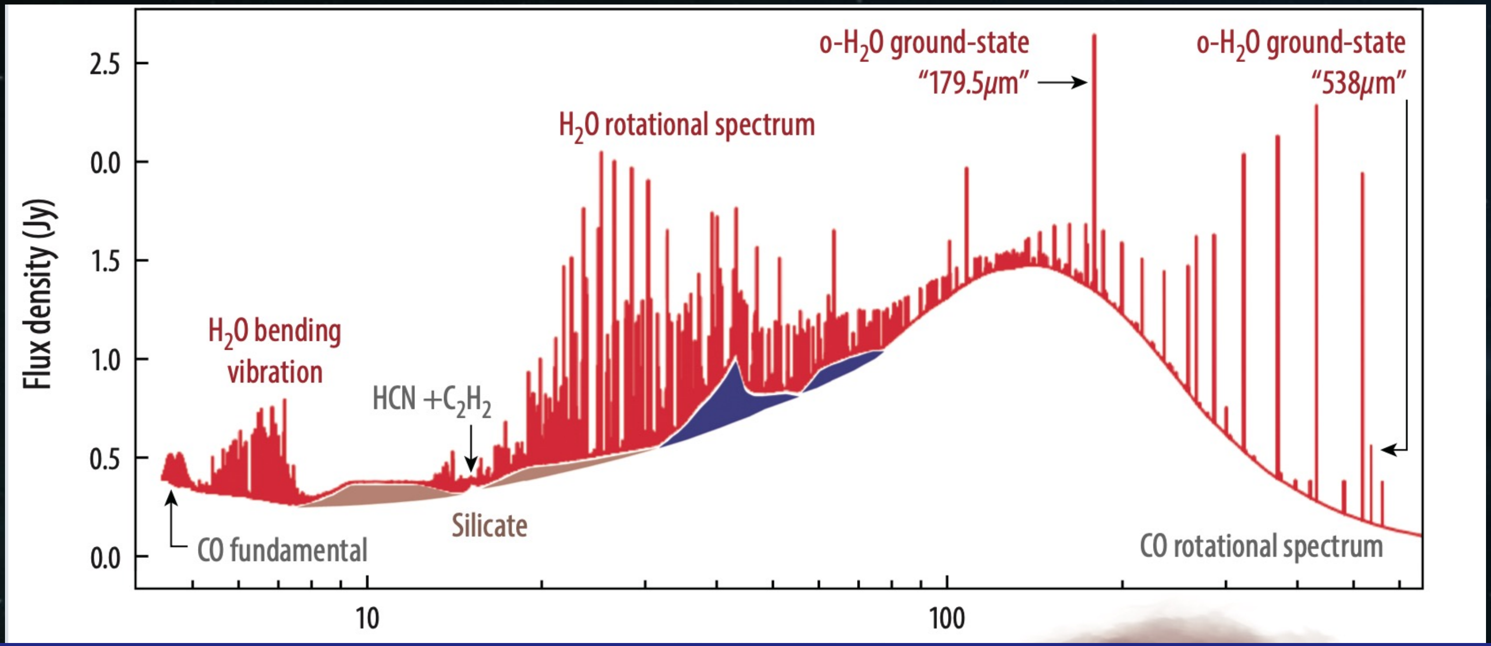




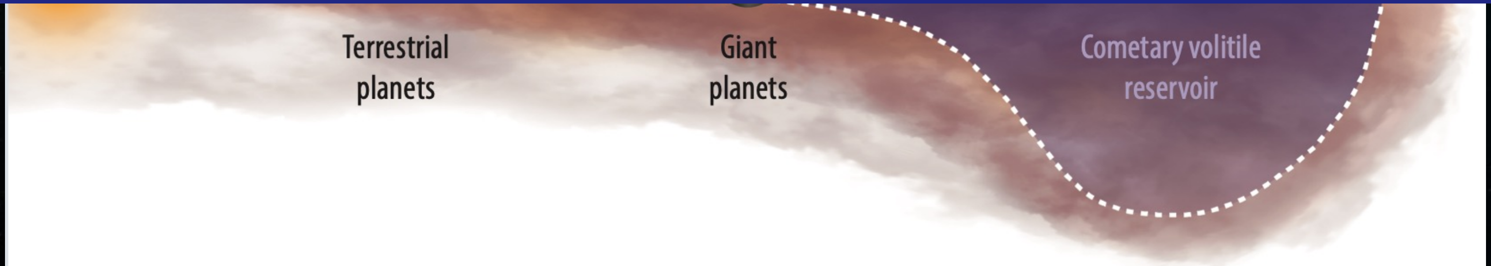
Water's role in planet formation: Protoplanetary disks



Water's role in planet formation: Protoplanetary disks



Sensitive measurements of water emission lines for ~ 1000 protoplanetary disks within 400 pc

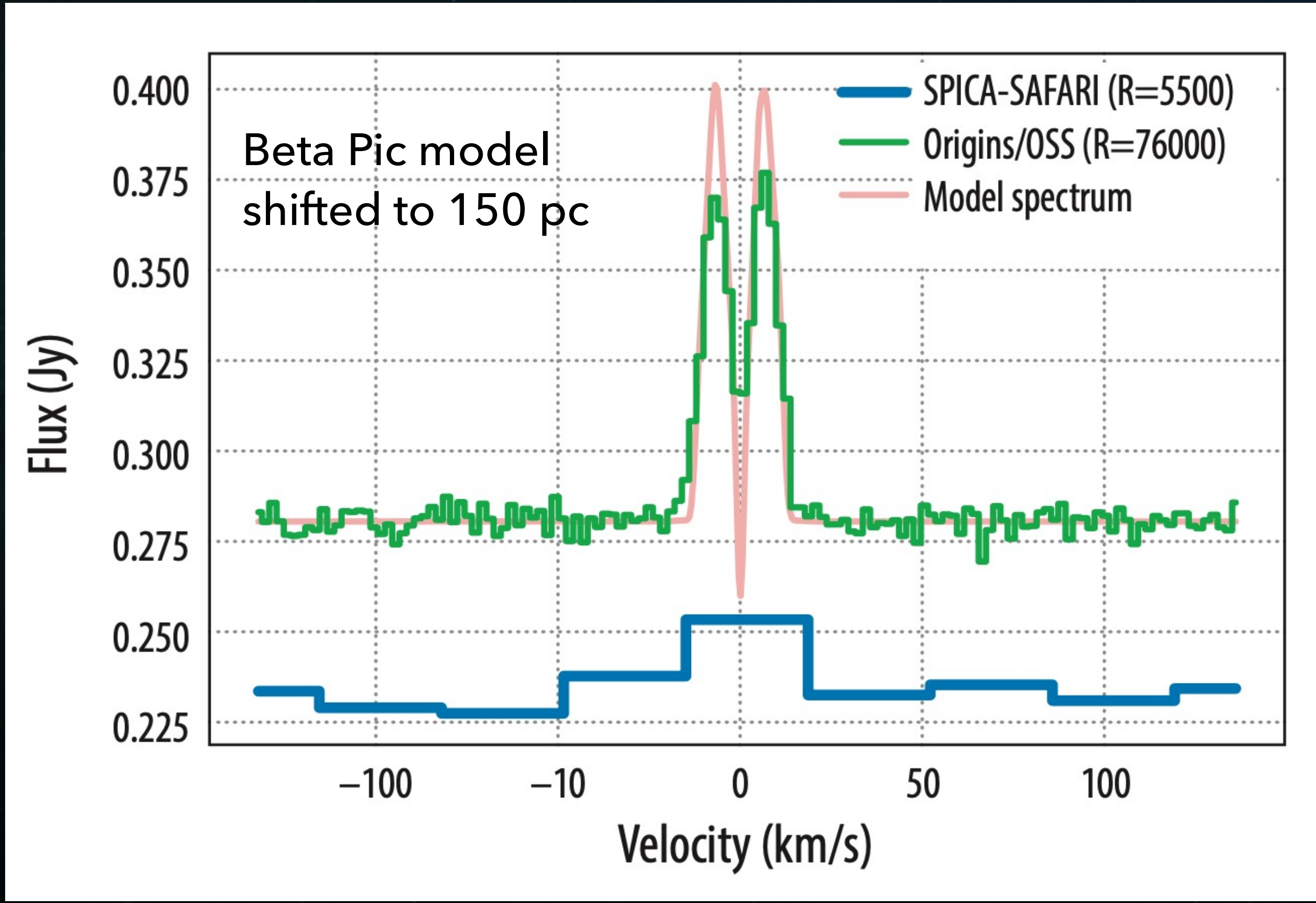


WATER'S ROLE IN PLANET FORMATION: DEBRIS DISKS

Low-density gas in debris disks coming from destruction of young planetesimals is poorly studied

Origins can survey for neutral oxygen (63 μm) and first-ionized carbon emission (157 μm)

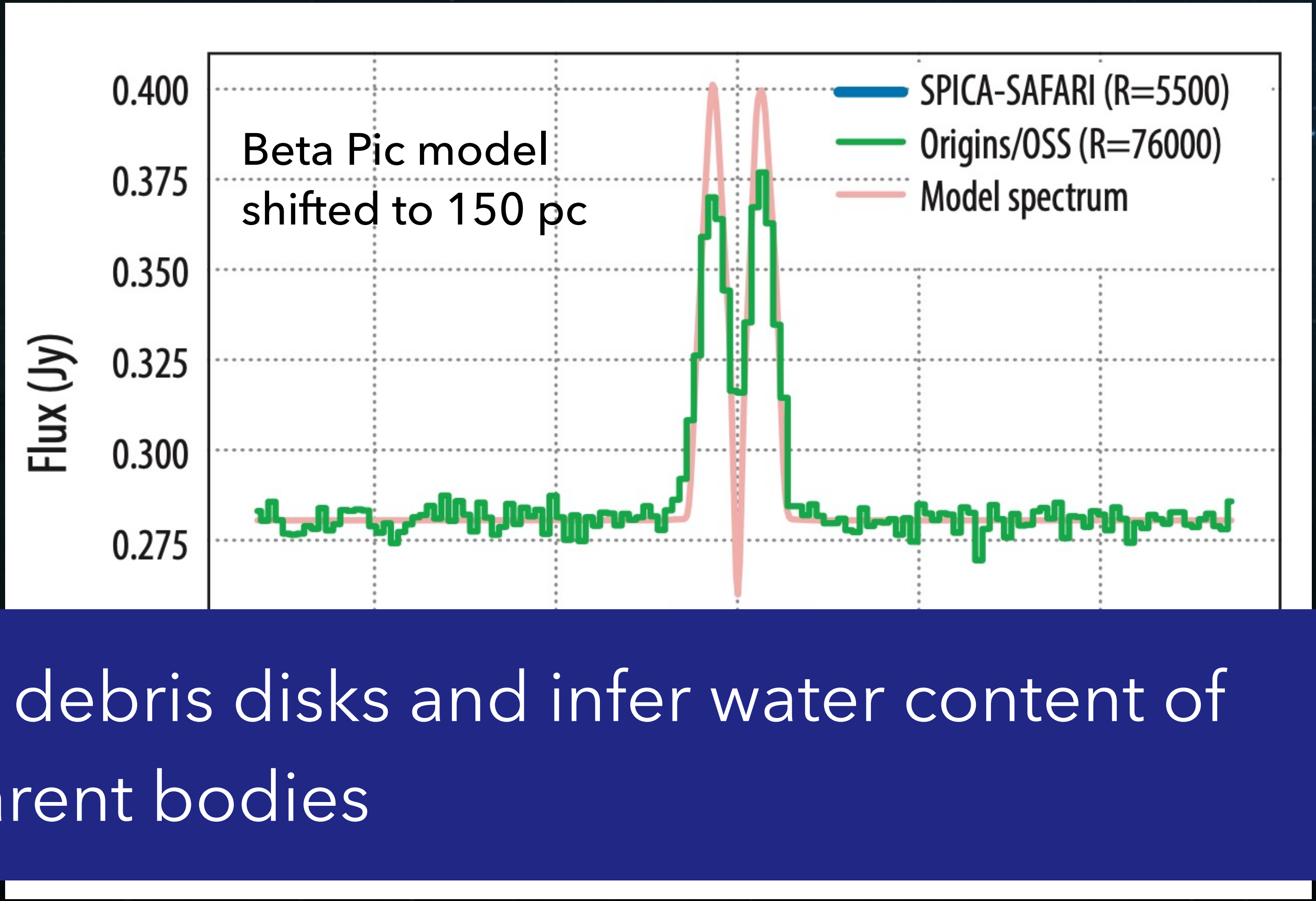
ALMA can access neutral carbon and CO



WATER'S ROLE IN PLANET FORMATION: DEBRIS DISKS

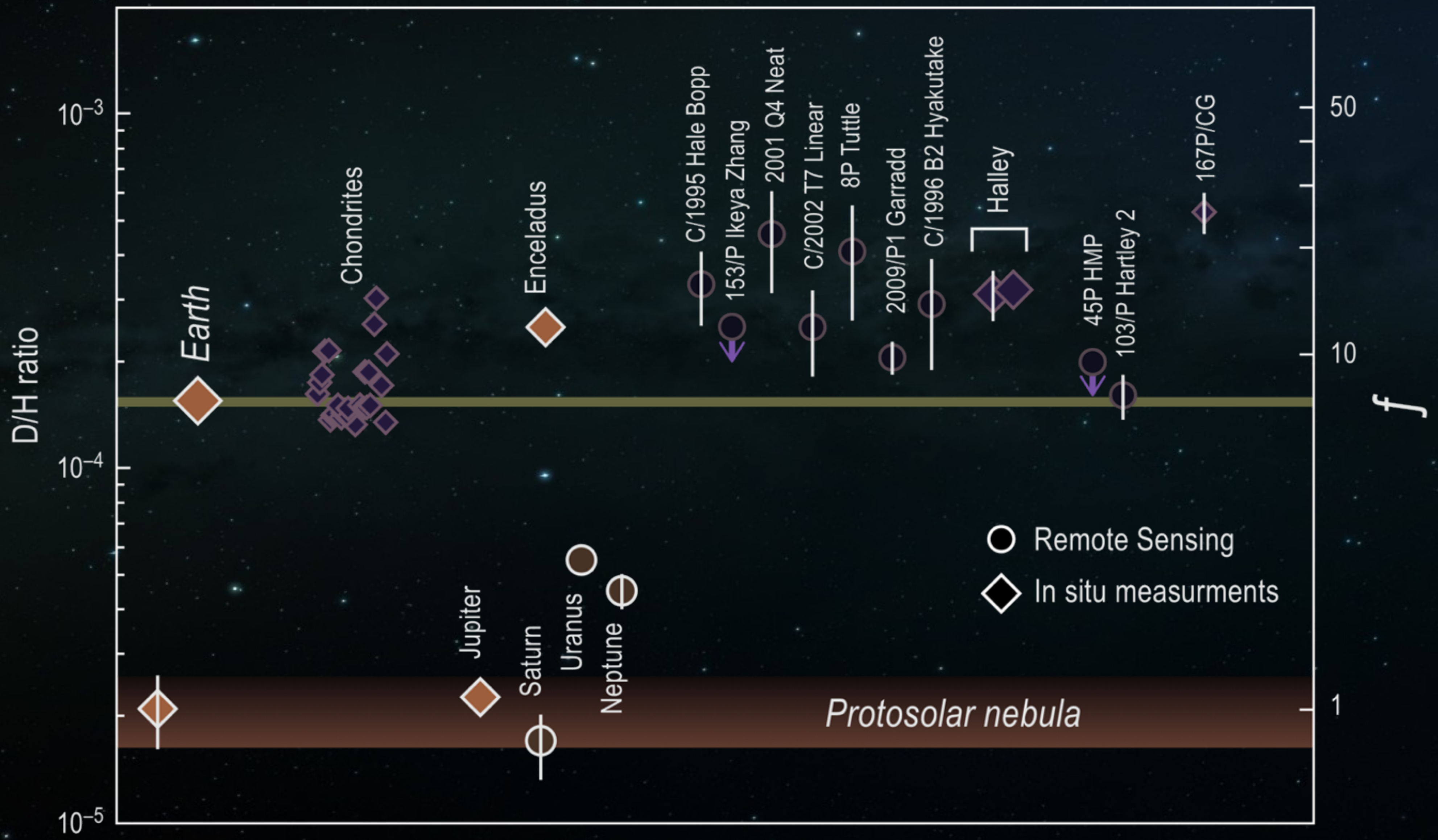
Low-density gas in debris disks coming from destruction of young planetesimals is poorly studied

Origins can survey for neutral oxygen (63 μm) and first-ionized carbon emission (157 μm)

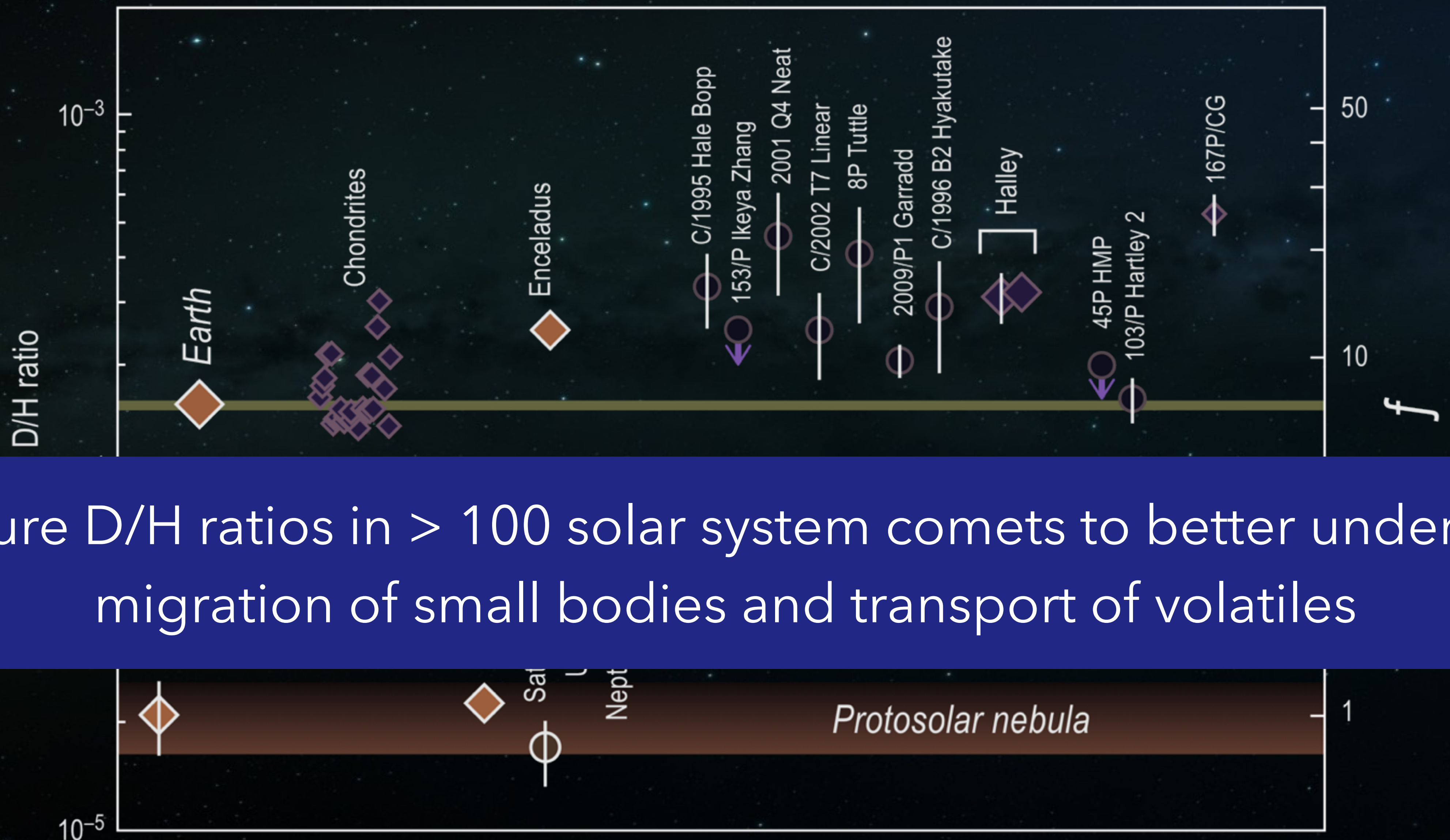


Measure C/O ratios for ~ 100 debris disks and infer water content of parent bodies

How were life's ingredients delivered? Comets



How were life's ingredients delivered? Comets



Measure D/H ratios in > 100 solar system comets to better understand migration of small bodies and transport of volatiles

How and when do planets form? Disk masses

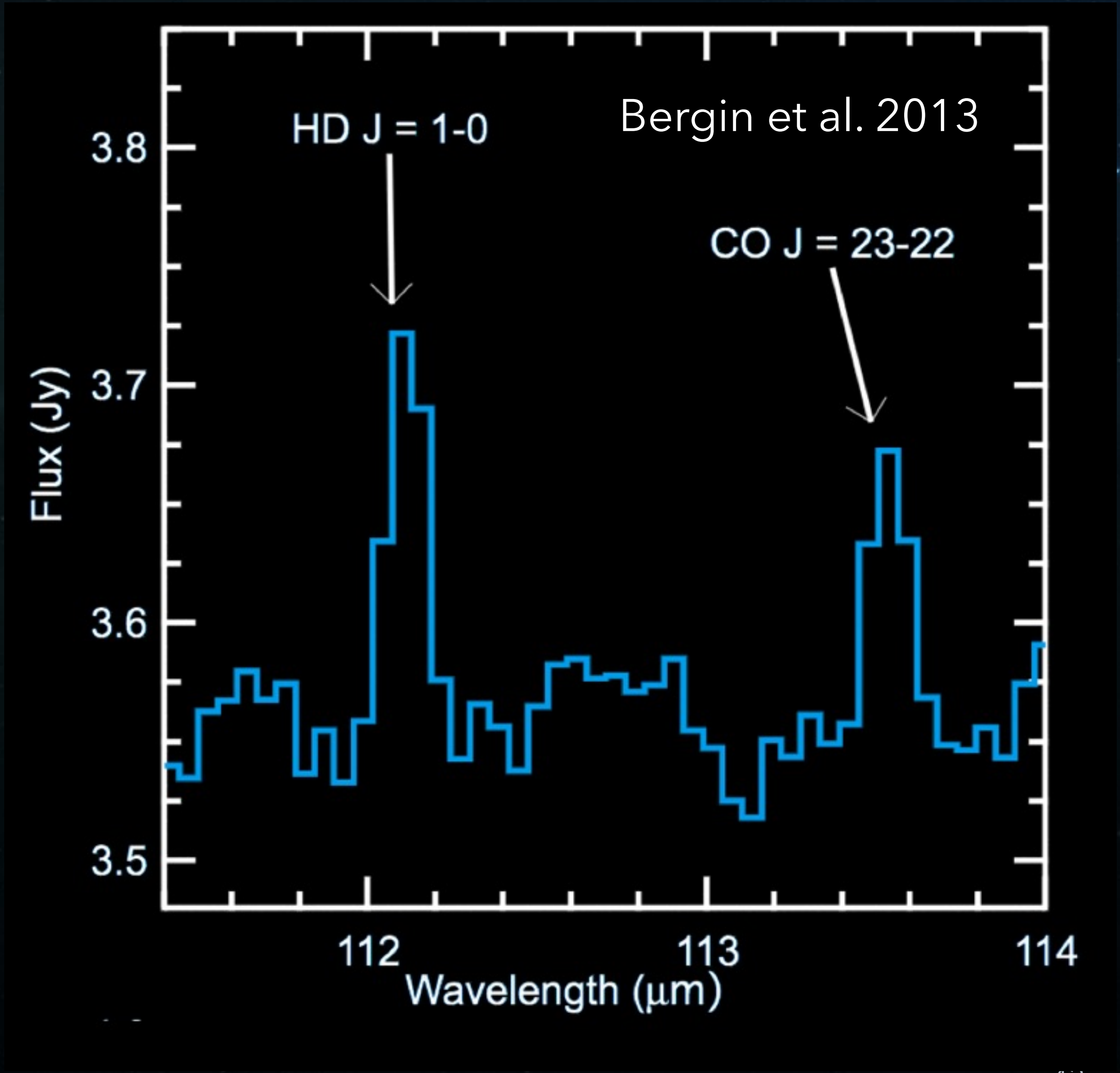
Total disk masses are critical inputs for planet formation models

Bulk of disk mass in H_2. Hard to observe in emission

Typically inferred from dust or CO, both minor constituents in protoplanetary disks

Factors of 10 – 100 uncertainty in masses

HD should be a more accurate proxy for H_2



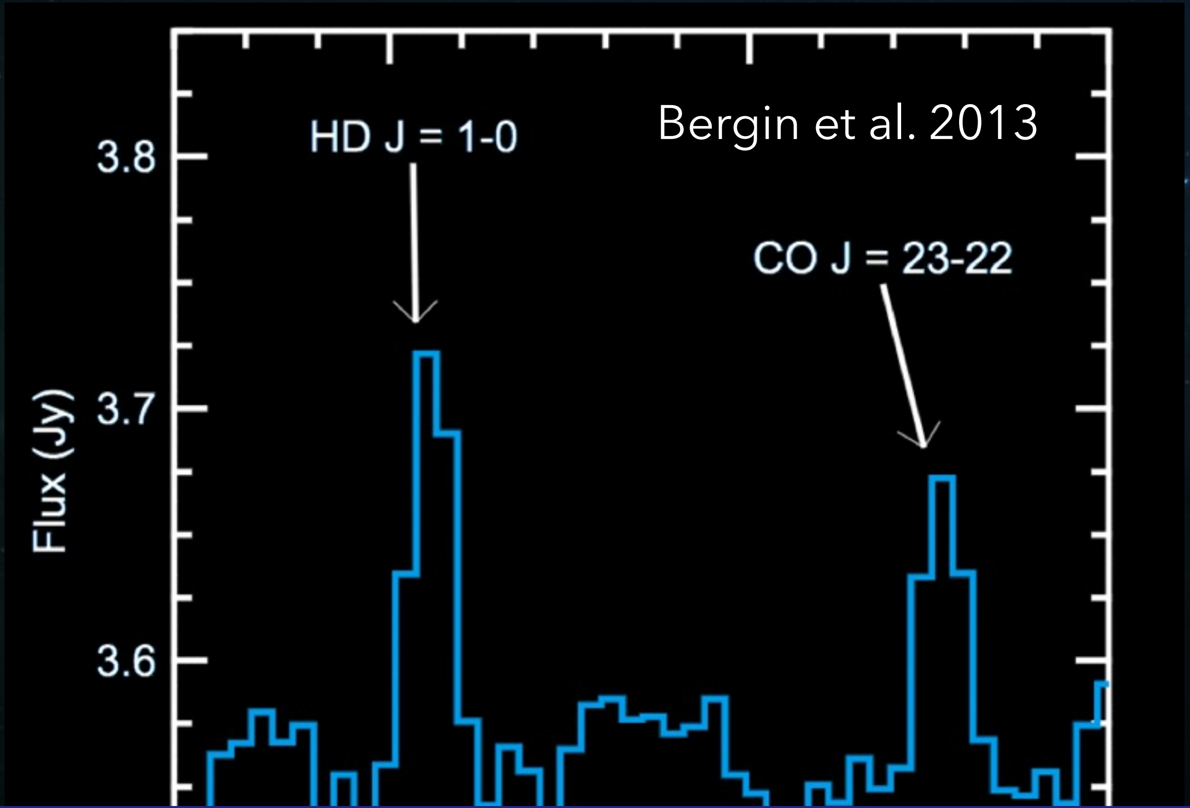
How and when do planets form? Disk masses

Total disk masses are critical inputs for planet formation models

Bulk of disk mass in H_2. Hard to observe in emission

Typically inferred from dust or CO, both minor constituents in protoplanetary disks

Factors of 10 – 100 uncertainty in masses



Survey for HD emission from 500 protoplanetary disks

Expect factors of 2 – 3 uncertainty in total disk masses

POTENTIALLY HABITABLE PLANETS AROUND M DWARFS

Mid-IR transit spectroscopy well-suited for studying potentially habitable planets around low-mass stars

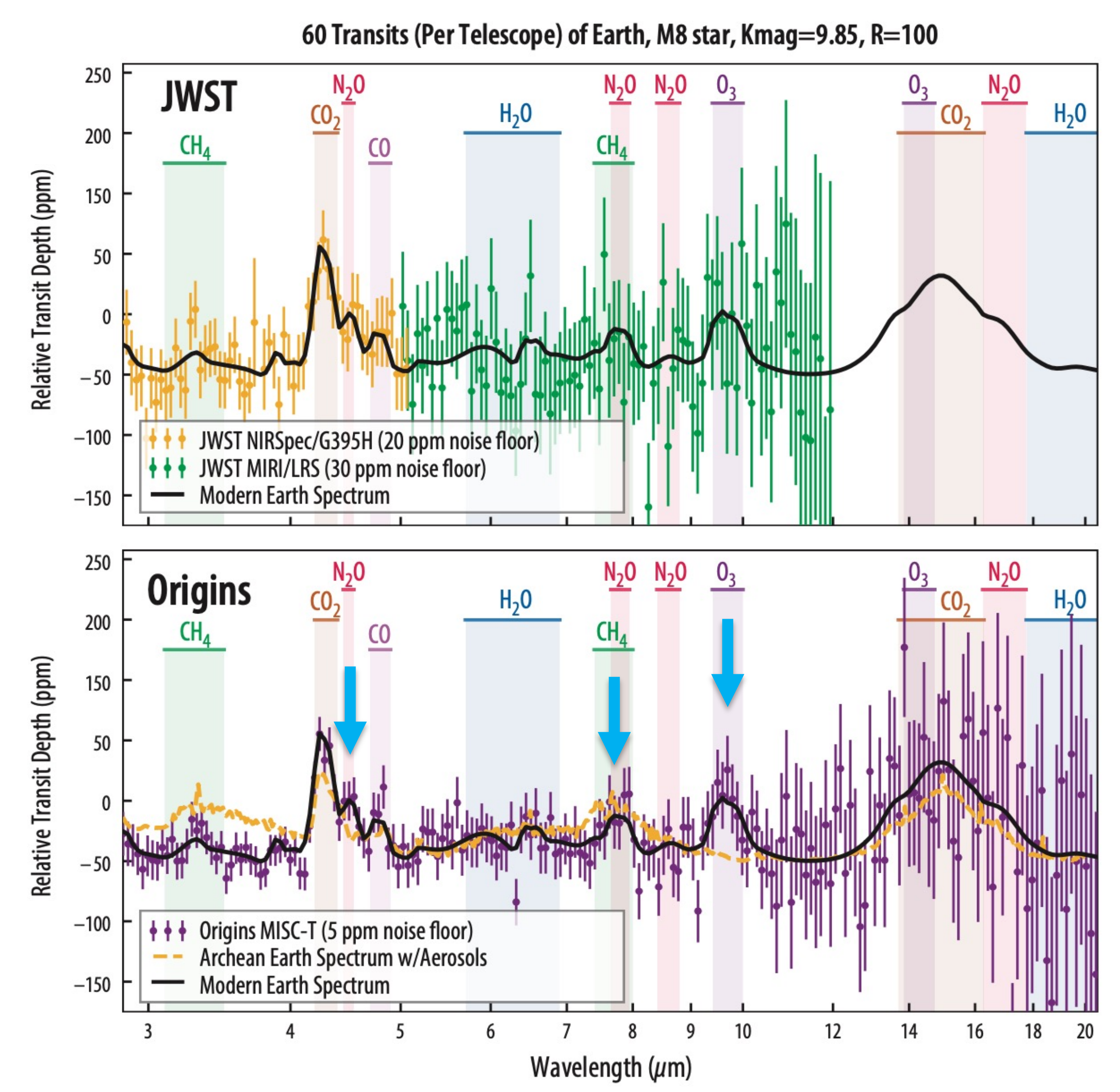
Starting Point for Origins Search for Life Program
At least 28 known temperate terrestrial planets transiting late-K to late-M dwarfs

Tier 1
Preliminary transit observations to distinguish cloudy / clear atmospheres using CO_2

Tier 2
Eclipse observations of ~ 14 clearest planets around mid- to late-M dwarfs to assess surface temperatures

Tier 3
Deep transit spectroscopy of ~ 10 most promising planets to look for potential biosignatures

Tier 3 – Deep transit spectroscopy



↓ Biosignature gas combinations in Modern Earth

LUVOIR

ORIGINS

Powerful capabilities of all three missions will enable even more amazing science we haven't thought of yet

HABEX