# BIG BANG TO BIOSIGNATURES: THE LUVOIR MISSION CONCEPT

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# What is LUVOIR ?

## Large UV / Optical / Infrared Surveyor (LUVOIR)

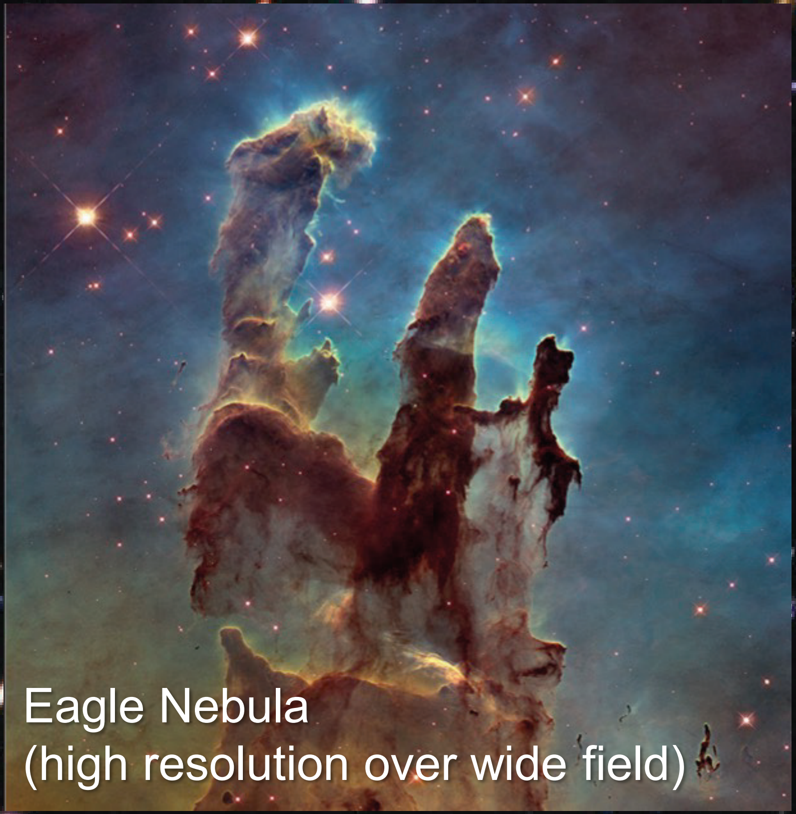
### A space telescope concept in tradition of Hubble

- Broad science capabilities
- Far-UV to near-IR bandpass
- Two architectures: 9-m and 15-m telescopes
- Suite of imagers and spectrographs
- Serviceable and upgradable
- Guest Observer driven

"Space Observatory for the 21st Century"

Ability to answer the questions of the 2030s and beyond

# Imagine Astronomy Without Hubble …



Eagle Nebula
(high resolution over wide field)

Hubble Ultra Deep Field
(ultra-deep imaging)

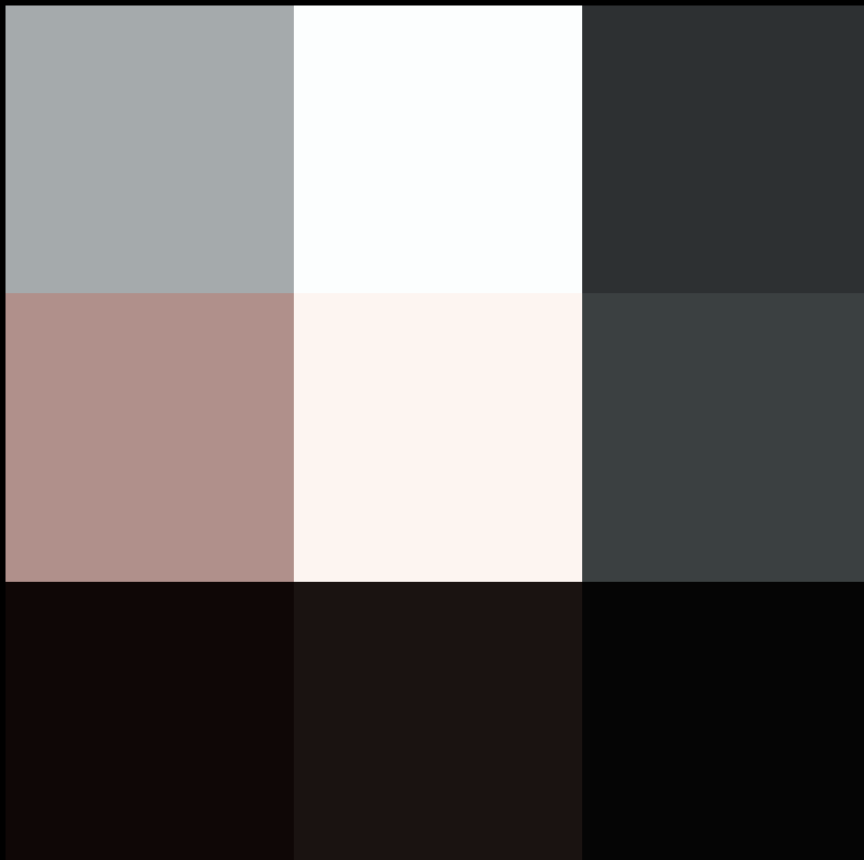
# Imagine Astronomy with LUVOIR …

Low-mass galaxy at z = 2 with HST

Low-mass galaxy at z = 2 with 15-m LUVOIR

Credit: G. Snyder (STScI)

# Imagine Astronomy with LUVOIR …



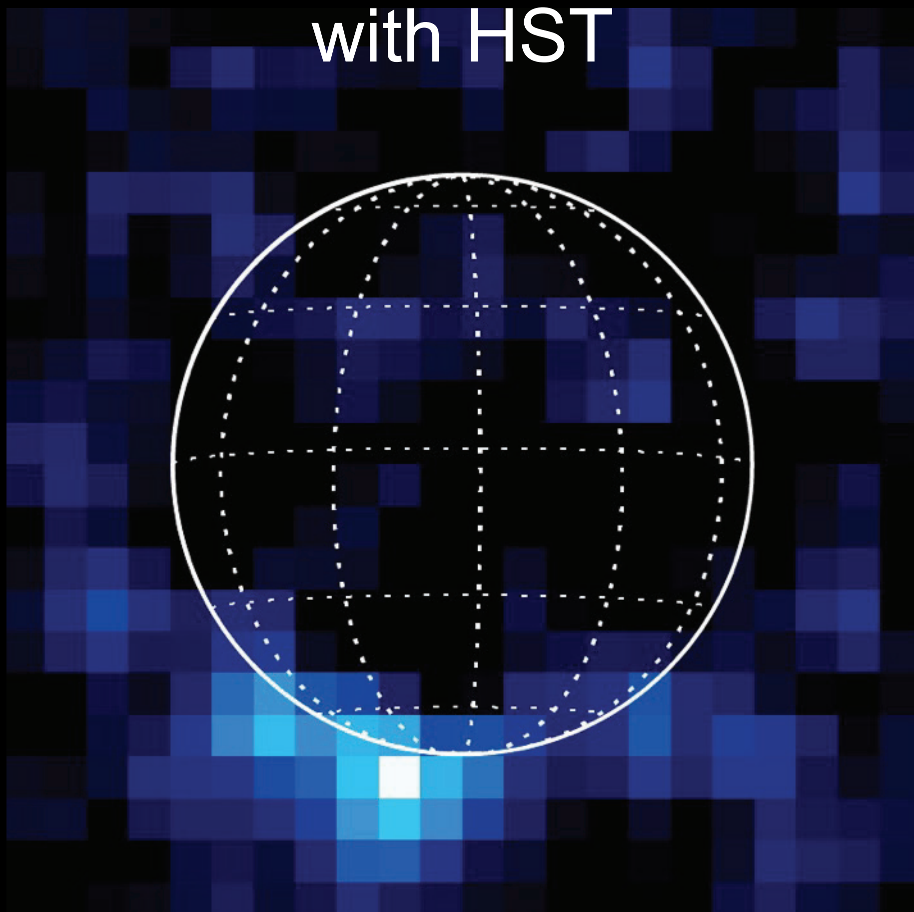
Pluto with HST

Pluto with 15-m LUVOIR

Credit: NASA / New Horizons / R. Parramon

# Monitoring Solar System Ocean Moons

Europa jets observed with HST



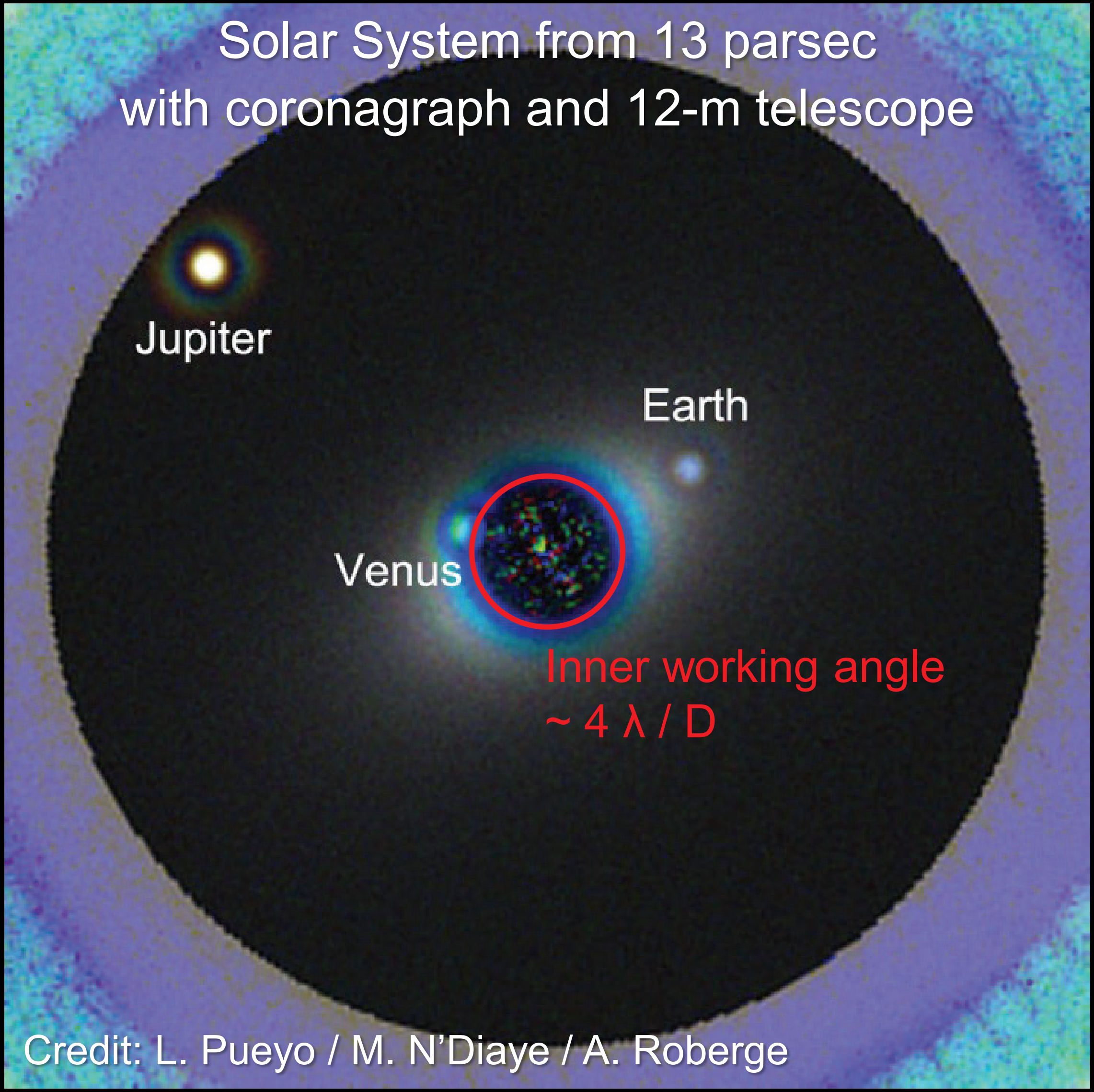
Europa jets observed with 15-m LUVOIR

Roth et al. (2014)

UV hydrogen emission

Credit: G. Ballester (LPL)

# Imaging Earthlike Planets



# Searching for Life

- Rayleigh scattering

0.4 microns 2.4 microns

# Searching for Life

Rayleigh scattering

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Rayleigh scattering

0.4 microns

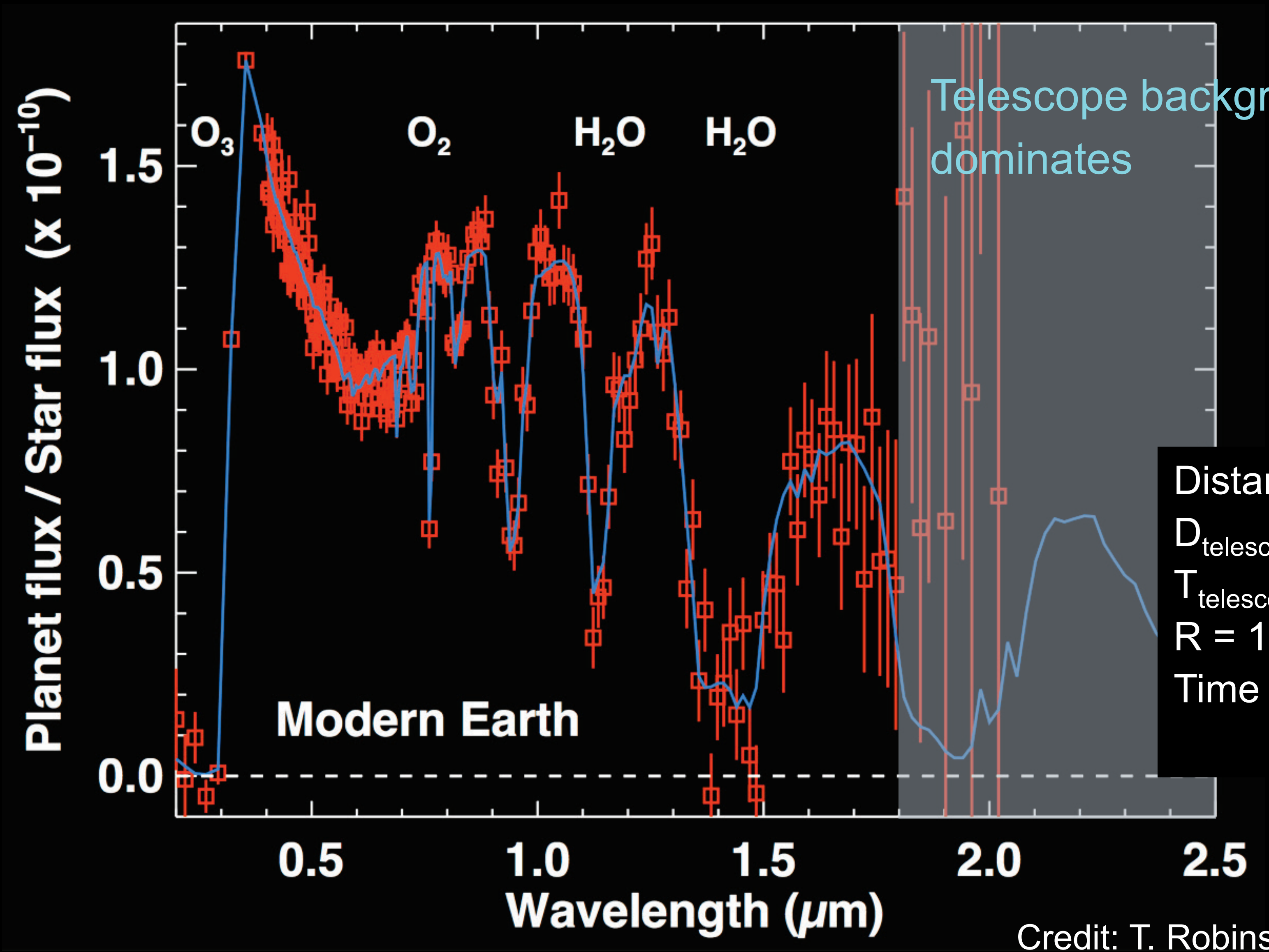
2.4 microns

# Searching for Life

Rayleigh scattering

0.4 microns 2.4 microns

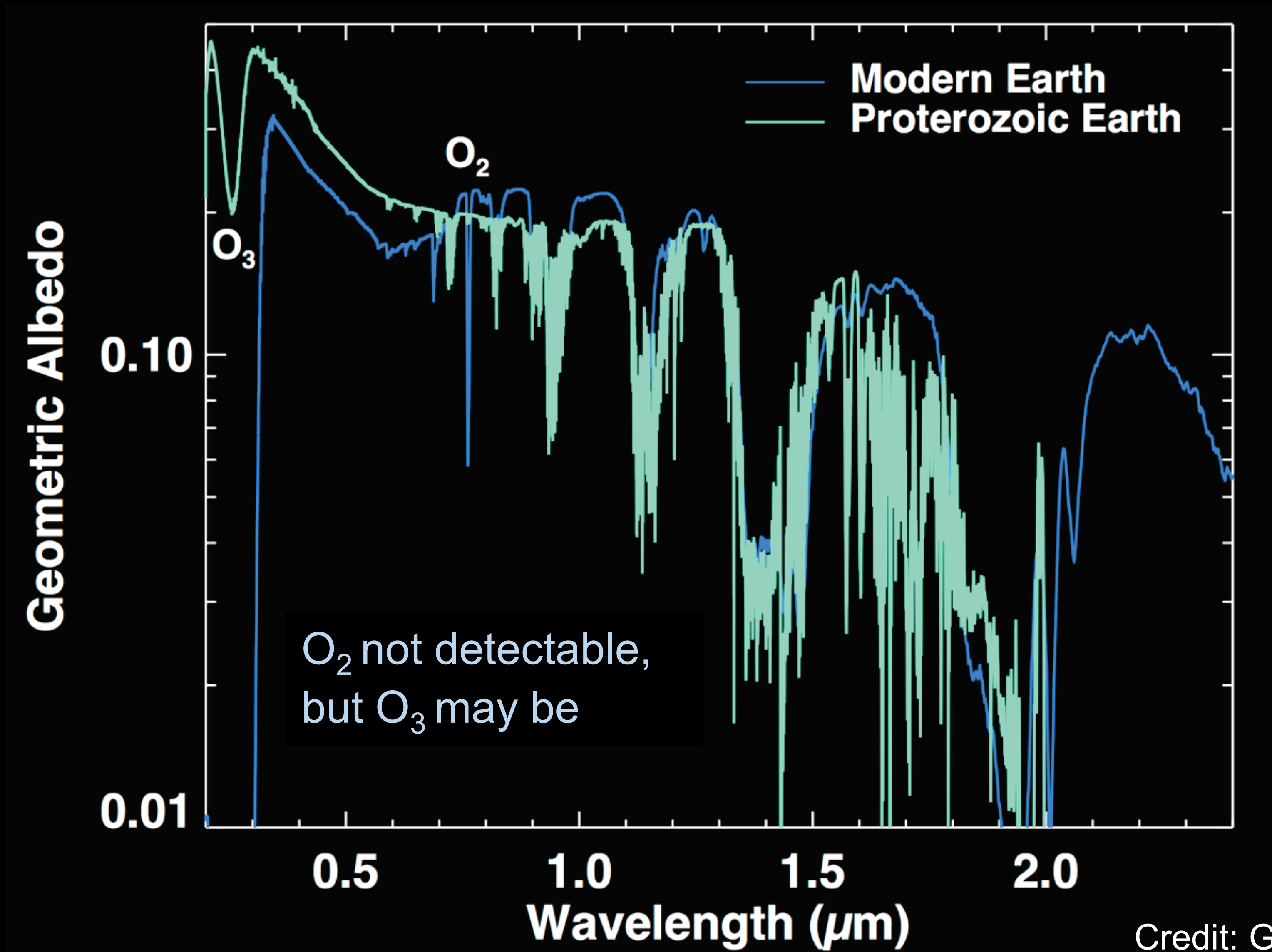
# Simulated LUVOIR Observation




Distance = 10 pc
$D_{telescope}$ = 15-m
$T_{telescope}$ = 270 K
R = 150
Time = 96 hrs per band

Credit: T. Robinson / G. Arney

# Early Earth Had a Different Spectrum




Credit: G. Arney

# How Will LUVOIR Confirm Biosignatures?

***Observational Challenges:***

1. Determine the state of the atmosphere → access **many molecules**
2. Measure abundances → observe **multiple bands** of same molecule
3. Rule out false positives → **broad bandpass** & **UV spectrum** of star

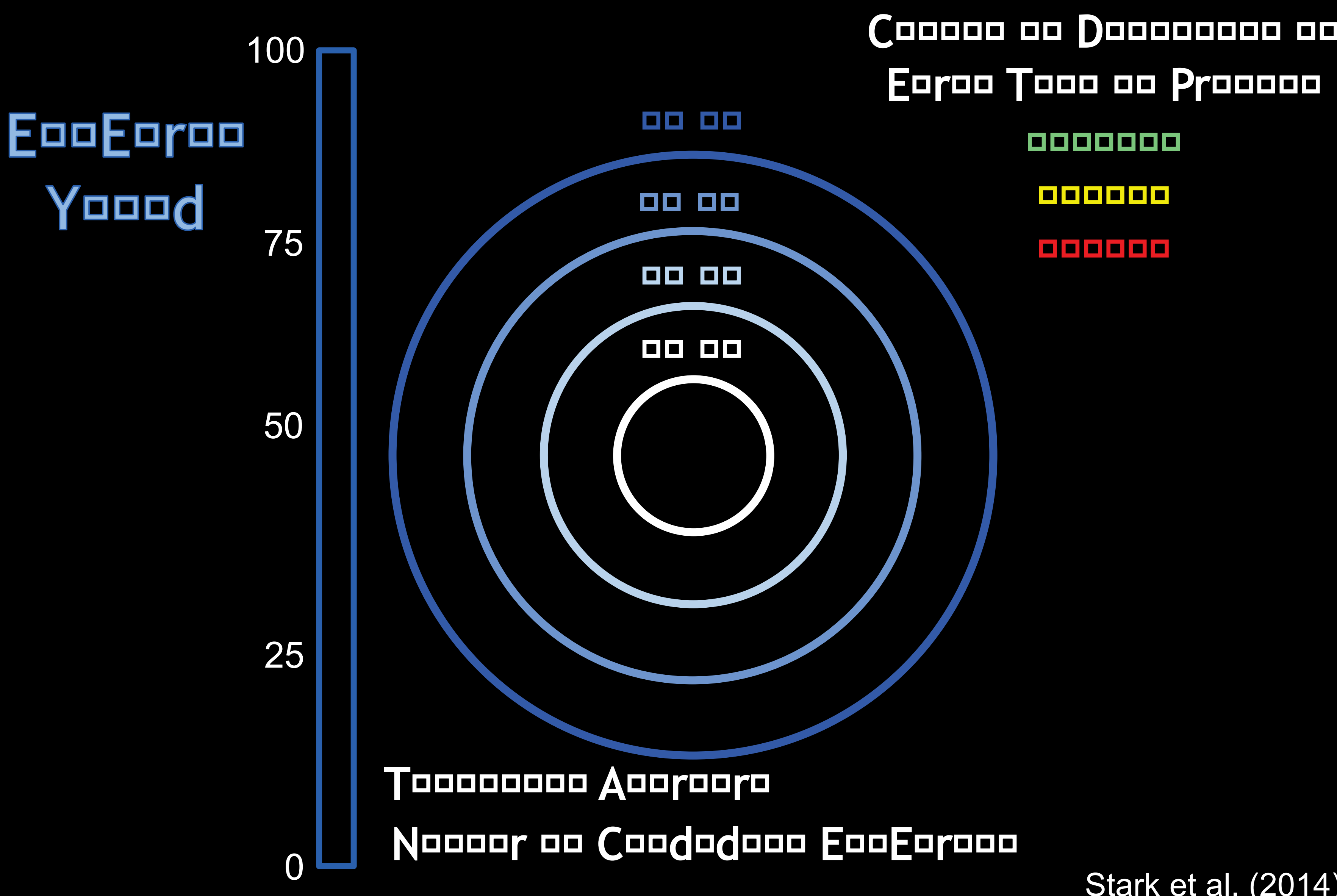
***LUVOIR's Approach:***

1. Observe over a **broad wavelength range**

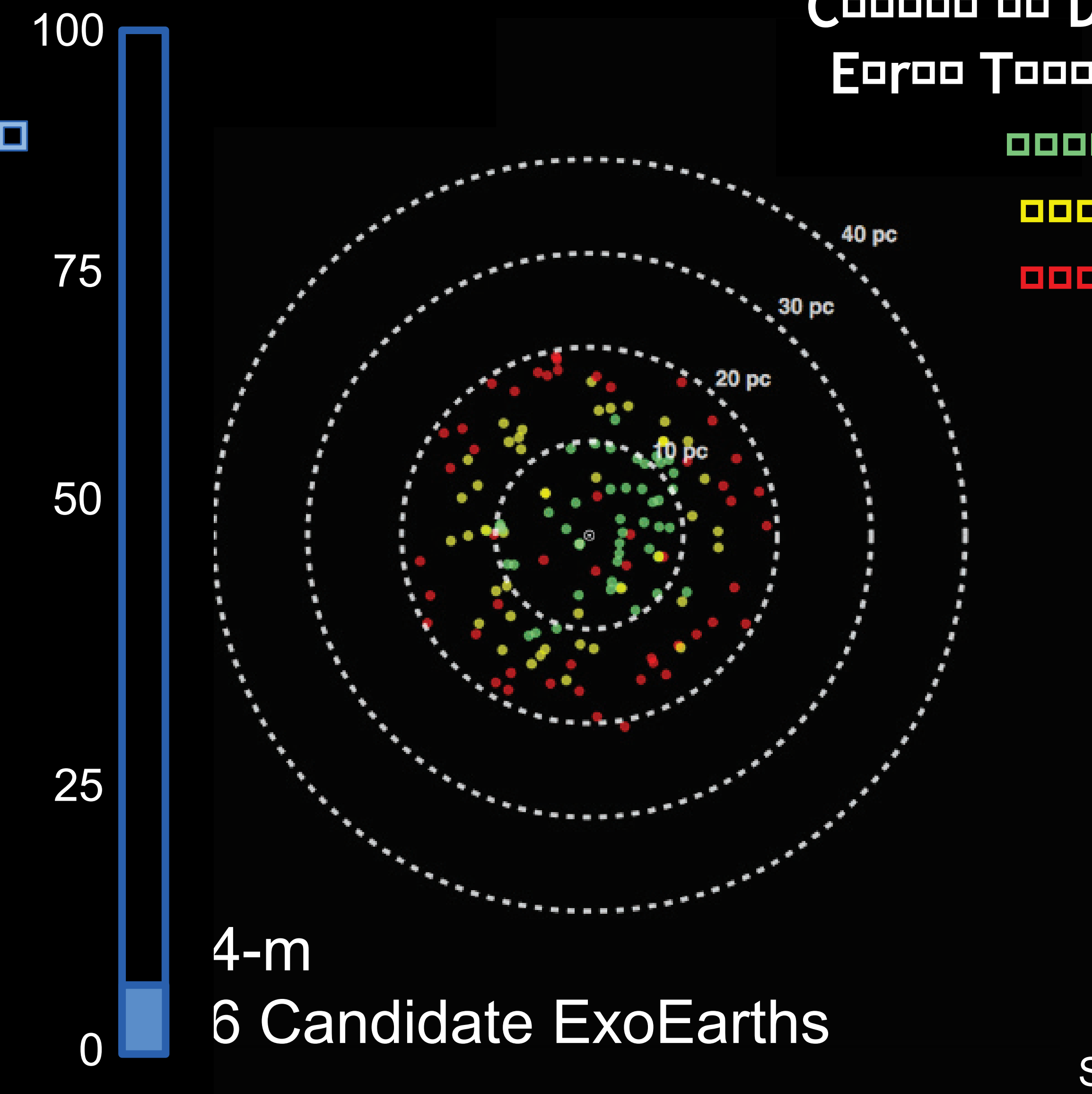
   0.2 – 2.0 μm contains absorption bands of $O_2$, $O_3$, $O_4$, $H_2O$, $CO$, $CO_2$, $CH_4$

2. Carefully **characterize host stars** (LUMOS, POLLUX)
3. Enable observations of habitable planets at longer wavelengths by building a **large aperture** & decreasing the inner working angle (IWA ~ λ / D)

# Larger Telescopes Survey More Stars



# Larger Telescopes Survey More Stars




Stark et al. (2014)

# Larger Telescopes Survey More Stars

E□□E□r□□
Y□□□d

C□□□□□ □□ D□□□□□□□□ □□
E□r□□ T□□□ □□ P□□□□□□

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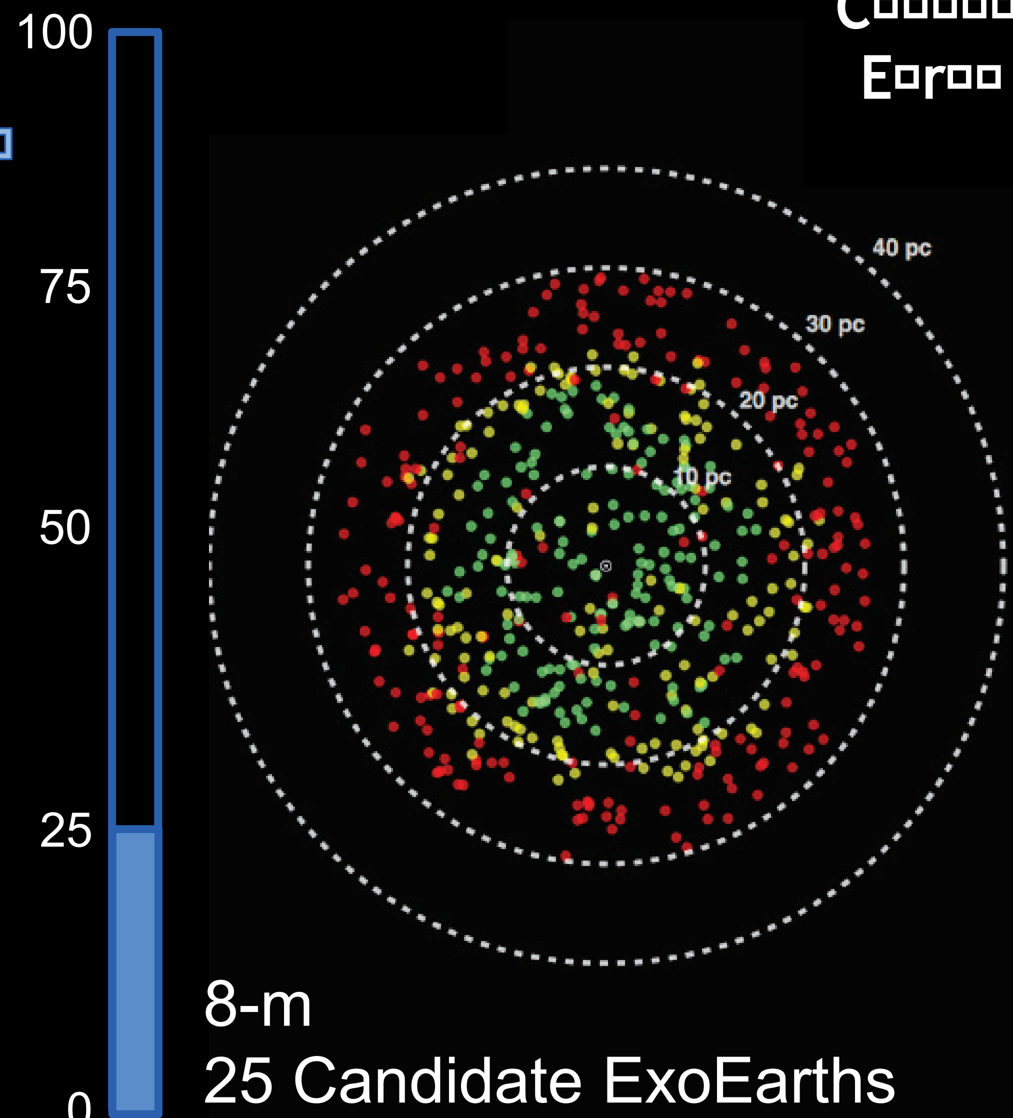
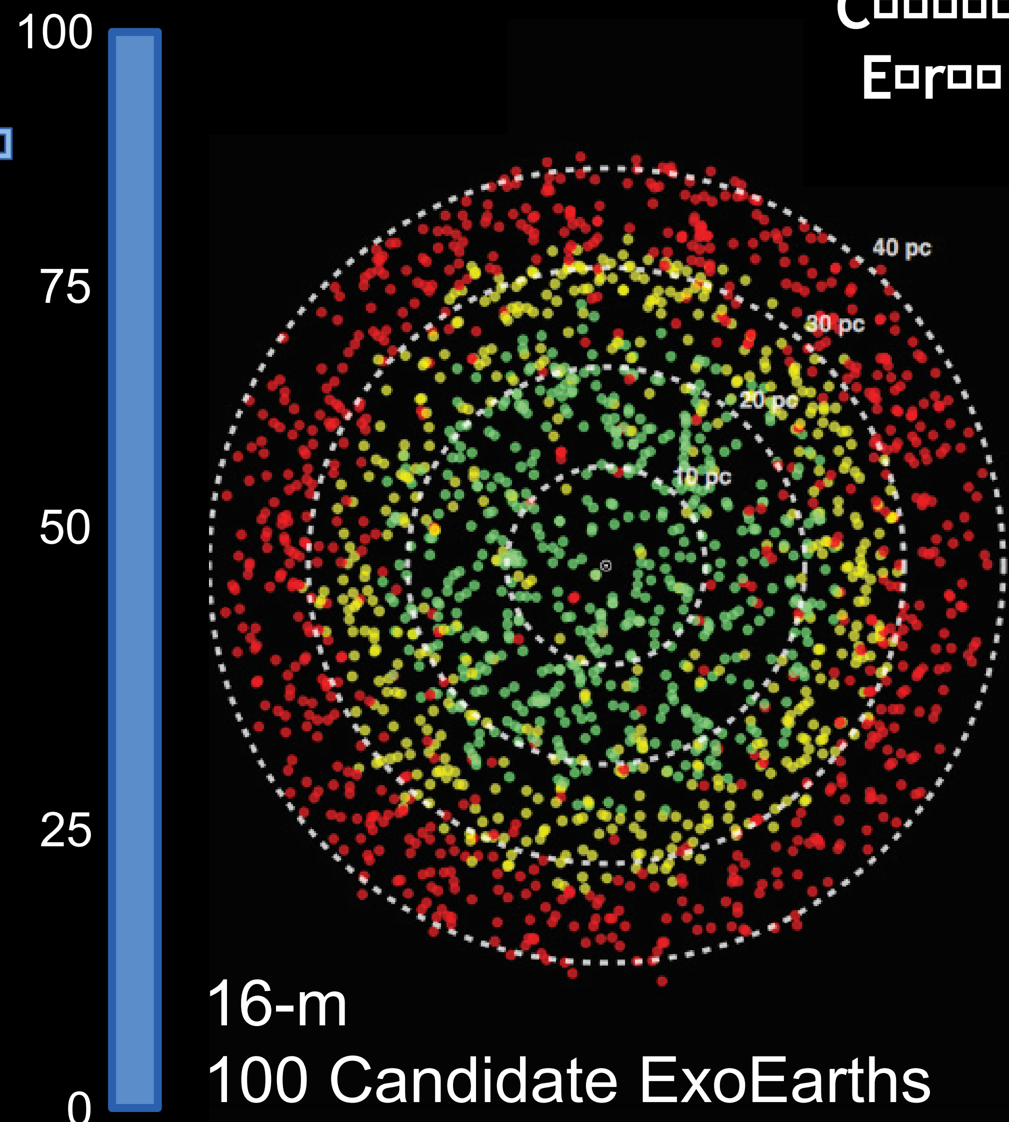


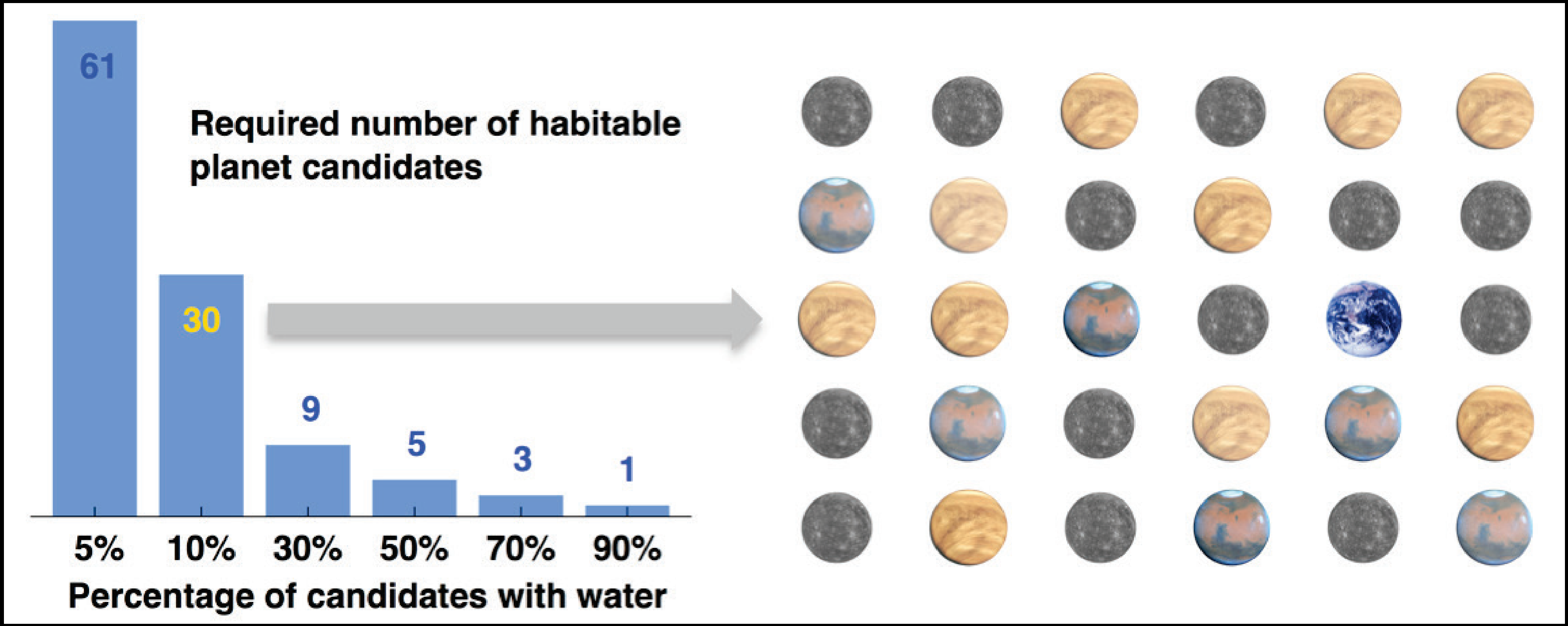

Stark et al. (2014)

# Larger Telescopes Survey More Stars



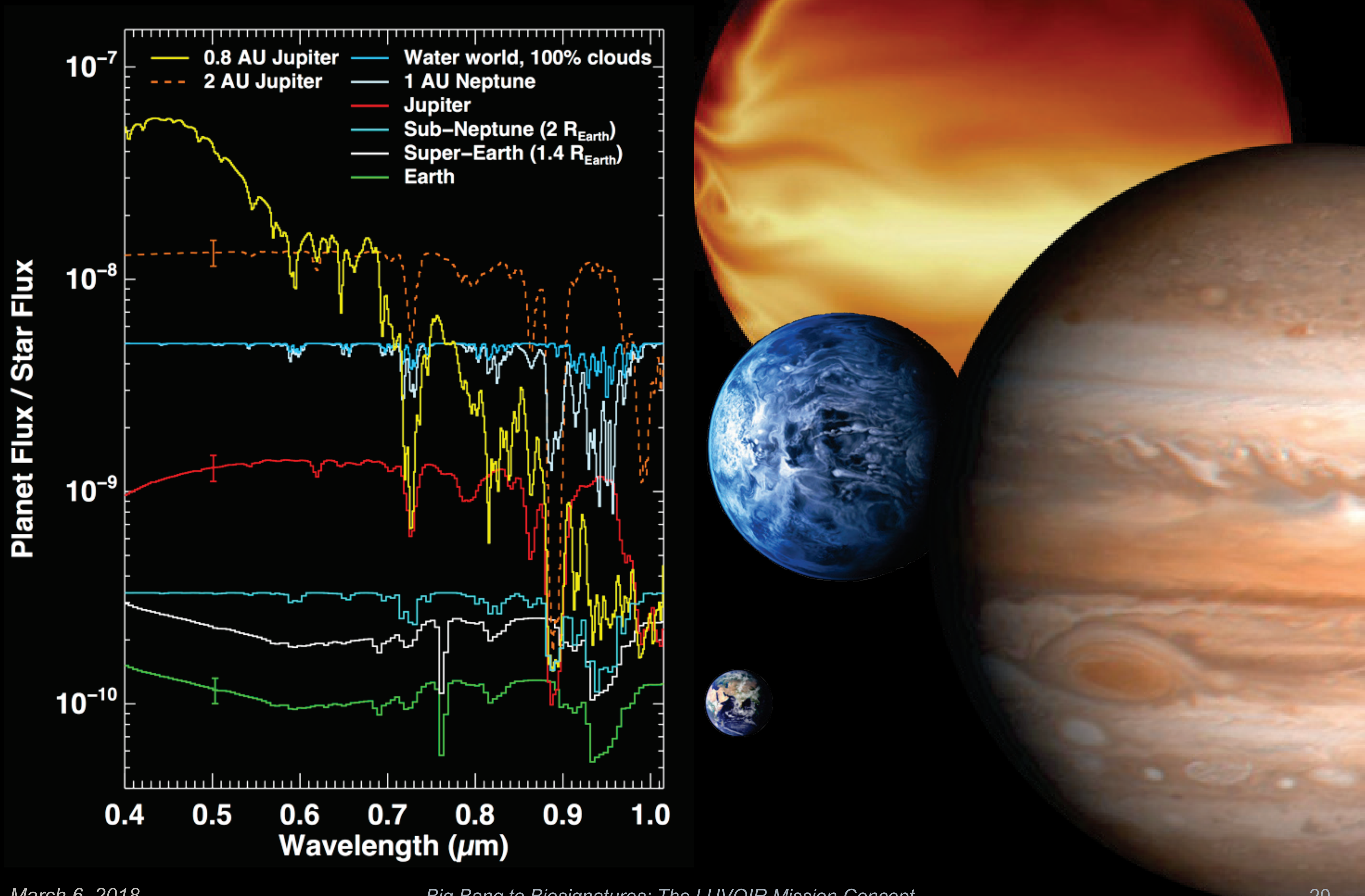

Stark et al. (2014)

# How Many Candidate Habitable Planets Do We Need to Observe to Find One With Water?




Credit: C. Stark / A. Roberge

# LUVOIR Enables Exoplanetology



# The LUVOIR Architectures

## Architecture A

- 15-m diameter telescope
- Fits in 8.4-m fairing
  - *Space Launch System Block 2*
- Bulk of work completed
- Refinements in progress

| Instruments |
|---|
| ECLIPS A |
| LUMOS A |
| High-Definition Imager |
| POLLUX |

## Architecture B

- 9-m diameter telescope
- Fits in 5-m fairing
  - *e.g., Delta IV Heavy, Falcon Heavy*
- Work began in September 2017

| Instruments |
|---|
| ECLIPS B |
| LUMOS B |
| HDI B |

# The LUVOIR Instruments

## Observational challenge

Faint planets next to bright stars

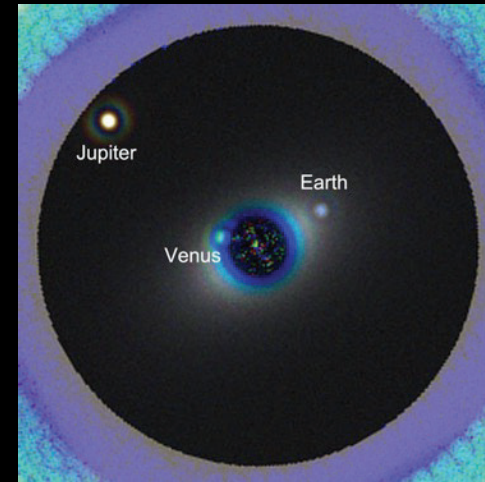
## Extreme Coronagraph for LIving Planetary Systems (ECLIPS)

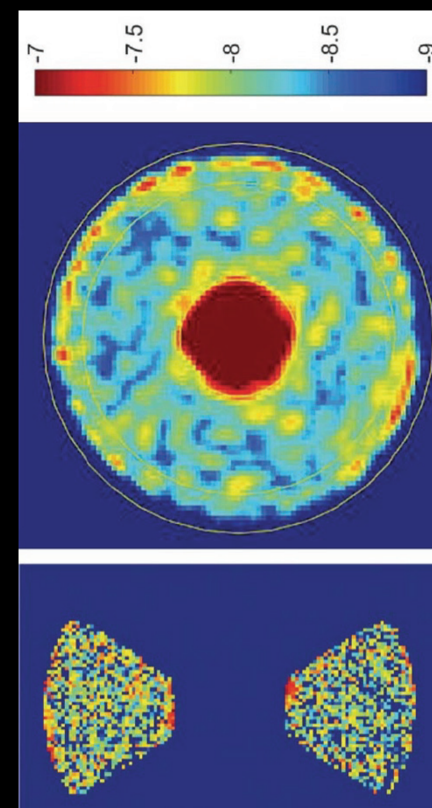
Contrast < $10^{-10}$

Low resolution imaging spectroscopy

Bandpass: 0.2 µm to 2.0 µm

Tech development via WFIRST coronagraph




WFIRST HLC

WFIRST SPC

# The LUVOIR Instruments

## Observational challenge

Very cold to very hot gases

## LUVOIR UV Multi-Object Spectrograph (LUMOS)

R = 500 – 63,000

Bandpass:  100 nm to 400 nm

FOV: 3' x 1.6' (FUV), 1.3' x 1.6' (NUV)

FUV imaging channel

Heritage from STIS, COS, & NIRSPEC

Europa geysers

HST STIS 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

Nyquist sampled

Micro-arcsec astrometry capability
(measure planet masses, etc.)

Heritage from HST WFC3 & WFIRST

HST Wide Field Camera 3

# POLLUX: a European contribution to the LUVOIR mission study

- UV spectro-polarimeter with high resolution point-source capability (R ~ 120,000).
- Circular + linear polarizations and unpolarized light
- Defined & designed by consortium of 10 European institutions, with leadership/support from CNES
- Builds off Arago mission concept.  Instrument study could serve as basis for a future ESA contribution to LUVOIR

# Design Your Own Observations Using Our Online Tools

## http://asd.gsfc.nasa.gov/luvoir/tools/


Science Design Team Tools Events Participate Resources Technology Press

## Tools

This page links to performance simulation and visualization tools for the LUVOIR mission, a future ultraviolet / optical / near-infrared observatory concept.

These widgets are experimental. If they are not working, email Jason Tumlinson (STScI). For the Planetary Spectrum Generator, email Geronimo Villanueva (GSFC).

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### Coronagraphic Spectra of Exoplanets

Simulate optical/near-IR reflection spectra of various exoplanets with realistic noise.

### Multiplanet Yield Tool

Tool for visualizing yields of observed exoplanets (of various types) as function of basic mission parameters.

### Planetary Spectrum Generator

Advanced tool for simulating spectra of Solar System bodies (with LUVOIR and other telescopes).

### HDI Photometric ETC

Basic exposure time calculator for optical photometry in multi-band images.

### LUMOS Spectroscopic ETC

Simple exposure time calculator for UV spectroscopy.

### UV MOS Visualizer

See the impact of UV multi-object spectroscopy on the study of stellar clusters and their feedback.

### High-Resolution Imaging

Examples of astronomical objects viewed with different sized telescopes.

SPACE FLIGHT CENTER

Curator: J.D. Myers
NASA Official: Phil Newman

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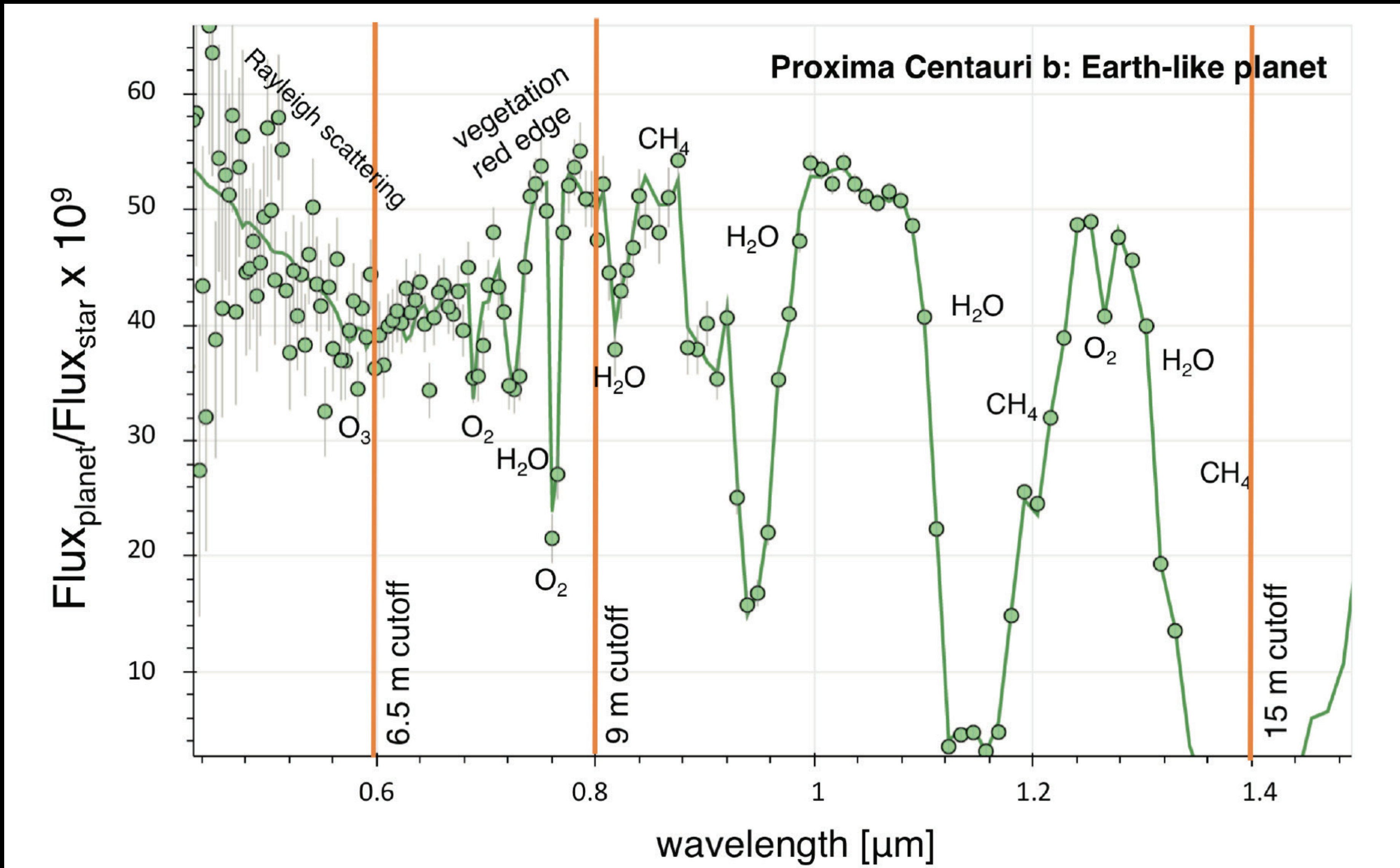
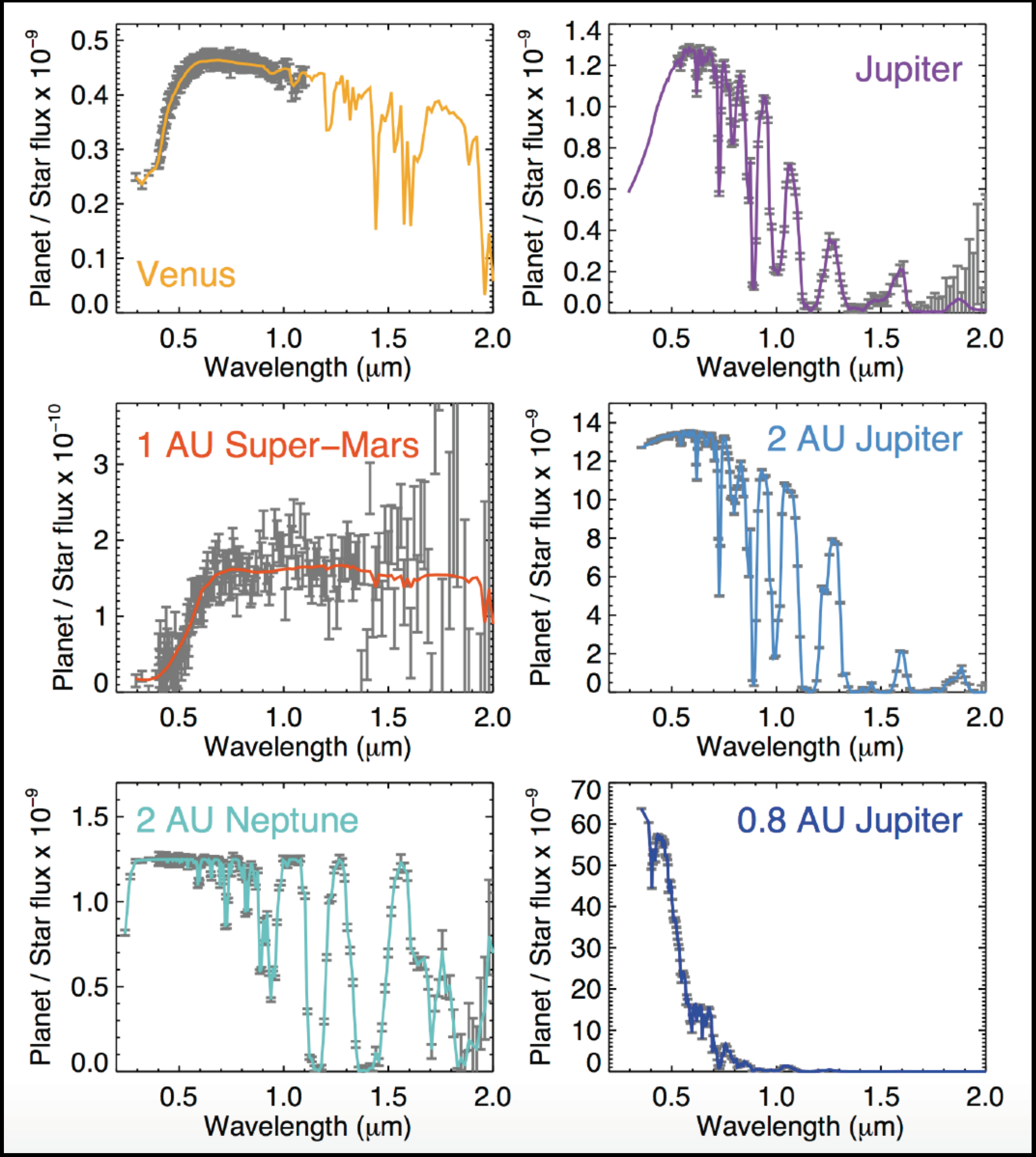
# Sample Observation: Spectrum of Proxima Centauri b




Credit: LUVOIR Tools

# Sample Observations: An "Exoplanet Zoo"



# Technological Challenges

## Deployment of large segmented telescope

To be demonstrated by JWST

LUVOIR Architecture A (15-m)

Credit: A. Jones (GSFC)

# Technological Challenges

## Need heavy lift launch vehicle with large fairing

Suitable vehicles (SLS and commercial) in development

## Compatibility of UV and coronagraphy

New lab work shows UV reflective mirrors are just fine for coronagraphy

## Ultra-high contrast observations with a segmented telescope

Coronagraphs can be designed for segmented telescopes. Working hard to demonstrate needed system stability

Series of short, readable "LUVOIR Tech Notes" available at http://asd.gsfc.nasa.gov/luvoir/tech/

# STDT Voting Members


Debra Fischer
(Yale)


Brad Peterson
(Ohio State / STScI)


Jacob Bean
(Chicago)


Daniela Calzetti
(U Mass)


Rebekah Dawson
(Penn State)


Courtney Dressing
(UC Berkeley)


Lee Feinberg
(NASA GSFC)


Kevin France
(Colorado)


Olivier Guyon
(Arizona)


Walter Harris
(Arizona / LPL)


Mark Marley
(NASA Ames)


Leonidas Moustakas
(JPL)

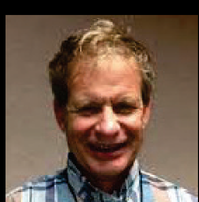

John O'Meara
(St. Michael's)


Vikki Meadows
(Washington)


Ilaria Pascucci
(Arizona)


Marc Postman
(STScI)


Laurent Pueyo
(STScI)


David Redding
(JPL)


Jane Rigby
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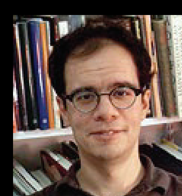
Aki Roberge
(NASA GSFC)


David Schiminovich
(Columbia)


Britney Schmidt
(Georgia Tech)


Karl Stapelfeldt
(JPL)

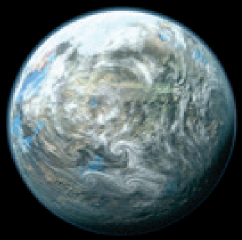

Jason Tumlinson
(STScI)

# Community Participation in LUVOIR

10 non-voting reps. of international space agencies

Community Working Groups

- Exoplanets
- Cosmic Origins
- Solar System
- Simulations
- Communications
- Technology

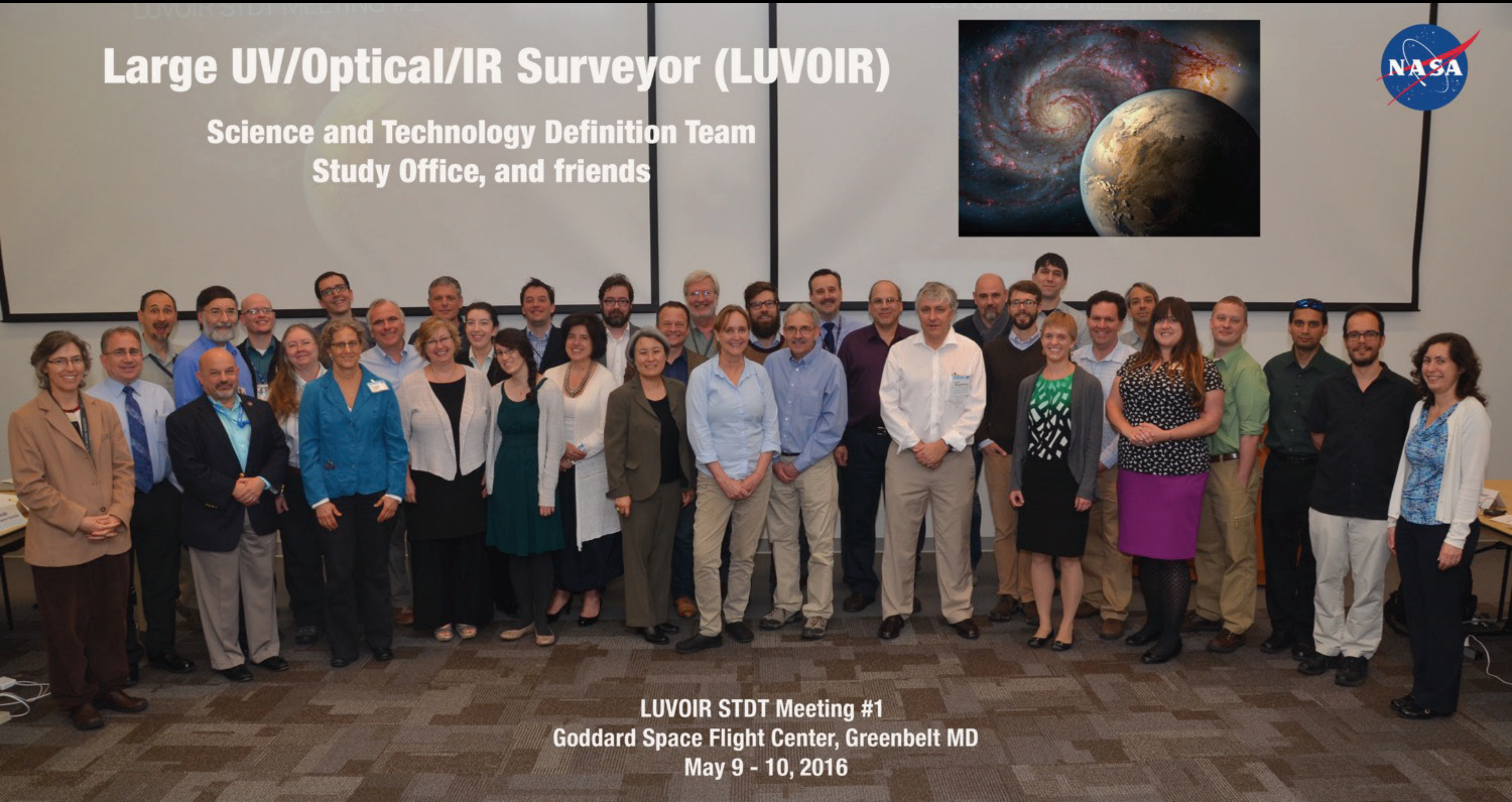


Instrument Teams

# Upcoming Meetings

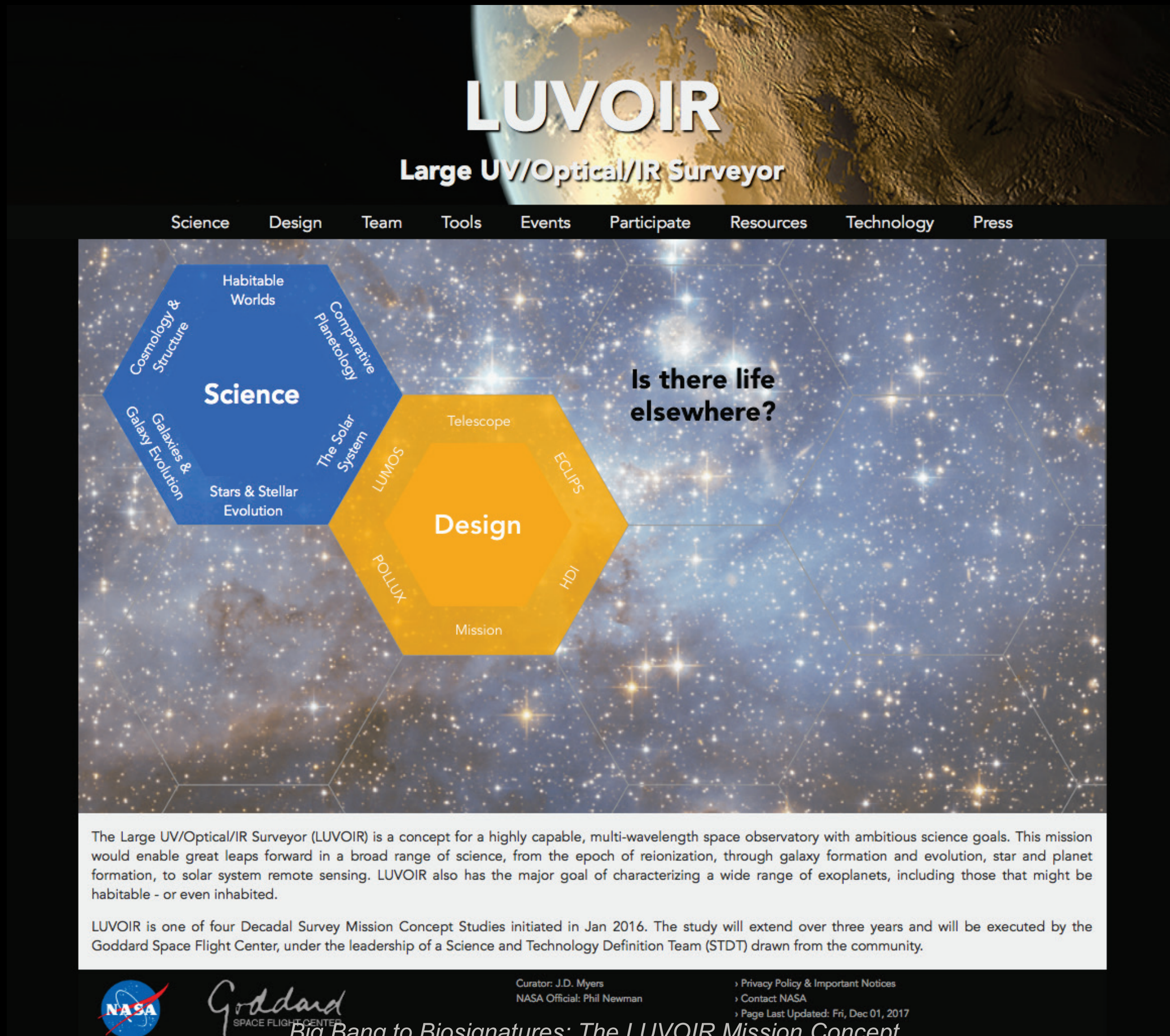
May 10 – 11: Face-to-face meeting at NASA Goddard

Observers welcome at all LUVOIR meetings & telecons



# Get Involved with LUVOIR

http://asd.gsfc.nasa.gov/luvoir/



# Summary

## LUVOIR has multiple primary science goals

1. Habitable exoplanets & biosignatures
2. Broad range of general astrophysics and Solar System observations

## LUVOIR will blend these goals into a single powerful mission

- **Detect & characterize potentially habitable planets**
- **Place limits on the frequency of habitable & inhabited worlds**
- **Significantly advance our knowledge of planets of all types**
- **Advance Goal #2 by factors of 100 relative to Hubble**

*Wide range of capabilities to enable decades of future investigations and unexpected discoveries*

# BACKUP

# Difference between LUVOIR and HabEx?

Both LUVOIR and HabEx have two primary science goals

- Habitable exoplanets & biosignatures
- Broad range of general astrophysics

The two architectures will be driven by difference in focus

- For LUVOIR, both goals are on equal footing. LUVOIR will be a general purpose "great observatory", a successor to HST and JWST in the 8 – 16 m class
- HabEx will be optimized for exoplanet imaging, but also enable a range of general astrophysics. It is a more focused mission in the 4 – 6.5 m class

Similar exoplanet goals, differing in quantitative levels of ambition

- HabEx will *explore* the nearest stars to "search for" signs of habitability & biosignatures via direct detection of reflected light
- LUVOIR will *survey* more stars to "constrain the frequency" of habitability & biosignatures and produce a statistically meaningful sample of exoEarths

The two studies will provide a continuum of options for a range of futures

# What Will LUVOIR & HabEx Cost?

Quite simply, *we don’t know* (yet)

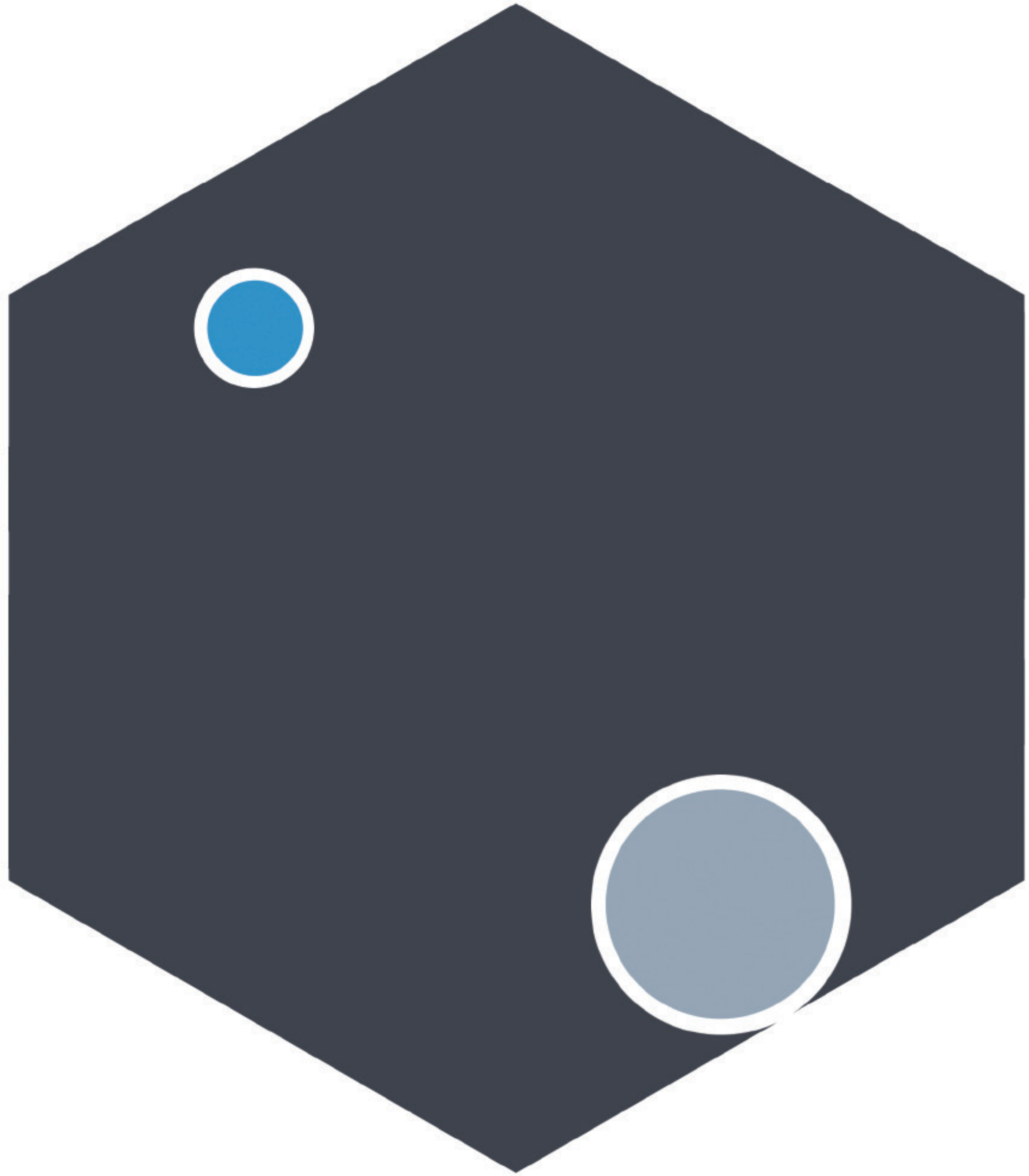
One of the major goals of these studies is to get accurate total mission cost estimates

- Internal team costing and independent costing by Aerospace Corp. will happen as part of the studies

Both teams are planning to study two mission architectures, each with different apertures and capabilities. Will provide a range of options covering a range of possible futures

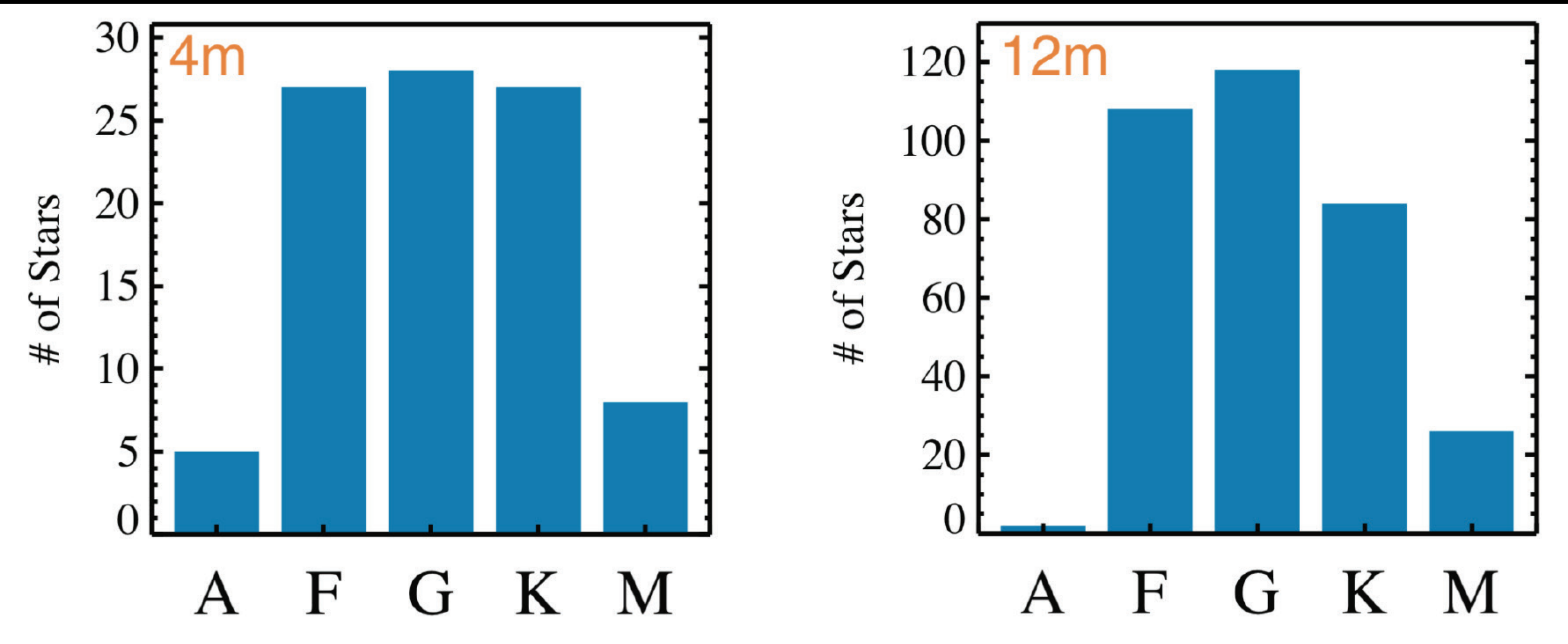
It is the responsibility of the Decadal Survey to judge the optimal science-to-cost ratio

It is not straightforward to intuit the total cost of a space observatory (complex process with many important parameters)



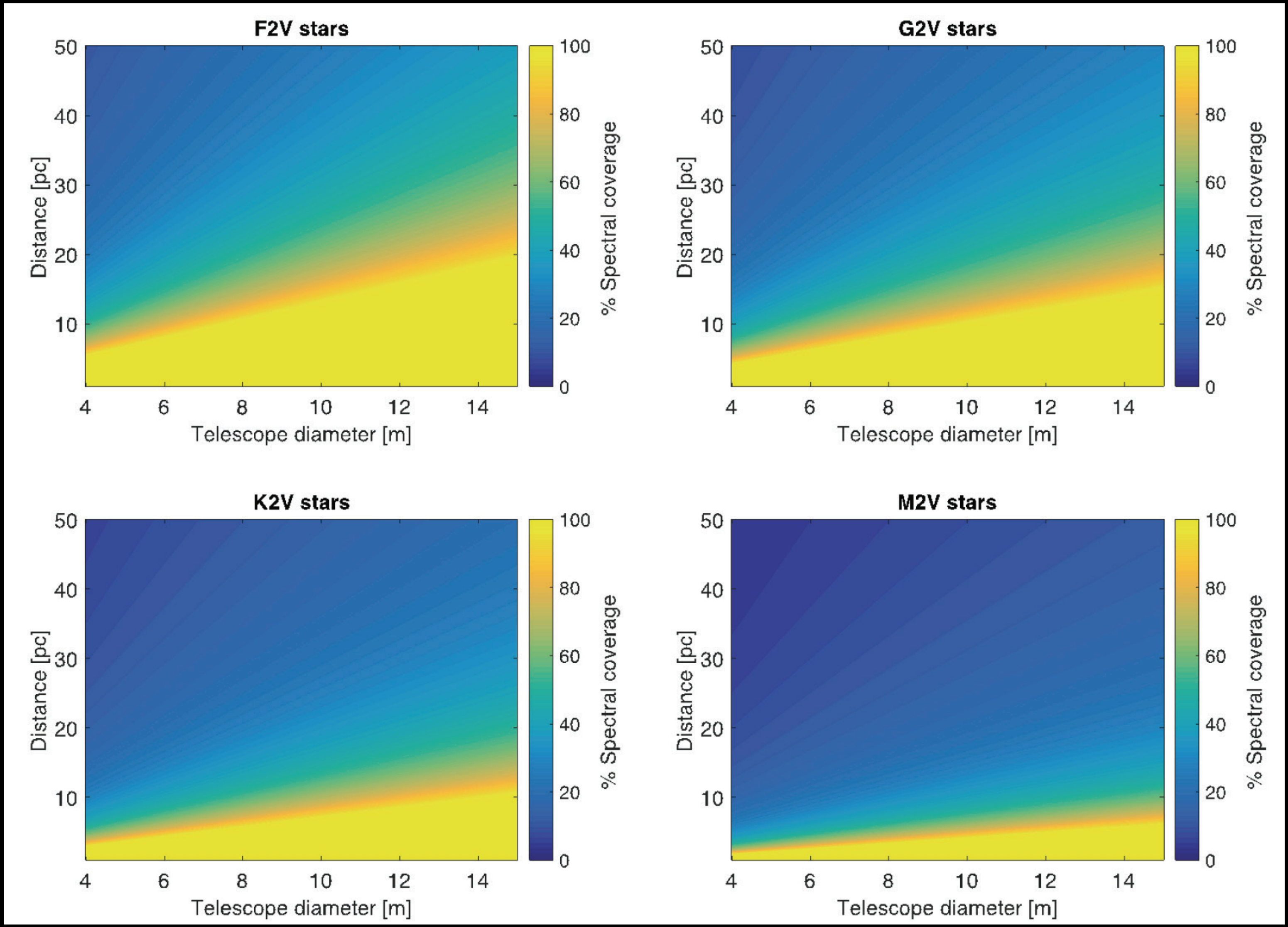
Are we alone?

# Which Stars Will LUVOIR Survey?



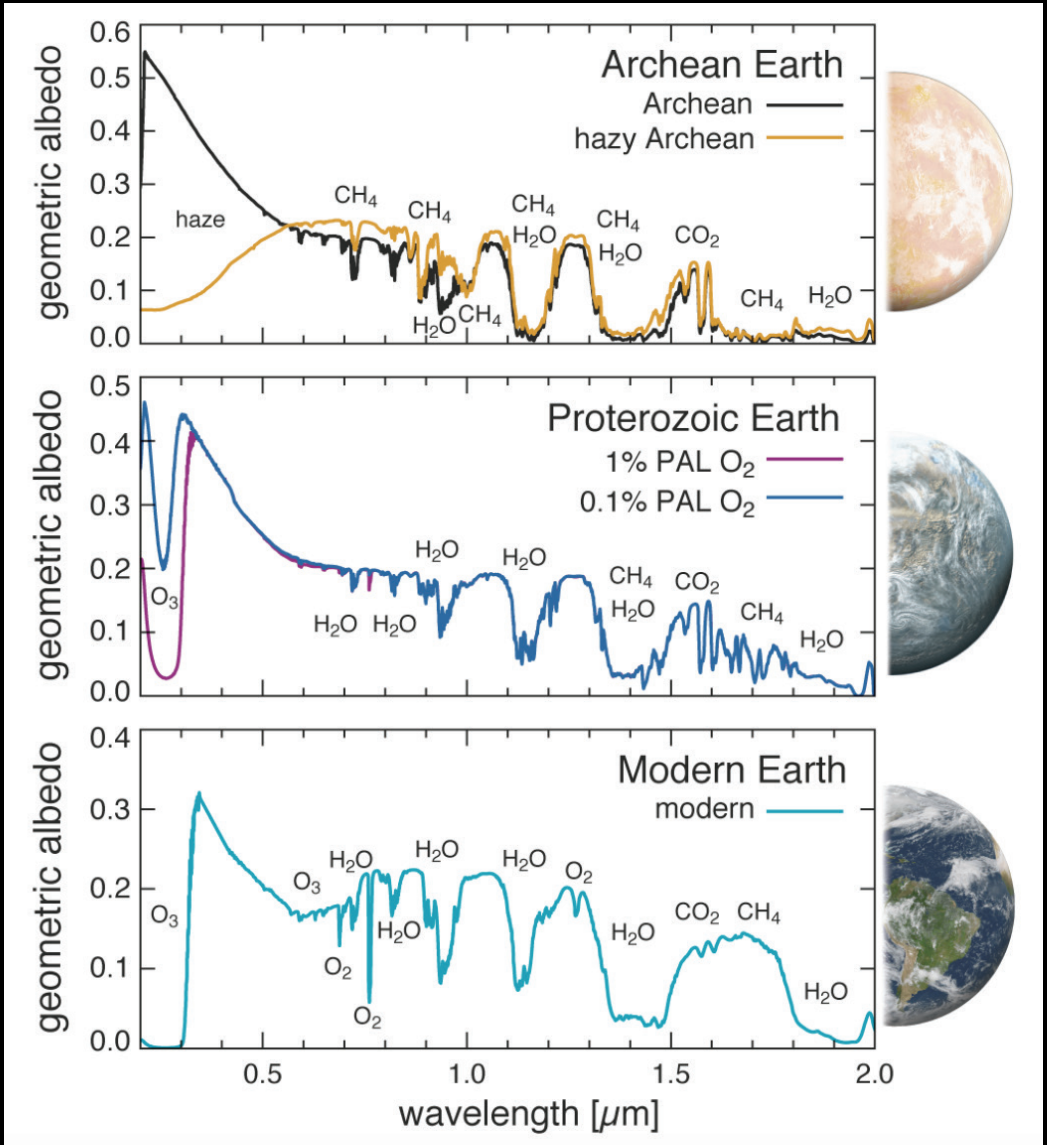

Credit: C. Stark

# Which Stars Will LUVOIR Survey?



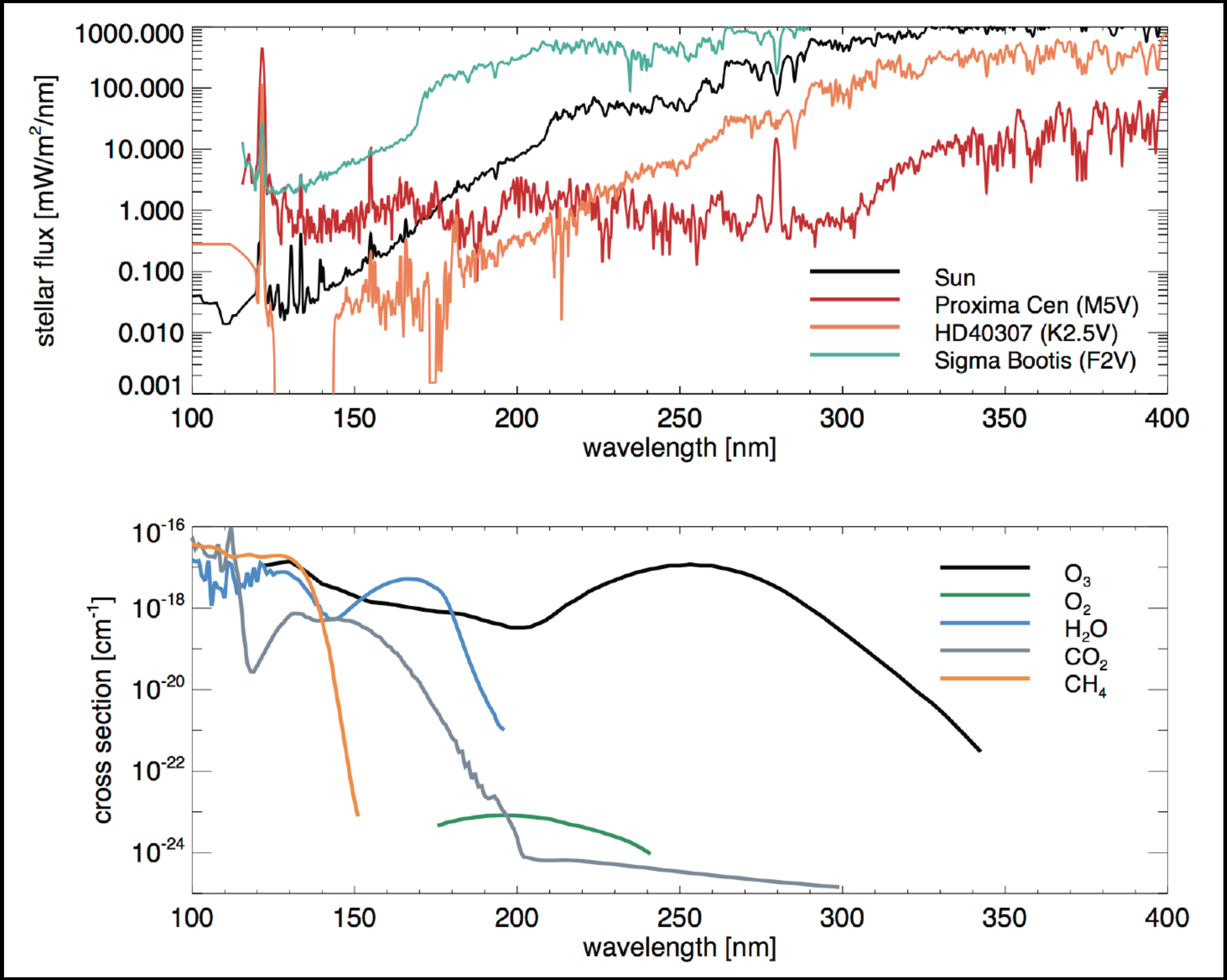

Credit: R. Juanola-Parramon

# A Closer Look at the Earth Through Time




Credit: G. Arney

# UV Spectra from LUMOS Will Be Essential for Interpreting Observations of Exoplanets




Credit: G. Arney

# Where Are the Signs of Habitability?

| Habitability Markers | | |
|---|---|---|
| Molecules/Feature | 0.2–1.8 μm | 1.8–2.5 μm |
| $H_2O$ | 0.65,0.72,0.82,0.94,1.12,1.4 | 1.85, 2.5 |
| $H_2$ | 0.64 – 0.66, 0.8 – 0.85 | |
| $CO_2$ | 1.05, 1.21, 1.6 | 2.01 |
| $CH_4$ | 0.6, 0.79, 0.89, 1.0, 1.1, 1.4, 1.7 | 2.31 |
| $S_8$ | 0.2-0.5 | |
| $H_2S$ | < 0.3 | |
| $SO_2$ | < 0.3 | 2.45 |
| Ocean glint | 0.8 – 0.9 (optimal) | |

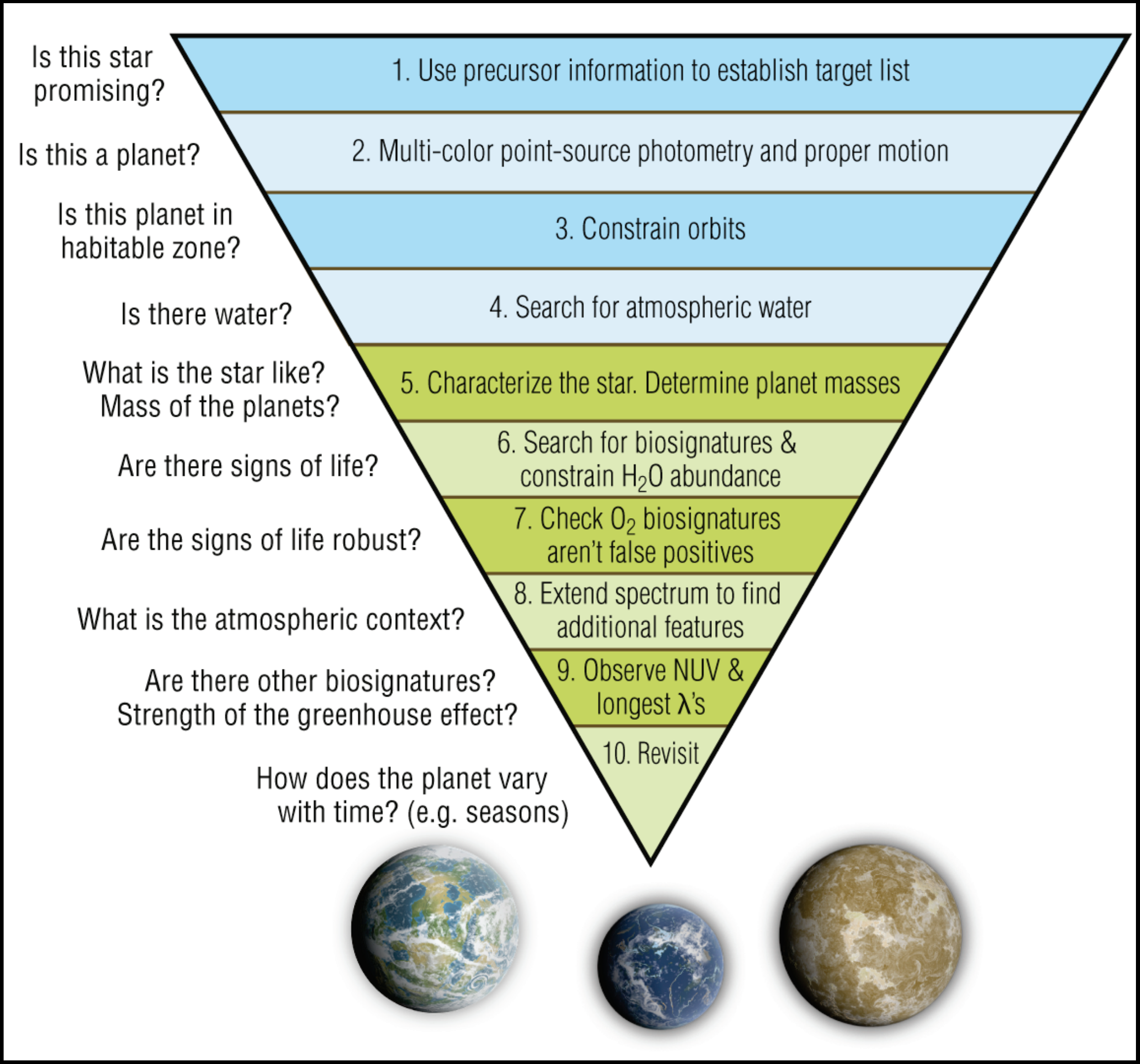
Table from LUVOIR Interim Report

# Where Are the Biosignatures?

| Biosignatures & False Positive Discriminants (indicated with *) | | |
|---|---|---|
| Molecules/Feature | 0.2 – 1.8 μm | 1.8 – 2.5 μm |
| $O_2$ | 0.2, 0.63, 0.69, 0.76, 1.27 | |
| $O_3$ | 0.2 – 0.3 (strong), 0.4 – 0.5 | |
| $O_4$ ($O_2$-$O_2$)* | 0.345, 0.36, 0.38, 0.45, 0.48, 0.53, 0.57, 0.63, 1.06, 1.27 (strong) | |
| CO* | 1.6 | 2.35 |
| $CH_4$ | 0.6, 0.79, 0.89, 1.0, 1.1, 1.4, 1.7 | 2.31 |
| $N_2O$ | 1.5, 1.7, 1.78 | 2.0, 2.11, 2.25 |
| Organic haze | < 0.5 | |
| Vegetation Red Edge | 0.6 (halophile), 0.7 (photosynthesis) | |

Table from LUVOIR Interim Report

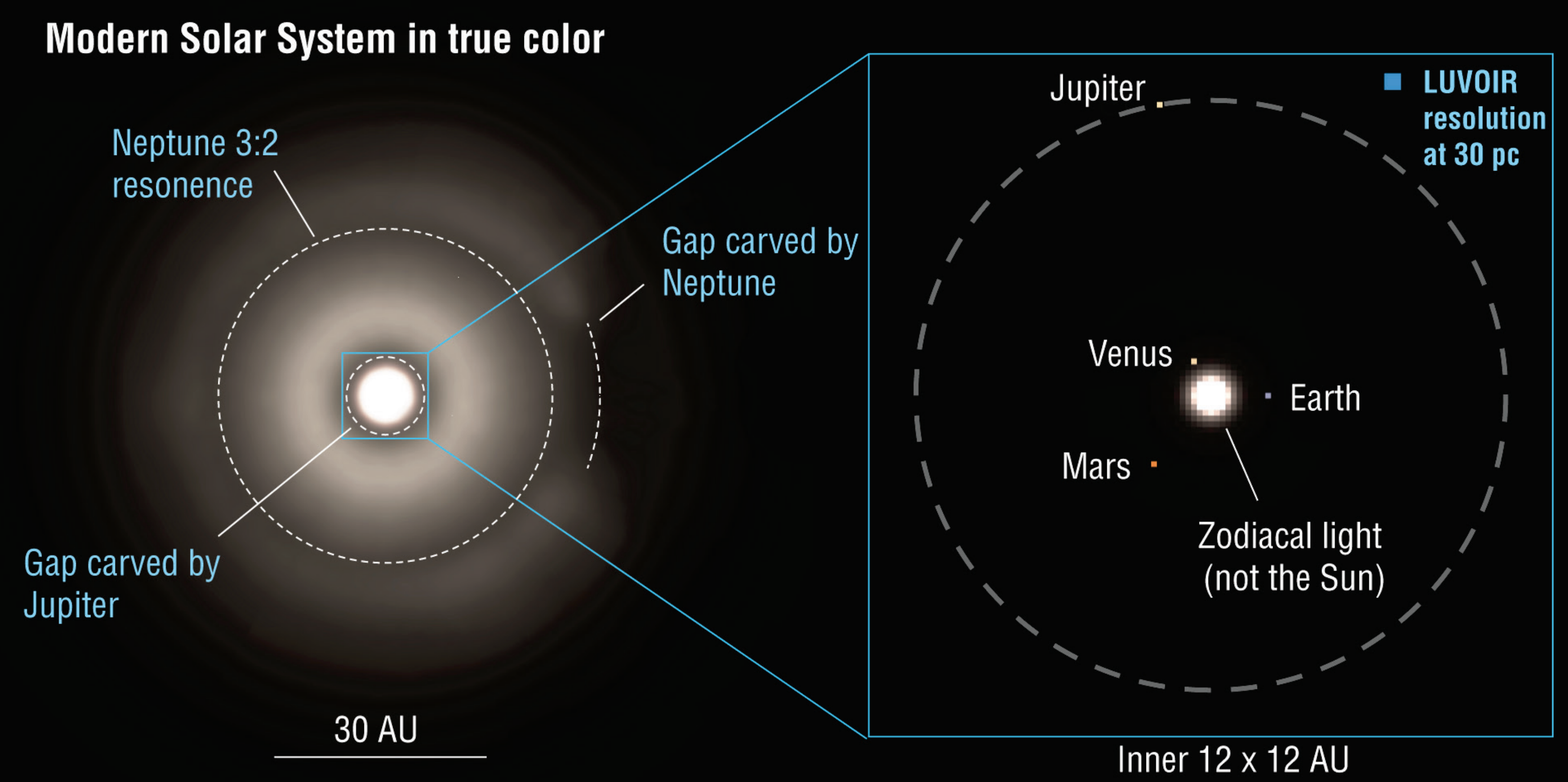
# Finding & Interpreting Biosignatures with LUVOIR




Credit: T. Griswold (NASA GSFC)

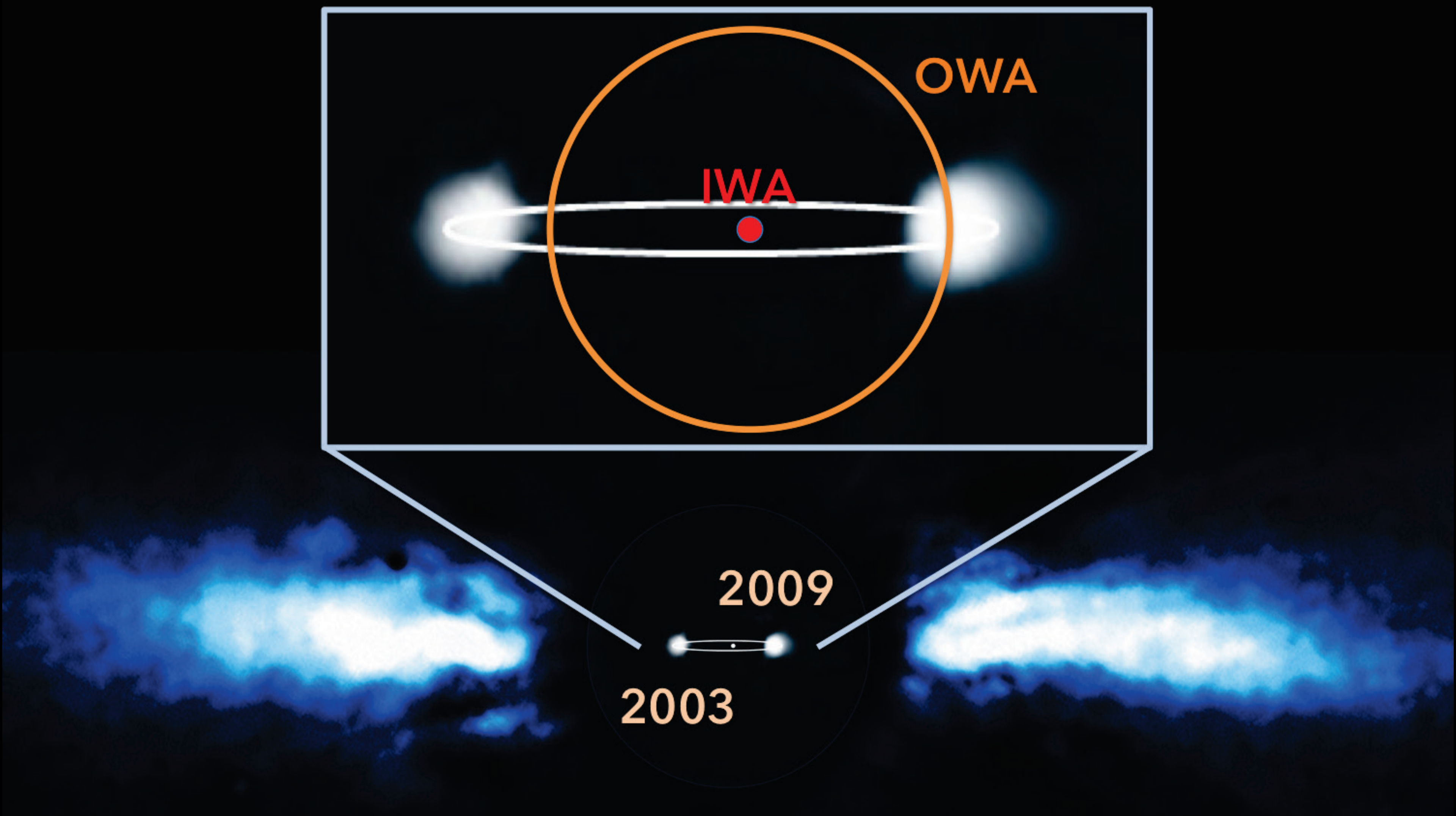
How do we fit in?

# How Might We Appear?



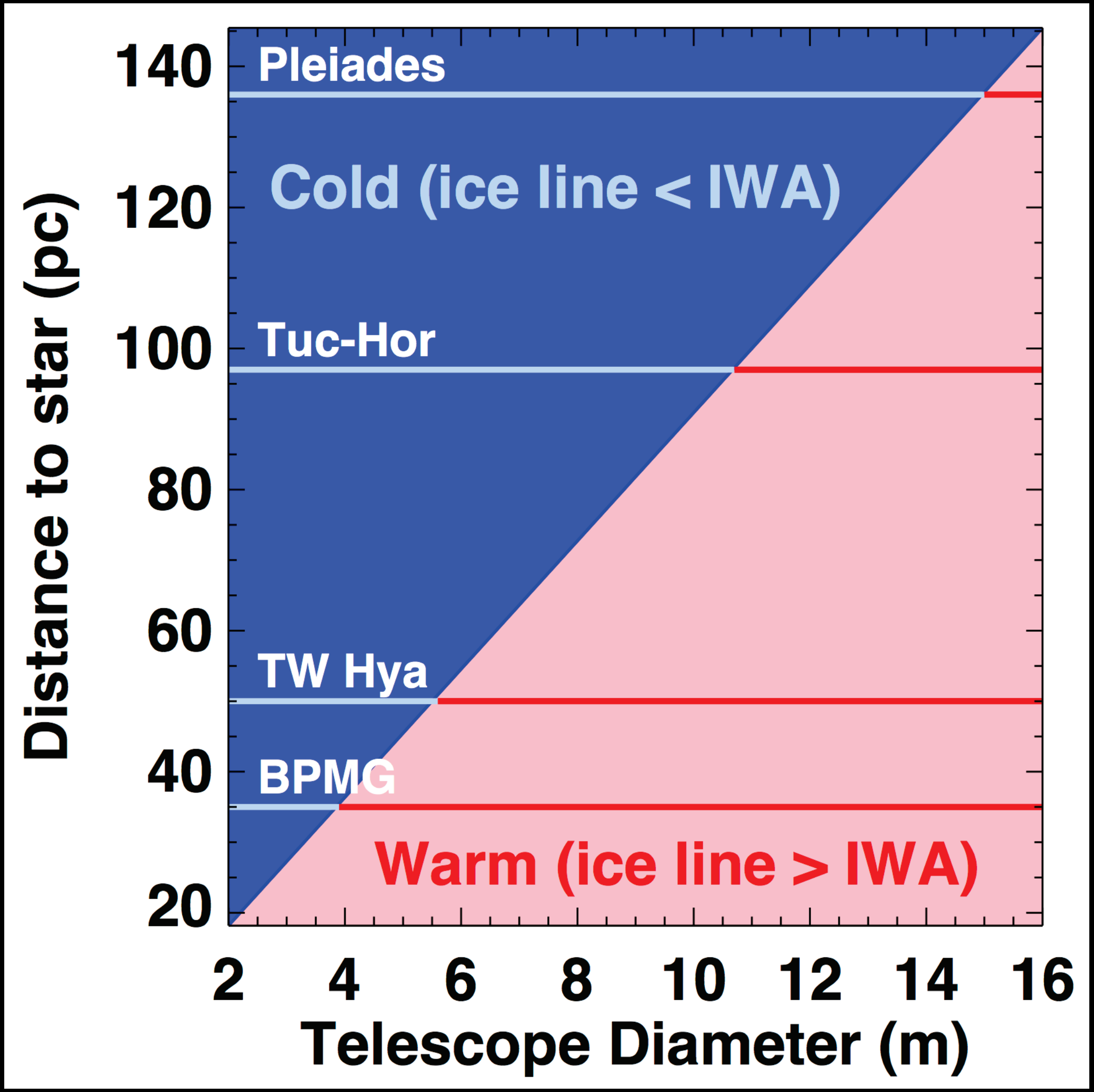

Credit: Roberge et al. 2017

# LUVOIR Can Search for Young Planets



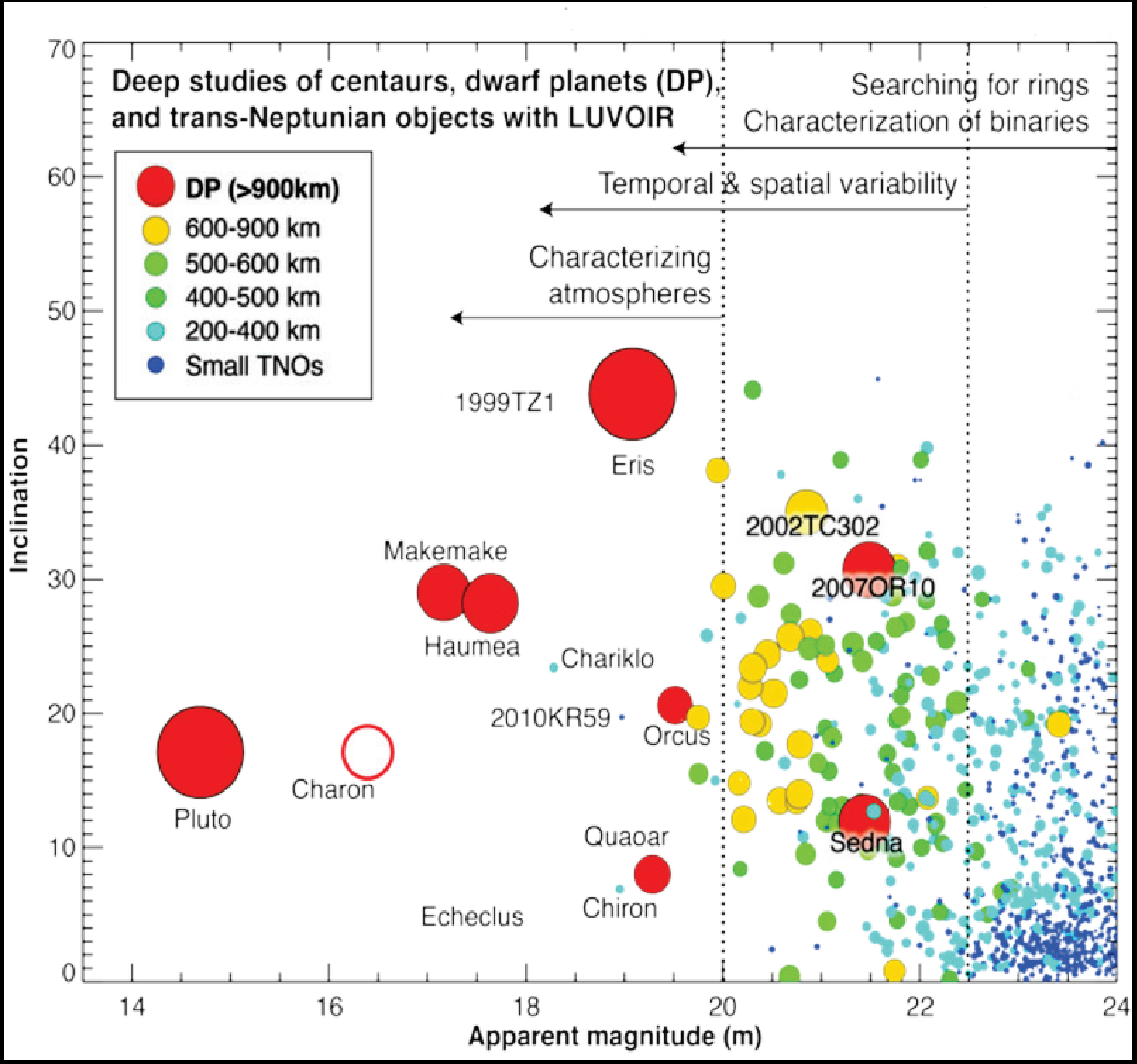

Credit: ESA / A.-M. Lagrange

# LUVOIR Can Search for Young Planets



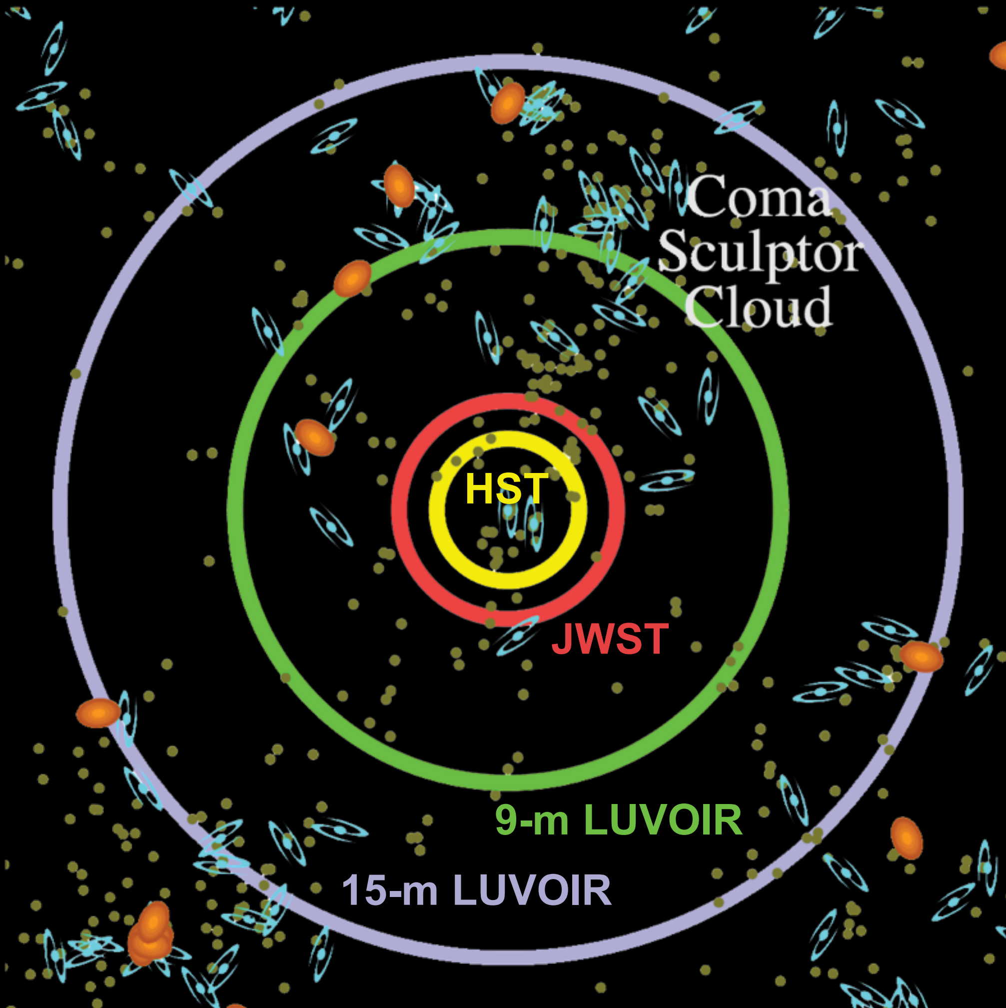

Credit: A. Roberge

# LUVOIR Can Conduct Detailed Studies of Solar System Bodies




Credit: G. Villanueva

# How Do Galaxies Assemble Their Stars?




Map of Galaxies within 12 Mpc of Our Galaxy

- Circles show distance out to which individual solar-type stars can be detected

  Provides ages and star formation histories

  Need LUVOIR to reach the nearest giant elliptical galaxies

= Large Elliptical Galaxy
= Large Spiral Galaxy
= Dwarf Galaxy

# How we're doing the study

Four large mission concept studies started in Jan 2016 to prepare for Astro2020 Decadal Survey

- LUVOIR
- Habitable Exoplanet Imaging Mission (HabEx)
- Origins Space Telescope (formerly Far-IR Surveyor)
- Lynx (formerly X-Ray Surveyor)

Study office and engineering team at GSFC

Science and Technology Definition Team

- 24 voting members from community
- 10 non-voting reps. of international space agencies