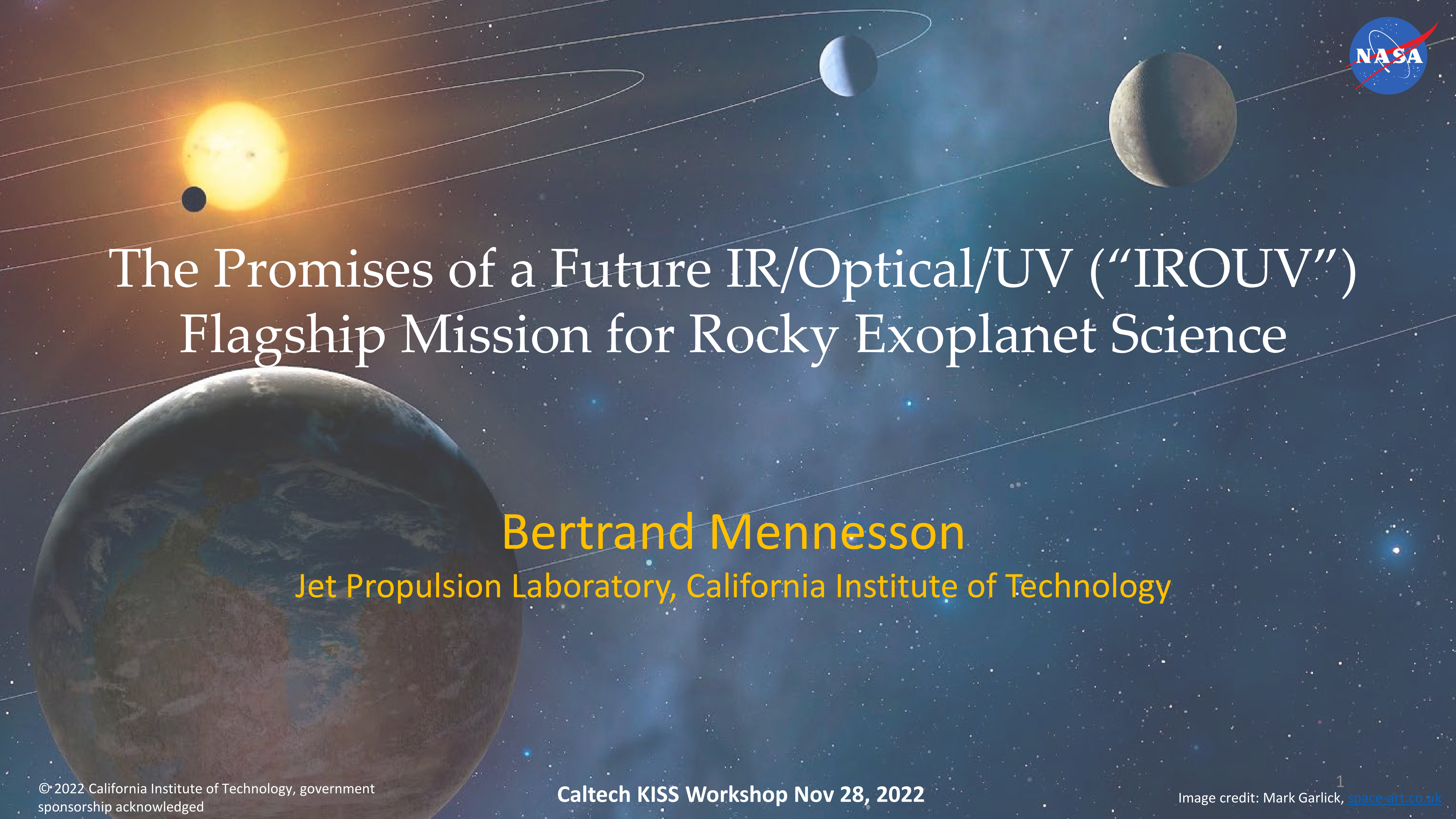

The Promises of a Future IR/Optical/UV ("IROUV") Flagship Mission for Rocky Exoplanet Science

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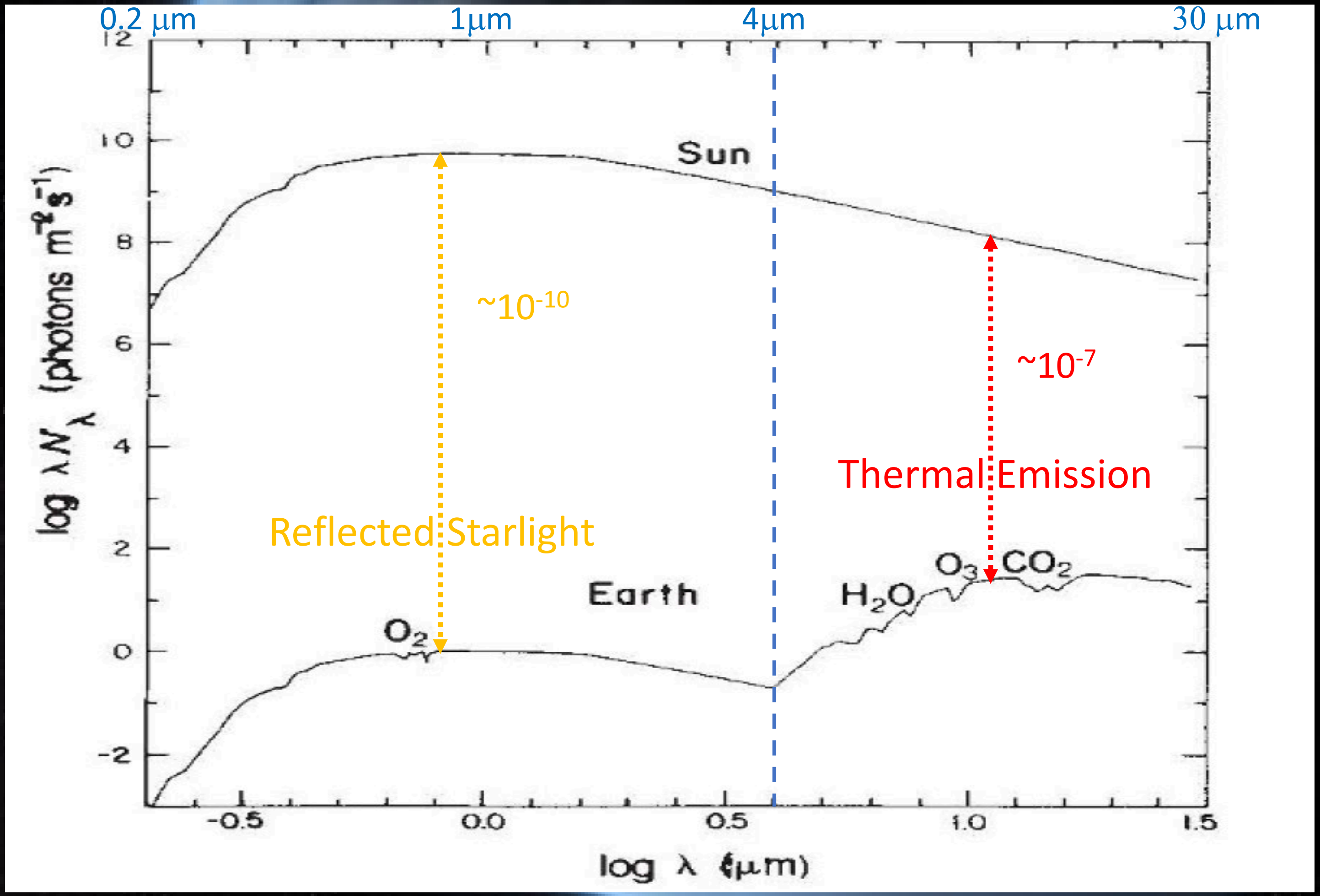
Image credit: Mark Garlick, space-art.co.uk

Detecting exo-Earths

What can – and cannot – be learned from reflected light observations of (rocky) exoplanets with a future ~6m "IROUV" mission?



Fluxes from the Sun and Earth between 0.2 μm to 30 μm as seen from 4pc (Angel et al., Nature 1986)

Key Rocky Exoplanet Science Questions Addressed by a Future IROUV Mission

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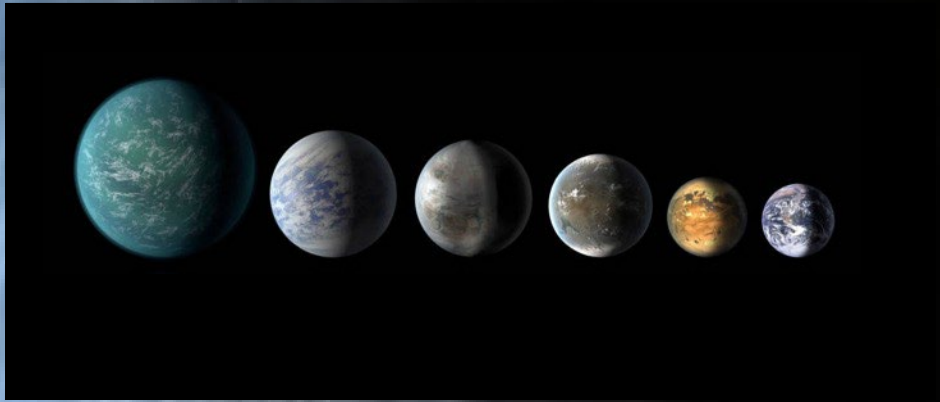
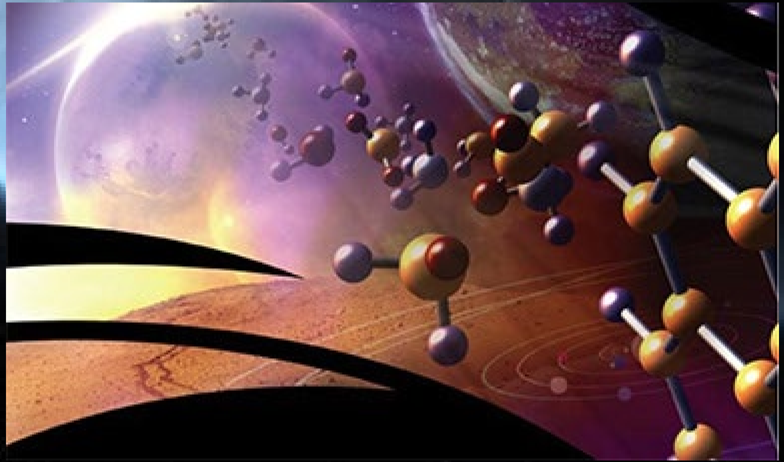
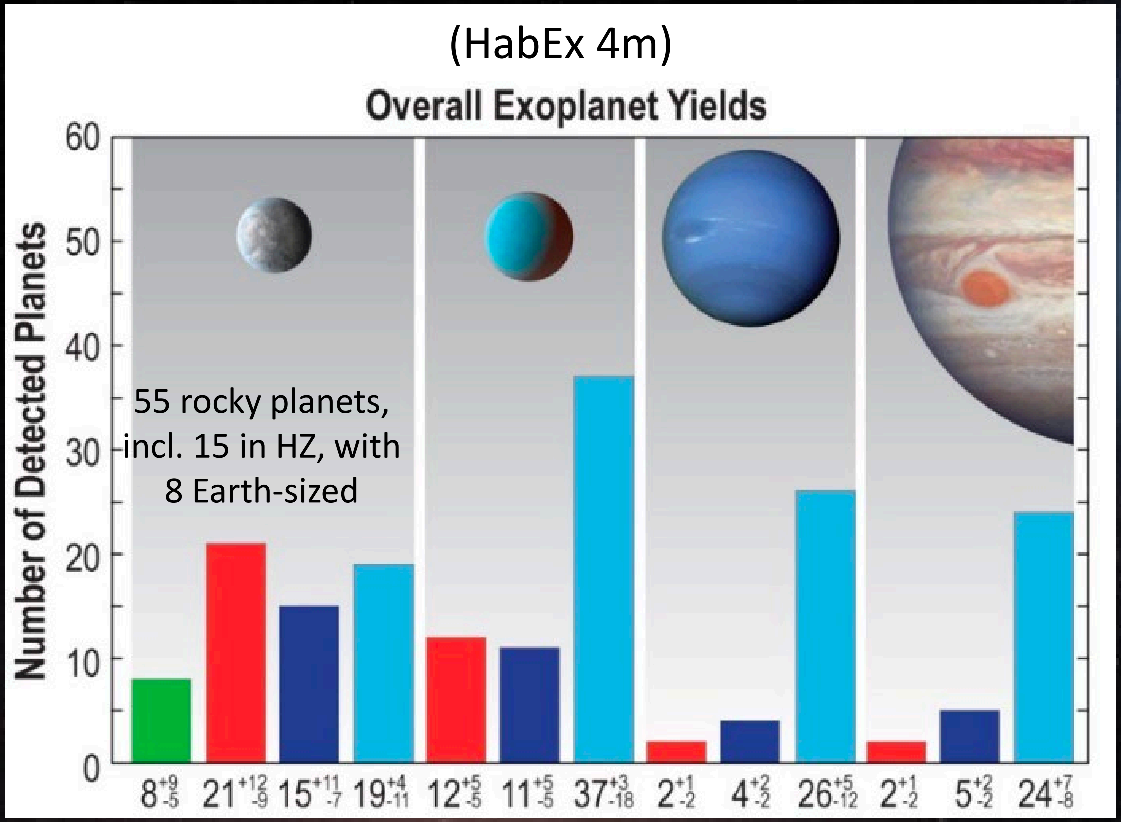
2. Are there small planets with habitable conditions (atmosphere and water oceans) around nearby Sun-like stars?

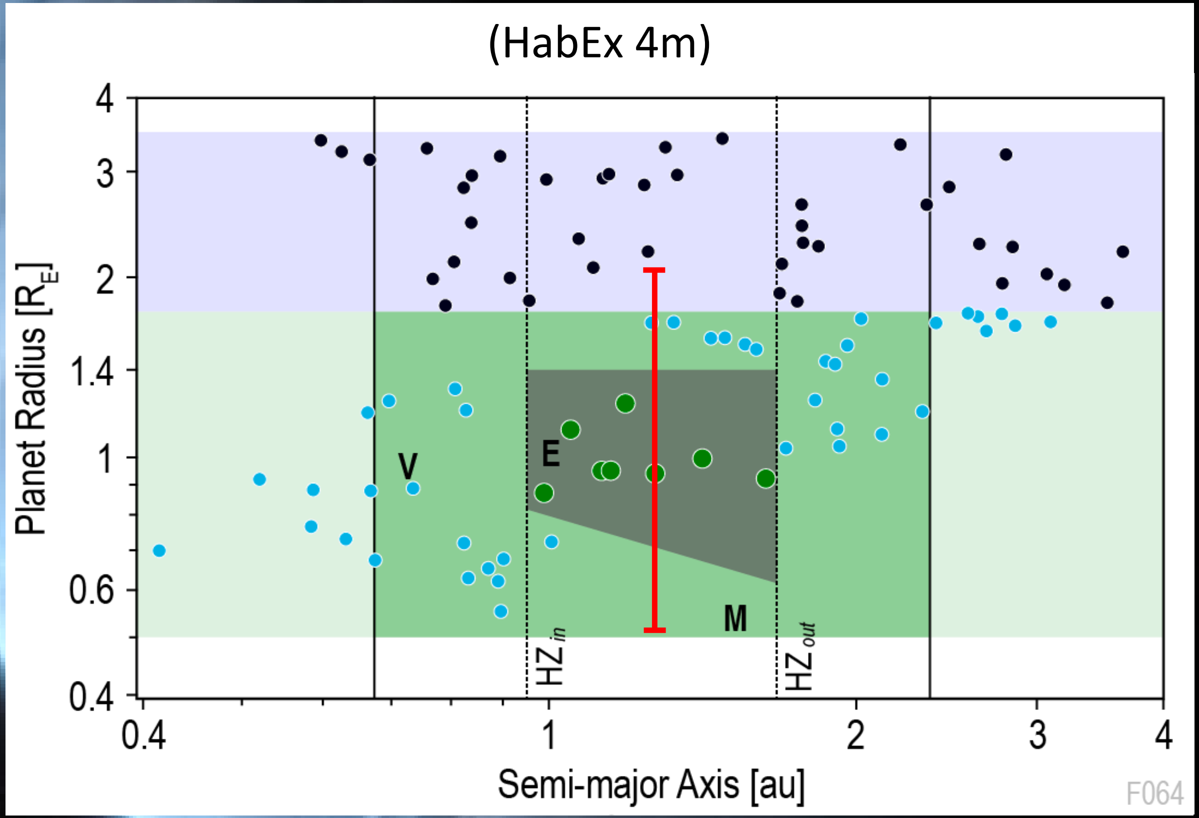
3. Do any of these also display bio-signatures (signs of life)?





1. Detecting Earth-sized Planets and Probing the Habitable Zone Concept





Estimates from HabEx 4m large mission study (LUVOIR 8m design estimate: 28 HZ Earth sized planets detected)

HabEx and LUVOIR study reports accessible at https://science.nasa.gov/astrophysics/2020-decadal-survey-planning

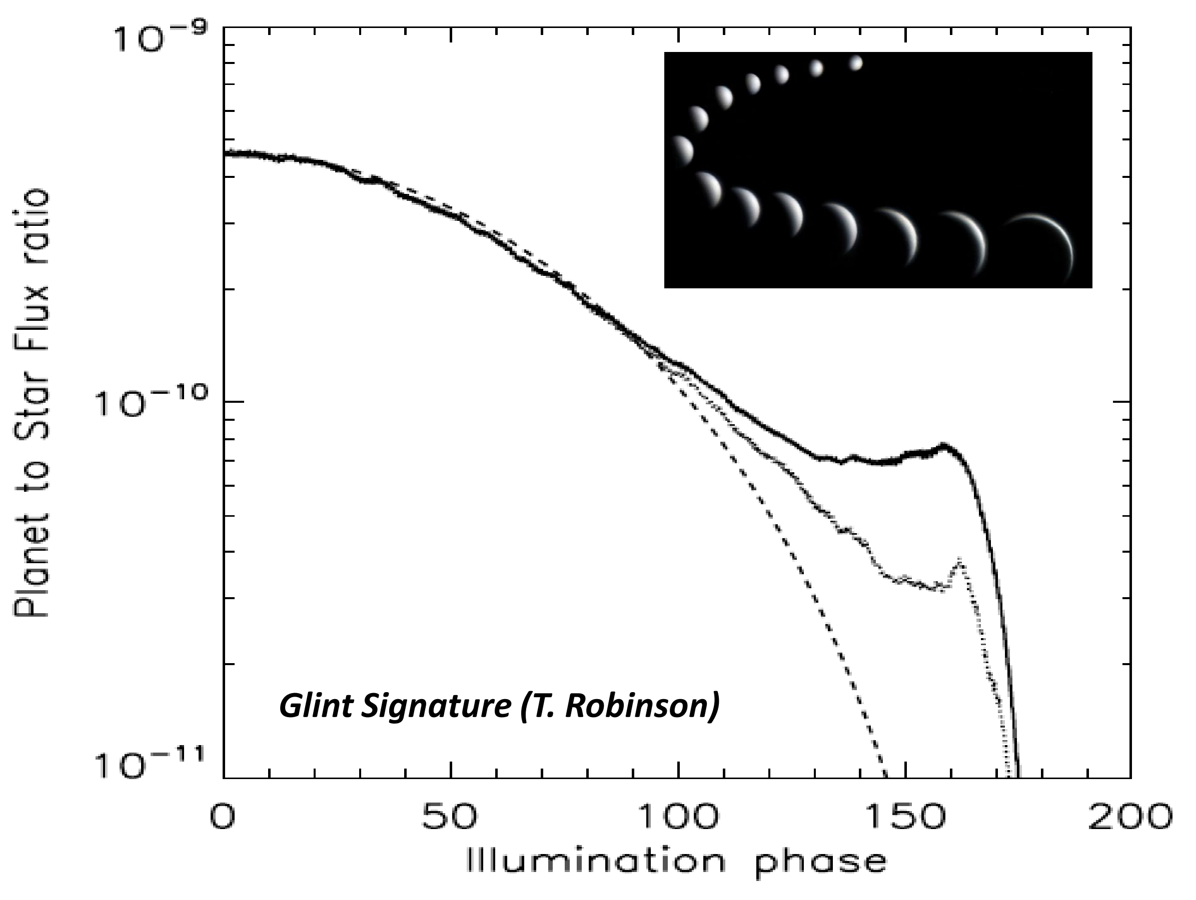
Most detected planets will be spectrally characterized

→ Provides empirical test of "habitable zone rocky planet" concept ... *but sizes poorly known!*

$$\frac{F_p}{F_s} = A_g(\lambda)\Phi(\lambda,\alpha)\left(\frac{R_p}{d}\right)^2$$

2. Finding Habitable Worlds

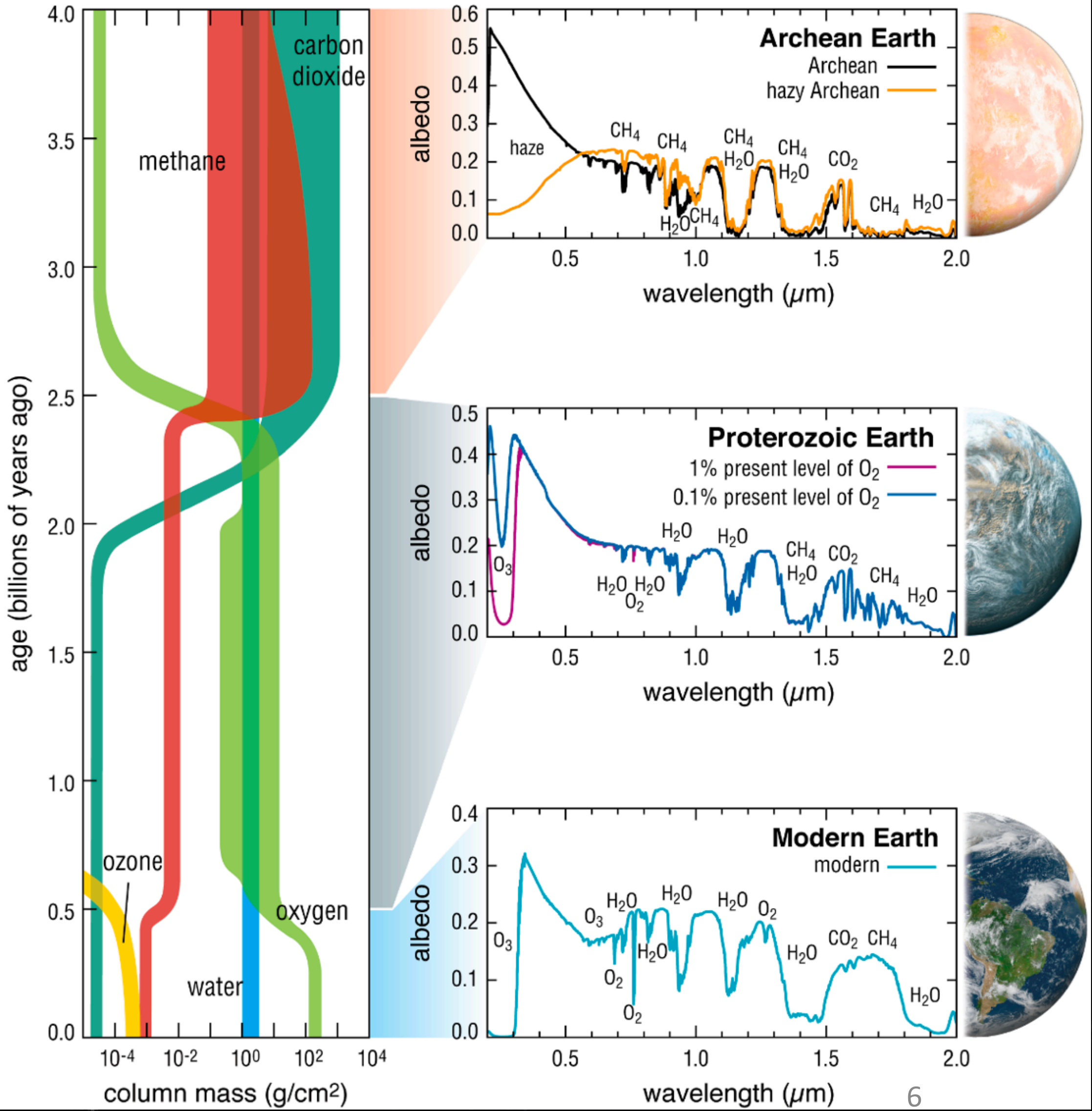
- "Follow the water":
  - Water is one of the few requirements shared by all life on Earth
  - Look for broad water vapor absorption features in the near IR
  - Search for exoplanets with global water reservoirs
  - Identifying liquid water oceans at the surface is difficult:
    - Requires phase dependent photometry to identify possible "glint" brightening effects or strongly polarized signal from ocean reflection



3. Finding Life: the Search for Bio-signatures and their Context

- Identify bio-signatures in "wet" Earth-like planets
  - Using the Earth at different times of its history as a benchmark
  - Able to infer the presence / absence of an atmosphere from Rayleigh scattering < 600nm
  - Modern or proterozoic Earth-like atmospheres:
    - Search for a possible chlorophyll red-edge beyond 700nm
    - Search for simultaneous absorption features of O_2 and its photo-chemical byproduct O_3 (< 330nm)
  - Archean Earth-like atmosphere
    - Search for high CH_4 as the main biomarker (prokaryotes)

- Put bio-signatures in context:
  - Look for further signs that these gases were created by biotic processes or not:
  - Modern and Proterozoic Earth-like atmospheres:
    - Low H_2O, high O_2 (or O_4) can be sign of abiotic production of O_2 via H_2O photodissociation and H-escape,
    - Characterize UV radiation from exoplanet host star (H-escape)
    - Look for secondary features inconsistent with abiotic processes: CH_4. Will only detect at 100x modern Earth level though
  - Archean Earth-like atmosphere with high CH_4:
    - High CO_2 would rule out abiotic production of CH_4



Promises and *Limitations* of an IROUV Mission Exploring Habitable Zone Rocky Planets

- Will detect, measure the orbits and spectrally characterize HZ rocky planets around the nearest ~100 Sun-like (FGK) stars
- Would detect the presence of an atmosphere, as well as H_2O (habitability tracer) if present at > 0.1 Earth abundance level
- Would detect O_2 (biosignature gas) if present at modern Earth abundance levels
- Would detect CH_4 and CO_2 if present at Archean Earth levels

- *Will be challenged to detect O_2 bio-signature at lower, e.g. Proterozoic Earth-like abundance levels (UV detection of O_3 is hard)*
- *Will be challenged to get spectral info longward of 3 um (spatial resolution constraints)*

- *Will not provide planet size estimates to better than a factor of 2*
- *Will not constrain the planet temperature*

Back-Up

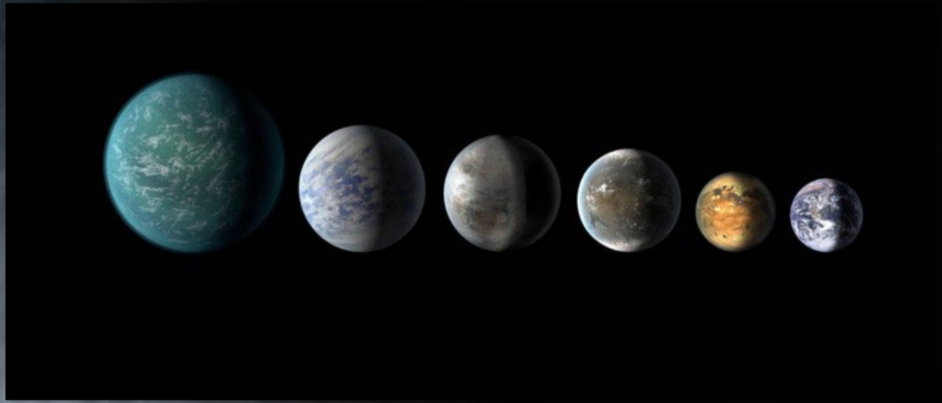
Context

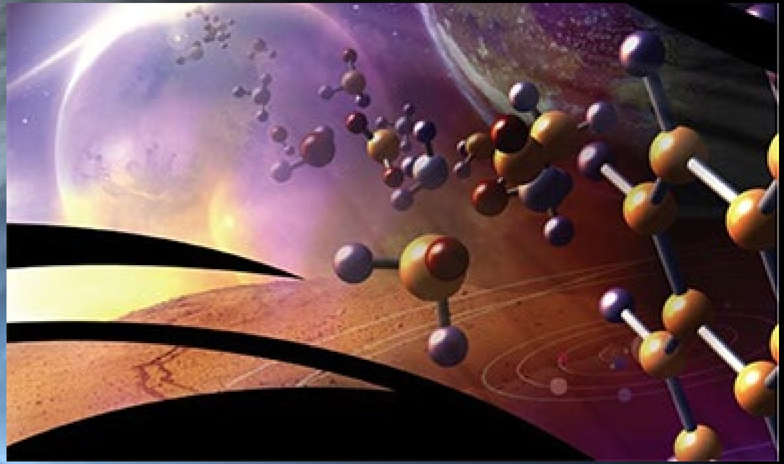
- Following ~20 years of NASA mission concept studies (e.g. TPF-C, exo-C, exo-S, HabEx and LUVOIR), the US Astro2020 Decadal Survey recommended:
  - The creation of a Great Space Observatories Maturation Program
  - **That the first mission to enter this program be a large (~6m) infrared / optical / ultraviolet ("IROUV") space telescope [...] designed to search for biosignatures from habitable zone planets around ~100 nearby stars**
  - Habitable Zone Planets will be characterized in reflected light only

What are the promises – and limitations – of such a mission for exoplanet science and rocky exoplanets characterization in particular?

Key Exoplanet Science Questions Addressed by a Future IROUV Mission

- Does the distribution of small and giant planets and interplanetary dust in nearby planetary systems resemble that of our Solar System?
- What is the diversity of planetary atmospheric conditions in nearby planetary systems?
- Are there small, Earth-sized, exoplanets continuously orbiting in the habitable zones of nearby Sun-like stars?
- Are there small planets with habitable conditions (atmosphere and water oceans) around nearby Sun-like stars?
- Do any of these also display bio-signatures (signs of life)?
- To what extent do planet size and stellar insolation drive volatile (e.g. water) condensation and retention?
- How do giant planets influence the volatile inventory of inner planetary systems (either through planetesimals scattering or orbital migration)?





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