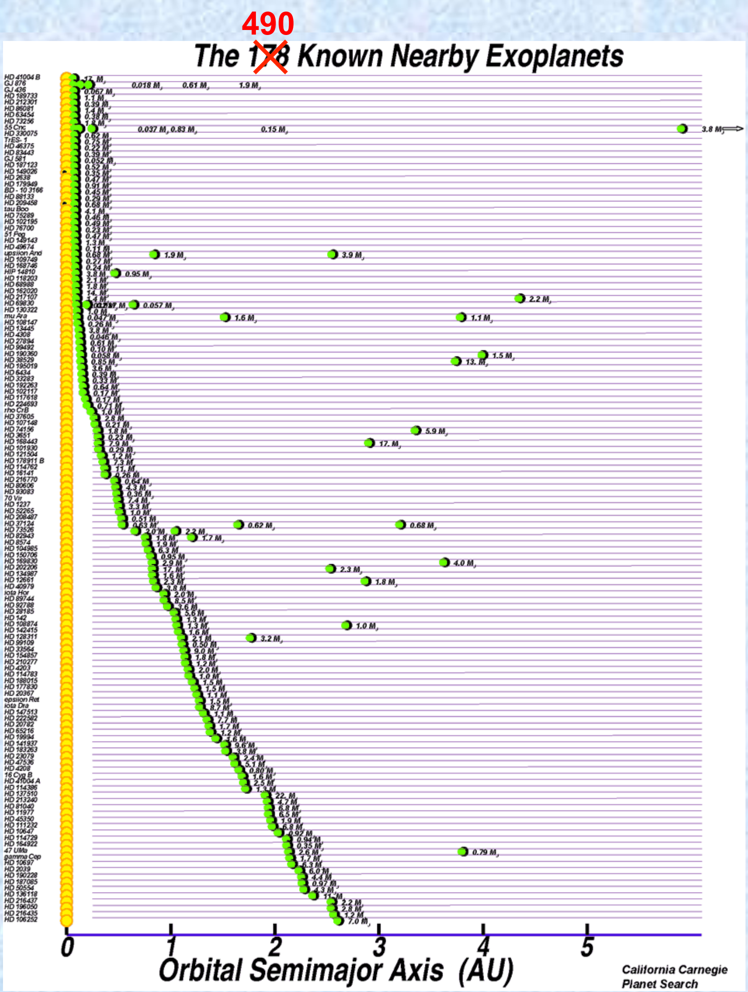
# ExoPAG Science Goals

Joint ExoPAG/COPAG meeting
Space Telescope Institute
April 26, 2011

James Kasting
ExoPAG Chair

# Known extrasolar planets




http://exoplanets.org/massradiiframe.html

- 528 extrasolar planets identified as of Feb. 25, 2011

  (not including those found by Kepler)
  - 490 by radial velocity
  - 122 transiting planets
  - 12 microlensing
  - 16 direct imaging
  - 8 pulsar planets
  - 60(?) multiple planet systems
- Few, if any, of these planets are very interesting, however, from an astrobiological standpoint
  - Gliese 581g (the "Goldilocks planet") is probably not real

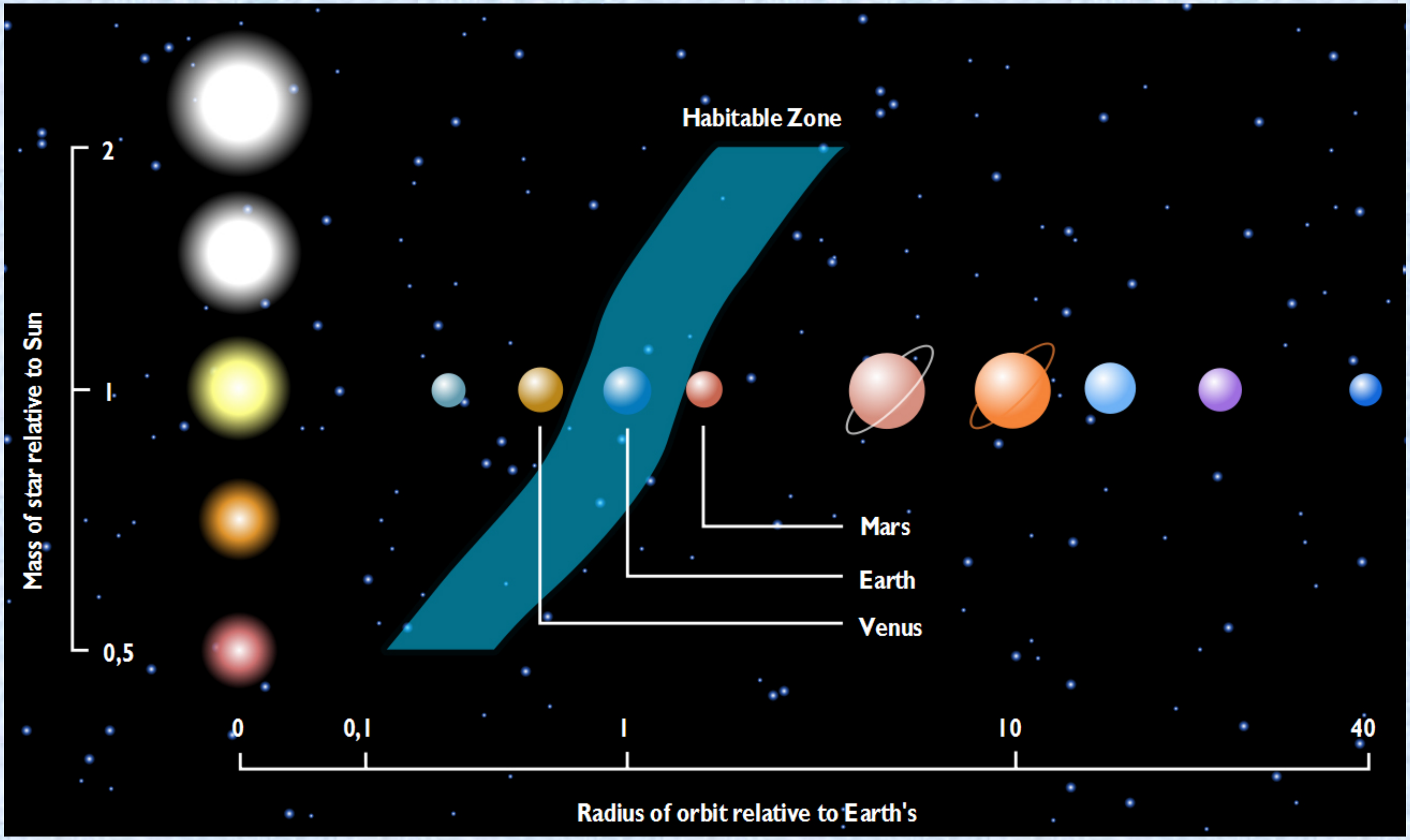
Info from *Extrasolar Planets Encyclopedia* (Jean Schneider, CNRS)

# Kepler Mission

- This space-based telescope points at a patch of the Milky Way and monitors the brightness of ~150,000 stars, looking for *transits* of Earth-sized (and other) planets
- $10^{-5}$ precision *photometry* $\Rightarrow$ can find Earths
- Launched: March 7, 2009
- 1235 “planet candidates” found so far (Spring, 2011)

http://www.nmm.ac.uk/uploads/jpg/kepler.jpg

# The (liquid water) habitable zone




- We are most interested in planets within the *habitable zone,* where liquid water can exist on a planet's surface
- Kepler's mission is to find the frequency of *rocky planets* within this region, designated as $\eta_{Earth}$

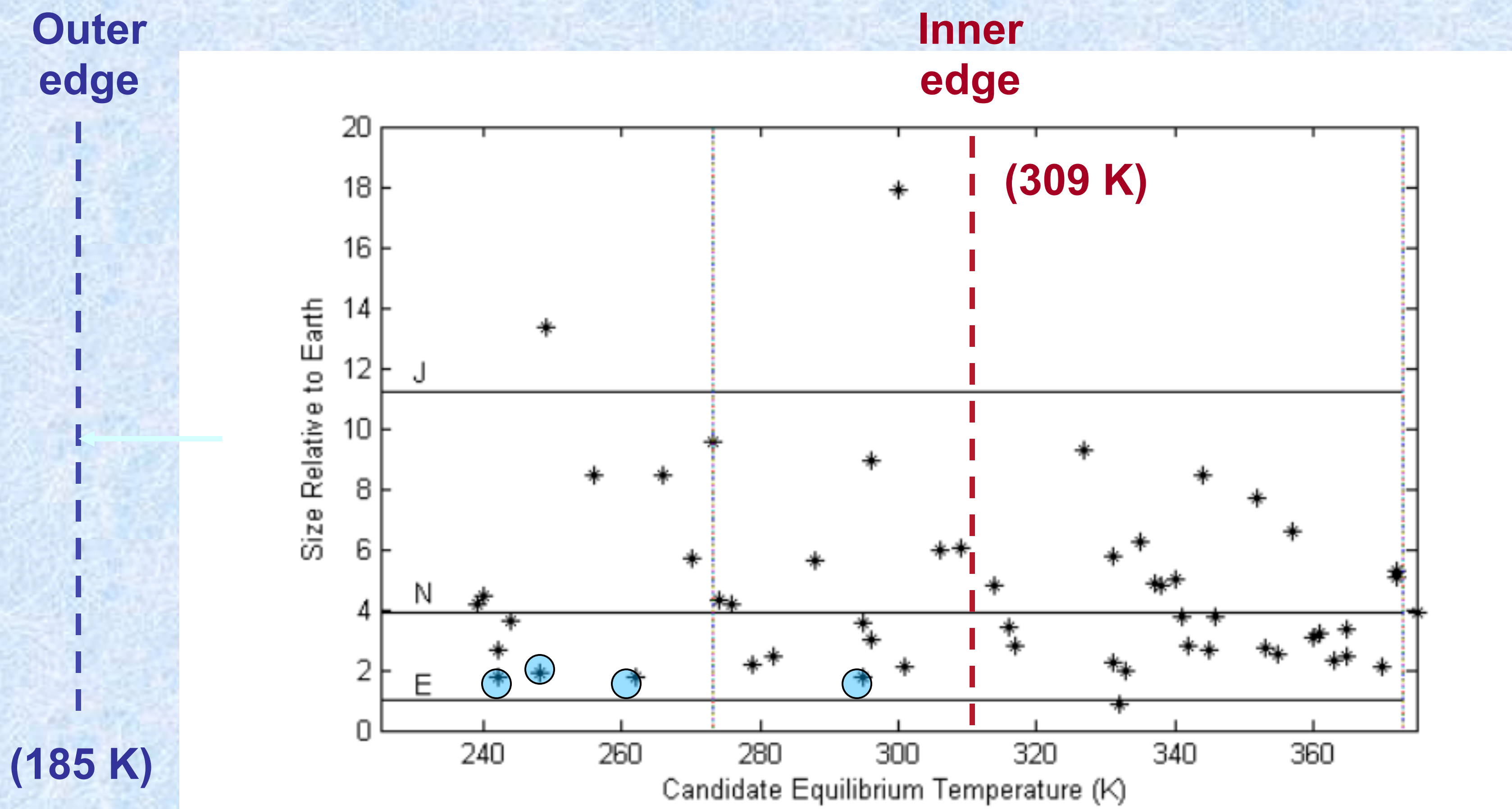
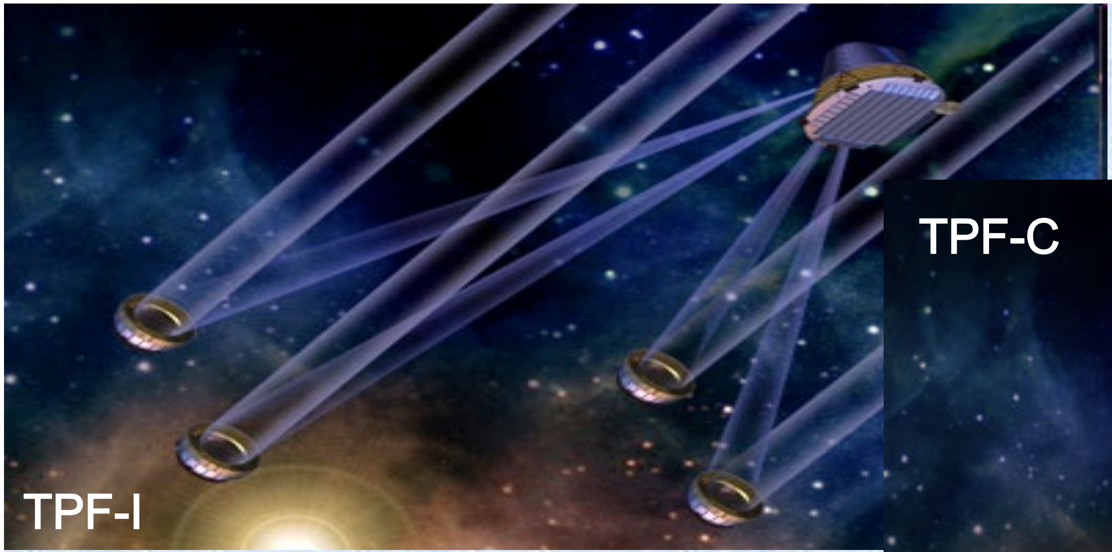
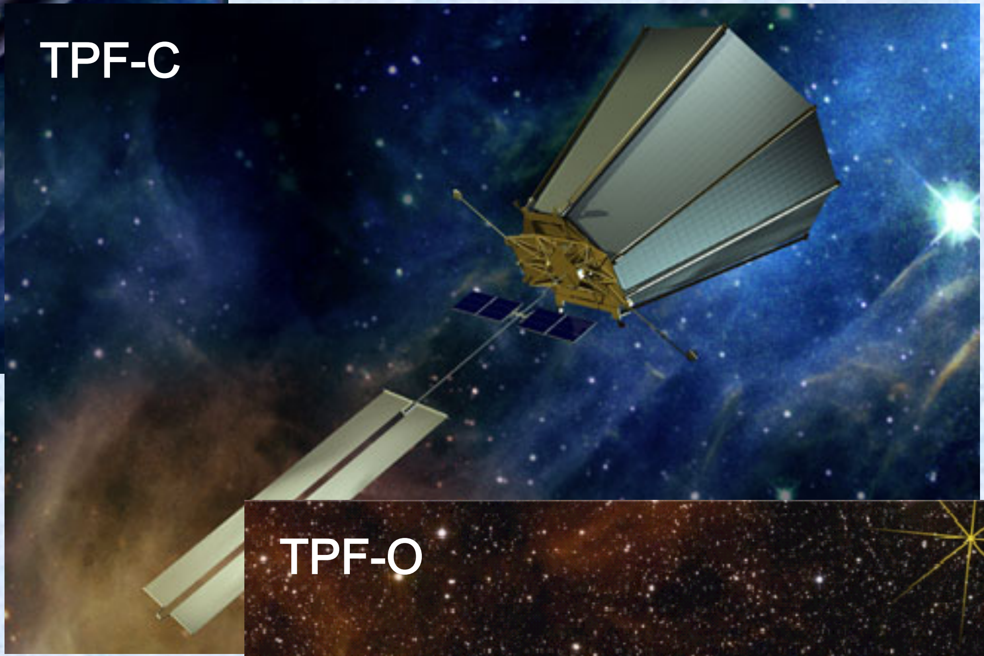


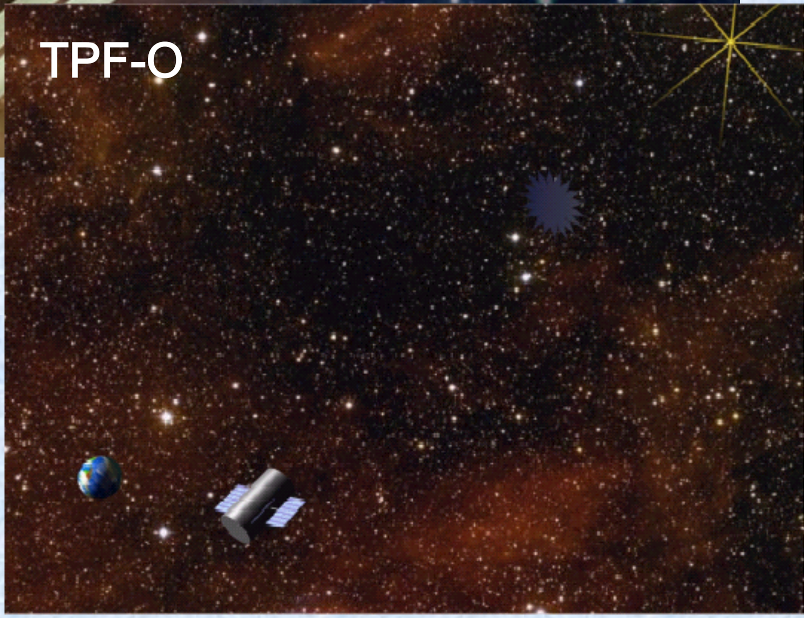

**Figure 13.** Candidate sizes for the estimated equilibrium temperature ($T_{eq}$) range centered on the habitable zone temperature range. The broken lines indicate the range of temperatures for water to exist as a liquid at one atmosphere of pressure. Uncertainties are discussed in the text.

- A generous definition of the habitable zone, using Kepler terminology, would be effective temperatures of 185-309 K (0.72-2.0 AU)
- I count 4 Earths or “super-Earths” within this range

- The problem with Kepler is that almost all of the target stars are far away
- We would to find planets around nearby stars
  - SIM Lite would have done this, but it was not recommended by the Astro2010 committee
- Our response is to bypass astrometry (for now) and use our next mission both to find nearby planets and study them *spectroscopically*
- Some transit spectroscopy of (mostly) giant planets has already been done from HST and Spitzer
  - A much better job will be done in the next few years by JWST
  - Nevertheless, *direct imaging* will likely be necessary to obtain spectra of true Earth-analog planets

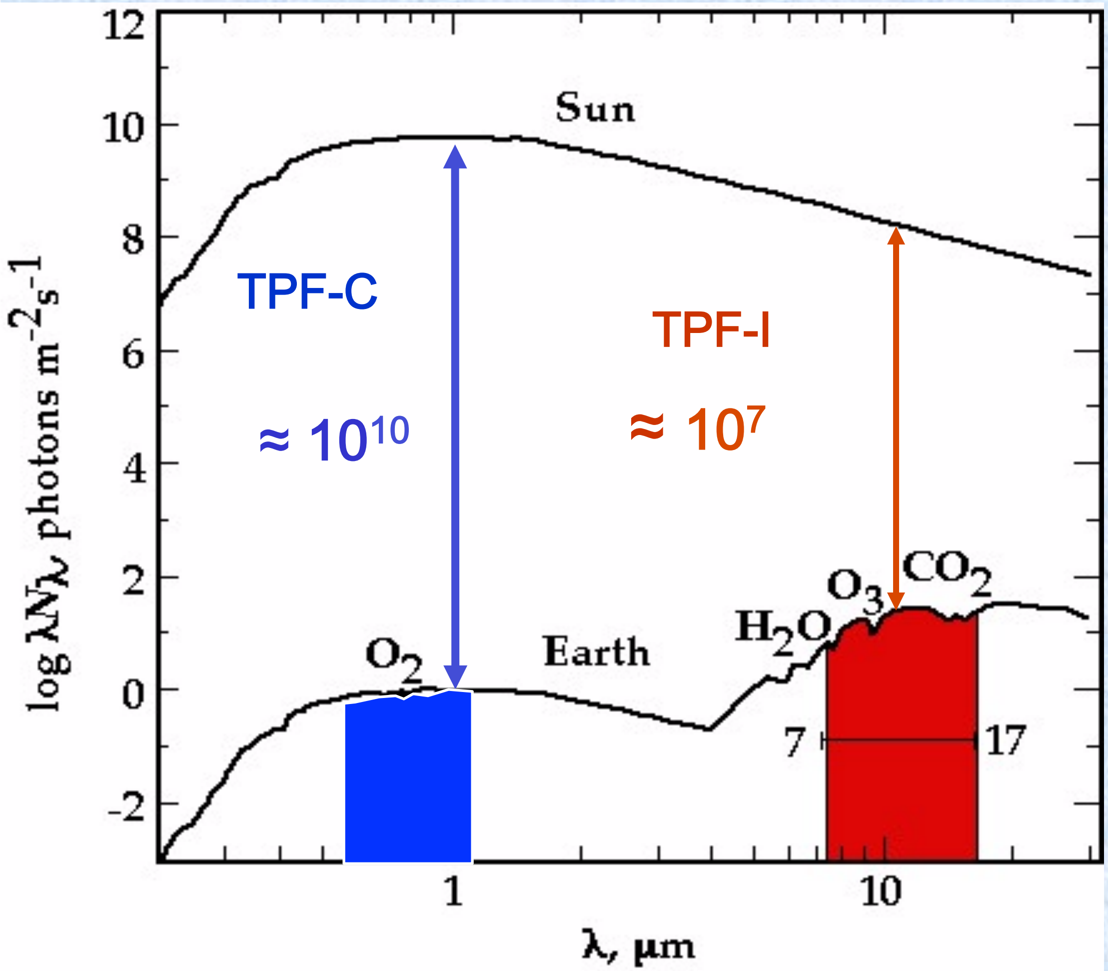



- What we' d really like to do is to build a big TPF (Terrestrial Planet Finder) telescope and search directly for Earth-like planets
- This can be done either in the thermal-IR (TPF-I) or in the visible/near-IR (TPF-C or –O)

# Terrestrial Planet Finder




Visible or thermal-IR?

- Contrast ratio:
  $10^{10}$ in the visible
  $10^{7}$ in the thermal-IR
- Resolution: $\theta \propto \lambda/D$
- Required aperture:
  4-8 m in the visible
  40-80 m in the IR

*Courtesy: Chas Beichman, JPL*

# Sizing the telescope

The required size of the telescope depends on several factors

- Must have the required angular resolution to find planets within the habitable zone
  - This depends on how far away the stars are, which in turn depends on how many we need to look at; hence, $\eta_{Earth}$ is important
  - This factor, along with the inner working angle of the coronagraph (*i.e.*, the factor 'n' in n $\lambda$/D) determines the minimum telescope diameter for coronagraphs
- Must be able to observe at the required contrast ratio
  - For occulters, this determines the required size of the starshade and its distance from the telescope
- Must also be able to collect enough photons to get a spectrum within a reasonable time period (~1 week) and to separate the planet from the exozodiacal background

# The Problem for Exoplanet Imaging

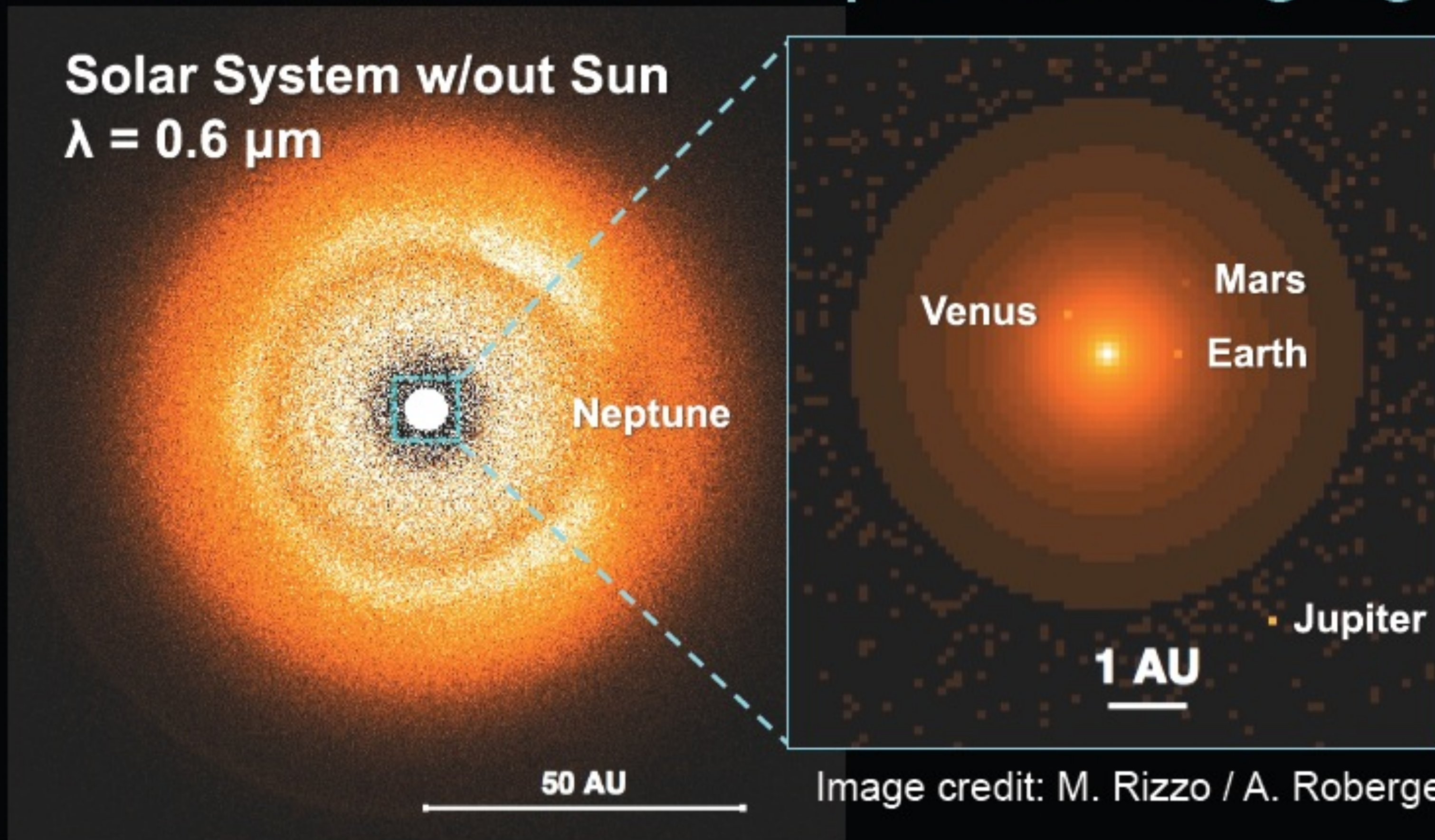



Image credit: M. Rizzo / A. Roberge

- Dust models from Kuchner & Stark (2010), Kelsall et al. (1998) + ZODIPIC

Courtesy of Aki Roberge

# Implications for visible Imaging

- Exozodi > 1 zodi will significantly impact the SNR and integration times for ***broadband detections*** of terrestrial planets greater than 5 pc away for telescopes with D < 4m
  - Many stars greater than 10 pc away will have prohibitively long integration times for planet searches even with large telescopes if Exozodi > 10 zodi (depends on both star and distance)
  - Modest D < 2.5-m telescopes are more severely impacted; can only tolerate up to a few zodi at 10 pc distance
- Spectroscopic characterization of detected planets can be impacted more severely:
  - More integration time is required for each planet, so even a modest increase can eliminate a planet or greatly limit the number studied
  - Measuring deep absorption bands like O2 will be very difficult because of the low signal from the planet coupled with the full noise of the exozodi
  - Even a 4-m telescope may be limited to characterizing planets (good SNR spectra) with less than a few zodi exozodi for stars at d > 10 pc.



Tom Greene, NASA Ames

# Sizing the telescope (cont.)

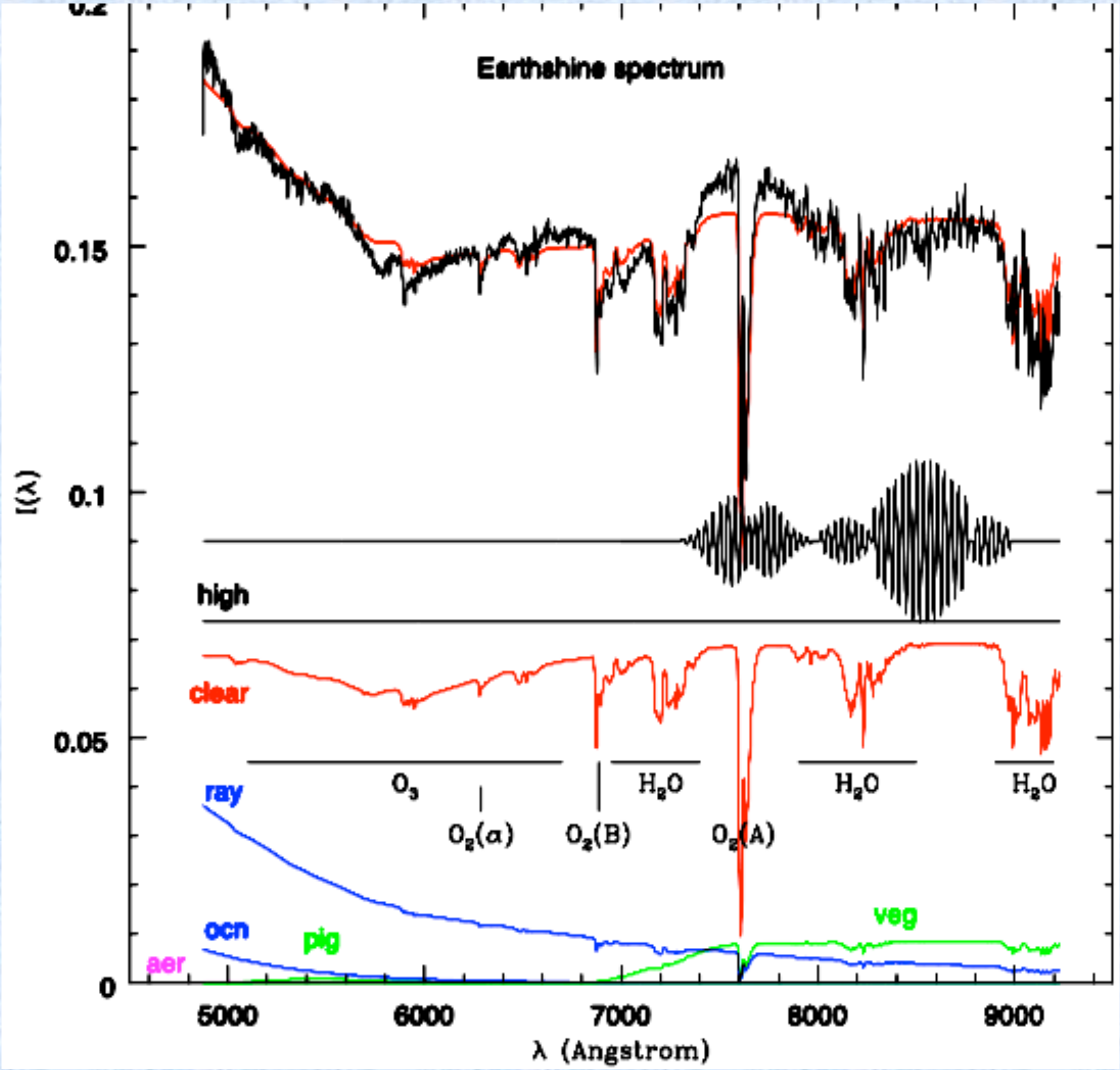
- The size of the telescope also depends on how good of a job we want to do in finding Earths or, alternatively, on how sure we want to be not to miss them
- This leads to a set of science requirements for such a mission
- We studied this problem carefully for TPF-C in 2005-06 $\Rightarrow$

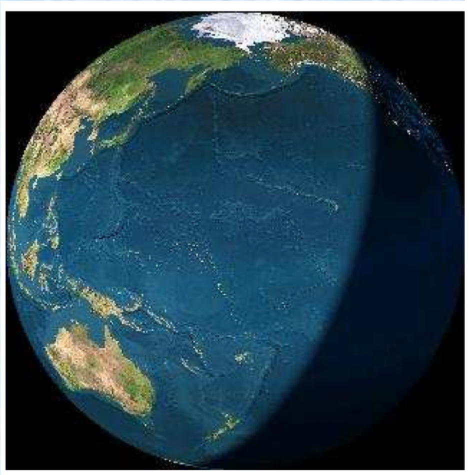
# TPF-C Science Requirements (first three)

1. TPF-C shall be able to detect an Earth twin in a Solar System twin at a distance of 10 pc.
2. TPF-C shall be able to detect a Jupiter twin at quadrature in this same system.
3. TPF-C shall be able to find ~30 potentially habitable planets if all target stars have one such planet. Equivalently, TPF-C shall have an excellent chance (95%) of detecting at least one planet that is potentially habitable, assuming that ten percent or more of all target stars have such a planet ($\eta_{\oplus}$ = 0.1). The following assumptions are to be made in estimating these numbers…

- Once we’ve found the nearby Earths, we will immediately want to begin collecting spectra. We have some ideas for the types of objects we might see…

# Visible spectrum of Earth

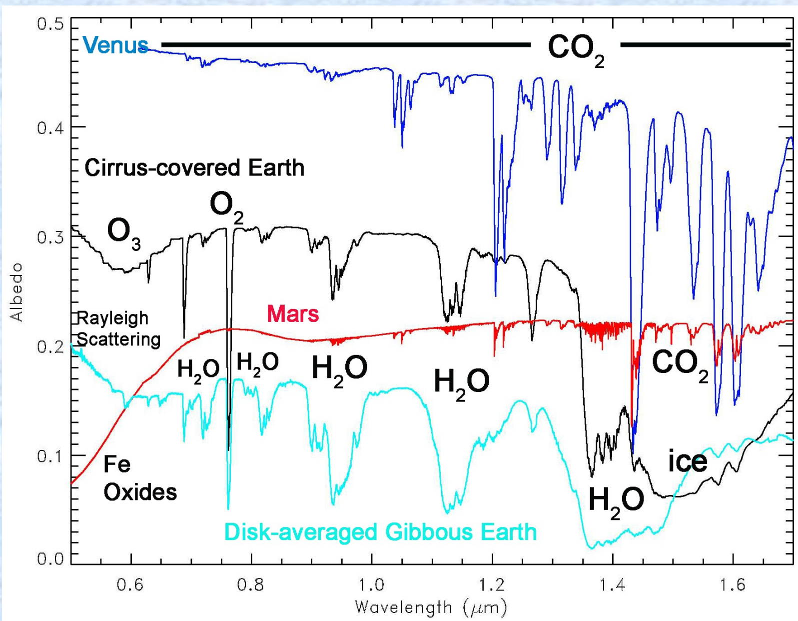


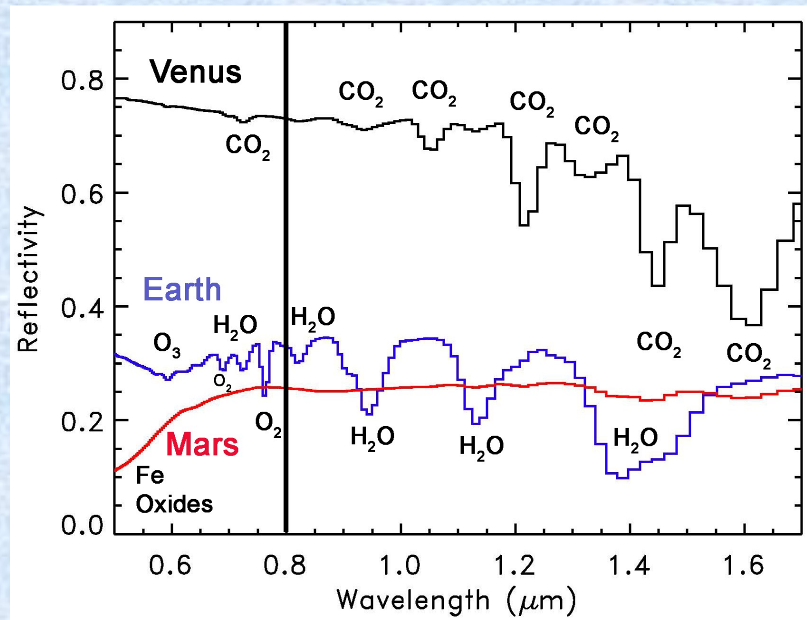



Integrated light of Earth, reflected from dark side of moon: Rayleigh scattering, chlorophyll, $O_2$, $O_3$, $H_2O$

Ref.: Woolf, Smith, Traub, & Jucks, ApJ 2002; also Arnold et al. 2002

# Simulated visible/near-IR spectra of Venus, Earth, & Mars (TPF-C)



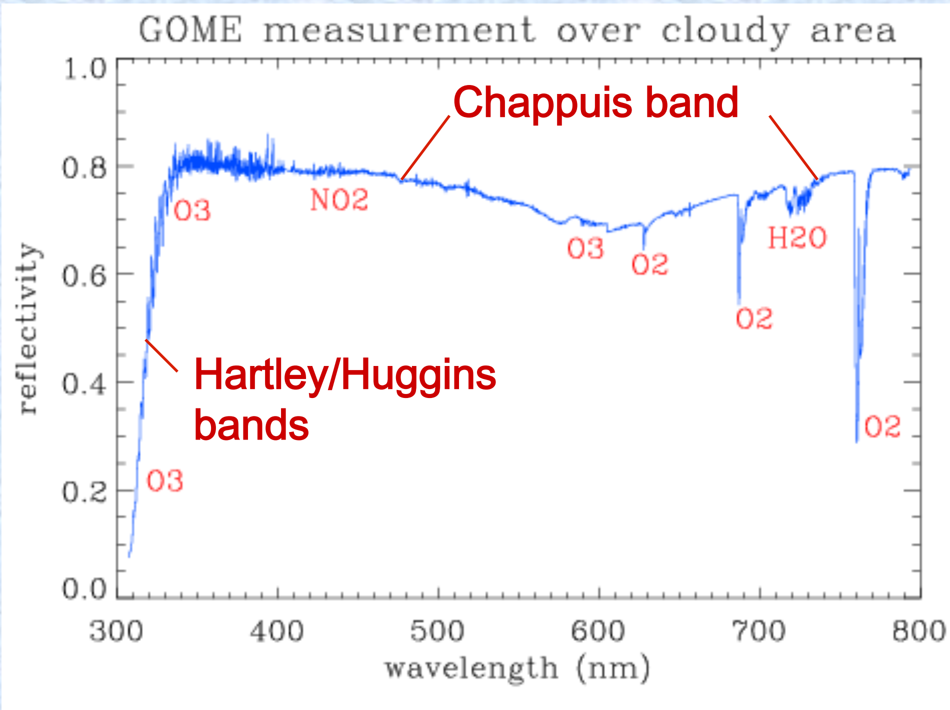

High resolution R $(=\lambda/\Delta\lambda) = 70$

- We would like to get out as far as possible into the near-IR in order to pick up bands of $CO_2$ and $CH_4$

*Courtesy of Vikki Meadows, Caltech*

# UV absorption by ozone

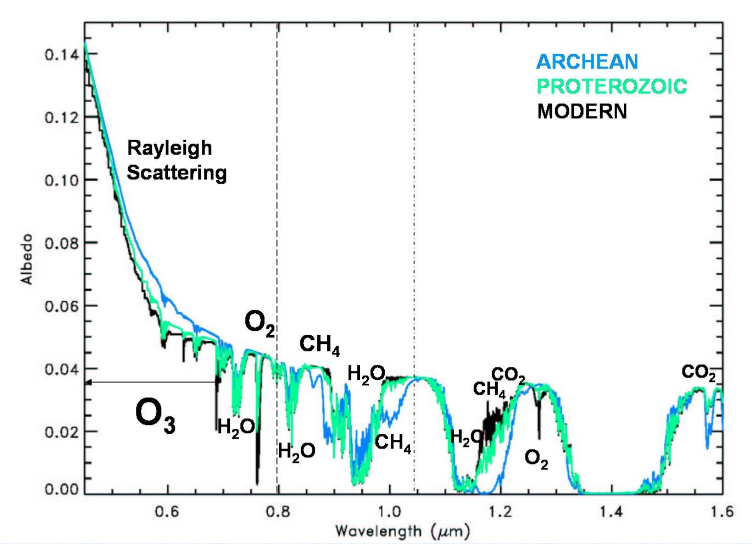
- If we can measure exoplanet spectra in the near-UV ($\lambda$ < 300 nm), we should see a sharp dropoff in reflectivity of Earth-like planets due to absorption by $O_3$
- This is not considered essential, though, because other $O_3$ and $O_2$ features can be found in the visible



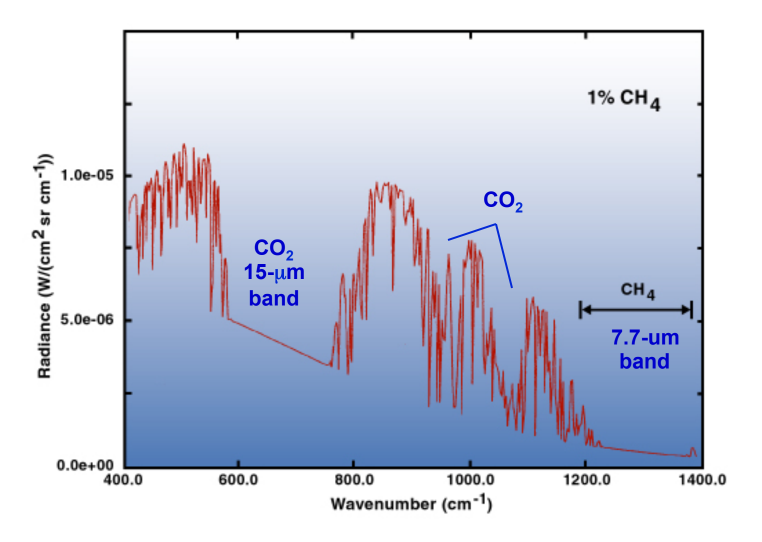

http://disc.sci.gsfc.nasa.gov/oceancolor/additional/science-focus/ocean-color/science_focus.shtml/ozone.shtml

# Early-Earth type planets

- $CH_4$ has absorption features in both the visible/near-IR and (especially) in the thermal-IR
- These features would be difficult to observe on a planet like modern Earth (because $CH_4$ is scarce), but might be seen on an early-Earth-type planet




TPF Science Requirements Document
(Courtesy of Vikki Meadows)




TPF book (Courtesy of Trent Schindler)

# The "Holy Grail" of remote life detection: $O_2$ and $CH_4$ together

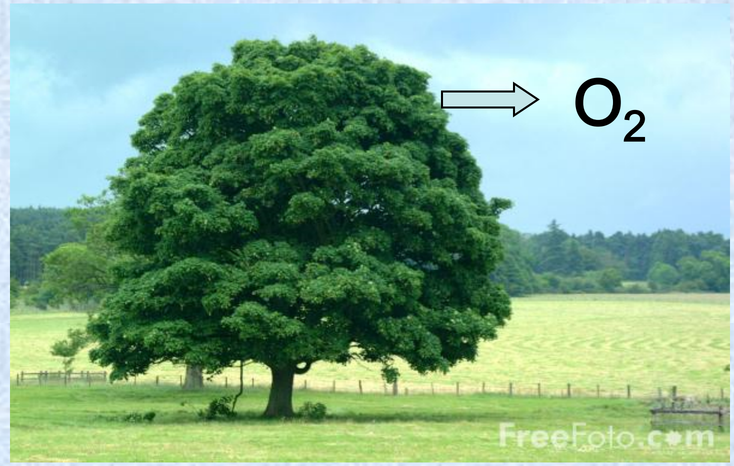
- Green plants and algae (and cyanobacteria) produce oxgyen from photosynthesis:

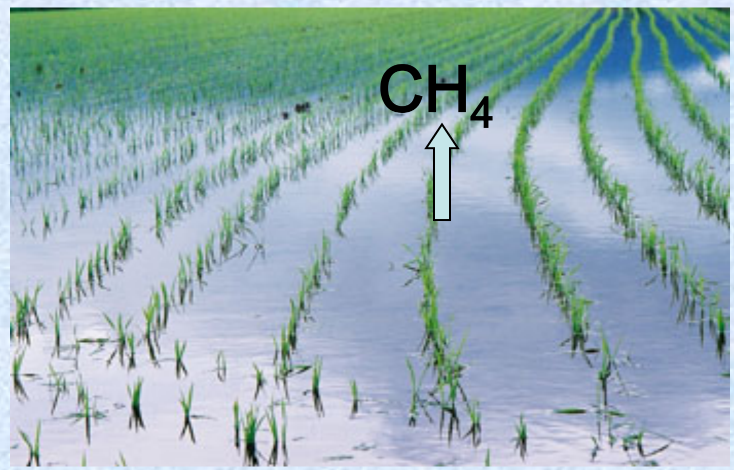
  $CO_2 + H_2O \rightarrow CH_2O + O_2$

- Methanogenic bacteria produce methane

  $CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$

- $CH_4$ and $O_2$ are out of thermodynamic equilibrium by 20 orders of magnitude!* *Hence, their simultaneous presence is strong evidence for life*



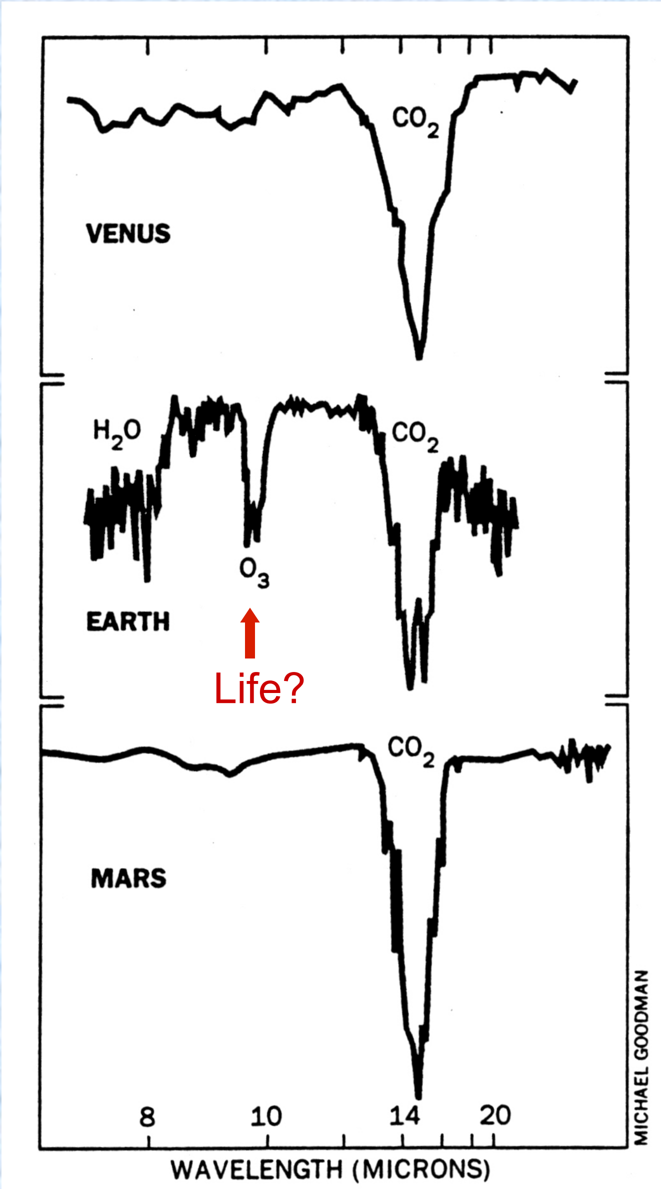

*As first pointed out by James Lovelock

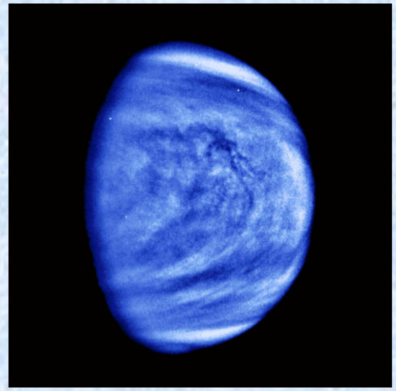
# Conclusions

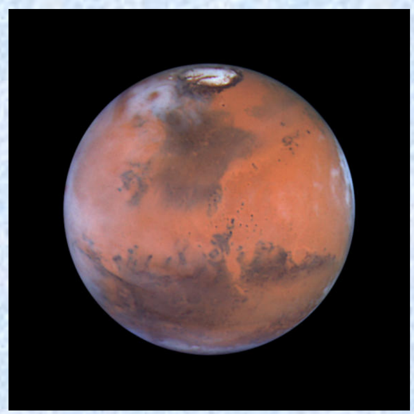
- The exoplanet community is interested in finding Earth-like planets around nearby stars, if they exist, and in searching them spectroscopically for signs of life
- We welcome *collaboration* with other astronomers who have different scientific interests but who might share the same tools, *i.e.*, a big, new UV/visible/near-IR space telescope

- Backup slides

# Thermal-IR spectra





Source: R. Hanel
Goddard Space Flight Center

- The thermal-IR region provides excellent (and complementary) biosignatures