

The search for life in our Galaxy: using the solar system planets as benchmarks

Playing billiards with
solar system planets



Enric Pallé, et al.
Instituto de Astrofísica de Canarias

ESO Astrobiology, 2015

Mars

KOI-961.03

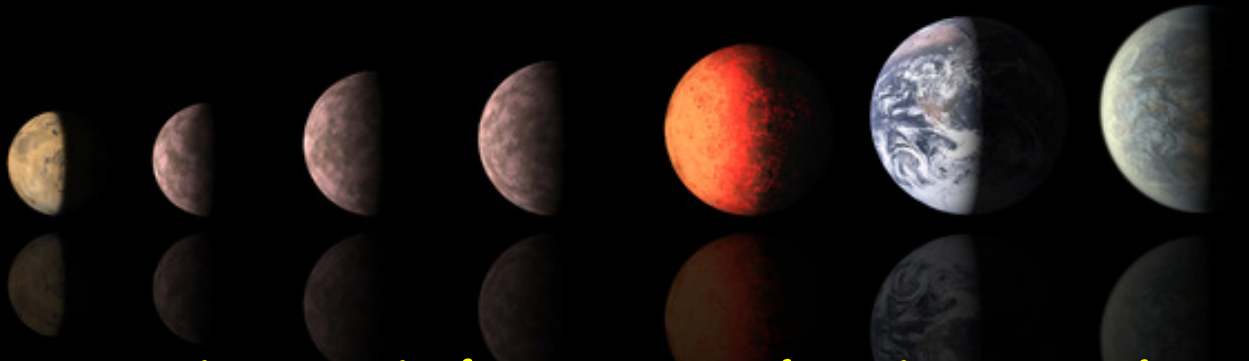
KOI-961.02

KOI-961.01

Kepler-20e

Earth

Kepler-20f



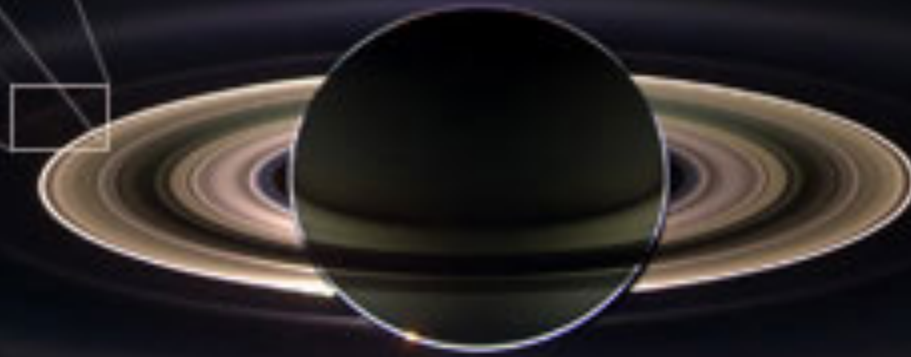
Habitable \neq Inhabited

How will we know?



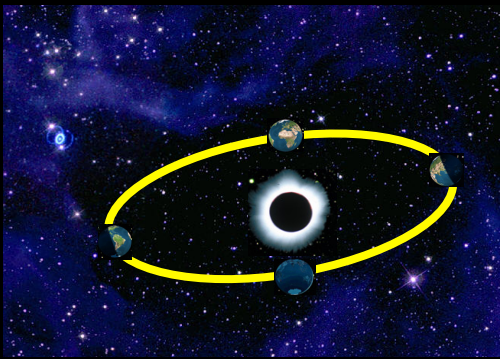
All light comes from a single point

Reflected light or transmission?



Cassini from Saturn

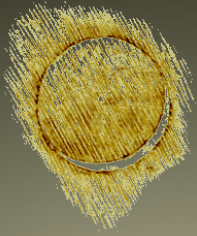
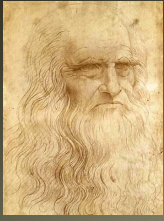
The solar system as a benchmark for exoplanet characterization



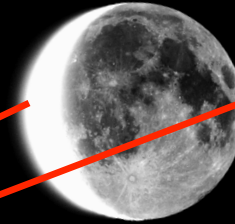
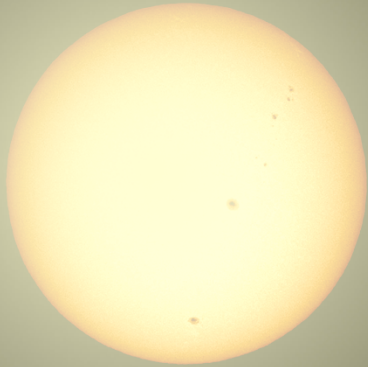
Measuring globally-integrated reflected light from solar system objects--> Proxy for the detection of direct light from exoplanets



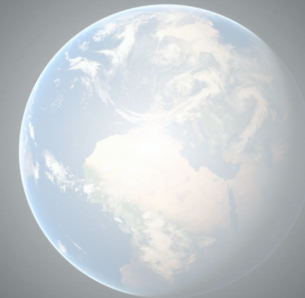
Measuring the transmission spectrum of solar system planets -> Proxy for transiting planets atmospheric characterization

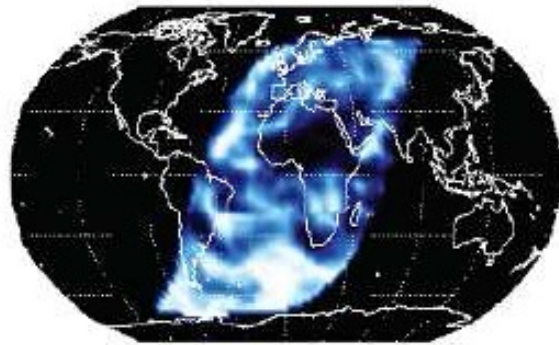


The Earthshine on the moon

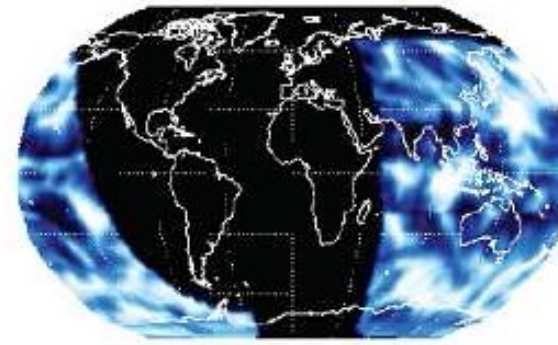
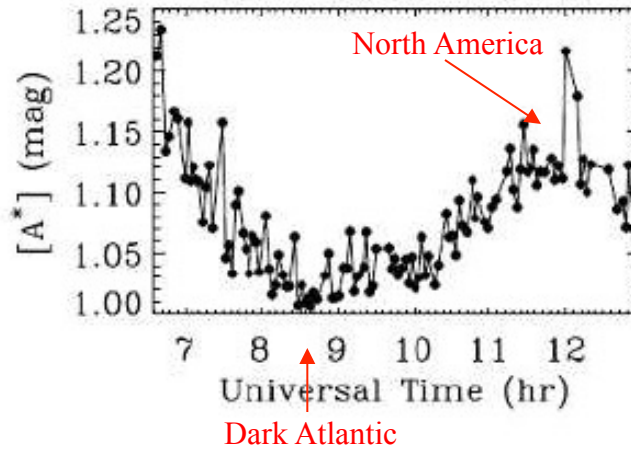


*ES/MS = albedo (+ geometry
and moon properties)*

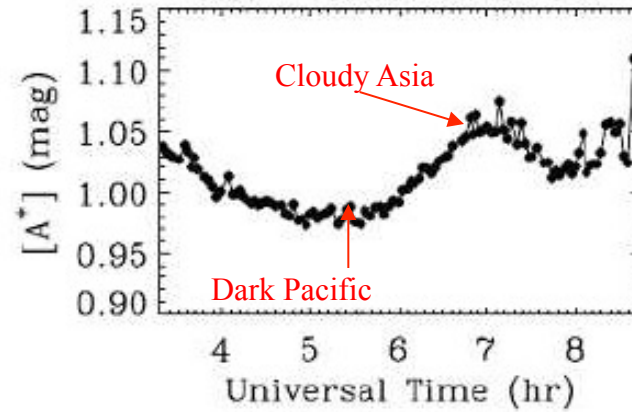




2004 December 3

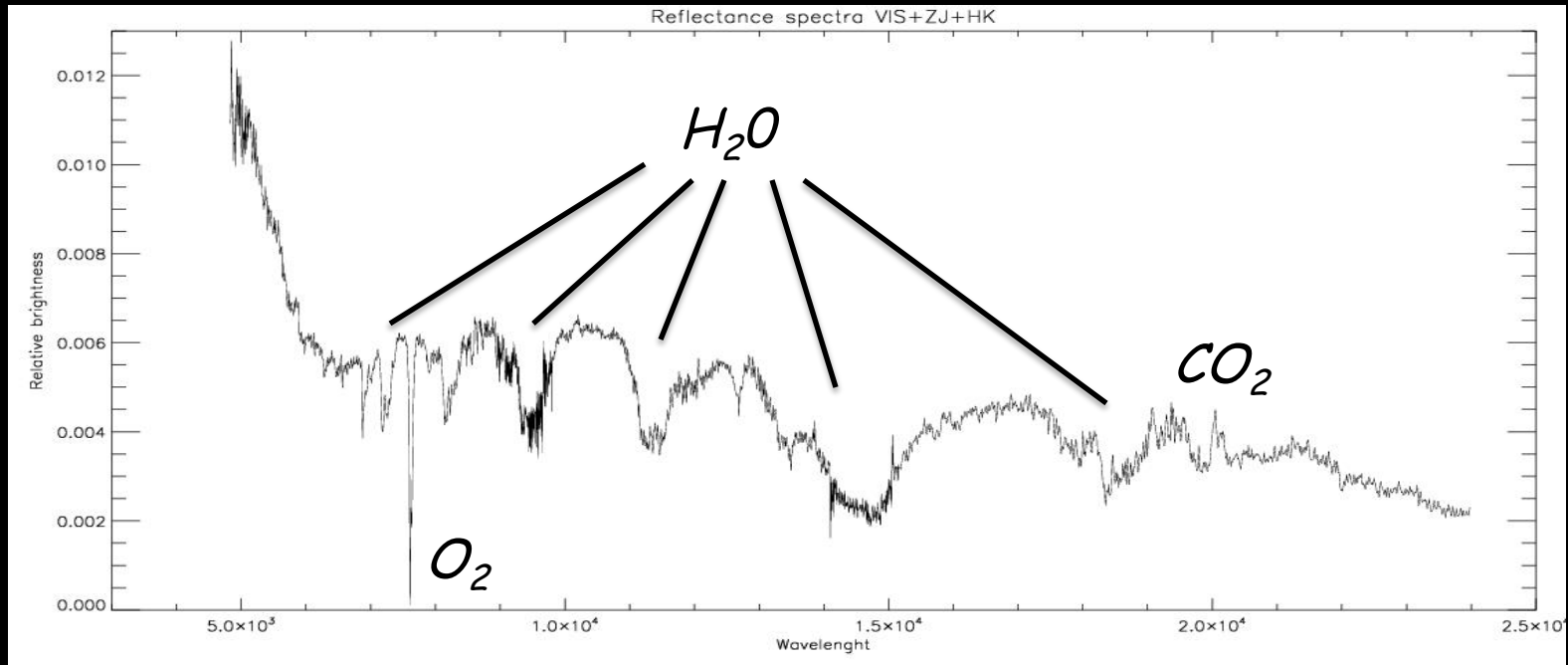


2004 December 20



Photometry: continents, weather

The spectrum of an inhabited planet



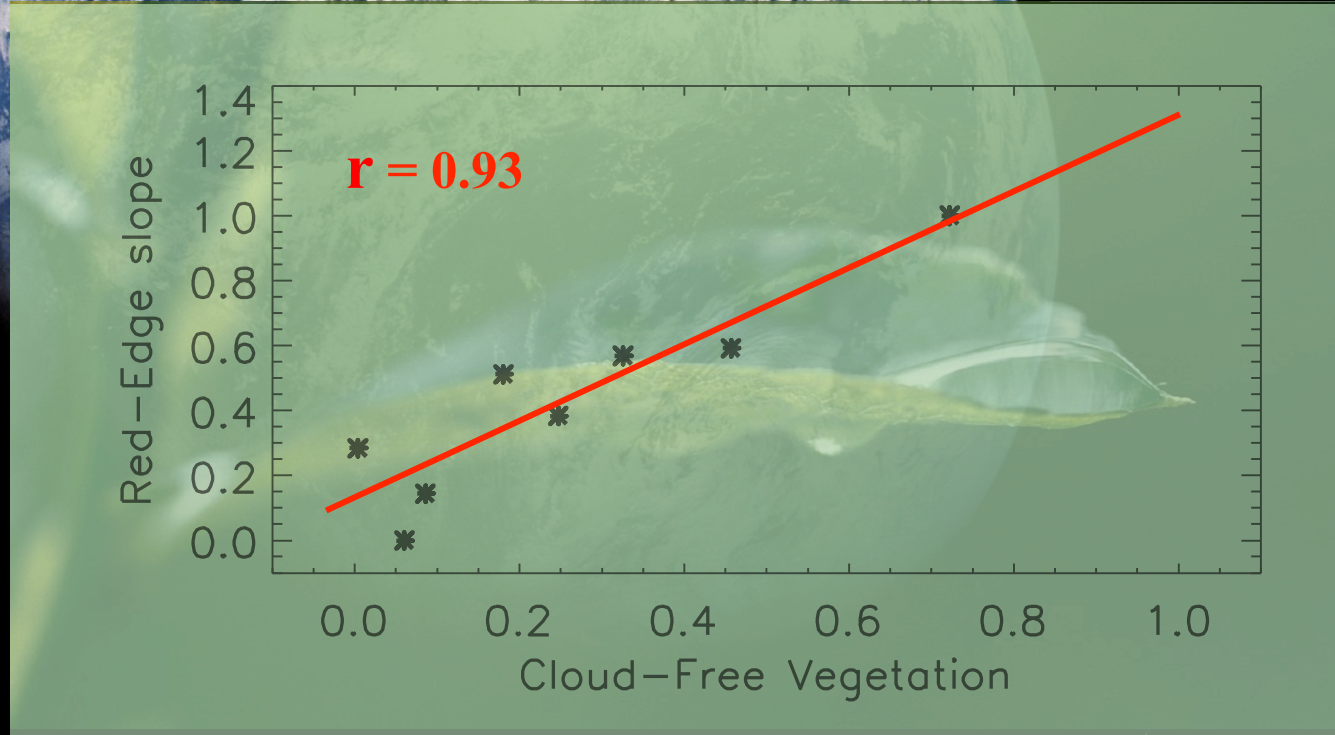
Simultaneous presence of:

- Water
- Ozone (Oxygen)
- Carbon Dioxide

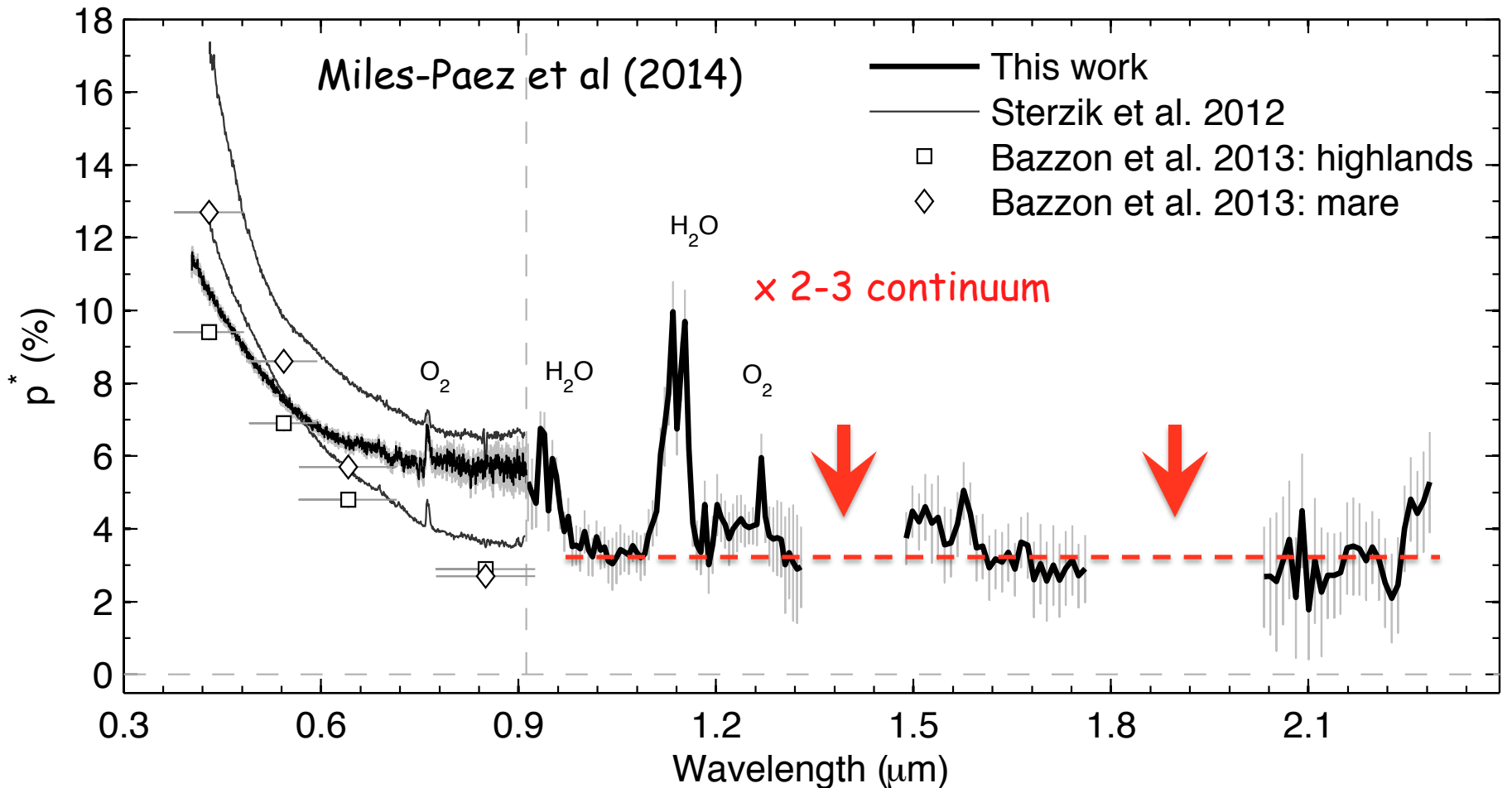
These three gases cannot co-exist in the atmosphere of a planet without the presence of life.



The terrestrial vegetation can be detected although the signal is small ...

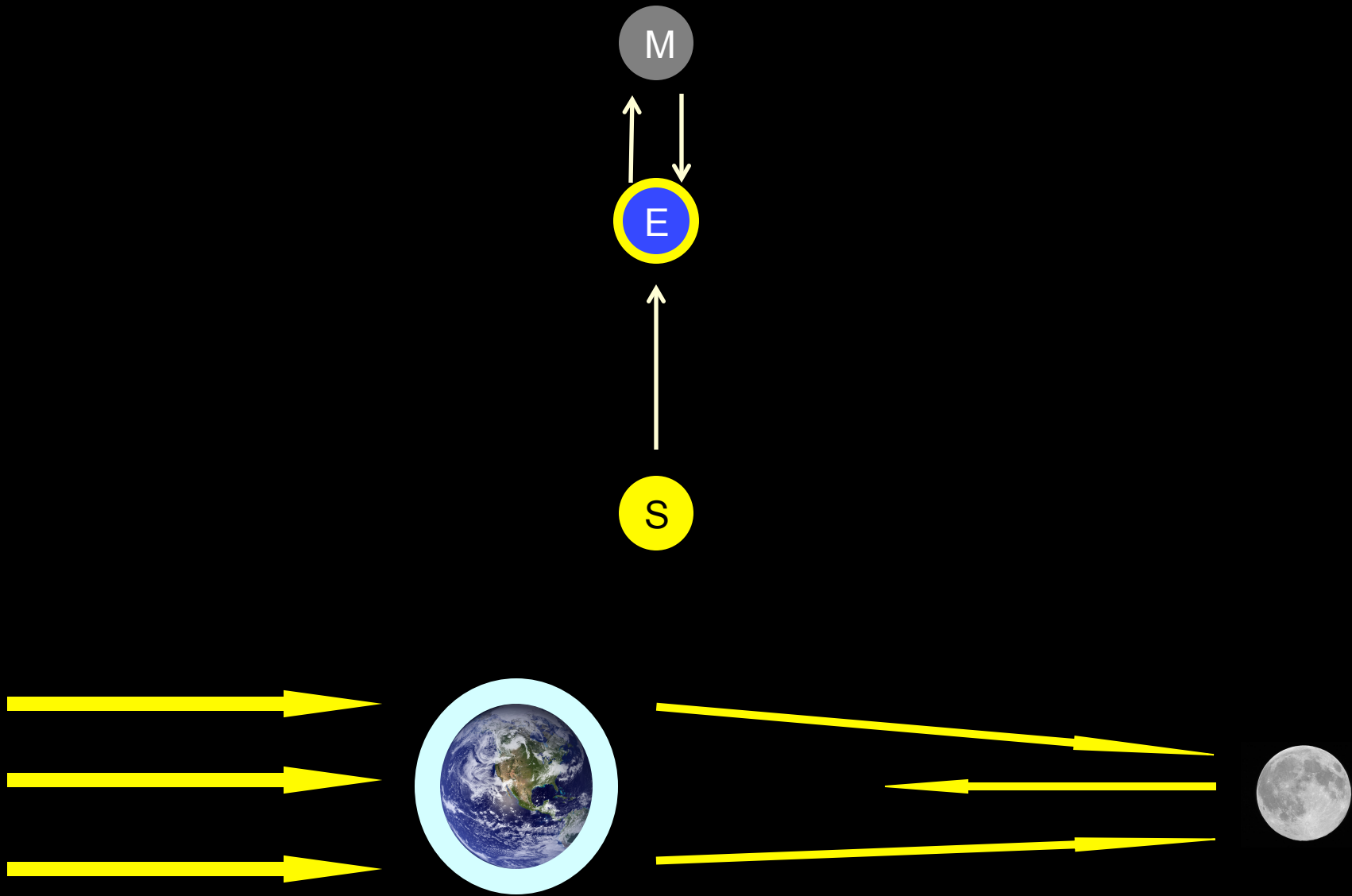


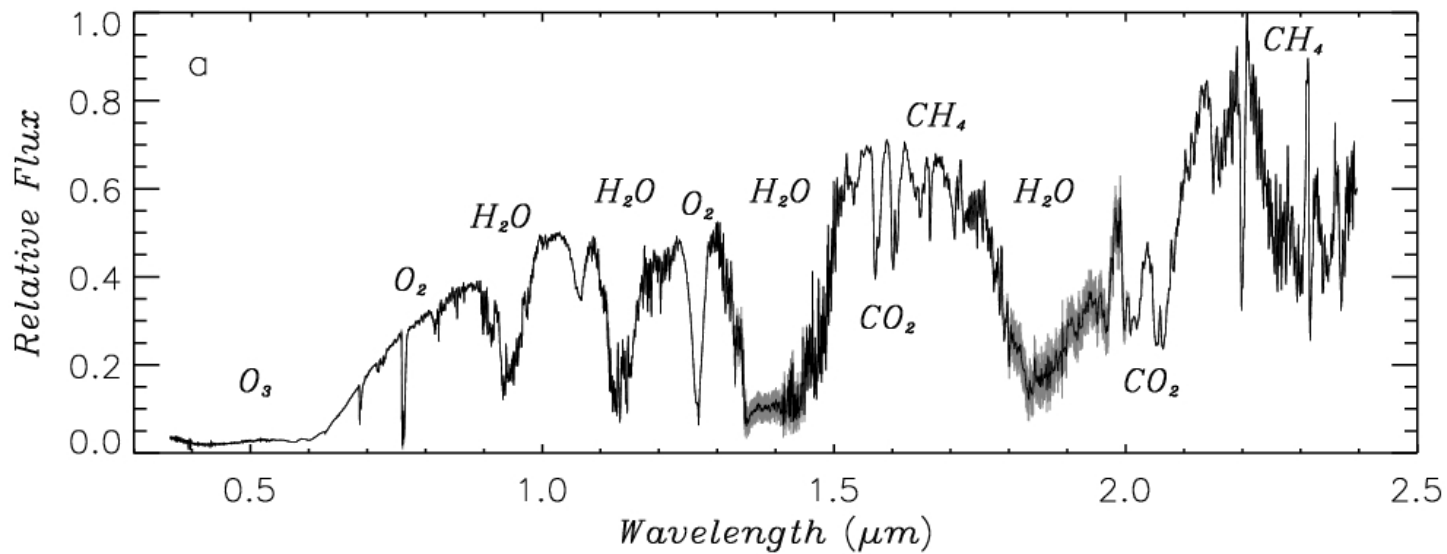
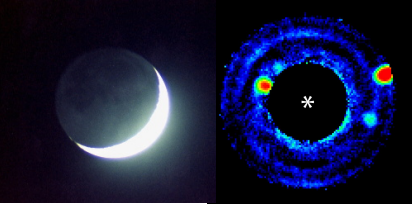
Earth atmospheric polarization signal



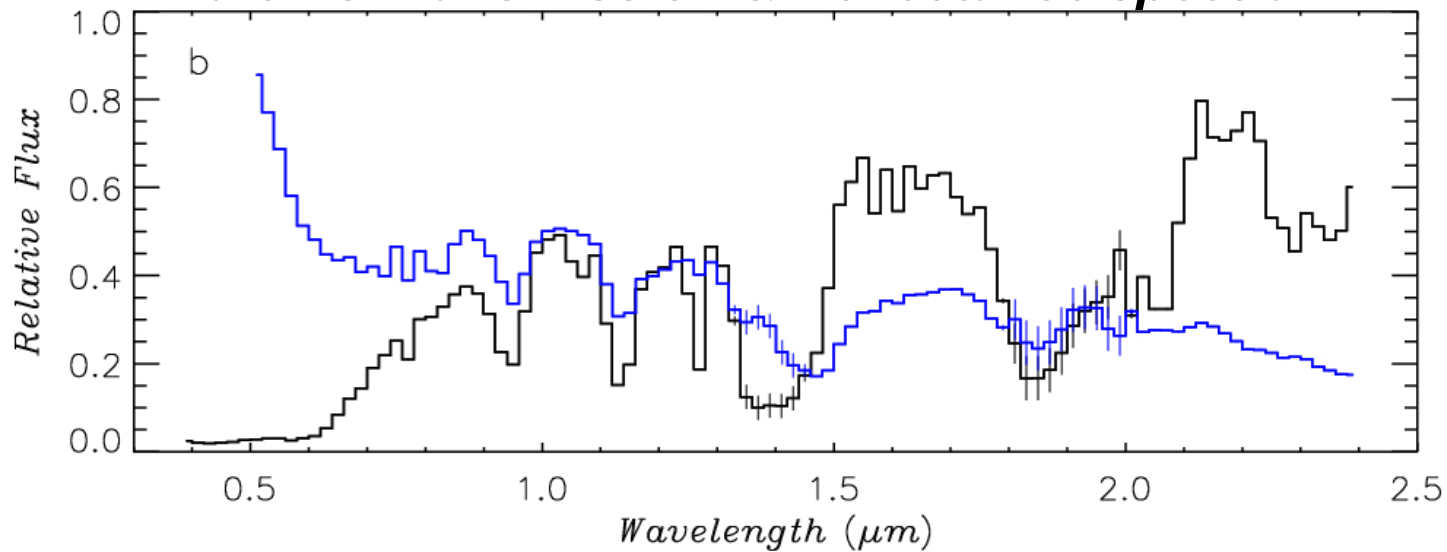
Eclipses as proxies for transits







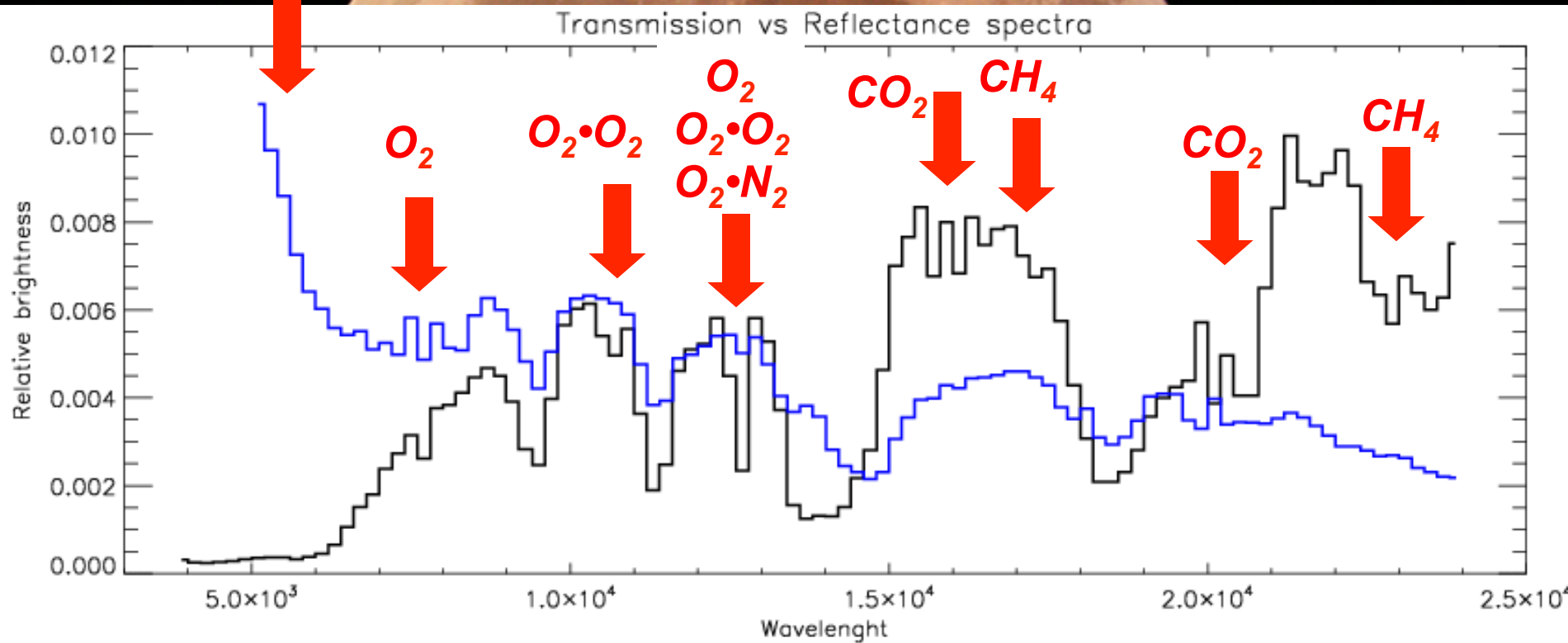
Earth's Transmission & Reflectance spectra



*Palle et al,
Nature, 2009*

Earth's Transmission Spectrum

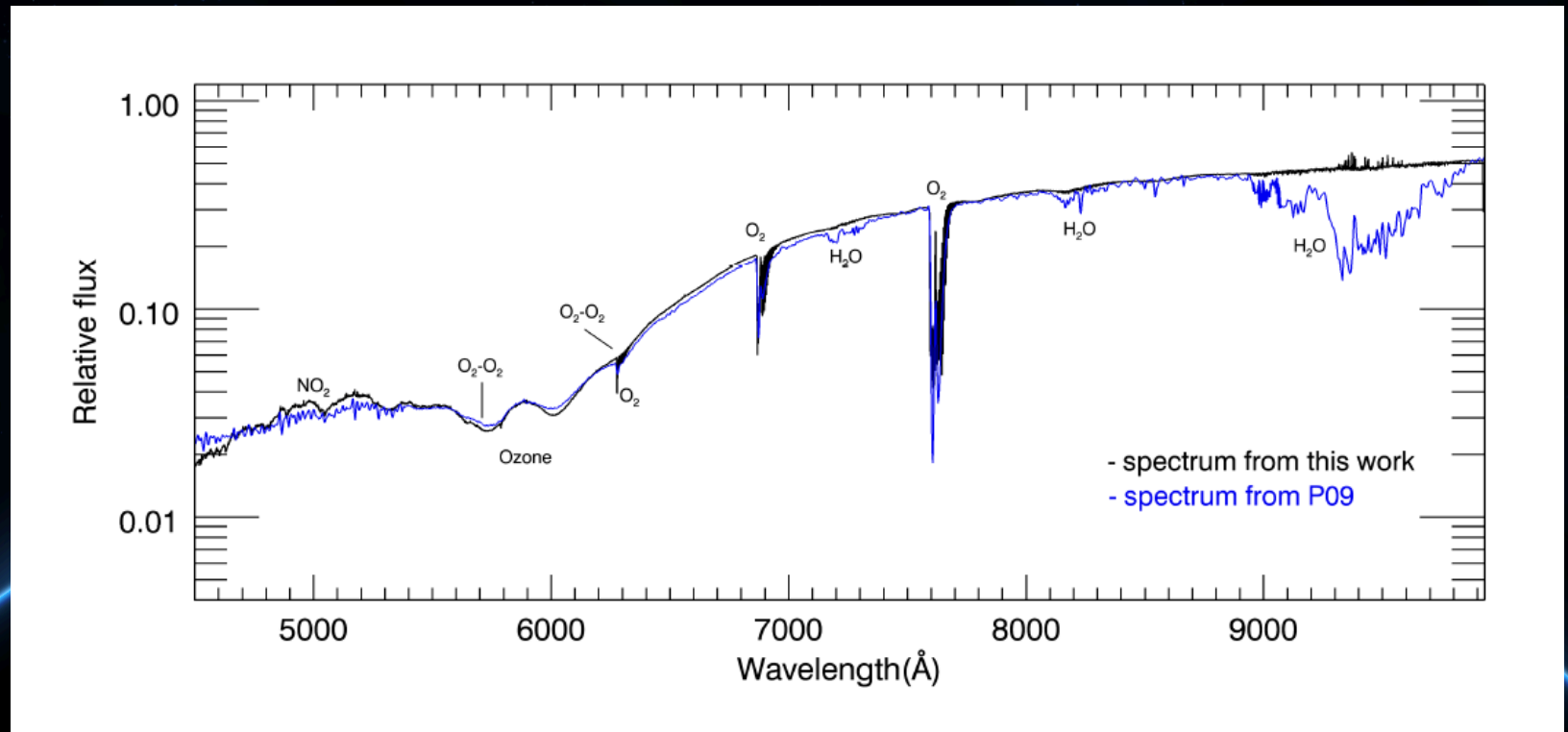
Blue planet?



Palle et al, Nature, 2009

© Daniel López

Different eclipses probe different atmospheric paths

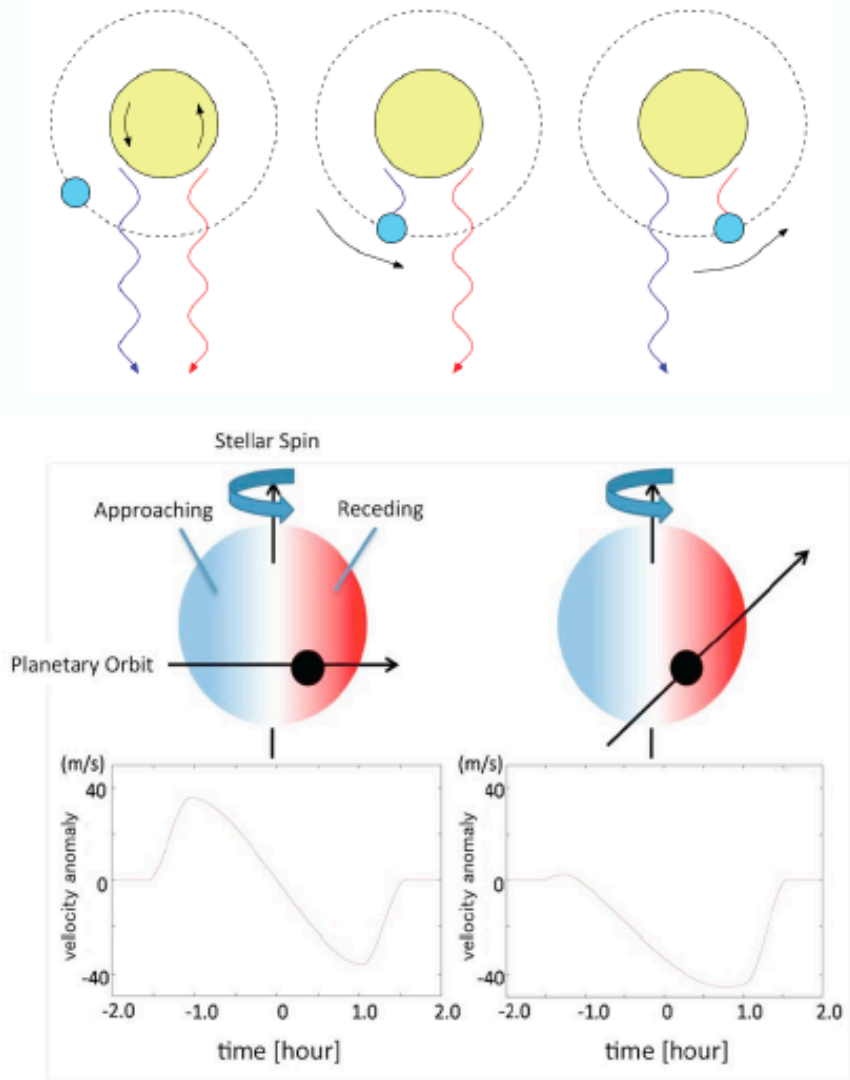


Yang et al, Astrobiology, 2014

HARPS-S: An eclipse proved using RV data

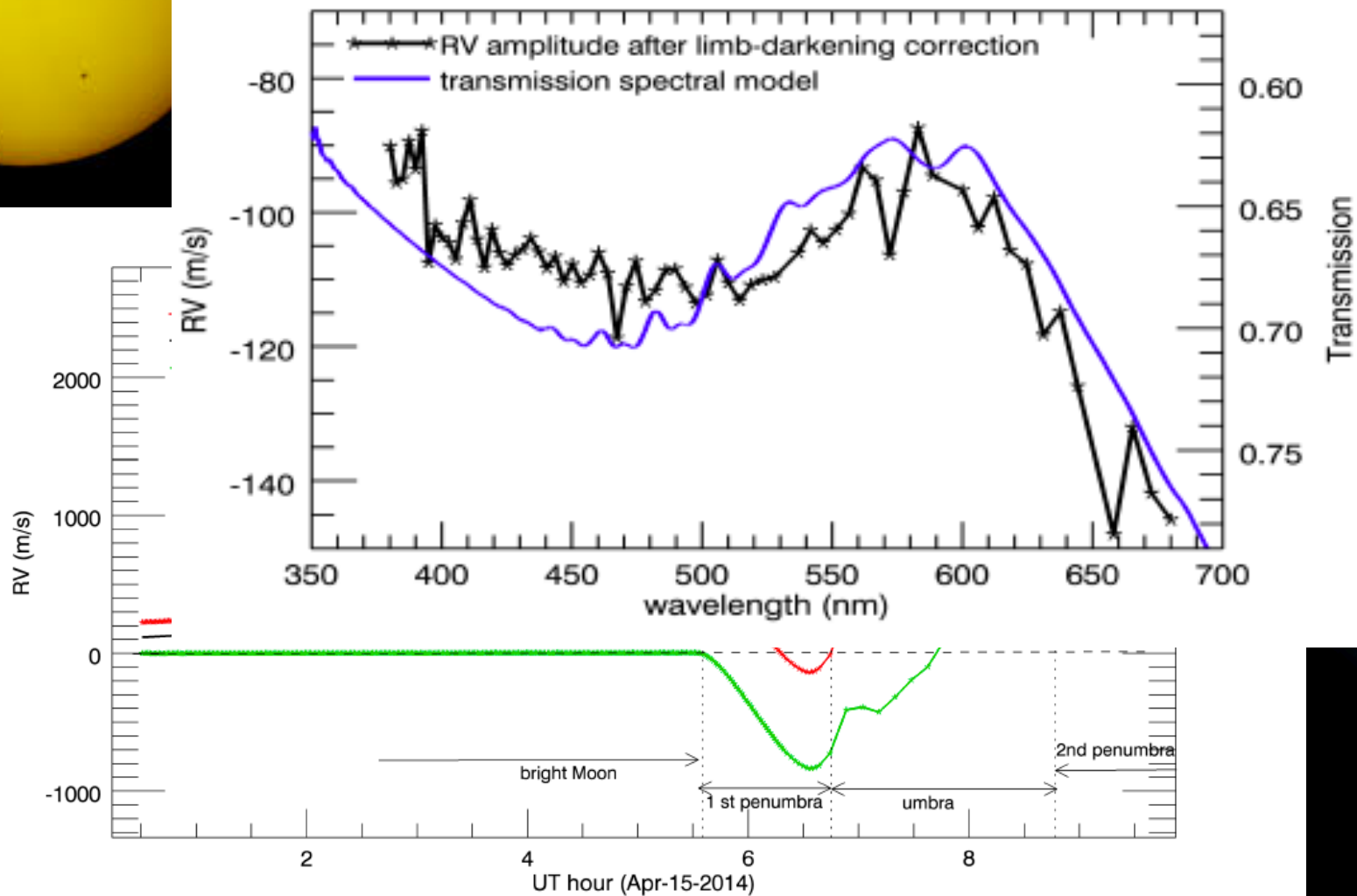
RM Effect:

Lambda
dependent !!



Gaudi & Winn 2007, ApJ

Using the Rossiter-McLaughlin effect to observe the transmission spectrum of Earth's atmosphere

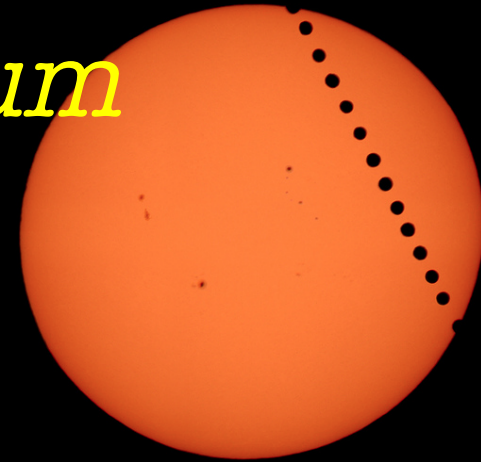


A real Earth + Moon transit



5 January 2014

The transmission spectrum of Venus

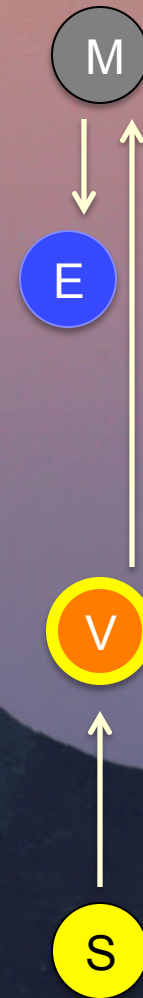


Transit of Venus - 6 June 2012

Can we detect the atmosphere?



*Meanwhile in Chile ...the
full Moon shines*



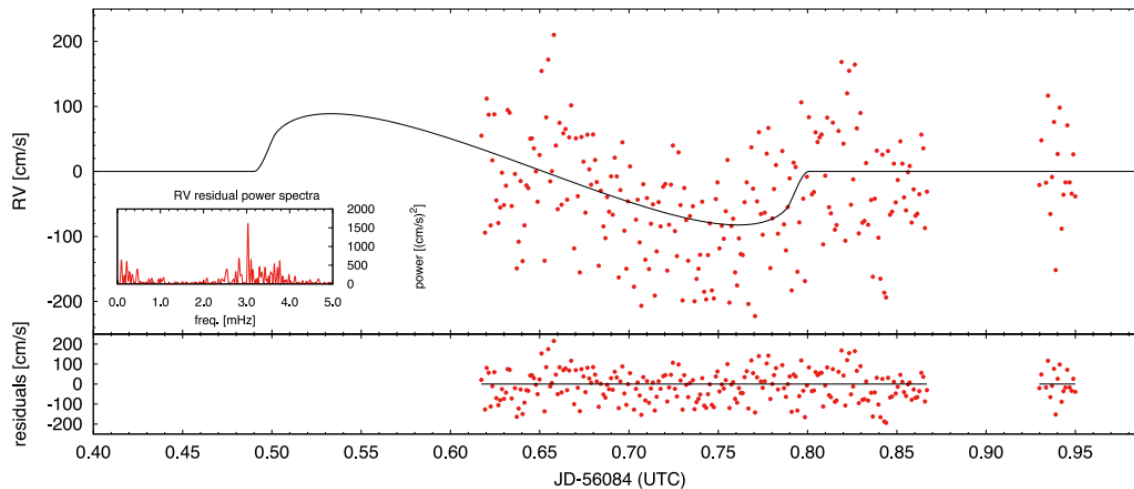
The June 6h 2012 Transit of Venus



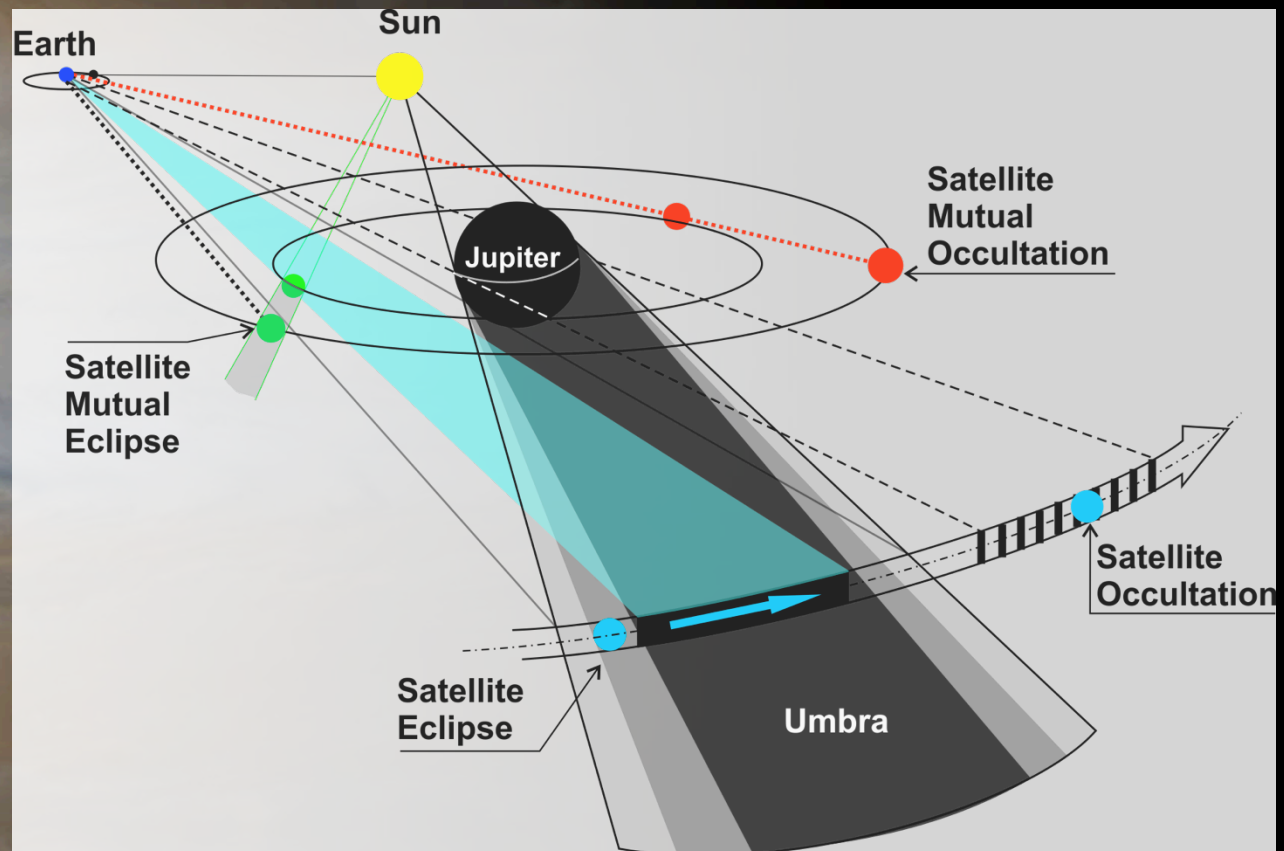
SOFI @ NTT in Chile
 2.1×10^{11} photons
Aprox. 3×10^8 photons per wavelength element

Transit depth 1mmag 10^{-3}
Atmospheric signatures $10^{-5/6}$

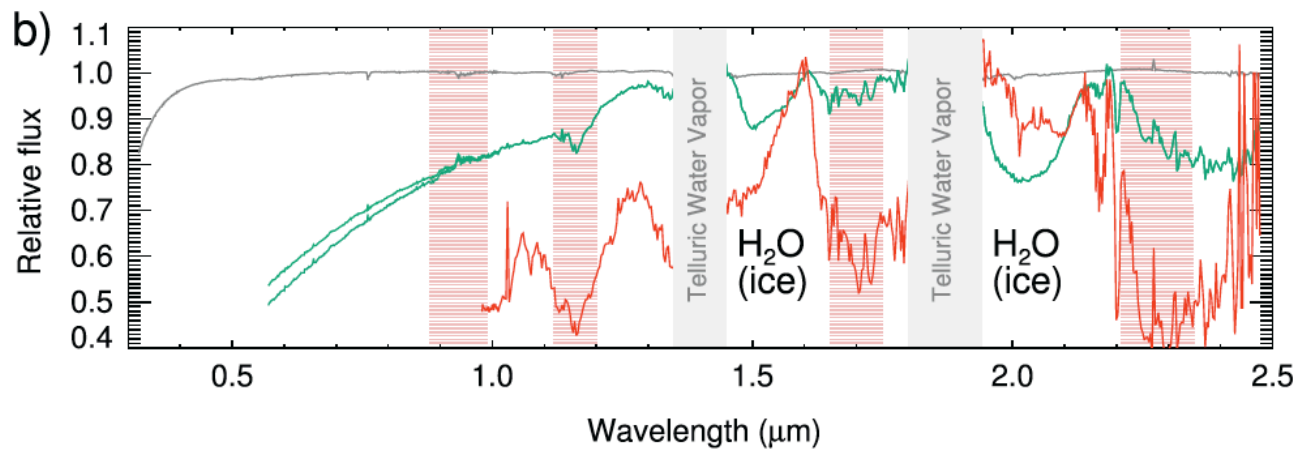
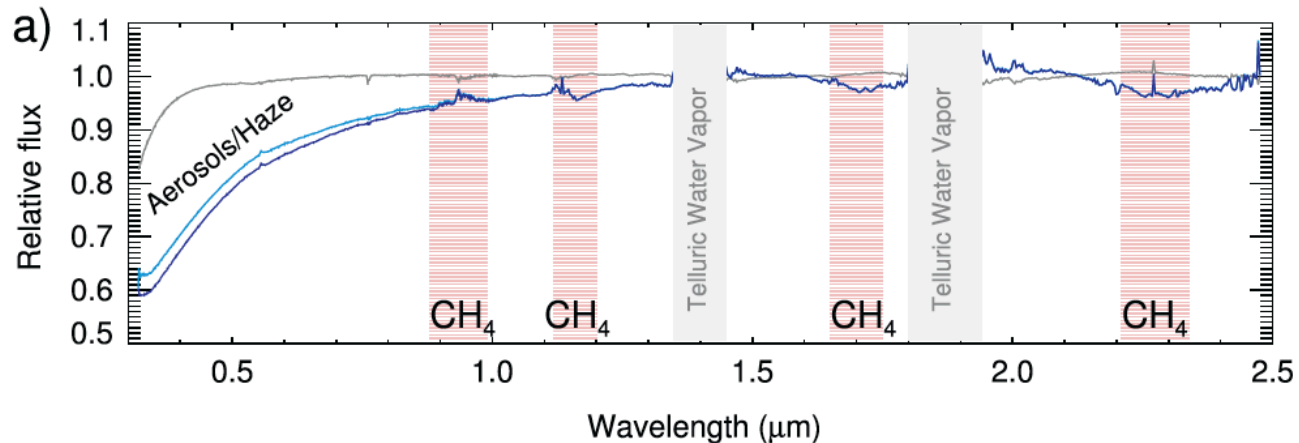
P. Molaro et al.



The transmission spectrum of Jupiter



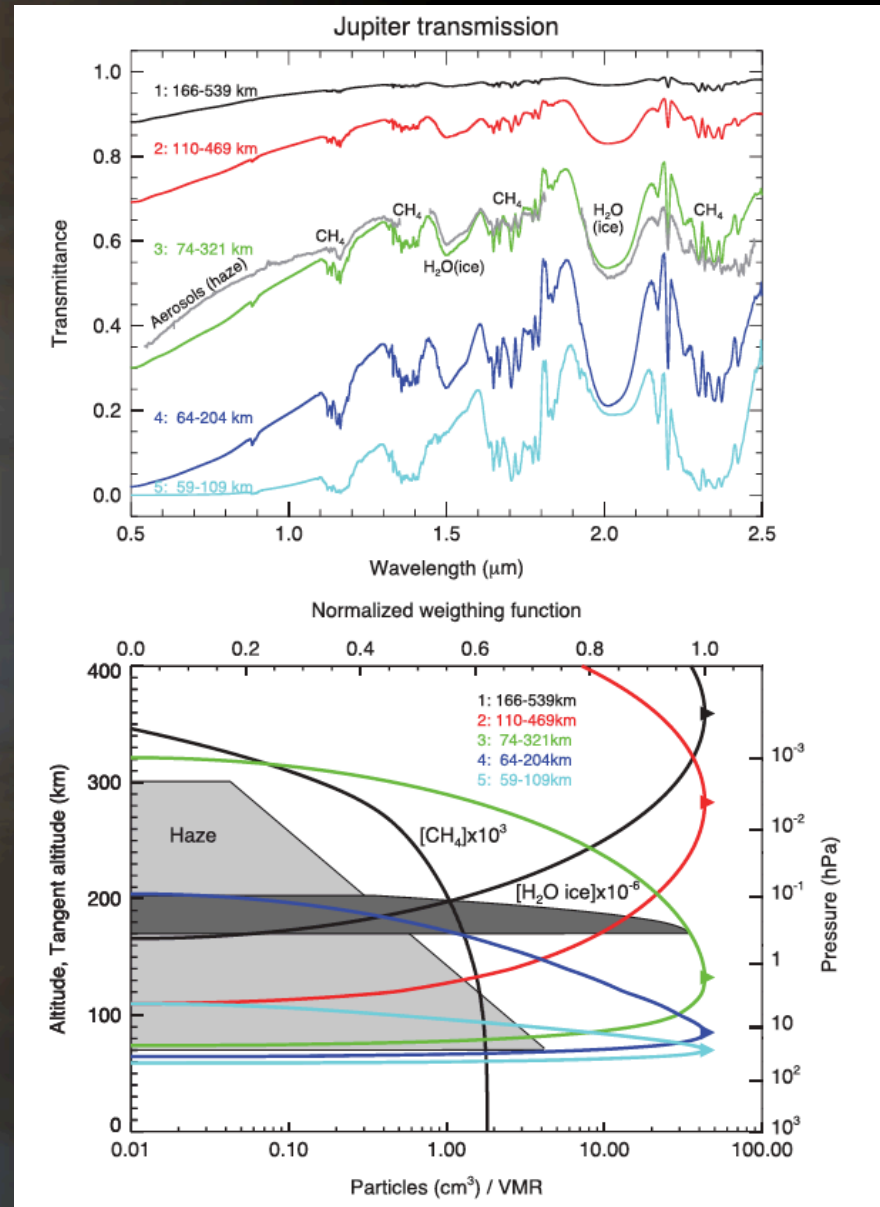
The transmission spectrum of Jupiter



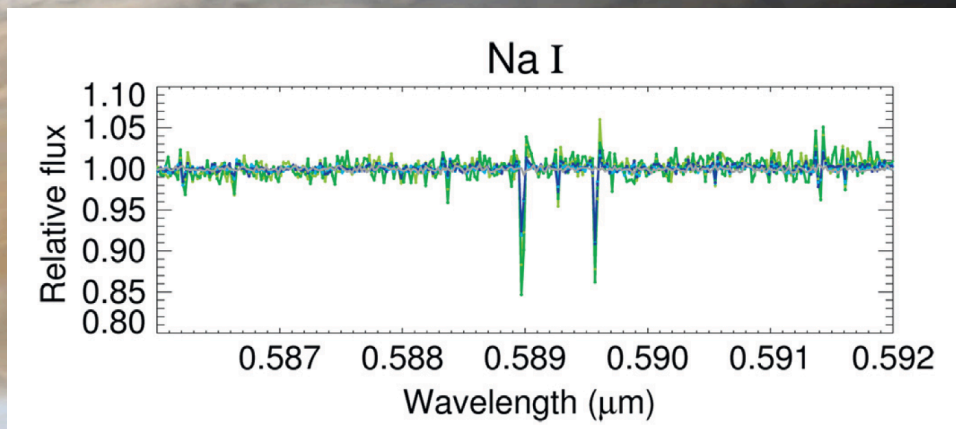
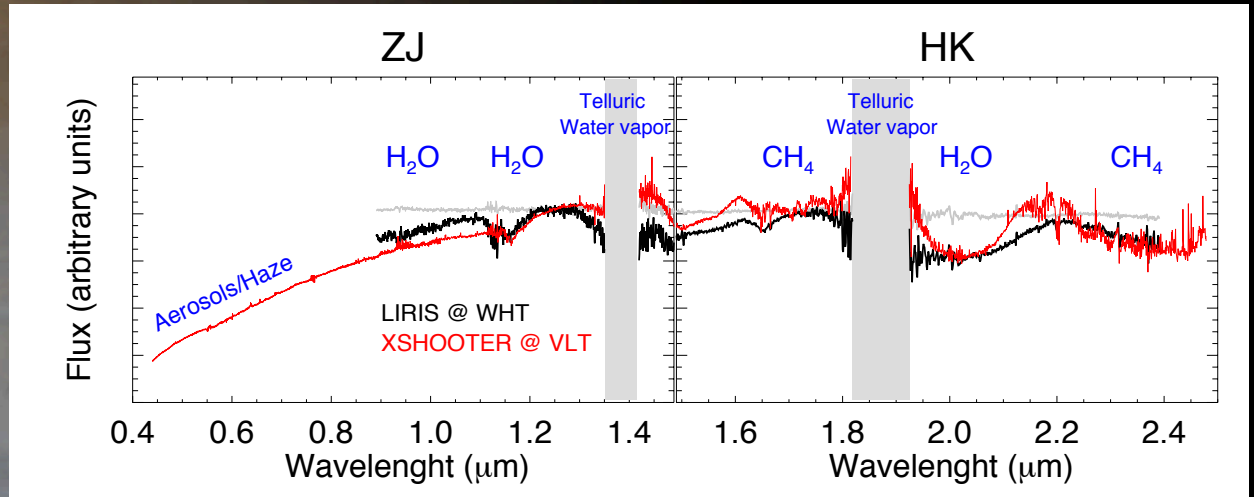
The transmission spectrum of Jupiter

Spectrum reveals:

- hazes
- Na layer
- Stratospheric haze of H_2O ice crystals



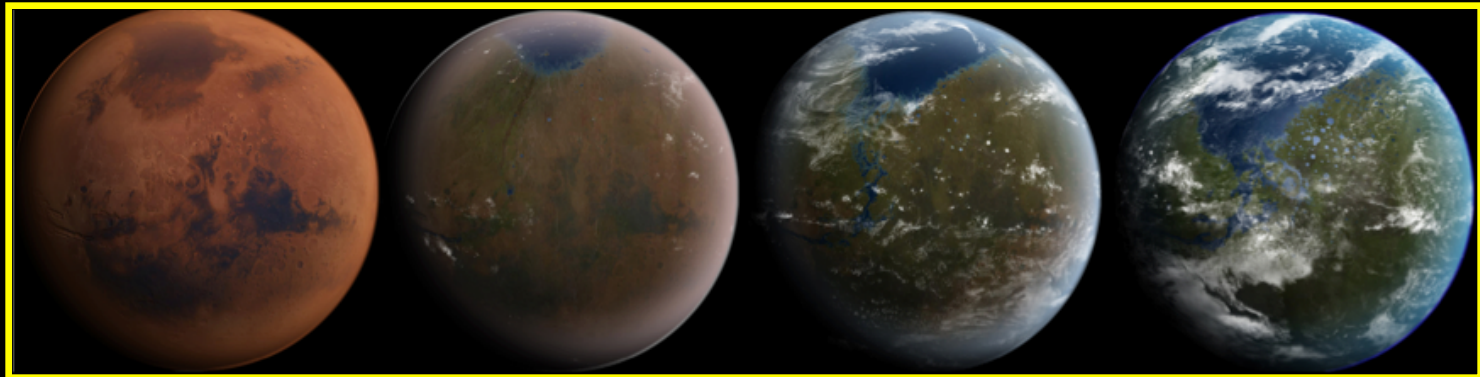
The transmission spectrum of Jupiter



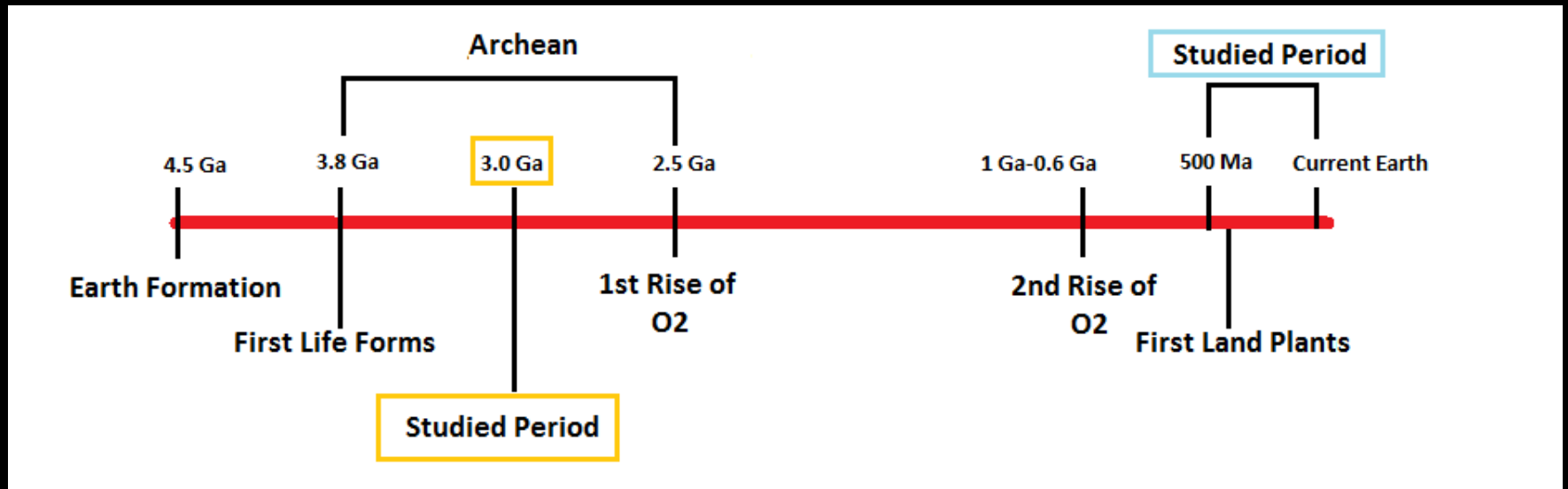
*Montaños-Rodríguez et al.,
ApJL, 2015*

The Archean Earth: the purple planet

Extrasolar planets are expected to exhibit a wide range of evolutionary stages, as the Earth did



The Archean Earth



- The Earth has been inhabited for at least 85% of its history
- We focused on Earth 3000 million years ago, when the atmospheric composition was very different from today's and the Sun was ~20% less bright
- To study the possibility of detecting primitive life forms

Purple bacteria

- One of the first life forms that colonized our planet.
- Can inhabit both aquatic and terrestrial environments
- Anoxygenic photosynthesis
- Can survive in extreme conditions
- Color: red, brown or purple



Laboratory measurements

Rhodobacter Sphaeroides (NASA's Ames
Research Center)



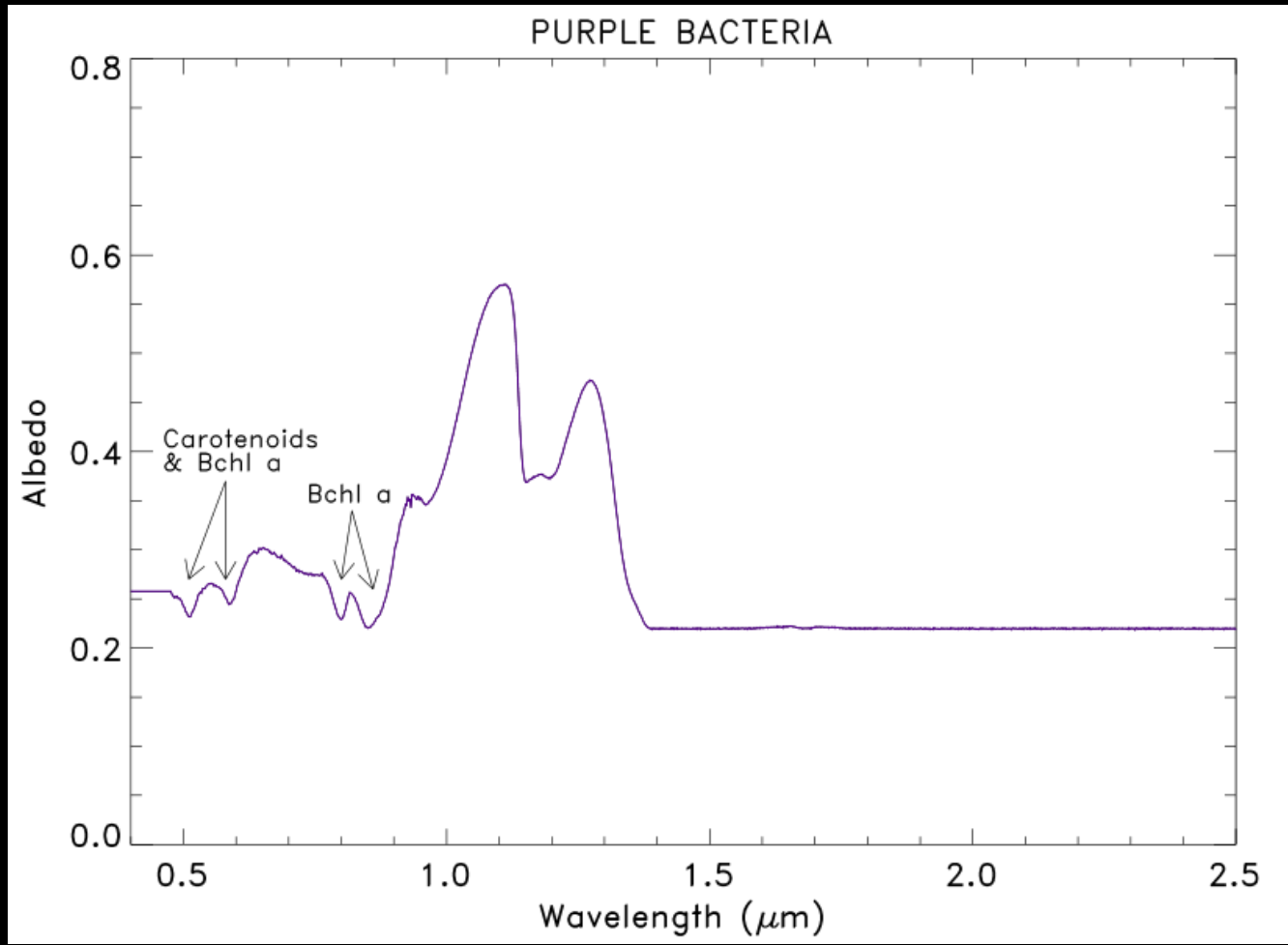
Rhodobacter Sphaeroides
(Department of Microbiology,
University of La Laguna)



Laboratory measurements

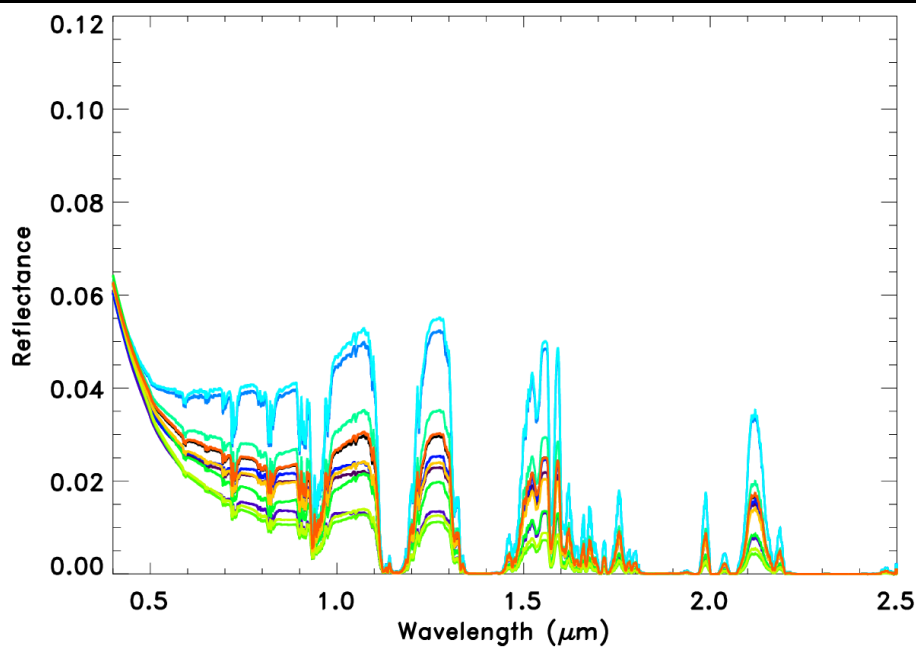


Laboratory measurements

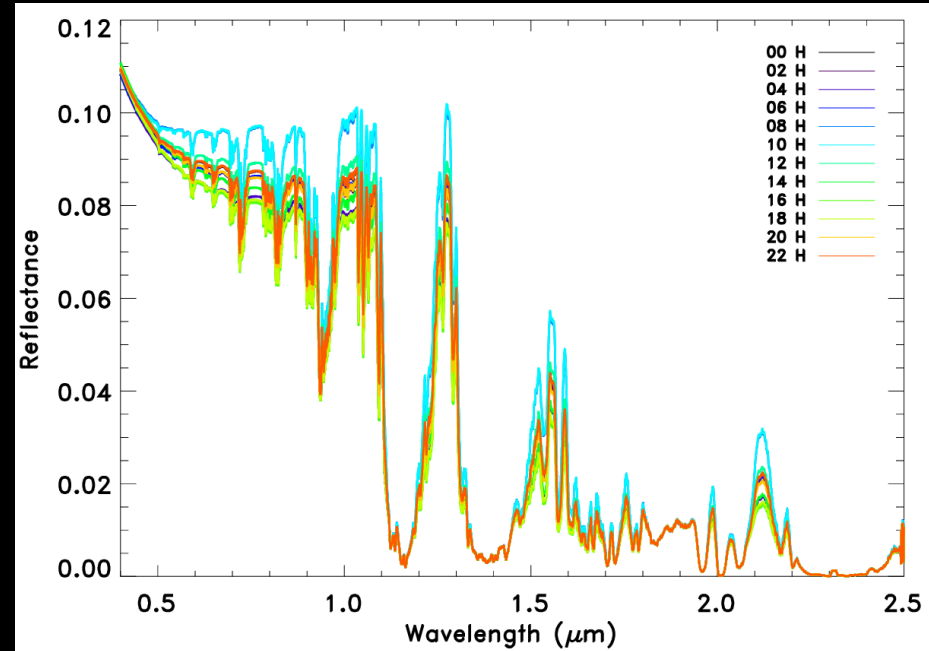


Rotational variability

Cloud free atmosphere



Cloudy atmosphere



- Purple bacteria in coastal areas: most likely scenario
- Purple bacteria readily detectable in the cloud-free case and still visible in the cloudy case
- *Only biomarker*



Thanks !!