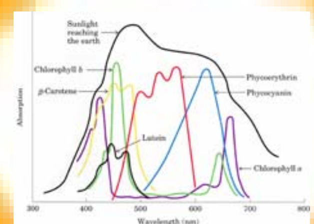
Giovanna Tinetti

ESA/Institut d'Astrophysique de Paris



γ

Exoplanet Atmosphere Characterization & Biomarkers

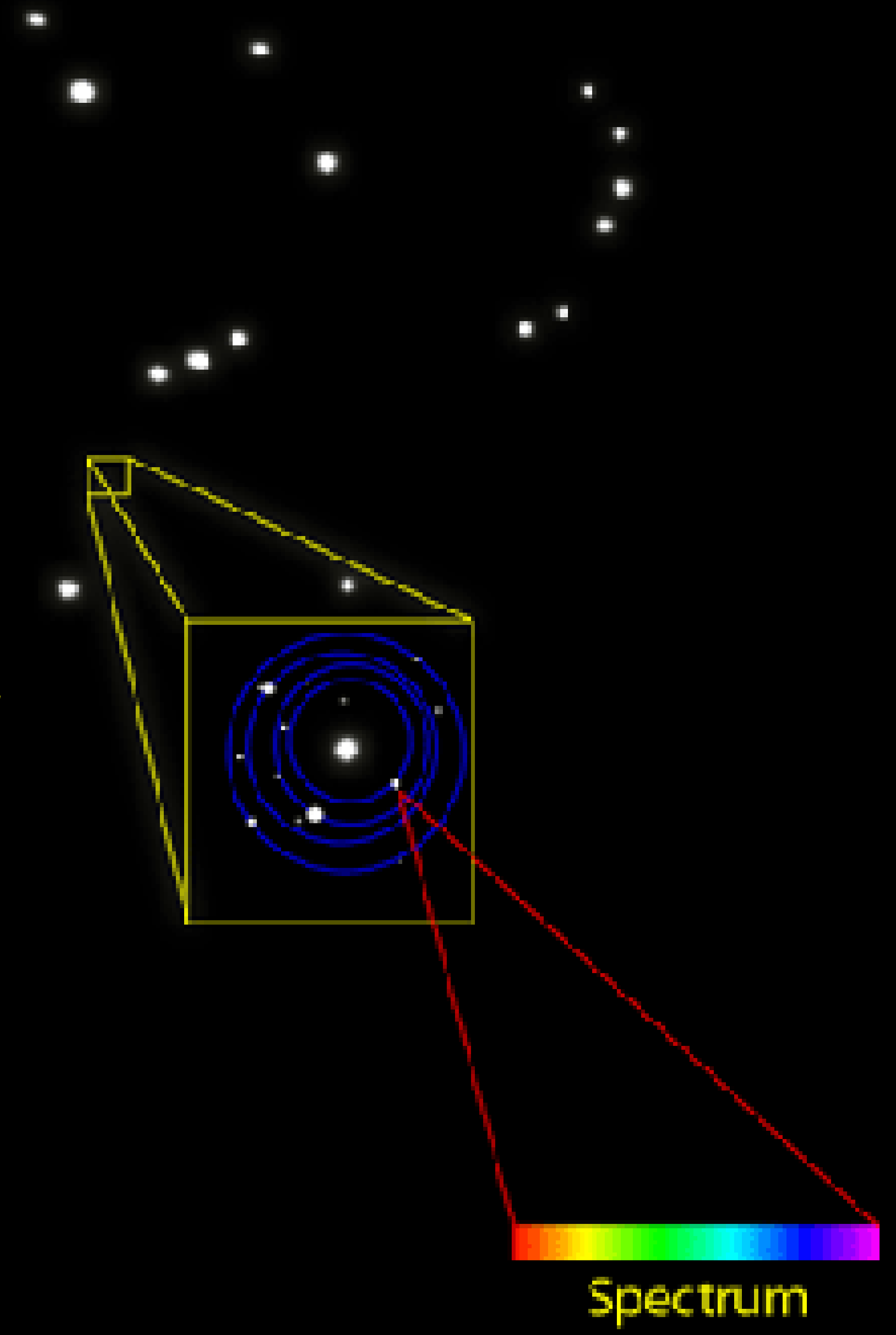
Can we use

Remote Sensing Spectroscopy,

- *Interaction between photon coming from the parent star and planet –*

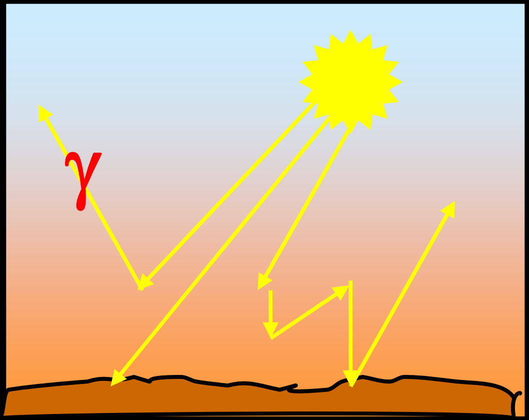
to characterize

Extrasolar Planets?



Photons reflected by the planet

VIS-NIR



Surface albedo /biosignatures

\+

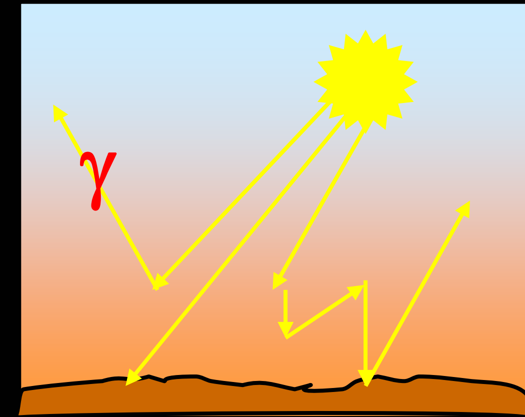
Atmospheric molecules (electronic transition)

\+

Cloud properties

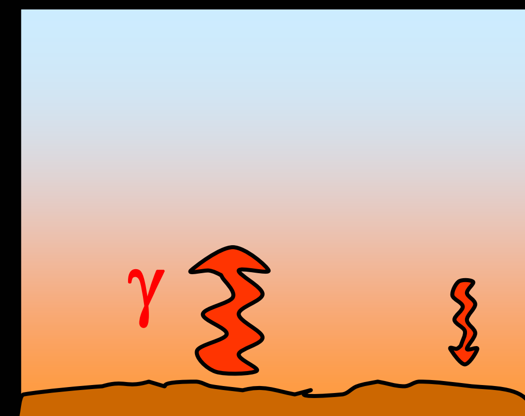
Photons reflected by the planet

VIS-NIR



Photons emitted by the planet

MIR



Atmospheric/Surface thermal properties

\+

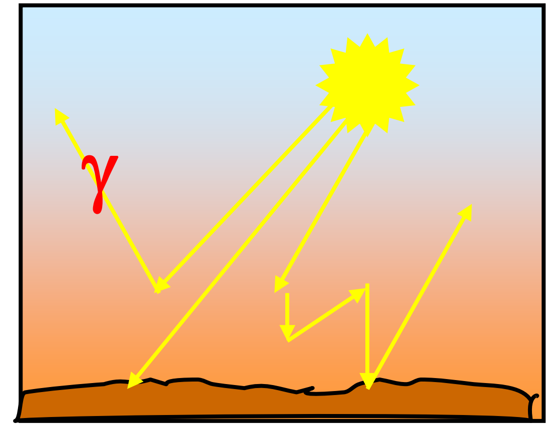
Atmospheric molecules (roto-vibrational modes)

\+

Clouds

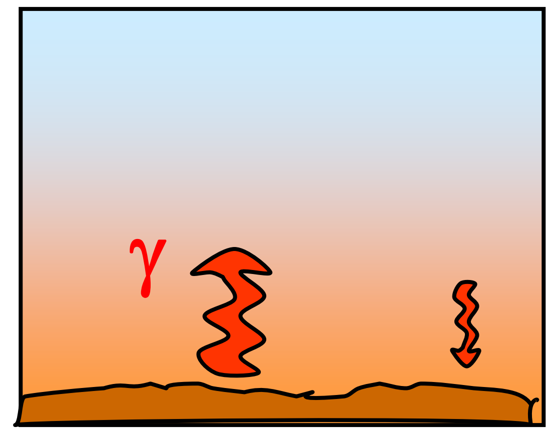
Photons reflected by the planet

VIS-NIR



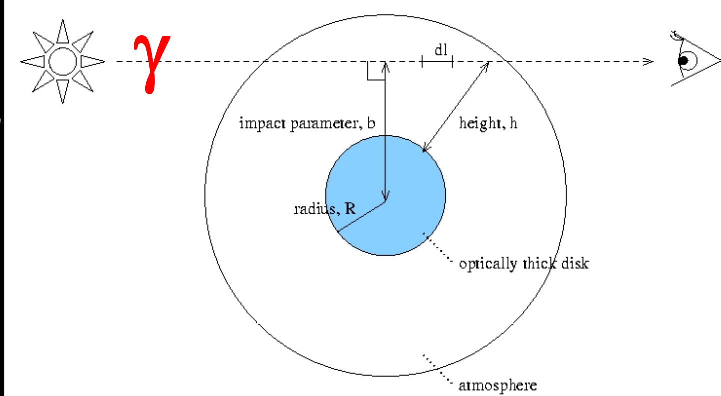
Photons emitted by the planet

MIR



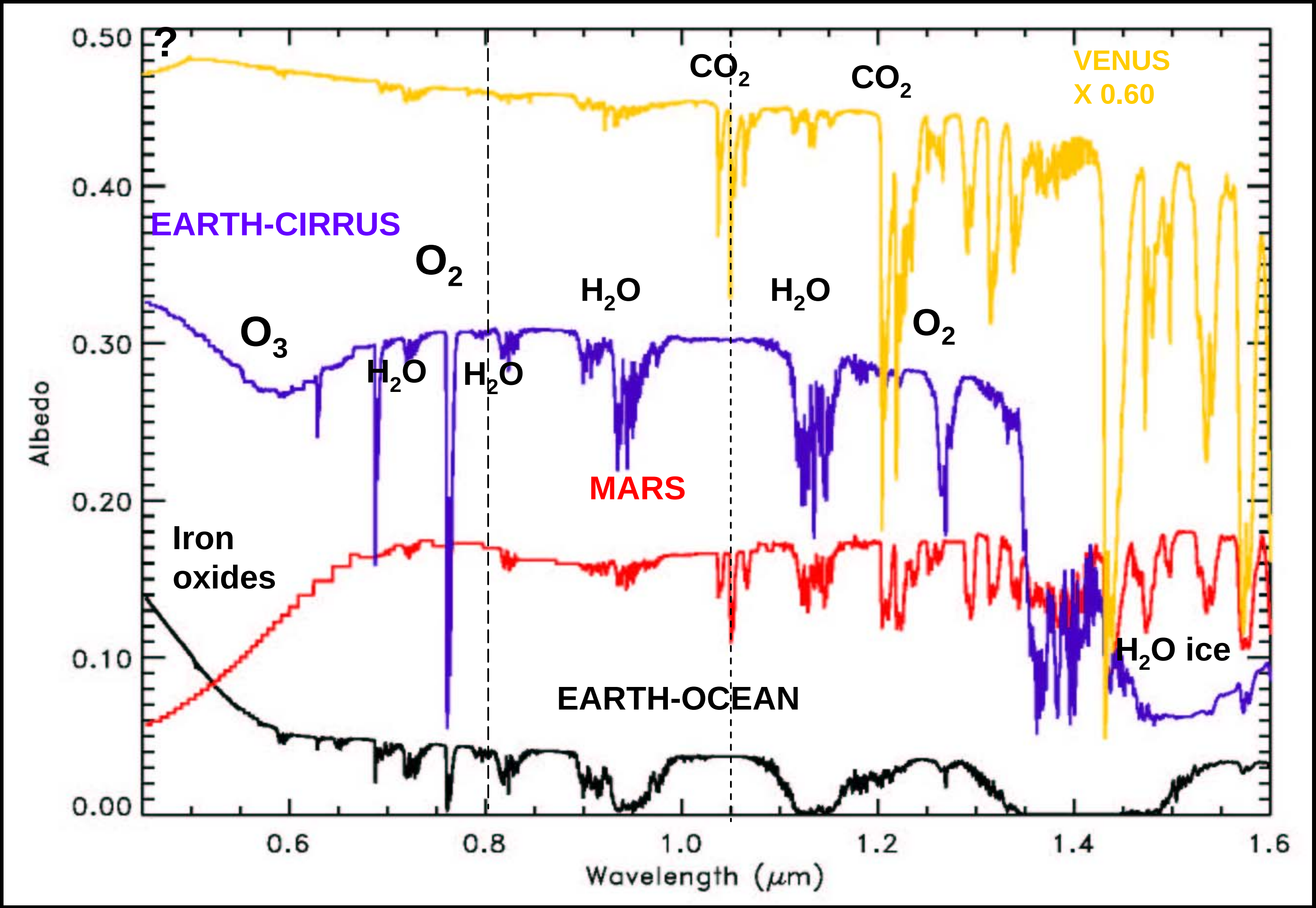
Photons transmitted by the planet

UV-VIS-IR



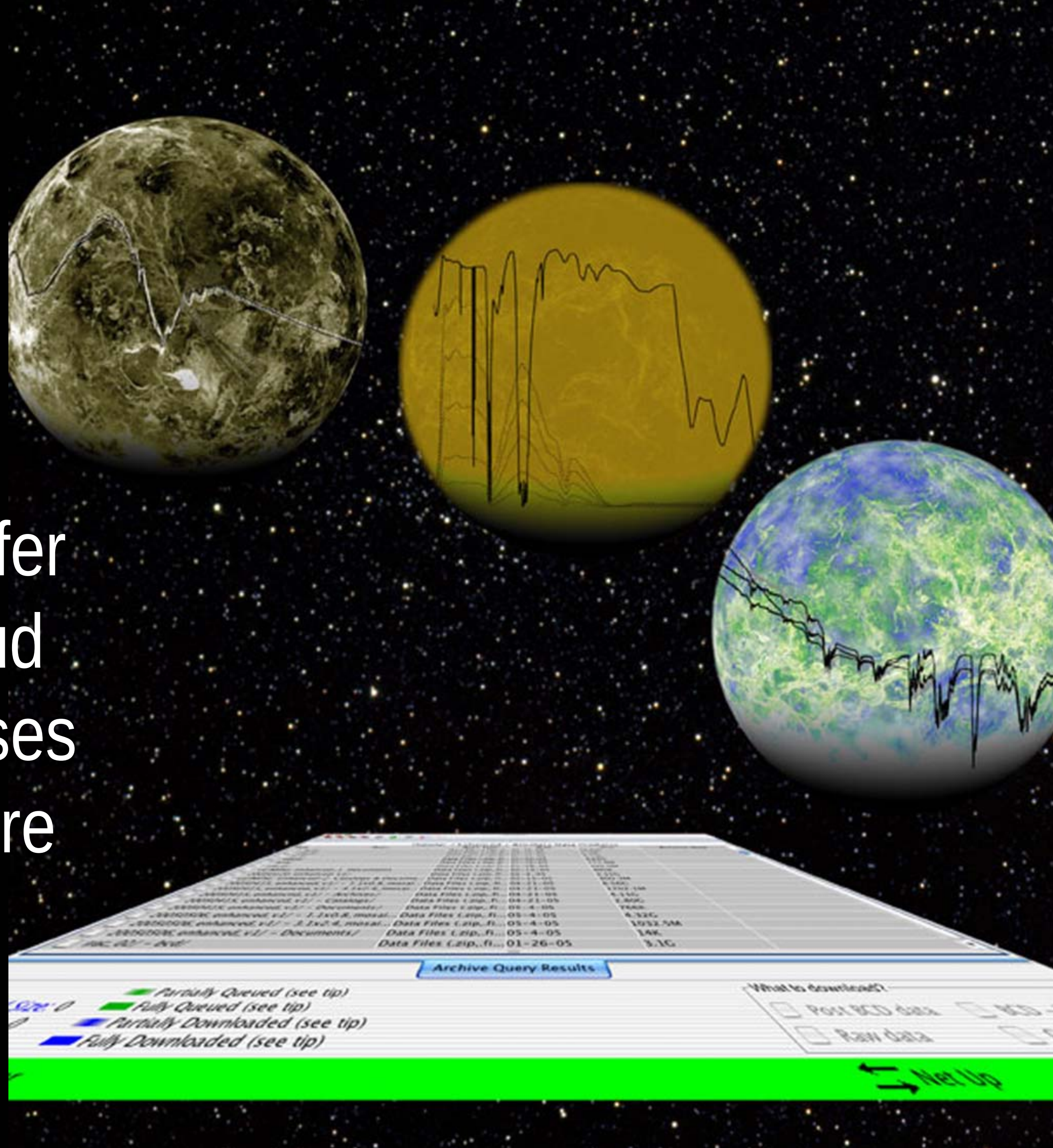
Learning from our solar system

Terrestrial planets in our Solar System offer diverse spectra which aid in their characterization.

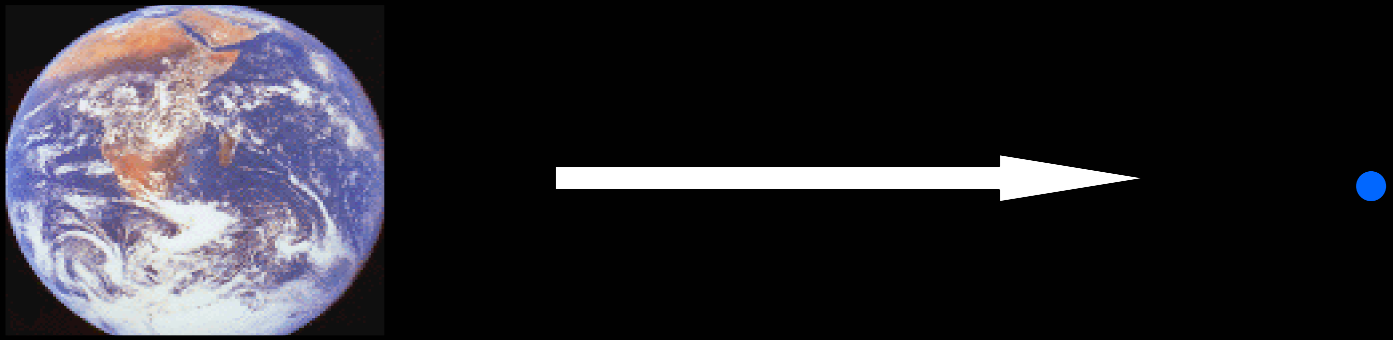


Searching for other Planets in the Galaxy

- Chemistry
- Radiative transfer
- Climate + Cloud
- Escape processes
- Internal structure



Averaging over disk and time

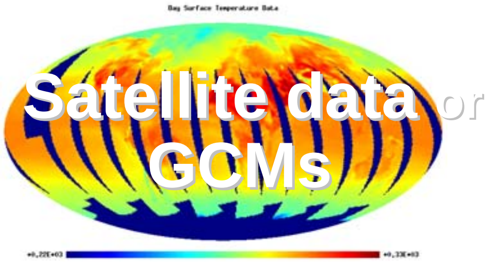


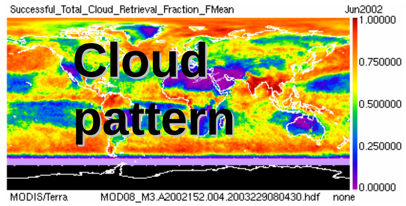
Extrasolar planet characterization missions

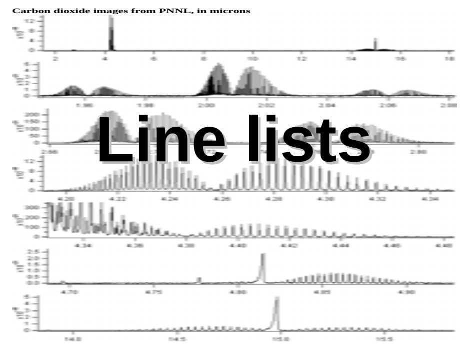
Tinetti et al, Astrobiology 2005, 2006

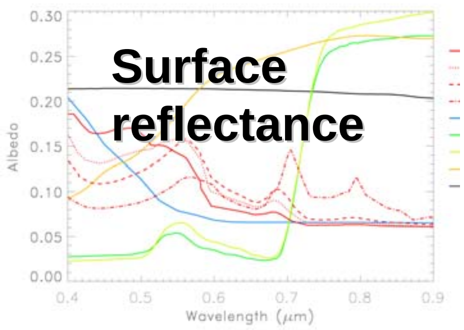
Generating spectra

- Input to the models

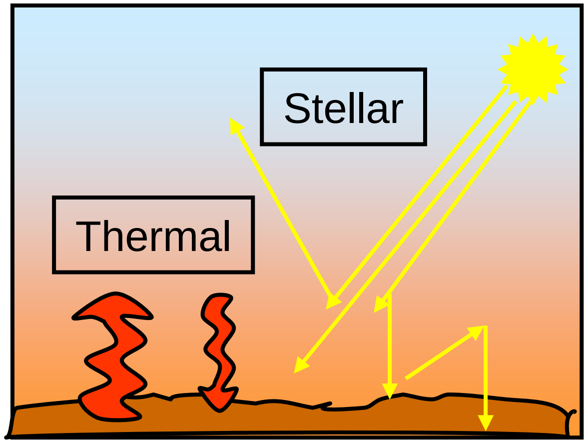


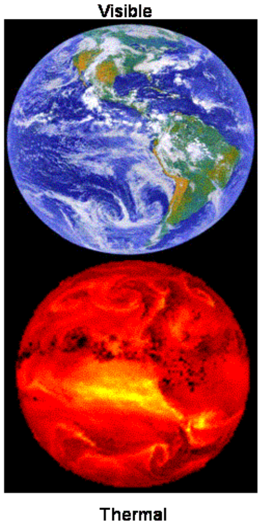


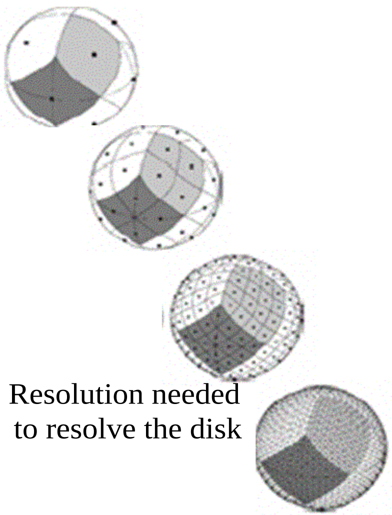




- Run radiative transfer algorithms to describe the complex interaction of the photon with the atmosphere and the surface of the planet

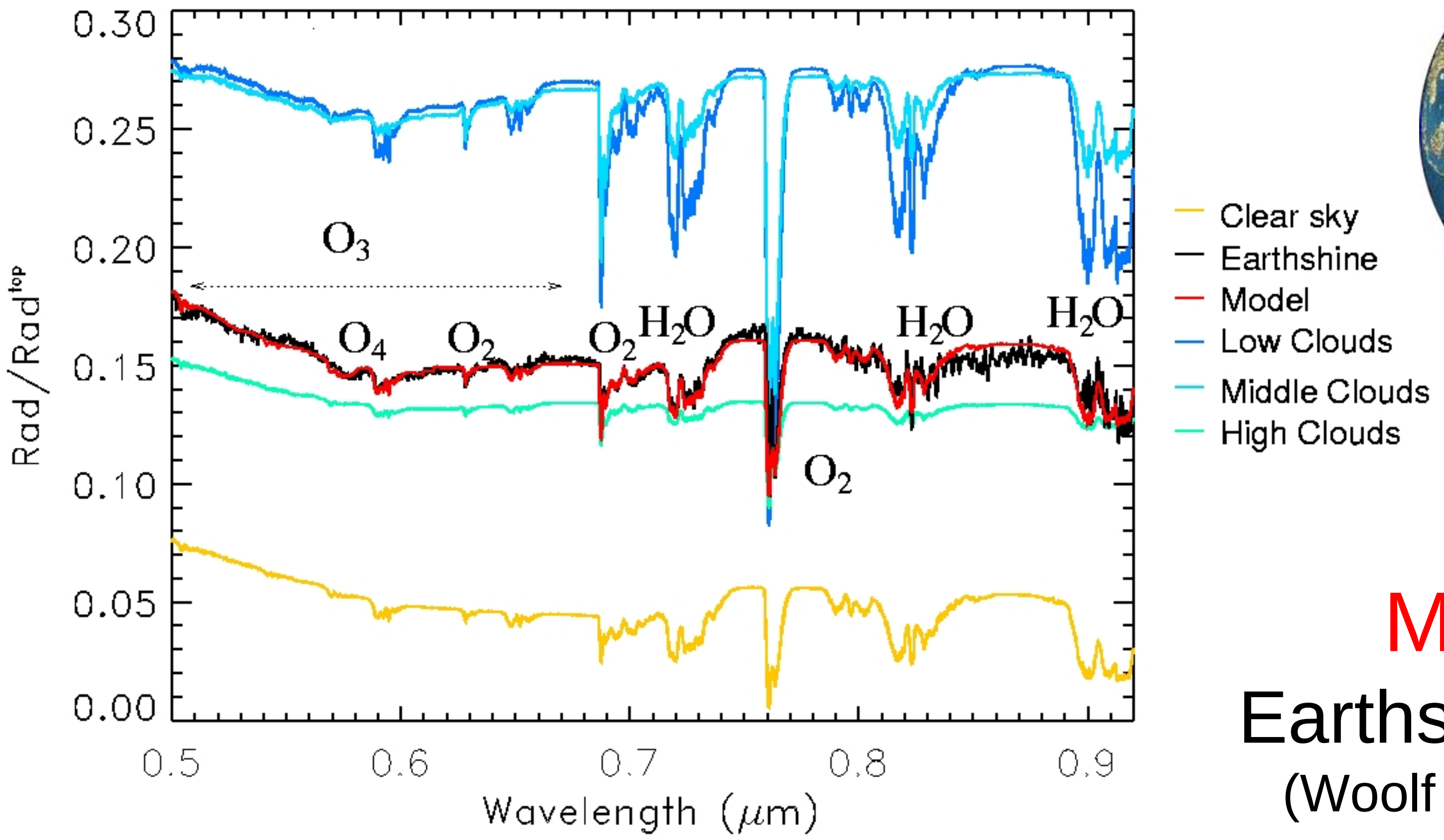






Use specific models to create the Disk-averaged spectra

Disk-averaged Earth spectra: VIS



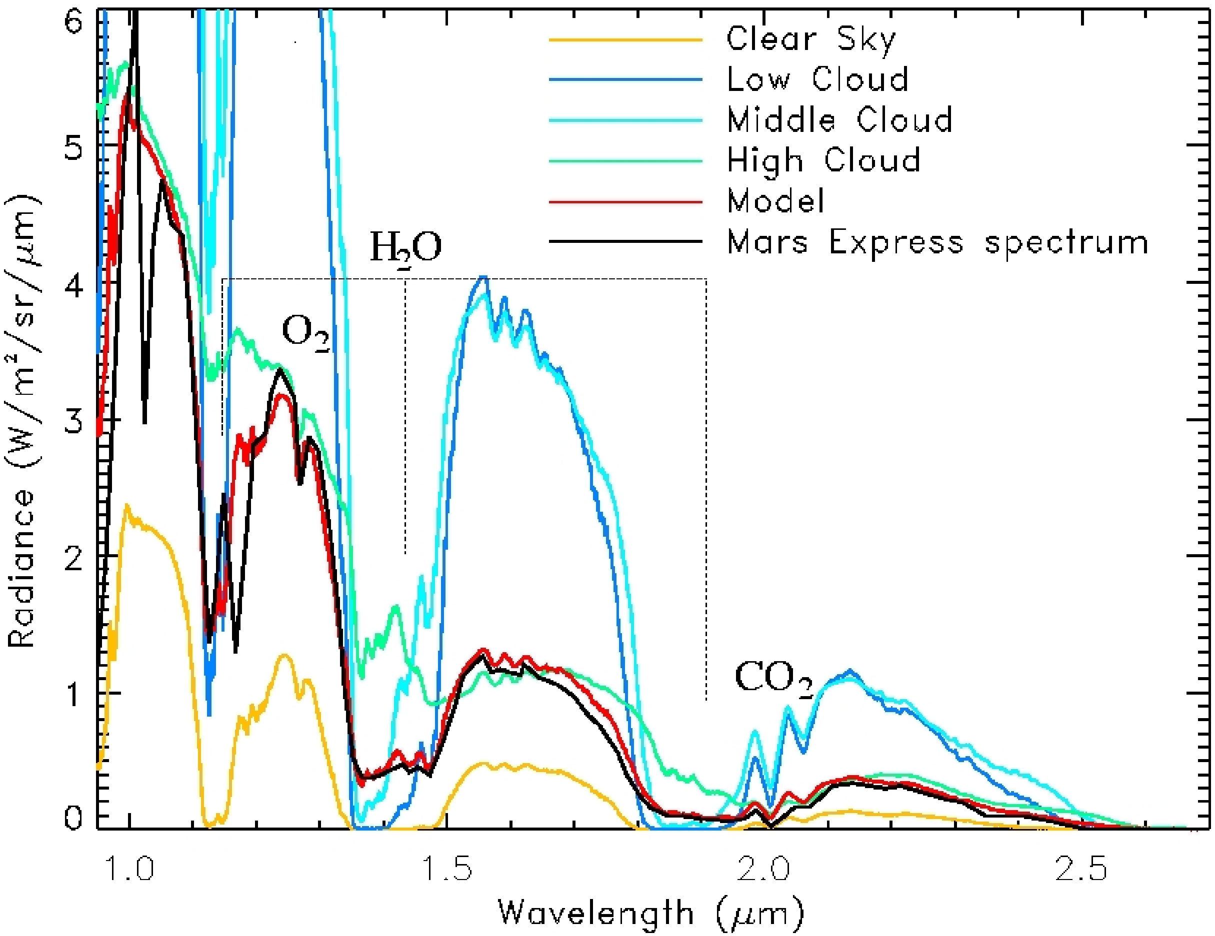
Model

Earthshine data

(Woolf et al. 2002)

Tinetti,et al, 2006

Disk-averaged Earth spectra: NIR

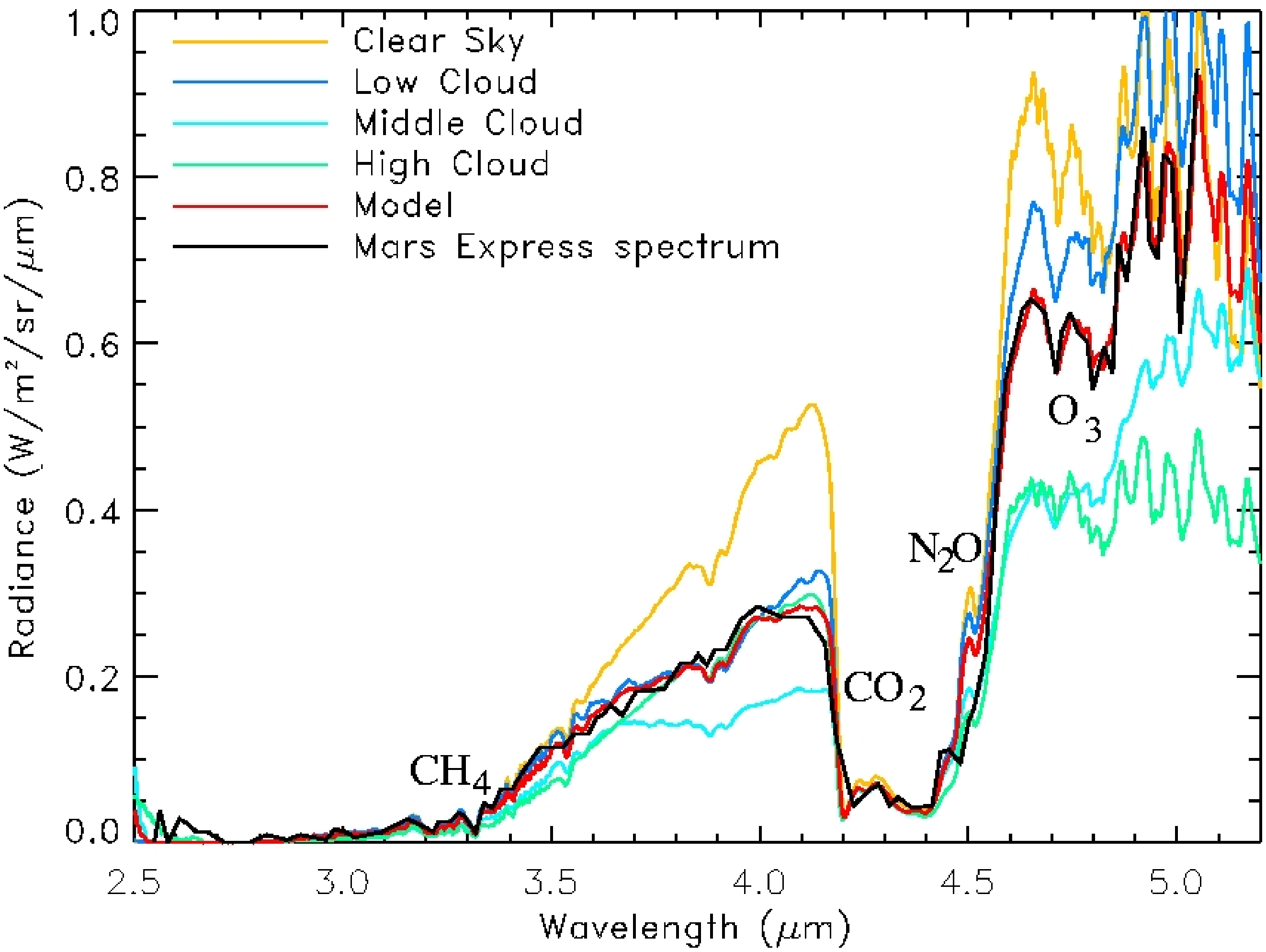


Model

Mars Omega Express data

Tinetti,et al, 2006

Disk-averaged Earth spectra: NIR

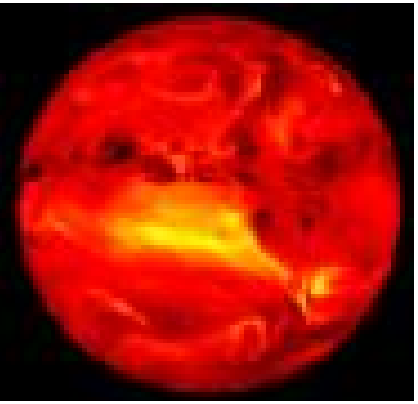


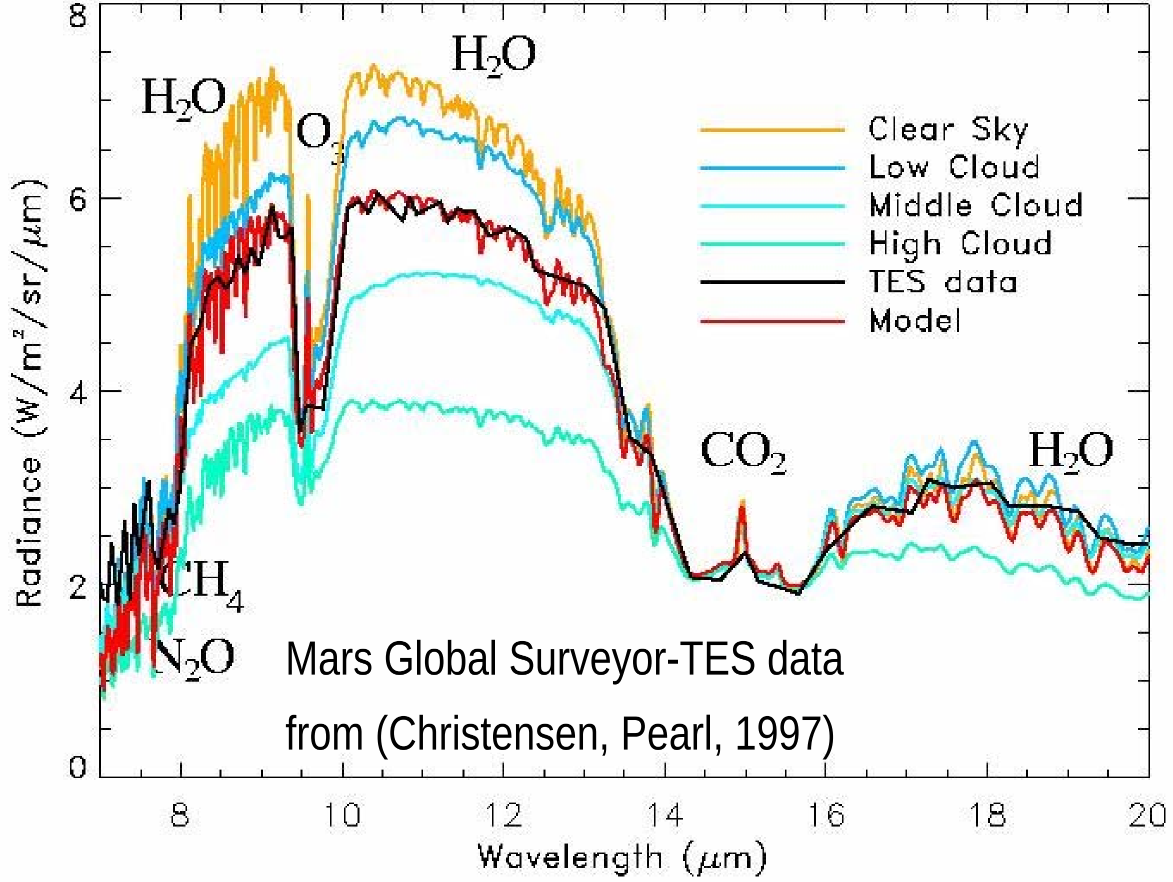
Model

Mars Omega Express data

Tinetti,et al, Astrobiology, 2006

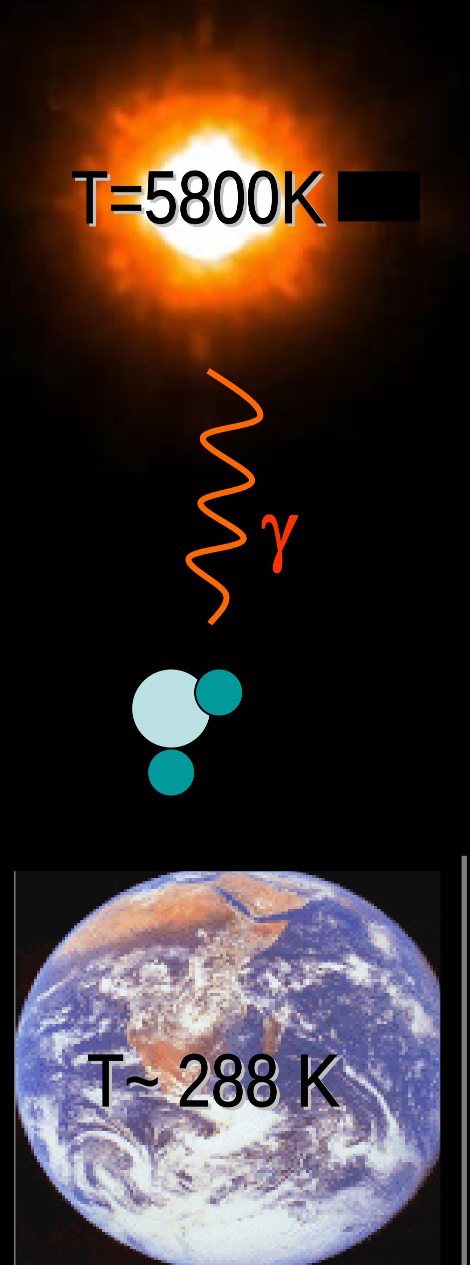
Disk-averaged Earth spectra: IR

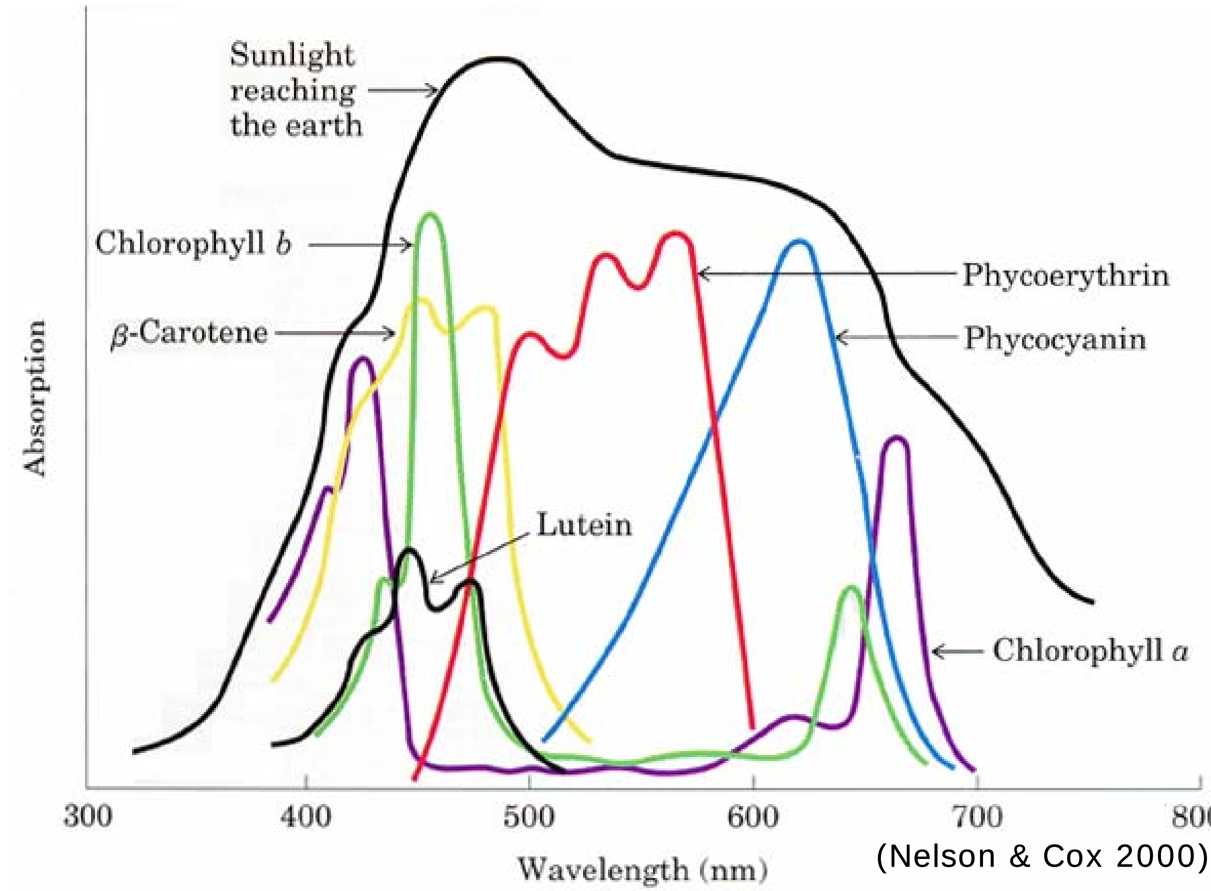




Tinetti,et al, Astrobiology, 2006, vol. 6, n. 1

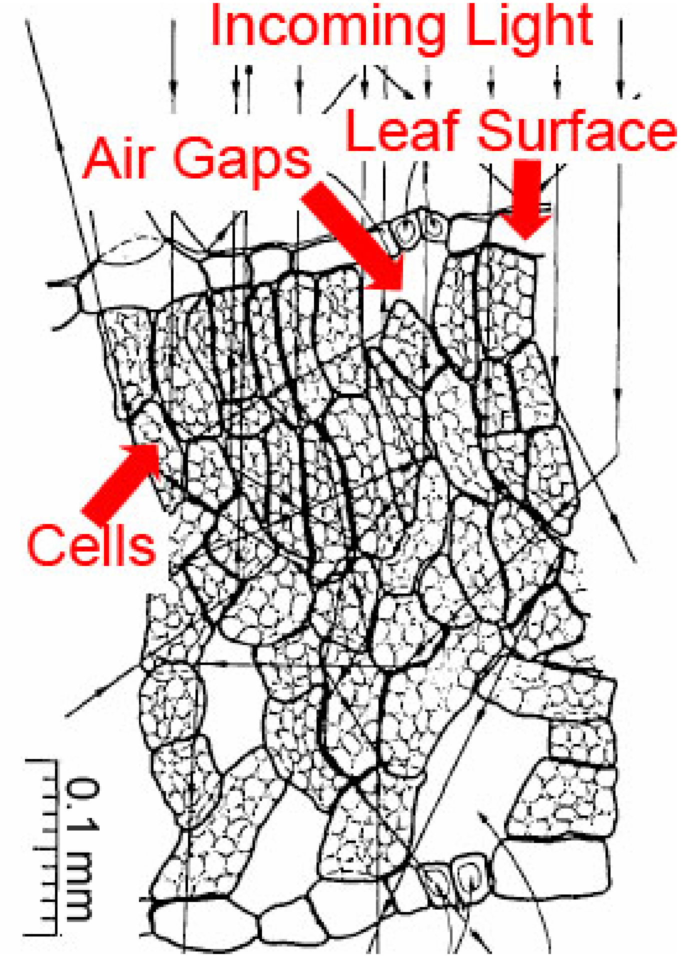
Clever vegetation!



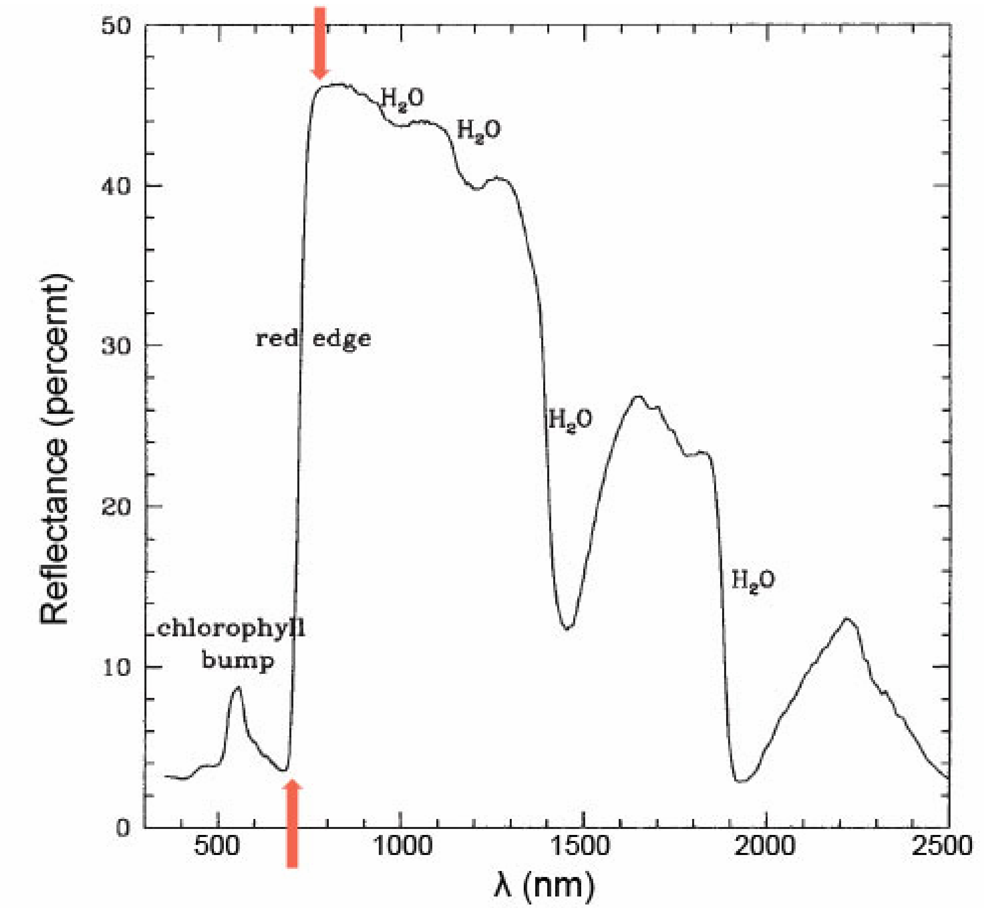


(Nelson & Cox 2000)

The Red-edge:a naturally Amplified Signal



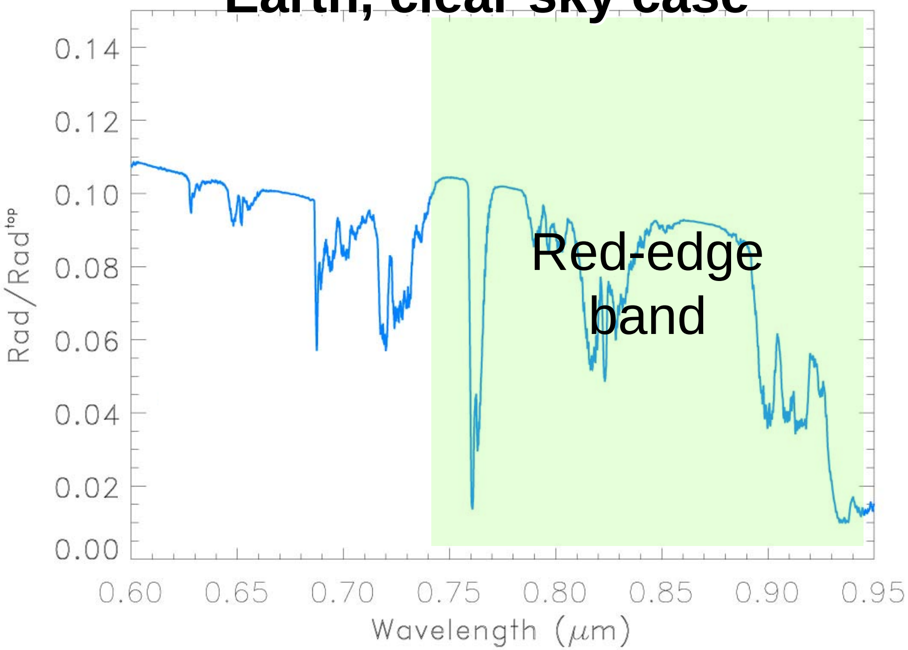
(Gates 1965, adapted)



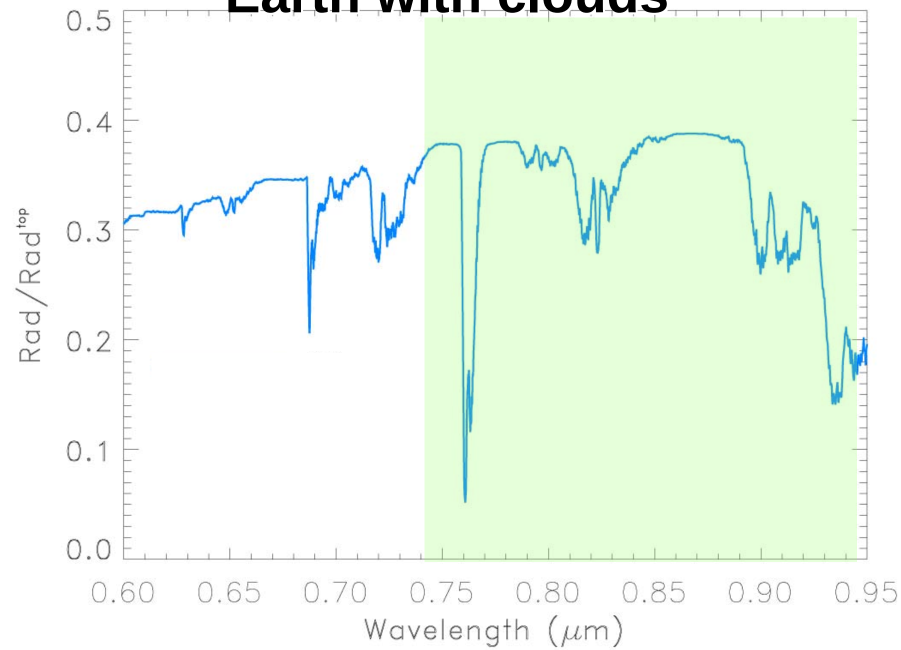
Arnold et al, 2002; Seager et al., 2005; Montanes-Rodriguez et al., 2005

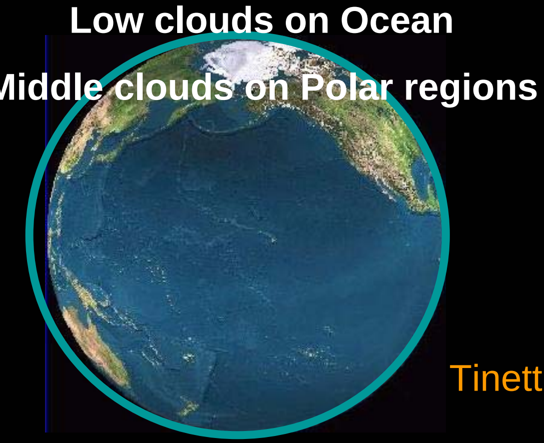
Vegetation in the diurnal cycle

Earth, clear sky case



Earth with clouds

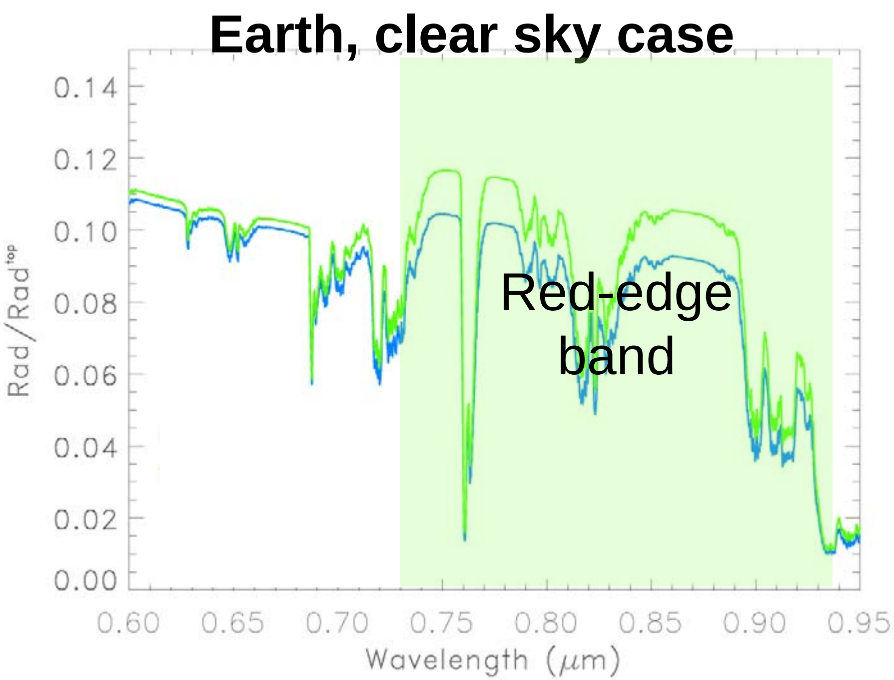


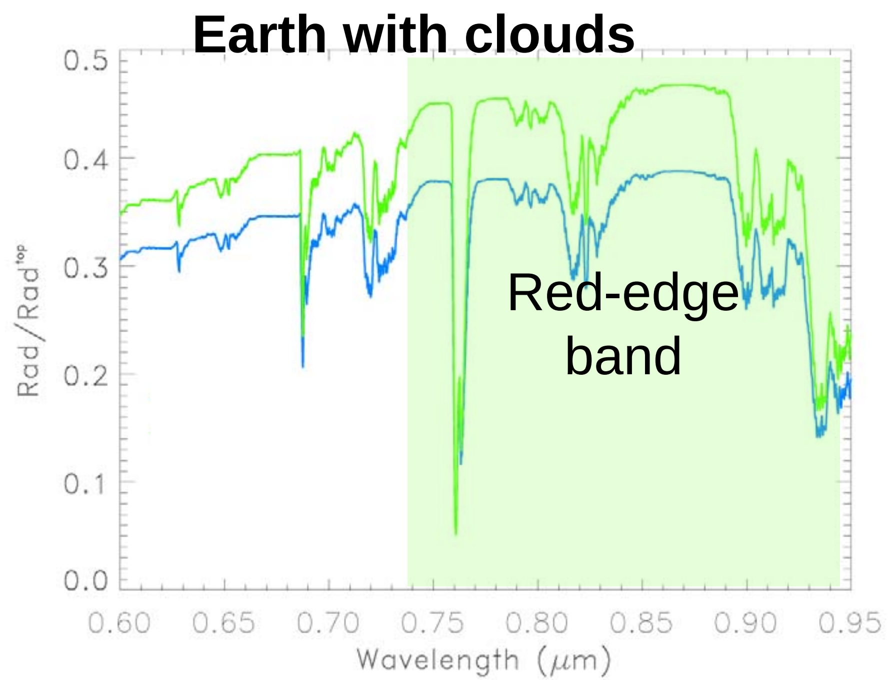


Earth disk-averaged spectra, detectability of surface biosignatures for TPF-C

Tinetti et al. 2006, Astrobiology

Vegetation in the diurnal cycle



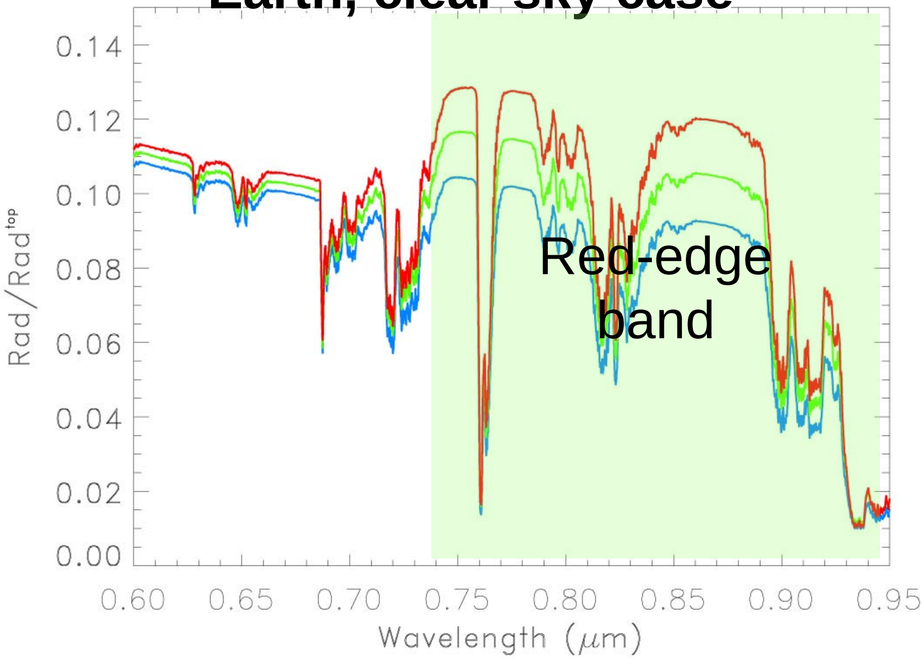


High clouds central America

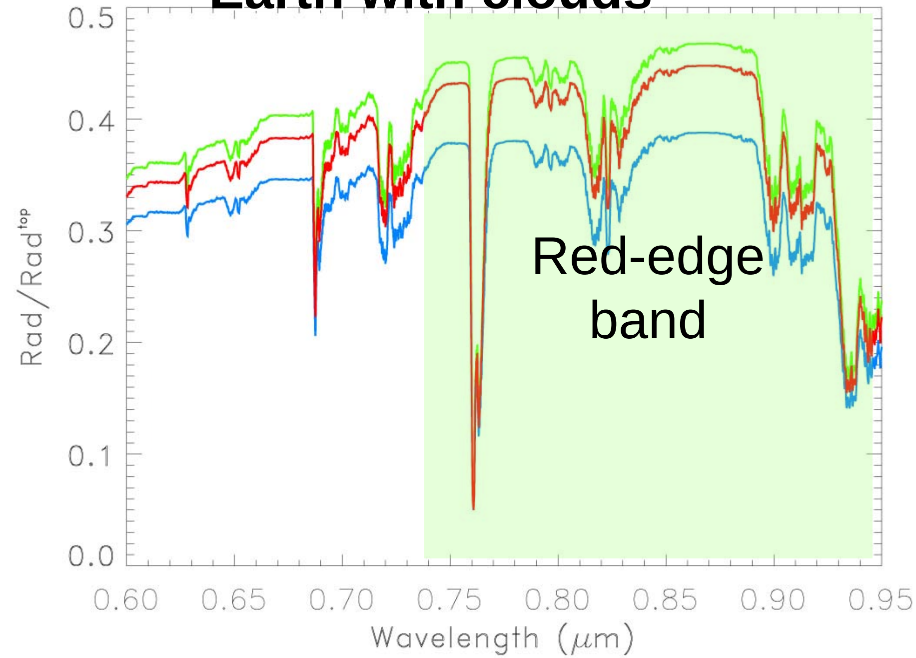
-Low clouds and middle clouds can be false positive for Red-Edge in some phases

Vegetation in the diurnal cycle

Earth, clear sky case



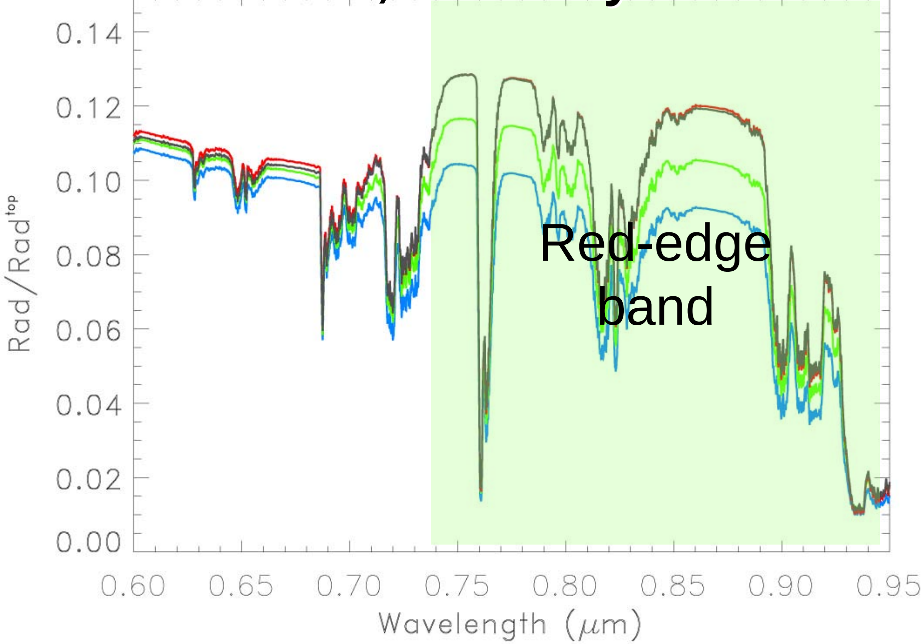
Earth with clouds



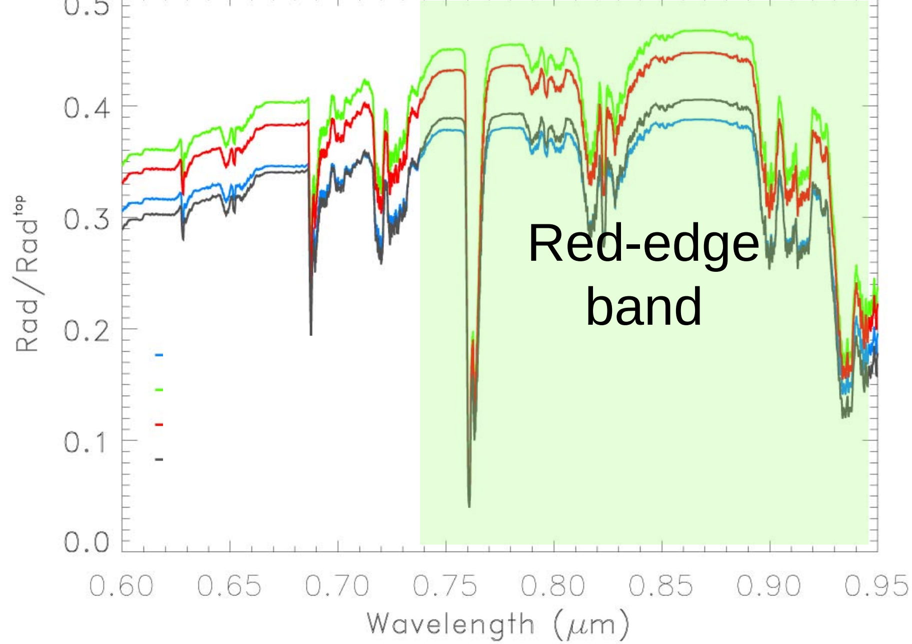
High clouds central Africa & Asia

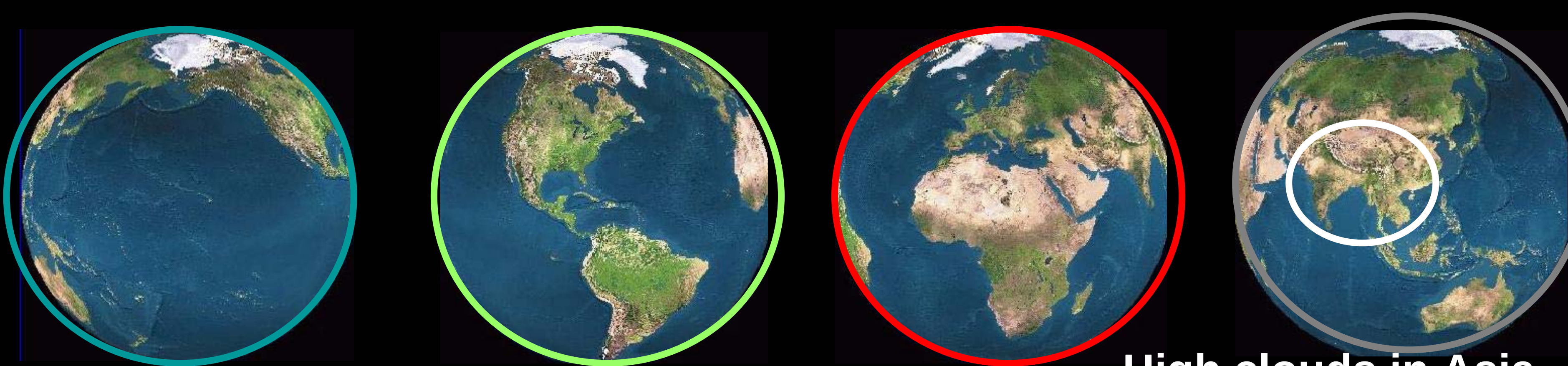
Vegetation in the diurnal cycle

Earth, clear sky case



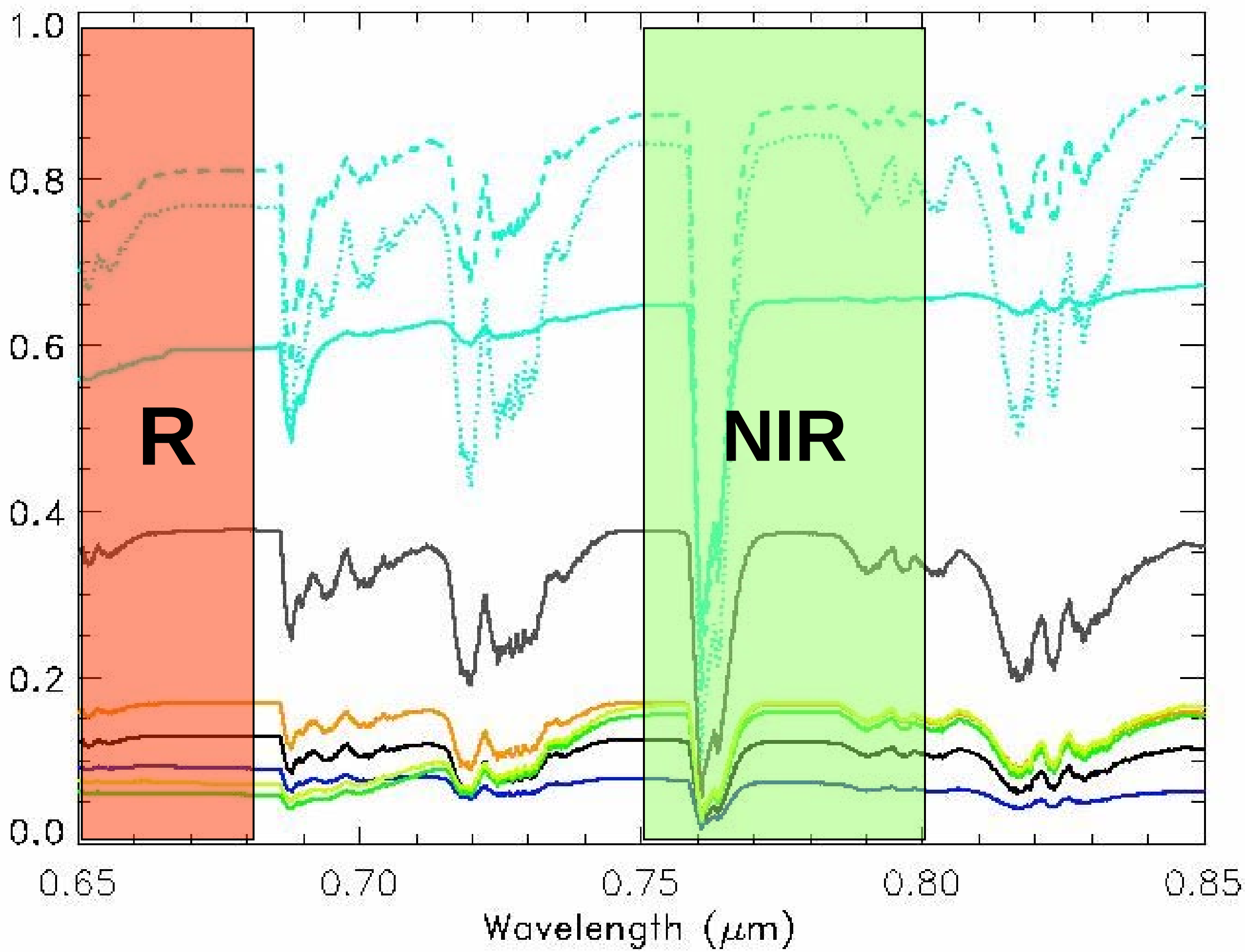
Earth with clouds





High clouds in Asia

Disk-averaged spectra with only one surface type



Ocean NDVI=

Grass

Forest

Tundra

Desert

Ice

Cirrus cloud

Cumulus cloud

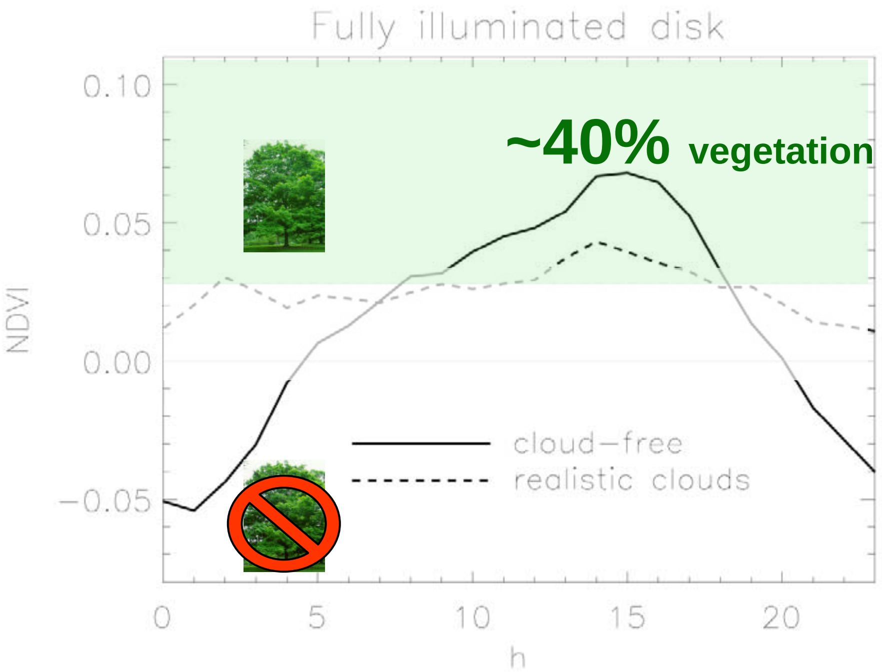
Stratus cloud

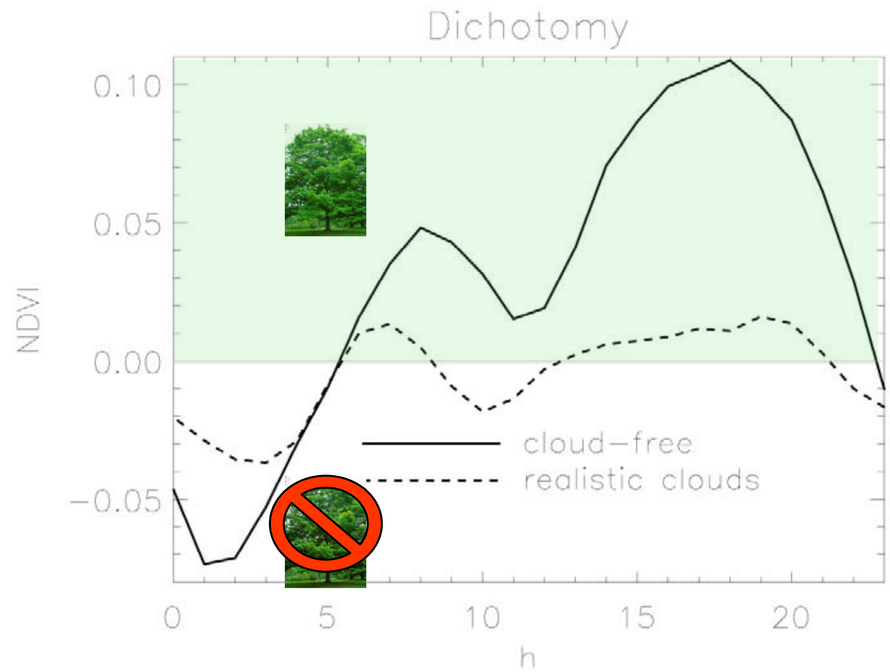
NDVI = (NIR – R) / (NIR + R)

Vegetation versus cloud

For all phases, NDVI is a useful index to discriminate vegetated areas.

Problems with fully illuminated (unobservable!) when clouds are present.



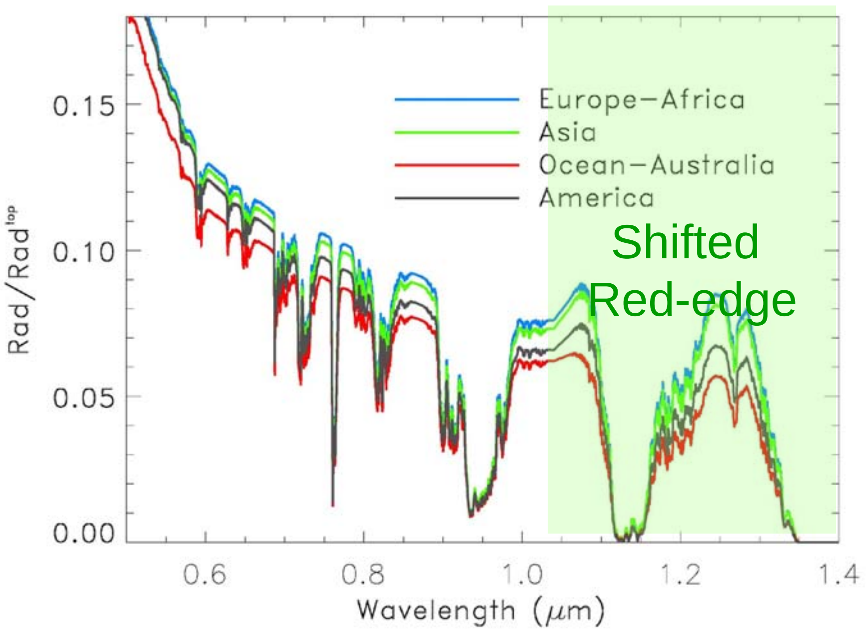


Caveat: On an extrasolar terrestrial planet the red-edge might be red-shifted,

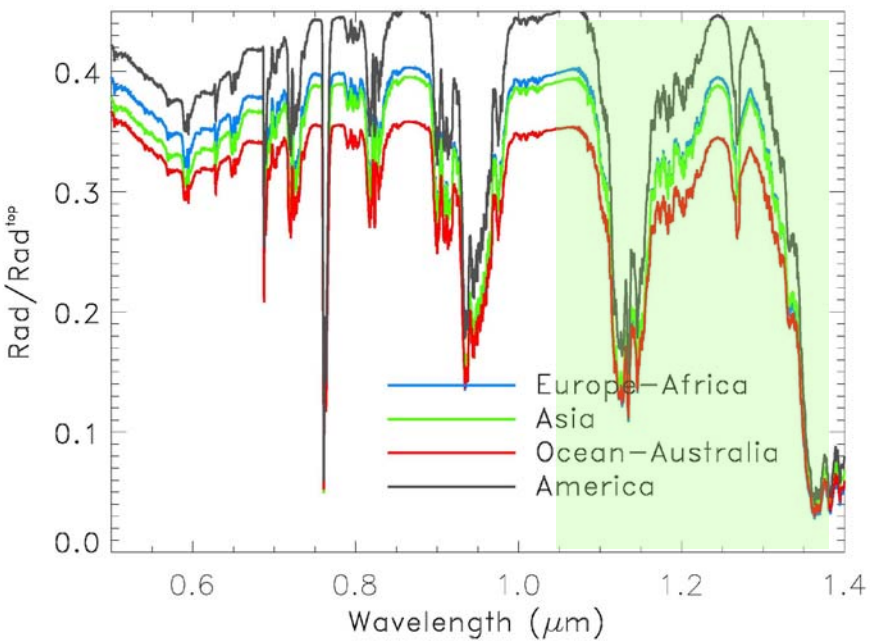
The cloud microphysics/scattering properties might be different

Red-edge shifted

Clear sky

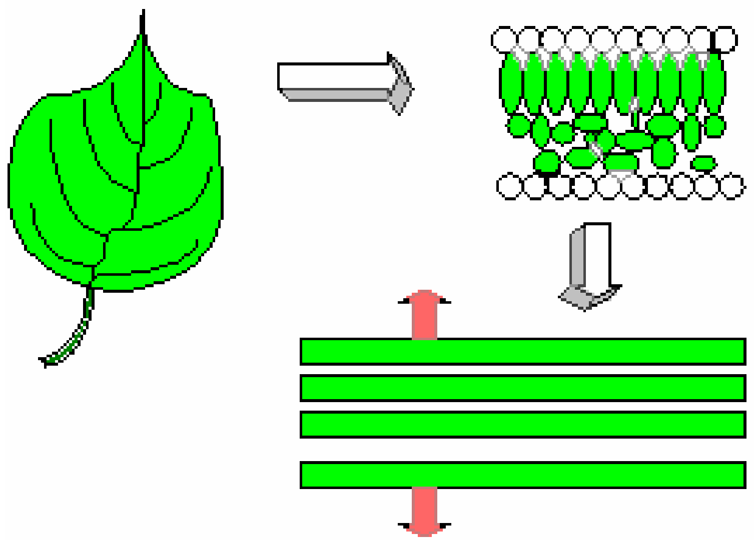


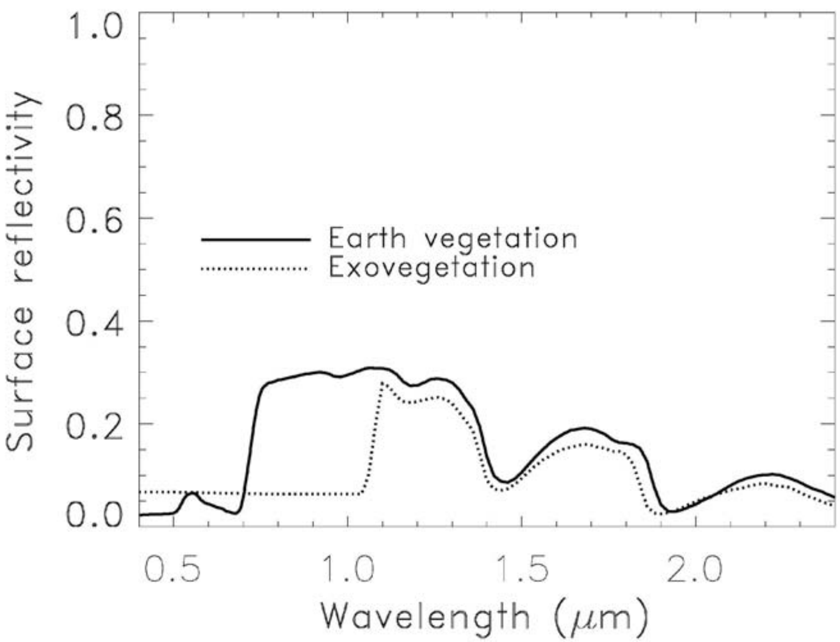
Realistic cloud pattern



G. Tinetti, S. Rashby, Y. Yung,2006,Apj

Leaf model & shifted Red-edge

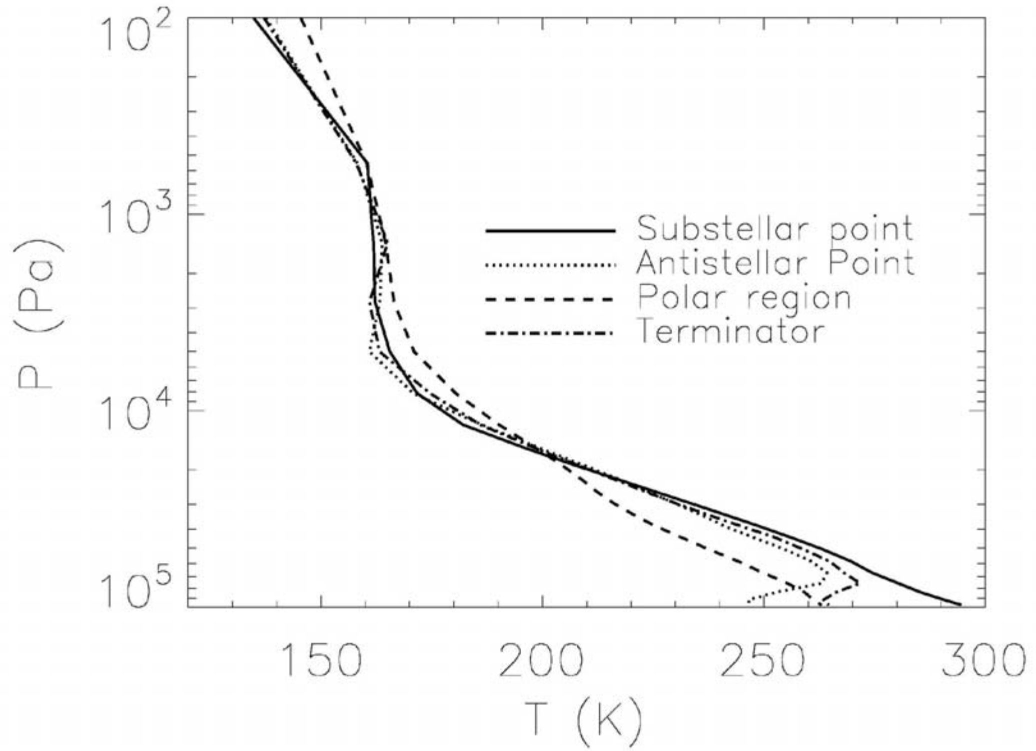




- 3-photon photosynthetic scheme (Wolstencroft and Raven, 2002)
- Optical model of plant leaves (Jacquemoud & Baret 1990)
- Modified pigment absorption properties
- Output: whole leaf spectrum shifted to longer wavelengths

Planetary model

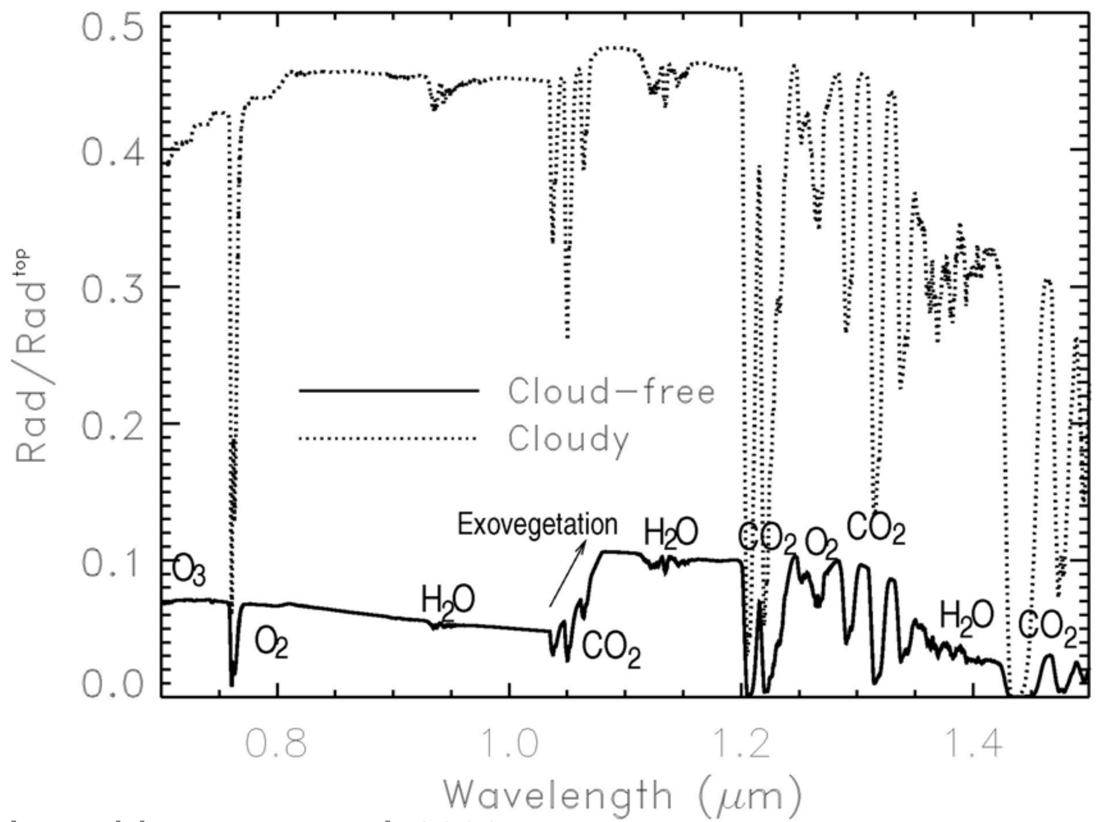
- Planet tidally locked
- 80% CO2
- 22% Low Clouds+
- 25% Middle Clouds+
- 25% High Clouds
- GCM T-P profile (Joshi 2003)



Tinetti, Rashby, Yung, *Apj, 2006*

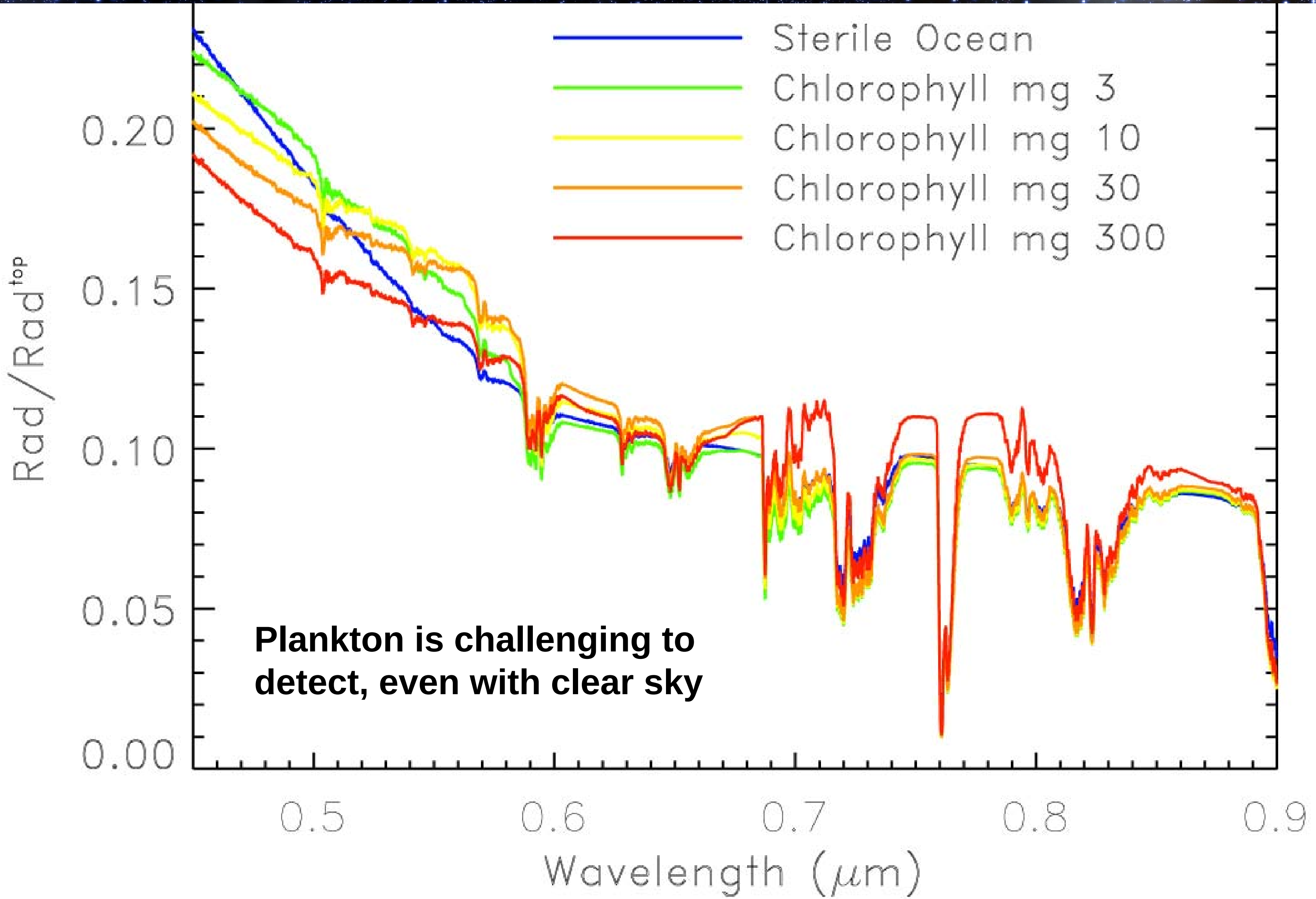
Simulated spectrum

- Exovegetation on the illuminated side



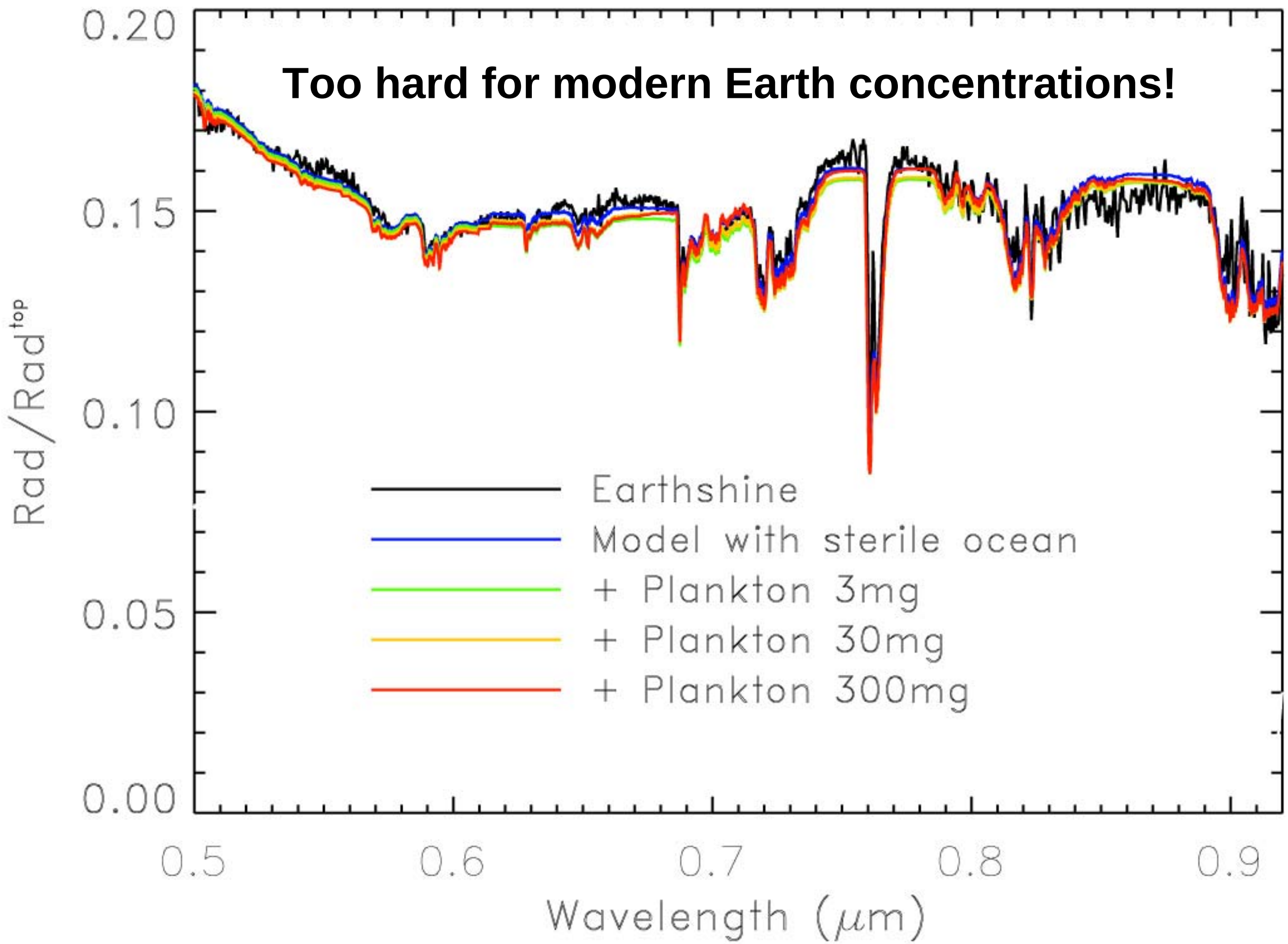
Tinetti, Rashby, Yung, *Apj, 2006*

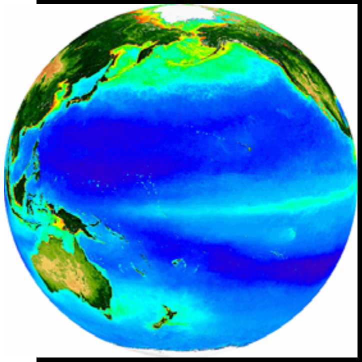
Plankton?



Plankton is challenging to detect, even with clear sky

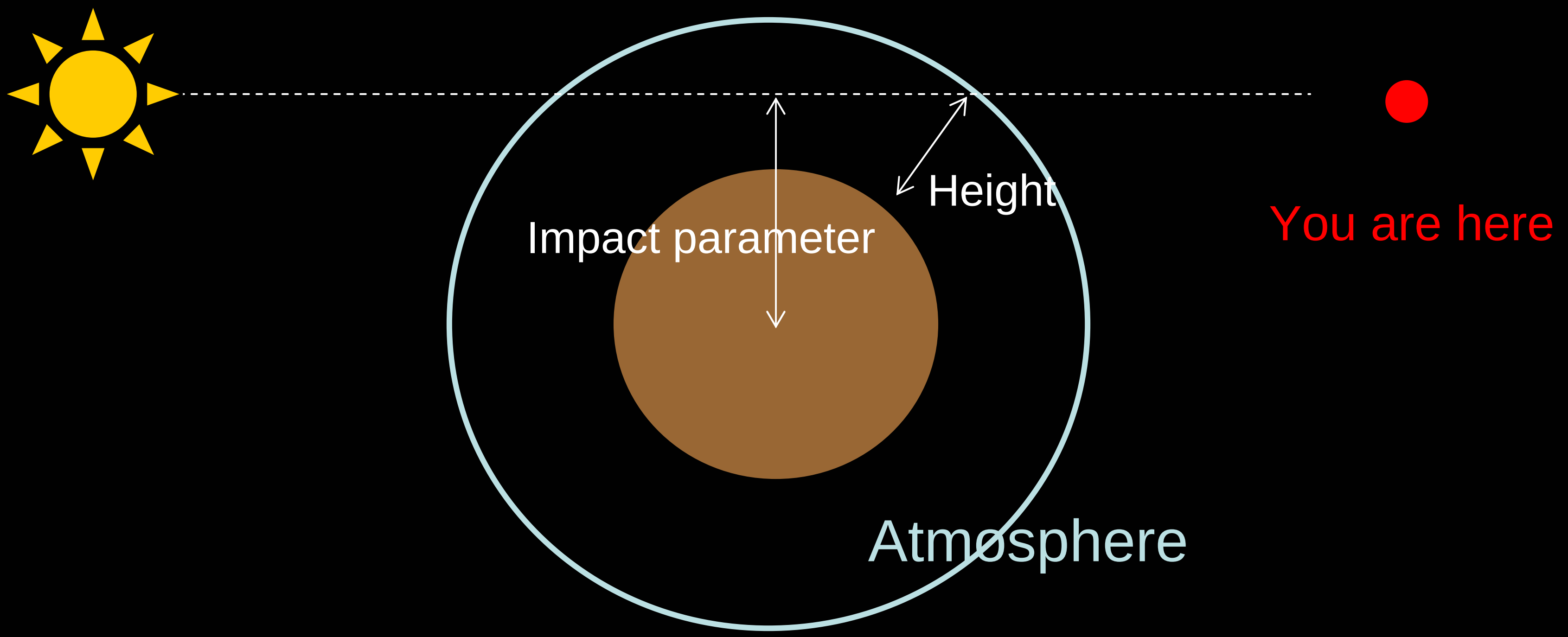
Plankton with clouds



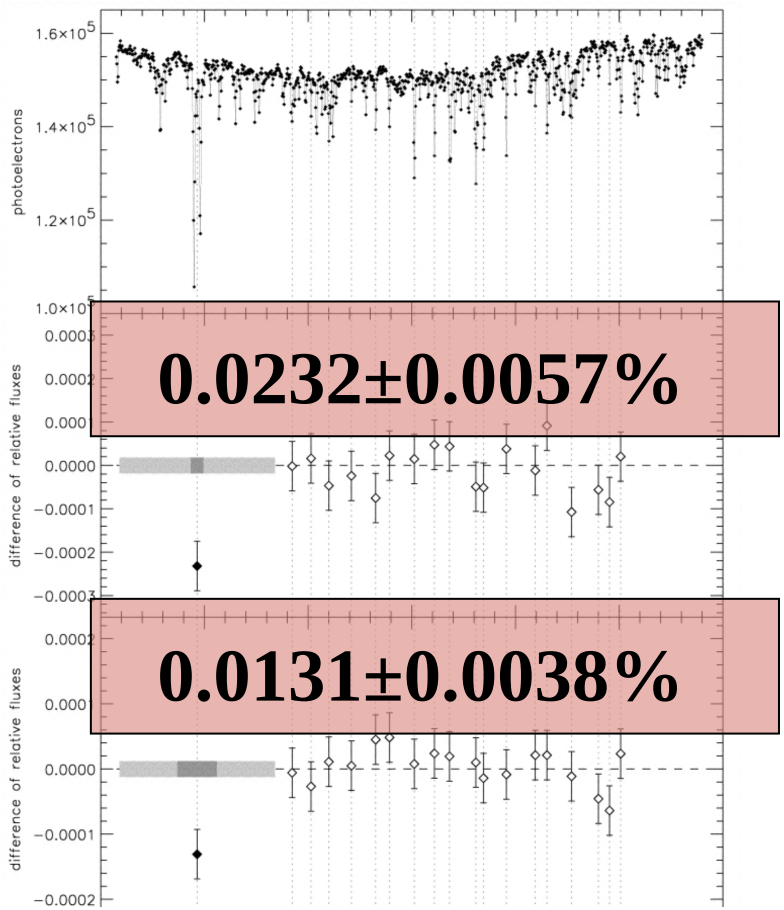


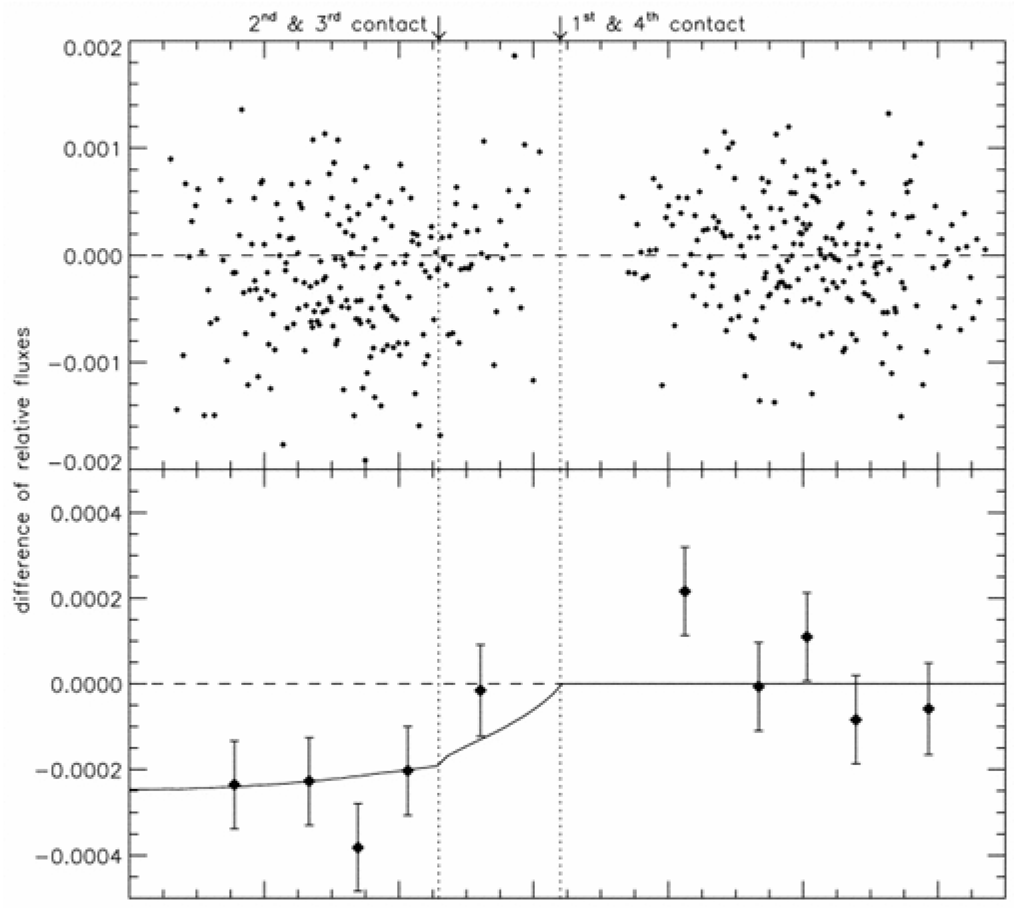
Tinetti et al., *2006, Astrobiology*

Stellar occultation



HD 209458: the atmosphere
(Charbonneau et al. 2002)



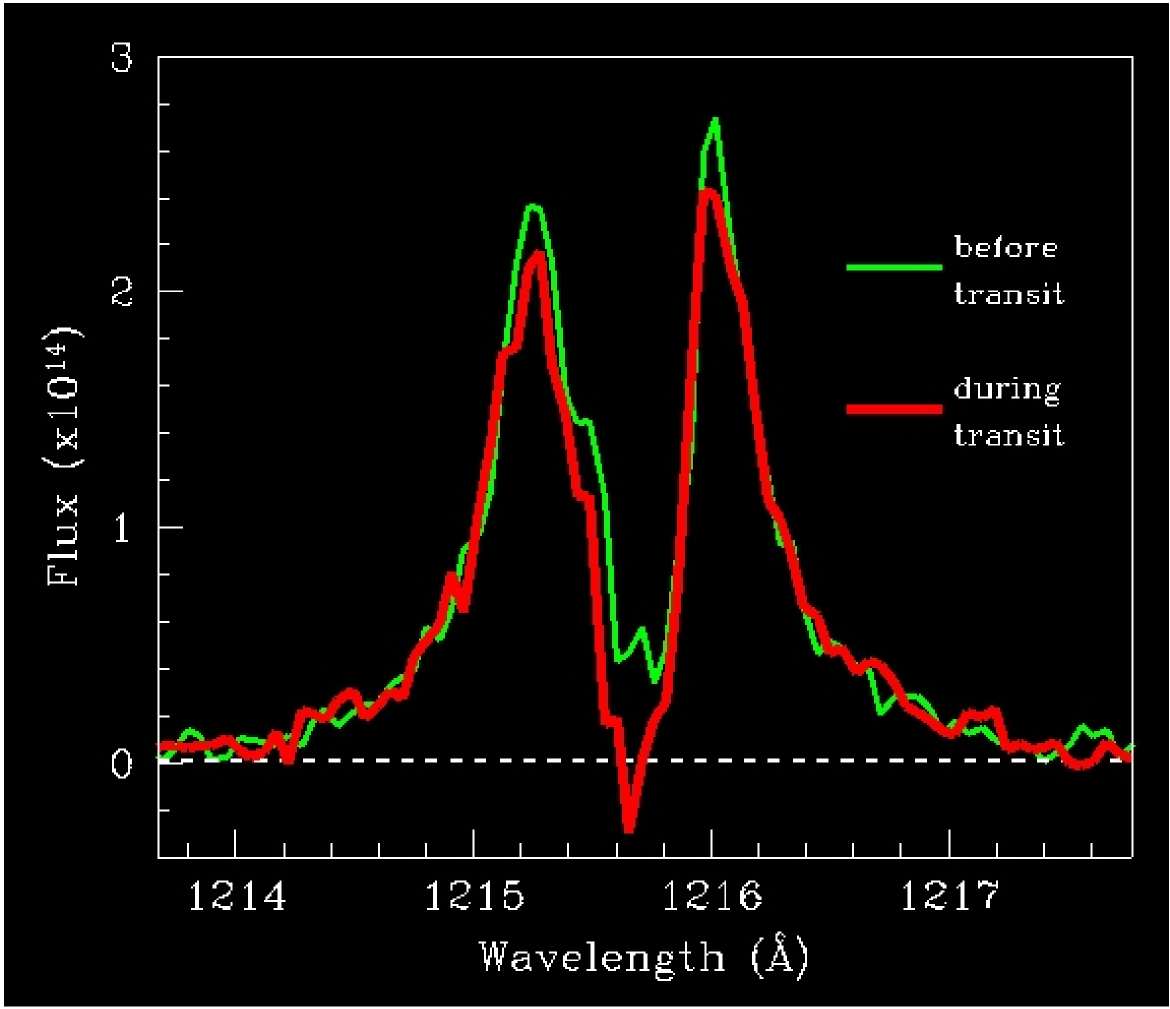


Explanations: clouds and ionisation (Brown, 2001; Fortney et al. 2003) or condensation Na to Na_2S on the dark side (Iro et al. 2005, Tinetti et al. 2006)

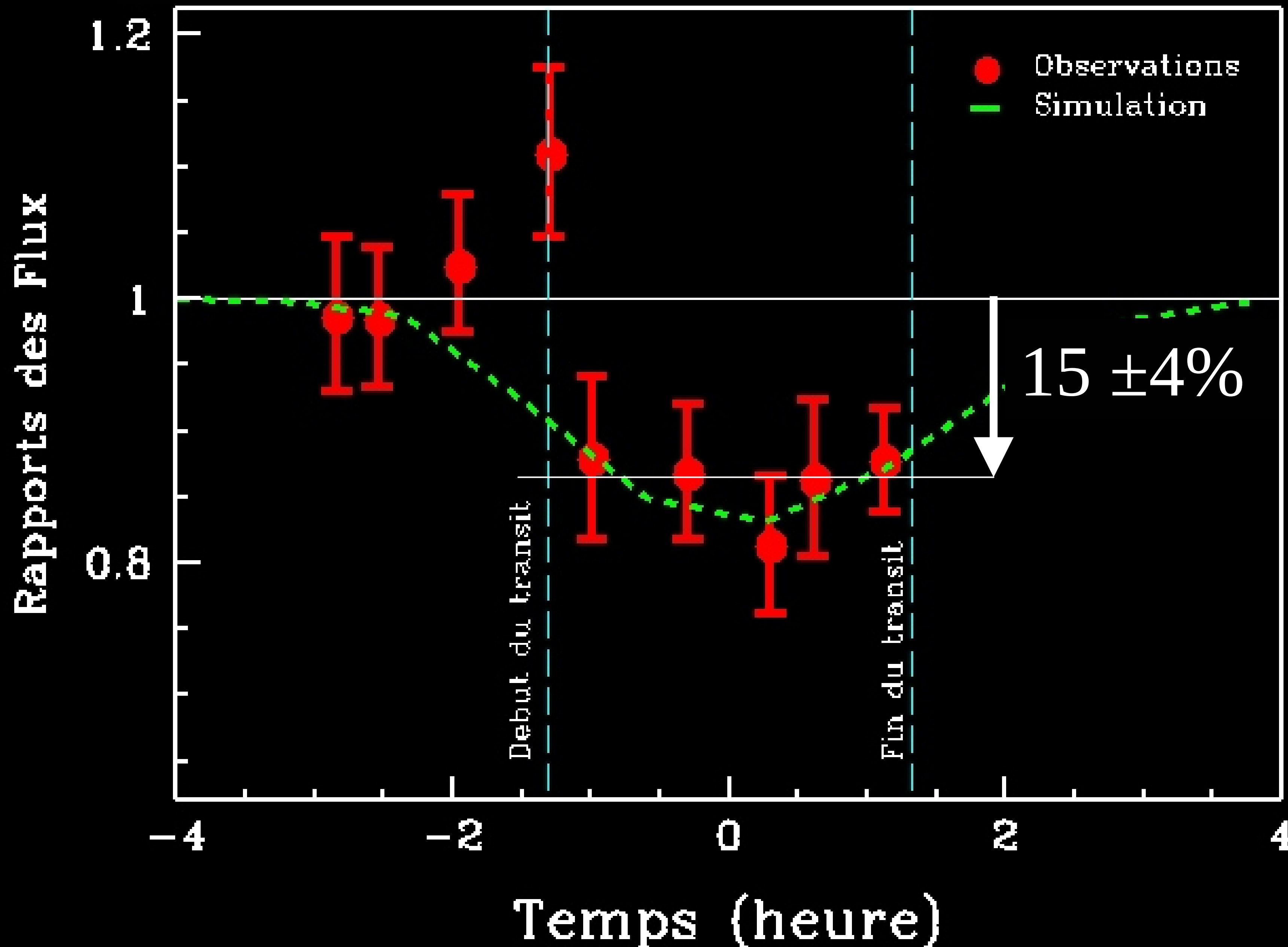
An extended upper atmosphere around the extrasolar planet HD209458b

A. Vidal-Madjar (IAP)
A. Lecavelier des Étangs (IAP)
J.-M. Désert (IAP)
G. E. Ballester (Univ. Arizona)
R. Ferlet (IAP)
G. Hébrard (IAP)
M. Mayor (Obs. Genève)

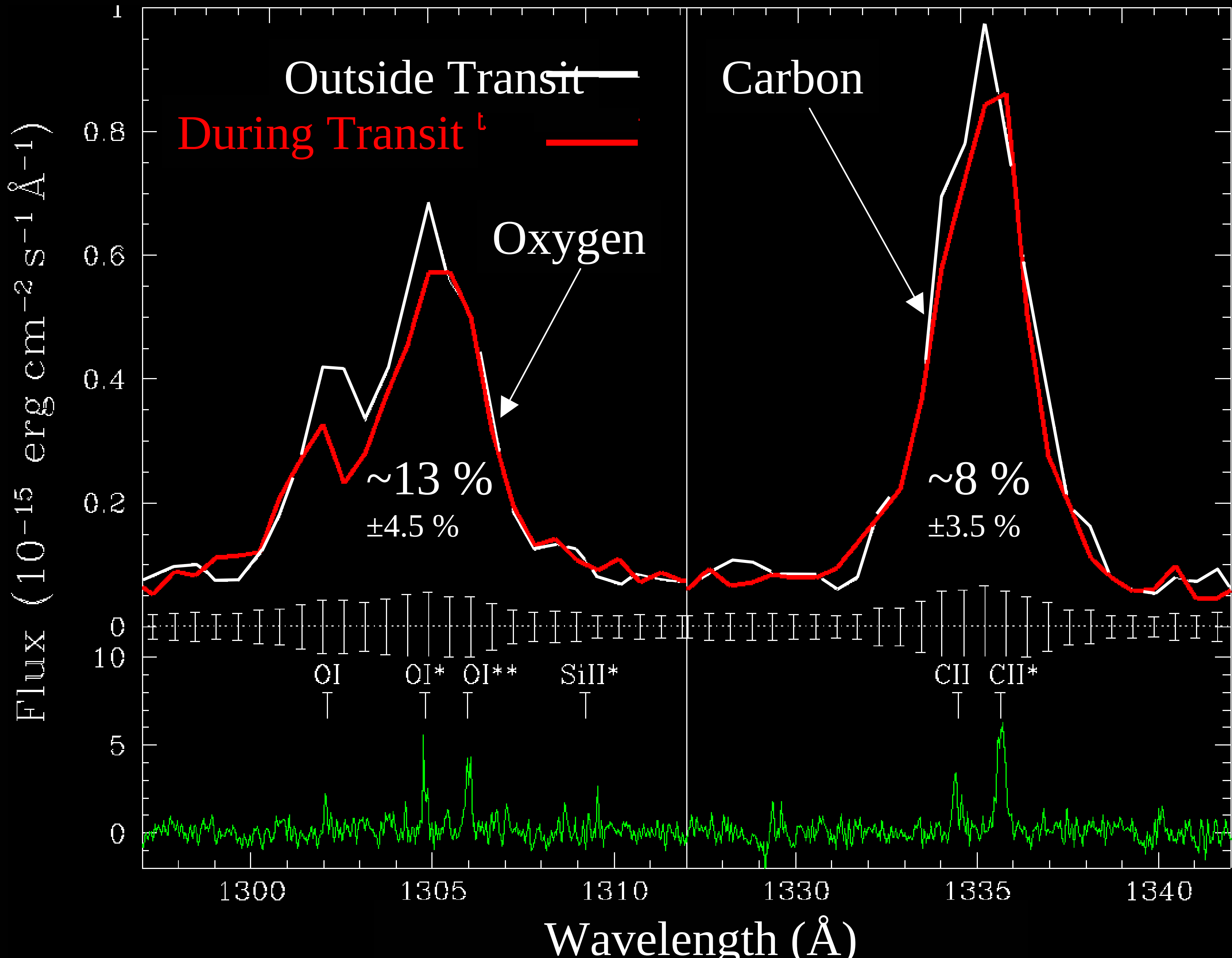
Nature 422, 143, 2003

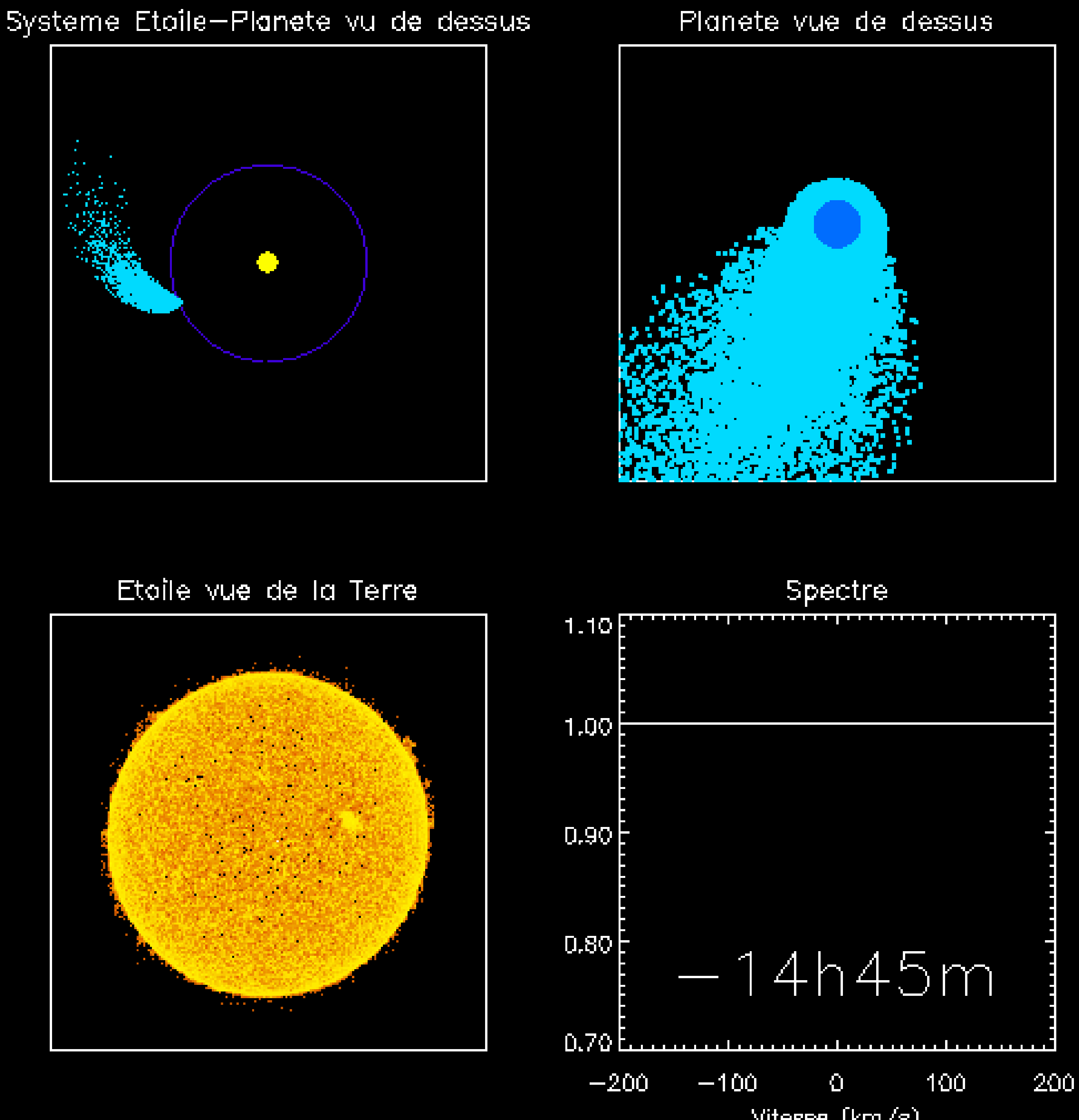


Evaporation rate > 10^{10} g/s

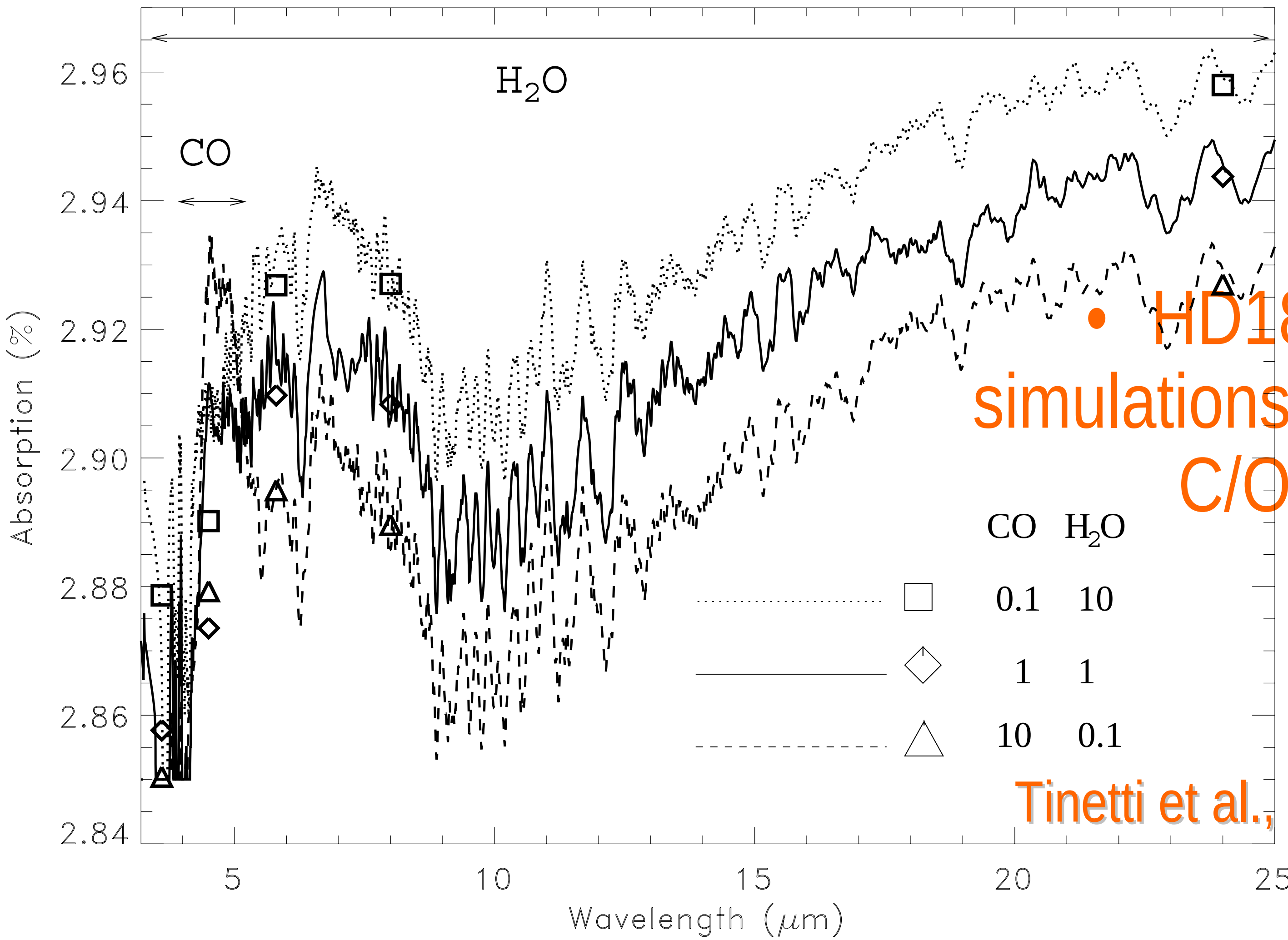


Detection of Carbon & Oxygen




Systeme Etoile−Planete vu de dessus
Planete vue de dessus
Etoile vue de la Terre
Spectre
1.10
1.00
0.90
0.80
0.70
−14h45m
−200
−100
0
100
200
Vitesse (km/s)

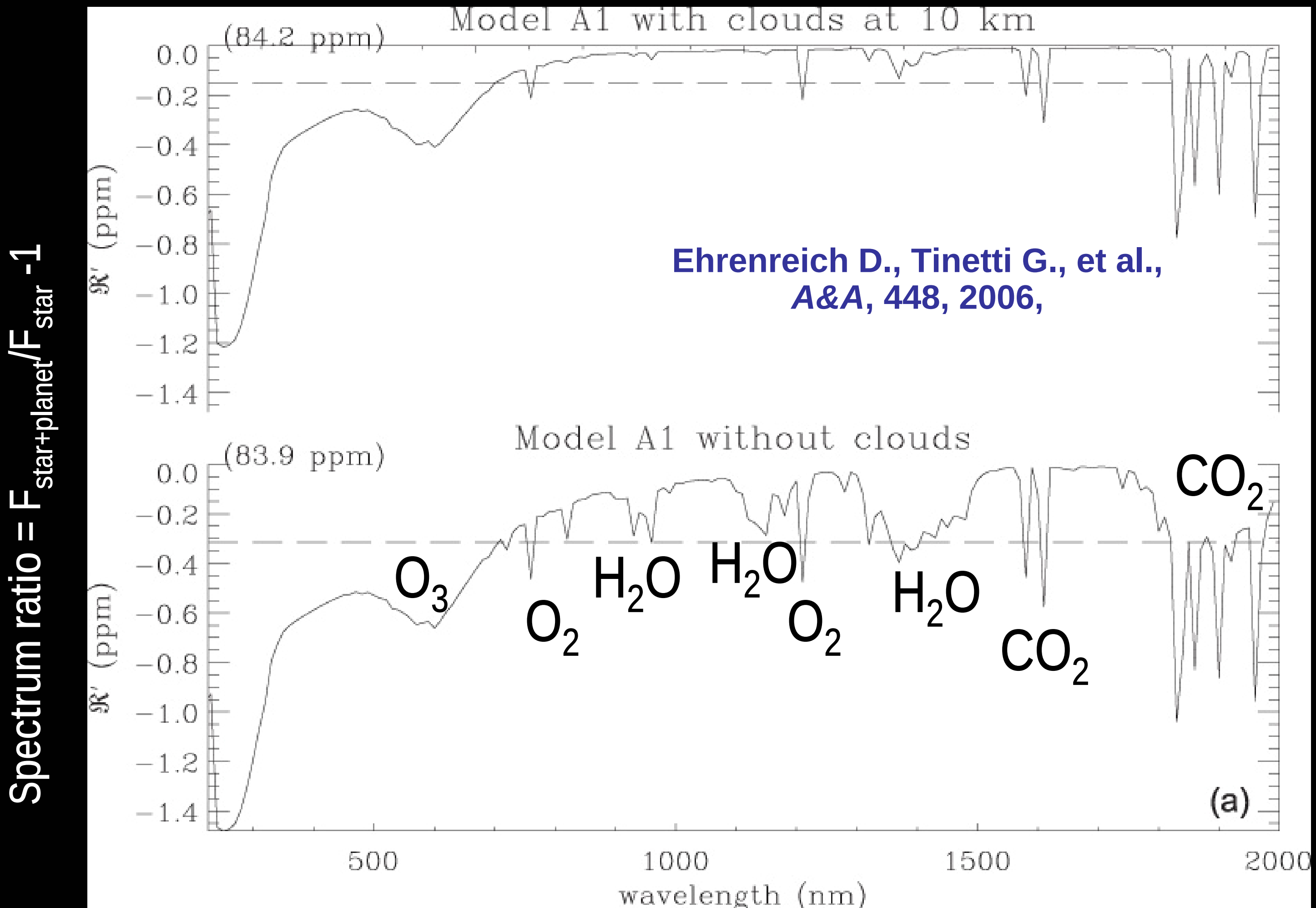
Transmission spectra of Hot Jupiters in the IR

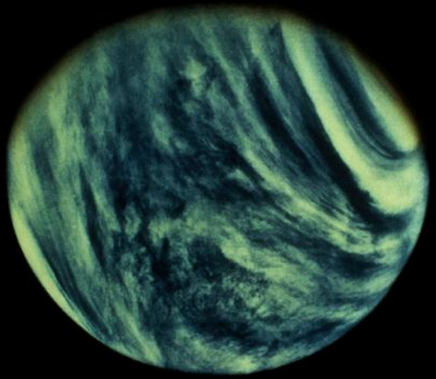


- HD183733b simulations with different C/O ratios

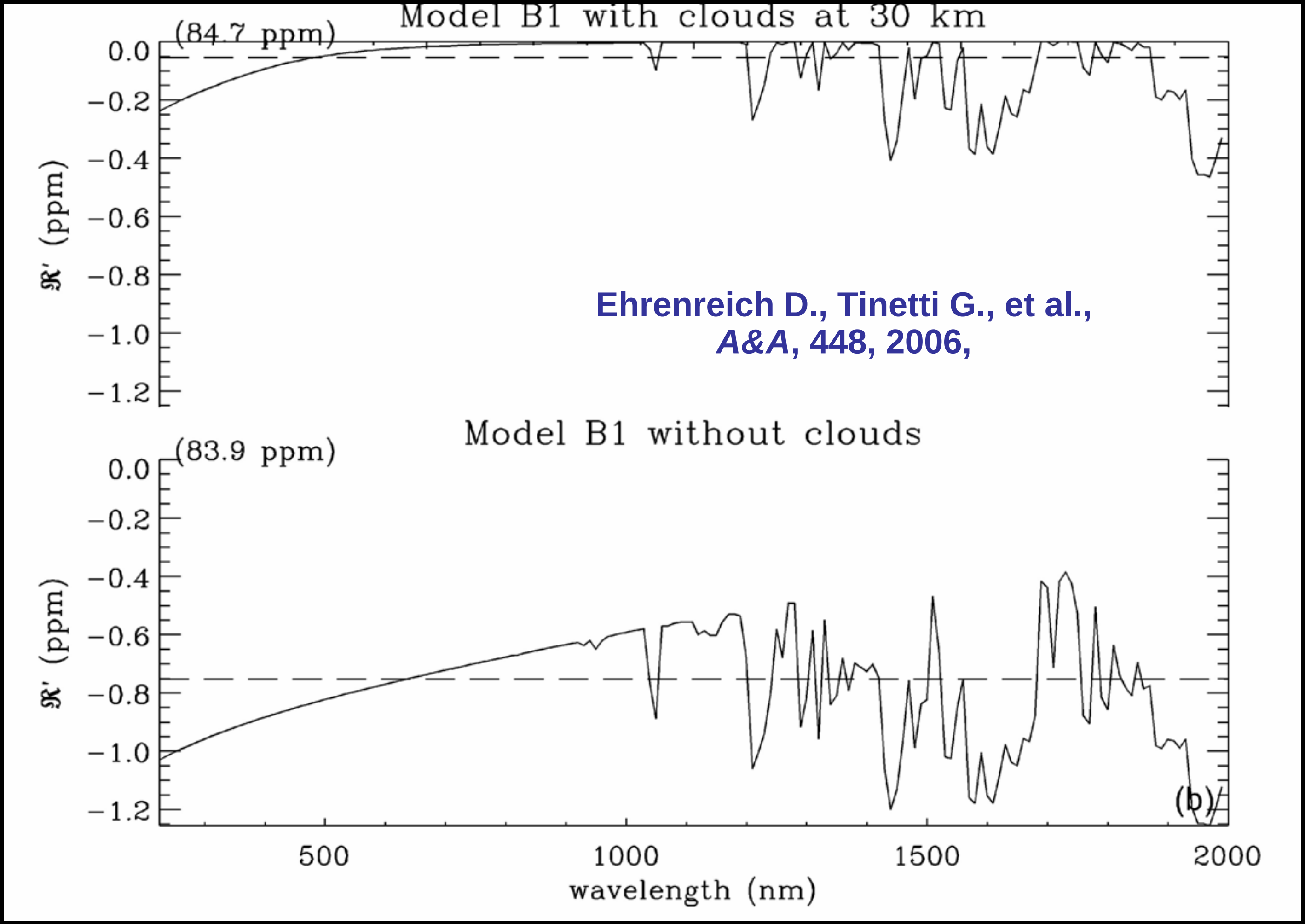
Tinetti et al., Apj, submitted

Earth-like planet in transit



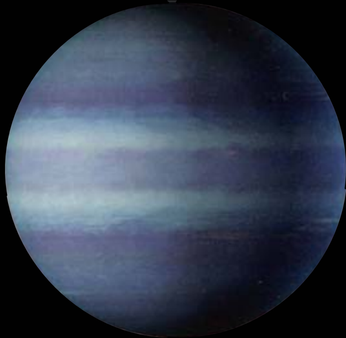


Venus-like planet in transit



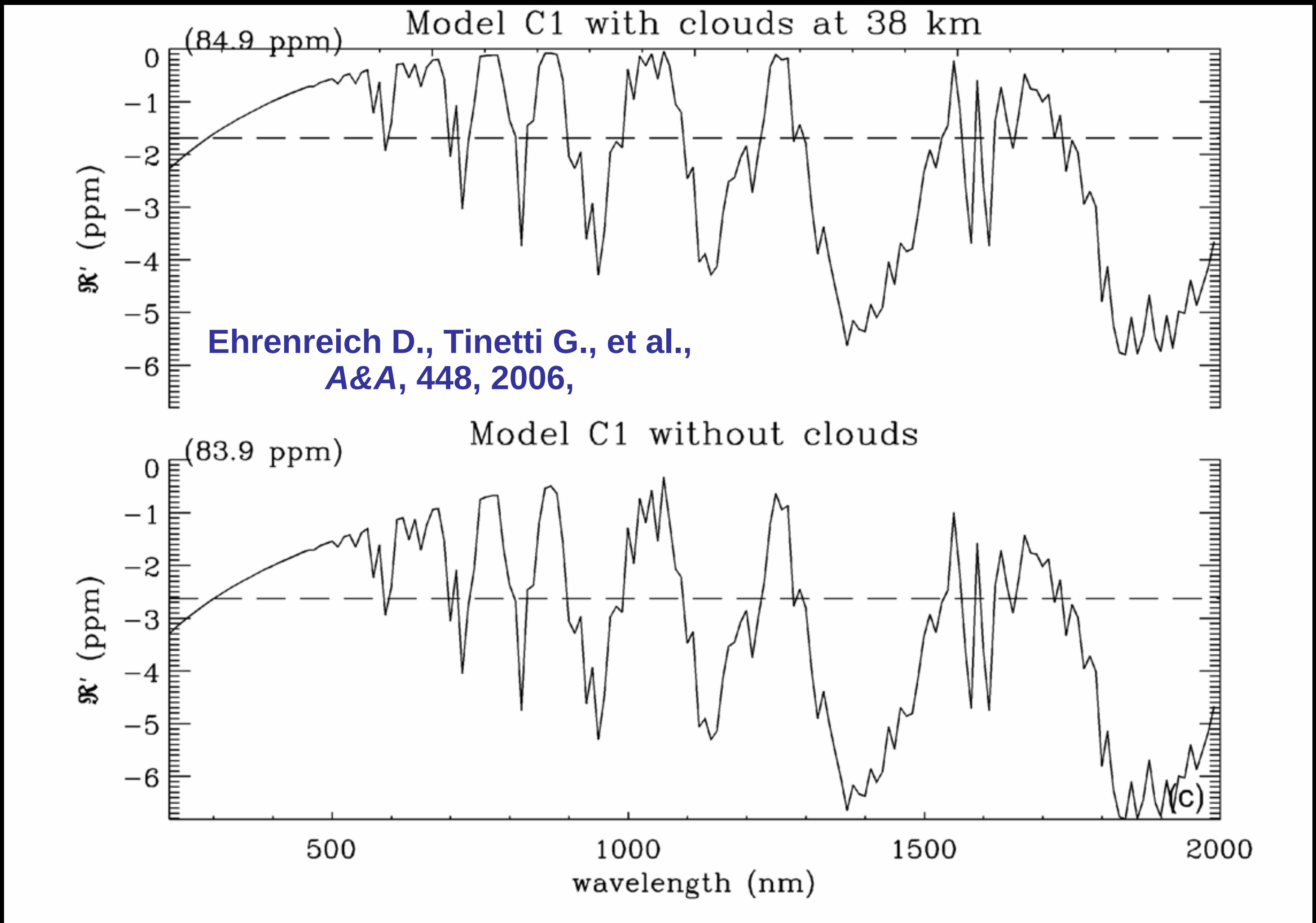
Spectrum ratio = $F_{star+planet}/F_{star}$ -1

Ehrenreich D., Tinetti G., et al.,
A&A, 448, 2006,



Ocean planet in transit

Spectrum ratio = $F_{star+planet}/F_{star}$ -1



Ehrenreich D., Tinetti G., et al., *A&A*, 448, 2006,

Earth-size exoplanets in transit

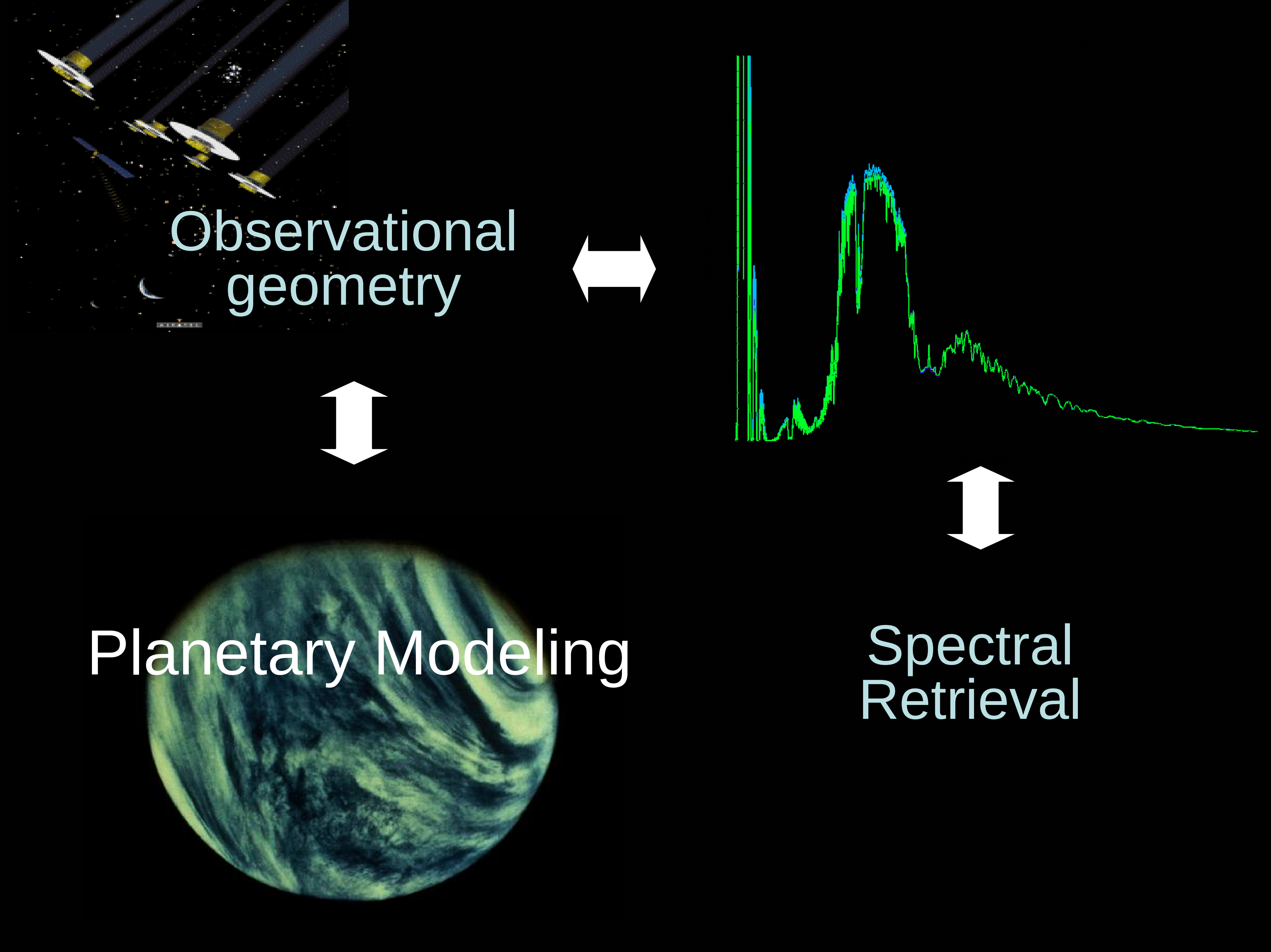
• Volatile-rich planets are favored

• Late type stars are favored (better S/N, more numerous)

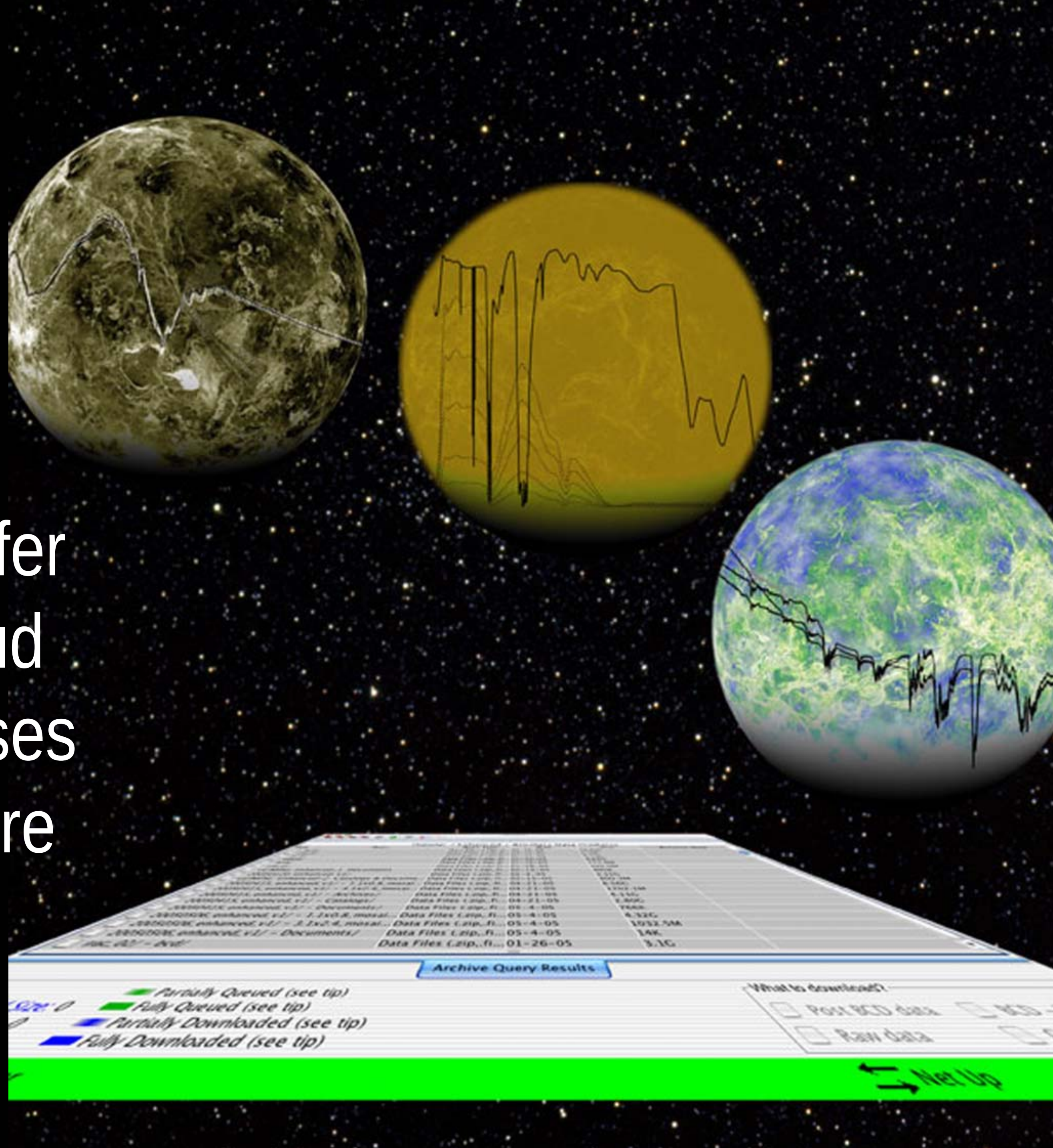
• Atmosphere of Earth-size planet might be detectable with 10-40m telescope, dep. on target

•Technique more sensitive to upper part of the atmosphere

Ehrenreich D., Tinetti G.,et al., 2006, A&A

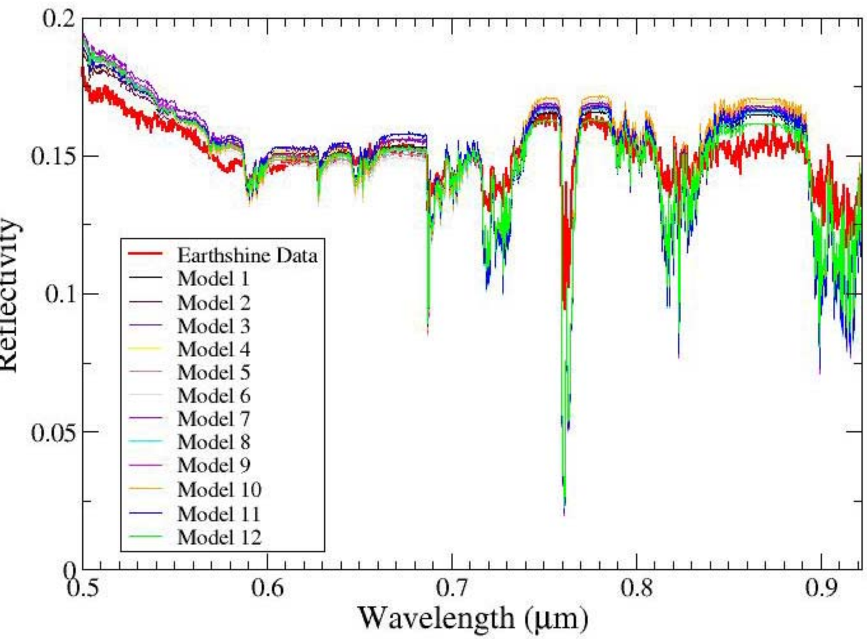

Observational geometry
Planetary Modeling
Spectral Retrieval

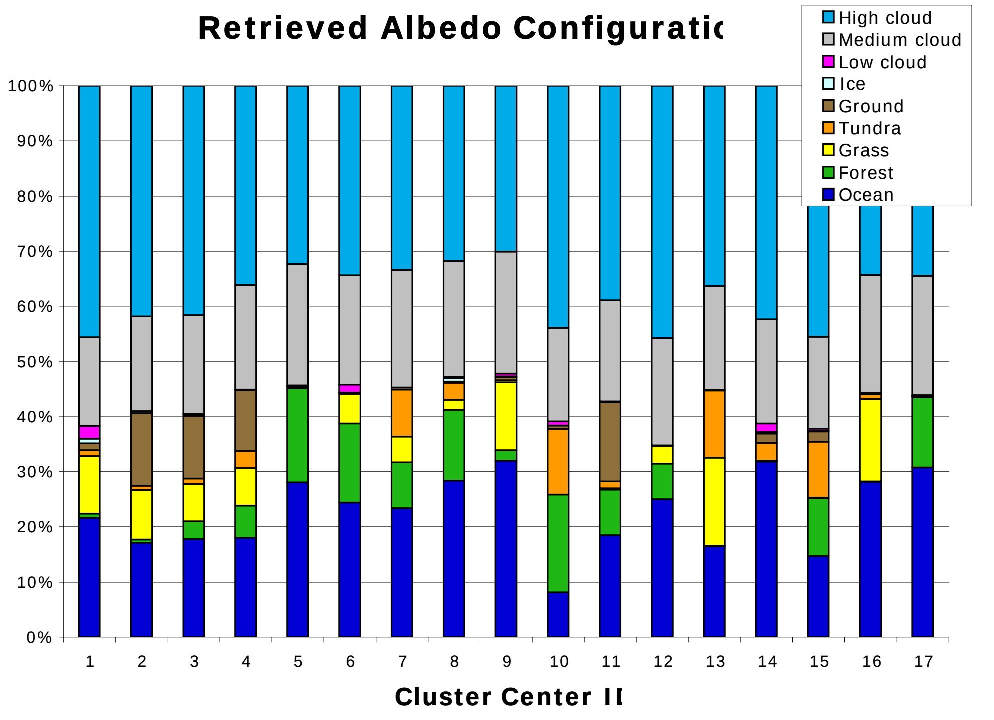
- Chemistry
- Radiative transfer
- Climate + Cloud
- Escape processes
- Internal structure



4D-Spectral Retrieval: the inverse problem

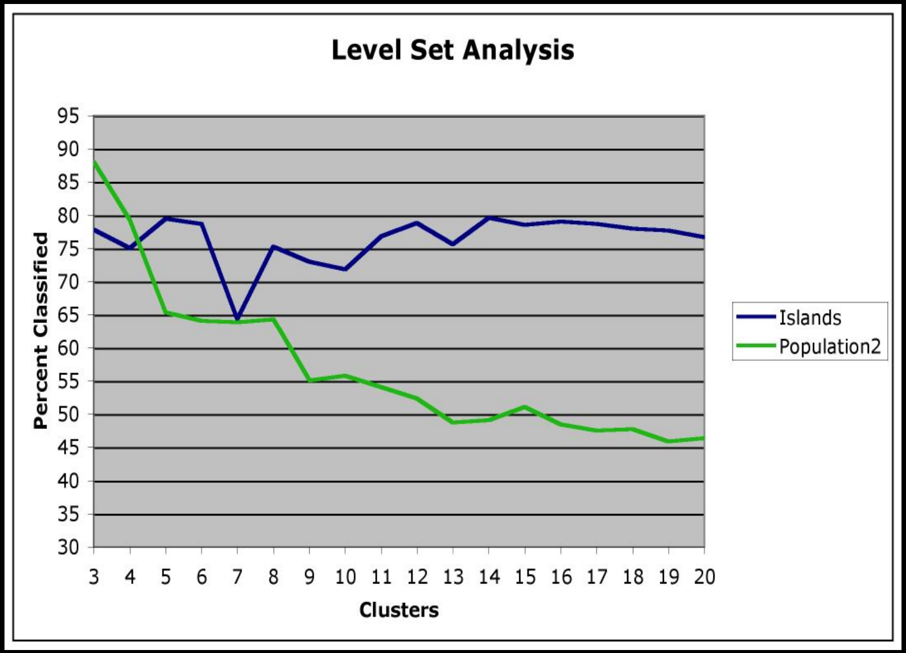
Direct 3D model + Genetic Algorithm & Simulated Annealing

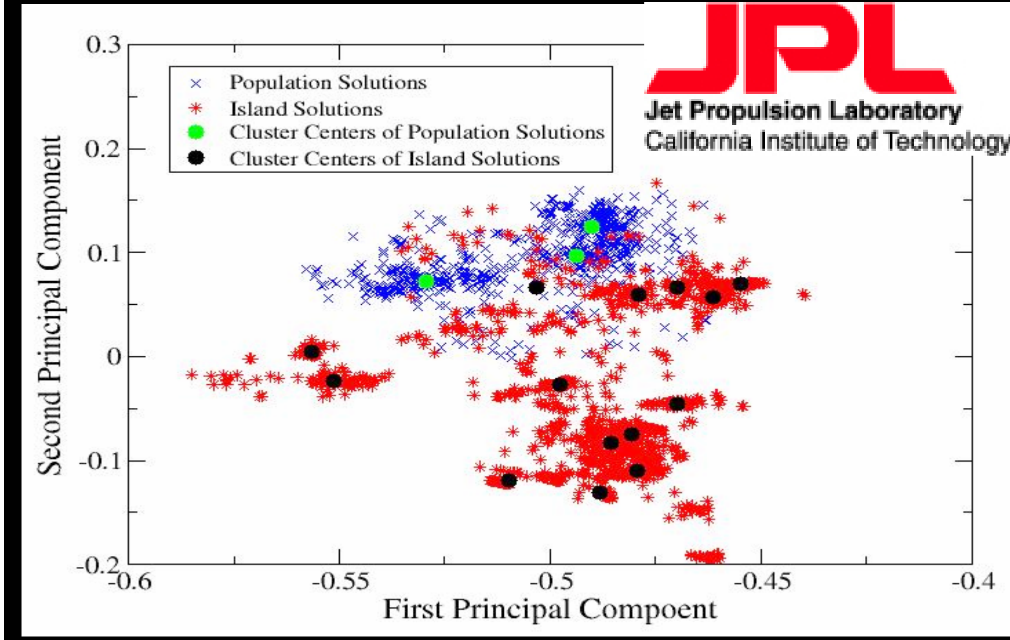




Terrile, Lee, Tinetti,et al., 2006

Evaluation of the Degeneracy

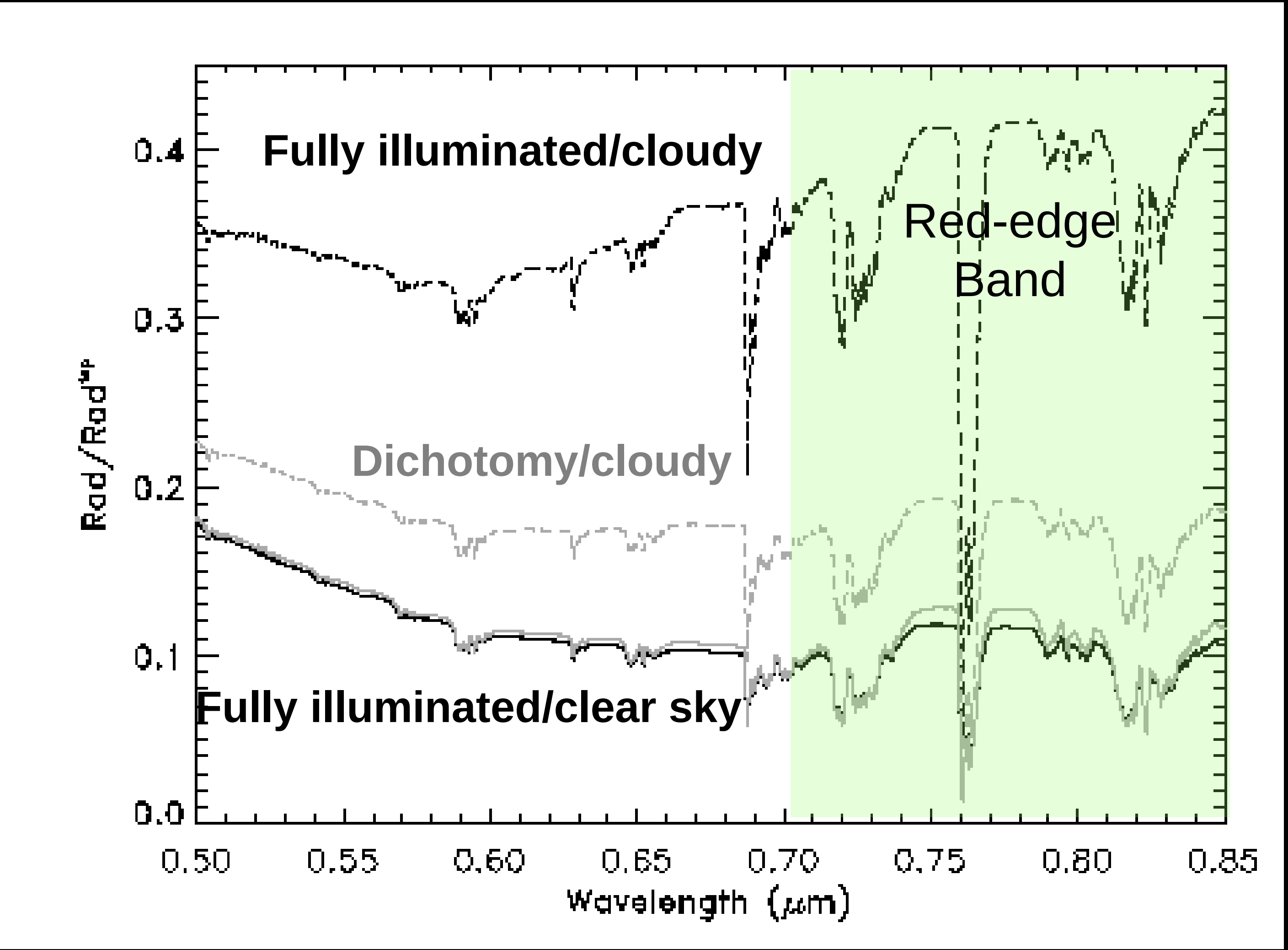




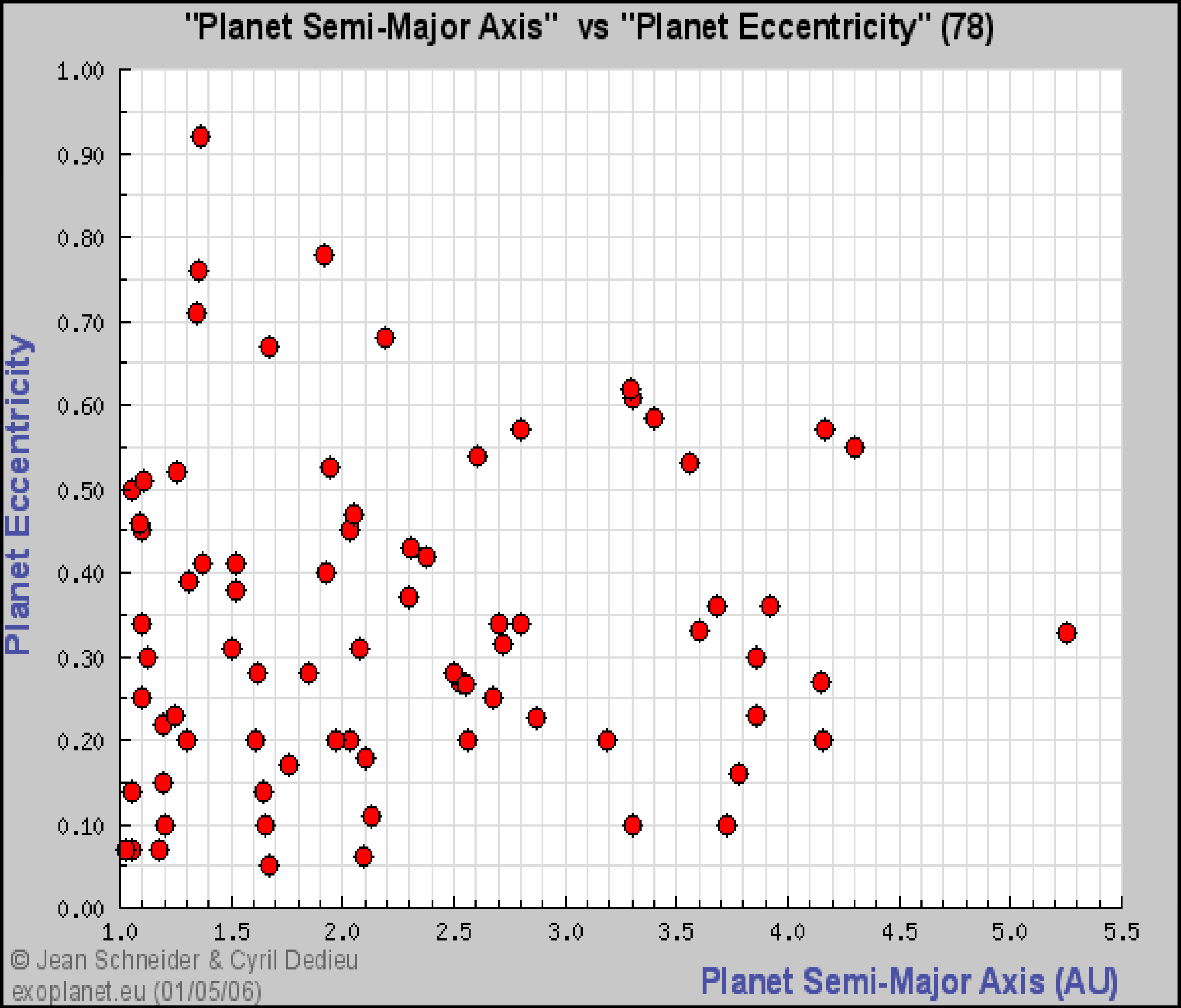
Terrile, Lee, Tinetti,et al., 2006

Disk-time averaged spectra

Average over the day

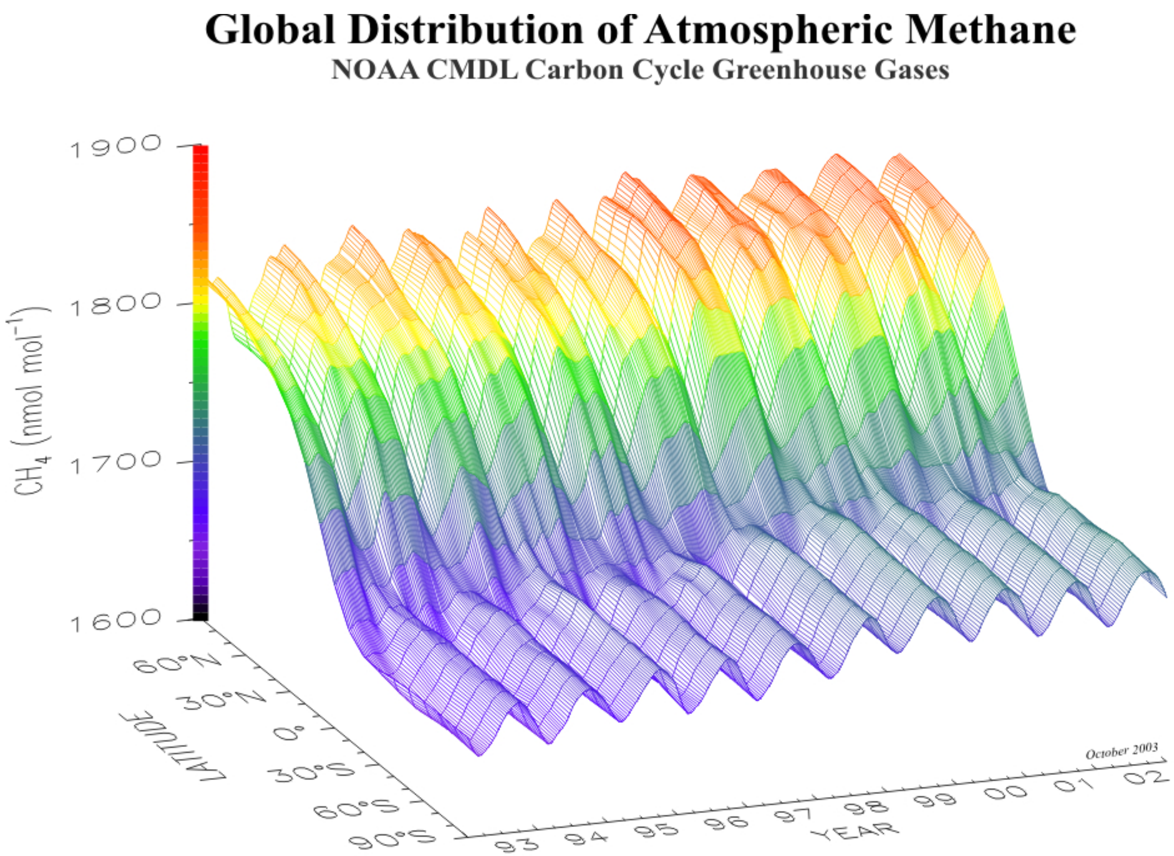


Following the planet during its orbit

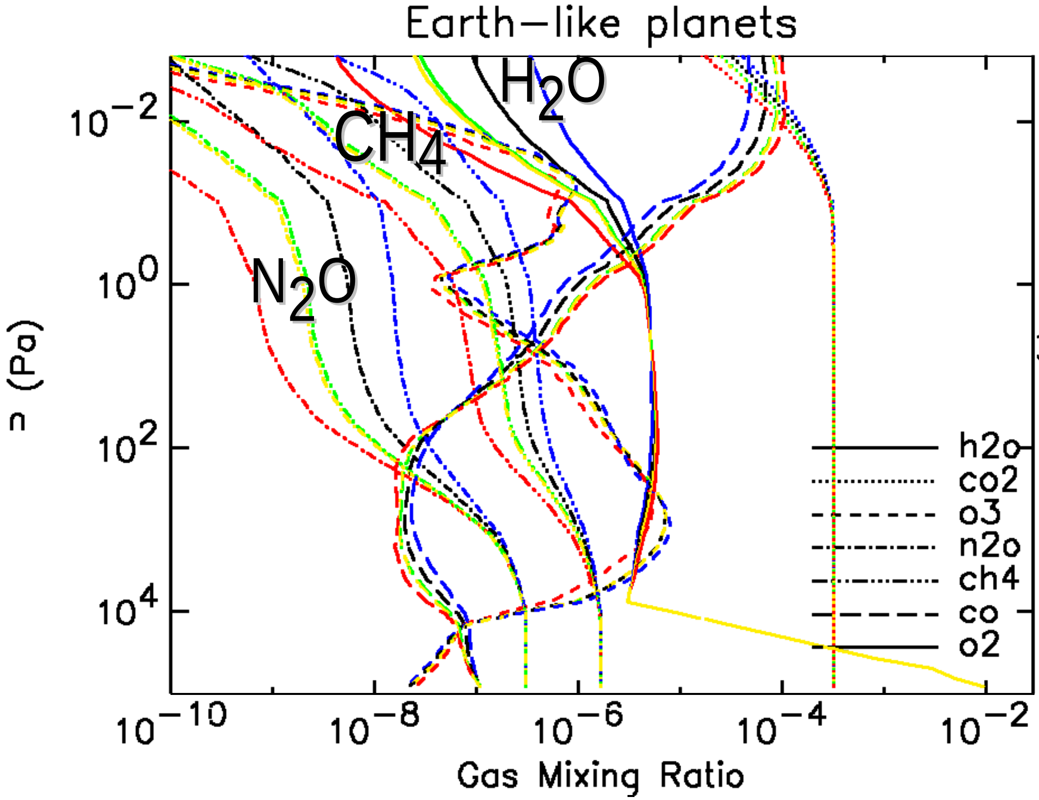


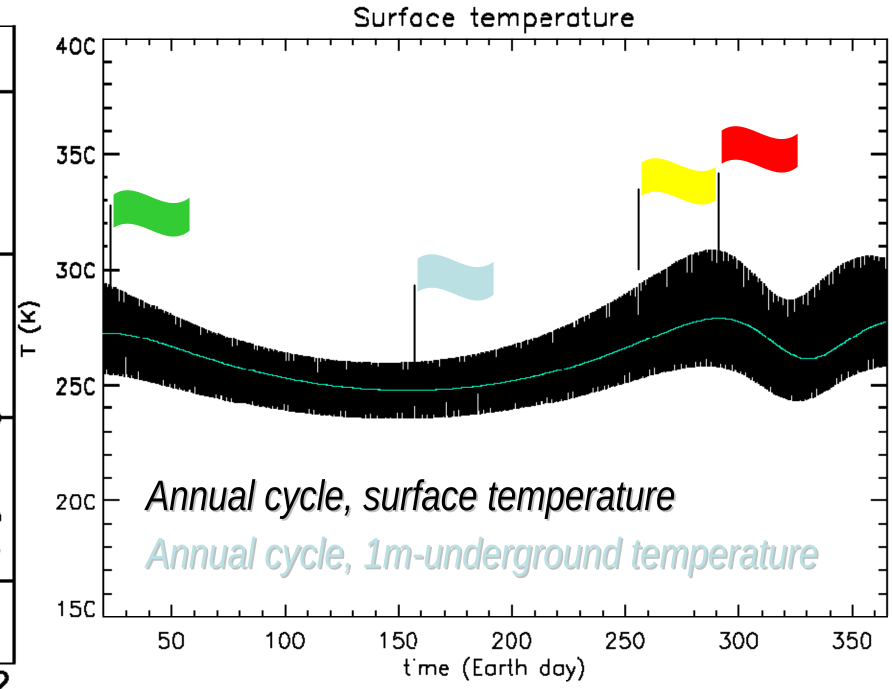
Temporal Atmospheric Signatures

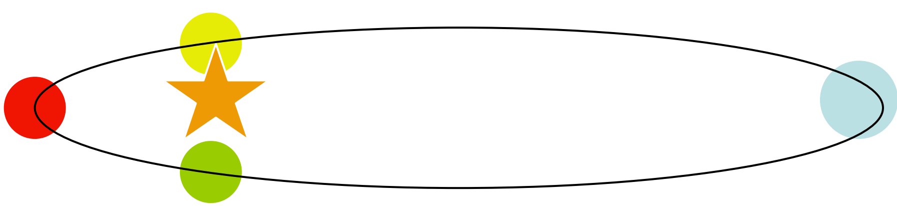
- On the Earth CH_4 and CO_2 both "breathe" with the seasons.
- Volcanic activity?
- CO2 cycle on Mars

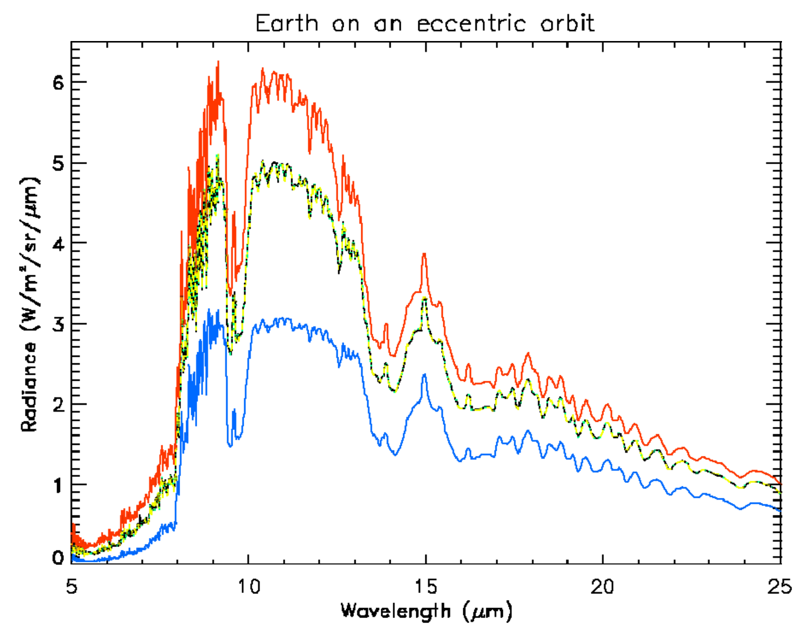


Three dimensional representation of the latitudinal distribution of atmospheric methane in the marine boundary layer. Data from the NOAA CMDL cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Principal investigator: Dr. Ed Dlugokencky, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6228 (ed.dlugokencky@noaa.gov, http://www.cmdl.noaa.gov/ccgg).





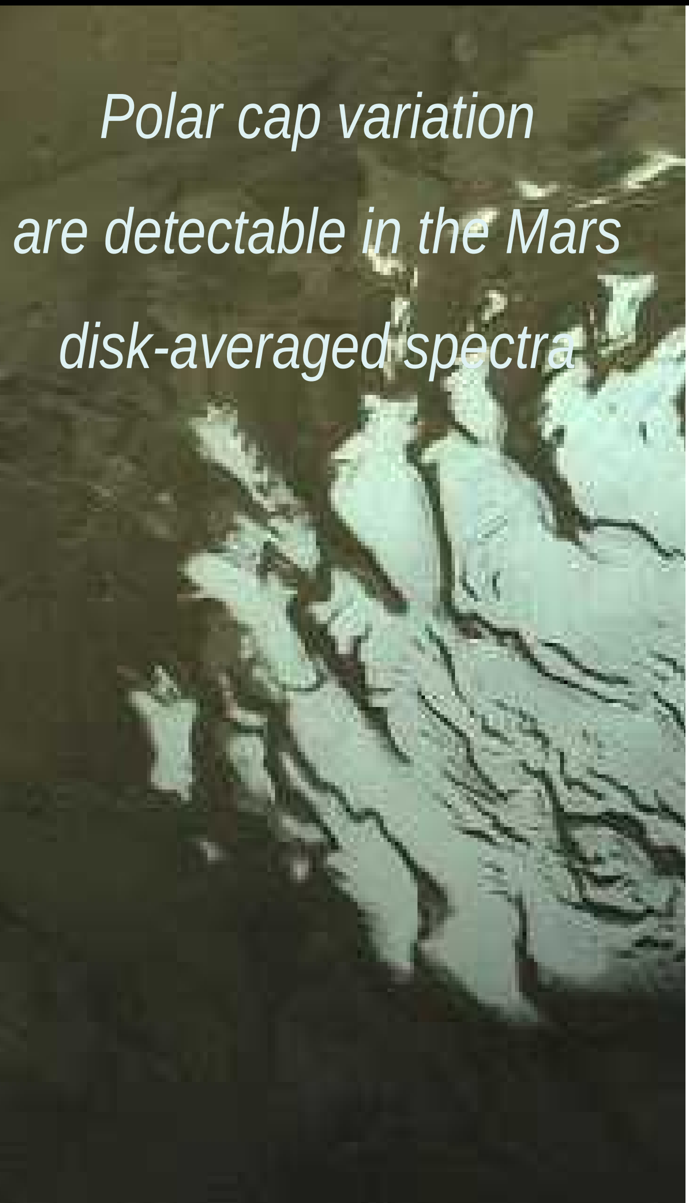


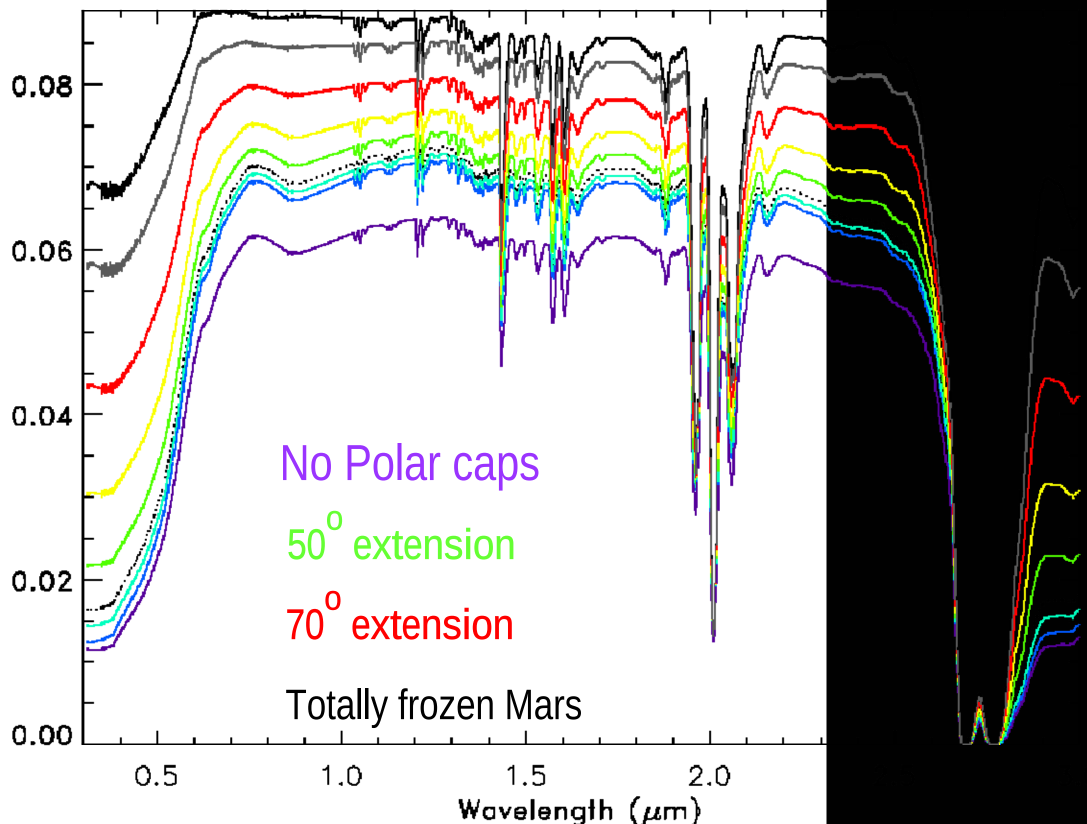


Earth on an eccentric orbit:

$\varepsilon = 0.4,\ \theta=45$

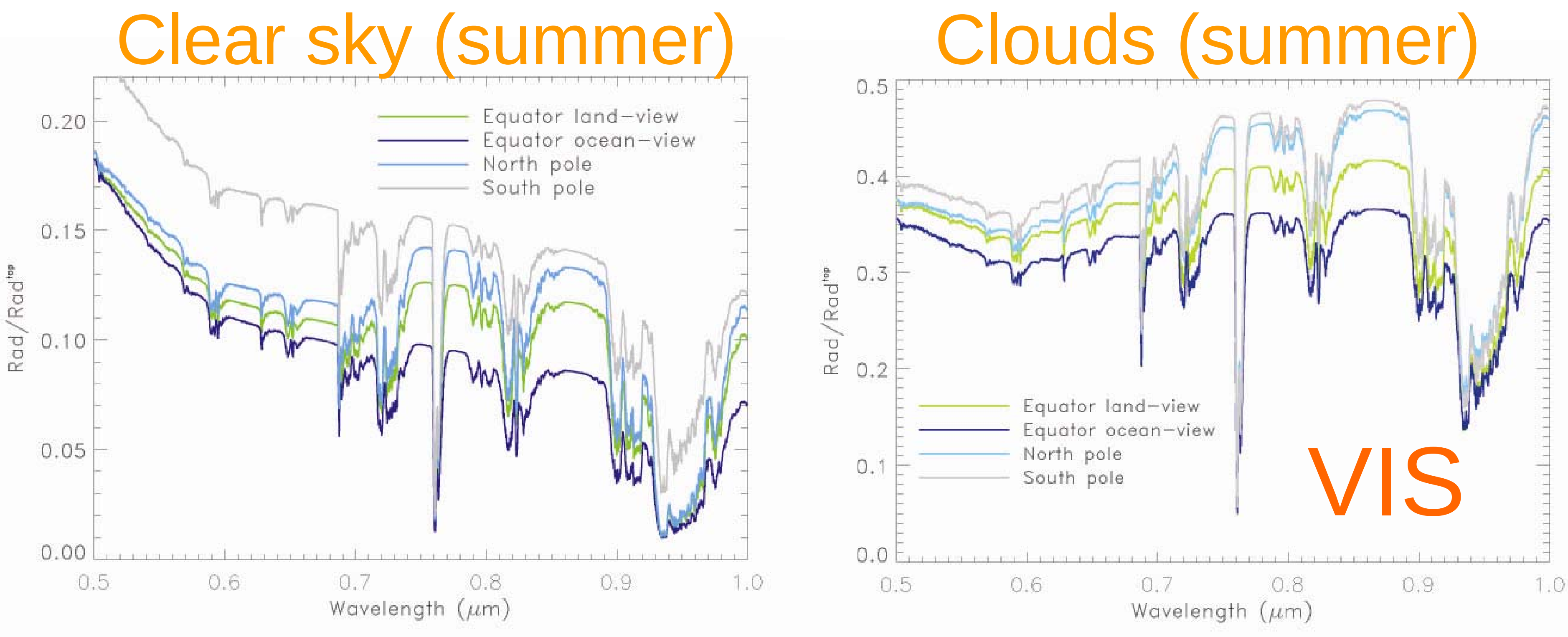
Temporal surface signatures

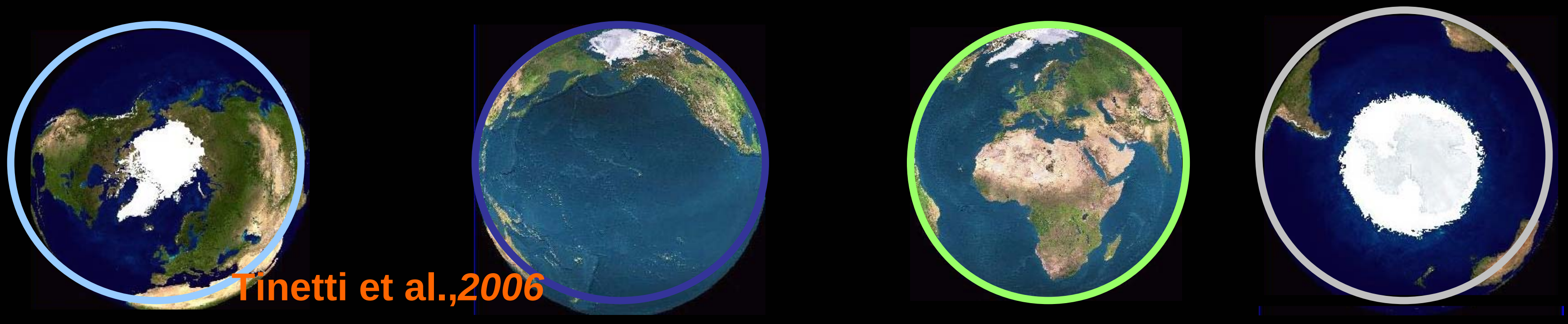




VIS+NIR

Sensitivity to Viewing geometry

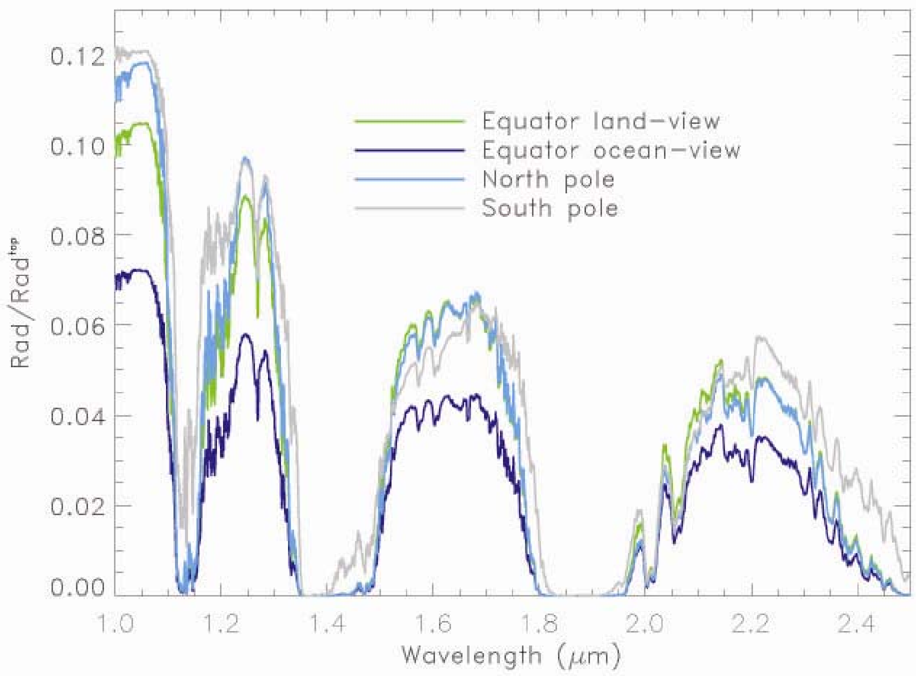




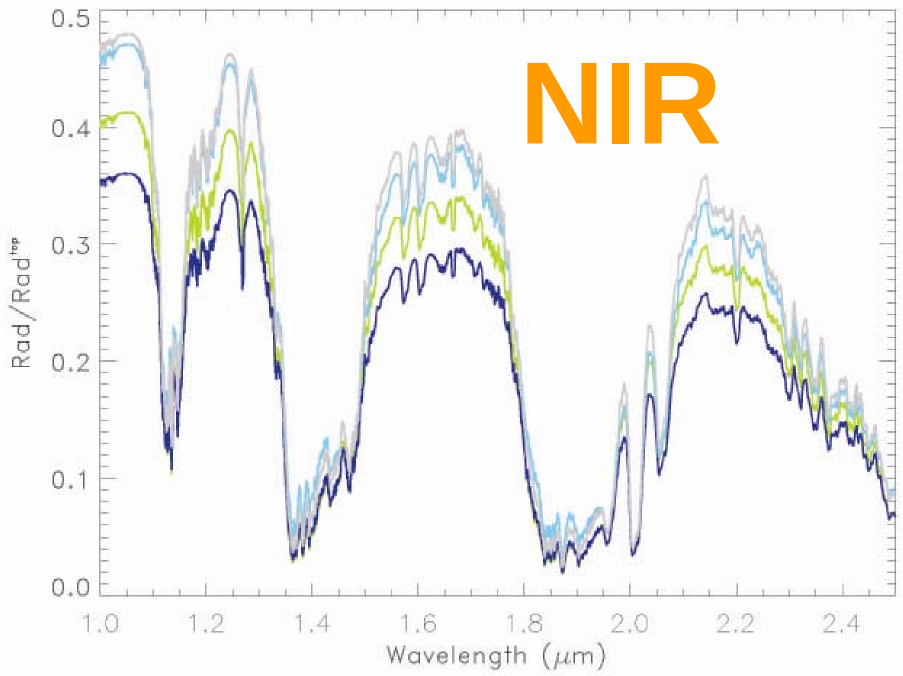
Tinetti et al., *2006*

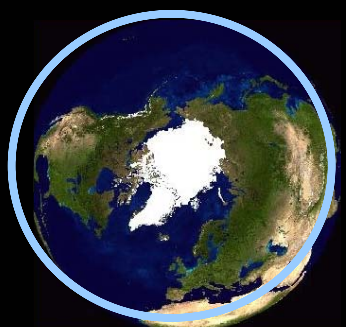
Sensitivity to Viewing geometry

Clear sky (summer)



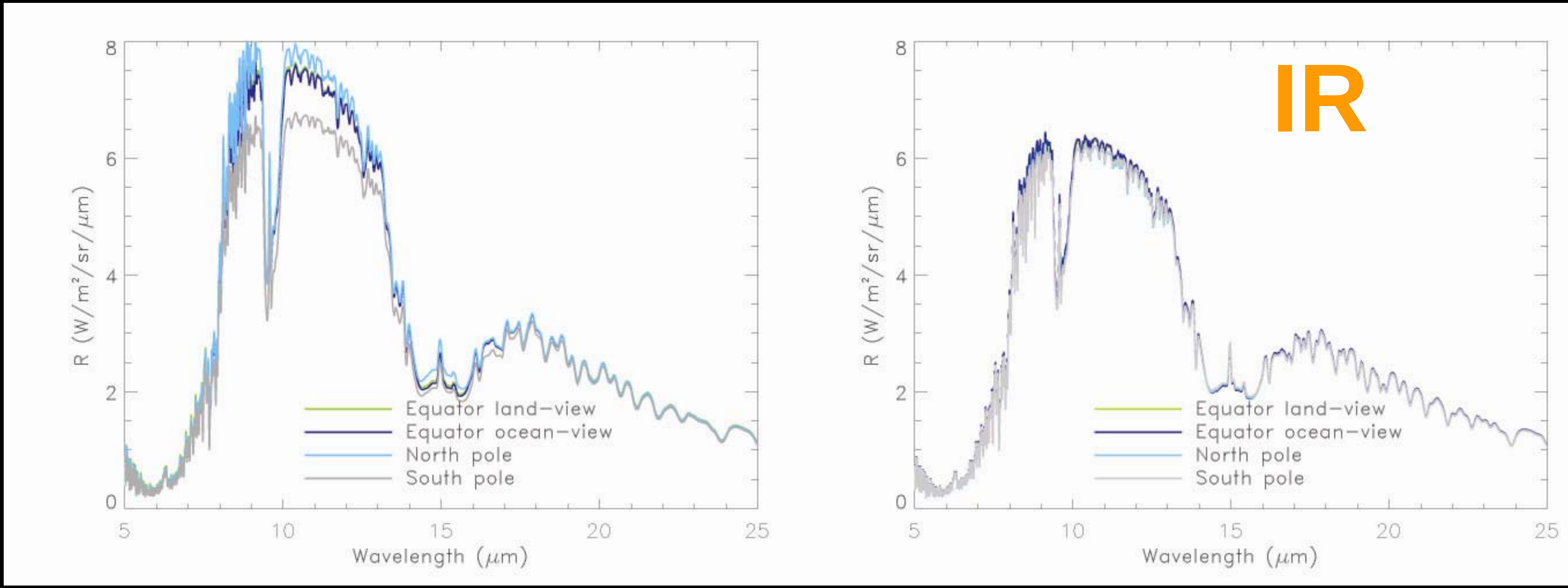
Clouds (summer)

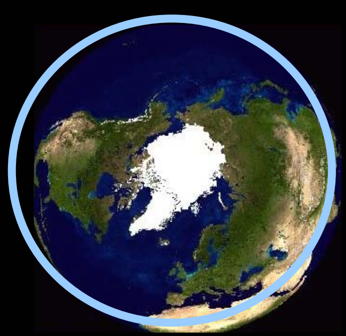




Sensitivity to Viewing geometry

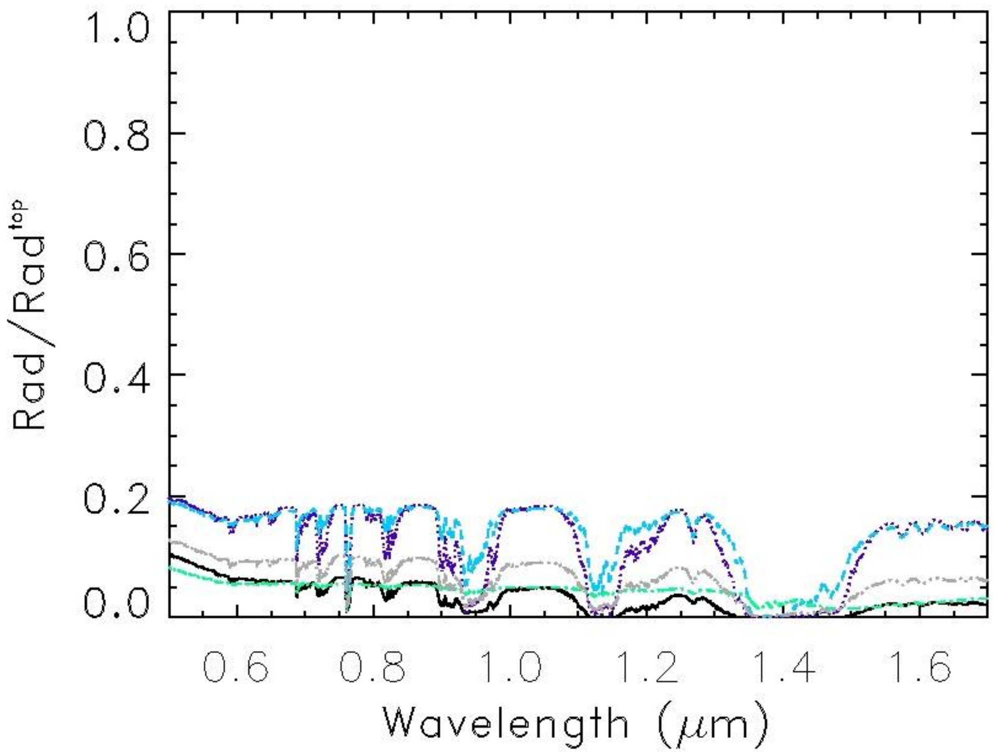
Clear sky (summer) / Clouds (summer)






Sensitivity to Phases

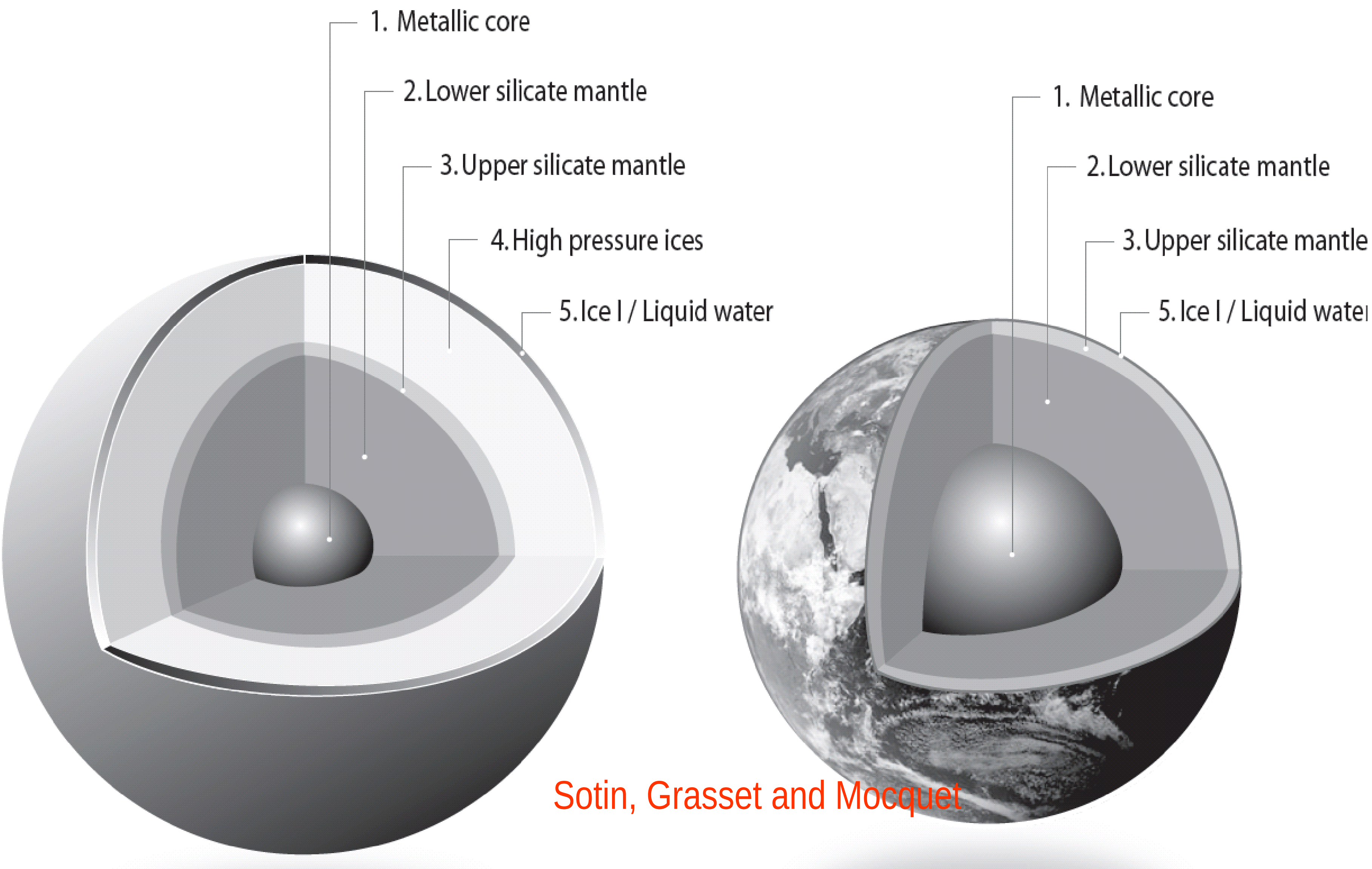
Earth disk-averaged spectra, 3D model, study for TPF-C



Cloud-less disk-averaged spectrum
Realistic clouds
100% Strato-cumulus clouds
100% Alto-stratus clouds
100% Cirrus clouds

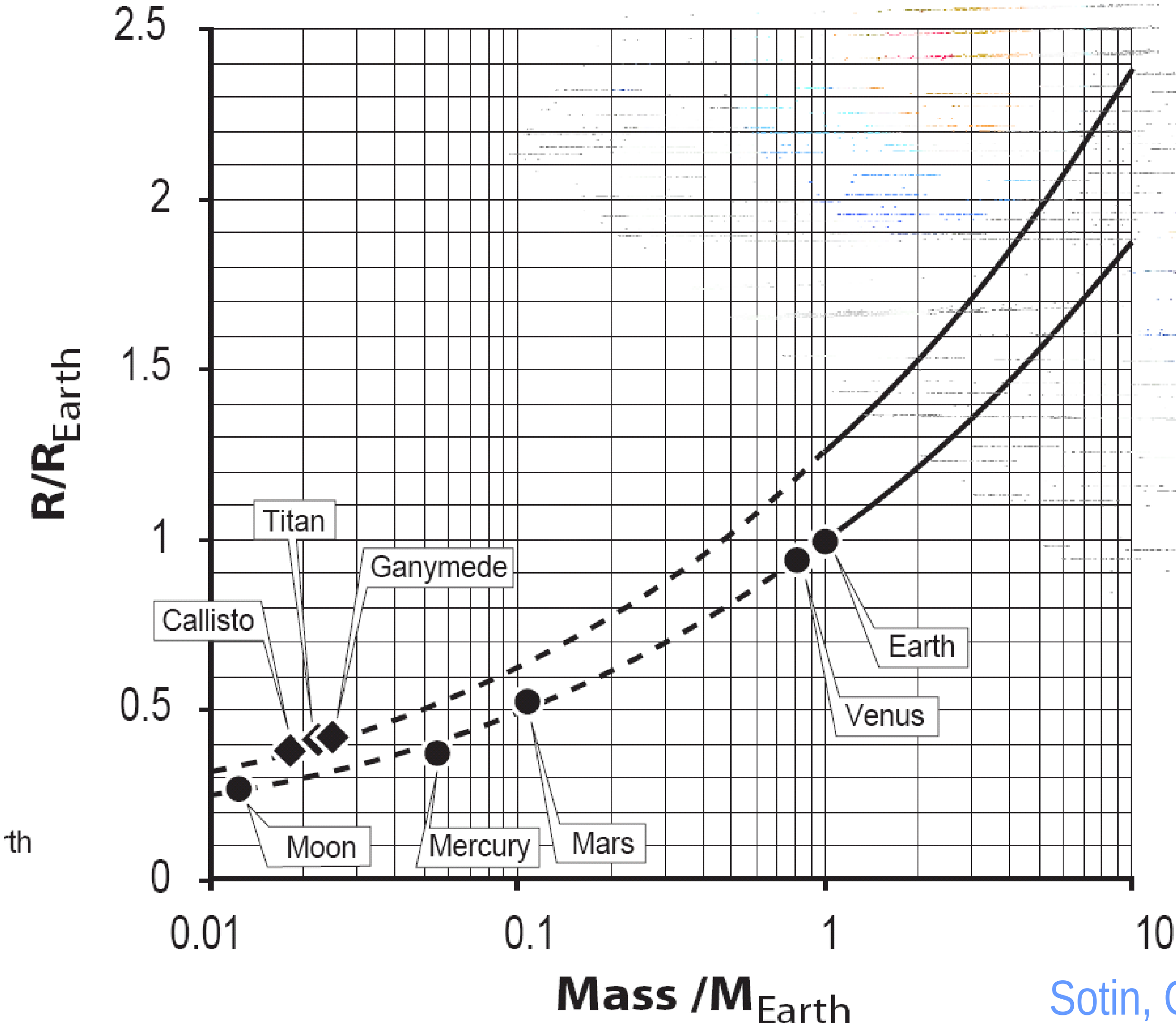
Tinetti et al.,*2006*

Ice versus silicate: why do we care?



Sotin, Grasset and Mocquet

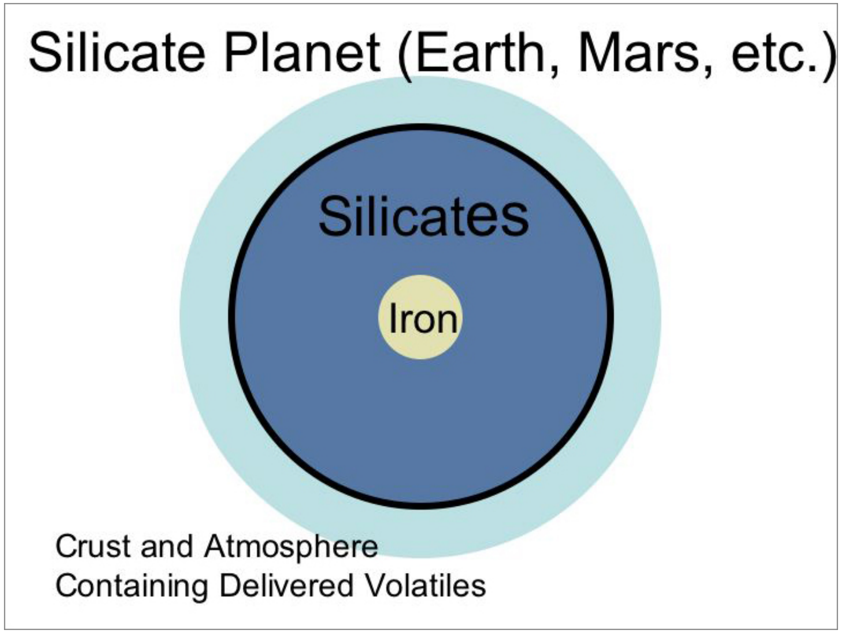
Radius/mass ratio

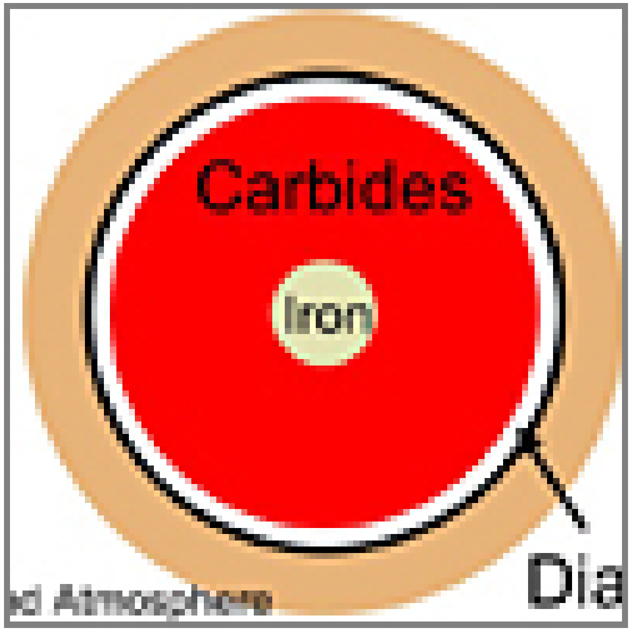


Sotin, Grasset and Mocquet

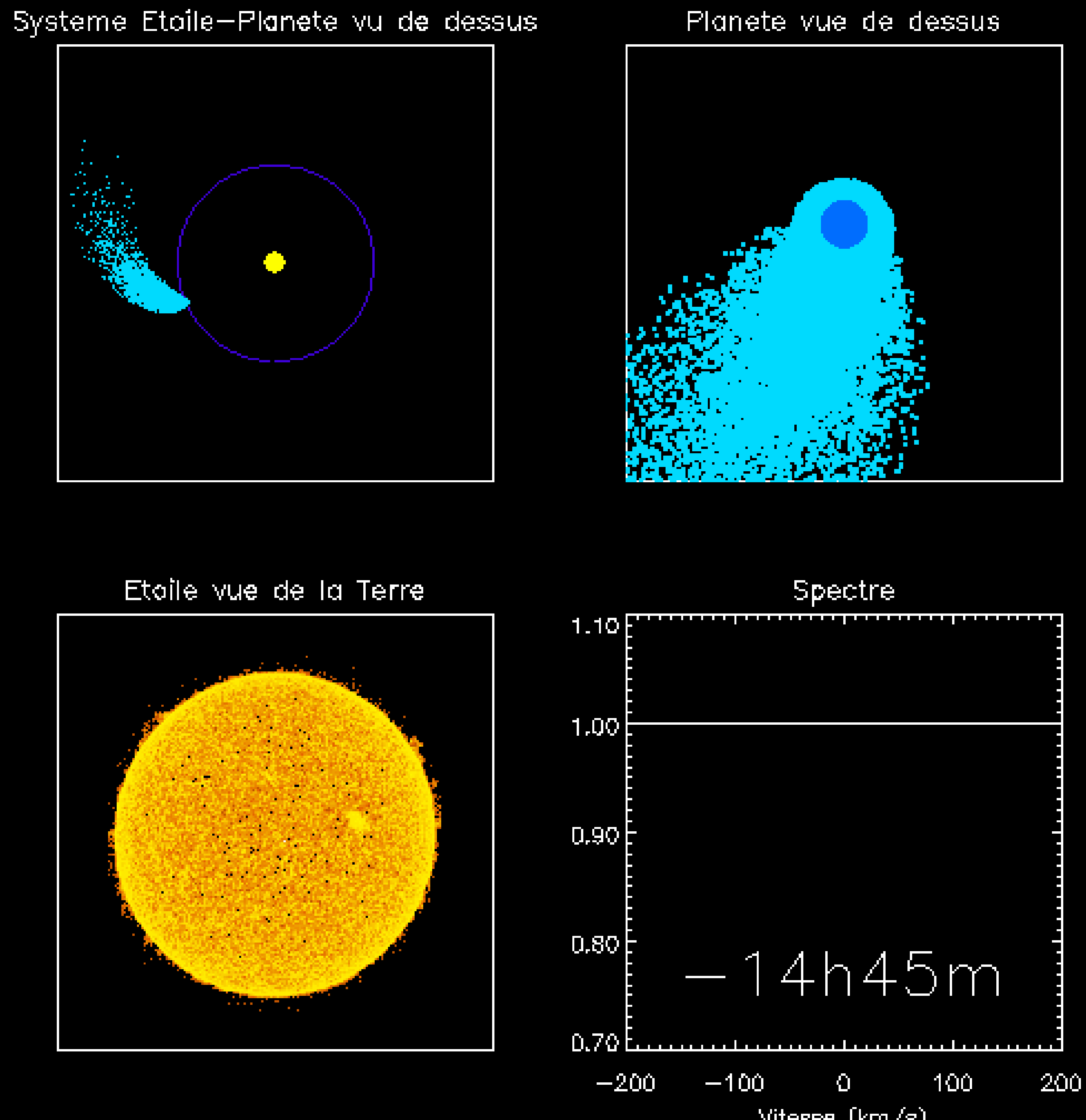
Carbon planets: do they exist?

- *Radius/mass different*
- *Atmosphere C rich (more CO than H_2O!!)*





Kuchner, Seager

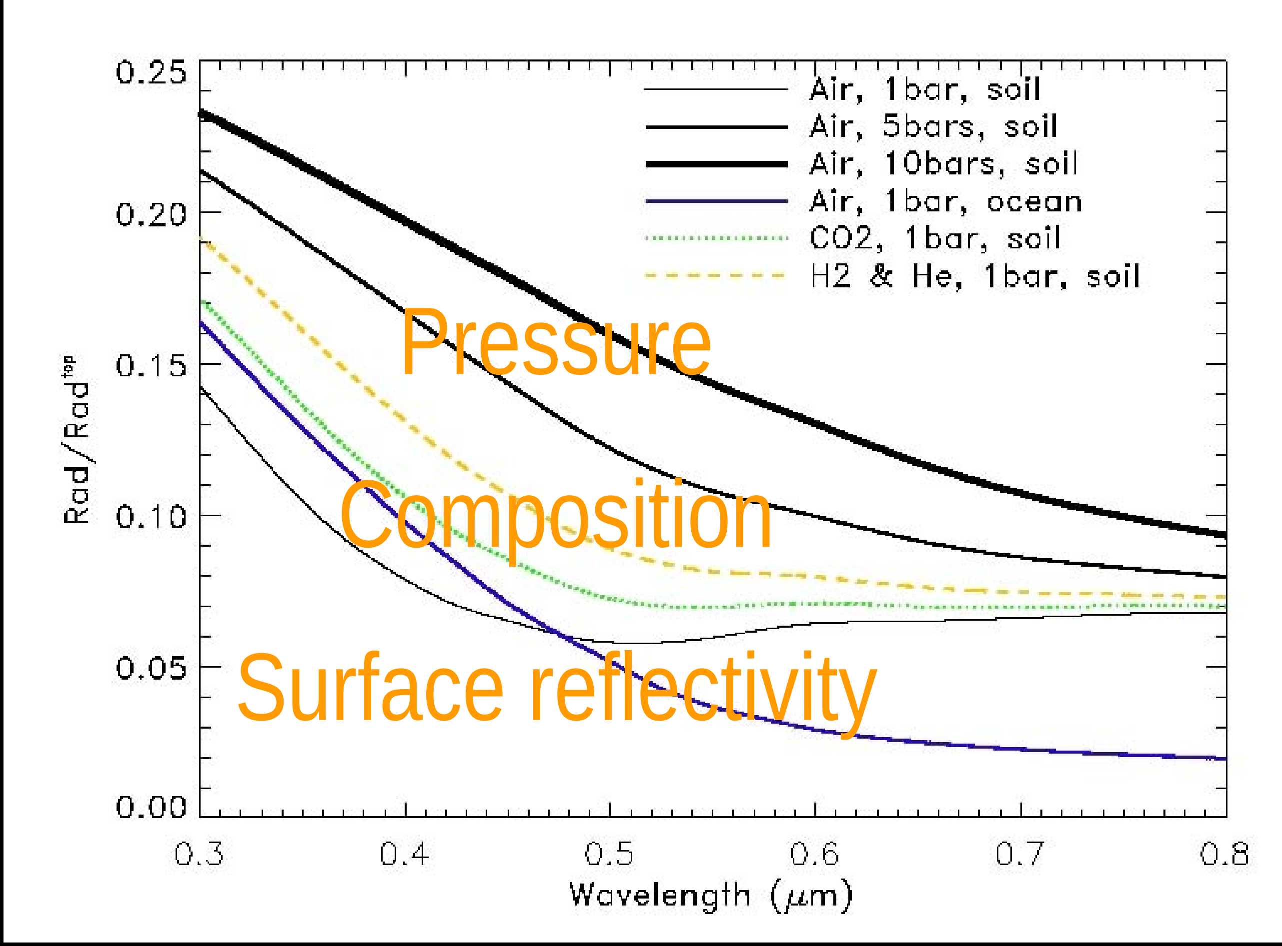

Systeme Etoile-Planete vu de dessus
Planete vue de dessus
Etoile vue de la Terre
Spectre
1.10
1.00
0.90
0.80
0.70
-14h45m
-200
-100
0
100
200

Rayleigh Scattering

Size parameter
~ a/λ

where *a*:

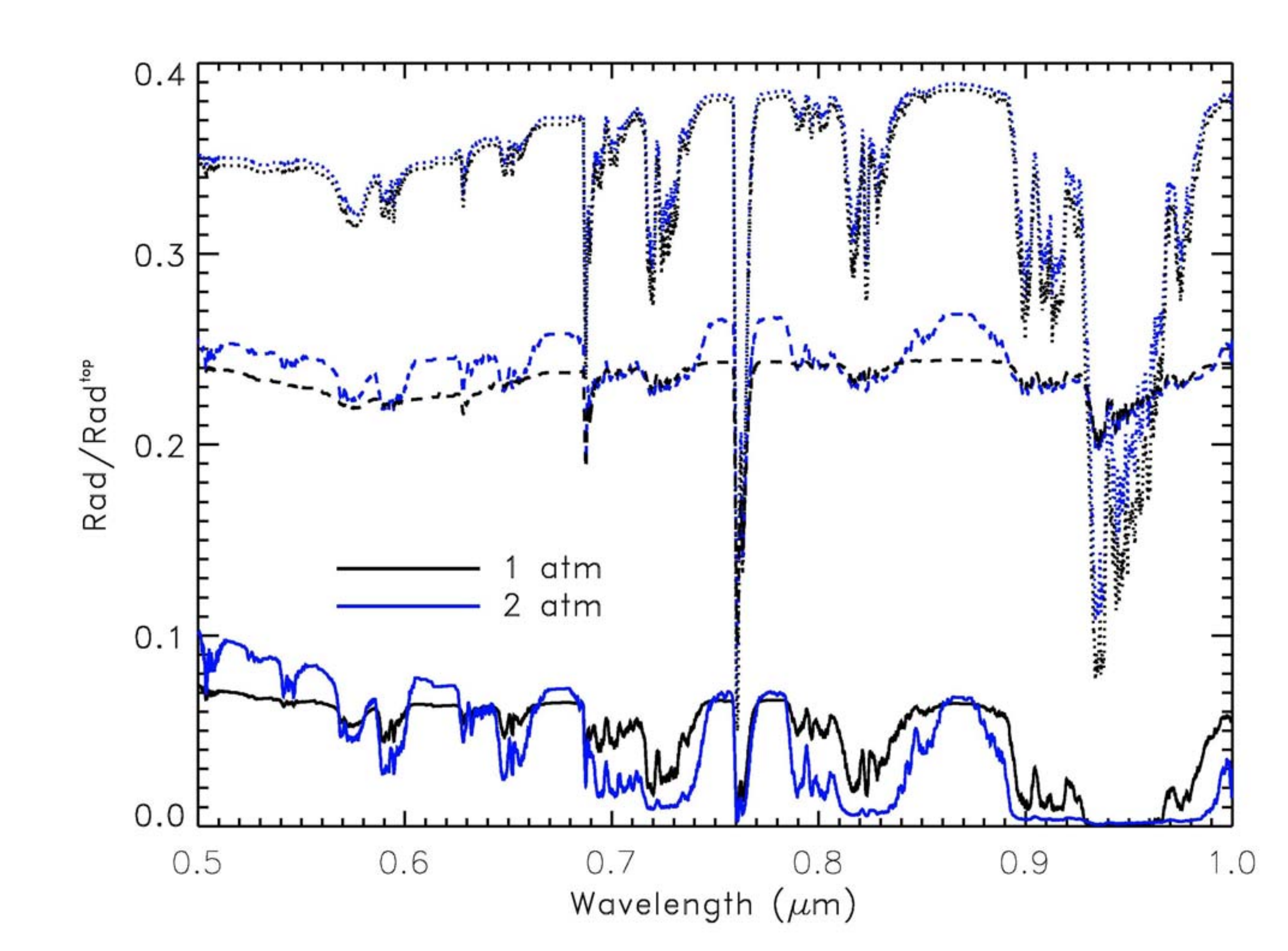
Gas molecules ~ 10^{-4} um
Aerosol ~ 1 um
Water droplets~ 10 um
Ice crystals ~ 100 um



Sensitivity to Pressure

1 and 2 bar Earth atmosphere:

deeper absorption features



Earth detection by TPF

TPF simulation by T. Velusamy