Earth as an alien world

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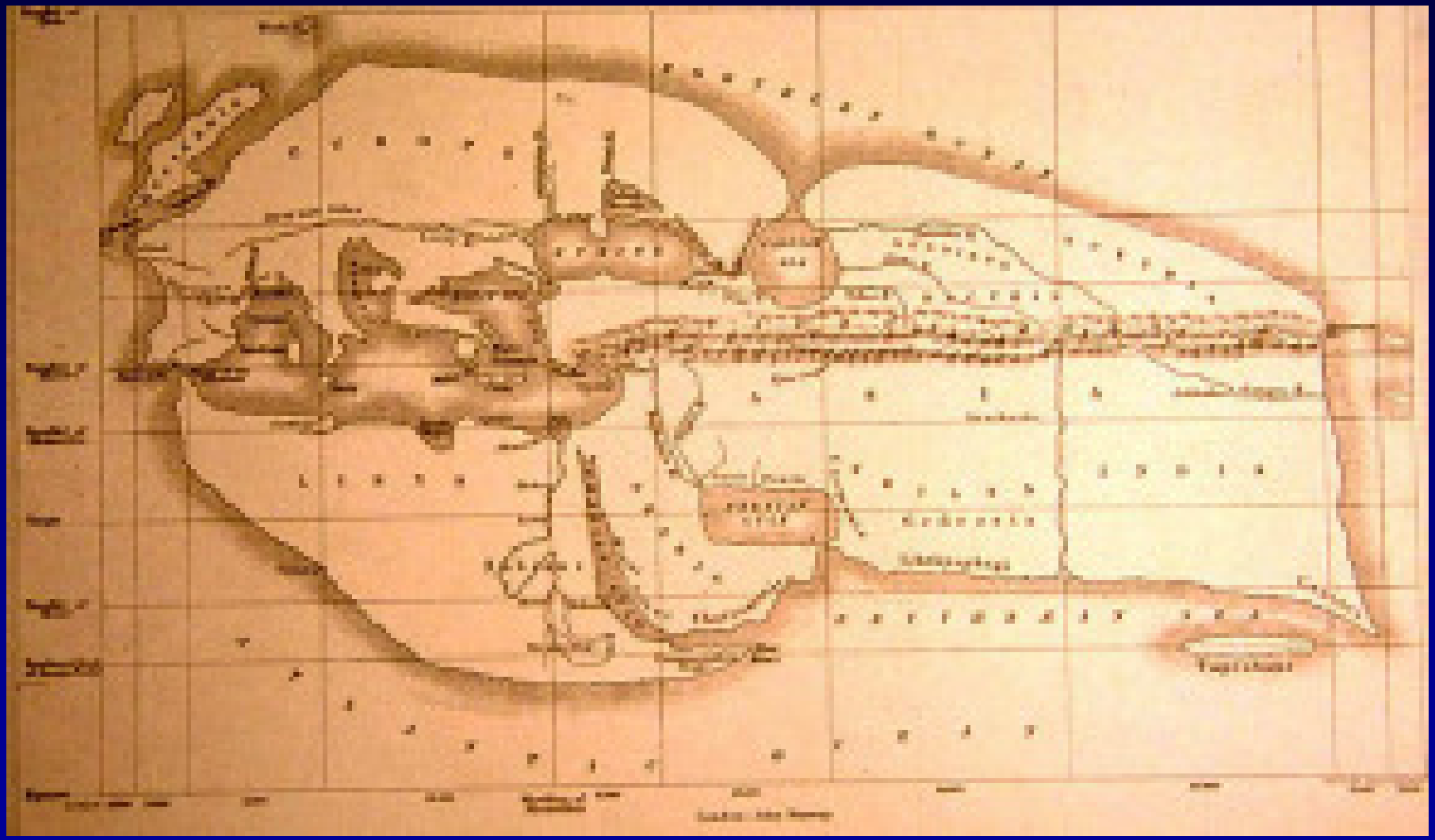
Kavli Institute of Theoretical Physics
Exoplanets Rising Conference – May 2010

A short history of Earth observations

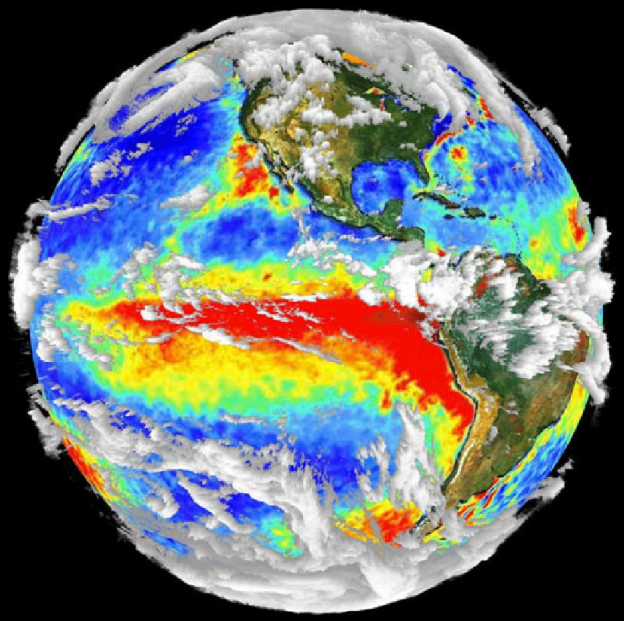


World Map by Eratosthenes, 194 B.C.

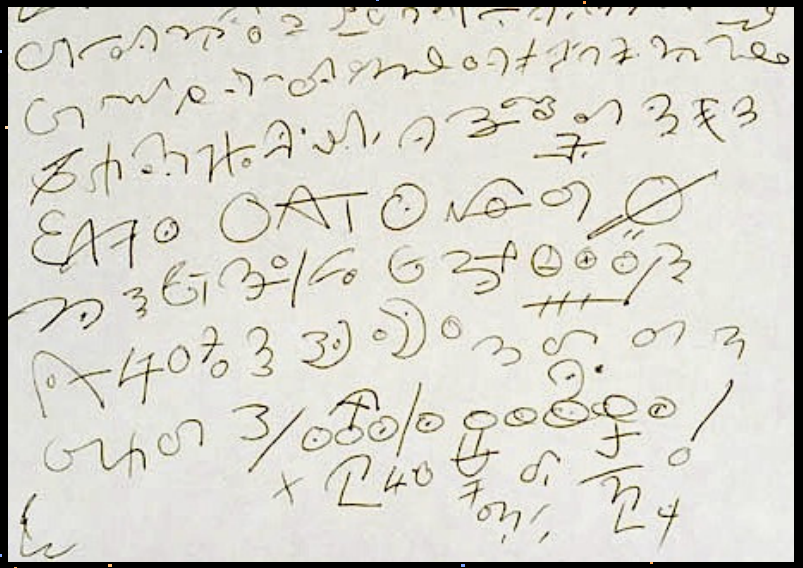
World Map by Martin Waldseemüller, 1507

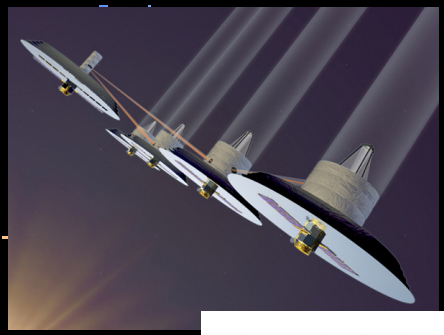

Apollo VIII, 1969

Nowadays we can monitor night lights, atmospheric changes, plankton blooms, forest health, etc...

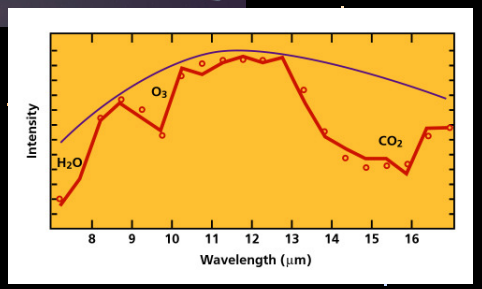


10 Year advance > Planet detection



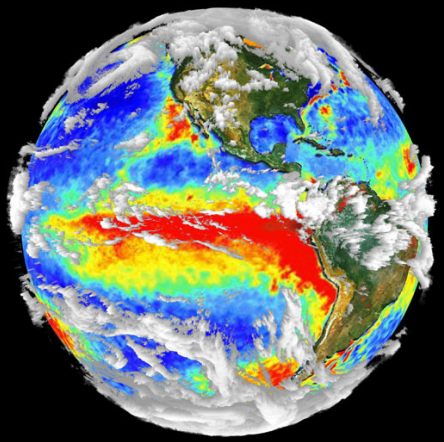


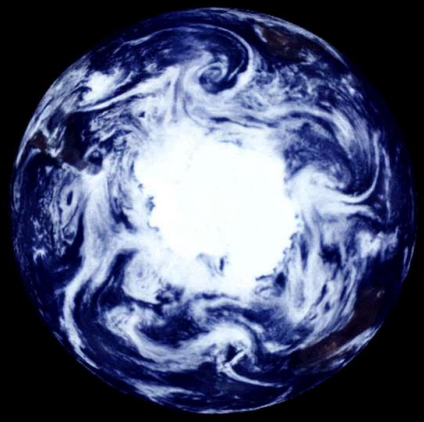
51 % rational thinking > Characterization



But, how does our planet look like to ET?

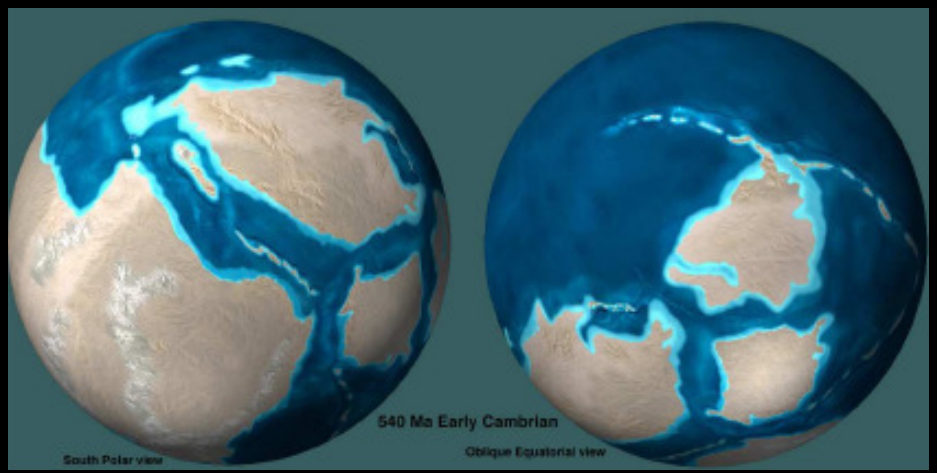
When observing an exoplanet, all the light will come from a single point.



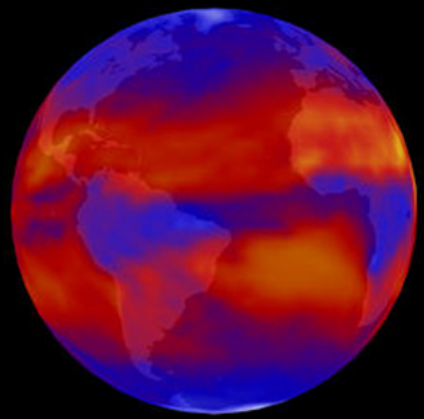


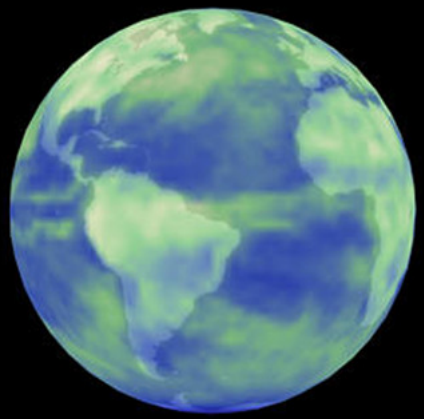
Different seasons, phase, geometry and weather

Age



Wavelength





Outgoing Longwave Radiation (Watts/sq.m)

Reflected Solar Radiation (Watts/sq.m)

Observing the Earth as a planet (no spatial resolution)

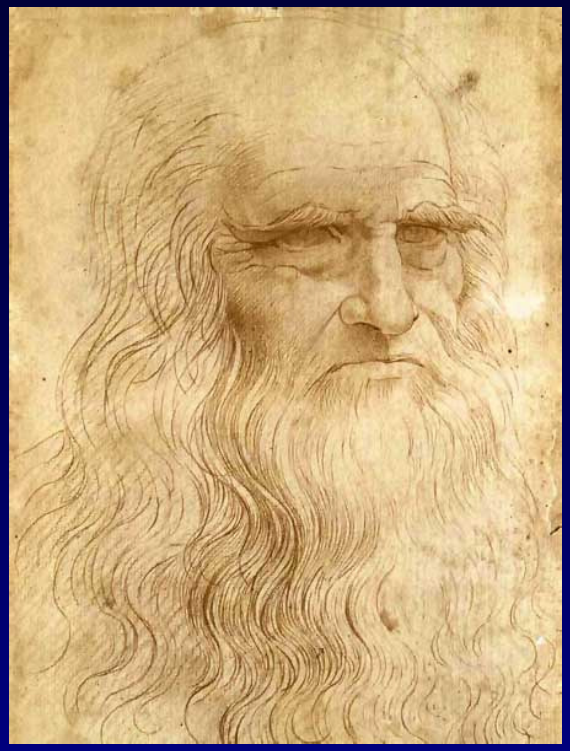
- *Earth–as-a-point observations with a very remote sensor*
- *A compilation of high spatial resolution data into a global spectra or photometry, and modeling*
- *Earthshine Observations: The Earthshine is the ghostly glow on the dark side of the Moon*

Earth observations from remote platforms

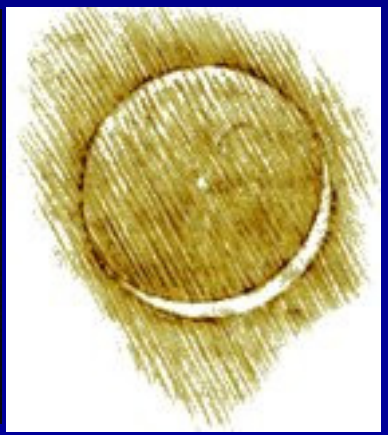
Mission	Date	Observations
[a] Voyager 1	1989	Pale blue dot image (6.4 billion *km*)
[b] Galileo	1990	Flyby Obs. Very low-resolution spectroscopy
[c] Mars Global Surveyor, TES	1996	Infrared spectroscopy
[d] Mars Express, OMEGA	2003	Low-res. visible and near-infrared spectra
[e] ROSSETTA, Virtis	2005	High-resolution visible and infrared imaging
[f] MESSENGER	2005	Imaging sequence of Earth during flyby
[g] CASSINI	2006	Image of Earth from Saturn's orbit
[h] ROSSETTA, OSIRIS	2007	Composite imaging, true colours
[i] EPOXI, EPOCh	2008	Composite imaging, true colours
[j] Venus Express	2007-08	Repeated visible and infrared spectroscopy

on the moon

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



Leonardo da Vinci, Codex Leicester, 1510

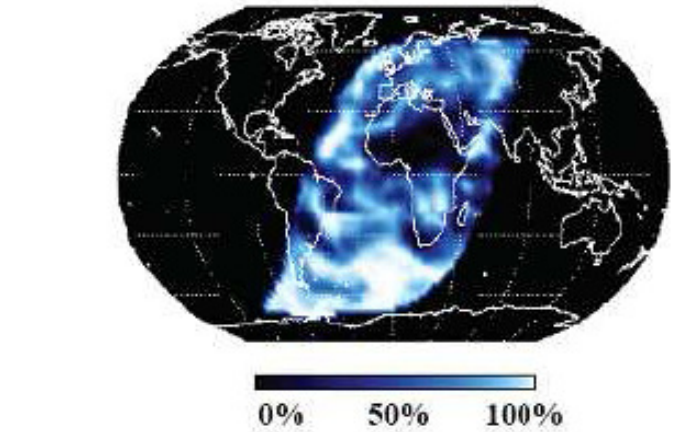


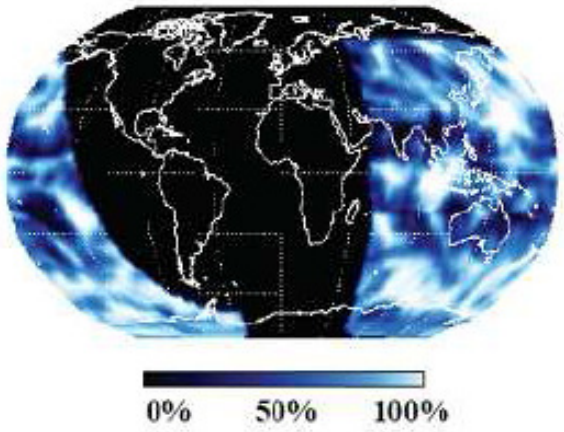
The page is titled "Of the Moon: No solid body is lighter than air."

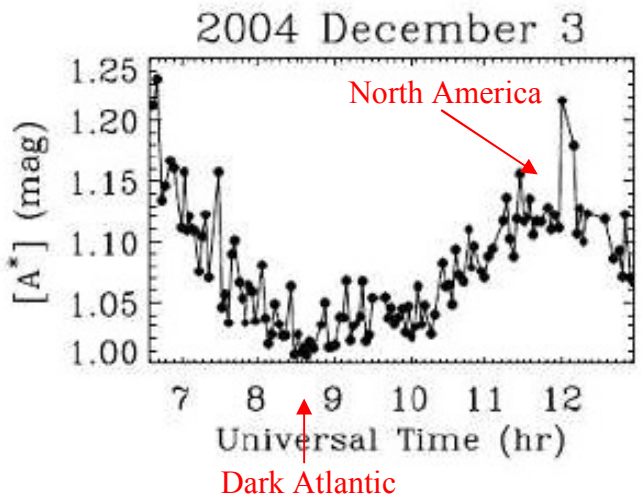
Here Leonardo repeats his belief that the moon shines because it is covered with water, and says that he believes the moon to be a heavy body with its own gravity and atmosphere.

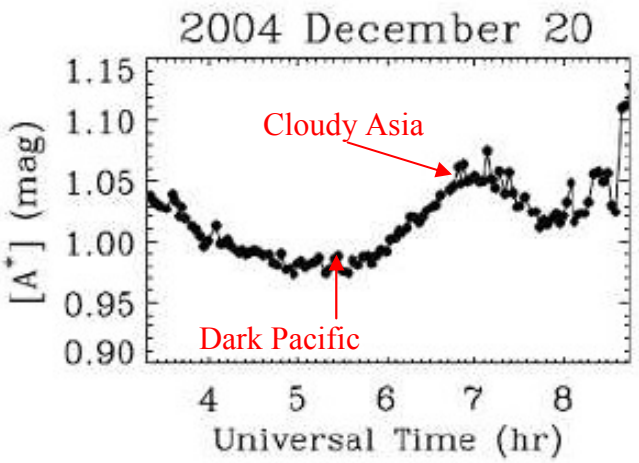
Here he explains how sunlight, reflected from the earth's oceans at sunset, causes the ghostly glow of the whole moon inside the crescent moon.

"...that glimmer visible in the middle between the horns of the new moon... this brightness at such a time being derived from our oceans, which are at that time illuminated by the sun, which is then on the point of setting..."





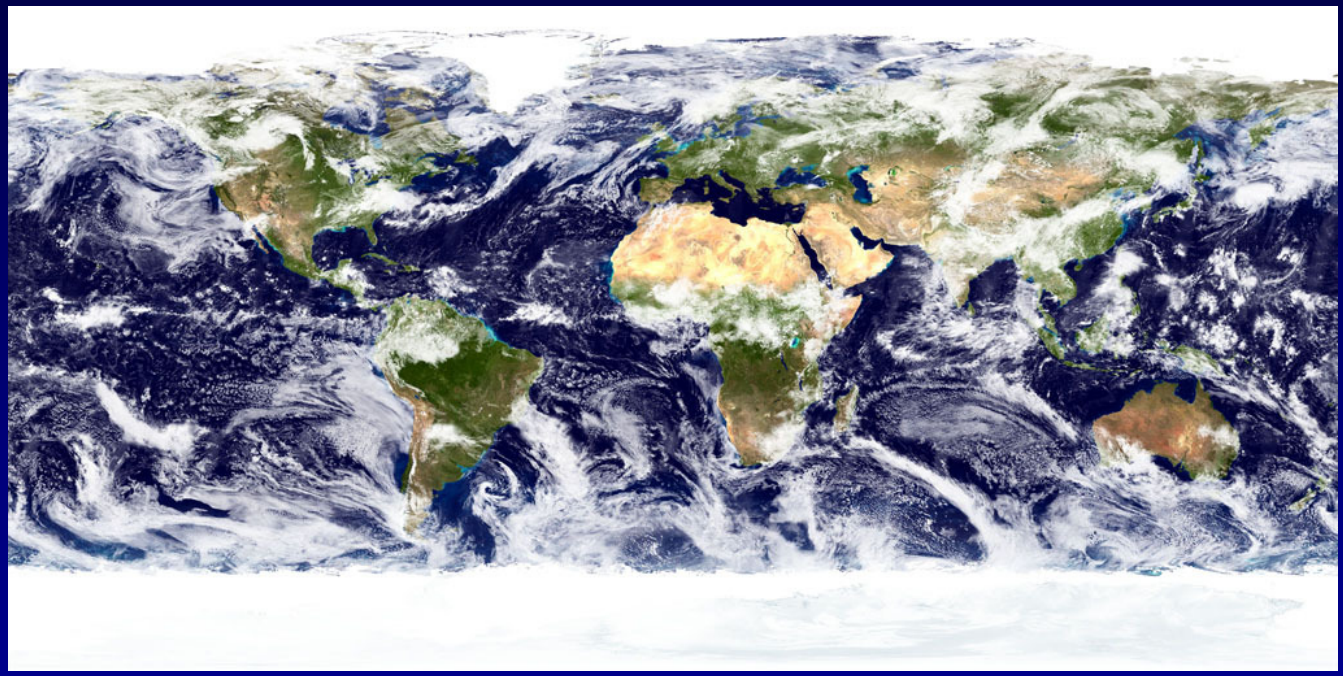




Global cloud data allow us a precise modeling of the earthshine-contributing area during our observations

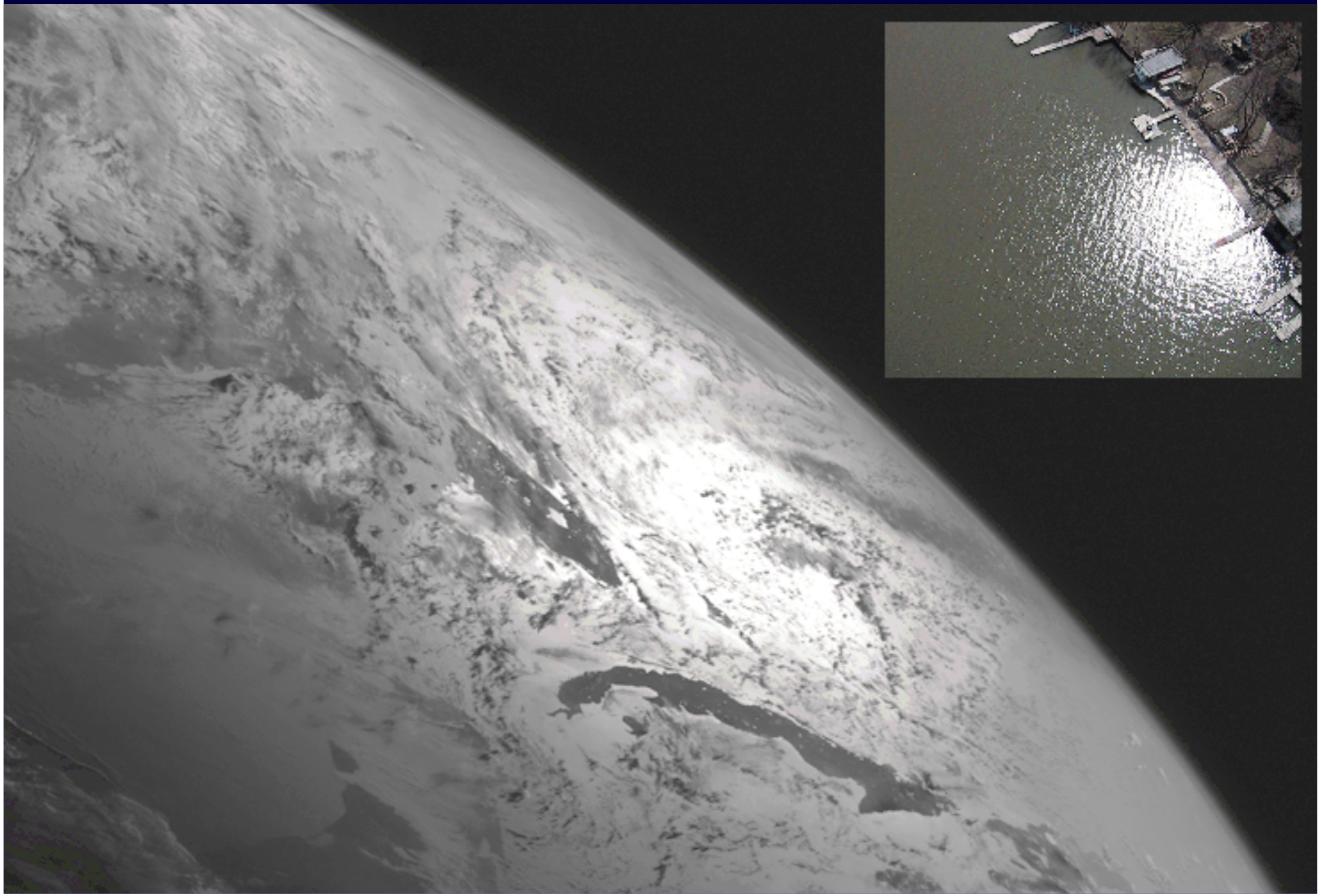
Palle et al, JGR, 2003

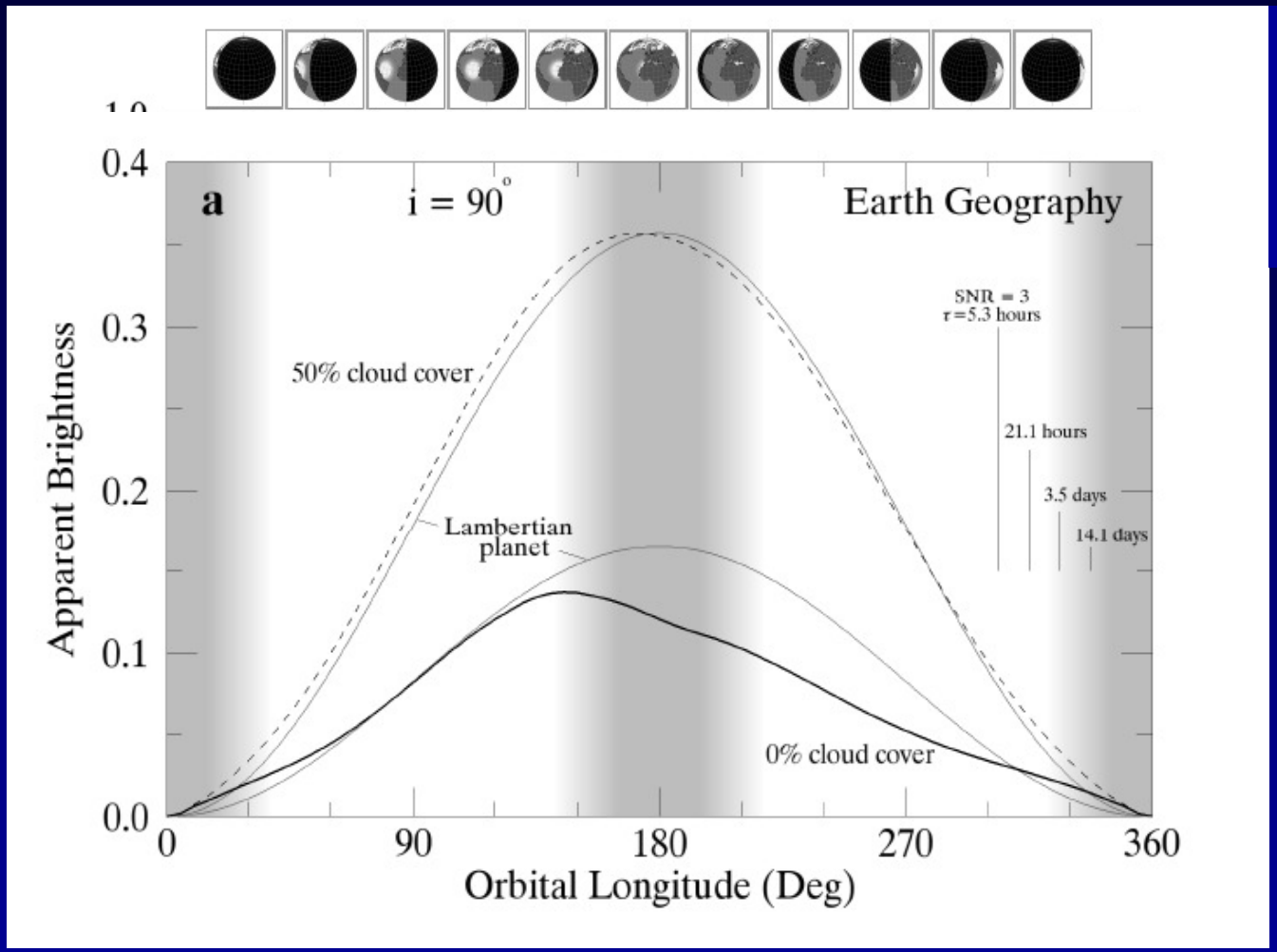
The Earth clouds: A unique feature in the solar system?



Even with the presence of clouds, there are clear daily and yearly photometric patterns with relatively large amplitude

Ocean Glint





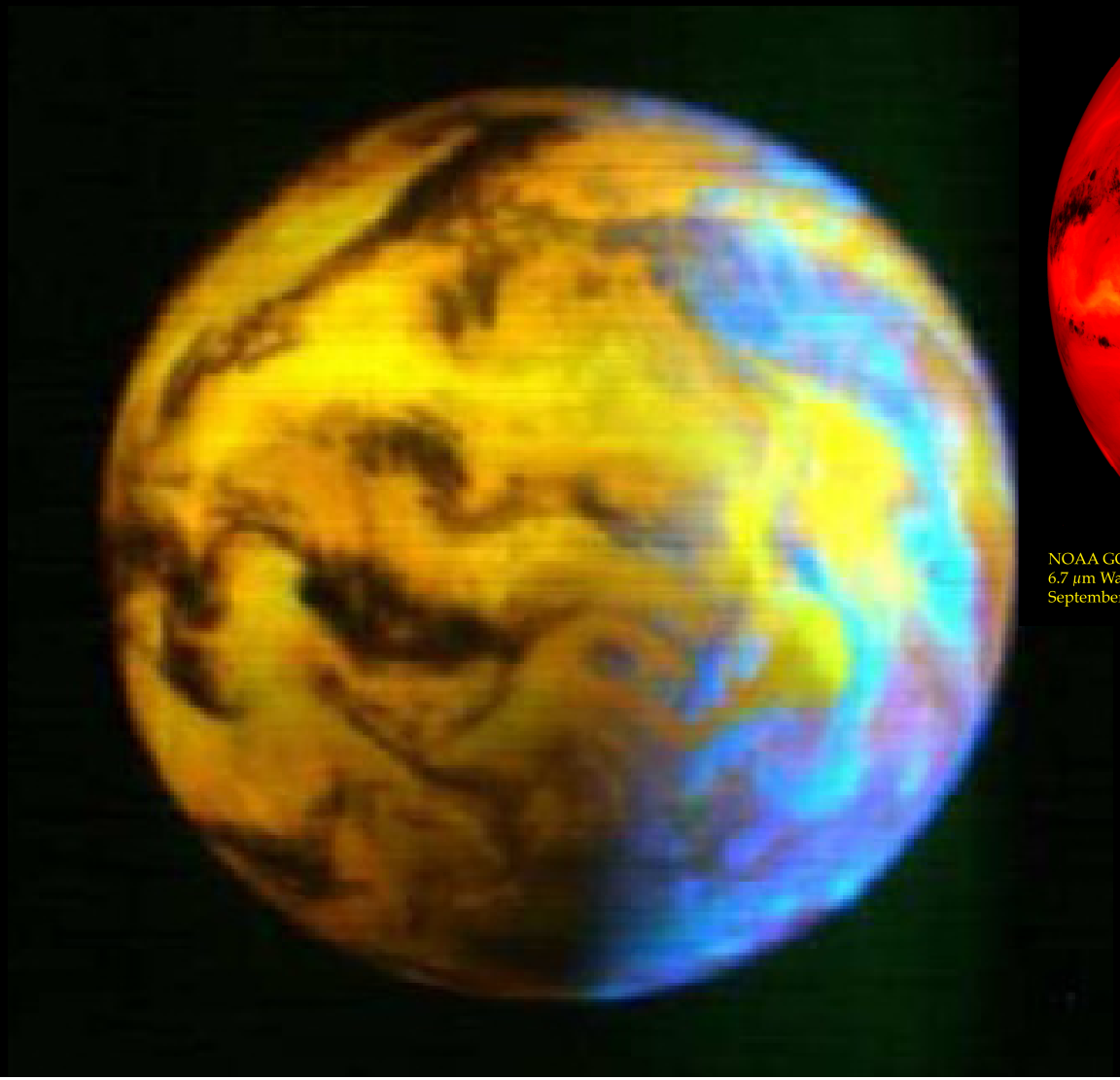
- ***Water***
- ***Smooth Ice***
- ***Thin clouds***
- ***Ethane***

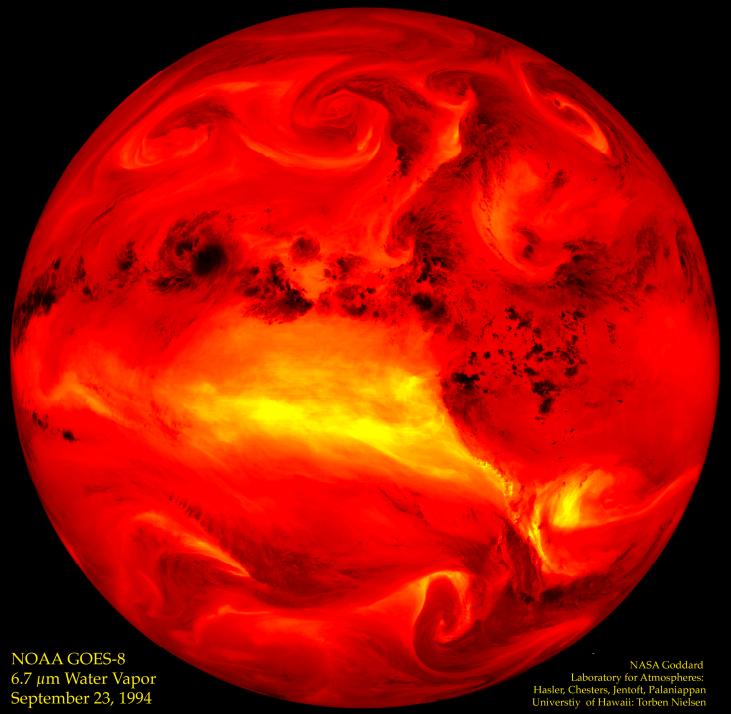
Williams & Gaidos, Icarus, 2008

Earthshine observations do not get us there and remote observations are missing


MESSENGER, 2005
2005-08-02T22:31:51.787612

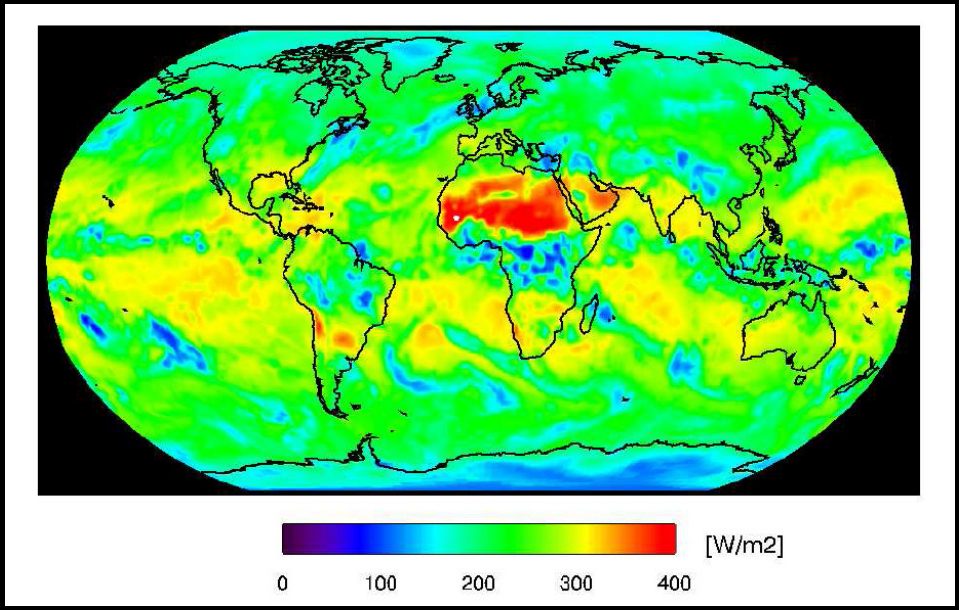
VIRTIS @ ROSETTA, 250,000 km from Earth





NOAA GOES-8
6.7 μm Water Vapor
September 23, 1994

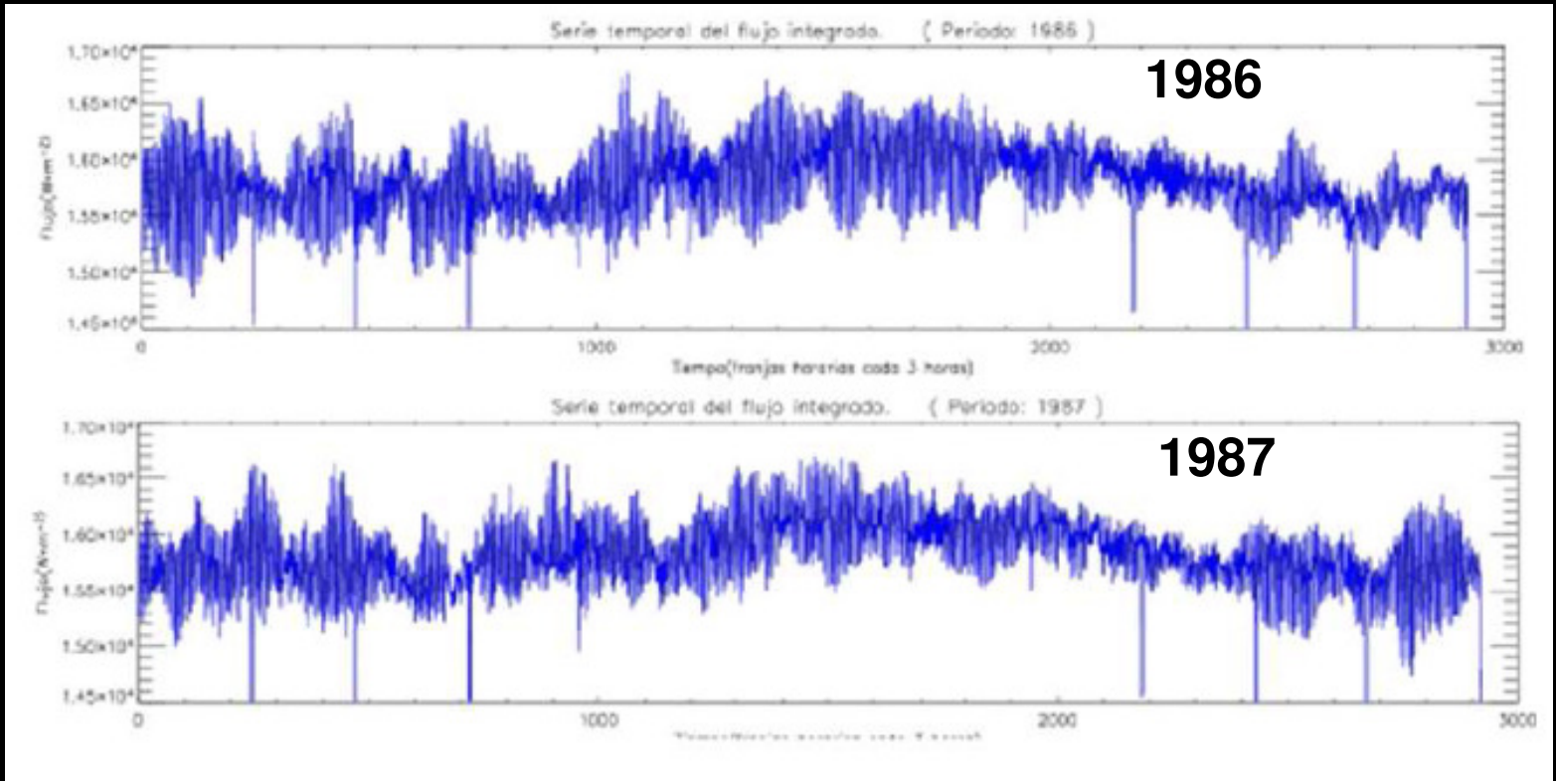
NASA Goddard
Laboratory for Atmospheres:
Hasler, Chesters, Jentoft, Palaniappan
Universtiy of Hawaii: Torben Nielsen



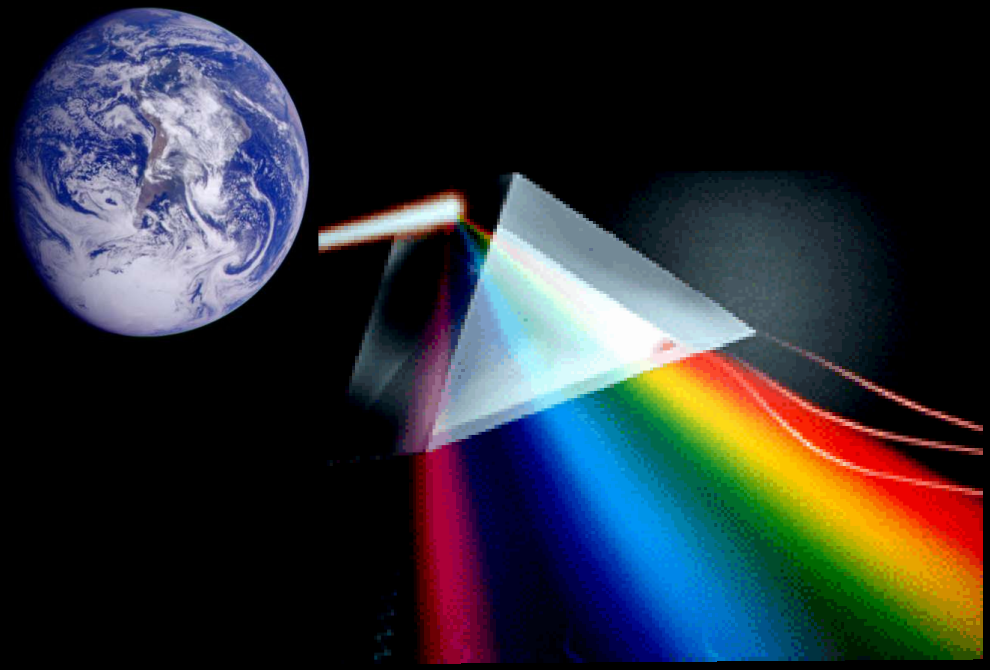
Variability in the IR is more muted than in the visible and strongly dependent con weather conditions.

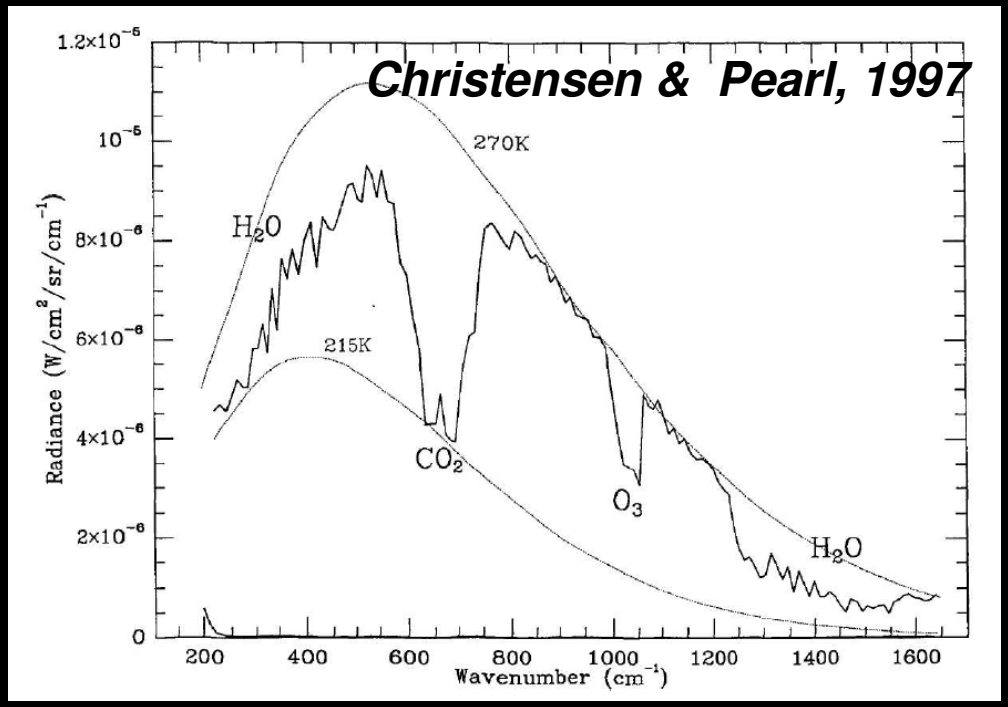
Sometimes the diurnal cycle is clear, sometimes it is missing.

Gomez, Palle, Selsis (in prep)

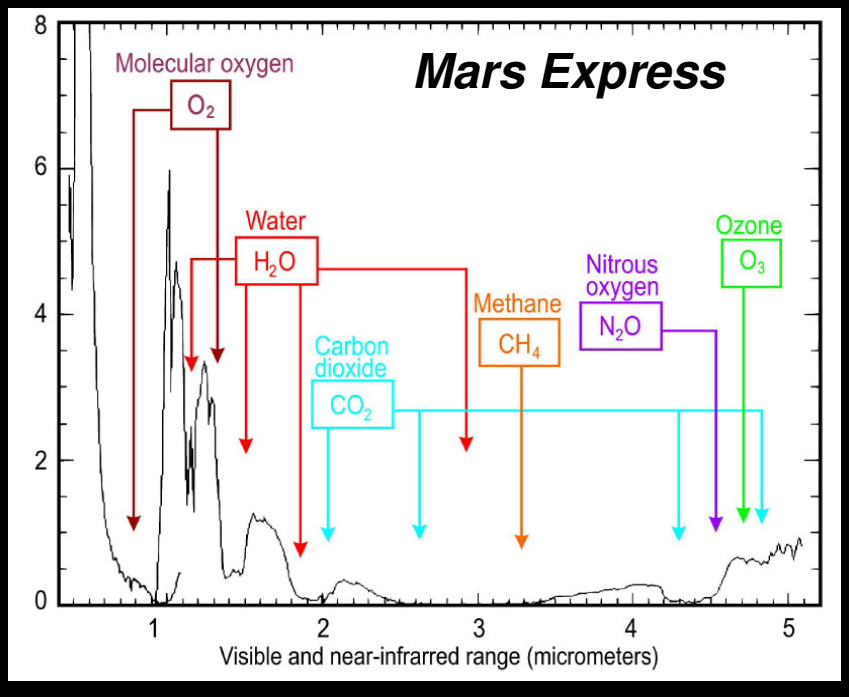


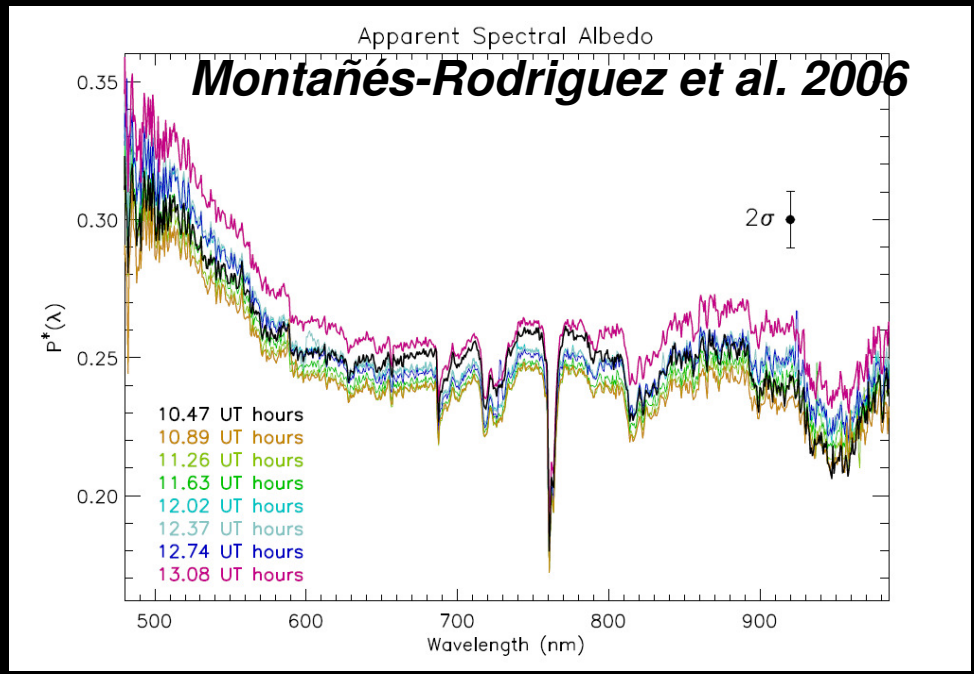
Earth's spectroscopy





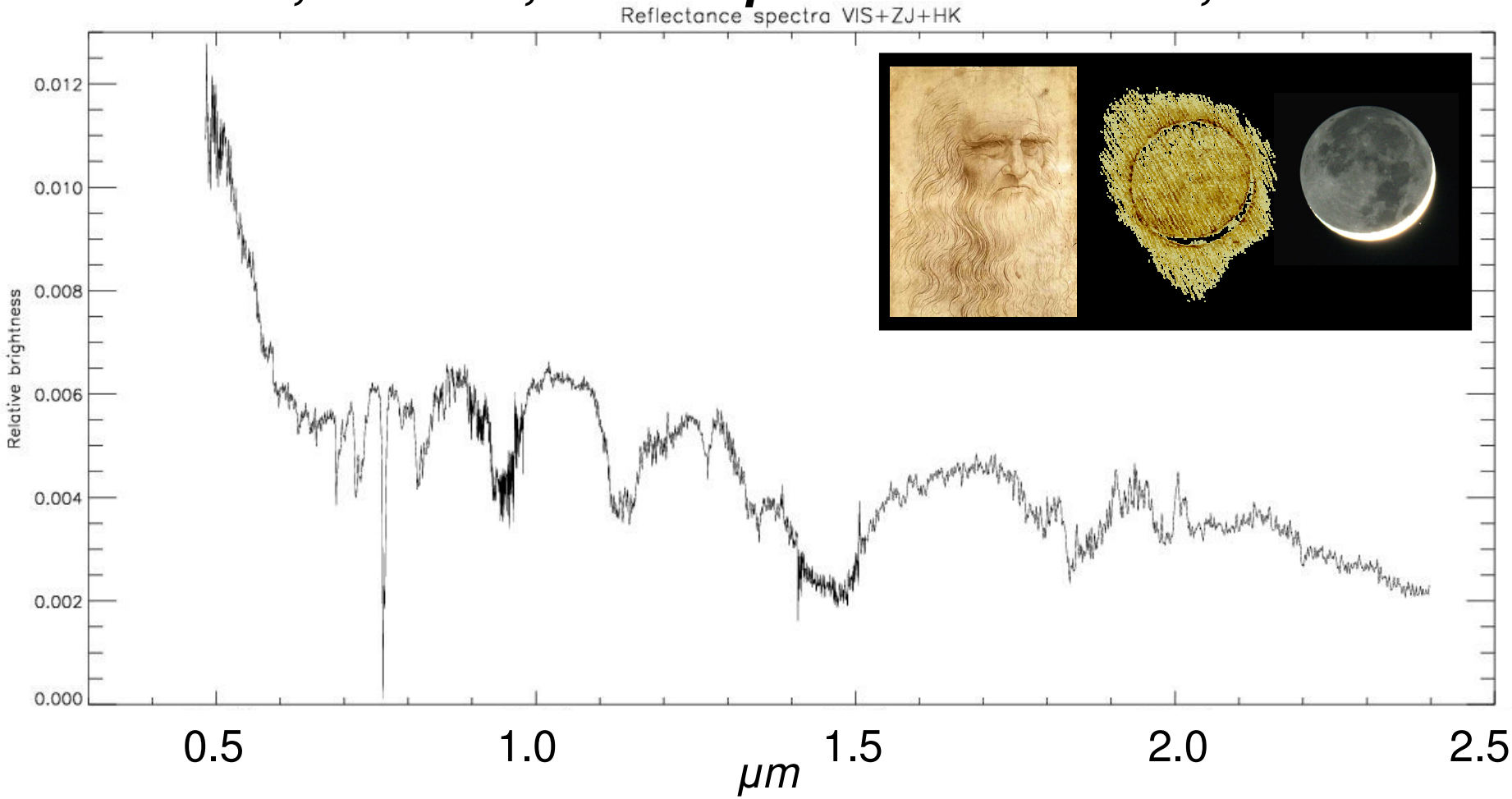
Atmospheric composition and major spectral features are well-characterized





Earth's Reflectance Spectrum: Earthshine

NOT, Visible, 0.4-1 μm
WHT, Near-IR, 0.9-2.5 μm ***La Palma, Canaries***



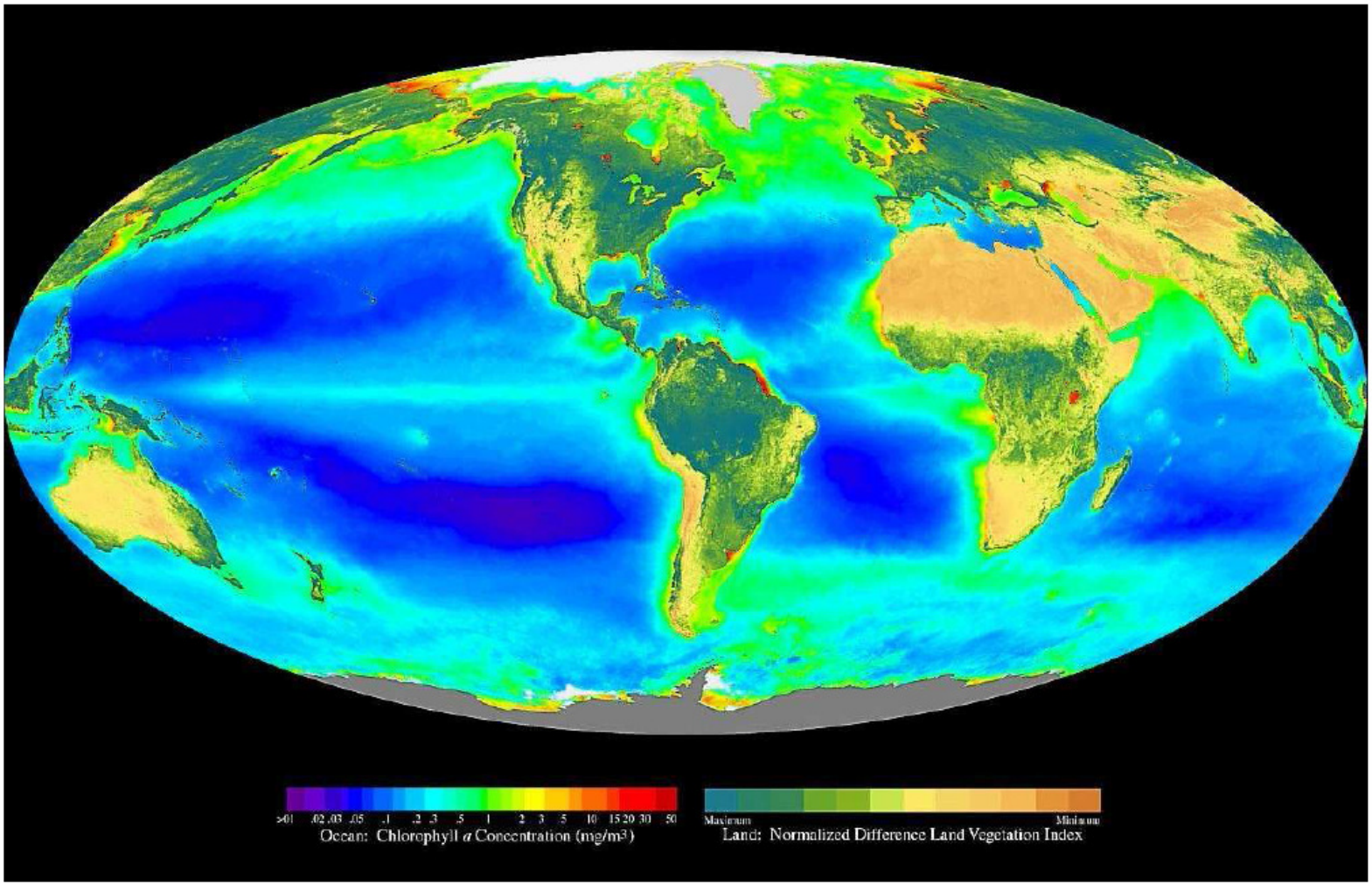


Fig. 5.8 This composite image gives an indication of the magnitude and distribution of global primary production, both oceanic (mg/m3 chlorophyll a) and terrestrial (NDVI). Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE. Data corresponding to the period September 1997 - August 1998

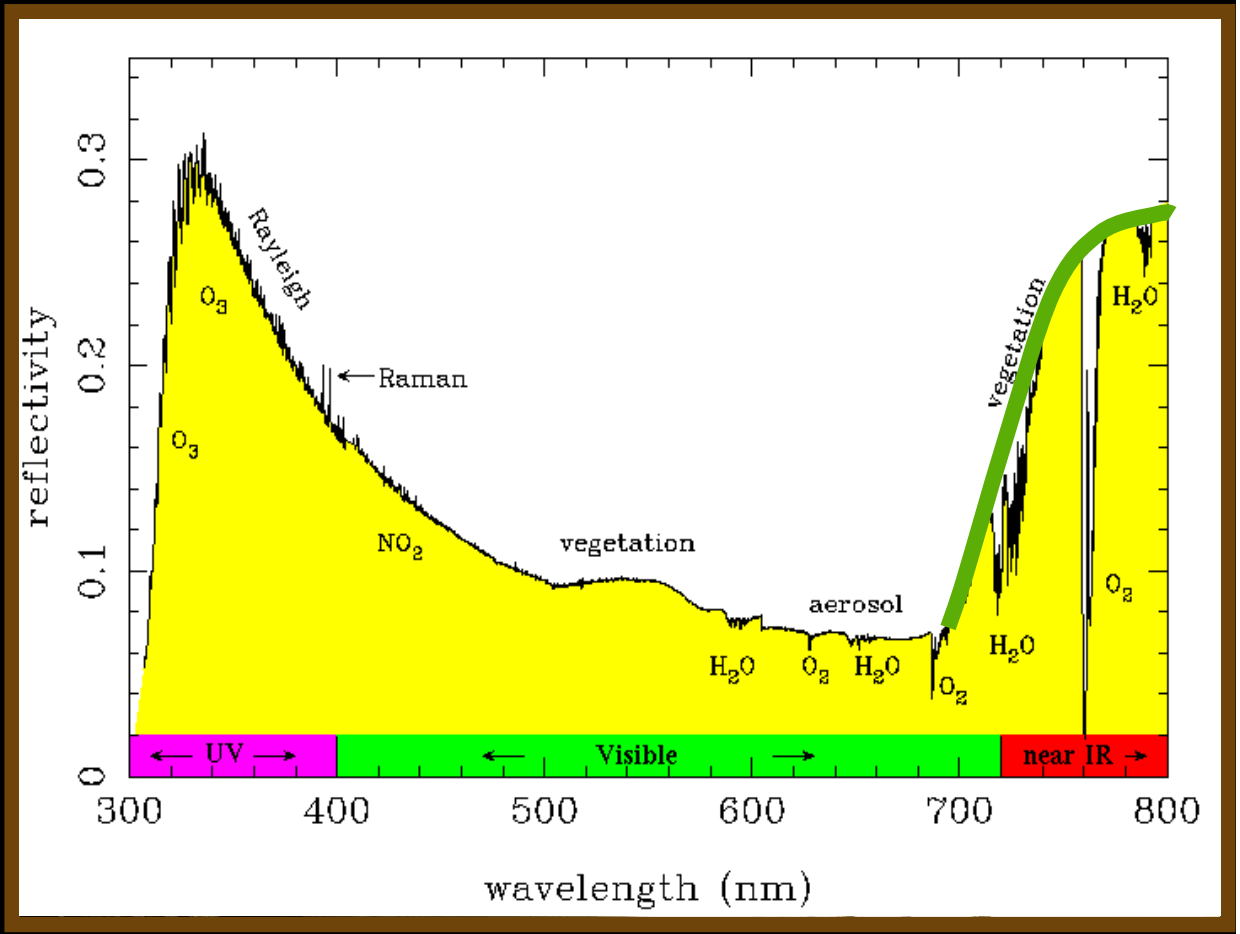
We searched for signatures of *complex life*

- Leaf reflectance has a sudden increase known as the “red edge” at approximately 700 *nm*

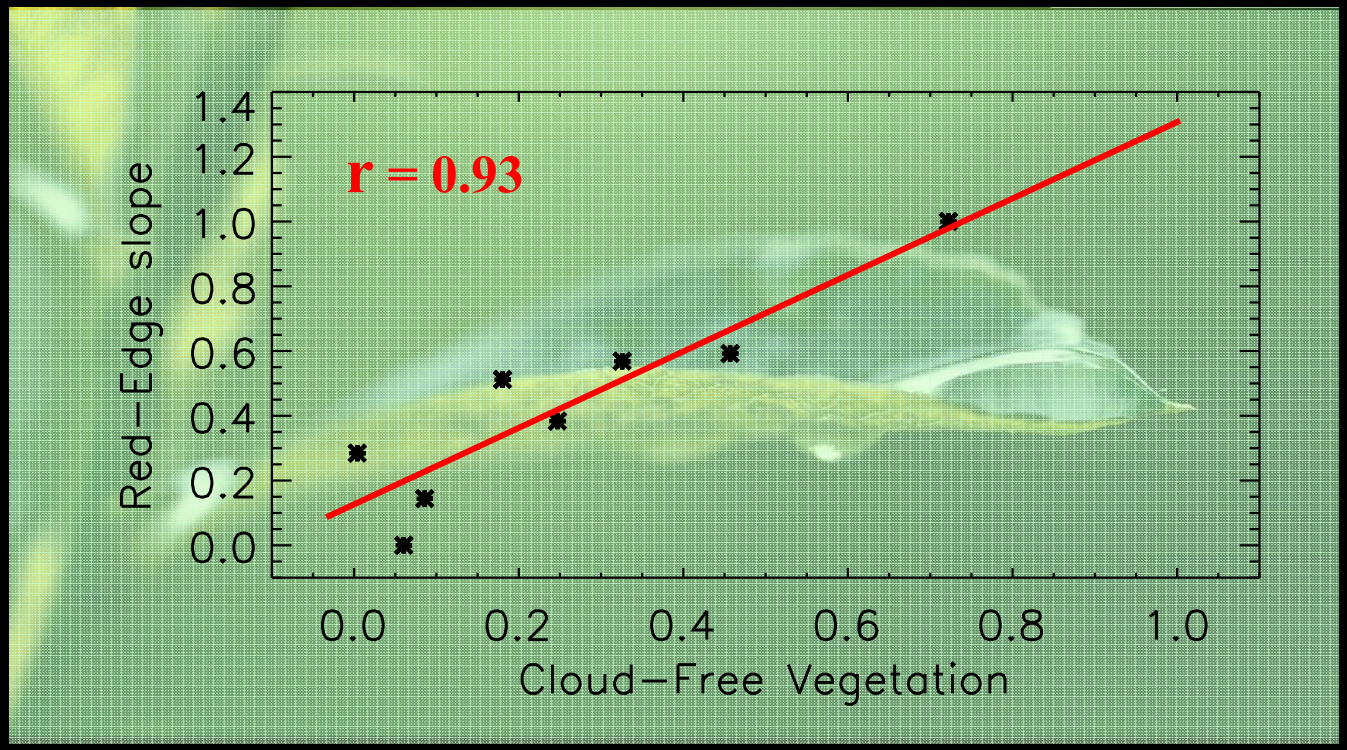
- Easily detected from aircrafts or satellites over spatially resolved green areas.

- Can it be detected at global scales?

60% of Earth’s surface is covered by clouds …

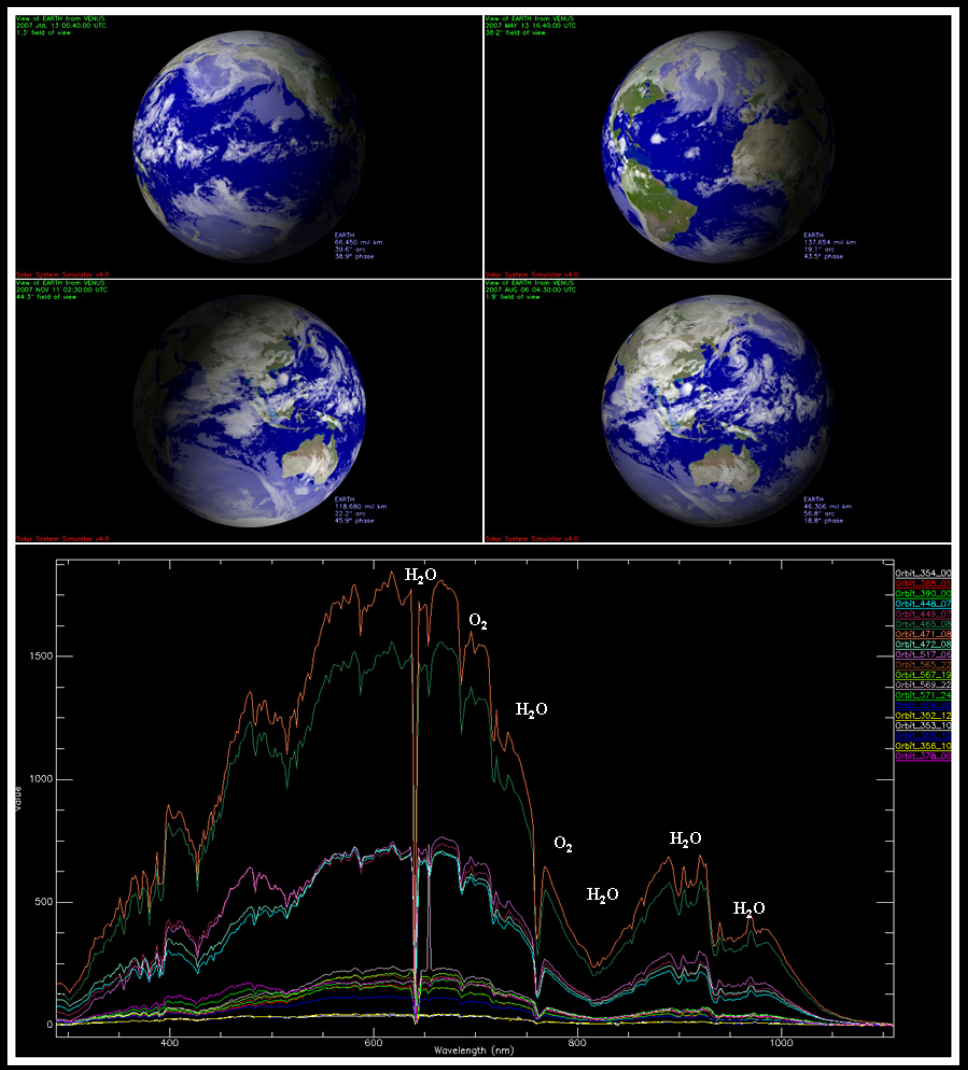


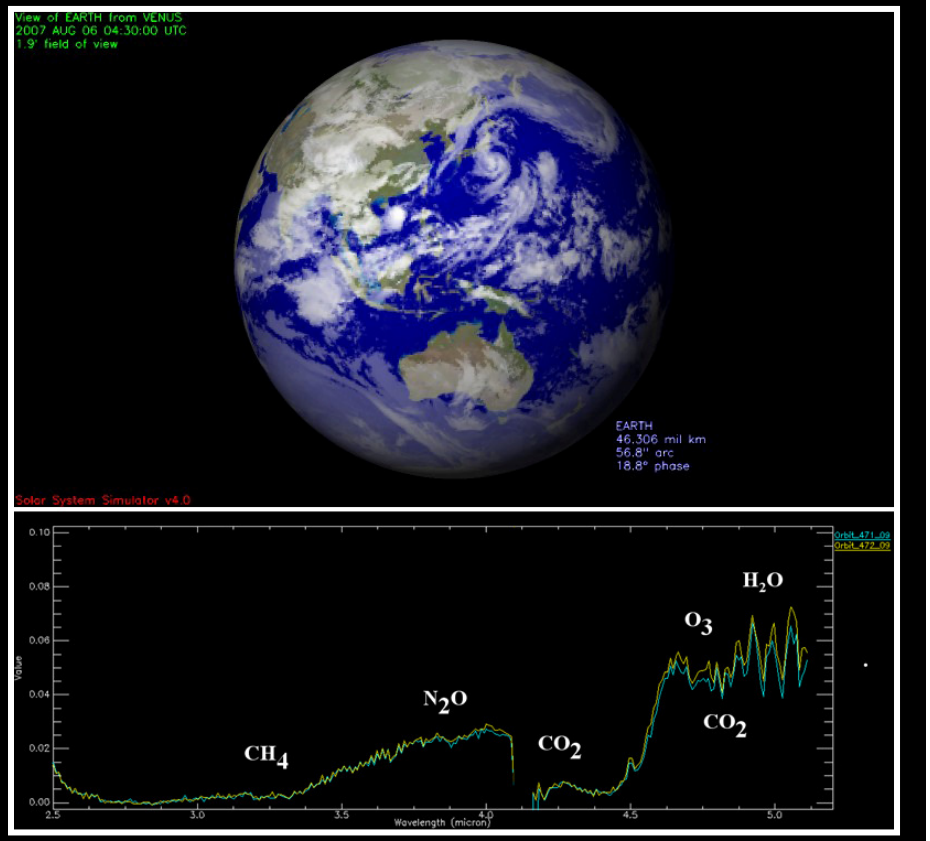
The terrestrial vegetation can be detected but the signal is very small ...



Montañes-Rodriguez et al ApJ, 2006

Venus Express repeated observations

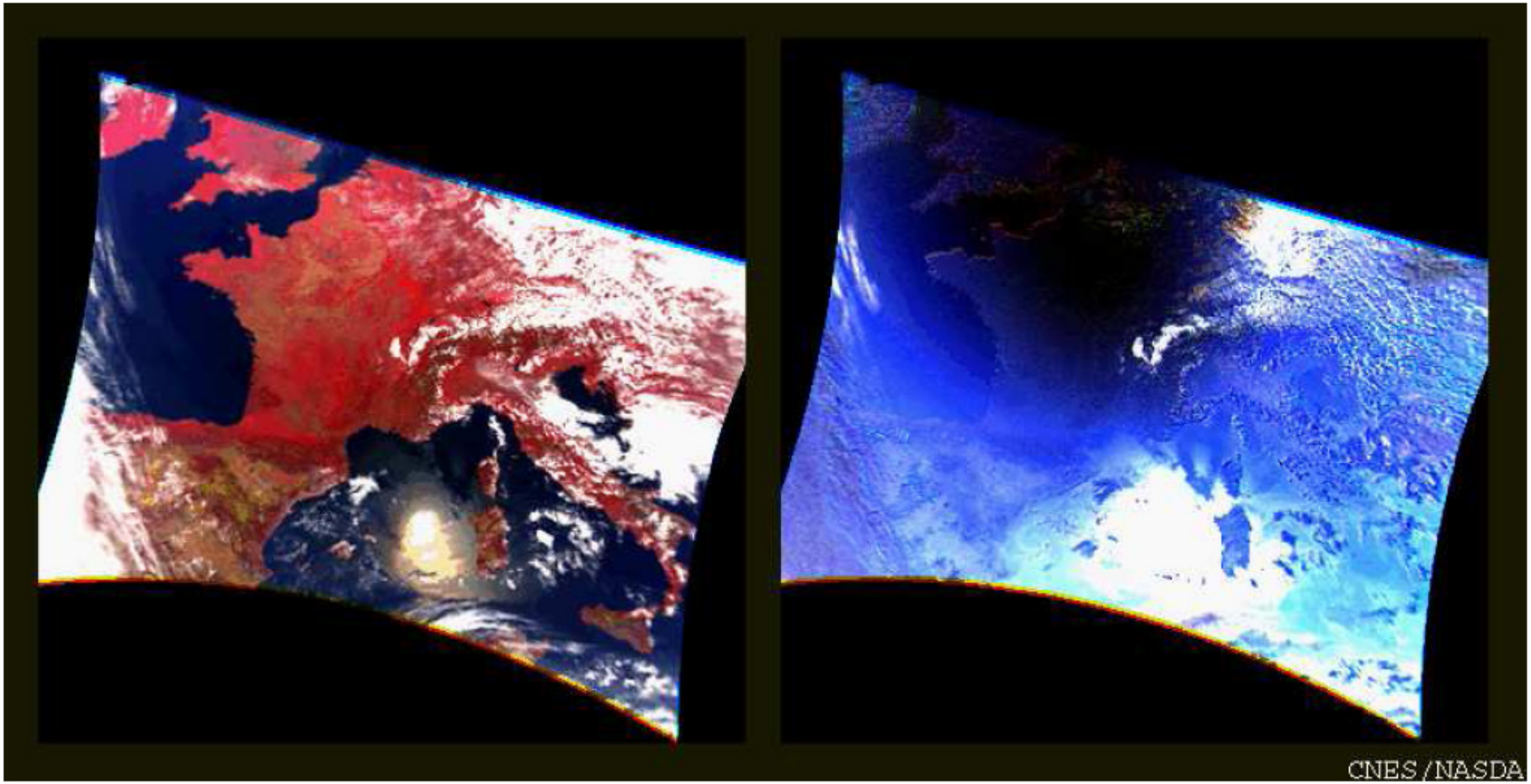




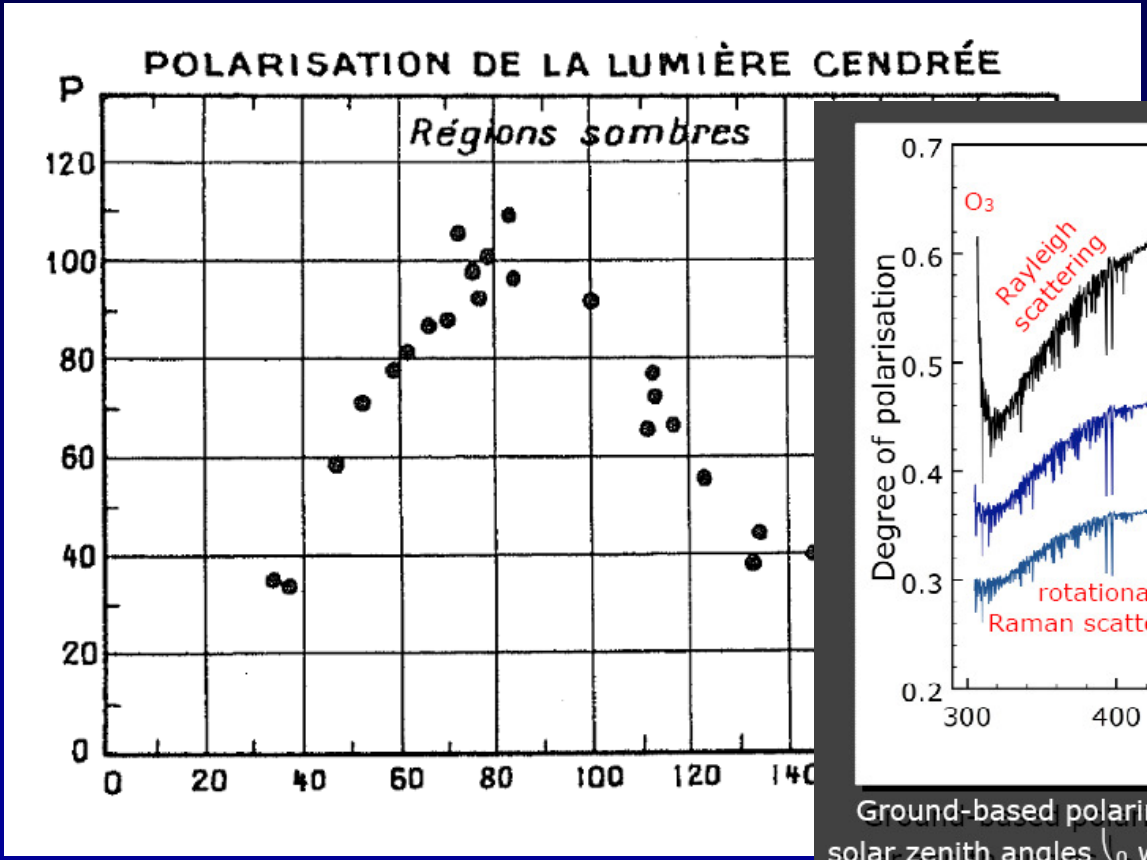
Earth's polarization

RGB composites from POLDER satellite

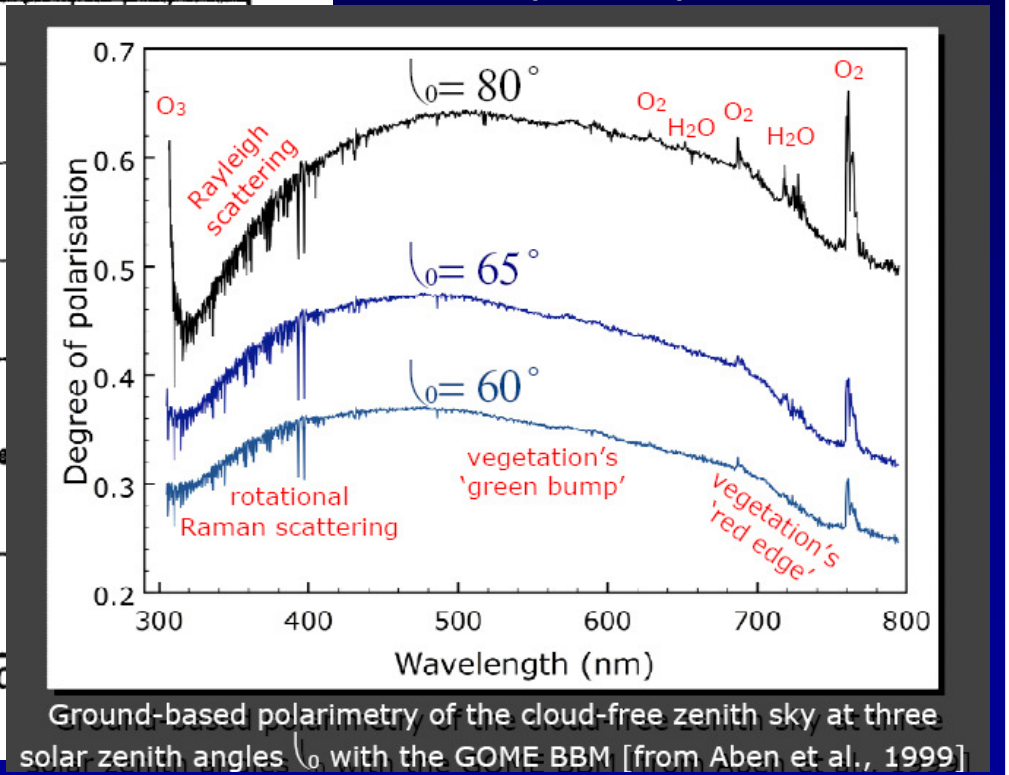
Un-polarized light ***Polarized light***



Dollfus (1945, 1957) made observations of the earthshine polarization at Pic du Midi, and obtained direct measurement of polarization from the ground from balloon observations.



Dollfus concluded that the atmospheric polarization

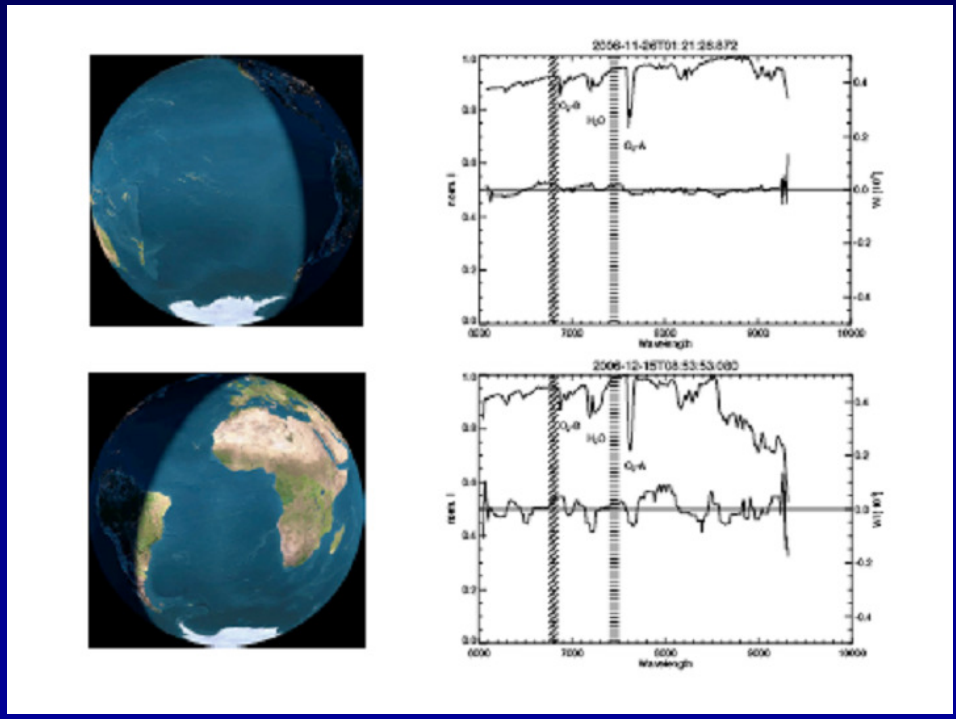


Ground-based polarimetry of the cloud-free zenith sky at three solar zenith angles θ_0 with the GOME BBM [from Aben et al., 1999]

McCullogh, 2008: Linear polarization could be a potentially useful signature of oceans and atmospheres of Earth-like extrasolar planets

Circular polarization

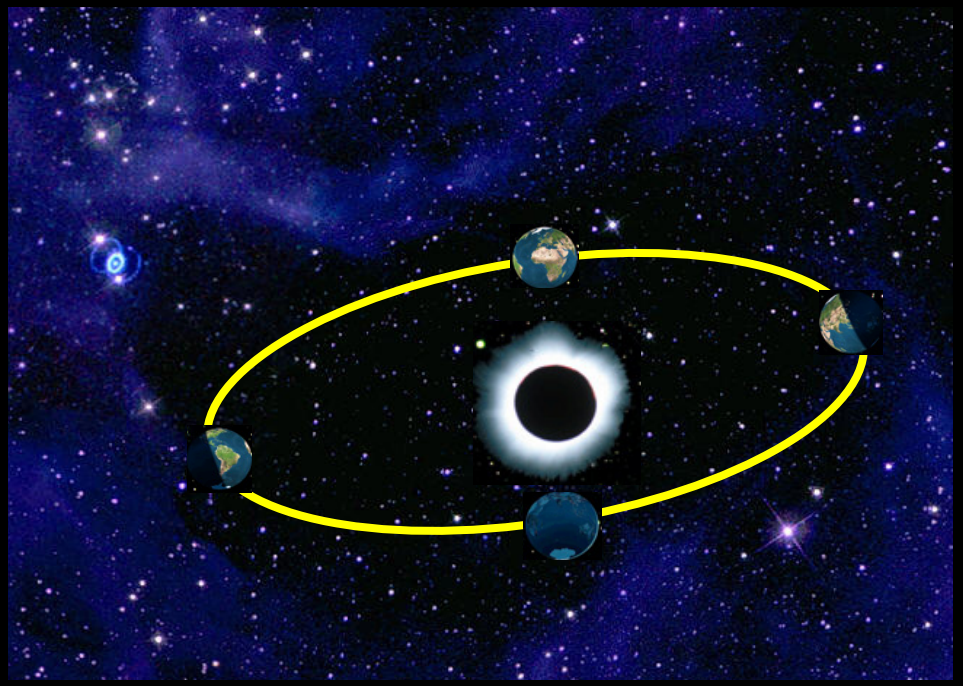
VLT, Chile. Sterzik et al, 2006



Homo-chirality, i.e. the exclusive use of L-amino acids and D-sugars in biological materials, causes a significant induction of circular polarization in the diffuse reflectance spectra of biotic material

Preliminary interpreted as the signature of biotic homochirality, and therefore life, on Earth

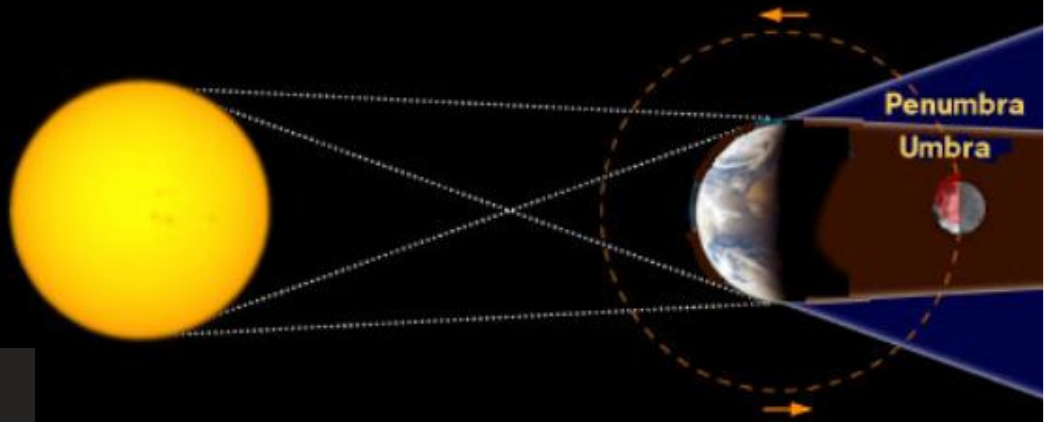
But what if direct detection is not possible?

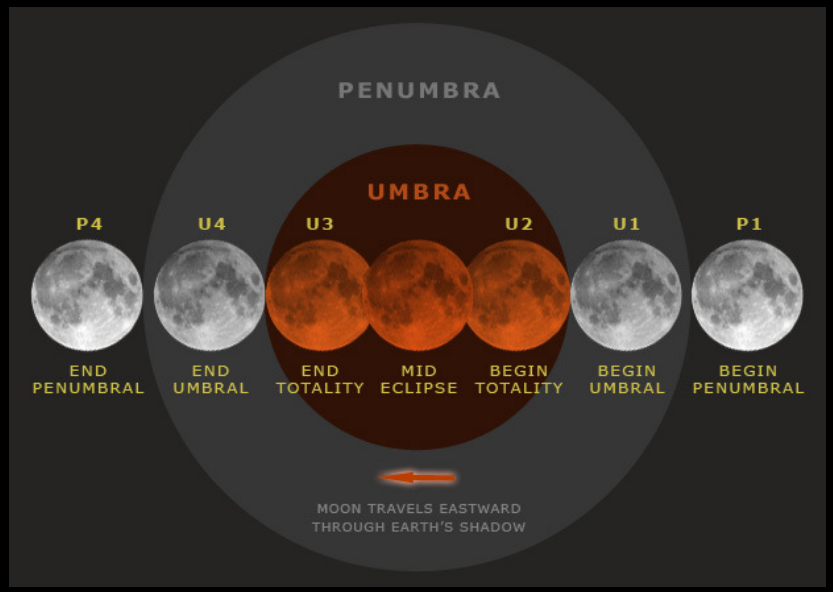


What about transiting Earths?

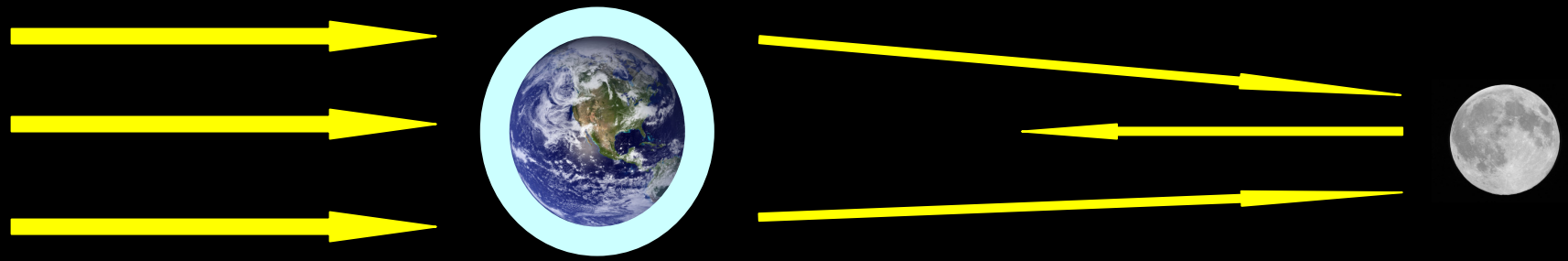
CoRoT
KEPLER

We can observe it during a lunar eclipse

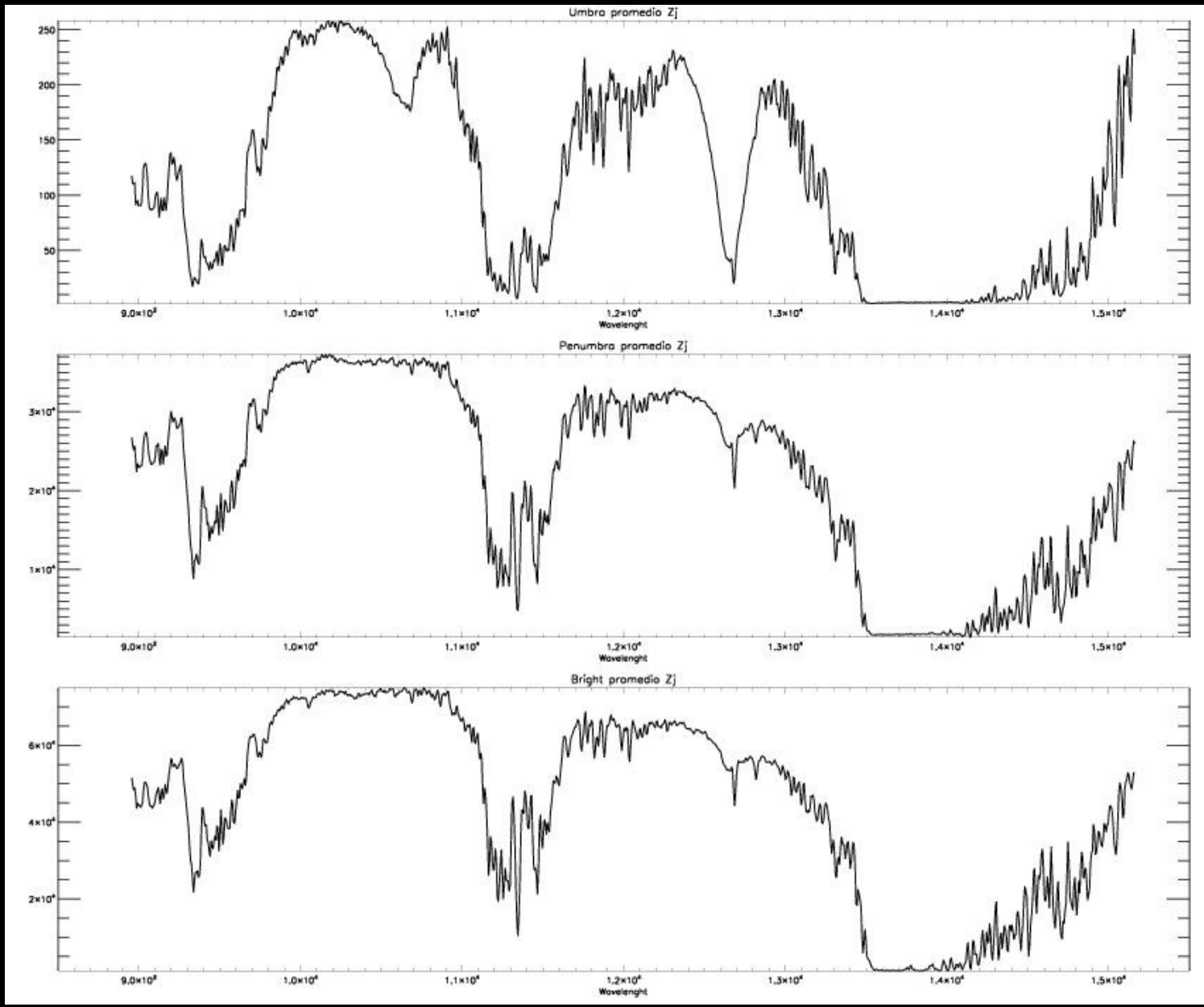




Same instrumentation only two months apart



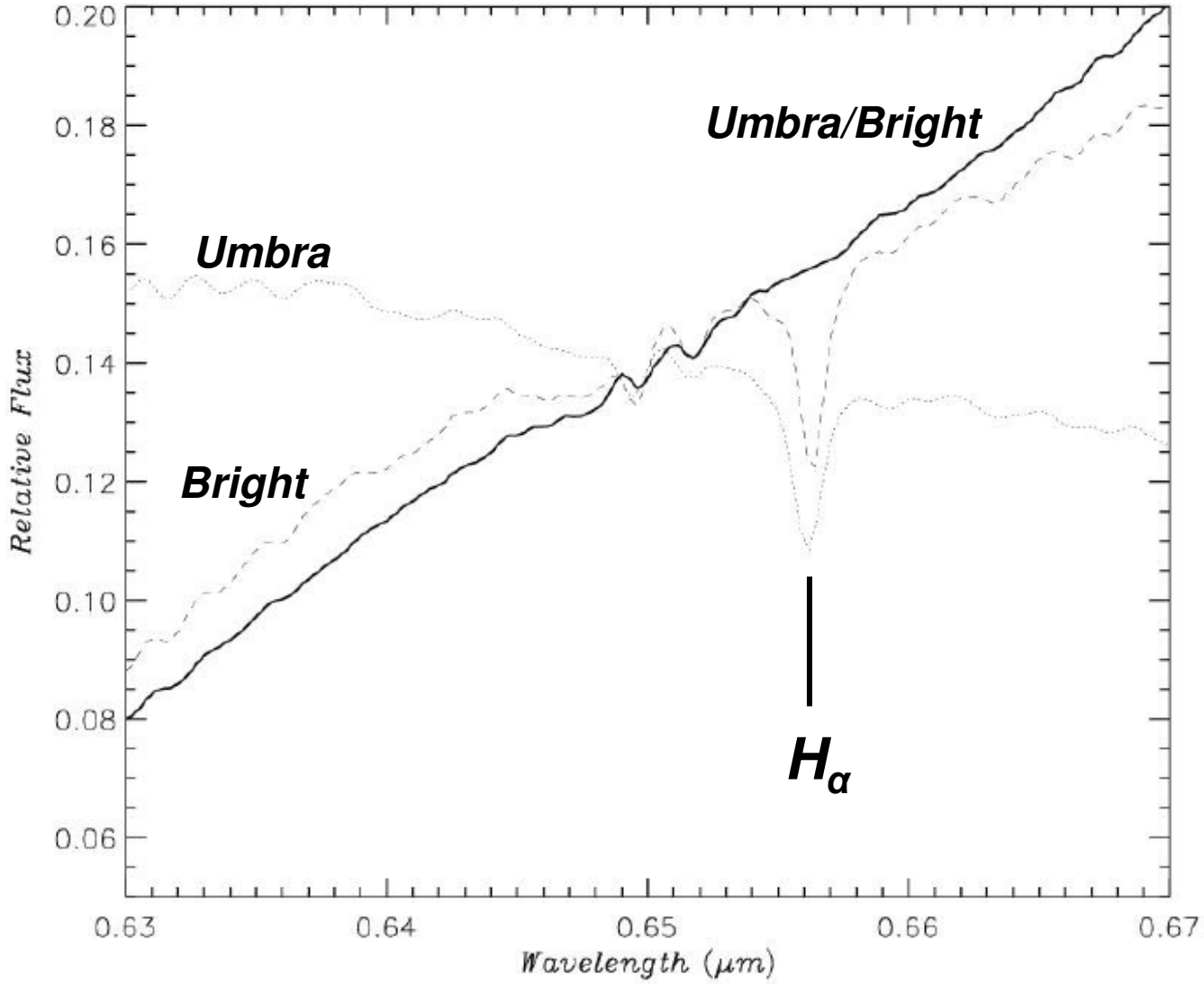

Lunar eclipse
August 16th 2008
um, 38m
FOV 94.5°
63.5 FPS
2008-08-16 21:22:04



Umbra

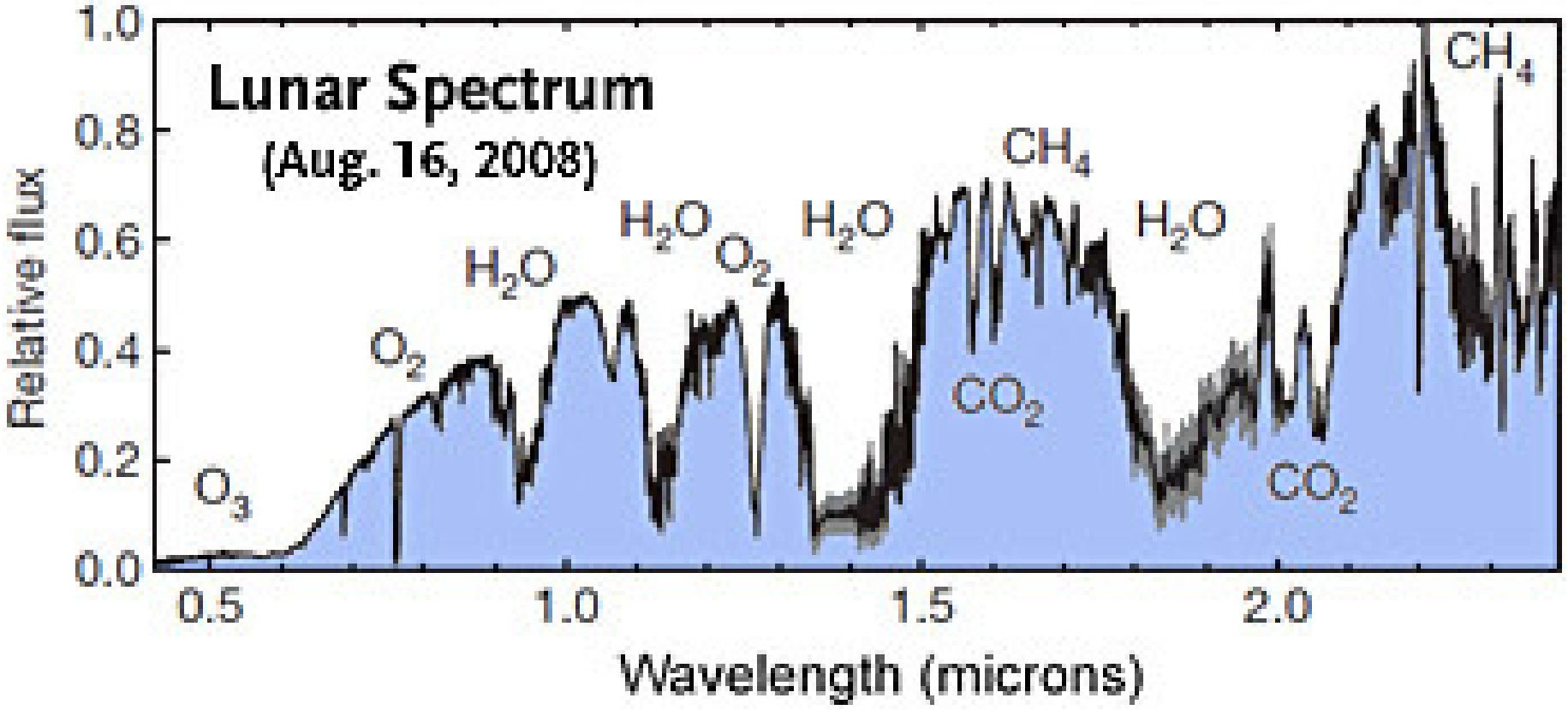
Penumbra

Brigth Moon

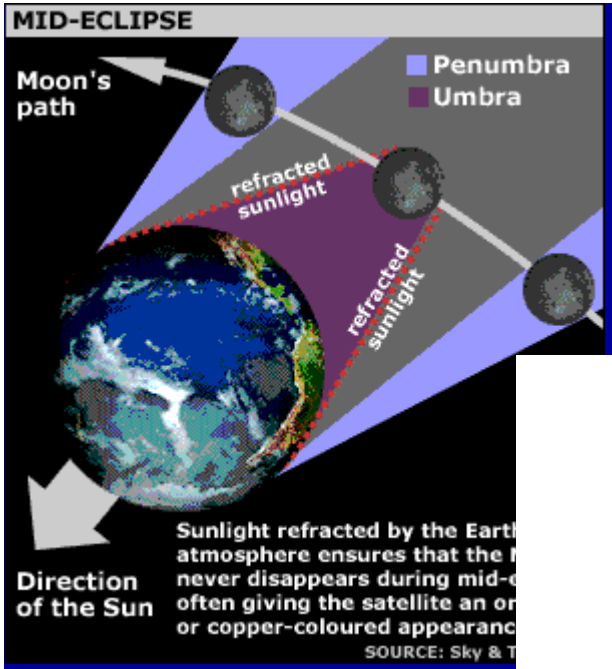

0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
Relative Flux
0.63
0.64
0.65
0.66
0.67
Wavelength (μm)
Umbra/Bright
Umbra
Bright
Hα

Earth's Transmission Spectrum

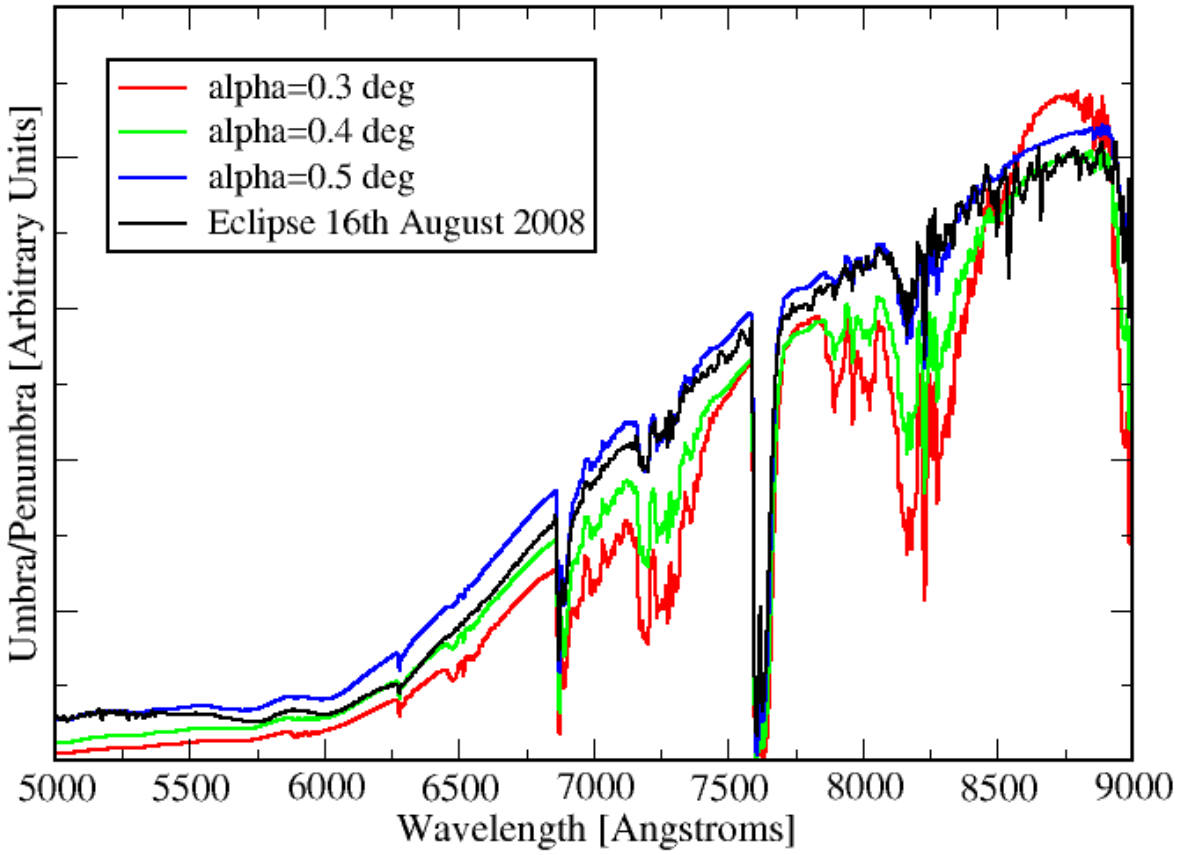
The pale *red* dot

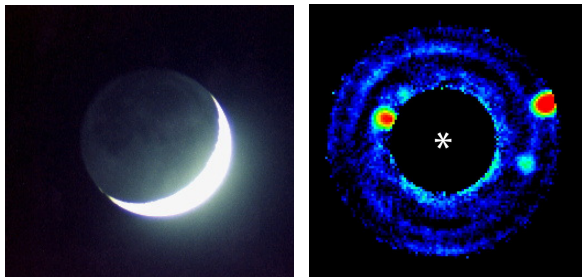


Palle et al, Nature, 2009



Garcia-Muñoz et al, in preparation

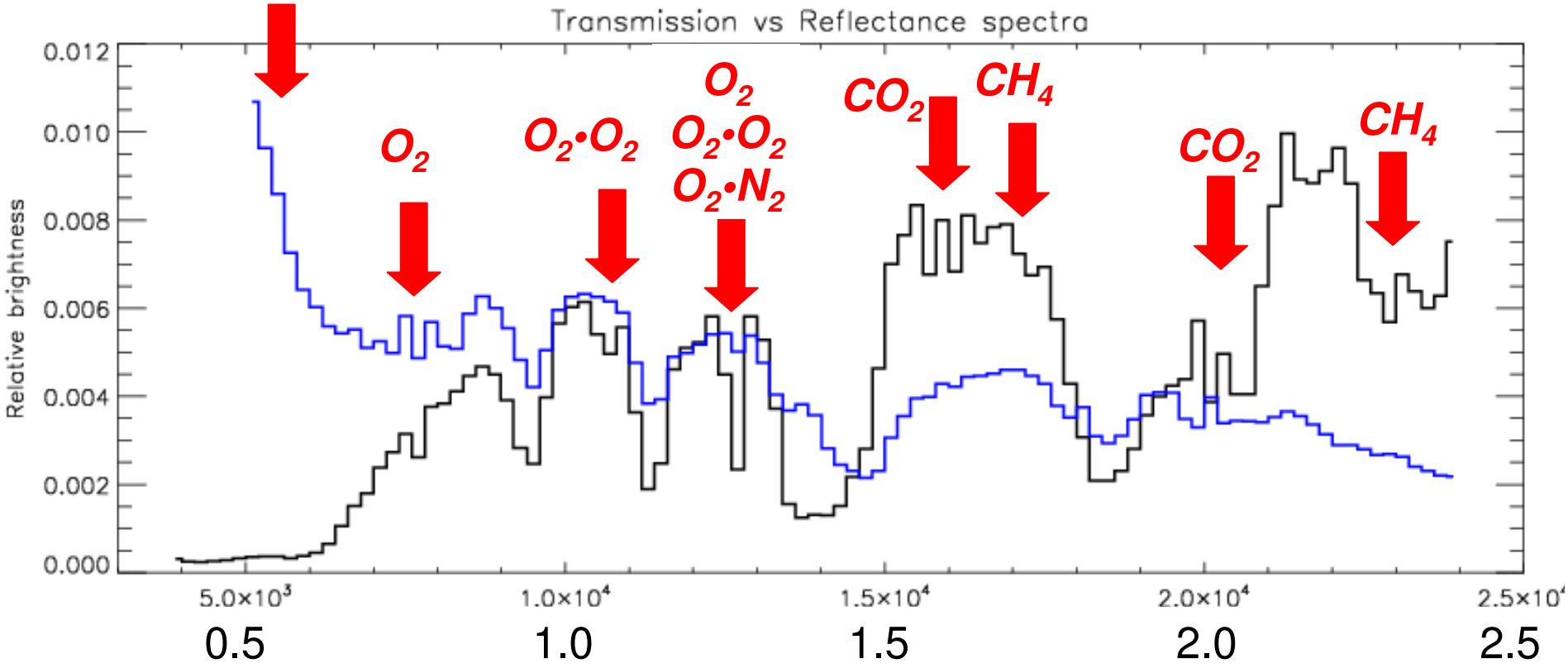




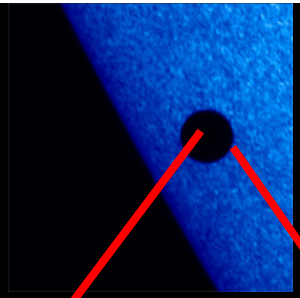
Reflected spectrum

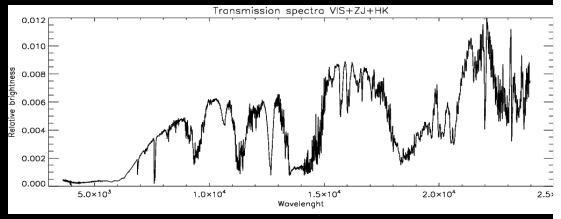
Transmission Spectrum

Blue planet?



Palle et al, Nature, 2009





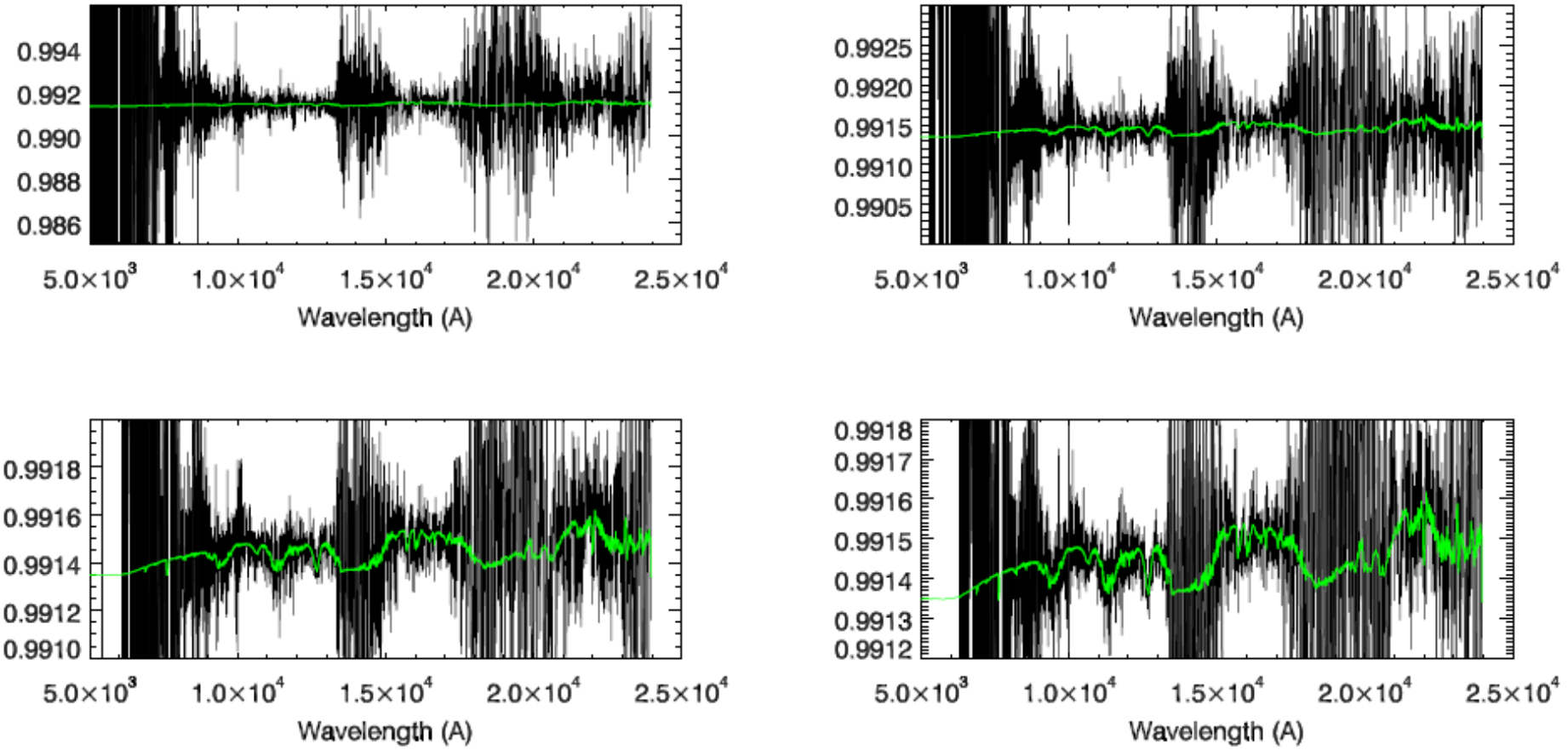
$$\frac{F^* - F^*\left(\frac{A_{p^*a}}{A_*}\right) + F^*\left(\frac{A_a}{A_*}\right) T}{F^*}$$

+ Noise

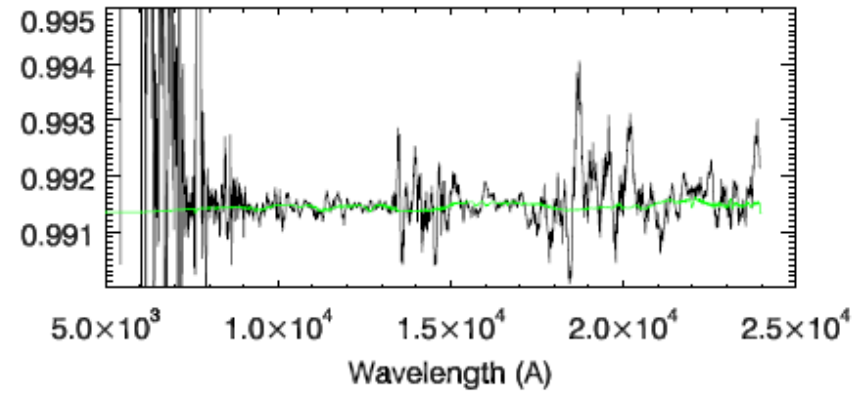
+ Noise

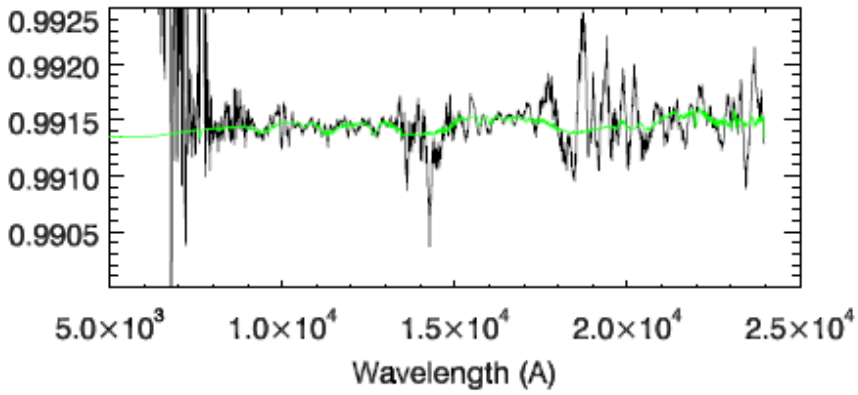
But, how far are we from making the measurements ?

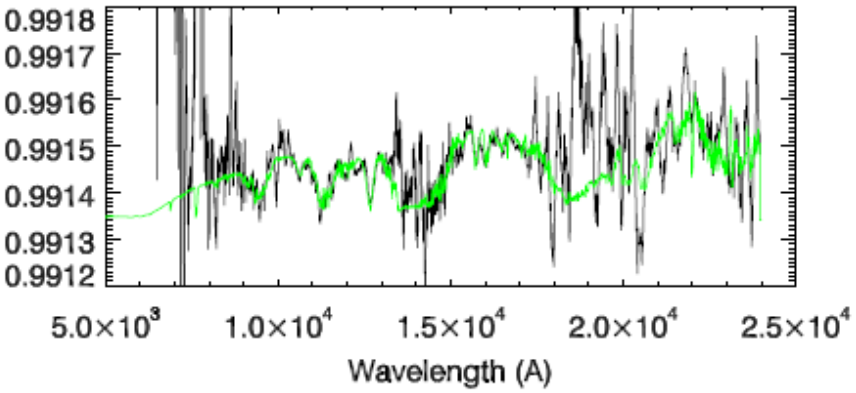
5, 20, 100 and 1,000 co-added observations

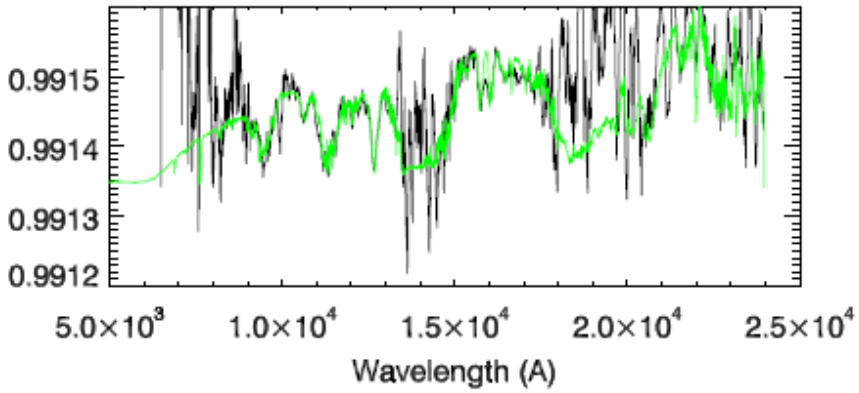


Palle et al, in preparation









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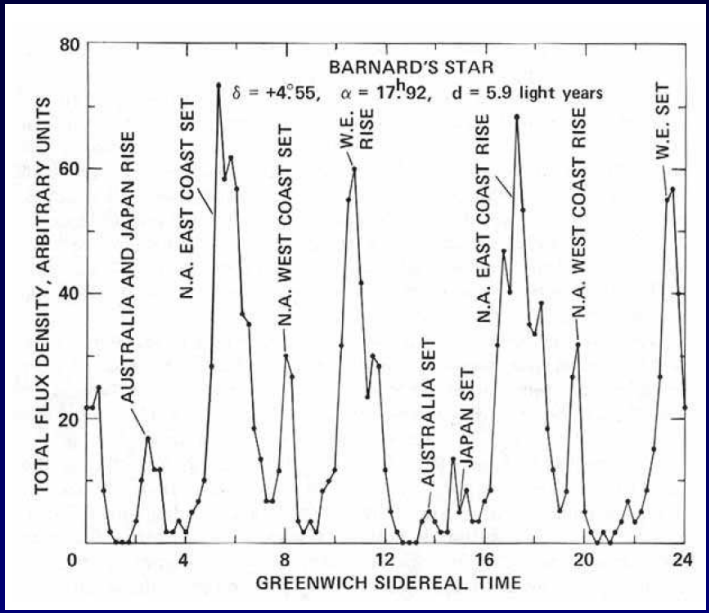
Amount of hours of in-transit integration to retrieve atmospheric species, supposing a 42-m ELT telescope and no telluric atmospheric effects

Star	Planet size		H_2O	$H_2O + O_2$	$H_2O + O_2 + (CH_4/CO_2)$
	R_p	R_{atm}[km]	Time [$hours$]		
M8	R_e	40	25	25	25
M8	R_e	100	5	5	5
M8	2^*R_e	40	1	5	5
M8	2^*R_e	100	1	1	5
M4	R_e	40	170	170	500
M4	R_e	100	5	50	500
M4	2^*R_e	100	5	5	5
G2	R_e	100	?	?	?
G2	2^*R_e	100	?	?	?

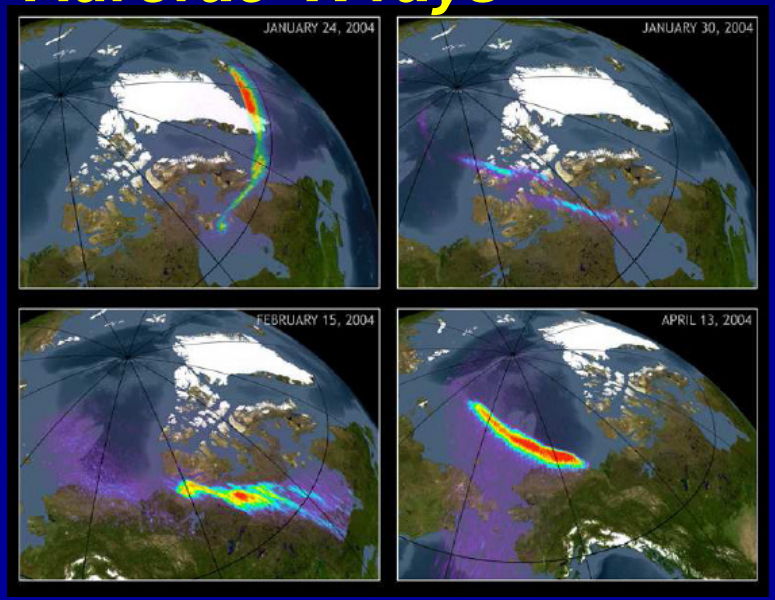
Palle et al, in preparation

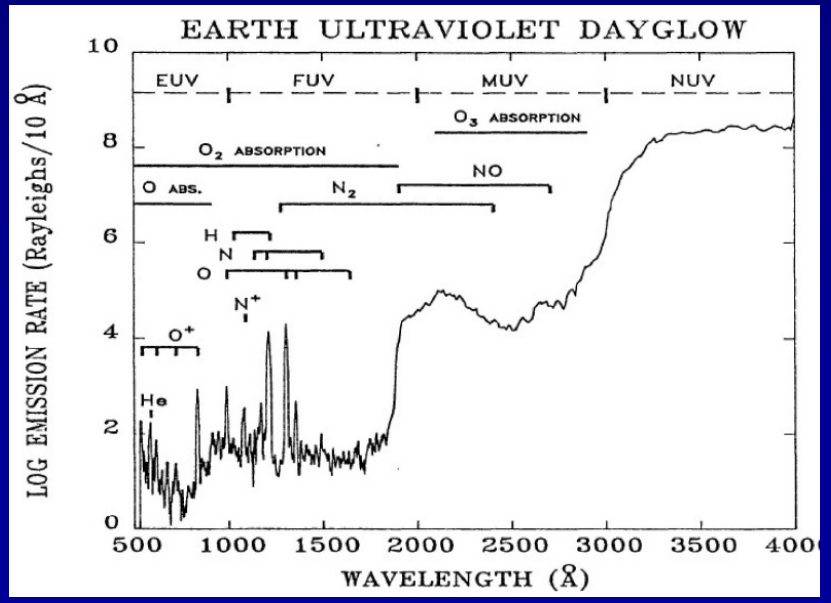
TV radiation



Geocorona - UV

Aurorae X-rays






T 04:00:20:00
UAF

"To do" list ... while waiting to reach 51%

- Determine what is detectable and what is not, and at what level
- Photometry
  - Infrared earth photometry data is missing
  - Characterization of the glint scattering
  - Variability characterization and modeling for exoplanets
- Spectroscopy:
  - Characterization of variability in IR range (no empirical data)
  - Characterizing the transmission spectra of earth along waveleght and time
  - High resolution observations to prepare for ground-base exoplanet detection.
- Polarization
  - Characterize size and variability of globally-integrated polarization (glint, clouds, dust,..)
  - Presence of biomass from circular polarization
- Modeling:
  - Exhaustive reflection and transmission models
  - .. but also flexible for extrasolar planet extrapolation
  - Need to improve molecular databases
  - Use the earth sciences databases available
  - Unexplainable atmospheric composition /properties