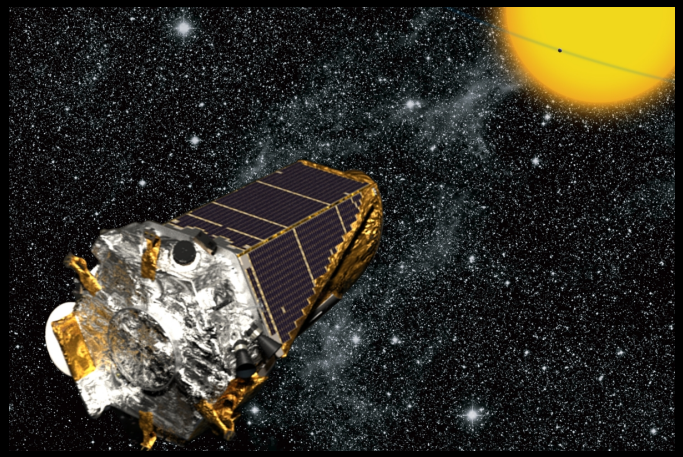
The Earth as a distant planet

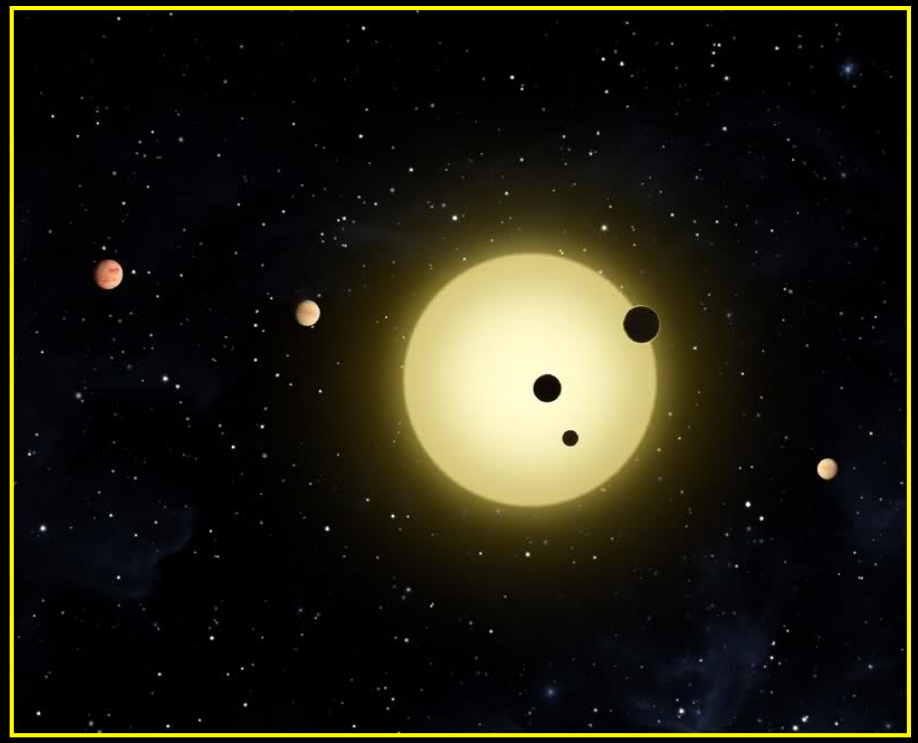
Enric Pallé & many more
Instituto de Astrofísica de Canarias

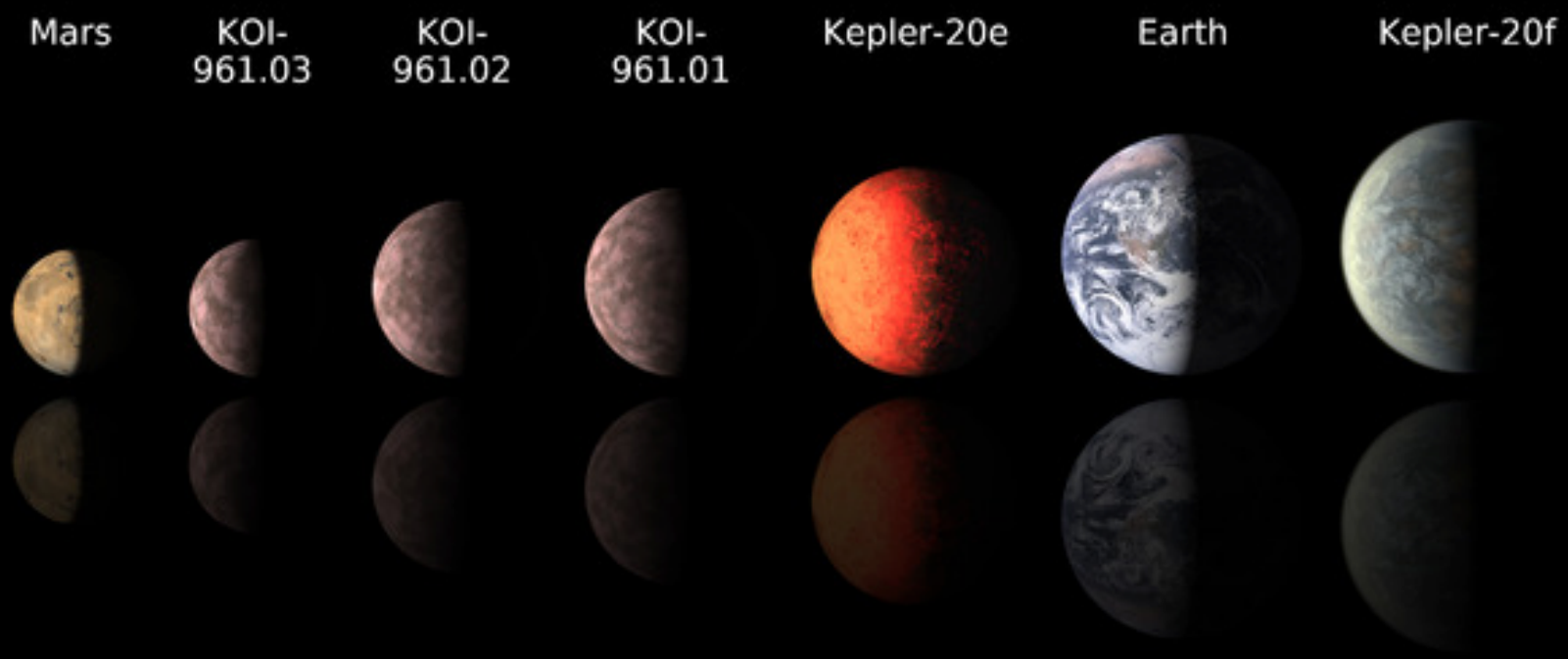
OPS II Vitacura 2012

Astrobiology and the search for life.

Last year….





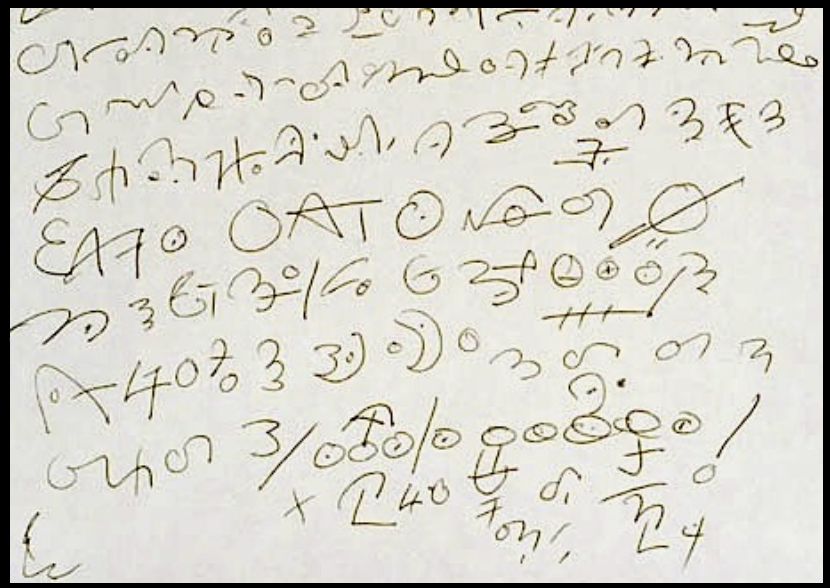

Mars
KOI-961.03
KOI-961.02
KOI-961.01
Kepler-20e
Earth
Kepler-20f

What have we learned so far?

- 20-30% solar-type stars with planets
- 17% stars have "hot Jupiters"
- 50% stars have Neptunes
- 60% stars have terrestrial planets
- At least 1 planet per star
- Multiple planetary systems are common
- Multiple rocky planet systems are common

- Repeatedly increasing detection capability limits

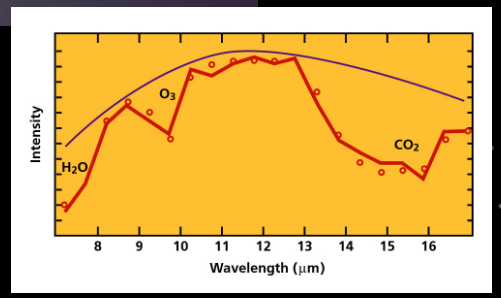
10 Year advance > Planet detection



Gl 892

Capella (Alpha Aur)

Mirphak (Alpha Per)



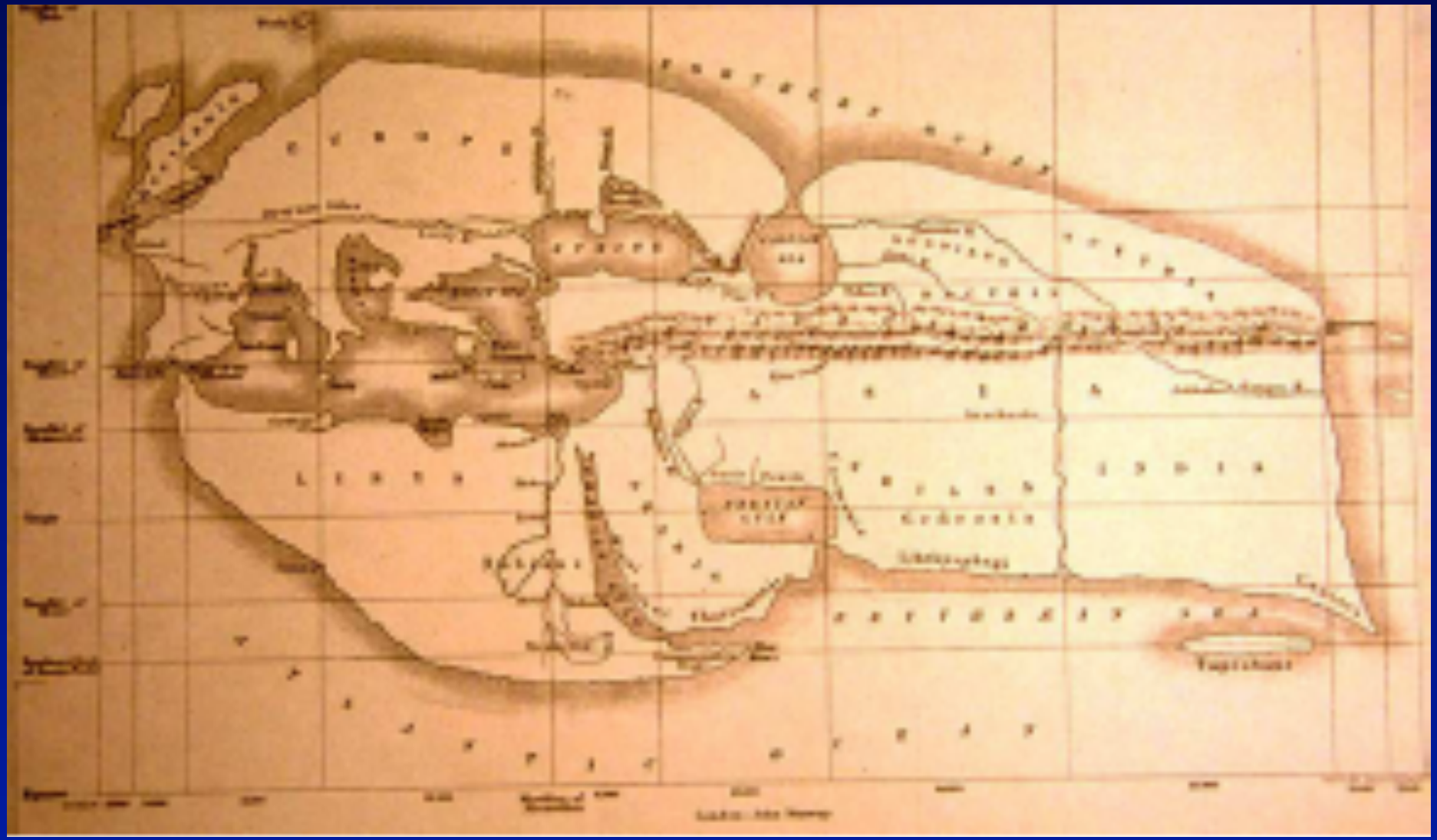
Next step > Characterization

http://www.astronexus.com

The Earth as an exoplanet

- Detection of super-earth and earth-size planets is becoming a reality.
- Characterization of their atmosphere and search for possible life is the next step.
- Observations of the solar system rocky planets will be our guidelines
- Idea: to study the Earth as if we were an extraterrestrial observer by means of earthshine
- Why the Earth? → Is the only known planet which harbors life

A short history of Earth observations

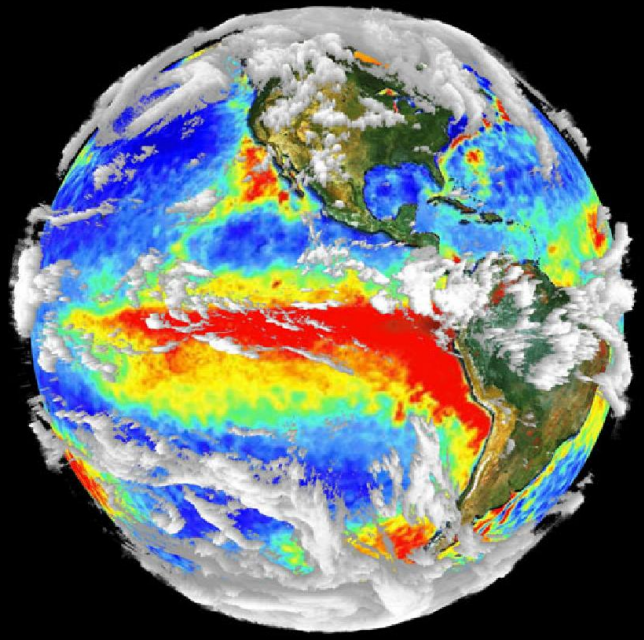


World Map by Eratosthenes, 194 B.C.

World Map by Martin Waldseemüller, 1507

Apollo VIII, 1969

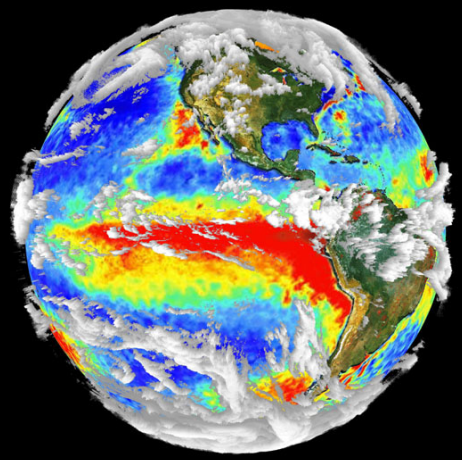
Nowadays we can monitor night lights, atmospheric changes, plankton blooms, forest health, etc...

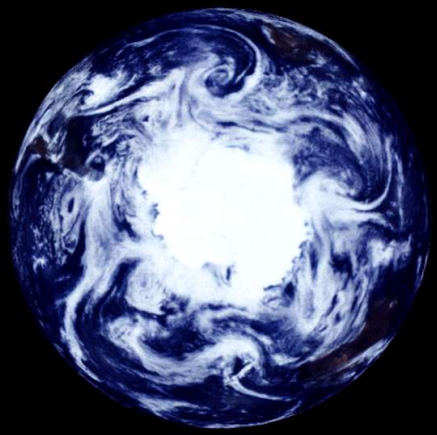


But, how does our planet look like to ET?

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

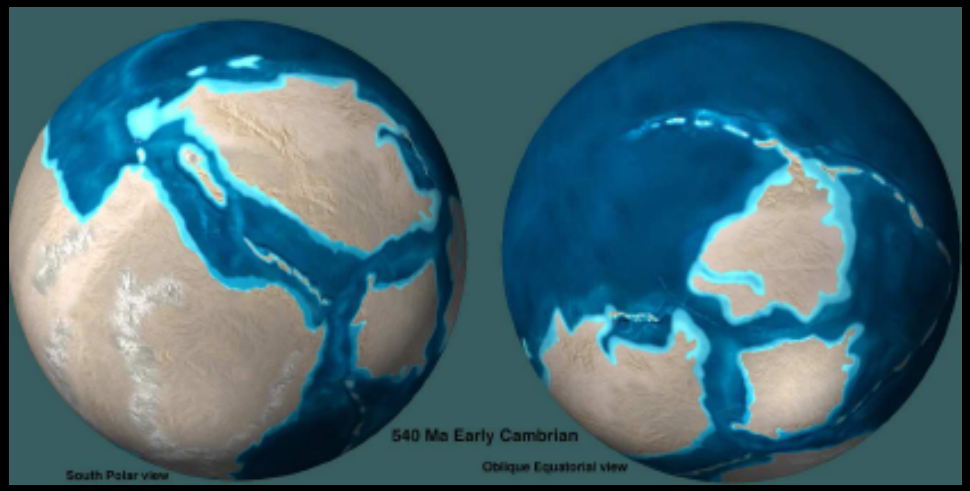
Saturn from Cassini



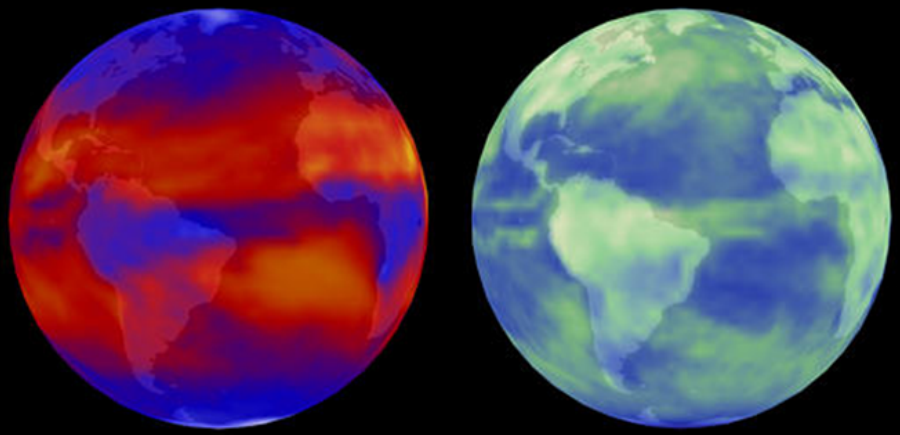


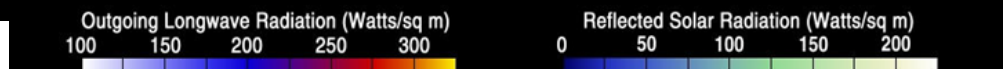
Different seasons, phase, geometry and weather

Age



Wavelength





Observing the Earth as a planet (no spatial resolution)

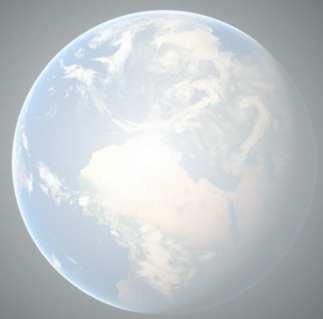
- *Earth–as-a-point observations with a very remote sensor*
- *A compilation of high spatial resolution data into a global spectra or photometry, and modeling*
- *Earthshine Observations: The Earthshine is the ghostly glow on the dark side of the Moon*

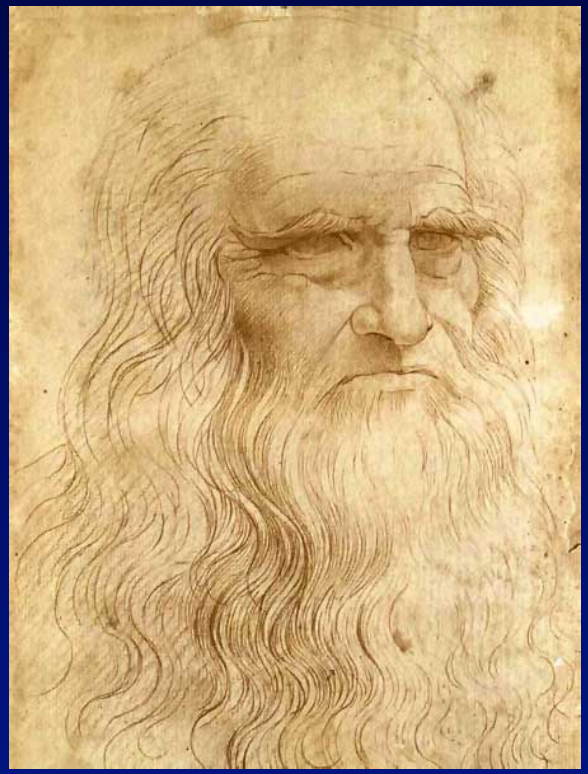
Earth observations from remote platforms

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

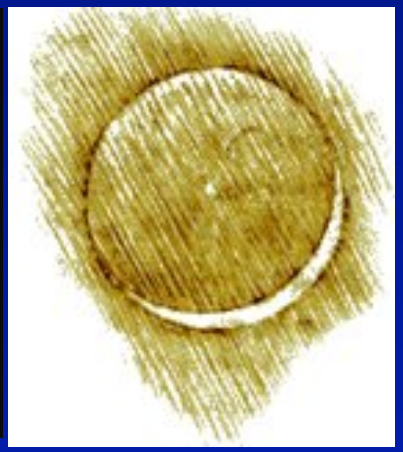
The Earthshine on the moon

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."

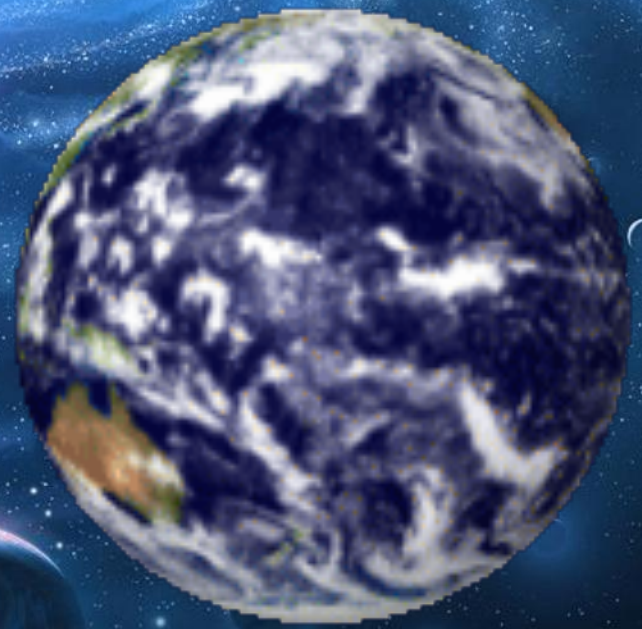
Here Leonardo repeats his belief that the moon shines because it is covered with water, and says that he believes the moon to be a heavy body with its own gravity and atmosphere.

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..."

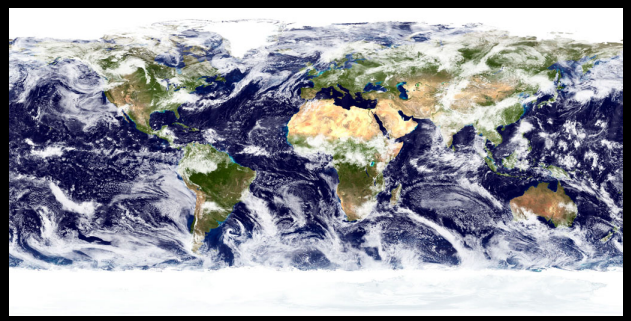
Earth photometry

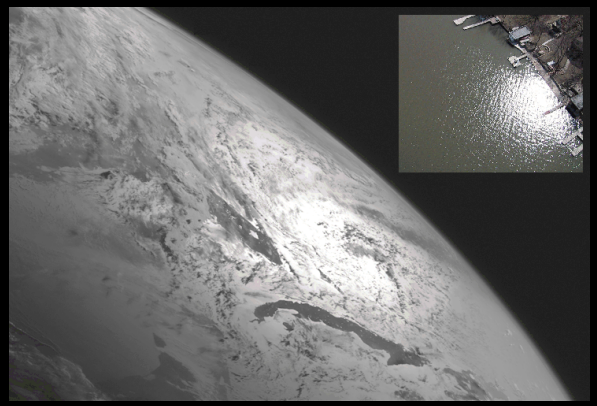
- Albedo: percentage of the incoming solar radiation which reaches the terrestrial surface and is reflected back into the space
- Earth albedo ~ 30%
- Depends on surface type
- Related to cloudiness
- Very important for the global climate of Earth

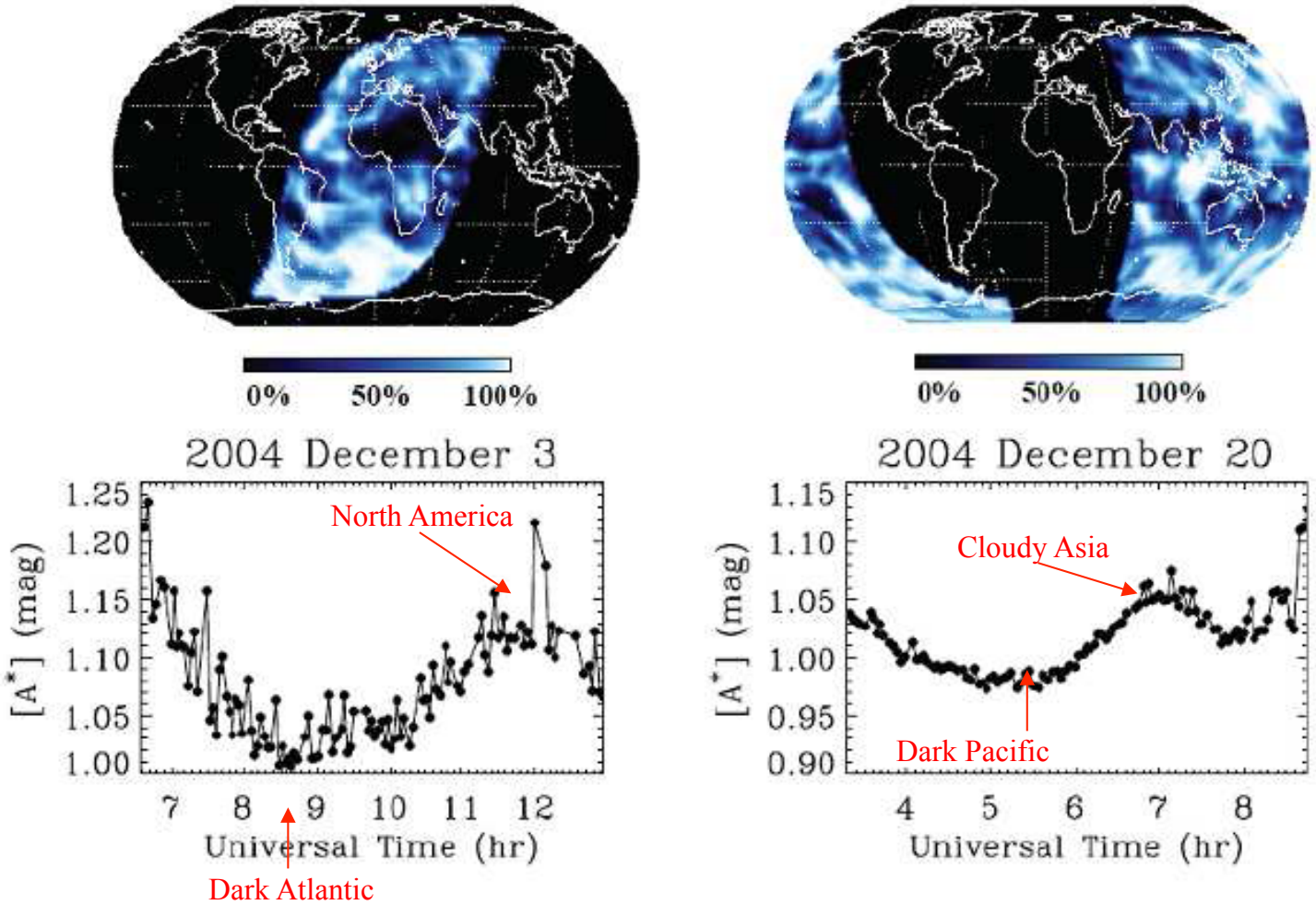


Reflected light observations allow to:

- *Atmospheric characterization*
- *Exploration of surface features*
  - *Presence of continents*
  - *Rotational period*
  - *Localized surface biomarkers (vegetation)*
- *Orbital light curve*
- *Ocean glints and polarization effects*

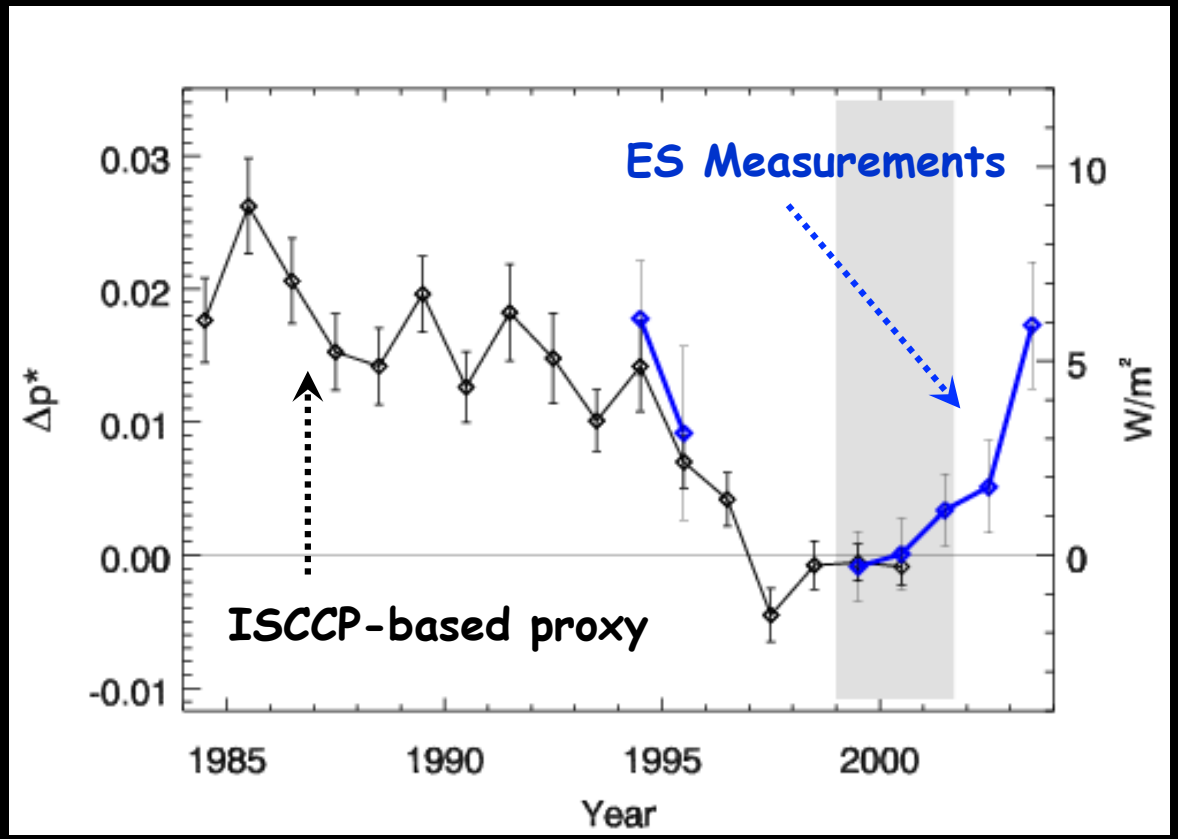




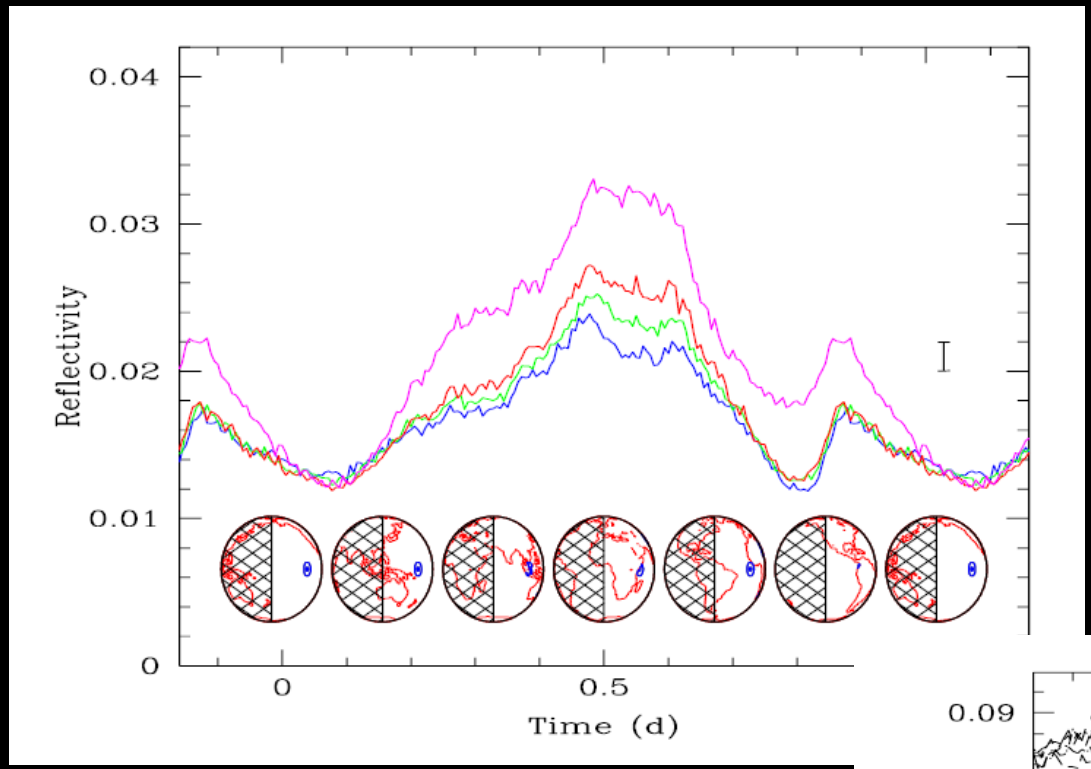


Palle et al, JGR, 2003

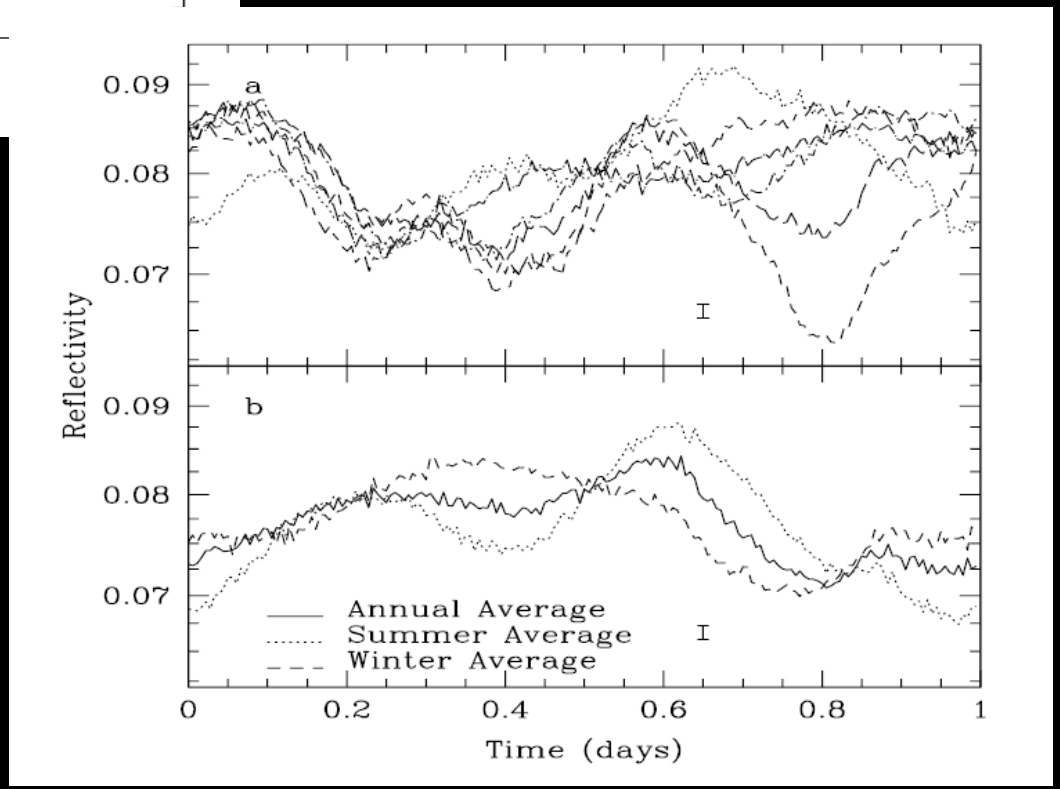
Decadal variations in Earth's reflectance



Palle et al, Science, 2004

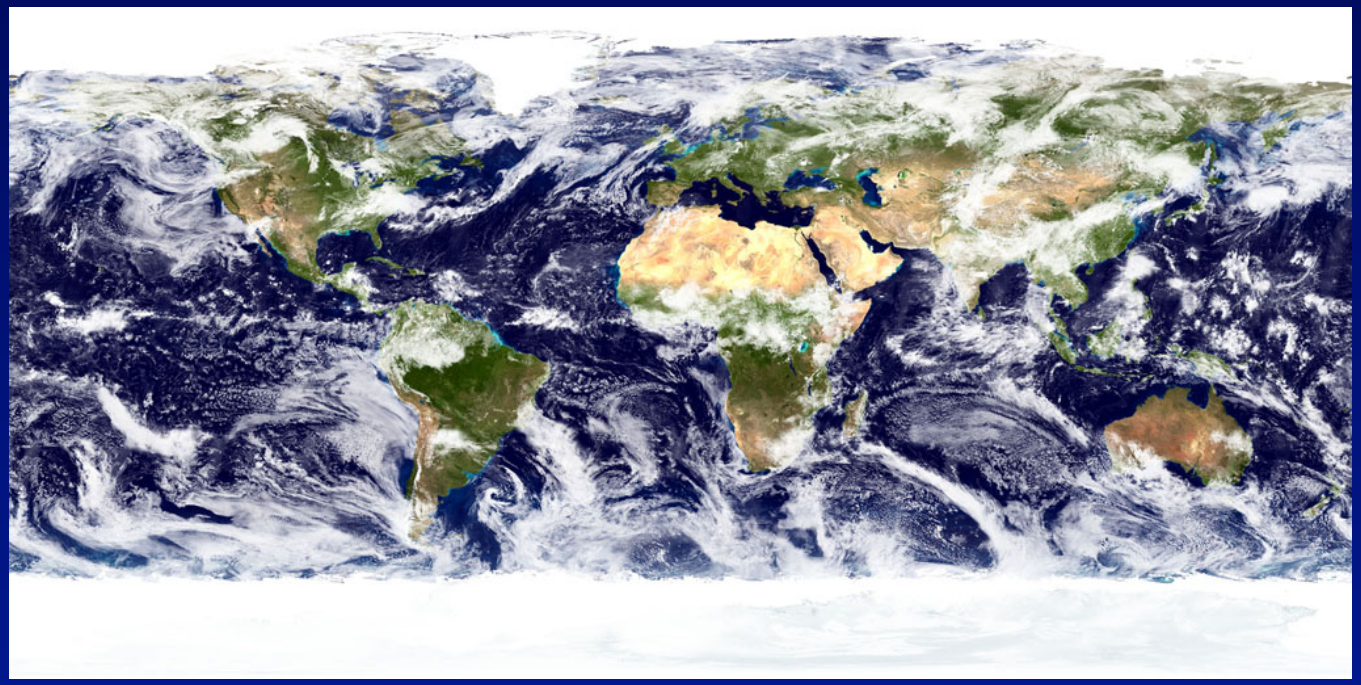


Color changes as the Earth rotates

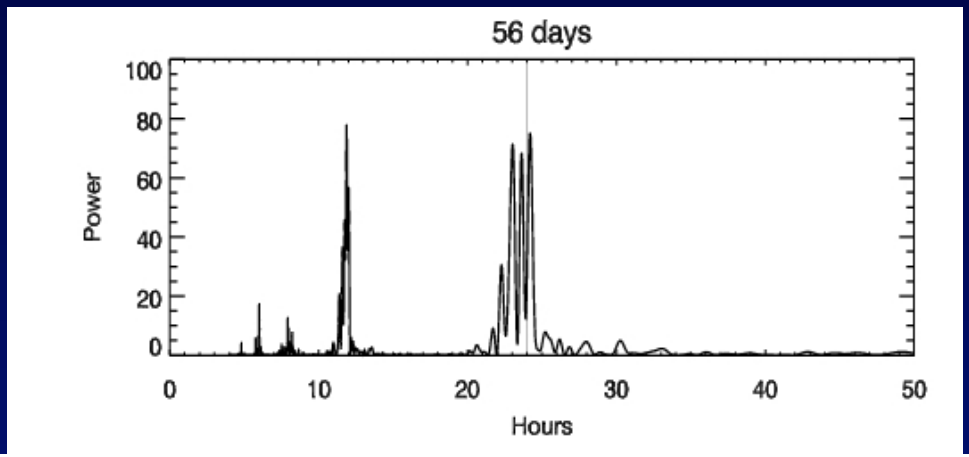


Ford et al, 2001

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

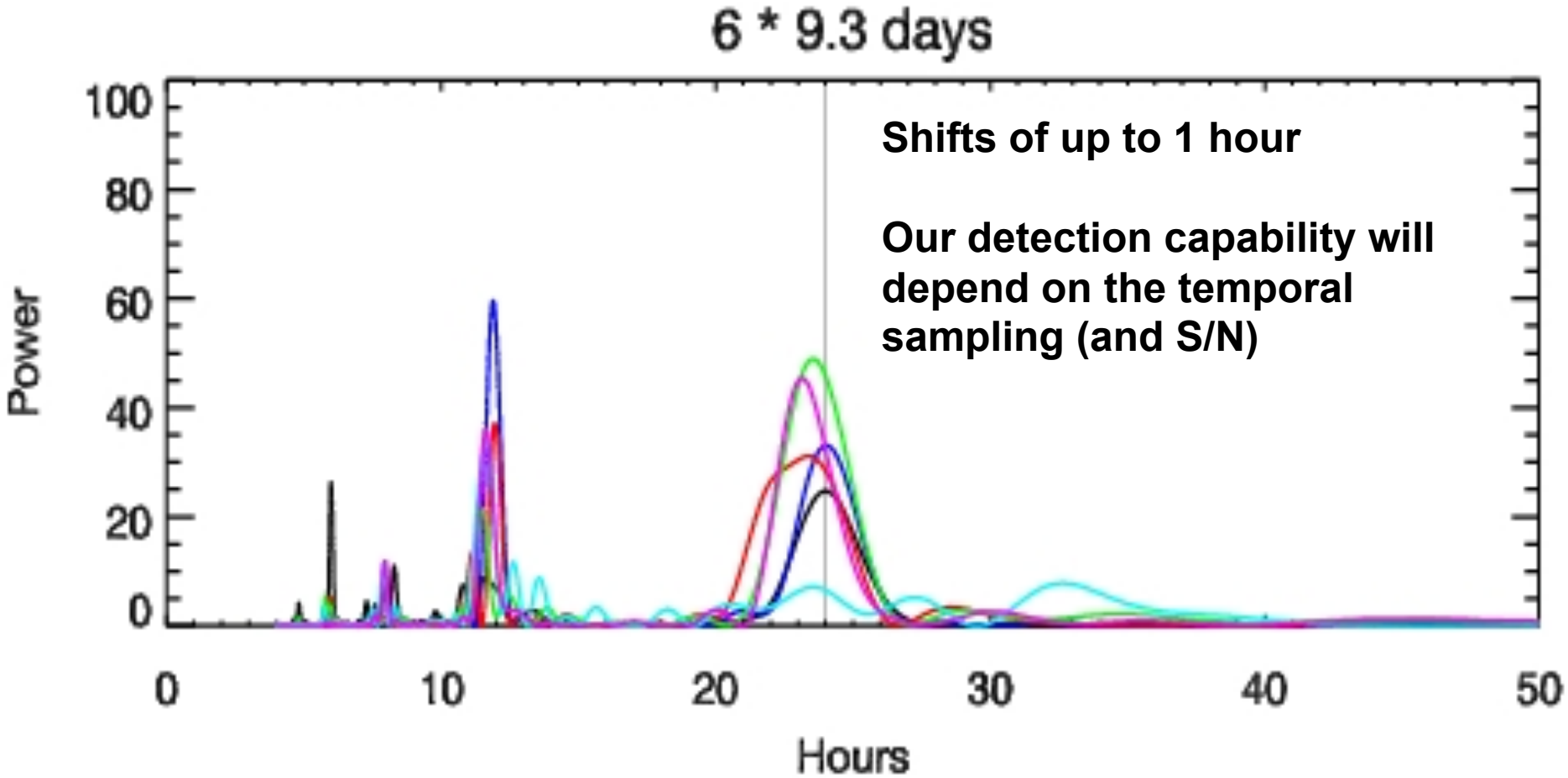


Even with the presence of clouds, there are clear daily and yearly photometric patterns with relatively large amplitude



Periodicity shifts

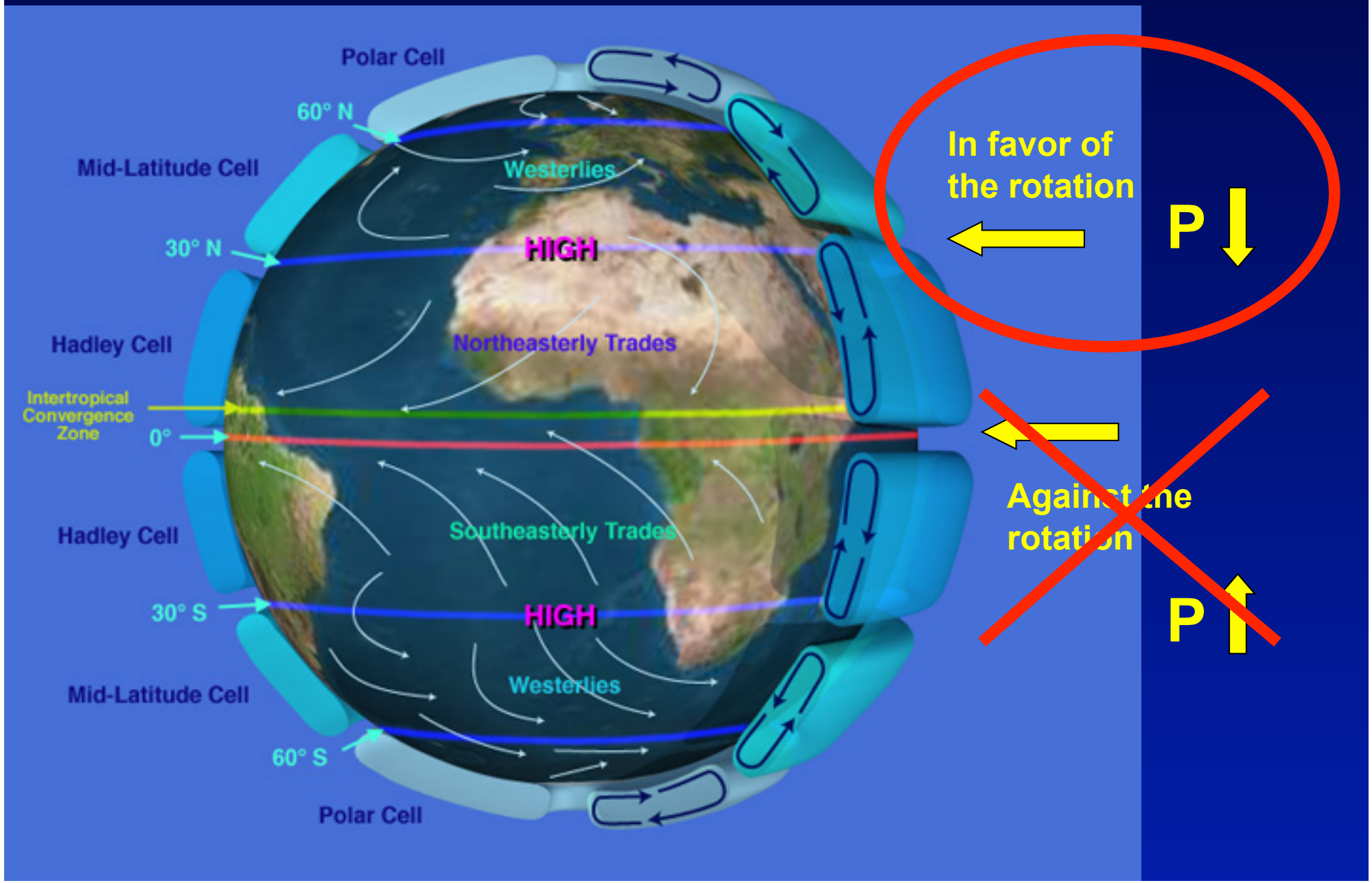
Palle et al, ApJ, 2008

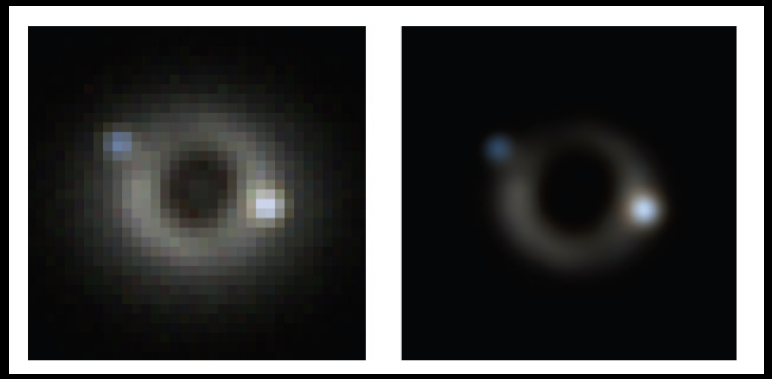


Shifts of up to 1 hour

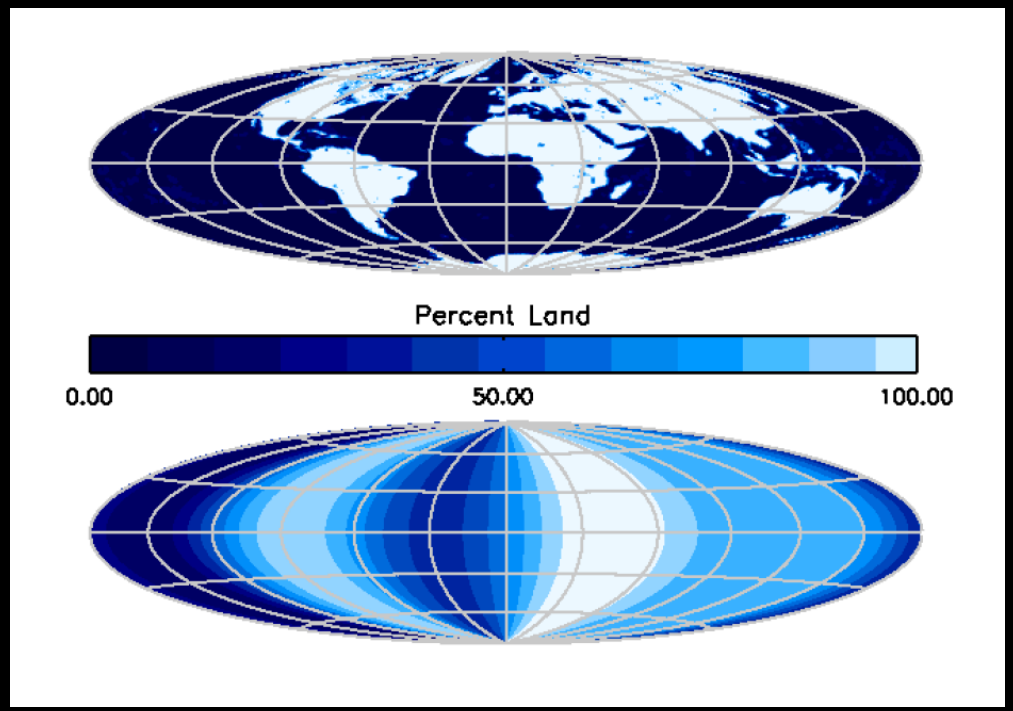
Our detection capability will depend on the temporal sampling (and S/N)

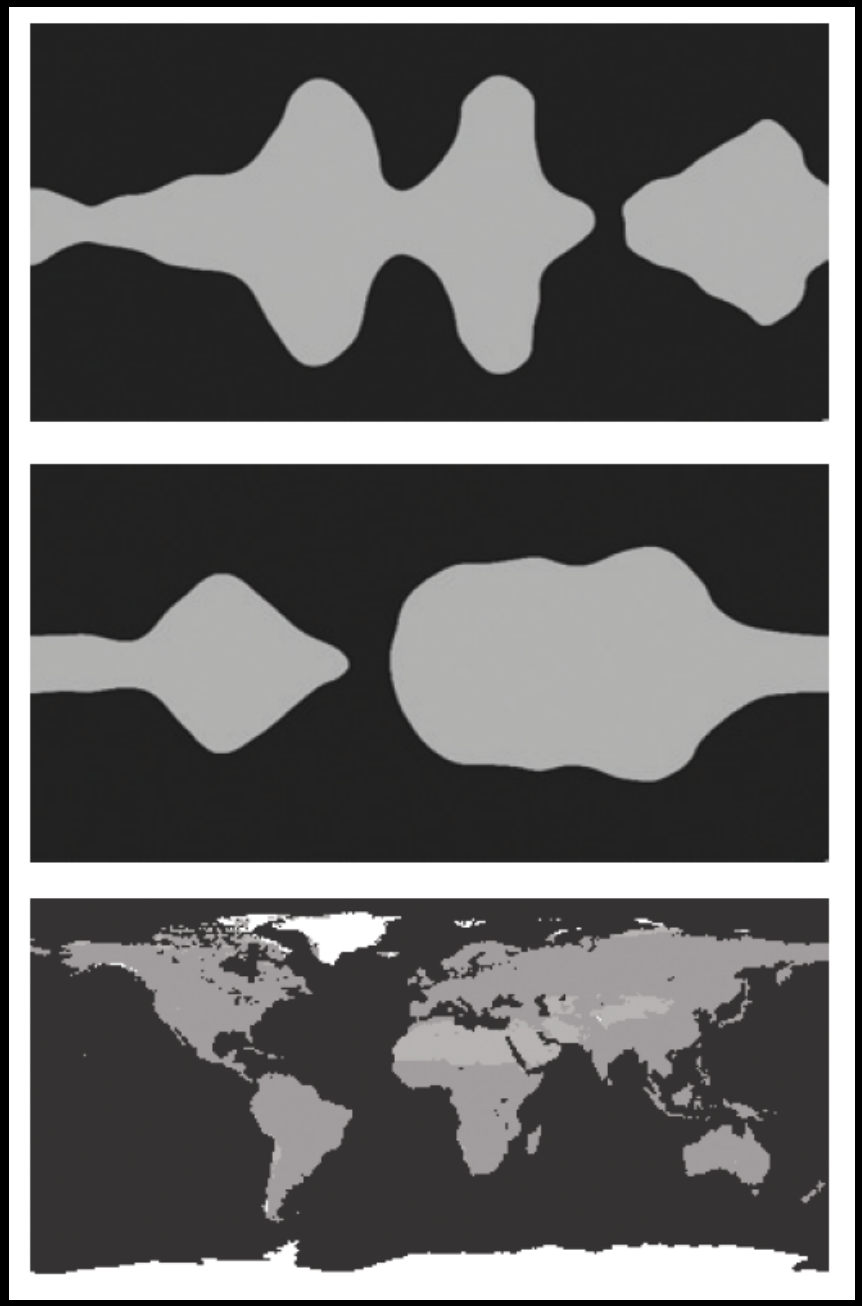
Weather and clouds at global scales



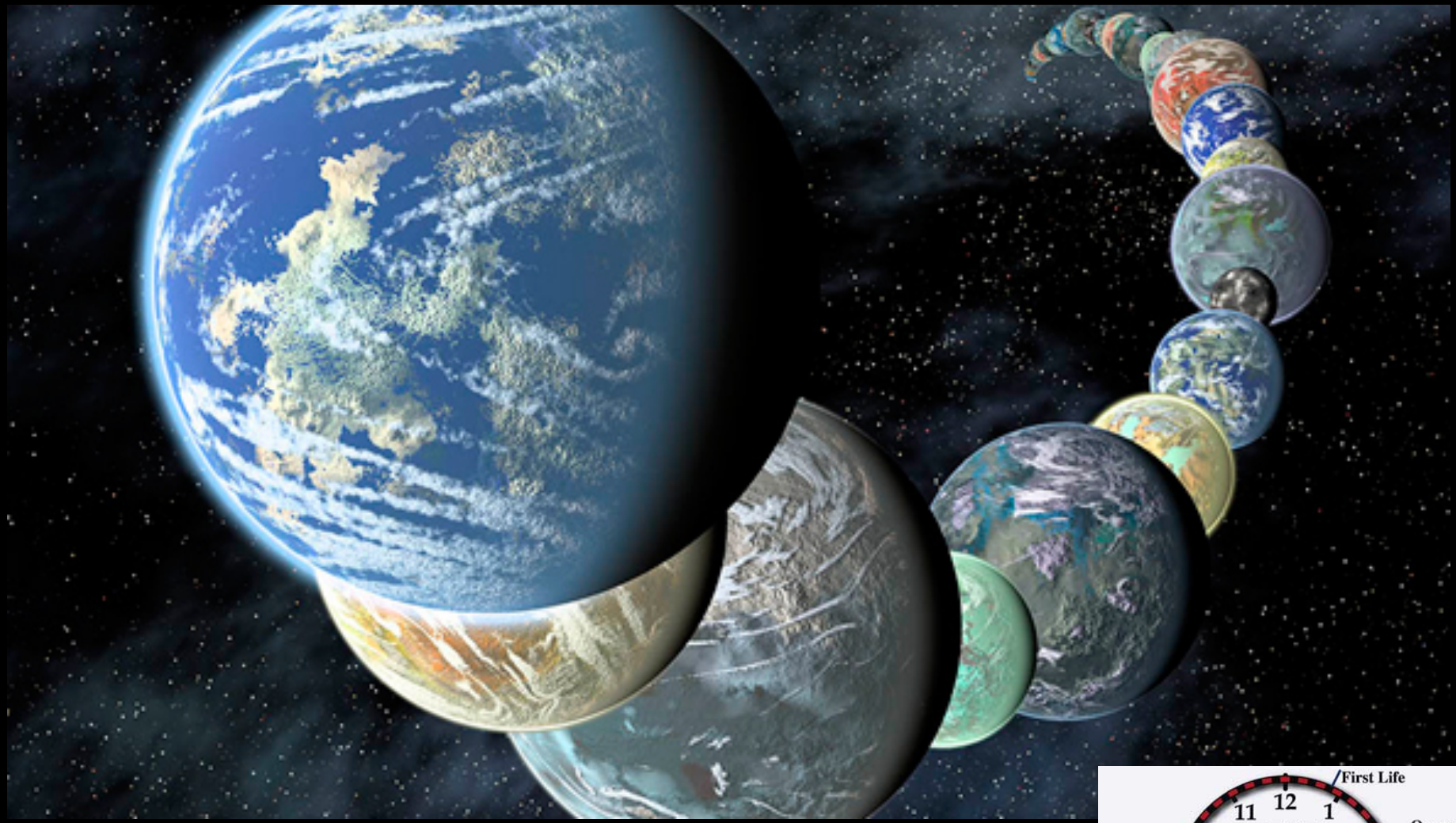


Oakely & Cash, ApJ, 2009
Cowan et al, ApJ, 2009



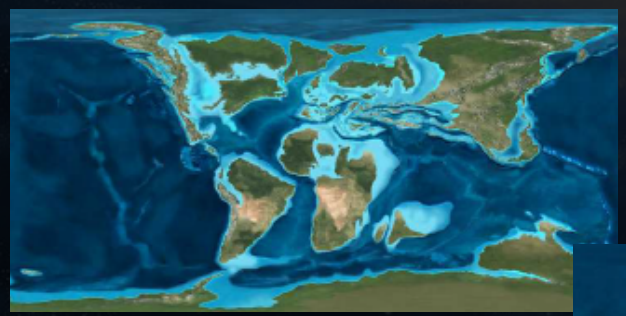


Planets evolve and so does life in them

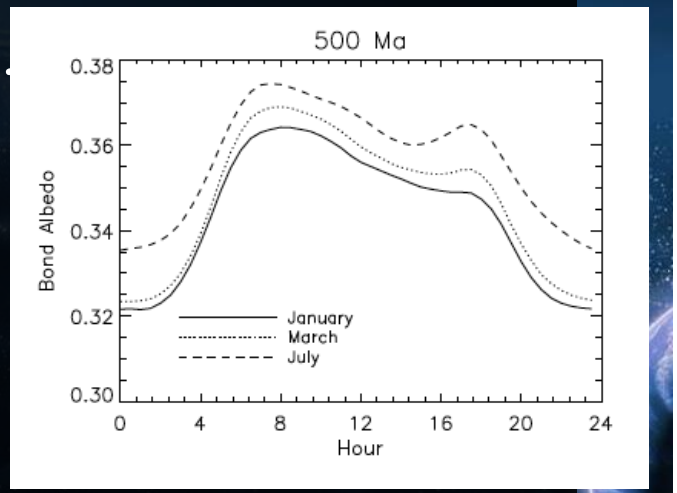


Reconstructing the photometric light curves of Earth

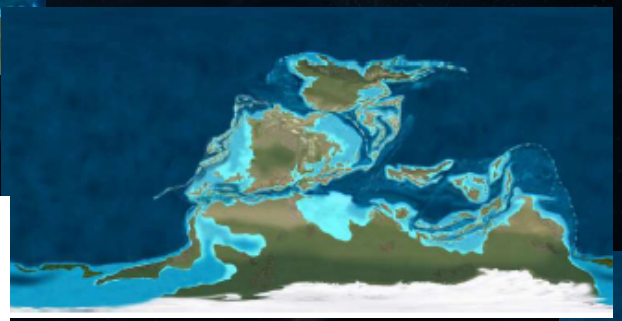
- The Earth: a planet with multiple



Late Cretaceous

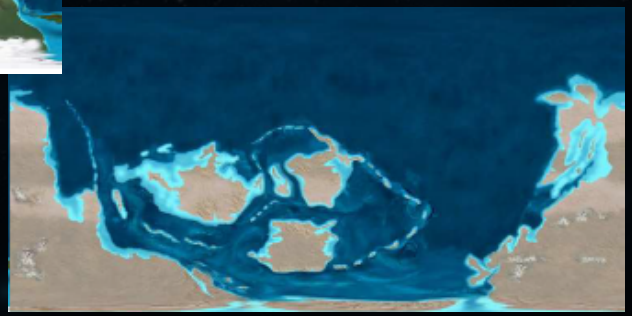


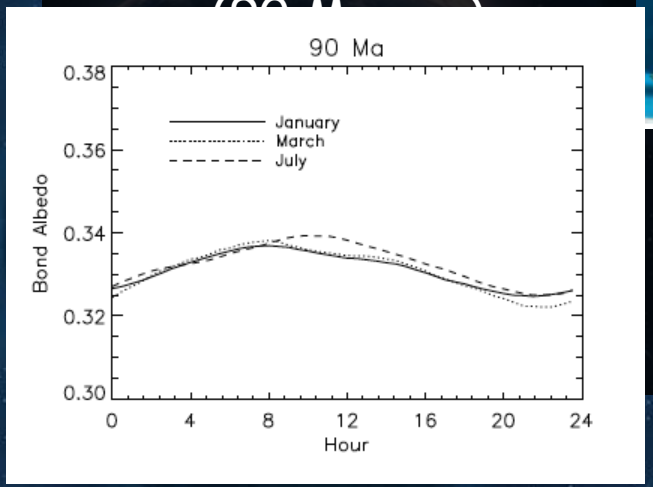
Late Cambrian
(500 Ma ago)



The Mississippian

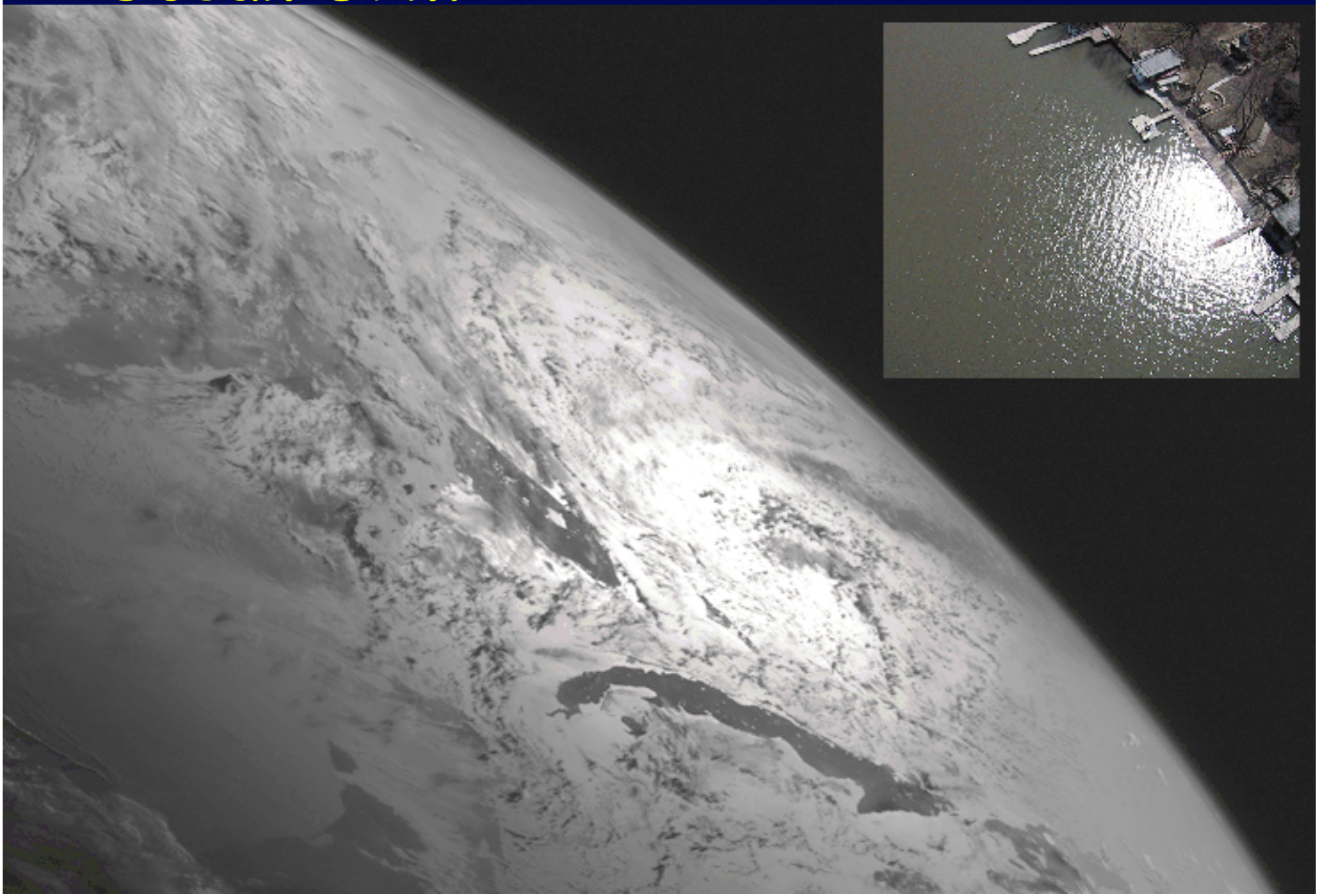
(340 Ma ago)

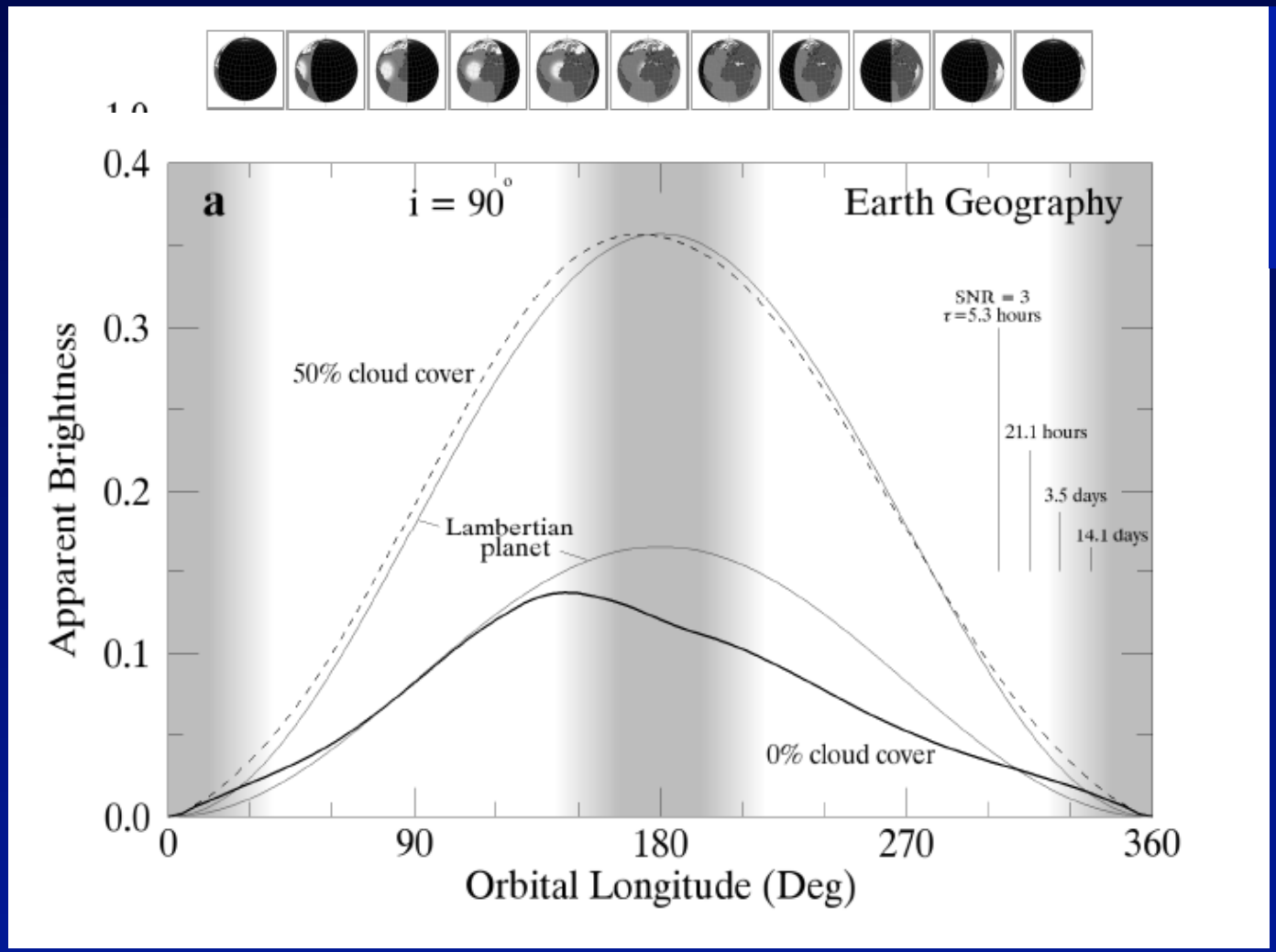




Sanroma and Palle, ApJ, 2012

Ocean Glint





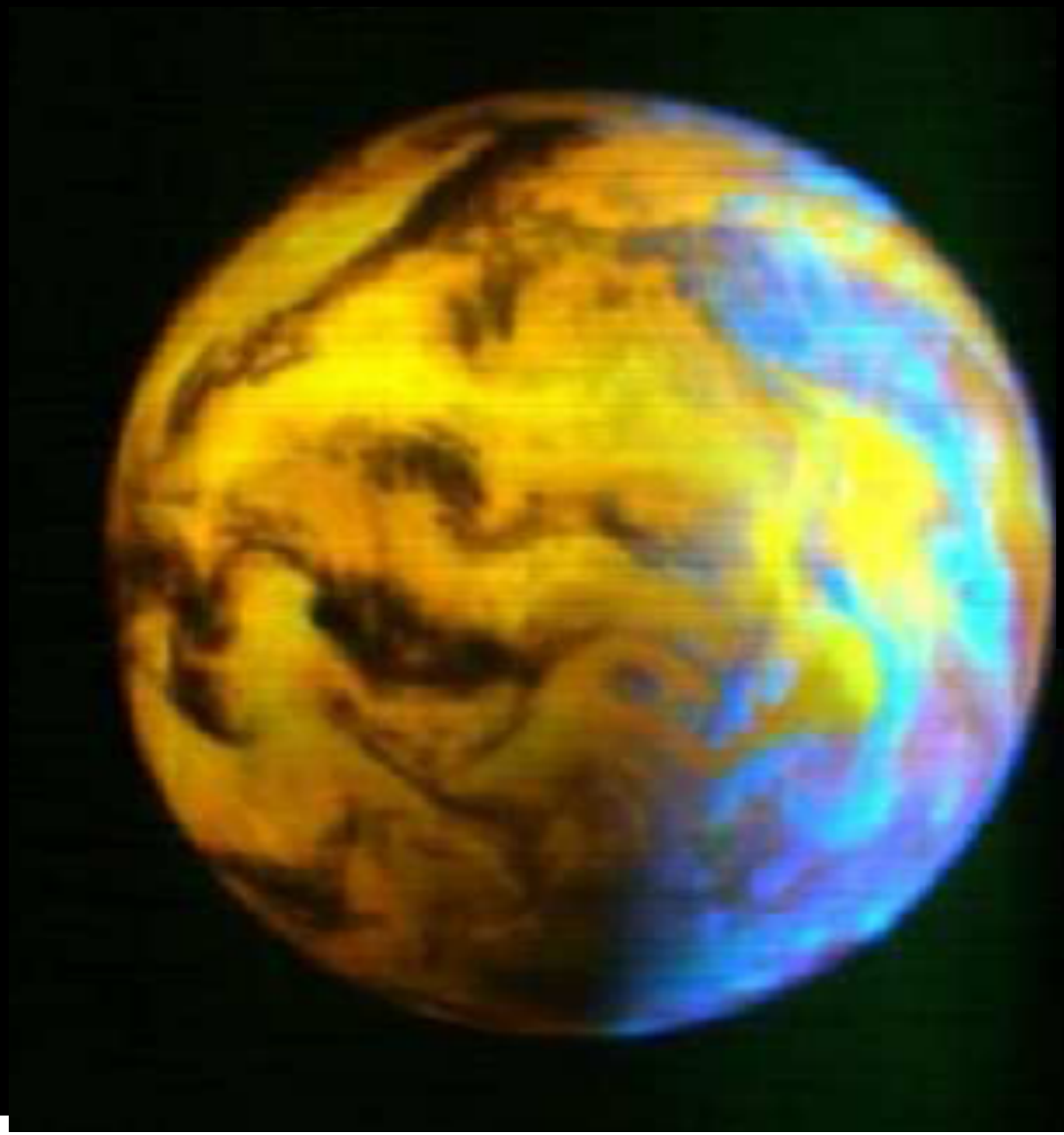
- ***Water***
- ***Smooth Ice***
- ***Thin clouds***
- ***Ethane***

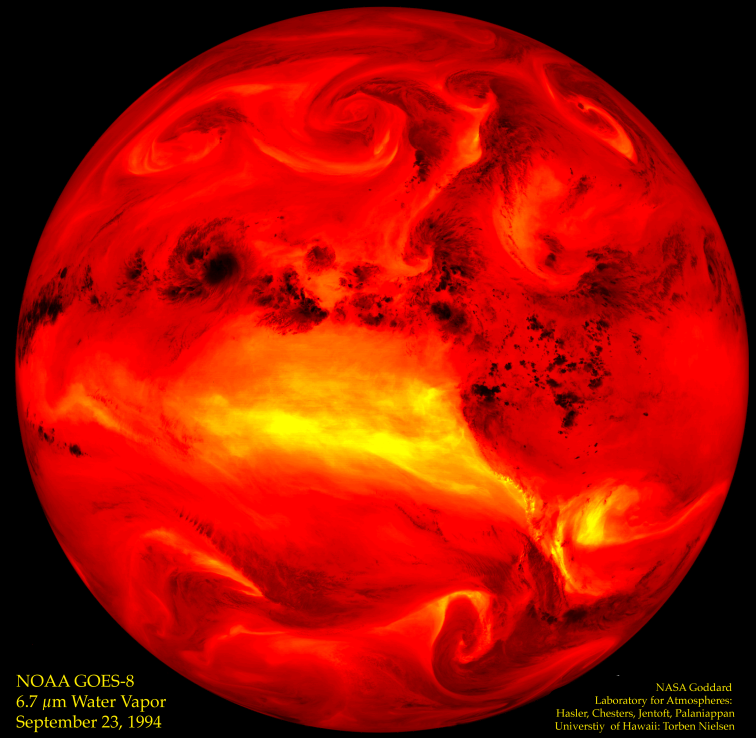
Williams & Gaidos, Icarus, 2008 ; Robinson & Meadows, 2010

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

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

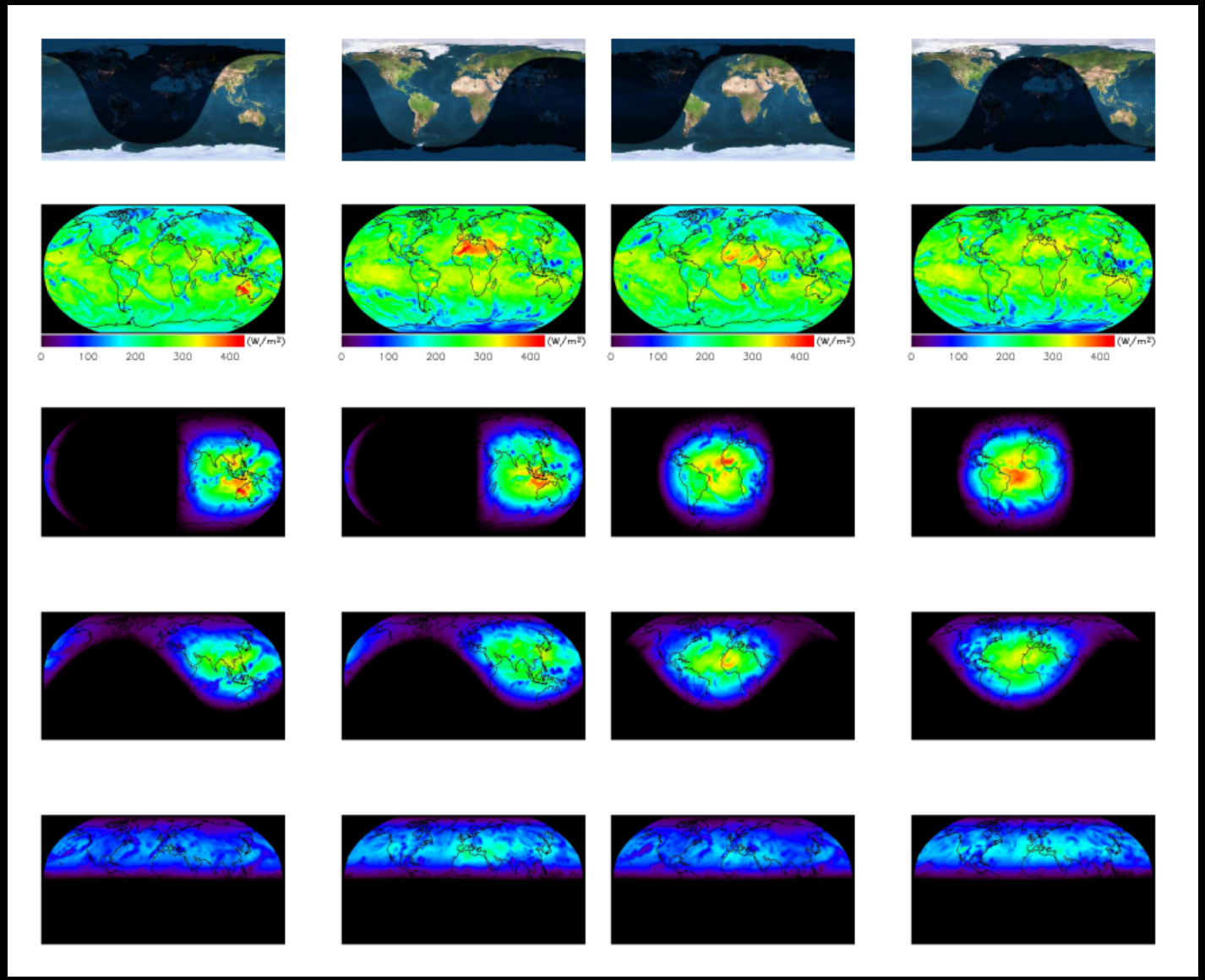
VIRTIS @ ROSETTA, 250,000 km from Earth



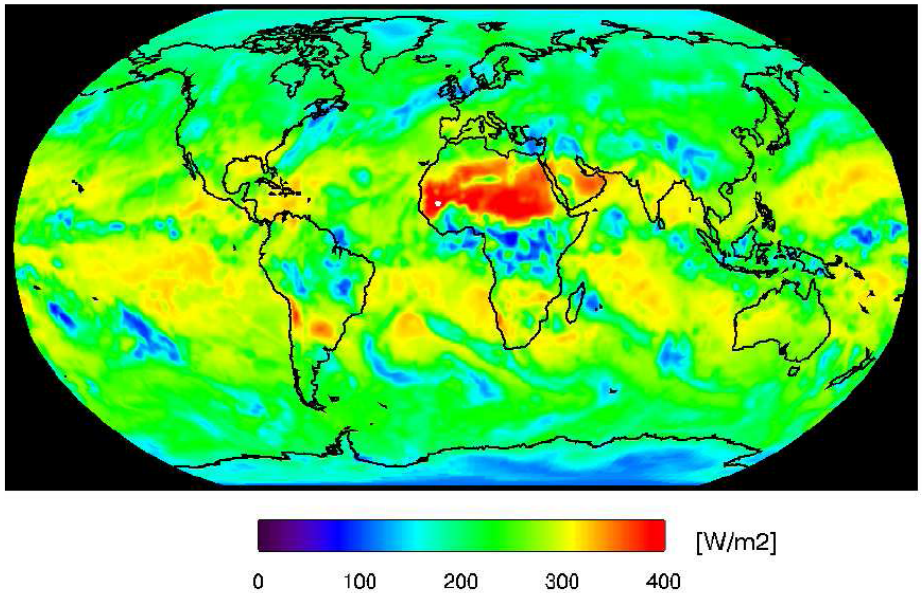


NOAA GOES-8
6.7 μm Water Vapor
September 23, 1994

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



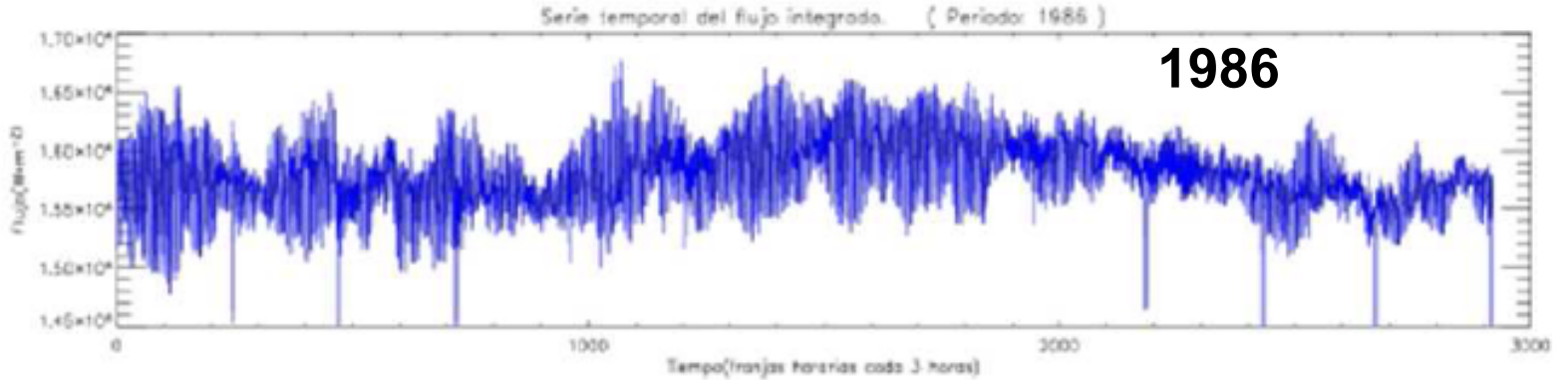
Gomez, Palle, Selsis (in prep)

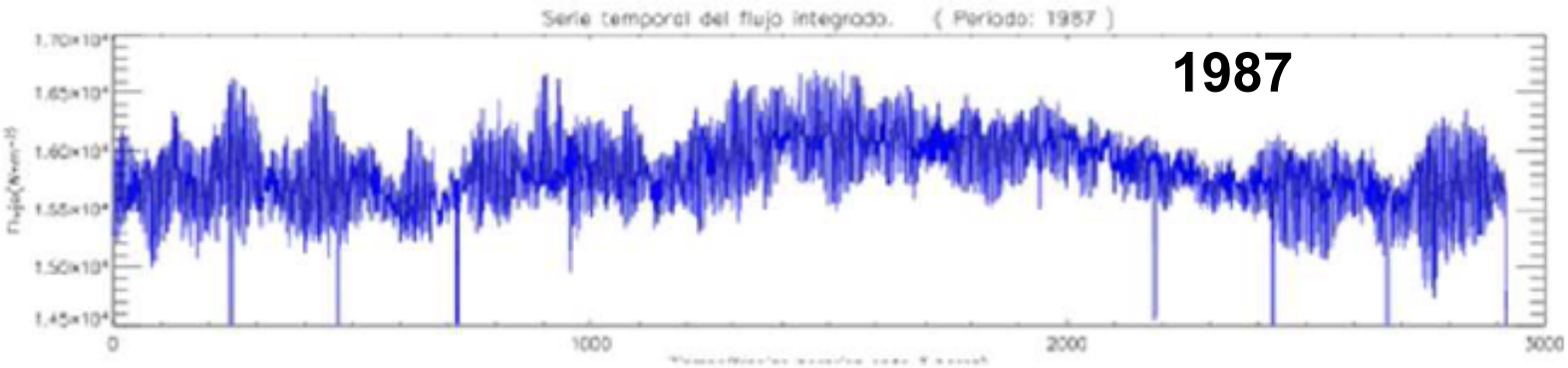


Variability in the IR is more muted than in the visible and strongly dependent con weather conditions.

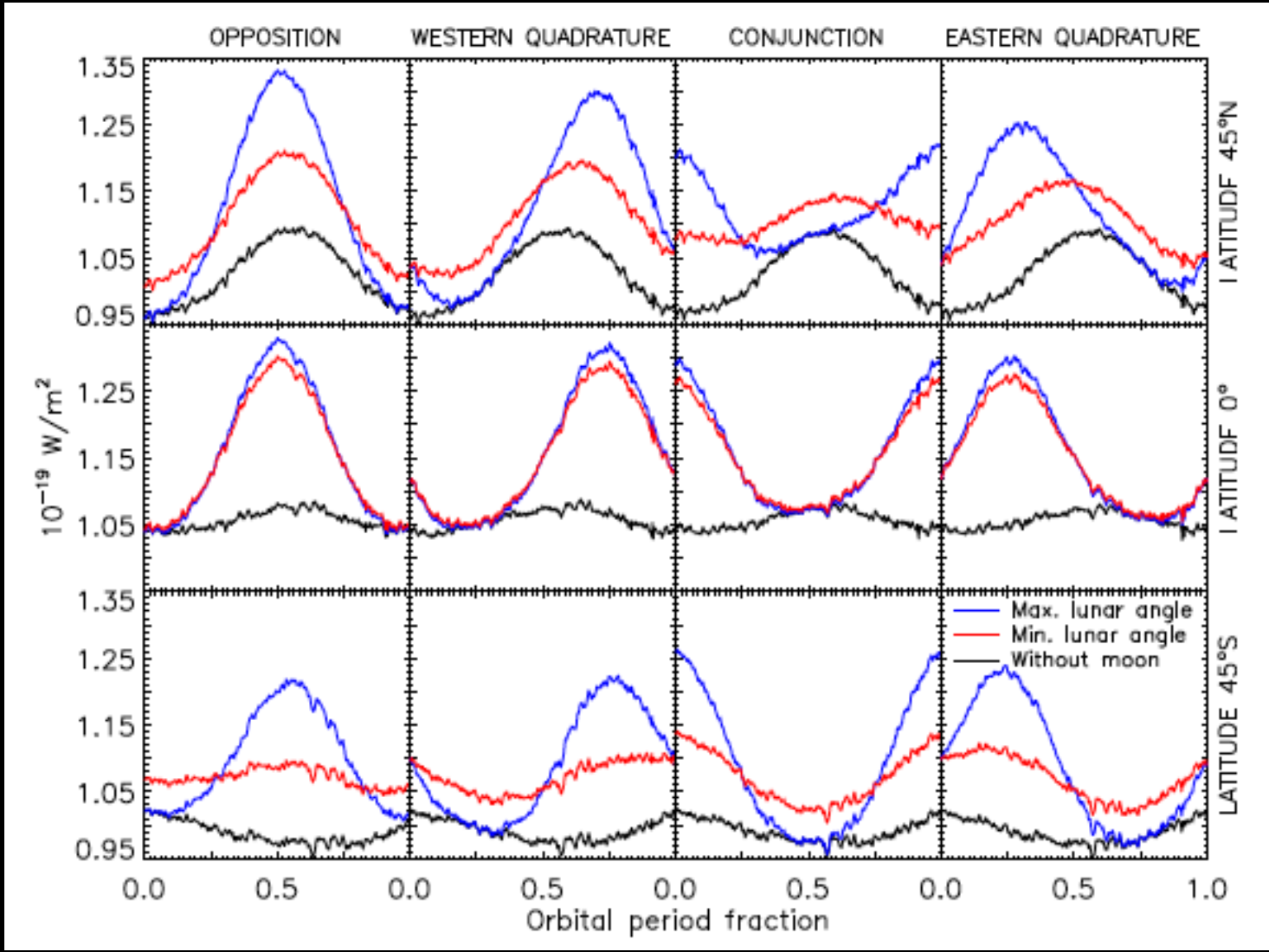
Sometimes the diurnal cycle is clear, sometimes it is missing.

Gomez, Palle & Selsis, ApJ, sub.



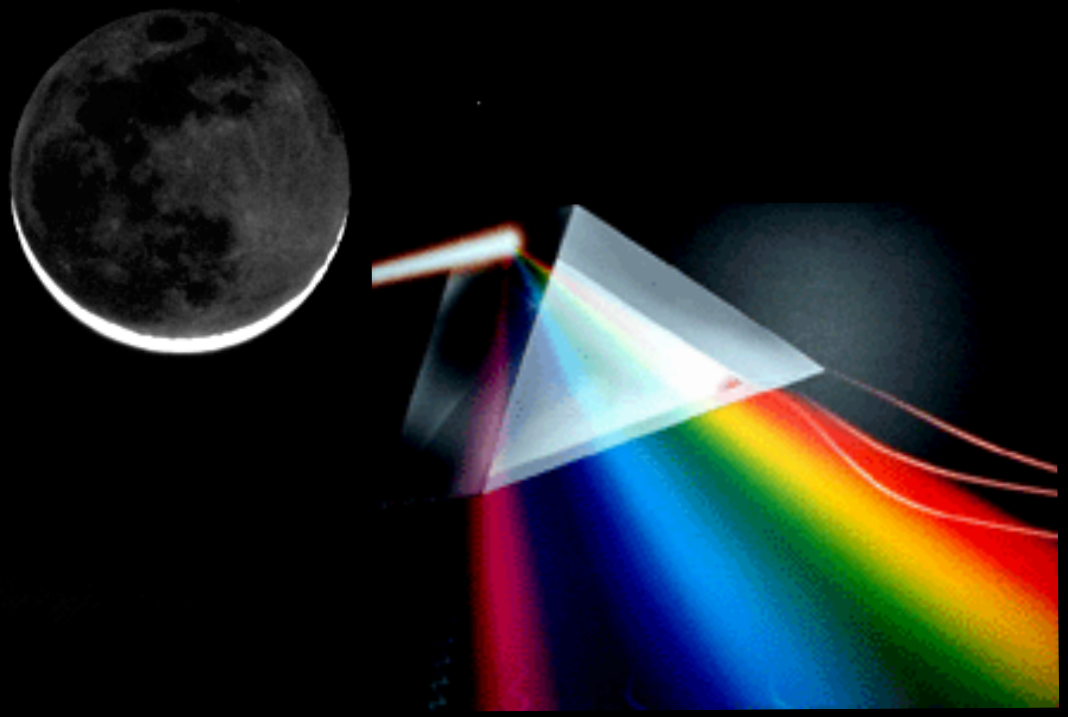


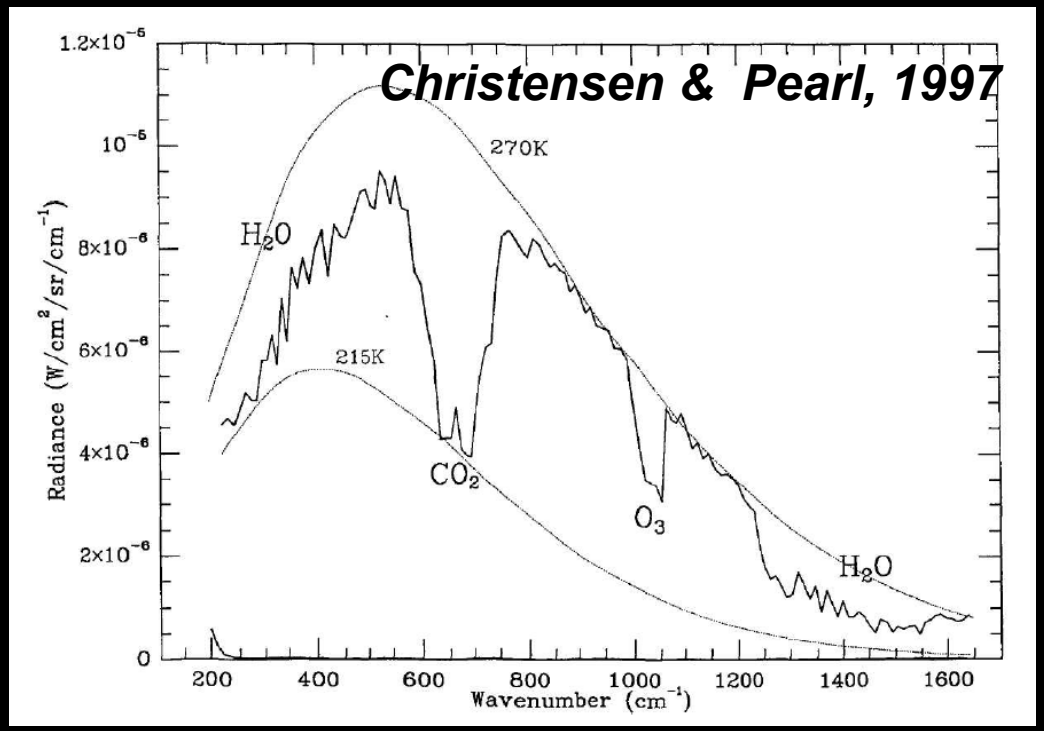
At IR wavelenghts the Moon's variability dominates the Earth-Moon sytems



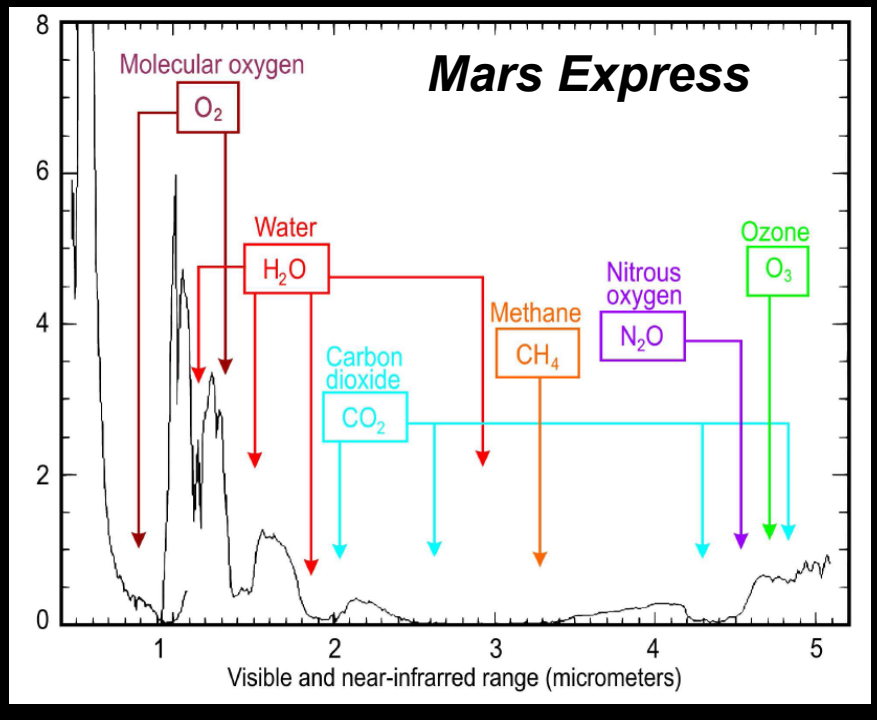
Gomez, Palle & Selsis, ApJ, sub.

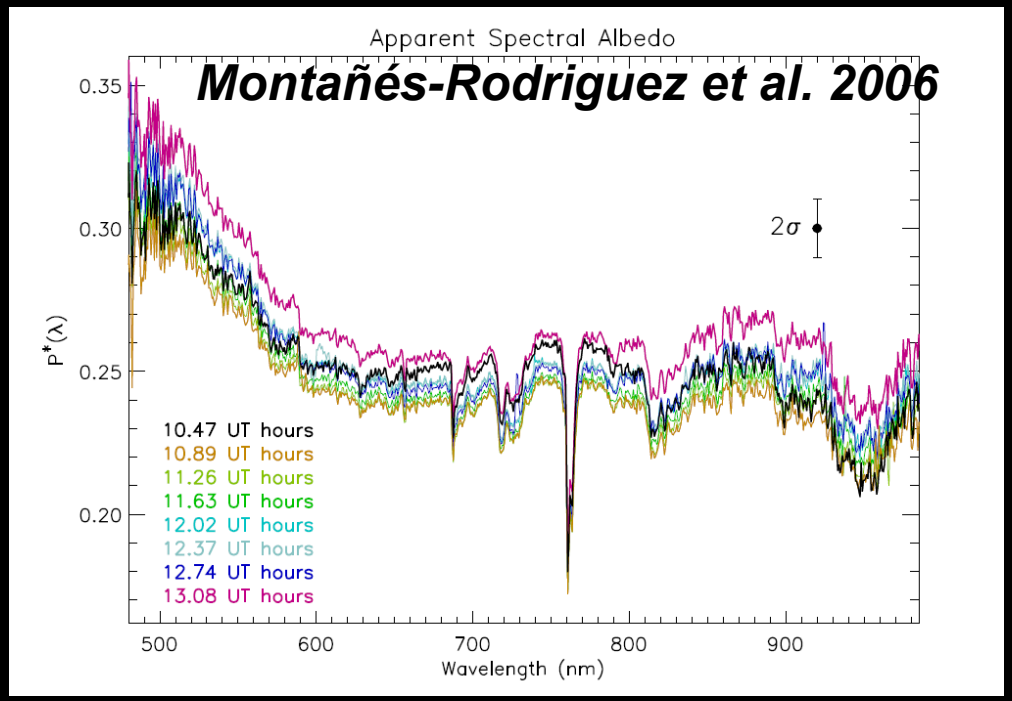
Earthshine spectroscopy



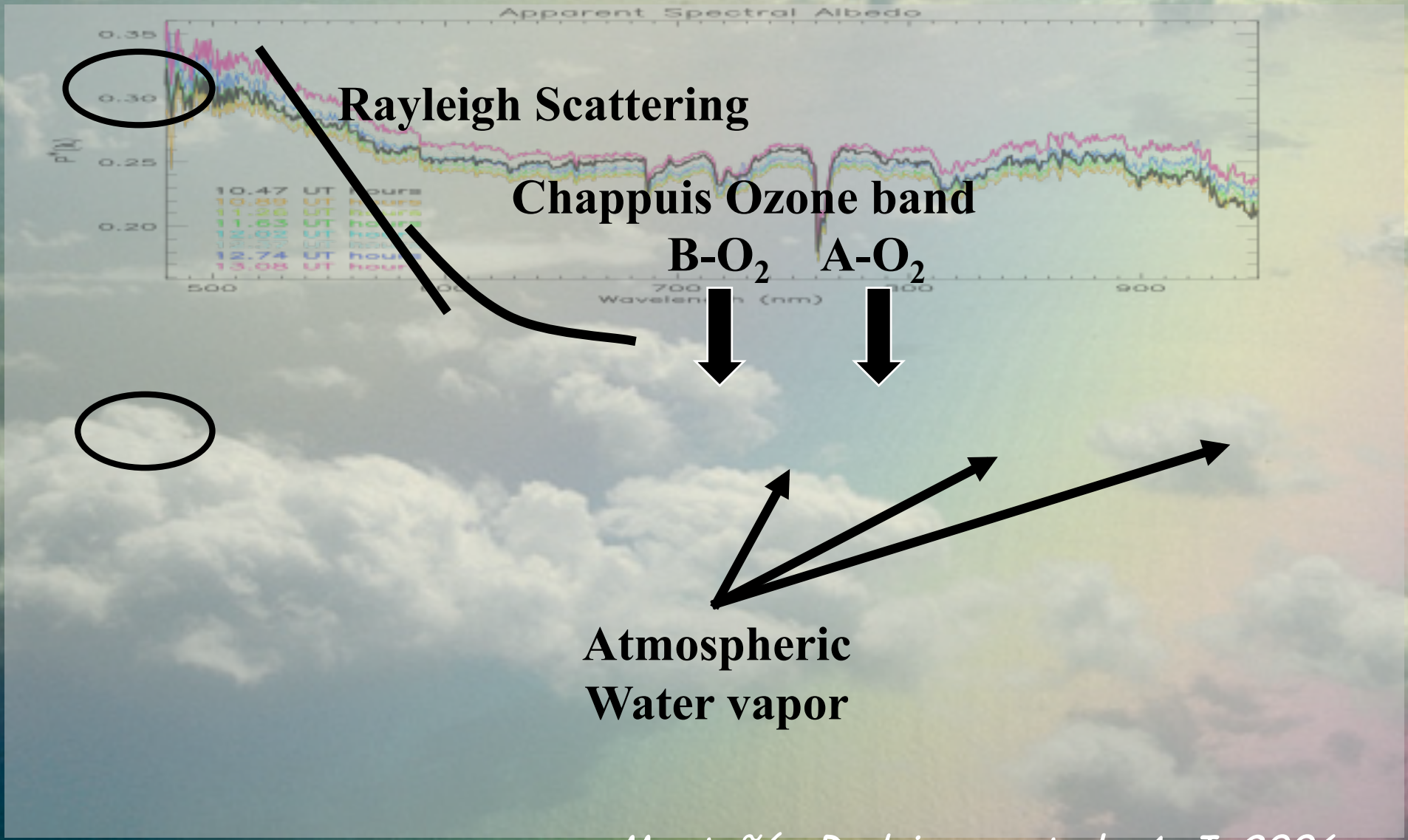


Atmospheric composition and major spectral features are well-characterized





Spectral Albedo of the Earth: 2003/11/19

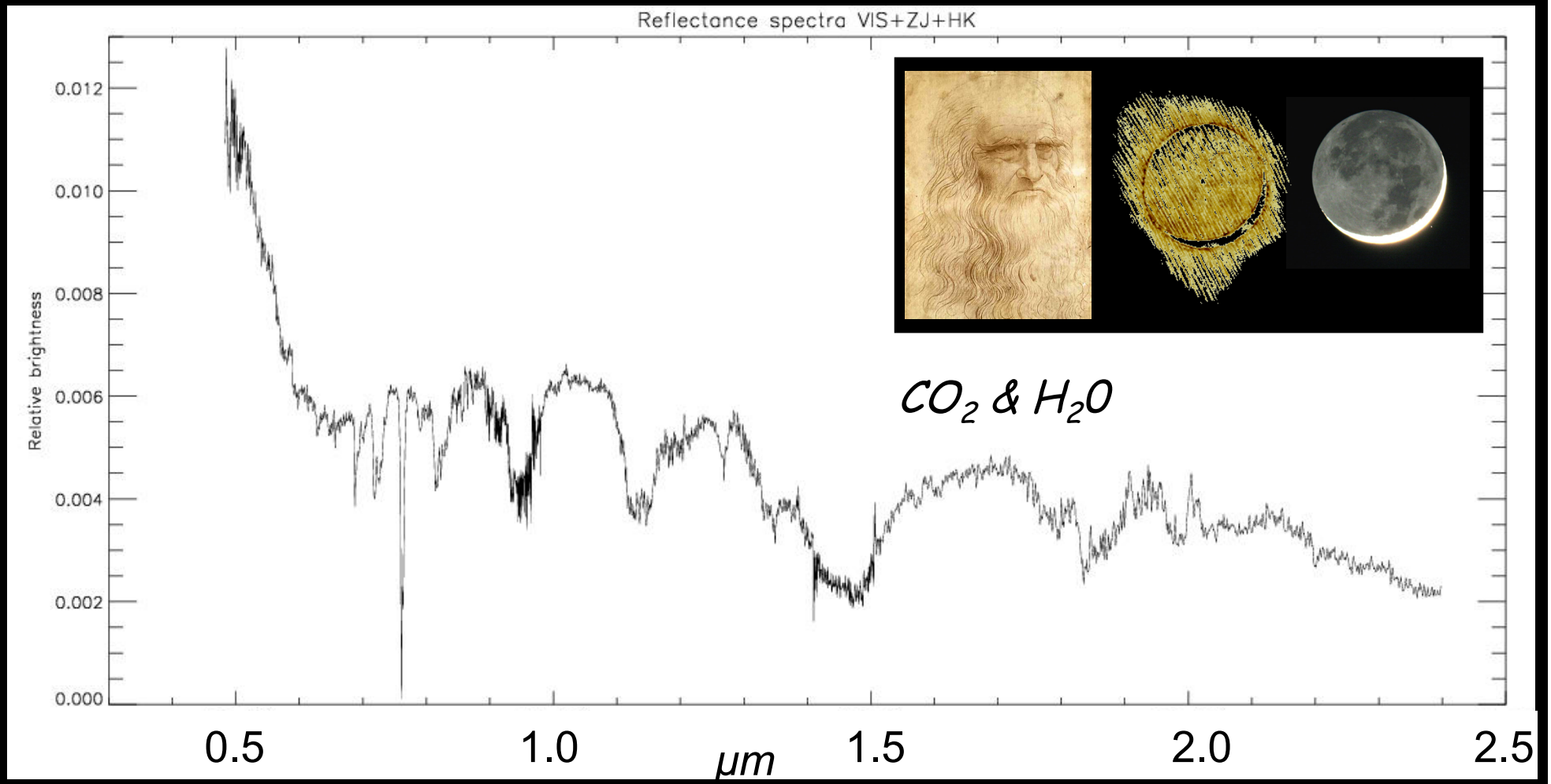


Montañés-Rodriguez et al., ApJ, 2006

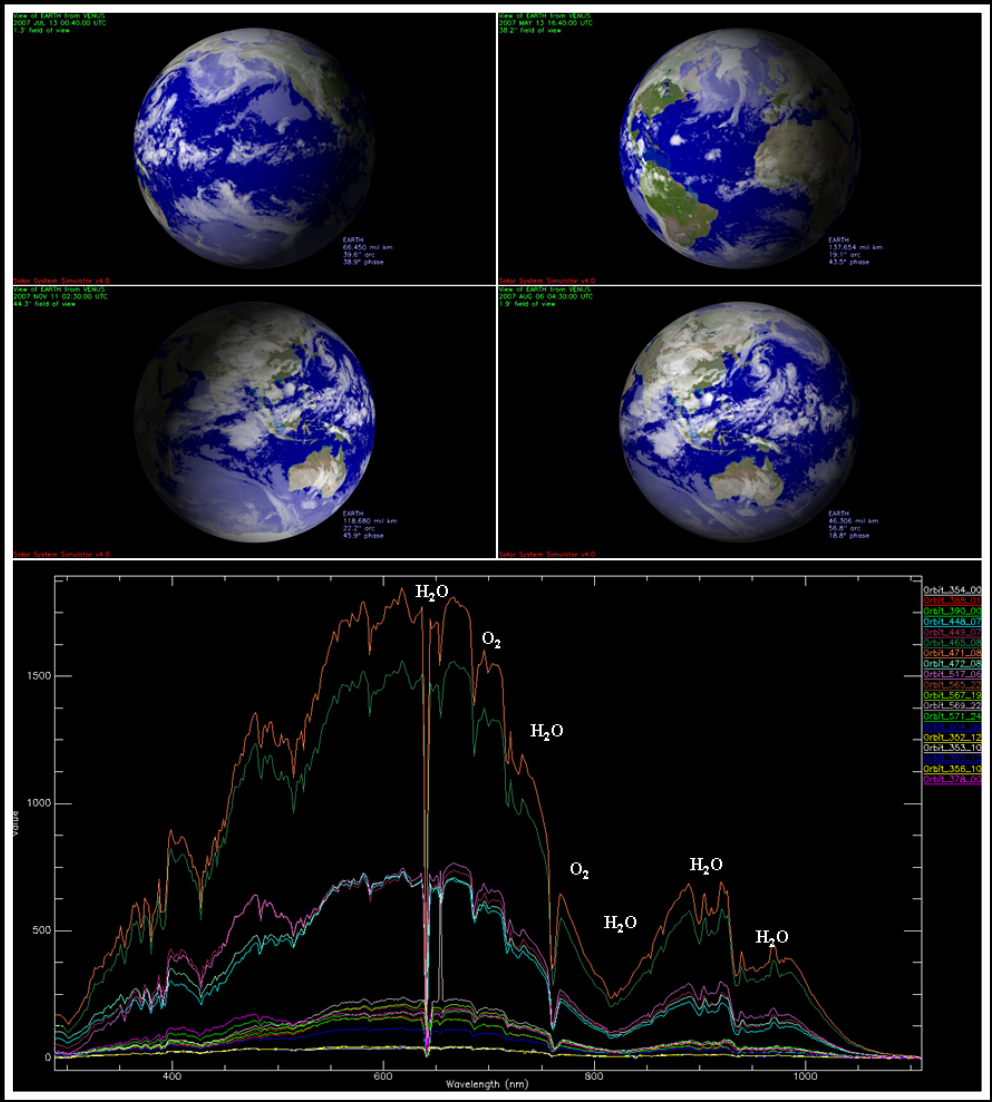
Earth's Reflectance Spectrum: Earthshine

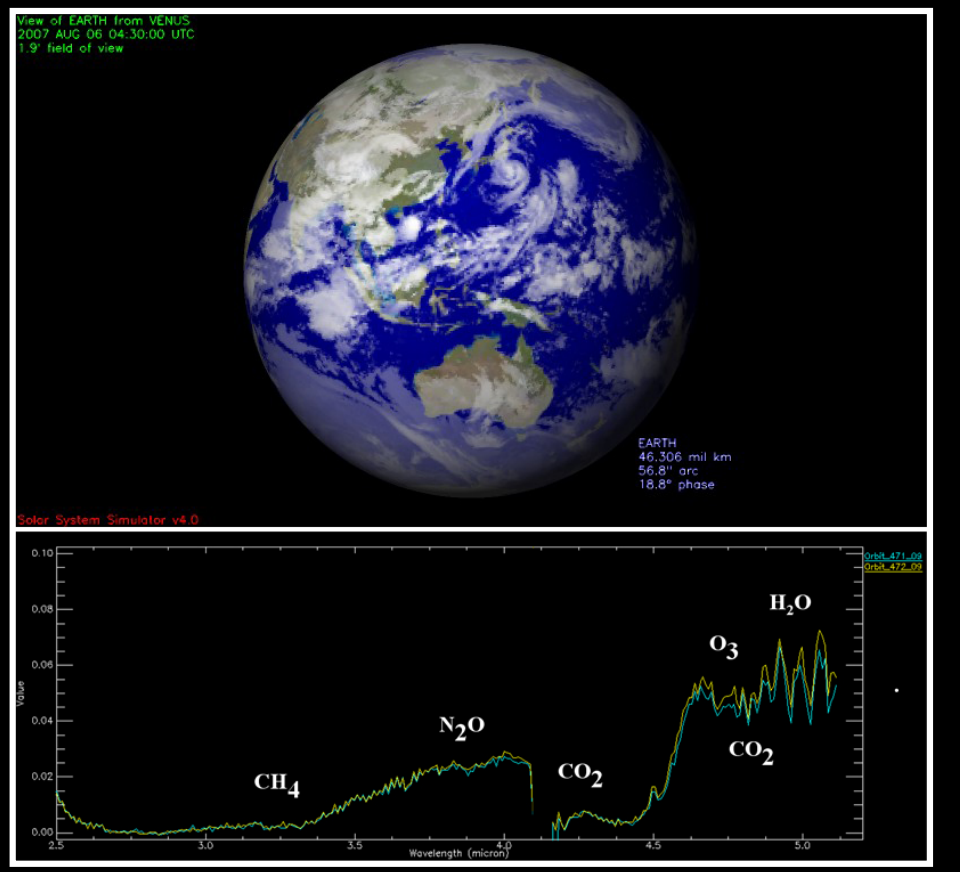
NOT, Visible, 0.4-1 μm
WHT, Near-IR, 0.9-2.5 μm La Palma, Canaries

"Classical biomarker" : H_2O , O_3 & CH_4 / CO_2



Venus Express repeated observations



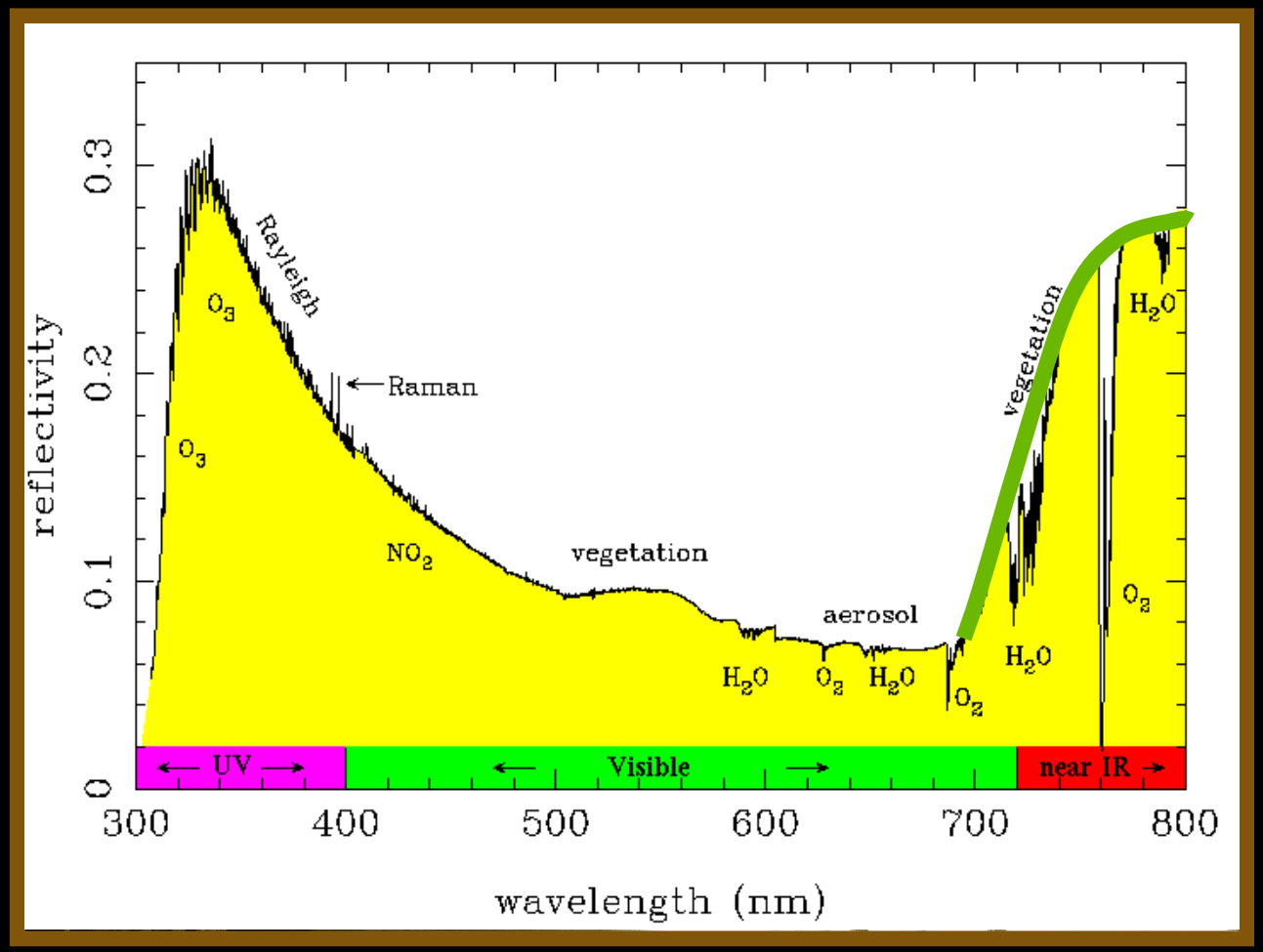


Once we detect an exoplanet spectrum, what can we learn from it?

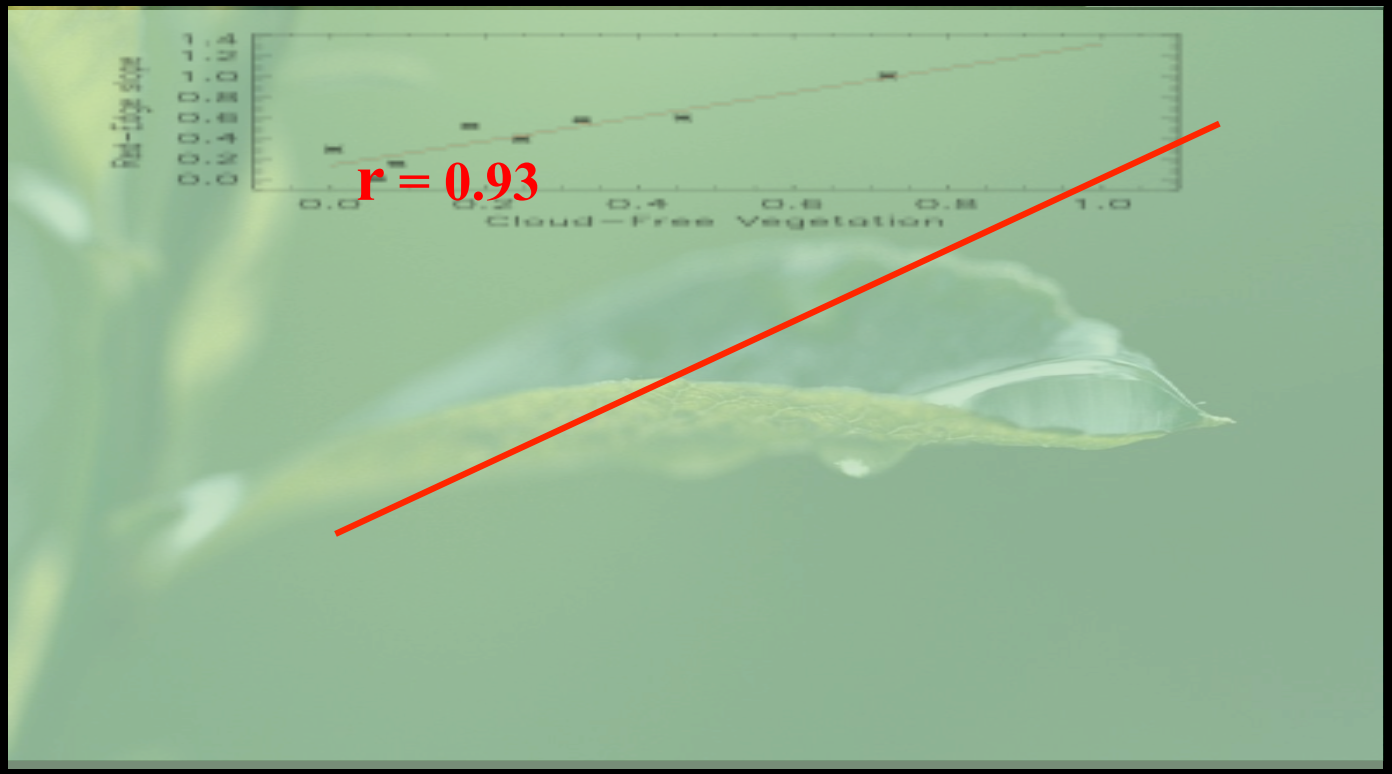
- Suppose a planet with the right physical properties is detected within the Habitable Zone of a star.
- The analysis of its atmospheric composition will give us indications of the presence of life.
- Some authors propose that bacterial life could be common but not complex life
- The vegetation's red edge is an indicator of *complex life.* Can we detect it for the easiest target: Earth?

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.
- This signal is also detectable at global scales

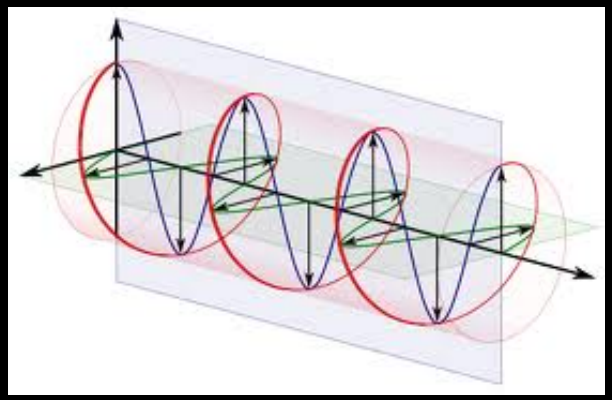


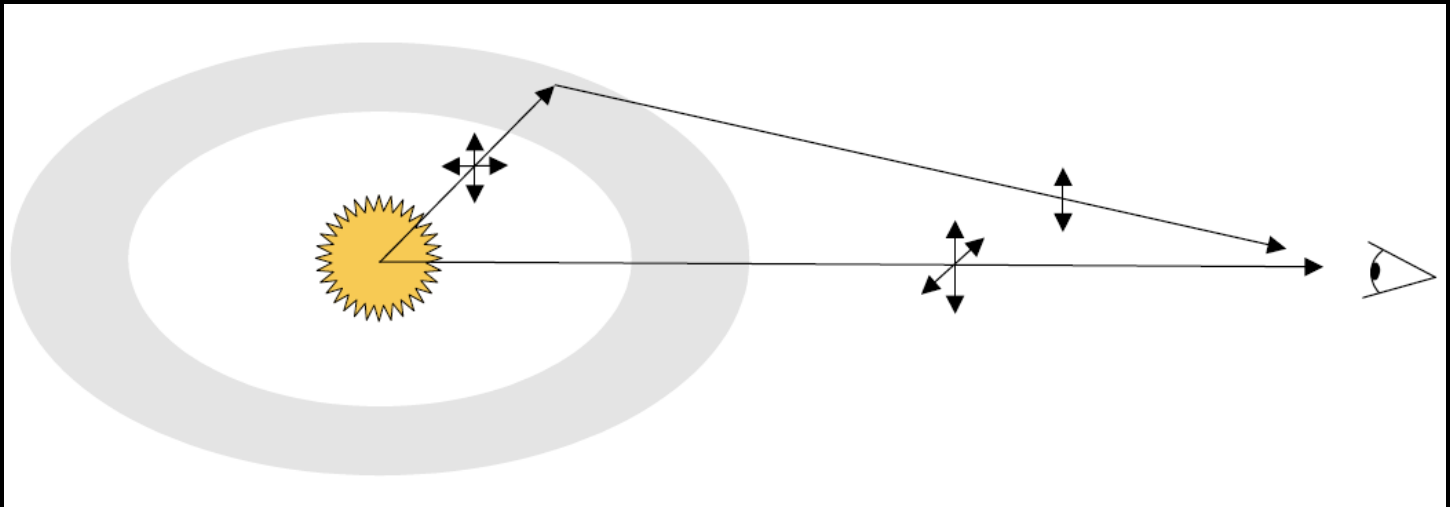
The terrestrial vegetation can be detected but the signal is very small ...



Montañes-Rodriguez et al ApJ, 2006

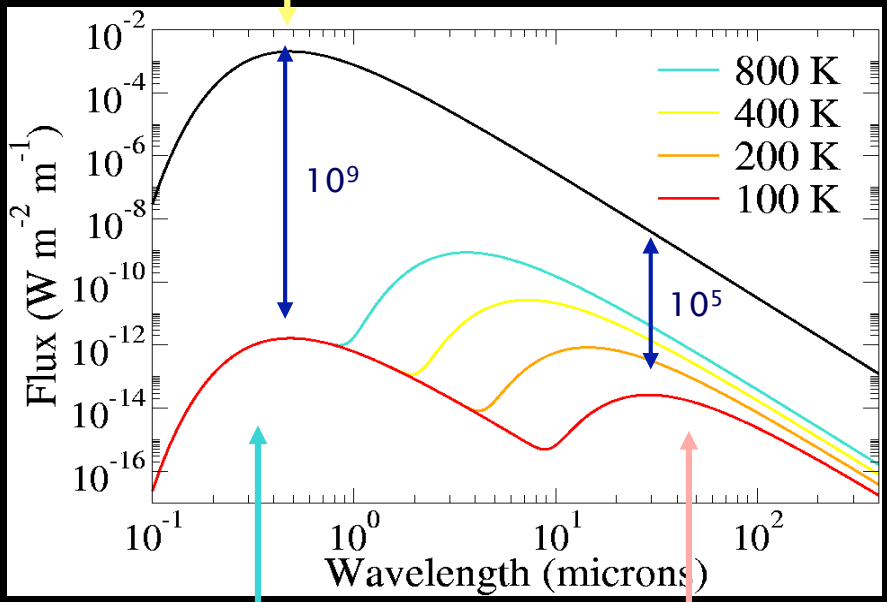
Earthshine polarization





direct starlight

unpolarized



reflected starlight

polarized

thermal radiation

unpolarized

Reflected planet light is generally polarized

Figures from D. Stam, 2009

THE ASTROPHYSICAL JOURNAL LETTERS, 728:L6 (5pp), 2011 February 10 doi:10.1088/2041-8205/728/1/L6
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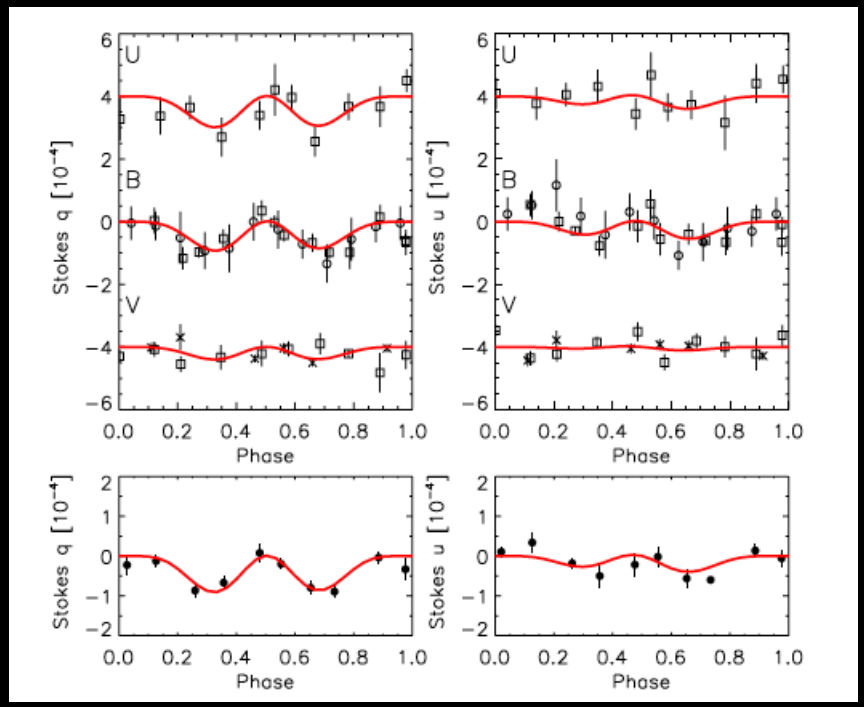
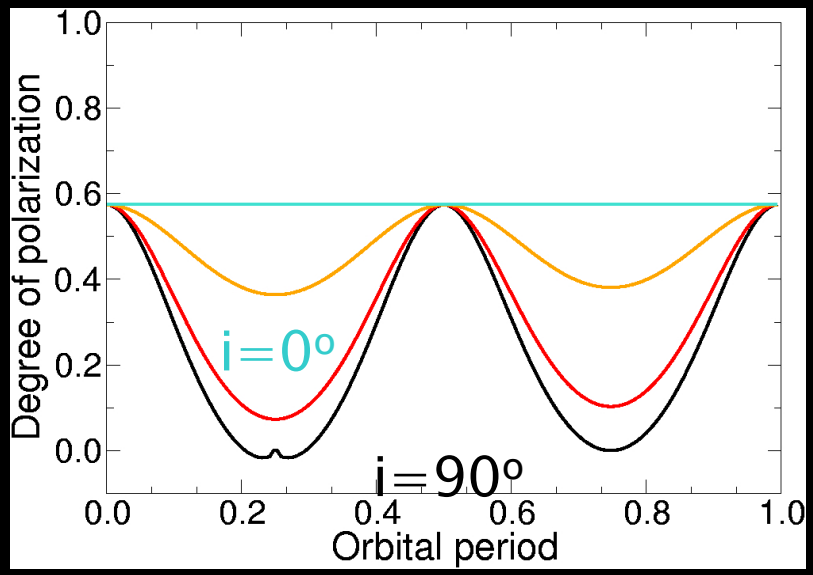
POLARIZED REFLECTED LIGHT FROM THE EXOPLANET HD189733b: FIRST MULTICOLOR OBSERVATIONS AND CONFIRMATION OF DETECTION

S. V. BERDYUGINA[1], A. V. BERDYUGIN[2], D. M. FLURI[3], AND V. PIIROLA[2]
[1] Kiepenheuer Institut für Sonnenphysik, Schöneckstrasse 6, D-79104 Freiburg, Germany; sveta@kis.uni-freiburg.de
[2] Tuorla Observatory, Department of Physics and Astronomy, University of Turku, Väisäläntie 20, FIN-21500 Piikkiö, Finland; andber@utu.fi, piirola@utu.fi
[3] Institute of Astronomy, ETH Zurich, CH-8093 Zurich, Switzerland; fluri@astro.phys.ethz.ch
Received 2009 December 15; accepted 2010 December 27; published 2011 January 18





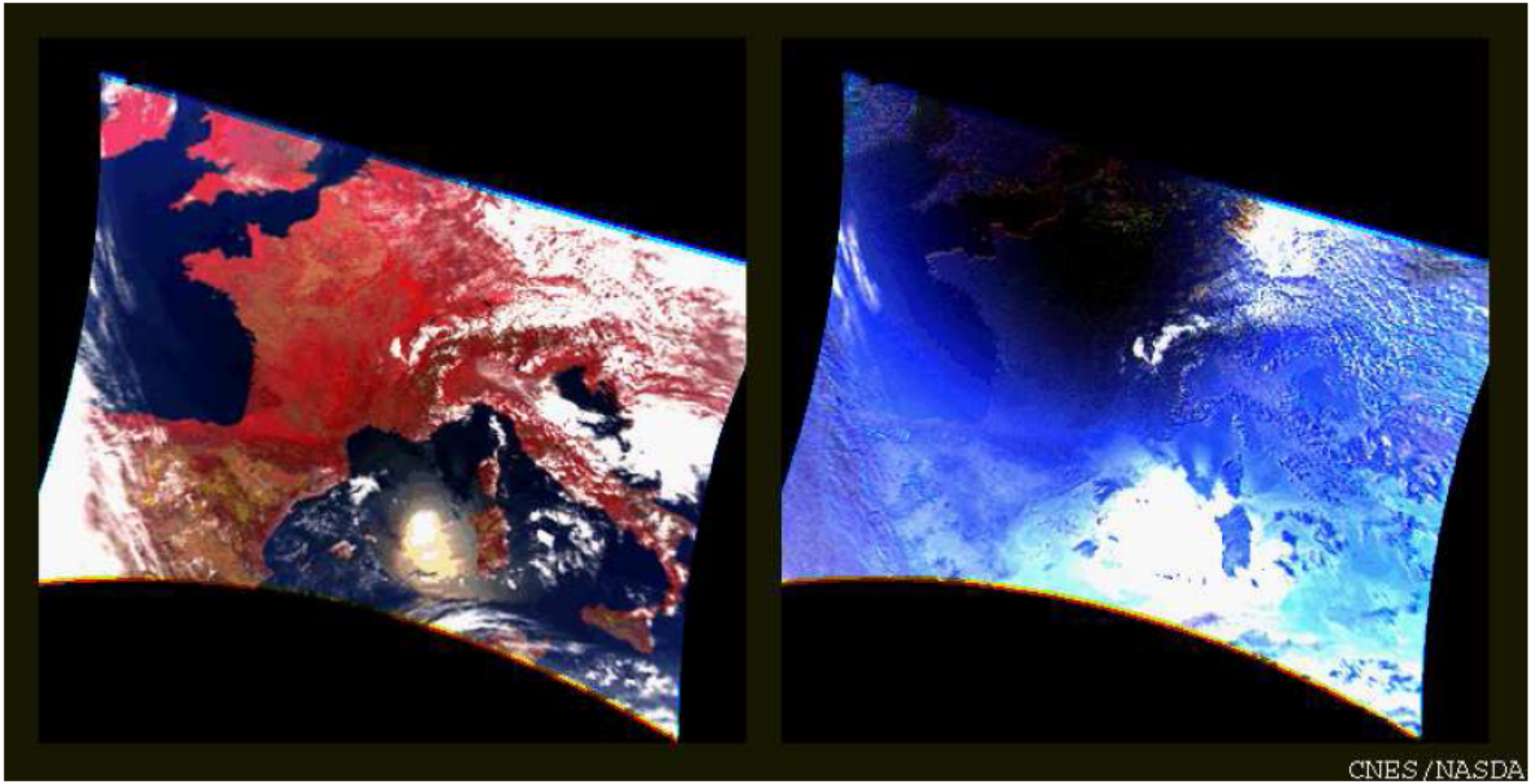
Berdyugina et al, ApJ, 2011

D. Stam, 2011

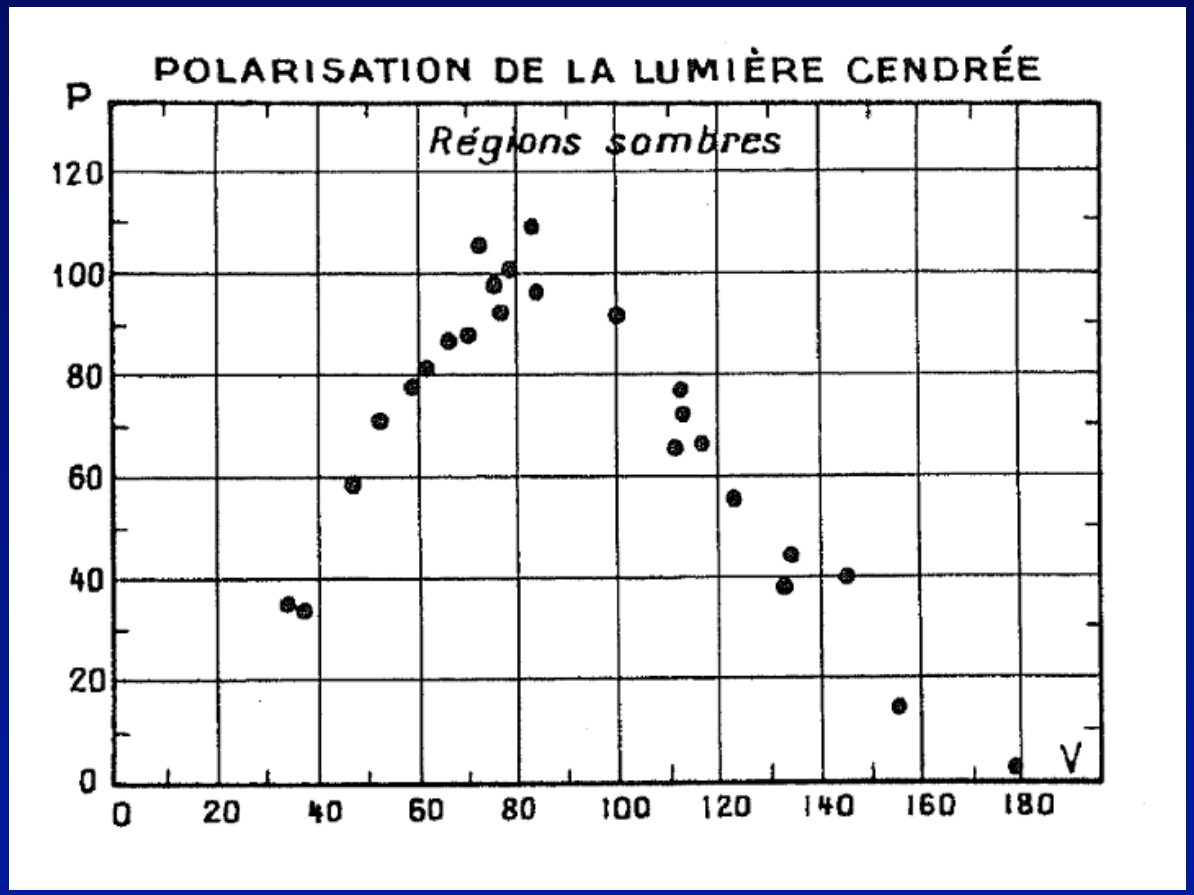
Earth's polarization

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.

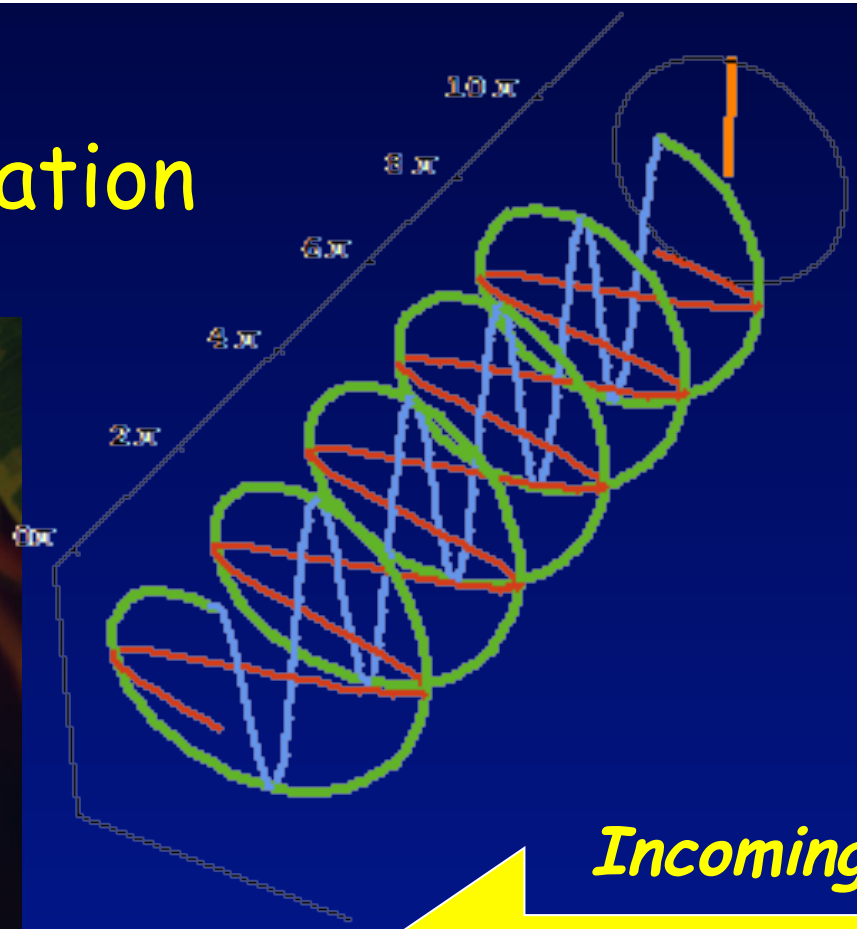


Dollfus concluded that the atmospheric polarization is by far larger than that introduced from the ground.

Averaged polarization for the combined terrestrial light may be *as high as 36%.*

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

Circular polarization



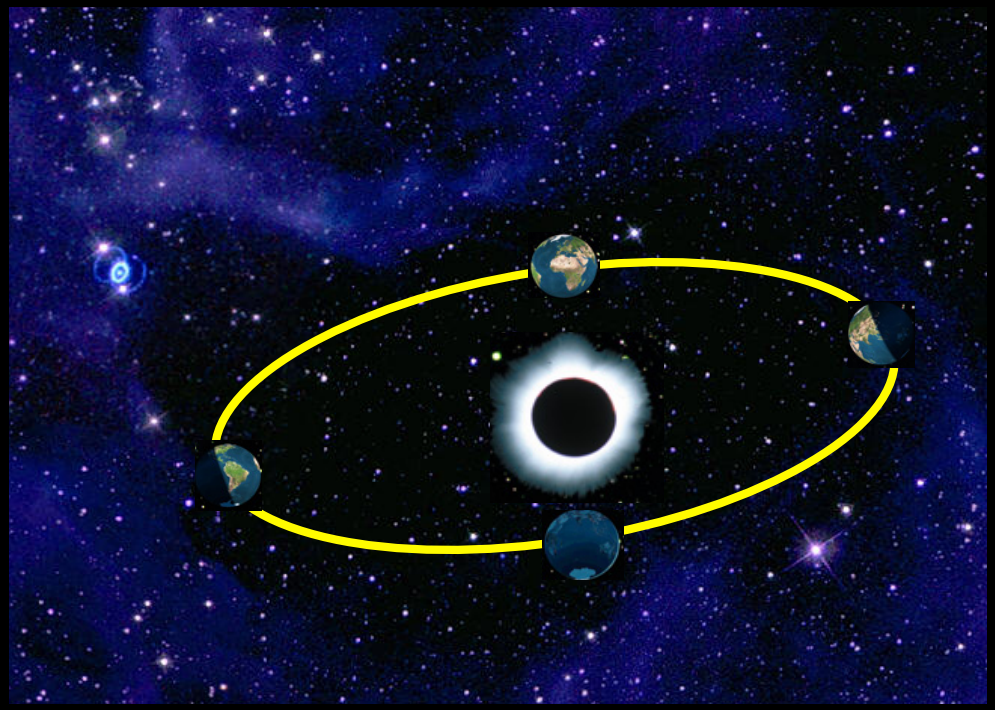
Incoming sunlight

Homochirality, 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

Earthshine spectropolarimetry

- Detection of polarimetric features including chemical composition and biomarkers (vegetation)
- Sensitivity to surface features
- Large room for model improvements
- Not as technically challenging as direct imaging. Just need to collect TONS of photons.
- Earth-Sun 0.5% P of transit
  - Out of 200 closest Earth twins only 1 will be sensible to transit spectroscopy.
  - We need spectropolarimetry !!

What about transiting Earths?

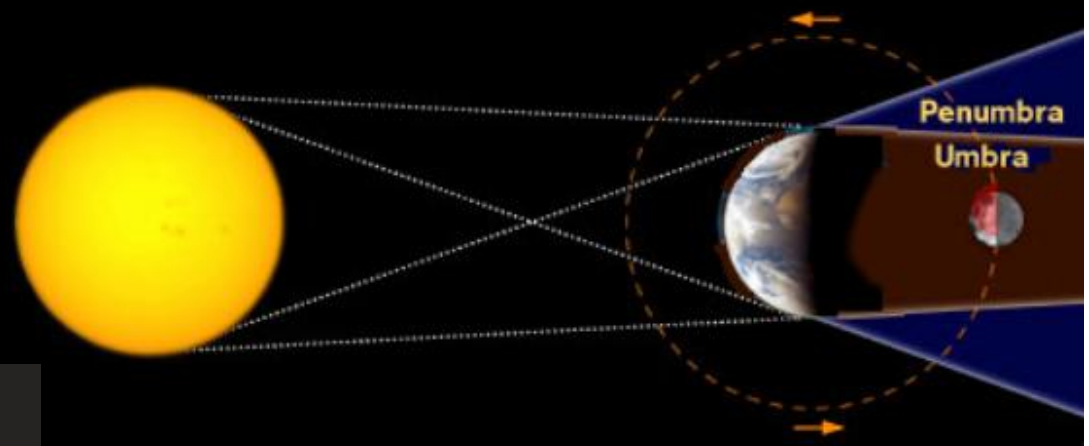


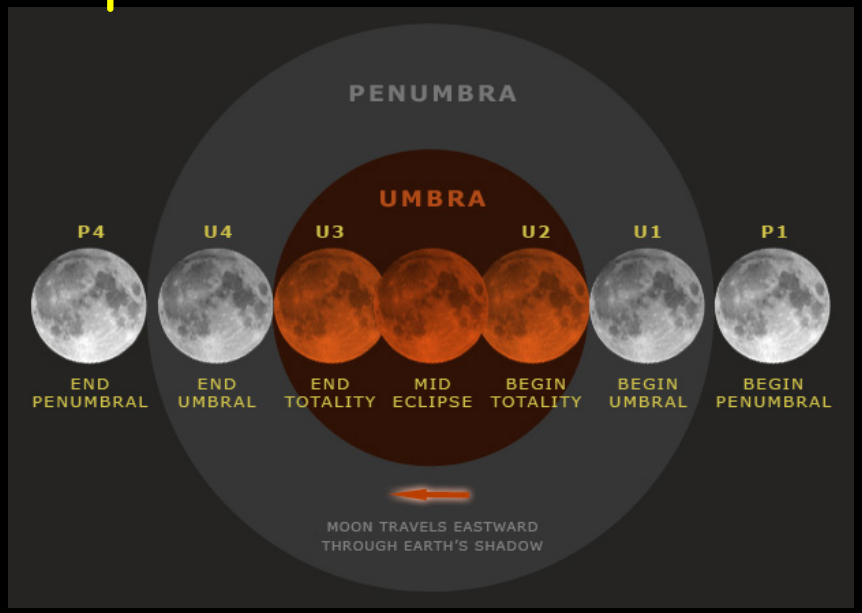
Photometry
Color photometry
Spectroscopy
Polarimetry
Spectro-polarimetry

CoRoT & KEPLER

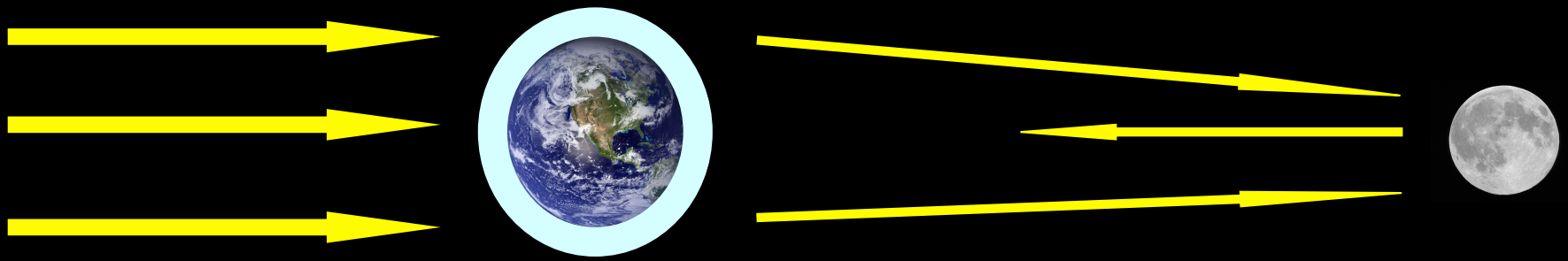
Transit spectroscopy

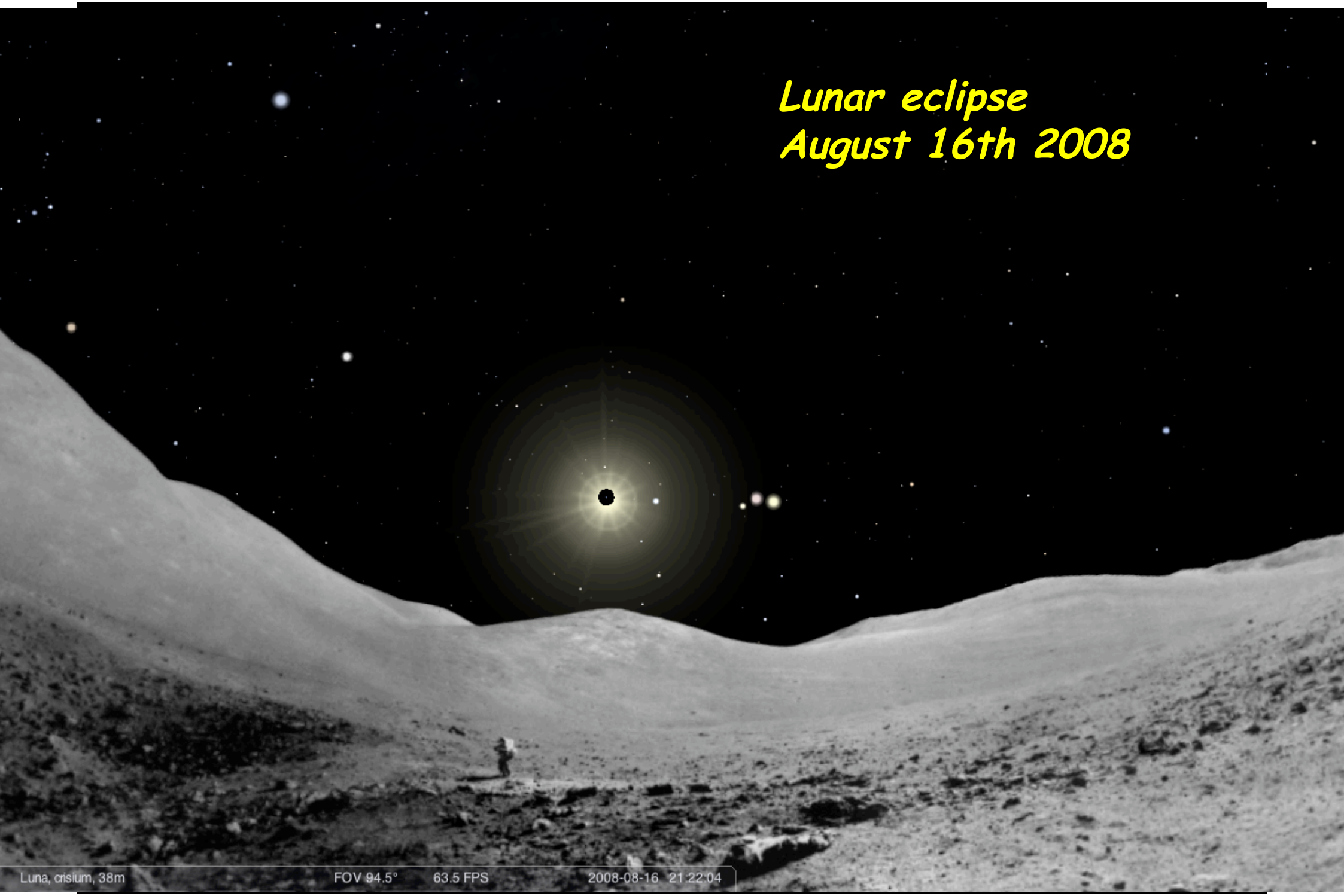
We can observe the Earths' transmission spectrum during a lunar eclipse





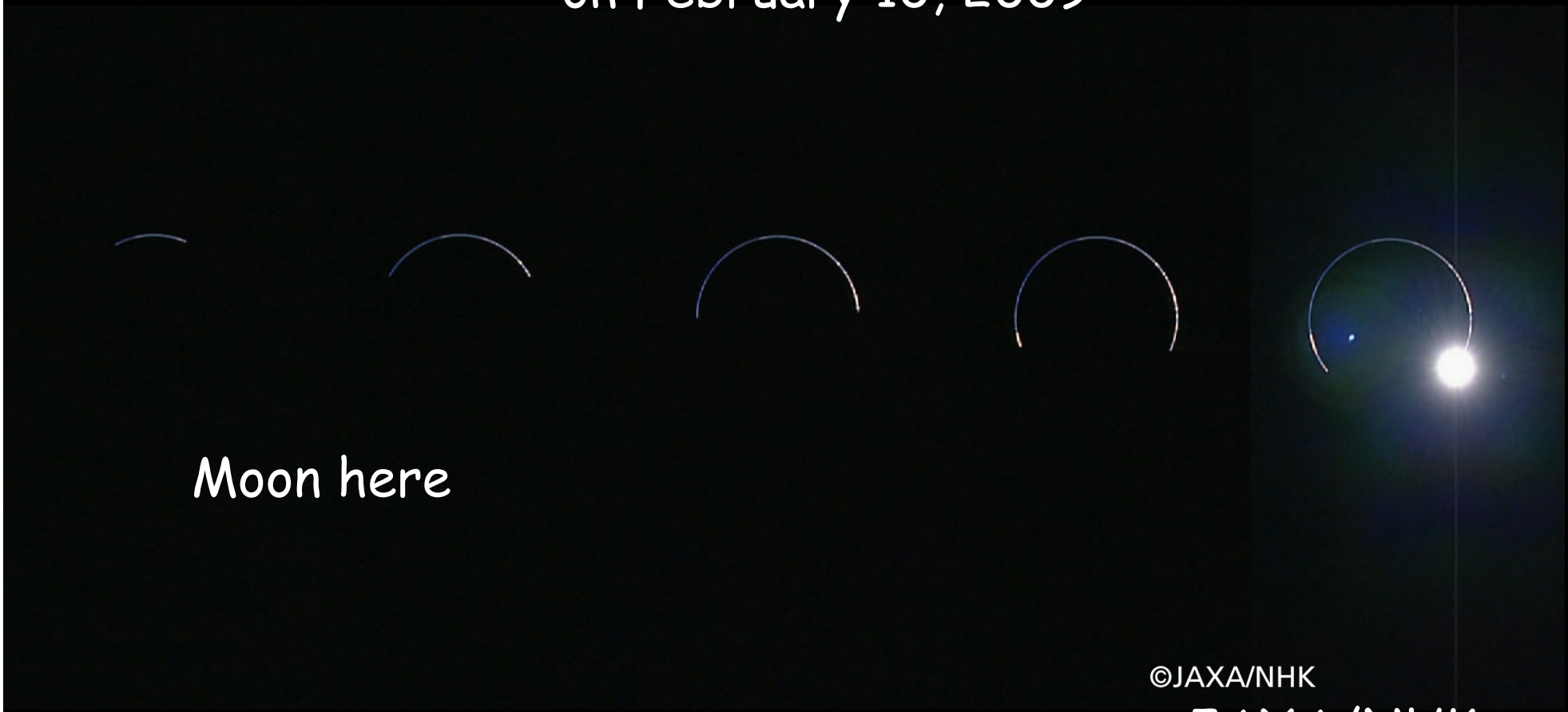
Same instrumentation only two months apart



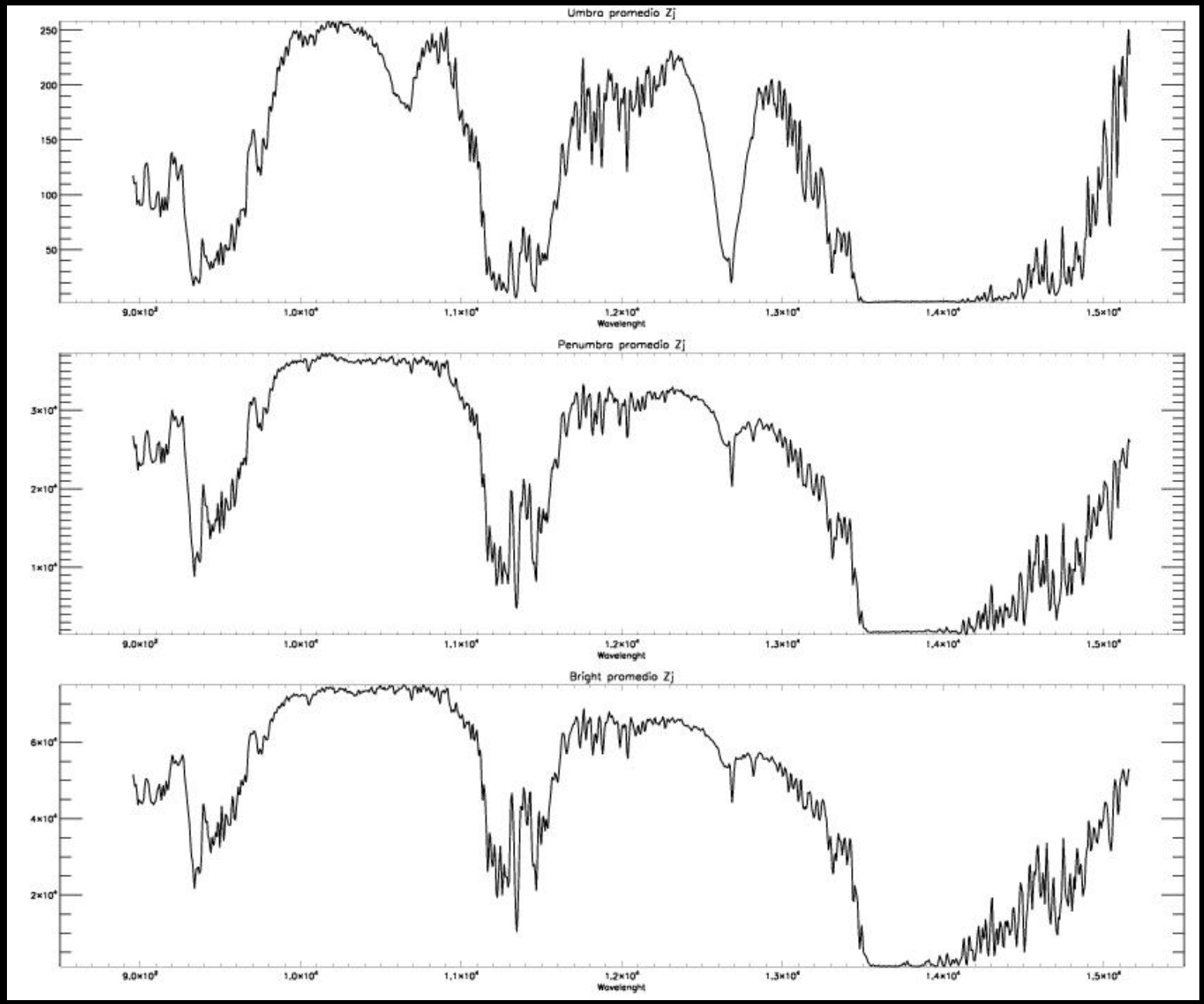

Lunar eclipse
August 16th 2008
Luna, crisium, 38m
FOV 94.5°
63.5 FPS
2008-08-16 21:22:04

A penumbral eclipse seen from the Moon

Lunar explorer "KAGUYA" (SELENE)
on February 10, 2009



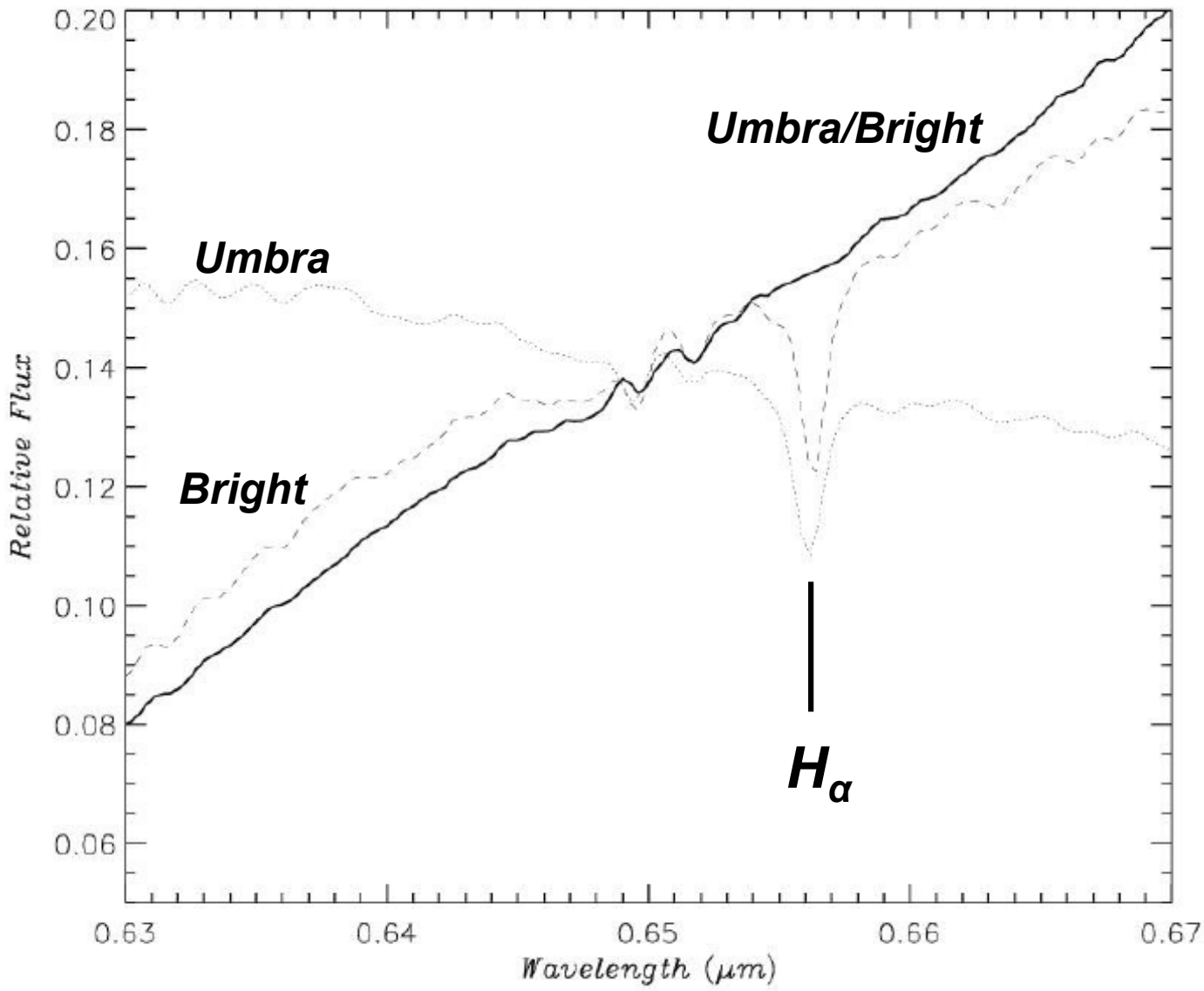
JAXA/NHK



Umbra

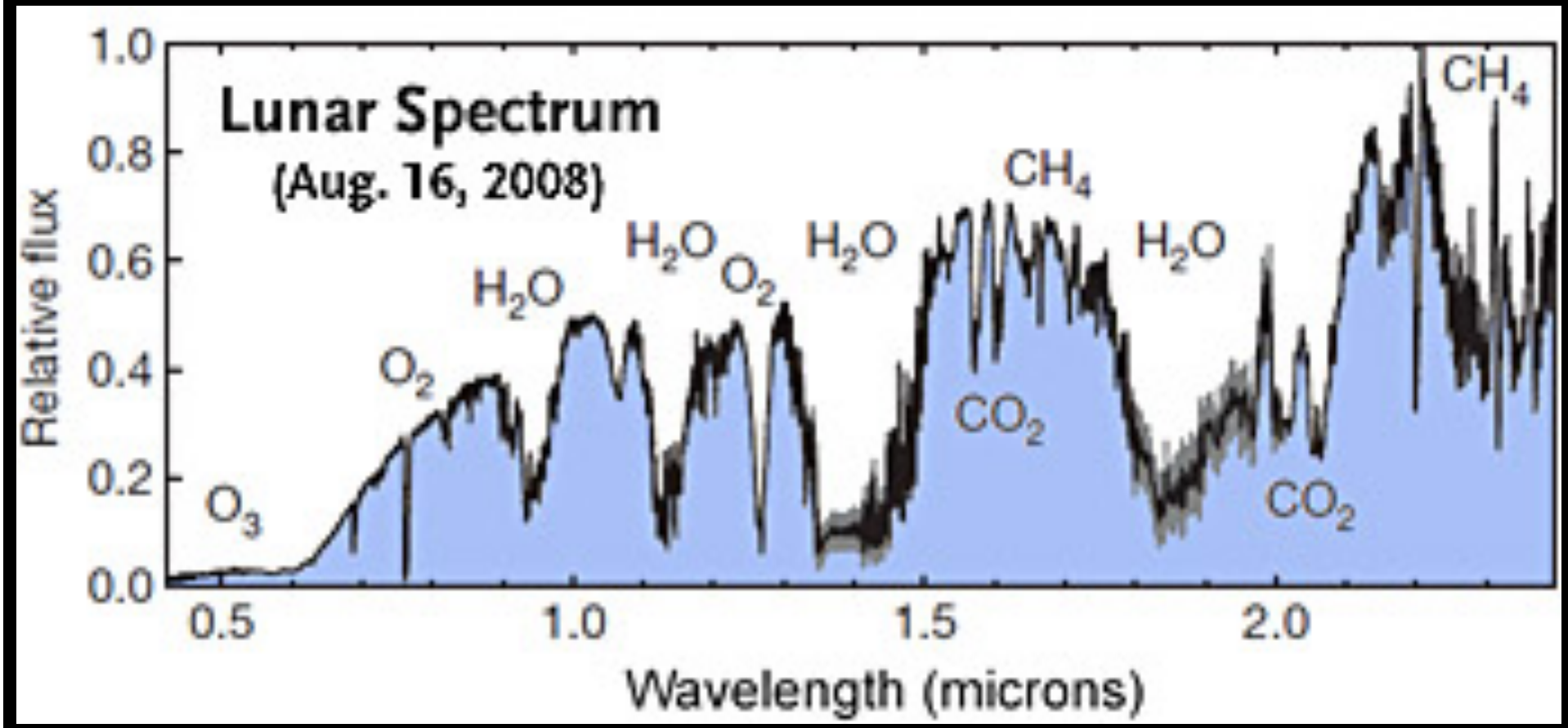
Penumbra

Brigth Moon


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

Earth's Transmission Spectrum

The pale *red* dot



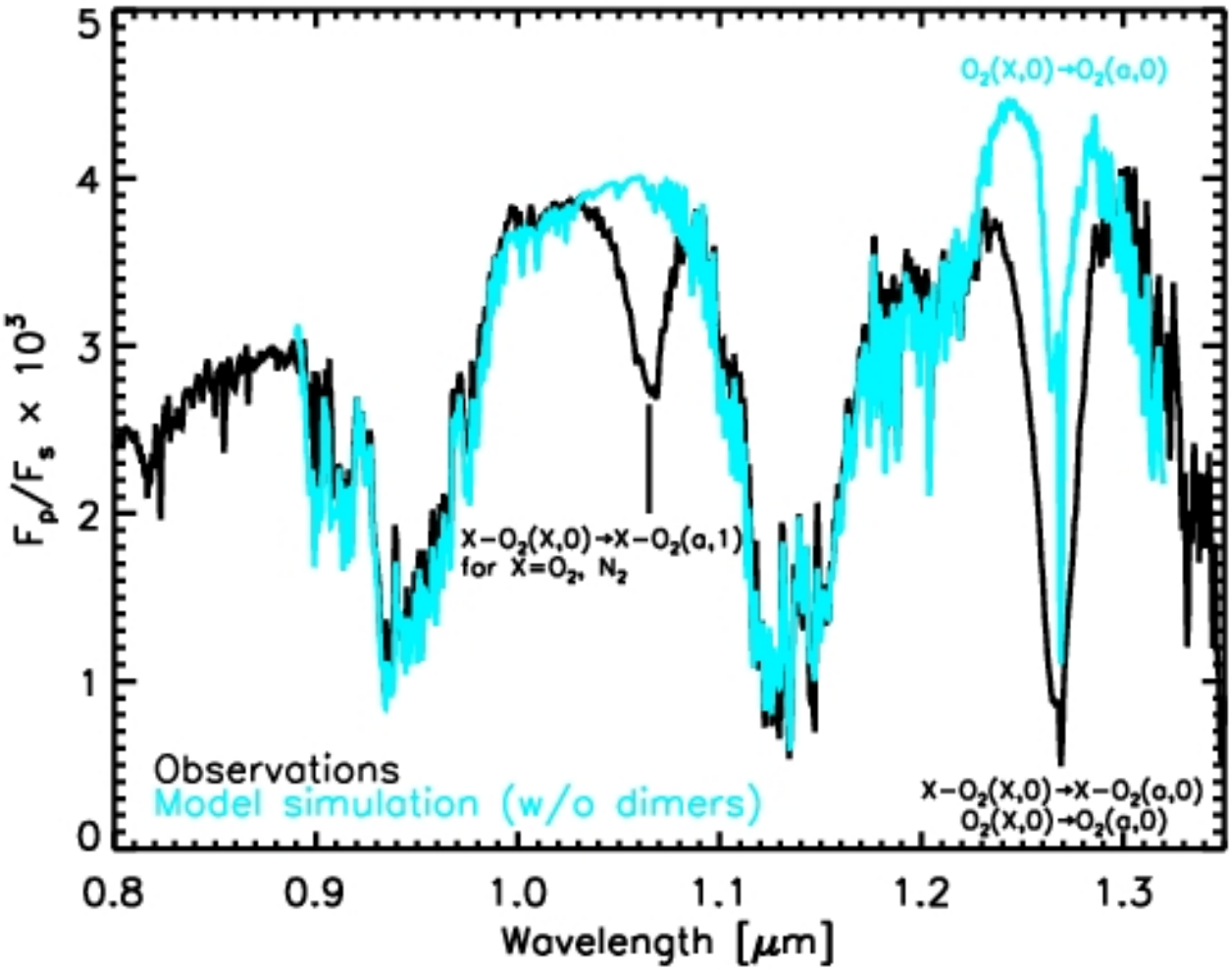
Palle et al, Nature, 2009

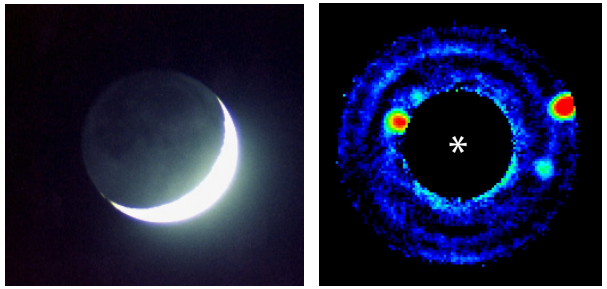
Oxygen complexes in the Earth's atmosphere: Oxygen dimers

Oxygen at near-IR wavelengths

$O_2 \cdot O_2$

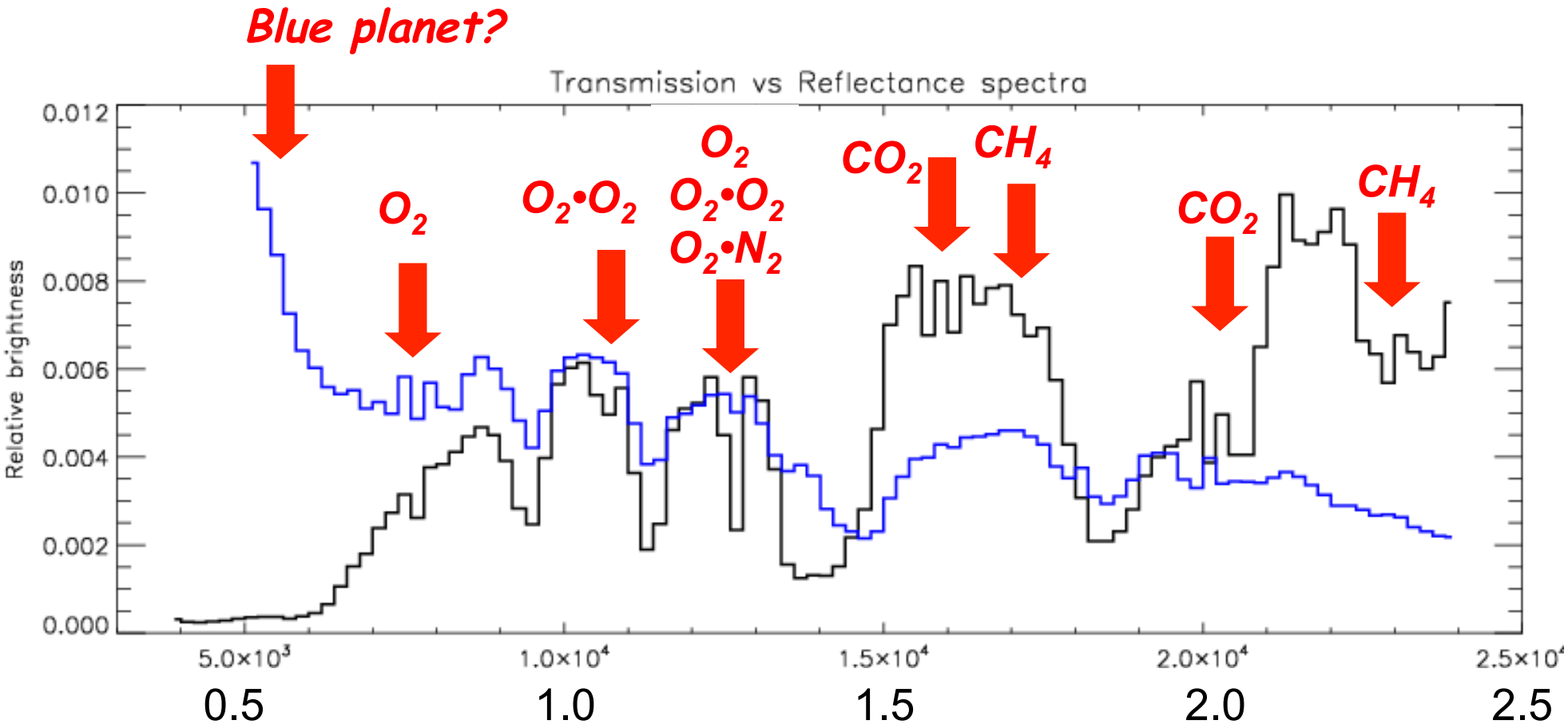
$O_2 \cdot N_2$





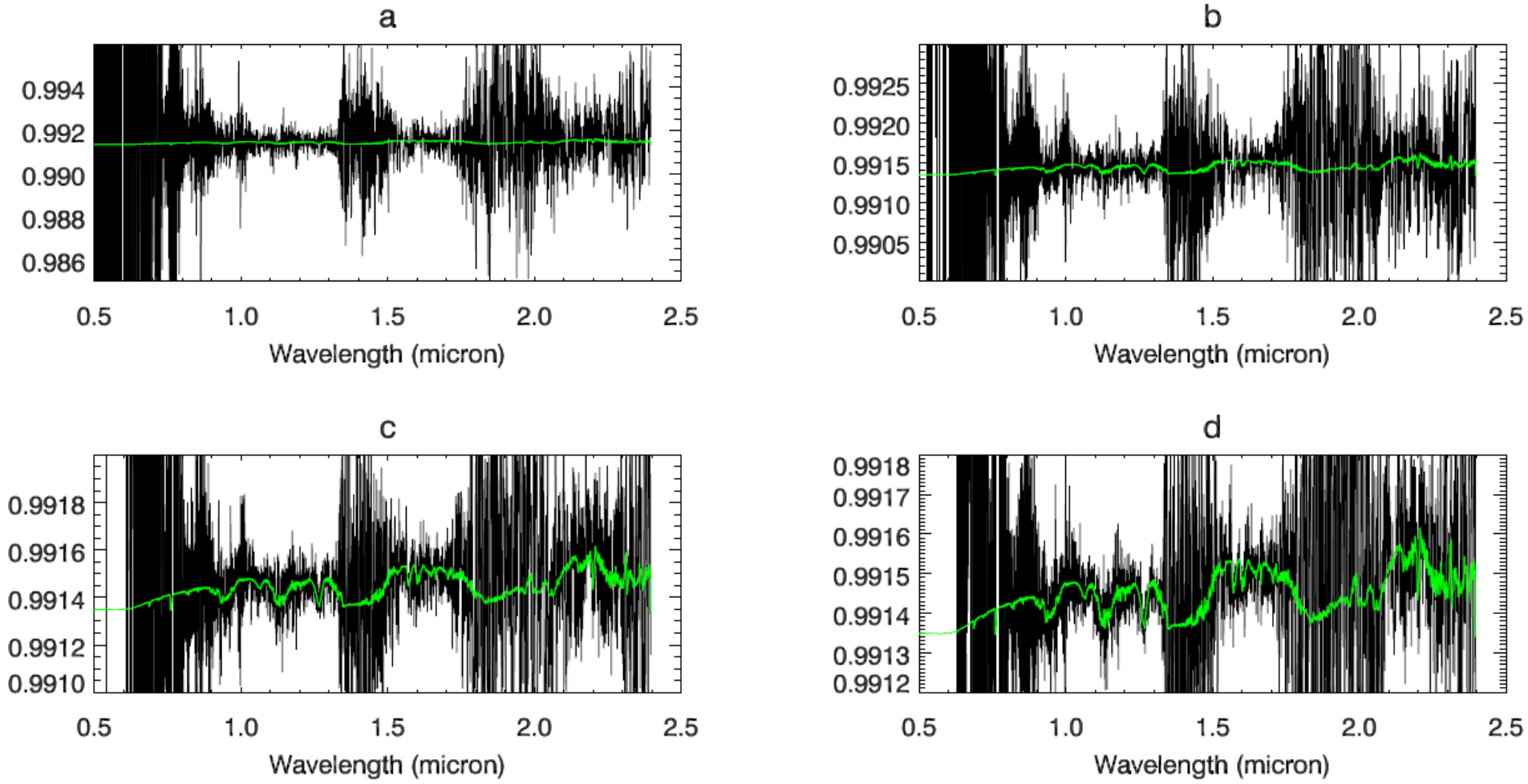
Reflected spectrum

Transmission Spectrum



Palle et al, Nature, 2009

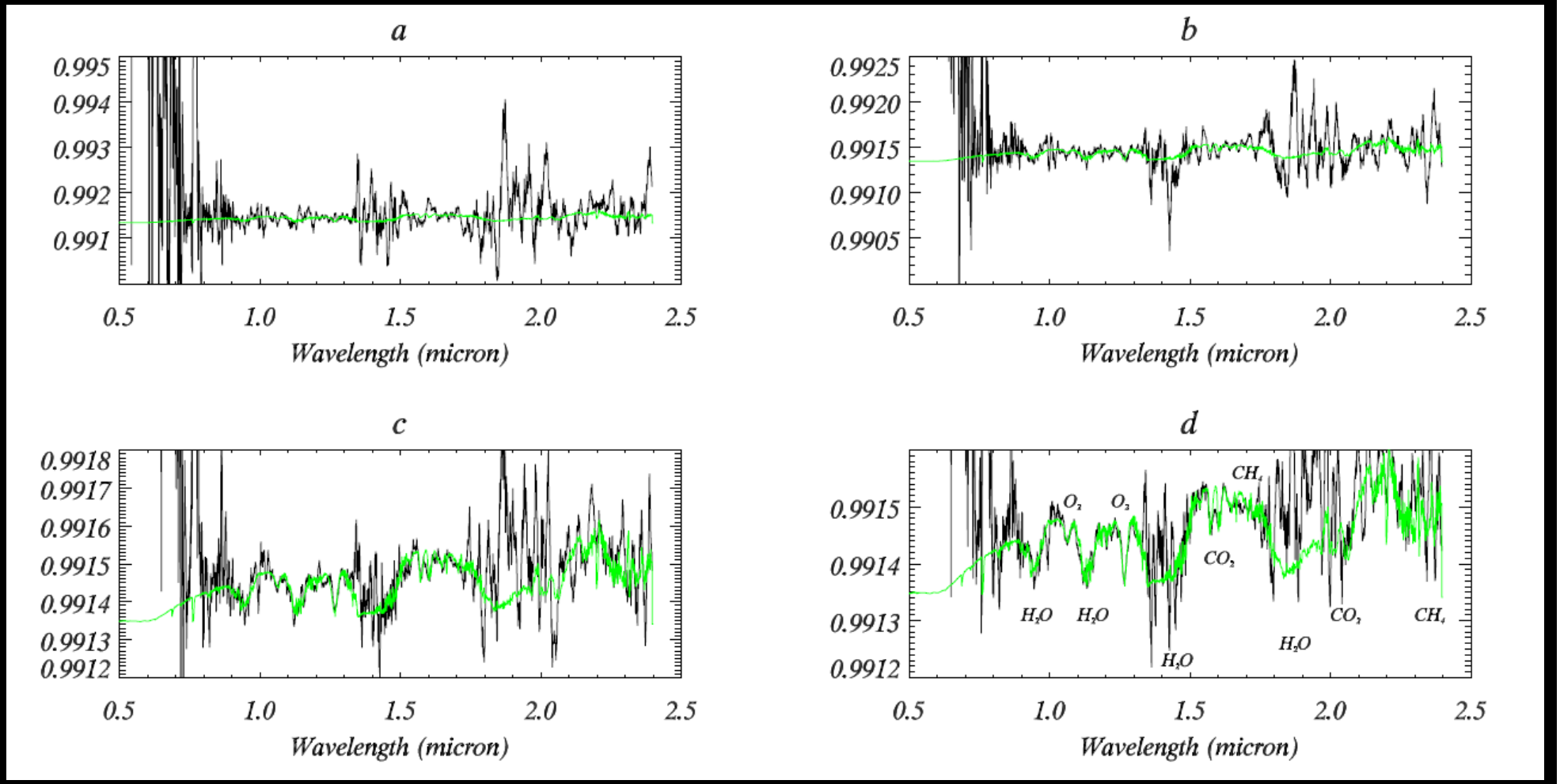
M8 star + 1 Earth ... with the E-ELT



Palle et al, ApJ, submitted

20, 100, 500, 1000 spectra combined - SNR 1000

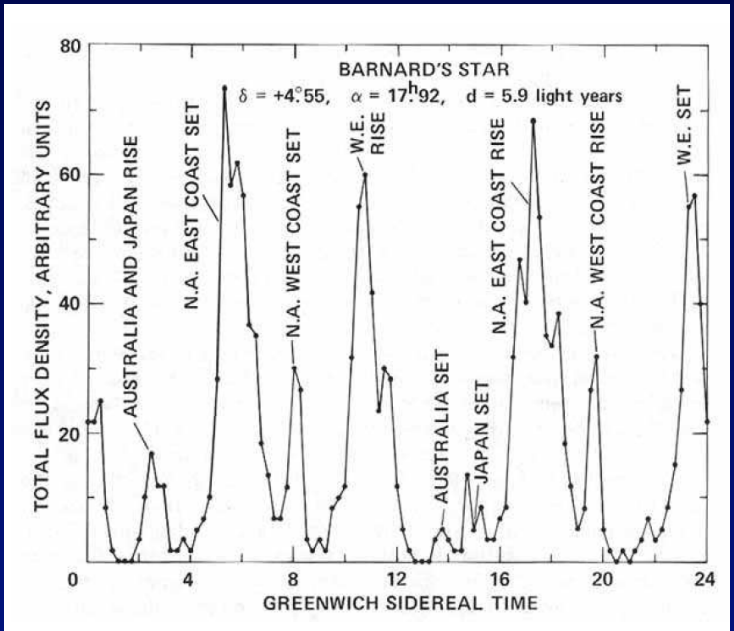
M8 star + 1 Earth ... with the E-ELT



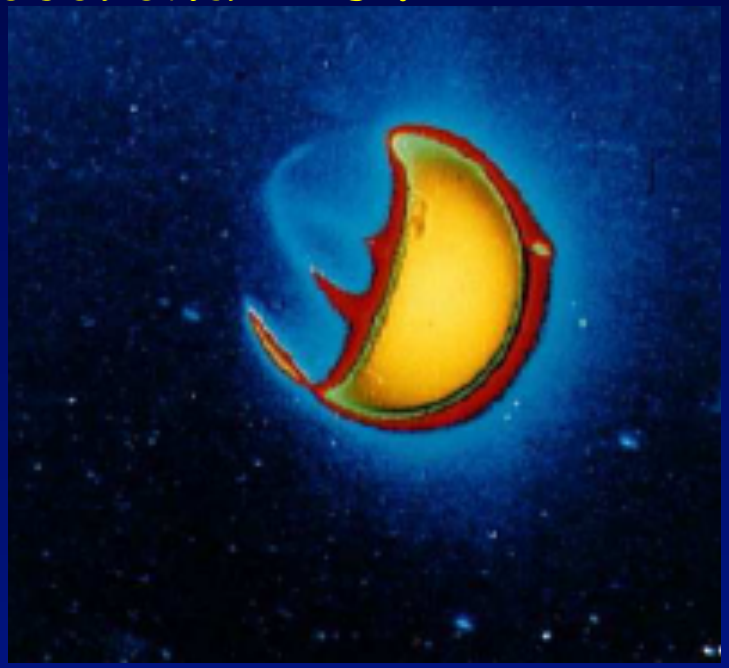
Palle et al, ApJ, 2011

20, 100, 500, 1000 spectra combined - SNR 1000

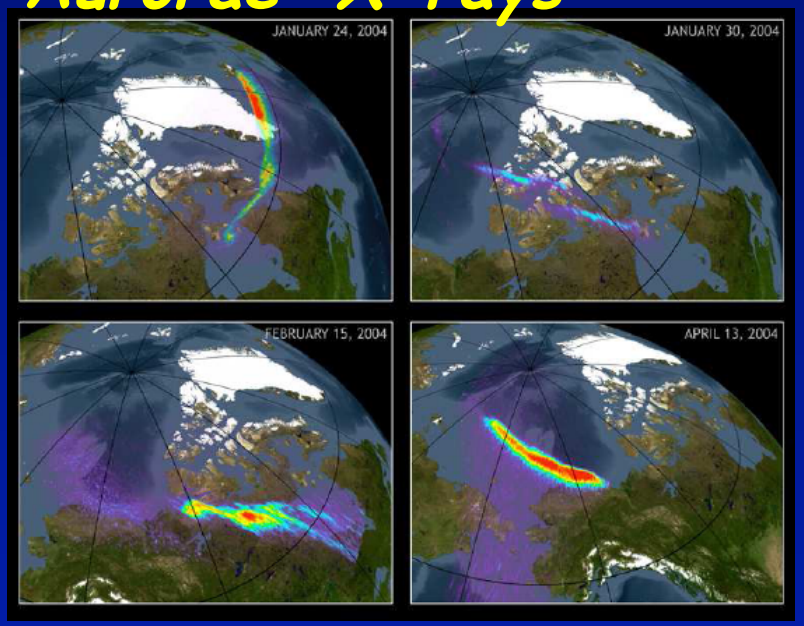
TV radiation

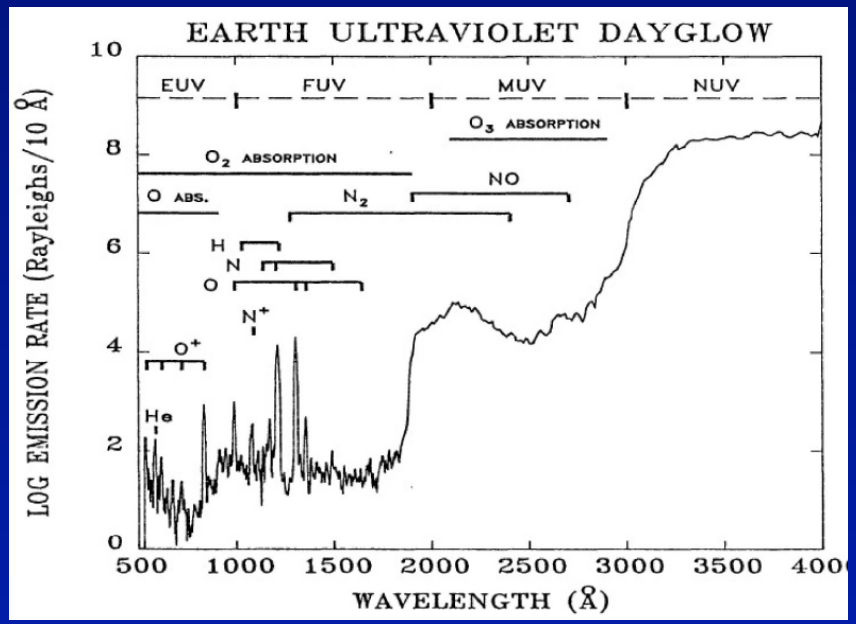


Geocorona - UV



Aurorae X-rays





T 04:00:20:00
UAF

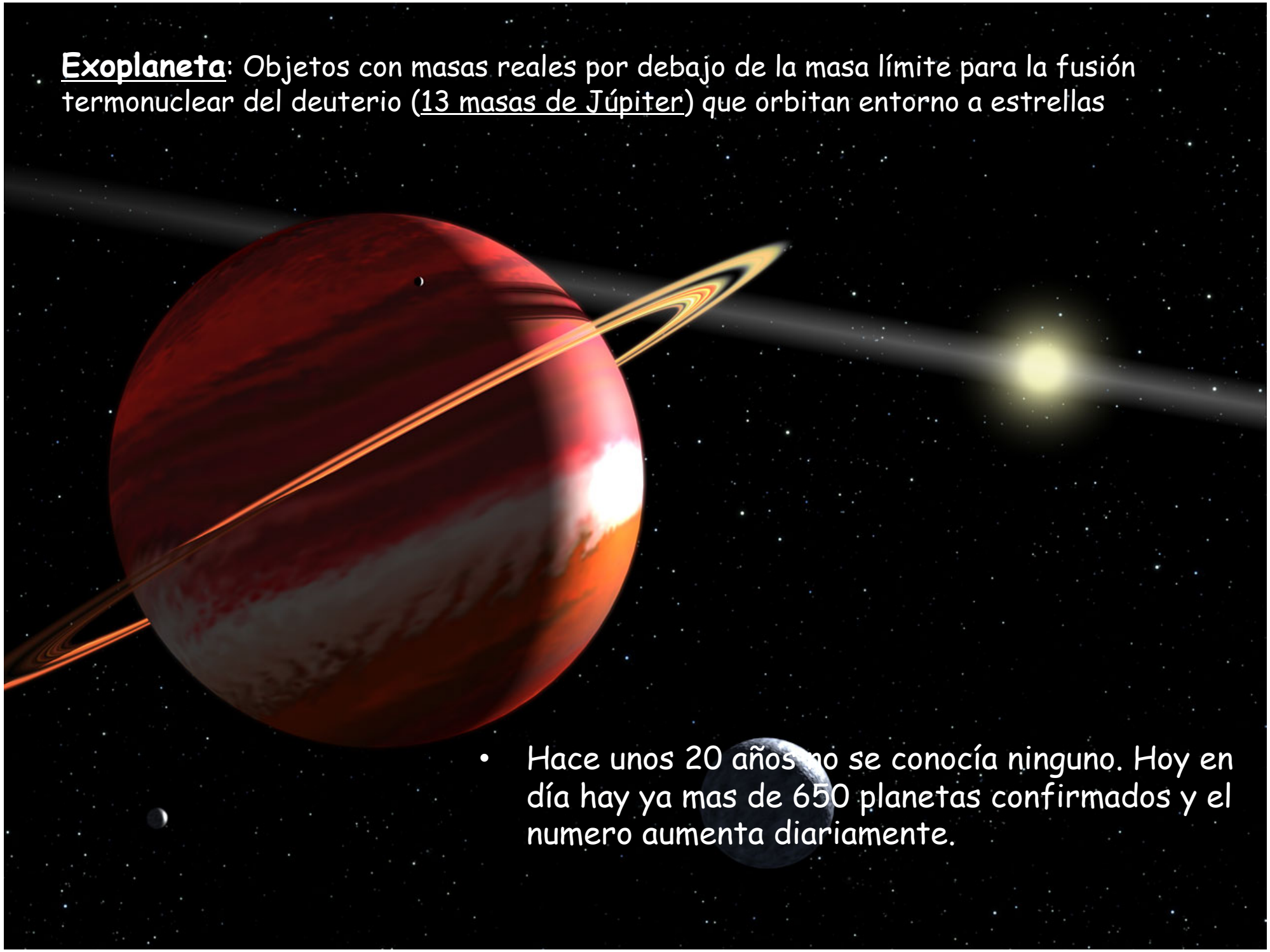
Thank you

Thank you
© Daniel López

Exoplanetas

Enric Palle

Exoplaneta: Objetos con masas reales por debajo de la masa límite para la fusión termonuclear del deuterio (13 masas de Júpiter) que orbitan entorno a estrellas



- Hace unos 20 años no se conocía ninguno. Hoy en día hay ya mas de 650 planetas confirmados y el numero aumenta diariamente.

Tierras y Super-Tierras:

Planeta "terrestre" extrasolar que posee entre una y diez veces la masa de la Tierra.

Hierro	34,6
Oxígeno	29,54
Silicio	15,2
Magnesio	12,7
Níquel	2,4
Azufre	1,9
Titanio	0,05
Otros	3,65

Varios tipos posibles: Terrestres, de Carbono, de Agua (océanos), de lava (oceanos), …

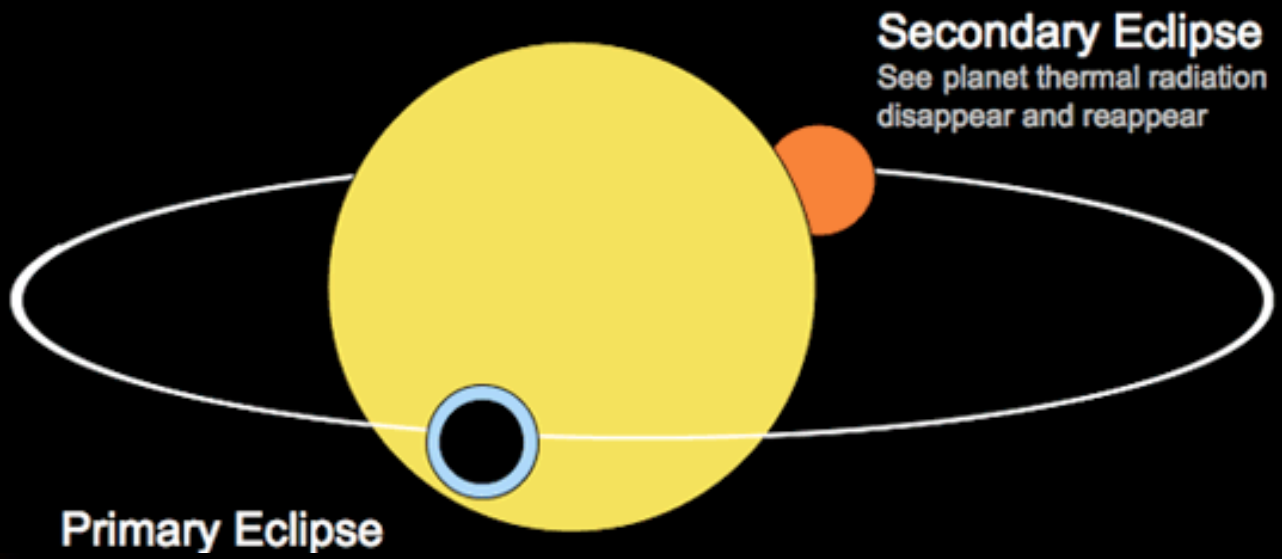
Tierras y Super-Tierras:

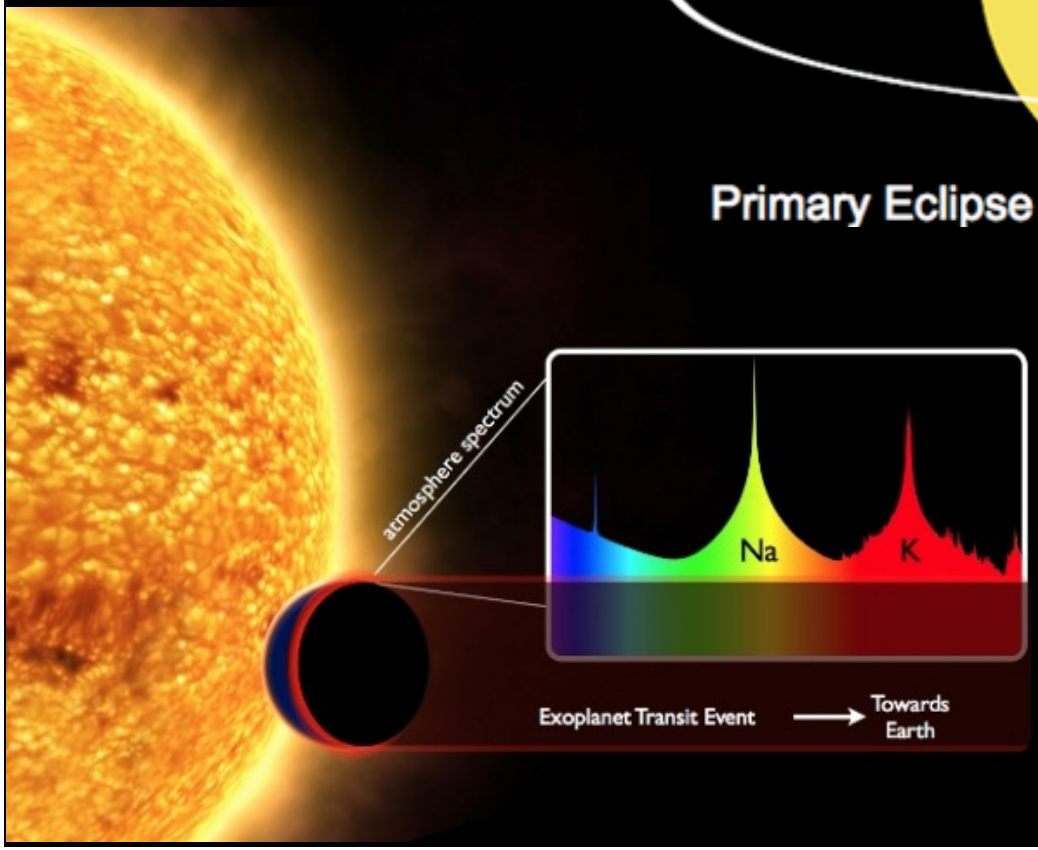
Planeta "terrestre" extrasolar que posee entre una y diez veces la masa de la Tierra.

Capaces de albergar vida
Conocemos ya decenas de ellos, algunos con tránsitos
De momento son supertierras "calientes"

¿Existen otros planetas con vida?

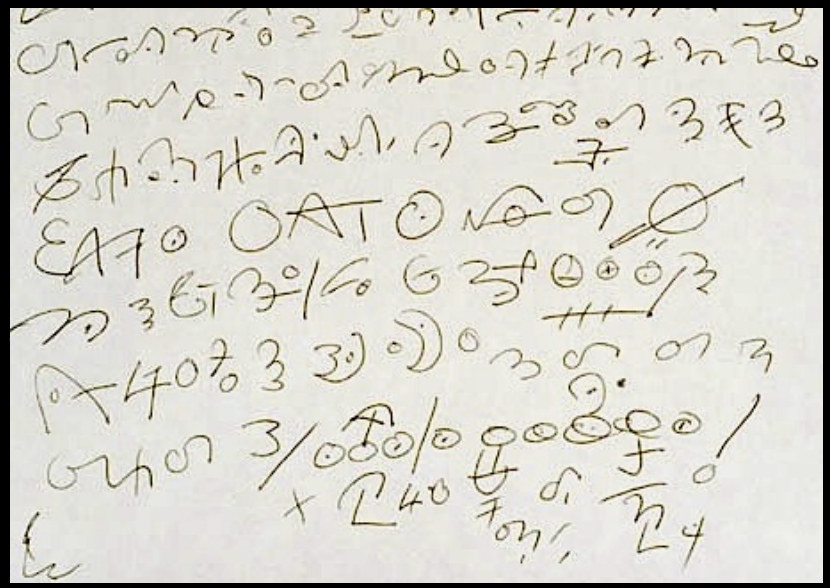
Espectroscopia de tránsitos: primera caracterización de atmosferas de exoplanetas

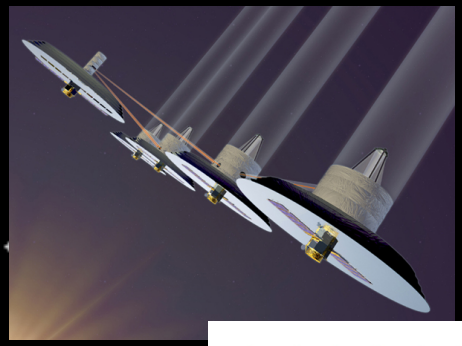


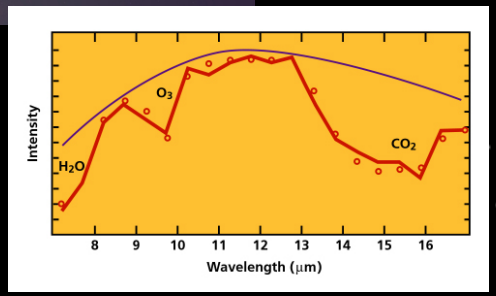


Composición Química !!

10 años de adelanto > Deteccion del planeta







Gl 892

Capella (Alpha Aur)

Mirphak (Alpha Per)

Siguiente etapa > Caracterizacion

http://www.astronexus.com

Habitable ≠ Habitado

¿Como lo sabremos cuando encontremos uno?

La Tierra como exoplaneta

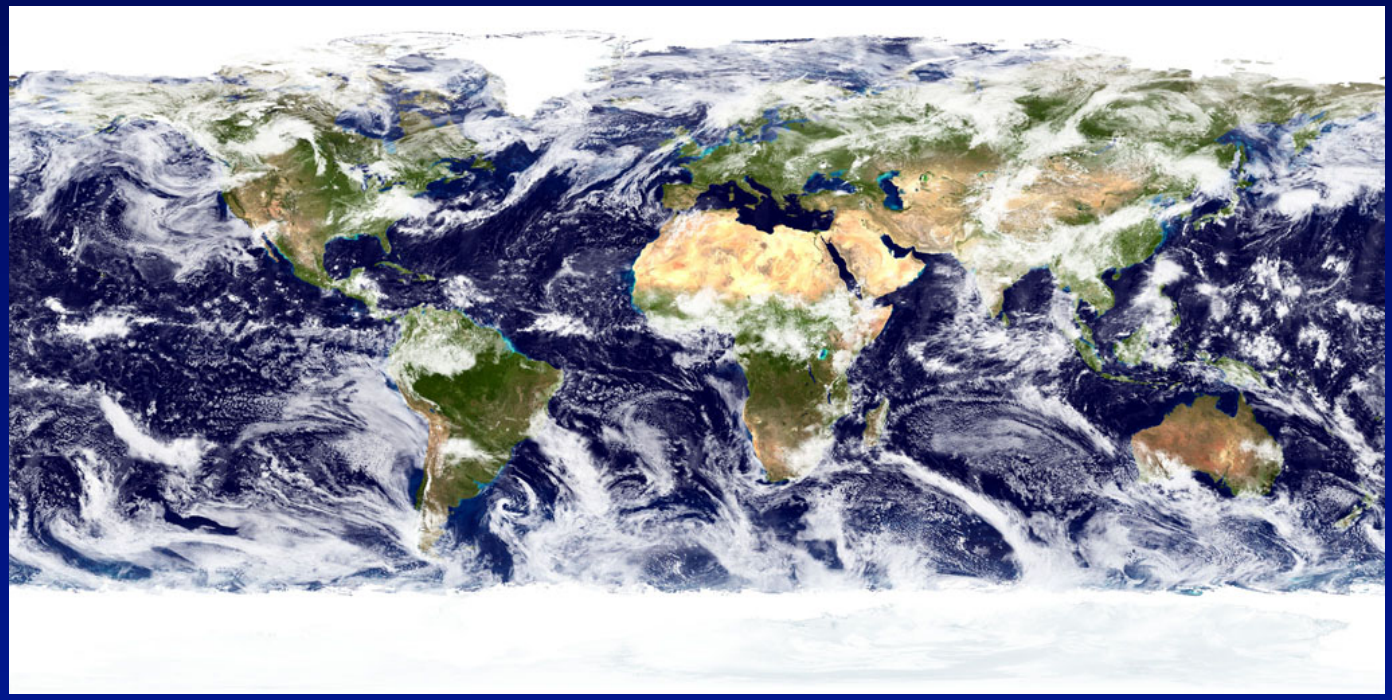
- Estudio de nuestro planeta: herramientas para interpretar observaciones
- Estudio de la Tierra como si fuéramos un observador extraterrestre
- ¿Por qué la Tierra? → único planeta conocido que alberga vida

Próximamente … en los mejores observatorios

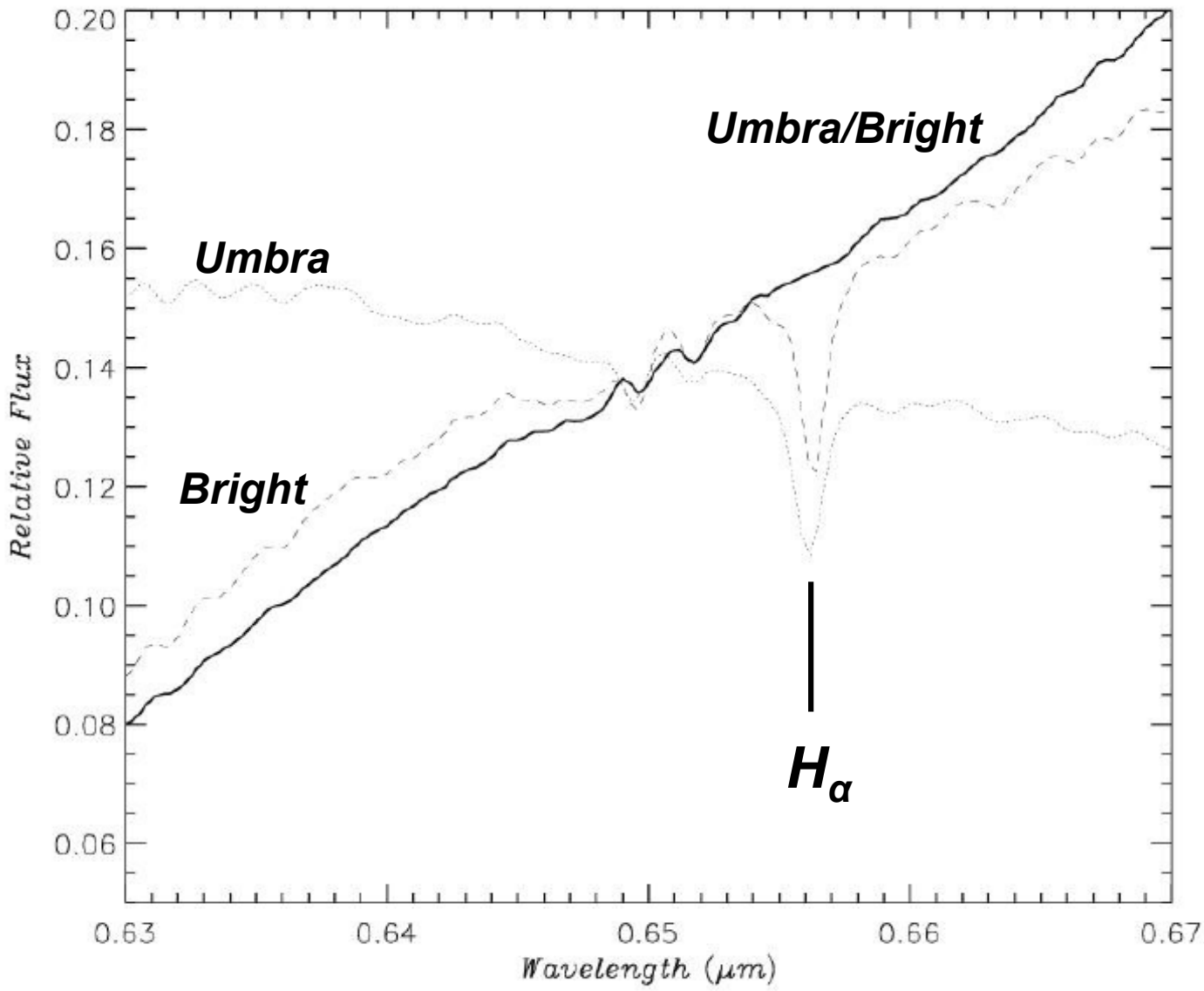
"To do" list ... while waiting to reach 51%

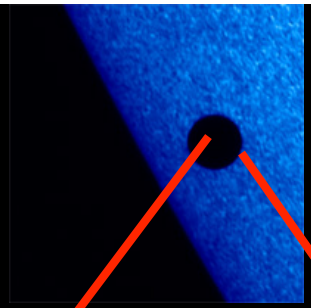
- Determine what is detectable and what is not, and at what level
- Photometry
  - Infrared earth photometry data is missing
  - Characterization of the glint scattering
  - Variability characterization and modeling for exoplanets
- Spectroscopy:
  - Characterization of variability in IR range (no empirical data)
  - Characterizing the transmission spectra of earth along wavelength 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:
  - Need to improve molecular databases
  - Construct flexible models to account for unexpected atmospheric composition / properties

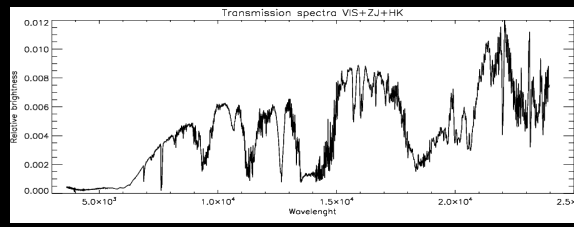
The Earth clouds: A unique feature in the solar system?



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


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

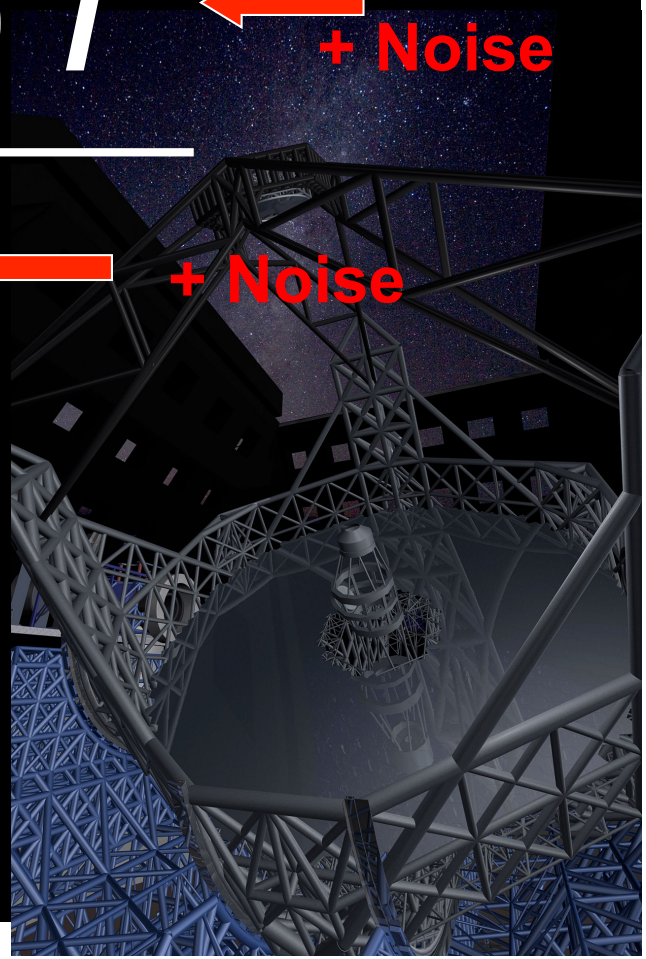




$$\frac{F^* - F^*\left(\frac{A_{p*a}}{A_*}\right) + F^*\left(\frac{A_a}{A_*}\right) T}{F^*}$$

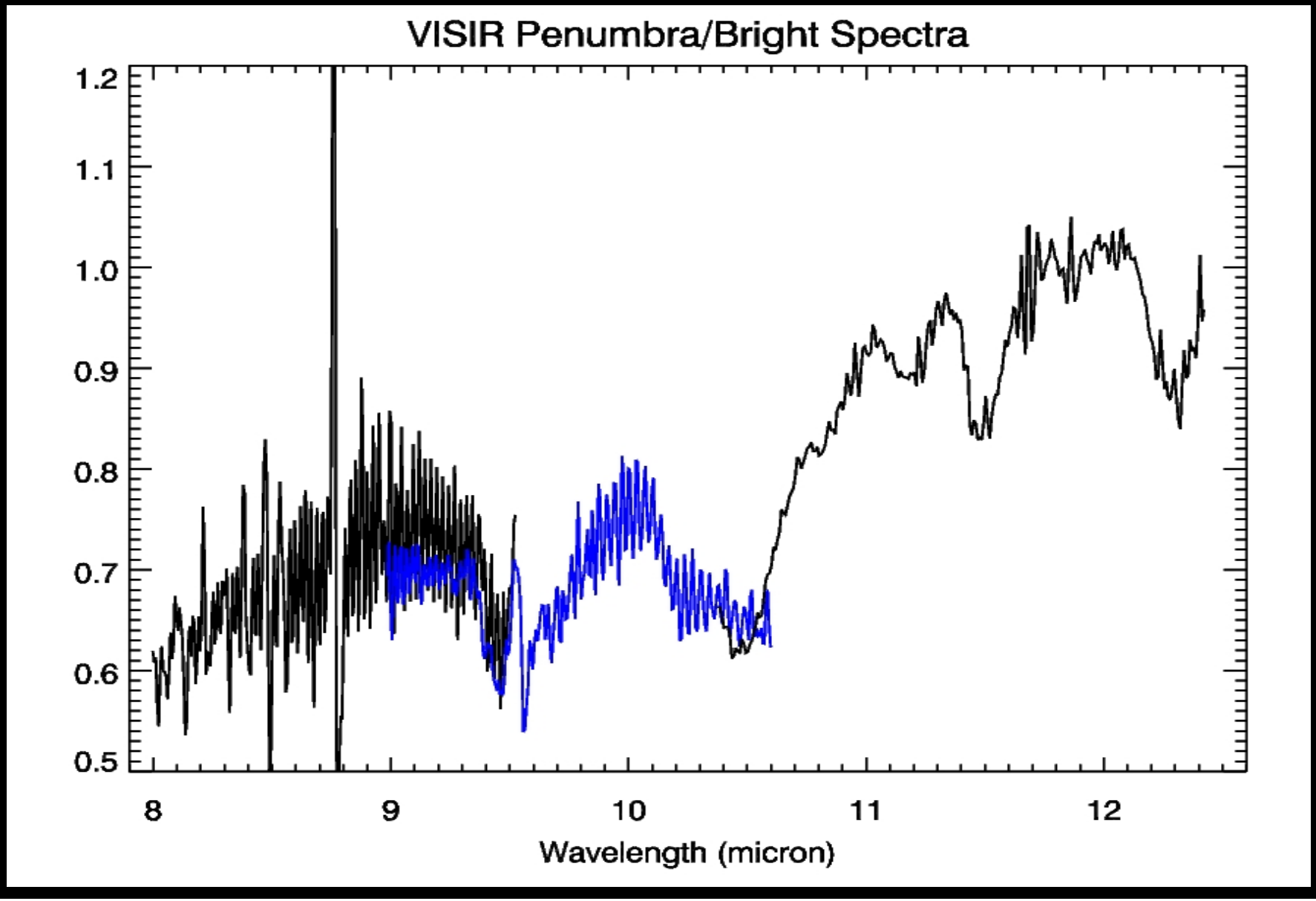
+ Noise

+ Noise



But, how far are we from making the measurements ?

Earth's transmission spectrum in the mid-IR



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

Detection Perspectives

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	>500	>500	>500
G2	$2*R_e$	100	>500	>500	>500

Palle et al, ApJ, submitted

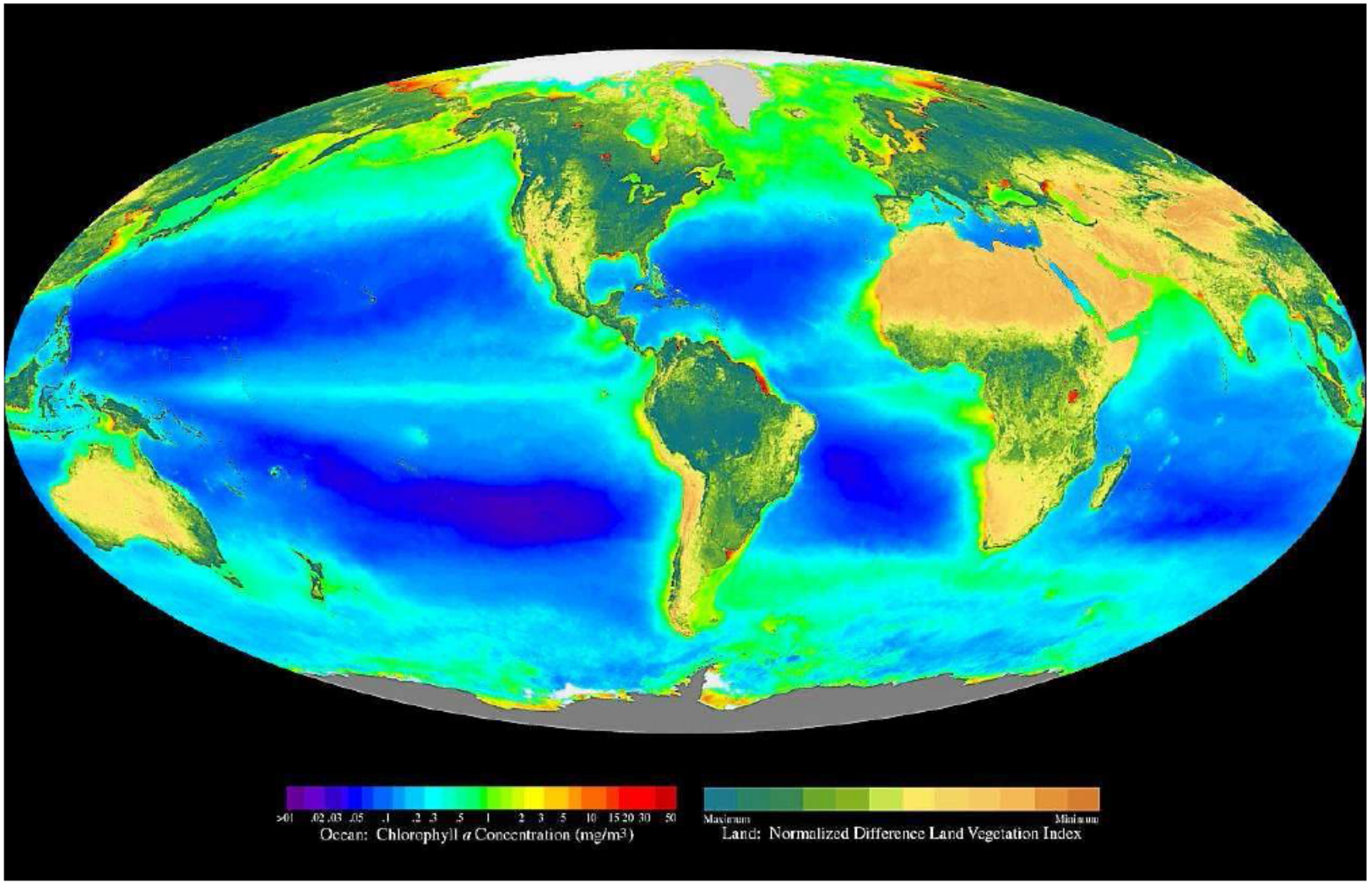
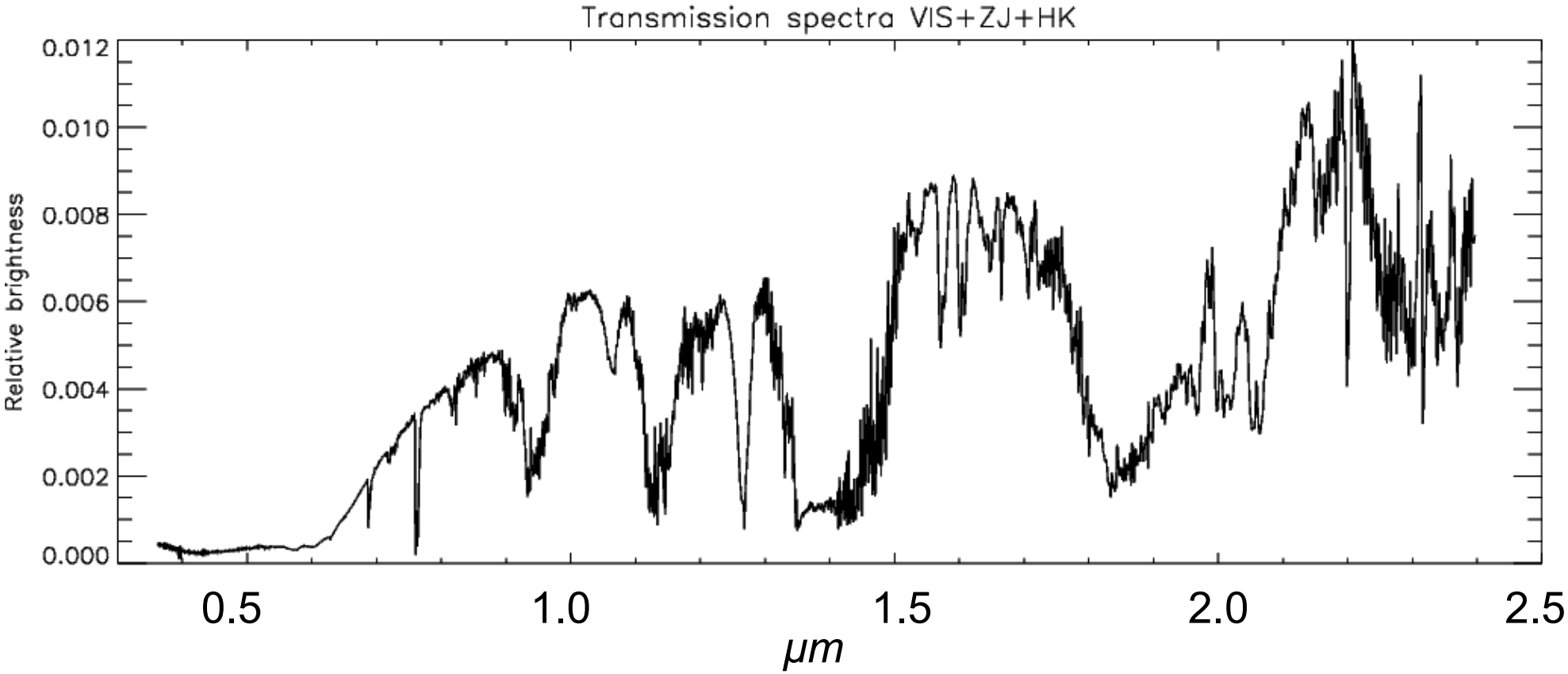


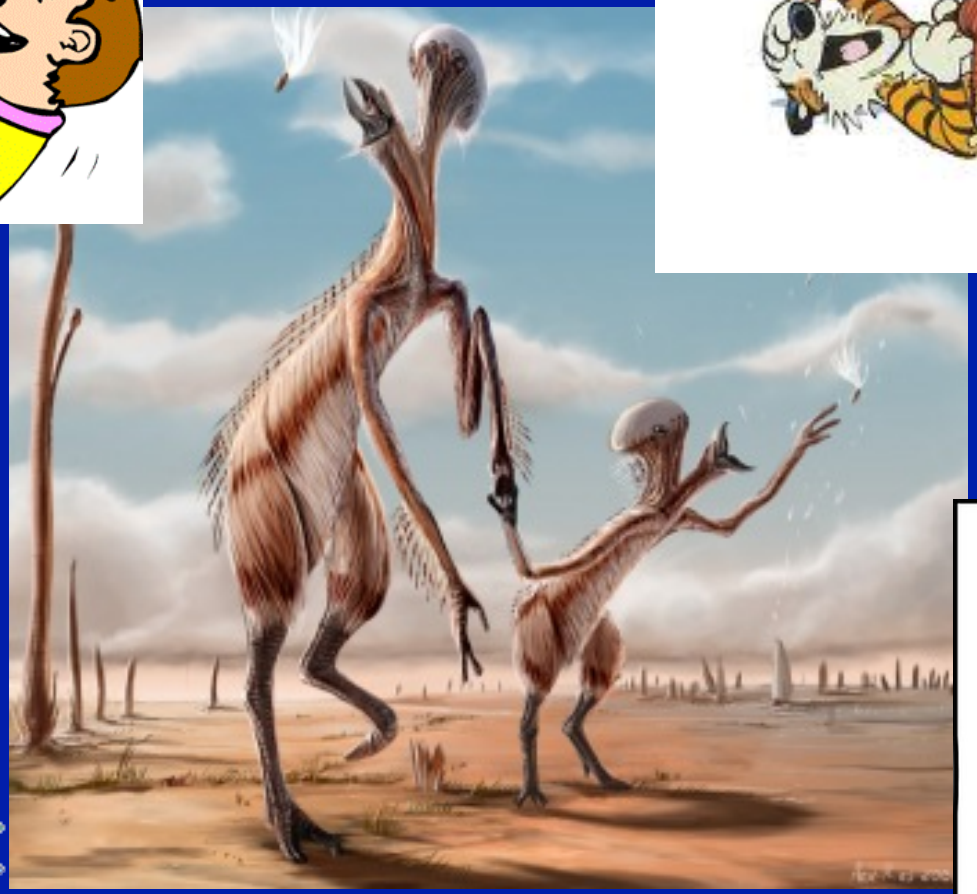
Fig. 5.8 This composite image gives an indication of the magnitude and distribution of global primary production, both oceanic (mg/m3 chlorophyll a) and terrestrial (NDVI). Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE. Data corresponding to the period September 1997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

Earth's Transmission Spectrum

The pale *red* dot



Palle et al, Nature, 2009



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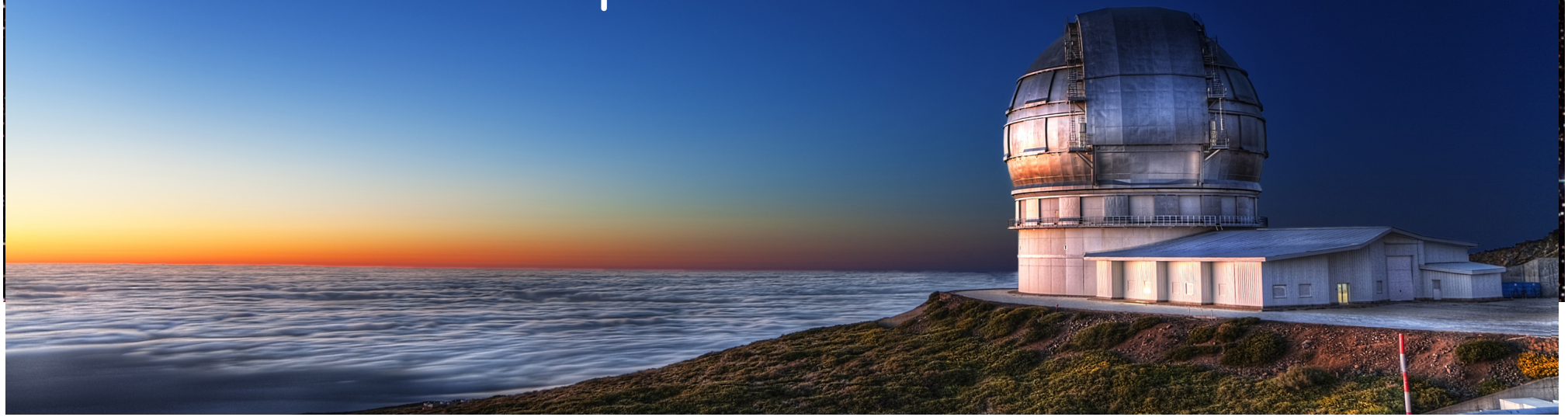
Búsqueda & Caracterización

Cada 100,000 fotones que nos llegan de la estrella, solo 1 ha cruzado la atmosfera del planeta