# Biosignatures in context

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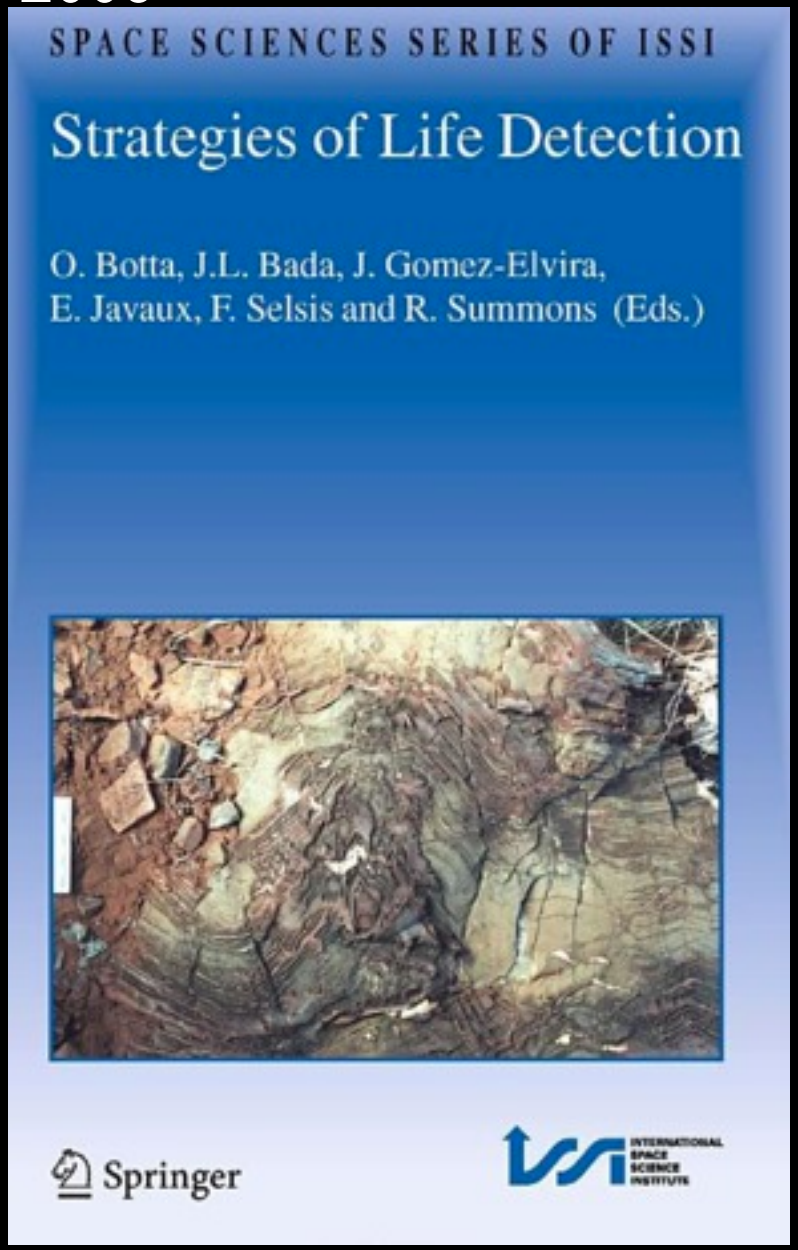
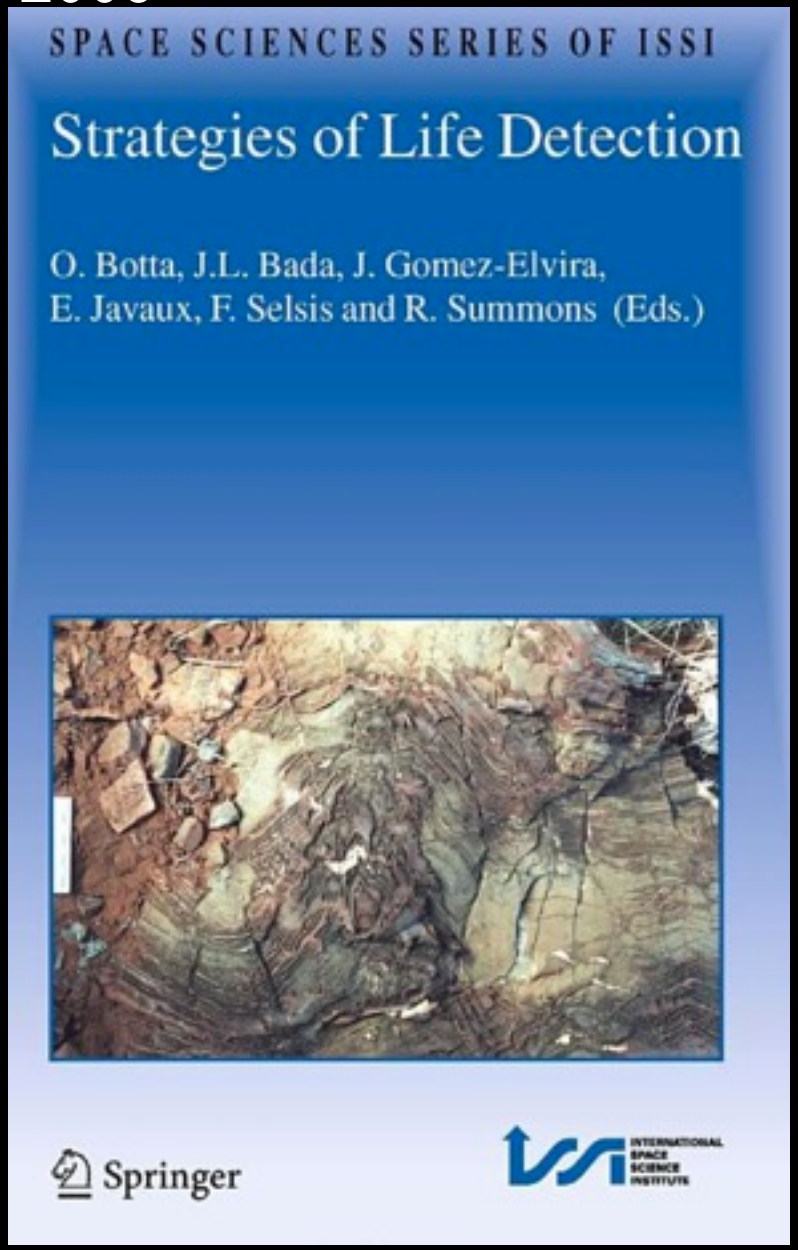
2005




At this stage, the best strategy to search for life on exoplanets may be to have no strategy but exploration.

This exploration may reveal anomalies (≠ fingerprint)

2005

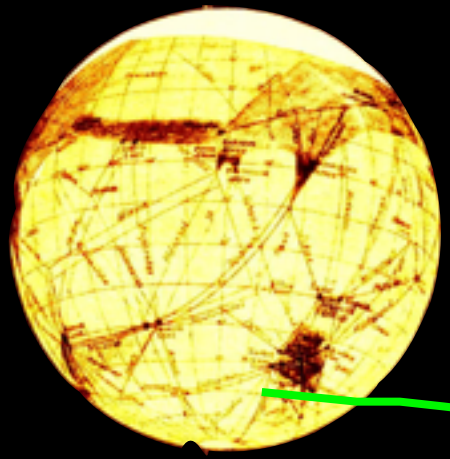



<u>no shortcut to finding extrasolar life</u>

exploration must come first and be as unbiased as possible

**- exploration of a large variety of planets**
comparative planetology

**- exploration of a given target**
anomalies can only arise from a comprehensive characterization of the target (and its host star & system)



martian
*biosphere*

observing
power

1869

today

# MÉMOIRES ET OBSERVATIONS.

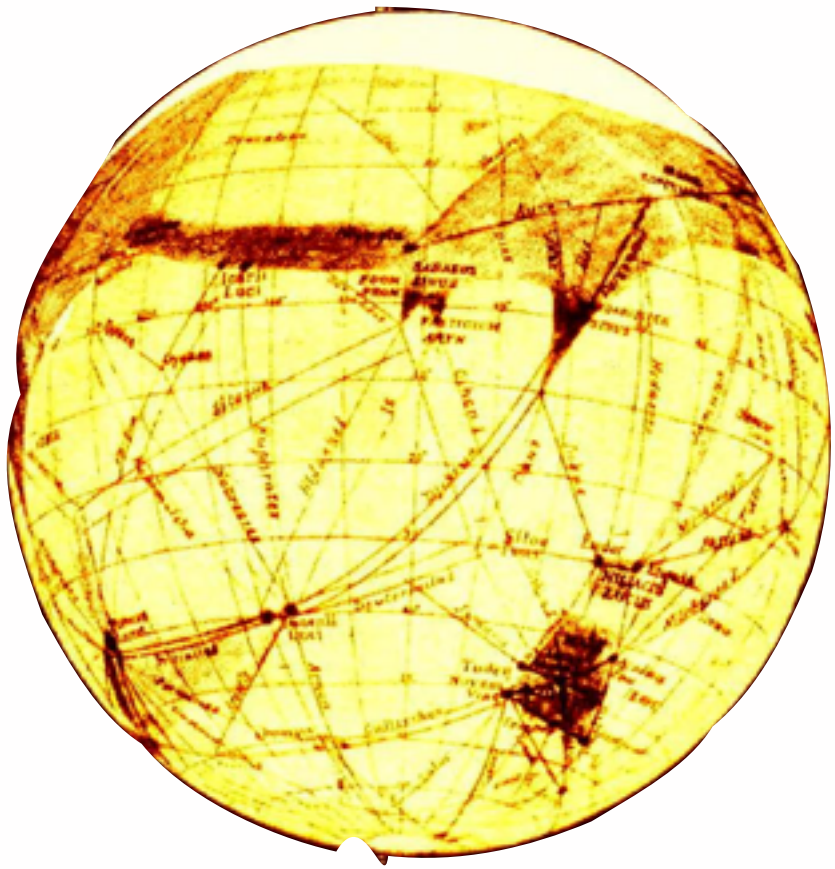
## PRIX PROPOSÉS PAR L'ACADÉMIE DES SCIENCES.

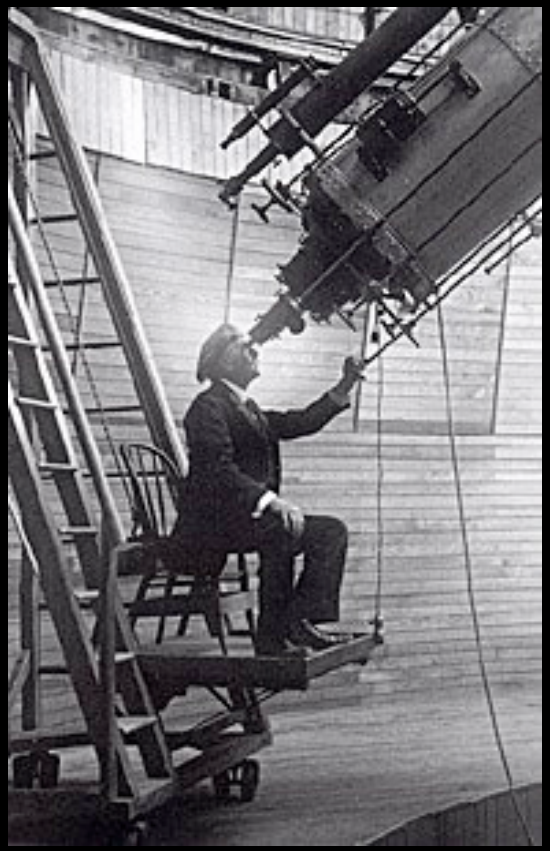
### Prix Pierre Guzman (100000fr).

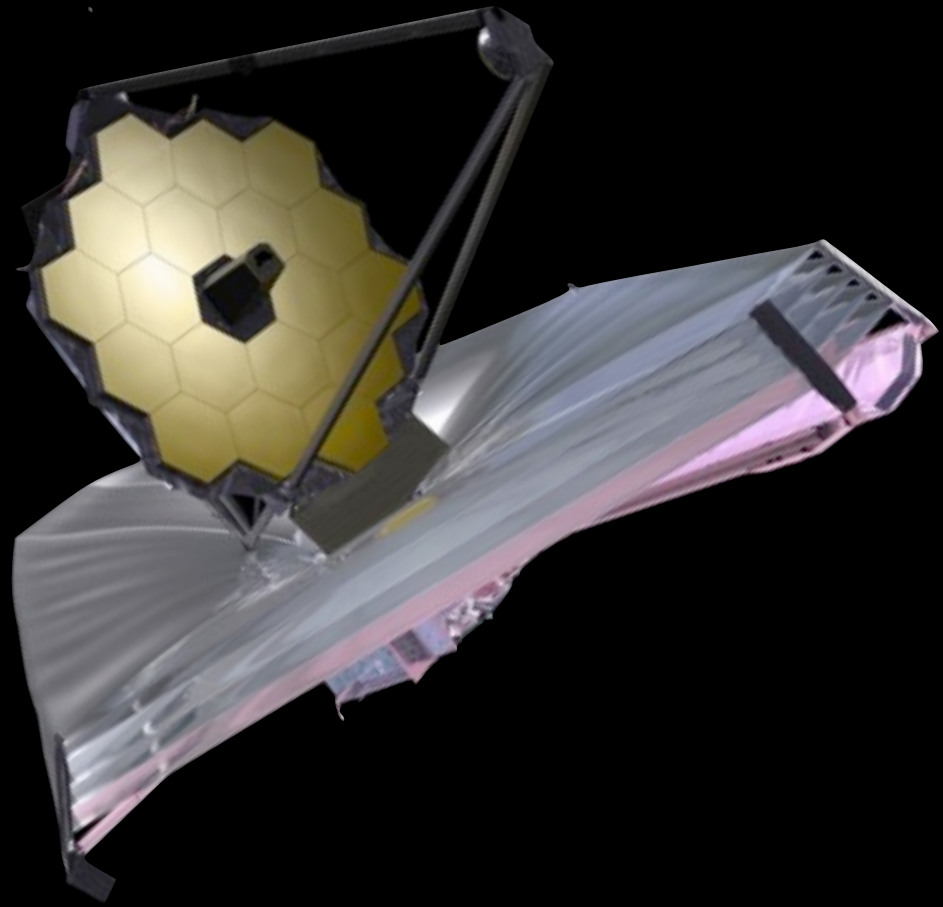
Mme Vve *Guzman* a légué à l'Académie des Sciences une somme de *cent mille francs* pour la fondation d'un prix qui portera le nom de *prix Pierre Guzman,* en souvenir de son fils, et sera décerné à celui qui aura trouvé le moyen de communiquer avec un astre autre que la planète Mars.

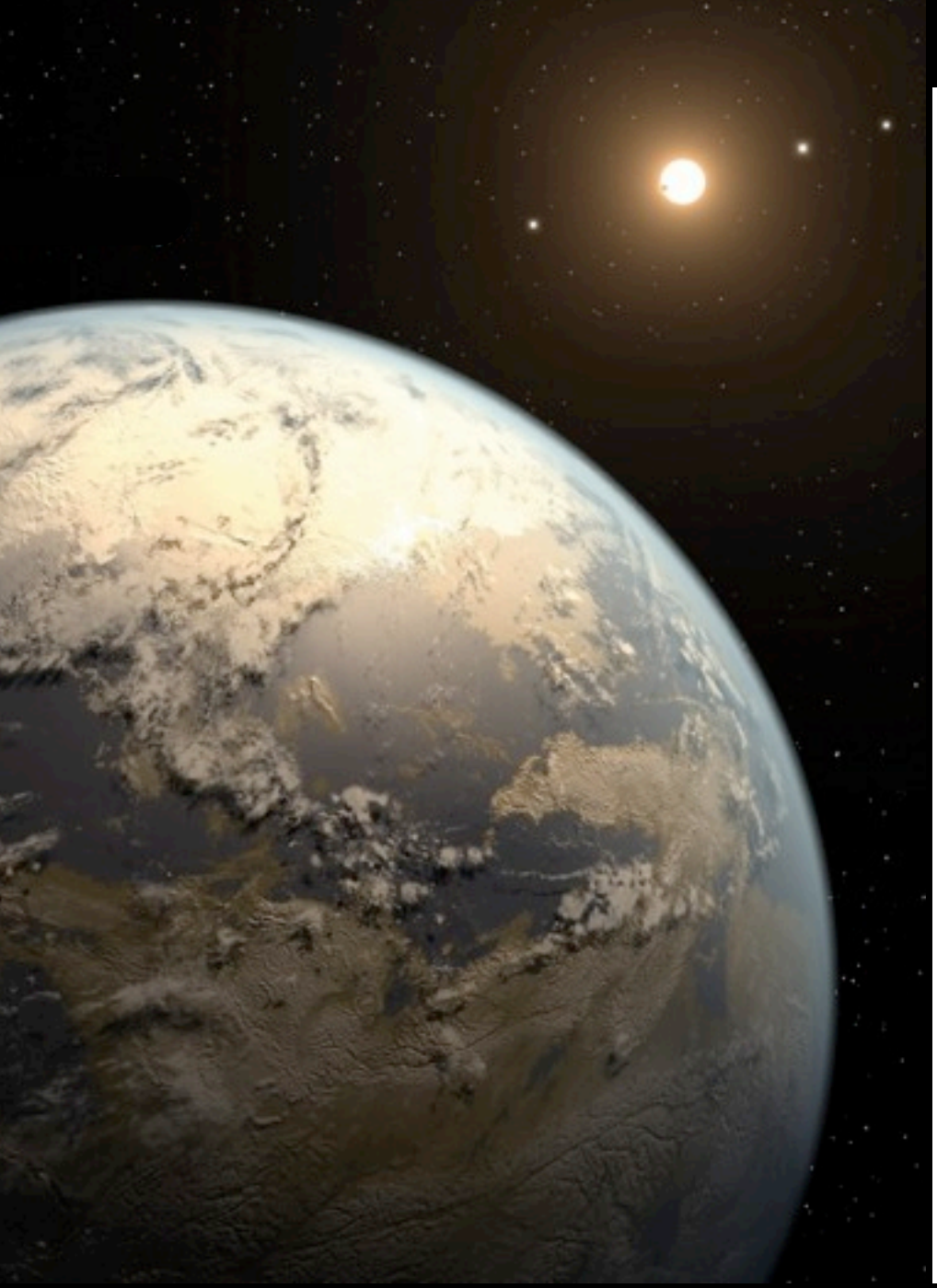
Prévoyant que le prix de *cent mille francs* ne serait pas décerné tout de suite, la fondatrice a voulu, jusqu'à ce que ce prix fût gagné, que les intérêts du capital, cumulés pendant cinq années, formassent un prix, toujours sous le nom de *Pierre Guzman,* qui serait décerné à un savant français, ou étranger, qui aurait fait faire un progrès important à l'Astronomie.

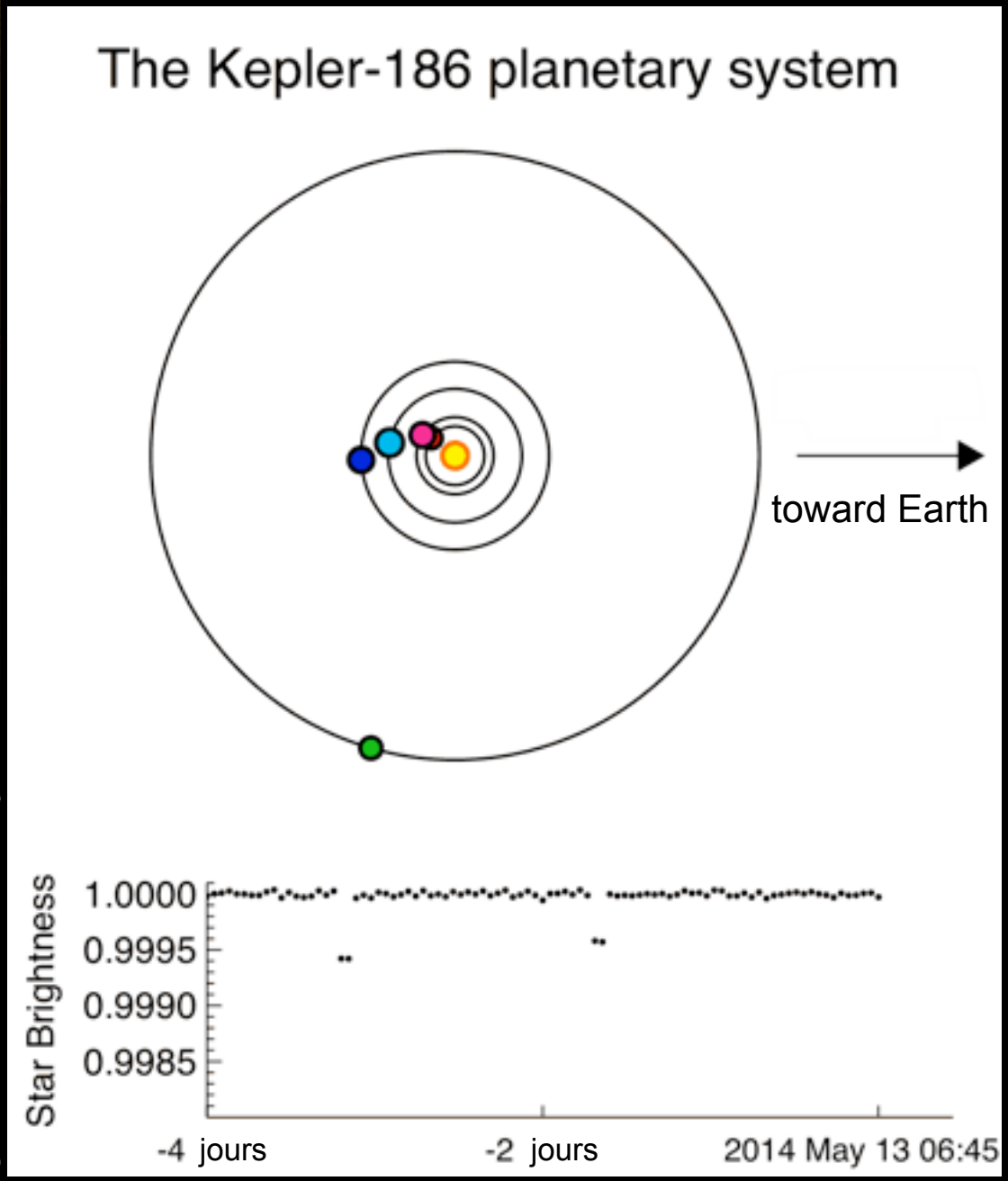
Le prix *quinquennal,* représenté par les intérêts du capital, sera décerné, s'il y a lieu, en 1910.



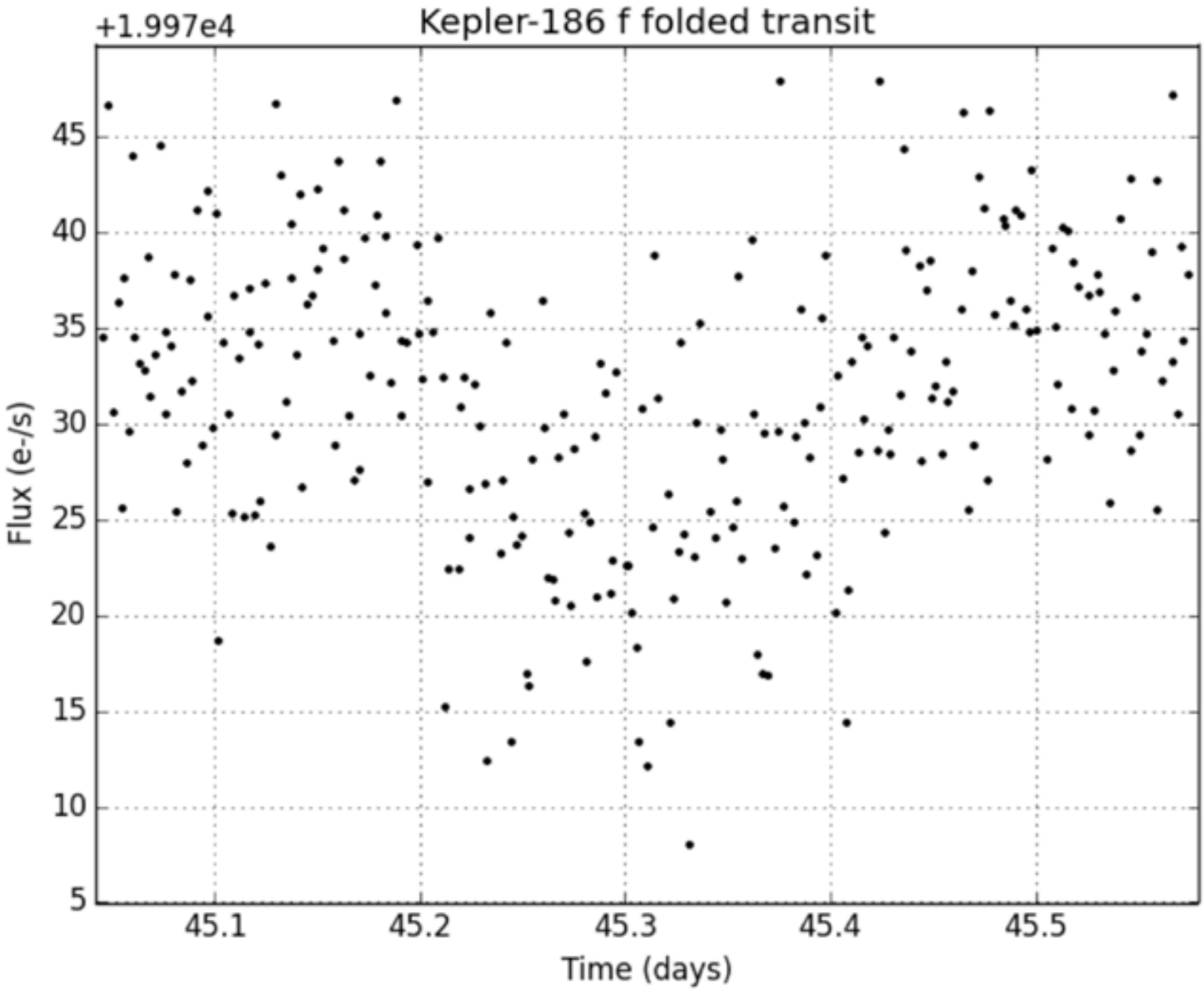




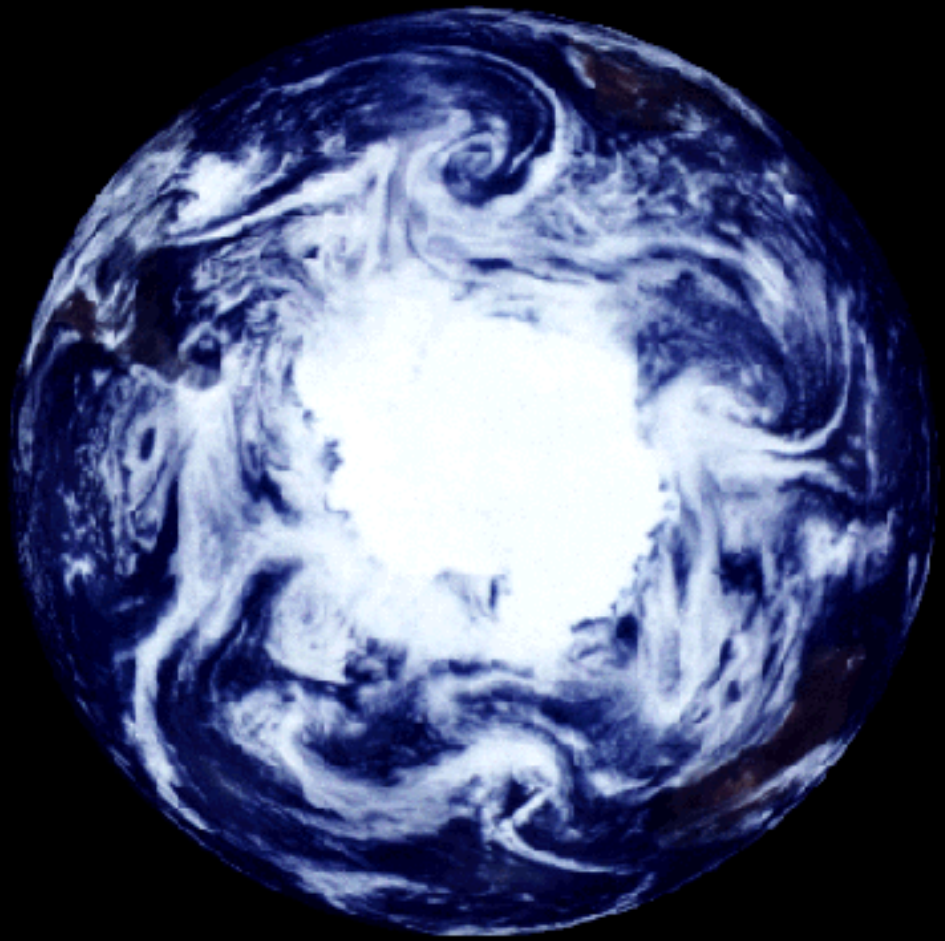


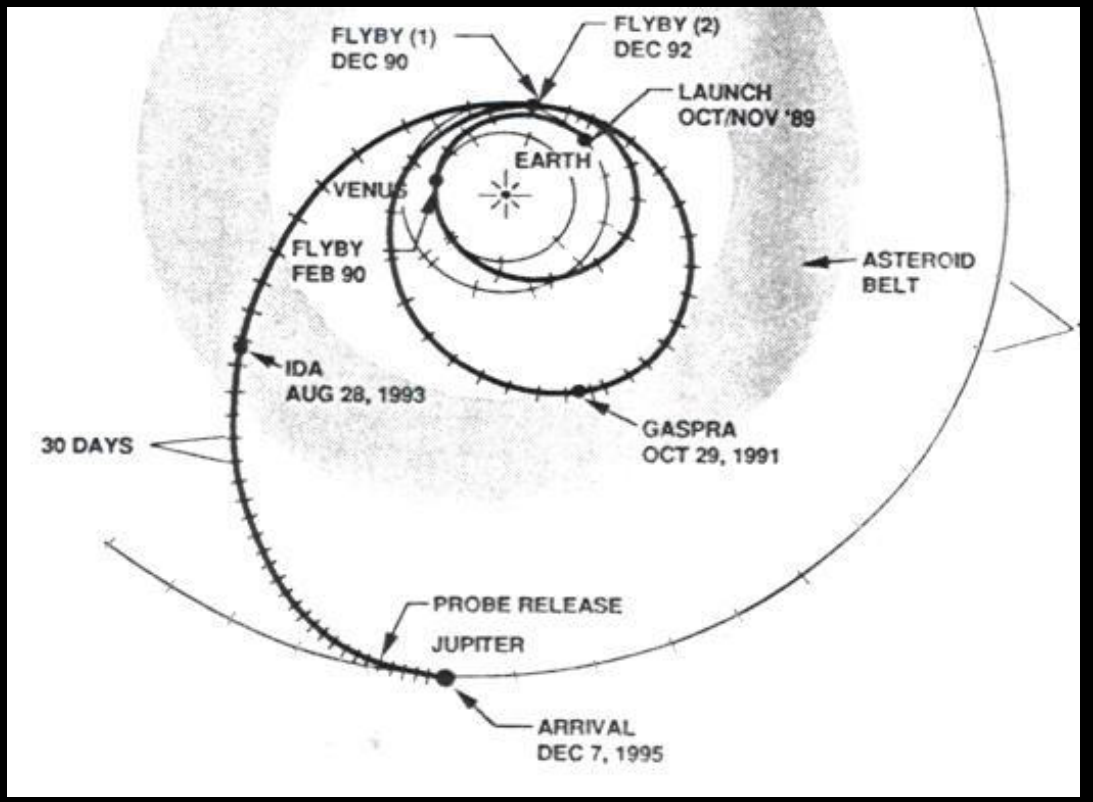



*Quintana et al., 2014* *animation by Sean Raymond*




a point of darkness (E. Gaidos' talk)

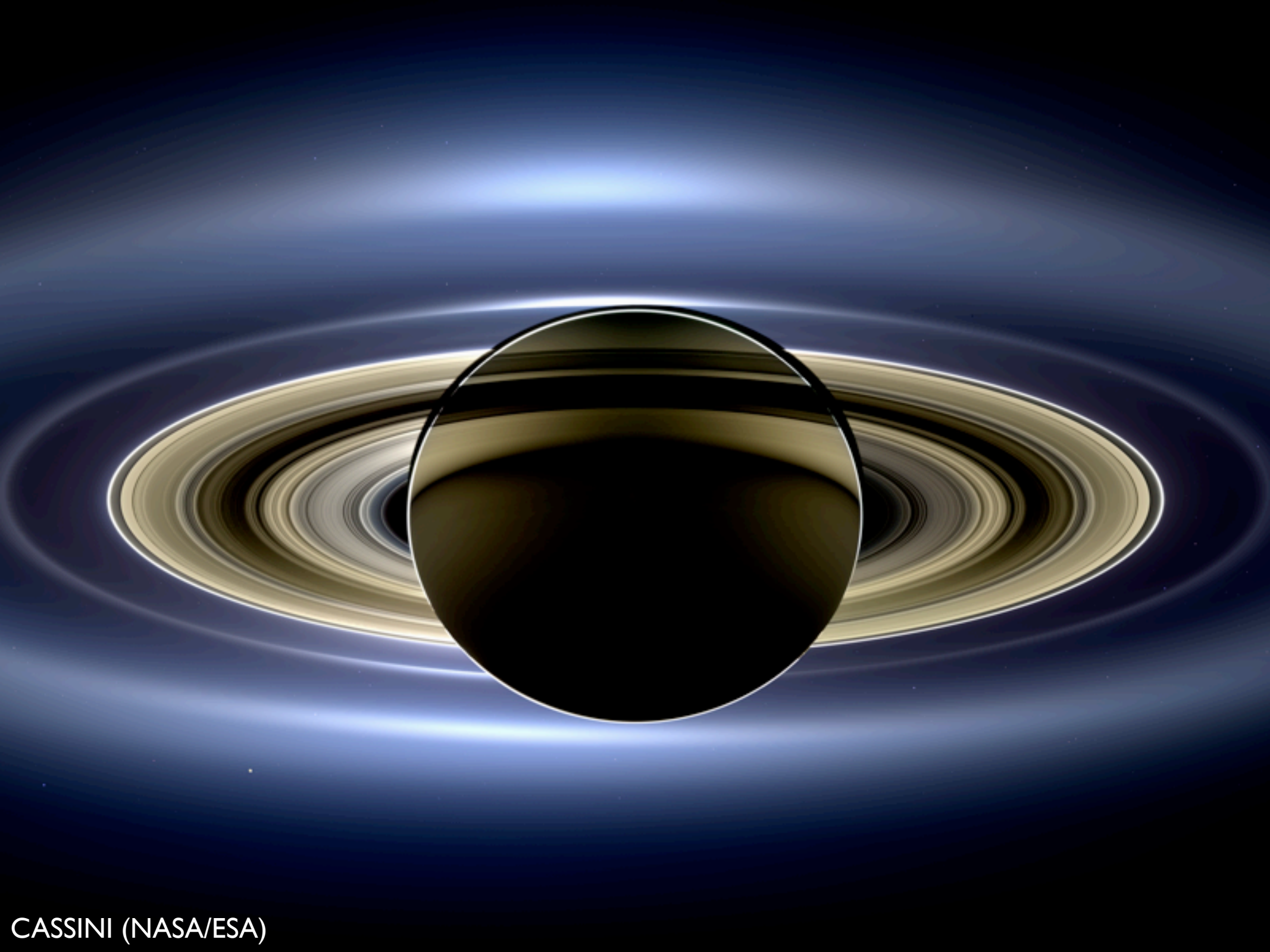




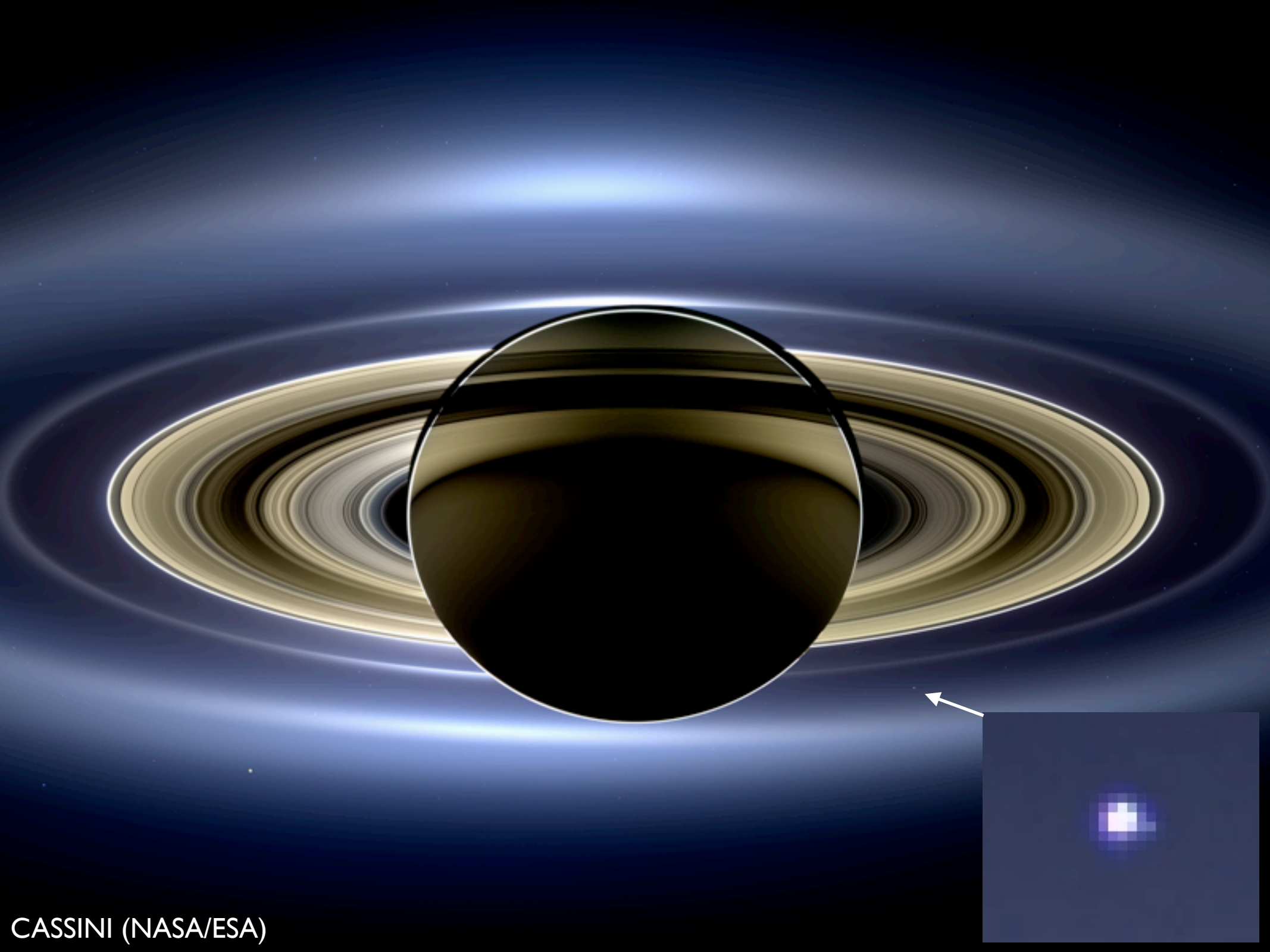

***A search for life on Earth from the Galileo spacecraft***
1993, Sagan et al.

In its December 1990 fly-by of Earth, the Galileo spacecraft found evidence of abundant gaseous oxygen, a widely distributed surface pigment with a sharp absorption edge in the red part of the visible spectrum, and atmospheric methane in extreme thermodynamic disequilibrium; together, these are strongly suggestive of life on Earth. Moreover, the presence of narrow-band, pulsed, amplitude-modulated radio transmission seems uniquely attributable to intelligence. These observations constitute a control experiment for the search for extraterrestrial life by modern interplanetary spacecraft.

inspired by Lovelock, 1975



CASSINI (NASA/ESA)



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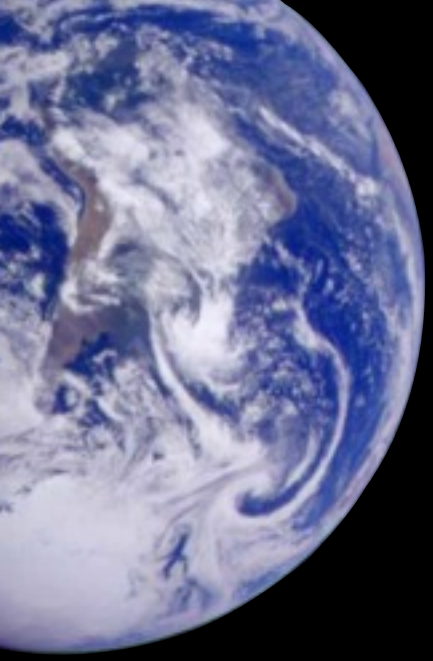
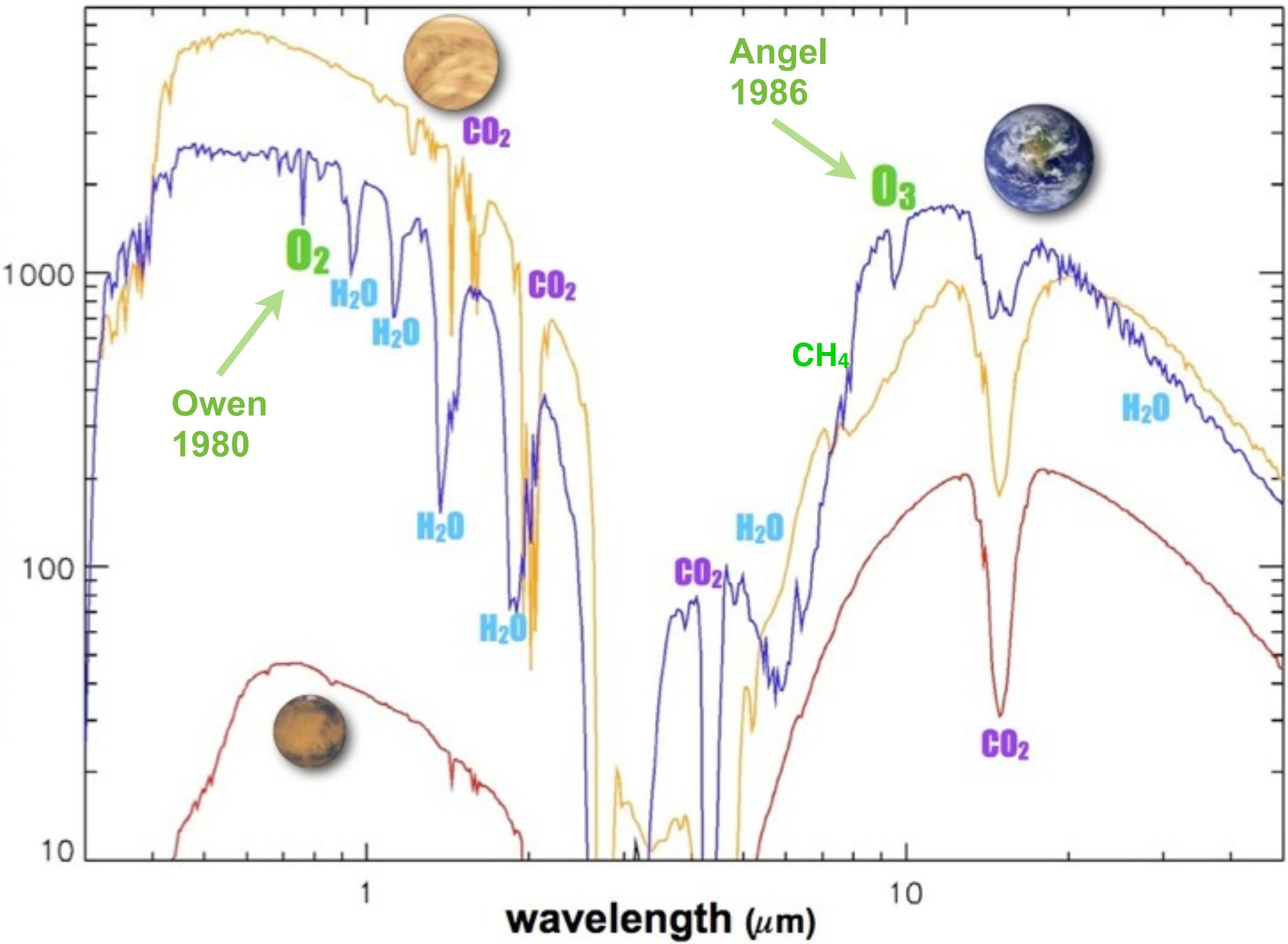
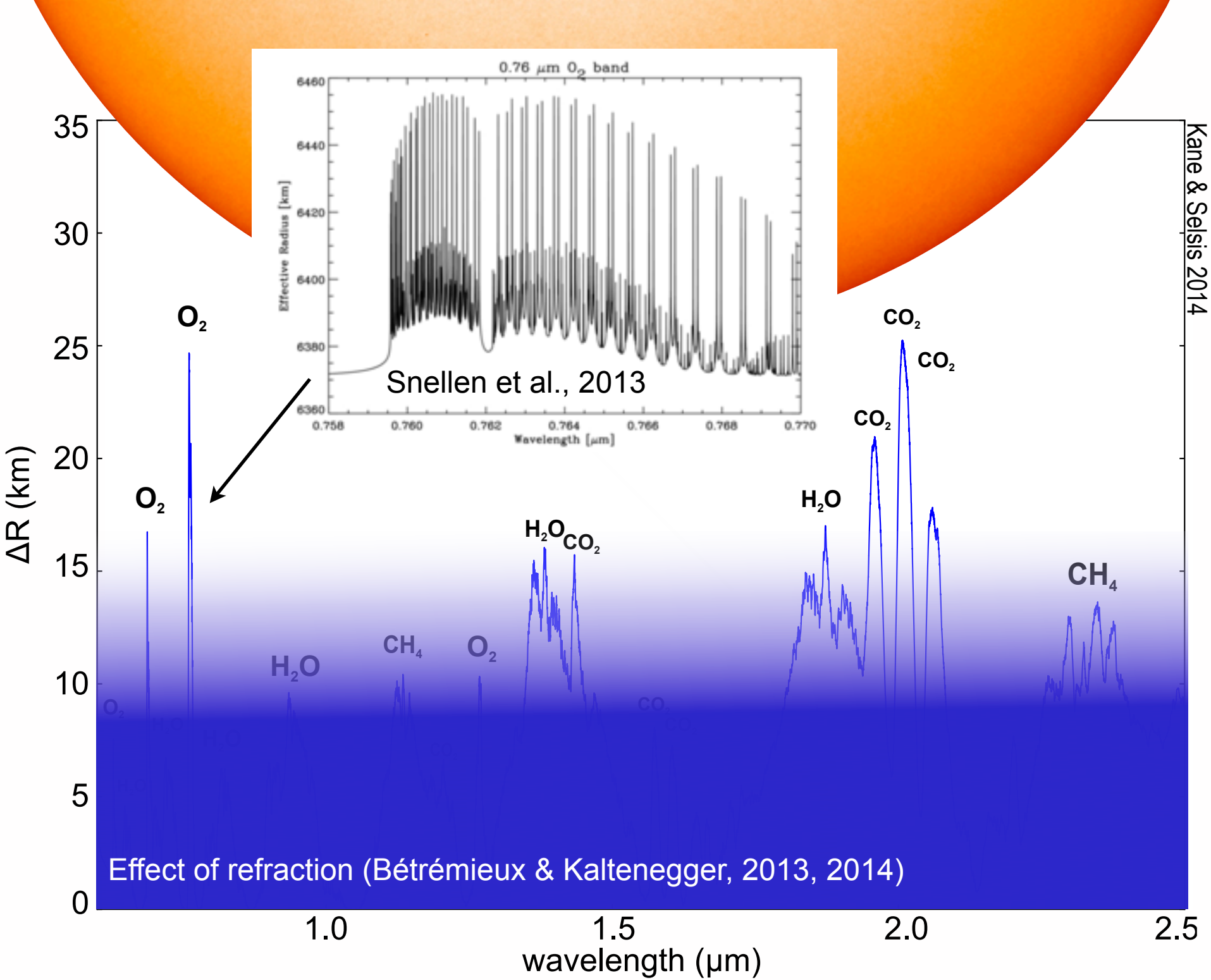
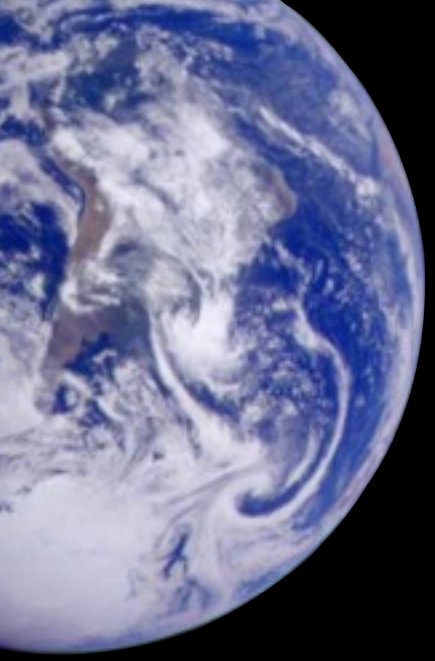





*(Selsis & Tinetti, Darwin Proposal, 2007)*


0.76 μm O2 band
Effective Radius [km]
Wavelength [μm]
Snellen et al., 2013
ΔR (km)
wavelength (μm)
O2
O2
H2O
CH4
O2
H2O
CO2
H2O
CO2
CO2
CH4
Effect of refraction (Bétrémieux & Kaltenegger, 2013, 2014)
Kane & Selsis 2014



Life → altered observables → Observer

instrumentation

Interpretation ?


Oxygenic photosynthesis

$$2H_2O + CO_2 + h\nu \rightleftharpoons CH_2O + O_2 + H_2O$$

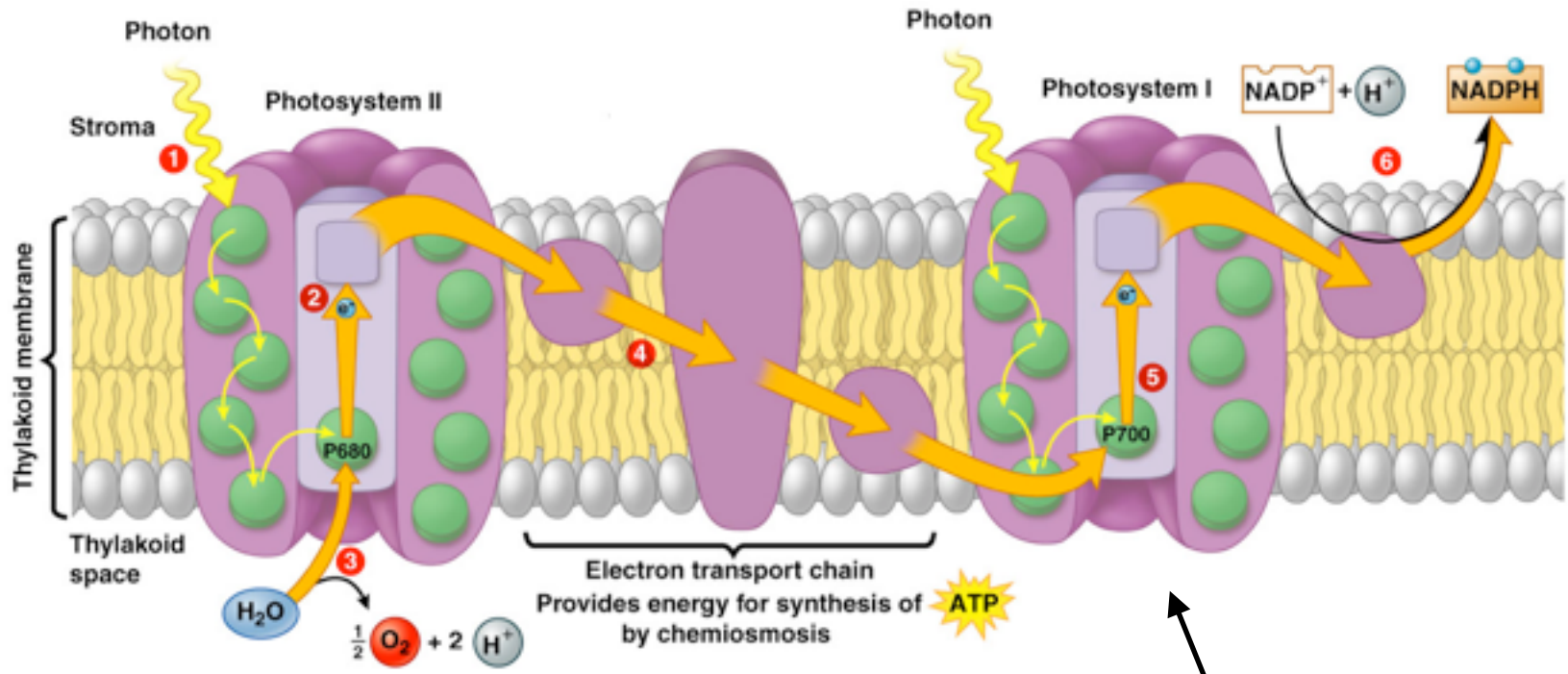
photosynthesis

respiration or oxidation

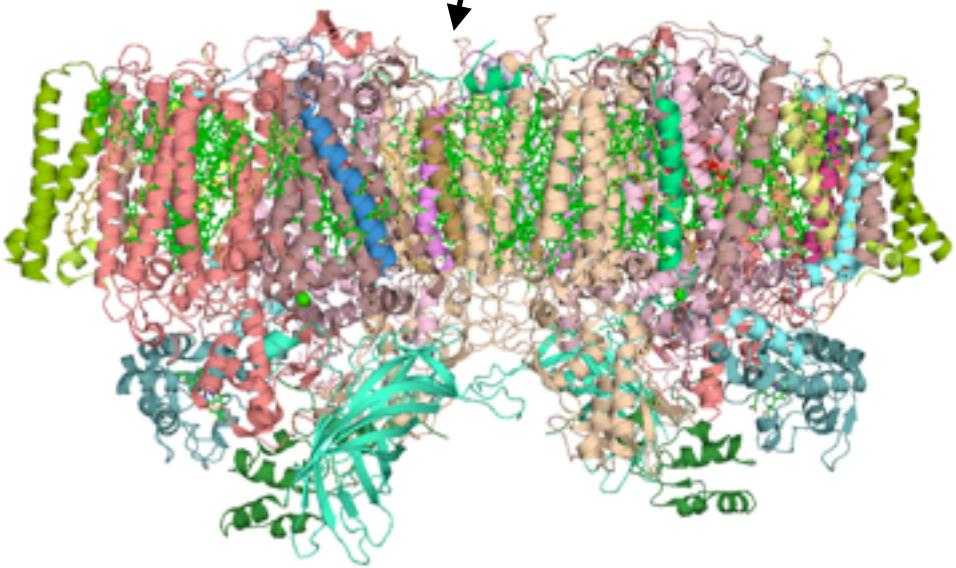
Net release of atmospheric $O_2$

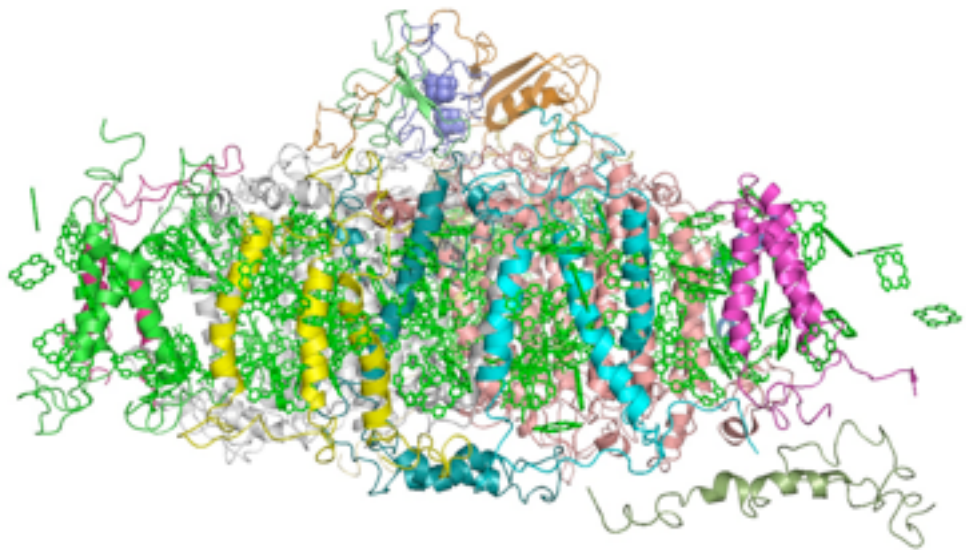
Burial of organic carbon

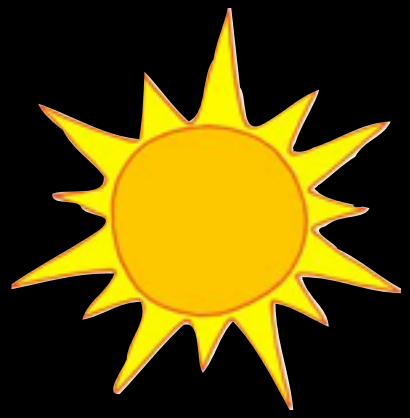
2850 kJ/mole of glucose (72 g of carbon)







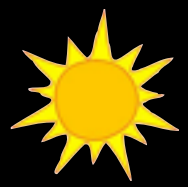


- solar flux at Earth surface: 163 W/m$^2$ (340 W/m$^{-2}$ -30% reflected back to space - 77 W/m$^{-2}$ absorbed by the atmosphere)

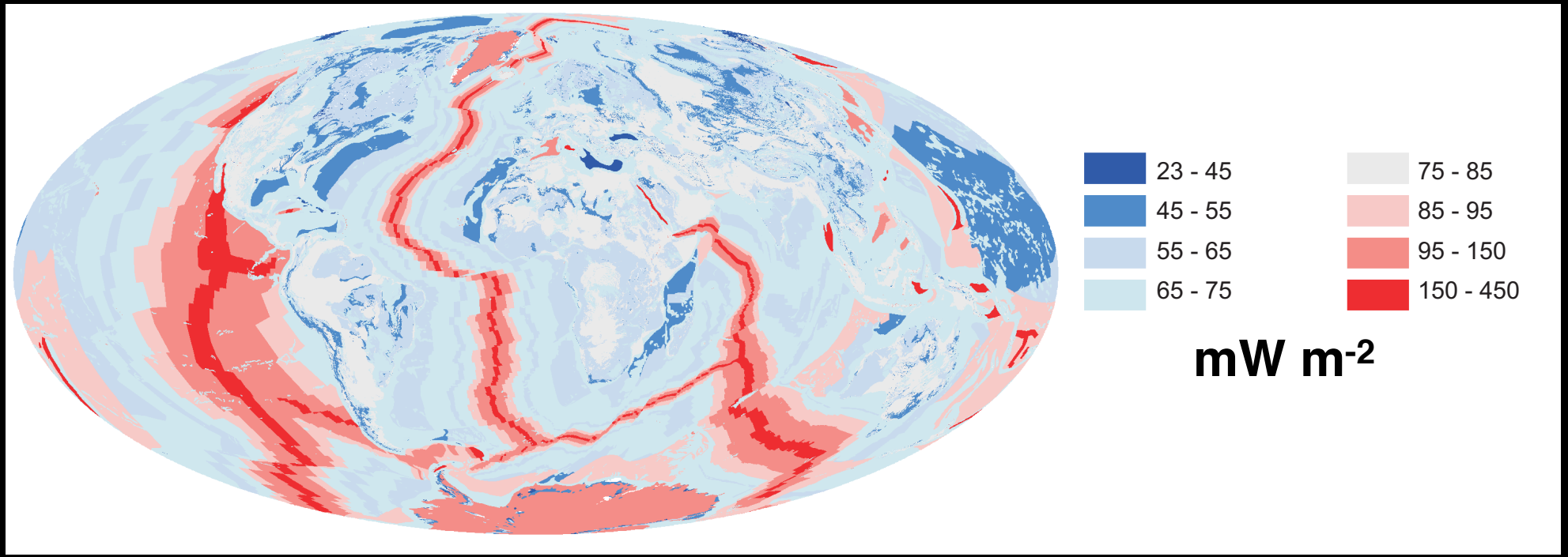
- carbon fixation by photosynthesis: 70x10$^9$ tons of carbon /yr

- the fixation of 72 g of carbon costs 2850 kJ

About 0.16% (0.268 W/m$^2$) is converted by photoautotrophic life into chemical energy.



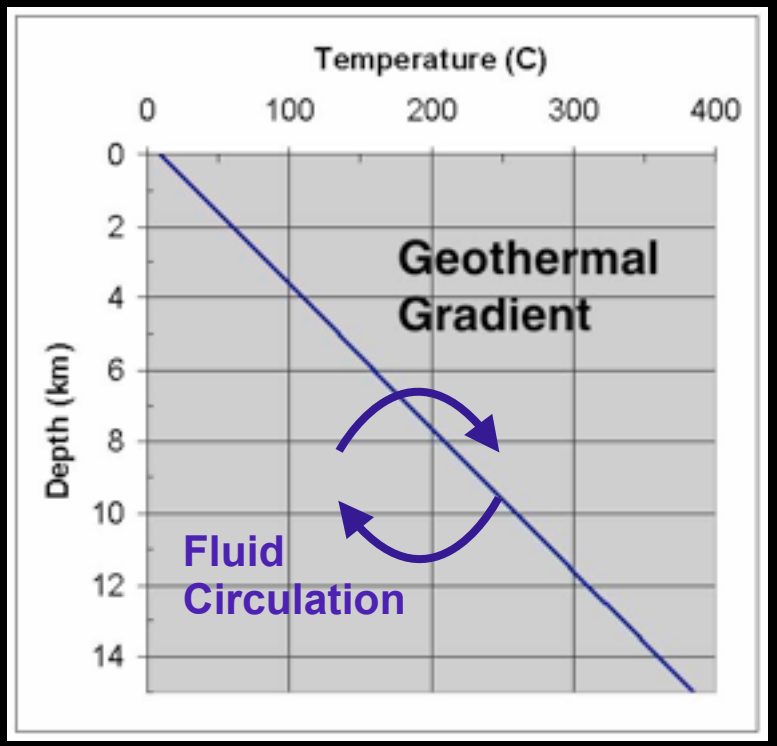
## 0.268 W/m$^2$ of sunlight is converted by photoautotrophic life into chemical energy




The average internal heat flux dissipated by the Earth is 0.075 W/m$^2$ in average

Less than $10^{-6}$ of this heat flux is converted by life into chemical energy (Rosing et al., 2005, 2006)

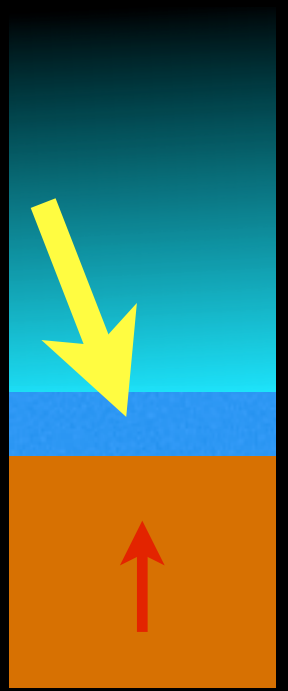
Photosynthetic life fixes at least **10 000 000 times** more carbon than other primary producers (chemoautotrophs)




**Chemoautotropic life relies on the thermal gradient (25K/km in average) produced by the internal heat flux and the redox gradient it generates**

**200 gC/yr/m²**

**< 56 gC/Myr/m²**



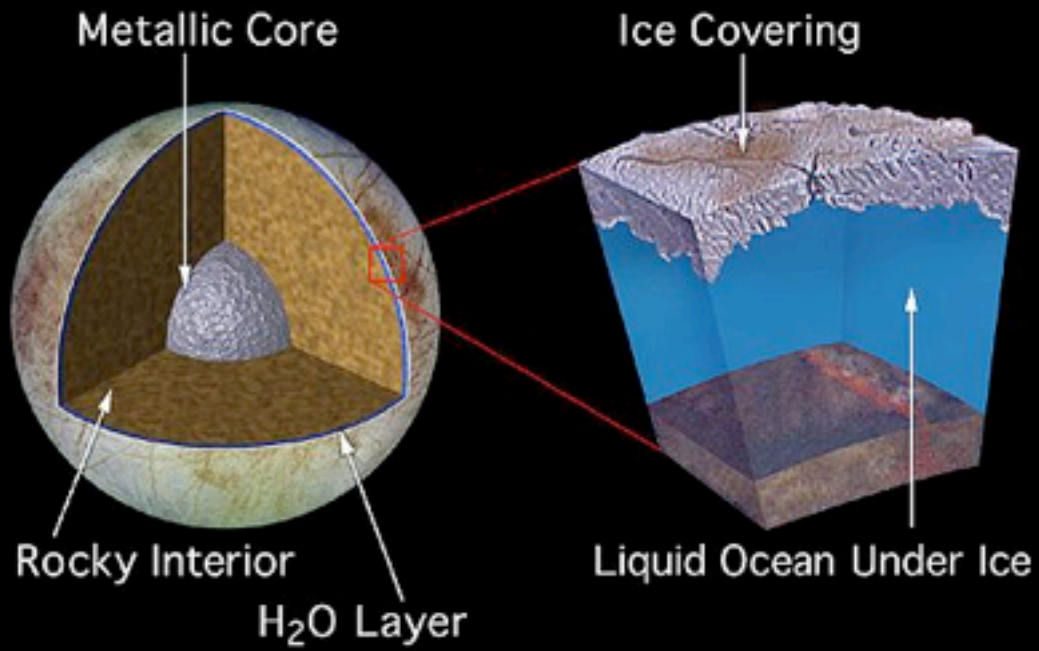
**Although Chemoautotrophy is known since 1890, the Earth *deep biosphere* was discovered only in the 1970s**

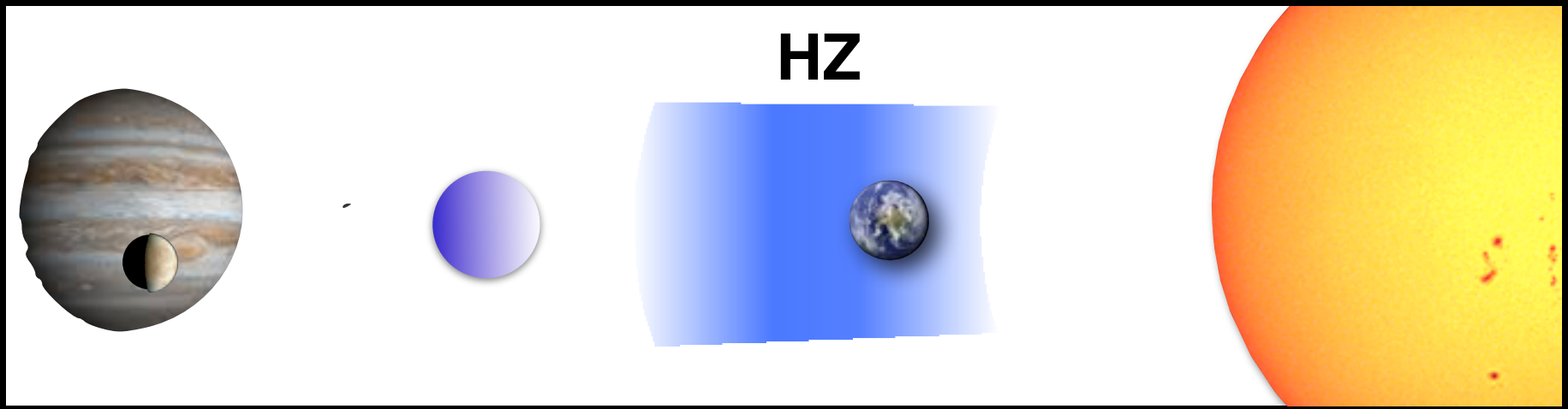
*In a world with a purely chemoautotrophic primary production, the organic sequestration would cause no significant biological effect on the global carbon cycle in the absence of photosynthesis*
*(Rosing et al., 2006)*

**200 gC/yr/m$^2$**

**< 56 gC/Myr/m$^2$**

# Biosignatures and the Habitable Zone

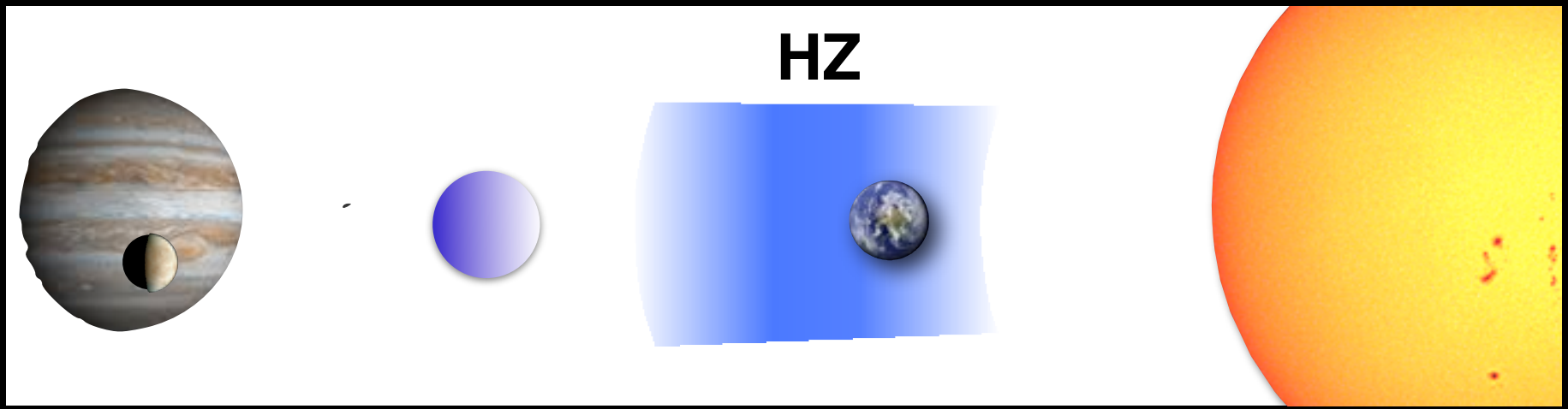


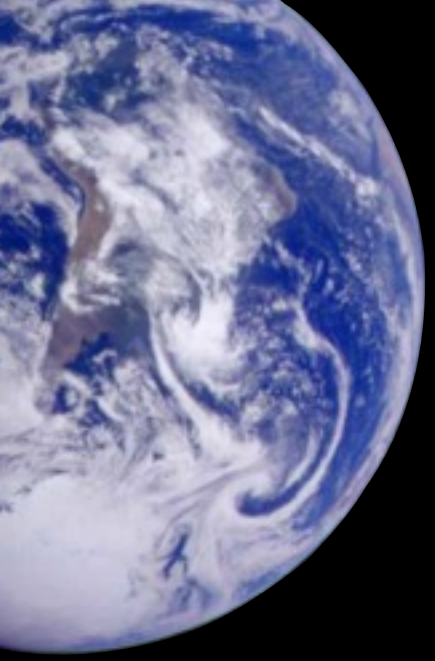



# Surf Zone ?

The *Habitable* Zone
(defined as the region where surface liquid water is stable)
is where liquid water and stellar light are simultaneously available.

Life may exist outside the HZ but can it be found by remote observations ?





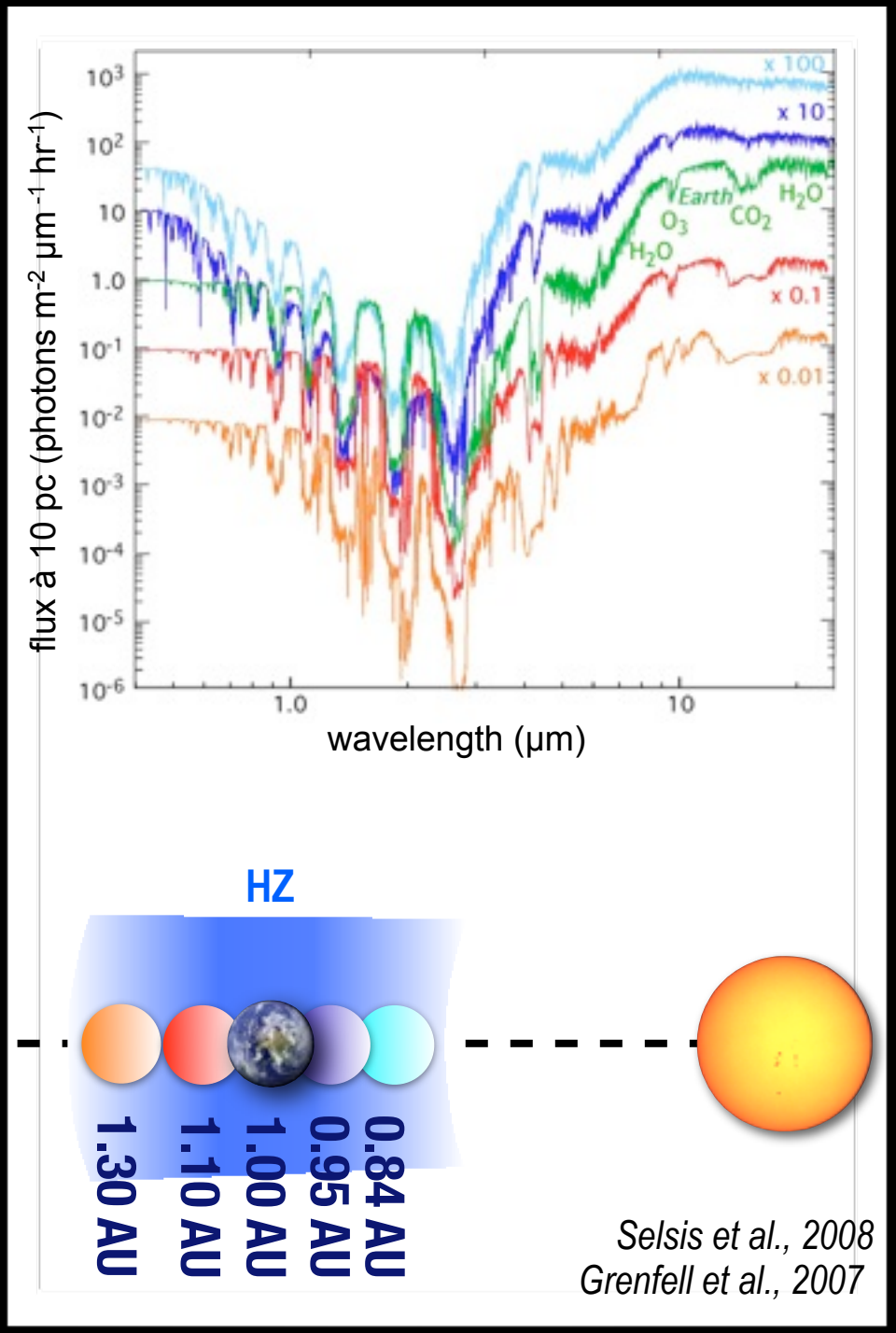
Life → altered observables → Observer

instrumentation

Interpretation ?

Life → altered observables

Life → altered observables



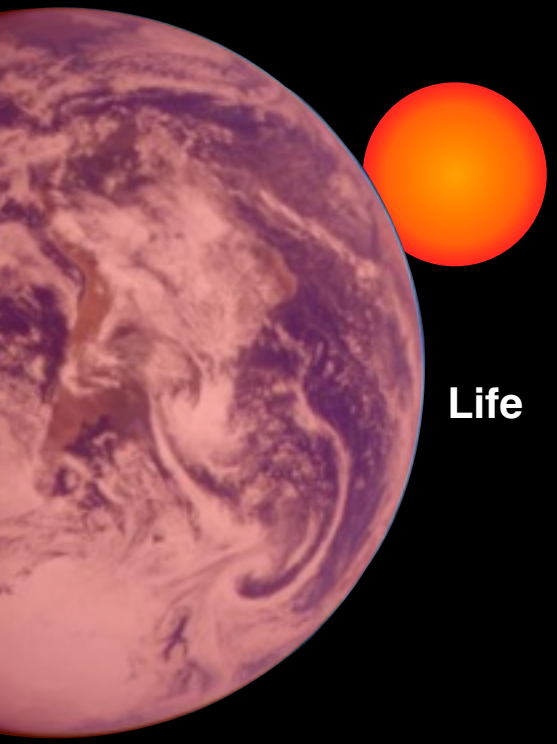
Life → altered observables

Life → altered observables

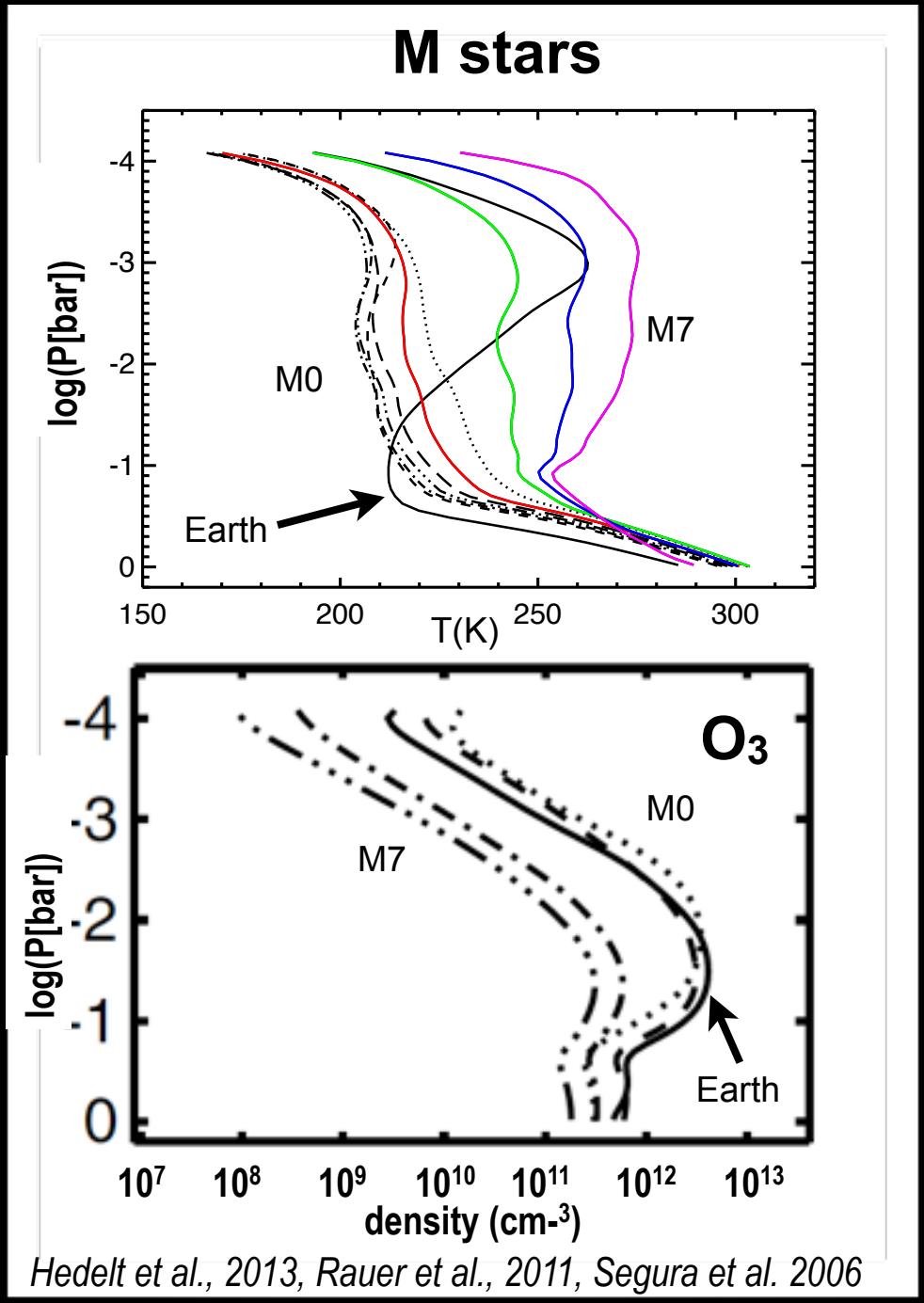
## K, G, F stars

Selsis, 2000
Segura et al., 2003
Hedelt et al., 2013
Rugheimer et al., 2013

Life → altered observables

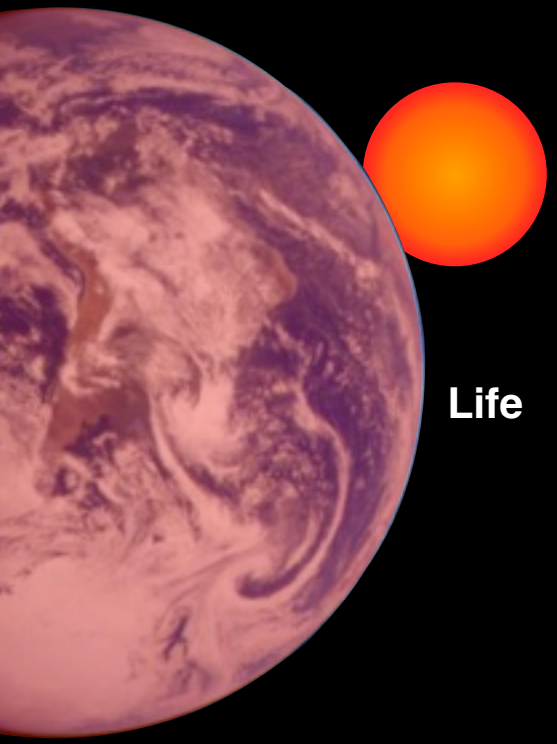


Life → altered observables

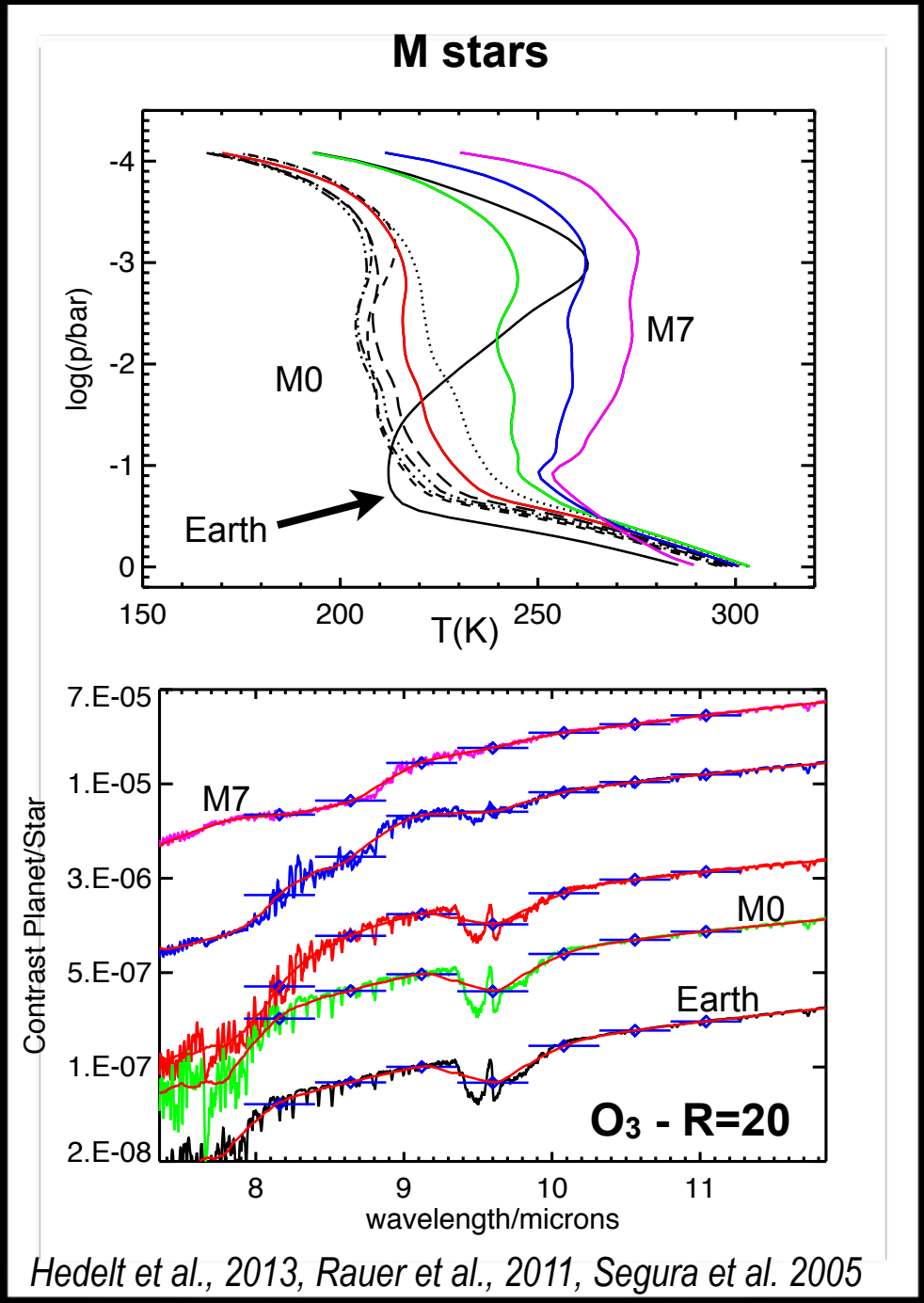



*Hedelt et al., 2013, Rauer et al., 2011, Segura et al. 2006*

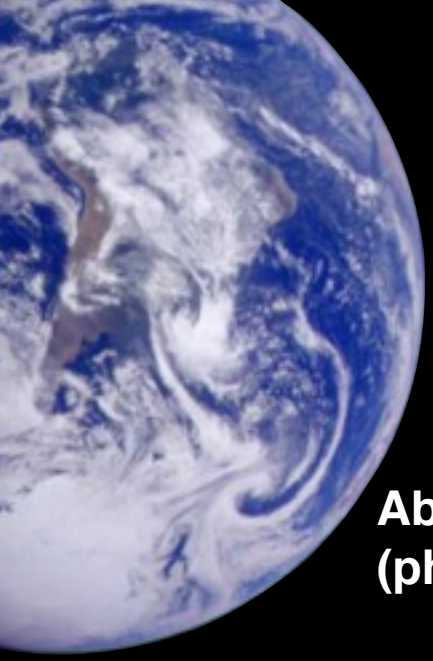
Life → altered observables



Life → altered observables



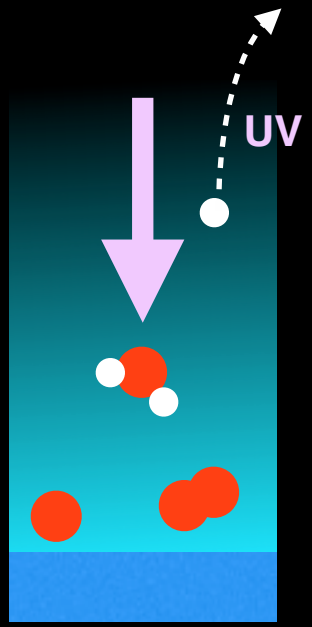

*Hedelt et al., 2013, Rauer et al., 2011, Segura et al. 2005*



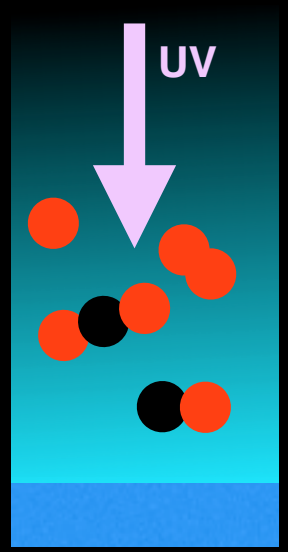
Life → altered observables → instrumentation → Observer

Interpretation ?

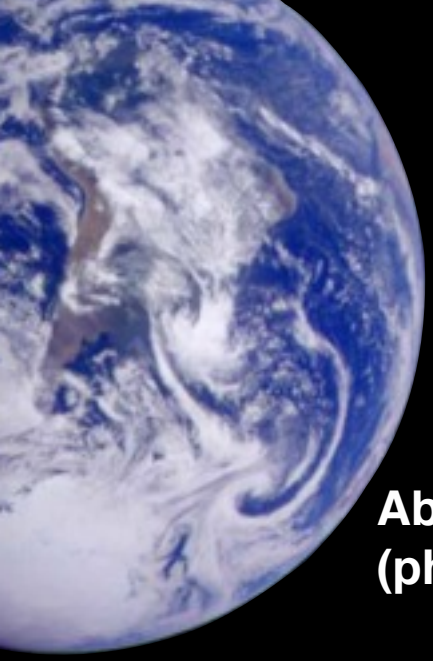
Abiotic (photo)chemistry → ?




early Venus
Icy satellites




Mars
Venus

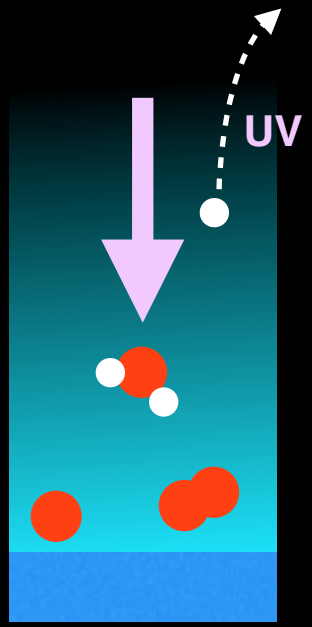


Life → altered observables → instrumentation → Observer

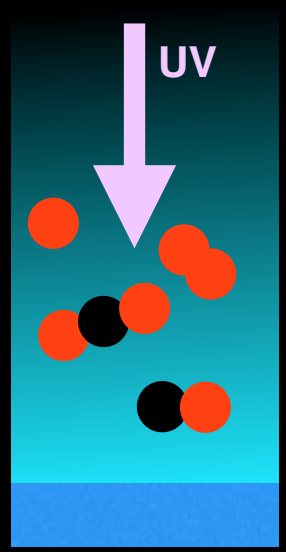
Interpretation ?

Abiotic (photo)chemistry → ?

**The efficiency of these processes depends - among other things - on the UV intensity and spectral distribution**

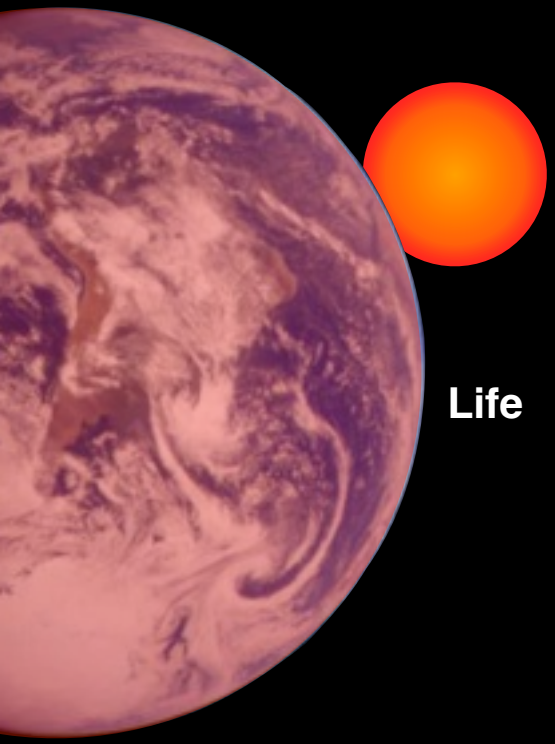



early Venus
Icy satellites



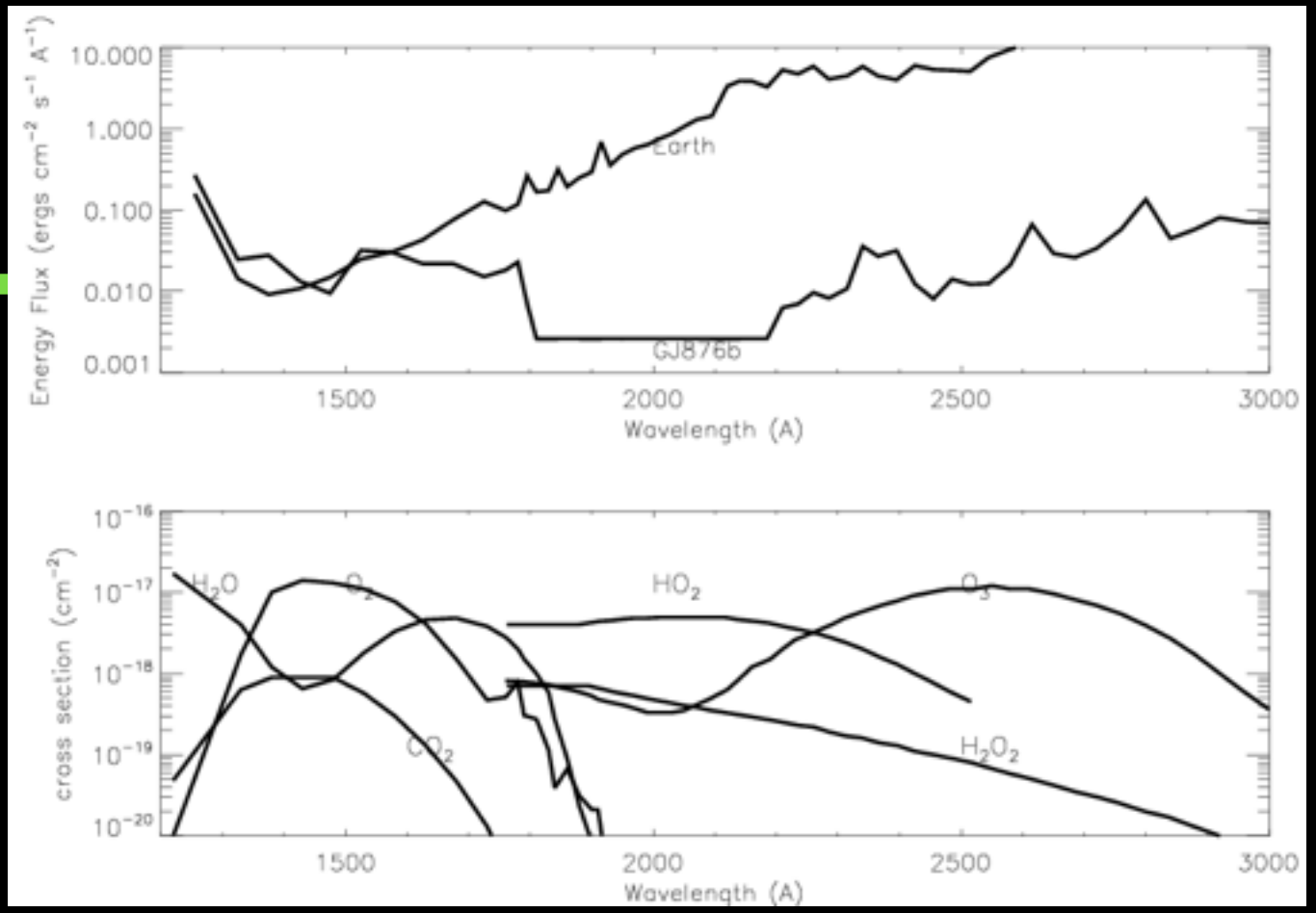

Mars
Venus

Life

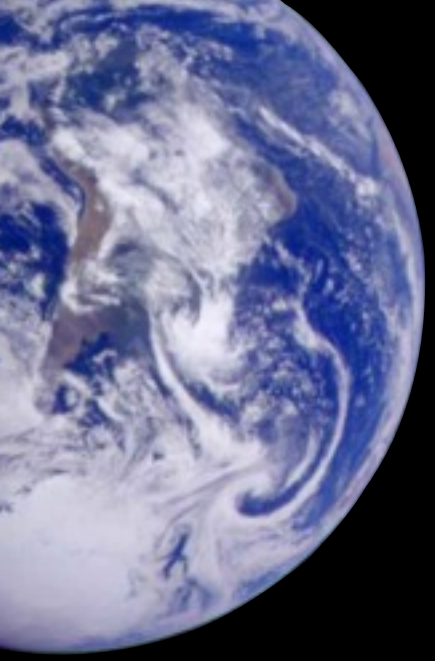


Life

altered observables




*France et al. 2013 ,Tian et al. 2013*

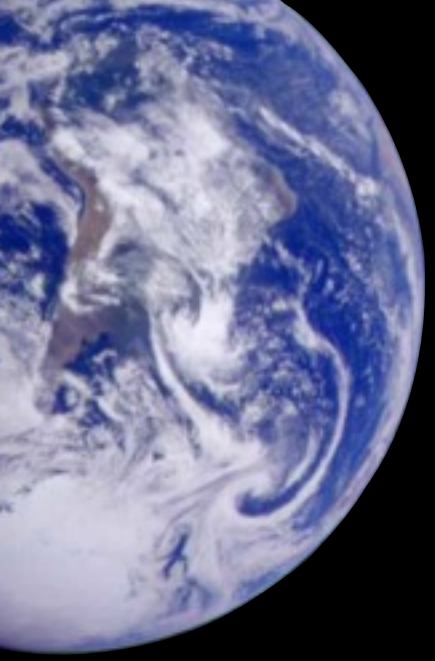


Life → altered observables → (instrumentation) → Observer

Interpretation ?

planetary atmospheres are not at chemical equilibrium

- UV ⟶ photochemistry
- thermal gradient + transport
- at habitable temperatures, endothermic reactions are extremely low
- exchange with a hot interior



Life → altered observables → (instrumentation) → Observer

Interpretation ?

Eventually, disequilibrium must be quantified, for instance in terms of ΔG (Gibbs free energy) and compared with possible abiotic sources of ΔG

Doable for UV. Much more difficult for quenching (exchange with a hot interior).

Implies a comprenhesive knowledge of the atmospheric elemental composition.

# context is the key

“if information from other experiments […] had not been available this set of data would almost certainly have been interpreted as presumptive evidence for biology”

Klein, H. P.: 1978, ‘The Viking Biological Experiments on Mars’, Icarus 34, 666–674.

# some concluding remarks

- attributing a spectral/chemical anomaly to the presence of life (if possible) will require many multiwavelength high-snr observations from different instruments

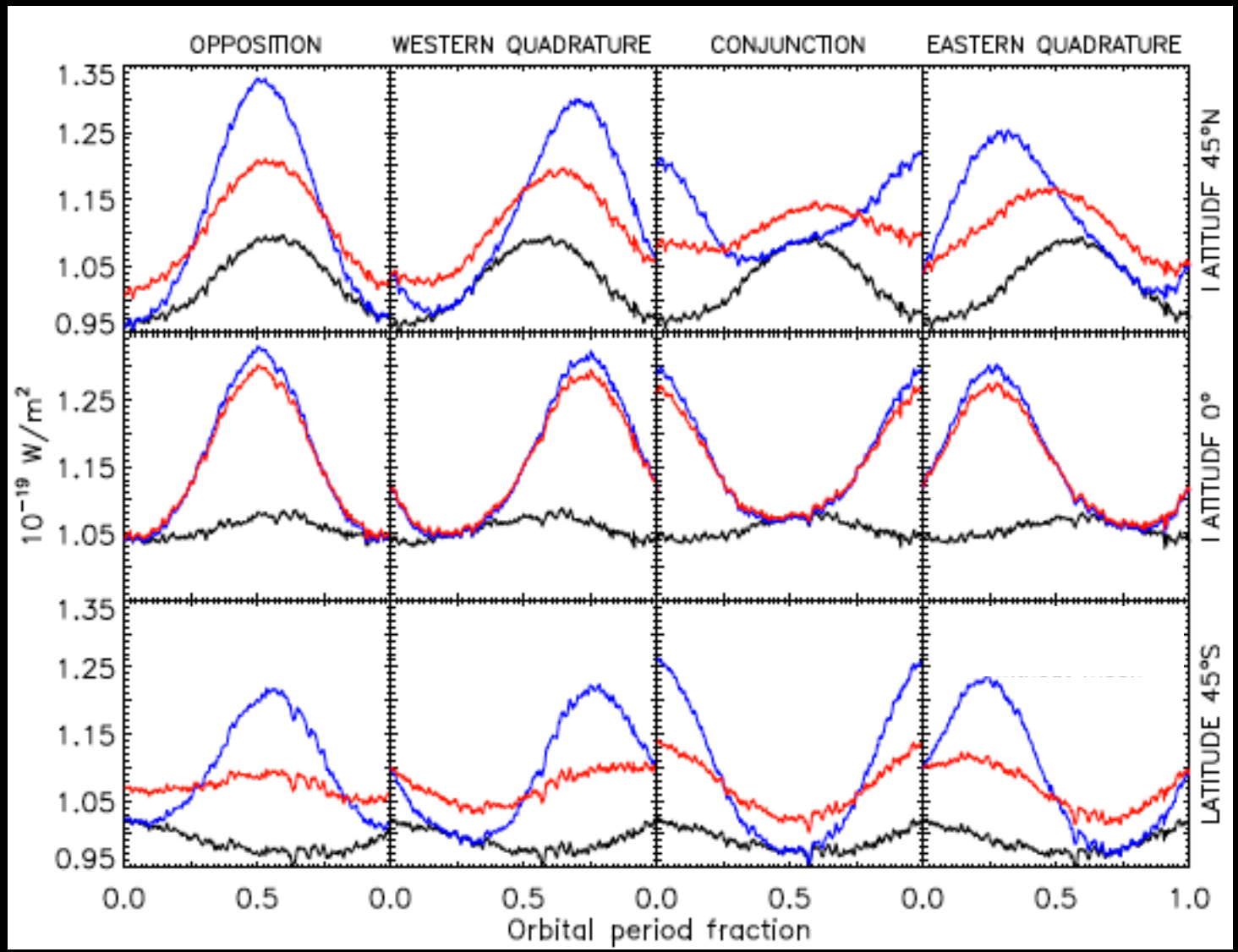
- The detection of such an anomaly is not the ultimate goal. It would be the beginning of the story.

- *dosit facit venenum* (measurement vs detection)

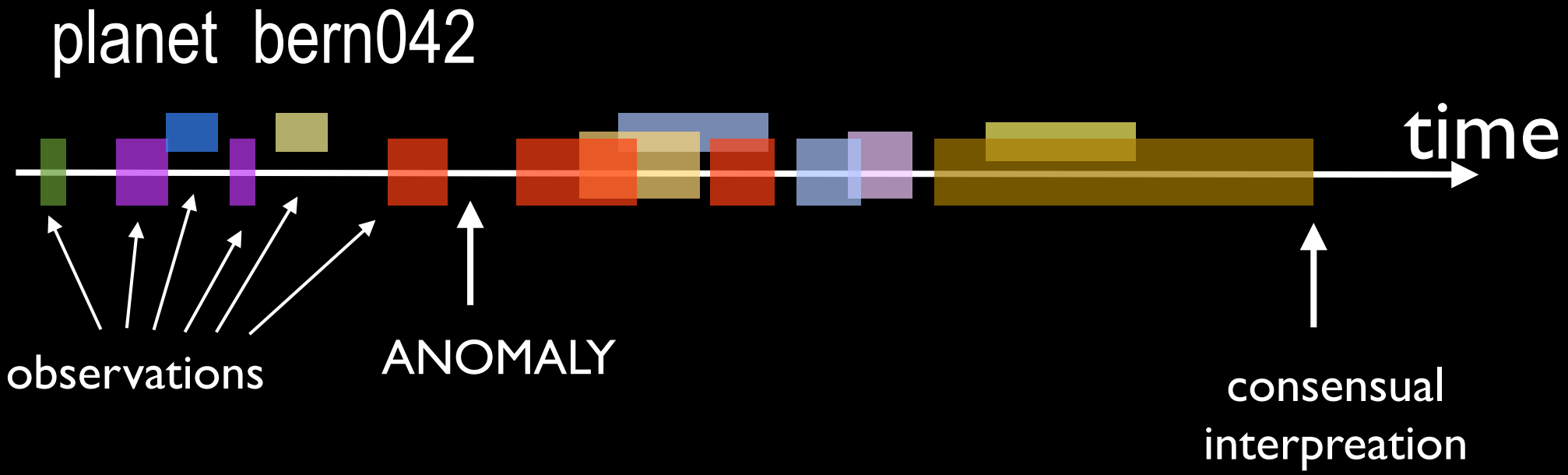
- we need to observe/study many different planets to understand the processes controling their diversity

- the success of the search for life does not depend only on our technology but also on the actual distribution/diversity of life in the Universe. It is therefore impossible to predict if/when such a discovery will be made.

- always question the assumptions !

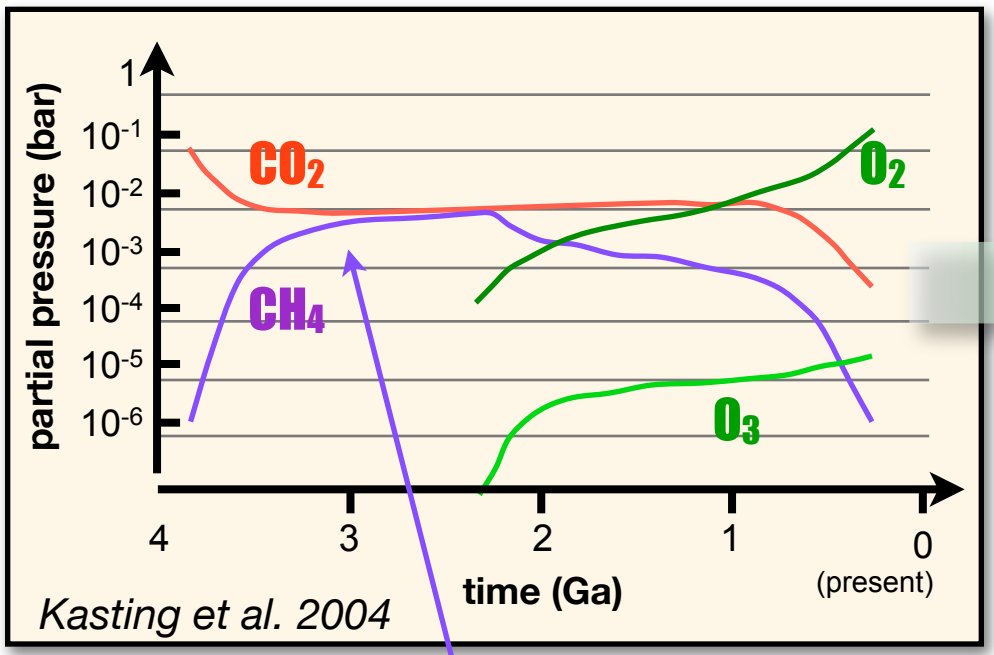



Gomez-Leal et al., ApJ, 2012

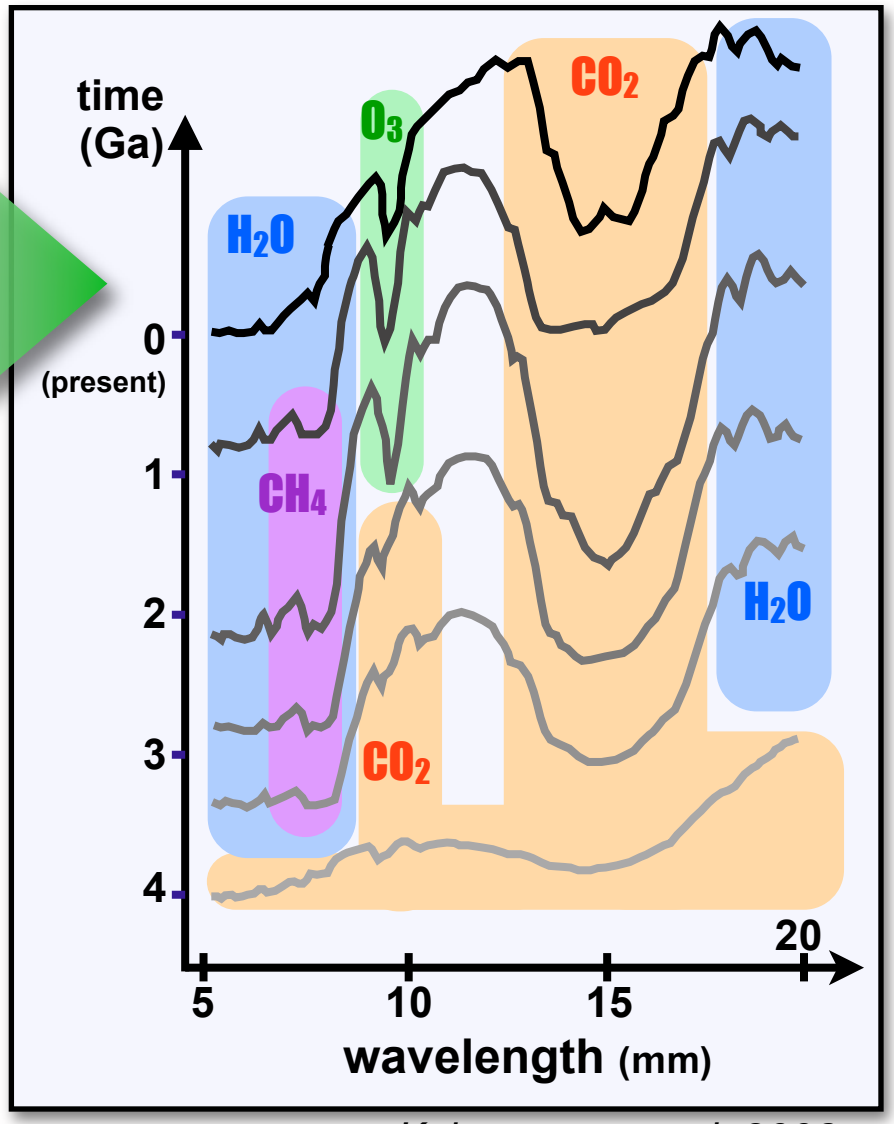

planet bern042
time
observations
ANOMALY
consensual
interpreation

# Earth in time

## From atmospheric evolution...




## ... to spectral evolution




*Kaltenegger et al. 2006*

An era of biogenic methane before the rise of oxygen ?