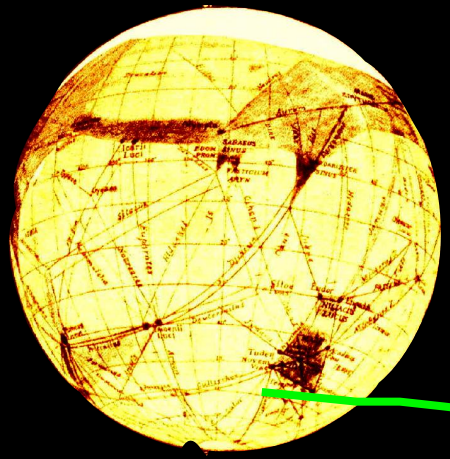
Biosignatures and context

Franck Selsis, Laboratoire d'Astrophysique de Bordeaux, fselsis@gmail.com

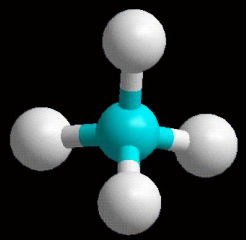
"if information from other experiments […] had not been available this set of data would almost certainly have been interpreted as presumptive evidence for biology"

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



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.

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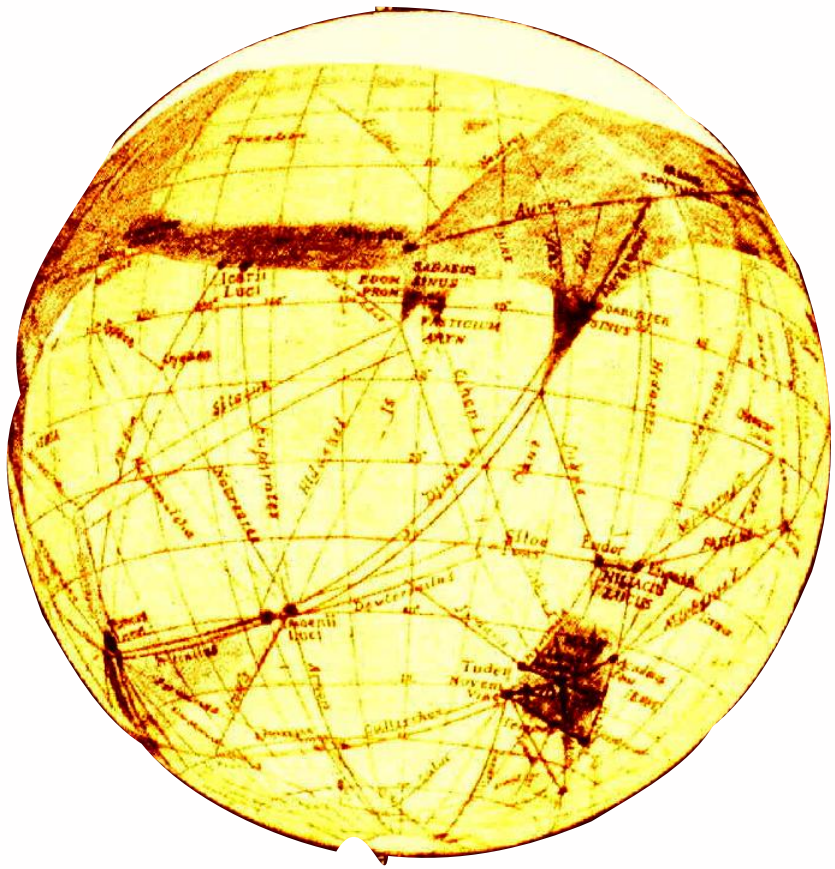

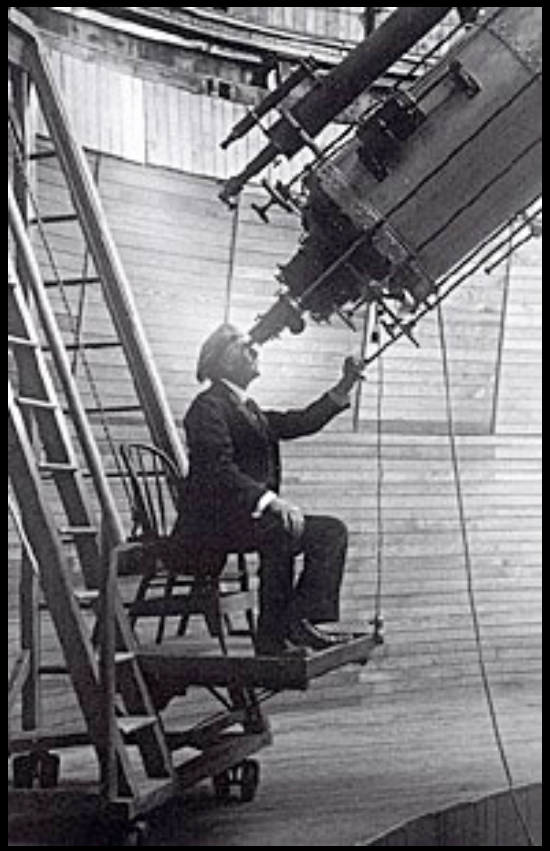

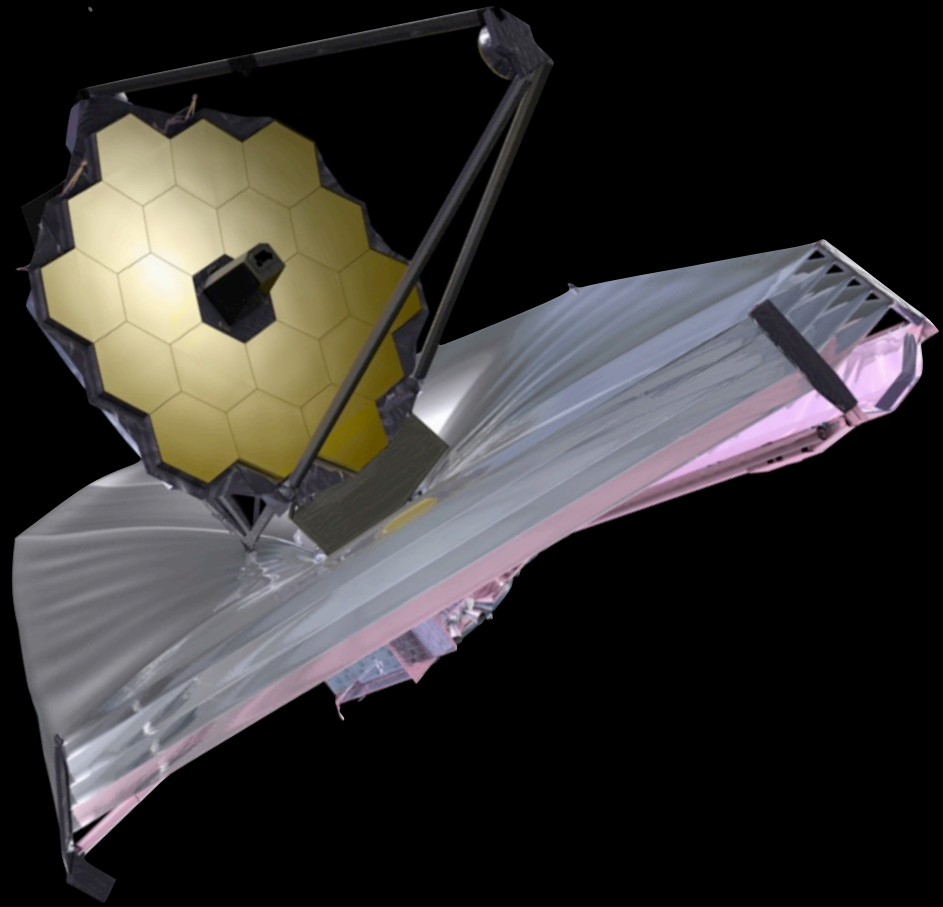

We'll Find Evidence of Alien Life within Next Two Decades, Top NASA Scientist Says

Apr 8, 2015 by Sci-News.com

« PREVIOUS | NEXT »

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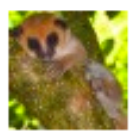

Montag
New Sp
Oct 12, 2

New Ho
Water I
Oct 12, 2

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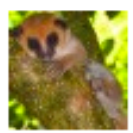
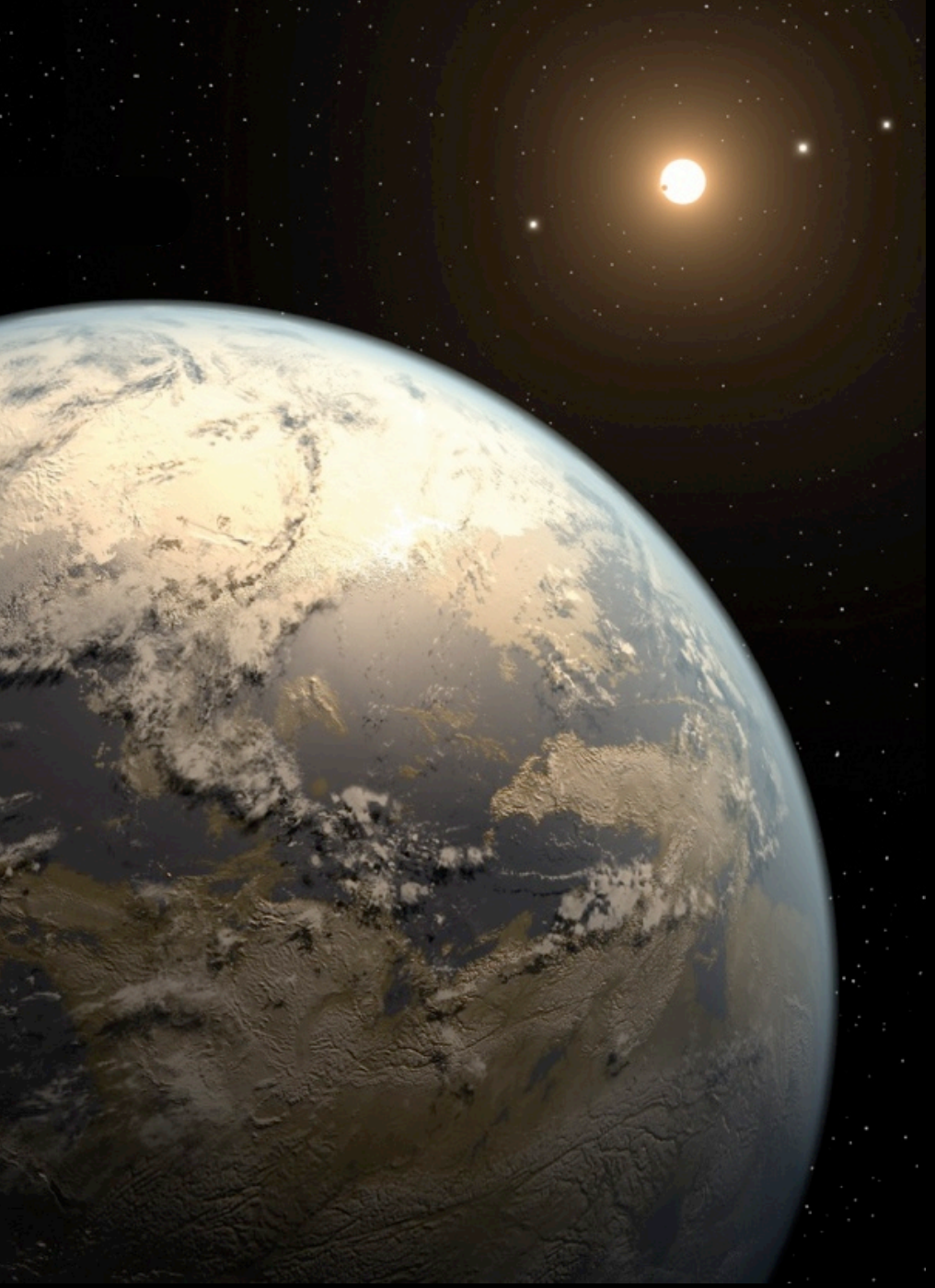


Montag
New Sp
Oct 12, 2

New Ho
Water I
Oct 12, 2

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.

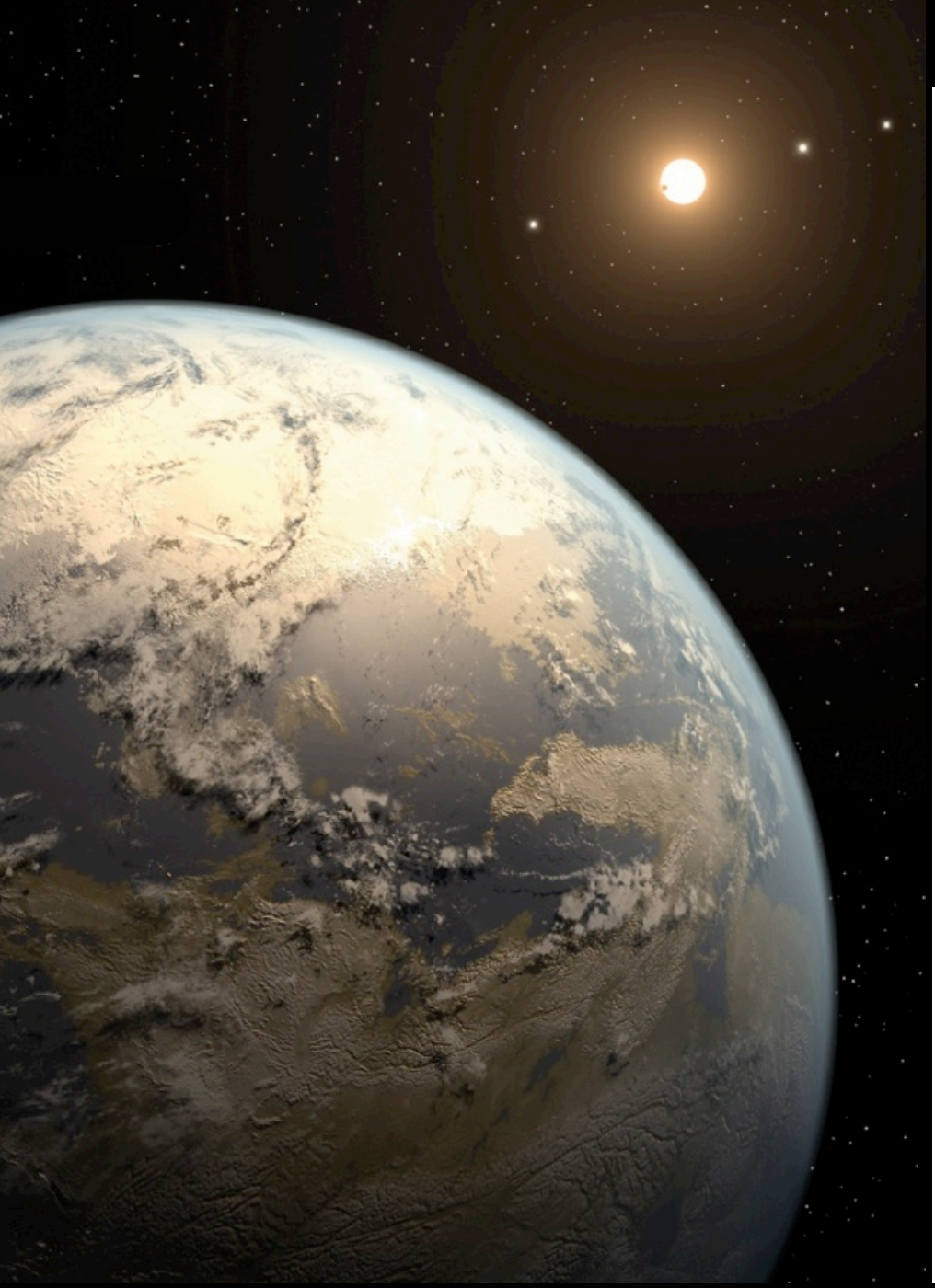


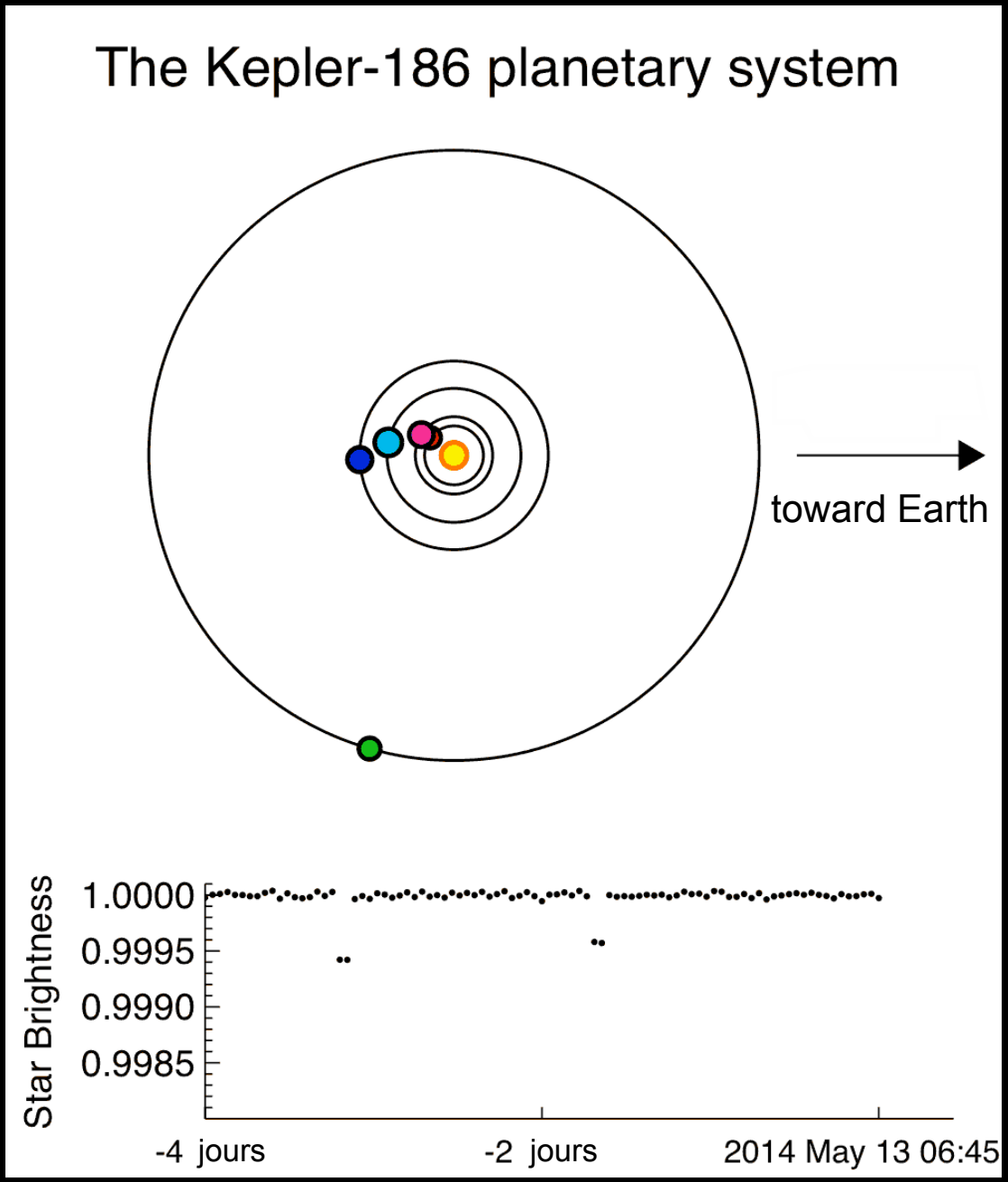
jours

jours

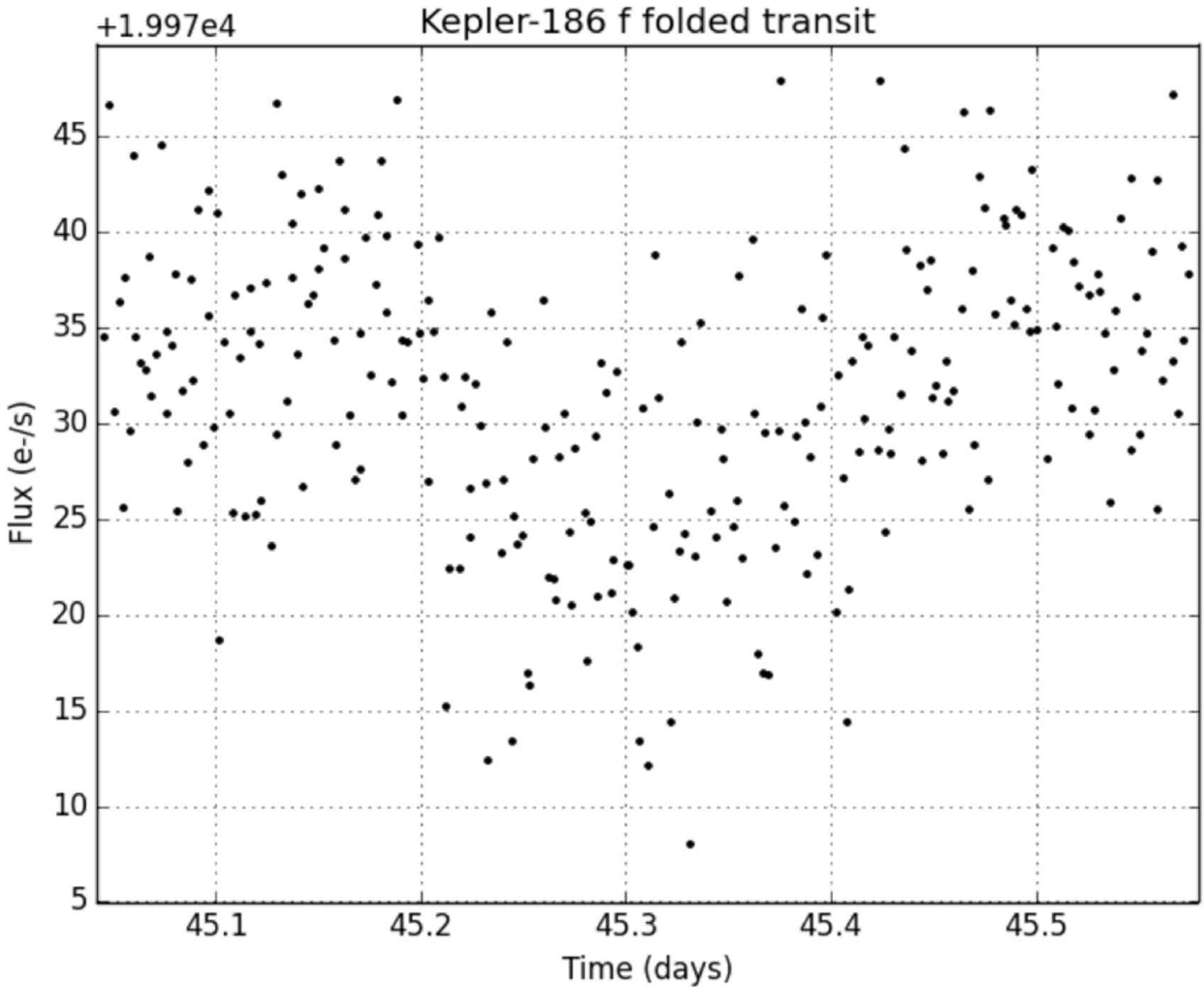
Quintana et al., 2014

animation by Sean Raymond



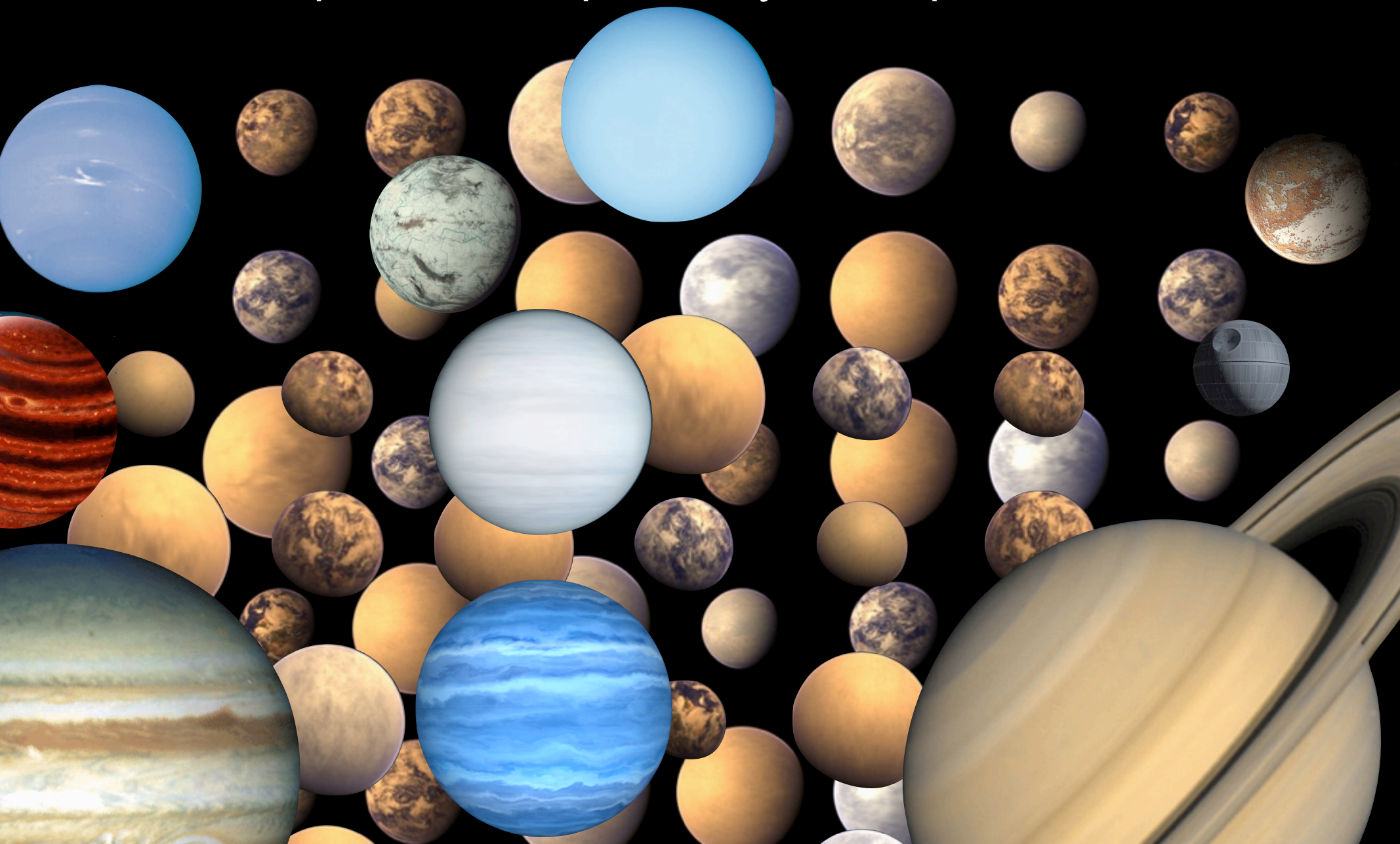


Quintana et al., 2014 *animation by Sean Raymond*


Kepler-186 f folded transit
+1.997e4
45
40
35
30
25
20
15
10
5
Flux (e-/s)
45.1
45.2
45.3
45.4
45.5
Time (days)

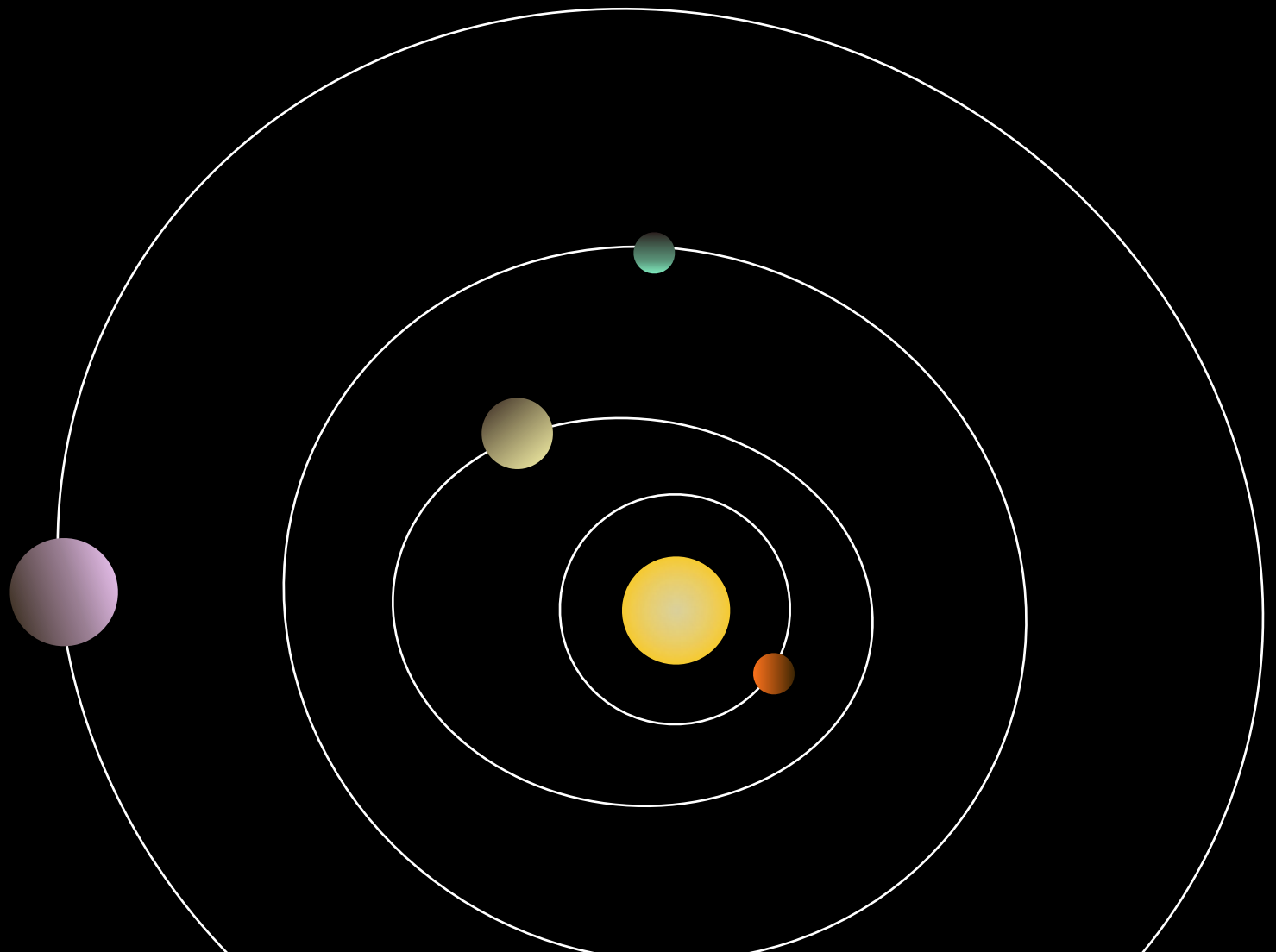
Context

1. What are planets and planetary atmosphere made of ?



Context

2. The host system



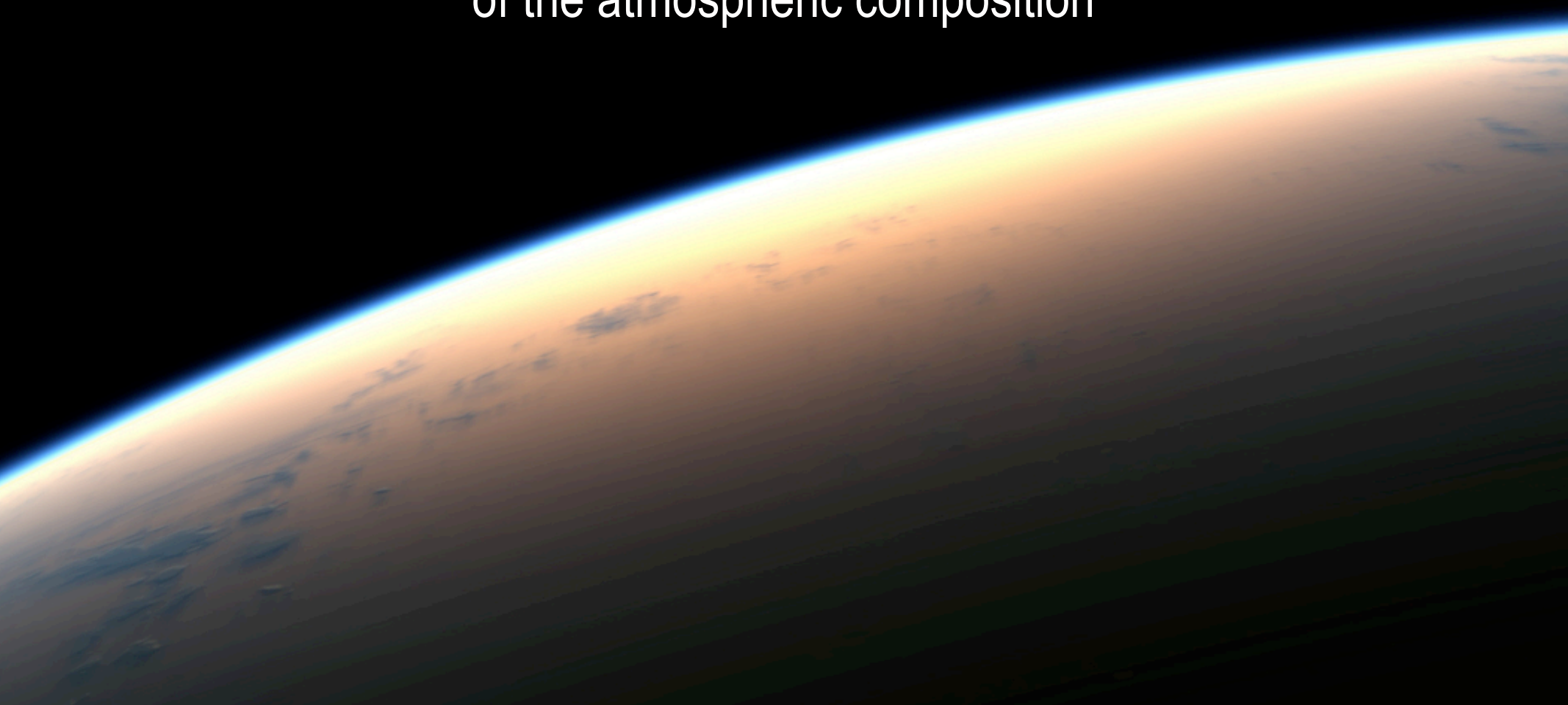
Context

3. The planet and its atmosphere

Context

3. The planet and its atmosphere

Quantifying the desiquilibrium implies a detailed knowledge of the atmospheric composition

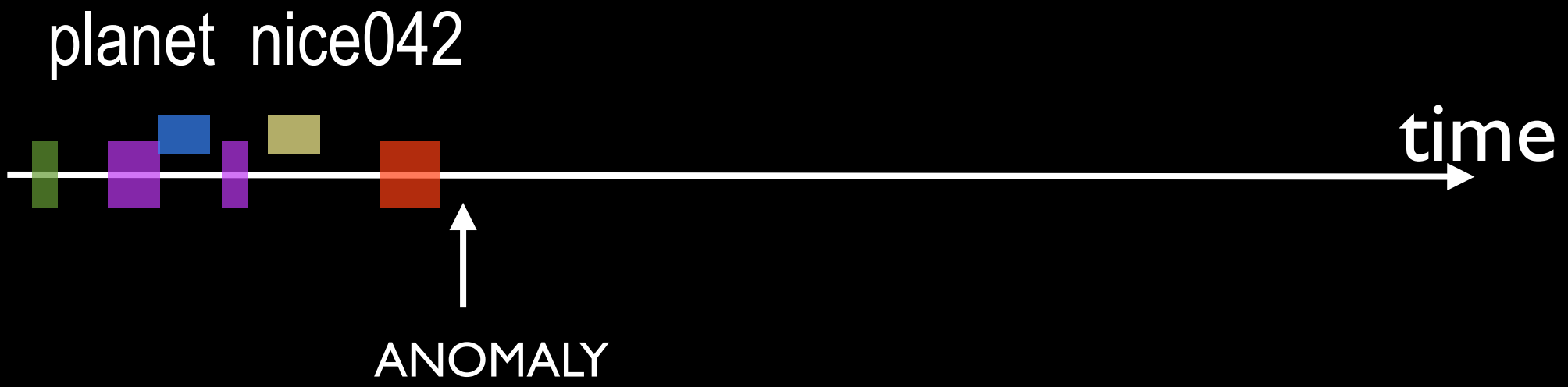


Should we select future instruments for their capacity

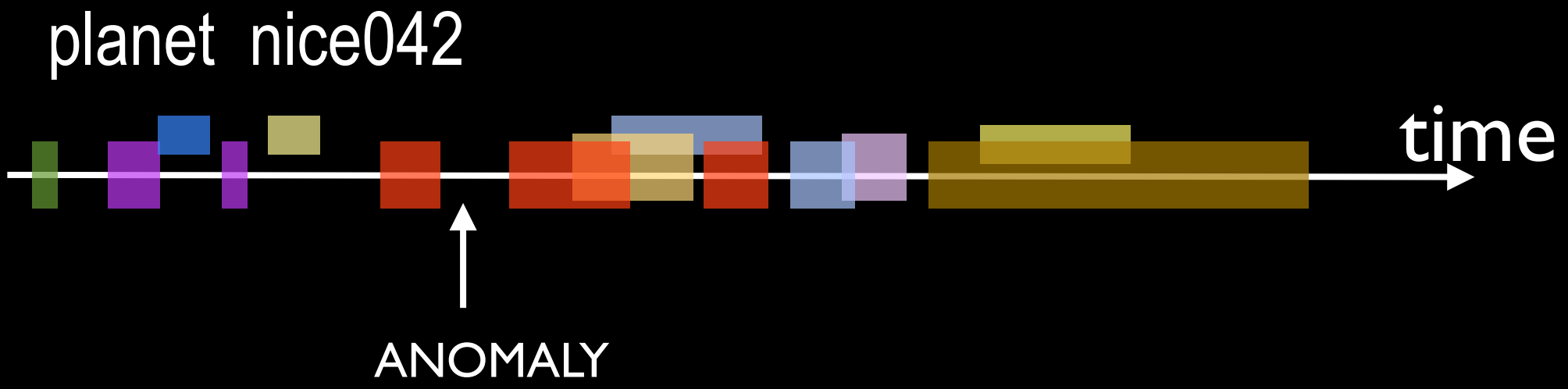
- to detect one specific feature on a few planets ?

- to make progress on the context (our understanding of planets and atmospheres)


planet nice042
time
observations


planet nice042
time
ANOMALY

We cannot identify a potential anomaly without understanding what is normal
→ unbiased exploration of large variety of planets must come first



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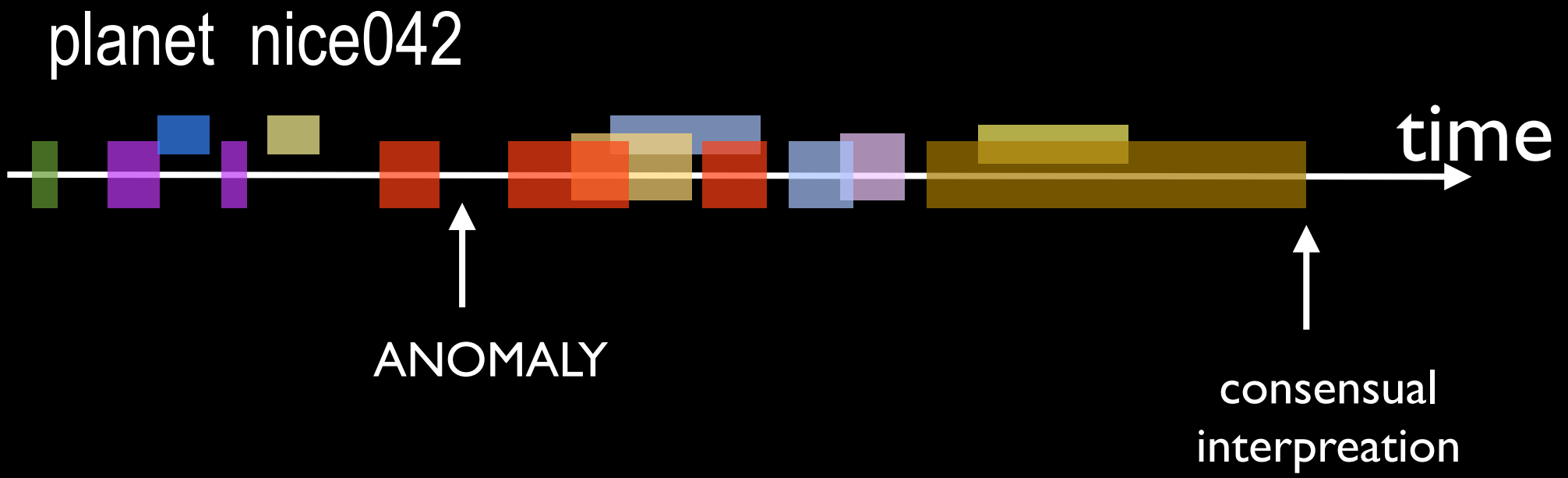

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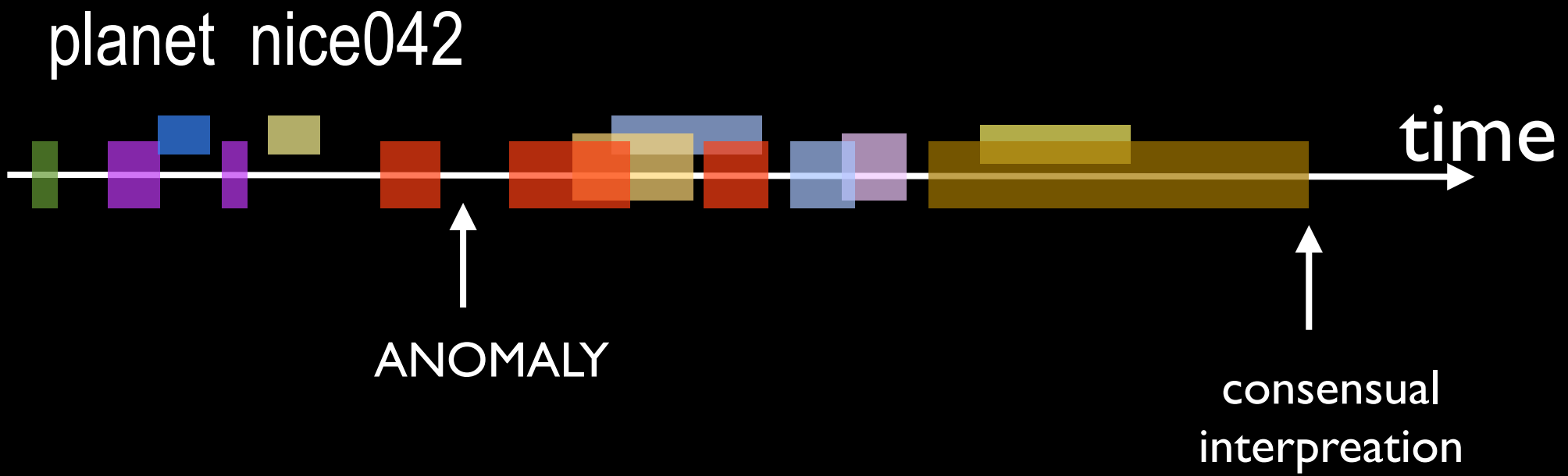
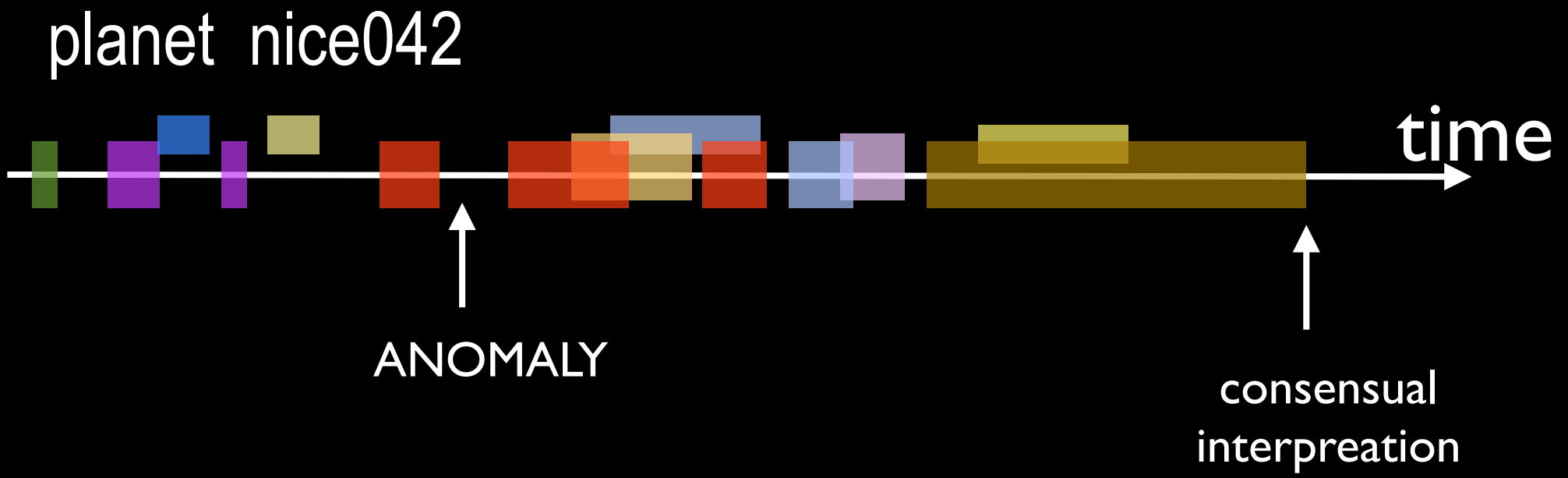


We cannot identify a potential anomaly without understanding what is normal
→ unbiased exploration of large variety of planets must come first

We cannot link an anomaly to the presence of life without an in-depth characterization of the target (and its host star & system)



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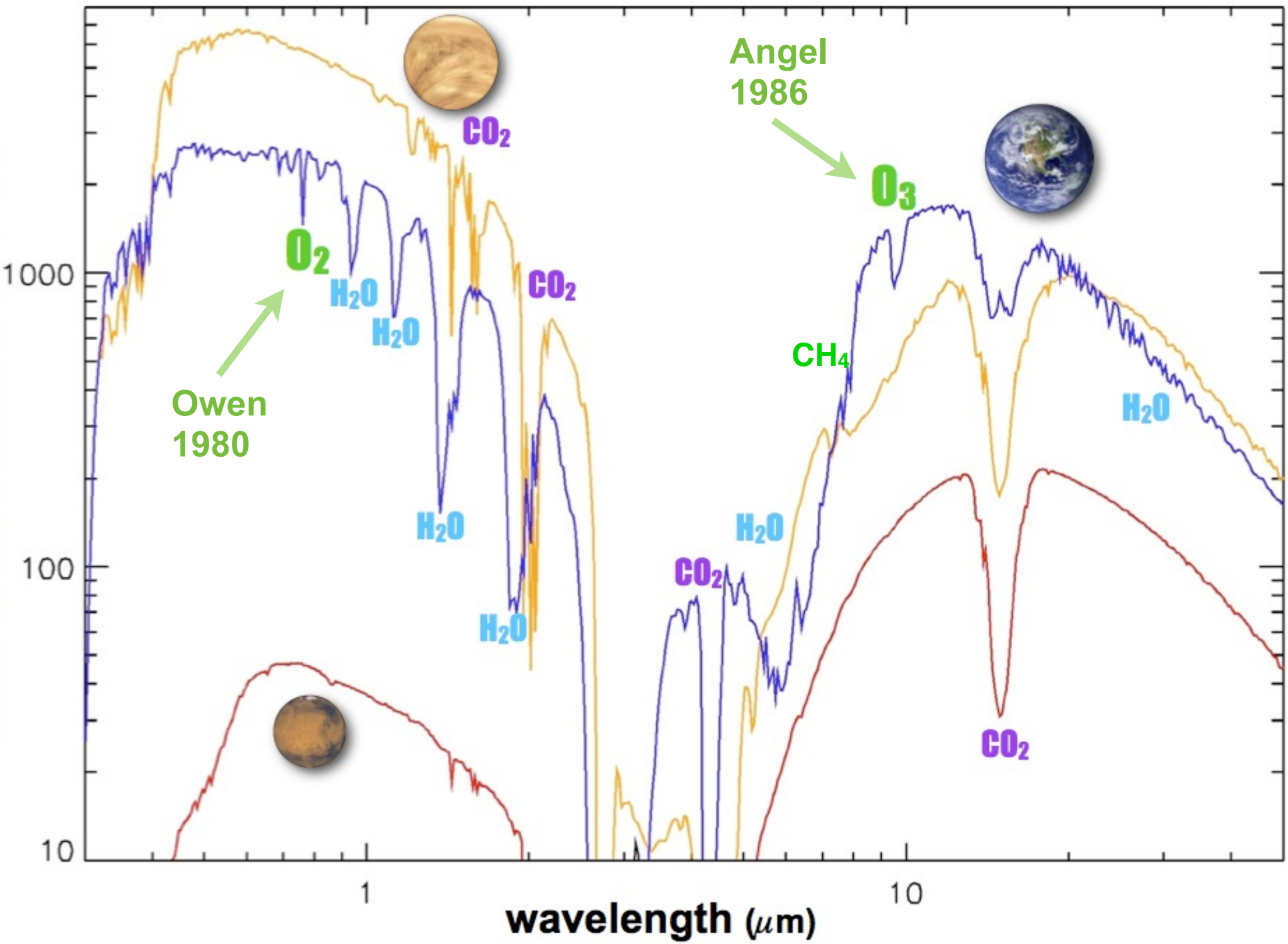
We cannot link an anomaly to the presence of life without an in-depth characterization of the target (and its host star & system)

NO SHORTCUT TO FINDING EXTRASOLAR LIFE

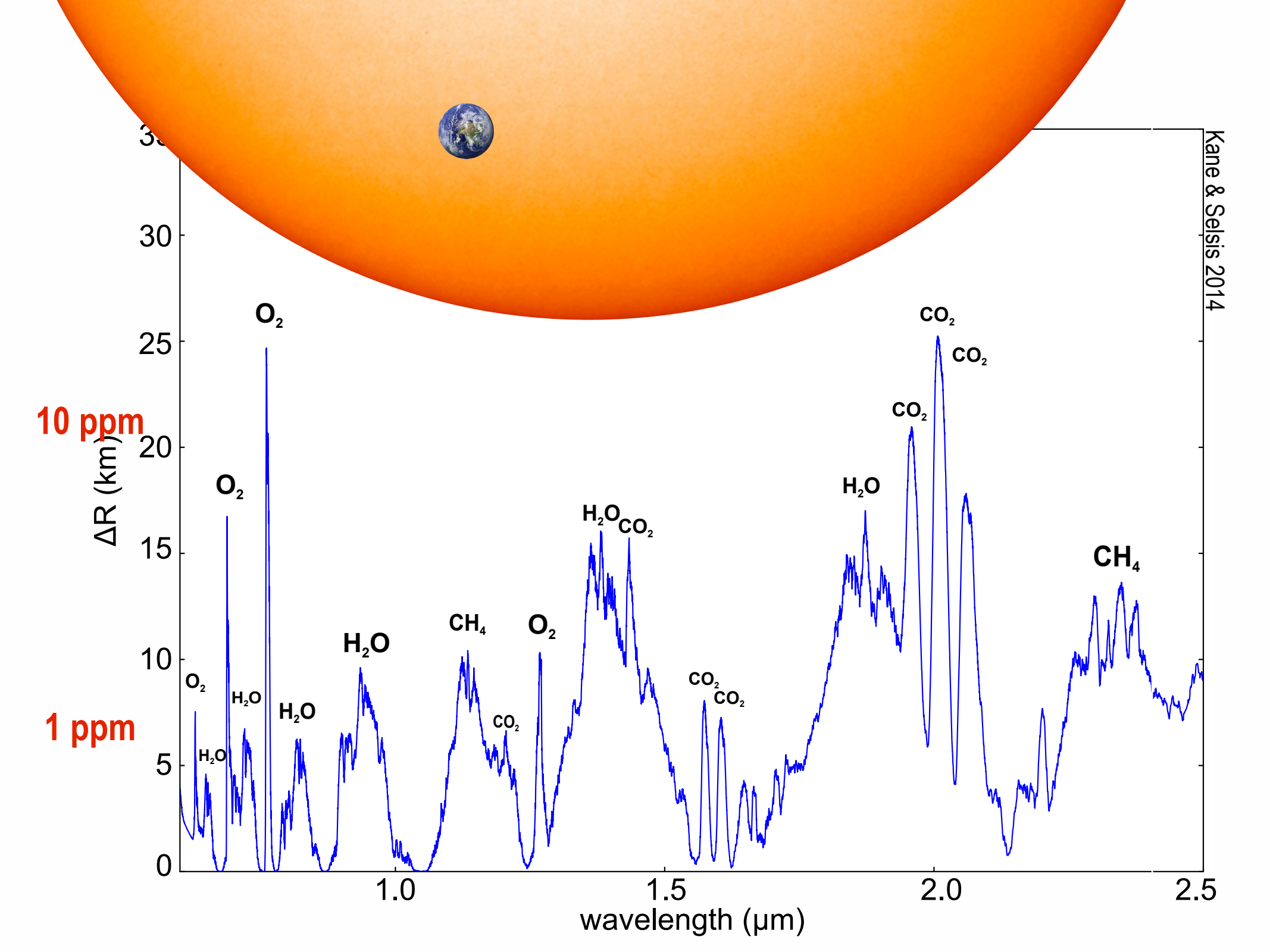
Life → altered observables → Observer

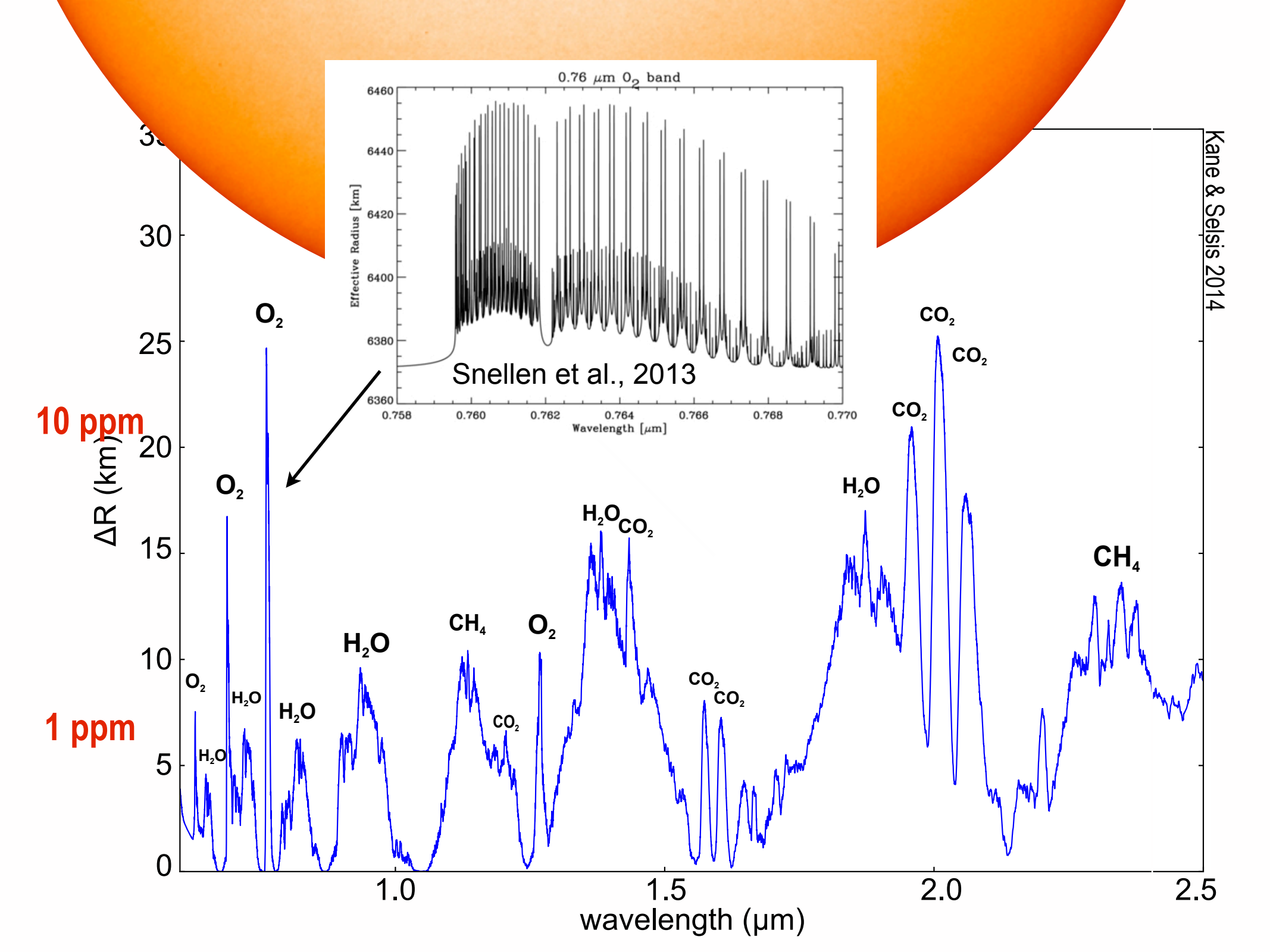
instrumentation

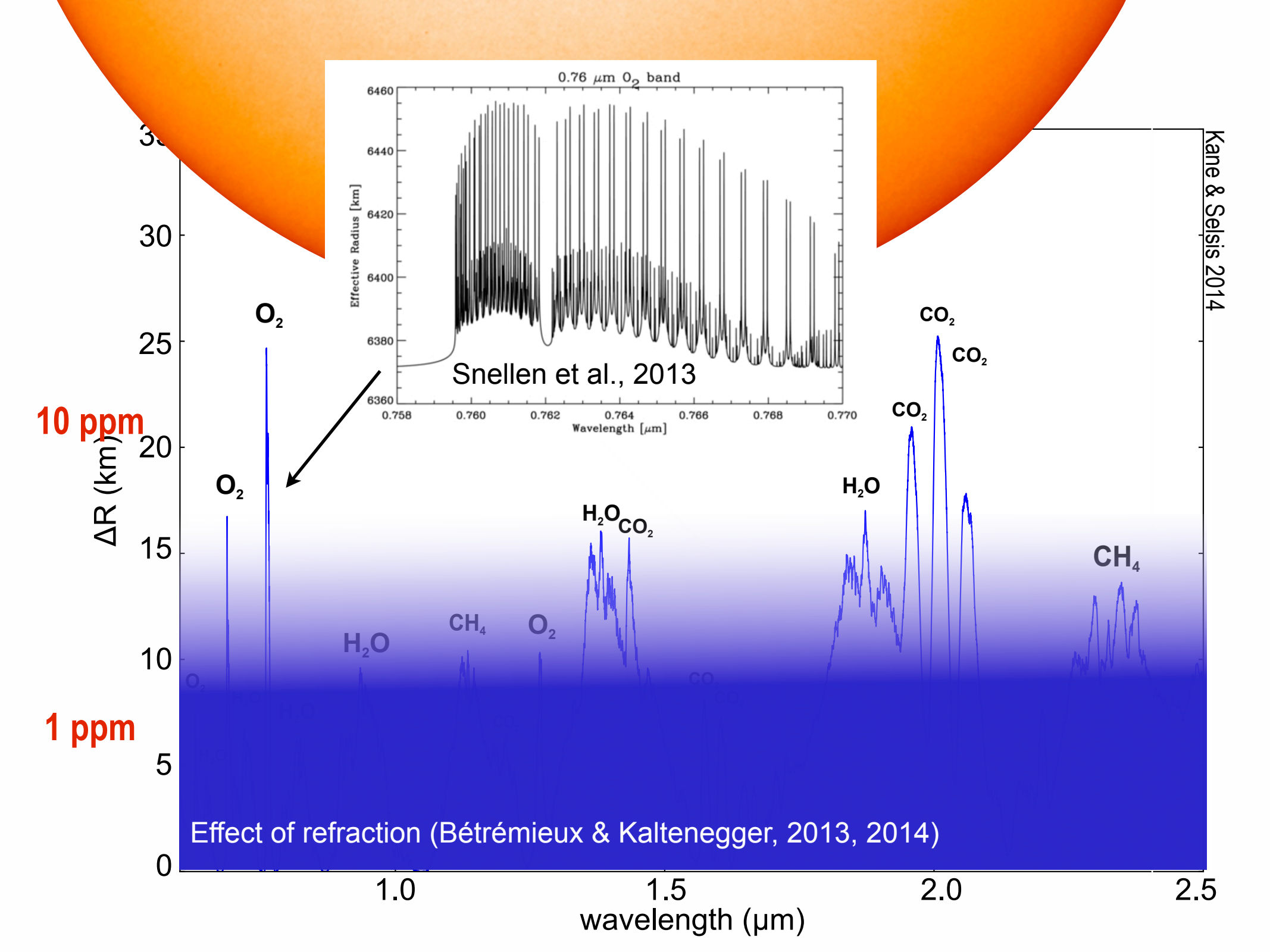
Interpretation ?



(Selsis & Tinetti, Darwin Proposal, 2007)


10 ppm
1 ppm
ΔR (km)
wavelength (μm)
Kane & Selsis 2014
O2
H2O
CH4
CO2


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

Oxygenic photosynthesis

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

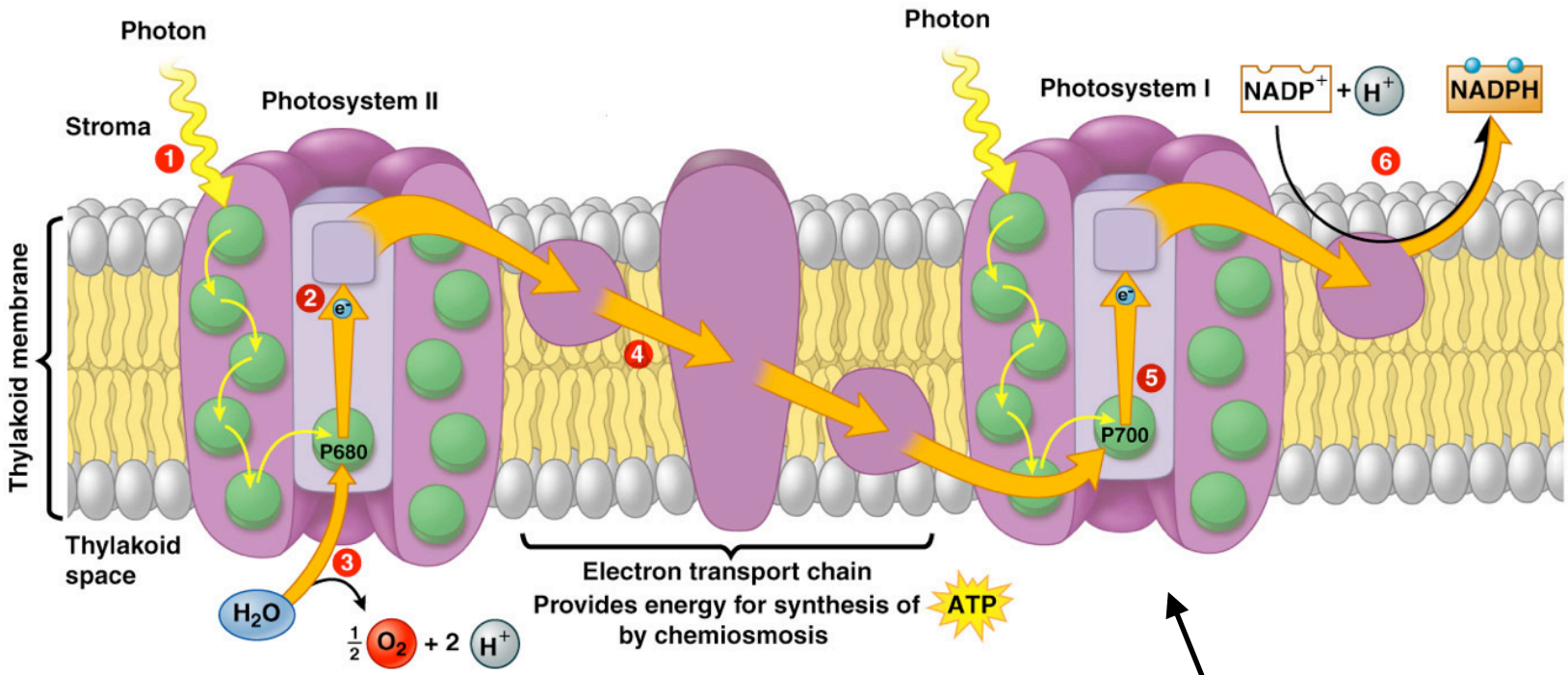
photosynthesis

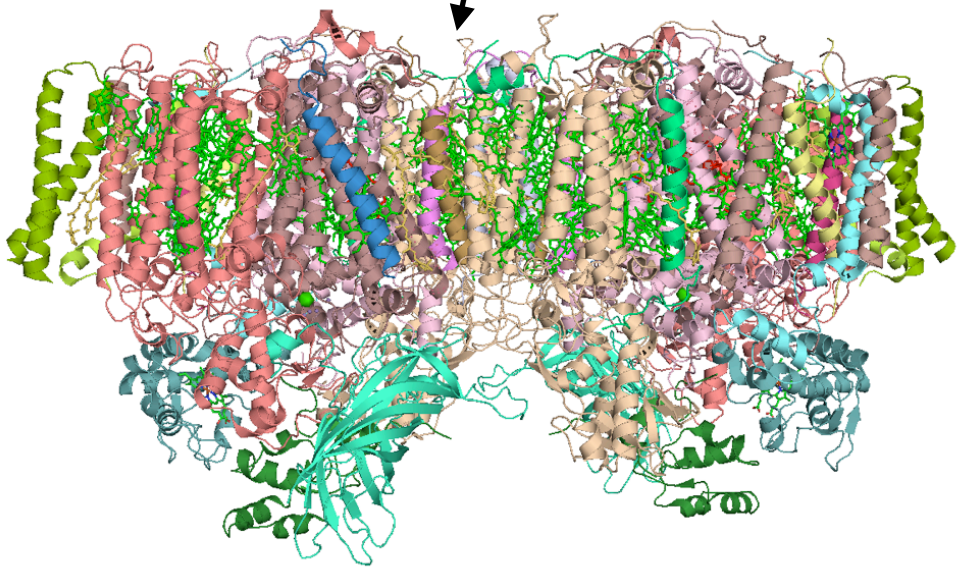
respiration or oxidation

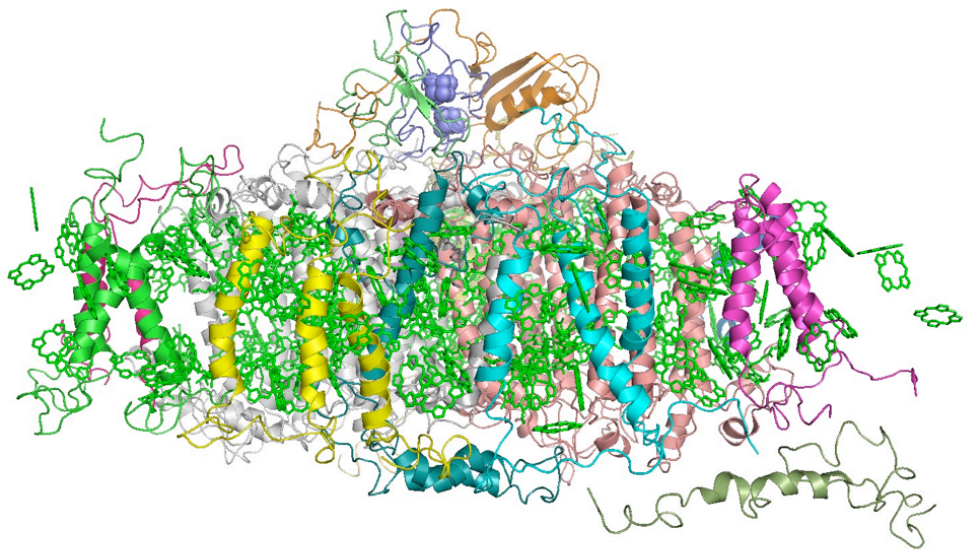
Net release of atmospheric O_2

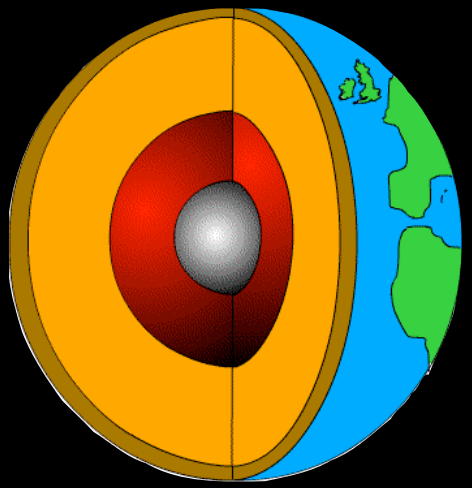
Burial of organic carbon

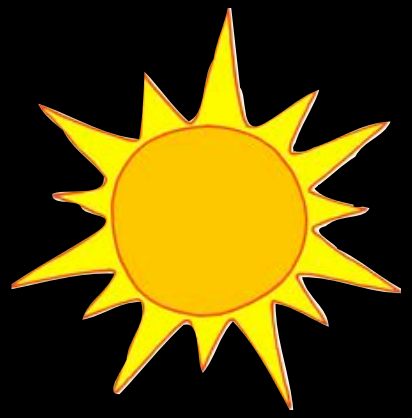
2850 kJ/mole of glucose (72 g of carbon)







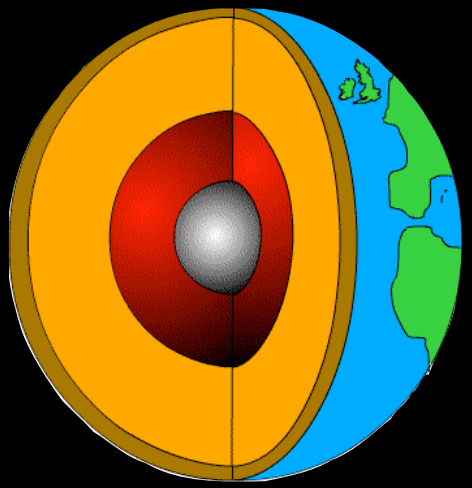


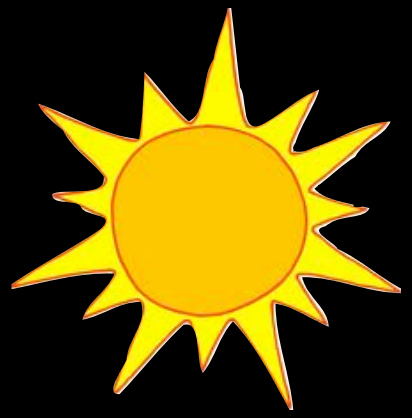


- solar flux at Earth surface: 163 W/m^2 (340 W/m^{-2} -30% reflected back to space - 77 W/m^{-2} absorbed by the atmosphere)

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

- the fixation of 72 g of carbon costs 2850 kJ





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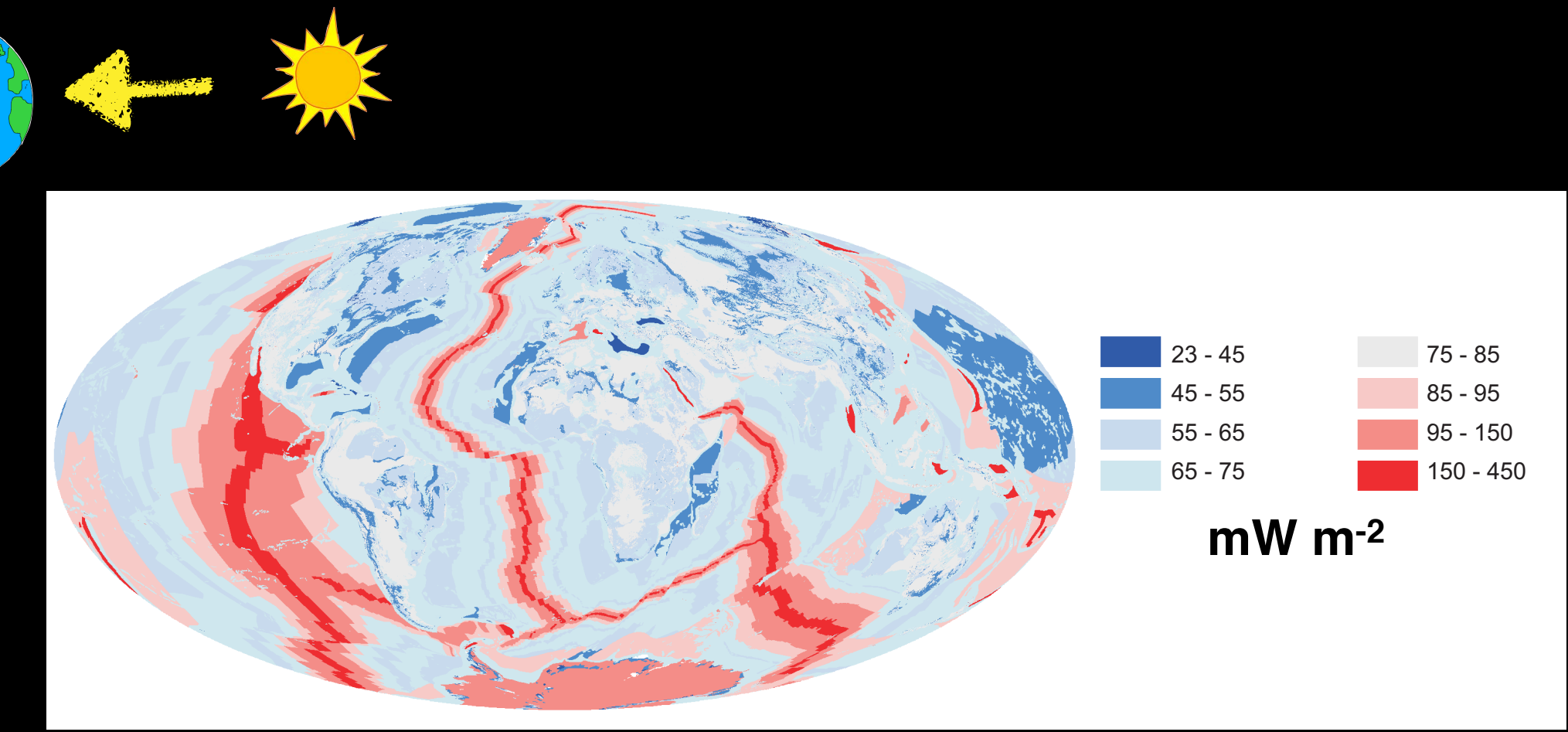
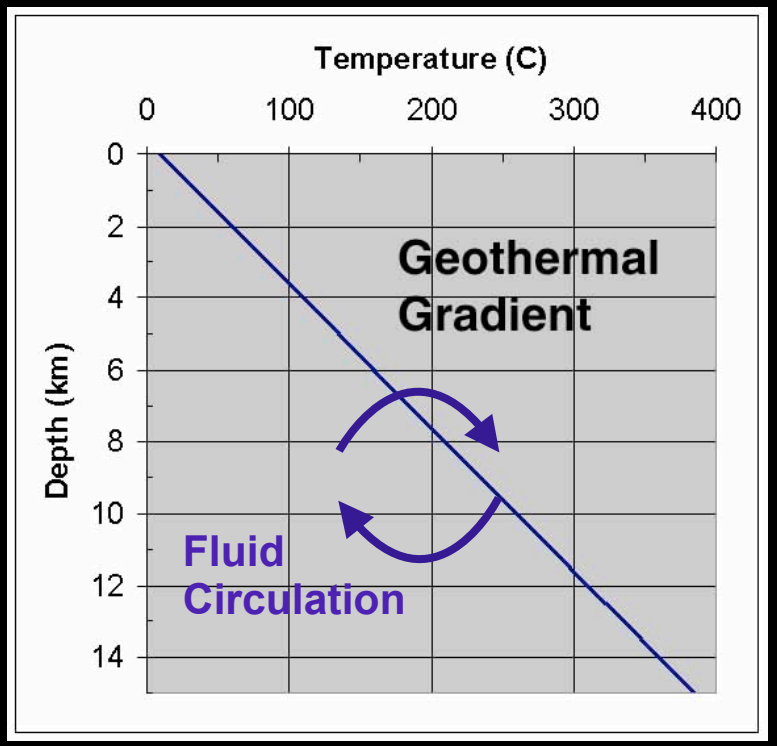
About 0.16% (0.268 W/m^2) is converted by photoautotrophic life into chemical energy.



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)

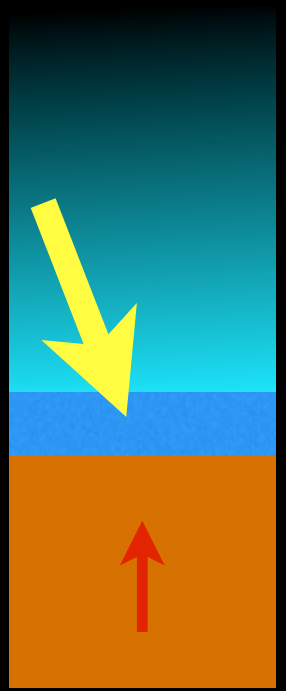
Photosynthetic life fixes at least 10 000 000 times more carbon than other primary producers (chemoautotrophs)



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

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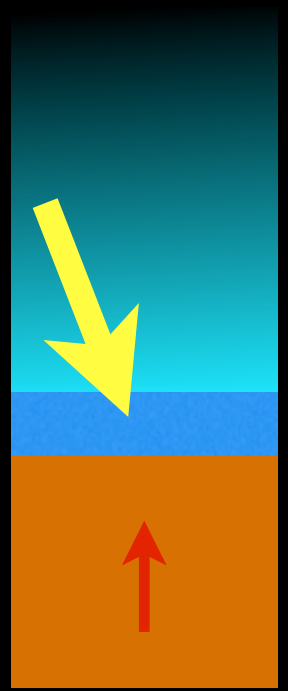
< 56 gC/Myr/m^2

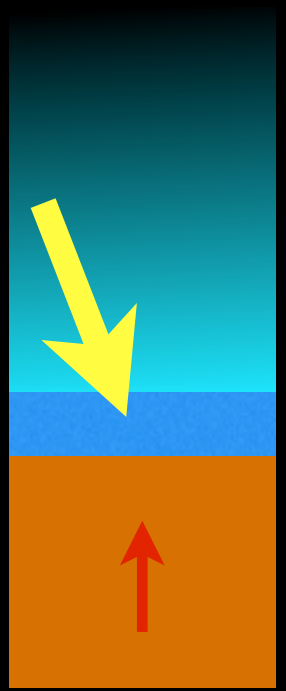


Although Chemoautotrophy is known since 1890, the Earth *deep biosphere* was discovered only in the 1970s

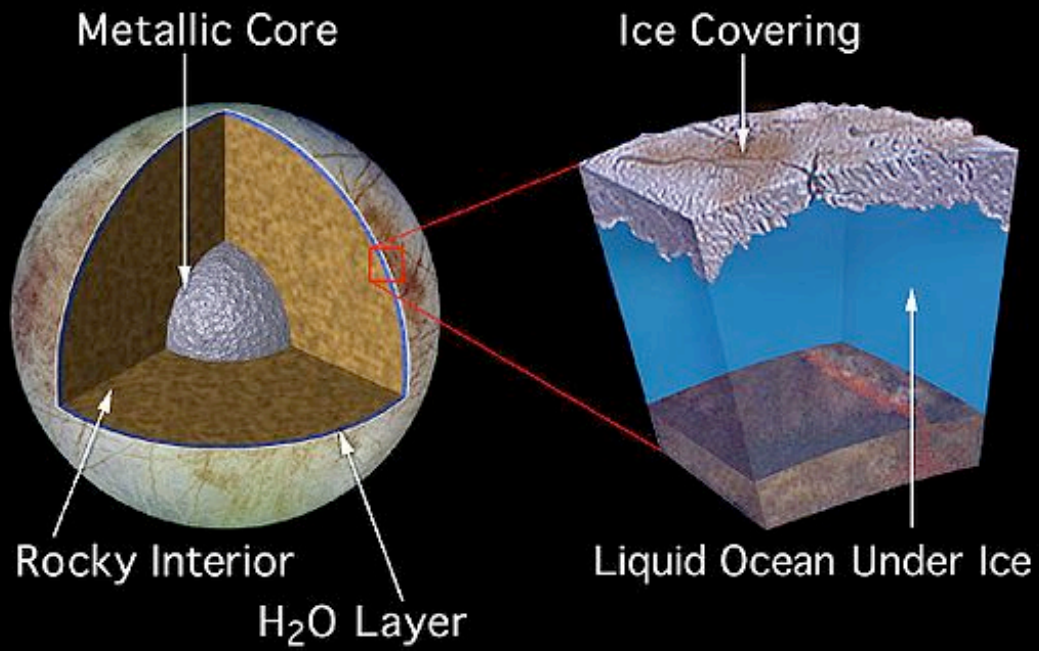
In a world with a purely chemoautotrophic primary production, the organic sequestration would cause no significant biological effect on the global carbon cycle in the absence of photosynthesis
(Rosing et al., 2006)

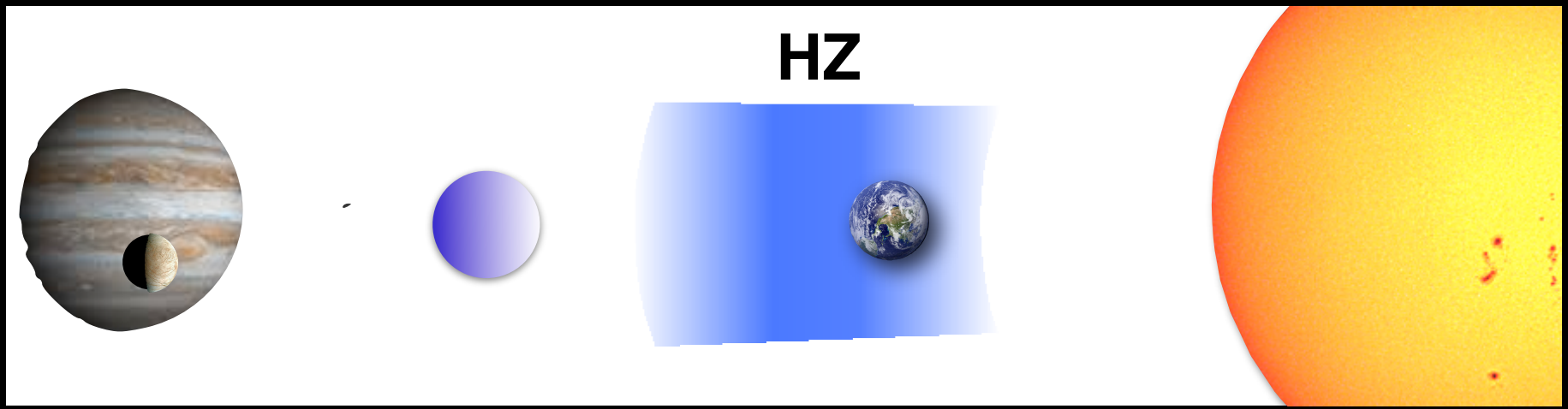
200 gC/yr/m^2

< 56 gC/Myr/m^2



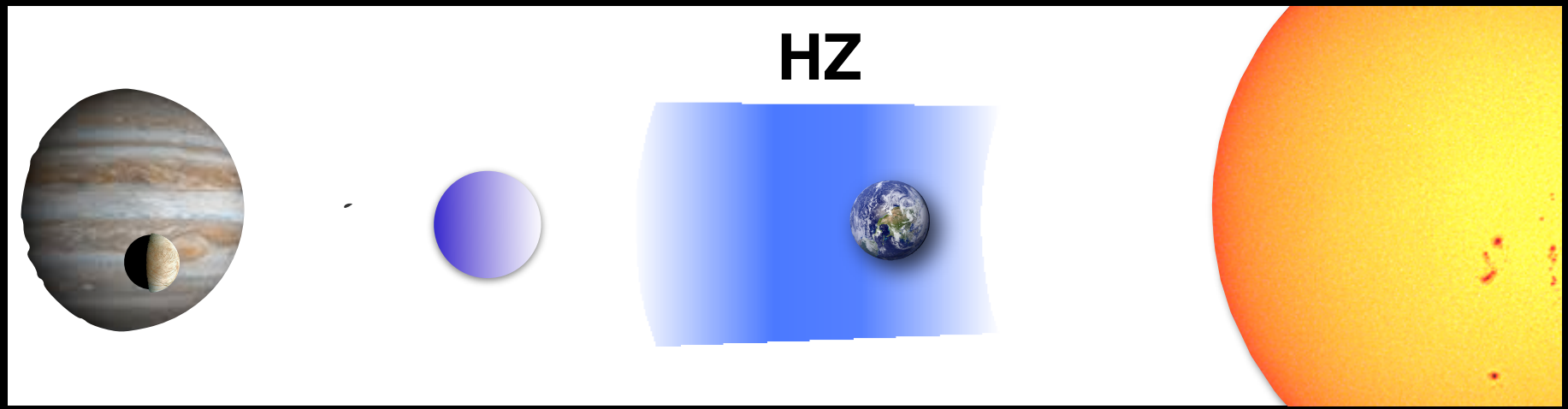
Biosignatures and the Habitable Zone





The *Habitable* Zone
(defined as the region where surface liquid water would be stable)
is where liquid water and stellar light can be <u>simultaneously</u> available.

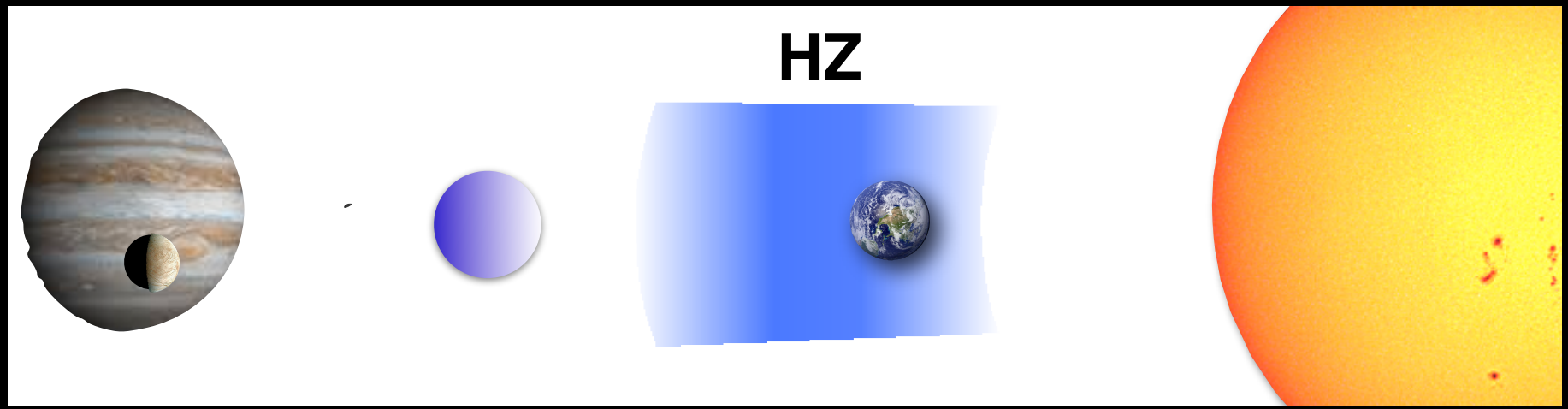
Life may exist outside the HZ but can it be found by remote observations ?



Surf Zone ?

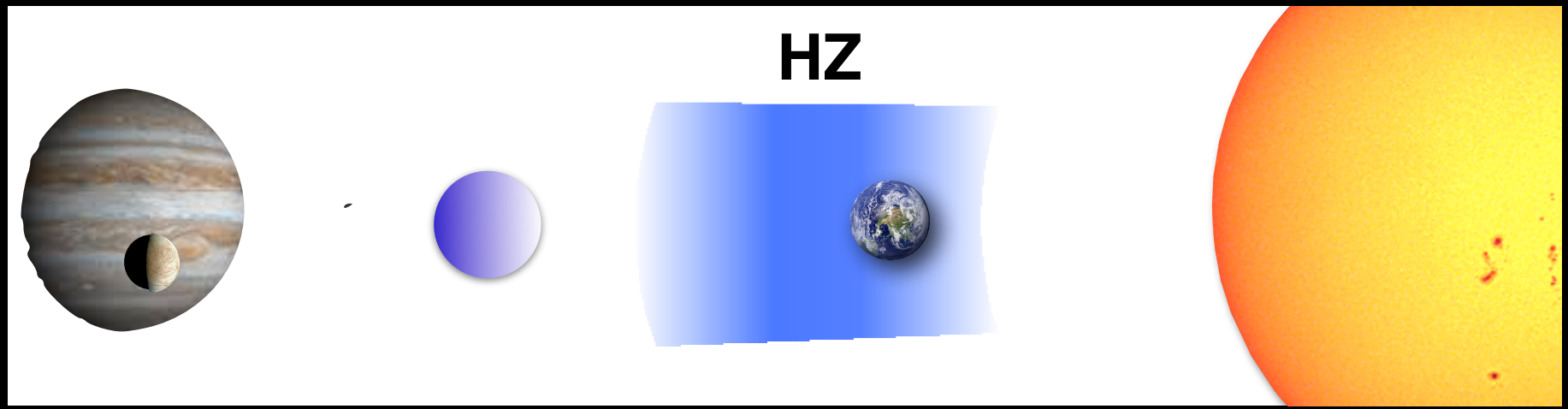
The *Habitable* Zone
(defined as the region where surface liquid water would be stable)
is where liquid water and stellar light can be <u>simultaneously</u> available.

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



The *Habitable* Zone
(defined as the region where surface liquid water would be stable)
is where liquid water and stellar light can be <u>simultaneously</u> available.

The emergence of life may require the same conditions (→Robert Pascal's talk)

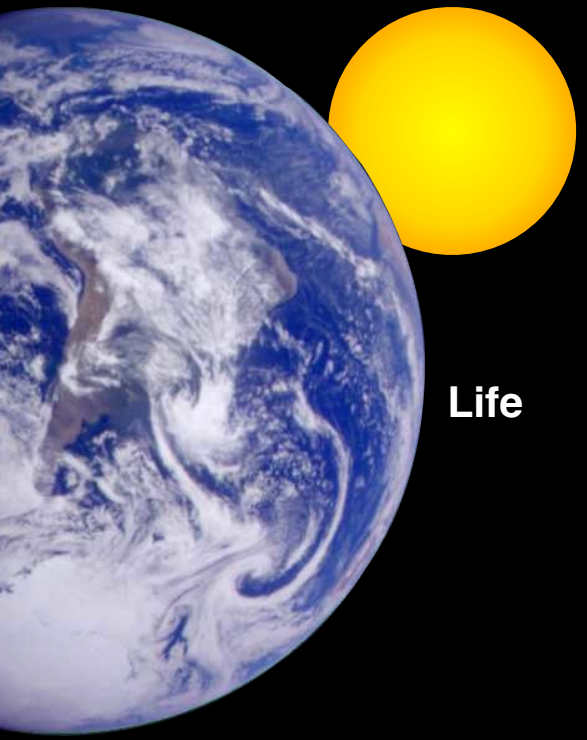


Life → altered observables → Observer

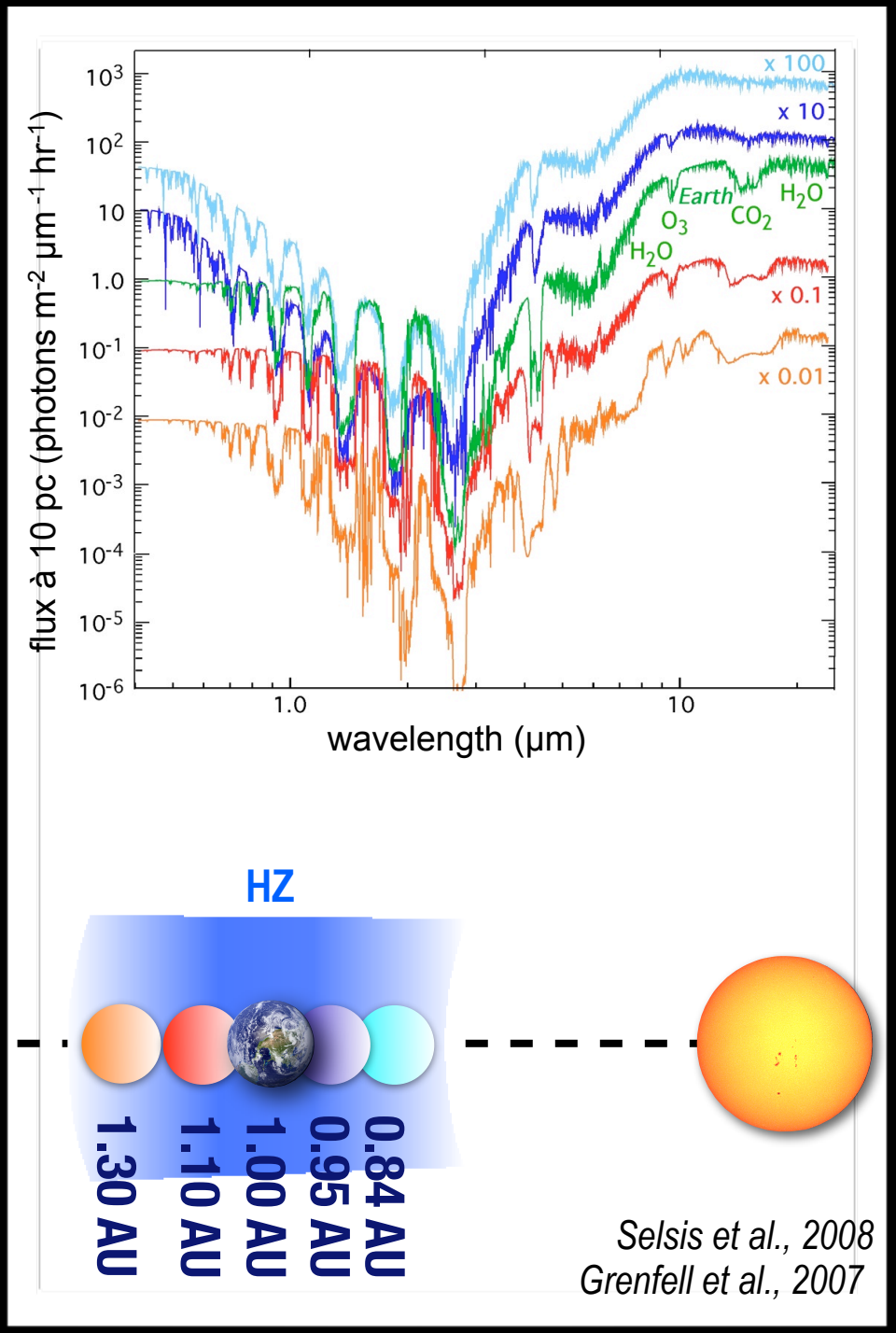
instrumentation

Interpretation ?

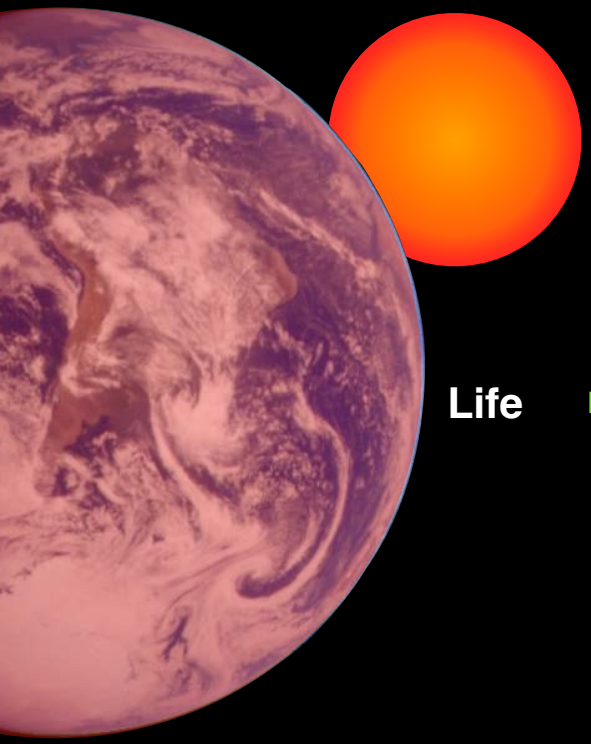
Life → altered observables



Life → altered observables



Life → altered observables

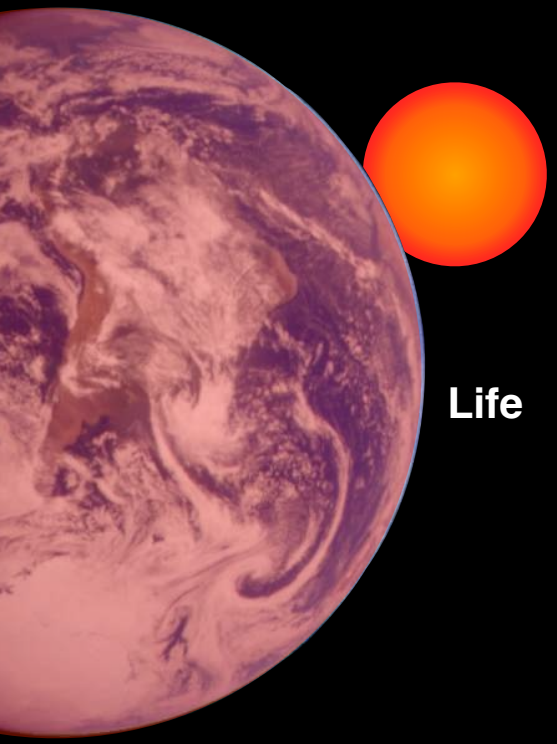


Life → altered observables

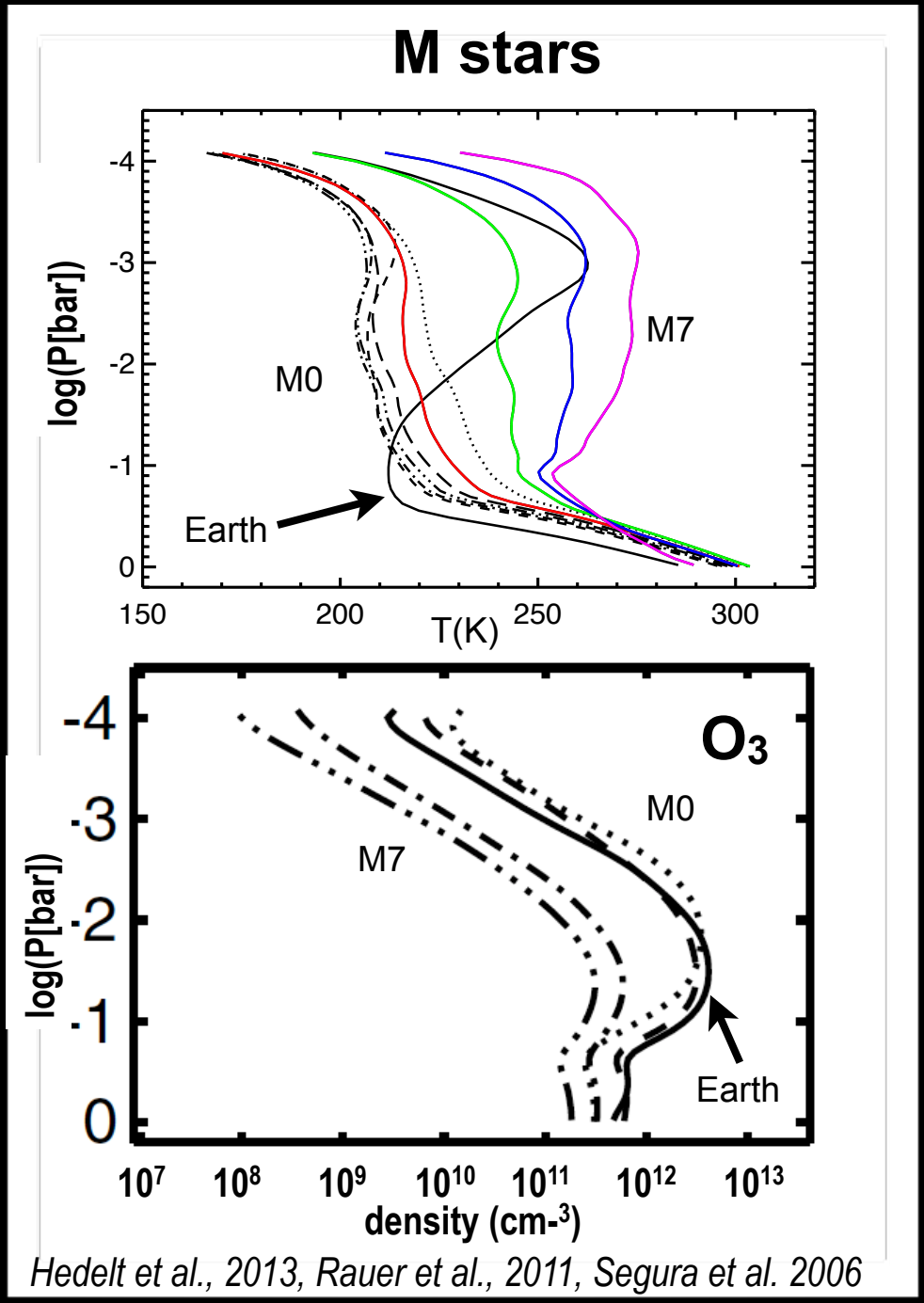
K, G, F stars

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

Life → altered observables

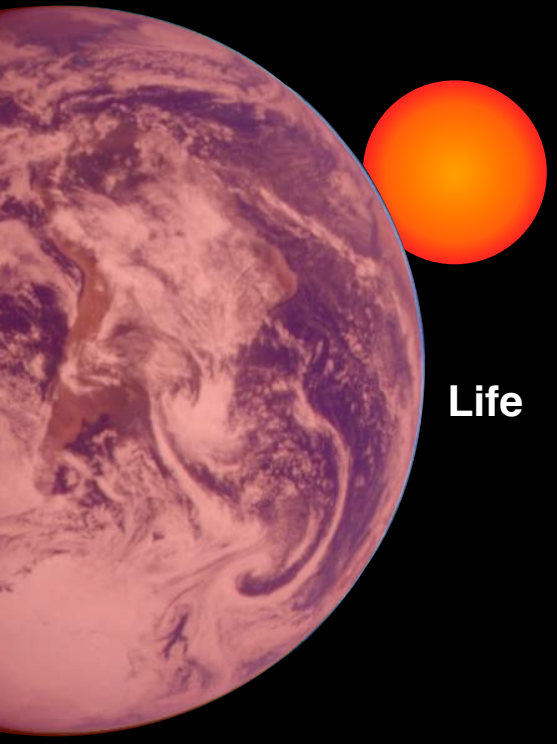


Life → altered observables

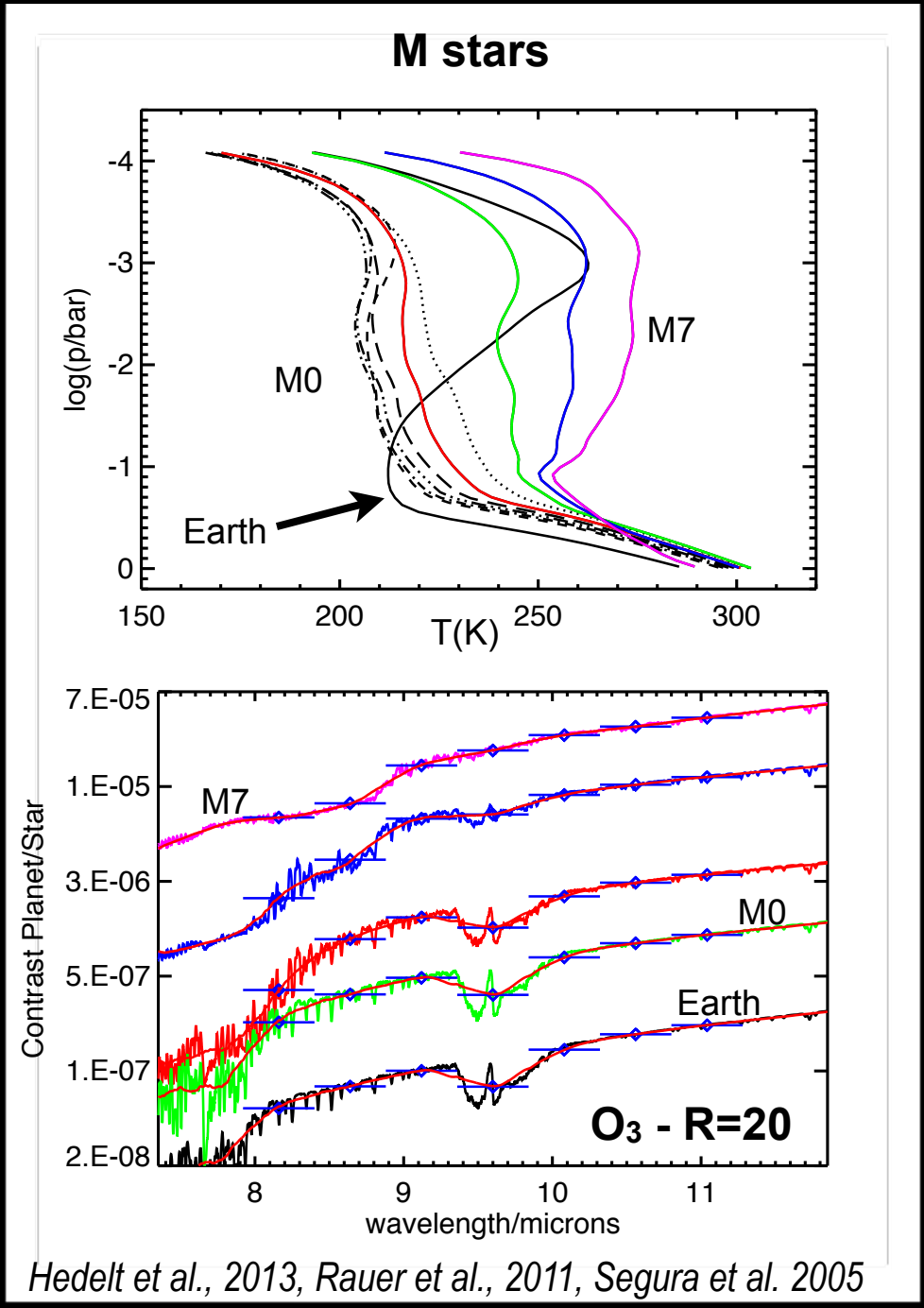


Hedelt et al., 2013, Rauer et al., 2011, Segura et al. 2006

Life → altered observables



Life → altered observables



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

Life → altered observables → Observer

instrumentation

Interpretation ?

Life

altered observables

instrumentation

Observer

Interpretation ?

Abiotic (photo)chemistry

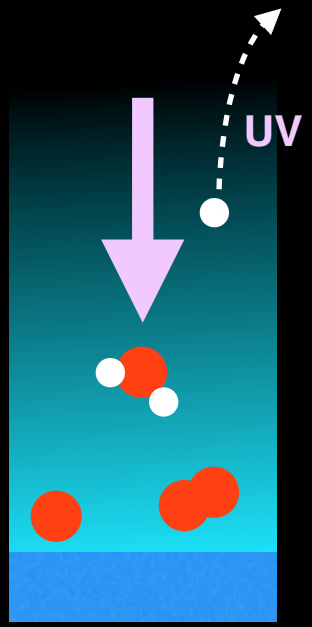
?

Life → altered observables → instrumentation → Observer

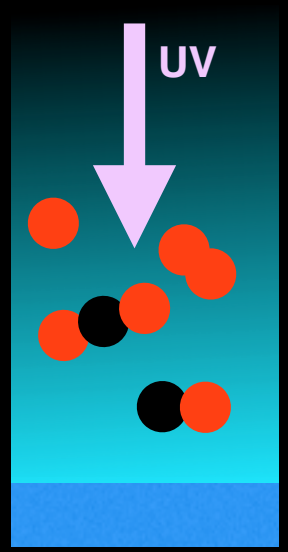
Interpretation ?

Abiotic (photo)chemistry → ?

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

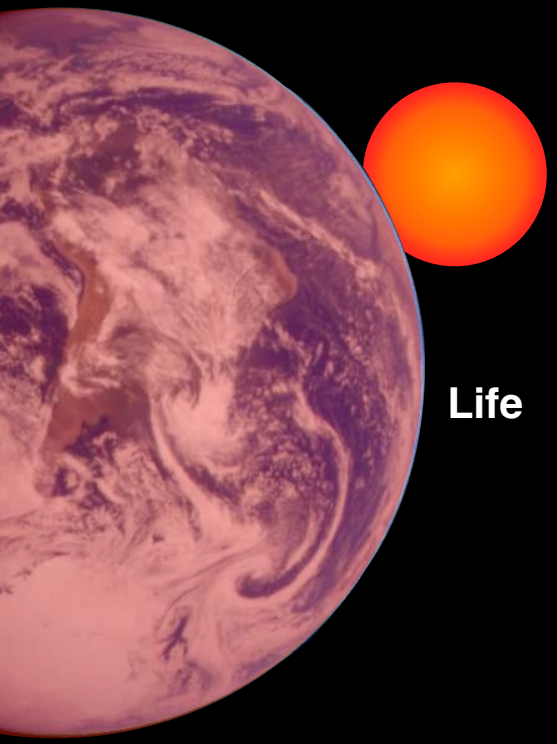


early Venus
Icy satellites



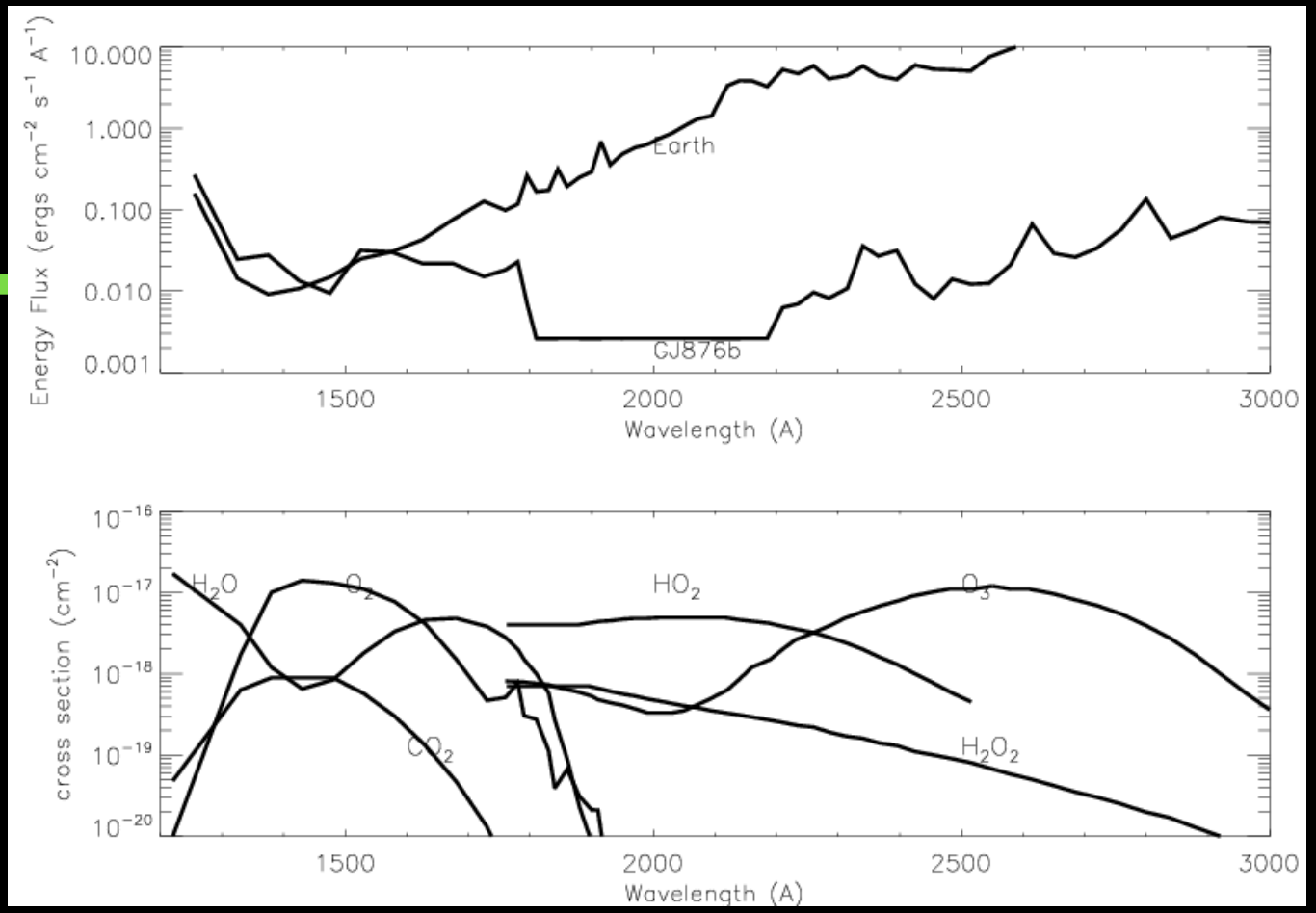
Mars
Venus

Life



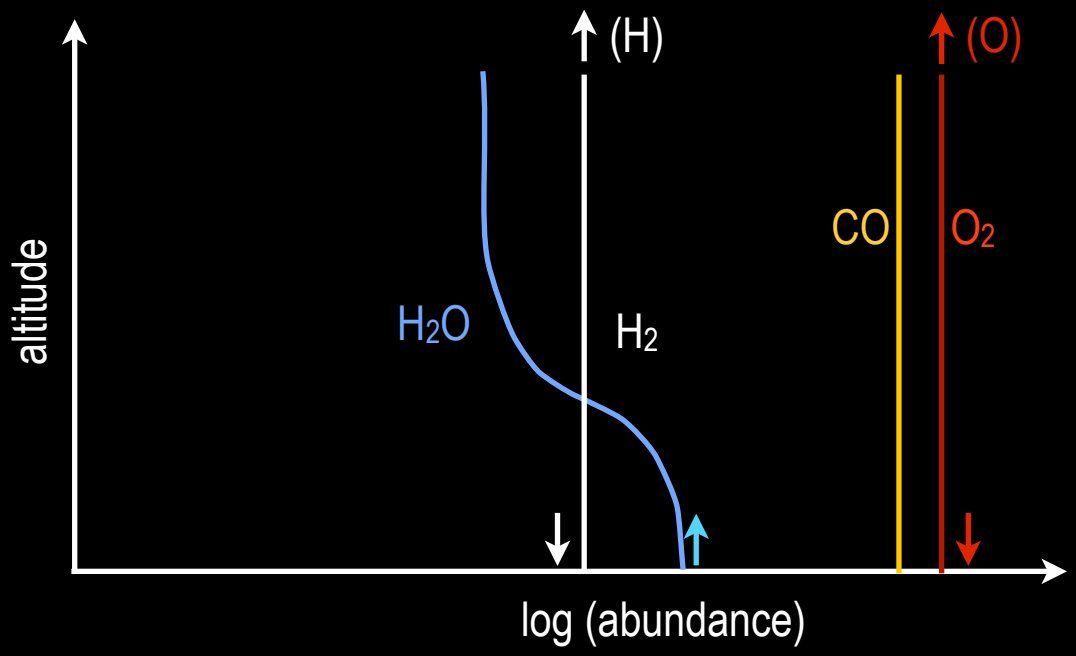
Life

altered observables

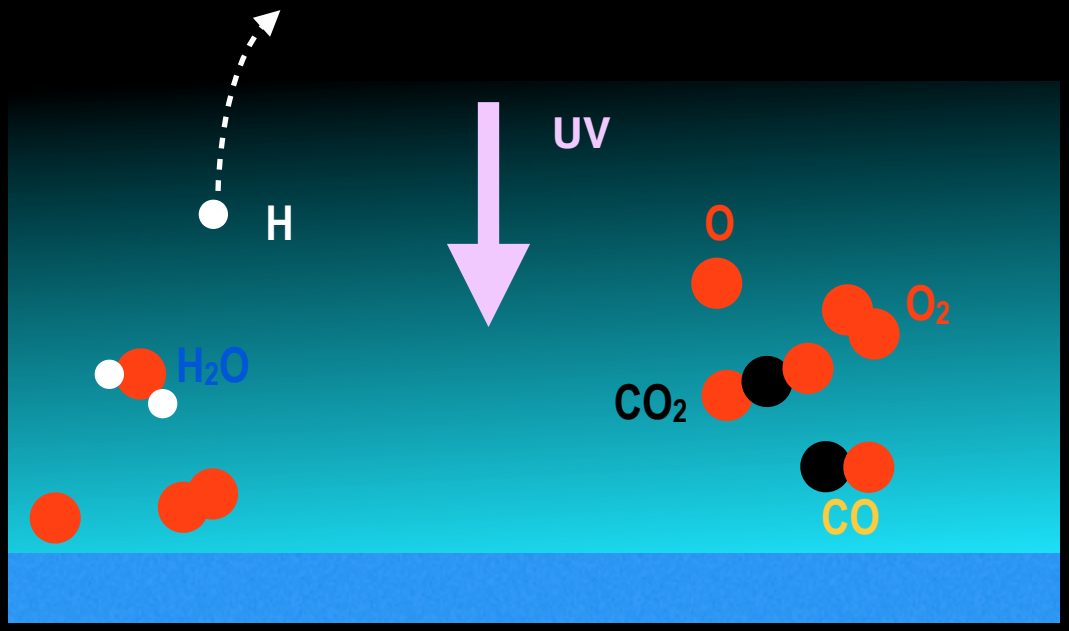


France et al. 2013 ,Tian et al. 2013

Abiotic formation of O2 in a Mars-like atmosphere



It also depends on the exchanges between
- **the atmosphere and space**
- **the atmosphere and the surface/interior**



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 comprehensive knowledge of the atmospheric elemental composition.

Life → altered observables → (instrumentation) → Observer

Interpretation ?

With some associations of species (for instance O_2 and CH_4, as suggested by Lovelock, and later Sagan) it may be possible to identify a disequilibrium without a full context.

In other cases, the anomaly is not thermodynamic. For instance a peculiar elemental fractionation. O_2 is the stable state of oxygen in an O-dominated mixture at room tempertaure (and in association with O_3 if UV irradiation). So the question becomes: why an O-rich atmosphere. There is no such thing as an out-of-equilibrium elemental composition

some concluding remarks

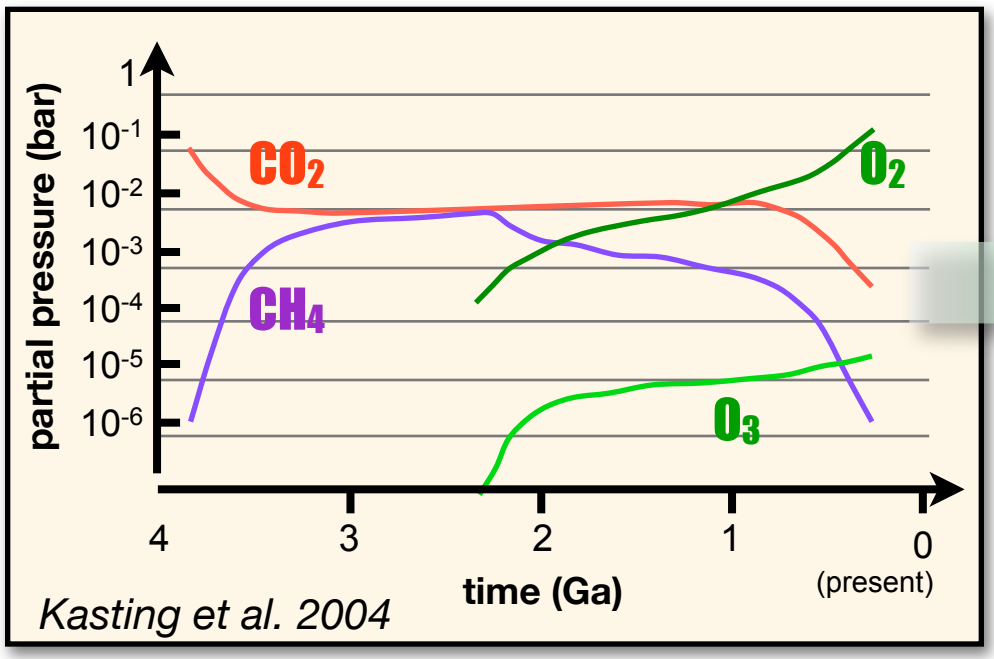
- attributing a spectral/chemical anomaly to the presence of life (if possible) will require many multiwavelength high-snr observations from different instruments

- we need to observe/study many different planets (in/out the HZ, gaseous to rocky) to understand the processes controling their diversity

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

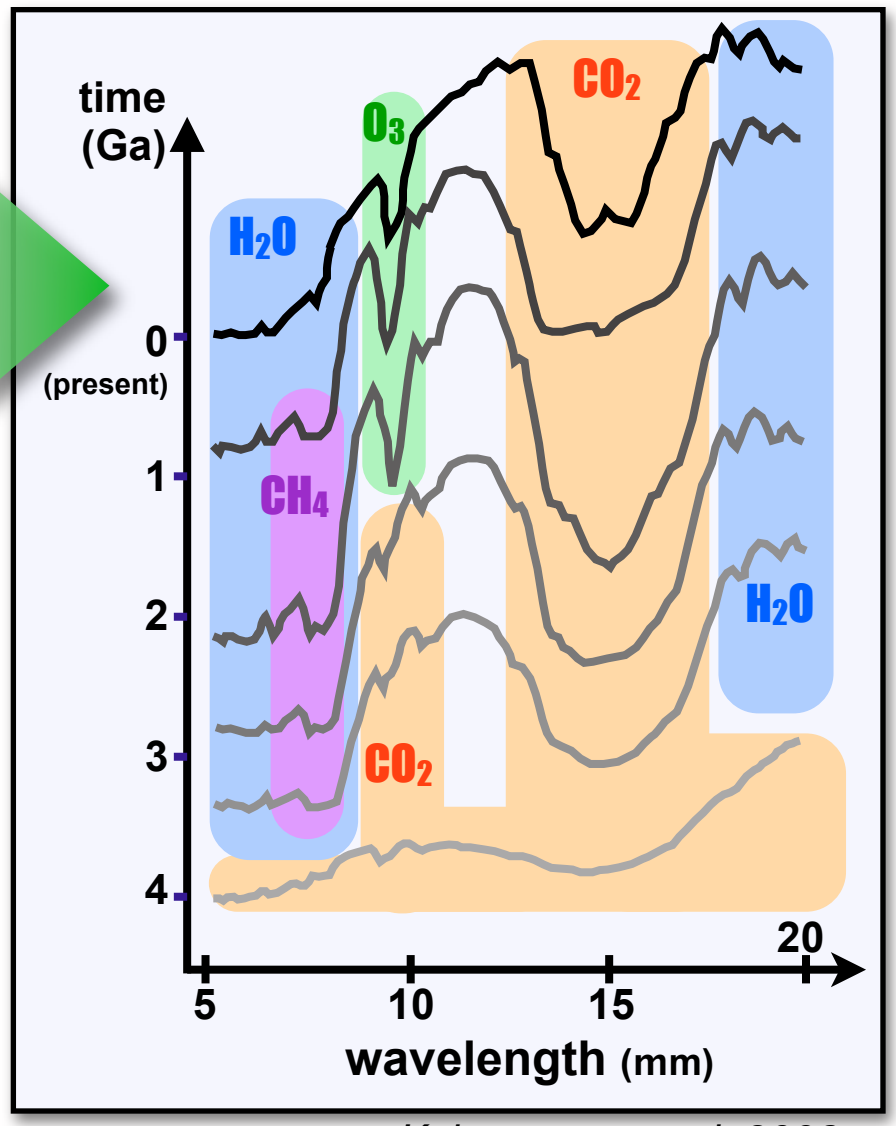
Earth in time

From atmospheric evolution...



Kasting et al. 2004

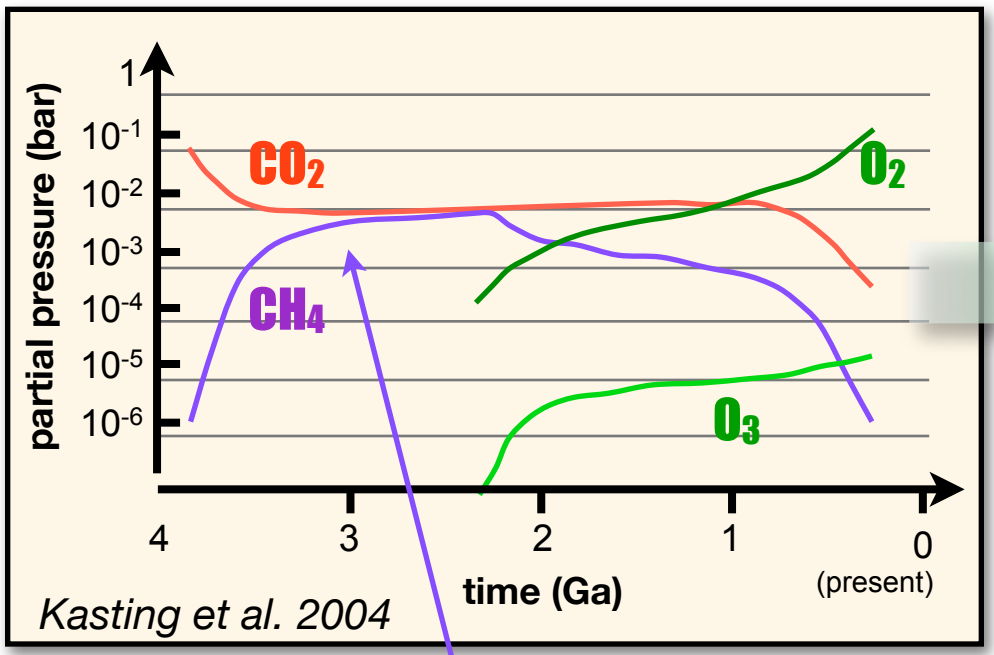
... to spectral evolution



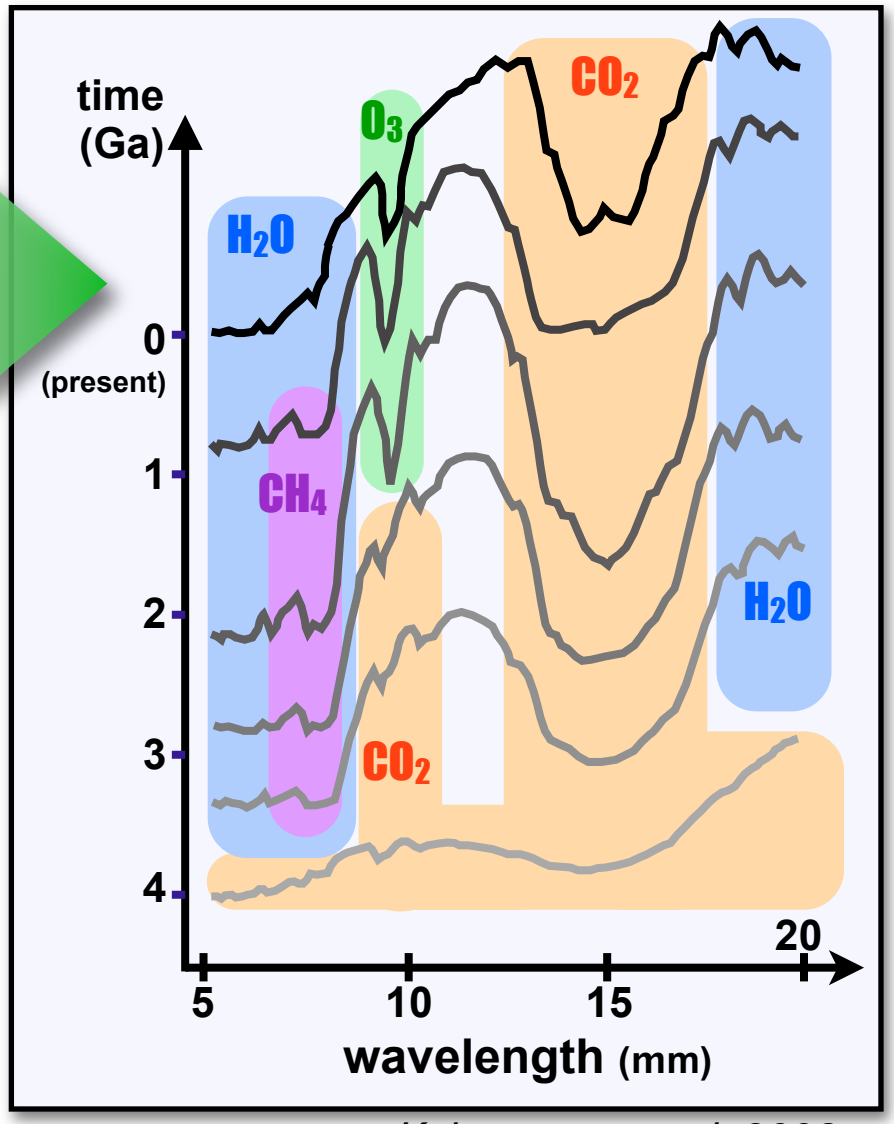
Kaltenegger et al. 2006

Earth in time

From atmospheric evolution...



... to spectral evolution



Kaltenegger et al. 2006

An era of biogenic methane before the rise of oxygen ?