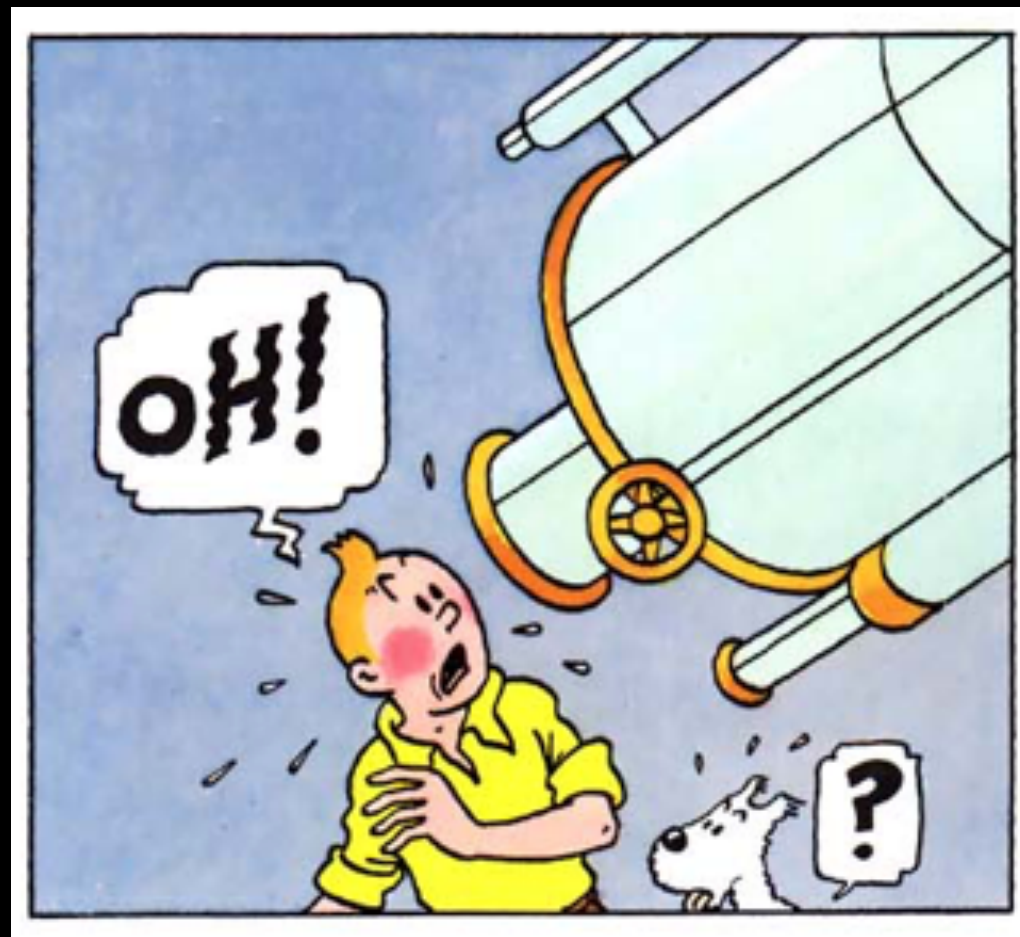
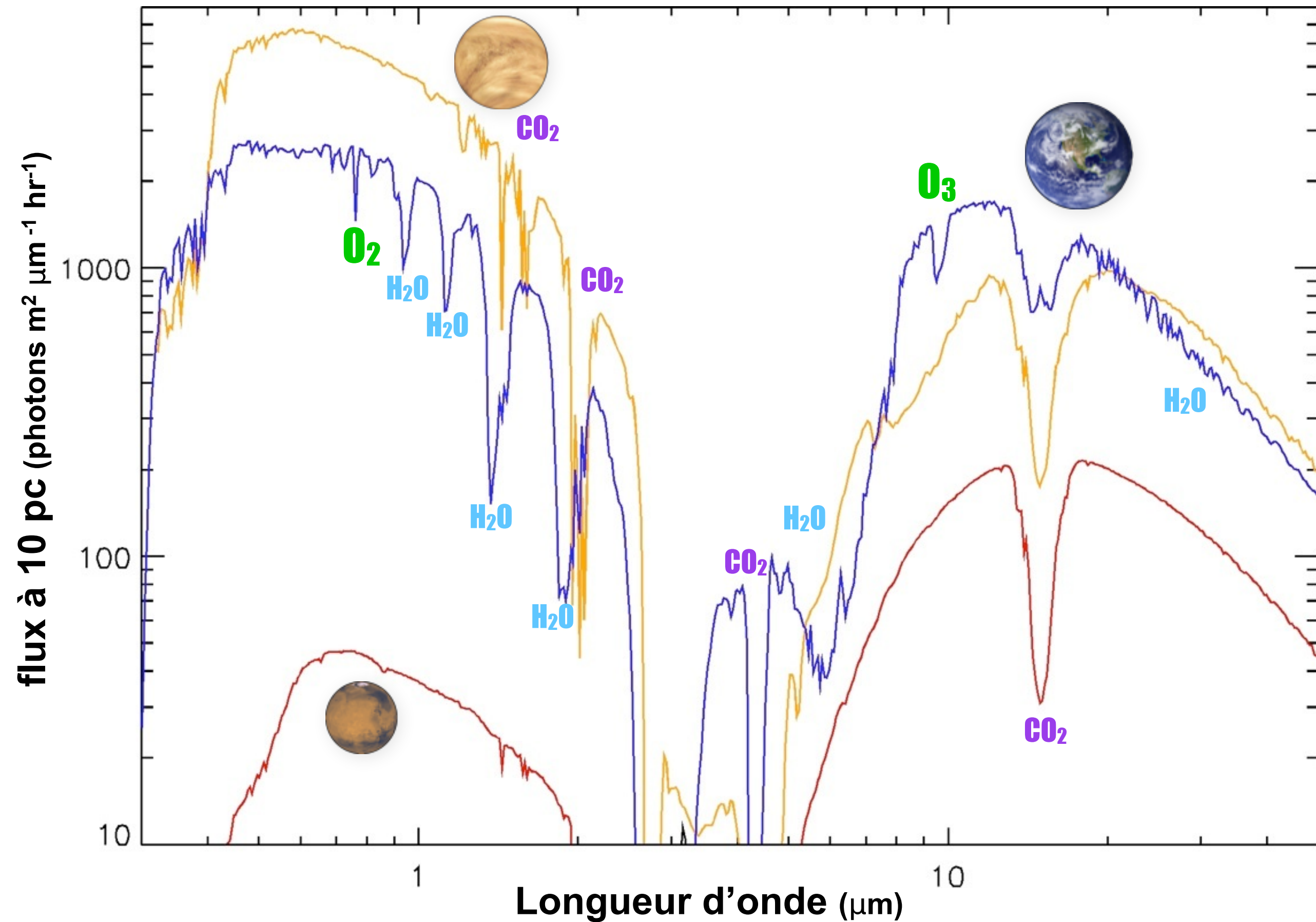


Est-on sur le point de (pouvoir) trouver de la vie sur une exoplanète ?

Le concept de biosignature atmosphérique

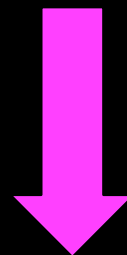
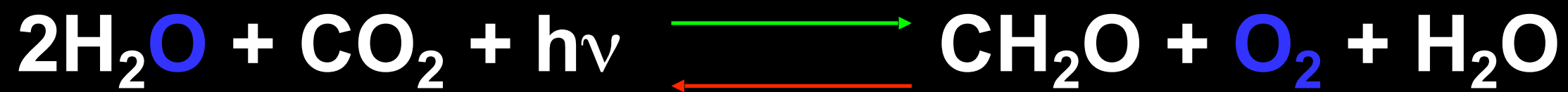


Selsis & Tinetti (2005)



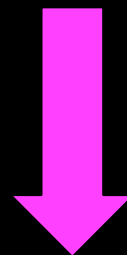
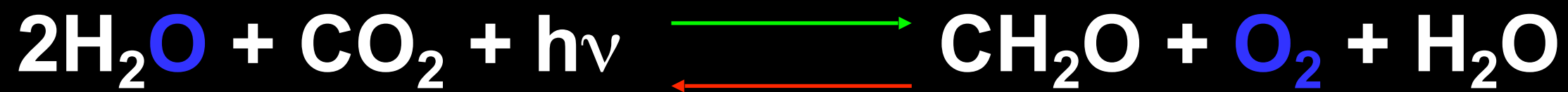


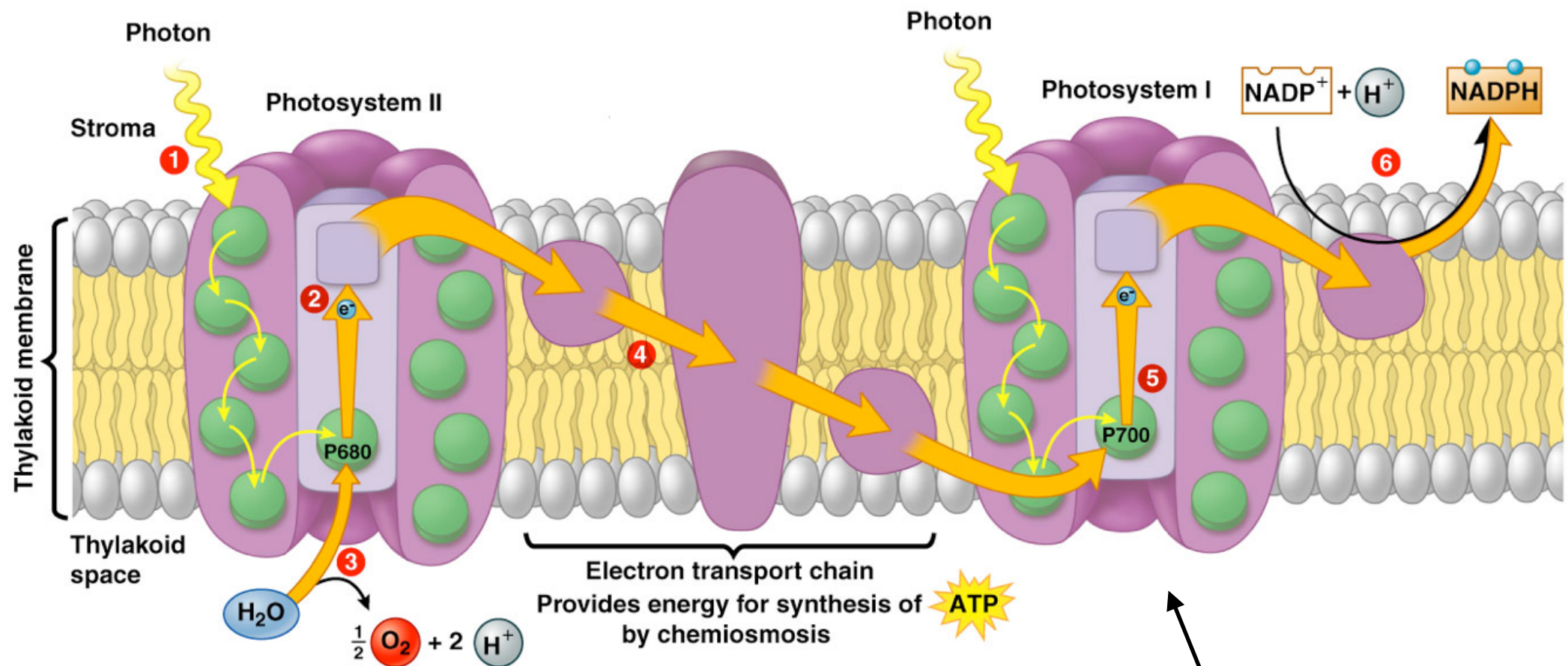
x10¹²



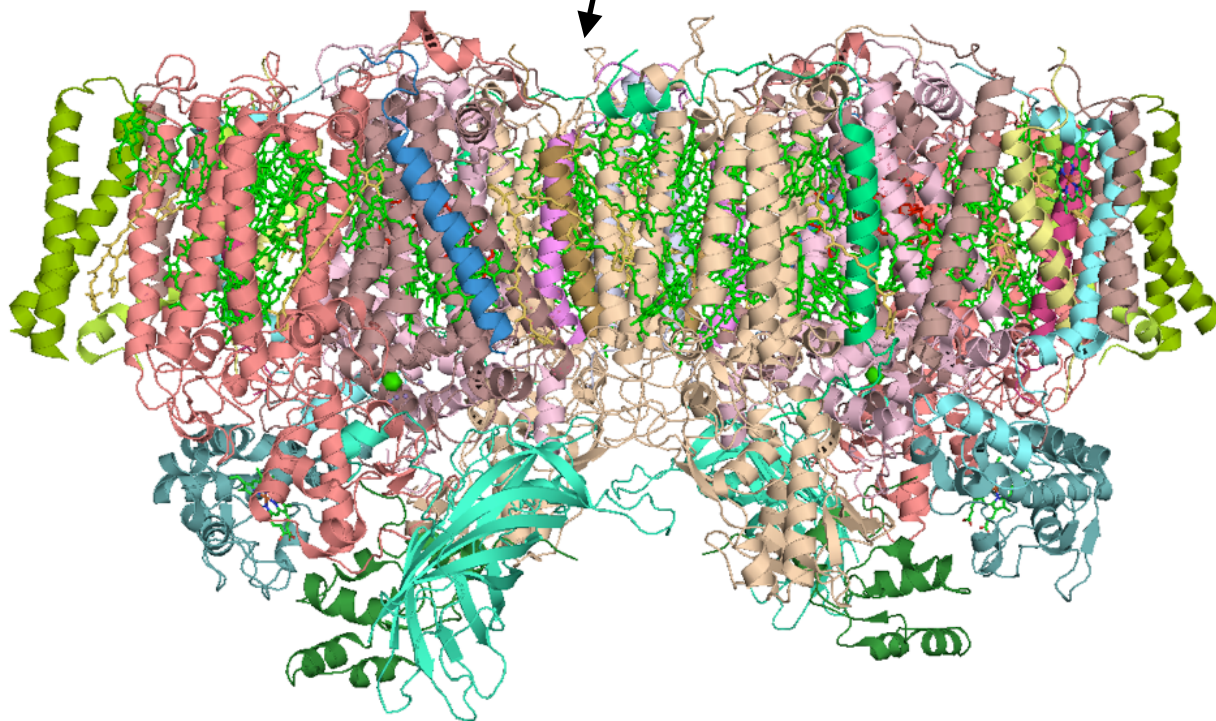


x10¹²

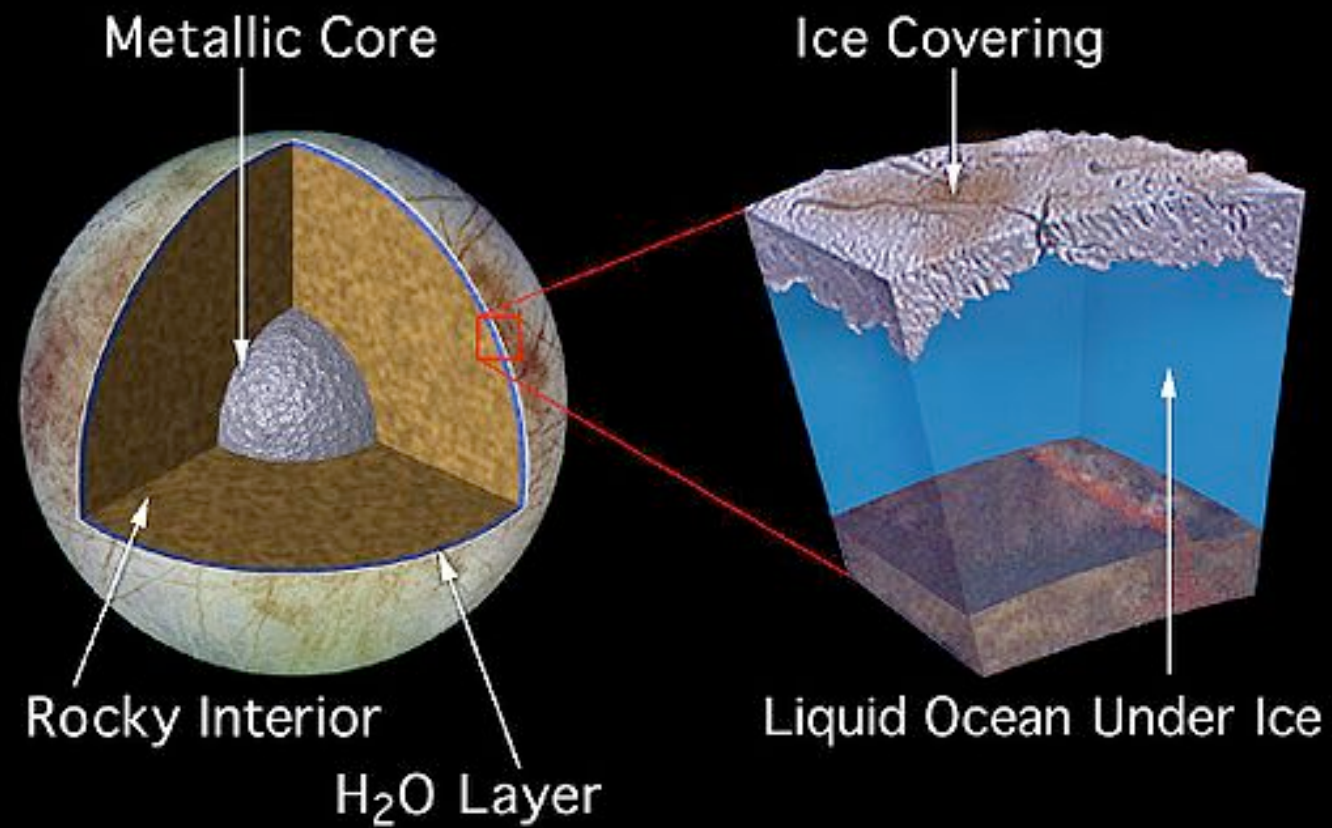




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Le concept de zone *habitable* est lié à celui de biosignature



Habitabilité

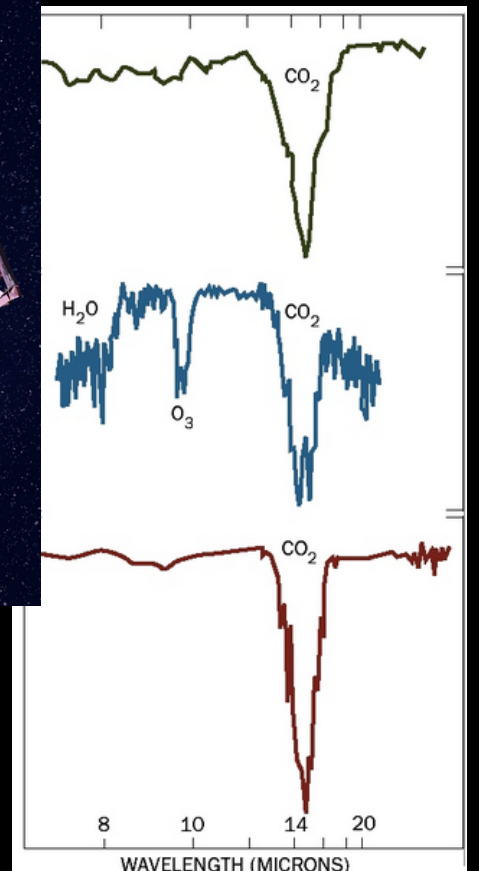
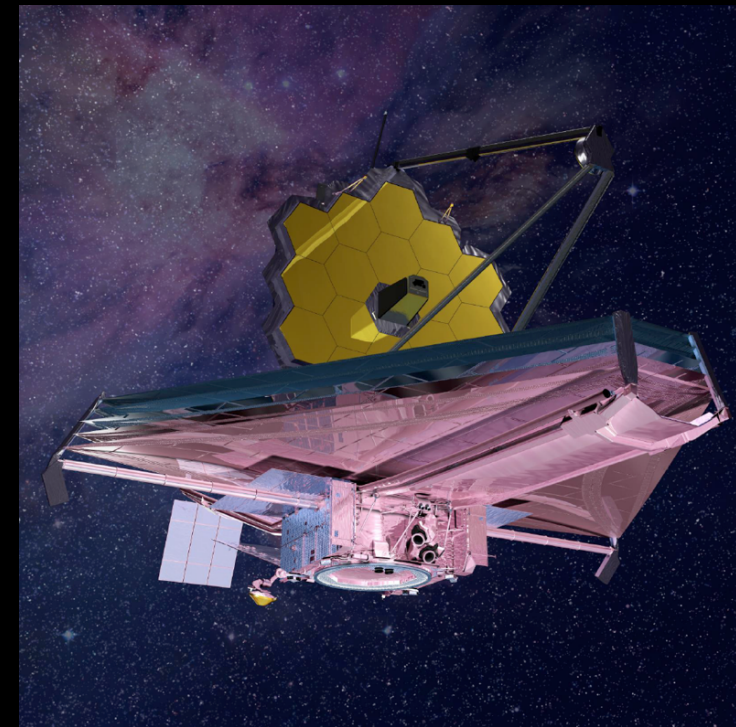
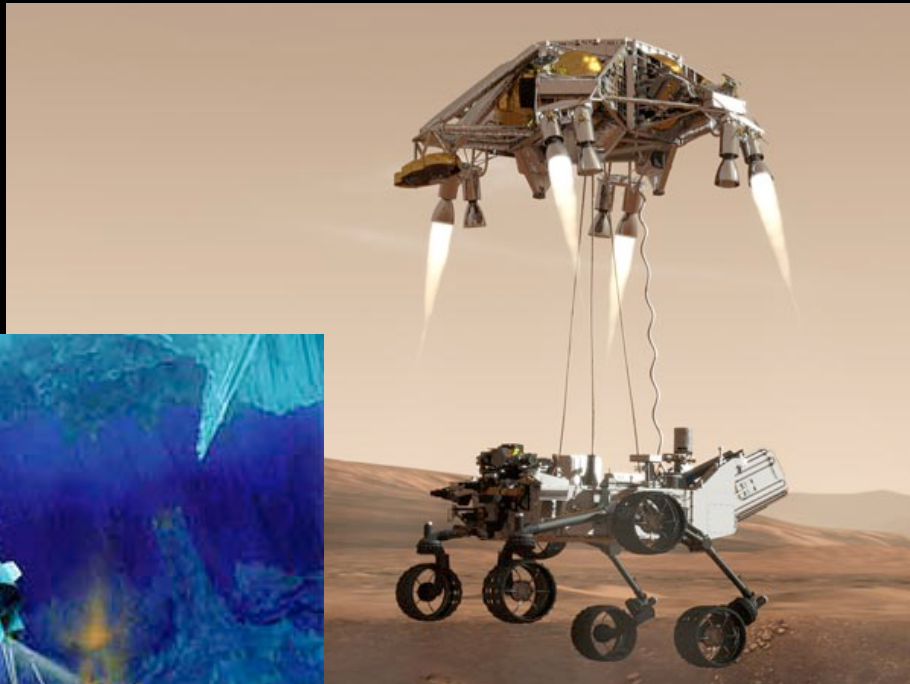
Où la vie peut exister ou Où l'on peut trouver la vie

Habitabilité

Où la vie peut exister ou Où l'on peut trouver la vie

système solaire

exoplanètes



**C'est la zone où une photosynthèse est possible
(eau et rayonnement stellaire disponibles simultanément)**

**C'est la zone privilégiée pour une future recherche de
signatures spectrales atmosphériques liées à la vie**



200 gC/yr/m²

< 56 gC/Myr/m²



*« 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/m²

< 56 gC/Myr/m²



Habitable Zone



~~Habitable Zone~~

Hunting Zone

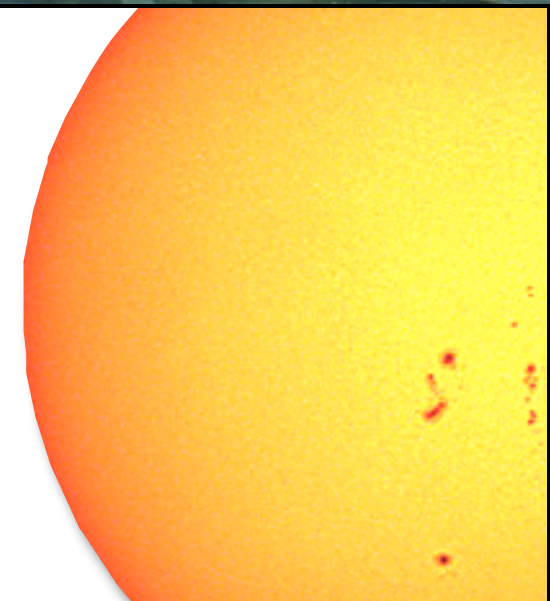
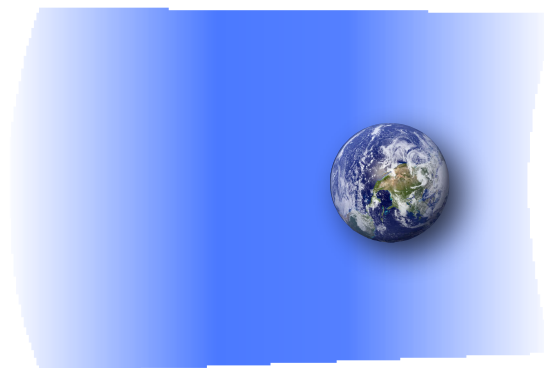
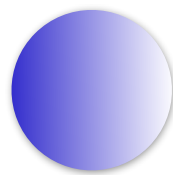


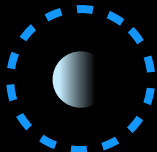
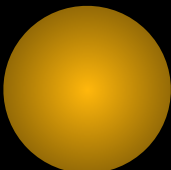
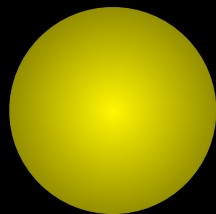
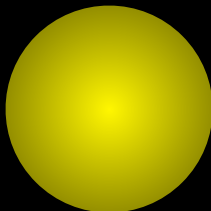
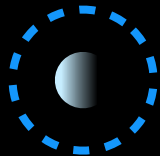
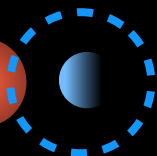
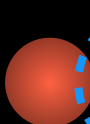
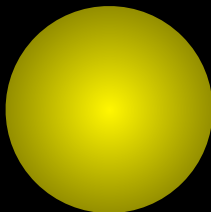
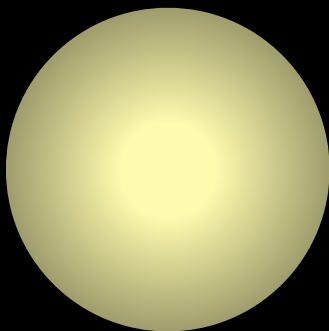
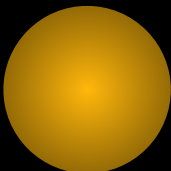
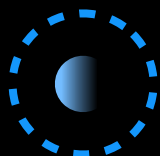
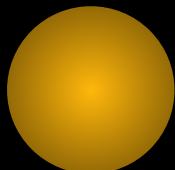
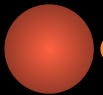
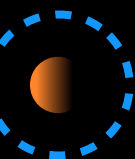
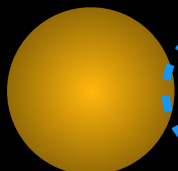
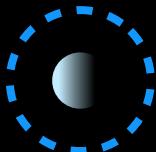
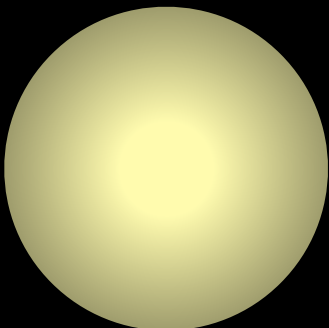
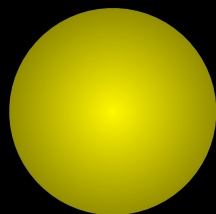
~~Habitable Zone~~

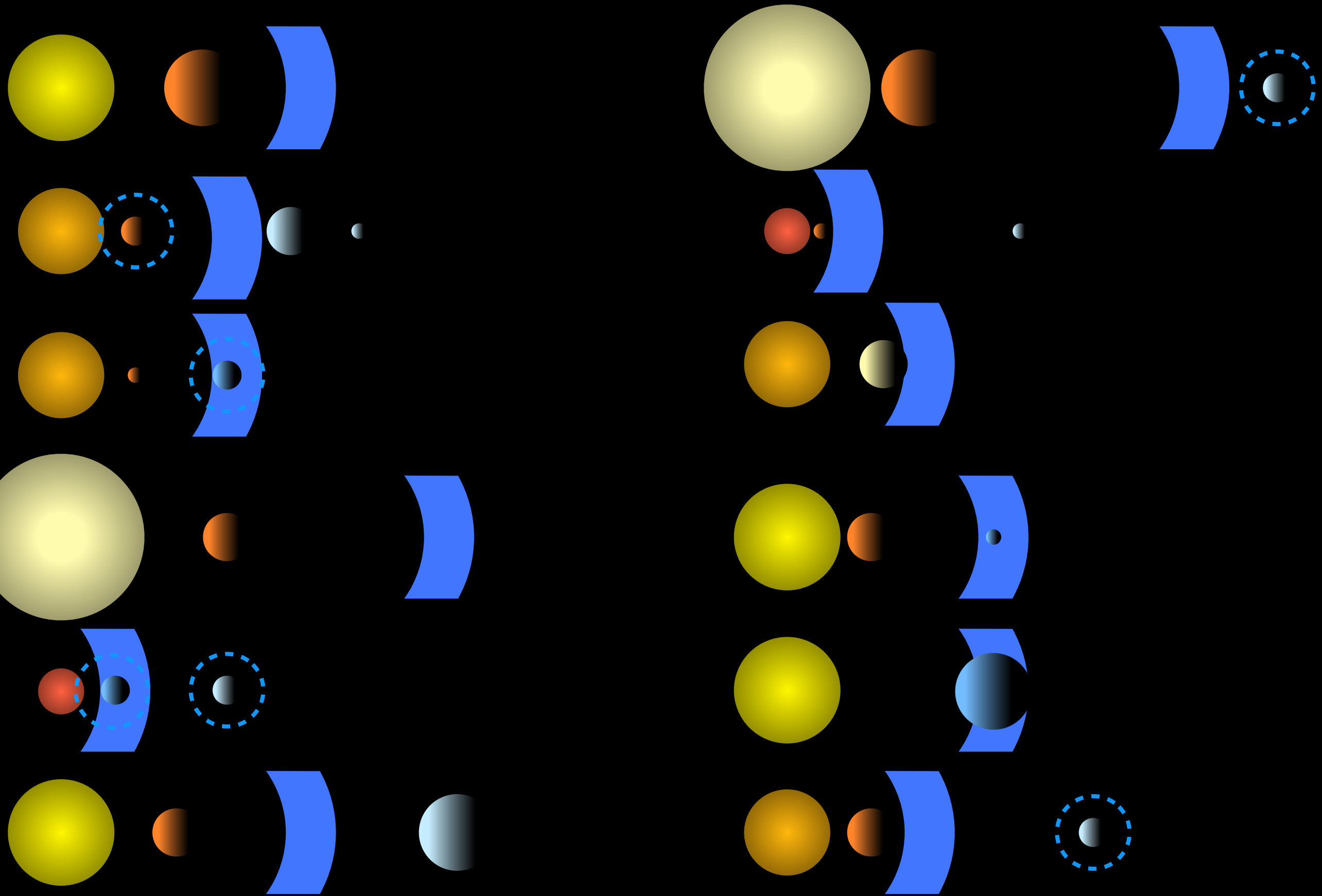
Hunting Zone

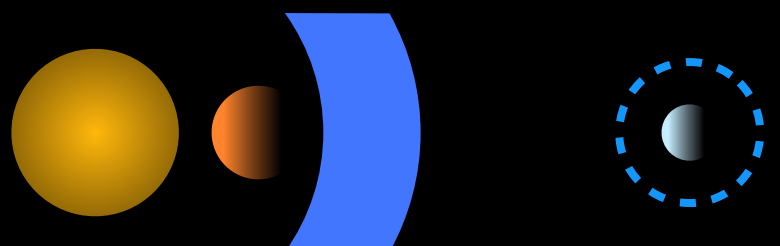
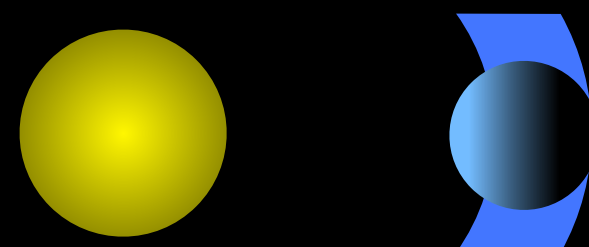
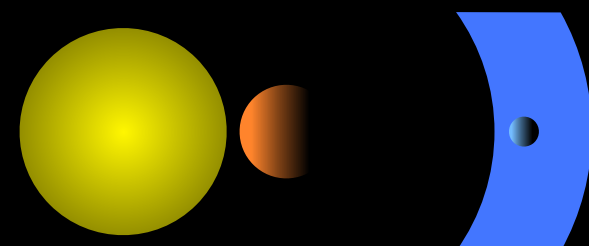
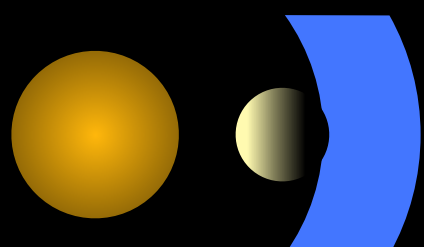
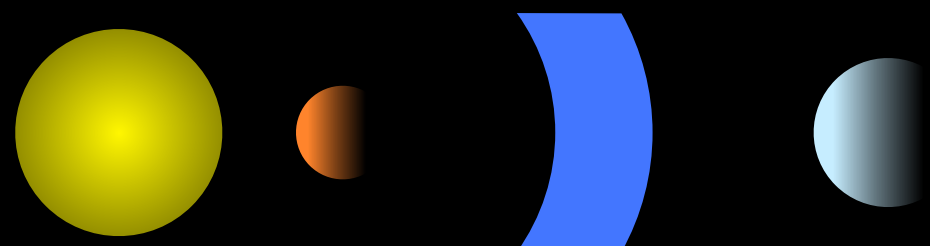
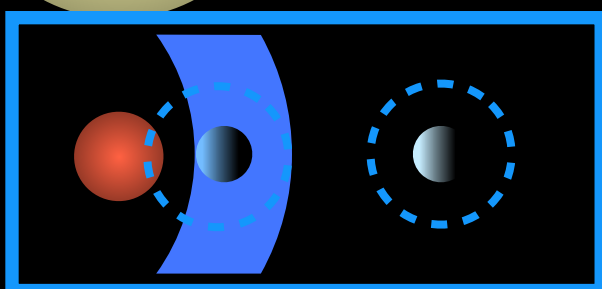
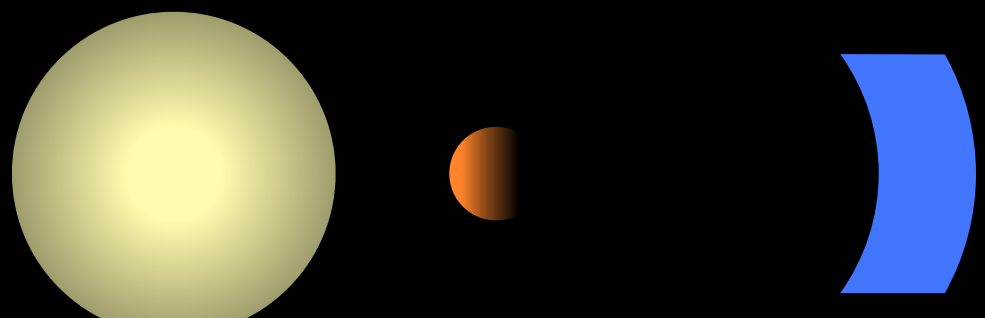
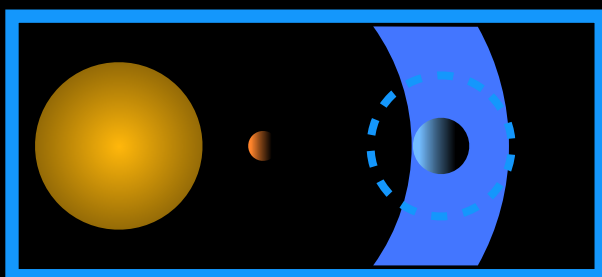
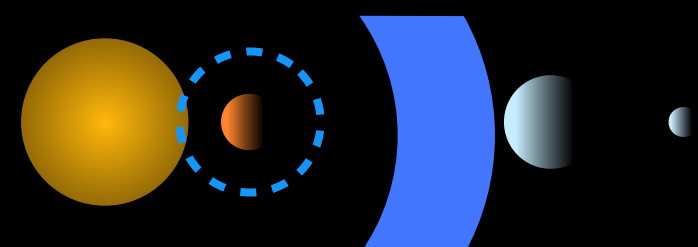
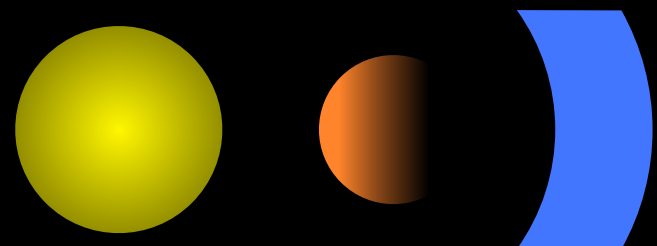


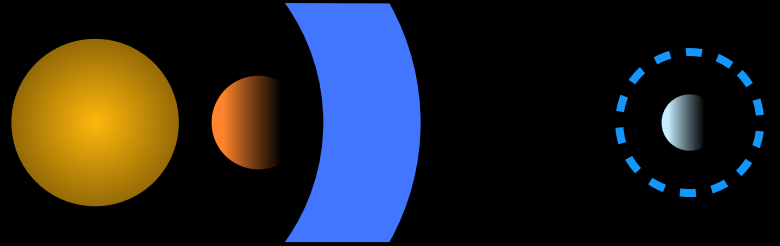
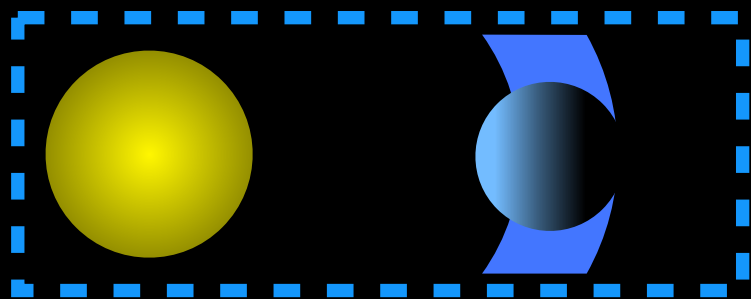
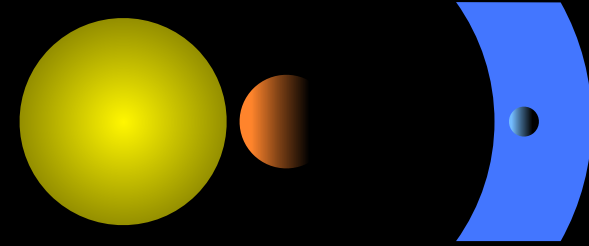
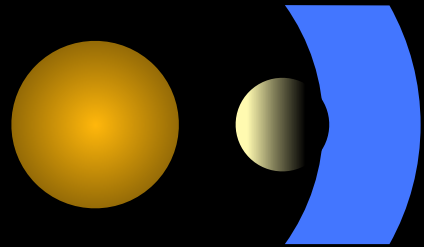
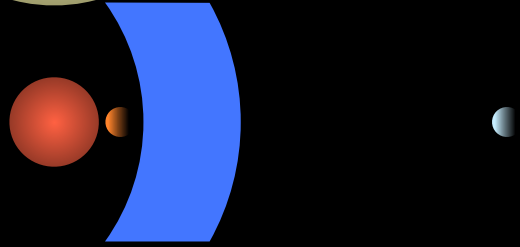
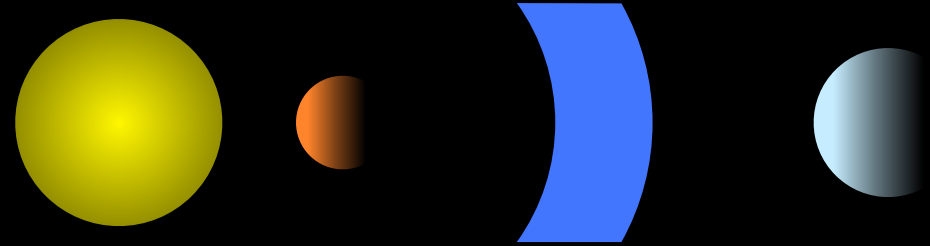
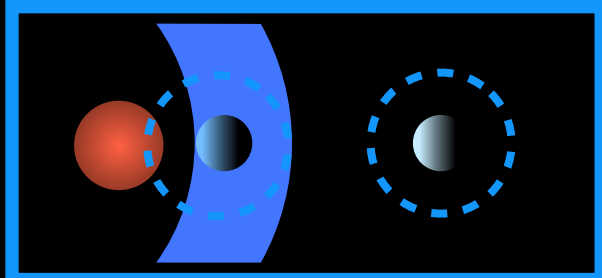
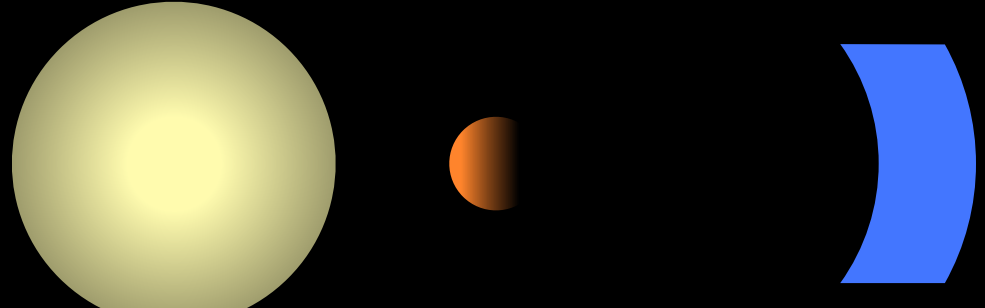
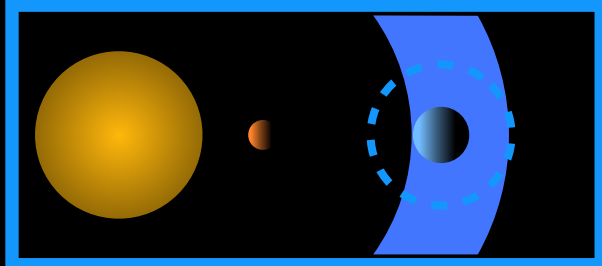
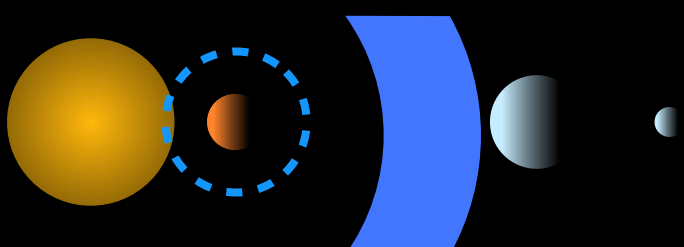
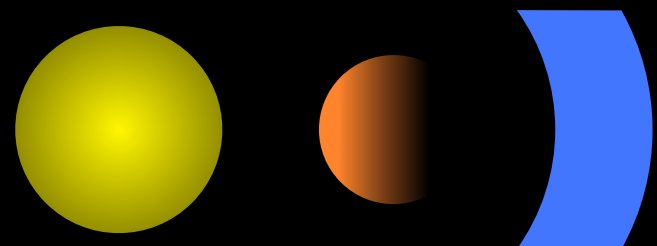
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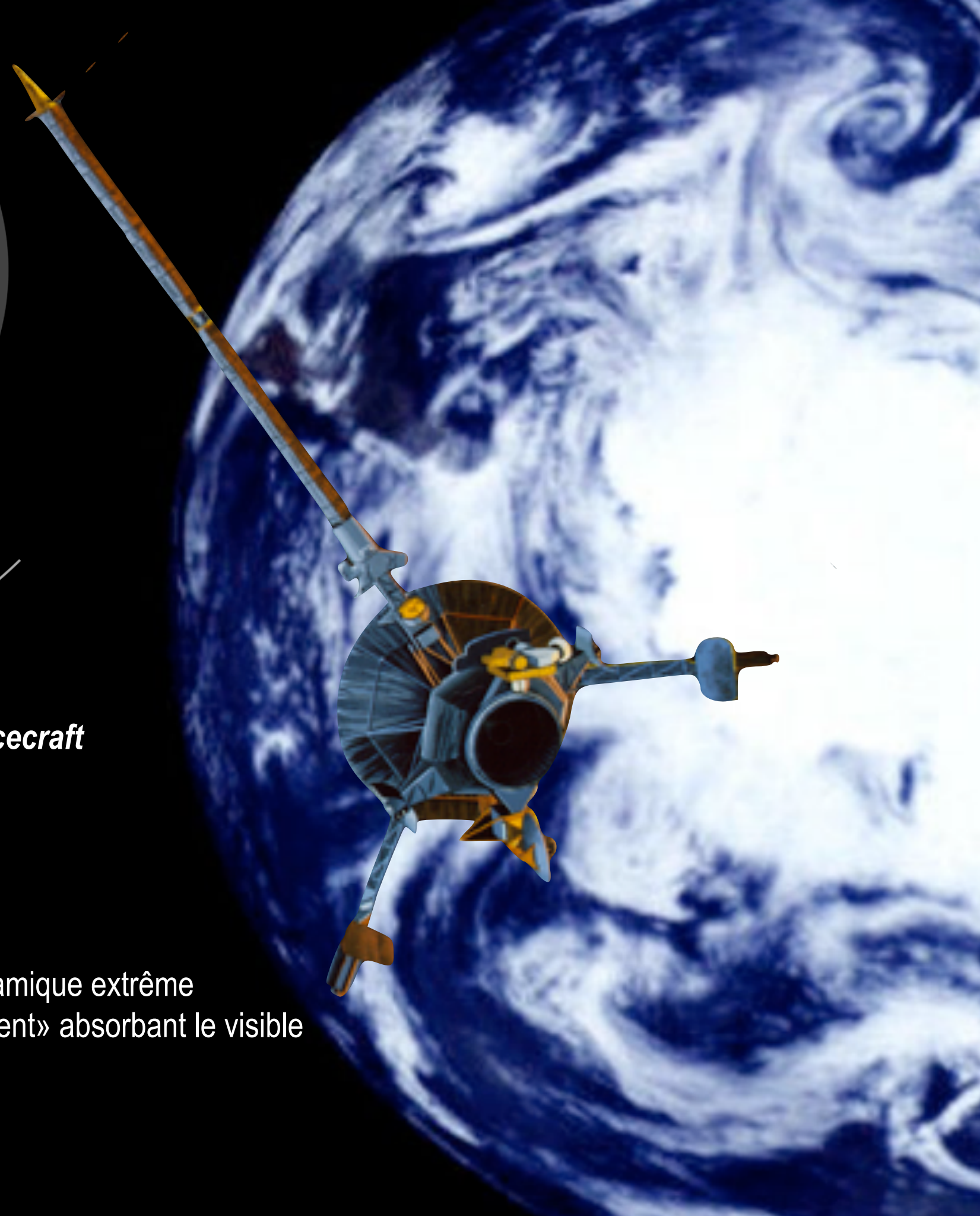
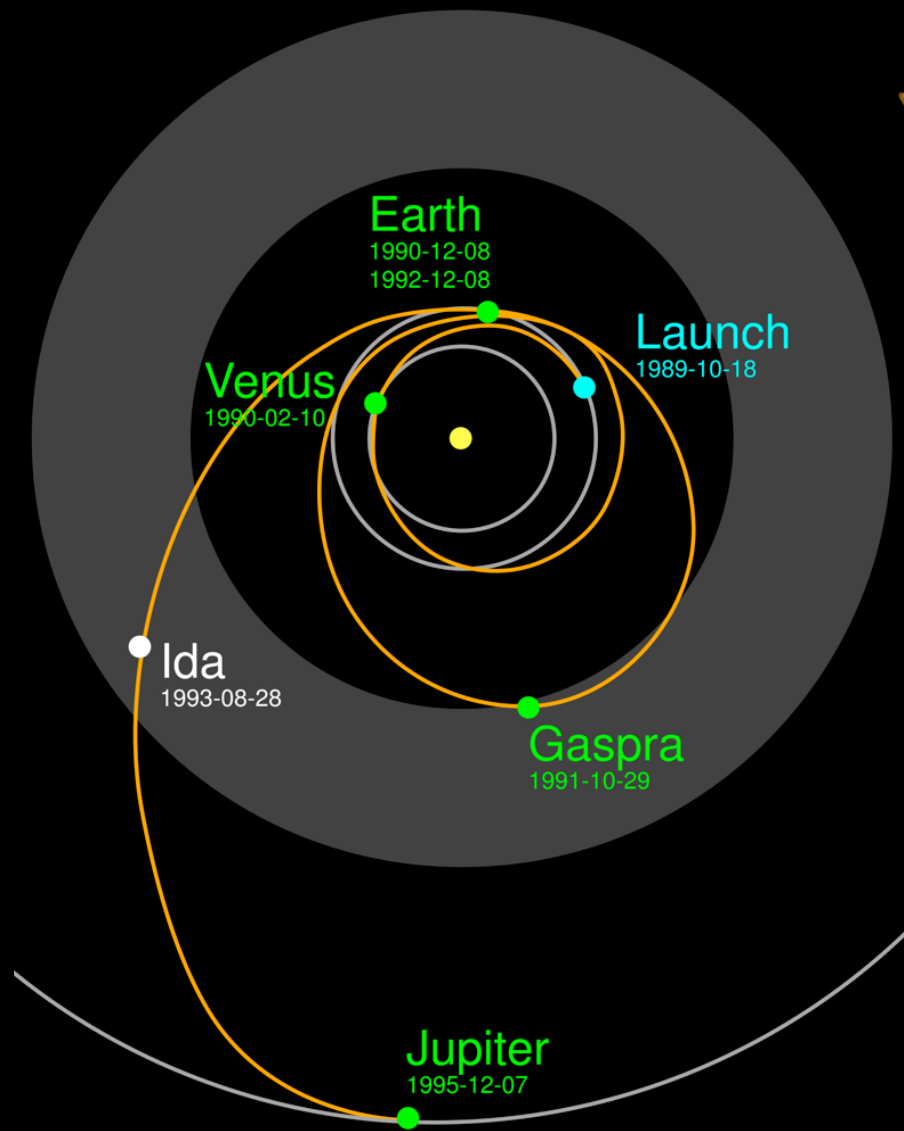








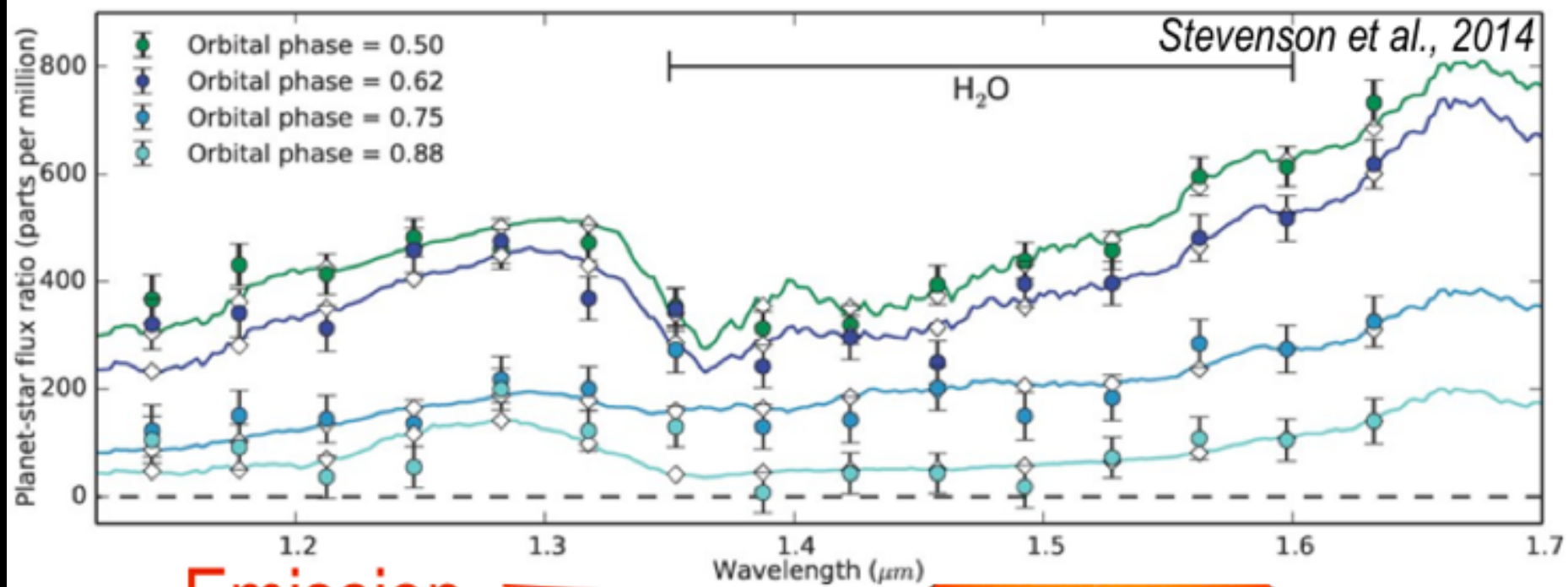




A search for life on Earth from the Galileo spacecraft
1993, Sagan et al.

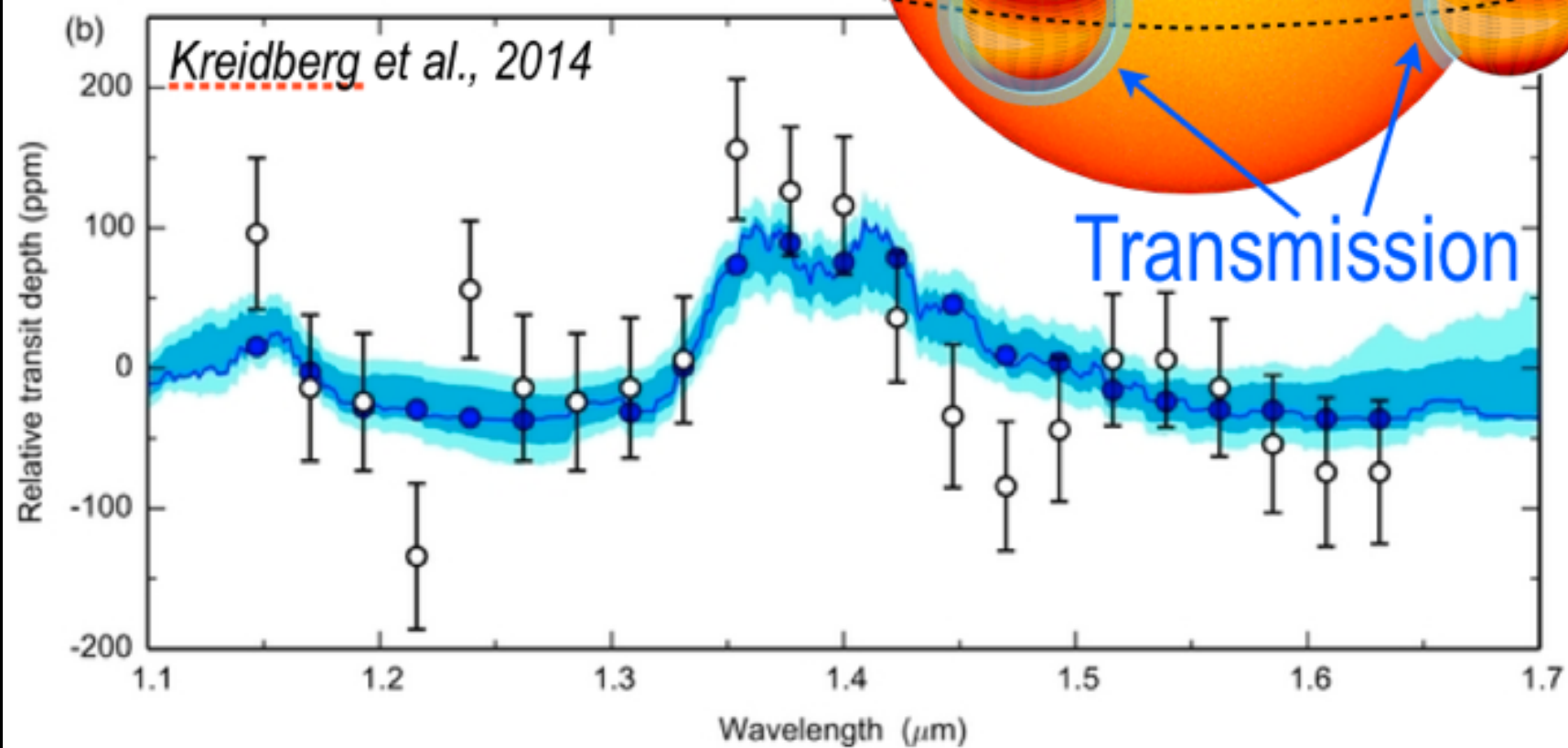
Survol de la Terre en décembre 1990.

- atmosphère riche en oxygène
- contient du méthane en déséquilibre thermodynamique extrême
- couverture partielle des continents par un «pigment» absorbant le visible
- signaux radios artificiels



Emission

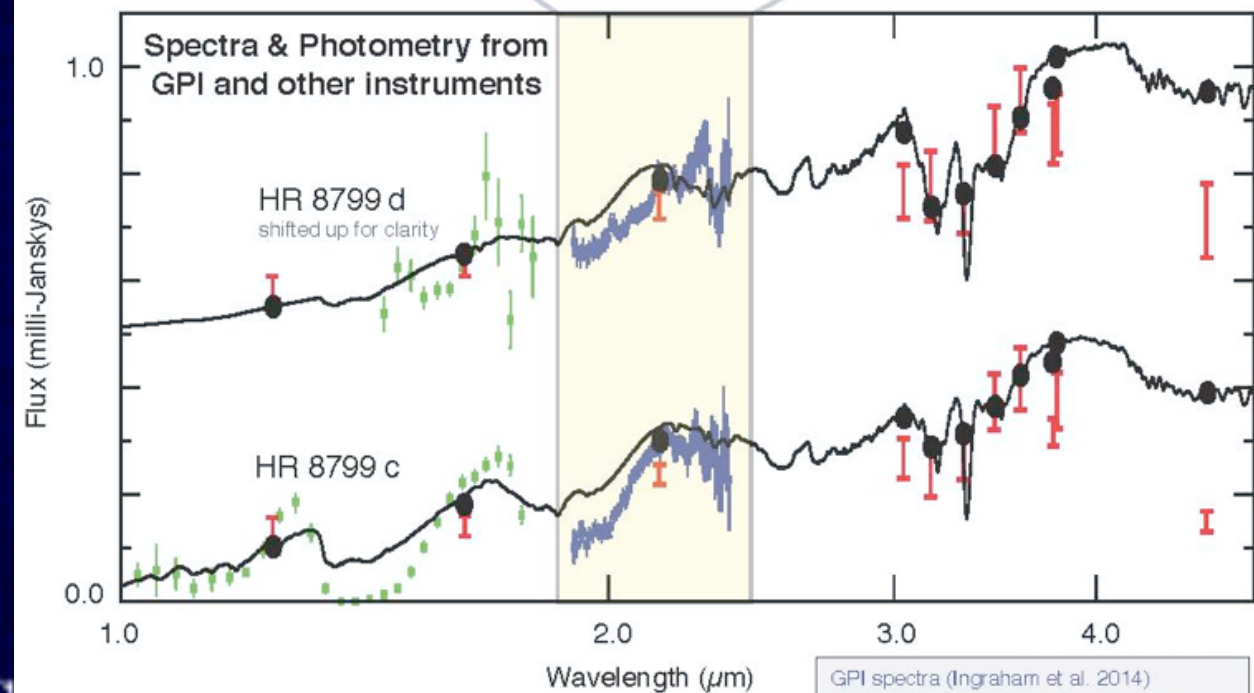
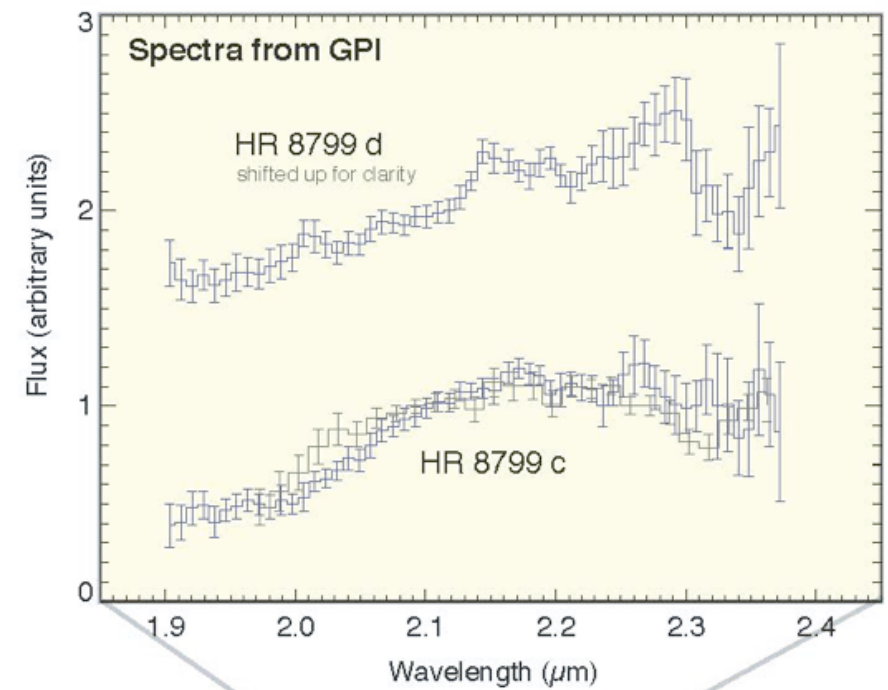
WASP 43b



HR 8799: 4 *bébés Jupiters*

2009-08-26

20 au

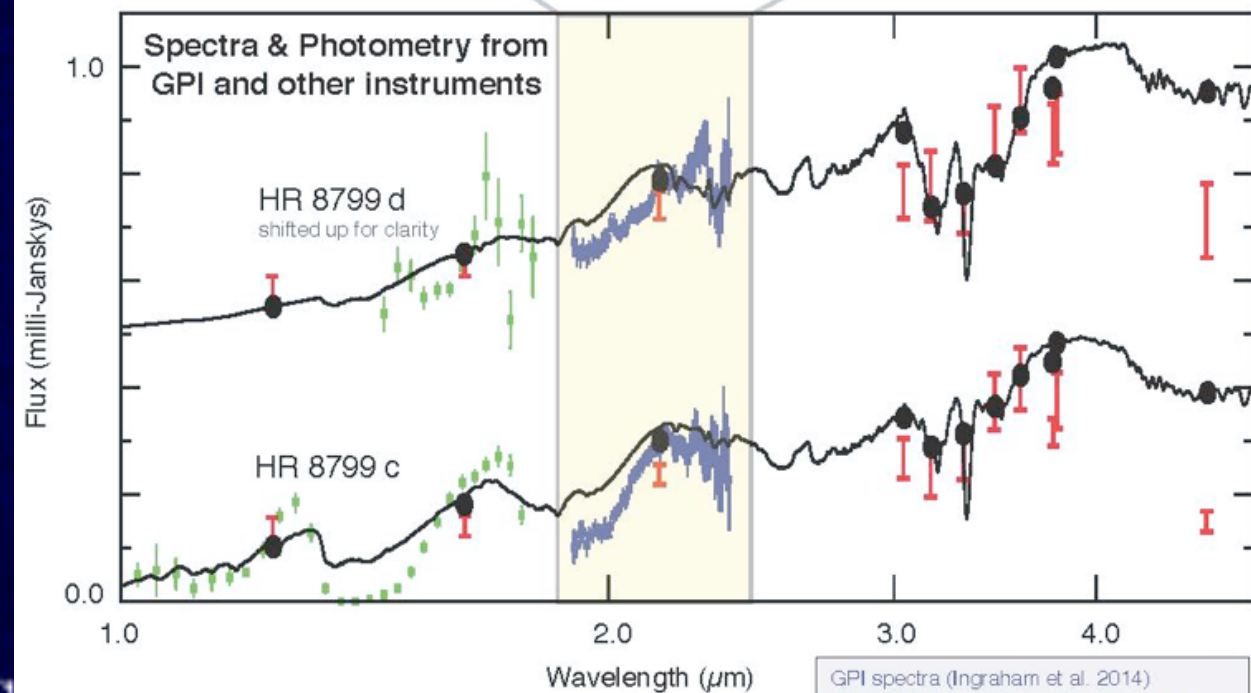
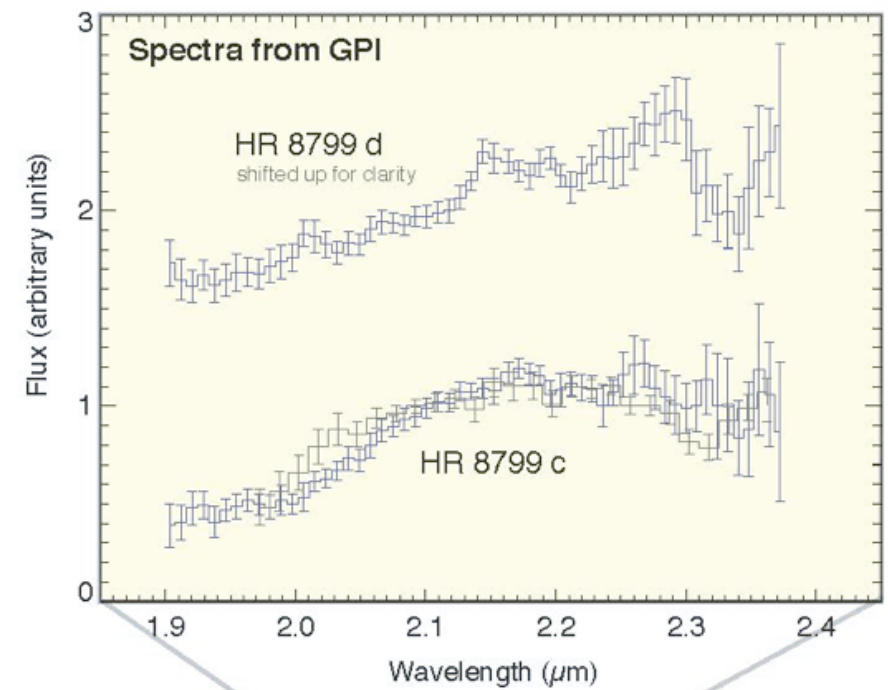


GPI spectra (Ingraham et al. 2014)
Spectra from Oppenheimer et al. (2013)
Photometry compiled in Skemer et al. 2014
Cloudy atmosphere models

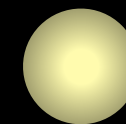
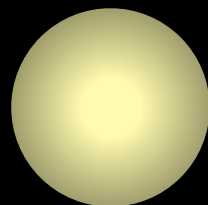
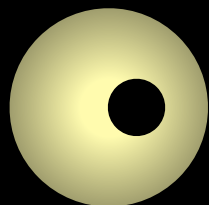
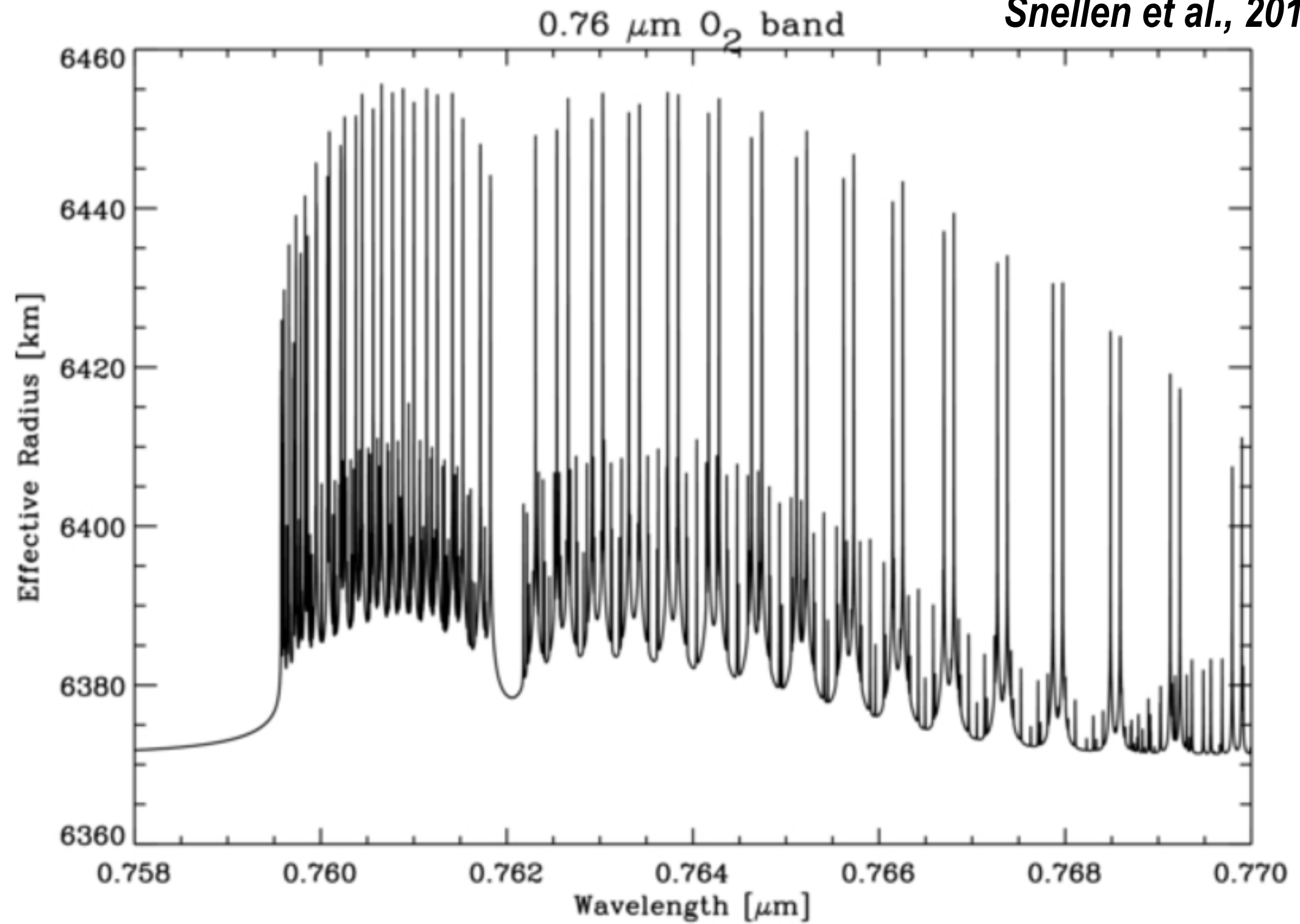
HR 8799: 4 *bébés Jupiters*

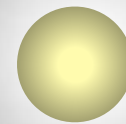
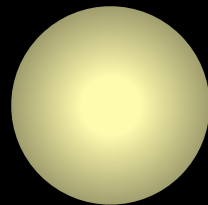
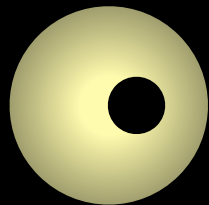
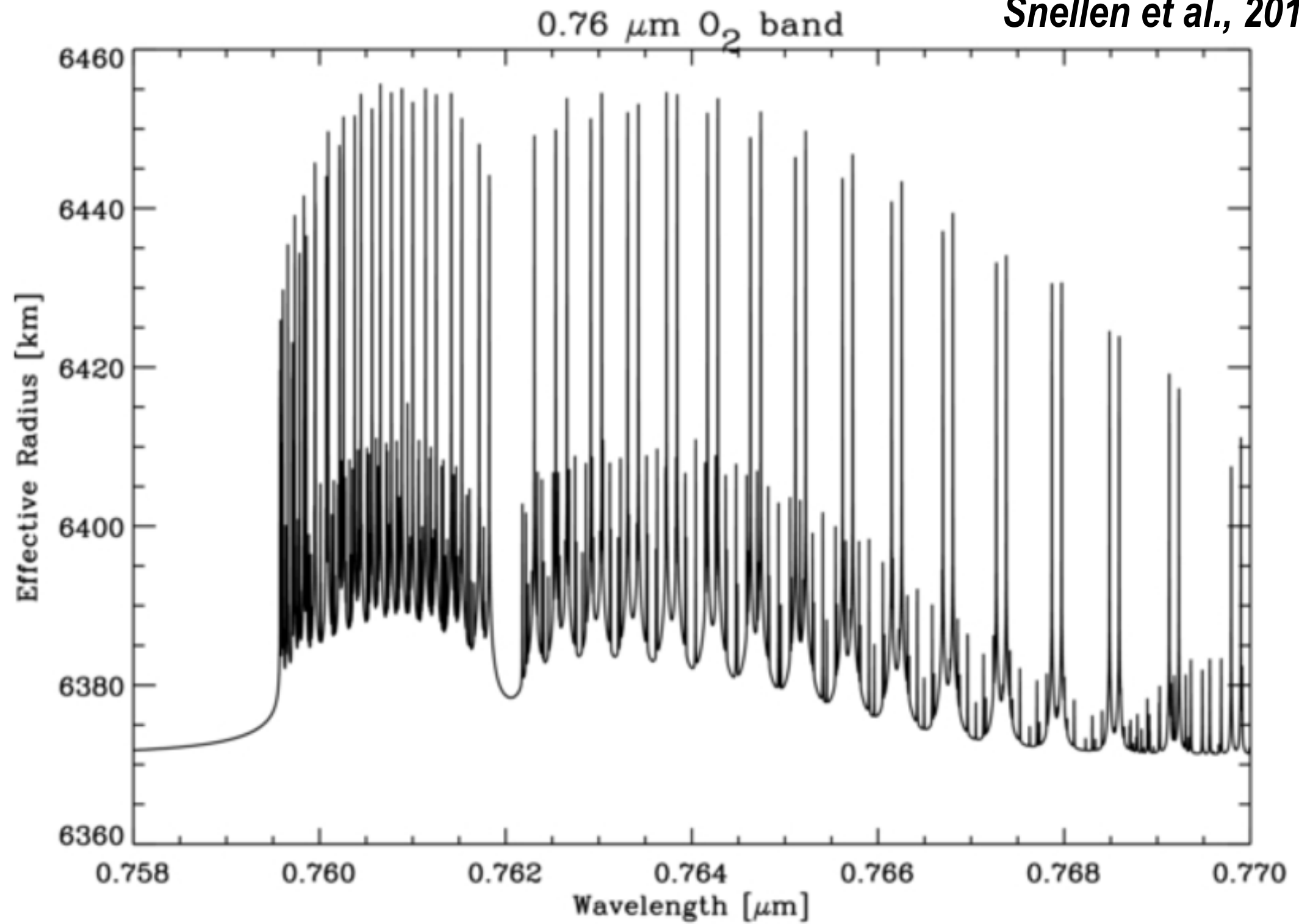
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GPI spectra (Ingraham et al. 2014)
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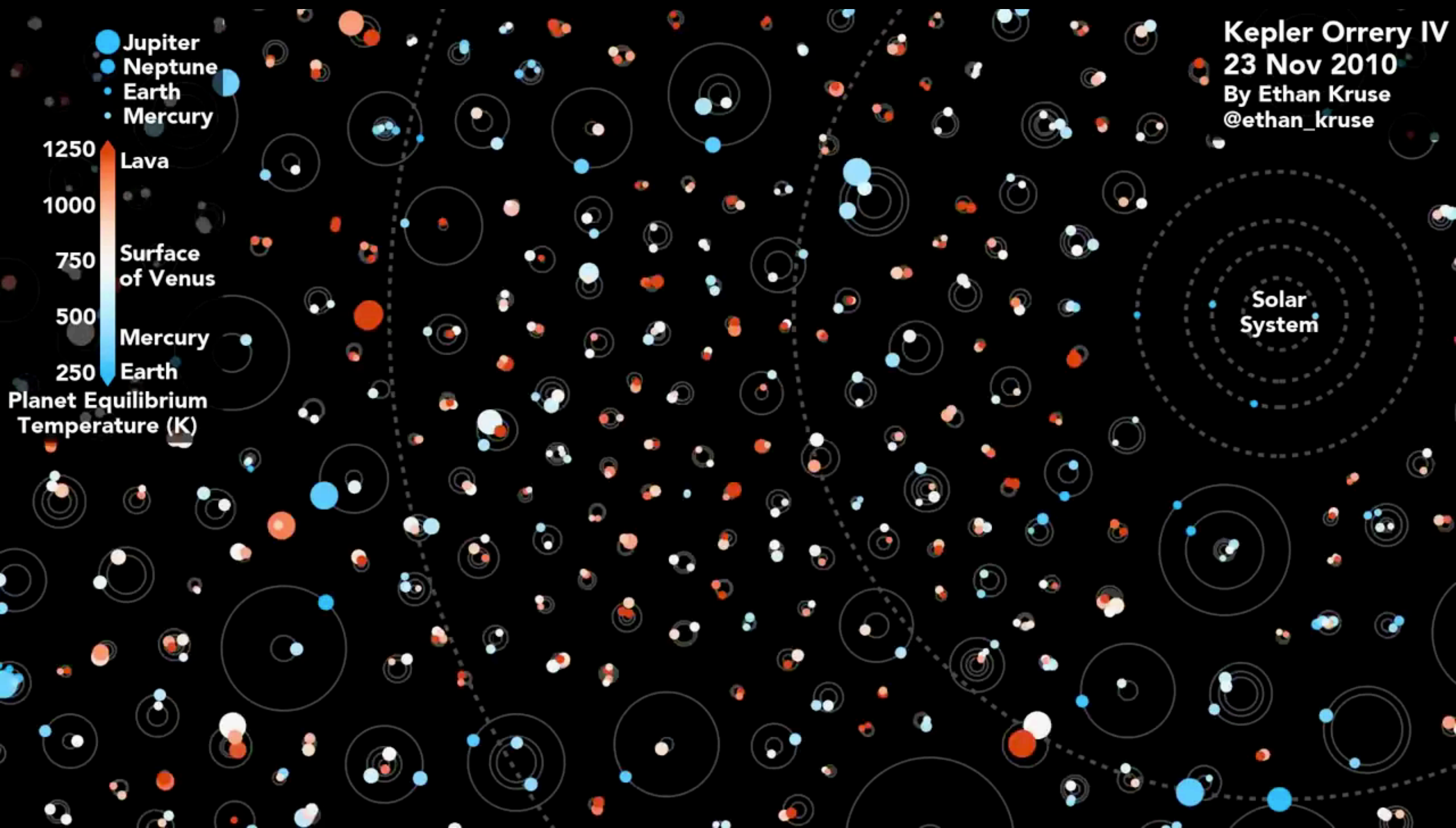
- 4.5 Gyr
- étoile G
- M-R
- architecture de système particulière

Kepler Orrery IV

23 Nov 2010

By Ethan Kruse

@ethan_kruse

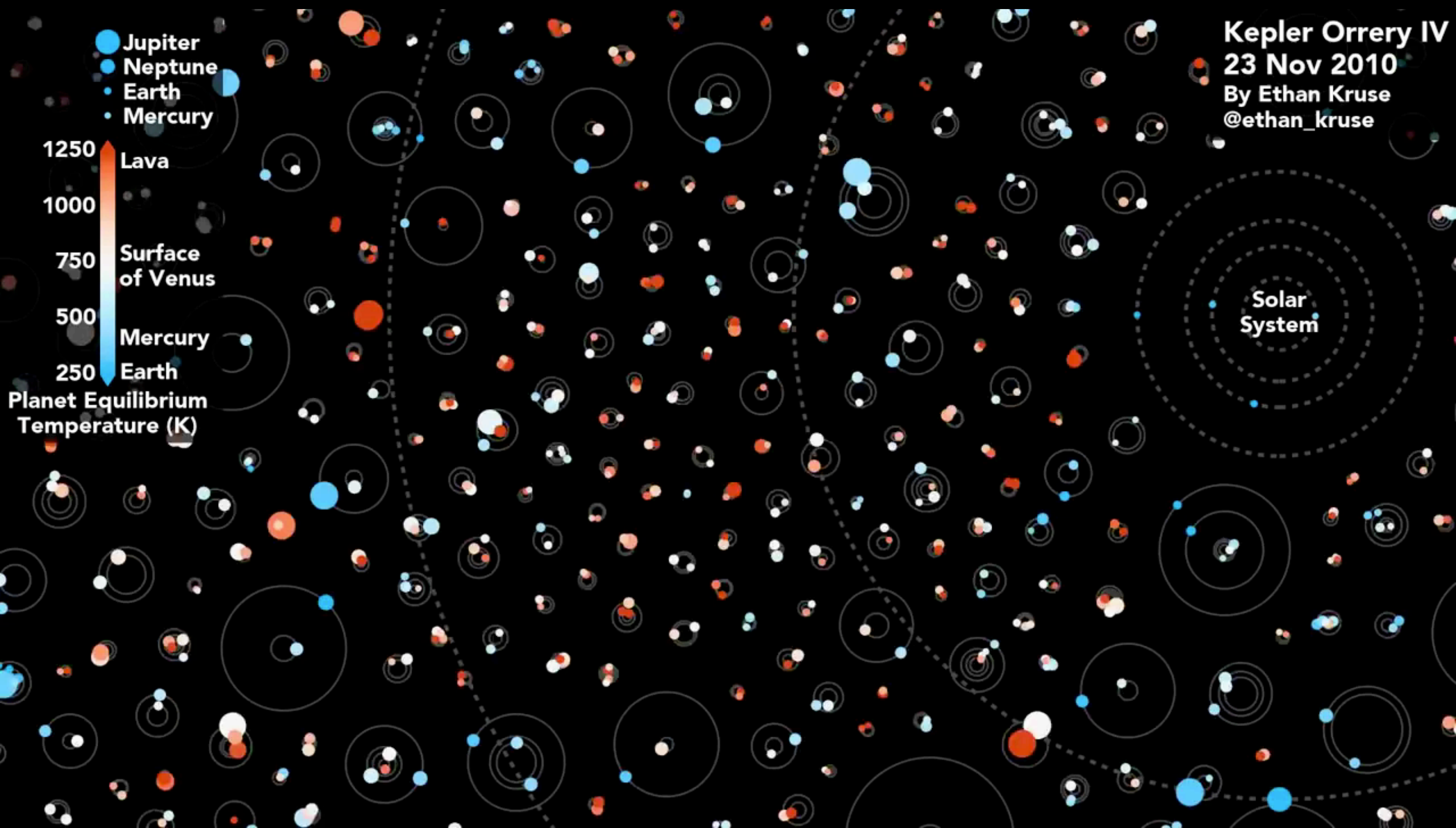


Kepler Orrery IV

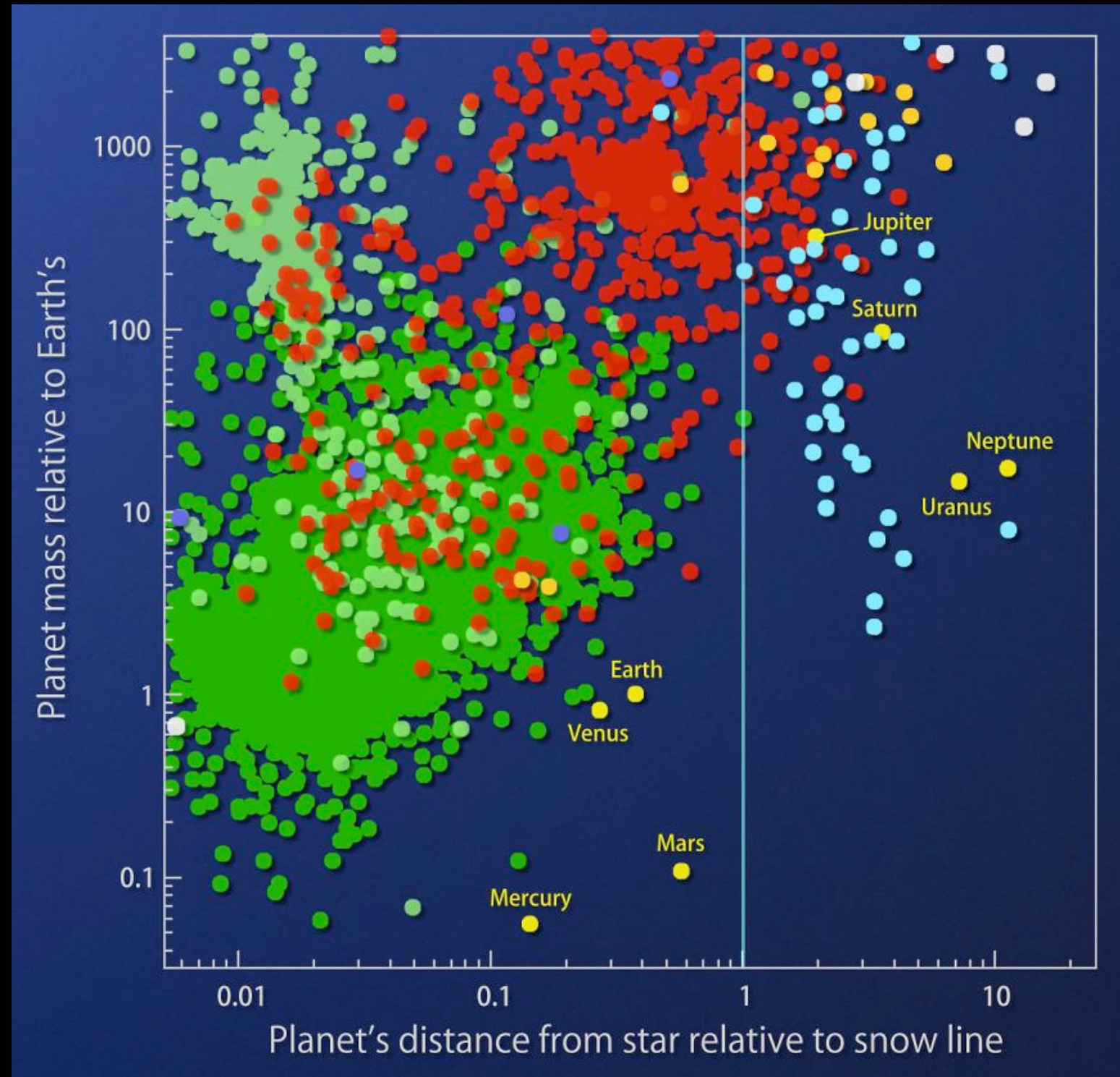
23 Nov 2010

By Ethan Kruse

@ethan_kruse



- tout est à apprendre concernant la formation, l'évolution et la diversité des atmosphères de planètes telluriques
- prérequis indispensable à l'éventuelle identification d'*anomalies* et de manifestations du vivant





Vie



**observables
générées ou
modifiées**

instrumentation



Observateur

Interprétation ?



Vie



**observables
générées ou
modifiées**

instrumentation



Observateur

Interprétation ?

Une chimie hors équilibre est-elle une biosignature ?

	Available Gibbs energy, Φ (J/mol of atmosphere) [†]	Lovelock (1975) Φ (J/mol of atmosphere)
Venus	0.059598	5
Earth(atm)	1.51348	Not reported
Mars	136.3485	13
Jupiter	0.001032077	<1
Titan	1.2126495	Not reported
Uranus**	0.0971394	Not reported

	Available Gibbs energy, Φ (J/mol of atmosphere) [†]	Lovelock (1975) Φ (J/mol of atmosphere)
Venus	0.059598	5
Earth(atm)	1.51348	Not reported
Earth	2325.76	55000
Mars	136.3485	13
Jupiter	0.001032077	<1
Titan	1.2126495	Not reported
Uranus**	0.0971394	Not reported

Table 10: Sensitivity of the numerical calculations of the available Gibbs energy, Φ , in the Earth's atmosphere-ocean system to perturbations in variables that are unobservable or difficult to observe for exoplanets.

		Available energy, Φ (J/mol)
Temperature	T= 273.15 K	1634.78
	T= 288.15 K	2325.76
	T= 298.15 K	2824.48
Pressure	0.1 bar	1354.20
	1.013 bar	2325.76
	10 bar	3891.96
	1000 bar	6878.35
Ocean pH	2	1983.28
	4	2314.26
	6	2325.71
	8.187 (Earth)	2325.76
	12	2325.65
Salinity	0 mol/kg	2290.01
	1.1 mol/kg	2325.76
	11.1 mol/kg	2276.40
Ocean volume	0.1 Earth ocean	413.62
	0.5 Earth ocean	1442.95
	1 Earth ocean	2325.76
	2 Earth oceans	4188.27
	10 Earth oceans	8956.34
	50 Earth oceans	12626.22



Vie



observables
générées ou
modifiées

instrumentation



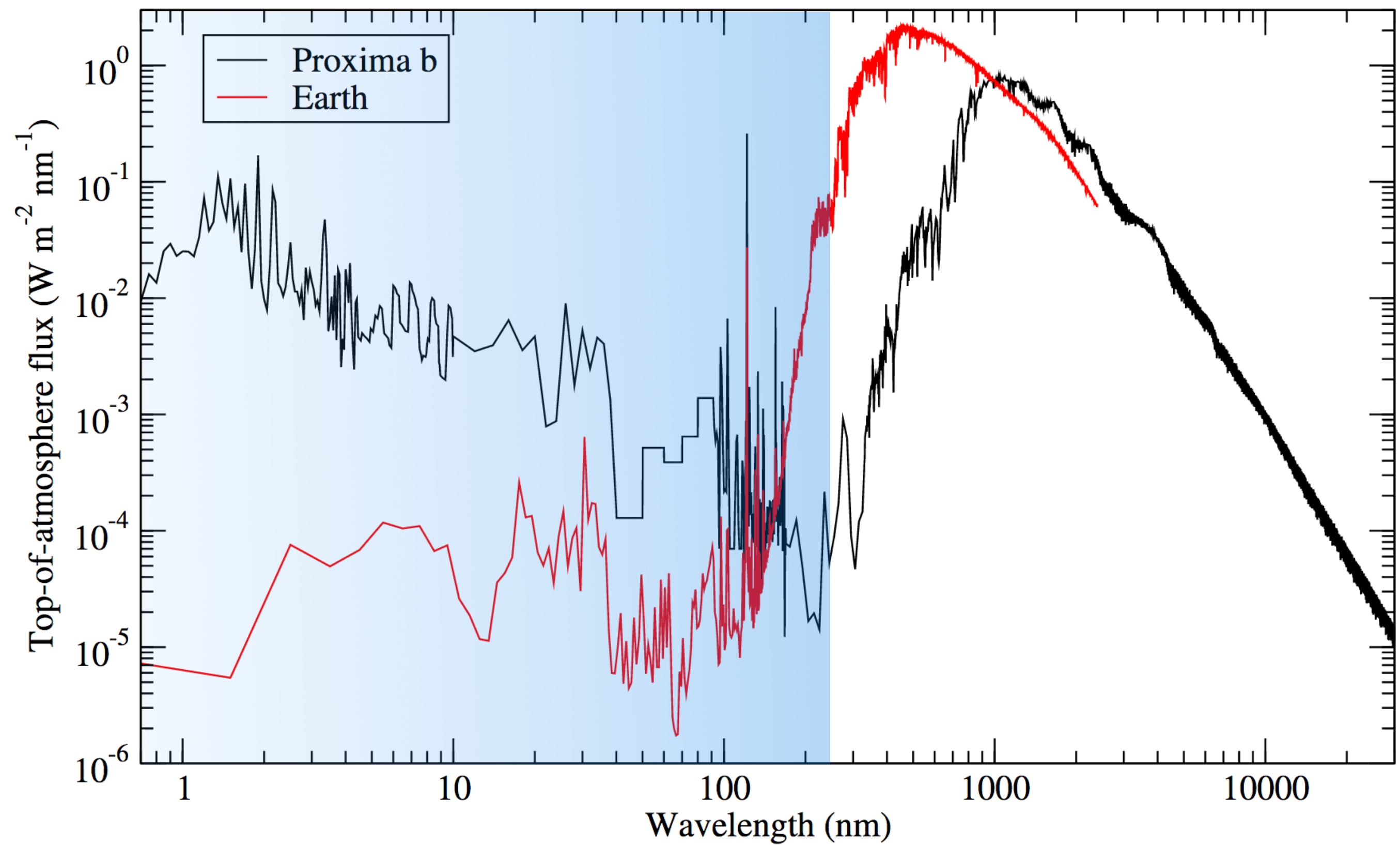
Observateur

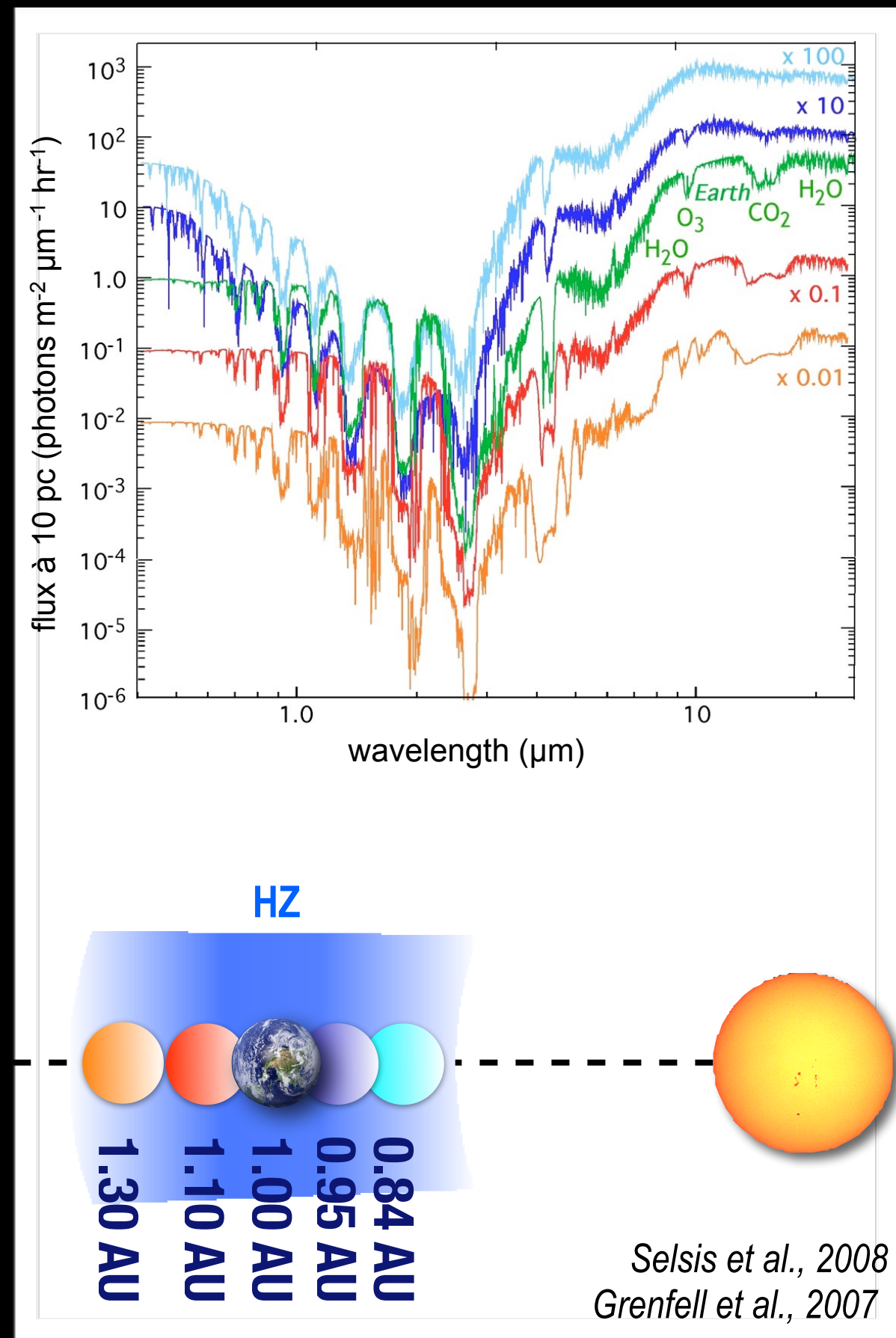
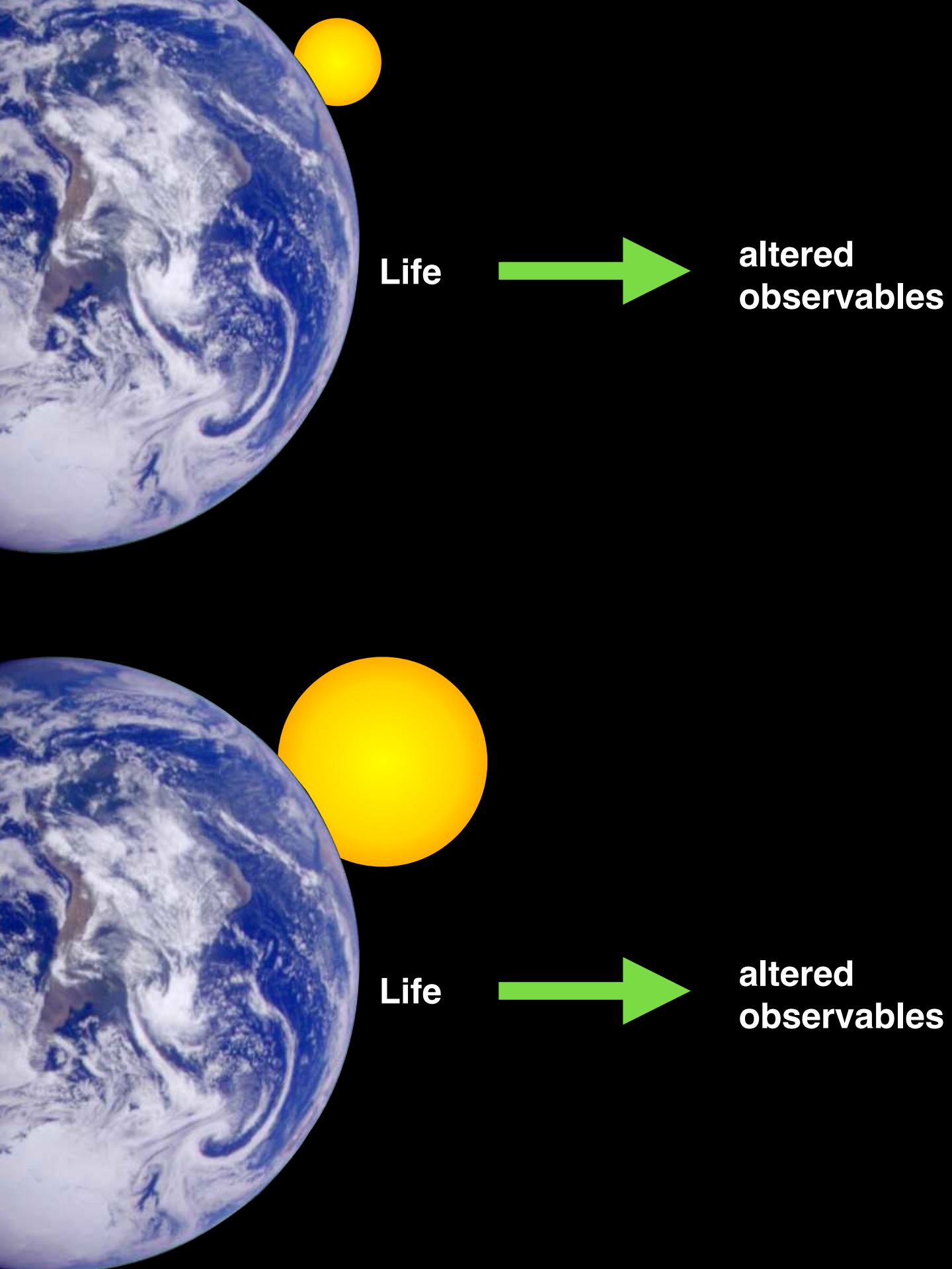
Interprétation ?

(photo)chimie abiotique

Vénus et Mars primitif
Satellites glacés

Mars
Vénus



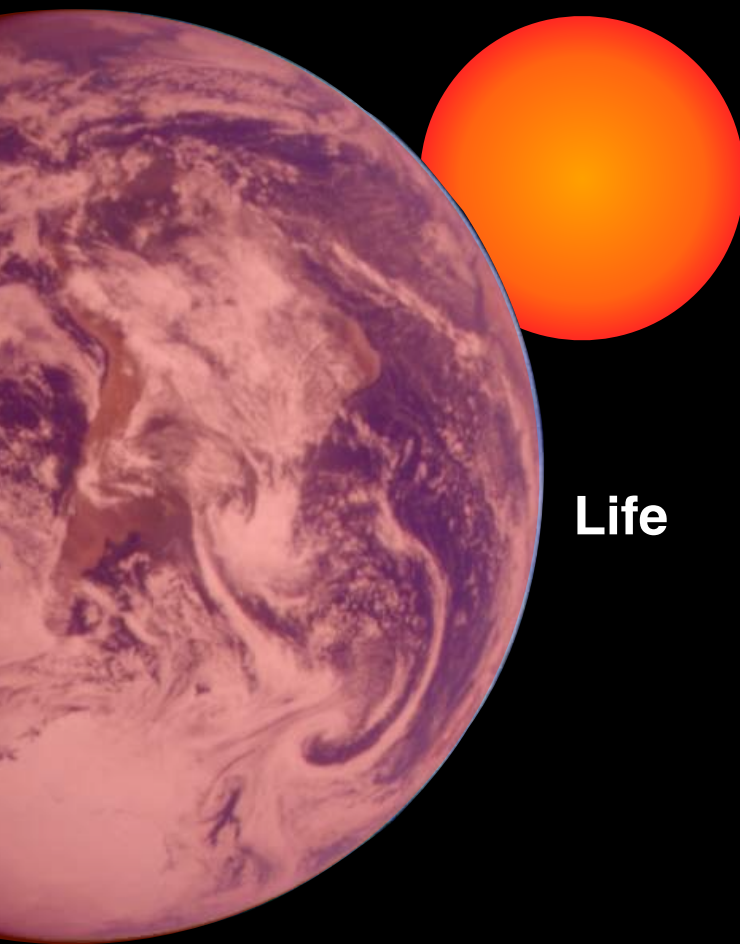




Life



altered
observables



Life



altered
observables

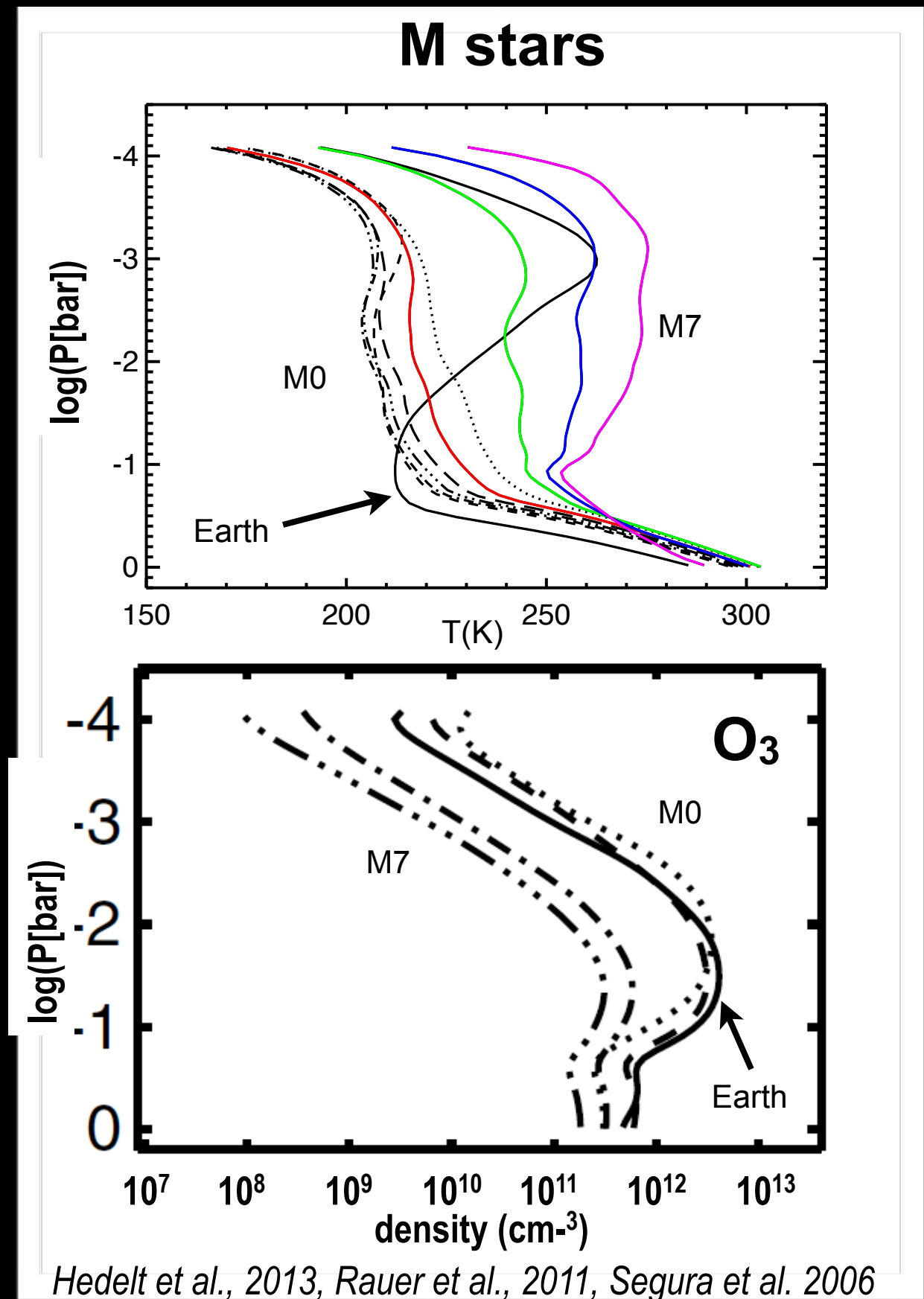
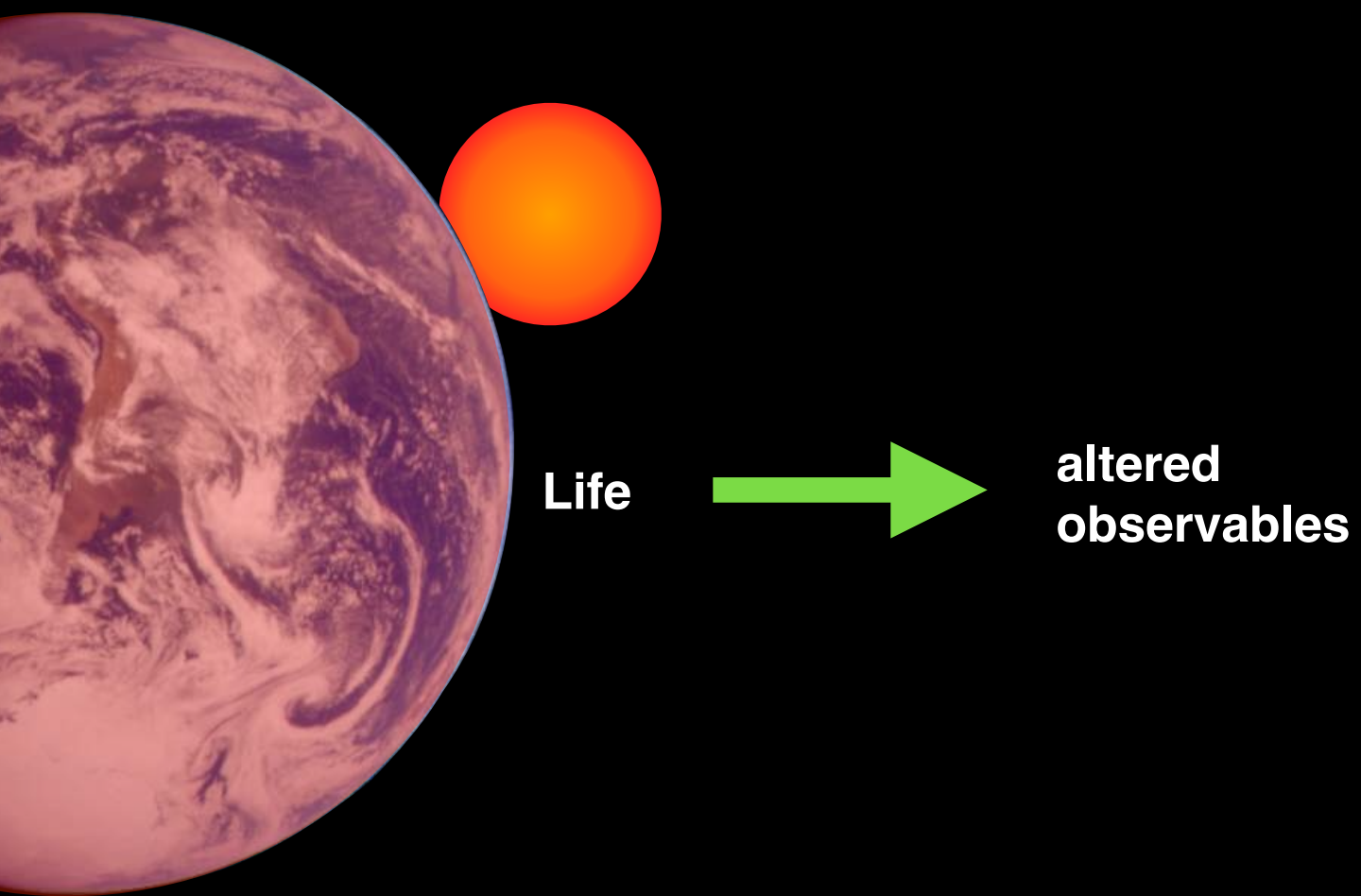
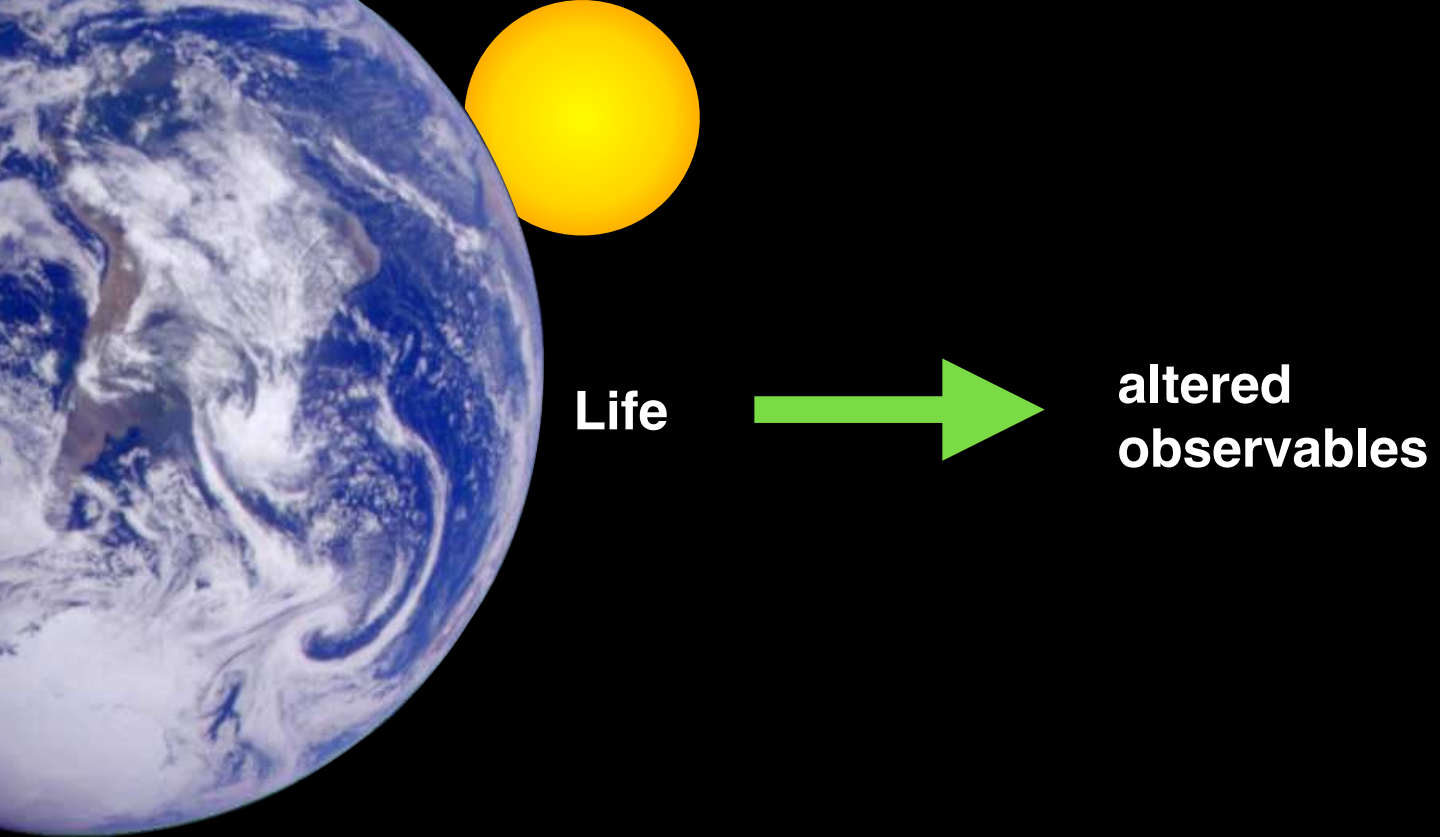
K, G, F stars

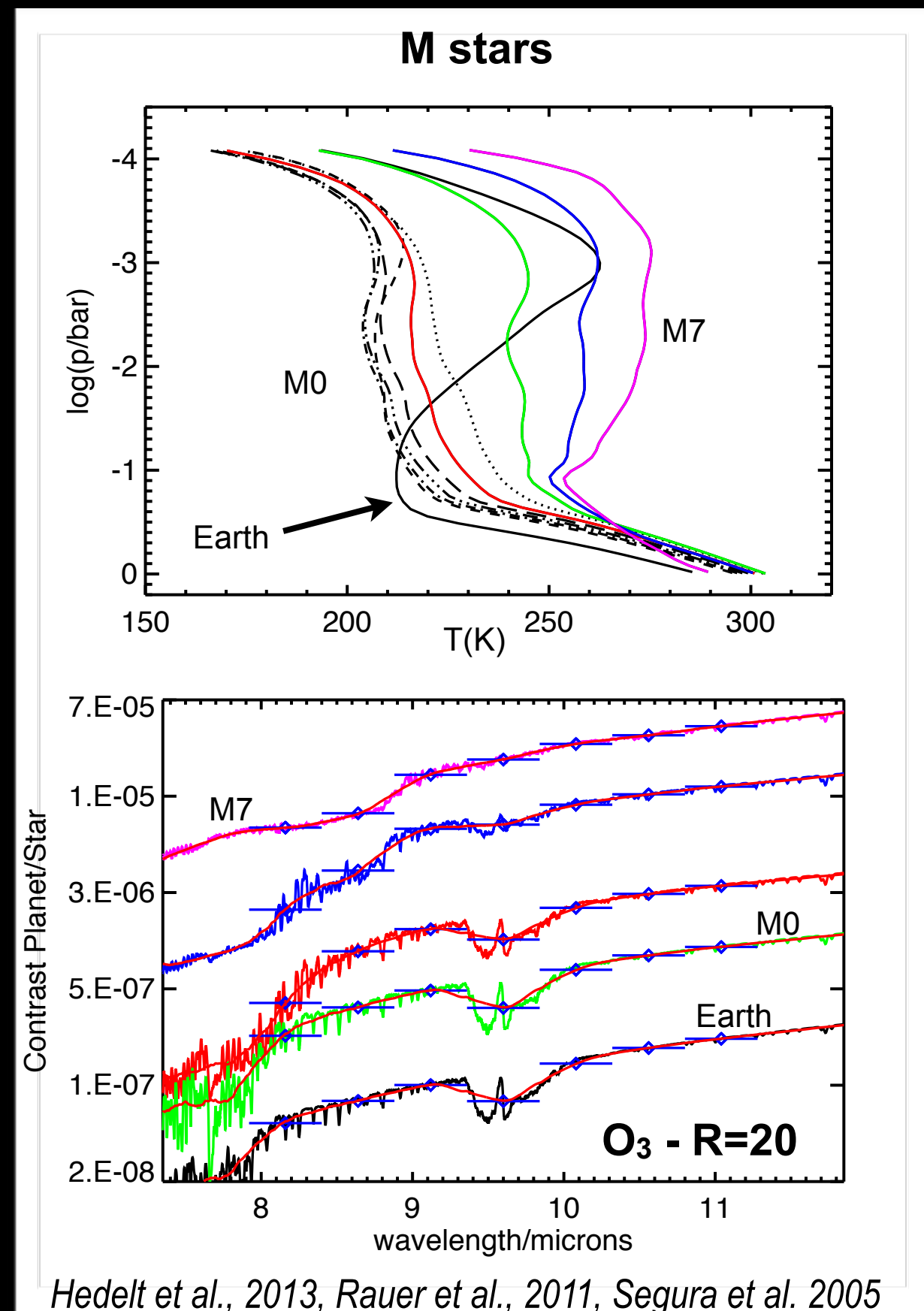
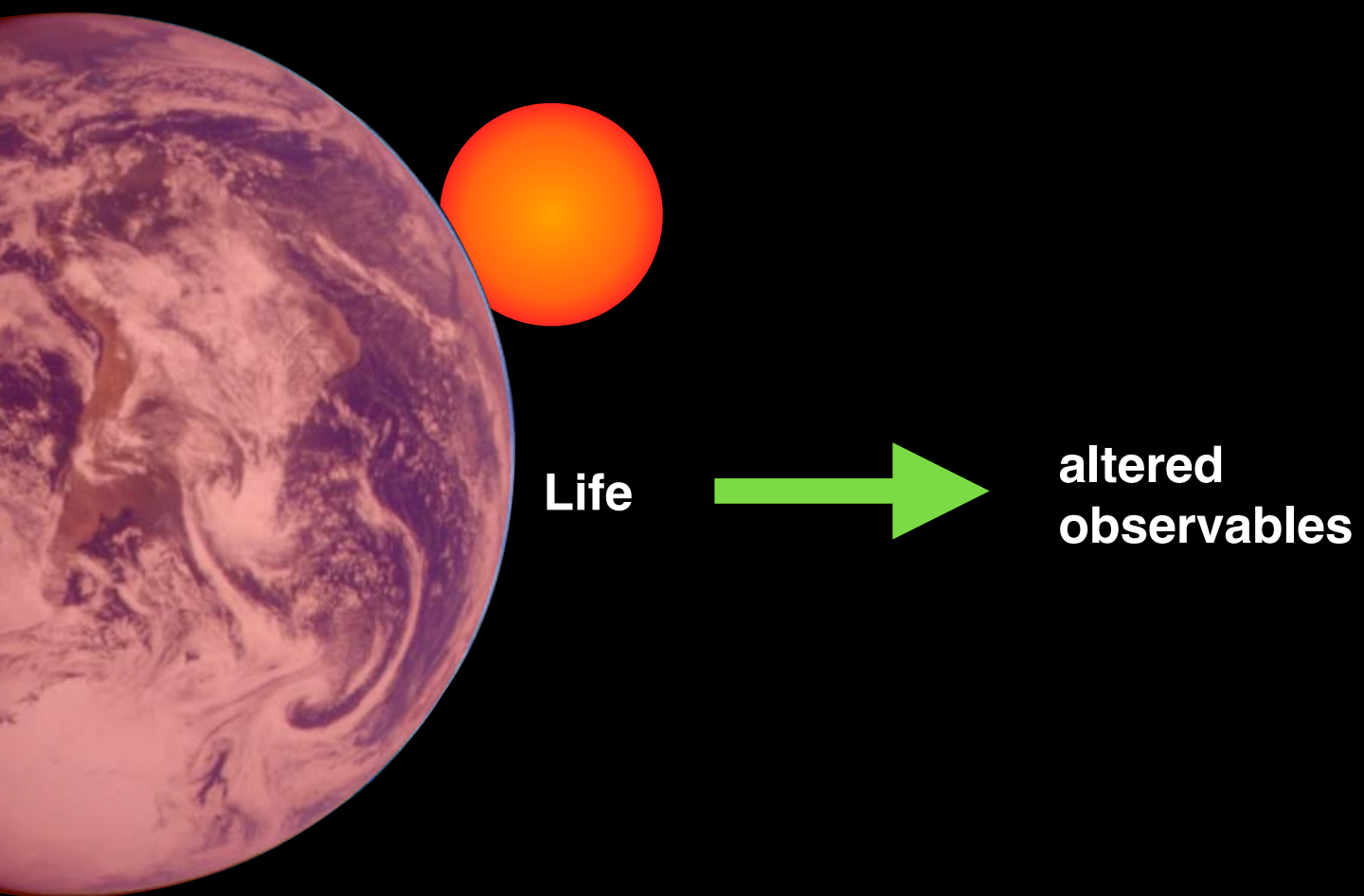
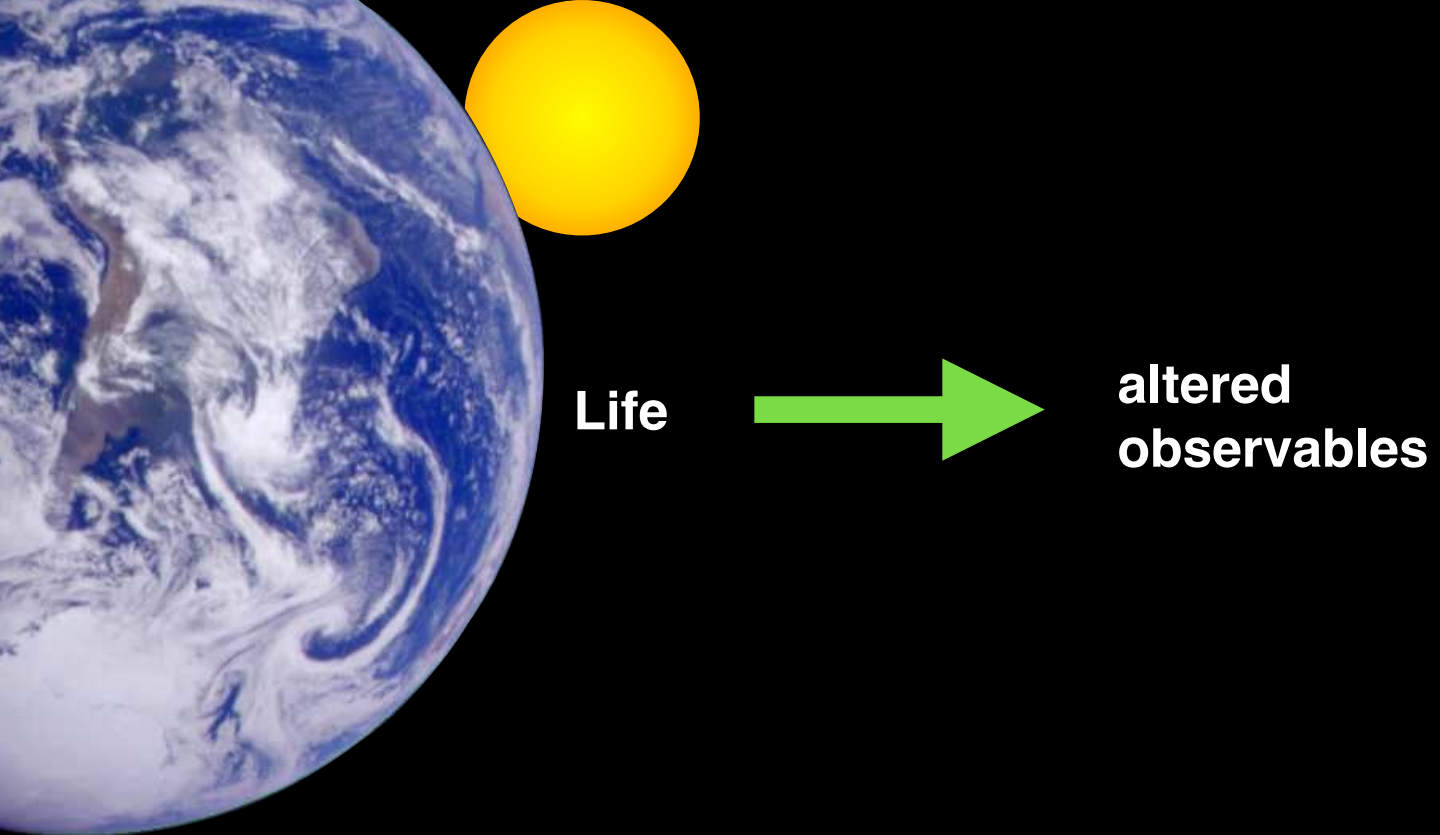
Selsis, 2000

Segura et al., 2003

Hedelt et al., 2013

Rugheimer et al., 2013







Une chimie hors équilibre est-elle une biosignature ?

Non, les atmosphères planétaires ne sont pas à l'équilibre chimique

- photochimie due aux UV stellaires

- (- gradient thermiques et circulation)

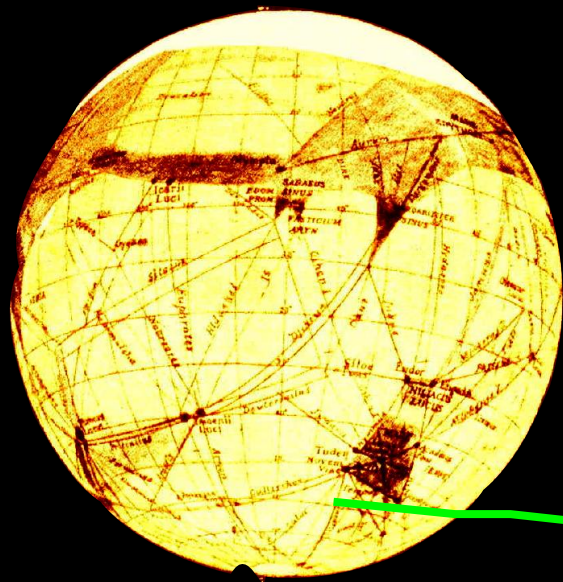
- aux températures *habitables*, les réactions endothermiques sont extrêmement lentes
- échanges avec un intérieur chaud

La clef : le contexte

“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.



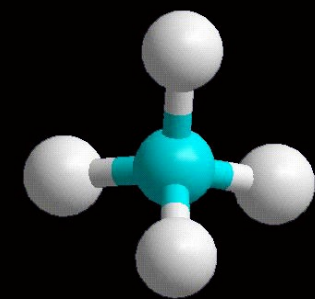


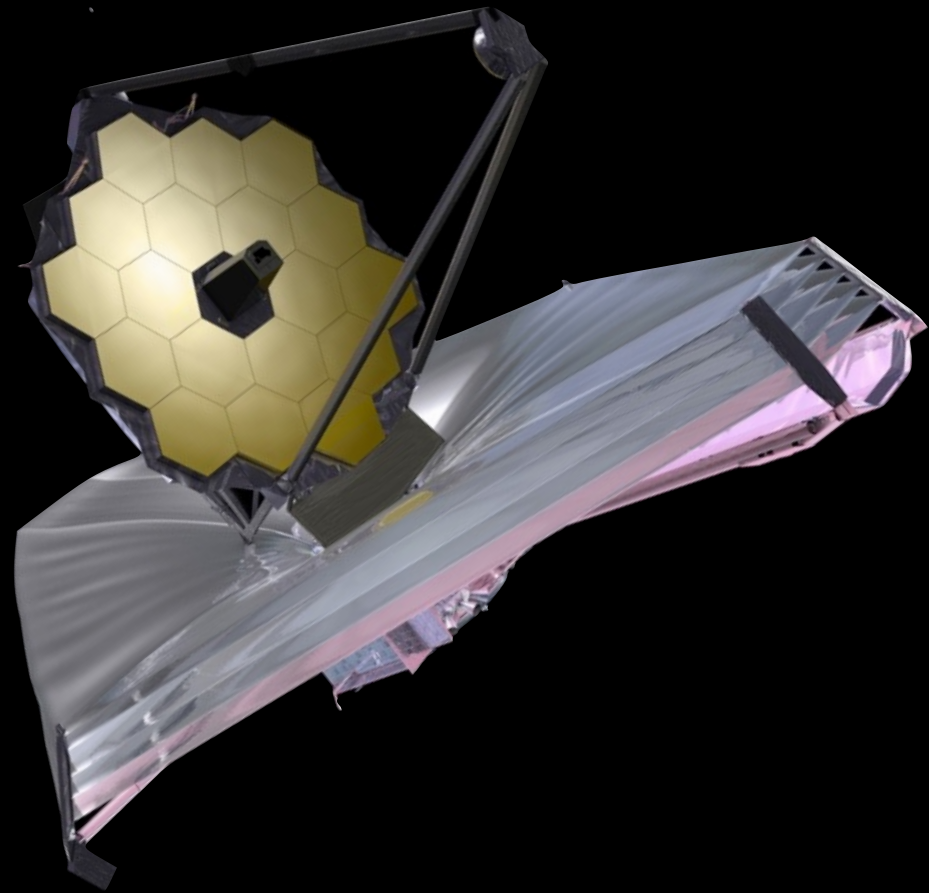
**Biosphère
martienne**

**pouvoir
d'observation**

1869

aujourd'hui





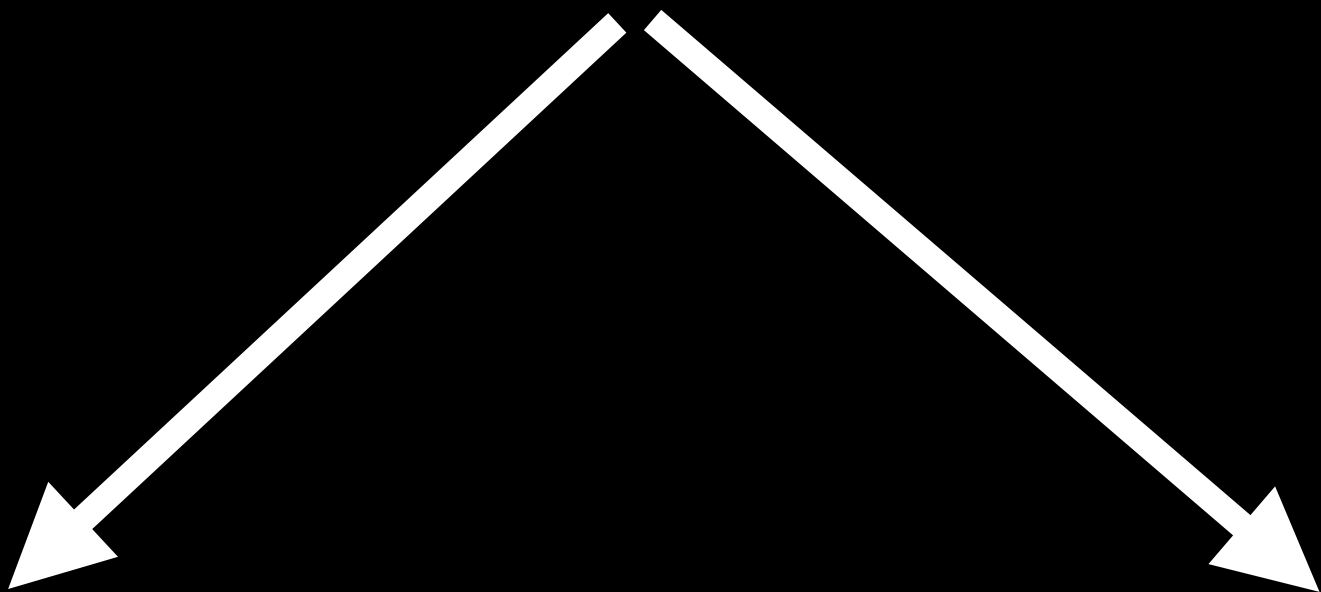
Faut-il

chercher la vie

ou

explorer des environnements nouveaux

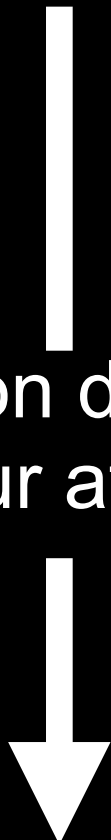
?



```
graph TD; A[ ] --> B[caractérisation des exoplanètes  
et de leur atmosphère]; A --> C[recherche de biosignature];
```

caractérisation des exoplanètes
et de leur atmosphère

recherche de biosignature



caractérisation des exoplanètes
et de leur atmosphère

recherche de biosignature



caractérisation des exoplanètes
et de leur atmosphère



recherche de biosignature



E

L

F

ENCELADUS LIFE FINDER

Morgan L. Cable, Jonathan I. Lunine, Linda J. Spilker and the ELF Science Team

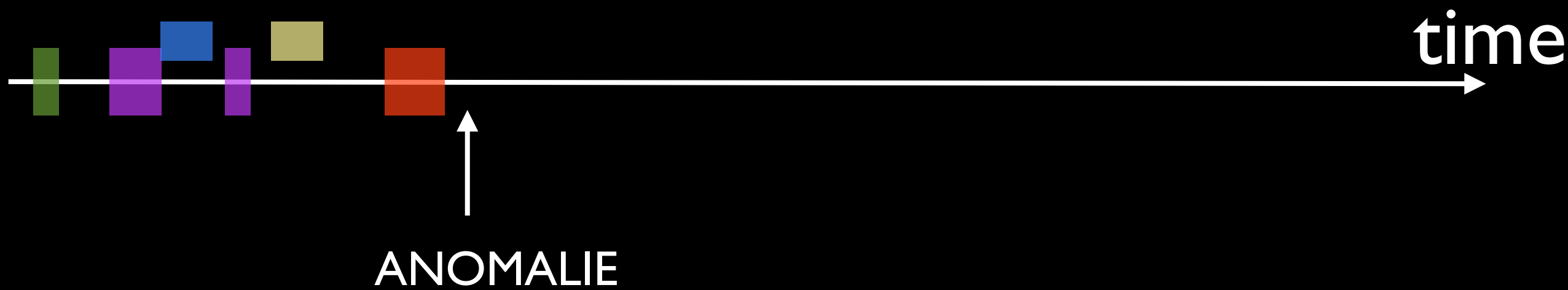
23 February 2017



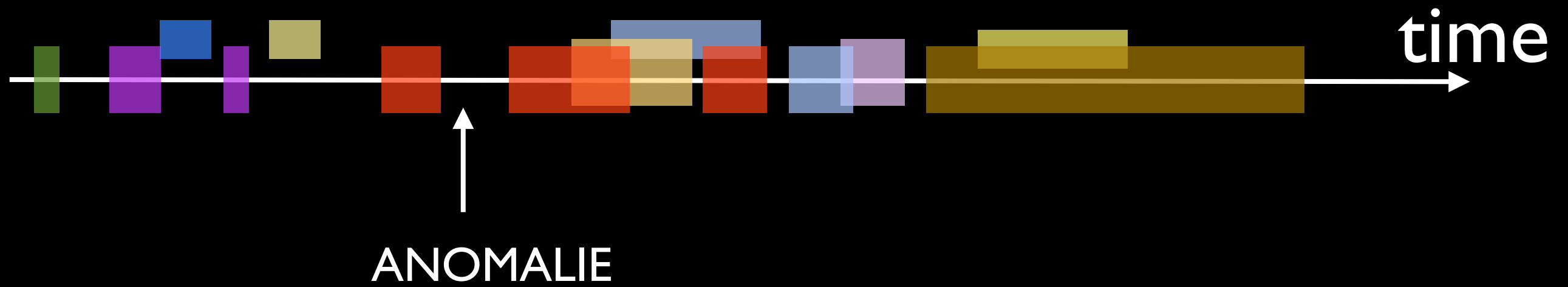
planète PLATO 1028c



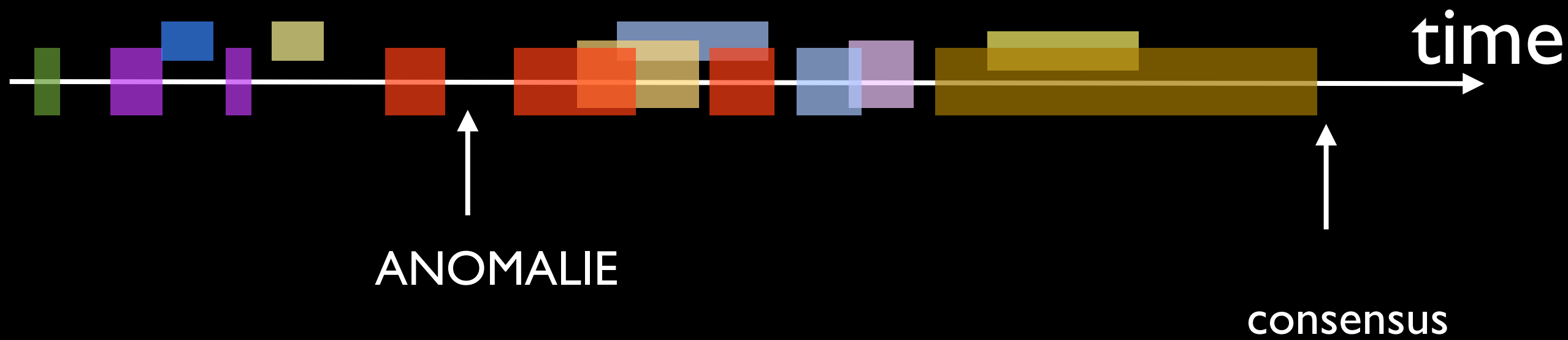
planète PLATO 1028c

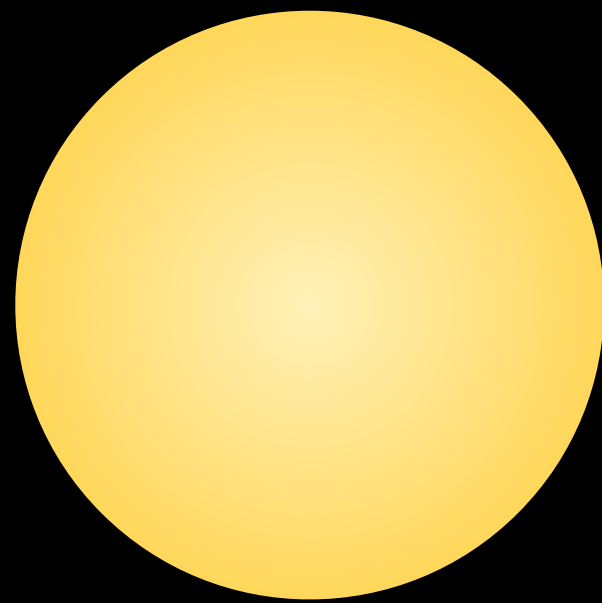


planète PLATO 1028c



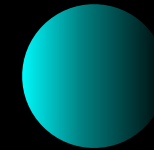
planète PLATO 1028c





Soleil
5800 K

Terre

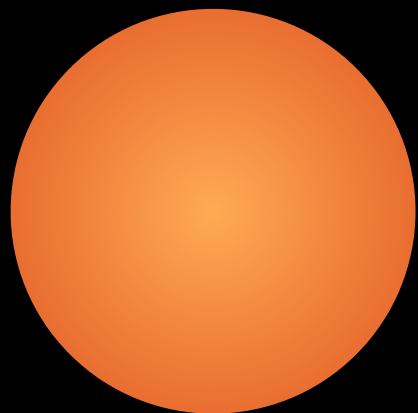


365 j

1 AU

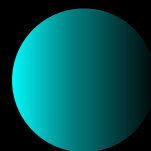


Proxima
3000 K



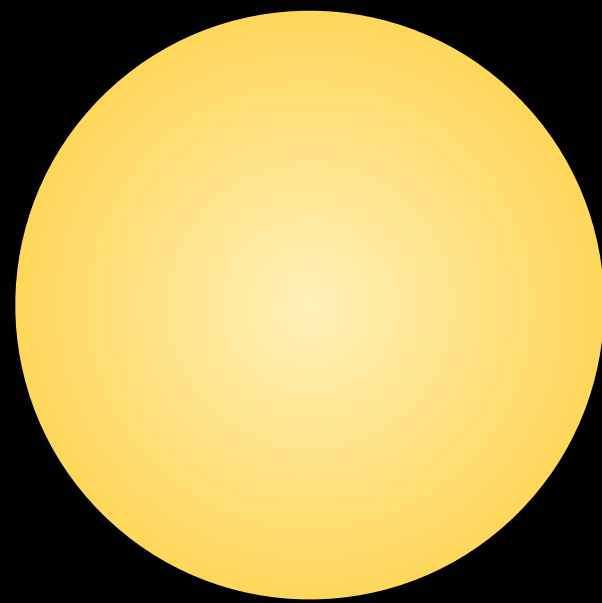
$L=0,0016 L_{\text{sol}}$
 $R=0,14 R_{\text{sol}}$
 $M=0,12 M_{\text{sol}}$

Proxima b



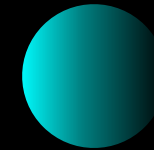
11,2 j





Soleil
5800 K

Terre

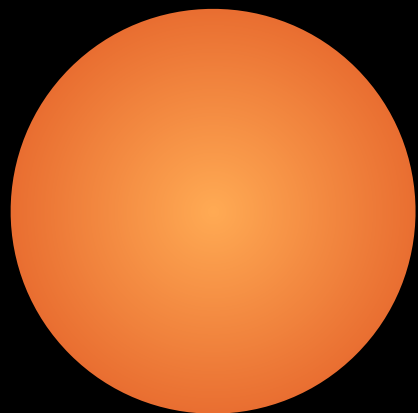


365 j

1 AU

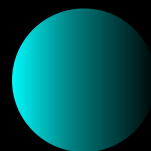


Proxima
3000 K



$L=0,0016 L_{\text{sol}}$
 $R=0,14 R_{\text{sol}}$
 $M=0,12 M_{\text{sol}}$

Proxima b

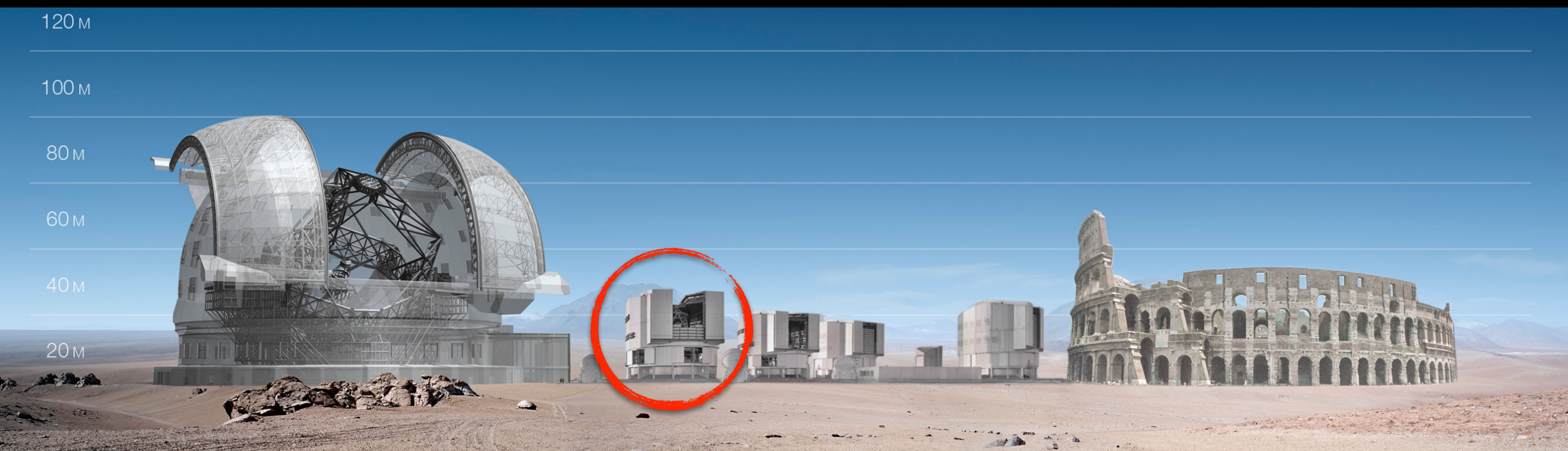


11,2 j

0.05 AU

65% S_{Terre}







120 m

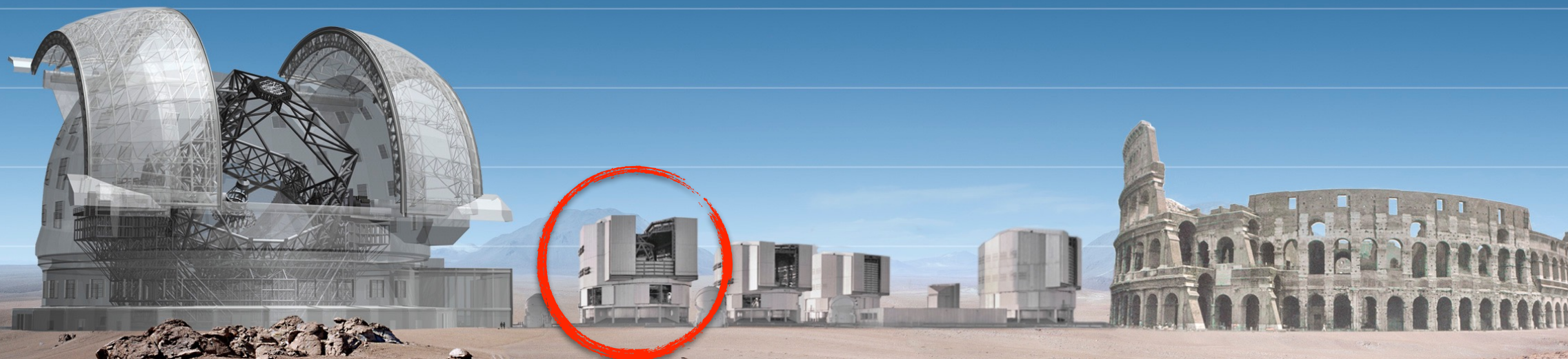
100 m

80 m

60 m

40 m

20 m





120 m

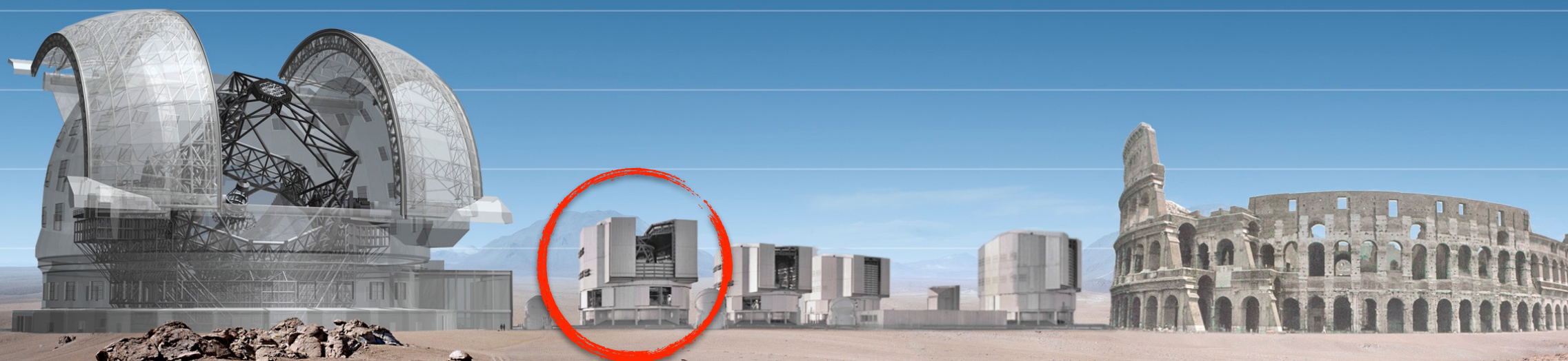
100 m

80 m

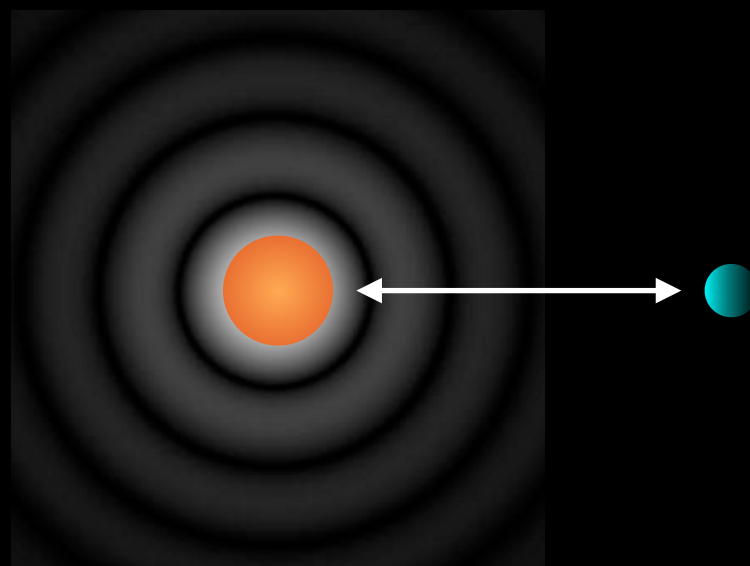
60 m

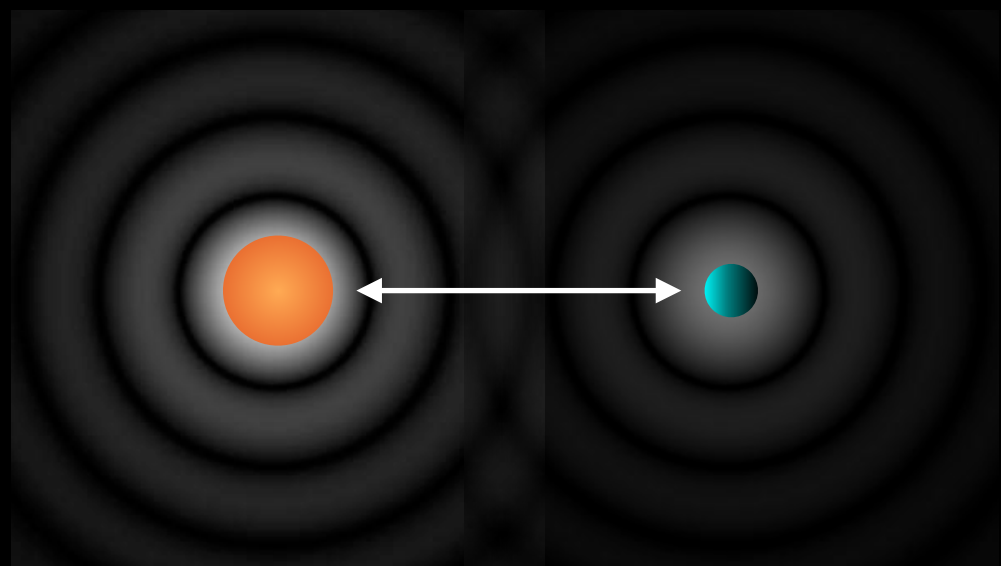
40 m

20 m

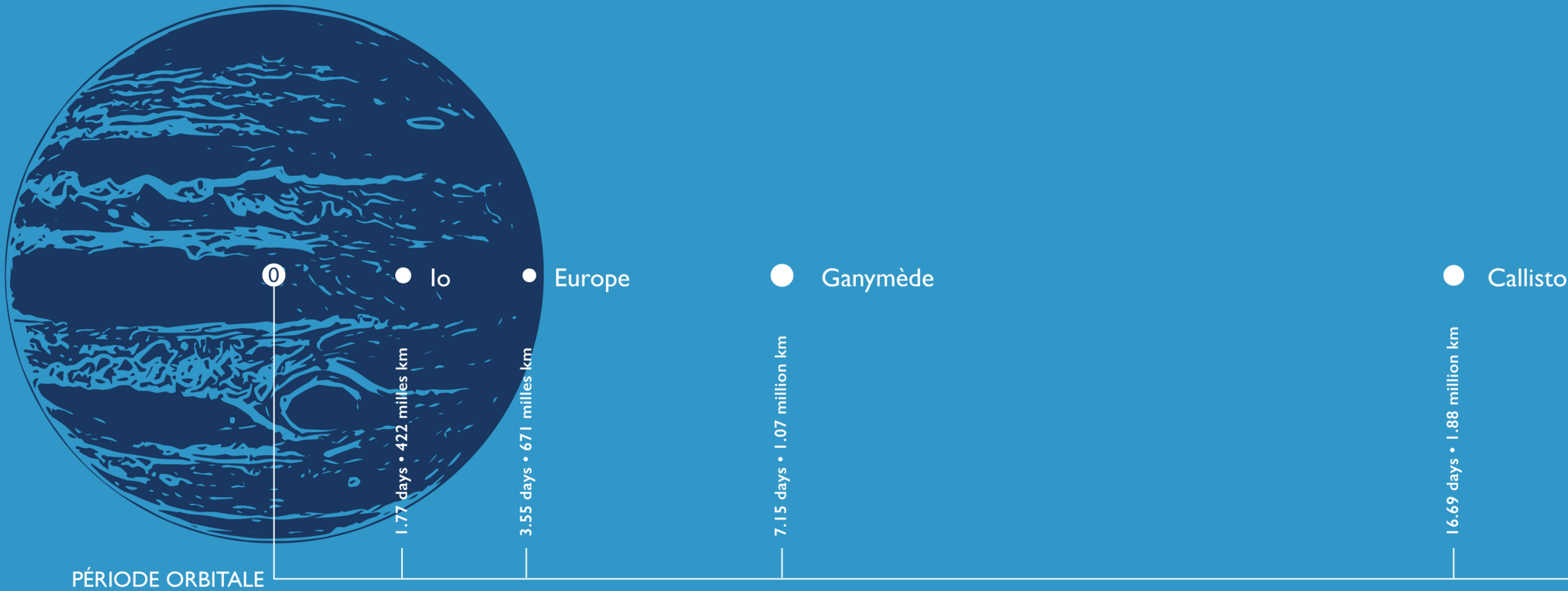




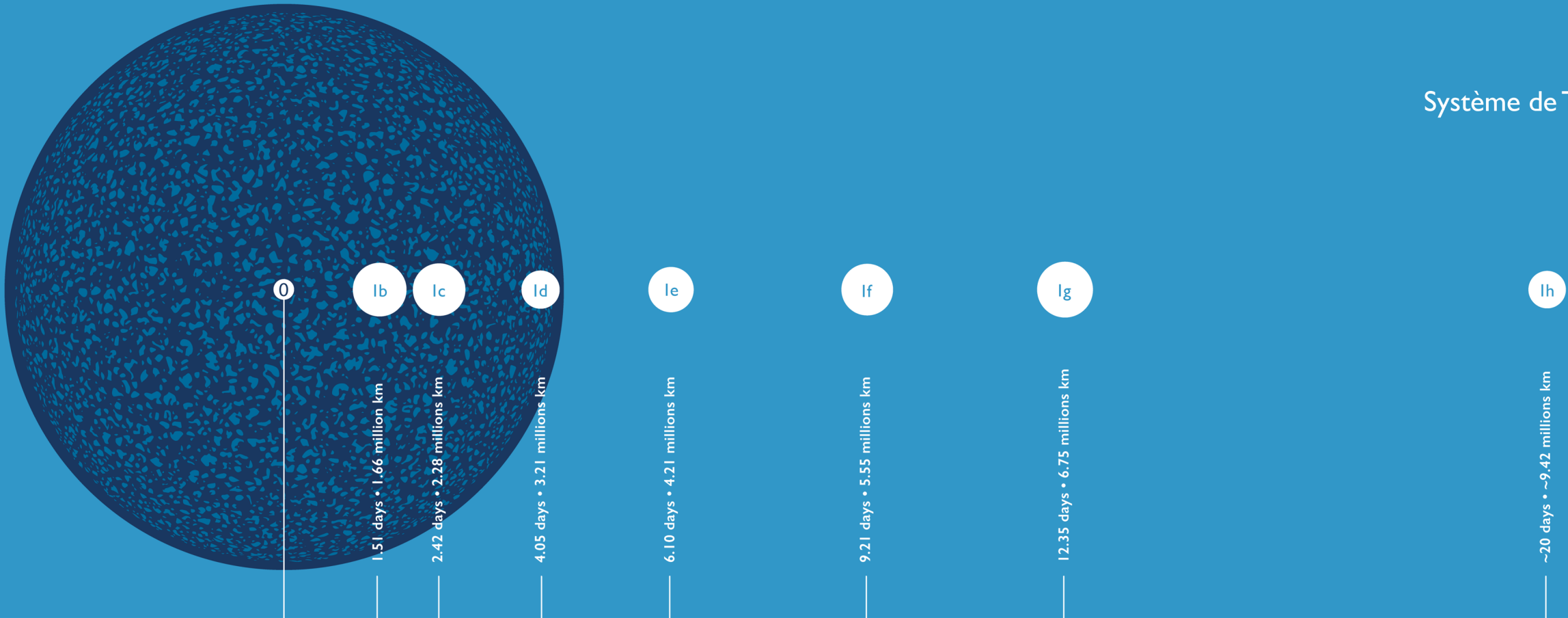




Système de Jupiter



Système de TRAPPIST-1



TRAPPIST-1

Comparaison des tailles et périodes orbitales.
Toutes les tailles sont relatives à Jupiter.

TRAPPIST-1 est un système qui contient sept planètes comparables à la Terre. Elles orbitent une petite étoile appelée une naine ultra-froide. La distance des planètes à l'étoile nous indique que l'eau liquide pourrait persister à leurs surfaces. Le système a été trouvé lorsque les planètes sont passées devant leur étoile, projetant une ombre appelée transit. Cette caractéristique indique que nous serons capable d'étudier leurs climats et compositions chimiques, une étape essentielle pour savoir si elles abritent de la vie.

TRAPPIST-1

ÉTOILE

mercure

Système solaire interne

lb

lc

ld

le

lf

lg

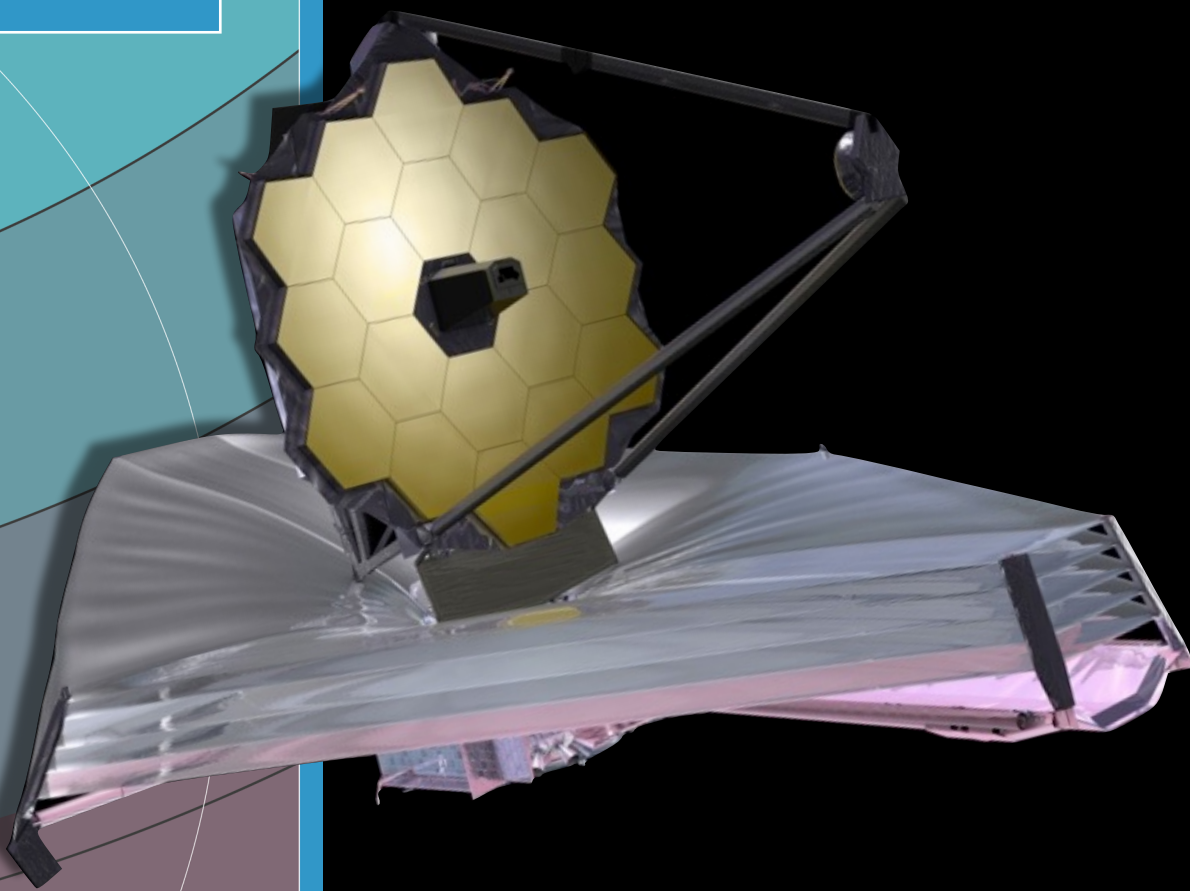
lh

vénus

terre

mars

ceinture
d'astéroïdes





dosit facit venenum : ne pas penser l'identification de la vie comme la seule détection de molécules. Il faut mesurer, quantifier, caractériser un environnement.



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La caractérisation détaillée de beaucoup de planètes/atmosphères dans des contextes différents (type d'étoile, âge, architectures de systèmes planétaires) semble un prérequis.

Pas de raccourci vers les signatures de vie !



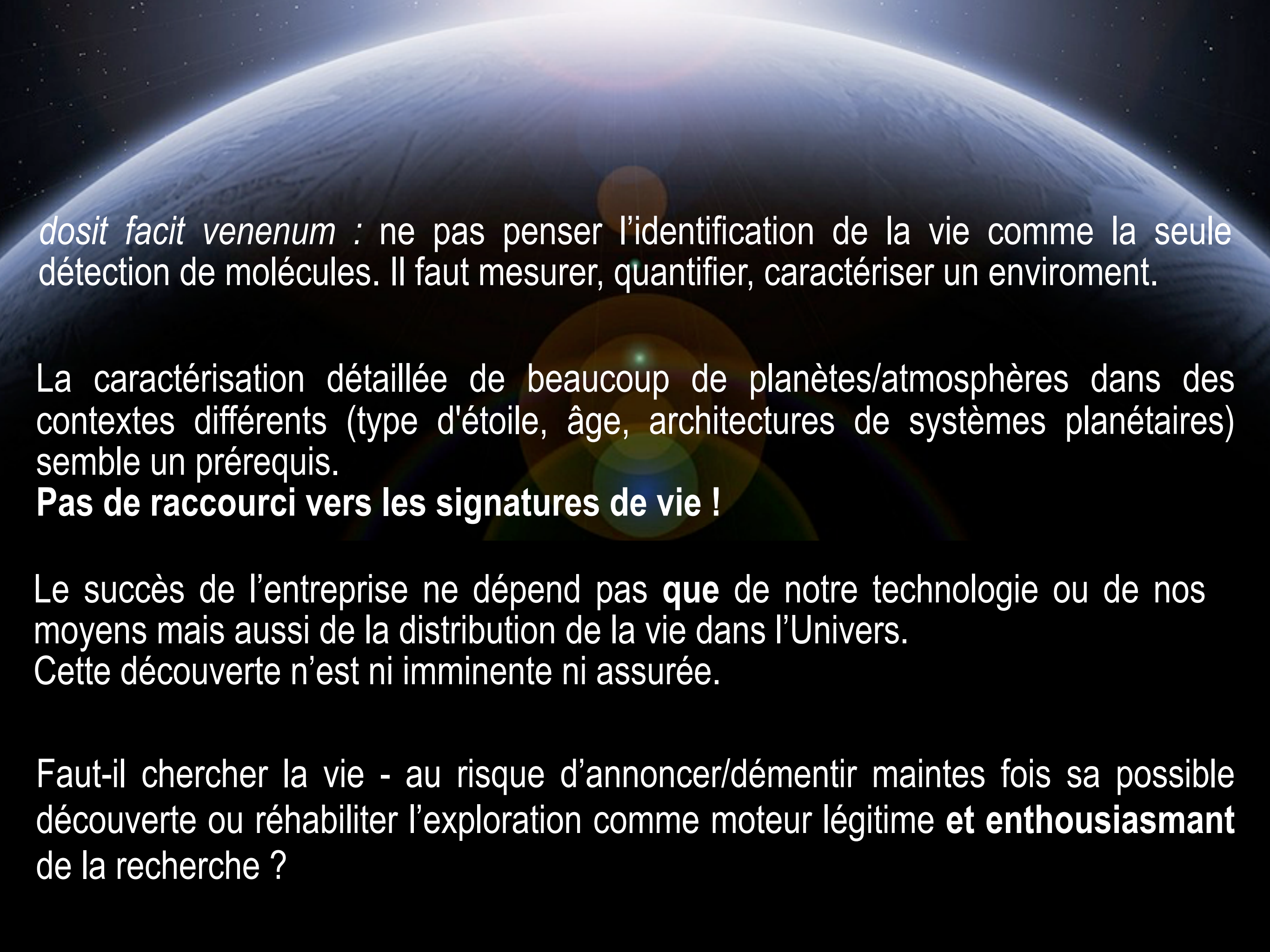
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Faut-il chercher la vie - au risque d'annoncer/démentir maintes fois sa possible découverte ou réhabiliter l'exploration comme moteur légitime **et enthousiasmant** de la recherche ?



MERCI !

questions ?

fselsis@gmail.com