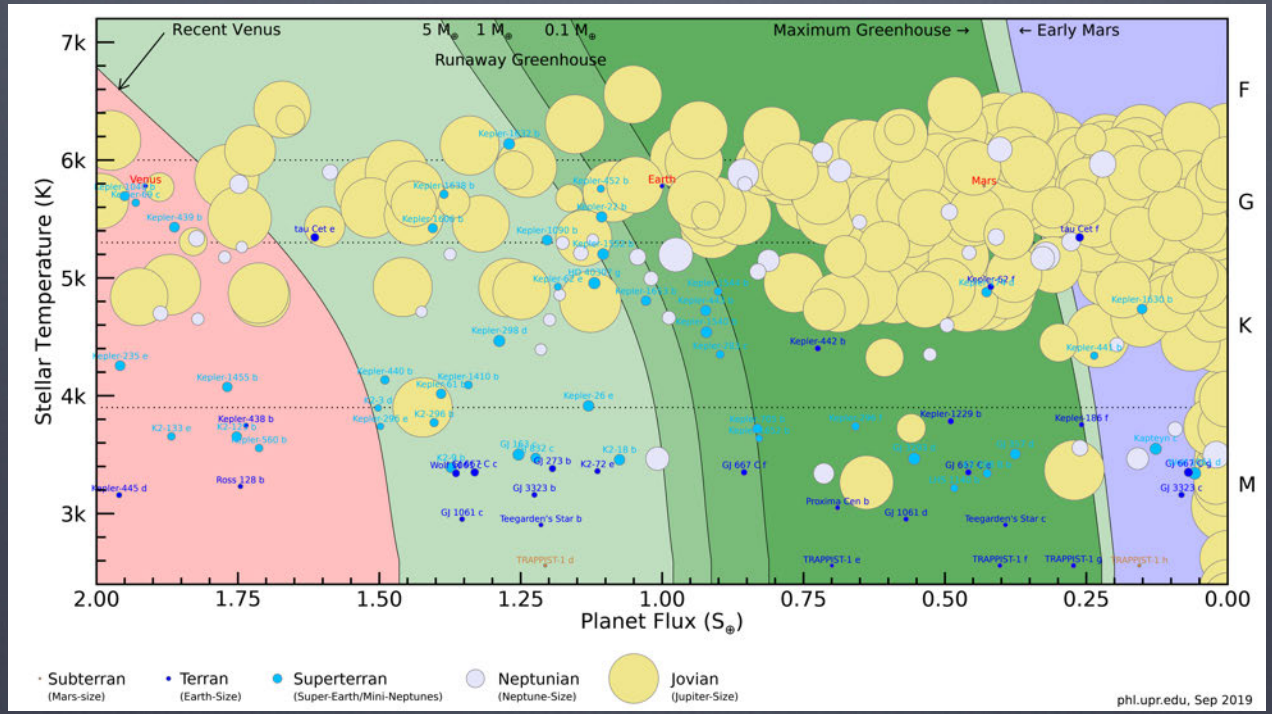
Fisica degli esopianeti

Cattedra Fermi 2019: Pianeti abitabili e non

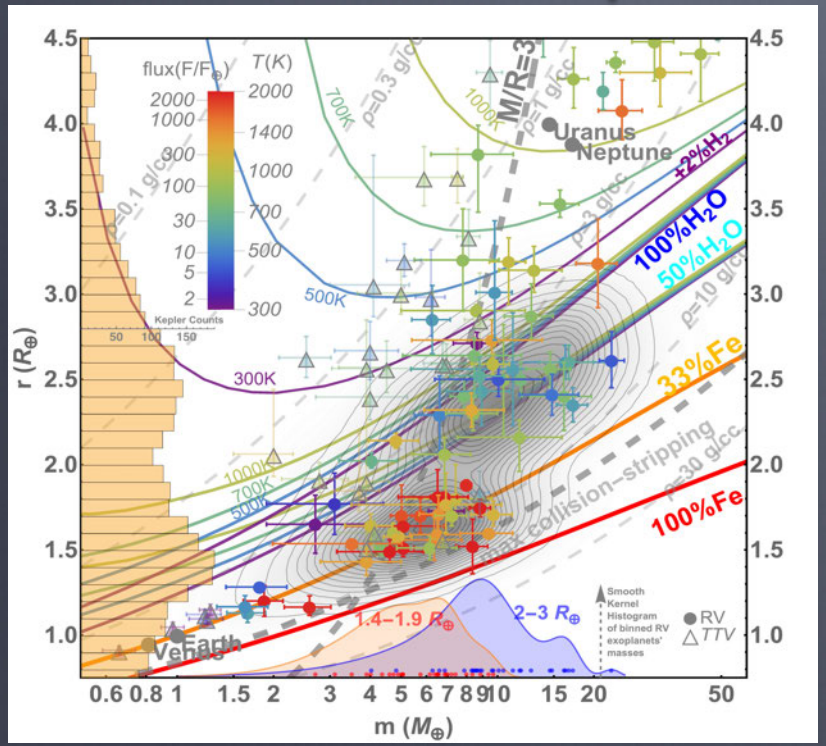
Image Credit: ESO/M. Kornmesser

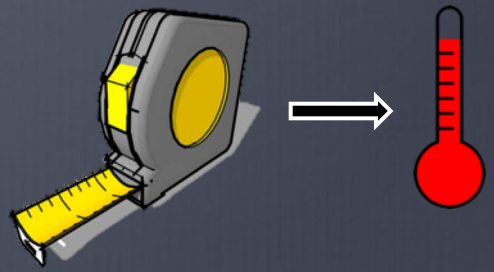
Zona abitabile

È davvero abitabile????



Che sappiamo di questi pianeti?





Zeng et al., 2019

Temperatura di equilibrio

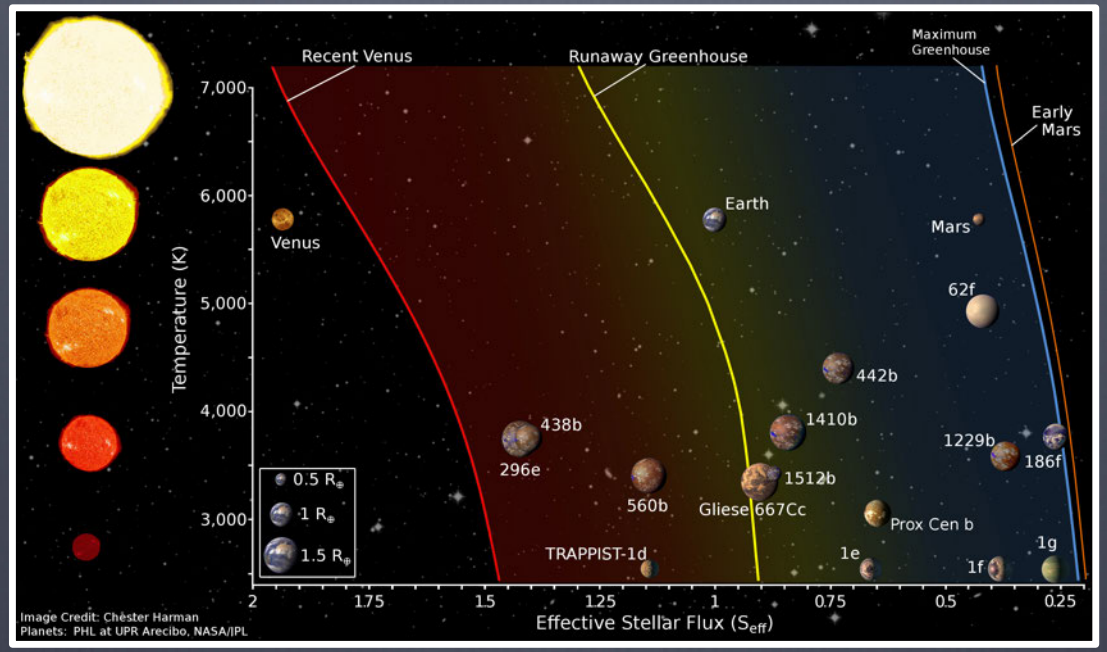
A e ε dipendono dall'atmosfera! Non le conosciamo a priori!

$$E_{in} = E_{out}$$

$$T_p = T_s \times [(1-A)/(1-\varepsilon)]^{1/4} \times R_s^{1/2}/(2a)^{1/2}$$

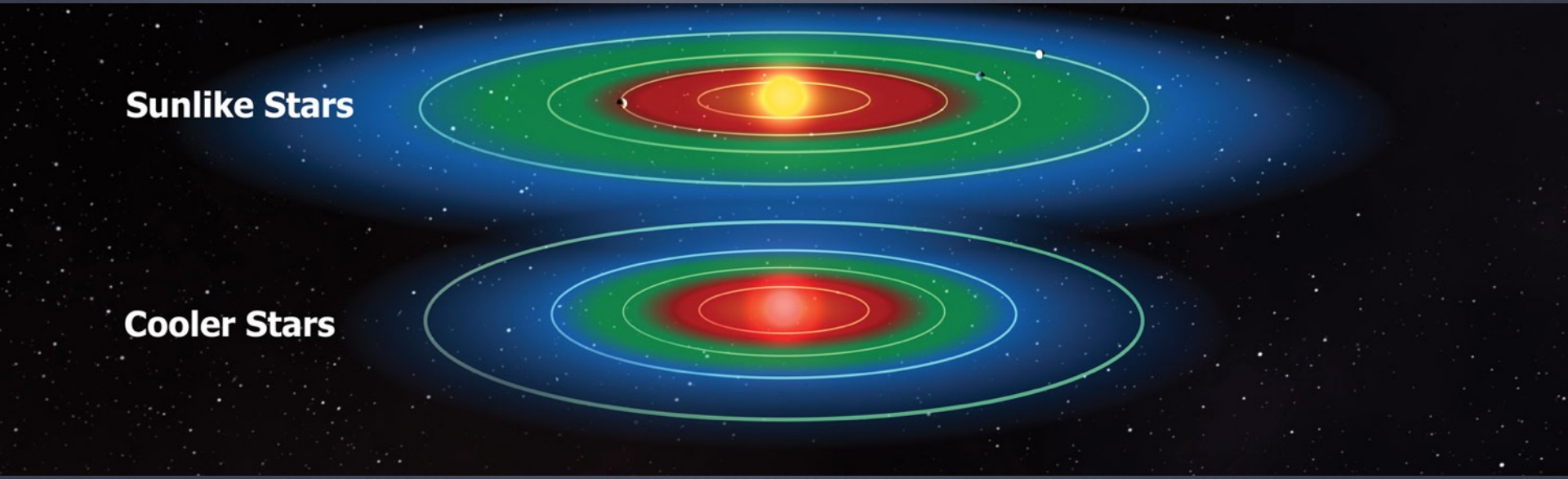
Zona abitabile

Intesa come zona dove la temperatura è compatibile con acqua liquida



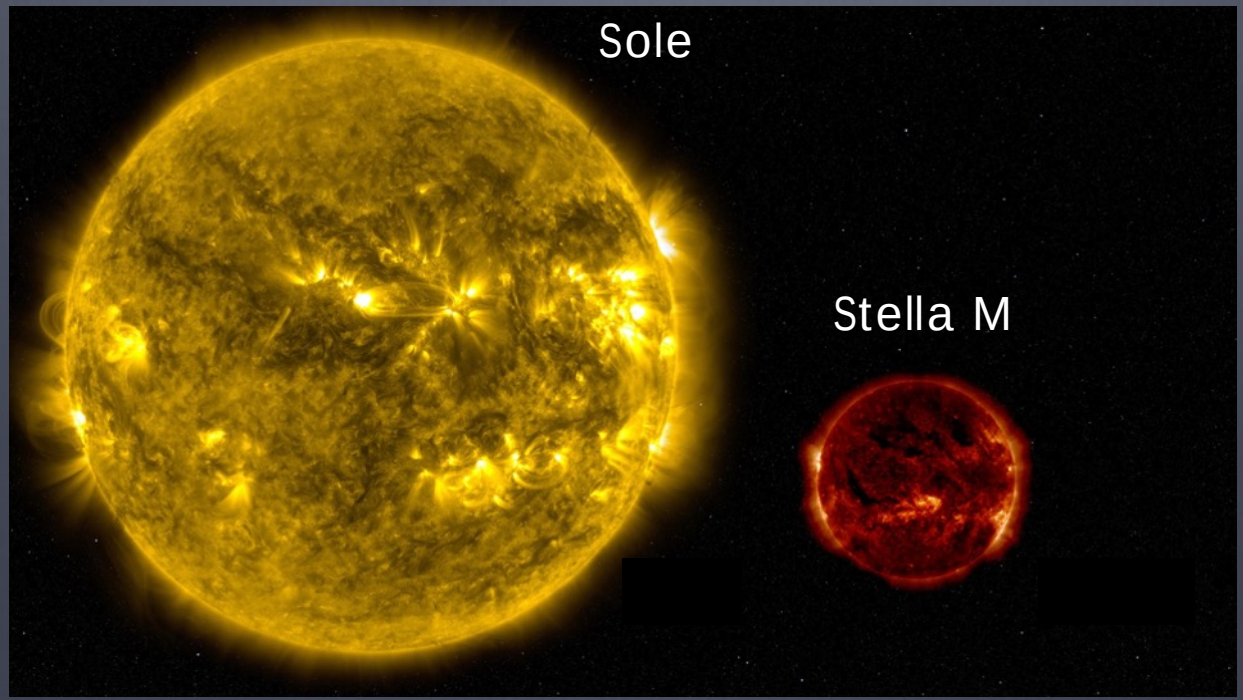
La zona abitabile

Intesa come zona dove la temperatura è compatibile con acqua liquida



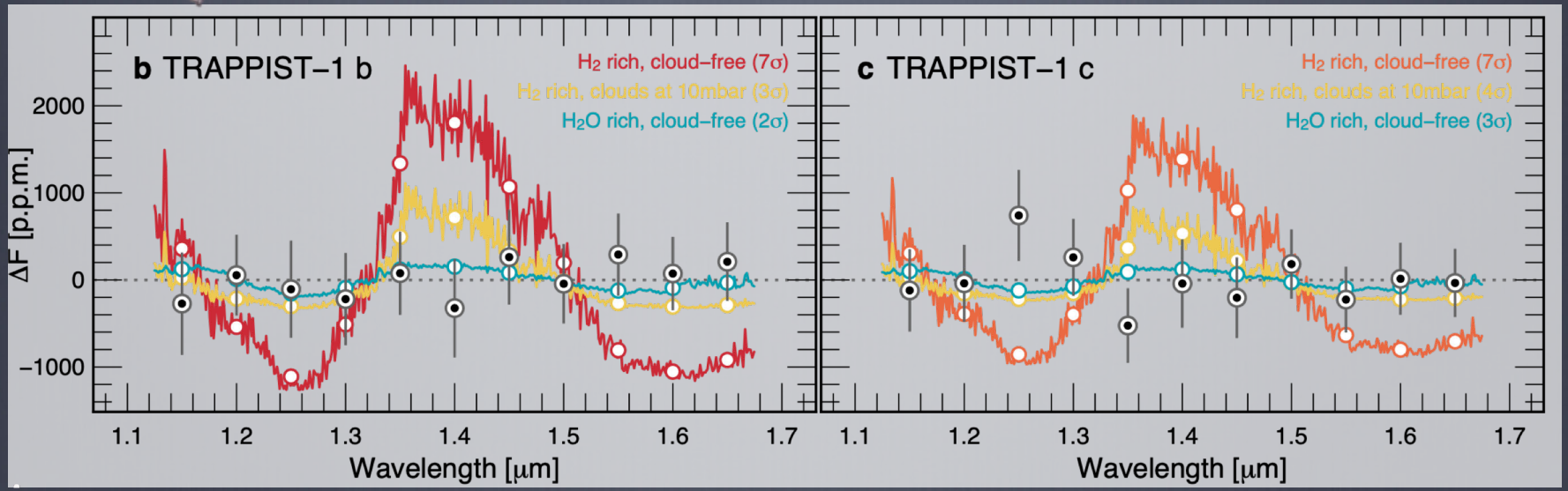
Non gemelli ma cugini

Molte delle super-Terre in zona abitabile orbitano stelle + fredde e piccole del Sole



TRAPPIST-1b & c

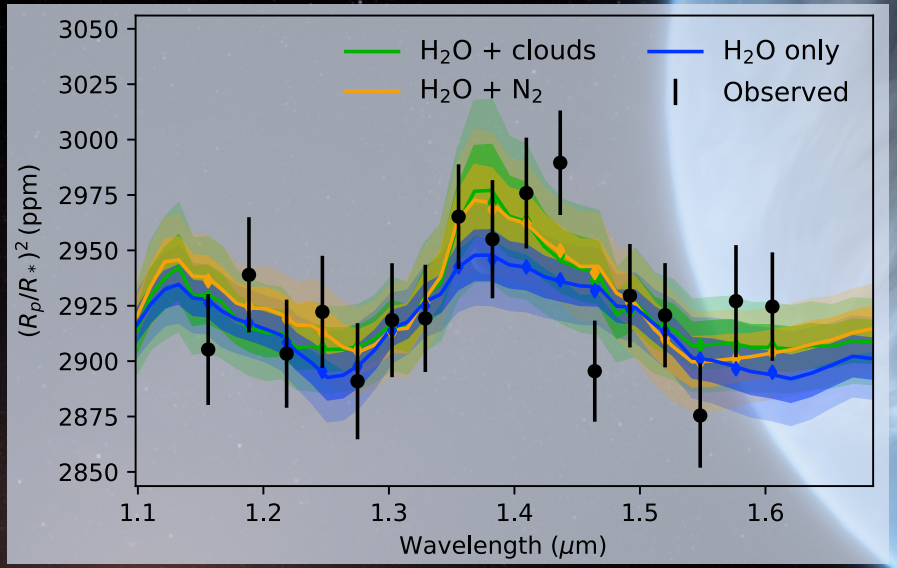
Nuvole? Atmosfera secondaria? C'è bisogno di osservazioni + precise



De Witt et al., 2016

La firma dell'H_2O su K2-18b

Super-Terra in zona abitabile con H_2O in atmosfera

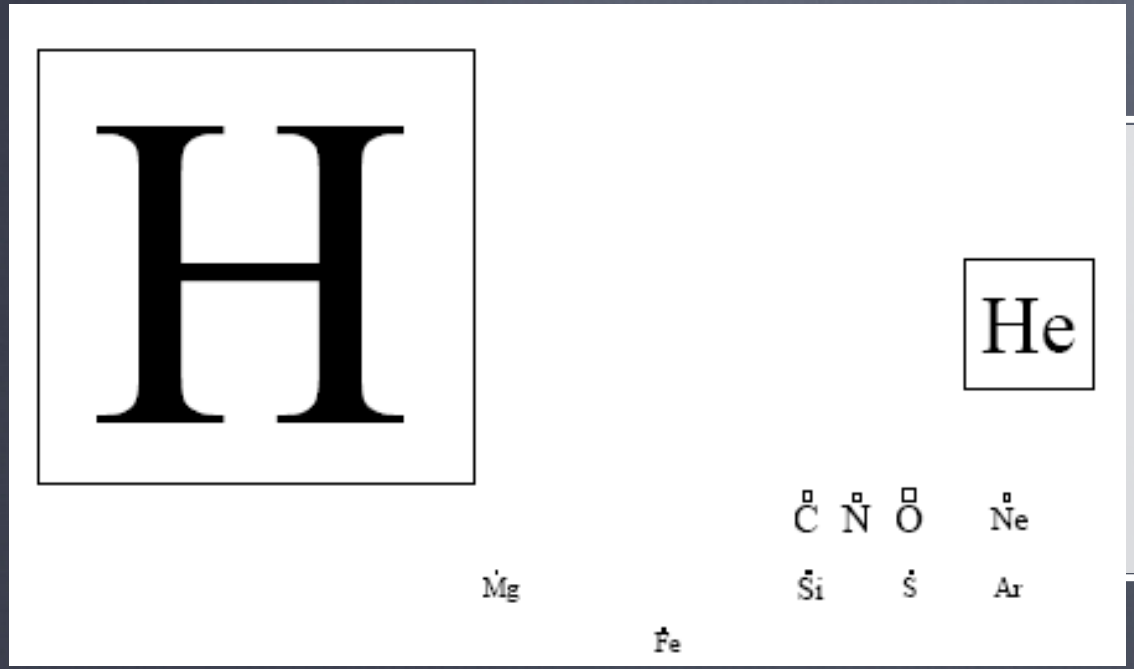


Tsiaras et al., *Nature Astron.*, 2019

NASA-ESA Hubble

Elementi + abbondanti

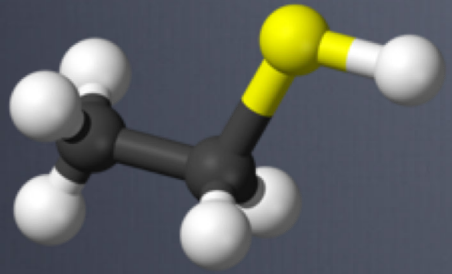
Nell'universo. La vita è fatta di elementi MOLTO comuni!



Element	Abundance	Element	Abundance
H	1.00	Mg	4.2×10^{-5}
He	0.075	Al	3.1×10^{-6}
C	3.5×10^{-4}	Si	4.3×10^{-5}
N	8.5×10^{-5}	S	1.7×10^{-5}
O	5.5×10^{-4}	Ca	2.2×10^{-6}
Na	2.1×10^{-6}	Fe	4.3×10^{-5}

Molecole osservate

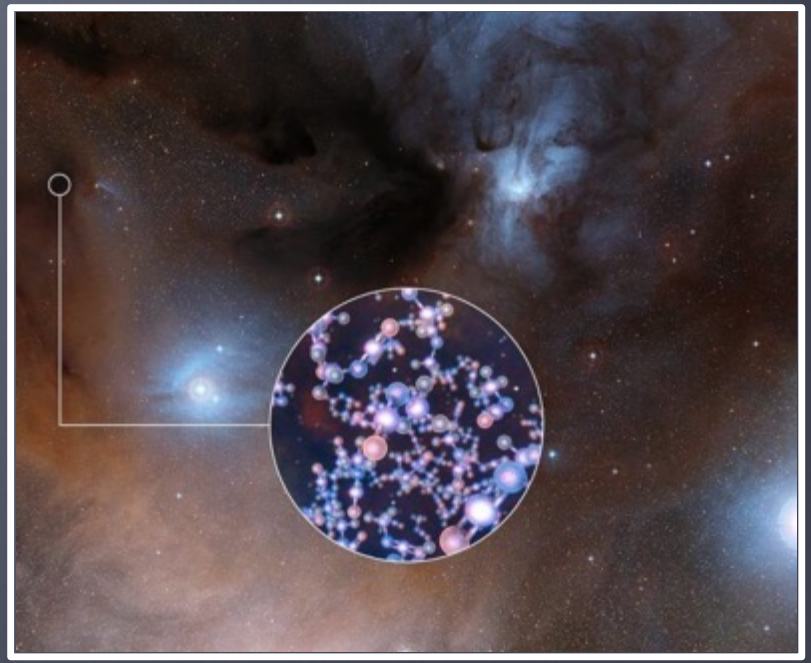
Nel mezzo interstellare: ~ 200 molecole complesse scoperte



Lista completa:

https://www.cv.nrao.edu/~awootten/allmols.html

https://en.wikipedia.org/wiki/List_of_interstellar_and_circumstellar_molecules

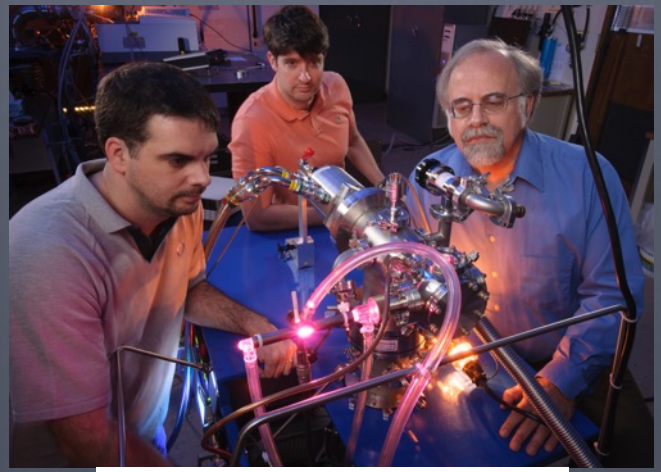


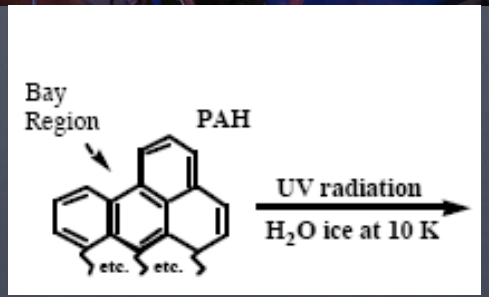
Molecole in laboratorio

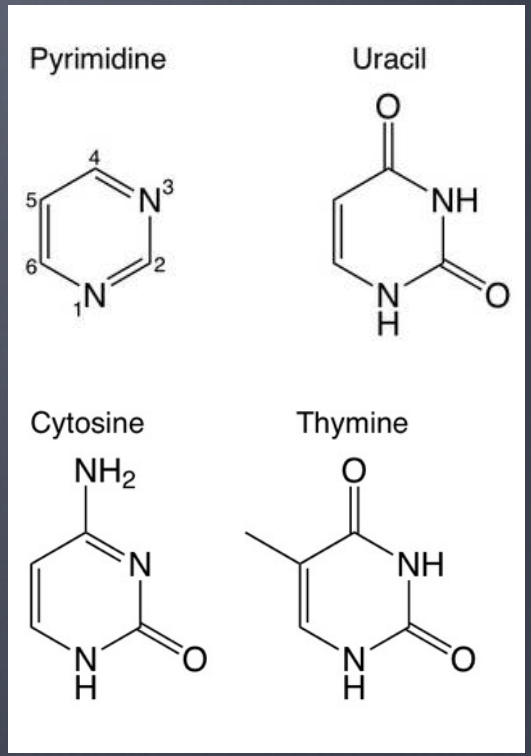
Da PAH a precursori di RNA e DNA

Idrocarburi policiclici aromatici (PAH) sono stati identificati nei meteoriti e zone di formazione stellare.

Esperimenti a NASA Ames:
quando la pirimidina è congelata nel ghiaccio è molto meno vulnerabile alla distruzione da radiazione di quanto sarebbe se fosse nella fase gassosa nello spazio aperto.
Invece di essere distrutte, molte molecole hanno assunto nuove forme, come i componenti dell'RNA / DNA uracile, citosina







James Lovelock

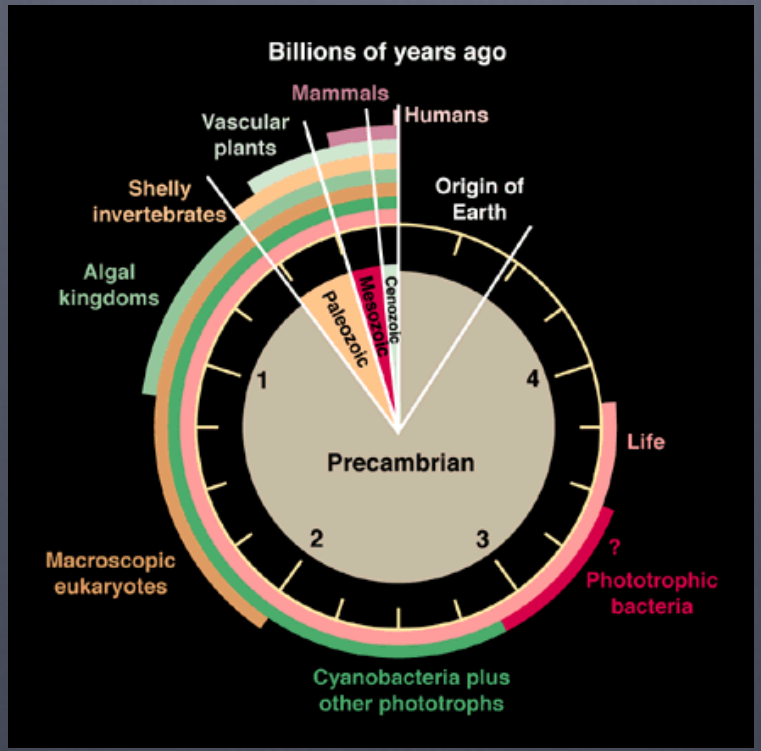
« The history of a planet can not be disentangled from the evolution of the organisms living on that planet »

Gaia A new look at life on Earth, publ. Oxford University Press 1979.

Bio-firme (Lovelock)

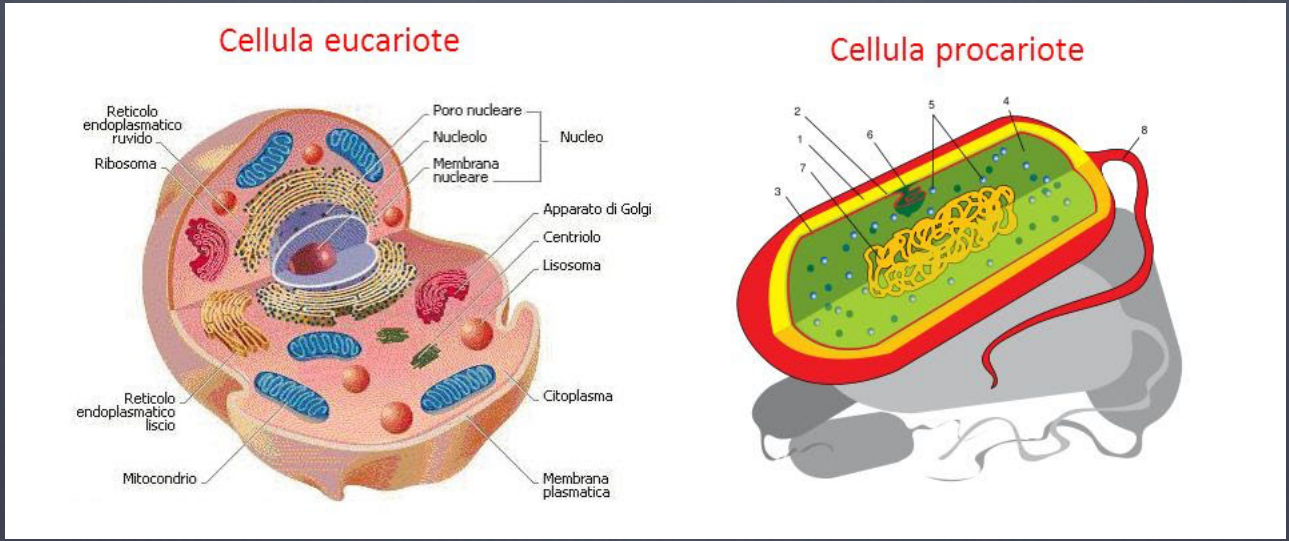
- La presenza di vita su un pianeta cambierebbe la composizione chimica della sua atmosfera, causando un disequilibrio chimico
- Il disequilibrio chimico può essere rivelato anche a distanze astronomiche
- In principio, la presenza di vita potrebbe essere rivelata in spettri emessi/riflessi e trasmessi da atmosfere esoplanetarie…

Vita sulla Terra

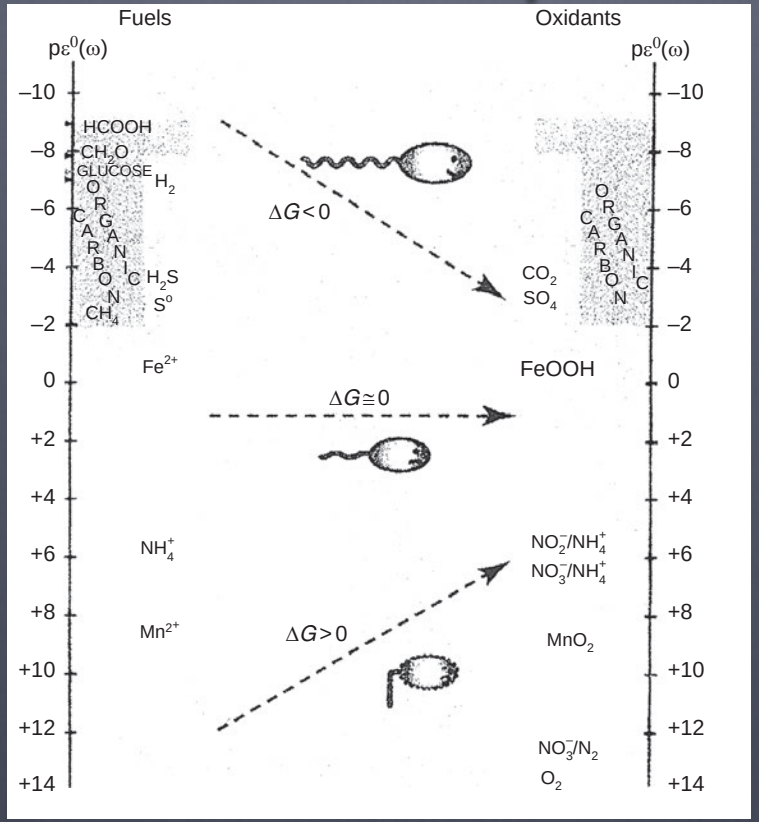


Eucarioti/procarioti

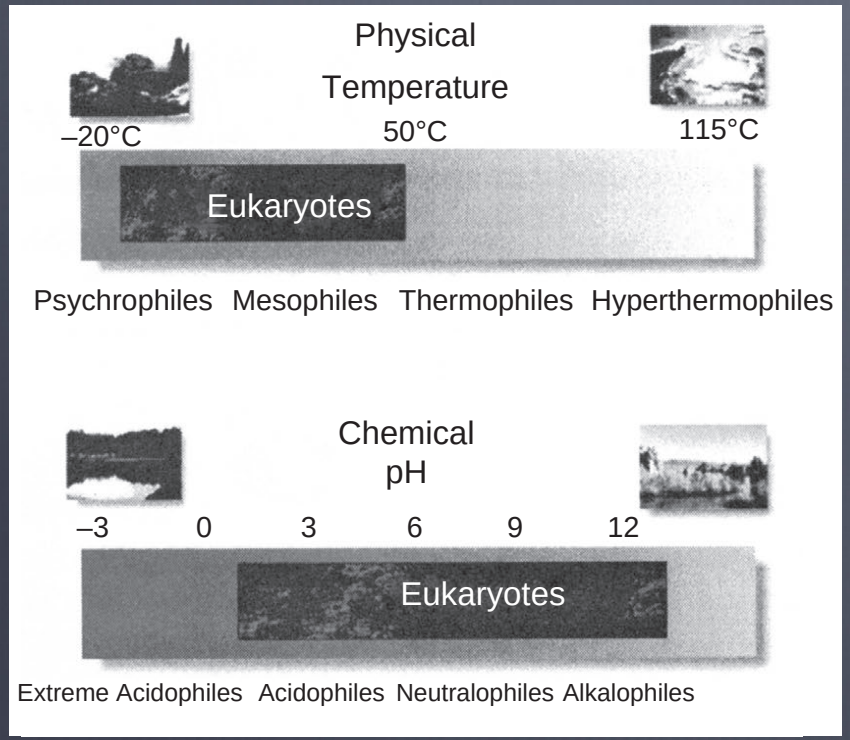
- Eucarioti: nucleo cellulare ben definito, contenente materiale genetico (DNA)

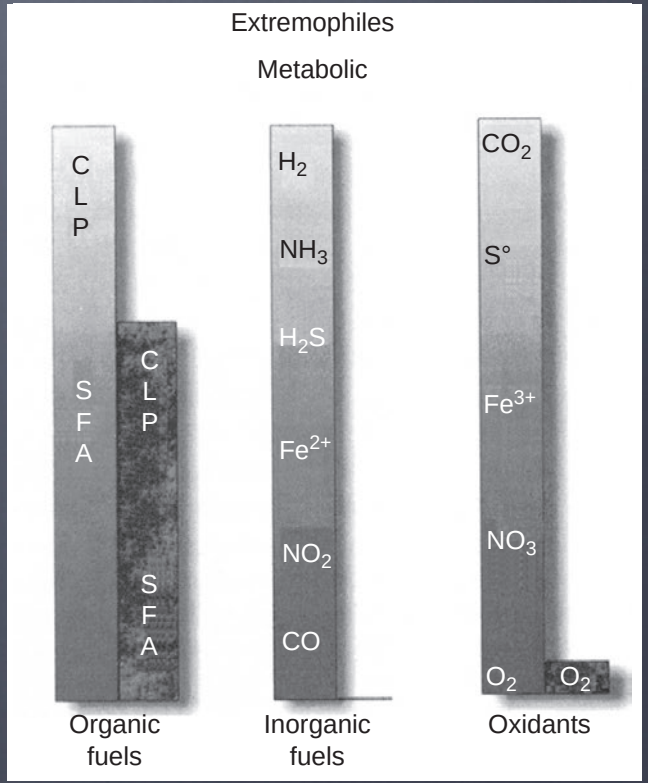


Metabolismo procarioti

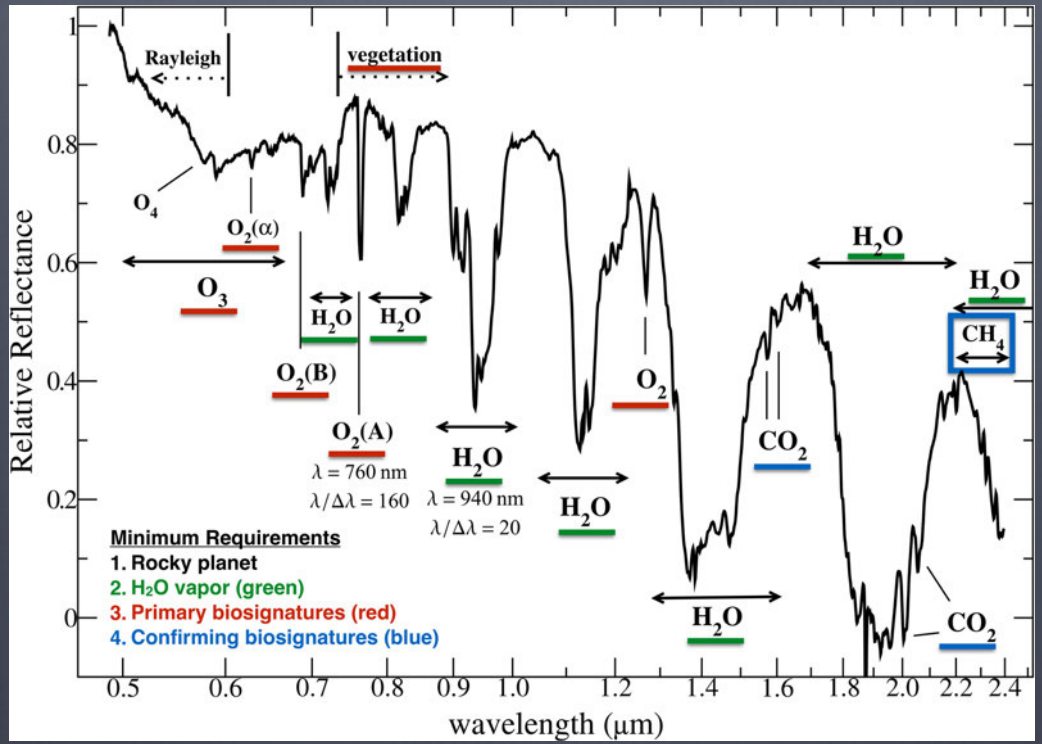


Eucarioti / procarioti

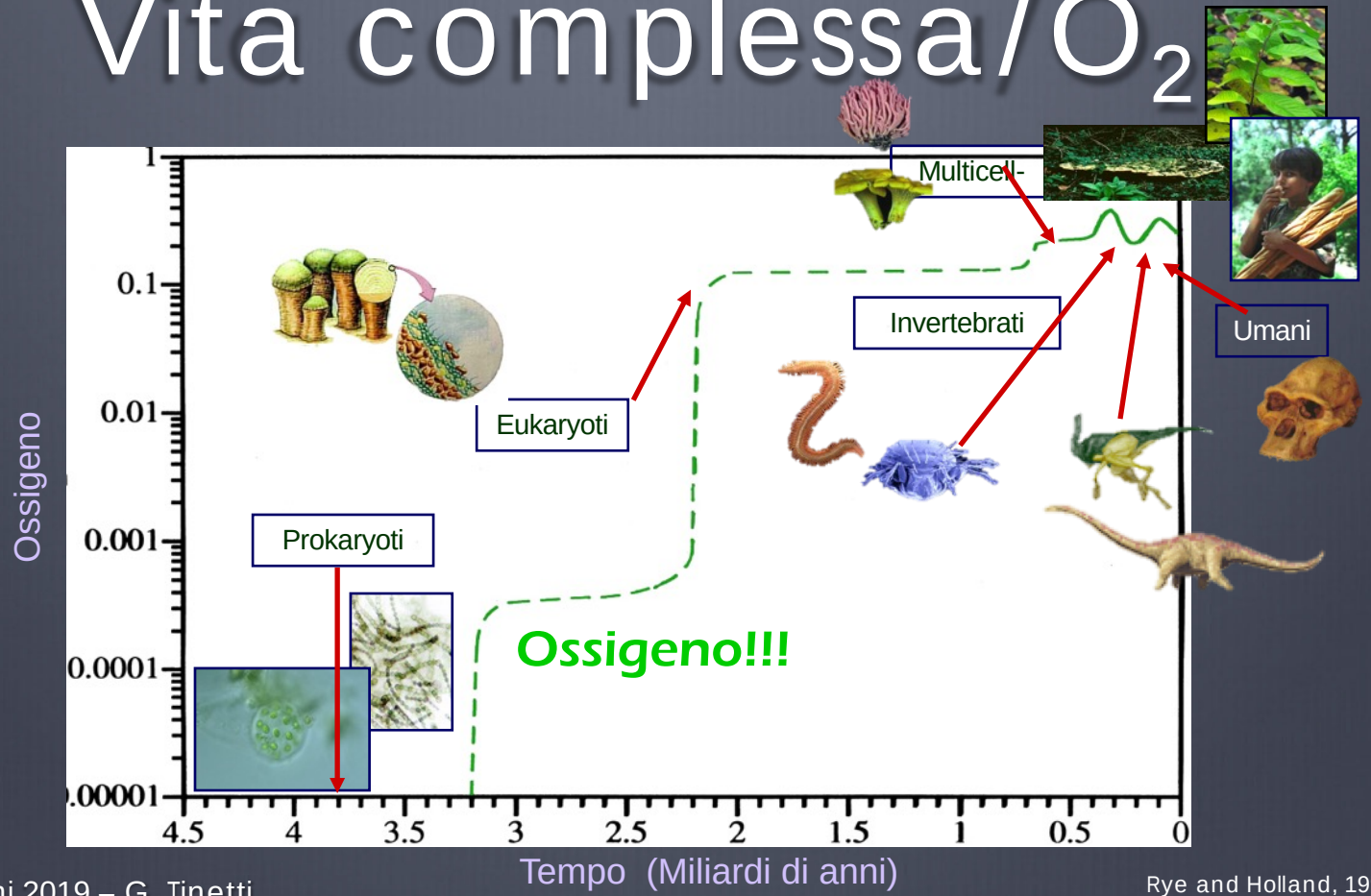




La Terra nel VIS-NIR



Vita complessa/O_2



Rye and Holland, 1998

La Terra nell'infrarosso

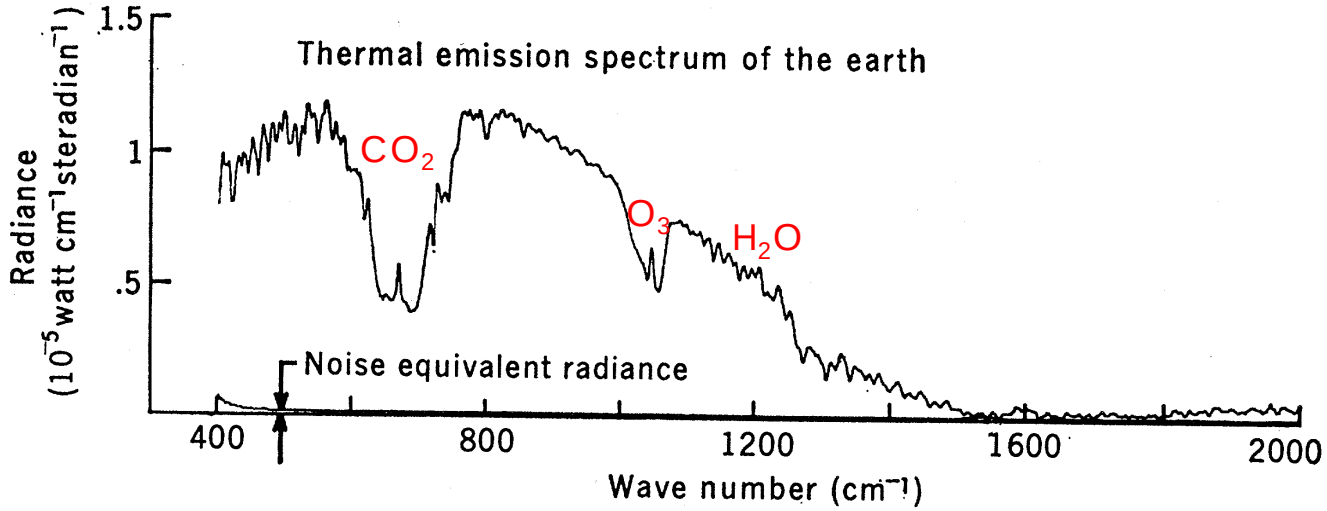
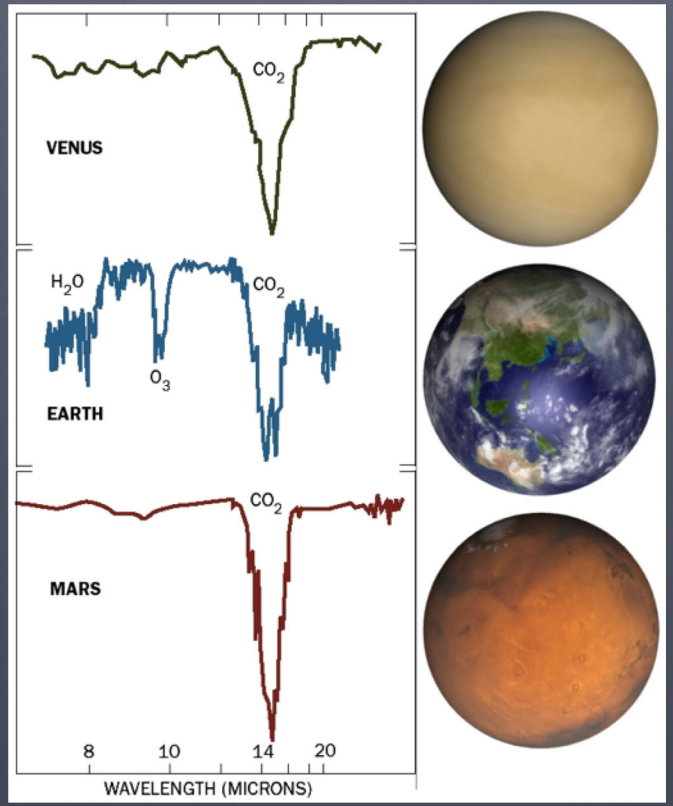


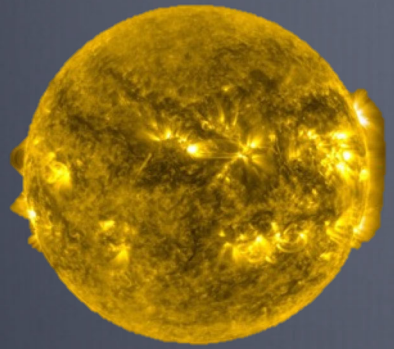
Fig. 1. Thermal emission spectrum of the earth obtained with the infrared interferometer spectrometer (IRIS) carried in the Nimbus 3 satellite. The spectrum was recorded over the equatorial Pacific Ocean on 15 April 1969.

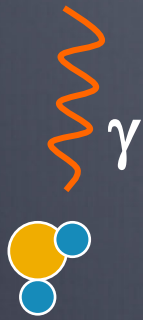
Hanel et al. (1969)

Terra/Venere/Marte



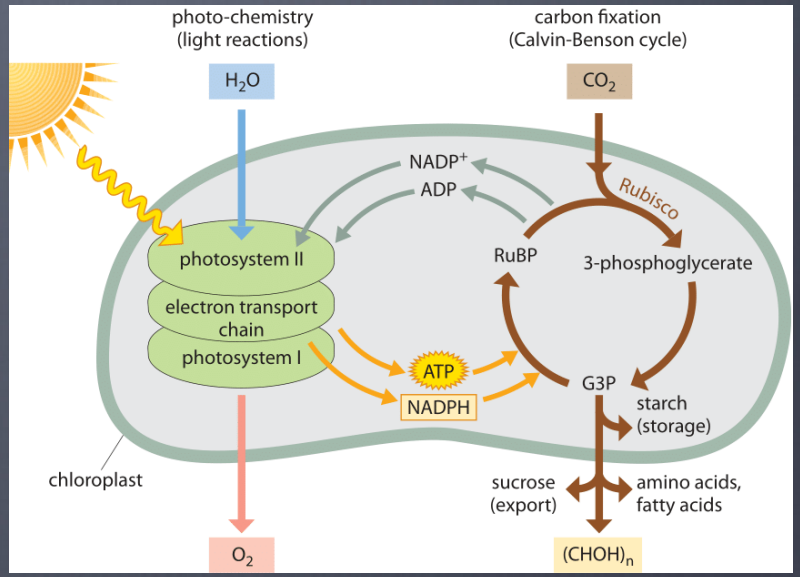
Fotosintesi





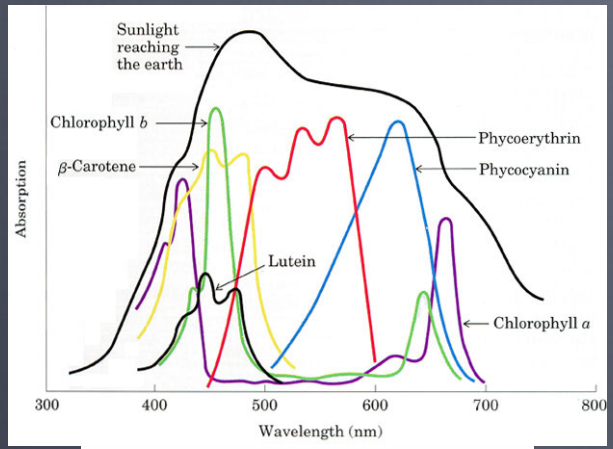
E_γ ~1.8 eV a 700 nm

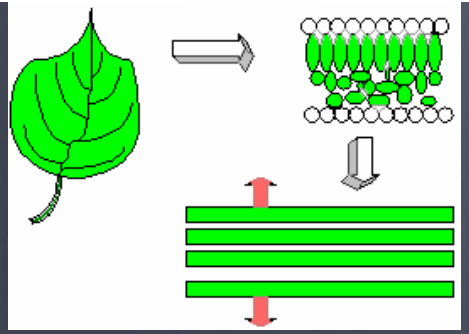
$6CO_2 + 6H_2O + \text{energia solare} \rightarrow C_6H_{12}O_6 + 6O_2$

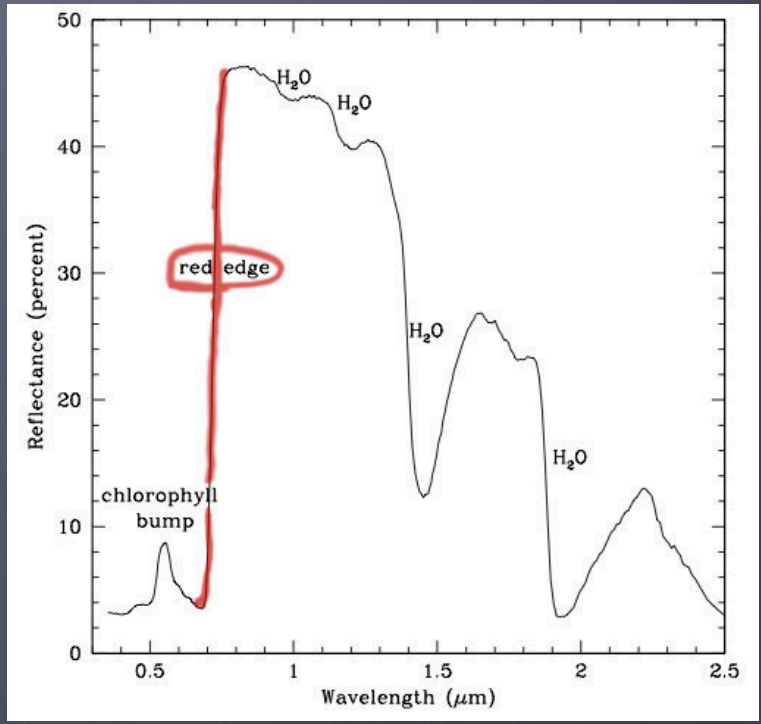


$6CO_2 + 12H_2S \rightarrow C_6H_{12}O_6 + 12S + 6H_2O$: anaerobica

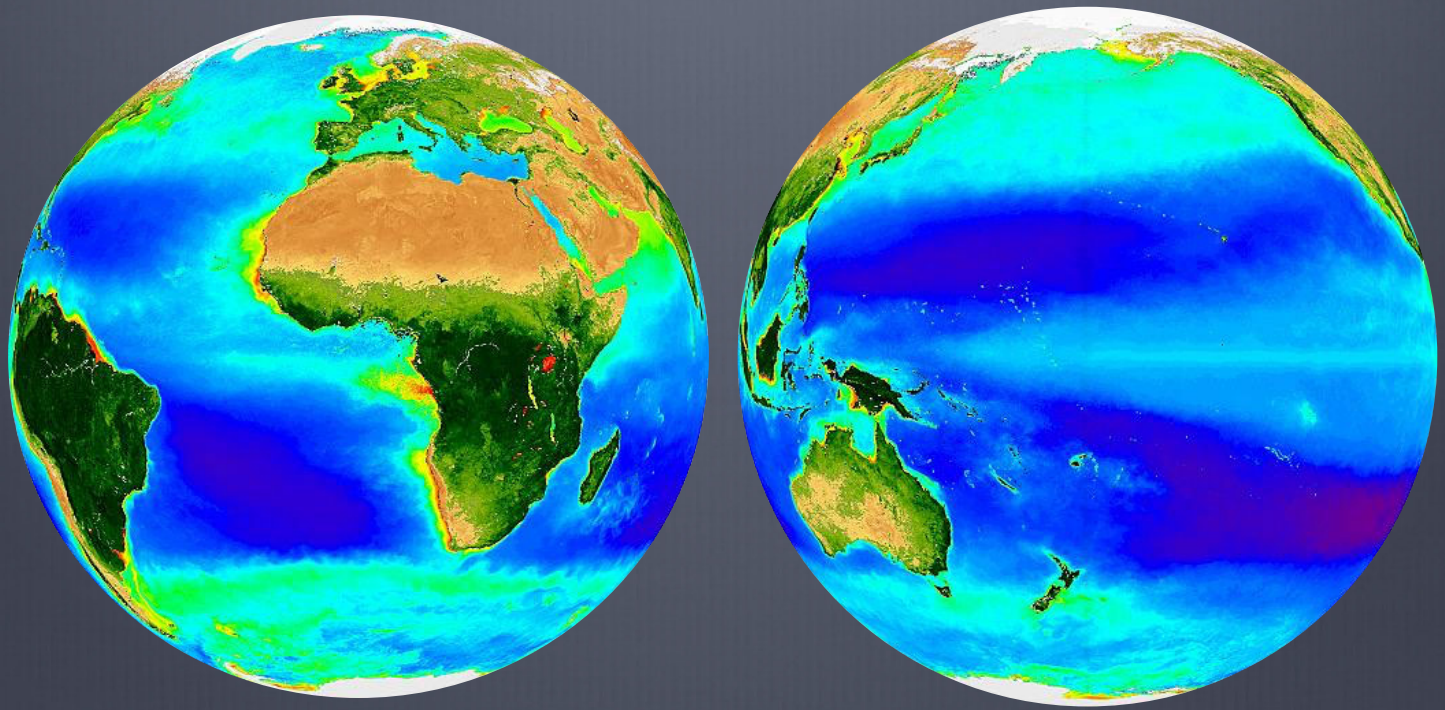
Il “Red-Edge”


Sunlight reaching the earth
Chlorophyll b
β-Carotene
Phycoerythrin
Phycocyanin
Lutein
Chlorophyll a
Absorption
300
400
500
600
700
800
Wavelength (nm)

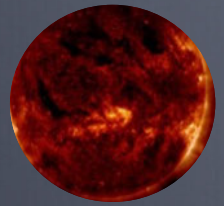


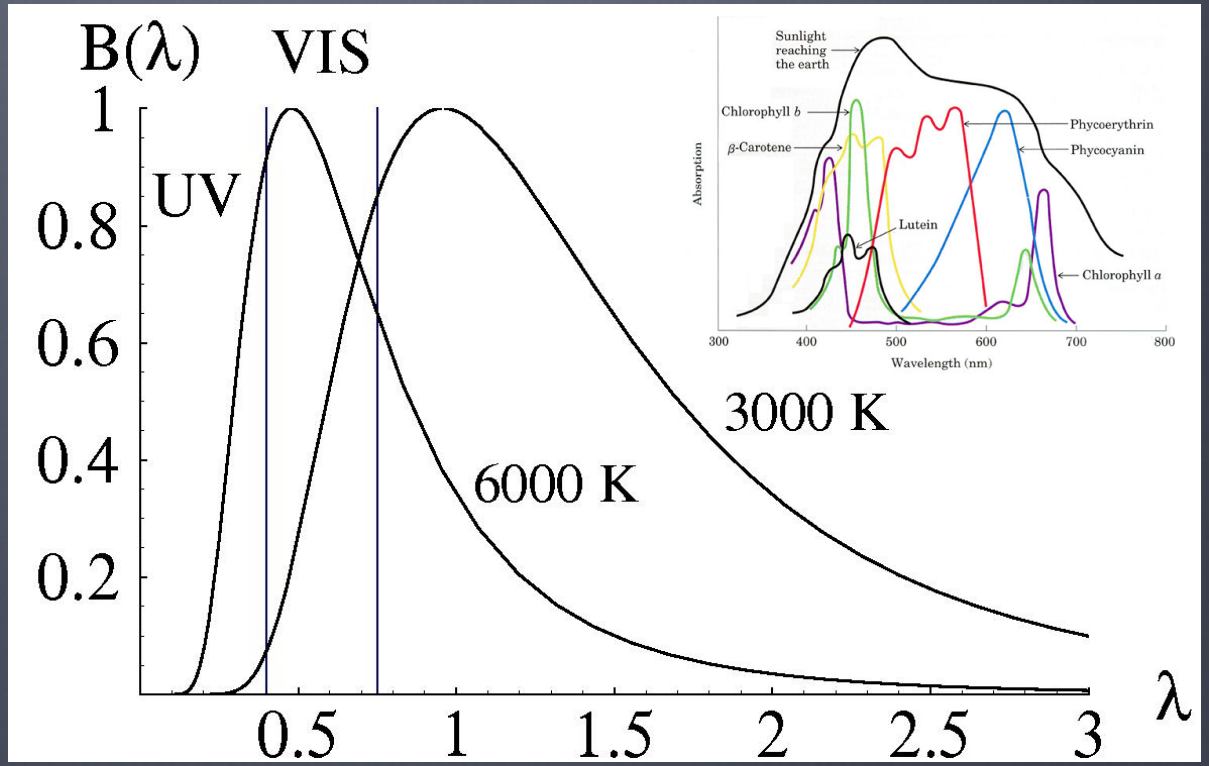

50
40
30
20
10
0
Reflectance (percent)
H2O
H2O
H2O
H2O
red edge
chlorophyll bump
0.5
1
1.5
2
2.5
Wavelength (μm)

Firma vegetazione



Fotosintesi per altre stelle





Fotosintesi x stelle M

Icarus **157**, 535–548 (2002)
doi:10.1006/icar.2002.6854

Photosynthesis: Likelihood of Occurrence and Possibility of Detection on Earth-like Planets

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Received August 4, 2000; revised February 21, 2002

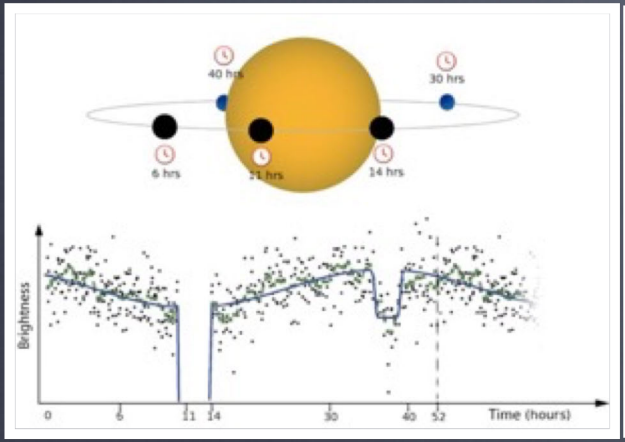
3 fotoni invece di 2!

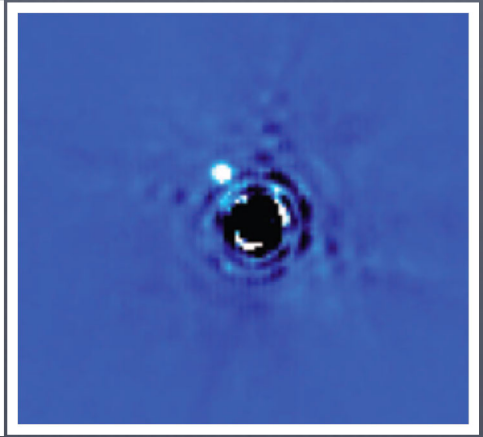
γ a 1050 nm

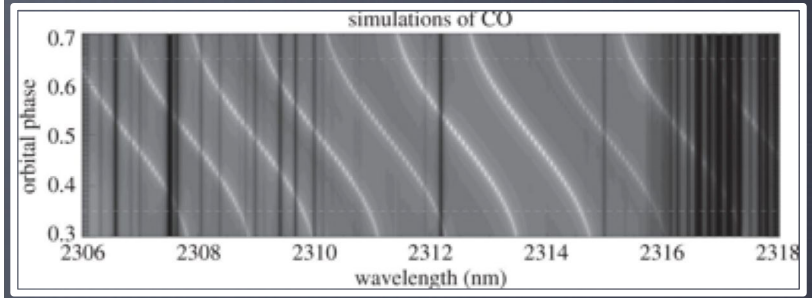
Red-edge su altri pianeti?

Spettroscopia esoplanetaria

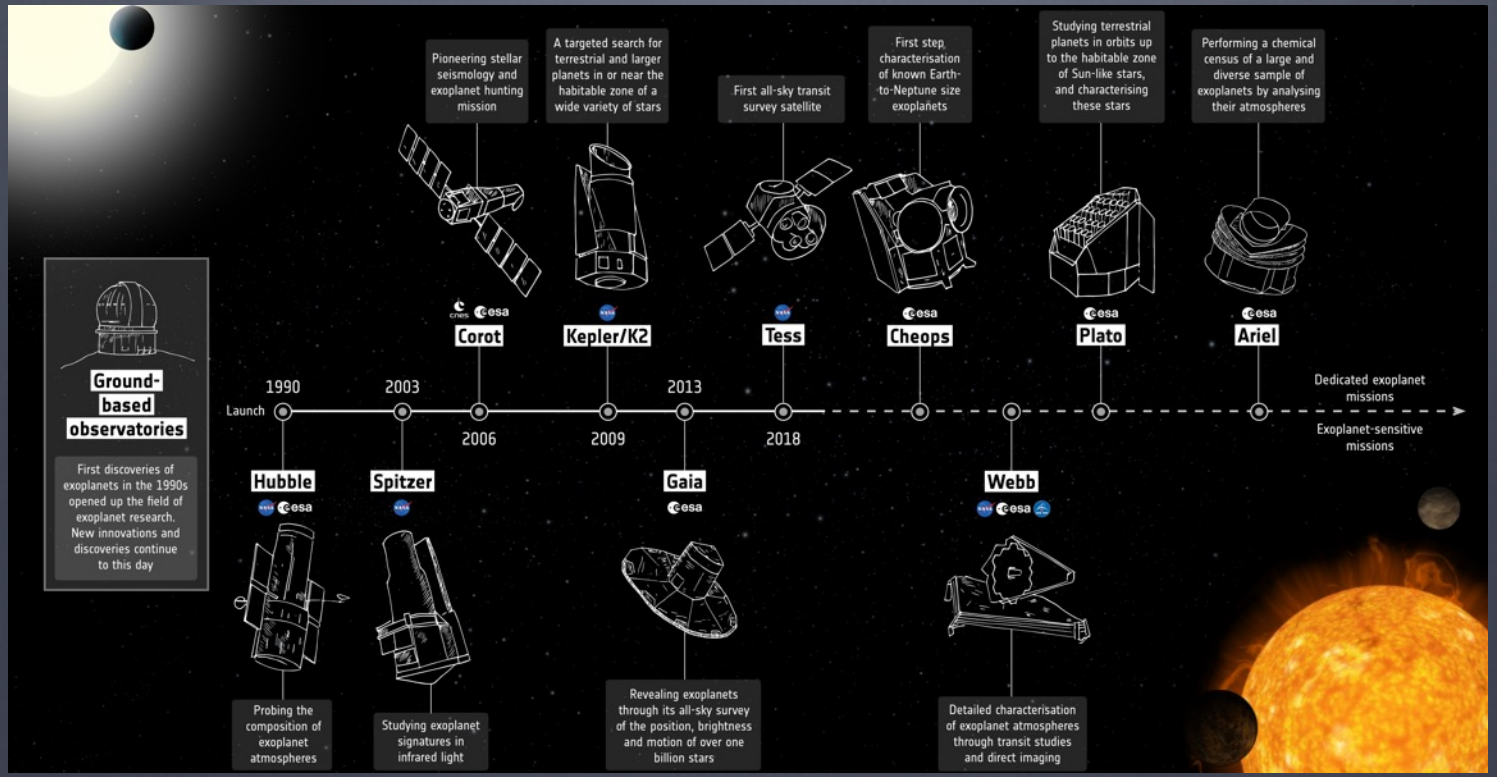
Varie tecniche







Il futuro…


Ground-based observatories
First discoveries of exoplanets in the 1990s opened up the field of exoplanet research. New innovations and discoveries continue to this day
Launch
1990
2003
2006
2009
2013
2018
Dedicated exoplanet missions
Exoplanet-sensitive missions
Hubble
Spitzer
Gaia
Webb
Corot
Kepler/K2
Tess
Cheops
Plato
Ariel
Pioneering stellar seismology and exoplanet hunting mission
A targeted search for terrestrial and larger planets in or near the habitable zone of a wide variety of stars
First all-sky transit survey satellite
First step characterisation of known Earth-to-Neptune size exoplanets
Studying terrestrial planets in orbits up to the habitable zone of Sun-like stars, and characterising these stars
Performing a chemical census of a large and diverse sample of exoplanets by analysing their atmospheres
Probing the composition of exoplanet atmospheres
Studying exoplanet signatures in infrared light
Revealing exoplanets through its all-sky survey of the position, brightness and motion of over one billion stars
Detailed characterisation of exoplanet atmospheres through transit studies and direct imaging

James Webb Space Telescope

Adatto a osservare pianeti che transitano nella zona abitabile di stelle M

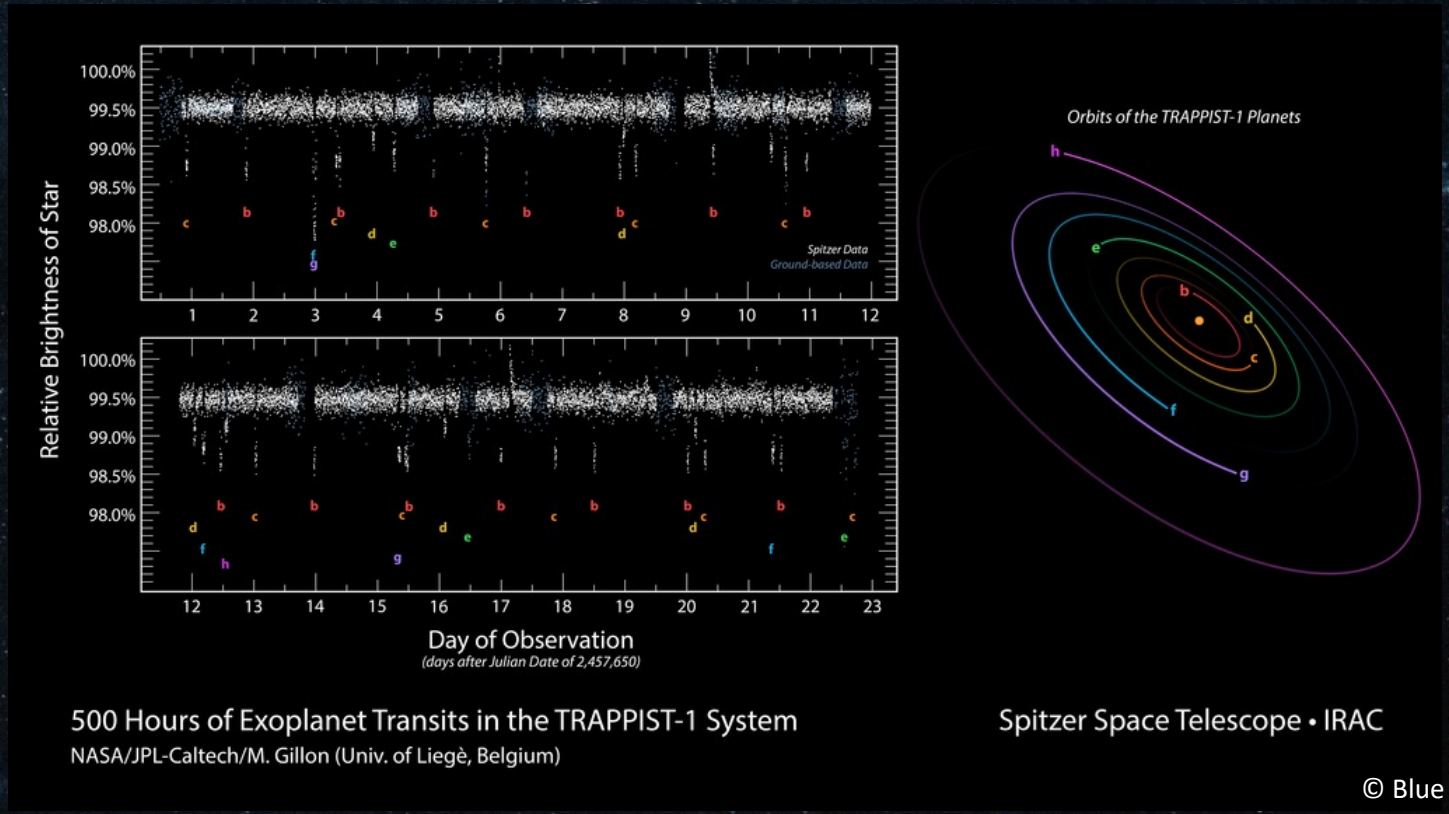
- Specchio 6.5 m di diametro,
- Lancio in L2 nel 2021
- Strumenti nell'infrarosso molto sensisbili

European Space Agency

Catt

Come scoprire più pianeti come i Trappist-1

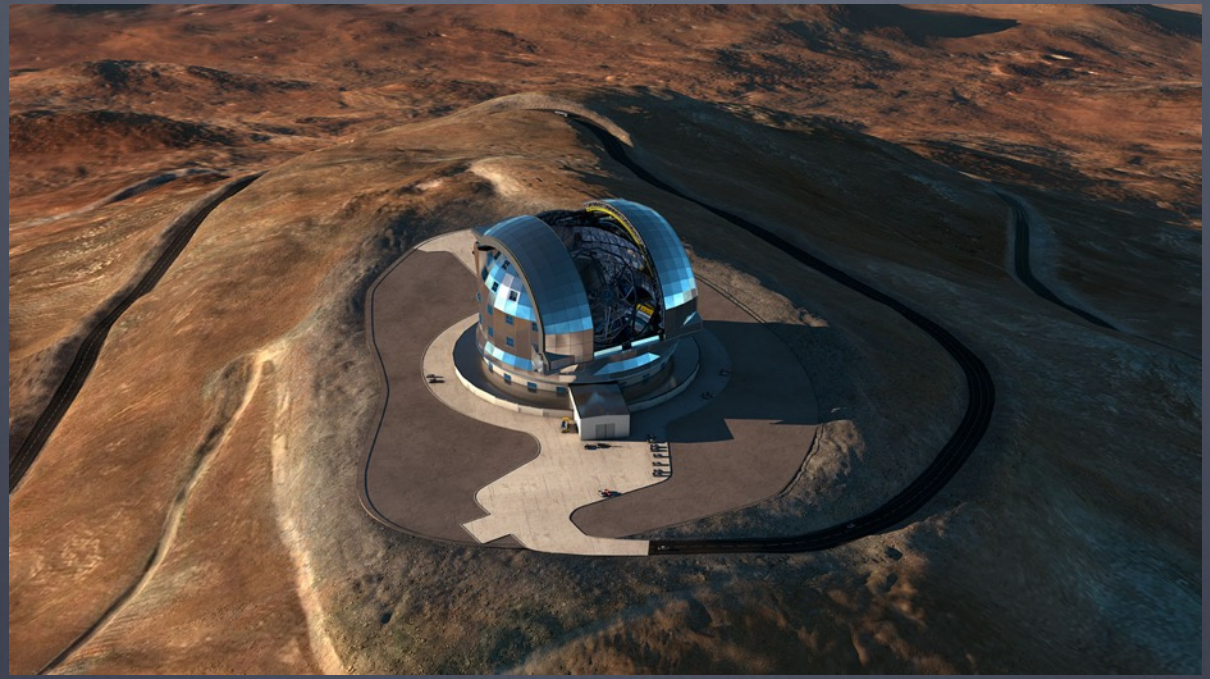
Con Twinkle unitamente a strumenti da terra



© Blue Skies Space 2019

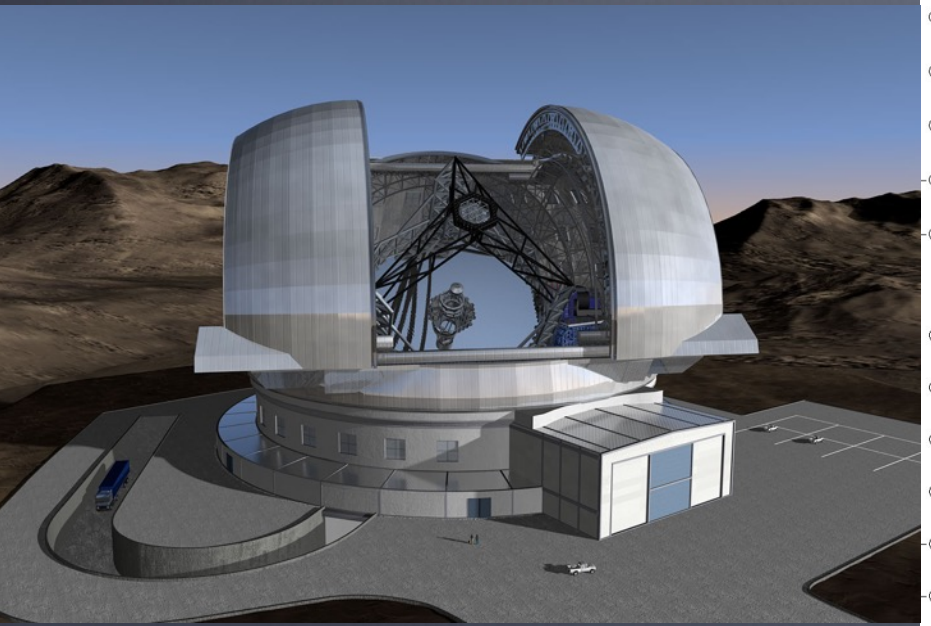
Extremely Large Telescope

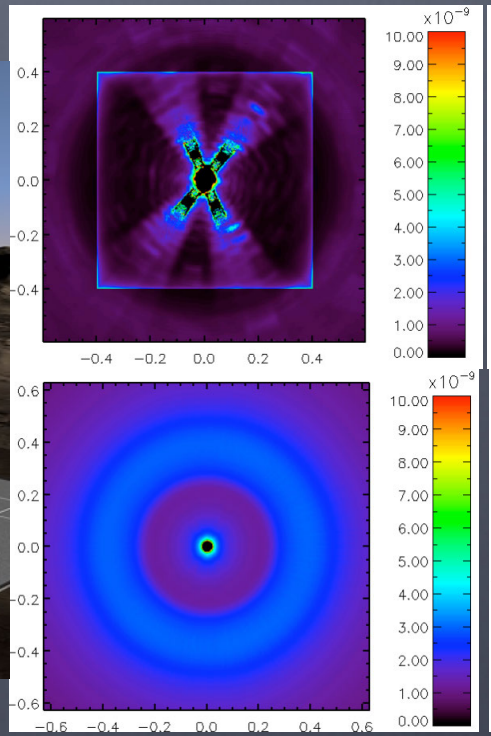
Telescopio di ~30m nel deserto dell'Atacama

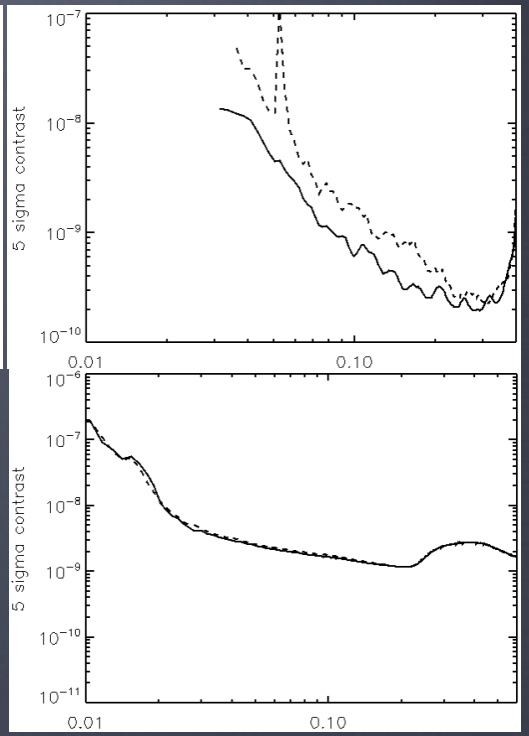


Estremely Large Telescope

Strumento EPICS studiato ma non ancora approvato





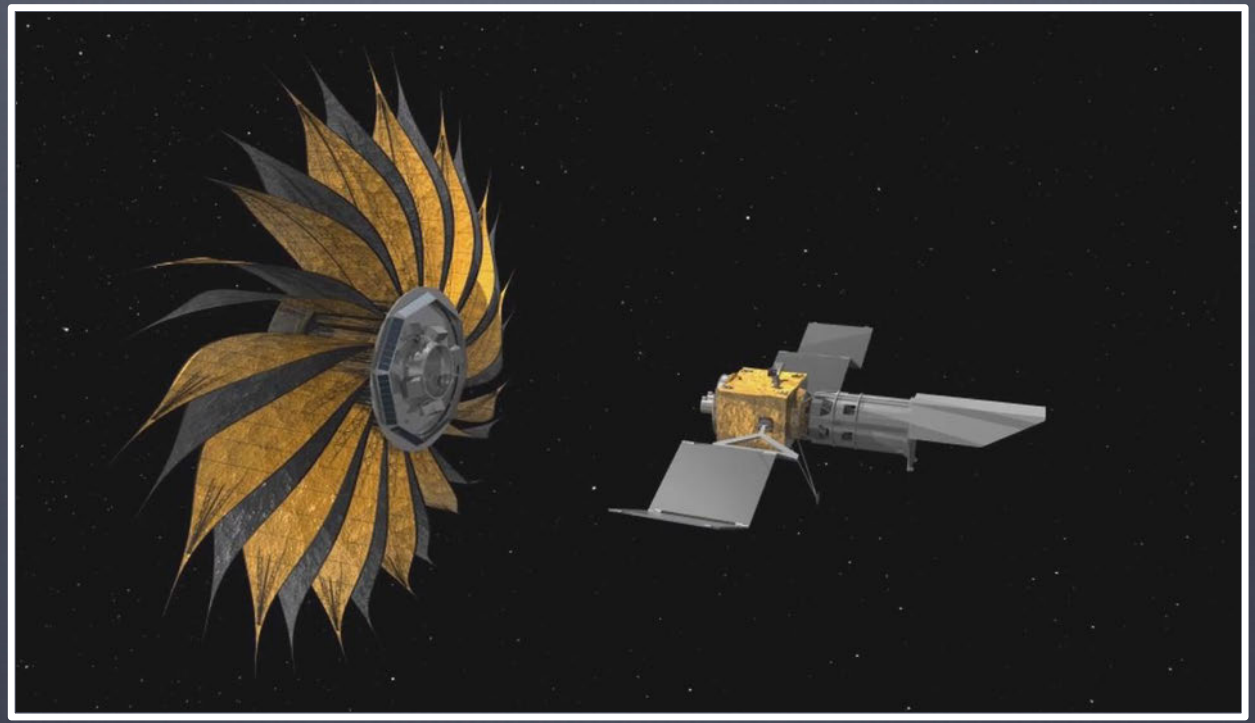


NASA WFIRST

Lancio 2025+. Gioviani freddi con direct imaging

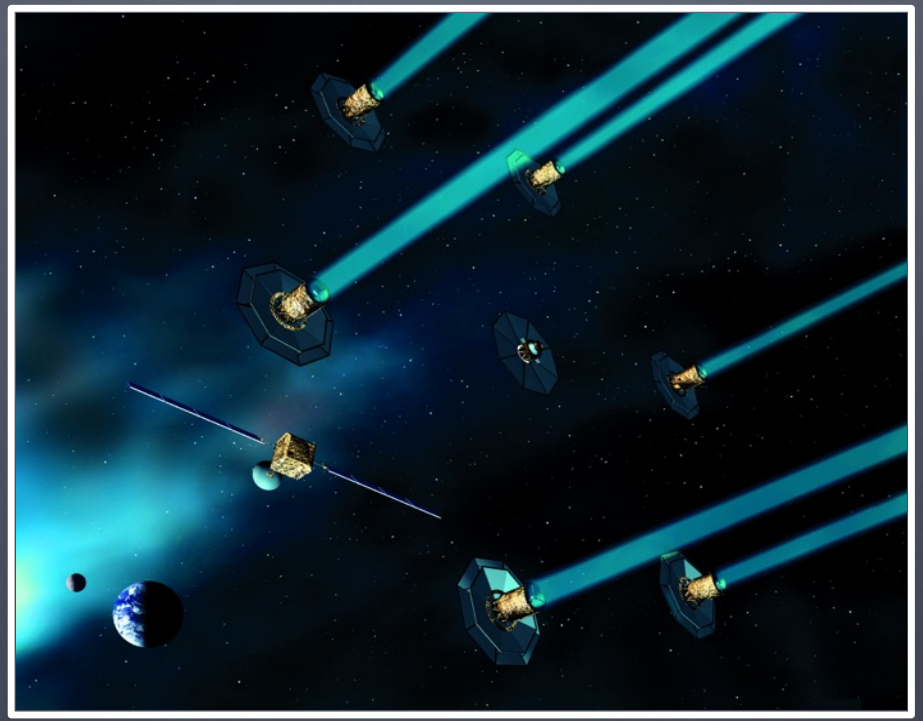
Coronagrafo esterno

Fantascienza?

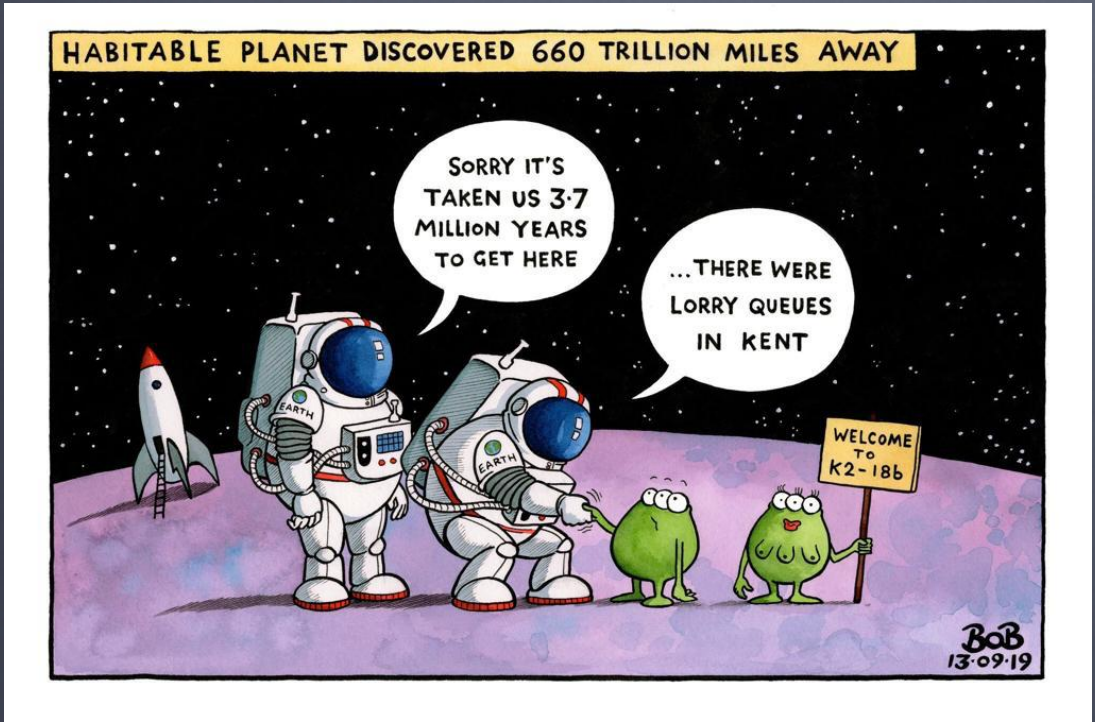


Interferometro nello spazio

Fantascienza?



Conclusione:



Abbiamo cura di questo pianeta!