Habitabilidade

O Problema
da “Cachinhos Dourados”

ou, mais prosaicamente,
sintonia fina

Habitabilidade
Três níveis

- Cosmos Biofílico
- Zona Habitável Galáctica
- Zona Habitável Estelar

Nível mais básico
da habitabilidade

“Zona da Cachinhos Dourados”
nos sistemas planetários

Zona Habitável Estelar

A História da Cachinhos Dourados

Nem quente demais, senão ferve

Nem frio demais, senão congela

No Sistema Solar:

- Vênus sempre foi quente demais
- Marte, no passado, já esteve no ponto.
- A Terra em geral esteve no ponto, exceto em duas ocasiões de quase total congelamento

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THE GOLDILOCKS PROBLEM: Climatic Evolution and Long-Term Habitability of Terrestrial Planets

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KEY WORDS: atmospheric evolution, greenhouse effect, Mars, Venus

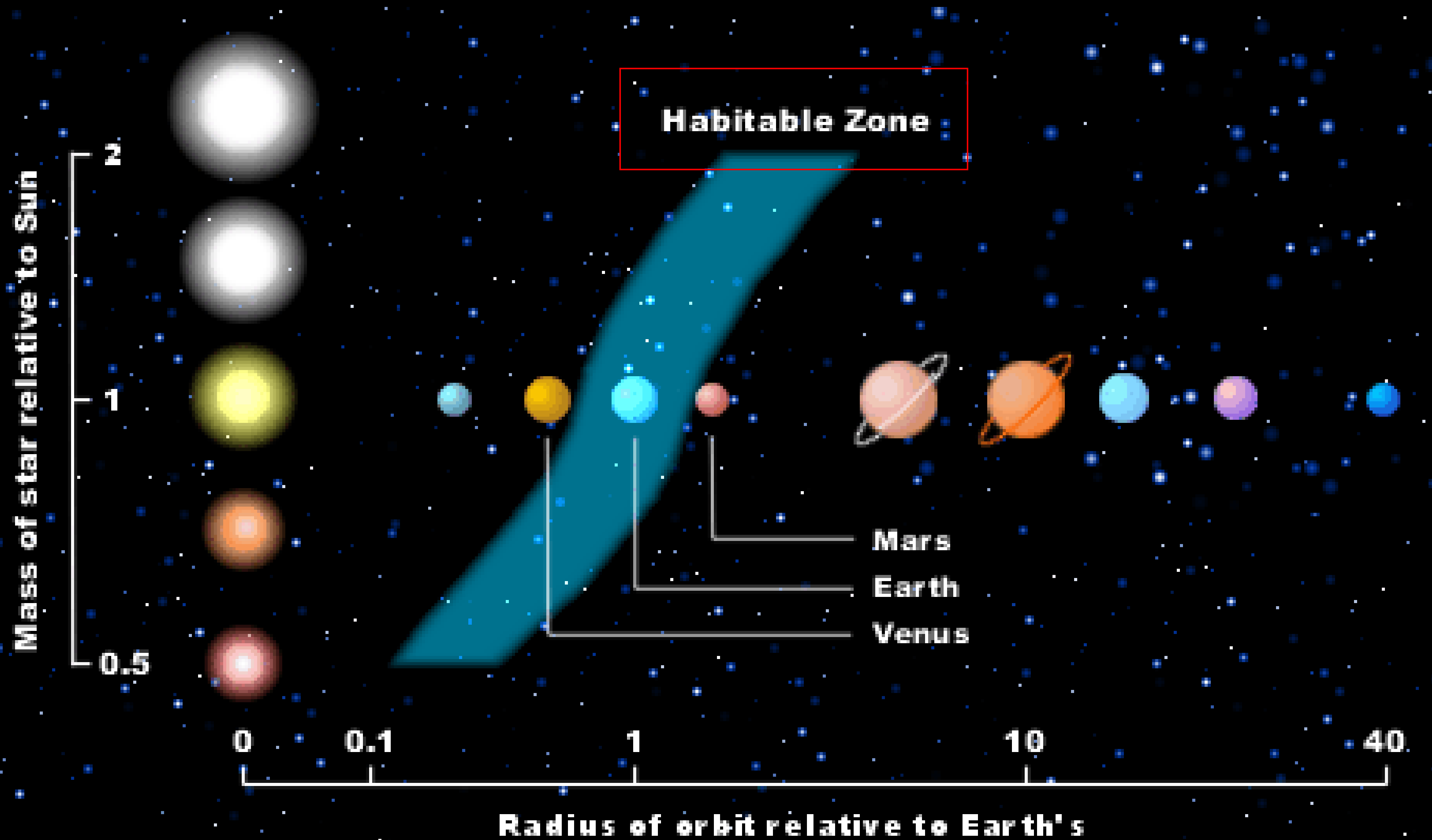
INTRODUCTION

Why is Venus too hot, Mars too cold, and Earth "just right" for life? (The allusion to the fairy tale involves the three bowls of porridge belonging to Papa Bear, Mama Bear, and Baby Bear—one too hot, one too cold, and one just right—tested by a hungry Goldilocks.) A simplistic answer might be that a planet's surface temperature is to a large extent a function of its distance from the Sun, and Earth just happens to be at the "right" distance for comfortable temperatures and liquid water. However, this is far from the whole story.

The Goldilocks Problem involves the early history of the planets and the evolution of their atmospheres. Its solution must also take into consideration the long-term evolution of the Sun, and hence the so-called faint young Sun problem, that is, the fact that the early Earth was apparently warm enough for liquid water despite the 25–30% lower luminosity of the early Sun (Newman & Rood 1977; Gough 1981). Had Earth been too cold initially for liquid water to exist on its surface, the resulting icy planet would have had a high albedo or reflectivity, lowering temperatures further, and might have become irreversibly ice-covered—the "white Earth catastrophe" (Caldeira & Kasting 1992a). Yet

Zona Habitável Estelar

Água Líquida → Zona Habitável



The Habitable Zone (HZ)

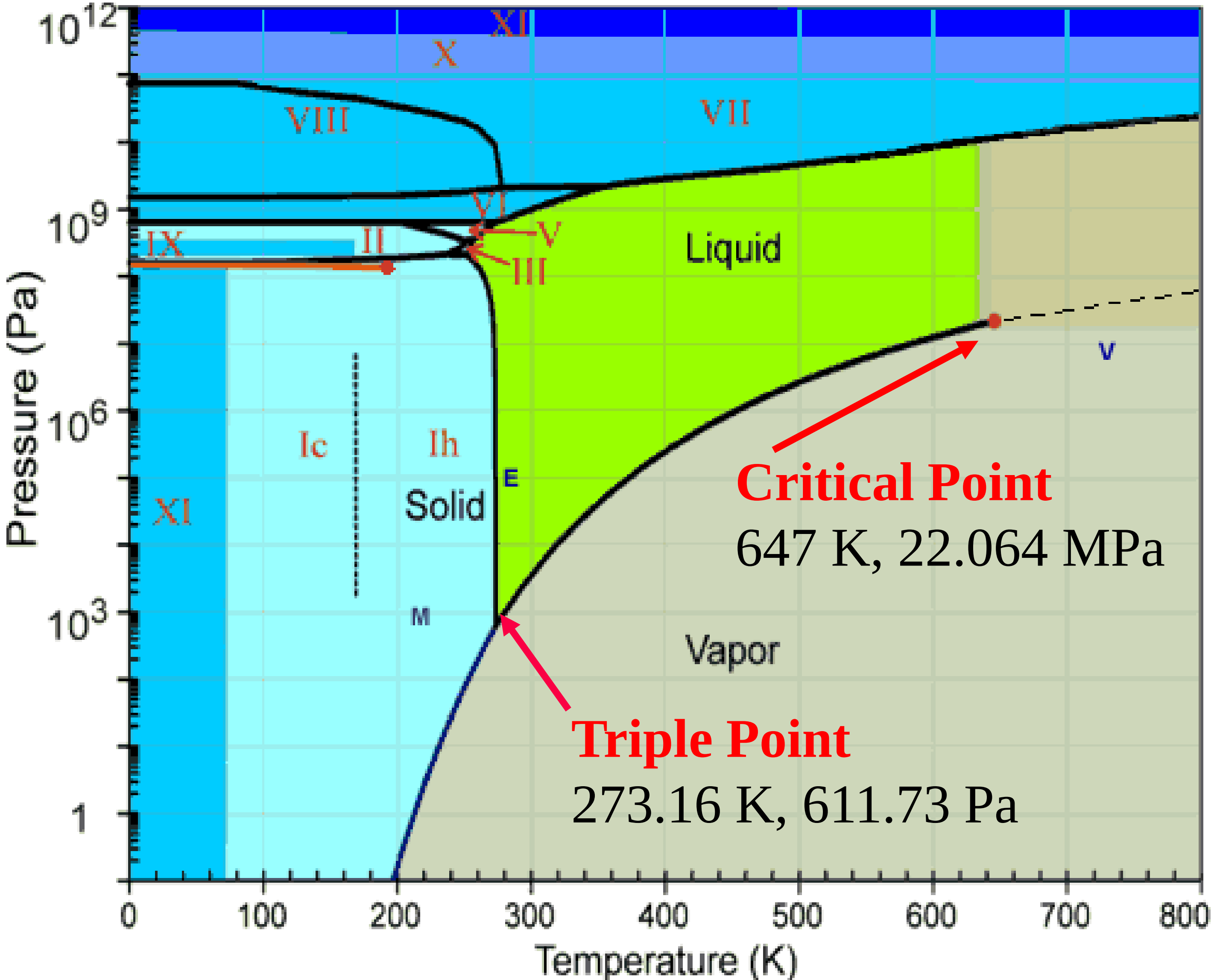
Definition: region around a star where the *Temperature* on the surface of an eventual planet or moon can afford the presence of liquid water.

Conditions: the position and width of the HZ depends on the presence and composition of the atmosphere (greenhouse effect - GE).

On **EARTH**: GE raises temperature by ~33 °C

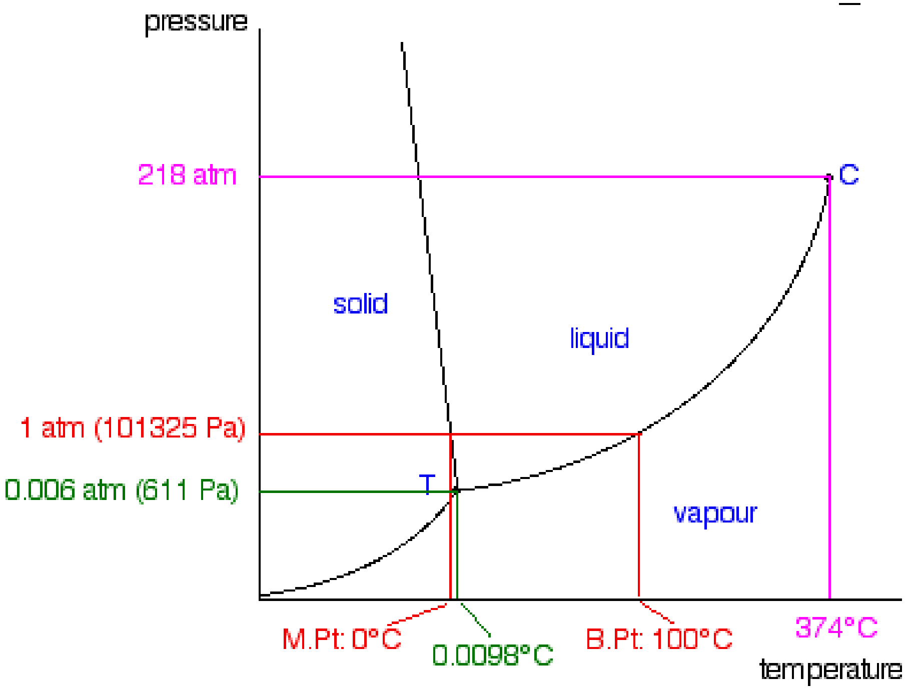
Dependence on pressure: the presence of liquid water requires not only a temperature range but also a minimum pressure (610 Pa)

Phase Diagram for Water

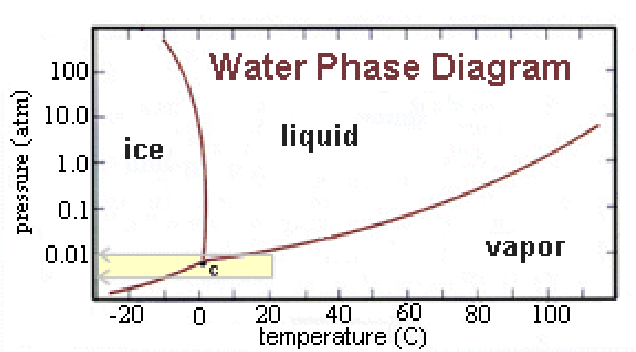


Não pode haver H_2O líquido abaixo de 0.006 atm (Marte)
Não pode haver CO_2 líquido abaixo de 5 atm – gelo seco

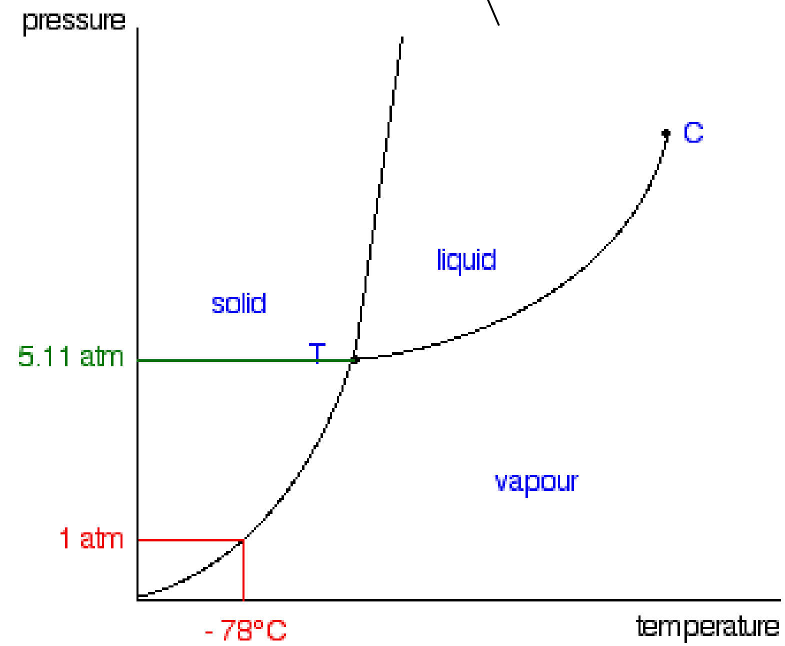
H_2O



Separatriz sólido-liquido
do H_2O inclinada para a direita
$\Rightarrow$ gelo da H_2O mais leve que a líquida
do CO_2 inclinada para a direita
$\Rightarrow$ gelo do CO_2 mais denso que o líquido

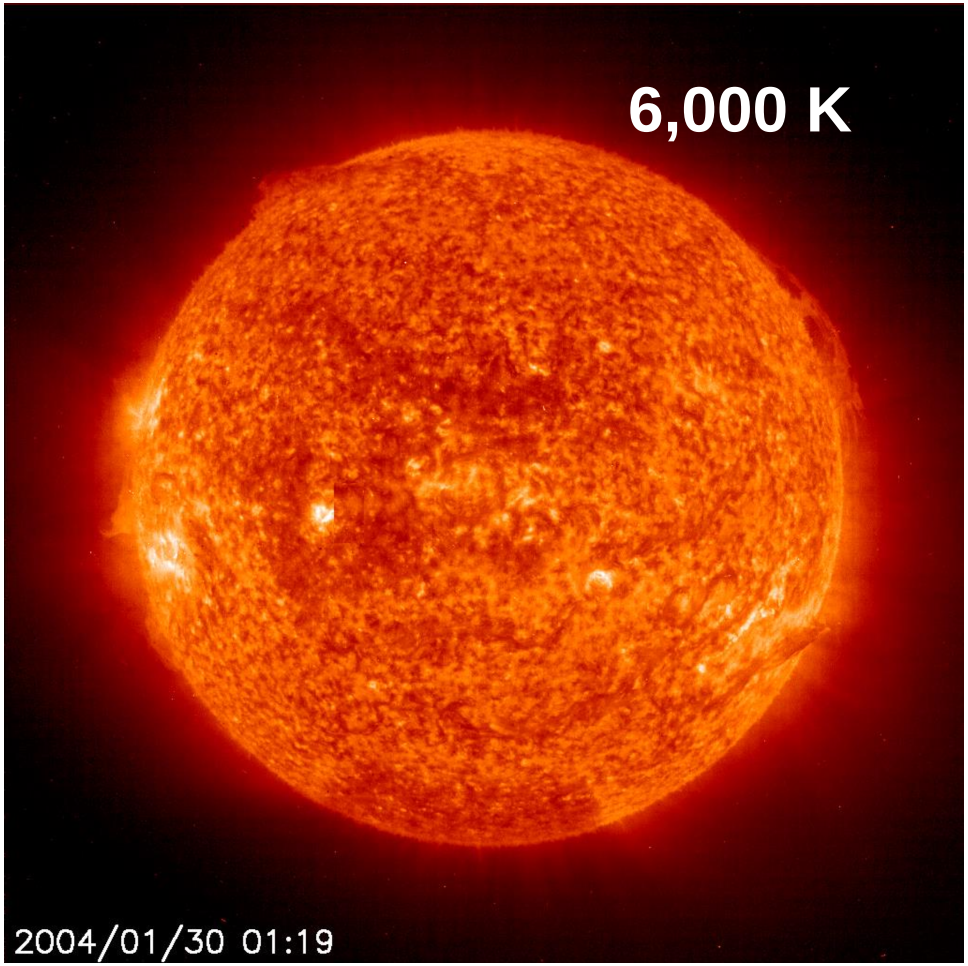


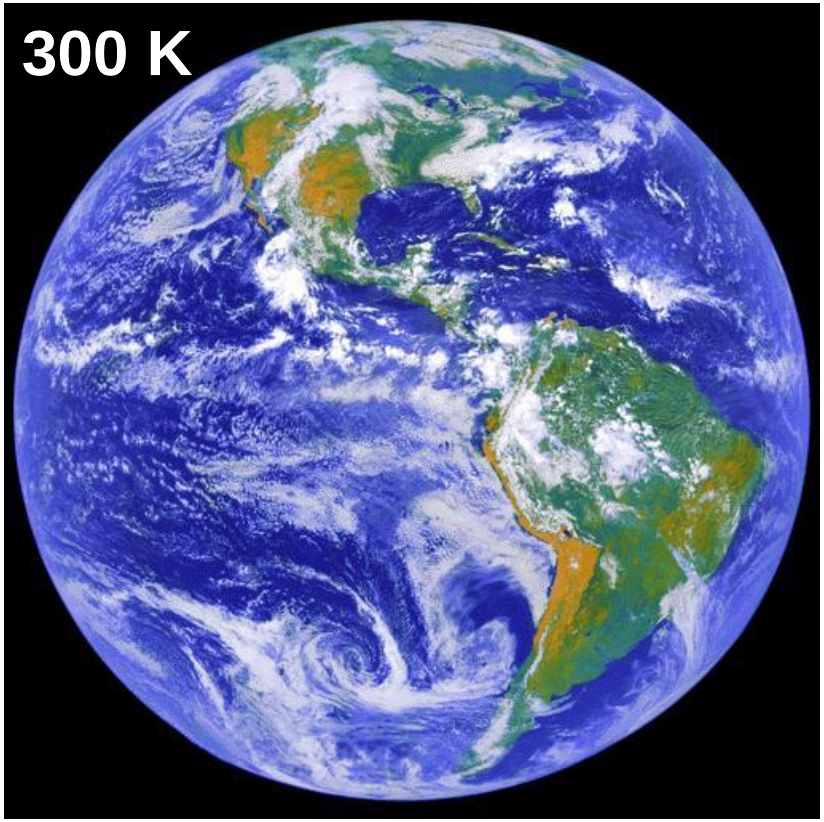
CO_2



Example: Earth-Sun

The Earth’s temperature (about 300K) is maintained by the energy radiating from the Sun.





Planetary Energy Balance

- We can estimate average planetary temperature using the Energy Balance approach

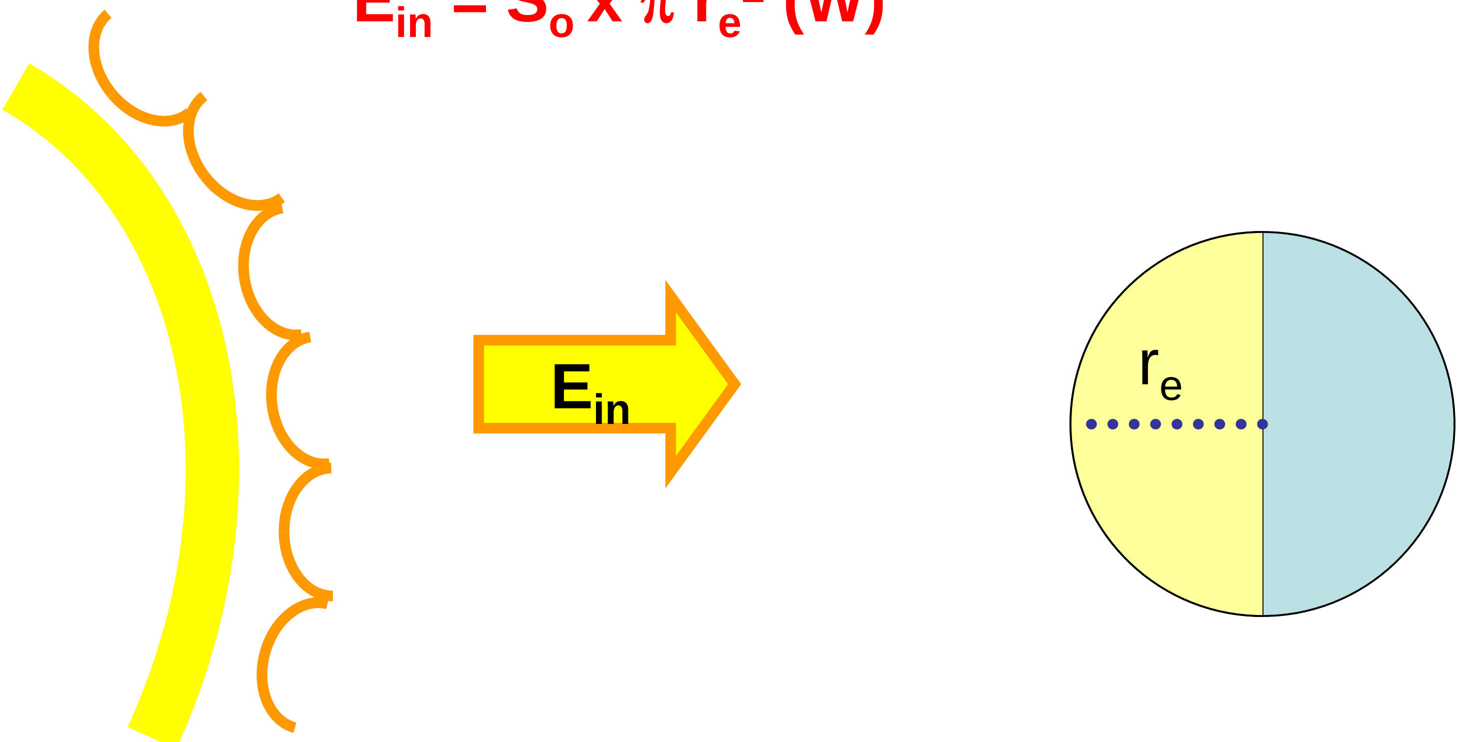
$$\mathbf{E_{in} = E_{out}}$$

E_{in}

How much solar energy gets to the Earth?

Assuming solar radiation covers the area of a circle defined by the radius of the Earth (r_e)

$$E_{in} = S_o\ (W/m^2) \times \pi\, r_e^2\ (m^2)$$
$$E_{in} = S_o \times \pi\, r_e^2\ (W)$$



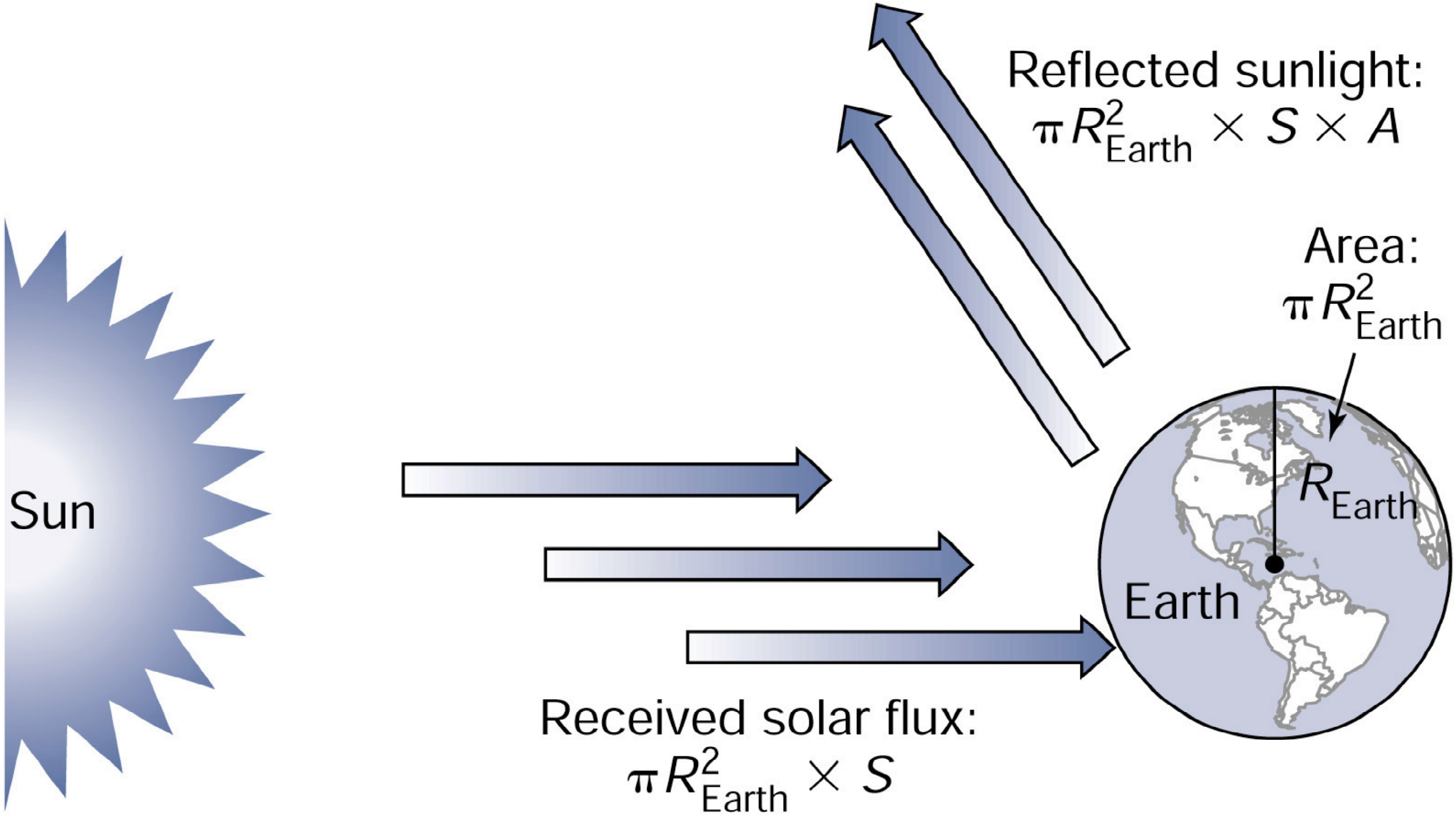
E_{in}

How much solar energy gets to the Earth's surface?

****Some energy is reflected away****

⇒ Albedo (A)

$$E_{in} = S_o \times \pi r_e^2 \times (1-A)$$

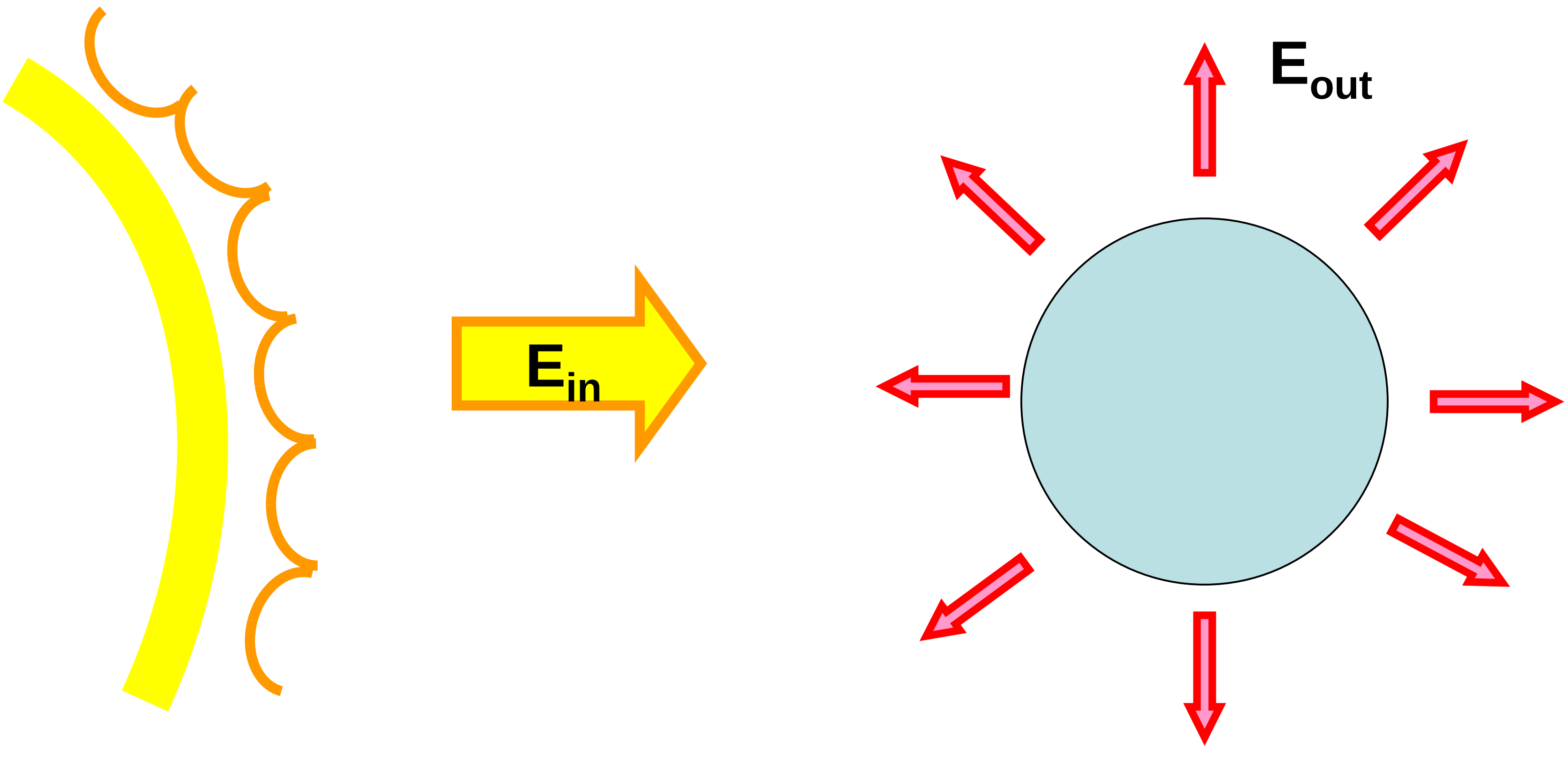


E_{out}

Energy Balance:

The amount of energy delivered to the Earth is equal to the energy lost from the Earth.

Otherwise, the Earth's temperature would continually rise (or fall).



E_{out}

➡ *Stefan-Boltzmann law*

$$F = \sigma T^4$$

F = flux of energy (W/m^2)

T = temperature (K)

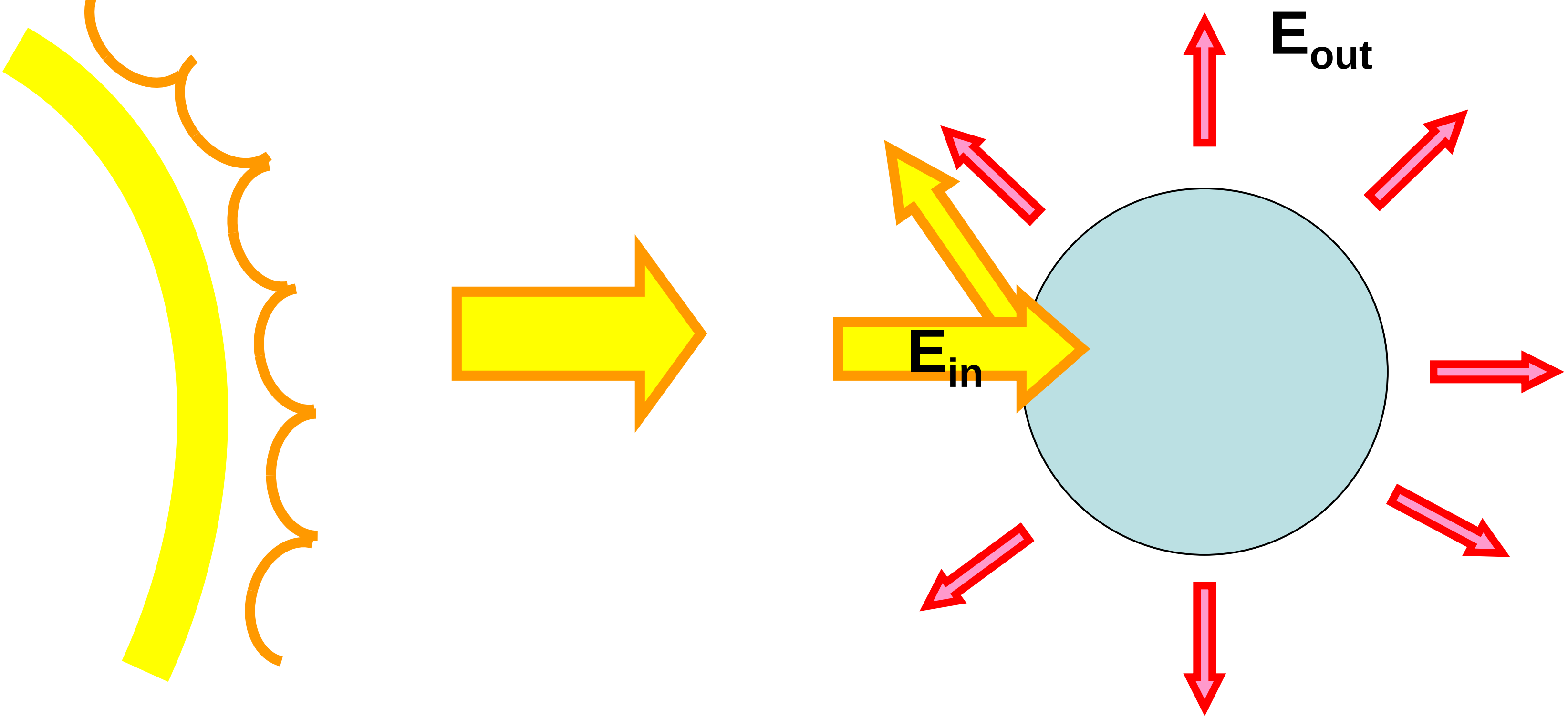
$\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$ (a constant)

Energy Balance:

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

$$E_{in} = S_o \, \pi \, r_e^2 \, (1\text{-}A)$$

$$E_{out} = \sigma \, T^4 (4 \, \pi \, r_e^2)$$

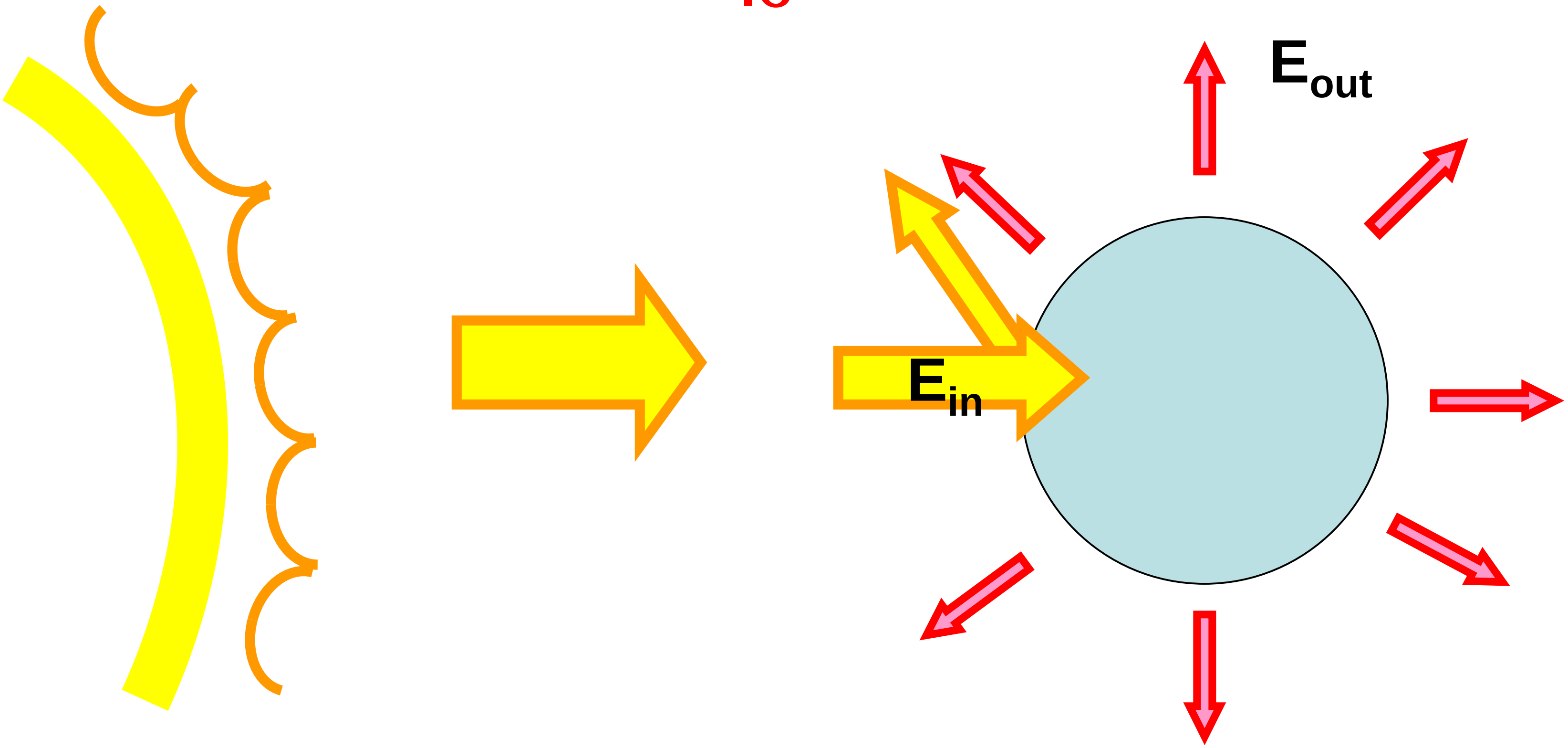


Energy Balance:

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

$$S_o\ (1-A) = \sigma\ T^4\ (4)$$

$$T^4 = \frac{S_o(1-A)}{4\sigma}$$



Objeto/Superfície	Albedo
Terra	0.306
Lua	0.22
Mercúrio	0.088
Vênus	0.76
Marte	0.25
Júpiter	0.503
Saturno	0.342
Urano	0.300
Netuno	0.290
Europa (lua de Júpiter)	0.67
Encélado (lua de Saturno)	0.81
19P/Borrely (cometa)	0.03
Terra cultivada (média)	0.16
Prado	0.21
Floresta tropical	0.12
Tundra	0.17
Neve	0.66
Gelo marítimo	0.62
Oceano	0.07

Earth's average temperature

$$T^4 = \frac{S_o(1-A)}{4\sigma}$$

For Earth:

$S_o = 1370\ W/m^2$
$A = 0.3$
$\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$

$$\mathbf{T^4 = \frac{S_o(1-A)}{4\sigma}}$$

For Earth:

So = 1370 W/m^2

A = 0.3

σ = 5.67 x 10^{-8}

$$T^4 = \frac{(1370\ \mathrm{W/m^2})(1-0.3)}{4\ (5.67 \times 10^{-8}\ \mathrm{W/m^2K^4})}$$

T^4 = 4.23 x 10^9 (K^4)

T = 255 K

Expected Temperature:

T_{rad} = 255 K

(^{o}C) = (K) - 273

So….

$\mathbf{T_{rad}}$ = (255 - 273) = **-18 ^{o}C**

O Efeito Estufa é tão mau assim?

No caso da Terra não

Temperatura do equilíbrio radiativo: $T_{rad} = -18\ ^oC$

Temperatura observada: $T_{obs} = 15\ ^oC$.

A diferença $T_{obs} - T_{rad} = \Delta T$ é o **efeito estufa** G :

$$G = T_{obs} - T_{rad}$$

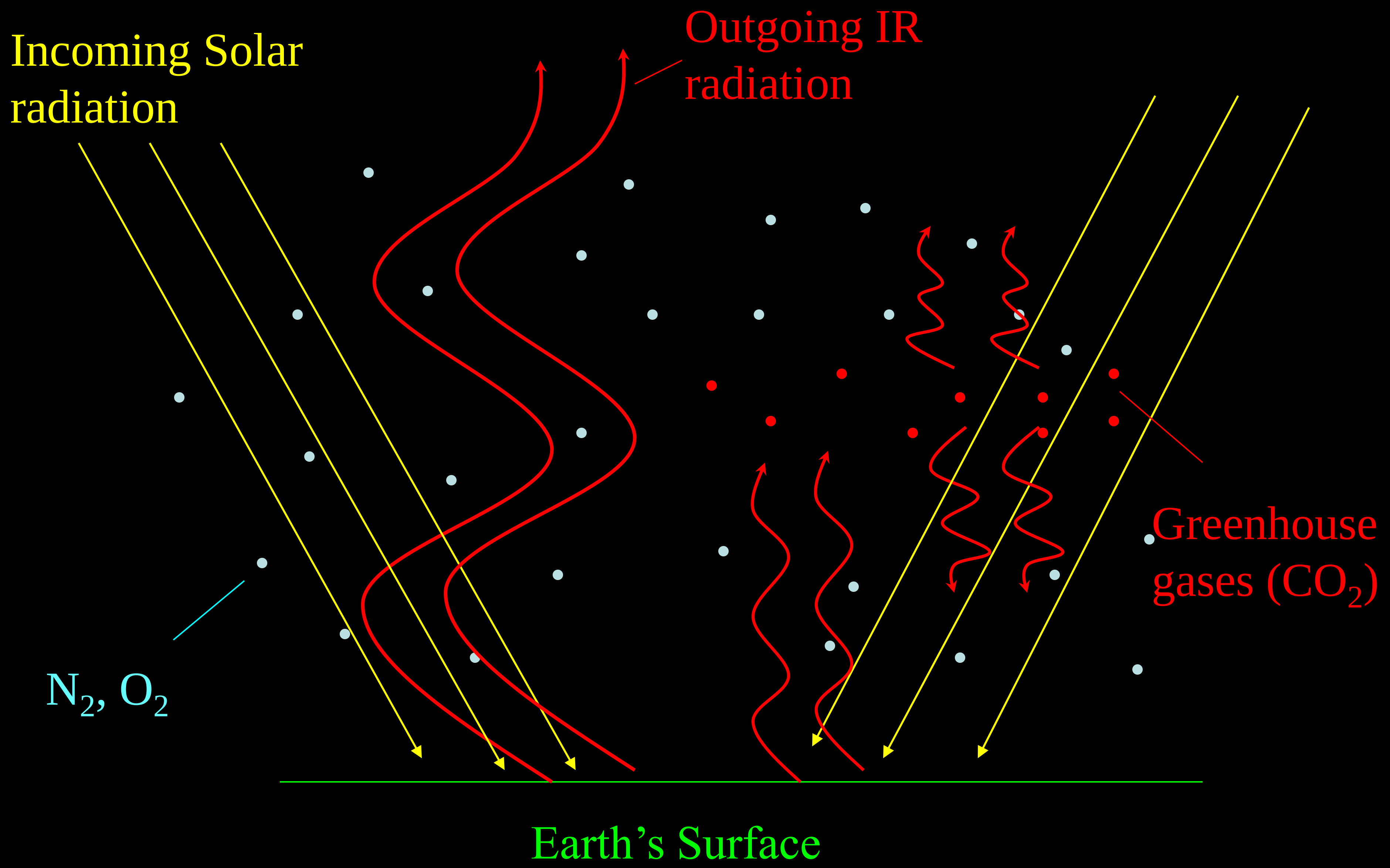
$$G = 15 - (-18)$$

$$G = +33\ ^oC = 33\ K$$

O efeito estufa tem um efeito de aquecimento

Sem o efeito estufa, a Terra estaria congelada!

Atmospheric Greenhouse Effect



Original Greenhouse

- Precludes heat loss by inhibiting the upward air motion
- Solar energy is used more effectively.
  Same solar input – higher temperatures.

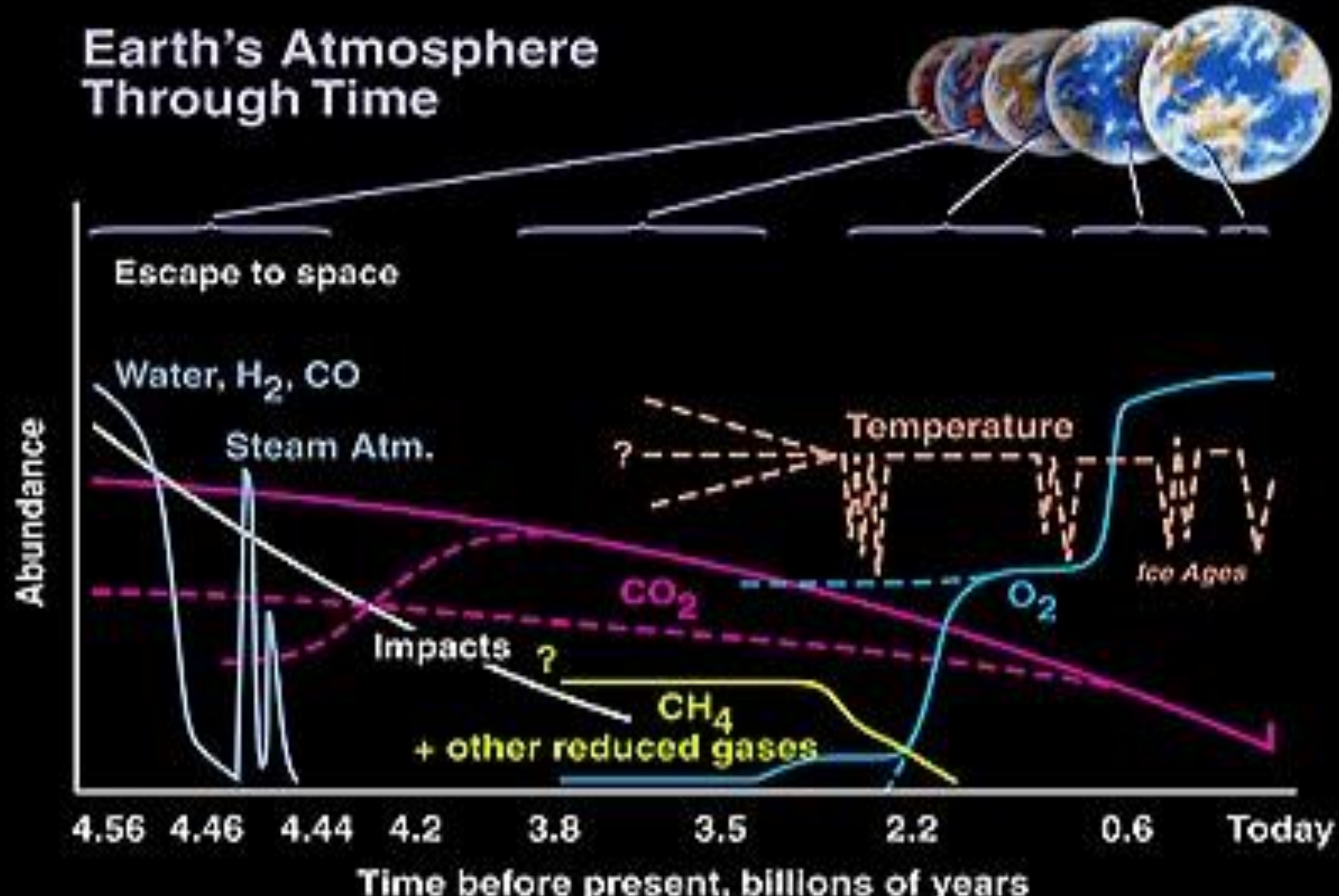
Warming results from interactions of gases in the atmosphere with incoming and outgoing radiation.

To evaluate how this happens, we will focus on the **composition** of the Earth’s atmosphere.

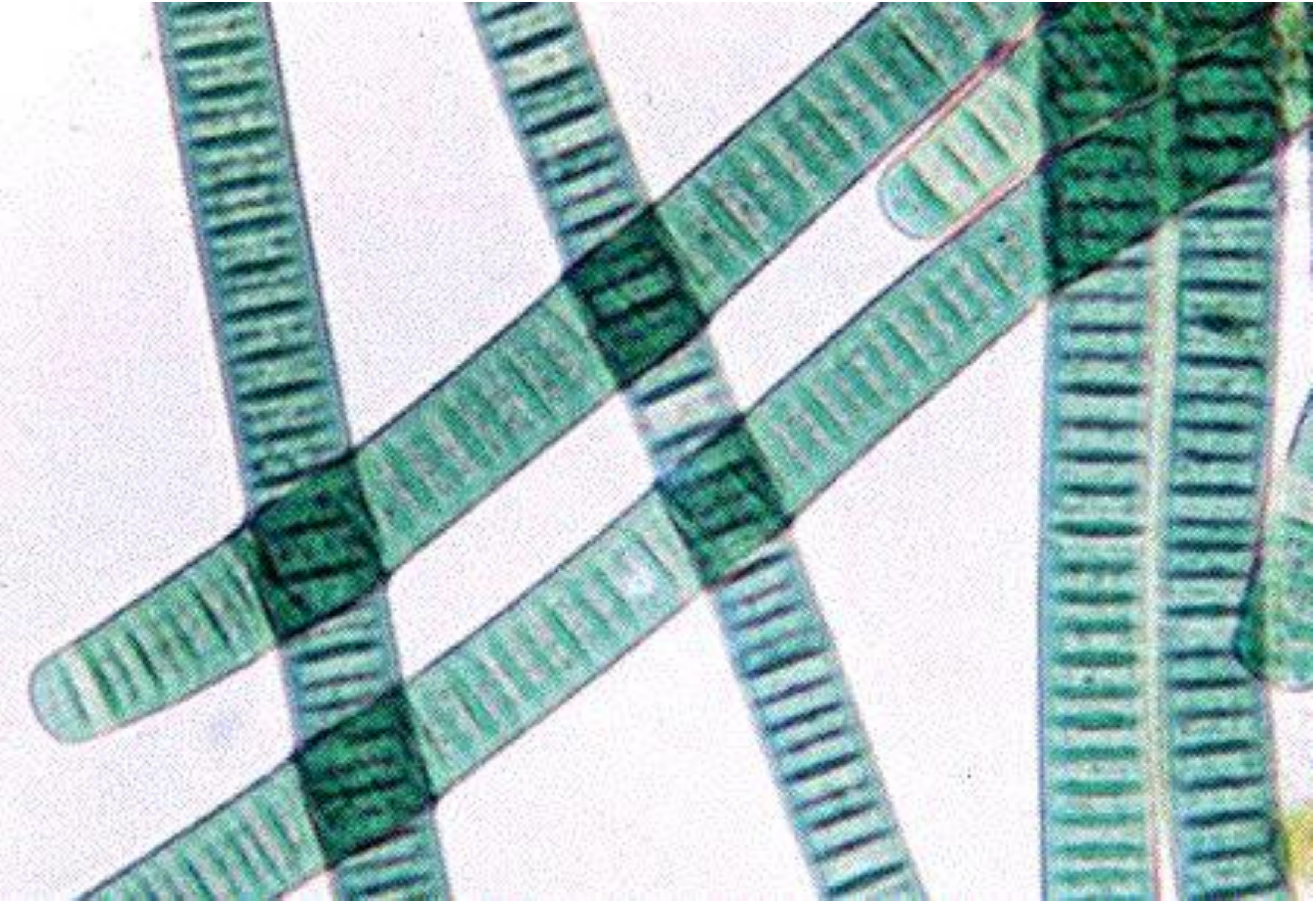
Composition of the Atmosphere

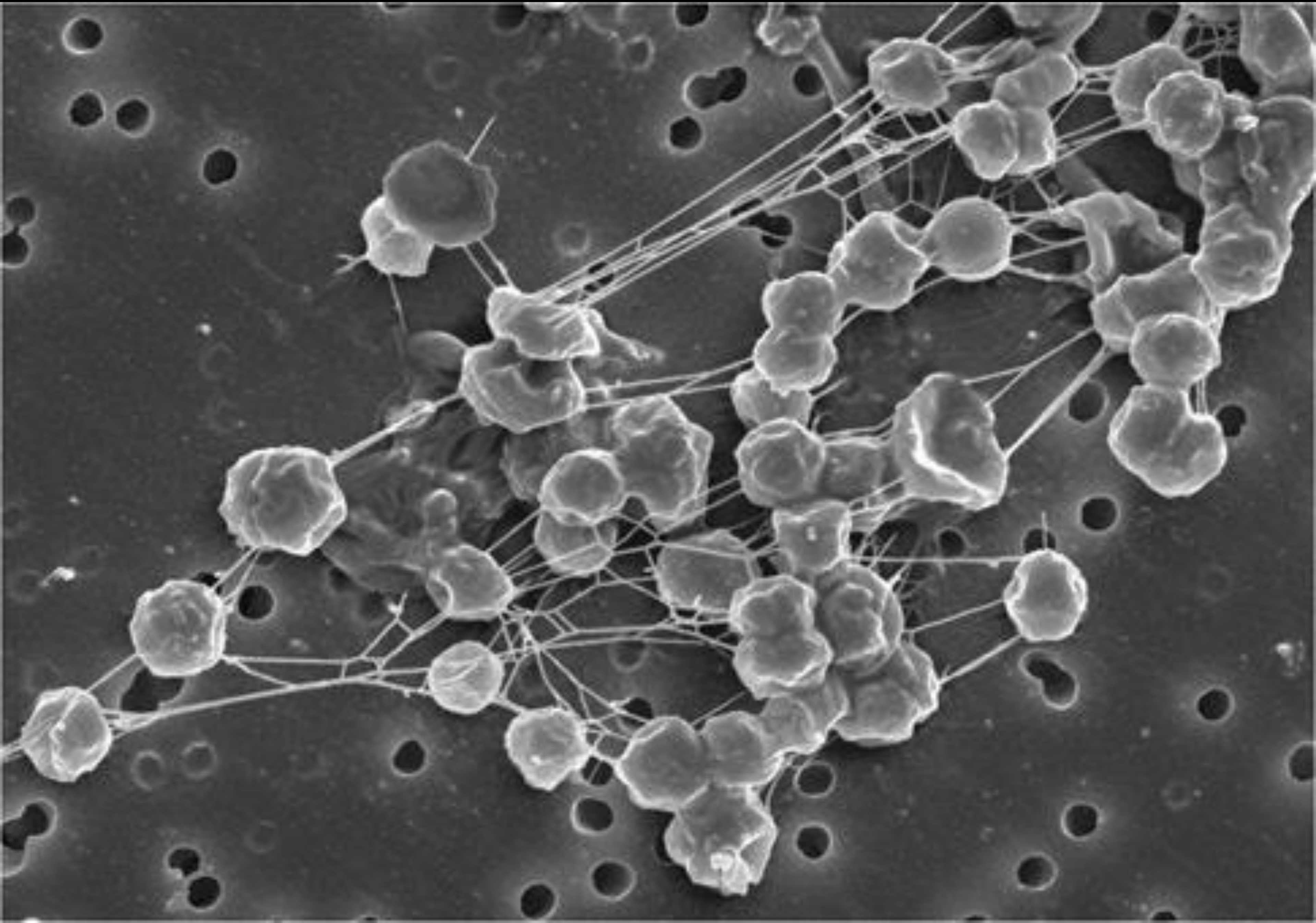
Air is composed of a mixture of gases:

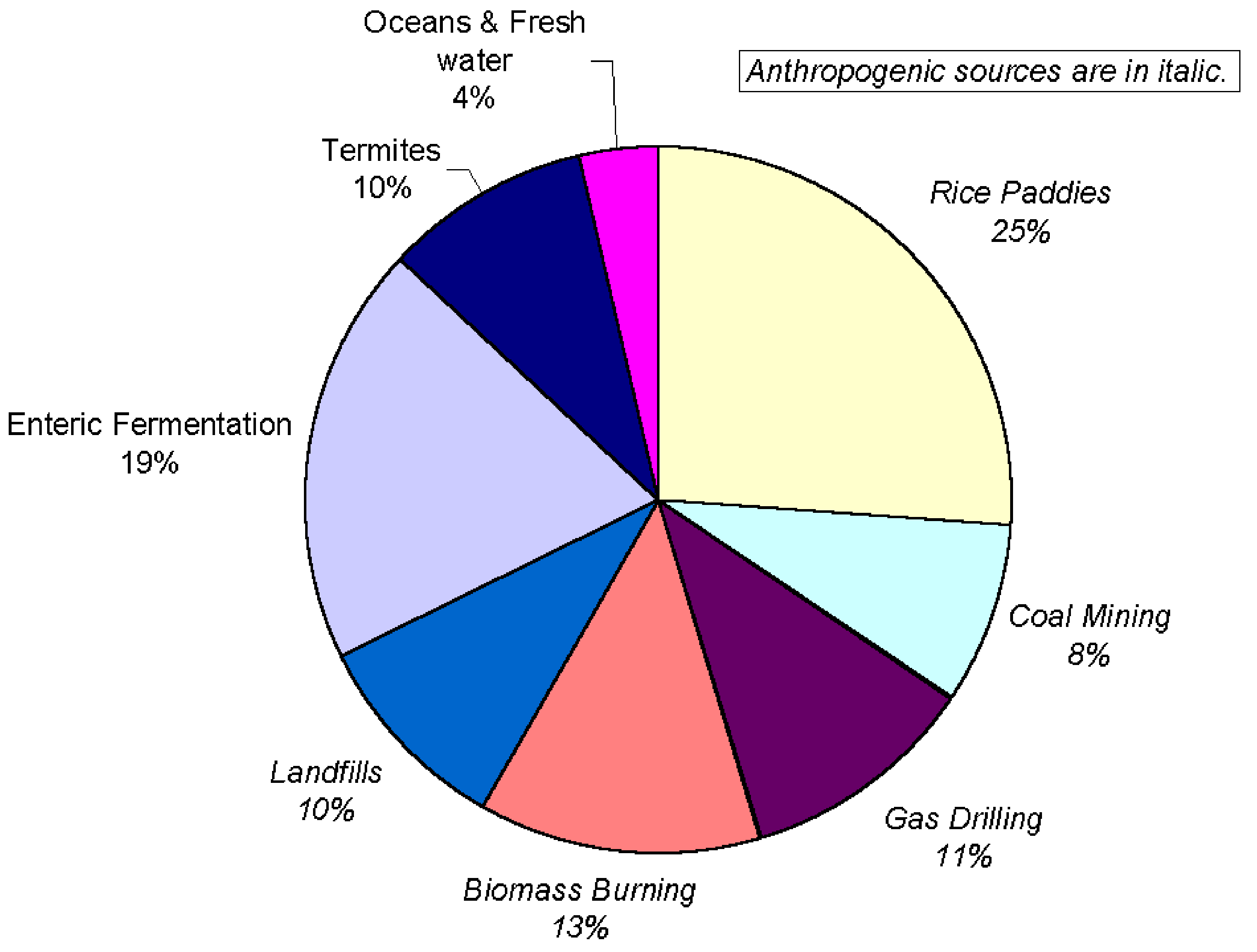
	Gas	concentration (%)	
	N_2	78	
	O_2	21	
	Ar	0.9	
greenhouse gases	H_2O	variable	
greenhouse gases	CO_2	0.037	370 ppm
greenhouse gases	CH_4		1.7
greenhouse gases	N_2O		0.3
greenhouse gases	O_3		1.0 to 0.01 (stratosphere-surface)



Earth's Atmosphere Through Time
Escape to space
Water, H_2, CO
Steam Atm.
Abundance
Temperature
?
Ice Ages
CO_2
O_2
Impacts
?
CH_4
+ other reduced gases
4.56
4.46
4.44
4.2
3.8
3.5
2.2
0.6
Today
Time before present, billions of years





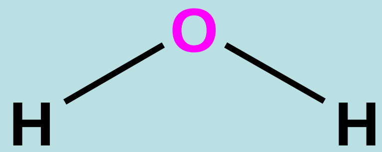


Fontes de Metano na Terra

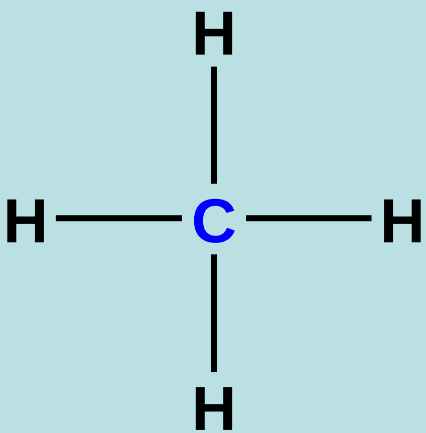
(University of Toronto, Dept. Atmospheric Physics)

Greenhouse Gases

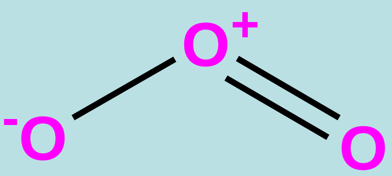
carbon dioxide



water



methane



ozone

Non-greenhouse Gases

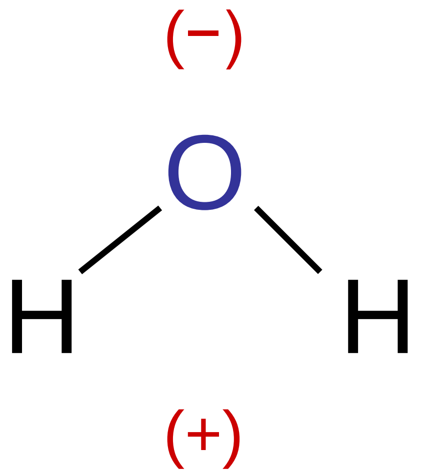
N_2 O_2

$N \equiv N$ $O = O$

Non-greenhouse Gases

Non-greenhouse gases have symmetry!

(Technically speaking, greenhouse gases have a *dipole moment* whereas N_2 and O_2 don’t)

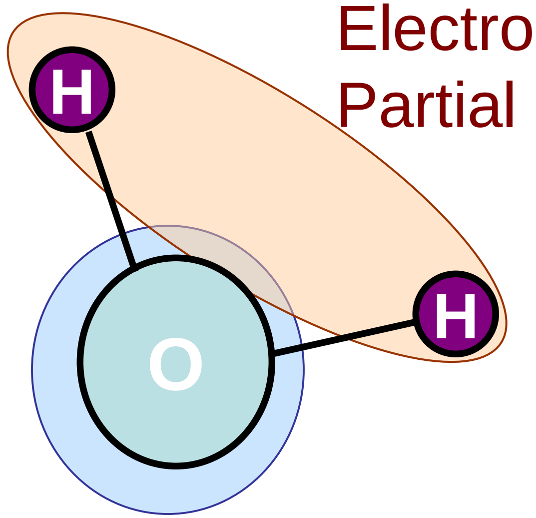


- Oxygen has an unfilled outer shell of electrons (6 out of 8), so it wants to attract additional electrons. It gets them from the hydrogen atoms.

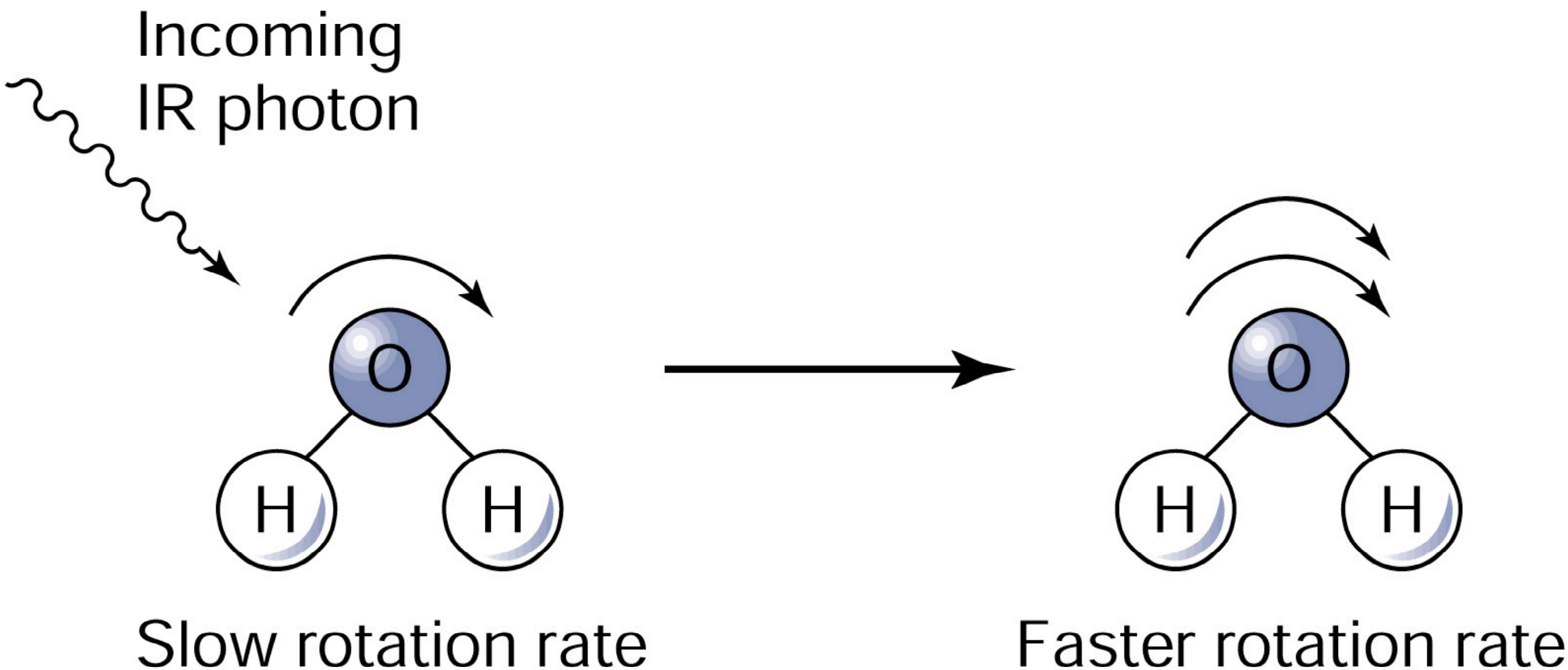
Molecules with an uneven distribution of electrons are especially good absorbers and emitters.

These molecules are called **dipoles**.

Water



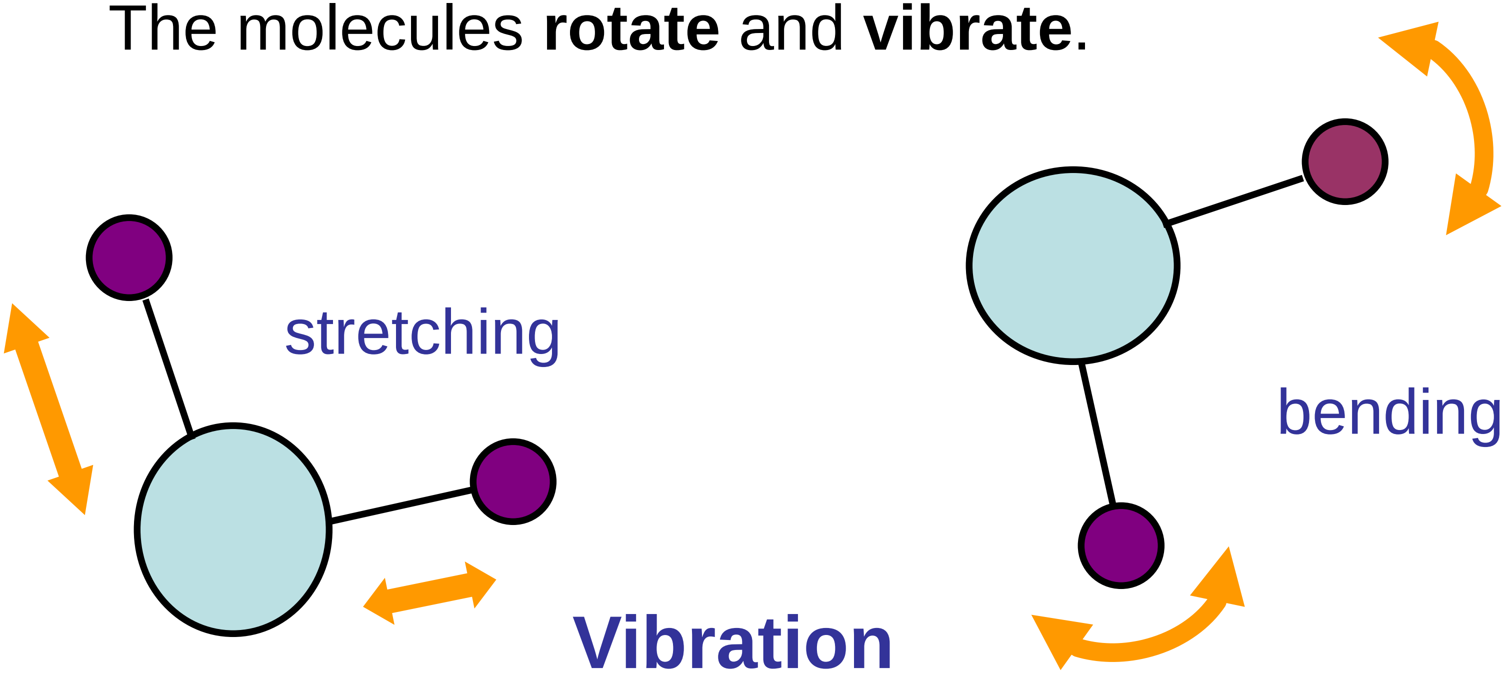
oxygen is more electronegative than hydrogen

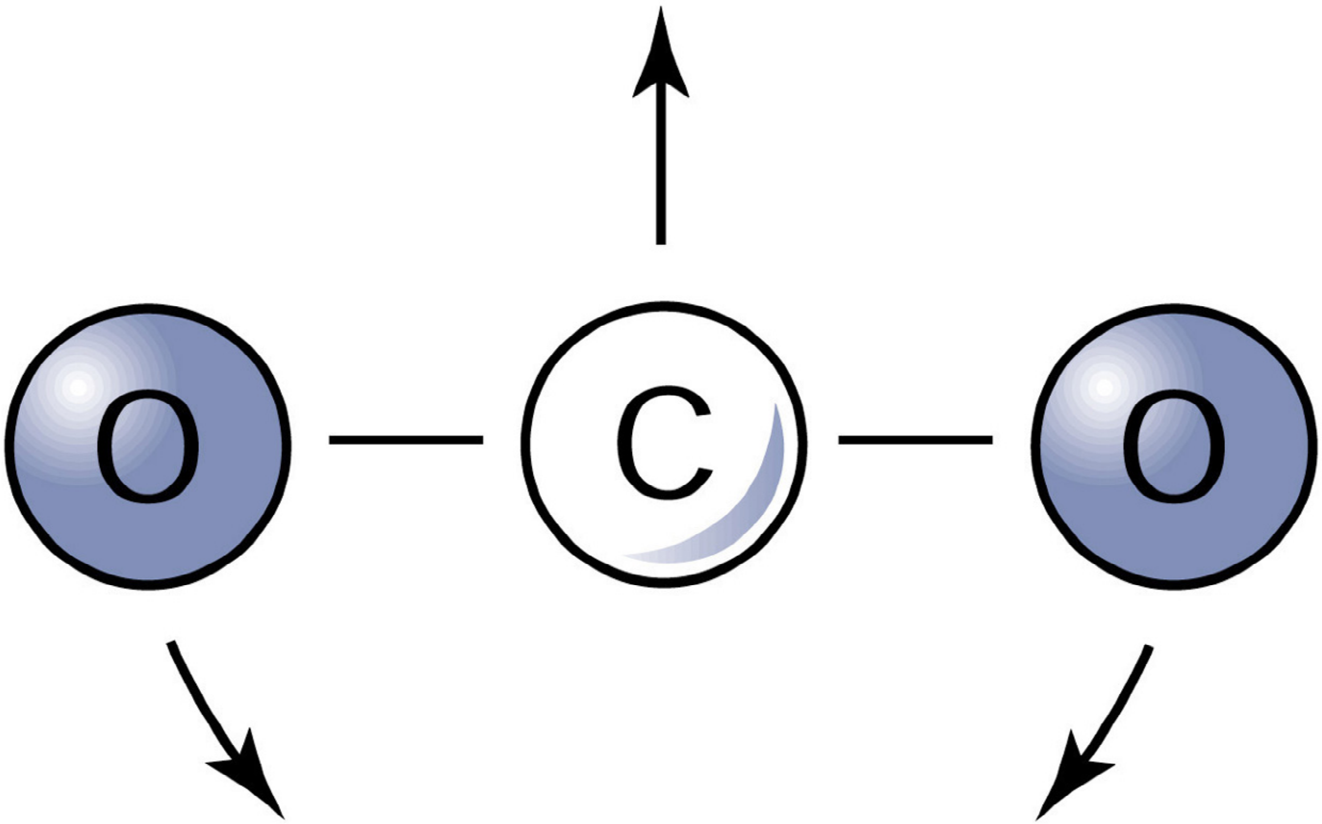

Incoming
IR photon
O
H
H
O
H
H
Slow rotation rate
Faster rotation rate

Molecules absorb energy from radiation.

The energy increases the movement of the molecules.

The molecules **rotate** and **vibrate**.

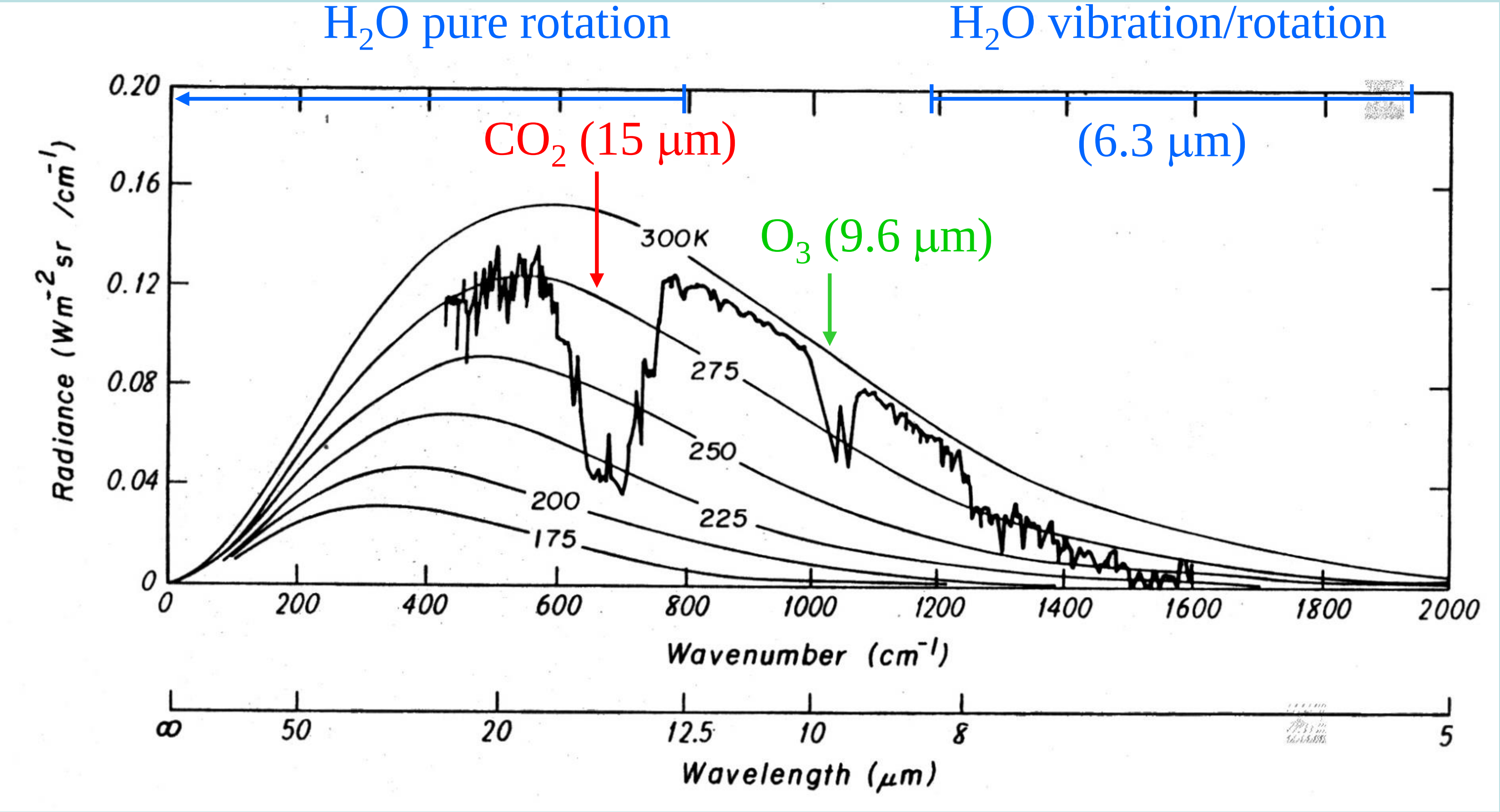




Bending mode
(15-μm band)

Thermal IR Spectrum for Earth

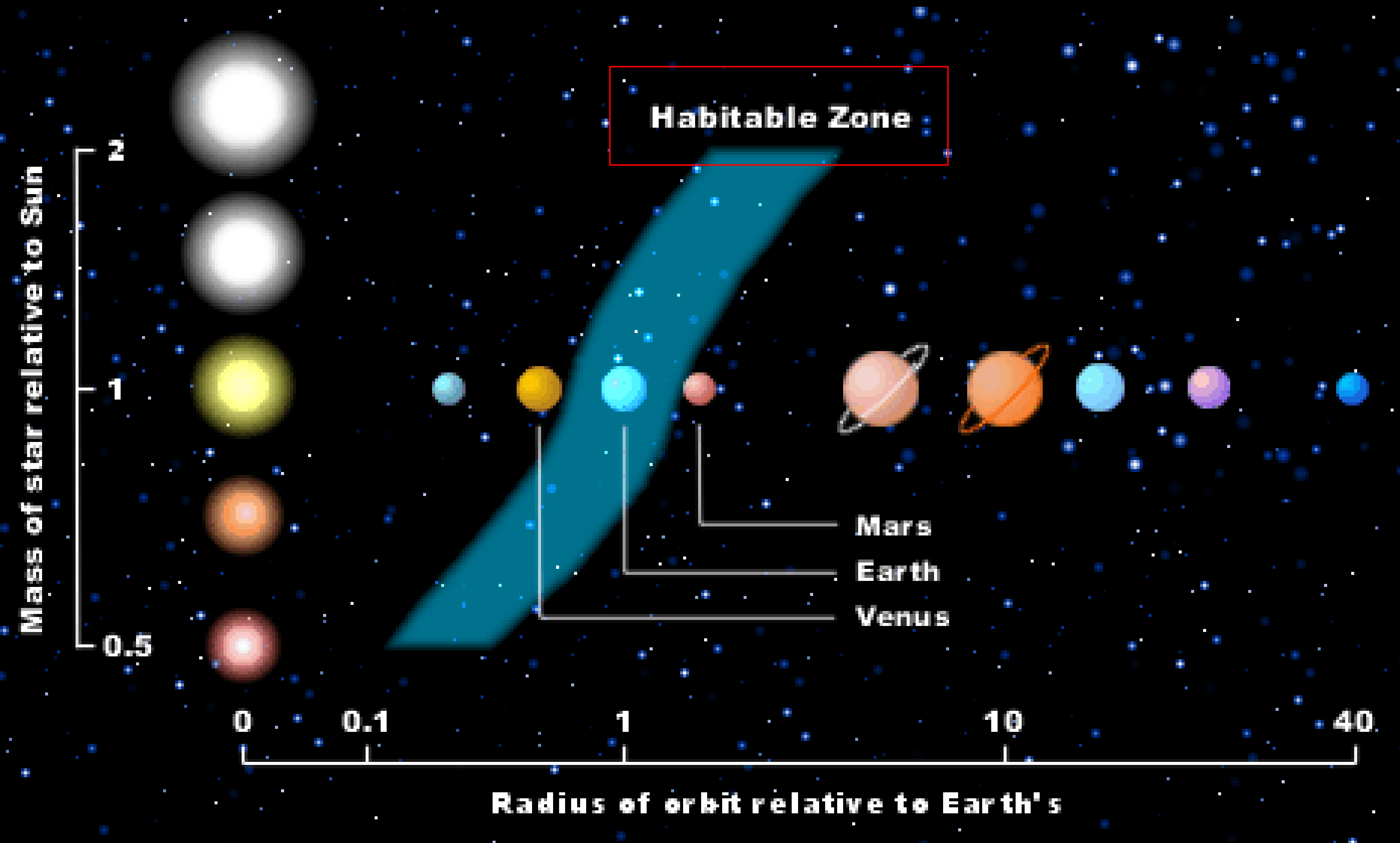
Greenhouse gases absorb IR radiation at specific wavelengths



Ref.: K.-N. Liou, *Radiation and Cloud Physics Processes in the Atmosphere* (1992)

Zona Habitável Estelar

Água Líquida → Zona Habitável



Boundaries of the HZ

- Stellar flux: $S = L/(4\pi R^2)$
- Planetary radiative balance equation:
  $S \times (1-A) = \sigma \times T^4 \times 4$

  $L/(4\pi R^2)$ **$\times (1-A) = \sigma \times T^4 \times 4$**

$$\sqrt{\frac{L \times (1-A)}{16 \times \pi \times \sigma \times T^4}} = R$$

Global surface temperature (T_s)

- Global surface temperature (T_s) depends on three main factors:

a) Stellar flux
b) Albedo (on Earth, mostly clouds)
c) Greenhouse Effect (CO_2, H_2O , CH_4, O_3 etc.)

- We can calculate T_{rad} from the radiative balance equation and add the greenhouse warming:

$$T_s = T_{rad} + G$$

Zona Habitável e Efeito Estufa Vênus x Terra x Marte

Vênus
T_{rad}=226,6 K
T_s=464 ºC G=+510 ºC

Terra
T_{rad}= 255,0 K
T_s=15 ºC G=+33 ºC

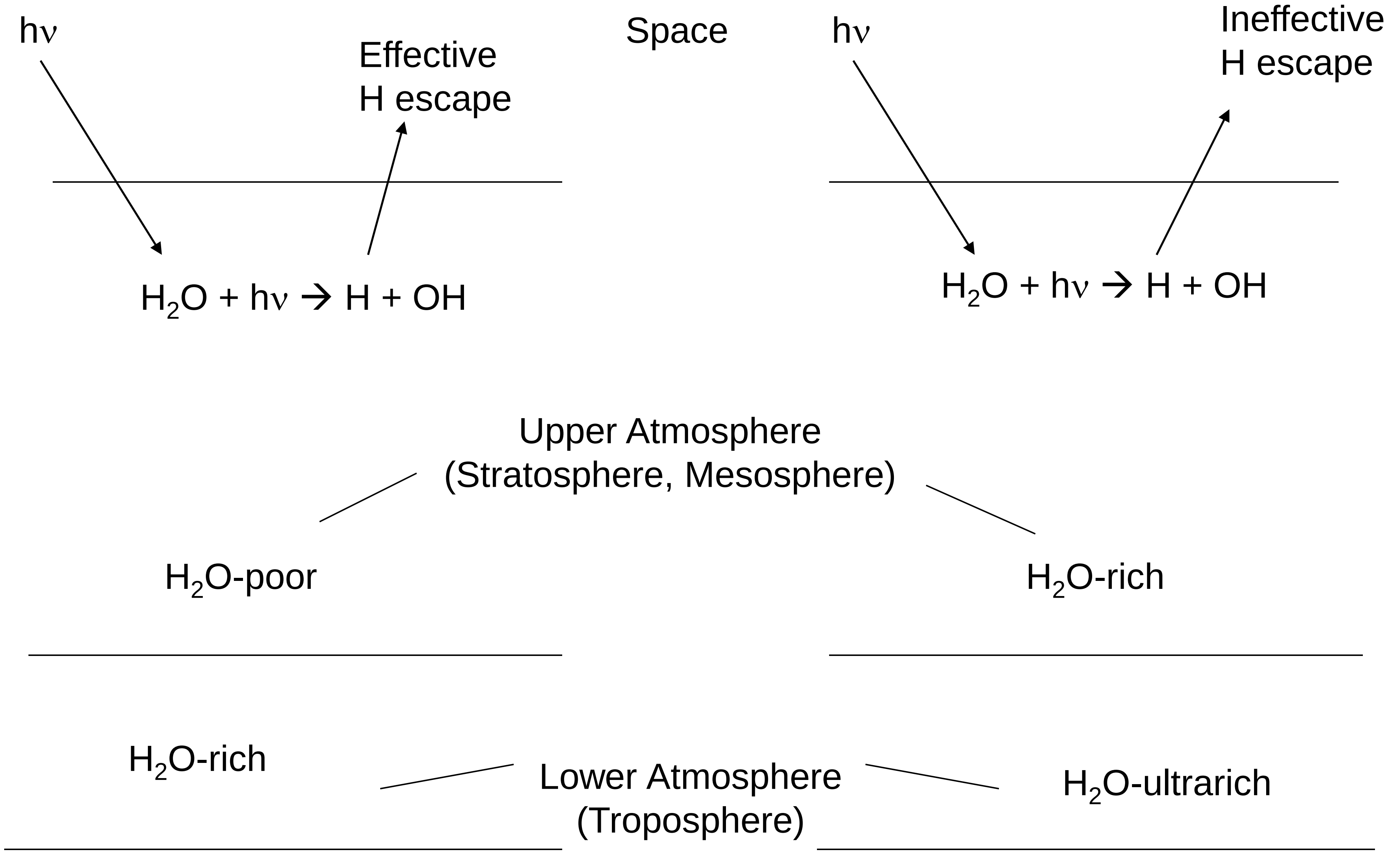
Marte
T_{rad}= 209,8 K
T_{ms}=-63 ºC G=+0,2 ºC

The inner edge of the HZ

- The limiting factor for the inner boundary of the HZ must be the ability of the planet to avoid a runaway greenhouse effect.
- Theoretical models predict that an Earth-like planet would convert all its ocean into the water vapor ~0.84 AU
- However it is likely that a planet will lose water before that.

Moist Greenhouse

- If a planet is at 0.95 AU it gets about 10% higher solar flux than the Earth.
- Increase in Solar flux leads to increase in surface temperature → more water vapor in the atmosphere → even higher temperatures
- Eventually all atmosphere becomes rich in water vapor → effective hydrogen escape to space → permanent loss of water

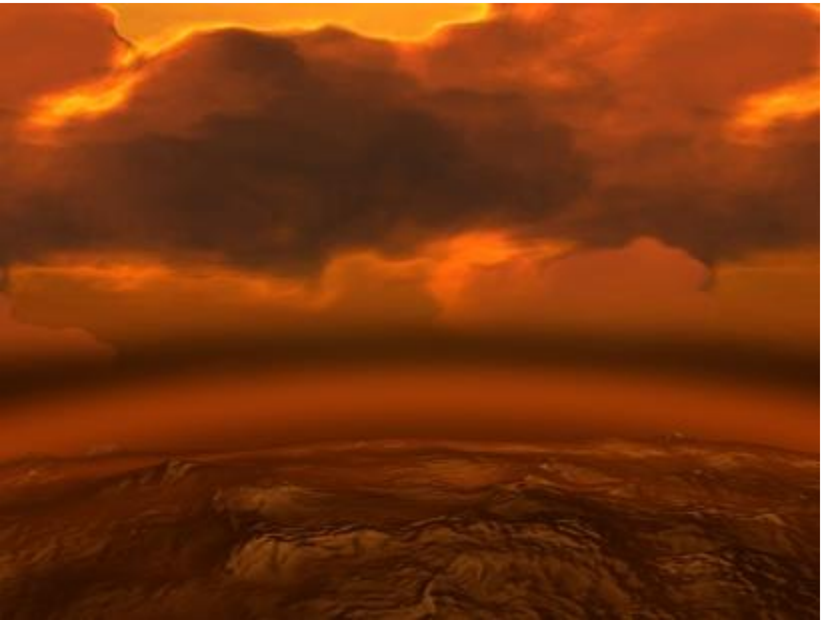


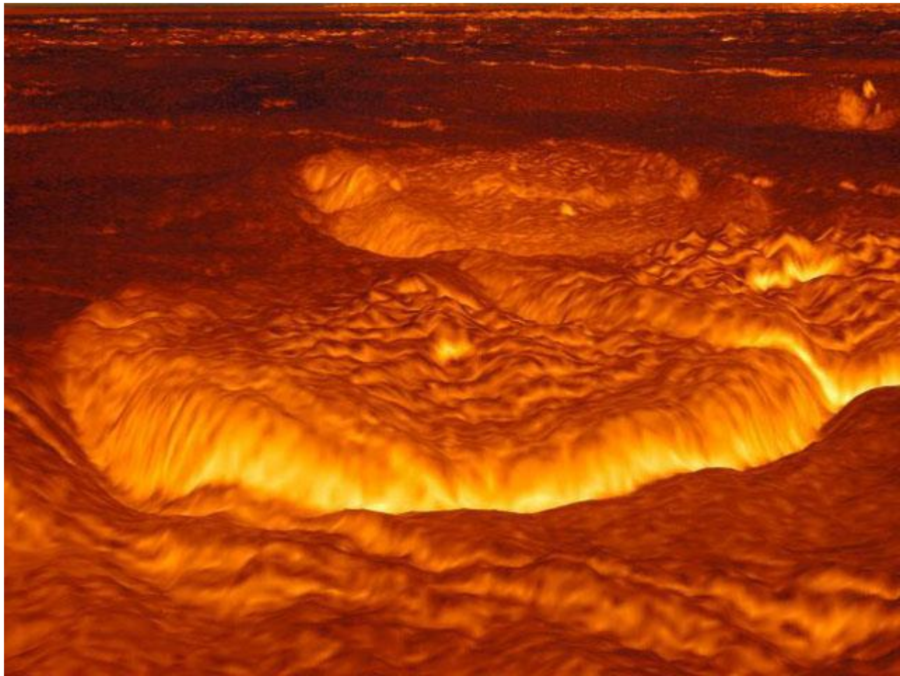
hν
Effective
H escape
Space
hν
Ineffective
H escape
$H_2O + h\nu \rightarrow H + OH$
$H_2O + h\nu \rightarrow H + OH$
Upper Atmosphere
(Stratosphere, Mesosphere)
H_2O-poor
H_2O-rich
H_2O-rich
Lower Atmosphere
(Troposphere)
H_2O-ultrarich

Venus fate

- Runaway (or moist) greenhouse and the permanent loss of water could have happened on Venus
- Venus has very high D/H (~120 times higher than Earth's) ratio suggesting huge hydrogen loss

- Without water CO_2 would accumulate in the atmosphere and the climate would become extremely hot – present Venus is ~ 90 times more massive than Earth's and almost entirely CO_2.
- Eventually Earth will follow the fate of Venus





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The end of life on Earth is not the end of the world: converging to an estimate of life span of the biosphere?

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Research Article

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atmospheric models; Earth system; end of life; evolution of biospheres; future of life; geophysical models; habitability

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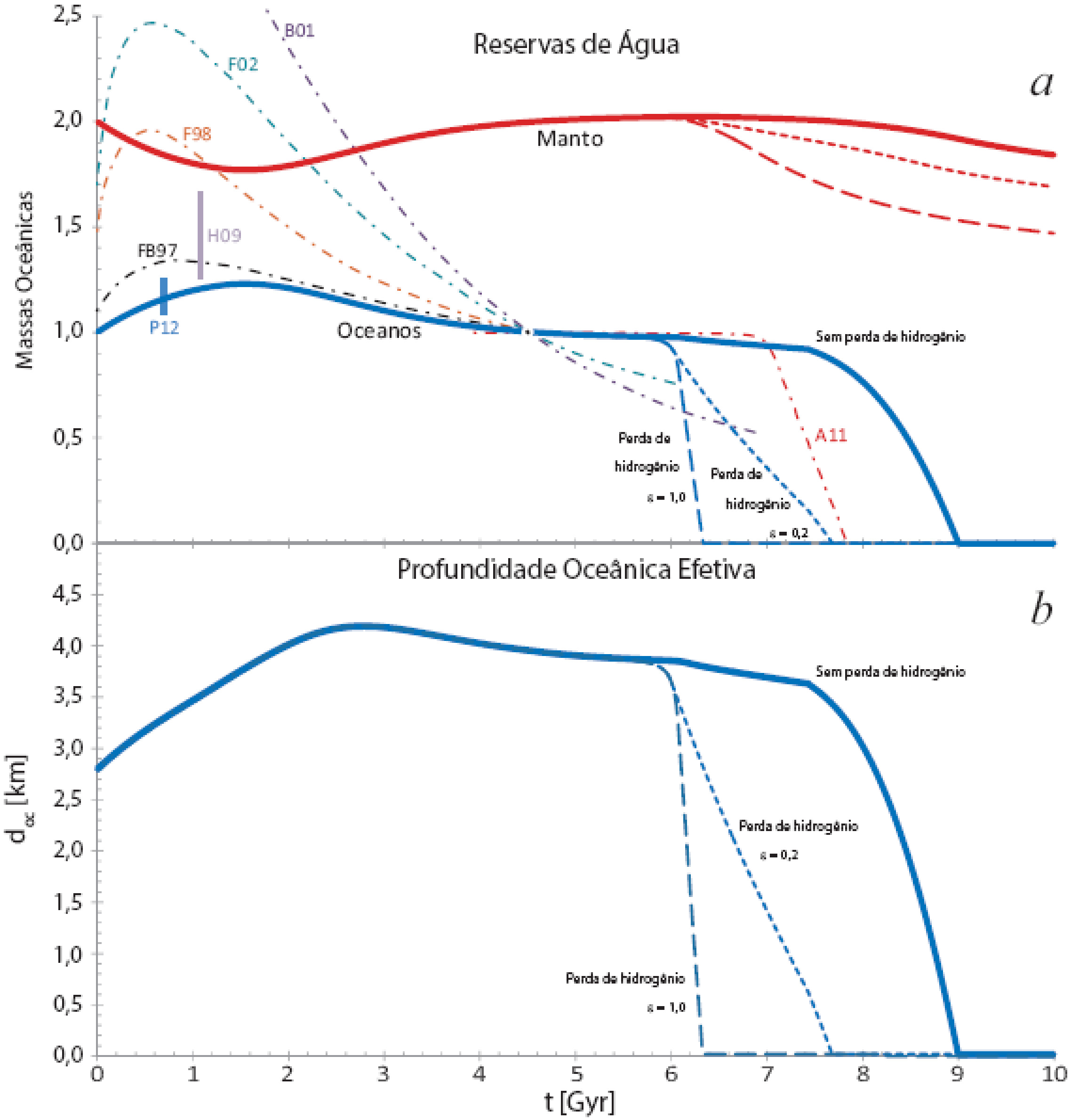
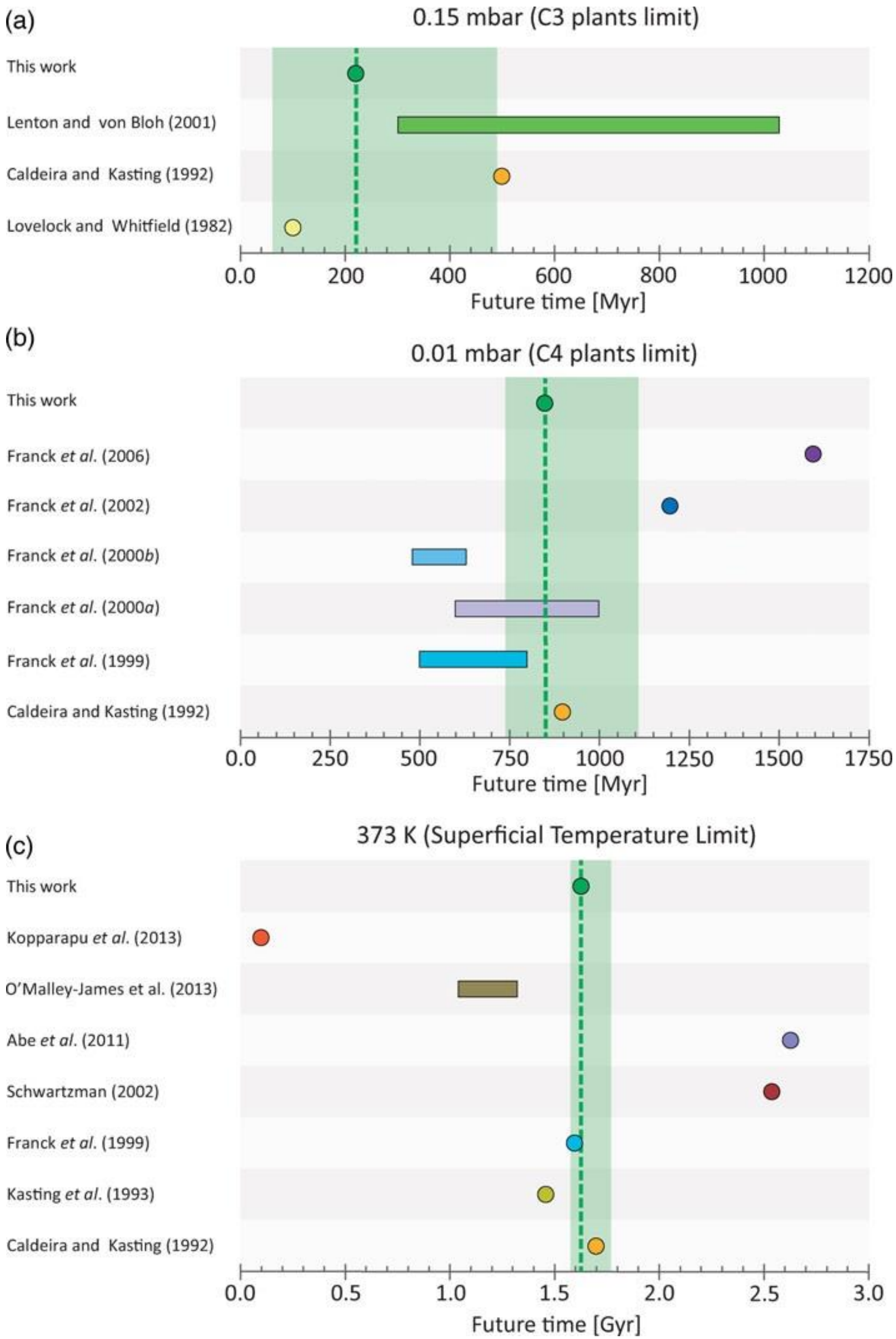
Abstract

Environmental conditions have changed in the past of our planet but were not hostile enough to extinguish life. In the future, an aged Earth and a more luminous Sun may lead to harsh or even uninhabitable conditions for life. In order to estimate the life span of the biosphere we built a minimal model of the co-evolution of the geosphere, atmosphere and biosphere of our planet, taking into account temperature boundaries, CO_2 partial pressure lower limits for C3 and C4 plants, and the presence of enough surface water. Our results indicate that the end of the biosphere will happen long before the Sun becomes a red giant, as the biosphere faces increasingly more difficult conditions in the future until its collapse due to high temperatures. The lower limit for CO_2 partial pressure for C3 plants will be reached in $170(+320, -110)$ Myr, followed by the C4 plants limit in $840(+270, -100)$ Myr. The mean surface temperature will reach 373 K in $1.63(+0.14, -0.05)$ Gyr, a point that would mark the extinction of the biosphere. Water loss due to internal geophysical processes will not be dramatic, implying almost no variation in the surface ocean mass and ocean depth for the next 1.5 billion years. Our predictions show qualitative convergence and some quantitative agreement with results found in the literature, but there is considerable scattering in the scale of hundreds of millions of years for all the criteria devised. Even considering these uncertainties, the end of the biosphere will hardly happen sooner than 1.5 Gyr.



Evolução da massa e profundidade efetiva do oceano.



Comparação dos resultados de diferentes modelos para os limite de pressão parcial de CO_2 para plantas C3 (a) e plantas C4 (b), e o limite de temperatura superficial (c).

The outer edge of the HZ

- The outer edge of the HZ is the distance from the Sun at which even a strong greenhouse effect would not allow liquid water on the planetary surface.
- Carbonate-silicate cycle can help to extend the outer edge of the HZ by accumulating more CO_2 and partially offsetting low solar luminosity.

Limit from CO_2 greenhouse

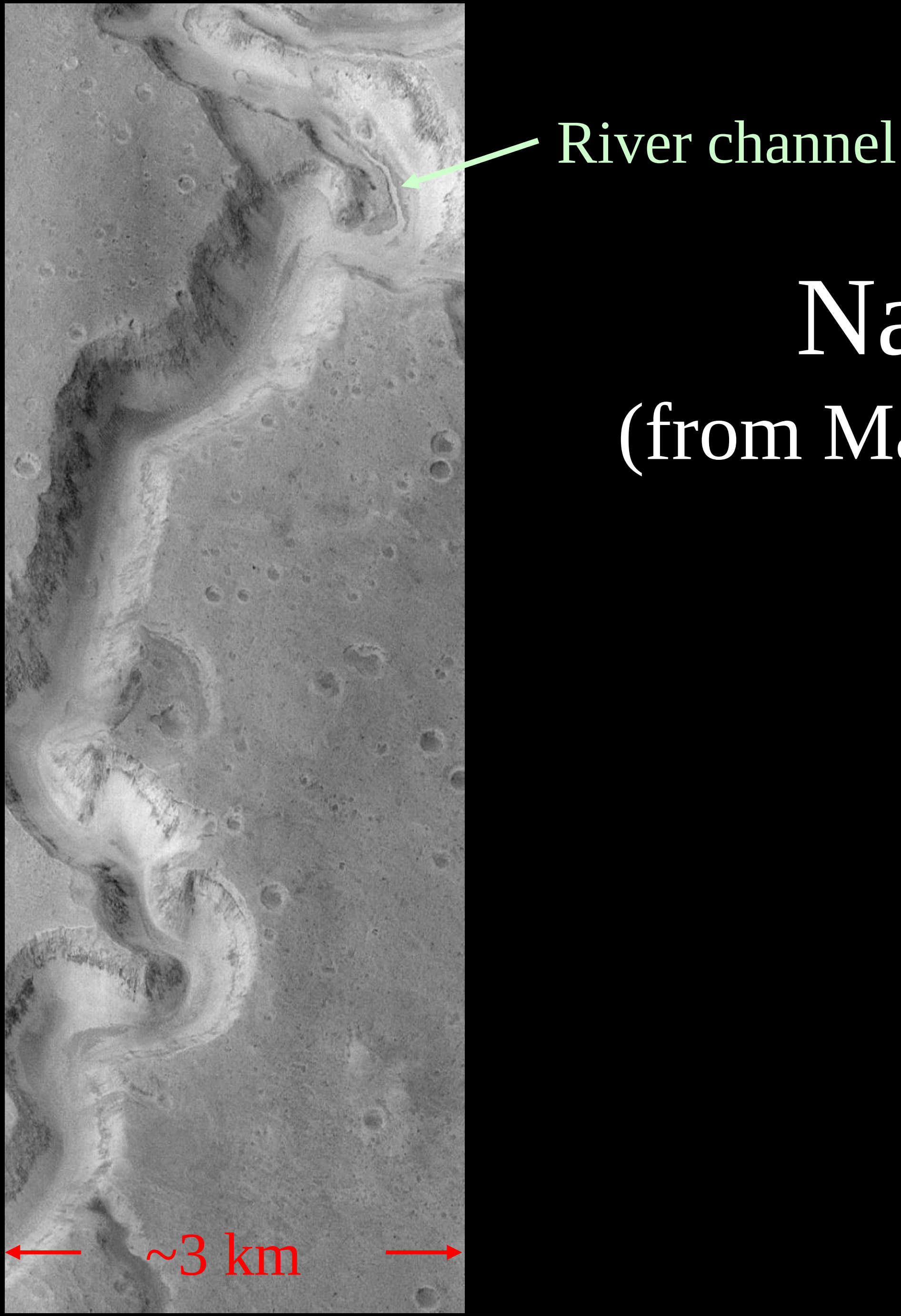
- At low Solar luminosities high CO_2 abundance would be required to keep the planet warm.
- But at high CO_2 abundance does not produce as much net warming because it also scatter solar radiation.
- Theoretical models predict that no matter how high CO_2 abundance would be in the atmosphere, the temperature would not exceed the freezing point of water if a planet is further than 1.7 A.U.

Limit from CO_2 condensation

- At high CO_2 abundance and low temperatures carbon dioxide can start to condense out (like water condense into rain and snow)
- Atmosphere would not be able to build CO_2 if a planet is further than 1.4 A.U.

Fate of Mars

- Mars is on the margin of the HZ at the present
- But! Mars is a small planet and cooled relatively fast
- Mars cannot outgas CO_2 and sustain Carbonate-Silicate feedback.
- Also hydrogen can escape effectively due to the low martian gravity and lack of magnetic field.



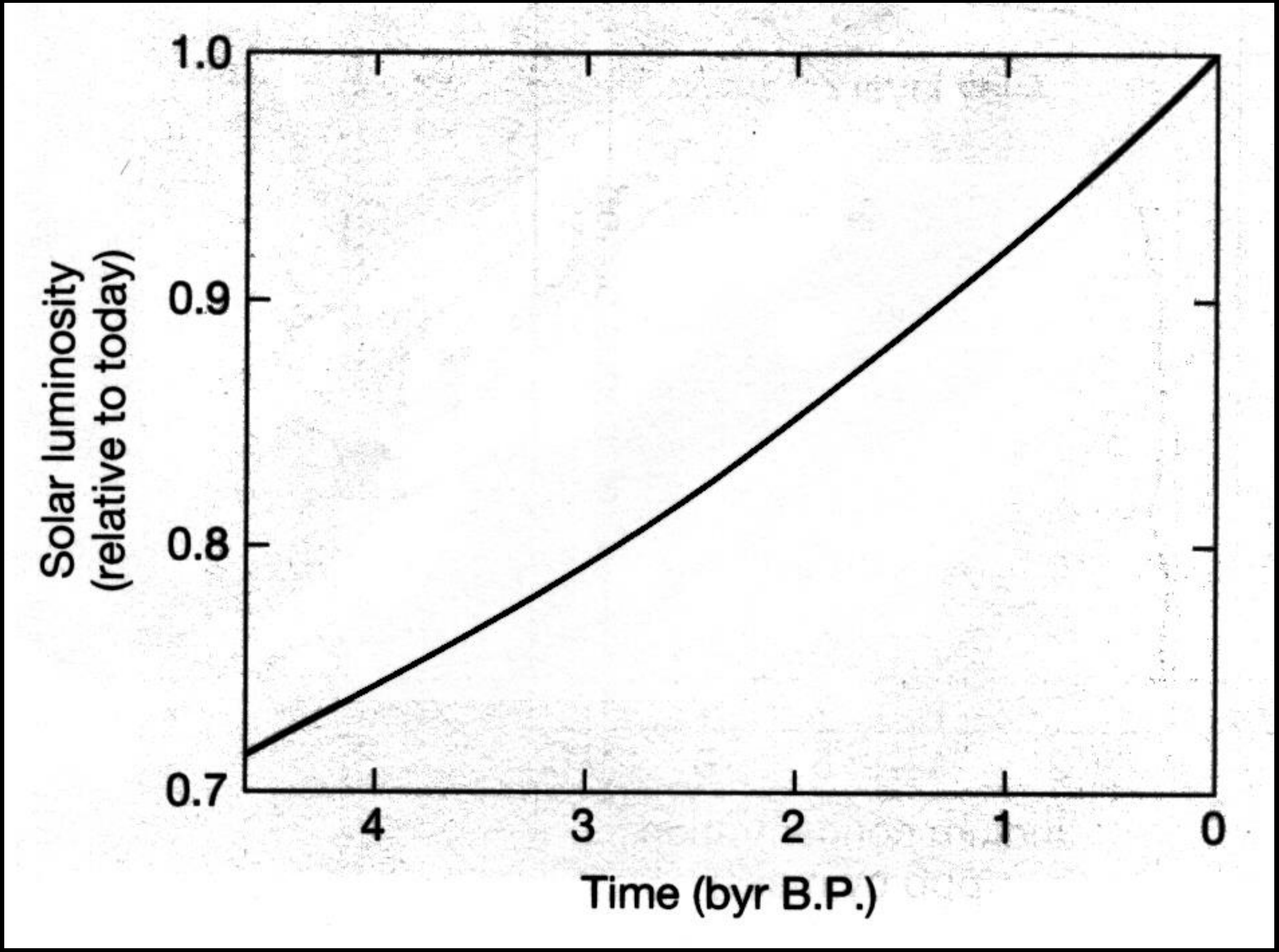
Nanedi Vallis

(from Mars Global Surveyor)

The Sun gets brighter with time

- H fuses to form He in the core
- Core becomes denser
- Core contracts and heats up
- Fusion reactions proceed faster
- More energy is produced $\Rightarrow$ more energy needs to be emitted

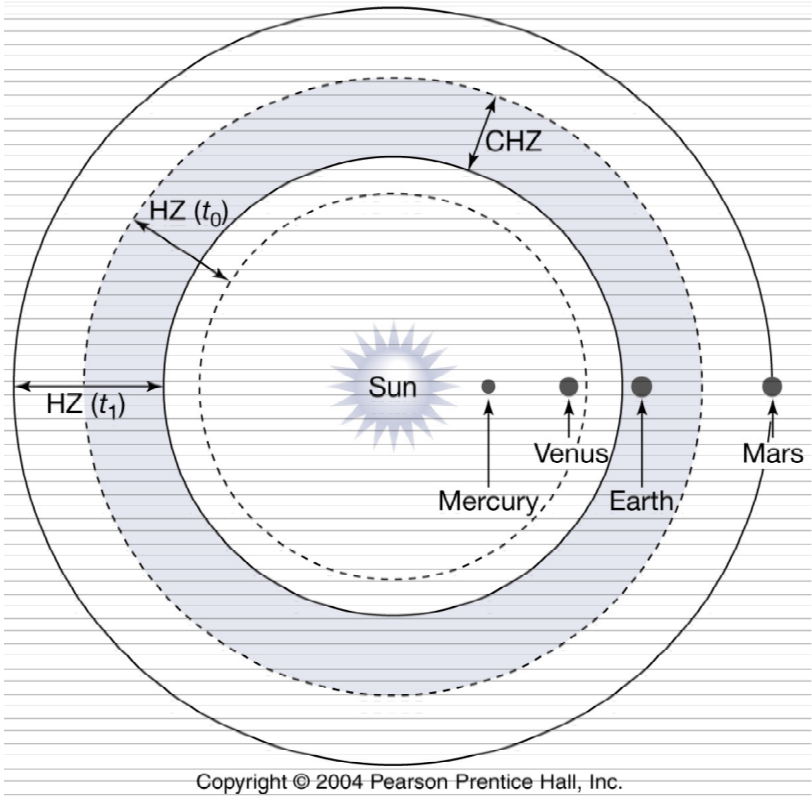
Solar Luminosity versus Time



See *The Earth System, ed. 2*, Fig. 1-12

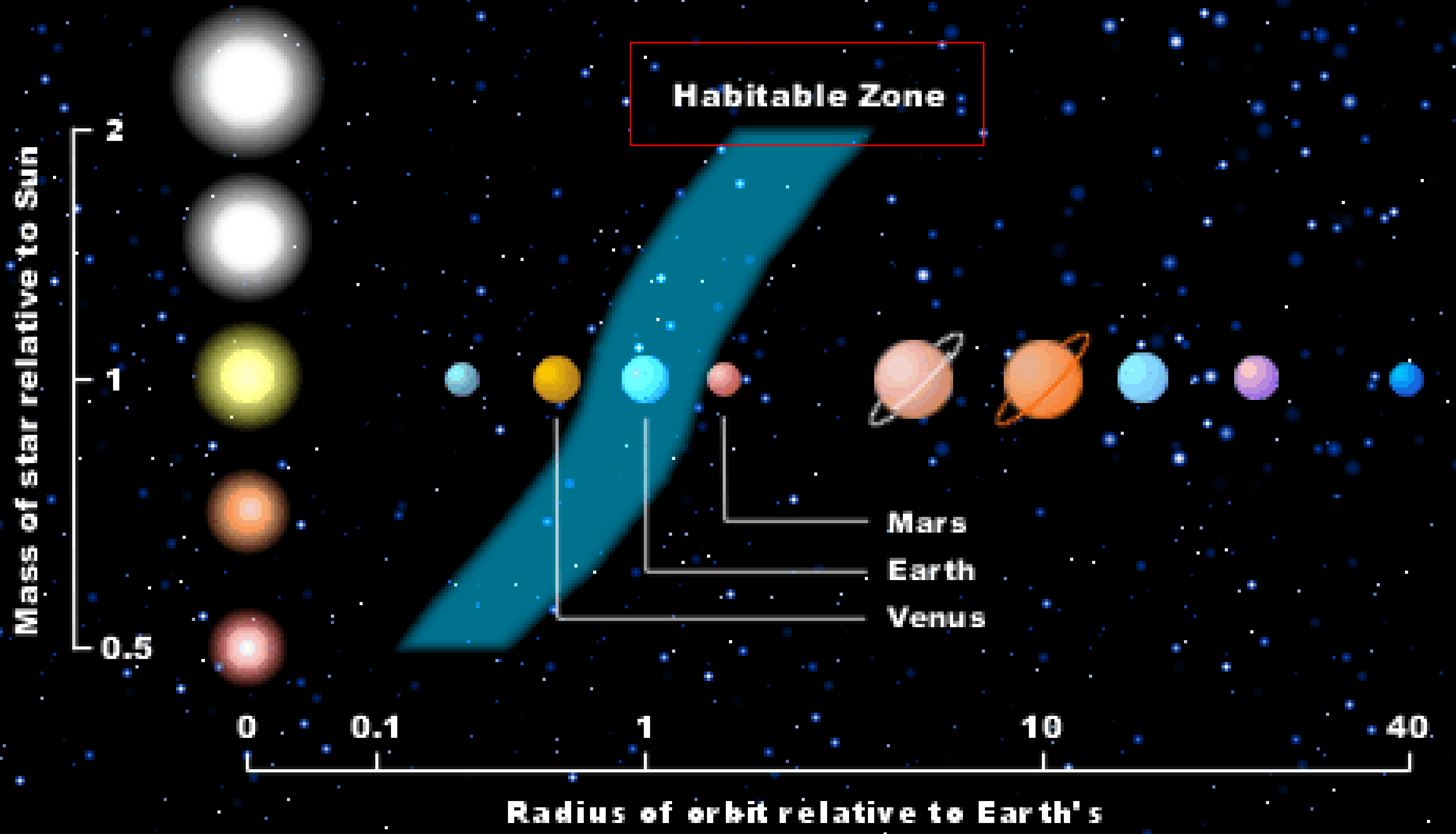
Continuous Habitable Zone (CHZ)

- A region, in which a planet may reside and maintain liquid water throughout most of a star's life.

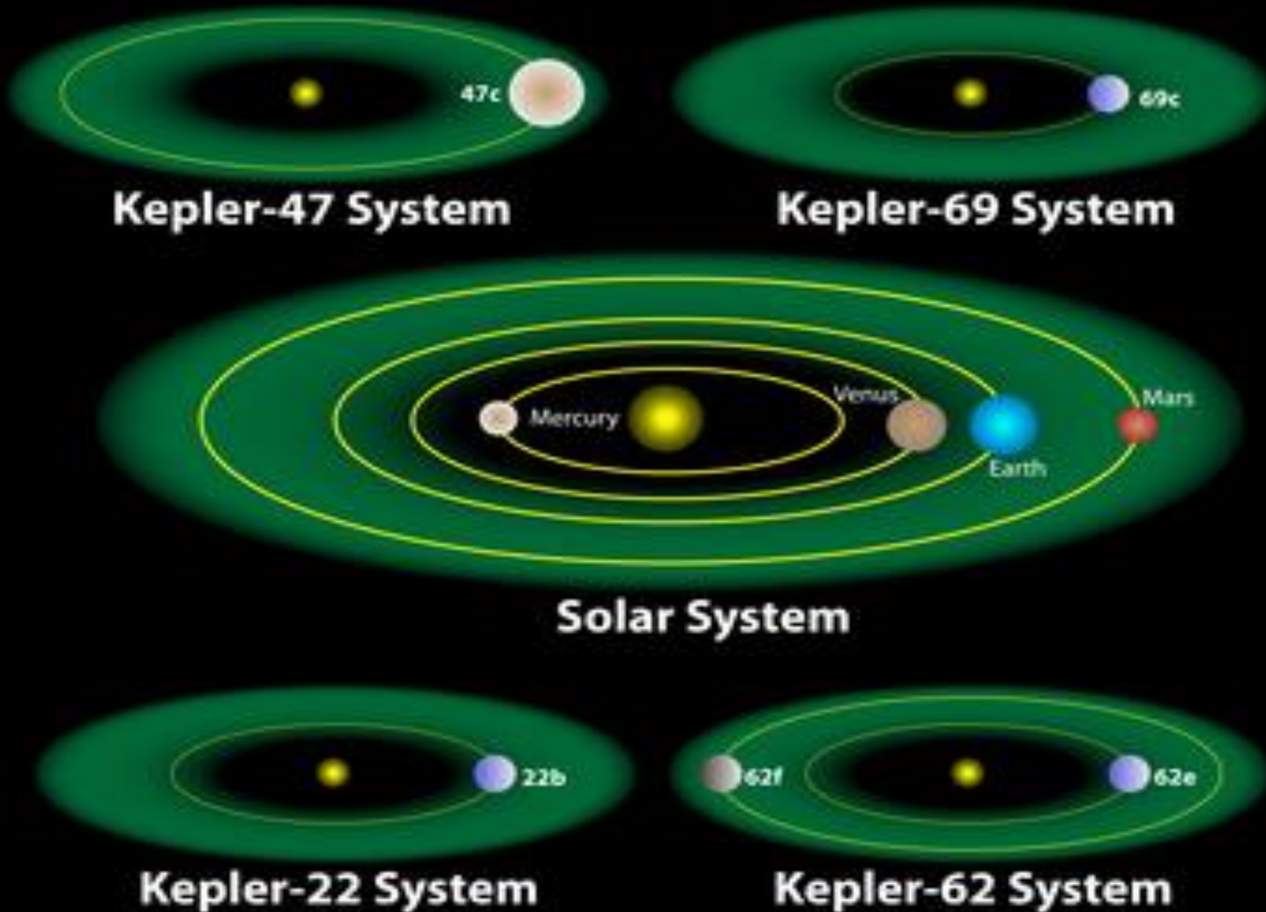


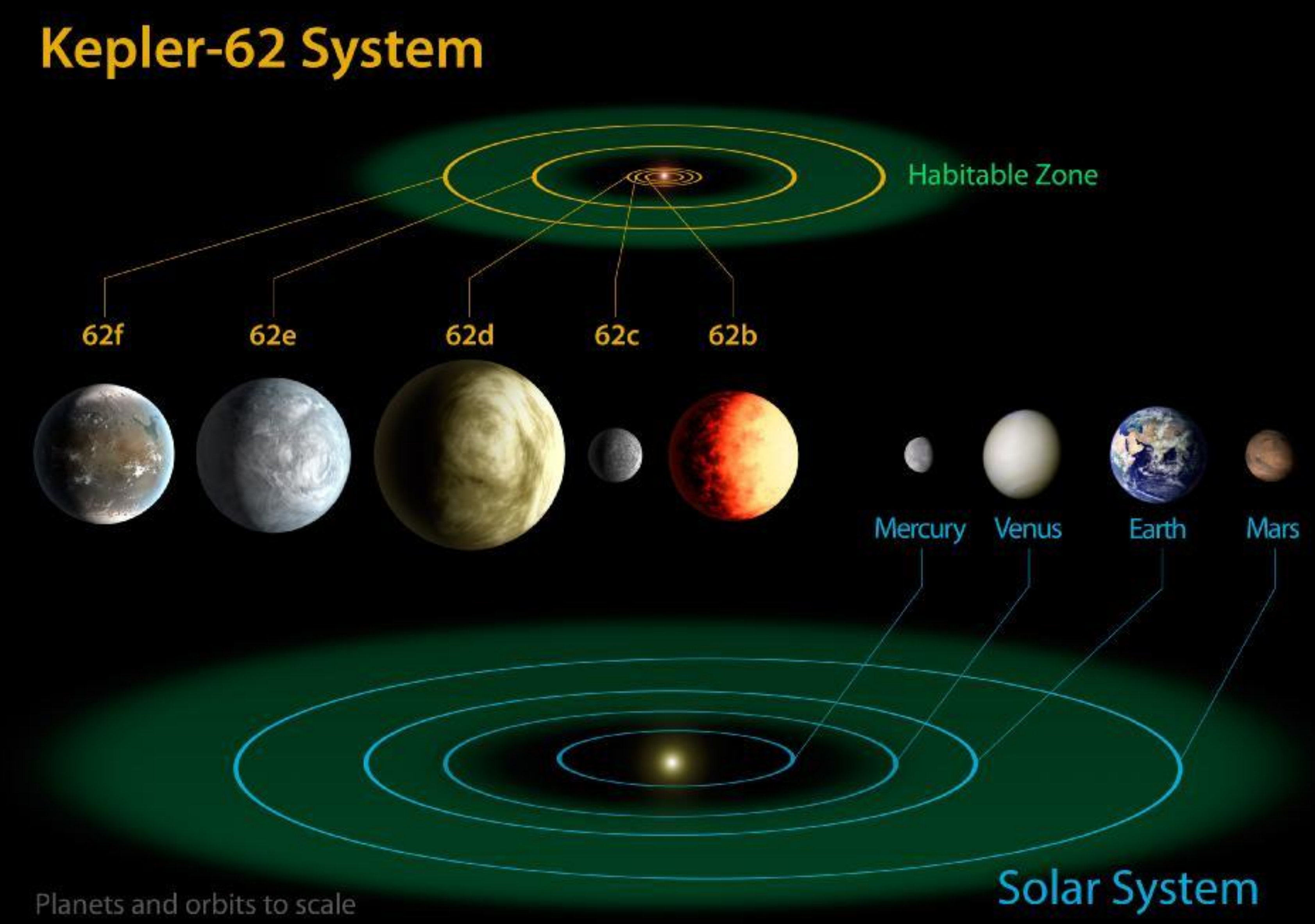
Zona Habitável Estelar

Água Líquida → Zona Habitável

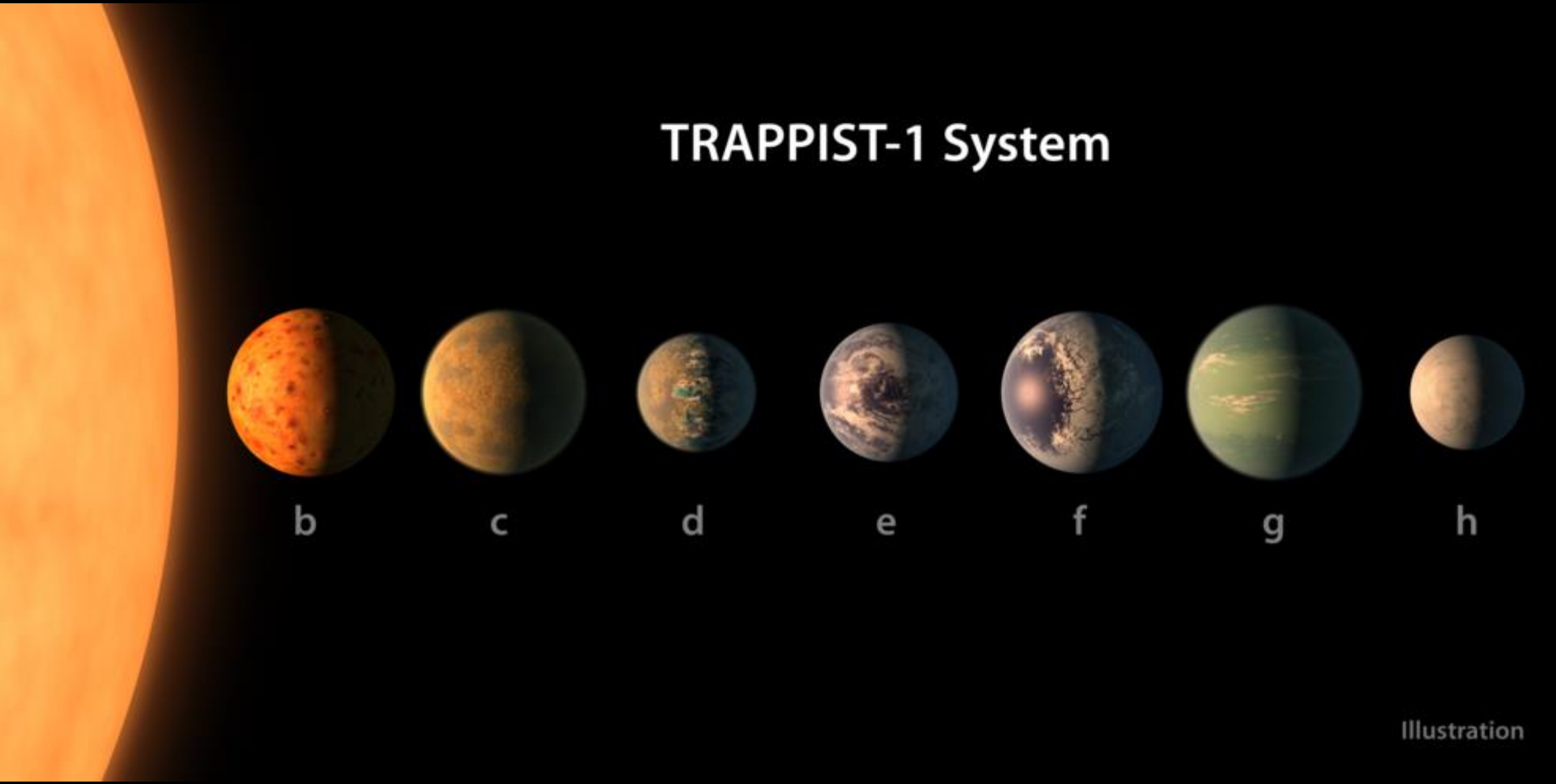


Habitable Zone





Kepler-62 System
Habitable Zone
62f
62e
62d
62c
62b
Mercury
Venus
Earth
Mars
Solar System
Planets and orbits to scale


TRAPPIST-1 System
b
c
d
e
f
g
h
Illustration

Illustrations

TRAPPIST-1 System

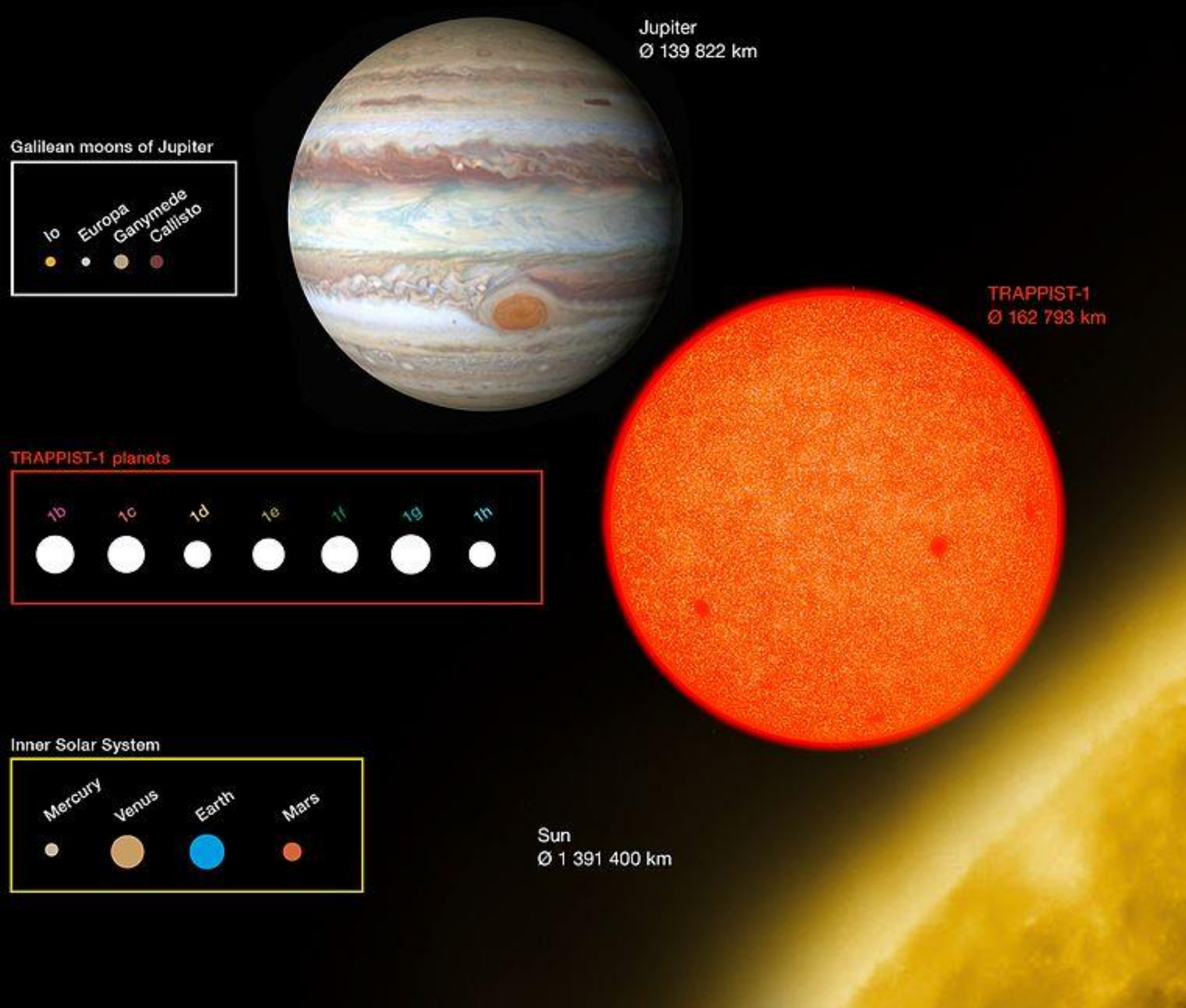
	b	c	d	e	f	g	h
Orbital Period *days*	1.51 *days*	2.42 *days*	4.05 *days*	6.10 *days*	9.21 *days*	12.35 *days*	~20 *days*
Distance to Star *Astronomical Units (AU)*	0.011 *AU*	0.015 *AU*	0.021 *AU*	0.028 *AU*	0.037 *AU*	0.045 *AU*	~0.06 *AU*
Planet Radius *relative to Earth*	1.09 R_{earth}	1.06 R_{earth}	0.77 R_{earth}	0.92 R_{earth}	1.04 R_{earth}	1.13 R_{earth}	0.76 R_{earth}
Planet Mass *relative to Earth*	0.85 M_{earth}	1.38 M_{earth}	0.41 M_{earth}	0.62 M_{earth}	0.68 M_{earth}	1.34 $_{earth}$	–

Solar System
Rocky Planets

	Mercury	Venus	Earth	Mars
Orbital Period *days*	87.97 *days*	224.70 *days*	365.26 *days*	686.98 *days*
Distance to Star *Astronomical Units (AU)*	0.387 *AU*	0.723 *AU*	1.000 *AU*	1.524 *AU*
Planet Radius *relative to Earth*	0.38 R_{earth}	0.95 R_{earth}	1.00 R_{earth}	0.53 R_{earth}
Planet Mass *relative to Earth*	0.06 M_{earth}	0.82 M_{earth}	1.00 M_{earth}	0.11 M_{earth}

Size Comparison

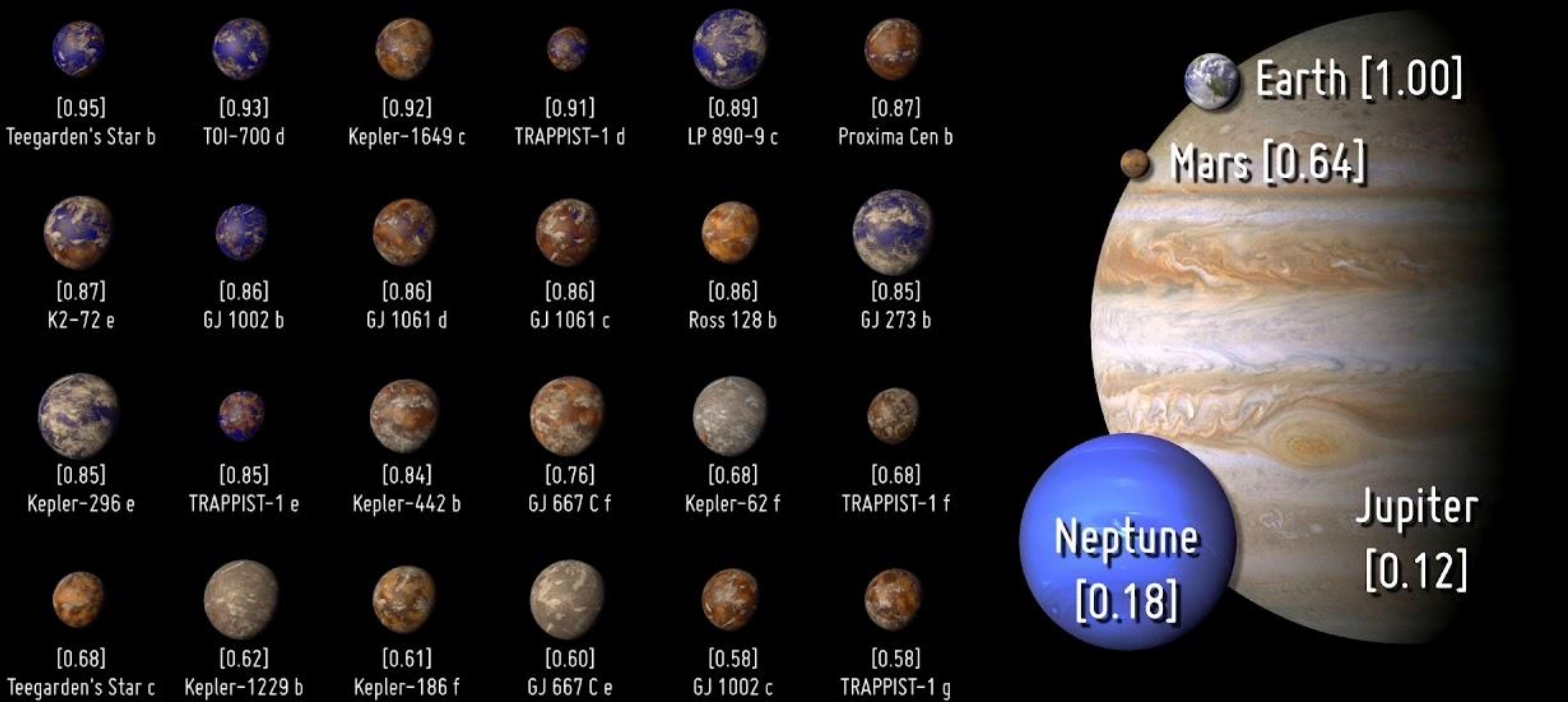
between **TRAPPIST-1** system, Galilean moons of Jupiter and the inner Solar System



Potentially Habitable Exoplanets

Sorted by the Earth Similarity Index (ESI)

PHL

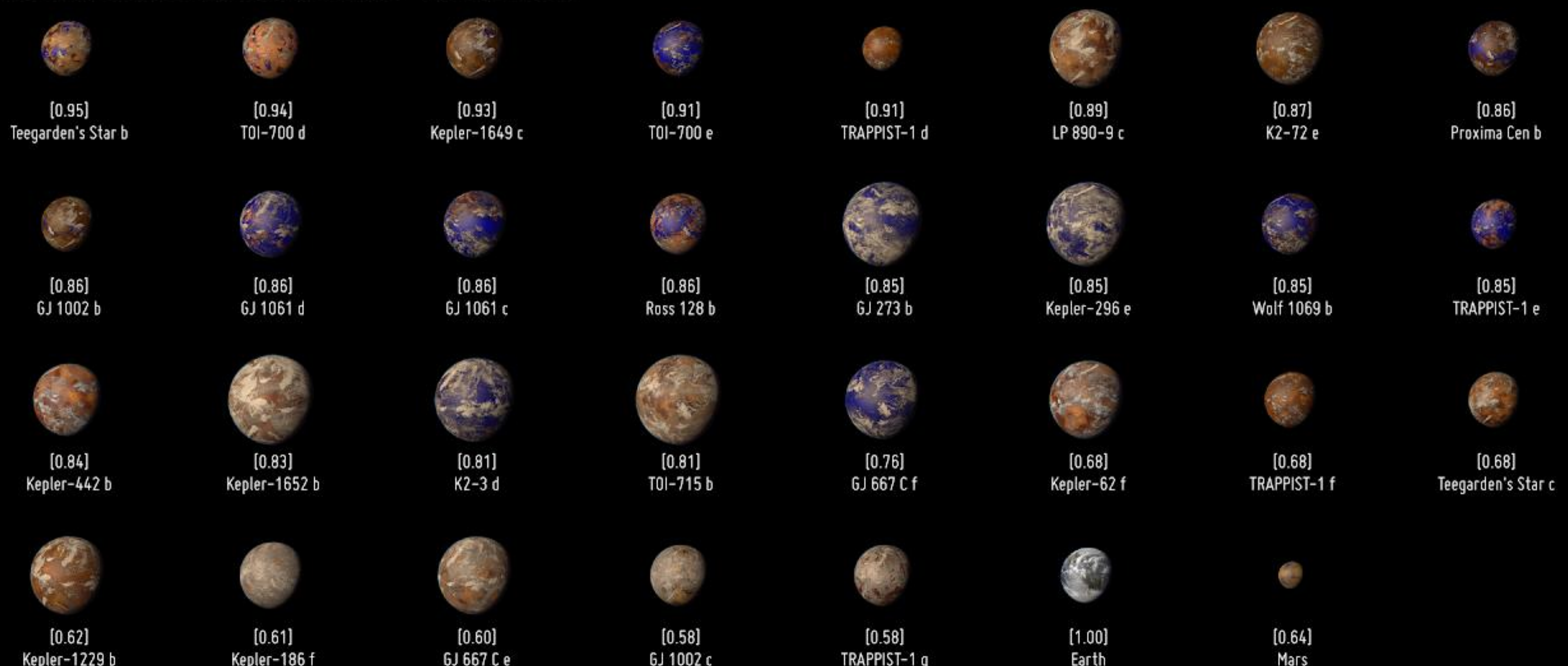


Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Similarity (ESI) to Earth's size and insolation is between brackets.

CREDIT: PHL @ UPR Arecibo (phl.upr.edu) Jan 5, 2023

Potentially Habitable Worlds

Sorted by the Earth Similarity Index (ESI)

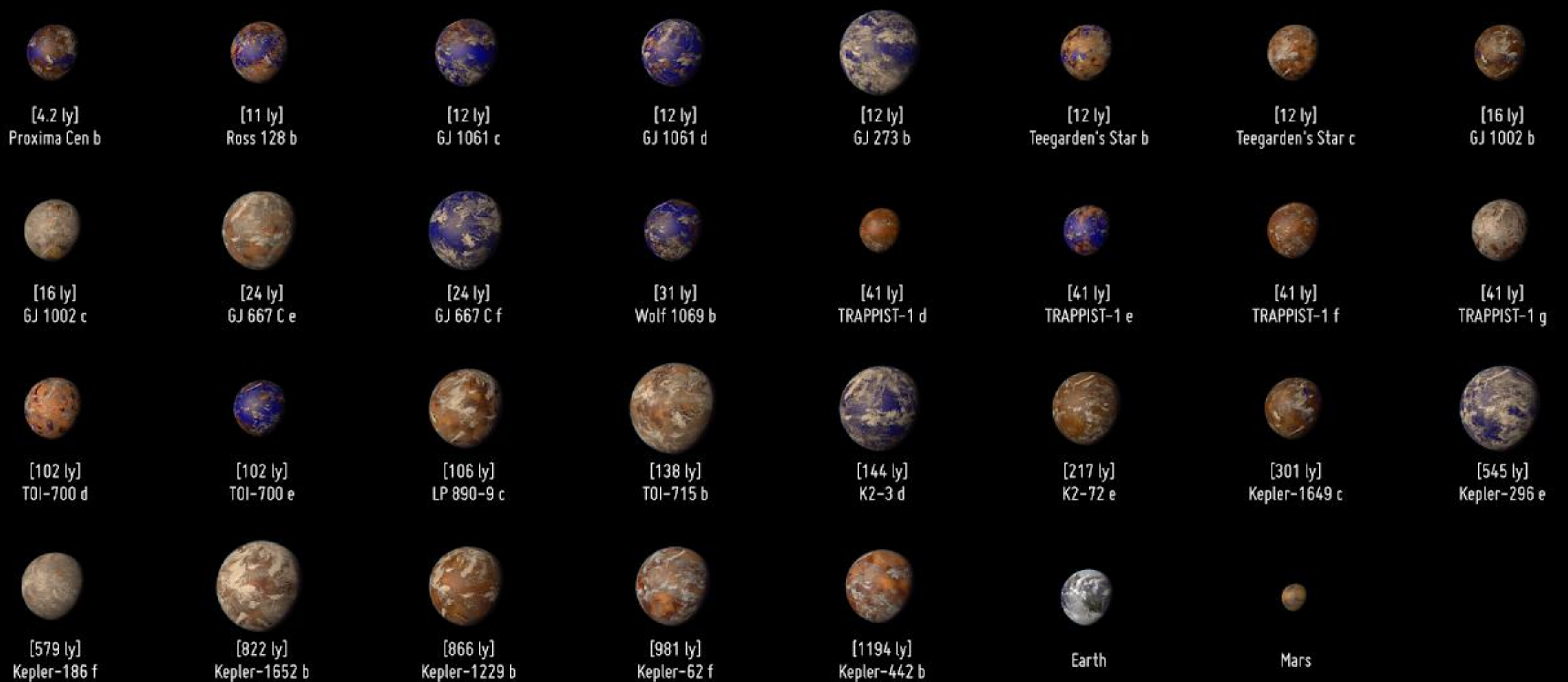


Artistic representations. Earth and Mars for scale.
Planets are organized in order of their decreasing similarity to Earth's size and insolation (ESI shown between brackets).

CREDIT: The Habitable Worlds Catalog, PHL @ UPR Arecibo (phl.upr.edu) Jan 2024

Potentially Habitable Worlds

Sorted by Distance from Earth



Artistic representations. Earth and Mars for scale.
Planets are organized in order of their increasing distance from Earth (shown between brackets in light-years).

CREDIT: The Habitable Worlds Catalog, PHL @ UPR Arecibo (phl.upr.edu) Jan 2024

Boa Notícia!

Proxima Centauri, a estrela mais próxima de nós, abriga um planeta bem parecido com a Terra (Proxima b)

PATENTS Personalized medicine takes hit from US Supreme Court **p.382**

PARTICLE PHYSICS Labs around the world vie to build the next LHC **p.383**

SCIENTIFIC LEGACY The highs and lows of Obama's presidency **p.385**

MEDICINE Non-profit claims secret to cut-price drug discovery **p.388**

RICARDO RAMIREZ

The newly discovered planet orbits Proxima Centauri every 11.2 days.

ASTRONOMY

Nearby star hosts planet

Earth-sized world orbiting Proxima Centauri could harbour water — and life.

BY ALEXANDRA WITZE

Proxima Centauri, the star closest to the Sun, has an Earth-sized planet orbiting it at the right distance for liquid water to exist. The discovery, reported this week in *Nature*[1], fulfils a longstanding dream of science-fiction writers — a potentially habitable world that is close enough for humans to send their first interstellar spacecraft to.

"The search for life starts now," says Guillem Anglada-Escudé, an astronomer at Queen Mary University of London and leader of the team that made the discovery.

Humanity's first chance to explore this nearby world may come from the recently announced Breakthrough Starshot initiative, which plans to build fleets of tiny laser-propelled interstellar probes in the coming decades. Travelling at 20% of the speed of light, they would take about 20 years to cover the 1.3 parsecs from Earth to Proxima Centauri.

Proxima's planet is at least 1.3 times the mass of Earth. The planet orbits its red-dwarf star — much smaller and dimmer than the Sun — every 11.2 days. "If you tried to pick the type of planet you'd most want around the type of star you'd most want, it would be this," says David Kipping, an astronomer at Columbia University in New York City. "It's thrilling."

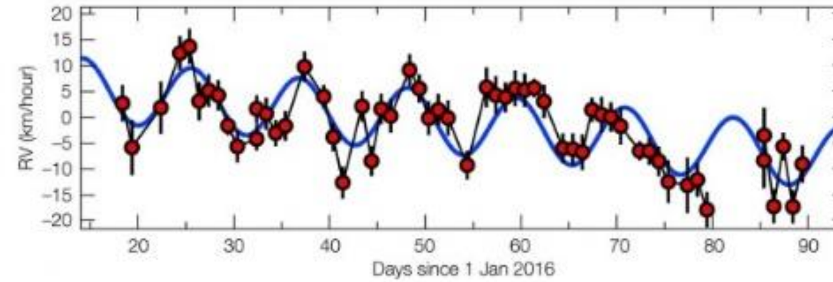
GRAVITATIONAL HINTS

Earlier studies had hinted at the existence of a planet around Proxima. Starting in 2000, a spectrograph at the European Southern Observatory (ESO) in Chile looked for shifts in starlight caused by the gravitational tug of an orbiting planet. The measurements suggested that something was happening to the star every 11.2 days. But astronomers could not rule out whether the signal was caused by an orbiting planet or another type of activity, such as stellar flares.

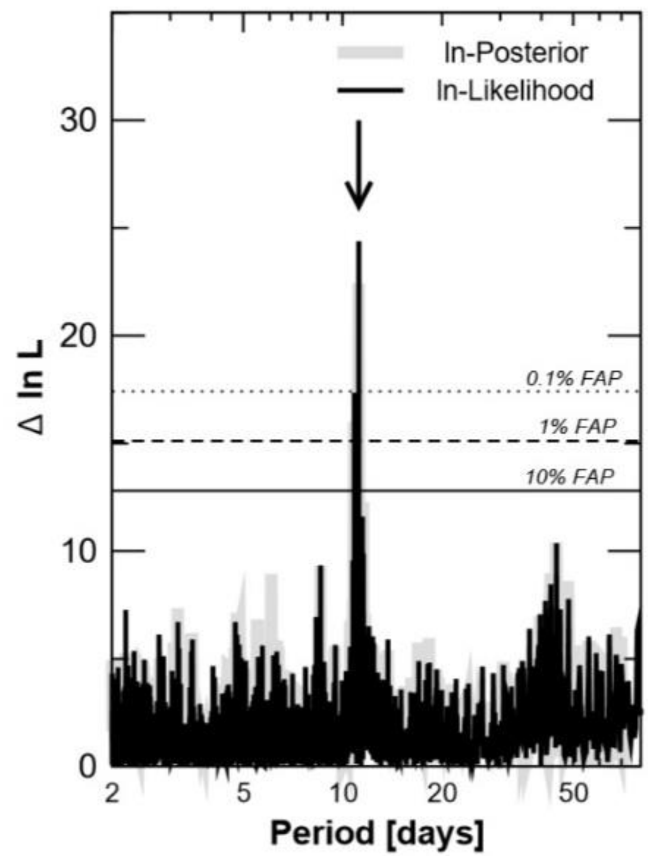
In January 2016, Anglada-Escudé and his colleagues launched a campaign to nail down the suspected Proxima planet. ESO granted their request to observe using a second planet-hunting instrument, on a different telescope, for 20 minutes almost every night between 19 January and 31 March. "As soon as we had 10 nights it was obvious," Anglada-Escudé says.

The team dubbed the work the 'pale red dot' campaign, after the famous 'pale blue dot' photograph taken of Earth by the Voyager 1 spacecraft in 1990. Because Proxima is a red-dwarf star, the planet would appear reddish or orangeish, perhaps bathed in light similar to the warm evening tints of Earth.

Although the planet orbits at a distance that would permit liquid water, other factors ▶



This plot shows how the motion of Proxima Centauri towards and away from Earth is changing with time over the first half of 2016. Sometimes Proxima Centauri is approaching Earth at about 5 kilometres per hour — normal human walking pace — and at times receding at the same speed. This regular pattern of changing radial velocities repeats with a period of 11.2 days. Careful analysis of the resulting tiny Doppler shifts showed that they indicated the presence of a planet with a mass at least 1.3 times that of the Earth, orbiting about 7 million kilometres from Proxima Centauri — only 5% of the Earth-Sun distance.



LETTER

doi:10.1038/nature19106

A terrestrial planet candidate in a temperate orbit around Proxima Centauri

Guillem Anglada-Escudé[1], Pedro J. Amado[2], John Barnes[3], Zaira M. Berdiñas[2], R. Paul Butler[4], Gavin A. L. Coleman[1], Ignacio de la Cueva[5], Stefan Dreizler[6], Michael Endl[7], Benjamin Giesers[6], Sandra V. Jeffers[6], James S. Jenkins[8], Hugh R. A. Jones[9], Marcin Kiraga[10], Martin Kürster[11], María J. López-González[2], Christopher J. Marvin[6], Nicolás Morales[2], Julien Morin[12], Richard P. Nelson[1], José L. Ortiz[2], Aviv Ofir[13], Sijme-Jan Paardekooper[1], Ansgar Reiners[6], Eloy Rodríguez[2], Cristina Rodríguez-López[2], Luis F. Sarmiento[6], John P. Strachan[1], Yiannis Tsapras[14], Mikko Tuomi[9] & Mathias Zechmeister[6]

At a distance of 1.295 parsecs[1], the red dwarf Proxima Centauri (α Centauri C, GL 551, HIP 70890 or simply Proxima) is the Sun's closest stellar neighbour and one of the best-studied low-mass stars. It has an effective temperature of only around 3,050 kelvin, a luminosity of 0.15 per cent of that of the Sun, a measured radius of 14 per cent of the radius of the Sun[2] and a mass of about 12 per cent of the mass of the Sun. Although Proxima is considered a moderately active star, its rotation period is about 83 days (ref. 3) and its quiescent activity levels and X-ray luminosity[4] are comparable to those of the Sun. Here we report observations that reveal the presence of a small planet with a minimum mass of about 1.3 Earth masses orbiting Proxima with a period of approximately 11.2 days at a semi-major-axis distance of around 0.05 astronomical units. Its equilibrium temperature is within the range where water could be liquid on its surface[5].

reduction codes[10]. As systematic calibration errors produce correlations among the observations for each night[11], we consolidated the Doppler measurements through nightly averages to present a simpler and more conservative signal search. This led to 72 UVES, 90 HARPS pre-2016 and 54 HARPS PRD epochs. The PRD photometric observations were obtained using the Astrograph for the South Hemisphere II telescope (ASH2 hereafter[12], with S II and Hα narrowband filters) and the Las Cumbres Observatory Global Telescope network[13] (with Johnson B and V band filters), over the same time interval and similar sampling rates as the HARPS PRD observations. Further details about each campaign and the photometry are detailed in Methods. All of the time series used in this work are available as Supplementary Data.

The search and assessment of the statistical significance (see below and Methods for more details) of the signals were performed using frequentist[14] and Bayesian[15] methods. The periodograms in Fig. 1

CATEGORIES

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Expert Insights (15)
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Biosignature Gases: A Needle in a Haystack
Interview to Didier Queloz – 'From 51 Pegasi to the search for life around small stars'
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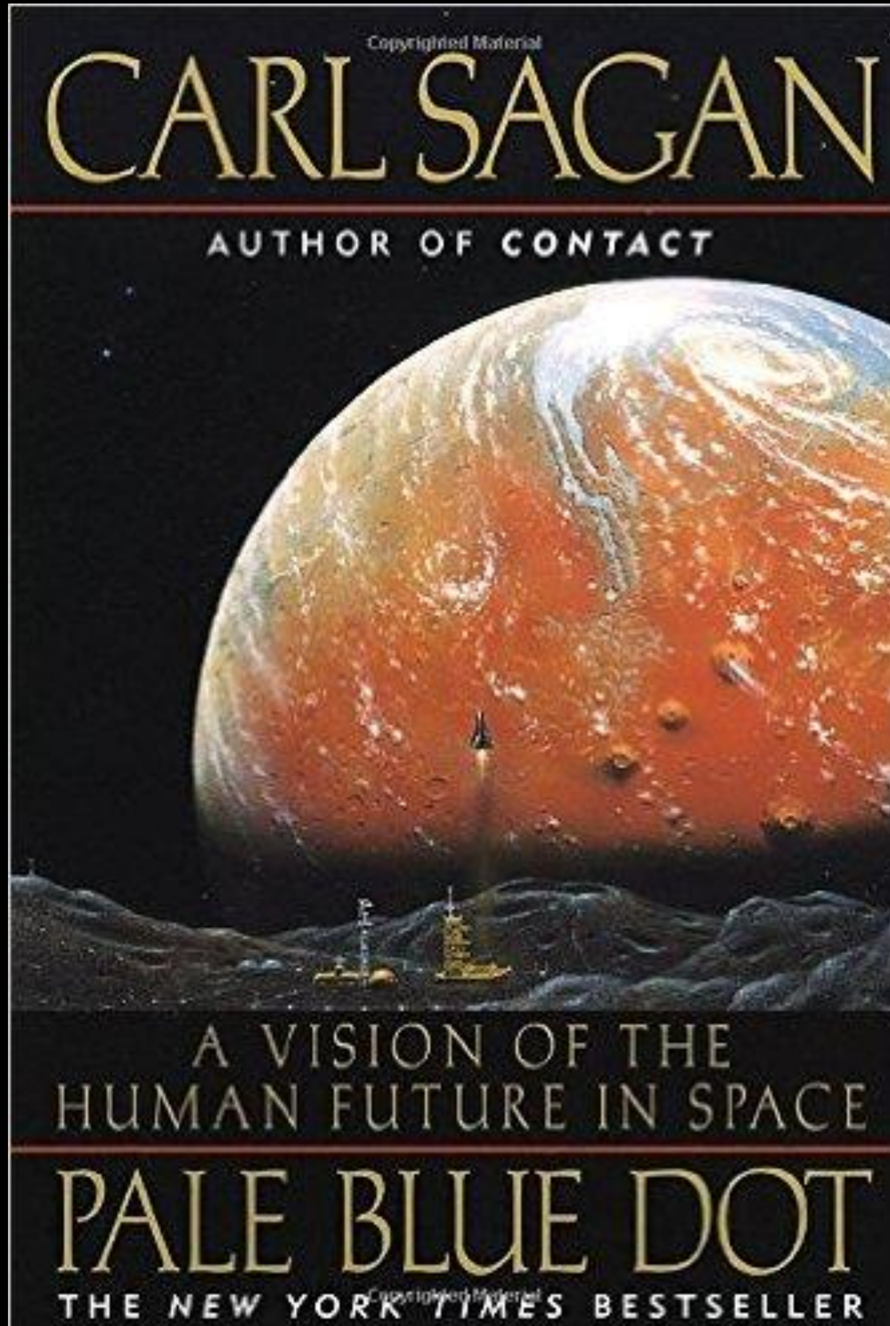
Magnetic Open Cluster Stars of a Peculiar Kind observed with HARPS-POL
Magnetic Fields: those troublemakers!
'A brief personal History of Exoplanets', by Paul Butler

PROJECT UPDATES

PROXIMA B IS OUR NEIGHBOR… BETTER GET USED TO IT!

AUGUST 24, 2016 PALE RED DOT 8 COMMENTS

It is true. We are convinced that there is a planet orbiting Proxima now. The evidence goes as follows : a signal was spotted back in 2013 on previous surveys (UVES and HARPS). The preliminary detection was first done by Mikko Tuomi, our in-house applied mathematician and his Bayesian codes. However, the signal was not convincing as the data was really sparse and the period was ambiguous (other possible solutions at 20 and 40 days, plus a long period signal of unknown origin). We followed up Proxima in the next years but our two observing runs were 12 days, barely sufficient to secure a signal which ended up being 11.2 days. So the Pale Red Dot was designed with the sole purpose of confirming or refuting its strict periodicity, plus carefully monitor the star for activity induced variability. We got very lucky with the weather so we obtained 54 out of 60 observations. The photometric monitoring telescopes (ASH2 and several units of Las Cumbres Observatory Global Telescope network), worked flawlessly so we could see the effect of spots, flares and rotation of the star, which also had a footprint on the spectra. However, nothing indicated that spurious variability would be happening at 11.2 days.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