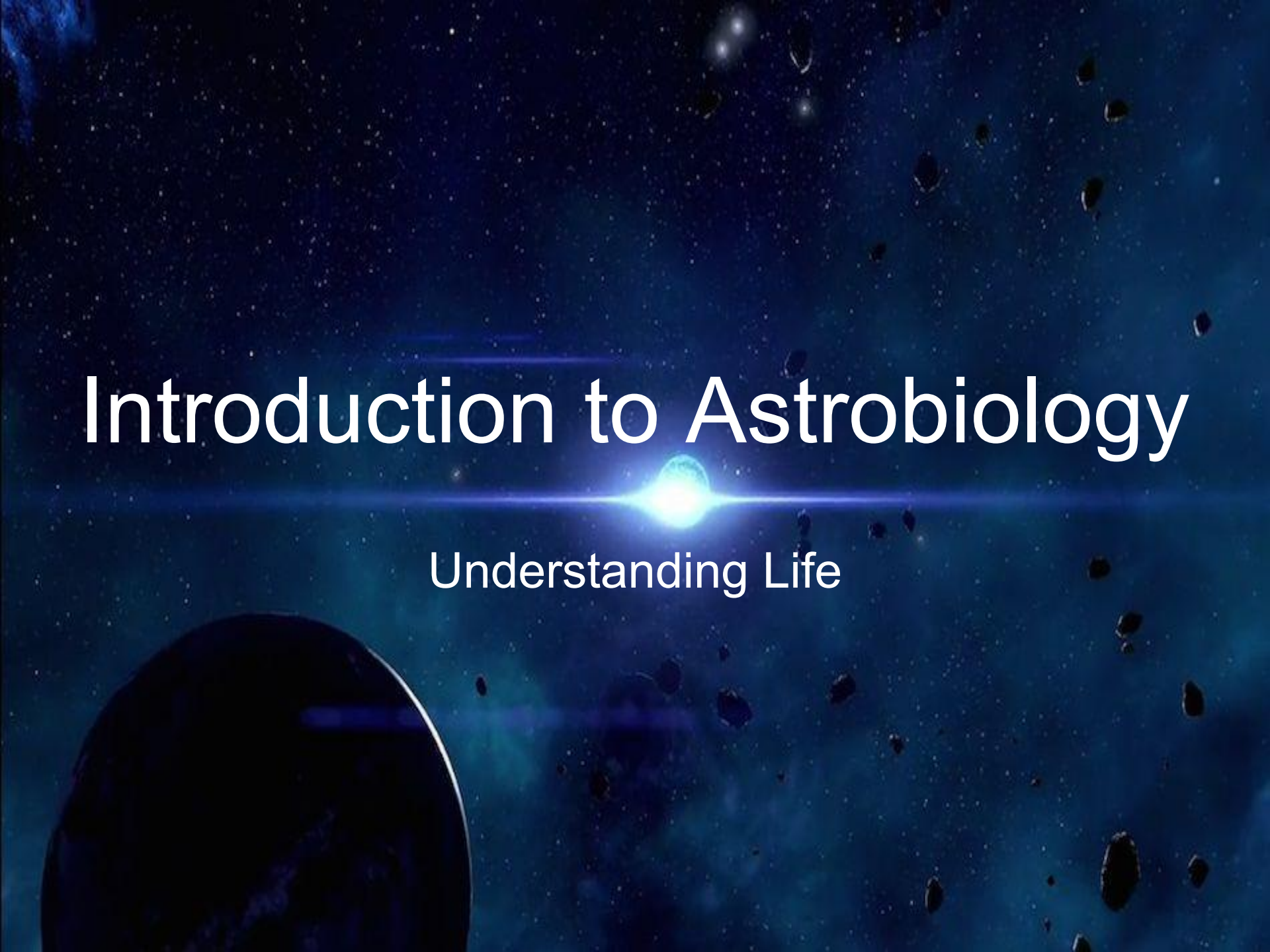
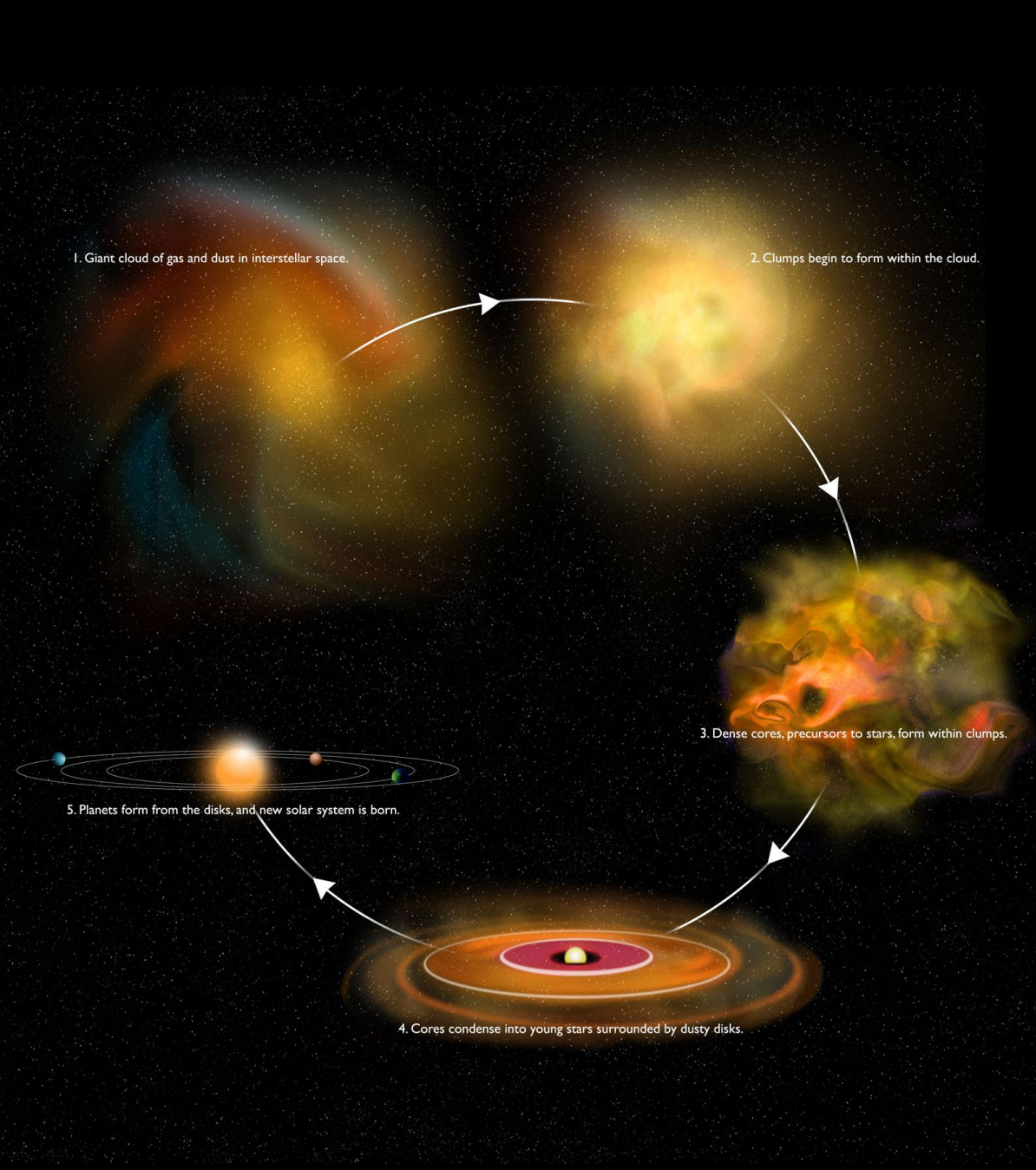
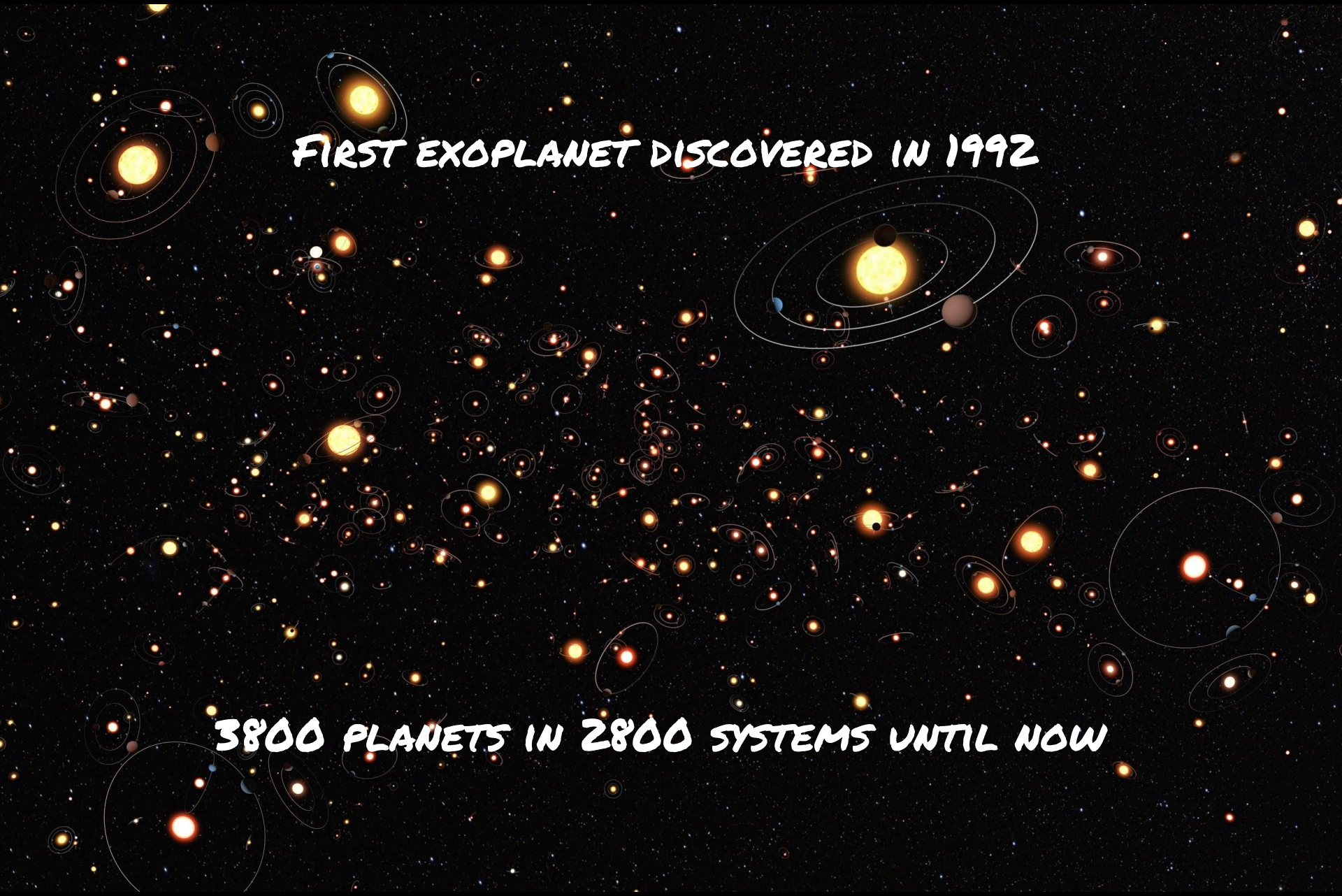
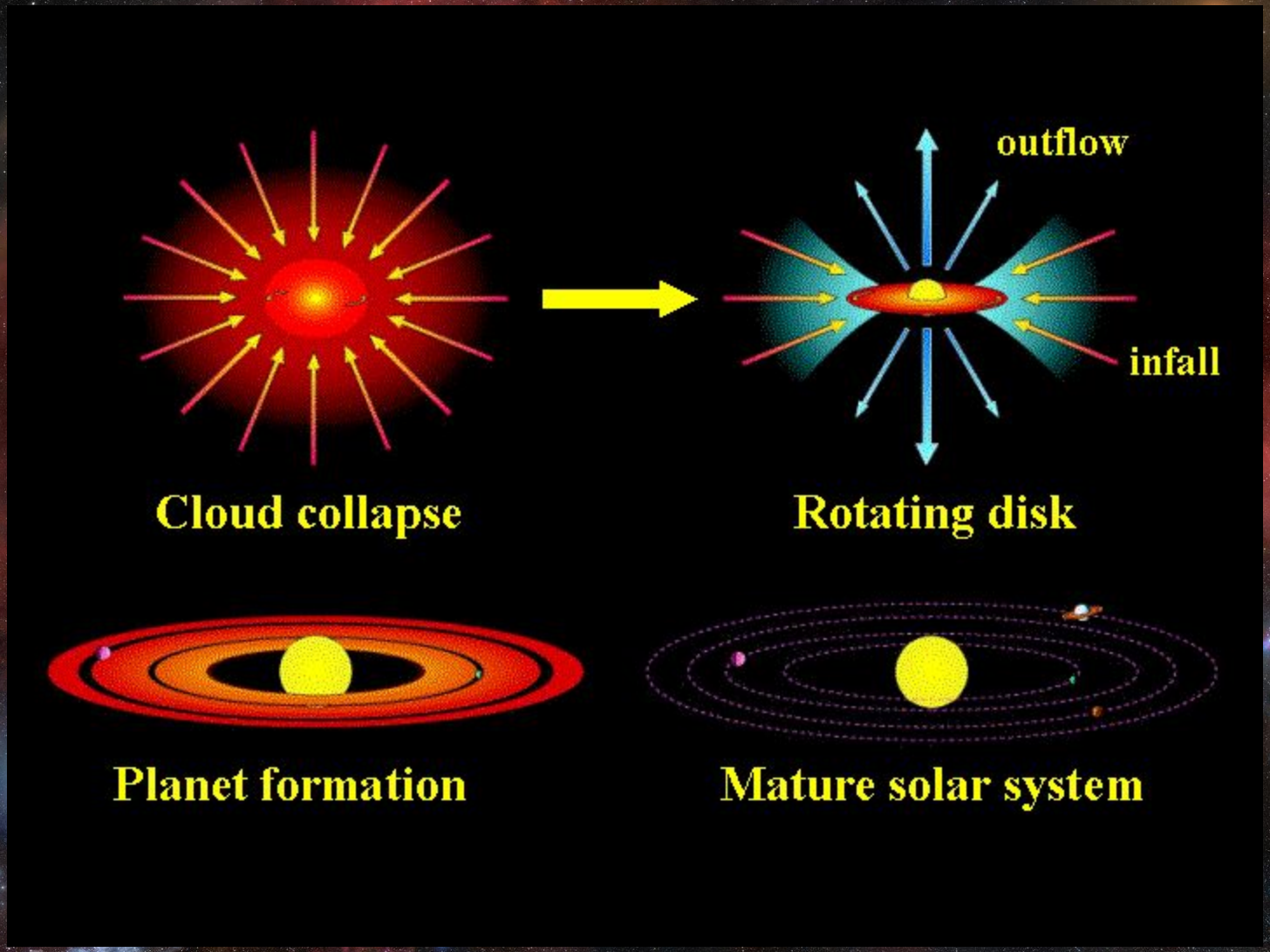
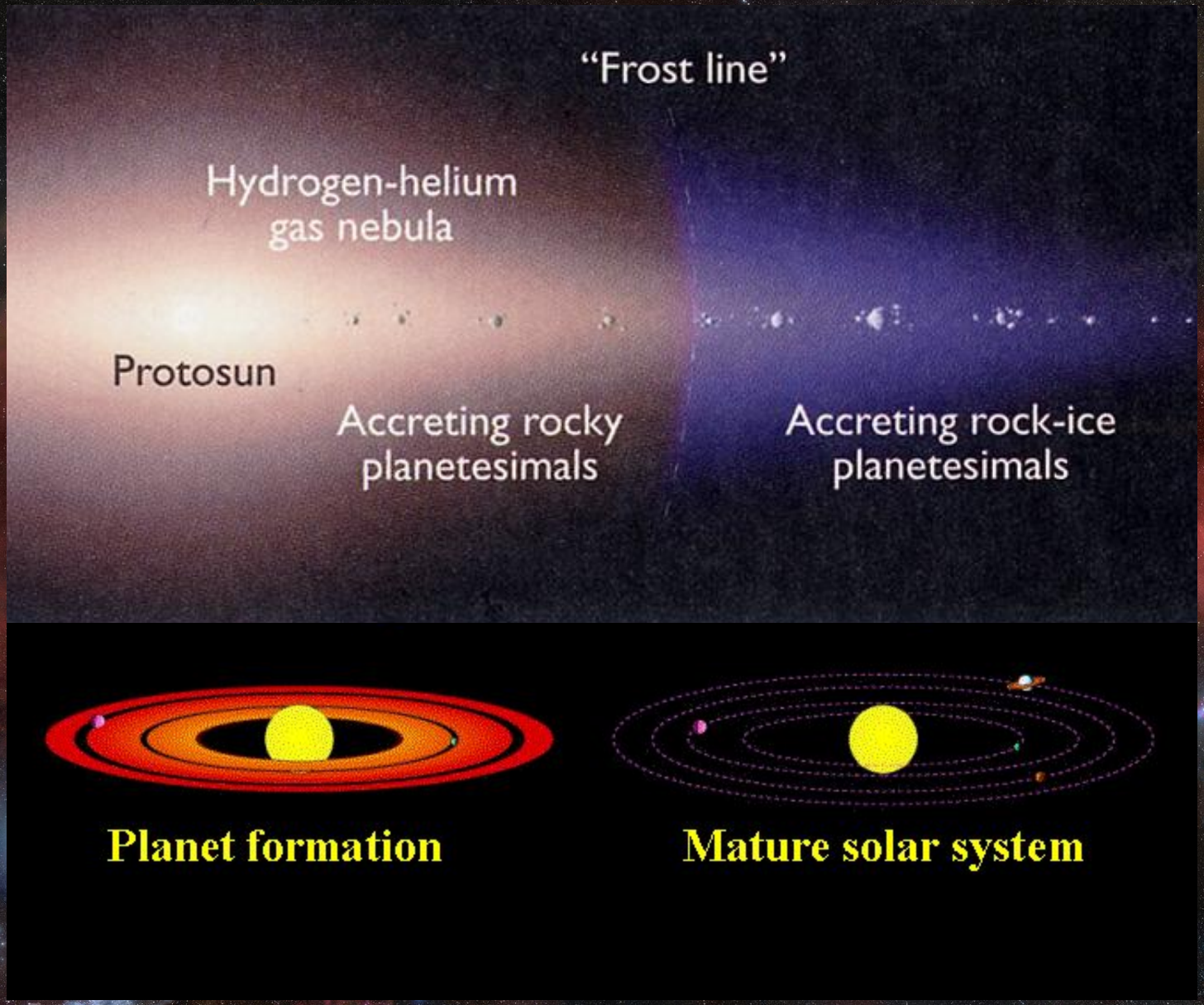
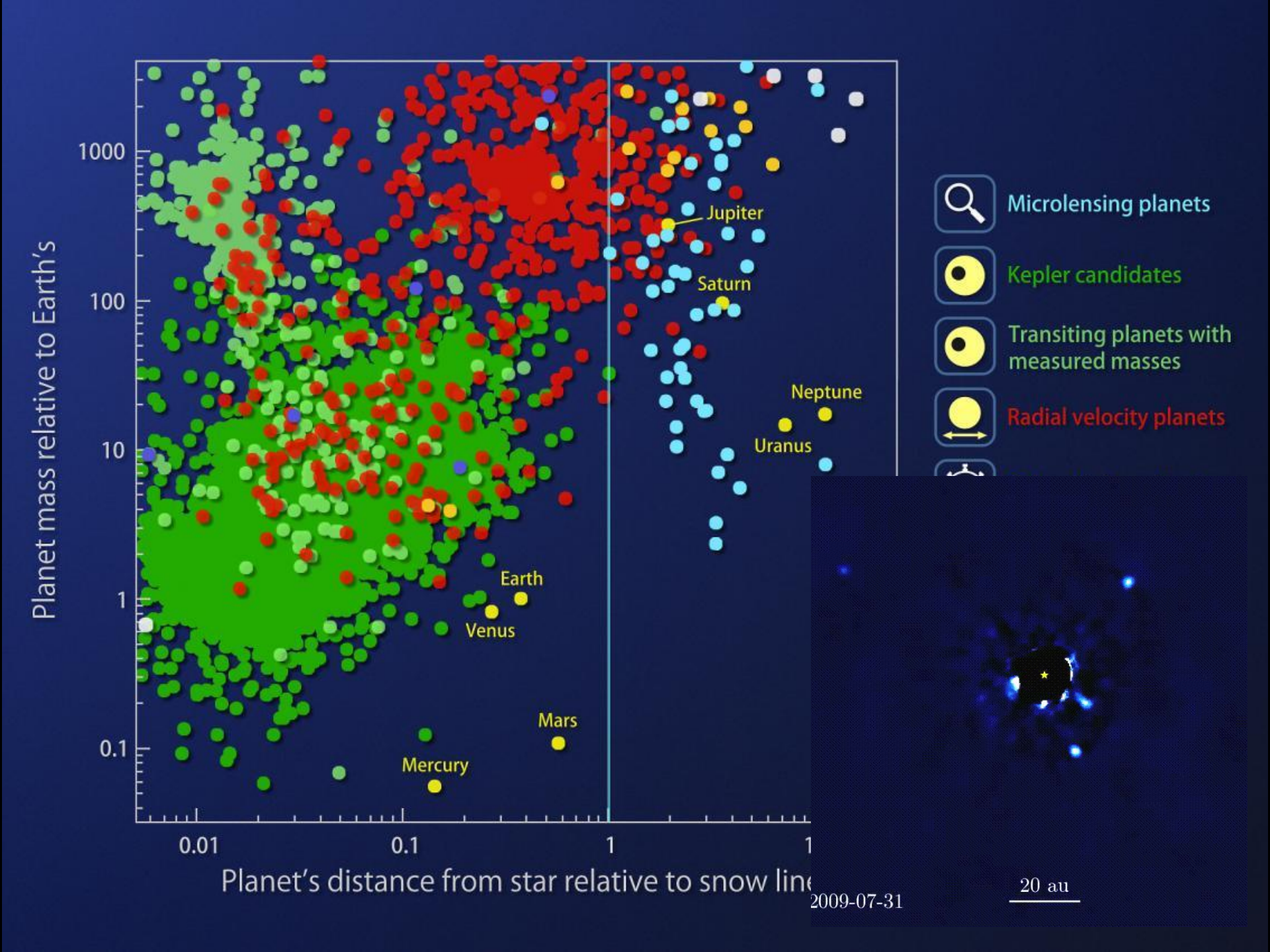

Introduction to Astrobiology
Understanding Life

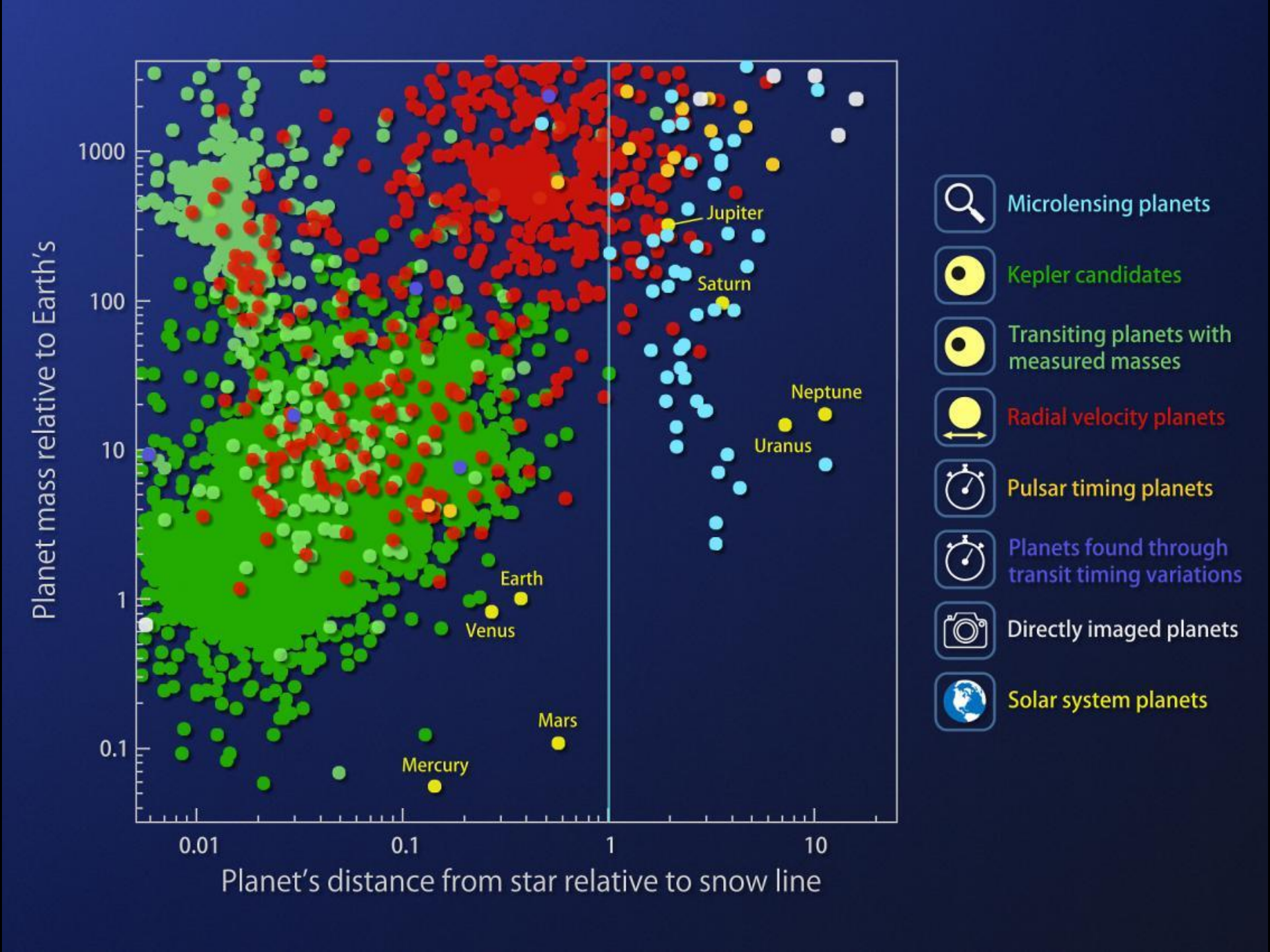

1. Giant cloud of gas and dust in interstellar space.
2. Clumps begin to form within the cloud.
3. Dense cores, precursors to stars, form within clumps.
4. Cores condense into young stars surrounded by dusty disks.
5. Planets form from the disks, and new solar system is born.


First exoplanet discovered in 1992
3800 planets in 2800 systems until now

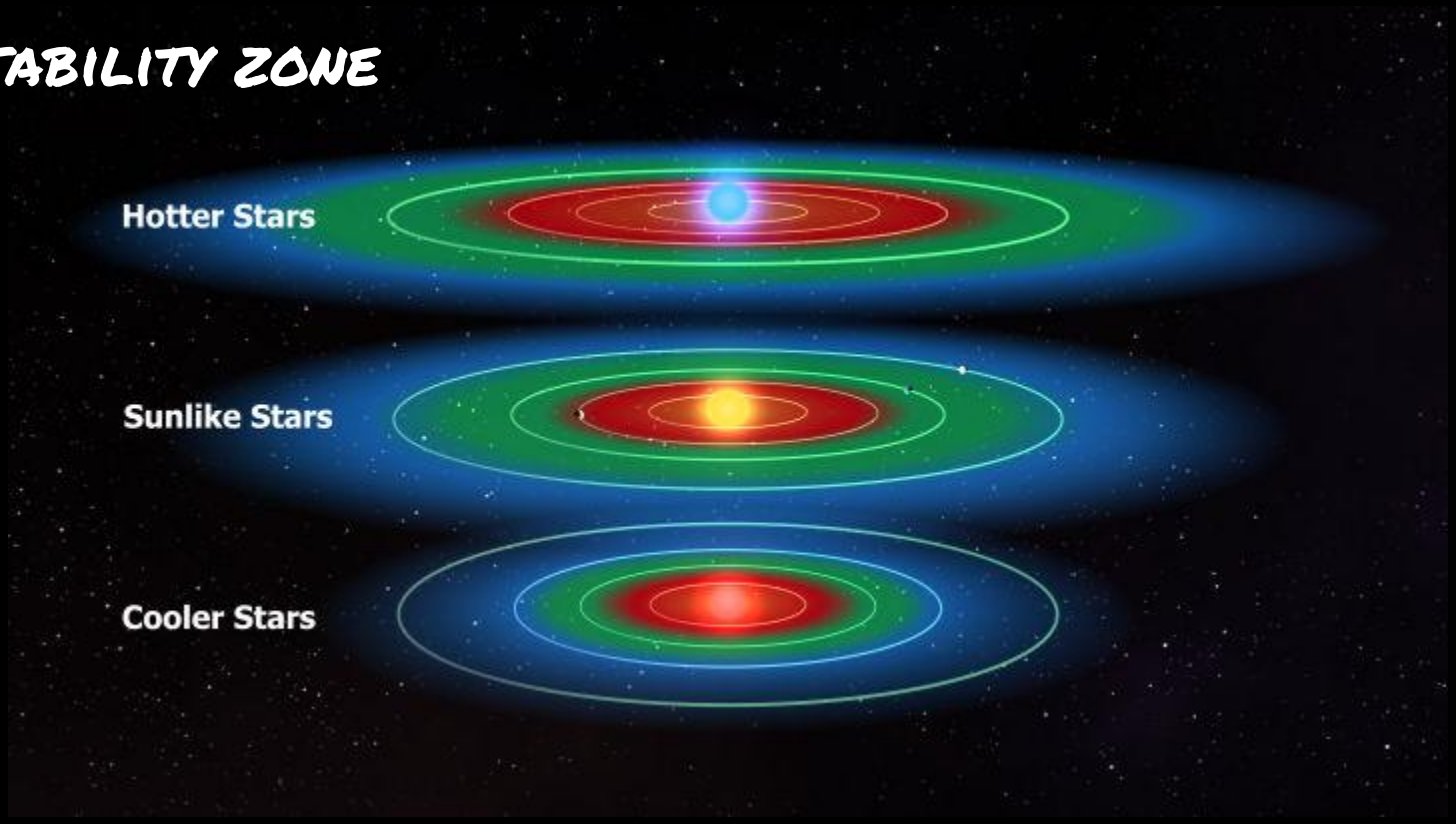

outflow
infall
Cloud collapse
Rotating disk
Planet formation
Mature solar system


"Frost line"
Hydrogen-helium gas nebula
Protosun
Accreting rocky planetesimals
Accreting rock-ice planetesimals
Planet formation
Mature solar system


Planet mass relative to Earth's
1000
100
10
1
0.1
0.01
0.1
1
Planet's distance from star relative to snow line
Jupiter
Saturn
Neptune
Uranus
Earth
Venus
Mars
Mercury
Microlensing planets
Kepler candidates
Transiting planets with measured masses
Radial velocity planets
2009-07-31
20 au


Planet mass relative to Earth's
1000
100
10
1
0.1
0.01
0.1
1
10
Planet's distance from star relative to snow line
Jupiter
Saturn
Neptune
Uranus
Earth
Venus
Mars
Mercury
Microlensing planets
Kepler candidates
Transiting planets with measured masses
Radial velocity planets
Pulsar timing planets
Planets found through transit timing variations
Directly imaged planets
Solar system planets

Habitability zone



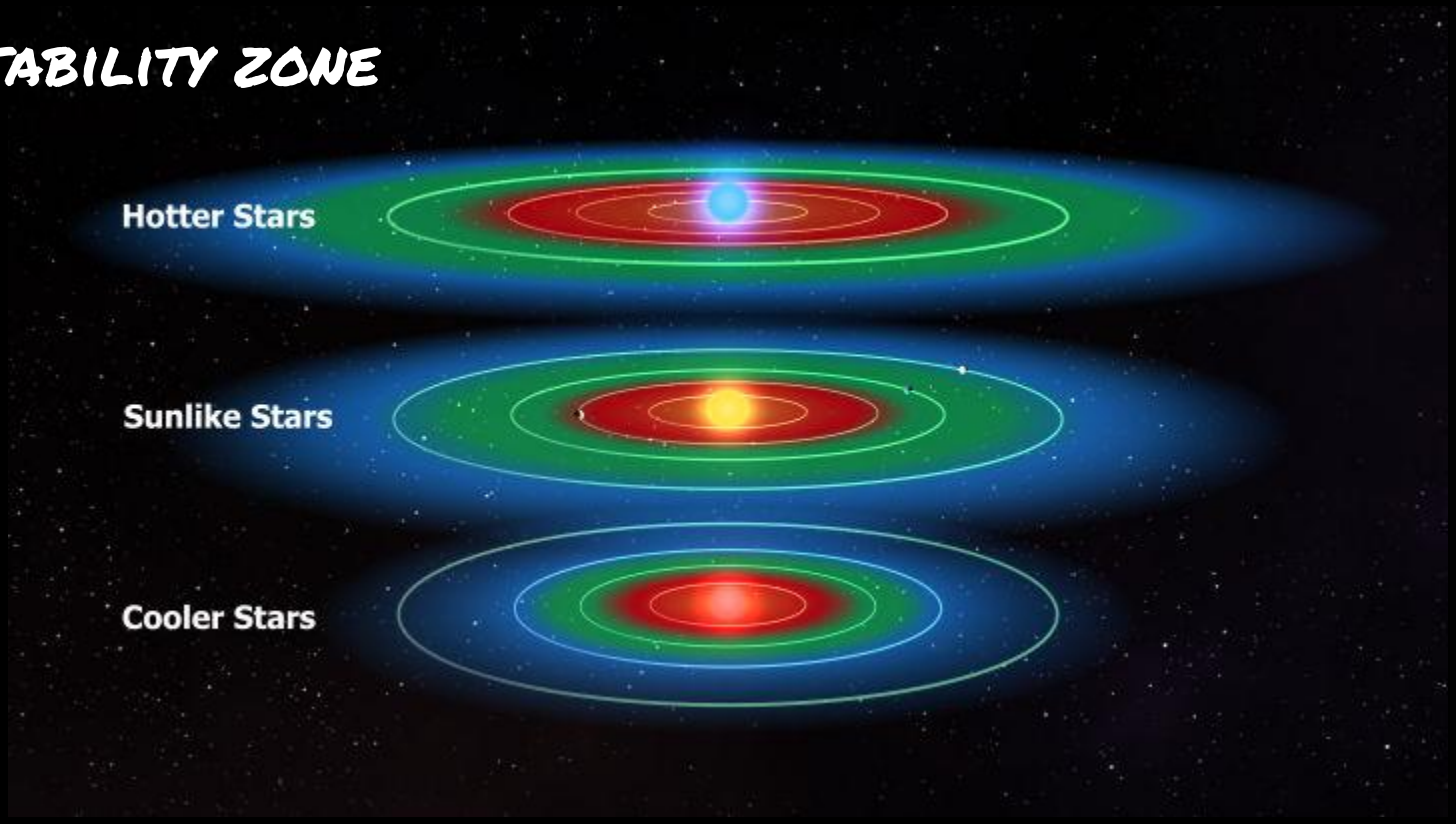
$$E_{\text{abs}} = \frac{(1-A)L_{\odot}}{4\pi a^2}(\pi R_p^2)$$

$$E_{\text{em}} = 4\pi R_p^2 \sigma T_p^4$$

$$a = \left[\frac{(1-A)L_*}{16\pi\sigma T_p^4}\right]^{1/2}$$

$$0.87 < \frac{a}{[A.U.]} < 0.47$$

Habitability zone



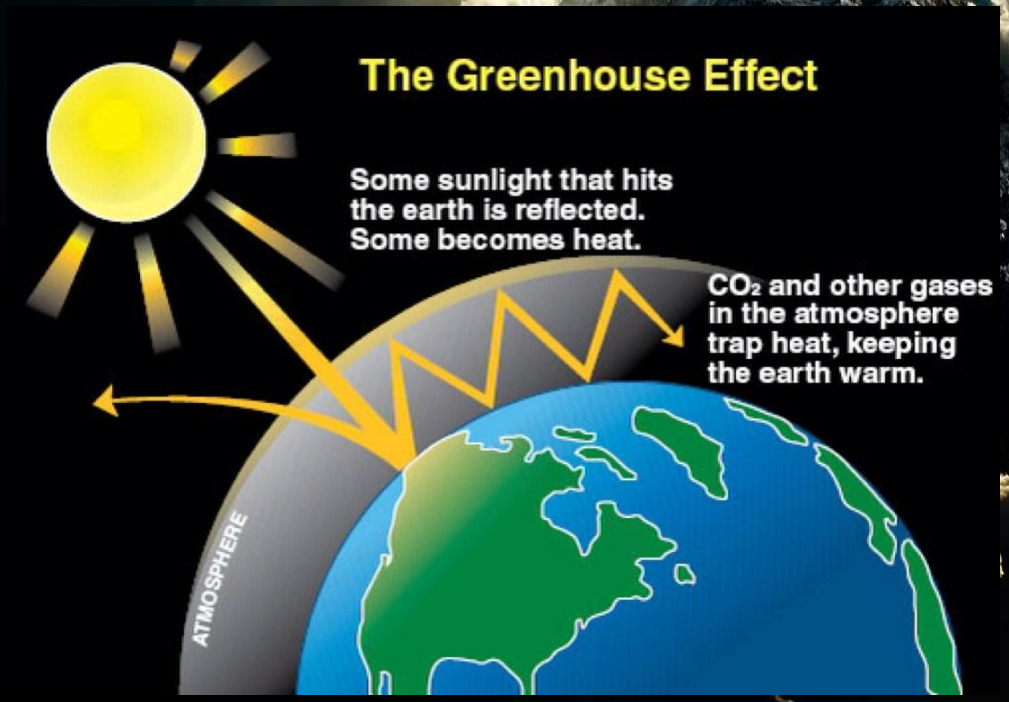
$$E_{\text{abs}} = \frac{(1-A)L_{\odot}}{4\pi a^2}(\pi R_p^2)$$

$$E_{\text{em}} = 4\pi R_p^2 \sigma T_p^4$$

$$a = \left[\frac{(1-A)L_*}{16\pi\sigma T_p^4}\right]^{1/2}$$

$$0.87 < \frac{a}{[A.U.]} < 0.47 \quad ??$$

The atmosphere significantly changes the planets temperature



Kepler-442b

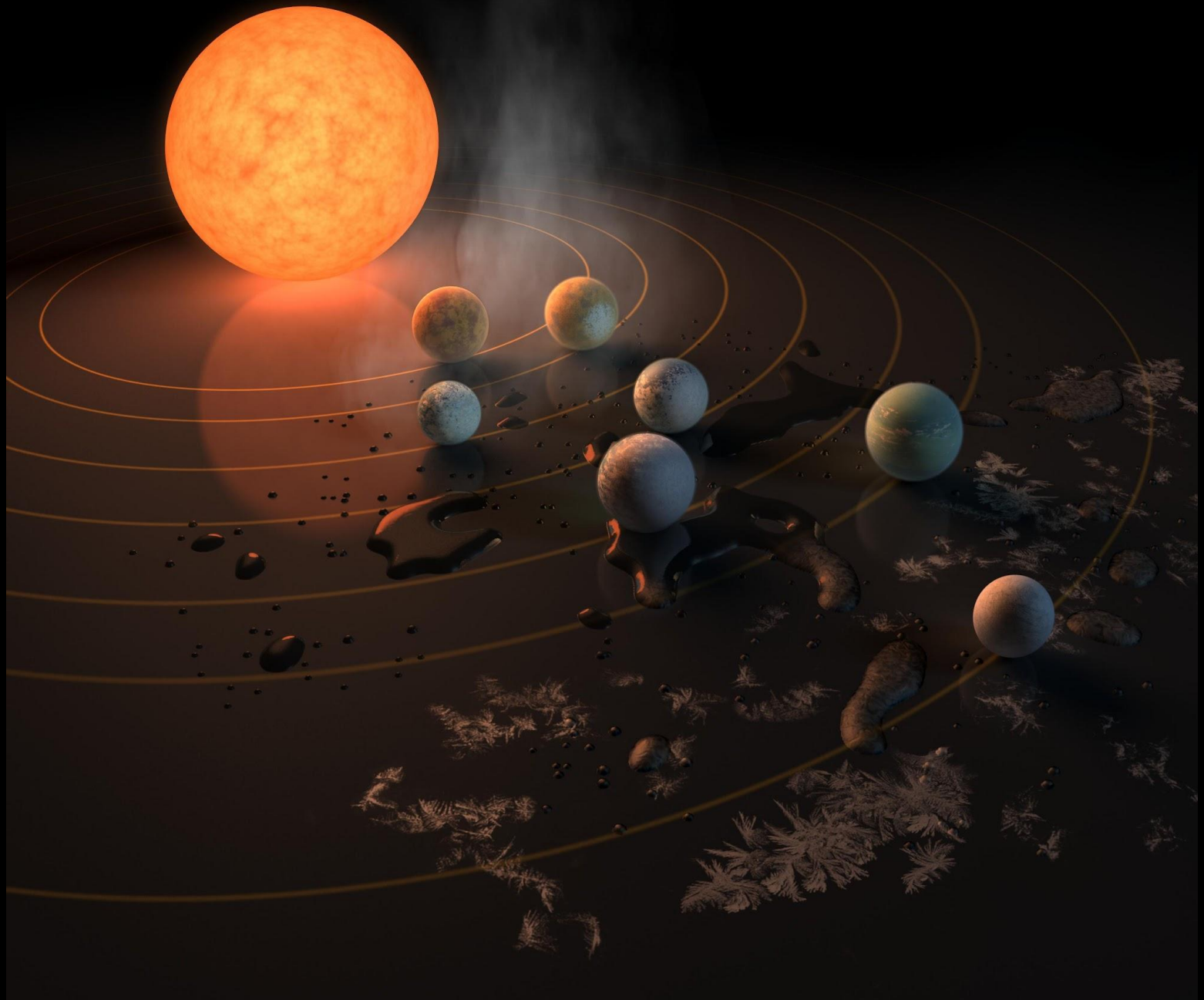
Physical characteristics

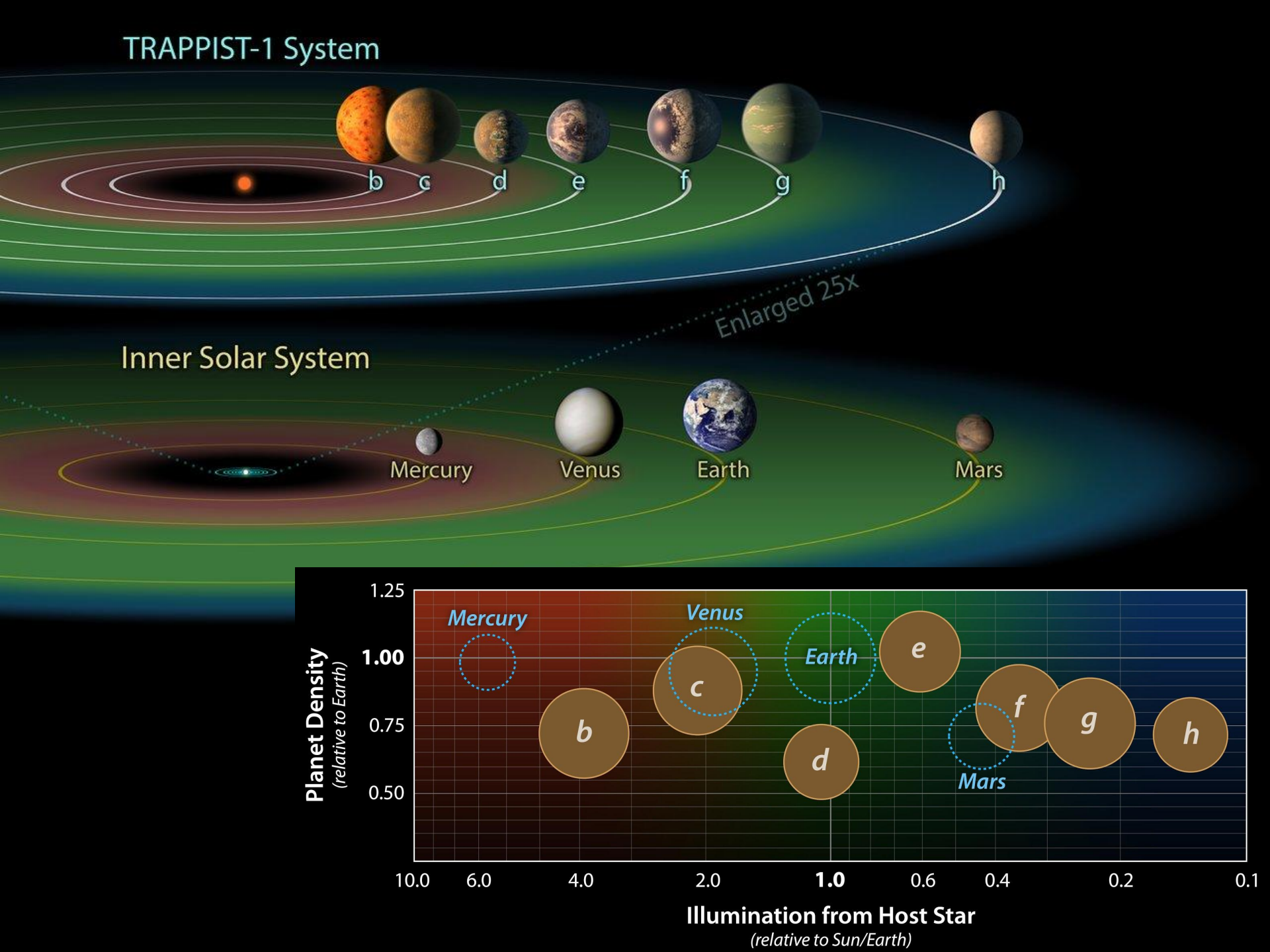
M = 2.3 $M_\oplus$
R = 1.34 $R_\oplus$
Flux = 0.7 $F_\oplus$
T = -40 °C
a = 0.4 AU
orbital period = 112 d

Parent Star

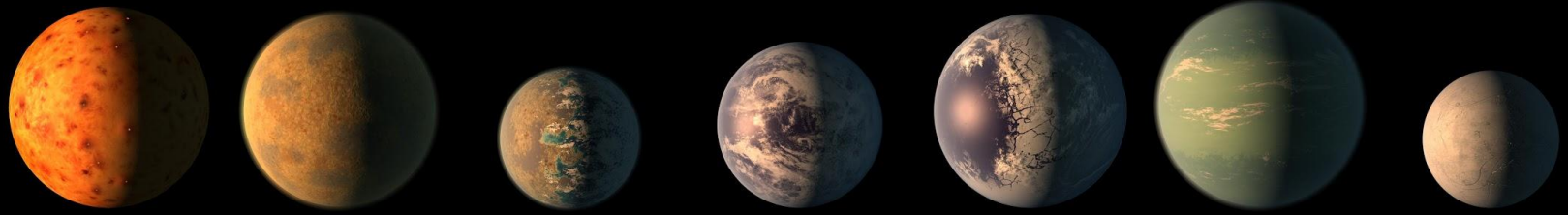
M = 0.6 $M_\odot$
R = 0.6 $R_\odot$
T = 4400 K

TRAPPIST-1 system has three planet in the habitable zone




TRAPPIST-1 System
b
c
d
e
f
g
h
Enlarged 25x
Inner Solar System
Mercury
Venus
Earth
Mars
Planet Density
(relative to Earth)
1.25
1.00
0.75
0.50
Mercury
Venus
Earth
Mars
b
c
d
e
f
g
h
10.0
6.0
4.0
2.0
1.0
0.6
0.4
0.2
0.1
Illumination from Host Star
(relative to Sun/Earth)

Illustrations

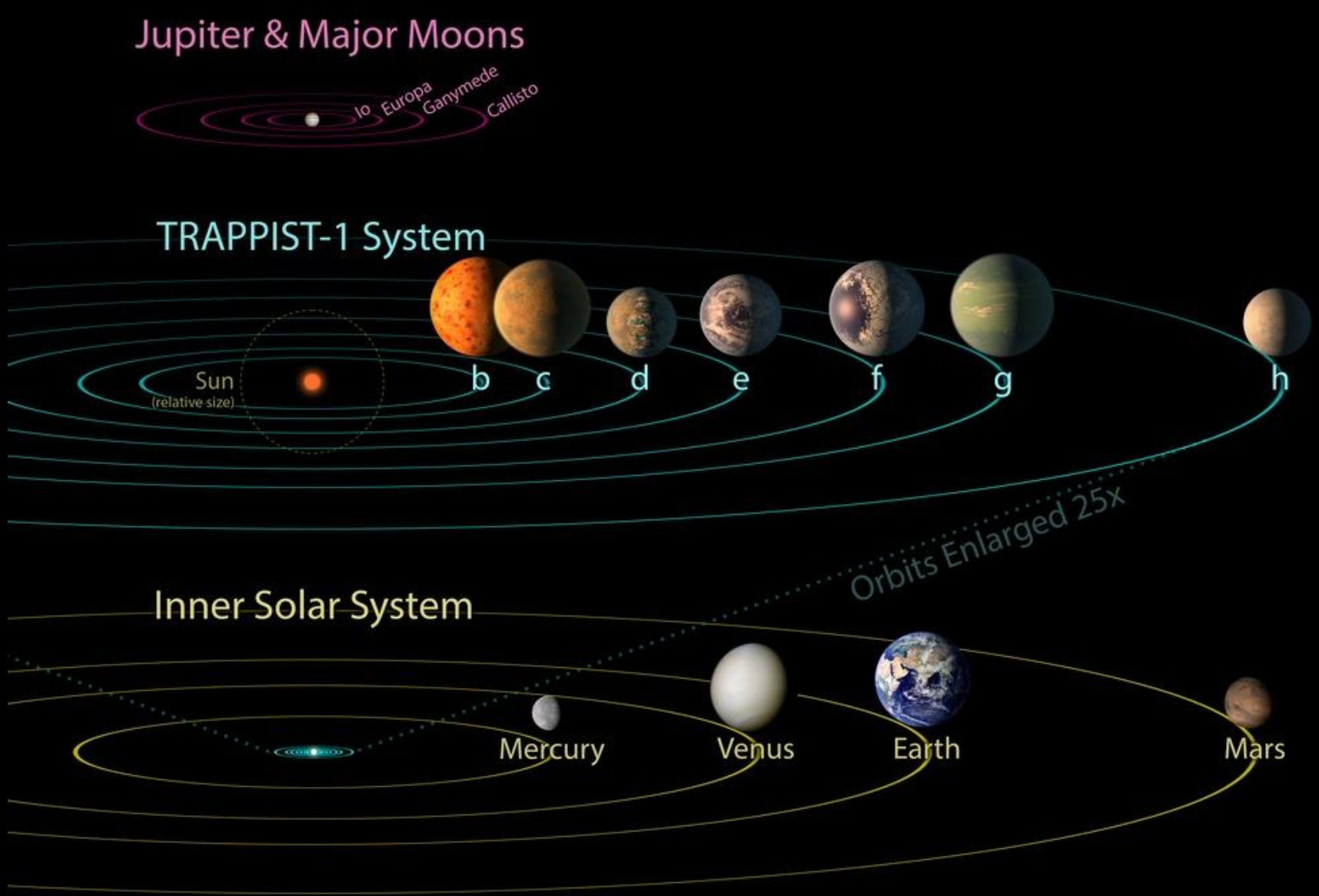


TRAPPIST-1 System

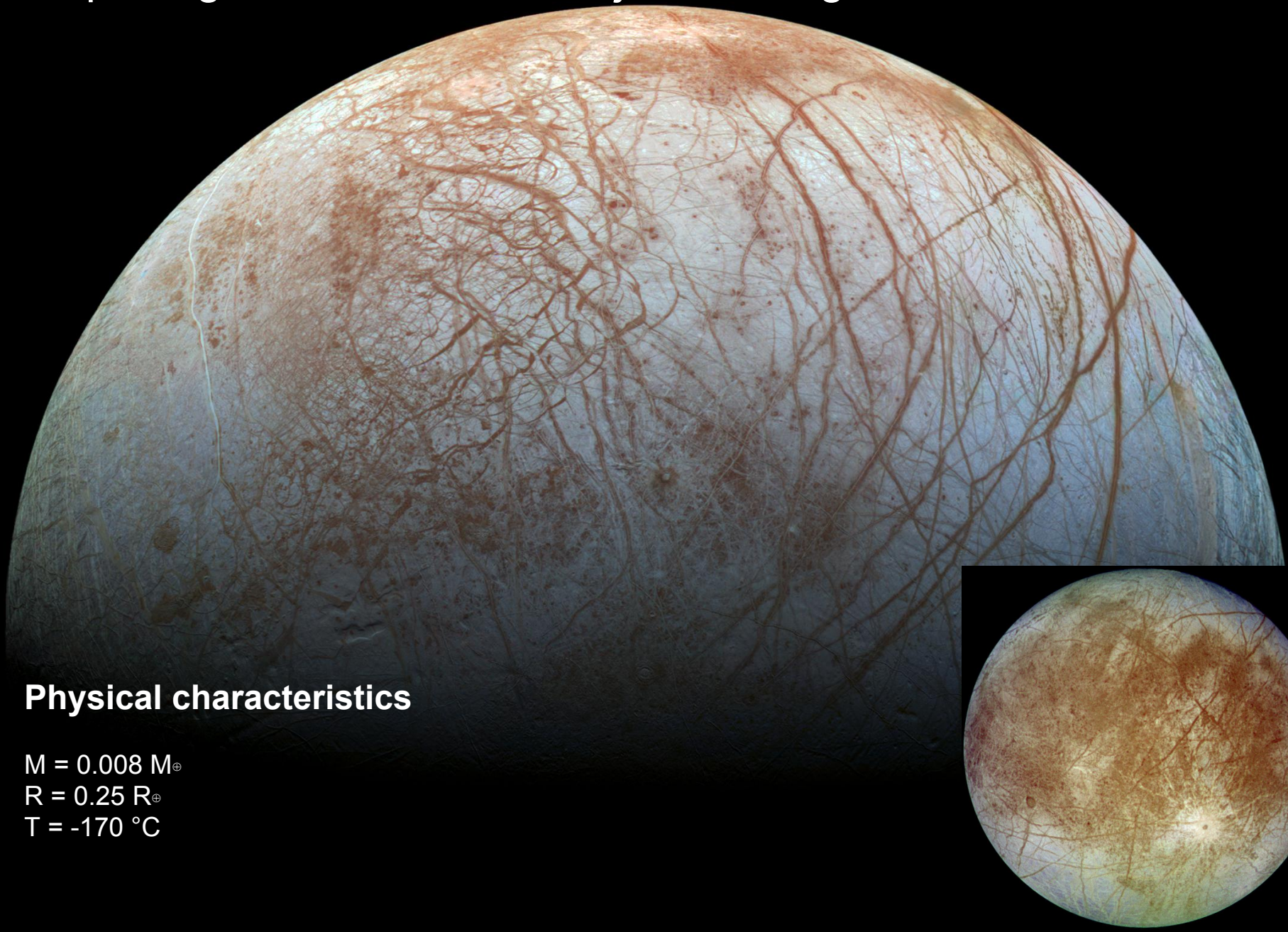
	b	c	d	e	f	g	h
Orbital Period *days*	1.51 *days*	2.42 *days*	4.05 *days*	6.10 *days*	9.21 *days*	12.35 *days*	~20 *days*
Distance to Star *Astronomical Units (AU)*	0.011 *AU*	0.015 *AU*	0.021 *AU*	0.028 *AU*	0.037 *AU*	0.045 *AU*	~0.06 *AU*
Planet Radius *relative to Earth*	1.09 R_{earth}	1.06 R_{earth}	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}

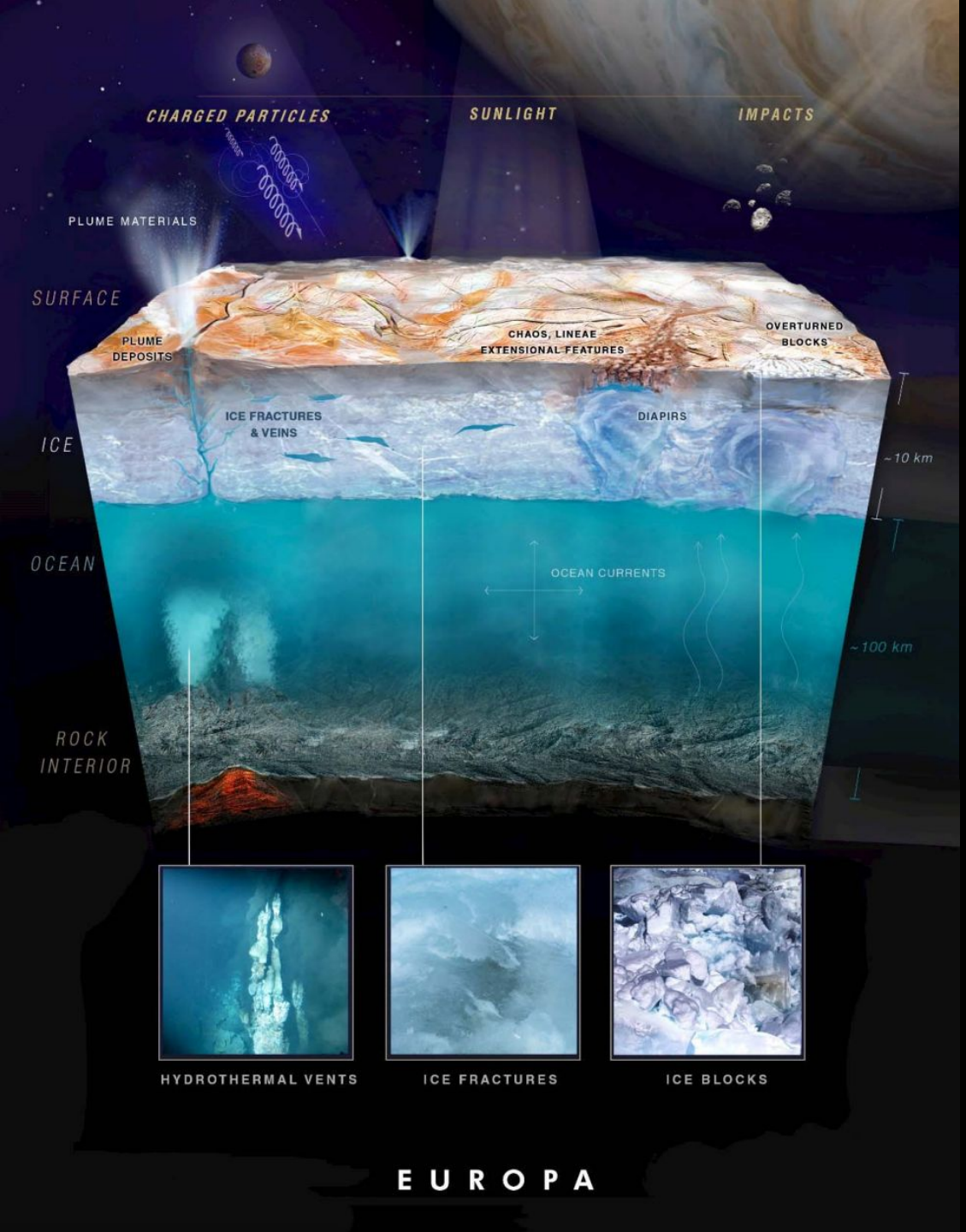

Jupiter & Major Moons
Io
Europa
Ganymede
Callisto
TRAPPIST-1 System
Sun
(relative size)
b
c
d
e
f
g
h
Orbits Enlarged 25x
Inner Solar System
Mercury
Venus
Earth
Mars

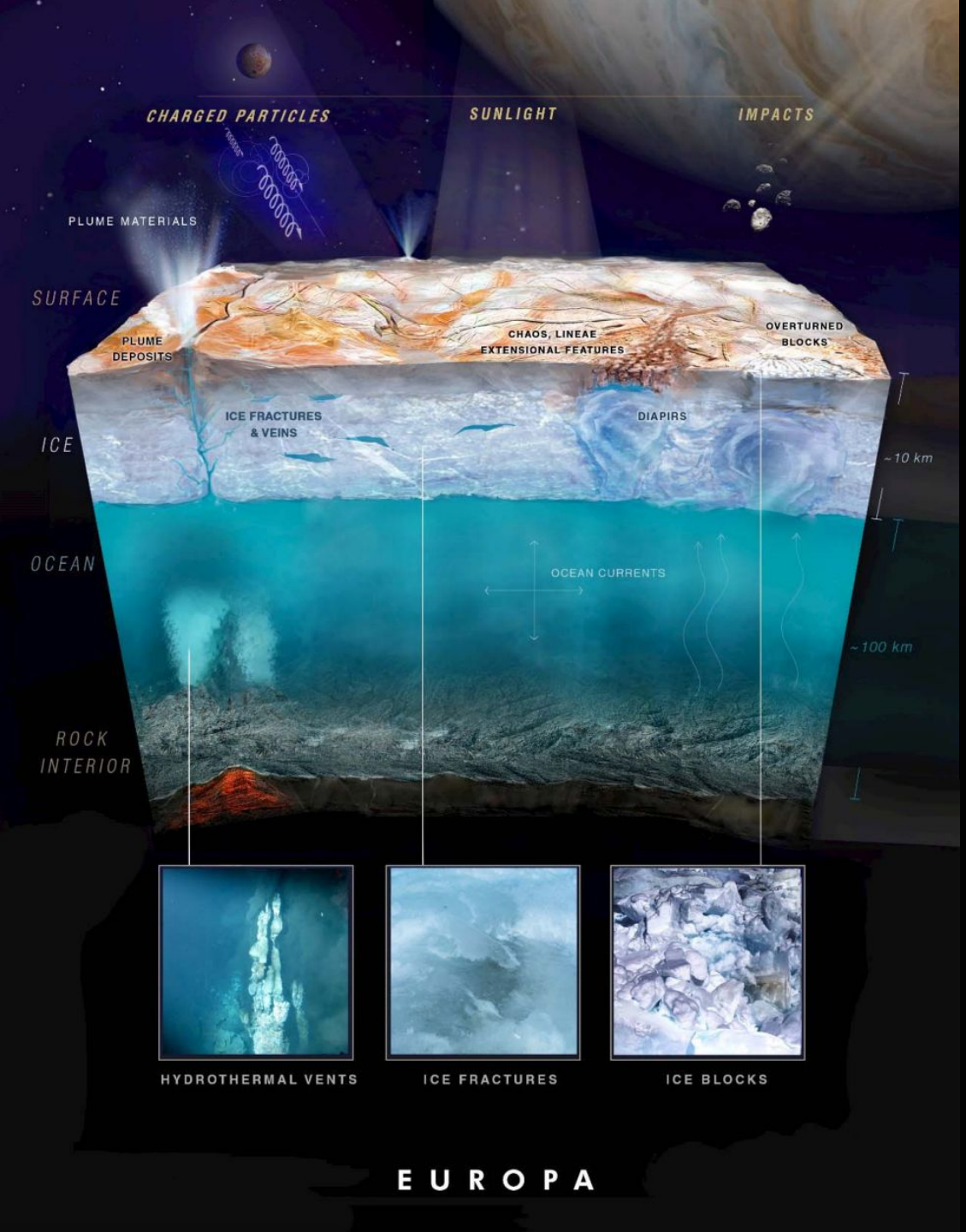
Europa might be the closest object hosting life



Physical characteristics

M = 0.008 $M_\oplus$
R = 0.25 $R_\oplus$
T = -170 °C


CHARGED PARTICLES
SUNLIGHT
IMPACTS
PLUME MATERIALS
SURFACE
ICE
OCEAN
ROCK INTERIOR
PLUME DEPOSITS
CHAOS, LINEAE EXTENSIONAL FEATURES
OVERTURNED BLOCKS
ICE FRACTURES & VEINS
DIAPIRS
~10 km
OCEAN CURRENTS
~100 km
HYDROTHERMAL VENTS
ICE FRACTURES
ICE BLOCKS
EUROPA

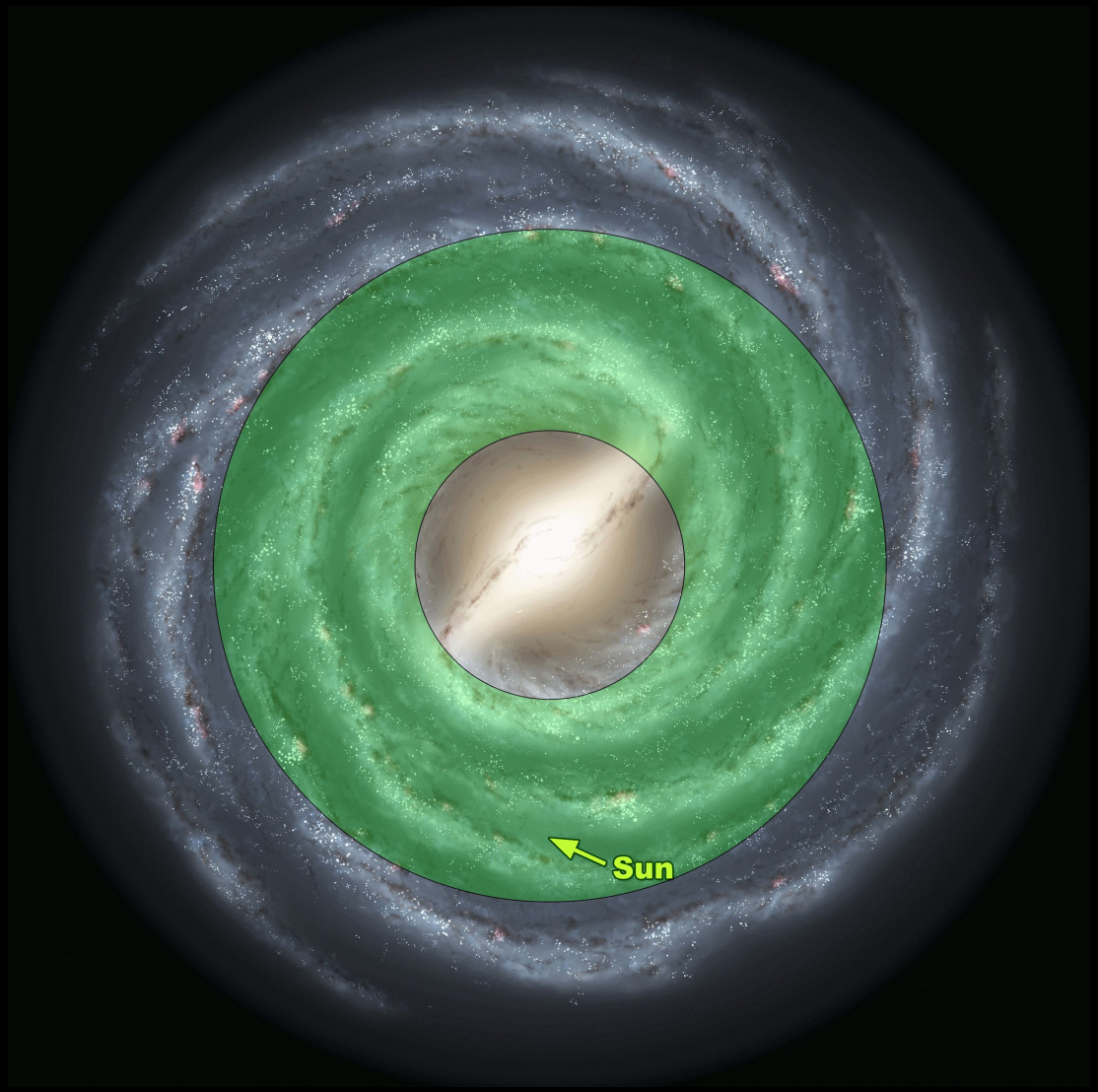

CHARGED PARTICLES
SUNLIGHT
IMPACTS
PLUME MATERIALS
SURFACE
PLUME DEPOSITS
CHAOS, LINEAE EXTENSIONAL FEATURES
OVERTURNED BLOCKS
ICE
ICE FRACTURES & VEINS
DIAPIRS
~10 km
OCEAN
OCEAN CURRENTS
~100 km
ROCK INTERIOR
HYDROTHERMAL VENTS
ICE FRACTURES
ICE BLOCKS
EUROPA

Earth is the only planet we know that harbors life

Earth is the only planet we know that harbors life

Rare Earth Hypothesis

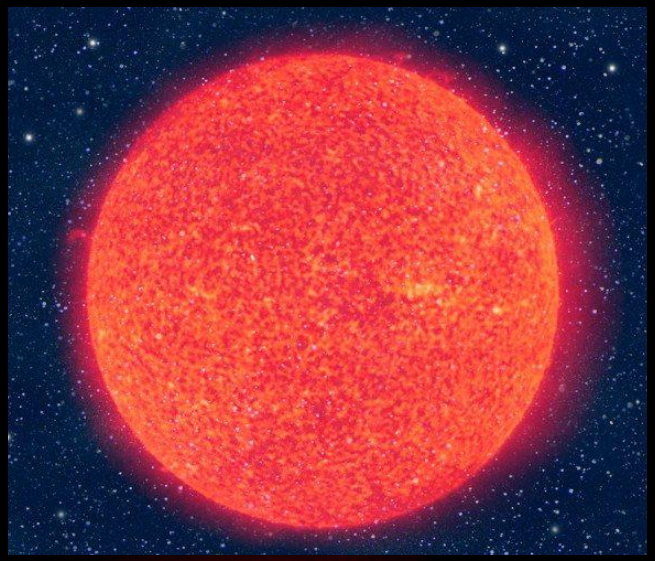
Rare Earth Hypothesis



Milky Way is a rather stable galaxy

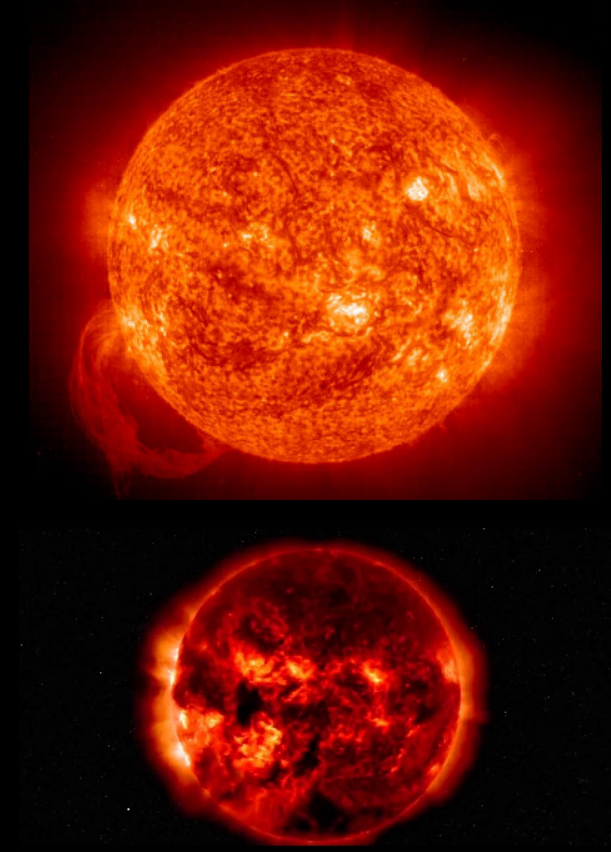
Galactic habitable zone

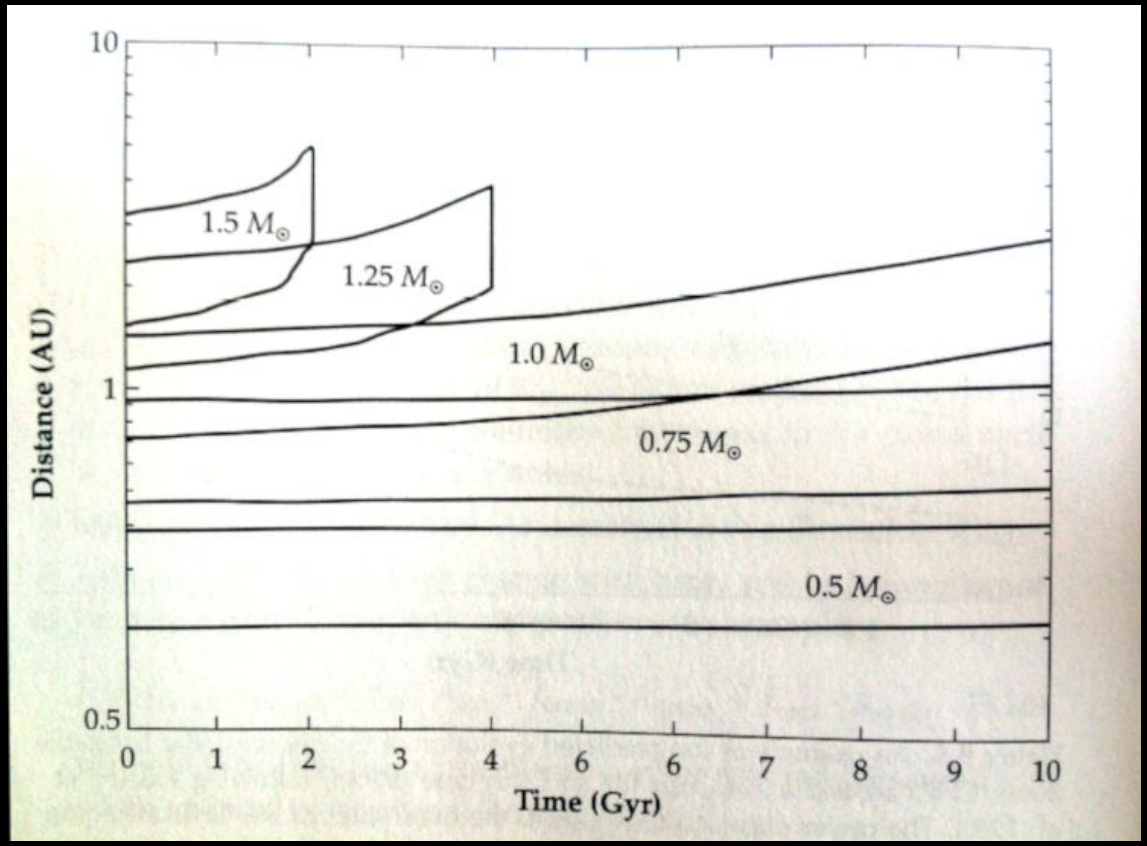
- Metallicity
- Radiation
- Disastrous events

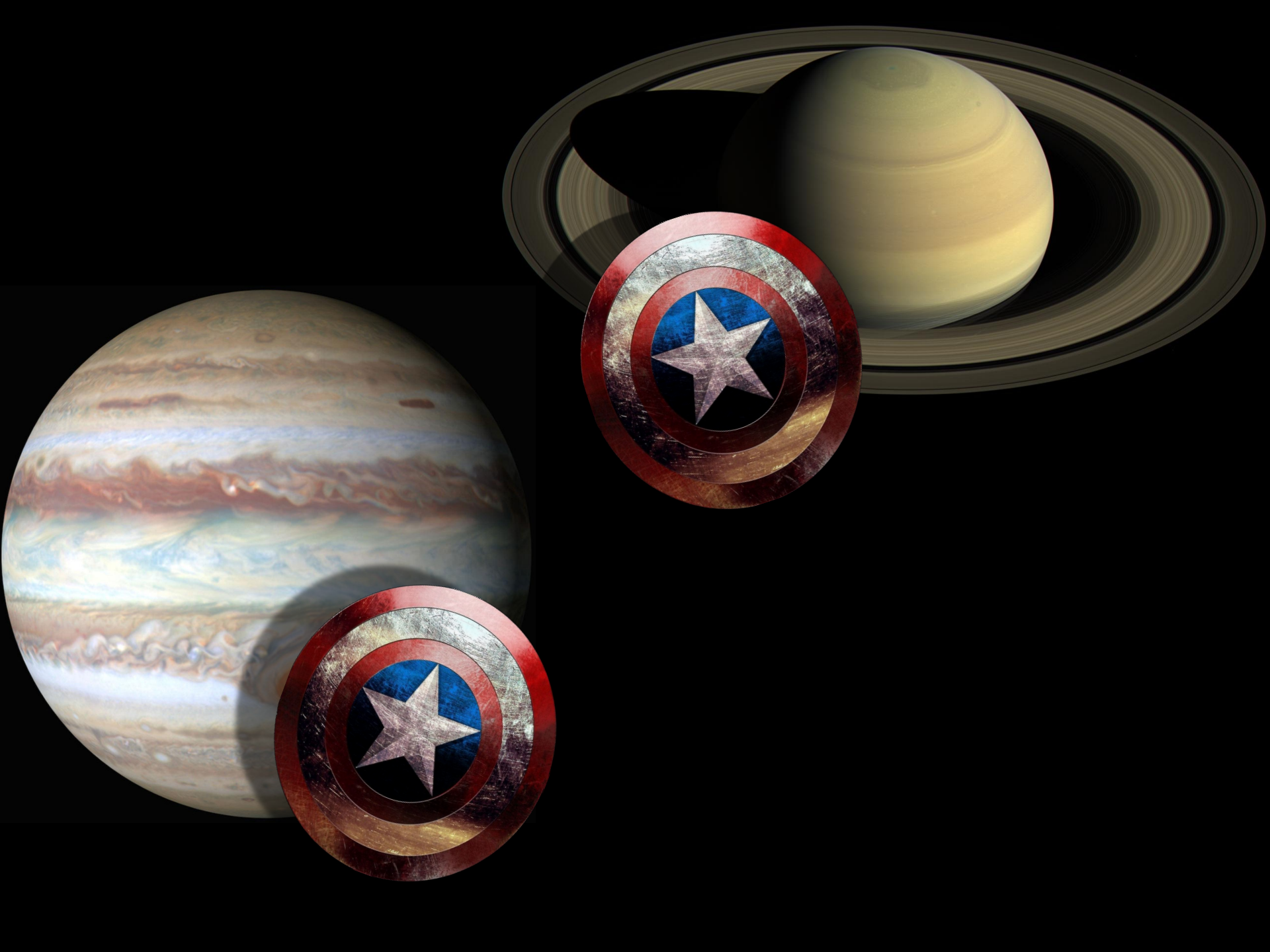


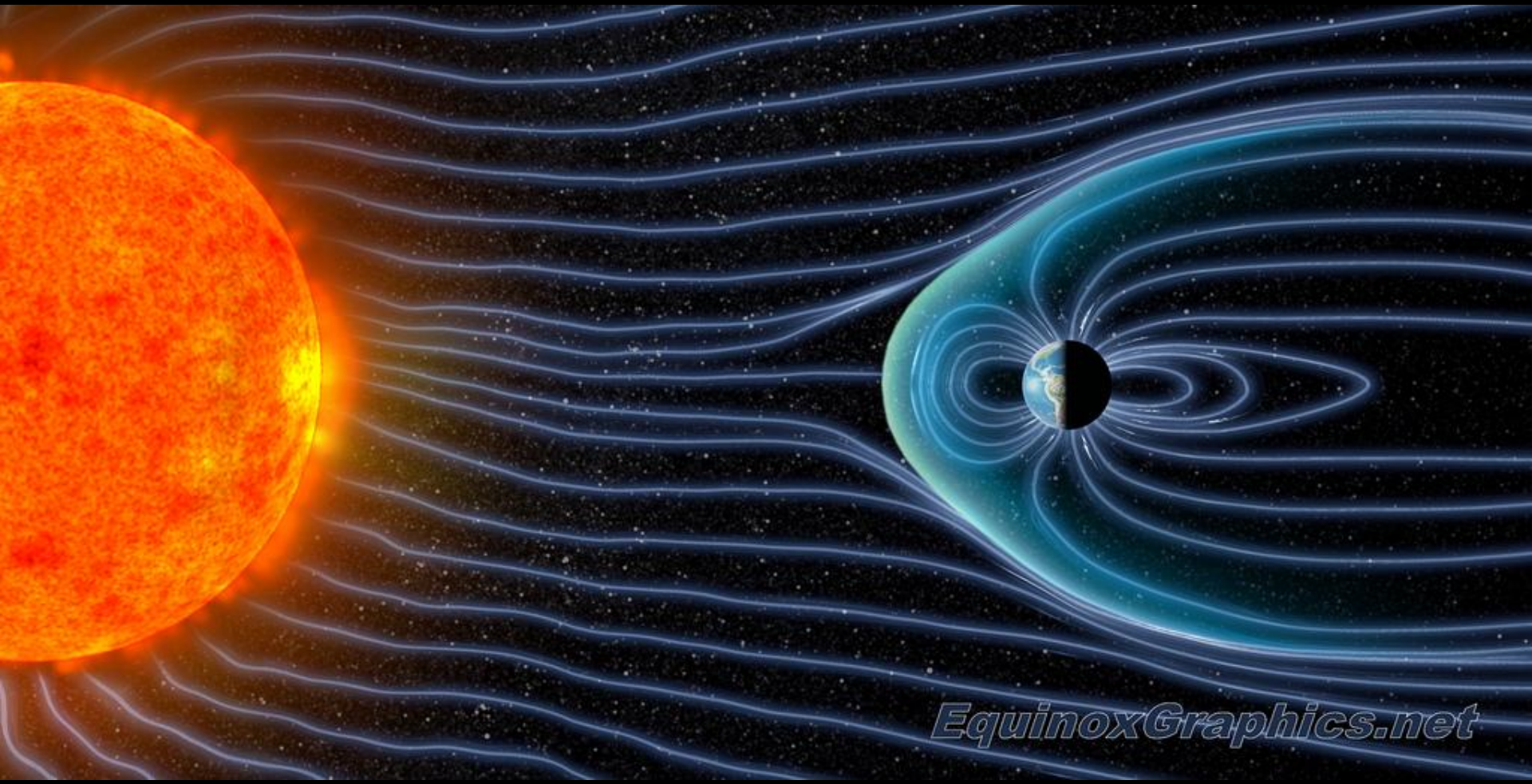
Stable star

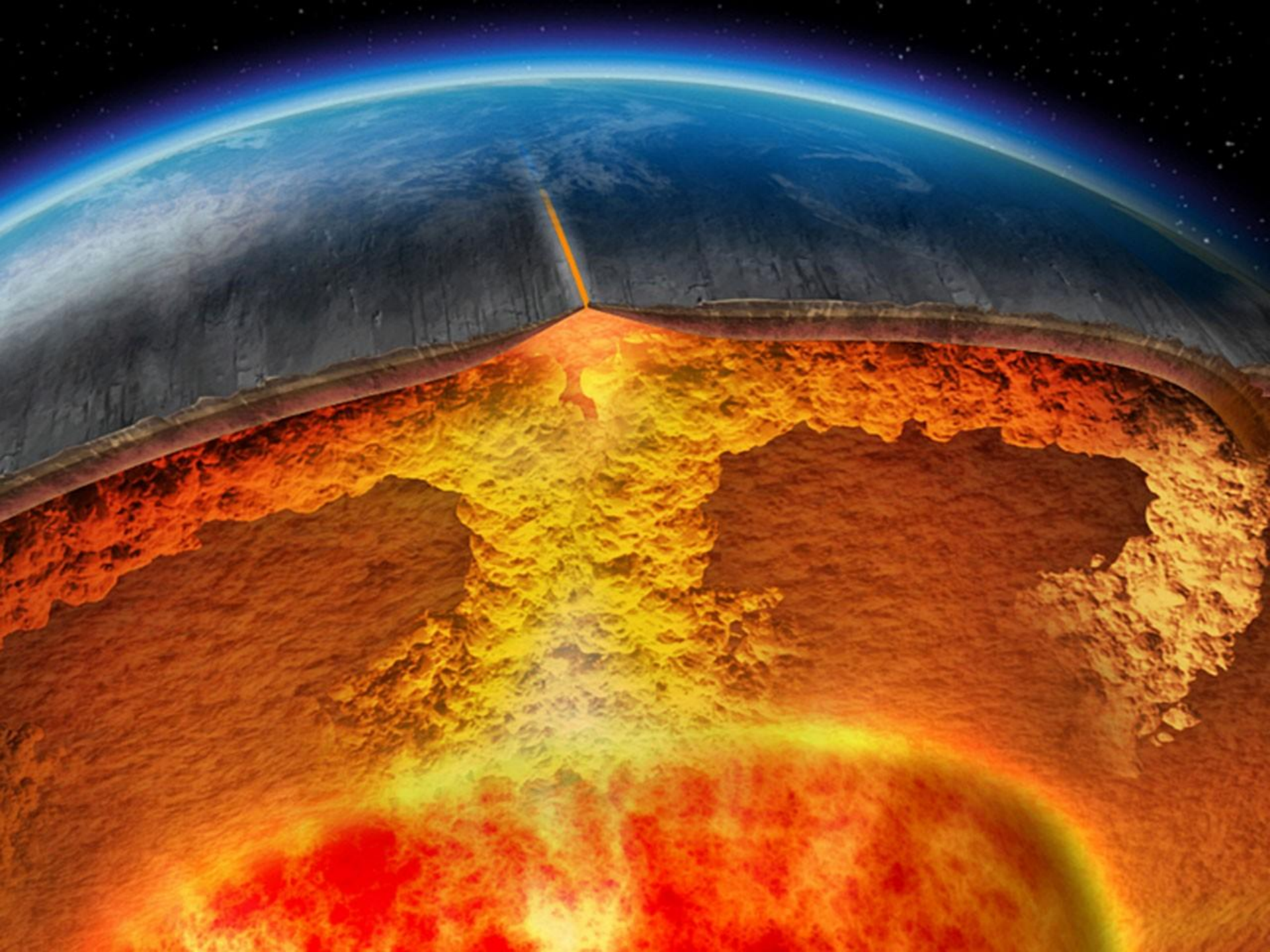
Stable Habitable Zone:
in time and space

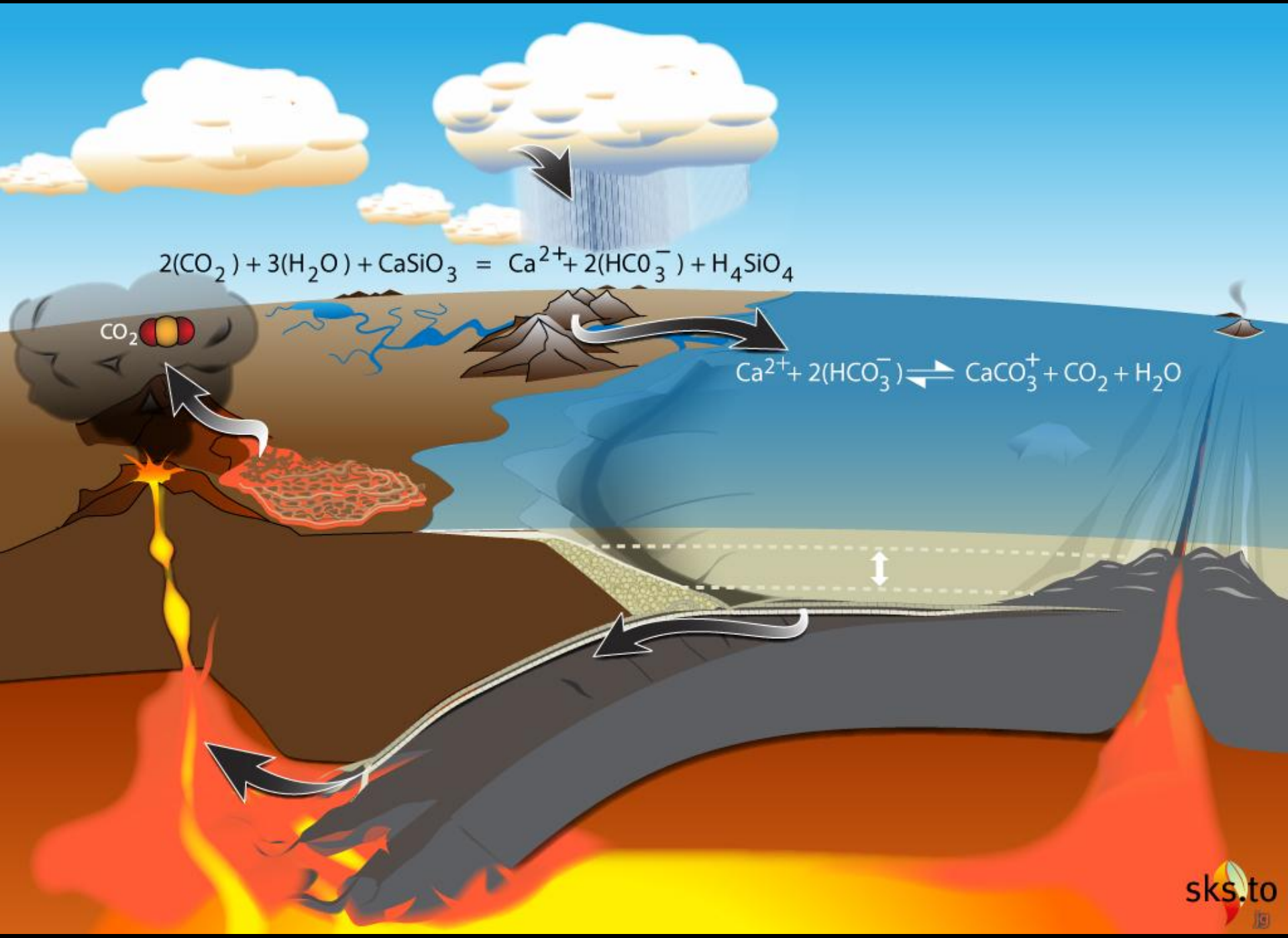


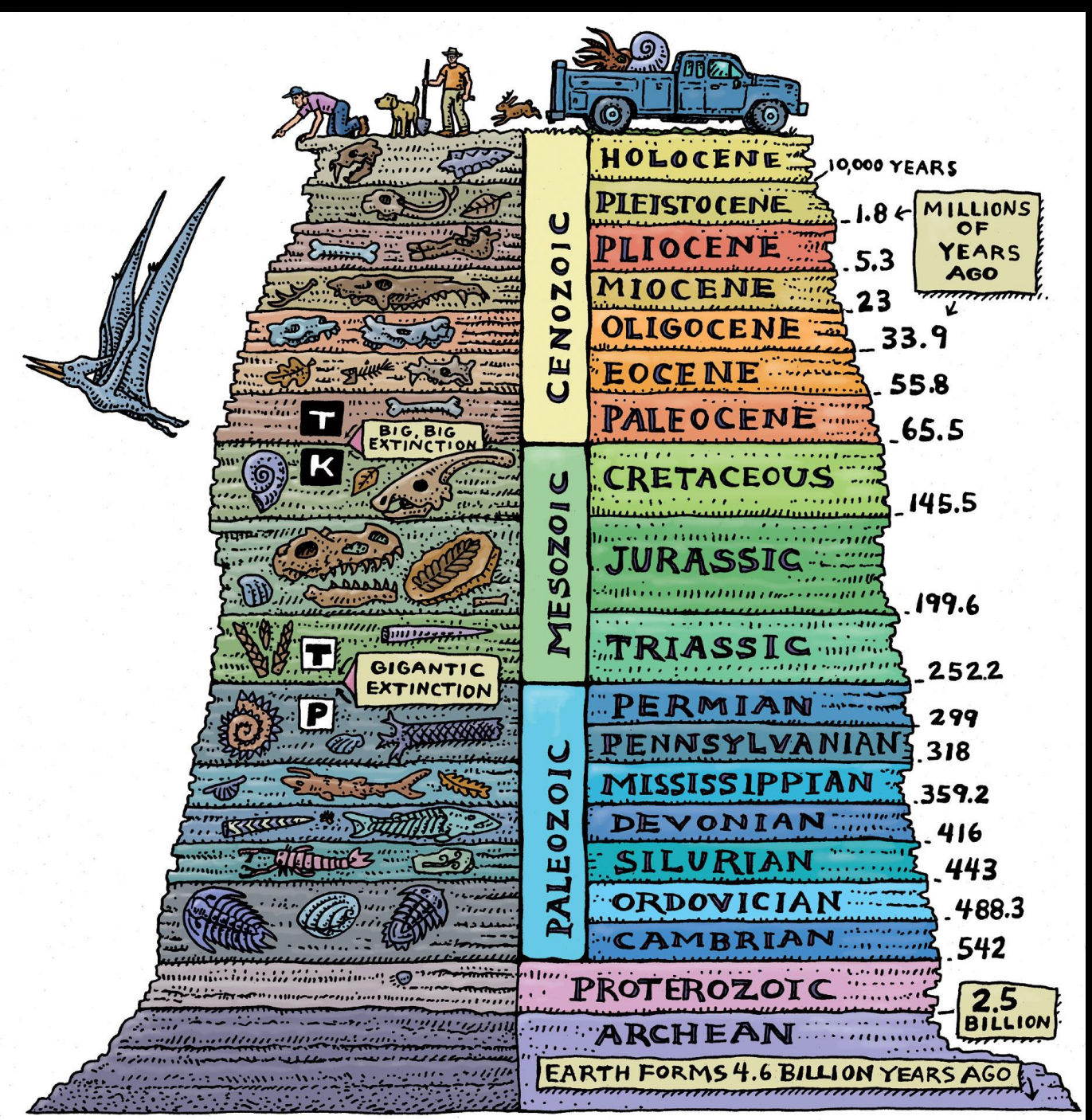


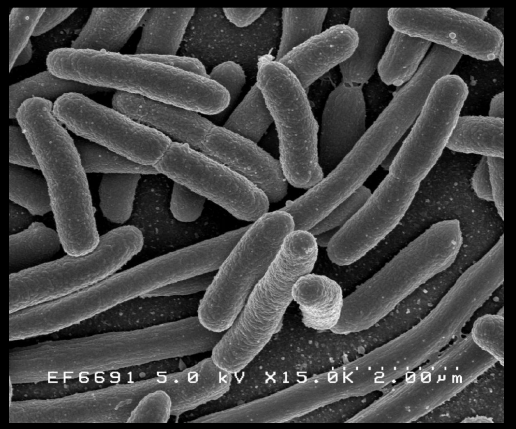


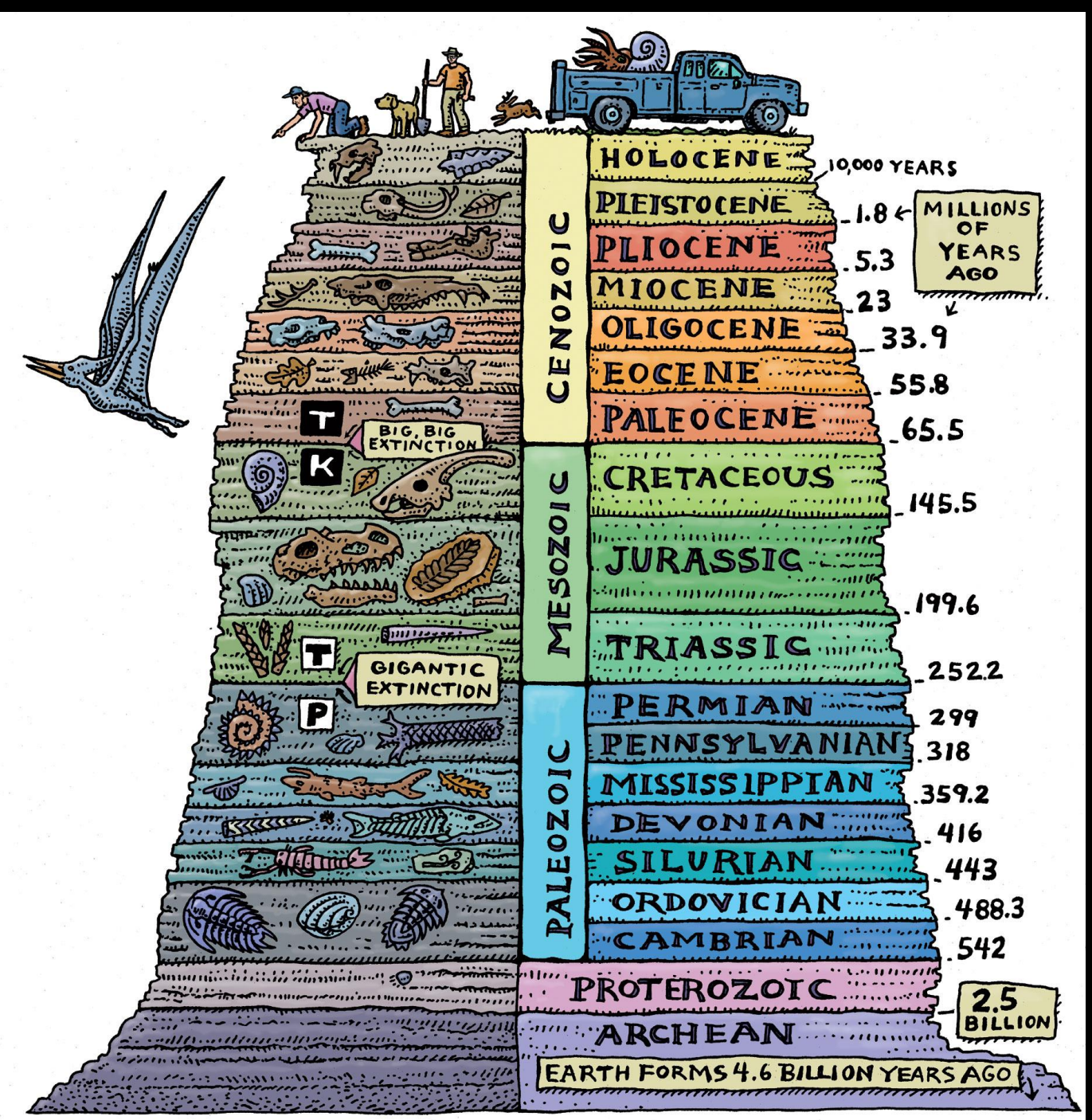

EquinoxGraphics.net

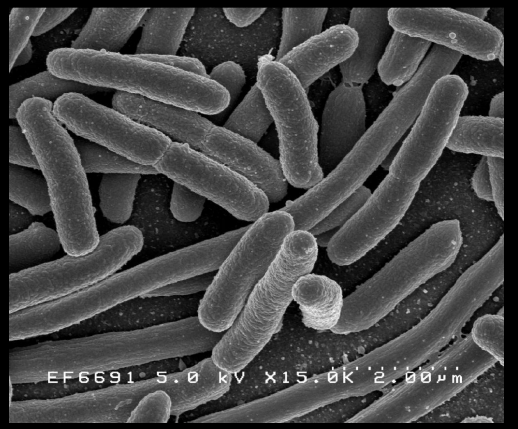


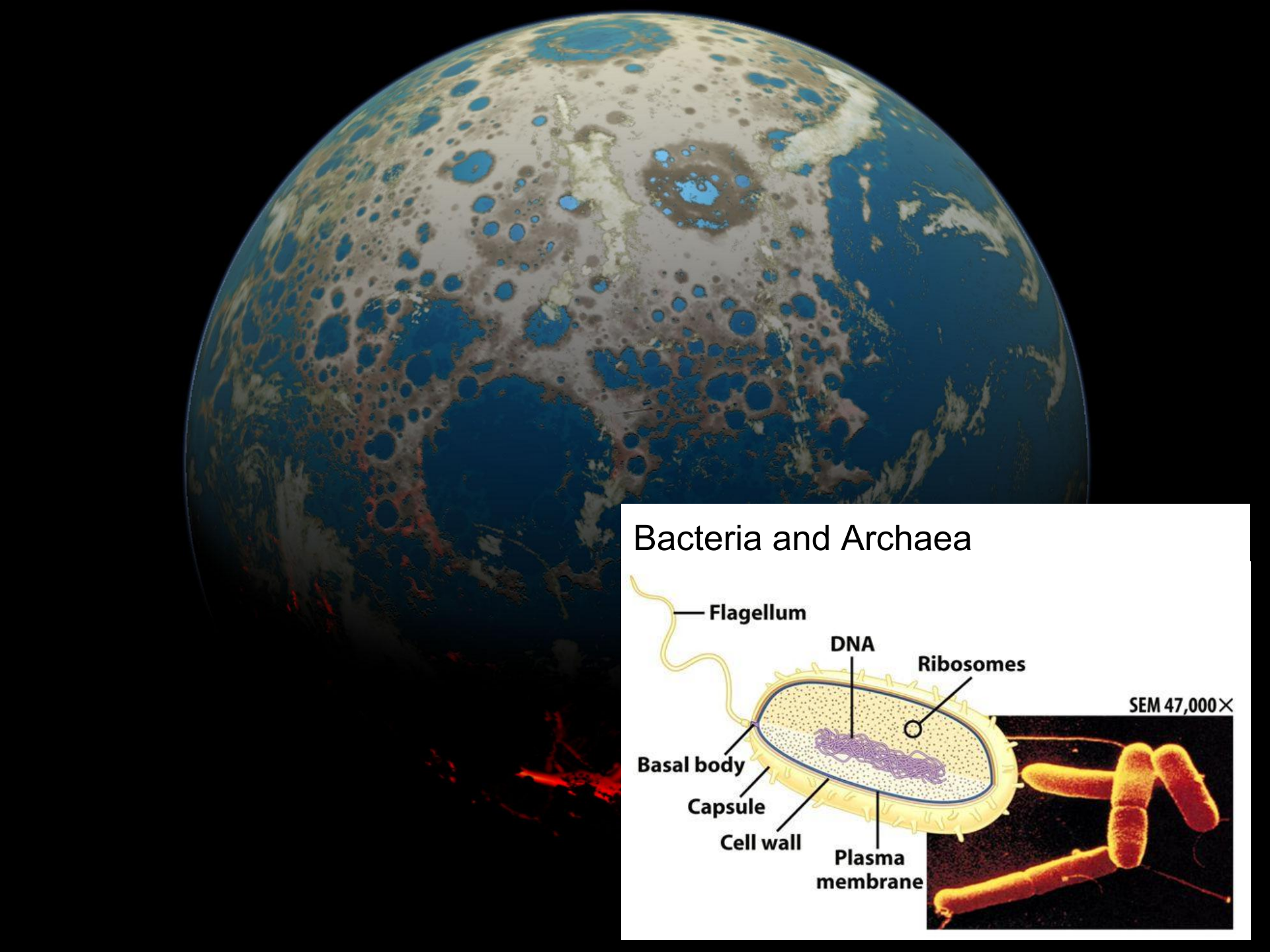

$2(CO_2) + 3(H_2O) + CaSiO_3 = Ca^{2+} + 2(HCO_3^-) + H_4SiO_4$
CO_2
$Ca^{2+} + 2(HCO_3^-) \rightleftharpoons CaCO_3 + CO_2 + H_2O$
sks.to


HOLOCENE
10,000 YEARS
PLEISTOCENE
1.8
MILLIONS OF YEARS AGO
PLIOCENE
5.3
MIOCENE
23
OLIGOCENE
33.9
EOCENE
55.8
PALEOCENE
65.5
CENOZOIC
T
K
BIG, BIG EXTINCTION
CRETACEOUS
145.5
JURASSIC
199.6
TRIASSIC
252.2
MESOZOIC
T
P
GIGANTIC EXTINCTION
PERMIAN
299
PENNSYLVANIAN
318
MISSISSIPPIAN
359.2
DEVONIAN
416
SILURIAN
443
ORDOVICIAN
488.3
CAMBRIAN
542
PALEOZOIC
PROTEROZOIC
2.5 BILLION
ARCHEAN
EARTH FORMS 4.6 BILLION YEARS AGO


EF6691 5.0 kV X15.0K 2.00µm


CENOZOIC
MESOZOIC
PALEOZOIC
HOLOCENE
10,000 YEARS
PLEISTOCENE
1.8
PLIOCENE
5.3
MIOCENE
23
OLIGOCENE
33.9
EOCENE
55.8
PALEOCENE
65.5
CRETACEOUS
145.5
JURASSIC
199.6
TRIASSIC
252.2
PERMIAN
299
PENNSYLVANIAN
318
MISSISSIPPIAN
359.2
DEVONIAN
416
SILURIAN
443
ORDOVICIAN
488.3
CAMBRIAN
542
PROTEROZOIC
2.5 BILLION
ARCHEAN
EARTH FORMS 4.6 BILLION YEARS AGO
MILLIONS OF YEARS AGO
T
K
BIG, BIG EXTINCTION
T
P
GIGANTIC EXTINCTION


EF6691 5.0 kV X15.0K 2.00µm



Bacteria and Archaea

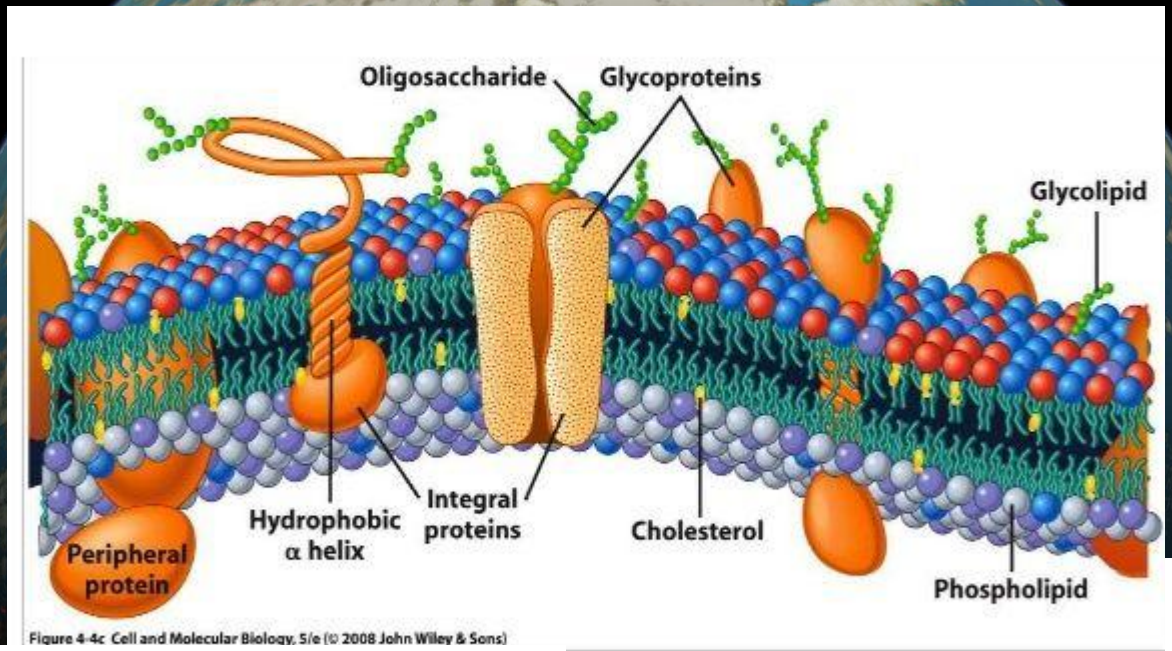
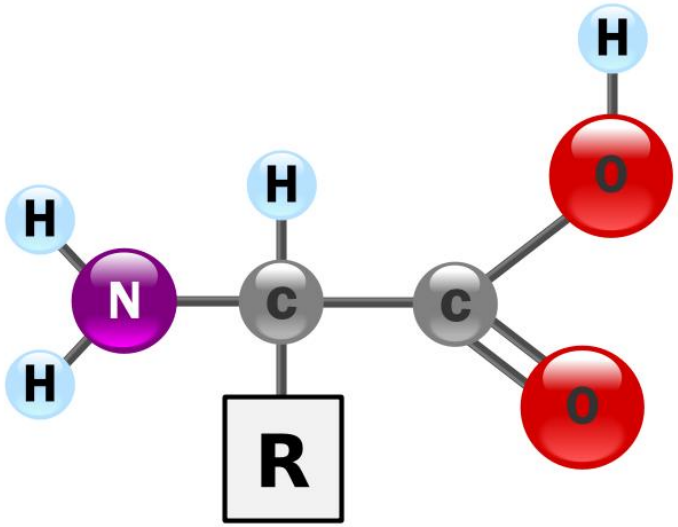
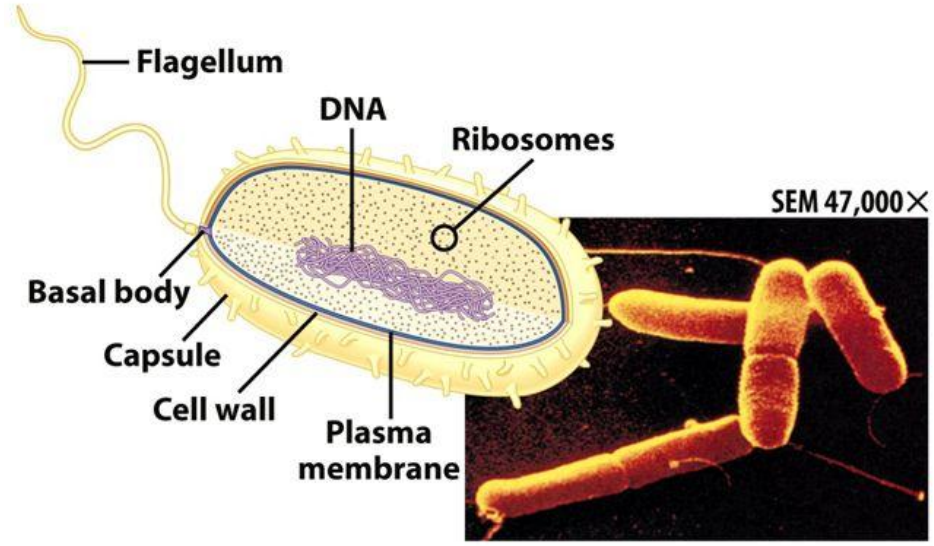
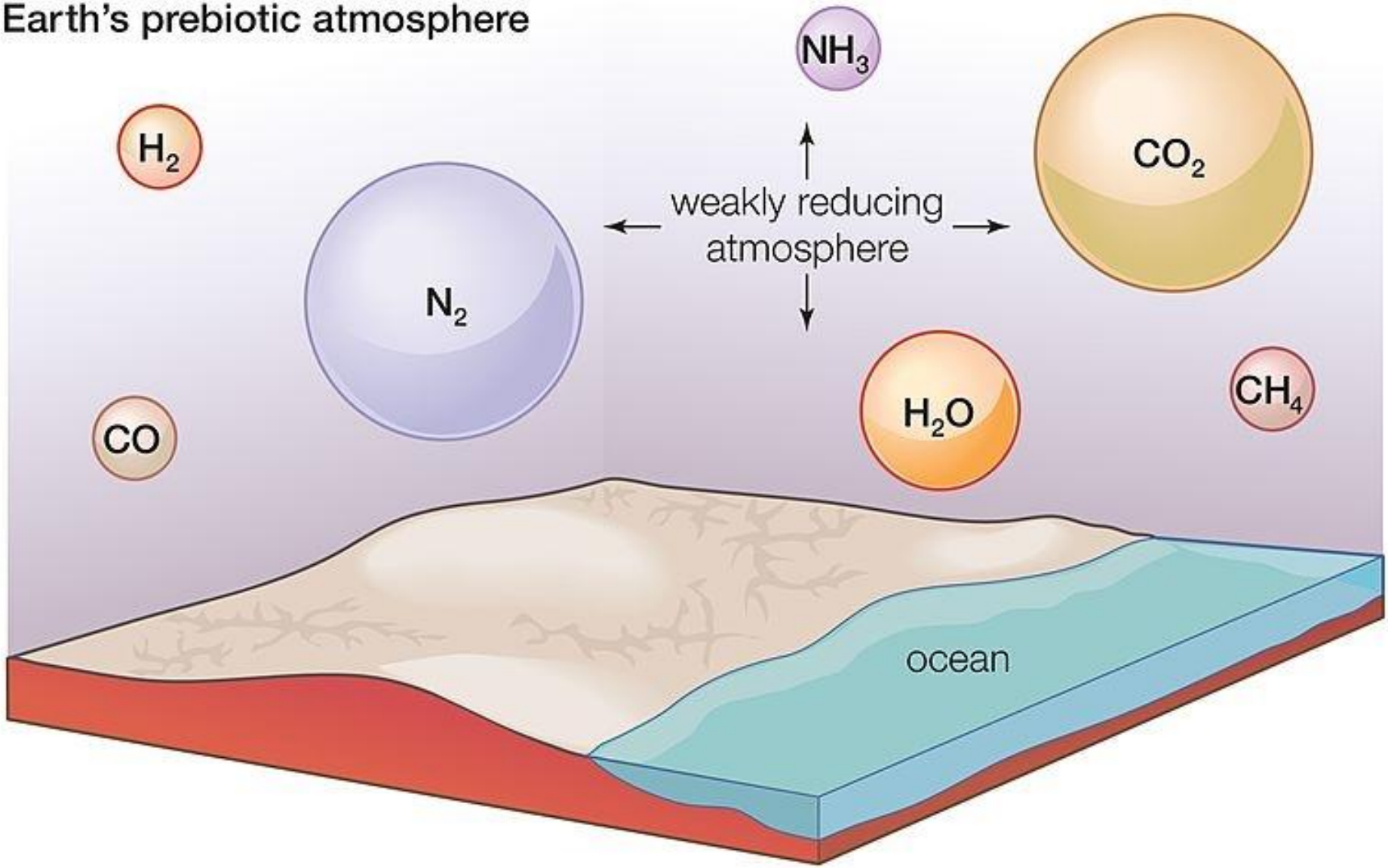
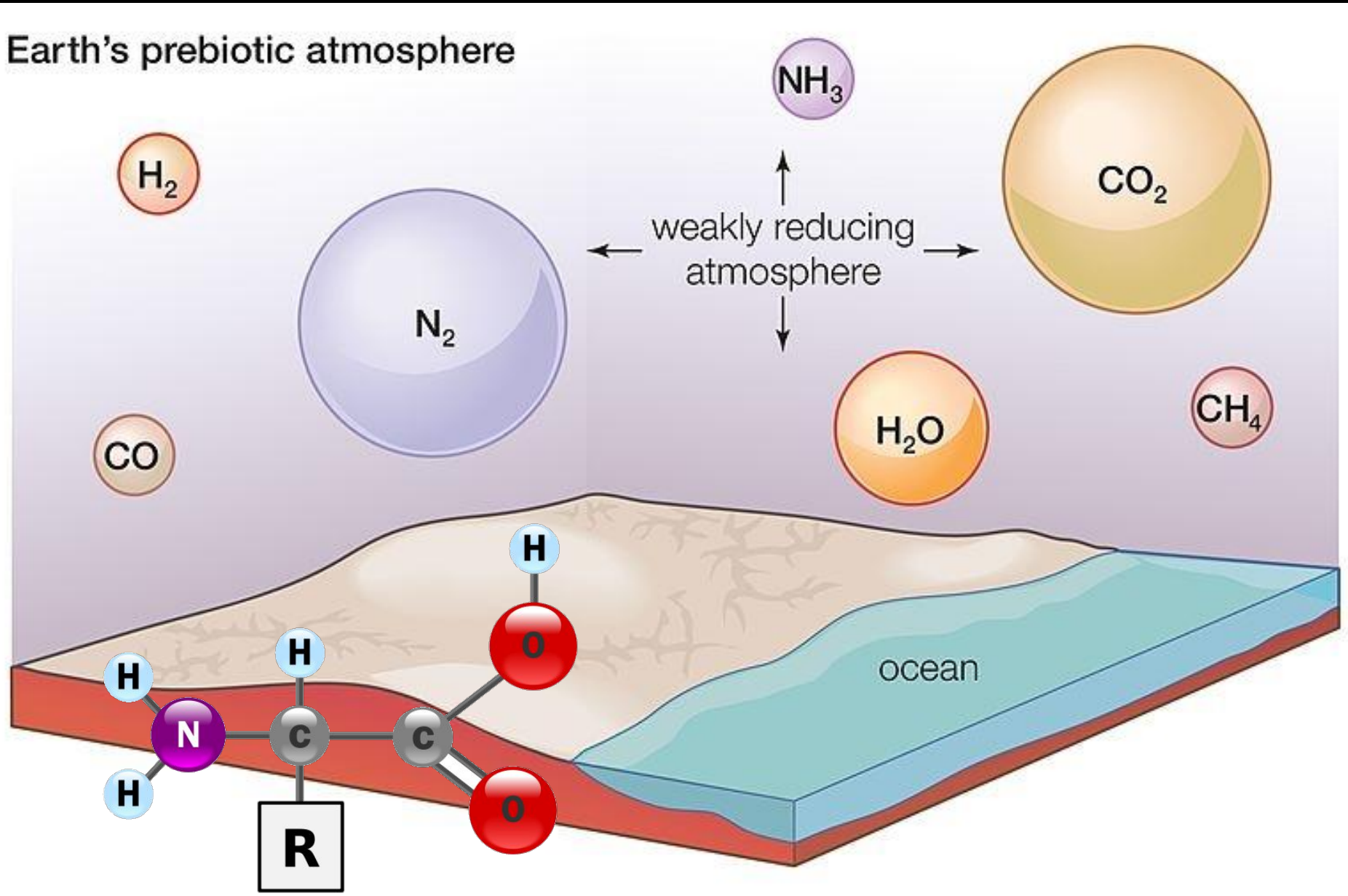


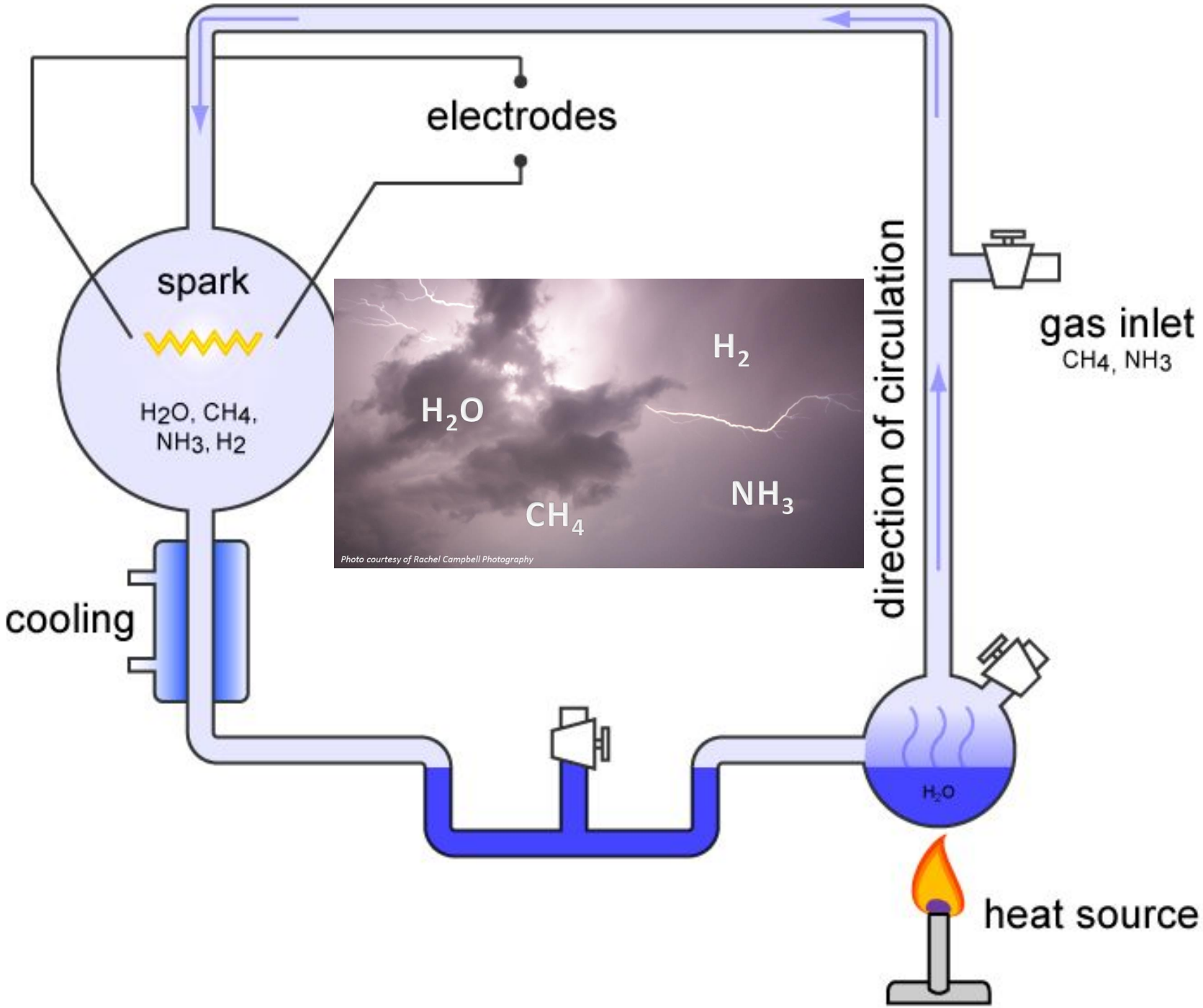
Figure 4-4c Cell and Molecular Biology, 5/e (© 2008 John Wiley & Sons)

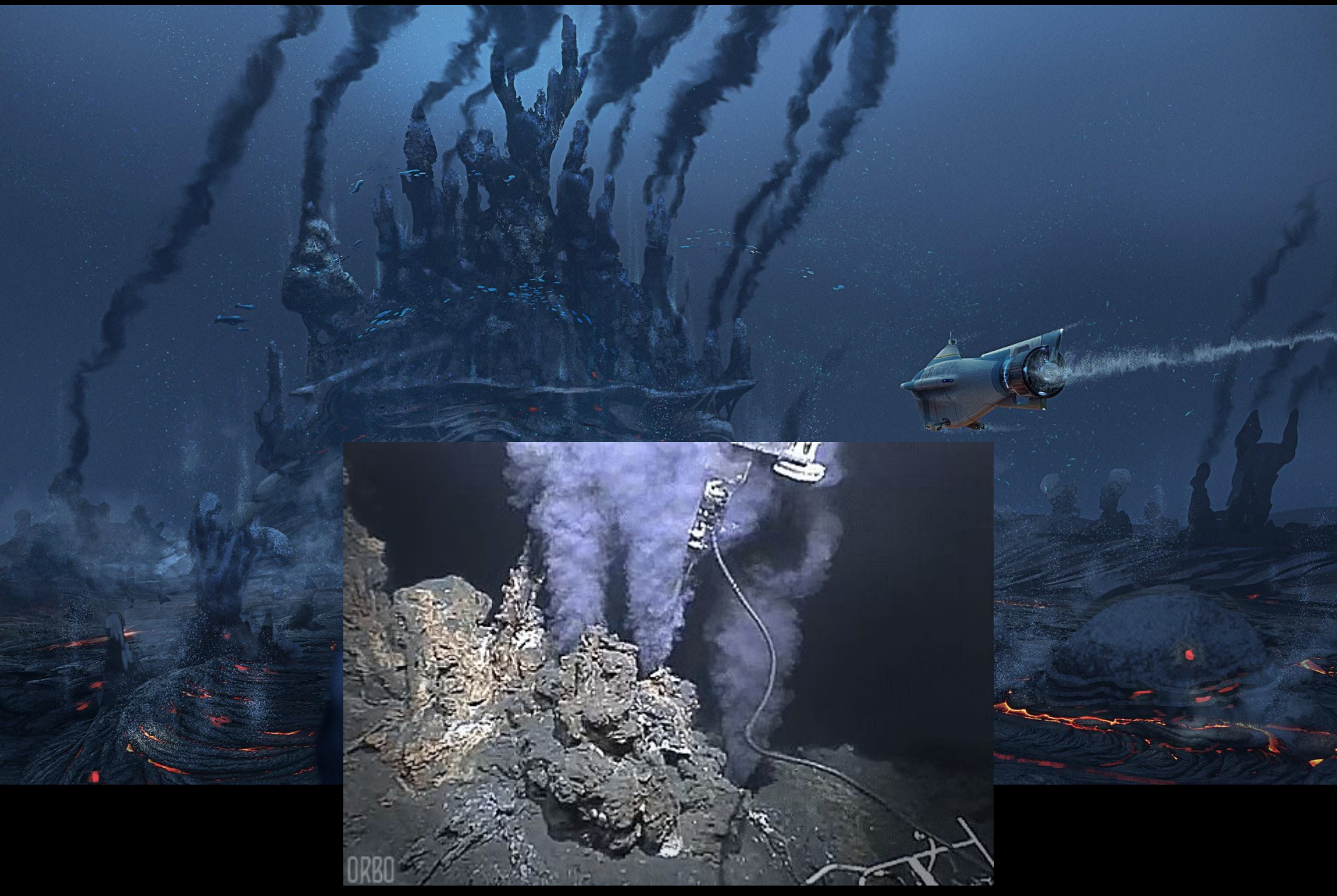


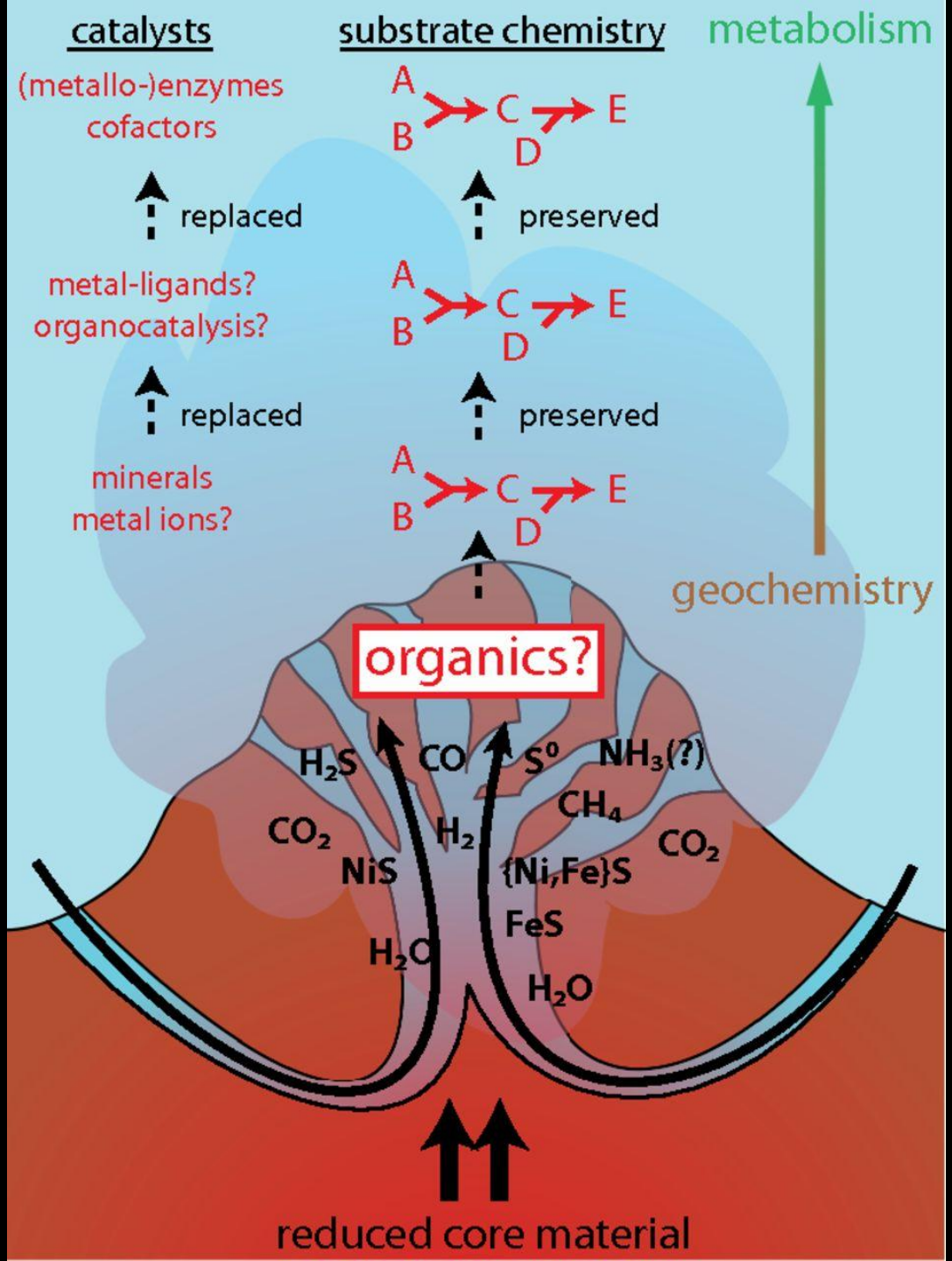


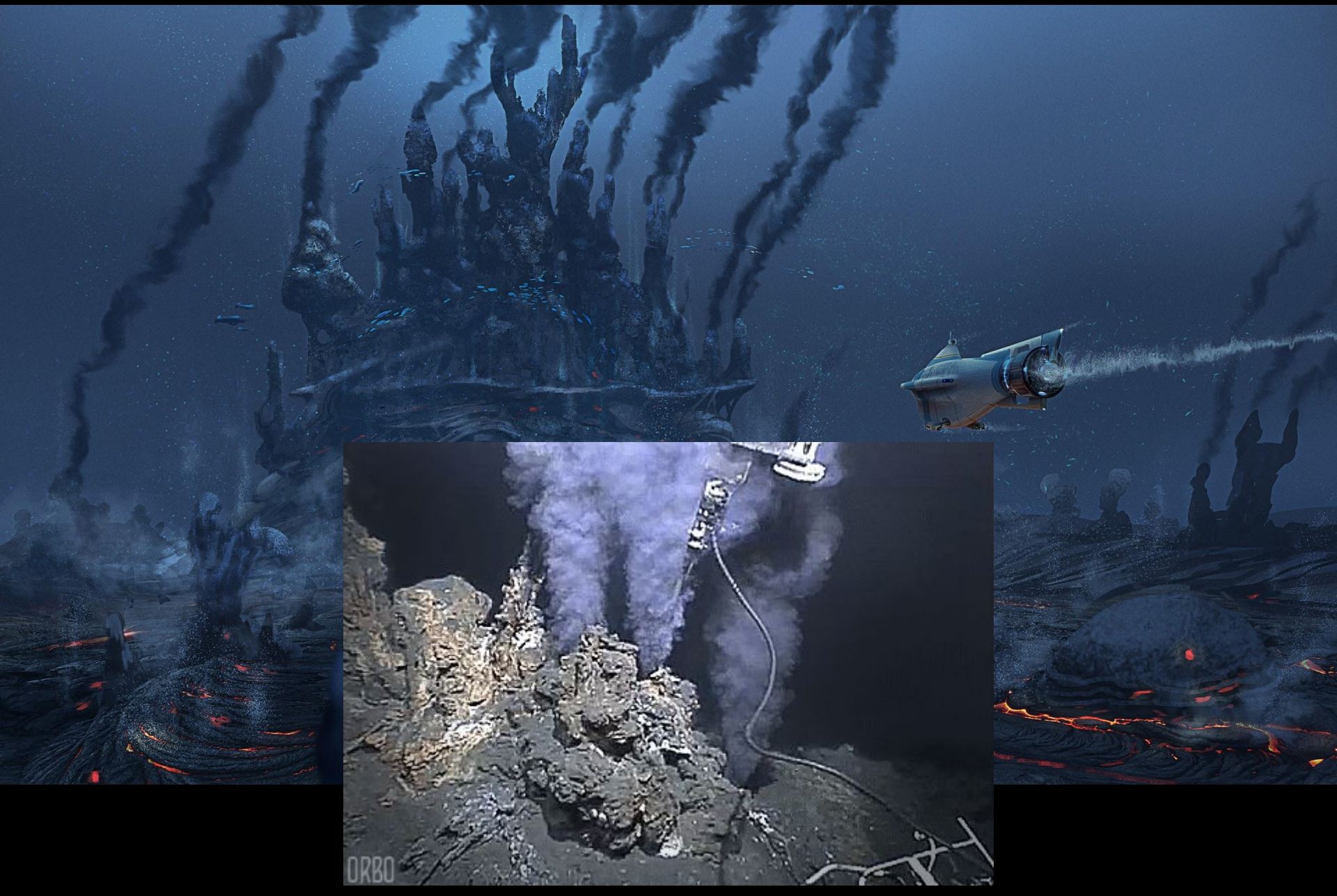

Earth's prebiotic atmosphere
NH_3
H_2
CO_2
weakly reducing
atmosphere
N_2
H_2O
CH_4
CO
ocean


Earth's prebiotic atmosphere
NH_3
H_2
CO_2
weakly reducing atmosphere
N_2
H_2O
CH_4
CO
ocean
H
O
H
H
N
C
C
O
H
R


electrodes
spark
H_2O, CH_4, NH_3, H_2
H_2
H_2O
NH_3
CH_4
Photo courtesy of Rachel Campbell Photography
direction of circulation
gas inlet
CH_4, NH_3
cooling
H_2O
heat source


ORBO

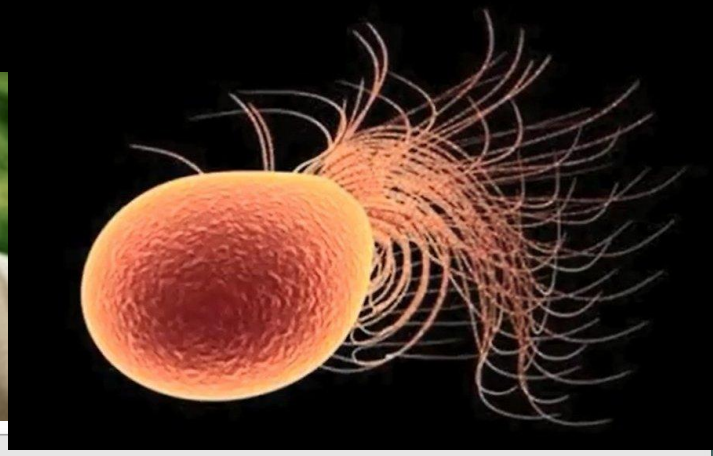

catalysts
substrate chemistry
metabolism
(metallo-)enzymes
cofactors
A
B
C
D
E
replaced
preserved
metal-ligands?
organocatalysis?
replaced
preserved
minerals
metal ions?
geochemistry
organics?
H_2S
CO
S^0
NH_3(?)
CH_4
CO_2
H_2
CO_2
NiS
{Ni,Fe}S
FeS
H_2O
H_2O
reduced core material


ORBO

Twenty Thousand Leagues Under the Sea *(or 4000 m in this case)*

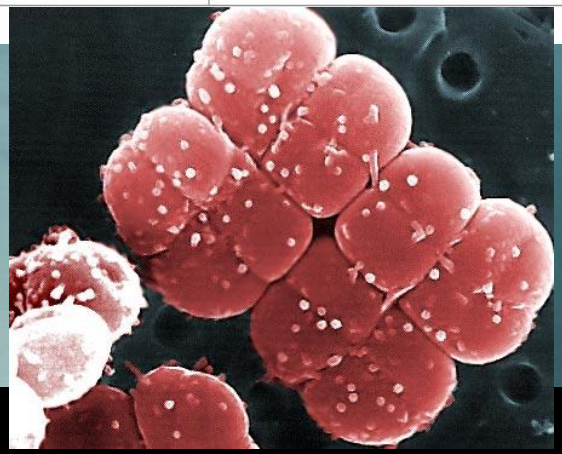
Extremophiles

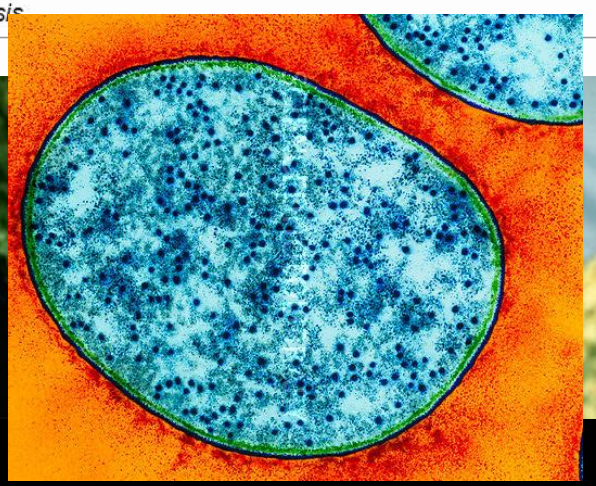
The limits of known life on Earth.[10]			
Factor	**Environment / source**	**Limits**	**Examples**
High temperature	Submarine hydrothermal vents	110 °C to 121 °C	*Pyrolobus fumarii*, *Pyrococcus furiosus*
Low temperature	Ice	-17 °C to -20 °C	*Synechococcus lividus*
Alkaline systems	Soda lakes	pH > 11	*Psychrobacter*, *Vibrio*, *Arthrobacter*, *Natronobacterium*
Acidic systems	Volcanic springs, acid mine drainage	pH -0.06 to 1.0	*Bacillus*, *Clostridium paradoxum*
Ionizing radiation	Cosmic rays, X-rays, radioactive decay	1,500 to 6,000 Gy	*Deinococcus radiodurans*, *Rubrobacter*, *Thermococcus gammatolerans*
UV radiation	Sunlight	5,000 J/m^2	*Deinococcus radiodurans*, *Rubrobacter*, *Thermococcus gammatolerans*
High pressure	Mariana Trench	1,100 bar	*Pyrococcus* sp.
Salinity	Low temperature systems	a_w ~ 0.6	*Halobacteriaceae*, *Dunaliella salina*
Desiccation	Atacama Desert (Chile), McMurdo Dry Valleys (Antarctica)	~60% relative humidity	*Chroococcidiopsis*



The limits of known life on Earth.[10]

Factor	Environment / source	Limits	Examples
High temperature	Submarine hydrothermal vents	110 °C to 121 °C	*Pyrolobus fumarii*, *Pyrococcus furiosus*
Low temperature	Ice	-17 °C to -20 °C	*Synechococcus lividus*
Alkaline systems	Soda lakes	pH > 11	*Psychrobacter*, *Vibrio*, *Arthrobacter*, *Natronobacterium*
Acidic systems	Volcanic springs, acid mine drainage	pH -0.06 to 1.0	*Bacillus*, *Clostridium paradoxum*
Ionizing radiation	Cosmic rays, X-rays, radioactive decay	1,500 to 6,000 Gy	*Deinococcus radiodurans*, *Rubrobacter*, *Thermococcus gammatolerans*
UV radiation	Sunlight	5,000 J/m^2	*Deinococcus radiodurans*, *Rubrobacter*, *Thermococcus gammatolerans*
High pressure	Mariana Trench	1,100 bar	*Pyrococcus* sp.
Salinity	Low temperature systems	a_w ~ 0.6	*Halobacteriaceae*, *Dunaliella salina*
Desiccation	Atacama Desert (Chile), McMurdo Dry Valleys (Antarctica)	~60% relative humidity	*Chroococcidiopsis*






Thanks for your attention...
... see you Space Cowboy