The Possibilities for Life and Human Habitability on Nearby Stars: Many Possible Homes for Our Elder(?) Race, But the Neighbors Are Likely Bacteria

- There are 100 Billion stars in our galaxy, and each has likely formed its own Earth sized planet. The Universe is 13.8 Billion yrs old, the Galaxy is about 13 Byrs old, and the solar system is 4.56 Byrs old. We live 2/3 of the way out from the weak central black hole, in the suburbs. Only FGKM stars last more than 1 Byr. With Kepler, we are entering the era of precision exoplanets.

- The Earth is a highly differentiated, *very unique* object with an overabundance of water on the surface, a giant moon stabilizing its spin, plate tectonics keeping it warm, and shielded with a magnetic field. Life is found in an incredibly narrow range, -10 to +60 miles from the geoid surface of a body 7600 miles across. We live, work, & die on the thinnest rind of the orange. Venus and Mars are failed harbors for life in our SS. Life has “polluted” the planet to be O_2 rich, providing biomarkers.

- Life has experimented with a huge # of forms over 4.56 Byrs on Earth, but Life is *only* found where liquid water exists and requires cells. The LUCA was a thermophile. Earth-life was blue-green, squishy, and single-celled from 1.0 – 4.0 Byrs, and Bacteria still rule.

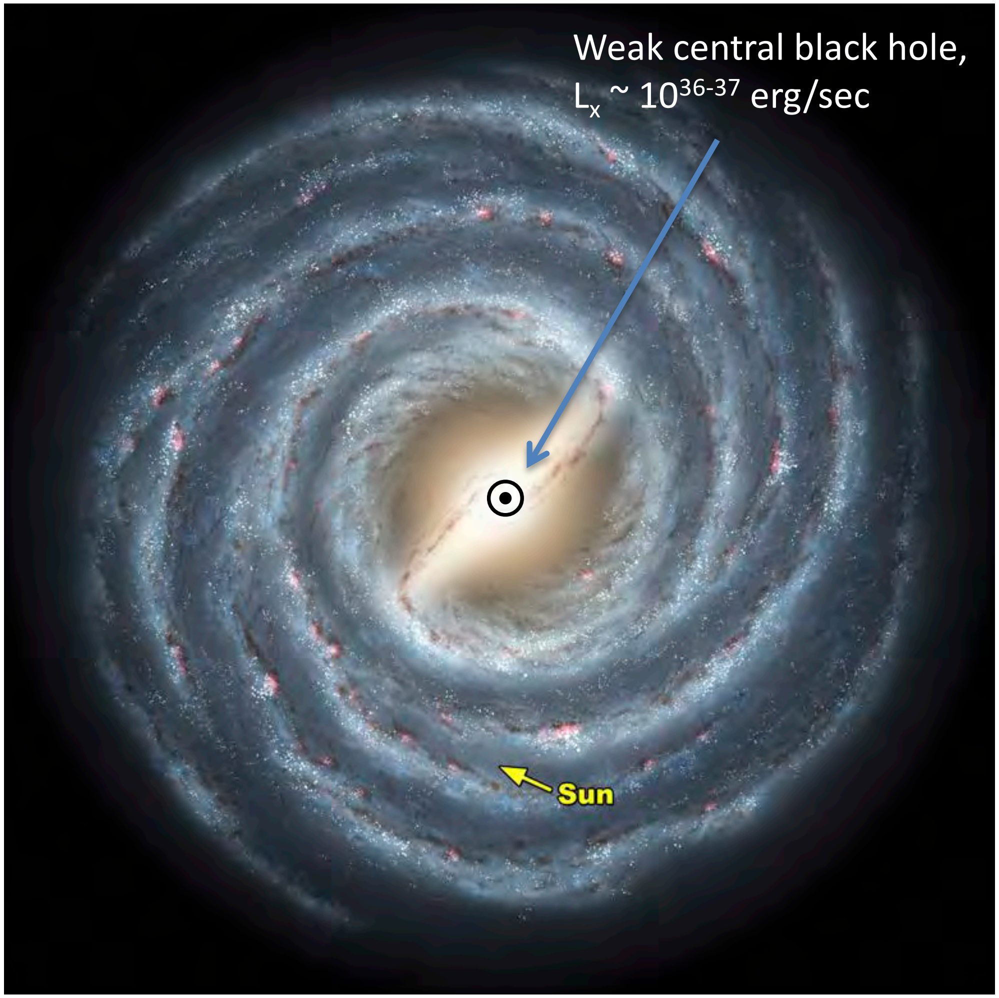
- Multi-cellular Life has gone through *at least* 4 unique stages and huge upheavals due to giant impacts. Bug Eyed Monsters, Horseshoe Crabs, or Giant Lizards would be ruling the place without them. We are the latest dominant species.

Carey Lisse, JHU Applied Physics Laboratory

APS -MASPG, 25 Apr 2018

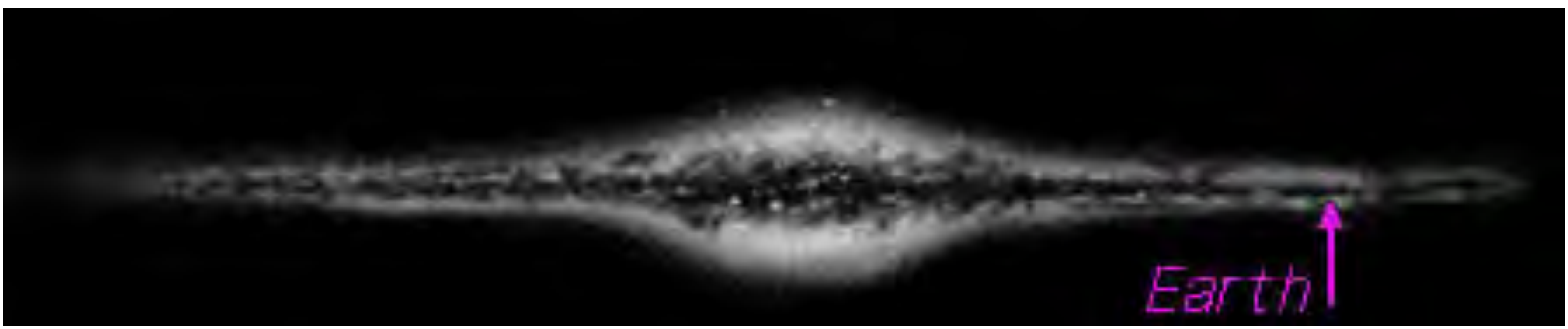
APL JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

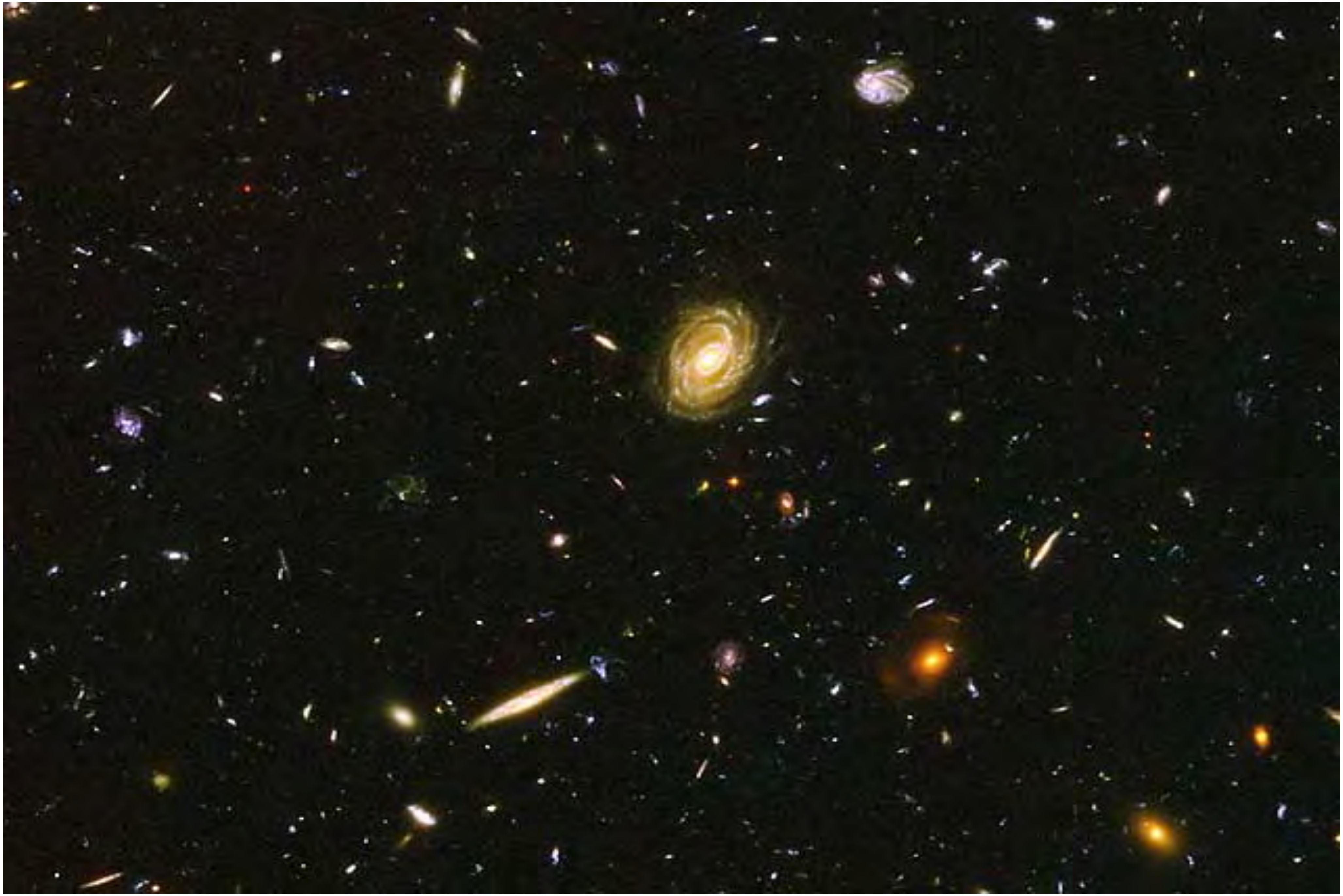
Life Near the Solar System



Time and Place:

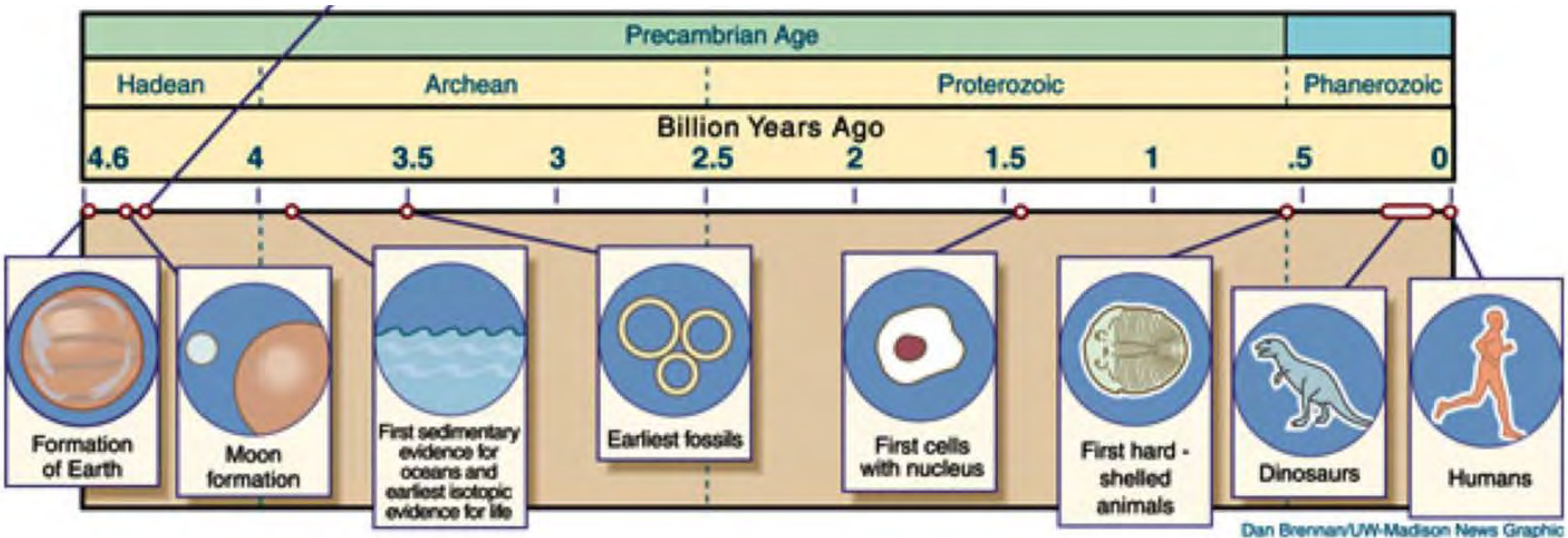
We live in the 'Burbs





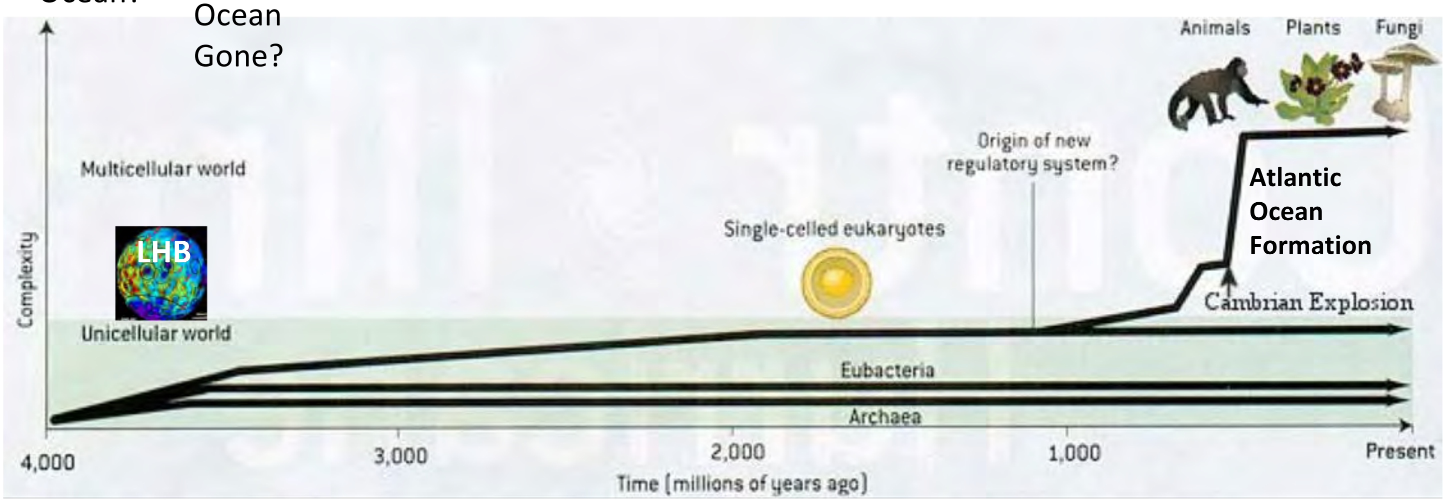
REALLY In the ‘Burbs….

Timescales: For the first ~ 1 Gyr, only astro- and geophysics. After, for Gyrs, the Earth harbored only Unicellular Life. The same unicellular life still dominates today, by mass & diversity.

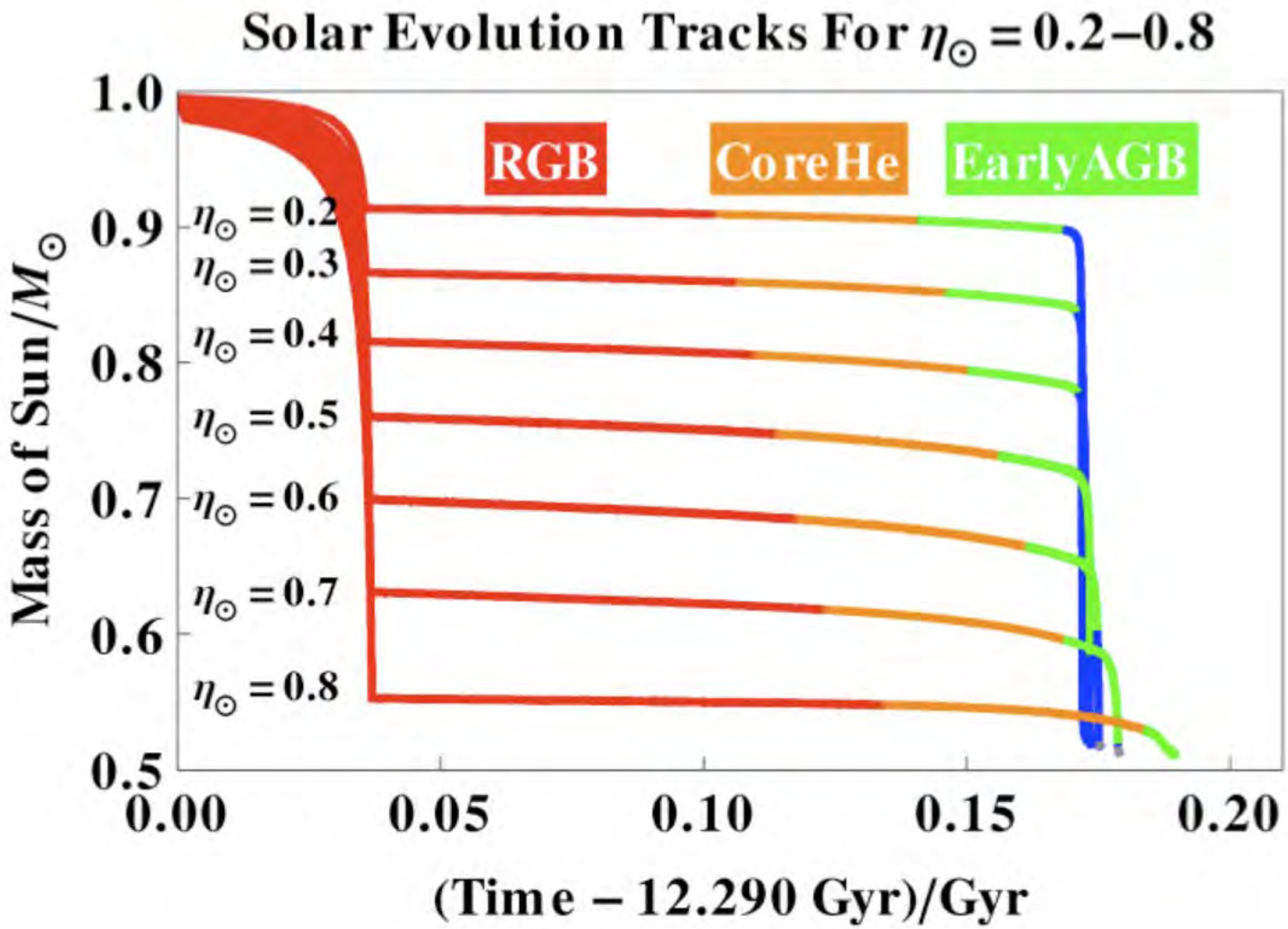


Martian Ocean?

Martian Ocean Gone?



The EndGame: We'll have another 5-6 Gyr of good times, and then…..



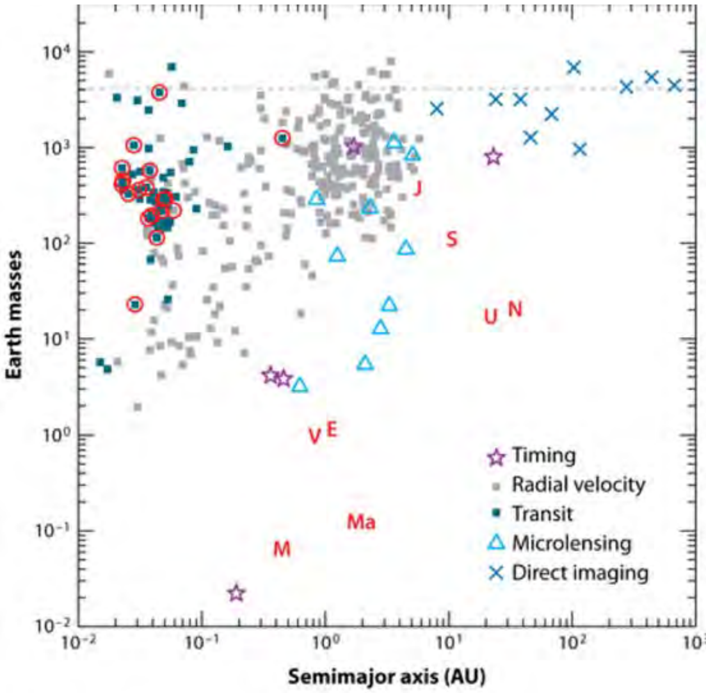
Or the Andromeda Galaxy impacts the Milky Way Galaxy 5 Gyr From Now. Or both.

Back to Astronomy!

Sustainable Habitable Zones :

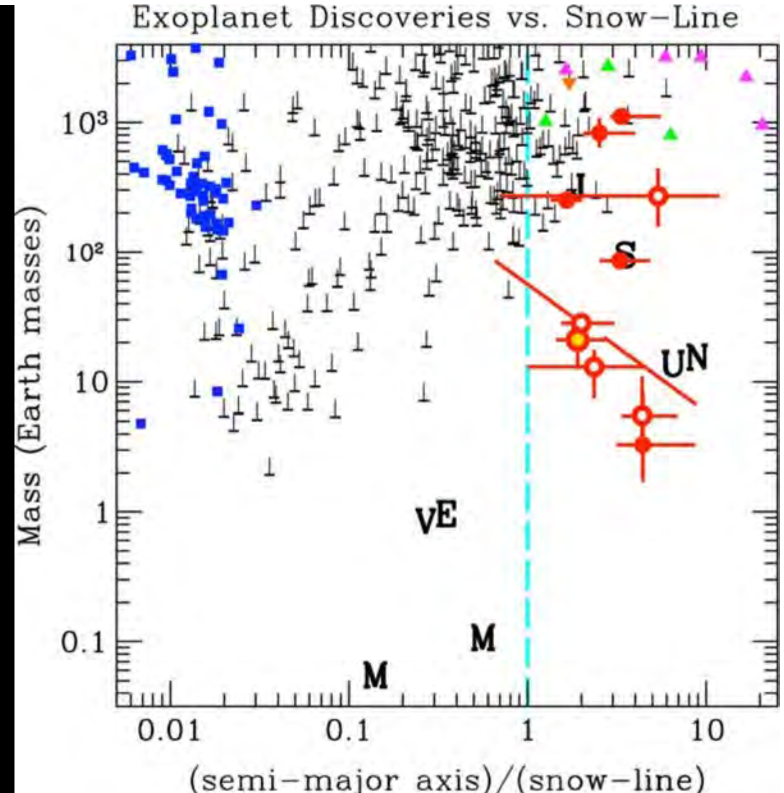
Finding Star Systems With Regions Where Aqueous-Carbonaceous Life Could Exist On a Planetary Surface Once the System is > 1 Gyr Old

(Note We Are Ruling Out Subsurface Living Systems, non-Carbon Systems, Polar non-Aqueous Solvents like NH_3, etc.)

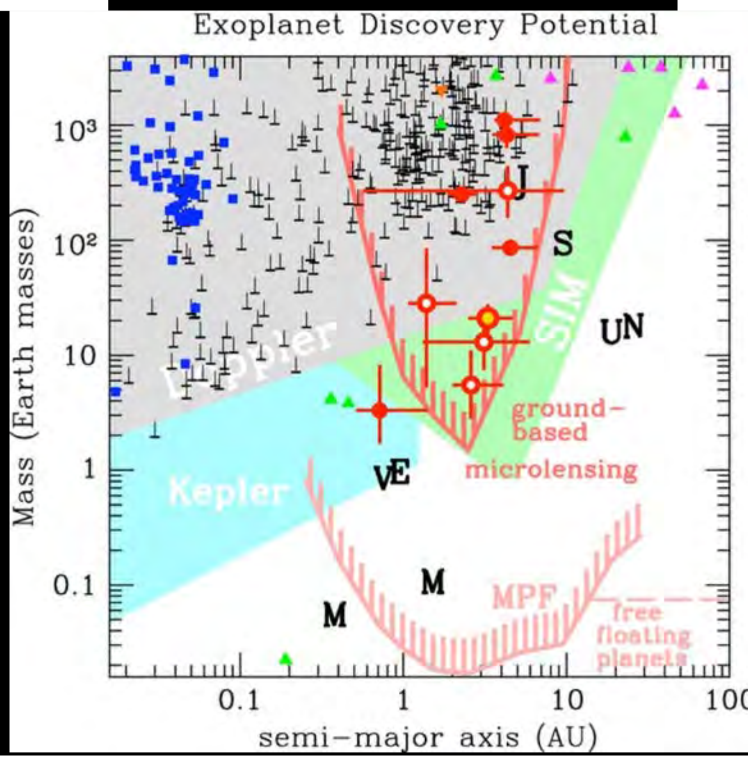


Seager S, Deming D. 2010.
Annu. Rev. Astron. Astrophys. 48:631–72

There Are Many More to Be Found – Most Studies Are Now Pointing to about 1 Earth Sized for Each of the Stars in the Galaxy.

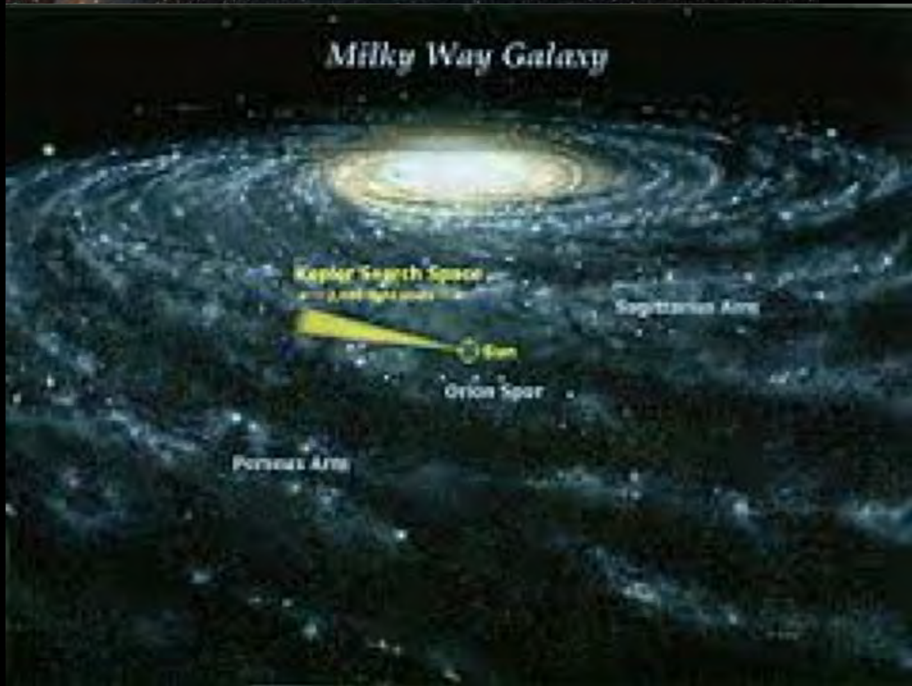


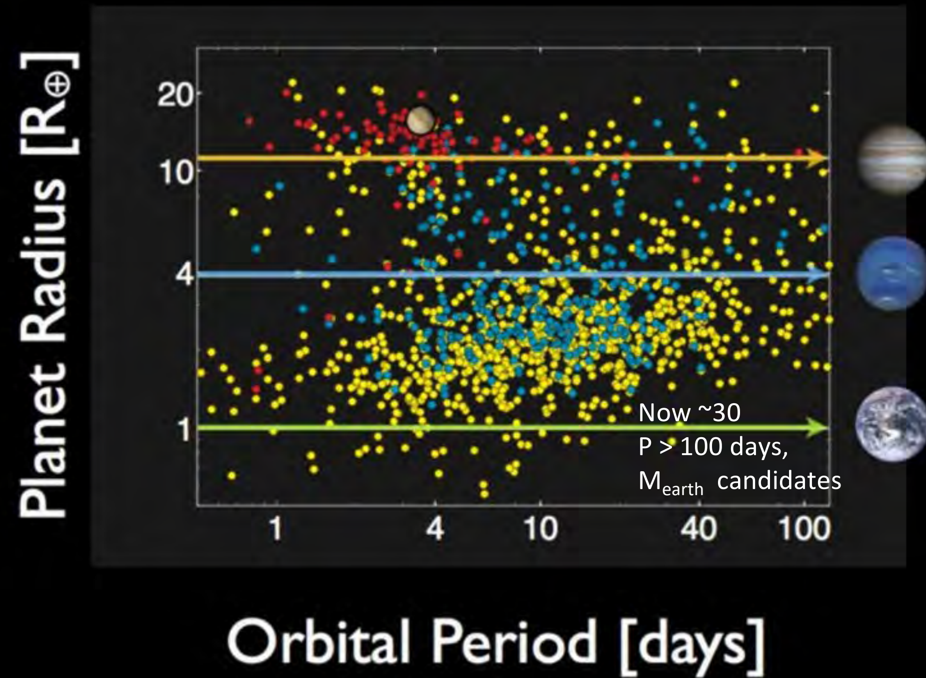
There Are Now More Than 700 Known Planets(!) Detected by Numerous Means, and another 2700 candidates waiting to be verified.



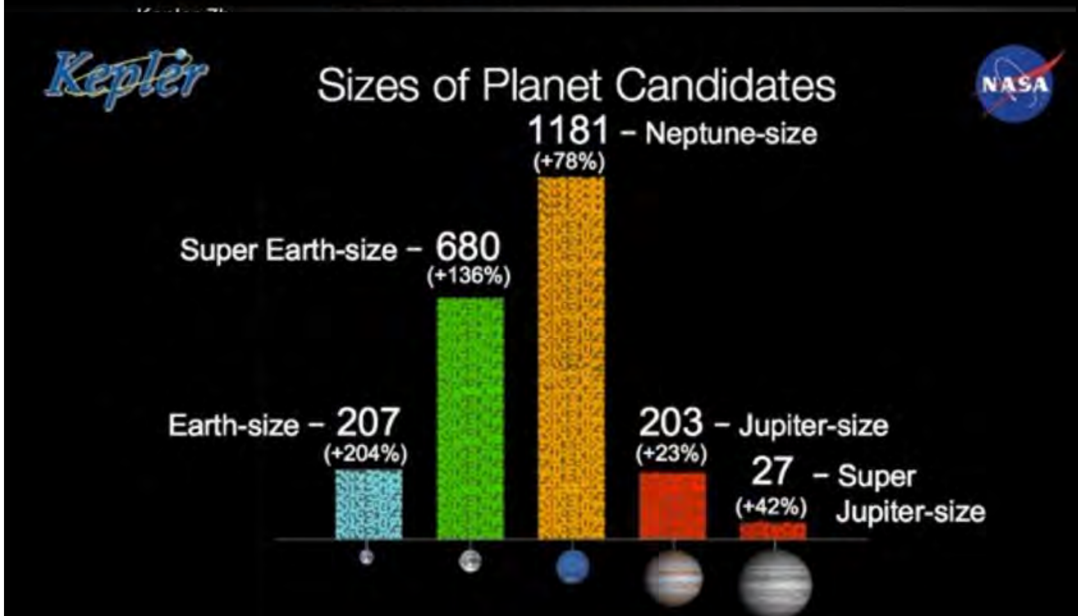
None of the Known Planets is Very Close to 1 M_{earth} at 1 AU Equivalent. (But Kepler Has Some 30 Candidates it is Watching.)

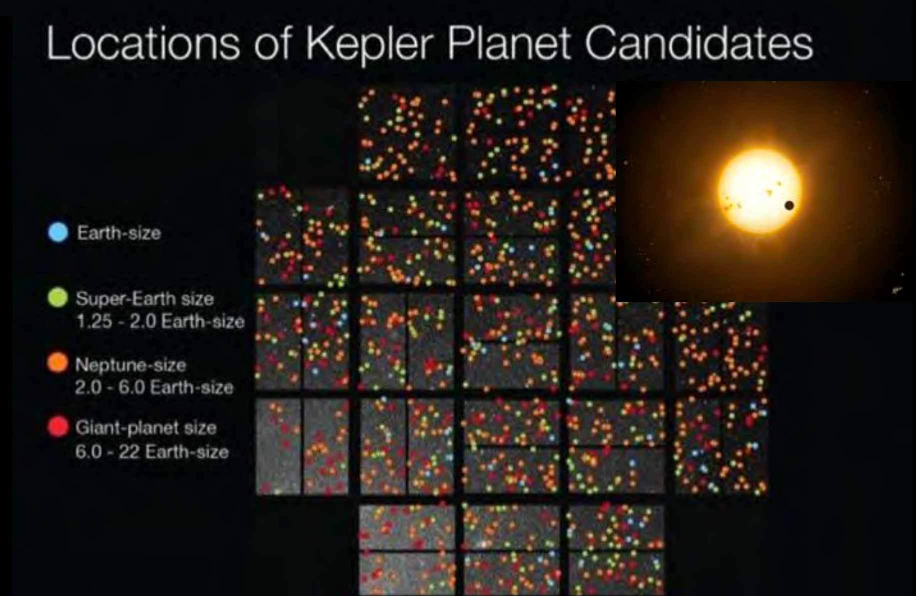
~2700 Kepler Planets : Staring in the Northern Cross at 1 Million Stars 24/7, Looking for Transits.



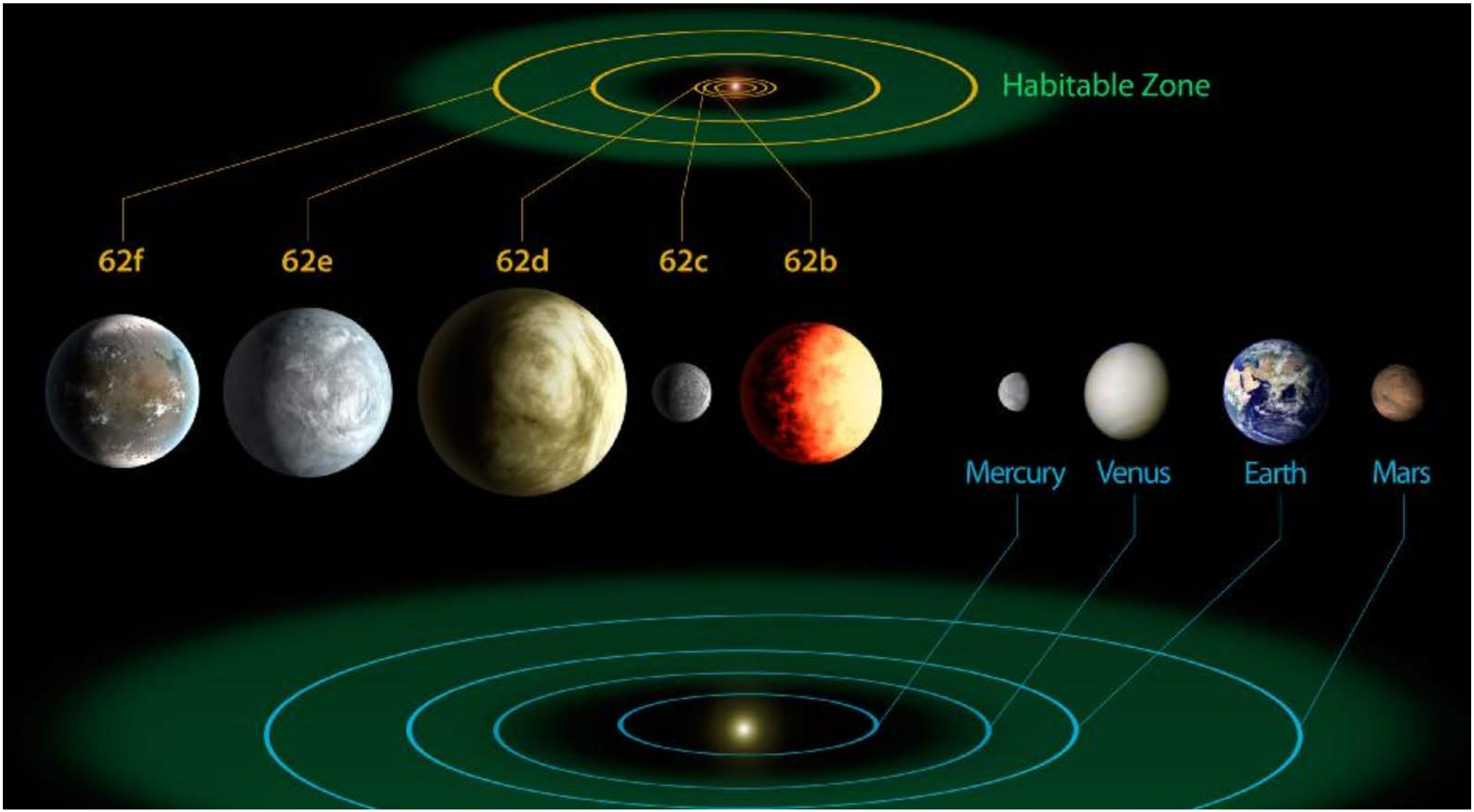


Planet Sizes

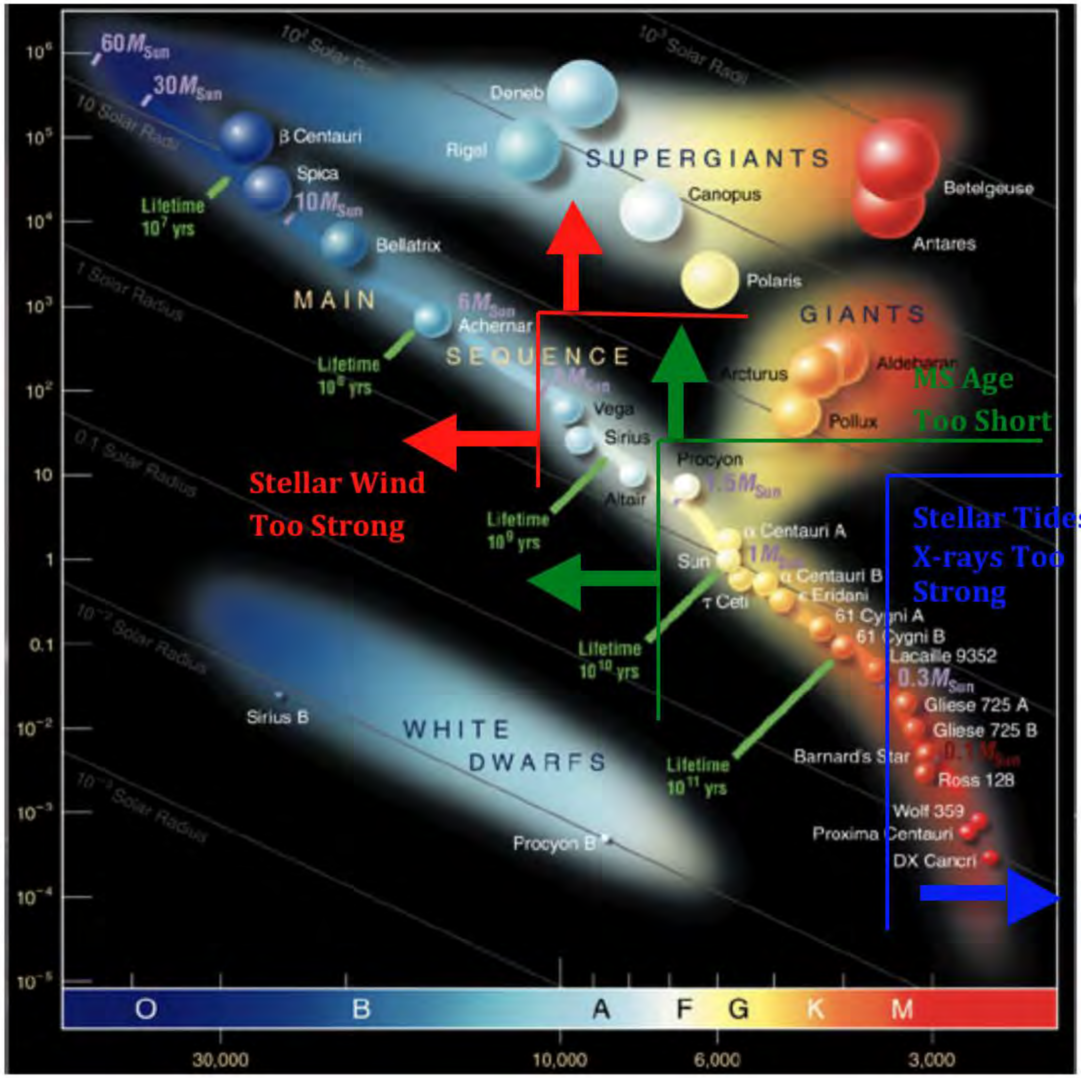


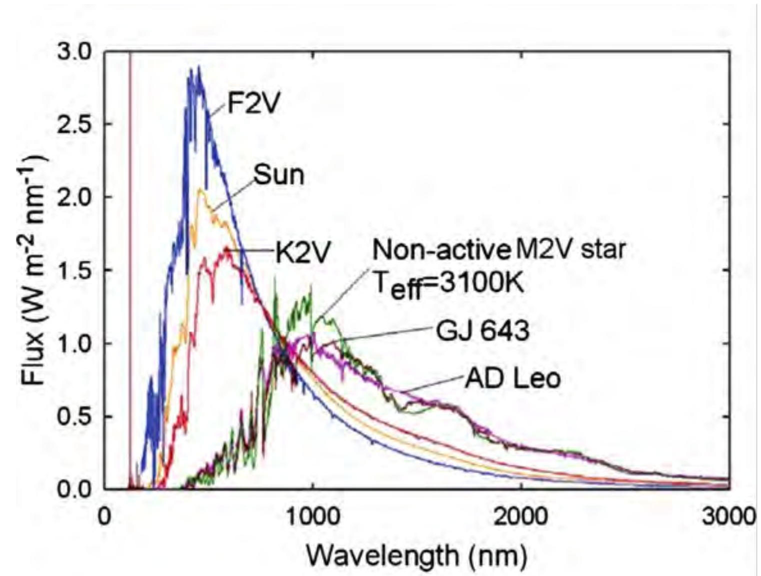


Kepler 62e,f: Just Announced 1.4 + 1.6 R_{Earth} planets around a K2V Star in 300-400K Terrestrial Habitability Zone



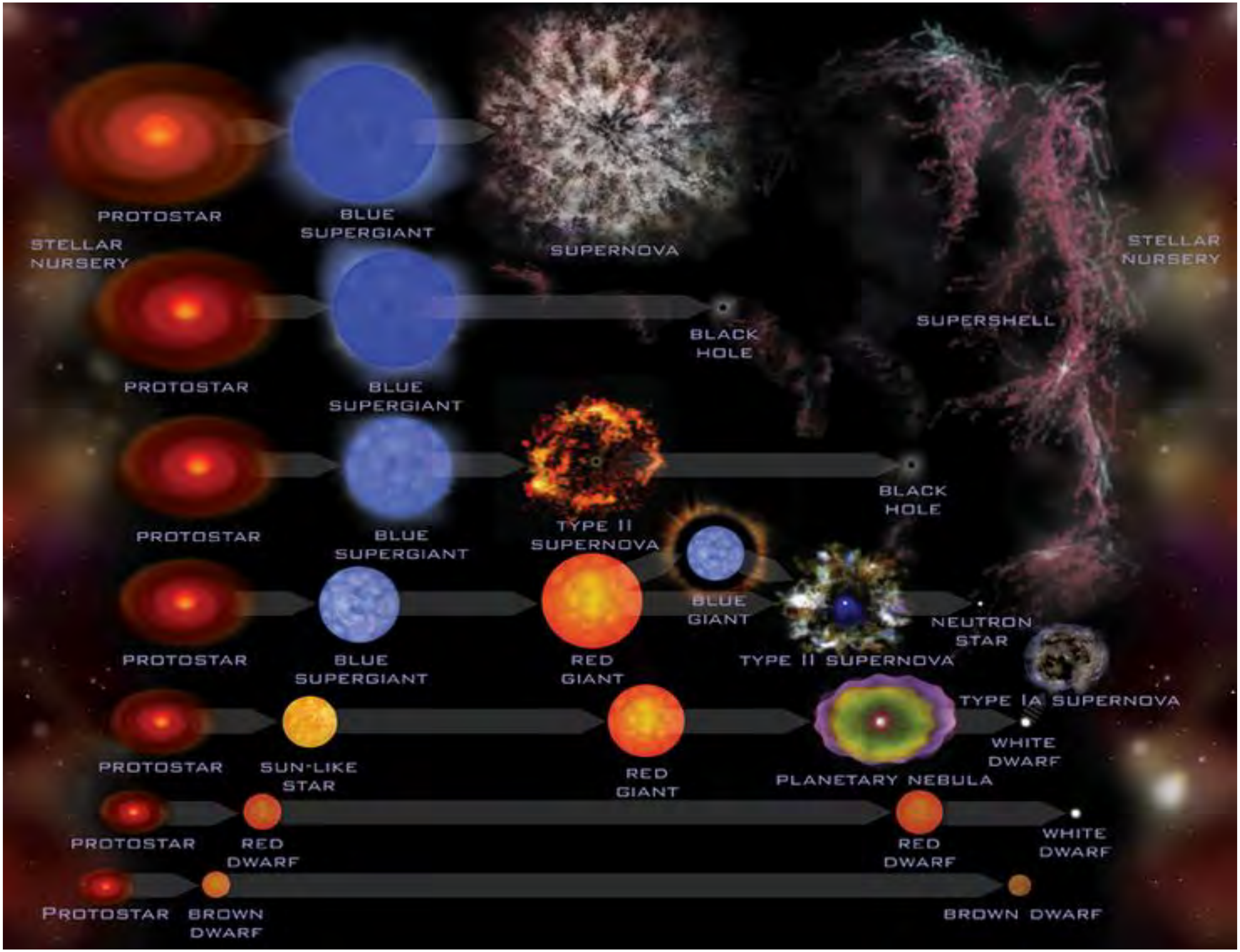
So Around Which Stars Do We Expect to Find Life?

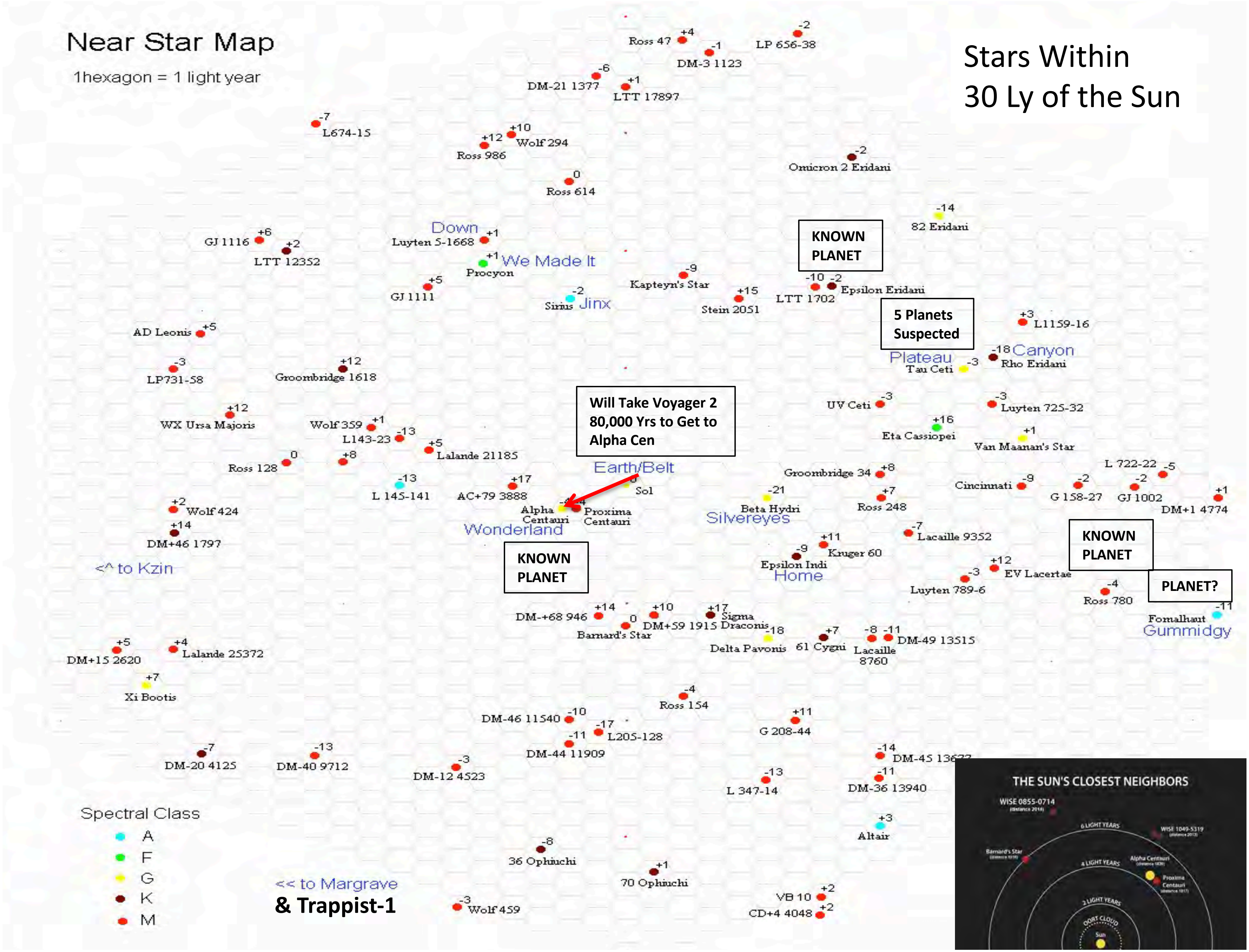


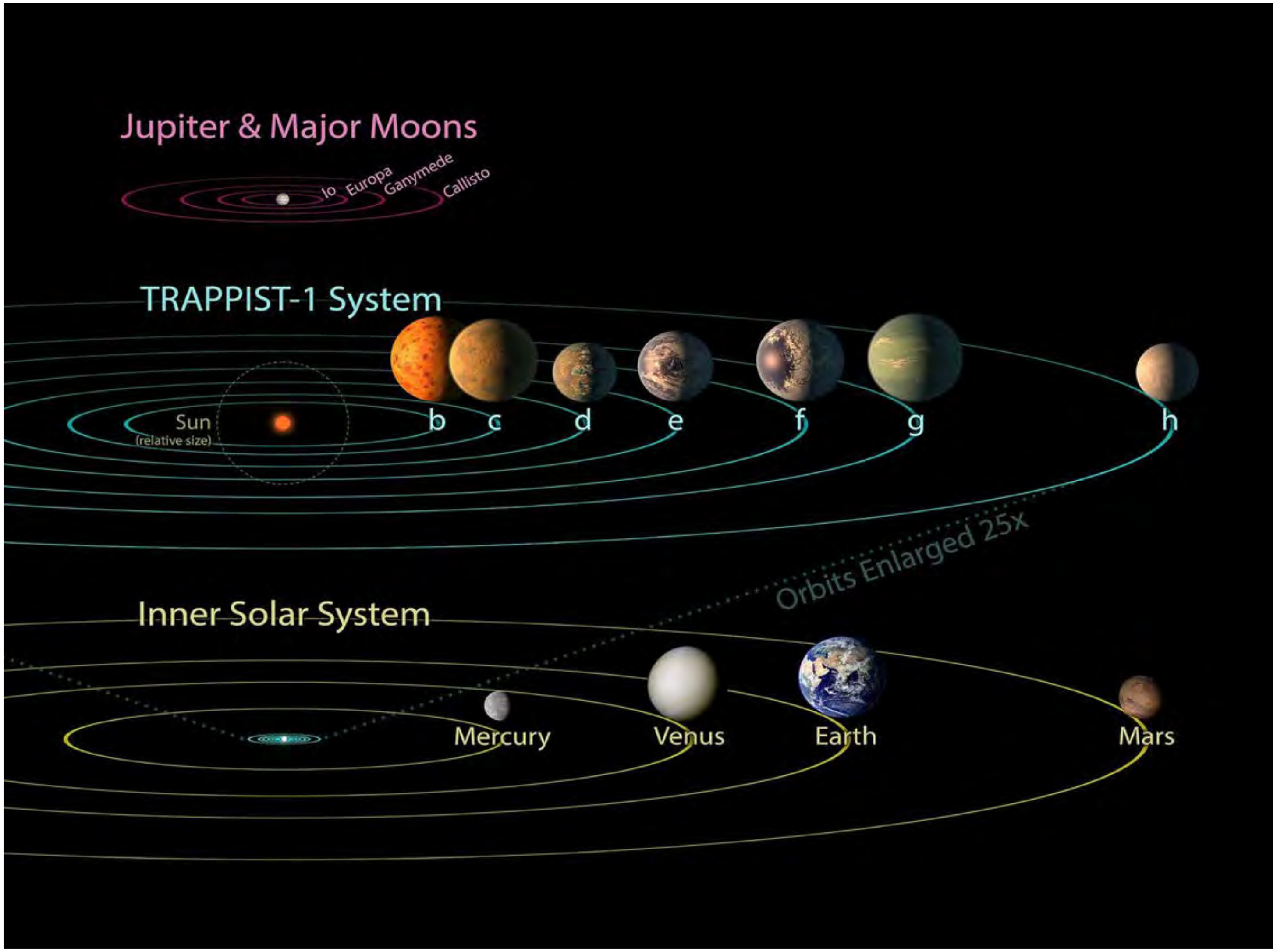


Terrestrial habitability vs. stellar class and luminosity for named bright stars. Procyon A, α Cen A & B, τ Ceti, ε Eridani, 61 Cyg A & B are all good candidates for life.

Stellar Mass = Stellar Destiny

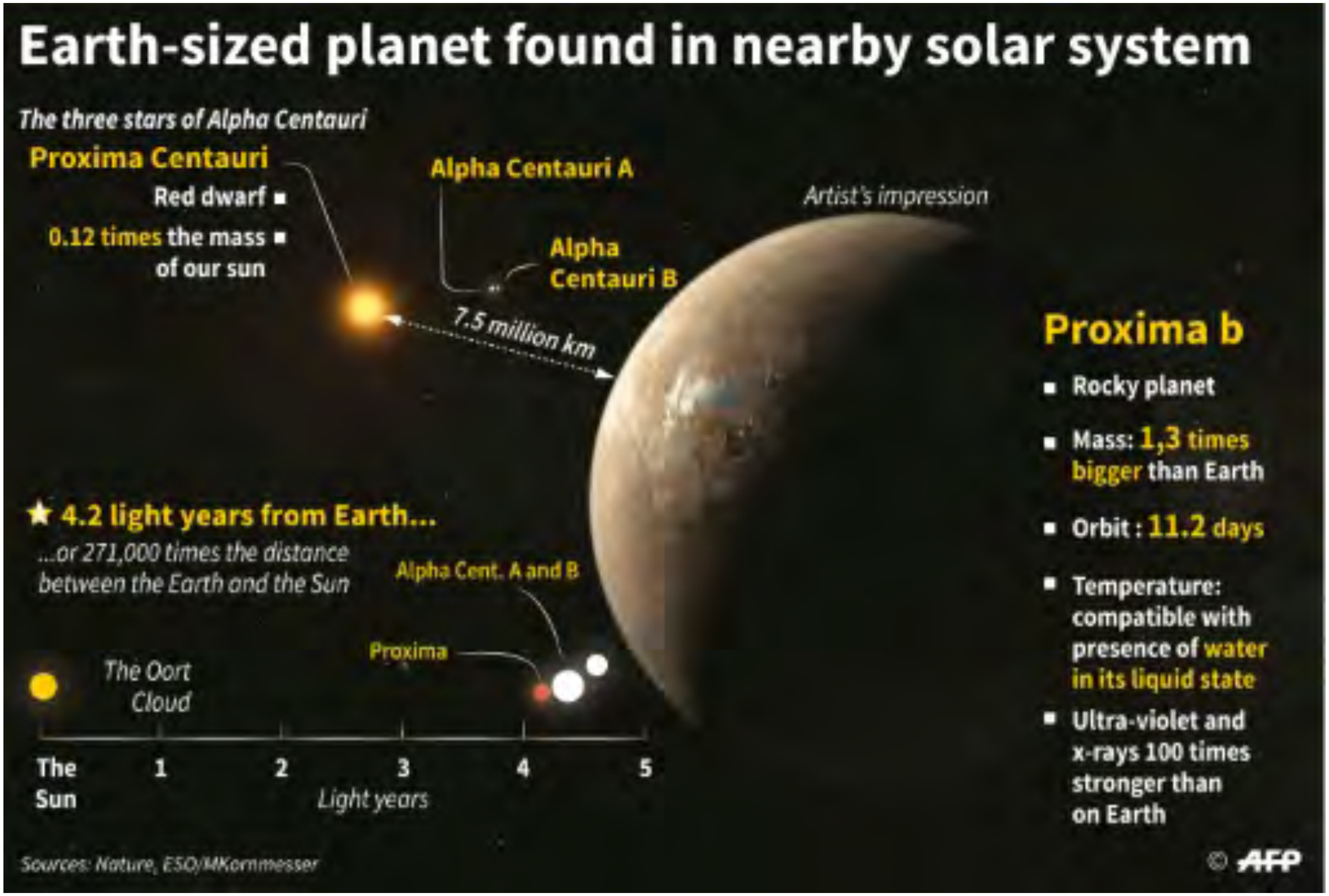



Near Star Map
1hexagon = 1 light year
Stars Within
30 Ly of the Sun
KNOWN PLANET
5 Planets Suspected
Will Take Voyager 2 80,000 Yrs to Get to Alpha Cen
KNOWN PLANET
KNOWN PLANET
PLANET?
Ross 47
LP 656-38
DM-3 1123
DM-21 1377
LTT 17897
L674-15
Wolf 294
Ross 986
Omicron 2 Eridani
Ross 614
82 Eridani
Down
Luyten 5-1668
GJ 1116
LTT 12352
We Made It
Procyon
GJ 1111
Sirius
Jinx
Kapteyn's Star
Stein 2051
LTT 1702
Epsilon Eridani
L1159-16
AD Leonis
LP731-58
Groombridge 1618
Canyon
Rho Eridani
Plateau
Tau Ceti
UV Ceti
Luyten 725-32
Eta Cassiopei
Van Maanan's Star
WX Ursa Majoris
Wolf 359
L143-23
Lalande 21185
Ross 128
L 145-141
AC+79 3888
Earth/Belt
Sol
Groombridge 34
Cincinnati
G 158-27
L 722-22
GJ 1002
DM+1 4774
Beta Hydri
Ross 248
Wolf 424
Alpha Centauri
Proxima Centauri
Silvereyes
Wonderland
DM+46 1797
Lacaille 9352
Kruger 60
Epsilon Indi
Home
EV Lacertae
Luyten 789-6
Ross 780
<^ to Kzin
DM-+68 946
Barnard's Star
DM+59 1915
Sigma Draconis
Delta Pavonis
61 Cygni
Lacaille 8760
DM-49 13515
Fomalhaut
Gummidgy
DM+15 2620
Lalande 25372
Xi Bootis
Ross 154
DM-46 11540
L205-128
DM-44 11909
G 208-44
DM-20 4125
DM-40 9712
DM-12 4523
L 347-14
DM-45 13677
DM-36 13940
Altair
36 Ophiuchi
70 Ophiuchi
<< to Margrave
& Trappist-1
Wolf 459
VB 10
CD+4 4048
Spectral Class
A
F
G
K
M
THE SUN'S CLOSEST NEIGHBORS
WISE 0855-0714
6 LIGHT YEARS
WISE 1049-5319
Barnard's Star
4 LIGHT YEARS
Alpha Centauri
Proxima Centauri
2 LIGHT YEARS
OORT CLOUD
Sun



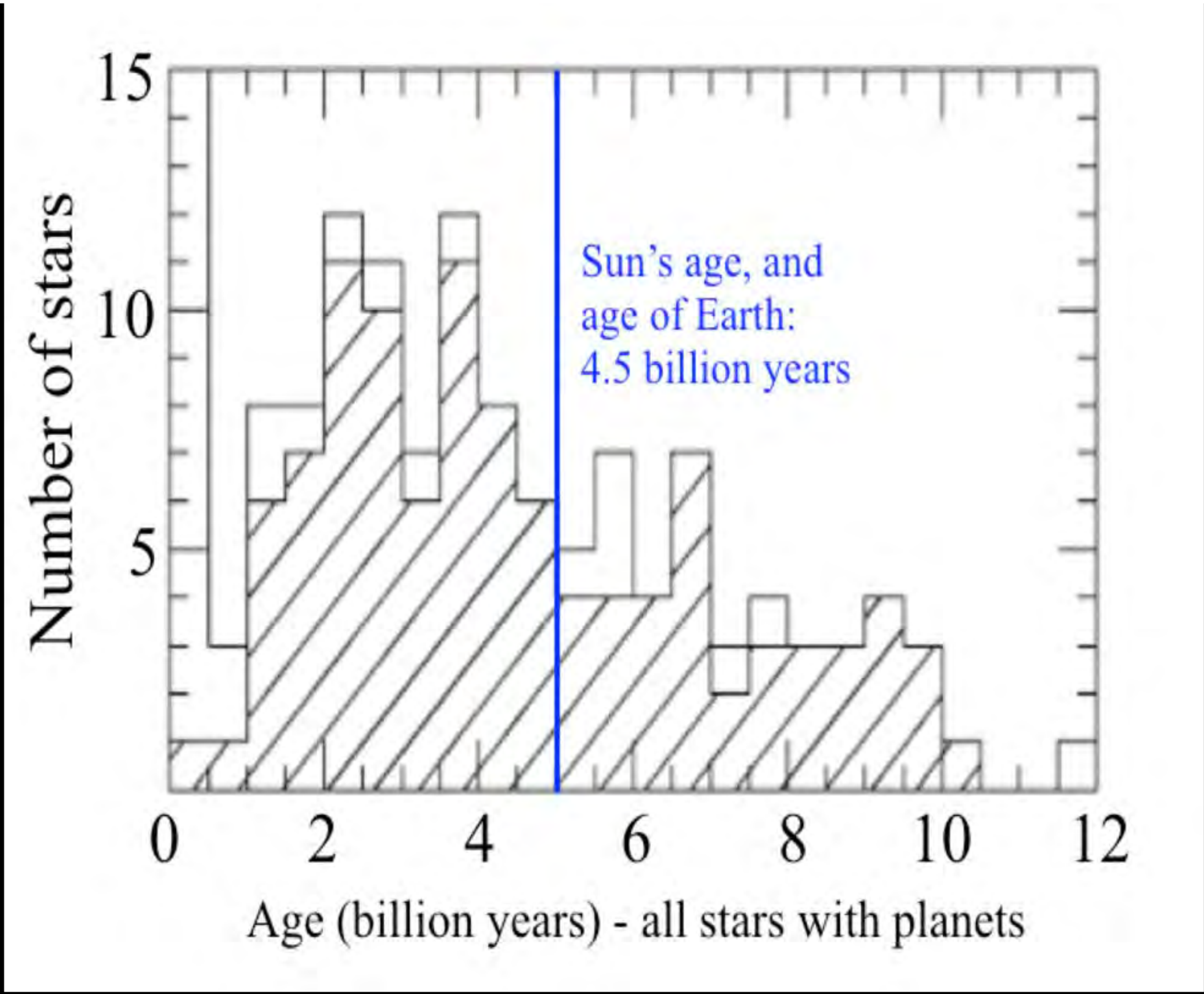
Trappist-1!

- “Seven temperate terrestrial planets around the nearby ultracool dwarf star TRAPPIST-1". Gillon *et al.*, *Nature* **536**, 437doi:10.1038/nature21360.
- Primary star is an M8V (T ~2550K, M ~ 83M_{Jup}), 12 pc distantl L ~ 0.0005 Lsun, not too active
- [Fe/H] 109% solar, > 1 Gyr old
- M_planet = 0.6 – 1.4 M_earth; 3 of the planets are in the THZ; 2 are separated by just 1.6 Rearth_moon
- System has some scaled similarities to the Jovian satellite system dynamically
- Life most likely happiest at terminator, poles.



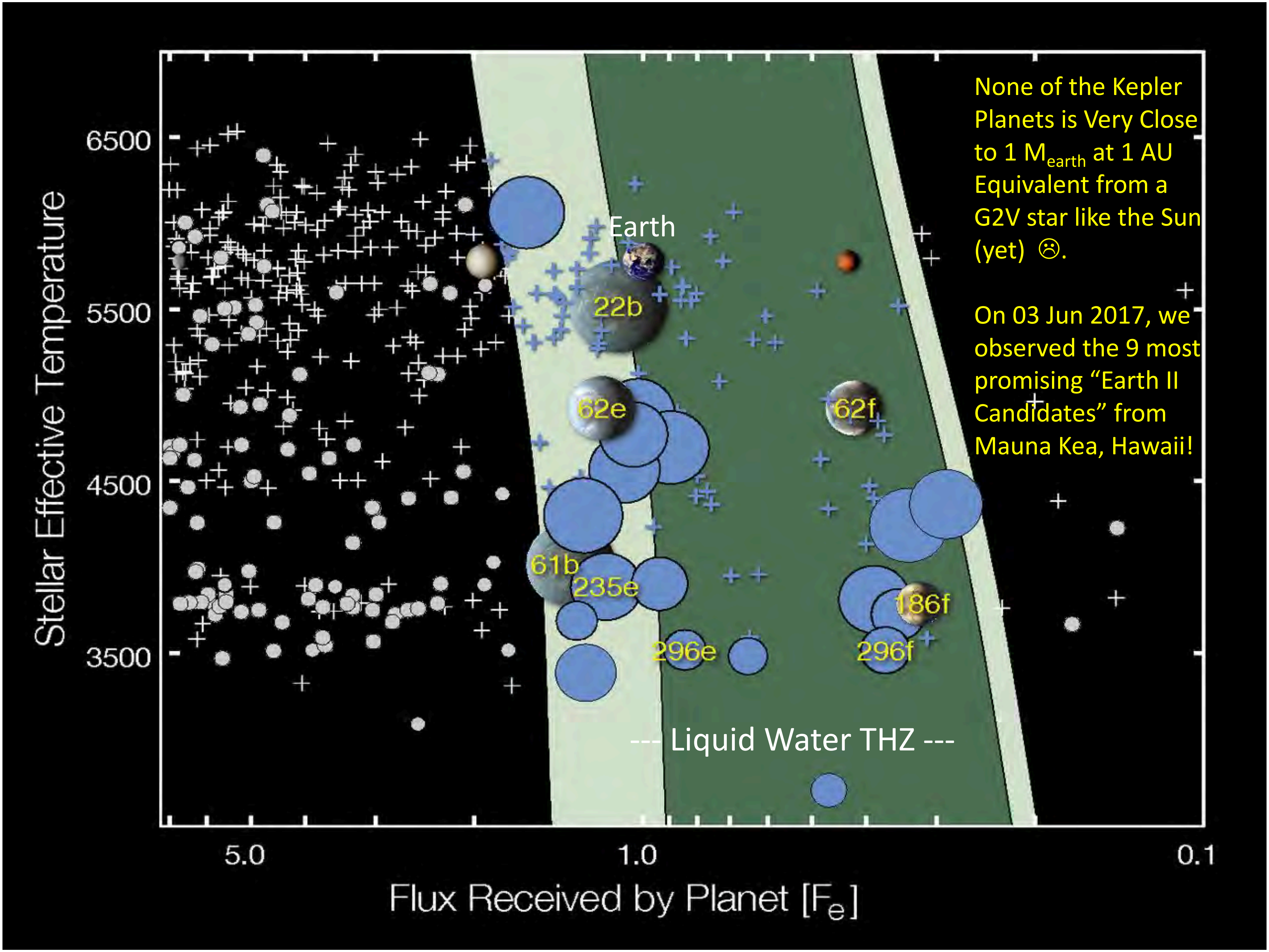
Proxma Centauri b!

- "A Terrestrial Planet Candidate in Temperate Orbit Around Prox Cen", Anglada-Escudé et al., *Nature* **536**, 437
- Measuring chemical abundances of Proxima is hard, use AlphaCen A & B as proxies => solar, 6 Gyr old
- Likely no H-atmosphere, $M \geq 1.3\ M_{Earth}$
- HST may be able to do thermal phase variations, reflected light photometry -> R_{planet} (Atmo probe)
- Planet gets ~0.6 L_{sun}, means if tidally locked subsolar pt has $T = 0.6^{0.25} * 1.4\ T_{subsolar,\ Earth}$
- Life most likely happiest at terminator, poles.
- Proxima Centauri = frequent flare star, so life there needs shelter (underwater)



Age of all stars currently known to have planets within 130 light years of the Earth: Median of distribution = 3 billion years

=> It is more likely that we will find microbial life on other planets rather than animals or human equivalents



None of the Kepler Planets is Very Close to 1 M earth at 1 AU Equivalent from a G2V star like the Sun (yet) ☹.
On 03 Jun 2017, we observed the 9 most promising "Earth II Candidates" from Mauna Kea, Hawaii!
Earth
22b
62e
62f
61b
235e
186f
296e
296f
--- Liquid Water THZ ---
Stellar Effective Temperature
6500
5500
4500
3500
Flux Received by Planet [Fe]
5.0
1.0
0.1

So Where is the Intelligent Life in the Galaxy?

Fermi Paradox: At the speed of light, one should be able to traverse the galaxy in a few Myr. Since the Galaxy is ~13 Gyr old, and planets should have formed earlier towards the center of the galaxy, where are the neighbors?
https://en.wikipedia.org/wiki/Fermi_paradox

(Unless they'So re hiding. And UFO's are alien teenagers buzzing the planet.)

(See also "Alone in the Universe" by H. Smith, Am. Sci. 99, Aug 2011)

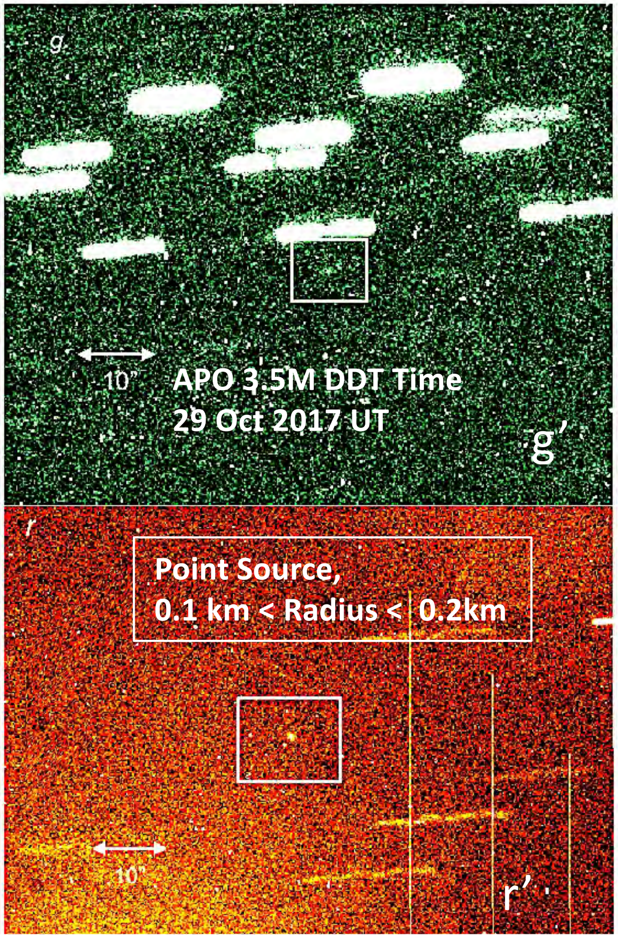
Photometric Imaging of 1st Detected Interstellar Object in the Solar System:

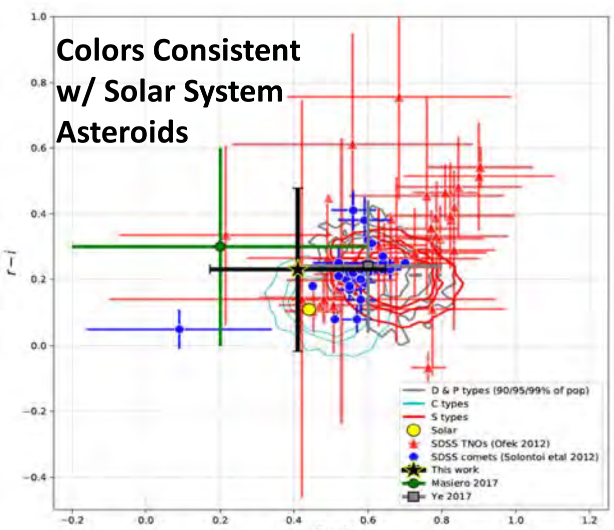
1I/'Oumuamua

(Sept-Nov 2017 asteroid or needle-nosed spaceship?)

Bolin, Weaver, Fernandez, Lisse+ 2017

arXiv:1711.04927v2





$r_{perihelion}$ = 0.25 AU
$r_{perigee}$ = 0.20 AU
eccentricity = 1.19

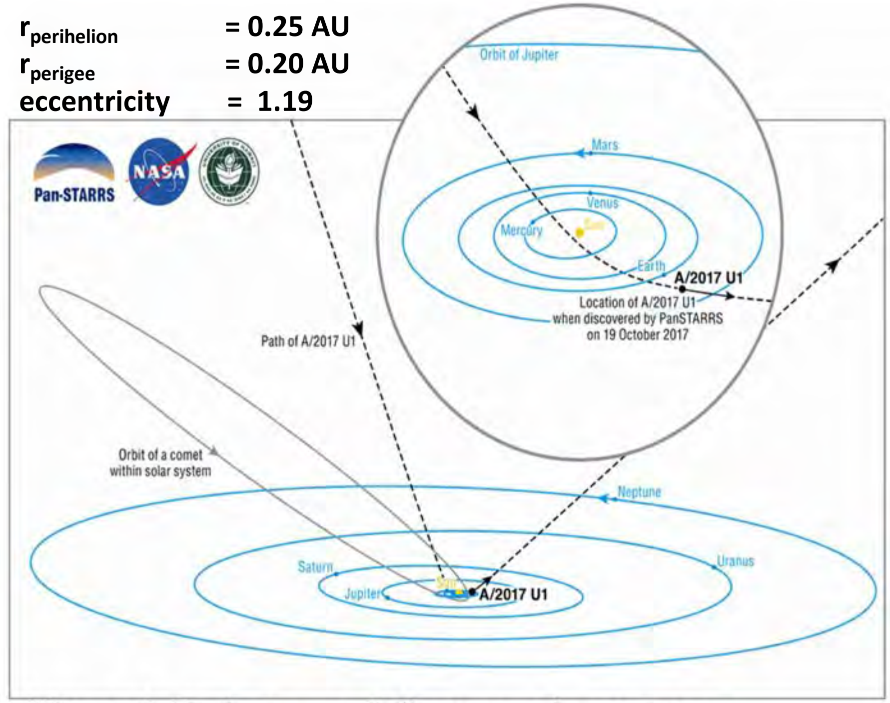
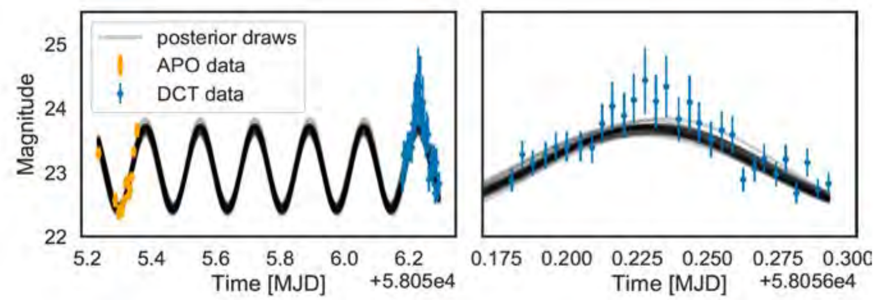
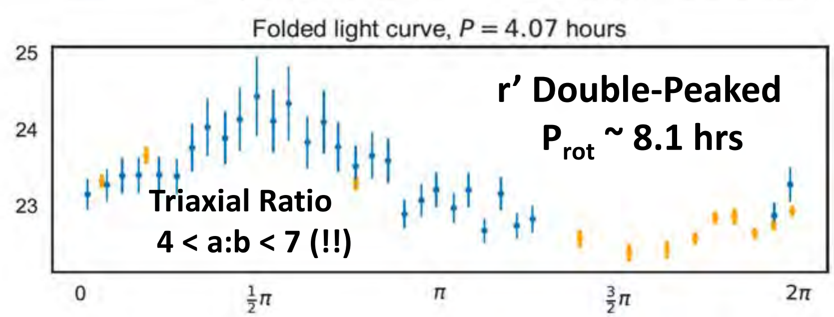


Figure 1: Trajectory and discovery circumstances for A/2017 I1-'Oumuamua.

Football Shaped Spheroid





Life in the Solar System

Habtiable Zones:
Necessary But Not Sufficient For Life

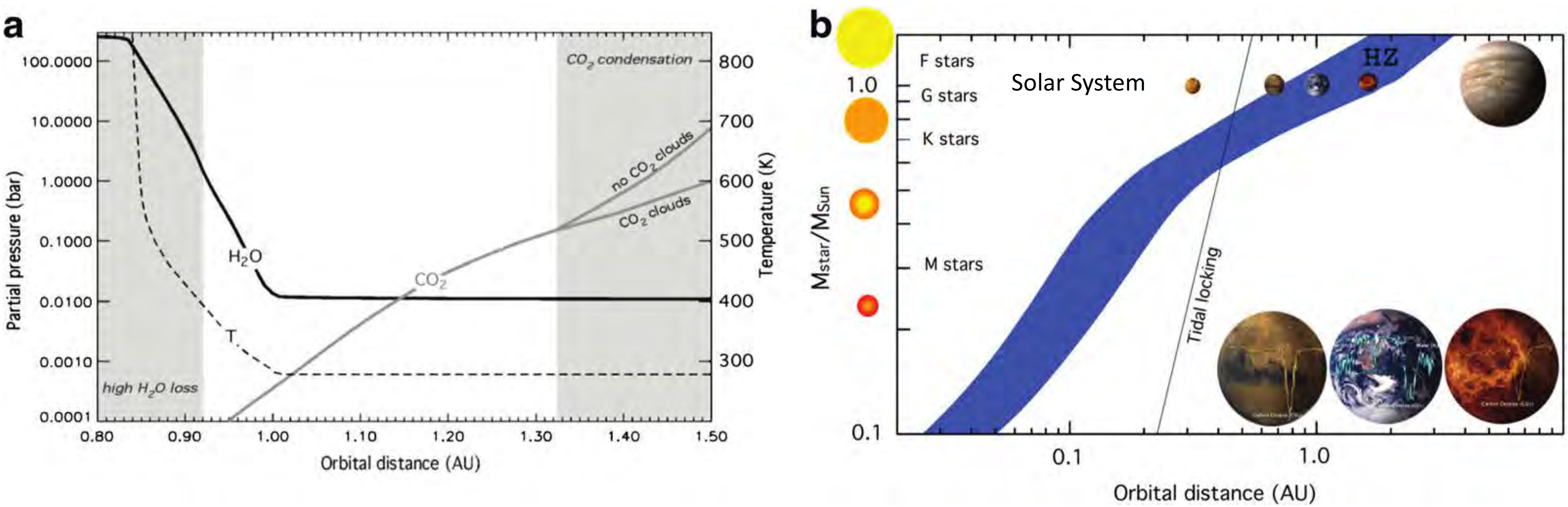
- Atmosphere of a Planet
- Age and Evolutionary State of A Star
- Orbital Obliquity
- Orbital Eccentcity

All Matter Too.

Habitability Zones W/ Liquid Water Potential:

Distance from Stars Where T(r) ~ 300 K

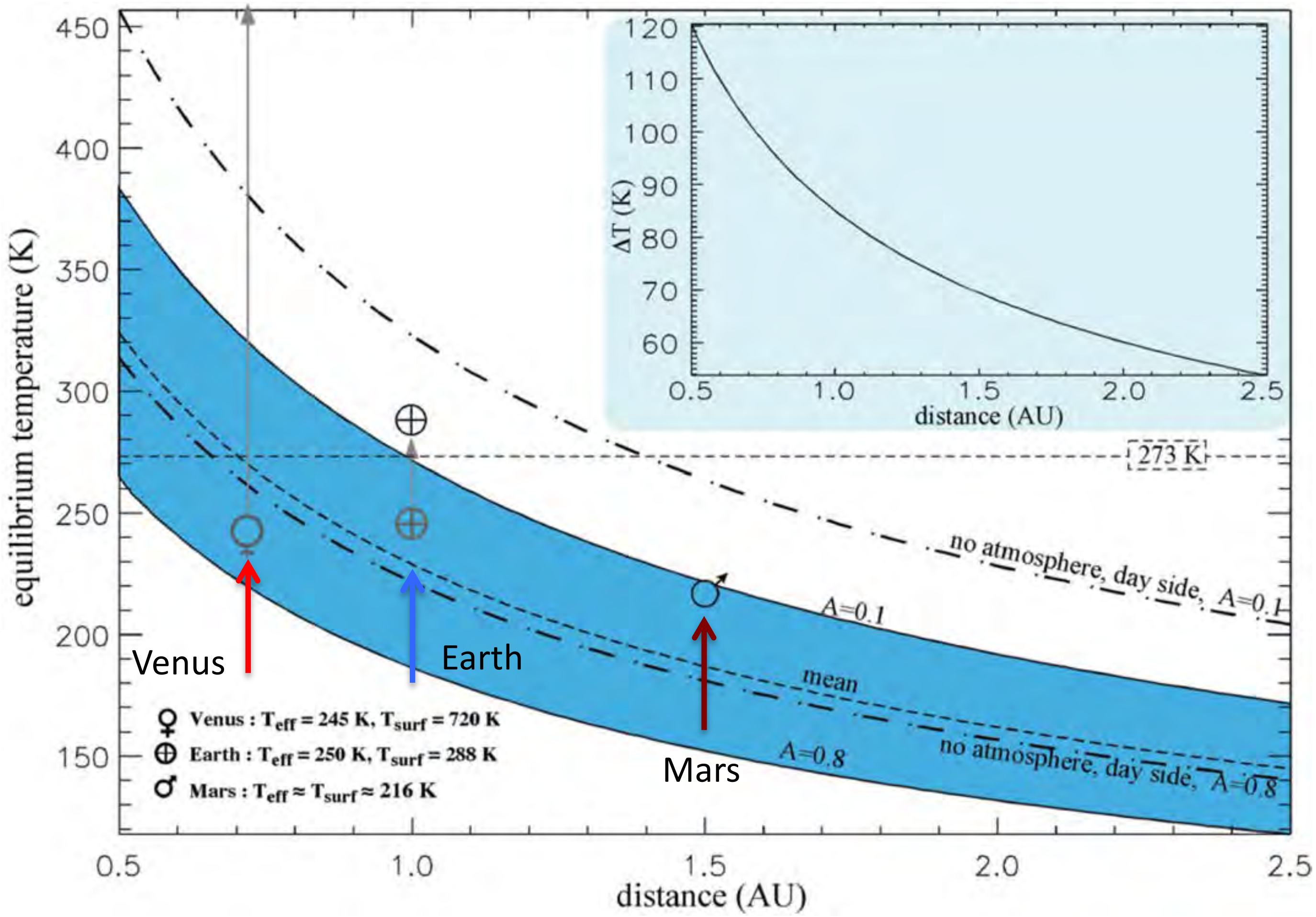
(assuming $L_*/4\pi r^2 = \sigma T^4$)



(a) Surface conditions on a habitable planet within the HZ (data adapted from Kasting et al., 1993; Forget and Pierrehumbert, 1997; Kaltenegger and Selsis, 2007) & **(b)** the HZ as a function of stellar type.

Planetary Surface Temp Depends on More Than Just Distance From the Primary:

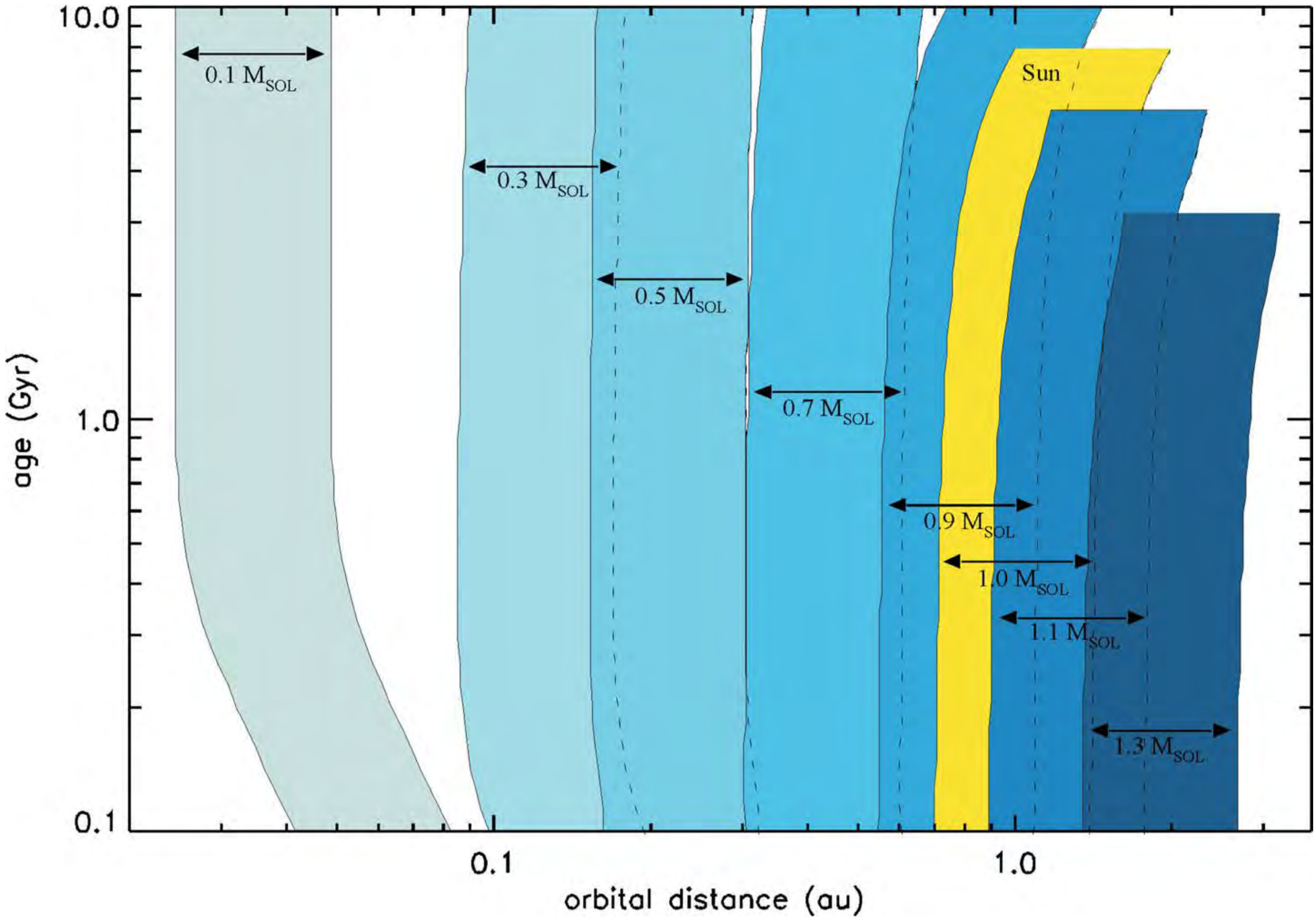
We Have & Need a Mild Greenhouse on Earth. Venus, Twin Sister of Earth, Has a DEADLY Runaway Greenhouse!



Move Earth to Venus' Location, We Get 100ºF Warmer, NOT 860ºF

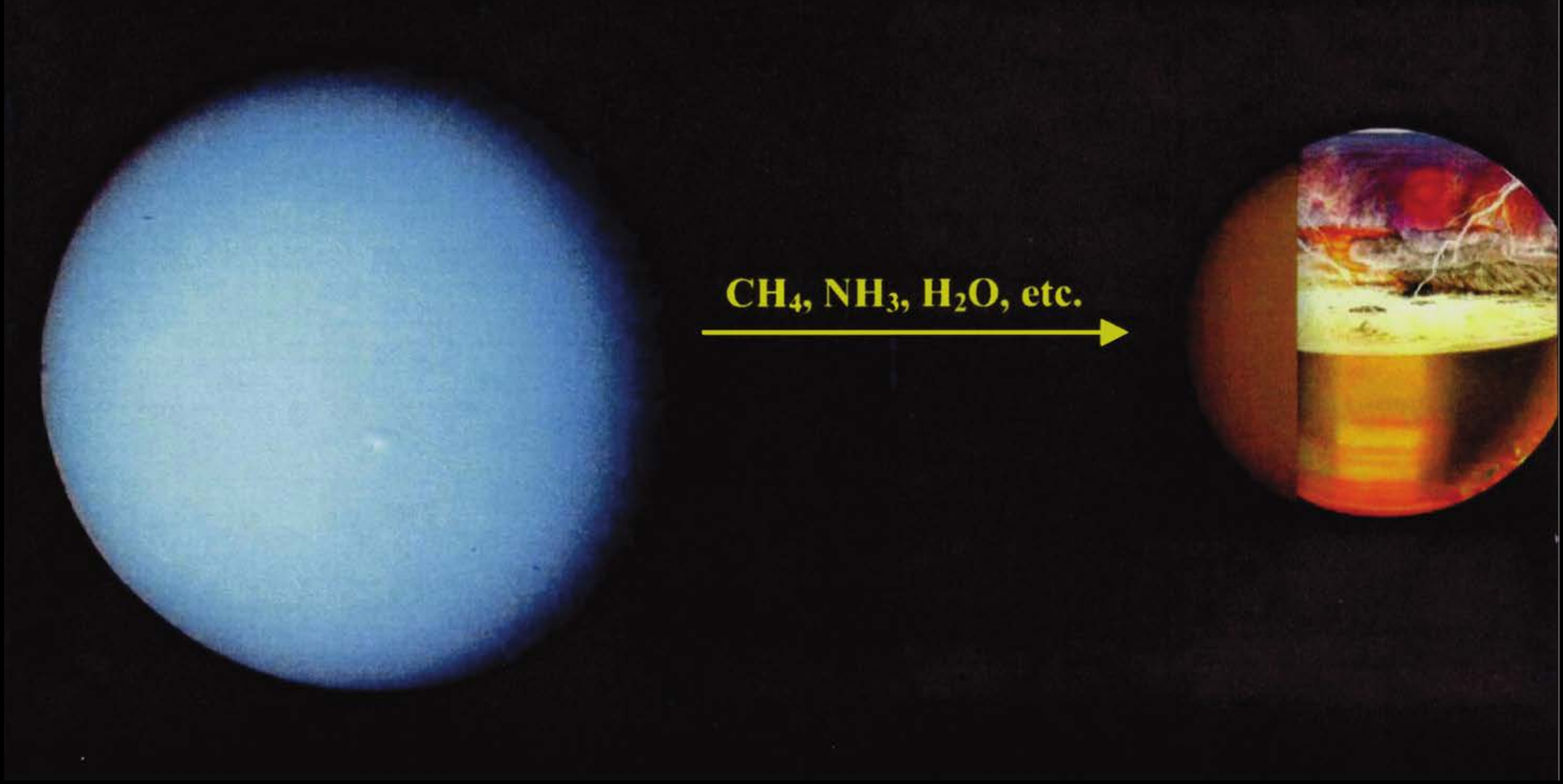
Lammer, Selsis, *et al.* 2010 *Astrobiology*

Equilibrium temperature and albedo. The orbital distance of a planet and its albedo (the fraction of the incoming light reflected to space) determine an equilibrium temperature, T_{eq}, corresponding to the temperature of a blackbody that reemits all it absorbs. **The surface of Earth, and especially of Venus, is heated by the greenhouse effect of the atmosphere: these two planets have similar effective temperatures (the temperature associated with the radiated IR flux). However, their T_{surf} differ by more than 400 K!! Orbital distance by itself is poorly indicative of T_{surf} of a planet.**



Boundaries of the HZ for main sequence stars of different masses, as a function of the stellar age. For stellar masses above 0.9 MSun, the main sequence lasts less than 10 Gyr. For G and F stars, the limits of the HZ move away from the star in response to the increase of luminosity. The evolution of stellar luminosity is taken from Baraffe et al. (1998).

Will Uranus Be a Good Place to Live in 5 Gyr When the Sun Goes Into Its Red Giant Phase?



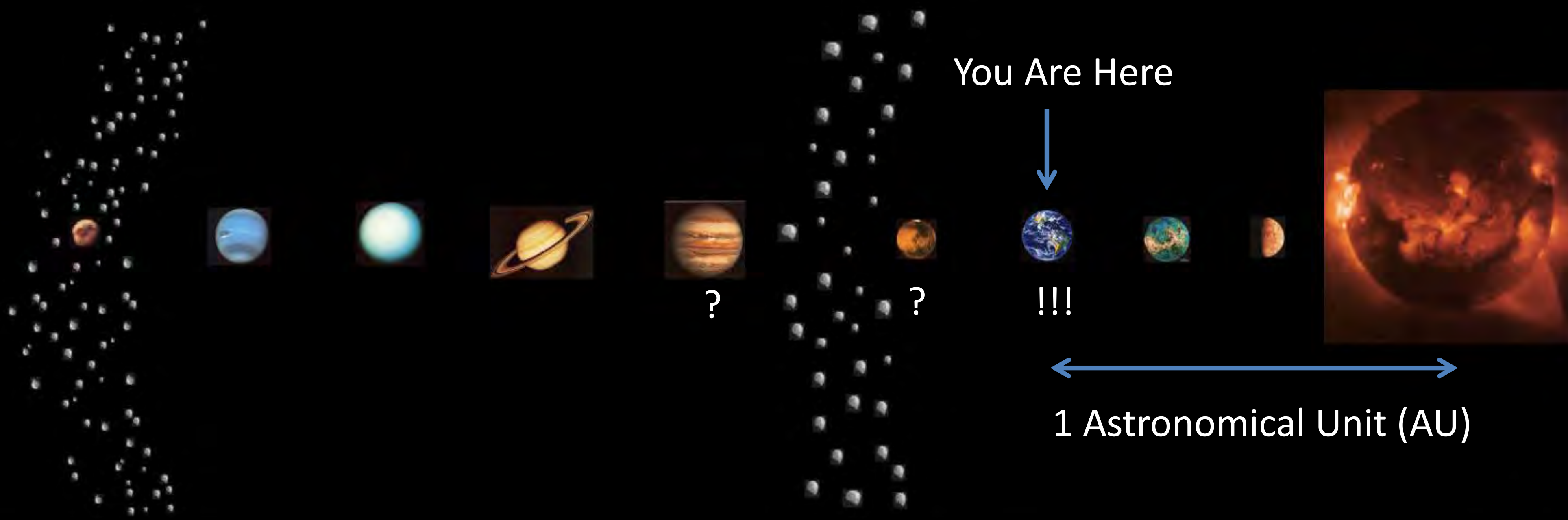
Migrating Uranus-class exoplanets may lose their dense hydrogen atmospheres due to EUV-driven hydrodynamic escape (Kuchner, 2003; Lammer et al., 2003b, 2009a; Lecavelier des Etangs, 2007; Penz et al., 2008b). The remaining cores of these bodies may melt and outgas volatiles like CH_4 and NH_3, which are trapped inside the ice and may evolve to large Titan- like ''terrestrial exoplanets'' with reduced atmospheres.

Life in the Solar System

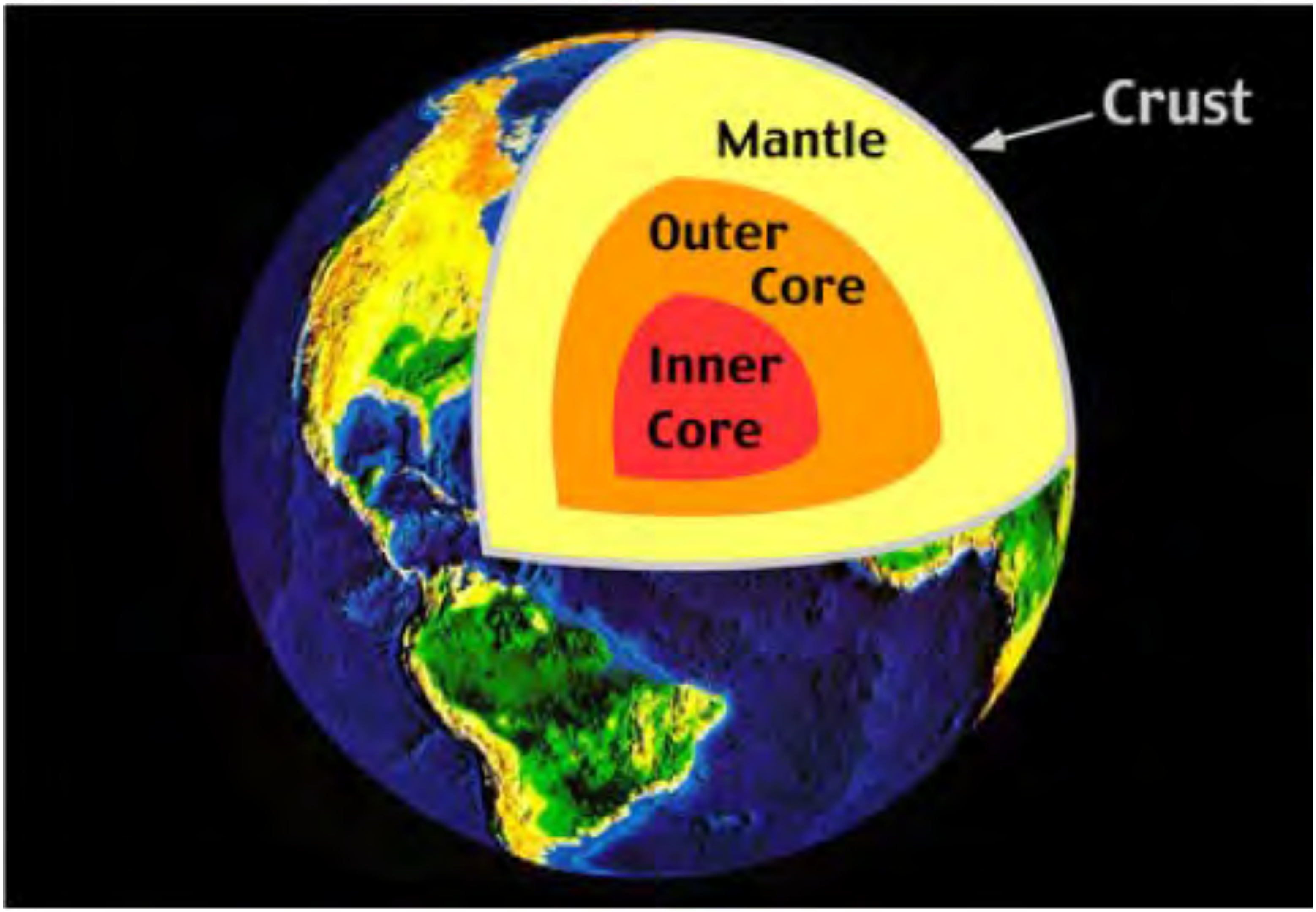
Life Exists on 1 Planet in Our Solar System, and Maybe on Another and Inside the Moon of a 3rd

Pluto-Kuiper belt
(short period comets)

Asteroid belt
(meteorites)



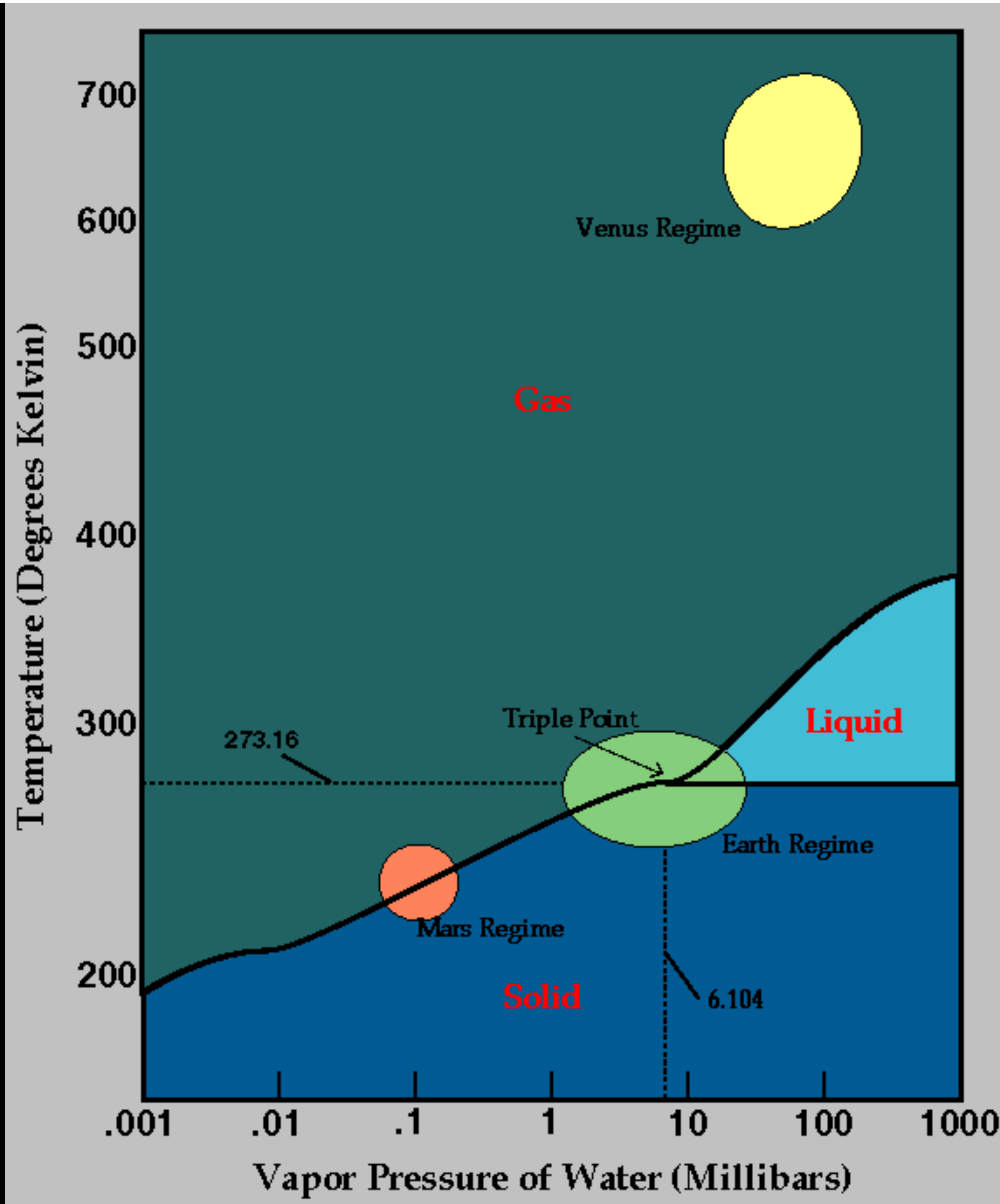
Gas giants << >> Rocky planets



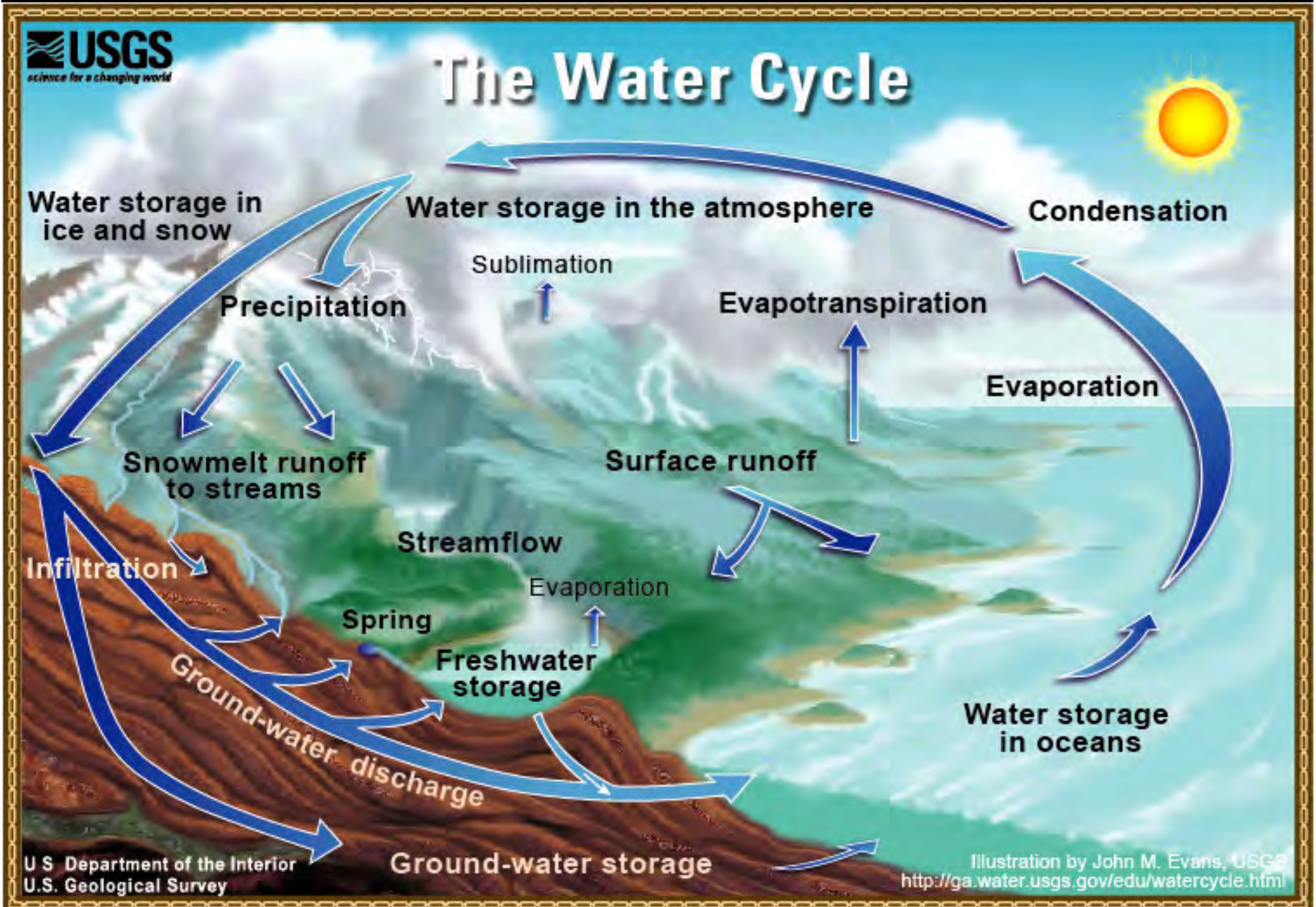
And life is found on the thinnest rind of our Small Blue Dot of ~6370 km radius ……from -10 to +60 km at last reckoning.

The Critical Roles of Water (short list :)

- Heat transfer is mediated by water on Earth
- All life we know of on Earth requires water
- Water is a major ‘greenhouse’ gas
- Thermostatic control (high heat capacity)
- Interacts with O_3 in ultraviolet light to remove ozone
- $CO_2 + H_2O$ dissolves surface rocks



700
600
500
400
300
200
Temperature (Degrees Kelvin)
Venus Regime
Gas
Triple Point
273.16
Liquid
Earth Regime
Mars Regime
Solid
6.104
.001
.01
.1
1
10
100
1000
Vapor Pressure of Water (Millibars)


USGS
science for a changing world
The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Snowmelt runoff to streams
Surface runoff
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
U S Department of the Interior
U.S. Geological Survey
Illustration by John M. Evans, USGS
http://ga.water.usgs.gov/edu/watercycle.html

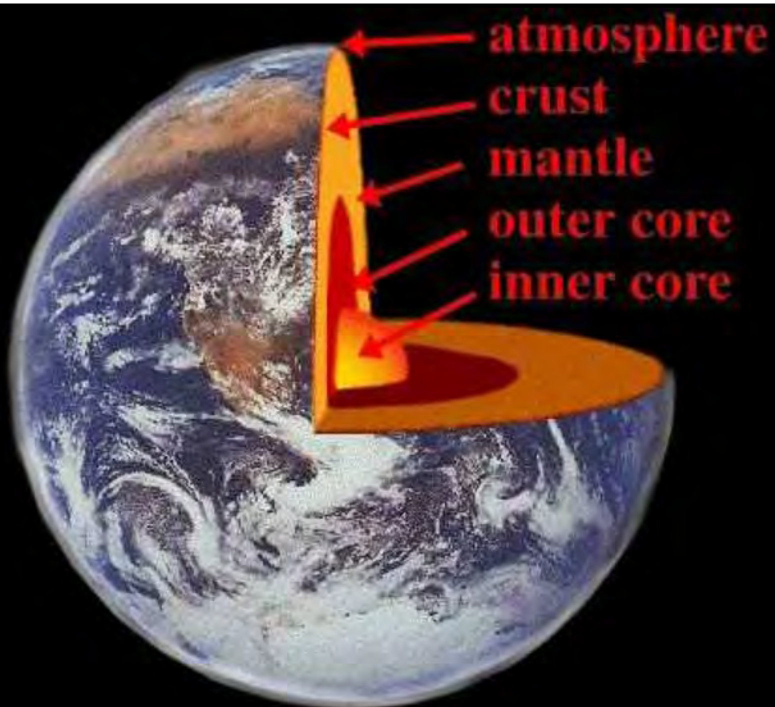
Lessons From the Solar System:

There Is Likely Lots More to Habitability Than Just Liquid Water!

(The Laundry List of Good Happenings @ Earth :-)

Right distance from the star	Habitat for complex life Liquid water Avoid tidal lock
Right mass of star	Long enough to develop biology & Not too much ultraviolet/x-ray
Stable planetary orbits	Low eccentricty, tilt; No orbital chaos from giant planets
Right planetary mass	Retain atmosphere and ocean Enough heat for plate technoics Molten core (magnetic field)
Jupiter-like neighbor	Clear out comets Not too close, not too far
Mars	Small neighbor to possibly seed life
Plate Tectonics	Enhance biodiversity Enable magnetic field

Large Moon	Stabilizes tilt
Right tilt	Seasons not too severe
Giant impacts	Few sterilizing impacts after life forms
Right amount of carbon	Enough for life BUT No runaway greenhouse effect
Atmospheric properties pressure for life	Maintain adequate temperature, composition and
Biological evolution	Successful evolutionary pathway
Evolution of oxygen	Invention of photosynthesis
	Not too much or too little
	Evolves at the right time
Right kind of galaxy	Mature, w/ Enough heavy elements => Not small, elliptical or irregular
Right position in galaxy	Not in center, edge or halo (galactic metallicity gradient)



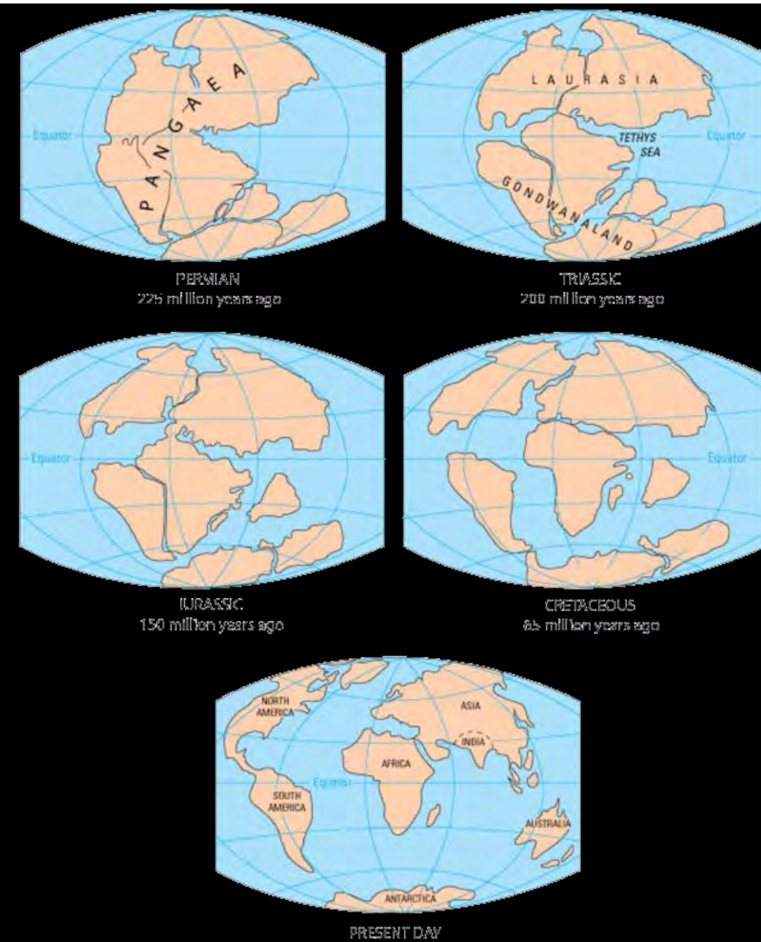
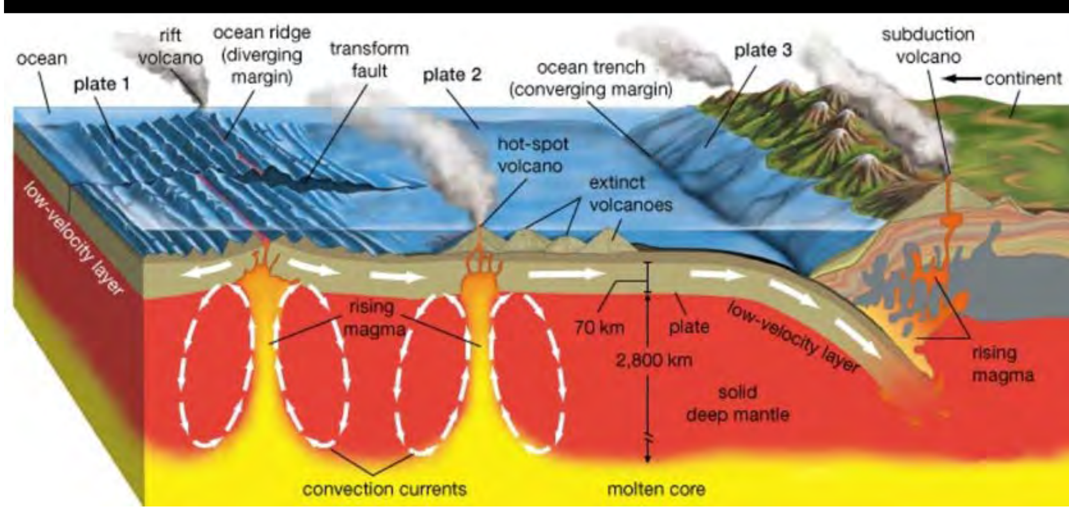
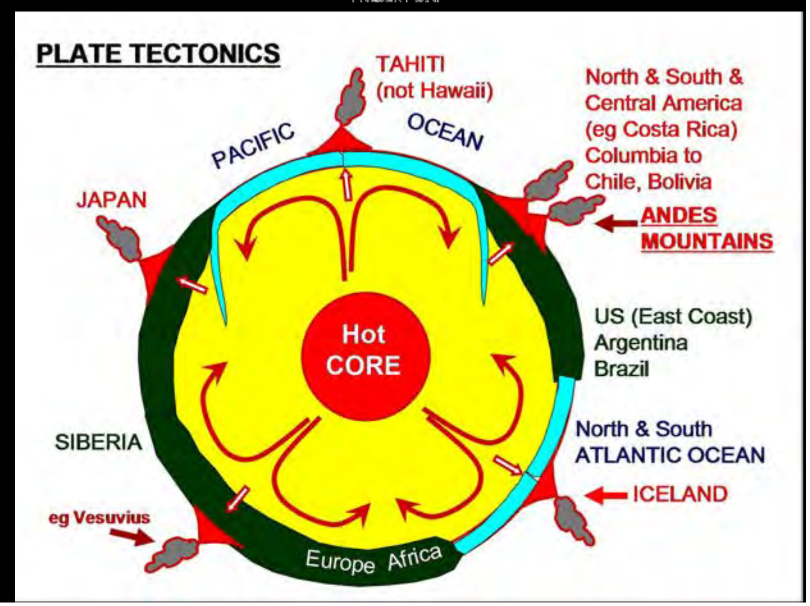
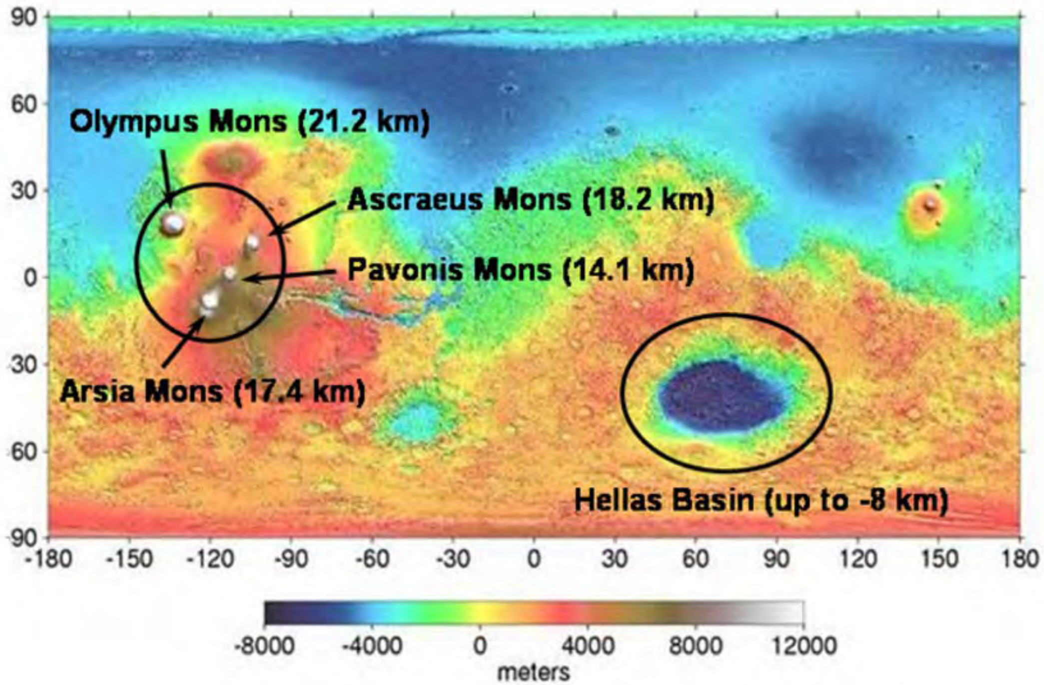


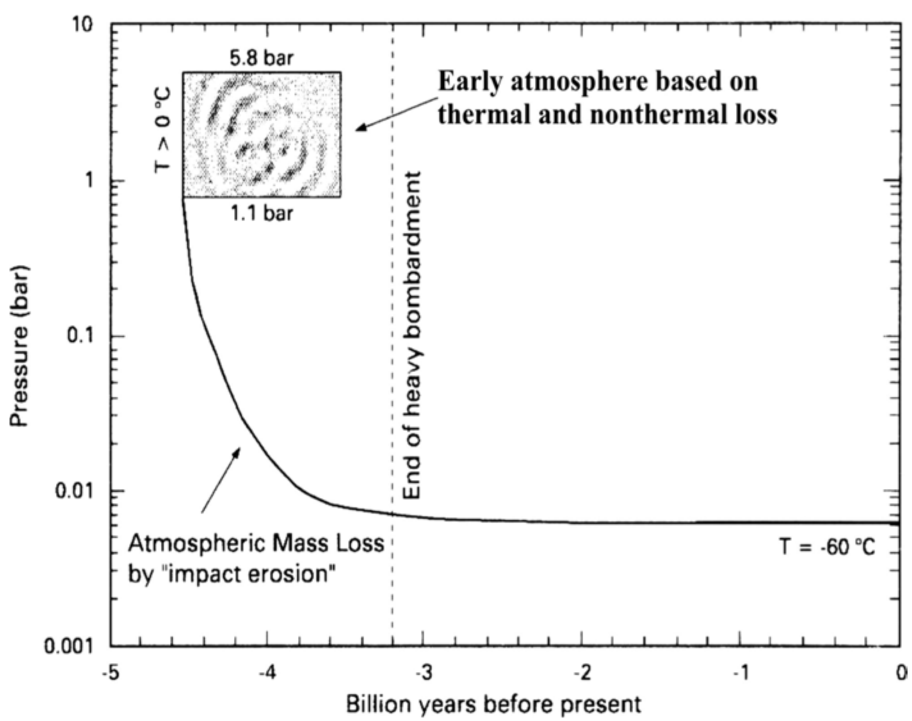
Plate Tectonics: Bad for Volcanoes & Earthquakes & Changing Lands…But Good for Warmish Earth & Steady Atmosphere



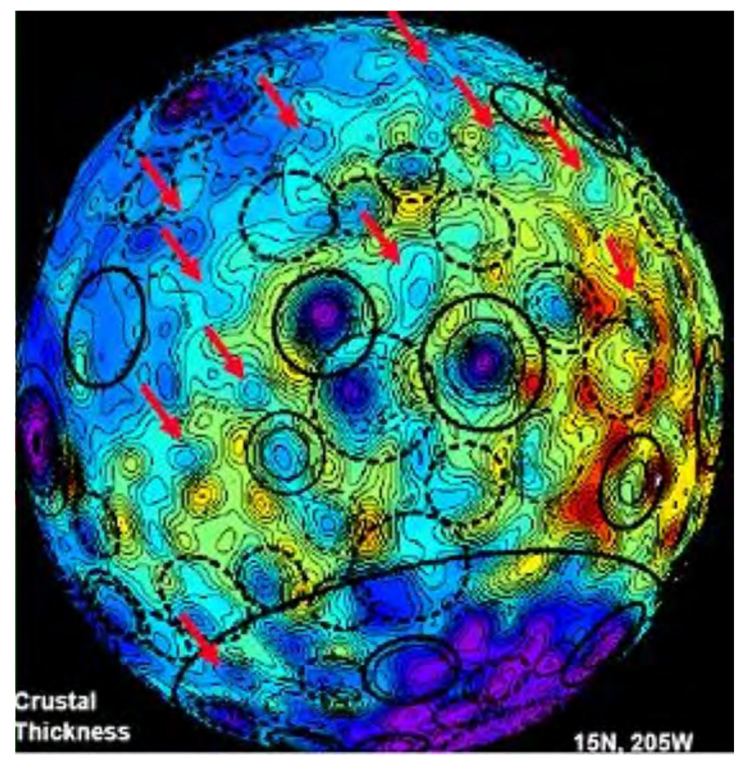




Mars' Largest Impact Basins – Evidence of Atmospheric Erosion, Too?

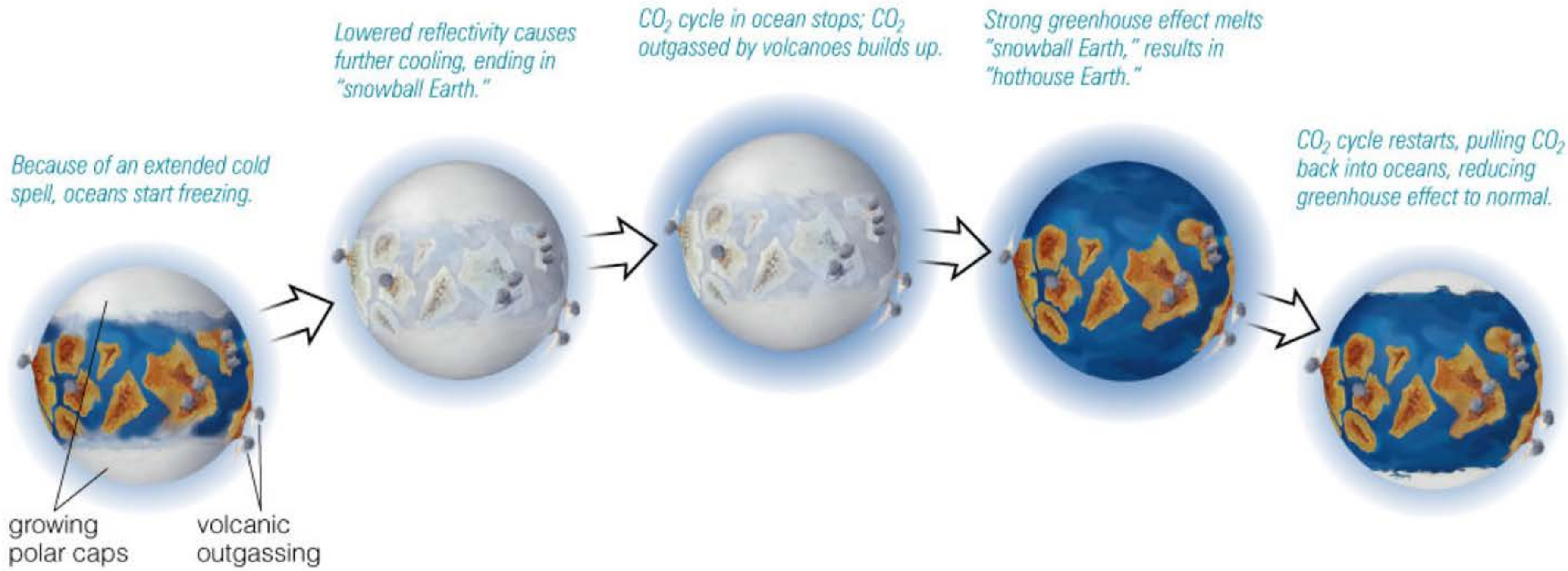


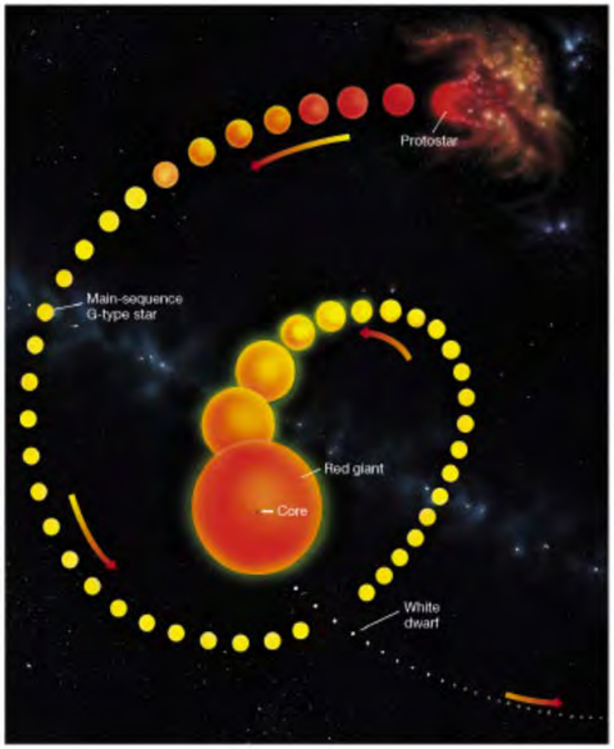
Contour Map of the Moon Showing its (LHB) Impact History



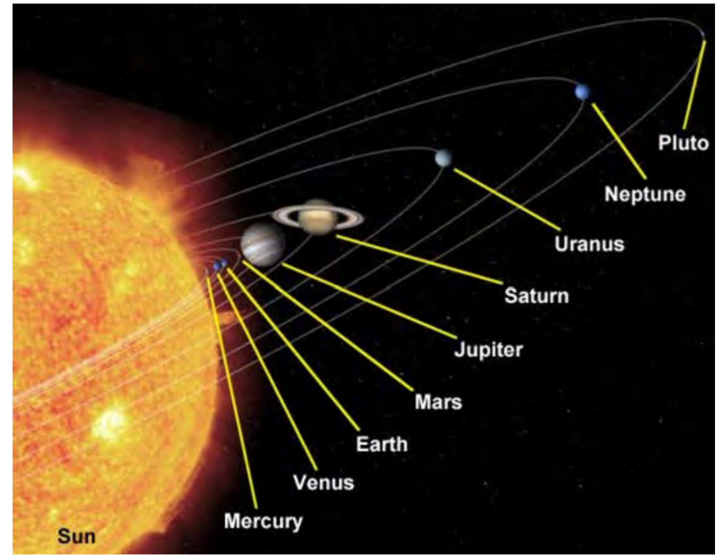
It Wasn‘t Always Straightforward & Easy:

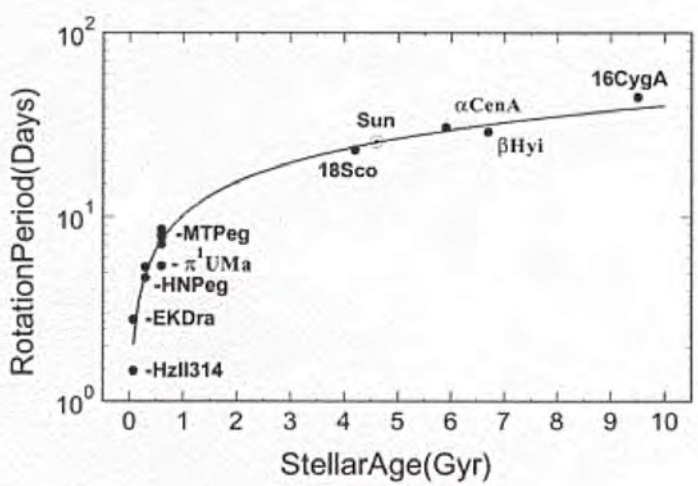
Impacts, Volcanism : Ways Into & Out of “Snowball Earth”? The Young Sun Was Much Dimmer, ~70% of Today‘s Luminosity, & Much More Active





Young Solar-Type Stars Are Very X-Ray Intense As They Spin Rapidly; Older Stars Slow Down & Lose Their Violent X-Ray/UV Emission, Allowing Surface Life





Rotation period vs. age for the Sun-type stars of Guinan & Ribas (2002). Solid line – power law fit to the data, indicating a spin-down with increasing age. Rotation period vs. age for the Sun-type stars of Guinan & Ribas (2002). Solid line – power law fit to the data, indicating a spin-down with increasing age. Luminosity$_{x\text{-}ray}$ ~ 1/Period^3

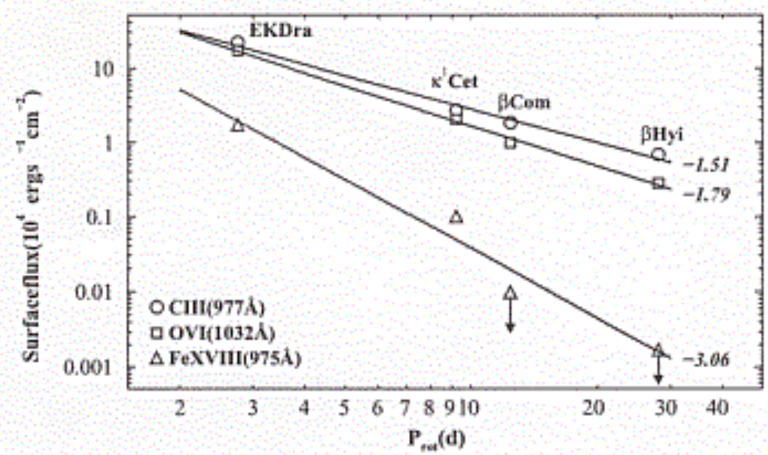
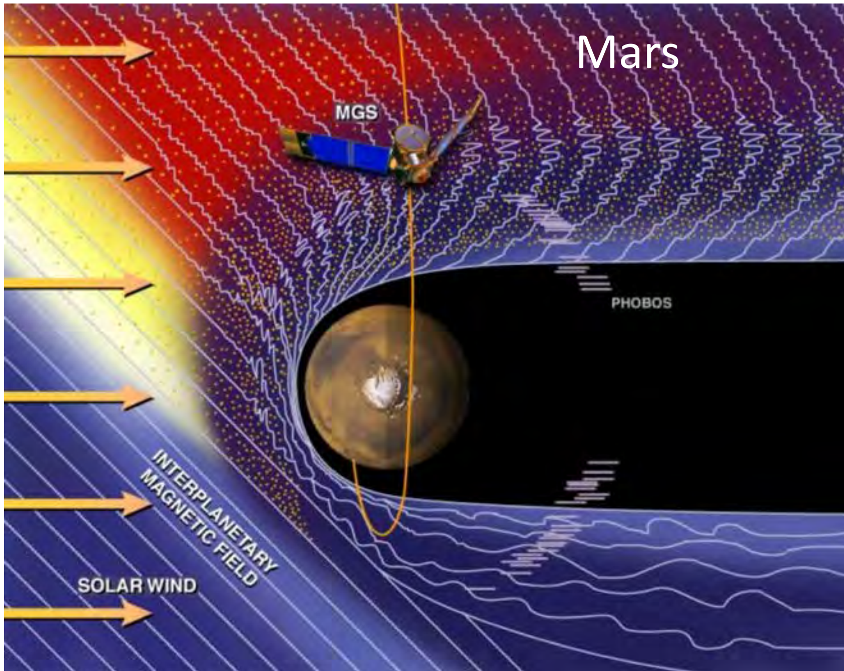
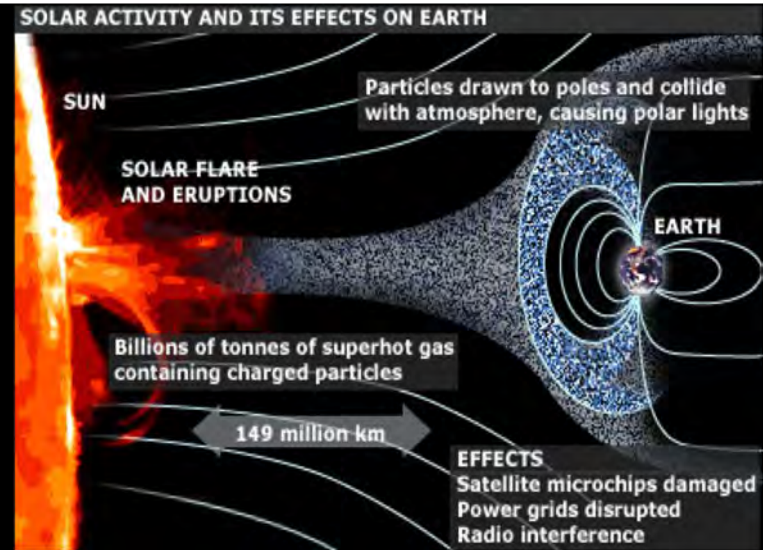


Figure 12. Integrated surface fluxes of C III 977 Å, O VI 1032 Å, and Fe XVIII 975 Å for some of our FUSE targets as a function of rotation period. The straight lines are power law fits to the measured data. The coefficients of the three fits are printed at the right end of the panel.

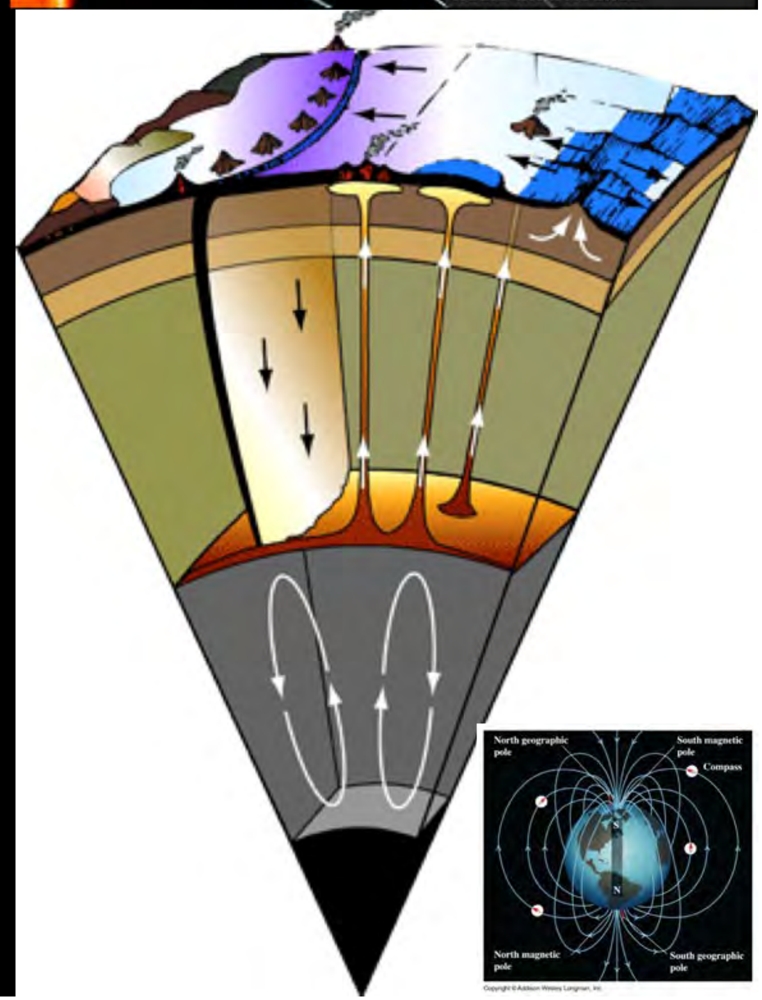


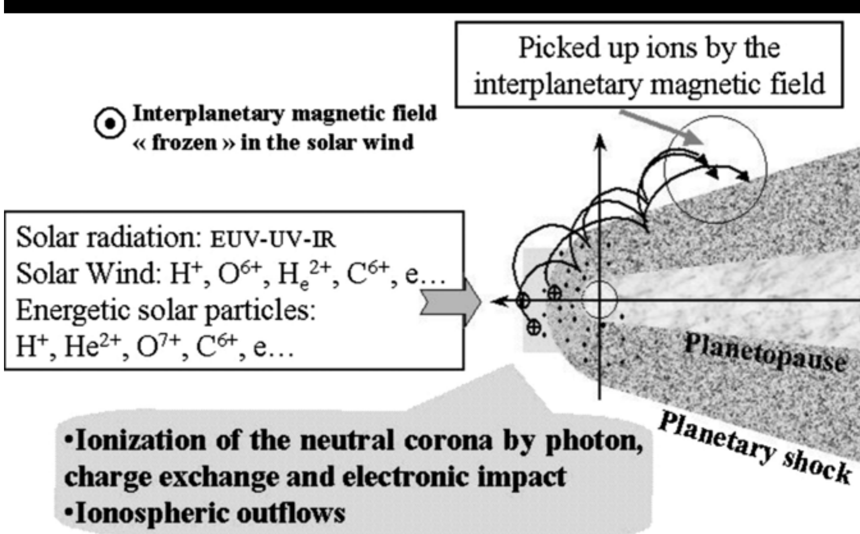
Earth's Internal Field Diverts Most SW Particles & Keeps All But the Strongest Flares and CMEs Channeled to the Polar Regions



(But Earth's field is gone in < 2 Gyr as Inner Core Solidifies & Grows!)

Mars, With Little Internal Convection & No Strong Intrinsic Magnetic Field, Is Unshielded From Solar Wind Erosion of Its Atmosphere



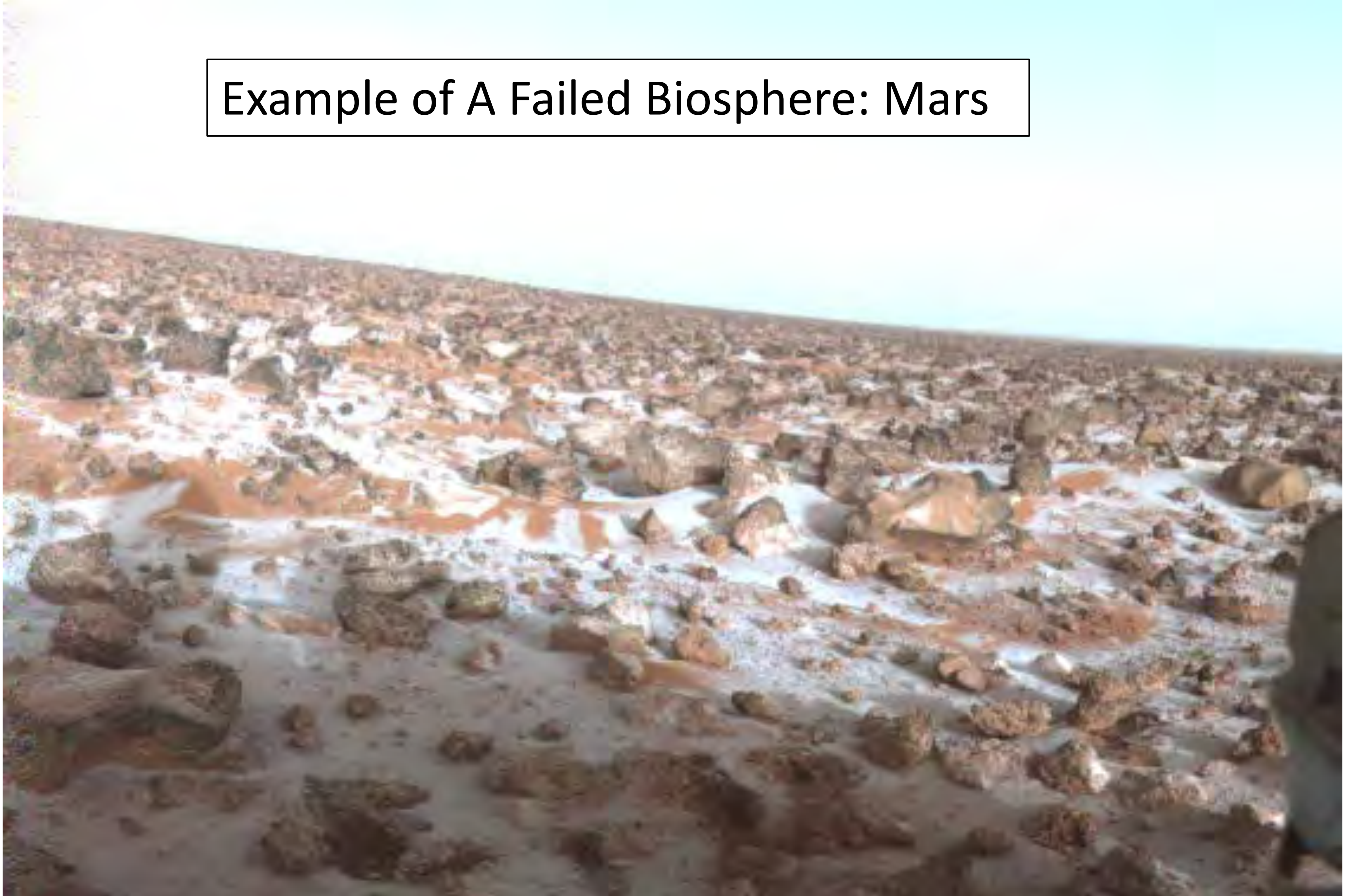


Atmosphere Scouring by the Solar Wind

Small Eccentricity, Obliquity, Stable Orbits: The Unsung Heroes

- Think of How Much We Like the Temperate, Evened-Out Tropical Climate
- And How Much the Winter/Summer Cycle Stresses and Forces Our Biota
- Moon Stabilizes Our Tilt (Obliquity)
- Mars has no such Stabilizer, and Its Polar Tilt Has Varied Enormously on ≤ Myr timescales (imagine London moving to the North pole and back)

Example of A Failed Biosphere: Mars



Frost (CO_2) seen by Viking 2 Lander (ca. 1978)

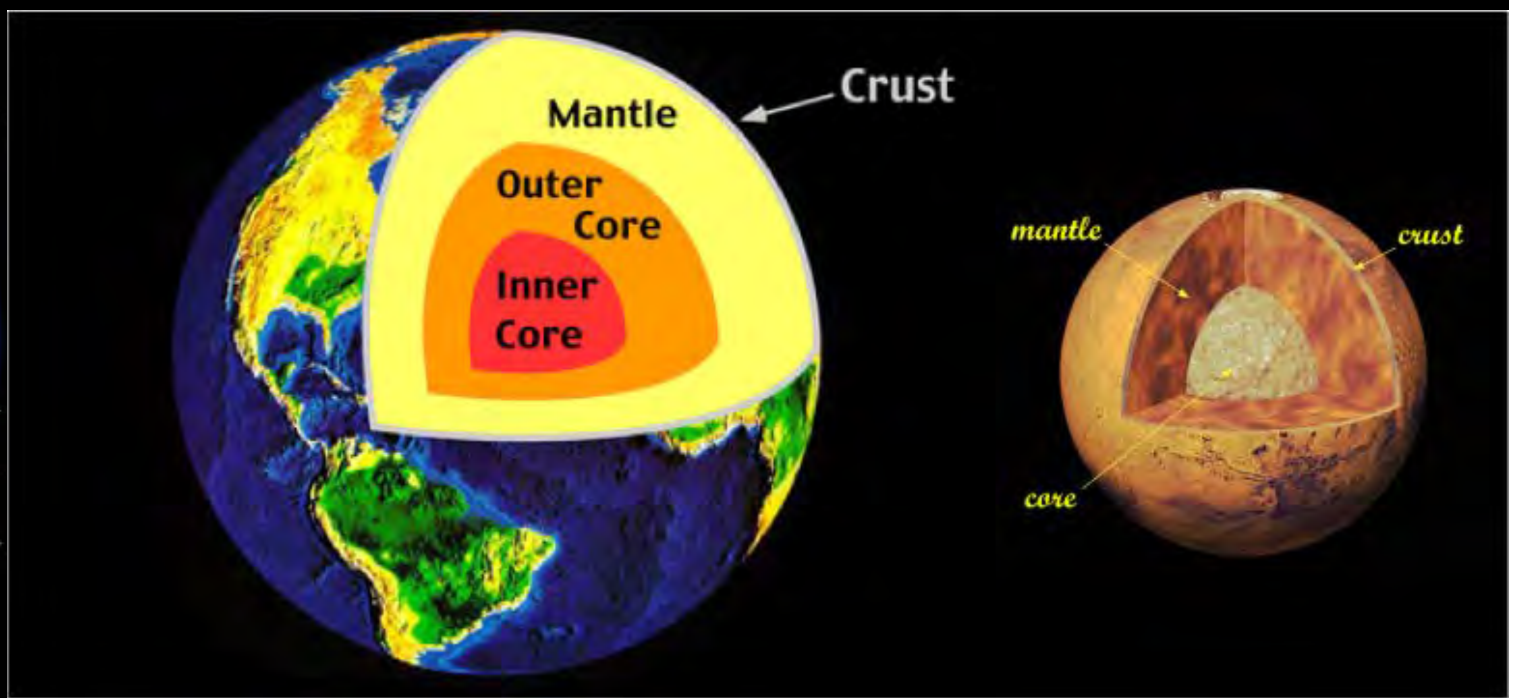
Mars, Relative to Earth

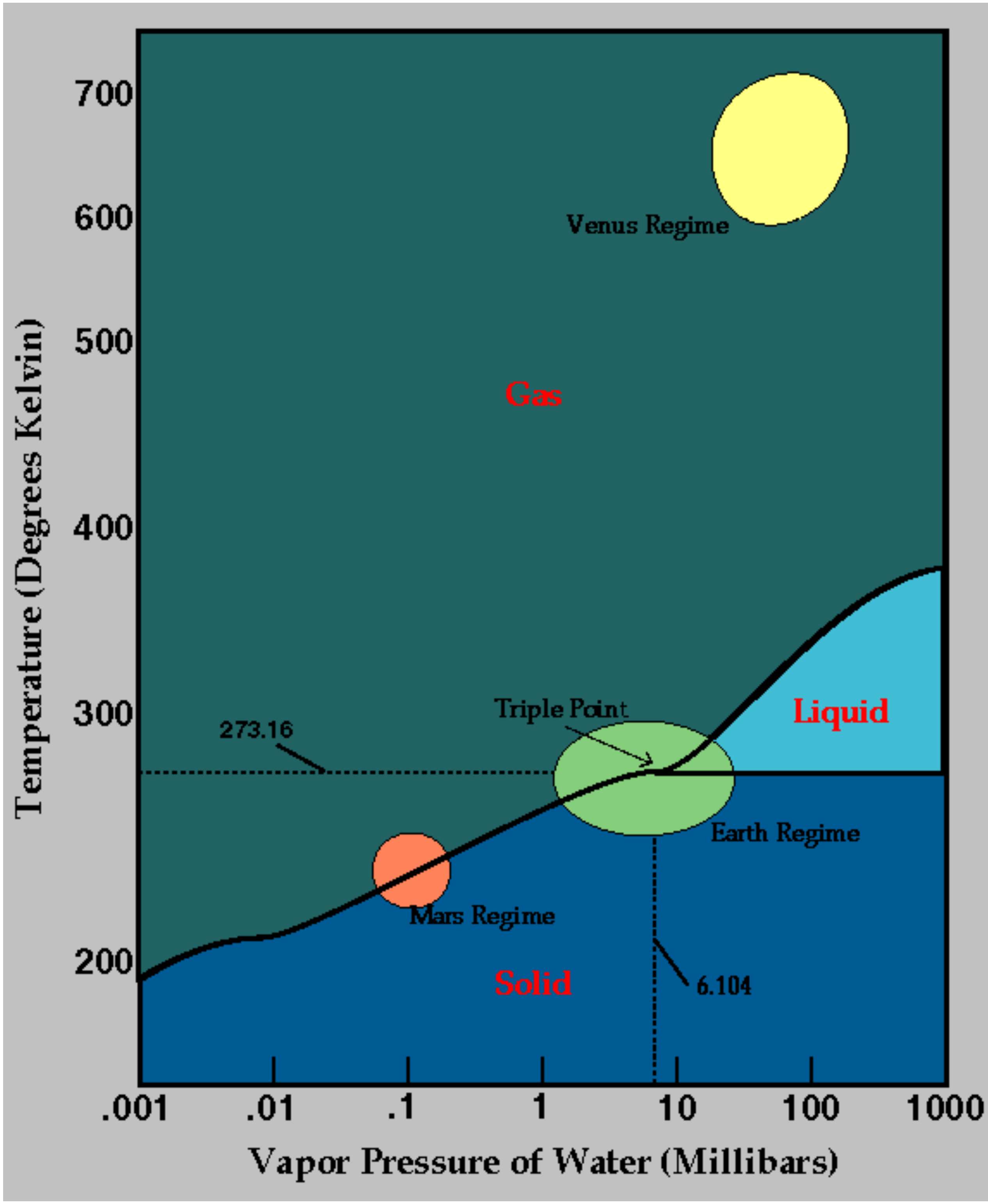
Smaller size:

- Faster Cooling > Mostly Solid Core > Very Weak Magnetic Field
- Lower Gravity > Loss Of Atmosphere To Space
- No Tectonics > Limited Chemical Cycling Of Elements

Location:

- Less Solar Irradiance
- Higher Eccentricity Of Orbit > Less Stable Long-term Climate

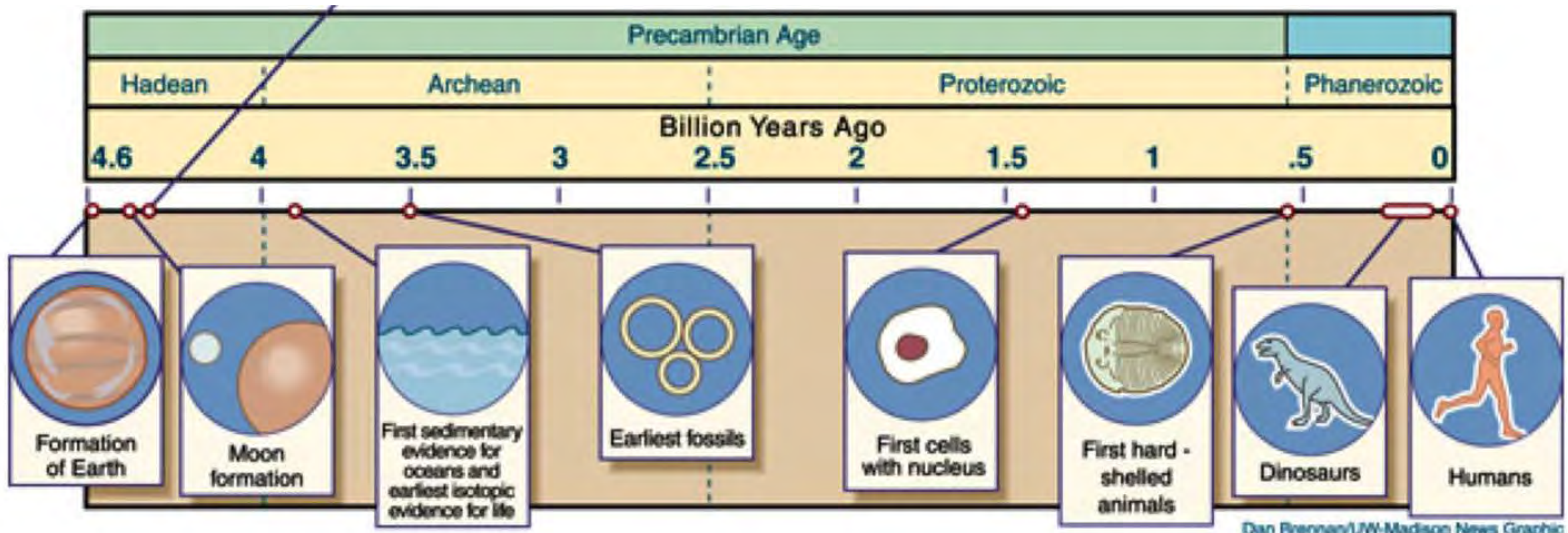




Question: What if Venus had formed where Mars is and Mars Had fromed where Venus is?

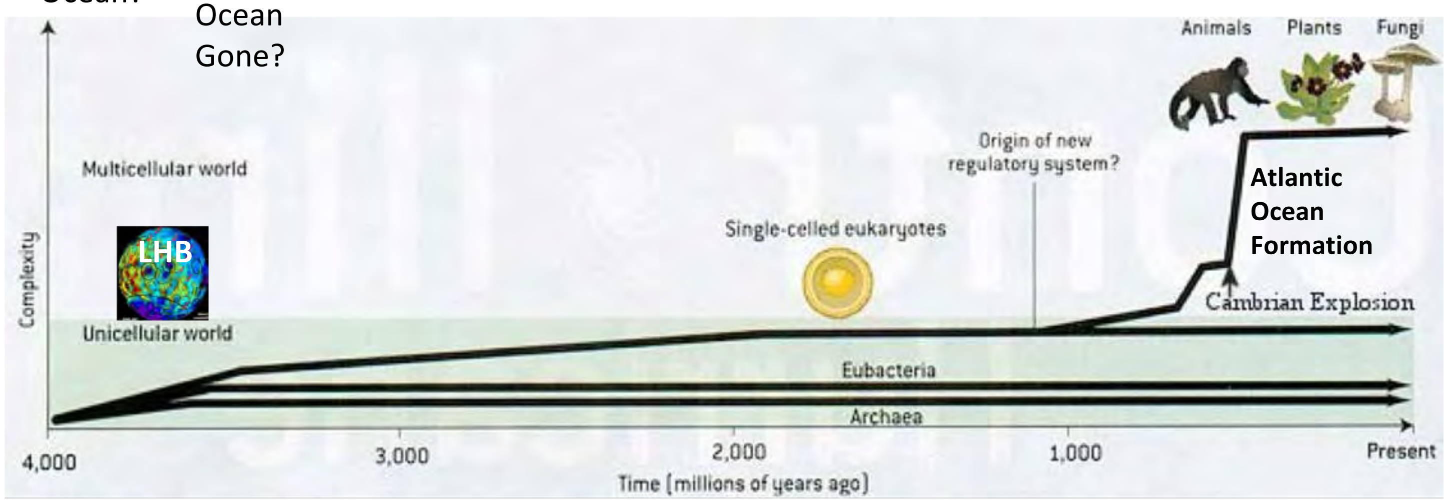
Would Venus then be a cool Earth twin and Mars have stayed Warm and wet? Or would Mars have just lost its water via H-strippping but kept warm enough to keep tectonics going?

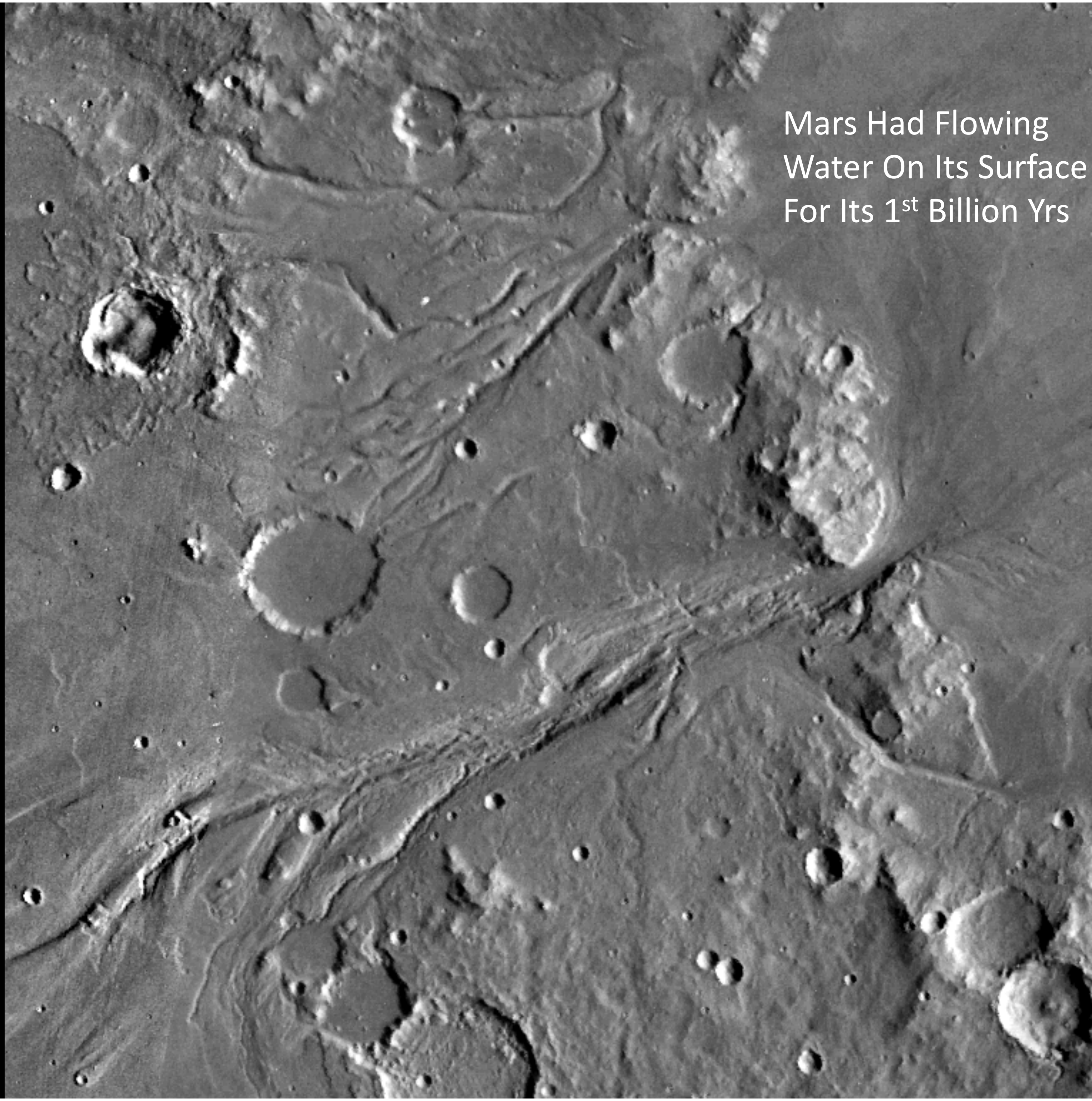
Timescales: For the first ~ 1 Gyr, only astro- and geophysics. After, for Gyrs, the Earth harbored only Unicellular Life. The same unicellular life still dominates today, by mass & diversity.



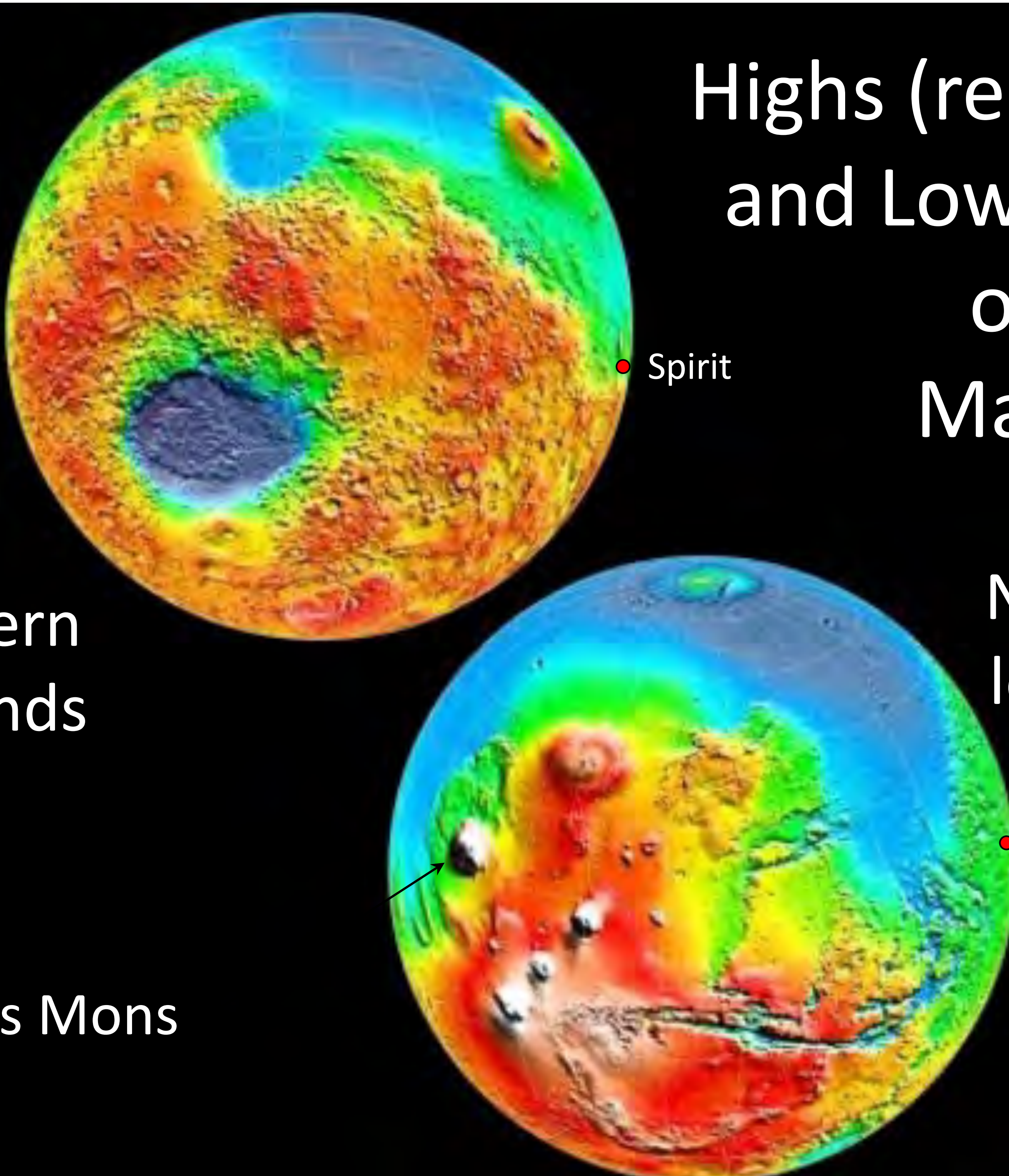
Martian Ocean?

Martian Ocean Gone?




Mars Had Flowing
Water On Its Surface
For Its 1st Billion Yrs

Highs (red, white) and Lows (blue) of Mars

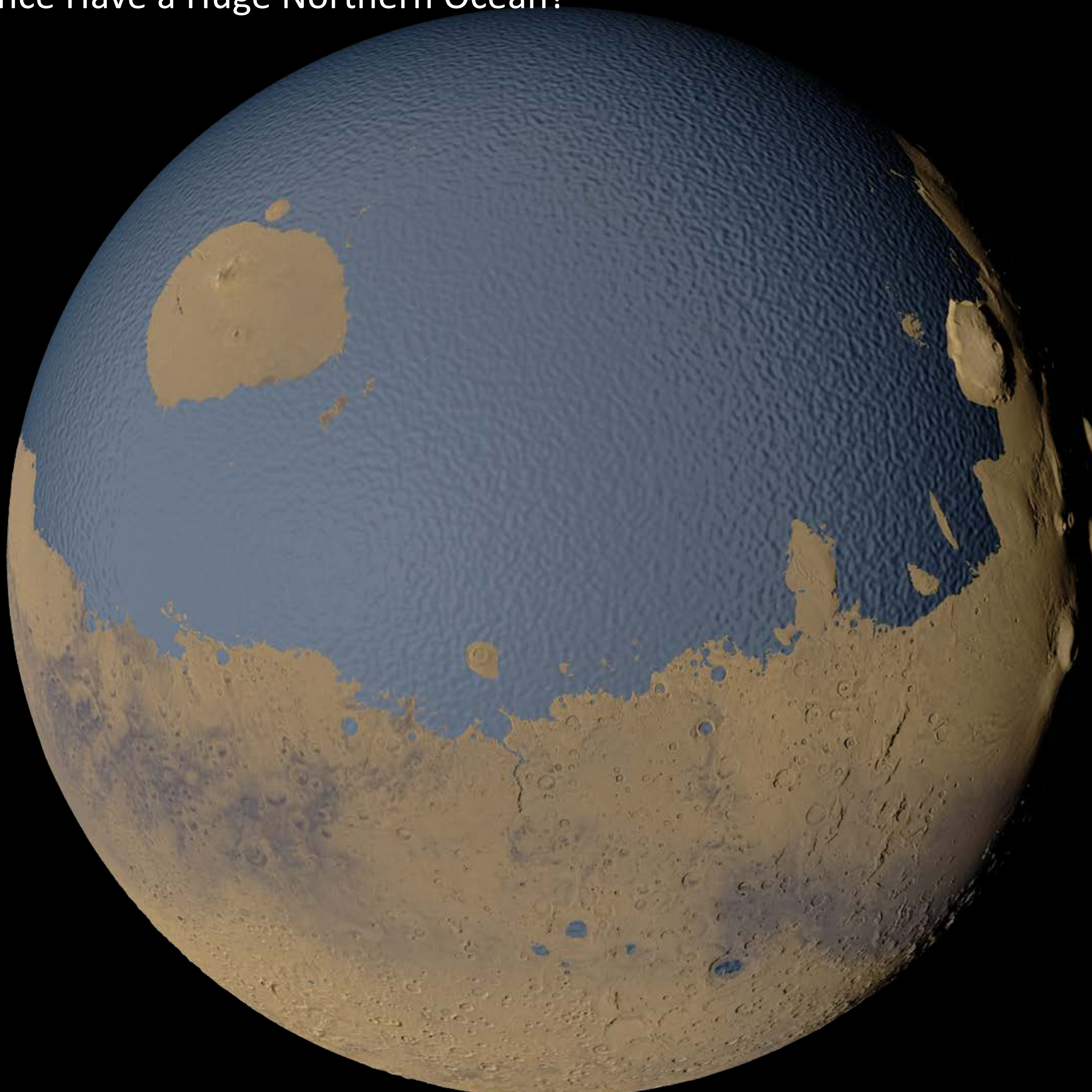


Southern highlands

Northern lowlands

Olympus Mons

Did Mars Once Have a Huge Northern Ocean?

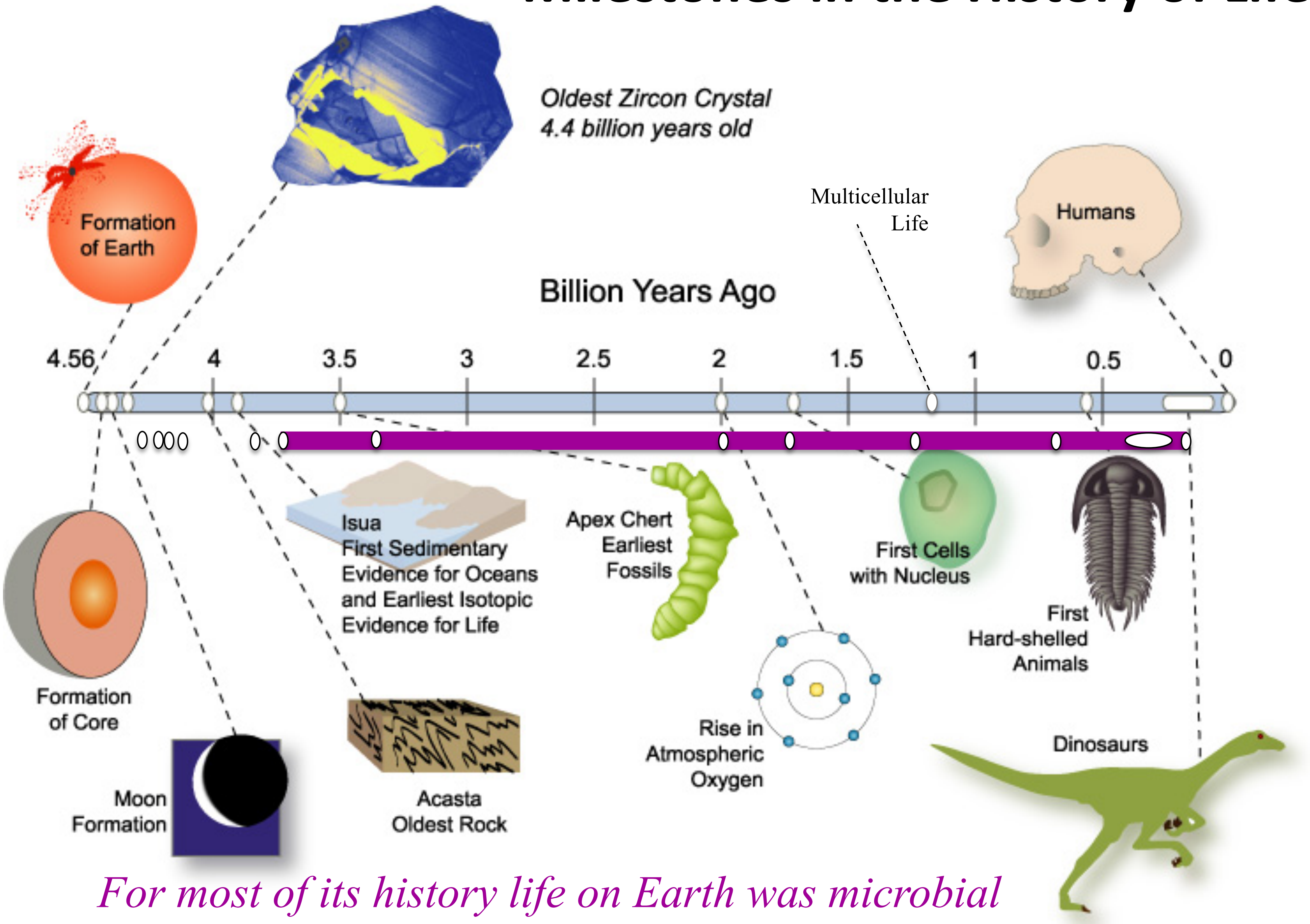


Life On Earth Over Time:

We Weren‘t The First or Second Animal Life Form Chosen to Run the Planet – We‘re Batting Cleanup (maybe).

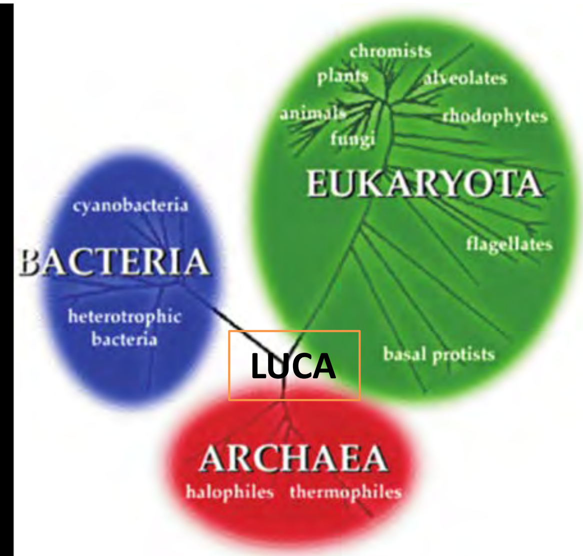
Intelligent Life‘s Duty Cycle on Planet Earth is Only 4 Myr/4.56Gyr < 10^{-3} !!

Milestones in the History of Life

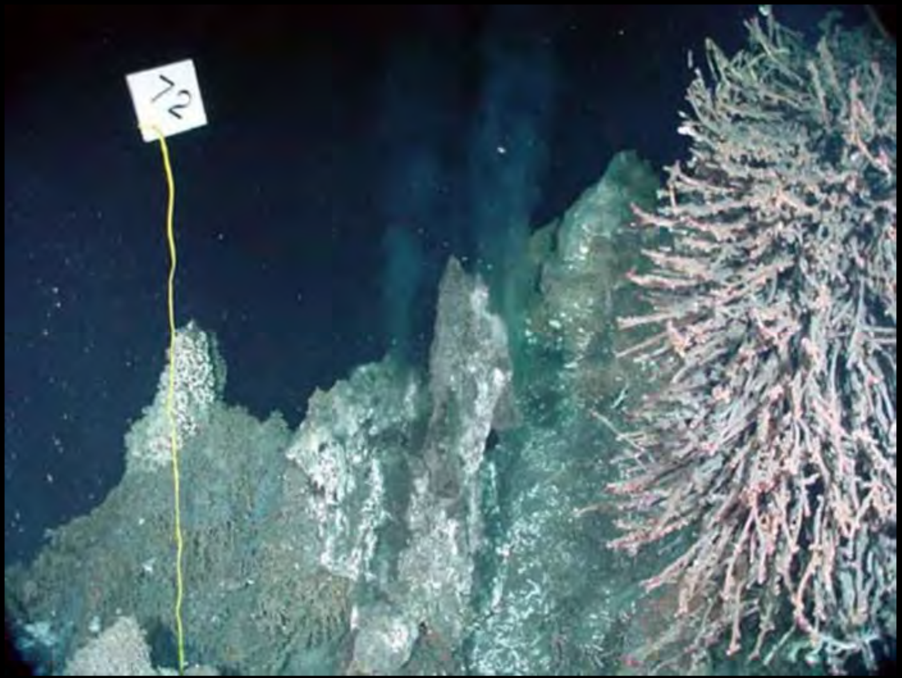


For most of its history life on Earth was microbial

OTH, unicellular life, which dominates Earth's biomass and its history, seems quite likely elsewhere! We see Archaea/Bacteria in extreme environments: high or low temperatures, high acidity, deep underground, rich in dioxins or arsenic or sulfur, can be agreeable environments for extremophiles! Pretty much wherever there is exploitable Free Energy, carbon compounds, & some liquid water….in arsenic rich lakes, eating dioxins, 10 miles down in rock or way under the Antarctic ice cap. One 30 Yr Human Generation ~ 50,000 Bacterial Generations!

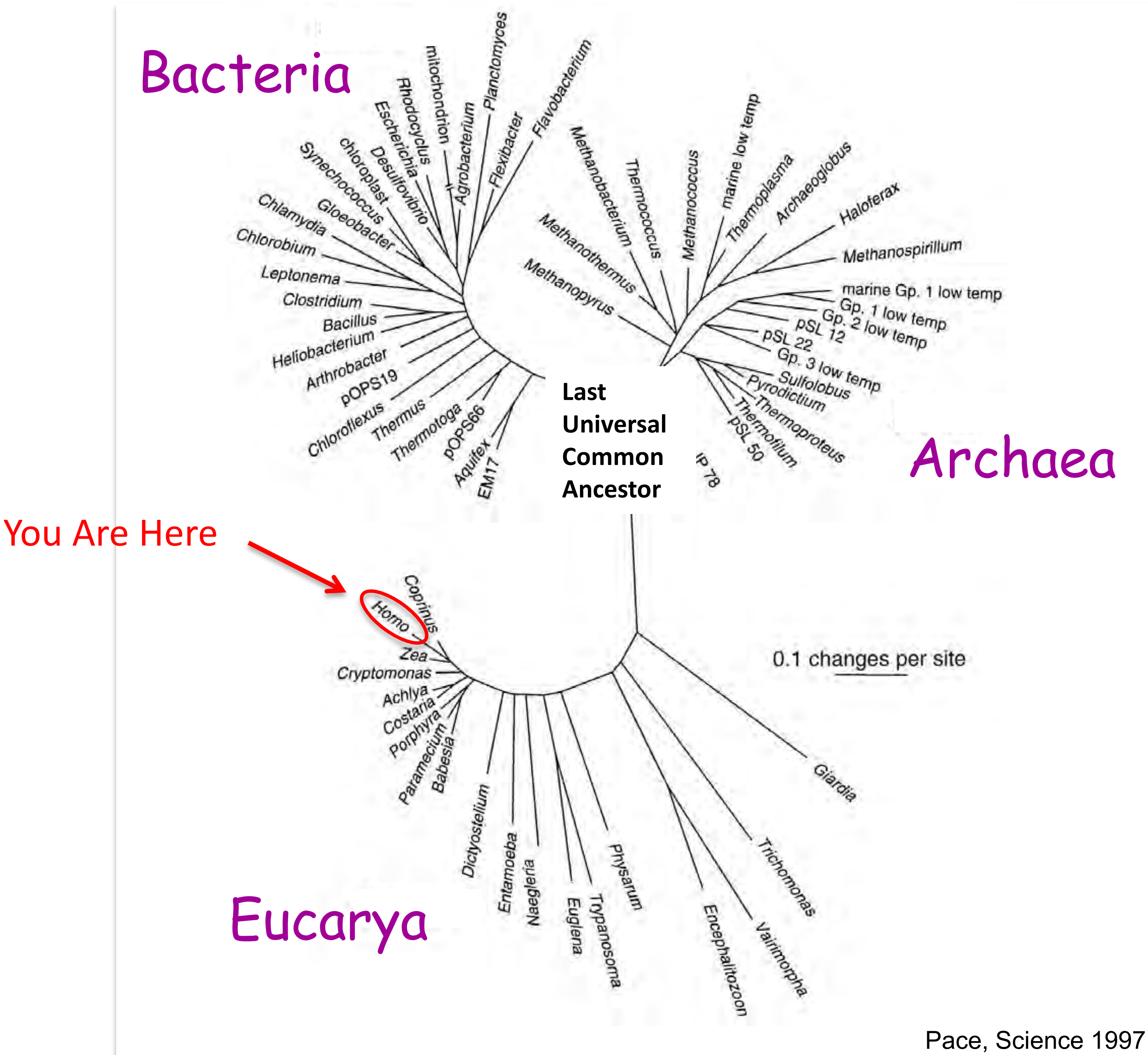


Acid, heat loving thermophiles in Yellowstone.



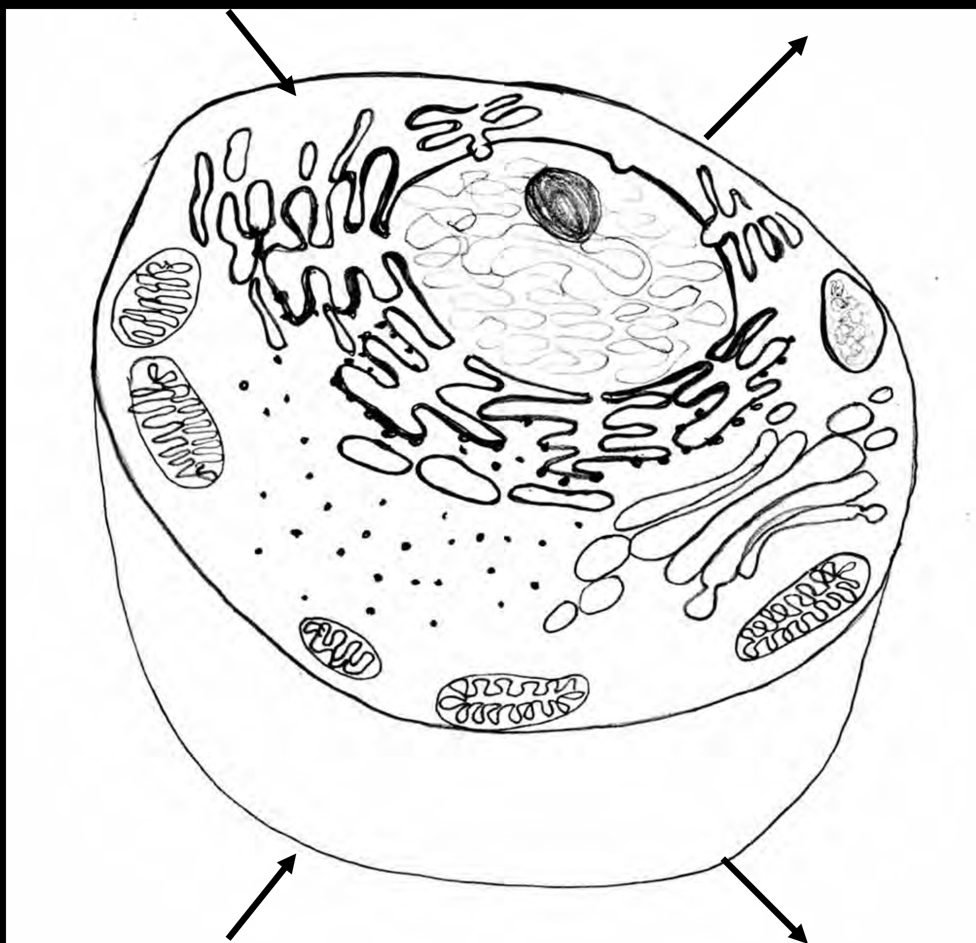
Chemosynthetic archaea at a black smoker.

The Big Tree of Life

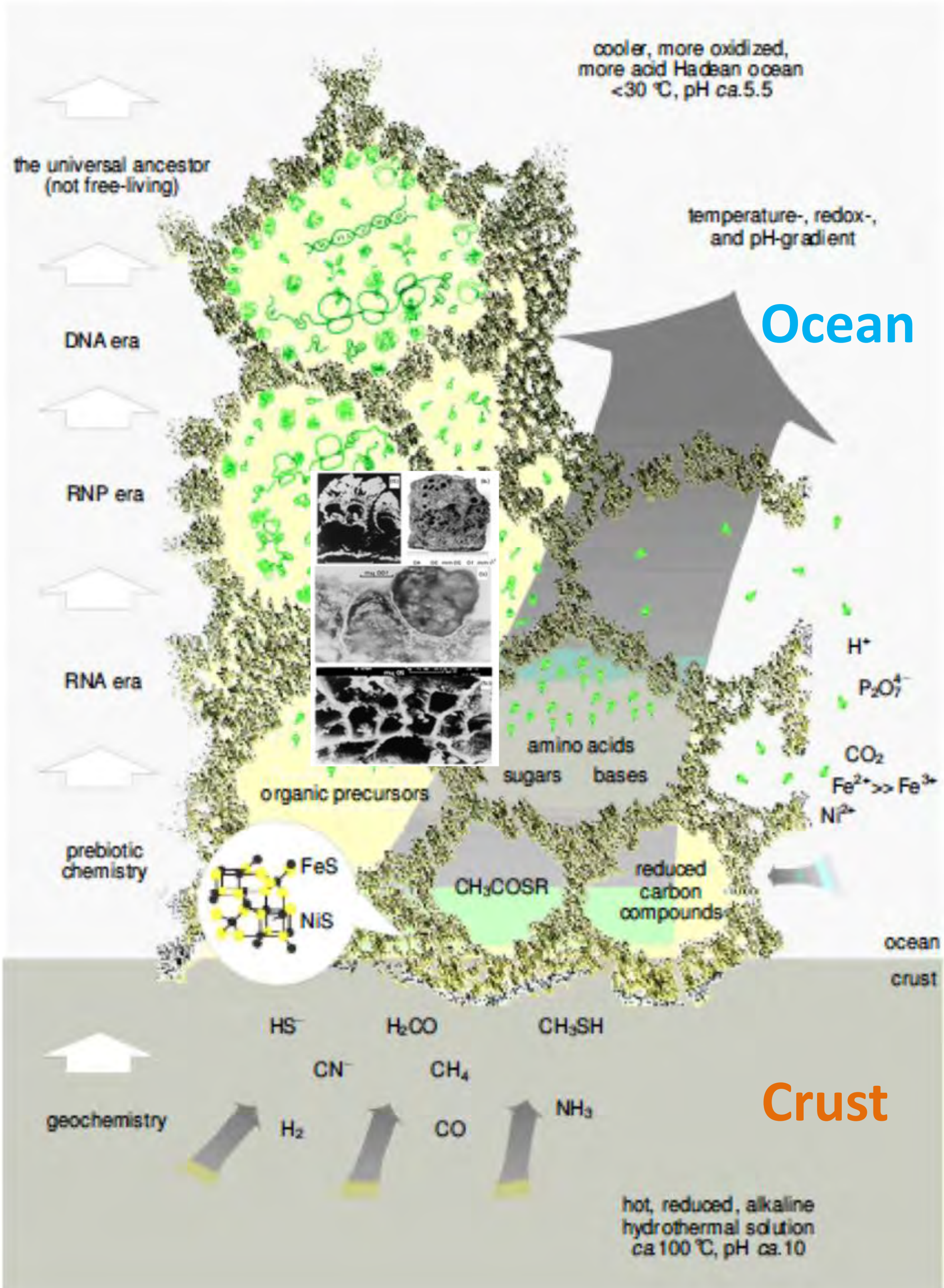


Pace, Science 1997

All life is cellular...defeating entropy by a steady-state burning of nutrients in an H_2O medium



- Confined within the cell membrane
- Interacts with its environment
- Complex biochemistry in aqueous solution
- All functions controlled by genetic information



Hypothesis for the formation of cellular life on Earth from FeS_x and NiS_x cell-like precipitates. The steady state flow of "nutrients" is provided by movement of hot, alkaline hydrothermal solutions associated with magma into colder, more acidic Hadean ocean water. (After Hall & Russell 2003).

If this picture is correct (e.g. recent findings of bacterial mats in the Marianas Trench, Cameron *et al*. 2012 AGU), then life in subsurface, internally heated oceans (e.g. **Europa, Enceladus, ancient Mars N. hemisphere**) is entirely plausible!!

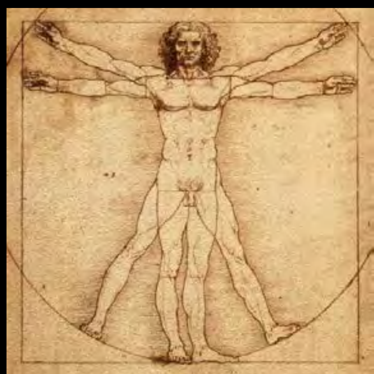
1 million microorganisms/ml of seawater
(upper ocean)

1 billion microorganisms/g of soil

5×10^{30} microorganisms on Earth

10^{31} viruses

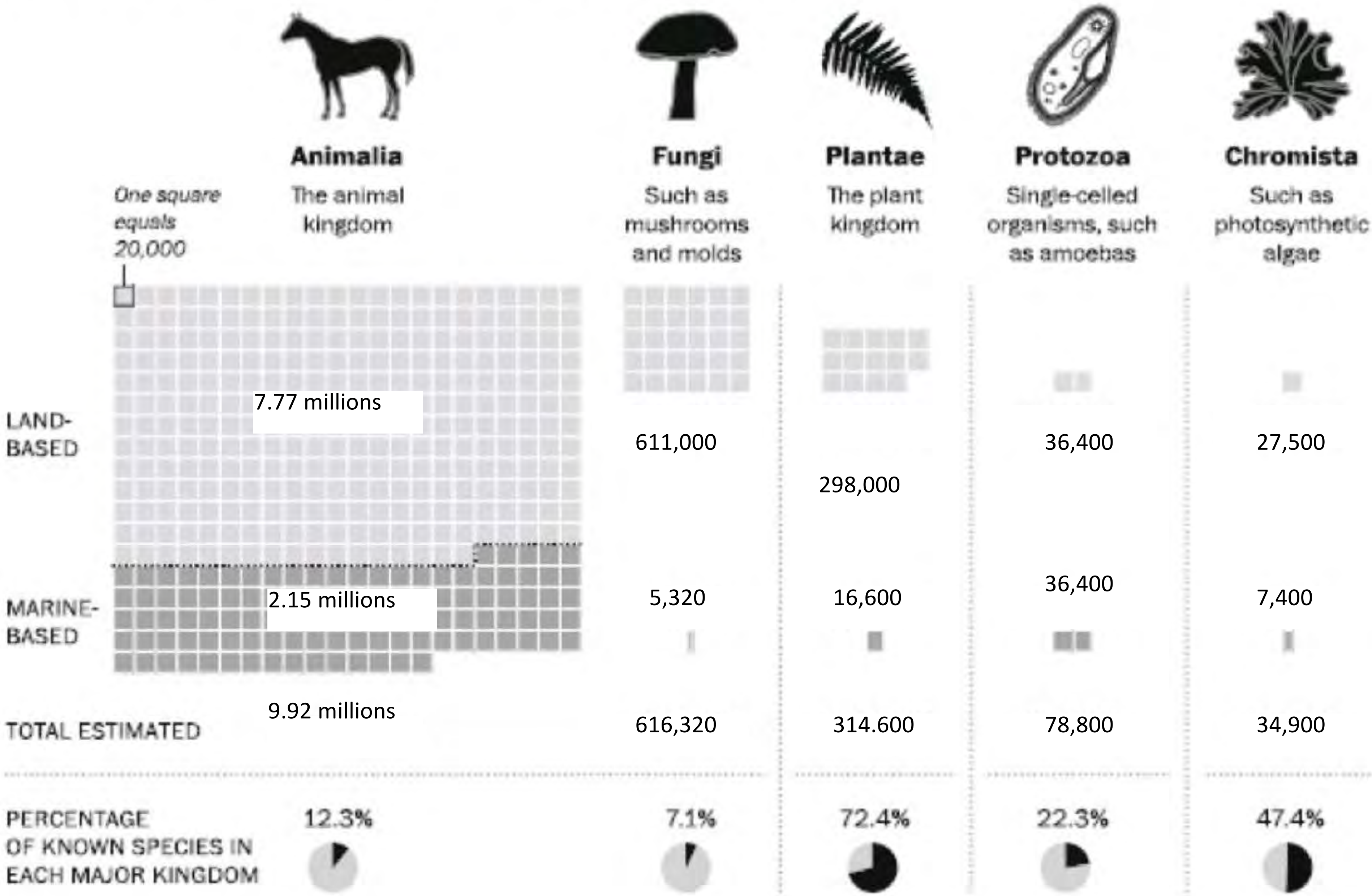
~ 10^{11} stars in our Galaxy



Less than 1% can be cultivated!

(Withman et al., 1998; Daniel, 2005)

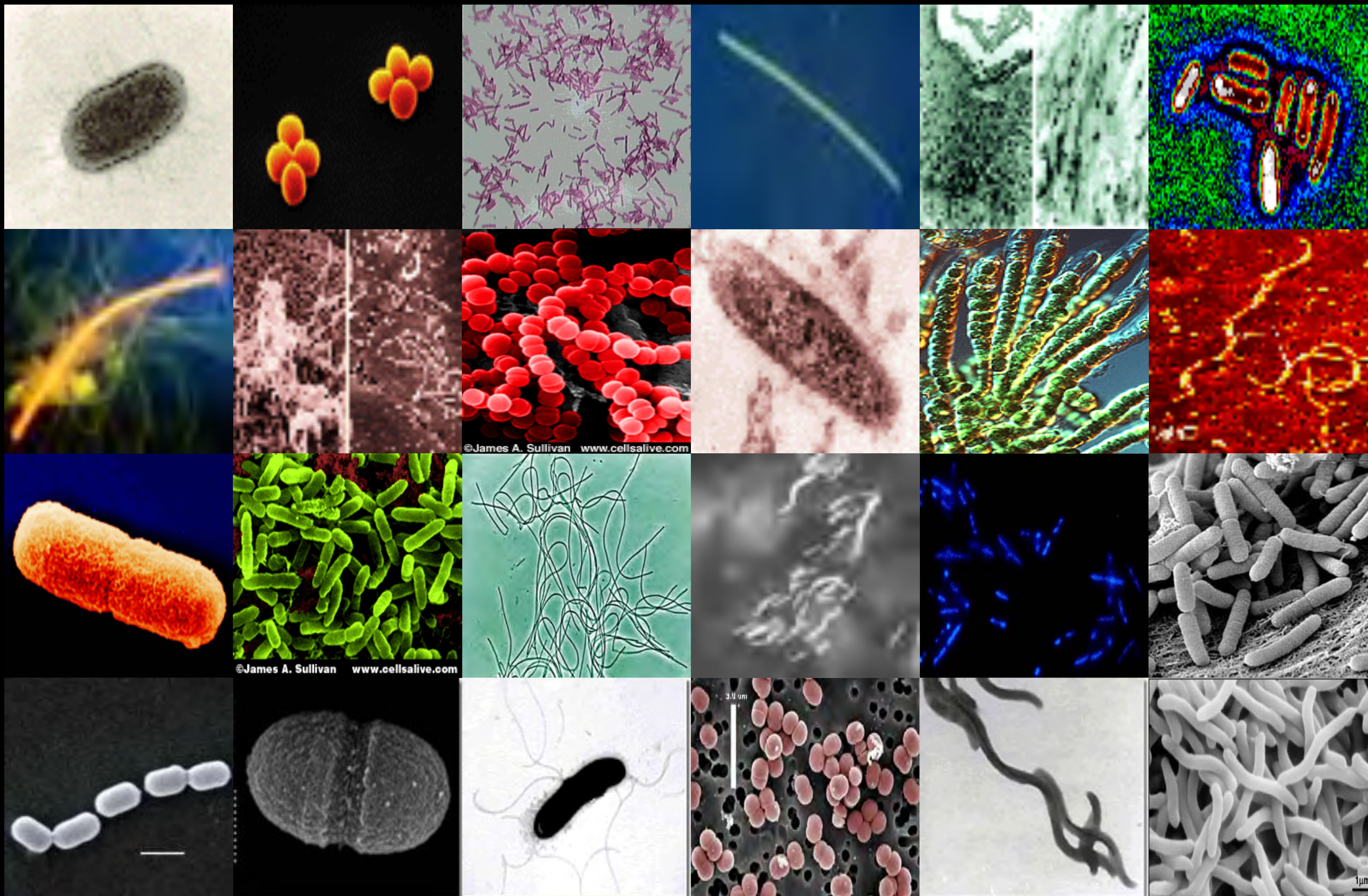
Estimated number of all distinct species, not including bacteria

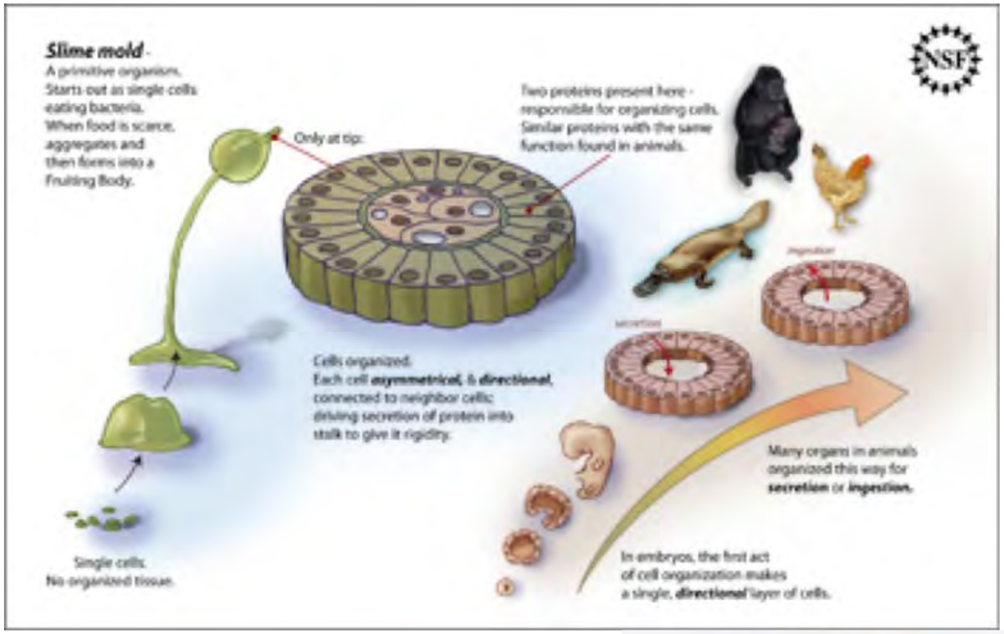


*The ocean database was substantially more complete than the database for the entire Earth, so PLoS Biology used the ocean database to estimate the total number of species in this taxon.

Diversity of Microbial Life

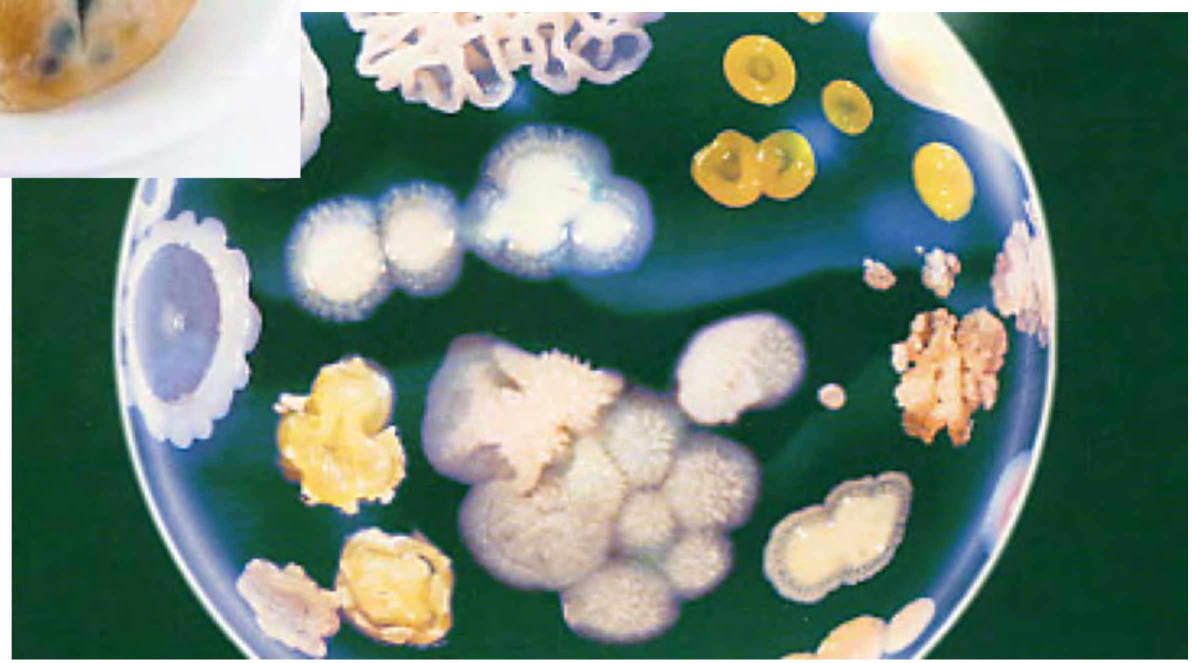
(aka bad breath, stinky feet, garbage, bread mold, pond scum, shower mold, poo...)



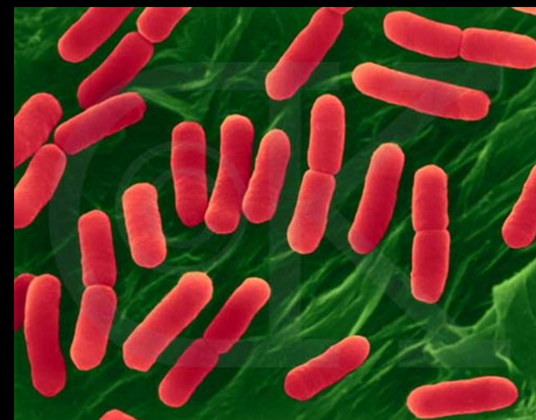


UniCellular Life Ruled Then…and Now

(On us, in us, on the ground, in our food, in the air)

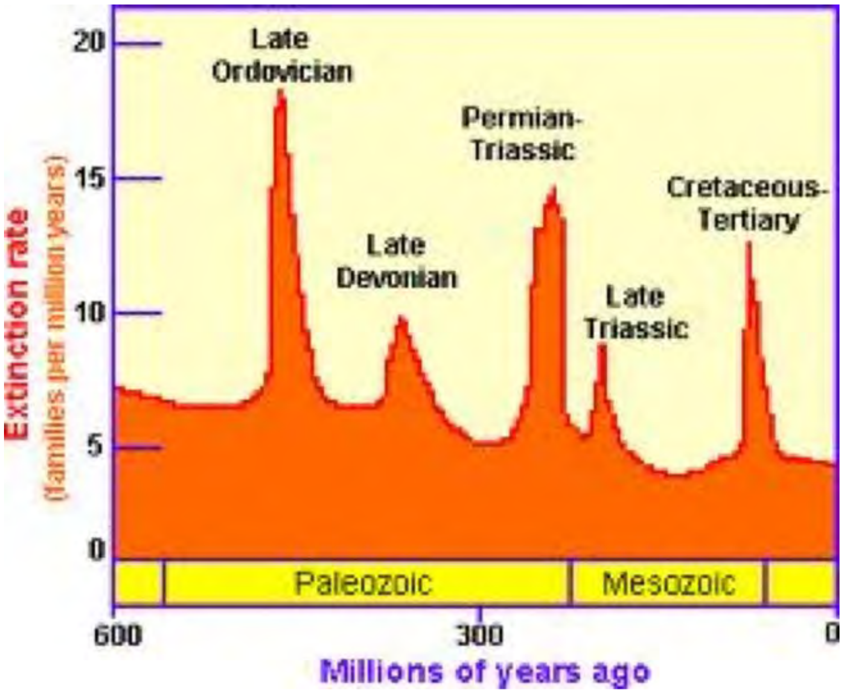


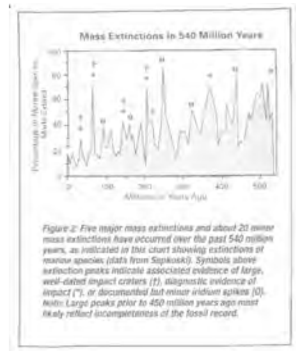
~1 trillion cells in human body
10 times more microorganisms in our body

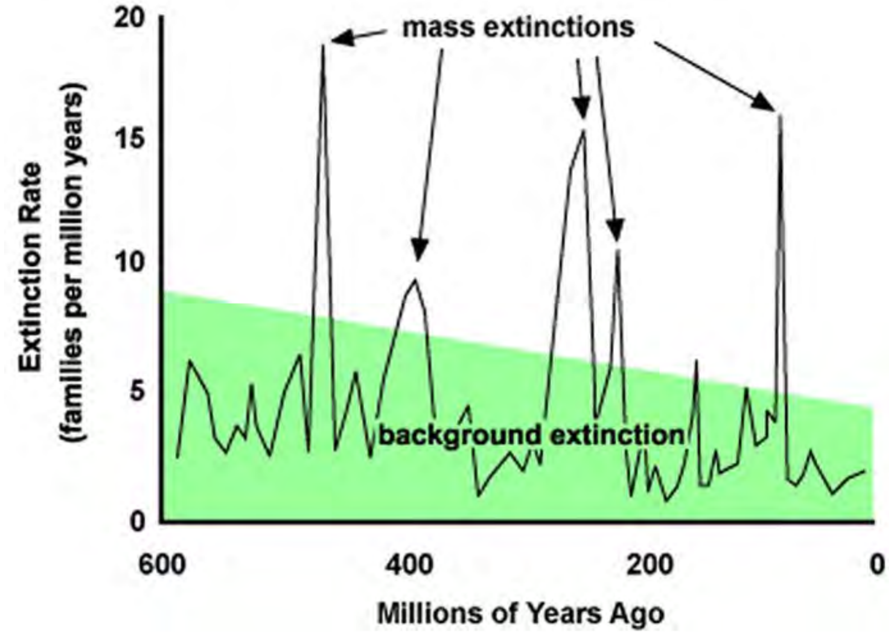


30,000 genes in human genome
100 times more microbial genes in our body

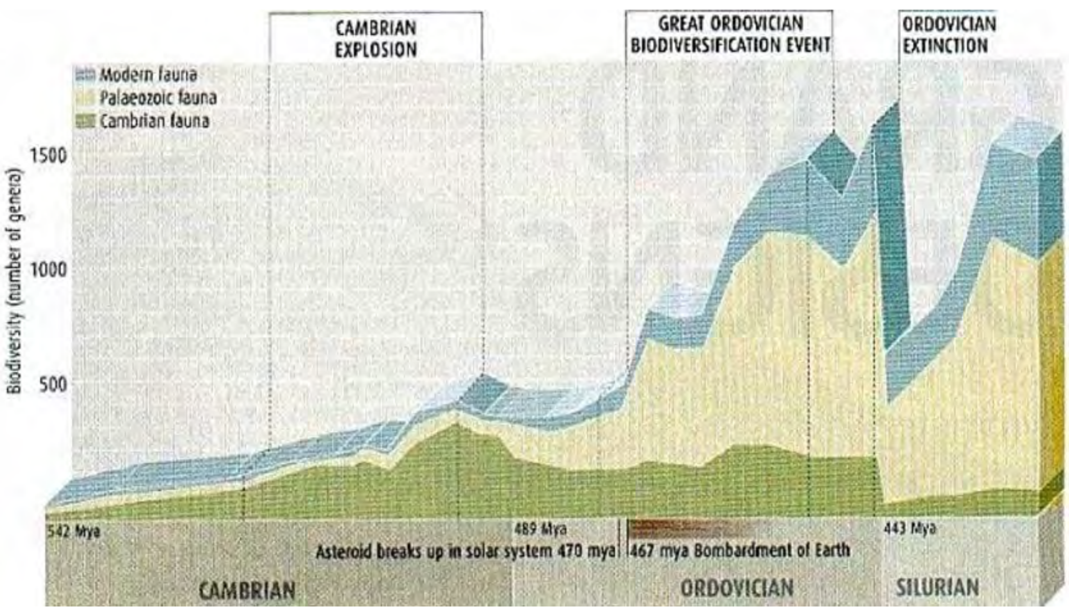
Multicellular Life Has Tried Many Different Ways to Occupy the Planet‘s Biomes



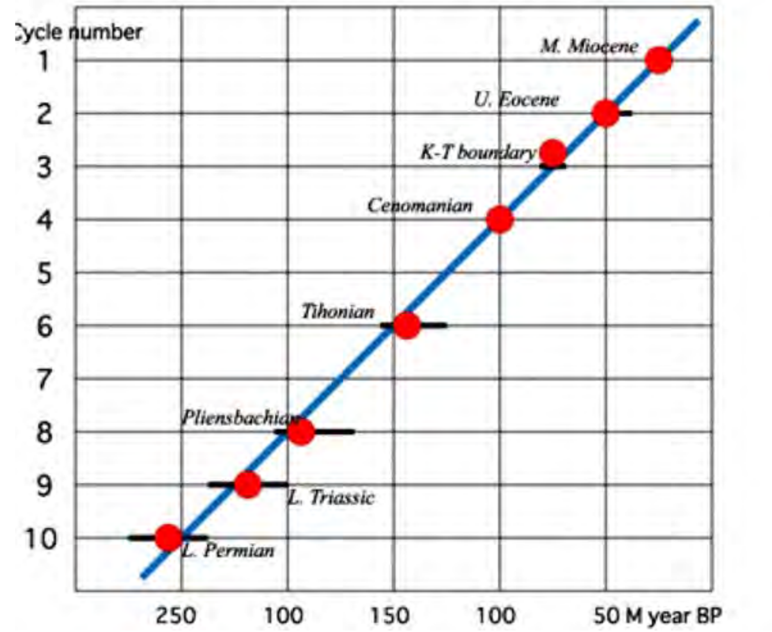


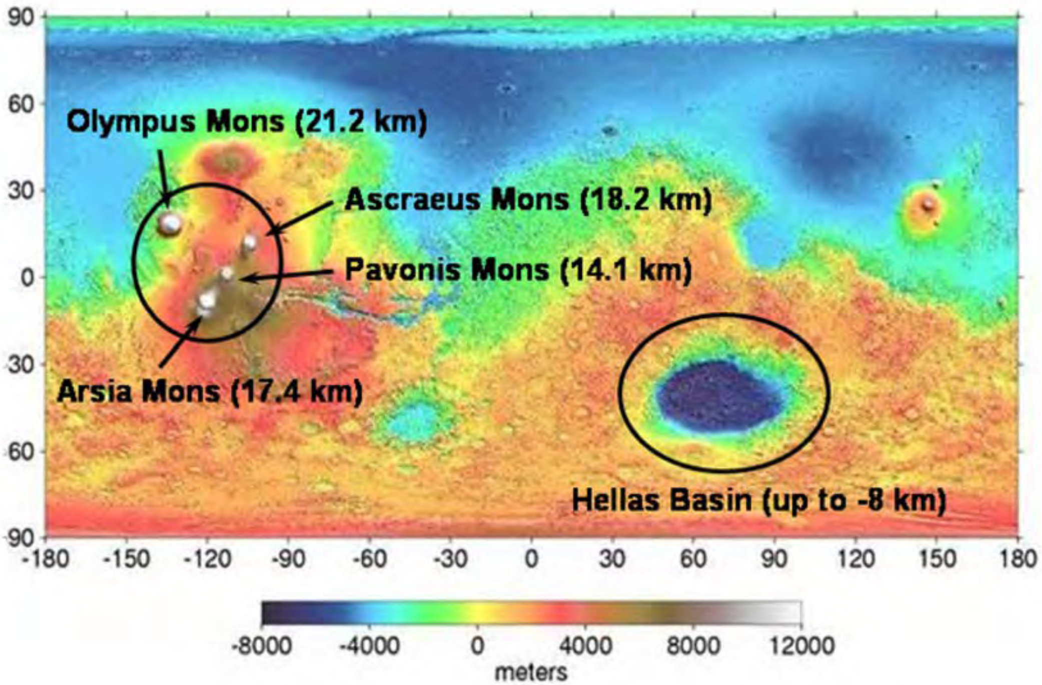


Something Has Infrequently Caused Large, Sudden Drops In Biodiversity on Our Planet



Periodic extiction events for past 250 M-years. The straight line fits 26 M-year-peiodicity





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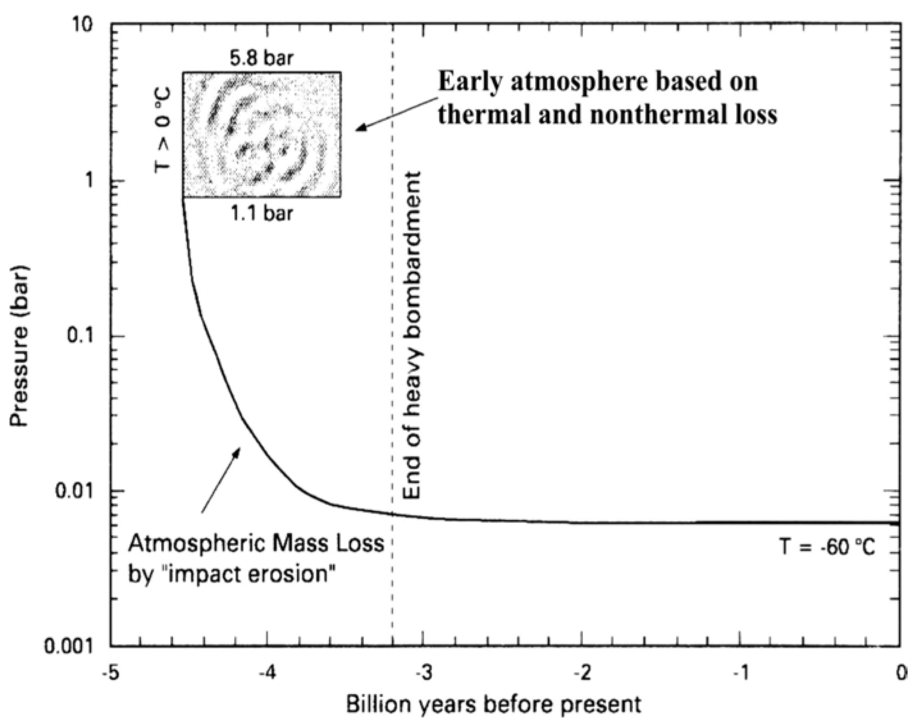

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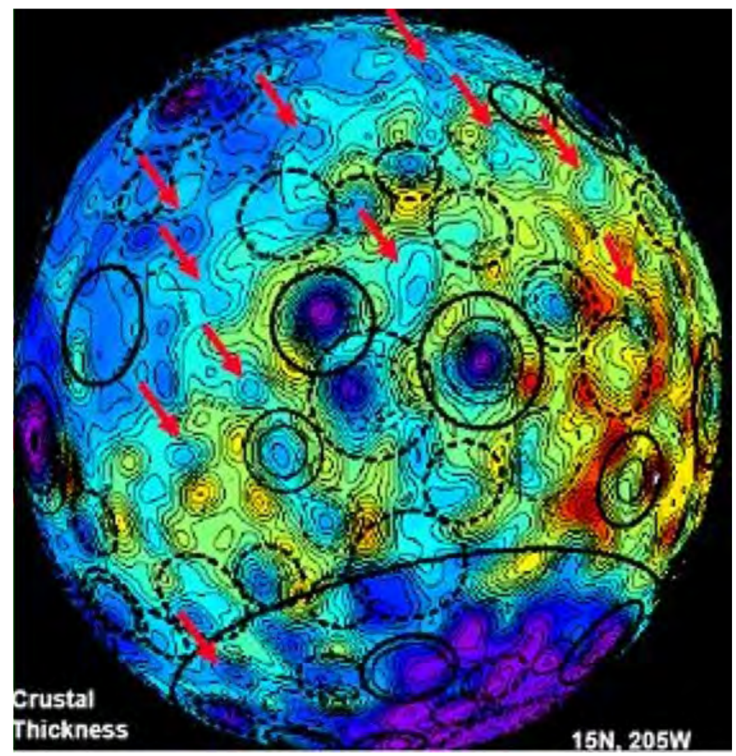


Is this an alien? Probably not, but of all the animals on Earth, the tardigrade might be the best candidate. That's because **tardigrades are known to be able to go for decades without food or water, to survive temperatures from near absolute zero to well above the boiling point of water, to survive pressures from near zero to well above that on ocean floors, and to survive direct exposure to dangerous radiations**. The far-ranging survivability of these extremophiles was tested in 2011 outside an orbiting space shuttle. **Tardigrades are so durable partly because they can repair their own DNA and reduce their body water content to a few percent. Some of these miniature water-bears almost became extraterrestrials recently when they were launched toward to the Martian moon Phobos** on board the Russian mission Fobos-Grunt, but stayed terrestrial when a rocket failed and the capsule remained in Earth orbit. Tardigrades are more common than humans across most of the Earth. Above: a mm-long tardigrade crawls on moss.

BioMarkers: Earth‘s Atmosphere

We live in a very special atmosphere –
Not too Cold (Mars, Moon)
Not too Hot (Venus, Mercury)
Not too Dense (Venus)
Not too Sparse (Mars, Mercury, Moon)

Earth‘s Atmosphere has been polluted!
The “typical” $CO_2/N_2/H_2O$ rocky planet atmosphere (Venus, Mars) has been forced out of equilibrium by Plants.
Turn off today‘s plants, and rocks will reabsorb the O_2.
(=> Be kind to your chlorophyll laden friends.)

Mild Greenhouse + Forced O_2 + Solid/Liquid/Gaseous Water + CO_2 Buffer = Life?

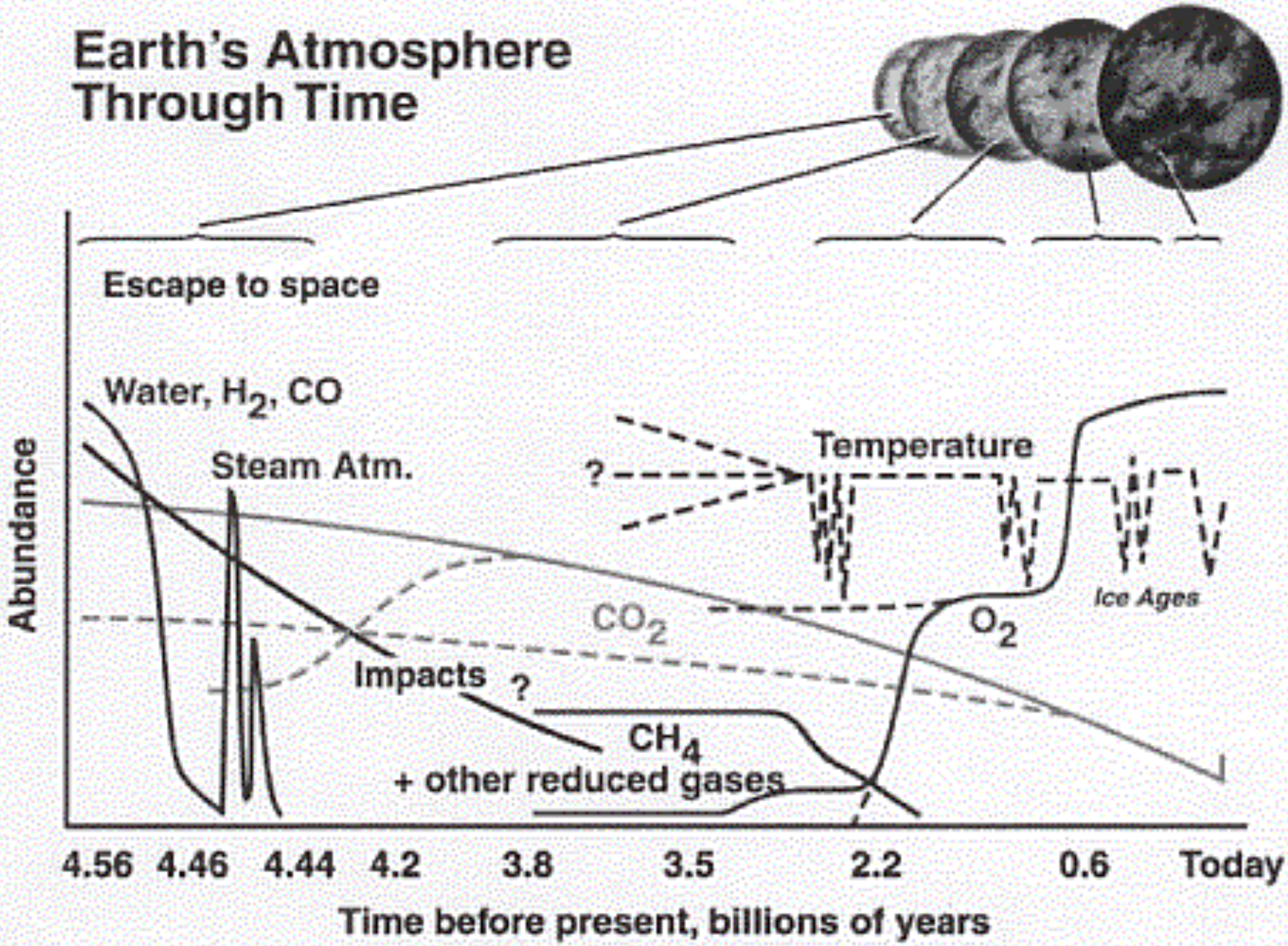
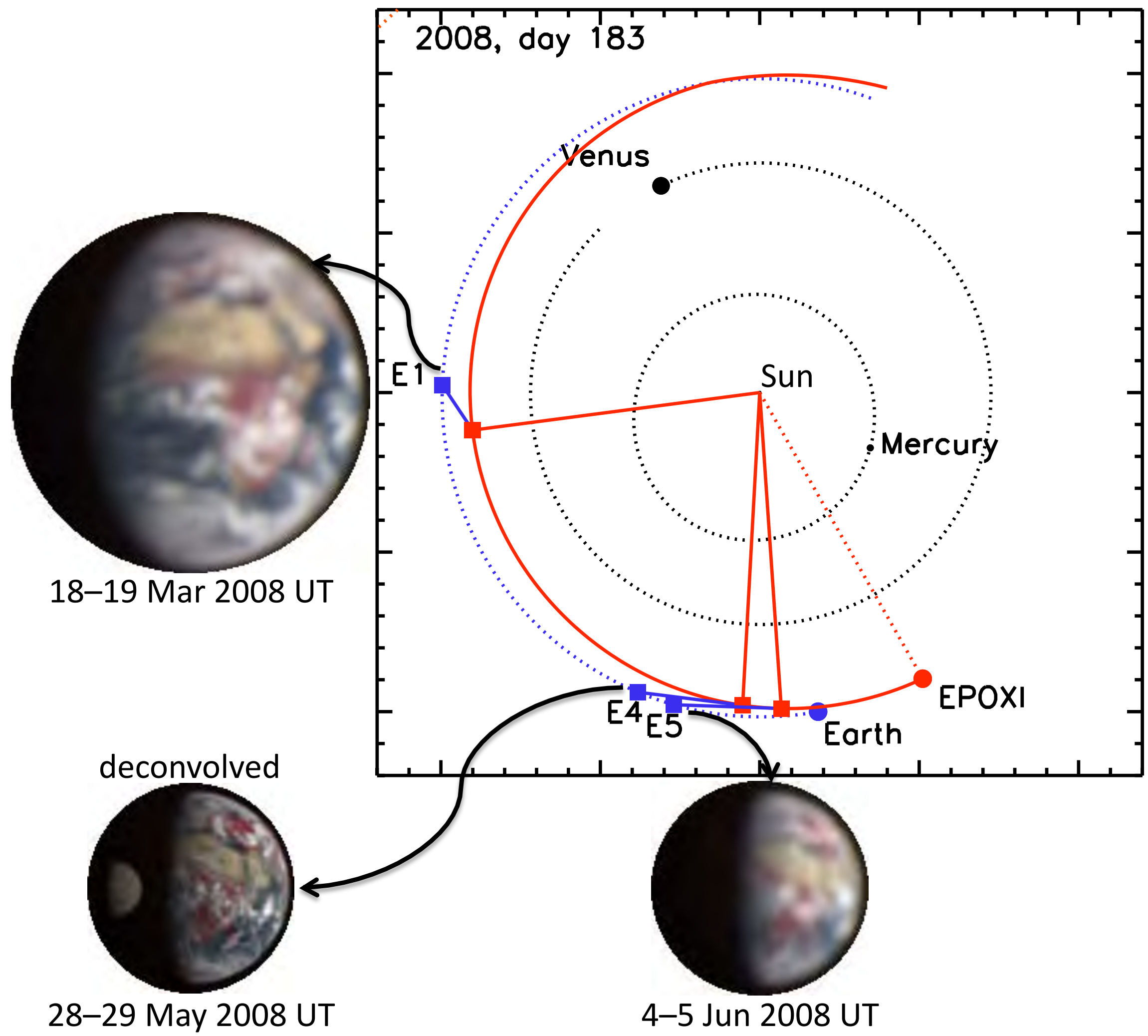


Figure 3. A sketch showing the expected evolution of the Earth's atmosphere. From the NASA website (`http://science.nasa.gov/headlines/y2002/10jan_exo-atmospheres.htm?list161037`).

The Deep Impact/EPOXI Spacecraft Stared at the Earth & Mars as it Traveled from Comet to Comet



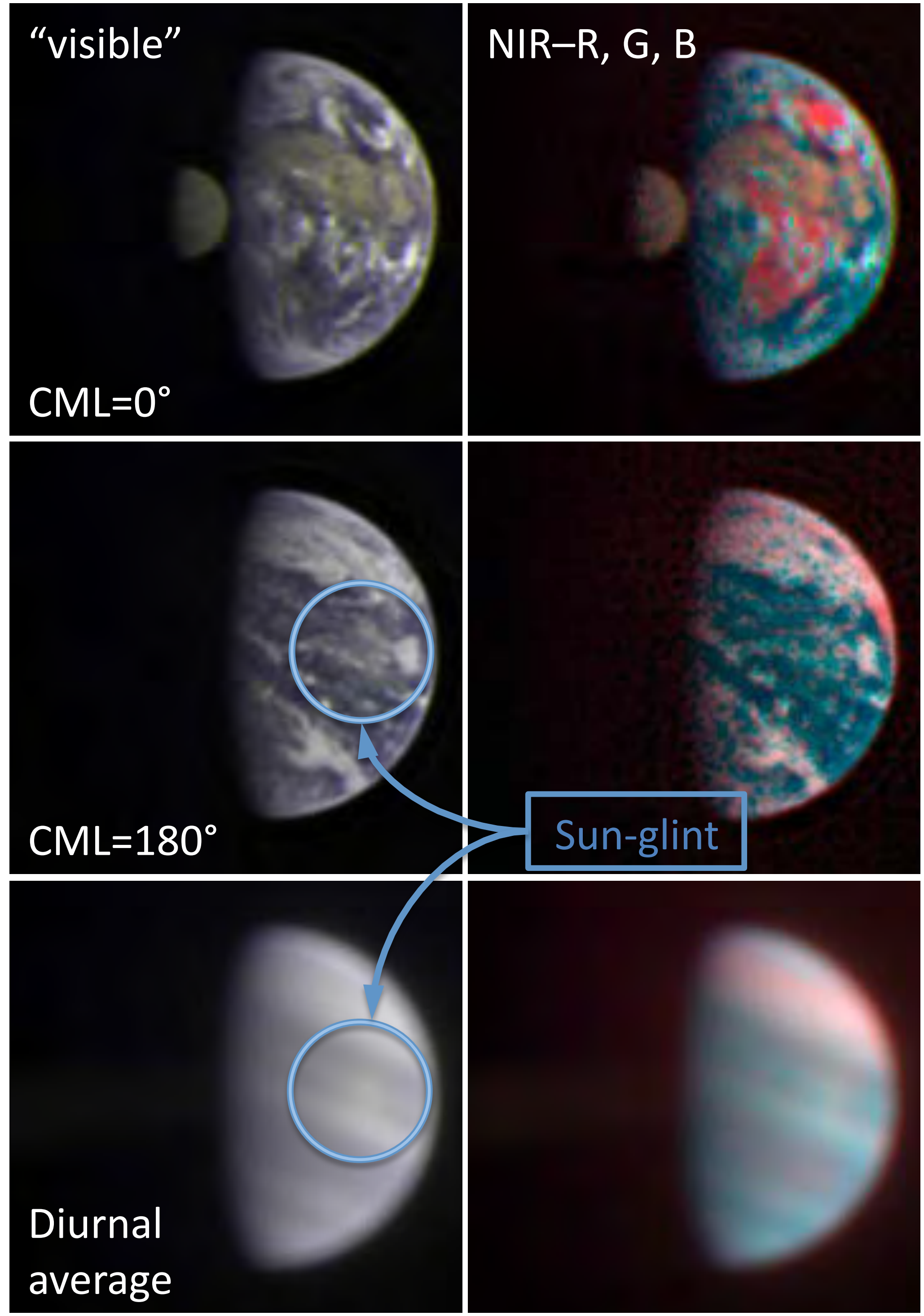
EPOXI Views of the Earth.

“Visible” = RGB Colors.
“NIR-R” = Chlorophyll Red Edge Color.

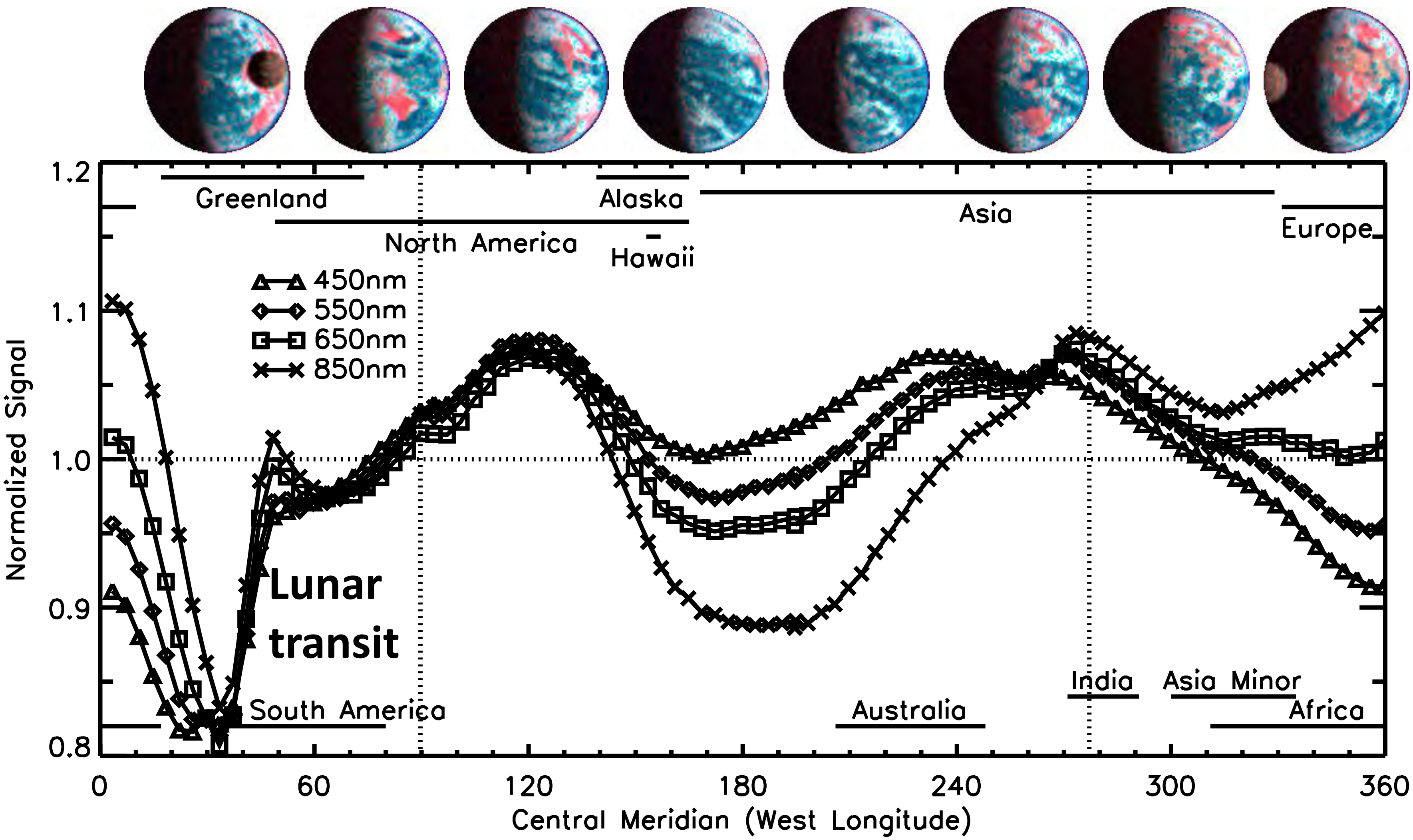
Top: Eastern Hemisphere, Africa Prominent.

Middle: Western Hemisphere, Centered on the Pacific Ocean.

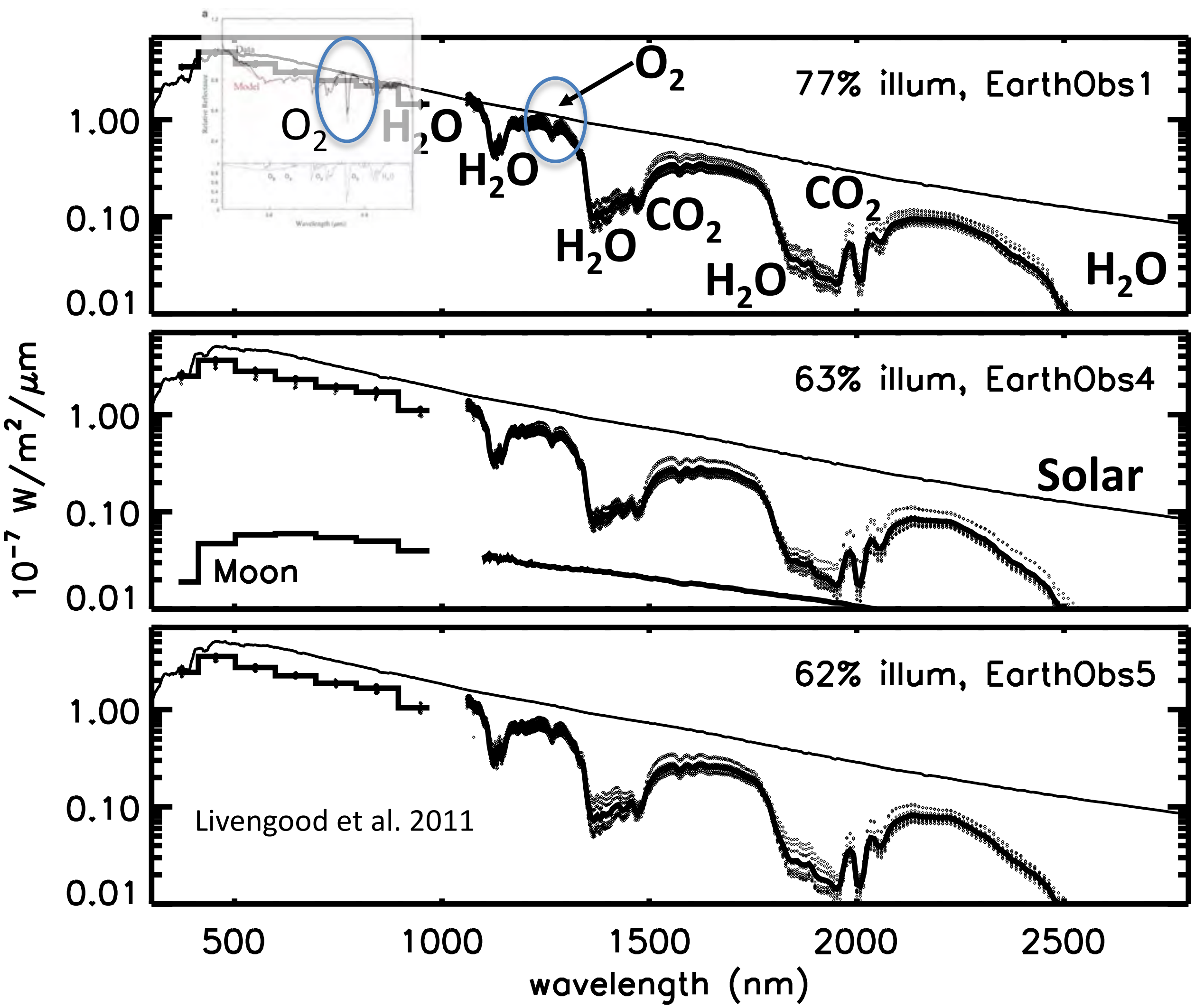
Bottom: Rotationally Averaged Image, Showing What a Realistically Imaged Exo-Earth Will Look Like.

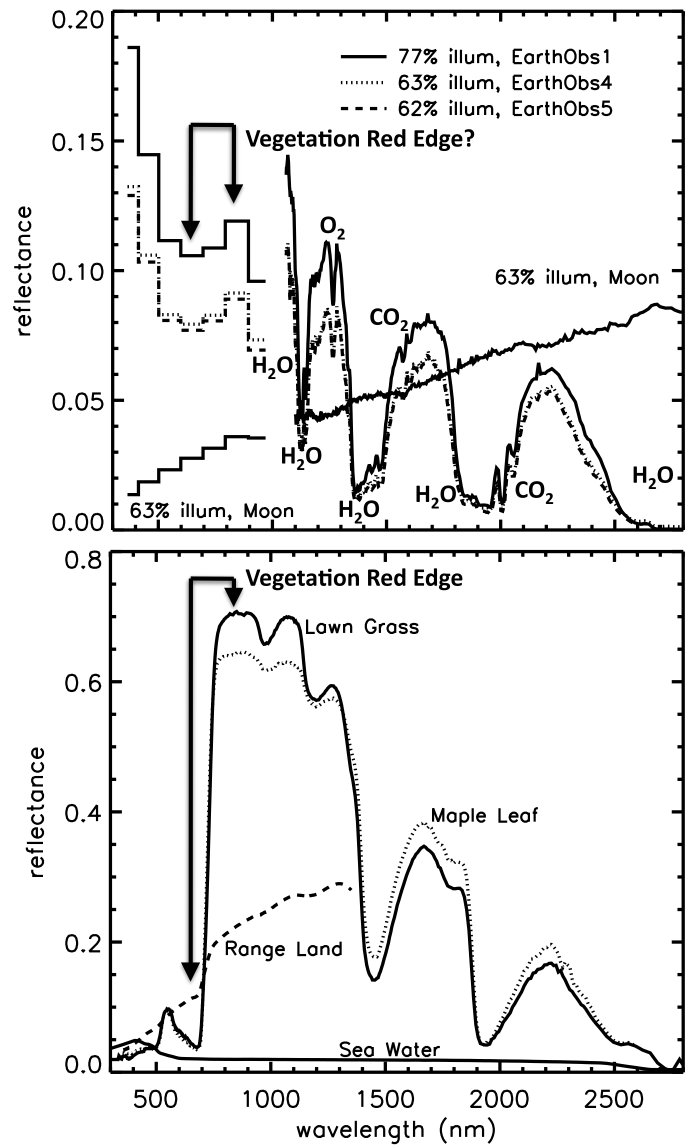


EPOXI Observed the Earth as It Rotated 1 Full Cycle, and as the moon Passed In Front

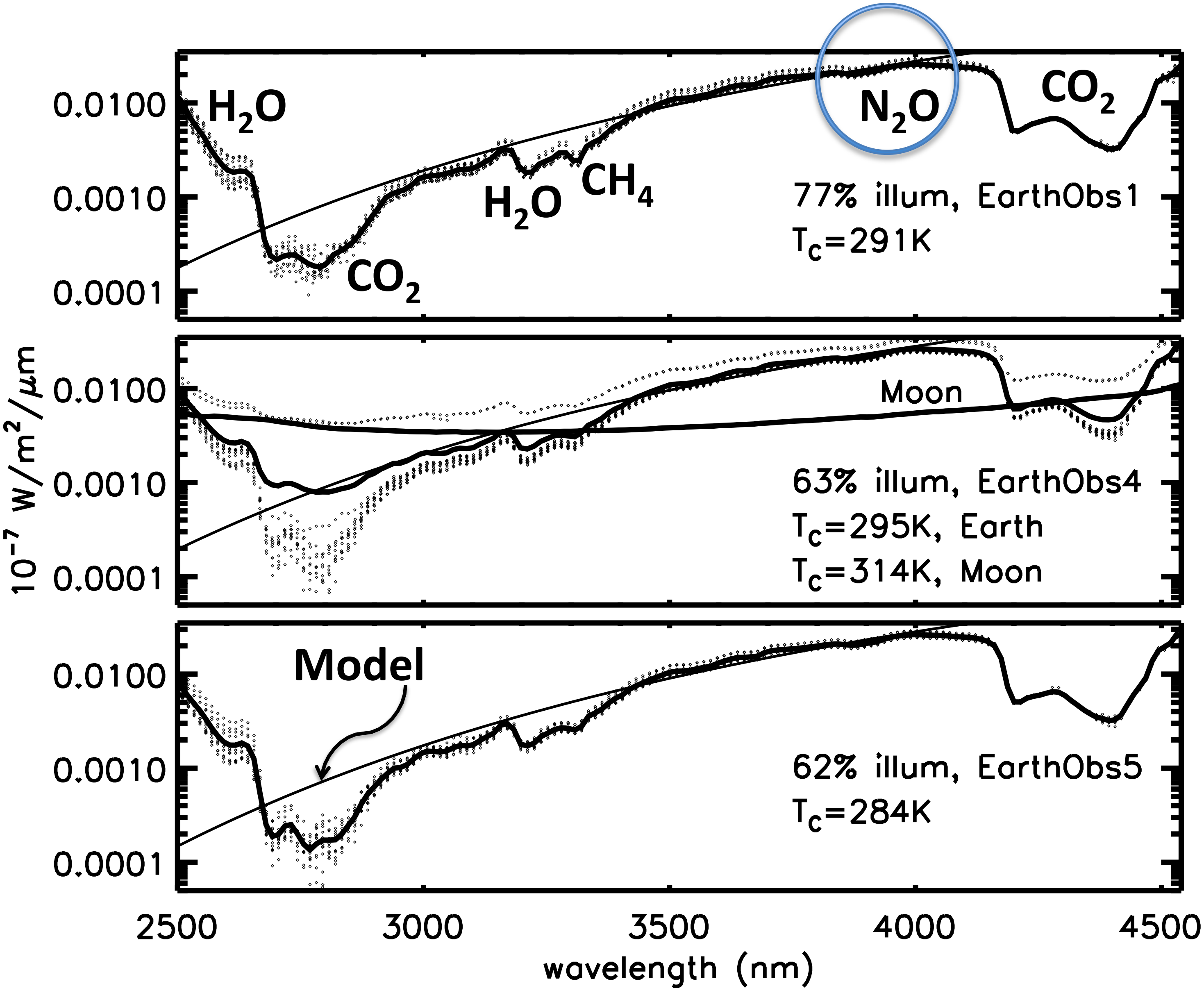


Best Measured EPOXI Optical/Near-IR Bio-Signatures Were Atmospheric Gases: H_2O, O_2, CO_2, CH_4, N_2O, Not Chlorophyll "Red Edge" at ~850 nm

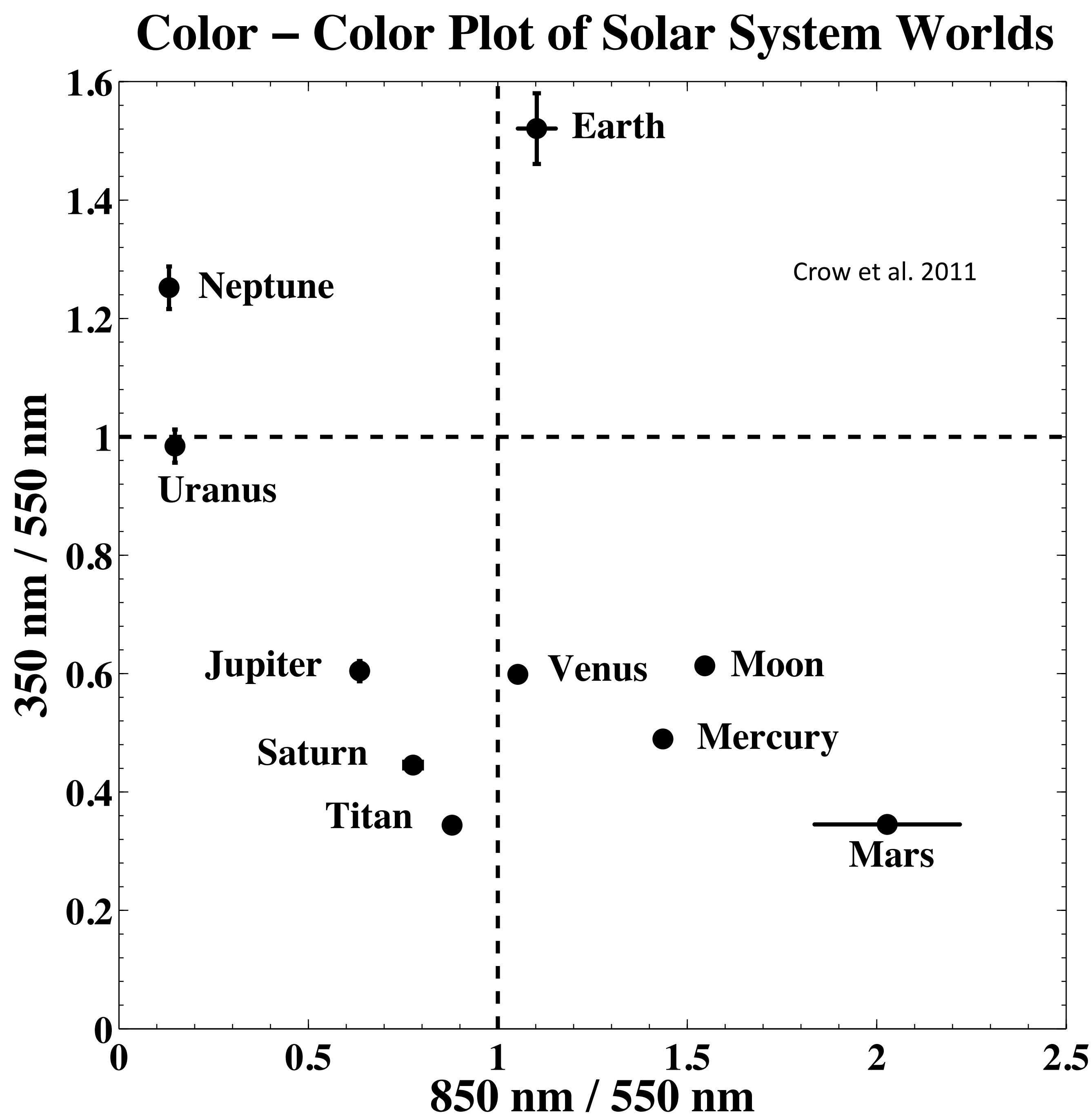




Earth's Atmospheric Signatures Farther in the Near-Infrared



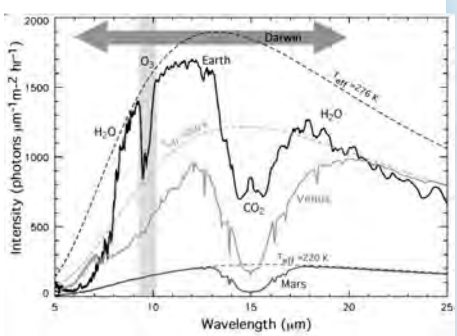
Earth's Atmosphere Stands Out in Simple Color Photometry, Too.

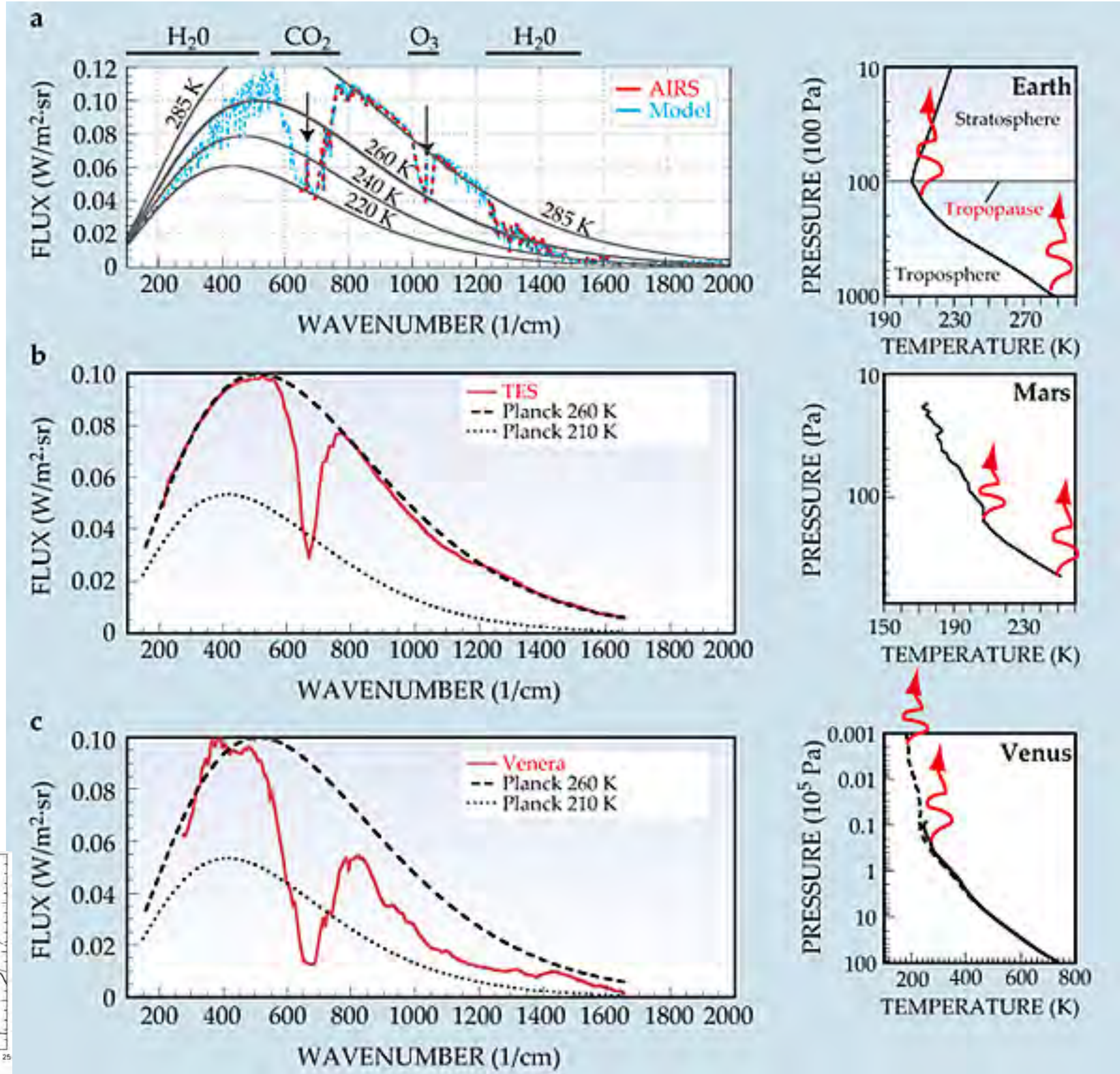


Life & Out of Equilibrium Atmospheres

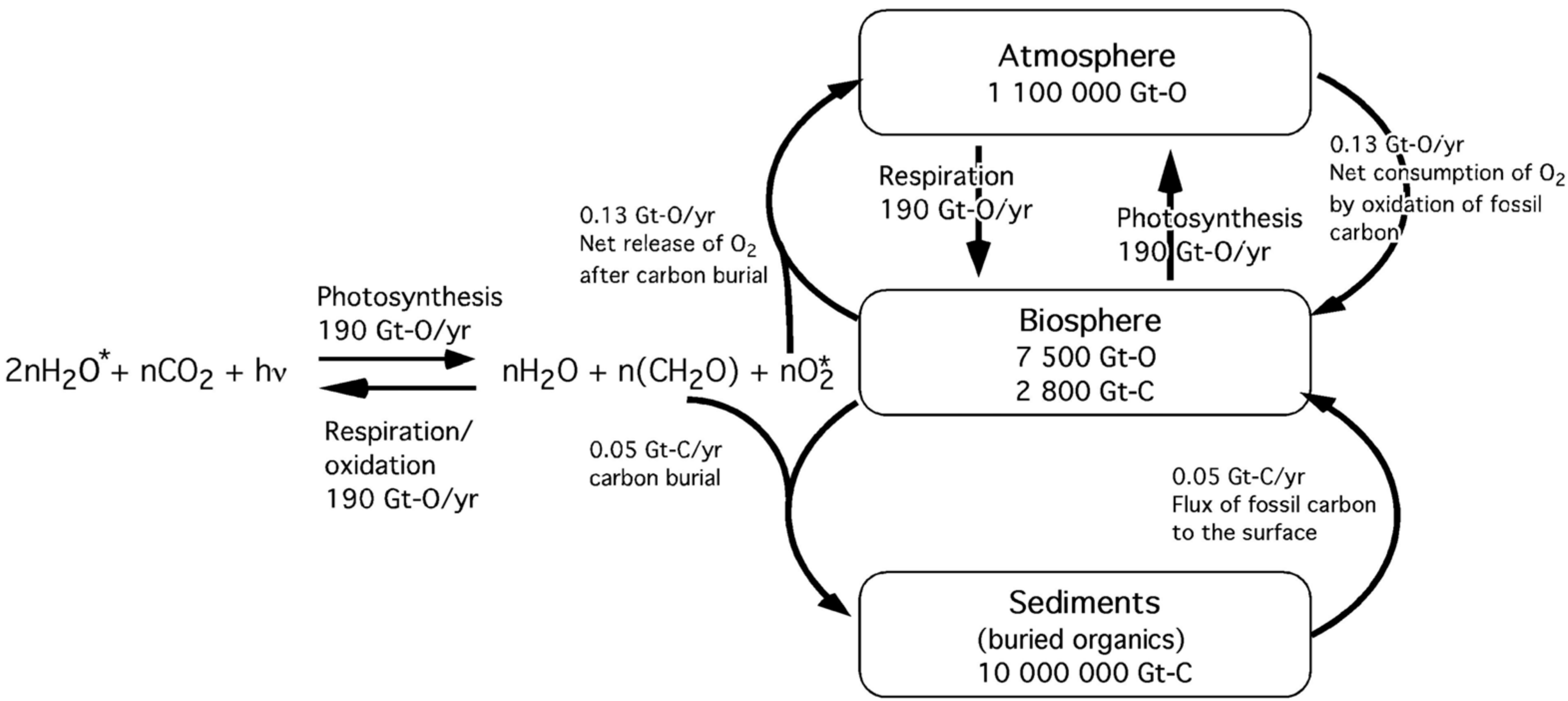
- Critical Idea: Our Current Atmosphere is Very Oxygen-Rich and Carbon Dioxide Poor.
- If We Turn Off All Green Plants Tomorrow, the Earth's Rocks Would Re-Absorb the Free O_2 and Return Us to a "Normal" Rocky Terrestrial Atmosphere
- This is What Makes O_2 (and O_3, a UV photolytic product of O_2) Such Good BioMarkers for Chlorophyll-based Life

Earth has CO_2 & N_2 like Mars & Venus, but also Unique O_2, O_3, H_2O & a Thermal Inversion.



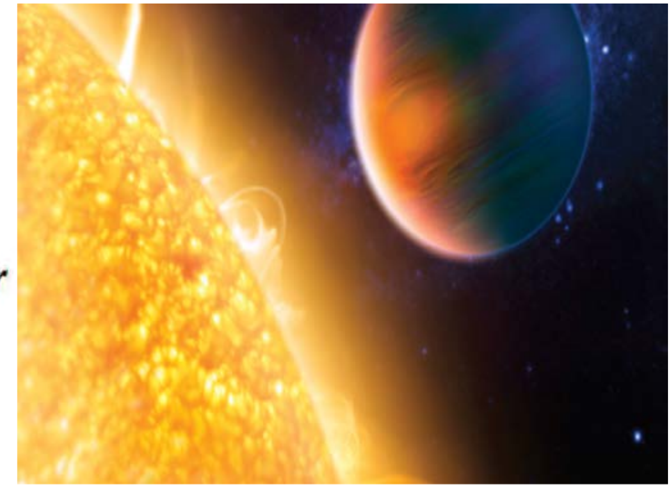


Net Photosynthesic Reactions Driving Alterations of the Earth‘s Atmosphere Today: Destruction of Native CO_2 and Creation of O_2 (O_3)



Alone in the Universe

Despite the growing catalog of extrasolar planets, data so far do not alter estimates that we are effectively on our own



Howard A. Smith **American Scientist 99, Aug 2011**

The first known extrasolar planet (that is, a planet orbiting around a normal star other than our Sun) was 51 Pegasi b, discovered only about 16 years ago. Today, thanks largely to NASA's orbiting Kepler satellite, there are more than 1,500 known extrasolar planets (or planetary candidates), about 431 with confirmed detections and reasonably well-determined parameters (such as radius, mass and orbital characteristics).

These discoveries are exciting not only to astrophysicists; the public is also keen to learn about Earthlike extrasolar planets and the possibility that some might host life, even intelligent life. Last year the Royal Society of London sponsored a symposium with the dramatic title "The Detection of Extra-terrestrial Life and the Consequences for Science and Society." Participants observed, "Should it turn out that we are not alone in the universe, it will fundamentally affect how humanity understands itself," and cited polls suggesting that most people believe we do have cosmic company (half of this group think aliens have already visited). The public wants to believe in aliens (or extraterrestrial intelligence, ETI), some say, because they believe that "ETI comes from 'utopian societies which are free of war, death, disease or any other … mid-20th century problems' and could 'help mankind overcome its problems.'"

Scientists and the press often encourage people to adopt these sensational attitudes. Last March, for example, the *New York Times* ran an op-ed piece on extrasolar planets by astronomer Ray Jayawardhana under an image of a sky full of stars labeled with "THEM" signposts. The author was reassuring: People should not fret about "life elsewhere, especially if it turns out to be in possession of incredible technology [that can] make us feel small and insignificant." He did not speculate on the possibility that this science-fiction scenario might instead make people feel inconsequential or prompt them to treat each other, or our planet, casually.

The dawn of the era of extrasolar-planet (or exoplanet) discovery provides us with the first bits of hard information to use in reconsidering the likelihood of this popular attitude. The spin has been that because planets ligent beings are the inevitable product of life and evolution. This view has been the traditional attitude, and one typical portrayer was Percival Lowell, an astronomer famous for his advocation of canals on Mars, who wrote in his 1908 book, *Mars as the Abode of Life*:

> From all we have learned of its constitution on the one hand or of its distribution on the other we know life to be as inevitable a phase of planetary evolution as is quartz or feldspar or nitrogenous soil. Each and all of them are only manifestations of chemical affinity.

Today we know that Mars has no artificial canals, and that this assertion was unsupported wishful thinking. Don Goldsmith and Tobias Owen, in their classic book, *The Search for Life in the Universe* (1993 edition), present a more modern view:

> We anticipate that all planetary systems will have a set of rocky inner planets, with atmospheres produced by outgassing, weathering and escape, for the same reasons

Assuming a radius of 1000 pc, or 100 human generations, as Search Space.

The Possibilities for Life and Human Habitability on Nearby Stars: Many Possible Homes for Our Elder(?) Race, But the Neighbors Are Likely Bacteria

- There are 100 Billion stars in our galaxy, and each has likely formed its own Earth sized planet. The Universe is 13.8 Billion yrs old, the Galaxy is about 12 Byrs old, and the solar system is 4.56 Byrs old. We live 2/3 of the way out from the weak central black hole, in the suburbs. Only FGKM stars last more than 1 Byr. With Kepler, we are entering the era of precision exoplanets.

- The Earth is a highly differentiated, *very unique* object with an overabundance of water on the surface, a giant moon stabilizing its spin, plate tectonics keeping it warm, and shielded with a magnetic field. Life is found in an incredibly narrow range, -10 to +60 miles from the geoid surface of a body 7600 miles across. We live, work, & die on the thinnest rind of the orange. Venus and Mars are failed harbors for life in our SS. Life has "polluted" the planet to be O_2 rich, providing biomarkers.

- Life has experimented with a huge # of forms over 4.56 Byrs on Earth, but Life is *only* found where liquid water exists. The LUCA was a thermophile. Earth-life was blue-green, squishy, and single-celled from 1.0 – 4.0 Byrs, and Bacteria still rule.

- Multi-cellular Life has gone through *at least* 4 unique stages and huge upheavals due to giant impacts. Bug Eyed Monsters, Pill Bugs, or Giant Lizards would be ruling the place without them. We are the latest dominant species.

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