Life in the universe

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Habitable zone

misnomer with best intentions

Classic concept

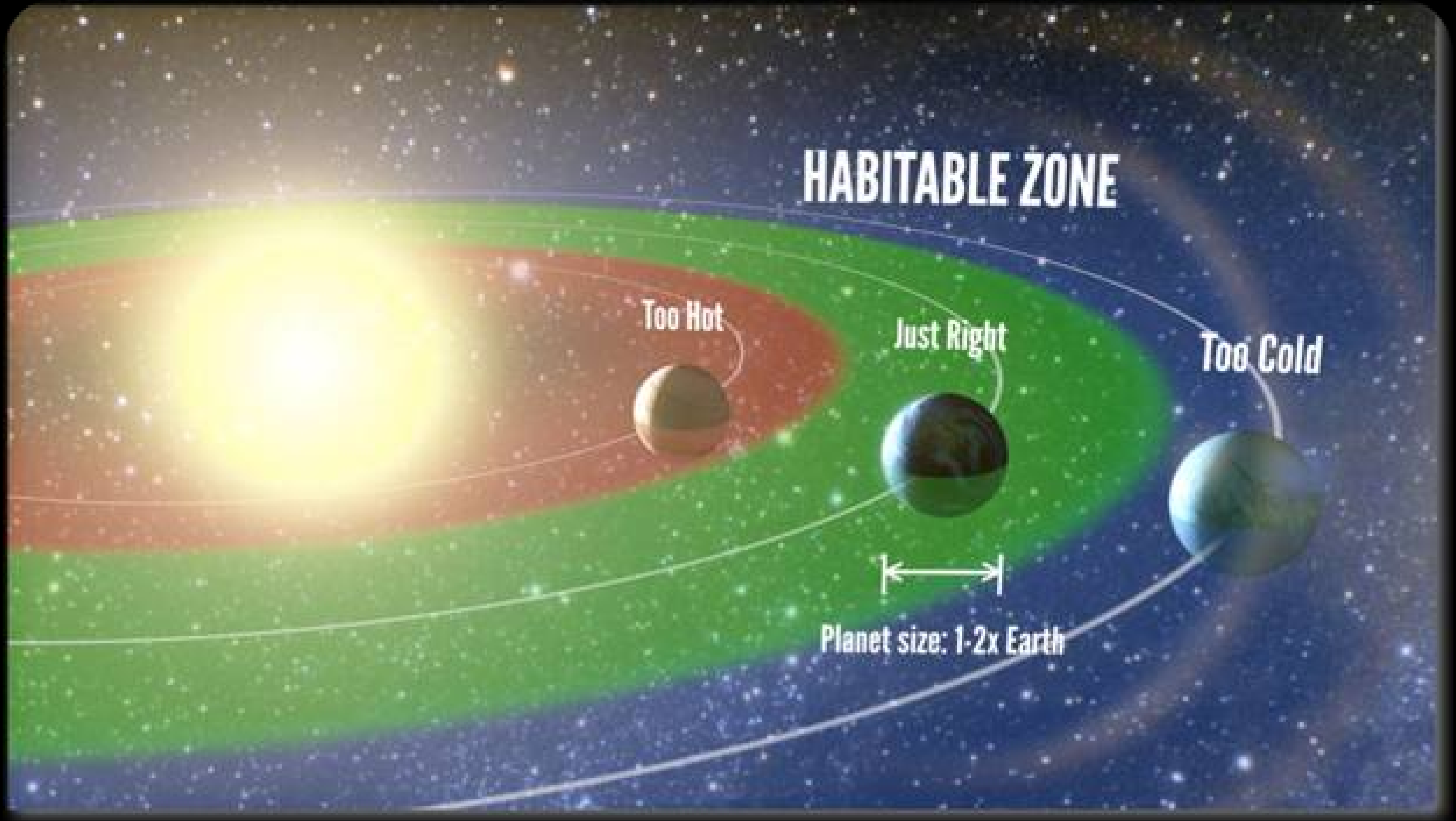
Earth-centric

The classic habitable zone

- Liquid water on surface possible.

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

If the whole planet surface radiates



The habitable zone corresponds to the range of orbital distances where liquid water can exist on a planet's surface.

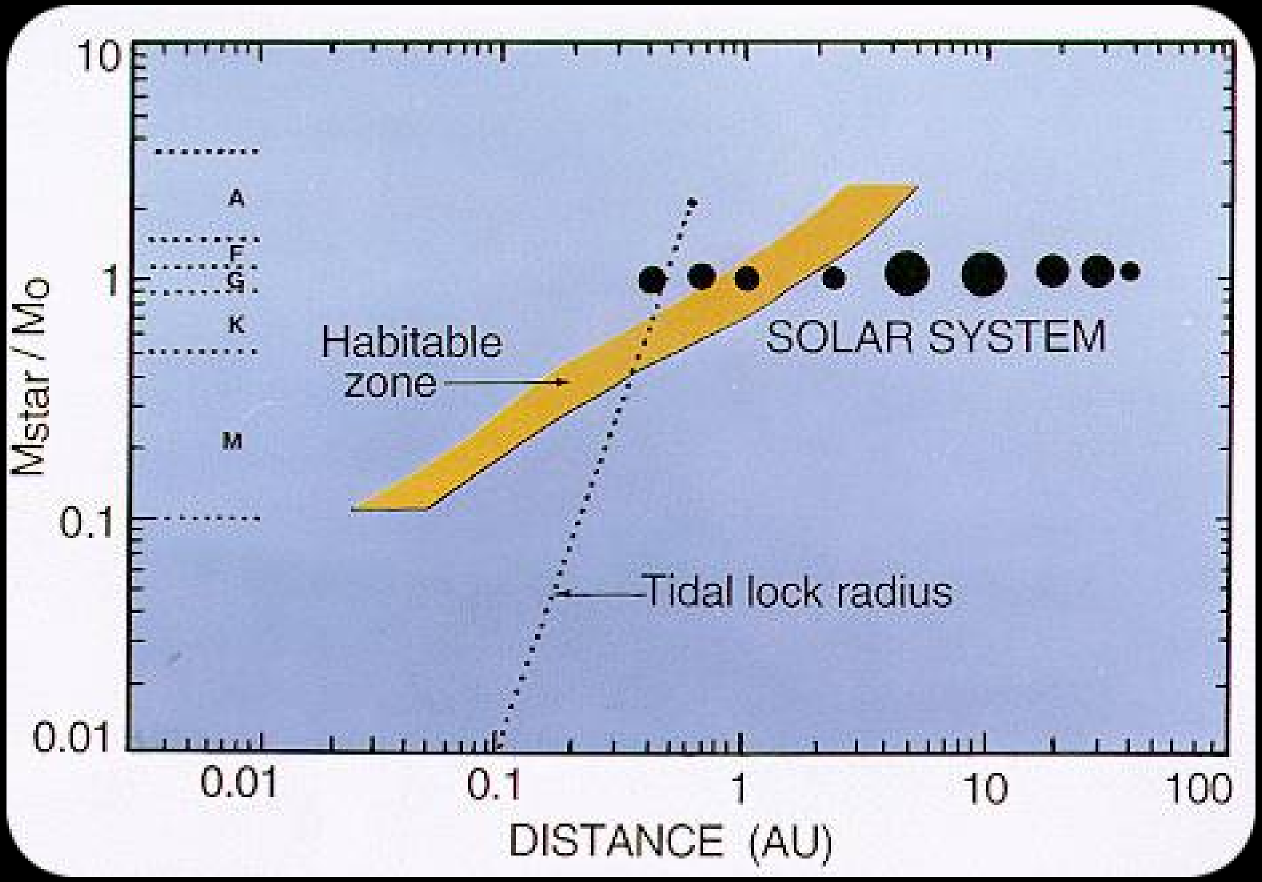
A_b Albedo of Surface
L_* Luminosity of Sun
a Radius of Planet
σ Stefan-Boltzmann
$5.67 \times 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}$

The classic habitable zone

- Liquid water on surface possible.
- Negative feedback between CO_2 and T_{surf} (greenhouse effect)
- CO_2 limited modulation of the habitable zone.

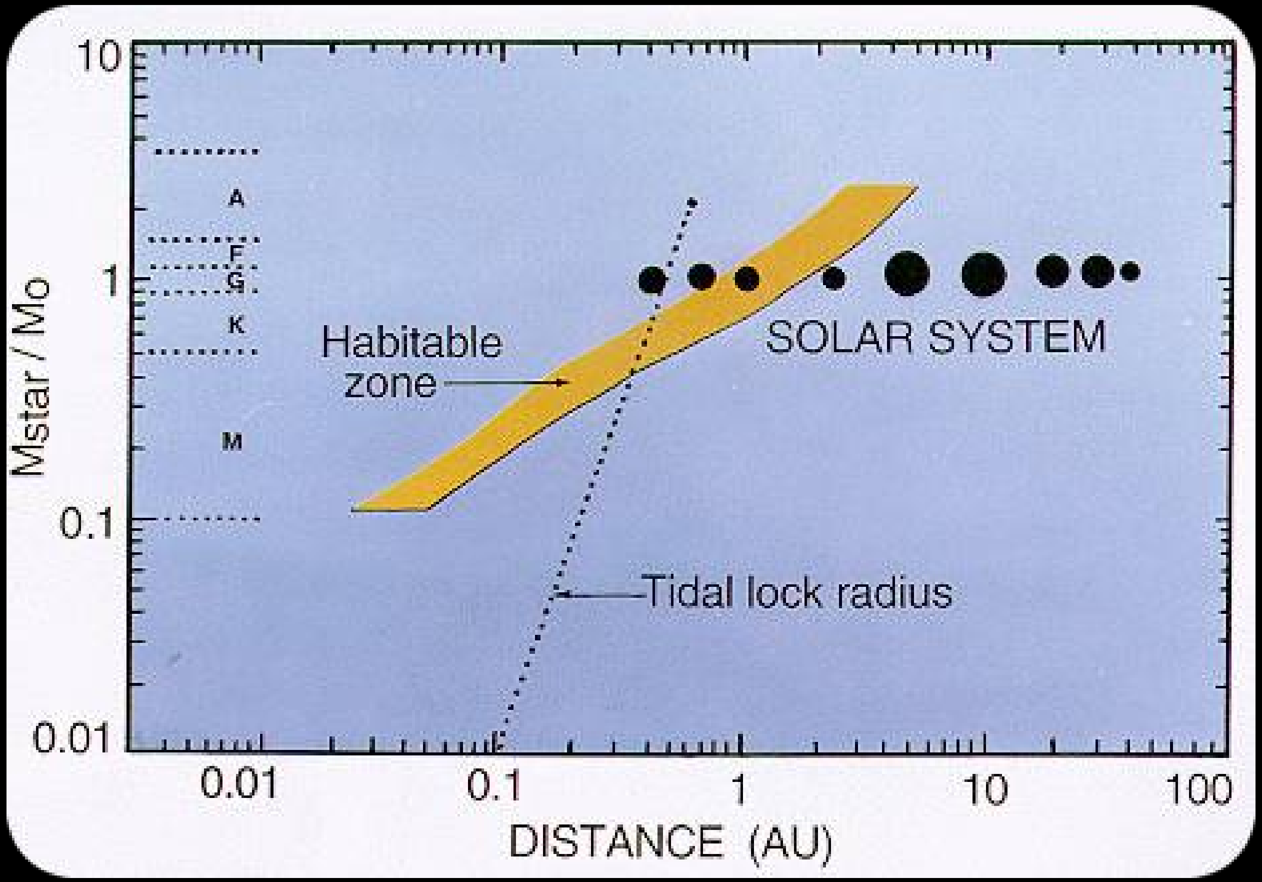
The classic habitable zone

- Inner edge: Runaway greenhouse
- Outer edge: Maximum greenhouse reached (CO_2 condensation).
- This creates the “classic habitable zone” which gets closer to the star with diminishing brightness ($L_{star} \sim (M_{star})^a$, with $2.3<a<4$).



The classic habitable zone

- Inner edge: Runaway greenhouse
- Outer edge: Maximum greenhouse reached (CO_2 condensation)
- If too close, tidally locked (*close to the star as torque ~$1/a^3$*)! Then modulation of heat budget depending on atmospheric ability to circulate.



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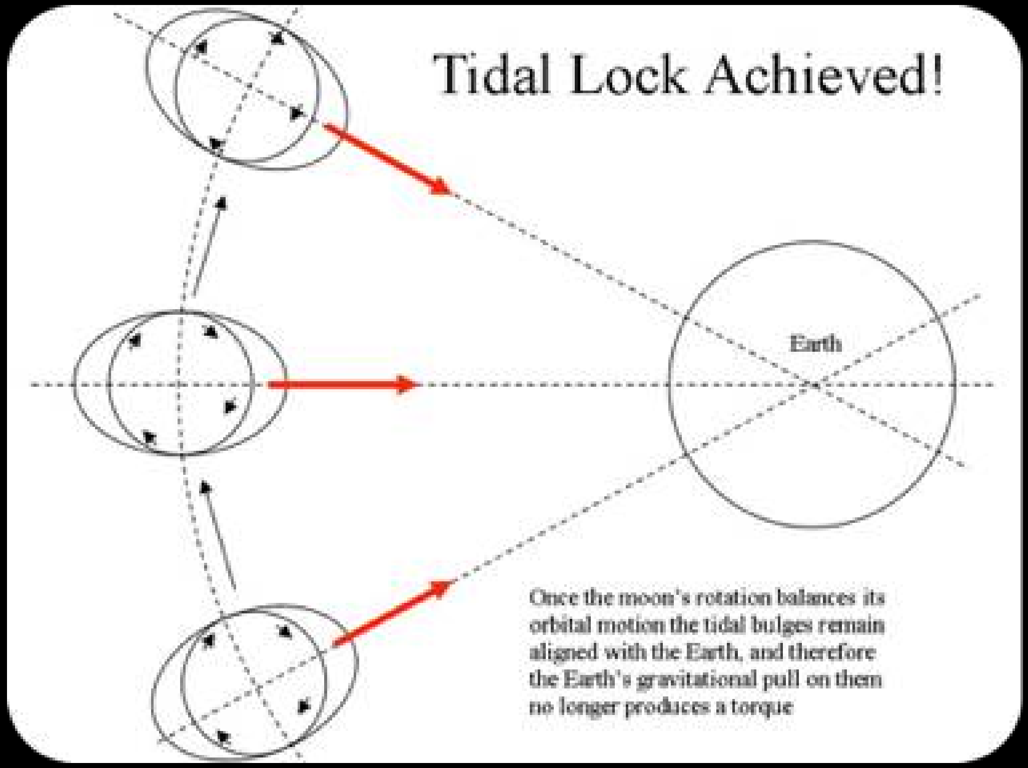


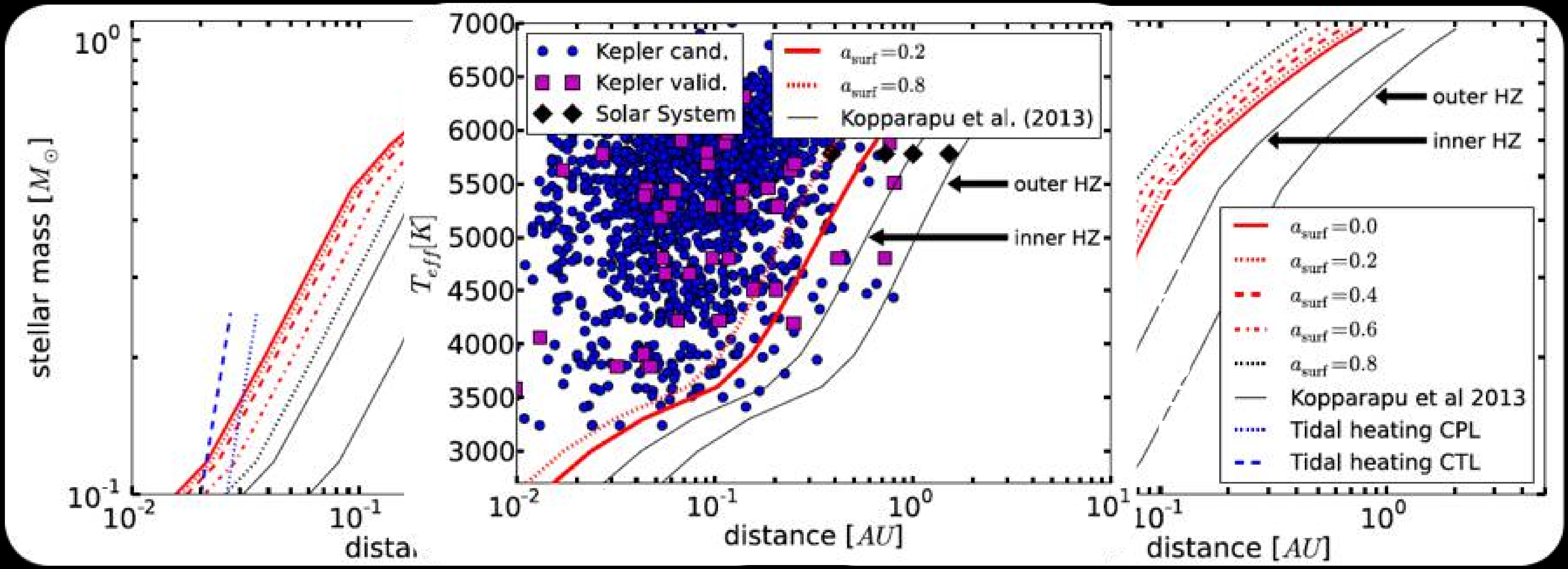
Inner/Outer edge extensions

from Dunes, over Io-Titan-Europas, to Rogue planets

Inner edge extension: dunes

$$\tau_w = \frac{N_{H_2O}}{A_{surf} n_{H_2O}^{top} V_{diff}}$$

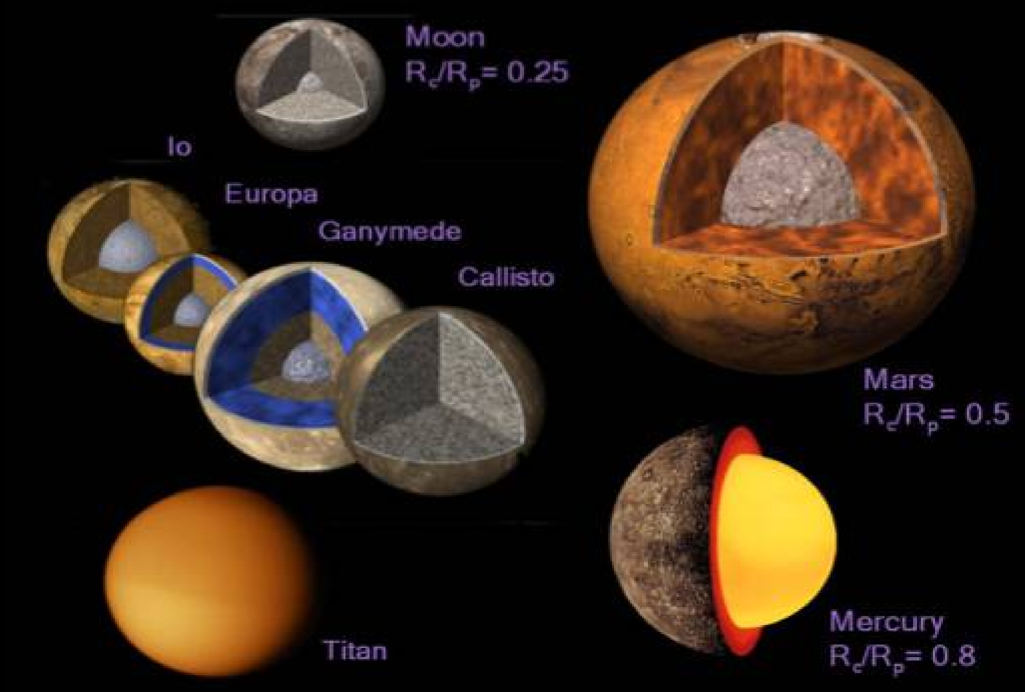
- Runaway greenhouse can be reduced by:
  - Increased albedo, less humidity. Dunes are out there…
  - H escape rate and greenhouse effect is proportional to H concentration (at smaller concentrations when there is no cloud formation), hence for small relative air humidity levels
  - For our sun: within the orbit of Mercury!



Zsom et al. 2013

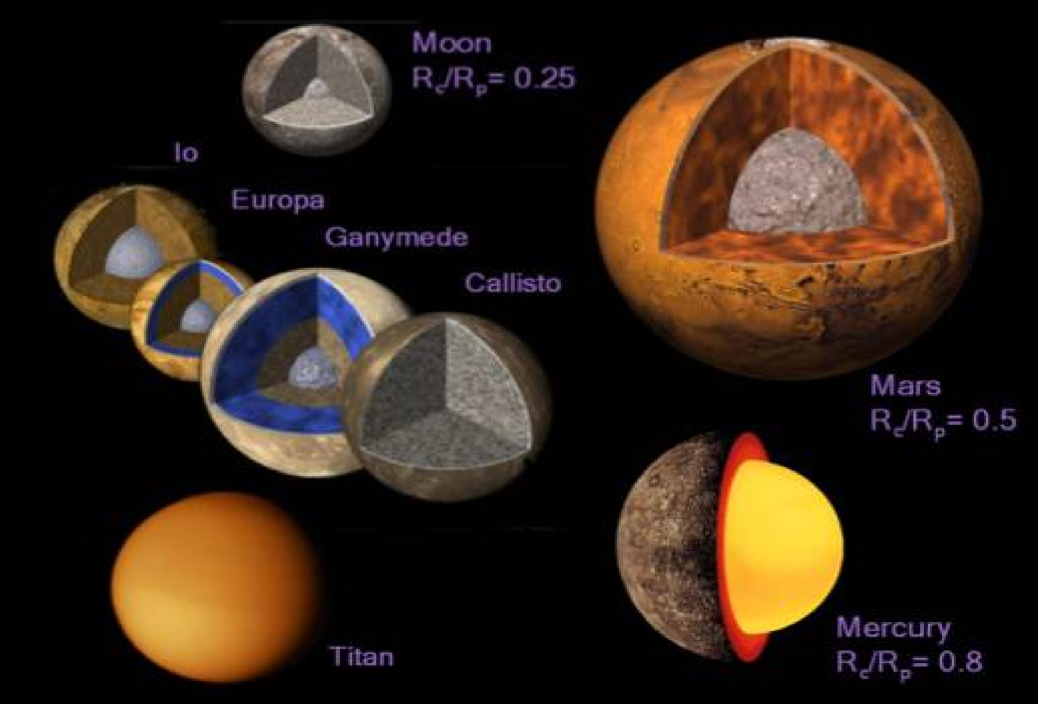
Outer edge extension: tidal heating

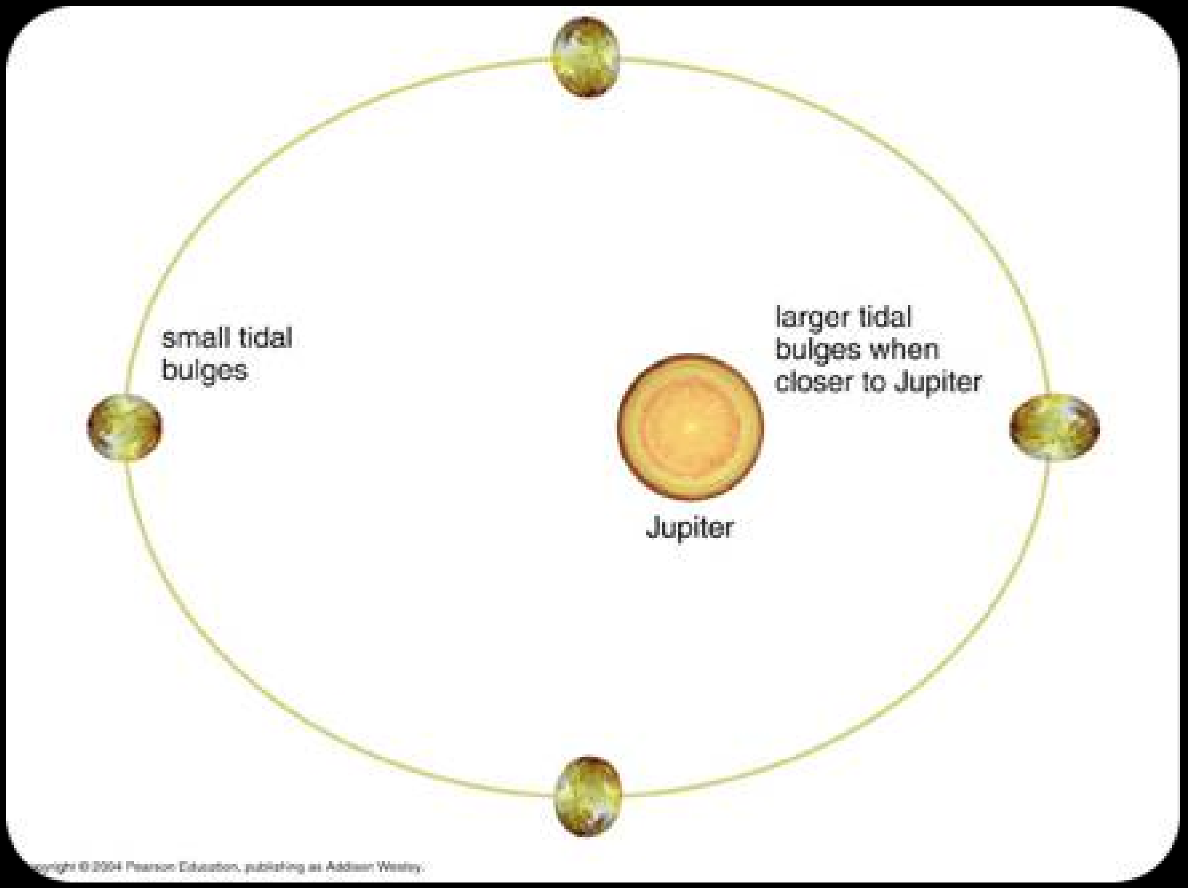
- Tidal heating can keep oceans liquid (Jupiter’s Europa)…and volcanoes erupting (Jupiter’s Io, Saturn’s Enceladus).



Outer edge extension: tidal heating

- Tidal heating can keep oceans liquid (Jupiter's Europa)…and volcanoes erupting (Jupiter's Io, Saturn's Enceladus).
- Tidal heating occurs on elliptical orbits: a change in tidal deformation due to varying distance from host leads to friction inside the planet's interior.





Outer edge extension: rogue planets

- Rouge planets for large H_2 atmospheres (excellent greenhouse gas).
  - Small stellar flux leads to small H escape rates (effective T~40K)
  - Heated by radiogenic decay of Th, U, K in the interior.
  - Liquid water for surface pressures above 1 kbar (1000 x Earth’s).
  - Life without sunlight (chemolithotrophs)!

e.g., Stevenson, 1999

There is so much more to habitability

from interiors to cosmic home

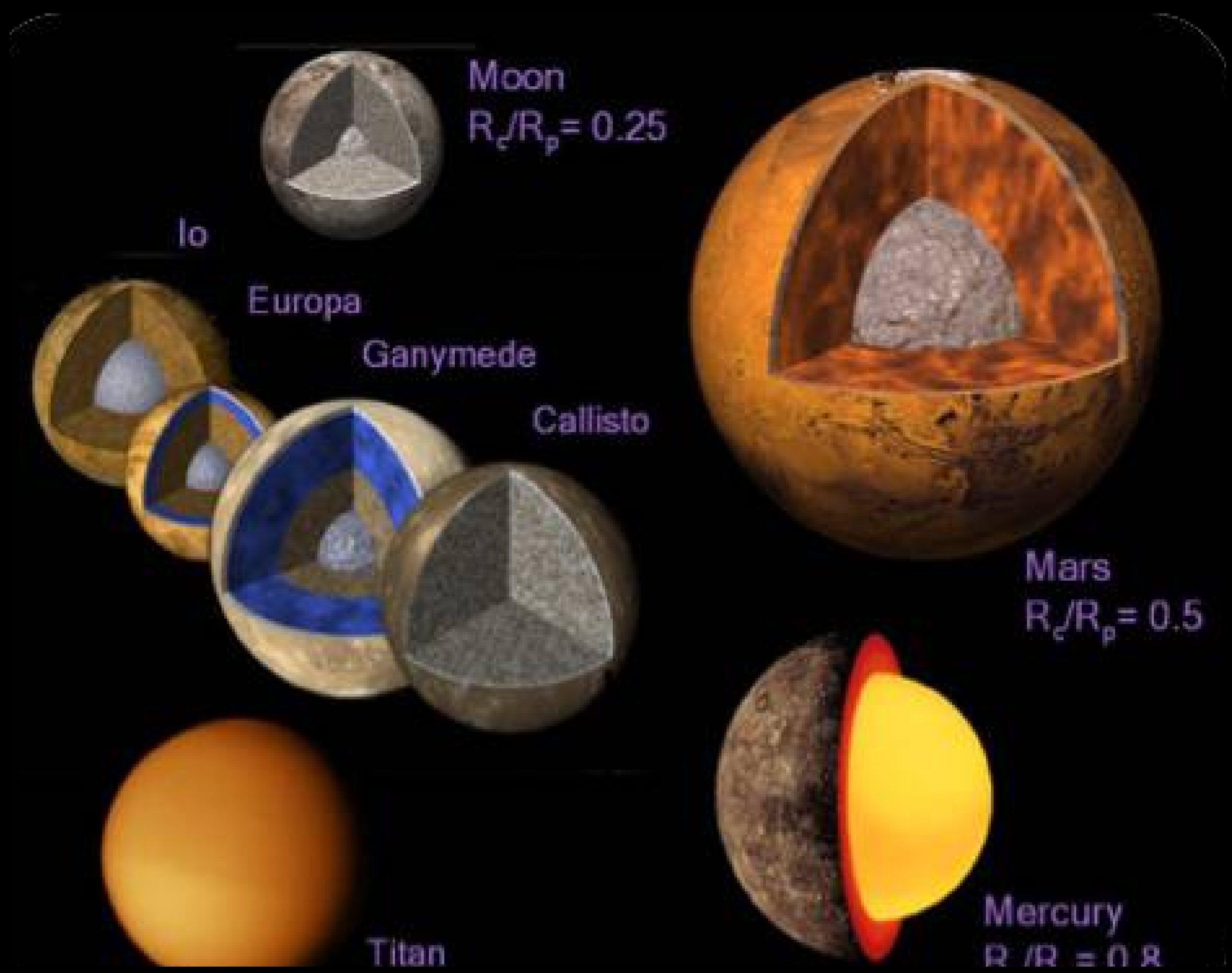
There is so much more to habitability

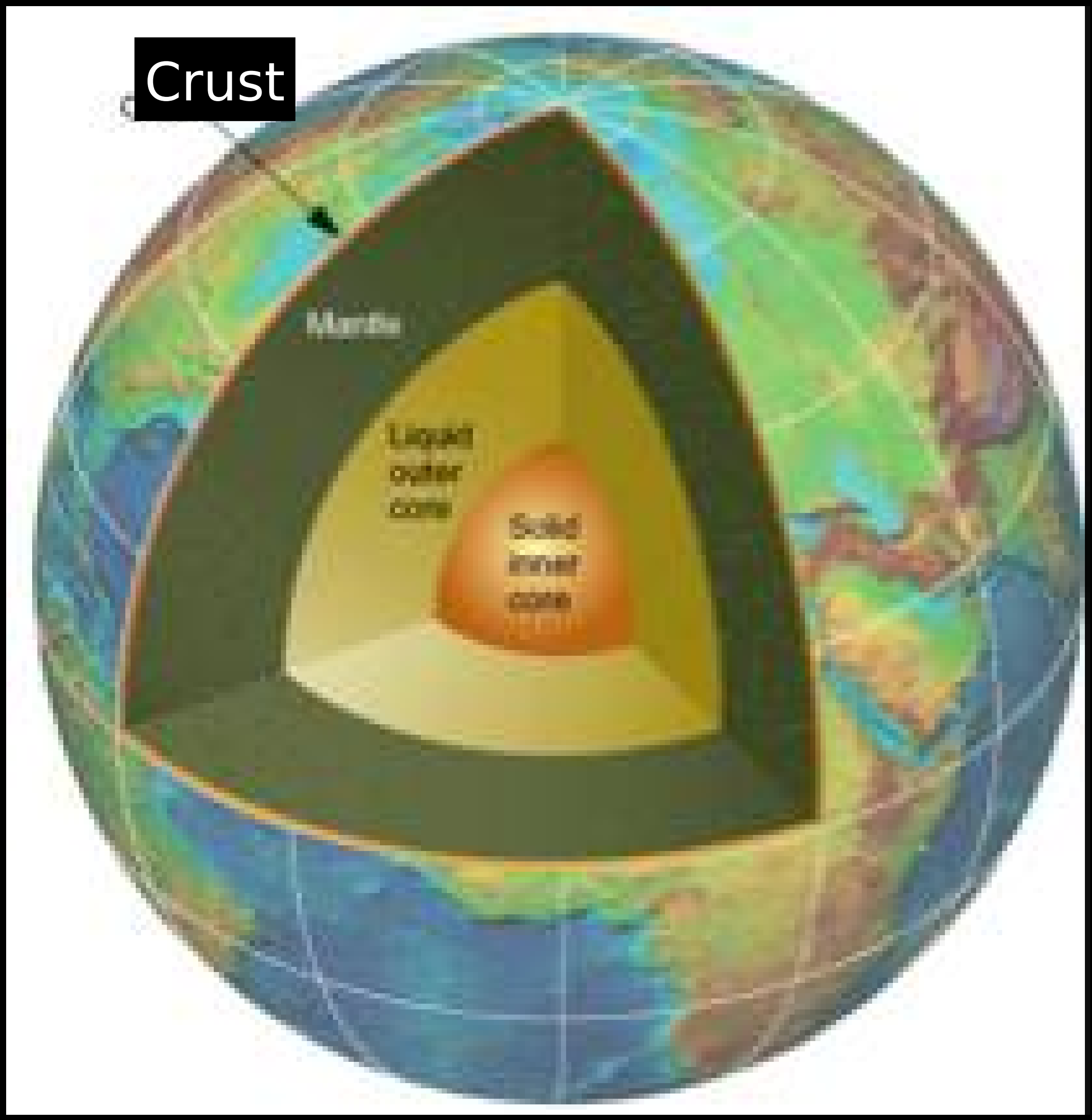
interiors

A look inside a planet

A look inside a planet

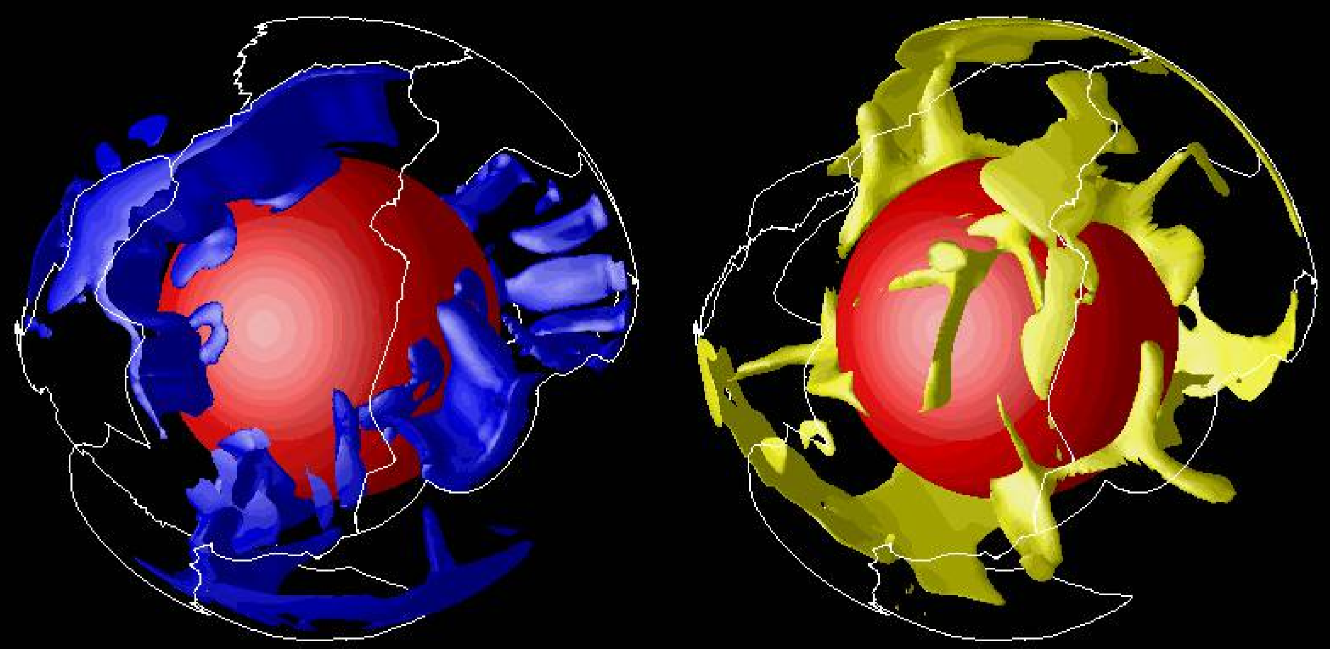
- Very diverse composition and structure.

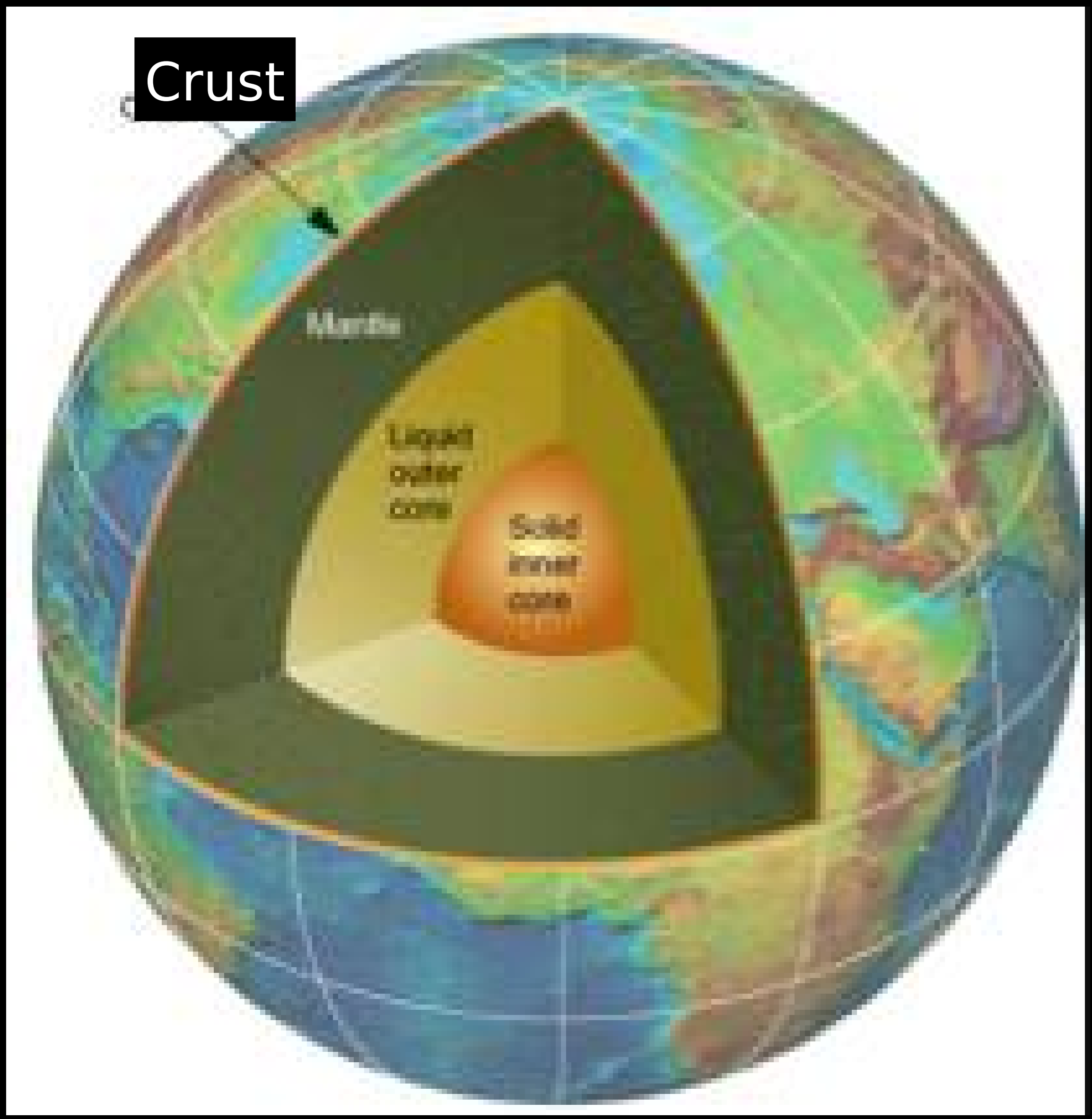




A look inside a planet

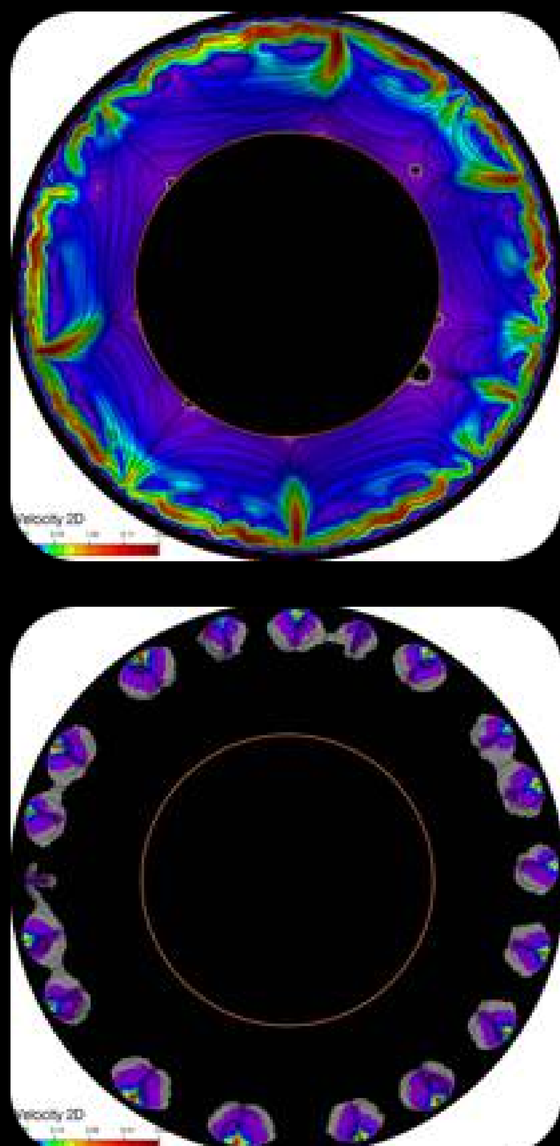
- Convective heat transport in larger terrestrial object.



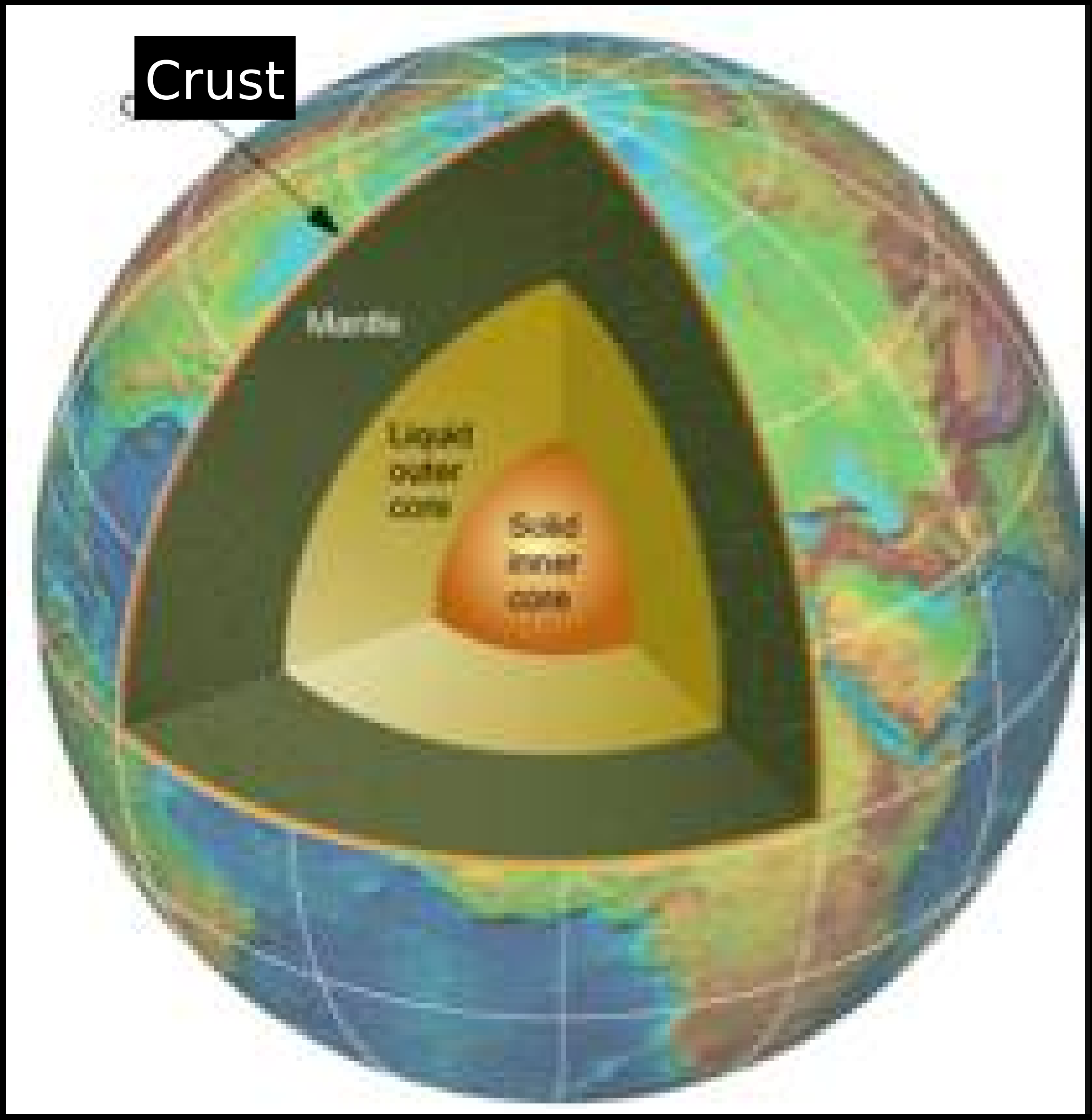


A look inside a planet

- What’s with convection when planet mass increases (super-Earths)?



Stamenković et al. 2012.



A look inside a planet

- Convection in the planet controls plate tectonics, volcanism, and magnetic field generation.
- They are all of importance to the habitability of a rocky planet.

Plate Tectonics (and Volcanism)

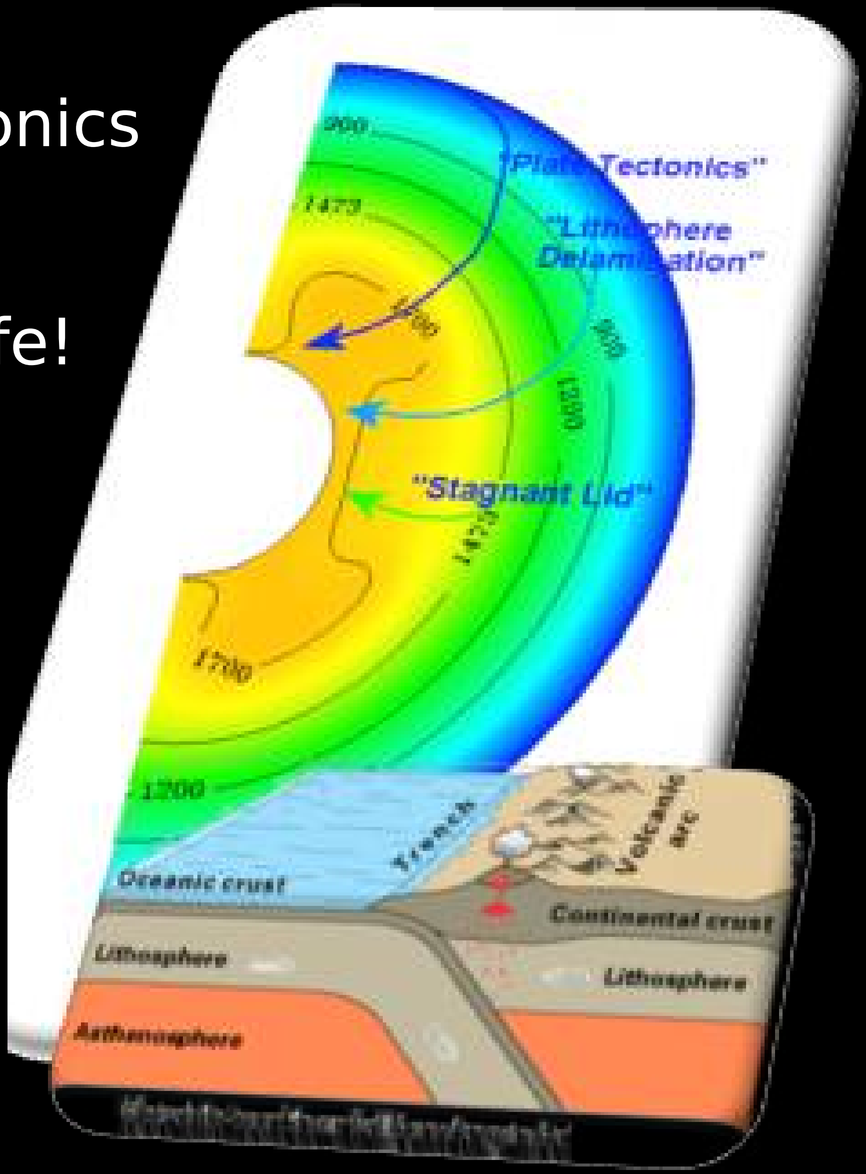
climate stabilizer and food delivery

What is plate tectonics?

- Heat transport in rocky planets is via conduction and convection.
- On Earth, convection dominates.
- Two end-members for mantle convection: stagnant lid and plate tectonics.
- In the latter, the lithosphere takes part in the convection process.
- Leads to continental drift.

Plate tectonics and life - myth or fact?

- Volcanism provides carbon for C-Si-cyle (Urey cycle - climate stabilization).
- Plate tectonics mostly leads to volcanism (*but why?*) - stagnant lid convection does not have to.
- Shallow C reservoir for volcanoes ⇒ plate tectonics replenishes internal C for later outgassing?
- Many open questions of great importance to life!

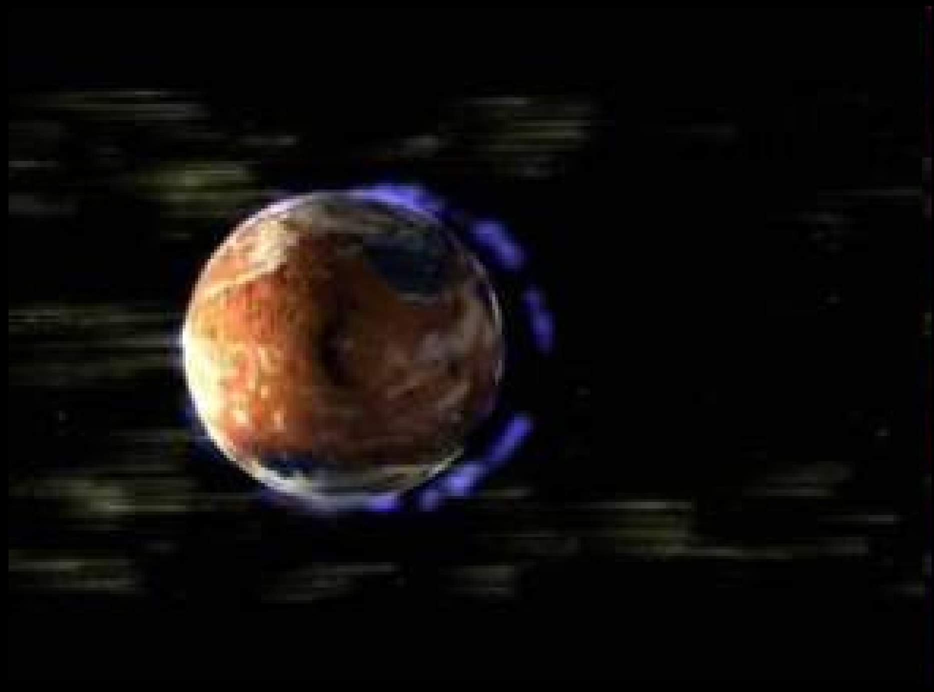


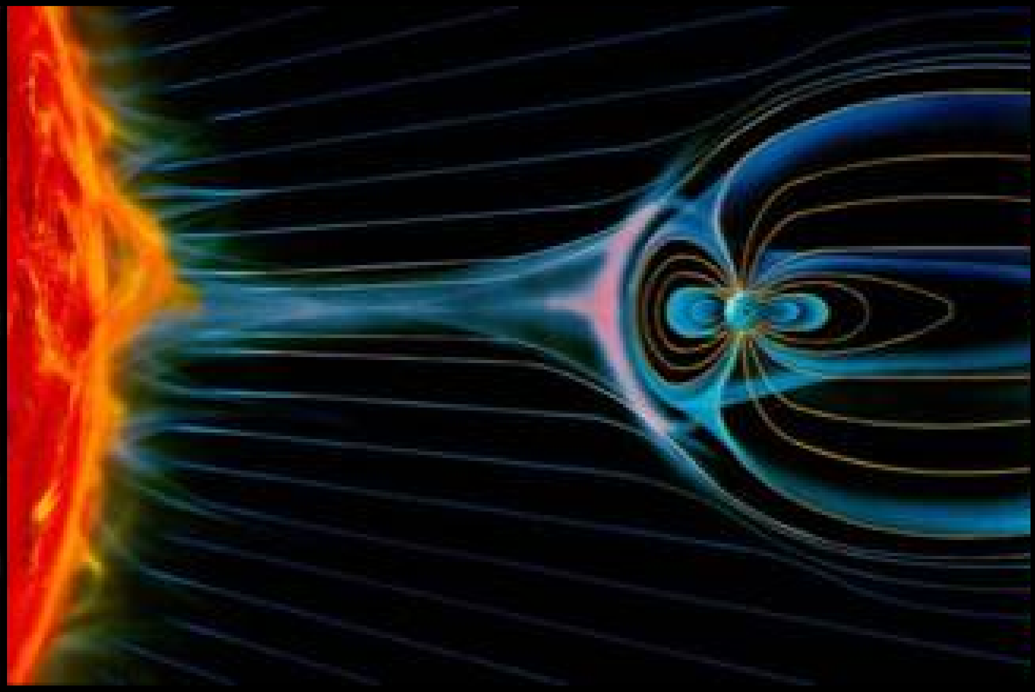
Magnetic fields?

Really?

Magnetic fields?

- Debated! But in early planet evolution for G-stars (longer for M-dwarfs), magnetic field might help to shield the atmosphere from solar flare erosion.





Magnetic fields?

- Created in the liquid cores or rocky planets.
- Needed: Thermal (*large heat flux* F_c) or compositional convection (*growth of inner core*).
- For super-Earths: steeply increasing melting temperature for iron as well as hotter mantle make thermal dynamos and compositional dynamos less likely -but there is so much we do not yet know about exoplanets, surprises await!

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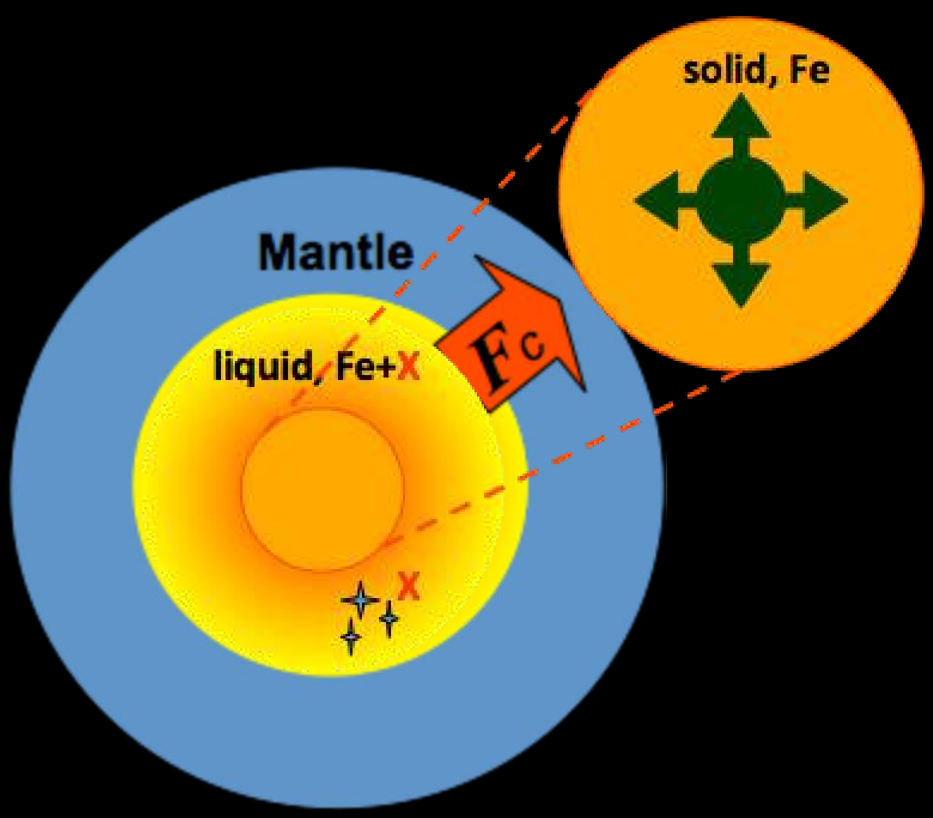
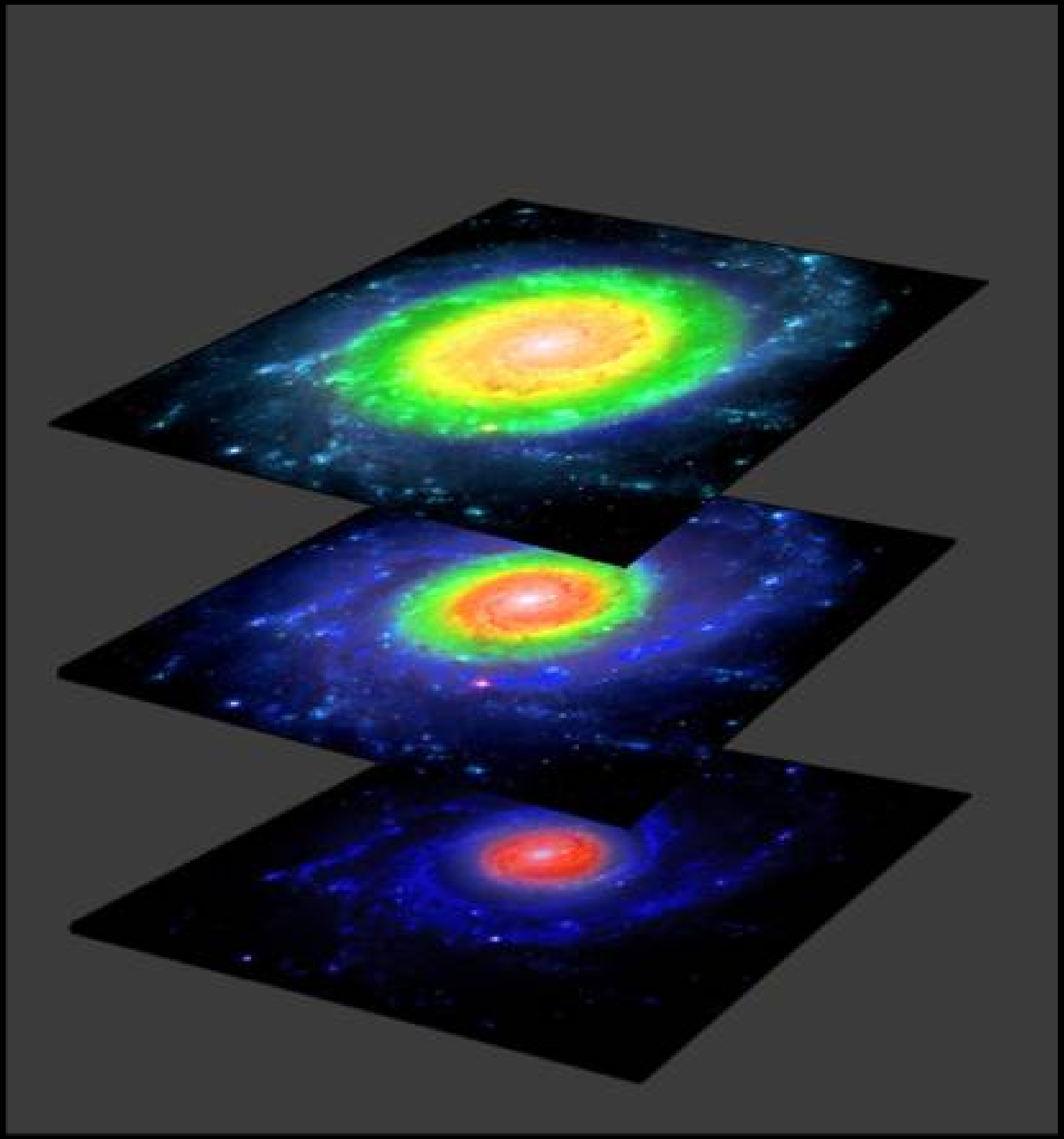


There is so much more to habitability

galactic

Galactic habitability

- Like in planetary systems, star formation location impacts the content of radiogenic heat sources, metals, occurrence rate of supernovae and gamma ray bursts and hence impacts the interior and surface processes of a planet and life.
- E.g., Halo stars are old and metal & Th poor?
- Close to the Galactic core supernova concentration increases.



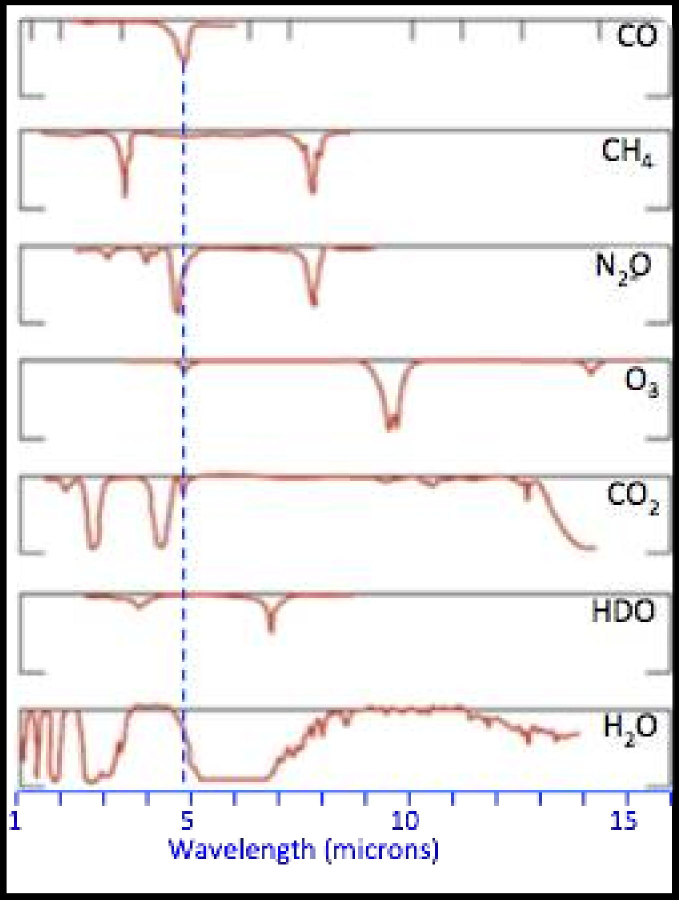
How to detect signs of (Earth-like) life?

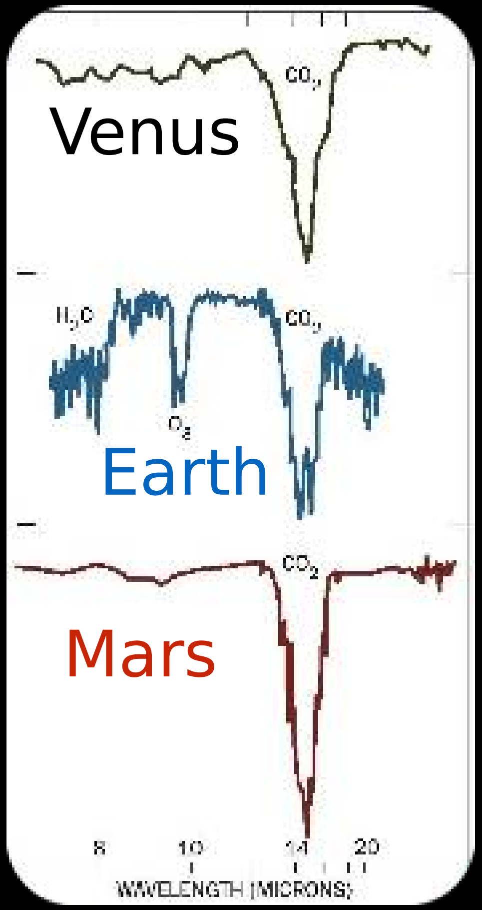
Detecting signs of life - absorption spectra

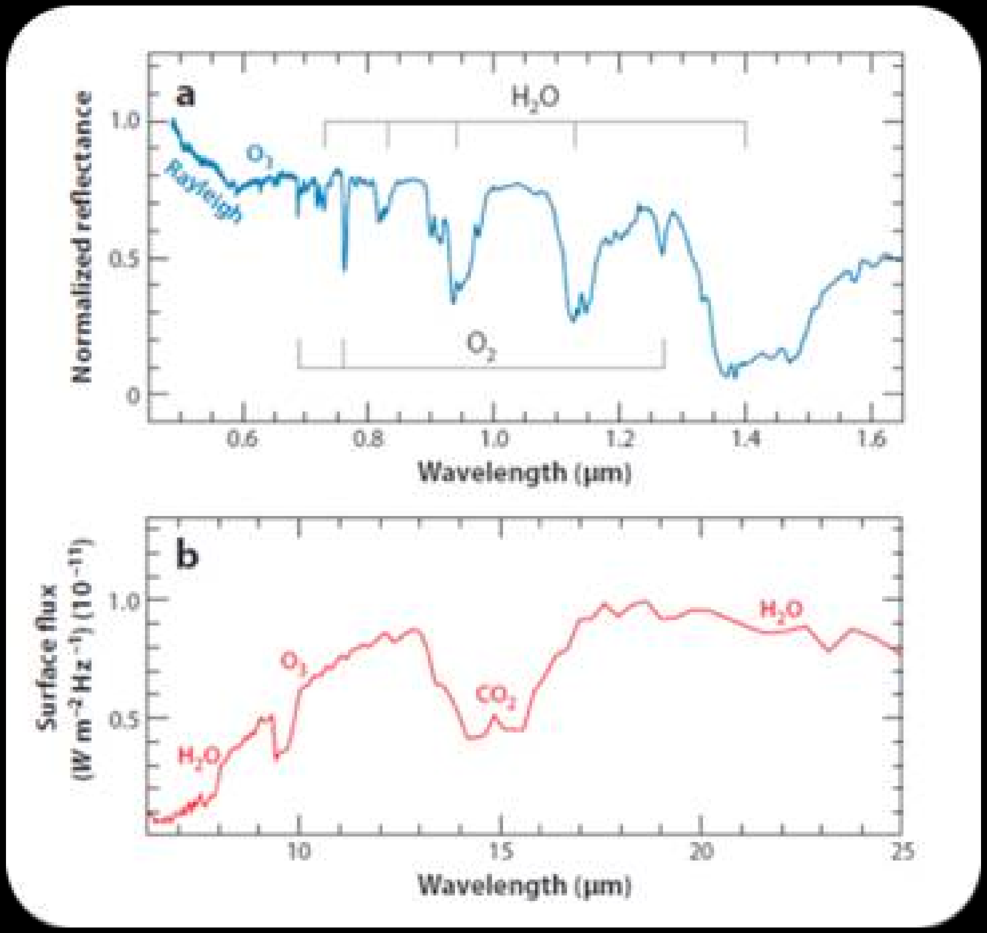
- Biosignature gases are *gases produced by life that accumulate in the atmosphere* (O_2, O_3, CH_4, H_2O, Ammonia NH_3).

- Stable disequilibrium (e.g., O_2 (via O_3) and CH_4).
  We need pairs, groups!

- 0.7micron-20micron in infrared is the best spectral fingerprint zone for biosignature gases.

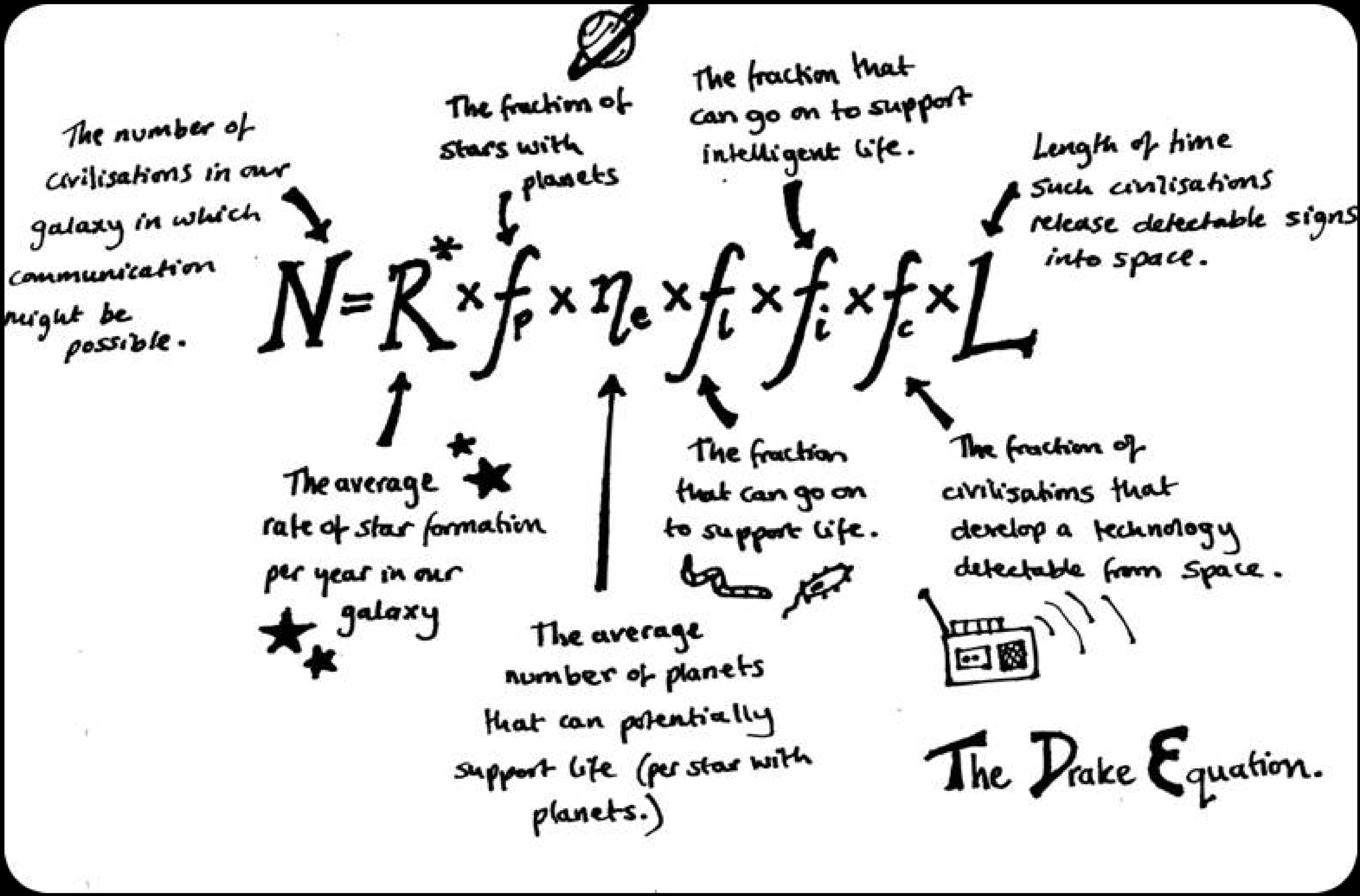






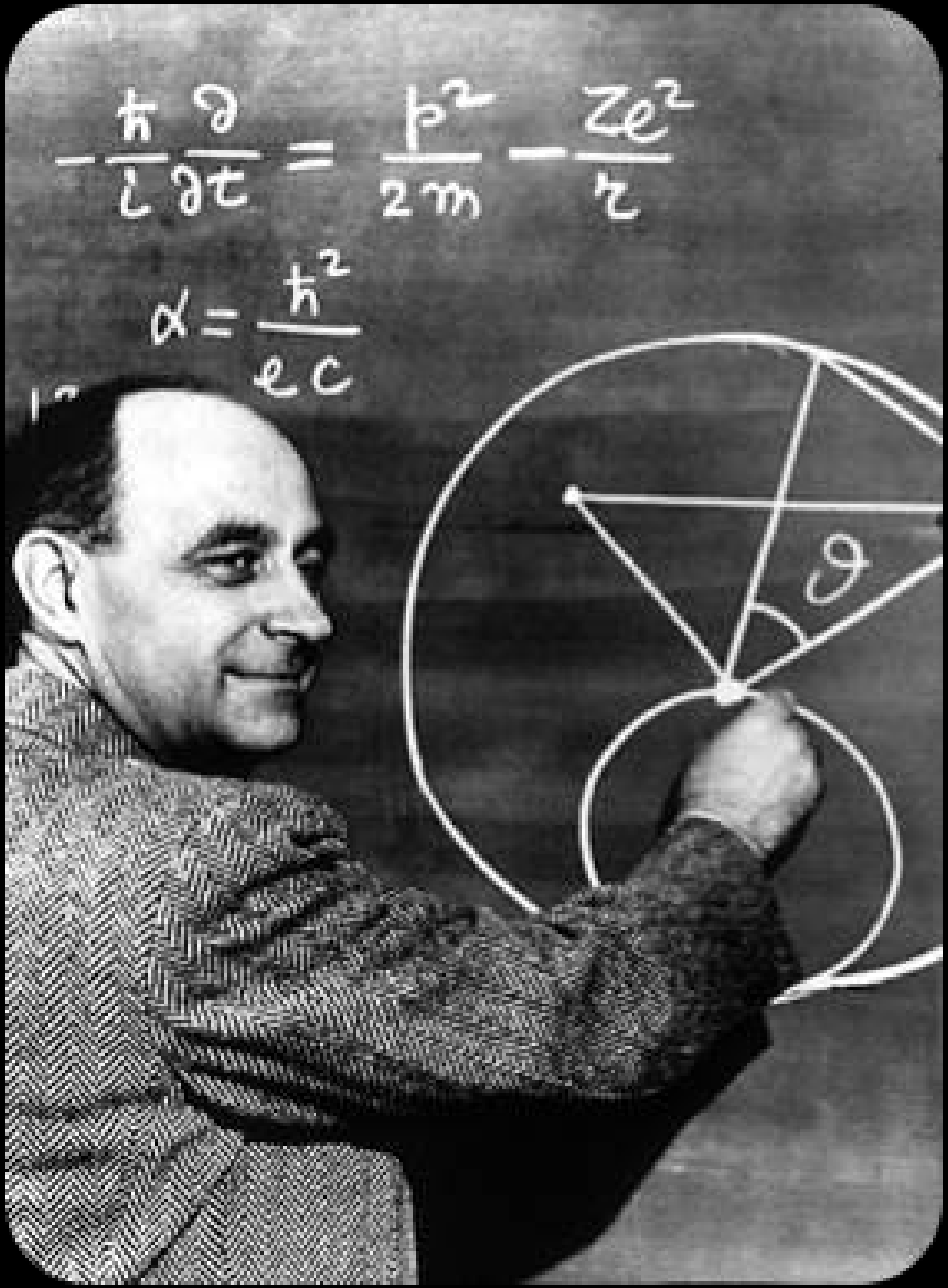
SETI?

SETI - Drake equation



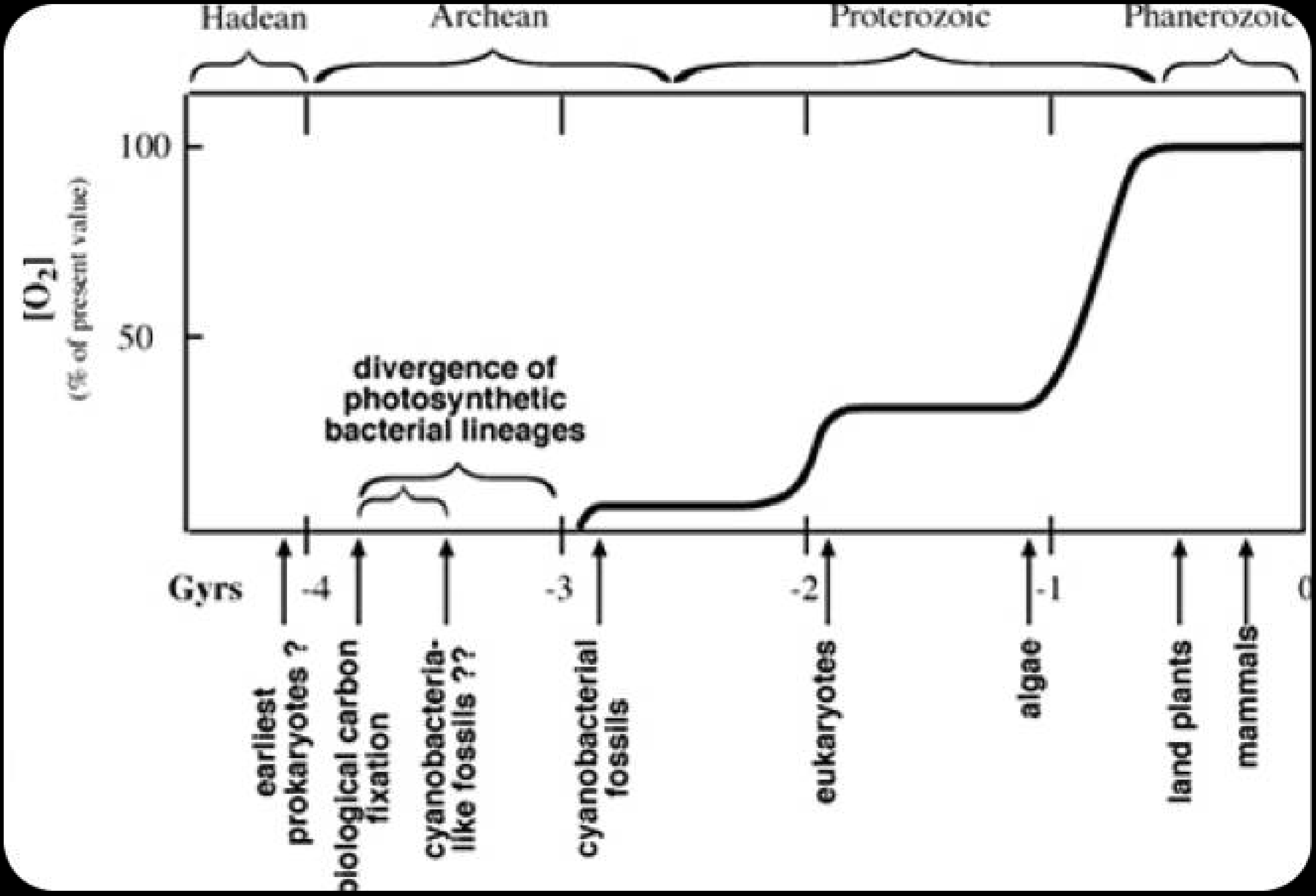
SETI - Fermi Paradox

- Where are they?
  - Communication cone limits?
  - No interest?
  - Not the right frequency?
  - Lost in all the data?
  - Or...lifetime of species is limited!



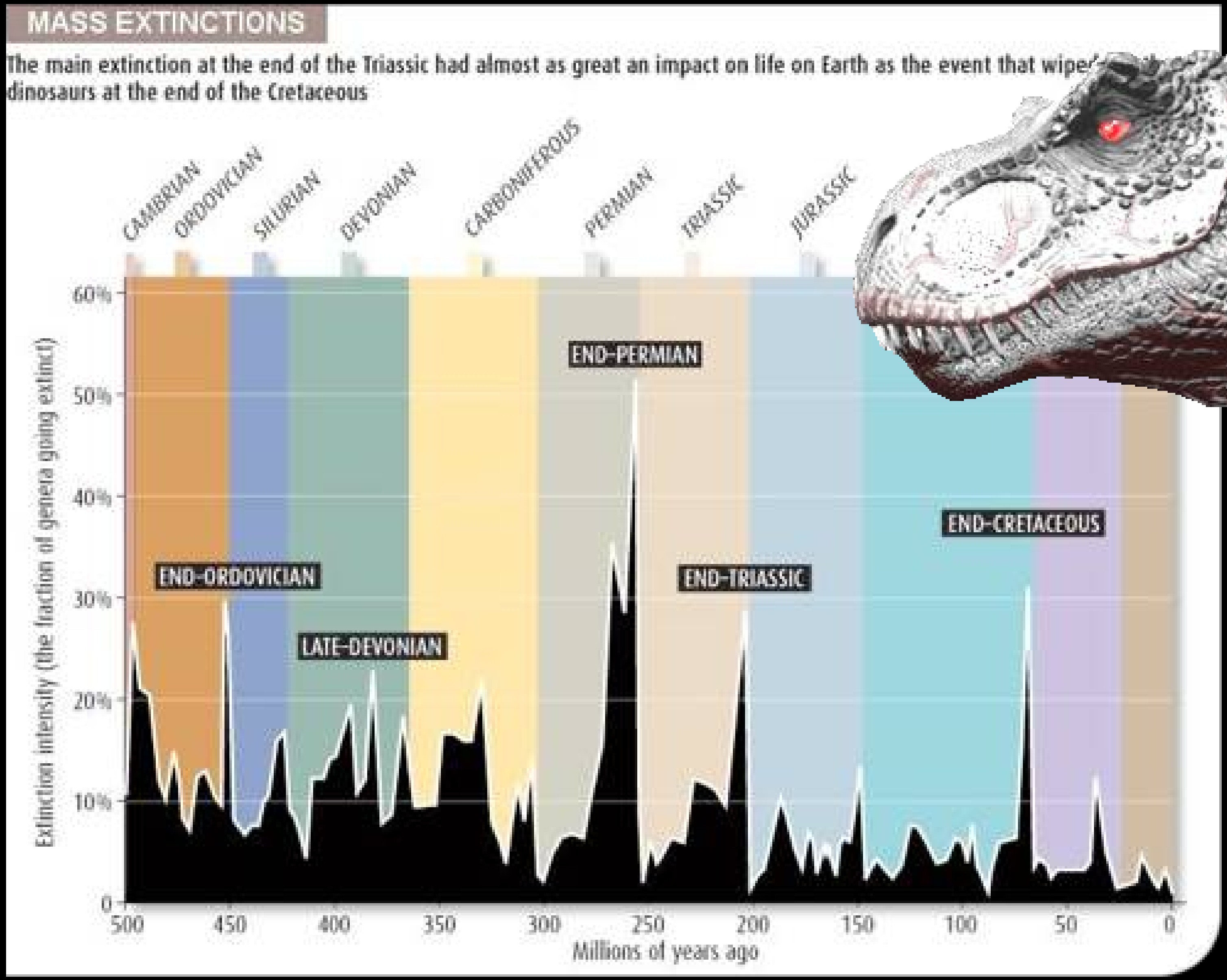
SETI: lifetime of species & environments

- Our environment has changed drastically in the last 4.5 Gyr!



SETI: lifetime of species & environments

- Our environment has changed drastically in the last 4.5 Gyr!
- Change is often associated with mass extinctions.



SETI: lifetime of species & environments

- Our environment has changed drastically in the last 4.5 Gyr!
- Our current “Anthropocene” might be of short duration.
- Do societies live short if they don’t develop skills to manipulate their planet?

Summary

- Habitability is complex.
- Defining "habitable zones=liquid water on surface" is the first step. But let us not be too Earth-centric. Atmospheric composition, volume, and surface properties can shape the classic habitable zone.
- Planet composition, mass, structure, as well as host star age & position in the Galaxy have a major say if a planet can be suitable for complex surface life.
- Biosignatures only work in couples, stable disequilibrium is the major fingerprint (e.g., CH_4/O_2). Often very non-unique, even oxygen.
- Major limit is the instability of the environment. Short lifetime of societies?

MORE QUESTIONS?

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