The Unifying Power of Astrobiology

Nader Haghighipour

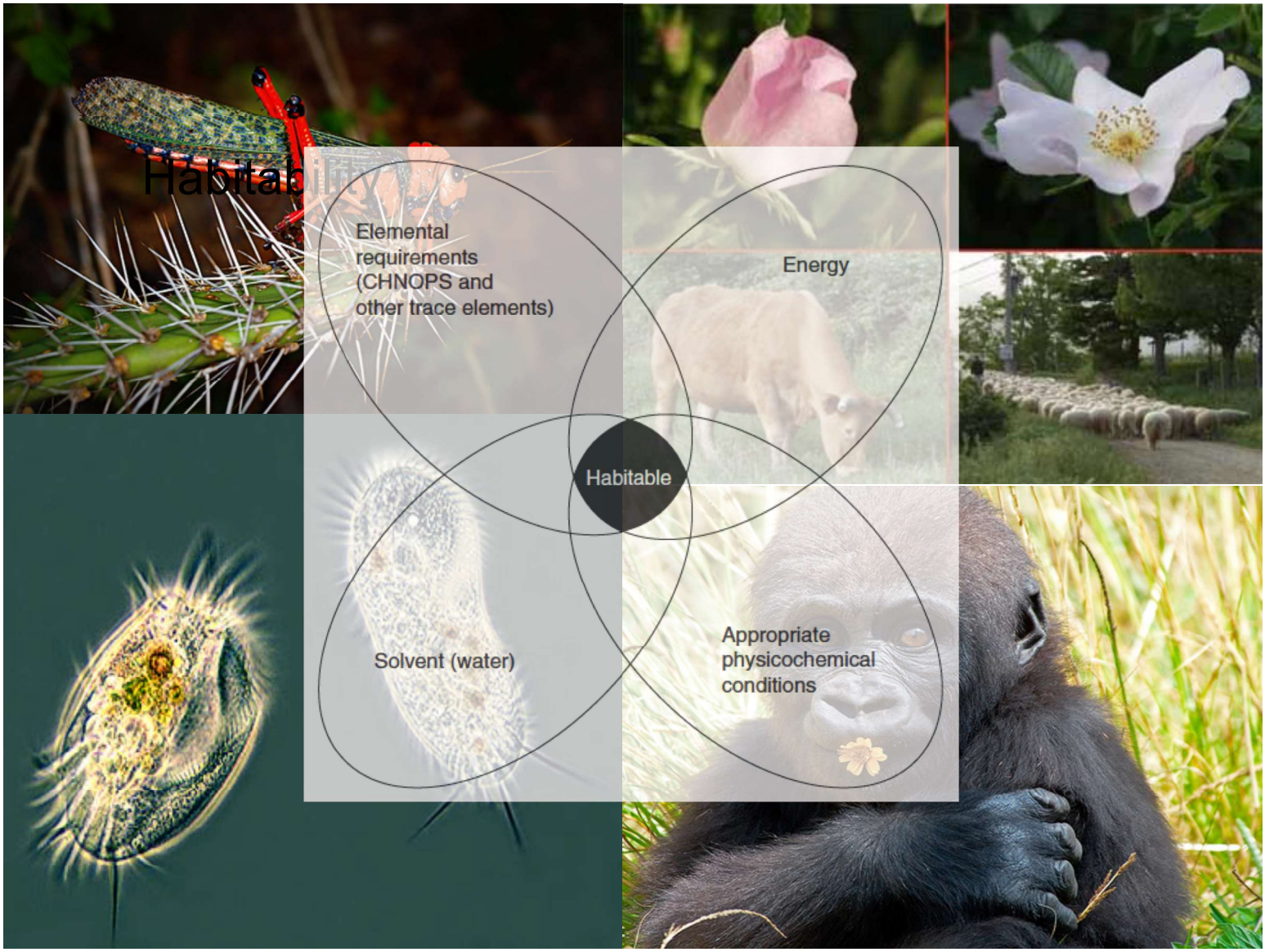
Institute for Astronomy, University of Hawaii-Manoa

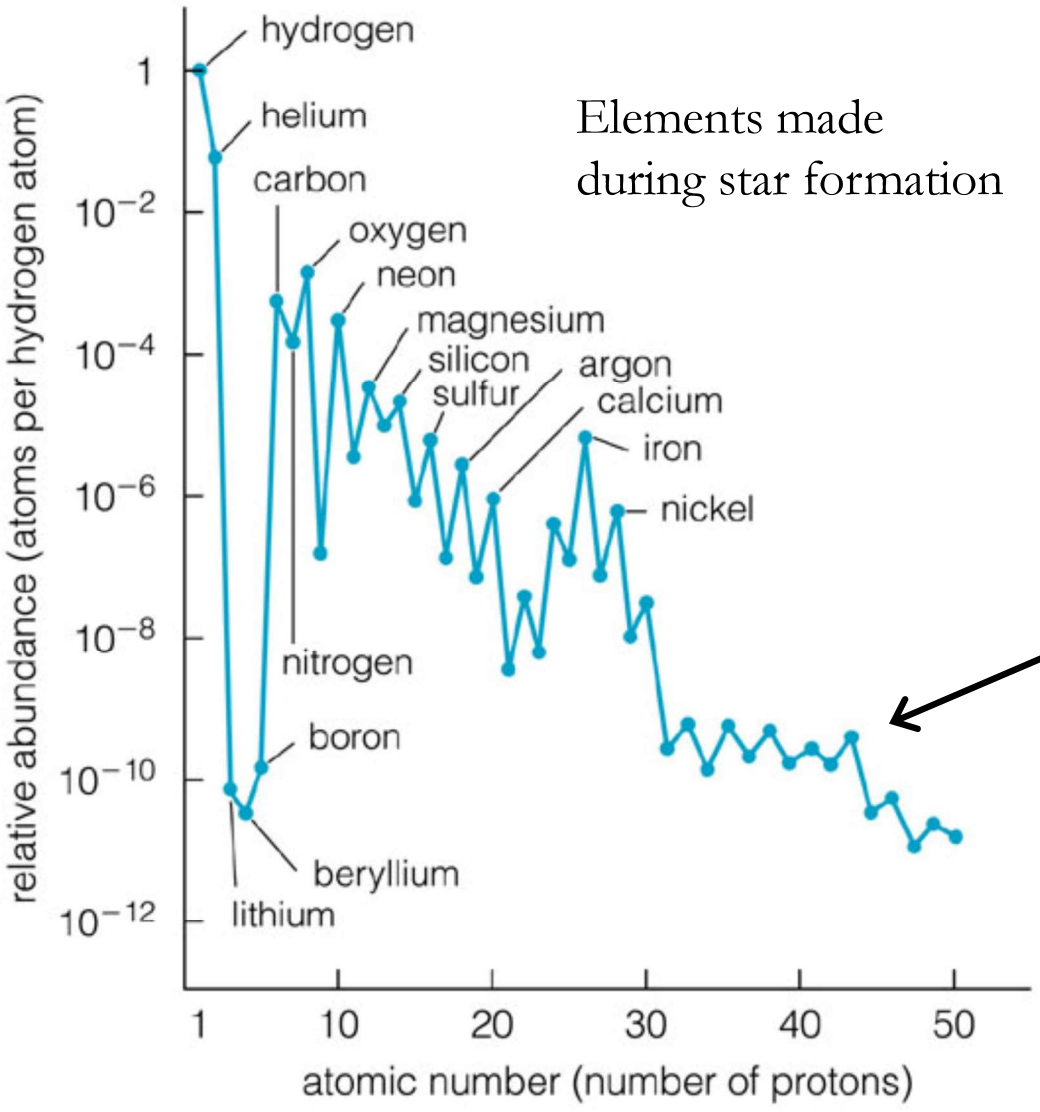
The goal of Astrobiology is to understand the origin of life and explore its existence elsewhere in the universe.

Habitability

- The only type of life known to us is the life on Earth
- The only life-harboring (habitable) planet known to us is Earth
- We can only detect Earthly life
- A habitable planet is a planet exactly similar to Earth, capable of developing and maintaining Earthly life

Habitability

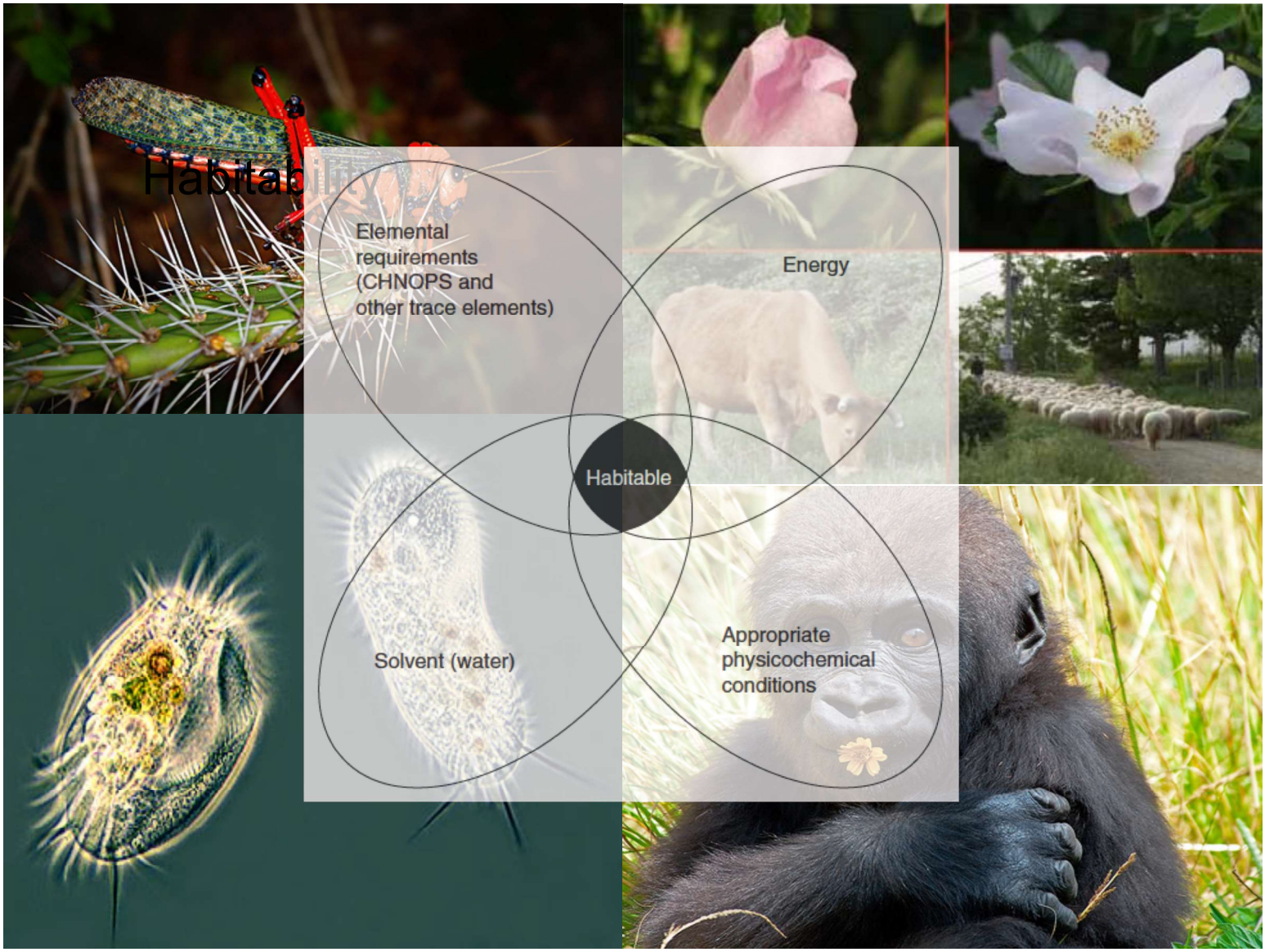




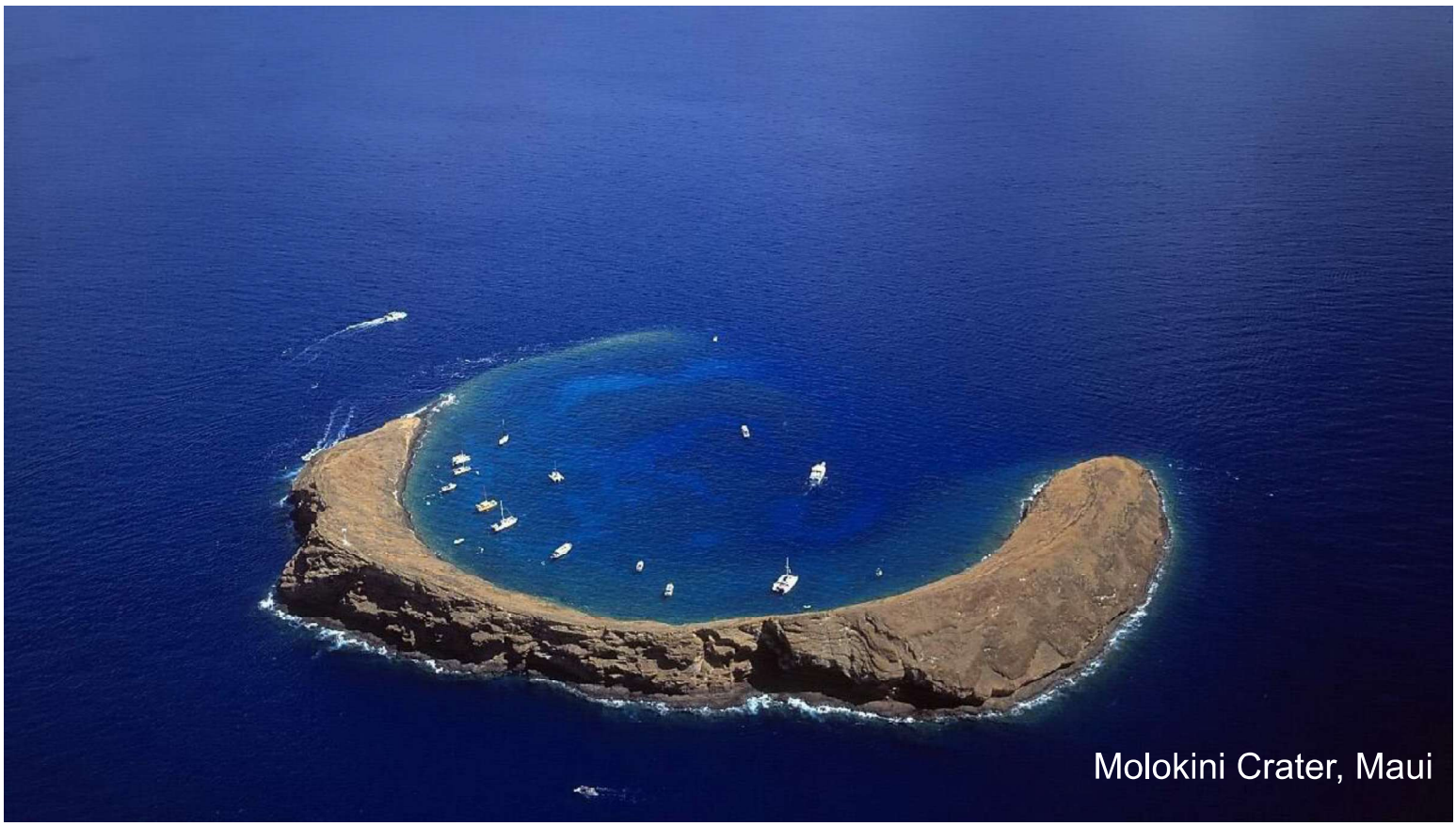
Elements made during star formation

Elements made during supernova explosion

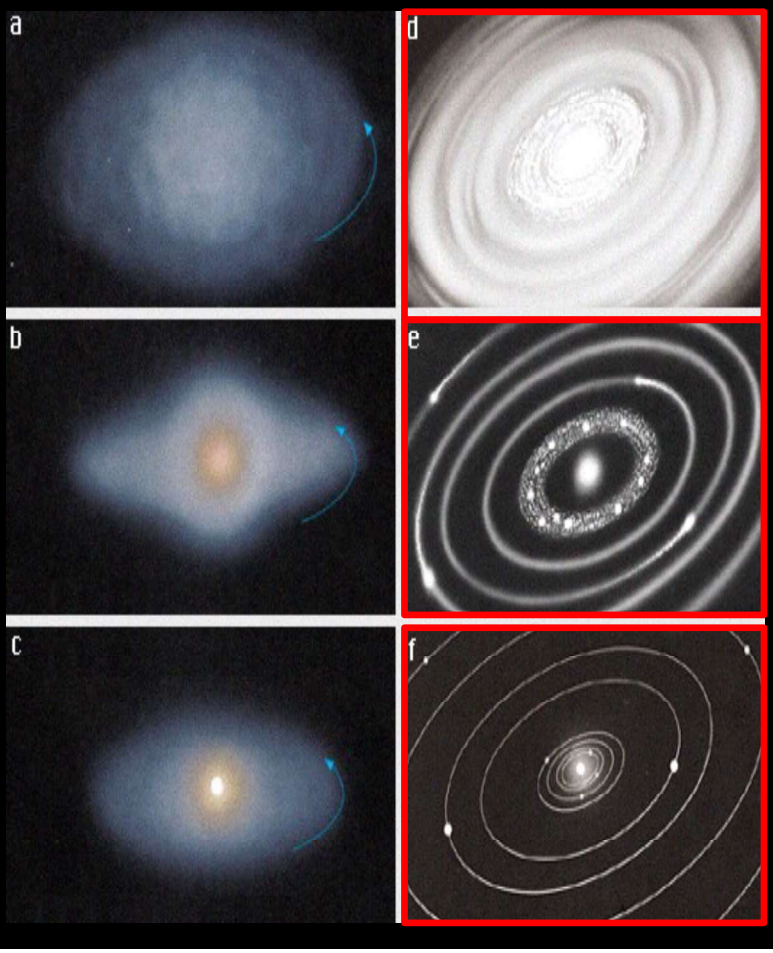
Habitability



What is the origin of Earth's water?



Formation of a Planetary System



d) Coagulation of dust grains to cm-sized objects and the formation of km-sized bodies

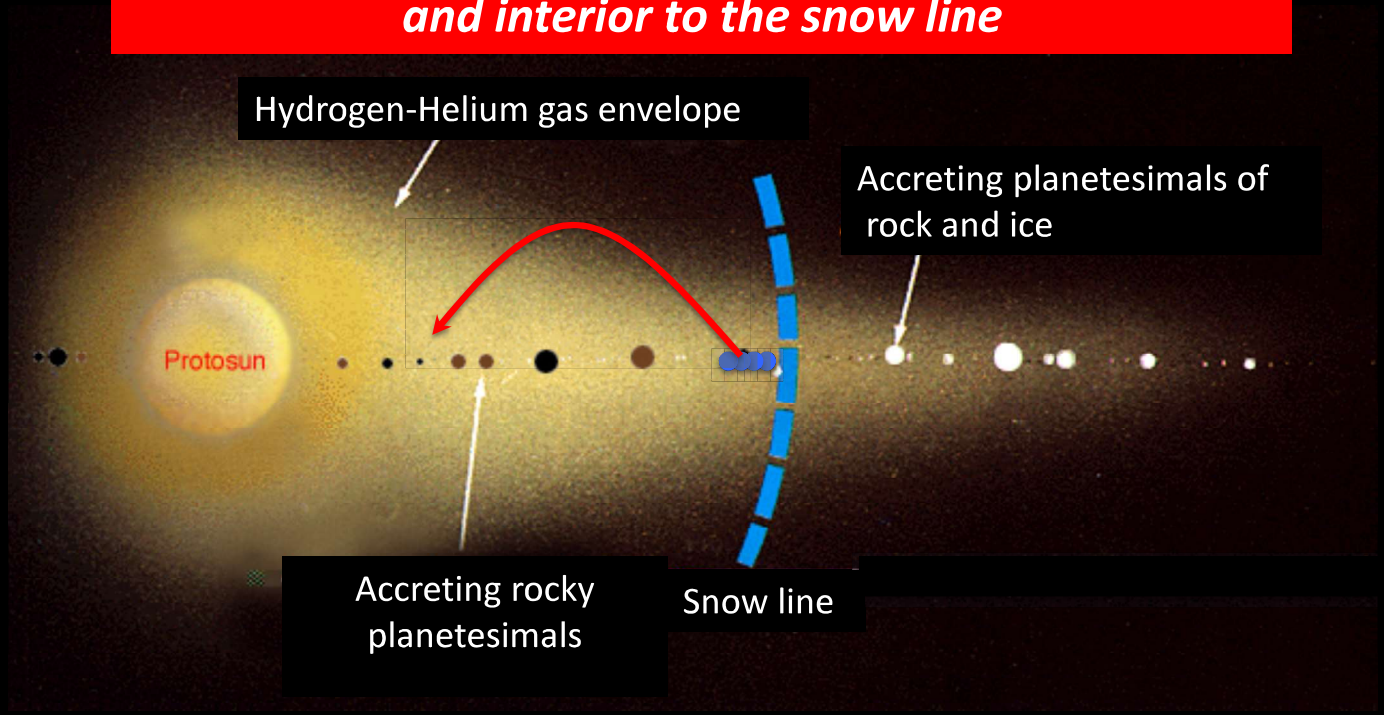
e) Collisional growth of km-sized bodies to Moon-to Mars-sized objects (planetary embryos)

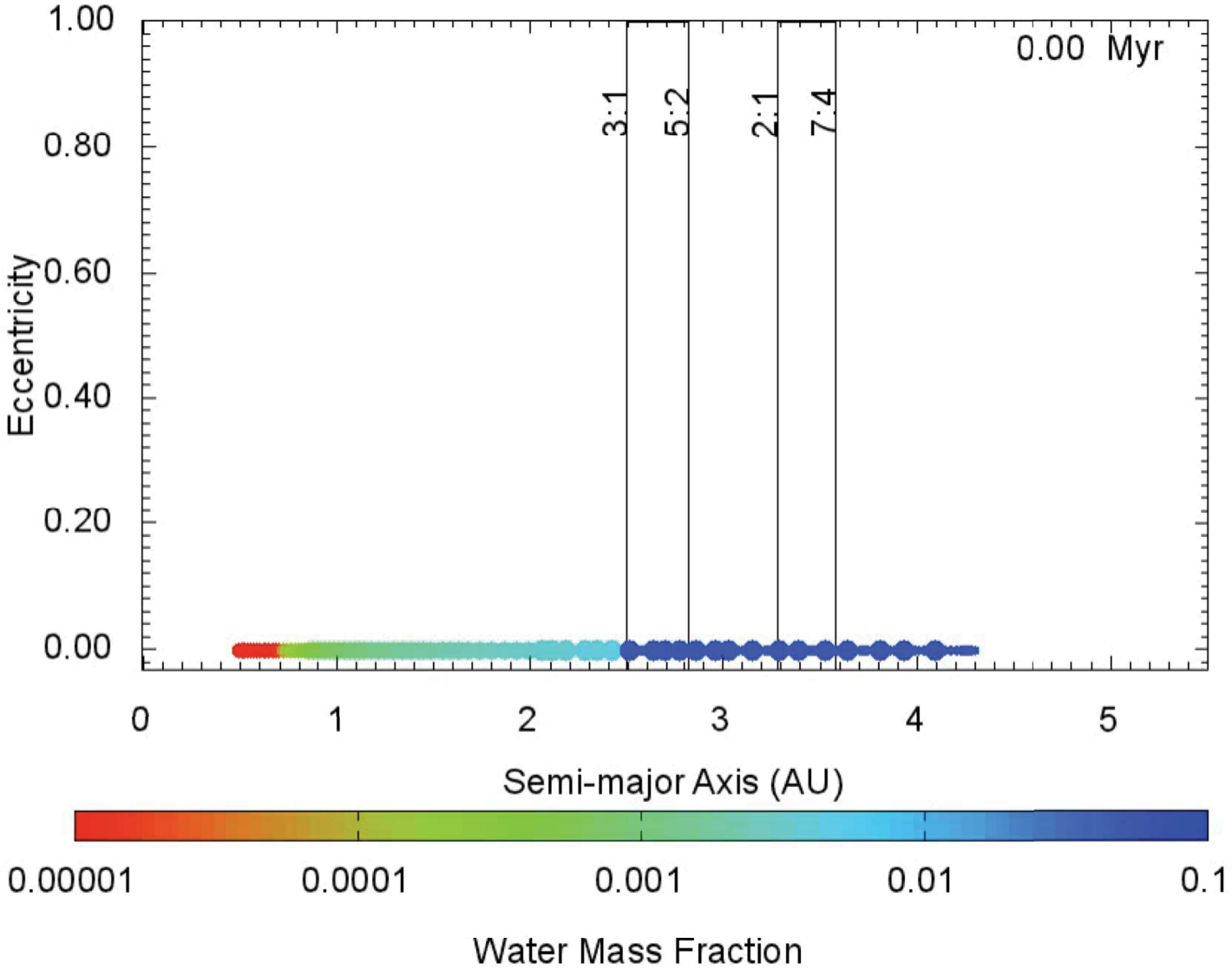
f) Big impacts and the formation of giant and terrestrial planets

Origin of Earth's Water

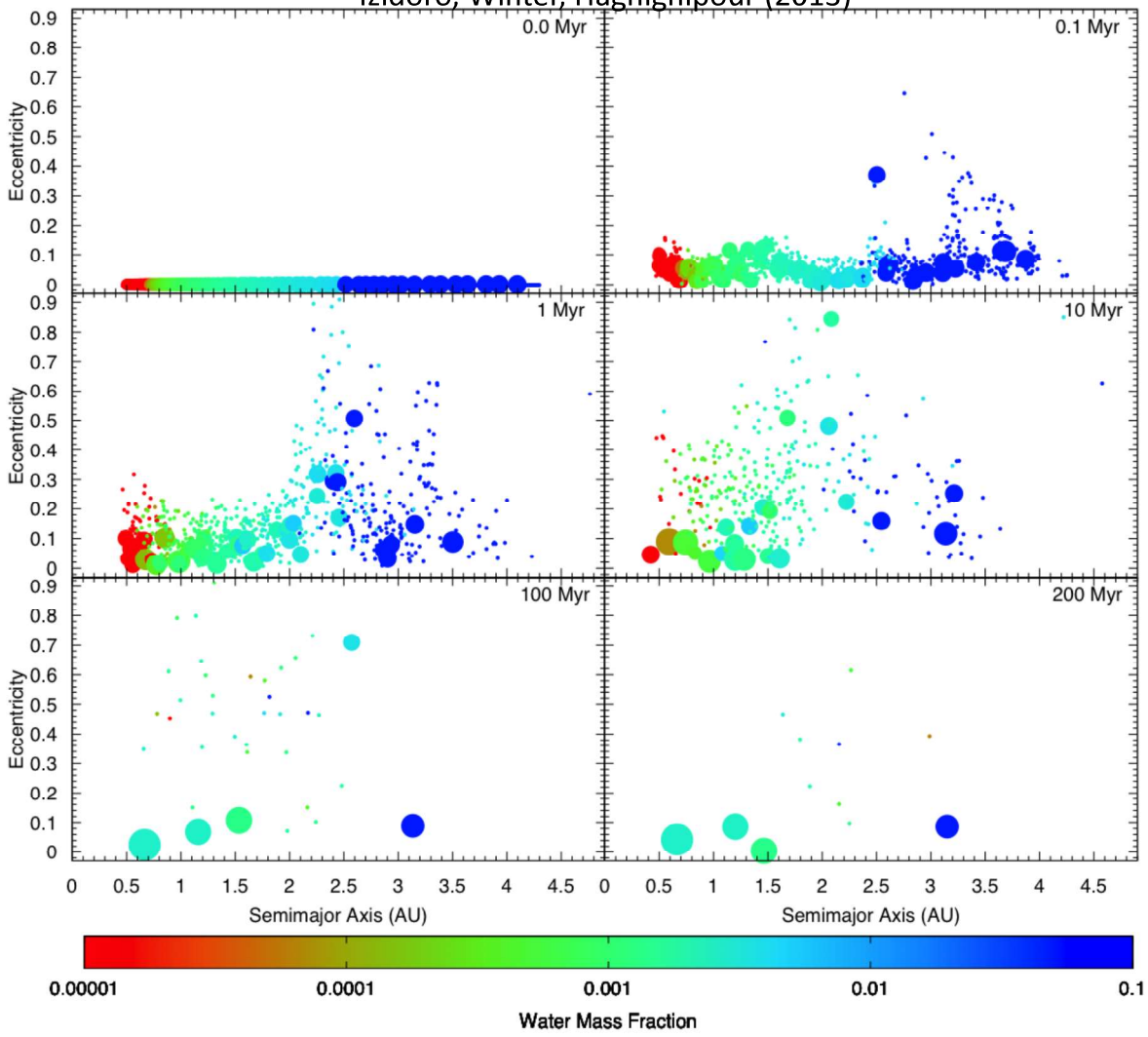
Because the building blocks of Earth are too close to the Sun to hold water, it would be natural to assume that water must have been added to Earth after its formation by collisions of objects originated from the regions beyond the snow line. However, calculations do not support that idea.

Water was delivered to Earth by large asteroids close and interior to the snow line

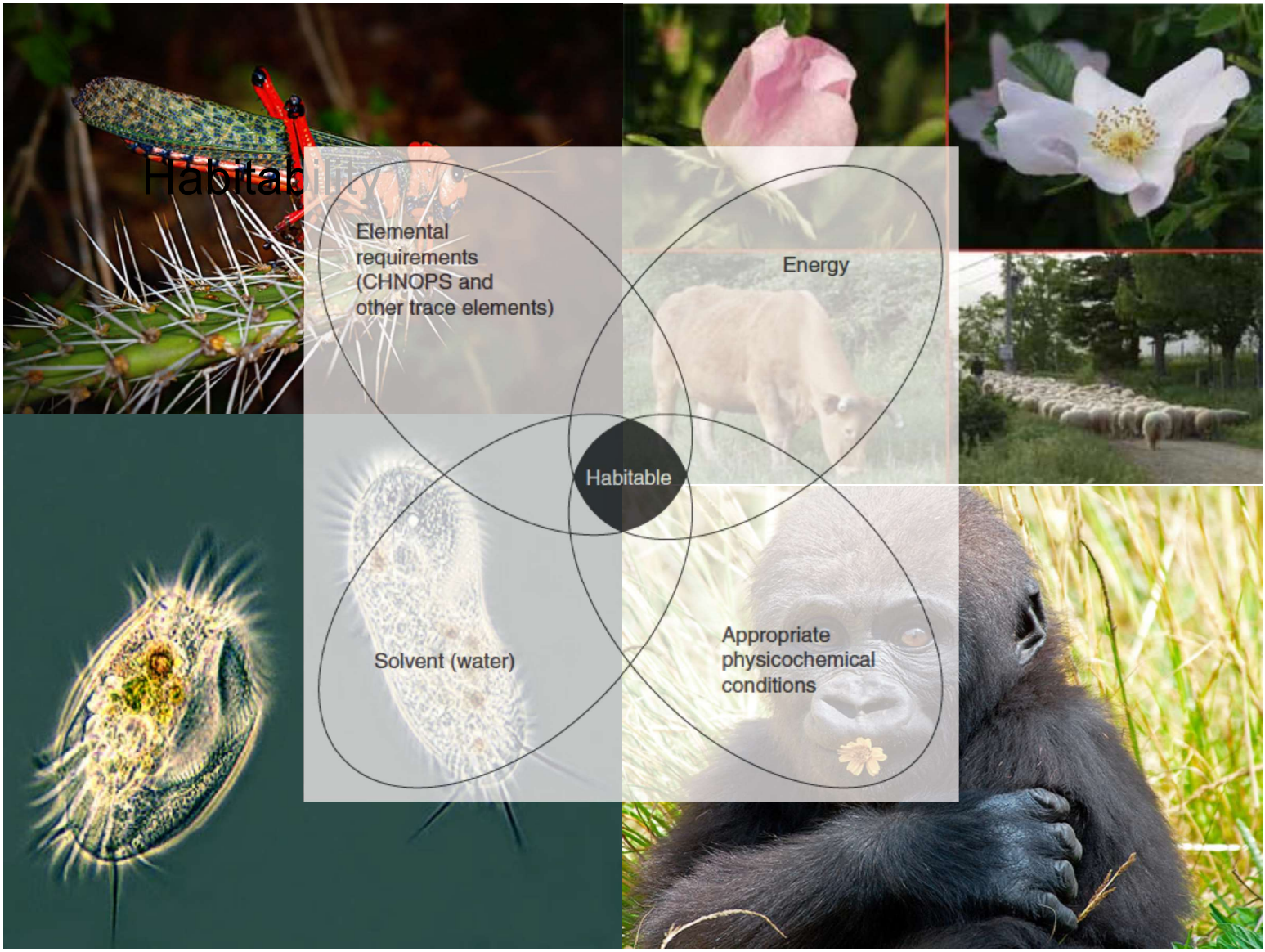



1.00
0.80
0.60
0.40
0.20
0.00
Eccentricity
0.00 Myr
3:1
5:2
2:1
7:4
0
1
2
3
4
5
Semi-major Axis (AU)
0.00001
0.0001
0.001
0.01
0.1
Water Mass Fraction

Izidoro, Winter, Haghighipour (2013)



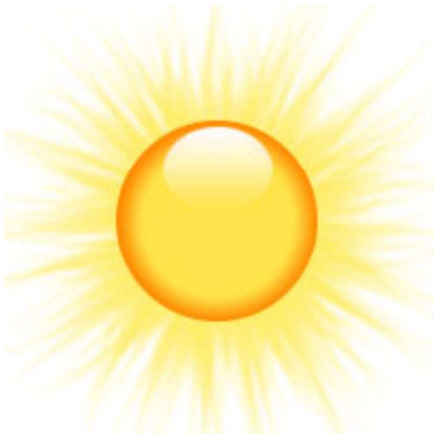
Habitability

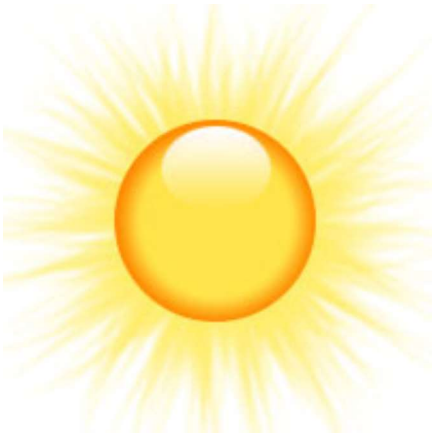


Energy comes from the Sun

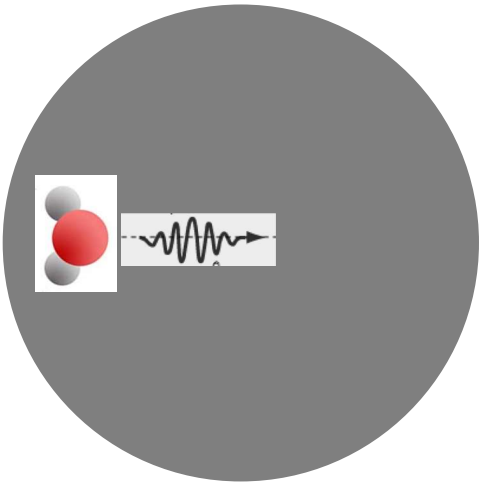
BUT

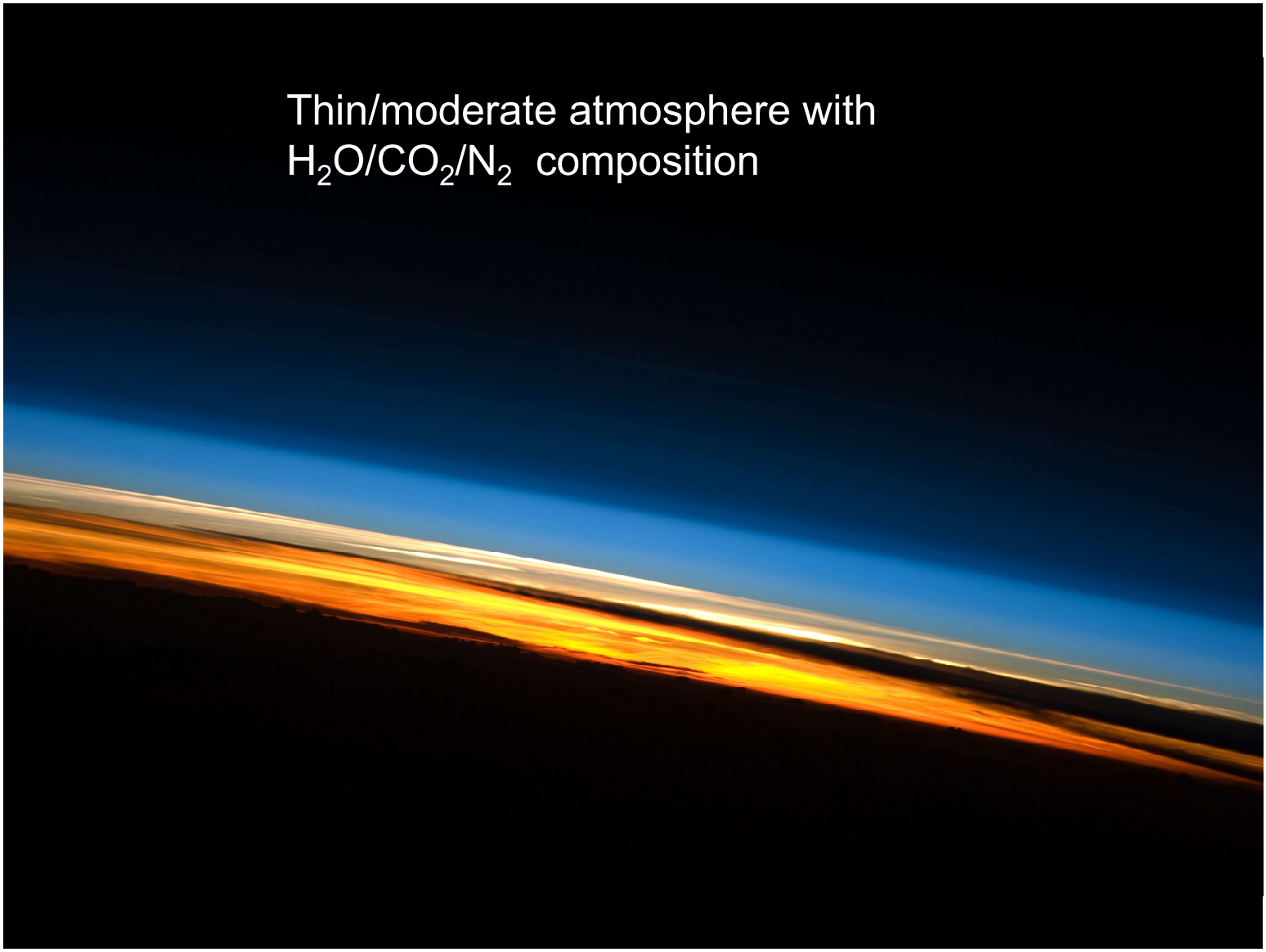
Earth is surrounded by atmosphere



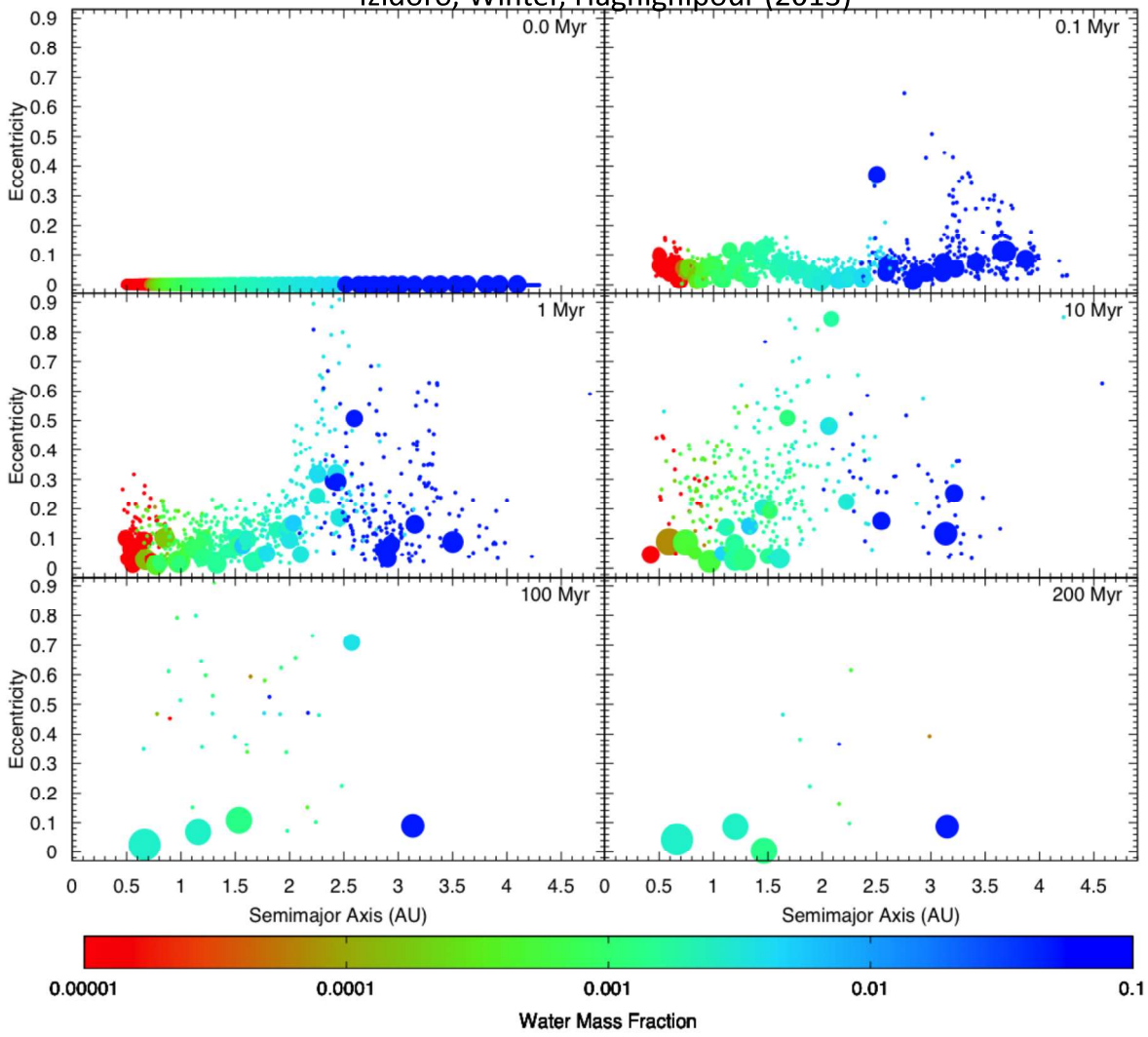


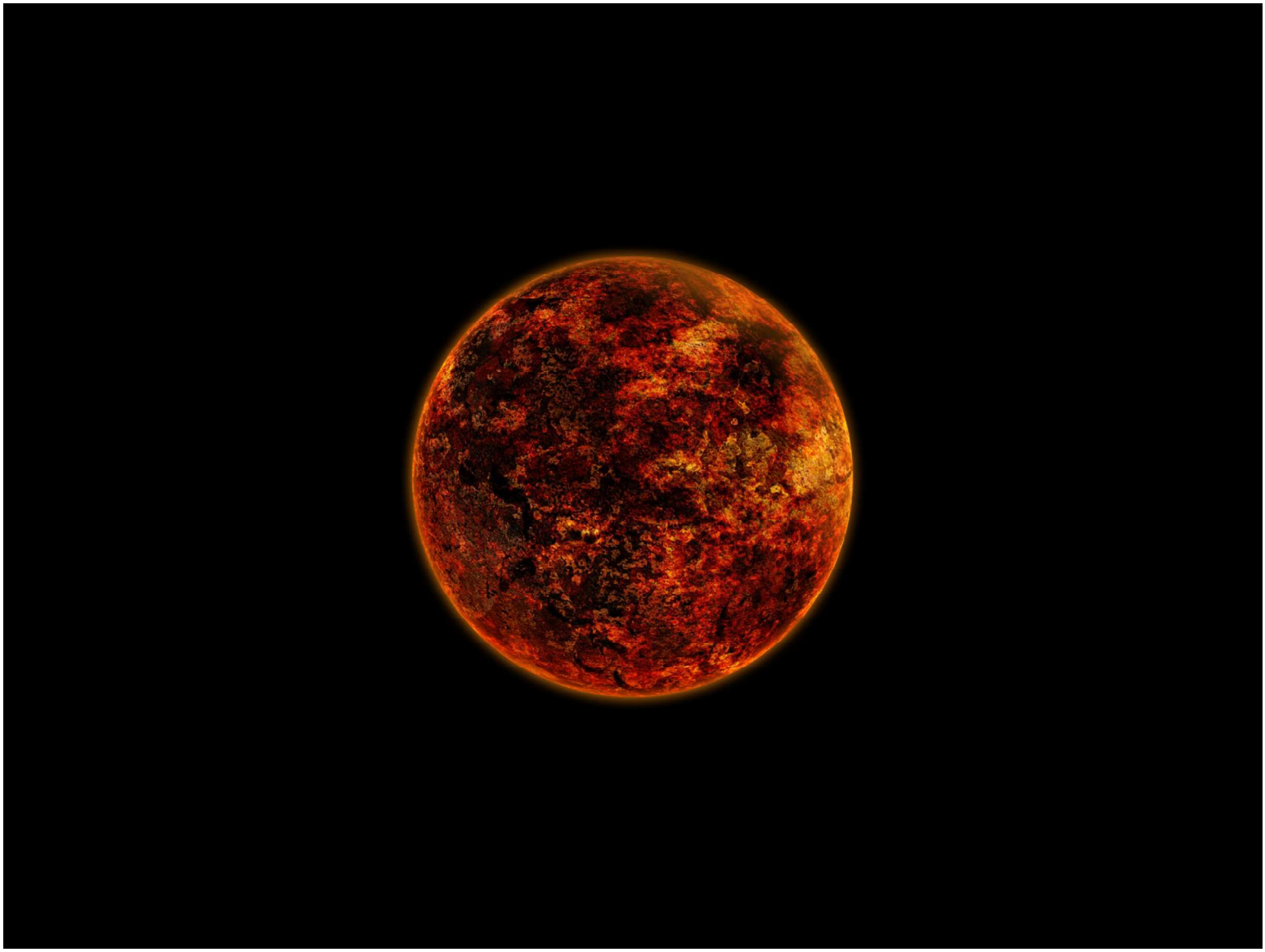
Planet's atmosphere is the medium where the stellar radiation is first received and the process of conversion from insolation to equilibrium temperature occurs.



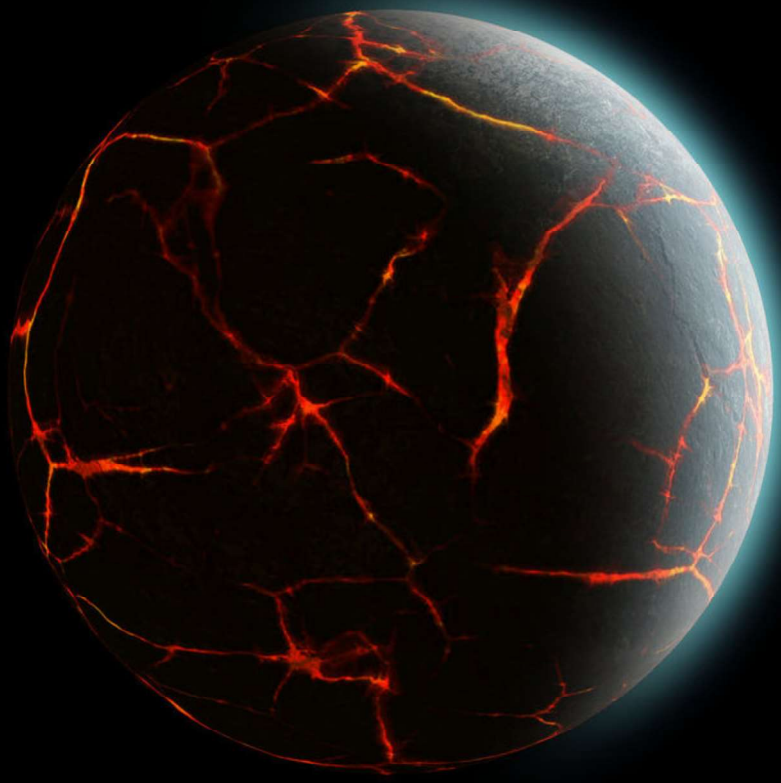

Thin/moderate atmosphere with
$H_2O/CO_2/N_2$ composition

Izidoro, Winter, Haghighipour (2013)





Out-gassing during the cooling process



Greenhouse Effect

Uniform Temperature

CO_2 Cycle

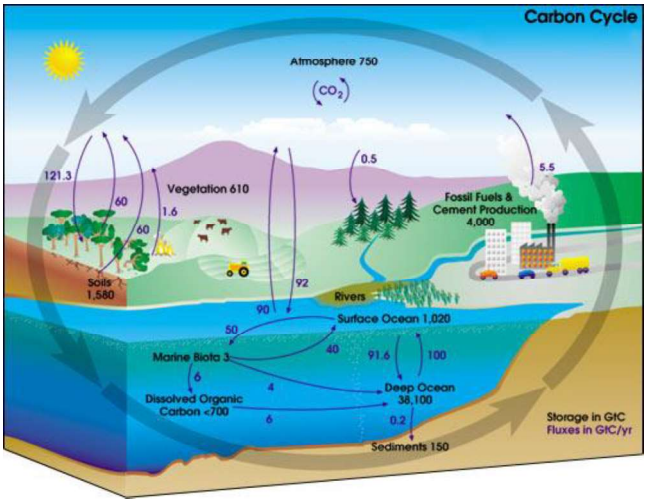
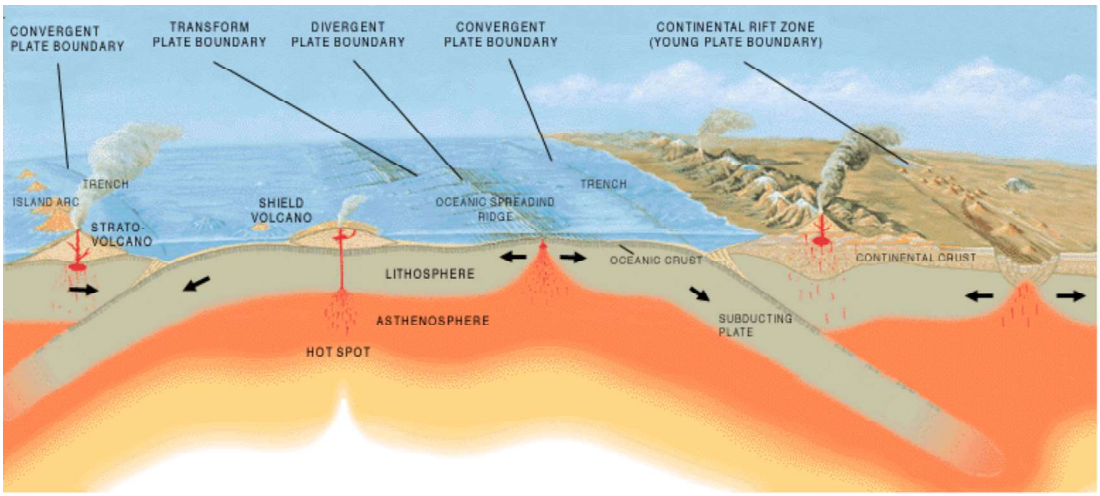
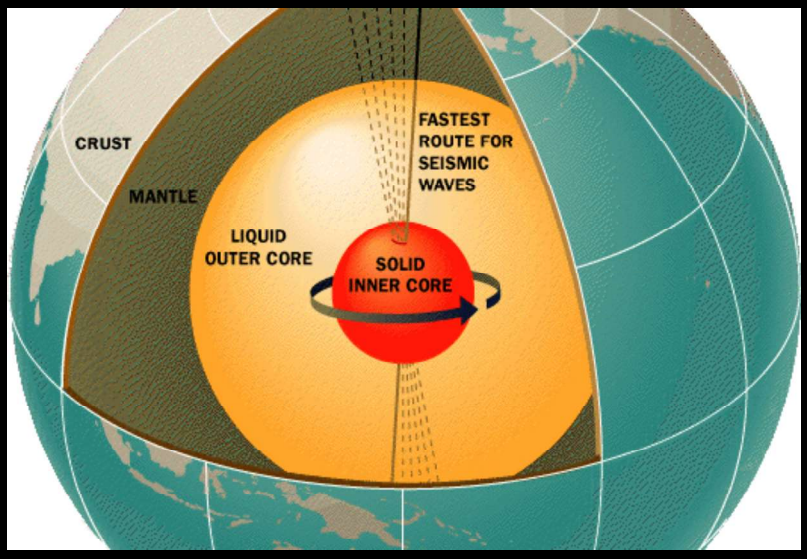


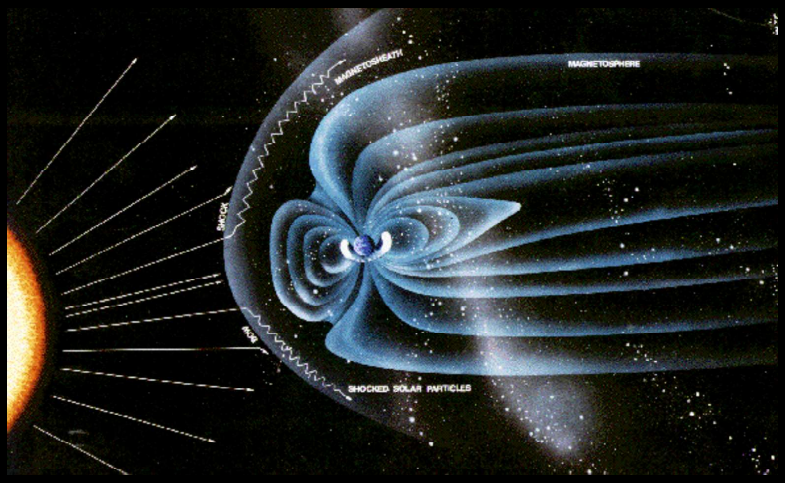
Plate Tectonics

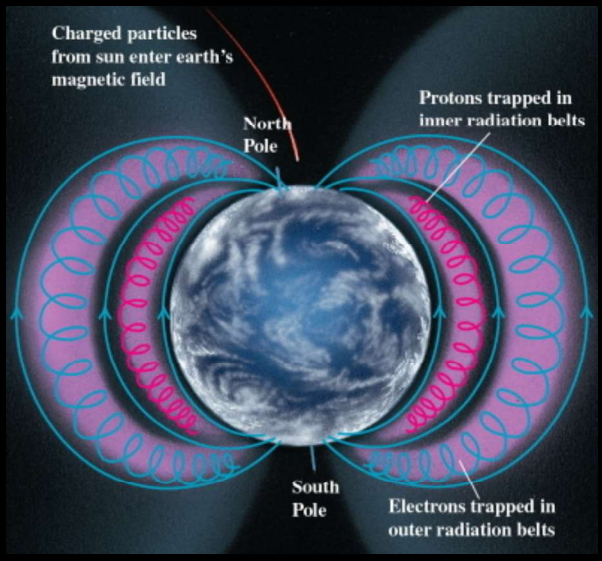


Magnetic Field

Protection against harmful radiations

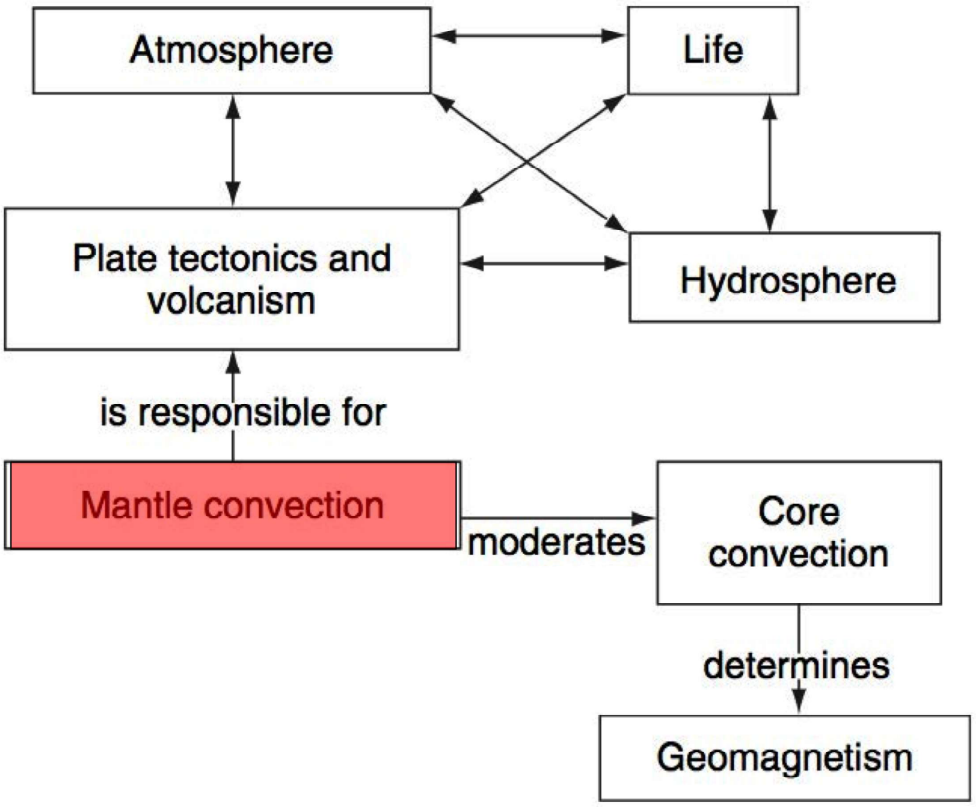






The Earth system:

everything is coupled



Stevenson 2007

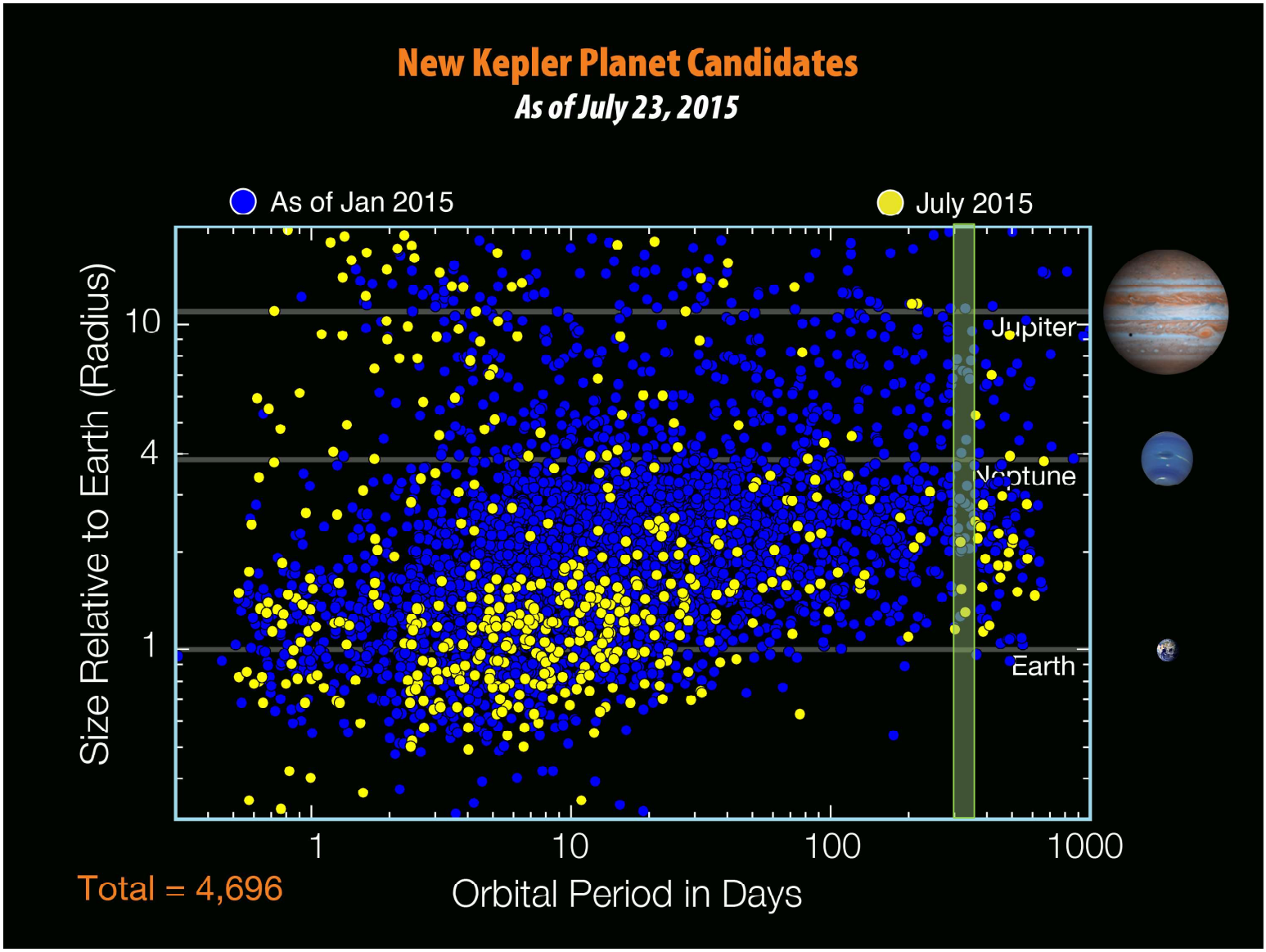
How do we search for and identify a habitable extrasolar planet?

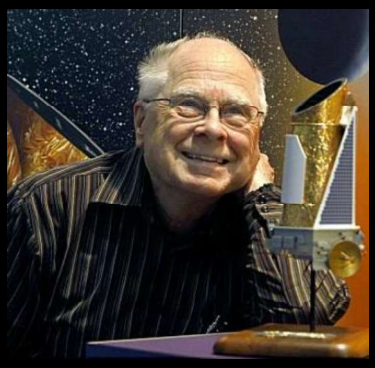
We need a gauge, a standard that allows us to assess the capability of a planet in developing and maintaining ***Earthly life*****.**

That gauge is called **HABITABLE ZONE (HZ)**

The definition of the HZ

1) can only be based on the current state of life on Earth, and that Earth is the only known habitable planet,
2) must be quantitative, meaning that it must contain items that can be measured and their quantities can be used to assess habitability.

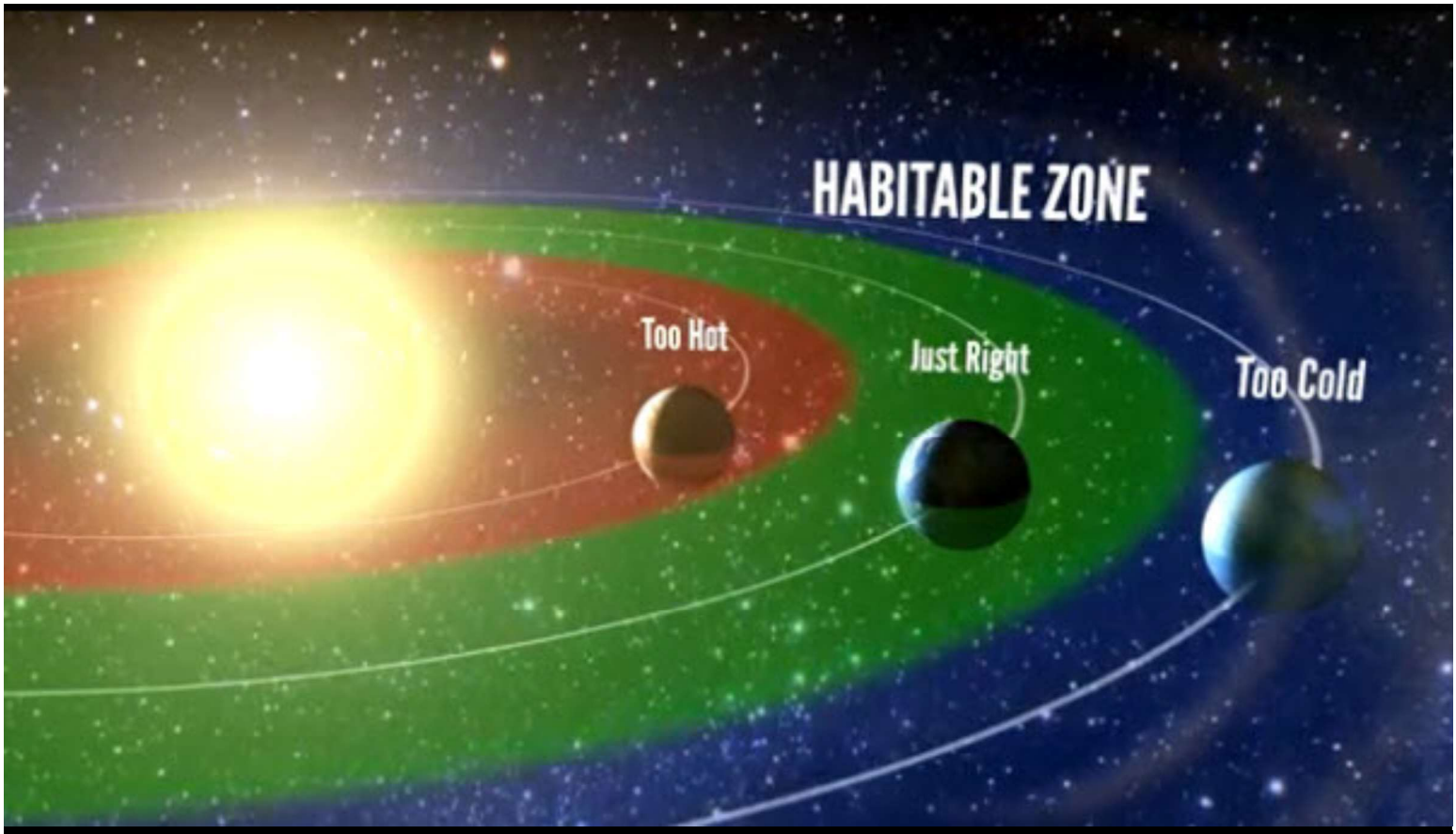

New Kepler Planet Candidates
As of July 23, 2015
As of Jan 2015
July 2015
Size Relative to Earth (Radius)
10
4
1
Jupiter
Neptune
Earth
1
10
100
1000
Orbital Period in Days
Total = 4,696

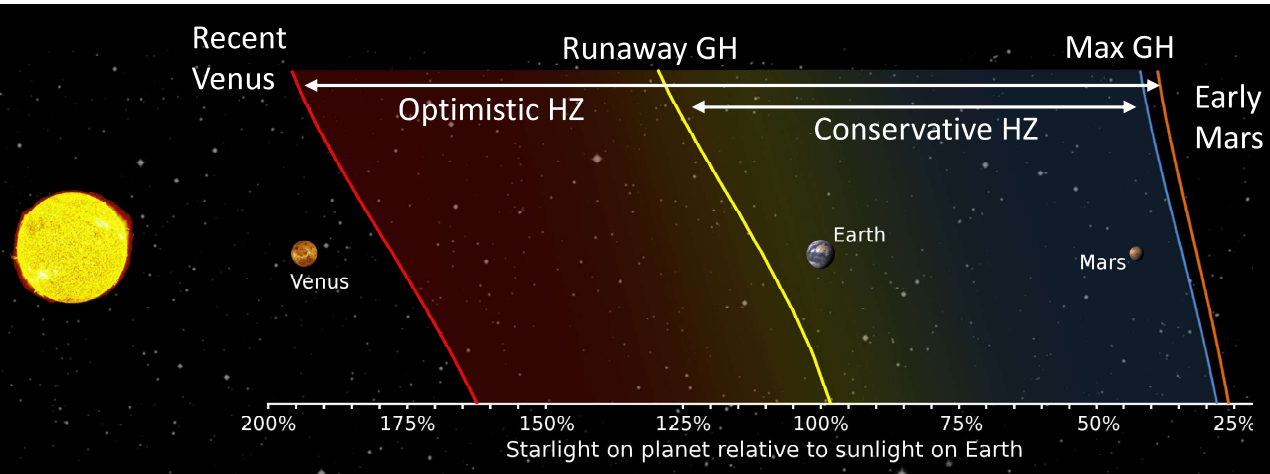

Kepler HZ Working Group

Natalie Batalha
Bill Borucki
David Ciardi
Nader Haghighipour
Lisa Kaltenegger
Stephen Kane
Jim Kasting
Ravi Kopparapu
Dimitar Sasselov
Franck Selsis



The HZ is an annulus around a star where a rocky planet with a $CO_2/H_2O/N_2$ atmosphere, sufficiently large water content (such as on Earth), and similar geodynamical properties can host liquid water permanently on its solid surface



Conservative Estimate of the HZ

Inner edge (Moist/runaway greenhouse limit): All surface water is evaporated, lost by photodissociation and escape of hydrogen to space. (For Sun~0.97-0.99 AU)

Outer edge (Maximum Greenhouse limit): The maximum greenhouse effect of a CO_2 dominated atmosphere (for Sun ~1.68 AU)

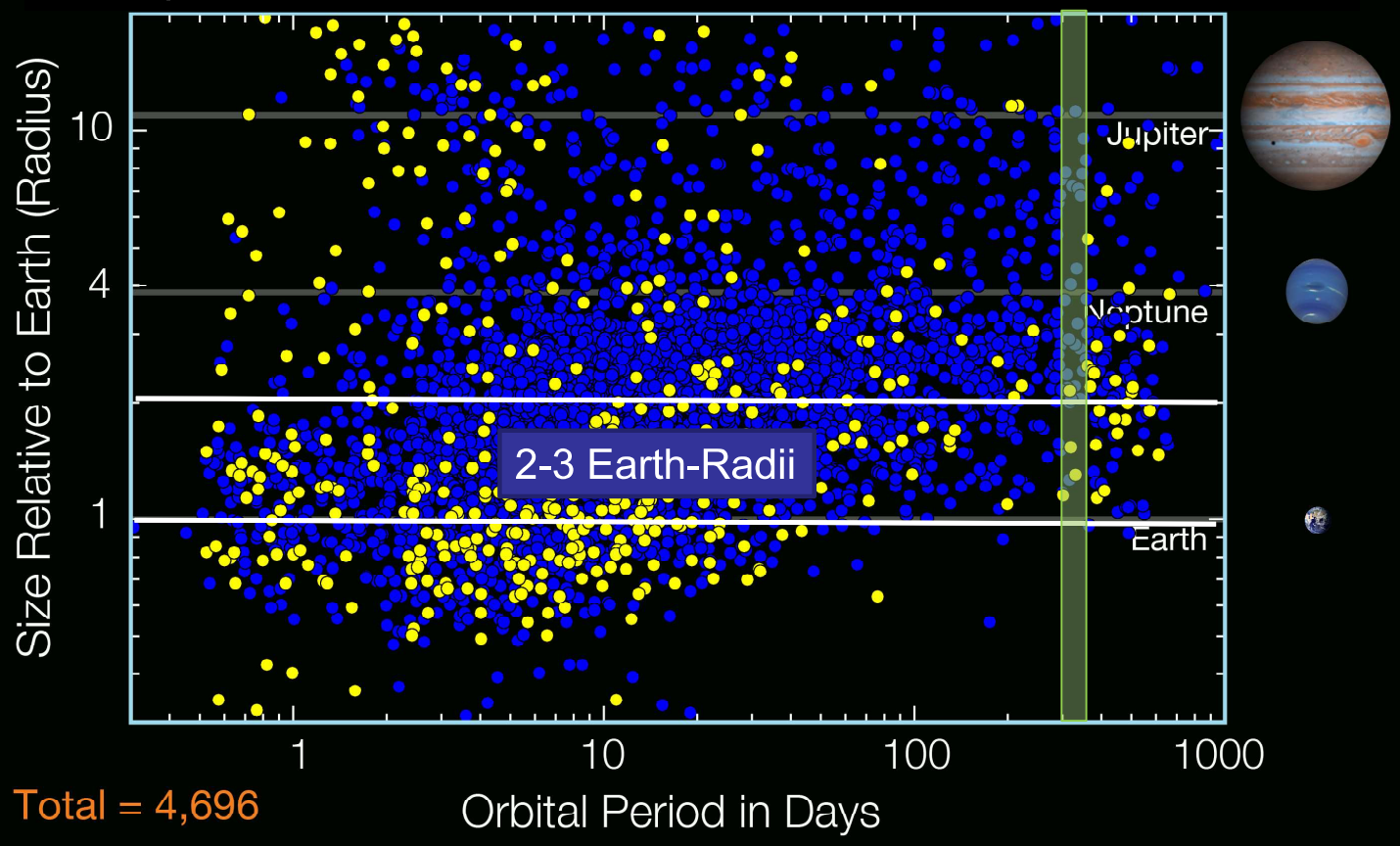
Optimistic Estimate of the HZ

Inner edge (Recent Venus limit): Empirical estimate based on the observation that Venus has already lost its water prior to ~ 1 Gyr ago (For Sun ~ 0.75 AU,)

Outer edge (Early Mars limit): Empirical estimate based on the inferred presence of liquid water on Mars' surface at or before 3.8 Gyr. (For Sun ~ 1.76 AU)

New Kepler Planet Candidates

We consider planets with radii ranging from 1 to 2 Earth-radii because models of the interior of Earth suggest that planets of such radii may develop similar tectonic activities as that in Earth.



Total = 4,696

A total of 114 HZ candidates have been identified (all in optimistic HZ)
Of these candidates, 63 in the conservative HZ

Rocky planets (radius smaller than 2 Earth-radii)
29 in the optimistic HZ of which 20 are in the conservative HZ

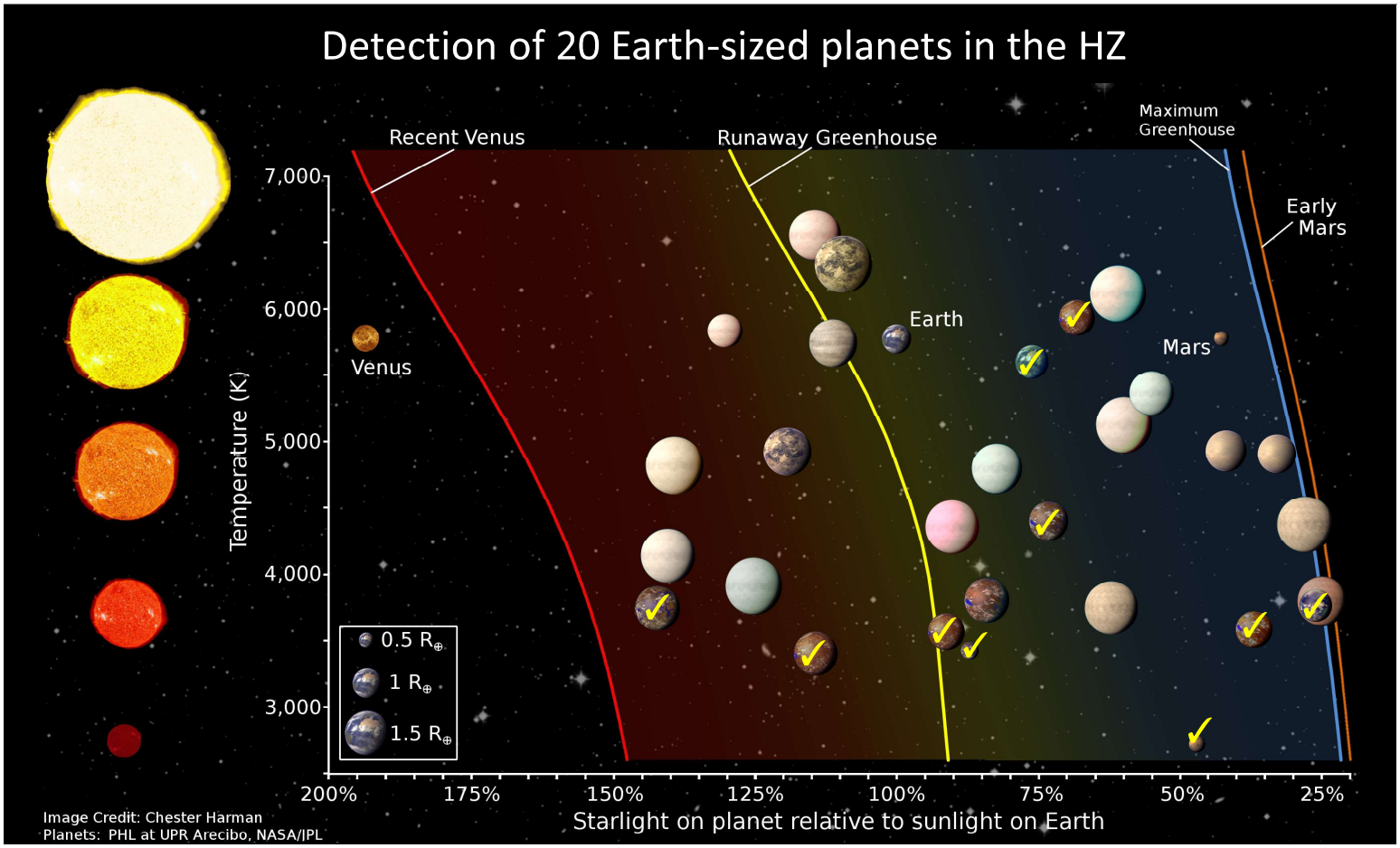
A total of 8 Saturn- to Jupiter-sized planets identified in the optimistic HZ
Of these candidates, 4 are in the conservative HZ

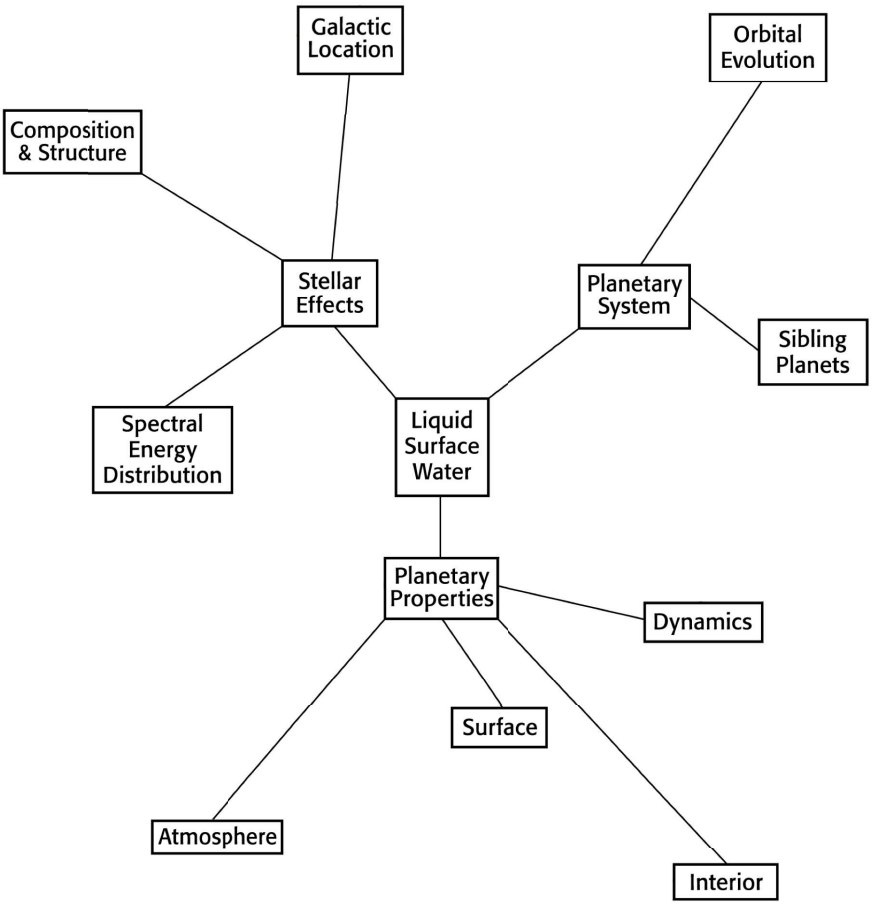
HZ candidates with any radius in conservative HZ (Kane, Haghighipour et al 2016)

KOI Name	Kepler Name	P (days)	a (AU)	R_p ($R_\oplus$)	$T_{\rm eff}$ (K)	$R_\star$ ($R_\odot$)	F_p ($F_\oplus$)	FPP (%)
K00433.02		328.23996 ± 0.00036	0.917	11.24 ± 0.85	5234 ± 103	0.85 ± 0.06	0.58 ± 0.13	0.270
K00518.03	Kepler-174 d	247.35373 ± 0.00200	0.677	2.19 ± 0.13	4880 ± 126	0.62 ± 0.03	0.43 ± 0.09	0.005
K00571.05	Kepler-186 f	129.94411 ± 0.00125	0.432	1.17 ± 0.08	3755 ± 90	0.52 ± 0.02	0.26 ± 0.04	15.840
K00701.04	Kepler-62 f	267.29099 ± 0.00500	0.718	1.41 ± 0.07	4925 ± 70	0.64 ± 0.02	0.42 ± 0.05	0.122
K00841.04		269.29425 ± 0.00423	0.812	3.09 ± 0.34	5251 ± 105	0.82 ± 0.05	0.69 ± 0.15	0.161
K00854.01		56.05605 ± 0.00025	0.226	2.05 ± 0.24	3593 ± 79	0.49 ± 0.04	0.71 ± 0.18	0.005
K00868.01		235.99802 ± 0.00038	0.613	11.00 ± 0.53	4245 ± 85	0.66 ± 0.03	0.33 ± 0.05	6.834
K00881.02		226.89047 ± 0.00110	0.668	4.68 ± 0.56	5067 ± 102	0.75 ± 0.04	0.75 ± 0.14	0.240
K00902.01		83.92508 ± 0.00014	0.304	5.04 ± 0.50	3960 ± 124	0.51 ± 0.04	0.62 ± 0.18	100.000
K00959.01		12.71379 ± 0.00000	0.049	2.31 ± 0.00	2661 ± 0	0.12 ± 0.00	0.26 ± 0.00	100.000

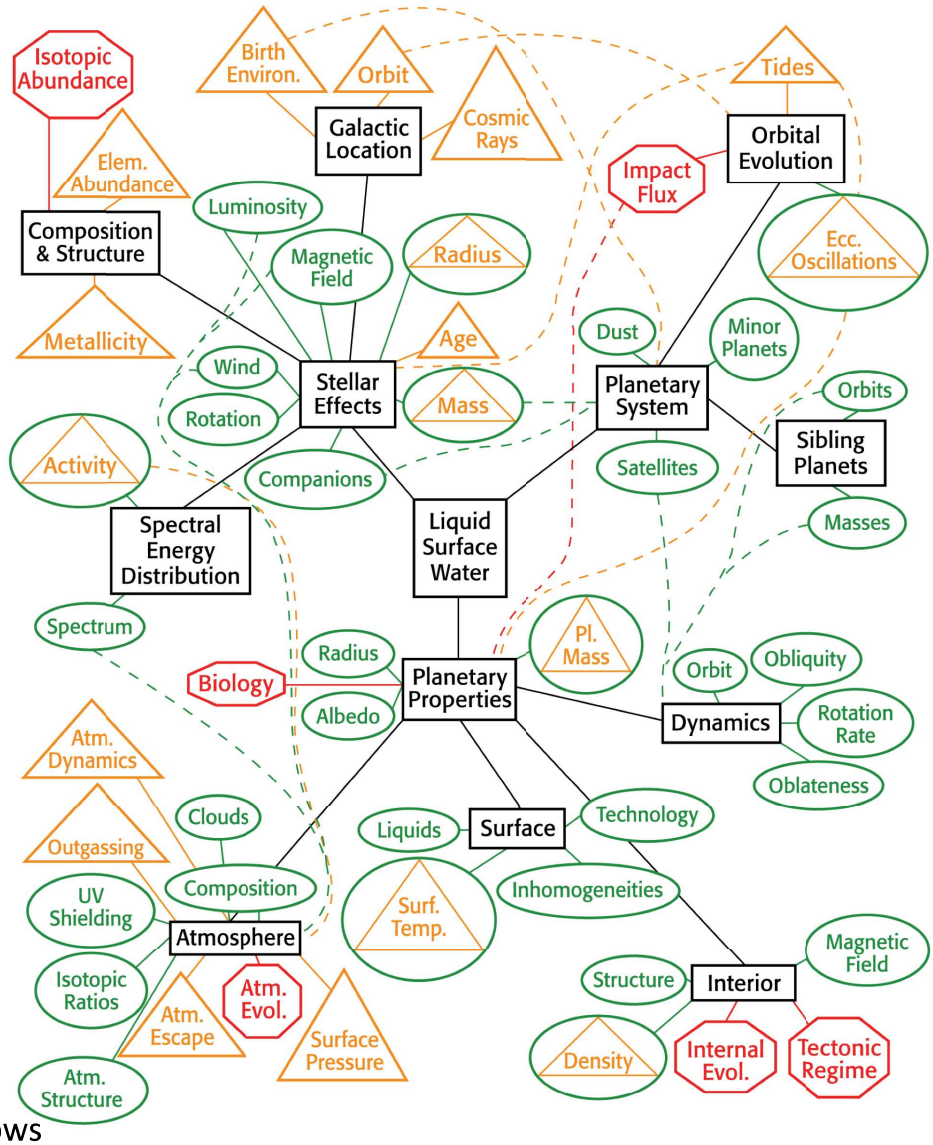
A CATALOG OF KEPLER HABITABLE ZONE EXOPLANET CANDIDATES

Stephen R. Kane[1], Michelle L. Hill[1], James F. Kasting[2], Ravi Kumar Kopparapu[3], Elisa V. Quintana[4], Thomas Barclay[4], Natalie M. Batalha[4], William J. Borucki[4], David R. Ciardi[5], Nader Haghighipour[6], Natalie R. Hinkel[1,7], Lisa Kaltenegger[8], Franck Selsis[9,10], Guillermo Torres[11]



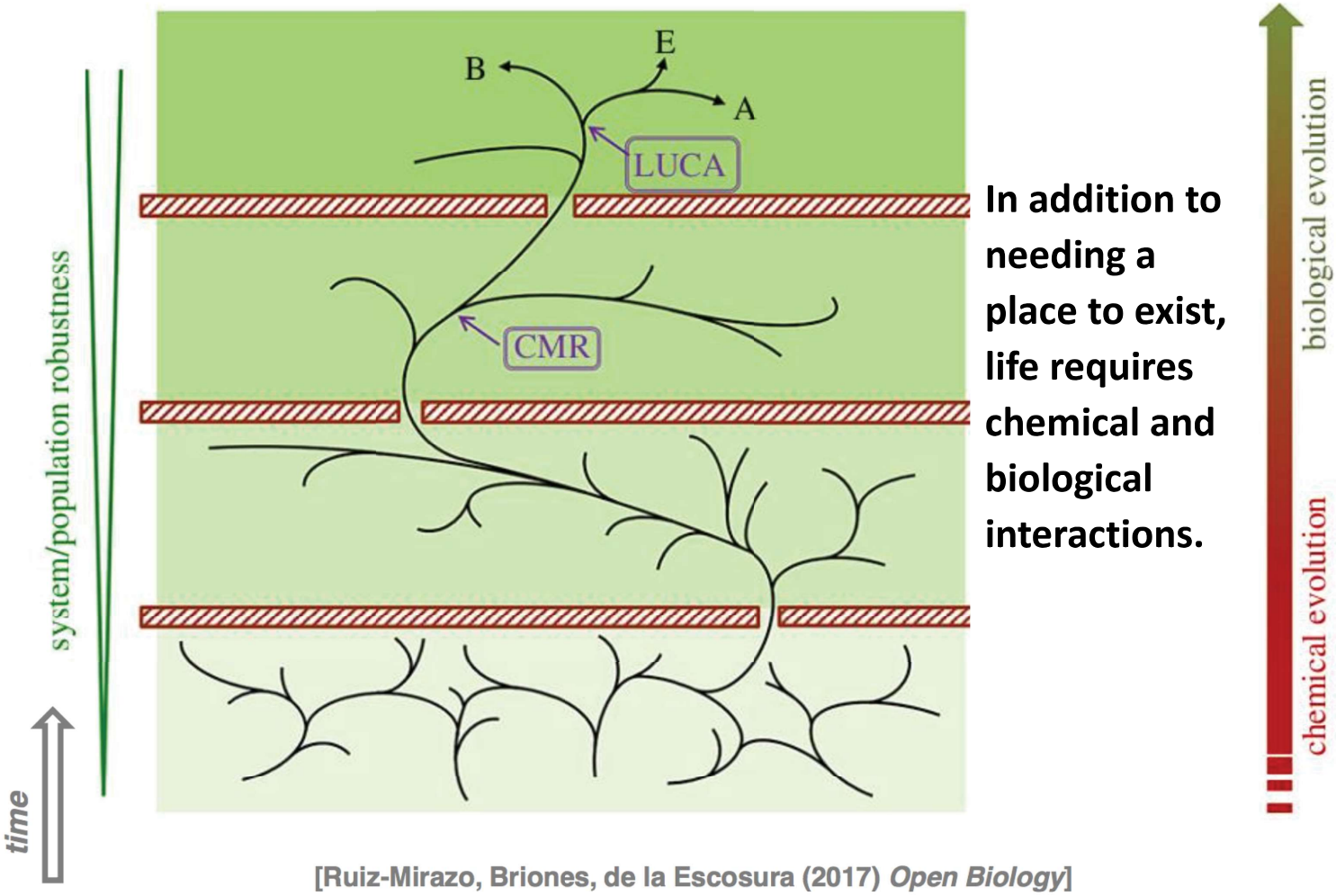


Courtesy of V. Meadows



Courtesy of V. Meadows

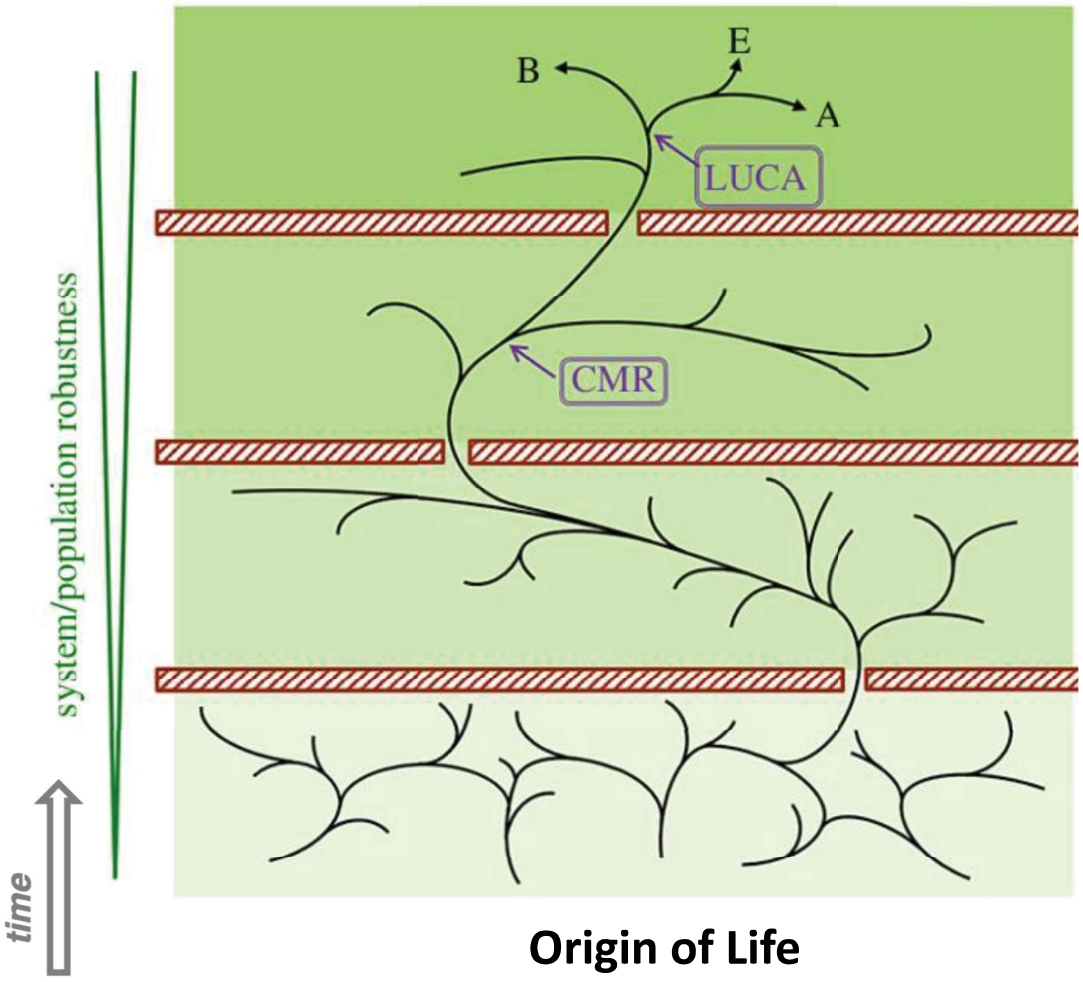
From chemical to biological evolution



In addition to needing a place to exist, life requires chemical and biological interactions.

[Ruiz-Mirazo, Briones, de la Escosura (2017) *Open Biology*]

From chemical to biological evolution

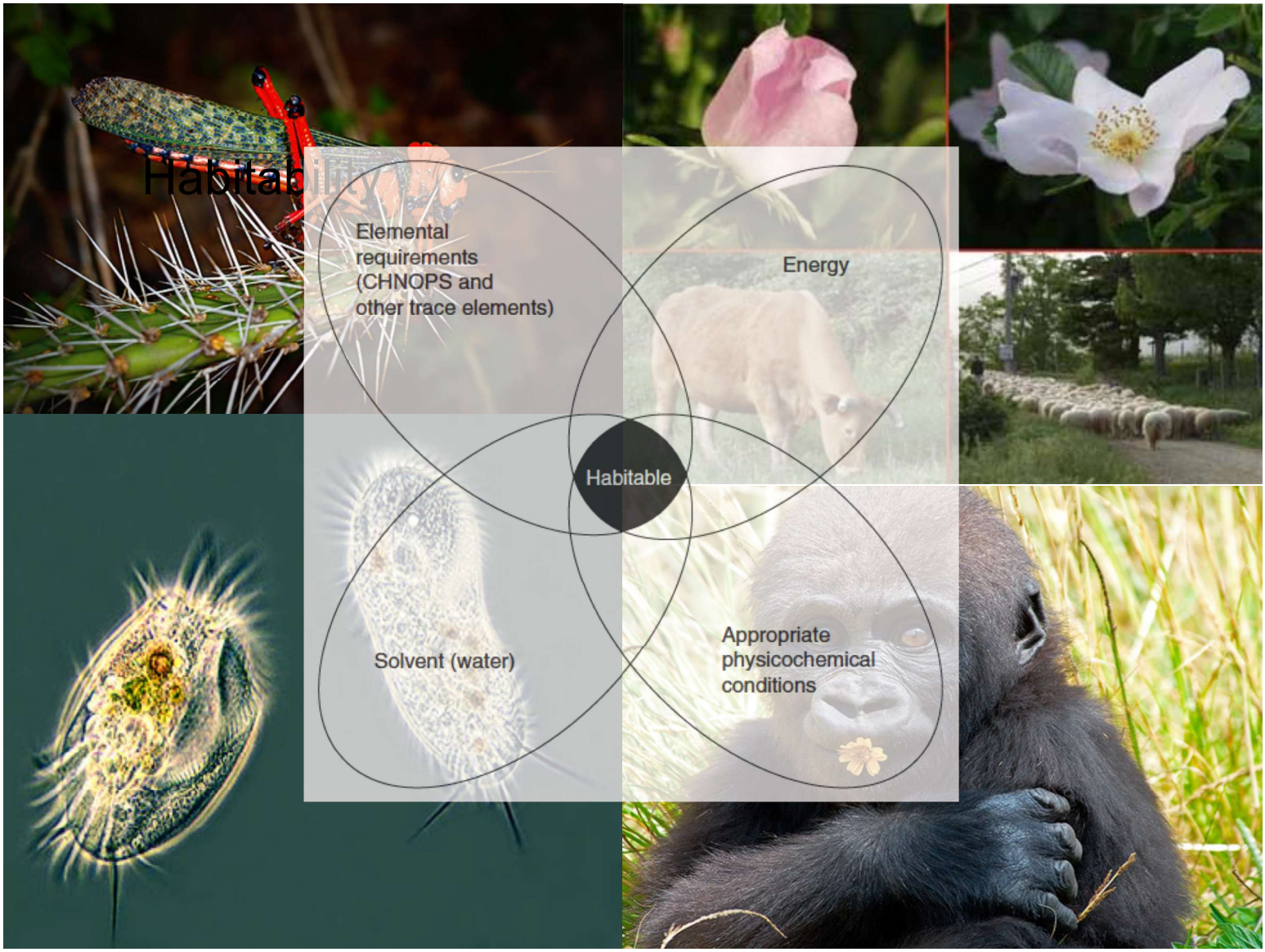


Origin of Life

We don’t know the origin of life. However, we know that life has gone through many paths and bifurcations.

Many of these paths were dead-ends (unsustainable). Only one pathway was sustainable, and that became the life as we know it.

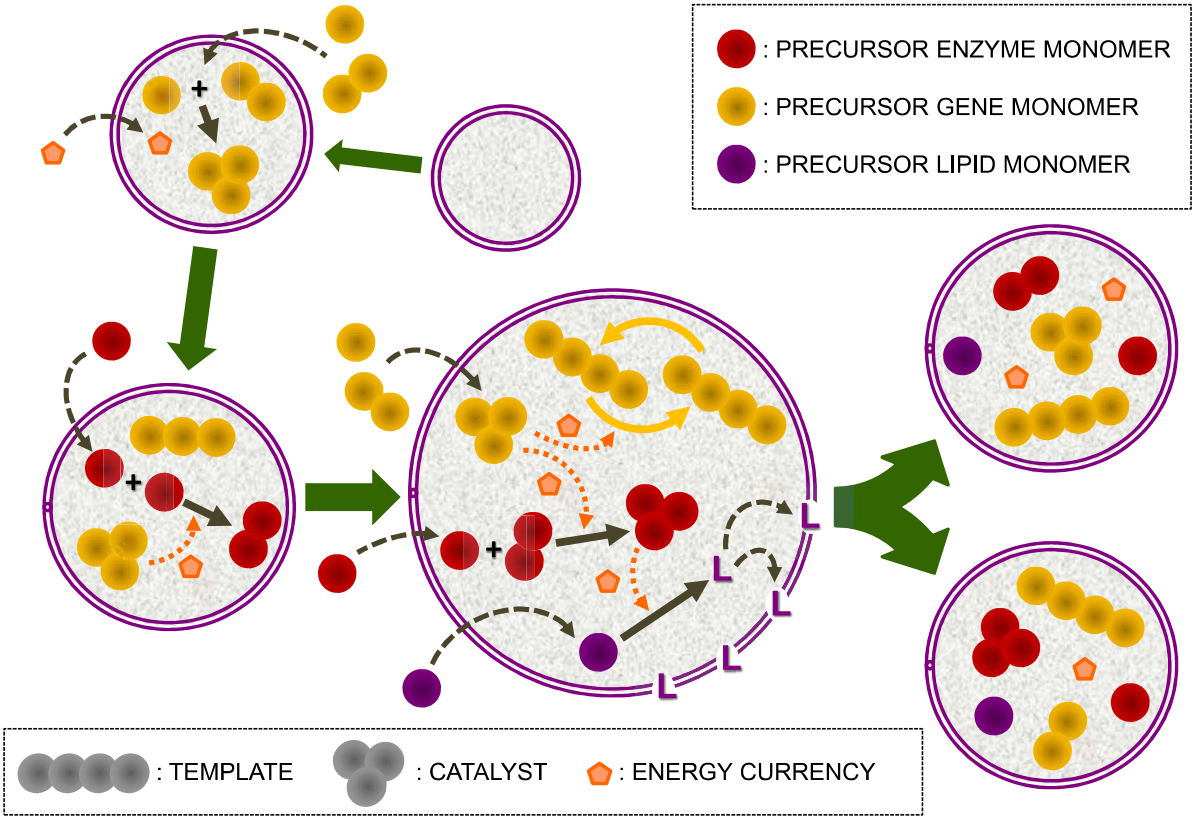
Habitability



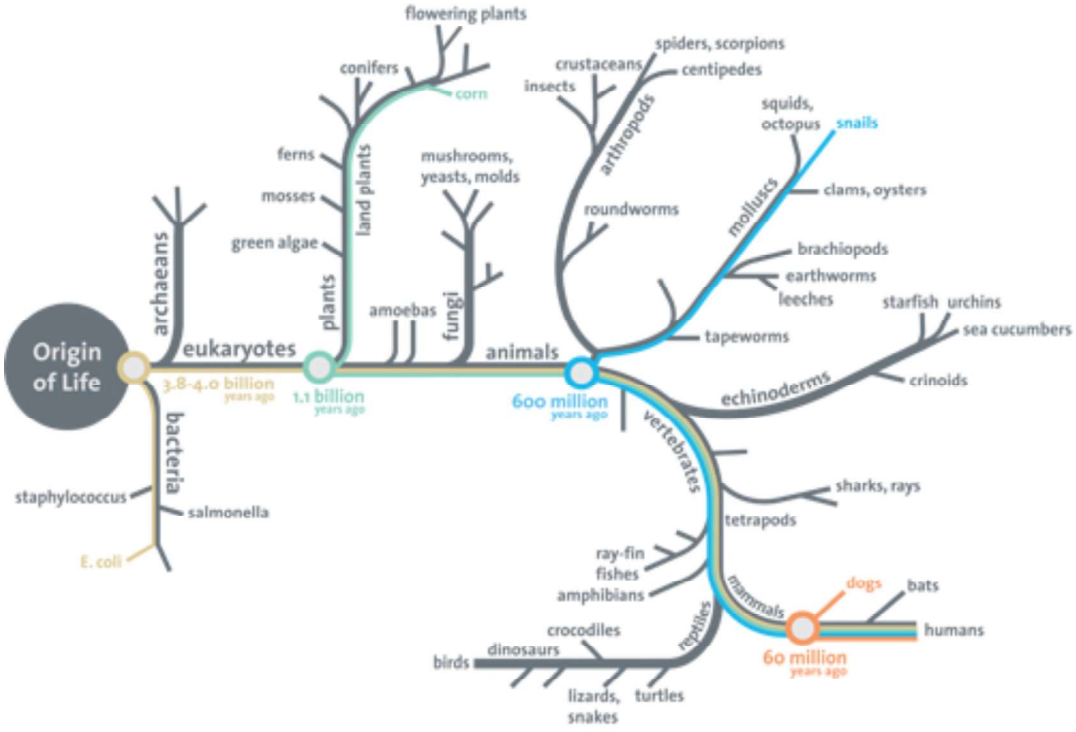
Replication-first
vs.
Metabolism-first
controversy

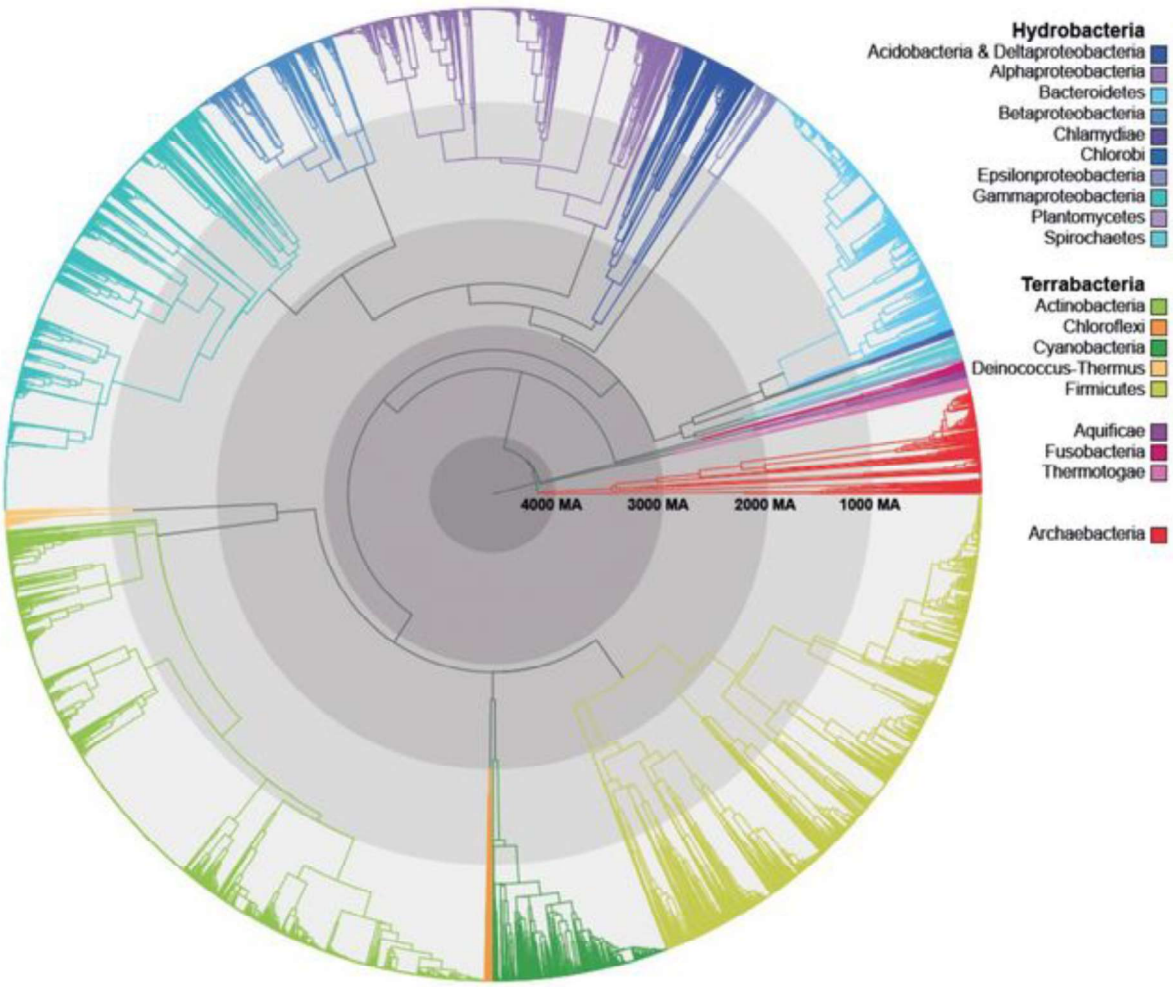
systems chemistry
molecular heterogeneity

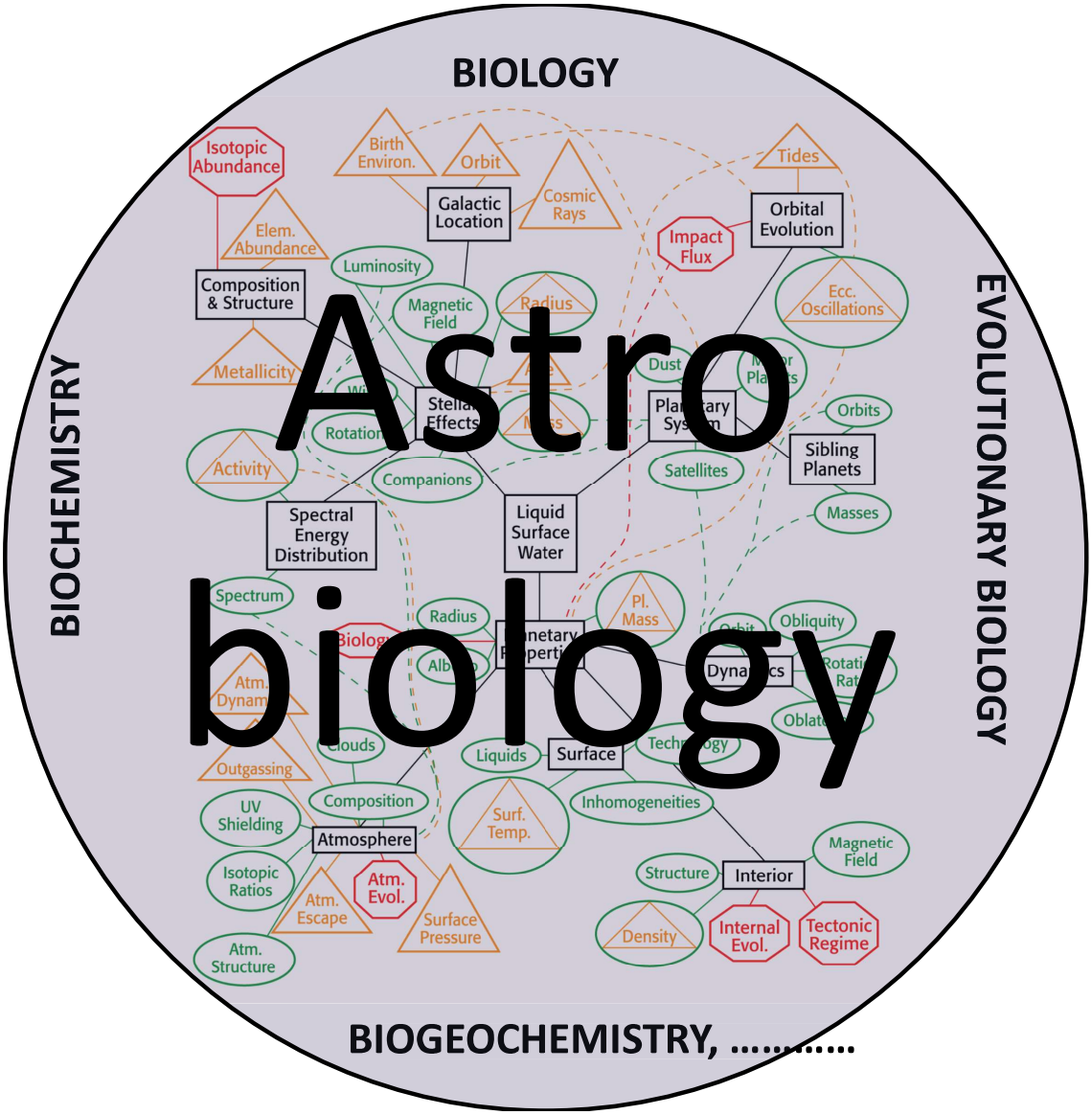
All basic molecules co-evolved from the beginning, forming heterogeneous, pre-bio-chemical interaction networks.



[Adapted from: De la Escosura, Briones & Ruiz-Mirazo (2015) *J. Theor. Biol.* 381]


Origin of Life
archaeans
eukaryotes
3.8-4.0 billion years ago
bacteria
staphylococcus
salmonella
E. coli
plants
1.1 billion years ago
land plants
flowering plants
conifers
corn
ferns
mosses
green algae
amoebas
fungi
mushrooms, yeasts, molds
animals
600 million years ago
arthropods
crustaceans
insects
spiders, scorpions
centipedes
roundworms
molluscs
squids, octopus
snails
clams, oysters
brachiopods
earthworms
leeches
tapeworms
echinoderms
starfish
urchins
sea cucumbers
crinoids
vertebrates
sharks, rays
tetrapods
ray-fin fishes
amphibians
reptiles
crocodiles
dinosaurs
birds
lizards, snakes
turtles
mammals
dogs
bats
humans
60 million years ago


Hydrobacteria
Acidobacteria & Deltaproteobacteria
Alphaproteobacteria
Bacteroidetes
Betaproteobacteria
Chlamydiae
Chlorobi
Epsilonproteobacteria
Gammaproteobacteria
Planctomycetes
Spirochaetes
Terrabacteria
Actinobacteria
Chloroflexi
Cyanobacteria
Deinococcus-Thermus
Firmicutes
Aquificae
Fusobacteria
Thermotogae
Archaebacteria
4000 MA
3000 MA
2000 MA
1000 MA


BIOLOGY
BIOCHEMISTRY
EVOLUTIONARY BIOLOGY
BIOGEOCHEMISTRY, ...
Astro
biology
Isotopic Abundance
Elem. Abundance
Composition & Structure
Metallicity
Activity
Spectral Energy Distribution
Spectrum
Atm. Dynam
Outgassing
UV Shielding
Isotopic Ratios
Atm. Structure
Atm. Escape
Atm. Evol.
Surface Pressure
Atmosphere
Composition
Clouds
Birth Environ.
Orbit
Galactic Location
Cosmic Rays
Luminosity
Magnetic Field
Radius
Rotation
Companions
Stellar Effects
Liquid Surface Water
Tides
Orbital Evolution
Impact Flux
Ecc. Oscillations
Dust
Orbits
Sibling Planets
Satellites
Masses
Pl. Mass
Obliquity
Radius
Liquids
Surface
Surf. Temp.
Inhomogeneities
Structure
Interior
Magnetic Field
Density
Internal Evol.
Tectonic Regime