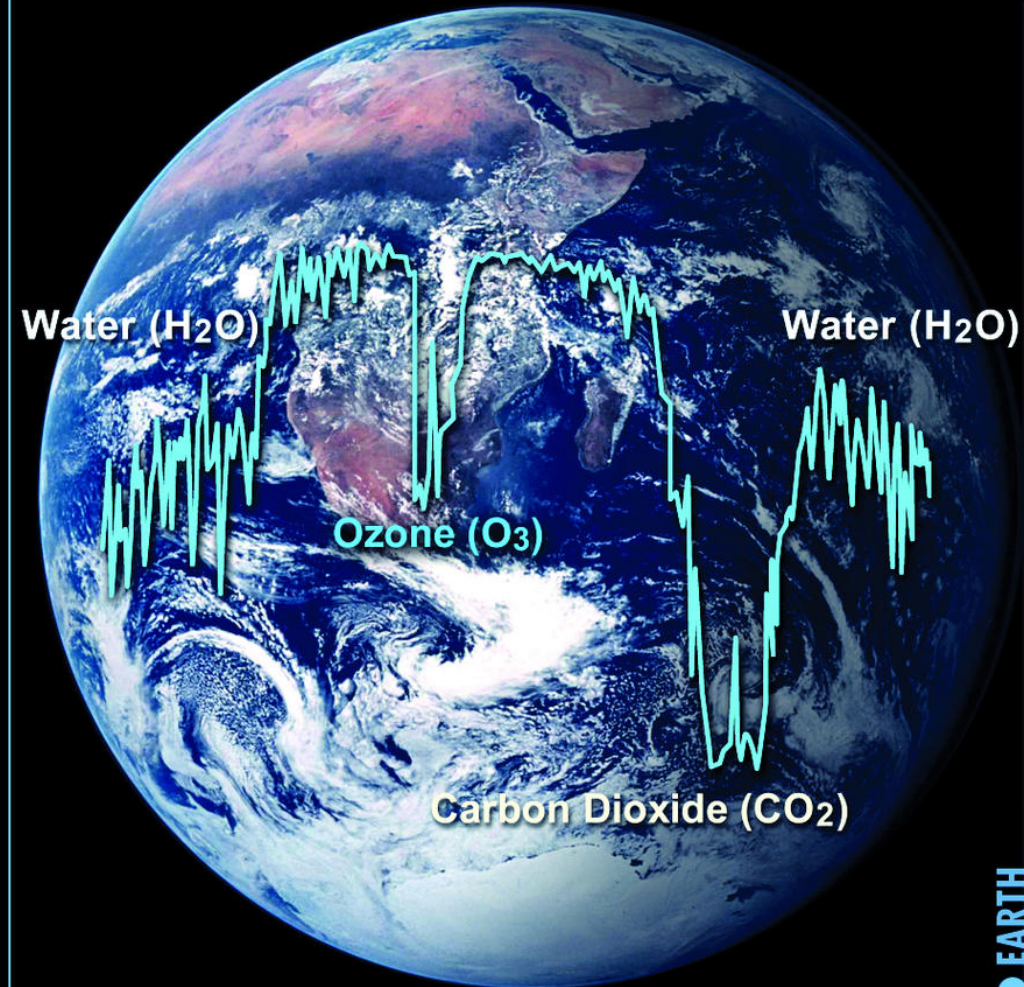
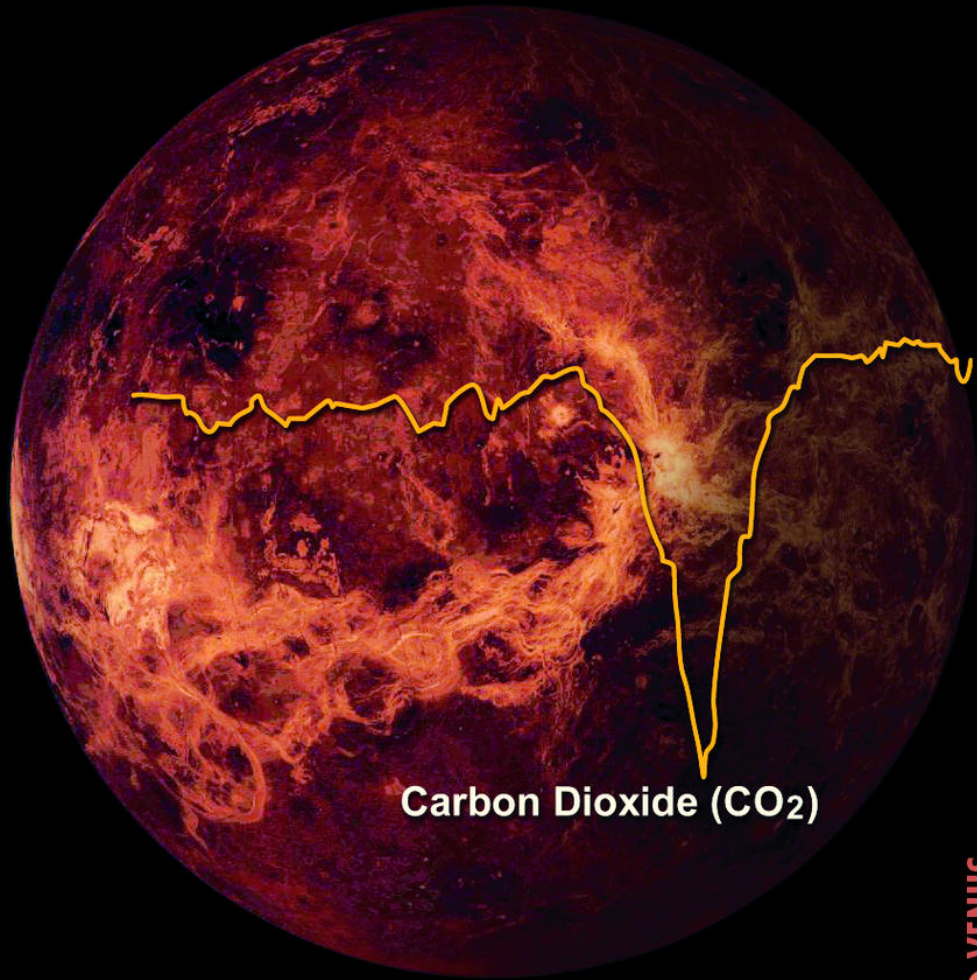


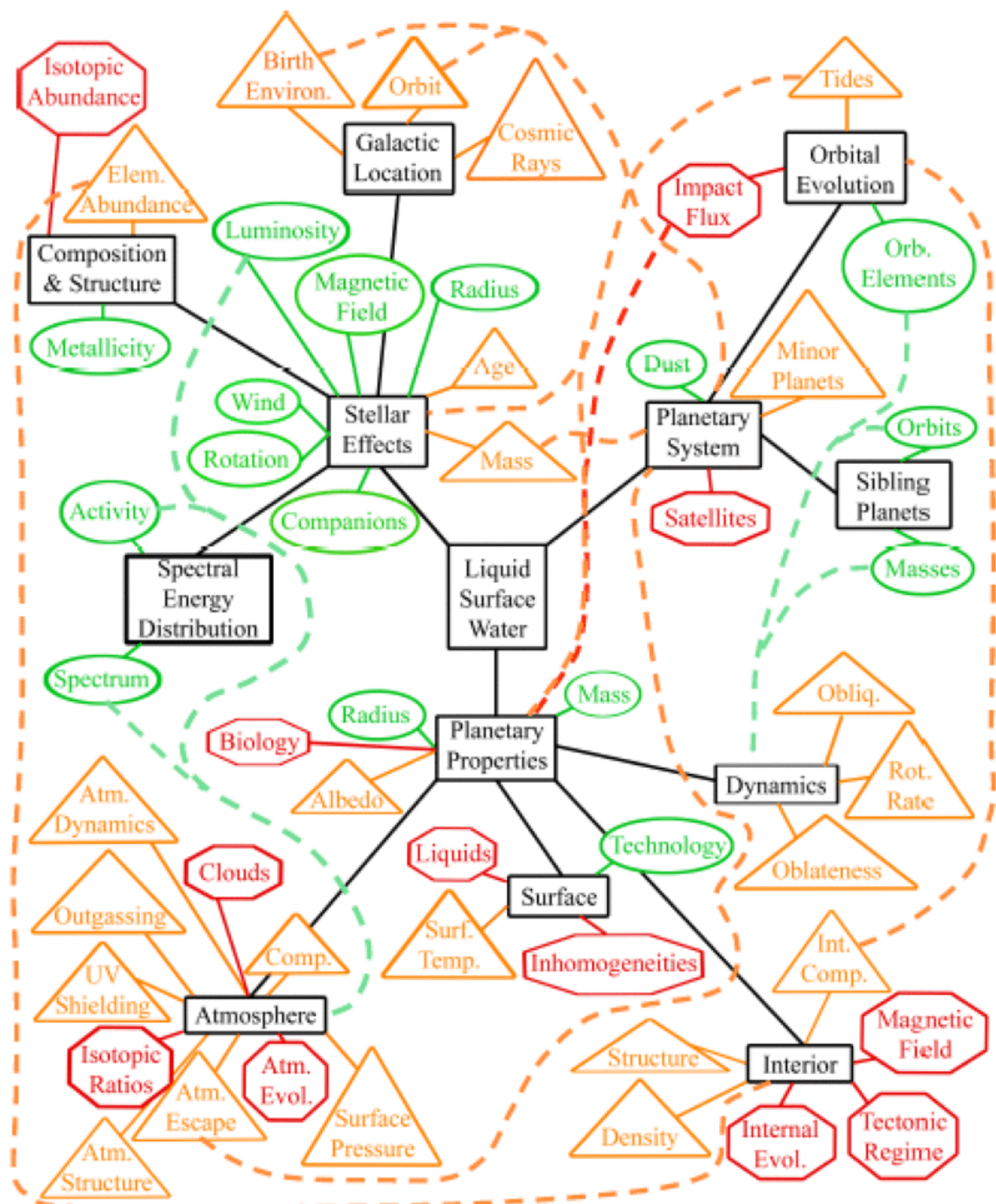
Planetary Habitability



Stephen Kane

Topics

- **Lecture 1 - Introduction**
- **Lecture 2 - Habitability Factors**
- **Lecture 3 - Stars**
- **Lecture 4 - Planetary Atmospheres**
- **Lecture 5 - Planetary Interiors**
- **Lecture 6 - Planetary Energy Balance**
- **Lecture 7 - Habitable Zone I**
- **Lecture 8 - Habitable Zone II**
- **Lecture 9 - Earth as a Living Planet**
- **Lecture 10 - Mars**
- **Lecture 11 - Icy Moons**
- **Lecture 12 - Venus**
- **Lecture 13 - Mercury & the Moon**
- **Lecture 14 - The Role of Giant Planets**
- **Lecture 15 - Stellar Influences**
- **Lecture 16 - Magnetic Fields**
- **Lecture 17 - Milankovitch Cycles**
- **Lecture 18 - Geological Cycles**
- **Lecture 19 - The Next Steps**
- **Lecture 20 - Summary/Discussion**



Habitable Zone Gallery

[Home](#) [Plots](#) [Table](#) [Gallery](#) [Movies](#) [About](#) [Links](#)

Click [here](#) for a key to the table headings. Click on a table heading to toggle sorting in descending or ascending order. Click on a planet name to jump to its location in the gallery. Click [here](#) to download the table CSV file.

Planet	M_p (M_J)	R_p (R_J)	P (days)	e	ω ($^\circ$)	t_{HZ}^c (%) \blacktriangle	t_{HZ}^o (%)	T_{eq}^a (K)	T_{eq}^b (K)	T_{eq}^c (K)	T_{eq}^d (K)
TRAPPIST-1 g	0.004	0.101	12.4	0.061	90.0	100.0	100.0	244	205	229	193
TRAPPIST-1 f	0.002	0.093	9.2	0.063	90.0	100.0	100.0	269	226	252	212
TRAPPIST-1 e	0.002	0.082	6.1	0.085	90.0	100.0	100.0	312	262	287	241
KIC 9663113 b		0.410	572.4	0.000	90.0	100.0	100.0	305	256	305	256
KIC 5951458 b		0.589	1320.1	0.000	90.0	100.0	100.0	289	243	289	243
KIC 10525077 b		0.491	854.1	0.000	90.0	100.0	100.0	264	222	264	222
Kepler-97 c	1.080		789.0	0.000	90.0	100.0	100.0	256	216	256	216
Kepler-712 c		0.433	226.9	0.000	90.0	100.0	100.0	315	265	315	265
Kepler-705 b		0.188	56.1	0.000	90.0	100.0	100.0	316	266	316	266
Kepler-68 d	0.840		625.0	0.000	90.0	100.0	100.0	305	257	305	257
Kepler-62 f	0.110	0.126	267.3	0.000	90.0	100.0	100.0	265	223	265	223
Kepler-553 c		0.999	328.2	0.000	90.0	100.0	100.0	293	246	293	246
Kepler-454 c	4.460		523.9	0.021	337.4	100.0	100.0	309	259	302	254
Kepler-453 b	0.050	0.553	240.5	0.036	185.1	100.0	100.0	331	278	319	268
Kepler-442 b		0.120	112.3	0.040	90.0	100.0	100.0	309	260	297	250
Kepler-283 c		0.162	92.7	0.000	90.0	100.0	100.0	323	271	323	271
Kepler-186 f		0.104	129.9	0.040	90.0	100.0	100.0	249	209	239	201
Kepler-174 d		0.195	247.4	0.000	90.0	100.0	100.0	268	225	268	225
Kepler-16 b	0.333	0.754	228.8	0.007	318.0	100.0	100.0	246	207	244	205
Kepler-1652 b		0.143	38.1	0.000	90.0	100.0	100.0	317	267	317	267
Kepler-1647 b	1.520	1.059	1107.6	0.058	155.0	100.0	100.0	298	250	281	236
Kepler-1636 b		0.288	125.5	0.000	90.0	100.0	100.0	319	268	319	268

An Incomplete List of Habitability Caveats

- How is water delivered?
- When did Mars have surface water?
- When did Venus have surface water?
- Did Venus and Earth have near identical starting conditions?
- How small can a planet be and remain habitable?
- Why don't we have a super-Earth?
- What does the T-P profile of a super-Earth look like?
- Does a giant planet beyond the snow line matter?
- Can life survive extreme eccentric orbits?
- How do terrestrial atmospheres respond to flux variations?
- Are circumbinary planets habitable?
- How does atmospheric erosion depend on magnetic field?
- Does a substantial moon create a more habitable world?
- How well do we need to understand the star?
- ***What observations/measurements do we need to make to test the Habitable Zone hypothesis?***

Habitability Factors

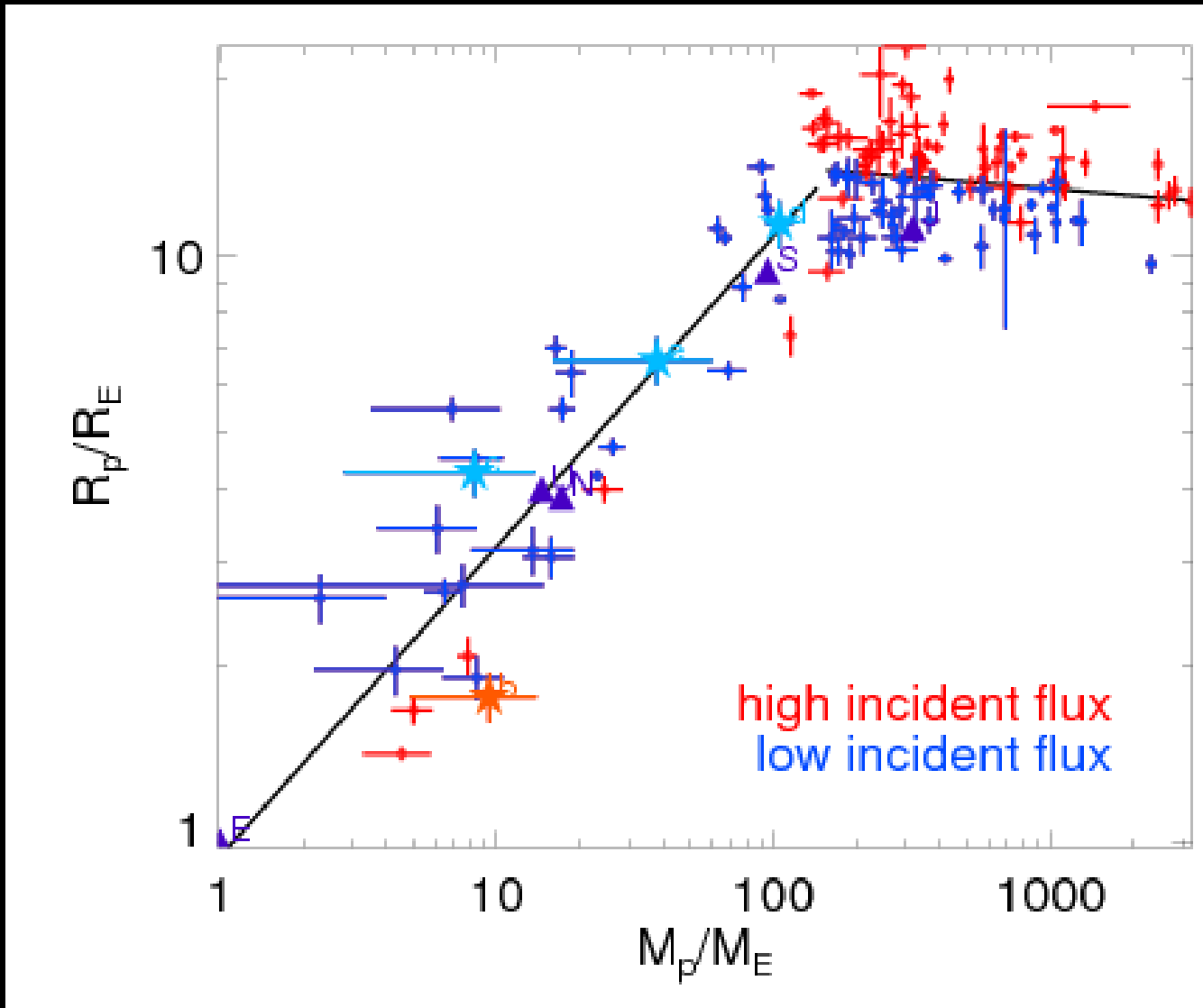
- **Not enough of the factor.**
- **Just right.**
- **Too much of the factor.**
- **What are the dependencies on other factors?**

Habitability Factors

- **Orbit - eccentricity, dynamics, obliquity**
- **Mass**
- **Size**
- **Rotation rate & direction**
- **Surface temperature**
- **Surface composition**
- **Surface water**
- **Interior - core, mantle**
- **Geology - outgassing, volcanism**
- **Plate tectonics**
- **Age**
- **Magnetic field**
- **Atmospheric composition**
- **Atmospheric structure**
- **Star - luminosity, temperature**
- **Tidal effects - eccentricity, moon(s)**

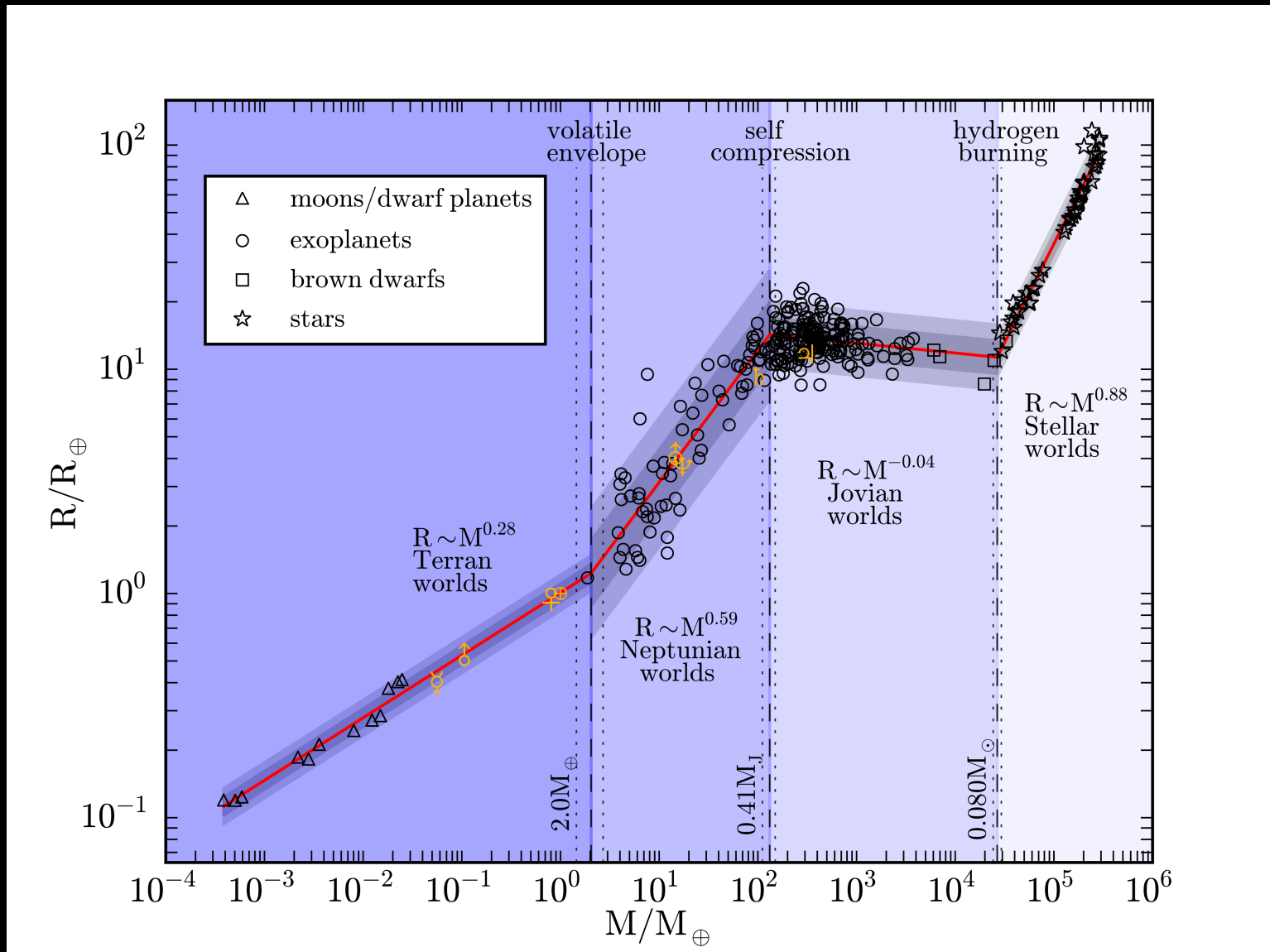
Sizes of exoplanets

- Mass-radius-flux relationship for exoplanets (Weiss et al. 2013, 2014).



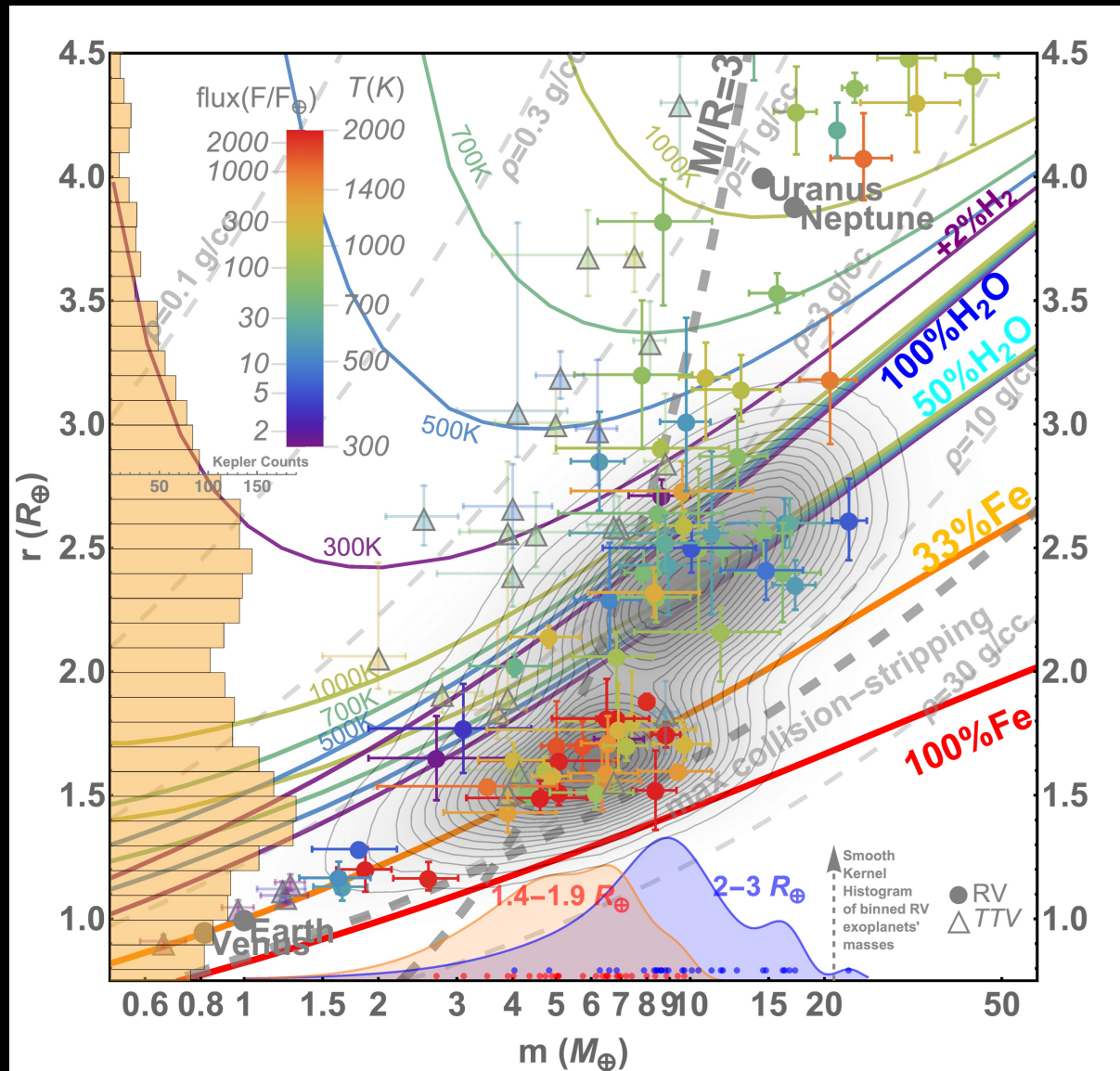
Sizes of exoplanets

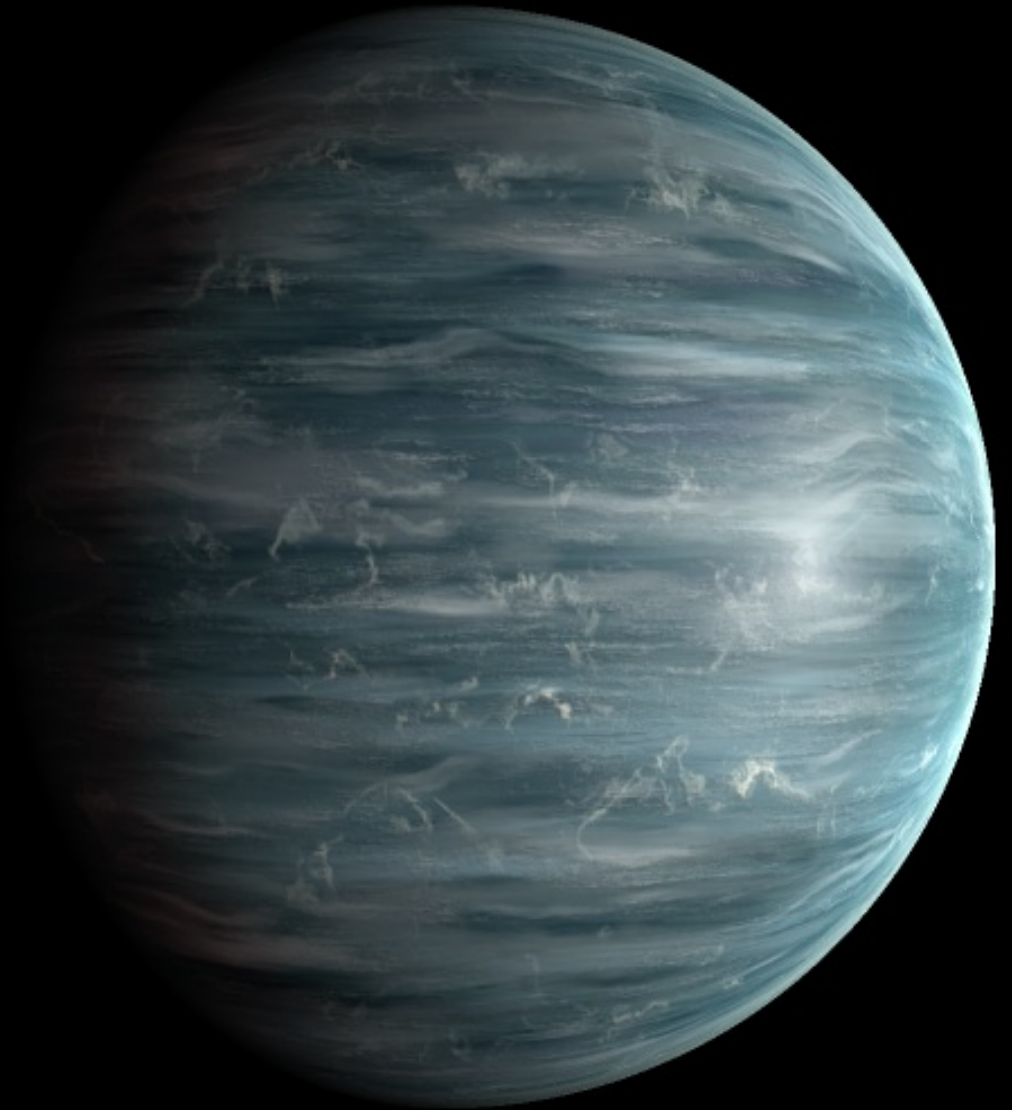
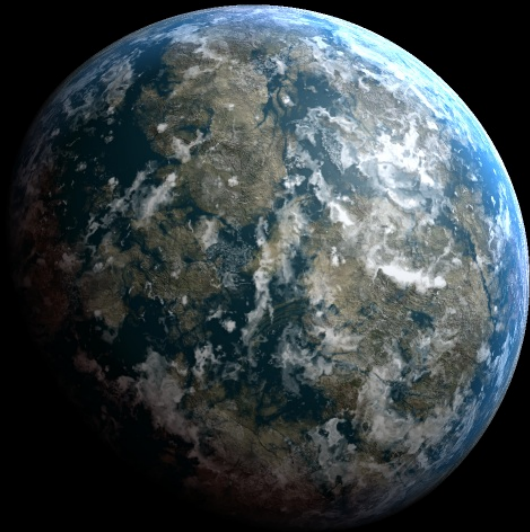
- Mass-radius-flux relationship for exoplanets (Chen & Kipping 2017).

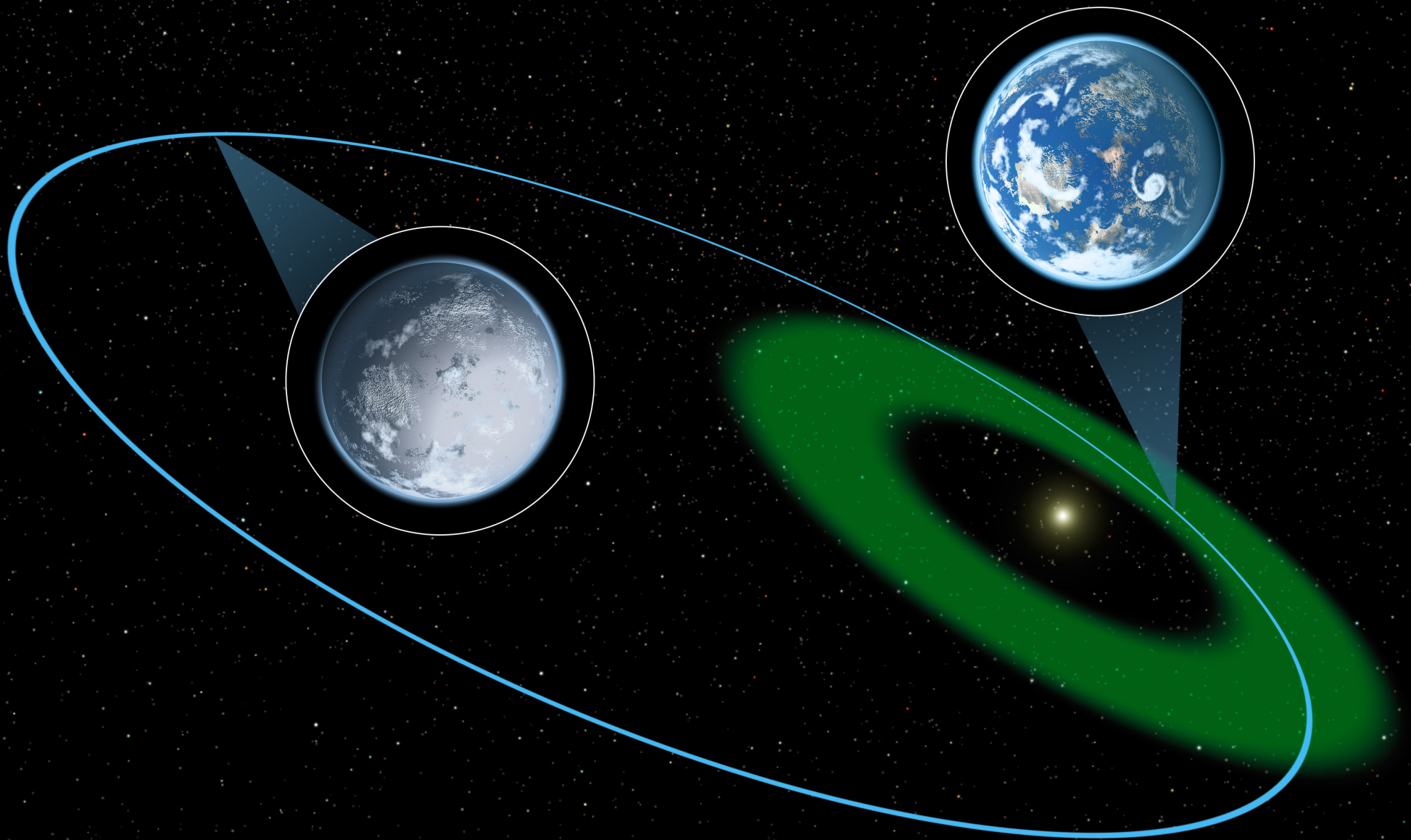


Sizes of exoplanets

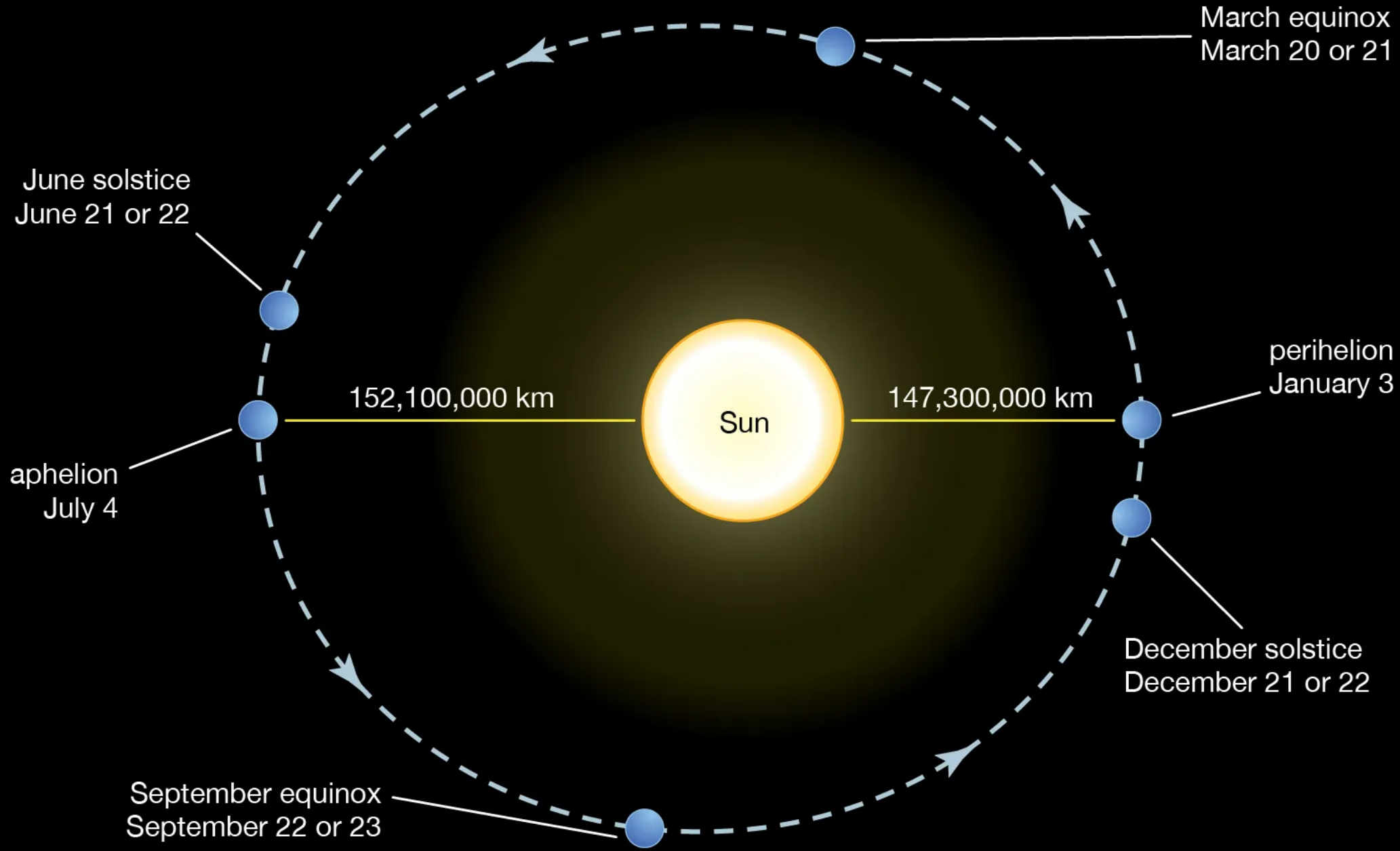
- Mass-radius-flux relationship for exoplanets (Zeng et al. 2019).







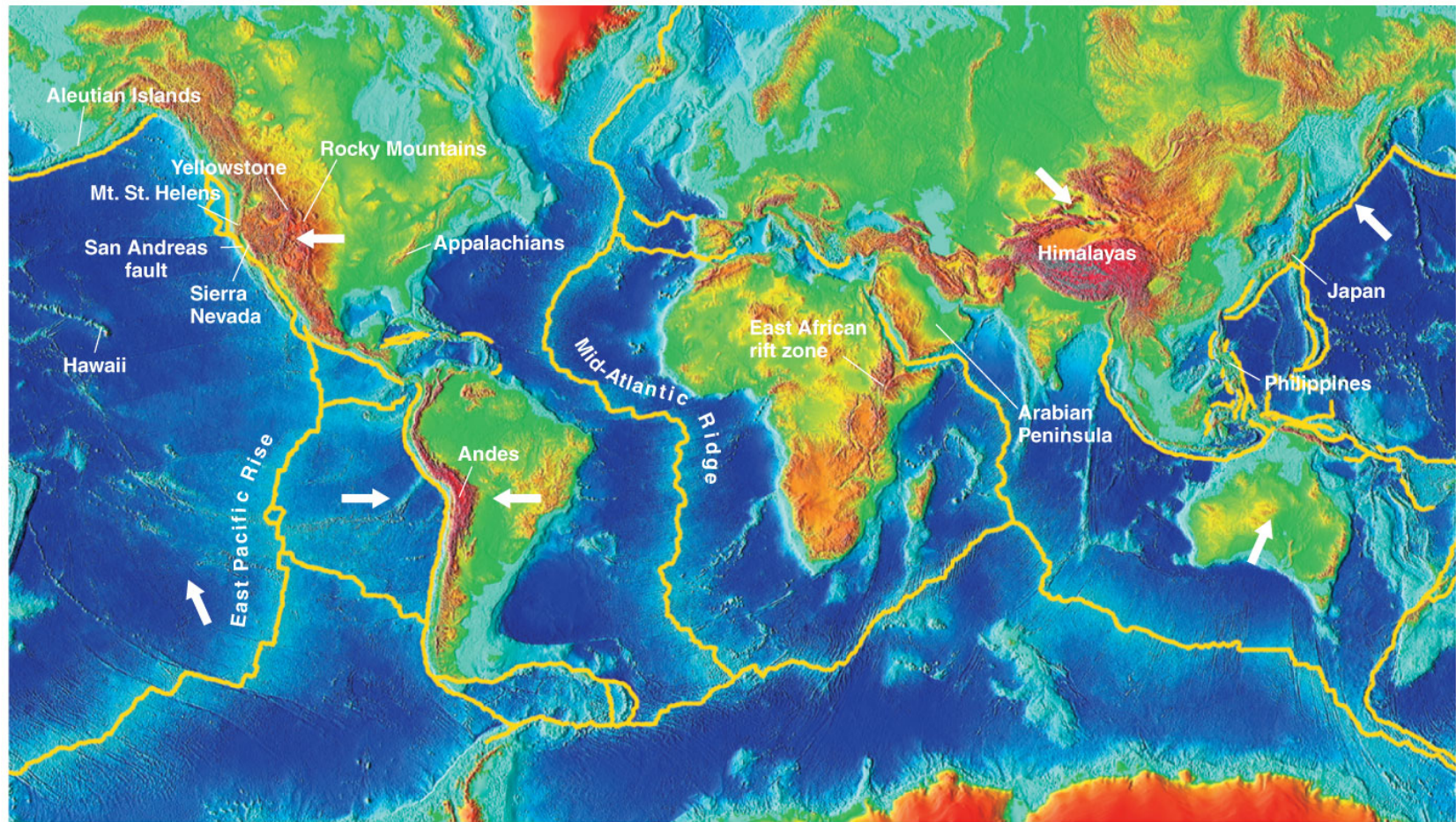
Earth's orbit around the Sun



Habitable Planets in Eccentric Orbits

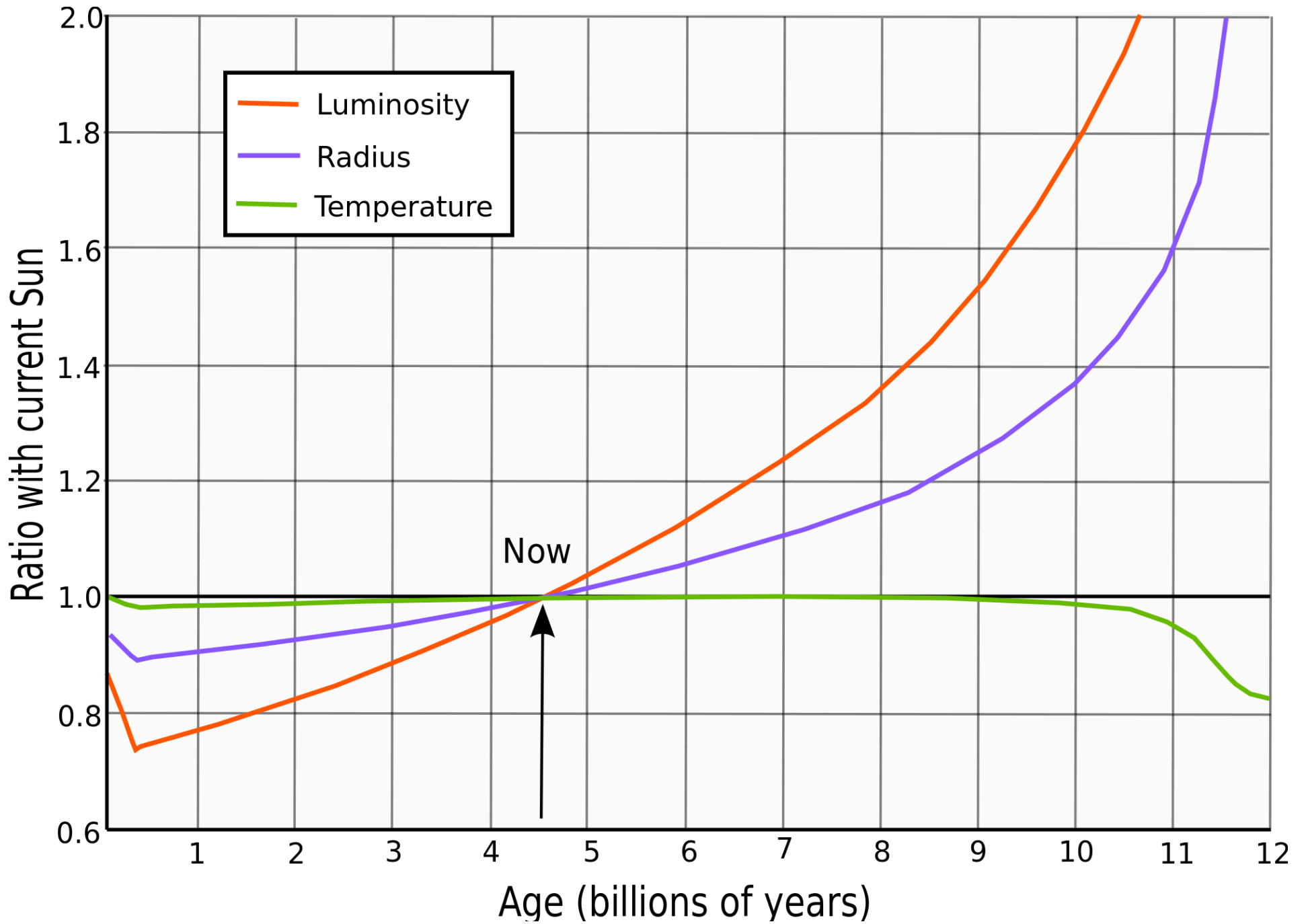
- **Time averaged flux compared with percentage of orbit in the Habitable Zone.**
- **Terrestrial extremophiles can withstand substantial periods of time under extreme temperature conditions in combination with vacuum, UV-C irradiation.**
- **Could organisms survive flash-heating events if buried under protective layers?**
- **Could organisms undergo metabolic slow-down for a period of hibernation.**
- **Orbital eccentricity is correlated with planetary mass (large eccentricity = high mass).**

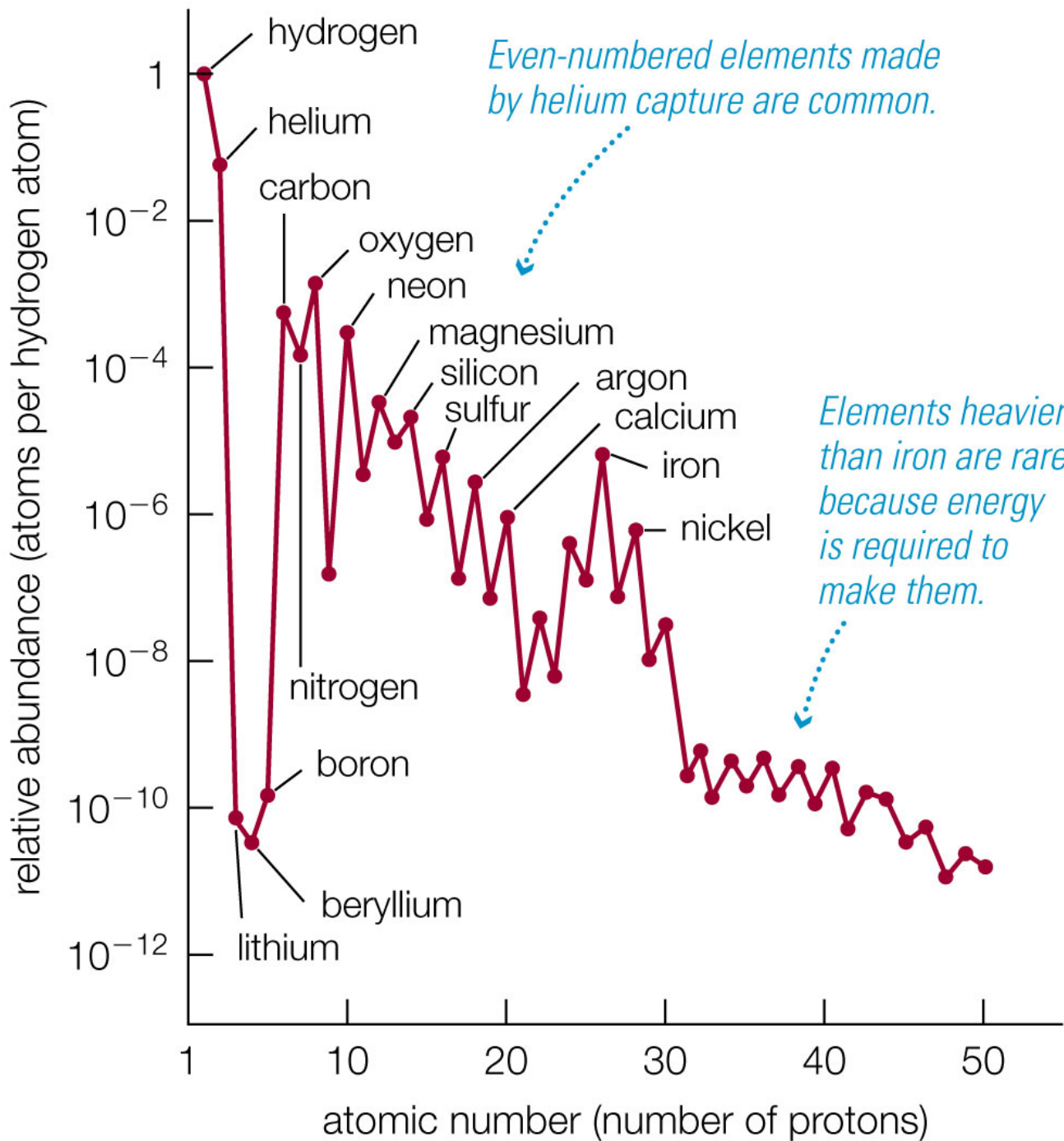
Climate and Habitability



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- It's also possible that plate tectonics are necessary to keep the climate of an Earth-like planet stable enough for life.



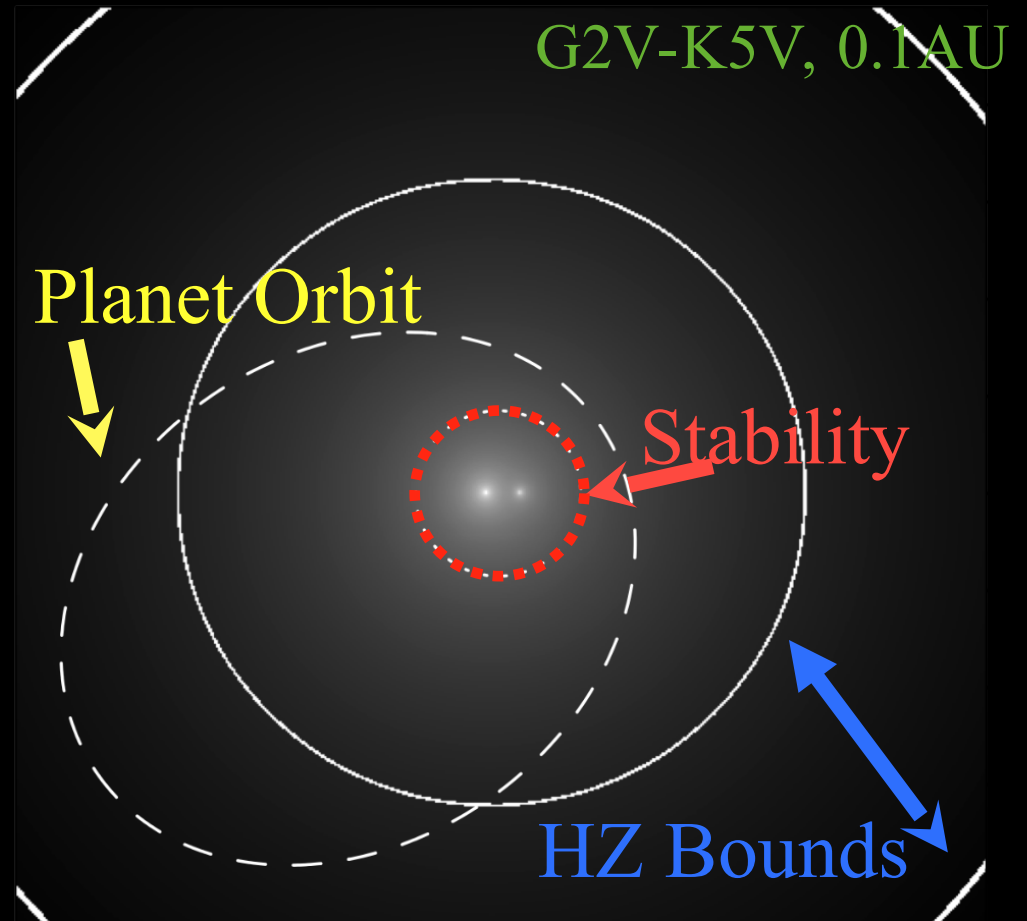


Bio-essential elements are amongst the most common in the universe.

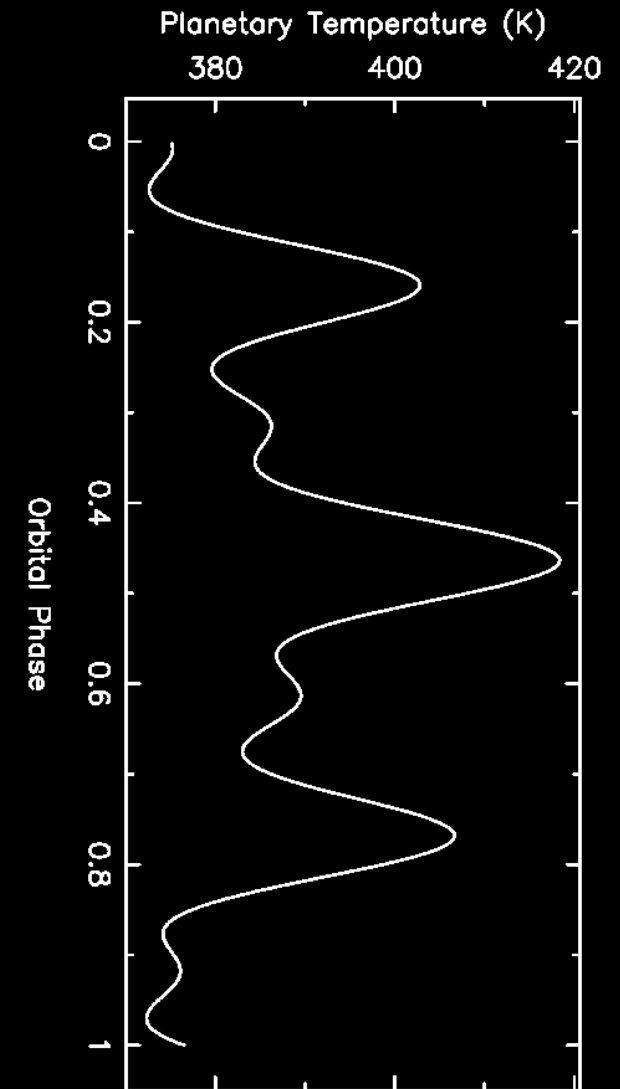
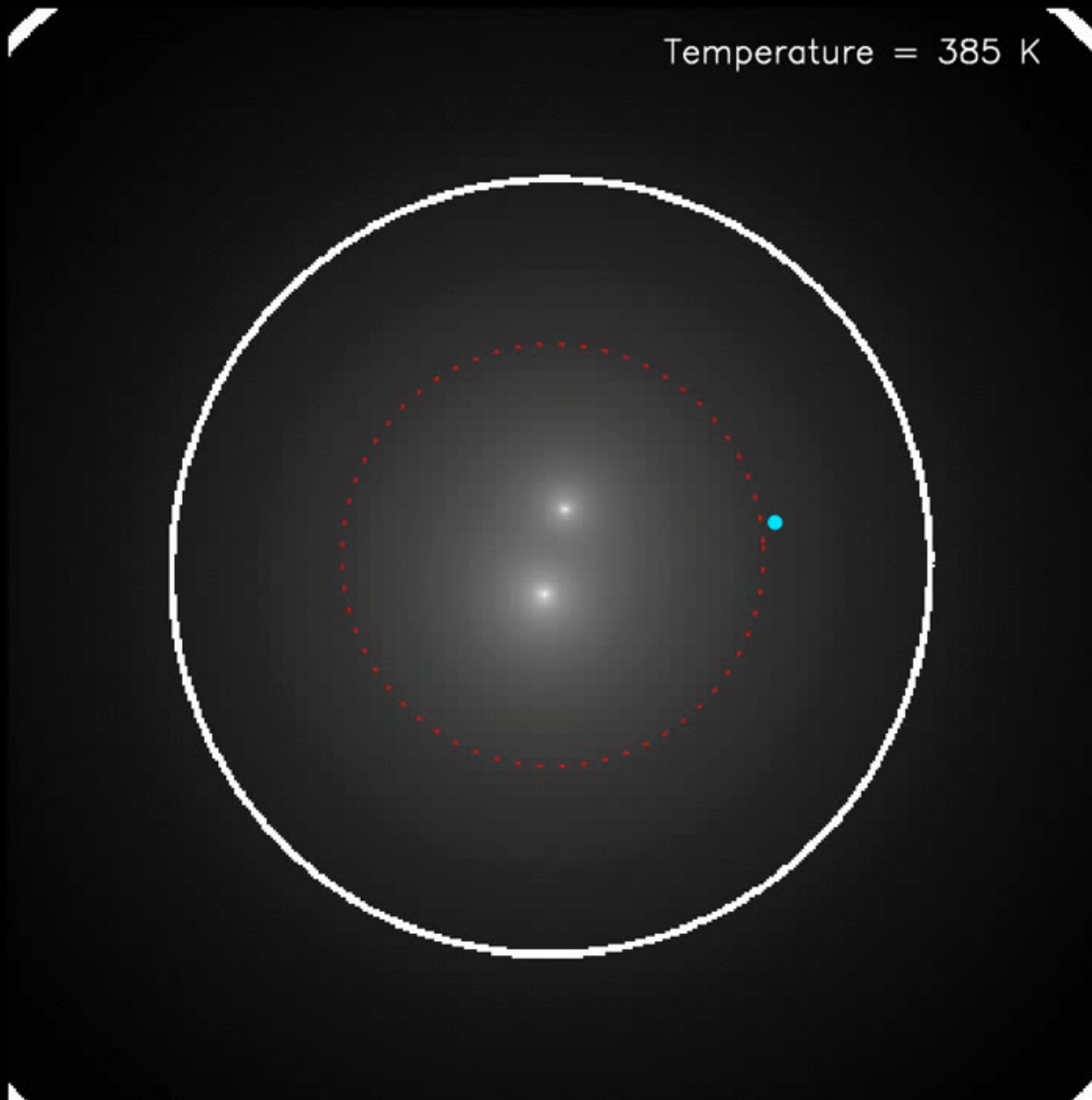
Hydrogen
Carbon
Oxygen

Circumbinary Stellar Flux

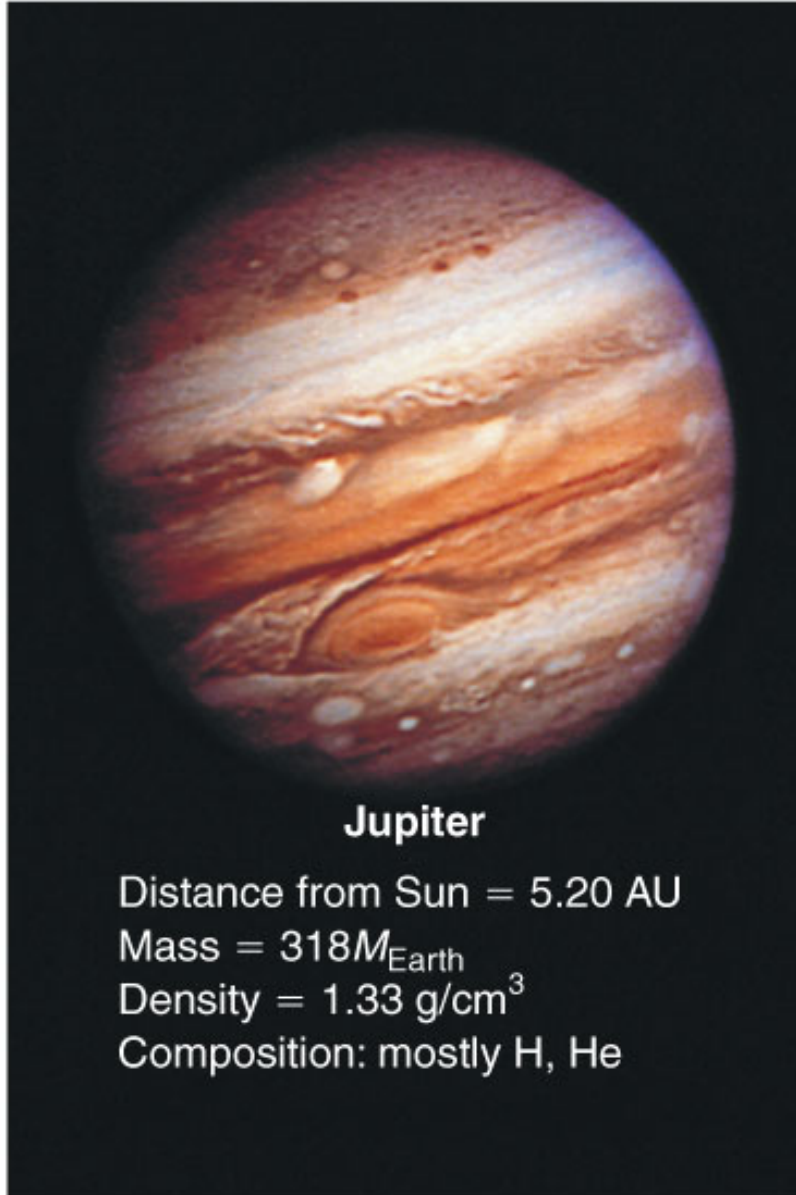
- Need to account for the time variable and wavelength dependent insolation from BOTH stars
- Also must account for the stability of planetary orbits
- Finally, take into account the orbital motion of both the binary and the planet which results in a **complicated temperature profile for the planet**
- The orbital period of the binary is much less than the orbital period of the planet



Kepler-35



Impacts and Habitability

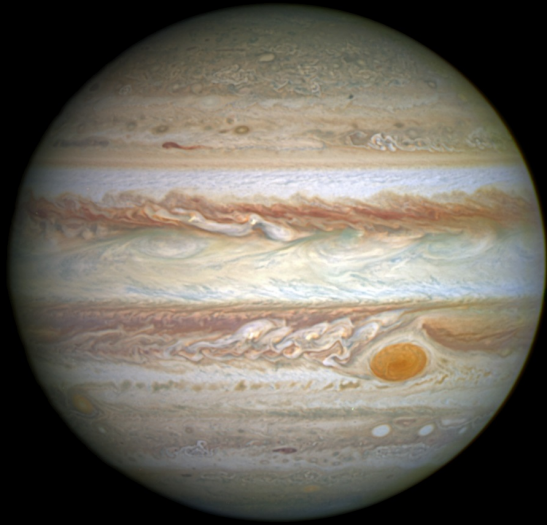


- It has been argued that Jupiter-like planets are necessary to reduce the rate of impacts.
- If so, then Earth-like planets are restricted to star systems with Jupiter-like planets.



The Moon and Habitability



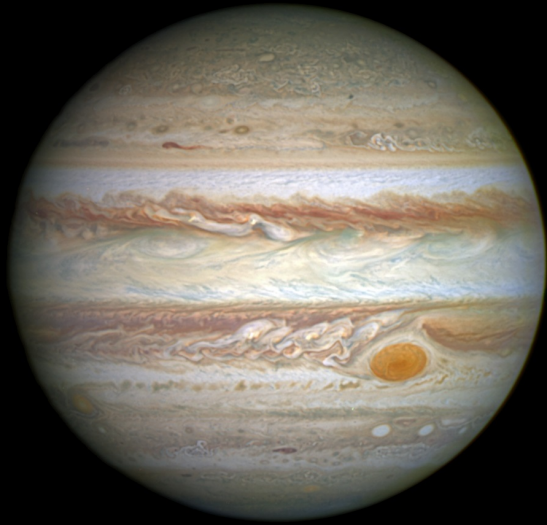


Jupiter
Semi-major axis ~5 AU
Hill radius ~ 50 million kms



~ 1 million kms

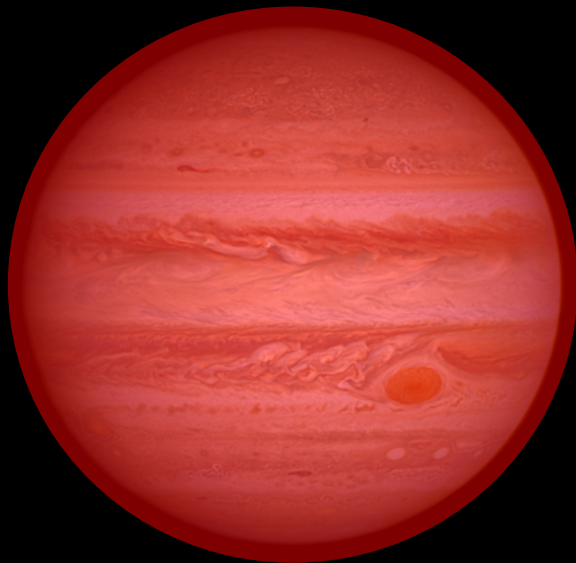




Jupiter
Semi-major axis ~ 5 AU
Hill radius ~ 50 million kms

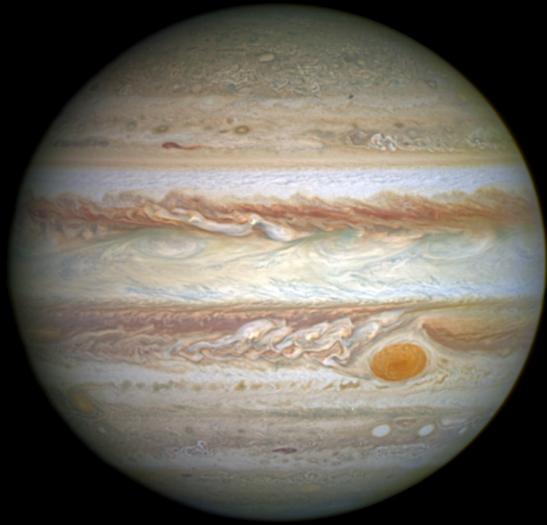


~ 1 million kms



Hot Jupiter
Semi-major axis ~ 0.05 AU
Hill radius ~ 0.5 million kms

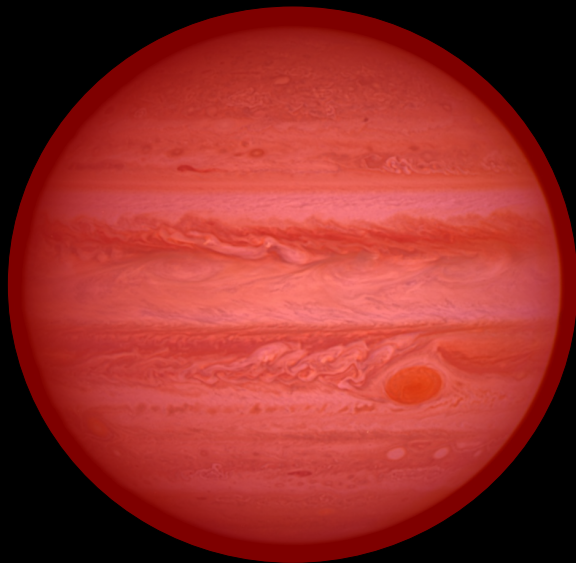




Jupiter
Semi-major axis ~ 5 AU
Hill radius ~ 50 million kms



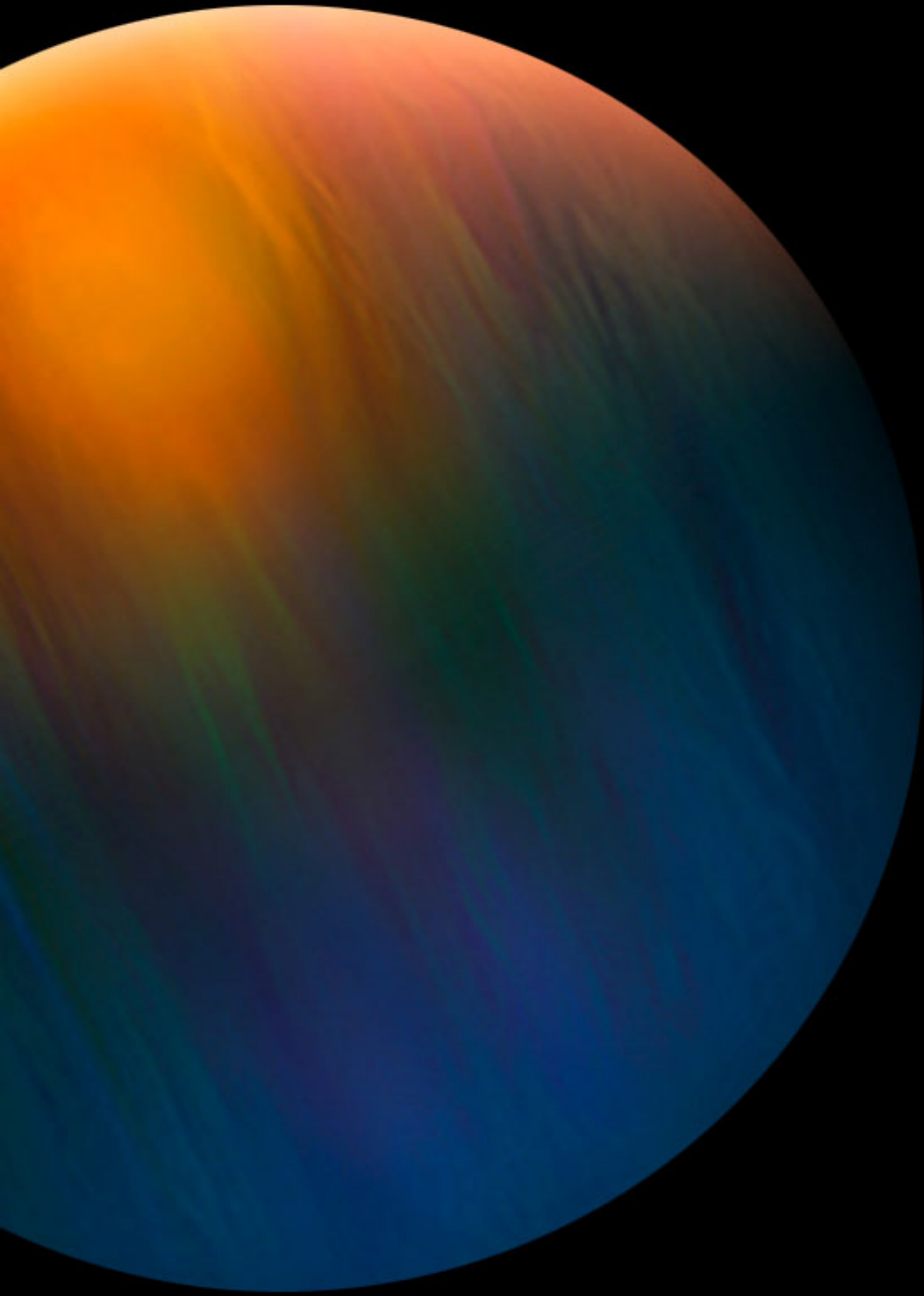
~ 1 million kms



Hot Jupiter
Semi-major axis ~ 0.05 AU
Hill radius ~ 0.5 million kms



**Not
Ganymede**



Roche limit

moon

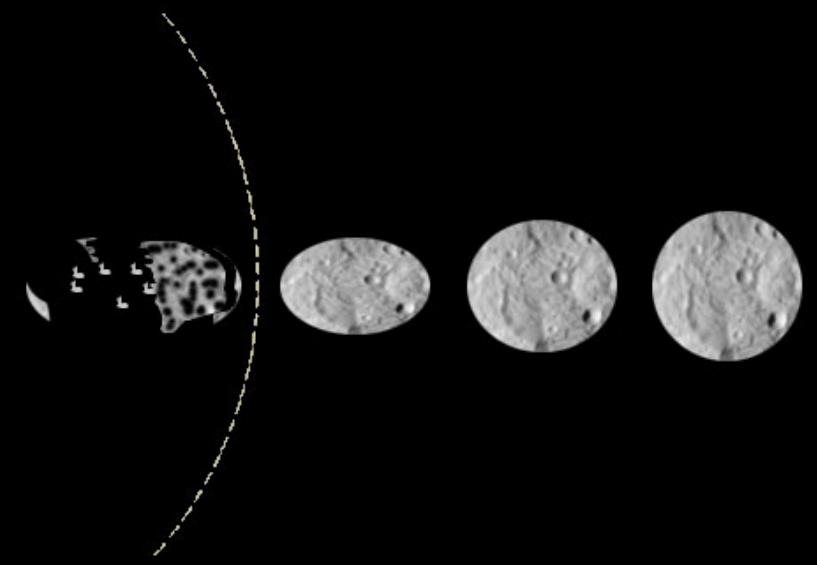
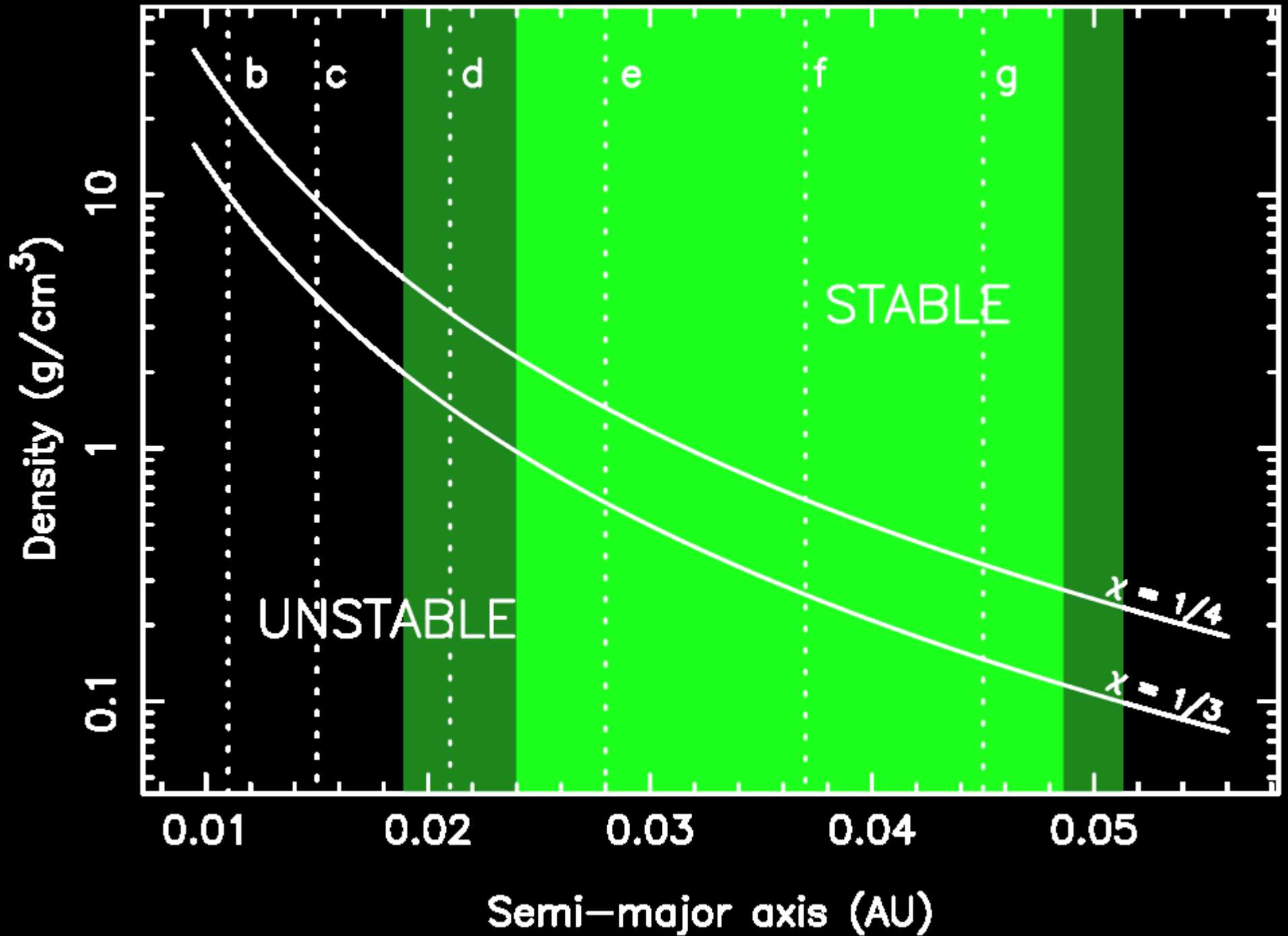


Table 1. TRAPPIST-1 planetary Hill radii and Roche limits

Planet	M_p (M_\oplus)	R_p (R_\oplus)	a (AU)	R_H (10^{-3} AU)	R_R (10^{-3} AU)	R_H/R_R
TRAPPIST-1 b	0.85	1.086	0.011	0.244	0.120	2.04
TRAPPIST-1 c	1.38	1.056	0.015	0.393	0.141	2.79
TRAPPIST-1 d	0.41	0.772	0.021	0.370	0.094	3.94
TRAPPIST-1 e	0.62	0.918	0.028	0.557	0.108	5.17
TRAPPIST-1 f	0.68	1.045	0.037	0.756	0.111	6.80
TRAPPIST-1 g	1.34	1.127	0.045	1.154	0.139	8.28
TRAPPIST-1 h	0.31	0.715	0.060	0.936	0.086	10.86

NOTE—Planetary masses, radii, and semi-major axes are from [Gillon et al. \(2017\)](#).



The Cosmic Shoreline

