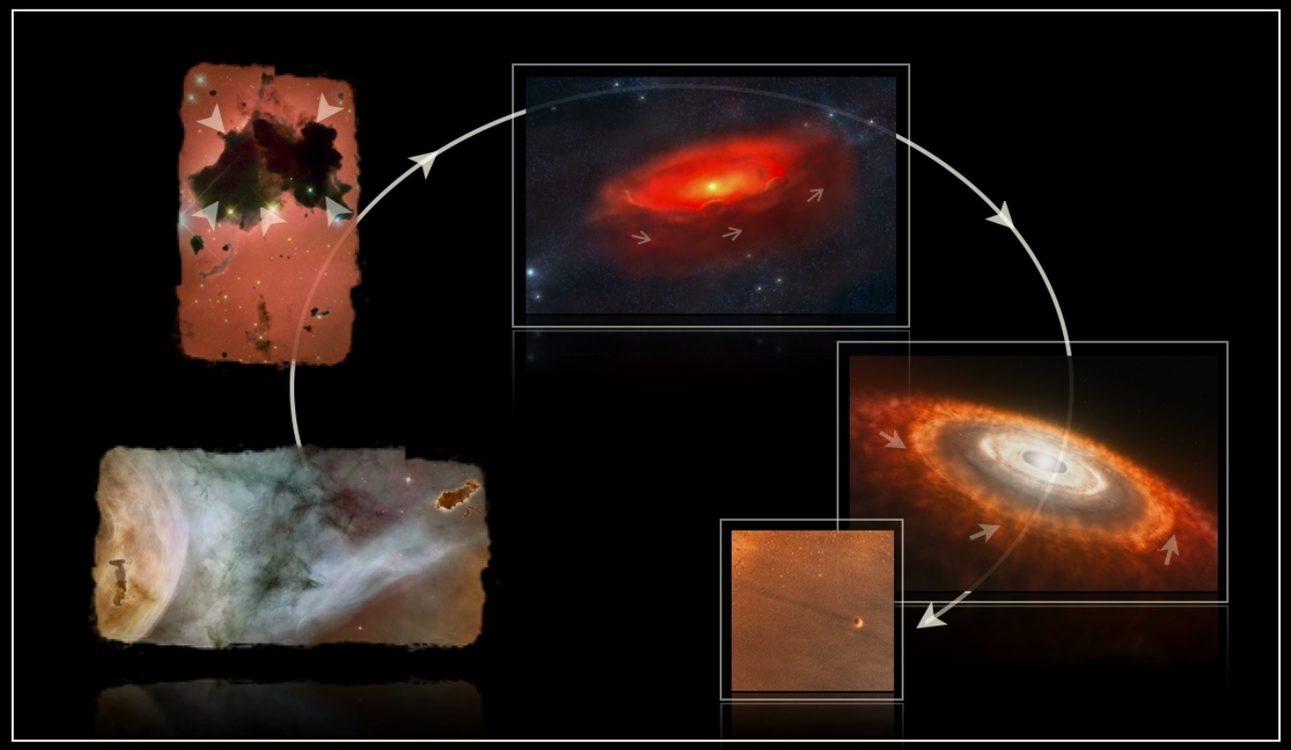
STARS, PLANETS AND GALAXIES



Earth twin and life detection…

Didier Queloz

Cambridge Centre for Climate Science

Universal Life

cambridge exoplanet research centre

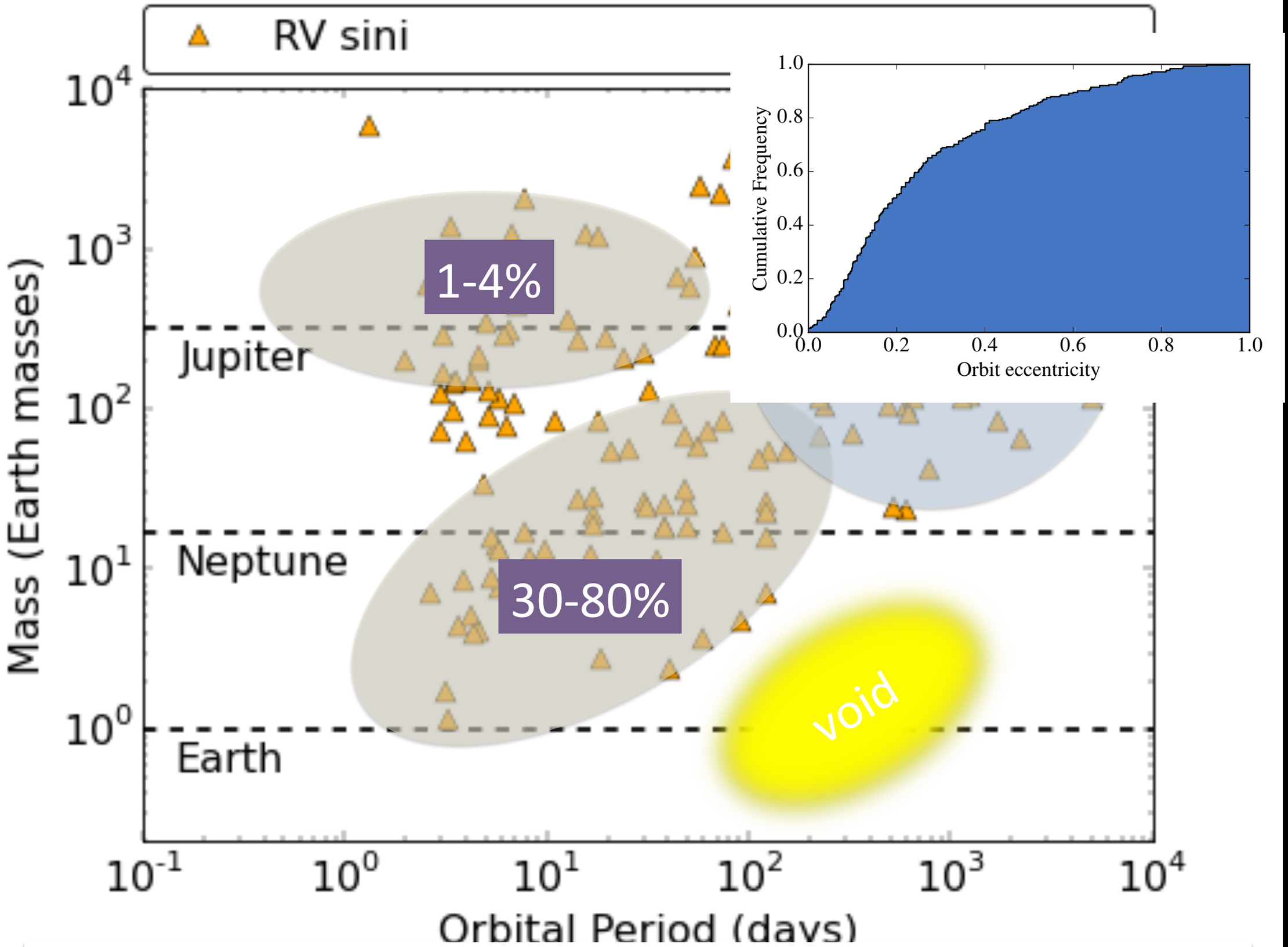
SIMONS FOUNDATION

Exoplanet Science is about

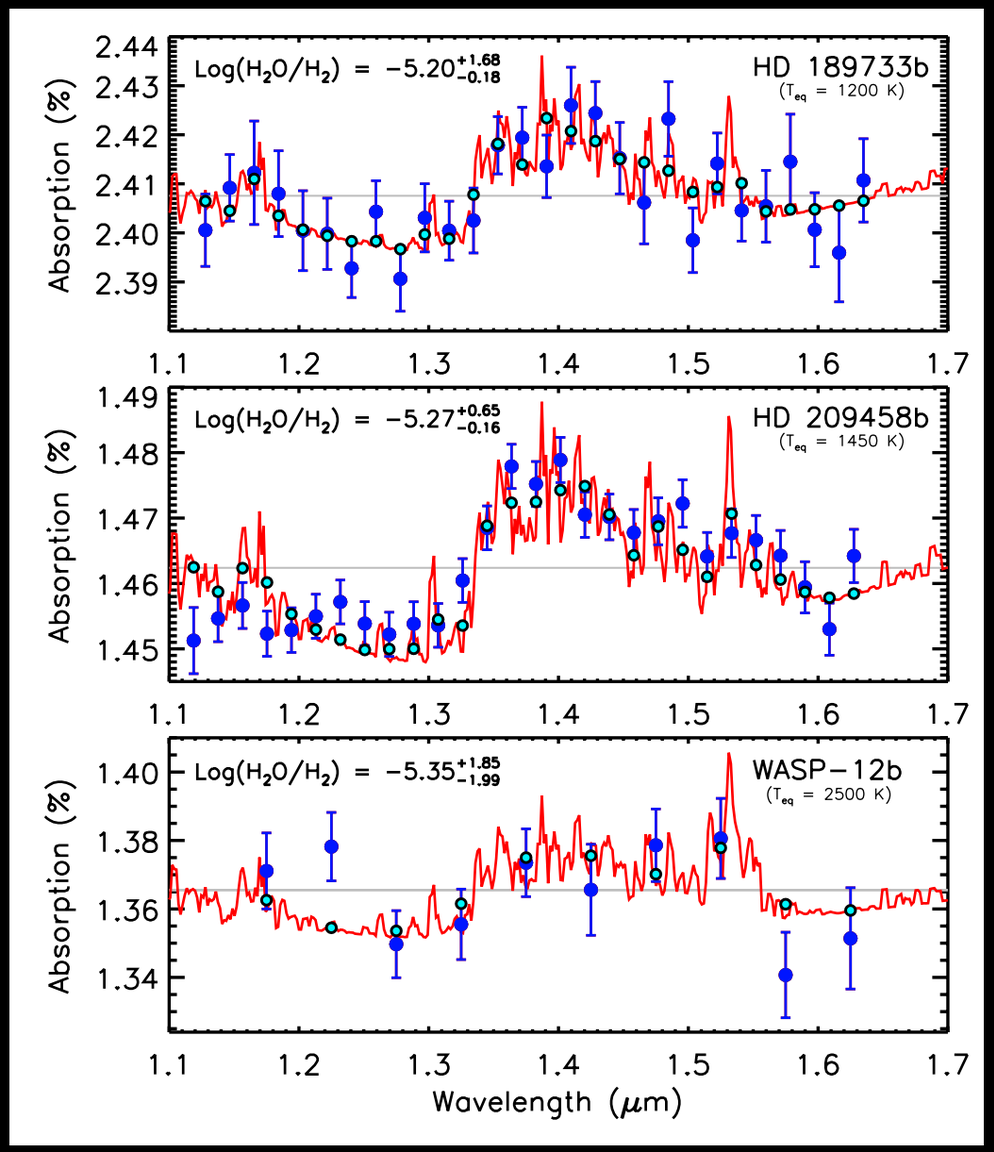
- **How do planets form and evolve ?**
  towards an universal model for planetary systems

- **How diverse are planetary systems ?**
  Our Solar system in perspectives

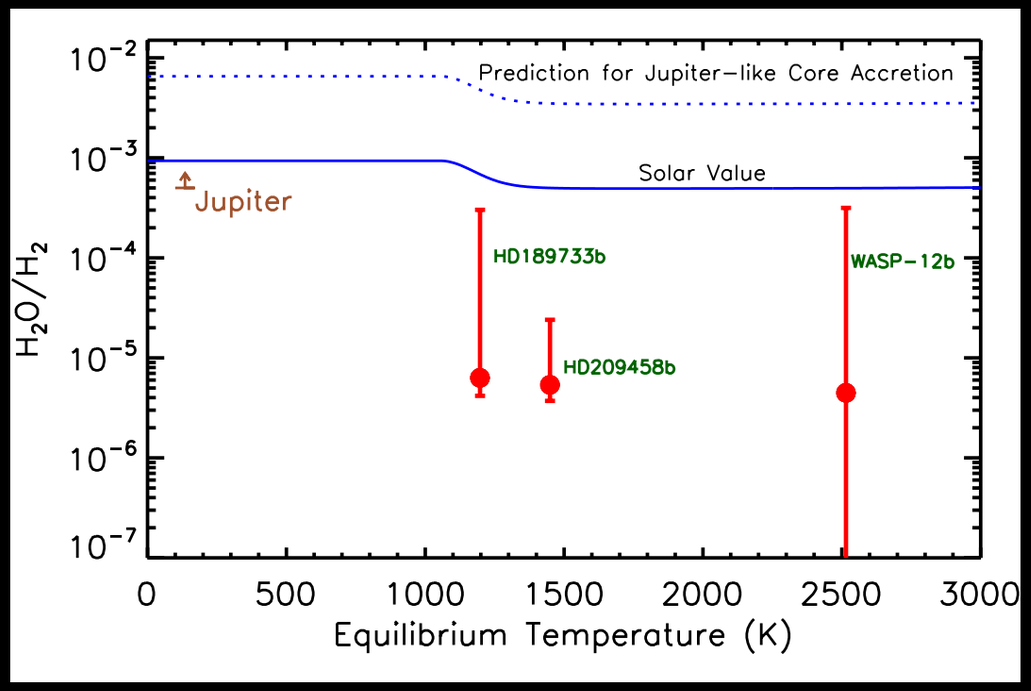
- **Is there life elsewhere ?**
  Understanding the origin, prevalence and nature of life in the Universe.


RV sini
Jupiter
Neptune
Earth
1-4%
30-80%
void
Mass (Earth masses)
Orbital Period (days)
Cumulative Frequency
Orbit eccentricity

Giant planets, tracers of planetary formation

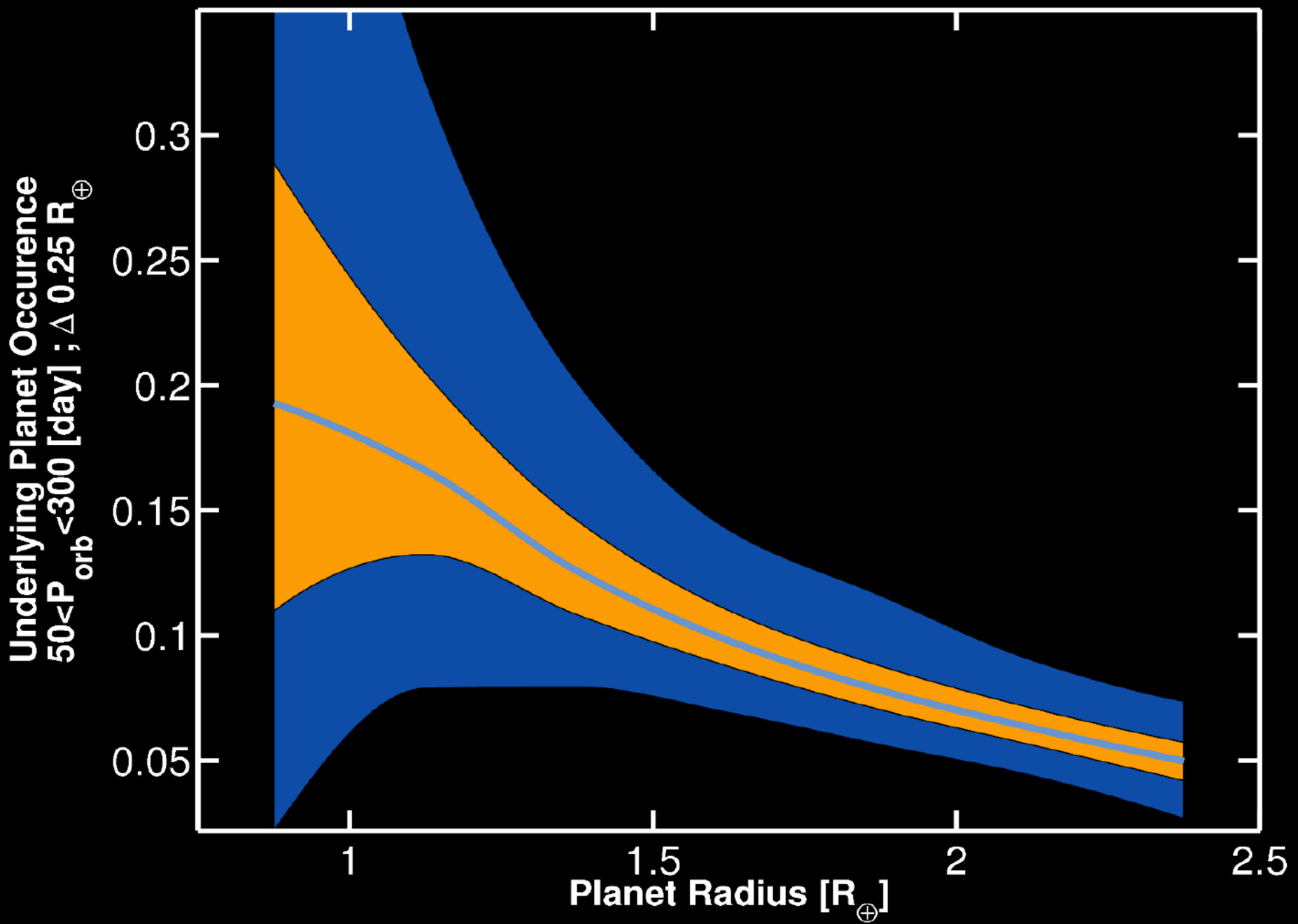


Water in hot Jupiter



Madhusudhan+ 2014

Kepler, Eta Earth measurement…



Courtesy Batalha

What do we know about small planets?

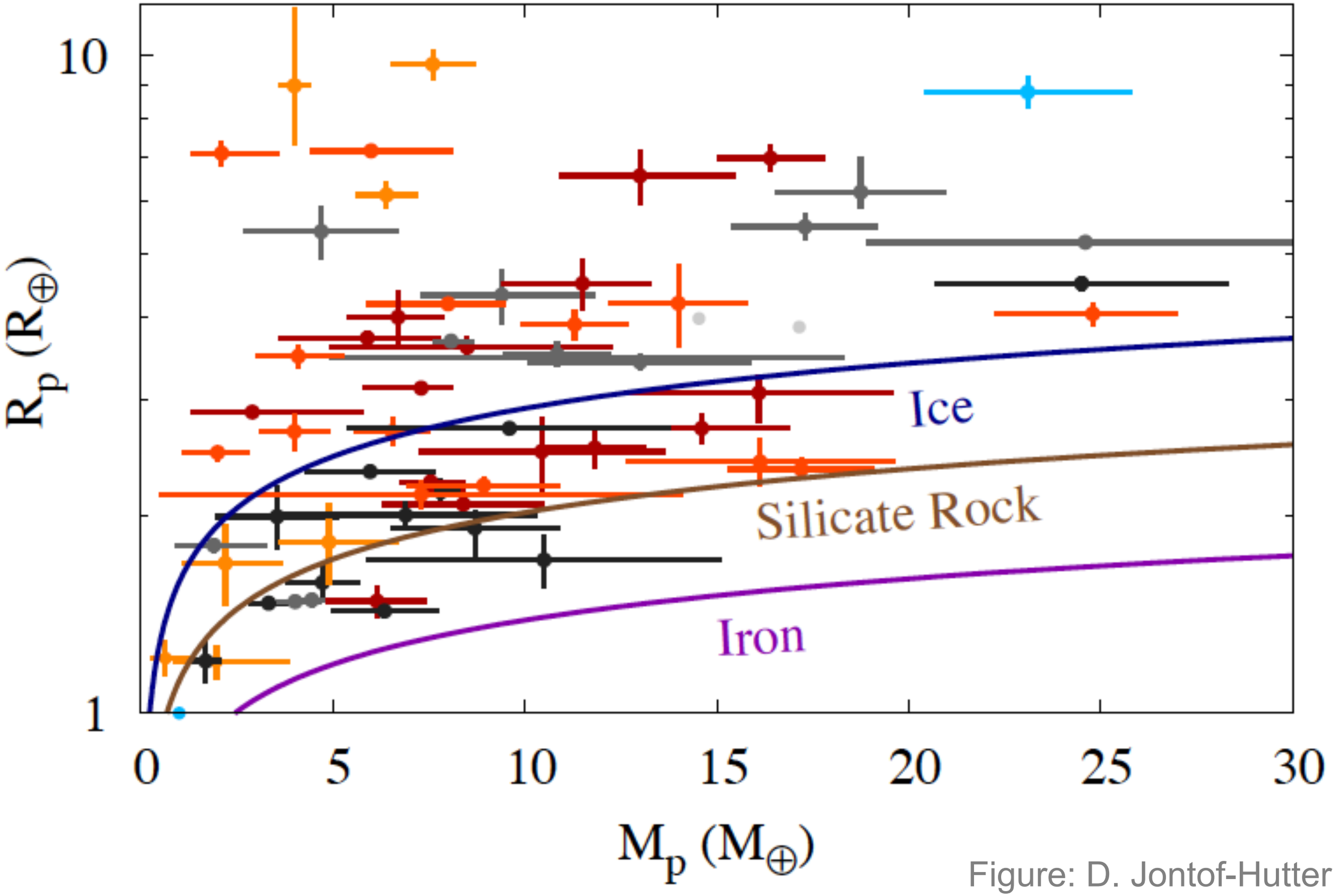
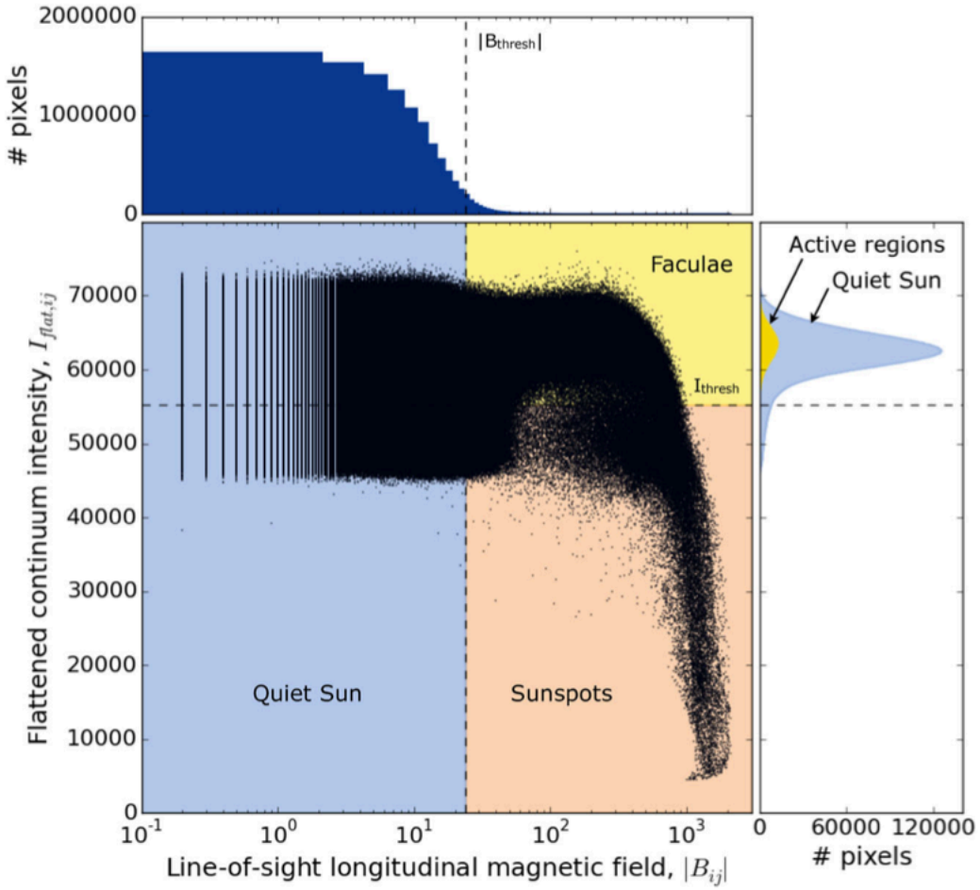
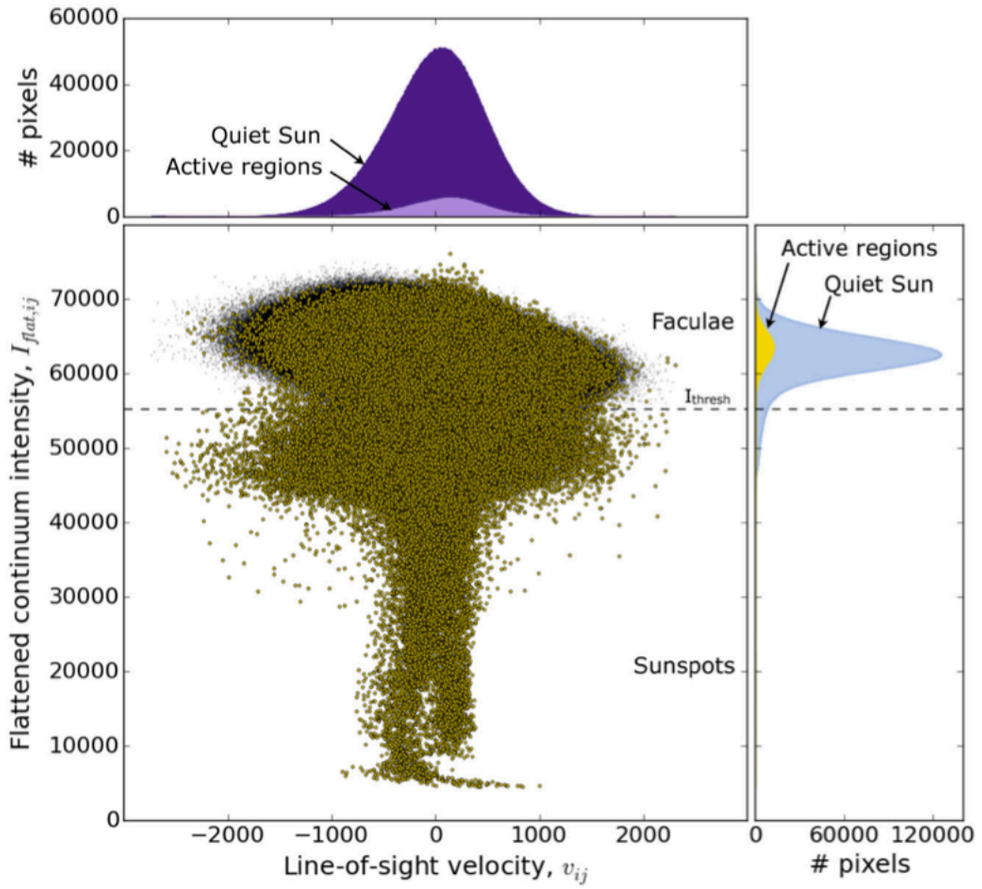
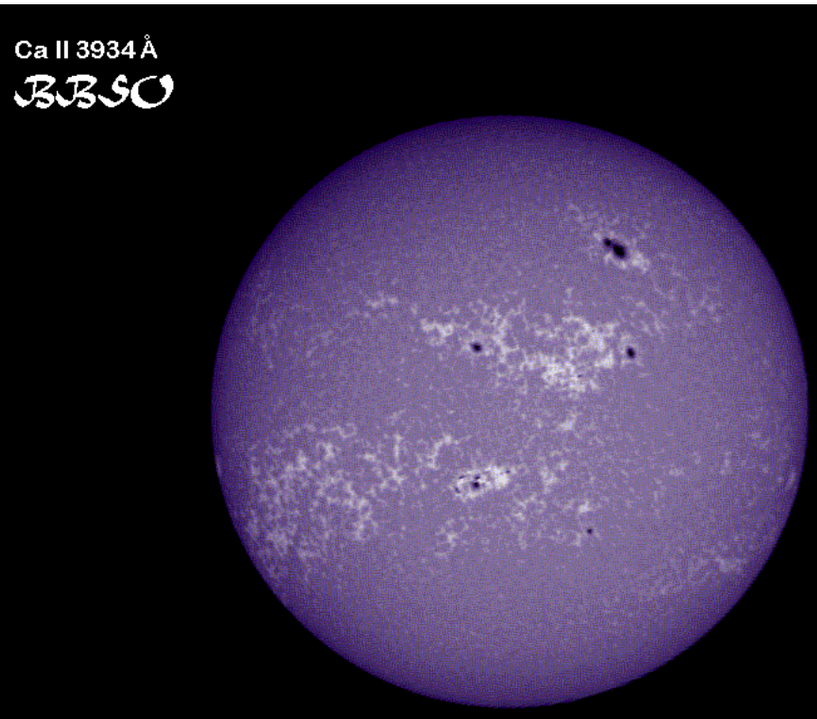


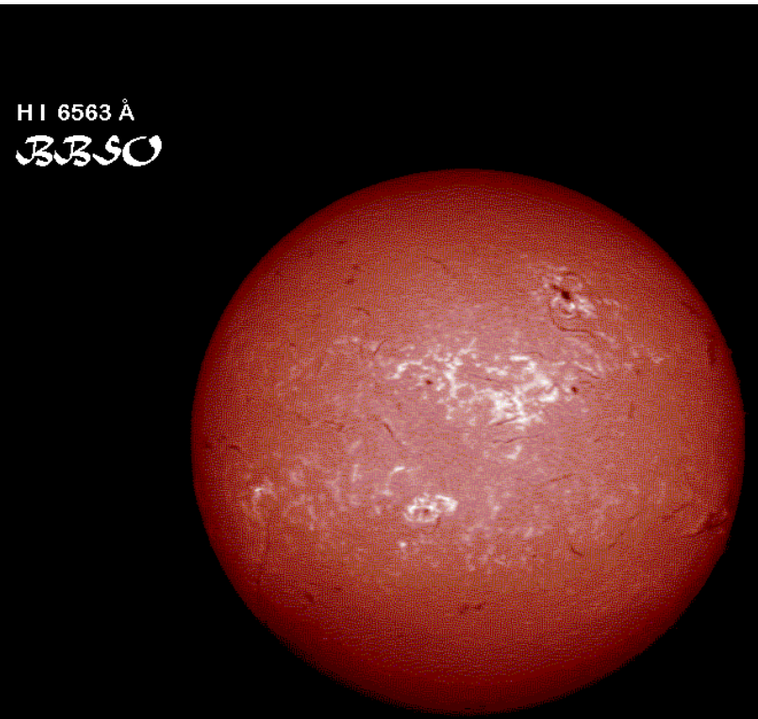
Figure: D. Jontof-Hutter

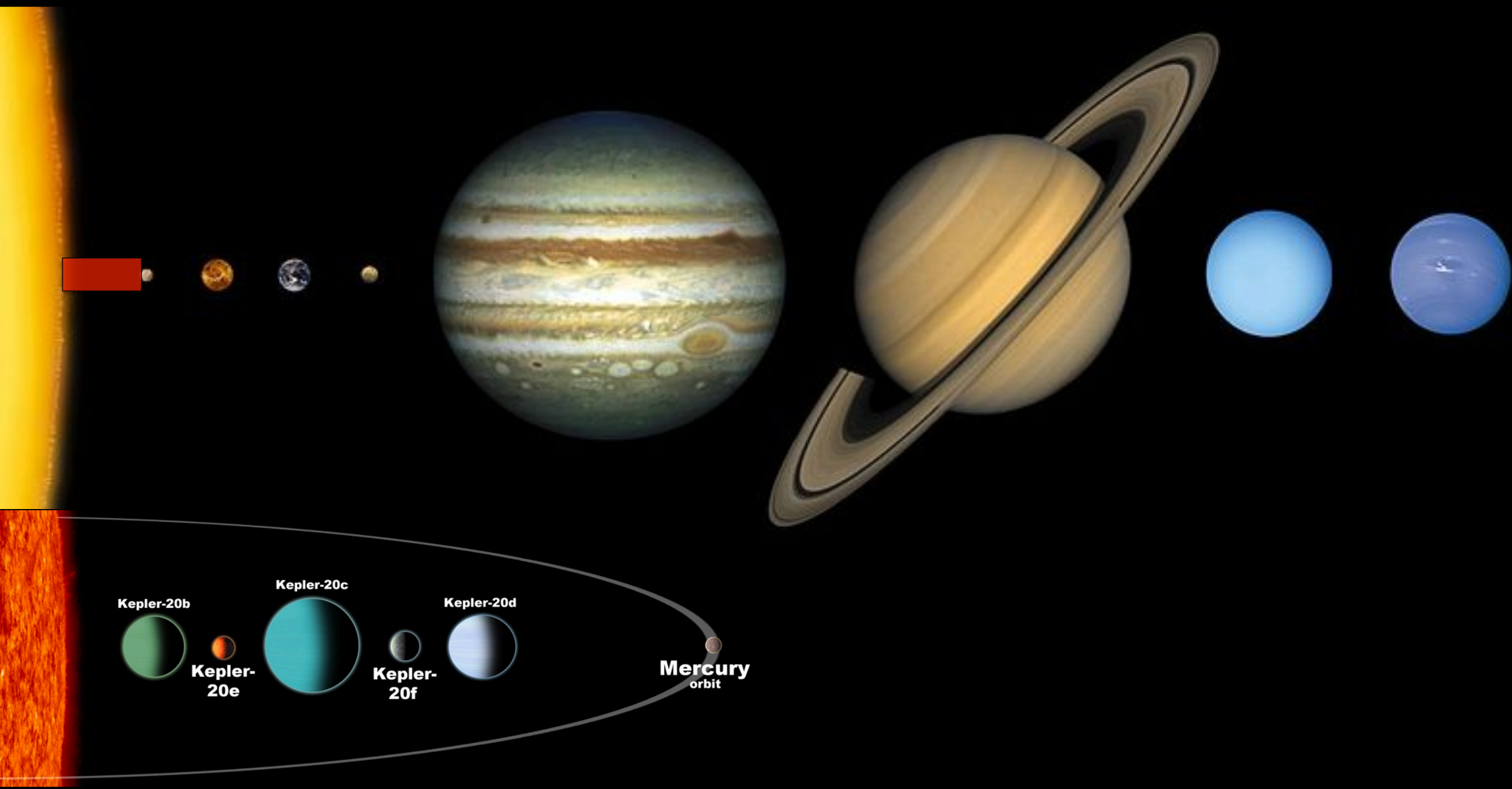
Haywood et al. 2017



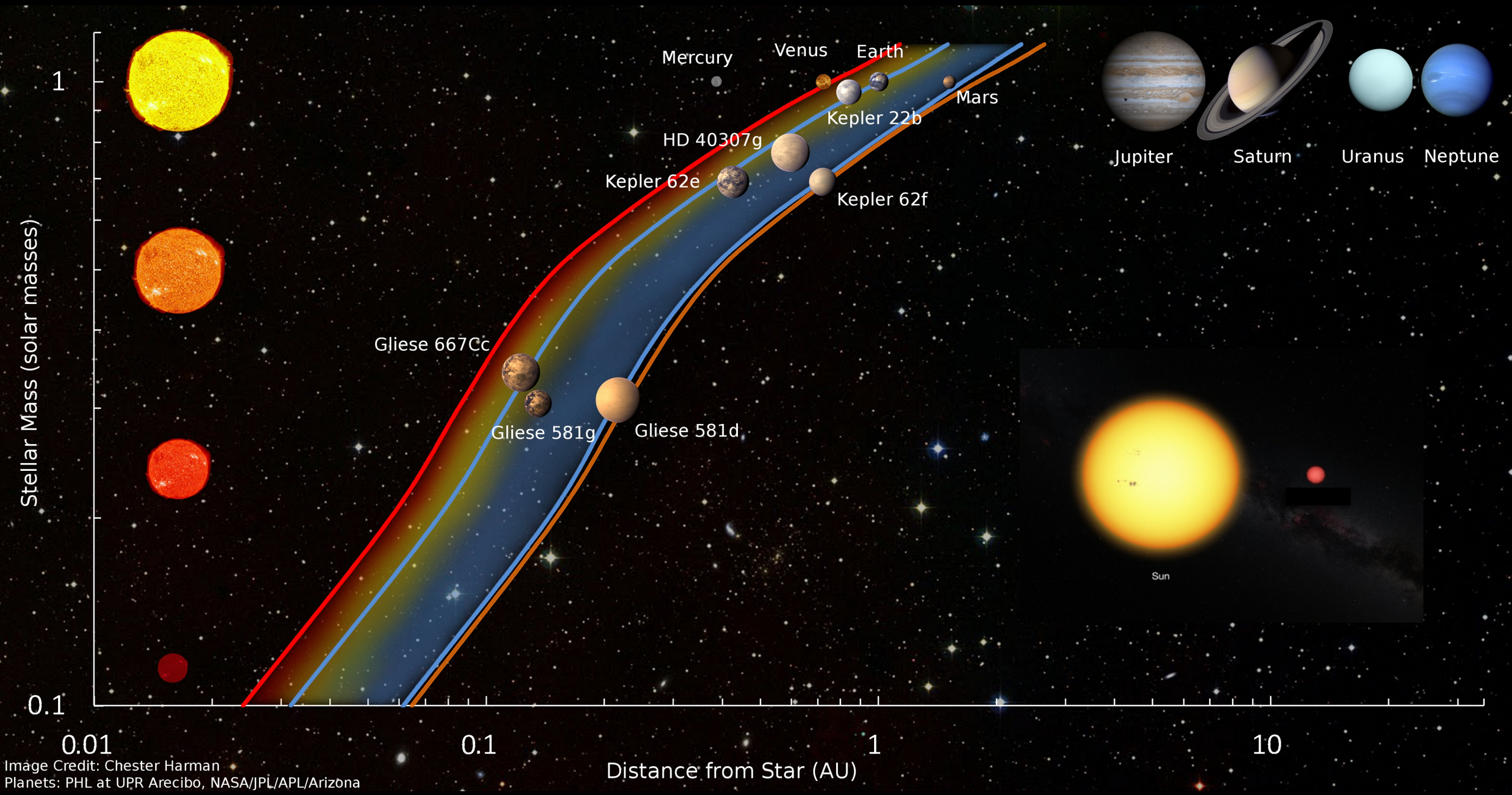


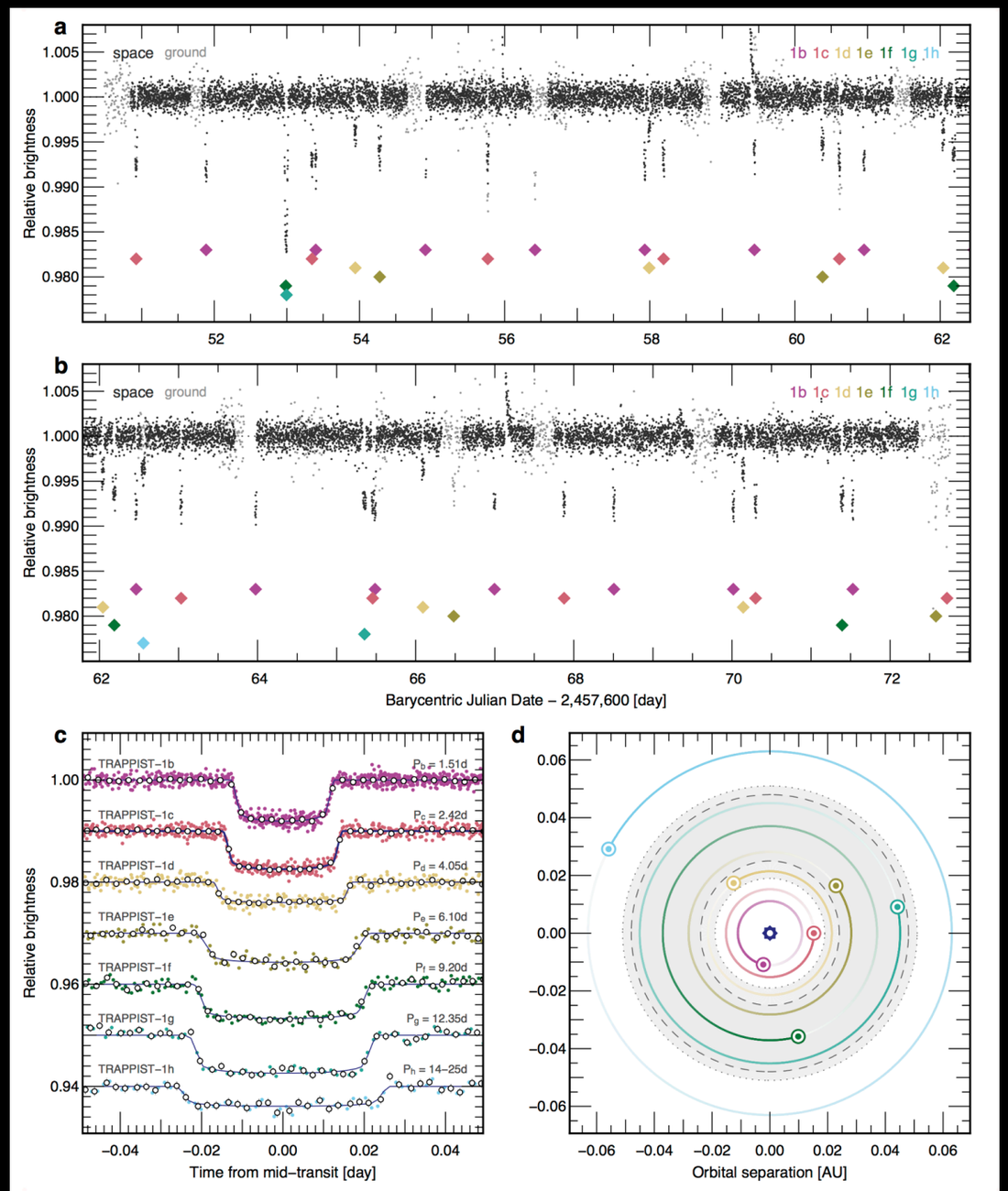





Kepler-20b
Kepler-20e
Kepler-20c
Kepler-20f
Kepler-20d
Mercury
orbit

HZ projection




a
space
ground
1b 1c 1d 1e 1f 1g 1h
Relative brightness
1.005
1.000
0.995
0.990
0.985
0.980
52
54
56
58
60
62
b
space
ground
1b 1c 1d 1e 1f 1g 1h
Relative brightness
1.005
1.000
0.995
0.990
0.985
0.980
62
64
66
68
70
72
Barycentric Julian Date – 2,457,600 [day]
c
TRAPPIST–1b
P_b = 1.51d
TRAPPIST–1c
P_c = 2.42d
TRAPPIST–1d
P_d = 4.05d
TRAPPIST–1e
P_e = 6.10d
TRAPPIST–1f
P_f = 9.20d
TRAPPIST–1g
P_g = 12.35d
TRAPPIST–1h
P_h = 14–25d
Relative brightness
1.00
0.98
0.96
0.94
–0.04
–0.02
0.00
0.02
0.04
Time from mid–transit [day]
d
0.06
0.04
0.02
0.00
–0.02
–0.04
–0.06
–0.06
–0.04
–0.02
0.00
0.02
0.04
0.06
Orbital separation [AU]


PLANET HOP FROM
TRAPPIST-1e
BHZ
VOTED BEST "HAB ZONE" VACATION WITHIN 12 PARSECS OF EARTH

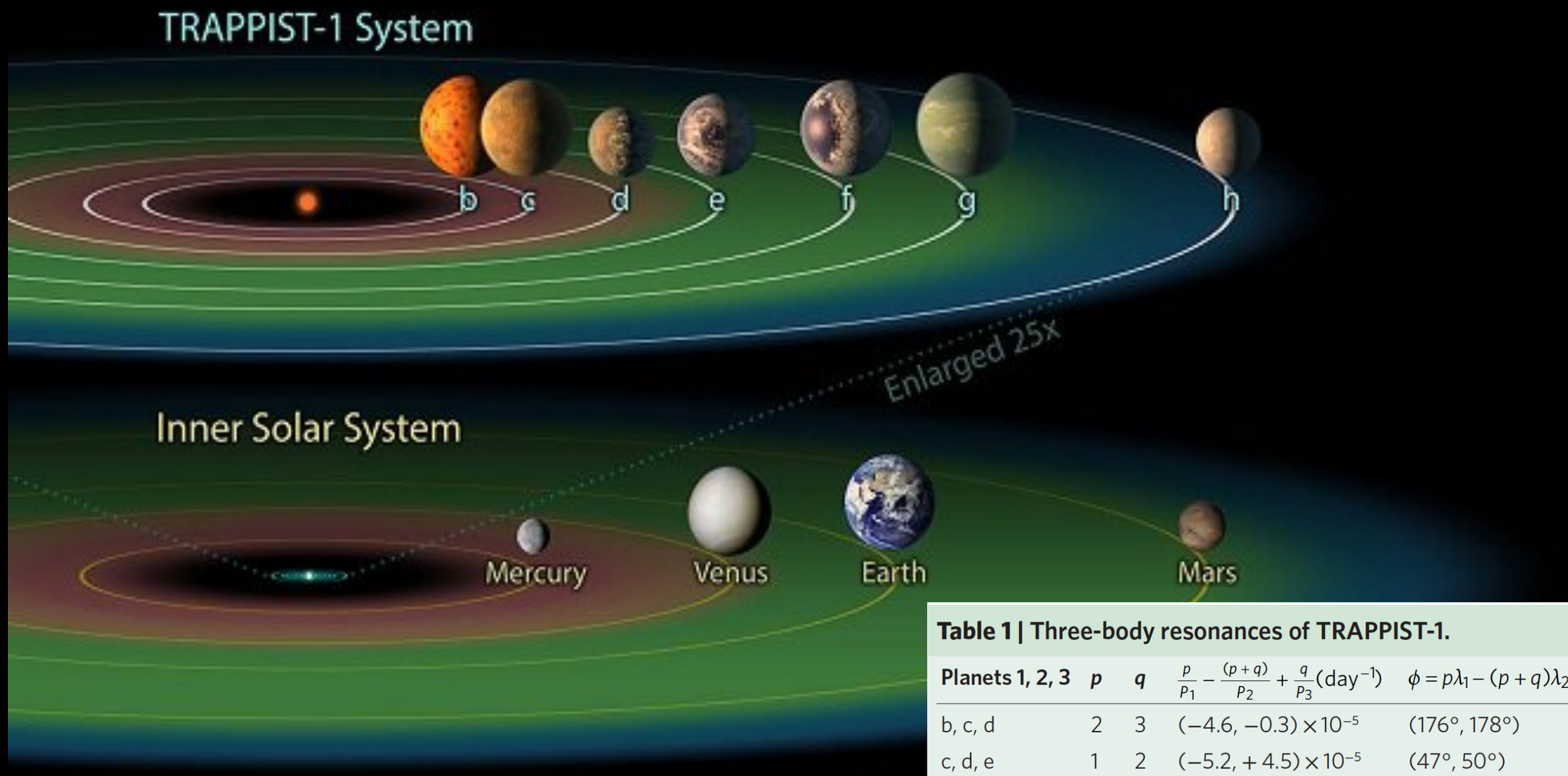
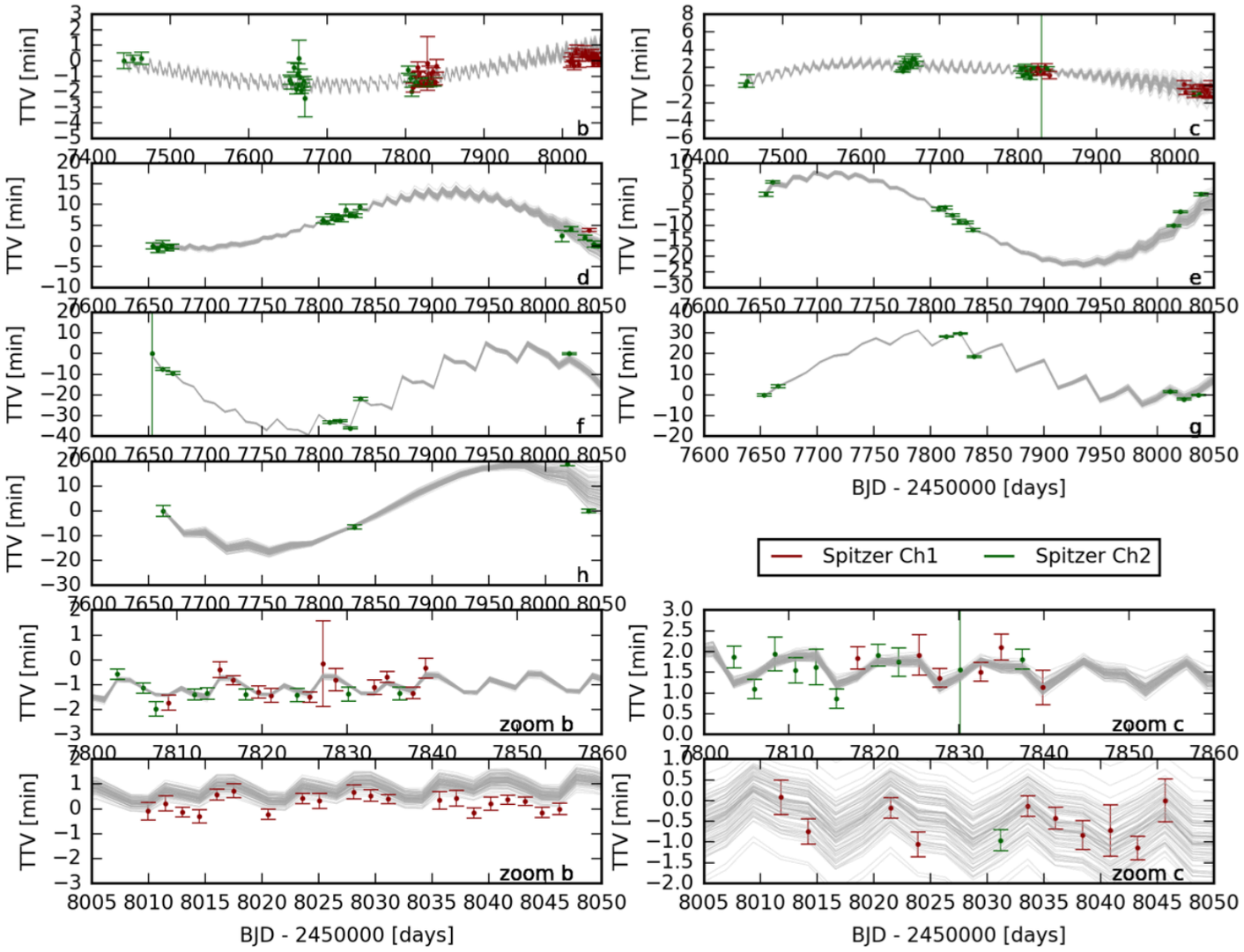


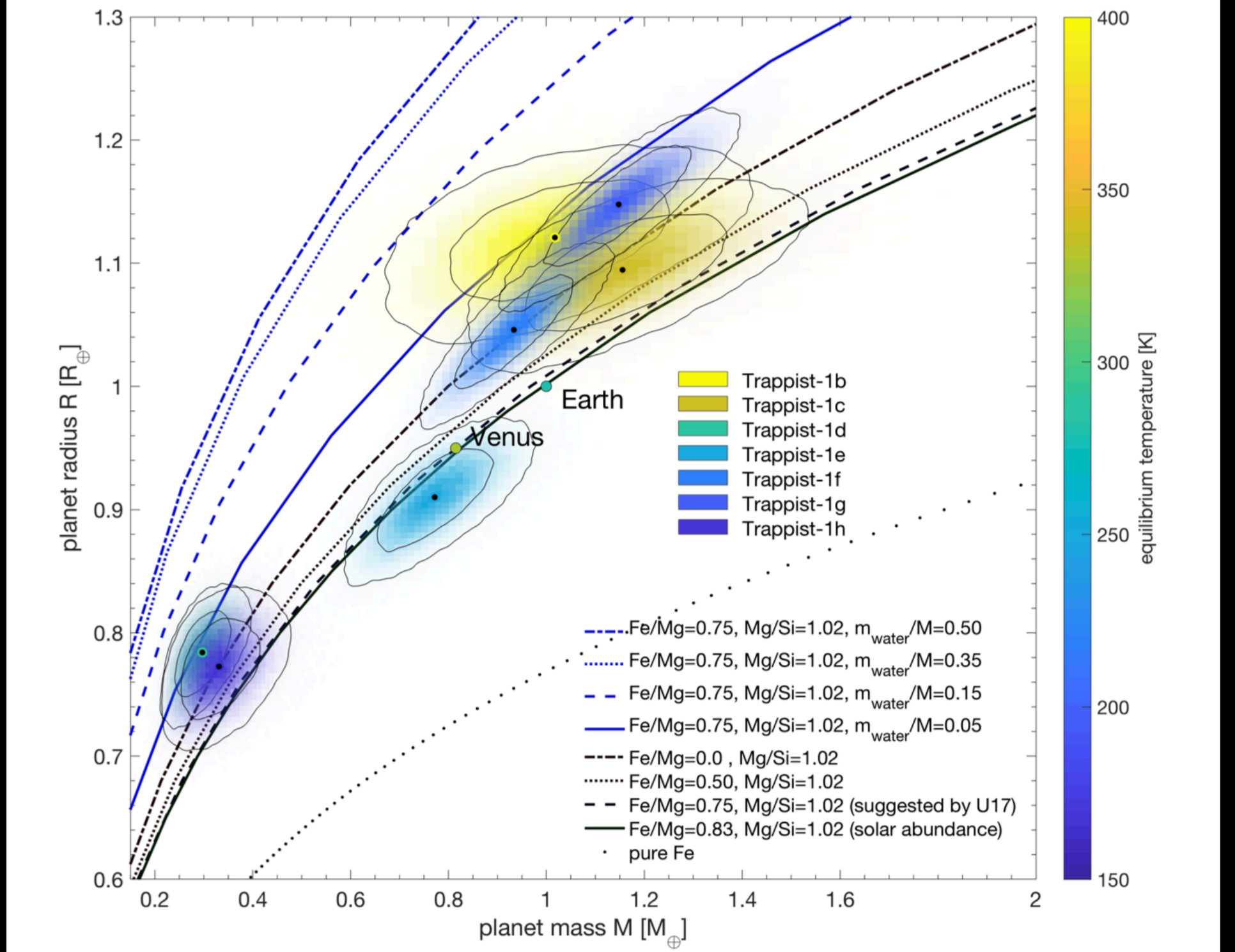
Table 1 | Three-body resonances of TRAPPIST-1.

Planets 1, 2, 3	p	q	$\frac{p}{P_1} - \frac{(p+q)}{P_2} + \frac{q}{P_3}$ (day^{-1})	$\phi = p\lambda_1 - (p+q)\lambda_2 + q\lambda_3$
b, c, d	2	3	$(-4.6, -0.3) \times 10^{-5}$	(176°, 178°)
c, d, e	1	2	$(-5.2, +4.5) \times 10^{-5}$	(47°, 50°)
d, e, f	2	3	$(-1.9, +1.9) \times 10^{-4}$	(−154°, −142°)
e, f, g	1	2	$(-1.4, +1.1) \times 10^{-4}$	(−79°, −72°)
f, g, h	1	1	$(-6.0, +0.2) \times 10^{-5}$	(176.5°, 177.5°)

The transit times are used to track the ϕ angles of each set of three adjacent planets over the dataset, assuming low eccentricities such that transits occur at a phase angle $\lambda = 90°$[11]. The ranges of three-body frequency and angle given encompass the changes—most likely librations—seen during the observations.

Resonances are good to get masses





Grimm et al. 2018

Life for astronomers

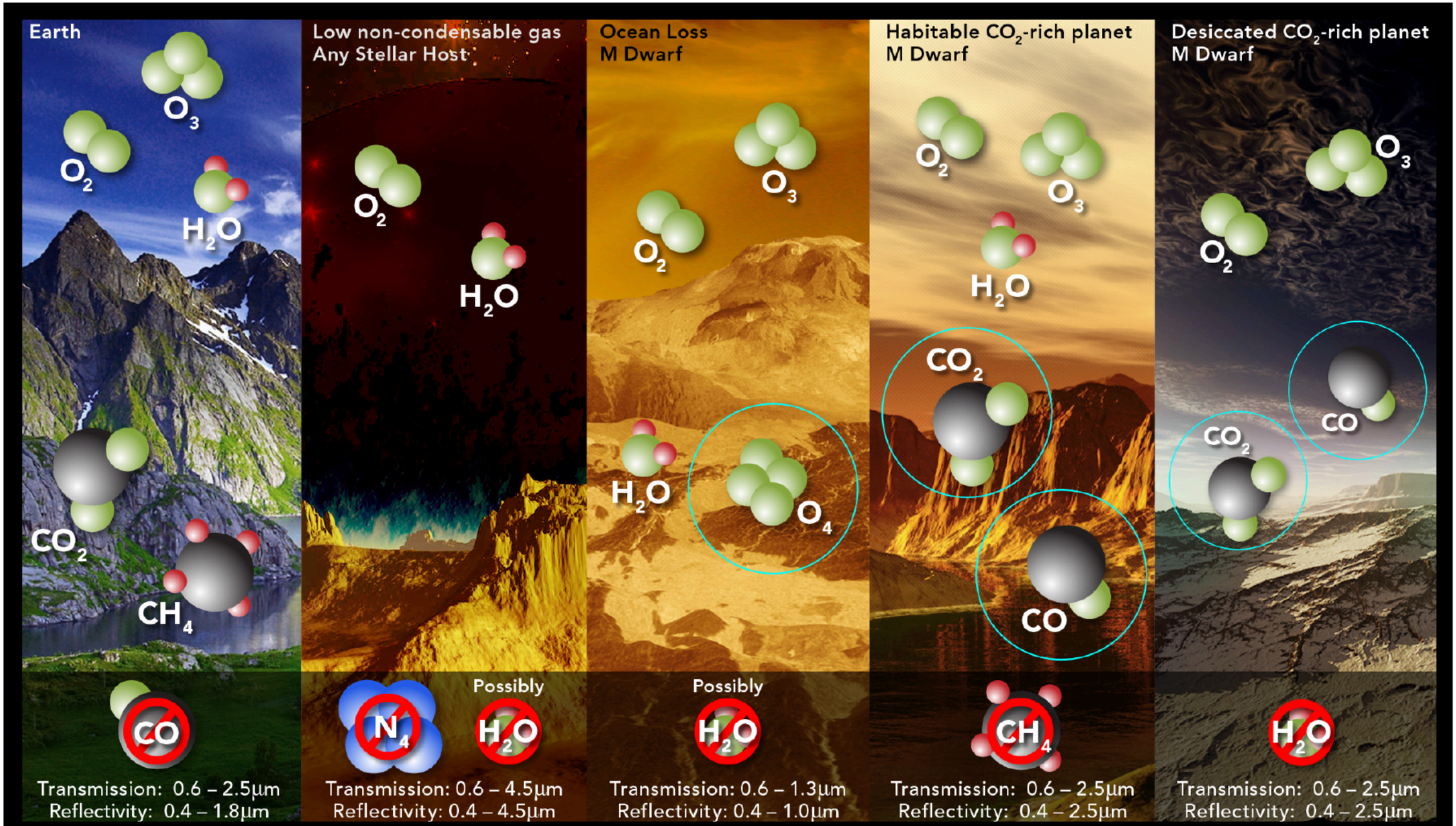
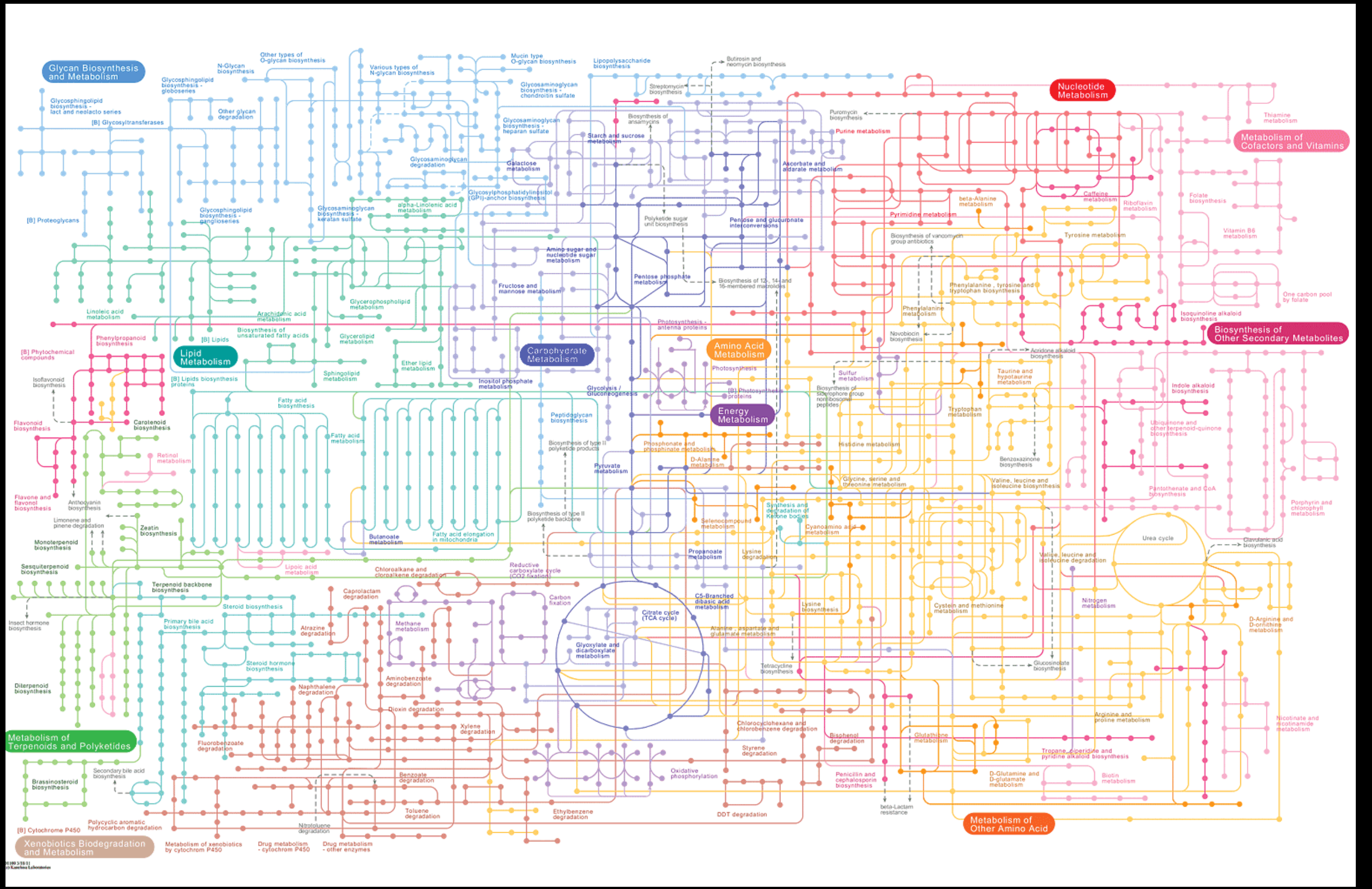


Figure Credit: Hasler/Meadows/Domagal-Goldman

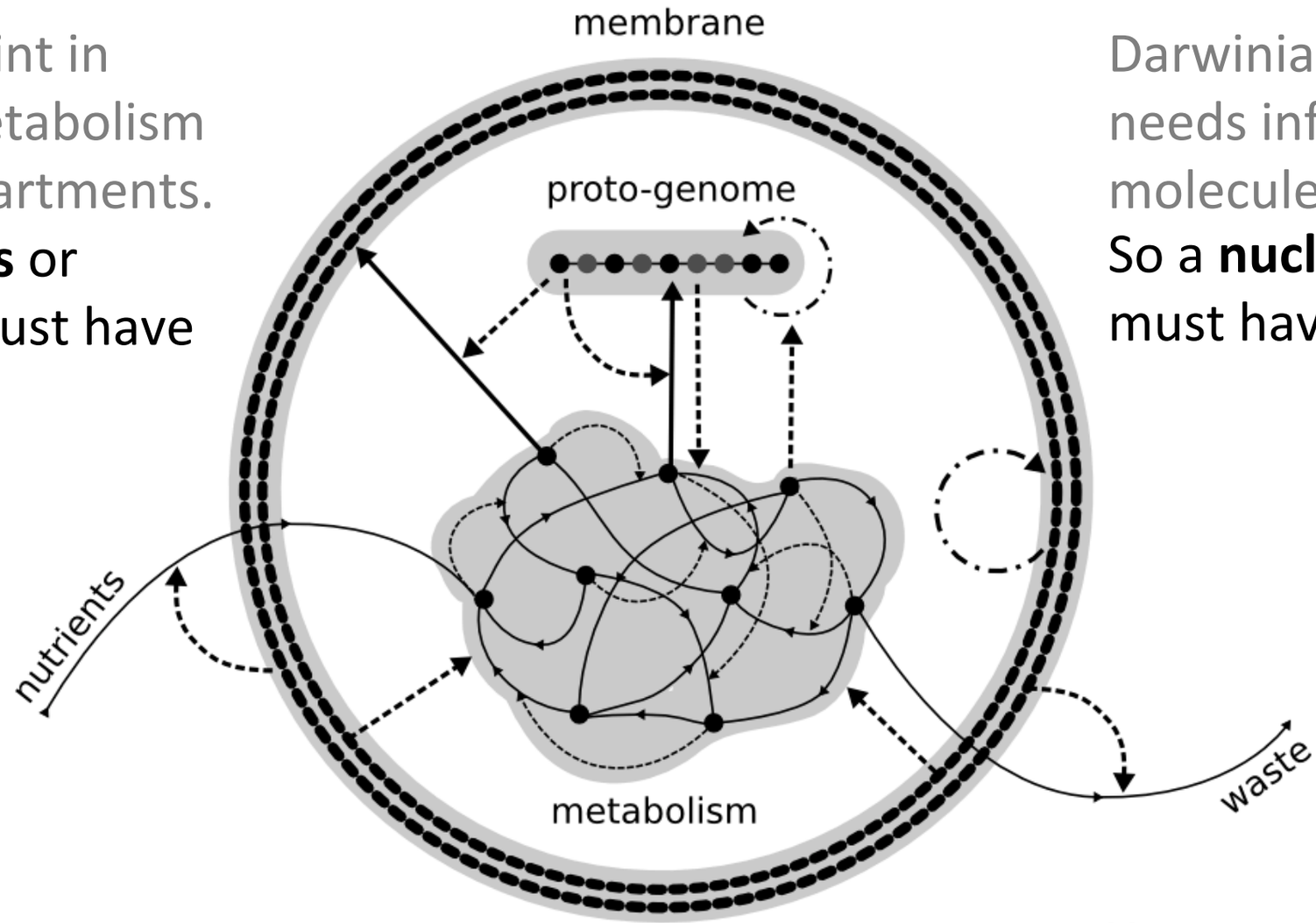
Meadows, 2016, submitted

Life on Earth is



50 years of attempted simplifications of the problem !

There is no point in genetics or metabolism without compartments.
So **membranes** or coacervates must have come first.

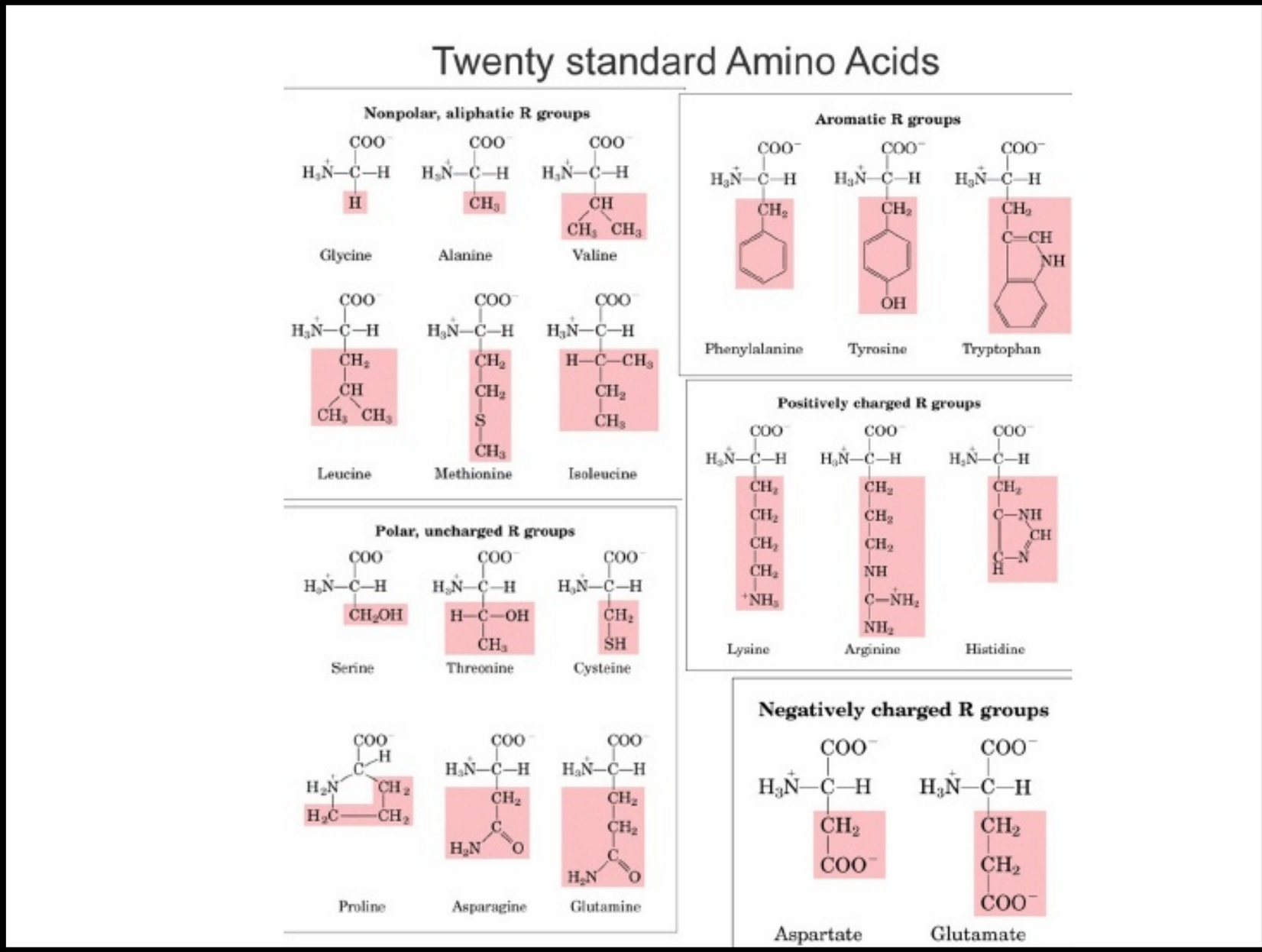


Darwinian evolution needs informational molecules.
So a **nucleic acid (RNA)** must have come first.

You can’t make or replicate anything without catalysts.
So **proteins** must have come first.

You need building blocks and energy.
So **metabolism** must have come first.

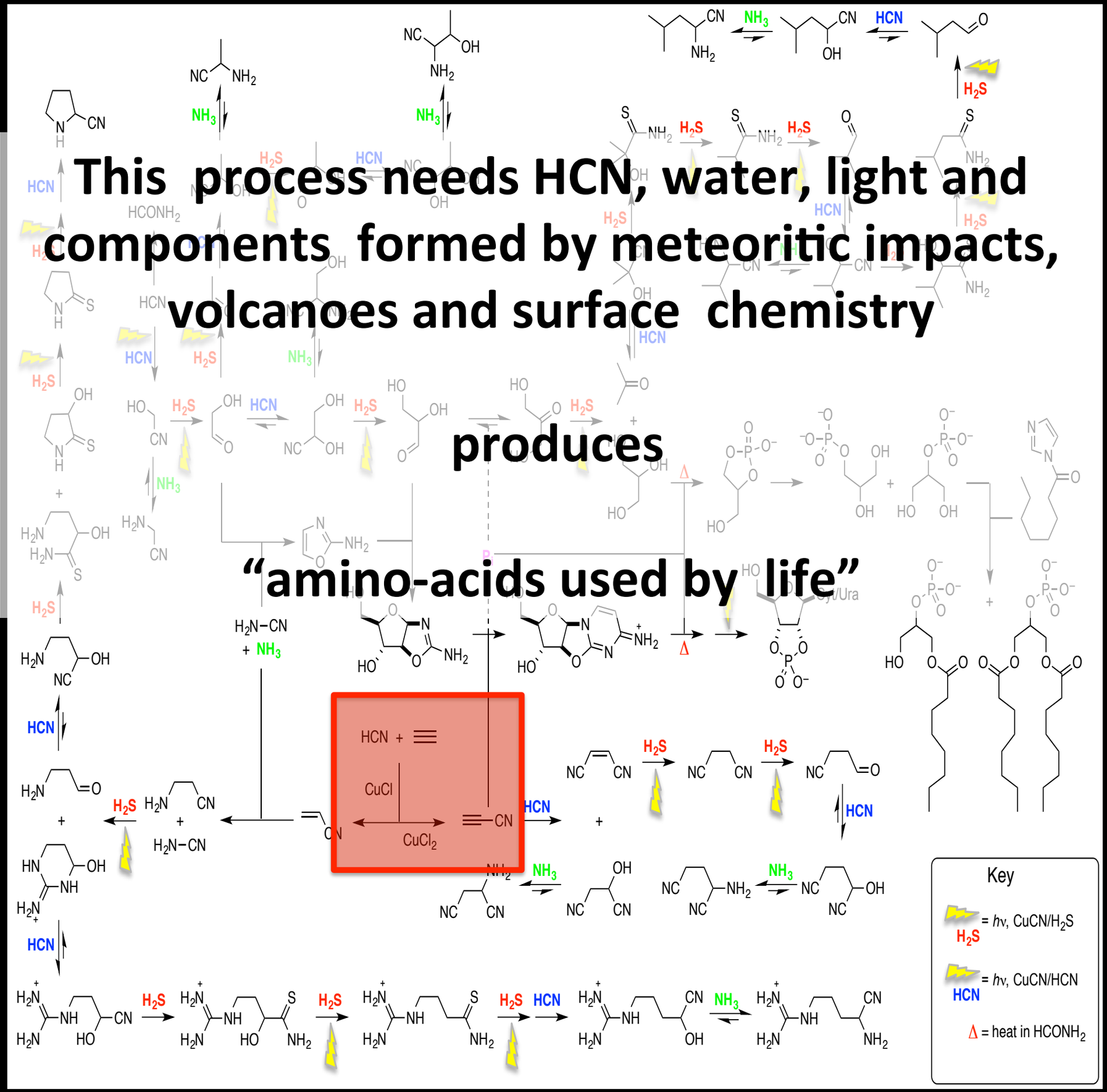
“Universal life” model



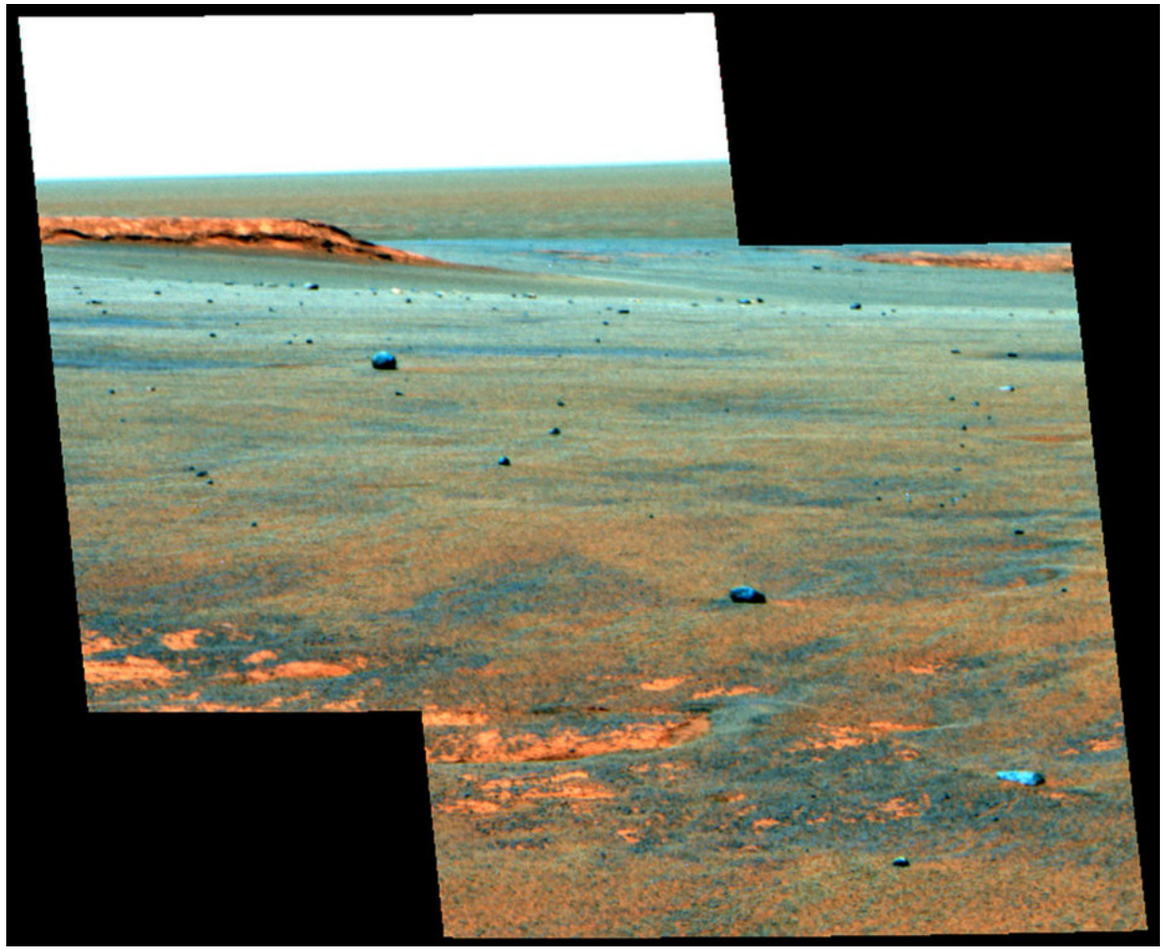
This process needs HCN, water, light and components formed by meteoritic impacts, volcanoes and surface chemistry

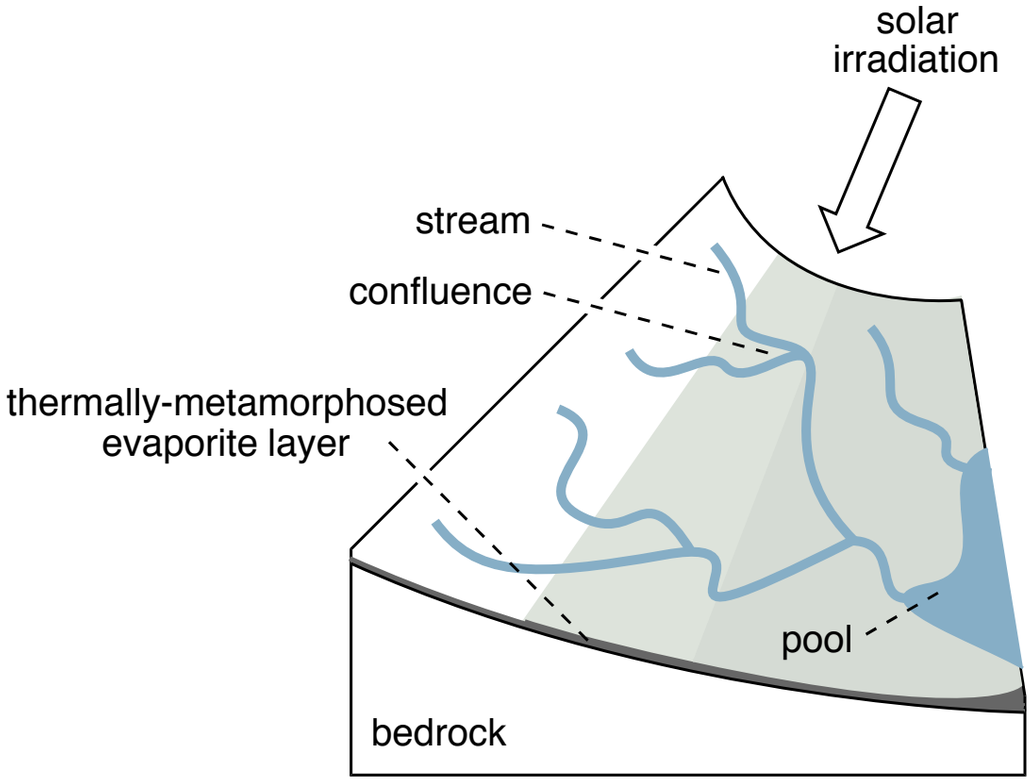
produces

“amino-acids used by life”



Patel et al..." Nature Chemistry 7, no. 4 (2015): 301-307.





nature COMMUNICATIONS

ARTICLE

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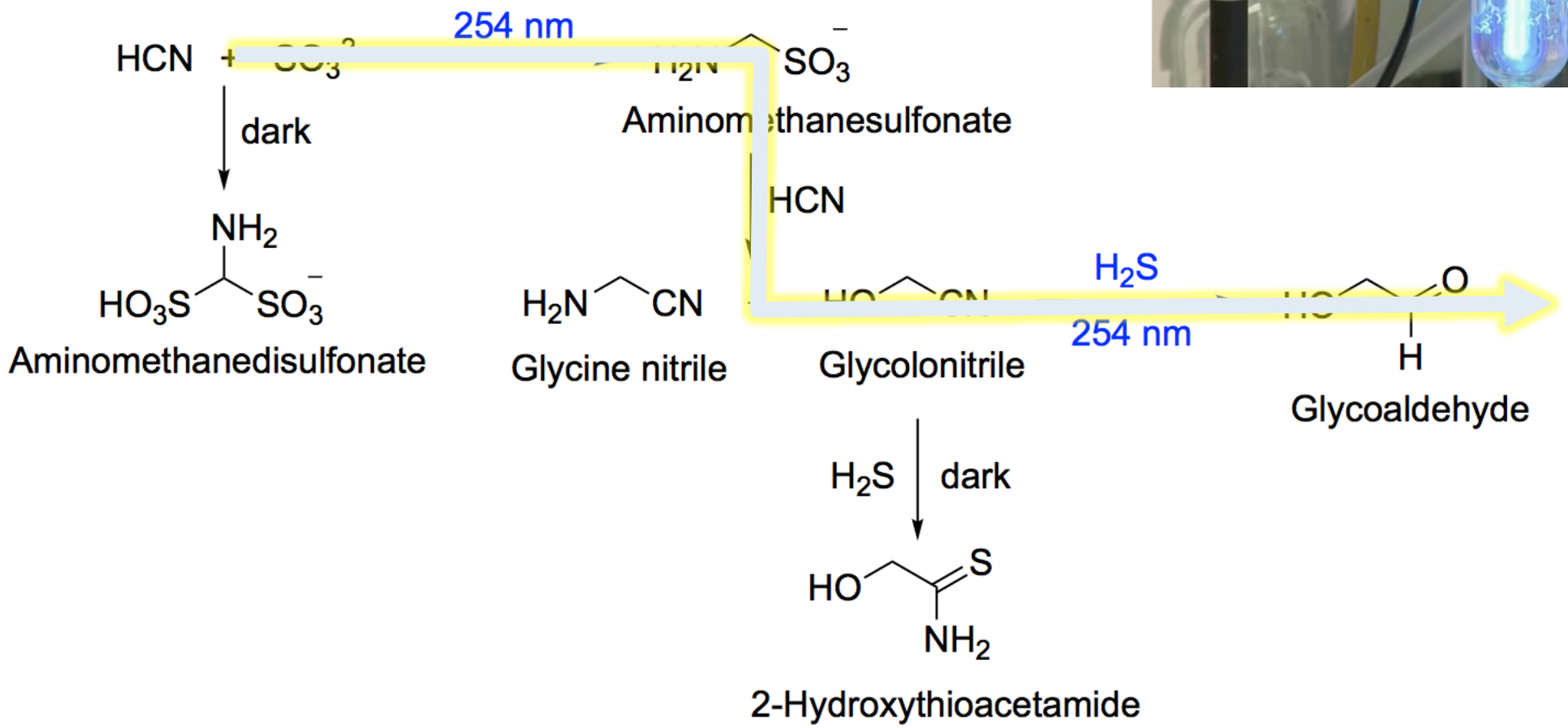
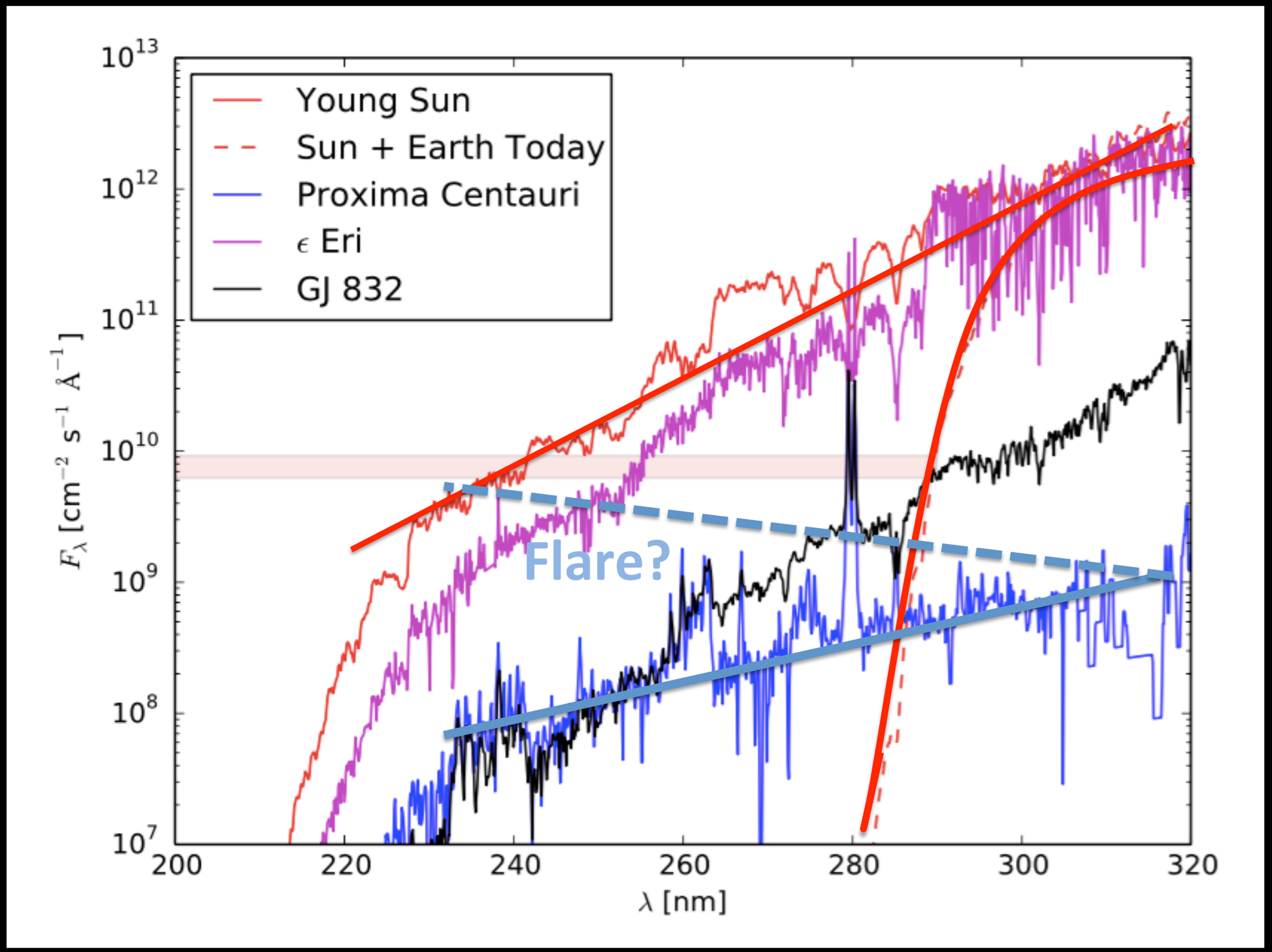
Amazonian chemical weathering rate derived from stony meteorite finds at Meridiani Planum on Mars

Christian Schröder[1], Phil A. Bland[2], Matthew P. Golombek[3], James W. Ashley[3], Nicholas H. Warner[4] & John A. Grant[5]

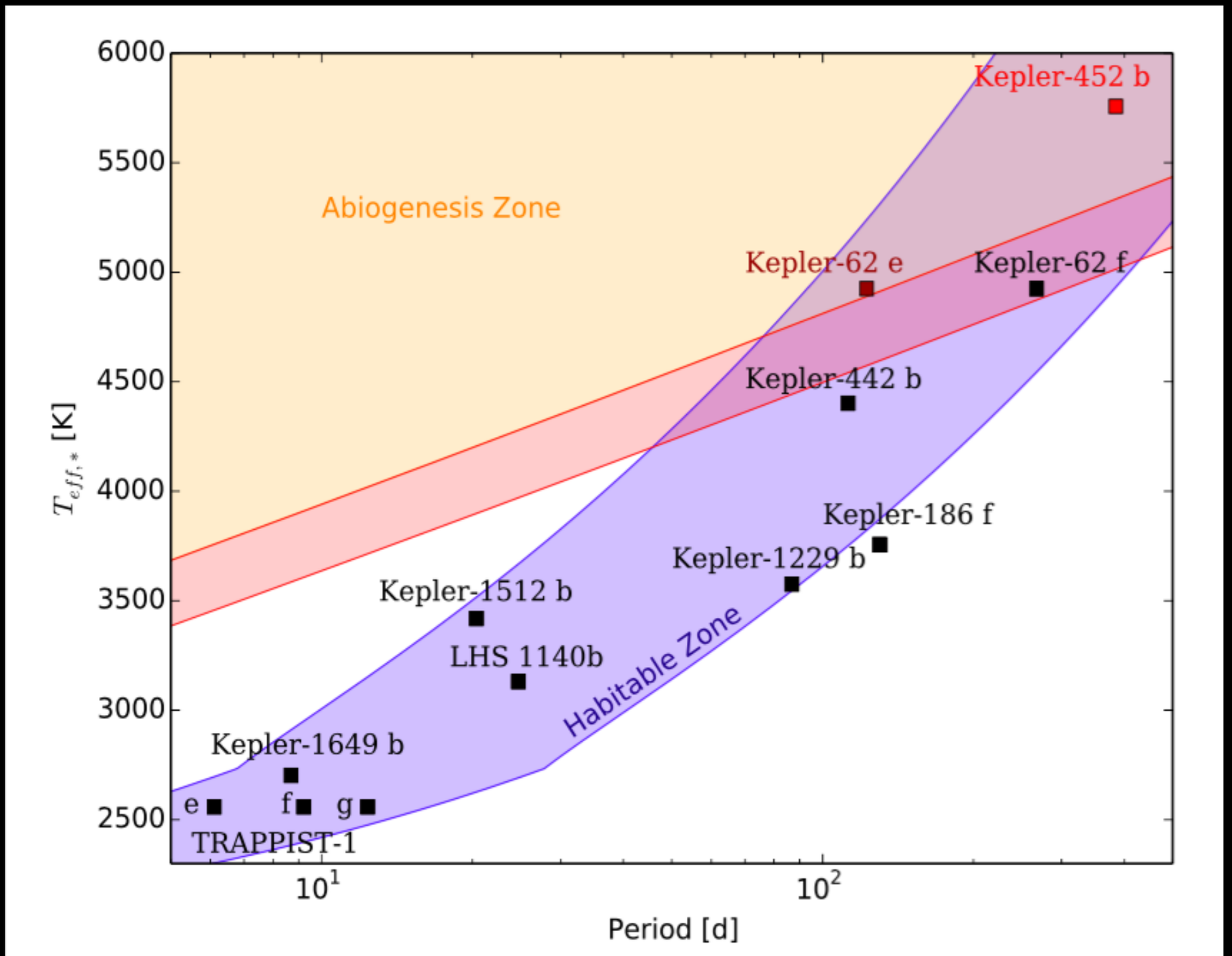
Dark vs light chemistry



Rimmer, P. et al. submitted to Science advances


Young Sun
Sun + Earth Today
Proxima Centauri
ϵ Eri
GJ 832
Flare?
F_λ [cm^{-2} s^{-1} Å^{-1}]
λ [nm]
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
200
220
240
260
280
300
320

HZ + AZ



Rimmer et al. 2018, submitted to Science aAdvances