GEOS 22060/ GEOS 32060 / ASTR 45900

What makes a planet habitable?

Exoplanets

Lecture 19

Tuesday 4 June 2019

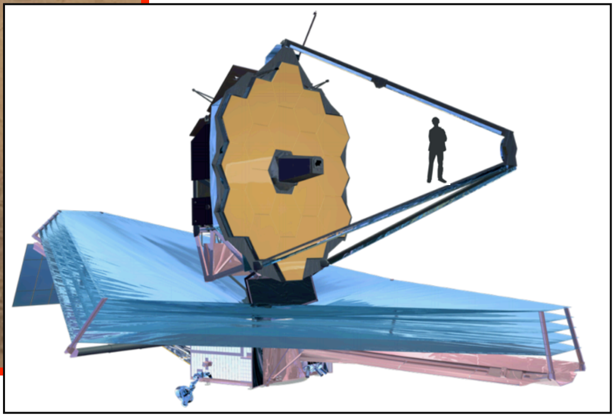
Is Earth a fluke, or are habitable climates common?

Habitable planets = subset of habitable-zone Earth-radius planets

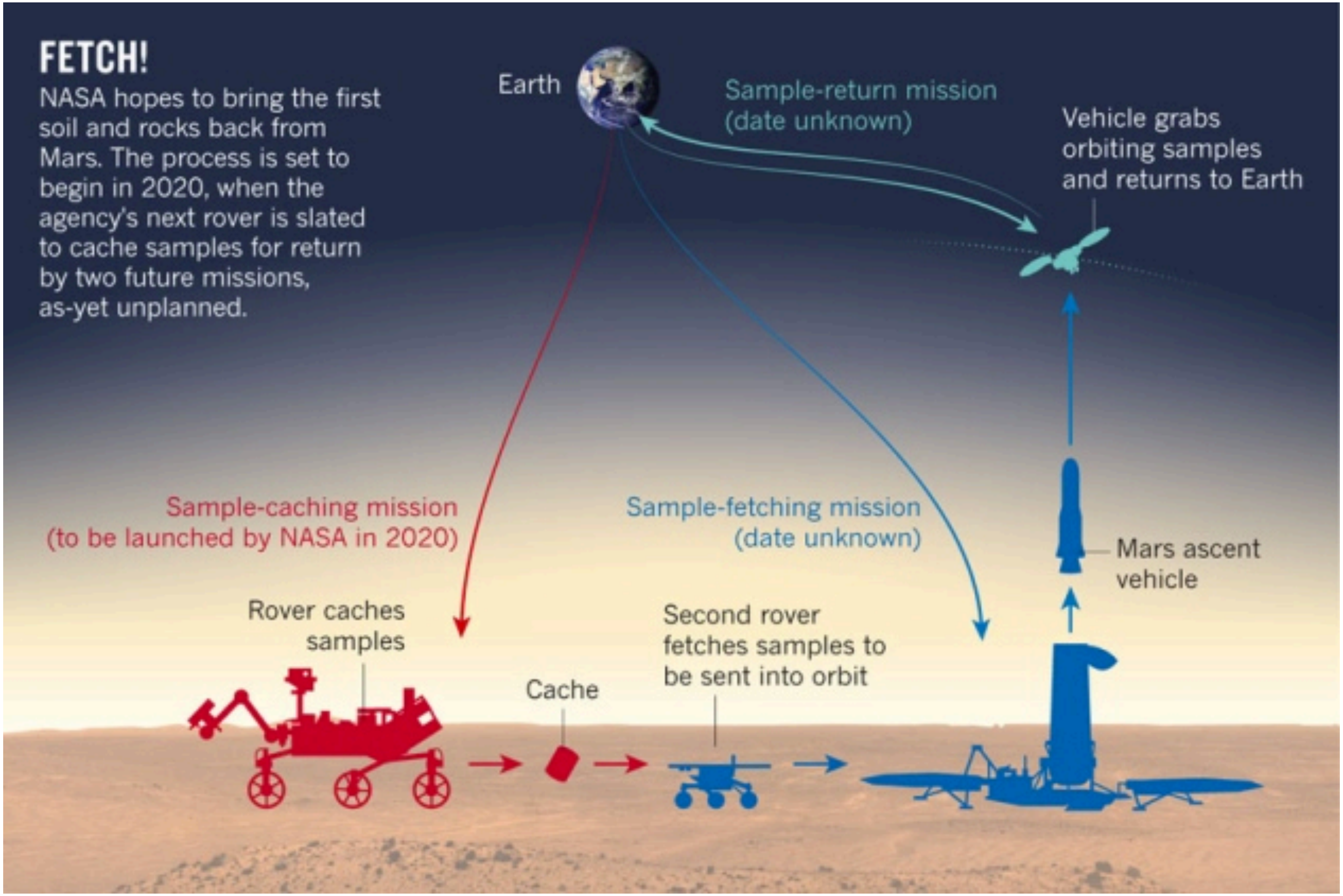
Yorkshire Coast, Earth
Toarcian OAE

Mars is the only planet known to record a major habitability transition in its sediments

Gale Crater, Mars
Habitability transition



Future large segmented telescopes
Exoplanet spectroscopy


FETCH!
NASA hopes to bring the first soil and rocks back from Mars. The process is set to begin in 2020, when the agency's next rover is slated to cache samples for return by two future missions, as-yet unplanned.
Earth
Sample-return mission (date unknown)
Vehicle grabs orbiting samples and returns to Earth
Sample-caching mission (to be launched by NASA in 2020)
Sample-fetching mission (date unknown)
Mars ascent vehicle
Rover caches samples
Cache
Second rover fetches samples to be sent into orbit

Exoplanet habitability

HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE NUMEROUS

HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE LIKELY DIVERSE COMPOSITIONALLY

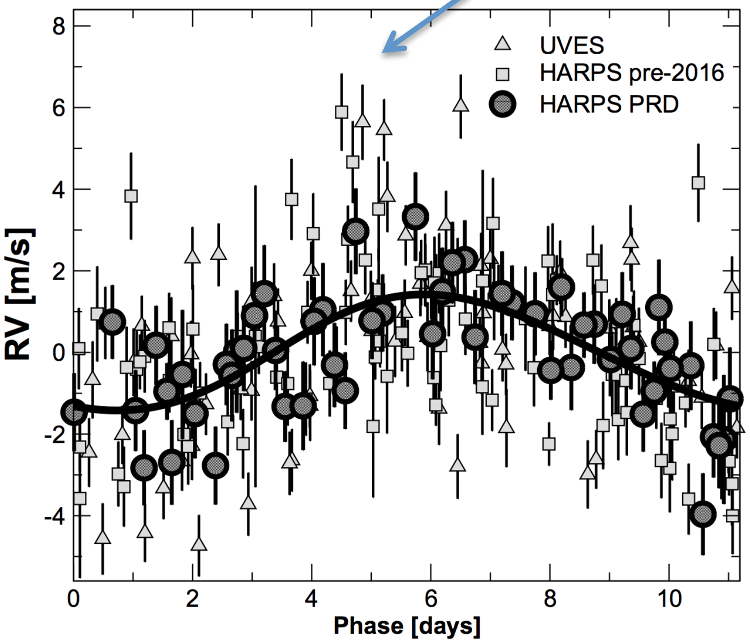
- MG/SI/FE
- WATER
- CARBON

THE M-STAR OPPORTUNITY

- PROBLEMS FOR HABITABILITY FOR PLANETS ORBITING M-STARS

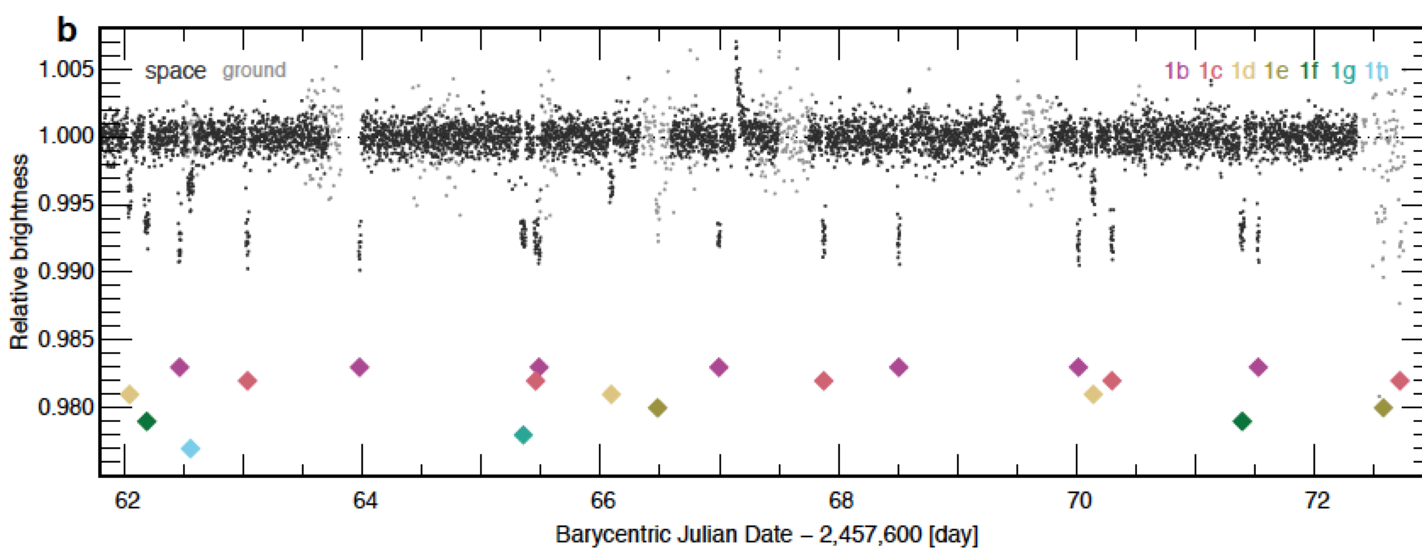
FUTURE MISSIONS

Exoplanets are detected mainly through radial velocity measurements and transits



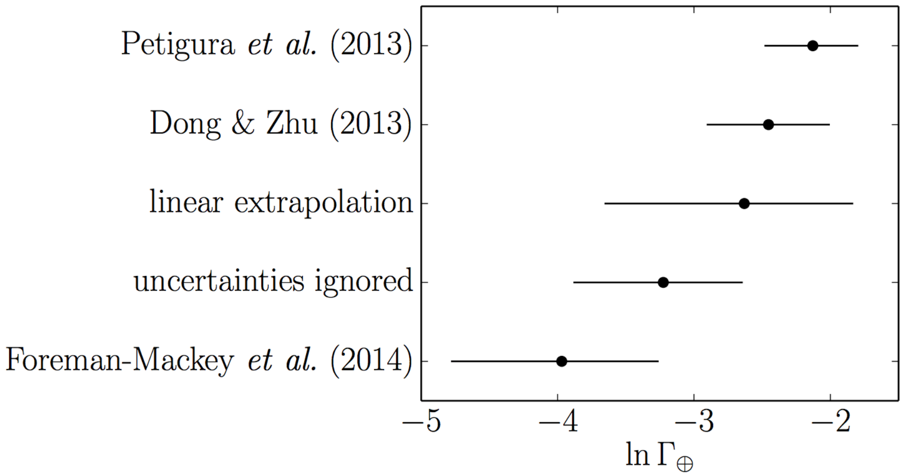
Proxima Centauri b
Anglada-Escudé et al. 2016

TRAPPIST-1 (Gillon et al. 2016)

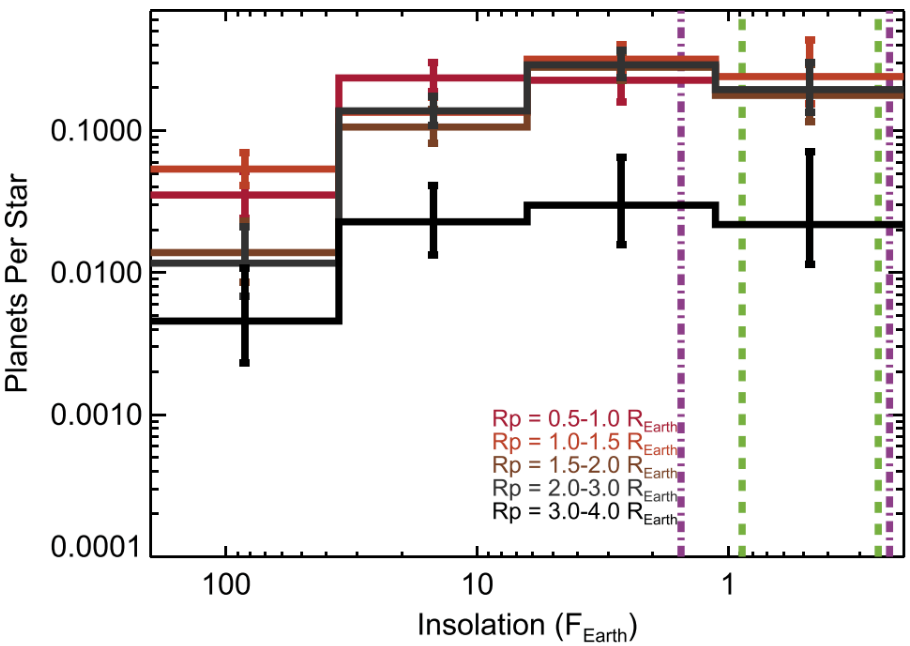


HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE NUMEROUS

Sunlike (FGK) stars:



Red dwarf (M) stars:



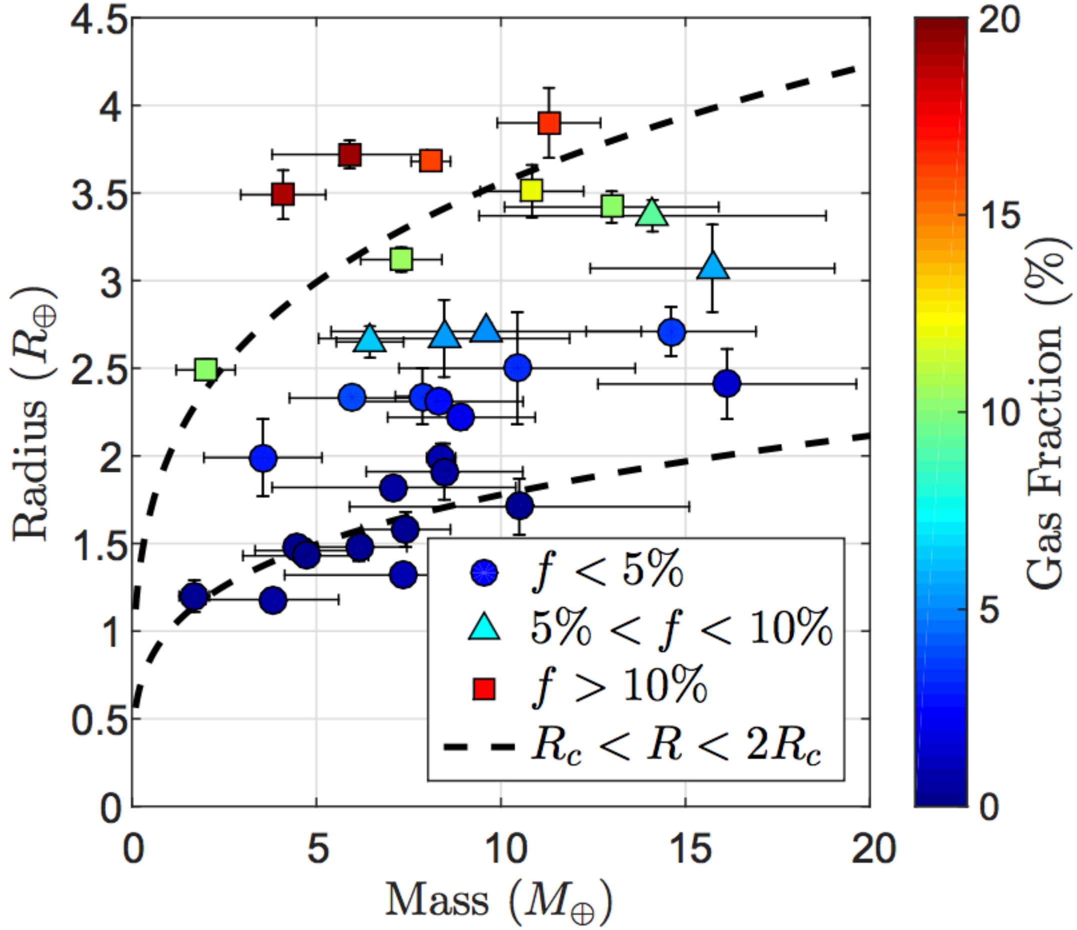
$$\Gamma_\oplus = \left.\frac{dN}{d\ln P \, d\ln R}\right|_{R=R_\oplus,\, P=P_\oplus}$$

Dressing & Charbonneau ApJ 2015

HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE LIKELY DIVERSE COMPOSITIONALLY

- HYDROGEN
- MG/SI/FE
- WATER
- CARBON

HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE LIKELY DIVERSE COMPOSITIONALLY - HYDROGEN

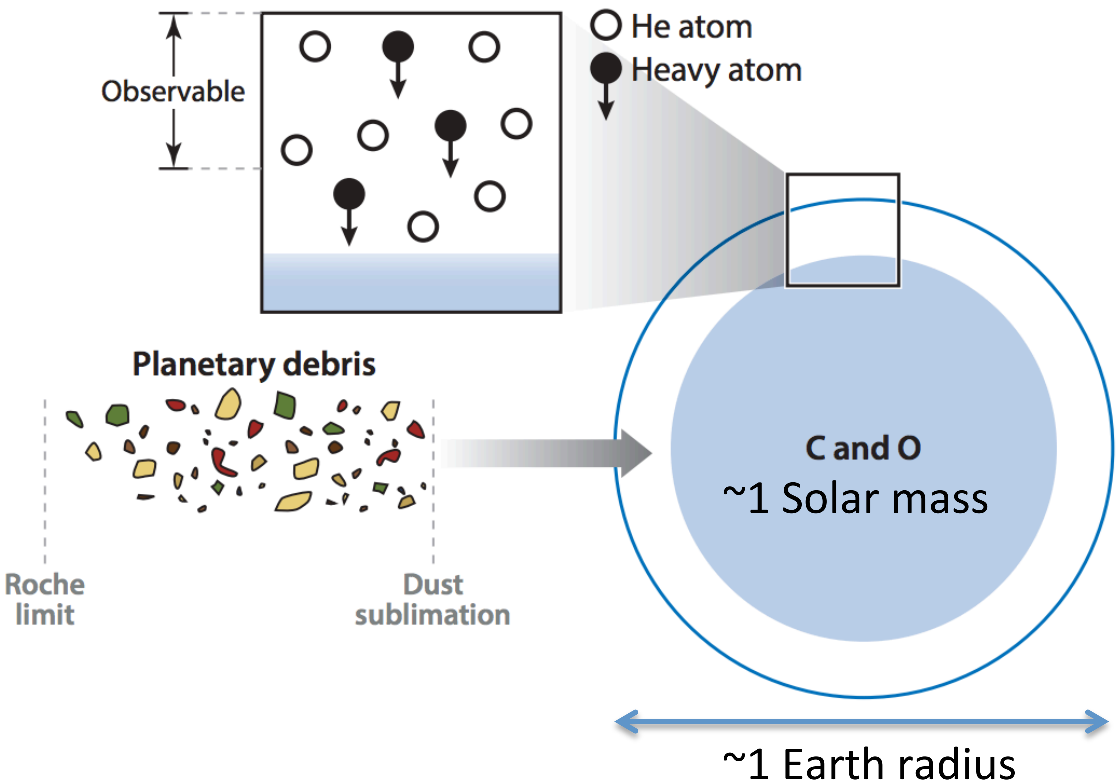


Ginzberg et al.
ApJ 2016

FIG. 2.— Observed super-Earth population (see text for details) from Weiss & Marcy (2014). The planets are grouped according to their gas mass fraction f, estimated by Equation (38), with low-density planets marked by triangles ($5\% < f < 10\%$) or squares ($f > 10\%$). The planet markers are also color-coded according to f. The two dashed black lines mark the radius of the rocky core $R_c(M_c)$ and $2R_c(M_c)$. Planets with substantial atmospheres are expected to be found roughly between the two lines.

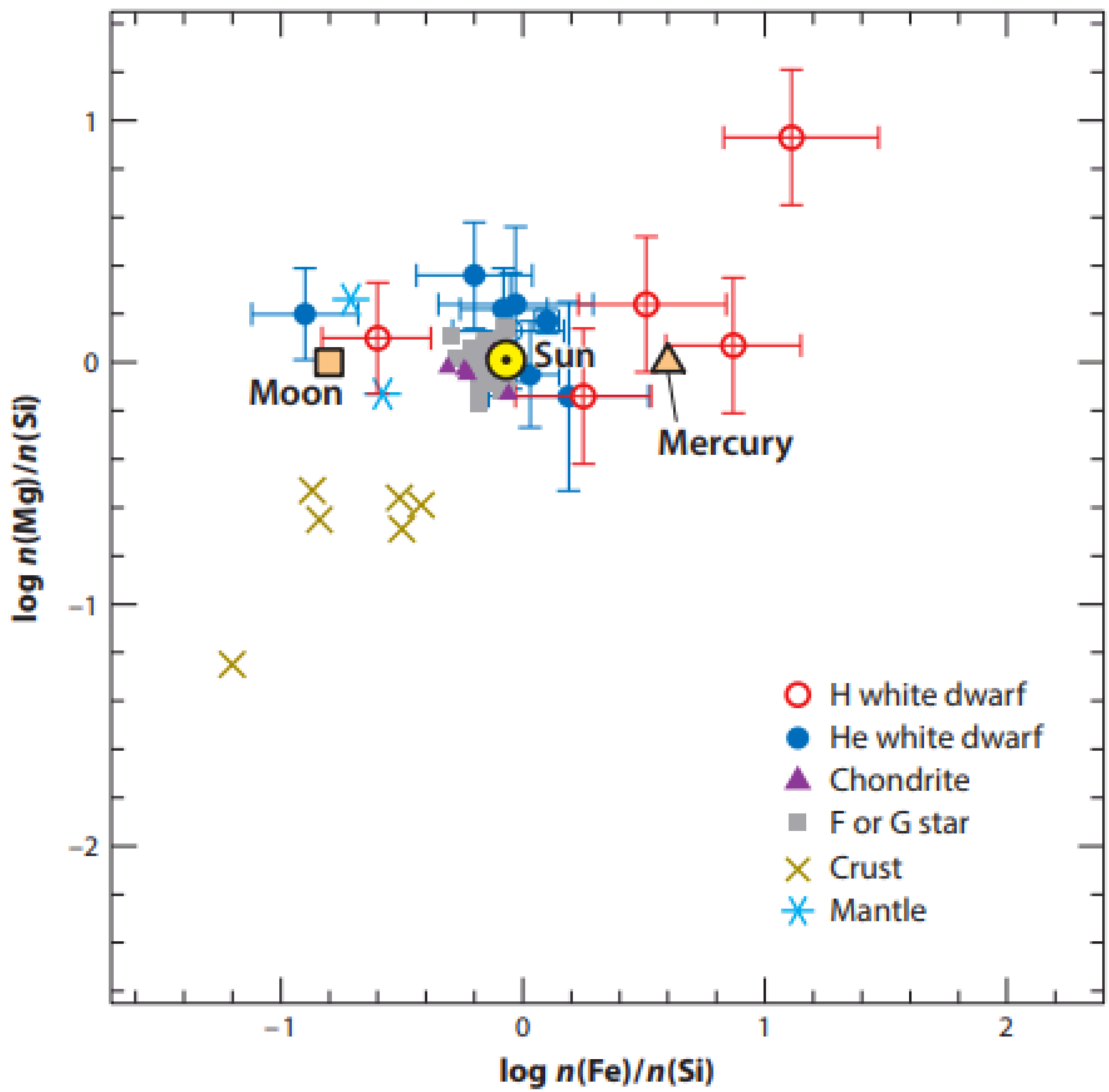
HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE LIKELY DIVERSE COMPOSITIONALLY

- MG/SI, MG/FE, e.t.c.



Constrained mainly by compositions of white dwarfs that are accreting material fderived from tidally shredded planets.

Jura & Young, ‘Extrasolar cosmochemistry,’ Annual Reviews, 2014



Jura & Young, 'Extrasolar cosmochemistry,' Annual Reviews, 2014

HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE LIKELY DIVERSE COMPOSITIONALLY

- WATER

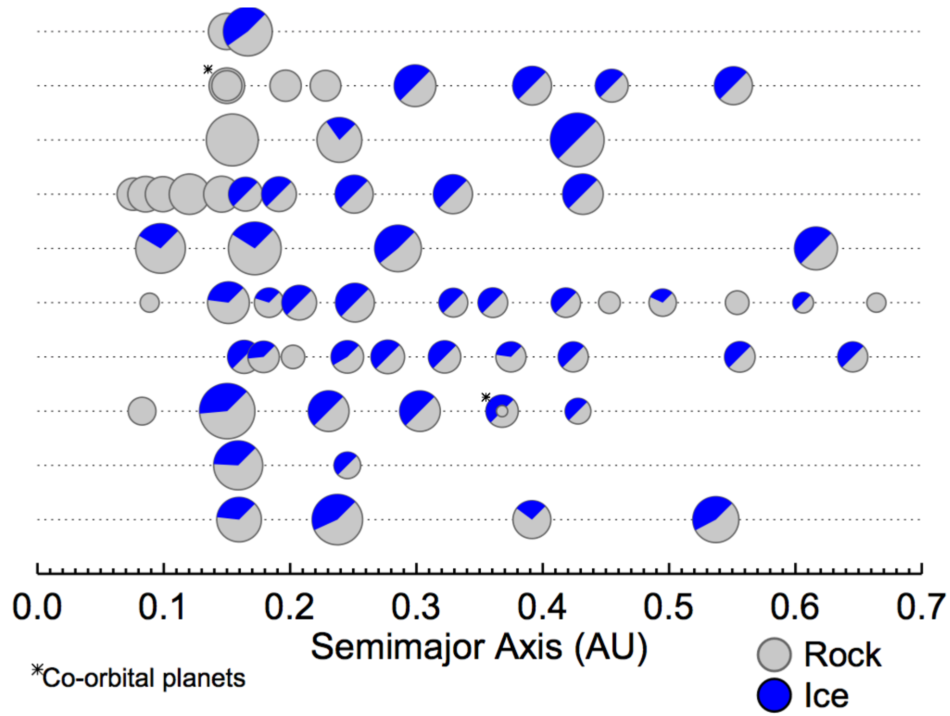
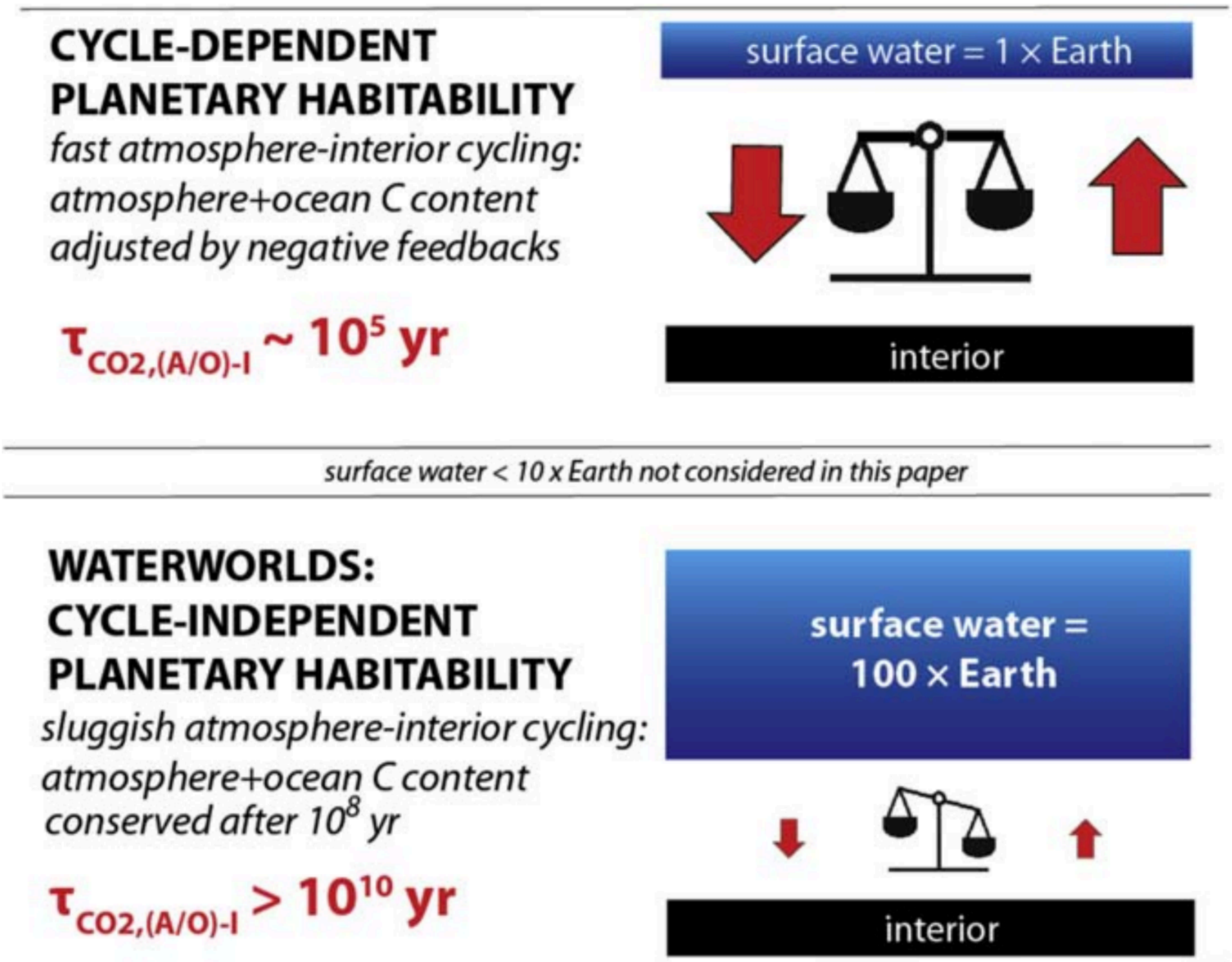


Figure 3. Final configuration of ten simulations illustrating the range of outcomes. Each planet's colors represent its rough composition: grey indicates rock and blue represents ice. Embryos that started past 5 AU started as 50-50 rock-ice mixtures and those from inside 5 AU were purely rocky. We do not account for various water loss processes and so the ice contents of simulated planets are certainly overestimates. The sizes of planets are scaled to their mass$^{1/3}$. The Kepler-36 analog system from Section 3 is at the top. Two co-orbital systems are marked with an asterisk.

Raymond et al.
MNRAS Letters 2018

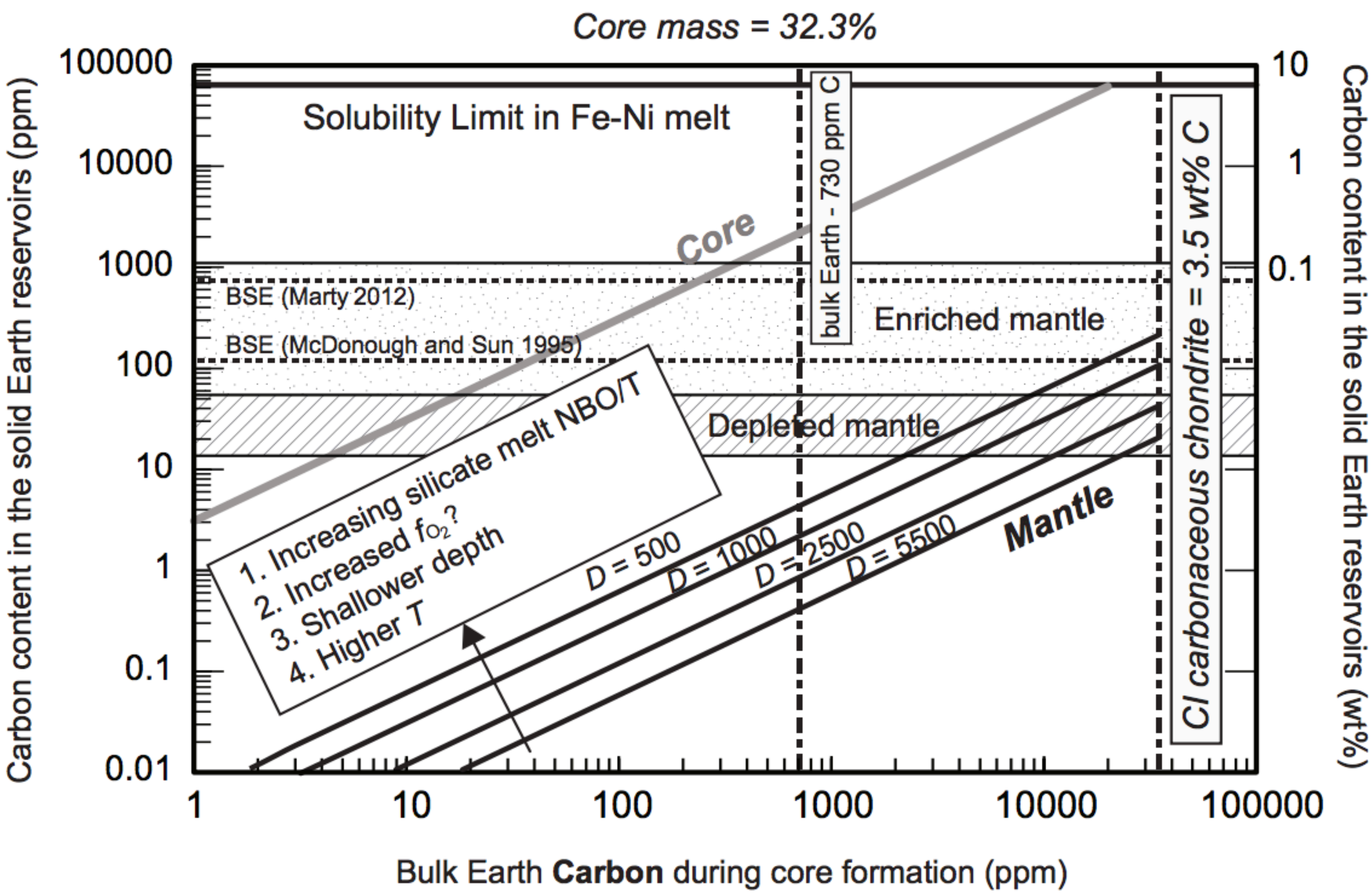
CYCLE-INDEPENDENT PLANETARY HABITABILITY ON EXOPLANET WATERWORLDS?



Kite & Ford, ApJ 2018

HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE LIKELY DIVERSE COMPOSITIONALLY

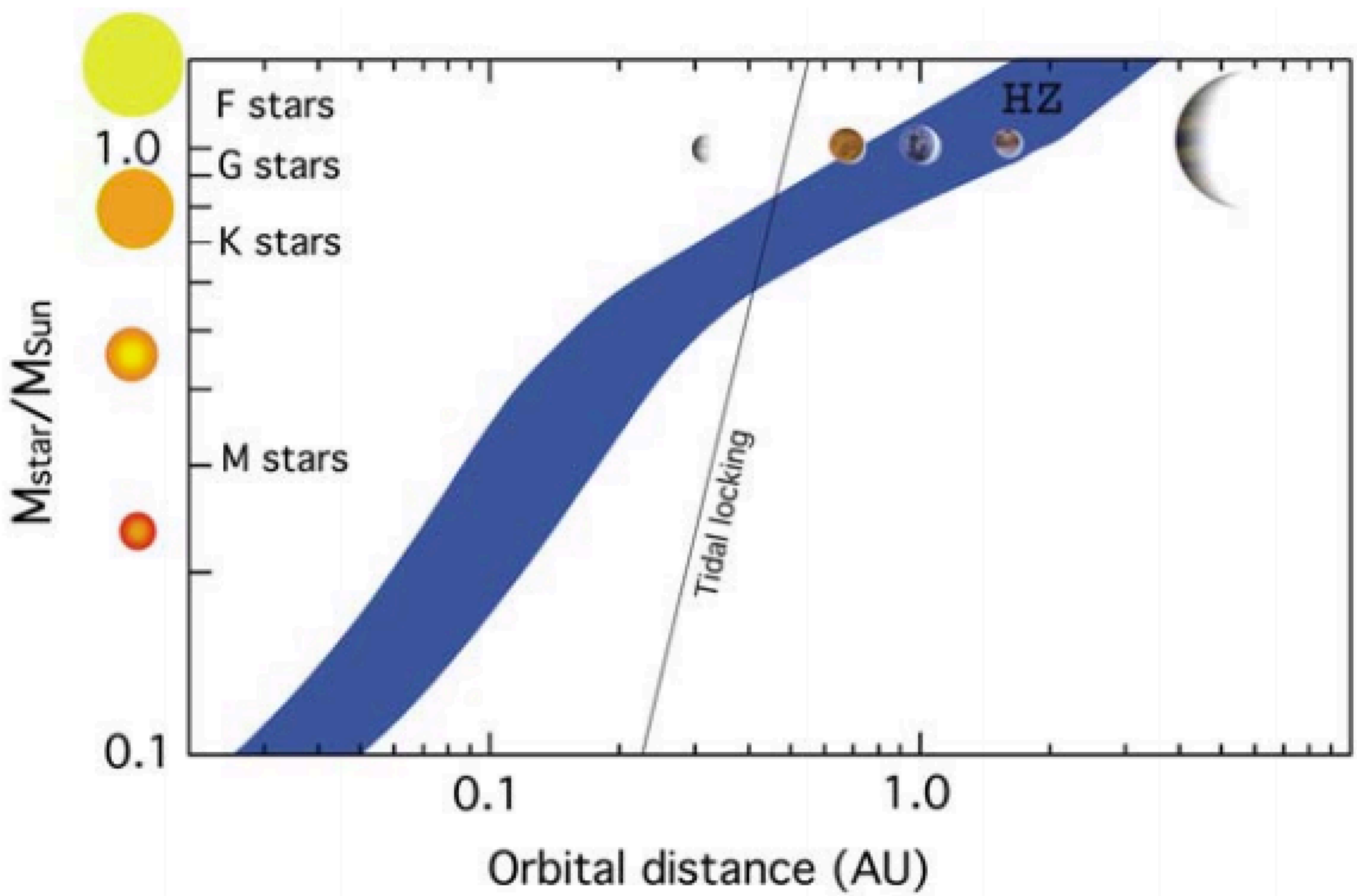
- CARBON



Dasgupta et al. 2013, Reviews in Mineralogy & Geochemistry

THE M-STAR OPPORTUNITY: RELATIVELY DEEPER AND MORE FREQUENT TRANSITS

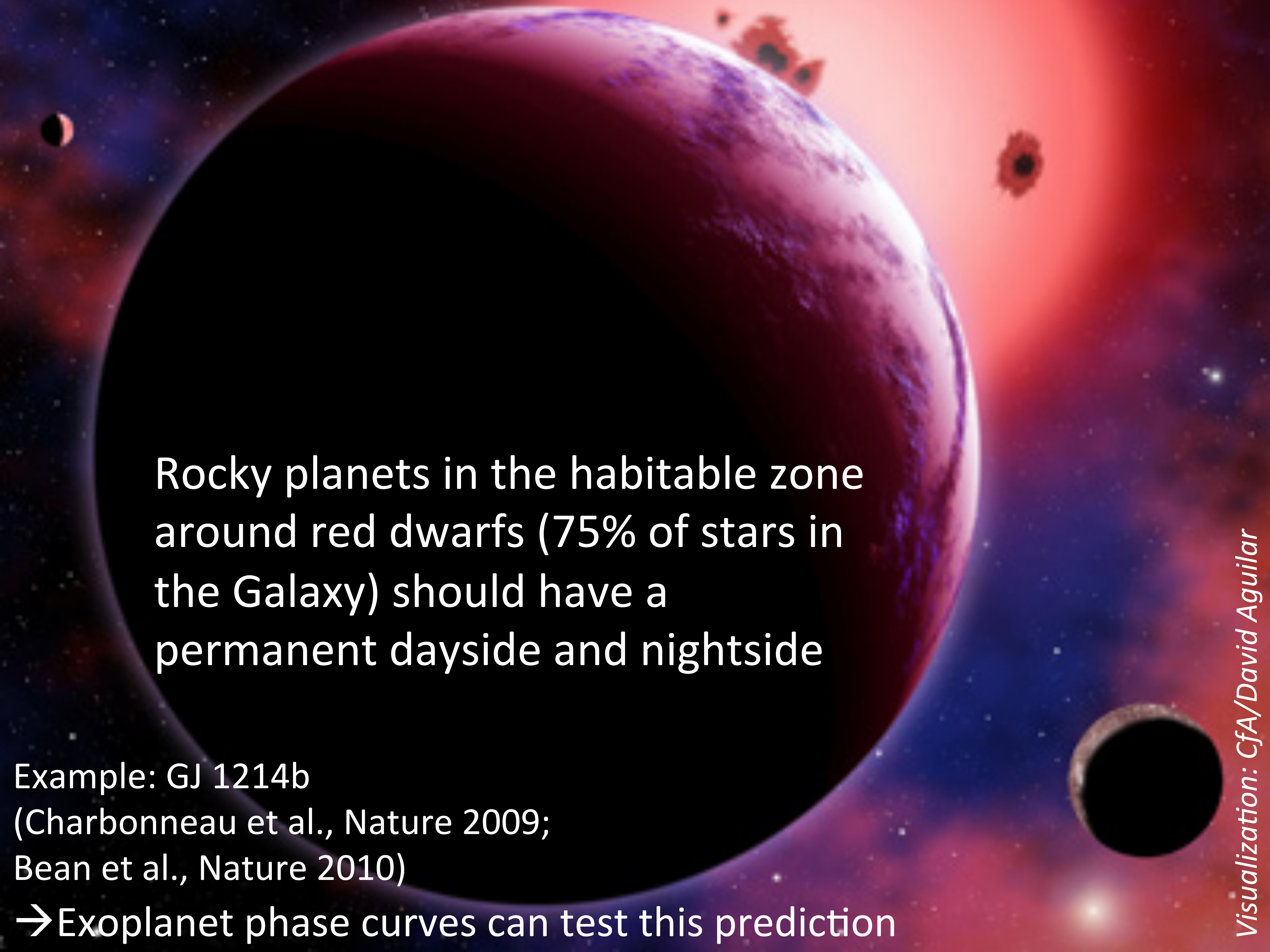
→ EASIER TO DETECT & CHARACTERIZE



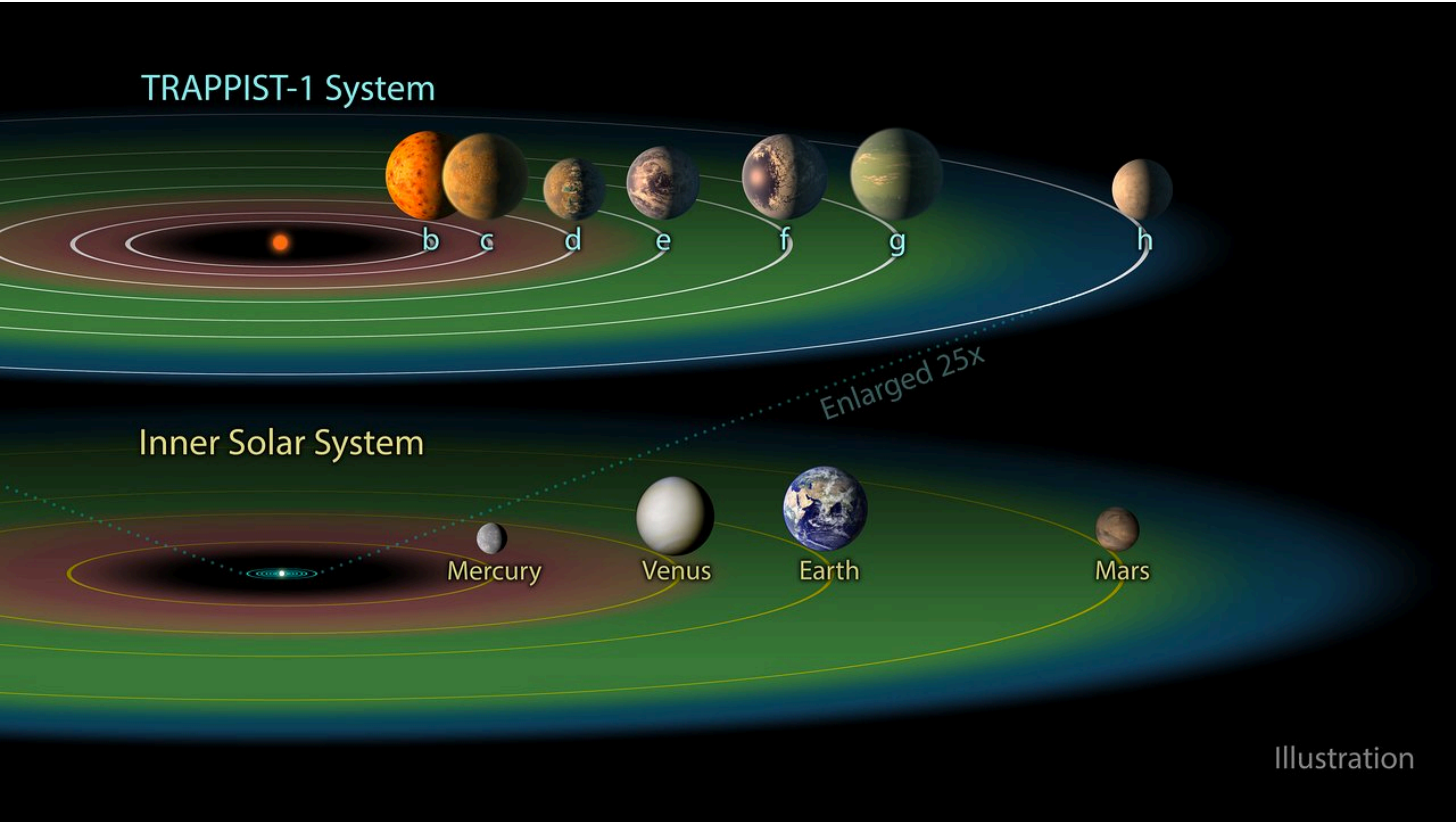
Rocky planets in the habitable zone around red dwarfs (75% of stars in the Galaxy) should have a permanent dayside and nightside

Example: GJ 1214b
(Charbonneau et al., Nature 2009;
Bean et al., Nature 2010)

→Exoplanet phase curves can test this prediction



Visualization: CfA/David Aguilar


TRAPPIST-1 System
b
c
d
e
f
g
h
Enlarged 25x
Inner Solar System
Mercury
Venus
Earth
Mars
Illustration

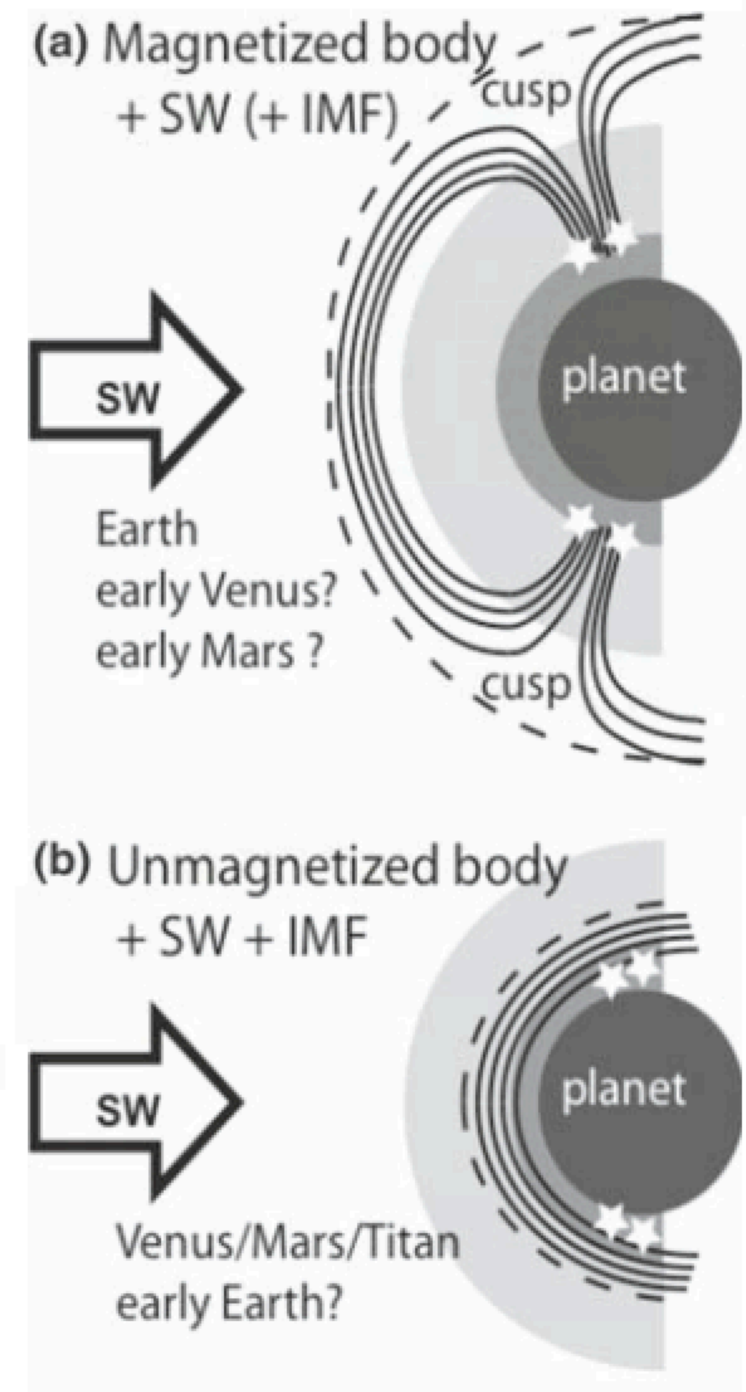
HIGH XUV FLUX SUSTAINED FOR LONG PERIOD FOR SMALL STARS

Table 3 Time span in Gyr where $L_x/L_{bol(Sun)}$ as a function of stars with masses $\leq 1 M_{Sun}$ where the $L_x/L_{bol(Sun)}$ is about 1,700 and $\geq$ 100 times larger than at the present Sun (after Scalo et al. 2007)

M_{Sun}	t [Gyr] for 1,700 $L_x/L_{bol(Sun)}$	t [Gyr] for $\geq 100 L_x/L_{bol(Sun)}$
1.0	~0.05	~0.3
0.9	~0.1	~0.48
0.8	~0.15	~0.65
0.7	~0.2	~1.0
0.6	~0.3	~1.47
0.5	~0.5	~2.0
0.4	~0.75	~3.0
0.3	~1.0	~4.15
0.2	~1.58	~6.5
0.1	~4.6	>10.0

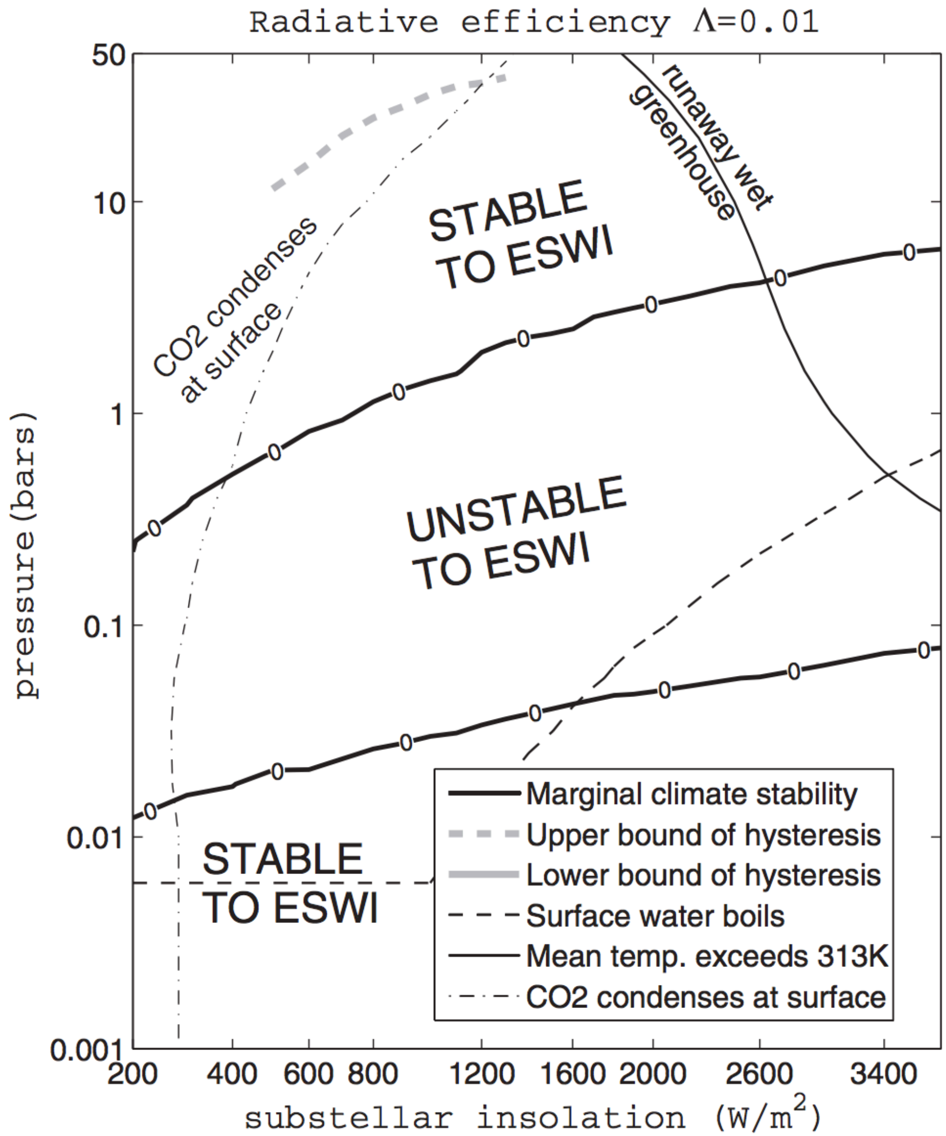
Lammer et al. 2009 Space Science Reviews

STRONGER STELLAR WIND → STRONGER NONTHERMAL ATMOSPHERIC ESCPAE



ADDITIONAL PROBLEMS FOR HABITABILITY FOR PLANETS ORBITING M-STARS

Enhanced Substellar Weathering Instability



Tarter et al. Astrobiology 2007

Kite et al. ApJ 2011

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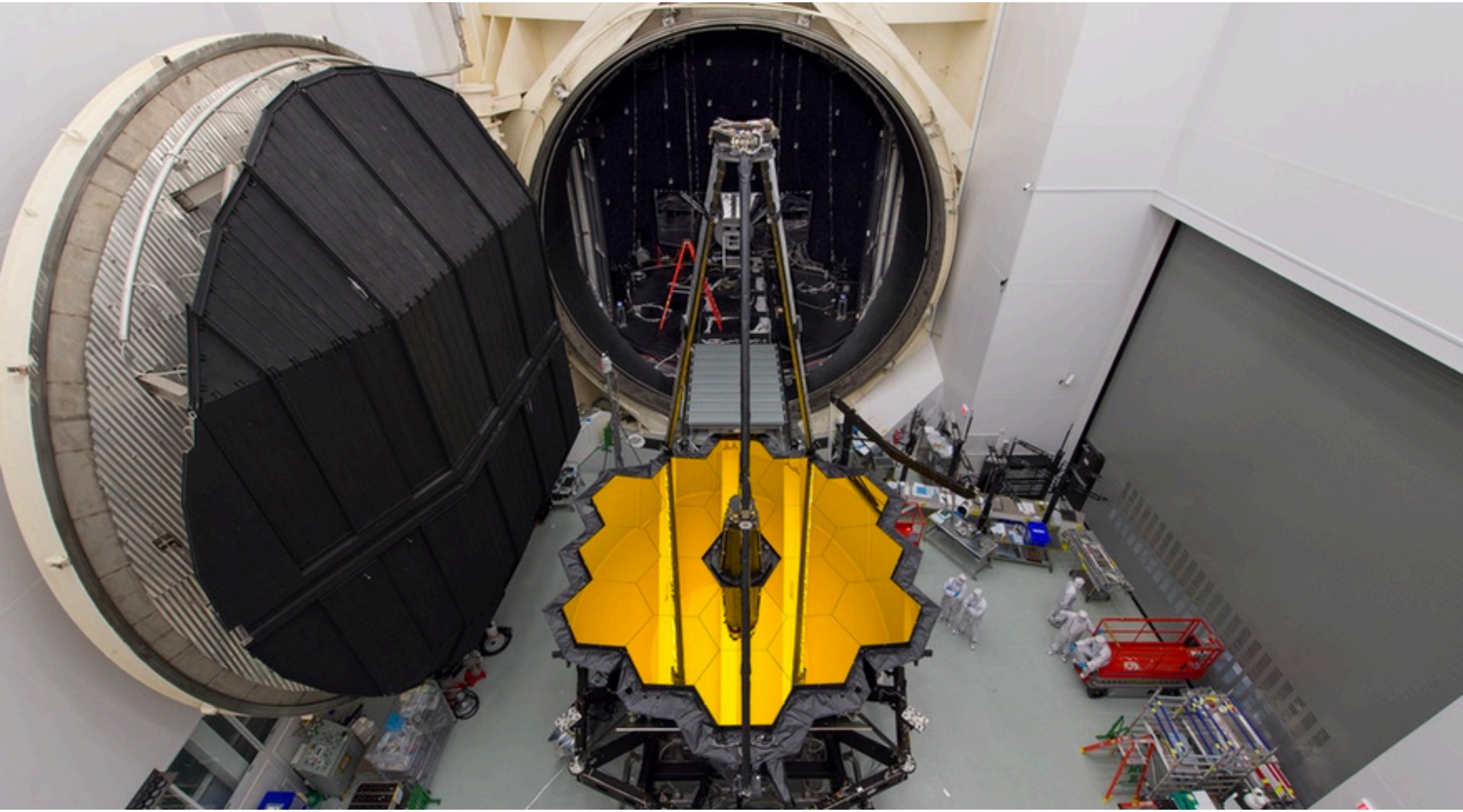
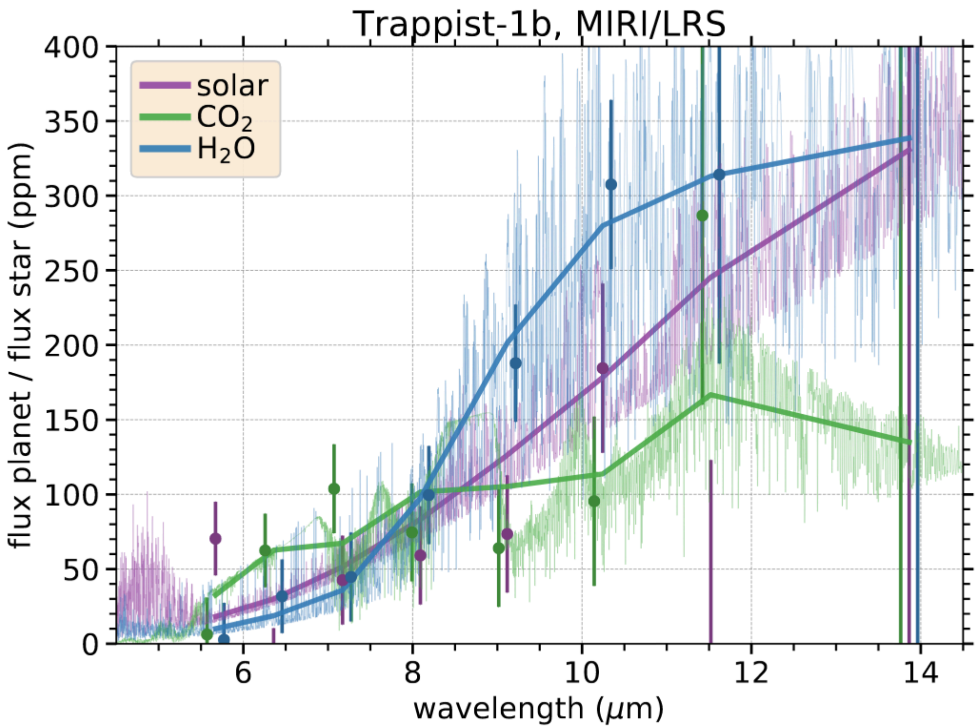
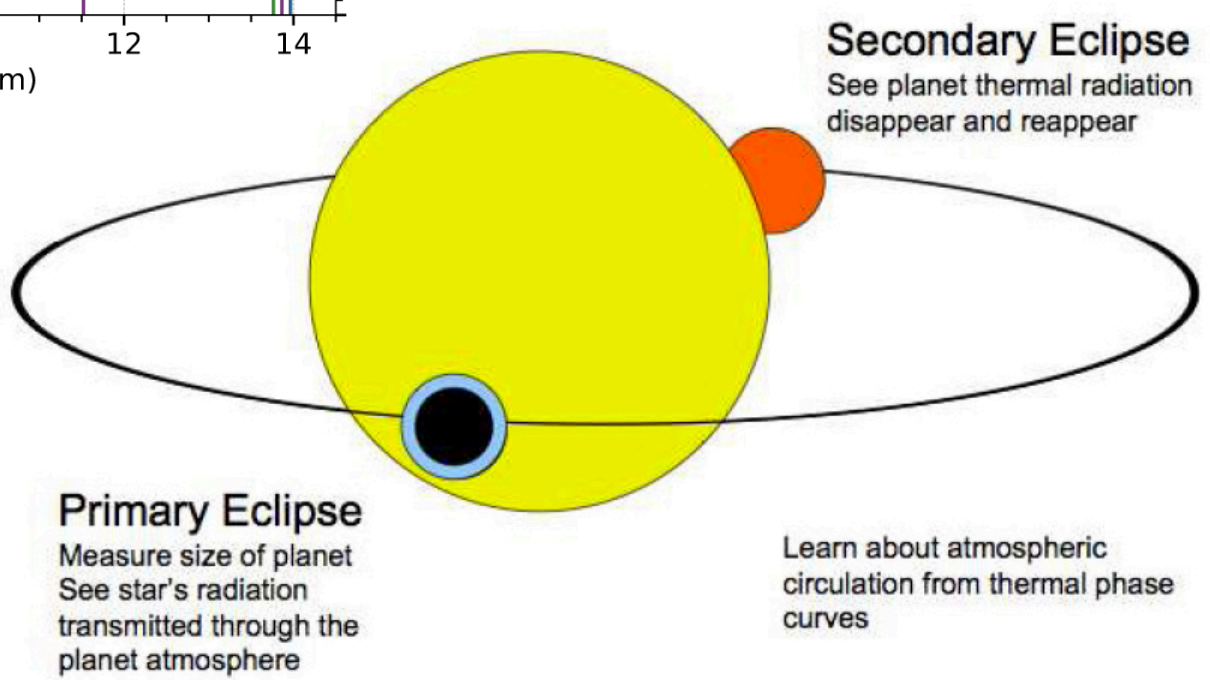
FUTURE MISSIONS

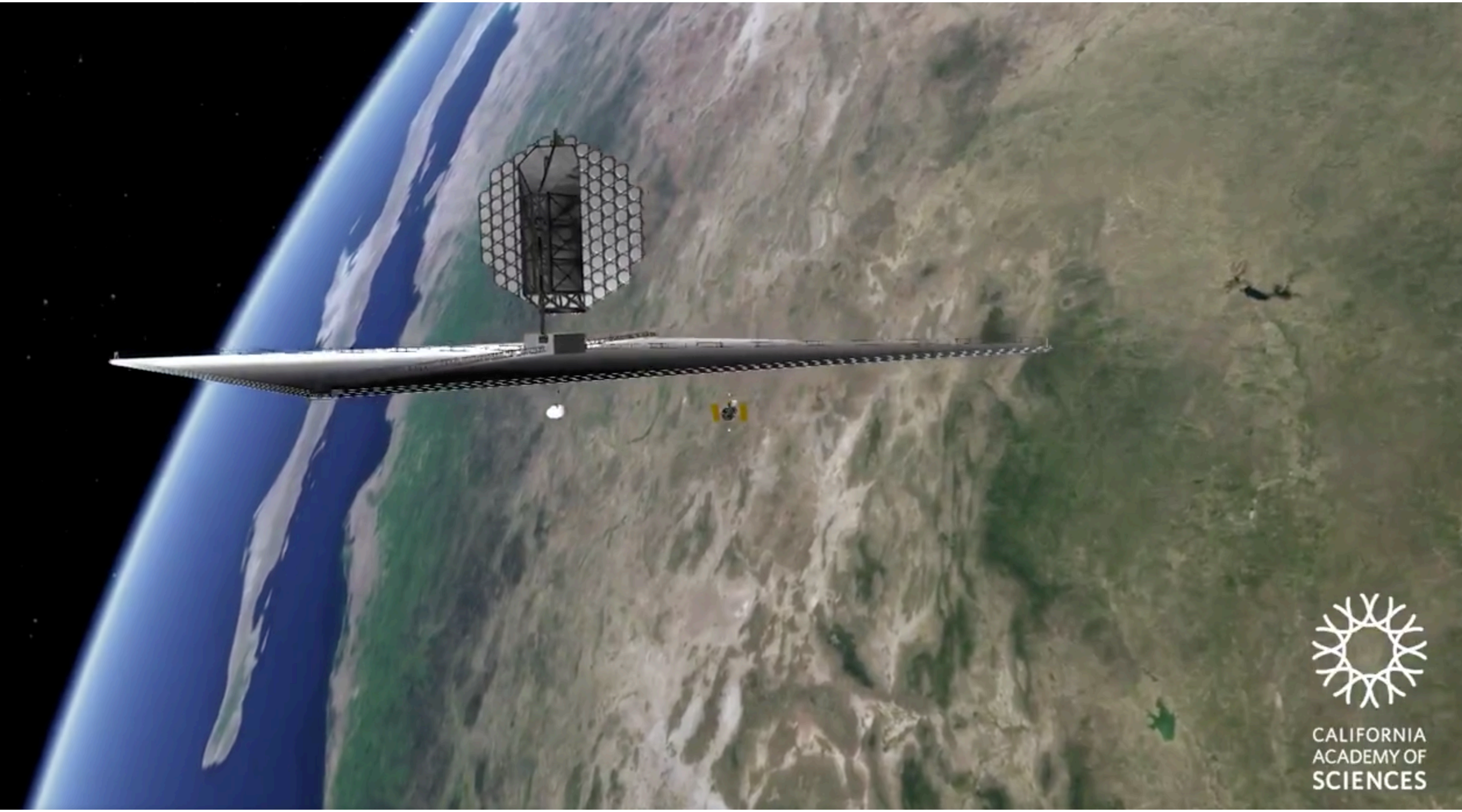


Simulated secondary eclipse spectra



Malik et al. in review

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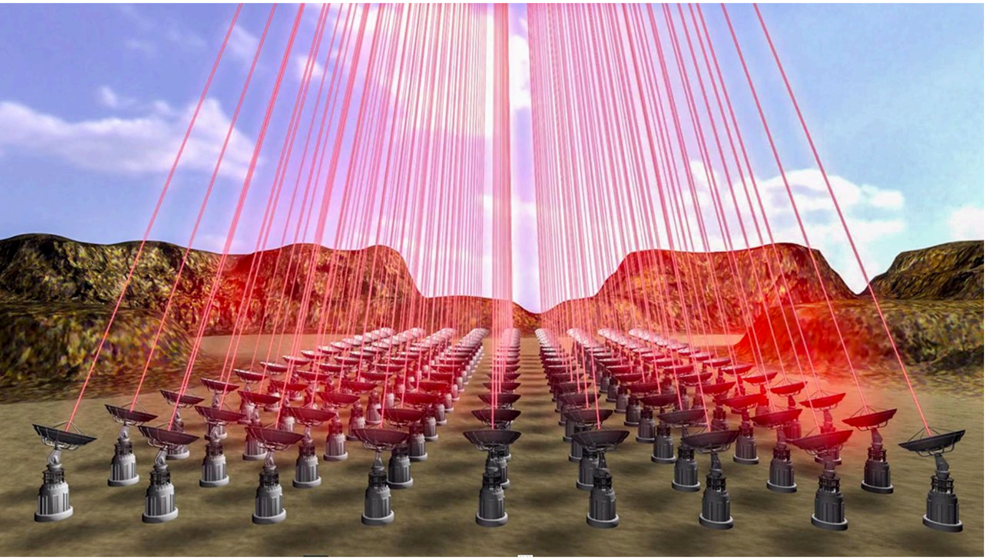
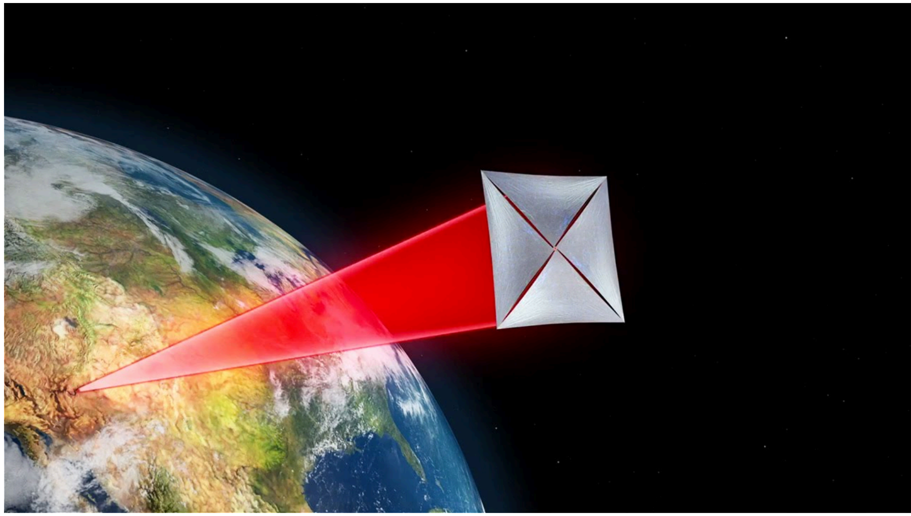
INTERSTELLAR MISSIONS?

- Current distance record: Voyager 1 @ 0.8 light-days
- No interstellar missions have been funded
- The technology for an interstellar mission does not currently exist
- Breakthrough Starshot is a philanthropically-funded technology development project for a laser-accelerated interstellar lightsail





50-70GW power, 0.1 gram payload, 5000g acceleration, 0.2c cruise speed

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