GEOS 22060/ GEOS 32060 / ASTR 45900

What makes a planet habitable?
Exoplanets

Lecture 19

Tuesday 10 March 2020

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

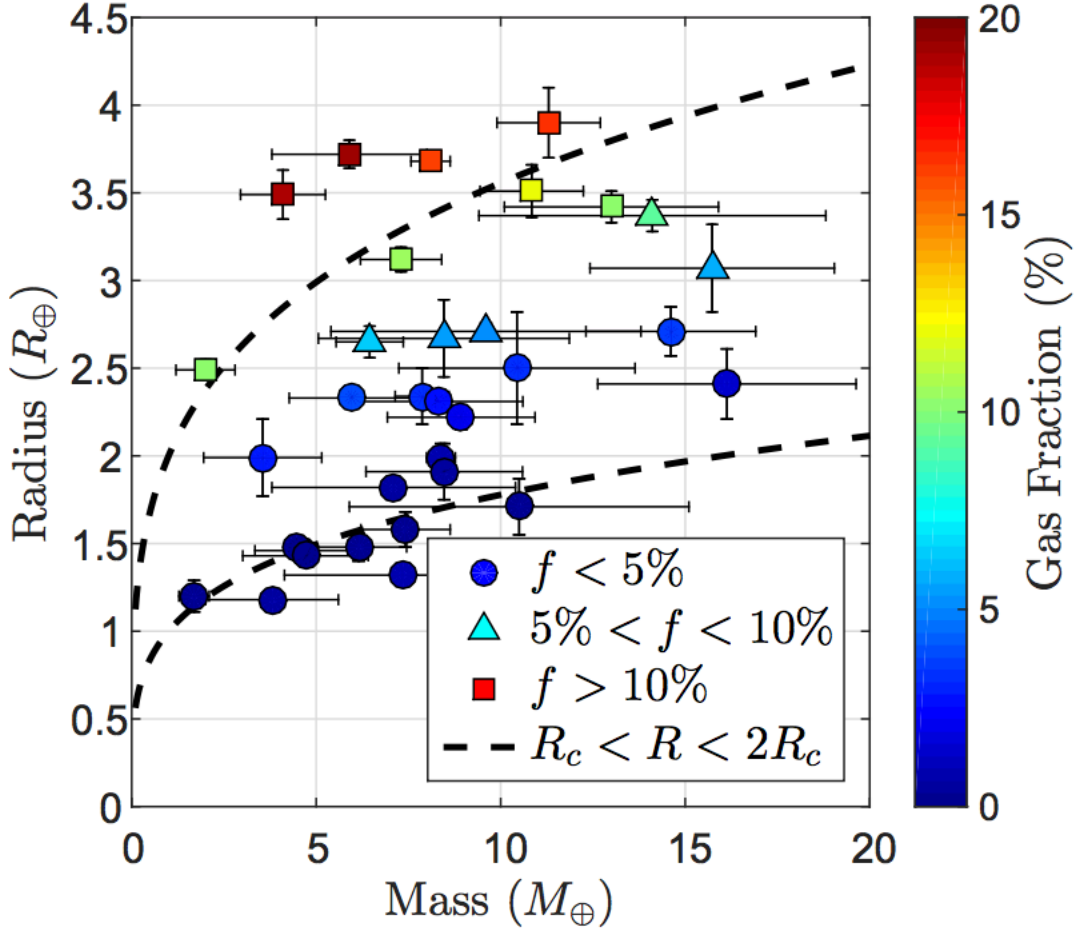
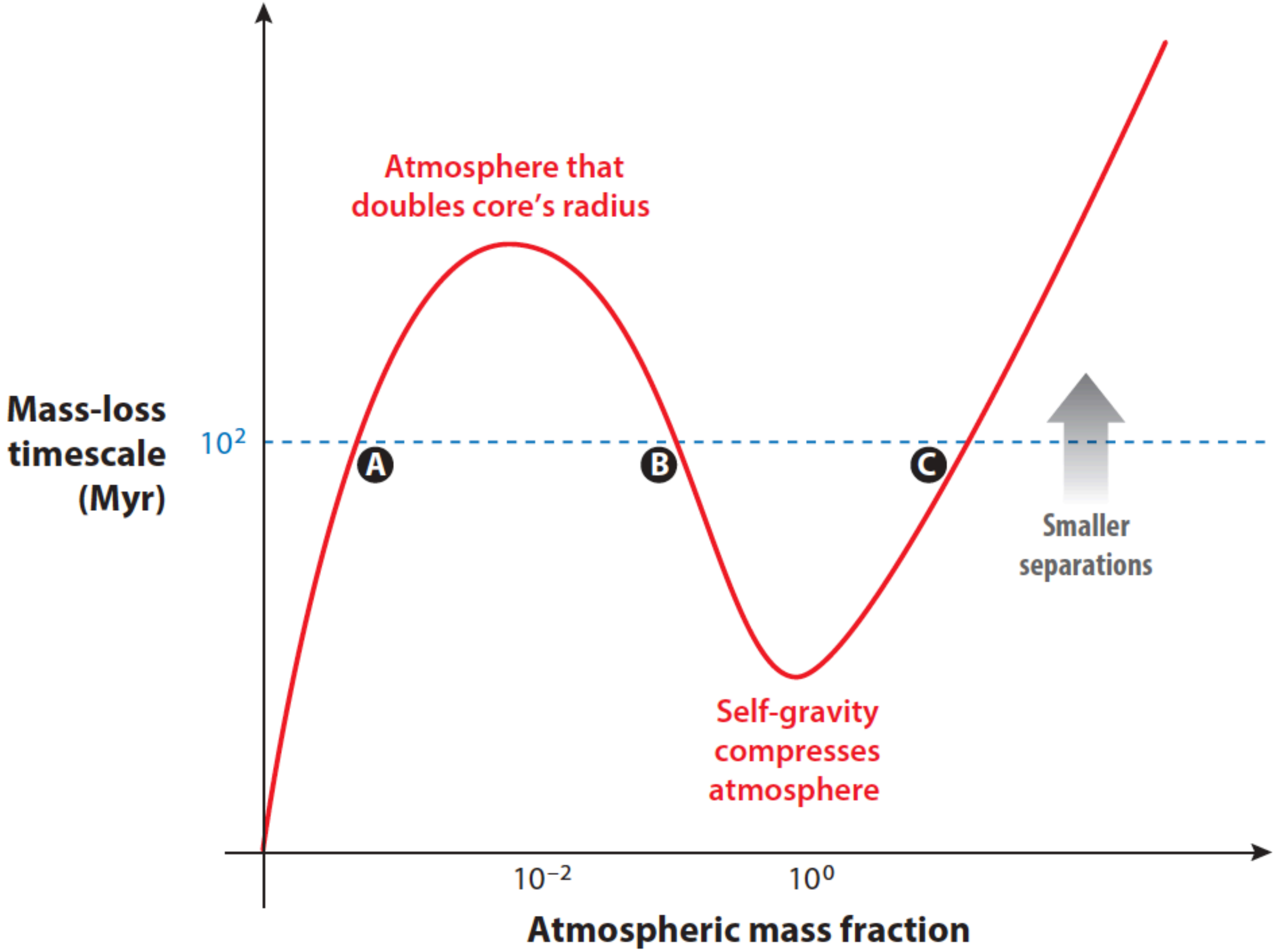


FIG. 2.— Observed super-Earth population (see text for details) from Weiss & Marcy (2014). The planets are grouped according to their gas mass fraction f, estimated by Equation (38), with low-density planets marked by triangles ($5\% < f < 10\%$) or squares ($f > 10\%$). The planet markers are also color-coded 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.

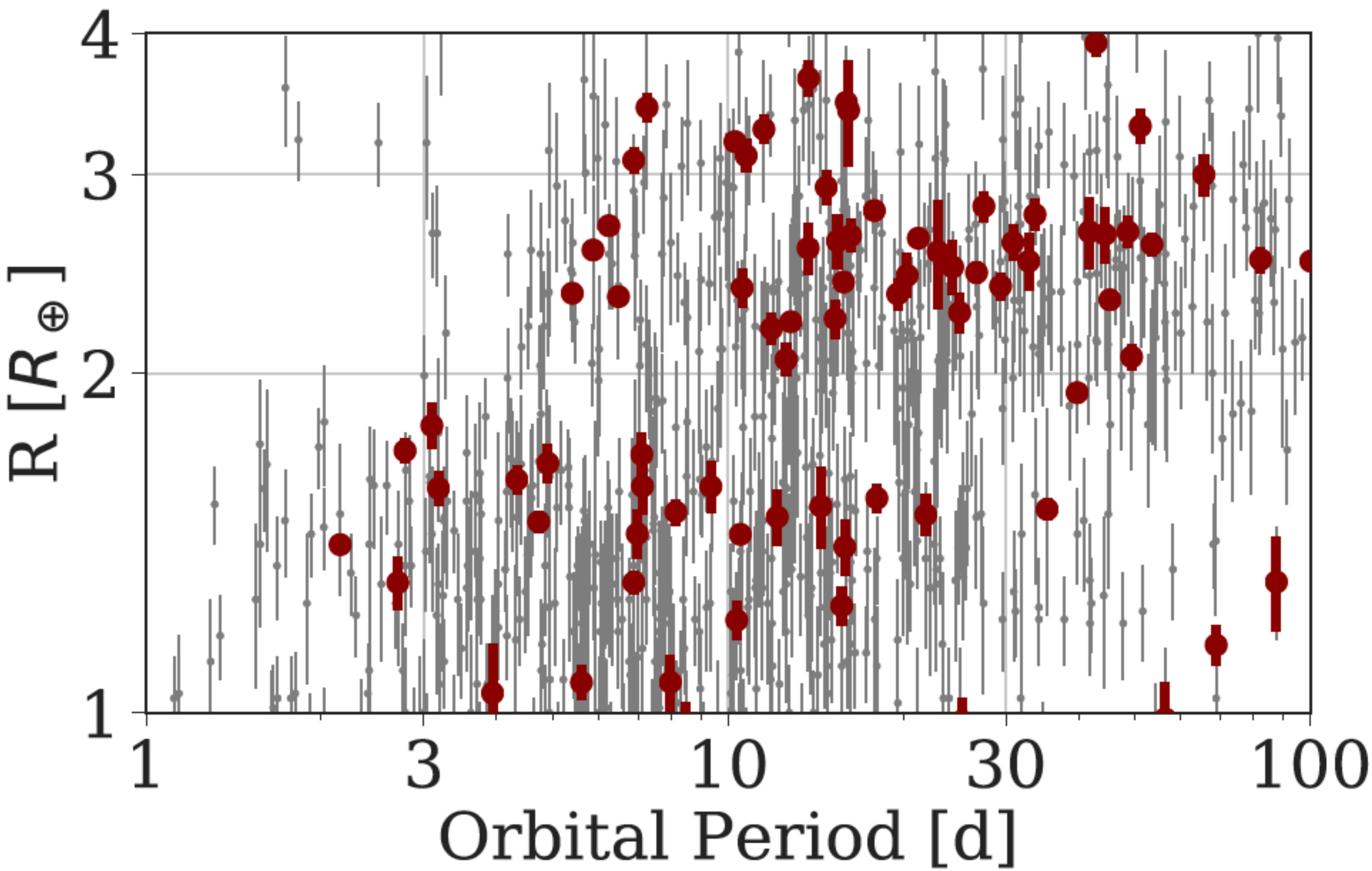
Ginzberg et al. ApJ 2016



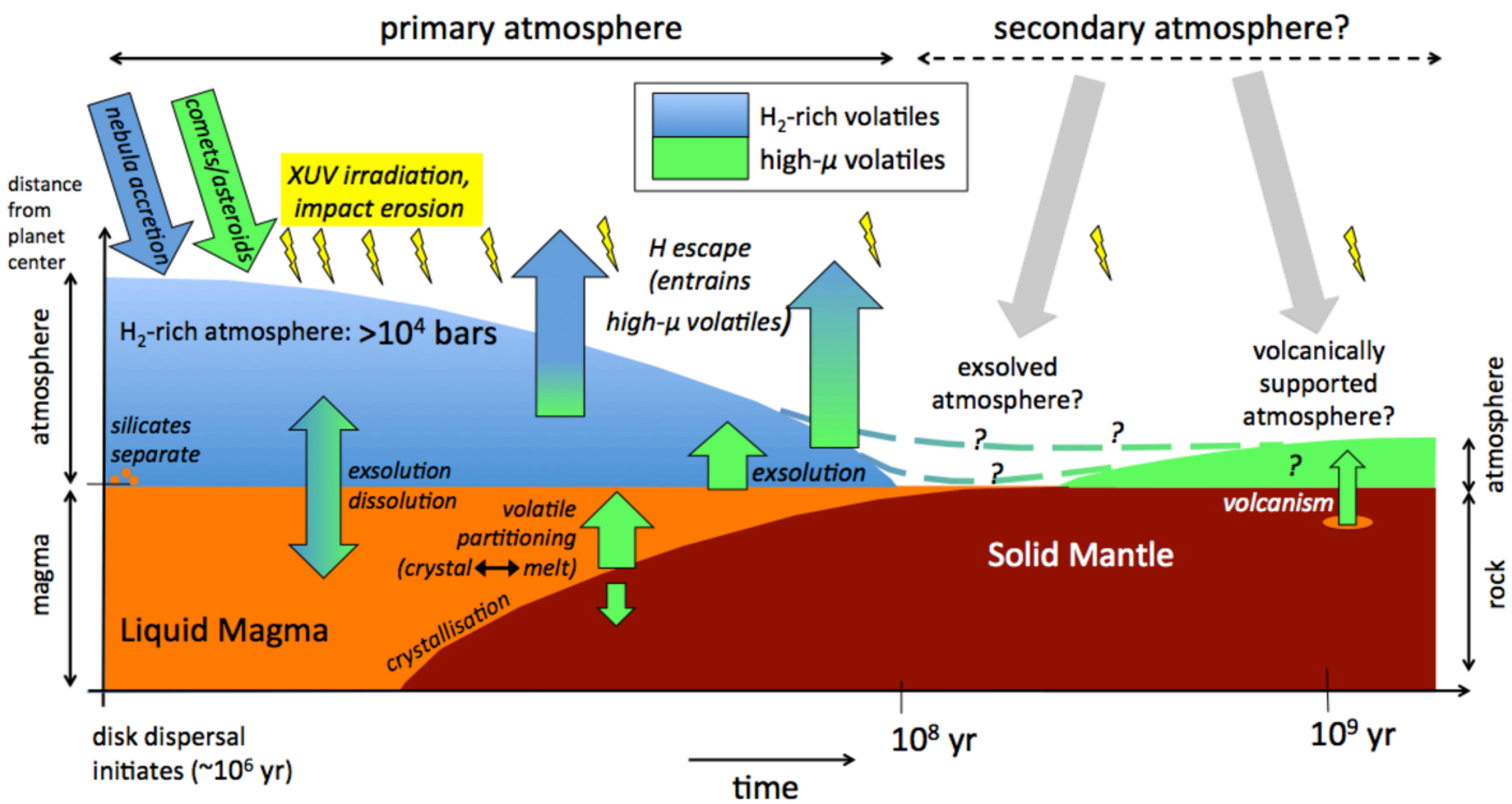
Owen 2019 Annual Reviews

Figure 4

Schematic plot showing the mass-loss timescale as a function of the atmospheric mass fraction for a planet with a fixed core mass. The blue dashed line represents a fixed timescale (roughly approximately 100 Myr) for mass loss to occur. Points A, B, and C represent the three minimally stable atmosphere masses. Atmosphere masses lower than those in point A are susceptible to complete stripping, and those atmosphere masses between points B and C will lose mass until the atmosphere mass is comparable to that at point B.



van Eylen et al. 2018 MNRAS



Kite & Barnett in prep.

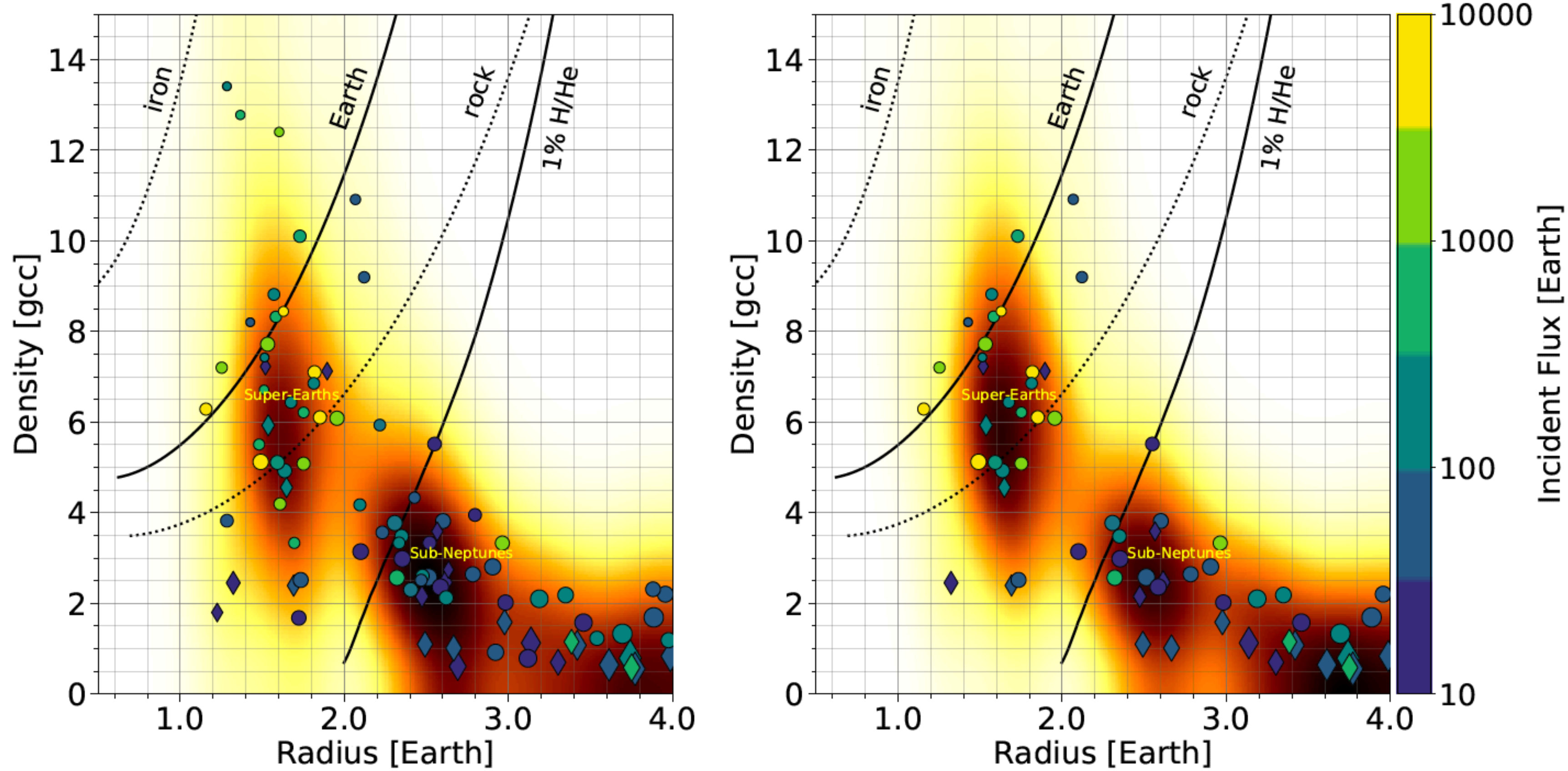
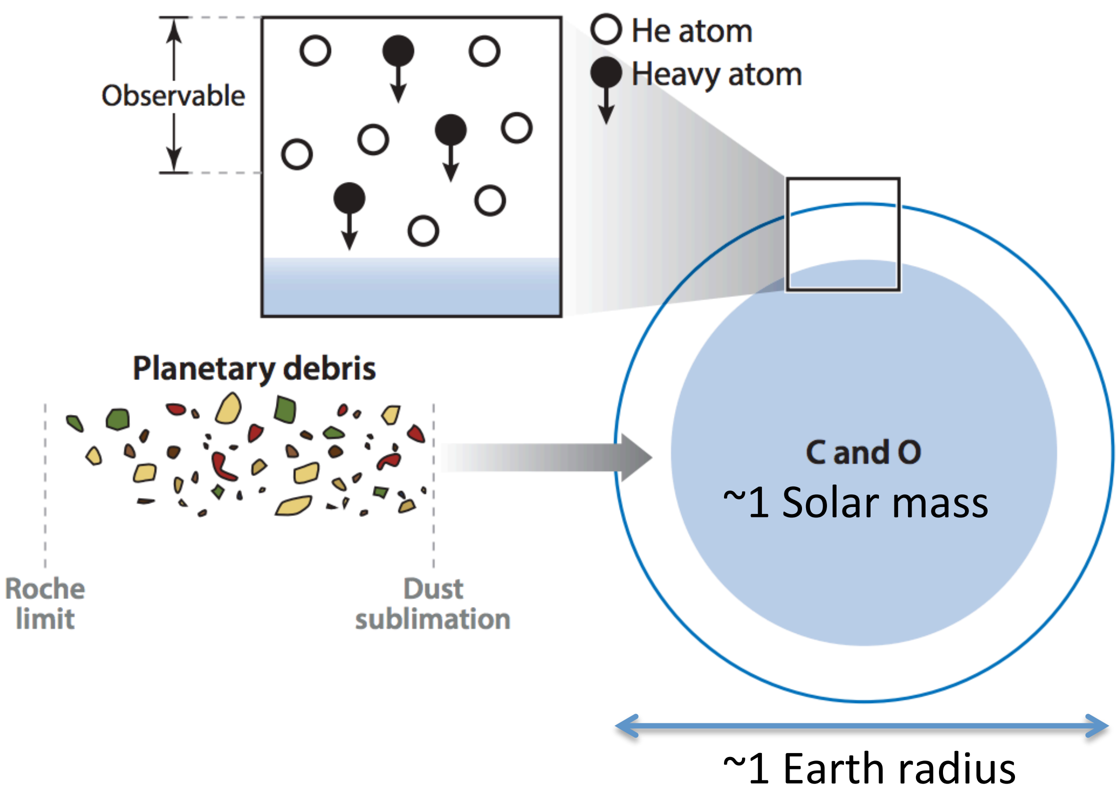


Figure 6.6: The density-radius distribution of our sample. The left panel shows all planets, while the right panel excludes planets whose masses are measured to better than 33% precision (i.e. a 3-σ detection). Points are colored according to planet incident flux and sizes scale as $1/\sqrt{\sigma_{\rho_p}}$. The background shading scales with the number density of points, weighted according to measurement uncertainties and smoothed using a Gaussian kernel. Distinct super-Earth and sub-Neptune populations are evident, with a gap between them, which is where planets with Earth-composition cores and $\lesssim$ 1% H/He envelopes would reside. This gap is likely caused by the complete photoevaporation of planets with tenuous envelopes. There is a residual population of 1–2 $R_\oplus$ planets with lower densities. These planets experience low levels of irradiation, so they are less susceptible to photoevaporation.

Sinukoff PhD thesis, 2018

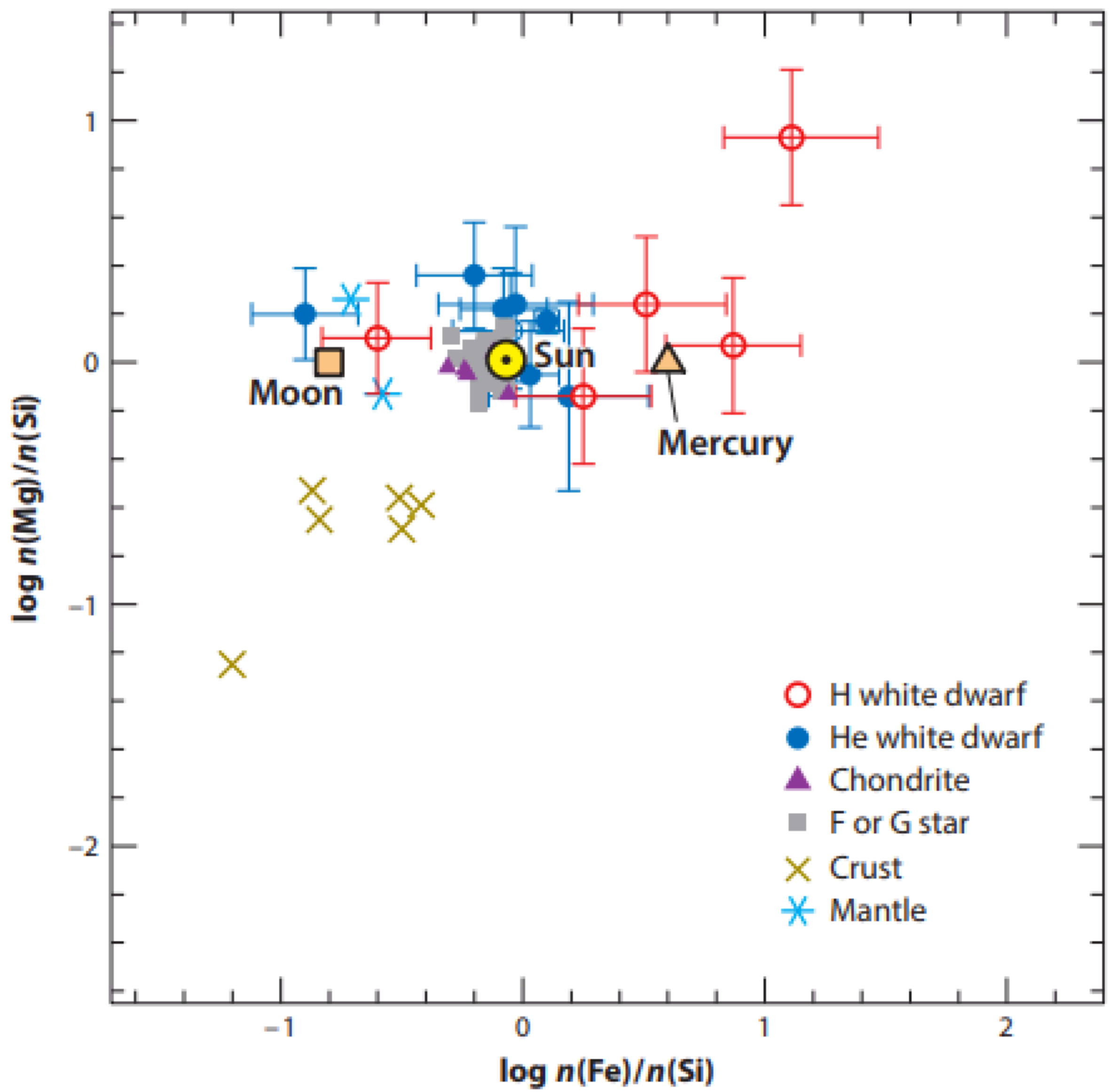
HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE LIKELY DIVERSE COMPOSITIONALLY

- 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

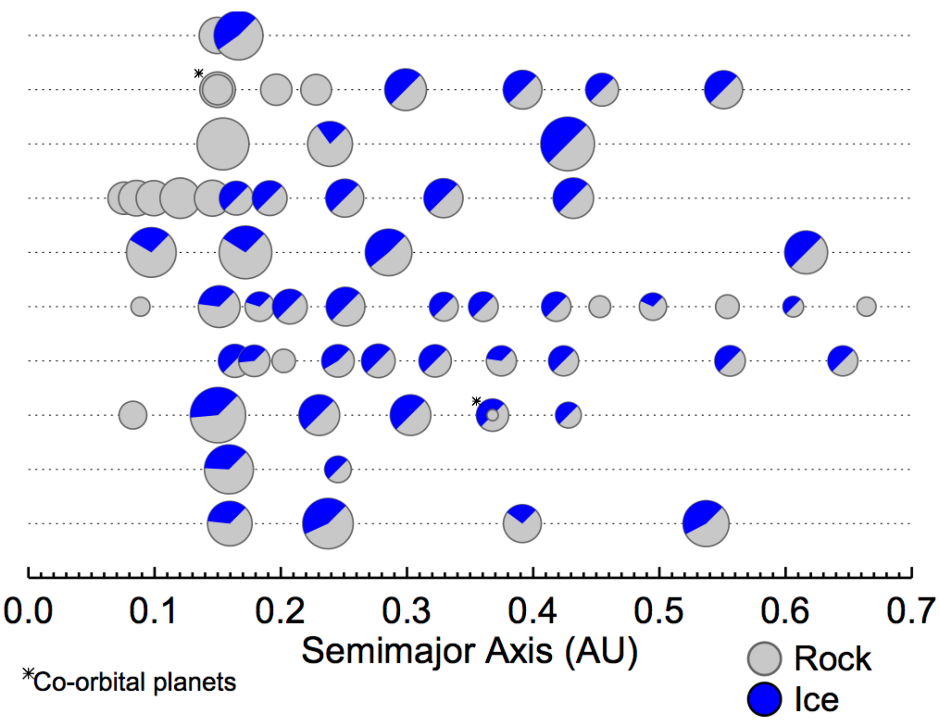
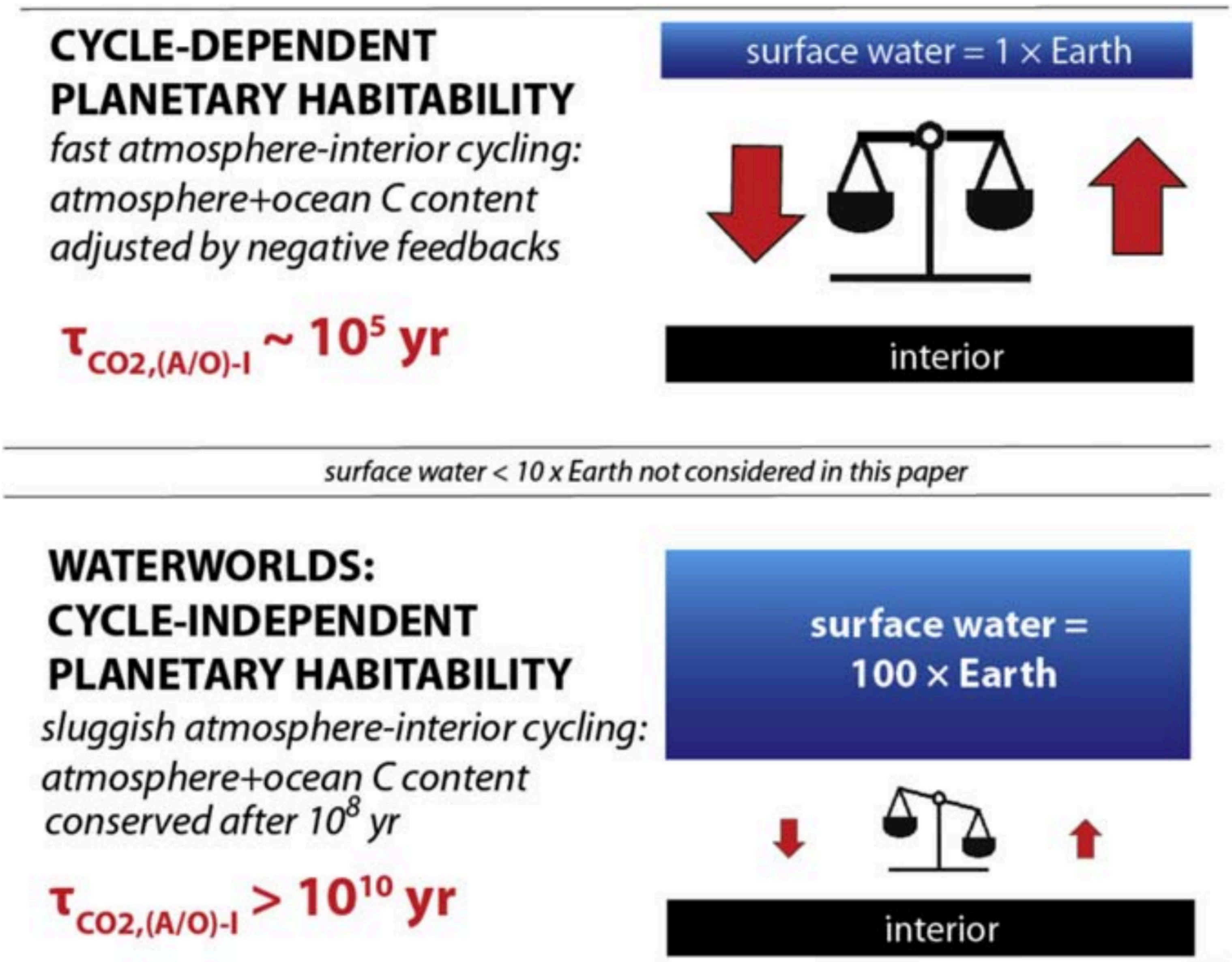


Figure 3. Final configuration of ten simulations illustrating the range of outcomes. Each planet's colors represent its rough composition: grey indicates rock and blue represents ice. Embryos that started past 5 AU started as 50-50 rock-ice mixtures and those from inside 5 AU were purely rocky. We do 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

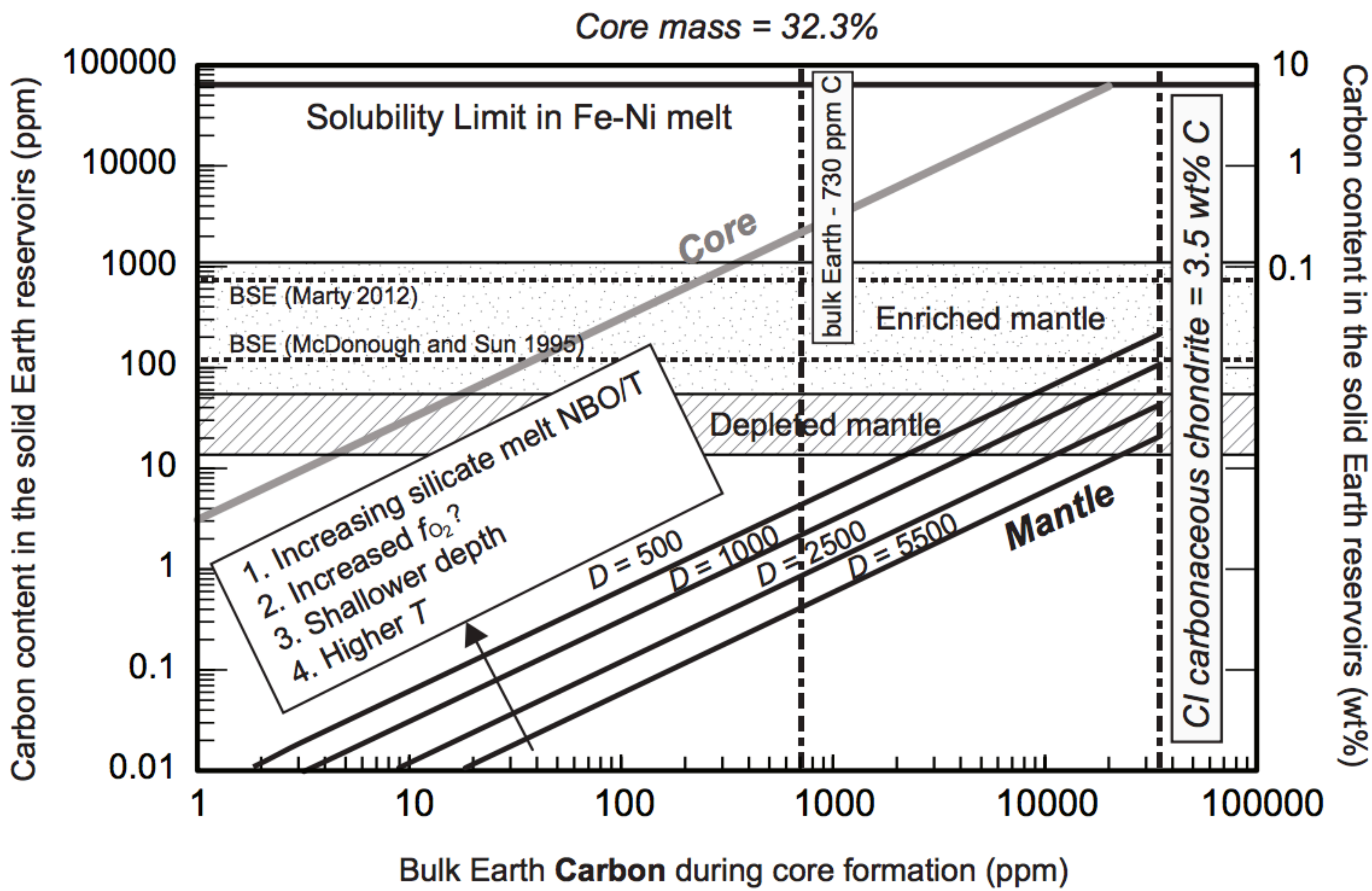
CYCLE-INDEPENDENT PLANETARY HABITABILITY ON EXOPLANET WATERWORLDS?



Kite & Ford, ApJ 2018

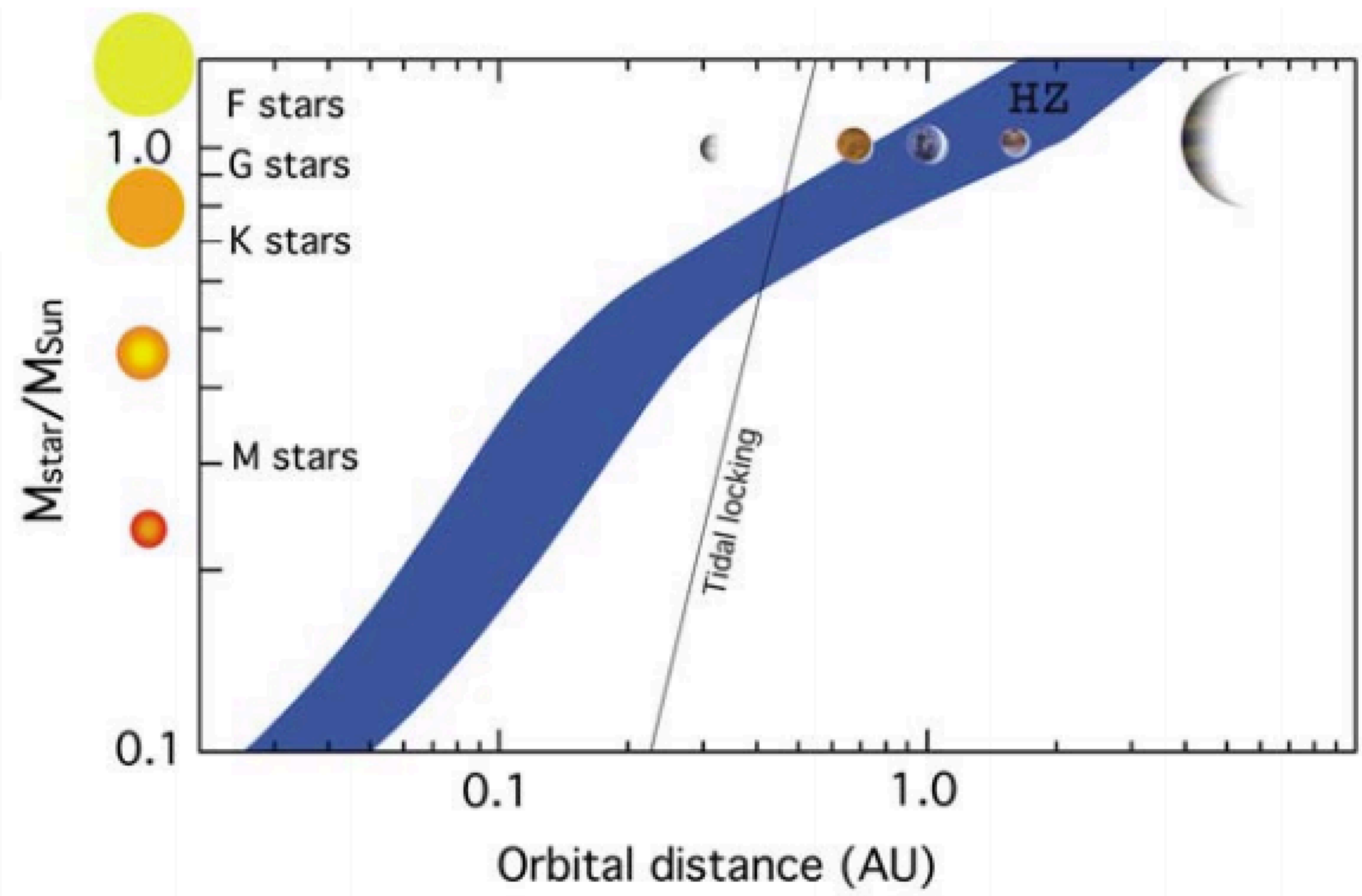
HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE LIKELY DIVERSE COMPOSITIONALLY

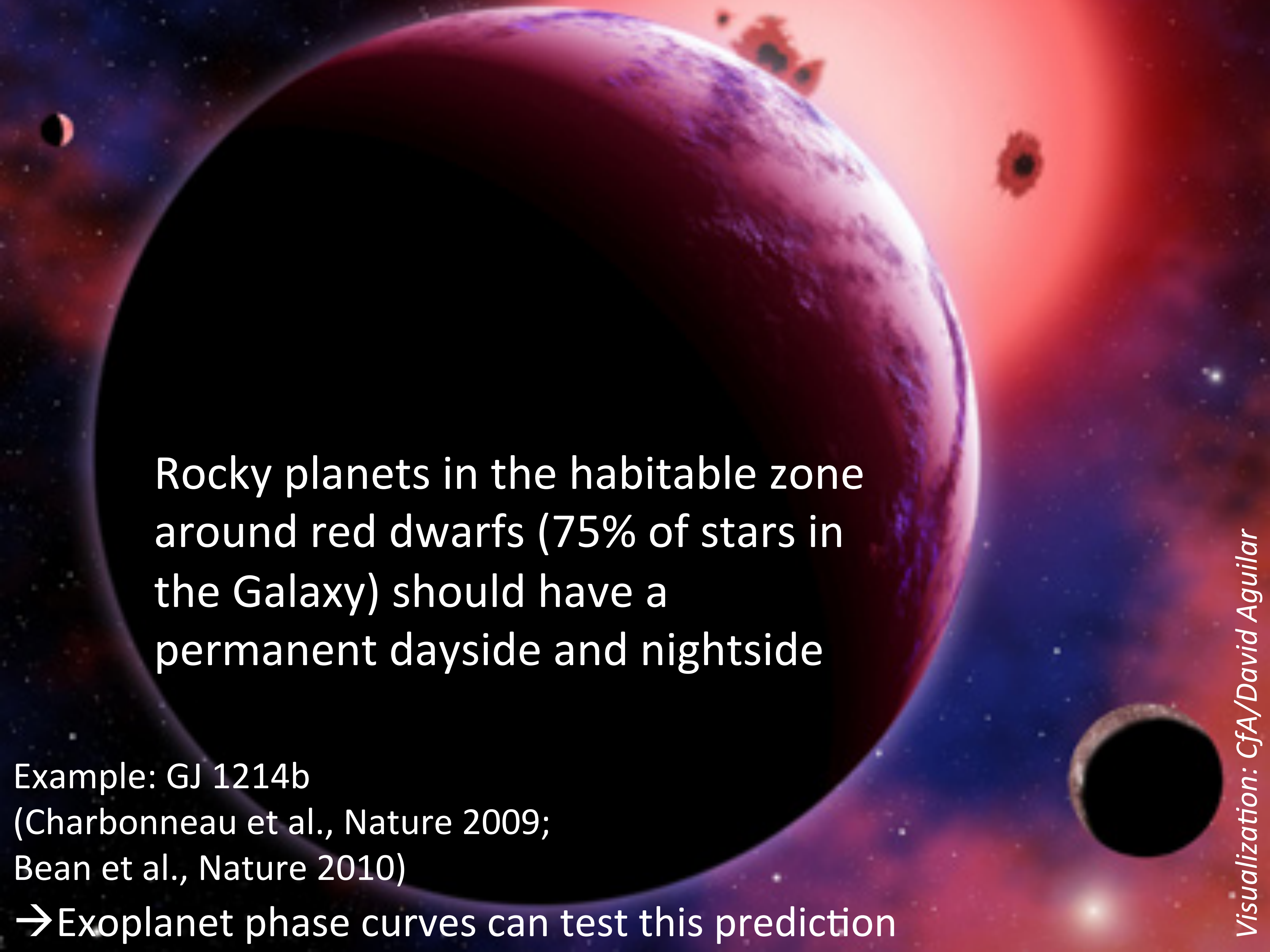
- CARBON



Dasgupta et al. 2013, Reviews in Mineralogy & Geochemistry

THE M-STAR OPPORTUNITY: RELATIVELY DEEPER AND MORE FREQUENT TRANSITS → EASIER TO DETECT & CHARACTERIZE



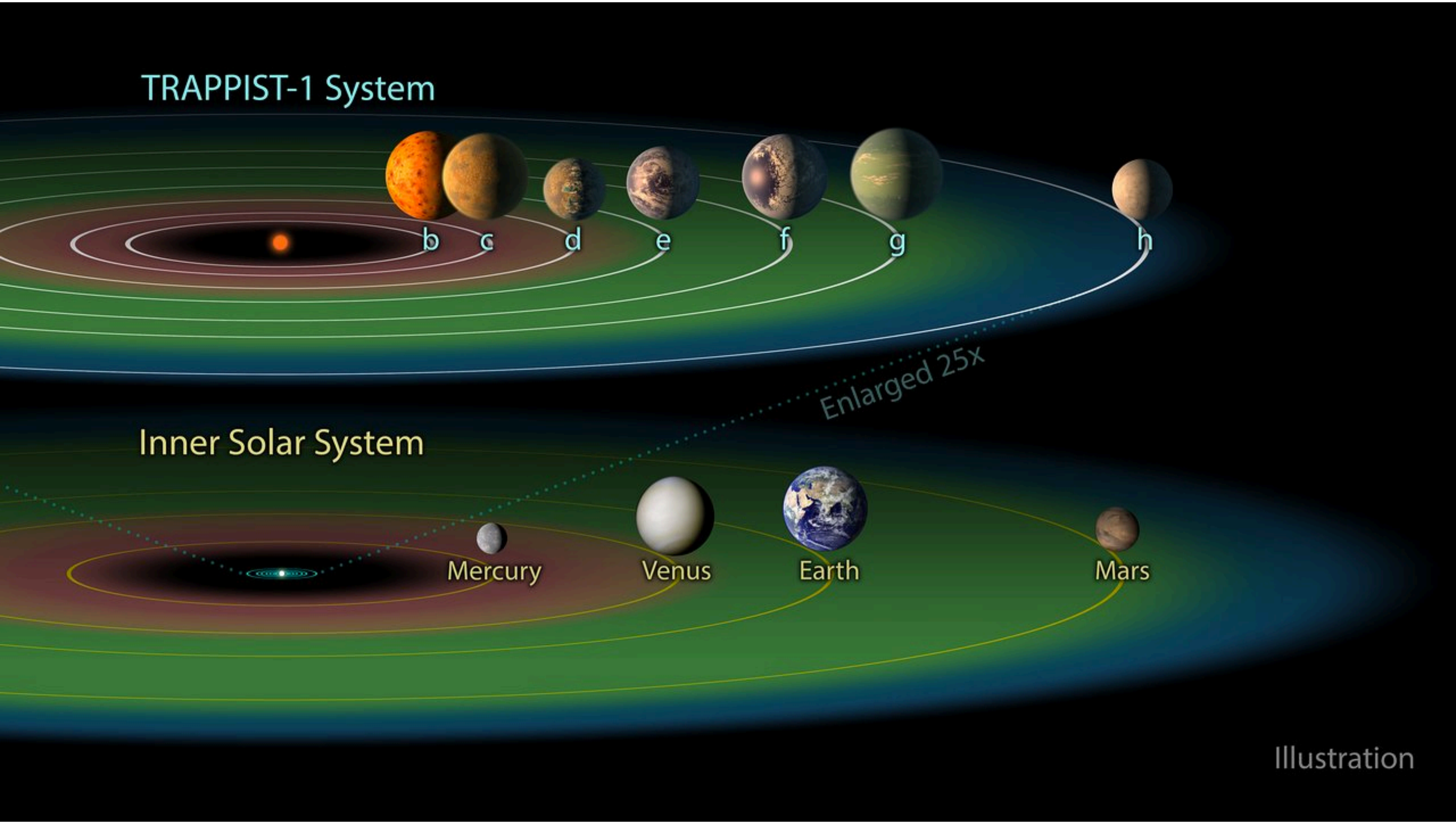


Rocky planets in the habitable zone around red dwarfs (75% of stars in the Galaxy) should have a permanent dayside and nightside

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

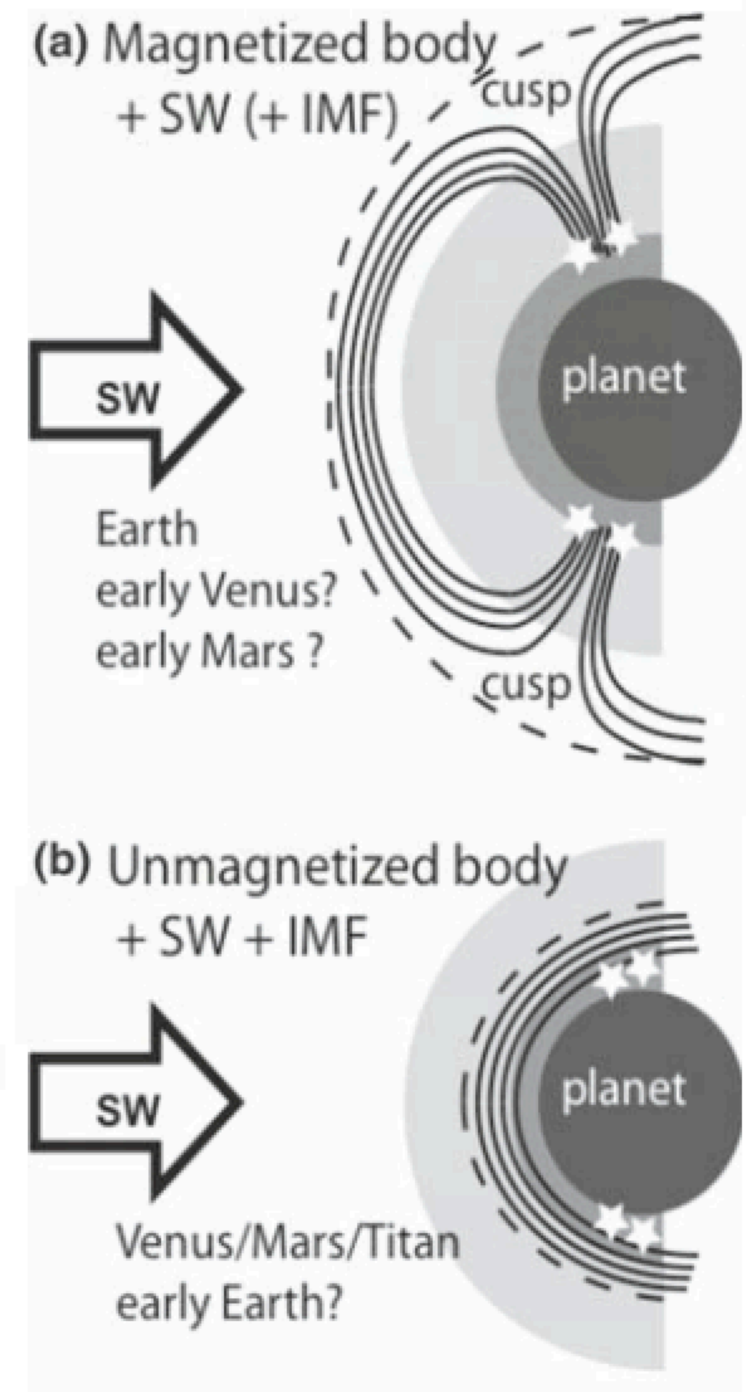
HIGH XUV FLUX SUSTAINED FOR LONG PERIOD FOR SMALL STARS

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 ≥ 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

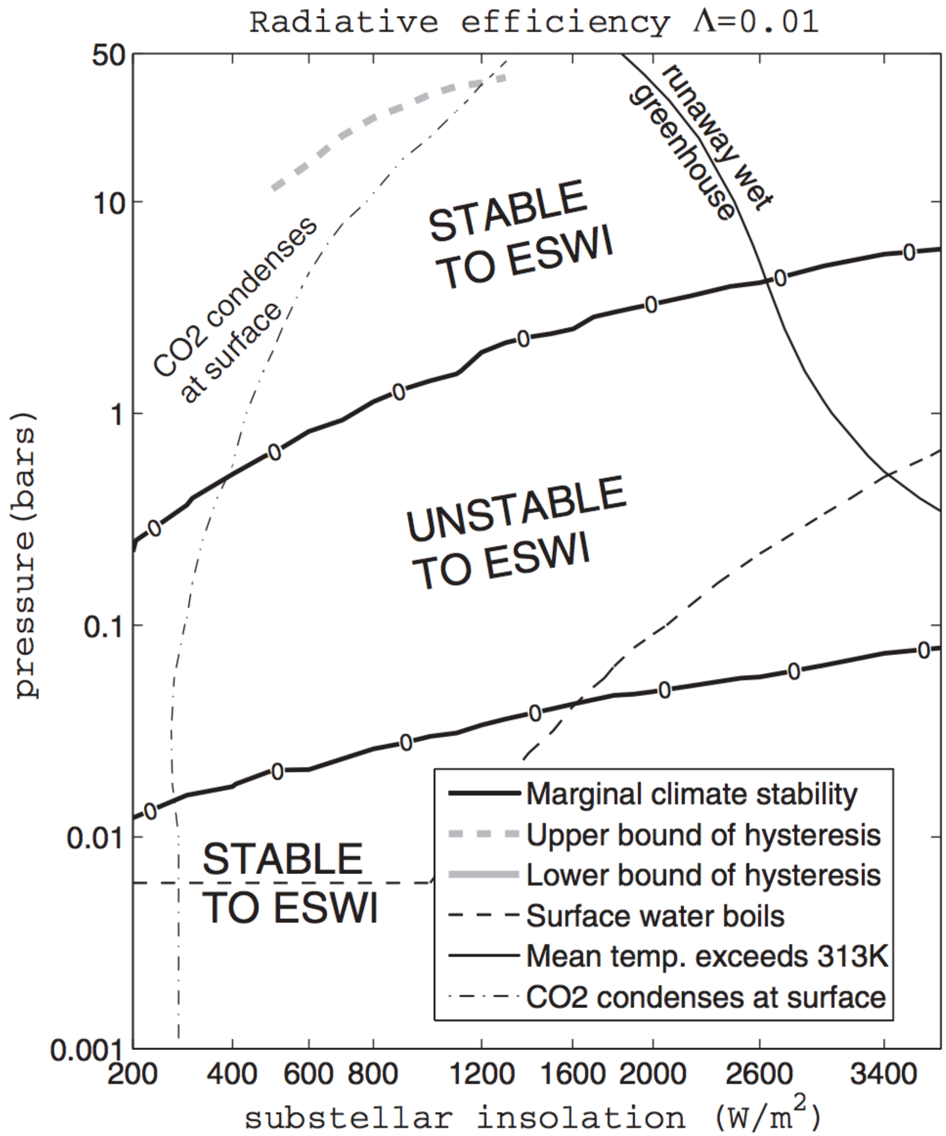
Lammer et al. 2009 Space Science Reviews

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

Exoplanet habitability

HABITABLE-ZONE 1-2 EARTH RADIUS PLANETS ARE NUMEROUS

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

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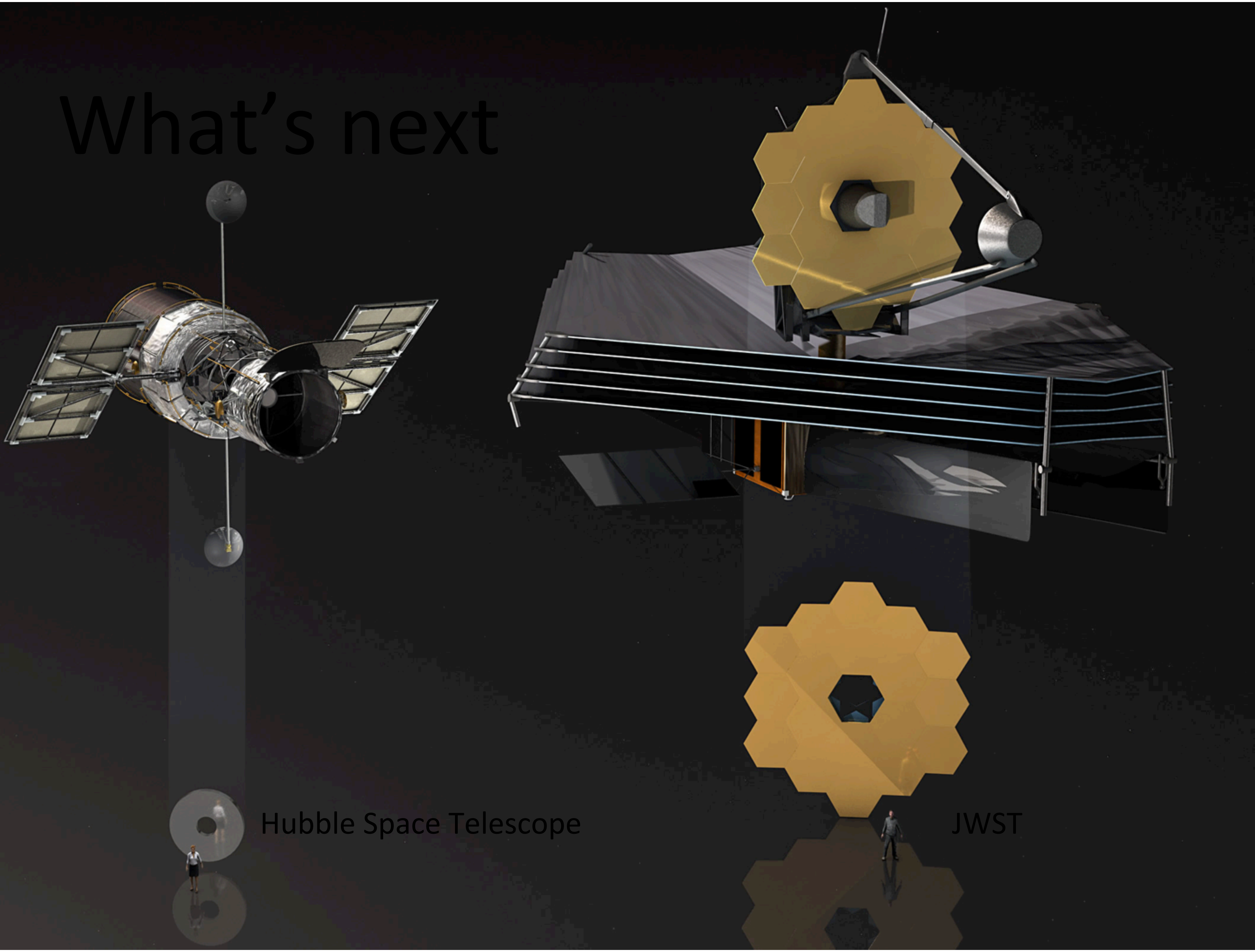
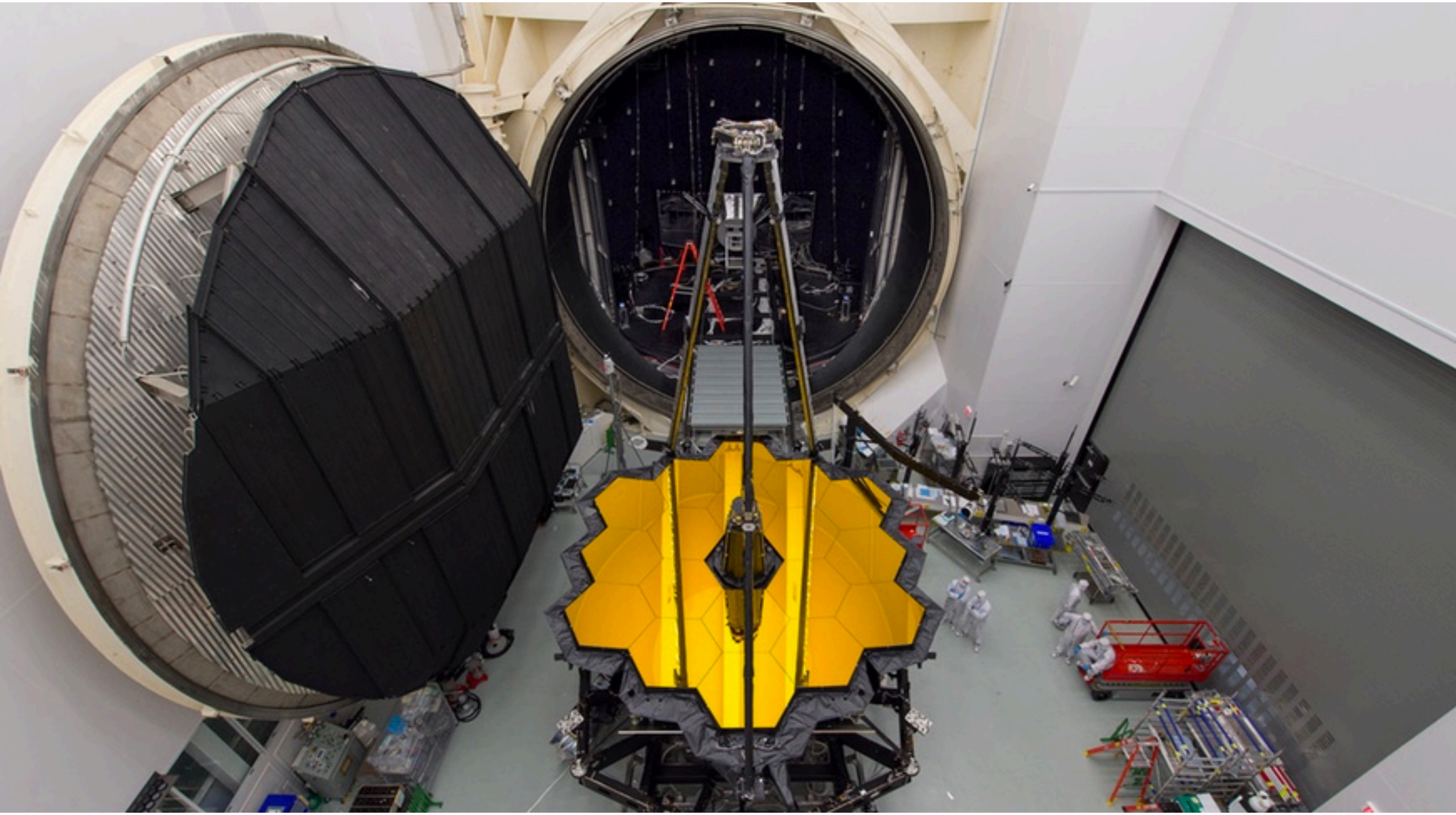
THE M-STAR OPPORTUNITY

- PROBLEMS FOR HABITABILITY FOR PLANETS ORBITING M-STARS

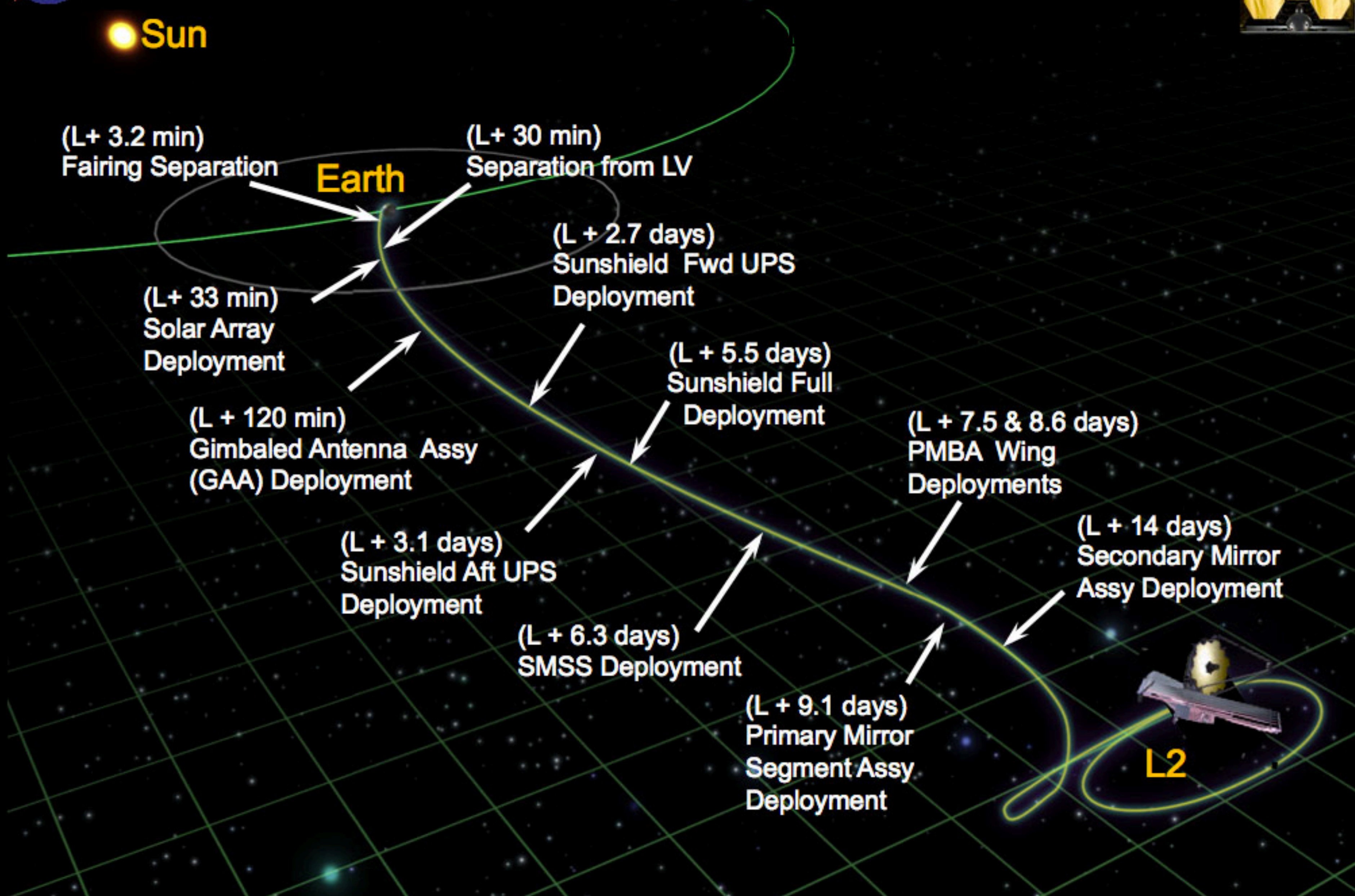
FUTURE MISSIONS

What's next

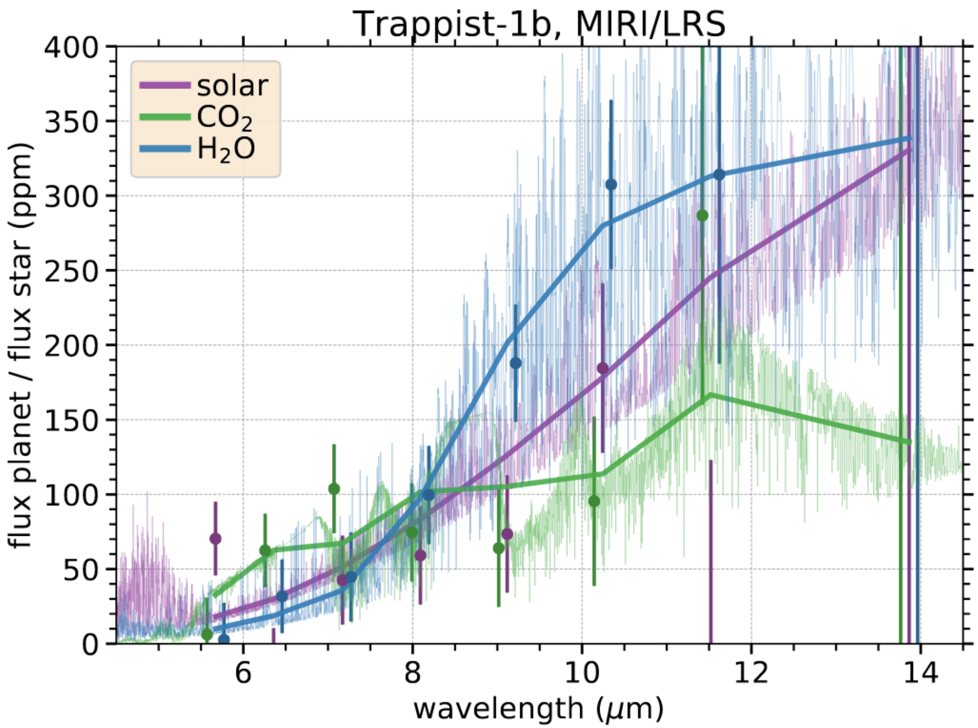




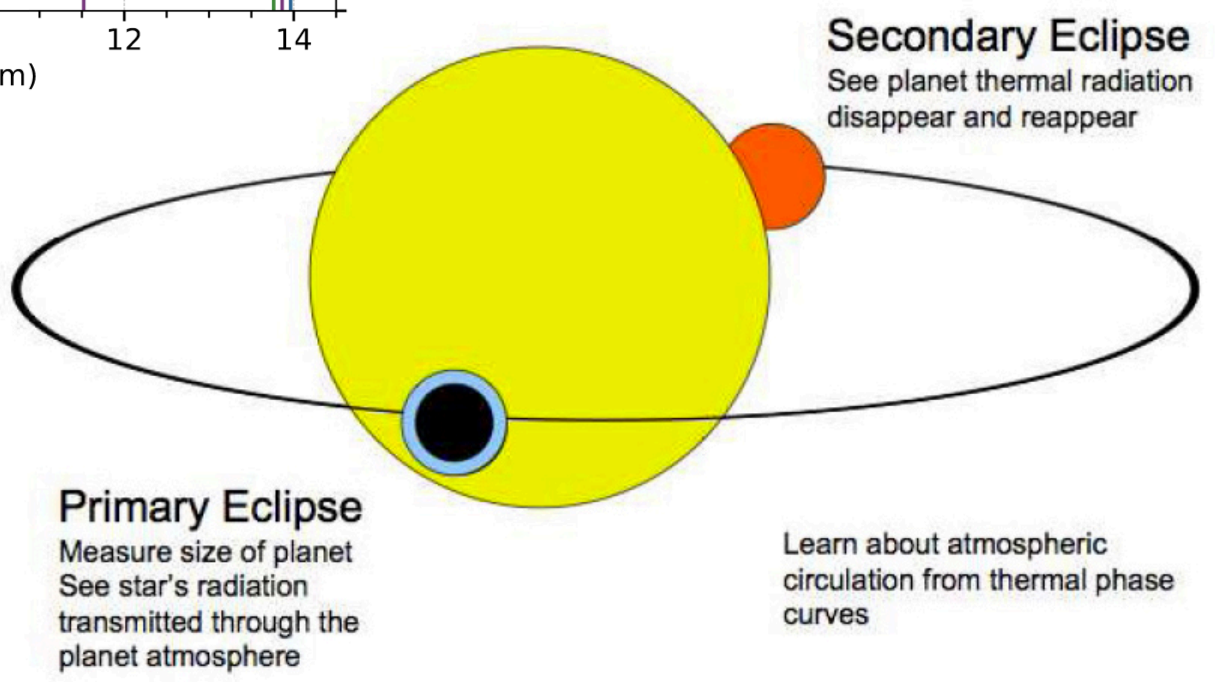
JWST Launch/Deployment Timeline

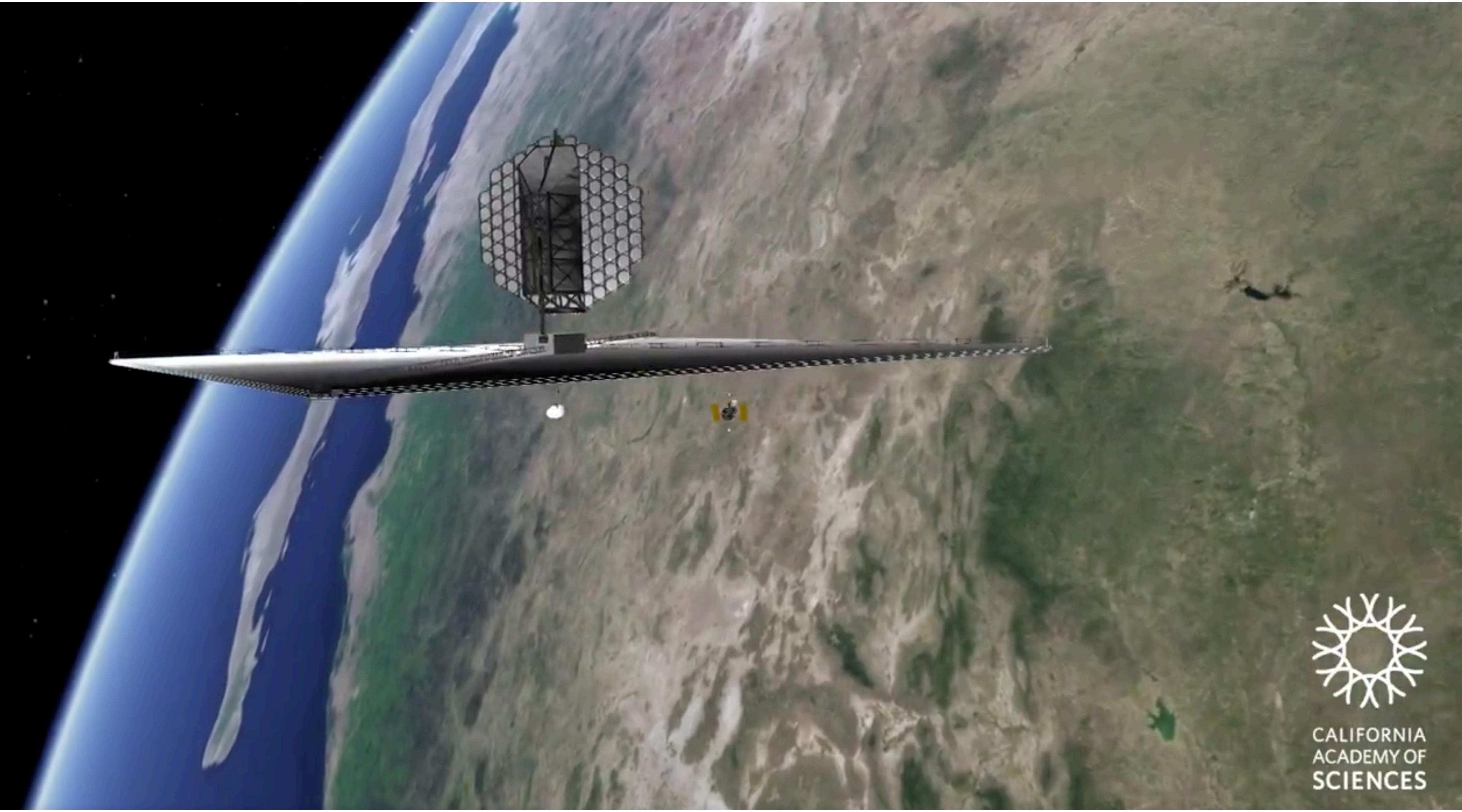


Simulated secondary eclipse spectra



Malik et al. in review

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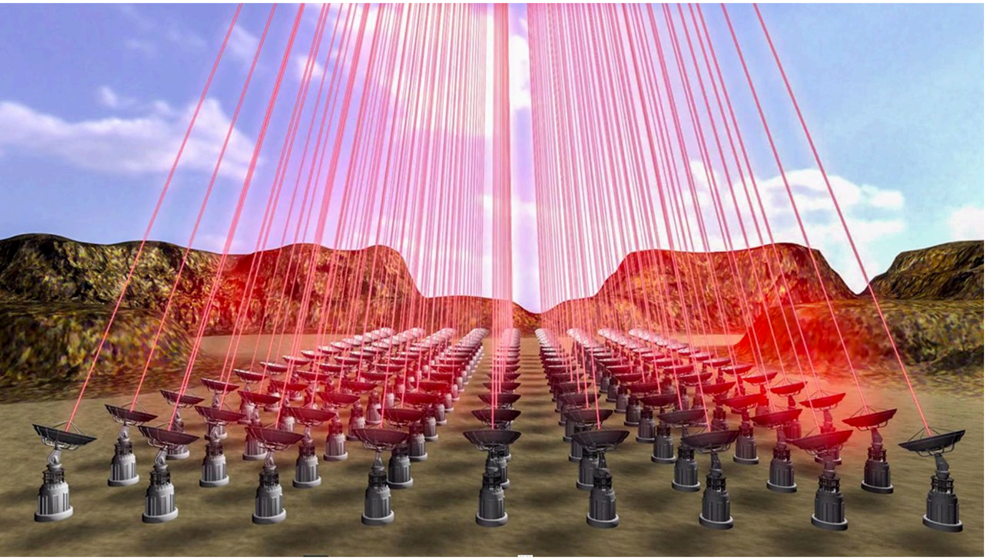
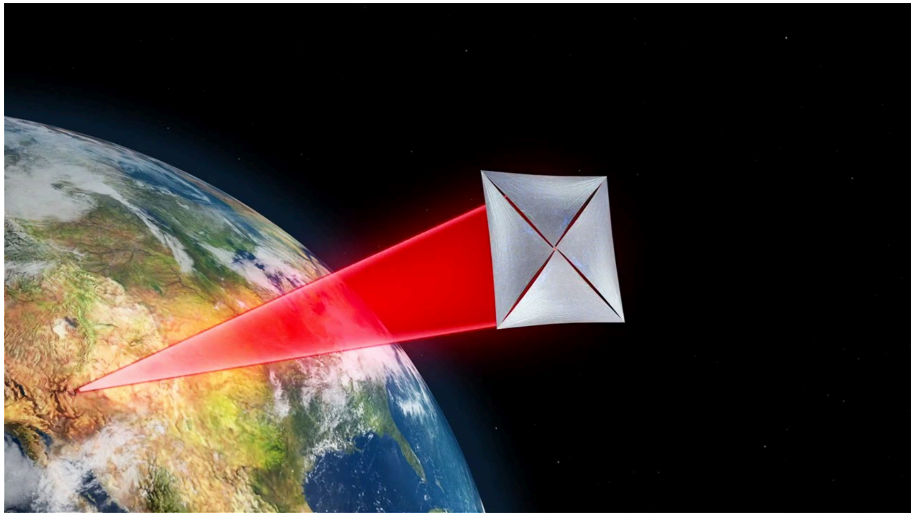
INTERSTELLAR MISSIONS?

- 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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