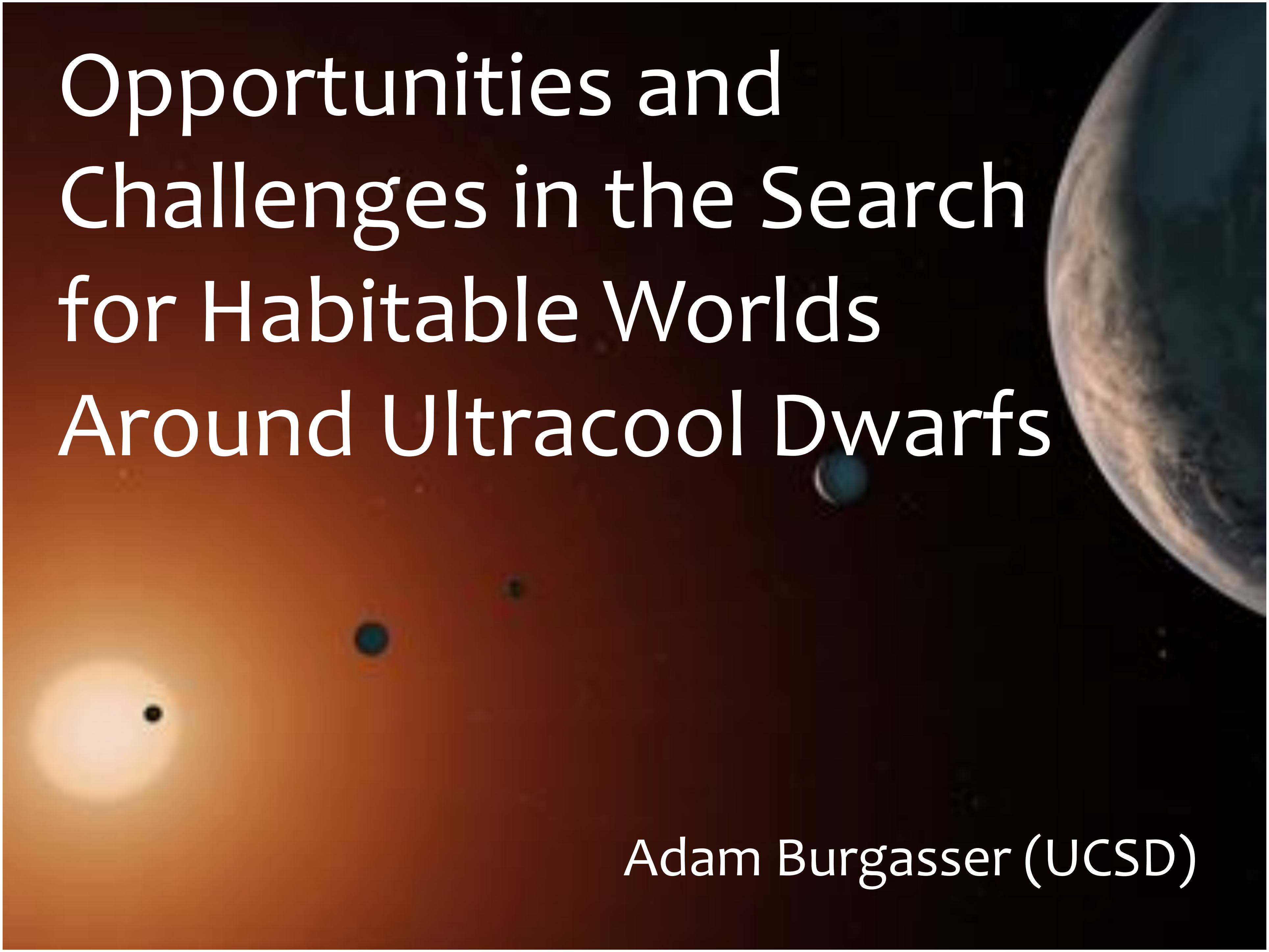
Opportunities and Challenges in the Search for Habitable Worlds Around Ultracool Dwarfs



Adam Burgasser (UCSD)


VANESSA FRIEDMAN
GUCCI'S FANCY DRESS FANDANGO

ANDY WARHOL
DEATH WASN'T SO SIMPLE, AFTER ALL

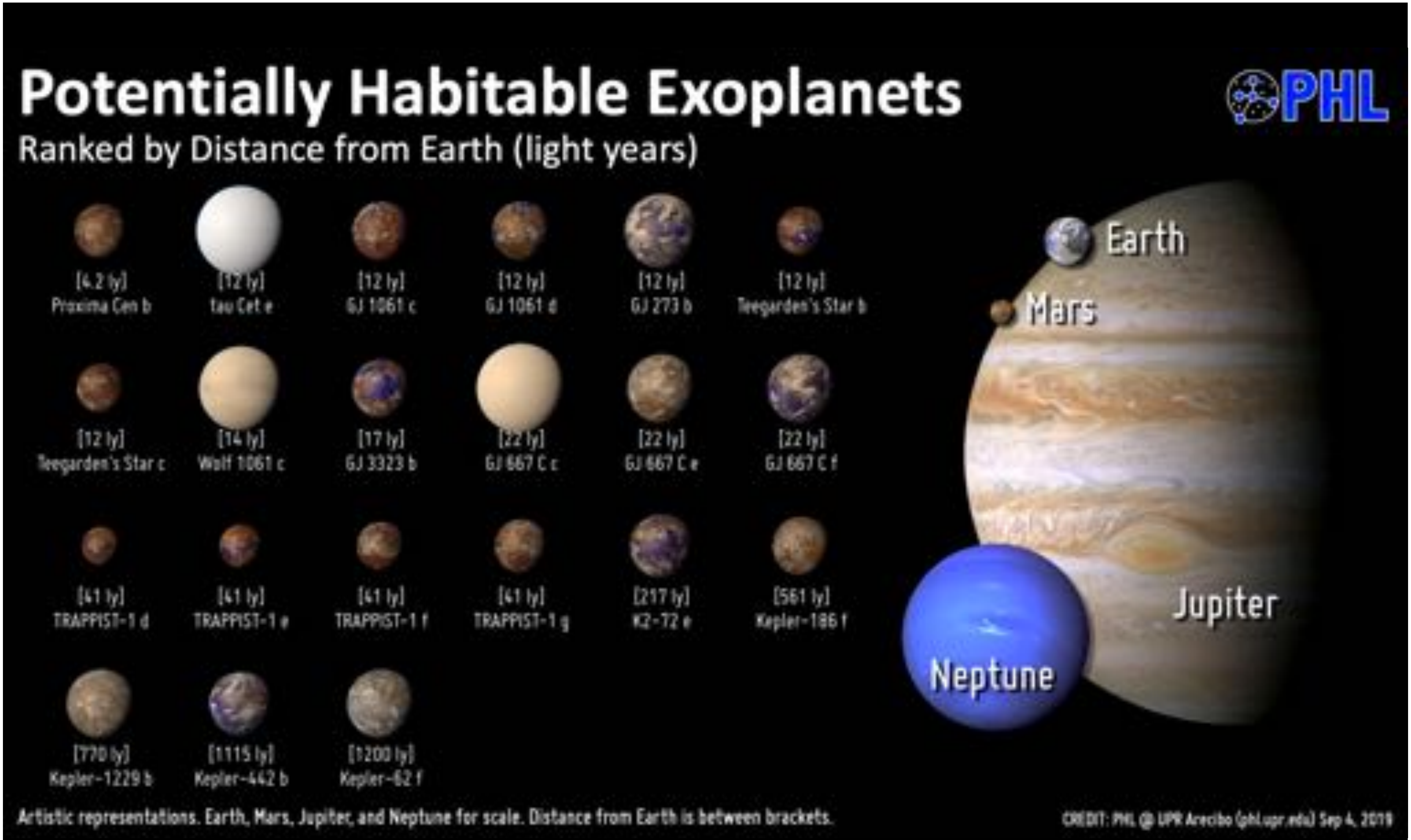
THE SEARCH FOR ALIEN LIFE
7 NEW EARTH-SIZE PLANETS TANTALIZE ASTRONOMERS

The New York Times

It's Lennon vs. Bannon for our soul

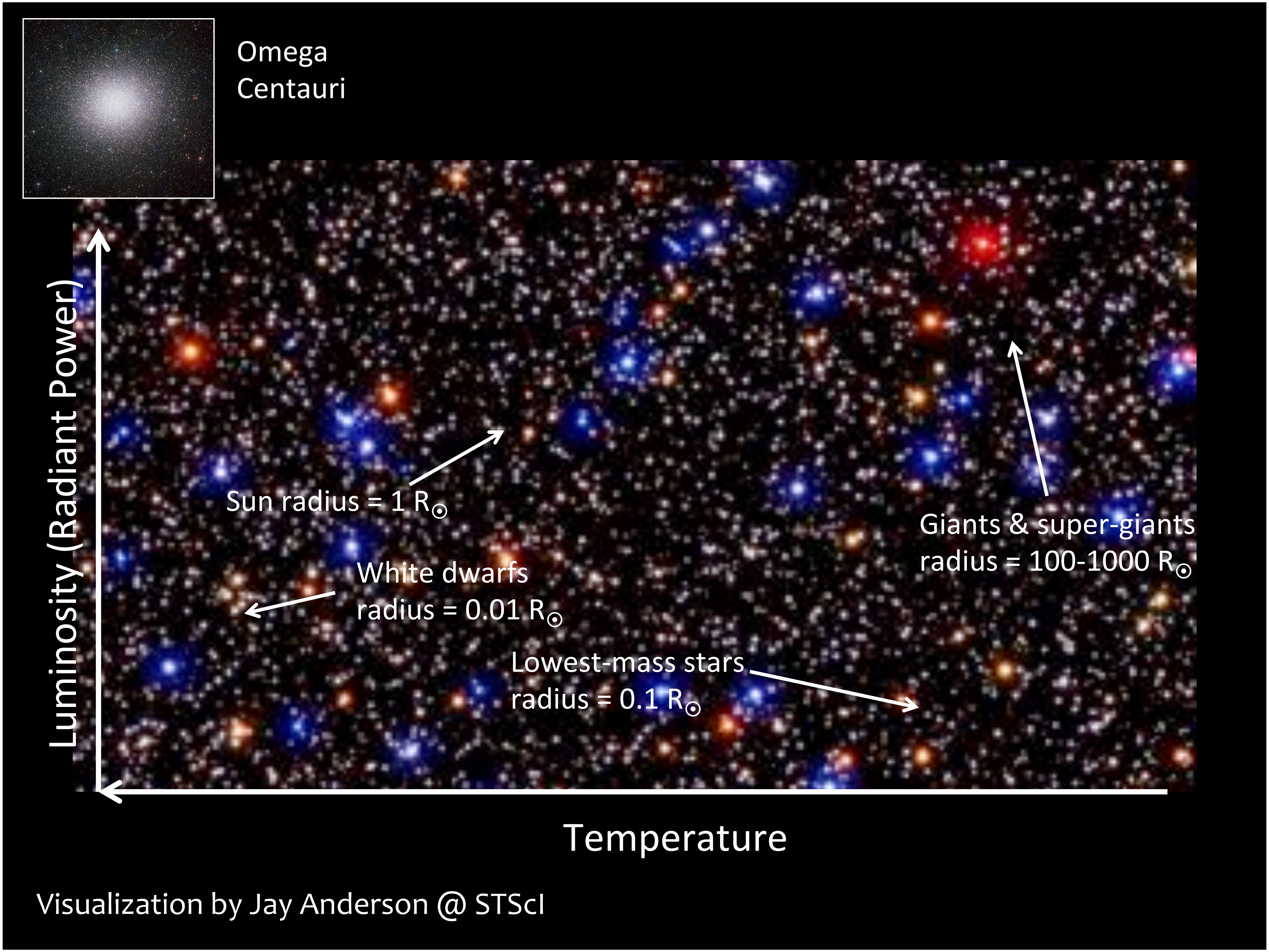
Consultants and lawyers find fortunes in 'Brexit'

February 2017



U. Puerto Rico @ Arecibo
Planetary Habilitability Laboratory
http://phl.upr.edu

95% of PHL's potentially habitable worlds orbit low mass stars


Omega
Centauri
Luminosity (Radiant Power)
Sun radius = 1 R☉
White dwarfs
radius = 0.01 R☉
Lowest-mass stars
radius = 0.1 R☉
Giants & super-giants
radius = 100-1000 R☉
Temperature
Visualization by Jay Anderson @ STScI

Stellar Mass, Size & Temperature

Lowest-mass stars
10% as large
10% as massive

Highest-mass stars
10x larger
40x more massive

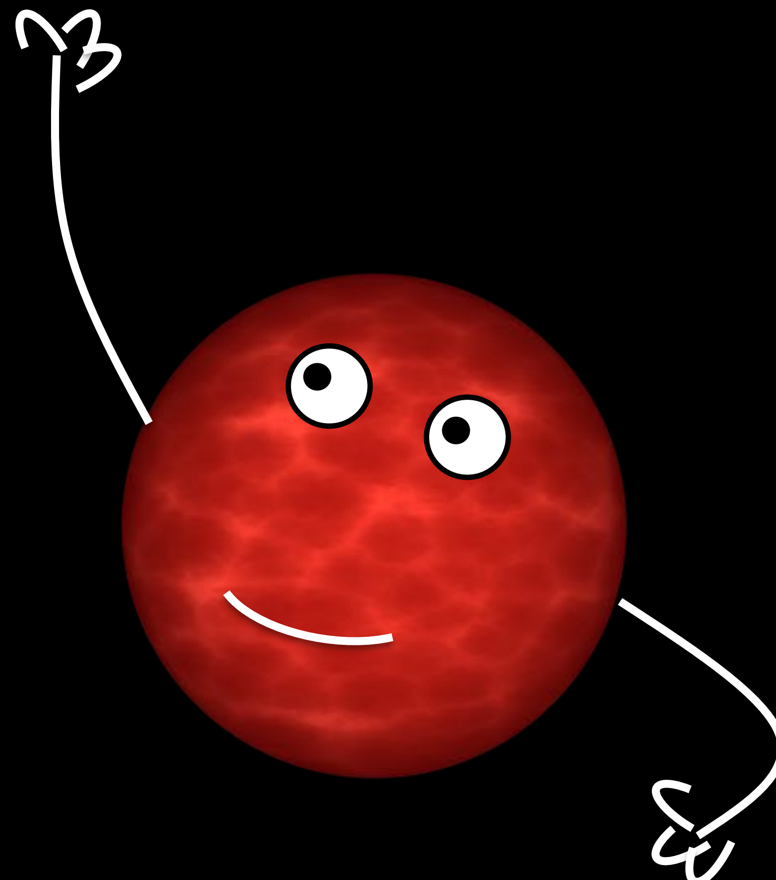
Wikipedia: http://en.wikipedia.org/wiki/File:Morgan-Keenan_spectral_classification.png

What defines an "ultracool dwarf"?

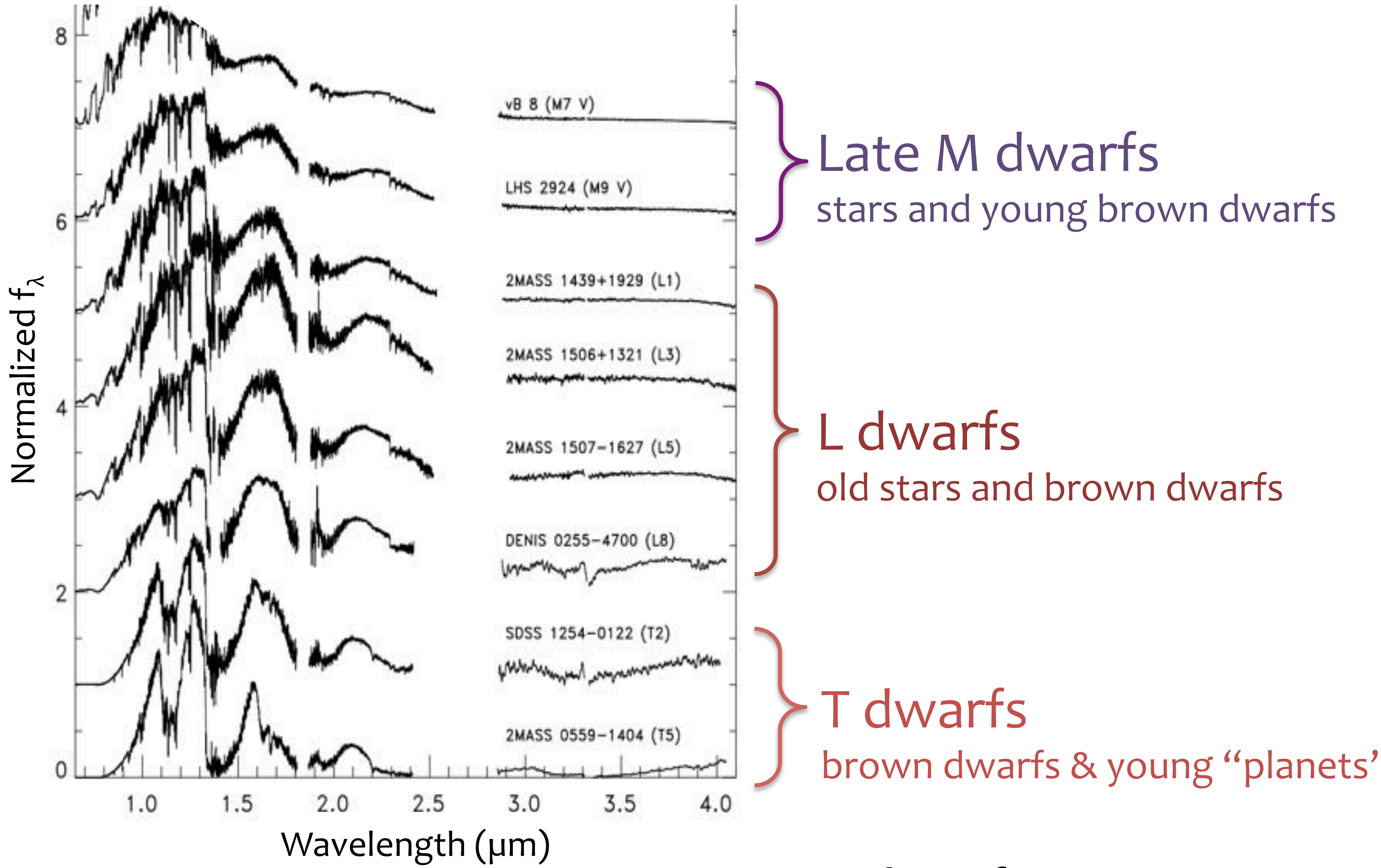
$M \leq 0.1\ M_{\odot}$

$T_{eff} \leq 3000$ K

SpT ≥ M7



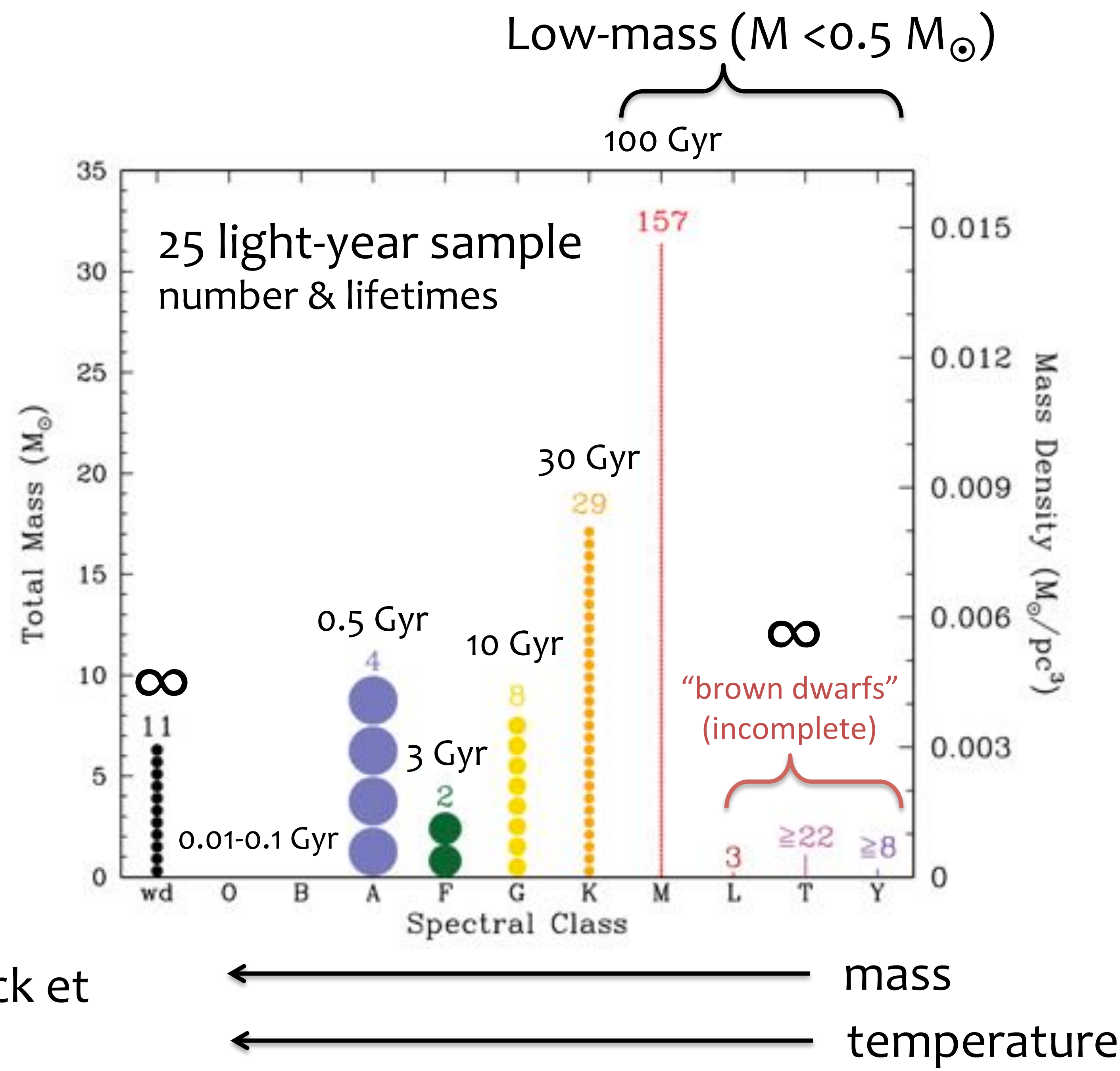
Kirkpatrick et al. (1997)



Cushing et al. (2005)

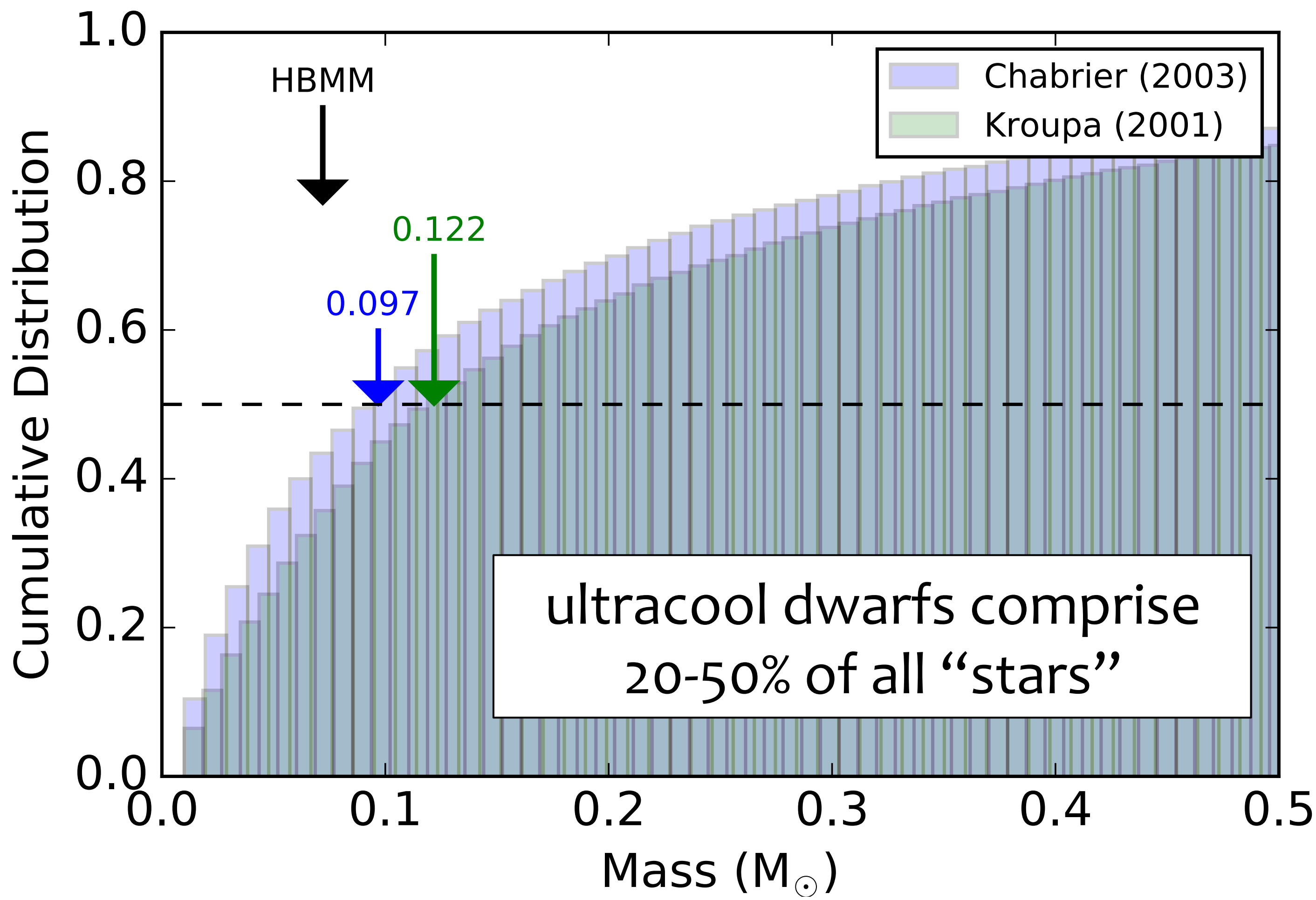
+Y dwarfs

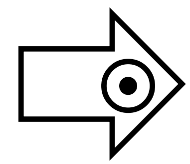
old brown dwarfs & "planets"



Kirkpatrick et al. (2010)

There are a lot of ultracool dwarfs in the galaxy…



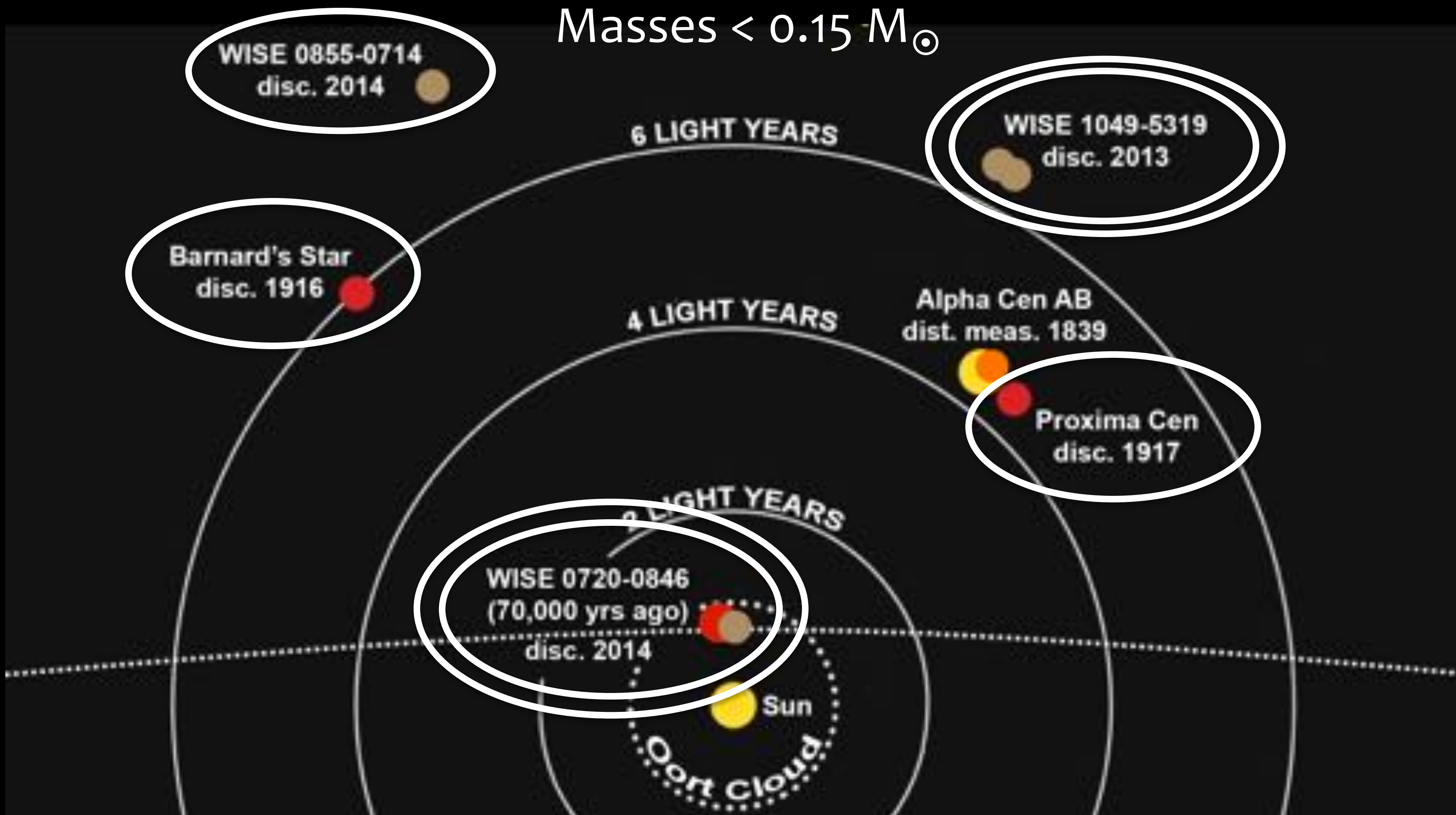


*assuming a mass range 0.01-10 $M_\odot$

MF: Kroupa (2001); Chabrier (2003)
LF: Mužic+ (2017); Kirkpatrick et al. (2019)

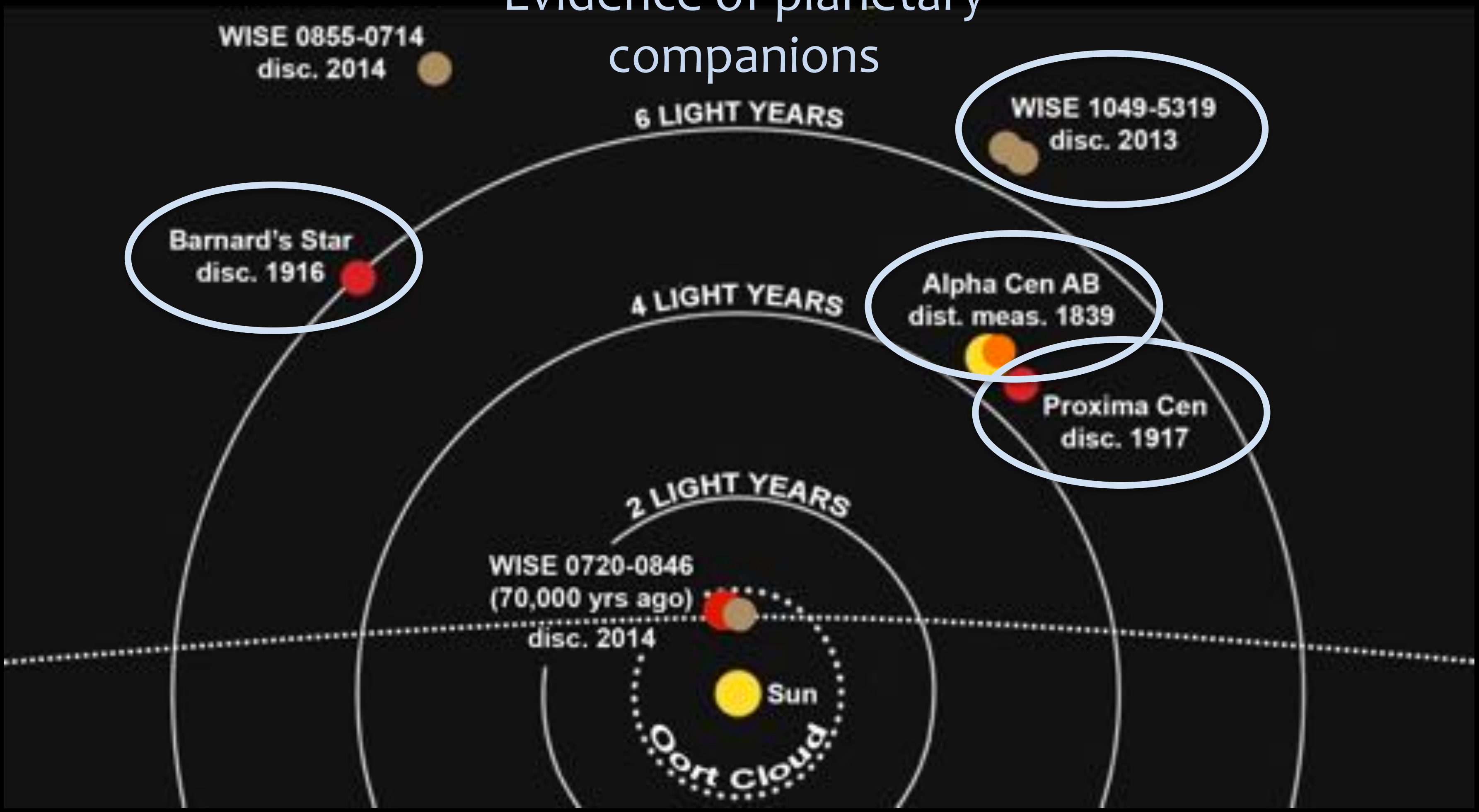
Our nearest neighbors are very low-mass stars and brown dwarfs

Masses < 0.15 $M_{\odot}$

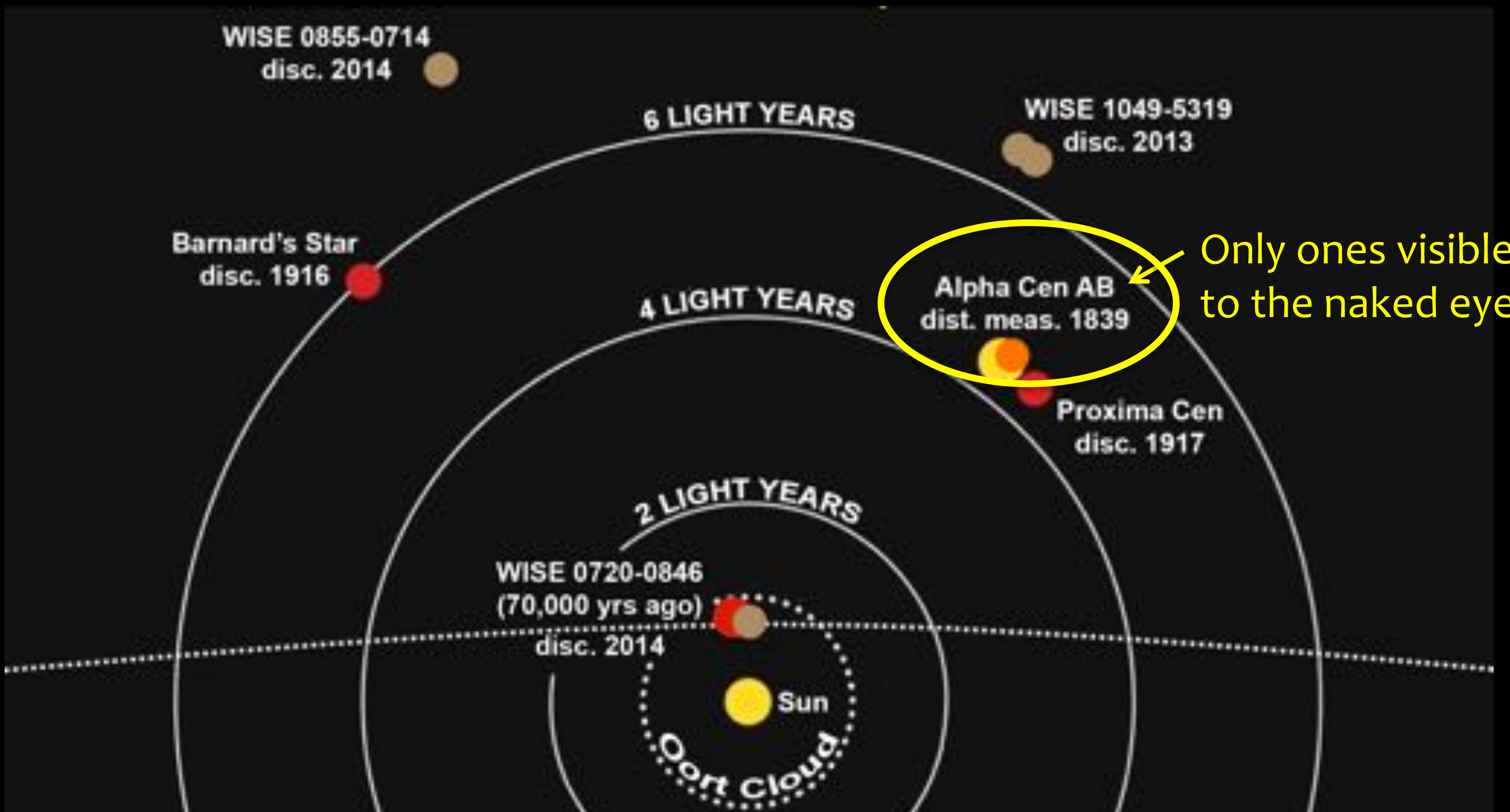


Our nearest neighbors are very low-mass stars and brown dwarfs

Evidence of planetary companions

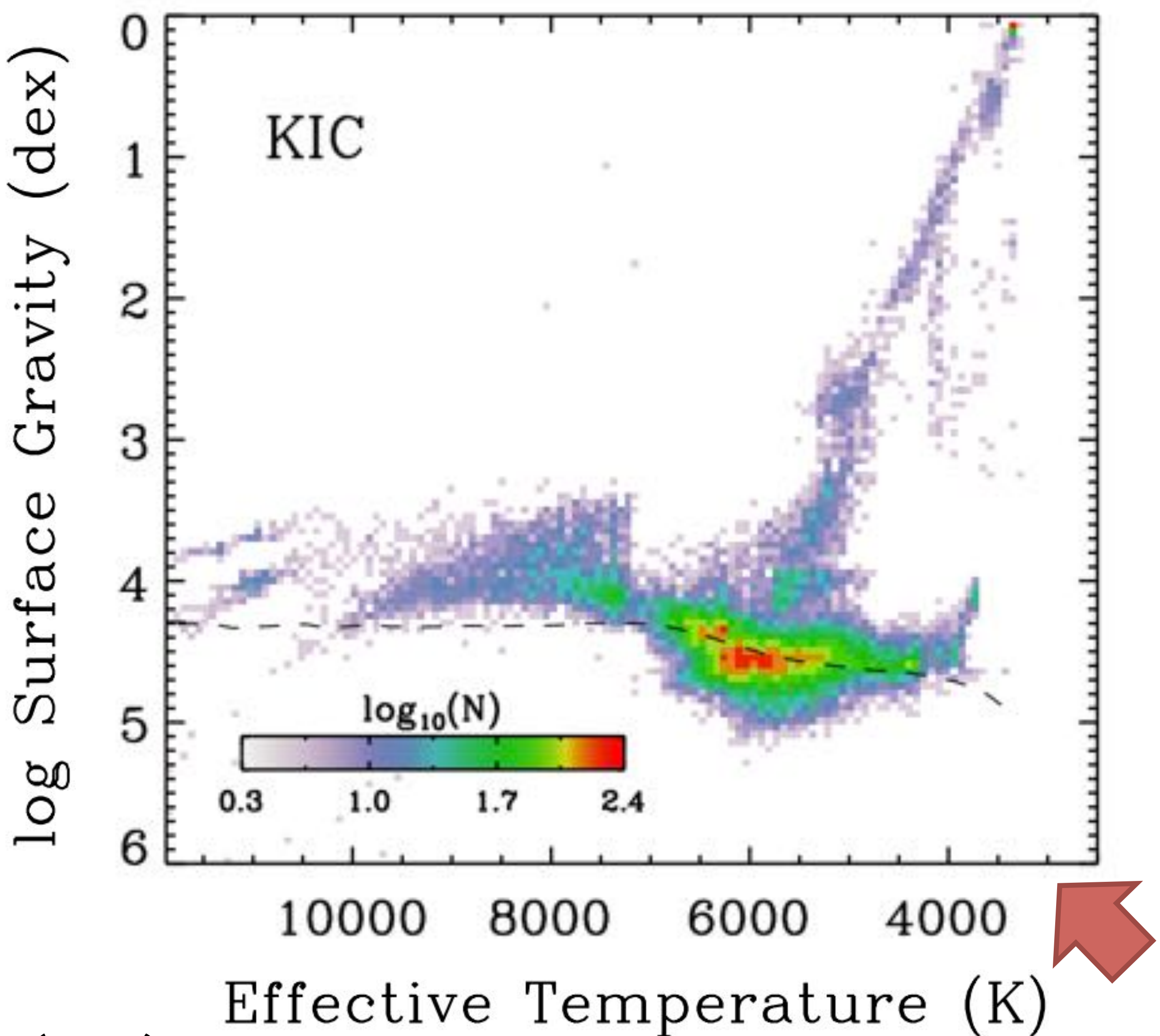


Our nearest neighbors are very low-mass stars and brown dwarfs



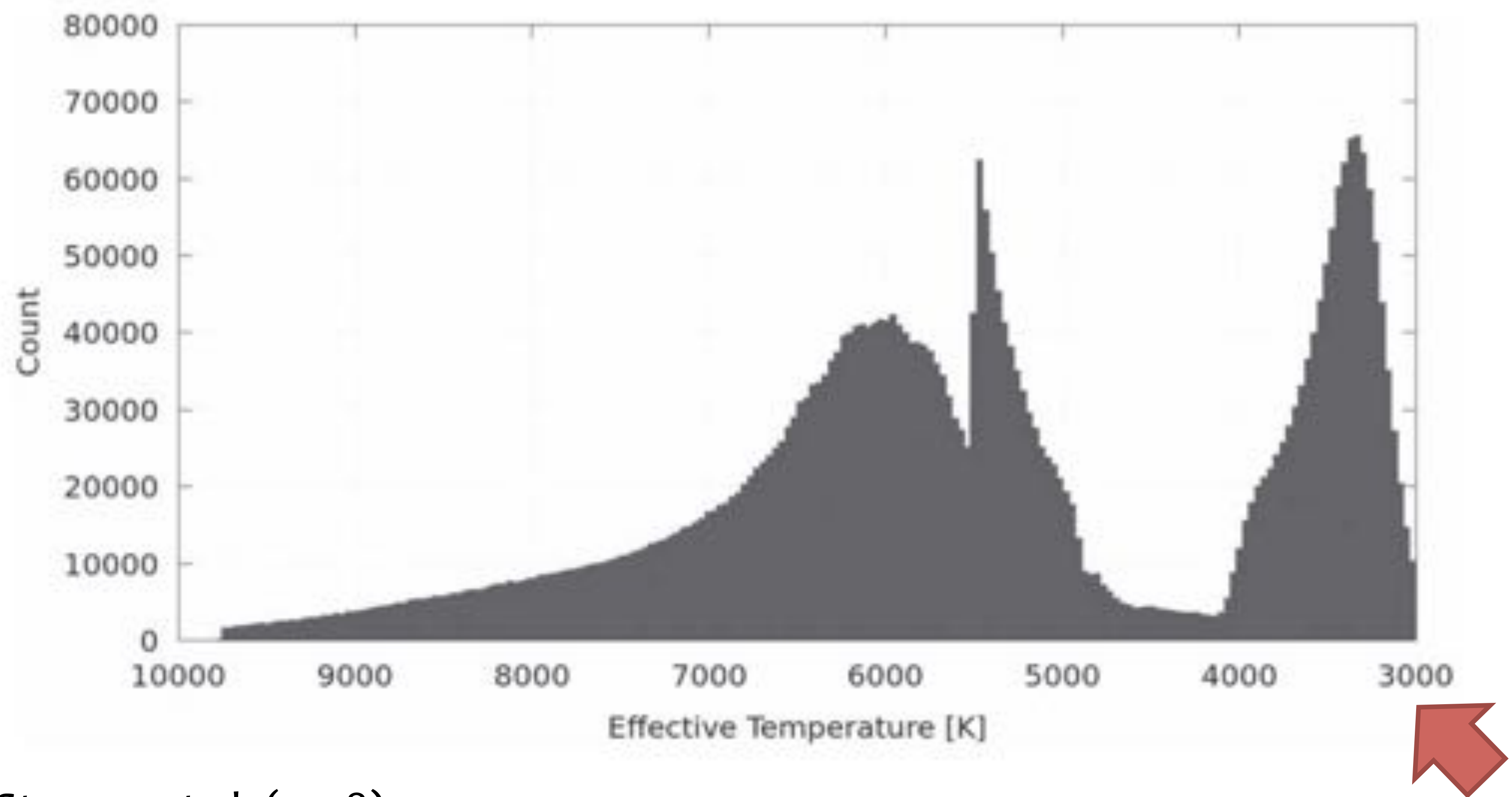
Accurate simulation of the night sky to V=6 for stars with masses < 0.5 $M_{\odot}$

Kepler Input Catalog (KIC)



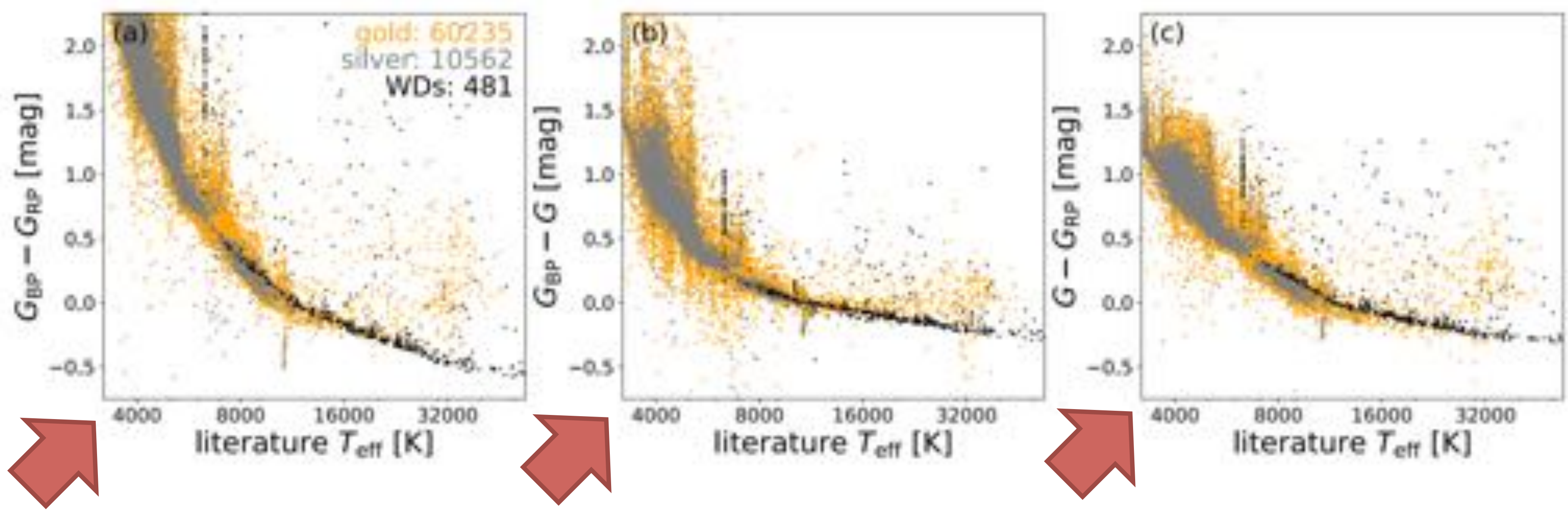
Huber et al. (2014)

TESS Input Catalog



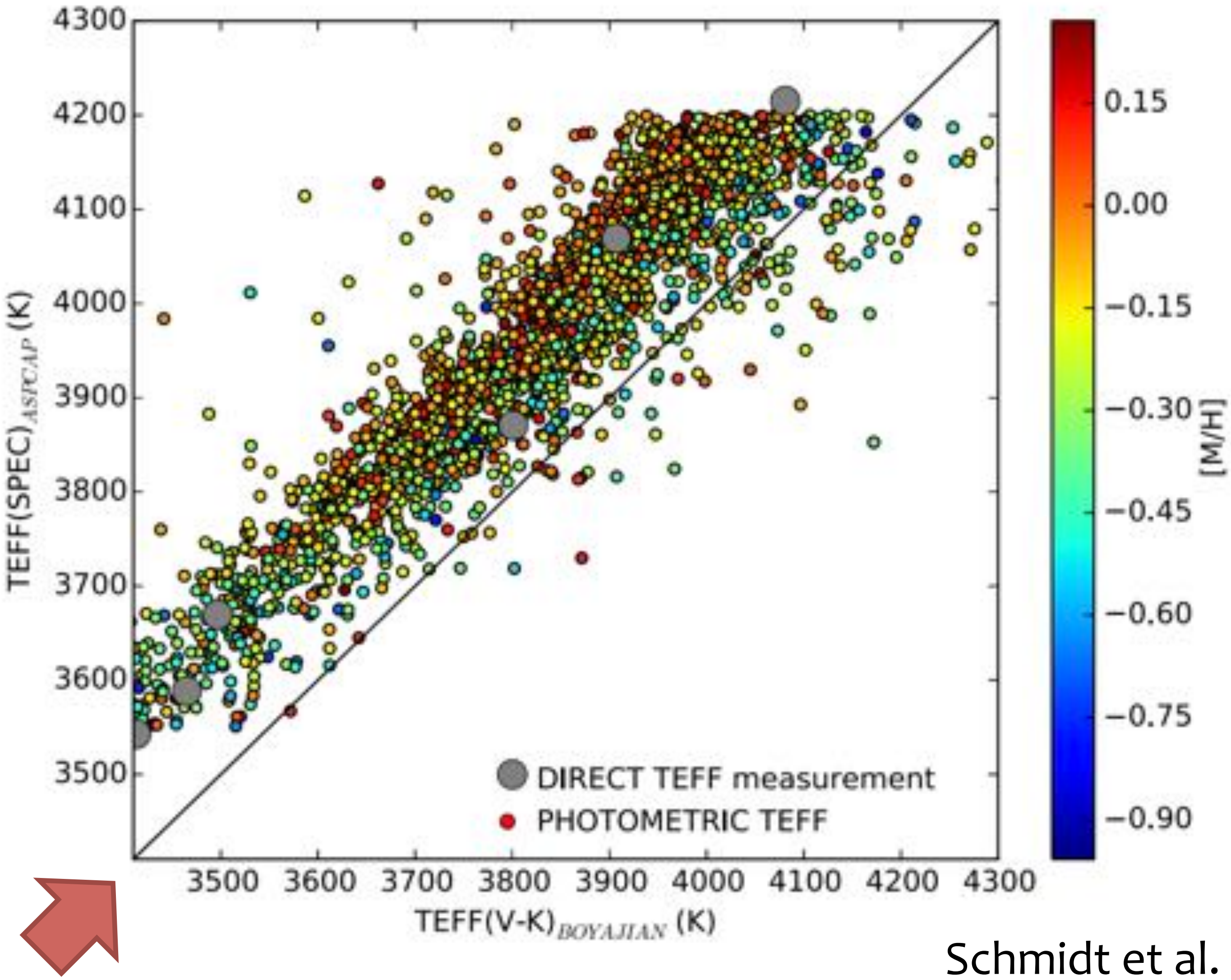
Stassun et al. (2018)

GAIA DR2 (APSIS)



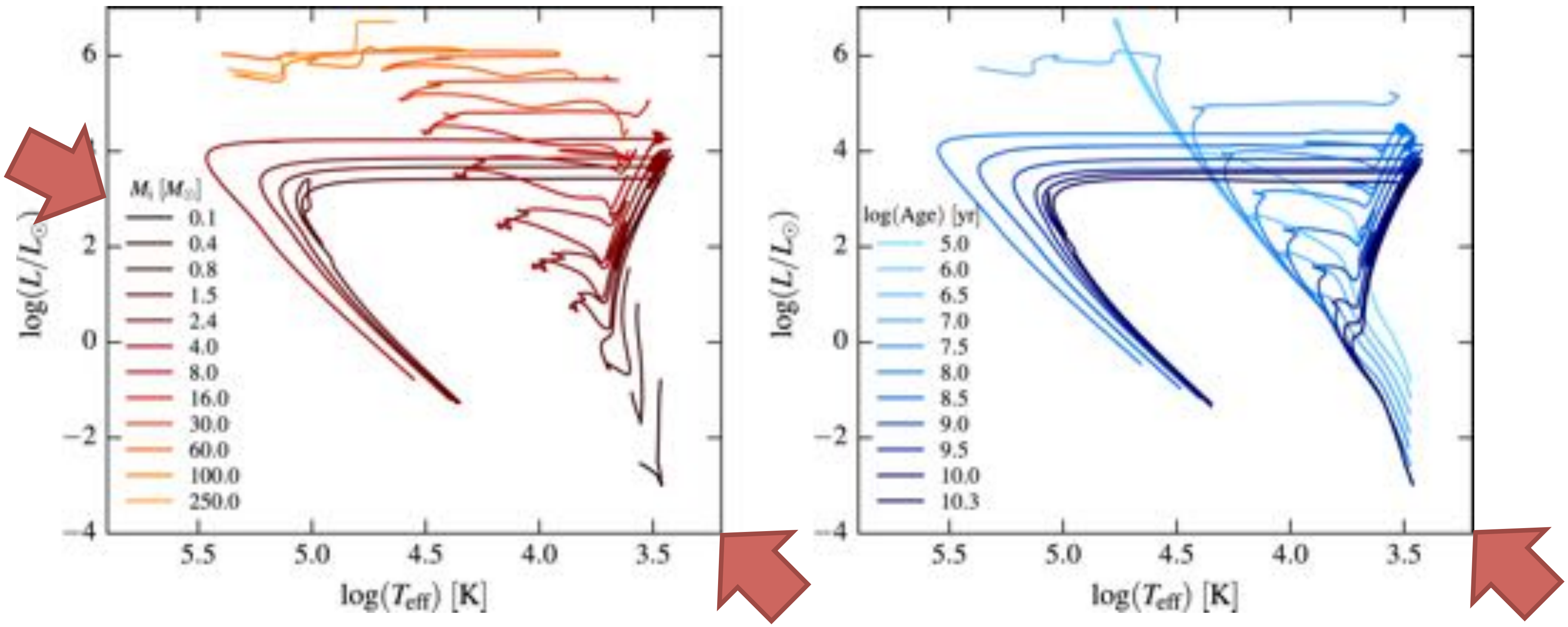
Andrae et al. (2018)

apogee (aspcap)



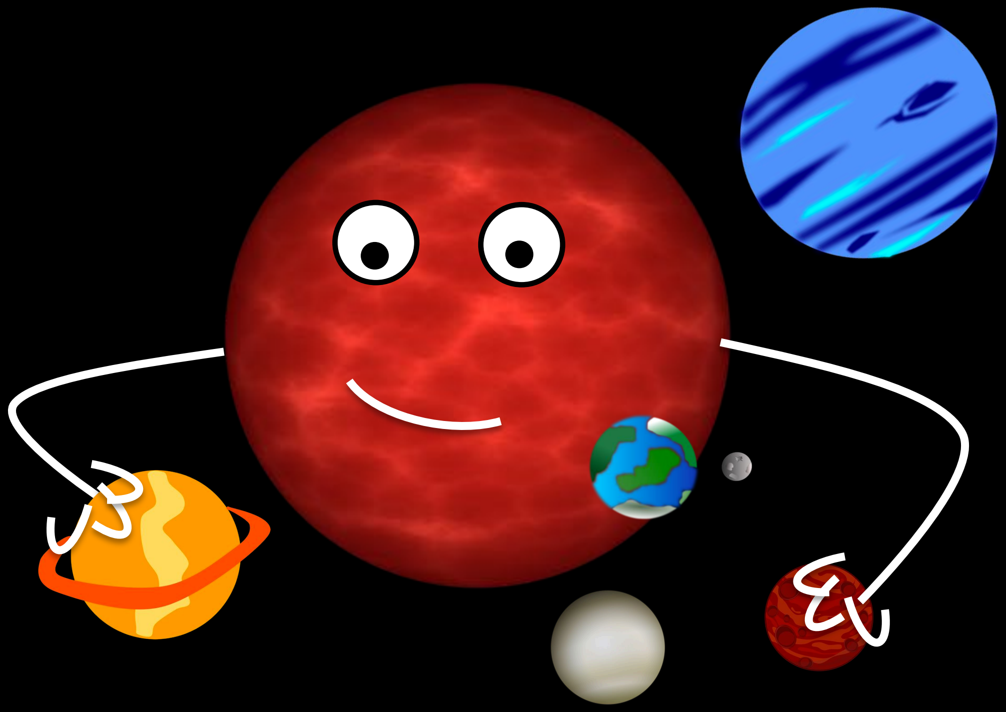
Schmidt et al. (2016)

MIST Isochrones

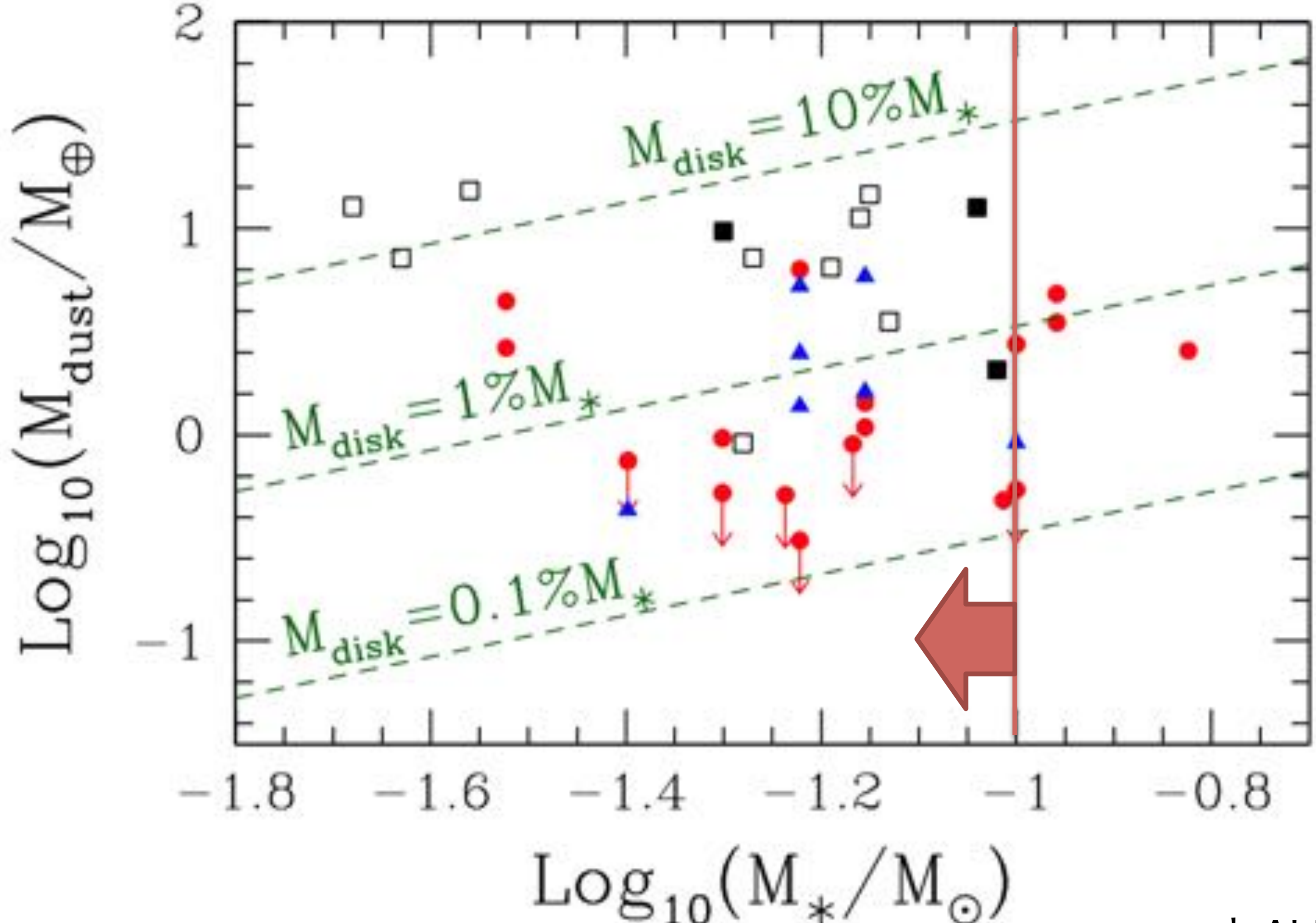


Dotter (2016)
Choi et al. (2016)

We should not ignore ultracool dwarfs as exoplanet hosts.

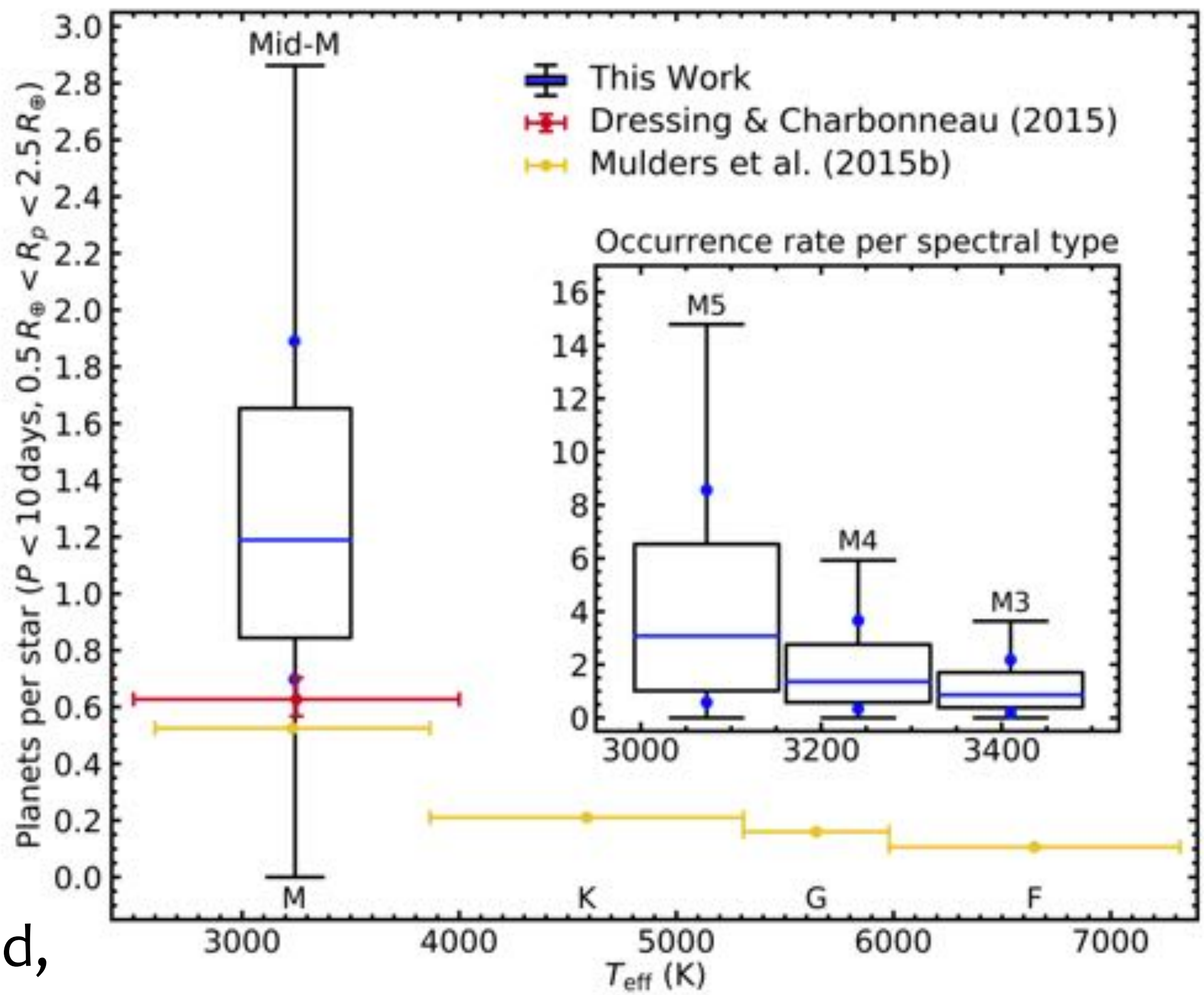


We're pretty sure they can make planets…



ρ oph ALMA disks
Testi et al. (2016)

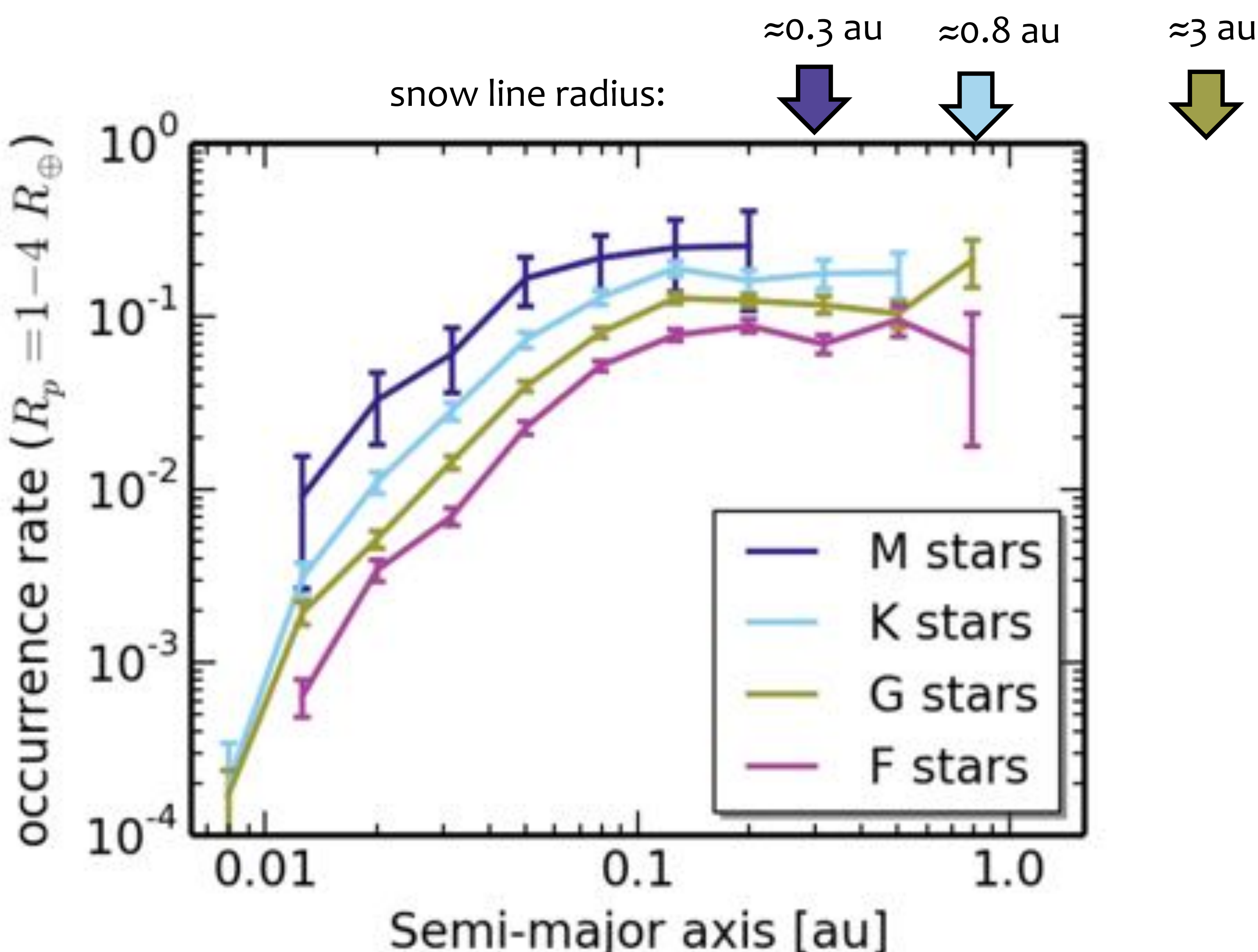
…maybe a lot of planets…



short period, small planet occurrence rate

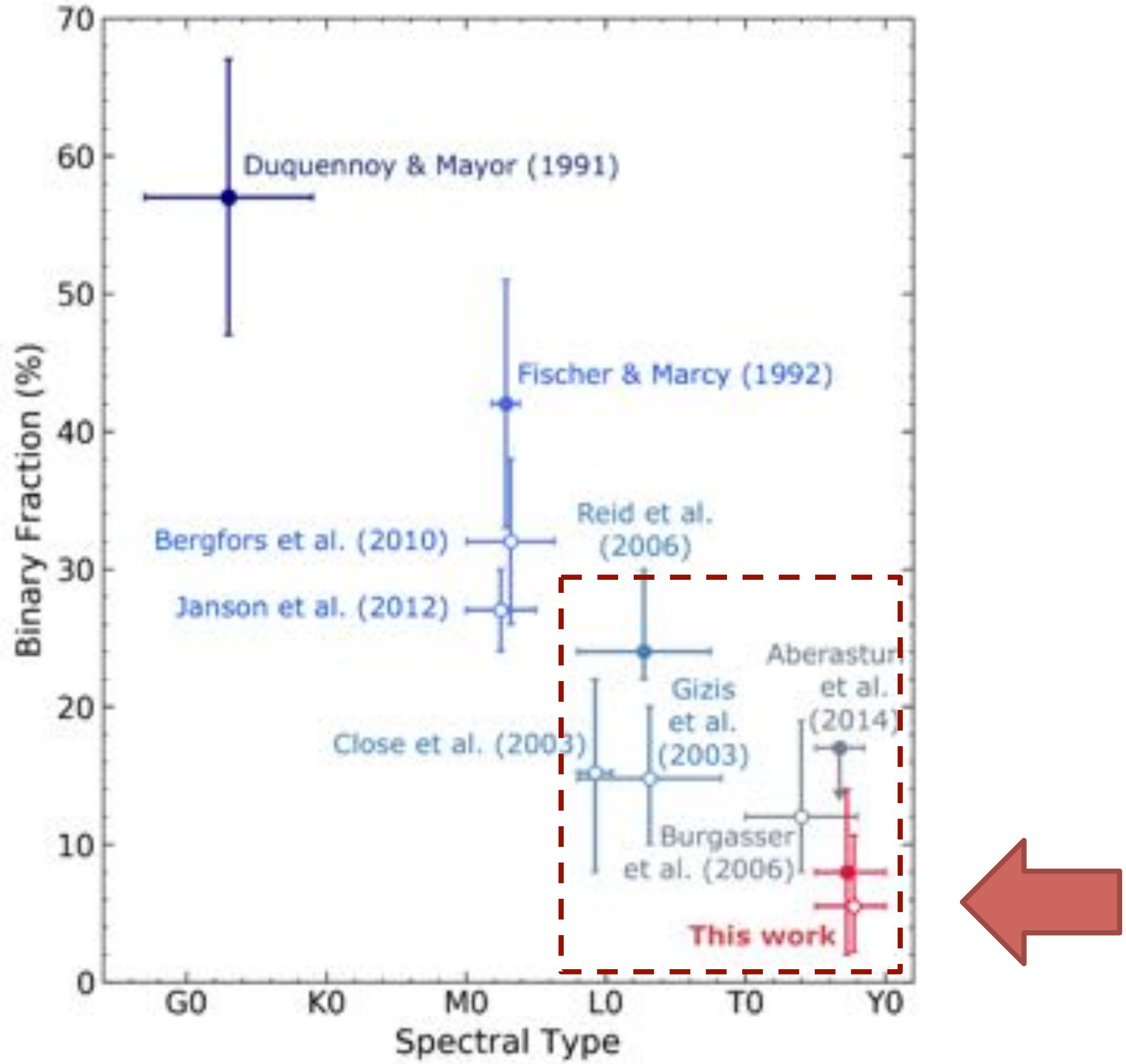
Hardegree-Ullman et al. (2019)
Tuomi et al. (2019): ≥3 planets per M dwarf

…maybe a lot of volatile-rich planets…



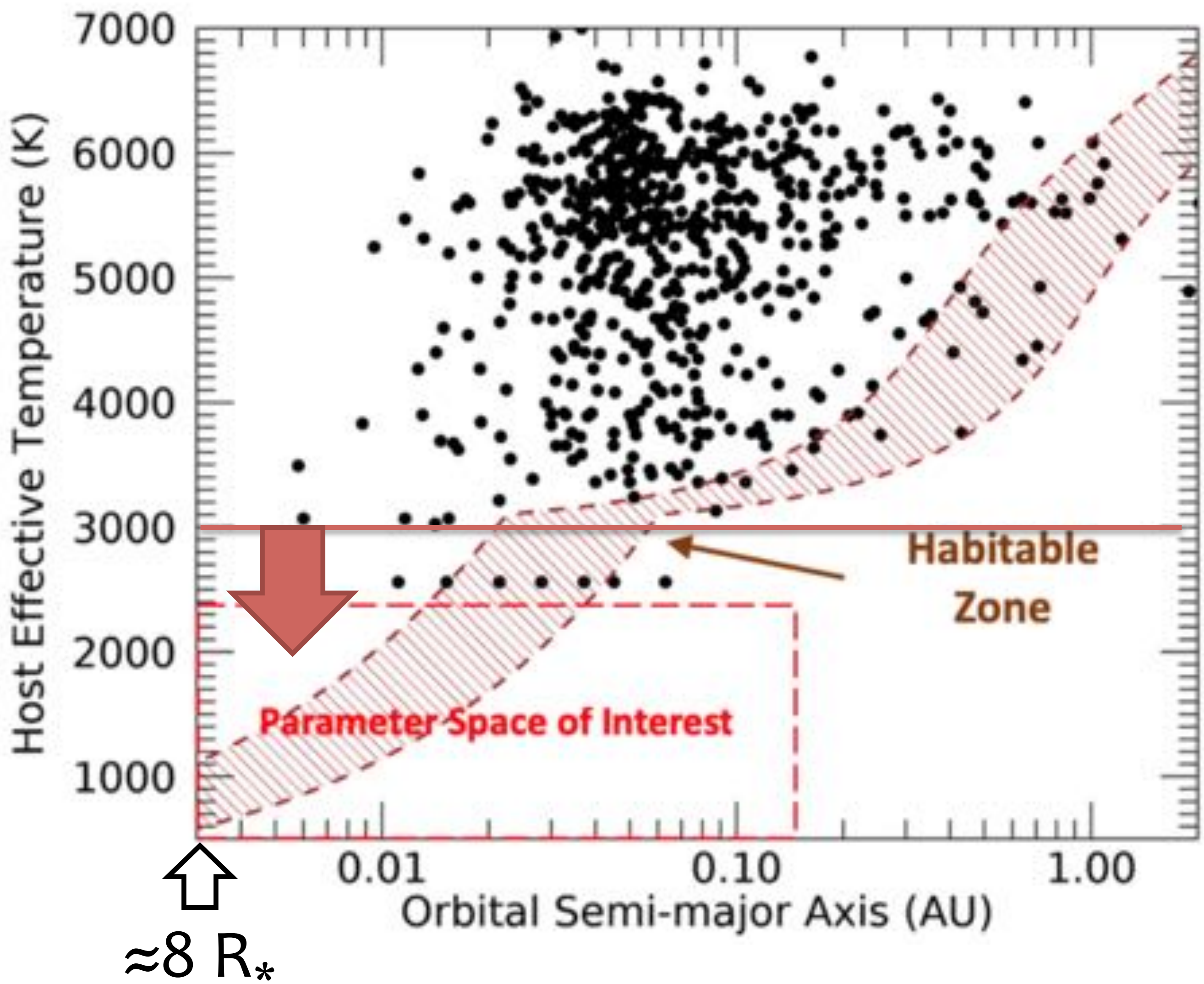
Mulders et al. (2015)

…less likely to be disturbed by binaries…



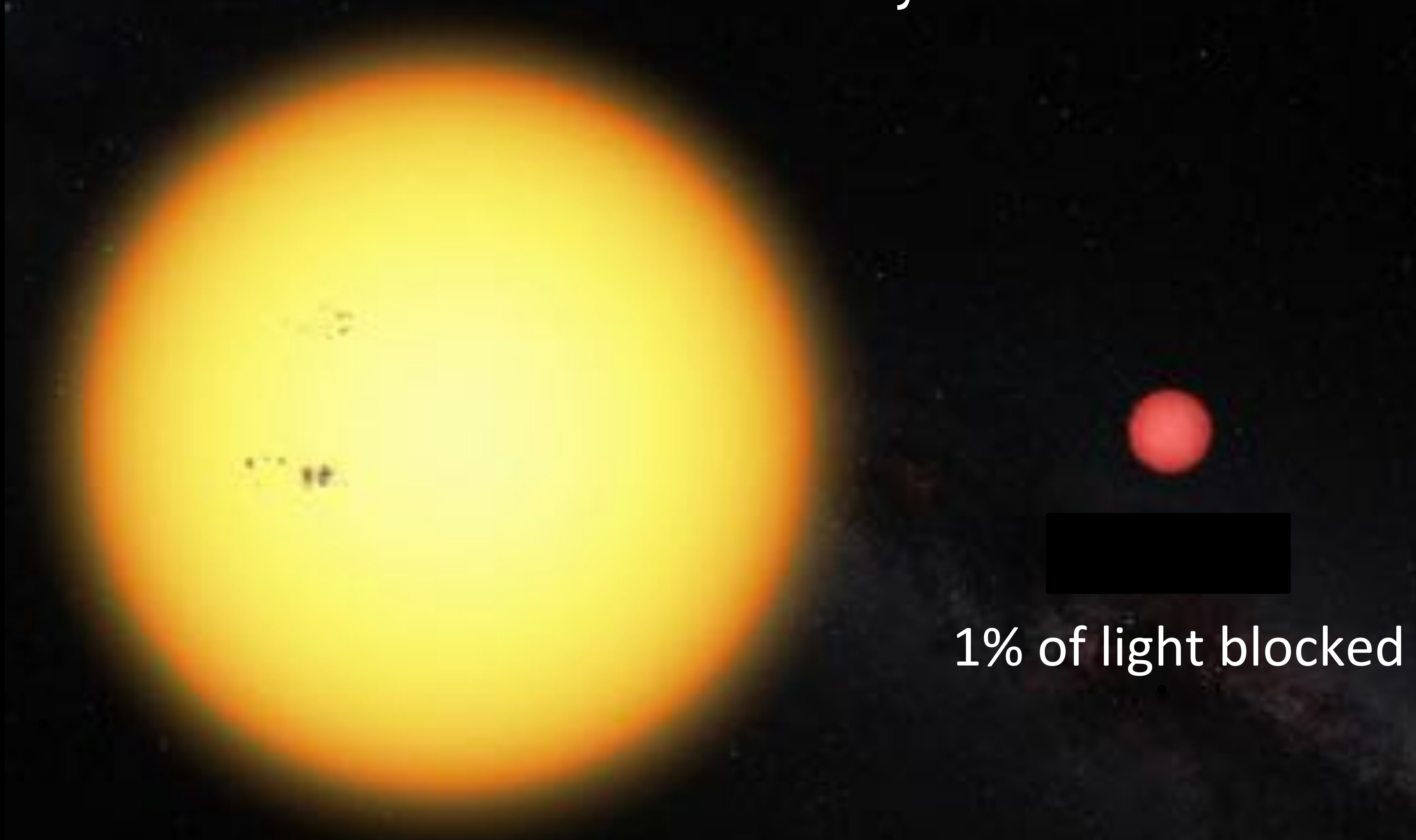
Fontanive et al. (2018)

…and their habitable zones are closer in…

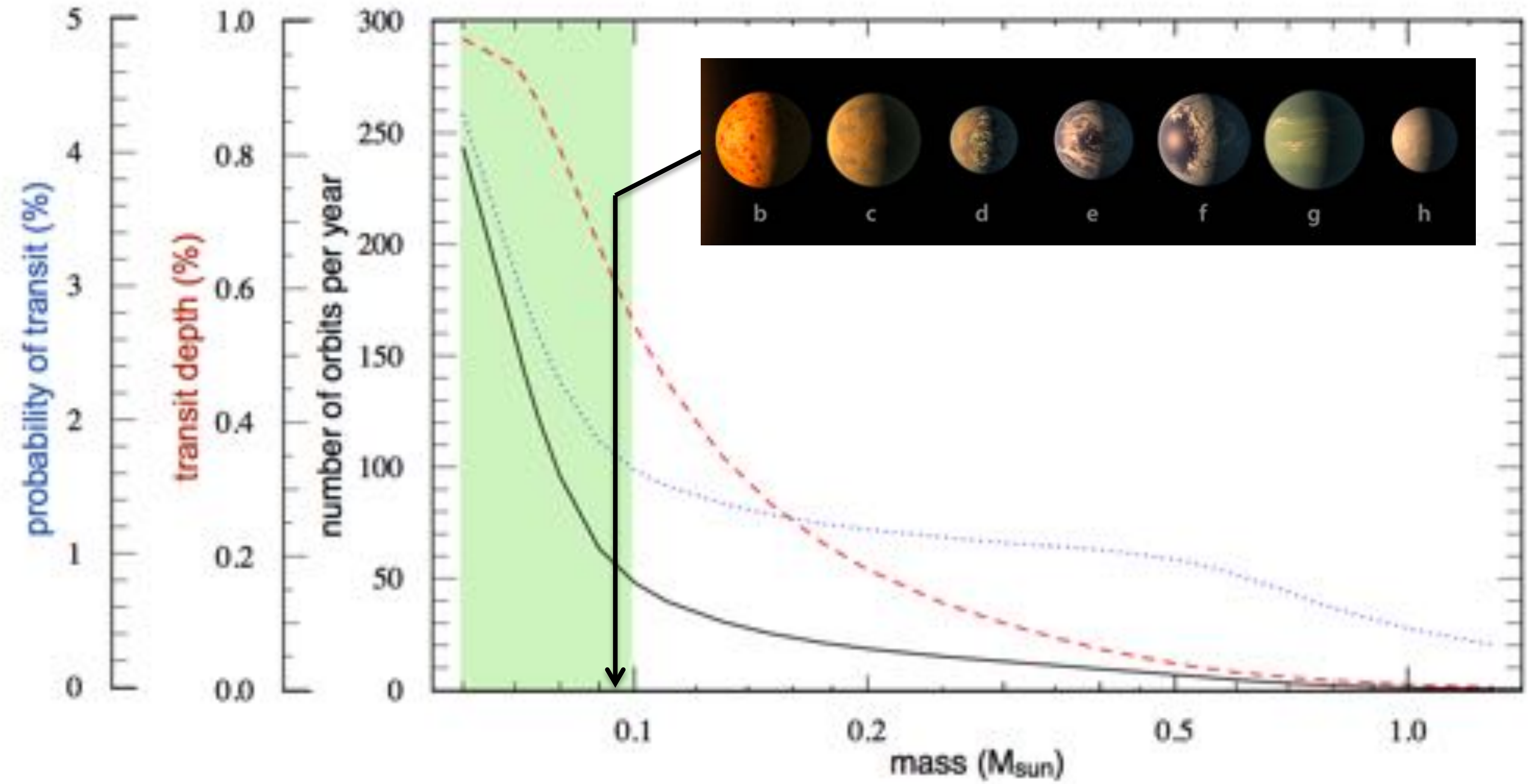


Muirhead et al. (astro2020 wp)

…making them easier to detect by
transit & radial velocity methods.



0.01% of light blocked



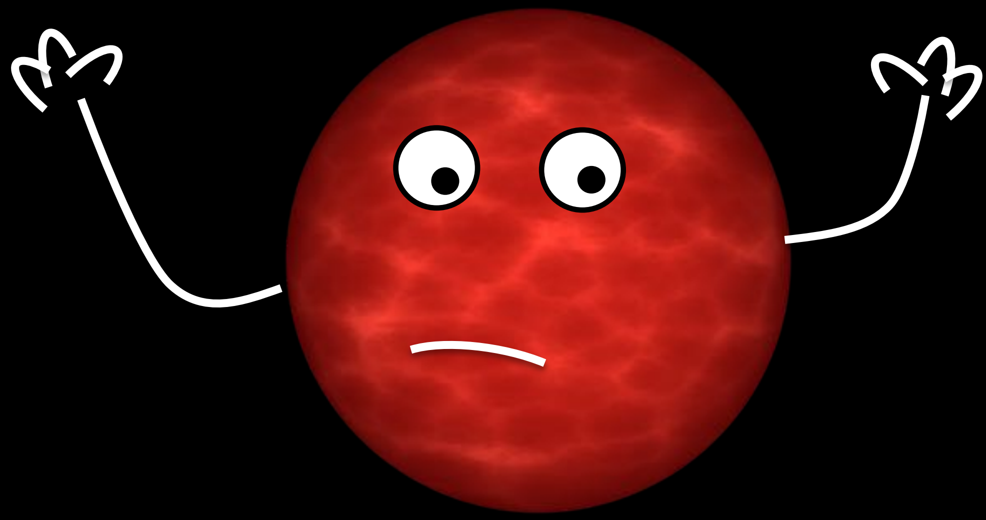
Triaud+ (2013); He+ (2017)

Aomawa Shields
(UC Irvine)

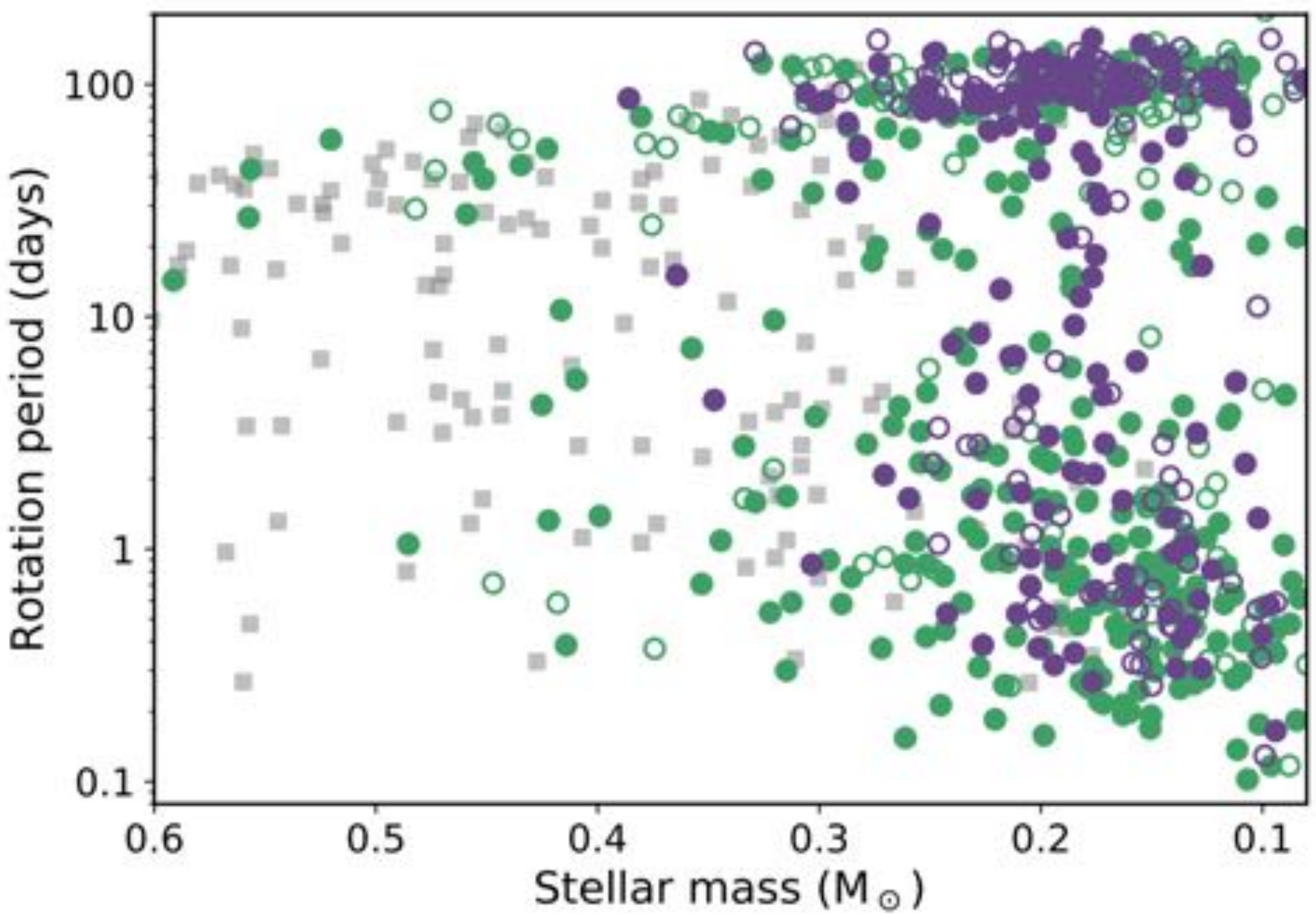
"….it has become clear that the M-dwarf stellar environment may be the primary type of environment that we look at in our search for another habitable planet like the Earth."

Shields, Ballard & Johnson (2016)

So what are the issues?

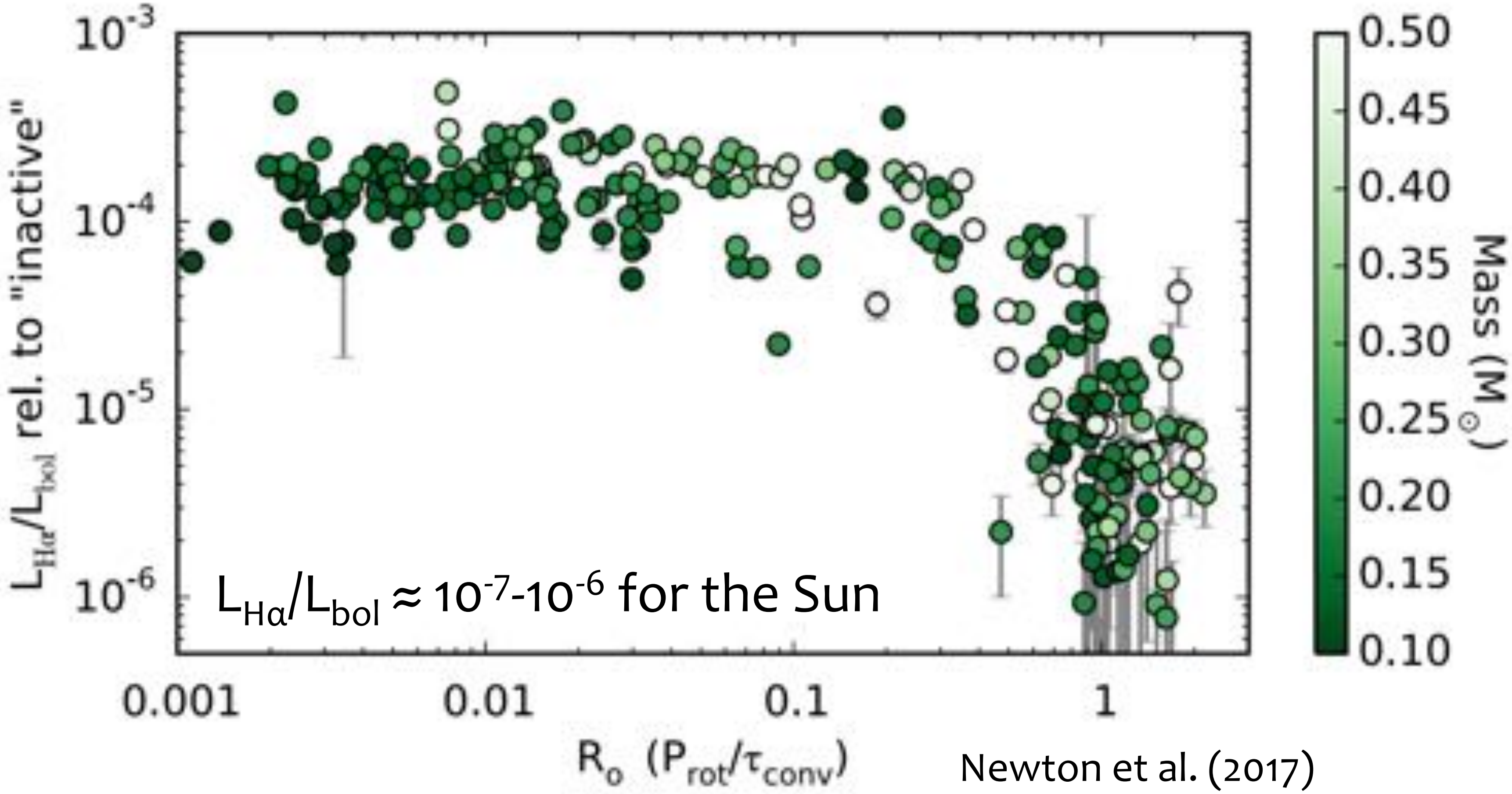


M dwarfs are “rapidly” rotating stars …



Newton et al. (2018)

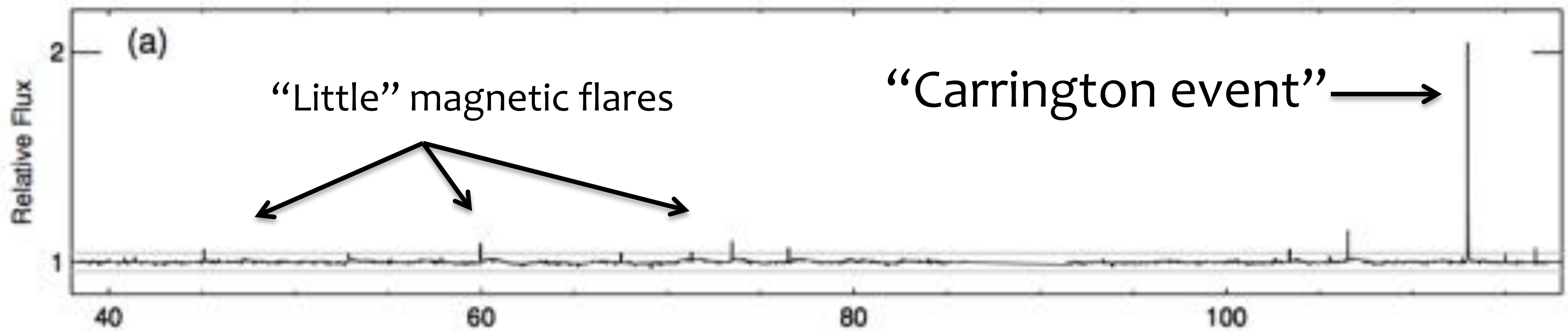
…and as a result they can be highly active.



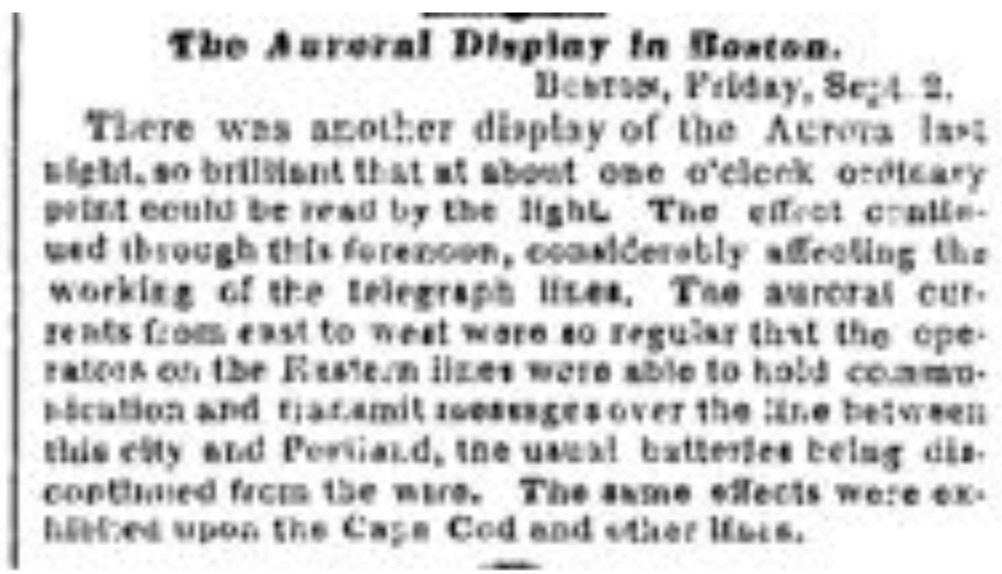
Newton et al. (2017)

NB: $\tau_{conv} \approx 100$ days for $M \approx 0.1\ M_\odot$ (Wright et al. 2011)

TRAPPIST-1



Lugar et al. (2017)



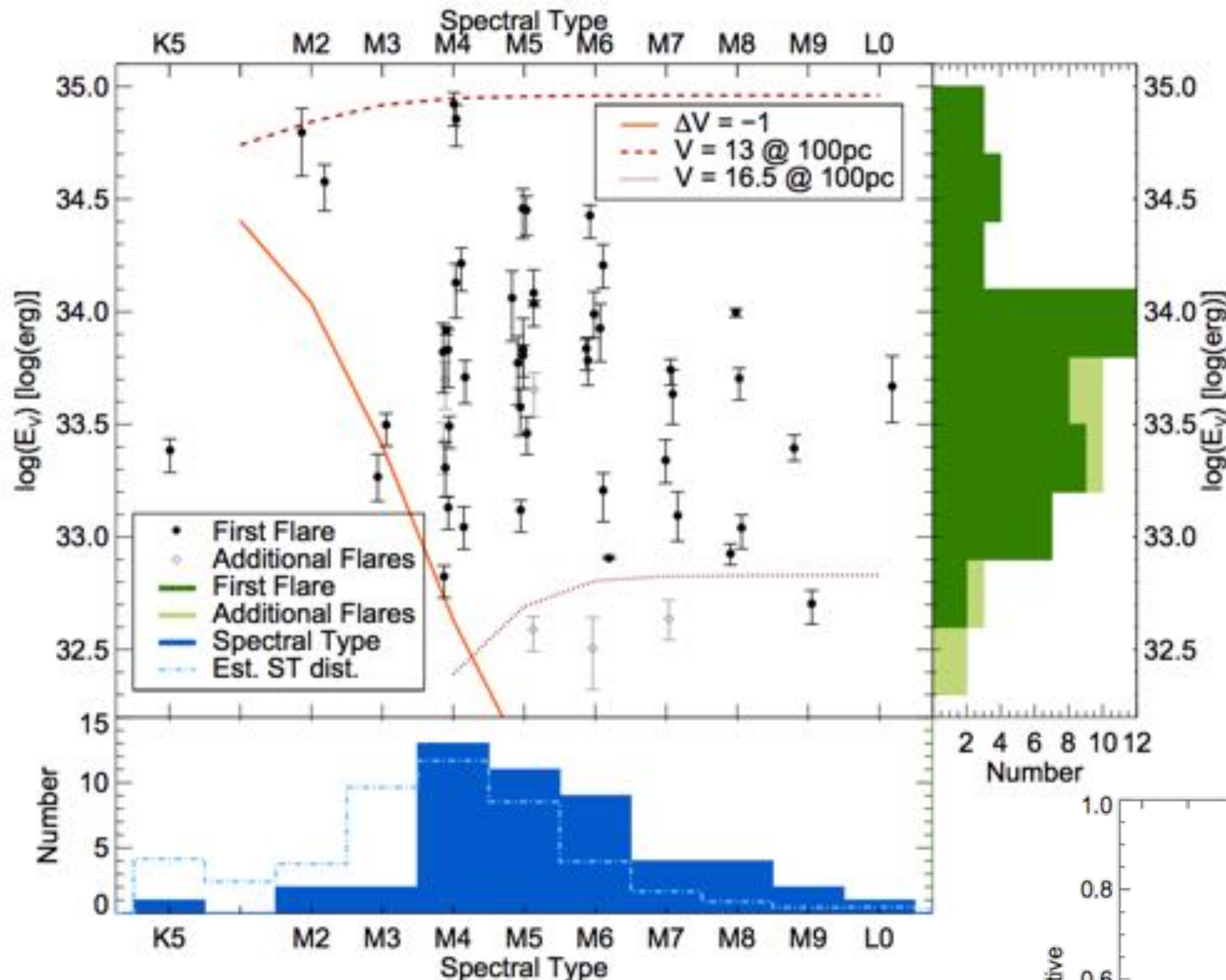
The Auroral Display in Boston.

Boston, Friday, Sept. 2.

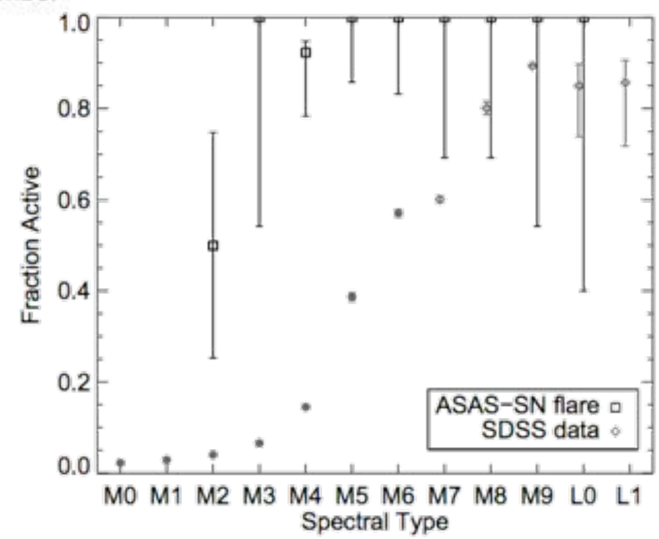
There was another display of the Aurora last night, so brilliant that at about one o'clock ordinary print could be read by the light. The effect continued through this forenoon, considerably affecting the working of the telegraph lines. The auroral currents from east to west were so regular that the operators on the Eastern lines were able to hold communication and transmit messages over the line between this city and Portland, the usual batteries being discontinued from the wire. The same effects were exhibited upon the Cape Cod and other lines.

New York Times (1859)

cf. Carrington event ≈ 10^{32} erg

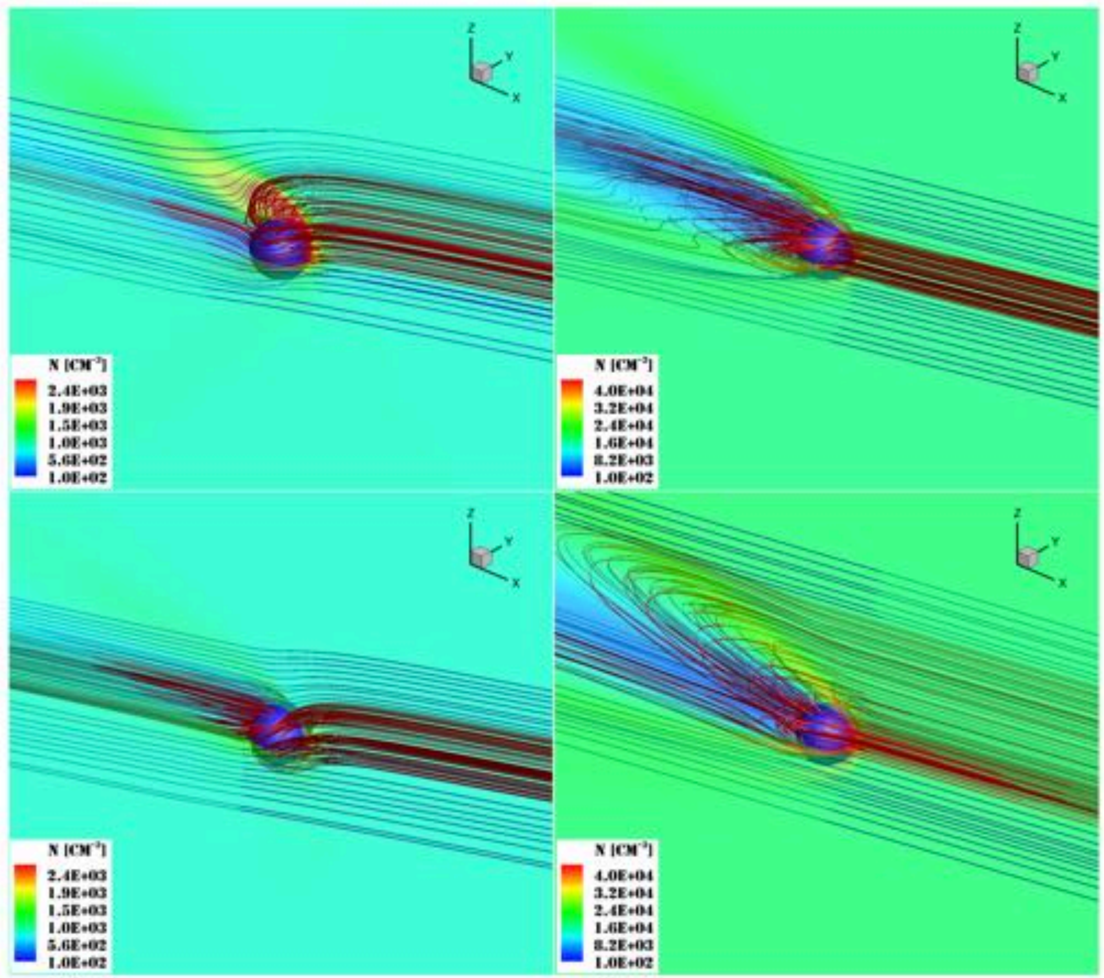


All M dwarfs flare!



Schmidt et al. (2019)
ASAS-SN M dwarf flares

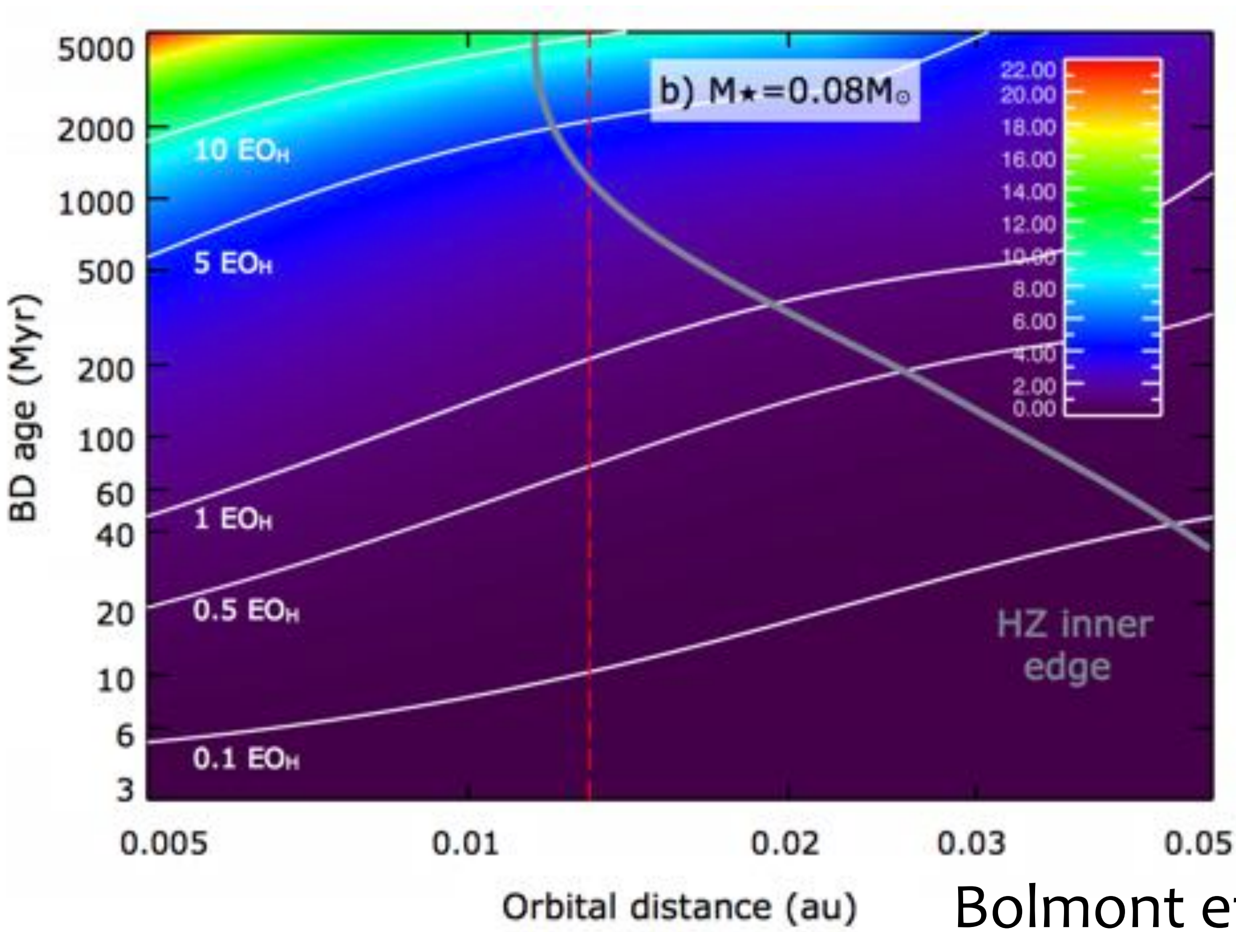
Are the planets in a "threatening" environment?



Garraffo et al. (2017)

MHD simulations predict solar winds 3-5 orders of magnitude higher than Earth, and **direct connection between stellar and planetary fields**

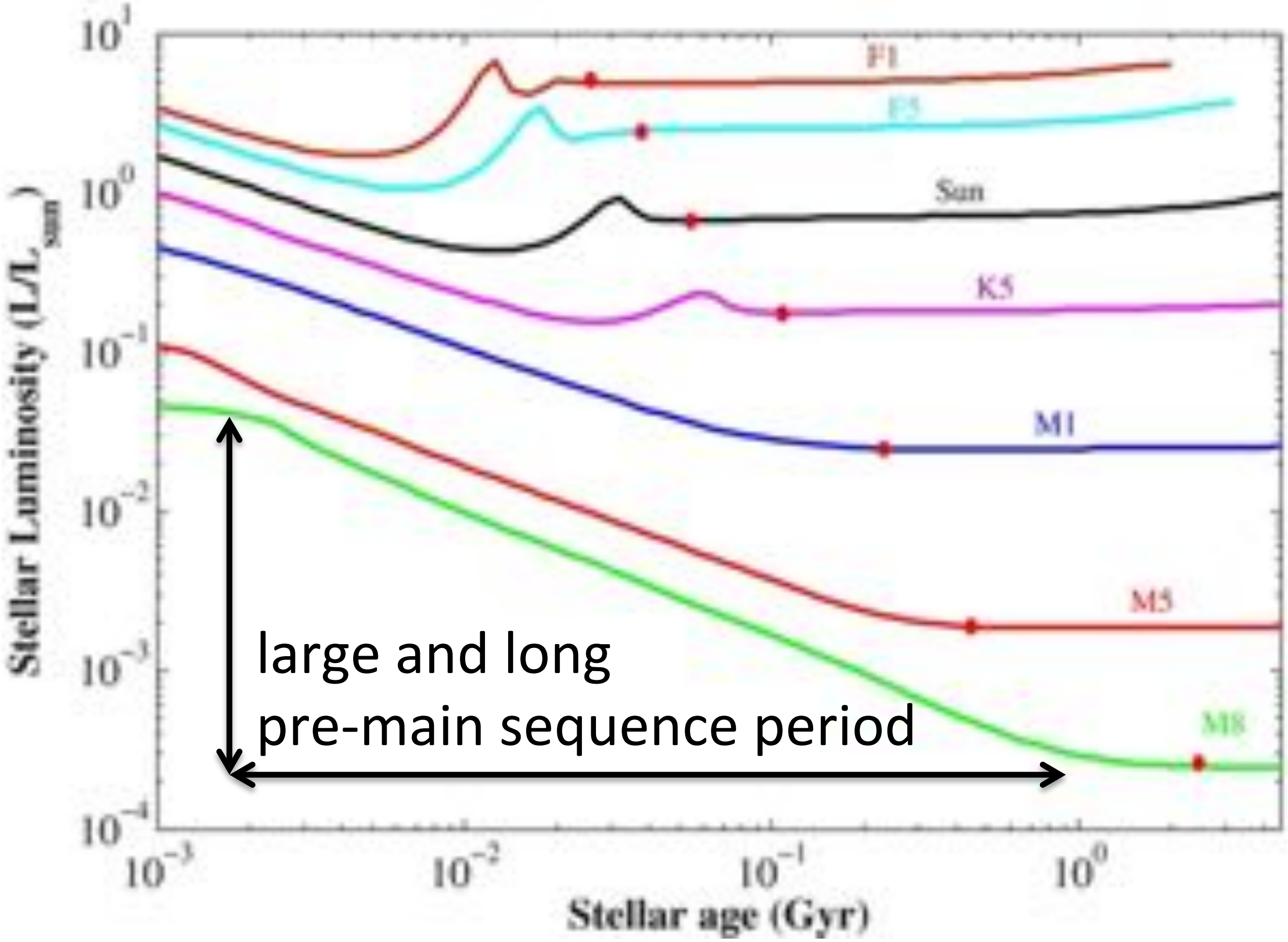
High energy radiation: Hydrogen loss



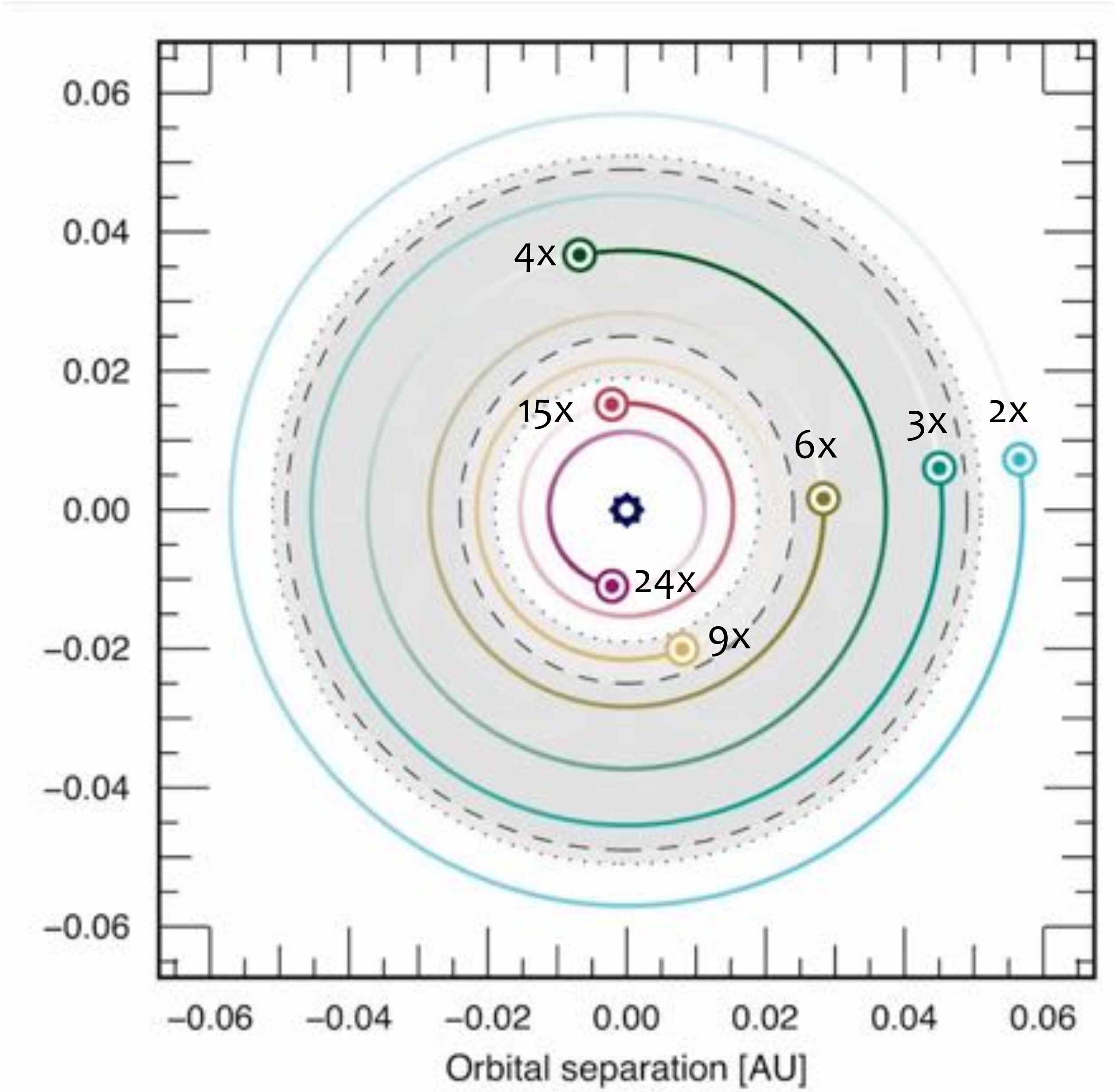
Bolmont et al. (2017)

Even "weakly active" M dwarfs have sufficient high-E radiation to evaporate tens of Earth oceans of H over its lifetime

Volatile loss may also be an issue during early evolution

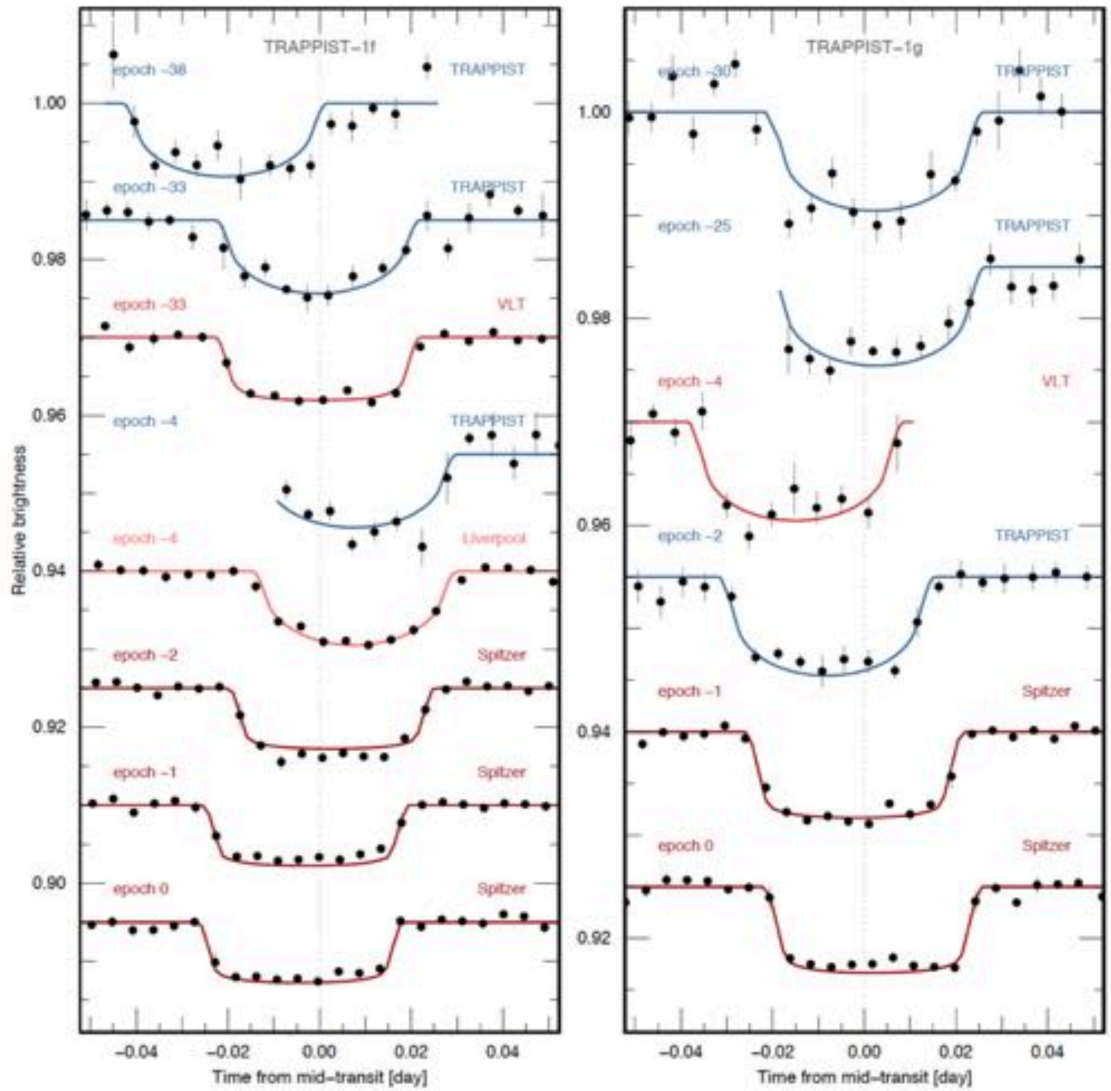


Ramirez & Kaltenegger (2014)



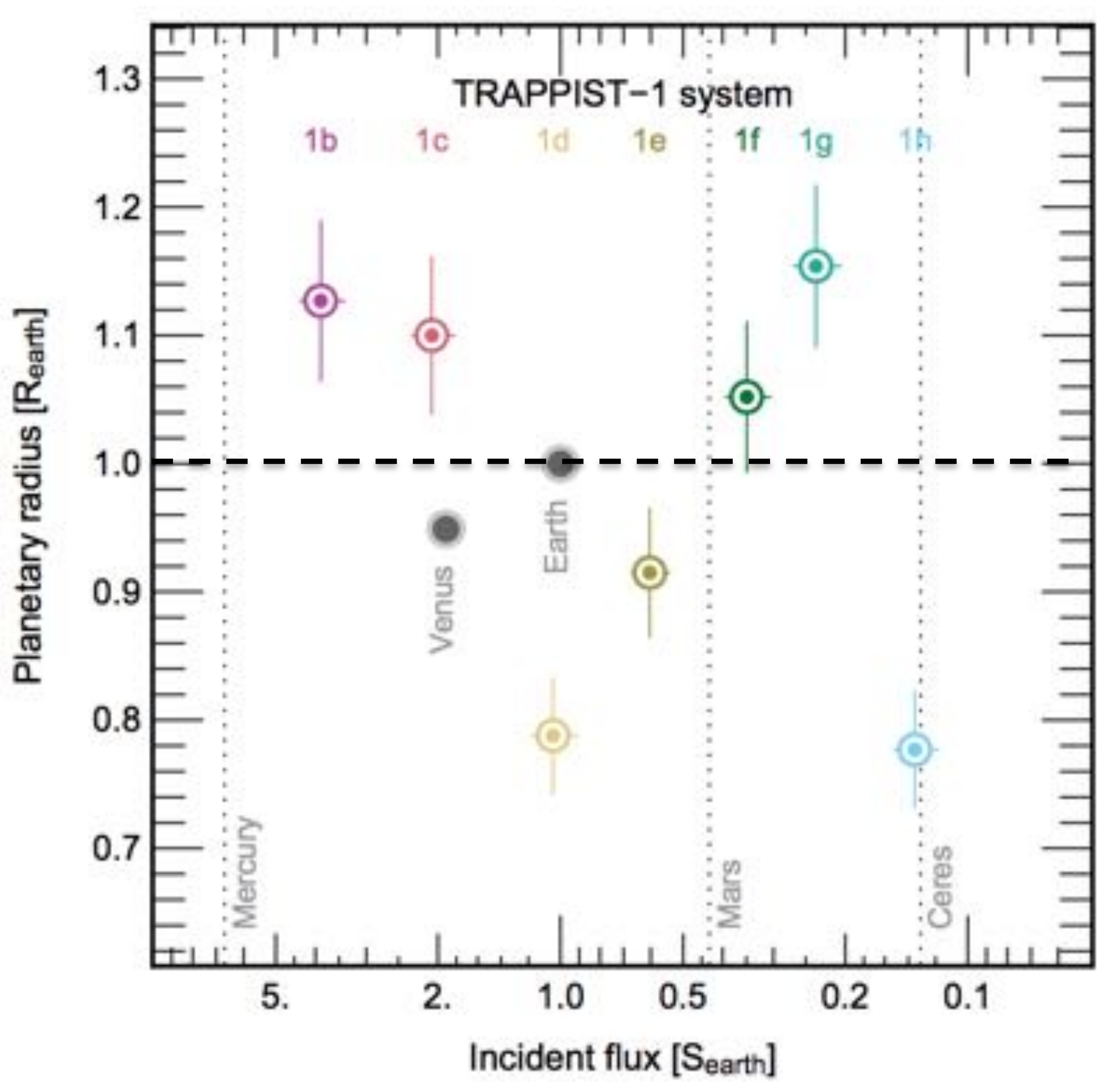
Gillon et al. (2017); Tamayo et al. (2017)

TRAPPIST-1 Transit Timing Variations (TTVs)



Gillon et al. (2017)

TRAPPIST-1 TTVs indicate low-densities for d, e & h



Delrez et al. (2018)

Nevertheless plenty of water?

Grimm et al. (2018)

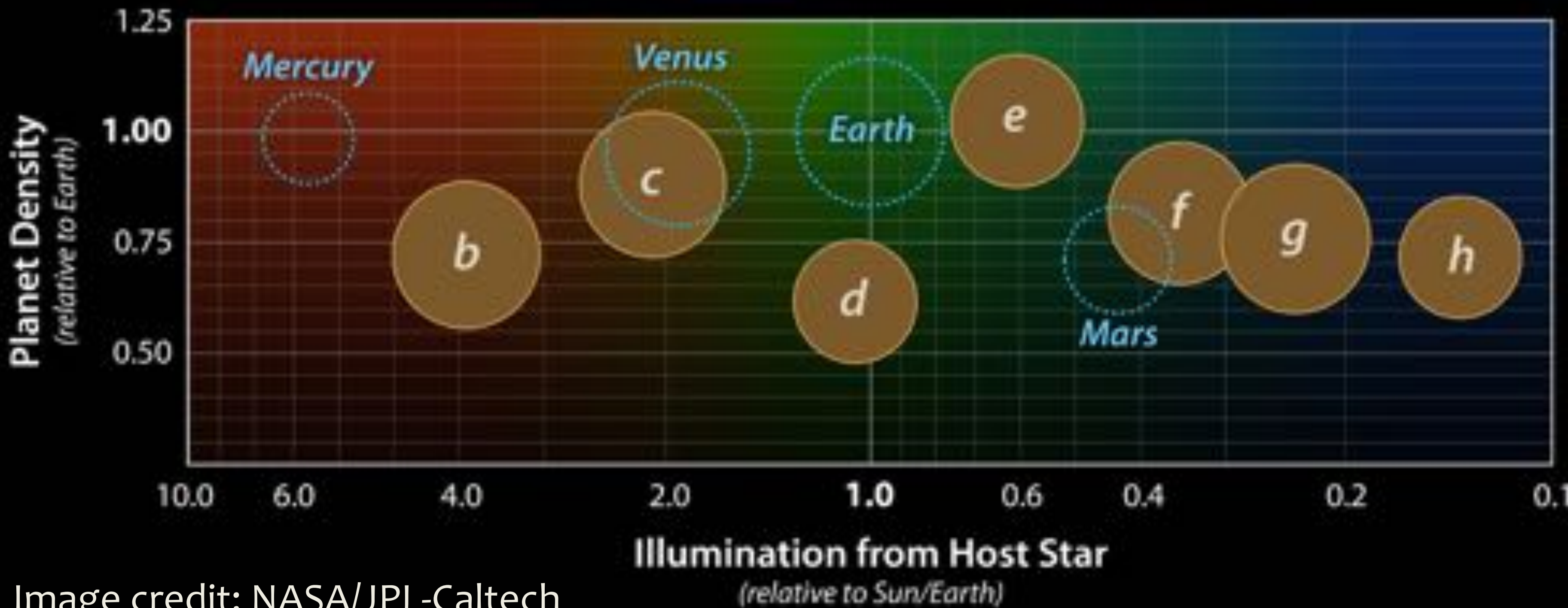
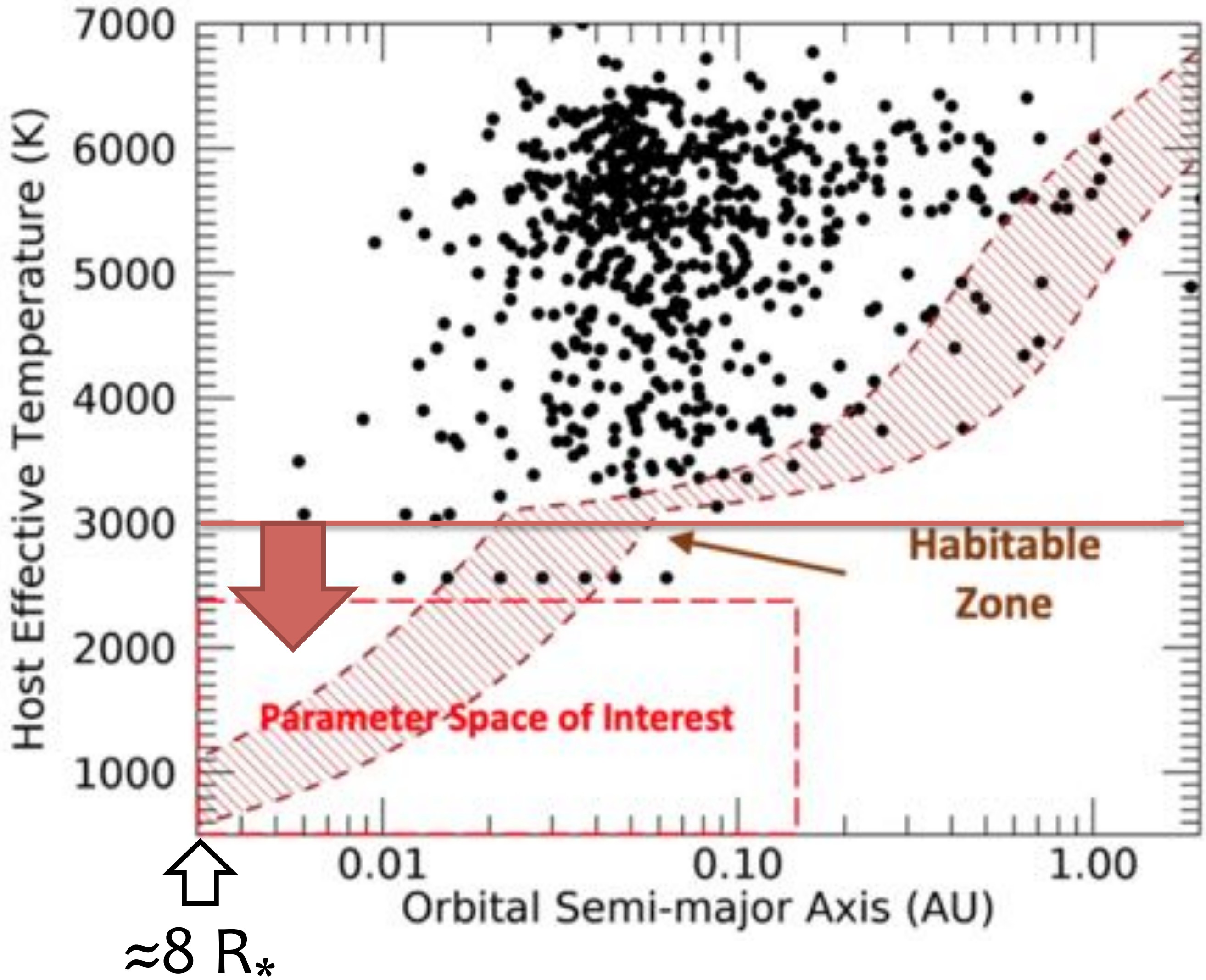


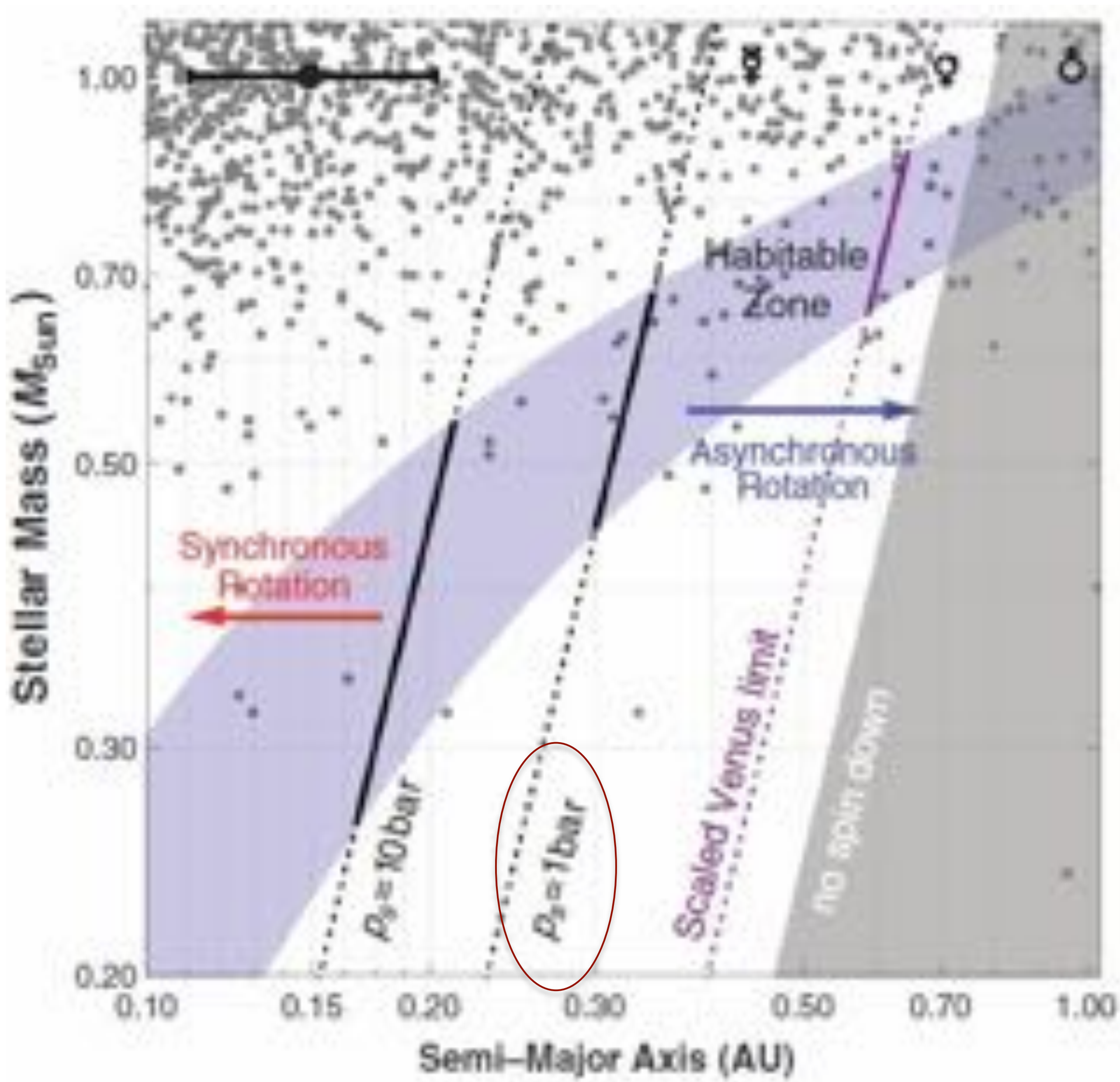
Image credit: NASA/JPL-Caltech

TRAPPIST-1d may have up to ≈100x more water than Earth

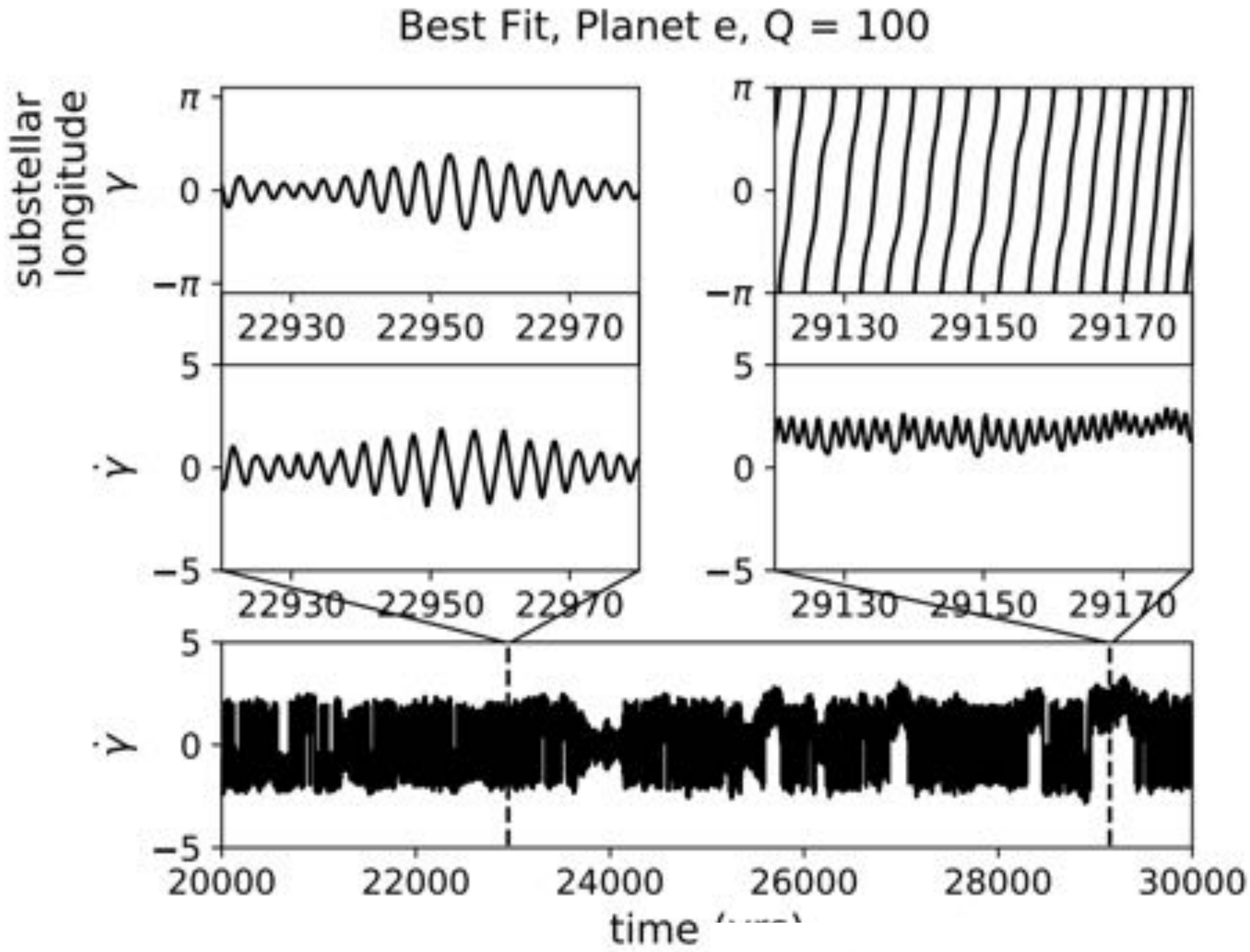
Are the habitable zones TOO close?



Muirhead et al. (astro2020 wp)



Leconte et al. (2015)

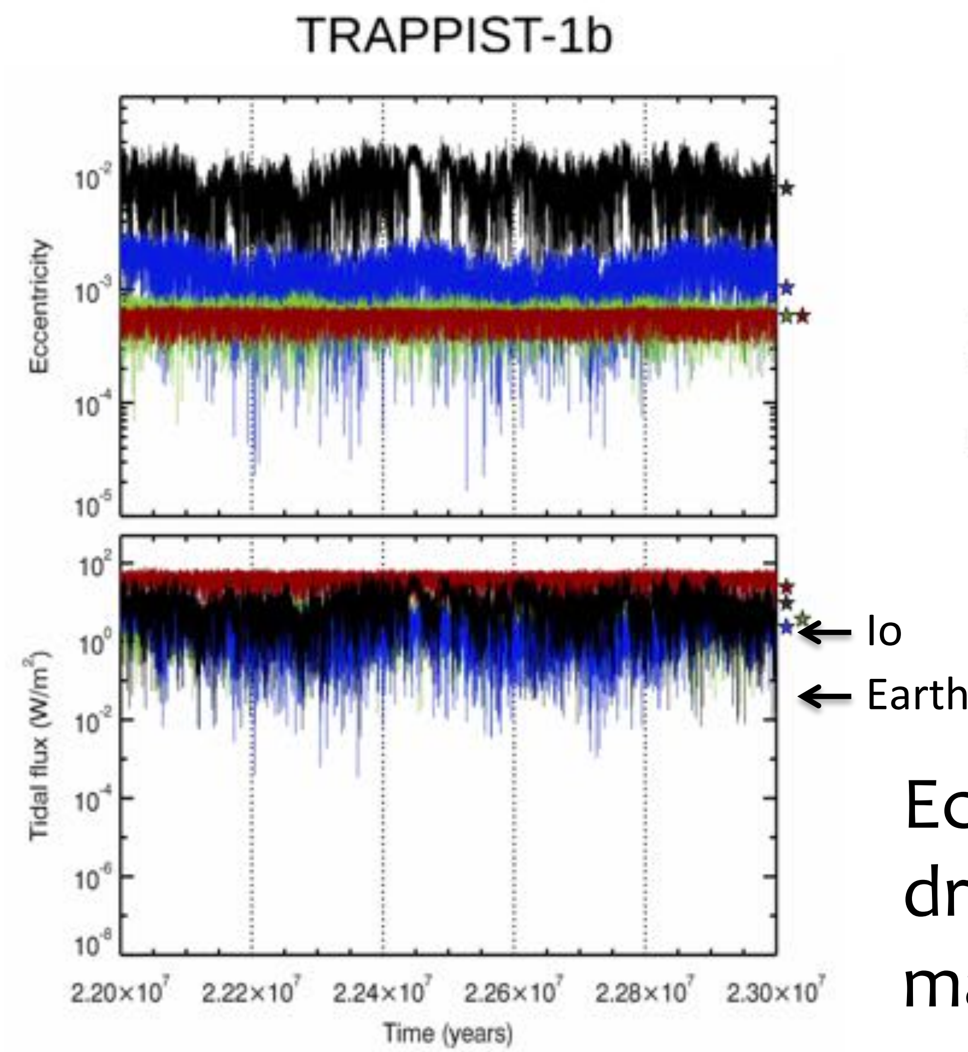


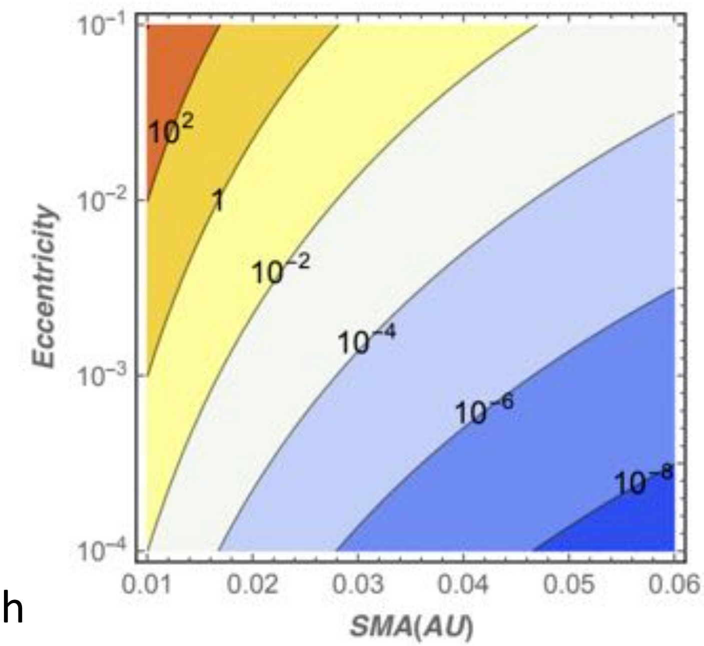
Vinson & Hansen (2017)
Vinson, Tamayo & Hansen (2019)

$$\ddot{\gamma} + \frac{1}{2}\omega_S^2 \sin 2\gamma + \dot{n} + \epsilon\dot{\gamma} = 0$$

Damped driven oscillator

Orbital Interaction & Tidal heating



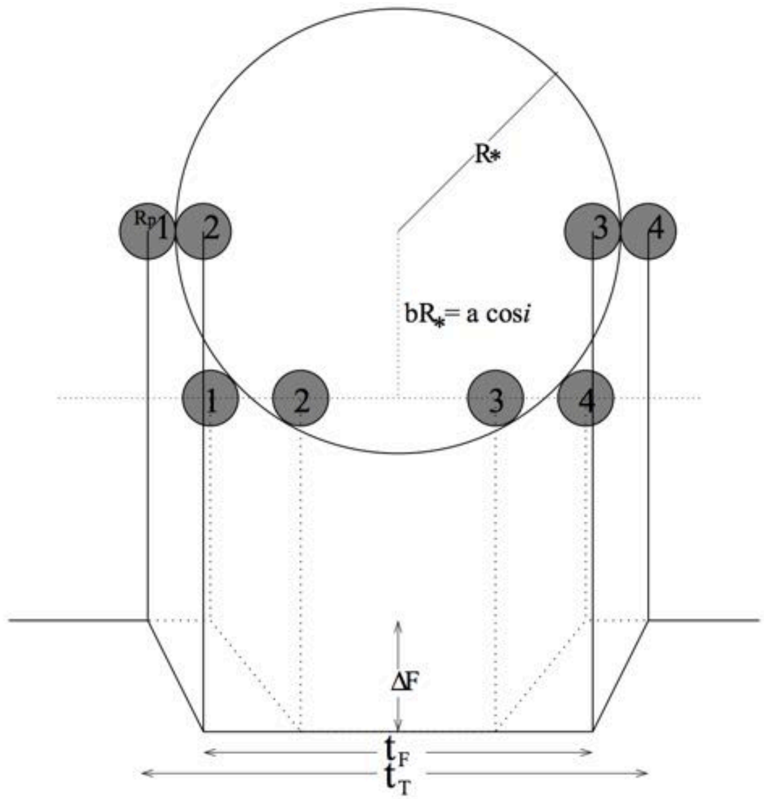


Eccentricity perturbations drive tidal dissipation that may be main heating source in T-1bcd

Turbet et al. (2017)

Opportunities of ultracool dwarf science

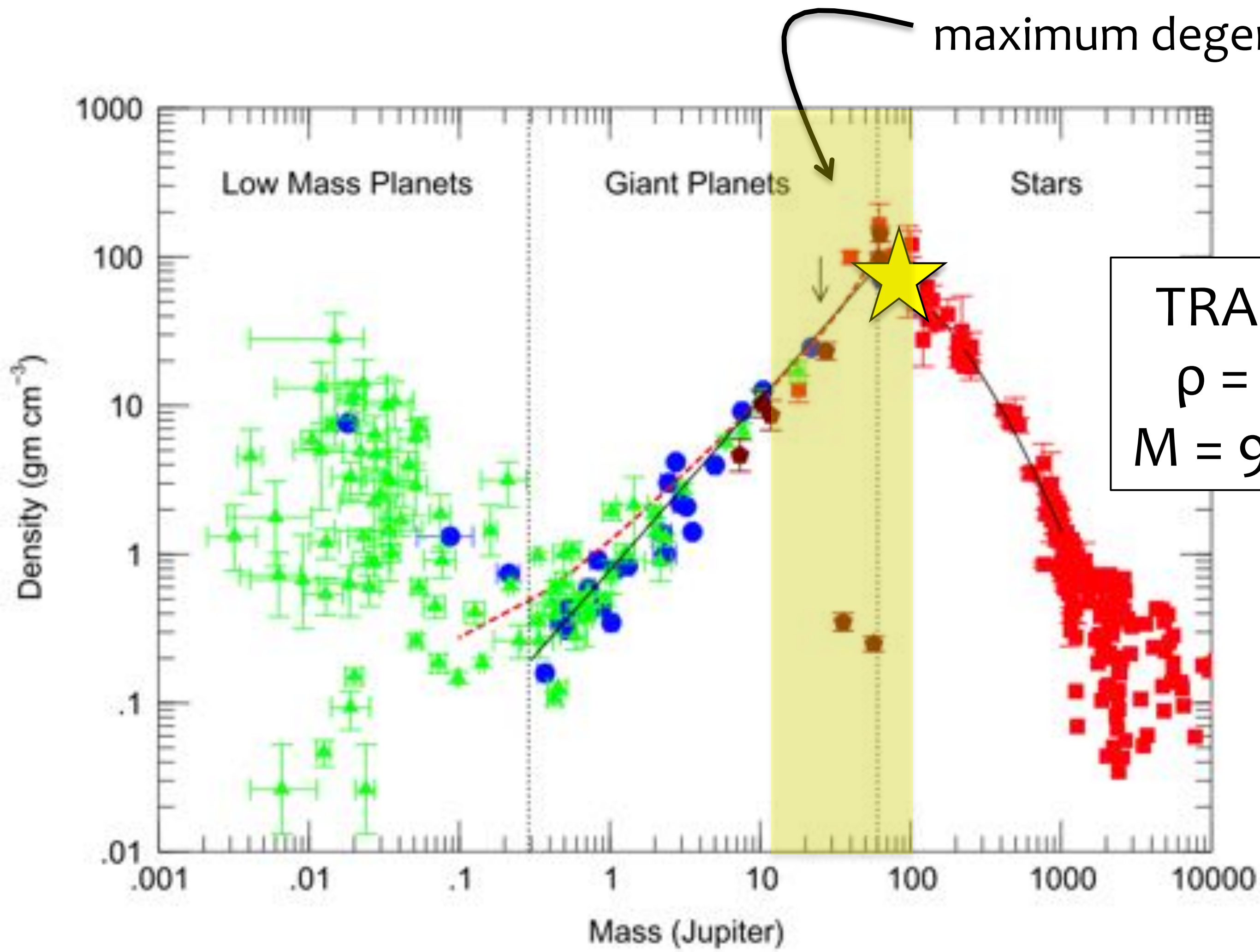
Stellar density measurements from transits



$$\rho_* \equiv \frac{M_*}{R_*^3} = \left(\frac{4\pi^2}{P^2 G}\right) \left\{ \frac{\left(1+\sqrt{\Delta F}\right)^2 - b^2\left[1-\sin^2(t_T\pi/P)\right]}{\sin^2(t_T\pi/P)} \right\}^{3/2}$$

Seager & Mallen-Ornelas (2003)

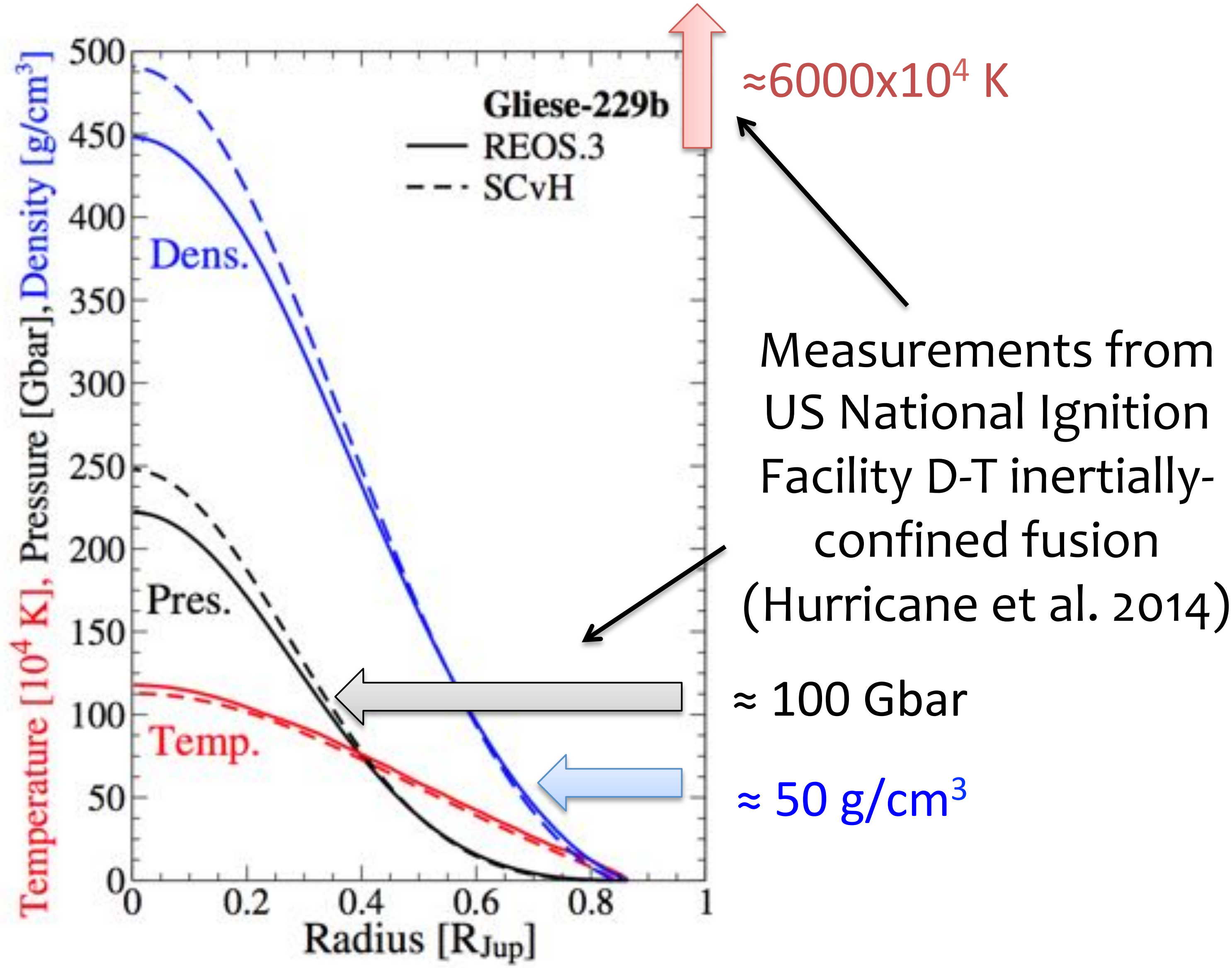
Exoplanet systems probe interiors…



TRAPPIST-1:
$\rho = 51.1\ \rho_\odot$
$M = 93 \pm 6\ M_{jup}$

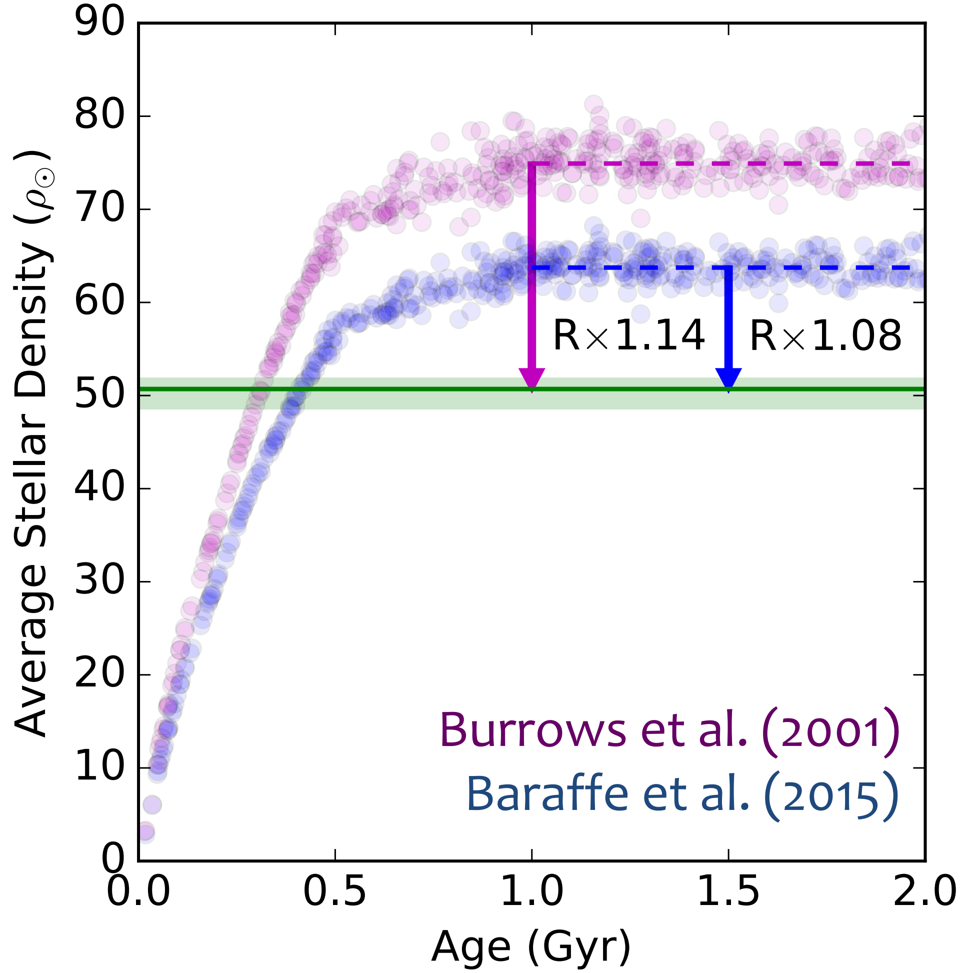
Hatzes & Rauer (2015)

Delrez et al. (2018); van Grootel et al. (2018); Fernandes et al. (2019)



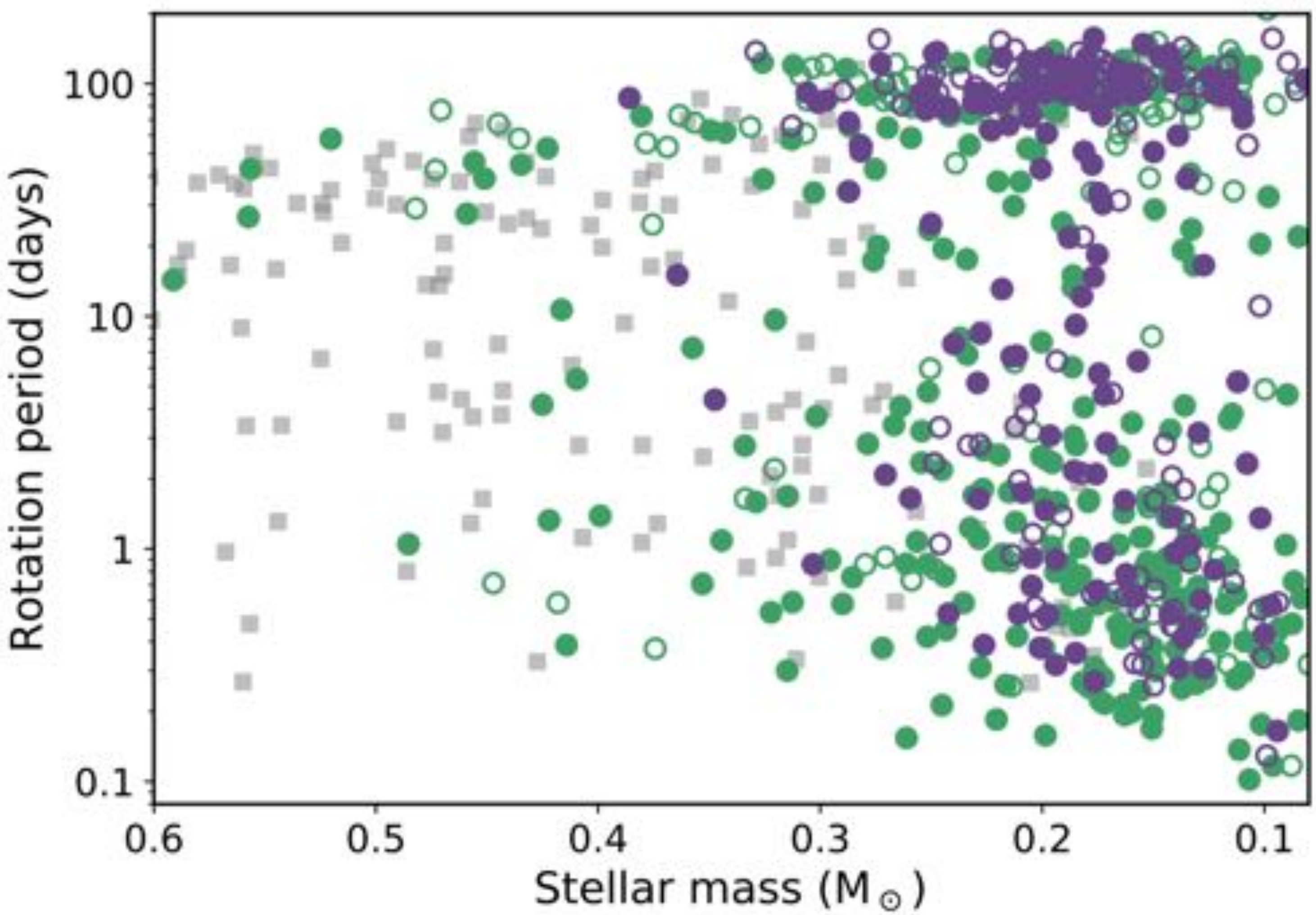
Becker et al. (2014)
EOS ab initio calculations

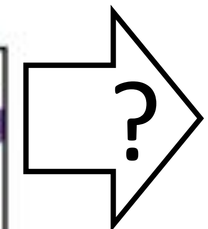
What other parameters influence structure?



Burgasser & Mamajek (2017)

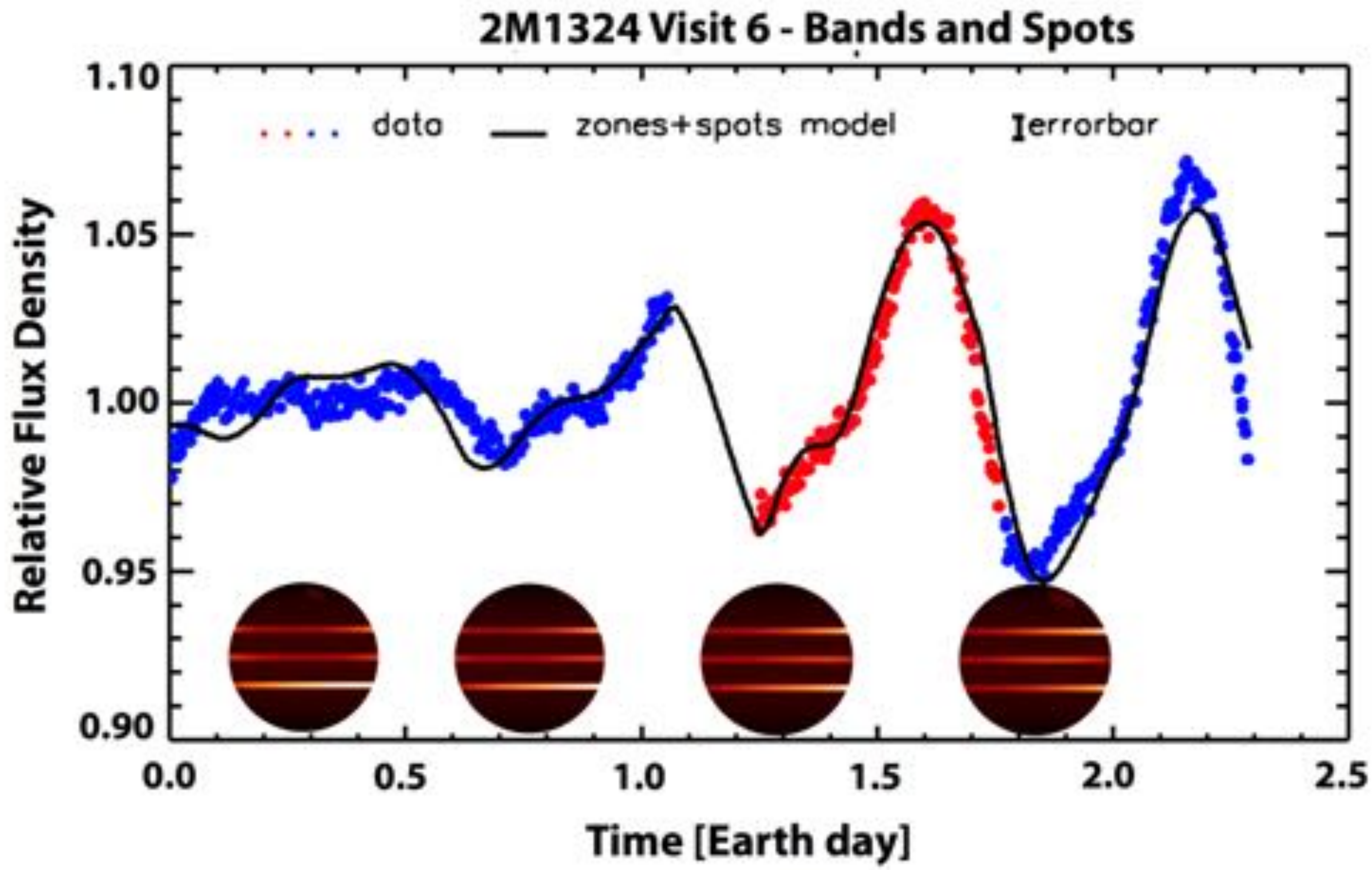
Variability measurements probe angular momentum evolution…

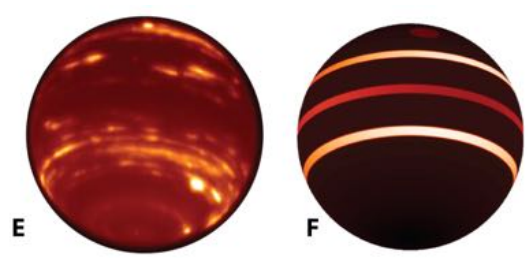




Newton et al. (2018)

…and weather

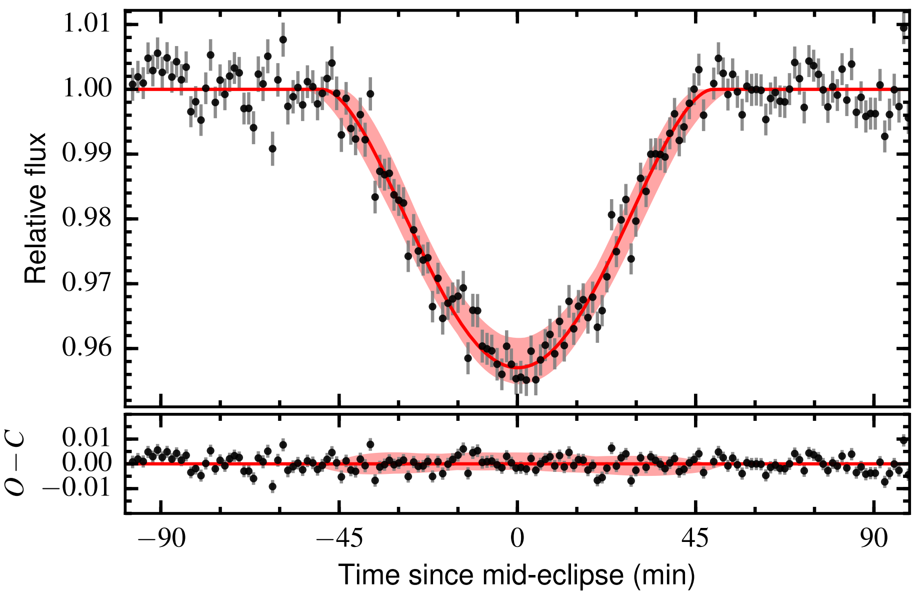


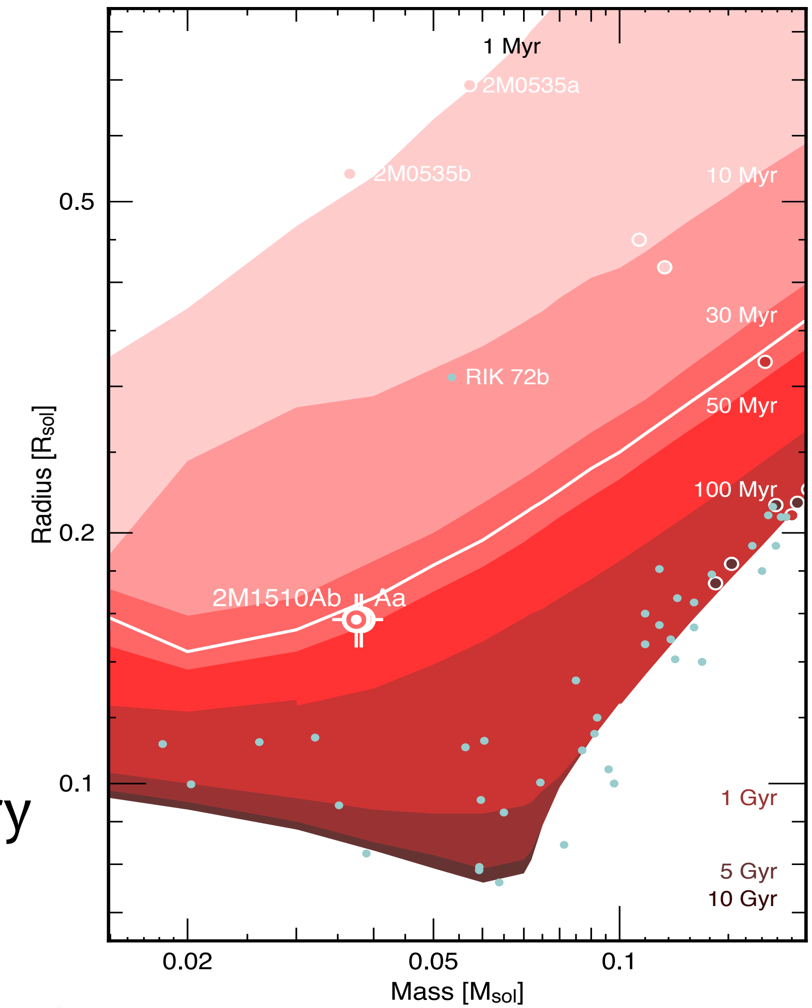


Neptune at 1.6 μm Best-fitting model for 2M1324 Visit 6

Apai et al. (2017)

Non-planet transits are also exciting!





Triaud et al. (submitted)

≈ 40 Myr old, 36 M_{Jup}+29 M_{Jup} binary

21-day elliptical orbit

Summary

- Ultracool dwarfs are important targets for exoplanet searches, but require effort to detect and care in interpretation (and still worth it!)
- Two key issues:
  - Activity: may deplete oceans/atmospheres, but perhaps plenty of reserves?
  - Tidal locking: may not be an issue in multi-planet systems
  - Tidal heating: could drive runaway greenhouse for inner planets
- There are many ancillary science opportunities in interior physics, age/activity/rotation, weather, etc.