

Other Planetary Systems

and why is ours so weird?

Lecture 5 of Planets Everywhere

Learners at Wind Crest

Feb 2020

- outline
- census of planetary systems
- visiting a few interesting ones... TOI-700, TRAPPIST-1, planets in binary systems, Proxima b, super-earths and sub-neptunes
- statistics and scatterplots
- how planets form: ALMA looks at proto-planetary disks
- direct imaging, notably beta Pic: actual pictures of real planets out there.
- Prospects for atmosphere characterization... e.g. the James Webb Space Telescope and the TRAPPIST-1 collaboration
-

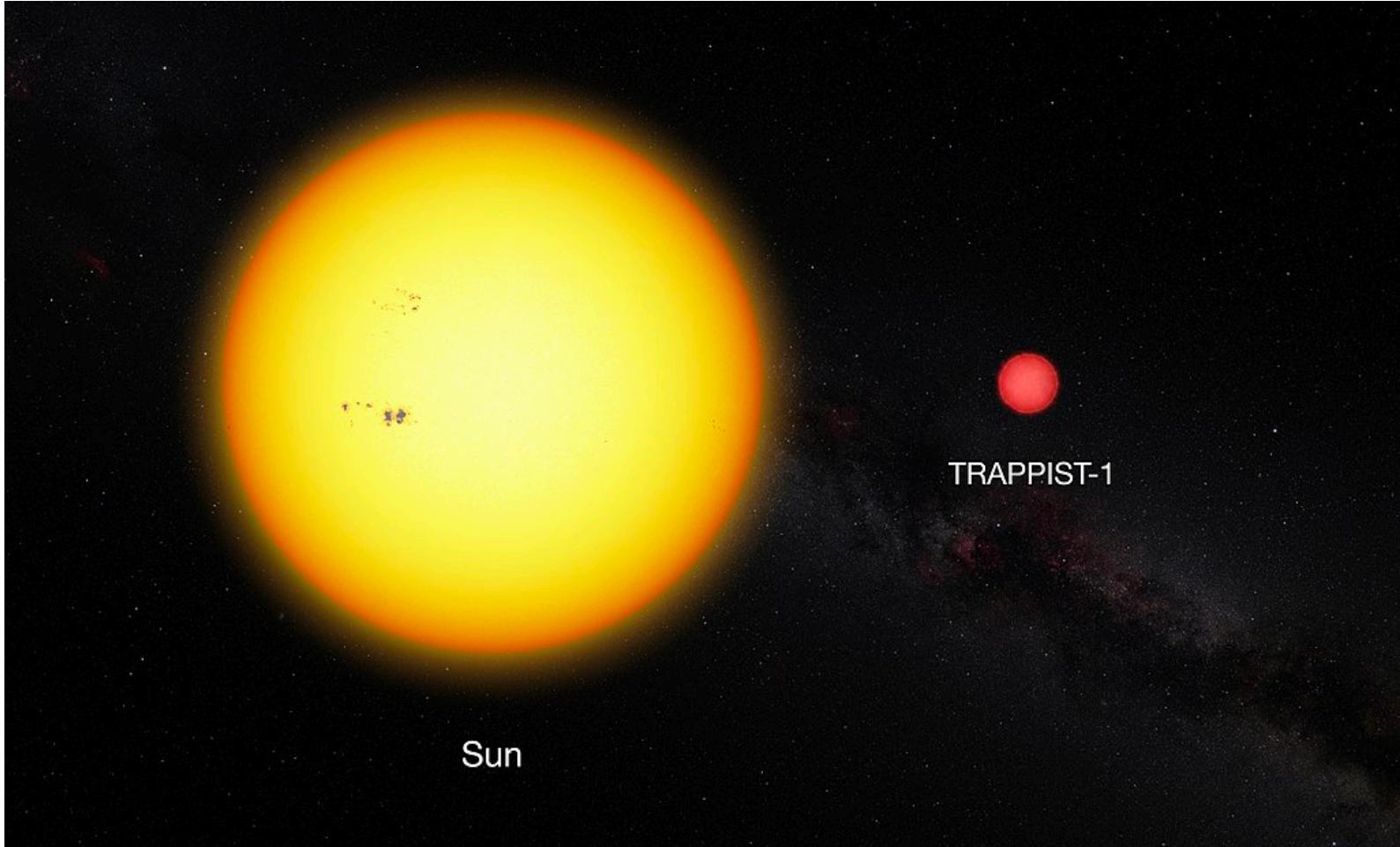
A few interesting planetary systems

- It's hard to wrap our heads around a population of 4000+ planets circling other stars.
- Let's look at a few interesting cases
- and then some statistical scatter-diagrams, to learn about the overall populations
- How weird is our solar system? Is that important to us being here (and asking this question)?
- Always keep in mind that we've missed 90-99% of the planets that are out there, because of limitations and biases in our methods.

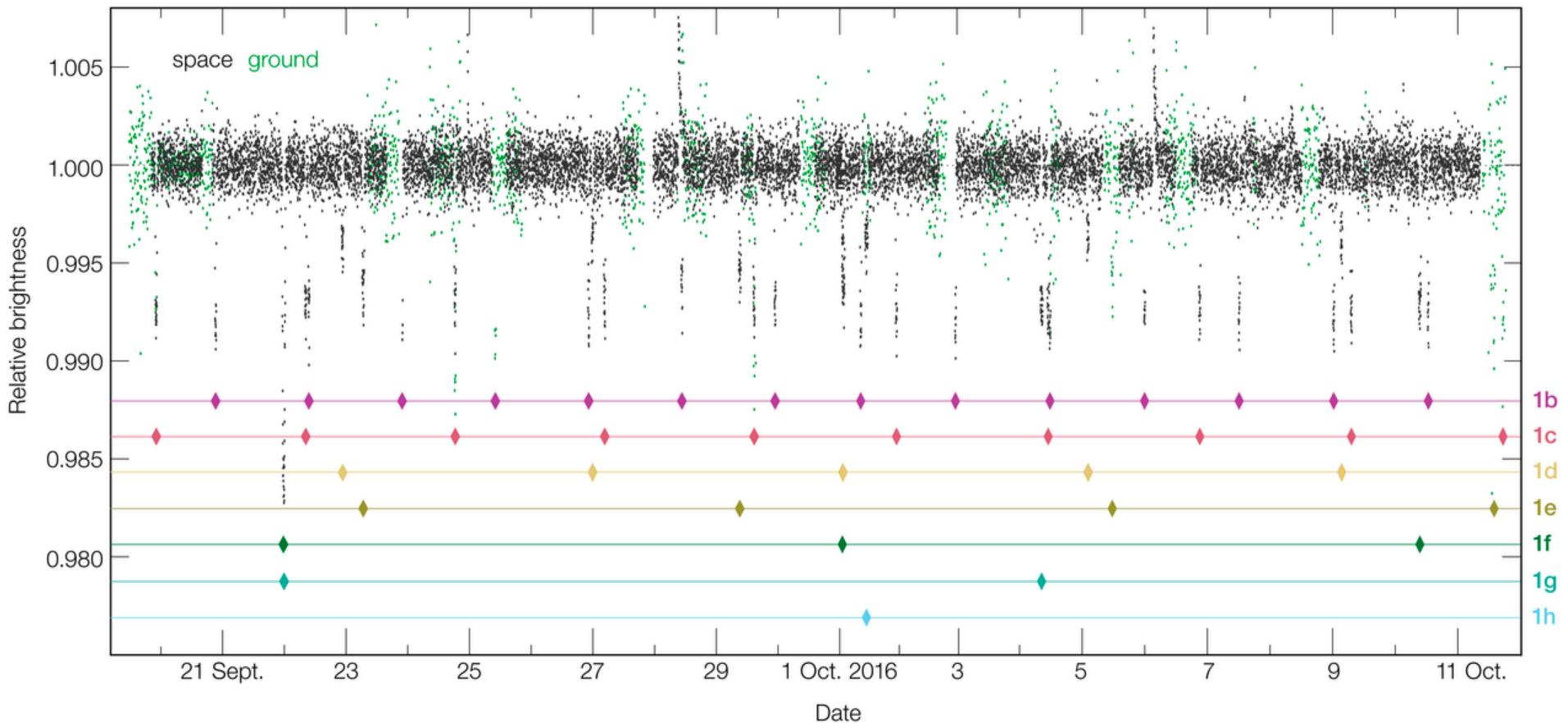
TRAPPIST-1 and its planets

- Michaël Guillon & friends at Liege, Belgium put together a search for transiting planets called TRAPPIST (Transiting Planets and Planetesimals Small Telescope. It's a 1-m telescope at La Silla in Chile, and a second one in Morocco.
- They found 3 planets around the star 2MASS J23062928-0502285, also known as TRAPPIST-1, in 2015. Followup observations found 4 more.
- The star is very small; 39 light years from us in the constellation Aquarius; $0.089 M_{\text{sun}}$, $0.121 R_{\text{sun}}$, temp 2500 K. It's very red and faint, luminosity 5.7×10^{-4} of our sun's.

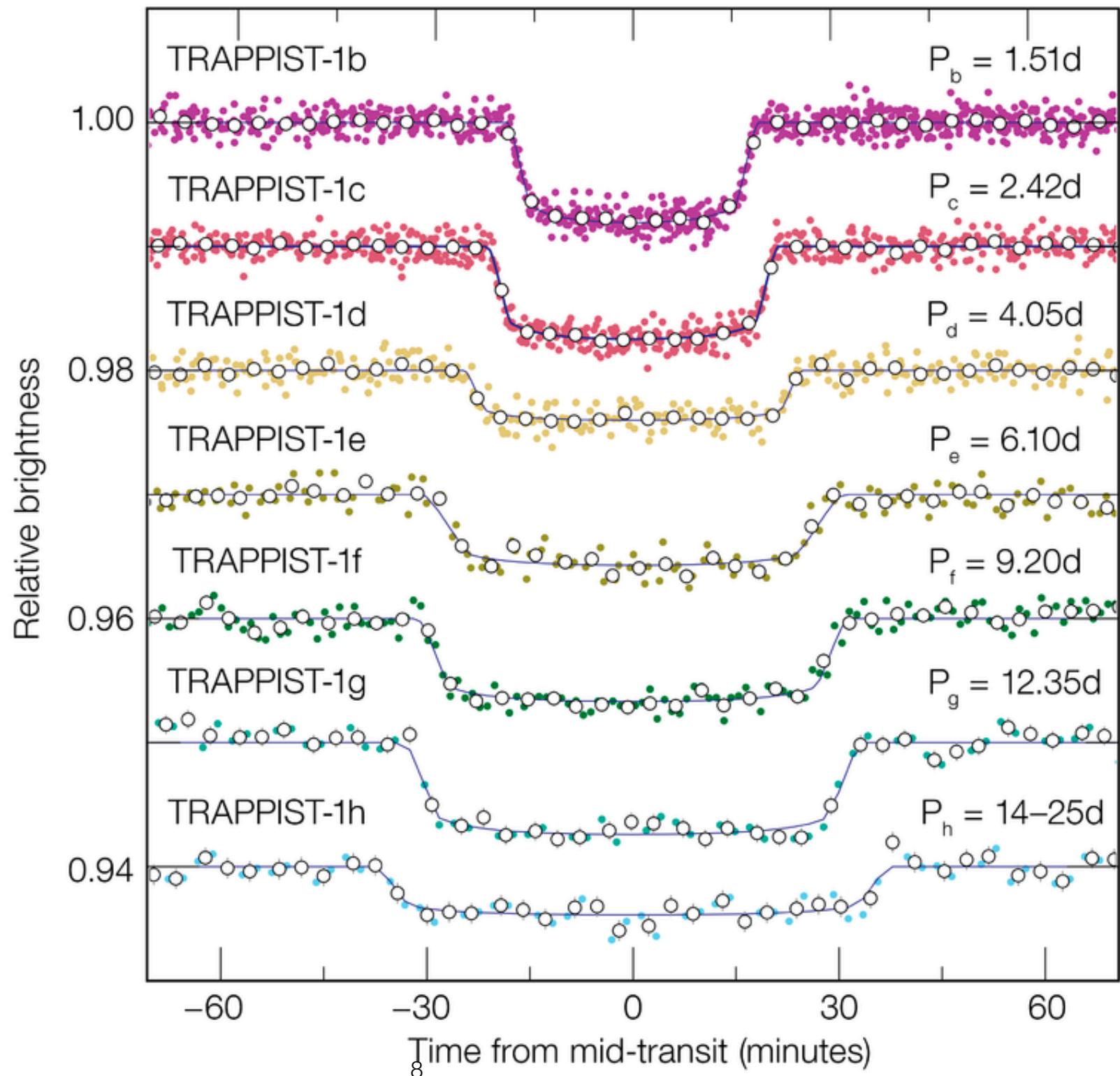
- The TRAPPIST-1 planetary system is very compact; all the orbits would fit well within Mercury's orbit.
- The planets are small and rocky, and up to six may be in an optimistic habitable zone, with estimated temperatures from 170 to 330 K (-103 to 57 C, or -154 to 134 F).
- Planet e is thought to be an earth-like ocean world; it's a good candidate for further study.



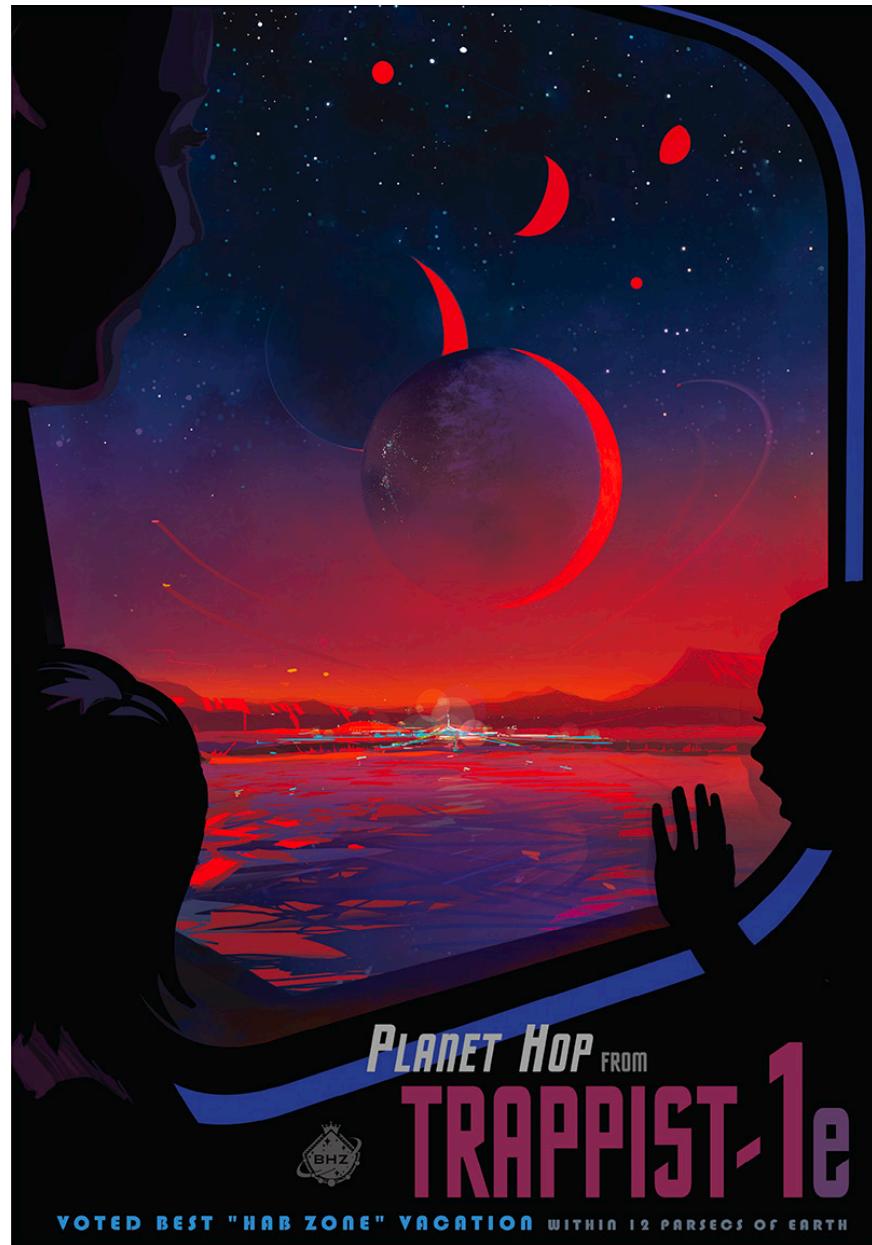
Trappist-1 compared to our sun.



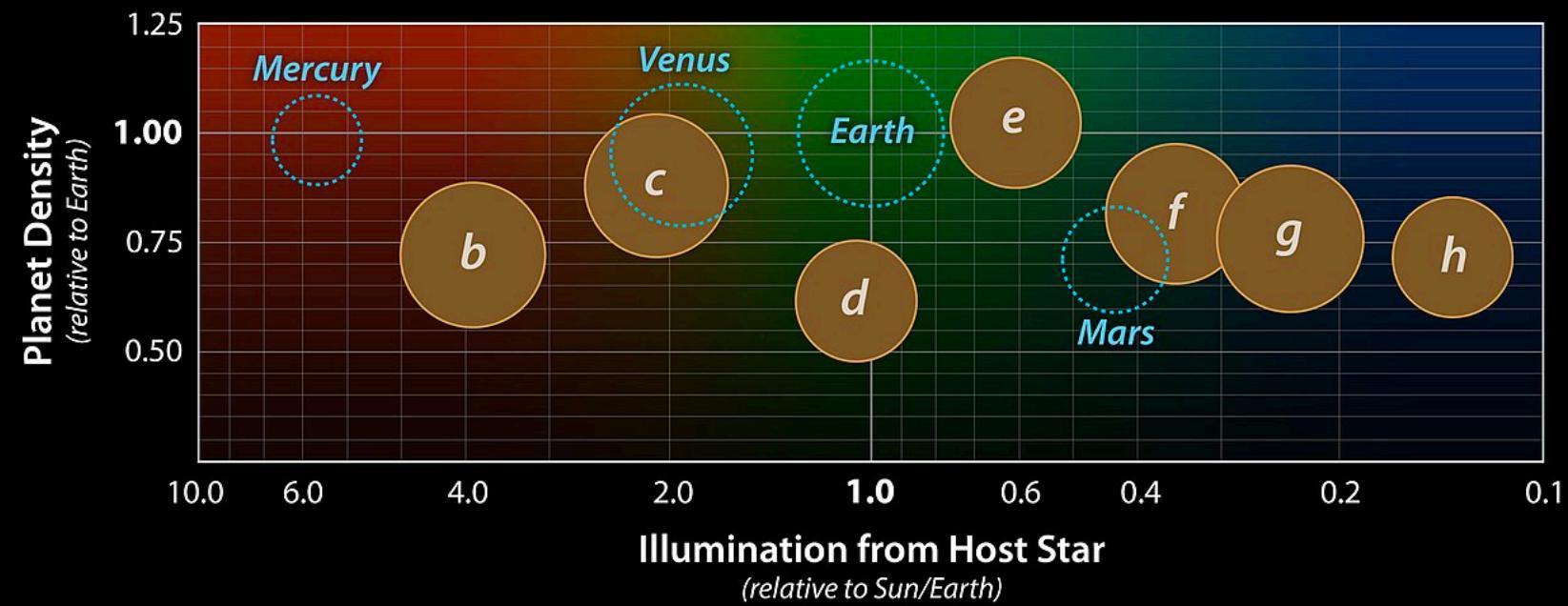
This is 22 days of data on TRAPPIST-1, showing transits of all 7 known planets. Green dots are ground data; black are space-based, from the Spitzer space telescope. Infrared works better because the star is so red and cold. If we figure out the periods and fold the data accordingly...



- There's a moving visualization of the system here: https://upload.wikimedia.org/wikipedia/commons/transcoded/c/c9/PIA21427_-TRAPPIST-1_Planetary_Orbits_and_Transits.ogv/PIA21427_-TRAPPIST-1_Planetary_Orbits_and_Transits.ogv.480p.vp9.webm
- Transit timing variations (TTV) let us calculate masses for the planets.
- They're very close together; passing planets would appear larger than our moon in their sky. There are probably no moons, as tidal forces would rip them apart. (Close enough to share life?)
- This system will be studied for years to come, notably by the James Webb Space Telescope, due for launch 2021.

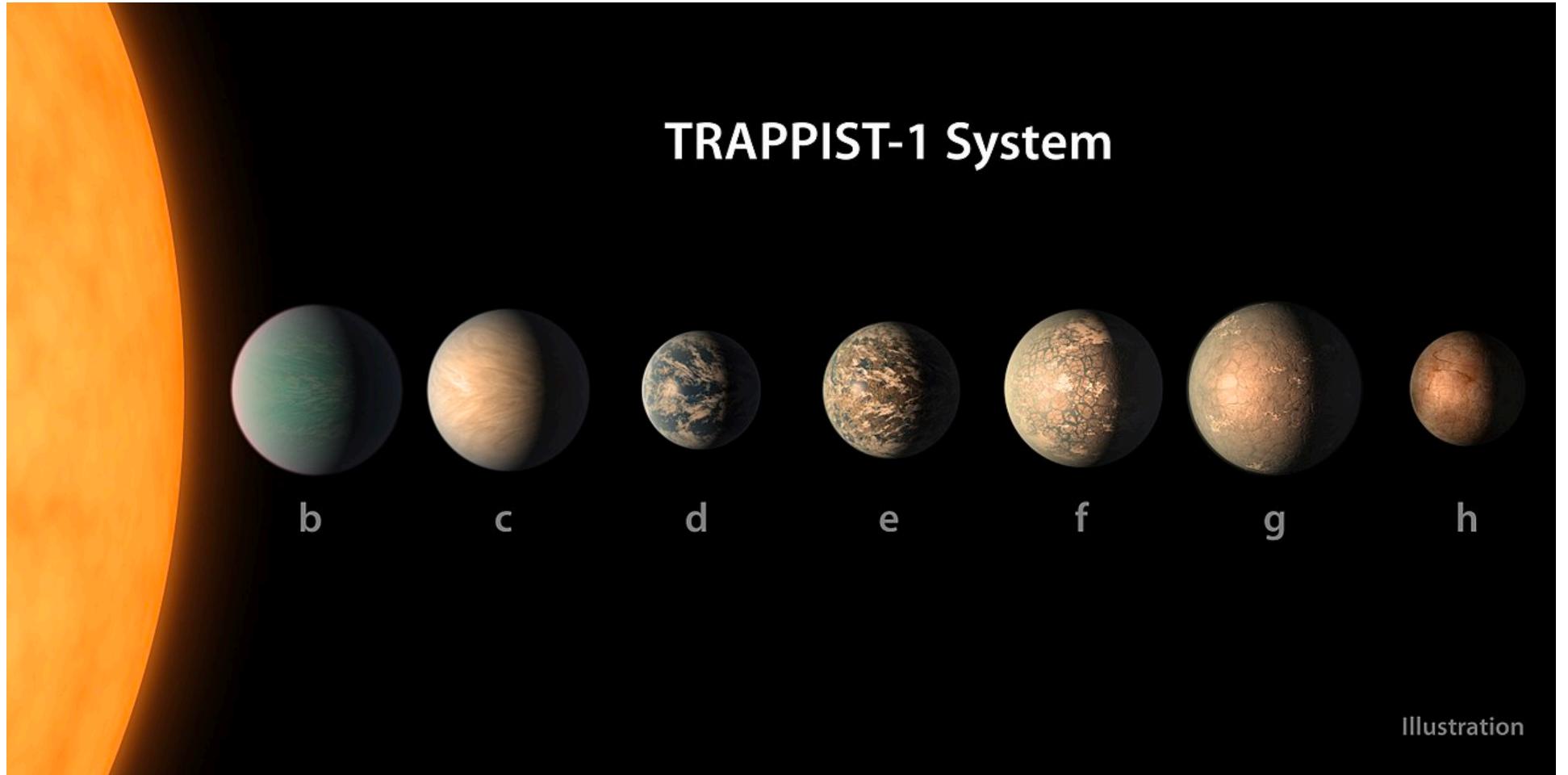


TRAPPIST-1/Solar System Comparison



This diagram plots density (vs. earth) and starlight energy received, for Trappist-1 planets and for our system. Size of circles represent sizes of planets.

TRAPPIST-1 System



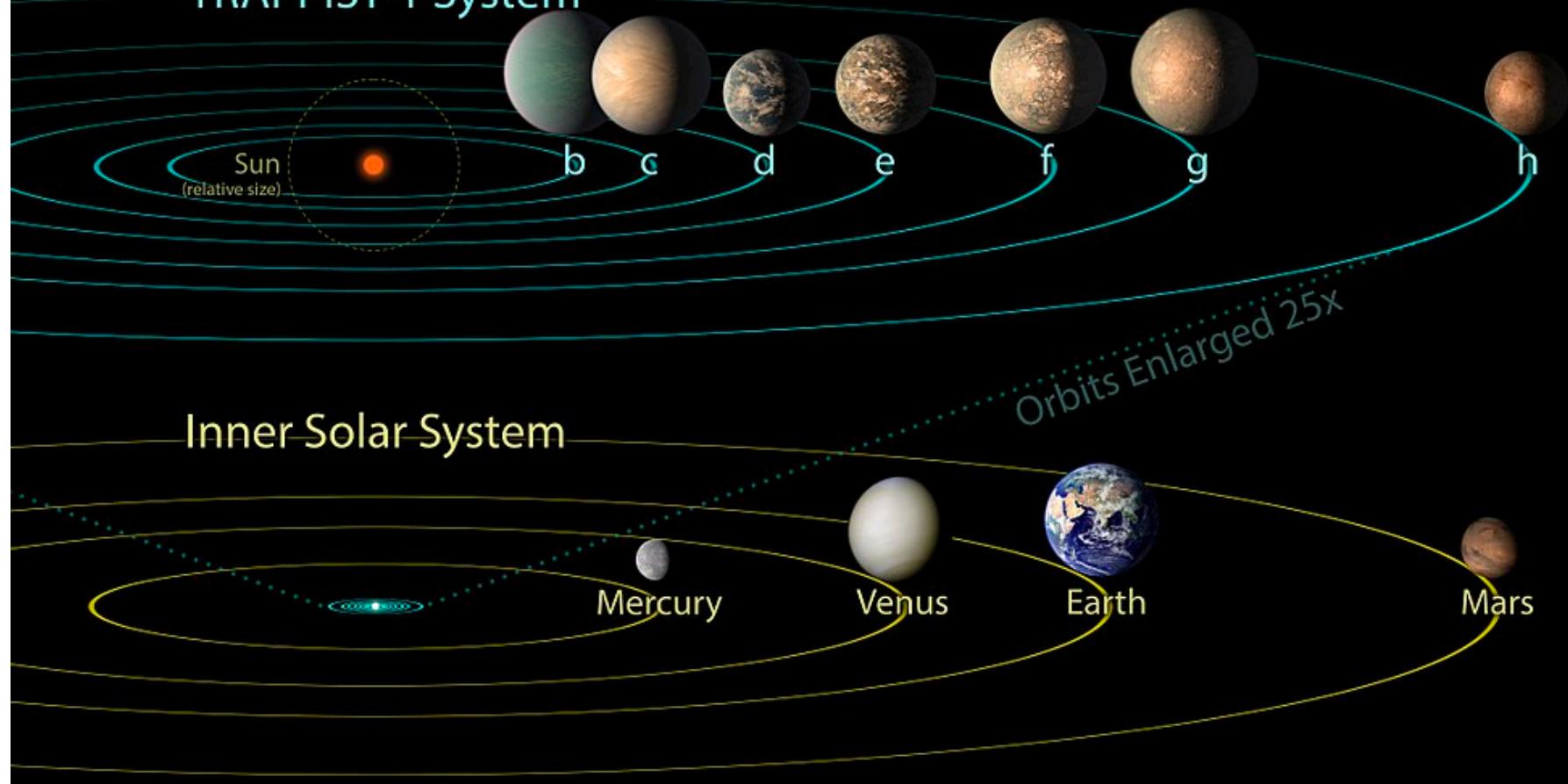
Illustration

This shows relative sizes (but not distances) of the planets and the star.

Jupiter & Major Moons



TRAPPIST-1 System



Orbits, enlarged 25x; they all fit well within Mercury's orbit.

TESS Object of Interest 700: TOI-700

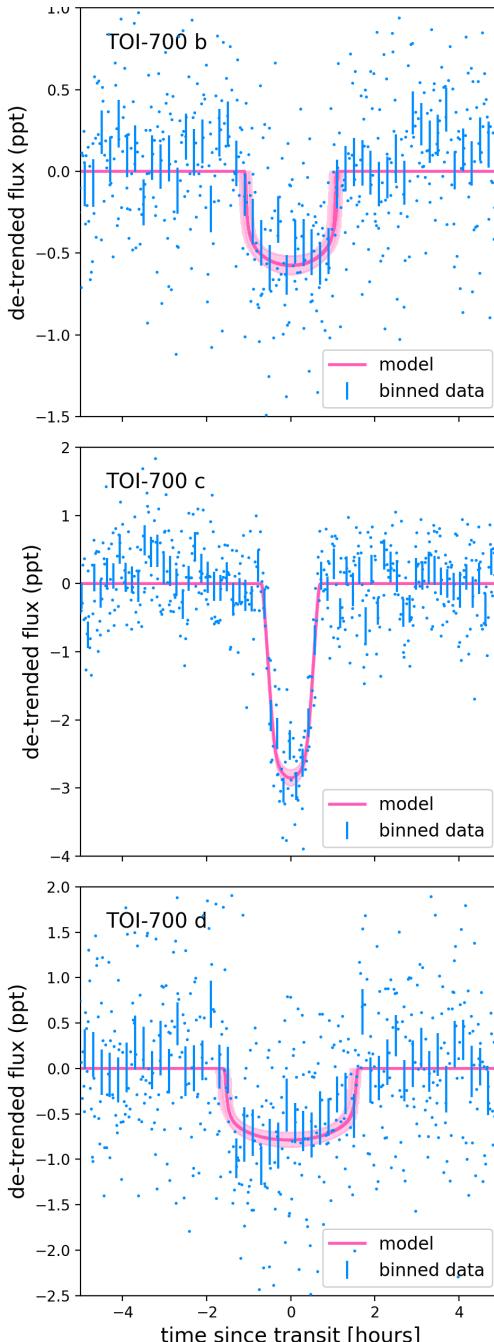
- The TESS mission (Transiting Exoplanet Survey Satellite) recently announced its first system with an earth-like planet in the habitable zone around its star.
- 3-planet system:
 - TOI 700 b is earth-sized, rocky, hot; 10-day orbit
 - TOI 700 c is 2.6 earth radii, probably gas-dominated (mini-Neptune); 16-day orbit
 - TOI 700 d is 1.2 earth radii, rocky, and in the habitable zone (37 day orbit, 86% of earth's energy input from its star)

Transit data for the 3 planets in the TOI-700 system.

Note vertical scale is in parts per trillion (!)

The star: 100 light-years away; $0.42 M_{\text{sun}}$, $0.42 R_{\text{sun}}$, Temp 3480 K

In the constellation Dorado, near the south ecliptic pole on the sky.

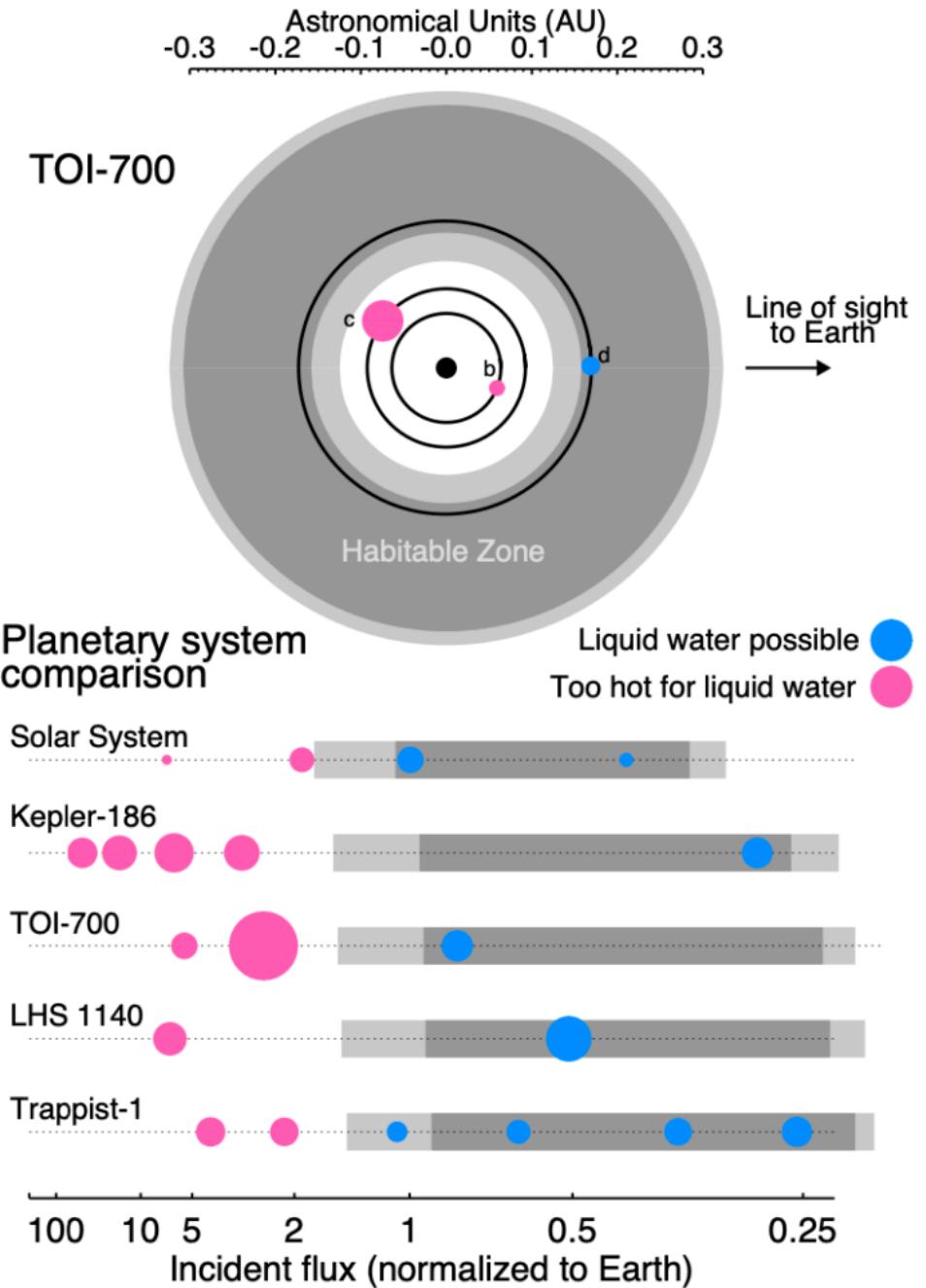


Comparing the inner parts of a few planetary systems

The TESS continuous viewing zone allowed for finding planets with orbits longer than a week or two.

TOI 700 d has a calculated temperature of 295 K, (22 C; 71 F)

The star seems remarkably calm for a red dwarf.

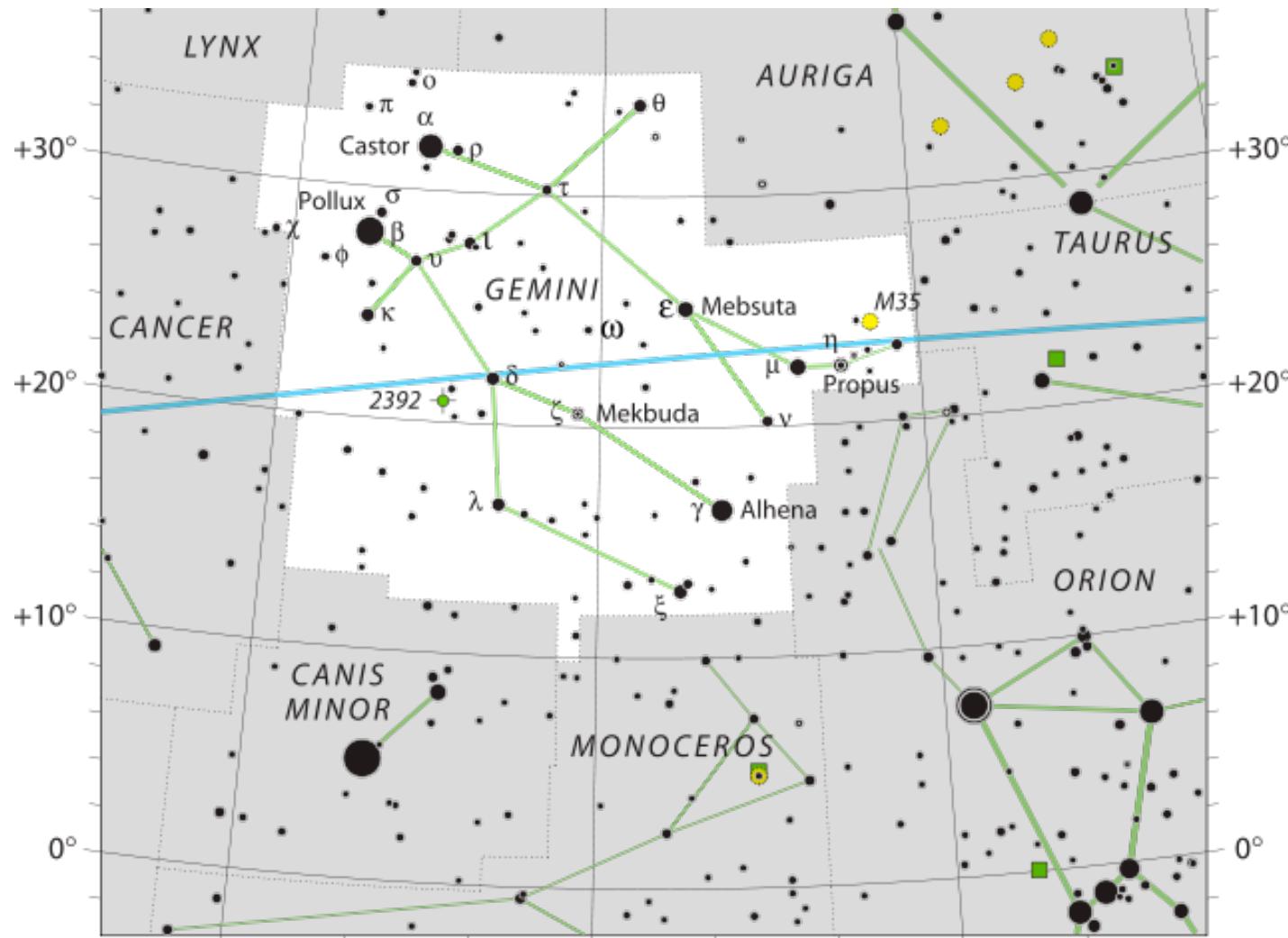


An extreme “hot Jupiter”: NGTS-10b

- The Next Generation Transit Survey found a planet with an 18 *hour* orbit. It has 2.1 M_{Jup}, 1.2 R_{Jup}, Temp 1300 K
- The star is a middling orange (K) star, 0.7 M_{Sun}, 0.7 R_{Sun} Temp 4400 K.
- It's likely that the orbit is getting smaller, i.e. the planet is spiraling into the star
- Detritus from the planet might be observable in the spectrum of the star
- Some theories of planet formation feature planets forced into their stars, or ejected from the system, or both.

A bright visible star with a planet: Pollux

- Pollux, also called Beta Geminorum, is an orange giant star; it's run out of hydrogen in the core and is expanding.
- 33 light years away, $1.9 M_{\text{sun}}$, $8.8 R_{\text{sun}}$, Temp 4700 K.
- Pollux b, formally named Thestias (for the mother of Pollux in mythology) has M_{min} $2.6 M_{\text{Jup}}$, orbits 1.6 AU from the star, in 589 earth days.



Gemini is high in the winter sky. Go out and look at it tonight if the weather is clear.

A circum-binary planet

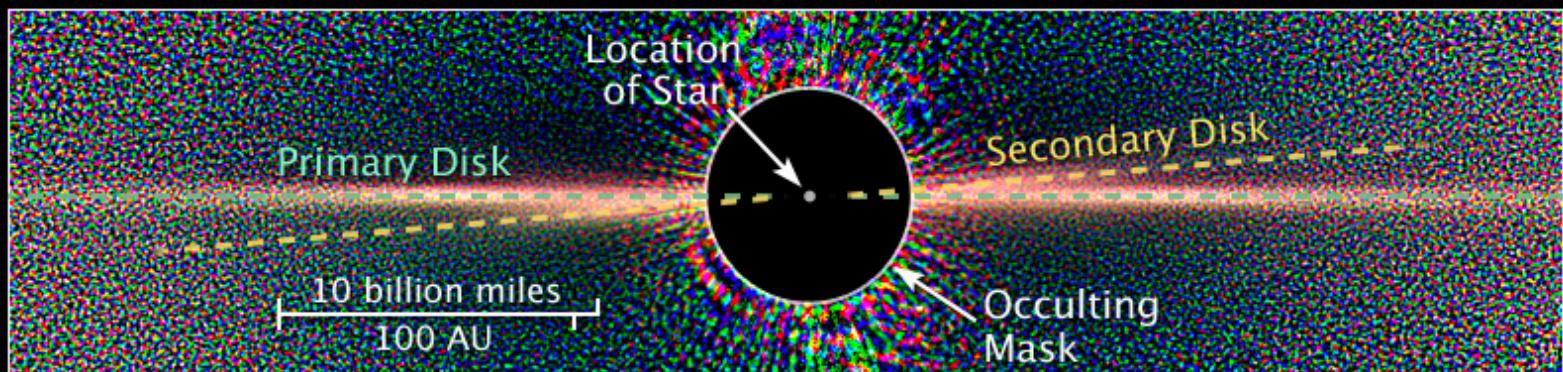
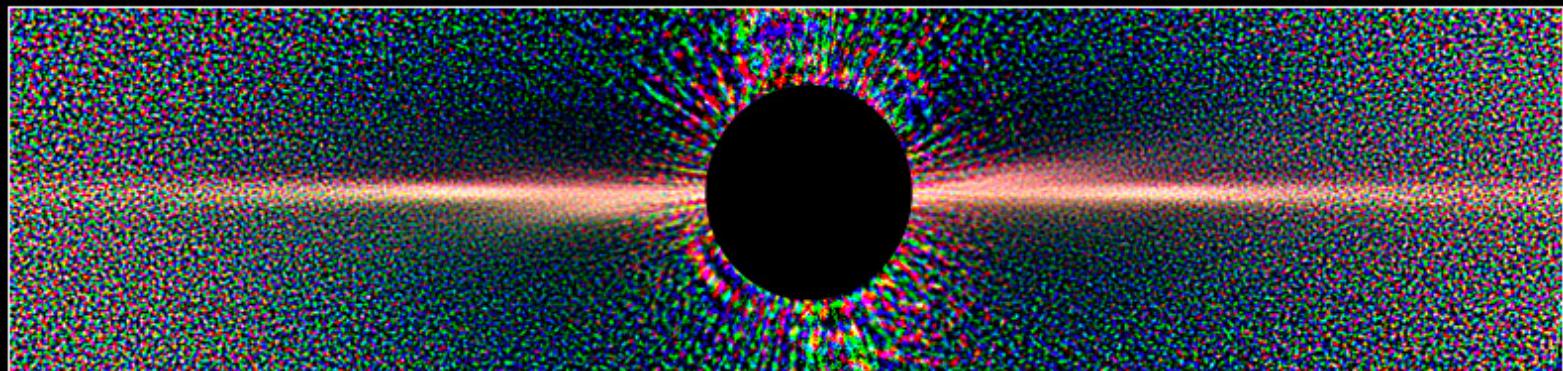
- TOI 1338 in Pictor, distance 1300 light years, is a binary system (1.2 and 0.3 M_{sun}) 15 day orbit.
- A planet was found by 17 year old intern Wolf Kukier in a 93 to 95 day orbit around the pair of stars. Transits are irregular because the stars are moving.
- TOI 1338 b is 6.9 times the diameter of the earth (larger than Neptune)

Beta Pictoris: A young planetary system still forming

- Beta Pic is about 64 light years away in the southern sky. It has $1.75 M_{\text{sun}}$, $1.8 R_{\text{sun}}$, Temp 8000 K, Luminosity is about 8.7 times our sun, age about 23 Myr.
- It's brighter than expected in the infrared; attributed to a disk of dust surrounding the star.
- A planet was found by direct imaging. There are now two known planets in the system.

Beta Pictoris

Hubble Space Telescope • ACS/HRC



NASA, ESA, and D. Golimowski (Johns Hopkins University)

STScI-PRC06-25

Hubble image of the dust disk around Beta Pic. The star is masked out so we can see the faint disk. It's very nearly edge-on.

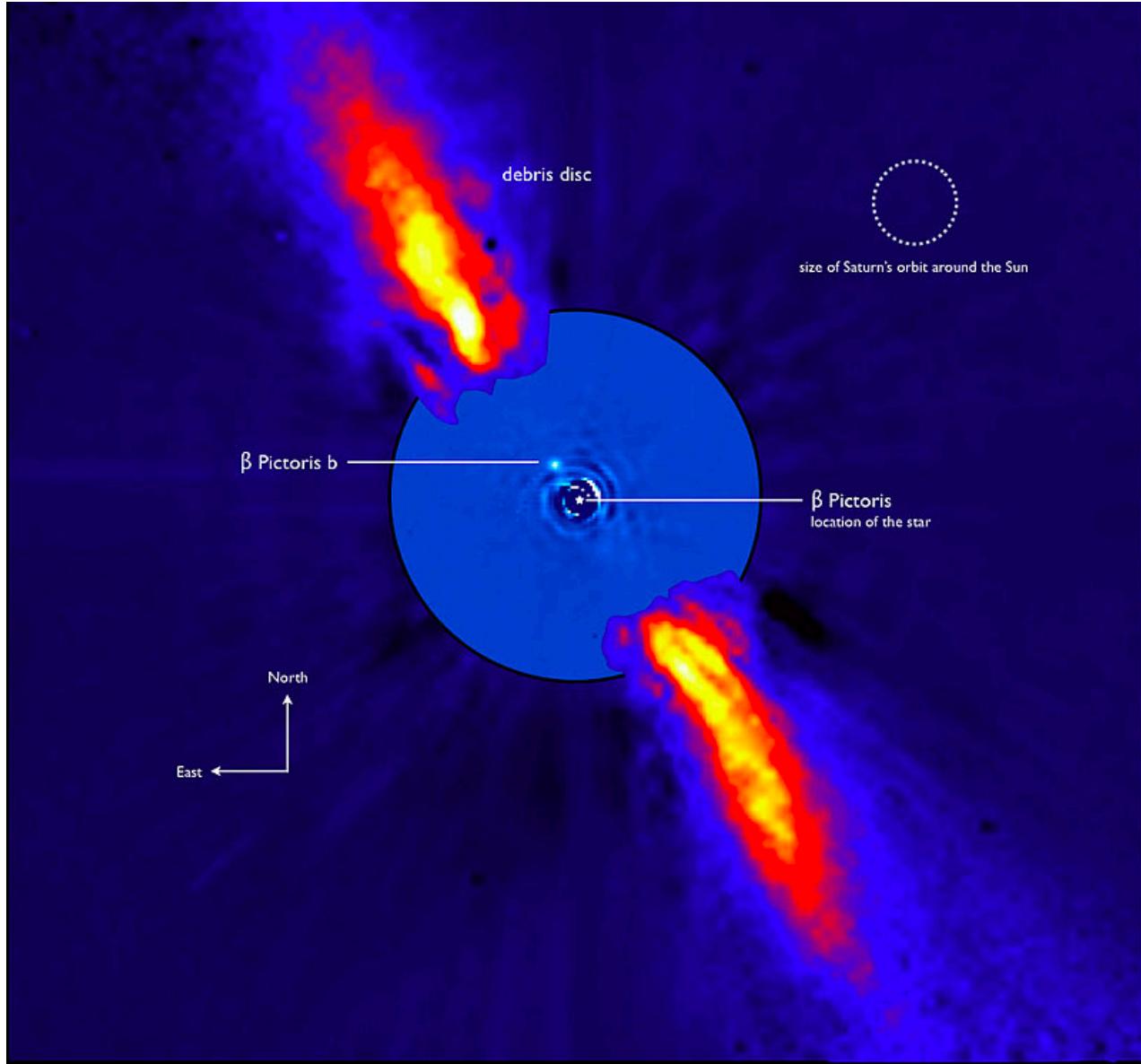
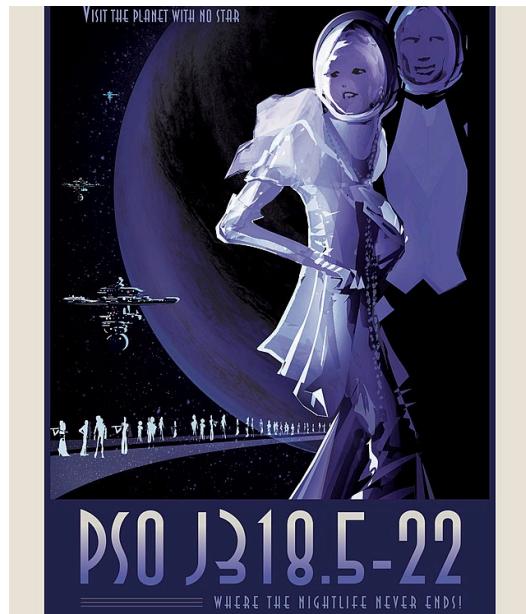


Image of the Beta Pic system including direct imaging of the planet Beta Pic b

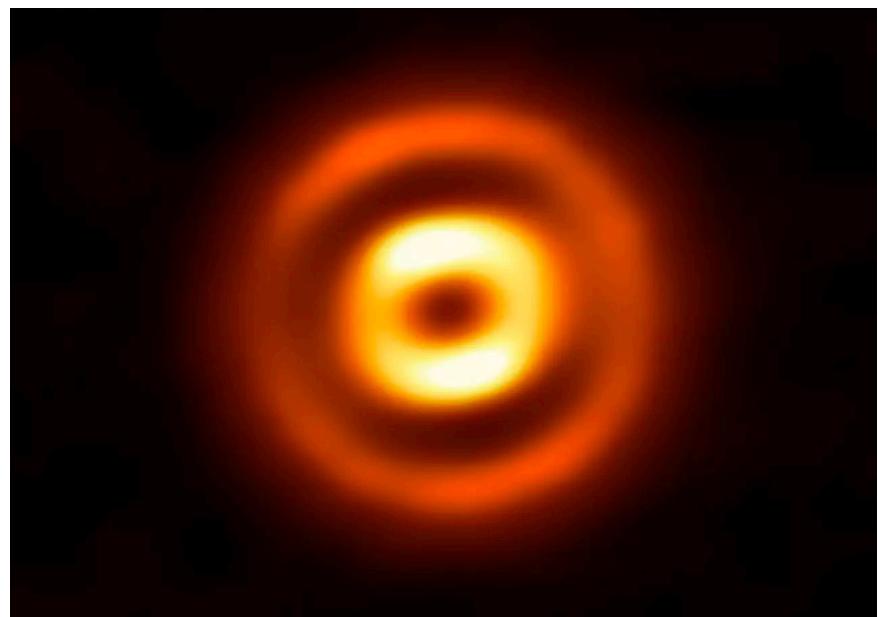
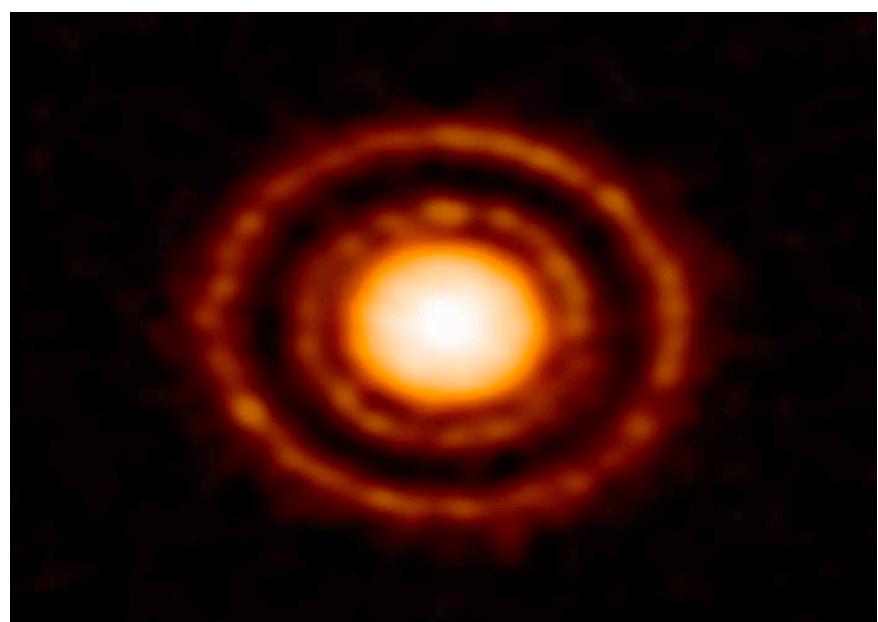
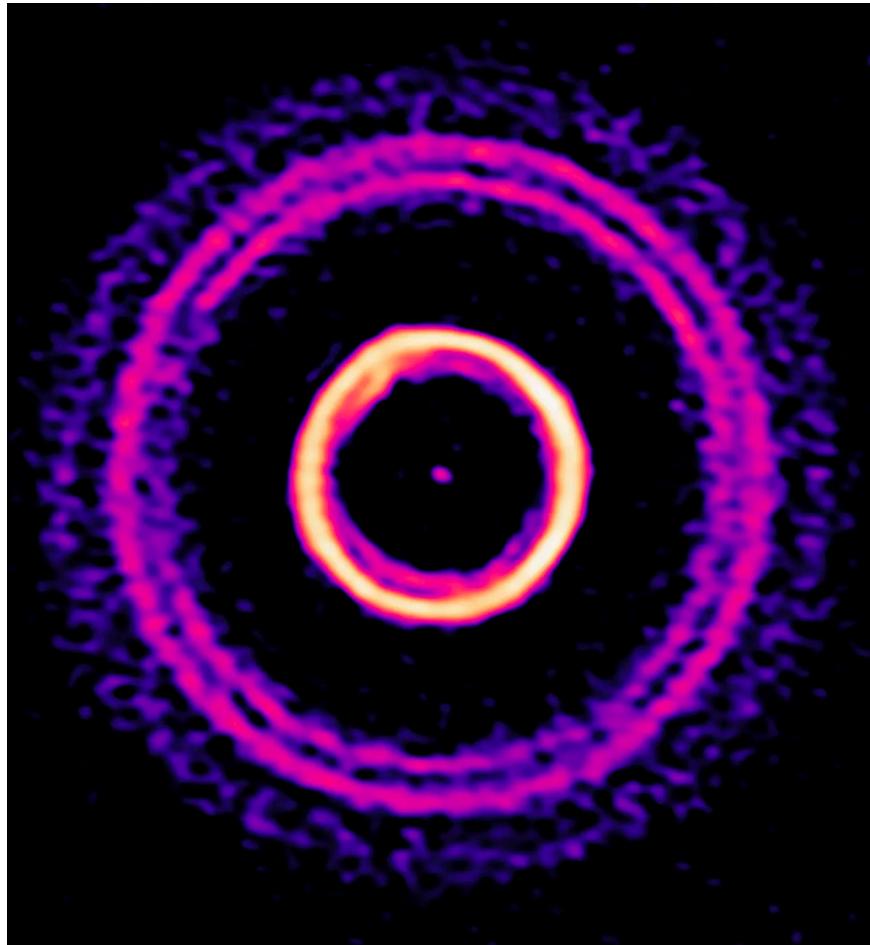
- There's a movie of the ESO data showing motion of the planet Beta Pic b, here: https://upload.wikimedia.org/wikipedia/commons/transcoded/9/9c/Beta_Pictoris_b_in_Motion.webm
- As instrumentation gets better, more features pop out of this system. There's a second planet, c, and the dust disk seems to be split into an “asteroid belt” and a “Kuiper belt” not unlike our own.

- A rogue planet, part of the group of stars co-moving with beta Pictoris
- Possibly ejected from a forming planetary system; probably quite young (~ 12 Myr) and still cooling from formation



Planet-forming disks

- The sub-mm (Terahertz) radio telescope array ALMA (Atacama Large Millimeter Array) in Chile can image disks around young forming stars, and follow chemistry by choosing interesting wavelengths.



Fomalhaut, a bright young (450 Myr) star 25 ly away in the southern sky, has a disk (ring?)

ALMA image -->

Hubble shows there's a planet at the inner edge of the ring, and can see it moving.

177 AU, ~1700 yr orbit

