Other Planetary Systems

and why is ours so weird?
Lecture 5 of Planets Everywhere
Learners at Wind Crest
Feb 2020

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.

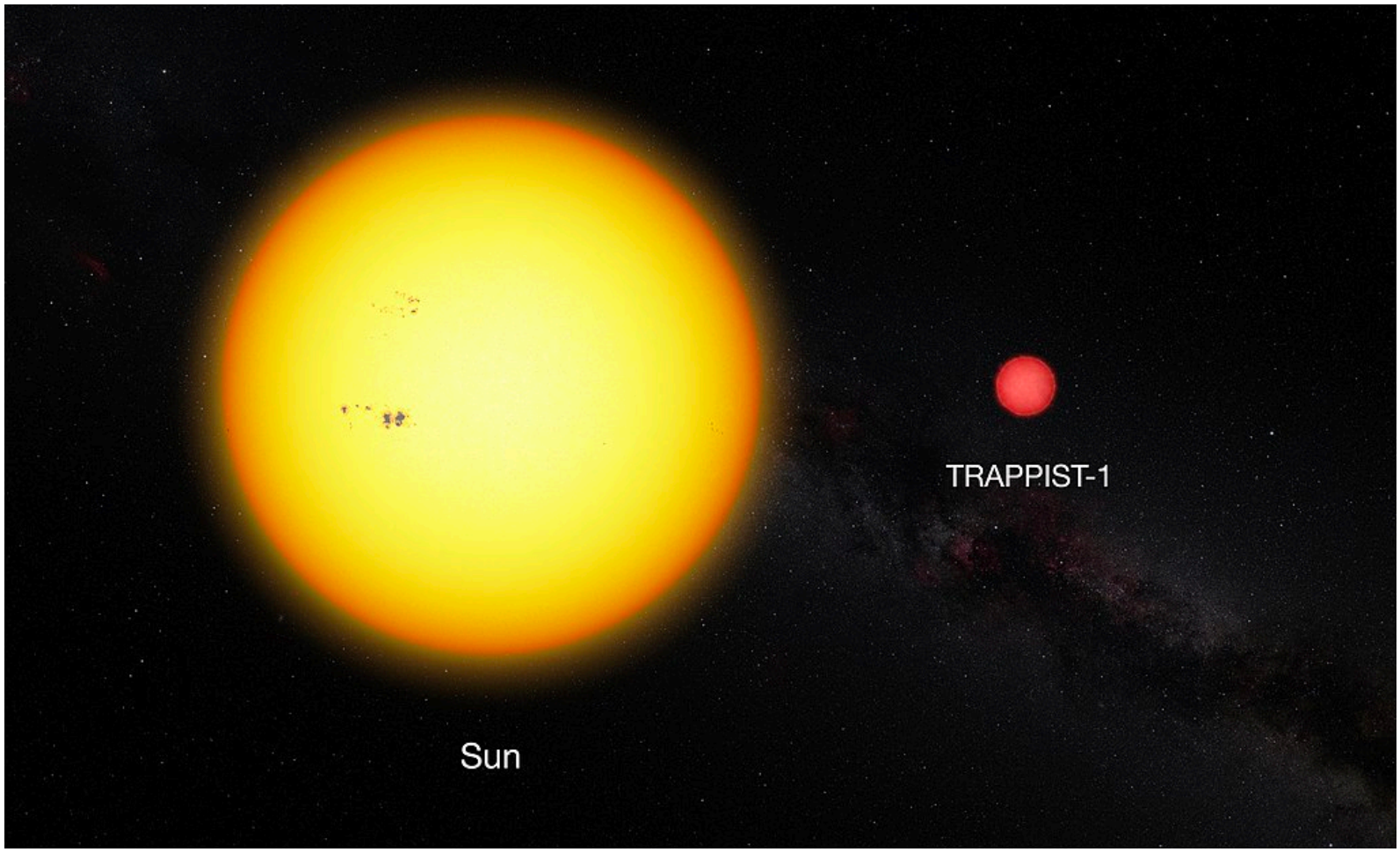
- They found 3 planets around the star 2MASS J23062928-0502285, also known as TRAPPIST-1, in 2015. Followup observations found 4 more.

- The star is very small; 39 light years from us in the constellation Aquarius; 0.089 M_{sun}, 0.121 R_{sun}, temp 2500 K. It's very red and faint, luminosity 5.7 x 10^{-4} of our sun's.

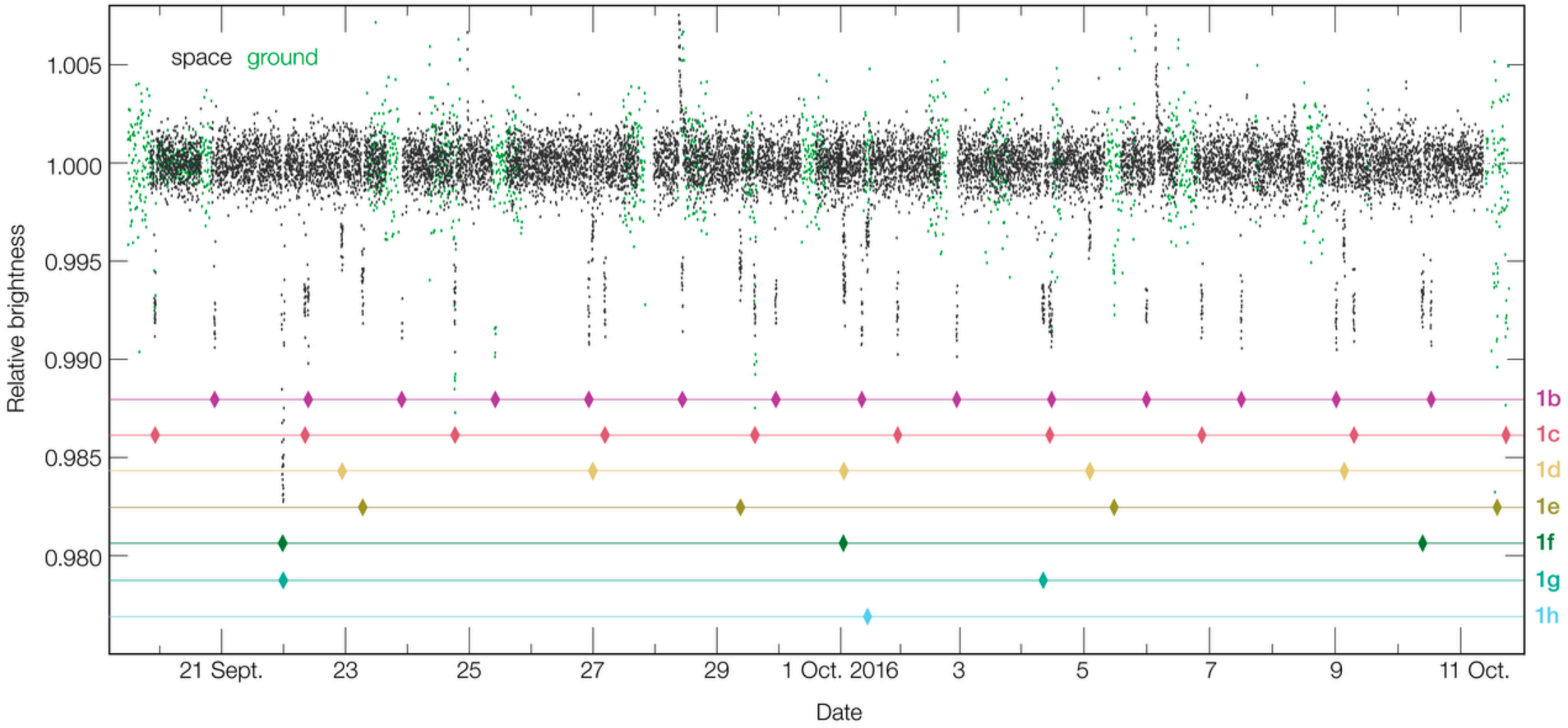
- The TRAPPIST-1 planetary system is very compact; all the orbits would fit well within Mercury's orbit.

- 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).

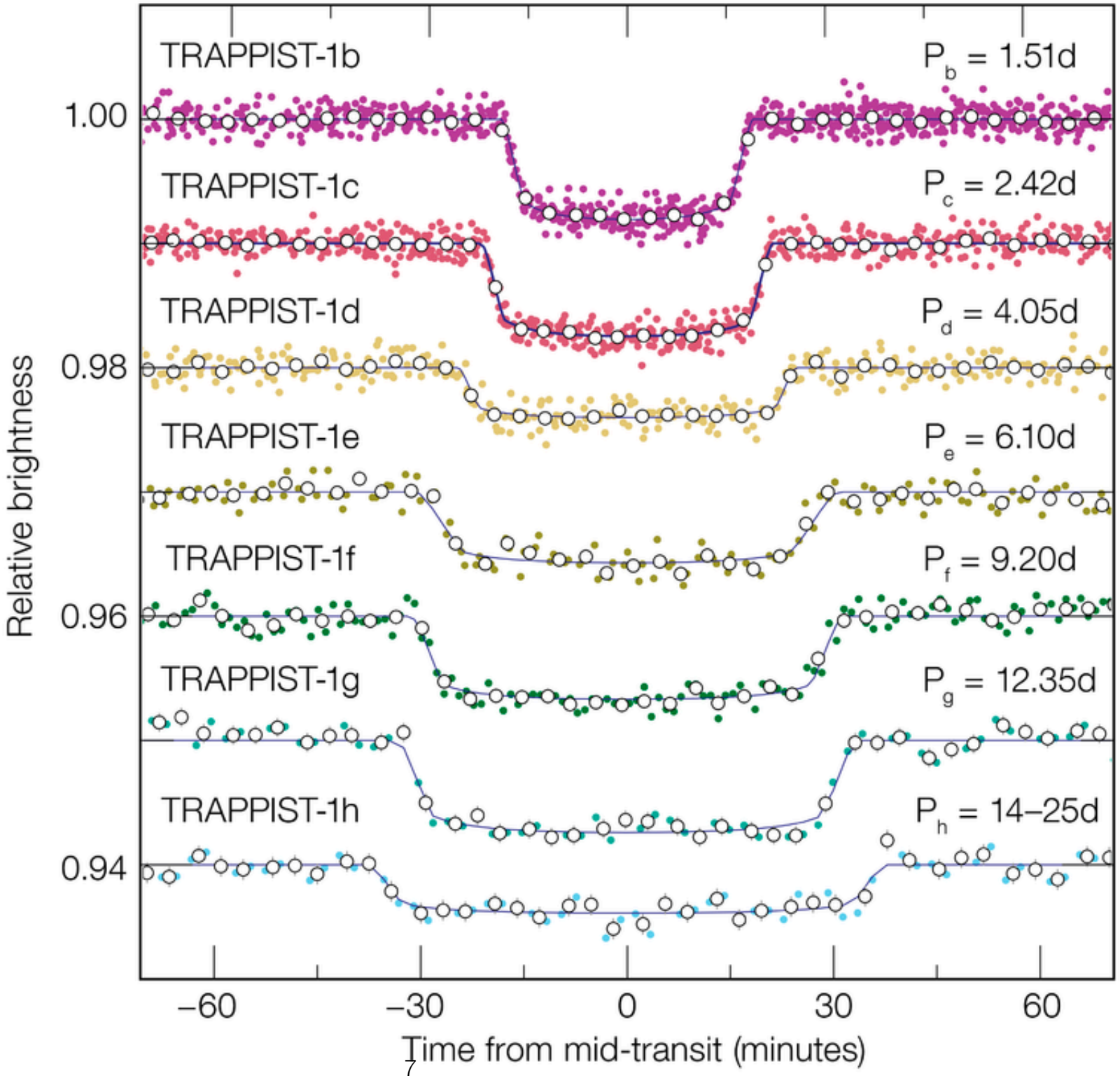
- Planet e is thought to be an earth-like ocean world; it's a good candidate for further study.



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…

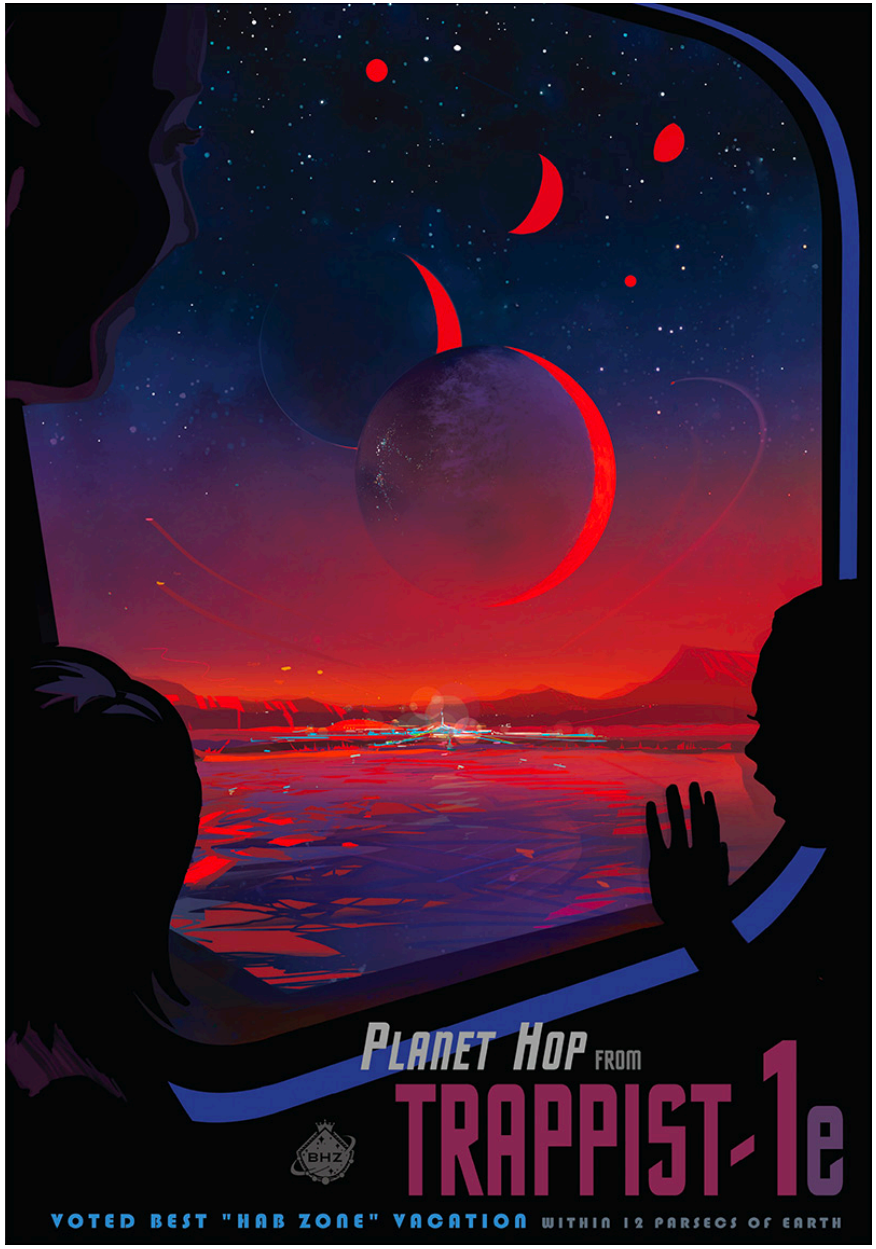

TRAPPIST-1b
P_b = 1.51d
TRAPPIST-1c
P_c = 2.42d
TRAPPIST-1d
P_d = 4.05d
TRAPPIST-1e
P_e = 6.10d
TRAPPIST-1f
P_f = 9.20d
TRAPPIST-1g
P_g = 12.35d
TRAPPIST-1h
P_h = 14–25d
1.00
0.98
0.96
0.94
Relative brightness
−60
−30
0
30
60
Time from mid-transit (minutes)

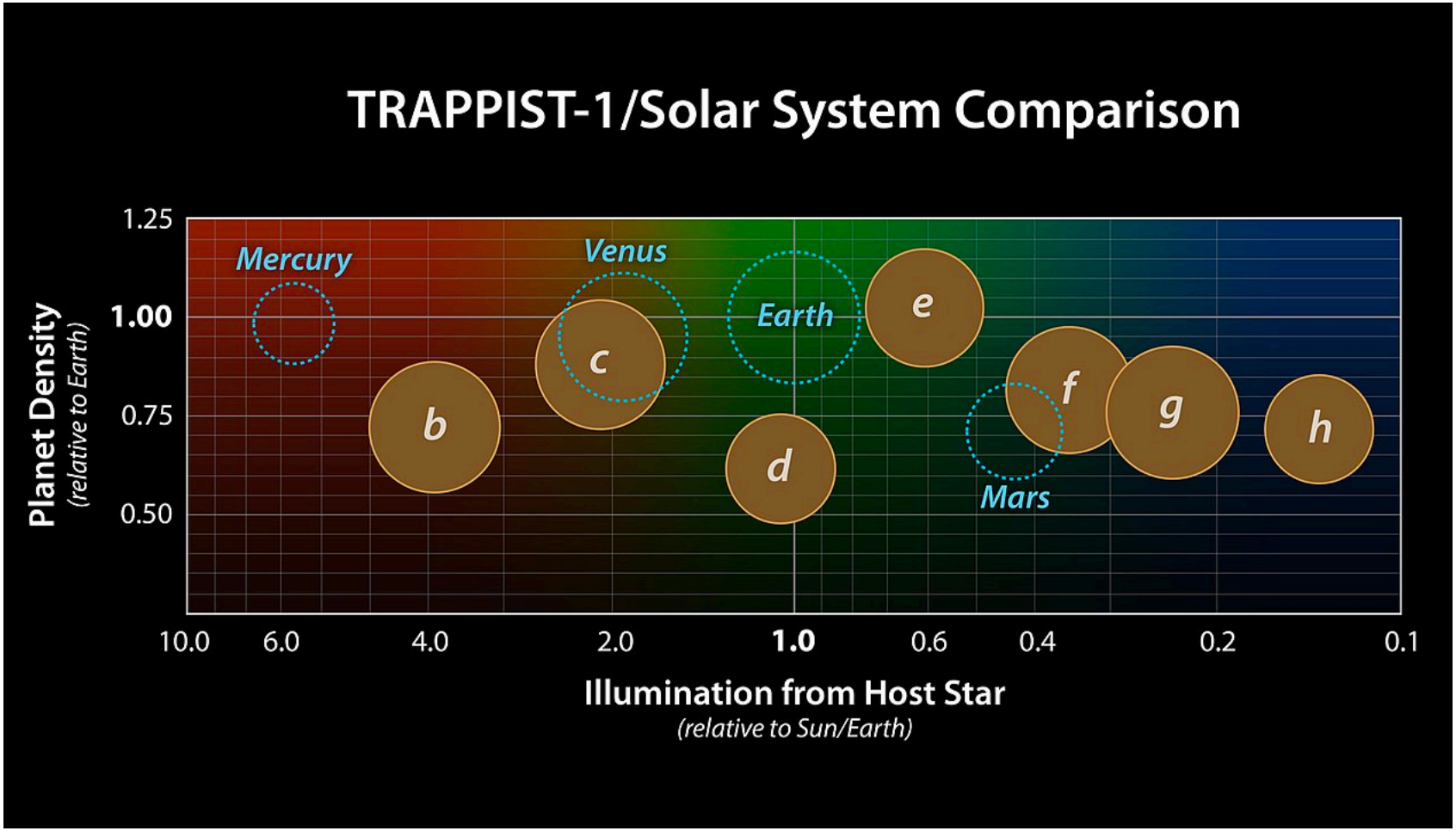
- There's a moving visualization of the system here: https://upload.wikimedia.org/wikipedia/commons/transcoded/c/c9/PIA21427_-_TRAPPIST-1_Planetary_Orbits_and_Transits.ogv/PIA21427_-_TRAPPIST-1_Planetary_Orbits_and_Transits.ogv.480p.vp9.webm

- Transit timing variations (TTV) let us calculate masses for the planets.

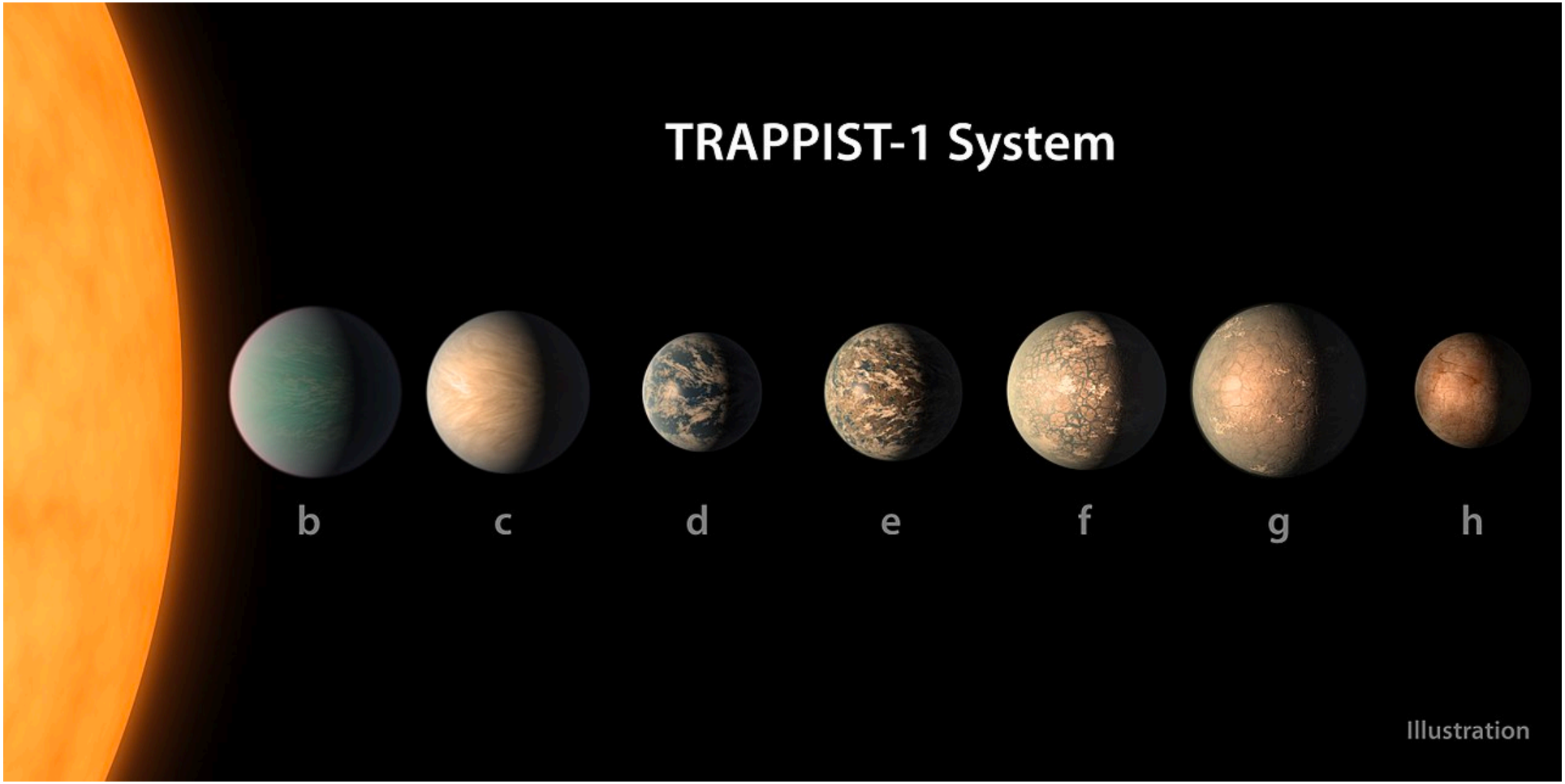
- They're very close together; passing planets would appear larger than our moon in their sky. There are probably no moons, as tidal forces would rip them apart. (Close enough to share life?)

- This system will be studied for years to come, notably by the James Webb Space Telescope, due for launch 2021.

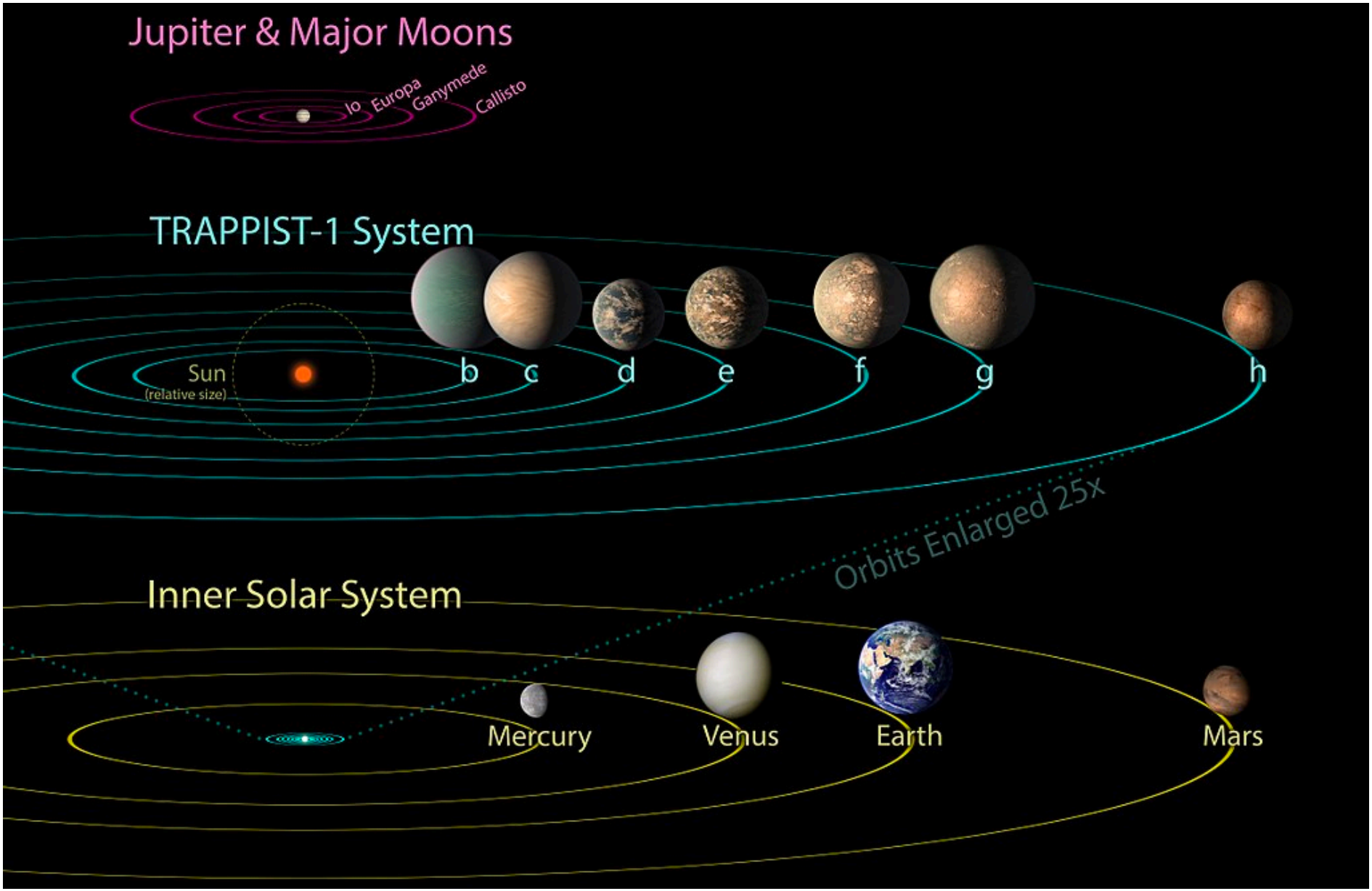

PLANET HOP FROM
TRAPPIST-1e
VOTED BEST "HAB ZONE" VACATION WITHIN 12 PARSECS OF EARTH



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.



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



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

TESS Object of Interest 700: TOI-700

- The TESS mission (Transiting Expolanet 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

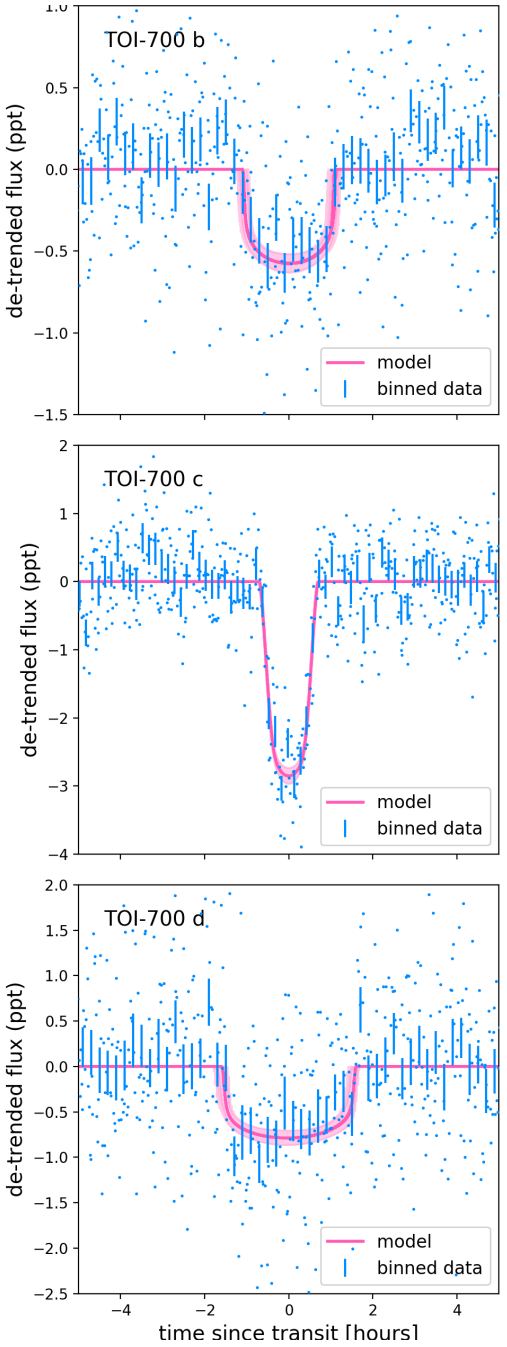
  - TOI 700 d is 1.2 earth radii, rocky, and in the habitable zone (37 day orbit, 86% of earth's energy input from its star)

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_{sun}, 0.42 R_{sun}, Temp 3480 K

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

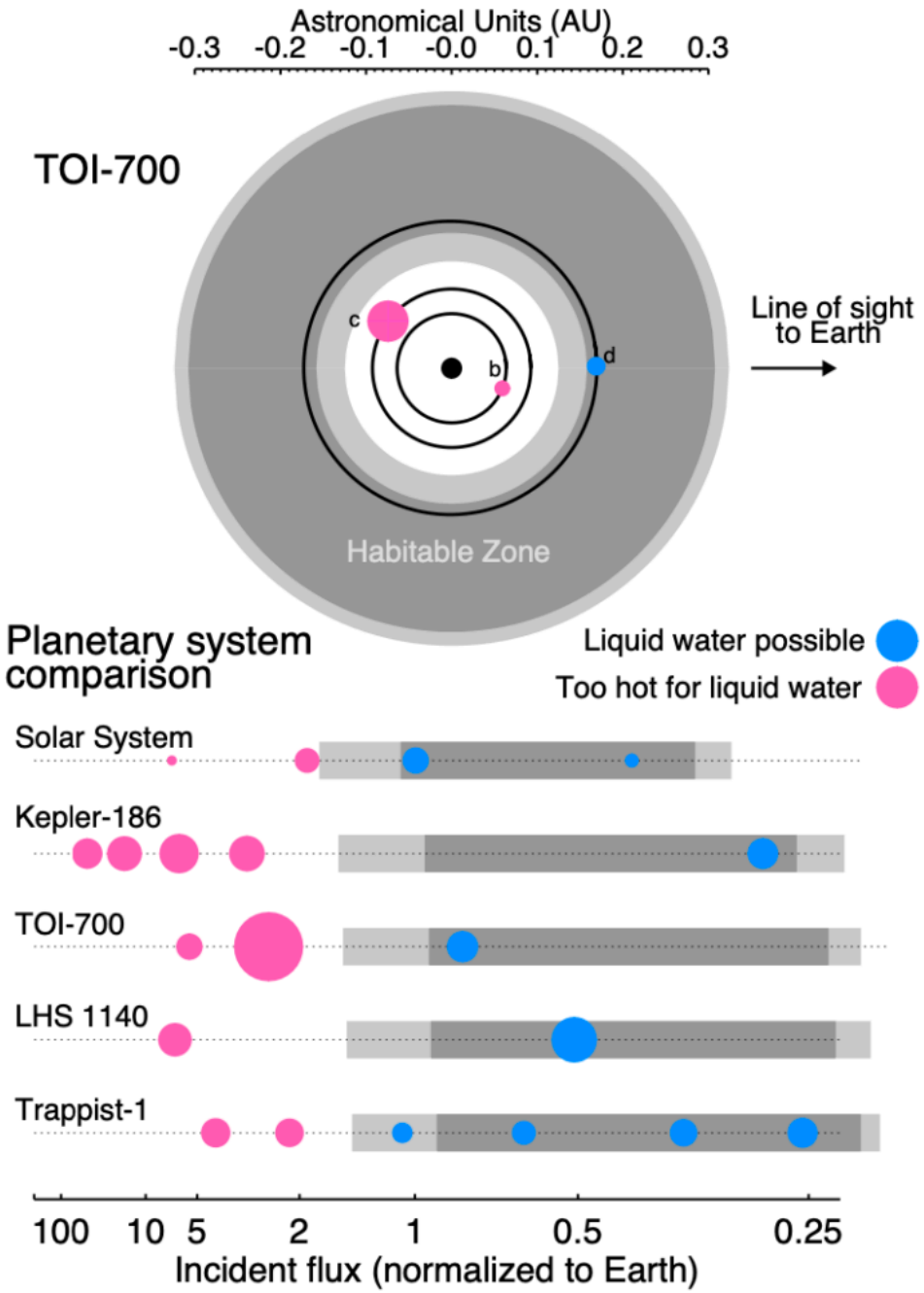


Comparing the inner parts of a few planetary systems

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.

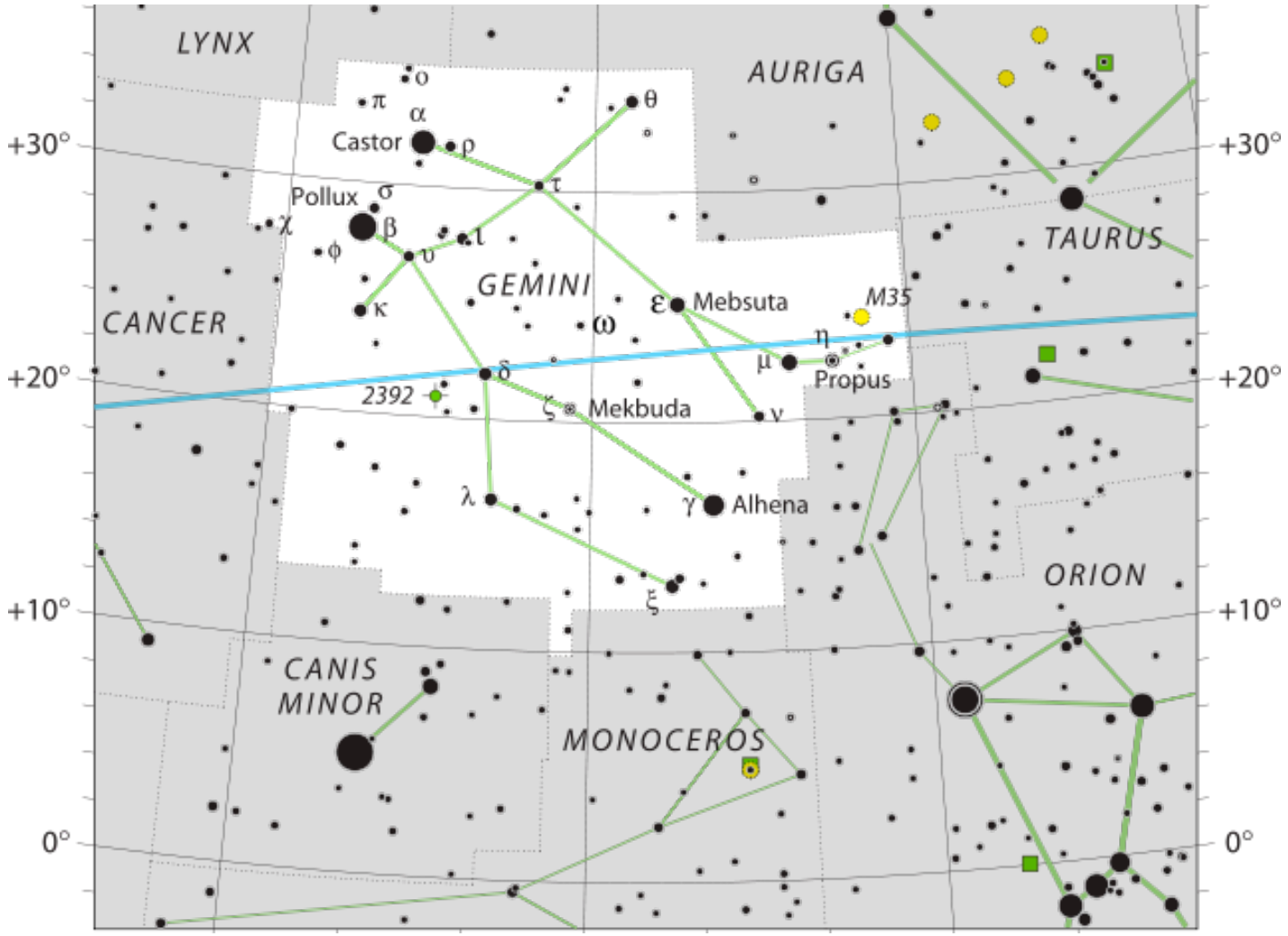


An extreme “hot Jupiter”: NGTS-10b

- 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 4400K.
- 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_{sun}, 8.8 R_{sun}, Temp 4700 K.
- Pollux b, formally named Thestias (for the mother of Pollux in mythology) has M_{min} 2.6 M_{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

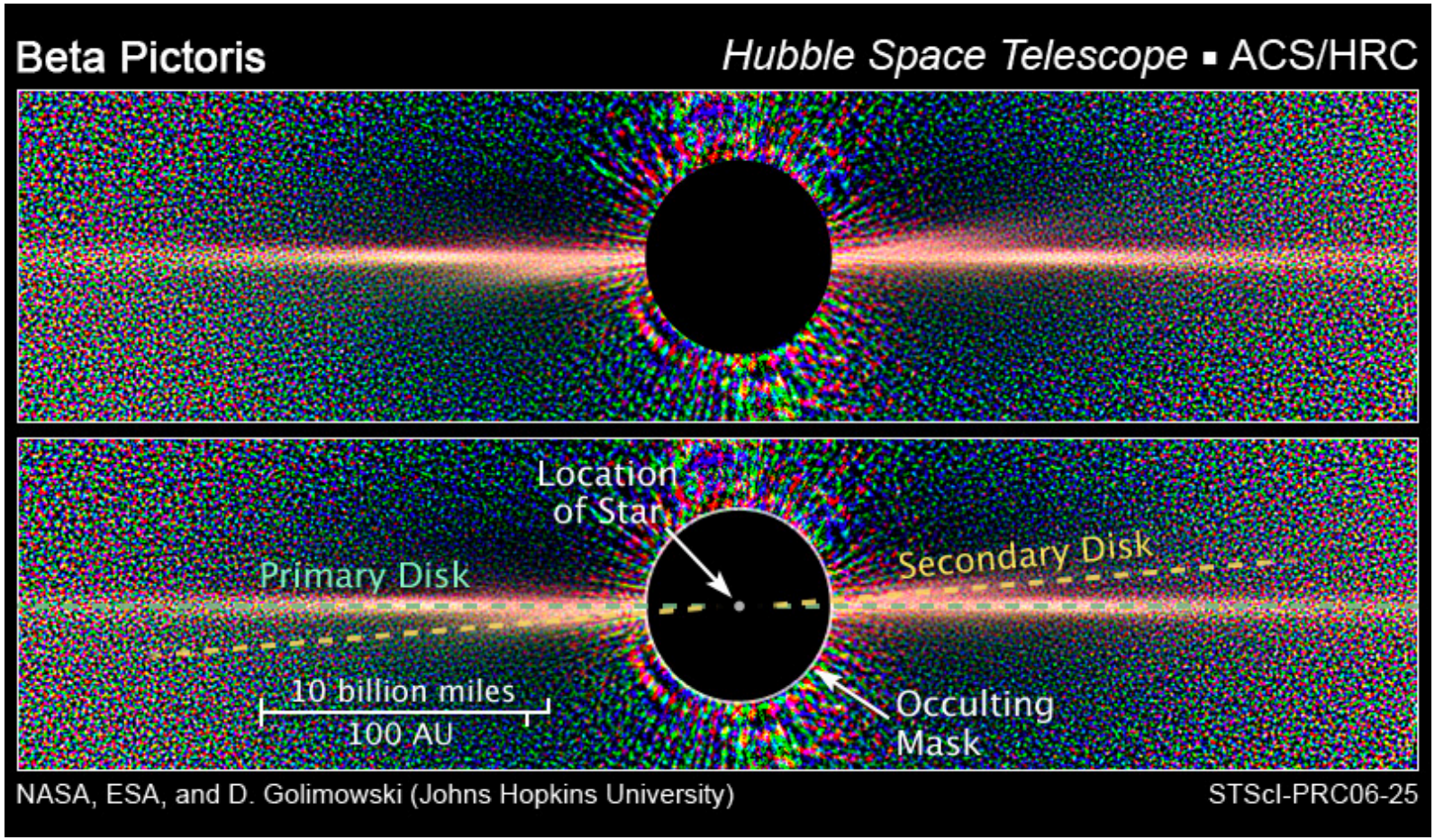
- TOI 1338 in Pictor, distance 1300 light years, is a binary system (1.2 and 0.3 M_{sun}) 15 day orbit.
- A planet was found by 17 year old intern Wolf Kukier in a 93 to 95 day orbit around the pair of stars. Transits are irregular because the stars are moving.
- TOI 1338 b is 6.9 times the diameter 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_{sun}, 1.8 R_{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.



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.

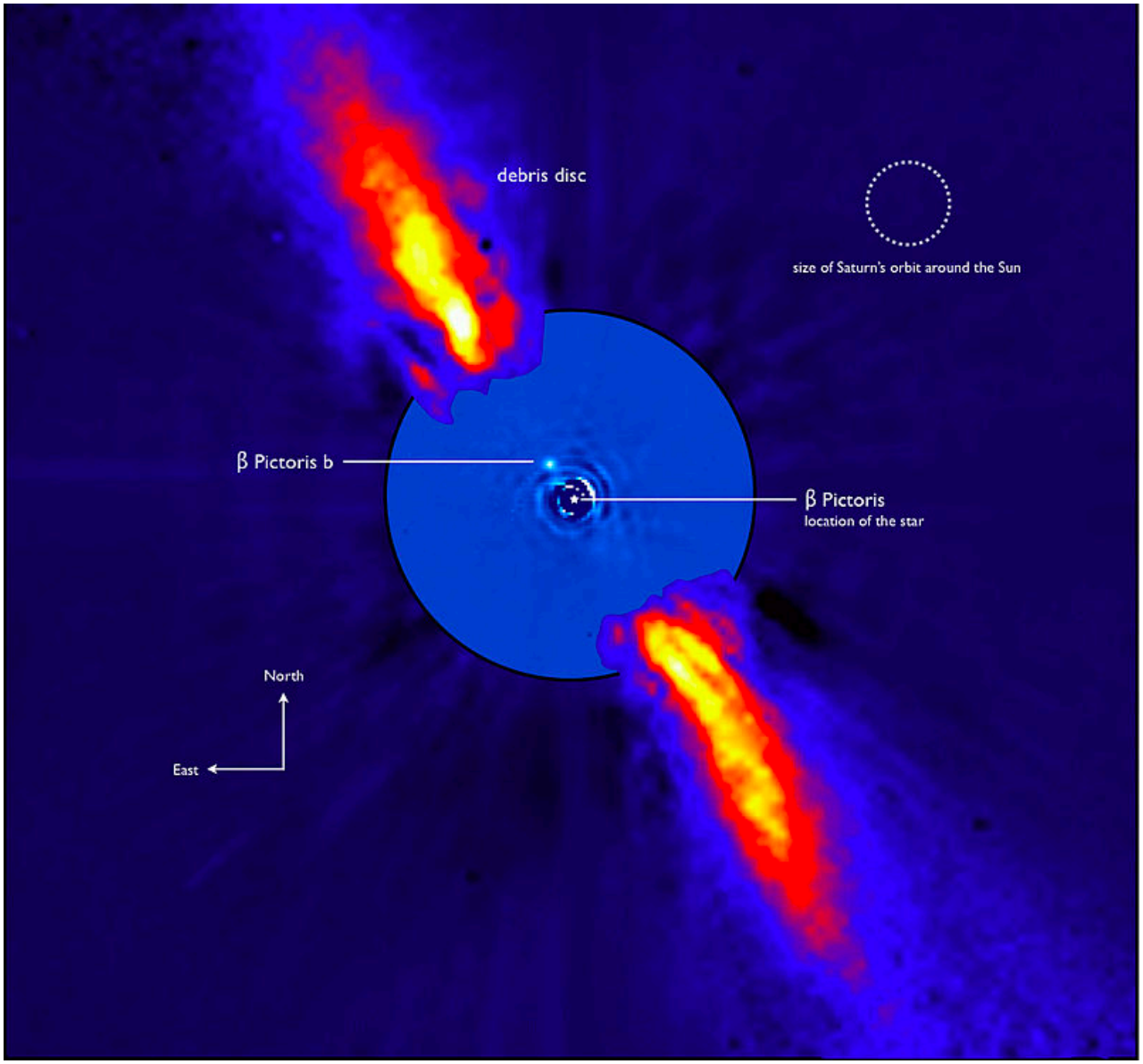


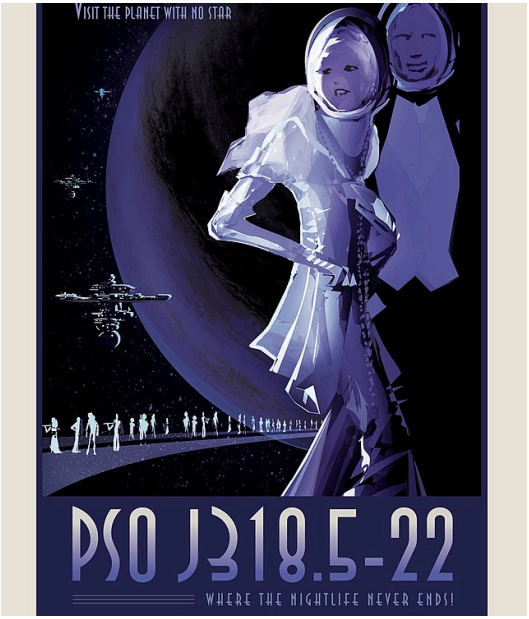
Image of the Beta Pic system including direct imaging of the planet Beta Pic b

- 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/Beta_Pictoris_b_in_Motion.webm.360p.vp9.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.

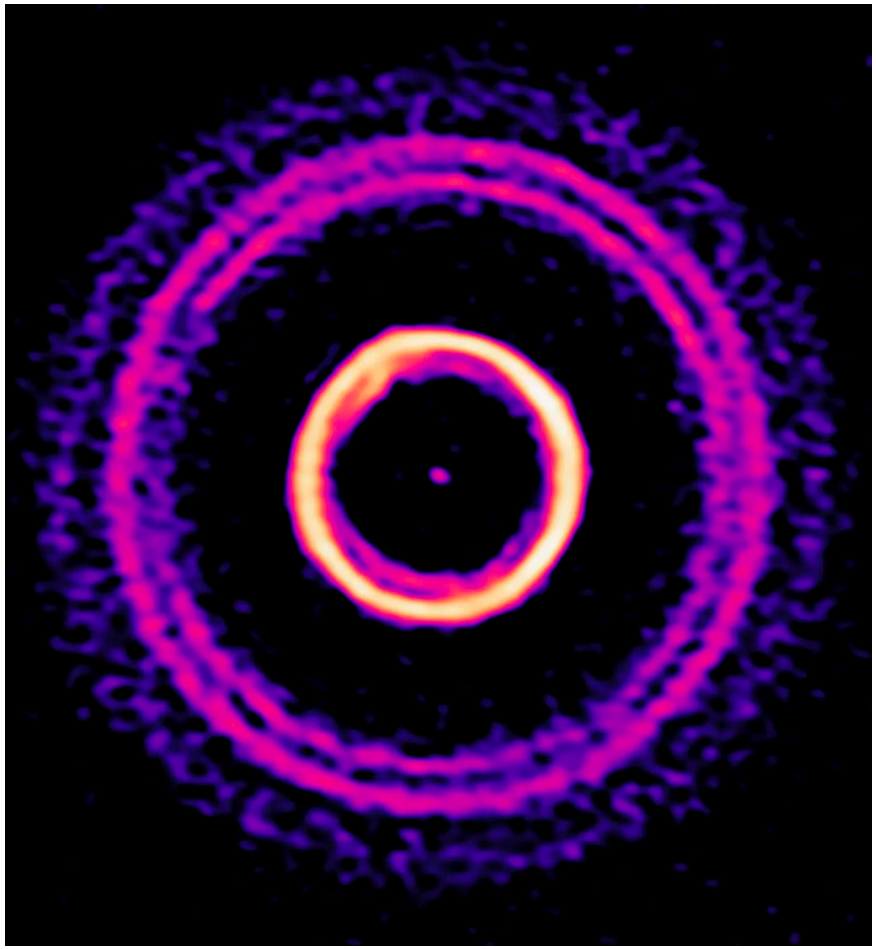
- A rogue planet, part of the group of stars co-moving with beta Pictoris

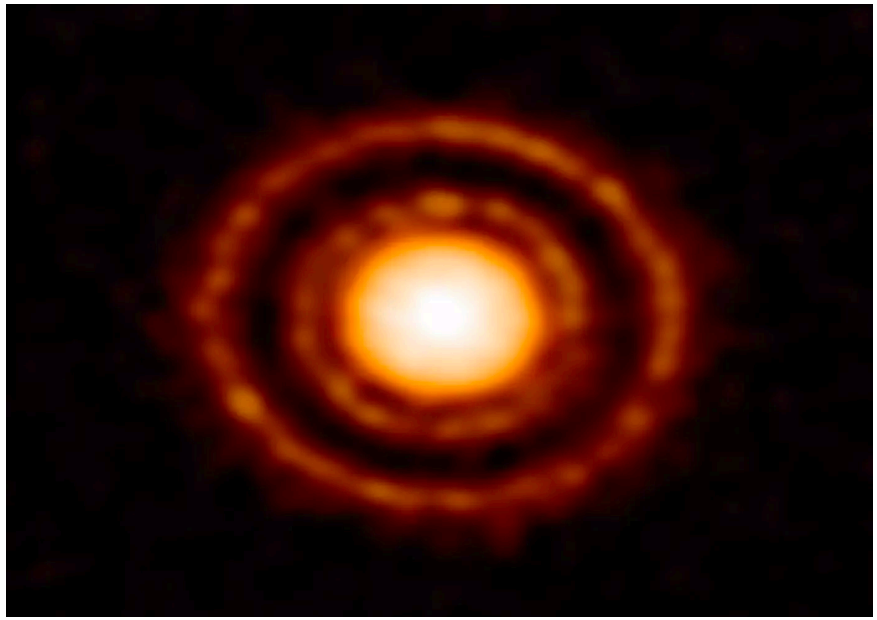
- Possibly ejected from a forming planetary system; probably quite young (~12 Myr) and still cooling from formation

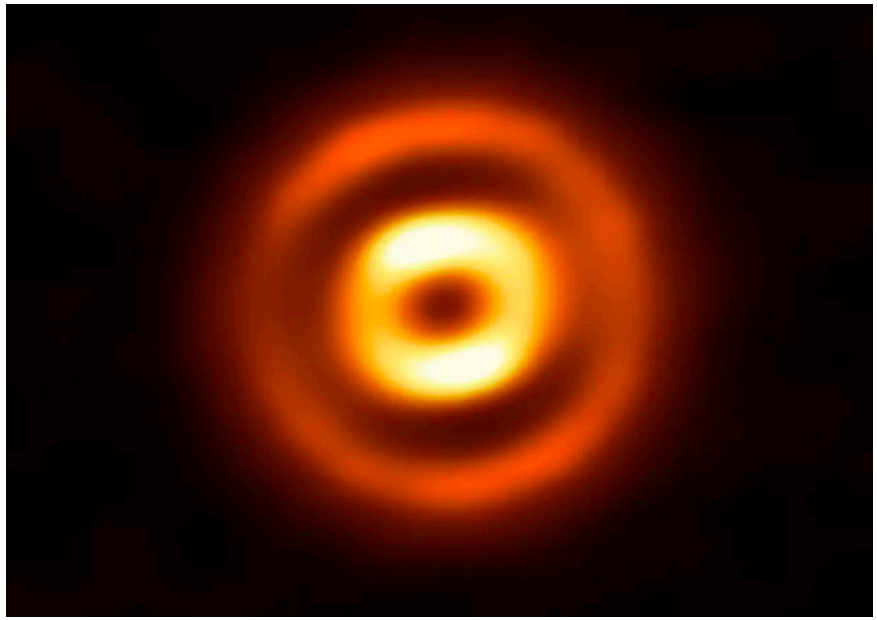


Planet-forming disks

- 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.

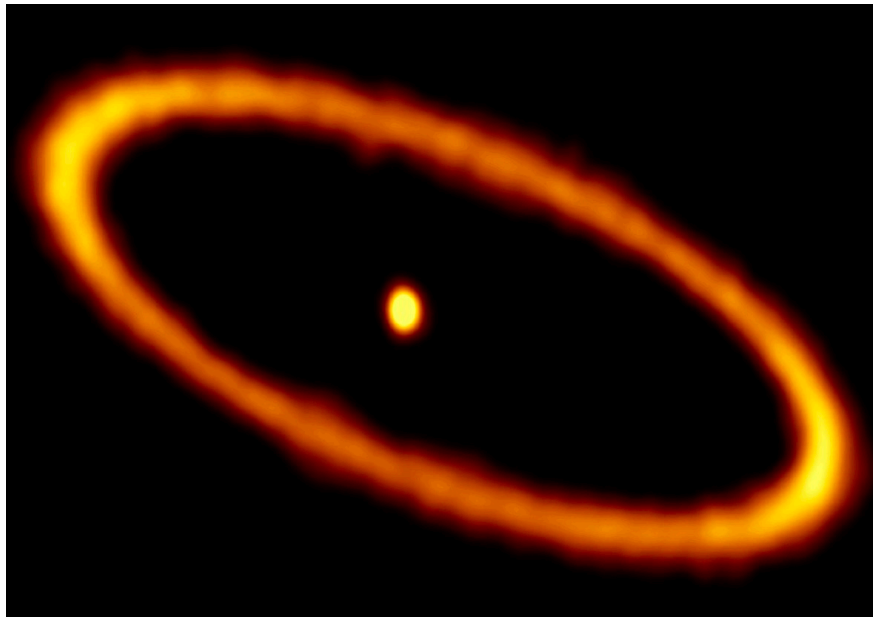






Fomalhaut, a bright young (450 Myr) star 25 ly away in the southern sky, has a disk (ring?)

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