

EXOPLANETS

Planets orbiting other suns



The Nobel Prizes in Physics 2019

James Peebles

“for theoretical discoveries in physical cosmology”

Michel Mayor and Didier Queloz

“for the discovery of an exoplanet orbiting a solar-type star”



Peebles

Mayor

Queloz



National Academy of Sciences:

Mayor and Queloz revolutionized our understanding of planetary science, led to the discovery of thousands of exoplanets, and spurred the search for extraterrestrial life in the universe

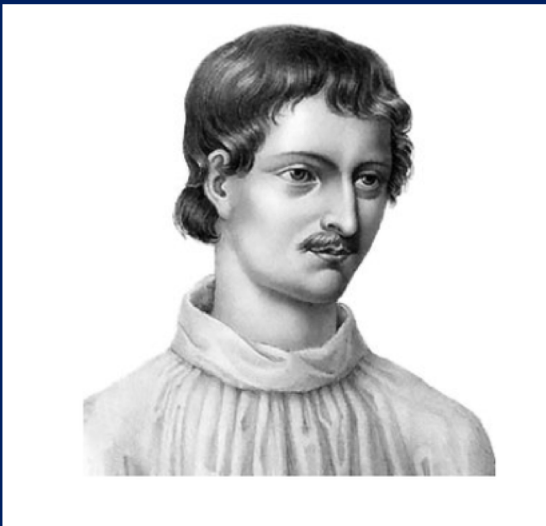


Extraterrestrial planets and planetary systems



People have been searching for life on other planets since Galileo, in the 16th Century, pointed his telescope toward the stars and discovered moons circling other planets.

His contemporary, the Dominican friar Giordano Bruno, wrote:



In space there are countless constellations, suns and planets; we see only the suns because they give light; the planets remain invisible, for they are small and dark. There are also numberless earths circling around their suns...

First exoplanet: 51 Pegasi b called 51 Peg in the constellation Pegasus

Discovered: July, 1995 from Earth

50.5 light-years away (one light year = six trillion miles)

Gas giant -- half the mass of Jupiter -- same radius

Thick, blown-up atmosphere containing silicates



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Discovered: July, 1995 from Earth

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Orbital period: 4.23 days (locked orbit)

Mercury, closest to our Sun (36 million miles),
orbits the Sun in 88 days

Distance from its sun: 5 million miles

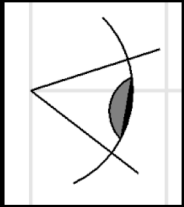
Surface temperature: 1850 F (Mercury = 800 F)

Detection method: radial-velocity or star “wobbling”

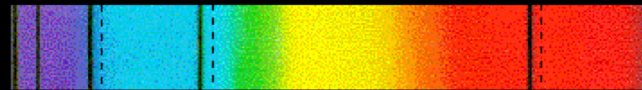


Mayor and Queloz were able to detect a wobble of only 30 miles per hour -- using the Doppler shift of light.

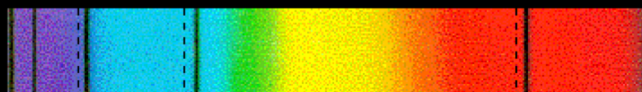
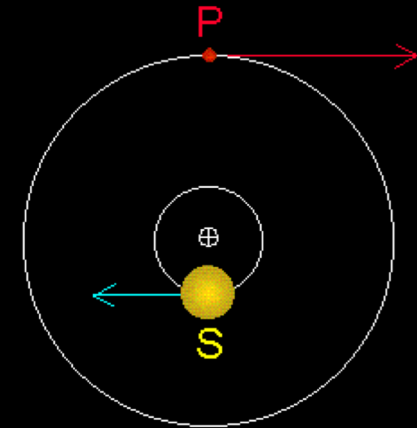
Doppler shift of star's (S) light as planet (P) orbits it



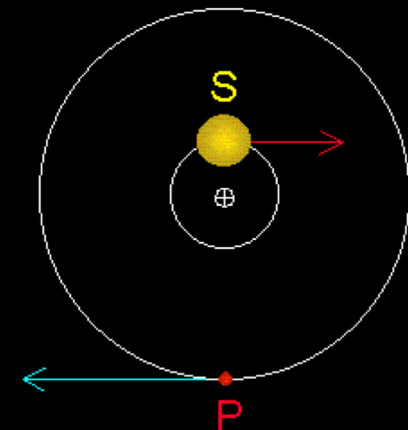
Observer



Star's spectrum shifts blueward



Star's spectrum shifts redward



EXOPLANETS

Planets orbiting other suns

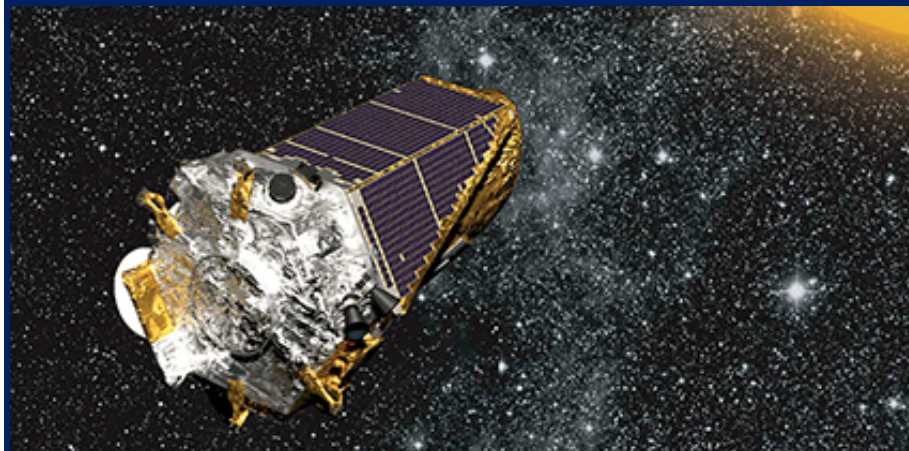
To see exoplanets well, we need to go above Earth's atmosphere. The best telescopes are:





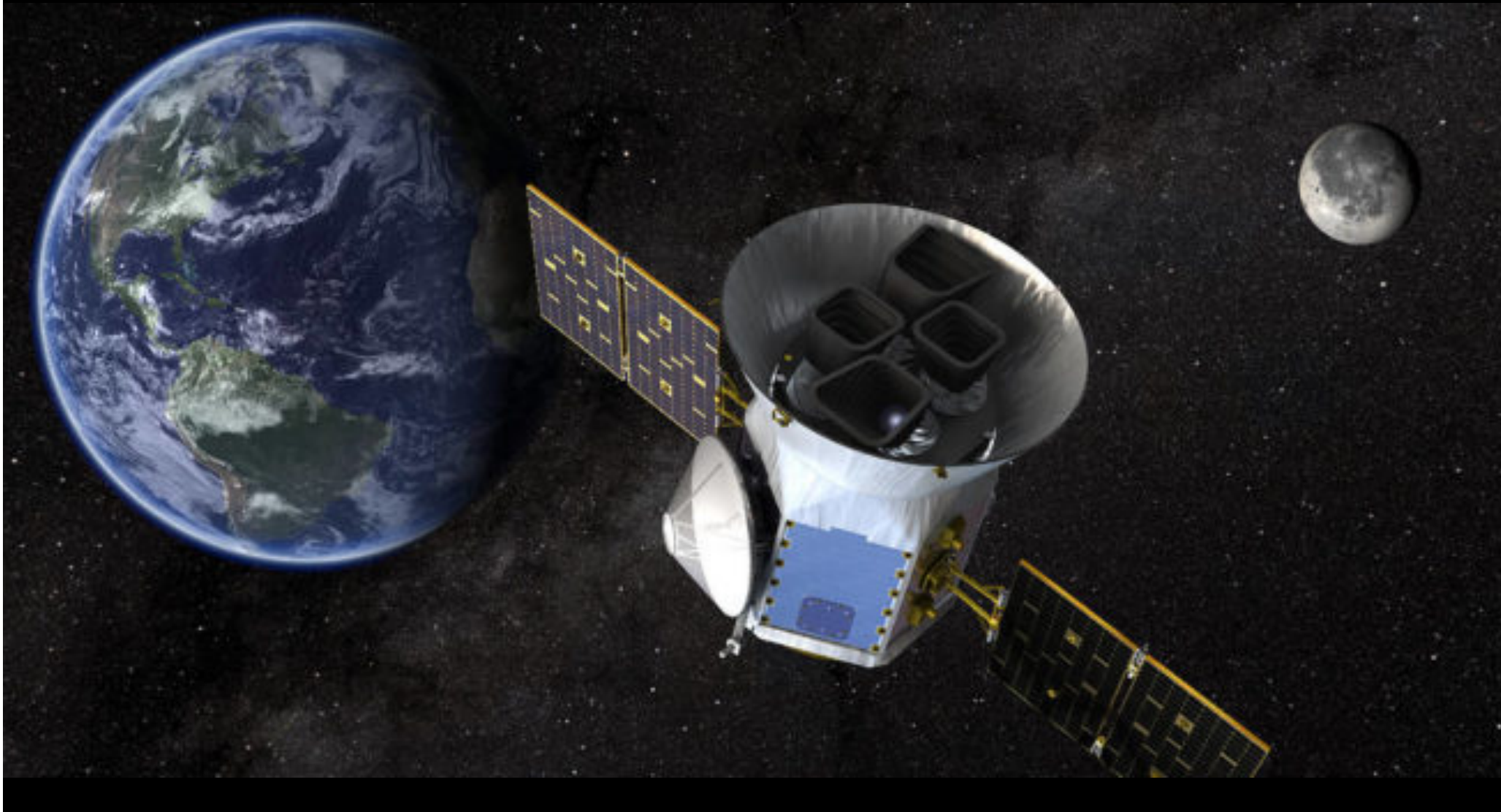
Hubble Space Telescope.
Launched 1990. Has given us
new insight into the Universe
and fabulous space images

Spitzer **Infrared** Telescope
launched 2003 and
just retired. Saw dust and
stars not visible to the
eye (seen in infrared light)

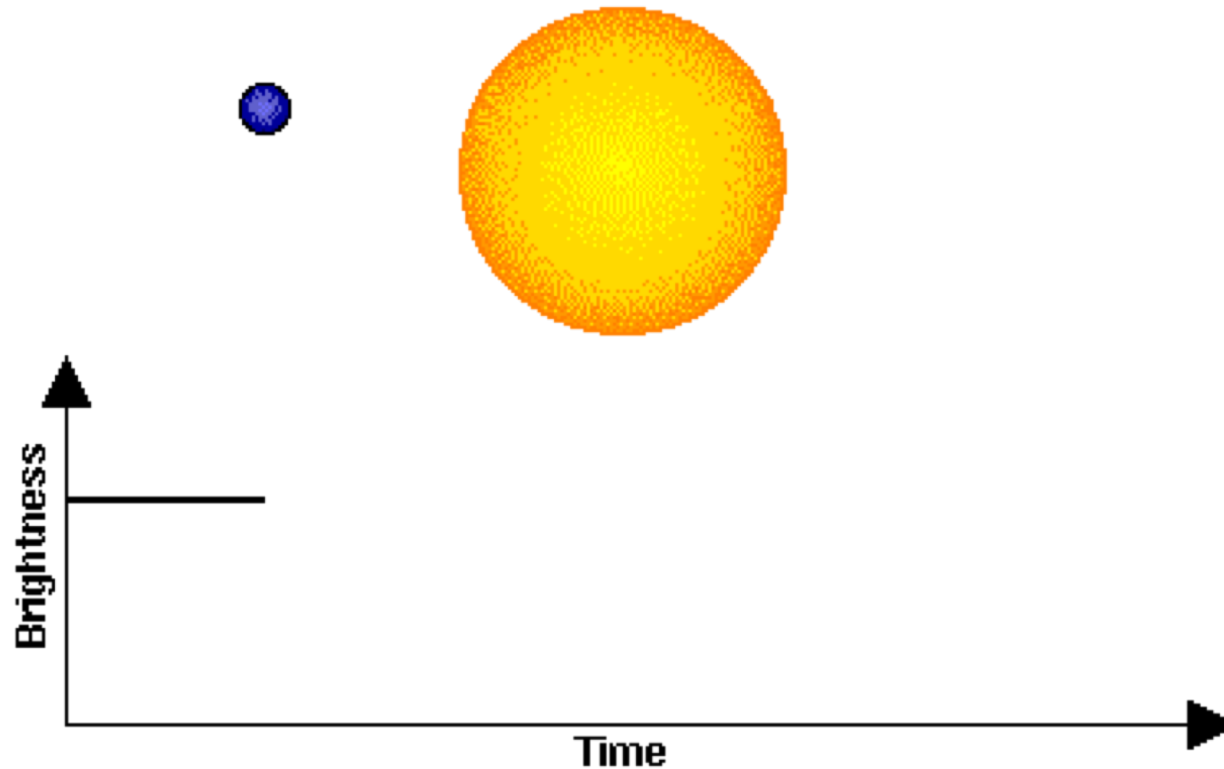


Kepler Space Telescope launched
2009, retired 2017. Designed to
find exoplanets. Observed over
.5 million stars and found 2,662
exoplanets

TESS – Transiting Exoplanet Survey Satellite – launched in 2018 to replace Kepler. Designed to search approximately 200,000 nearby stars for exoplanets and planetary systems

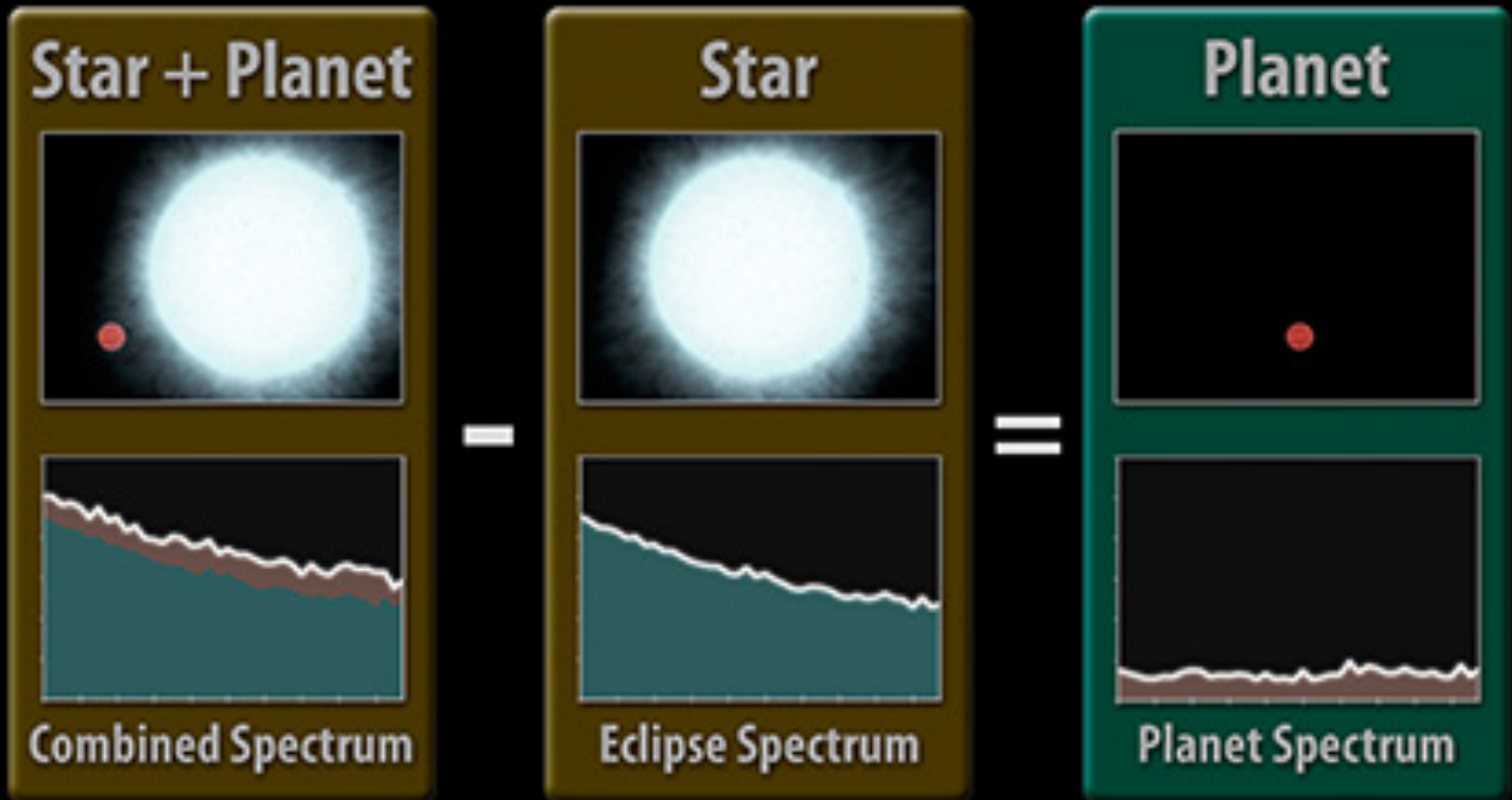


Kepler and TESS use the eclipse (transit) method to find a planet:



77% of all exoplanets have been found this way

Spitzer measured the infrared light coming from a star, then star and planet pair, then planet only:



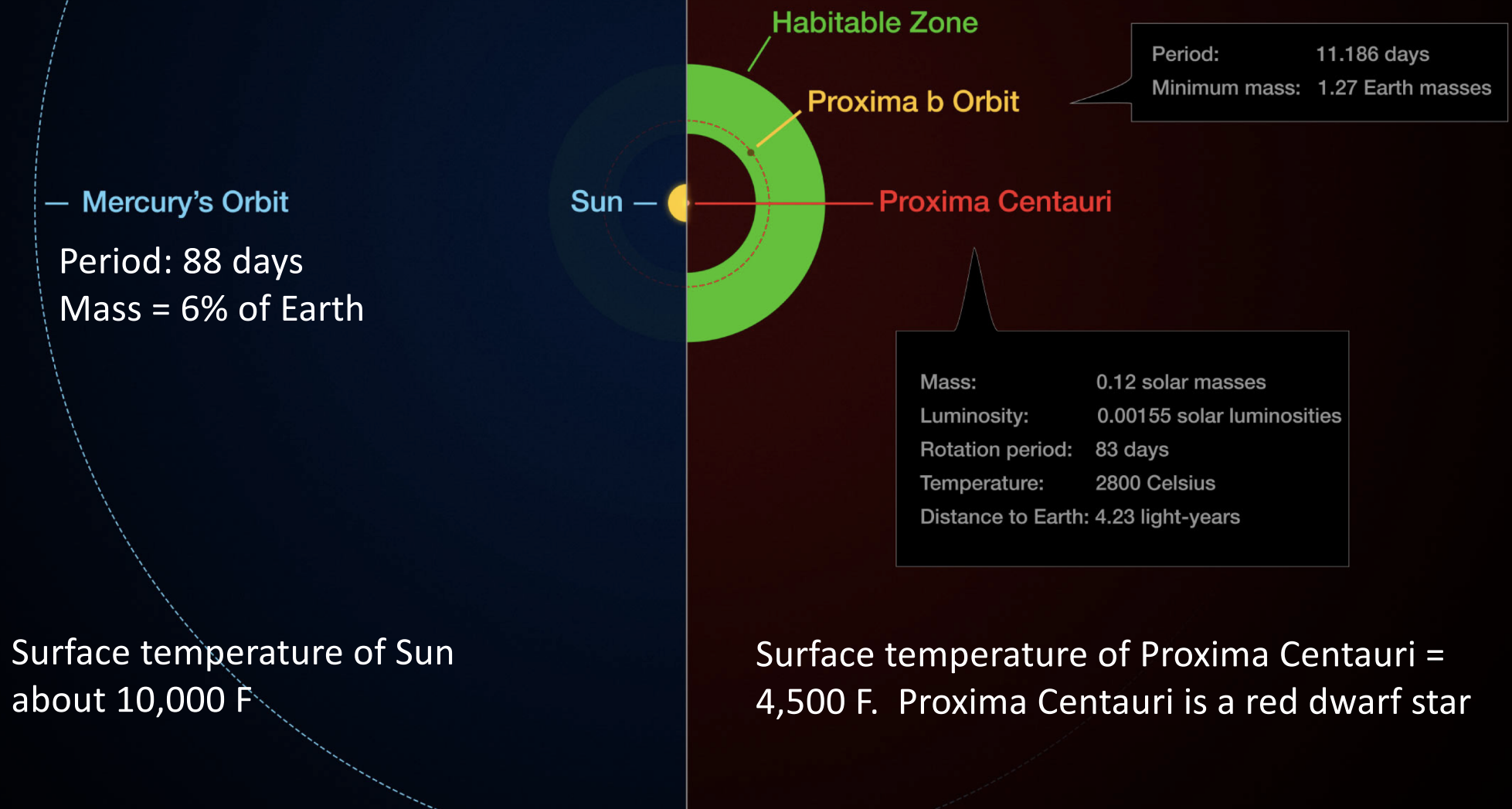
Isolating a Planet's Spectrum

As of June 2020 the space telescopes have found:

- * 4,171 exoplanets + 4,562 unconfirmed
- * **3,079 star systems with one to eight planets**
- * 60+ **two-star** systems with one planet
- * 20+ **three-star** systems with one planet
- * 4 **three-star** systems with **three** planets
- * 2 **three-star** systems with **FIVE** planets
- * 2 **four-star** systems with one planet

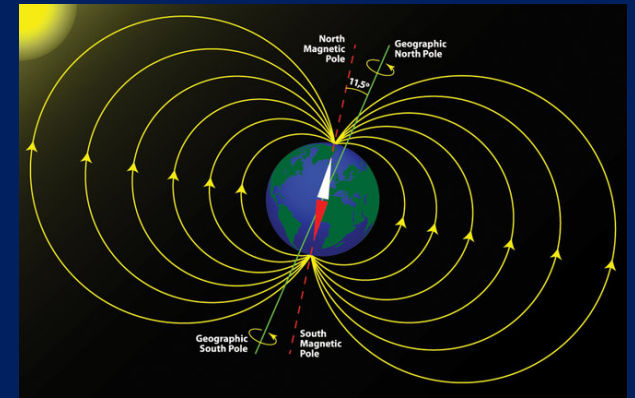
Nearest exoplanet and nearest neighbor: *Proxima Centauri b*, an Earth-sized planet which orbits its host star *Proxima Centauri* in 11 days. 4.2 light-years away

The habitable zone around a star is where an Earth-like planet can have liquid water and possibly support life as we know it.



What is needed for life?

An Earth-like planet, i.e., rocky surface, atmosphere, a magnetic field, and water



Some 40 billion Earth-sized, Earth-like planets orbit in the habitable zones of Sun-like stars in the Milky Way

But human-like life has occupied only 1/10000 of life of sun

EXOPLANETS

A planet orbiting another sun

Characteristics



4171 Confirmed Exoplanets

Terrans

Giants

160

1293

1395

1317

Miniterran
Mercury-size

Subterranean
Mars-size

Terran
Earth-size

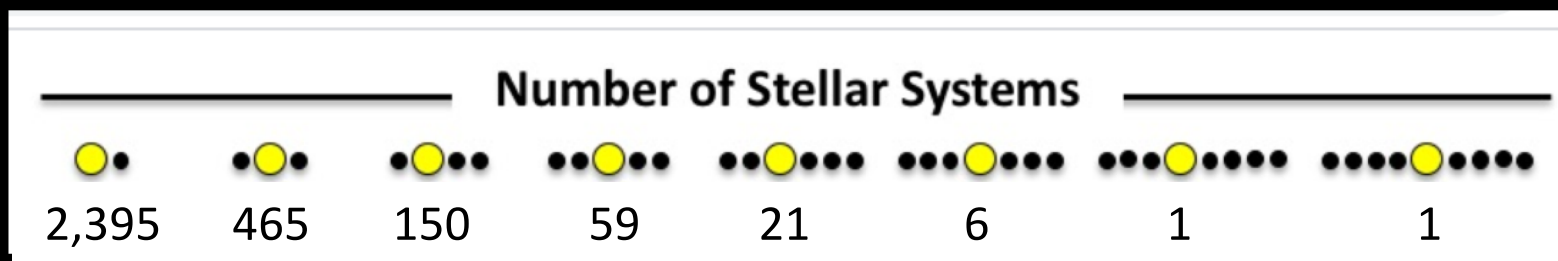
Superterranean
*Super-Earths and
Mini-Neptunes*

Neptunian
Neptune-size

Jovian
Jupiter-size

Ca. 2/3 are giants

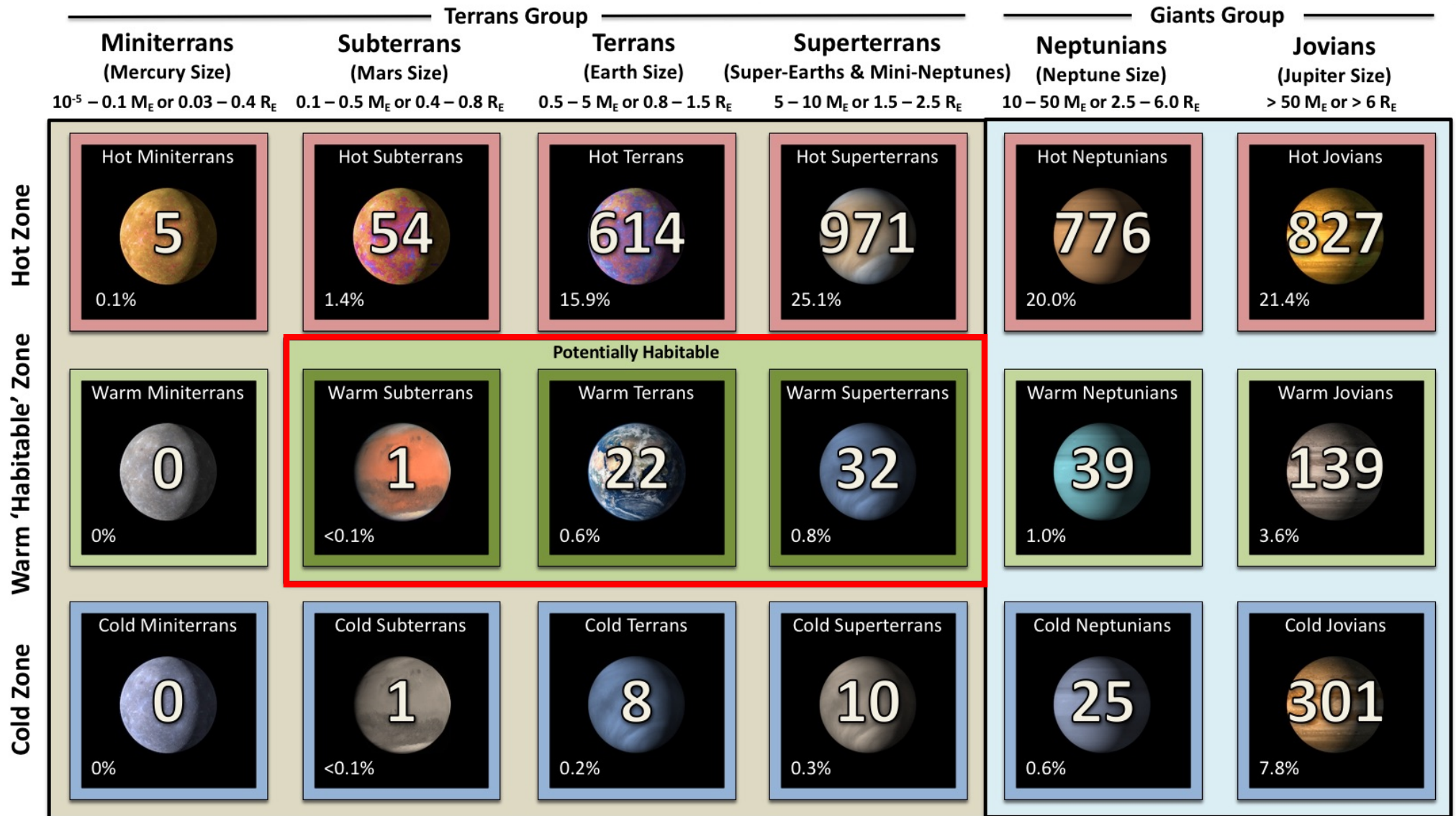
Credit: PHL @ UPR Arcibo (phl.upr.edu) Nov 2017





The Periodic Table of Exoplanets

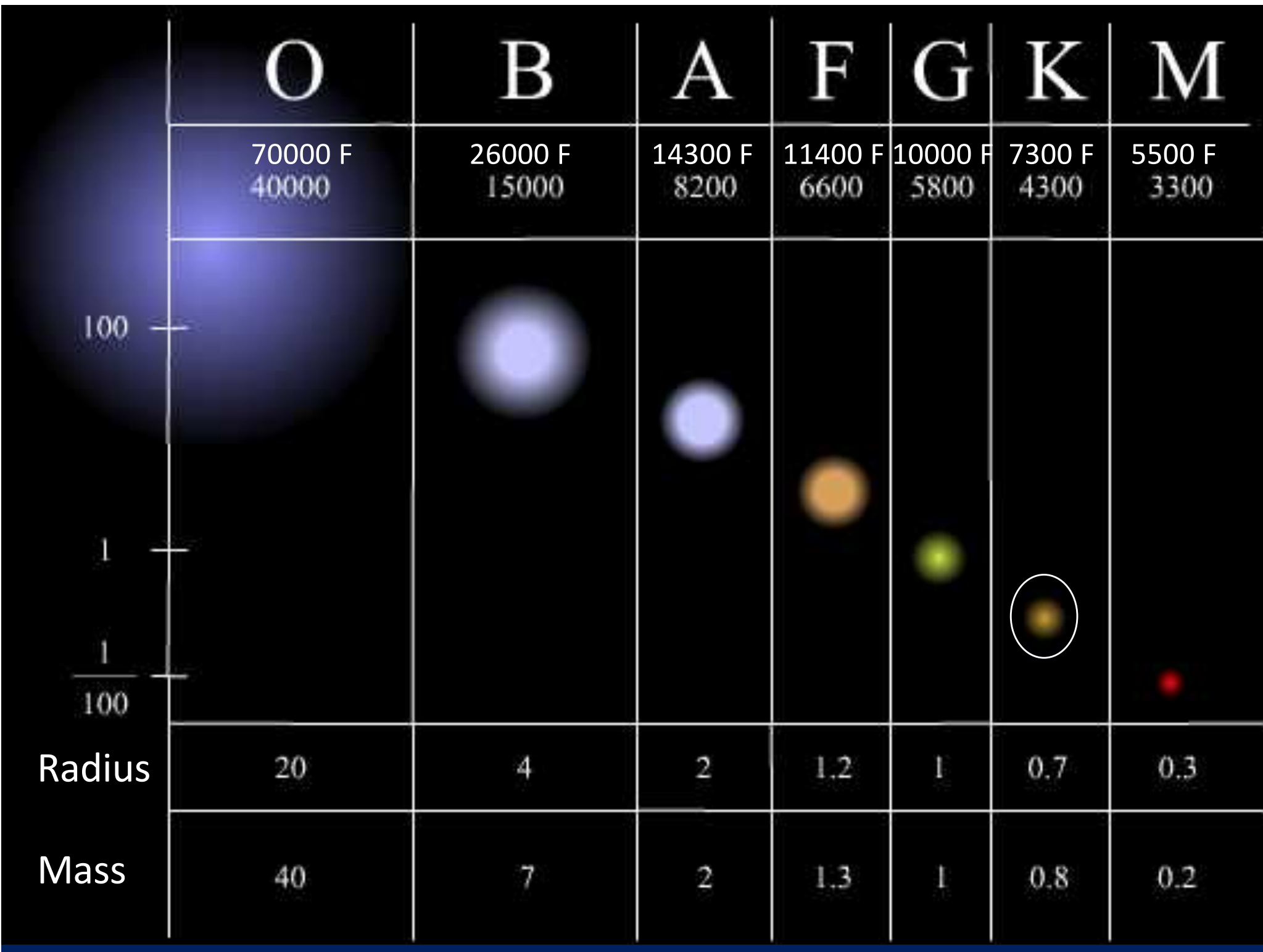
Over 3800 Exoplanets July, 2018



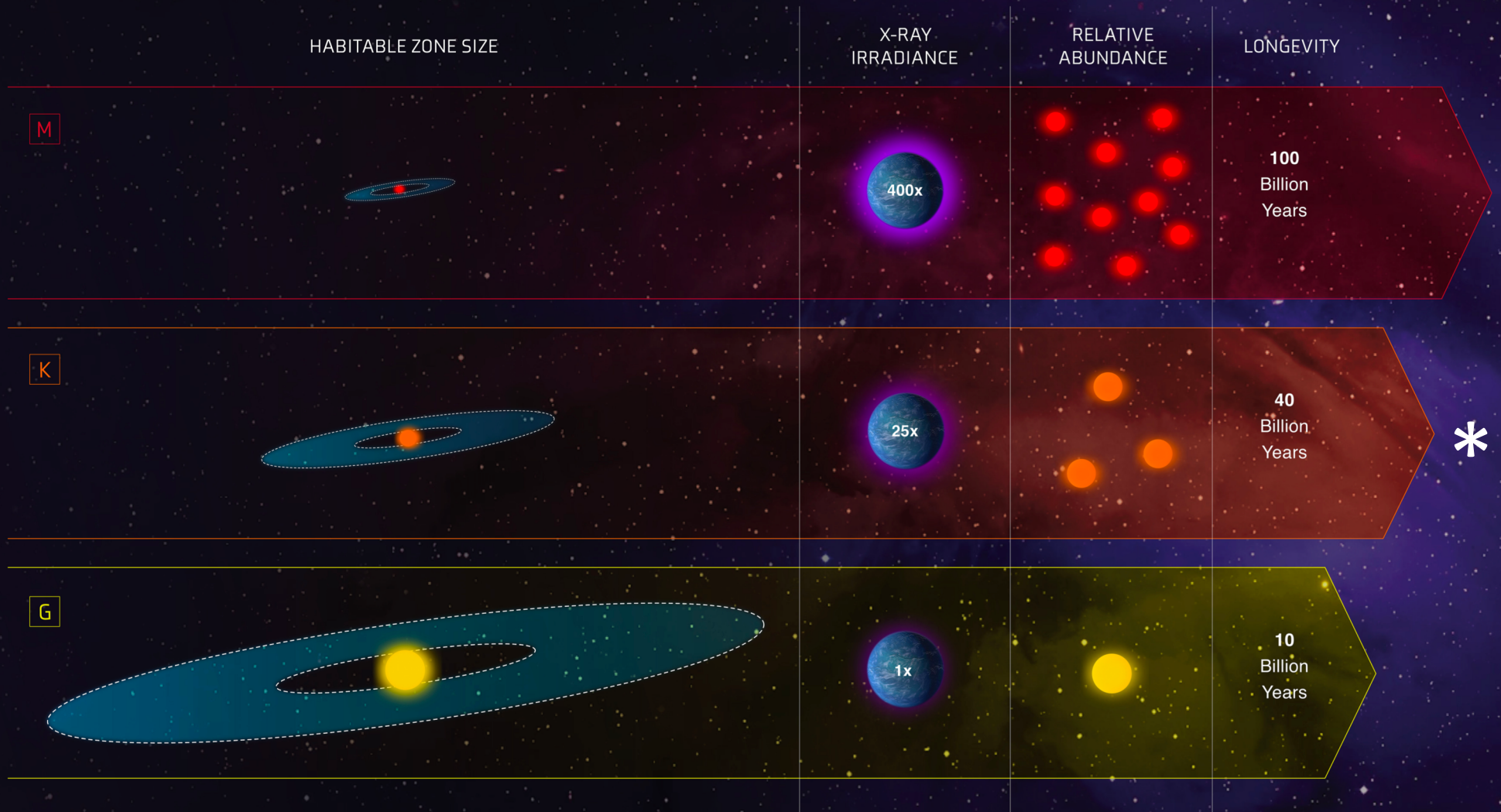
M_E = Earth Mass, R_E = Earth Radius

CREDIT: PHL @ UPR Arcibo (phl.upr.edu) Jul 2018

Ca. 300 more exoplanets have been confirmed as of June 2020

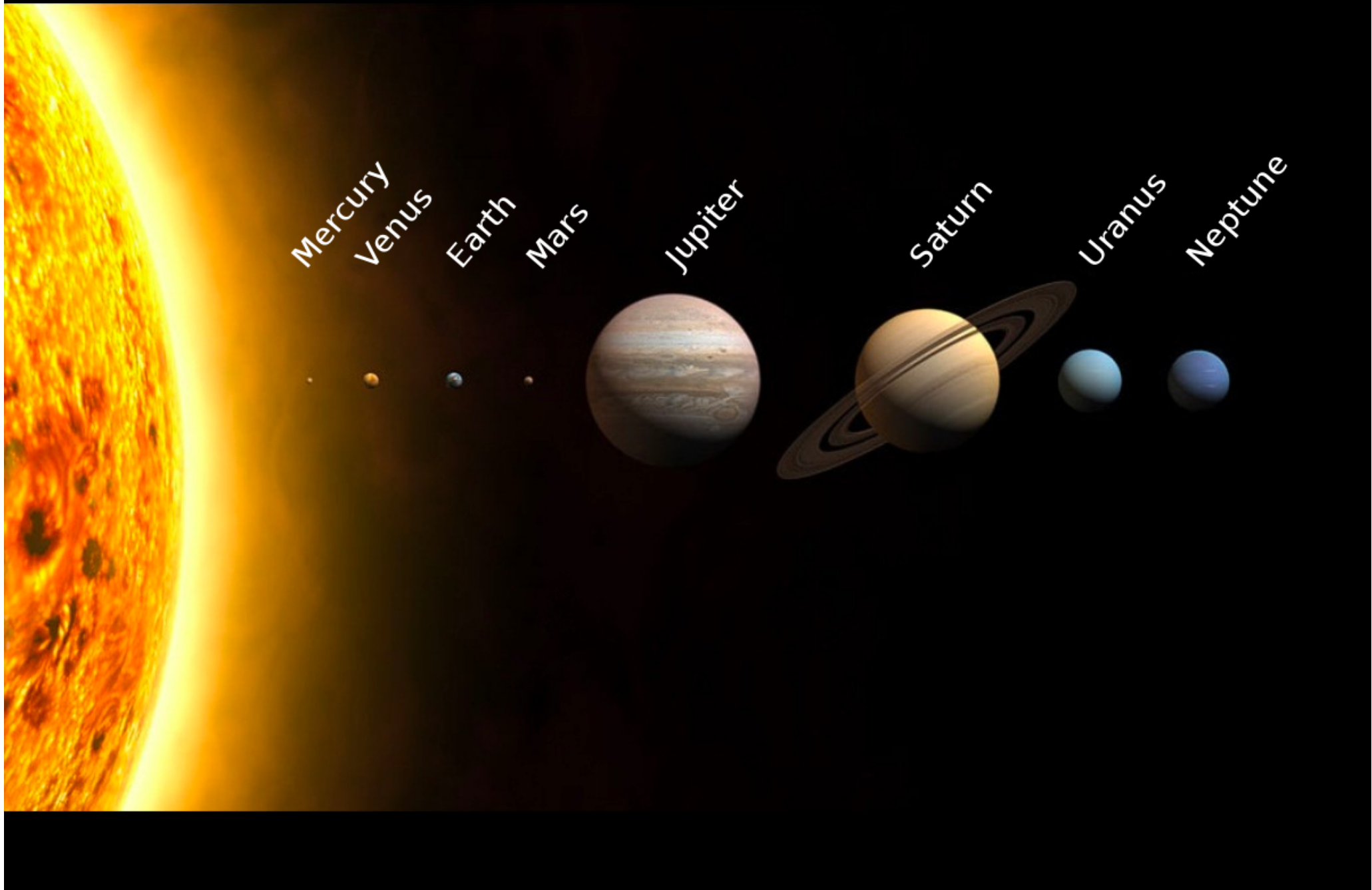


K stars: The optimal host stars for planets



K stars: Surface temperatures 7000F good for habitability
Radiation: 5-25 x Sun (not good)
13% of total number of stars in our Galaxy

The Solar System (not to scale)



Kepler-62 System

- * Five-planet system about 1,200 light-years from Earth in the constellation Lyra (the Lyre)
- * Orbiting a K2* dwarf star (orange)



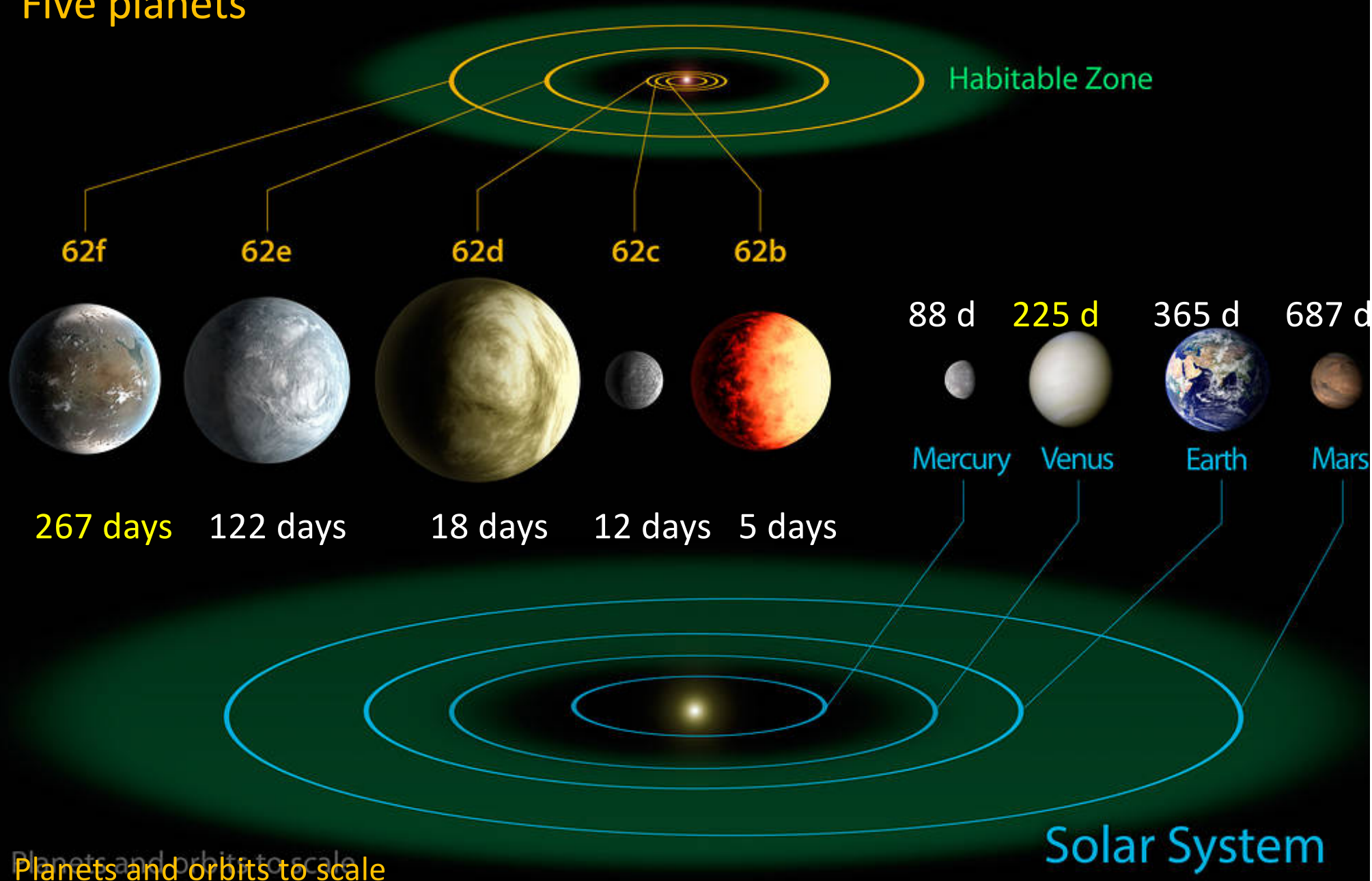
Kepler-62 System, cont.

- * Five-planet system about 1,200 light-years from Earth in the constellation Lyra (the Lyre)
- * Orbiting a K2 dwarf star about 7000 F
- * 2/3 of Sun's mass
- * Two planets, Kepler-62f and Kepler-62e, in habitable zone (the region around a star in which an Earth-like planet can possess liquid water and possibly support life)
- * Kepler-62f is 40% and Kepler-62e is 60% larger than Earth

Kepler-62 System

Five planets

1,200 light-years away

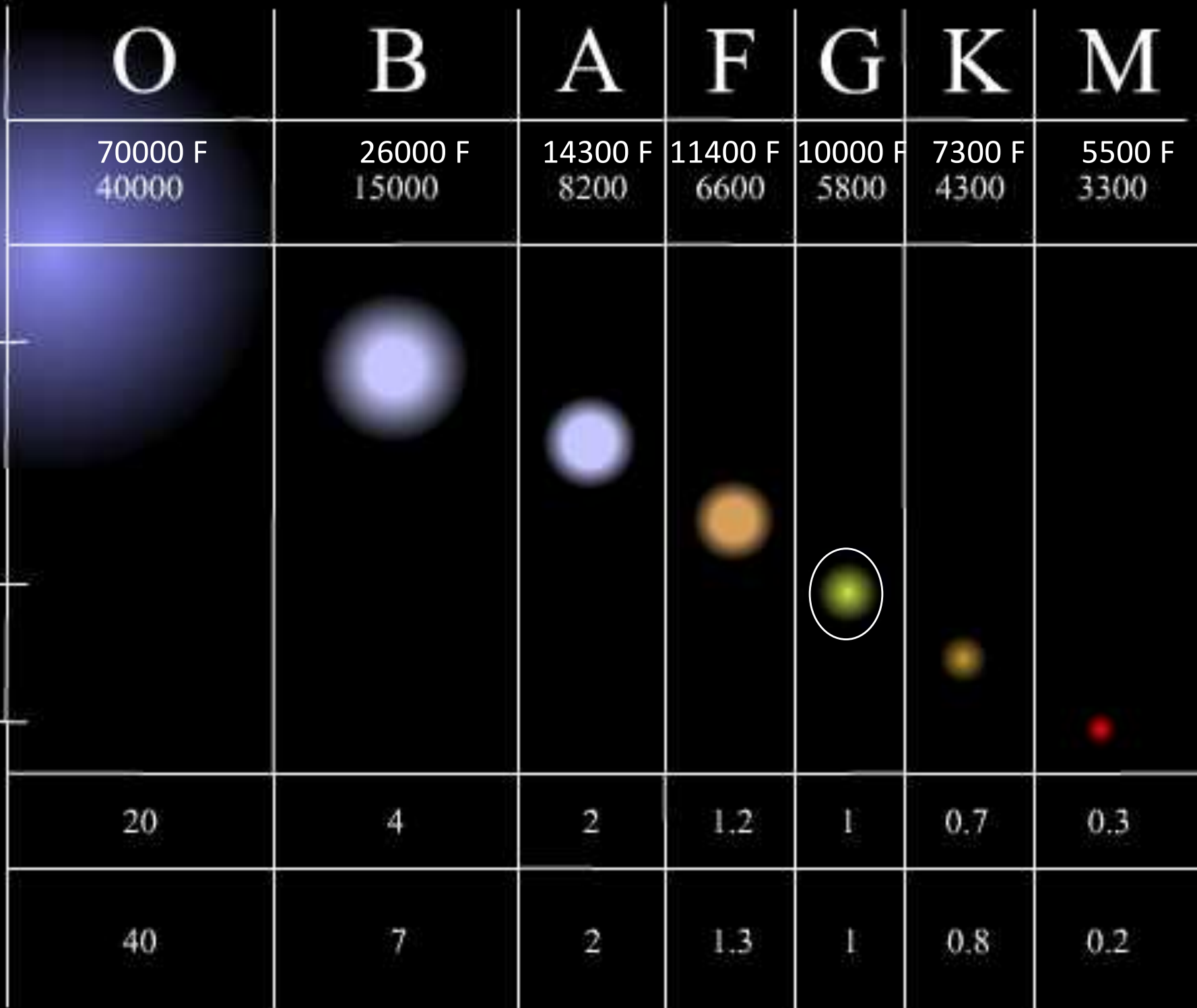


Kepler-69 System

- * Two-planet system about 2,700 light-years from Earth in the constellation Cygnus (the Swan)

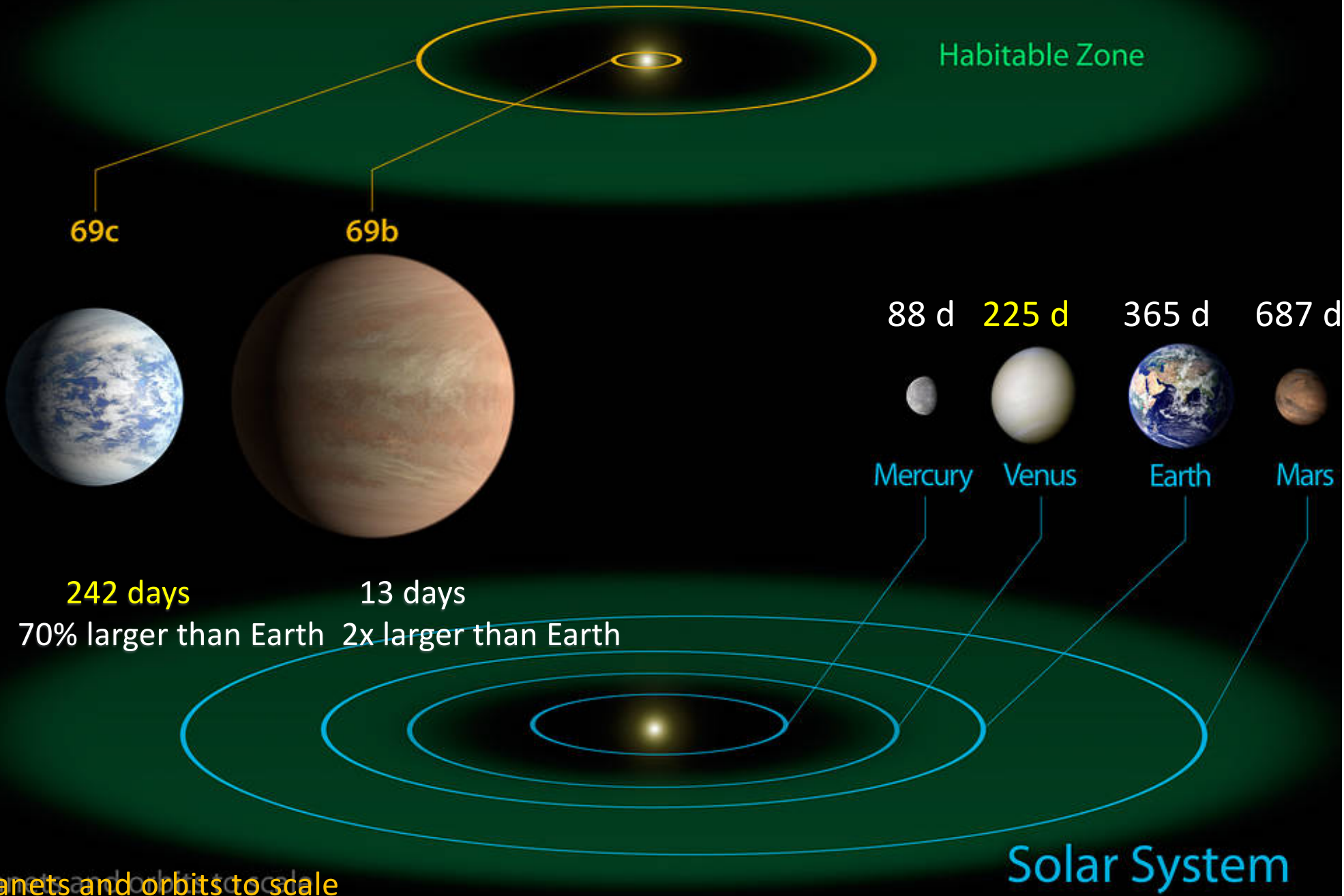


- * Orbiting a **G star like our Sun, about 10,000 F**
- * One planet, Kepler-69c barely in the habitable zone
- * Kepler-69c is 70% larger than the Earth



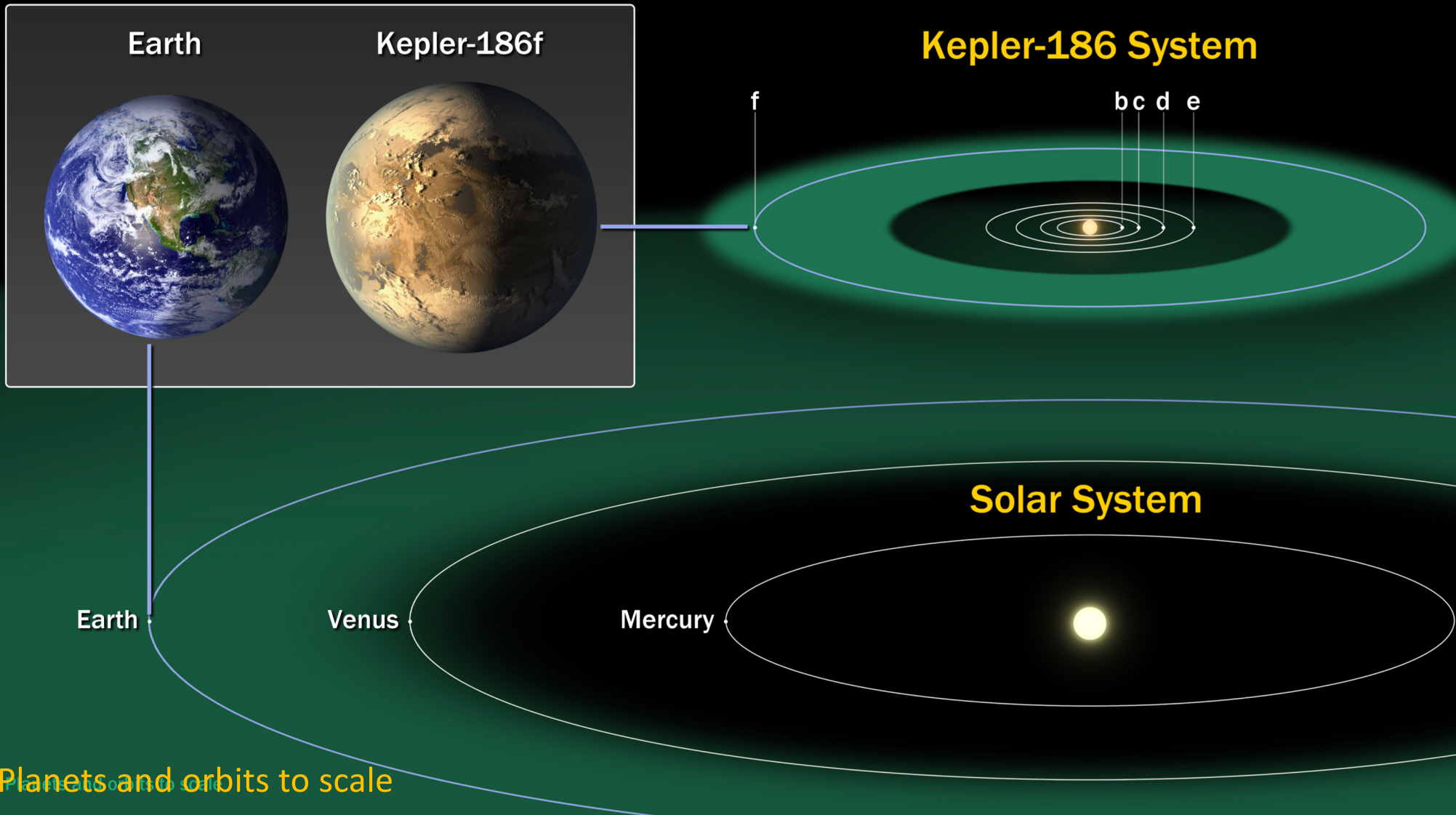
Kepler-69 System

2,700 light-years away



Kepler-186

5 planets, 4 very close to the M star (3000 F) 500 light-years away



1,400 light-years
one planet

Kepler-452 System

500 light-years away
5 planets, 4 very
close to the M star

Kepler-186 System

Solar System

Mass: 5x Earth
Orbit: 385 days

Kepler-452b

Kepler-186f

130 days

Mercury Venus

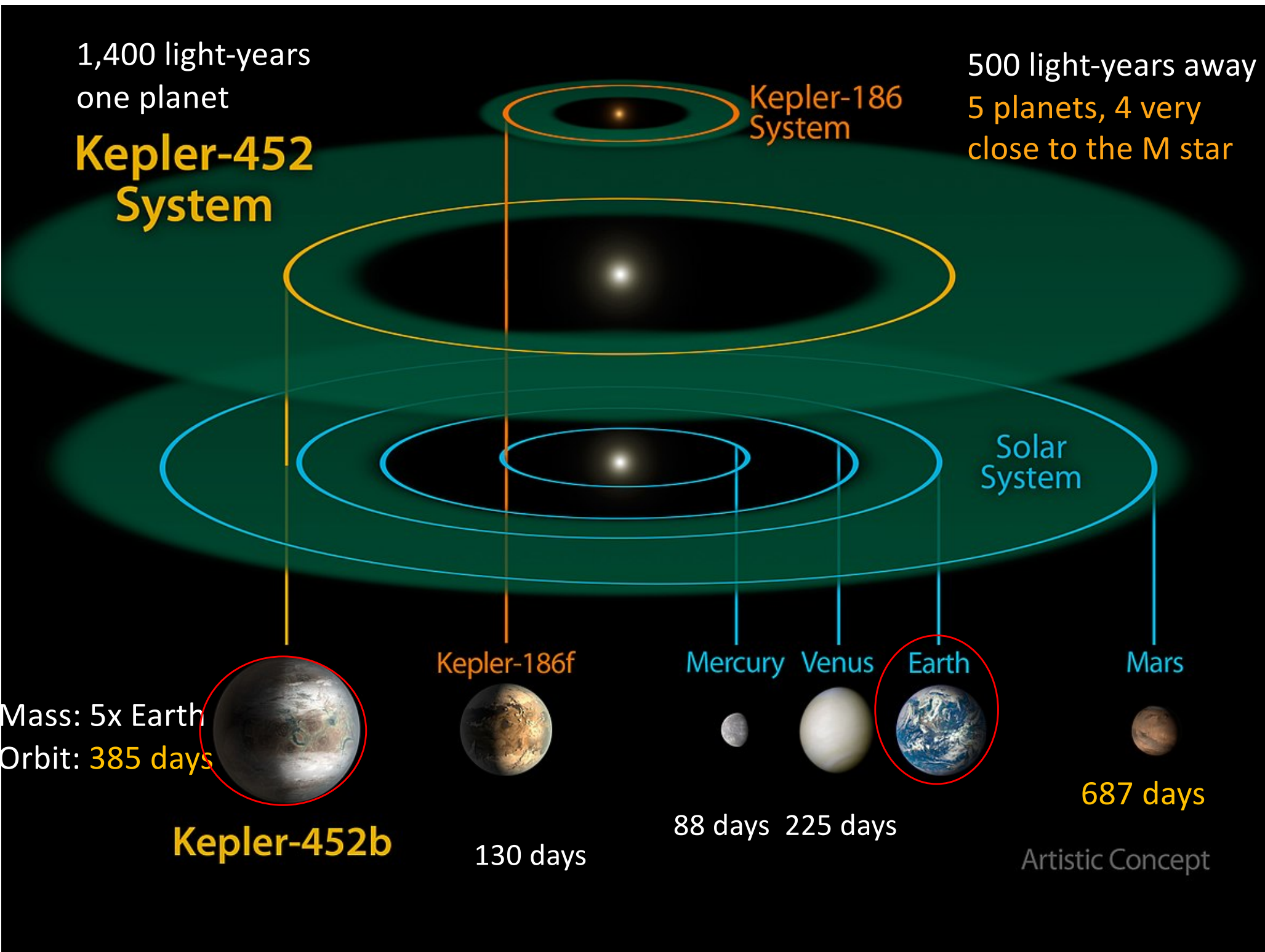
88 days 225 days

Earth

Mars

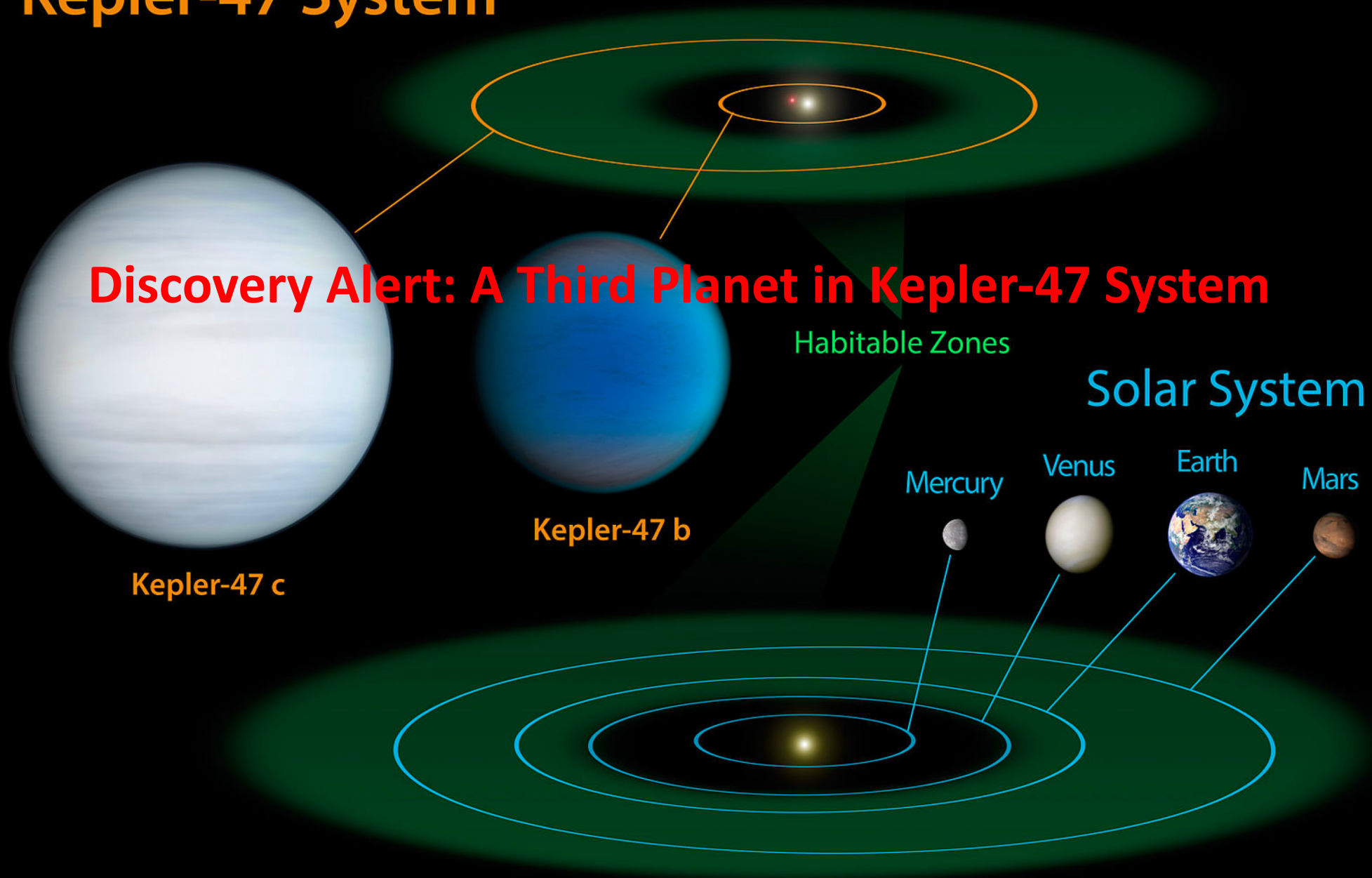
687 days

Artistic Concept



Kepler-47 System

****Two planets orbiting two stars****



Discovery Alert: A Third Planet in Kepler-47 System

Habitable Zones

Solar System

Kepler-47 c

Kepler-47 b

Mercury

Venus

Earth

Mars

Planets and orbits to scale

Kepler 16b: A planet orbiting TWO stars

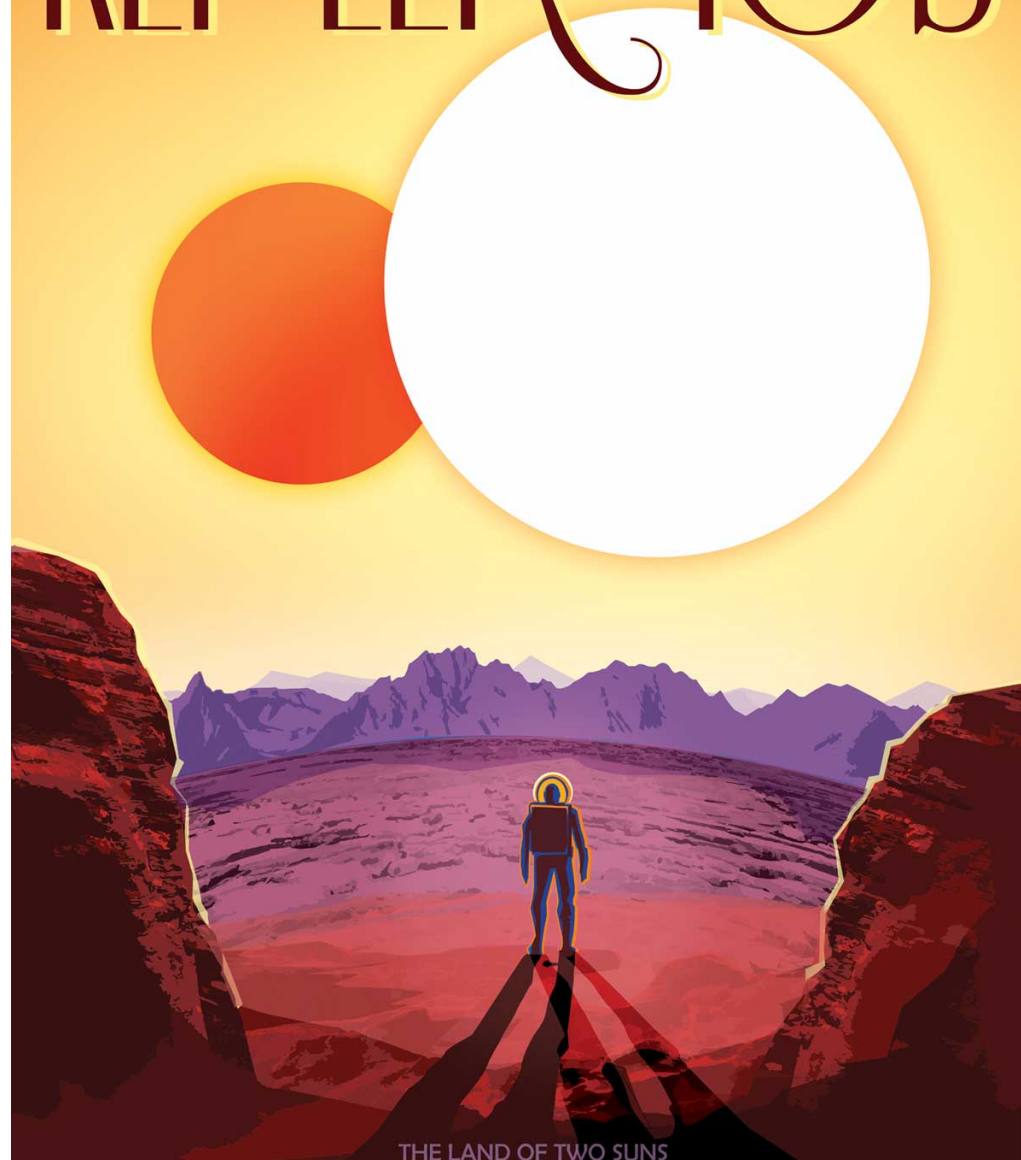


Kepler

*NASA's Kepler Mission
Discovers Planet Orbiting
Two Stars*



RELAX ON
KEPLER-16b



THE LAND OF TWO SUNS

WHERE YOUR SHADOW ALWAYS HAS COMPANY

Kepler-90 System Planet Sizes

(Artist's Concepts)

Kepler-90b

Kepler-90c

Kepler-90i

Kepler-90d

Kepler-90e

Kepler-90f

Kepler-90g

Kepler-90h

*A Solar System copy

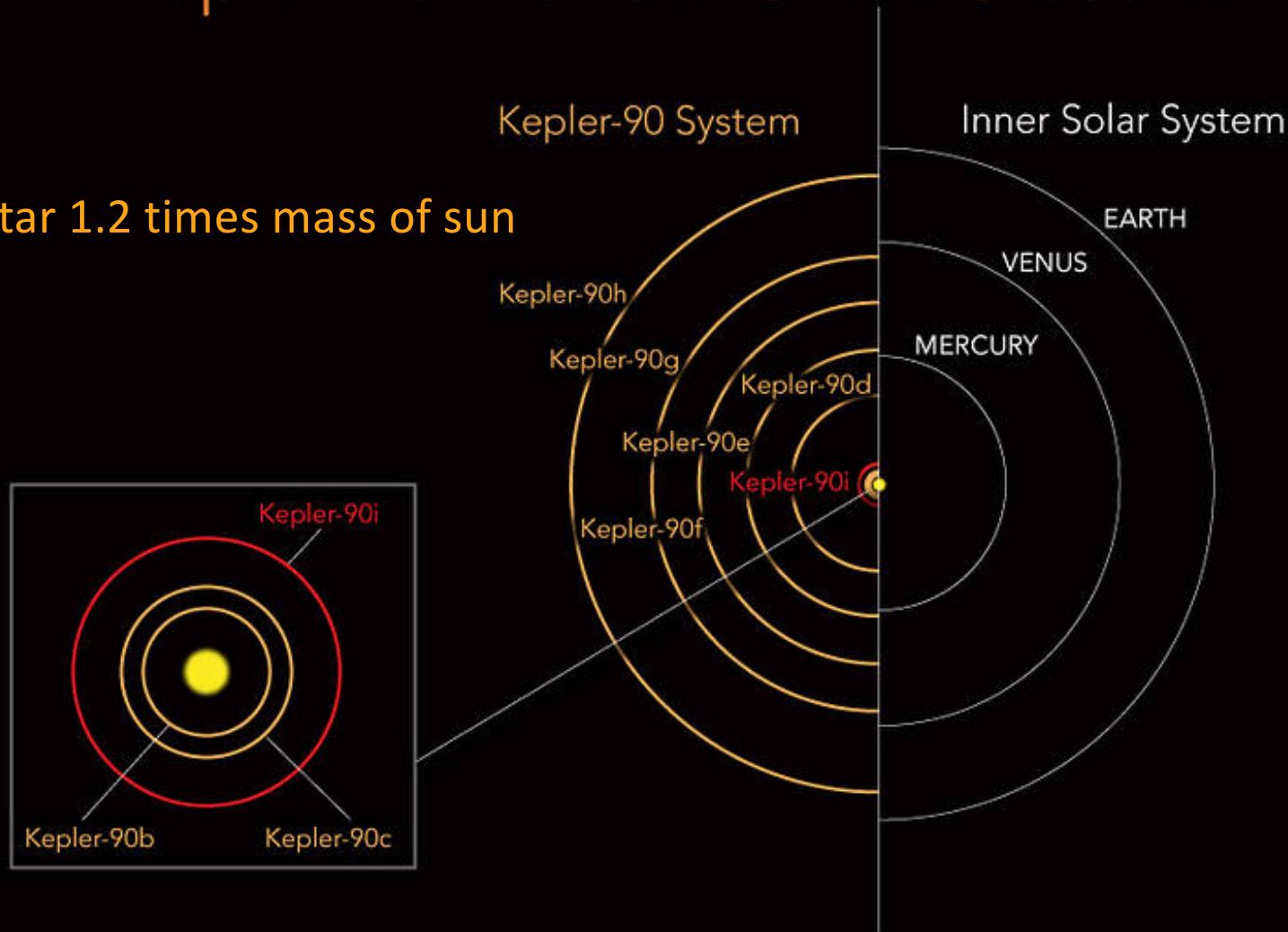
Solar System

Planet sizes are to scale, distances are not

Kepler-90 is an **eight planet system**, discovered in 2013, 2,544 light-years away. Last planet found in Dec. 2017

Kepler-90 Planets Orbit Close to Their Star

Star 1.2 times mass of sun



The inner planets have extremely tight orbits with a “year” on **Kepler-90i** lasting only 14.4 days. In comparison, Mercury’s orbit is 88 days. **Kepler-90i** has an average surface temperature of **800 degrees F**

Could Kepler-90 Have More Planets?

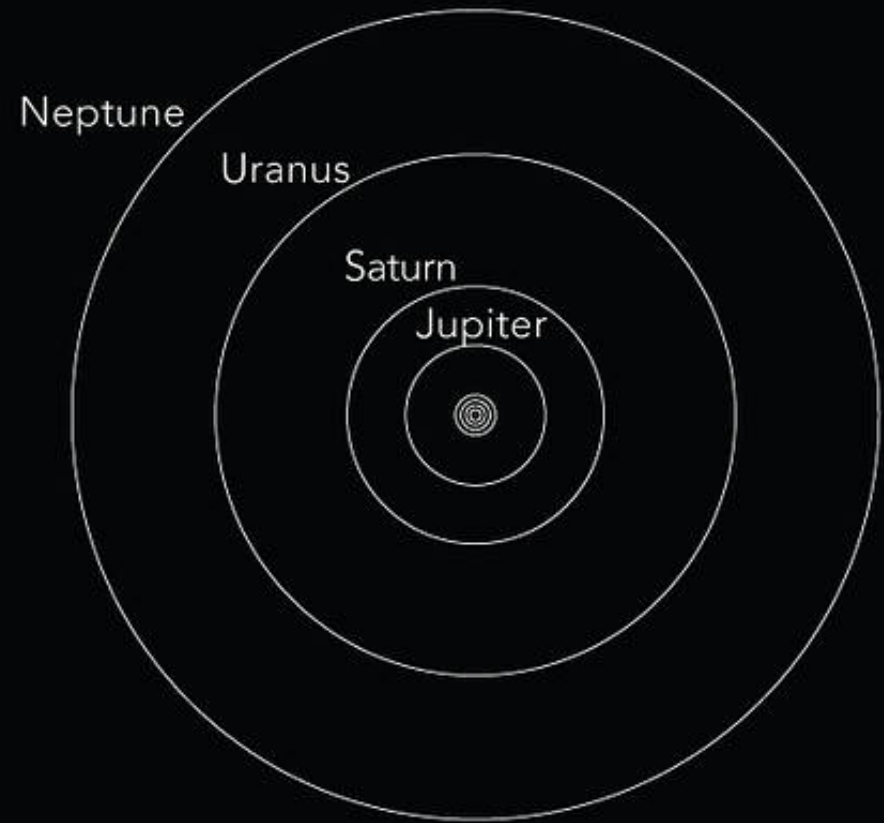
Kepler-90 System

Searched by Kepler



Not searched by Kepler

Solar System



Absolutely!

The Kepler-160 Planetary System, discovered 2010 (+2014) 3,141 light years away

The star Kepler-160: almost same size and luminosity as our Sun (9500 F)

Two planets:

Planet b:

Potentially rocky

3 x mass of Earth

1.5 x radius of Earth

Orbital period: 3.4 days

A hot hell

Planet c:

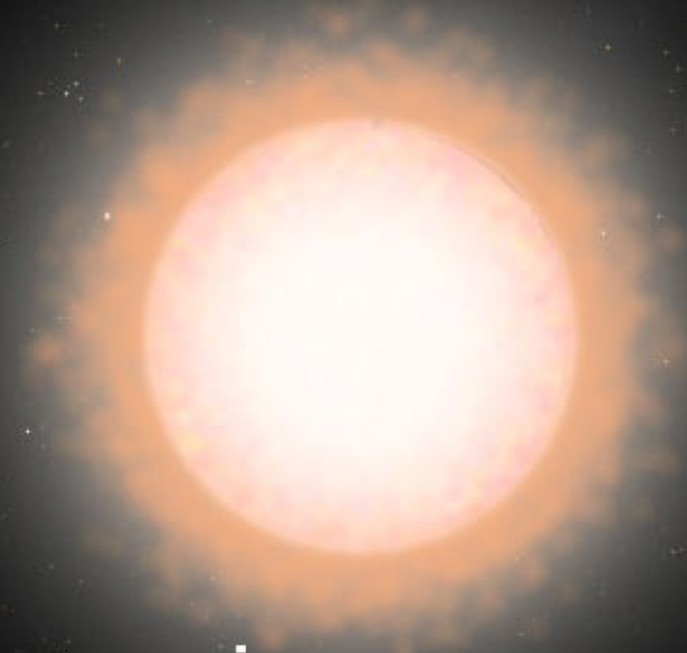
Gas giant

13 x mass of Earth

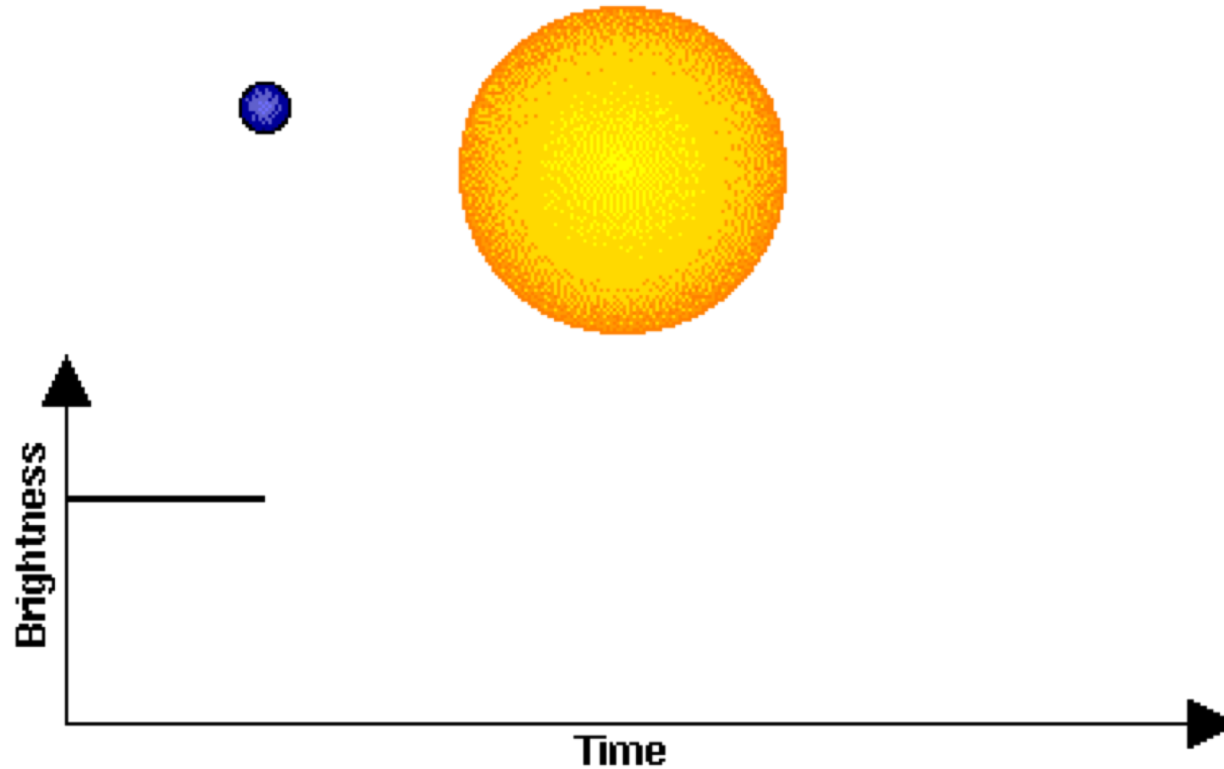
3 x radius of Earth

Orbital period: 13.7 days

A hot hell



Kepler used the eclipse (transit) method to find the planets



The Kepler-160 Planetary System: 2020, two more planets!

Planet e:

- * Potentially rocky
- * Habitable zone
- * 1.9 x radius of Earth
- * Orbital period: 378 days
- * Earth-like temperature atmosphere, water, 42 F

Planet d:

1-100 x mass of Earth
Orbital period: 7-50 days
non-transiting

One of the most amazing planetary systems yet:

TRAPPIST-1: a stellar system with 7 planets
40 light-years away

Discovered Feb. 2017



TRAPPIST-1 is an ultra cool red dwarf star

Age: between 5.4 and 9.8 billion years

Temperature: 4200 F (Sun = 10,000 F)

Mass: 8% of Sun

A Once in a Lifetime Adventure

TRAPPIST-1

Planetary System



Within 40 light-years of Earth

BOOK NOW www.trappisttours.com

TRAPPIST = TRAnsiting Planets and Planetesimals

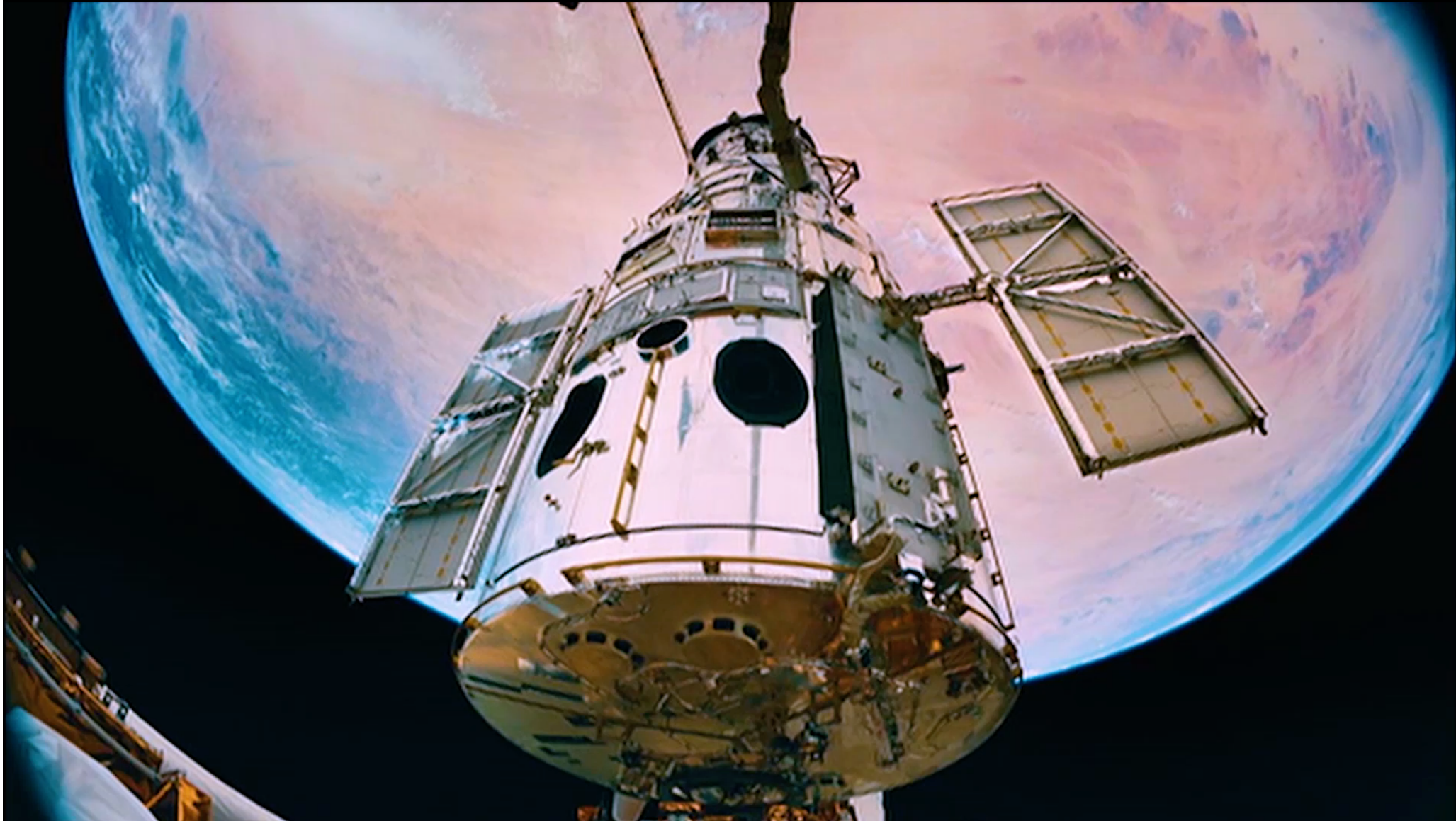
Small Telescope in Chile. **ALSO**

a Belgian controlled telescope associated with the famous Trappist beer, which the astronomers who discovered the planetary system drank to toast to their discovery.

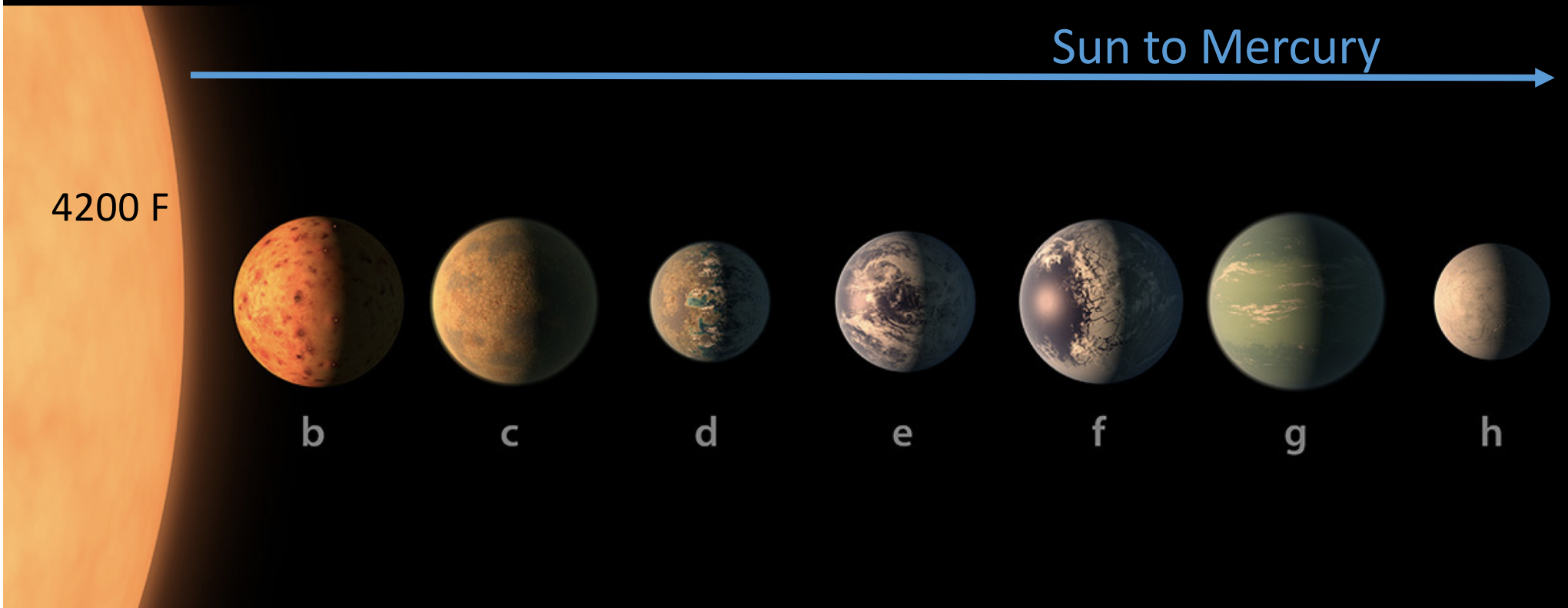


N.B. Also available with Trappist fruit cake.

TRAPPIST 1 Planetary system



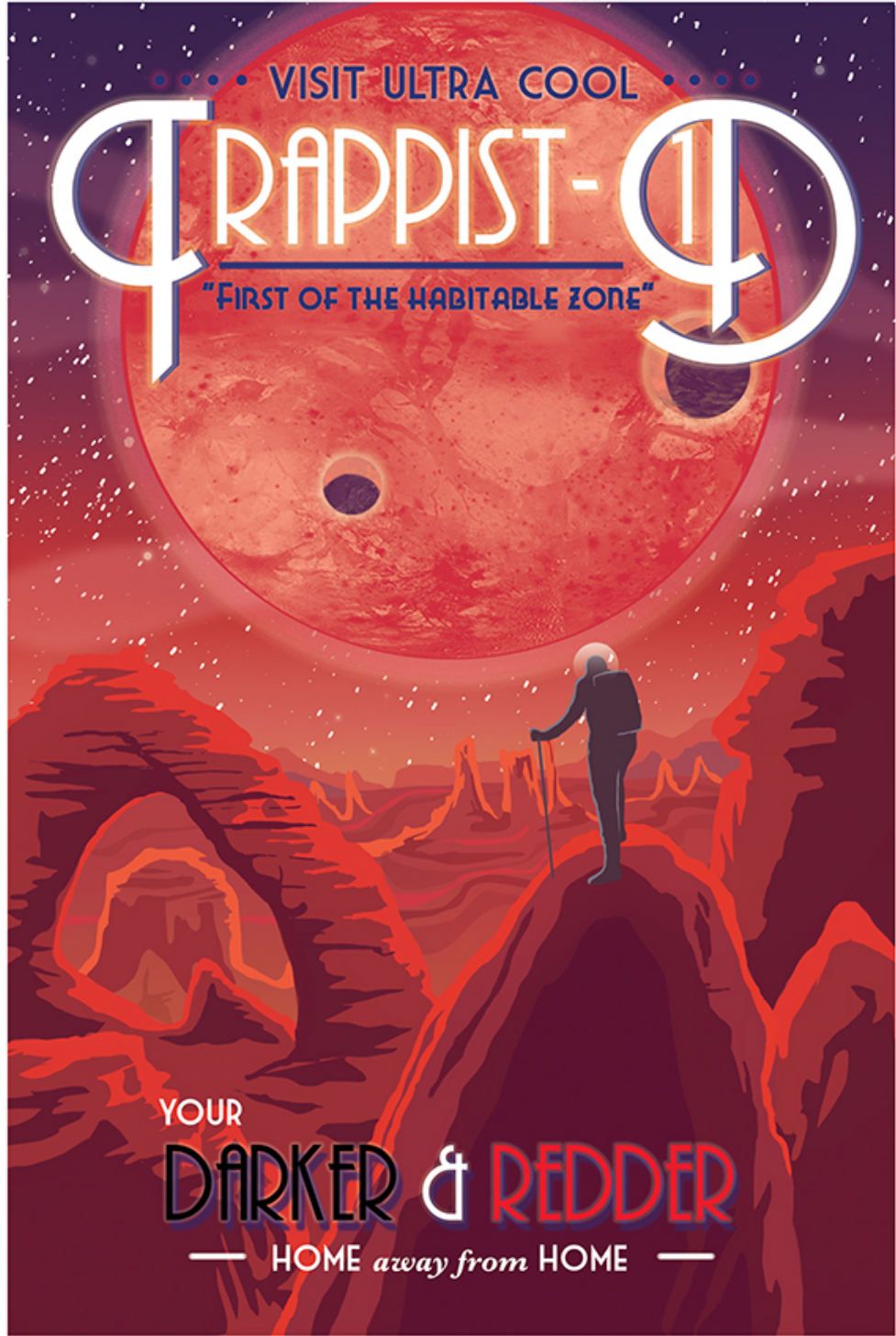
The TRAPPIST-1 solar system: 7 terrestrial planets **b, c, e, f, g** are same size as Earth, **e, f, g** are within the habitable zone. All the planets are closer to TRAPPIST-1 than



Orbital period (length of "year"):

b = 1.5 days, c = 2.4, d = 4.5, e = 6.1, f = 9.2, g = 12.4, h = 18.77

Rotation period: same as "year" (the rotation is locked). Always face the same side toward sun



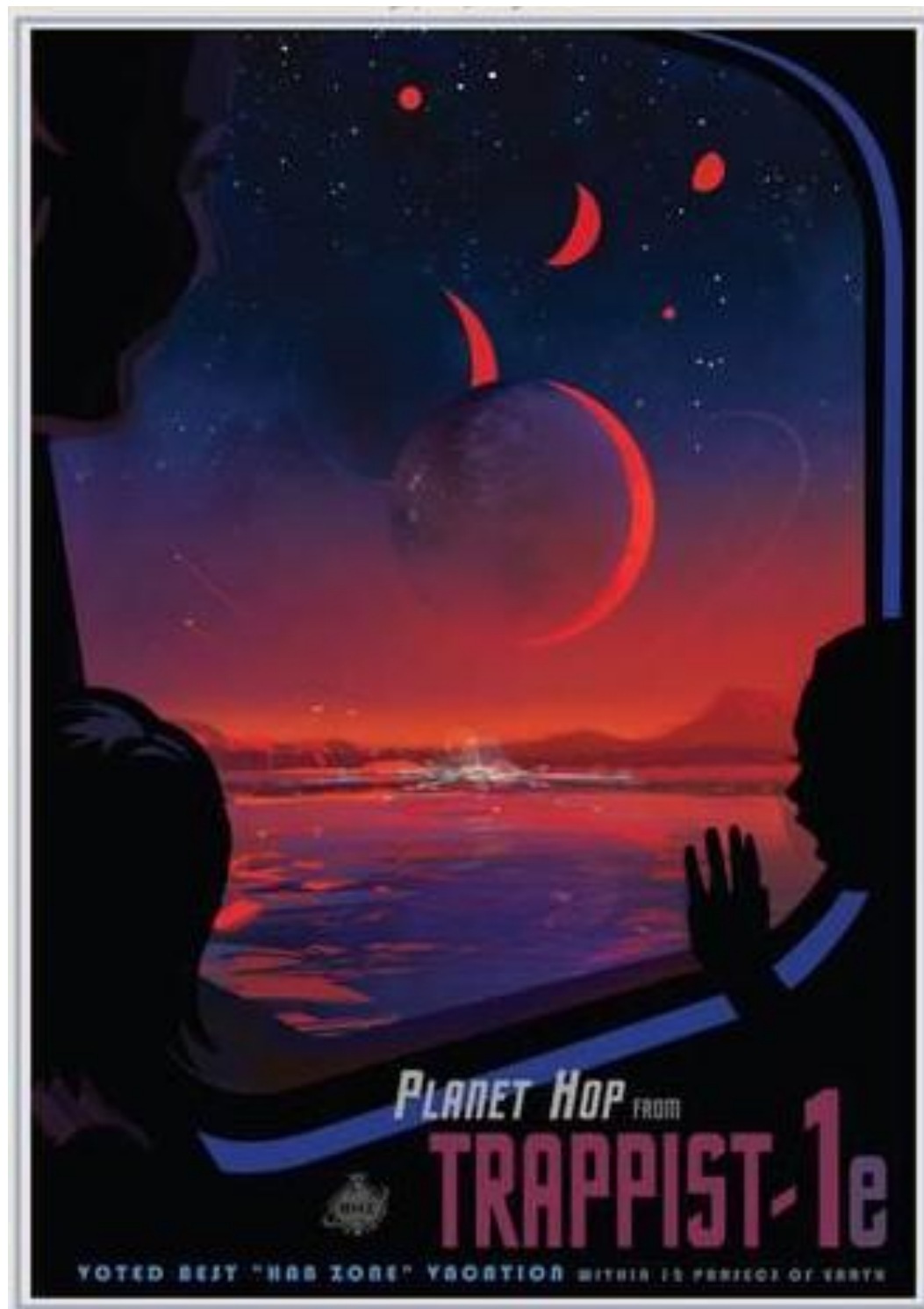
••• VISIT ULTRA COOL •••

TRAPPIST-1

"FIRST OF THE HABITABLE ZONE"

YOUR
DARKER & REDDER

— HOME *away from* HOME —



Voted best “Hab zone” vacation within 40 light years of Earth

TRAPPIST-1F

12 PARSECS AWAY FROM THE SOLAR SYSTEM



SEE SHADOWS SPAN THE DISTANCE BETWEEN WORLDS AS ONE PLANET
ECLIPSES THE SUN FROM ANOTHER.



TRAPPIST-1H
WORLD OF ICE AND FIRE
SEVEN TERRESTRIAL PLANET SYSTEM  EACH PLANET VISIBLE FROM THE OTHER

EXOPLANETS

Exoplanet: A planet orbiting another sun

What have we seen?

How are they found?

Characteristics

How do planets form?



PLANETARY STANDARD MODEL

The conventional planetary-formation theory explains how our Solar System developed more than 4.6 billion years ago.

CONTRACTION

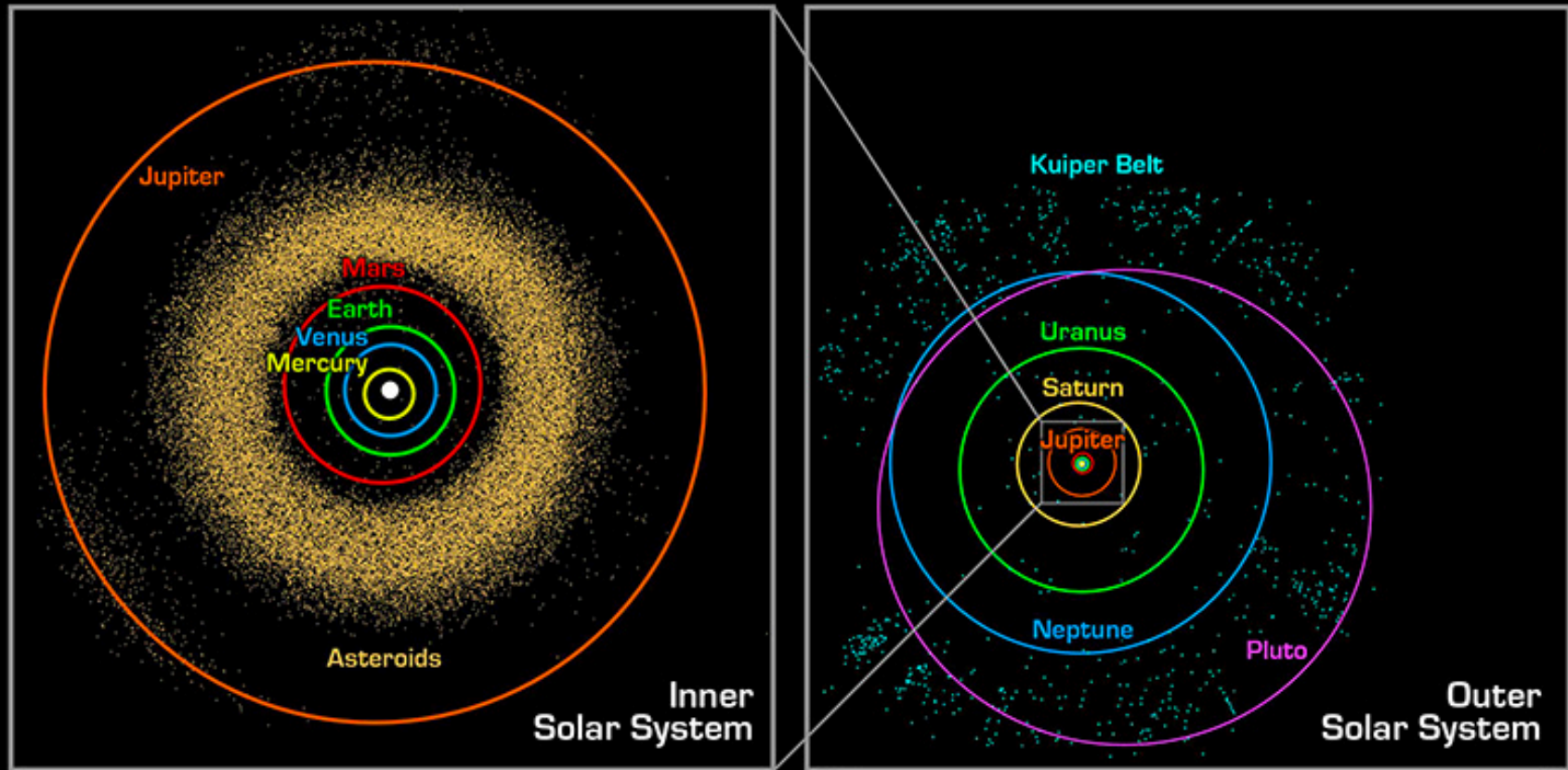
Planets are thought to form along with their stars — a process that starts with a cloud of interstellar hydrogen and helium contracting because of its own gravity.

IGNITION

The cloud swirls into a flat, spinning disk with a dense blob in the centre. Temperatures and pressures at its core trigger thermonuclear fusion, and the blob begins to shine as a star.



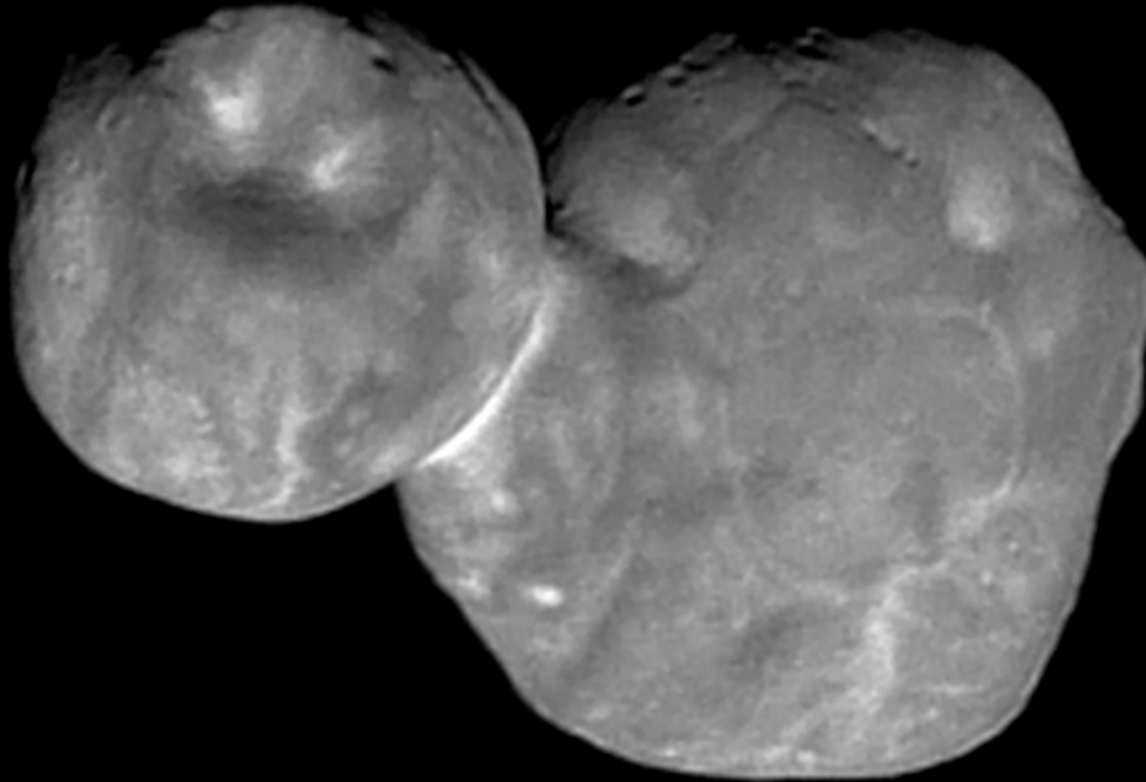
The Solar System is filled with “leftovers” from the formation of our Planetary System



The Itokawa asteroid, 1,100 feet in diameter, is located in the Asteroid Belt. The Japanese spacecraft probe (*Hayabusa*) landed on the asteroid 13 June 2019

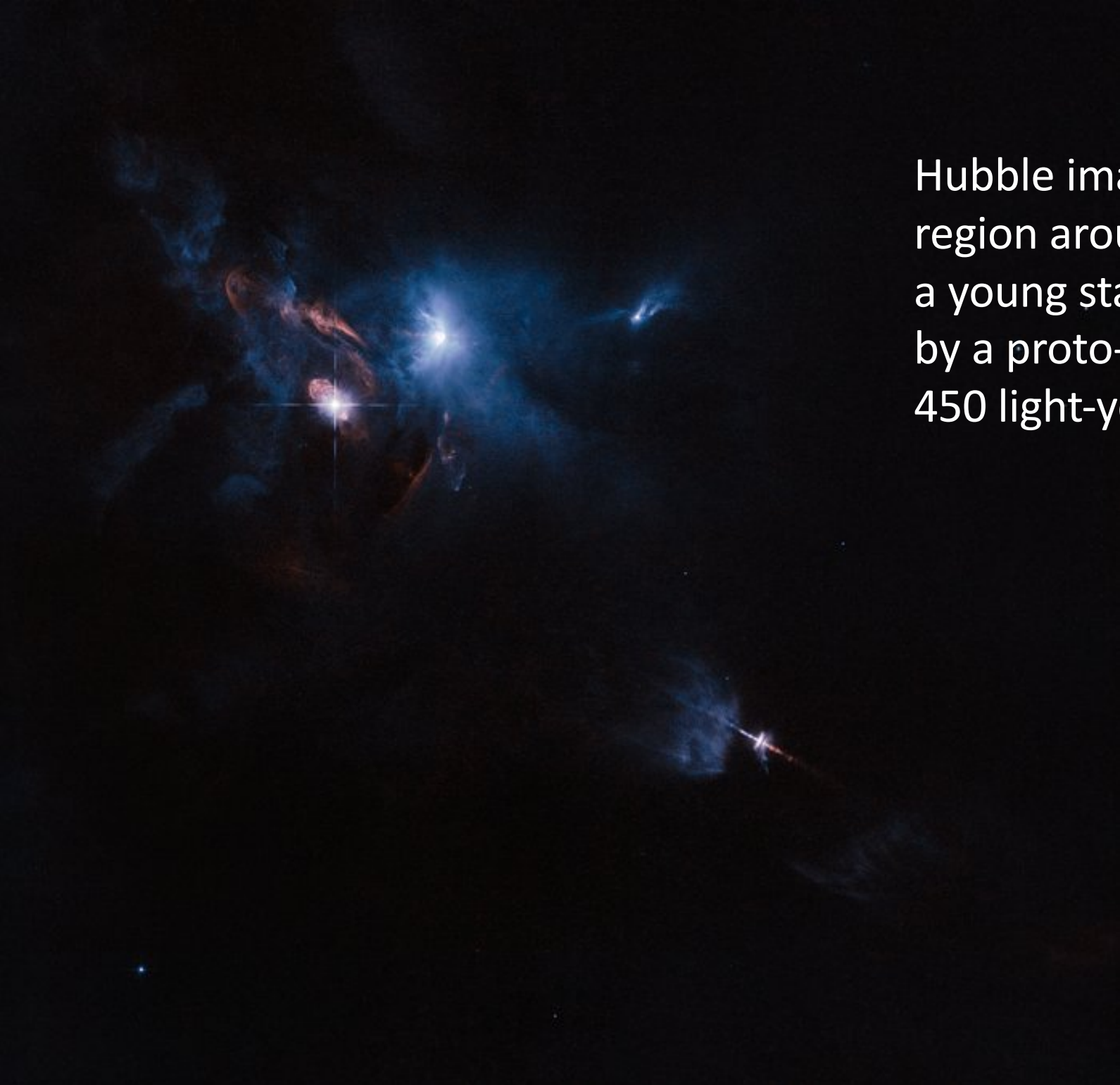


Ultima Thule: the farthest and most primitive object ever explored. It is located in the Kuiper Belt



New Horizons mission

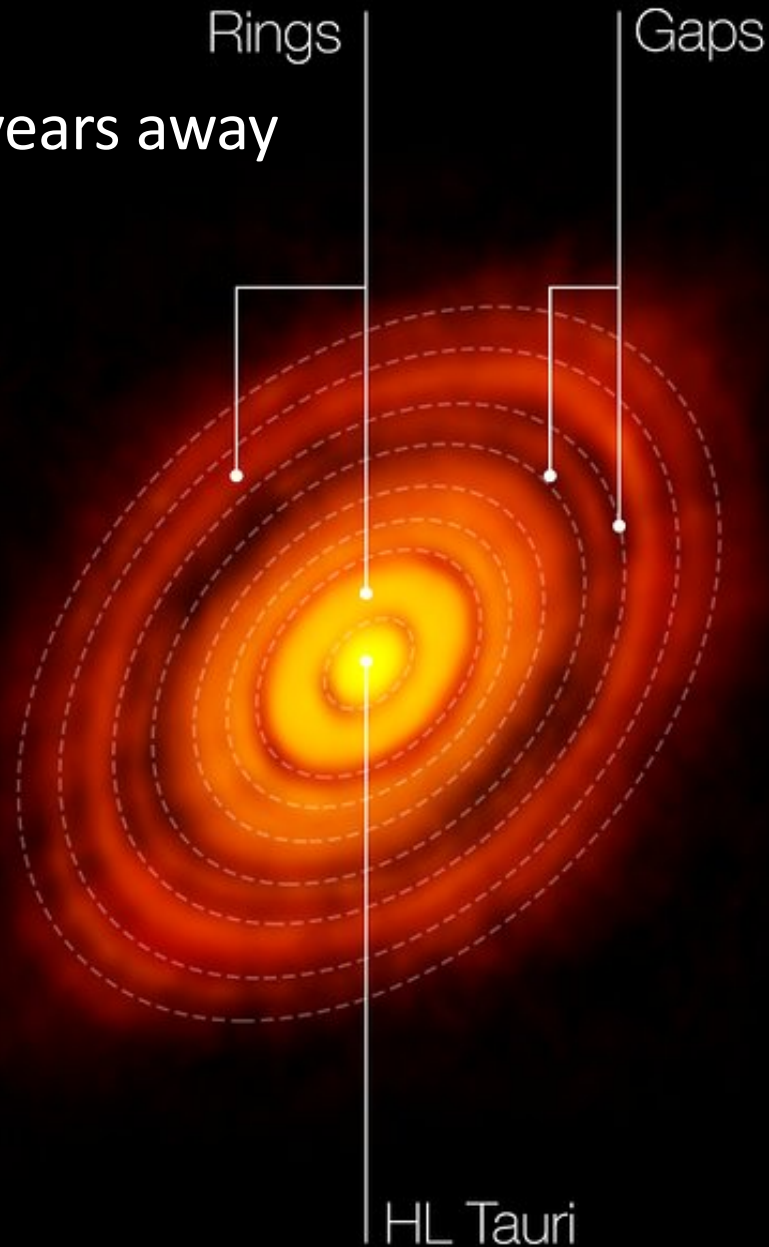
Called a *contact binary*, 22 miles long, 4 billion miles away

A Hubble Space Telescope image of the HL Tauri region. The image shows a young star, HL Tauri, surrounded by a proto-planetary disk. The star is a bright blue-white point source. The disk is a large, reddish-brown structure with a complex, filamentary appearance. The surrounding region is filled with blue and reddish nebulae, indicating the presence of interstellar dust and gas. The image is set against a dark background of space.

Hubble image of
region around HL Tauri,
a young star surrounded
by a proto-planetary disk
450 light-years away.

HL Tauri

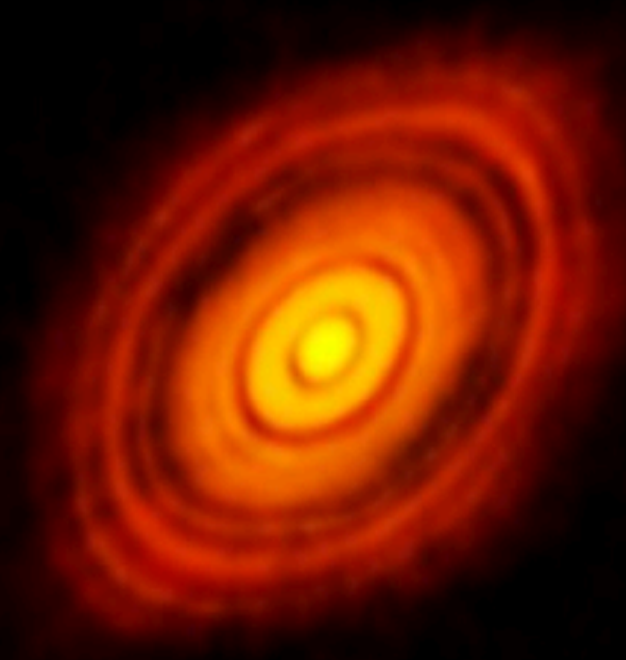
450 light years away



The Planetary accretion disk in HL Tauri **photographed (!!)** with ALMA (Atacama Large Millimeter Array) in Chile

Surprise!

HL Tauri is only about 1 million years old, and was thought to be much too **young** to have planets already forming around it



HL Tauri

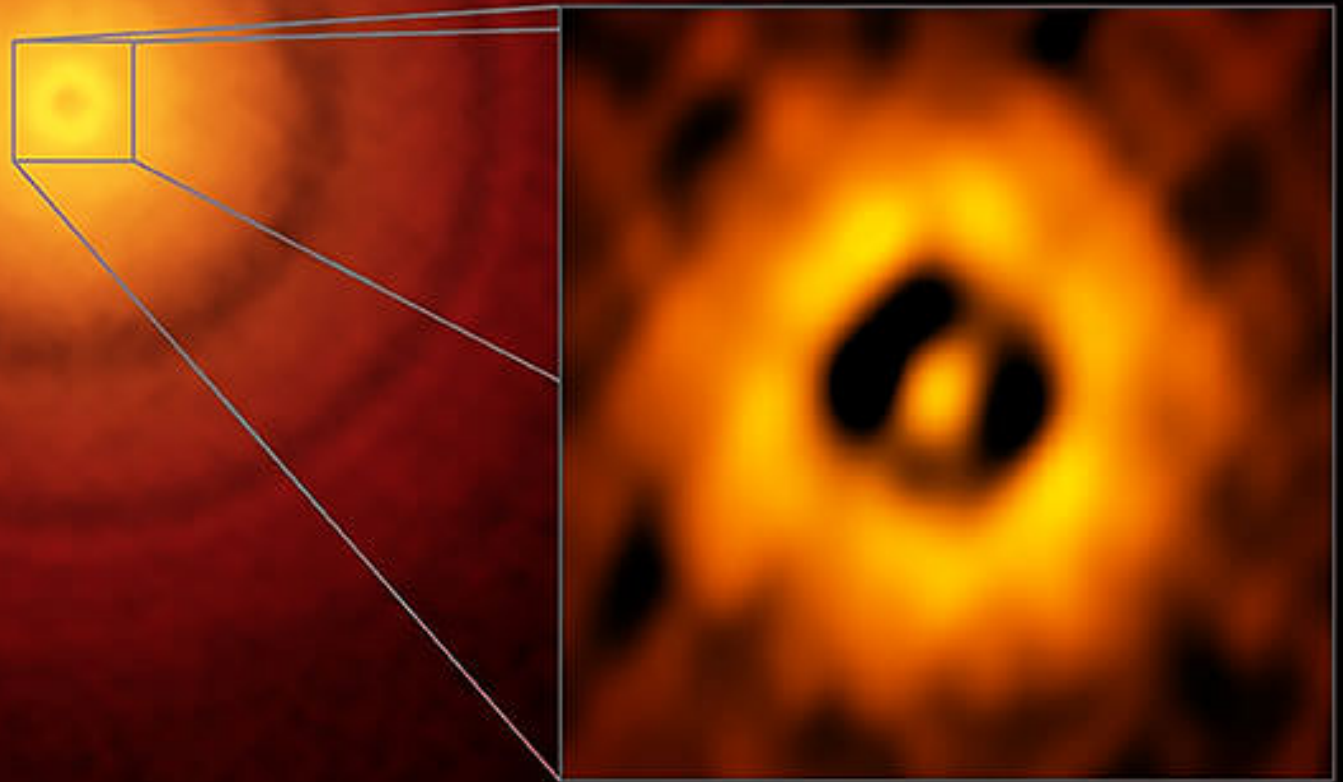


Solar System

Comparison of the Solar System with HL Tauri and its surrounding proto-planetary disk. Although HL Tauri is much smaller than the Sun, the disk stretches out to almost **three times** as far from the star as Neptune is from the Sun.

TW Hydra, 10 mill. year old proto-star with proto-planetary disk, showing planet formation

Star is still contracting and is too young to have started fusion – burning hydrogen



Zooming in on the newly formed **dwarf star PDS 70**, 370 light-years from Earth, **and its planet**, located ca. **1.8 billion miles** from the central star, roughly equivalent to **the distance between Uranus and the Sun**.



PDS 70**b** is a giant gas planet with a mass a few times that of Jupiter. The planet's surface has a temperature of around 1800°F, making it much hotter than any planet in our own Solar System. Surface temperature on Uranus is -370° F.

