E X O P L A N E T S

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

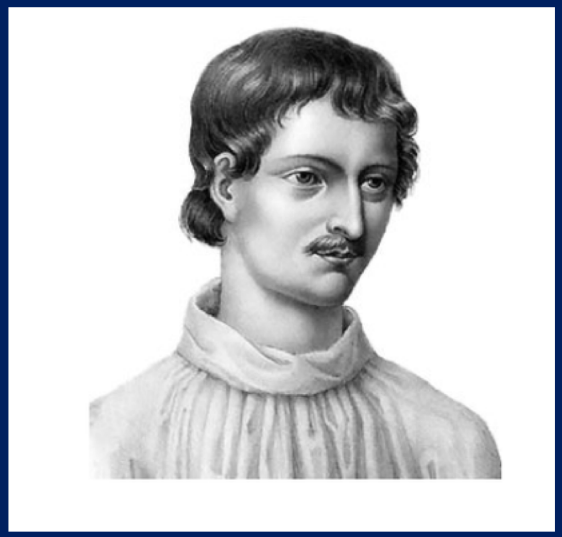
National Academy of Sciences:

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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Thick, blown-up atmosphere containing silicates

Orbital period: 4.23 days (locked orbit)

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

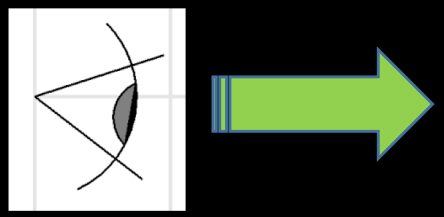
Distance from its sun: 5 million miles

Surface temperature: 1850 F (Mercury = 800 F)

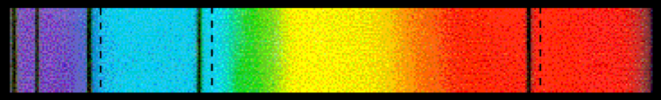
Detection method: radial-velocity or star “wobbling”

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

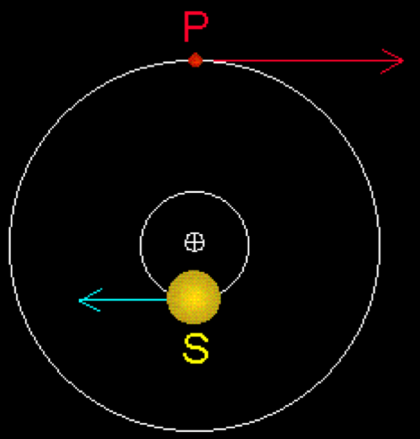
Doppler shift of star's (S) light as planet (P) orbits it

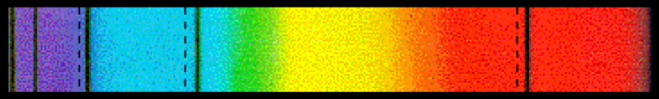


Observer

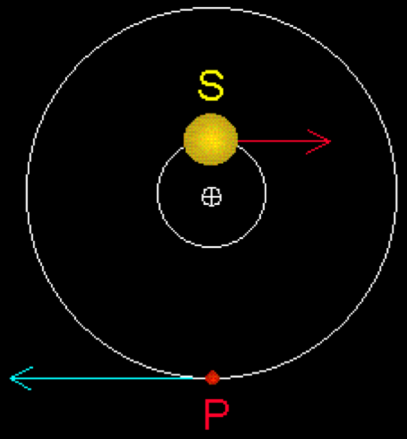


Star's spectrum shifts blueward





Star's spectrum shifts redward



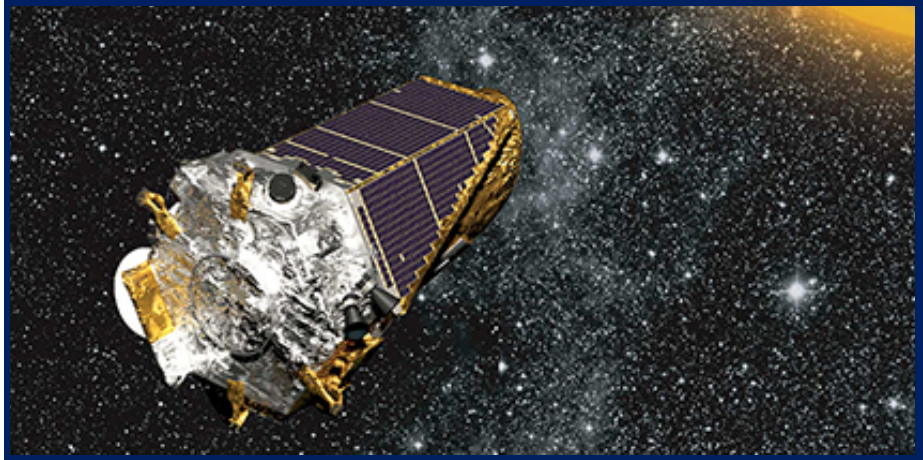
E X O P L A N E T S

Planets orbiting other suns

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

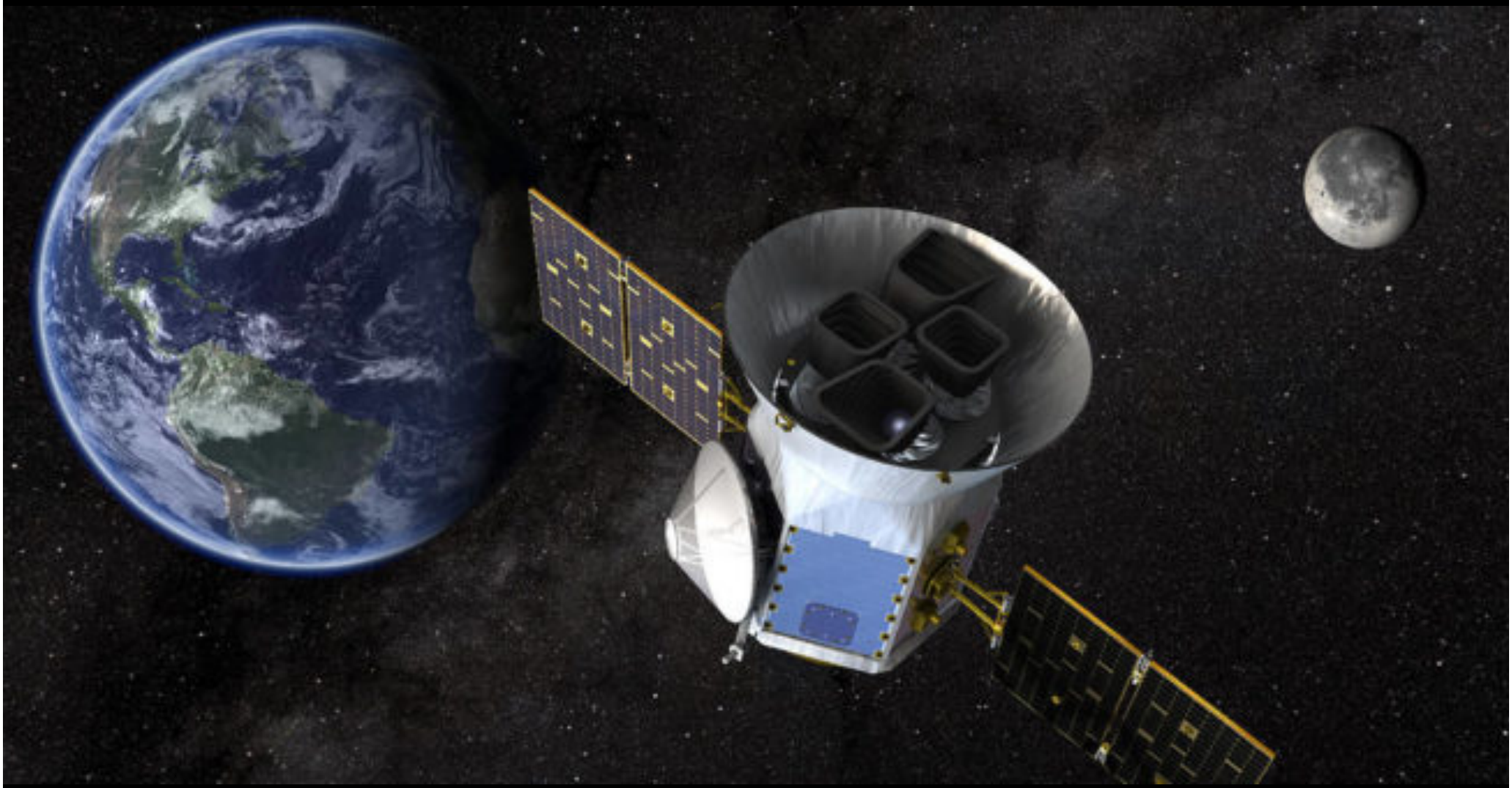
Hubble Space Telescope. Launched 1990. Has given us new insight into the Universe and fabulous space images

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

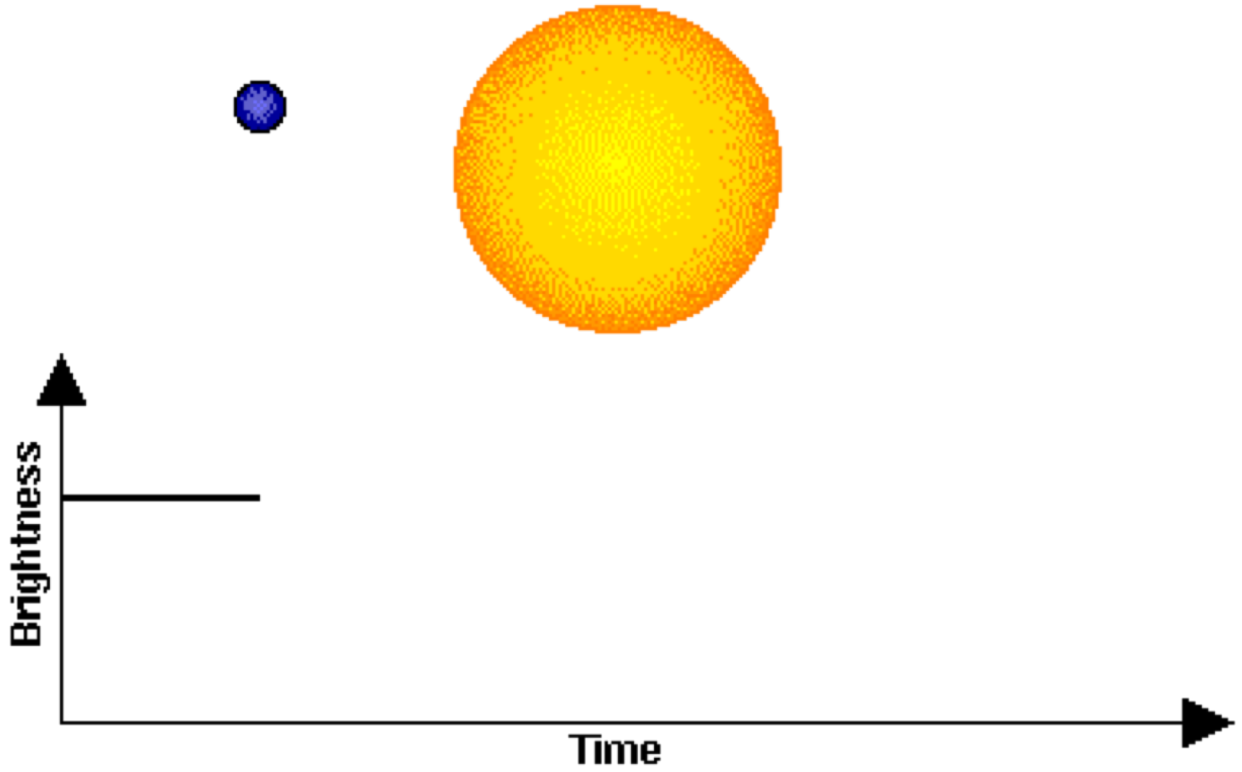


Kepler Space Telescope launched 2009, retired 2017. Designed to find exoplanets. Observed over .5 million stars and found 2,662 exoplanets

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:

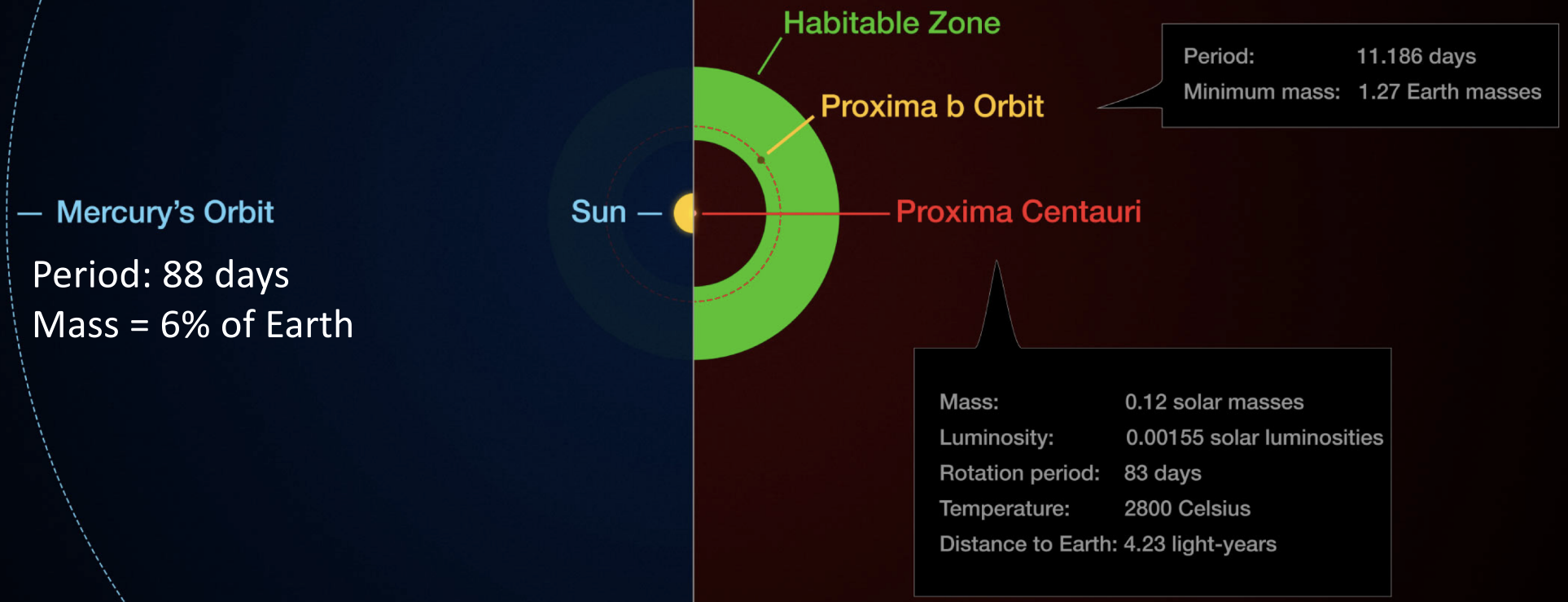
Isolating a Planet's Spectrum

As of June 2020 the space telecopes 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.



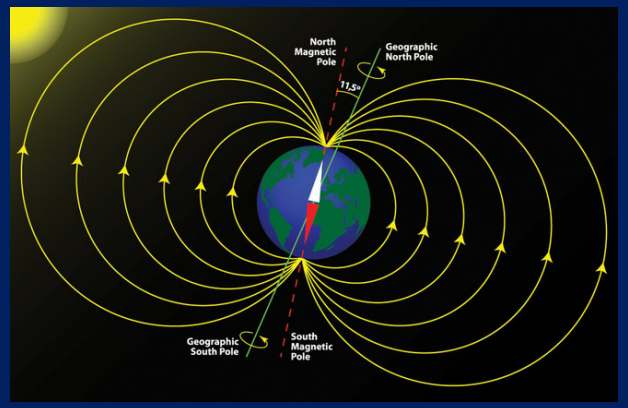
Period: 88 days
Mass = 6% of Earth

Surface temperature of Sun about 10,000 F

Surface temperature of Proxima Centauri = 4,500 F. Proxima Centauri is a red dwarf star

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

E X O P L A N E T S

A planet orbiting another sun

Characteristics

4171 Confirmed Exoplanets

PHL
MAPPING THE HABITABLE UNIVERSE

Terrans

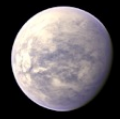
Giants

160

1293

1395

1317



Miniterran
Mercury-size

Subterran
Mars-size

Terran
Earth-size

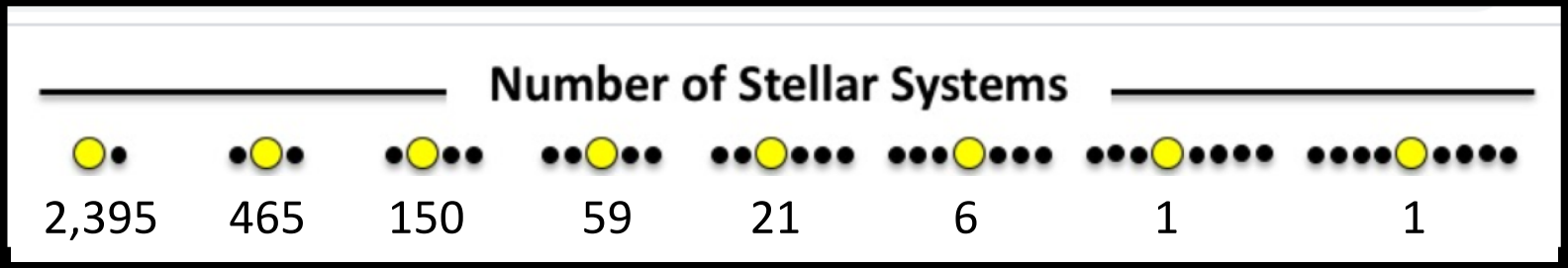
Superterran
Super-Earths and Mini-Neptunes

Neptunian
Neptune-size

Jovian
Jupiter-size

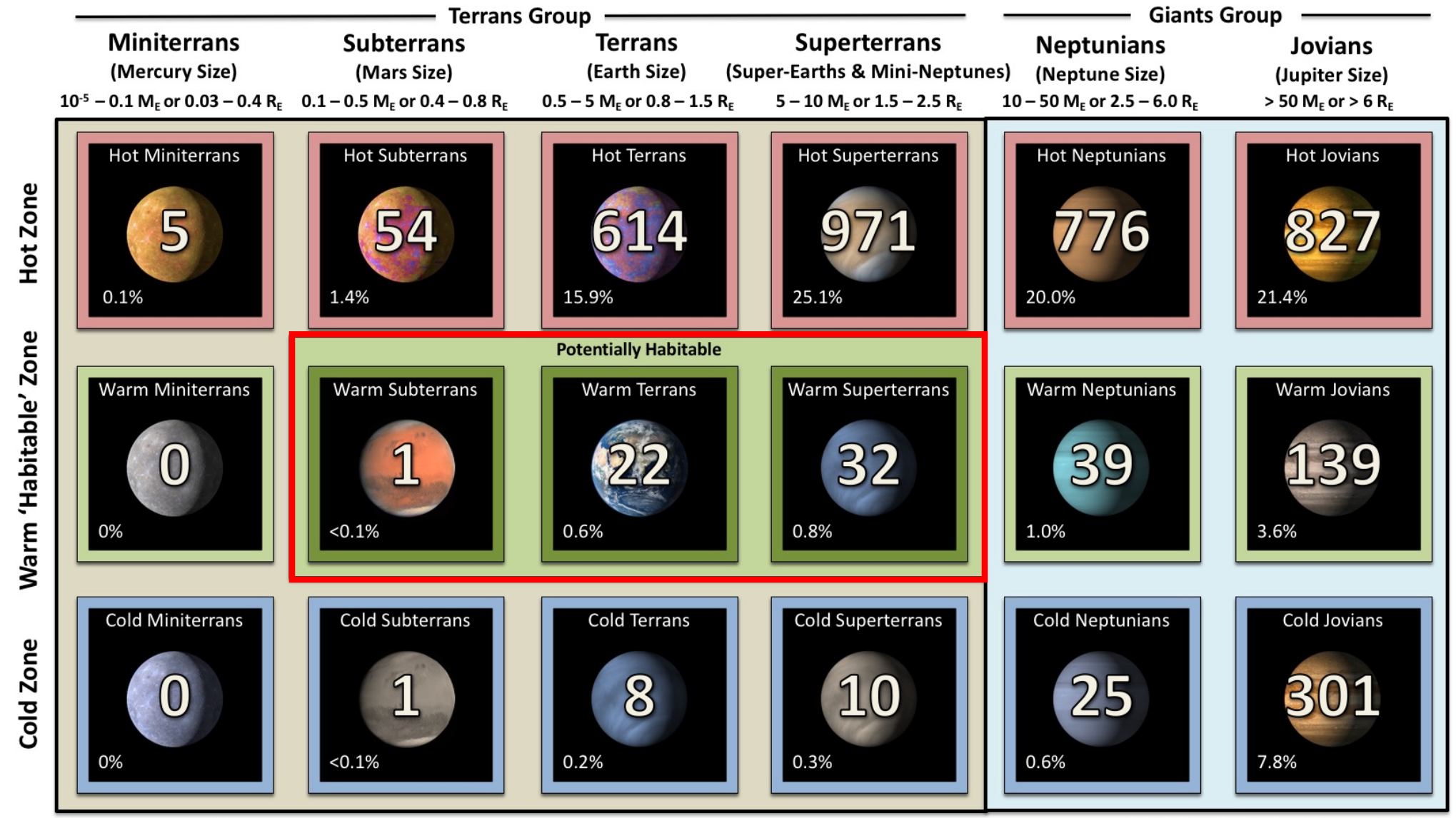
Ca. 2/3 are giants

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



The Periodic Table of Exoplanets

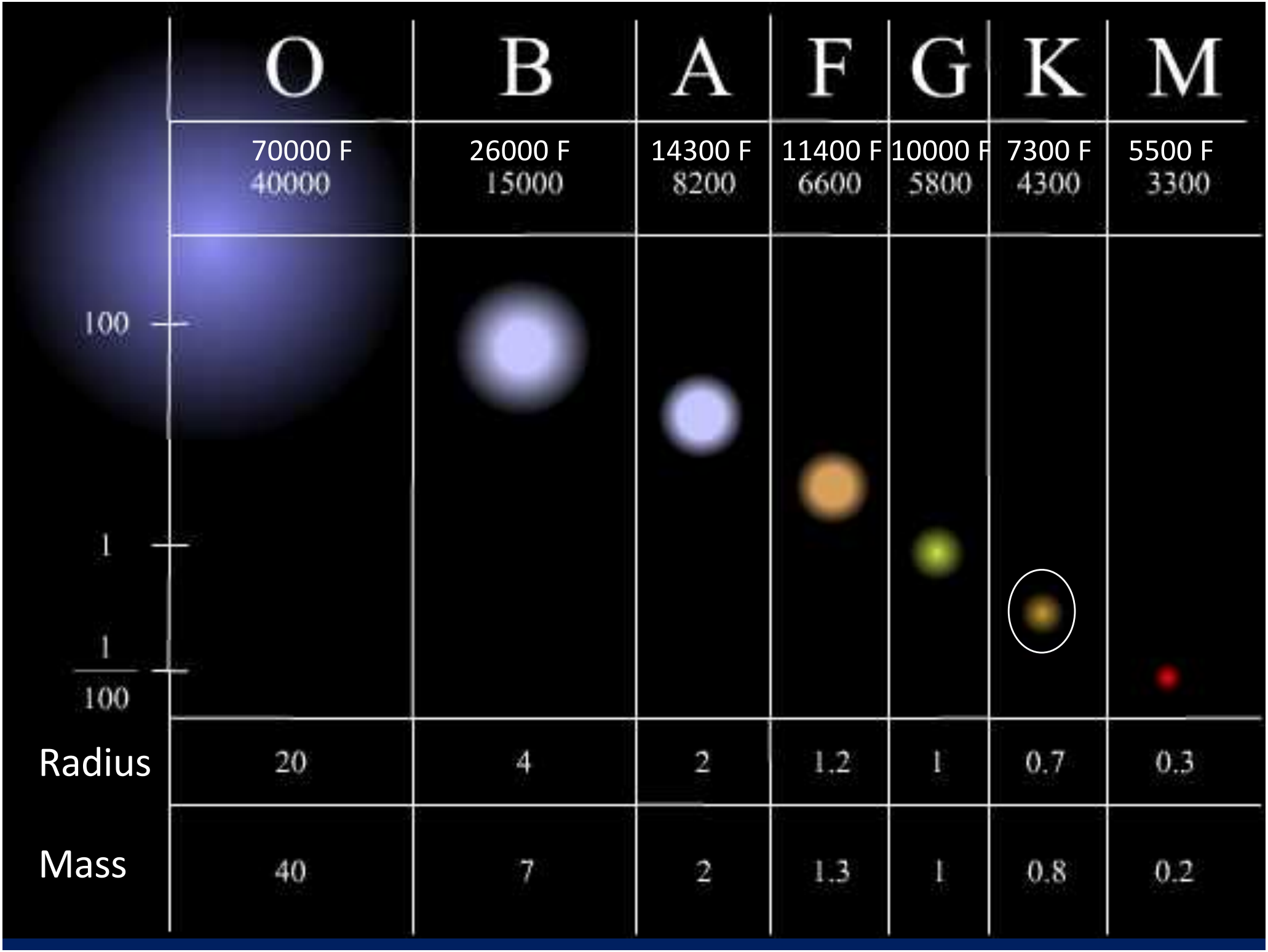
Over 3800 Exoplanets July, 2018



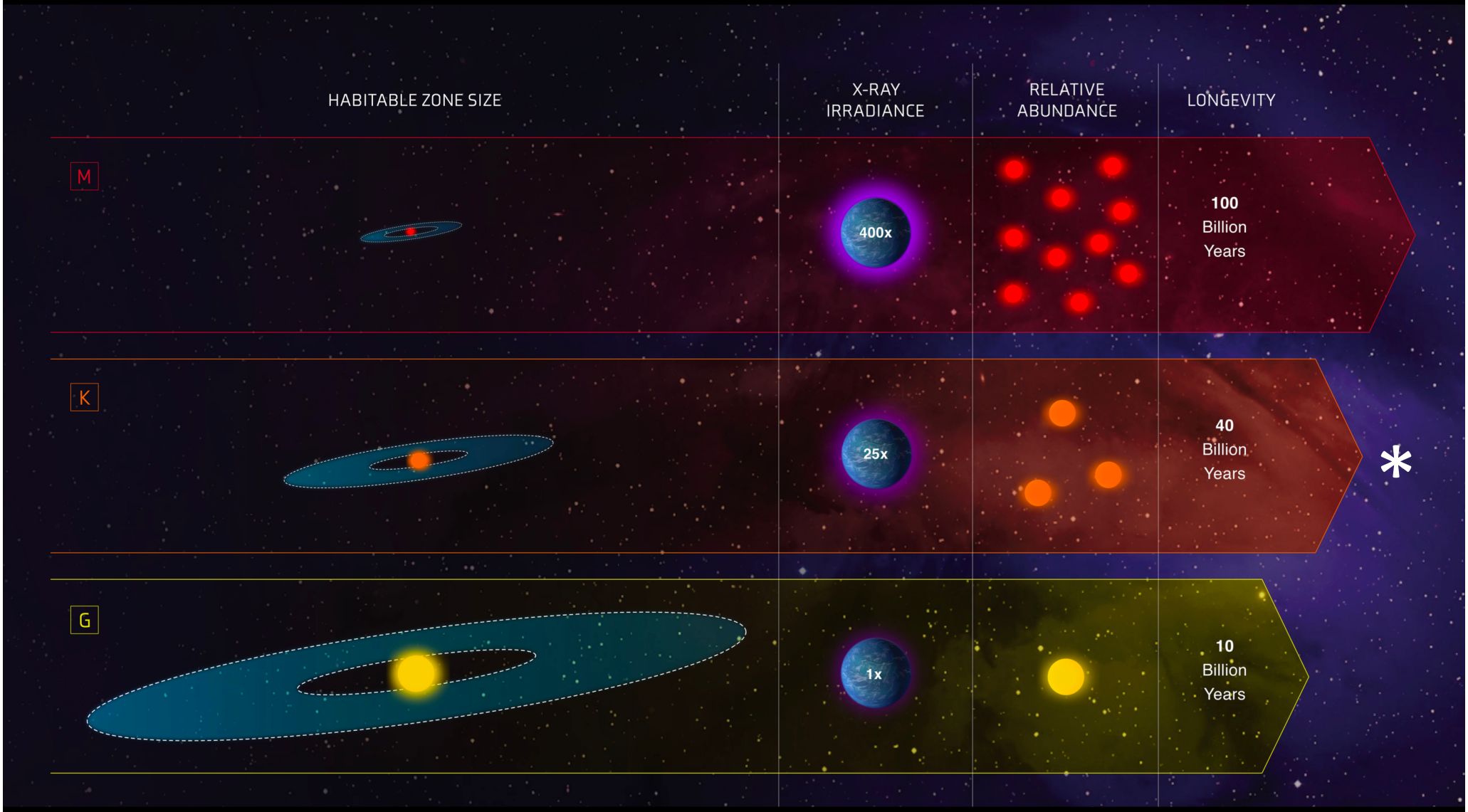
M_E = Earth Mass, R_E = Earth Radius

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

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


O
B
A
F
G
K
M
70000 F
40000
26000 F
15000
14300 F
8200
11400 F
6600
10000 F
5800
7300 F
4300
5500 F
3300
100
1
1/100
Radius
20
4
2
1.2
1
0.7
0.3
Mass
40
7
2
1.3
1
0.8
0.2

K stars: The optimal host stars for planets

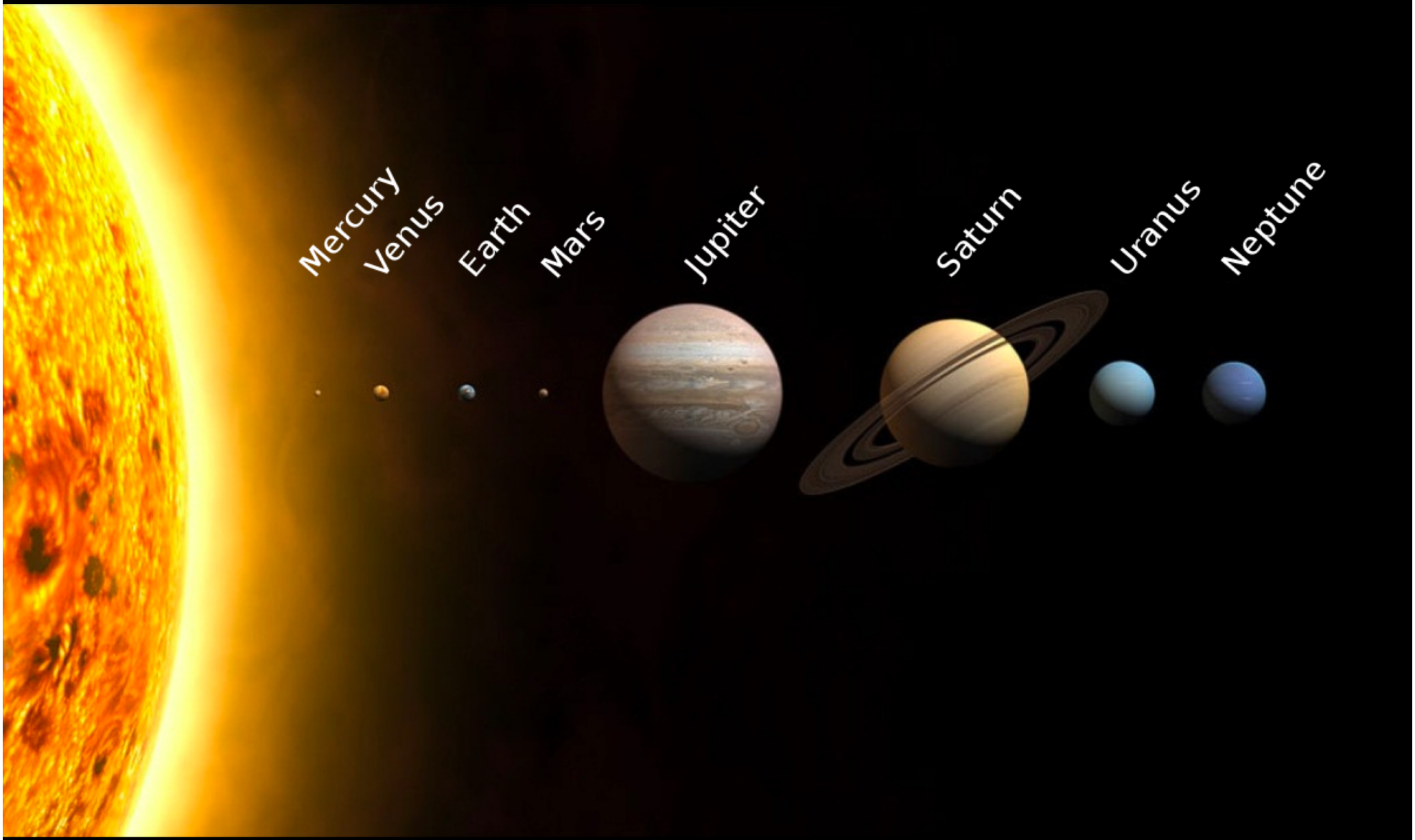


K stars: Surface temperatures 7000F good for habitability

Radiation: 5-25 x Sun (not good)

13% of total number of stars in our Galaxy

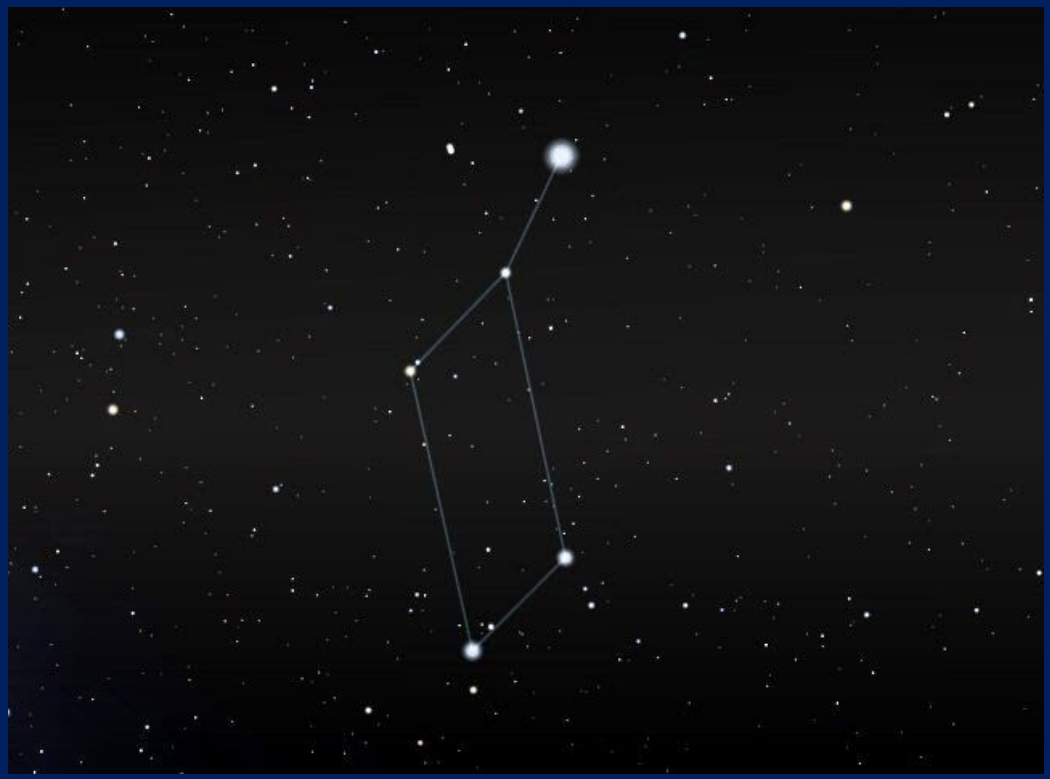
The Solar System (not to scale)



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.

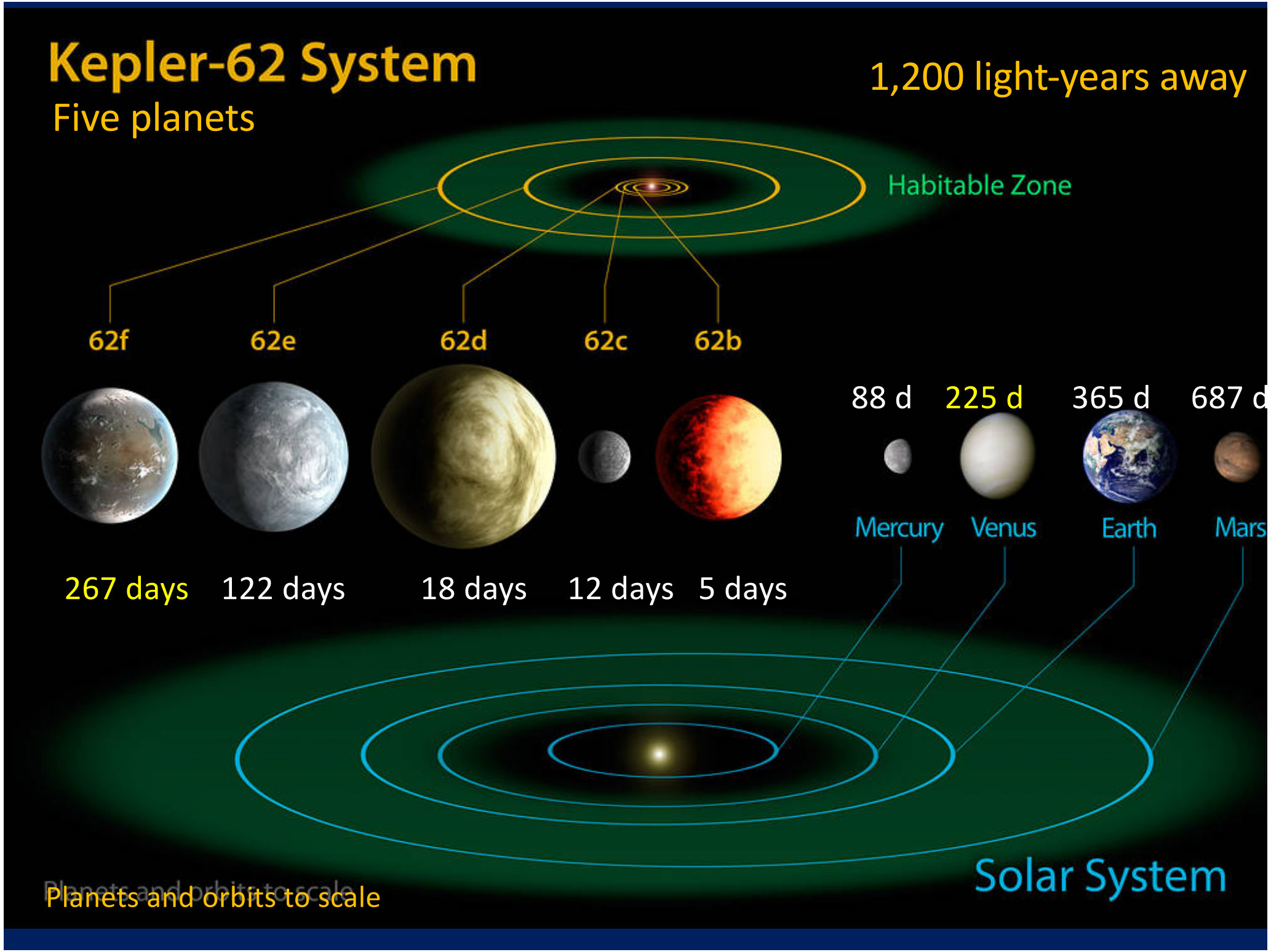
* Five-planet system about 1,200 light-years from Earth in the constellation Lyra (the Lyre)

* 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)

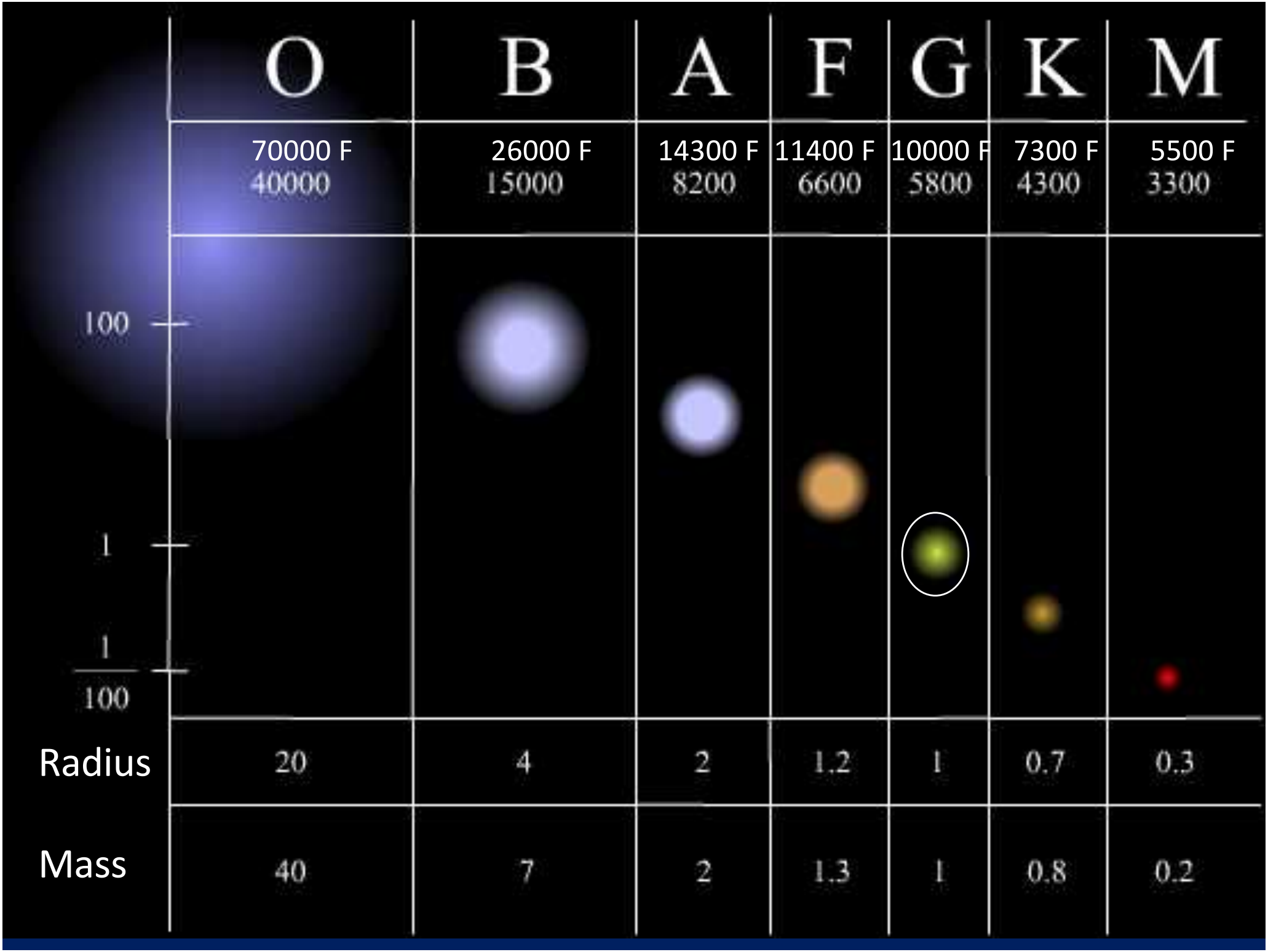
* Kepler-62f is 40% and Kepler-62e is 60% larger than Earth

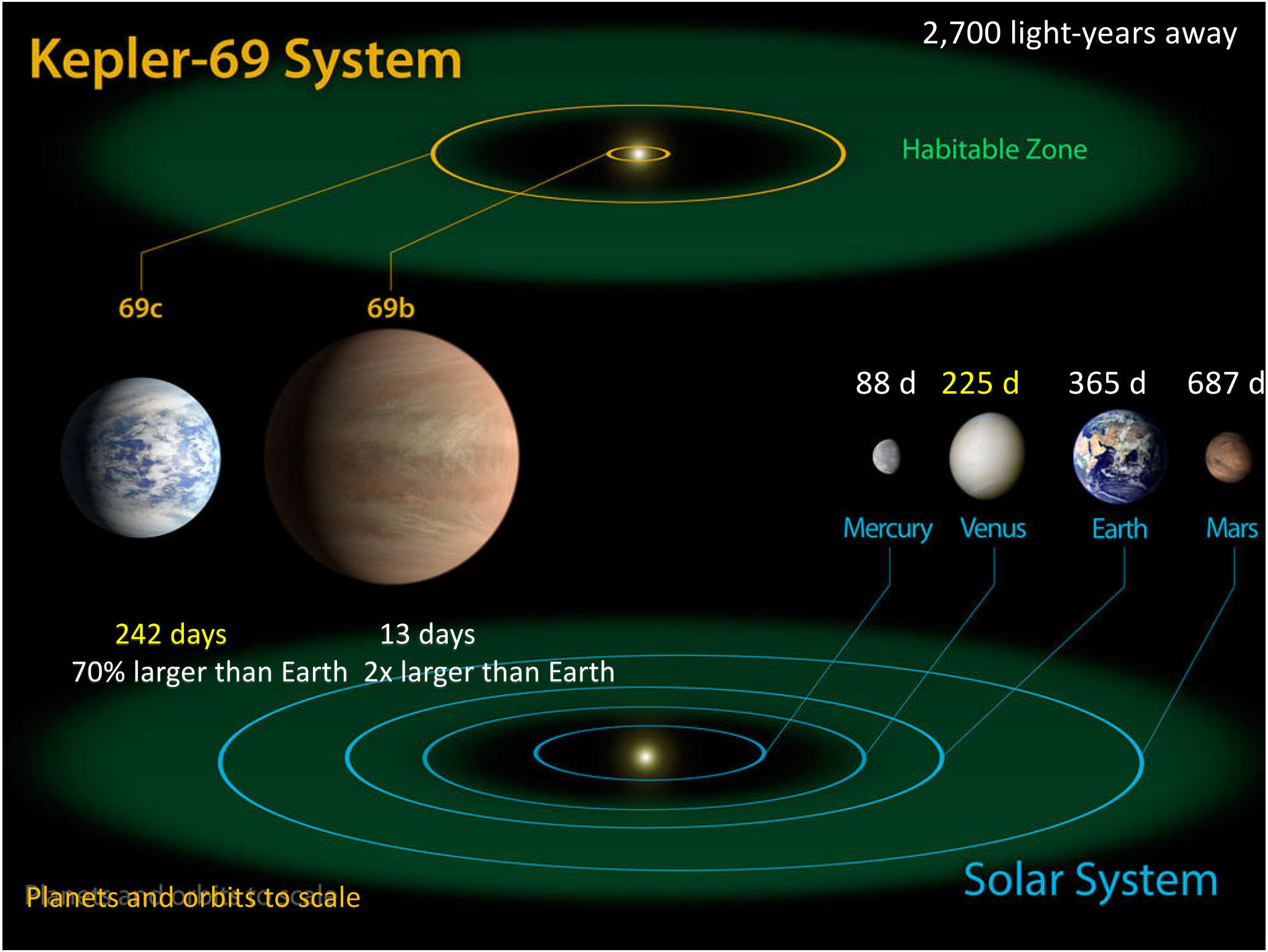

Kepler-62 System
Five planets
1,200 light-years away
Habitable Zone
62f
62e
62d
62c
62b
267 days
122 days
18 days
12 days
5 days
88 d
225 d
365 d
687 d
Mercury
Venus
Earth
Mars
Solar System
Planets and orbits to scale

Kepler-69 System

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

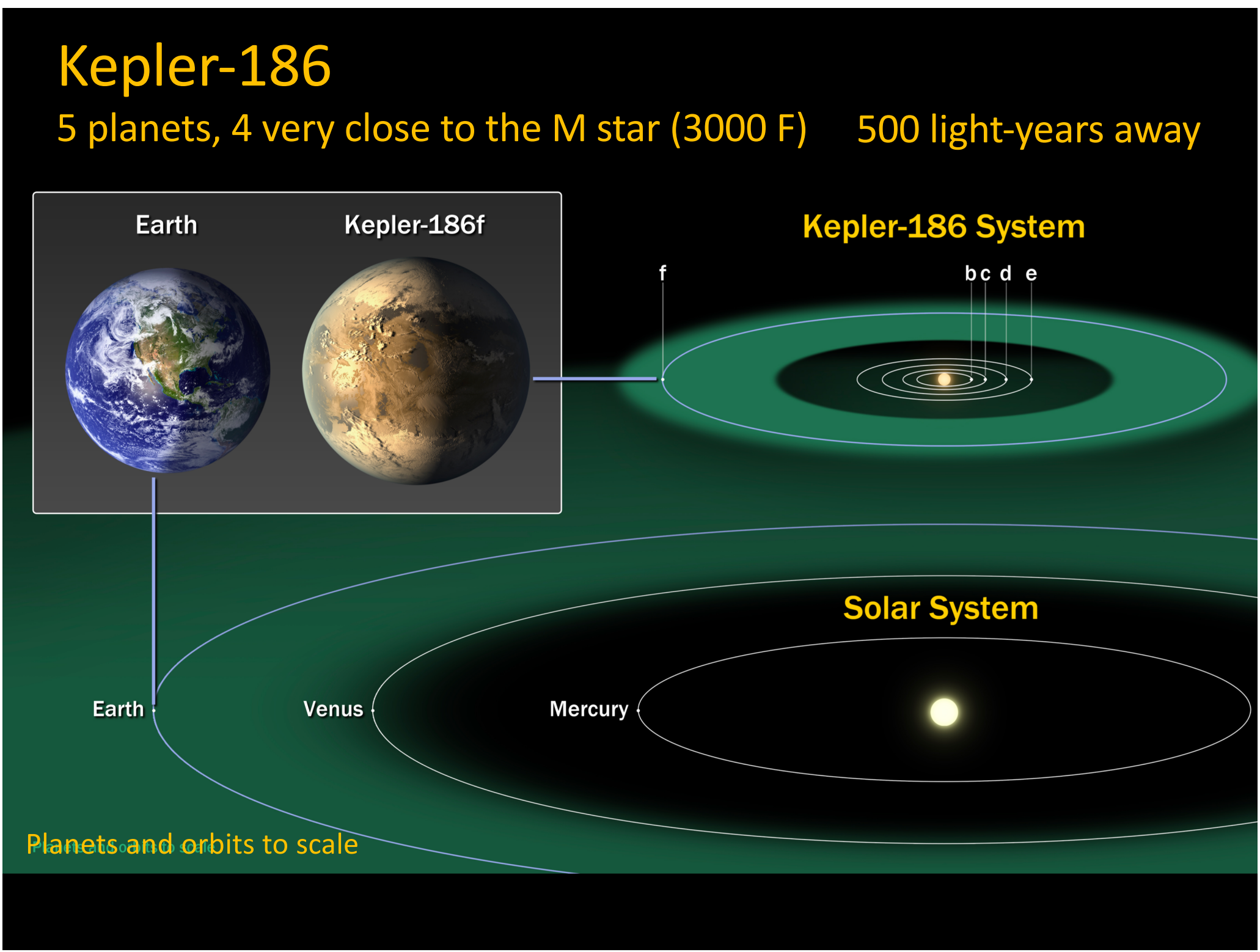
* Orbiting a G star like our Sun, about 10,000 F
* One planet, Kepler-69c barely in the habitable zone
* Kepler-69c is 70% larger than the Earth

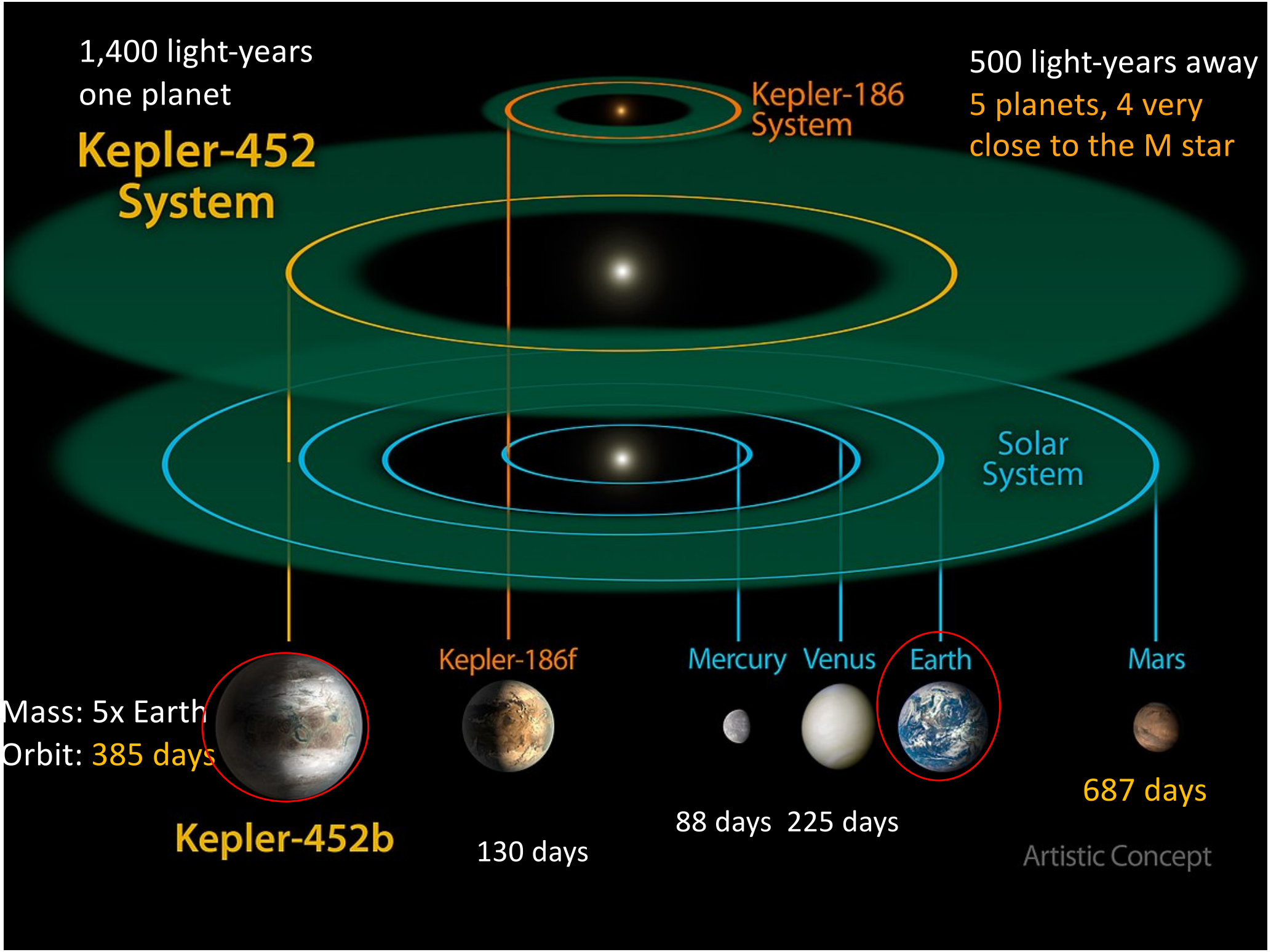

O
B
A
F
G
K
M
70000 F
40000
26000 F
15000
14300 F
8200
11400 F
6600
10000 F
5800
7300 F
4300
5500 F
3300
100
1
1/100
Radius
20
4
2
1.2
1
0.7
0.3
Mass
40
7
2
1.3
1
0.8
0.2

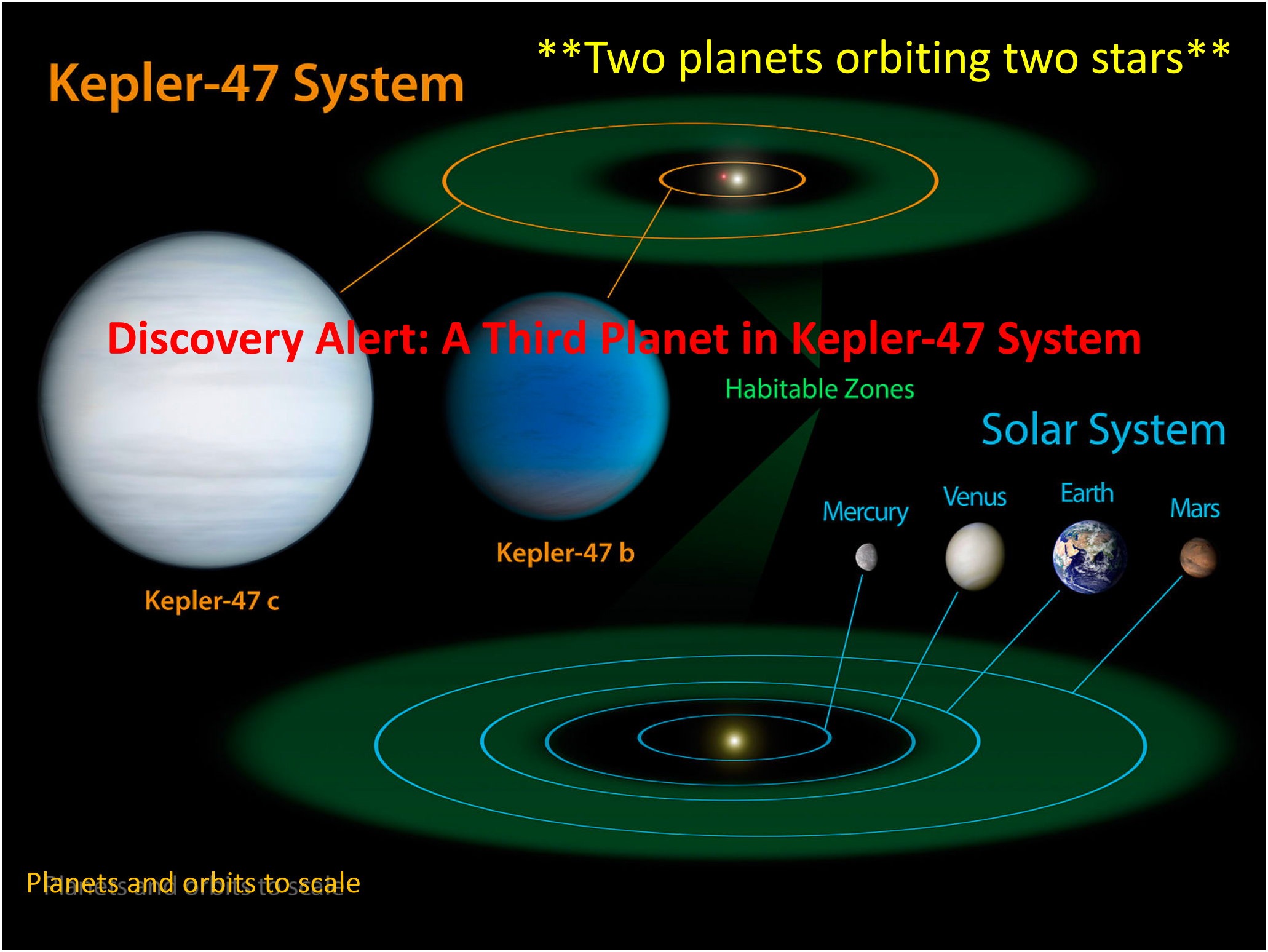

Kepler-69 System
2,700 light-years away
Habitable Zone
69c
69b
88 d
225 d
365 d
687 d
Mercury
Venus
Earth
Mars
242 days
70% larger than Earth
13 days
2x larger than Earth
Solar System
Planets and orbits to scale

Kepler-186

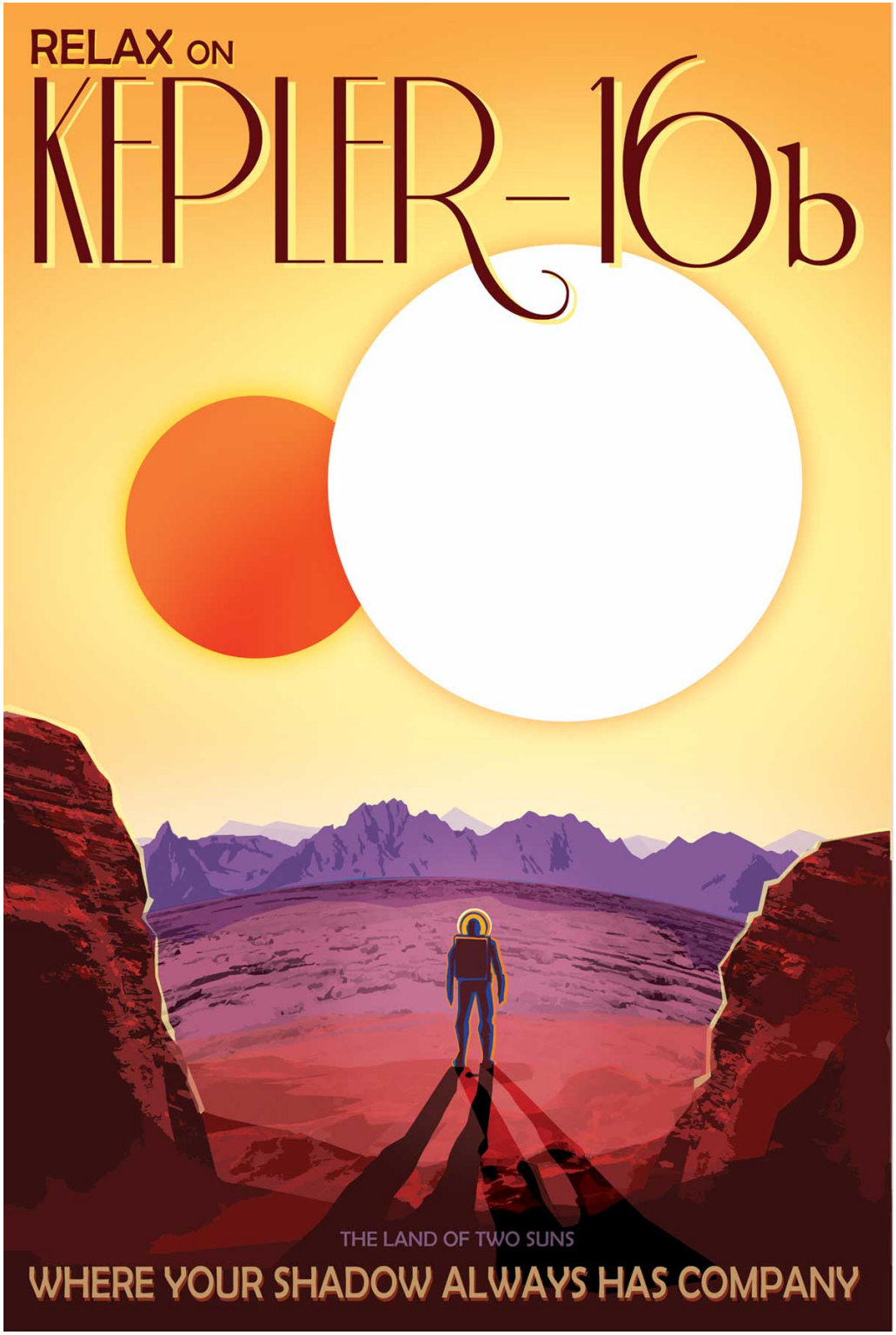
5 planets, 4 very close to the M star (3000 F) 500 light-years away

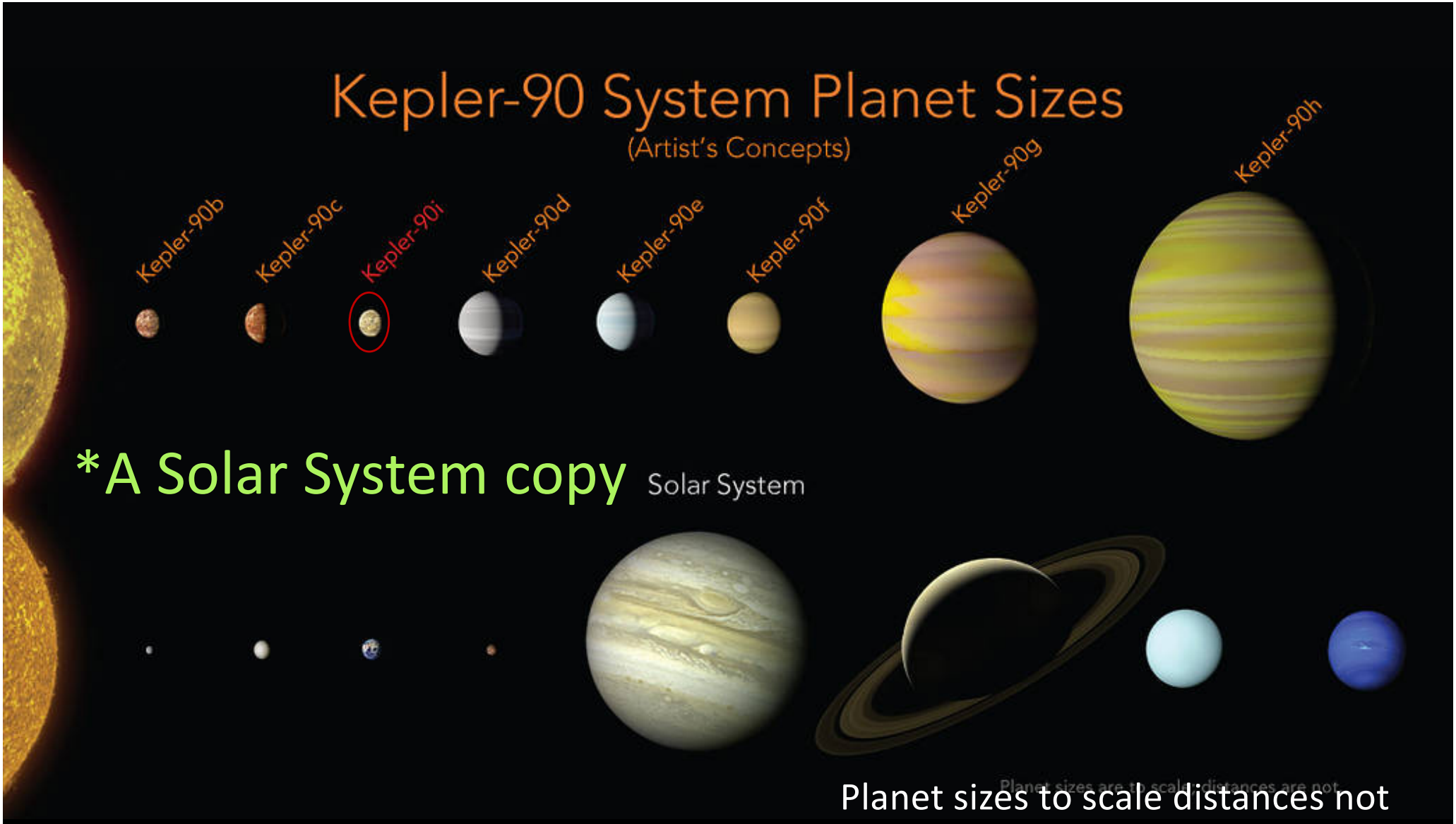



1,400 light-years
one planet
Kepler-452
System
500 light-years away
5 planets, 4 very
close to the M star
Kepler-186
System
Solar
System
Mass: 5x Earth
Orbit: 385 days
Kepler-452b
Kepler-186f
130 days
Mercury
88 days
Venus
225 days
Earth
Mars
687 days
Artistic Concept


Kepler-47 System
Two planets orbiting two stars
Discovery Alert: A Third Planet in Kepler-47 System
Habitable Zones
Solar System
Mercury
Venus
Earth
Mars
Kepler-47 b
Kepler-47 c
Planets and orbits to scale

Kepler 16b: A planet orbiting TWO stars

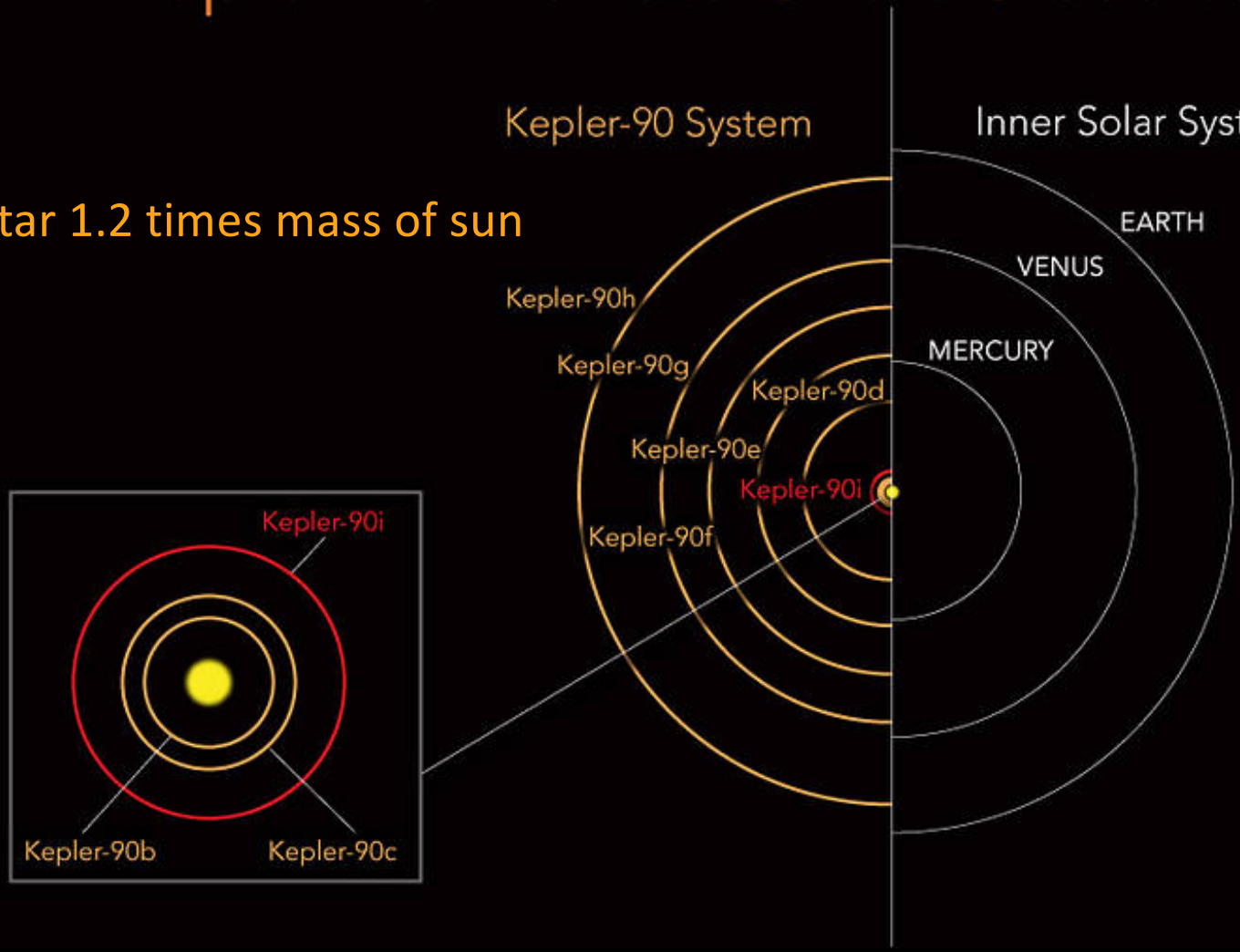

RELAX ON
KEPLER-16b
THE LAND OF TWO SUNS
WHERE YOUR SHADOW ALWAYS HAS COMPANY



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

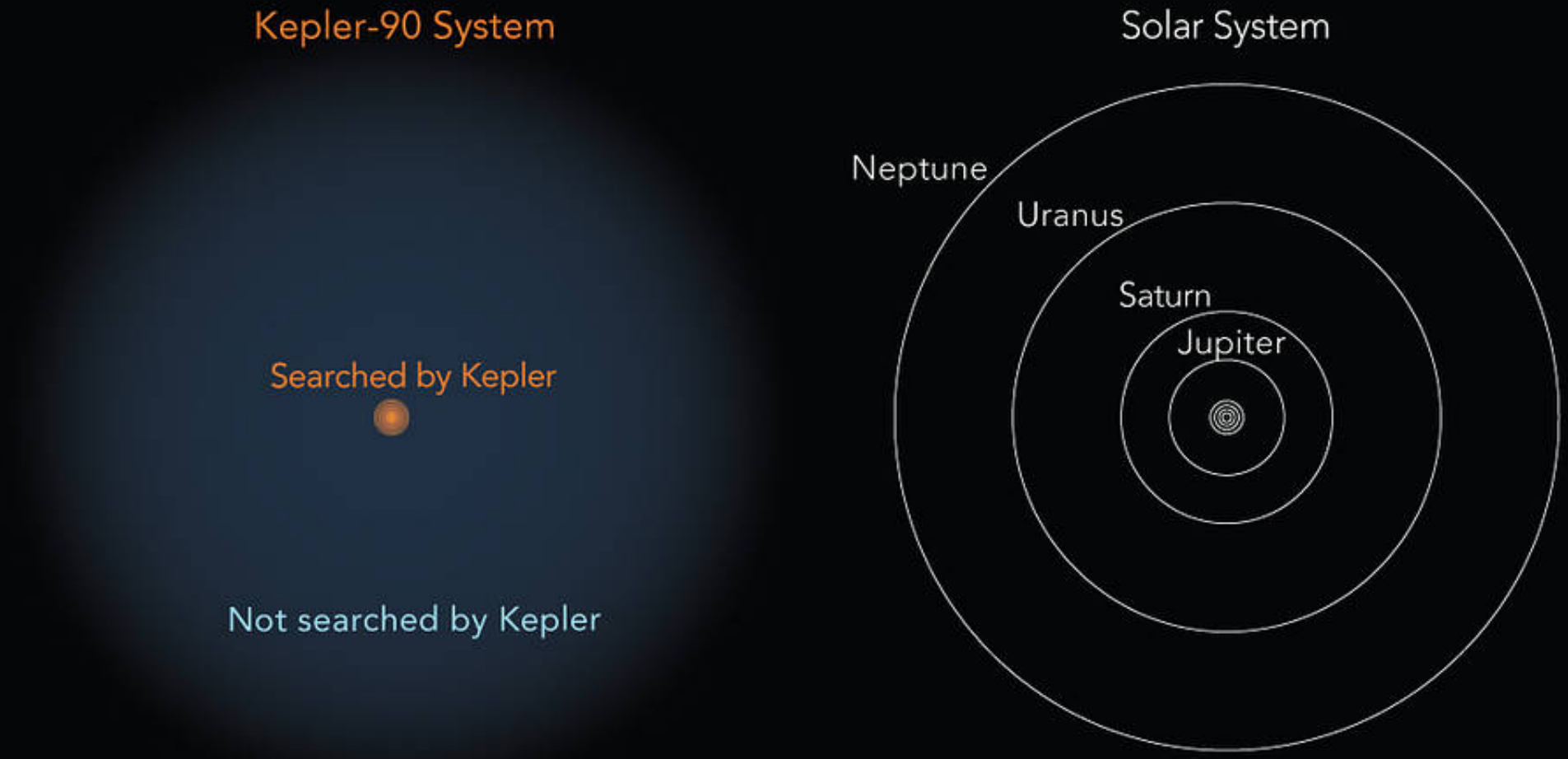
Kepler-90 Planets Orbit Close to Their Star

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?



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

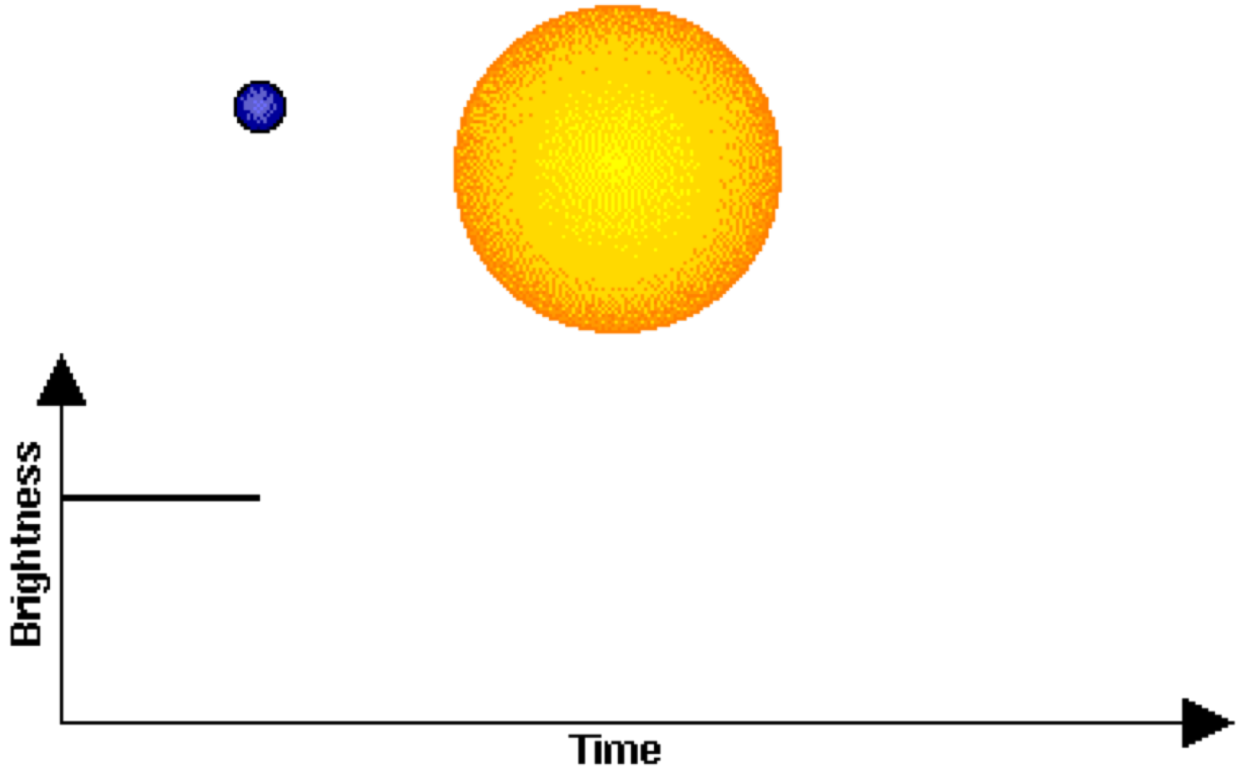
13 x mass of Earth

3 x radius of Earth

Orbital period: 13.7 days

A hot hell

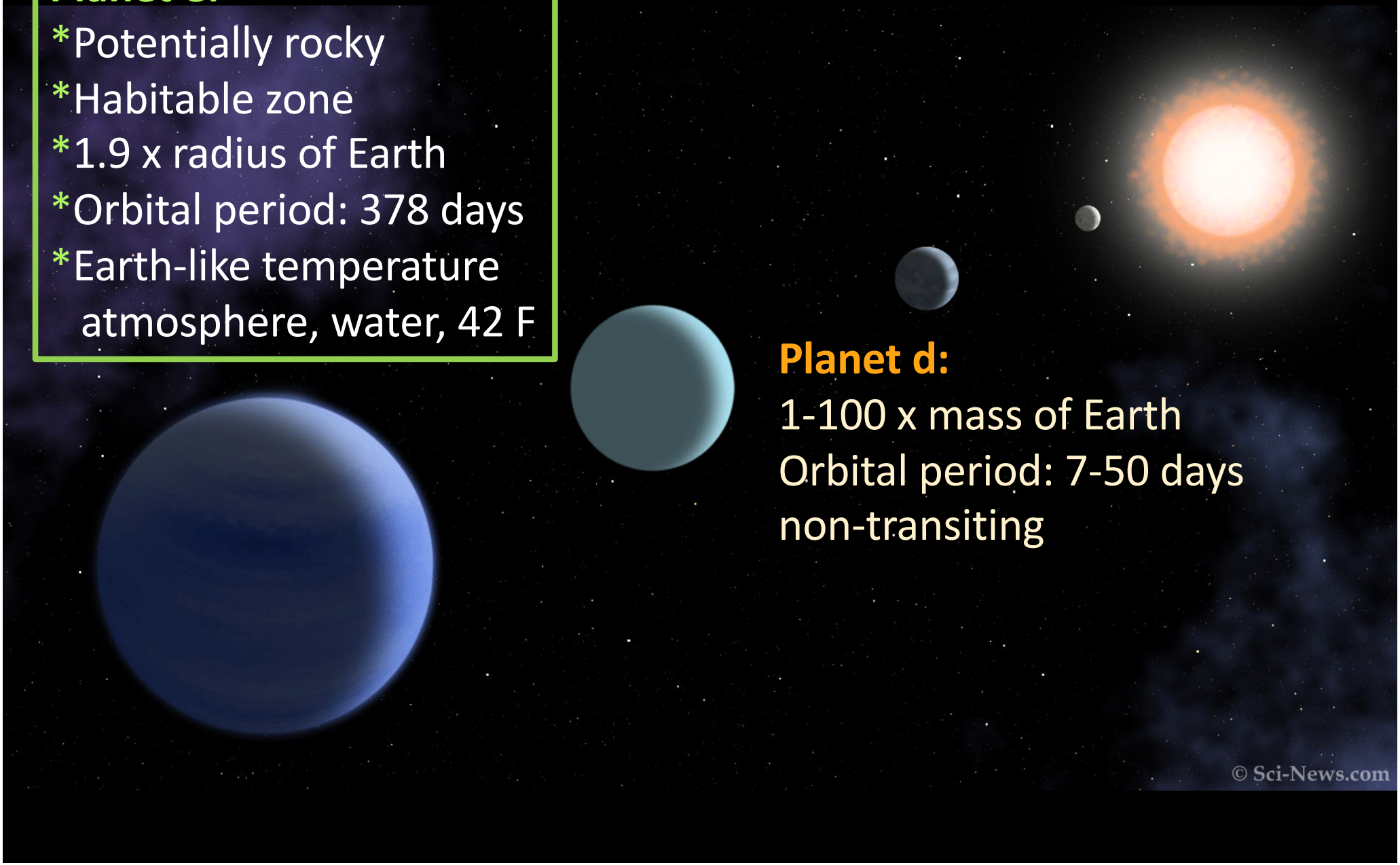
Kepler used the eclipse (transit) method to find the planets



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)

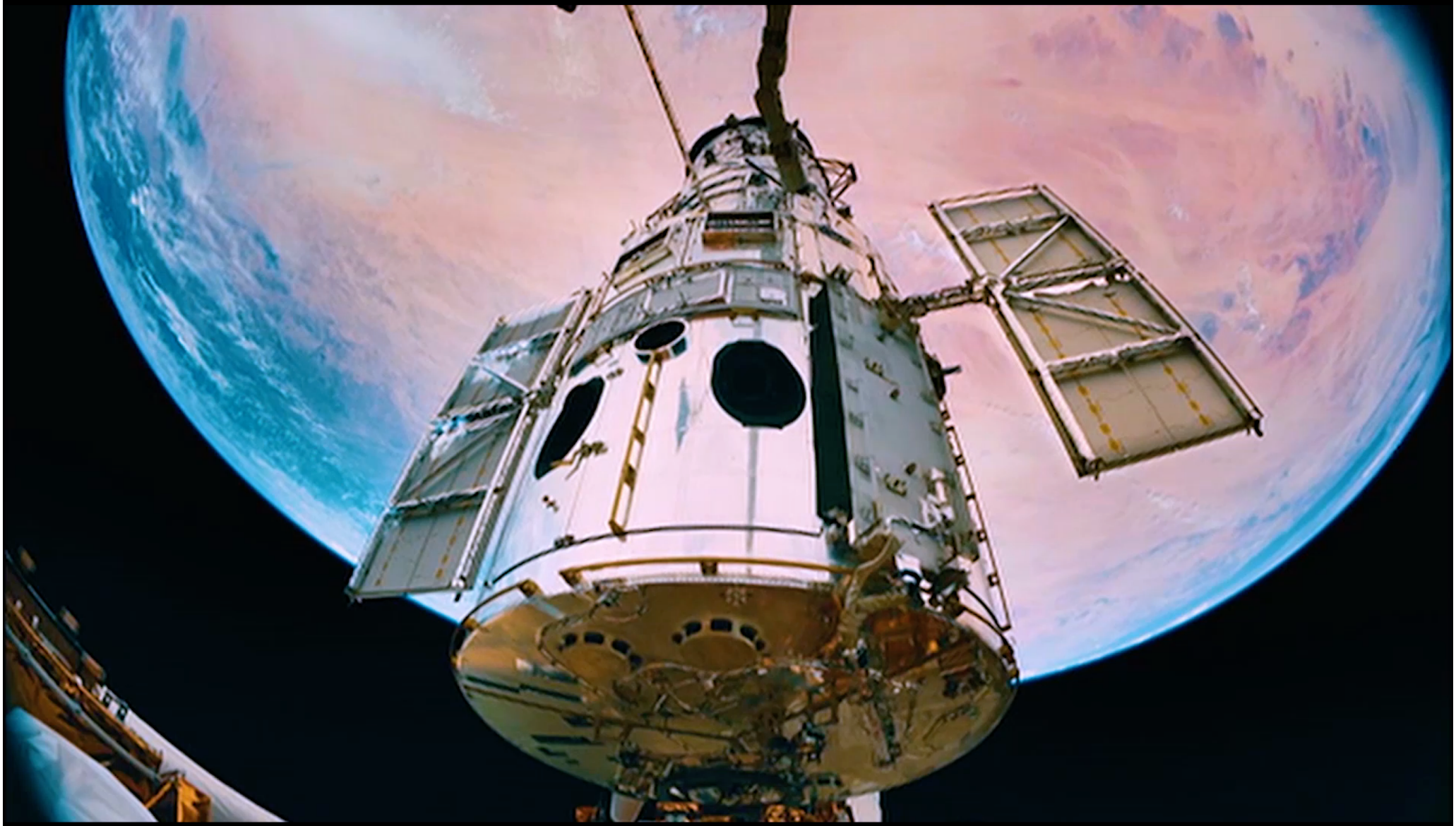
Mass: 8% of Sun


A Once in a Lifetime Adventure
TRAPPIST-1
Planetary System
Within 40 light-years of Earth
BOOK NOW www.trappisttours.com

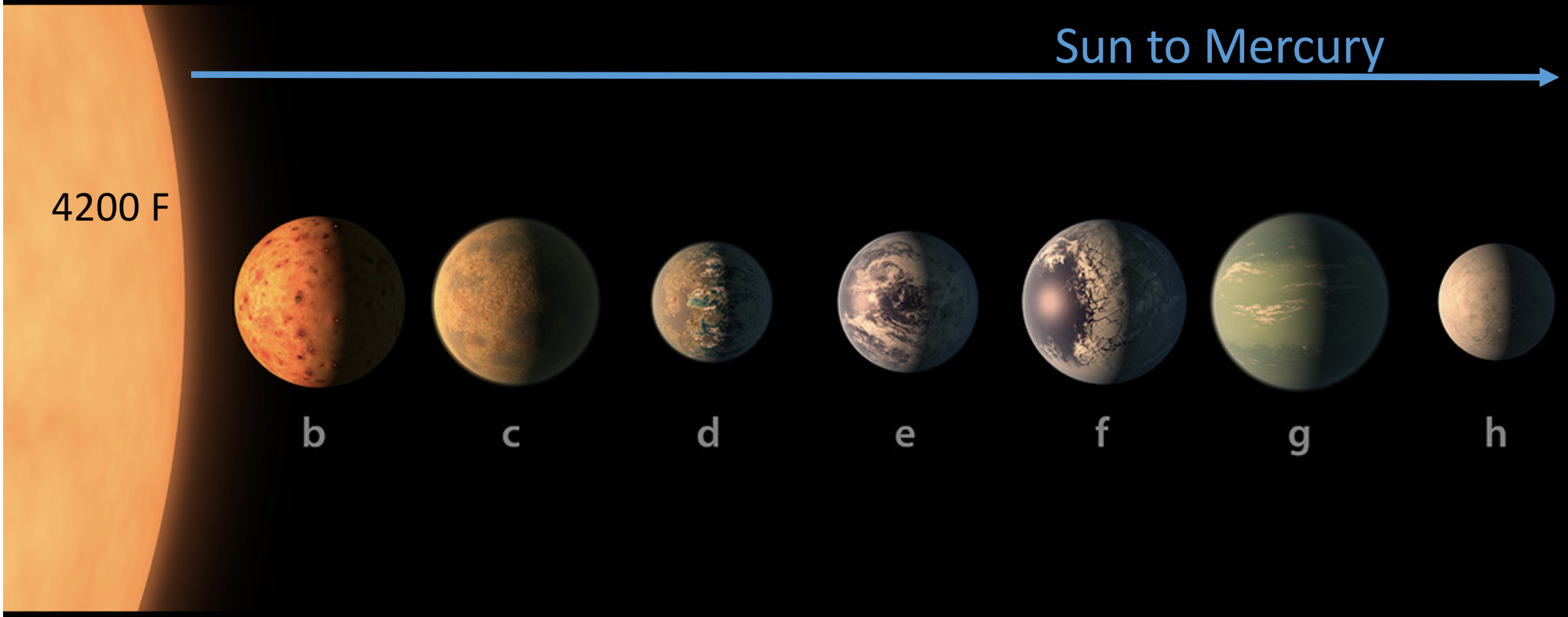
TRAPPIST = TRAnsiting Planets and Planetesimals Small Telescope in Chile. ALSO a Belgian controlled telescope associated with the famous Trappist beer, which the astronomers who discovered the planetary system drank to toast to their discovery.

N.B. Also available with Trappist fruit cake.

TRAPPIST 1 Planetary system



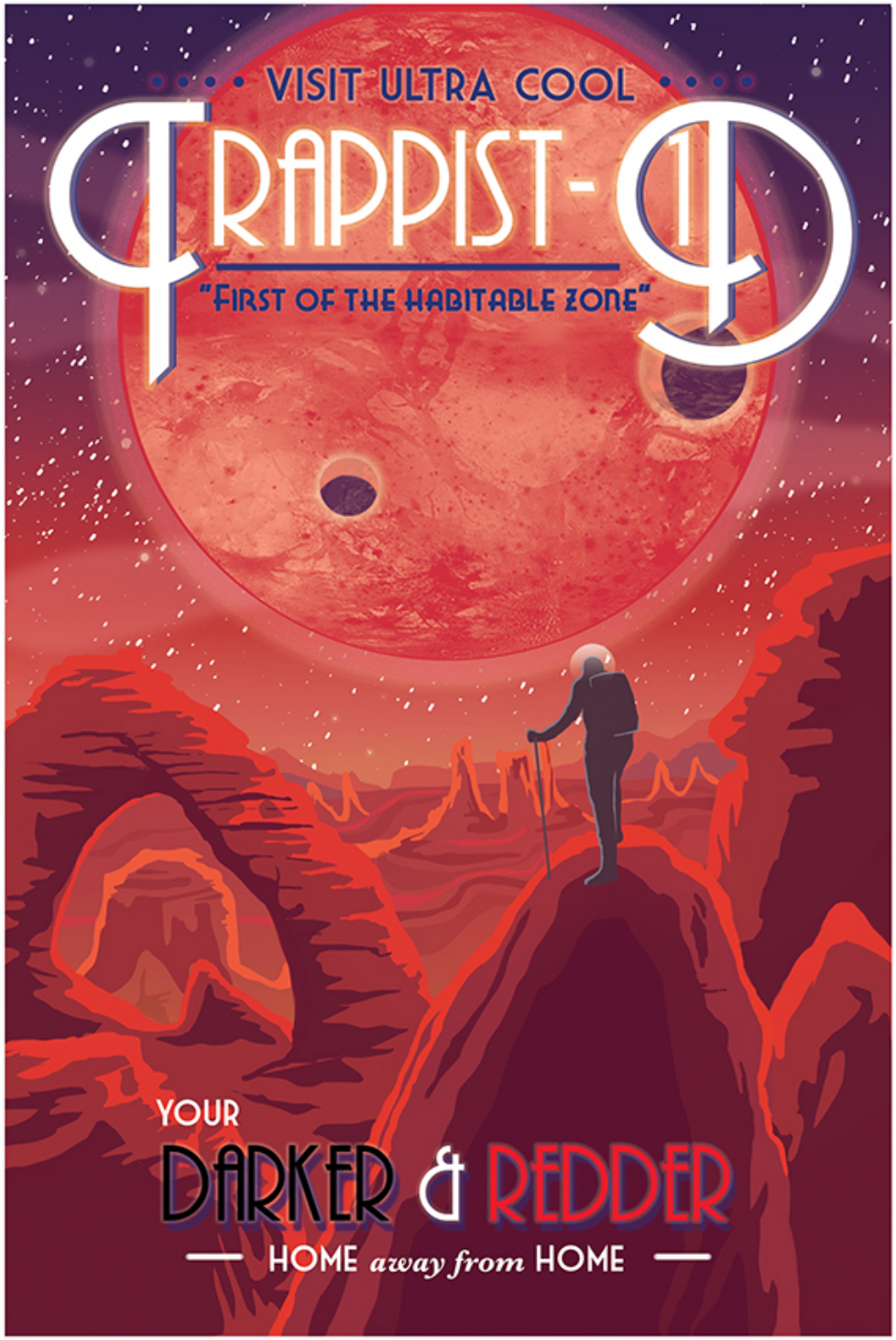
The TRAPPIST-1 solar system: 7 terrestrial planets b, c, e, f, g are same size as Earth, e, f, g are within the habitable zone. All the planets are closer to TRAPPIST-1 than



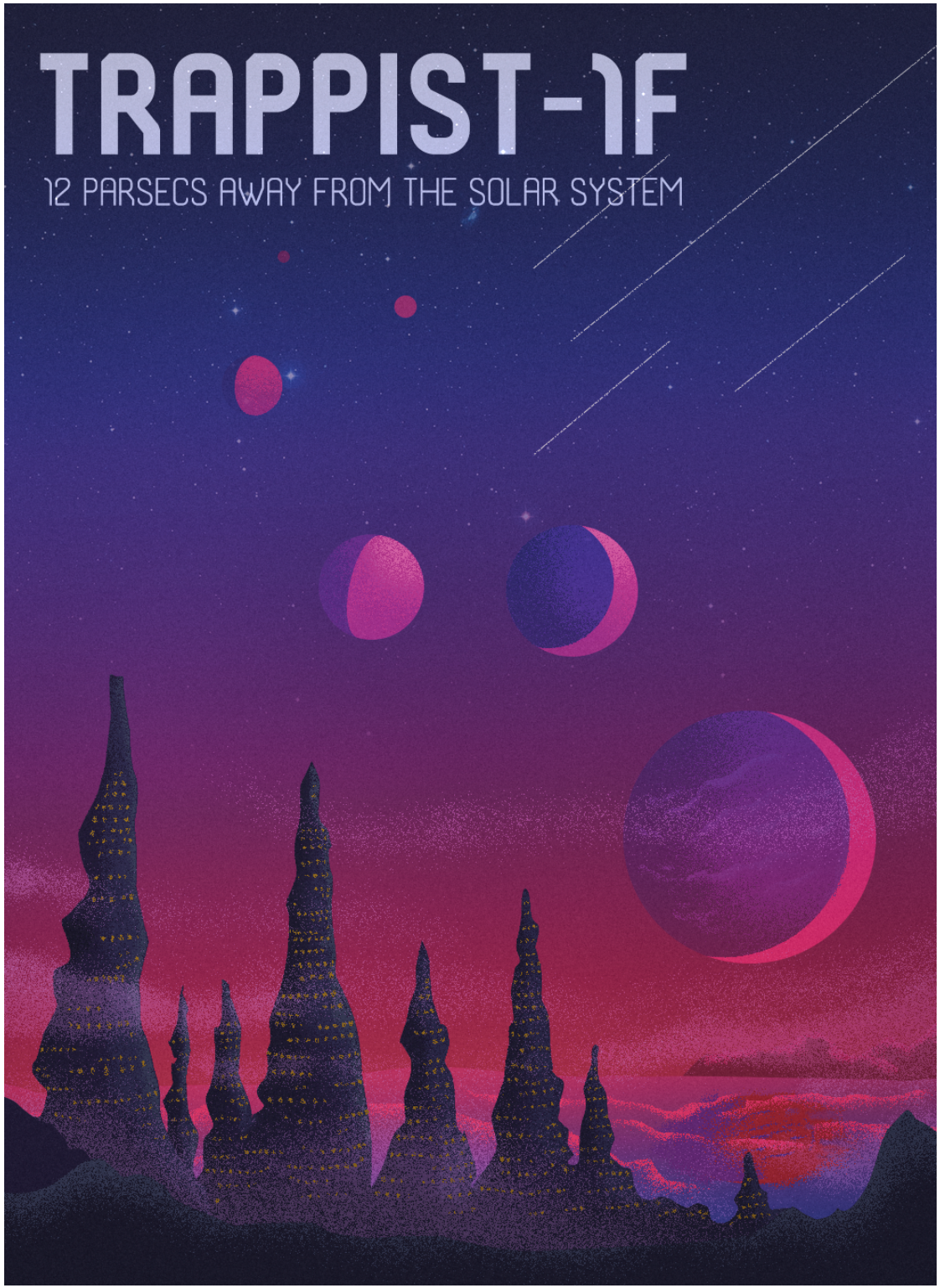
Orbital period (length of ”year”):

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

E X O P L A N E T S

Exoplanet: A planet orbiting another sun

What have we seen?

How are they found?

Characteristics

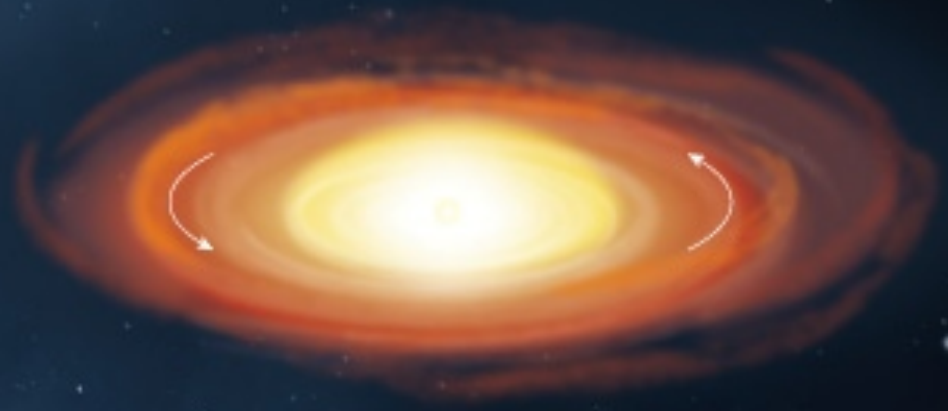
How do planets form?

PLANETARY STANDARD MODEL

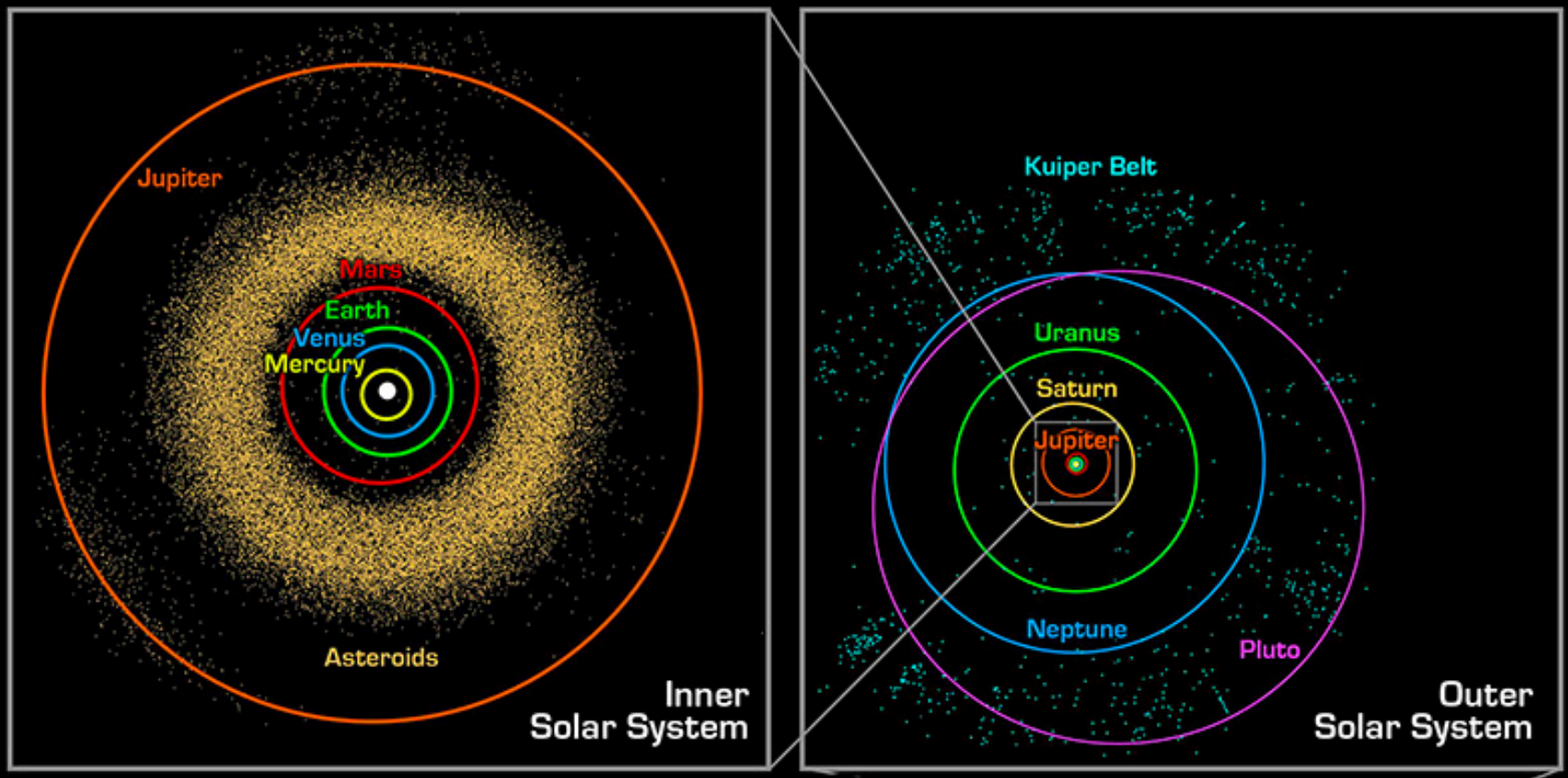
The conventional planetary-formation theory explains how our Solar System developed more than 4.6 billion years ago.

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.

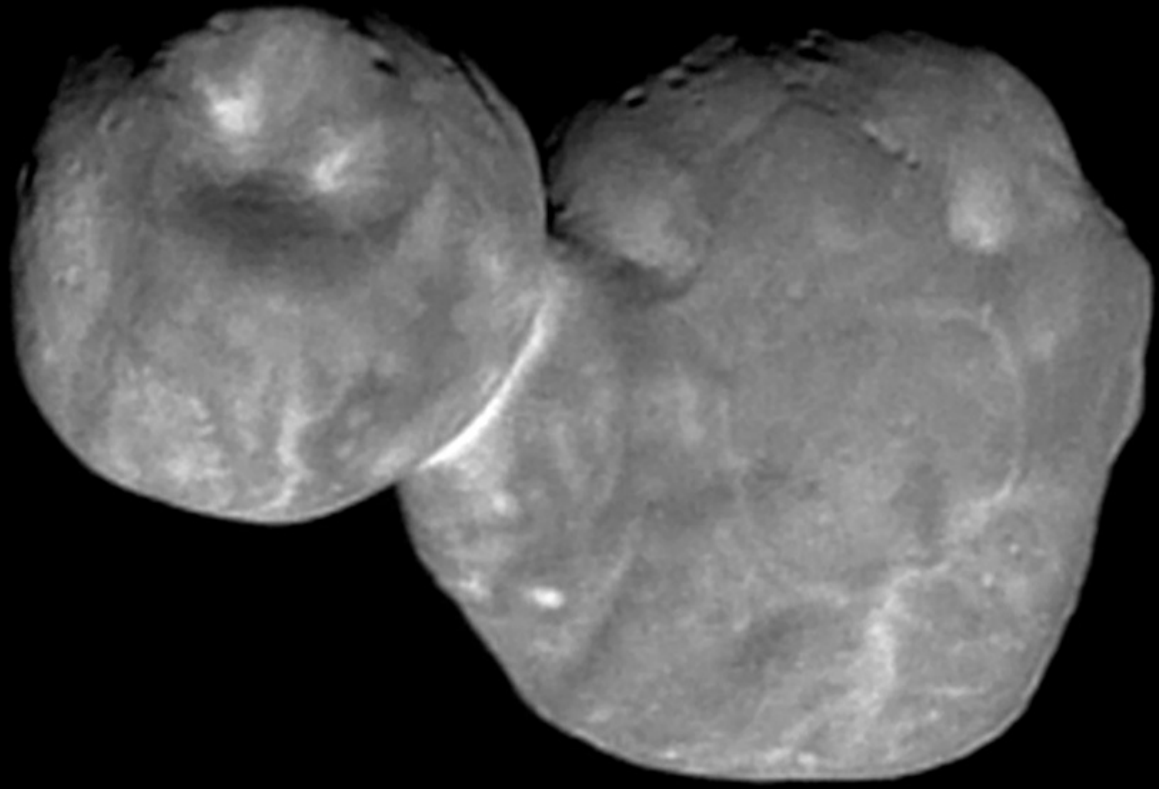


The Solar System is filled with “leftovers” from the formation of our Planetary System



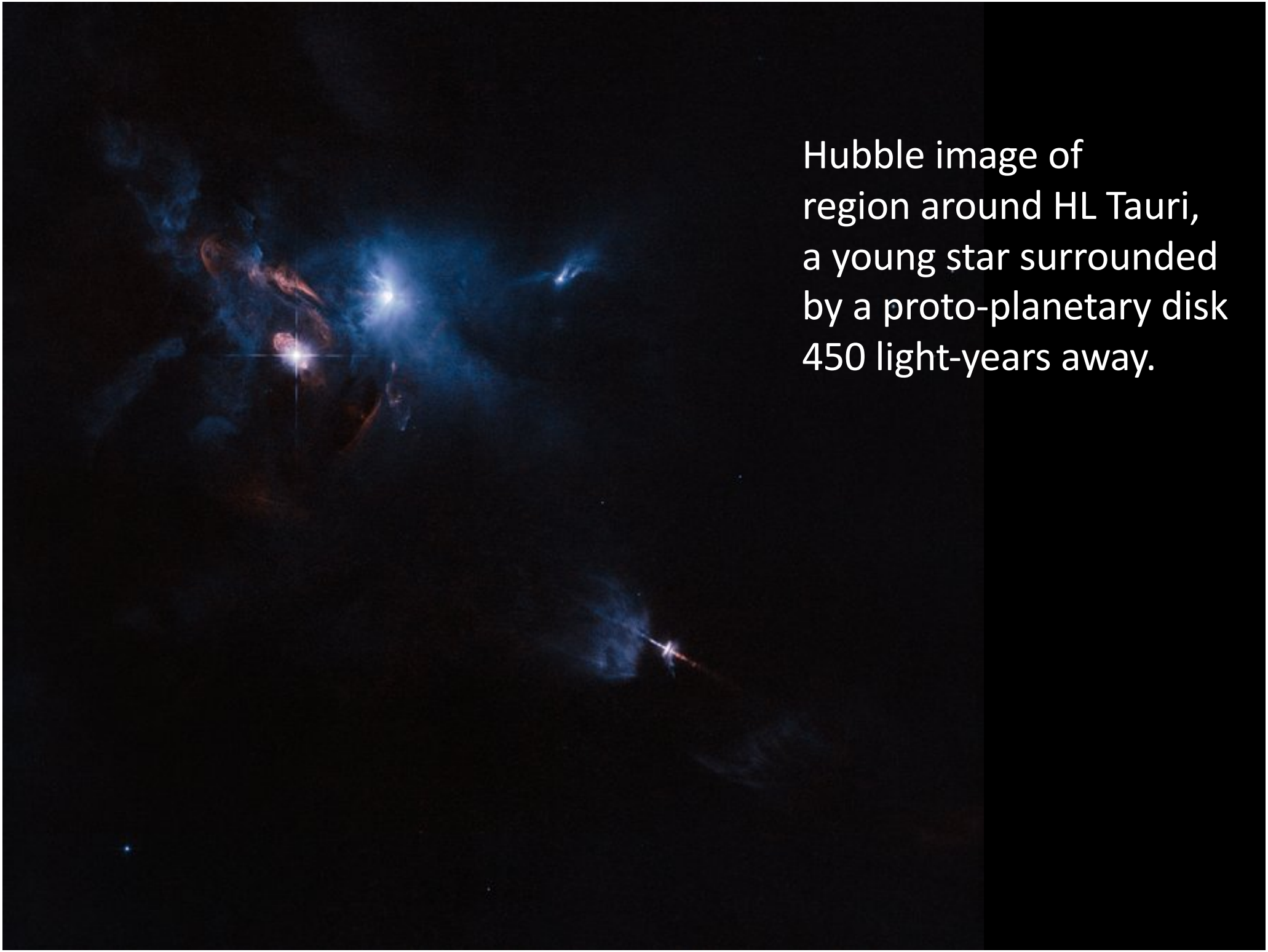
The Itokawa asteroid, 1,100 feet in diameter, is located in the Asteroid Belt. The Japanese spacecraft probe *(Hayabusa)* landed on the asteroid 13 June 2019

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



New Horizons mission

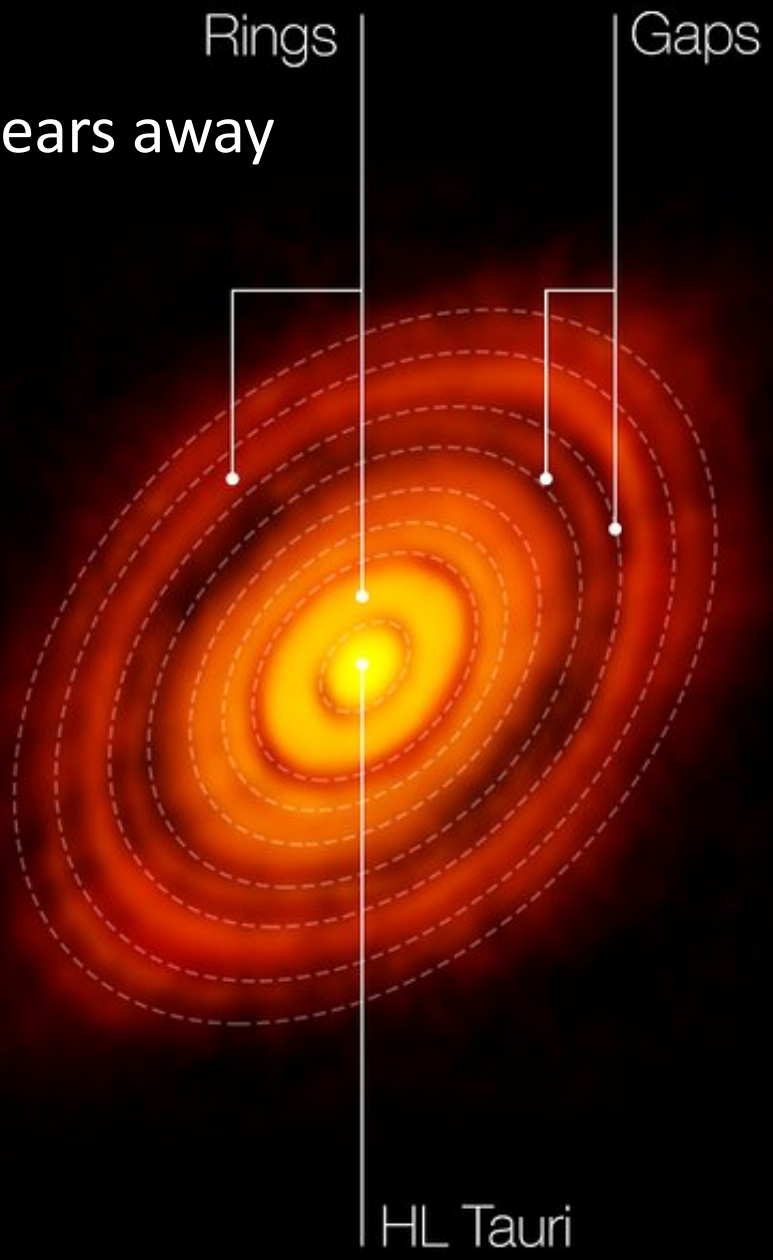
Called a *contact binary,* 22 miles long, 4 billion miles away



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

HL Tauri

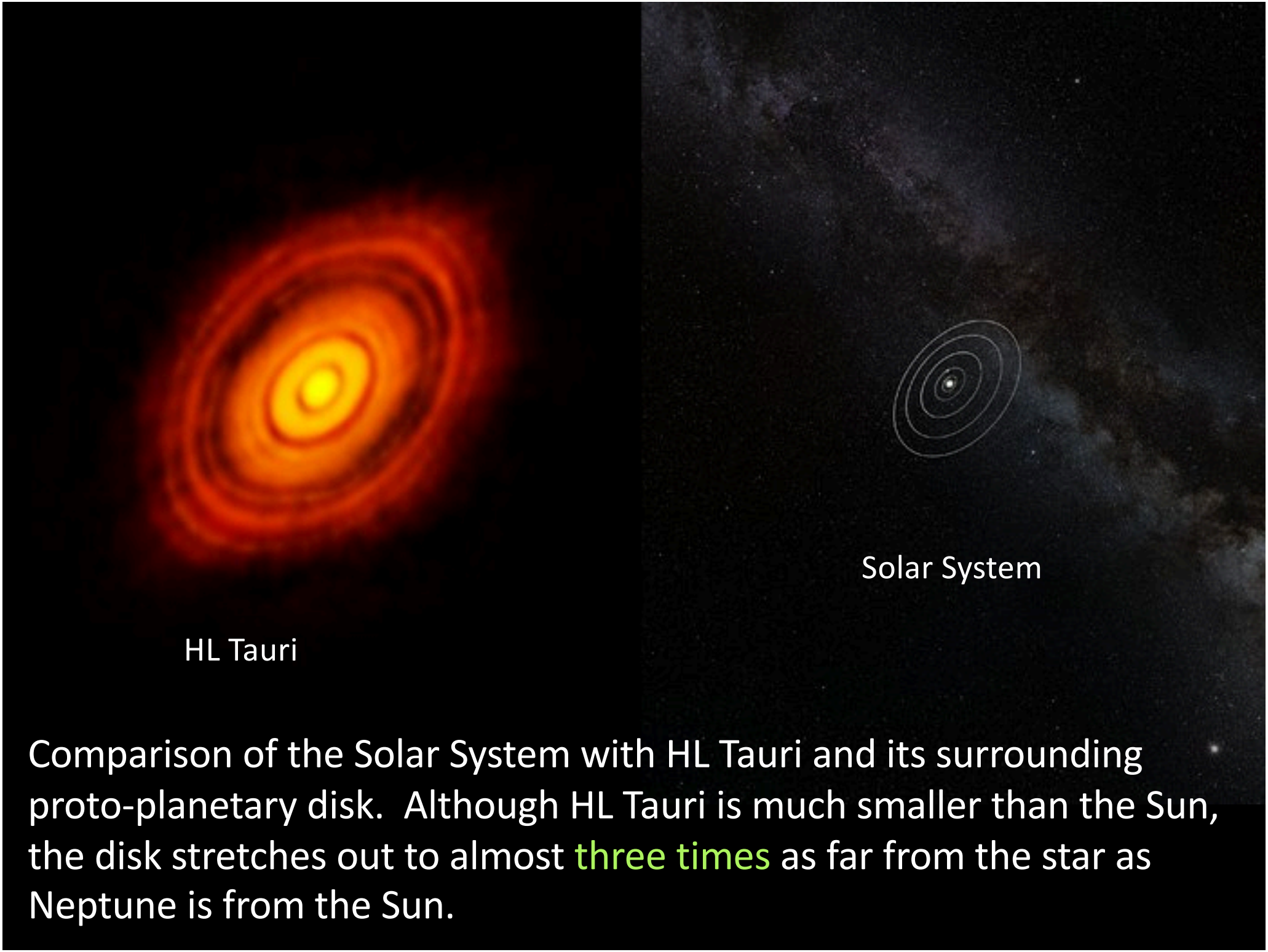
450 light years away



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

Surprise!

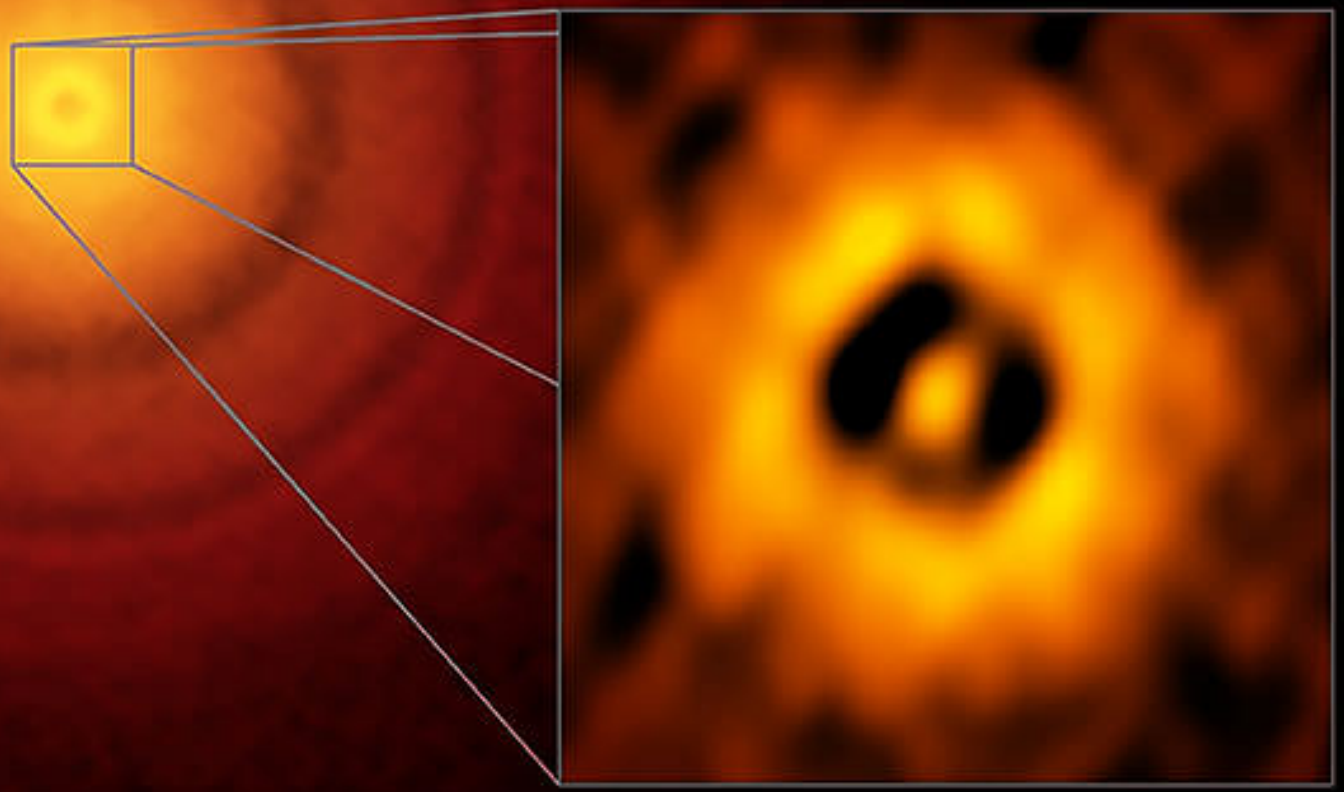
HL Tauri is only about 1 million years old, and was thought to be much too young to have planets already forming around it



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.

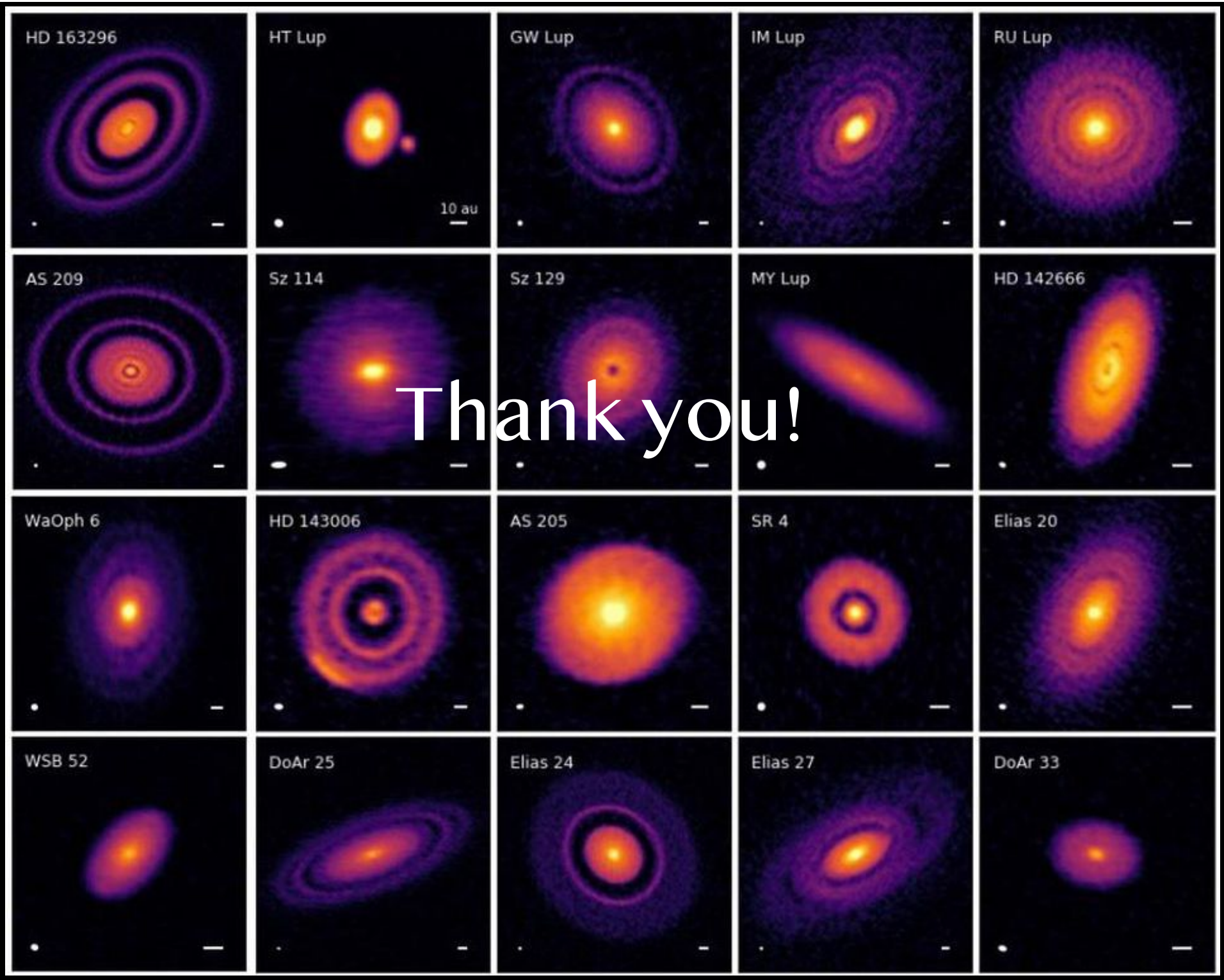
TW Hydra, 10 mill. year old proto-star with proto-planetary disk, showing planet formation

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 70b 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 -370^0 F.


HD 163296
HT Lup
10 au
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RU Lup
AS 209
Sz 114
Sz 129
MY Lup
HD 142666
Thank you!
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HD 143006
AS 205
SR 4
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WSB 52
DoAr 25
Elias 24
Elias 27
DoAr 33