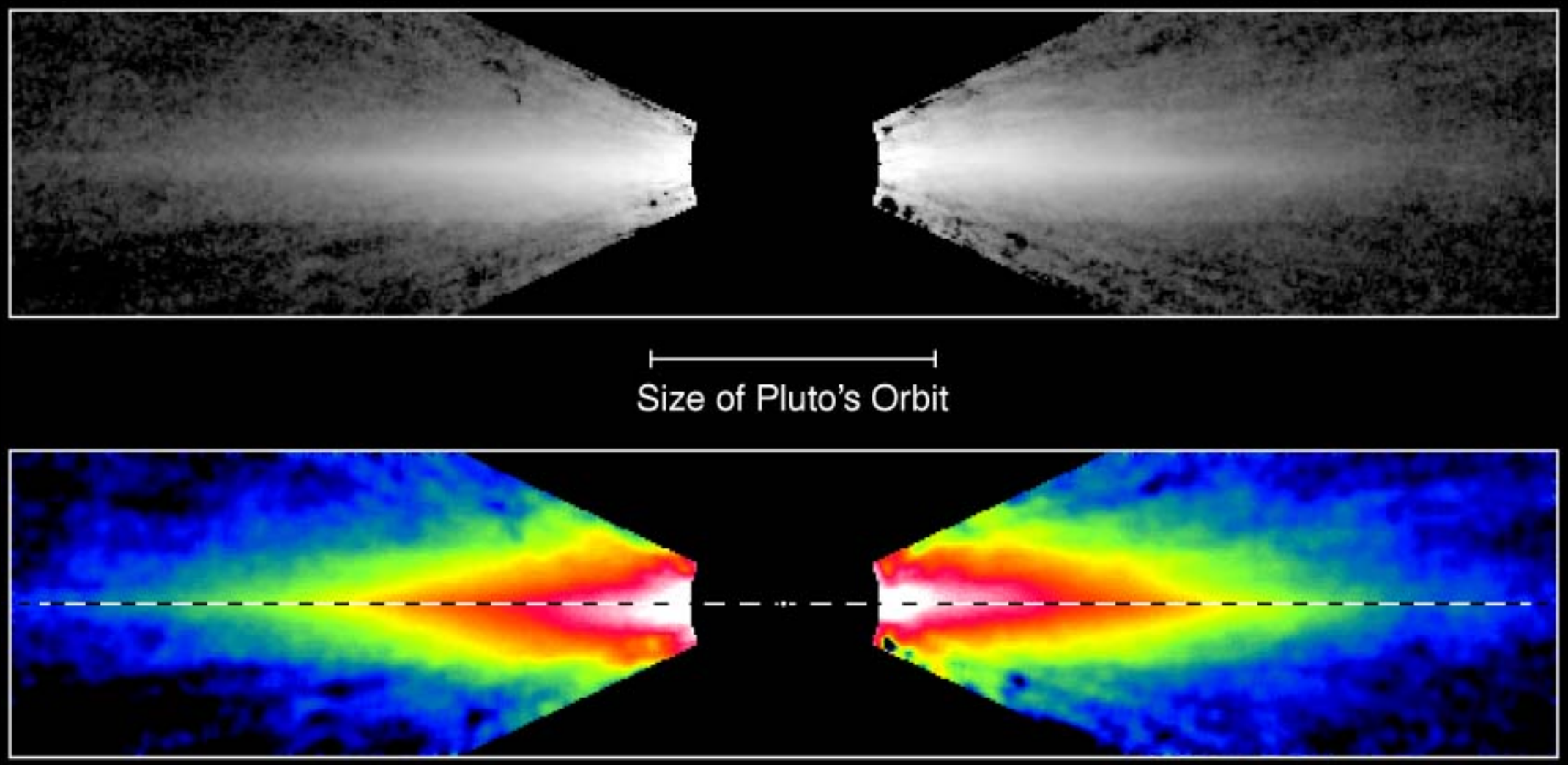
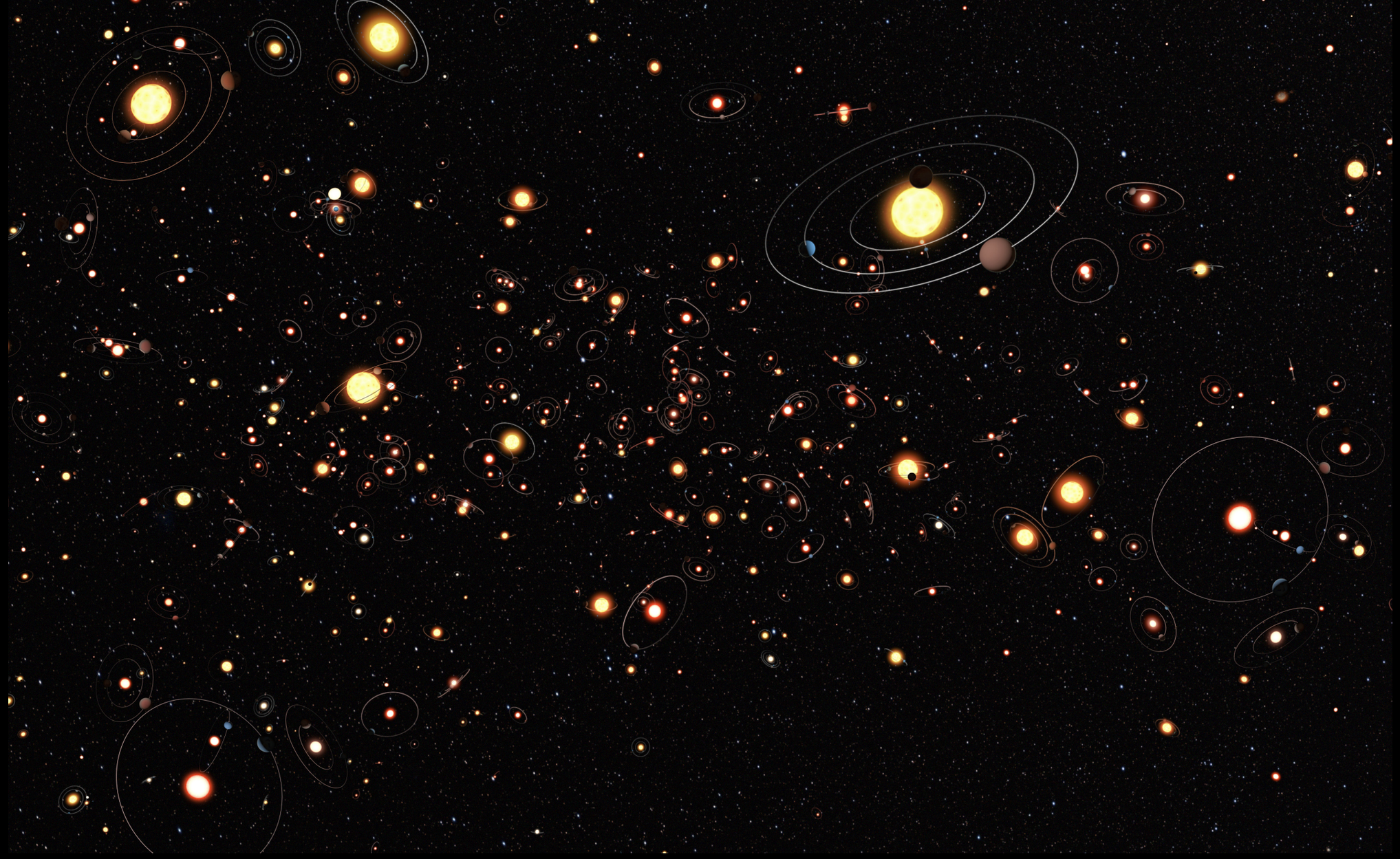


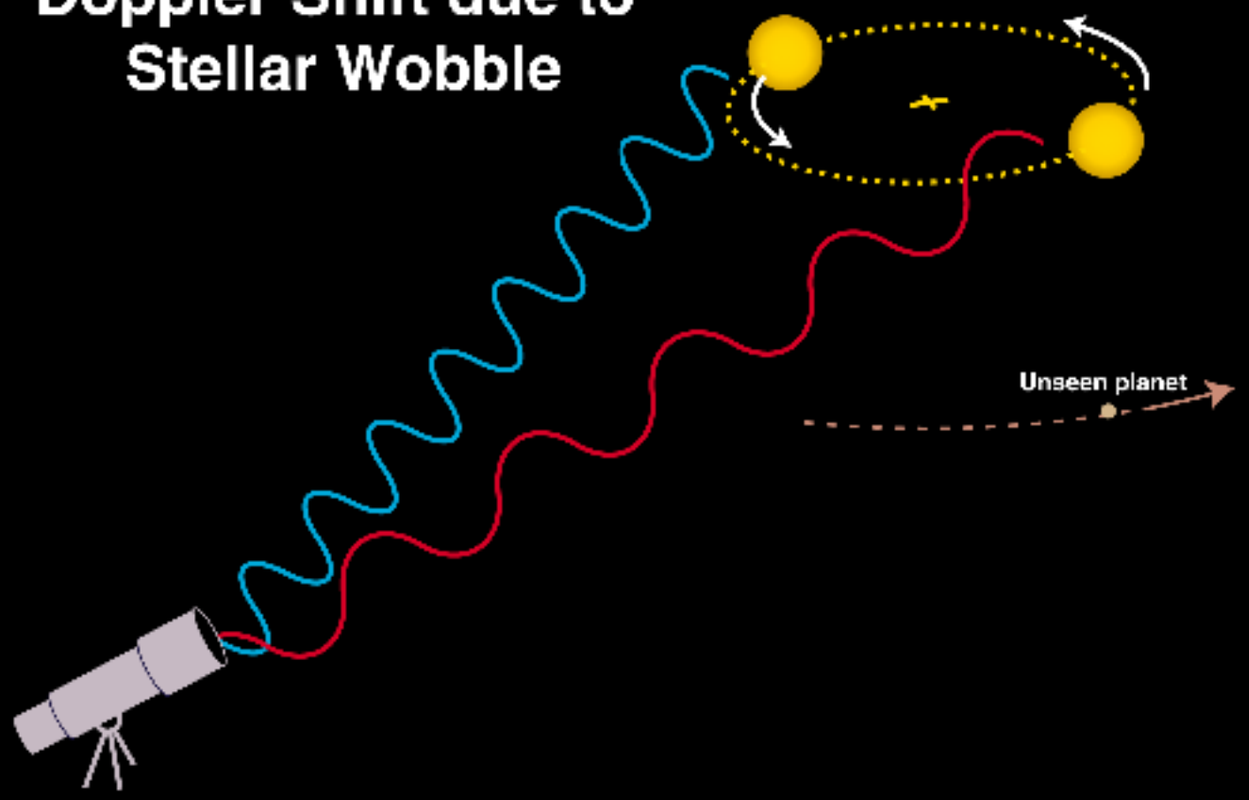
Extrasolar Systems or Exoplanets:

Support for the protoplanet hypothesis has been found by the detection of disk material around of stars, such as Beta Pictoris (below). Thus, the possibility of other solar systems seemed high.



An exoplanet or extrasolar planet is a planet that orbits a star other than the Sun. The first scientific detection of an exoplanet was in 1988. On average, there is at least one planet per star, with a percentage having multiple planets. About 1 in 5 Sun-like stars have an "Earth-sized" planet in the habitable zone. Assuming there are 200 billion stars in the Milky Way, one can hypothesize that there are 11 billion potentially habitable Earth-sized planets in the Milky Way, rising to 40 billion if planets orbiting the numerous red dwarfs are included.

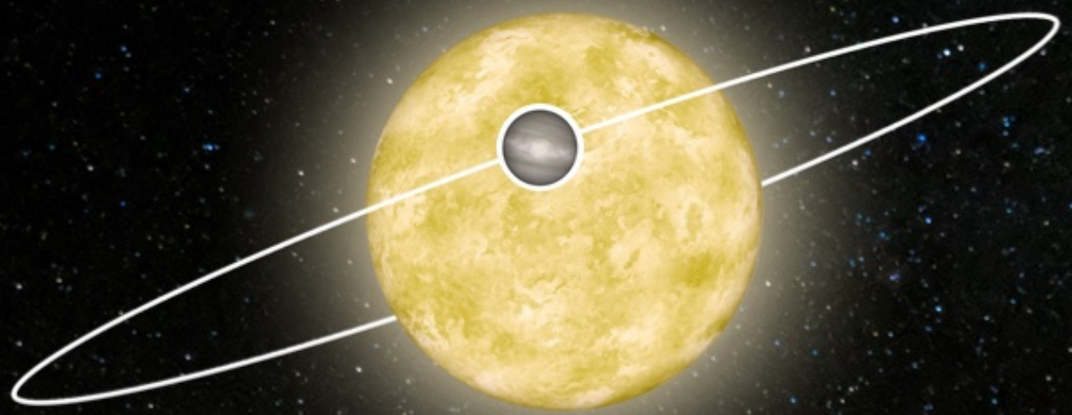
Doppler Shift due to Stellar Wobble



Doppler spectroscopy is used to detect the periodic velocity shift of the stellar spectrum caused by an orbiting giant planet. This method is also referred to as the radial velocity method. From ground-based observatories, spectroscopists can measure Doppler shifts greater than 3 m/sec due to the reflex motion of the star This corresponds to a minimum detectable mass of 33 Earth masses for a planet at 1 AU from a one solar-mass star.

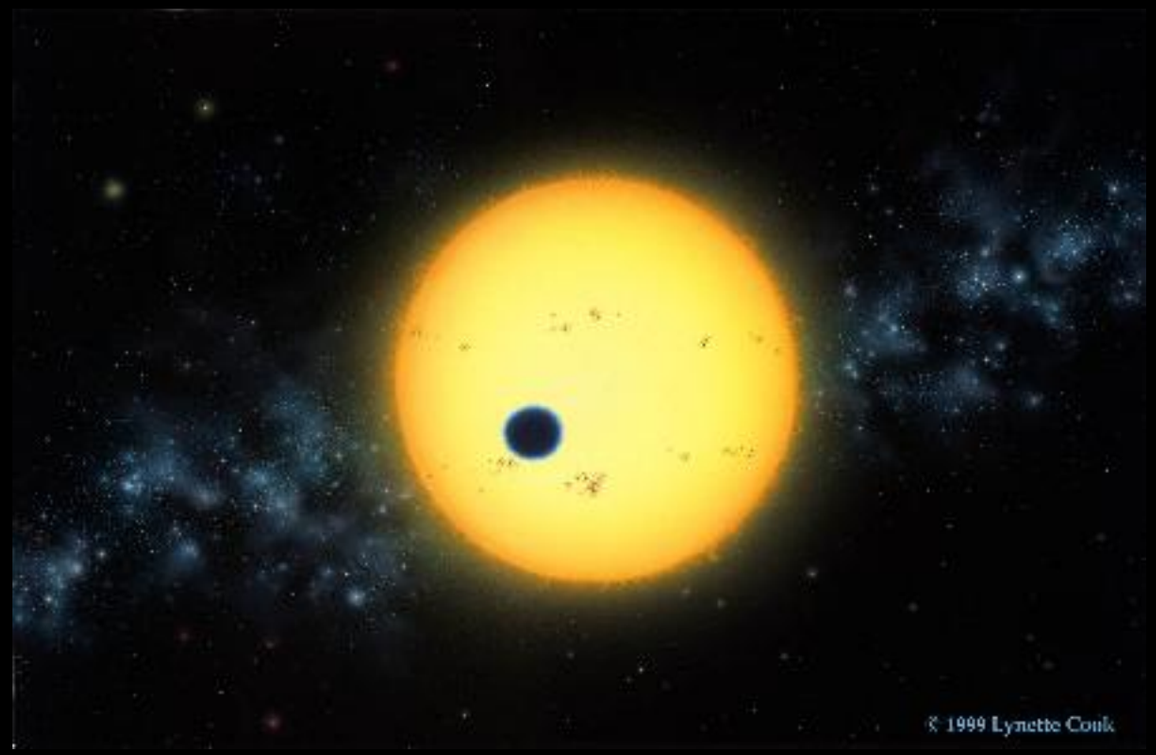
VIEW FROM ABOVE

VIEW FROM TELESCOPE

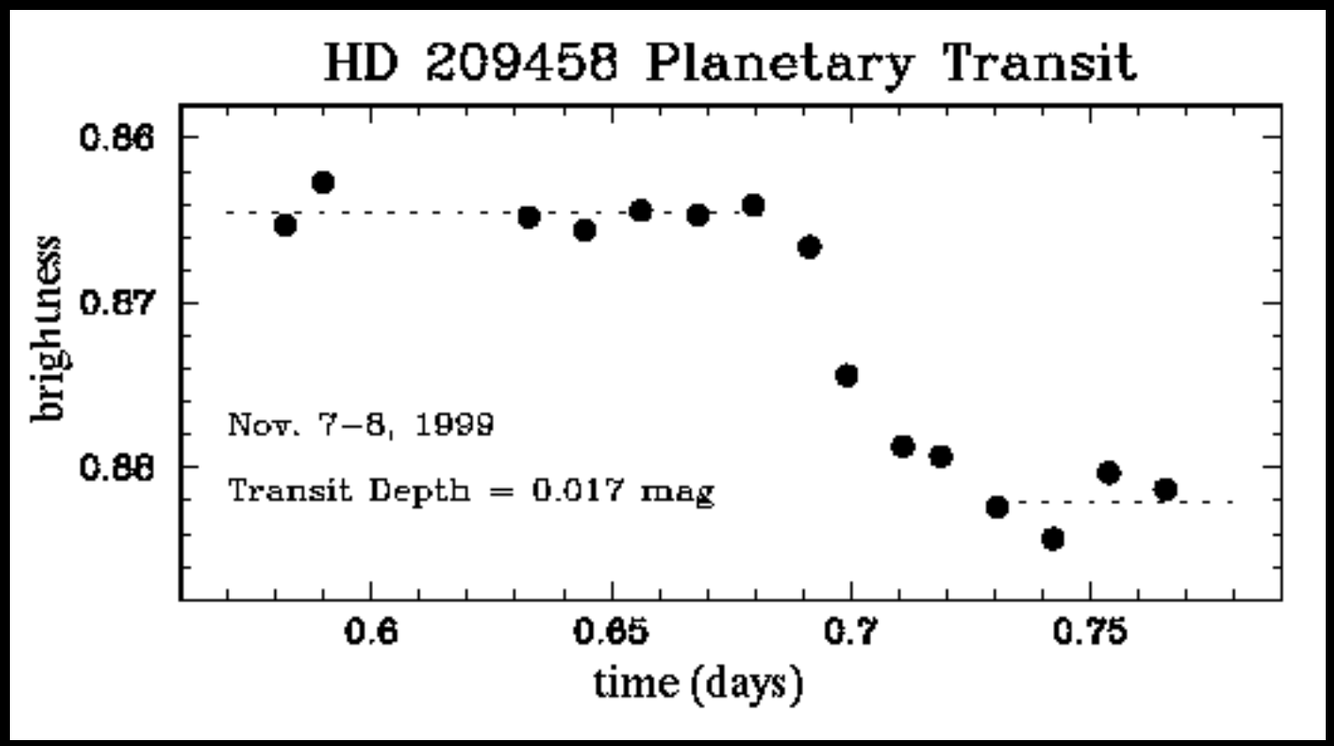


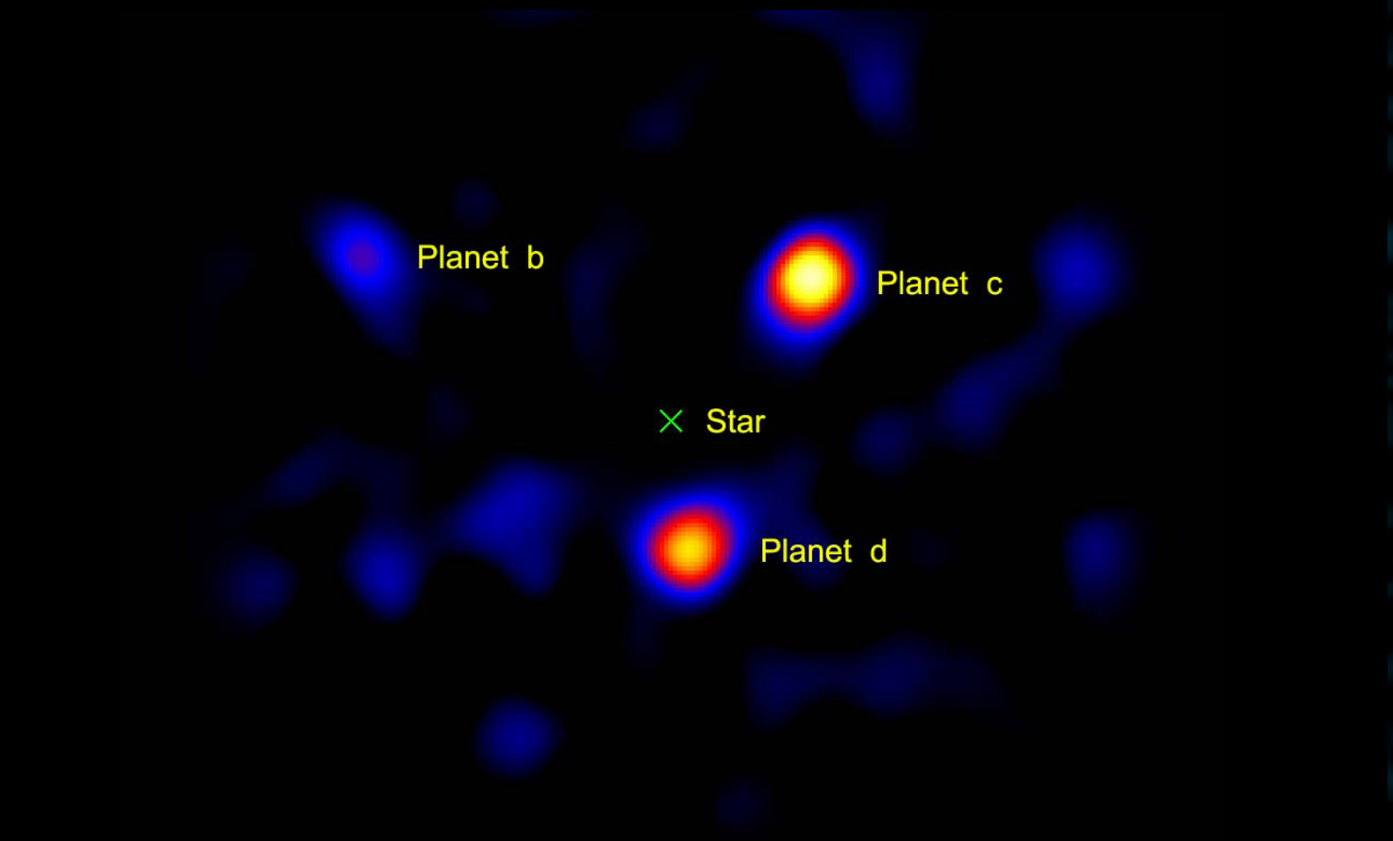
LIGHT CURVE

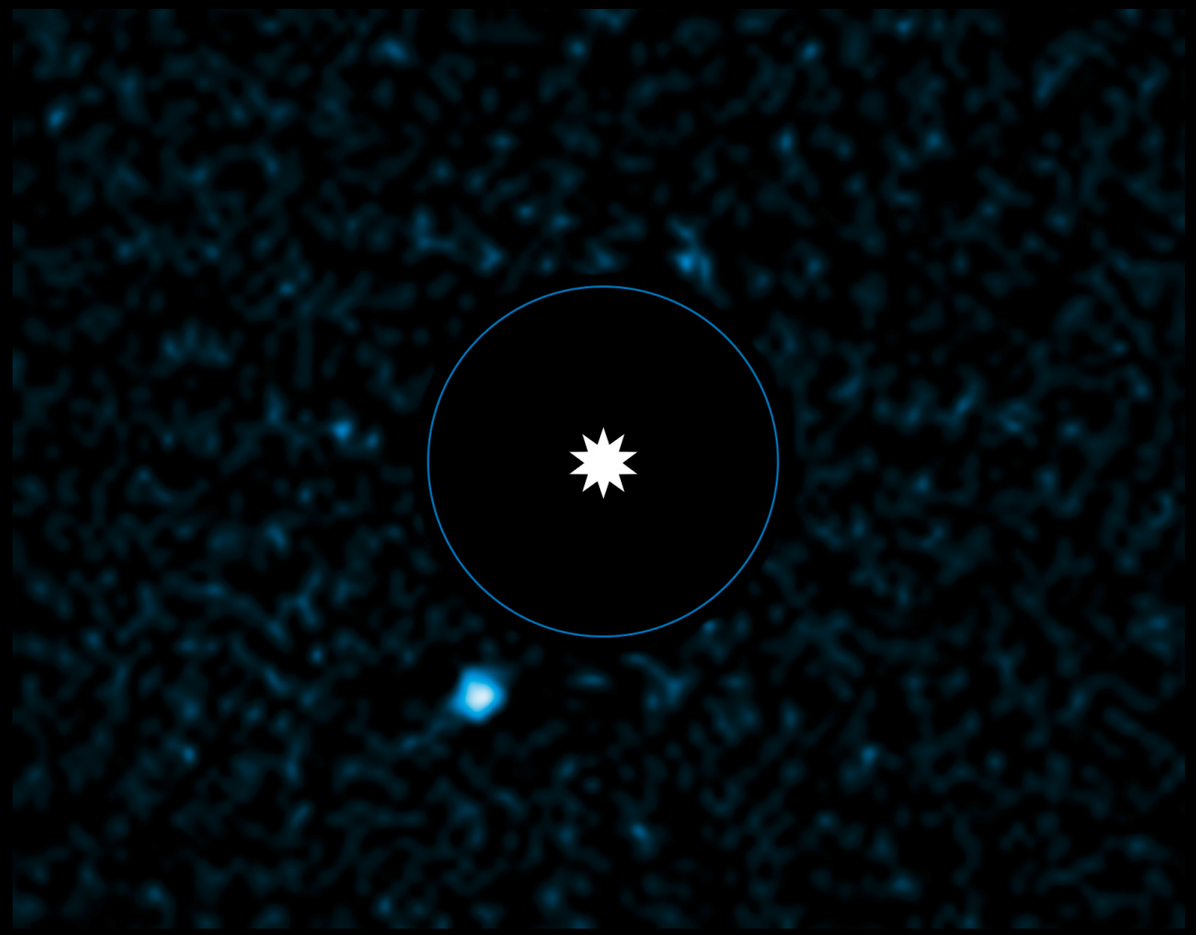
Artist conception, not to scale



A more direct measure occurs is a planet transits across the front of a star, as happened with HD 209458, a distant planet passing in front of its star, providing direct and independent confirmation of the existence of extrasolar planets.





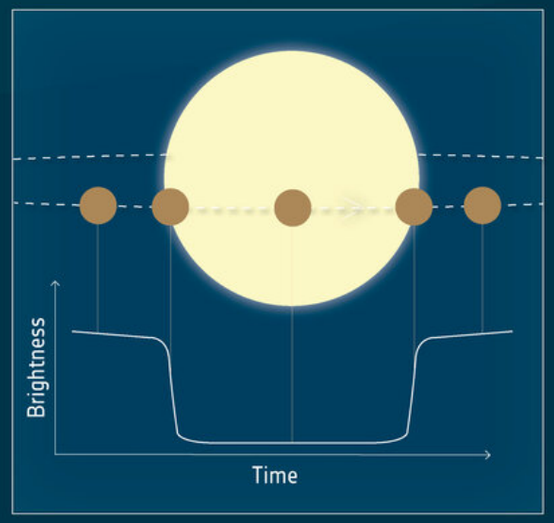


Planets are extremely faint light sources compared to stars, and what little light comes from them tends to be lost in the glare from their parent star. So in general, it is very difficult to detect and resolve them directly from their host star. Planets orbiting far enough from stars to be resolved reflect very little starlight, so planets are detected through their thermal emission instead.

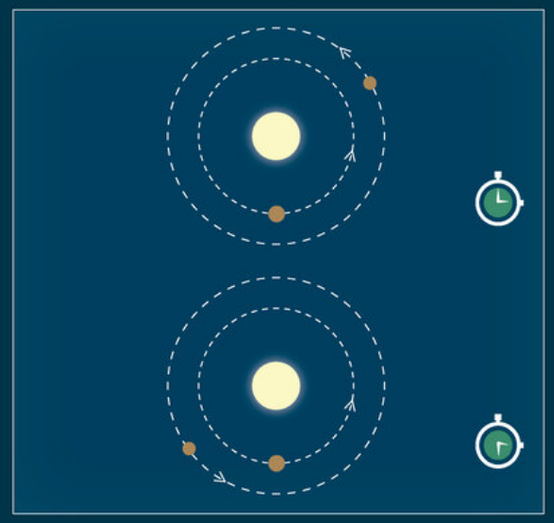
→ EXOPLANET DETECTION METHODS

esa

Transit photometry



Transit-timing variation

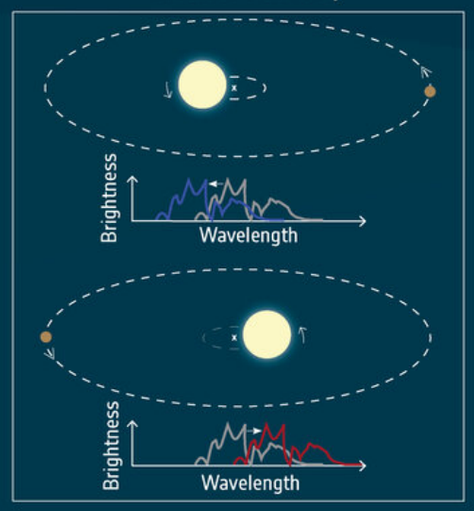


Transit photometry is one of the main techniques used to **discover** exoplanets. Cheops will use this technique to **measure the sizes** of known exoplanets and to start to **characterise** them.

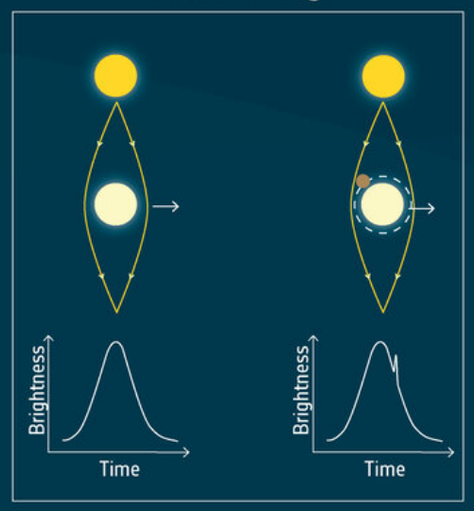
By using the **transit-timing variation** technique, Cheops will be able to **discover** additional, previously unknown planets around some stars, and also determine the planet **masses**.

Other techniques used to discover new exoplanets (not employed by Cheops) are: radial velocity, microlensing, astrometry and direct imaging.

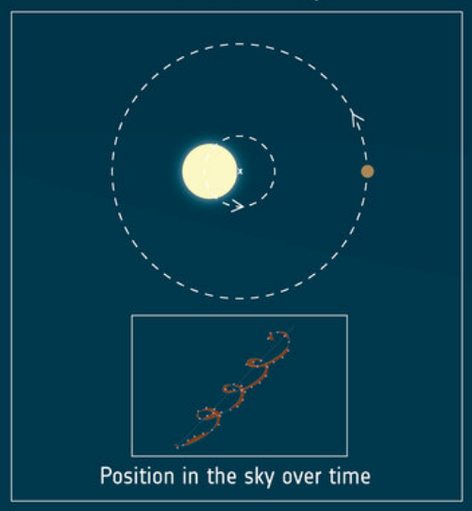
Radial velocity



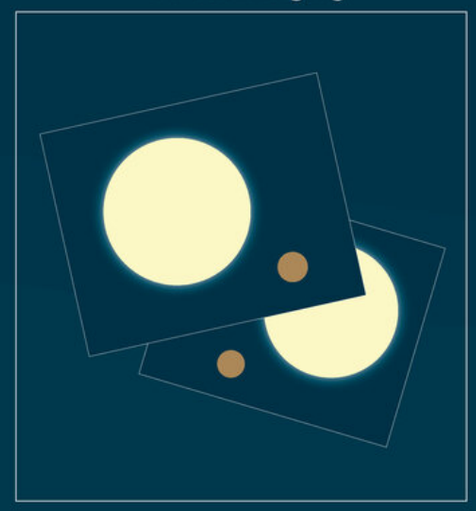
Microlensing



Astrometry



Direct imaging



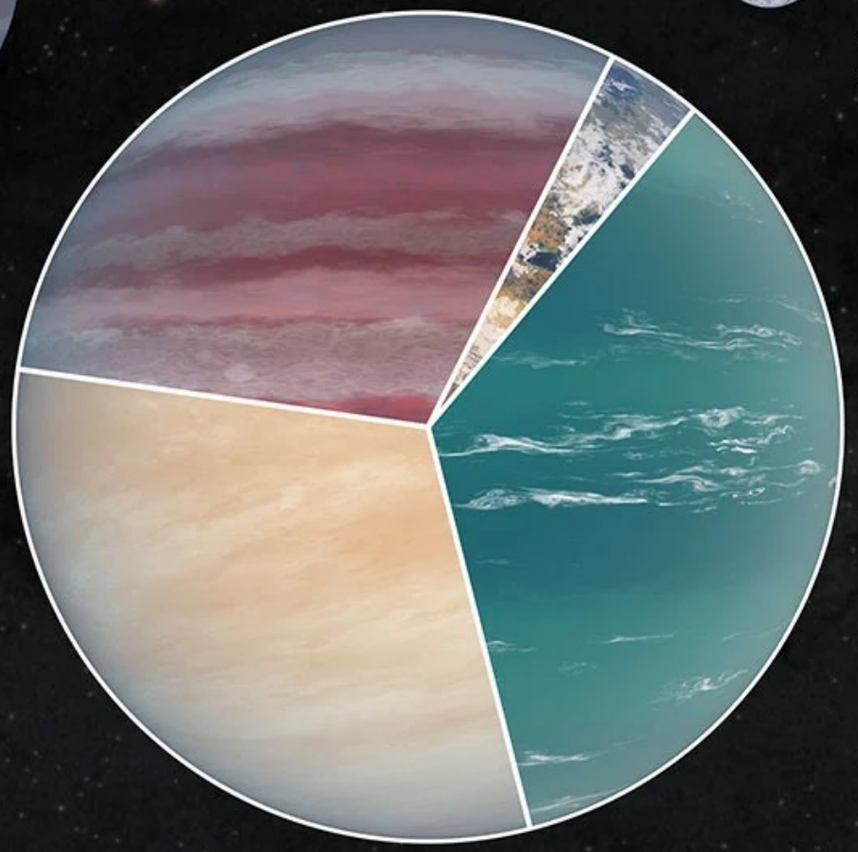
#cheops

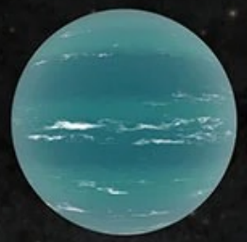
30%
GAS GIANT

The size of Saturn or Jupiter (the largest planet in our solar system), or many times bigger. They can be hotter than some stars!

4%
TERRESTRIAL

Small, rocky planets. Around the size of our home planet, or a little smaller.





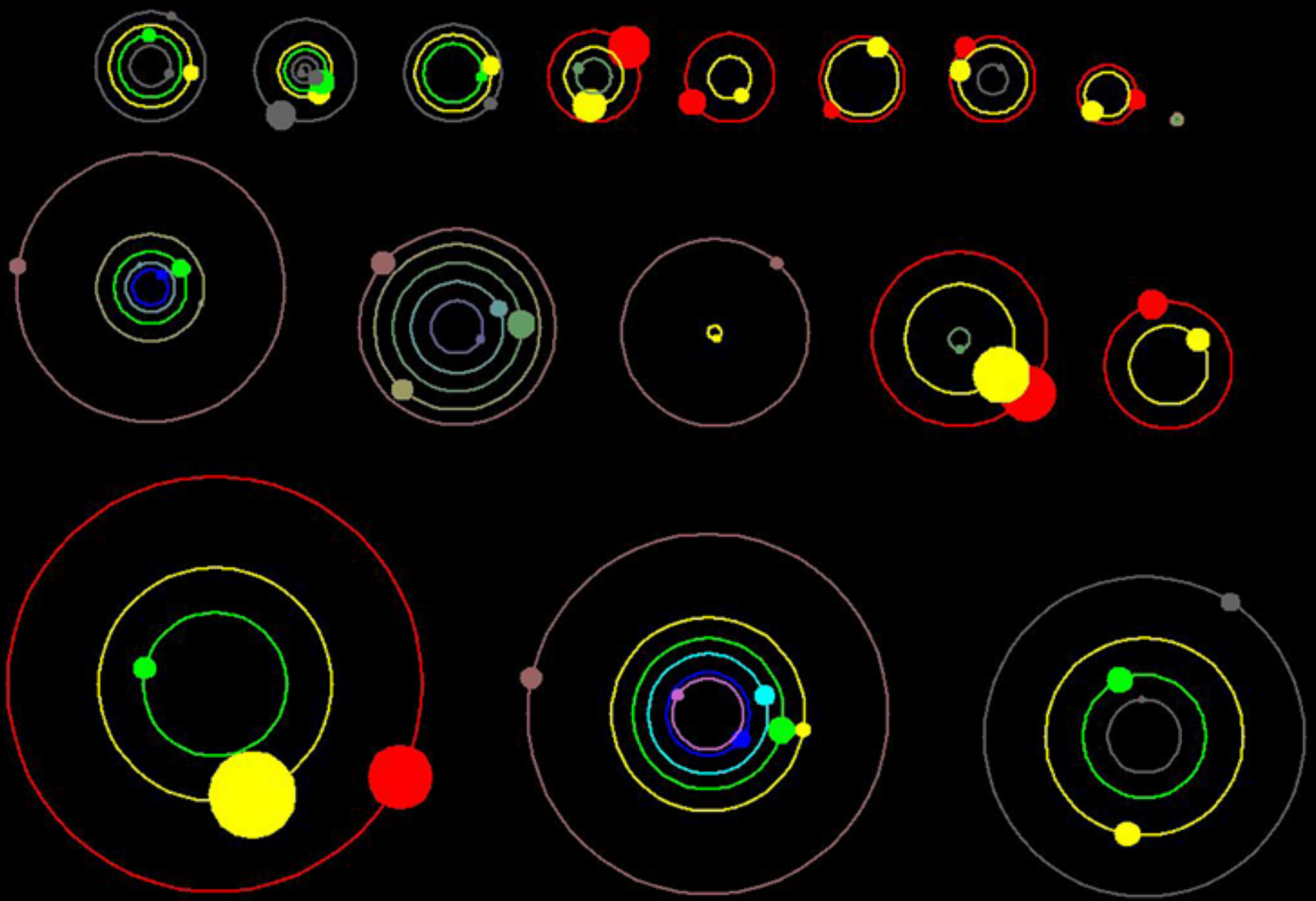
35%
NEPTUNE-LIKE

Similar in size to Neptune and Uranus. They can be ice giants, or much warmer. “Warm” Neptunes are more rare.

31%
SUPER-EARTH

Planets in this size range between Earth and Neptune don’t exist in our solar system. Super-Earths, a reference to larger size, might be rocky worlds like Earth, while mini-Neptunes are likely shrouded in puffy atmospheres.

5000+
PLANETS FOUND



Initially, most known exoplanets were massive planets that orbited very close to their parent stars. Astronomers were surprised by these "hot Jupiters", because theories of planetary formation had indicated that giant planets should only form at large distances from stars. But eventually more planets of other sorts were found, and it is now clear that hot Jupiters make up the minority of exoplanets.

→ EXAMPLES OF PLANETARY SYSTEMS

esa

Solar System

Sun

Mercury

Venus

Earth

Mars

Jupiter

Saturn

Uranus

Neptune

51 Pegasi

Planet: **51 Pegasi b**
Type: Hot Jupiter
Orbital period: 4.2 days
Discovery method: Radial velocity (1995)

First exoplanet discovered around a Sun-like star

COROT-7

COROT-7 b
Terrestrial planet
0.8 days
Transit (2009)

COROT-7 c
Super Earth
3.7 days
Radial velocity (2009)

COROT-7d
Candidate, to be confirmed
Radial velocity (2010)

?

First discovery of a terrestrial exoplanet

TOI-270

TOI-270 c
Mini Neptune
5.7 days
Transit (2019)

TOI-270 b
Super Earth
3.4 days
Transit (2019)

TOI-270 d
Mini Neptune
11.4 days
Transit (2019)

System with super Earth and mini Neptune exoplanets

55 Cancri

Double star system

55 Cancri e
Super Earth
0.7 days
Transit (2004)

First discovery of a super Earth exoplanet

55 Cancri b
Warm Jupiter
14 days
Radial velocity (1996)

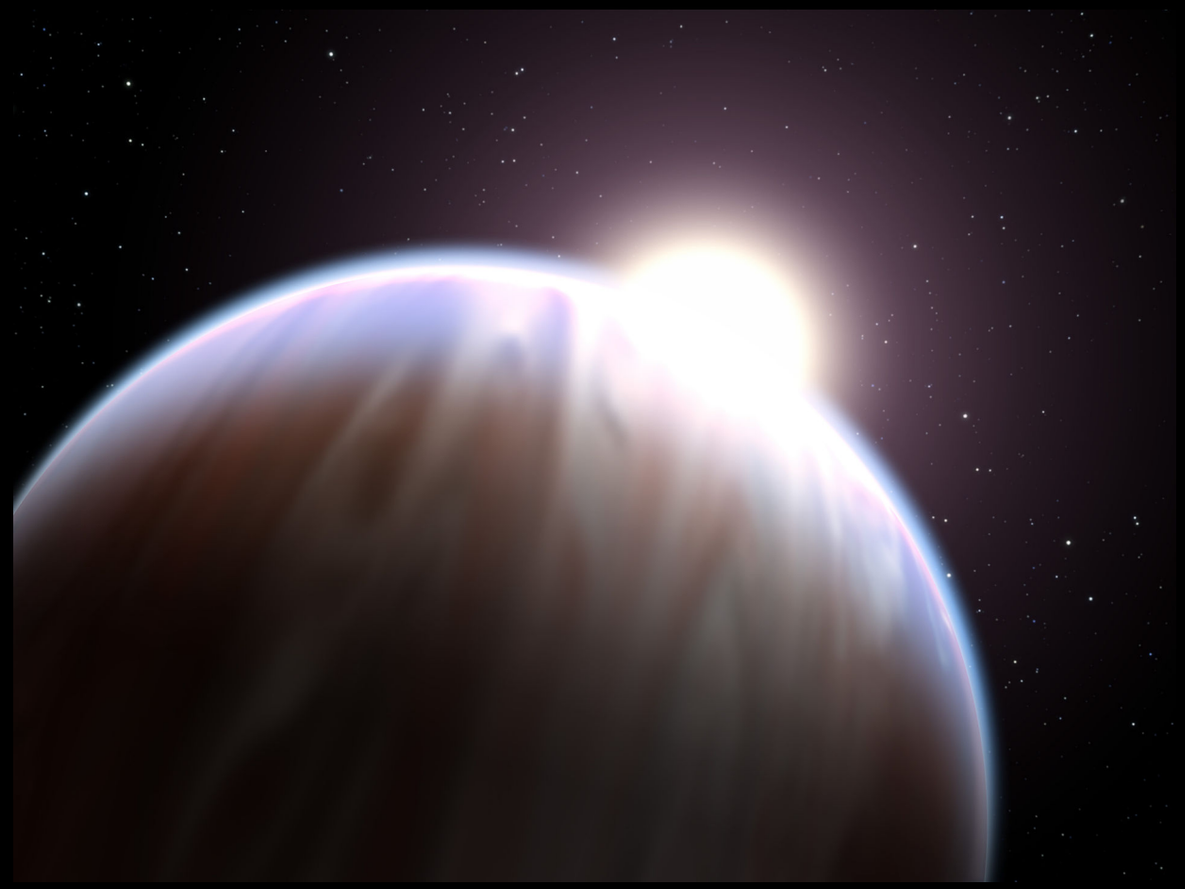
55 Cancri c
Super Neptune
44 days
Radial velocity (2002)

55 Cancri f
Super Neptune
260 days
Radial velocity (2007)

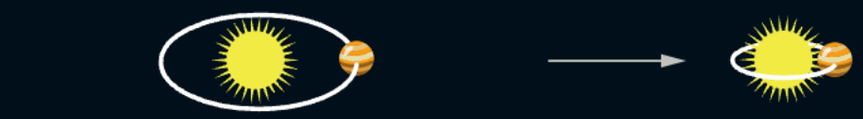
55 Cancri d
Super Jupiter
4867 days
Radial velocity (2002)

Relative sizes and distances are not to scale

#cheops

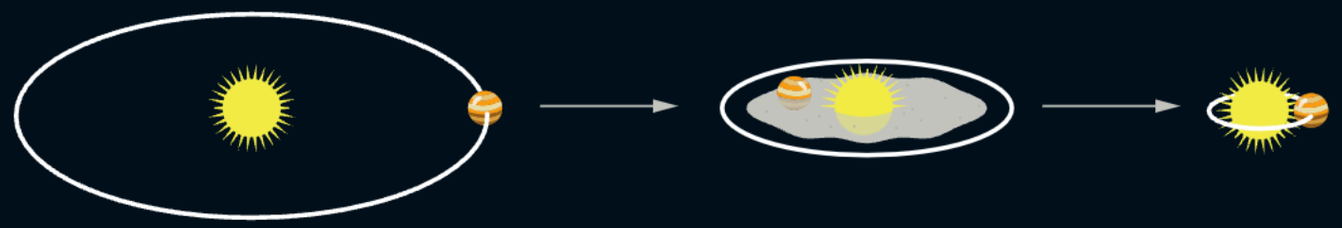


Hot Jupiters (also called roaster planets, epistellar jovians, pegasids or pegasean planets) are a class of exoplanets that are inferred to be physically similar to Jupiter but that have very short orbital radii with semi-major axes from 0.015 to 0.05 astronomical units. The close proximity to their stars and high surface temperatures resulted in the moniker "hot Jupiters".



Close in

Planet forms near star and migrates inward to its current location.



Pulled in

Planet forms far from star, at a distance where gas giants are commonly found. Interactions with gas and dust later pull it into a closer orbit.

Close encounter

Planet forms far from star, then is pulled off-kilter by another object, such as a planet. The resulting eccentric orbit eventually stabilizes close to the star.

CHEOPS REVEALS A RUGBY BALL-SHAPED EXOPLANET

esa

ESA's exoplanet mission **Cheops** has revealed that an exoplanet orbiting its host star within a day has a deformed shape more like that of a rugby ball than a sphere. **This is the first time that the deformation of an exoplanet has been detected**, offering new insights into the internal structure of these star-hugging planets.

WASP-103
Host star

Size
~ 10% of its host star

Orbit
~ 1 day

WASP-103b
Planet

Atmosphere
Solid core
Fluid layer

Internal structure
Likely very similar to that of Jupiter

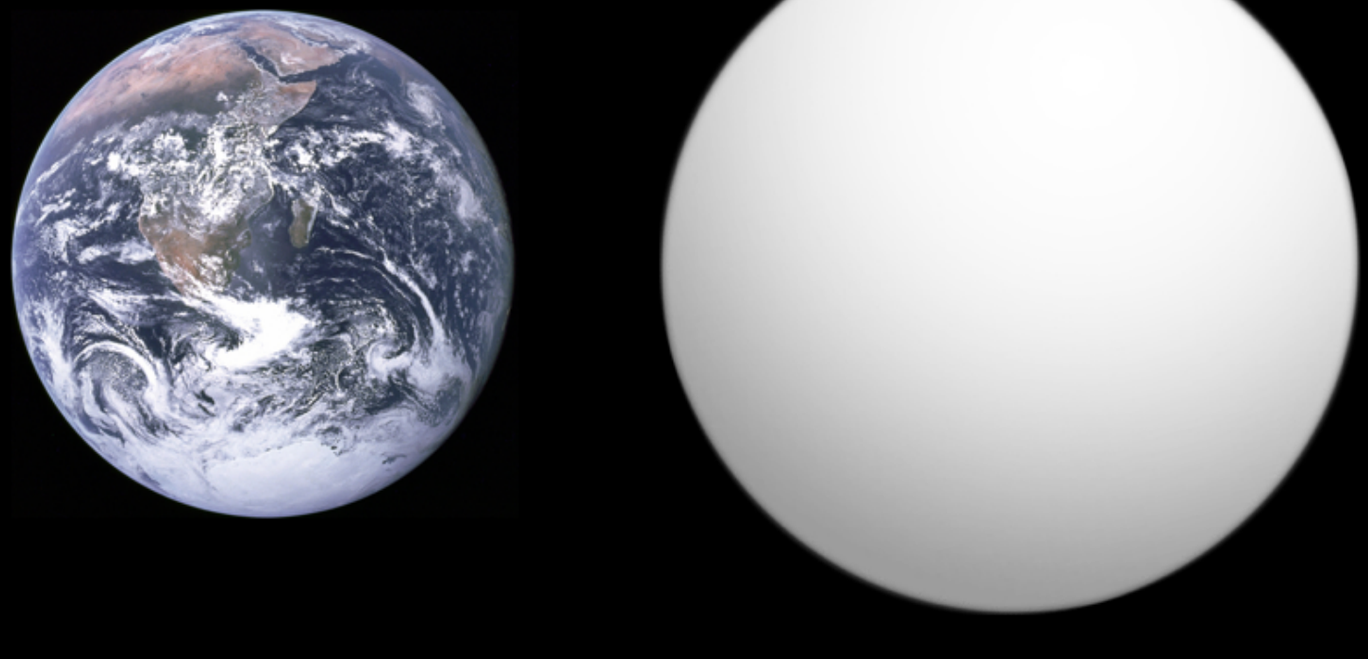
Mass
1.5 x Jupiter

Radius
2 x Jupiter

Temperature
20 x hotter than Jupiter

Cheops spotted a small difference in the typical transit light curve, caused by the deformation of the planet

#CHEOPS



A super-Earth is an extrasolar planet with a mass higher than Earth's, but substantially below the masses of the Solar System's ice giants, Uranus and Neptune, which contain 15 and 17 Earth masses respectively. The term super-Earth refers only to the mass of the planet, and so does not imply anything about the surface conditions or habitability.

The TOI 270 System

Earth
- 365-day orbit
- 1 AU from Sun
- Habitable

59 F, 15 C

TOI 270 c
- 5.7-day orbit
- 0.05 AU
- 2.4 Earth radii
- Largest in system

300 F, 150 C

TOI 270
M3-type dwarf star

TOI 270 b
- 3.4-day orbit
- 0.03 AU
- 1.25 Earth radii
- Likely rocky

490 F, 254 C

TOI 270 d
- 11.4-day orbit
- 0.07 AU
- 2.1 Earth radii
- Temperate

150 F, 67 C

Earth

Metals and rocks

Kepler-138 d

Metals and rocks

High-pressure water

Water vapour

Water World: Exoplanet GJ 1214b

From Nature 17 Dec. 2009; Review by Marcy; Letter by Charbonneau et al.

GJ1214b

GJ1214b is a "super-Earth", being 2.7x the size of Earth

Our Sun

Earth

Star GJ1214

Planet GJ1214b

GJ1214b's total mass: ~ 6.6x Earth's mass

Average density : 1.9 g/cm^3

Possible hydrogen- helium atmosphere

Water: 50% of GJ1214b's mass

Silicate mantle

Iron-Nickel core

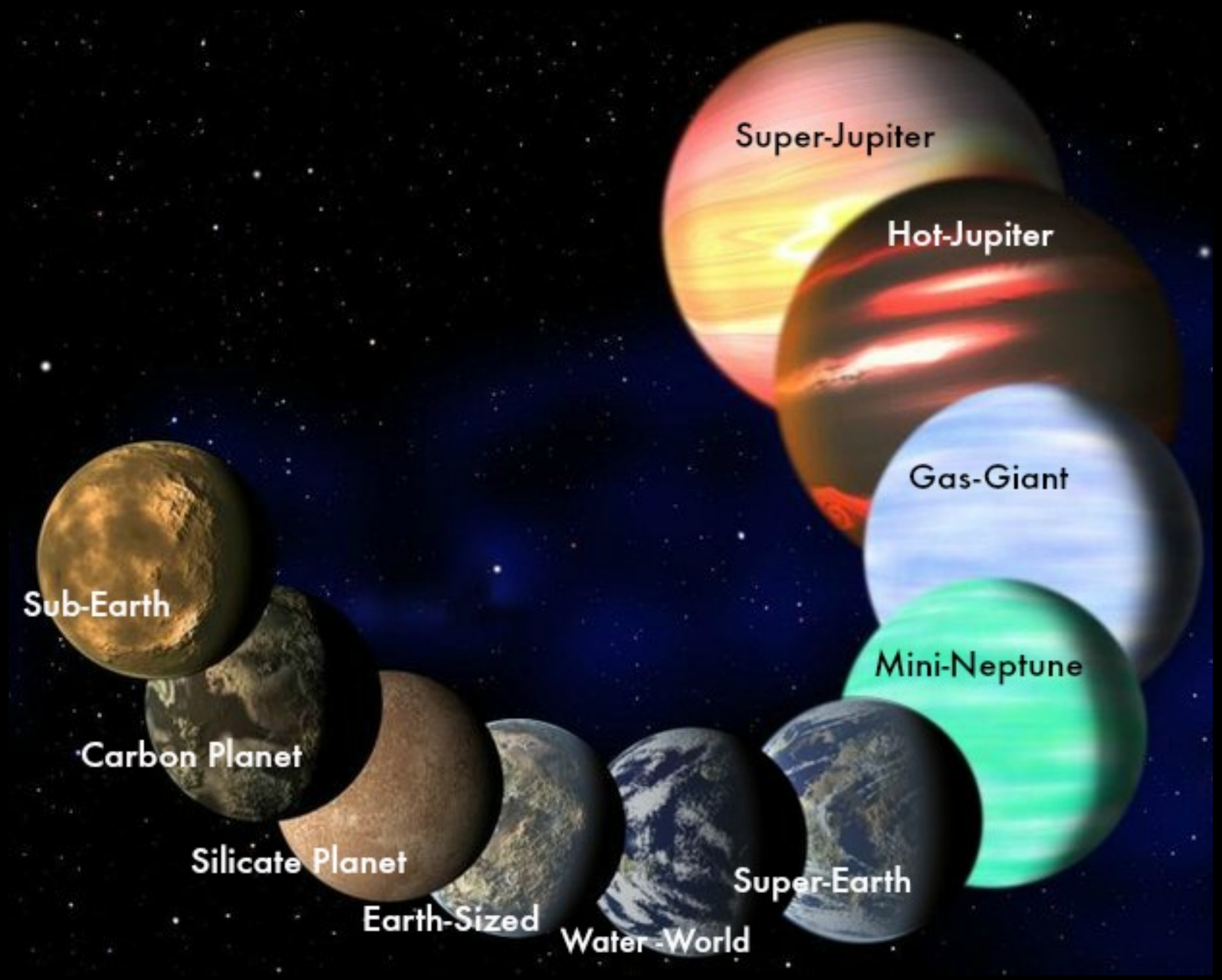
Granite-basalt crust

Silicate mantle

Fe-Ni core (inner and outer cores shown

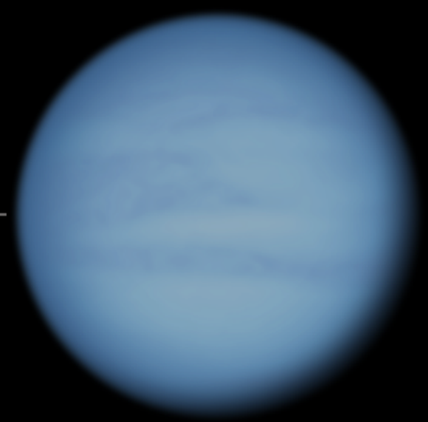
Average density : 5.5 g/cm^3

Water: 0.06% of Earth's mass


Super-Jupiter
Hot-Jupiter
Gas-Giant
Mini-Neptune
Super-Earth
Water -World
Earth-Sized
Silicate Planet
Carbon Planet
Sub-Earth

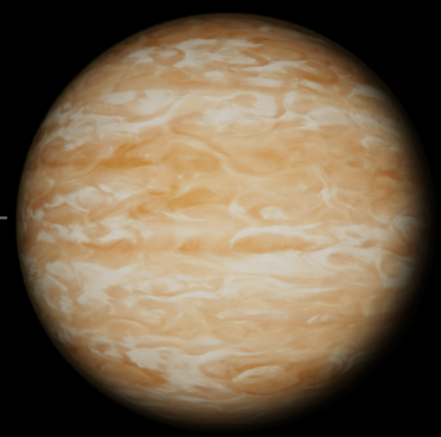
Earth
(Rocky)

Radius: 6,370 kilometers (3,960 miles)
Mass: 6×10^{24} kilograms
Density: 5.5 × water



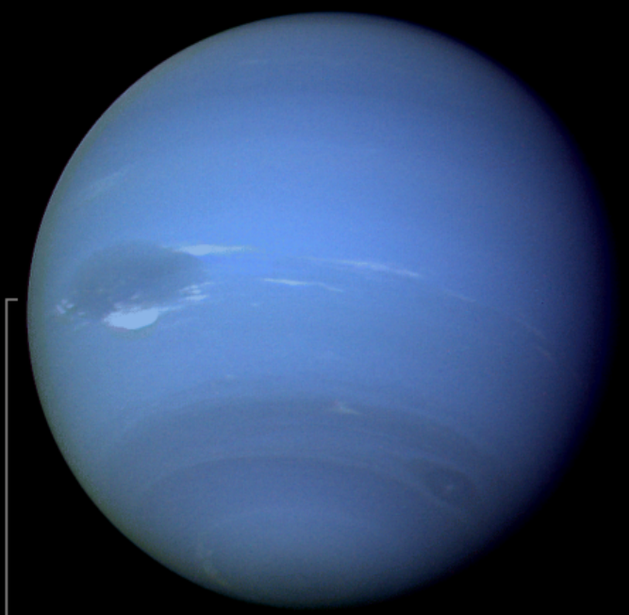
TOI-421 b
(Hot Sub-Neptune)

Radius: 2.68 × Earth
Mass: 7.2 × Earth
Density: 2.05 × water



GJ 1214 b
(Warm Sub-Neptune)

Radius: 2.74 × Earth
Mass: 8.2 × Earth
Density: 2.2 × water

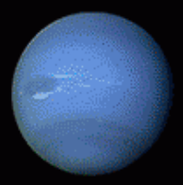


Neptune
(Ice Giant)

Radius: 3.88 × Earth
Mass: 17 × Earth
Density: 1.6 × water

Exoplanet Radius vs. Distance from Star

Jupiter



Neptune

Earth

HOT

WARM

Planetary Radius (Earth = 1)

20

10

5

1

0.7

Hot Neptune Desert

GJ3470b

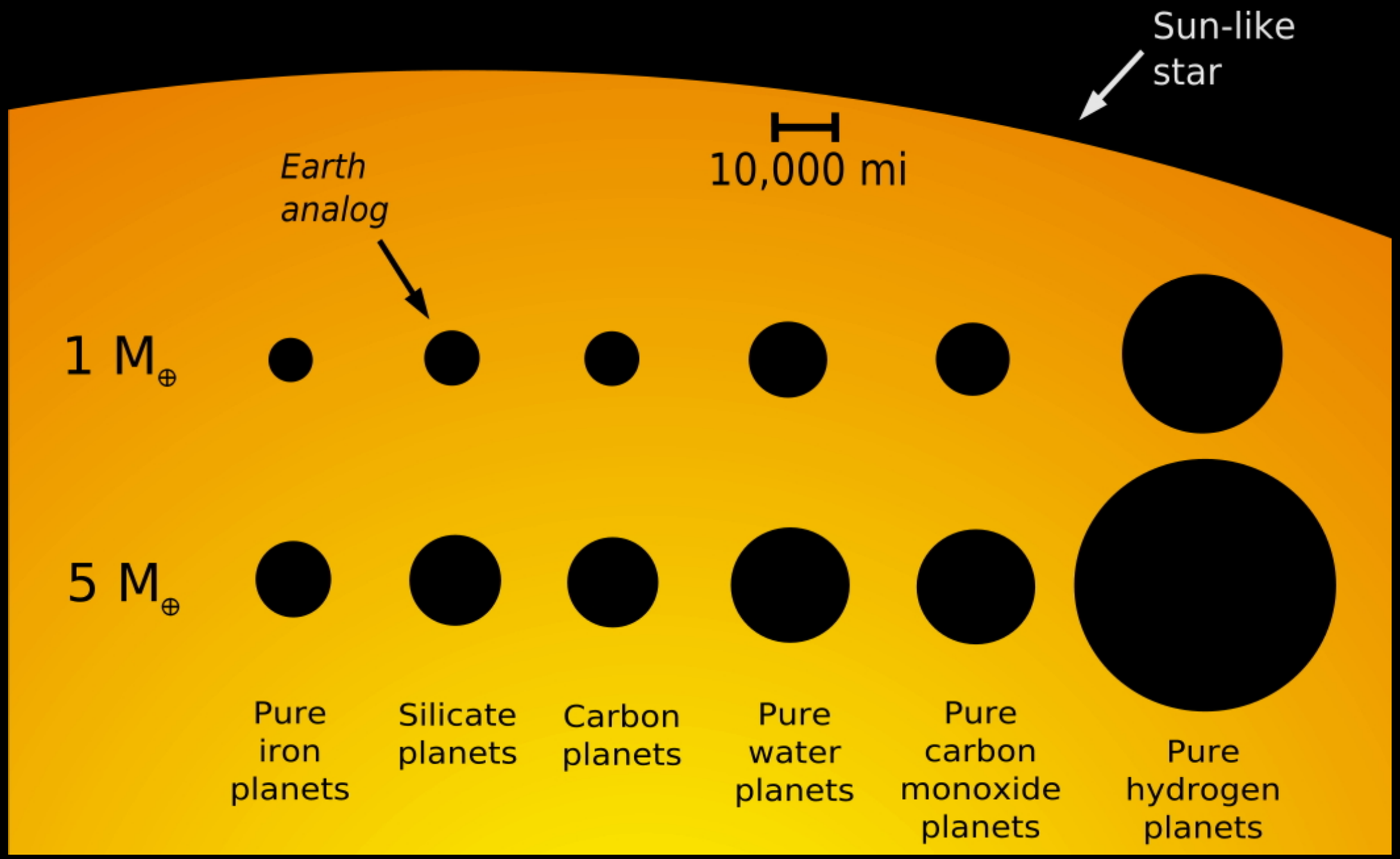
1 Million Miles

10 Million Miles

100 Million Miles

Distance from Star

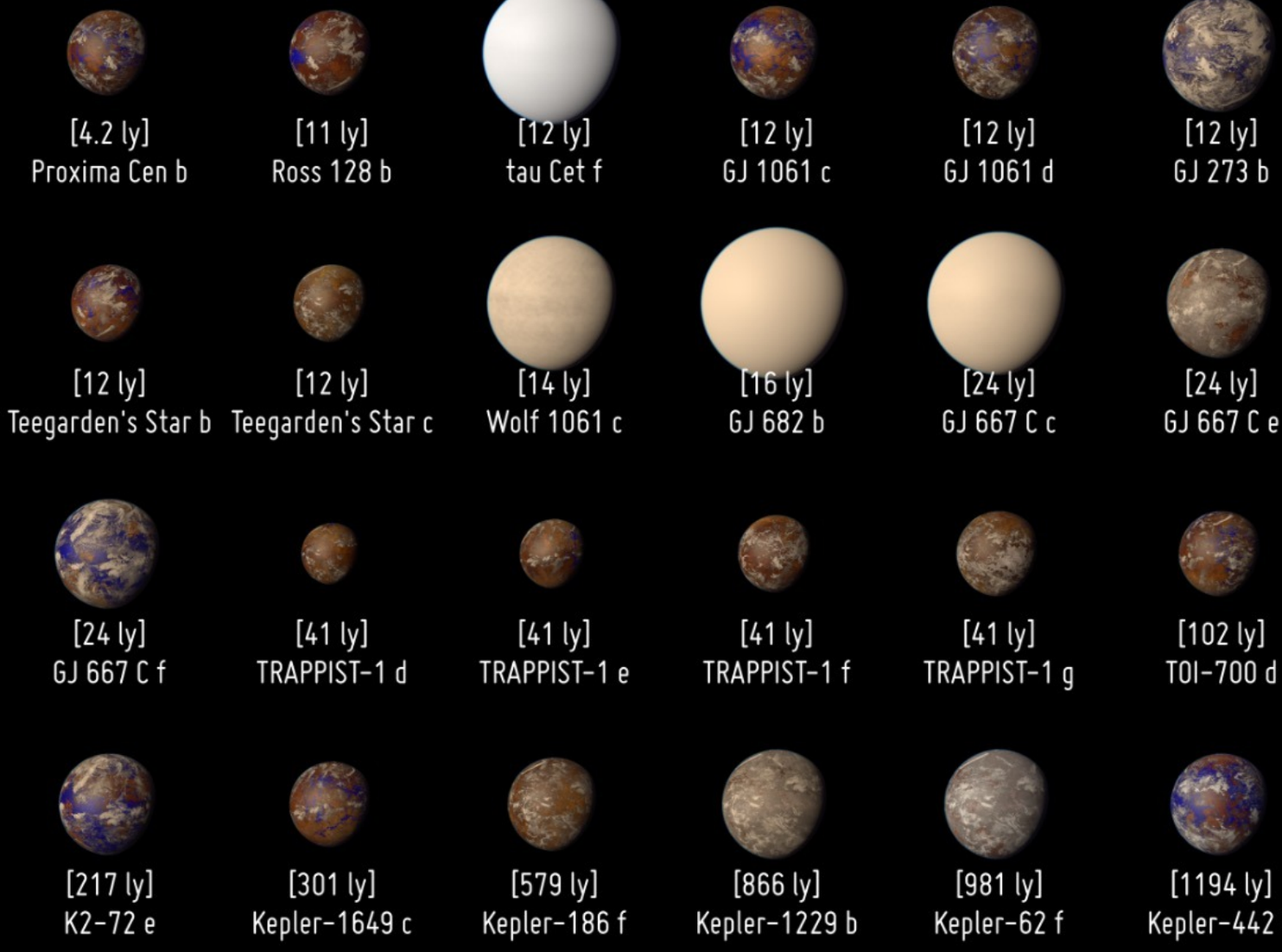
Predicted sizes of different kinds of planets

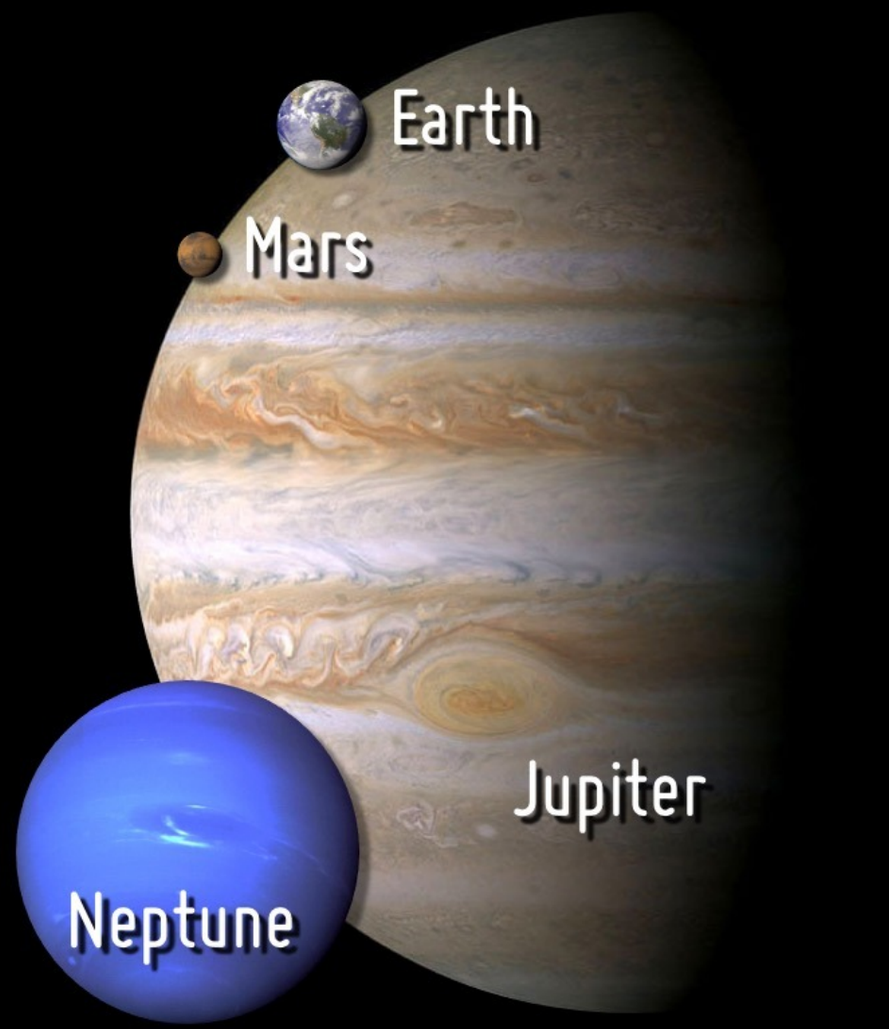


Potentially Habitable Exoplanets

PHL

Ranked by Distance from Earth (light years)





Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Distance from Earth is between brackets.

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