

Science for You: Planets

Week 11, Spring 2026:
April 30, 2026

Lecture 21:

What the Biggest Exoplanets Reveal

Explore the methods scientists have used to rapidly discover thousands of exoplanets—planets around other stars—from “hot Jupiters” to “mini-Neptunes” to planets whose clouds rain molten glass. Some are analogs of our own solar system’s planets, but some are completely different. We’ve learned that ours is not the only possible type of planetary system!

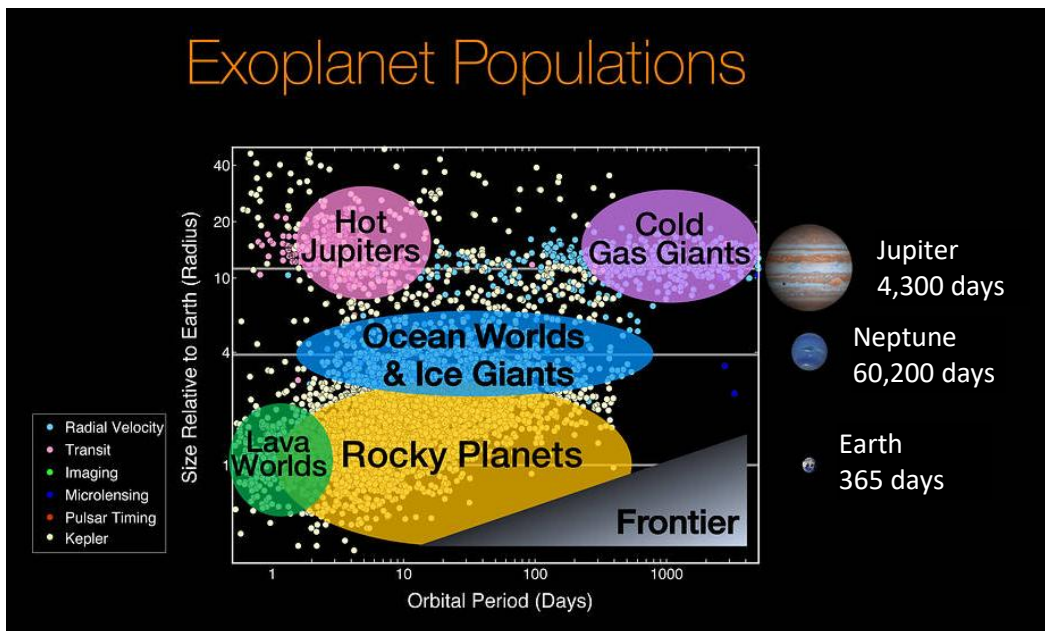
Pulsar Planets

- The first two confirmed exoplanets were discovered in 1992, each about 4 times more massive than Earth. In 1994, a third planet, with a mass of only 2% of Earth’s mass, was discovered in the same system. The 3 planets all orbit within 0.5 astronomical unit (AU) from their star.
- Their star is a pulsar—a tiny, hyper-dense, rapidly rotating neutron star—named Lich (pronounced “like”), after an undead creature that controls others with magic. It is in the Virgo constellation, about 2300 light-years away from Earth. Lich has a mass about 40% larger than the Sun but a radius of only 10 km (6 mi) and spins many times a second.
- Pulsars form when large stars run out of fuel and gravitationally collapse in a supernova explosion. Scientists didn’t expect to find any planets around a former supernova: it should have blown away everything in orbit, just before becoming a neutron star.

Planets around Main-Sequence Stars

- Main-sequence stars are still in the prime of their lives. The first confirmed exoplanet around a main-sequence star, found in 1995, orbits the star 51 Pegasi (“PEG-uh-see”) some 50 light-years away from Earth. The star is quite similar to our Sun, with similar mass and temperature. The planet, about half the mass of Jupiter and 150 times more massive than Earth, is assumed to be a gas giant. Its orbital distance is only 5% of an AU, about 8 times closer than Mercury is to the Sun!

- The name of an exoplanet is [StarName] followed by a letter indicating the order that the planet was discovered. So, the first planet discovered around the star 51 Pegasi is named 51 Pegasi b. The star itself is named 51 Pegasi a, though that's rarely used.



Hot Jupiters

- From 1995 to 2000, 27 planets were discovered around main-sequence stars. These Jupiter-like planets are very close to their stars, between 0.04 and 2.5 AU. These are dubbed hot Jupiters because of their high temperatures, large masses, and close orbits.
- Based on our understanding of solar system formation at the time of their discovery, these planets shouldn't exist! Gas giants are supposed to form in the outer solar system, where temperatures are low enough for ices to condense.
- There are 3 theories for how hot Jupiters can form. It's possible that all are correct and that different formation mechanisms work in different planetary systems.
 - Their protoplanetary disks were much more massive than in our solar system.
 - Hot Jupiters could have formed farther away from their stars and then migrated inward because of gravitational drag forces within the remaining disk.
 - The gas giants could have formed in the outer regions of their solar system but got gravitationally perturbed by a massive object (another giant planet or a companion star) even farther out. Their orbits eventually moved very close to the star.

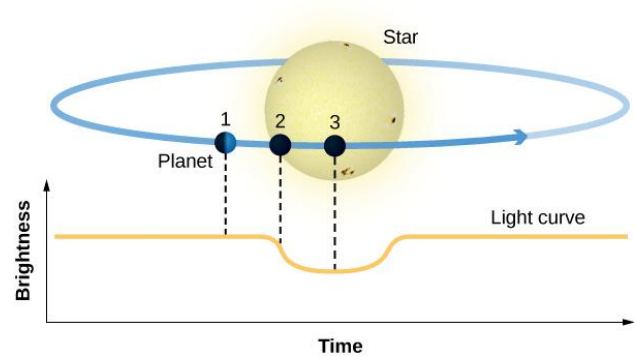
The Radial Velocity Method

- Biases in the methods used to detect exoplanets make it easier to find very massive planets orbiting very close to their stars, so that hot Jupiters were the most likely to be discovered first.

- The radial velocity method relies on the fact that planets don't just orbit stars that are fixed in the center of the system, but both orbit the center of mass—the location of the averaged mass—of the system.
- The motion of the star as seen from Earth looks like it wobbles about the center of mass: the star heads toward us as the planet heads behind it, and away from us as the planet moves in front. The speed of the wobble is related to the mass of the planet, and the period of the wobble tells us the period and ellipticity of the planet's orbit. The orbital period relates to the planet's distance from the star.
- By 2019, over 800 exoplanets had been detected using the radial velocity method. According to the NASA Exoplanet Archive, 1179 exoplanets had been discovered using radial velocity as of 4/2026. (The URL for the NASA Exoplanet Archive is https://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html)

The Transit Method

- In the transit method, we detect the dimming of the light coming from the star whenever a planet passes in front of it. The amount of dimming is related to the size of the planet, and the dimming repeats every time the planet orbits the star. The composition of a planet's atmosphere can also be detected as the planet transits the star.
- TESS, the Transiting Exoplanet Survey Satellite, was launched in April 2018 and monitors millions of stars for temporary drops in brightness caused by planetary transits. (<https://tess.mit.edu/>)
- According to the NASA Exoplanet Archive, 4637 exoplanets had been discovered using the transit method as of 4/2026.



Direct Imaging

- A few exoplanets can be observed directly, at least in the infrared. This works best when the planets are far from their star, and when the planets are young and very massive so that they are radiating more internal heat and are therefore brighter in the infrared. The smallest planet detected by direct imaging is less than twice the mass of Jupiter. The biggest problem with direct imaging is that the light from the star is so much brighter than the light from the planet that it's hard to see the planet.
- Close to 20 exoplanets were discovered with this method from 2008 to 2019. According to the NASA Exoplanet Archive, 96 exoplanets had been discovered using imaging as of 4/2026.

What We Can Learn About Exoplanets

- Minimum mass of the planet and its orbital period can be determined by studying the star's wobble with the rotational velocity method.
- Distance from the star is found by knowing the orbital period.
- Ellipticity of the orbit will be shown by a graph of the star's wobble: a circular orbit will produce a smooth sine wave.
- Radius of the exoplanet can be determined by the transit method. The amount of dimming is related to the size of the planet.
- Orbital period can be determined by the period of the dimming using the transit method.
- Density can be calculated from the mass (RV method) and radius (transit method) of the exoplanet. Density allows conclusions about the exoplanet's composition.
- Atmospheric composition can be analyzed during the transit, when the exoplanet's atmosphere blocks some wavelengths of starlight.
- Spectrum of light coming from the exoplanet can be determined by subtracting the star's light (when the planet is hidden behind it) from the total light (when both planet and star are visible). Emission lines from the planet's spectrum indicate the elements and molecules that are present.
- Clouds can be revealed by their reflected light. Clouds reflect light and affect the albedo (reflectivity) of the planet.
- Thickness of atmosphere can be revealed when the atmosphere blocks some of the star's light at the beginning and end of the transit. The duration of the atmospheric blockage indicates the thickness of the atmosphere.
- Atmospheric temperatures can be determined based on the total light coming from the planet in the infrared.
- Temperature maps can be made based on the temperatures observed of the different phases of the planet as it orbits the star.
- Winds help balance the temperatures of the day side and night side of the planet. If the difference is less than expected, winds must be carrying the heat from the day side to the night side.
- Wind speeds can be estimated by looking at the Doppler shifting of the spectral lines from the planet's atmosphere.



Lecture 22:

Closing in on Earthlike Exoplanets

Between 2009 and 2013, the Kepler Space Telescope had identified about 1,200 new planets with a variety of Earthlike features, including presence in a “habitable” zone. But what do we mean by *Earthlike*? Learn why billions of Earthlike planets are estimated to exist in our galaxy.

Exoplanet Varieties

- While Hot Jupiters were the first exoplanets to be discovered, they actually make up the minority of exoplanets. Smaller worlds are more abundant.
- Rocky planets much bigger than Earth are named “super-Earths.” Some may contain up to 50% water.
- Lava worlds are rocky planets so close to their stars that their surfaces have melted into global magma oceans.

Earthlike Criterion 1: Mass or Size

- To be like Earth, an exoplanet must be orbiting a Sun-like star. These are main sequence stars, in the prime of their lives, fusing hydrogen into helium and sustaining their brightness. About 90% of all stars are main sequence stars. About 10% of the stars in our galaxy are yellow dwarfs, like our Sun.
- The size of the planet should be like Earth, and it should have a similar mass. The NASA Exoplanet Archive contains 550 Earth-size exoplanets, defined as having a radius of less than 1.25 Earth radii. There are 111 exoplanets with an Earthlike mass, defined as less than 3 times Earth’s mass.
(https://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html)
- But size and mass are not enough to classify a planet as Earthlike: it might be a miniature gas giant or have a large amount of water.

Earthlike Criterion 2: Composition

- An exoplanet’s mean density can be calculated from its mass and radius and compared to Earth’s to estimate its composition. The bigger the planet, the more it compresses under its own gravity. This can be plotted on a mass-radius diagram to determine whether the exoplanet is similar to Earth’s composition.

Earthlike Criterion 3: Habitability

- To be like Earth, an exoplanet must have a temperature like Earth's, in a range for liquid water to be stable. This is how planetary scientists define "habitable."
- A planet's temperature depends on how much heat it receives from its star, which depends on the type of star and the planet's distance from it. For each type of star, there is a specific distance range of orbits where habitable planets could be found. This is called the habitable zone. In our solar system, the habitable zone goes from about Venus's orbit to the inner asteroid belt. (But just being in the habitable zone doesn't mean that a particular world is habitable!)
- In 2015, 7 Earth-sized and smaller planets were discovered orbiting the star TRAPPIST-1—which is only 40 light-years away in the direction of the Aquarius constellation—and at least 3 of them are in the habitable zone.

Earthlike Criterion 4: Atmosphere

- The Hubble Space Telescope and the James Webb Space Telescope are being used to study the atmospheres of planets in the habitable zone. Does the exoplanet have an uninhabitable atmosphere, like Venus's, or an atmosphere more like Earth's?
- The large amount of oxygen in Earth's atmosphere is produced by life. So, determining the composition of the atmospheres of exoplanets also gives a way to search for life.

Earthlike Criterion 5: A Moon

- The Moon is important for stabilizing the tilt of the Earth, which helps control the climate. So to be Earthlike, an exoplanet should have a large moon, like Earth does.
- There have been hints of possible exomoons, but finding them will require better detectors that can detect fainter signals.

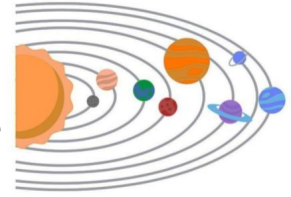
Exoplanet Statistics

- The data so far includes very few examples of exoplanets with orbits longer than a few hundred days, but this is a known bias in the data. Adjusting to work around these biases, we might estimate the number of Earthlike worlds like this:
 - About 20% of Sunlike stars have an Earth-sized planet in their habitable zones.
 - There are around 200 billion stars in the galaxy.
 - About 10% of those are Sunlike stars, so there are 20 billion stars like our Sun.
 - If 20% of those stars have Earth-sized planets, there are around 4 billion Earth-sized planets in the habitable zones of Sunlike stars.
 - If we include smaller red dwarf stars, which are 70% of all stars, and about 1/5 to 1/2 of red dwarfs have an Earth-sized planet in their habitable zones, this suggests that there are tens of billions of Earthlike planets.

Next class (5/7/2026) (Last class!)

Lecture 23: Planets Migrated in Our Early Solar System!

Learn about the evidence for a “Late Heavy Bombardment” on the Moon, Mars, and Mercury, how migration of one or more giant planets could have caused it, and how such migration could have affected the solar system we see today.



Lecture 24: Human Futures in the Solar System

Consider the fascinating future technologies of centimeter-sized satellites propelled by laser photons, liquid mirror telescopes on the Moon, a magnetic shield large enough to help terraform Mars, and more.