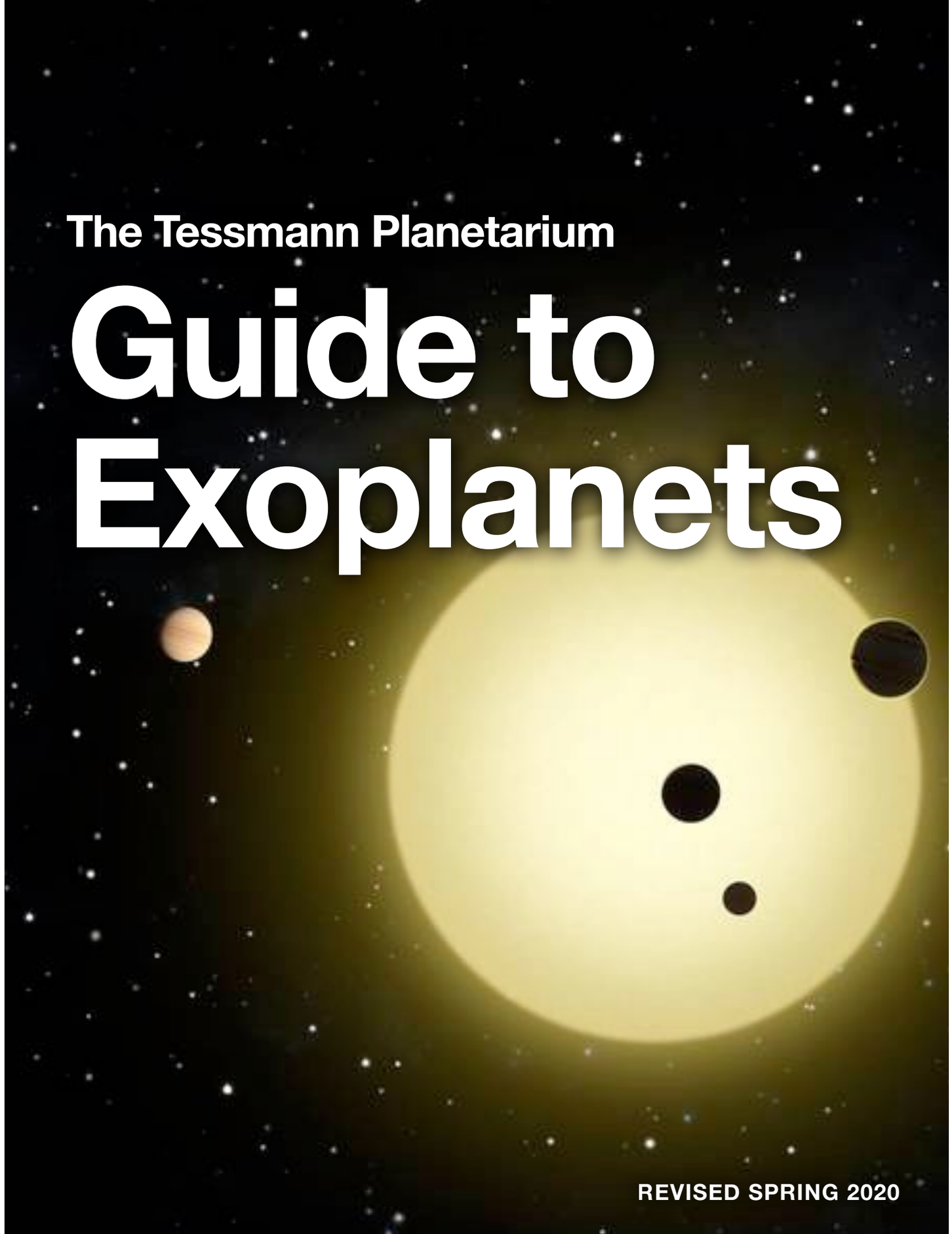
The Tessmann Planetarium

Guide to Exoplanets



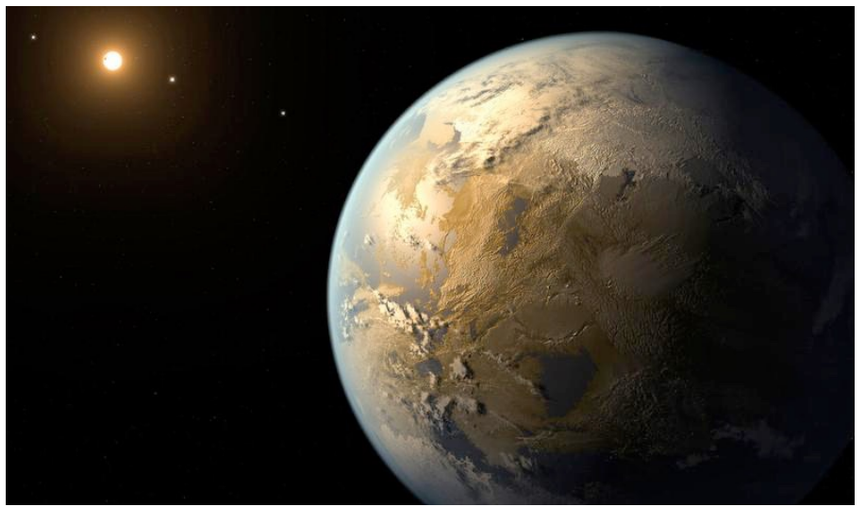
REVISED SPRING 2020

That is the big question we all have: Are we alone in the universe? Exoplanets confirm the suspicion that planets are not rare.

-Neil deGrasse Tyson

What is an Exoplanet?

WHAT IS AN EXOPLANET?

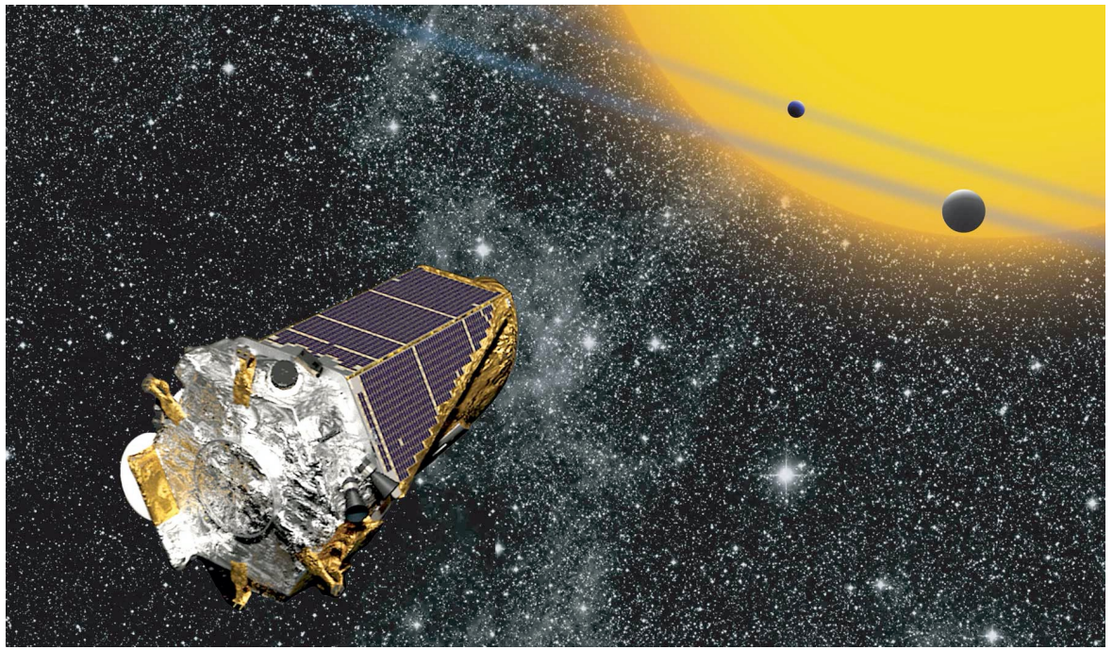


Some Factoids:
An earth-sized planet, TOI 700d, was discovered by TESS in January 2020. This planet is in its star's Goldilocks or habitable zone. The planet is about 100 light years away, in the constellation of Dorado.

According to NASA, we have discovered 4158 exoplanets in 3081 planetary systems. 696 systems have more than one planet. NASA recognizes another 5220 unconfirmed candidates for exoplanets.

In 2020, a student at the University of British Columbia, named Michelle Kunimoto, discovered 17 new exoplanets, one of which is in the habitable zone of a star.

Before 1990, we had not yet discovered any planets outside of our solar system. We did not have the methods to discover these types of planets. But in the three decades since then, we have discovered at least 4158 confirmed planets outside of our system – and the count seems to be increasing almost every day. We call these worlds **exoplanets**. These worlds have been discovered with the help of new and powerful telescopes, on Earth and in space, including the Hubble Space Telescope (HST). The Kepler Spacecraft (artist's conception, below) and the Transiting Exoplanet Survey Satellite (TESS) were specifically designed to hunt for new planets. Kepler discovered 2662 planets during its search. TESS has discovered 46 planets so far and has found over 1800 planet candidates. In particular, TESS is looking for smaller, rocky exoplanets of nearby, bright stars.



Methods of Discovery

How We Discover Planets

You're probably wondering how we discover discover new planets. Scientists use several methods, but there are 3 main approaches.

The Wobble Method

One method is to look for wobbles in the motions of stars. If a star has planets, the pull of gravity between the planets and the star sometimes results in a wobble in the star. This method is very tricky because the wobbles are extremely slight. Wobble observations have to be carried out very carefully and precisely.

The Eclipse (or Transit) Method

The second and more successful method is to look for an eclipse. This is similar to an eclipse that we observe from the Earth when the moon passes in front of our Sun and blocks all or some of its light. When planets pass in front of distant stars (known as transits), they do block out some of the light – but a very small amount. If the planet passes in front of a star, and it happens in our line of sight, powerful telescopes and spacecrafts can measure the small drop in brightness of the star – sometimes a reduction as little as 1% of the brightness.

When one of these telescopes repeatedly detects a drop in brightness, astronomers study the star using other telescopes and methods. They make predictions about the orbit of the planet or planets orbiting the star. They try to predict how long the orbit take. Then they watch to see if the star's brightness decreases during its next orbit. Eventually they can confirm if a star has one or more planets.

Some planets are close to their stars, especially Super Jupiters. Their orbits are very short and the drop in brightness can be observed over a few weeks or months. Planets that have orbits that take years to complete take a lot more time to confirm. But some planets may have orbits of hundreds of years. For example, Neptune, in our own solar system, takes 186 years to orbit our Sun. In such cases, we can't wait for these planets to make a complete orbit.

Photography

A brand new method is now being used. Devices have been developed that can block out the light of a star in major telescopes. Then astronomers use powerful cameras to capture an image of one or more planets around the blocked star. One such camera, called the Gemini Planet Imager, is being used with telescopes in South America.

Photo of an Exoplanet

BETA PICTORIS

This is a photo of an exoplanet orbiting the star Beta Pictoris. Scientists block out the light of the star in their telescopes, using a device known as a coronagraph. Normally, the light of a star would “drown out” the the light reflected by a planet. With the the light of the star covered by the coronagraph, the planet may then become visible.

New telescopes that will begin observing during the 2020s may have enough resolution to image or detect the color and atmosphere of exoplanets.

Factoid:
About 20 exoplanets have been photographed as of June 2020.

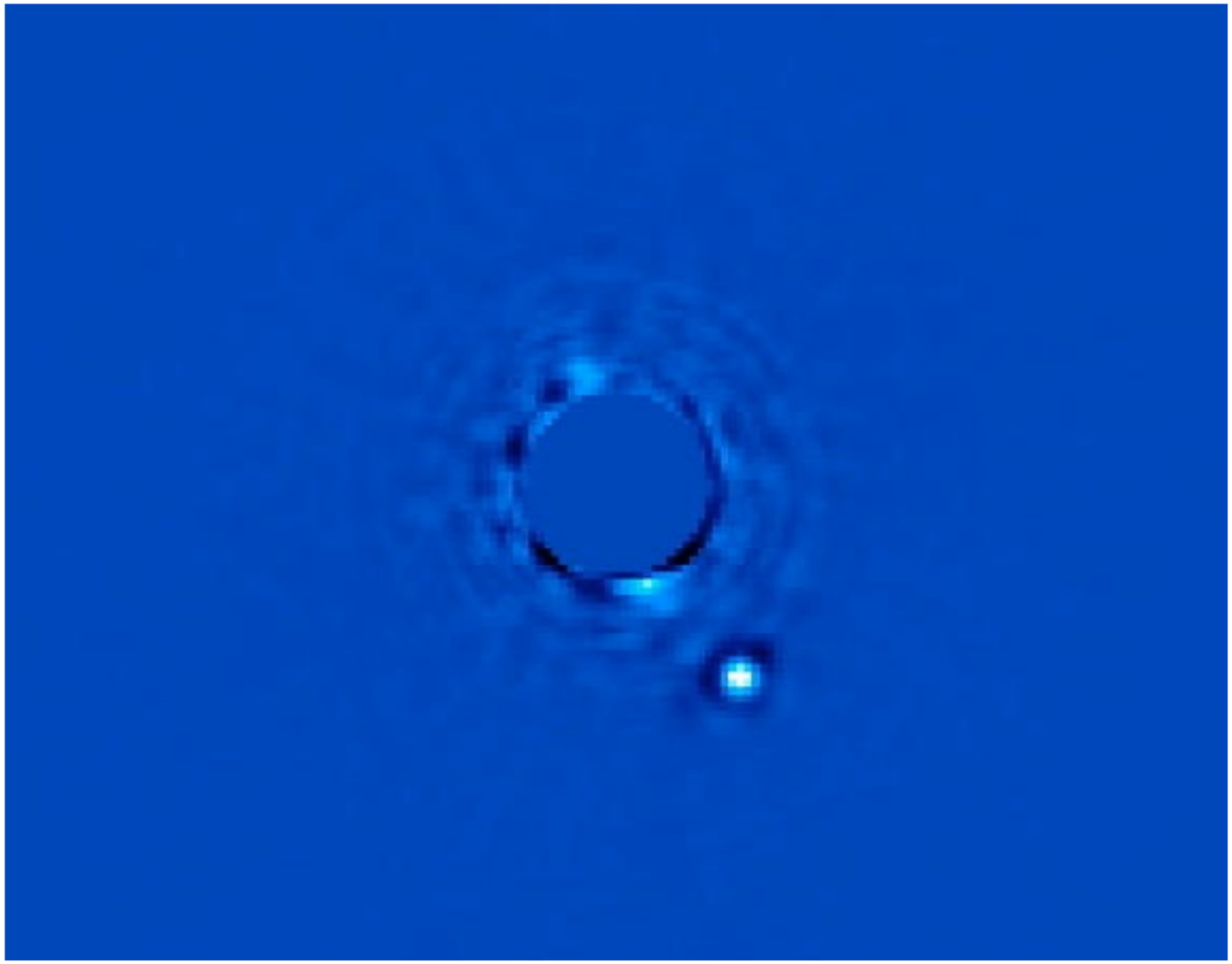


Image courtesy of Gemini Observatory, processing by Christian Marois/NRC Canada.

Types of Planets

Types of Planets

At one time, we put planets in one of three categories: rocky, gas giants and ice planets. Later, we added dwarf planets as a category. But the discovery of exoplanets has prompted us to create new categories.

Super Jupiters

One group of observed planets is known as Super Jupiters. These are the easiest to discover because they are so big. These worlds can be up to 10 times the size of Jupiter; if they got much bigger, they would actually be considered stars called brown dwarfs.

Brown dwarfs are stars of low temperature and mass. They are very difficult to observe with optical telescopes, because they are much smaller than other stars and don't give off much light.

Super Jupiters, like our Jupiter, are primarily made out of hydrogen gas, and are typically called gas giants. Super Jupiters fall into two categories – hot Jupiters and warm Jupiters.

Warm Super Jupiters

Warm Super Jupiter are a lot like Jupiter in our own solar system, but much larger. They are significantly distant from their star and are often found in planetary systems with many other planets.

Hot Super Jupiters

Hot Super Jupiters orbit, much like our planet Mercury, very close to their star. But unlike Warm Super Jupiters, they are most likely (but not always) the only planet in the system. One theory is that they started life farther away from their star, but as time went on, they moved closer to the star. As they moved closer, other planets were flung out of their planetary systems due to their tremendous gravity of the Super Jupiter. They are, so to speak, the last planets left in a game of cosmic musical chairs. They are considered hot because they are very close to their star. We have even found one Super Jupiter that is so close to its star that it is slowly evaporating before our very eyes.

Types of Planets and the Goldilocks Zone

Neptune Class Planets

Another common type of planet is called the Neptune Class. These planets may be gas giants, but smaller than Super Jupiters, but much larger than Earth. We have discovered a lot of Neptune class planets recently as they are larger and easier to pick out than Earth-sized planets.

Super Earths and Earth-sized Planets

The category we are most interested in are planets that are similar to our own planet Earth. These are rocky planets and some may even have an atmosphere and water. These planets may be the size of our planet, or up to four or five times larger than the Earth's diameter. We are searching for these worlds because these are the ones that have the best chance for supporting life.

Because they aren't very large, it's difficult to find planets that are the same size as the Earth, but we have found some that are just a bit bigger – we have found a few that have diameters that are 1.5 and 1.7 times larger than our world.

We have discovered a number of super Earths so far. Two planets circle a star named Kepler 62 that are right in the middle of the "Goldilocks Zone." Perhaps there is life on one or both of these worlds.

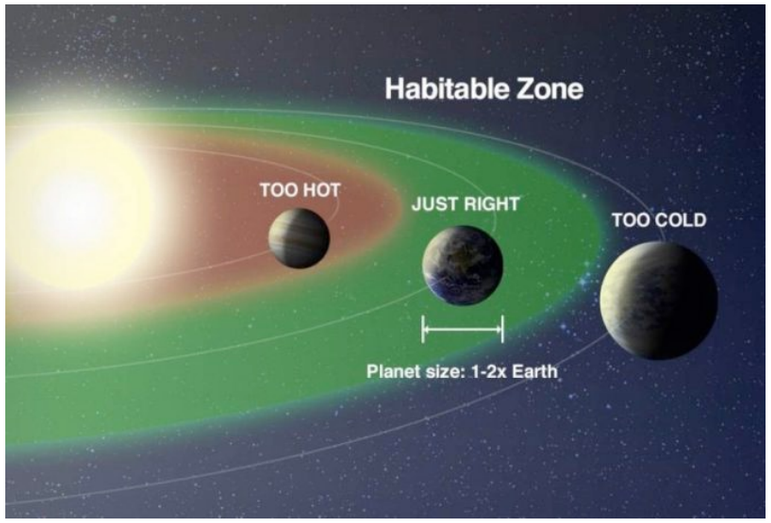
But have we found a planet that is similar to our Earth, one that might support life? Well, before we answer that question, we need to consider where we might find a world like this. So we need to discuss the "Goldilocks Zone."

The Goldilocks or Habitable Zone

Around stars that might be able to support life, there is an area that gives the best chance for life to exist. It is an area that is not too hot and not too cold, but is just right—just like the story of Goldilocks and the Three Bears. So we call this area the Goldilocks zone. The temperature in this area is "just right" to allow water to exist. We believe that water must be present for life to exist. The zone may exist around any stars, but especially those that have a similar size of our sun, and even around smaller stars called red dwarfs. Around red dwarfs, the Goldilocks Zone is much closer to the star, because these stars are cooler and smaller than our sun.

Where We Might Find Life

PLANETS THAT MIGHT SUPPORT LIFE



Not too hot, not to cold, but just right!

Water on a planet too close to a star would no doubt evaporate from the star's heat. If it is too far away, temperatures would be below freezing point and water will exist as ice. In the Goldilocks zone, water can exist as a liquid.

On April 17, 2014, NASA made an historic announcement – the first discovery of an Earth-sized planet orbiting in the Goldilocks Zone of another star. The planet may have the potential for life to exist.

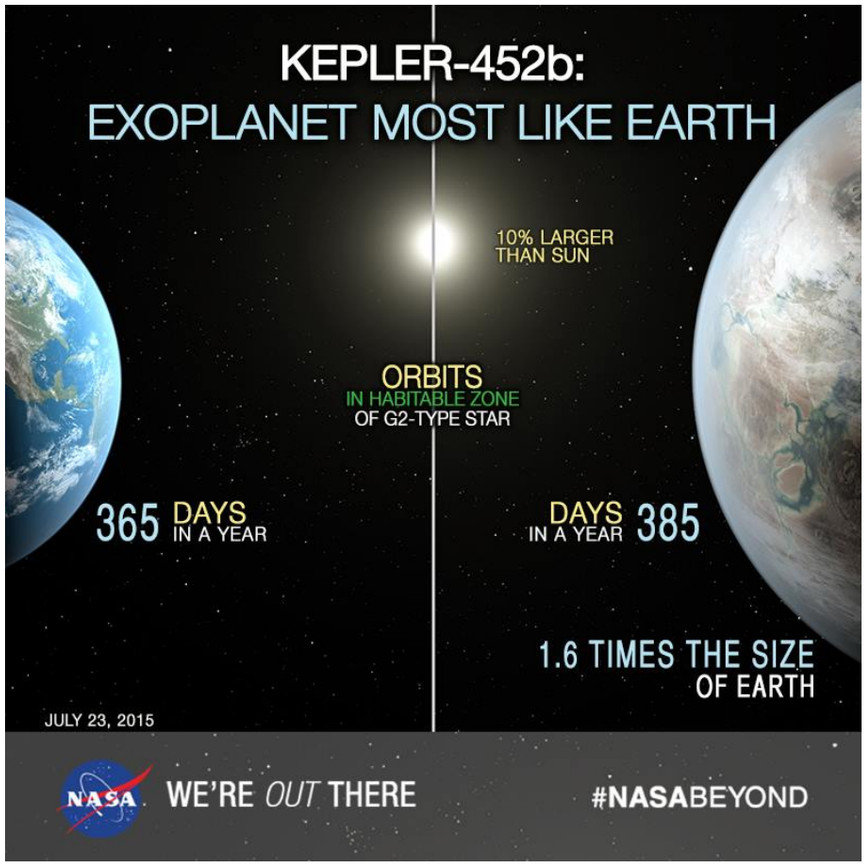
The exoplanet circles a red dwarf star in the constellation of Cygnus and is about 500 light years away. The planet is known as Kepler 186f and is about 10% larger than the Earth. It is the outermost planet in the 186 system and takes 130 days to orbit its star.

Red dwarfs are known as "M" class stars. They are smaller, less bright and much cooler than our Sun, which is known as a "G" class star. Kepler 186 is one of the hottest red dwarf stars we have discovered. 186f is about the same distance from its star as Mercury is from our Sun. Because Kepler 186 is much smaller than our sun, the Goldilocks zone is closer to the star. It appears that 186f is in the Goldilocks Zone where water, and perhaps life, can exist. Photosynthesis may be possible on 186f. Photosynthesis is the way plants change sunlight into oxygen and other chemicals that are necessary for life to exist on a planet.

The discovery of 186f demonstrates that Earth-sized planets can exist in habitable zones of red dwarf stars. About 7 out of 10 stars in our galaxy, as well as most of our Sun's nearest neighbors, are red dwarfs. Planets around "M" class stars may be the most common type of habitable worlds in the universe.

The Most Earth-Like Planets Discovered So Far

KEPLER-452-B THE MOST EARTH-LIKE PLANET



Besides Kepler-186f, we have discovered other worlds that are Earth-like.

Kepler 452b is 1.6 times the size of the Earth and orbits its star in the habitable zone, meaning it could support life. Kepler 452-b takes 385 days to orbit the star and is just slightly larger than our Sun. It is 1400 light years away in the constellation of Cygnus.

Early in 2020, TESS observed a planetary system known as TOI 700. The star has about 40% mass of the Sun. The system is currently known to have at least three planets. The outermost planet, known as TOI 700d, is about 20% larger than the Earth and orbits every 37 days. It receives about 85% of the mount of the energy from its star than the amount that the Earth receives from the Sun.

Although TOI 700 d is the only planet in the system in the Goldilocks zone, the system also contains two other planets. TOI 700 b is Earth-size and orbits once every 10 days. TOI c is about 2.5 times the size of the Earth and orbits every 16 days.

The Trappist-1 system has seven planets, five of which are Earth-sized and the other two are smaller than Earth. Three of the planets are in the star's Goldilocks zone. Trappist 1 is a red dwarf star about 40 light years away in the constellation of Aquarius. Trappist-1e is the most Earth-like and the most likely candidate for life in the Trappist system.

Other Types of Planets

Sub Earths

Sub Earths are also rocky planets and are smaller than the Earth. Mars and Mercury are sub Earths. Because they are so small, we have come across only a few of this type of exoplanet.

Dwarf planets

A few years ago, everyone was upset when Pluto was “demoted” from a planet to a dwarf planet. At the time, creating a new category of planets didn’t seem like a popular idea. However, it is now making a lot more sense as we create more and more new categories of planets to keep up with all our discoveries.

Dwarf planets are now being discovered because we have created newer and more powerful telescopes and techniques. Since the beginning of the 21st century, we developed telescopes that could discern new objects out past the frozen confines of Pluto. Scientists made observations and studies of these new worlds and decided to create a brand new category for them.

There was precedent for this. In the 19th century, a new category was created when the best new telescopes of that time began to discover asteroids. At first they called these minor planets. After a while, they realized that asteroids came in all sorts of shapes – and differed in size from the major planets.

And so it is with dwarf planets. There may be hundreds of these frozen worlds out past Pluto. Despite our advances in telescopes, they still aren’t that easy to spot.

A dwarf planet must be round, or nearly round. They need to have enough gravity to clear out some of the area in their orbits. This is why Ceres the asteroid is considered a dwarf planet. It is the only round asteroid and the only asteroid that is a dwarf planet.

However, the definition of a dwarf planet has been challenged after we learnt more of Pluto when the New Horizons spacecraft flew past this icy world in 2015. We did not discover much debris surrounding Pluto. And Pluto turned out to be a much more complex environment than we expected. There may even be an underground ocean beneath Pluto’s frozen surface. Many scientists and the general public have called for Pluto to be reinstated as a planet. No doubt, the debate over Pluto will continue for years to come.

Exotic Planets

Protoplanets

Some worlds are failed planets. They may have started out as planets, but some catastrophic event changed the course of their growth. The asteroid Vesta falls into the category. NASA's Dawn spacecraft orbited Vesta several years ago. Dawn discovered that Vesta must have been struck by a large object early in its history, breaking it apart. Vesta might have become the ninth planet in our solar system, but now is now considered a protoplanet.

Tatooine Planets

In the original Star Wars movie, Luke Skywalker looks at the sunset on his home world of Tatooine, and sees two suns in the sky. In other words, his planet orbits two suns. You might be interested to know that several planets have been discovered that are considered "Tatooines" so far. A two star system is also referred to as a circumbinary star system.

Super Saturn?

One planet has been discovered that seems to have gigantic rings. Another possibility is that it may be a micro-solar system. It will take a lot more observations to figure out how to classify this unusual world.

What Else is Out There?

Using the Kepler and TESS spacecrafts and observatories, we have discovered almost 4260 planets and thousands of candidates that may be confirmed as planets someday. We have been surprised at the variety of planets we have discovered. Who knows what other sort of planets we may come across?

And here's an interesting fact: We have not yet discovered another planetary system that is just like our own. At one time, we thought most planetary systems would be similar to ours – rocky planets near the sun, a few gas giants father away and then a realm of icy worlds in the far reaches. Who knows what sort of worlds and systems await discovery? It seems like each time we turn our telescopes toward the cosmos, we find something brand new.

Solar System or Planetary System?

While we are talking about our solar system, you might think that any star that has one or more orbiting planets is called a solar system. Technically speaking, the only solar system is our own. The Sun is sometimes known as Sol. So SOLar system specifically refers to our own system. Technically speaking, all other systems should be referred to as planetary systems.

Proxima B: The Planet Closest To Earth

PROXIMA B

The Alpha Centauri system consists of three Stars. Alpha Centauri A, Alpha Centauri B and Proxima Centauri (circled in red).

A planet, similar in size to the Earth, has been confirmed around Proxima Centauri by researchers at the University of Geneva. Proxima is the star closest to our Sun. Measurements were made with an ultra-precision device called EXPRESSO, which is installed on the Very Large Telescope in Chile.

Proxima Centauri is our nearest neighbor, only 4.2 light years away. It is a member of the Alpha Centauri system, which consists of three stars. The planet around the star is known as Proxima B and is twenty times closer to its star than the Earth is to the Sun. But Proxima Centauri is a red dwarf, much smaller than our Sun, so the planet receives about as much energy as the Earth does from the Sun. This means that water, and possibly life, could exist there. There is a problem, however. Proxima B receives about 400 times the amount of x-rays that the Earth does. Does Proxima B have an atmosphere that can protect life from these deadly rays? Scientists also wonder if its atmosphere contains elements such as oxygen that can harbor life. Future observations will no doubt shed more light on these questions.

Recently, observations suggest that another planet, smaller than Earth, may exist in the Proxima system. As of spring 2020, this candidate has not as yet been confirmed.

Confirming Planetary Candidates

Is It Really a Planet?

Every so often, as a careful study is made of a planetary candidate, it is discovered that it is not a planet at all. Recently, we received data that seemed to point to the discovery of a new planet. It turns out that the data came from large, disruptive sunspots on a star.

Each year, we fine tune our methods and equipment. This means we continually update our findings. Some discoveries of planetary candidates may not be what they seem. But by careful studies, we discover new forces at work in space – and those discoveries help us find new ways to hunt for planets.

Keep in mind we are studying stars and planets that are unimaginably far away. It is actually pretty amazing that we can learn anything at all. We are pushing the boundaries of knowledge itself. We're bound to make mistakes and miscalculations. But that's ok. That's how it is with science. We will use what we learn from both our discoveries and mistakes to better understand the nature of the cosmos.

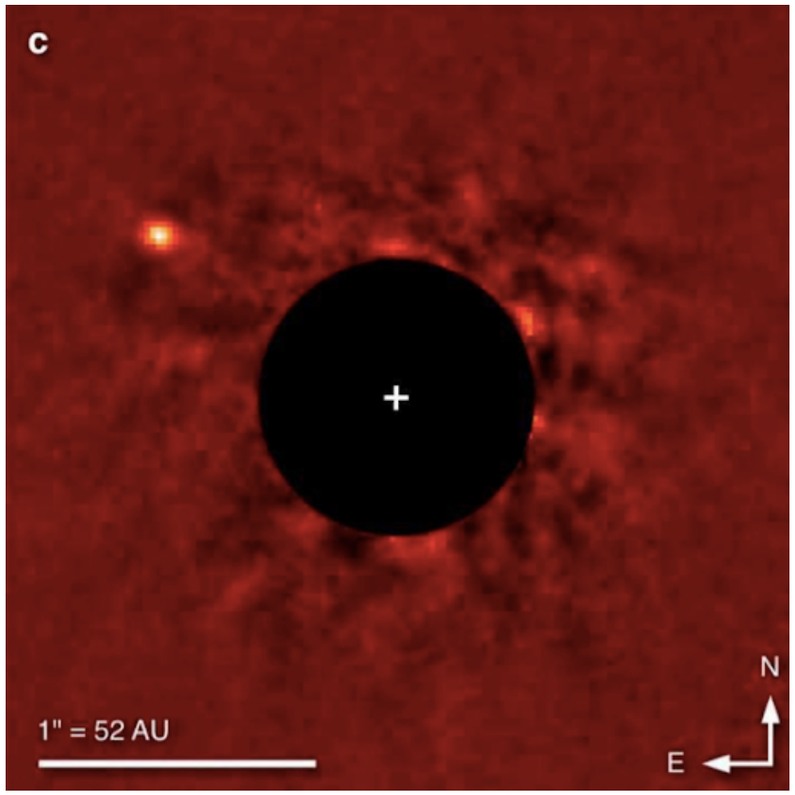
"There are many hypotheses in science which are wrong. That's perfectly all right: it's the aperture to finding out what's right. Science is a self-correcting process." – Carl Sagan

"Anyone who has never made a mistake has never tried anything new." – Einstein

"Test ideas by experiments and observations. Build on those ideas that pass the test. Reject the ones that fail. Follow the evidence wherever it leads, and question everything. Accept these terms, and the cosmos is yours." – Neil deGrasse Tyson

More Exoplanet Factoids

SOME INTERESTING EXOPLANETS



Planet photographed orbiting Kappa Andromedae.

Image courtesy of NAOJ / Subaru / J. Carson (College of Charleston) / T. Currie (University Toronto)

Based on the findings of the Kepler Spacecraft mission, scientists currently estimate that as many as 40 billion Earth-sized exoplanets may orbit in the Goldilocks zones of stars in our Milky Way galaxy.

Most stars in the Milky Way appear to have at least one planet in their system.

Kepler 64b orbits about 4 stars. At least 11 Tatooine or circumbinary planets (planets that orbit two or more stars) have been discovered so far.

K2-137b orbits its star every 4 hours 56 seconds, the shortest exoplanet year known.

The most distant exoplanet confirmed is Kepler-443b, 2,540 light-years distant. However, an exoplanet candidate has been detected in the Andromeda galaxy 2,185,247 light years away.

The smallest exoplanet discovered so far is Kepler 37b. It has a radius just slightly larger than our Moon. It was detected in the constellation of Lyra.

The exoplanet that is the most distant from its parent star is TYC 9486. It is 6900 times farther away from the star than the Earth is from our Sun. It ‘s about 12 times heavier than Jupiter.

One of the largest exoplanets is orbiting a star called Kappa Andromedae. It’s 13 times more massive than Jupiter and has been photographed (see the bright spot in the image at the left).

Links

USEFUL LINKS

By the time you read this Guide, some information contained within will no doubt be out of date. It seems like we discover new exoplanets almost every week and our knowledge of worlds beyond our Sun is growing by leaps and bounds.

Most information about exoplanets can be found on-line and is updated almost daily. Just type “exoplanets” or related terms into a search engine such as Google. Keep an eye out for the frequent news stories that pop up on this subject. The following are just a few of the many useful and cool exoplanet sites:

http://kepler.nasa.gov/ (click the “education” panel for cool activities)
http://www.almaobservatory.org/en/visuals/images (click “astronomy”)
https://exoplanets.nasa.gov/alien-worlds/strange-new-worlds/
http://www.keckobservatory.org/
http://exoplanets.org/rpf.html
https://exoplanets.nasa.gov/exoplanet-catalog/ (NASA’s Exoplanet Catalog)
http://www.exoplanets.org/
https://www.planetary.org/explore/space-topics/exoplanets/ (Planetary Society)
http://en.wikipedia.org/wiki/List_of_exoplanet_extremes
https://en.wikipedia.org/wiki/Lists_of_exoplanets
https://www.nasa.gov/feature/jpl/20-intriguing-exoplanets

An excellent app is available for Mac users called Exoplanet.

Images in this guide are courtesy of NASA, ESA and Wikipedia. Images from other sources are noted on individual pages.

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or visit our webpage at www.sac.edu/planetarium

You might also like to check our Guide to the Solar System and Guide to Comets, also available for free on our Teacher Resource page.

Somewhere, something incredible is waiting to be known.

-Carl Sagan