

EARTH'S TWINS? SEARCHING FOR EXO-EARTHS

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ABSTRACT

High school students are very interested in astronomy, especially, in modern astronomical discoveries. The most exciting recent discoveries refer to exoplanets. Among the approximately 2000 known exoplanets there are several dozens which orbit in the habitable zone of their host stars. There are some Earth-like exoplanets, too. Finding a true Earth-like exoplanet, which hosts life, is one of the main goals of searching for exoplanets. We have to illustrate to our students the differences and similarities between our and other planetary systems. Let's explore with our pupils the wonderful new world of exoplanets.

ARE WE ALONE IN THE UNIVERSE?

For thousands of years people have wondered if there are other worlds like ours and other living beings, especially intelligent forms of life in the universe. The study of the scientific questions associated with the search for life in the universe gets more and more attention each year. Since Copernicus, we know that the Earth is not in the centre of the Solar System, nor is the Solar System in the centre of the Milky Way galaxy, and even our galaxy is not in the centre of the Universe.

Today, life is only known on the Earth, but there are many other planets outside the Solar System that can host life, suggesting we are not alone. Life is so common on the Earth that it can be found in any harsh environments. The question is how prevalent life is in the Solar System, in the Milky Way, and in the Universe.

There are many questions awaiting answers. What is our place in the universe? How did we get there? Are we alone? Where are the other beings? (Enrico Fermi) Shall we find intelligent life? (SETI) What is life? Is there life beyond Earth and how could we detect it? How did life evolve on the Earth? What makes a world habitable? Could we live elsewhere in the universe? What fractions of stars host planets? Are Earth-sized planets, in the habitable zone of stars, common or rare in our galaxy? Are there Earth-like planets around our neighbouring stars? And we could continue the list. Some decades ago we did not have any answers for these questions, but now we are able to answer some of them.

Are we alone in the universe? The answer is almost certainly "no" according to Ellen Stofan, chief scientist for the National Aeronautics and Space Administration (NASA). "I believe we are going to have strong indications of life beyond Earth in the next decade and definitive evidence in the next 10 to 20 years", "We know where to look, we know how to look, and in most cases we have the technology" she said at a NASA panel discussion [1].

In this paper we deal with habitable planets, especially the Earth-like planets that could harbour life.

SEARCHING FOR EARTH-LIKE PLANETS IN THE SOLAR SYSTEM

The Solar System consists of the Sun, the planets, dwarf planets, moons, asteroids, and comets. There are eight planets in the Solar System, each very different and peculiar in its own way. We know that at least one harbours life, the Earth. Although men have only been on the Earth and the Moon, we have detailed pictures of most of the planets, their moons and of some asteroids and comets. These have been taken and sent to us by spacecrafts, rovers and space telescopes.

Our two neighbouring planets, the Venus and the Mars are the most similar to the Earth in the Solar System (see Fig.1.). Although Venus is hardly different in size from our planet and formerly people imagined a rich wildlife on it, due to its hellish surface circumstances our interest is focused on Mars. While the Venus's surface is obscured by thick clouds, Mars has a thin atmosphere.

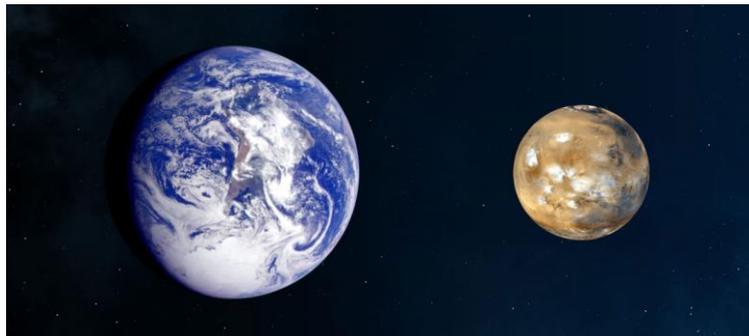


Fig.1. Comparison of Earth and Mars, NASA

Scientists have been curious for centuries whether life exists on Mars, yet we do not know if Mars has ever hosted life. In 1877 the Italian astronomer Giovanni Sciaparelli observed Mars 'channels' through his telescope. The American astronomer Percival Lowell thought that there was intelligent life on Mars, capable of constructing large canals which he saw as lines in his telescope. The public mind has spread this perception. Scientists expect that if we discover life on Mars, it will most likely be simple bacterial life and not humanoid aliens like most of the Martians one has seen in the movies. Many missions have orbited and landed on the surface of Mars, but so far no evidence of life has been discovered. Mars is a right target for searching life beyond the Earth, because it is easily reachable and could have been habitable in the past [2].

Though we might find life on other celestial bodies (for example on some moons) in the Solar System, we do not discuss them in this paper.

SEARCHING FOR EARTH-LIKE PLANETS BEYOND THE SOLAR SYSTEM

To search for life beyond our Solar System, one of the first steps is to find an exoplanet that might support life. An extrasolar planet, or exoplanet, is a planet that orbits a star different from the Sun. As astronomers discovered that the stars in the sky are other suns, and the galaxies consist of hundreds of billions of stars, they suggested that planets must orbit around them. However, there was not any proof until the early 1990s. Exoplanets are difficult to observe, because most of them are too small, too far away and too faint to be detected directly.

How are the discoveries made?

Astronomers have developed several methods for finding exoplanets. They use telescopes armed with photometers (a device that measures light), spectrographs and infrared cameras.

One way how astronomers look for exoplanets is the **radial velocity method**. If a star has a planet (or planets) around it, the planet and the star orbit their common centre of mass. Because the star is much more massive than its planets, the centre of mass is usually within the star and the star appears to wobble slightly as its planets revolve around it. These wobbles can be detected with a spectrograph. If a star is moving towards us, its light and all the dark (absorption) lines in the spectrum will appear blueshifted, while if it is moving away, the light will be redshifted (Doppler-effect). A big, Jupiter-like exoplanet might cause a star to wobble by several meters per second. But a small, Earth-like exoplanet might only wobble its star by ten centimetres per second. The first exoplanet discoveries were 'hot-Jupiters' (that are much larger than Jupiter and orbit very close to their stars) because it was easier to detect them than the smaller ones or others that orbit farther from their stars. We can determine the (minimum) mass of an exoplanet, as well as its orbital period and distance by using the radial velocity method [3].

Another effective exoplanet searching method is the **transit technique**. If an exoplanet's orbit crosses the line of sight between its parent star and Earth, it will block some of the light and cause the star to dim. Extremely sensitive instruments can measure the tiny drop in the star's brightness. By measuring its depth and knowing the size (radius) of the star, we can determine the size (radius) of the exoplanet. By measuring the elapsed time between consecutive transits we learn the orbital period of the exoplanet. Using Kepler's Third Law of Motion, we can calculate the average distance of the exoplanet from its star [3]. Although only a small fraction of exoplanets produce occultation, still it is the most successful exoplanet detecting method. CoRoT and Kepler are two space telescopes whose goals were to search for exoplanets by using the transit method. CoRoT discovered the first small rocky exoplanet (CoRoT-7b) [4]. Kepler detected the first Earth-sized exoplanet, which was in the 'habitable zone' of its star (Kepler186f) [5].

As I have mentioned before, the exoplanets are faint because they do not emit own light. It is very difficult to search for an exoplanet near its star in a photo. One way to see a dim planet near a bright star is to blot out the star using a device called coronagraph. The **direct imaging method** uses infrared lights to observe exoplanets because in these wavelengths the host star not as bright as its exoplanet compared to visual wavelengths. This method works for planets that are very far from their stars [3].

There are other exoplanet searching methods as well, for example astrometry, the gravitational microlensing method and pulsar timing [3].

The discovery and characterization of exoplanets (see Fig.2.) is one of the most exciting and fast-changing areas in modern astronomical research. Today we know that exoplanets are common around different types of stars. It is possible that every single star we can see at night has at least one planet. That would mean that there are at least a hundred billion exoplanets just in our galaxy. According to recent discoveries, it is possible that most stars have planets in their habitable zones, among them there are some Earth-like planets, too [6].

Astronomers are discovering new extrasolar planets incessantly. But the goal is to find habitable, Earth-like exoplanets, that are rocky, roughly have the same size as our planet, orbit a star similar to our own, and have a right surface temperature for liquid water.

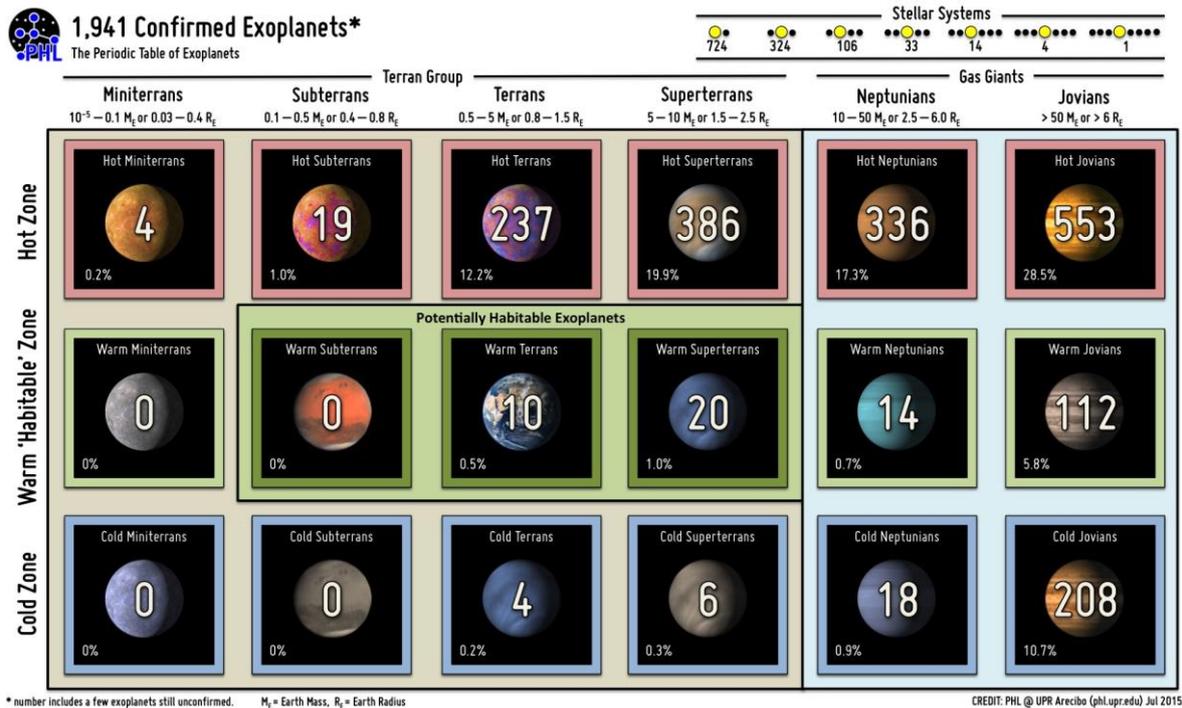


Fig.2. ‘Periodic Table of Exoplanets’ (The Earth is a warm planet.), PHL@UPR Arcibo

HABITABLE ZONE

The habitable zone or Goldilocks zone is the region around a star where the temperature is just right to have liquid water on the surface of a planet (see Fig.3.). If a planet is too close to its parent star, it will be too hot and the water would evaporate. If a planet is too far from a star, it is too cold and the water is frozen. Stars that are smaller, cooler and have a lower mass than the Sun (for example M-dwarfs) have their habitable zone much closer to the star than the Sun. Stars that are larger, hotter and more massive than the Sun have their habitable zone much farther out from the star. The habitable zone is not the only place in the planetary system that supports life, it is possible that an exomoon being outside the habitable zone gets enough energy from the tidal heating to be habitable. Tides are due to differences in the strength of gravitational force acting on an exomoon orbiting its host exoplanet. When an exomoon is moving around an exoplanet, the tidal attraction of the exoplanet distorts the shape of its satellite. The created bulges migrate around on the exomoon. Tidal dissipation can result in internal heating that could be enough for example to maintain liquid water beneath an icy surface.

The Kepler-452b and its star is the most similar to the Earth-Sun system found yet. Before its discovery, the Kepler-186f, Kepler-62f, and Kepler-22b were the “most similar” exoplanets to the Earth. Kepler-186f is 17 percent larger (in its radius) than the Earth, and makes a revolution around its star every 130 days in the habitable zone. The host star is a red-dwarf star that is much cooler than our Sun and only half of its size, so Kepler-186f gets about one-third of the energy from its star that Earth gets from the Sun. Kepler-62f is a “super Earth” about 40 percent larger than our home planet. Its star is cooler and smaller than the Sun, and Kepler-62f orbits in its habitable zone. Kepler-22b was the first of the Kepler planets found within the habitable zone, and its star is very similar to our Sun. Kepler-22b is about 2.4 times of the Earth’s size [7].

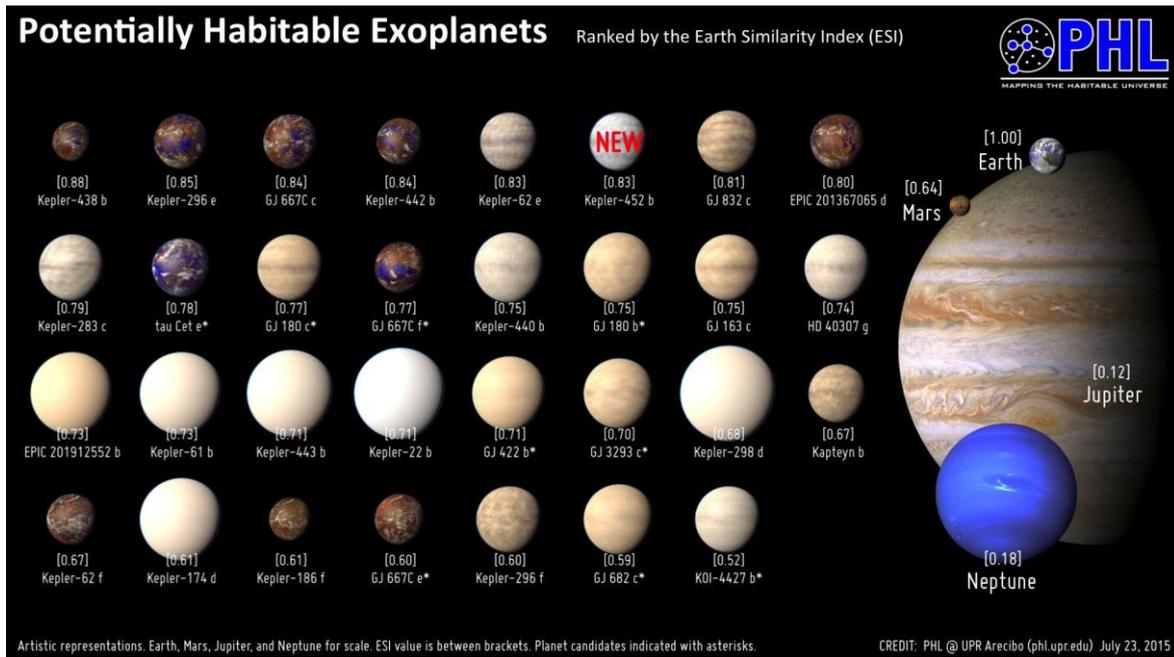


Fig.3. Artistic representation of the habitable exoplanets. Earth, Mars, Jupiter, and Neptune are shown for scale on the right. Source: <http://phl.upr.edu>

Not all the Earth-like exoplanets were discovered by the Kepler Space Telescope. For example Gliese 667Cc was detected by the European Southern Observatory's 3.6-meter telescope in Chile. The planet's mass is at least 4.5 times that of the Earth's mass. It orbits around a red dwarf in the habitable zone with a 28-day period. Gliese 667Cc receives around 90 percent of the flux we get from the Sun. This planetary system is 22 lightyears from the Solar System. There are five more exoplanets in this planetary system, among them two in the habitable zone [8].

Kepler-452b the most Earth-like exoplanet we know, circles a sunlike star at about the same distance as Earth orbits the Sun. This exoplanet is about 60 percent larger than our home planet, therefore it is not a true "Earth twin", rather an "Earth cousin". Kepler-452b's orbital period is 385 days, just 20 days longer than our own year. Its star is just 4 % larger, 1.5 billion years older and 20% brighter than the Sun. Kepler-452b is the first known possibly rocky habitable exoplanet orbiting around a Sunlike star [7].

Scientists have found a Jupiter's twin. They used the ESO 3.6-metre telescope to identify an exoplanet (HIP 11915b) orbiting at the same distance from a Sun-like star, HIP 11915, as the Jupiter orbits the Sun. The host star has the same age as the Sun and there may be rocky planets in this planetary system, too [8].

The search for Earth's twins is speeding up. In the years ahead even more improved methods will allow us to detect many exoplanets like Earth. Whether they harbour life is a harder question that we might answer in decades. Another difficult question is how we could travel or send a spacecraft to an exoplanet. We can use the Interstellar Trip Planner (<http://planetquest.jpl.nasa.gov/system/interactable/5/>) to get to know how long it would take to travel to an exoplanet by different space vehicles. I recommend another interesting, interactive website about the exoplanets: <http://eyes.nasa.gov/eyes-on-exoplanets.html>.

SPACE TELESCOPES AND FUTURE EXOPLANET MISSIONS

The NASA Kepler Space Telescope was designed to seek exoplanets and determine their size and orbital period. This most successful space telescope found the first Earth-sized planet in the habitable zone of a star (Kepler-186f).

The Transiting Exoplanet Survey Satellite (TESS, 2017 NASA) will measure light curves of stars in the whole sky. The main goal of the TESS mission is to detect Earth-sized exoplanets around bright stars near our Solar System.

The James Webb Space Telescope (JWST, 2018 NASA) will use the infrared light. It will study the atmospheres of exoplanets to find an Earth's twin among other scientific goals.

CHaracterizing ExOPlanet Satellite (CHEOPS, 2017 ESA) will detect exoplanetary transits of bright stars already known to have exoplanets. The CHEOPS mission will determine the bulk density of small exoplanets orbiting bright stars.

The PLAnetary Transits and Oscillations of stars (PLATO, 2024 ESA) mission will find and characterise Earth-sized exoplanets and super-Earths. It will help understand the planet formation, too.

WHY TO STUDY AND TEACH EXOPLANETS?

Teaching exoplanets in the school is usually a challenge for physics teachers, because it is a complex subject of physics and other fields of science. Astronomy, especially teaching exoplanets is a very efficient way to teach science including physics.

The more we learn about exoplanets, the more we know about how our Earth and the Solar System function, how planets form and interact with each other. Students would like to know more about exoplanets, and they take part enthusiastically in assigned projects related to habitable exoplanets.

We live in a special era, when we can determine some properties of planetary systems hundreds of light-years away and able to answer some questions about the universe that humans have asked for a long time. We efficiently explore our Solar System and beyond to understand our place in the Universe, and look for extraterrestrial life. The search for and the understanding of life in the Universe are fundamental questions in the natural sciences as well as in philosophy, psychology, sociology and theology.

ACKNOWLEDGMENTS

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REFERENCES

1. <https://www.youtube.com/watch?v=GNjuz6MO0eU>
(Space Experts Discuss the Search for Life in the Universe, NASA, April 7, 2015)
2. <http://mars.nasa.gov/> (NASA, Mars Exploration)
3. Michael Perryman: *The Exoplanet Handbook*, Cambridge University Press, Cambridge, 2011
4. <https://www.eso.org/public/news/eso0933/> (eso0933-Science Release)
5. <https://www.nasa.gov/ames/kepler/nasas-kepler-discovers-first-earth-size-planet-in-the-habitable-zone-of-another-star>
6. <http://phl.upr.edu/> (PHL Mapping the Habitable Universe)
7. <http://kepler.nasa.gov/>
8. <http://exoplanet.eu/>