LOOKING FOR OTHER WORLDS OUT THERE

SUMA N MURTHY

Are there worlds outside our Solar System? How do we look for them? What can we learn from them? In this article, the author shows how recent advances in technology have made the search for exoplanets more exciting than ever before!

Questions regarding the uniqueness of the solar system, and more particularly that of Earth, have haunted the human mind for ages. The possibility that planetary systems outside our own existed in the universe was first suggested in the sixteenth century, by the Italian philosopher Giodano Bruno. According to Bruno, distant stars could just be like our own Sun, in hosting planets, and even life. Voicing similar thoughts, Sir Isaac Newton referred to exoplanets towards the end of the 1713 edition of his celebrated work, Principia, stating that:

"...this most beautiful System of the Sun, Planets, and Comets, could only proceed from the counsel and dominion of an intelligent and powerful being. And if the fixed Stars are the centers of other like systems, these, being formed by the likewise counsel, must be all subject to the dominion of One; especially since the light of the fixed Stars is of the same nature with the light of the Sun, and from every system light passes into all the other systems ..."

An extrasolar planet, or an exoplanet – as it is called today, is defined as a planet that orbits a star other than the Sun. While many people claimed to have detected exoplanets, the first such claims to be confirmed were in 1992, when the astronomers Aleksander Wolszczan and Dale Frail observed 3 planets revolving around a pulsar – a rapidly rotating star almost at the end of its lifetime, called PSR B1257+12. Three years later, the Swiss astronomers Didier Queloz and Michel Mayor discovered another exoplanet, one that was revolving around a yellow star, called 51 Peg, which was similar to our own Sun. This was followed by the discovery of two more exoplanets, in 1996, by a team of American astronomers, led by Paul Butler and Geoff Marcy. This team went on to discover around 70 of the 100 exoplanets known by the end of the subsequent decade. The launch of the Kepler Space Telescope in 2009 has brought about a revolution in this field. This telescope has been used to collect enormous amounts of data, keeping astronomers busy mining it for clues to other exoplanets.

Box 1. A slice of history

The world famous Arecibo telescope was shut down for repair in the early 1990s and became unavailable for normal use by the general astronomy community. The astronomer Wolszczan made use of this rare opportunity by using this telescope to search for pulsars. This search led to the discovery of the pulsar PSR B1257+12, and later revealed the existence of planets around it.

At almost the same time, another group of astronomers led by Prof. Matthew Bailes claimed that they had discovered a planet around the pulsar PSR 1829-10. The American Astronomical Society convened a meeting at Atlanta, in January 1992, to discuss these two exciting discoveries.

However, before the meeting could convene, the group led by Bailes found out that their discovery was an error caused by ignoring certain effects caused by the interstellar medium. In a fantastic display of scientific ethics and honesty, deeply appreciated by the scientific community, Bailes publicly acknowledged this mistake in the meeting. Consequently, Wolszczan and Frail were acknowledged as the discoverers of the first set of exoplanets.

(To read a detailed description of this entire episode in Wolszczan's own words, go to www.sciencedirect.com/science/article/pii/S1387647311000418).

How do we find exoplanets?

Astronomers use a variety of methods to detect exoplanets. Many of these are indirect and determine the presence of exoplanets by looking at how they affect their host star and its actions. This is because, except in certain cases, the host stars are so far away and so bright, that they outshine their planetary companions.

This is similar to our own solar system where the Sun's brightness at visible wavelengths is a billion times greater than Jupiter. In other words, if we were to observe the solar system from a distance, for every 1,000,000,000 light particles we receive from the Sun, we would be able to see about 1 light particle from Jupiter. In contrast, if we were to observe the Sun and Jupiter from a distance of even 15 light years away, the two would seem to be separated from each other by only 1/3600th of a degree, which is about the width of a strand of hair! As you can see from this analogy, imaging even a large planet under these circumstances is as challenging as photographing a fire-fly fluttering very close to a flood light!

To be able to really "see" those worlds (and their inhabitants, if any) in their entirety, we will need far-better technology than what exists today. Till the time these improvements happen, we will continue to infer the presence of exoplanets, studying them in all the ways permitted by current technology! Some of the most common detection methods we use for this purpose are described below.

Radial Velocity Tracking

This is a very successful method for hunting down exoplanets. It was in fact used by the astronomers Queloz and Mayor to detect the first exoplanet revolving around a normal (non-pulsar) star. If an orbiting planet is massive, its gravitational pull on the parent star can cause the star to wobble. This slight movement of the host star, facilitated by the Doppler effect (refer Box 2), can be used to detect the presence of exoplanets.

Box 2. Doppler effect

Have you noticed the sudden change in pitch in the sound of an ambulance siren or a speeding motorbike as it speeds towards you and then passes you to speed away? This effect, called the Doppler effect, is described as an increase (or decrease) in the frequency of sound, light, or other waves as the source and observer move towards (or away from) each other. Astronomers use this effect to determine the speed with which stars or galaxies approach or move away from us on Earth, identified as the degree of shift in frequency of the light that we receive from them. Thus, stars moving away from us show a shift to longer wavelengths of light – called red shift, while those moving towards us show a shift towards the shorter wavelengths – called blue shift.

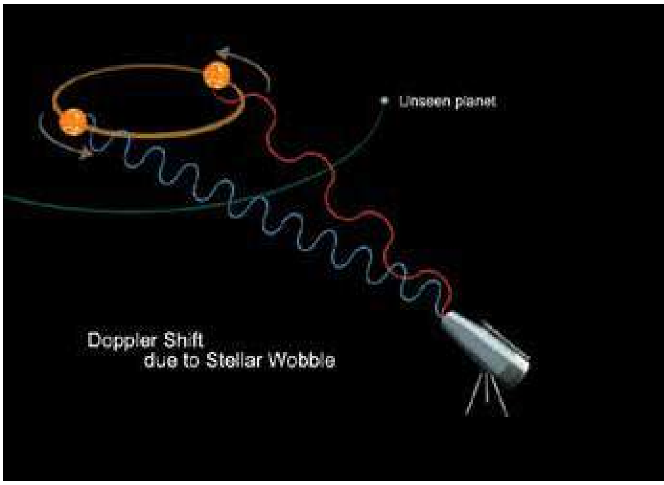

Fig.1. Catching a moving star. The star orbits about the planetary system's center of mass. As it moves towards us, the light from it is 'blue-shifted' and as it moves away from us, it is 'red-shifted'.

Credits: NASA, Night Sky Network. URL: https://nightsky.jpl.nasa.gov/news-display.cfm?News_ID=682. License: Public domain.

Big gas giant planets, like Jupiter, induce wobble velocities of several tens of meters per second on their host stars. Current technology allows us to detect wobble velocities as small as half a metre per second (this is how fast we walk on a leisurely stroll). Every improvement in this technology will increase the possibility of detecting much smaller and rockier planets, like the Earth, in other planetary systems.

Astrometry

Astrometry is a process that involves measuring the positions of stars in the sky as precisely as possible. As we've seen earlier, the presence of a planet causes its star to wobble slightly. This wobble is reflected as a subtle change in the position of the star in the sky. As this change can be very slight, we need high precision measurements to detect it. It is for this reason that the presence of exoplanets was not confirmed through this method until 2009.

Astrometry gained importance in 2013, when the European Space Agency launched a space observatory called Gaia, purely for astrometric purposes. In its lifetime of about 10 years, Gaia is expected to enable us to detect and characterise the orbits of around 70,000 exoplanets!

Transit Method

We use the transit method to detect exoplanets when a star and its planet are aligned towards us in such a way that the planet eclipses the star as it passes by.

The brightness of the star drops ever so slightly during the eclipse. This drop can be detected through observations by high-resolution telescopes trained on it over a period of time. This method works best for large planets with orbits close to the parent star, as this causes a greater and, thus, more easily detectable drop in the star's brightness.

This method has yielded the maximum number of exoplanet detections till date – especially of Earth-like planets, the kind we are most interested in! The main reason behind this huge number of detections is the launch of the space-based Kepler mission in 2009. This mission surveys certain portions of our galaxy to discover planets of the size of Earth and smaller, by using the transit method. Kepler has so far aided in the discovery of 4706 exoplanet candidates, of which 2330 have already been confirmed. That the Kepler mission is space-based is the main reason behind its spectacular success.

Box 3. Why go to space?

The Earth's atmosphere distorts images of outer space, limiting how accurately we can carry out measurements. Placing a telescope outside the atmosphere removes this constraint. As space provides a stable observing platform, it becomes possible to obtain the very fine measurements required to carry out precision astronomy (see figure 2 for comparison).

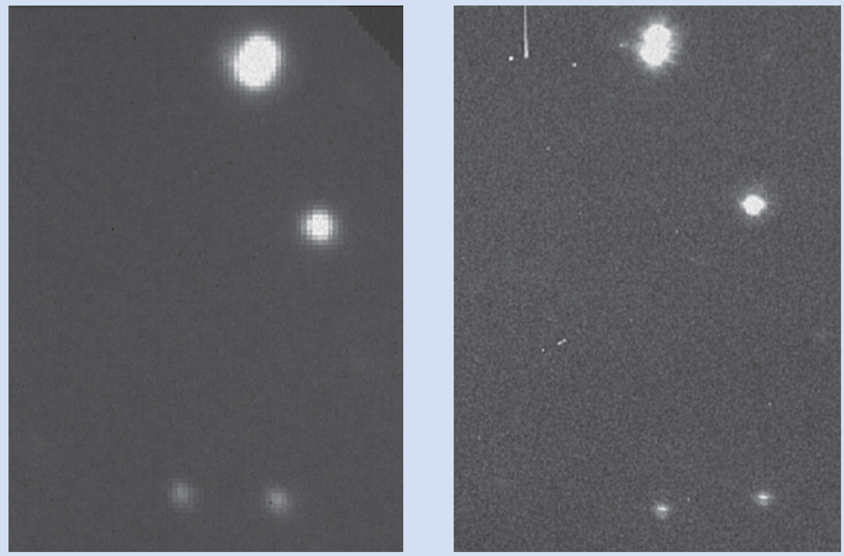

Fig. 2. Ground vs. Space. Here is a comparison between the images of a region of the sky taken by Las Campanas, Chile, Observatory (to the left) and the Hubble Space Telescope (to the right). Did you notice that, in addition to improved clarity, there are also more stars seen in the Hubble image?!

Source: NASA. URL: https://www.nasa.gov/content/hubbles-first-light. License: Public domain.

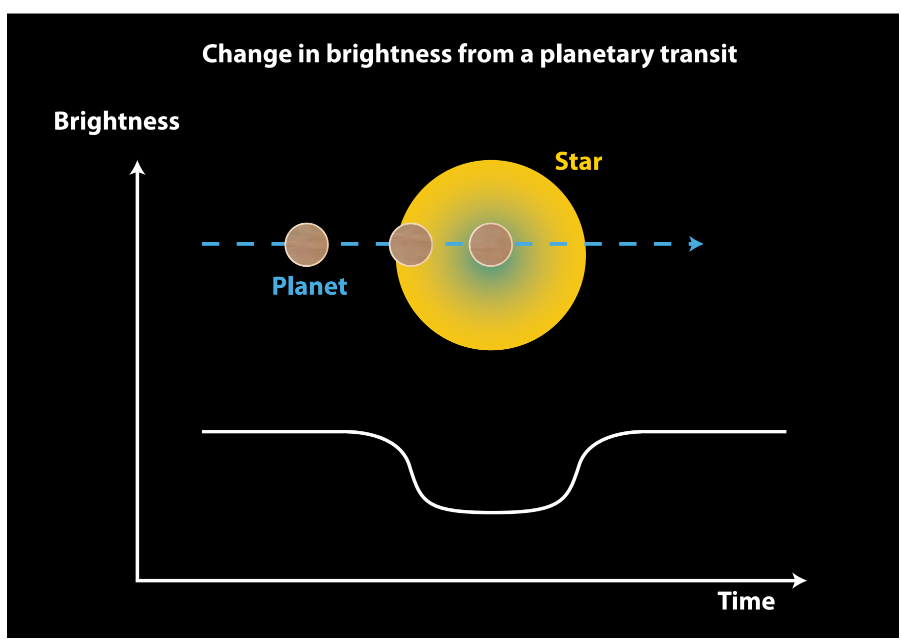

Fig. 3. Caught while transiting! This figure demonstrates how the brightness of a star varies as the planet moves across it. As the planet starts eclipsing the star, we see a gradual drop in brightness which then remains constant as long as the planet is in front of it and later gets back to its original brightness.

Credits: SuperWASP, NASA. URL: http://www.superwasp.org/how.htm. License: Public domain.

Box 4. Tabby's Star!

The star KIC 8462852 is better known by its nickname–Tabby's star, after the scientist Tabetha S Boyajian, who was the first to study it. This star was picked up by the Kepler telescope, which also found that it showed very strange brightening and dimming episodes. This strange behaviour of the star kept extra-terrestrial life enthusiasts on their toes for a while. When attempts to explain these variations through natural causes remained unsuccessful, scientists suggested that they were caused by structures called Dyson swarms, built by an advanced civilization to harness the star's energy. A search for signals from intelligent extra-terrestrial life around this star by the Search for Extra Terrestrial Intelligence (SETI) team has, however, yielded negative results.

Gravitational Micro-Lensing

The general theory of relativity tells us that massive objects can bend light around them. Called gravitational lensing, this effect magnifies the light of a distant star when a nearby faint star moves across it. This is analogous to the effect we see by placing the foot of a wine glass in front of a candle (as seen in Fig. 5).

The brightness of the distant star in the background increases at first, then decreases steadily as the invisible foreground star moves past it, and finally reverts to its usual constant value once the star in the foreground has moved away completely. If the invisible star in the foreground has a planet orbiting around it, then there will be a short time interval during which this planet will also contribute to the lensing effect of the star in the background (see Fig.6). This can be detected and used to infer the presence of exoplanets.

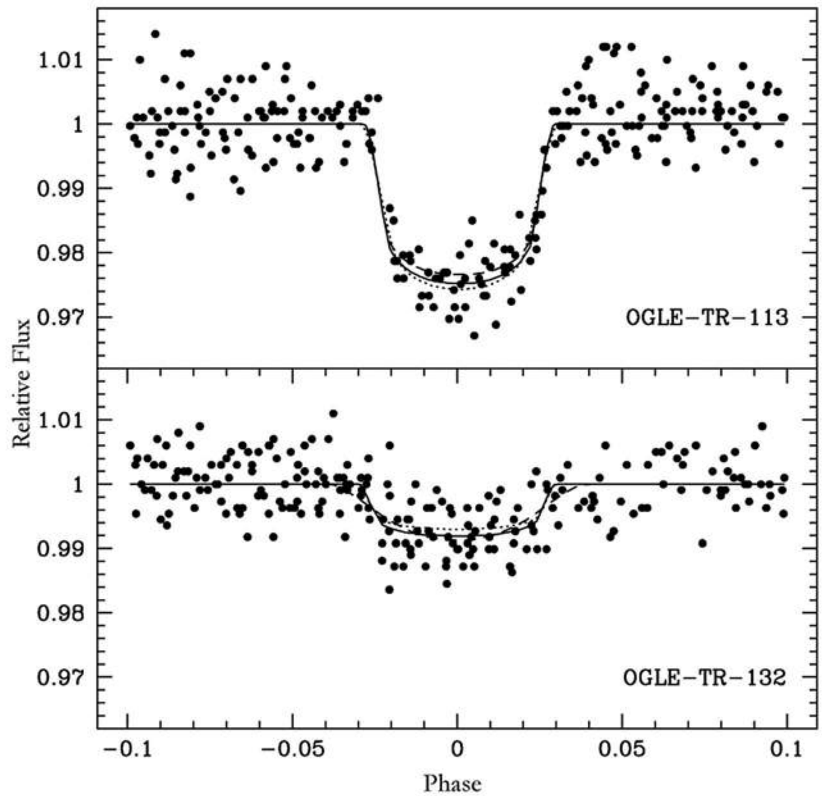

Fig. 4. Science in the real world. The black dots in this image demonstrate how the varying brightness of a star hosting planets appears in reality.

Credits: ESO. URL: https://www.eso.org/public/news/eso0415/. License: Public domain.

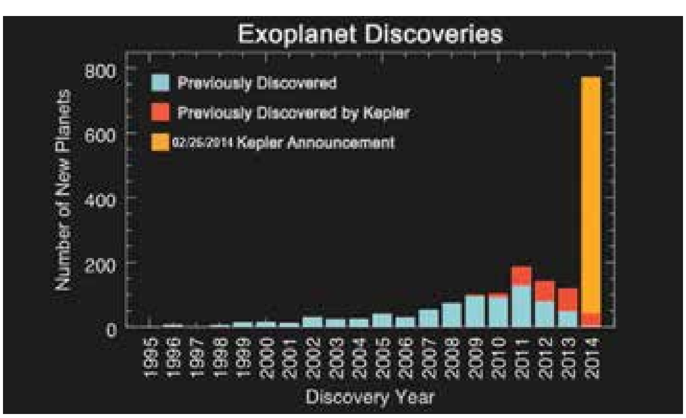

Fig. 5. Kepler steps in with a bang! This histogram shows the number of exoplanets discovered since 1995. Note the sudden jump in the number of discoveries after the Kepler team announced the discovery of about a thousand planets.

Credits: NASA. URL: https://www.nasa.gov/content/exoplanet-discoveries. License: Public domain.

Fig. 6. A model gravitational lens: The way a wine glass distorts the candle light in the background is almost similar to how a massive object distorts light.

Credits: KIPAC, Kavli Insitute of Particle Physics and Cosmology. URL: http://kipacweb.stanford.edu/research/gravitational_lensing. License: Public domain.

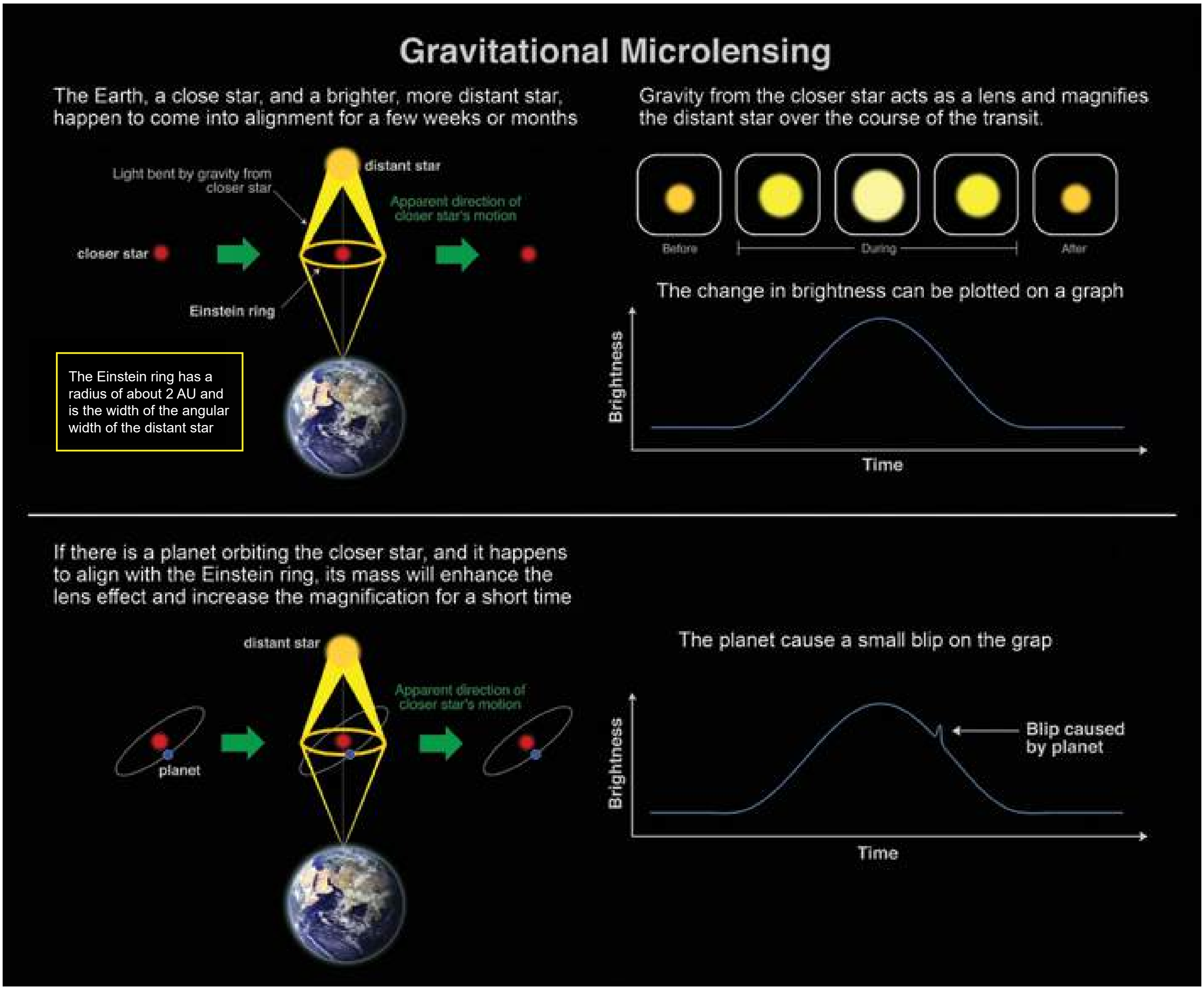

Fig. 7. Microlensing in detail. This is how the gravitational microlensing technique works.

Credits: LCOGT, IFLSCIENCE. URL: https://lco.global/files/spacebook/Gravitational%20Microlensing%20timeline.png. License: Public domain.

Direct Imaging

As mentioned earlier, at visible wavelengths, our Sun is around one billion times brighter than Jupiter. However, at infrared wavelengths – wavelengths longer than the visible light, our Sun is only a hundred times brighter. Provided the circumstances are favourable, we can image the planetary system at these wavelengths. For example, if a planet is very far from its star, and we block the light that we receive from the star, the fainter planet will show itself. This direct imaging method has taken off only recently, enabling us to discover around 33 planets so far.

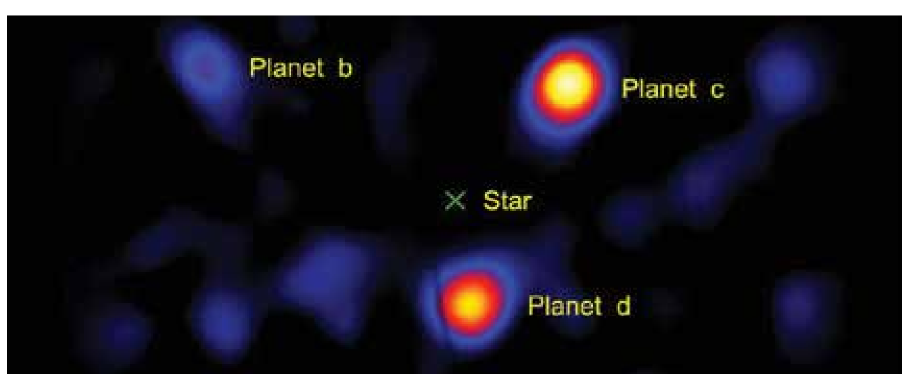

Fig. 8. Photographing the neighbours! This image shows the light we receive from three planets – called HR8799b, c and d - all orbiting a single star, called HR8799. The star is located at the spot marked with an "X." The three planets, are thought to be gas giants like Jupiter, but more massive.

Credits: NASA/JPL-Caltech/Palomar Observatory. URL: http://www.nasa.gov/topics/universe/features/exoplanet20100414-a.html. License: Public domain.

Making large strides!

Since the life span of our solar system is unimaginably longer than our own lifetimes, studying its origin and evolution is not possible even with many generations of continuous research. The best way to go about this is to study similar systems at different stages of evolution, and then piece together the evidence we gather from them.

As we have just seen, other planetary systems are not uncommon at all, and we should be able to study them if only we can detect them in sufficient numbers and diversity. In fact, we have come a long way from the discovery of the first exoplanet, in 1992. Current technology, including the famous Hubble telescope and the Kepler mission, has already helped us detect thousands of planets outside our solar system, and with every advance, we may learn of many more.

Box 5. See them work!

If you want to 'see' how all the detection techniques described here work, please visit https://exoplanets.nasa.gov/interactable/11/.

NASA hopes to launch a Transiting Exoplanet Survey Satellite (TESS) sometime in 2017. The aim of this survey will be to discover planets ranging from those the size of the Earth to those much greater than Jupiter, and with host stars of varied types. Similarly, the James Webb Space Telescope, scheduled to be put into orbit later in 2018, will study the atmospheres of exoplanets and shed light on the ambient conditions in those worlds.

We can now look at the systems just born and understand the early stages of planetary formation; systems slightly older will tell us about the interaction among the planets; and extreme planets orbiting dead stars tell us of the different evolutionary paths possible. We can put to test theories on the formation of our own solar system based on all that we see. We can even study the atmospheres of exoplanets and determine their habitability to a large extent. But more importantly, the study of exoplanets is a major stride towards satiating our own curiosity regarding the existence of habitable worlds and intelligent life out there!

Box 6. Be a citizen scientist!

Probed by mega projects like the Kepler mission, the Milky Way is only too happy to give away the whereabouts of exoplanets. Huge amounts of data have been collected, but now a huge amount of human resource is needed to make sense of this. Planet Hunters is a citizen project which makes use of the human capability of pattern recognition to extract signals betraying the presence of exoplanets. This project has around 300,000 volunteers, and many planet discoveries to its credit, including the weirdness of Tabby's star! So, if you are dying to join the search for exoplanets, the Planet Hunters group will certainly be very happy to take you into their fold! Visit www.planethunters.org and help scientists discover new worlds!

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Want to know more?

1. A (very) technical paper on the detection techniques: http://www.mpia.de/homes/ppvi/chapter/fischer.pdf.
2. About Kepler mission: http://kepler.nasa.gov/ and http://www.nature.com/nature/journal/v513/n7518/pdf/nature13781.pdf.
3. About Gaia mission: http://sci.esa.int/gaia/ and https://arxiv.org/pdf/1411.1173v1.pdf.
4. Some websites to tell you all about the recent gossip in the field: http://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html and https://exoplanets.nasa.gov/newworldsatlas/.
5. About some of the upcoming missions: https://tess.gsfc.nasa.gov/overview.html and http://www.jwst.nasa.gov/.

Suma N Murthy is a student of astronomy who has completed her post-graduate studies in Astronomy and Astrophysics from Indian Institute of Space Science and Technology, Thiruvananthapuram.