The Search for Planetary Systems

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September 2019

A planetary system is defined as a collection of non-stellar objects in orbit around one or more stars [1]. Since the ancient times, it is known that the Earth, along with other companions, formulate one we call the solar system. For centuries to come, astronomers have focused predominantly on the movement of celestial bodies orbiting the sun and it wasn't until 1995 that they confirmed another planetary system composed of one planet [2]. Since then, the interest for discovering extrasolar planets has been increasing significantly. Undeniably, one of the main motivation of those searches is the discovery of a habitable world; a planet with just the right conditions to support life.

1 Planet Detecting Techniques

The question that is immediately raised is how do astronomers detect extrasolar planets which are located light years away? Today, a plethora of methods are used to detect them, of which four are used extensively. The essence of discovering a planet is not just to identify its existence but also, to measure some of their geophysical and orbital characteristics.

1.1 Doppler Spectroscopy Method

It is known that for any planetary system, the planets and the stars are orbiting a specific point in space called the barycenter. The stronger the gravitational pulls from the planets is, the more intense the the star's motion will be around it. Thus, these movements could principally reveal information about the planets in orbit. Information about the star's motion is extracted by monitoring the Doppler effect on its spectrum; by tracking the blue shifts and red shifts of it, scientists extract its radial velocity, as shown in Figure 1.

To analyse things further, let's consider a simple system consisting of a planet with mass m orbiting a star of mass M. For all practical purposes, we will assume that $M + m \approx M$. By Kepler's third law, the semi-major axis α of the orbit and the period of the planet around the star P are connected by the relation:

$$\alpha = \left(\frac{GM}{4\pi^2} P^2\right)^{1/3} \tag{1}$$

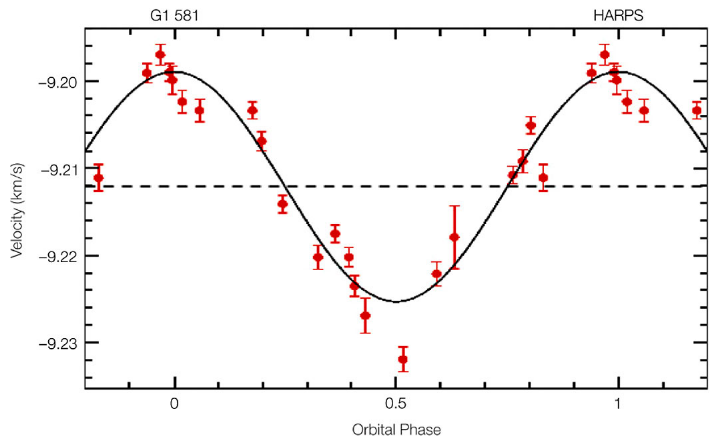

Figure 1: Radial velocity of the star Gliese 581 with respect its orbital phase [6].

where G is the universal gravitational constant. The barycenter, sun and the planet are co-linear points at all times. Thus, the period P equals the periodicity of the spectrum fluctuations of the star, which can be extracted by the velocity curve [3]. The mass m of the planet can be computed by balancing out the product of masses times the distance to the center of mass of both bodies [3]. Thus, one proceeds as follows:

$$m \cdot D_1 = M \cdot D_2 \Rightarrow m = M \cdot \left(\frac{D_2}{D_1}\right)$$

where D_1 and D_2 are the distances from the barycenter of the planet and the star respectively.

Planetary systems usually consist of more than one planets. Thus, how do scientist know that they are looking at such system? The answer lies in the principle of superposition. In such incident, the star's motion is the result of the superposition of the gravitational tugs caused by each planet individually. After collecting data of the star's motion, astronomers decompose the measured curve and detect the celestial objects responsible for its movements.

As of today, one out of five verified exoplanets was found with the forementioned technique. There are two significant drawbacks of it that need to be mentioned. In order to graph the star's true radial velocity, the orbital plane needs to be along the observatory's line-of-sight. The preceding fact renders the method weak in acquiring precise information from planets whose orbital doesn't fall into the said category. Secondly, by observing the star's motion, astronomers can't determine geophysical quantities like atmospheric composition and the radius of the exoplanet.

1.2 Transit Photometry Method

The transit method discovers planets by monitoring and assessing the flux received by a specific star. If the orbital plane of a planet is such that it passes in between the Earth and its host – defined as a *transit*, then the received light intensity from it dims for a short period of time. However, the converse of the latter assertion isn't always correct. In fact, there are a two major observations that need to be had in order for astronomers to be certain they are looking at a planet. First, the dimming should occur at specific time intervals reflecting the fact that the observed object is orbiting the star. Second, the dip in the star's flux should be symmetrical with respect to time, revealing the roundness of the object; a basic aspect of all planets. A transit can reveal information about the size of the planet. The flux drop ΔF observed by Earth is given by:

$$\Delta F \approx \left(\frac{R_p}{R_*}\right)^2 \cdot F_* \tag{2}$$

where R_p, R_* are the radii of the planet and star respectively, while F_* is the regular flux received by the star [15]. Rearranging for the planet's radius R_p, yields:

$$R_p = \sqrt{\frac{R_*^2 \cdot \Delta F}{F_*}} \tag{3}$$

Since F_* and ΔF can be measured by astronomical instruments, all one needs to know is the radius of the star, which can be calculated using other astrophysical methods. Furthermore, this method is capable of extracting information about the atmospheric composition of the observed planet. As the transit unfolds, star light passes through the exoplanet's atmosphere and when it reaches Earth, we observe that some of the frequencies are missing from the received spectrum. That is because, the molecules in the planet's atmosphere absorbed them [4]. By assessing the numerical values of those frequencies, astronomers are able to determine the molecules responsible for their absorption.

Although the transit method has assisted scientists detect more than three thousand exoplanets, it does entail a significant limitation. It relies on the observation of a transit; that is, the planet must pass in front of the star. Unfortunately, the probability of such event is generally low for all types of planets having all types of orbits. For example, during its operational lifetime, the *Kepler* telescope tracked the brightness of about 530,506 stars and detected only 2,662 planets [7].

1.3 Microlensing Method

According to the general theory of relativity, massive objects distort the fabric of spacetime causing the bending of photons' trajectory; a phenomenon which can be exploited to find exoplanets. The basic mechanism of this technique is that as light is passing by a star from a more distant one, it bends in all directions around the former, causing the photons to focus to a segment along the line that connects the two. If Earth happens to belong in that segment, then the distant star appears brighter in the sky for a short period of time [11]. The forementioned arrangement can be thought of as a classical system in optics, where the nearest star acts as a lens and the distant one as a source of light. The observed brightness of the distant star changes slightly when the lens star is accompanied by an orbiting planet. The reason for this is that the planet's gravity is also capable of focusing the source star's light. When that happens, the additional focused light by the planet, results in a sudden bump in the background star's light curve [12], as shown in figure 2. This phenomenon is referred as *exoplanet microlensing.*

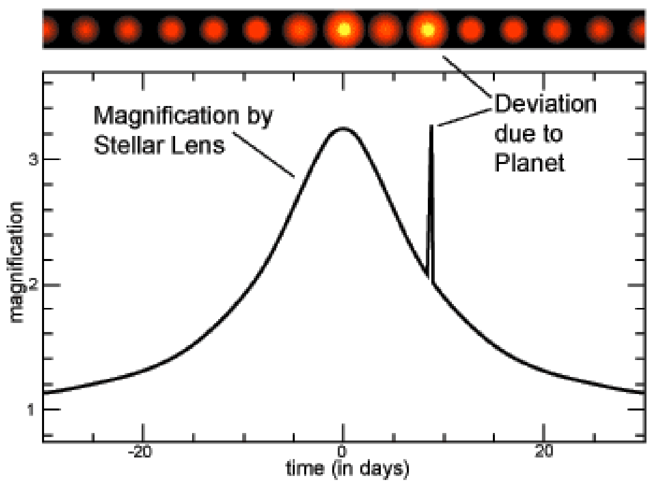

Figure 2: Example of a graph showing the magnification of the light received by a specific region in the sky with respect to time [10].

The described technique accounts for approximately 2 % of the identified exoplanets as microlensing events require the stars and the Earth telescopes to be at the right positions; a condition that renders them extremely rare.

1.4 Direct Imaging Method

From Earth, it is quite easy to take pictures of planets in the solar system. In fact, amateur astronomers across the globe are doing that annually. On the other hand, photographing exoplanets which are located couple of hundreds of years light years away is unimaginably challenging. The reason this is the case is because their host star's radiation dominates over the light they reflect from it. However, the signal telescopes receive does contain the photons radiated away by the exoplanet. Thus, scientists have tried to make devices which are capable of removing the luminous glare of the star from the captured pictures, allowing the light of exoplanets to be isolated and studied. One piece of equipment that is able to produce such result is called a cononagraph [8]; an add-on on optical telescopes that removes star light.

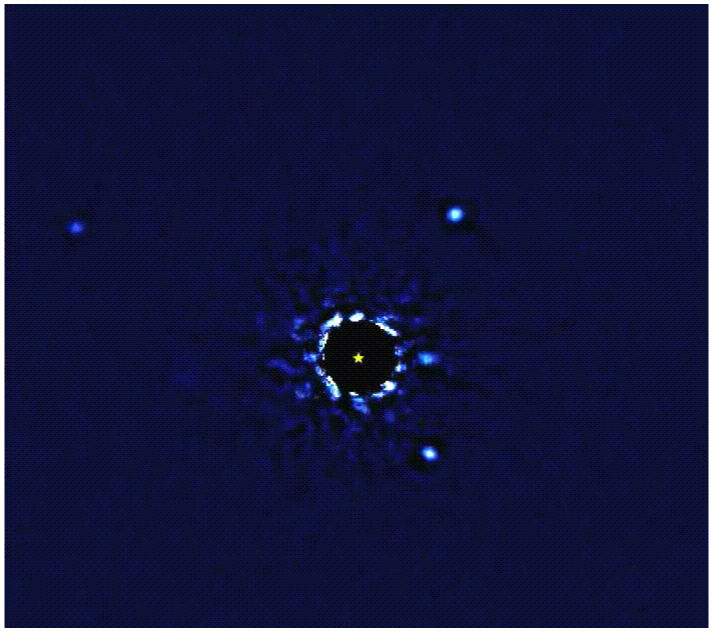

Figure 3: Captured image of the star HR 8799 and four exoplanets in orbit around it. The picture was taken by the W. M. Keck Observatory [9].

Although direct-imaging technologies are still on their infancy, there is a lot of hope within the astronomical community that this technique is going to become pivotal for exoplanet searching in the near future.

2 Measuring Planet Habitability

An intriguing question about exoplanets is: how does one measure their habitability? that is, their potential to sustain life on their surface. Scientists are certain, based on life on Earth, that for life to form and evolve on an exoplanet, it needs to fullfill specific geophysical, chemical and orbital criteria.

First and foremost, the exoplanet's orbit should such that its distance variations from its star produce a steady mean temperature to it, with a magnitude that allows for liquid water to exist on its surface. As for the scale of the planet-star separation, it greatly depends on the astrophysical nature of the star. An astronomical unit is a perfect separation for a planet orbiting a star like the Sun, but the same distance would make life-sustaining conditions unachievable had the star been twenty times more luminous. Although there are living organisms with extreme temperature tolerance, such an environment is not appropriate for the support of complicated life forms. In fact, temperature sensitivity increases with life complexity [13]. In addition to the forementioned conditions, the planet's orbit should stay at that state for extended periods of time; at least over a billion years, allowing evolution to unfold unrestricted. The preceding assertions render planets with near circular orbits as good habitable candidates while completely rule out distant ones with intensely elliptical orbits. Secondly, the planetary mass should produce a gravitational field that is strong enough to keep molecules bound to it; an assertion that constrains both the mass and the radius of the planet. Molecules in planets with weak gravity can easily acquire escape velocities by solar winds or meteoroid collisions. That makes the formation of a thick atmosphere impossible, an aspect that can have a life-supporting role as it protects the surface from high-frequency radiation and meteoroid impacts. Lastly, based on observations about life on Earth, astrobiologists expect habitable planets' atmospheres to consist of an abundance of life-related molecules, like C, H, P, N, O and S. Although there is speculation within the scientific community on the existence of different kinds of biochemistries, current understanding about them is limited and no experiment has proved their existence [14].

3 Conclusion

With the elaborated techniques, astronomers have identified 3,014 planetary systems and a total of 4,055 planets since the dawn of exoplanet hunting [5]; an accomplishment that made planetary astronomy one of the fastest growing fields in physics over the last three decades. But, aside the indisputable success, we only had a glimpse of the oceans of planets hiding in the skies and barely scratched the surface on understanding life formation.

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