Planetary Science

Project 1

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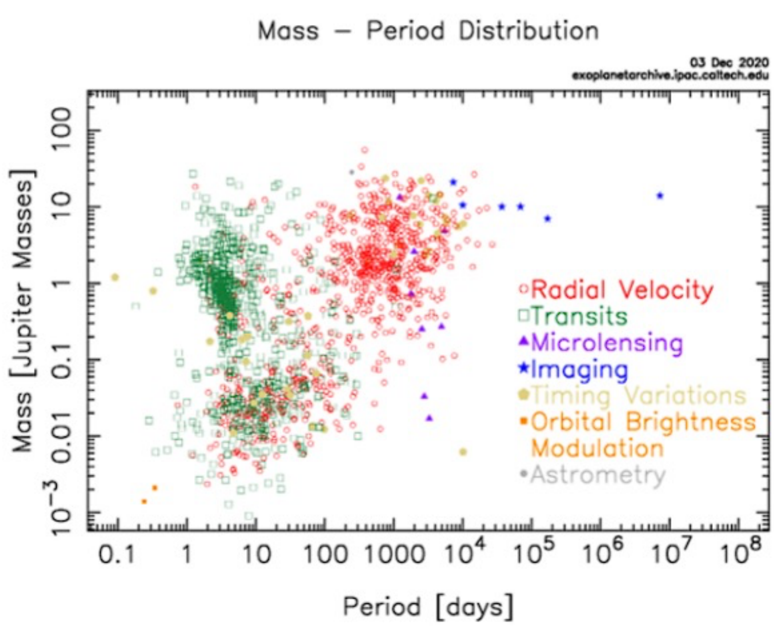
Introduction/Motivation: An exoplanet is a world that exists outside of our solar system. Astronomers have developed many detection techniques to identify these exoplanets. Radial Velocity, Astrometry, Gravitational Microlensing, Transit, and Direct Imaging are the most popular and effective ways to detect them. Each method has its benefits and drawbacks, allowing for each detection method to have its own place in observation. So, by understanding each method of detection, we can determine which method is best suited for finding exoplanets in different circumstances.

Method: In order to compare the most popular detection methods, we analyzed each method and its sensitivity limits to show which methods are useful in different scenarios. Each plot consists of many exoplanets found by a particular method. Their graphs consist of plotting the information relevant to that method against each other. Included in each plot is the lower limit of the detection. Finding exoplanets below this lower limit is unlikely.



Wang, J. (2023). *Exoplanet Detection and Population*
[45] The Ohio State University.
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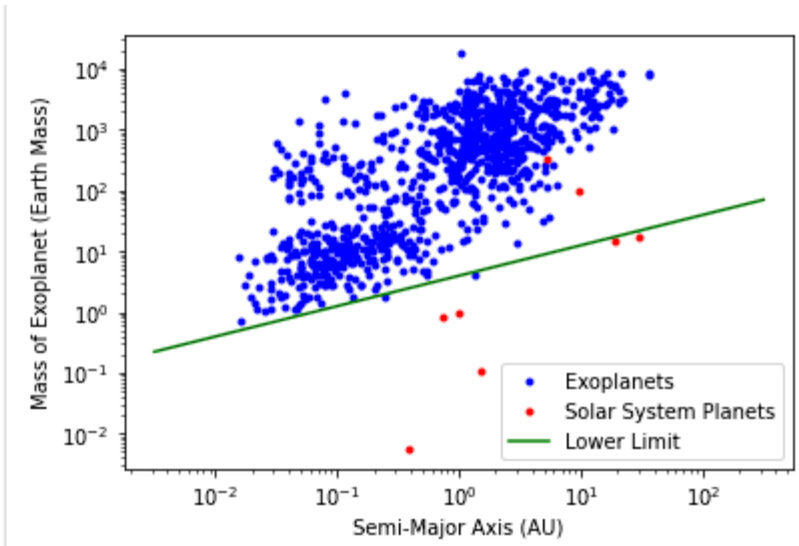
Results

Radia Velocity: This method observes small wobbles in a star's motion caused by the gravitational pull of an orbiting planet. This is done by measuring the Doppler shift of the star's spectral lines, which shifts slightly as the star moves towards or away from Earth due to the planet's orbit. By measuring these shifts over time, astronomers can determine the presence of an exoplanet and calculate its orbital period, mass, and distance from the star. To do this an astronomer would typically use a high-resolution spectrograph to measure the star's spectral lines with high precision.

According to the textbook Exoplanets (Seager,2011) The signal of the radial velocity method is given the by the equation:

$$= \sqrt{\frac{G}{(m_1 + m_2)a(1 - e^2)}} \cdot m_2 \sin i \cdot (\cos(\omega + f) + e \cos \omega)$$

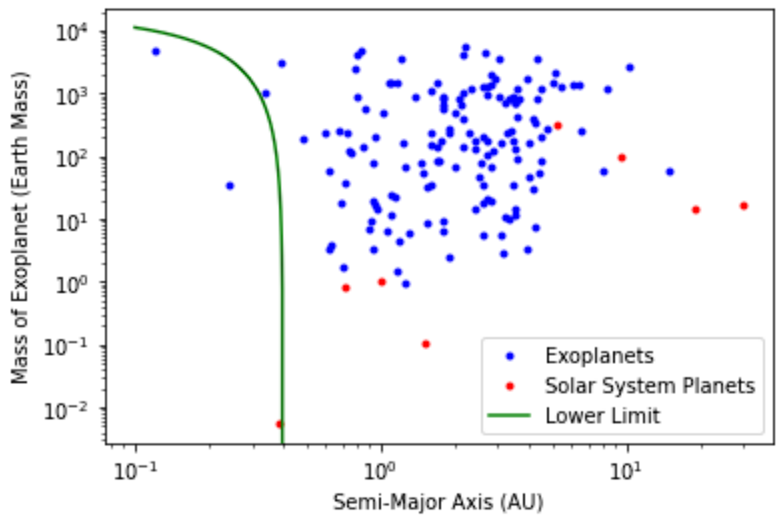
Exoplanets found by Radial Velocity tend to be Cold Juptiers, Jupiter-sized planets with a large orbital period. Just over 1000 exoplanets have been found by this method



Plot of exoplanets found by the Radial Velocity Method

Astrometry: This method is done by measuring the small changes in a star's position caused by the gravitational pull of an orbiting planet. This is done by observing the star over a period and measuring its position relative to other stars in the sky. As the planet orbits the star, it causes the star to move slightly, and this movement can be detected by observing the star's position over time. To do this, an astronomer would typically use a high-precision telescope and a camera to take images of the star and its surrounding area, then use specialized software to measure the star's position in the images with very high accuracy. By observing the star over a period and measuring its position at different points in the orbit, the astronomer can detect the slight movement caused by the orbiting planet. Astrometry is a challenging method for exoplanet detection because it requires the star's position to be measured with very high precision and the planet's signature is very small compared to the star, it would require more time observing the star and more advanced instruments than Radial Velocity method. Only ~2 exoplanets have been discovered using Astrometry. Both exoplanets are high mass with a very low orbital period of ~10 days (Seager, 2011).

Gravitational Microlensing: This is another method of exoplanet detection. When a massive object, such as a planet, passes in front of a distant star, its gravity bends and amplifies the light from that star, creating a temporary brightening effect known as a "microlensing event" or "lensing event." The deviation is caused by the presence of an orbiting planet, which causes an additional and distinct brightening in the light curve, which deviates from the light curve caused by the lensing star alone. Gravitational microlensing is a rare event, so it requires a lot of observation time and a large field of view to detect exoplanets, but it has the advantage of being able to detect exoplanets regardless of their orbital distance or the intensity of the light of their host star. It can also detect cold, low-mass, and distant exoplanets that are difficult to detect by other methods. There have been ~150 exoplanets discovered using Gravitational Microlensing (Seager, 2011).



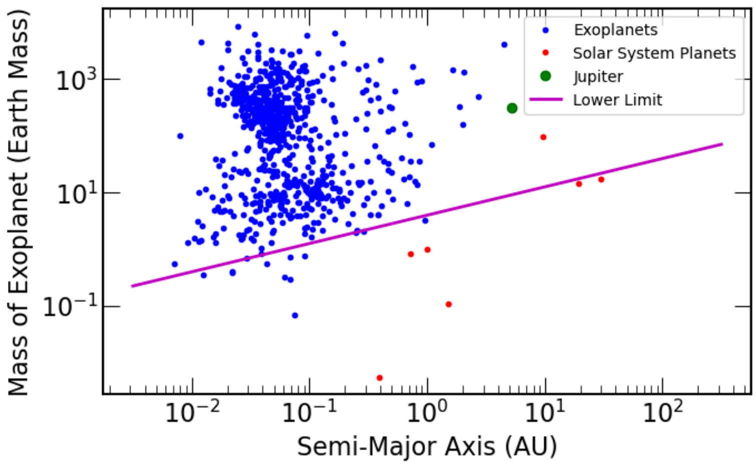
Plot of exoplanets found by gravitational microlensing

Transit: Transit detection is a method used to detect exoplanets by observing the small decrease in a star's brightness that occurs when a planet passes in front of it, as seen from Earth. This decrease in brightness is known as a "transit." By analyzing multiple transits and measuring the duration, depth, and timing of the transits, astronomers can determine the properties of the planet, such as its size and orbital period. The transit method is one of the most efficient ways to detect exoplanets, especially for smaller and closer-in planets, and has been used to detect thousands of exoplanets. (Seager, 2011)

Direct Imaging: is another method used to detect exoplanets by taking a direct photograph or a series of images of a planet and its host star. This is done by blocking out the bright light of the star and observing the planet's light separately. This method is challenging because planets are typically much fainter than their host stars and they are close together, so they appear as a single point of light. This method is one of the most challenging ways to detect exoplanets because it requires a large telescope, advanced technology, and a lot of observation time. However, it has the advantage of being able to detect exoplanets regardless of their orbital period and it can also detect exoplanets that are not detectable by other methods, such as young and massive exoplanets that are still forming. (Seager, 2011)

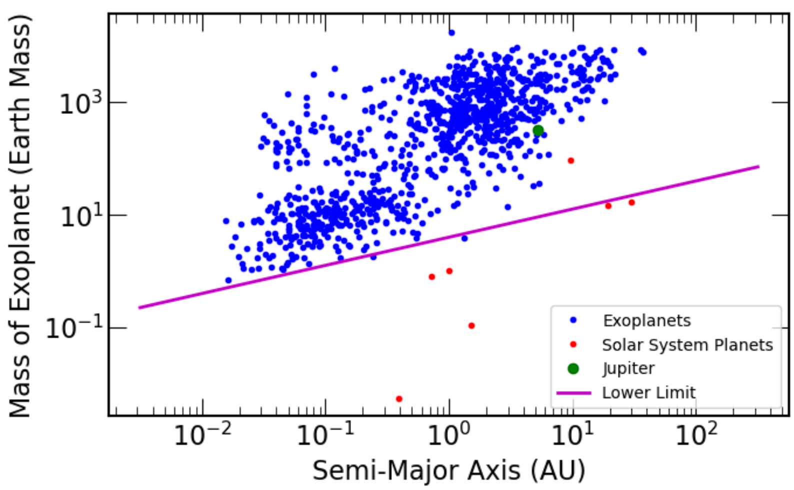
II. A Jupiter-like planet around a Sun-like star.

To get a better idea of how effective these detection methods are, it is useful to apply them to our own solar system. By analyzing how the detection methods would work on a Jupiter-like planet that is orbiting around a sun-like star. By checking where Jupiter lies on the previous plots, we can see if it is likely that such a planet would be detected for each method. Jupiter will be shown by a large green dot. We will check the Transit Method, the Radial Velocity method, and the Direct Imagining Method. First, we check the Transit method.



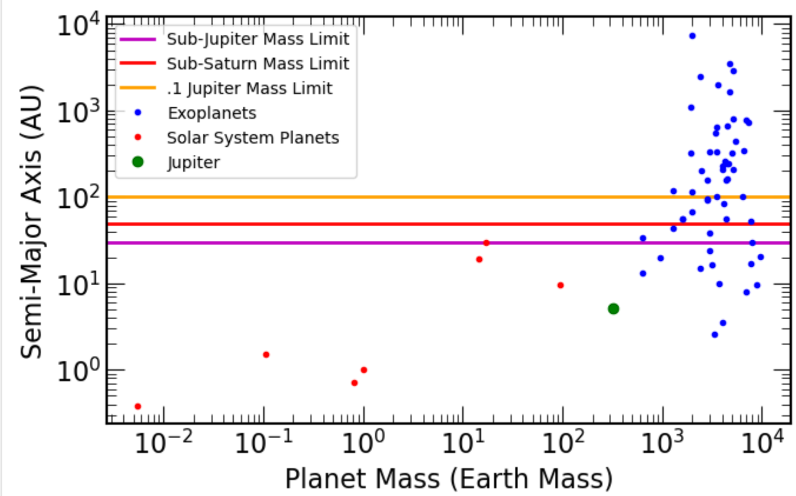
Checking the plot, it is shown that Jupiter is well above the lower limit of detection for the Transit Method. It is likely that a Jupiter-like planet around a sun-like star would be detected by the transit method. The signal given by the transit method would be the decrease in light received from the star. In the case of a Jupiter-like planet around a sun-like star, the light received would decrease by 1%.

For the Radial Velocity method, analyzing the plot shows that Jupiter is located above the lower limit of detection.



A Jupiter-like planet around a sun-like star would most likely be detected by the Radial Velocity method. The signal of Radial Velocity is an amplitude and for a sunlike star with a Jupiter around it, the value would be K = 0.5 m/s. (Glaze et al, NA)

For the Direct Imaging method, analyzing the plot shows what sized planets can be detected at certain Semi-Major Axes.



The plot shows that only exceedingly large planets, larger than Jupiter are detected using Direct Imagery. It is unlikely that a Jupiter sized planet around a sunlike star would be detected using the direct imaging method. This method is best for finding very large Jovian planets that are distant from their stars, so that they are not eclipsed by the brightness of their star.

Conclusion: Due to the nature of each of these detection methods, they are each good at finding different types of exoplanets. Thus, when using these methods, one must be aware of confirmation bias. Often observation methods will make certain types of exoplanets looks very common and other types very rare, but this is due to the method not being able to detect those other types. It is possible to estimate how common other exoplanet types are using the Occurrence Rate method. Using simulated data to see how often an exoplanet type is found compared to a known true value allows for an estimation for the number of exoplanets missed.

Contribution Statement:
-Dax took the lead with creating the Jupyter Notebook as they have the most experience with coding in Python. The rest of the group worked along with them to check their work.
-Greg wrote half of the report, while also being one of two presenters of the group.
-Matthew wrote the other half of the paper along with Greg. Matthew also helped to catch errors made in the code and presentation.
-Omar took the lead with creating the slides and crafting the oral presentation. He also worked to catch any errors in the code.

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