**Exoplanet Data Exploration and Detection Signal of Jupiter around a Sun-like Star**

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One of the key reasons why astronomers search for exoplanets is to help learn how planets are formed, and to see if we truly understand the functions that formed our own solar system. This can be achieved by examining data on exoplanets and drawing conclusions about why exoplanets have certain qualities. This is the heart of this project, for us to start learning how and preparing to draw conclusions based on exoplanet data. We explored and graphed data on exoplanets that we gathered from NASA’s Exoplanet Archive, focusing on mass and radius data of the exoplanets, as well as the period and semi-major axis of their orbits in order to gain familiarity with using and manipulating exoplanet data. We then used these methods and relations to understand our detection capabilities of signals from Jupiter-like planets around Sun-like stars.

The motivation we had for this project revolved around familiarizing ourselves with the basics of exoplanet detection. First, we wanted to learn how to gather data from NASA’s Exoplanet Archive, and display that data using Python, and become well-versed in using the Python package Astropy. We also wanted to start learning more about the different methods involved in exoplanet discovery, namely the methods of radial velocity, planetary transit, and direct imaging. Our goal was to become familiar with these methods, know how and when to implement them, and understand their detection limits in order to recognize their bias in exoplanet detection. Our final goal was to learn about the distribution of exoplanets with regards to their mass, radius, period, and the semi-major axes of their orbits. Once these goals were accomplished, we would have a decent grasp of the basics of exoplanet data recovery and analysis.

While there are many different methods of detection, we focused on the methods of radial velocity, planetary transit, and direct imaging. The radial velocity method of exoplanet detection is possible because a star actually revolves around the shared center of gravity it has with a planet that revolves around it. This shared center of gravity is known as the barycenter. The star wobbles slightly as it revolves around the barycenter and this motion produces a cyclical red and blue shifting in the light from the star. We can detect this wavelength shift and the periodicity of it in order to determine the mass ratio of the exoplanet to its parent star and the period of the orbit by calculating the radial velocity.

Where K is the observed radial velocity, Mp is the mass of the planet, Mstar is the mass of the star, a is the semimajor axis and i is the inclination of the system to our point of view. We are able to observe the period directly and use it to calculate the semimajor axis. If we assume an inclination, or choose to ignore it, we can use the observed radial velocity and semimajor axis to find the mass fraction.

Planetary transit involves a planet transiting across our plane of view of the star- like an eclipse that only blocks part of the star’s light. We can detect a planetary transit by looking for periodic dips in the flux of light received from a star. This periodic dip tells us the period of the planetary transit, as well as the ratio of the exoplanet’s radius to that of the star’s radius.

Where f is the fraction of light blocked by the transiting planet and Rstar and Rp are the radii of the star and planet respectively. We are able to find the ratio of the radii, which is the depth of transit.

Direct imaging appears to be simplest of these methods, however, is actually rather complex. It involves removing the overwhelming glare from the host star in order to take a picture of the starlight reflecting off of the exoplanets orbiting the star. From this method we are able to observe both the radius of the exoplanet as well as the semimajor axis of its orbit.

Where f is the fraction of the starlight that is reflected off of the exoplanet, Rp is the radius of the planet, a is the length of the semimajor axis, and A is the albedo of the planet.

Using the above methods and looking up the most state-of-the-art exoplanet detection equipment, we plotted their sensitivities against the exoplanet data we found earlier. This was done in order to demonstrate the biases we have in finding exoplanets.

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The lines represent the different limiting sensitivities depending on the method. It is very difficult to find planets that have a small mass, and therefore a small radius as well, that aren’t very close to their host star. For this reason, the data is skewed towards finding planets that are both massive and close to their host star. It is important to note that the reason some of the plots look slightly different even though they use the same data is that not every planet has every type of data. For example, we might have the mass of a planet known, but not its radius; therefore, it would not show up on a graph that involves planetary radii. It is interesting to observe that the planets in our solar system are at the edge of the data, almost undetectable with some equipment. This does not mean that our planets are unusual, it simply means that our detection methods are biased towards detecting planets unlike those in our solar system.

In order to see these detection methods in use, we tested the different methods out on a hypothetical planet. If we were looking at a distant star system with a Sun-like star, we tried to determine using the above methods whether we would find a Jupiter-like planet. Based on the Radial Velocity method of detection, we were able to determine that the star’s observed radial velocity K would be 13.1 meters per second (assuming an inclination of 90 degrees). Based on the Transit method, we determined that a Jupiter-like planet would block about 1 percent of a Sun-like star’s light while transiting. Using the direct imaging method, the signal we expect from a Jupiter-like planet would be a reflection of 6.9\*10-8 percent of the star's light.

Based on the most sensitive equipment available right now, we determined that we would be able to locate a Jupiter-like planet around a Sun-like star with the Radial Velocity method, as the most sensitive equipment is able to pick up variations as low as 0.5 meters per second. The reasons we would be likely to see the planet with this method is because Jupiter is very massive and decently far away, this means the ‘wobble’ that the Sun undergoes as it orbits the barycenter is also large. However, Jupiter being so far away also means that its period is very large, this leads to a large Signal-to-Noise ratio, via the following equation.

Where SNR is the signal to noise ratio, delta is the transit depth, sigma is the precision of the detecting equipment, n is the number of transits per 90 days, and t is the transit duration. Using our data for Jupiter and the precision of the Kepler telescope, we determined an SNR value of 1.51\*10-4, which is much less than the minimum value of 10 that Kepler can detect. Jupiter having such a large semimajor axis also lead to the fact that it does not reflect a lot of the Sun’s light. These facts mean that it would be impossible, with our current technology, to detect Jupiter-like planets around Sun-like stars using the transit method or direct imaging.

**Contributions:**

Paper- Frank Hegedus

Presentation- Brendan Kirsh

Detection Signal Analysis- Alyssa Whalen

Sensitivity Research and Exoplanet Analysis- John Kushan

**Sources:**

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