Exoplanet Data Explorer

ASTRON 5202 Project 1

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1 Introduction

The study of exoplanets has rapidly advanced in recent decades, driven by improvements in observational techniques and the accumulation of large datasets. Understanding the characteristics of exoplanets and the methods used to detect them is crucial for identifying biases in current detection techniques and refining future searches. This project analyzes exoplanet data from the NASA Exoplanet Archive (NEA) to explore the distribution of exoplanets in different parameter spaces and investigate the limitations of various detection methods.

Using the NEA, we compiled and visualized exoplanet characteristics to examine trends and correlations among planetary and orbital parameters. Additionally, we analyzed the detection signal of a Jupiter-like exoplanet, comparing it to the performance of state-of-the-art detection techniques. The primary objectives of this study are to gain proficiency in accessing and interpreting NEA data, understand how detection biases shape exoplanet discoveries, and assess the effectiveness of different observational methods. By doing so, we aim to contribute to a broader understanding of the current limitations in exoplanet detection and the ongoing efforts to improve detection accuracy.

2 Methods

To analyze exoplanet data and detection techniques, we used Python to process and visualize data from the NASA Exoplanet Archive (NEA). The workflow consisted of two main components: visualizing key relationships between planetary parameters and analyzing the detection signal of a Jupiter-like exoplanet around a Sun-like star.

2.1 Data Collection and Visualization

We accessed and downloaded exoplanet data from the NEA, focused on key planetary characteristics such as mass, radius, period, and semi-major axis. Using python libraries including matplotlib and numpy, we generated plots to examine distributions such as:

- Mass vs. Period
- Mass vs. Semi Major Axis
- Radius vs. Period
- Radius vs Semi Major Axis

To provide some reference points, we overlaid data of our own Solar System planets on those plots. Additionally, we researched the performance of various exoplanet detection techniques (e.g. transit, radial velocity, direct imaging) and plotted their sensitivity limits to highlight biases in exoplanet discoveries.

An example of how we calculated the sensitivity line can be seen here with the Radial Velocity equation:

$$K = m_p/m_* \cdot \sqrt(Gm_*/a) \cdot sin(i) \tag{1}$$

We assumed an edge-on orbit (i is 90 degrees) and the equation is rearranged to be:

$$m_p = K \cdot m_* \cdot \sqrt{a/Gm_*} \tag{2}$$

We then used the state-of-the-art K value of 0.5 m/s and 0.5 solar mass to finish the calculation for the line. That line is plotted in plotted in Figure 3.

3 Results

3.1 Exoplanet Parameter Relationships

We analyzed the relationships between key exoplanet parameters using data from the NASA Exoplanet Archive.

- **Mass vs. Period:** The plot shows that the majority of all the data points are clustered in the bottom left corner. This shows that there is a strong relationship between a shorter orbital period in days with a smaller mass in $M_Jupiter$.
- **Mass vs. Semi-Major Axis:** There is less of a trend with this relationship. Most of the points fall under a semi-major axis of 10 AU and 10 $M_Jupiter$ which can show that planets of less mass tend to be closer to their host star. But what is interesting is that there is a good amount of planets with Jupiter-like mass that orbit very close to their star.

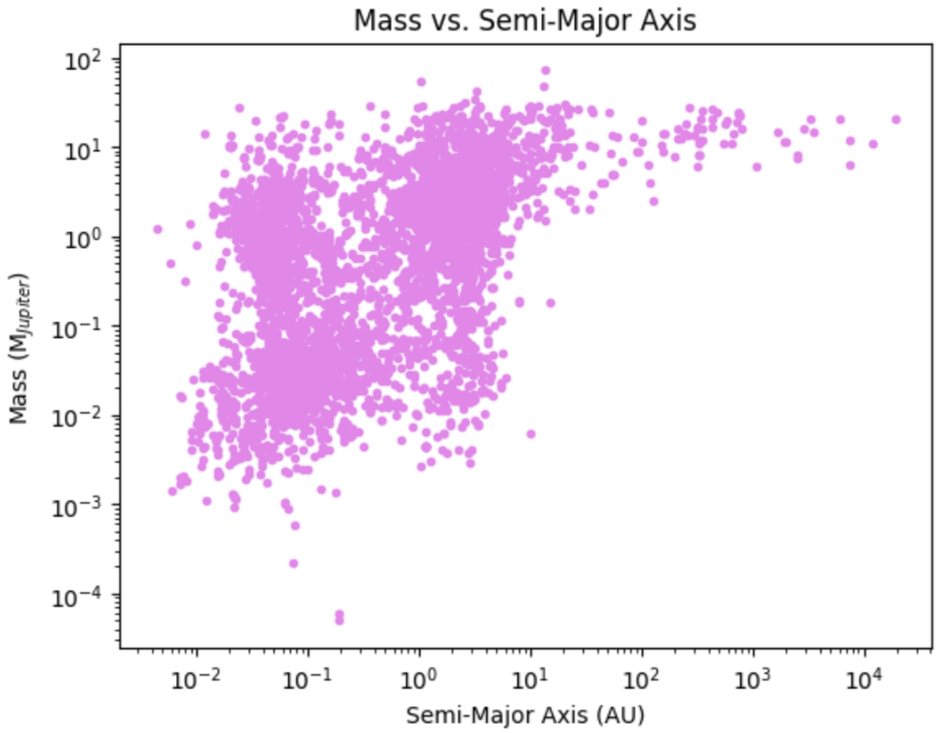

Figure 1: Mass vs. Semi-Major Axis

- **Radius vs. Period:** This relationship shows the same trend as the Mass vs Period graph. A shorter orbital period in days coincides with a smaller radius in $R_Jupiter$.
- **Radius vs. Semi-Major Axis:** This looks almost identical to the previous graph but the only difference is that a smaller semi-major axis in AU corresponds to the same range of radii in $R_Jupiter$.

To provide context, Solar System planets were overlaid on these plots. An example is shown below to see how our own planets fit into these detected exoplanets.

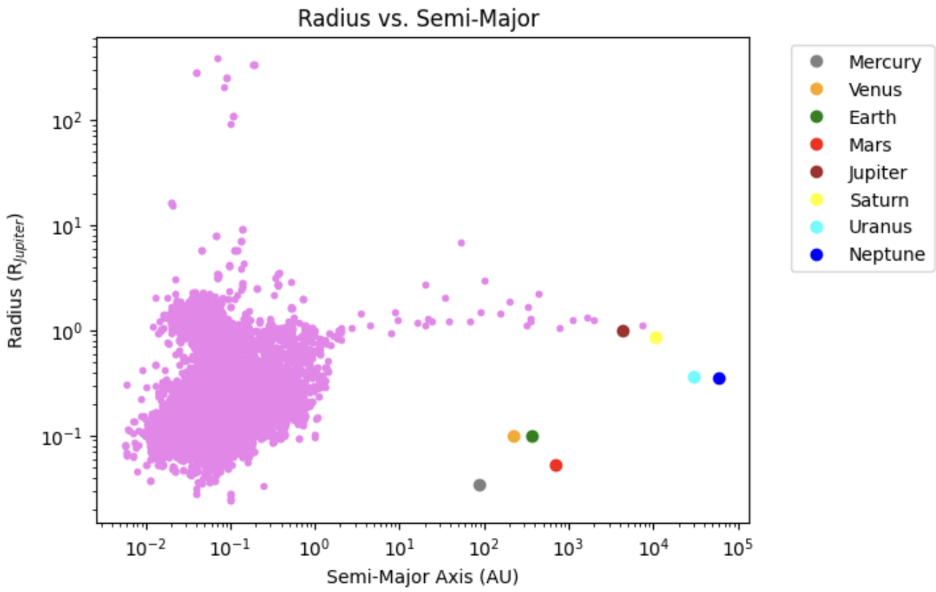

Figure 2: Mass vs. Period
This plot shows that a lot of exoplanets are closer to their host star than Earth is as well as they have a much smaller radius than Jupiter does. Including the solar system planets show that our solar system hosts planets that are typically farther from the star than typical exoplanets.

The fact that our planetary system does not align well with the detected exoplanet population suggests that there may be many more undiscovered exoplanets that our current methods are unable to detect.

3.2 Detection Sensitivity of Different Methods

To understand biases in exoplanet detection, we compared the sensitivity limits of various detection techniques. The method that gives the best results is from the radial velocity technique.

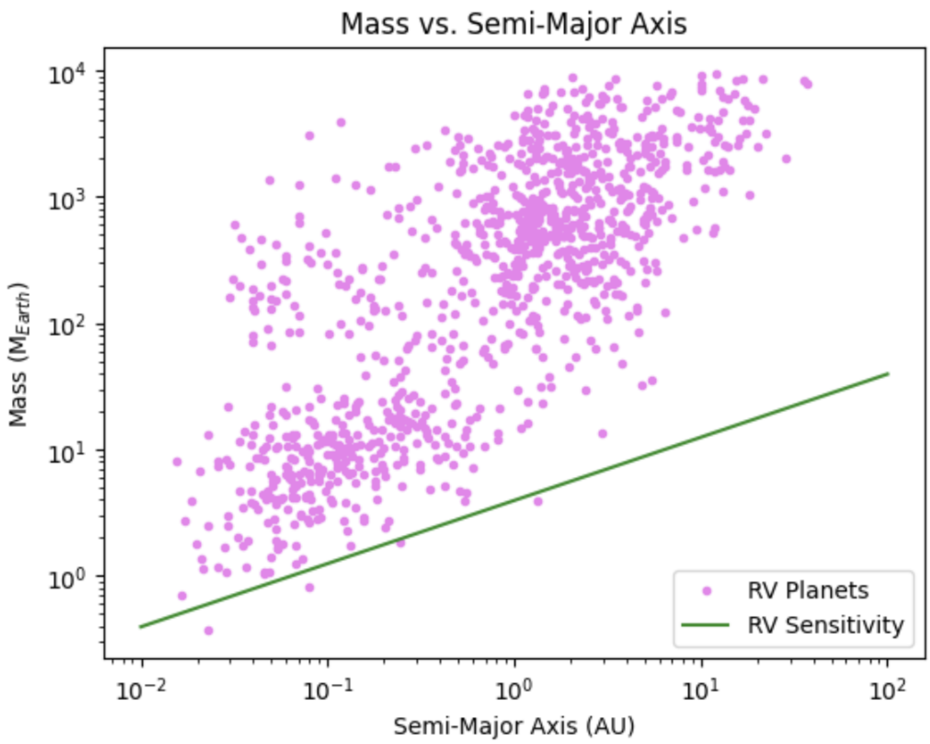

Figure 3: Mass vs. Period
This shows that the Radial Velocity method of detecting exoplanets is very strong!

The sensitivity line is basically a threshold. Any data that is above the calculated line is able to be detected using this method. One can observe that all but a few exoplanets are above the line, showing that the sensitivity is very strong for planets that are pretty close to their host star as well as very large. These type of planets are called hot Jupiters. The radial velocity detection method tends to favor detecting large, close-in planets.

3.3 Detection Signal of an Earth-like Exoplanet

We analyzed the detection signal of an Earth-like planet orbiting a Sun-like star. The expected signal strength for different techniques was found to be the most responsive using the Radial Velocity method.

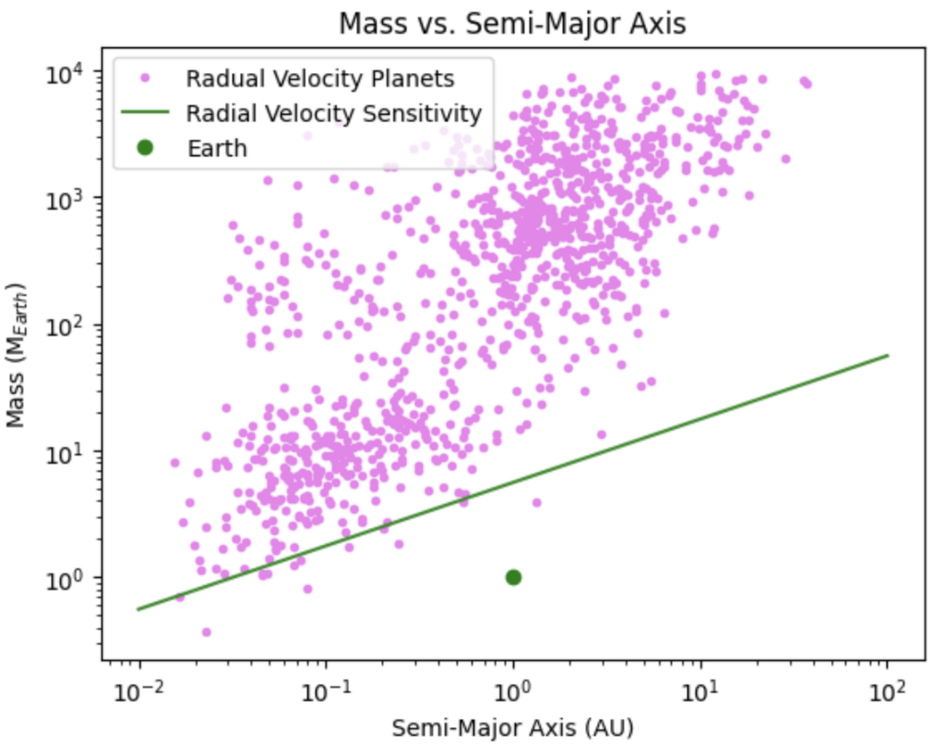

Figure 4: Mass vs. Semi-Major Axis with Earth-Like planet

When we plotted an Earth-like planet around a Sun-like star against different detection methods, it fell below the sensitivity limits for almost all of them. This means that, with current technology, Earth-like planets are largely undetectable. This finding strongly suggests that there could be a vast number of terrestrial, potentially habitable planets that remain undiscovered simply because our detection methods are not yet sensitive enough to find them.

The Earth is clearly underneath the sensitivity line in Figure 4, suggesting what was mentioned above in that our current radial velocity techniques are not valid for Earth-like exoplanets.

4 Conclusion

This study highlights the distribution of exoplanets and the biases inherent in current detection methods. The mass vs. semi-major axis and other parameter plots reveal clustering of planets, emphasizing the prevalence of large, short-period exoplanets that are more easily detected by current technology. Our analysis showed that smaller, long-period planets, particularly Earth-like worlds, are largely undetectable with current methods. The comparison with our solar system further illustrates the extent of these biases, as the solar system planets barely appear on the exoplanet distributions.

These findings underscore that the current exoplanet catalog is likely a small fraction of the true diversity of planetary systems. As detection techniques improve, particularly with upcoming missions like the James Webb Space Telescope (JWST), we will be able to explore deeper into planetary populations and discover more potentially habitable planets, bringing us closer to answering fundamental questions about life beyond Earth.