Astronomy 5205
Project 1
Project Contribution

Code and Plots

- Mass vs. Period - Leandra Hogrefe
- Mass vs. semi-major axis - Leandra Hogrefe
- Radius vs. Period - Karish Seebaluck
- Radius vs. semi-major axis - Andy Miller

Calculation

- A temperate Earth-like planet around a Sun-like star calculation - Andy Miller

Sensitivity limits of exoplanet detection techniques

- Andy Miller and Karish Seebaluck

Presentation Lead

- Leandra Hogrefe

Paper Lead

- Jacob Borison

Project 1: Detecting Earth-Like Exoplanets

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Section 1: Introduction and Motivation

Life in our universe has been discovered on only one, small planet. With large sums of exoplanet population data, astrophysicists can study the ingredients necessary for life in the universe. The NASA Exoplanet Archive is exactly this, a massive database holding valuable information about thousands of exoplanets outside of our solar system. With this data, exoplanets with the possibility of harboring life - now or in the future - can be located and studied in detail. Other questions surrounding the formation of our solar system can also be probed using the same data.

Before answering such large scale questions, the NEA data is first compiled and the exoplanets are compared to Earth on several ***metrics***. To locate a possible life harboring exoplanet, the mass of the exoplanet must be within a certain range. For example, the body cannot be too massive or runaway growth can occur resulting in a gas giant. The body also cannot be too small, or it will not be able to retain a substantial atmosphere. This general theme is consistent for any ***metric*** used to study a planet: for all values, the exoplanet must be within a goldilocks zone of not too large and not too small. In this investigation, the specific metrics studied for each exoplanet are exoplanet mass, radius, orbital period, and orbital semi major axis. With these values, the collection of exoplanet data can be compared to the Earth.

Section 2: Methods

No single data point can summarize all four values for an exoplanet in one detection. Various detections using different equipment and methods are combined for each datapoint to collect a fuller description of the object. Specifically, the four values stated above are collected for each exoplanet using five primary detection methods - radial velocity, transit, direct imaging, gravitational microlensing, astrometry.

Radial velocity data locates exoplanet systems using the light emitted by their host stars. When large planets orbit in close proximity to a star, both bodies orbit the combined center of mass. For the star, this results in a small circular orbit about the center of mass, appearing as a wobble. This wobble causes a doppler shift in the star's emitted spectrum, sinusoidally changing the frequency of light received by the observational hardware. The change in frequency is measured and used to understand the mass, period, and semimajor axis of the star-exoplanet system (*Lovis et al. 2010*). The measurement signal, K, is taken and input into the following equation to determine the mass of the exoplanet.

$$K = \frac{M_p}{M_*}\sqrt{\frac{GM_*}{a}}sin(i) \rightarrow M_p = KM_*\sqrt{\frac{a}{GM_*}}$$

The measurement signal is dependent on the state-of-the-art equipment used to make the detection. M_p and M_* are the masses of the planet and star respectively, while a is the semi-major axis of the orbit and G is the gravitational constant. Additionally, the inclination angle, i, is assumed to be 90 degrees (edge on with respect to the orbit), so the sin term goes to unity.

While radial velocity detections observe the spectrum of starlight emitted by the host star, transit detections observe the intensity of the host star. When viewing a system edge on, exoplanets will periodically eclipse their host stars and block a portion of their light from being viewed by the observer. On an intensity plot, this can be seen as large dips every orbital period of the exoplanet. This will occur with a probability dependant on the star's and exoplanet radii, R_* and R_p respectively, and the semi major axis of the orbit a.

$$P = \frac{R_* + R_p}{a}$$

This measurement offers information about the exoplanet's size in comparison to the host star, informing the observer on the fraction of light blocked from the star. Specifically, the area ratio of the star and exoplanet is equivalent to the depth of transit, f,

$$f = \left(\frac{R_p}{R_*}\right)^2$$

Where R_p and R_* are the radii of the exoplanet and star. Determining the true values of the exoplanets mass and radius require the integration of information obtained from radial velocity measurements, and other information regarding the host star (*Winn 2010*).

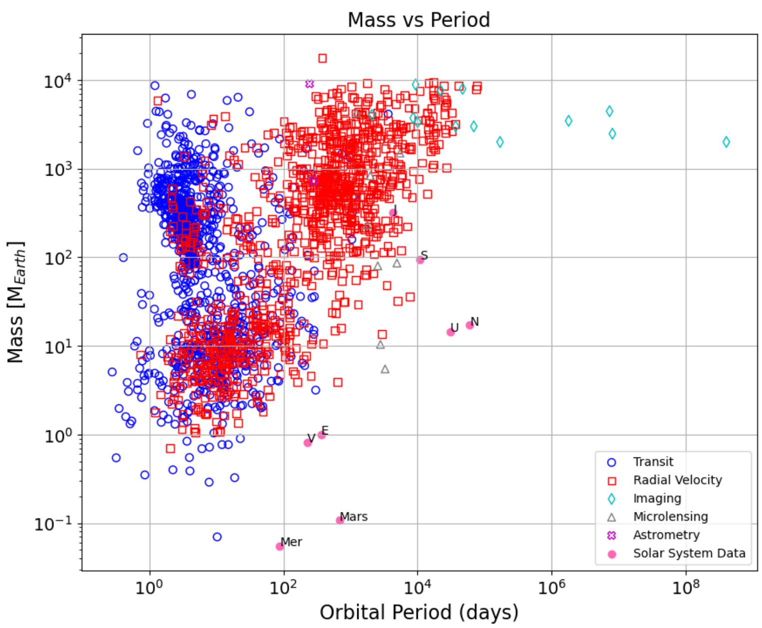
Direct imagine arguably offers the most information about an exoplanet within each measurement. Using this method, exoplanets are directly photographed conveying information regarding the size, orbit, temperature, atmosphere, and composition. This is accomplished by using precise instrumentation to block the host star's light in order to resolve the much dimmer exoplanet. Without blocking the star, the starlight would greatly overwhelm the instrumentation and the exoplanet would not be resolvable. The fraction of starlight reflected off the exoplanet is dependant on the exoplanet radius, R_p, Albedo, A, and semimajor axis a.

$$f = 4A\left(\frac{R_p}{a}\right)^2$$

Combining multiple exoplanet images of the same system relays the orbital and rotational information of the exoplanet. The atmosphere and composition are studied by observing the spectrum of light absorbed and reflected by the exoplanet received by the host star, allowing researchers to search specifically for the ingredients of life (*Traub et al. 2010*).

Section 3: Results

Understanding these five detection methods, the NEA data can be studied and analyzed. The results of this study are presented by the leading researchers for each objective. First, Leandra Hogrefe presents the relationship between exoplanet mass and period, as well as mass and semi major axis. Karish Seebaluck presents the relationship between exoplanet radius and period,while Andrew Miller presents the relationship between radius and semi major axis. Lastly, Andrew Miller also calculates the expected detection signal for a temperature Earth-like exoplanet orbiting around a Sun-like star.



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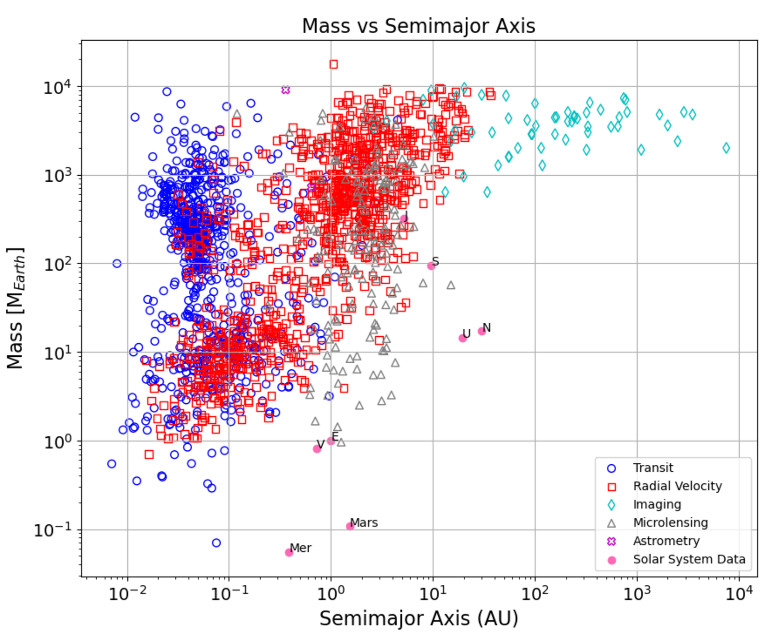

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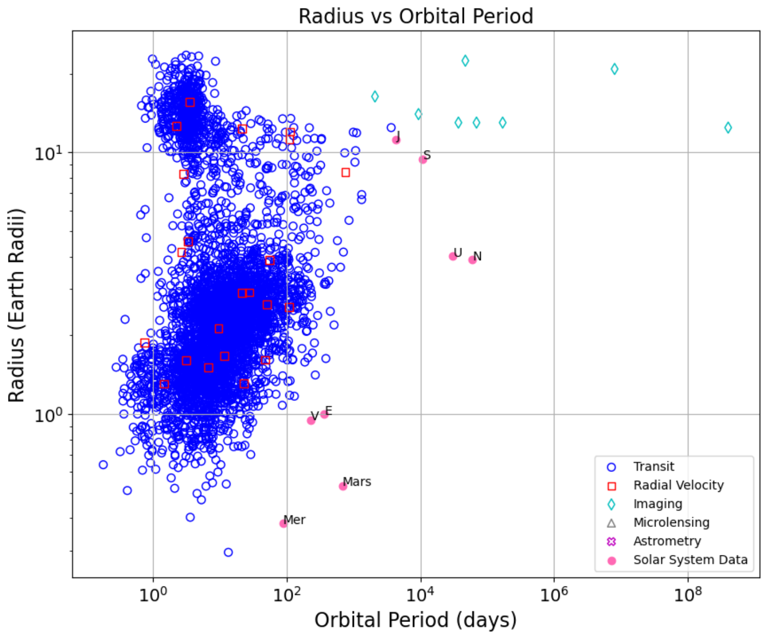

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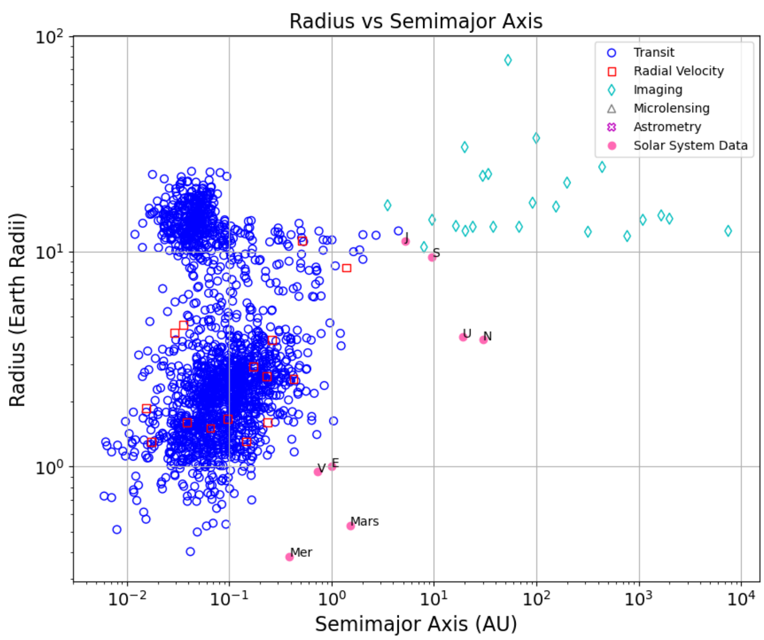

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Section 4: Discussion and Conclusion

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