Exoplanet Detection

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Motivation

- To understand the distribution of exoplanets in parameter spaces that relate to their size and other properties.
- To understand the detection limit of various detection methods, as well as any biases in them.
- To understand to what extent these detection methods can detect exoplanets.
- To understand the detection signal of various representative cases and compare to state-of-the-art exoplanet detection methods.

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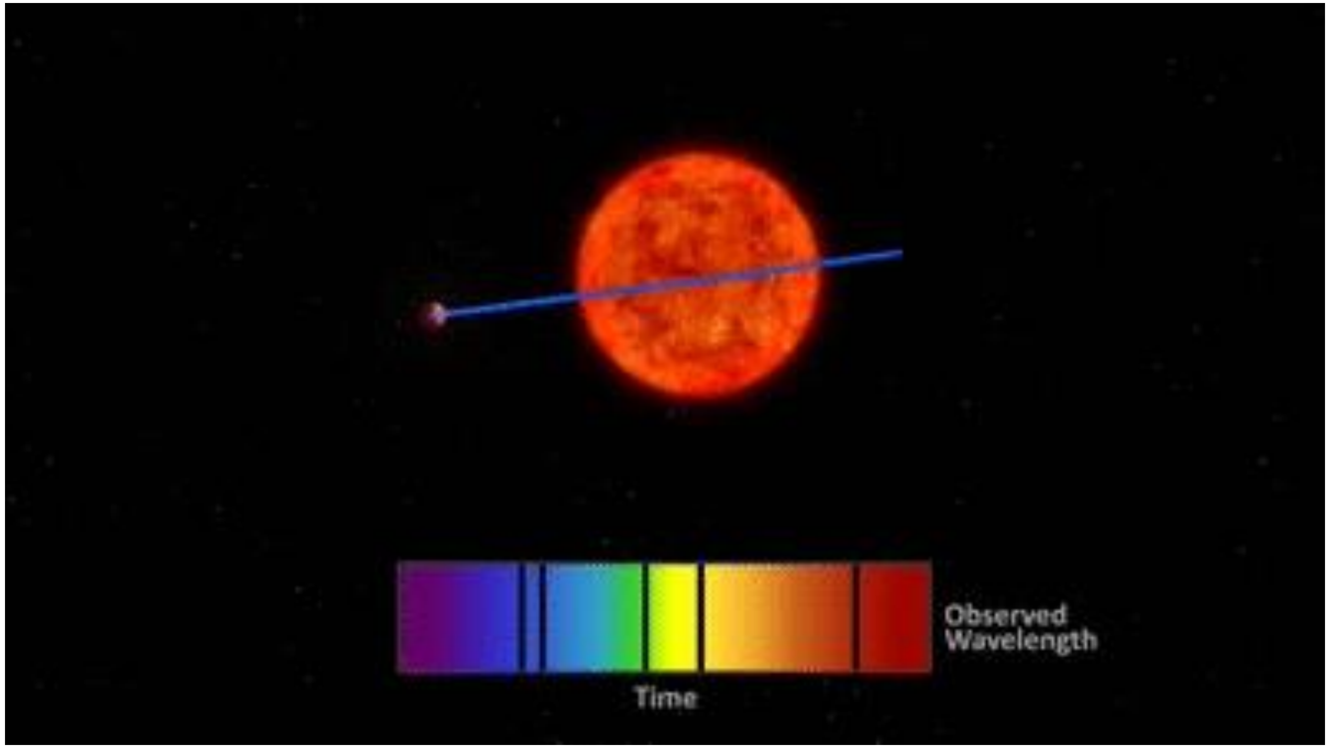
Methods – Radial Velocity



Rate of detection: $K = \frac{m_p}{m_*} \cdot \sqrt{\frac{G\, m_*}{a}} \cdot \sin i$

- Assumptions -
  - K-value of 0.5 m/s (from state-of-the-art performance)
  - m∗ minimum 0.5 solar masses
  - i = 90 degrees

Minimum mass that can be detected $m_p = K \cdot m_* \cdot \sqrt{\frac{a}{Gm_*}}$

Methods - Transit

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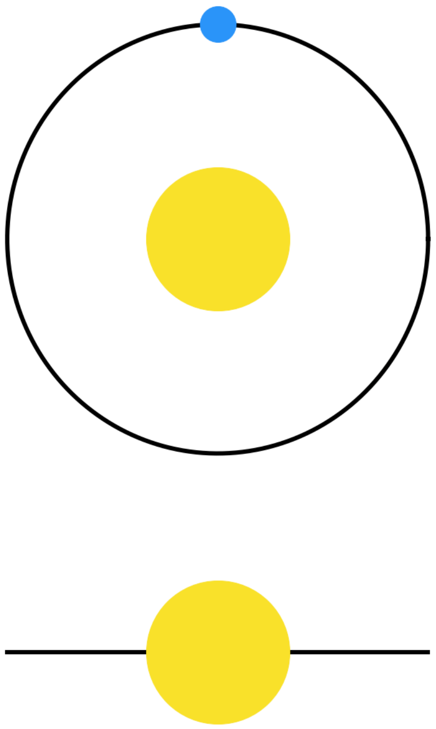
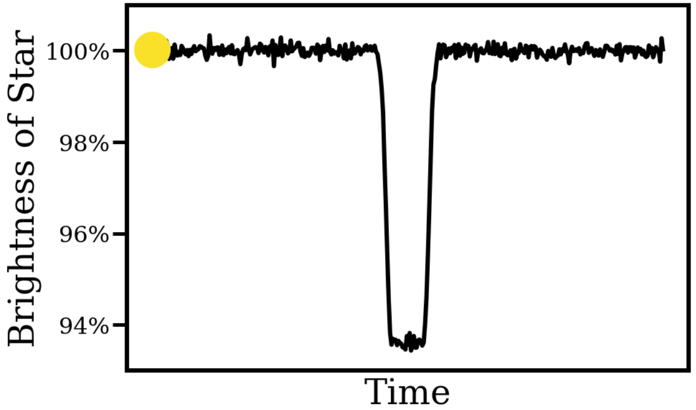
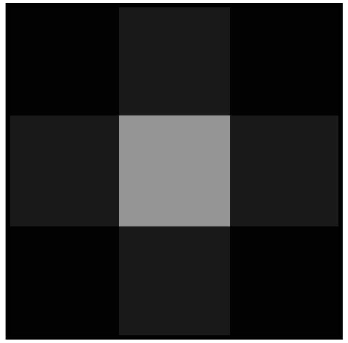






Rate of detection

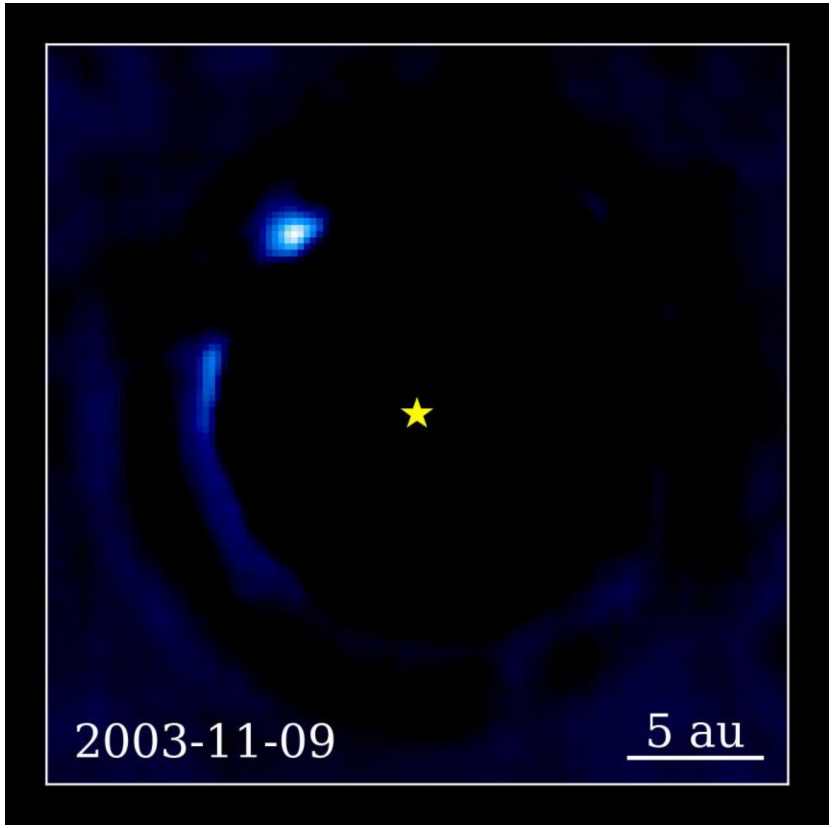
$$R_\oplus = \frac{m_p}{\sqrt{3 \cdot \sqrt{\frac{period}{time}}}}$$

Minimum radius that can be detected

$$r_p = \sqrt{3 \cdot \sqrt{\frac{period}{time}}} \cdot R_\oplus$$

- Assumptions -
  - i = 90 degrees
- We scale in terms of Earth radii
- Time constant of 1 year

Methods – Direct Imaging



$$f = f_{reflected} + f_{emitted}$$

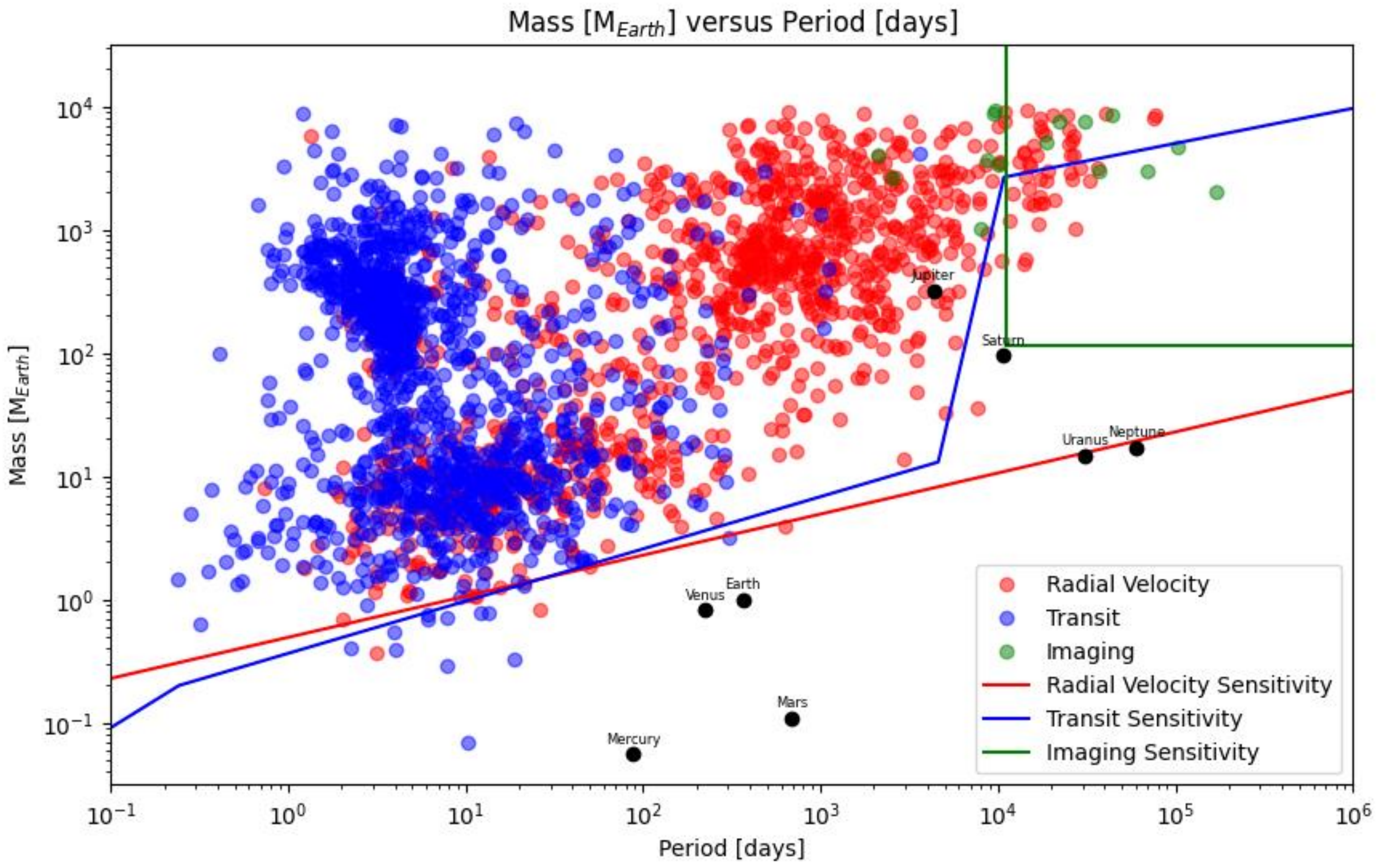
$$f = \left(\frac{R_p}{R_*}\right)^2 \left[\frac{1}{4}\left(\frac{1}{aR_*}\right)^2 + \frac{(\exp(\frac{hc}{\lambda k_B T_*}) - 1)}{(\exp(\frac{hc}{\lambda k_B T_p}) - 1)}\right]$$

$$f_{reflected} \ll f_{emitted}$$

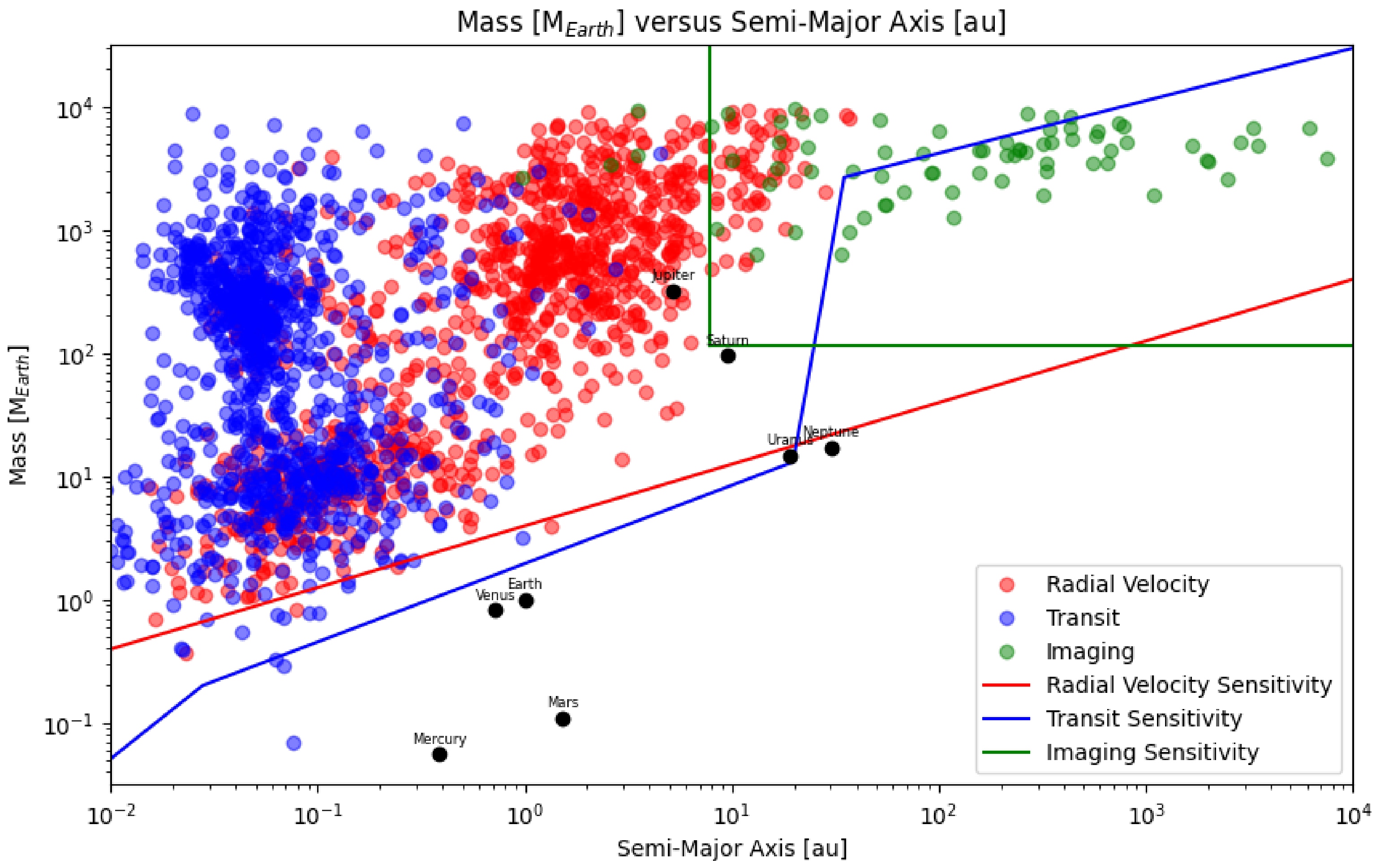
$$R_p = R_* \sqrt{\frac{f}{\frac{(\exp(\frac{hc}{\lambda k_B T_*}) - 1)}{(\exp(\frac{hc}{\lambda k_B T_p}) - 1)}}}$$

- Assumptions -
  - Tstar = Tsun
  - Tp - 130K
- Found that minimum radius = 16 Earth radii (115 Earth masses)
- One of the most difficult methods for detecting exoplanets due to this size constraint

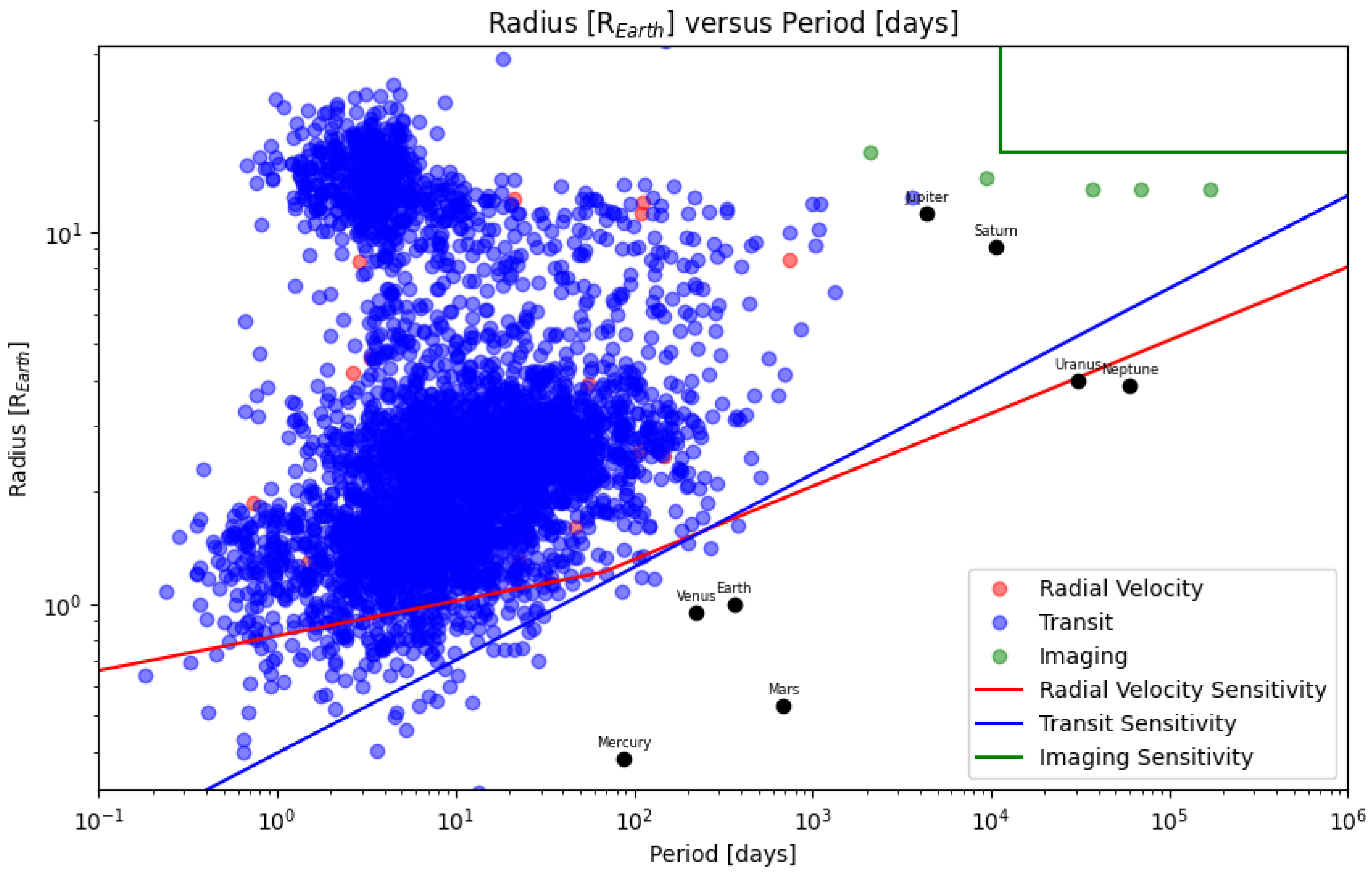
Wang, J. (n.d.). *Orbit movies*. Exoplanet Orbit Movies. https://jasonwang.space/orbits.html



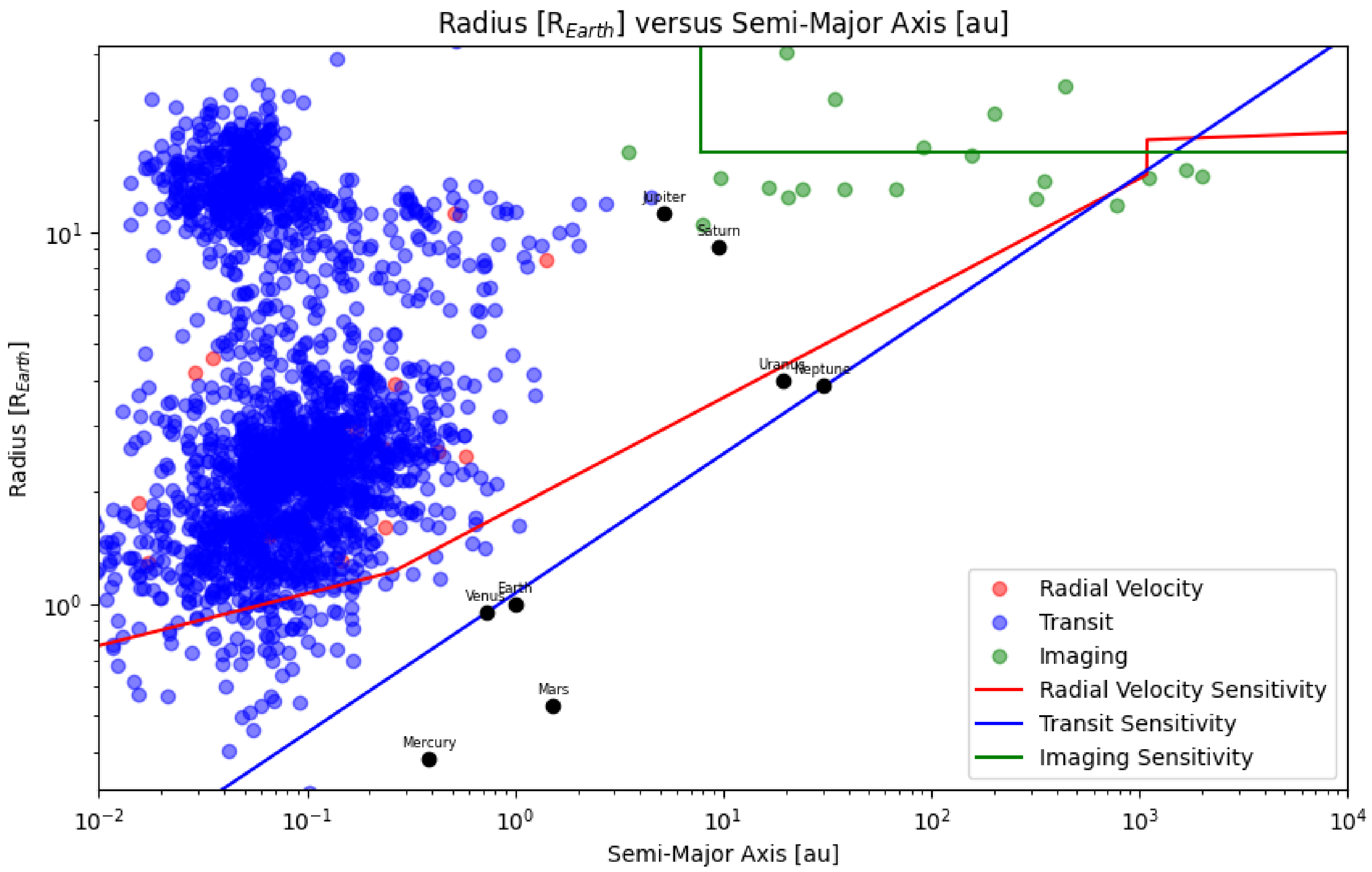
Mass vs Period



Mass vs Semi-Major Axis



Radius vs Period



Radius vs Semi-Major Axis

Results

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- Overplot of Solar System onto our plots
  - Most if not all planets would not be detected based on the data gathered and results shown.
  - Mercury – Mars fell below every sensitivity line
- Detection through RV and transits are much more sensitive compared to direct imaging.
  - Planets with longer orbital period & semi-major axis are more easily detected through RV
  - Planets with shorter orbital period & semi-major axis but with high mass are more easily detected through transits
    - Radius of a planet only detected through transits
- Direct imaging is only viable when -
  - Large mass
  - Period/semi-major axis is incredibly large (10^3 days or 10 au)

Results

- Precision limits given by sensitivity lines were fairly accurate -
  - RV – 99% of planets fell within our sensitivity line
  - Transiting – 98% of planets fell within our sensitivity line
  - Direct Imaging – 86% of planets fell within our sensitivity line
- Jupiter around a Sun-like star -
  - Using RV, amplitude was 17.6 m/s, which is greater than our detection limit of 0.5 m/s
  - Using transits, time necessity was 2.47 days, which is within our detection limit of 1 year
  - Using direct imaging, we determined that the radius and semi-major axis of Jupiter (11.2 EarthRad and 5.2 au) were outside the detection limit of 16.4 EarthRad and 8 au.

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Conclusion

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The purpose of this research was to determine the sensitivity limits of three different detection methods of discovering exoplanets. Each of the three methods (radial velocity, transits, and direct imaging) required assumptions regarding the state-of-the-art technology being utilized and assumptions regarding the planet itself. We can conclude that both Radial Velocity and Transit Photometry would be able to detect a Jupiter-like planet around a Sun-like star, while Direct Imaging would not be able to, as this theoretical planet is both too small and too close to its parent star.