Exoplanets and Their Detection Limits

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Introduction

Objective/Goals

- Obtain/analyze exoplanet data

Planetary/Stellar Mass (Earth/Jupiter), Planetary/Stellar Radius (Earth/Jupiter), Period (days) and Semi-major axis (AU)

- Understand detection limits using different methods

Radial Velocity, Transit, Direct Imaging

- Investigate detection signals of a target case

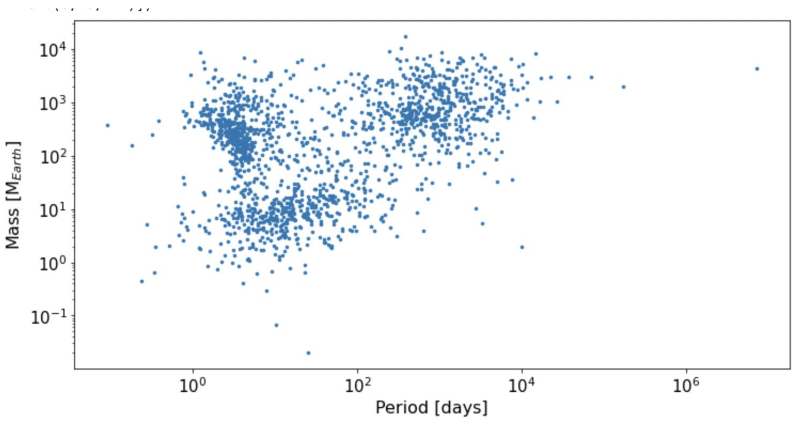
“A temperate Earth-like planet around a Sun-like star.”

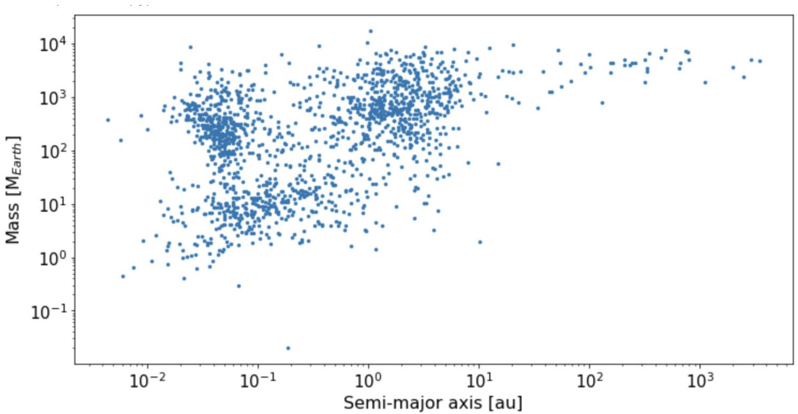
Methods

Use Python to extract and graph exoplanet data

Observations

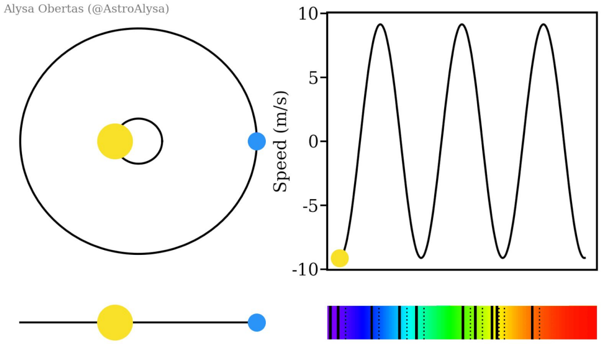
- Period ∝ +Semi-major axis
- Hot and Cold Jovian groups
- Hot Mini-Neptune group
- Hot terrestrial Group





Methods (cont.)

Understand detection methods using state-of-the-art instrumentation



Radial Velocity

Observables

- Amplitude of the RV signal (K):
  - Proportional to Mass of Planet/Star and Semi-major axis.
- Period (P):
  - Proportional to Mass of Star and semi-major axis.

$$K = \frac{M_p}{M_\star}\sqrt{\frac{G * M_\star}{a}} \sin i.$$

$$P = 2\pi\sqrt{\frac{a^3}{GM_*}}$$

State-of-the-art

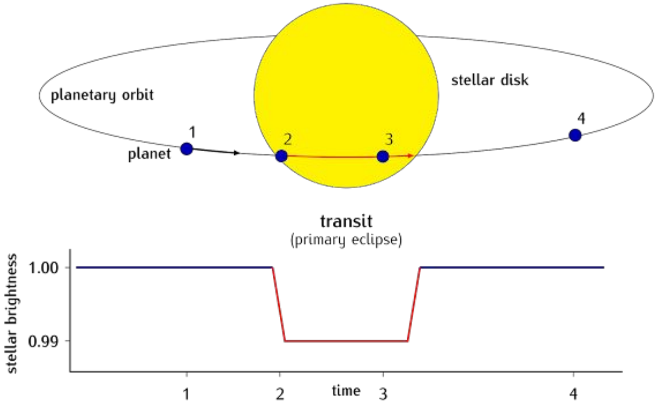
- Top precision for K ~ 0.5 m/s (Seager)

Methods (cont.)

Transit

Observables

- Depth of Transit (f)
  - Proportional to Radius of Planet/Star
- Probability of Transit (P)
  - Proportional to Radius of Planet/Star and semi-major axis



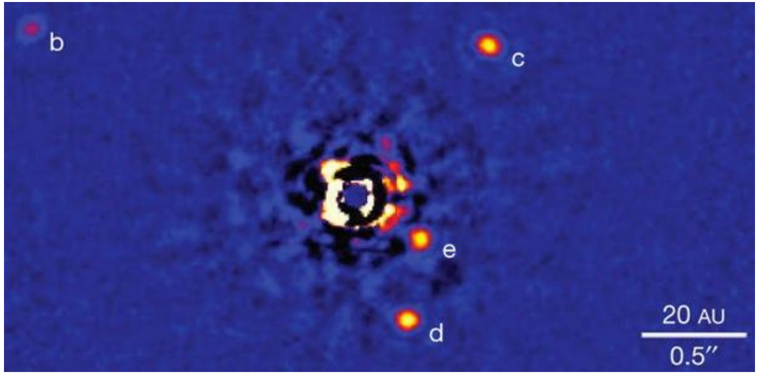
$$f = \left(\frac{R_p}{R_*}\right)^2$$

$$P = \frac{R_s + R_p}{a}$$

State-of-the-art

- Top precision for f ~ 110 ppm (Seager)

Methods (cont.)



Direct Imaging

Observables

- Planet/Star Contrast (fc)
    - Proportional to Radius of Planet/Star
- Radial Arc (theta)
    - Proportional to the wavelength and the diameter of the telescope

$$f_c = \left(\frac{R_p}{R_s}\right)^2 \frac{\exp(h\nu/k_B T_s)-1}{\exp(h\nu/k_B T_p)-1}$$

$$\theta \sim 1.22\frac{\lambda}{D}$$

State-of-the-art

- Top precision for fc ~ 20 micron (Seager)

Results

Fitting State-of-the-Art Detection Limits

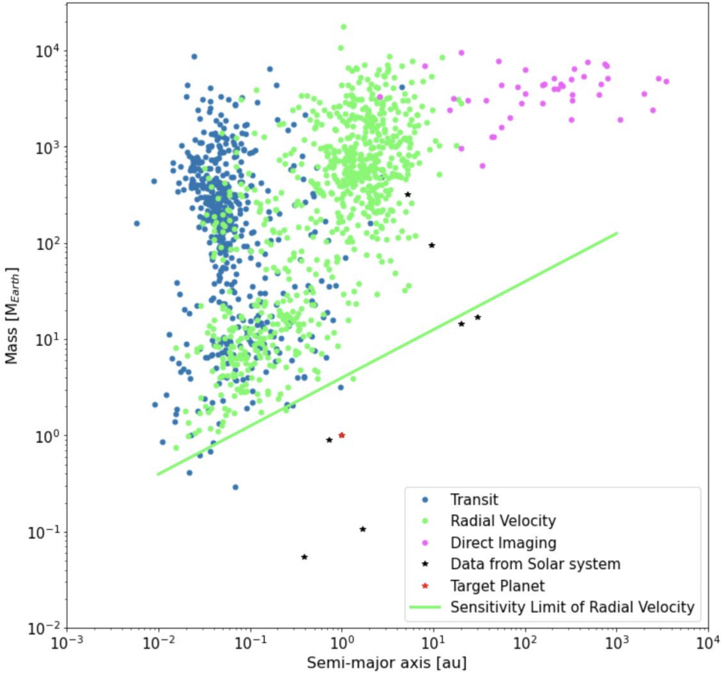
Radial Velocity

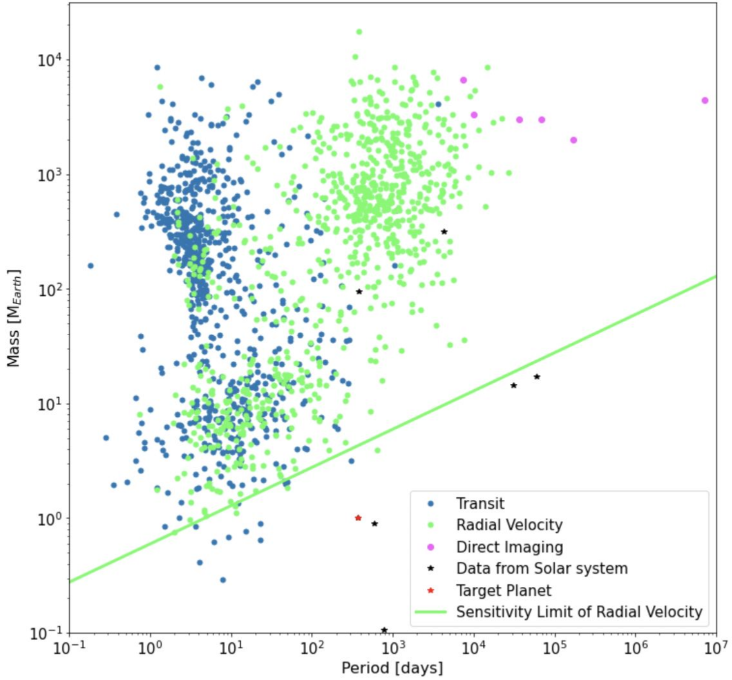
We have $M_p = K * M_\star \sqrt{\frac{a}{GM_\star}}$. from measurements of K. **Mass - Semimajor axis**

We have $M_p = K \cdot m_* \cdot \sqrt{\frac{\left(\frac{T^2 GM_*}{4\pi^2}\right)^{\frac{1}{3}}}{Gm_*}}$ from Period -Semimajor axis relation. **Mass - Period**

Results (cont.)

Radial Velocity - Mass Relation





Results (cont.)

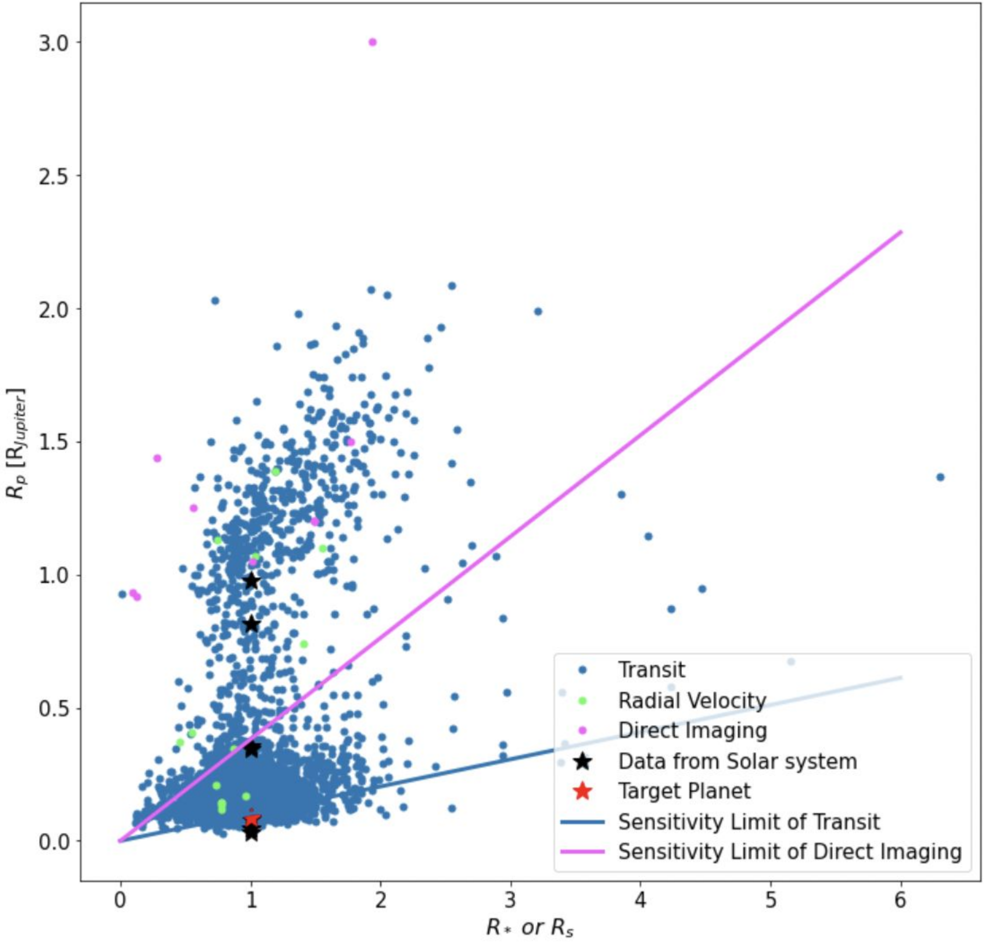
Transit and Direct Imaging - Radius Relation

Transit

We have $R_p = \sqrt{f} \cdot R_s$ from measurements of f. **Planet Radius - Stellar Radius**

Direct Imaging

We have $R_p = R_s\sqrt{\frac{f_c}{c}}$, where c is equal to the max value of $\frac{\exp(h\nu/k_BT_s)-1}{\exp(h\nu/k_BT_p)-1}$ in a 20 micron range. **Planet Radius - Stellar Radius**



Results (cont.)

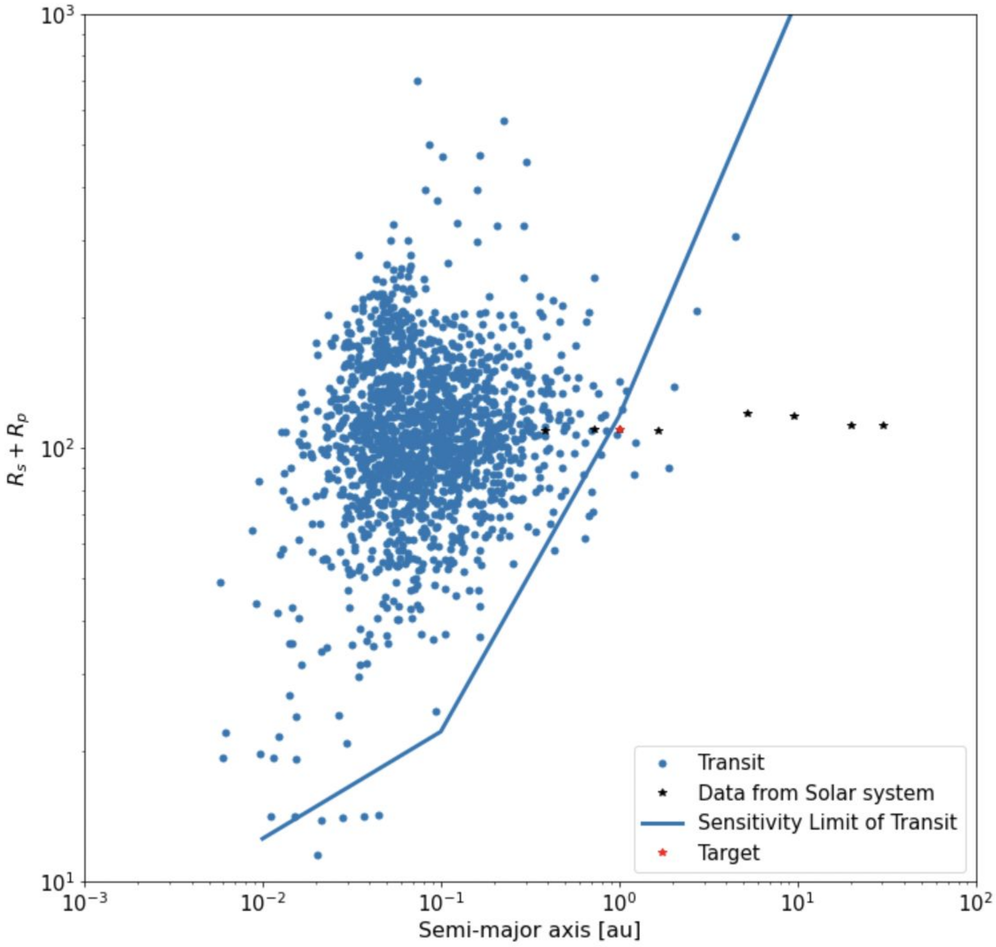
Closer look at the transit method

- Using the probability of transit:

$$P = \frac{R_s + R_p}{a}$$

we find the relation $a \cdot p = R_s + R_p$.

- To find the minimum probabilities from the data, we use the mean-value of the smallest 20 points as a baseline.



Results (cont.)

Investigating detection signal of an Earth-like planet around a Sun-like star

Radial Velocity (K)

$$K = \frac{M_p}{M_\star}\sqrt{\frac{G*M_\star}{a}}\, sin\; i.$$

K~ 0.0895 m/s

Transit (f & P)

$$f = \left(\frac{R_p}{R_*}\right)^2 \qquad P = \frac{R_s+R_p}{a}$$

f~ 84.05 ppm , P = 0.469 %

Direct Imaging (fc)

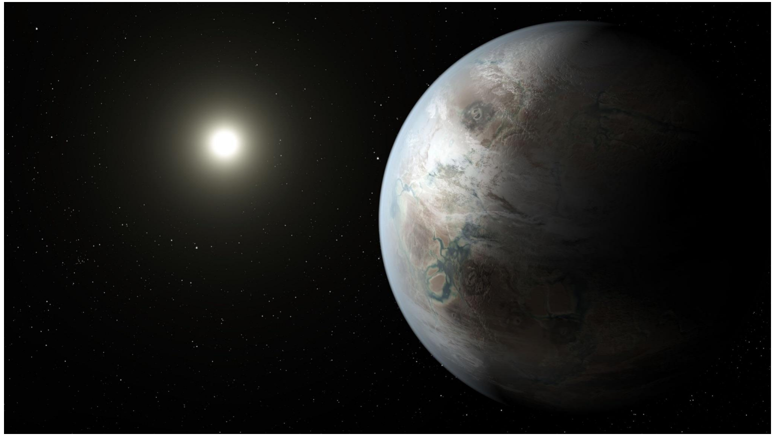
$$f_c = \left(\frac{R_p}{R_s}\right)^2 \frac{\exp(h\nu/k_B T_s)-1}{\exp(h\nu/k_B T_p)-1}$$

fc~ 1.097 micron

Optimal Telescope Diameter

$$\theta \sim 1.22\frac{\lambda}{D}$$

D ~ 41.253 m



Conclusion

Earth-like Signals / State-of-the-Art

- RV (K value): 0.179 ~ 18%
- Transit (f value): 0.764 ~ 76%
- Direct Imaging (fc value): 0.055 ~6%

An Earth-like planet around a Sun-like star is **undetectable** using current state-of-the-art instrumentation. The transit method is the most viable for future exploration.