CIERA Northwestern

Exoplanet Transit Analysis of KIC 8462852

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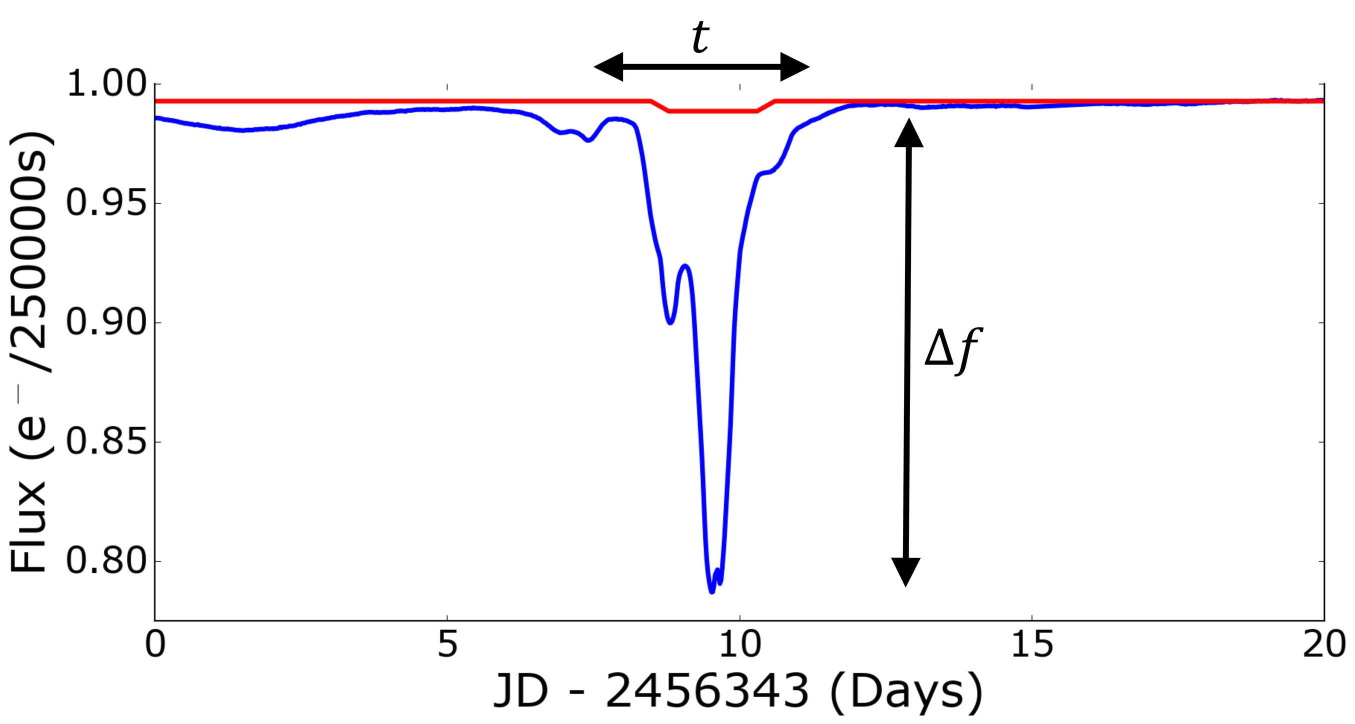
A Curious Light Curve

KIC 8462852 ("Tabby's Star") was among the ~100k stars observed by NASA's Kepler Satellite in its search for exoplanets. Unlike a typical exoplanet harboring star, its light curve exhibits an abnormal shape and multiple depths of unexpectedly large magnitude.

There are several explanations for KIC 8462852's light curve, which include circumstellar dust or families of comets[1]. Though these theories fit portions of the data, they do not explain it entirely. We test the hypothesis that the dips in KIC 8462852's light curve are created by exoplanets orbiting the star.



One observed dip[2] of KIC 8462852 and **the dip Jupiter would create** if orbiting it.

In the transit method, the width and depth of the light curve correspond to the **transit duration (t)** and the **change in flux (Δf)** respectively.

Planet Properties

Mass (M_J)	SMA (AU)	T (yr)	P_{Mass}	P_{SMA}	P_{Mass} x P_{SMA}
0.35	16.1	54.1	2.2×10^{-1}	1.0×10^{-5}	2.3×10^{-6}
0.64	15.8	52.6	1.8×10^{-1}	1.3×10^{-5}	2.3×10^{-6}
0.99	15.6	51.4	1.5×10^{-1}	1.5×10^{-5}	2.2×10^{-6}
1.38	15.3	50.3	1.2×10^{-1}	1.7×10^{-5}	2.0×10^{-6}
20.3	12.8	38.2	7.5×10^{-7}	8.6×10^{-5}	6.4×10^{-11}
88.2	10.7	29.2	1.6×10^{-25}	3.2×10^{-4}	5.2×10^{-29}

Our calculated properties for Jupiter-like exoplanets orbiting KIC 8462852 at assumed transit duration $t = 3$ days, excluding those of mass $\gg 84\ M_J$ (The minimum mass of stars).

Extreme Exoplanets

Assuming a circular orbit with zero inclination, we used Newton's 2nd law, Newton's law of universal gravitation, and geometry to derive the equations for the **period (T)**, **transit duration (t)**, and **radius (R_p)** of the exoplanets:

$$T = 2\pi\sqrt{\frac{a^3}{GM_*}} \qquad t = 2\sqrt{\frac{a^3}{GM_*}}\sin^{-1}\left(\frac{R_* + R_p}{a}\right) \qquad R_p = R_*\sqrt{\frac{\Delta f}{f}}$$

Unlike a traditional light curve, KIC 8462852's drops have no clearly defined start or end times so we chose several transit durations (3, 5, 8, 10, and 15 days) for each characteristic depth.

Applying these equations to our transit durations and the depths found by Boyjian et. al[1], we determined planet radii **R_p = 0.7 to 7.21 R_J (Jupiter Radii)** and Semi-Major Axes (SMA) **a = 8.27 to 402.65 AU**.

Assuming a density equal to that of Jupiter, we used the radii to calculate **planet masses M_p = 0.36 to 375.04 M_J (Jupiter Masses)**.

Fitting the Planet Hypothesis

With mass and SMA data from 5344 planets taken from the Exoplanet Orbit Database[3], we implemented the gradient descent algorithm in Python to create a maximum likelihood fit for each property with the **probability density function (PDF) f** given by:

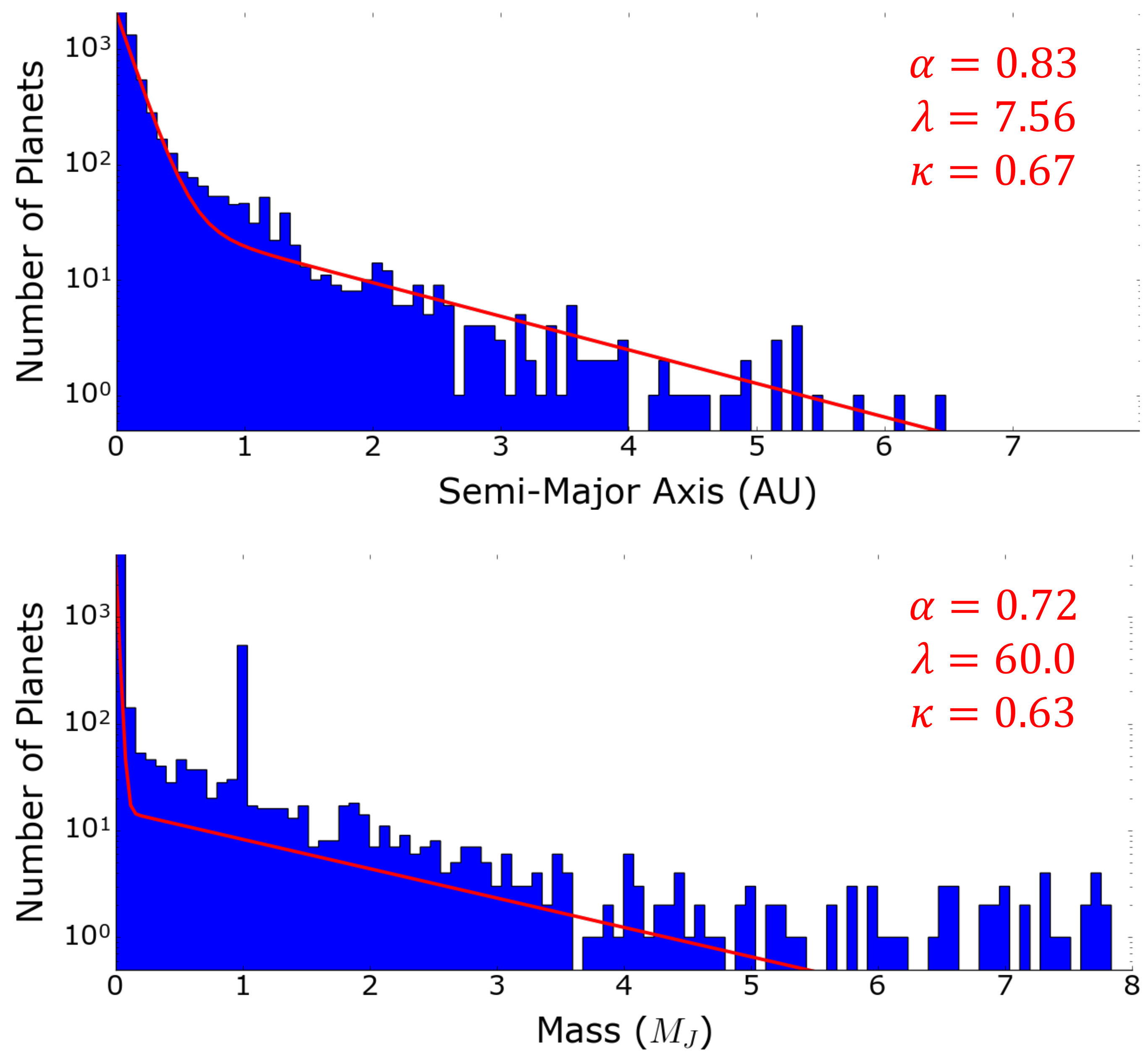
$$f(x) = \alpha\lambda e^{-\lambda x} + (1-\alpha)\kappa e^{-\kappa x}$$

After finding **parameters α, λ, and κ** for the mass and SMA distributions, we calculated the **tail-probabilities (P_{Mass} and P_{SMA})** of each for KIC 8462852's potential exoplanets by integration of the PDF:

$$P(x) = \int_x^\infty f(x')dx' = \alpha e^{-\lambda x} + (1-\alpha)e^{-\kappa x}$$

It is important to note that although intrinsic distributions of exoplanet masses and SMAs as assumed in our work would be ideal to use, this is not possible due to selection effects and incomplete understanding of planet formation.

Observed Distributions



Observed exoplanet masses and semi-major axes[3] with **their fitted probability density functions** over plotted.

Results

Assuming the mass and SMA are independent for each planet and multiplying, our planets have a probability of being drawn from observed distributions of only **2.41 x 10^{-163} (M_p = 375 M_J, a = 207 AU) to 7.59 x 10^{-5} (M_p = 0.64 M_J, a = 16 AU) %.**

For the larger masses and SMAs corresponding to the largest dips, extremely low probabilities are further proof that the exoplanet theory is unlikely. The probabilities are not as remote for the smaller dips with reasonable masses and SMAs, but their light curve is inconsistent with typical transits.

References

1. Boyjian, T. S., et al. Planet Hunters X. KIC 8462852 – Where's the Flux? *Monthly Notices of the Royal Astronomical Society* 457.4 (2016): 3988-4004.
2. MAST Database (archive.stsci.edu)
3. Exoplanet Orbit Database (exoplanets.org)

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