Finding the parameters of exoplanets

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Introduction: Following the launch and 4 year collection of data by NASA's Kepler spacecraft, a huge amount of data remains. Using the programming language Python we have been analysing the data of several exoplanets. The data provided by the Kepler mission shows the Periodic dimming of the light when a planet passes in front of the star during its orbit. This is seen in the form of light curves for each of the observed stars.

Theory

Light visible from stars dims as exoplanets move in front of them. The light from stars does fluctuate slightly on its own, but only by very small amounts: fluctuation from the stars we are observing is ~0.1%

This is how over 70% of Kepler's exoplanets were discovered.

With this we are also able to tell other values of the exoplanet such as the radius, semi major axis and orbital period.

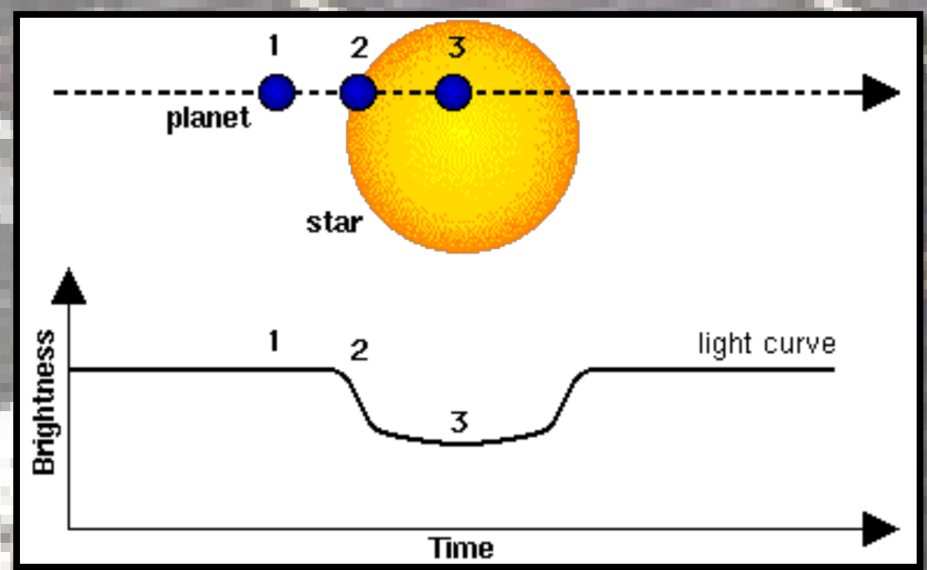

Figure 1:
A representation of how the observed brightness of a star dips during transit

Phase Folding

Phase folding is when you estimate an orbital period, then folding the data due to the orbital period which was guessed. This will show you all the orbits overlaid giving us more data points in a time period from which to make a model of the system and gather our data.

When phase folding the light curve, we found it challenging. However, in the case of the first star we observed, Kepler 8, we managed to come up with the figure 3.5225 days per orbit.

This figure had to be precise. If not folded correctly to an accuracy of 0.0001 days (or ~9 seconds!) it would give us a wrong trend line (see figure 3).

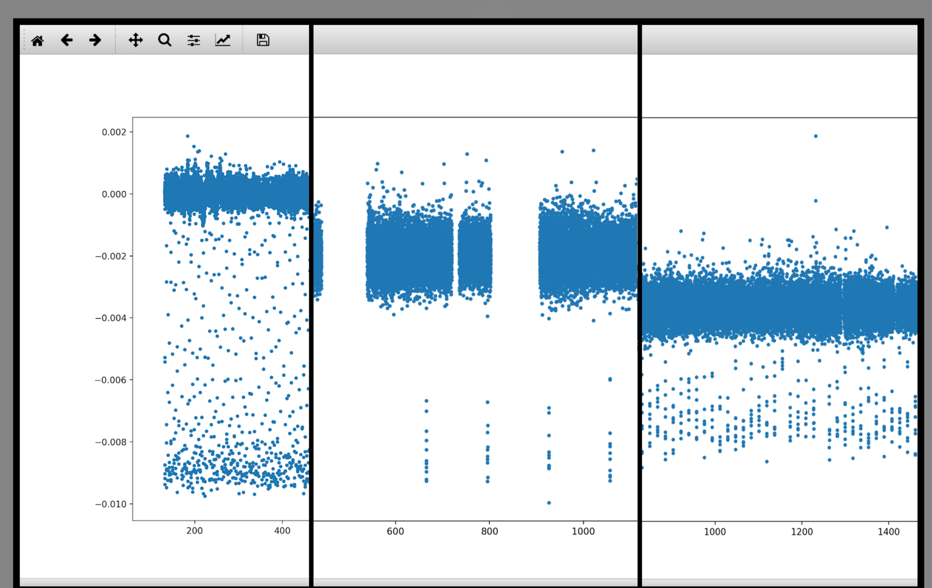

Figure 2:
Sections of detrended light curves from planets Kepler-8 b, Kepler-952 b, and Kepler-562 b

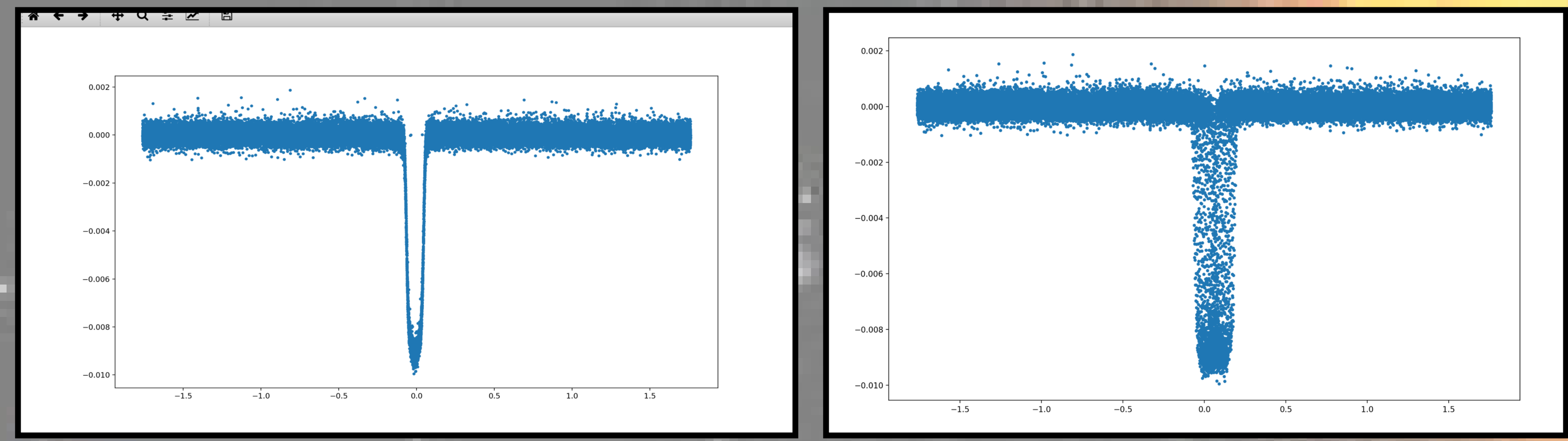

Figure 3:
The correctly phase shifted light curve of Kepler-8 b, compared with phase shift orbital period error of 30 seconds.

Once we had phase folded the light curve, we added the line of best fit, which is actually made up of different dots relating to each of the data points collected by the Kepler mission.

We tested the accuracy of our model using the Chi-squared test, which shows how accurate to the data our model is.

Finally, upon arriving at a highly accurate model, we analysed the data our model provided to calculate the physical parameters of the planets.

$$\chi^2 = \frac{1}{N} \sum_{i=1}^{N} \frac{(F_i - F_m)^2}{\sigma^2}$$

Figure 4:
The Chi-squared formula

Physical measurements

The light curves we looked at came from three systems, Kepler-8, Kepler-952, and Kepler-562 (see figure 2).

From the Kepler data analysed (and some pre-known data of the star's radius and $\log_{10}g$) we were able to calculate: the orbital periods, the radius of the planet, the semi-major axis of the planet, the impact parameter of the planet, and the orbital inclination. (see figure 5)

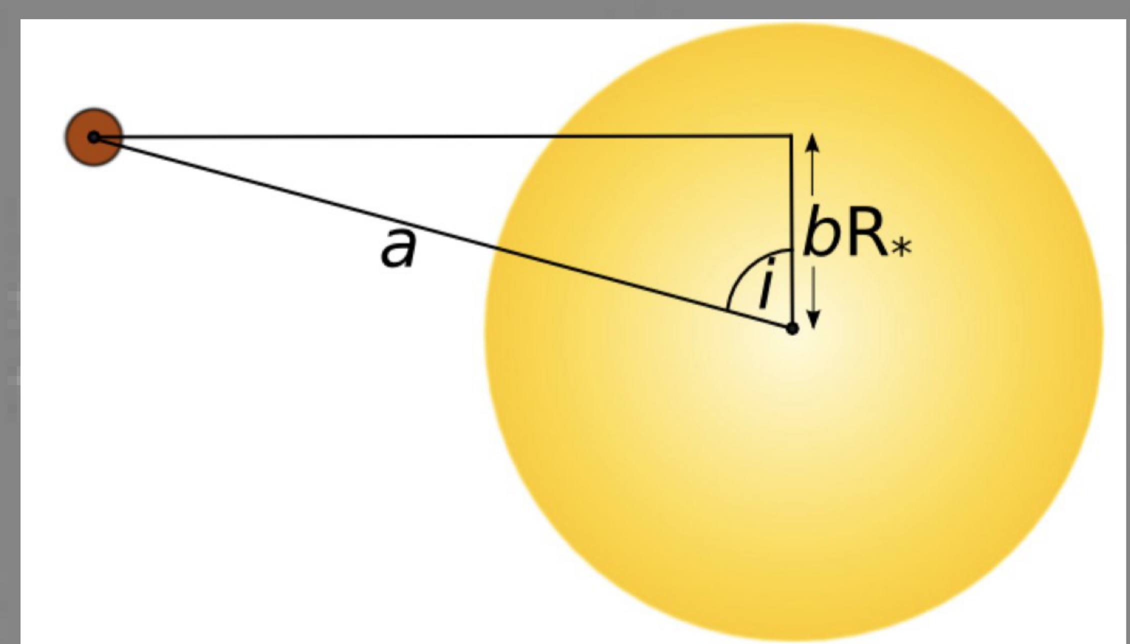

Figure 5:
A diagram showing the relationship of the semi-major axis (a), the impact parameter of the planet across the star (bR*), and the inclination (i) of the planet.

Results

Looking at our results, in the areas with collected data, ours are very similar. This is exciting because it means that in the area where there is no existing data, our results are, to an extent, reliable, and we have found previously unknown data about the planets.

The data itself suggests all three planets to be "hot Jupiter's", since they orbit close to the star at a high speed, and are much larger than earth.

Kepler-8 b	Our data	Actual data
Planet radius (R_{Earth})	14.7827	15.87
Orbital period (days)	3.5225	3.5225
Semi-major axis (AU)	0.0473	0.0474
Impact Parameter (R_{Star})	0.6924	0.7191
Orbital Inclination (degrees)	84.3212	83.98

Kepler-952 b	Our data	Actual data
Planet radius (R_{Earth})	7.7188	7.65
Orbital period (days)	130.3514	130.3547
Semi-major axis (AU)	0.5047	No data
Impact Parameter (R_{Star})	1.0713	No data
Orbital Inclination (degrees)	89.4395	No data

Kepler-562 b	Our data	Actual data
Planet radius (R_{Earth})	5.2612	5.21
Orbital period (days)	18.0093	18.0093
Semi-major axis (AU)	0.1315	No data
Impact Parameter (R_{Star})	1.0534	No data
Orbital Inclination (degrees)	88.0773	No data

What's next?

We plan to continue the project after this. Next, we want to look at a system with two stars, or two planets, and consider how that will change the pattern of light dips and increases in the light curve, combined with the movement of the planet orbiting around them. This will be a difficult, but fun challenge, to take this project further.

Acknowledgements:

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References:

Mayor, M., Queloz, D., A Jupiter-mass companion to a solar-type star, 1995, Nature, 378, 355-359

Borucki, W.J. et al, Keper Planet-Detection Mission: Introduction and First Results, 2010, Science, 327, 977

Information about the Kepler mission: https://kepler.nasa.gov/index.cfm NASA Exoplanet Archive: http://exoplanetarchive.ipac.caltech.edu

Exoplanet Data Explorer (useful for generating plots of exoplanet properties and exploring the statistics of the exoplanet population): http://exoplanets.org

Extrasolar Planet Encyclopedia (similar to the Exoplanet Data Explorer): http://exoplanet.eu

A reference site for documentation on Python commands and libraries: http://scipy.org

A website which provided information on understanding the Chi squared test: sphweb.bumc.bu.edu/otlt/MPH-Modules/BS/BS704_SummarizingData/BS704_SummarizingData6.html