# Planet Hunting with Python

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## Overview

Our project was based on detecting exoplanets using the programming language Python to model light curves from data collected from NASA's Kepler missions. We focussed on understanding multi-planetary systems, in particular, we aimed to detect planets orbiting Kepler-9 (a sun-like star). From our analysis, we were able to determine features of these planets such as their radius, and orbital period. We chose to carry out this project in order to develop our understanding of (exoplanet) research and to develop our Python programming skills.

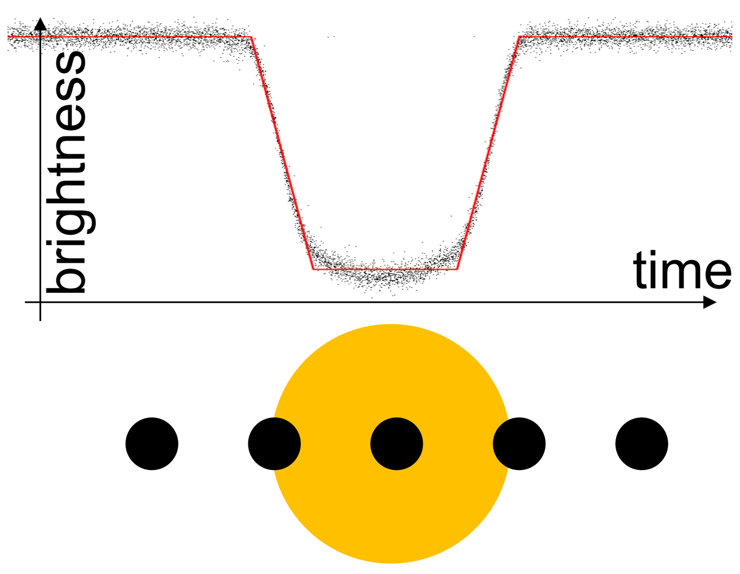
## Aims

We aimed to detect exoplanets using data from NASA's Kepler mission by constructing a piecewise model of their light curves, from whose analysis we could discover some of these planet's properties.

## Background information

Exoplanets: planets outside our solar system.

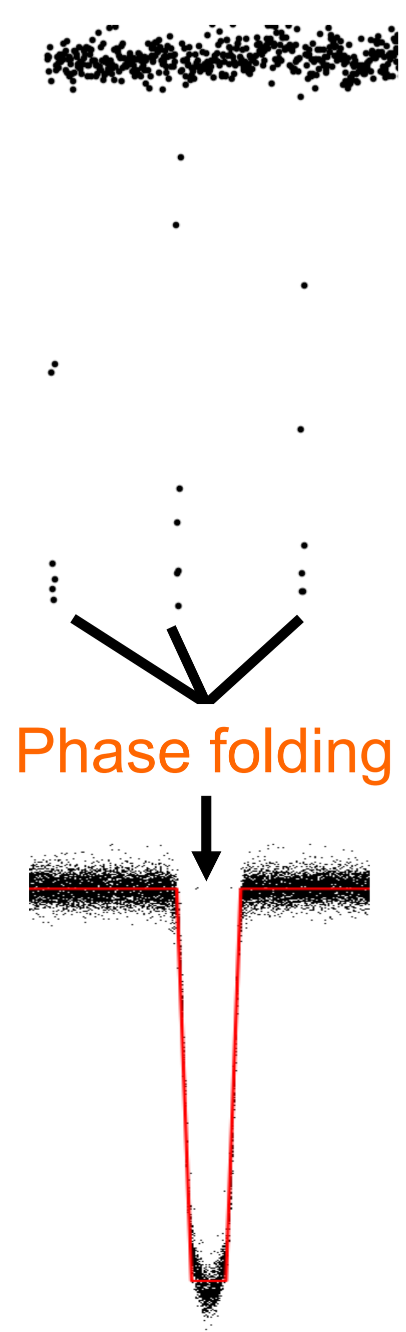
Transit photometry method: as the planet passes in front of star, it blocks some of the light. Since the star's mass, $M_s$, is known, we can deduce the planet's radius using Kepler's third law of planetary motion (Period$^2$ ~ semi-major axis$^3$). The frequency of the dimming also tells us the orbital period (length of a year on that planet). Using Newton's law of Gravity ($F = \frac{GM_sM_p}{r^2}$), we can determine the planet's semi major axis.

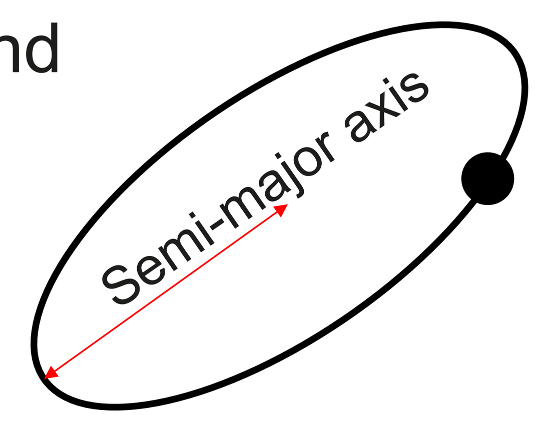



Transit photometry method

## Methodology

1. Use Python (with Matplotlib and NumPy) to plot light curves (light intensity against time graphs)
2. From this we worked out the orbital period
3. Using the orbital period we phase folded the light curve. This means overlapping the data from each orbit to get a much clearer curve
4. We then fitted a piecewise (defined separately for different ranges) model to the curve, using the Chi squared test to find the best fit
5. Using known value of star's radius, we worked out the planets' radii and semi-major axes using $GM_sP^2 = a^3 4\pi^2$ and $R_p^2 = \frac{R_s^2 f_{max}}{\Delta f}$, where a = semi-major axis, f = flux (brightness) $M_s$ = star mass, $R_s$/$R_p$ = star/planet radius respectively




## Results and Conclusion

**Planet 1:** Radius: 12.7 Earth radii, Orbital period: 38.9 days, Semi-major axis: 11.5 AU

**Planet 2**: Radius: 13.3 Earth radii, Orbital period: 19.2 days, Semi-major axis: 7.18 AU

Upon analysis of the Kepler-9 data, we discovered 2 "hot Jupiters" (gas giants orbiting near the star). We found our calculated orbital periods of Kepler-9b and Kepler-9c to differ by 0.01% and 0.22% from the accepted values respectively. We also discovered evidence of a possible third planet which had a much smaller effect on star's brightness. This suggests that it was smaller and closer to the star than the others. This is supported by other research which has found a 'super-Earth' (a planet close in size to Earth), Kepler-9d, which is believed to be about 1.64 times the mass of the Earth and orbits Kepler 9 every 1.6 days.

## Evaluation

The main limitations of the accuracy of our calculations were our ability to accurately phase fold the data, and from this to extract the average change in flux. Uncertainty from both of these could be reduced by getting the computer to compute both of these. This could be achieved by using statistics and machine learning to optimize the phase folding and construct a model from which more precise measurements may be taken.

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