Writing Report of Project 4

Cosmo Lei, Haechan Jung, Yuhang Mao

The study of exoplanets, planets located outside our solar system, is a rapidly advancing field in astronomy. Among various methods of exoplanet detection, the transit method has proven to be one of the most effective. This method involves observing the periodic dimming of a star as a planet passes in front of it, blocking a fraction of the starlight. The dimming produces a characteristic light curve, revealing critical information about the planet’s size, orbital period, and distance from the star.

This project focuses on analyzing the light curve data of an exoplanet system using observational data and mathematical modeling. By fitting the light curve with a transit model, we aim to derive key physical properties of the exoplanet, such as its radius and transit duration, as well as evaluate the goodness-of-fit of the model to the data.

The primary objective of this project is to process and analyze observational light curve data of an exoplanet transit and estimate the physical parameters of the exoplanet, including transit depth, duration, ingress/egress time, and background flux.

The analysis is grounded in mathematical and physical principles of planetary transits and stellar photometry:

1. Transit Depth: The transit depth, δ, is related to the planet-to-star radius ratio (δ ≈ (R\_p/R\_∗)^2). It is derived from the normalized flux decrement during the transit.

2. Transit Duration: The duration depends on the planet’s orbital parameters and the geometry of the transit.

3. Ingress and Egress Times: These phases occur as the planet enters and exits the stellar disk, creating sloped edges in the light curve.

4. Trapezoidal Transit Model: This model accounts for the ingress/egress phases by introducing a linear transition, providing a more realistic fit than a simple box model.

5. Bayesian Inference and MCMC: To determine the best-fit parameters and their uncertainties, we use Markov Chain Monte Carlo (MCMC) sampling with Bayesian statistics.

6. Reduced Chi-Squared Statistic: This measure evaluates the goodness-of-fit of the model to the data by considering the residuals and their uncertainties.

The project began with importing observational light curve data in ASCII format. The dataset contained time, normalized flux values, and associated uncertainties. After preprocessing the data, the time series was centered around the transit event to simplify analysis.

A simple rectangular model was implemented first, representing a constant transit depth during the planetary transit. While computationally efficient, this model does not account for ingress and egress phases. To improve accuracy, a trapezoidal model was developed. This model introduced a linear transition for the ingress and egress phases, offering a better representation of the transit.

图表, 直方图

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Using the trapezoidal model, the key parameters (“center time”, “duration”, “depth”, “delta flux”, and “ingress”) were estimated. The following methods were applied: MCMC Sampling: The `emcee` Python library was used to perform MCMC sampling, enabling posterior distributions for each parameter. Bayesian Analysis: Prior distributions were set based on physical constraints, and the posterior probability was calculated as a product of the likelihood and priors.

The quality of the fit was evaluated using: Residual Analysis: Residuals (differences between observed and model fluxes) were plotted to ensure they were randomly distributed. Reduced Chi-Squared Statistic: A reduced χ2 value close to 1 indicated a good fit, with no significant under- or over-fitting.

背景图案

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In the end we get that the trapezoidal model successfully fitted the observational data, capturing both the flat-bottomed transit and the sloped ingress/egress phases. The estimated parameters were Center Time: 0.00117 ± 0.00047 days, Duration: 0.08772 ± 0.00097 days, Depth: 0.01515 ± 0.00033, Delta Flux: -0.00018 ± 0.00023 and Ingress: 0.01950 ± 0.00057 days.

The reduced chi-squared statistic was calculated as 0.795, indicating an excellent fit.The corner plot revealed no significant parameter correlations, and parameter uncertainties were small.

This project demonstrated the power of mathematical modeling and statistical inference in analyzing exoplanet transit data. By employing a trapezoidal model and Bayesian MCMC techniques, the analysis yielded precise and physically meaningful parameters for the exoplanet. The reduced chi-squared value confirmed the accuracy of the fit, while the corner plot provided insights into parameter distributions and correlations.

Future work could involve applying the same techniques to other datasets, incorporating limb-darkening effects for more realistic models, or exploring different transit scenarios such as grazing transits or multi-planet systems. The methodology and results provide a robust foundation for advancing exoplanet studies.

AI statement:

We used Gemini when coding.

Used ChatGPT on Research, theoretical understanding, understanding teacher code and report writing.

Contribution statement

The presentation and written report are done by our three based on Lei’s code.