Astronomy 1221 Written Report 4

Sam Grobelny, Sacha Wible, Wentao Zhong

Introduction

Planetary transits provide a powerful method for detecting and studying exoplanets. When a planet passes in front of its host star, it blocks a fraction of the starlight, producing a periodic dip in the observed stellar flux. This event, known as a transit, is recorded as a light curve. By analyzing the light curve, astronomers can extract vital information about the planet, including its size, orbital period, and other key characteristics.

This report focuses on modeling transit light curves for two known exoplanets: HD 189733b and GJ 436b. Synthetic light curve models are generated using transit parameters such as the mid-transit time (t0), transit duration (τ), and transit depth (δ). The models are then compared with observational data to evaluate their accuracy and infer the properties of these exoplanets.

Theory

The transit light curve reflects the variation in stellar flux caused by the planet passing in front of its host star. The shape and features of the light curve are governed by the following parameters:

Transit Depth (δ): The fractional decrease in stellar flux during the transit is determined by the ratio of the planet's radius (Rplanet) to the star's radius (Rstar), following the relationship:

$$\delta = \left(\frac{R_{planet}}{R_{star}}\right)^2$$

Which can be simplified as

$$R_{planet} = \sqrt{\delta} \cdot R_{star}$$

Larger planets relative to their host stars produce deeper transits.

Transit Duration (τ): The time span of the planet's passage across the stellar disk depends on the orbital speed and the inclination of the planet's orbit. It is influenced by the planet's distance from the star and the star's size.

Mid-Transit Time (t0**)**: This is the moment of closest alignment between the planet and the star as viewed from Earth. It provides a reference point for determining the orbital period and phase.

The observed flux variations are modeled by applying these parameters to a simple theoretical framework. By comparing the modeled light curves to the observational data, one can infer the physical properties of the planet and validate the model's accuracy.

Conclusion:

The analysis of transit light curves for HD 189733b and GJ 436b demonstrates the effectiveness of the transit method in characterizing exoplanets. For each system, synthetic models were constructed using key parameters such as t0, τ, and δ, and these were fine-tuned to match the observed data.

The calculated reduced chi-squared values quantitatively validate the models, highlighting the precision of the parameter estimates. This iterative process underscores the power of transit modeling in deriving critical information about exoplanets, such as their size and orbital configuration. Future studies could extend this methodology to systems with more complex transit dynamics or secondary effects, such as limb darkening or atmospheric scattering.

Methods:

Synthetic Light Curve Generation:

a synthetic light curve was generated using a python function. this function models the flux variation of a star during the transit of an exoplanet based on three key parameters:

- **mid-transit time (t0):** specifies the central moment of the transit event.
- **transit duration (τ):** the time the planet spends crossing the star's disk.
- **transit depth (δ):** the fractional drop in observed flux caused by the planet obscuring part of the star.

for both hd 189733b and gj 436b, time arrays were constructed from observational data. we initialized the model with estimated values of t0, τ, and δ derived from literature and previous studies. these parameters were iteratively adjusted to fit the observed light curves. the observed flux was then overlaid with the model output for comparison.

Observational Data Handling:

Data from the hd189733b.tbl and gj436b.tbl files were loaded and pre-processed to isolate the relevant transit events. for each dataset:

- **time normalization:** the time arrays were shifted such that the earliest recorded time was set to zero.
- **flux normalization:** observed flux values were adjusted to have a mean value of 1 outside transit events.

Fitting and Validation:

we applied a reduced chi-squared ($\chi 2$) method to evaluate the goodness of fit for the synthetic model. the reduced $\chi 2$ is calculated as:

Where:

- F_obs and f_model are the observed and modeled flux values, respectively,
- Sigma_obs is the uncertainty in the observed flux,
- dof is the degree of freedom (number of data points minus number of model parameters).

Parameter Refinement

using the reduced $\chi 2$, we iteratively refined t0, τ, and δ to minimize residuals. visual inspection of residual plots (observed – model flux) ensured there were no systematic deviations indicative of unmodeled effects.

Results:

hd 189733b:

The synthetic light curve closely matched the observed data for hd 189733b. the refined transit parameters were:

mid-transit time (t0): 3.8 ± 0.1 hours

transit duration (τ): 1.8 ± 0.1 hours

transit depth (δ): 0.025 ± 0.001

with a reduced $\chi 2$ of 1.05, the fit was statistically consistent with the observational noise. the residuals showed no significant structure, confirming the validity of the model.

gj 436b

Similar results were obtained for gj 436b. the optimized parameters were:

mid-transit time (t0): 2.3 ± 0.1 hours

transit duration (τ): 0.8 ± 0.1 hours

transit depth (δ): 0.008 ± 0.001

for this dataset, the reduced $\chi 2$ was 1.12, indicating a good fit. The residuals also lacked significant trends, further supporting the robustness of the model.

AI and Contribution

We did not use AI.

Contribution

Introduction, Theory and Conclusion: Wentao Zhong
Methods and Results: Sam Grobelny
Slide: Sacha Wible