# Exoplanet (Project 4)

## Motivation

The study of exoplanet transits offers a powerful tool for understanding distant planets. When an exoplanet crosses the face of its host star, it causes a measurable dimming in the star's light, known as a transit. By analyzing this light curve, astronomers can infer critical information about the exoplanet, such as its radius, orbital period, and sometimes atmospheric composition.

This project focuses on modeling the transit light curve of the exoplanet GJ 436b. We create a synthetic transit light curve based on selected parameters, including the transit midpoint ($t0$), transit duration ($\tau$), and depth ($\Delta$). We fit this model to observational data and assess the goodness of fit using statistical metrics. We gain insights into the exoplanet's properties by interpreting the model and observational comparison.

Exoplanet transit studies are not only foundational for determining planetary characteristics but also serve as a stepping stone for detecting Earth-like planets and studying their habitability.

## Methods

1. **Mathematical Framework**

A transit light curve can be modeled as a flat baseline flux of 1.0 (normalized stellar brightness), with a decrease ($1.0-\Delta$) during the transit duration. The model assumes a simple box-like light curve, neglecting limb-darkening effects for simplicity. Future iterations could incorporate more realistic models with stellar limb darkening.

2. **Data Preparation**

Observational data from the file gj436b.tbl was used. The file contains HJD (Heliocentric Julian Date) which is time of observations and Relative Flux which is normalized stellar brightness during the observations.

The HJD values were converted to hours, relative to the first observation ($HJD-HJD0$), to make the time data more intuitive and suitable for plotting.

The flux values were used directly as provided since they were already normalized to the out-of-transit brightness of the star.

3. **Transit Model Implementation**

The function generate_transit_lightcurve was implemented to simulate a transit light curve. It follows these steps:

1. Create a baseline flux array of 1.0.
2. Identify time indices within the transit duration
3. Adjust flux values at these indices to $1.0-\Delta$.
4. Return the resulting light curve.

4. **Statistical Analysis**

To quantify how well the model fits the observed data, the chi-squared statistic ($\chi 2$) was computed. The reduced chi-squared statistic accounts for the number of free parameters and data points. A smaller chi-squared value indicates a closer match between the model and the observations, but its absolute value depends on the number of data points and the uncertainties. The reduced chi-squared value is dimensionless and provides a standardized metric for evaluating the goodness of fit.

5. **Visualization**

Plots were generated to compare the modeled and observed flux. Synthetic light curves with varying parameters ($t0,\tau,\Delta$) to test model flexibility. A final comparison of the best-fit model with the observational data.

**Results**

1. **Synthetic Light Curve**

Using the parameters $t0=2.3$ hours, $\tau=1.0$ hour, and $\Delta=0.008$, the model produced a light curve with a dip to flux=0.992 during the transit. The flat baseline before and after the transit matched expectations.

2. **Observational Data**

The flux data from GJ 436b exhibited a clear dip consistent with a planetary transit. The transit midpoint and depth aligned well with the model's predictions.

3. **Statistical Metrics**

The chi-squared was 63.971, and reduced chi-squared values was 0.151. The reduced chi-squared value was significantly less than 1, indicating an excellent fit but suggests the uncertainties ($\sigma=0.01$) might be slightly overestimated. This result also implies that systematic noise is minimal, and the model captures the key transit features effectively.

4. **Visual Comparison**

The plot comparing the observed data with the modeled light curve showed excellent alignment during and outside the transit. Minor residuals could result from small observational errors or the box-like model approximation.

## Conclusion

This analysis demonstrates the effectiveness of a simple transit light curve model in characterizing exoplanetary transits, specifically for GJ 436b. By adjusting three primary parameters, transit midpoint($t0$), duration($\tau$), and depth ($\Delta$), the model was able to closely replicate the observed light curve. The statistical analysis, particularly the low reduced chi-squared value, validates the model's accuracy and confirms the absence of significant deviations or noise in the observed data.For future improvements, re-evaluating the observational uncertainties would provide a more accurate assessment of the reduced chi-squared value. This project underscores the importance of computational tools in exoplanetary research and demonstrates how simple models can yield meaningful insights.

## AI usage

In this project, We used Gemini offered as a feature in colab, in hopes of more efficiently debugging our code and further supplementing it.

**Link to Slides:**
https://docs.google.com/presentation/d/1i-ZEqvw-o7yUz0gCD0WMrzQkr2CG9F2WFDKVYHqTp9g/edit#slide=id.g31cc8561a90_0_237