Lab 3: Measuring Transit Depth with HST Data

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The Hubble Space Telescope, while an amazing instrument for science, has several issues in its data that usually require cleaning and detrending. These include photon noise, a slow linear trend in time, and outliers due to cosmic rays. Some of these are unavoidable facts of detection, while others come from degradation of the imaging hardware over time [1]. When using HST to measure transit depths of planets in front of stars, we also need to detrend the flux variations of the star itself.

This project involved cleaning artificial HST data by removing outliers, then detrending the linear and periodic components of the signal. This produced a clean transit signal in the light curve which we measured the transit depth from.

We additionally corroborated our results from the single model fit with a 6 parameter MCMC.

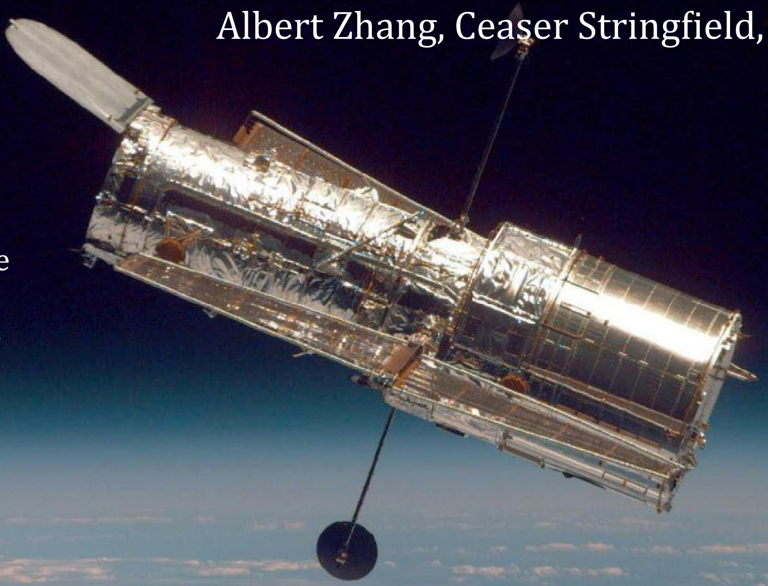
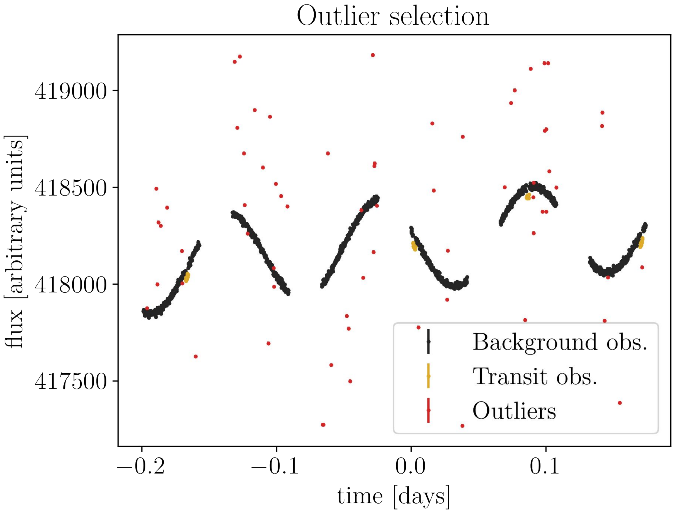
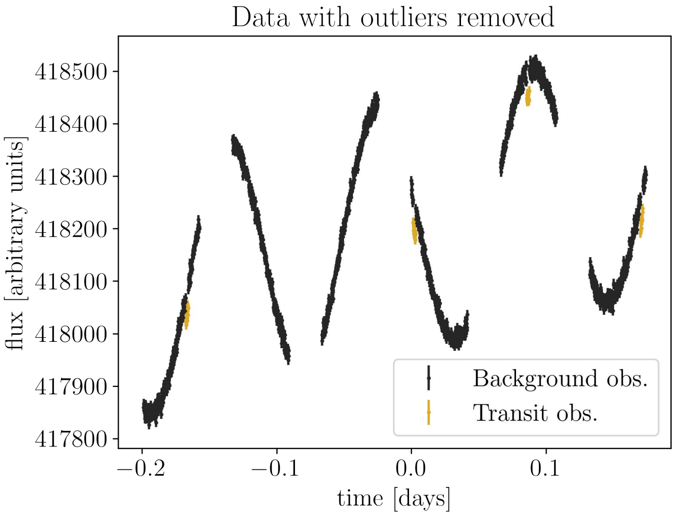


Photo source: BBC Sky at Night Magazine, May 2019

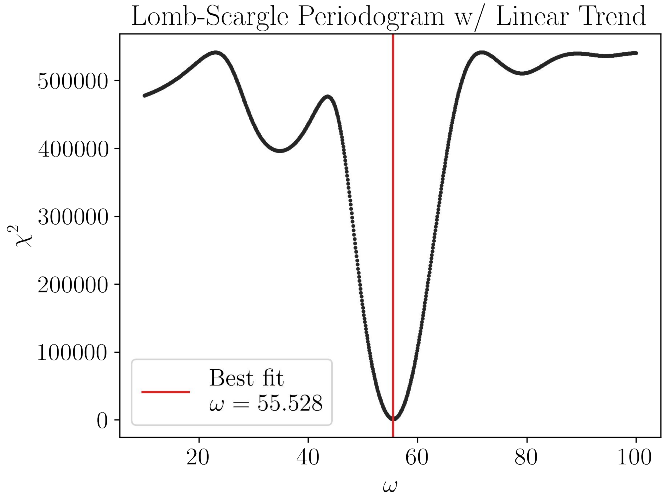


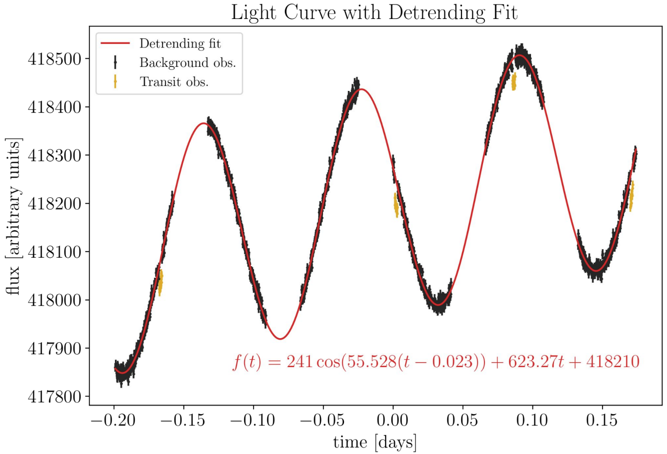
Detrending

We first took a rolling median (bandwidth of 5 points) in both flux and time. Points more than 3σ from the rolling median interpolation were flagged as outliers and removed (red points in top left). We then masked out the transit points based on the known transit period and duration (bottom left).



Next, we made a Lomb-Scargle periodogram, adding a column for a linear trend in the design matrix, to find the best fitting frequency for the background data (top-right). We used the normal equation to find the least-squares best fit coefficients on the sinusoidal and linear terms. We ended up with the detrending model (bottom right), which, at least visually, matches the data well.

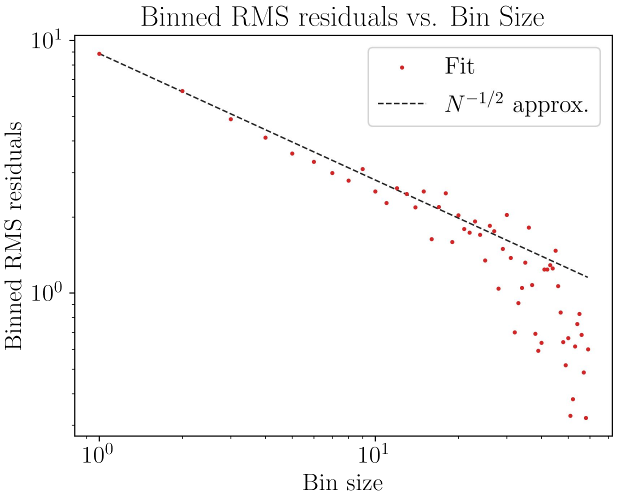


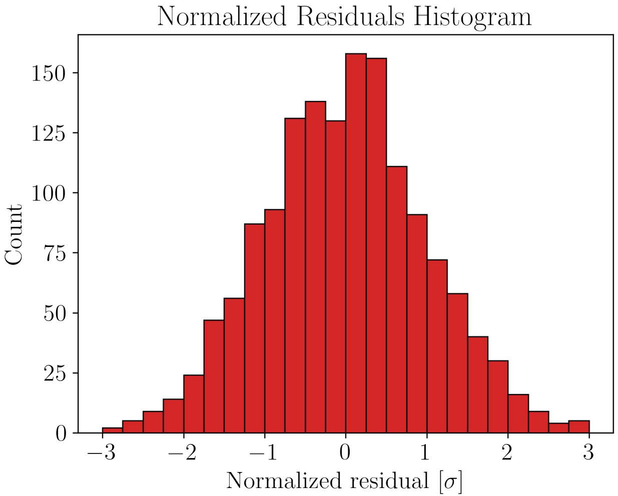


Data source: artificial, provided by instructors

Results & Robustness

To evaluate our detrending, we made plots of the binned RMS residuals vs bin size and the histogram of normalized residuals. The RMS vs bin size plot obeys the expected inverse square root relation for small bins relative to the observation window size (~250 observations) and overperforms for large bins. The normalized residuals histogram is approximately normal, but there noticeable asymmetry around 0. Based on these metrics, our detrending is quite good but not perfect.





We calculate the transit depth as the mean relative change in flux of the transit observations from our background detrending curve at those points. The light curve folded by period is plotted below. We obtain a value for the transit depth of **1.206 x 10^{-4}**. This value is corroborated by a 6-parameter MCMC fit we performed on the data with outliers removed but pre-detrending (bottom right). The MCMC gave us an uncertainty for the transit depth measurement of of **+/- 0.031 x 10^{-4}**.