Planetary Systems Around Milky Way Stars

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Background:

- We used stellar light curves from NASA's **Transiting Exoplanet Survey Satellite (TESS)** mission in our analysis. We were looking for signals from transiting exoplanets that cause periodic dips in the light curve, the plot of brightness versus time, of their host star.
- Several Python packages developed by other researchers were also useful:
  - **BAsic Transit Model cAlculatioN (BATMAN)** generates synthetic exoplanet signals in light curves from user-provided system parameters (Kreidberg 2015).
  - **Transit Least Squares (TLS)** is an optimized algorithm that searches stellar light curves for periodic signals that could be exoplanet transits (Hippke & Heller 2019).
    - The **signal detection efficiency (SDE)** is a measure of the goodness of fit of TLS's best predicted transit.

Can we recognize the presence of transits from exoplanets that are too small to find individually by combining a large number of signals?

Results:

- In our tests of synthetic data, we could confidently state that a sample of light curves contained transits when exoplanets had a radius of approximately **1.75 REarth orbiting a solar analog with 300 ppm noise**, which is consistent with the established limits of TLS.
- With our tests of TESS data:
  - The **random sample** does not differ significantly from Gaussian noise, suggesting that there are few exoplanets in the sample.
  - The **confirmed exoplanets** differ significantly from Gaussian noise, as expected.
  - **TESS Objects of Interest** (TOIs), which are stars that have been identified as potential planet hosts, differ significantly from Gaussian noise *(see Figure 2)*, but further research is needed to determine whether these differences arose from transiting exoplanets or another astrophysical source.

We have plans to continue our search for exoplanets by training convolutional neural networks (CNNs), a type of machine learning architecture, to search for and identify likely exoplanet candidates.

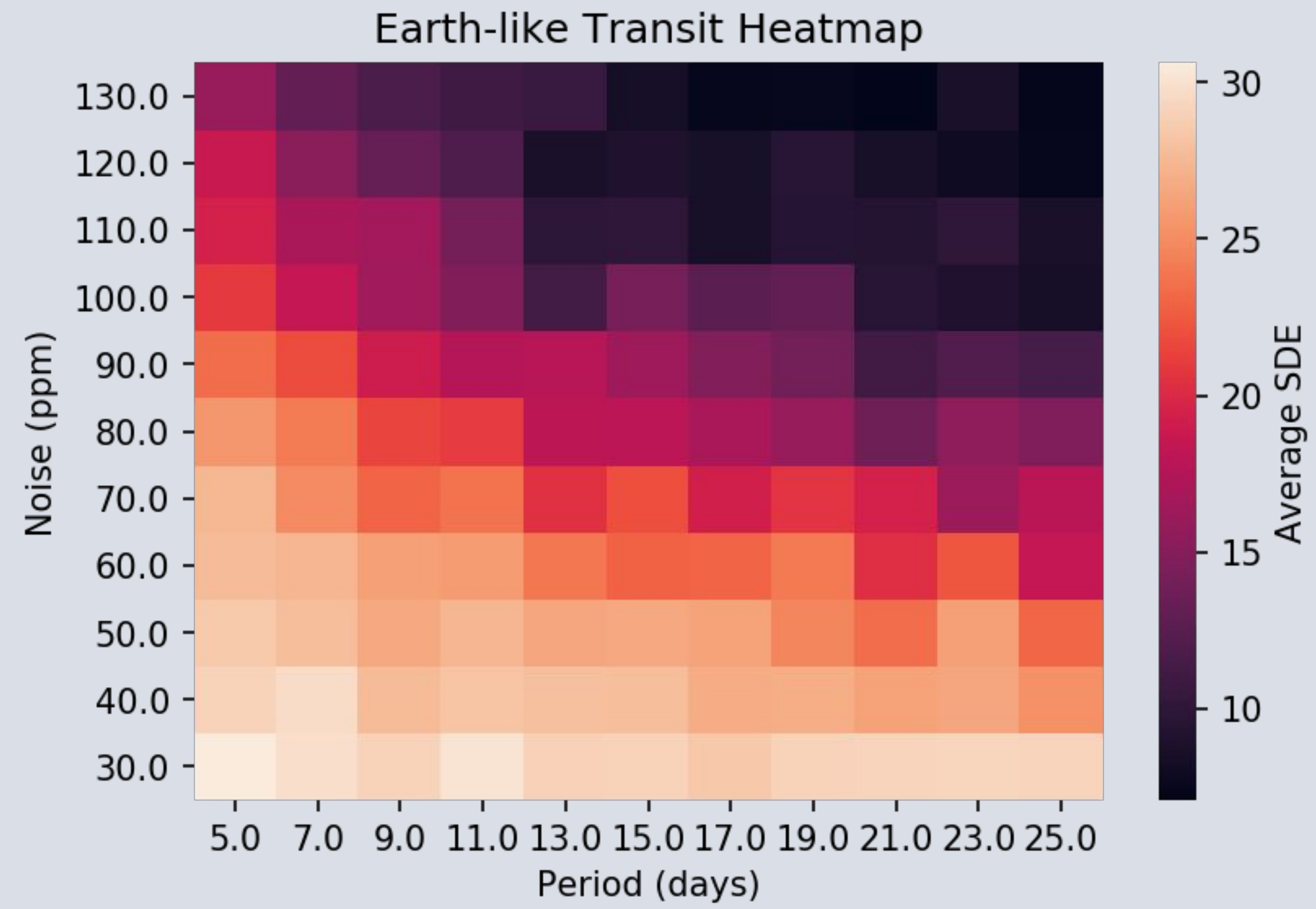

Figure 1 - The signal detection efficiency (SDE), or power, of the TLS detection of simulated Earth analog transits with varying noise levels and periods. We used this figure to identify the combination of conditions at which the SDE dropped below the acceptable significance threshold for a detection.

Methods:

Make **synthetic true positive light curves** with Gaussian noise + inserted transits using the BATMAN software.

Make **synthetic false positive light curves** with Gaussian noise.

Determine the signal strength at which **TLS no longer recovers the correct transit** and where the SDE is too weak for a solid detection *(see Figure 1)*.

Binning the SDE of each light curve by period, apply the **Anderson-Darling Test**, a statistical test used to determine the probability that two samples arose from the same distribution, to the SDEs from the false positive and true positive synthetic light curves.

Apply our technique with the Anderson-Darling Test to TESS data to **compare real light curves to our synthetic false positives** *(see Results)*.

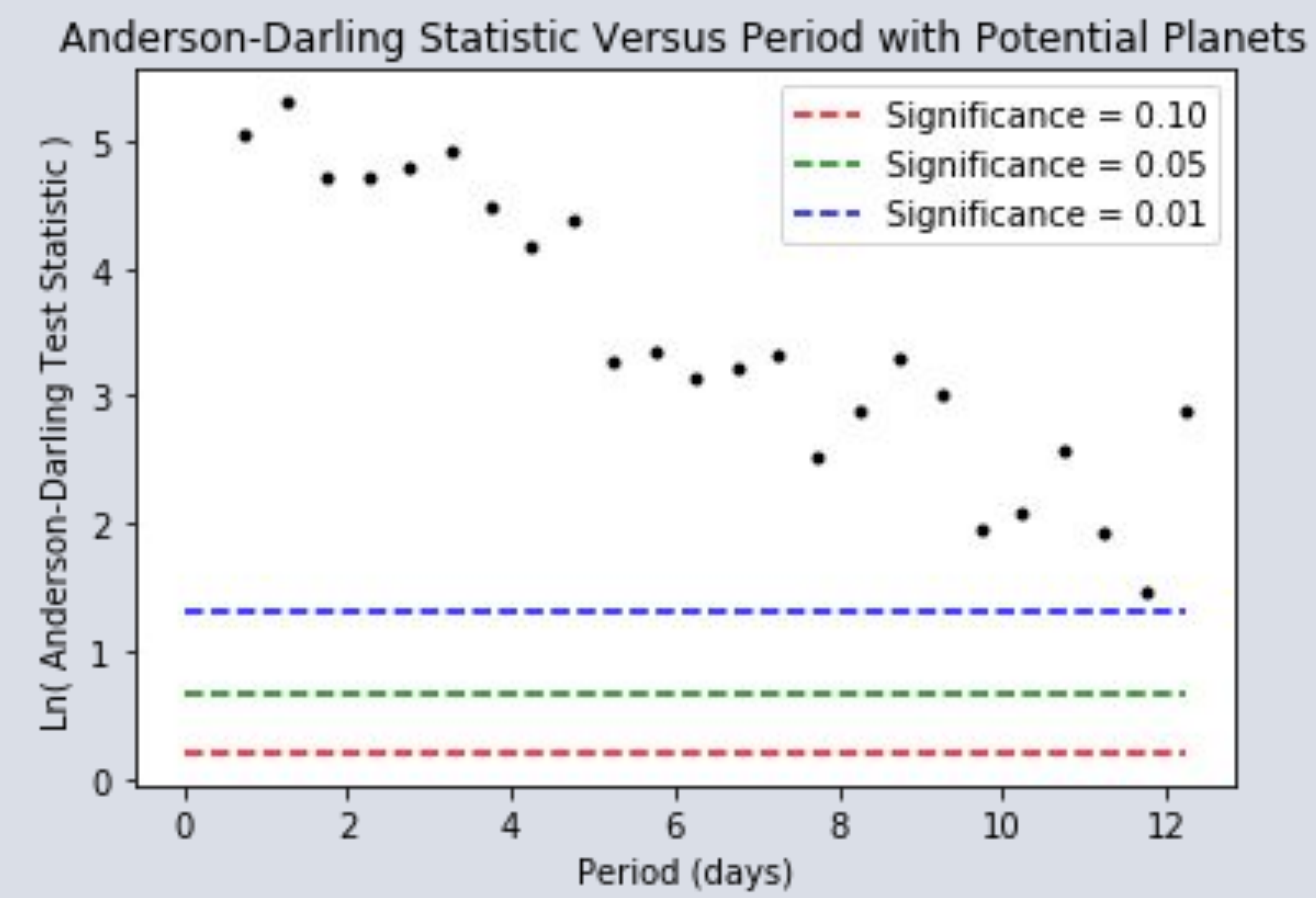

Figure 2 - Natural log of the Anderson-Darling Test statistic in each period bin of width 0.5 d. The statistic is used to compare the SDEs from TLS tests run on TESS Objects of Interest (TOIs) and simulated false positive light curves with Gaussian noise. The test statistic is above the standard significance threshold of 0.05 (the green line) for all period bins, providing a strong detection of non-Gaussian events. The test statistic likely decreases with period due to a higher frequency of non-Gaussian events at lower periods.

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