



University of
New Hampshire

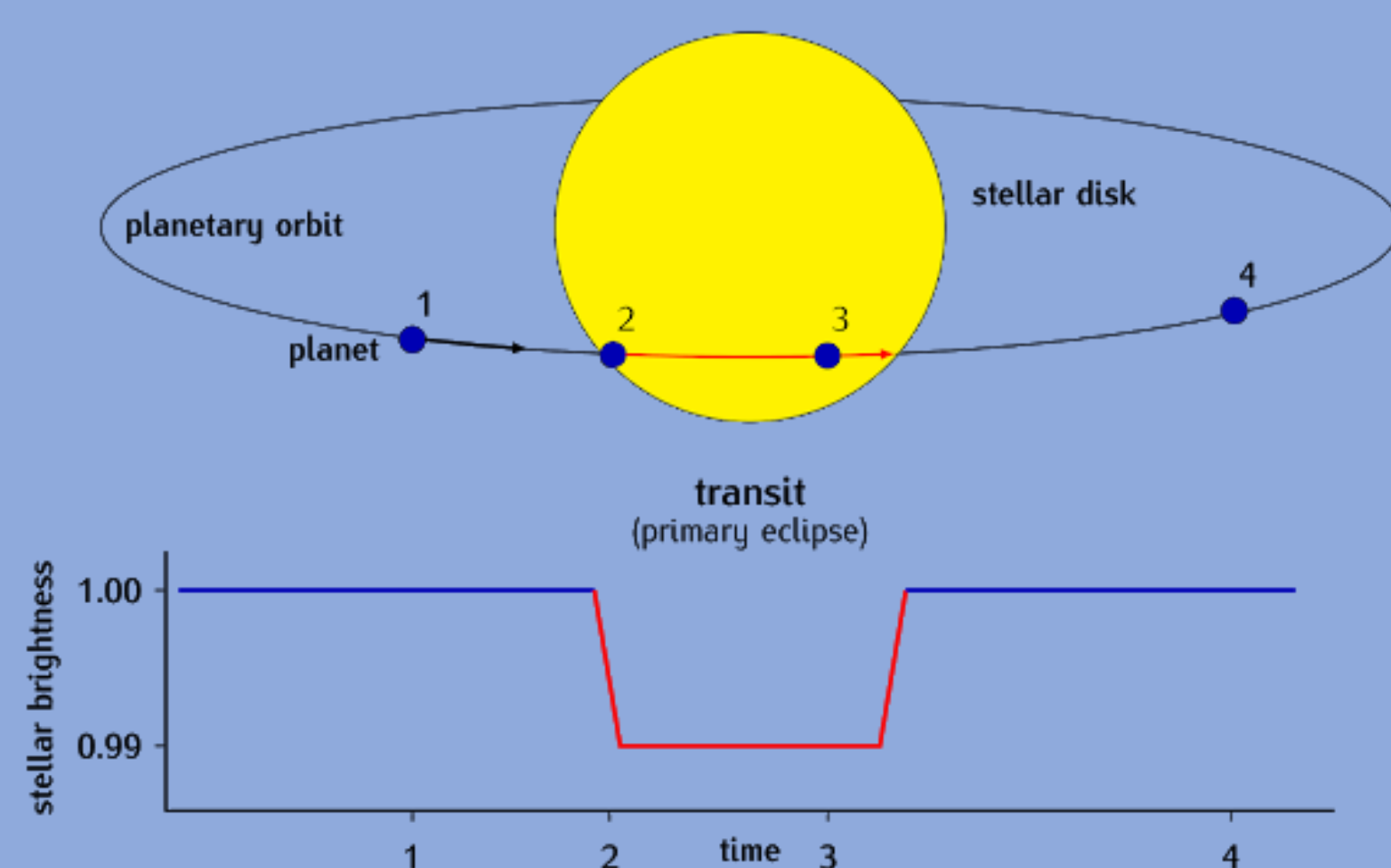
UNH Observatory Exoplanet Transit Depth Limit

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1) Introduction

Exoplanet transits occur when planets that are not part of our solar system pass in front of their parent star relative to our line of sight. This causes the brightness of the star to decrease when the planet passes in front of it, allowing astronomers to deduce properties of the planetary system.



This dip in brightness is measured in magnitudes, a unitless number that is defined as:

$$(1) \Delta M = -2.512 * \log\left(1 - \frac{\Delta F}{F_0}\right)$$

ΔF = Change in flux mid transit
 F_0 = Flux when not in transit

Where:

$$(2) \frac{\Delta F}{F_0} = \left(\frac{R_p}{R_*}\right)^2$$

R_p = Radius of exoplanet
 R_* = Radius of star

2) Goals and Methods

GOALS:

The goal of this project is to determine the UNH Observatory minimum exoplanet transit depth. This value is important to the observatory because it allows the university to obtain potential exoplanet datasets from survey telescopes such as NASA's Transiting Exoplanet Survey Satellite (TESS). We can then confirm and / or perform follow up transit observations on the newly discovered systems. This allows the university's observatory to become more research capable.

METHODS:

- Data taken with the UNH observatory underwent differential photometry analysis in AstrolmageJ (AIJ).
- AIJ fits a curve to the transit by taking the transit period, stellar radius, orbital inclination and quadratic limb darkening coefficients as parameters.
- AIJ uses this curve and the parameters listed above to estimate planetary radius. This value is used with equations (1) and (2) to produce a transit depth.



- Mean spread and standard deviations from residuals of two transits are averaged. An error analysis of the transit allows us to estimate the minimum detectable transit with the current Observatory instrumentation.

3) Analysis

The transit observation chosen for the photometry depth analysis was **HAT-P-56b**, an F type star at a distance of 310 parsecs. After going through the photometric process using AIJ, the fit yielded a (χ^2/df , goodness of fit) of 0.97. The transit depth calculated using quadratic limb darkening values (found by Huang et al.), and other parameters obtained from *The Extrasolar Planet Encyclopedia* is 0.0112 ADU (analog-to-digital units). This translates to a depth of 12.24 mmag (10^{-3} mag). According to the Exoplanet Transit Database (ETD), the accepted transit depth is 12.0 mmag, giving an error of 0.23 mmag or 2%.

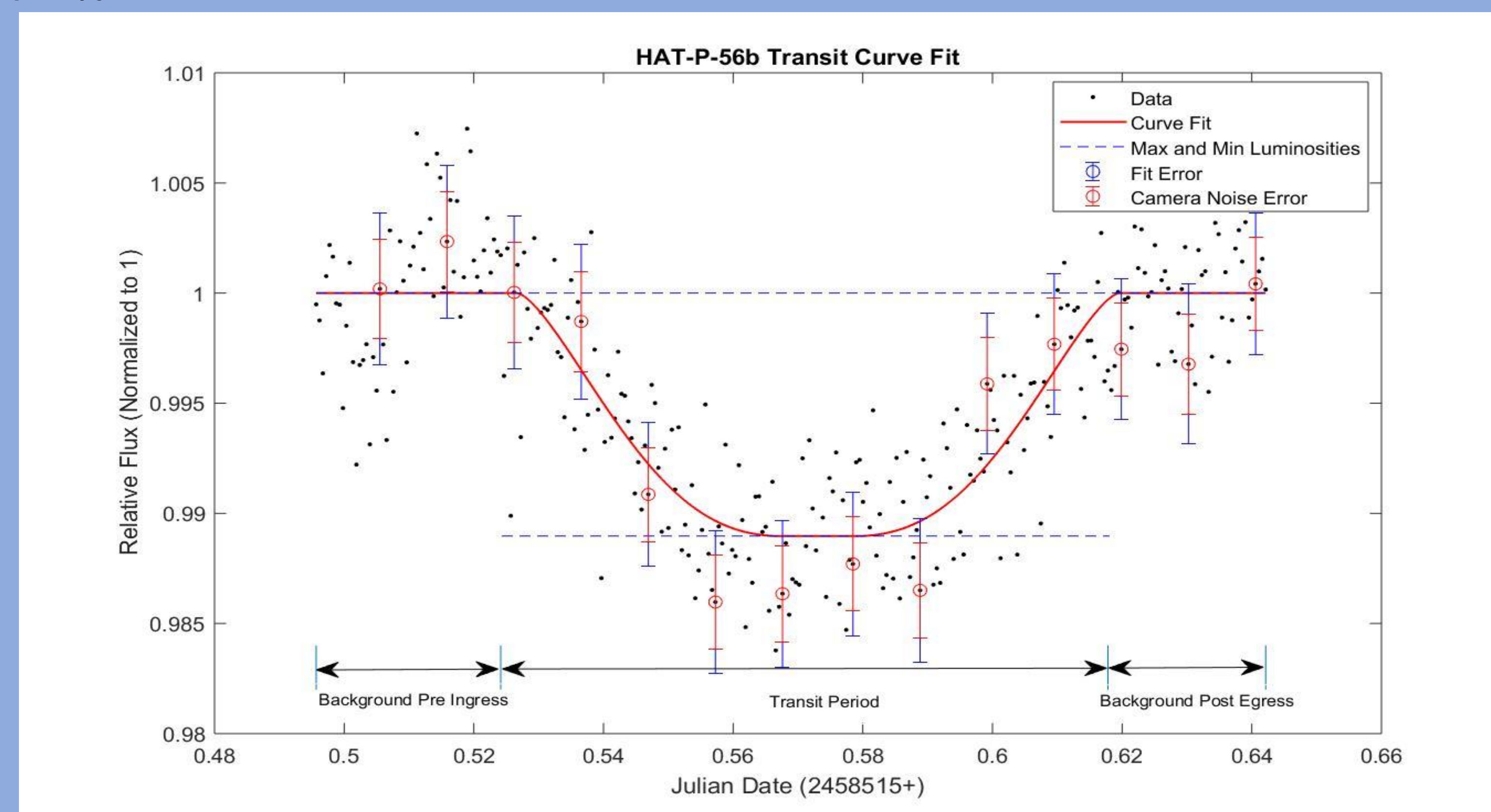


Figure 1. HAT-P-56b transit with AIJ fit and noise error bars. Background and transit regions are labeled.

Z-Scores, or the number of standard deviations from the mean were used to probabilistically determine if the transit is statistically significant, or if it is due to noise or other factors. This assumes the data spread follows a normal distribution.

The Z-Score shown below was calculated for this transit at 3.57. For example, using a 95% confidence level with a Z-score of 3.0 gives a probability of ~ 0.01% of occurrence. This means the probability of the measured transit depth occurring due to random fluctuations is < 0.01%, or the transit can be deemed statistically significant.

$$(3) Z = \frac{|x - \mu|}{\sigma}$$

Where: x = Transit Depth,
 μ = Population Mean,
 σ = Population Standard Deviation

To determine the minimal transit depth that we can deem statistically significant, we needed a standard deviation and population mean averaged from transits performed with the best seeing conditions.

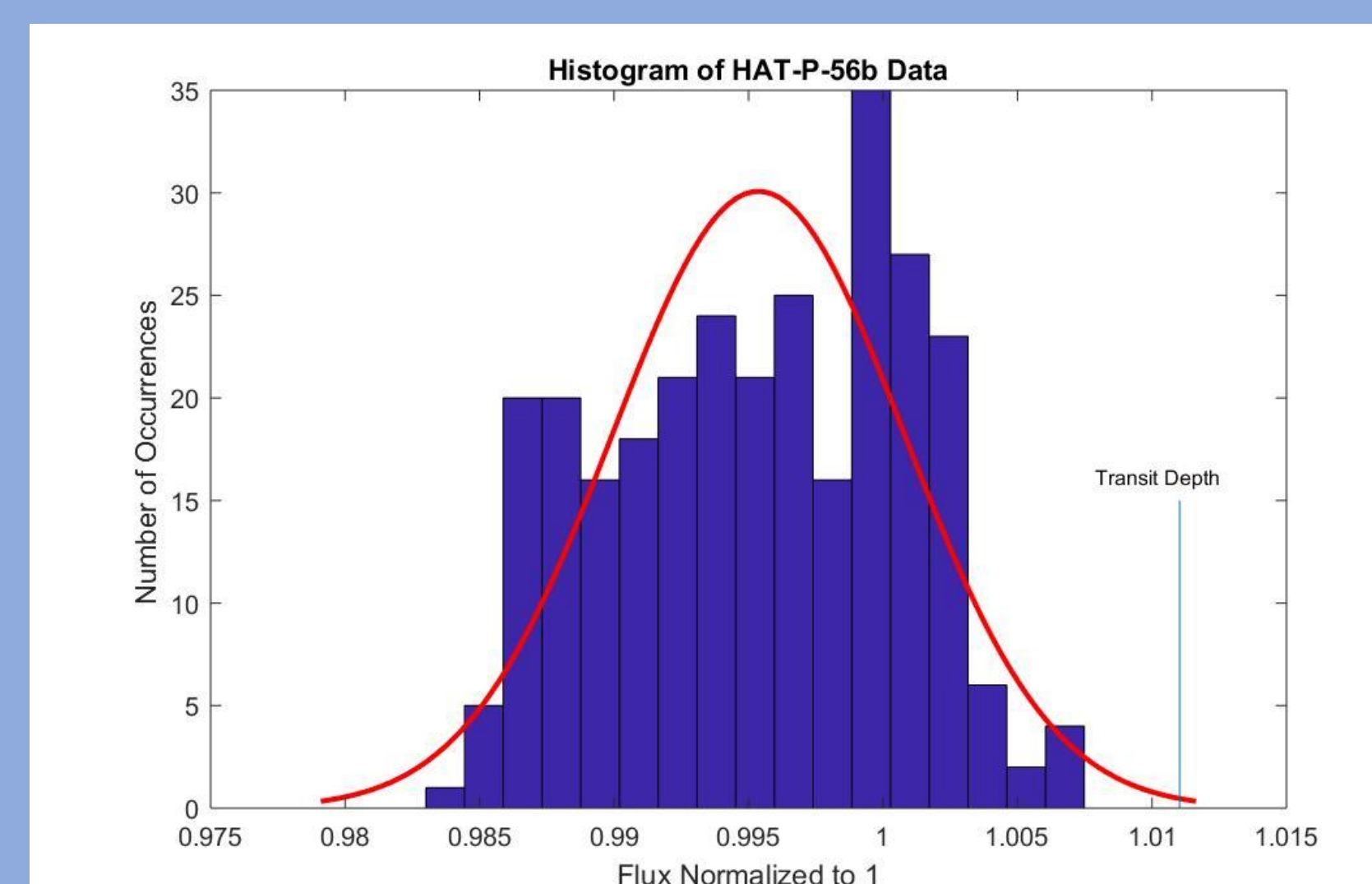


Figure 2. Histogram of HAT-P-56b, demonstrating statistical significance of depth

We needed to determine a Z-Score to set a limit for significance. This value was chosen at 1.7σ , corresponding to a approximately 10% chance of the measured transit being due to error. Standard deviations and means were averaged from WASP-10b, a transit observation also performed on a night with ideal seeing conditions. The population mean due to the fit procedure is always nearly one. The Z-Score equation was then solved for x , the transit depth. Uncertainties in this value are calculated using standard error.

After transits are deemed statistically significant, transit depth should be calculated using limb darkening coefficients, which take into account the darkened edges of a star.

4) Results

By averaging the mean spread from the background of two of the most ideal transits, or those performed on the nights with best seeing conditions (HAT-P-56b and WASP-10b), the standard deviation of the data after performing photometry in AIJ was determined to be 0.0034 ADU, which translates to 3.69 mmag.

Since the decision was made to make the Z-Score, or the allowed number of standard deviations of the mean from the background data 1.7σ , we estimate the transit depth to be:

$$7.4 \pm 0.6 \text{ mmag, or } \pm 8\%$$

A later transit observation is planned on being performed to experimentally confirm this value.

5) Discussion / Future Work

Now that a lower transit depth limit to within some uncertainty is determined, the University of New Hampshire will be able to contact exoplanet survey telescope teams and / or databases to retrieve more accurate datasets for future research. This essentially will help make the UNH Observatory more capable to participate in follow-up exoplanet transits observed by ground and space based observatories.

Other thesis projects performed by colleagues will make the observatory more capable by enabling autoguiding and demonstrating the effects of data reduction using flat field frames. Both of these contributions should make data collection for transits easier and increase data quality, potentially lowering the current estimate at the transit depth limit.

6) Acknowledgements and References

I would like to thank UNH Observatory Director John Gianforte and Professor James Ryan in assisting me in the processes and completion of this project over the course of my Junior and Senior years. Tom Ireland and Anthony Cappuccio's work at this conference on image calibration and autoguiding respectively will improve the observatories research capability and potentially provide a lower depth limit.

References:

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