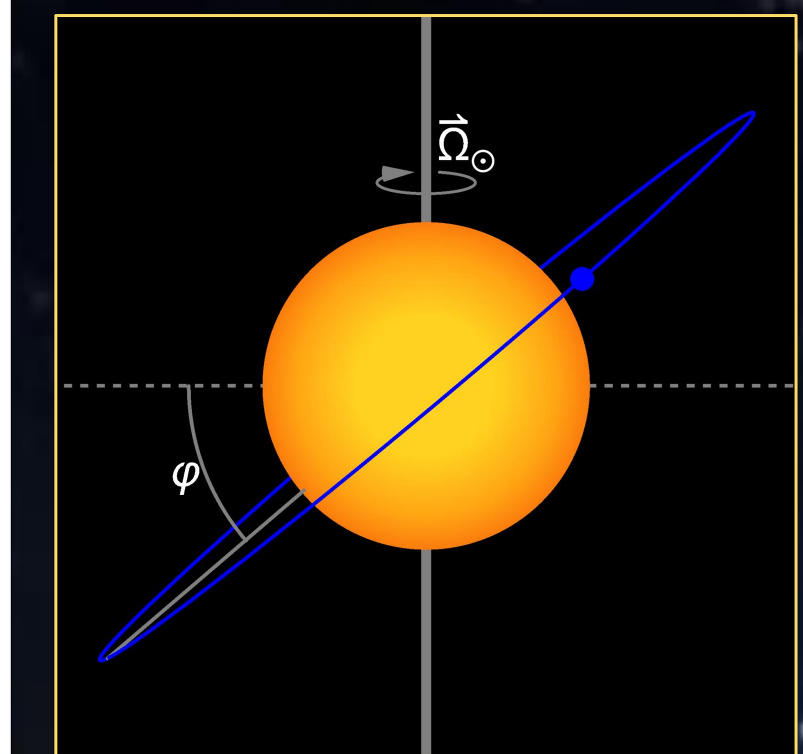
Constraining Planetary Formation with Gravity Darkening on Variable Stars

Samuel A. Myers[1], Jason W. Barnes[1], John P. Ahlers[2]

1: University of Idaho – Department of Physics; 2: NASA Goddard Space Flight Center

Introduction

Figure 1

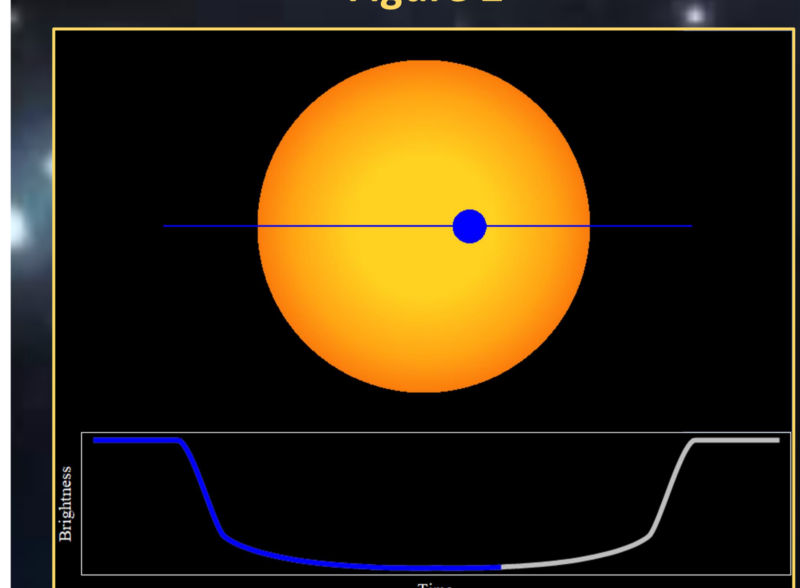


Above: Example of a planet, shown in blue, orbiting a star with rotation rate $\Omega_\odot$, in an orbit misaligned by angle φ.

- Observations of exoplanets have revealed many systems to be misaligned (Figure 1)
  - This goes against our understanding of planetary formation[3]
- New models of planetary formation are needed, requiring precise data to constrain these models
- We set out to measure the spin-orbit misalignment of systems whose alignment is likely conserved from initial formation
  - This will provide a wealth of statistical data with which to constrain new theories of planet formation

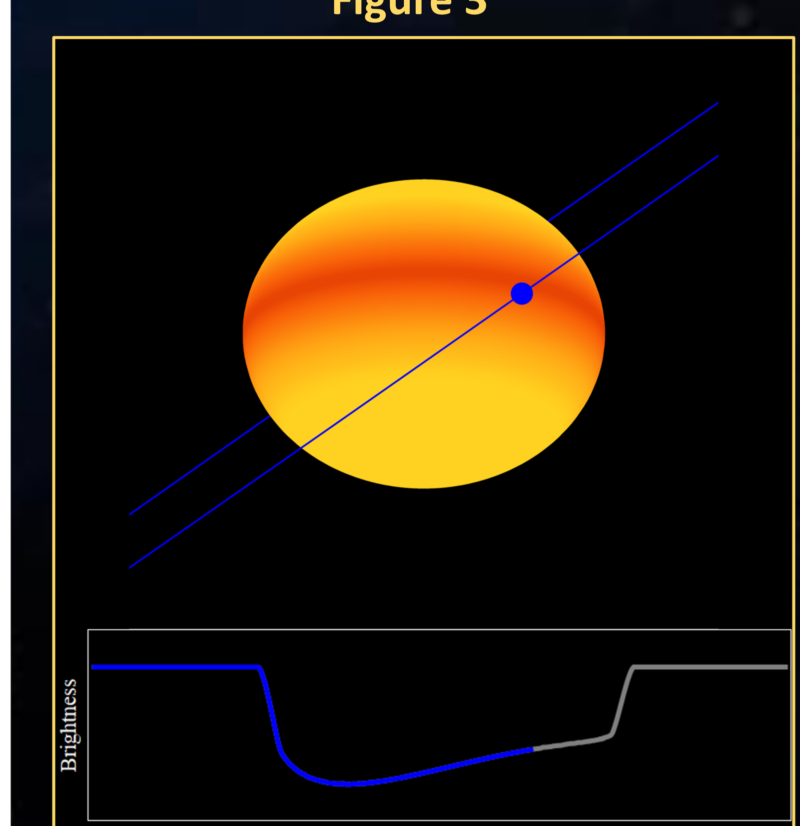
Methods

Figure 2



Above: A planet passes in front of a star, blocking some of its light, creating a dip in brightness referred to as a transit.

Figure 3

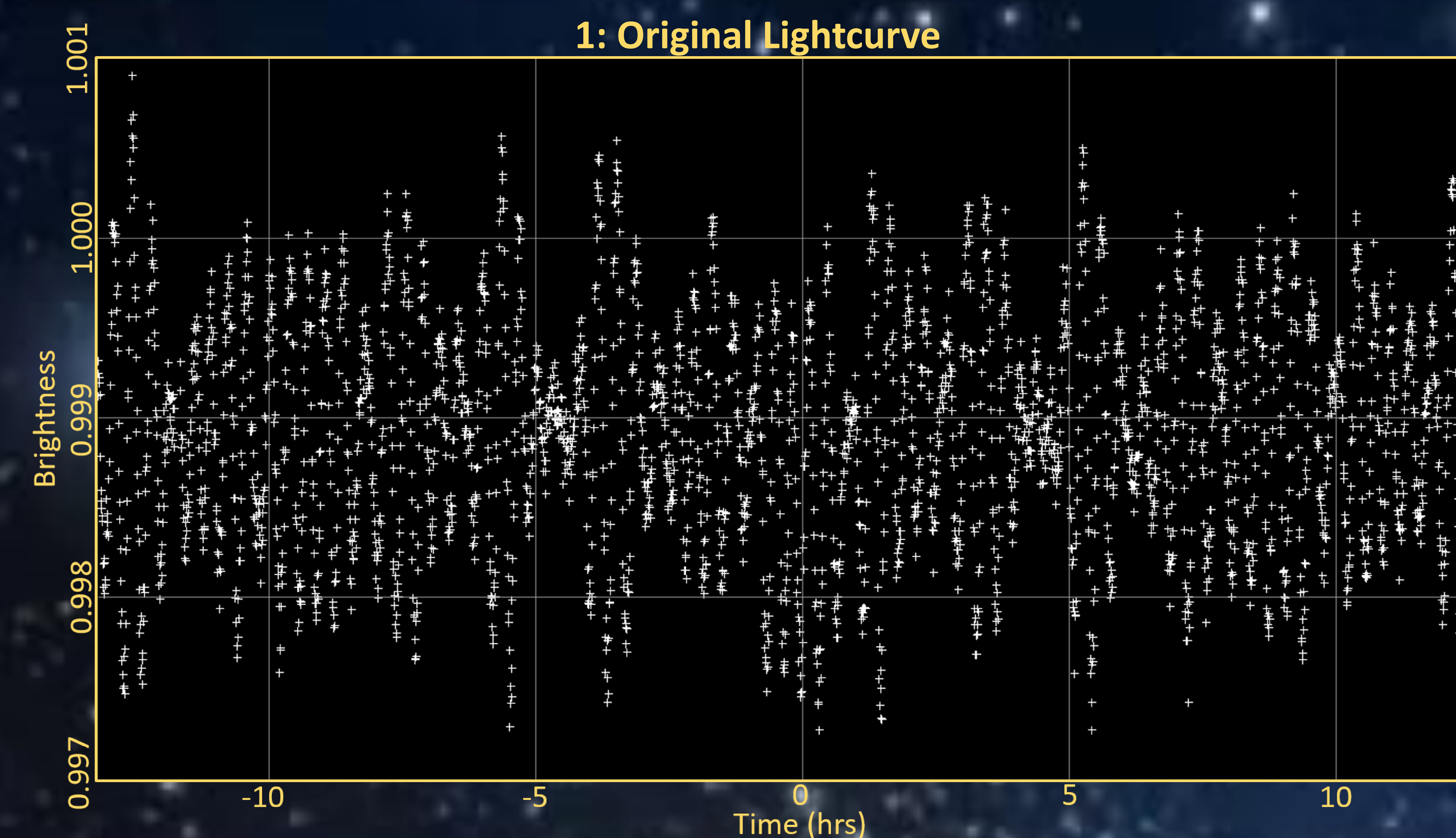


Above: A misaligned planet passes in front of a gravity darkened star. As it passes the warmer (brighter) south pole it blocks more light than as it passes the colder (dimmer) equator, producing an asymmetric transit.

- We measure spin-orbit misalignment using data from the *Kepler* Space Telescope
  - *Kepler* produced stellar brightness graphs called transit light-curves (Figure 2)
- We study fast-rotating stars that display a pole to equator dimming known as gravity darkenening[2]
  - This produces asymmetric lightcurves (Figure 3) and makes it easy to measure spin-orbit misalignment
- Gravity darkened stars are often variable stars
  - These stars have inherent variation in their brightness (KOI-972 1)
- This variation also contains information about the star-planet system
  - We can independently use variability to measure spin-orbit misalignment[1]
  - Variability can also obscure the transit
- We need a technique to remove and analyze the variability

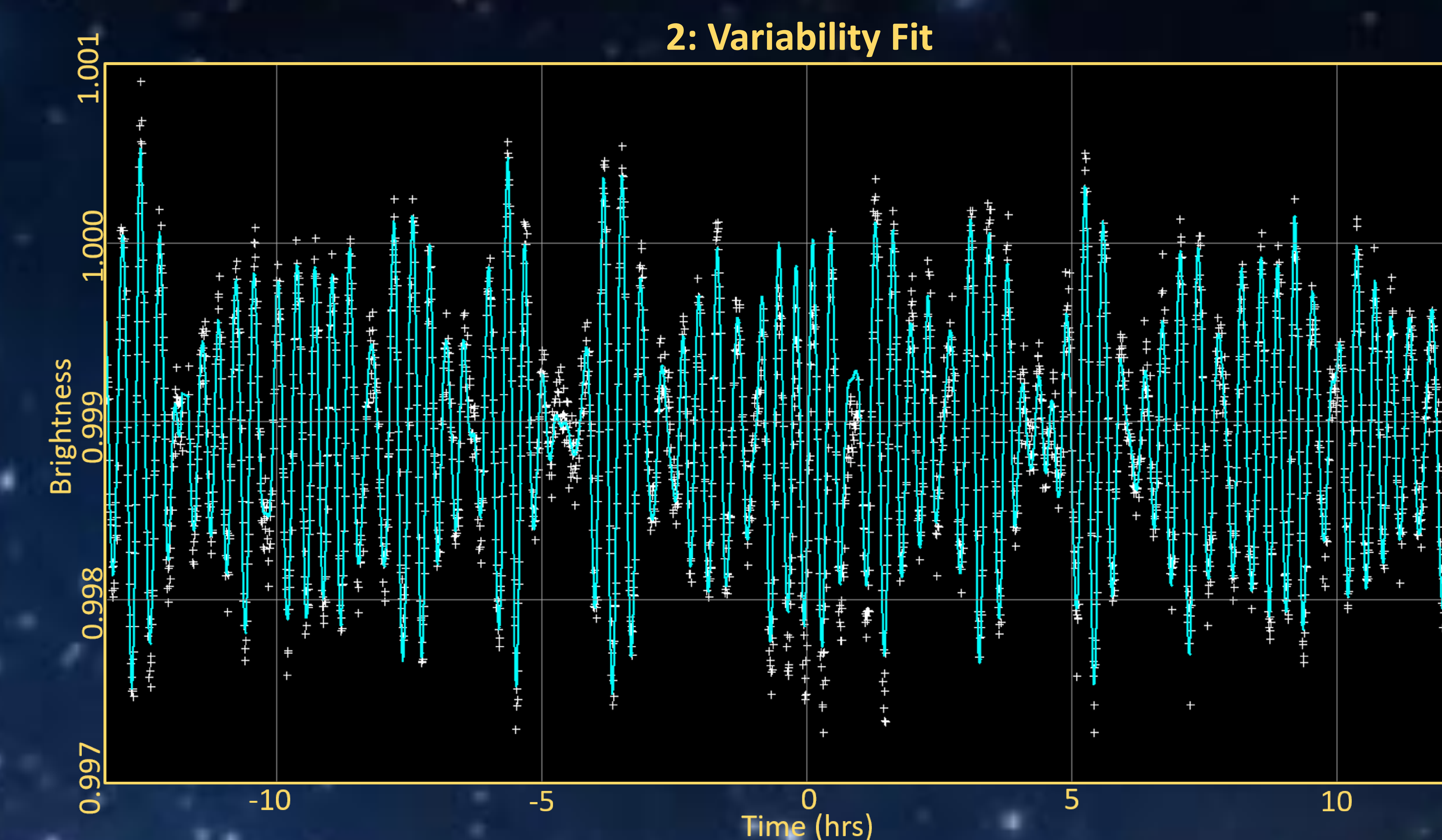
KOI-972

1. KOI-972.01 is a planetary candidate orbiting a star with an effective temperature of 7800 Kelvin and a high projected rotational velocity. KOI-972.01 orbits with a period of about 13 days and its star is highly variable, making it an ideal candidate for our technique.



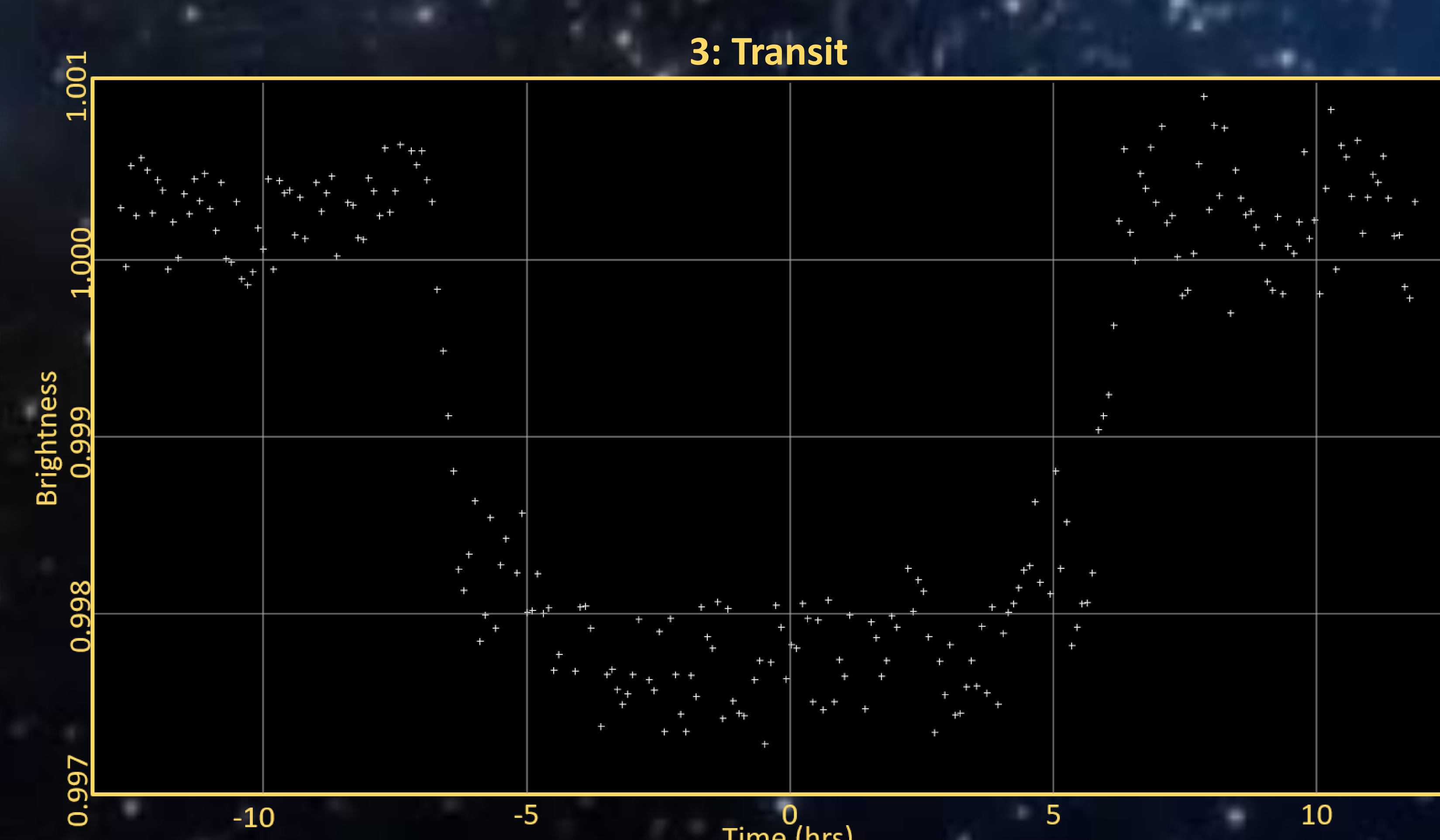
Above: Section of KOI-972 shortcadence lightcurve, made by sampling the star's brightness every 60 seconds.

2. We first select portions of continuous data spanning 30 days and measure the variability signal. From here we can make our first measurement of the stellar obliquity, a precursor to measuring the spin-orbit misalignment, defined as the angle between the star's pole and our line of sight. We measure a stellar obliquity between 70° and 74°.



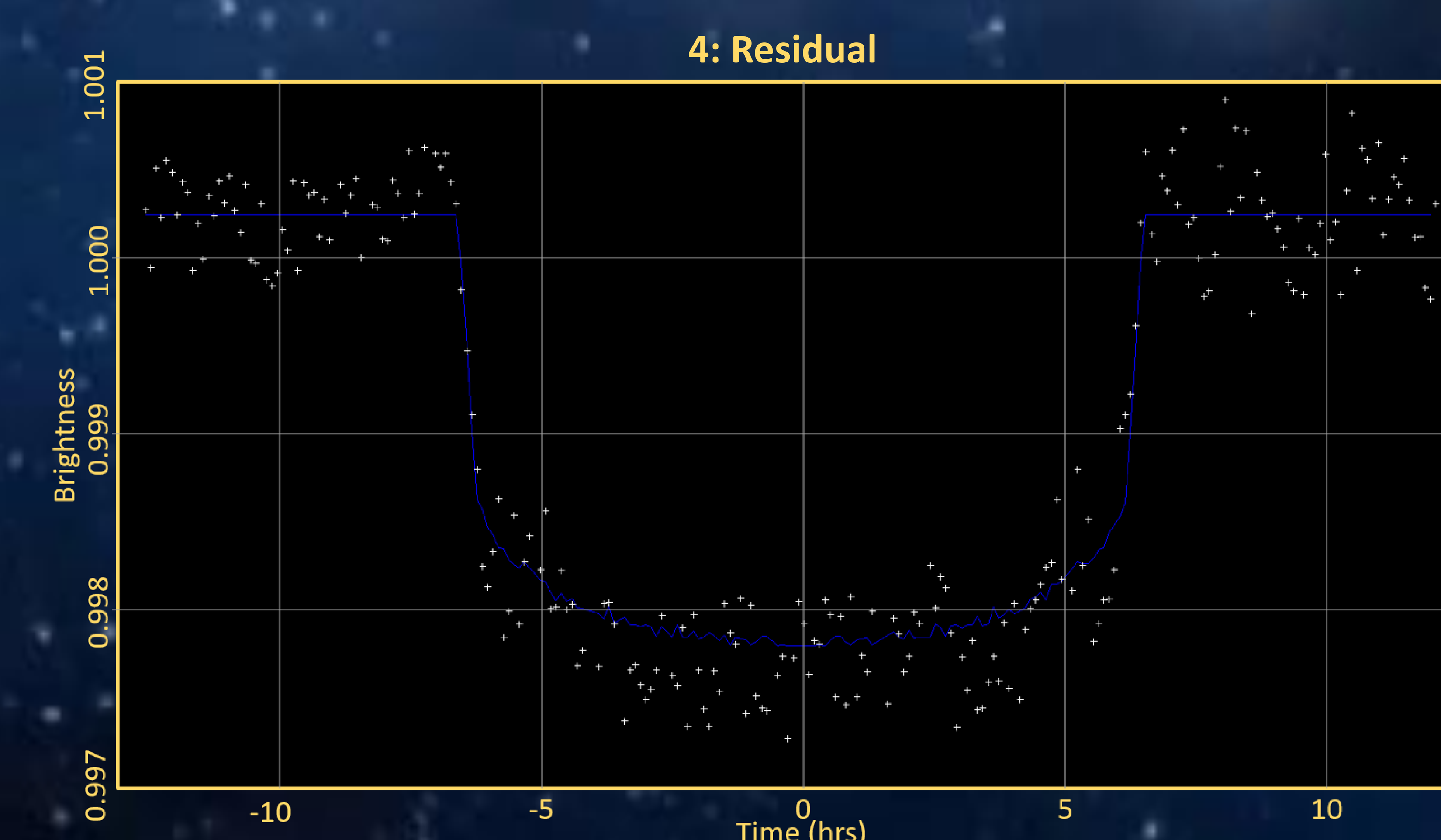
Above: Section of KOI-972 lightcurve with our fit of the stellar variability superimposed on top. The fit closely matches the variable signal.

3. Once the variability is measured, we are able to subtract it from the original lightcurve. By combining multiple 30 days portions together we are then able to reveal the transit.



Above: Transit of KOI-972.01 revealed after subtracting the variability from the lightcurve and folding/binning the data.

4. We apply our gravity darkening technique and fit for the transit parameters, providing our second measurement of the stellar obliquity. Gravity darkening fits indicate an obliquity around 340°.



Above: Transit of KOI-972.01 with gravity darkening fit superimposed on top.

Results

Gravity darkening and stellar variability analysis have given two different measurements of the stellar obliquity. We believe this discrepancy is due to an oversimplification in our stellar variability analysis. Once this discrepancy is resolved we will not only have a measurement of the spin-orbit misalignment for KOI-972, but we also hope to apply this technique to planets discovered by NASA's *Transiting Exoplanet Survey Satellite* (*TESS*). This would allow us to measure the spin-orbit misalignment of many more systems and create a better overall picture of planetary formation.

Funding

We would like to thank the following sources for funding this work:

1. University of Idaho Honors Program
2. University of Idaho Office of Undergraduate Research
3. Dr. Brian and Gayle Hill
4. NASA Astrophysics Data Analysis Program Grant NNX14AI67G

References

1. Goupil, M-J, et. al. (2000). Rotational Splitting of delta Scuti Stars. Delta Scuti and Related Stars, Vol 210.
2. von Ziepel, H. (1924). The Radiative Equilibrium of a Rotating System of Gaseous Masses. Monthly Notices of the Royal Astronomical Society, Vol. 84, p.665-683.
3. Woolfson, M. M. (1993). The Solar System-its Origin and Evolution. Quarterly Journal of the Royal Astronomical Society, 24, 1-20.