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Using Gravity Darkening and Asteroseismology to Measure the Misalignment of KOI-972.01

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Abstract

We use a joint technique to measure the spin-orbit misalignment of *Kepler* Object of Interest - 972.01. KOI-972.01 is a 8.25 $R_\oplus$ planetary candidate on a 13 day orbit around a star with T_{eff} of 7221 K. KOI-972 is a rapidly rotating star with vsini of approximately 120 km s^{-1} and displays stellar variability consistent with that of a δ-Scuti variable. We therefore employ both gravity-darkening analysis and asteroseismology to obtain two independent measurements of the spin-orbit misalignment.

1. Introduction

A key aspect of planetary formation and evolution theory is explaining the occurrence of spin-orbit misaligned planets. In order to test these theories it is necessary to obtain precise measurements of the spin-orbit misalignment of exoplanetary systems. However, making spin-orbit misalignment measurements is difficult, particularly for high-mass stars. High-mass stars, as a result of being "inside out", with convective exteriors and radiative interors, produce asteroseimic variability [5]. This variability complicates transit light curve analysis [4]. Additionally, many high-mass stars are also rapid rotators, further complicating analysis efforts. In order to measure the spin-orbit misalignment of planets orbiting these high-mass, rapid rotators, we therefore employ a joint technique of gravity-darkening and asteroseismology analysis. KOI-972, a δ-Scuti variable, displays a clear variable signal in *Kepler* shortcadence data that has impeded efforts to analyze the system. Our joint-technique allows us to overcome these inherent difficulties in analyzing the system and measure some of the system's bulk parameters.

1.1. Gravity-Darkening

The first element of our joint-technique is gravity-darkening analysis. Some high-mass stars become distorted into oblate spheroids as a result of their rapid rotation. This change in shape causes the star's apparent surface gravity to decrease at the equator and increase at the pole. As a result of the direct relation between stellar apparent surface gravity and stellar effective temperature, rapid rotation creates a pole-to-equator temperature gradient referred to as gravity-darkening [7]. A misaligned planet transiting in front of such a gravity-darkened star will therefore produce an asymmetric transit as it passes over the brighter polar region and darker equatorial region of the stellar disk [2] (Figure 1). Thus, a measurement of the planet's spin-orbit misalignment can be made by fitting the shape of the asymmetry [3].

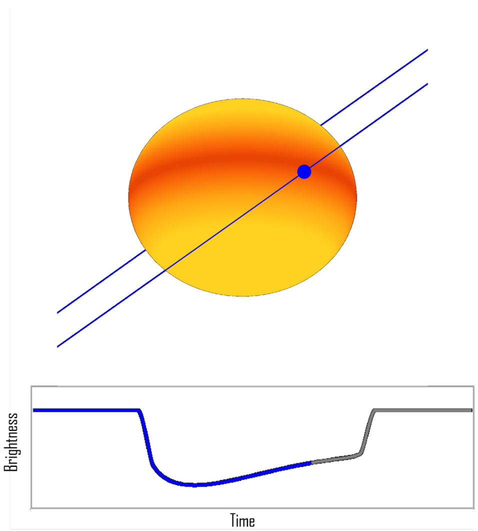

Figure 1: A misaligned planet passes in front of a gravity-darkened star, producing an asymmetric transit. The exact shape of the transit is determined by the spin-orbit misalignment as this determines at what point during transit the planet passes in front of warmer or colder regions of the stellar disk.

1.2. Asteroseismology

In addition to gravity-darkening, high-mass stars can display photometric variability. This variability can both obscure transit data and provide an independent means of transit analysis [6]. We measure the stellar variability using our Linear Algorithm for Significance Reduction [1] (LASR). By employing the fact that δ-Scuti variability can be modeled as a linear combination of sine waves, we are able to separately fit each independent frequency of oscillation that appears in the variable signal. We are then able to subtract the variable signal from the data set, revealing the transit for gravity-darkened analysis (Figure 2). Additionally, we are able to apply asteroseismic theory to the measured variability to obtain a second measurement of the spin-orbit misalignment.

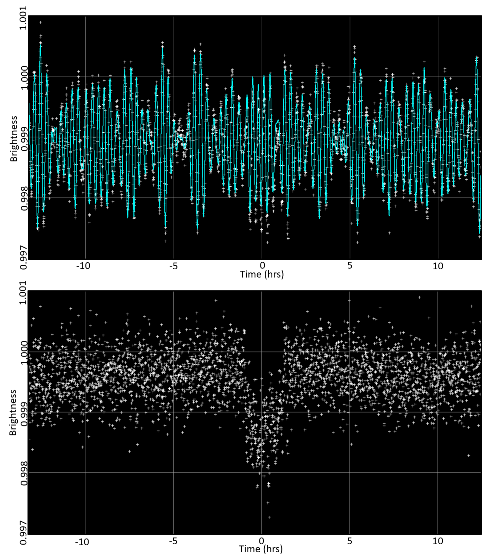

Figure 2: Top: Our combined fit of the asteroseismic variability. Bottom: The transit revealed after removal of the measured variability.

Acknowledgements

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