The Physics of Sun and Star Spots
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The effects of star spots on transit photometry

John R. Hodgson II and Damian J. Christian

Physics and Astronomy Department, California State University, Northridge
18111 Nordhoff Street, Northridge, California 91330-8268, United States of America
email: John.Hodgson.71@my.csun.edu
Damian.Christian@csun.edu

Abstract. We have undertaken an observational program to photometrically monitor several transiting planet host stars. The Rabus *et al.* result for TrES-1 showed the dramatic effects star spots can have on transit photometry. We will investigate the effects of spots on transit light curves and estimates of planetary radii. The observed spot patterns will be used to derive the rotational periods of our sample. Our sample includes several of the newly discovered transiting ESPs from the SuperWASP, HAT, TrES, and Kepler projects.

Keywords. Stars: starspots, planetary systems, techniques: photometric

1. Introduction

Currently, the discovery of new extra-solar planets is occurring nearly every day. Approximately 20% of these are 'transiting' extra-solar planets (TESPs) found through photometric observations of their host stars. Precision photometry combined with radial velocity measurements constrain the values of the planetary radii in addition to the calculated inclination angle of the planetary system. Variations in the photometry of a planetary system is often due to stellar activity. While these variations are normally detrimental to establishing the physical parameters of the planetary system, they can be used to gain information about the host stars.

Stellar activity is a prominent problem in deducing the planetary parameters of late type stars. The occultation of stellar activity by a planet changes the shape of the transit light curve and can lead to incorrect estimates of the planet's radius. An example of this occurred during observations of the active K0V star TrES-1 and was reported by (Rabus *et al.* 2009, Rabus *et al.* 2009). Their report stimulated a search for other instances of stellar activity on Tres-1 and other stars with known transiting extra-solar planets. Additionally, planetary transits may be used to infer physical properties of stellar spots, and the multiple transits easily available from space-based missions, such as CoRoT and Kepler have been used for these studies (Silva-Valio *et al.* 2010).

2. Overview

We have undertaken an observational program to photometrically monitor several transiting planet late-type host stars that are expected to have starspots. We are interested in investigating how starspots effect the transit depth and derived planetary radii. Additionally, information on stellar rotation rates can be determined from stellar activity present over multiple transits. In the current paper, we present our initial findings for this project.

Table 1. Known characteristics of targets selected for follow-up photometry.

Target Name	Spectral Type	Stellar Magnitude [V]	Stellar Radius [R_{Sun}]	Rotational Period [days]	Planet Radius [R_J]	Planetary Period [days]	Inclination [degrees]
WASP-10	K5	12.7	0.783	11.9 ± 0.2	1.08	3.093	86.8
Kepler-6	G1	13	1.391	≈ 6	1.323	3.234	86.8
Kepler-7	F8\G0	13.9	1.843		1.478	4.886	86.5
Kepler-8	F7\9	13.9	1.486		1.419	3.523	84.07
TrES-1	K0V	11.79	0.82	$40.2^{+22.9}_{-14.6}$	1.081	3.030	86.4

Table 1 contains an overview of some of our primary targets that have been selected for follow-up photometry.

Below is a list of the properties we will be looking for.

Planetary Radii. The radii of exoplanets is found from the change in the host star's intensity during a transit. When a starspot is occulted by the transiting planet, a decrease in the transit depth results which can cause an underestimate of the planet's radius. Similarly, when a plage is occulted by a transiting planet, an increase in the transit depth results which can cause an increase in the calculated planetary radii.

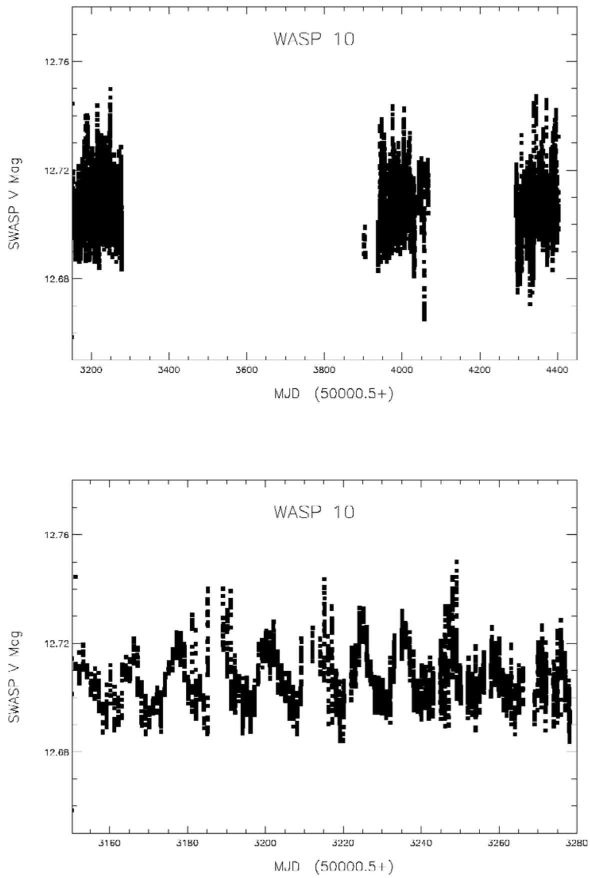

Figure 1. SuperWasp lightcurve of WASP-10 data from 2004 to 2007 (1 January 2004 is JD 2453005.5). The lower image is an expanded view of the smoothed 2004 WASP-10 data showing the 11.9 day period.

Stellar Rotation. The observed occultations of a star spot over multiple transits can yield the rotation rate of the host star. Given the radius of the star, one only needs to measure the distance the spot has migrated across the stellar disk and the time between the transit measurements (Silva-Valio 2008). Assuming no change in the spot's area, variations in the modulations caused by the spot can be used to measure the inclination of the stellar rotational axis.

3. Discussion

In the first phase of our program we have analyzed photometric data from the SuperWASP and Kepler archives and searched for possible stellar rotation periods. We have focused on the stars in Table 1. We have determined a rotational period for WASP-10 of 11.9 days (see Figure 1) in agreement with Christian *et al.* (2008) and more recently with Maciejewski *et al.* (2010), and determine a suggested rotational period of approximately 6 days for Kepler-6 (Figure 2). These specific cases are discussed below.

WASP-10. Currently, the radii of WASP-10b and its K5 host star are under debate. Christian *et al.* (2008) and Dittman *et al.* (2009) both find the radius of WASP-10b to be 1.28 R_J, but Johnson *et al.* (2009) found a radius of 1.08 R_J. This variation is explained by Johnson to be a difference in the transit depths of the normalized light curves, while Dittmann relates it to systematic errors from Johnson's optical system. Intervals of approximately one year interceded the data collection for these measurements and the Johnson and Dittmann teams only used data from a single transit for their findings. A contributing factor to the discrepancy could be star spots located off the transit chord causing a diminished transit depth in the light curve (Silva-Valio (2008); Valio; Boise 2010, these proceedings). If the data collected by Johnson *et al.* occurred during a period of increased stellar activity, this could cause a decreased transit depth. Although the required covering fraction is large, starspots have been found to cover up to 40% of the stellar disc (O'Neal *et al.* 1998).

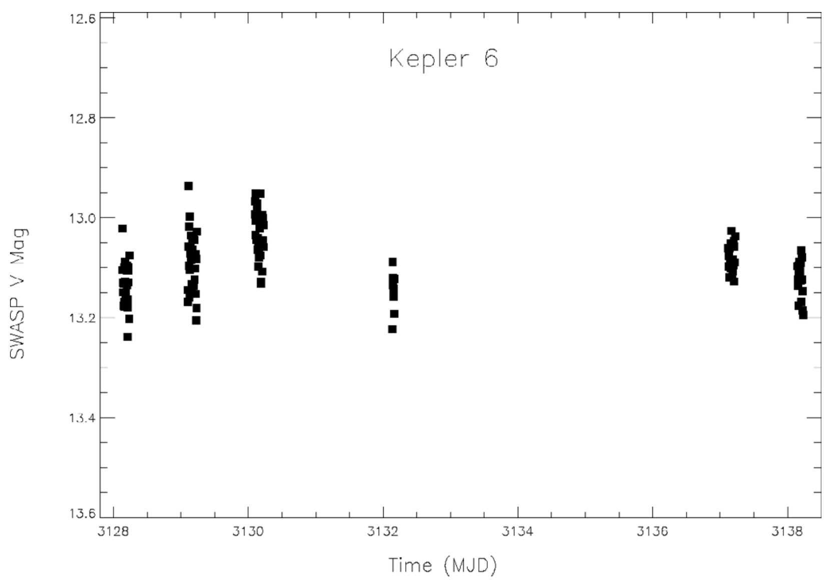

Figure 2. SuperWASP light curve of Kepler-6 from May 2004 (MJD 53128.5 corresponds to 03 May 2004).

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Kepler. Data on the Kepler targets have only recently been acquired by the Kepler mission. However, a review of the SuperWASP light curves for the Kepler targets has shown variation in some of the light curves and a rotational period of approximately 6 days for Kepler-6.

4. Future

We will continue to gather and analyze data on our current targets to establish activity cycles and rotational periods, and then investigate individual transits to derive both planetary and stellar parameters. Further interrogations of the SuperWASP and Kepler archives are under way and new targets being considered.

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