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The Shocking Variability Of Exoplanet Transits

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Abstract

Asymmetries in exoplanet transits are proving to be a useful tool for furthering our understanding of magnetic activity on both stars and planets outside our Solar System. Near-UV observations of the WASP-12 system have revealed asymmetries in the timing of the transit when compared with the optical light curve [2]. A number of possible explanations have been suggested for this variation, including the presence of a magnetospheric bow shock arising from the interaction of the planet's magnetic field with the stellar wind from it's host star [5, 3]. Such observations provide the first method for directly detecting the presence of a magnetic field on exoplanets. The shape and size of such asymmetries is highly dependent on the structure of the host stars magnetic field at the time of observation. This implies we may observe highly varying near-UV transit light curves for the same system. These variations can then be used to learn about the geometry of the host star's magnetic field. For some systems, such as HD 189733, we have maps of the surface magnetic field of the star at various epochs. In this work we will show how incorporating these maps into a stellar wind model, we can model the formation of a bow shock around the planet and hence demonstrate the variability of exoplanet transits.

1. Magnetic Maps and Wind Model

We use magnetic surface maps of HD189733 from June 2007 and also a year later in July 2008 [1]. They use the tomographic method known as Zeeman-Doppler Imaging (ZDI) to reconstruct the large-scale magnetic field on the surface of the star. This method works by inverting a series of circular polarised spectra of the star. The technique enables us to map the latitude and longitude of the largest magnetic features on the star.

These magnetic maps are then used as the lower boundary condition for our wind simulation. We make use of a three-dimensional magnetohydrodynamic (MHD) numerical code called `BATS-R-US` developed at The University of Michigan [4]. The code takes the stellar magnetic surface map and computes the properties of the stellar wind up-to and beyond the orbital distance of the planet, HD189733b.

2 Shock Model

The formation of a bow shock is a direct consequence of the relative velocities between the interaction of the planetary magnetic field and the stellar wind occurring at supersonic speeds. The stellar wind is forced around the magnetosphere of the planet resulting in a empty region in the wind. The distance and geometry of the shock is related to the local stellar wind properties near the planet. The shape of the shock is described as:

$$R(r_M, \theta) = \frac{r_M}{\sin\theta}\sqrt{3\left(1 - \frac{\theta}{\tan\theta}\right)}, \qquad (1)$$

where r_M is the distance to the nose of the shock [6].

The angle the shock makes with the azimuthal direction of the planetary motion is defined as θ_0, and is determined by the geometry of the stellar wind impacting on the planet. The angle is calculated by

$$\theta_0 = \arctan\left(\frac{u_r}{u_{\text{planet}} - u_\varphi}\right), \qquad (2)$$

where u_{planet} is the orbital motion of the planet, and u_r and u_φ are the radial and azimuthal stellar wind speeds respectively [5].

3 Results

Figure 1 shows a typical bow shock transit of HD189733b. The resultant light curve would begin earlier than the corresponding optical light curve because the shock will begin occulting the stellar disc before the planet. The depth of the transit will also be deeper due to the additional absorbing material. By

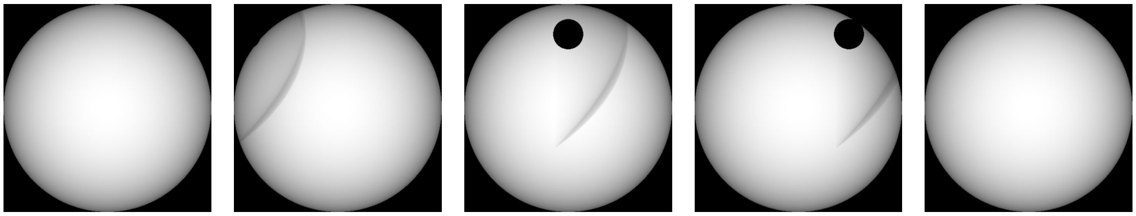

Figure 1: Images showing a typical transit of HD189733b and the bow shock. The first image shows the limb-darkened stellar disc before the planet and the shock begin transiting. The second image shows the shock transiting over the stellar disc before the planet begins occulting the stellar disc; which would result in an early ingress being recorded in the transit light curve. The middle image is mid-transit where both the planet and the shock are transiting over the stellar disc; this would result in a deeper light curve when compared to the optical transit. The fourth image shows the bow shock leaving the stellar disc before the planet. The final image shows the end of the transit, once both the planet and the shock have left the stellar disc.

using our wind simulations we are able to create various light curves to predict the differences in bow shock shape and density as the planet orbits around the host star. We simulate different light curves for the magnetic maps of June 2007 and July 2008. Some light curves for June 2007 are shown in Figure 2. They show that depending on the phase of the host star the transit shape may be very different to the previous or next transit.

References

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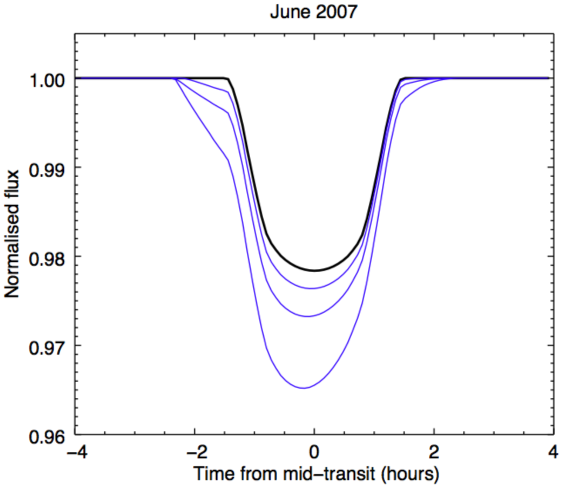

Figure 2: Simulated light curves for HD189733b. The optical transit is shown in black with various bow simulated near-UV light curves in blue. The size and shape of the light curve is determined by the stellar wind which varies as the planet orbits over different longitudes of the star. For some longitudes the absorption almost entirely disappears, whilst at others the presence of extra material is clearly visible.