The Shocking Variability Of Exoplanet Transits

J. Llama, A.A. Vidotto, M.M. Jardine and R. Fares
(1)SUPA, School of Physics & Astronomy. University of St Andrews. North Haugh. St Andrews. Fife. KY16 9SS
(joe.llama@st-andrews.ac.uk)

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 its 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:

\[
R(r_M, \theta) = \frac{r_M}{\sin \theta} \left( 3 \left( 1 - \frac{\theta}{\tan \theta} \right) \right),
\]

(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 \( \theta_0 \), and is determined by the geometry of the stellar wind impacting on the planet. The angle is calculated by

\[
\theta_0 = \arctan \left( \frac{u_r}{u_{\text{planet}} - u_{\varphi}} \right),
\]

(2)

where \( u_{\text{planet}} \) is the orbital motion of the planet, and \( u_r \) and \( u_{\varphi} \) 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
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


