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Simulation of polarimetric effects in planetary system HD 189733

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In this paper we present results of linear polarization modelling for HD 189733 in the U filter using the Monte Carlo method. Our simulations are based on the well known effect that linear polarization of a centrosymmetric unresolved star becomes non-zero during the planet transit or in the presence of spots on its surface. HD 189733 is currently the brightest ($m_V = 7.67^m$) known star to harbour a transiting exoplanet. This fact, along with the short orbital period (2.2 d), makes it very suitable for different types of observations including polarimetry. Since we are interested in occultation effects, a very important parameter is the ratio of the planet to star radii, which is also very large (0.15). As the host star is active and spots may cover up to 1% of the planetary surface, we perform our simulations for different spot parameters such as sizes, locations on the stellar disk, and temperatures.

Key words: polarization, HD 189733, methods: numerical; planetary system

INTRODUCTION

More than 700 exoplanets have been discovered to date and substantial efforts are taken to determine the characteristics of these objects.

There are several successful methods for detecting and studying exoplanets such as the radial velocity technique, transit photometry, microlensing and so on. All of them have their pros and cons, which justifies the development of other techniques. To detect the polarization of the very weak flux that comes from exoplanets, the polarimeter must be exceedingly sensitive. According to theoretical predictions, the polarimeter sensitivity should be at least 10^{-6} [9] to enable the detection of the polarization from the planetary atmosphere.

In 2008 Berdyugina et al. [1] reported on the possible detection of polarized scattered light in planetary atmosphere HD 189733b. They performed polarimetric measurements of the orbital period in the B filter, and obtained two polarization maxima near elongation with an amplitude of $\sim 2 \times 10^{-4}$. However, Lucas et al. [8] considered this value to be too high for the planet and proposed that it could also be explained by the stellar activity. In 2011 Berdyugina et al. [2] confirmed these results and showed that polarization from the spots can reach up to $\sim 3 \times 10^{-6}$ and that the variations of linear polarization obtained from observations cannot be explained by spots. In all these papers the entire phase curve was analysed, but linear polarization arising during the planetary transit were not taken into account. Kostogryz et al. [6] obtained linear polarization (Stokes parameters Q and U) for HD 189733 that appears during the planetary transit using the Chandrasekhar's data [4], which is similar in magnitude to the Berdyugina et al. [1] results. In this study we present the results of modelling the polarization resulting from the planetary transits and stellar spots in the system HD 189733, using the solar polarization [10].

THE METHOD OF CALCULATIONS

This method was thoroughly described by Carciofi & Magalhães [3], Kostogryz et al. [6] and Kostogryz et al. [7]. Here we briefly summarise only the main points of the simulations.

For a given set of parameters (e. g., planetary-to-star radii ratio, semi-major axes and position on the stellar disk) describing configuration of the star-planet system, the following procedure was adopted. Each photon packet (PP), emitted from a randomly selected point on the stellar surface towards the observer, is determined by the weight:

$$\varepsilon_i = \frac{f(\mu) L_*}{N},$$

where L_* is the luminosity of the star, N is the number of iterations, and $f(\mu)$ is a limb darkening law [5], which depends on the wavelength, spectral type, surface gravity, and metallicity.

The weight indicates the radiation emanating from the star and reaching the observer. In addi-

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tion, PP is characterised by linear polarization:

$$Q_i = \varepsilon_i P(\mu)\cos(2\varphi),$$
$$U_i = -\varepsilon_i P(\mu)\sin(2\varphi),$$

where $P(\mu)$ is the centre-limb continuum linear polarization calculated in [10].

For PP emitted in the hemisphere opposite to the observer the weight is equal to zero. On the other hand, when PP is emitted from the visible hemisphere, we can determine whether its trajectory crosses the planet or the spot. The latter ones absorb the photon packet and it is given a zero weight.

After N iterations the flux and Stokes parameters can be found from the following formulae:

$$F_\psi = \sum_N \varepsilon_i, \quad q_\psi = \frac{\sum\limits_N Q_i}{F_\psi}, \quad u_\psi = \frac{\sum\limits_N U_i}{F_\psi},$$

where the index ψ indicates the position of the planet. F, q and u are calculated using time intervals for different positions of the planet.

Assuming different parameters of the spots such as temperature, size and coordinates, we evaluated the flux and polarization variations resulting from stellar activity.

RESULTS AND CONCLUSIONS

We present the results of Monte-Carlo simulations of flux and linear polarization due to a planetary transit and the presence of spots on the stellar surface.

Figure 1 shows the flux, Stokes parameters (Q and U) and polarization degree in the U band. It should be mentioned that in [6] similar simulations for a planetary transit are described, but their results differ from those obtained here due to the differences in the centre-to-limb stellar polarization and filters adopted. Kostogryz et al. [6] used Chandrasekhar's centre-to-limb polarization [4] and limb darkening law for B filter as it was shown there that 3D modelling of the solar polarization [10] is not very suitable for late spectral type stars. On the other hand, Chandrasekhar's data are inappropriate for cool late-type star as well. In this paper, we use the solar polarization [10] for our simulations as any other calculations of centre-to-limb polarization for cooler stars does not exist. Therefore, the next step of our study should be the simulation of the centre-to-limb polarization for cooler atmospheres.

As it was shown in [11], HD 189733 is an active star and spots can cover up to 1 % of the stellar surface. Figs. 2-8 show the same parameters as in Fig. 1 but for different positions of starspots.

The largest value of the polarization degree is found for the case when only one spot is present covering an area of about 1 % of the stellar surface. When this 1 % area is divided into 10 spots, the polarization becomes very small.

We thus show that the influence of spots on the total polarization for HD 189733 is too small as compared to that resulting from the planet transit, $\sim 3 \cdot 10^{-6}$ that is the same as in [2]. These results necessitate further planetary transit observations in order to achieve better statistics and polarimetric accuracy.

REFERENCES

[1] Berdyugina S. V., Berdyugin A. V., Fluri D. M. & Piirola V. 2008, ApJ, 673, L83

[2] Berdyugina S. V., Berdyugin A. V., Fluri D. M. & Piirola V. 2011, ApJ, 728, L6

[3] Carciofi A. C. & Magalhães A. M. 2005, ApJ, 635, 570

[4] Chandrasekhar S., 1950, 'Radiative Transfer', Oxford, Clarendon Press

[5] Claret A. 2000, A&A, 363, 1081

[6] Kostogryz N. M., Yakobchuk T. M., Morozhenko O. V. & Vid'machenko A. P. 2011, MNRAS, 415, 695

[7] Kostogryz N. M., Yakobchuk T. M. & Vidmachenko A. P. 2012, IAU Symposium, 282, 209

[8] Lucas P. W., Hough J. H., Bailey J. A. et al. 2009, MNRAS, 393, 229

[9] Seager S., Whitney B. A. & Sasselov D. D. 2000, ApJ, 540, 504

[10] Trujillo Bueno J. & Shchukina N. 2009, ApJ, 694, 1364

[11] Winn J. N., Noyes R. W., Holman M. J. et al. 2005, ApJ, 631, 1215

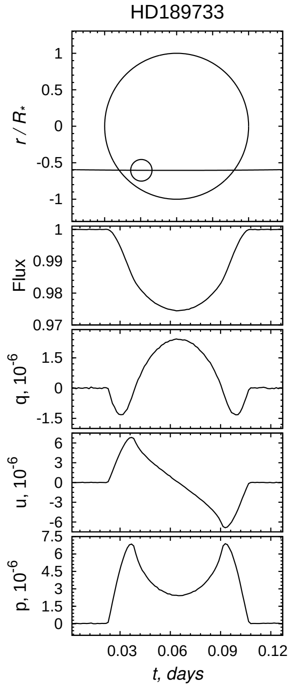

Fig. 1: Modelling planet transit in U band without spots.

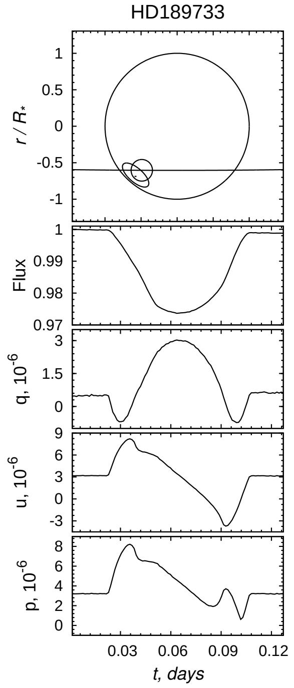

Fig. 2: Modelling planet transit in U band with 1 spot at latitude from -20° to -50°.

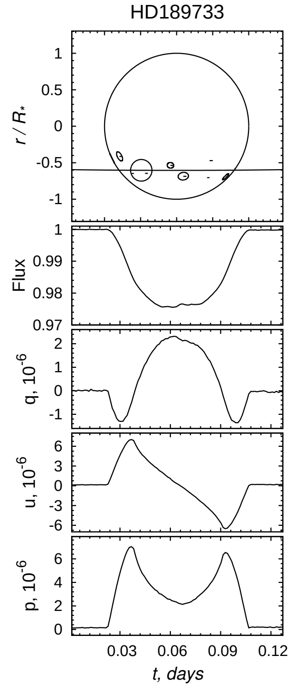

Fig. 3: Modelling planet transit in U band with 10 spots at latitude from -20° to -50°.

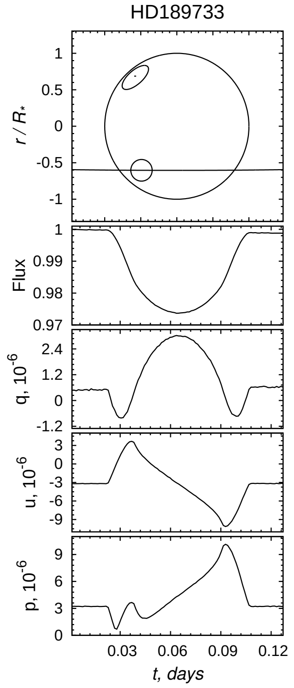

Fig. 4: Modelling planet transit in U band with 1 spot at latitude from 20° to 50°.

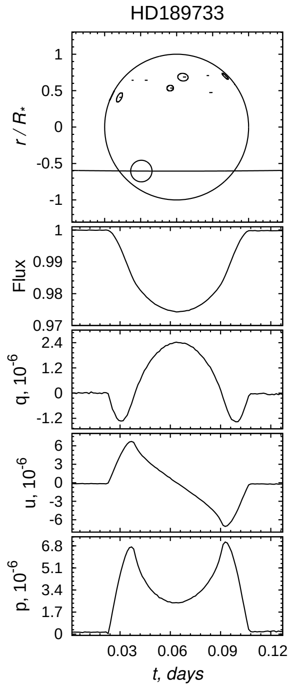

Fig. 5: Modelling planet transit in U band with 10 spots at latitude from 20° to 50°.

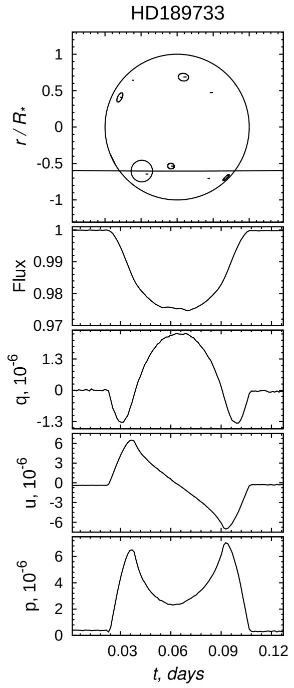

Fig. 6: Modelling planet transit in U band with 10 spots at latitude from -50° to 50°.

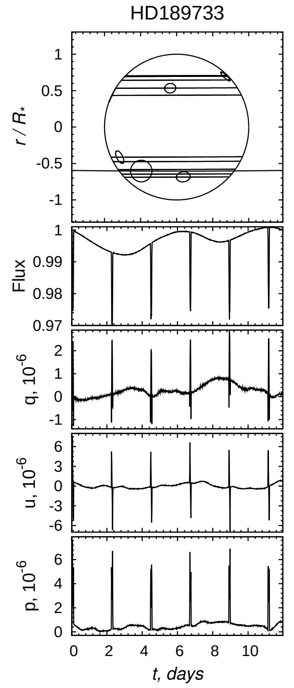

Fig. 7: Modelling planet transit in U band with 10 spots at latitude from -20° to -50° and from 20° to 50° during period of the star.

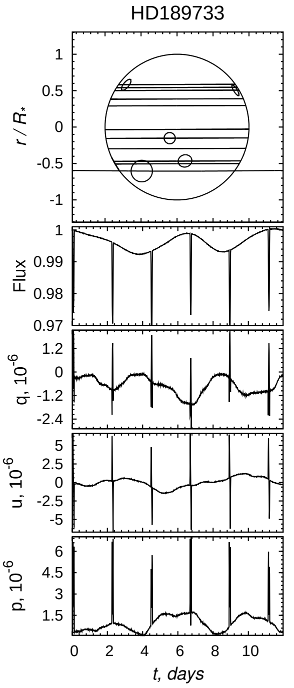

Fig. 8: Modelling planet transit in U band with 10 spots at latitude from -50° to 50° during period of the star.