The (Phased?) Activity of Stars Hosting Hot Jupiters

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Abstract. The activity of stars harboring hot Jupiters could be influenced by their close-in planets. Cases of enhanced chromospheric activity are reported in literature, suggesting magnetic interaction at well determined planetary phases. In X-rays and FUV, we have studied star-planet interaction (SPI) occurring in the system of HD 189733.

In X-rays, HD 189733 shows features of high activity that can be ascribed to the influence of the magnetic field of its planetary companion. Through a wavelet analysis of a flare, we inferred a long magnetic loop of $2R_*$ to $4R_*$, and a local magnetic field of strength in $40-100$ G. The size of the flaring loop suggests a role of the hot Jupiter in triggering this kind of X-ray variability.

In FUV, HST-COS spectra of HD 189733 shows temporal variations in intensity and Doppler shifts of Si III and Si IV lines that can be ascribed to plasma flowing from the planetary atmosphere and accreting onto the star under the action of the combined magnetic field of star and planet. The material from the planetary atmosphere can flow onto the parent star as predicted by MHD models. The foot point of the accretion on the stellar surface results in phased variability observed in X-rays and FUV, when the point, comoving with the planet, emerges at the limb of the star.

1. Introduction

Some stars with hot Jupiters have shown variations of their activity phased with the planetary motion, due to star-planet interaction (SPI) of magnetic and tidal origin, e.g., μ And

HD 179949, τ Boo and HD 189733 (Shkolnik et al. 2003, 2005, 2008; Walker et al. 2008). We focused on the X-ray and FUV variability of HD 189733 observed with *XMM-Newton*−EPIC and HST−COS instruments. Observations in these two bands suggest that phased variability is occurring at $\phi \sim 0.55 - 0.65$ just after the planetary eclipse as result of magnetic SPI and planetary evaporation.

1.1 The target

HD 189733 is the best studied among systems with a transiting hot Jupiter. It is in a binary system, with a quite inactive and old ($t > 5$ Gyr) M4 type star as companion (see Table .1). The activity detected in the primary star is suspiciously high for an age of 5 Gyr (Pillitteri et al. 2010b; Guinan 2013; Pillitteri et al. 2014; Poppenhaeger & Wolk 2014).

Table .1: HD 189733 by numbers

	HD 189733A	HD 189733b	HD 189733B
Type	K 1.5V	planet	M4V
Mass	$0.81 M_\odot$	$1.15 M_{jup}$	$0.2 M_\odot$
Radius	$0.76 R_\odot$	$1.26 R_{jup}$	–
Orbital Period	–	$2.219 d$	$3200 yr$
Mean orbital radius	–	0.003 AU	216 AU
Age	same as companion		≥ 5 Gyr

2. *XMM-Newton* observations

In 2009, 2011, and 2012 we observed HD 189733 with *XMM-Newton*at the eclipse of the planet and the following phases (Pillitteri et al. 2010, 2011, 2014). In all of the three observations a bright flare was observed; the phases of the three flares were in the range $\phi = 0.52 - 0.65$. The flaring activity in HD 189733 results higher than in field stars and in younger active stars.

We conducted a wavelet analysis of the light curve of *pn* from 2012 epoch observation (fig. .1), assuming that a magneto-acoustic oscillation inside the flaring loop is on going during the decay. The oscillation period depends on the loop length, the plasma density and the constraining magnetic field in the loop. A damped oscillation in the main flare with period of 4ks is detected. Combined with density from RGS data $n_e = 3 - 11 \times 10^{10}$ cm^{-3}, we obtain a measure of magnetic $B = 40 - 110$ G and a loop length estimate of $2 - 4R_*$. The size of the loop suggests a magnetic SPI origin for the variability.

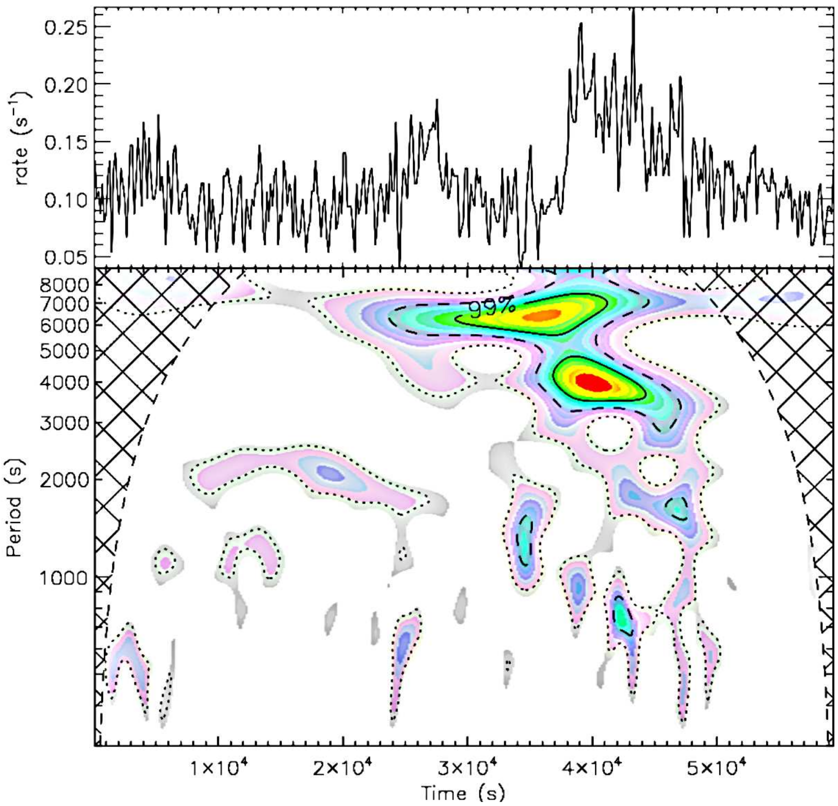

Figure .1: *pn* light curve and wavelet deconvolution of the light curve (see Gomès de Castro et al. 2013, Mitra-Kraev et al. 2005).

3. HST observations

We observed HD 189733 in September 12, 2013 with a visit of five HST orbits, to follow the egress of the planet and the same phases already observed three times with *XMM-Newton*. We acquired high quality COS spectra in the wavelength range 1150-1450 Å. Fig. .2 shows the position of the planet during the HST exposures. At two peculiar phases ($\phi = 0.52, 0.59$) we observed variability of many lines of ions around Ly α. Fig. .2 shows the profile of Si IV, Si III, CII and NV during the first orbit (black spectrum, when the planet is obscured), at phases 0.52 (red spectrum) and 0.59 (blue spectrum). Fig. .4 shows the light curves of the intensity and the centroid shift of Si IV, Si III and C II lines during the HST observation. The two main line increases are visible in most of the spectrum lines, while the centroid red and blue shifts are visible mostly in Si IV and Si III.

4. Conclusions

With *XMM-Newton* and HST-COS observations we determined that high flaring activity is detected in both X-ray and FUV bands after the planetary eclipse. From a wavelet analysis

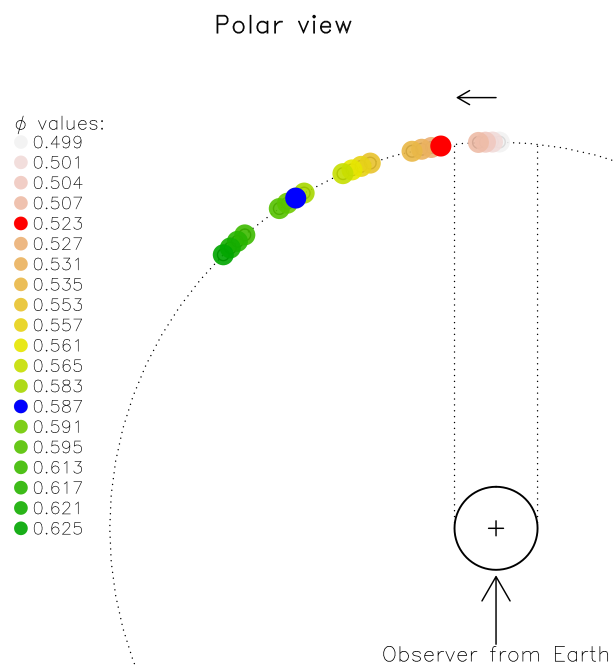

Figure .2: Position of the planet during the HST exposures. The values of the phases are listed on the left.

of the X-ray flare light curve, we infer a long magnetic loop and a magnetic link as a result of interaction between planet and star.

FUV lines of ions around Ly α show two increases of profile intensities. The red shift seen during the first intensity enhancement is perhaps an evidence of the evaporating atmosphere of the planet. The blue shift in the second line brightening is interpreted as the FUV counterpart of phased variability due to magnetic SPI already observed three times in X-rays and occurring in a restricted orbital phases of the planet. MHD models (Matsakos et al., submitted, see also poster by Matsakos et al. at Cool Stars 18) predict that the gas evaporating from the planet can stream and accrete onto the stellar surface driven by the magnetic field. The foot point of the strem on the star can lead the sub-planetary point and explain the phased variability observed in HD 189733.

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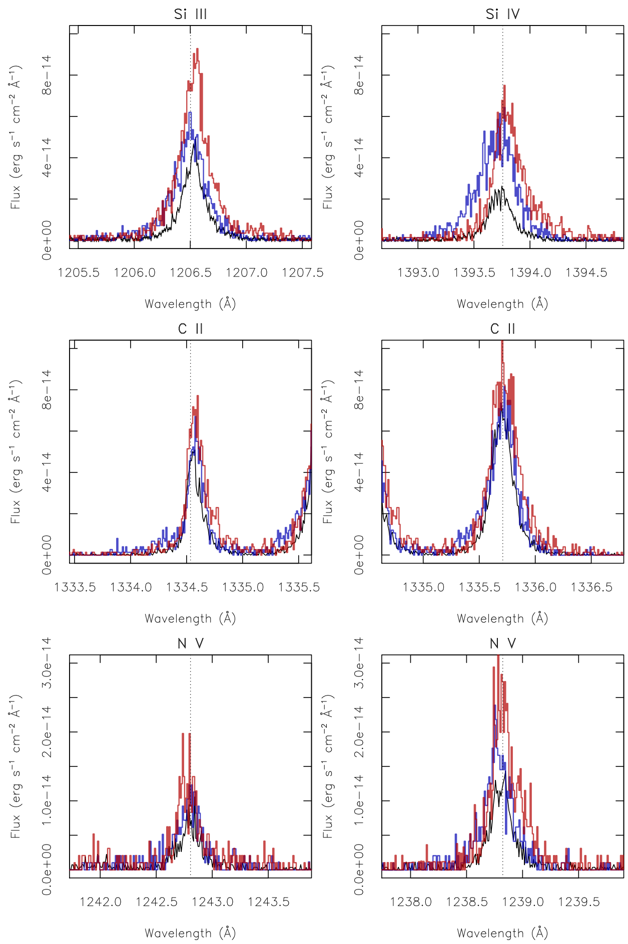

Figure .3: Profiles of lines of the ions Si III, Si IV, CII and NV during the quiescent state (black), phase $\phi = 0.52$ (red), and phase $\phi = 0.59$ (blue). At these two phases increase of line fluxes and opposite centroid shifts are observed.

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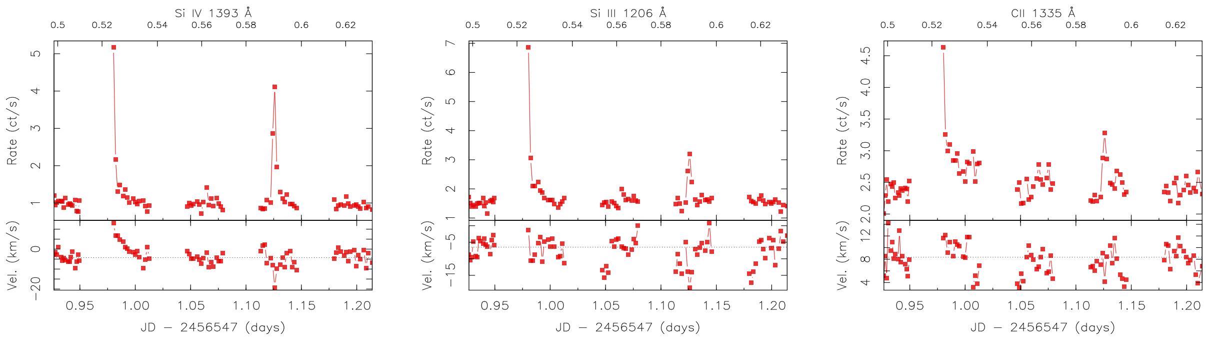

Figure .4: light curves of profile intensity and centroid shift of Si IV at 1393Å, Si III at 1206 Å, and C II at 1335Å.

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