Investigating Star-Planet Interactions in Chromospheric Activities

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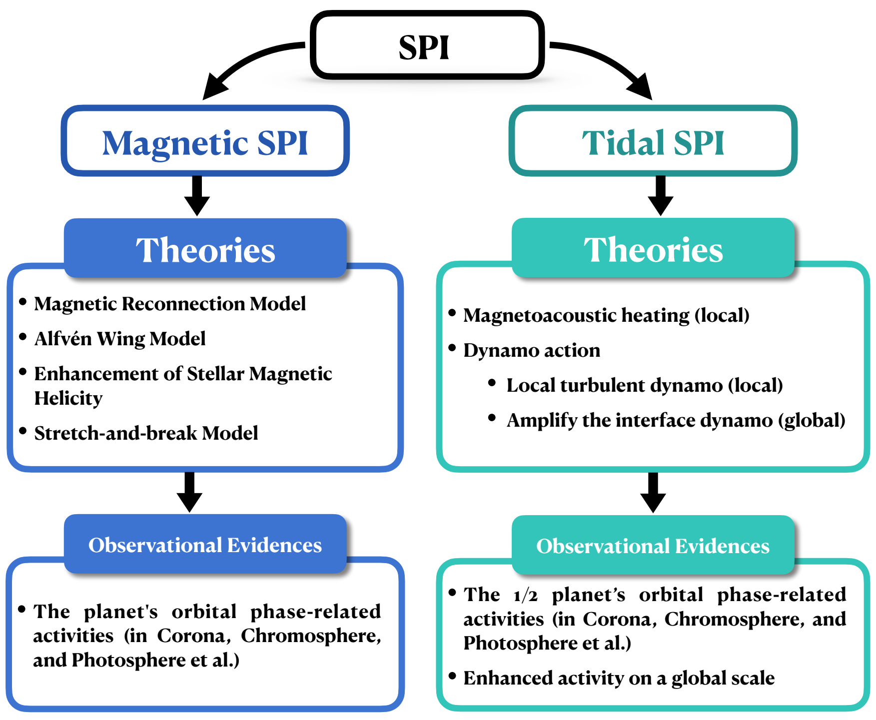
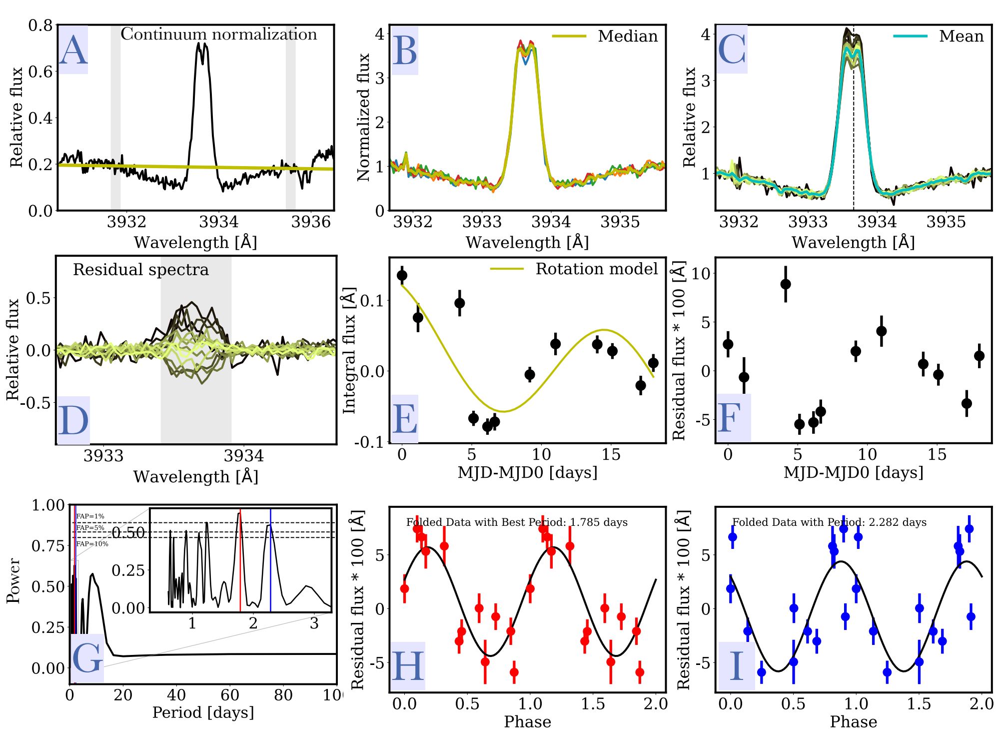
Introduction

The magnetic star-planet interactions (SPI) is a crucial window for studying planetary magnetic fields, which provides insights into the internal structure and habitability of planets. When tidal and magnetic interactions directly affect the atmosphere of stars, they can increase local turbulent velocity, leading to enhanced activity in localized regions of the stellar surface, which can generate activity modulation at 1/2 orbital and one full orbital period separately[1]. Analyzing the periodic components in chromospheric emission flux has been employed to search for stellar-planet interaction events[2][3]. Studies indicate that the strength of such interactions not only depends on orbital distance and planetary mass but also on the magnetic activity cycle of the star itself[4][5][6]. In this study, the periodic characteristics of chromospheric magnetic activity in HD 179949, HD 189733, τ Boo, and υ And have been investigated using the Ca II K, based on Polar archive data[7].



Method



A. Linear fitting is performed on the data (grey) around 2 Å from the line center of the Ca II K line. The fitted line (yellow) is then considered as the continuum, and the spectrum is normalized accordingly.

B. Taking the median of all observed spectra for each observing night (yellow line) to characterize the chromospheric activity level of that night.

C. Taking the average spectrum (cyan line) of all median spectra for individual epochs to represent the chromospheric activity level of each epoch.

D. Subtracting the average spectrum of from the median spectrum to obtain the residual spectrum. Integrating the residual spectrum within a 0.5 Å region around the spectral line center (grey) to obtain the integral flux.

E. Using Equation (1) in Cauley et al. (2018)[2], fitting the integrated flux with MCMC to establish a rotational modulation model (yellow line).

F. Subtracting the rotational modulation model from the integrated flux to remove the rotational modulation.

G. The GLS periodogram of residual flux. The period corresponding to the strongest power (red line) and the period closest to the planetary orbital period (blue line) are marked respectively.

H. Folding the data according to the period with the highest power.

I. Folding the data according to the period closest to the orbital period.

Note: Steps A to F are referenced from Cauley et al. (2018)[2].

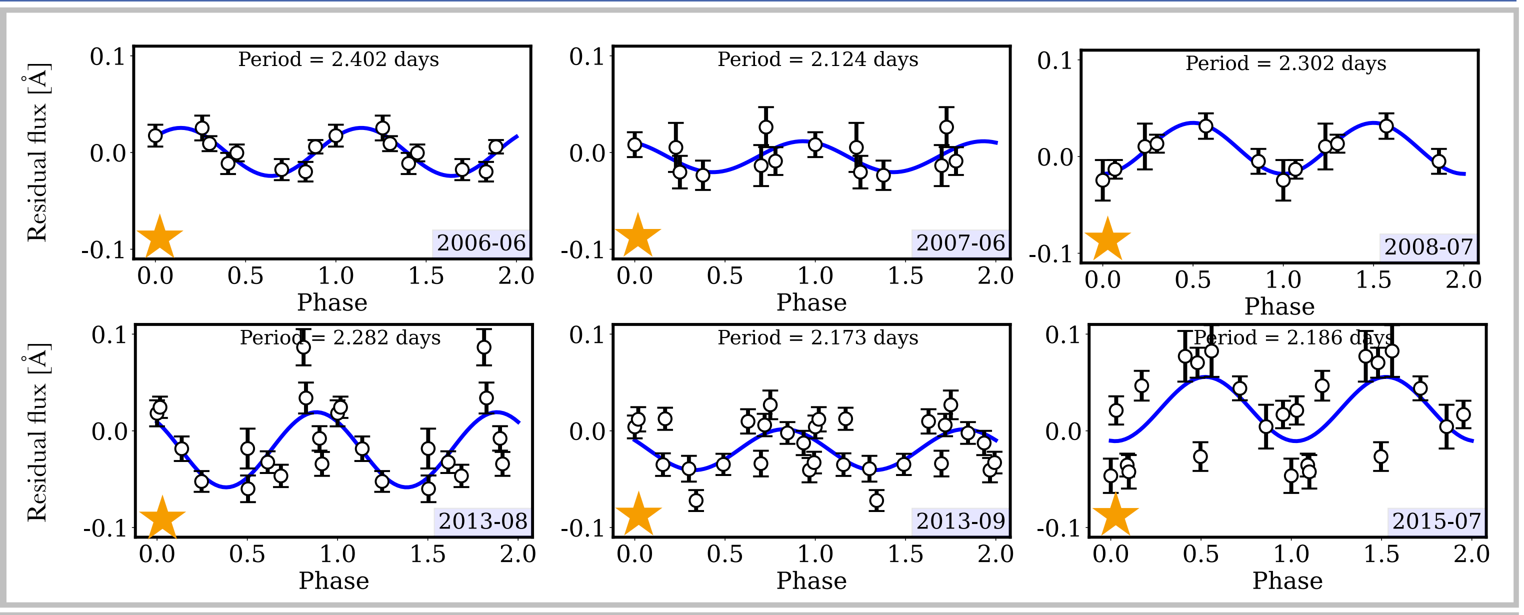
Systems

Objects	P_rot [days]	Age [Gyr]	a_p [AU]	M_planet [M_jup]	P_orb [days]
HD 189733	11.9 ± 0.16	6.8 ± 5.0	0.031	1.14 ± 0.03	2.2186
HD 179949	11.0 ± 0.8	2.56 ± 1.4	0.044	1.04 ± 0.08	3.0925
τ Boo	3.7 ± 0.1	1.64 ± 0.5	0.048	6.13 ± 0.34	3.3124
υ And	12.0 ± 0.1	3.12 ± 0.22	0.059	0.69 ± 0.06	4.6170

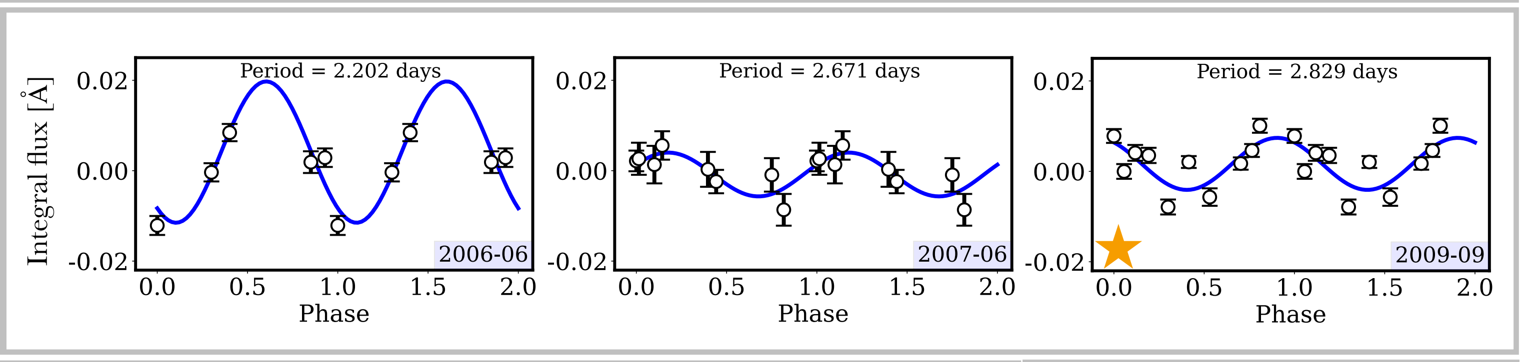
The rotational period (P_rot), age, semi-major axis (a_p), planetary mass (M_planet), and orbital period (P_orb) of the systems[3].

Results

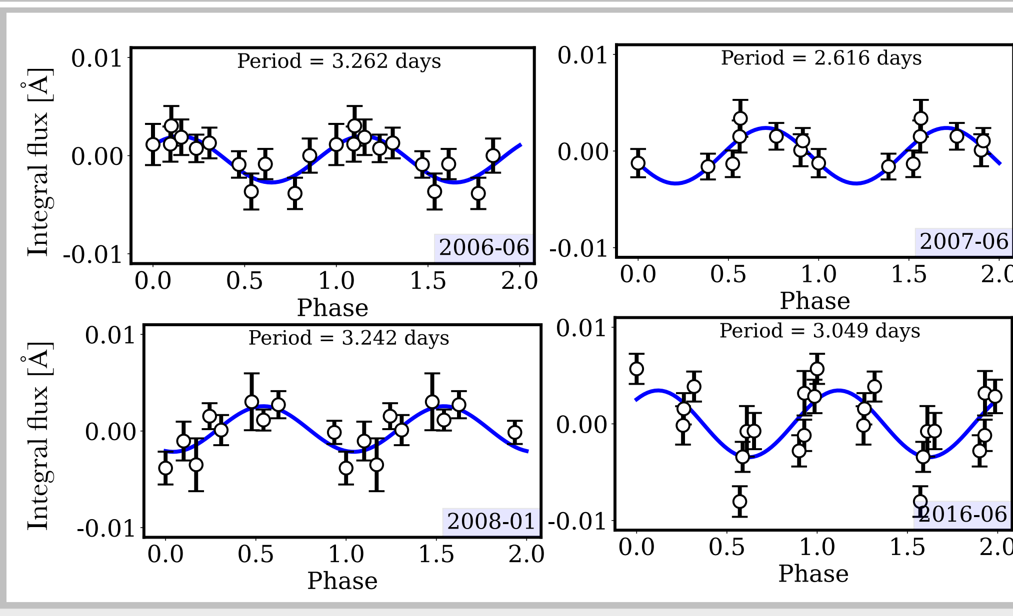
HD 189733



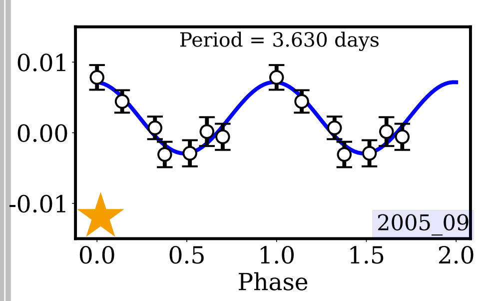
HD 179949



τ Boo



υ And



Folding the data according to the period closest to the planetary orbital period in the GLS periodogram. The ★ denote the dataset processed through the complete A to I procedures, while the remaining datasets skip steps E and F, directly utilizing integrated flux to obtain the GLS periodogram. It is noteworthy that we removed stellar rotational modulation from the datasets of HD 179949 in September 2013 and υ And in September 2005, as the period component with the strongest power detected in these two datasets coincides with the stellar rotation period.

	HD 189733 (P_orb=2.219)						HD 179949 (P_orb=3.093)			τ Boo (P_orb=3.312)				υ And (4.617)
GLS_P_orb	2.402	2.124	2.302	2.282	2.173	2.186	\	2.671	2.829	3.262	\	3.242	3.049	\
GLS_3/4 *Porb							2.202				2.616			3.630
Mean	2.245 ± 0.094 (2.29 ± 0.4 [2])						2.750 ± 0.079			3.184 ± 0.096				3.63

GLS_P_orb indicates the periods detected near a planetary orbital period in the periodogram of each observing season, whereas GLS_3/4 * Porb represents periods with the highest power close to 3/4 of an orbital period. The Mean is obtained from the average of all GLS_P_orbs for each system. The errors are obtained from the standard deviation of GLS_P_orbs. For HD 189733, our results are consistent with Cauley et al. (2018)[2].

Summary

- The periodic components close to P_orb in HD 189733, HD 179949, and τ Boo support the presence of star-planet magnetic interactions in these systems
- The rotational modulation of stellar activity exists in HD 189733, HD 179949, and υ And systems, highlighting the necessity of period retrieval.
- 3/4 * P_orb was detected in HD 179949, and υ And systems. It is unclear whether this period component originates from a physical phenomenon or is unrelated noise.
- 1/2 * P_orb also detected in HD 179949 and τ Boo. This may result from tidal interactions or be a harmonic of the orbital period.

References

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