Determining Magnetic or Tidal Star-Planet Interactions for HD 156279 using Ca II H & K emission lines.

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Planets interact with their host stars in a variety of ways and one of the ways we can study these interactions is through the emission lines that are created in the chromosphere, Ca II H & K in specific. These lines are sensitive to magnetic or tidal influence, and this influence could come from planets that have a close-in orbit to the host star. Studying these star-planet interactions can further our understanding of exoplanets and solar evolution. For my research study, I took the change in flux from emission lines in the chromosphere and compared them to the position of the planet as it orbited the star. If we can get hot jupiters, that are close to the star and has an eccentric orbit, we should be able to see if the planet has any distinct interaction with the star, either tidal or magnetic. I took spectra from the Keck Observational Archive for the star HD 156279 and the hot Jupiter HD 156279b and measured the flux for 38 observations. Then I plotted it against the phase or position of the planet and compared it to a work in progress model by Nicolas Iro, that showed my data suggested I had a magnetic interaction. Further comparisons to work by Evgenya Shkolink also correlated to a magnetic interaction. My research was able to show a magnetic interaction for my selected system and an indication that the planet HD 156279b has a magnetic field. Further studies can improve our modeling and understanding of star-planet interactions.

I. INTRODUCTION

The discovery of the a planet orbiting 51 Peg in 1995 (Mayor and Queloz 1995) [5], opened up a whole new field of astronomy and the study of exoplanets. Many of the first exoplanets discovered were in short 3 to 4 day orbits, 20 to 25 times closer to their host star then we are to our Sun. These were nicknamed "hot-Jupiters" owing to their proximity to their host star. It was then realized these massive planets may have effects on their host star and increase its activity (Shkolnik 2004) [8]. This also opens the question if this extra activity would affect the planet's habitability. This increased activity caused by the planet has been called "star-planet interactions" or SPI.

The study of exoplanets is especially important due to the variability of their planetary systems, which differs from our own. As we continue to explore these systems, we can gain a better understanding of how star-planet interactions depend on magnetic fields. Our research specifically focuses on exoplanets with highly eccentric orbits, allowing us to observe their host stars both before, during, and after the planet passes through perihelion. By examining data from various exoplanets, we aim to determine the primary cause of increased activity, whether it is due to magnetic or tidal interactions. This will further our understanding of planetary atmosphere evolution and help us better assess the habitability of exoplanets.

After analyzing data obtained from the Apache Point Observatory 3.5m telescope and high-resolution echelle spectrograph, I identified a suitable candidate in the Keck Observatory Archive (KOA) using the Keck High-Resolution Echelle Spectrometer (HIRES).

The star I chose is a G-type star, located 118 light-years away from Earth (Diaz et al. 2012) [2] which has two orbiting planets. For the purposes of observing flux, we are focusing on the planet known as HD 156279b. This planet has an orbital distance of 0.50 AU, a period of 133.4 days (Feng et al. 2022, Rosenthal et al. 2021) [3, 6] a mass of approximately 9.42 times that of Jupiter (Mj), and a radius of 1.12 times that of Jupiter (Rj). The eccentricity is 0.65. This information is presented in (Diaz et al. 2012) [2]

In this paper I will analyze the observed change in flux caused by the star planet interaction between HD 156279 and HD 156279b. The flux can be seen in Results IV, along with the plot for the Flux vs Phase. Comparisons of my findings to established magnetic or tidal interactions can be found in the Discussion V section.

II. THEORY

When considering SPI, we want to focus on the activity of the star, and this is best done measuring the chromosphere specifically. So we're using the Ca II H & K emission lines that occur in the middle chromosphere to measure the variability of their flux

[9]. The Ca II H & K doublet lines occur in the near-ultraviolet at wavelengths of 3969 nm and 3934 nm, and have been a well known measure of our Suns and stellar activity. [7]

The star HD 156279 also needs a compatible companion exoplanet to produce noticeable changes in its magnetic field, luckily we have HD 156279b in orbit around our host star. The exoplanet needs to be large, both with a mass and radius similar or bigger than Jupiter, and must also have an eccentric orbit. An eccentric orbit refers to how elliptical an orbit is, with 0 being a perfect circle and 1 being a parabolic orbit that would cause our exoplanet to get flung out of the star system, less than ideal for our situation if that were the case. The planet HD 156279b, thankfully, has both the mass and radius (9.42 Mj, 1.12 Rj) and the eccentric orbit we need (0.65). [2]

The highly eccentric orbit allows us to track the changes in flux as the planets orbit gets closer to the host star, its closest approach is called Perihelion, the furthest is Aphelion. We should see an increase in the emission of Ca II H & K as the planet interacts either magnetically or tidally with the star as it goes about its orbit. [8]

The types of interaction we're looking for are magnetic or tidal, both having different effects on the chromosphere and therefor would show up at different times during the planets orbit or phase.

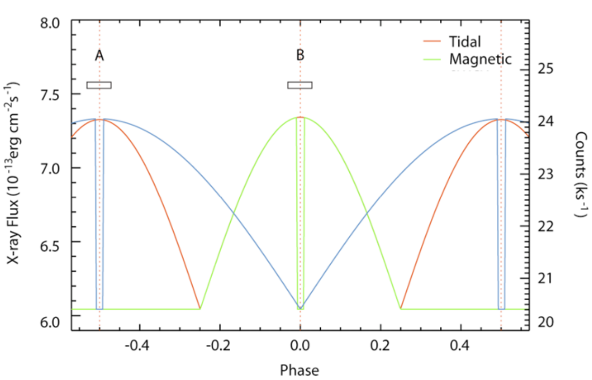

Figure 1. Prediction model for Magnetic or Tidal interactions by Nicolas Iro, work in progress

This model by Nicolas Iro shows how the Magnetic or Tidal interactions will show up when plotting the Flux vs the Phase of the planet. The phase is calculated using equation 2, where the phase has a range of 0 to 1, with 0 being the planets periapsis, the point in the path of the planet that is closest to the body it orbits. When we have a magnetic interaction, we should see the SPI near the periapsis or phase 0.0 of the planets orbit, if we have a tidal interaction we should see two peaks in the 0.5 phase. [4] We can then compare the flux vs phase of our SPI to the prediction model to make a determination on what is causing the SPI in the HD 156279 system.

III. METHODS

Using HIRES observational data for four different observational periods, we took the spectra and used Image Reduction and Analysis Facility (IRAF) to sort through the data and used the Splot facility to display and analyze the spectra, allowing us to find the Ca II H & K emission lines. An example shown in Figure 2 We were able to gather the change in flux for forty-two separate observations that spanned four years from 2009 to 2013. The data for the 2013 observations can be seen in Table I in Results §IV

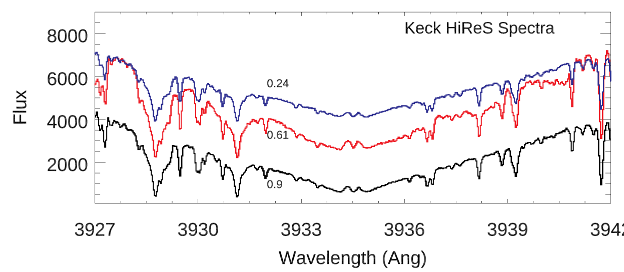

Figure 2. Example of Flux used to calculate Ca II H & K lines with IRAF, the doublet lines can be seen around 3969 nm and 3934 nm

The Ca II H & K lines are doublets so I combined them to get an overall change in flux and converted our forty-two observations dates into Modified Julian Date (MJD). MJD simplifies date calculations, where each integer corresponds to a single day, and decimal numbers represent the time of day down to the seconds when the observation was made. The Julian era began on January 1st, 4713 B.C. at noon, so day one would be 0. The MJD calculation starts at midnight on November 17th, 1858, and the conversion from Julian Date (JD) to MJD is

$$MJD = JD - 2400000.5 \quad (1)$$

An example, for the day of July 20th, 1969 at 20h 17m and 00s converted to JD you get 2440405.34514 and if you use equation 1 for MJD it would be 40404.84514.

In order to compare our flux against the models, I need to convert MJD into the phase. The phase is the position of the planet in relation to the host star, similar to the phases of the moon as it goes around the earth.

$$Phase\phi = FractionalPart(JD(obs) - JD)/P \quad (2)$$

Using Eq. (2)We can get the phase, where time is the date of observation converted to JD(obs), P is the period of the orbit and JD is given as the time at periapsis from Feng et al. (2002) and Rosenthal et al. (2021) [6] [3] The periapsis is the closest point to the attracting body, in this case the star. When calculated as a phase, this point would be 0.0 and it ranges between 0.0 and 1.0, this allows us to plot the flux vs the Phase. Now I can compare how the CaI K emissions change over time as the planet orbits its host star.

I calculated the phase using a script on Python that took the converted Julian Date from my observations [JD(obs)], subtracted the given JD date for the periapsis and divided it by the period of 133.4 [6] [3], then used the fractional function to get my phase between 0.0 and 1.0. I plotted my Ca H & K II emission flux vs the Phase (historically Ca H may be blended with H-epsilon and Ca K is a preferred diagnostic), overlapped all four years of my observation data and extended the phase another cycle to 2.0. See Figure 3

Due to issues with the spectra, we were only able to use 38 observations of the 49 we gathered from the Keck Observatory Archive. Some of the emission lines were poorly defined or too difficult to get a reading from. I removed the unusable data for the graphs. I also removed the data for 2009 as it didn't provide a lot of observations and the data didn't provide any insight.

IV. RESULTS

A. Table of Flux Data gathered from IRAF

Flux for observations between 01/27/2013 through 02/21/2014 can be seen in Table I, we measured the Ca K emission lines, which has a left and right components due to line absorption in the core. The total flux is the sum of the left + right Ca K components. The MJD is found using the NASA MJD converter, I also used the MJD Eq 1 to find the JD date to use for the Phase Eq 2. I have similar data for the four years of observation.

Flux L	Flux R	L+R	MJD	Phase
46.7399	26.6502	73.3901	56319.66582	0.95
61.9727	43.0221	104.9948	56328.6596	0.02
35.508	29.5599	65.0679	56432.37426	0.80
28.6844	19.6917	48.3761	56468.39942	0.07
44.4597	29.6196	74.0793	56485.25251	0.20
102.734	71.666	174.4	56551.21376	0.69
53.8065	41.4258	95.2323	56585.21034	0.94
51.7929	35.5591	87.352	56709.61422	0.88

Table I. Flux for Ca II H & K doublet lines shown as the left (L) and right (R) side, then combined (L + R) along with the converted date in MJD format. Then I show the calculated phase for those observation dates.

B. Flux vs Phase

Figure 3 shows the Flux vs Phase for the four years in our observation, with clear fluxes over 150 counts near phase 0.75 and 0.7. in years 2012 and 2013 respectively. We also have a flux over 150 near 0.1 in the year 2010. The 2011 data has some fluxes right below the 150 count around phase 0.1 and 0.45.

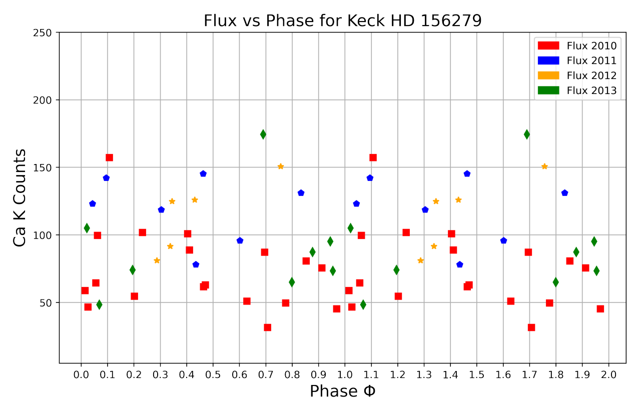

Figure 3. Plot of Flux vs Phase through all four years of data, shows spike in flux for 2010 at phase 0.1, 0.75 for 2012 and 0.7 for 2013. We see a couple of spikes at 0.1 and 0.5 for 2011.

V. DISCUSSION

Looking through my data I can see two flux increases for the years 2012 and 2013. For 2012 I have the phase at 0.75 and for 2013 it's at 0.69. If we consider the model by Iro 1 we can see that we have the single flux increase in our phase that suggests it's a magnetic interaction. However this phase doesn't fall right at the 0.0 phase point as suggested by the Iro Model. We can consider the study by Shkolink,

(2018) 4 where the system they studied also had a single peak showing a higher flux in the 0.75 phase range. They attributed this flux to magnetic interaction.

The increase in our flux running ahead of the position of the planet, or phase, is expect, as magnetic fields extend in front of and behind the planet, the magnetic interactions should begin to occur as the planet gets to periapsis and not right at phase 0.0 like the Iro model 1 suggest, so having a single peak in flux increase in the 0.75 phase range like the Shkolink (2018) 4 study we can reasonably conclude that there is a SPI between HD 156279 and our planet HD 156279b.

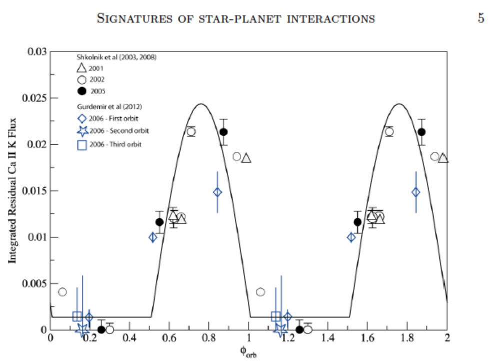

Figure 4. SPI from Shkolnik (2018) [9] showing a flux around phase 0.75 that shows an indication of a magnetic interaction.

We can also look at the data for 2010 to see a single peak increase at 0.11 phase, which can mean this interaction is running behind the planet as it is leaving periapsis, which is the inverse observation of my 2012/2013 data where the interaction was leading the planet, or the additional activity at phase 0.11 may be due to intrinsic stellar activity. Thus, our observations are consistent with the magnetic interaction model.

However my data for 2011 didn't give me a clear flux, and as discussed in Cauley et al (2018) [1], magnetic interactions depend on orientations of both the star and planet magnetic fields, as well as general flux in magnetic field strength that can cause the SPI activity to appear diminished.

VI. CONCLUSION

In conclusion, in order to better understand star planet interactions, I took observational data from the KOA for the star HD 156279 and its HJ HD 156279b. I was looking for magnetic or tidal interactions between the star and planet using Ca II H & K emission lines, which are calcium atoms in the chromosphere which react highly to magnetic fields or gravity, giving us the best indication of the type of interaction happening in the system. I was able to see a clear peak of increased flux activity for my data in 2012 and 2013 that was in the 0.70 phase range, which according to models suggest there is a magnetic interaction happening between HD 156279 and HD 156279b, we can predict that this planet has a magnetic field. The data for 2010 also showed a trailing flux and my 2010 data didn't show any increased activity which can be due to magnetic field and solar activity variability. Additional high resolution studies of hot Jupiter's in eccentric orbits are needed to further improve SPI theories.

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