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Moderate-Separation Binary Companions May Influence Young Stellar X-ray Luminosity

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ABSTRACT

Young pre-main sequence stars exhibit elevated X-ray levels due to their strong magnetic activity. Understanding young stars' X-ray activity is essential for contextualizing the forming planets that they host. Binary stars present a unique environment that may influence planet formation and evolution. In this work, we assembled a sample of 65 systems with stellar characterization from the literature and X-ray fluxes from the XMM-Newton Extended Survey of the Taurus Molecular Cloud to investigate the potential relationship between binary separation and X-ray flux. We found that binary stars with separations smaller than the sample median may exhibit elevated X-ray flux compared to single stars. This suggests that binary companions could influence stellar and planetary evolution and warrants further investigation.

1. INTRODUCTION

The Classical T Tauri phase is a stage in pre-main sequence stellar evolution where the young stars, $\sim 1-5$ Myr, are surrounded by a circumstellar disk (Joy 1945). Classical T Tauri stars are young enough to be rotating at the stellar breakup velocity. This saturates their magnetic dynamos and leads to the expectation of constant normalized X-ray emission across all masses. In binary stars, deviations from the expected normalized X-ray flux could be indicative of the companion impacting the stellar formation and evolution process. In close binaries (periods $\lesssim 100\,$d), magnetic interaction between the two stars often causes increased X-ray flux. For moderate separation binaries (10-100 AU), deviations from the expected flux could be indicative of the binary companion affecting spin-down processes and stellar evolution. In this work we compared the X-ray flux of young binary stars in Taurus to single stars to investigate stellar evolution.

2. SAMPLE

We began with a sample of 160 T Tauri stars in the Taurus star-forming region (∼1-3 Myr, e.g., Krolikowski et al. 2021) from Sullivan & Kraus (2022), who drew their sample from Herczeg & Hillenbrand (2014). To obtain X-ray data for our analyses, we cross-referenced our target list with sources detected by XEST (G del et al. 2007). In total, we matched 75 sources from XEST. For sources with multiple X-ray measurements, we used the median X-ray luminosity as the representative value.

The cross-matched sources included some higher order multiple configurations. We discarded higher order multiple systems, identified from Kraus et al. (2011), Kraus & Hillenbrand (2012), and Daemgen et al. (2015). We also removed systems with a total mass greater than $2.5\,M_{\odot}$. Our final sample included 26 binary systems and 39 single stars.

3. METHODS

For our analysis, we needed X-ray and bolometric luminosities and a system mass for both the single and binary sources in the sample. For the binaries, we also needed to obtain the mass ratio and separation. G del et al. (2007) calculated an X-ray luminosity for each source, using a differential emission measurement distribution (DEM) model and adopting a distance of 140 pc for each source. We rescaled these luminosities, as well as the bolometric luminosity in Herczeg & Hillenbrand (2014), using the *Gaia* distances from Sullivan & Kraus (2022). We computed the ratio of X-ray to bolometric luminosity of each source, which produced a normalized X-ray flux (R_x).

To determine system masses for the binaries, we calculated an absolute K magnitude for each source using distance and apparent K magnitude, corrected for extinction, as reported in Sullivan & Kraus (2022). To estimate the masses of the single stars and system masses for the binary stars, we bilinearly interpolated the MIST stellar evolution tracks (Paxton et al. 2015; Paxton et al. 2013; Paxton et al. 2011; Choi et al. 2016; Dotter 2016;

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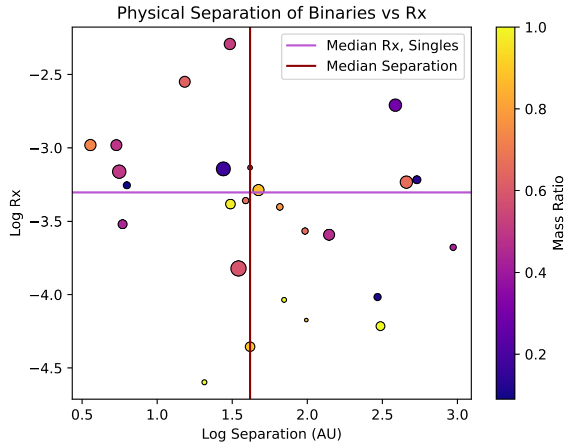

Figure 1. Distribution of the normalized X-ray flux (R_x) of the binary sample as a function of separation (AU) sized by the system mass. The horizontal purple line depicts the median R_x of the single star sample and the vertical red line depicts the median separation of the binaries in our sample. The smaller-separation binaries may have elevated R_x as compared to the single stars. A KS test returns a p-value of 0.1265, which is suggestive of a trend in R_x, but not statistically significant.

Paxton et al. 2018) in age (as reported by Herczeg & Hillenbrand 2014) and absolute K magnitude.

We then calculated mass ratios for the binaries. Using the ΔK mag reported in Kraus & Hillenbrand (2012) and Daemgen et al. (2015), and the absolute K magnitude that we calculated, we determined a K magnitude for each component of the binary. This was then used to estimate a mass for each component, as above. When available from Kraus et al. (2011), we used existing precomputed mass ratios.

Finally, we rescaled the physical separations in Kraus et al. (2011) and converted the angular separations in Daemgen et al. (2015) and Kraus & Hillenbrand (2012) to a physical separation using the *Gaia* distances in Sullivan & Kraus (2022).

4. RESULTS

Our results are presented in Figure 1. The median separation of the binaries in our sample was 42 AU, shown as the vertical line in Figure 1. We found that 62% of the binaries with separations less than the median had greater R_x than the single star median R_x, while this fraction was only 31% of the binaries with wider separation than the median.

We performed a Kolmogorov–Smirnov (KS) two-sample test using `scipy stats` (Virtanen et al. 2020), comparing the R_x distributions of the binaries with separations larger and smaller than the median. The KS-test returned a p-value of 0.1265 between the smaller and larger separation R_x distributions. While this is suggestive of a trend in R_x, it is not statistically significant.

5. DISCUSSION

Potentially elevated R_x levels in the closer binary sample could be indicative of impacts on stellar formation processes that elevate their X-ray flux. This might also impact planets forming around the closer binaries.

Future work should explore whether this result is strengthened in larger sample sizes or in star forming regions of different ages. In this effort, we were restricted to the Sullivan & Kraus (2022) sample, which has minimal overlap with either the eROSITA eRASS or the ROSAT all-sky surveys. Expanding to a larger sample covered by other X-ray surveys would be a useful next step. Determining whether this result is replicated in other star-forming regions of different ages, such as Upper Scorpius, would be valuable in understanding the evolution of the binary systems. If this result persists at older ages by altering spin-down, we would expect to see elevated R_x in the binaries, above the expected value for the single stars at older ages, once more massive stars have begun to spin down.

While further work is needed to confirm our findings across larger samples and other star-forming regions, our study provides an important step toward understanding how binarity shapes the evolutionary properties of young stars and their planetary companions.

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