A Possible Alignment Between the Orbits of Planetary Systems and their Visual Binary Companions

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67 TESS Exoplanets in Gaia DR2 Visual Binary Systems; 960 systems in control sample

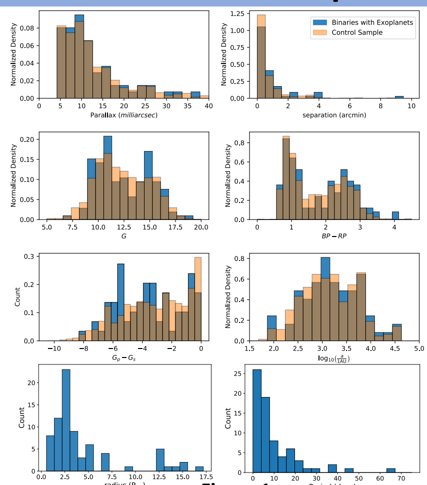

Figure 1

We used the El-Badry & Rix (2018) catalog as our base binary sample. Systems with possibly incorrect astrometric parameters were removed. We also constructed a control sample of binary systems from the El-Badry & Rix (2018) catalog. The control sample was chosen to match the properties of the binary systems with exoplanets (Figure 1).

Orbital inclination of binaries inferred from relative proper motion

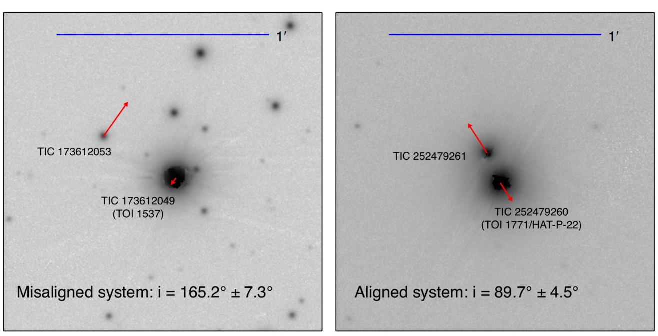

Figure 2

If the relative proper motion vectors are parallel to the plane connecting the two stars in the binary system, the system has an inclination of 90° (aligned with the exoplanet).

Constraining the orbit of a system requires knowledge of the total mass of the system. In order to determine the masses of each star, we use isochrone fitting on Gaia photometry and spectroscopy – when available -- from various sources.

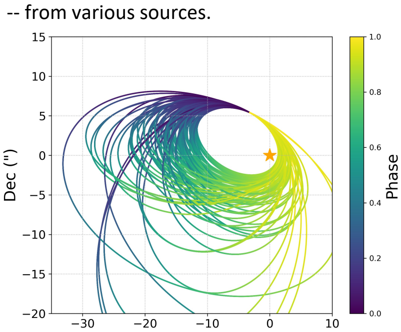

Figure 3

We use the LOFTI Python package (Pearce et al. 2020), a Monte-Carlo based sampling method, to constrain the orbits of our systems. 100 orbits from a LOFTI fit are shown in Figure 3.

Statistically significant alignment (p = 0.0048) between planets and binaries

All Exoplanets discovered using the transiting method have inclinations of approx. 90°. Thus, relative inclination between binary system and exoplanet can be measured as |90-i[binary]|. **Overabundance of |90-i[binary]| near 0 indicates a preference for alignment.**

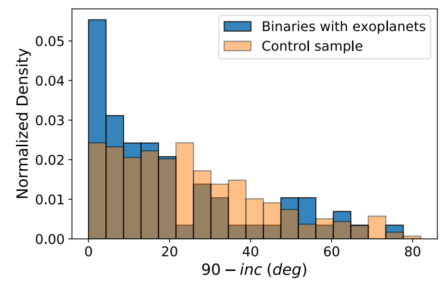

Figure 4

There is a clear overabundance of aligned systems around 0° compared to the control sample (expected random PDF of inclination is sin[i]). A KS test between binaries with exoplanets and control sample returns a p-value of 0.0048

Alignment observed primarily below 700 AU

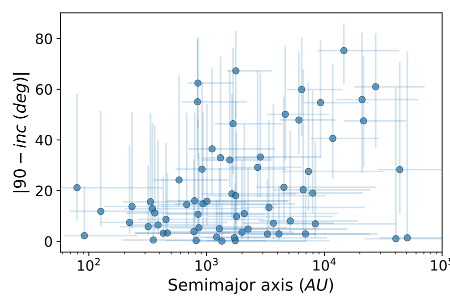

Figure 5

There is a larger fraction of aligned systems below 700 AU (this dividing line has large error due to the sparse number of observations). A KS test of systems below 700 AU compared to those above 700 AU returns a p-value of 0.0172.

Possible Explanation for Alignment

We believe the most likely explanation for the alignment is a torque from the binary companion (Batygin 2012), causing the protoplanetary disk to oscillate and dissipate energy, moving to its lowest energy state of alignment with the binary system.

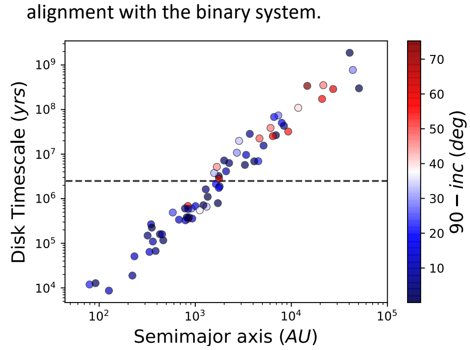

Figure 6

Recent theoretical work suggests this explanation could explain the alignment (Roisin et al. 2021) and intriguingly, the aligned population has timescales of rotation of the protoplanetary disk less than the lifetime of the protoplanetary disk (the dashed line in Figure 6).

References

Batygin, K. 2012, Nature, doi: 10.1038/nature11560
El-Badry, K., & Rix, H.-W. 2018, doi: 10.1093/mnras/sty2186
Pearce, L. A., et al., doi: 10.3847/1538-4357/ab8389
Roisin, A., et al.. 2021, arXiv e-prints, arXiv:2107.06832.1793

QR Code (link here) to the LOFTI code, a program central to our analysis.