Statistical Study of Spectroscopic Binaries (SB1) of Solar Type Stars from MARVELS.

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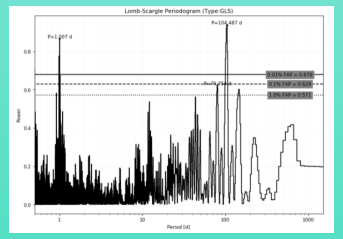
Introduction

Binary systems are important for measuring stellar masses, studying stellar populations and star formation. However, there is lack of a large sample of spectroscopically measured binaries to study their statistical properties. This study was performed on over 200 single-lined spectroscopic binaries (SB1s) identified and selected from the homogeneous sample of 3,300 stars surveyed and monitored by The Multi-object APO Radial Velocity Exoplanet Large-area Survey (MARVELS), which is part of the SDSS-III program. Analysis of solved radial velocity orbits for these SB1s has concluded: 1) Period and eccentricity correlation reveals near circular orbits at low periods (P < 11 days) due to tidal circularization at shorter periods; 2) Period distribution displays a significant drop-off at P = 85 d and two peaks indicating two possible mechanisms of binary formation; 3) Eccentricity distribution exhibits the same, double peak pattern at e = 0.2 and e =0.5; 4) Mass distribution of SB1s shows a peak at q=0.25; 5) The frequency rate for single-star system is 50%; and most importantly 6) A completely new discovery that mass distributions constrained to e<0.2 and e>0.2 exhibit significant differences, with a marked drop off at q=0.4. Here, we present the methods, results, and indications of our statistical analysis.

Methodology

For spectroscopic binaries, radial velocity (RV) is measured by monitoring the shifts of stellar absorption lines with a spectrograph. After obtaining the radial velocity data using Doppler spectroscopy, we developed and used a custom program to fit a radial velocity orbit to each spectroscopic binary target, from which we can obtain important stellar parameters including period, eccentricity, and velocity semi-amplitude, as well as the average RMS error, residual plots, and parameter errors. We then used the Markov Chain Monte-Carlo (MCMC) to estimate parameter uncertainties, optimize fitting, and provide a corner plot displaying posterior distribution.

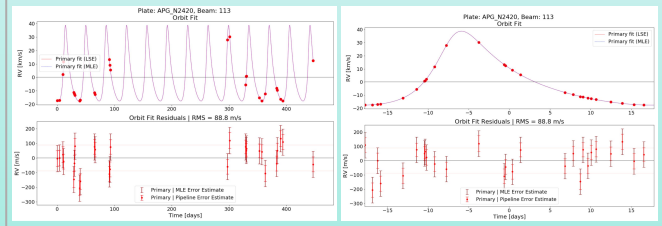
In short, potential binaries identified from 5,520 stars in the MARVELS survey by Thomas, N. were analyzed by us using the radial velocity method and several orbital fitting programs. Over 300 binaries (SB1s) were confidently identified and fit with low RMS errors, and were used as part of our final sample for analysis.



Sample periodogram used in program

MCMC Fitting of Keplerian Orbits

A completed orbital fit for one spectroscopic binary. Left: A radial velocity orbit fit using python package RadVel and optimized using MCMC displaying a residual plot and RMS errors. Right: A folded orbital fit also displaying residuals and RMS error. Not included: A corner plot displaying posterior distribution for all major parameters

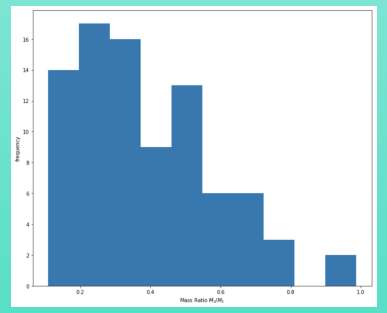


Results

Given the velocity semi-amplitude K, eccentricity e, period P, and primary star mass M1, the binary mass function solves for the secondary mass M2, and a simple M2/M1 ratio can be taken to solve for mass ratio, q.

For the first time ever, we partitioned the mass ratio distribution into two subsections by eccentricity: e>0.2 and e<0.2. The distribution with e < 0.2 is continuously decreasing, with a significant excess at q=0.1, but the distribution with e < 0.2 is not continuous but rather peaks at both q=0.25 and at q=0.5, a distribution never seen in binary mass distributions before. As can be seen more clearly with distributions in slightly different bins, we attribute the peak at q=0.5 to fluctuation in our data. The non-continuous peak at q=0.25, however, is significant.

We propose that the differences in distribution between high eccentricity and low eccentricity binaries can be attributed to an evolutionary relationship and difference in formation, related to the accretion of material onto the binary.



Mass ratio q = M2/M1 distribution for e>0.2, exhibiting a significant excess at q=0.25, as well as some fluctuation for q > 0.4.

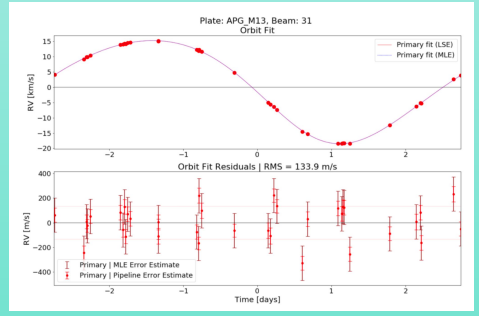
Results

Although the overall relationship is consistent with period v eccentricity results in previous publications, we reject several important earlier claims and propose new ones in place.

Specifically, the previously noted tidal circularization effect on binaries with P < 11 [1] or P < 12 [2] is not apparent in our data. Instead, we propose a much more restrictive cutoff for 'tidally-circularized orbits' at P<9. This is explained by tidal interactions in close-orbit binaries that circularize orbits, resulting in low period and near-zero eccentricity [3]. In addition to the well known tidal effect, when the primary star is a slow rotator, the orbit is circularized while keeping the orbital angular momentum unchanged [4].

In addition to our much more restrictive cutoff, our data also includes several outliers that, even at P<9 days, are not completely circularized (e>0). Thus, our research indicates that there are exceptions to to circularization of close binaries. As special targets of interest that may receive further research, we have identified and listed all outliers below. A target is considered an exception to circularization if it has P < 9 and e > 0.05.

StarName	per1	tc1	e1	w1	k1
TYC-2588-01606-1	5.49257	1.81607	0.11459	2.5625	16888.29455
TYC-0154-01462-1	4.27	3.428	0.09564	1.59023	14289.45
TYC-4126-01967-1	3.59	0.335	0.051	1.1	39610.1



Top: Table containing the primary parameters for all 3 targets that are exceptions to the circularization at low periods rule. Bottom: The folded orbital fit for TYC-2588-01606-1, 1 of 3 targets that are well fit and do not conform to tidal circularization at P<9d.

Note that though we have several other significant results and conclusions (see introduction), we are unable to include all of them in this poster due to lack of space. Instead, only the most important ones and/or new discoveries are presented.

Conclusion

We have studied the unbiased sample of 302 spectroscopic binaries taken from a sample of over 3,300 Bright stars from the MARVELS survey. By working with the largest sample of binaries ever, this study has concluded that:

1. Mass Ratio distribution for high eccentricity binaries (e>0.2) has a significant excess at q=0.25, in contrast to a continuously decreasing distribution for e<0.2.
2. Binaries at P < 9 are indeed circularized by tidal interactions. However, several exceptions have now been found to this rule, possibly caused by an early formation age.

Because this was the largest unbiased sample of spectroscopic binaries ever, these conclusions are also far more certain than ever before. However, to explain many observed phenomenons with certainty, further work and investigation is required.

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References

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[2]Raghavan D., et al., 2010, ApJS, 190, 1, *A Survey of Stellar Families: Multiplicity of Solar-type Stars*

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[4] Hurley J. R., Tout C. A., Pols O. R., 2002, MNRAS, 329, 897, *Evolution of binary stars and the effect of tides on binary populations*