41

Detecting Short-Period Binary Companions to Sub-Subgiant Stars

Jonah Wilkes, Edin Peskovic, Elaine Bai, Emily Leiner

Department of Physics, Illinois Institute of Technology

Abstract

Sub-Subgiants (SSGs) are unique stellar phenomena that are fainter and cooler than the typical giants and subgiants. The cause of these anomalies is not well understood, though one hypothesis is that SSGs are binaries with companion stars in short-period orbits of 2 - 30 days. Tidal forces between the stars may synchronize the rotation period of the SSG to the orbital period, and the resulting rapid rotation generates strong magnetic fields. These magnetic fields may inhibit energy transport in the star, creating giants that are cooler, larger in radius, and less luminous than their slower rotating counterparts. To test this hypothesis, we utilize data taken using the Robert G. Tull Coudé spectrograph on the 2.7 m Harlan J. Smith telescope at McDonald Observatory. We determine radial velocity (RV) measurements for 56 stars in the SSG Sample. Many SSGs are found to have highly variable RVs, indicating they are short-period binary systems. We simulate several possible binary populations with a variety of underlying orbital period distributions including the full distribution of periods observed in galactic binary populations, a limited galactic binary period range of about 2 to 30 days, and include a tidally synchronized sample population sampled from the Variable Star Index (VSX) as is hypothesized for the SSGs. We find that our observed population closely resembles the RV distribution expected from our simulation of binaries with periods of 2 to 30 days, supporting the hypothesis that a very high fraction of SSGs are standard short-period binaries and contrary to the hypothesis that they may be tidally synchronized.

We can test the hypothesis that Sub-Subgiants are short-period binaries by looking for Radial Velocity variations in a spectroscopic sample of 56 Sub-Subgiant stars.

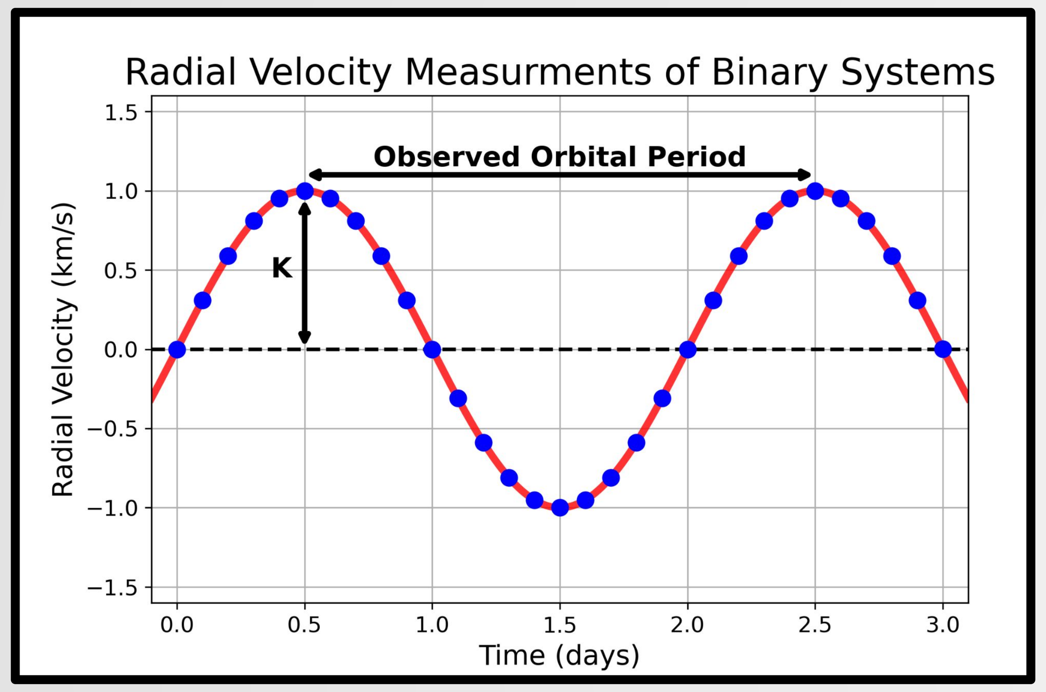

Figure 1. In the ideal circular orbit case a measured binary will have the variable radial velocity measurements shown in this figure.The RVs will follow a simple sine wave whose peak radial velocity, denoted by K, is the semi-amplitude of the measurements. The period of the system's orbit is the periodicity of this wave.

The ideal binary mass function used to simulate each possible period distribution is:

$$\frac{M_2^3 \sin^3 i}{(M_1+M_2)^2} = \frac{P_{\rm orb}\, K^3}{2\pi G}\left(1-e^2\right)^{3/2}$$

The sample: 34 spectra of 56 sub-subgiant stars. Each SSG in our sample has at least 3 spectroscopic measurements.

RV Measurement Technique: Compute broadening functions from spectra (see Figure 2, left). Fit a Gaussian to the broadening function to measure the radial velocity (RV) of each observation (Figure 2, right).

Assessing Binarity: Compute the standard deviation of the RV measurements for each star. A standard deviation greater than 1 km/s indicates the SSG is RV variable, and thus has a binary companion.

Population Statistics of the SSG Sample: Perform a Monte Carlo simulation to simulate possible RV distributions using three orbital period distributions:

1. Log Normal distribution of binary periods from Duquennoy and Mayor (1991) and Raghavan et al 2010.
2. A Log Normal distribution (Duquennoy and Mayor (1991)) limited to periods less than 30 days.
3. Assume tidal synchronization such that the orbital periods of all SSGs are equal to their rotation periods given in Leiner et al. 2022.

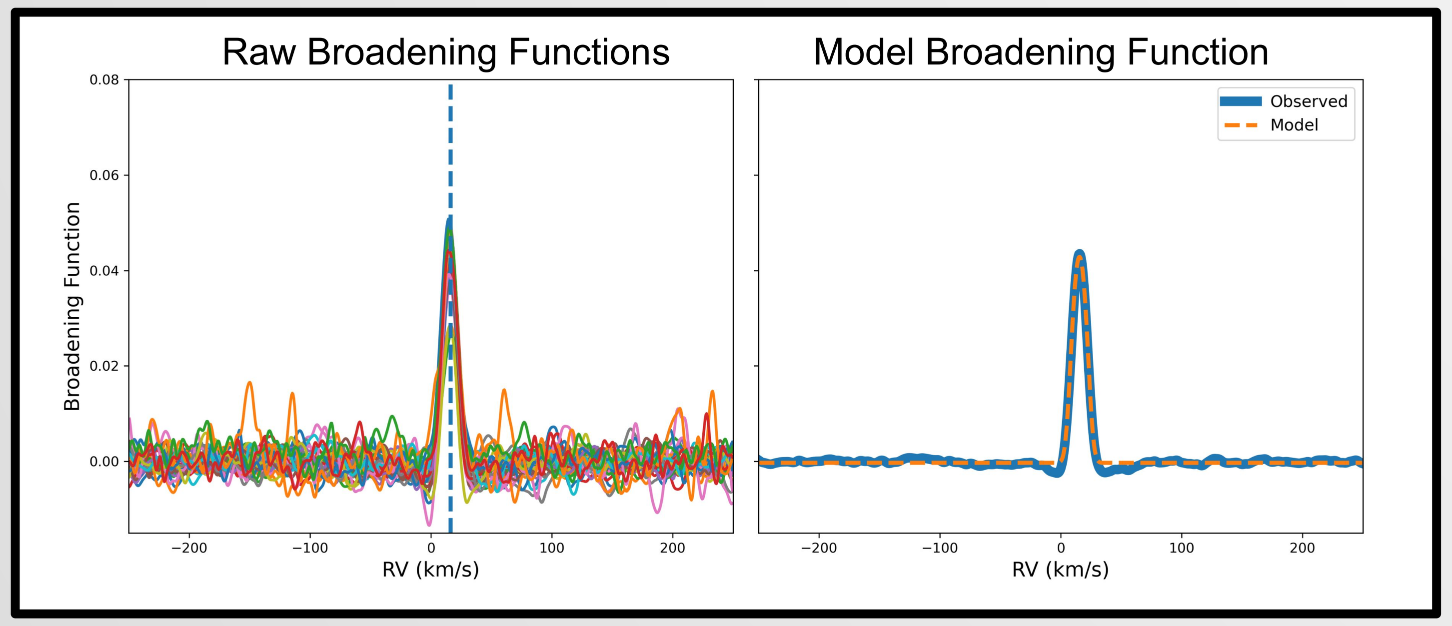

Figure 2. The Python package Saphires was used to develop broadening functions for the entire spectrum observed, for each observation date (left). From this function estimates for the peak of each measurement were made and the reduced function was fit (right). We use the fitted profile to obtain a highly accurate RV measurement.

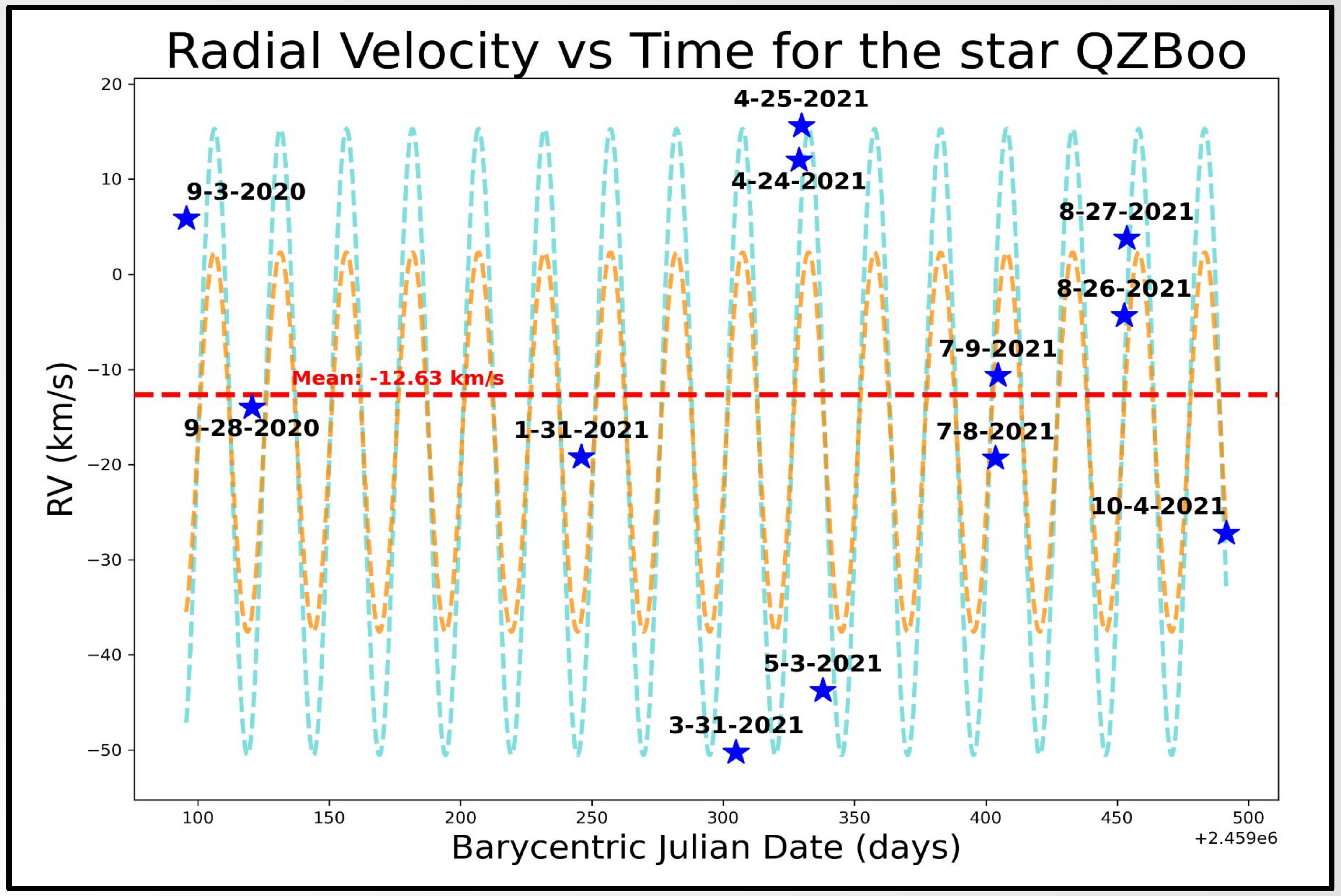

Figure 3. This plot displayed our observed radial velocities (blue) over time for QZBoo, one of the 56 stars analyzed. The high variability of these measurements indicates a quickly rotating binary system. Overlaid are two estimations of period measurements for this star, which assumes a period of approximately 4 days. The light blue line represents a K value using the true Amplitude of the recorded RVs, while the orange line represents an assumed amplitude of the Standard Deviation of these measurements. It is important to distinguish between the two for the final measurements, as the Standard Deviation assumption does not account for the entire range of recorded values, especially for highly variable RVs.

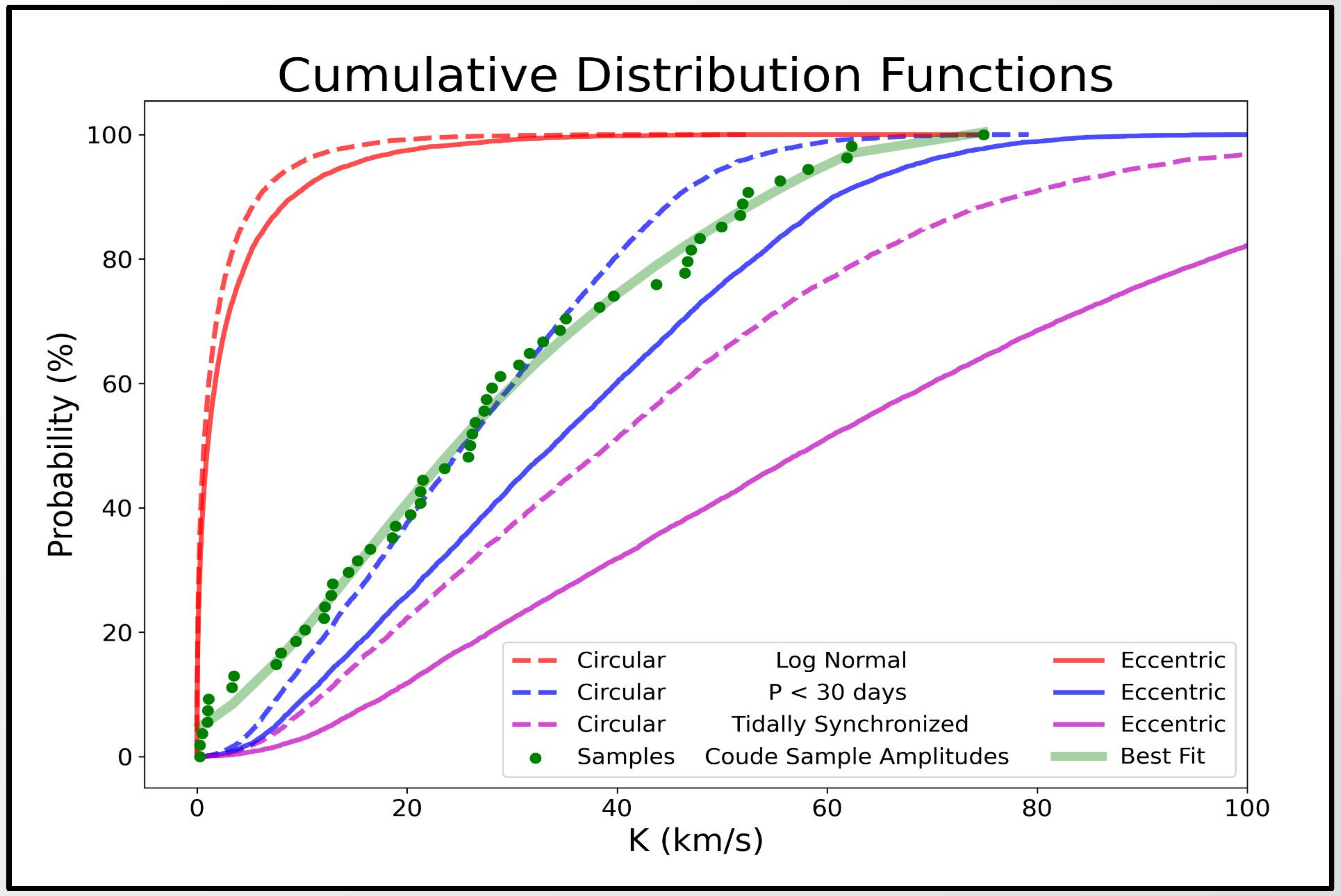

Figure 4. This plot displays the simulated amplitude values compared to the recorded amplitudes from our Coudé sample (green). The full Log Normal distribution (red) shows that we can expect most of the radial velocities (K) to be relatively small, as expected from longer period variables. As the range is limited to less than 30 days (blue), the probability that the radial velocity is slow decreases as the stars must orbit faster. The tidally synchronized sample (purple) is simulated from the visual variability of stars and produces an even faster distribution of stellar periods. Circular orbit assumptions are shown by the dashed lines, while eccentric assumptions are solid.

Conclusions

The orbital period simulations that best match the observed RV variation of the SSGs is the assumption of a log-normal period distribution with a maximum period of 30 days (Figure 4). This supports that hypothesis that SSGs are found almost exclusively in short-period binaries. However, our results are not consistent with the assumption that all SSGs are in tidally synchronized binaries.

Next Steps

- Investigate the best metric of measuring orbital amplitude from RV observations by simulating binary orbits with randomly sampled RV measurements.
- Simulate more possible orbital period distributions

Sources

Duquennoy, A., & Mayor, M. 1991, A&A, 248, 485
Leiner, E., Geller, A. et al. 2022, ApJ, 927, 222
Raghavan, D., McAlister, H. A., et al. 2010, ApJS, 190, 1
Tofflemire, Ben - Direct Communication