Global Star Cluster Rotation in the Pleiades

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Fig 4. Picture of Pleiades Star Cluster taken with eVscope from Angell Hall Rooftop

Introduction

Understanding the evolution of star clusters is key to understanding star formation, the stellar populations in the disk of the Milky Way, and assessing the prospects for stellar-mass black hole mergers in the cores of massive star clusters. New instruments enable taking hundreds of stellar spectra in clusters simultaneously and many large surveys are underway. Most are kinematic studies of star clusters to understand their internal dynamics. The same data can be used to measure (or put limits on) the global cluster rotation and ultimately determine the total angular momentum of the star cluster. These estimates could be used to test models of formation and evolution of molecular clouds as well as the evolution of star cluster angular momentum. The Pleiades is a nearby (135 pc) young star cluster (~150 Myr) with est $M_{tot} = 735\ M_{sun}$ (Pinfield et al, 1998) with half mass (370 M_{sun}) radius of 1.25 pc, and most stars < 1 M_{sun} implies est no. of stars > 1000. (Figure 4)

Methods

- We start with a catalog of 455 stellar radial velocities (Fernandez et al, 2017) in the Pleiades as a function of position (Figure 1).
- Removed the binary stars which had a calculated Kepler rotational velocity impact > 9.12 km/s as perform iterative sigma clipping at 4 sigma and dispersion 2.28. Achieved convergence at 404 stars.
- Perfored manual integration as per the graph obtained for the range of mass and separation for which the K value was greater than 9.12 km/s using binary star population model of Meyer et al (submitted) estimated fraction of stars greater than 4 sigma deviation expected. About 11.8% was the final percentage of stars which had a significant impact.
- Searched for the first moment in the velocity distributions as a function of the angle on the sky (east of north) and found the position angle (Rigliaco et al, 2016) at which the signal is greatest using the KS-Test (Figure 2).
- Function of distance from the cluster center along the position angle with fit line using the least-squares. Can assume solid-body rotation.
- Expect 10-12% of stars in green zone to have a companion star. (Figure 3)

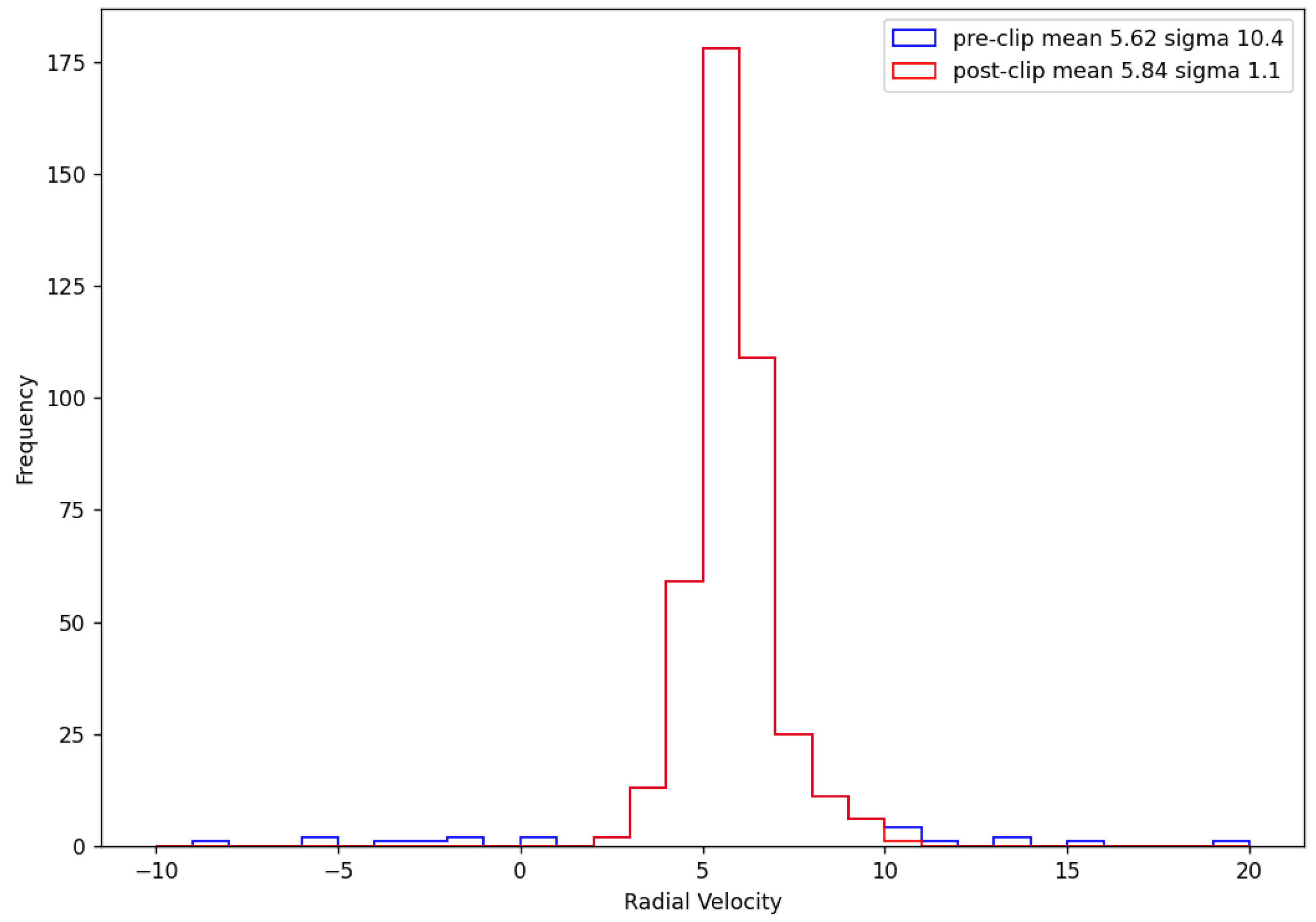

Fig 1. Distribution of radial velocities from the APOGEE survey (Fernandez et al, 2017). We show before and after iterative 4 sigma clipping to remove outliers due to binary star motions.

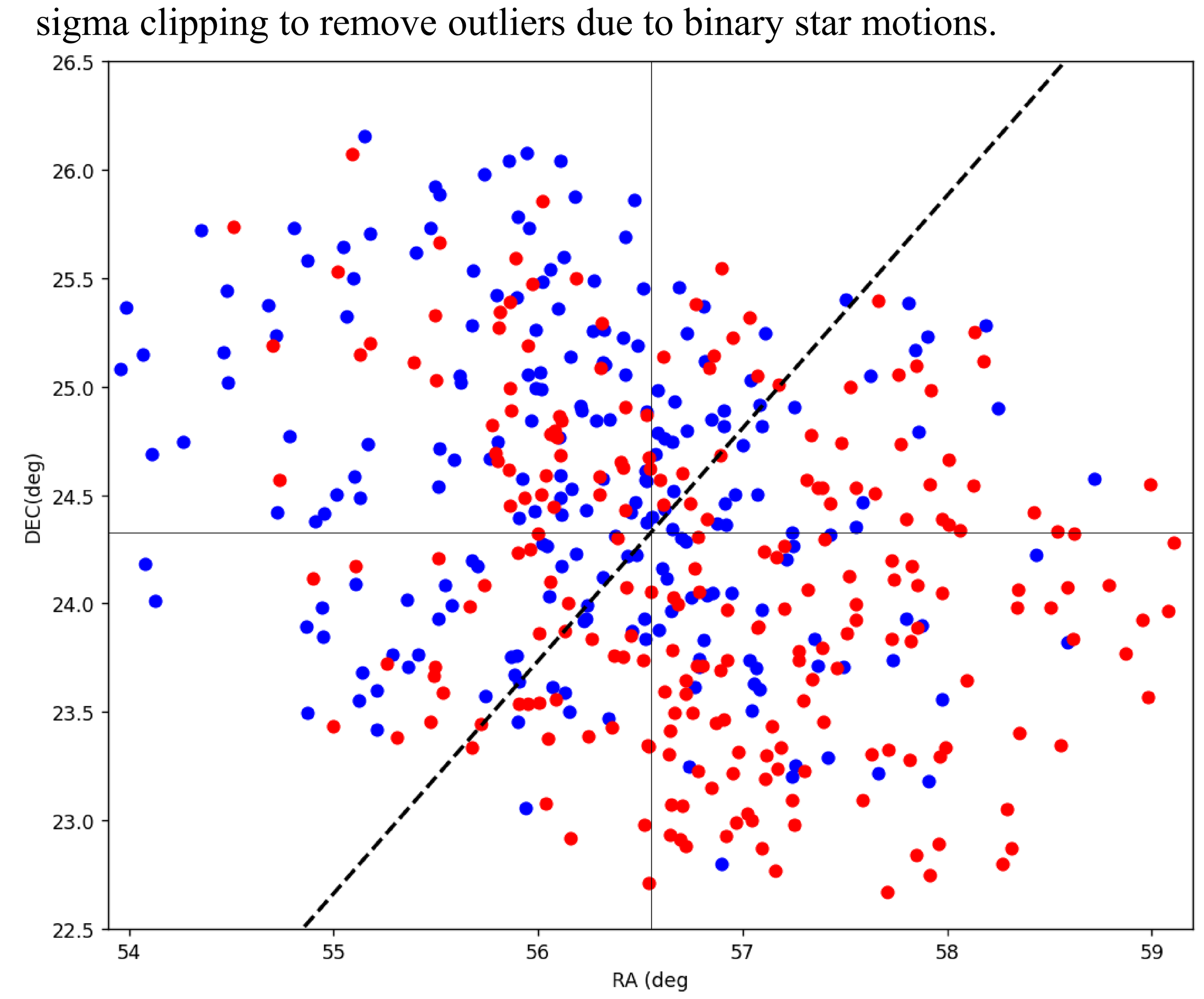

Fig 2. Red (blue) stars red-shifted (blue-shifted) velocity relative to cluster mean as projected on the sky. Heavy dashed line is position angle with largest difference between red and blue-shifted star motions relative to the origin shown.

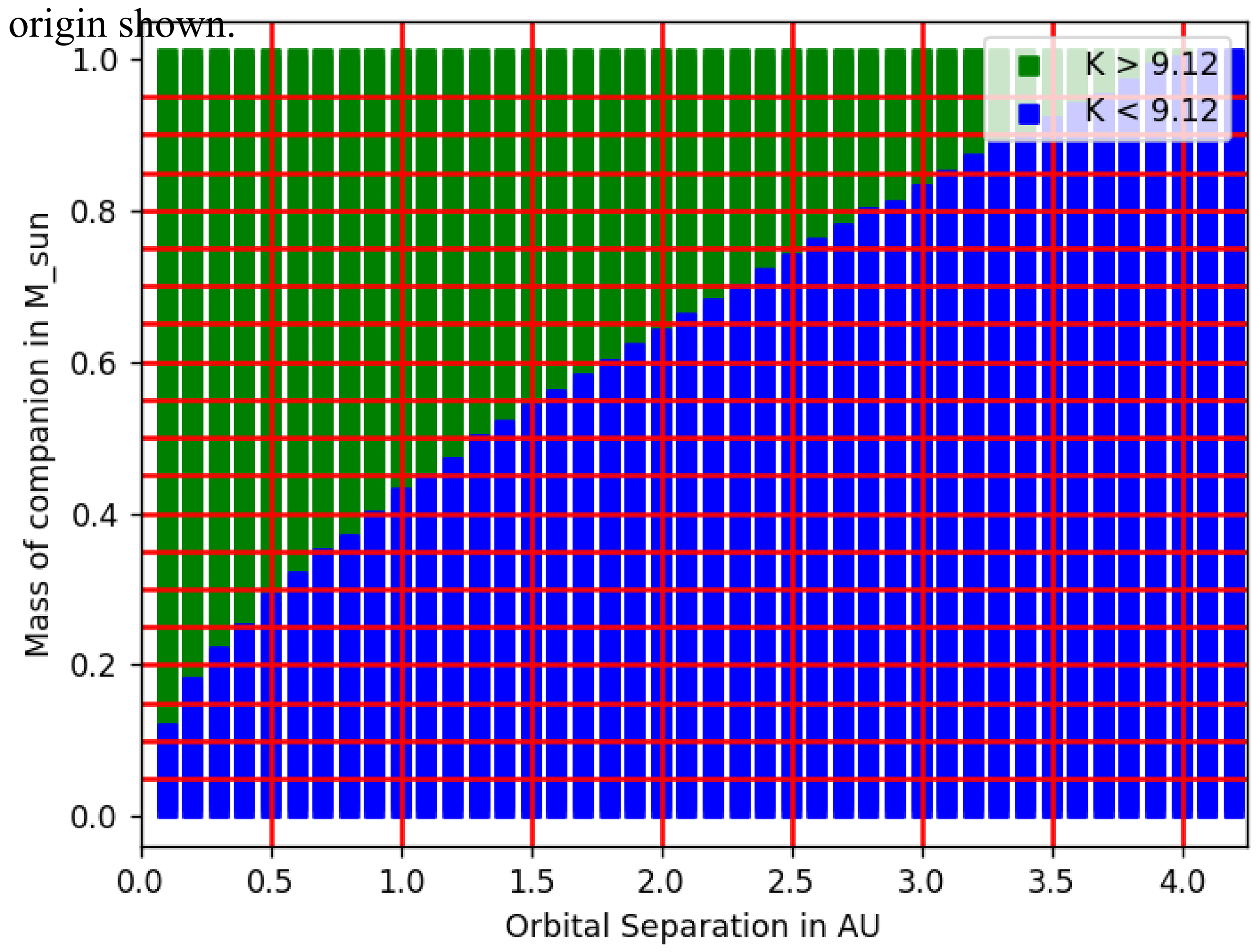

Fig 3. We show Companion Mass vs Orbital Separation color-coding expected Kepler orbital velocity > 9.12 km/s (more than 4 sigma from the mean). This is used in iterative sigma clipping.

Results and Future Directions

- $KE_{rot} << KE_{tot} \sim PE$, indicating that the cluster is in virial equilibrium
- Plot of radial velocities with the distance from the center had a least-squares line fit with a positive slope of 0.372- consistent with solid body rotation and a strong case for a small rotation of the order of $1.39*10^{-13}$ Hz of the Pleiades star cluster about a central axis.
- Number of stars clipped as outliers consistent with expected binary population (~10%)
- An in-depth 3D analysis including astrometry data from GAIA would give insight into how complex systems such as star clusters form and evolve.

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References

[1]Fernandez, et al. (2017). In-sync VI. identification and radial velocity extraction for 100+ double-lined spectroscopic binaries in the apogee/in-sync fields. *Publications of the Astronomical Society of the Pacific*, *129*(978), 084201.

[2]Meyer et al A&A submitted

[3]Pinfield, D. J., Jameson, R. F., & Hodgkin, S. T. (1998). The mass of the Pleiades. *Monthly Notices of the Royal Astronomical Society*, *299*(4), 955–964

[4]Rigliaco, et al.. (2016). The Gaia-ESO survey: Dynamical Analysis of the L1688 region in Ophiuchus. *Astronomy & Astrophysics*, *588*