MEASURING PROPER MOTIONS OF FORNAX AND ITS 5 GLOBULAR CLUSTERS USING *GAIA DATA RELEASE 2*

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ABSTRACT

Fornax is one of the most massive dwarf spheroidal satellite galaxies of the Milky Way and is unusual for it contains 5 globular clusters (GCs). Based on the standard distribution of dark matter in galaxies, the Fornax GCs are predicted to have spiraled into the center of Fornax by now. Their long-term survival has implications for the nature and distribution of dark matter in galaxies, which makes measuring their proper motions (PMs) even more crucial. Due to the far distance of Fornax and its GCs, measurements of their PMs are difficult to obtain. However, with the release of *Gaia Data Release 2* (*Gaia* DR2), we are given the largest and most precise measurements of an all sky survey to date. From *Gaia* DR2, we examined Fornax and its 5 GCs in PM space. We conclude with a PM measurement of Fornax and the first ever PM measurement of GC2. An overcrowding issue prevented the PM measurements of the 4 other GCs. Although the current precision of Gaia is not high enough to improve our understanding of the dark matter halo, future Gaia releases will be able to.

INTRODUCTION

Fornax is a classical dwarf spheroidal satellite galaxy of the Milky Way. It is dark matter dominated with an oddity of 5 GCs. With the current understanding of dark matter in galaxies, the current infall times for the GCs are ~2 Gyrs for a cuspy dark matter profile or ~10 Gyrs for a core profile; according to *Goerdt et.al 2006* [1]. Many have hypothesized reasons for their presence, but no conclusions can be made without further investigation into the galaxy; specifically, the PMs. By measuring their PMs, we can further explore their orbits which is essential to understanding the dark matter distribution within the galaxy.

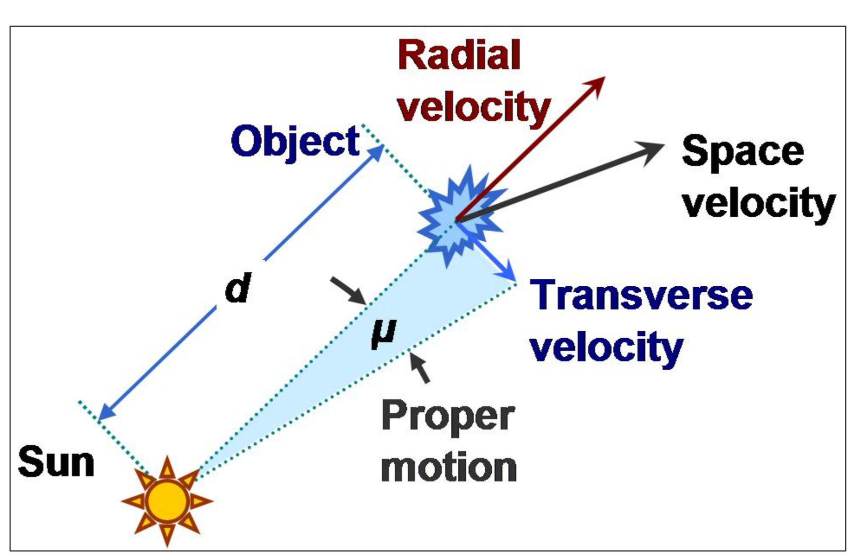

Figure 1. Proper motion (μ) is the angular movement of an object across the sky. μ is related to the transverse velocity (v_t) by the equation: $v_t = 4.74\mu d$ where d is distance in parsecs. v_t is related to the to the true space motion (v) by $v^2 = v_t^2 + v_r^2$, where v_r is the radial velocity [4].

As stated in Figure 1, PM is the angular movement of an object across the sky. Knowing the PMs of the GCs, as well as Fornax, will allow for a deeper analysis of the structure and overall behavior of the dark matter halo fueling this galaxy. PM also depends on distance to an object. The farther away the object is, the harder it is to obtain a PM. Presently, there is a literature PM measurement of Fornax, but none for its GCs.

With the release of *Gaia* DR2, PM measurements were taken for nearly 1,331,909,727 objects. This all sky survey provided the largest query of star positions and PM measurements to date. Using *Gaia* DR2, we analyzed over 28,800 stars for Fornax and its 5 GCs.

DATA ANALYSIS

Six sets of data were pulled from the *Gaia* DR2 archive; 1 for each cluster and 1 for Fornax. Figure 2 shows Fornax GC2, before any cuts were performed.

The GCs first went through a parallax cut, because of their far distances. Any star in a data set with a measured parallax is too close to us and therefore cannot be a member of the cluster. The second cut was an astrometric cut. This cut out any stars that did not fit the astrometric solution well. The third cut was an isochrone cut, as shown in Figure 3. Taken from the *Gaia Collaboration 2018*, we used their isochrone of Fornax to identify what stars were either too metal rich or poor to be a member [2]. The fourth cut was a radius cut, shown in Figure 4. using *Mackey et.al 2003* measured core radii [3]. We set the parameters such that any star not within 5 times the core radius would be ruled out as member of the individual clusters. Figure 6 shows the remaining stars of GC2 and their measured PMs.

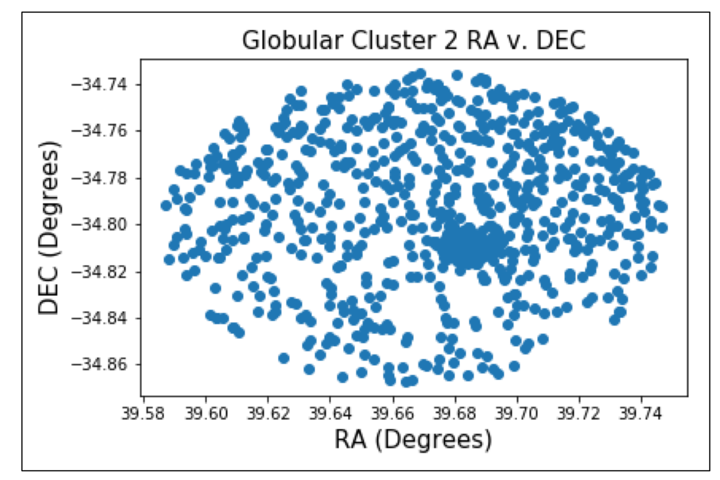

Figure 2. A plot of right ascension vs. declination of GC2 taken from *Gaia* DR2 with no cuts performed on the data set.

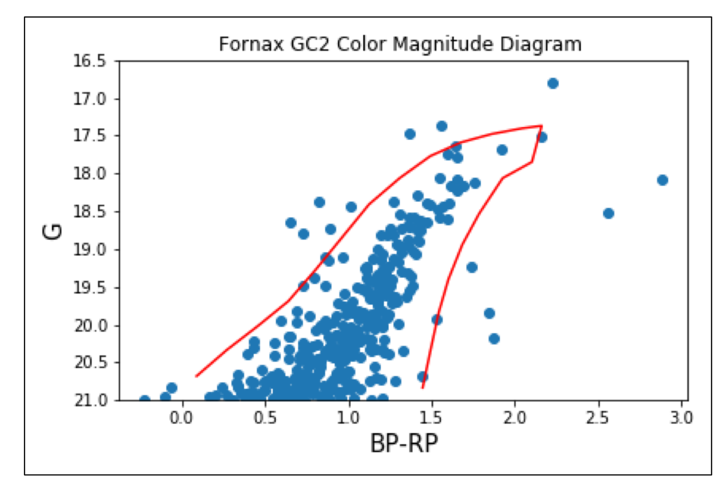

Figure 3. A plot of BP-RP vs. G magnitudes of GC2 taken from *Gaia* DR2 with the parallax and astrometric cuts subtracted. The red line indicates the isochrone of Fornax. Any star that does not fall within the isochrone will be ruled out as not a member.

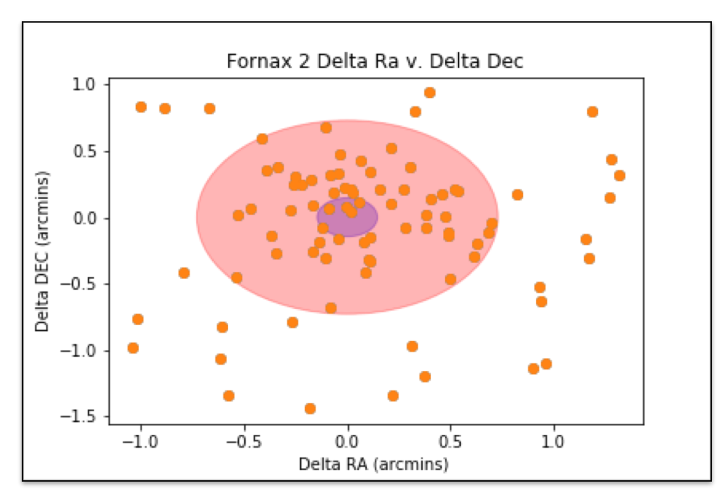

Figure 4. A plot of Delta RA v. Delta DEC with (0,0) corresponding to the center of GC2. The blue circle corresponds the core radius and the red circle corresponds to 5 times the core radius.

The Fornax data set underwent a similar data analysis. It received a parallax cut, astrometric solution correction, and isochrone fitting. In lieu of a radius cut, all 5 GCs were subtracted out of the Fornax data set. This was done to reduce any contamination in the remaining data.

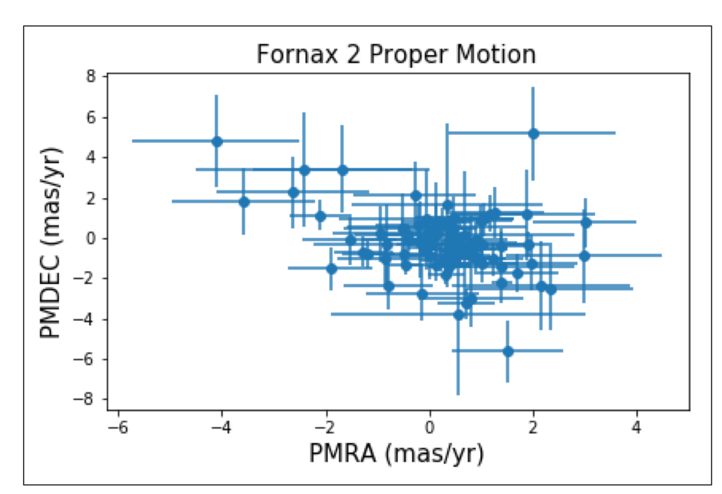

Figure 5. A plot of proper motion right ascension vs. proper motion declination for Fornax GC2.

RESULTS

Unfortunately, a majority of the GCs experienced an overcrowding issue that made us unable to obtain an accurate measurement of their PMs. As shown in Figure 6, there is an obvious over density, however, in Figure 7 there are no stars within 5 times the core radius.

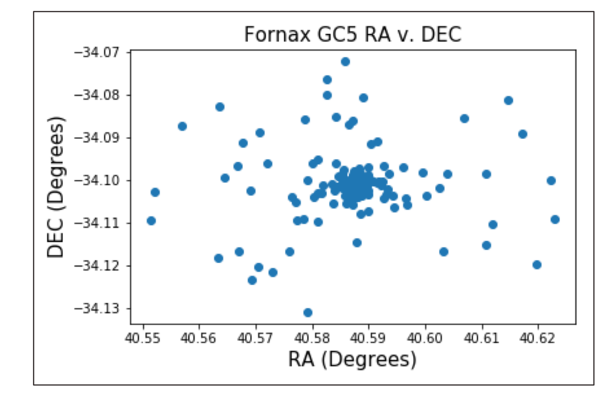

Figure 6. A plot of right ascension vs. declination of GC5.

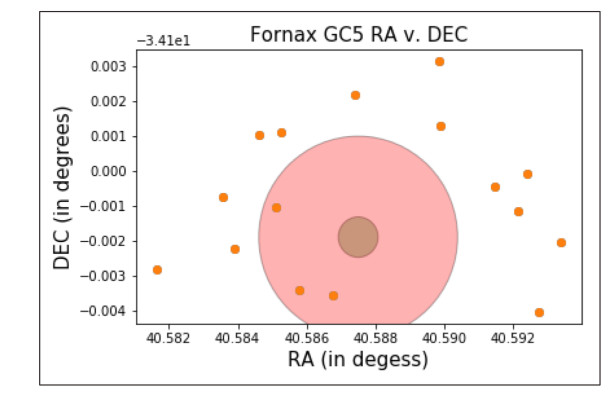

Figure 7 A plot of right ascension vs. declination of GC5 showing the core radius (green circle) and 5 times the core radius (red circle).

This issue was consistent throughout all GCs except for GC2.

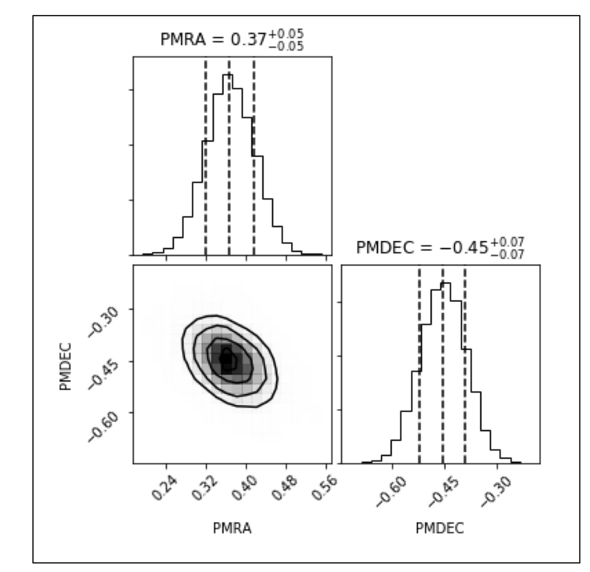

Figure 8. The PM measurement of Fornax GC2 using a MCMC.

With Fornax and GC2, we performed a Markov Chain Monte Carlo (MCMC) in order to obtain PMs and the statistical errors attached to them.

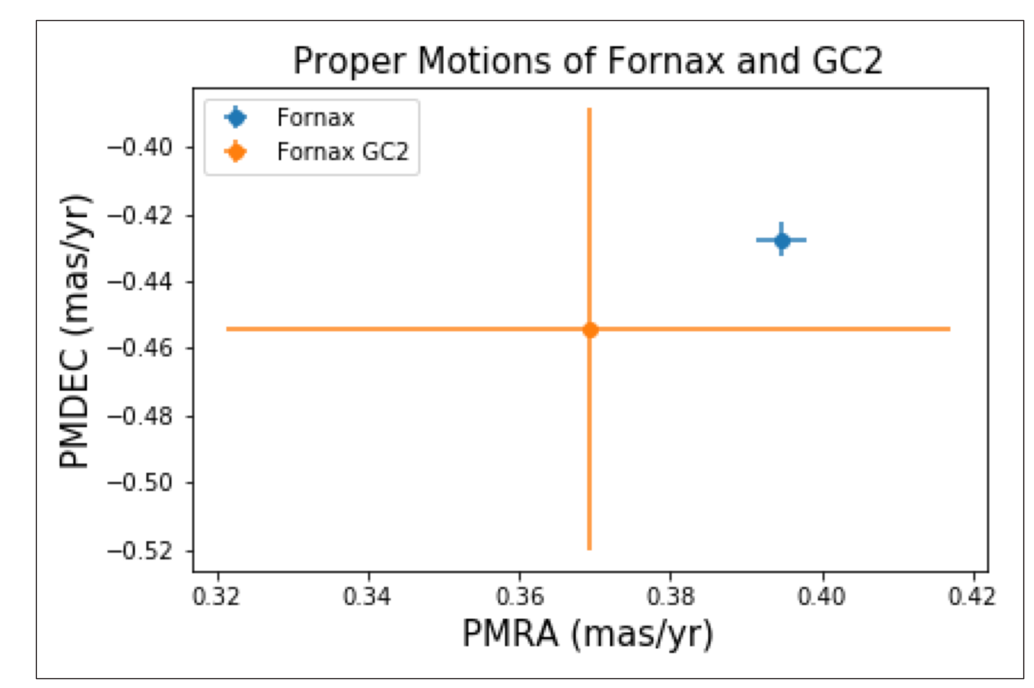

Figure 9. A comparison of PMs between Fornax and Fornax GC2.

The final result is shown in Figure 9. We acquired final PM measurements with error bars for both Fornax and Fornax GC2.

CONCLUSION

With *Gaia* DR2, we have measured a PM for the dwarf spheroidal galaxy Fornax, which is in agreement with current literature values. We also measured, for the first time ever, a PM for one of Fornax's GCs, GC2. Presently, the next *Gaia* release is set for late 2020. With future releases of *Gaia,* we will be able to measure the PMs of the remaining GCs of Fornax.

REFERENCES

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