# White Dwarf Stars and the Age of the Milky Way

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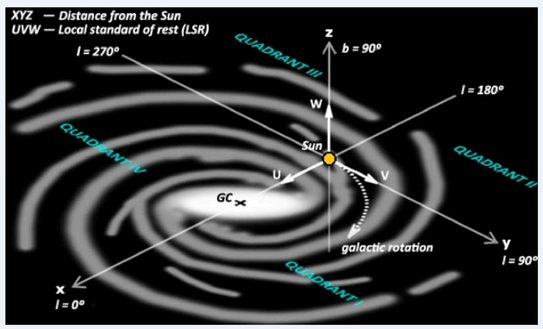
## Abstract

The goal of this paper is to develop a technique to determine the age of formation of the Galactic thin and thick disks. To achieve this goal, we calculated the U, V, and W velocity components for thousands of Gaia white dwarfs and ran the BASE-9 Astro statistics software modules singlePopMcmc and sampleWDMass. Classifying the white dwarf stars into three Galactic populations was another important part of the study. We classified 101418 thin disk stars, 3158 thick disk stars, and six halo stars. The findings suggest that one out of the six halo stars —star 4108—is a white dwarf star that we can model. Its age is 5.62 Gyr, which is inconsistent with the age of the Galactic halo and thus this star is probably a velocity interloper. To further investigate stellar populations, we will apply the same method for the thick disk population candidates. The age of the thick disk would help broaden our knowledge of this star population and place it more fully into the history of the formation of the Milky Way.

Figure 1: UVW Velocities




## Methods

Equation 1: UVW velocities

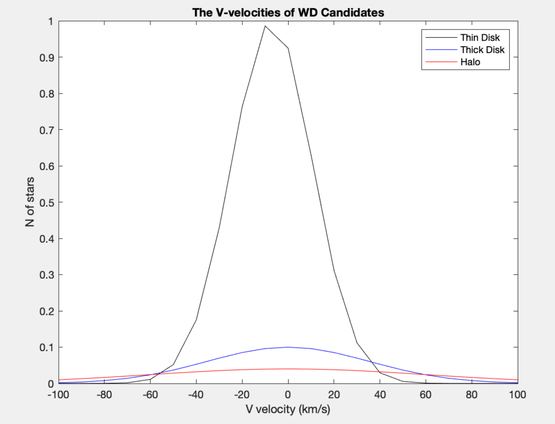
$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = B \begin{bmatrix} \rho \\ \frac{k\mu_\alpha}{\pi} \\ \frac{k\mu_\delta}{\pi} \end{bmatrix}$$

Equation 2: Uncertainty in the probability

$$\Sigma_{P(i)}{}^2 = \left(\frac{(u_{mean}(i)-u_{low})}{\sigma_{u(i)}{}^2} * P_i\right)^2 \sigma_u{}^2 + \left(\frac{(v_{mean}(i)-v_{low})}{\sigma_{v(i)}{}^2} P_i\right)^2 \sigma_v{}^2 + \left(\frac{(w_{mean}(i)-w_{low})}{\sigma_{w(i)}{}^2} P_i\right)^2 \sigma_w{}^2$$

1. We used the Gaia Data Release 3 astrometry to calculate the UVW velocities for all WDs.
2. Calculated these velocities with respect to the LSR.
3. We found the probability that these stars belong to thin, thick disk, or halo populations.
4. Next, we found the uncertainties in these probabilities.
5. We created an HR diagram and found hat five out of 6 halo candidates are white dwarfs.

Figure 2: V-Velocities of WD Stars




## Findings

Table 1: The UVW Velocities of the Stars

*Table 1: Average Galactic Velocities of Stars by Stellar Population (km/s)*

| velocity component | U | | | V | | | W | | |
|---|---|---|---|---|---|---|---|---|---|
| population | thin | thick | halo | thin | thick | halo | thin | thick | halo |
| mean | 0 | 0 | 0 | 0 | -40 | -196 | 0 | 0 | 0 |
| standard deviation | 35 | 50 | 141 | 18 | 45 | 75 | 25 | 50 | 85 |

Source: Pasetto, Greber, Zwitter et al. 2012

Having taken these six stars' positions on the HR diagram and their stellar characteristics into consideration, we can conclude that all these stars, with the likely exception of 2173, are white dwarfs. However, further research, with higher precision data, is required to make valid age determinations for these five halo candidates.

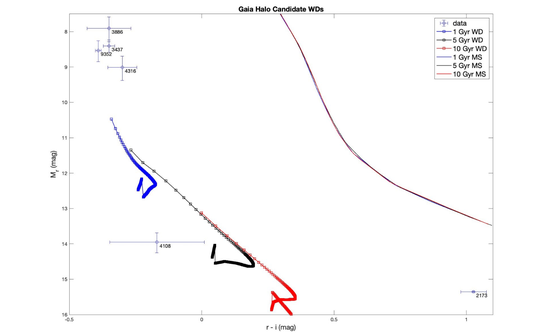
Table 2: Values used when running *SinglePopMcmc* for the six WD stars

| Star | Absorption | Metallicity | *Parallax (arcseconds)* | σ Parallax (arcseconds) |
|---|---|---|---|---|
| 2173 | 0.050 | -1.500 | 0.009359 | 0.00007210 |
| 3437 | 0.000 | -1.500 | 0.001365 | 0.0001108 |
| 4108 | 0.000 | -1.500 | 0.005707 | 0.0007427 |
| 3886 | 0.000 | -1.500 | 0.0009798 | 0.0001556 |
| 4316 | 0.000 | -1.500 | 0.001242 | 0.0001937 |
| 9352 | 0.000 | -1.500 | 0.001220 | 0.0001652 |

Table 3: Stellar characteristics of star 4108

| Age (years) | Zams Mass | Metallicity | Parallax (mas) | Temperature (K) | Log(g) | Cooling Age (years) |
|---|---|---|---|---|---|---|
| $5.62 * 10^9$ | 4.00 | -1.25 | 5.75 | 7079.5 | 8.25 | $1.88 * 10^9$ |

Figure 3: The HR Diagram of the Six Halo Candidates




## Future Work

Our age results are inconclusive because BASE-9 does not yet incorporate models for sufficiently young and hot white dwarf stars. To further investigate stellar populations, we will apply the same method for the thick disk candidates. Studying their ages would be valuable because scientists have yet to determine the age of this star population.

## Works Cited

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