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3D IMAGE OF POLARIS FIELD STARS

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ABSTRACT. We present a three-dimensional model of the positions of 20 stars in the field of the Cepheid α UMi (Polaris) – 18 main sequence stars (spectral types A0–G0 V), the K-giant HD 6319 (K2 III) and Polaris itself (F8 Ib) – which was created using the 3D calculator Desmos 3D, based on the calculated U, V and W components of the full velocity vector of the stars in the Galactic coordinate system. In this paper, stellar radial velocity estimates from Usenko et al. (2023) were used. Two versions of the U, V, and W components were calculated based on Gaia DR3 parallaxes and photometric parallaxes. The resulting 3D image showed that, in both scenarios, 15 main-sequence stars, a K-giant, and Polaris form a noticeable clamp, while three stars (HD 14718, HD 90162, and HD 11696) are located outside of it. HD 14718 and HD 90162 belong to the thick disk, while HD 11696 is a remnant of a possible open cluster in Polaris's field. The K-giant HD 6319 is located inside the clamp and quite close to the Cepheid, and it is quite possible that this clamp is part of the main component of the probable open cluster Polaris, dissolved in the field of the Cepheid. Using a 3D calculator to construct a spatial image of stars may serve as a good tool for studying the structure and dynamics of open clusters in the future.

Key words: open clusters: stars: U, V, W components; GAIA parallaxes; photometric parallaxes; Cepheids, K-giants, main-sequence stars; Cepheids: α UMi; individual stars: HD 6319, HD 14718, HD 90162, HD11696.

АНОТАЦІЯ. Ми представляємо тривимірну модель положень 20 зір у полі цефеїди α UMi

(Полярна зоря) – 18 зір головної послідовності (спектральні типи A0–G0 V), К-гігант HD 6319 (K2 III) та самої Полярної зорі (F8 Ib) – яка була створена за допомогою 3D-калькулятора Desmos 3D, на основі розрахованих U-, V- та W-компонент повного вектора швидкості зір у Галактичній системі координат. У цій статті були використані оцінки радіальної швидкості зірок з Усенка та ін. (2023). Було розраховано дві версії компонентів U, V та W – на основі паралаксу Gaia DR3 та фотометричного паралаксу. Отримане 3D-зображення показало, що в обох сценаріях 15 зір головної послідовності, К-гігант і Полярна зоря утворюють помітний кламп, тоді як три зірки (HD 14718, HD 90162 та HD 11696) розташовані поза ним. HD 14718 та HD 90162 належать до товстого диска, тоді як HD 11696 є залишком можливого розсіяного скupчення в полі Полярної зорі. К-гігант HD 6319 розташований всередині клампу та досить близько до цефеїди, і цілком можливо, що цей кламп є частиною основного компонента ймовірного розсіяного скupчення навколо Полярної зорі, розчиненого в полі цефеїди. Використання 3D-калькулятора для побудови просторового зображення зір може служити гарним інструментом для вивчення структури та динаміки розсіяних скupчень у майбутньому.

Ключові слова: зорі розсіяних скupчень, U-, V- та W-компоненти, GAIA паралакси, фотометричні паралакси, цефеїди, К-гіганти, зорі головної послідовності, цефеїди α UMi, окрім зірки: HD 6319, HD 14718, HD 90162, HD11696.

1. Introduction

In our previous study (Usenko et al. 2023), we examined 18 main-sequence stars (spectral types from A0 V to G0 V located in the field of the Polaris Cepheid to confirm that these objects could be members of an open star cluster. Based on the analysis of their proper motions, radial velocities and parallaxes, it was shown that 15 stars belong to the same moving group, one star belongs to another group, and two more stars belong to the thick disk. For greater clarity, we decided to calculate the U, V, and W components of the total velocity vector for each of the 18 +1 stars (data for HD 6319, K2 III, were added), as well as Polaris (F8 Ib). These calculated components allow us to construct a 3D image and examine the positions of these stars in space relative to the Polaris Cepheid.

2. Objects and U, V, W calculations

Table 1 summarizes the U, V, W data for the 20 targets - Cepheid α UMi (Polaris), K-giant HD 6319 and 18 main-sequence objects taken from Usenko et al. (2023). U, V, W are the components of the full velocity vector of a celestial object in the Galactic coordinate system. U is the velocity component directed along the X-axis, V is along the Y-axis, and W is along the Z-axis, where they represent the radial and tangential velocities of the star relative to the local coordinate system. Strictly speaking, U (radial velocity) is the projection of velocity directed along the line of sight. The sign of "U" depends on the direction of the star's motion: positive if it is moving away from us, and negative if it is approaching. V (local velocity): the component of the star's velocity directed in the galactic coordinate system along the "Y" axis or along the galactic plane axis. W (vertical velocity): the velocity component of the star is directed perpendicular to the galactic plane, along the "Z" axis.

The Galactic components U, V, W were calculated according to the technique described in Johnson & Soderblom (1987) which uses a right-handed coordinate system for them so that they are positive in the directions of the Galactic center, the Galactic rotation and the North Galactic Pole. Using a right-handed system allows the same matrix to be used to transform both coordinates and velocities. Matrix systems allow for the calculation of these components and their uncertainties. Calculating these components requires such parameters as the star's equatorial and galactic coordinates, its proper motion, parallax, and radial velocity. Radial velocities were determined from spectra obtained at TCO (Usenko et al. 2023), and two types of parallaxes were used: from the Gaia DR3 catalog or photometric ones from Turner (see the spreadsheet Turner's ZAMS.xls

at <https://ap.smu.ca/~turner/A5500.html>). The remaining parameters were selected from the SIMBAD database. Calculations were performed using a program written in Python. The calculated values of U, V and W in Table 1 are given in two versions because of the noticeable difference in the parallax estimates between Gaia DR3 (2022) and Turner's photometric data (see Usenko et al. 2023).

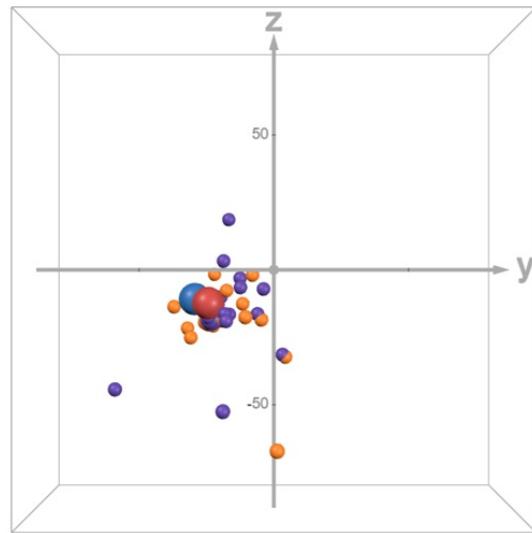


Figure 1: Polaris field stars. View along the X (U) axis, directed away from the observer. Symbols are described in Chapter 3.

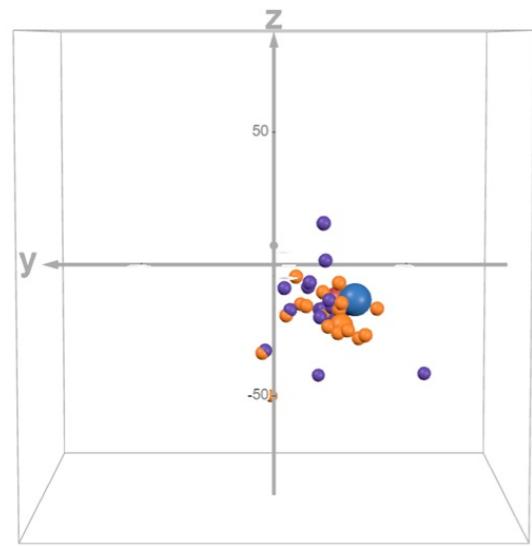


Figure 2: Polaris field stars. View along the X (U) axis, directed toward the observer.

Table 1: UVW data for Polaris field stars

| Star | GAIA DR3 PARALLAXES | | | | | | PHOTOMETRIC PARALLAXES | | | | | |
|-----------|-------------------------|--------------------------------|-------------------------|--------------------------------|-------------------------|--------------------------------|-------------------------|--------------------------------|-------------------------|--------------------------------|-------------------------|--------------------------------|
| | U km s ⁻¹ | σ km s ⁻¹ | V km s ⁻¹ | σ km s ⁻¹ | W km s ⁻¹ | σ km s ⁻¹ | U km s ⁻¹ | σ km s ⁻¹ | V km s ⁻¹ | σ km s ⁻¹ | W km s ⁻¹ | σ km s ⁻¹ |
| Polaris | -13.38 | 138.81 | -24.76 | 165.12 | -12.48 | 54.87 | -20.07 | 9.48 | -30.02 | 11.15 | -11.06 | 3.70 |
| HD 6319 | -31.02 | 0.01 | -24.61 | 0.01 | -19.36 | 0.00 | -27.29 | 1.92 | -23.82 | 2.76 | -18.80 | 0.92 |
| HD 5914 | -36.77 | 0.97 | -26.80 | 2.24 | -20.35 | 0.79 | -29.32 | 1.95 | -23.02 | 4.56 | -18.16 | 1.60 |
| HD 10772 | -49.83 | 1.04 | -23.26 | 2.28 | -1.78 | 0.69 | -33.95 | 0.75 | -13.02 | 1.64 | -3.19 | 0.50 |
| HD 11696 | -61.90 | 0.02 | -23.78 | 0.03 | -18.42 | 0.01 | -51.40 | 0.72 | -17.69 | 1.61 | 19.72 | 0.56 |
| HD 14369 | -7.71 | 0.01 | 4.33 | 0.03 | -32.56 | 0.01 | -7.45 | 1.03 | 3.26 | 2.29 | -31.70 | 0.85 |
| HD 14718 | 74.46 | 1.01 | 1.14 | 2.10 | -61.53 | 0.92 | 51.00 | 0.72 | -17.86 | 1.60 | -49.52 | 0.57 |
| HD 16335 | 19.22 | 0.07 | -10.33 | 0.13 | -17.15 | 0.05 | 14.01 | 2.32 | -17.46 | 4.79 | -18.66 | 1.53 |
| HD 66368 | -6.12 | 4.77 | -4.64 | 10.26 | -18.60 | 4.35 | -6.46 | 1.92 | -6.13 | 4.12 | -16.45 | 1.75 |
| HD 90162 | -18.28 | 0.01 | -31.49 | 0.01 | -25.63 | 0.00 | 14.94 | 4.07 | -58.00 | 8.79 | -43.60 | 4.03 |
| HD 163988 | -24.43 | 0.09 | -11.91 | 0.23 | -12.94 | 0.09 | -15.70 | 1.77 | -3.91 | 4.84 | -7.21 | 1.92 |
| HD 203317 | -31.94 | 0.70 | -19.83 | 2.00 | -19.60 | 0.66 | -25.00 | 0.89 | -16.99 | 2.53 | -16.98 | 0.83 |
| HD 209556 | -23.32 | 0.21 | -18.03 | 0.56 | -7.88 | 0.19 | -19.05 | 1.23 | -19.07 | 3.36 | 3.36 | 1.08 |
| HD 224687 | -34.17 | 0.98 | -33.30 | 2.39 | -22.48 | 0.67 | -17.44 | 0.69 | -24.65 | 1.74 | -17.97 | 0.49 |
| HD 224991 | -24.80 | 0.04 | -8.15 | 0.09 | -1.99 | 0.03 | -17.10 | 4.38 | -12.65 | 10.93 | -6.63 | 3.18 |
| Polaris B | -23.04 | 0.03 | -38.02 | 0.06 | -14.04 | 0.02 | -18.51 | 2.17 | -31.27 | 5.01 | -13.54 | 1.82 |
| BD +86 44 | -5.04 | 0.03 | -18.52 | 0.06 | -18.96 | 0.02 | -2.66 | 1.87 | -18.28 | 3.86 | -16.46 | 1.29 |
| BD +87 16 | -29.13 | 0.10 | -23.88 | 0.24 | -13.73 | 0.08 | -25.06 | 0.43 | -21.33 | 0.96 | -13.17 | 0.34 |
| BD +87 26 | -35.07 | 0.07 | -24.55 | 0.15 | -10.60 | 0.05 | -27.92 | 1.24 | -20.27 | 2.60 | -10.36 | 0.91 |
| BD +88 75 | -35.11 | 0.11 | -23.36 | 0.25 | -21.54 | 0.12 | -28.54 | 0.41 | -20.64 | 0.96 | -19.36 | 0.43 |

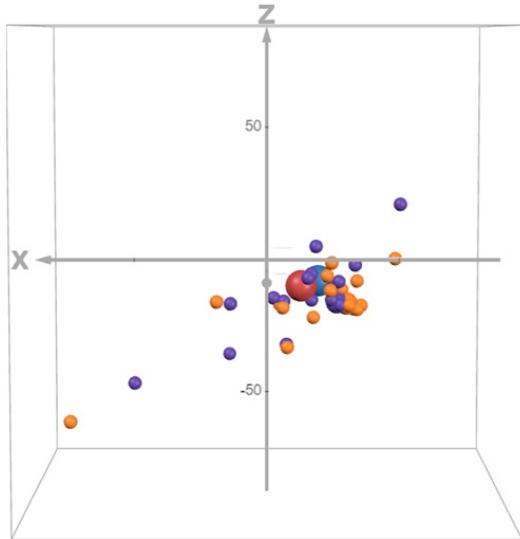


Figure 3: Polaris field stars. View along the Y (V) axis, directed away from the observer.

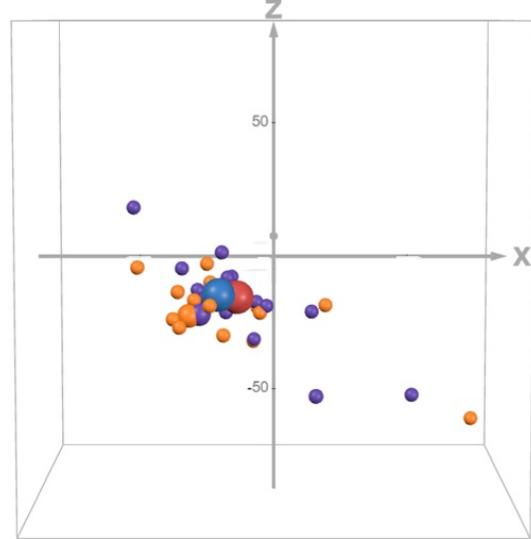


Figure 4: Polaris field stars. View along the Y (V) axis, directed toward the observer.

3. 3D image of Polaris field stars using U, V, W coordinates

To create a 3D image of 20 stars from the Polaris field, we used a 3D calculator from Desmos Studio¹. This calculator not only allows you to position the objects along three coordinates but also view them from different angles by rotating the resulting graph along the three coordinate axes. As mentioned earlier, the U, V, and W data were positioned along the calculator's X, Y, and Z axes, respectively. The resulting 3D images of the stars from Table 1 are presented here as

¹<https://www.desmos.com/3d>

2D graphics (Figures 1-8), showing how our stars appear from different viewing angles. The large red and blue symbols correspond to the coordinates of Polaris for the Hipparcos - Gaia DR3 parallax and photometric parallax, respectively. Similarly, the medium-sized symbols in orange and dark blue represent the giant HD 6319, while the small symbols of the same colors represent the remaining 18 main sequence stars.

As can be seen from the figures, the overwhelming majority of stars from both groups, despite the differences in coordinates associated with parallax estimates, form a kind of clamp together with Polaris. The exception, as already mentioned by Usenko et

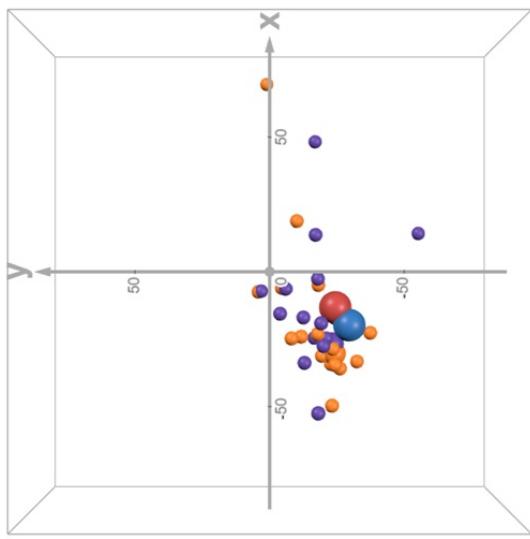


Figure 5: Polaris field stars. View along the Z (W) axis, directed away from the observer.

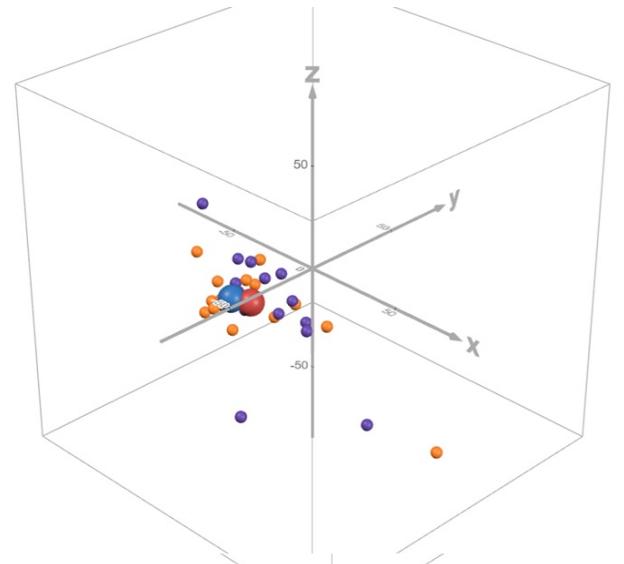


Figure 7: Polaris field stars. View at 45 degrees to the Z (W) axis from above.

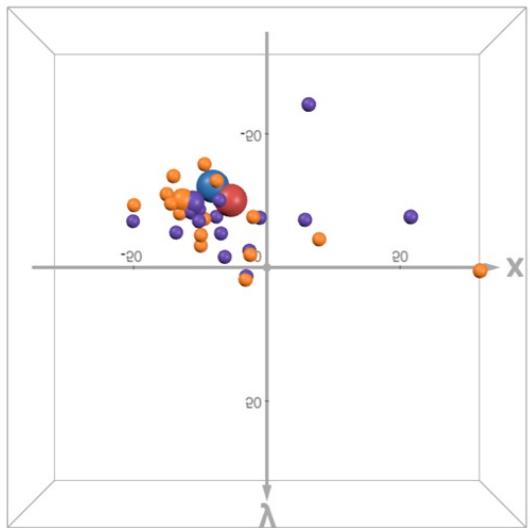


Figure 6: Polaris field stars. View along the Z (W) axis, directed toward the observer.

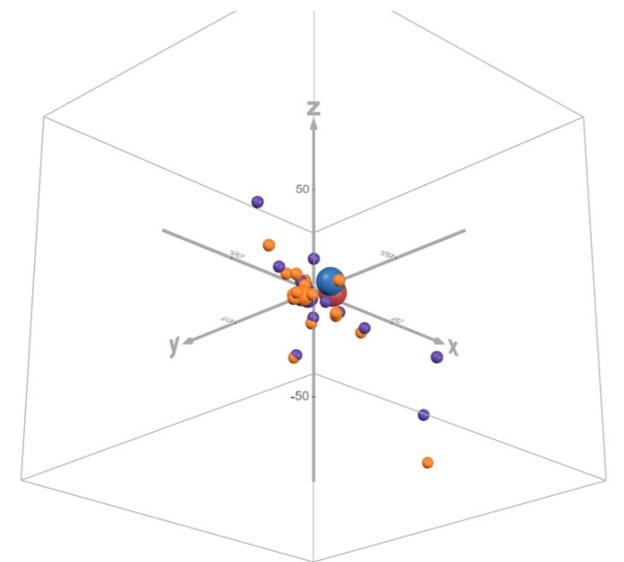


Figure 8: Polaris field stars. View at 45 degrees to the Z (W) axis from below.

al. (2023), are three stars: HD 14718 and HD 90162, which belong to the thick disk, as well as HD 11696, which probably belongs to another group of stars in the Polaris' field. However, it is obvious that these three objects are located far from the clamp. It should be noted that the K-giant HD 6319 is located quite close to Polaris, and this fact may serve as evidence that the Cepheid is surrounded by the remains of an open cluster (Turner 2009).

4. Summary

1. For the first time, we applied a 3D calculator to the three-dimensional U, V and Z coordinates of 20 stars in the Polaris field to clearly show their locations in space.
2. Despite the differences in the parallax estimates for these stars, 17 objects form a noticeable clamp with Polaris, while three objects fall outside it. Two outlier objects belong to the thick disk, and one is a possible remnant of another cluster within

Polaris's field.

3. The close proximity of the K-giant HD 6319 to Polaris and its location within the clamp may be evidence of the existence of the remains of one of the open clusters in the Cepheid field.
4. Use of 3D calculators to produce spatial plots may serve as a new tool to study the structure and dynamics of open clusters in the future.

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