A three-dimensional map of the Milky Way based on classical Cepheids

Dorota Skowron[1] and OGLE Team

1. Astronomical Observatory, University of Warsaw, Al. Ujazdowskie 4, 00–478 Warszawa, Poland

We present a three dimensional map of the Milky Way based on a sample of 2431 classical Cepheid variable stars. The distances were determined with the use of mid infrared (IR) data from the WISE and Spitzer telescopes. We show that the Galactic disk is significantly warped and flared. We also present a simple simulation that shows that Cepheids were born in episodes of star formation in the spiral arms.

1 Introduction

Classical Cepheids are young (< 400 My) supergiants with luminosities of about $10^2 - 10^4\,L_\odot$, that pulsate regularly with periods of $1-100$ days. They are excellent targets for investigating the structure of our Galaxy: they are very bright which makes them visible throughout the entire Milky Way disk, and they follow a well defined period-luminosity (PL) relation (Leavitt & Pickering, 1912), that allows for precise and direct distance determination.

Here we present the results recently published by Skowron et al. (2019).

2 Data

The sample of Cepheids consists mainly of the Optical Gravitational Lensing Experiment (OGLE) collection of 1514 Galactic Cepheids (Pietrukowicz et al., 2013; Soszyński et al., 2011, 2017; Udalski, 2017). This was supplemented with 917 classical Cepheids from several other sources, i.e. GCVS, ASAS (Pojmanski, 2002), ASAS-SN (Jayasinghe et al., 2018), and ATLAS (Heinze et al., 2018). Fig. 1 shows the on-sky distribution of the entire sample.

Distances to Cepheids were obtained by using the mid-IR data for these objects from the WISE (Wright et al., 2010; Mainzer et al., 2011) and Spitzer (Benjamin et al., 2003; Churchwell et al., 2009) surveys and the mid-IR PL relations from Wang et al. (2018). The use of mid-IR data minimizes the effects of extinction which is very large and difficult to account for in the optical bands. We found counterparts for 2222 classical Cepheids in the WISE and Spitzer catalogs and their distribution is presented in Fig. 2. For details on distance determination refer to Skowron et al. (2019).

3 Results

3.1 The Warp

We found that the disk of the Milky Way is significantly warped (Fig. 3). The warping starts at about 8 kpc from the Galactic center and reaches the edge of the

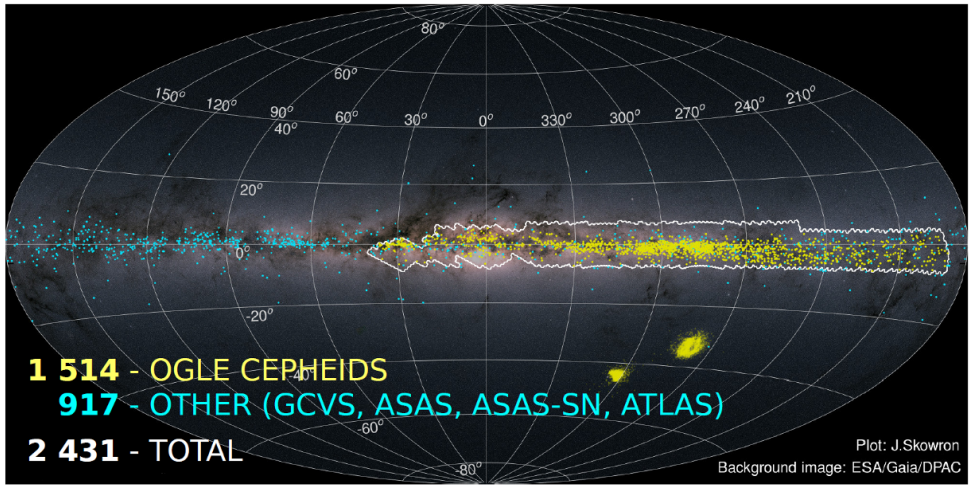

Fig. 1: The sample of classical Cepheids used in this work on top of the all-sky Gaia image. The OGLE Cepheids are marked with yellow dots, while Cepheids from other sources are marked with cyan dots.

Galaxy at about 20 kpc galactocentric distance. To constrain the warping, we fit a polynomial surface to the distribution of Cepheids, which is plotted in Fig. 3.

The scale height of the Galactic disk is $H = 73.5 \pm 3.2$ pc and the Sun is displaced from the galactic plane by $z_0 = 14.5 \pm 3.0$ pc. We also found that the flaring of the disk is significant and matches previous observations of neutral hydrogen.

3.2 The Age Distribution

The age of the classical Cepheid can be calculated based on its pulsation period (Anderson et al., 2016). Fig. 4 shows an age tomography of the Milky Way. The youngest Cepheids are located closer to the Galactic center, while the oldest ones are more dispersed and at larger distances on average. We also see that Cepheids of similar ages form structures that resemble spiral arms. This suggest that Cepheids in these overdensities may have formed together in past star formation episodes.

To test this hypothesis, we simulated Cepheid formation episodes for the three most prominent age groups that would produce the distribution that is observed now. The final result of the animation that was presented during the conference talk in the video form, is shown in Fig. 5. We see that even a simple model can reproduce the current shape and ages of the overdensities. For details on the simulation and the results see Skowron et al. (2019).

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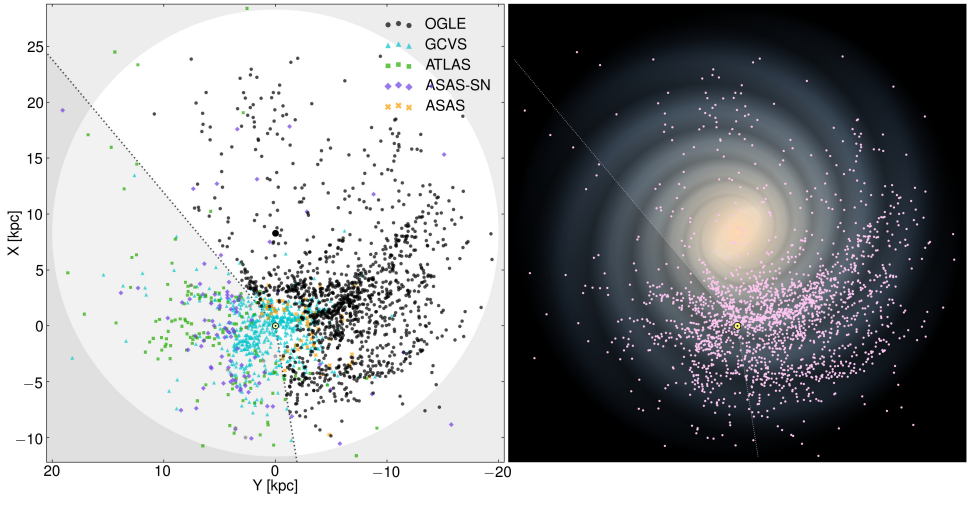

Fig. 2: The on-sky view of the Milky Way showing distances to all classical Cepheids, marked with various symbols, depending on the Cepheid origin (left) and marked with purple dots (right).

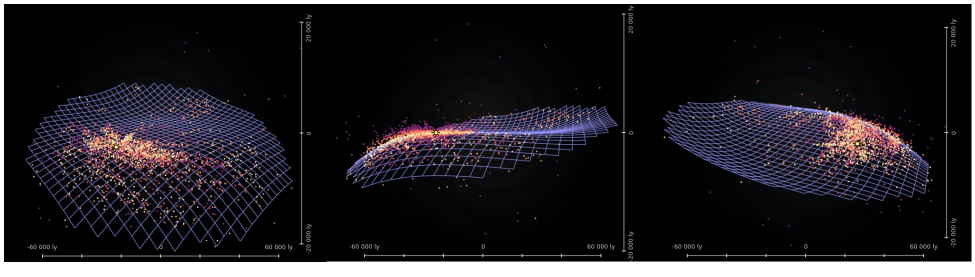

Fig. 3: Screenshots from the video presented during the talk. The warp of the Galactic disk seen from three selected viewing angles.

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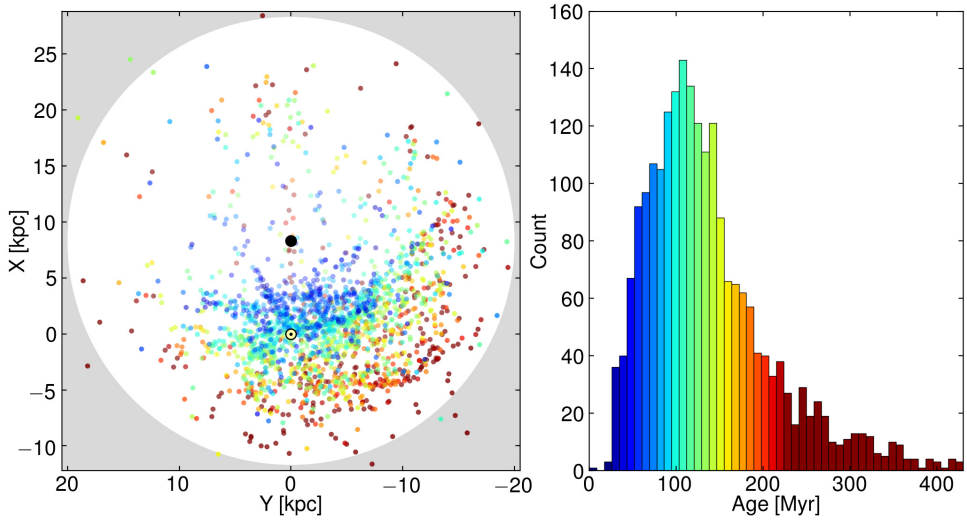

Fig. 4: The distribution of ages of classical Cepheids marked with different colors (left) and the histogram of ages (right). The colors on both panels correspond to the same ages.

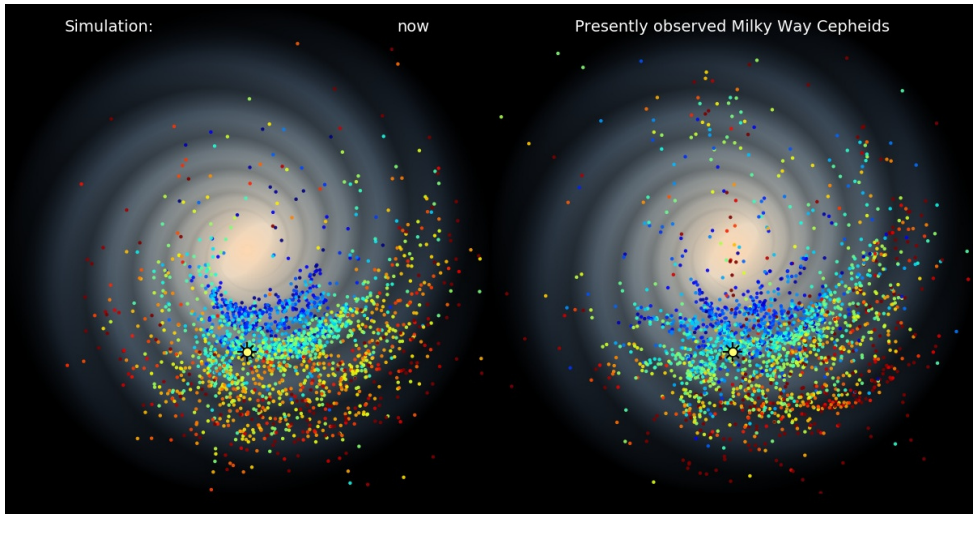

Fig. 5: The comparison of a simulated (left) and real (right) distribution of classical Cepheids in the Galactic disk. The youngest stars (blue) are 30 million years old while the oldest ones (blue) are 400 million years old.