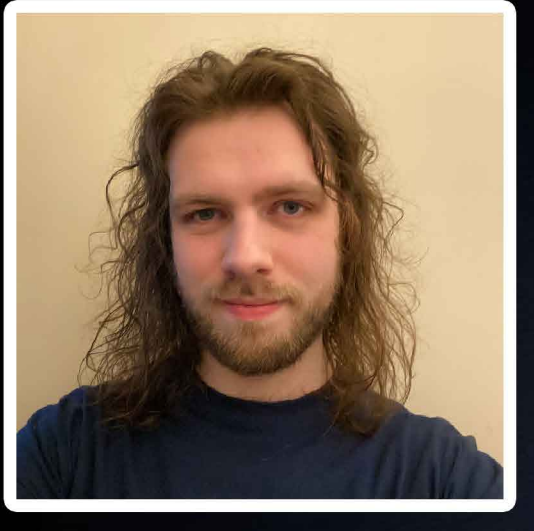


Massive Stars at Extreme Heights

Above the Galactic Plane



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Massive star formation is thought to occur within the Galactic disk, so the presence of massive stars at a Galactic height of more than a kiloparsec is unexpected, given their short lifetime. Using the Alma Luminous Star (ALS) III catalogue [1] and Gaia DR3 data, we determine the scale height of over 17,000 Galactic OB candidate stars (64 ± 4 pc) and find 90 of them at a Galactic height exceeding 750 pc up to 2 kpc. We term these objects eXtreme Galactic Latitude Objects (XGLOs). Based on their current position and velocity (if available including the radial velocity), and taking into account the Galactic potential, we reconstruct their paths to find out whether these objects could have originated from the Galactic plane within their estimated lifetimes. We find that all XGLOs left the Galactic plane within a timeframe of 5 - 65 Myr; three of them seem to originate from near the Galactic center. Our hypothesis is that these XGLOs are OB runaways that were born in the Galactic plane and were ejected by dynamical interactions within their parent cluster or with the supermassive black hole Sgr A*.

The XGLO Sample

The Alma Luminous Star (ALS) III catalogue [1] includes 17,284 luminous stars of which the majority is expected to be massive ($> 8 M_{\odot}$) and of spectral type O and B. Using the Gaia DR3 Galactic longitude, latitude, and parallax, we determine the spatial distribution of all ALS III stars, displayed in Figure 1. Using the elevation above or below the Galactic plane, we derive a scale height for this sample of 64 ± 4 pc. By defining a threshold of ~ 750 pc¹, we find 90 OB stars in a range from 750 to 2000 pc. We call these stars eXtreme Galactic Latitude Objects (XGLOs).

The spatial distribution of these XGLOs is concentrated towards the Galactic center, with 84% located within the Solar orbit around the Galactic center. This is not unexpected, as massive stars are formed in large molecular clouds which are found in the inner regions of the Galaxy, and are concentrated towards the Galactic disk [2]. As massive stars are formed in the Galactic disk [3], **how could these XGLOs have reached such extreme Galactic heights within their relatively short lifetimes?**

1: The Earth's atmosphere is considered to 'end' at 11.7 scale heights. Using a similar criterion, we arrive at a threshold of 749.3 pc.

Tracing XGLO Origins

We have traced back the paths of all XGLOs using their measured position and velocity, taking into account the solar motion and the Galactic potential [6]. All XGLO paths pass through the Galactic disk; a few examples are displayed in Figure 2. This demonstrates that the **XGLOs likely originate from the Galactic disk**. From these paths, we derive the travel time from the Galactic plane to their current location; the **Time of Flight (ToF)** ranges from 5 to 65 Myr. From these reconstructed paths, we also find that XGLOs would have ejection velocities ranging from 30 to 475 km/s.

For 3 out of 90 XGLOs, the most likely origin is within 2 kpc from Sgr A*, the supermassive black hole in the Galactic center (Fig. 2d). These 3 XGLOs may belong to the category of **hypervelocity stars** [7,8], but do not tick all the boxes.

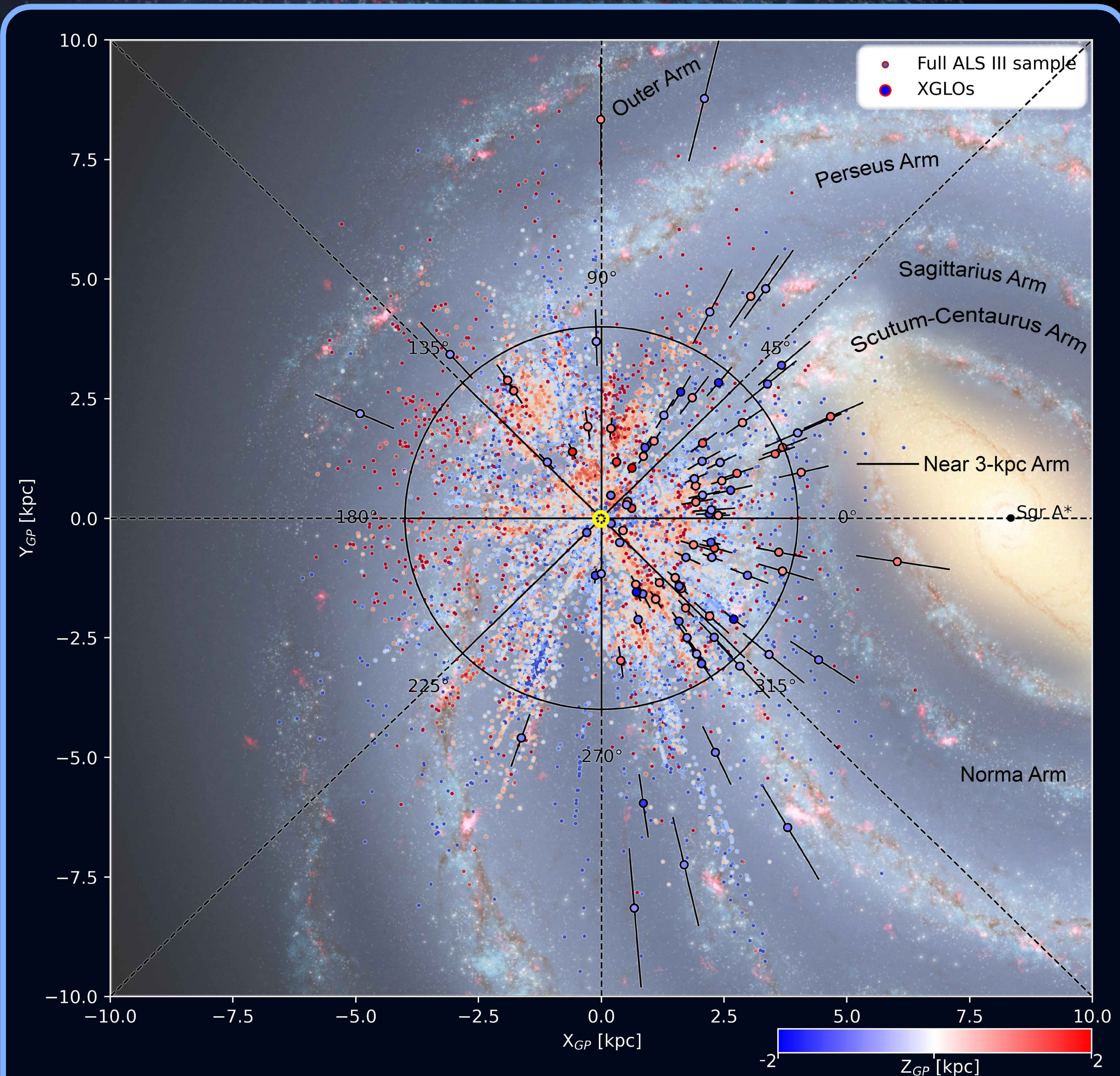


Figure 1: A top-down view showing the distribution of all ALS III stars (17,284 small dots) and the 90 eXtreme Galactic Latitude Objects (XGLOs) at more than 750 pc above the Galactic plane (large dots color coded based on the measured Galactic height). As a reference, we show an artist's impression of the Milky Way [5]; the Sun is shown as a yellow symbol. Most XGLOs are found within the Solar circle.

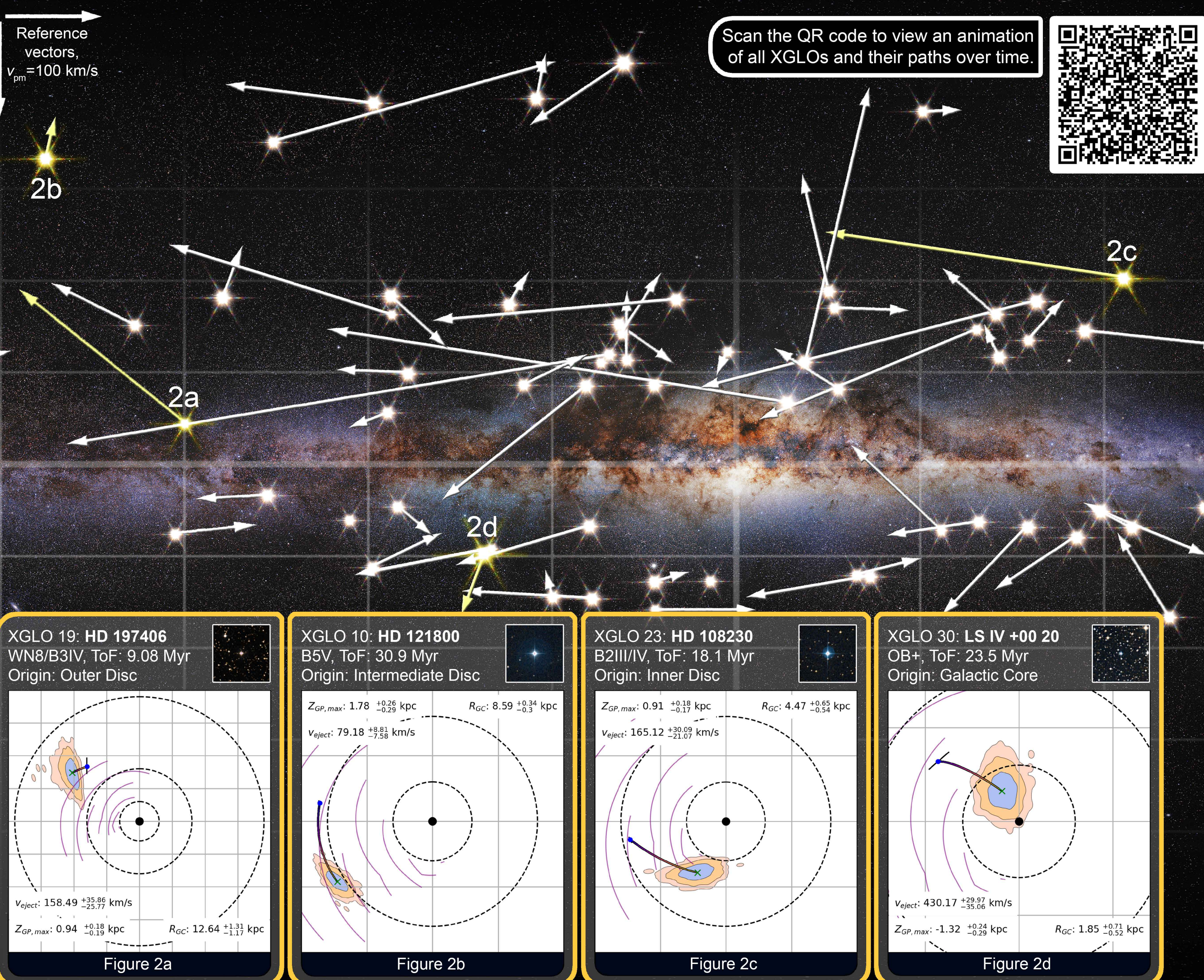


Figure 2: The position and velocity (white arrows) of the XGLOs with respect to the night sky in Galactic coordinates. For 4 cases (yellow arrows), panels are shown with top-down views of the Galactic plane in a 5x5 kpc grid, showing their current locations (blue dot), likely origins (green cross), colored zones indicating 1σ , 2σ and 3σ KDE origin likelihoods, and trajectories. Spiral arm models [4] are added, traced back to the ejection time of each XGLO. Note that objects may be closer than they appear.

A Matter of Age

To find out whether these travel times are feasible within the expected lifetime of the star, we estimated their current age using isochrone fitting [9,10,11]. In Figure 3 we compare the ToF with the estimated age of the XGLO and observe a peak where these timescales are equal, albeit with a large uncertainty.

Our hypothesis is that XGLOs are OB runaways that were ejected from their parent cluster just after birth, which is consistent with other studies done on OB runaways [12,13].

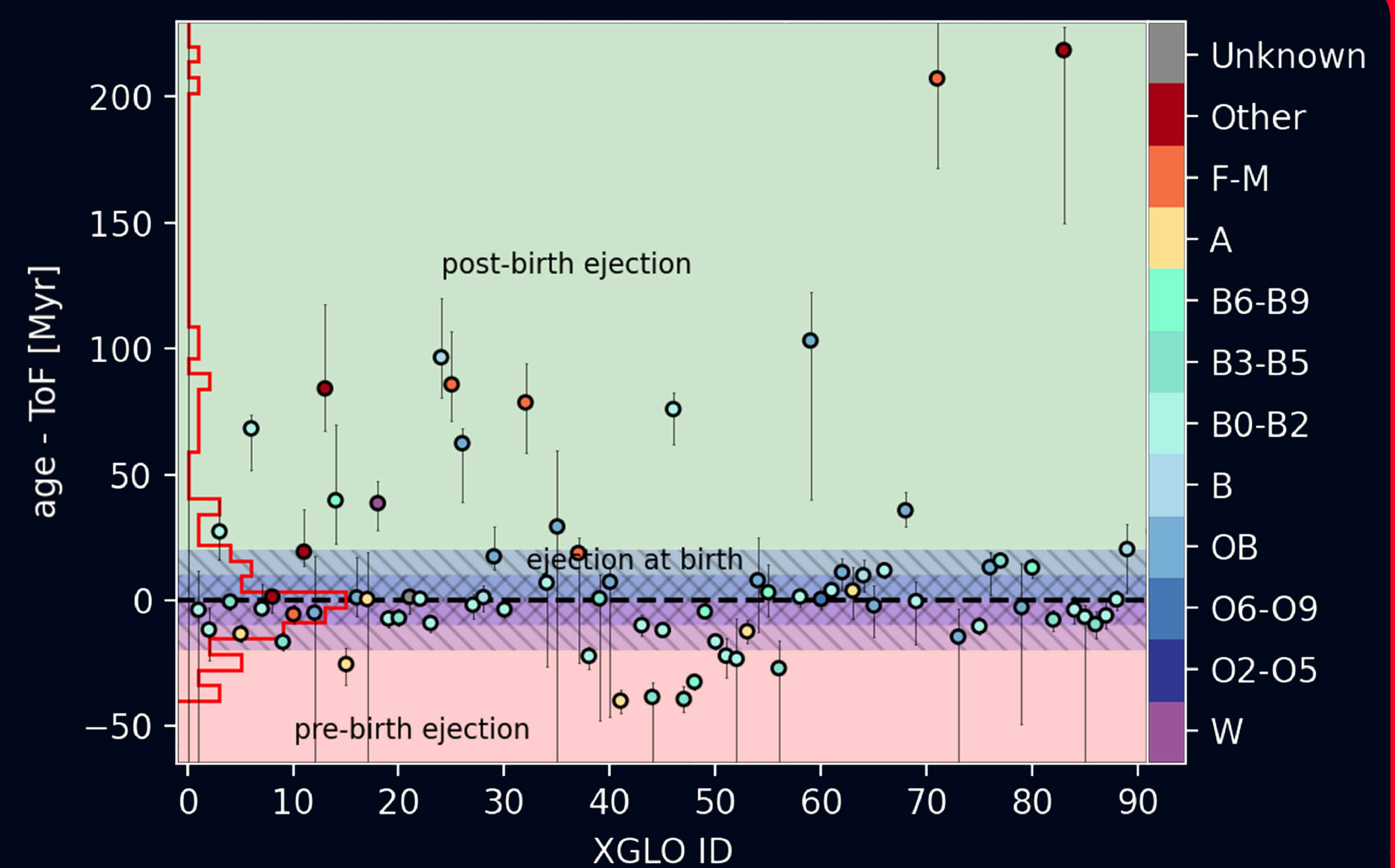


Figure 3: For each XGLO the difference between the derived Time of Flight and the estimated age through single star isochrone fitting [9,10,11] is shown. A positive value would be consistent with ejection from the Galactic disk after birth. The red histogram to the left indicates that the derived (age - ToF) distribution peaks at zero, with a relatively large width of about 10 Myr. The spectral type of the XGLO is indicated to the right; most XGLOs are of spectral type B.