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Structure, kinematics and time evolution of the Galactic Warp revealed by Classical Cepheids

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In this work we presented an analysis of the warp's structure using a Fourier decomposition in vertical high (Z) and vertical velocity (V_z) traced by Cepheids. Also, we found that the joint analysis of the Fourier decompositions in Z and V_z reveals the time evolution.

The warp is a well-known undulation of the Milky Way disc. Its structure has been widely studied, but only since Gaia DR2 has it been possible to reveal its kinematic signature beyond the solar neighborhood. In this work, we explore with detail the structure, kinematics, and time evolution of the warp considering its asymmetries without assumptions on the radial dependency of the Fourier parameters.

To study the warp, we have used the catalogue of Milky Way Cepheids from Skowron et al. (2019). The catalogue contains 2385 Classical Cepheids from which 1997 meet our quality filters. We cleaned the sample by keeping stars with RUWE < 1.4, an error in $Z \leq 0.1$ kpc, and an error in $V_z \leq 13$ km/s. To decompose the warp signal, we divide the disc into various concentric rings, and in each of them we fit a Fourier sum (up to the $m = 2$ mode) to Z and V_z.

We found a clear but complex signal that reveals an asymmetrical warp in both variables. In Z we found the warp to be almost symmetric in amplitude at the disc's outskirts but with the two extremes never diametrically opposed at any radius. The line of nodes presents a twist in the direction of stellar rotation for $R > 11$ kpc (black line in Fig. 1).

For the kinematics, we found that in V_z an $m = 2$ mode is needed to represent the kinematic signal of the warp, reflecting its azimuthal asymmetry. We also found that the line of maximum vertical velocity (green line in Fig. 1) is similarly twisted but does not overlap with the line of nodes, it trails behind by ≈ 25 deg, we conclude that this

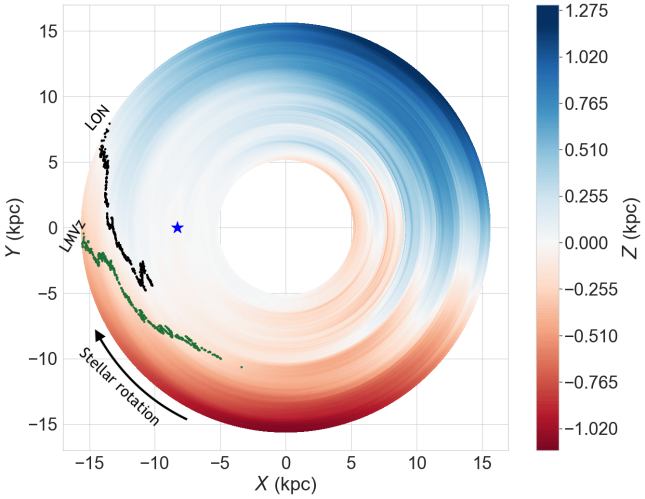

Figure 1. Face-on view of the best fitting warp model for the Cepheids. The color scale represents the mean Z of the disc (blue above the plane and red below it). The line of nodes (LON) (black curve). The dark green curve indicates the line of maximum vertical velocity.

is due to the lopsidedness of the warp. We have shown how the twisted line of maximum V_z creates "arches" in the mean V_z as a function of radii, a signature of global warp kinematics that has been observed with other tracers with less azimuthal coverage of the disc (Cheng et al., 2020; Gaia Collaboration et al., 2021).

Finally, a joint analysis of the Fourier decompositions in Z and V_z allows us to develop a new model-independent formalism to derive the pattern speed and change in amplitude of each mode at each radii. By applying it to our results for the Cepheids we found, for the $m = 1$ mode, a constant pattern speed in the direction of stellar rotation of 9.18 ± 3.1 km/s/kpc, a constant amplitude up to

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$R \approx 14$ kpc and a slight increase in amplitude at larger radii, in agreement with previous works (Dehnen et al., 2023).

References

Cheng, X., Anguiano, B., Majewski, S. R., et al. 2020, ApJ, 905, 49, doi: 10.3847/1538-4357/abc3c2

Dehnen, W., Semczuk, M., & Schönrich, R. 2023, MNRAS, 523, 1556, doi: 10.1093/mnras/stad1502

Gaia Collaboration, Antoja, T., McMillan, P. J., et al. 2021, A&A, 649, A8, doi: 10.1051/0004-6361/202039714

Skowron, D. M., Skowron, J., Mróz, P., et al. 2019, AcA, 69, 305, doi: 10.32023/0001-5237/69.4.1

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