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The Selection Function of Gaia DR3 RR Lyrae

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ABSTRACT

The Third Data Release (DR3) of the Gaia mission almost doubled the number of RR Lyrae (RRL) stars release in its Specific Object Studies (SOS) catalog, in comparison with DR2. Here I provide empirically inferred 2D and 3D completeness maps for the Gaia DR3 SOS RRL catalog along with maps for the combined Gaia SOS+PS1+ASAS-SN-II catalog. The latter currently has the best performance with an improvement of 9% relative to Gaia DR3 alone and close to 20% relative to Gaia DR2 for the VC+SOS RRL, while significantly smoothing out the effect of the Gaia scanning law.

Keywords: stars: variables: RR Lyrae — astronomical databases: miscellaneous

1. INTRODUCTION

RR Lyrae (RRL) stars are an important and increasingly popular tracer of Galactic structure thanks mainly to their standard candle nature, which provides precise distances with errors usually well below 10%. For certain applications like the determination of the density profile of Galactic components, the knowledge of the selection function or completeness of an RRL catalog across the sky and versus distance are indispensable.

In Mateu et al. (2020, M20) we empirically derived completeness maps for the PS1, ASAS-SN-II and Gaia DR2 RRL catalogs (Sesar et al. 2017; Jayasinghe et al. 2019; Clementini et al. 2019). This work showed the completeness for the SOS RRL (Specific Object Studies) catalog was severely affected by the Gaia scanning law pattern, and that complementing it with the VariClassifier (VC) catalog provided a more complete sample, albeit with relevant information such as period and amplitudes not available for the VC stars. Gaia's DR3 offered an enormous improvement in variable star catalogs, in particular, with the SOS RRL increasing from > 140K stars in DR2 to > 270K in DR3 (Clementini et al. 2023). Here, I followed M20 to produce updated completeness maps for Gaia DR3 SOS RRL at the combined Gaia SOS+PS1+ASAS-SN-II catalog.

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2. COMPLETENESS MAPS FOR GAIA DR3 SOS RR LYRAE

The completeness maps provided here were obtained following the procedure described in detail in M20 and using the tools provided with the `rrl_completeness` GitHub repository available here. The methodology used there, devised by Rybizki & Drimmel (2018), requires two *independent* catalogs from which the completeness of both can be derived, wherever there is overlap between the two. The combined PS1+ASAS-SN-II RRL catalog was used as the second (independent) catalog. Together, these span Gaia's full magnitude range with ASAS-SN-II spanning the full sky down to $G \sim 17$ and PS1 down to (and beyond) Gaia's limit of $G = 20.7$, for $DEC > -30°$. As in M20, the sky coverage of the completeness maps for $DEC < -30°$ was completed at the faint end by filling the map at each line of sight with the region diametrically opposed in ecliptic coordinates.

The 2D and 3D completeness maps were produced separately for Gaia DR3's SOS RRab and RRc stars, for i) the full sample (271,779 stars), and for three sub-samples with commonly used quality filters: ii) RUWE: stars with `ruwe`$<$ 1.4, iii) BEP: stars with `phot_bp_rp_excess_factor` < 3 and iv) RUWE_BEP: stars in the RUWE $\cap$ BEP sample. We also provide 2D and 3D completeness maps for the combined Gaia DR3 SOS+PS1+ASAS-SN-II catalog which, under the assumption that the catalogs are independent, is straightforward to compute using the individual maps.

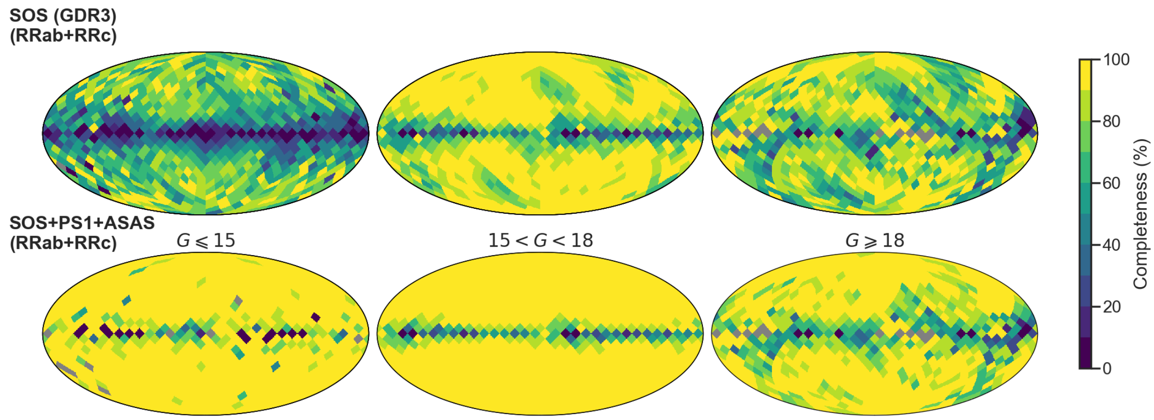

Figure 1. Completeness maps (Mollweide projection) in Galactic coordinates for the Gaia DR3 SOS RRL (top row) and for the combined SOS+PS1+ASAS-SN-II RRL catalog (bottom row), in three ranges of apparent magnitude. In both cases, the RUWE sample for SOS was used. The center of the map corresponds to $l = 0^\circ$ with longitude increasing to the left.

Figure 1 shows the 2D completeness maps for the RUWE Sample (ii) of Gaia DR3 SOS RRL stars (top), compared to the combined SOS+PS1+ASAS-SN-II catalog (bottom) in three magnitude ranges.

3. CONCLUSIONS

Overall the completeness of the Gaia SOS catalog is now comparable ($\sim 3\%$ higher on average) to that reported by M20 for Gaia VC+SOS for DR2, with the advantage that current (SOS) have many more light curve attributes than the VC sample in DR2, particularly periods, necessary for distance computations based on Period-Luminosity relations. The average completeness of Gaia SOS RRL at the bright end ($G \leqslant 15$) is found to be lower than that for the $15 < G < 18$ magnitude range, similarly to the findings reported by M20 for Gaia DR2. This means that, for the brighter RRL stars the ASAS-SN-II catalog remains more complete than Gaia overall (see Figs. 8 and 3 in M20), for both RR*ab* and RR*c*.

The most complete catalog therefore, both in terms of the selection function as in terms of light curve attributes for each RRL, is given by the combination of the Gaia SOS, PS1 and ASAS-SN-II catalogs. This combined catalog provides a map with a higher completeness over the full distance range, compensating Gaia's relative incompleteness at the brighter end, and also showing a smaller dependence on Gaia's scanning law pattern, particularly at the faint end, resulting in a (spatially) smoother map as illustrated by Figure 1.

The full tables containing 2D and 3D maps for the four samples of the Gaia DR3 SOS and VC+SOS catalogs, as well as the combined SOS+PS1+ASAS-SN-II catalog, are publicly available at the `rrl_completeness` GitHub repository. A dedicated example notebook shows how to query the maps and reproduce all computations involved.

Software: astropy (Astropy Collab. et al. 2018)

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