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DUST AND STAR DISTRIBUTION IN THE MILKY WAY DISK

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Abstract. We are curently in the large surveys era. These surveys, more complete and deeper than previous ones, are providing many new and important information. Through them we can unravel distances of structures of dust and star in the Milky Way disk.

Using various infrared surveys (2MASS - UKIDSS - VVV) together with the Gaia data release 2 (DR2), we look for to obtain the join distribution of dust and stars in several fields of views of the galactic disk. To do so, we are developing the FEDReD algorithm (Field Extinction - Distance Relation Deconvolver) which compares observational data to an observational HR diagram using a Bayesian approach which takes the selection functions into account.

Keywords: Galactic Structure, Galactic Disk, Dust, Extinction

1 Introduction

Stars light up the sky, but we see them in 2 dimensions. The lack of distances information in addition to interstellar extinction, hide the galactic morphology.

Today we know some of disk structures, such as spiral arms. Different works traced spiral arms with gas clouds (e.g. Nakanishi & Sofue 2016), masers (e.g. Reid et al. 2014) and star forming complex (e.g. Russeil 2003) but no agreement on their number has been reached yet. For the last decade, the Milky Way structures have also been tracked with 3D extinction map (e.g. Marshall et al. 2006).

However previous works were focused either on extinction or on stellar structures. We develop FEDReD to study stars and extinction simultaneously. Thanks to the Gaia mission (Gaia Collaboration et al. 2016), and especially the second data release (Gaia Collaboration et al. 2018b; Evans et al. 2018; Lindegren et al. 2018), the parallax of a large set of stars is now known. Using this distance information, and crossing it with the infrared photometry given by 2MASS (Skrutskie et al. 2006), we can now deconvolve the distance and the extinction in a given field of view. By analysing all the Milky Way disk, we are able to highlight some structures.

This proceeding only summarise the working process of FEDRed. All details will be explained in Babusiaux et al. 2019 and Hottier et al. 2019.

2 FEDReD algorithm

Our algorithm is applied to the galactic disk, field by field. FEDReD uses infrared photometry of each observed star in the sky area of interest, complemented by parallax and photometry coming from Gaia DR2.

We work in the distance modulus (μ) - A_0 (extinction at 550 nm) space. The first step of analysis is to process of the probability distribution function (PDF) in the phase space of each observed star. We then proceed with a Richardson-Lucy deconvolution to merge the density of each star.

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2.1 Star's PDF

This first step consists of processing the probability density of each star in the distance modulus - extinction domain. One star is described by several observational parameters, the photometric data, which can be in magnitude or in flux, in different wavelength bands. For some stars, the Gaia parallax is also known.

To compute the likelihood of the observation of a given star O, at a given distance D - extinction A_0 ($P(O|A_0, D)$), we compare its observational parameters to an empirical HR diagram. Knowing the absolute photometry of reference stars we can infer the theoretical expected magnitude at the distance D extincted by A_0, in each studied photometric bands and compare it to the observed value.

In Figure 1 we represent the PDF of a main sequence star and a red clump star. The true (A_0, D) is at $(3, 4)$. One can notice that it is the red clump stars which provide more information.

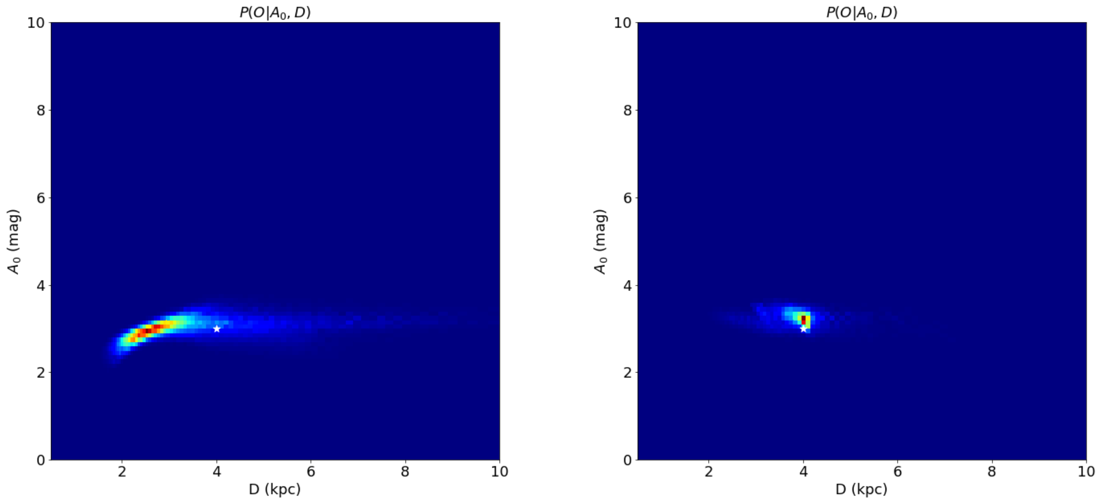

Fig. 1. PDF of two different stars. Left : one main sequence star. Right : one red clump star. Both stars are at 4 kpc with extinction of $A_0 = 3$ mag, this position is represented by a white star.

2.2 Deconvolution

Once the probability density for each star in a field of view is known, we have to combine them. To do this we use a Richardson - Lucy deconvolution. We proceed iteratively to get the distribution of $P(A_0, D)$. To avoid noise interpreted as a spurious signal, for a large number of iterations, we need to stop the process when the evolution between two successive iterations is small enough.

To initialise this algorithm we set probability priors. $P(A_0|D)$ is set to be flat, in order to let the distribution evolve freely. As the prior $P(D)$ we use a simple exponential profile of the Galaxy.

We also have to consider the selection function S of the field of view. This selection function is just a model of near-infrared survey completeness, which allows to compute $P(S|A_0, D)$. This quantity enable us to derive $P(A_0, D)$ from $P(A_0, D|S)$, which is the actual quantity obtained by the deconvolution.

Once the $P(A_0, D)$ distribution has been computed, we fit a constrained spline, using the *cobs* R package (Ng & Maechler 2007). This increasing spline draws the most probable distance - extinction relation for the considered line of sight. To get the stellar density we have to marginalise the $P(A_0|D)$ PDF, to obtain the $P(D)$. This part of FEDReD is not yet fully functional, and will be discussed in Babusiaux et. al. 2019 and Hottier et. al. 2019.

3 Empirical HR diagram

To compare observed stars, we have implemented two different references. The first one uses the Bressan et al. (2012) isochrones. We process the weight of each point using an initial mass function and a stellar formation rate (see Babusiaux et al. 2019 for more details). This process has been applied before Gaia DR2 and provided good result. We can now build a new reference star set, which is not depending on a model but uses directly the Gaia DR2 observations to extract an empirical HR diagram.

We selected only stars within 50 pc from the galactic plane, with low extinction according to the 3D extinction map of Capitanio et al. (2017), and after applying the astrometric and photometric filters described in Lindegren et al. (2018); Gaia Collaboration et al. (2018a). We then assign a weight for each point of the obtained HR diagram, according to the observed stellar density, and we correct it by the selection function induced by our selection cut. In order to get the magnitudes of each HR point in the J, H and K band, we used the cross match between Gaia DR2 and 2MASS (Marrese et al. 2018) and we build colour-colour relations.

We use this HR diagram is the same along all the disk.

4 Extinction Coefficient

In order to compare the stars in our empirical HR diagram to observed stars, we have to convert the reference extinction value (A_0) to extinctions in different photometric bands. Due to the wideness of Gaia photometric bands, extinction coefficients are functions of both the intrinsic star colours, and the extinction itself.

To take this variation into account, we use the polynomial model for extinction coefficients described in Danielski et al. (2018), fitted using the Fitzpatrick & Massa (2007) extinction law and the Kurucz Spectral Energy Distributions (Castelli & Kurucz 2003). As can be seen in Figure 2, the variation of coefficients is far from negligible and could create wrong individual distribution of observed stars if colours are not taken into account.

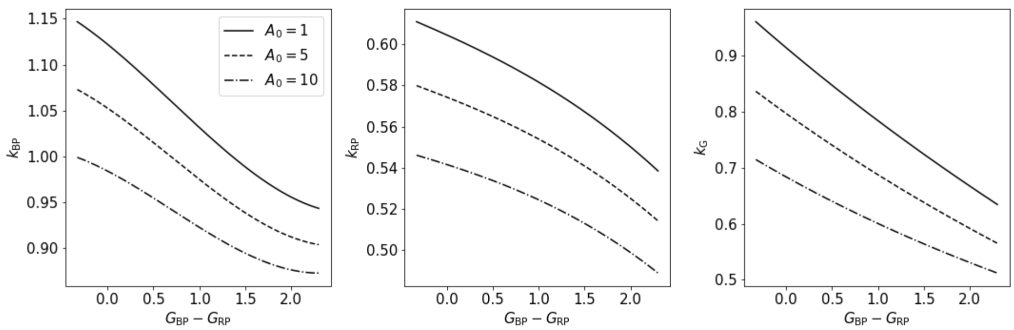

Fig. 2. Extinction Coefficients k_G, k_{BP} and k_{RP} as a function of intrinsic colour $G_{BP} - G_{RP}$, for different A_0 extinctions (continuous line : $A_0 = 1$ mag, dash line $A_0 = 5$ mag and dotted dash line $A_0 = 10$ mag)

5 Results

We test our algorithm on a simulated field of view. The left panel of Figure 3 represents the result of FEDReD and the input distance - extinction relation. Along the line of sight, the true relation is always contained in the confidence area (more validation tests will be presented in Babusiaux et al. 2019).

The right panel of Figure 3 represents the application of FEDReD in many fields of view in the direction of the galactic centre. This is a preliminary map but it already shows some agreement with Reid et al. (2014) masers.

6 Conclusions

The testing phase of FEDReD is almost finished. Preliminary results are encouraging. We will finalise all the analysis chain, and proceed to a systematic analysis of the Milky Way disk using 2MASS and Gaia DR2. Then we can use FEDReD to go deeper into the disk by using UKIDSS (Lawrence et al. 2007) and VVV survey (Minniti et al. 2010).

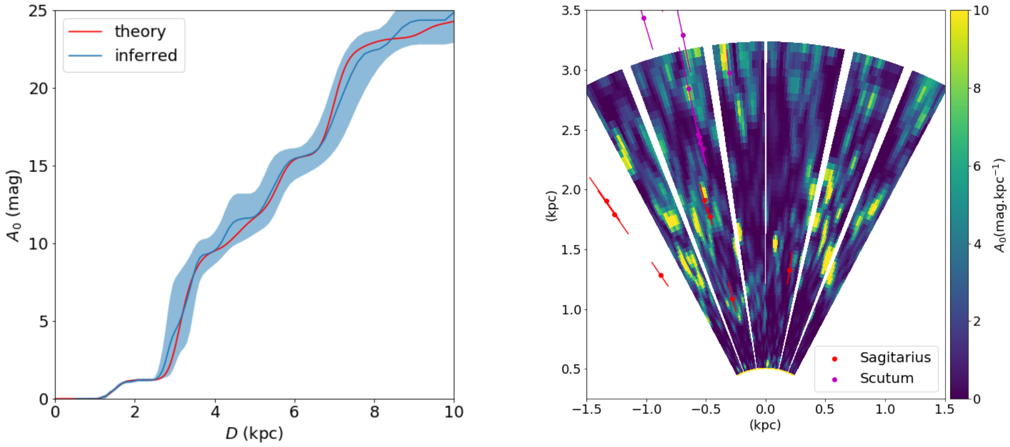

Fig. 3. Left Panel : the true distance - extinction law in red line, the FEDReD best inferred relation in blue line and the 5 σ cobs confidence interval in blue area. Right Panel : Extinction map of the milky way disk $b = 0°$ with $l \in [-30°, 30°]$. The Sun is at $(0, 0)$ and the milky centre is at $(0, 8)$. Dots represent the of Reid et al. (2014) maser's corresponding to Scutum and Sagittarius arms.

References

Bressan, A., Marigo, P., Girardi, L., et al. 2012, Monthly Notices of the Royal Astronomical Society, 427, 127

Capitanio, L., Lallement, R., Vergely, J. L., Elyajouri, M., & Monreal-Ibero, A. 2017, Astronomy & Astrophysics, 606, A65

Castelli, F. & Kurucz, R. L. 2003, in Modelling of Stellar Atmospheres, ed. N. Piskunov, W. W. Weiss, & D. F. Gray, Vol. 210, A20

Danielski, C., Babusiaux, C., Ruiz-Dern, L., Sartoretti, P., & Arenou, F. 2018, Astronomy & Astrophysics, 614, A19

Evans, D. W., Riello, M., Angeli, F. D., et al. 2018, Astronomy & Astrophysics, 616, A4

Fitzpatrick, E. L. & Massa, D. 2007, The Astrophysical Journal, 663, 320

Gaia Collaboration, Babusiaux, C., van Leeuwen, F., et al. 2018a, Astronomy & Astrophysics, 616, A10

Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018b, Astronomy & Astrophysics, 616, A1

Gaia Collaboration, Prusti, T., de Bruijne, J. H. J., et al. 2016, Astronomy & Astrophysics, 595, A1

Lawrence, A., Warren, S. J., Almaini, O., et al. 2007, Monthly Notices of the Royal Astronomical Society, 379, 1599

Lindegren, L., Hernández, J., Bombrun, A., et al. 2018, Astronomy & Astrophysics, 616, A2

Marrese, P. M., Marinoni, S., Fabrizio, M., & Altavilla, G. 2018, arXiv:1808.09151 [astro-ph], arXiv: 1808.09151

Marshall, D. J., Robin, A. C., Reylé, C., Schultheis, M., & Picaud, S. 2006, Astronomy & Astrophysics, 453, 635

Minniti, D., Lucas, P., Emerson, J., et al. 2010, New Astronomy, 15, 433

Nakanishi, H. & Sofue, Y. 2016, Publications of the Astronomical Society of Japan, 68, 5

Ng, P. & Maechler, M. 2007, Statistical Modelling: An International Journal, 7, 315

Reid, M. J., Menten, K. M., Brunthaler, A., et al. 2014, The Astrophysical Journal, 783, 130

Russeil, D. 2003, Astronomy & Astrophysics, 397, 133

Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, The Astronomical Journal, 131, 1163