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Orbits and radial migration of galactic tracers using Gaia+

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Abstract

It will be in the forthcoming years that a large set of stars with full 6D phase space information will be available. In this contribution, we focus on the study of the radial migration stellar kinematic tracers may suffer. By assuming a potential for the Milky Way, we analyze the capabilities of Gaia and future spectroscopic data to trace back in time the orbital evolution of both, Red Clump stars, excellent tracers of large scale disc structure, and the members of the Young Local Associations, nearby stars with accurate astrometry in the upcoming TGAS catalog. By considering different mechanisms causing radial migration, namely the bar and/or the spiral arms, we study future capabilities to ascertain a single origin to these tracers.

1 Introduction

The high quality astrometric and photometric data already collected by Gaia during these almost two years of successful scientific operation allow us to anticipate that, in few years, Gaia will revolutionize our understanding of our own Galaxy, the Milky Way, and its surroundings. Gaia Data Release 1 (GDR1), with unprecedented astrometric accuracies for distances and proper motions of nearby sources is already public. This release, ready for the first Gaia Science Exploitation tasks, will provide to the open community the first 3D map of the solar neighborhood, with parallaxes and proper motions with unprecedented accuracy for more than two million Tycho sources. Estimated astrometric errors are deeply discussed in [5] and validation tasks indicate these expectations are being accomplished. The accuracy in astrometric data for Hipparcos sources ($\sim 10^5$ stars) will improve in a significant factor. Parallax accuracy will be improved by a factor $2-10$, and proper motions by a factor more than $25-30$. For Tycho sources ($\sim 2 \cdot 10^6$ stars) we will have an astrometric accuracy better than that published for the Hipparcos sources in 1997. The second release (GDR2), with full astrometry (five astrometric parameters) for stars up to magnitude about $\mathrm{G} = 19-20$ will be a reality in one or two years[1]. In this work we present a set of scientific cases from the scientific exploitation of these two releases. In both cases, we find the need to combine/cross-match the Gaia data with complementary spectroscopic surveys to have full 6D phase space information. As an example, in this contribution we explore the possibility of using the future WEAVE radial velocity data[2] to trace back-in-time kinematic tracers in realistic Galactic potentials.

2 Scientific case for GDR1: the Young Local Associations

The Young Local Associations (hereafter, YLAs) are defined as groups of stars of ages between $8-100$ Myr, at less than 100 pc from the Sun, which share common motions and are chemically homogeneous. As excellent tracers of the young population in the solar neighbourhood, they allow us to study the mechanisms driving the star formation process and secular evolution of the Milky Way (hereafter, MW) thin disc population. Several YLAs have been defined thanks to the first Hipparcos astrometry [10, 4]. Nonetheless, their discovery and membership evaluation is highly demanding in terms of both, the observational data required and the kinematical and dynamical analysis. The 6D phase space (positions and velocities) shall be combined with realistic Galactic potentials to integrate their orbits back-in-time to characterize this population at birth. Undoubtedly, Gaia data combined with accurate spectroscopy will provide critical new insights in this study.

In this work we focus our study on whether the traceback analysis method we present below will be useful to study the origin and evolution of these YLAs. In this work we use two well-tested analytic Galactic potentials: the Galactic bar model as described in [9], and the PERLAS spiral arms model as described in [6]. For the spiral arms, we consider a spiral pattern speed of 20 km $\mathrm{s}^{-1}\mathrm{kpc}^{-1}$ and a pitch angle of $12°$. The traceback analysis method consists of the following integration steps. First, *Setting YLA present position*, we define a mother particle (M) at $T = 0$ with an initial position $\vec{R}_{M,0}$ and initial velocity $\vec{V}_{M,0}$ and we integrate this mother particle back a given time T. At this point the particle coordinates are $\vec{R}_{M,-T}$ and $\vec{V}_{M,-T}$. Second, *At birth*, we generate N particles (P) at the same position as the mother particle $\vec{R}_{P,-T} = \vec{R}_{M,-T}$ and with the same mean velocity but with an isotropic velocity dispersion of $(\sigma_U, \sigma_V, \sigma_W) = (2, 2, 2)$ km s^{-1}. Third, *At present*, we integrate the N particles forward in time the same time T, i.e. up to the present. Fourth, *Errors*, we apply observational errors to positions, parallax, proper motions and RV. Finally, *Back-in-time*, we integrate the orbits back-in-time the same time T.

[1]http://www.cosmos.esa.int/web/gaia/release
[2]http://www.ing.iac.es/weave/

We have considered four different scenarios, summarized in Table 1. Before Gaia represents essentially the current available data, based on Hipparcos astrometry and current RV surveys. DR1 TGAS-Hip and DR1 TGAS-Tyc are the two subsets of TGAS. Finally, Gaia+ represents the end-of-mission astrometric data together with complementary accurate RV. We assume that the YLA has N detected members with mean apparent magnitude $\langle V \rangle$ and a dispersion of 1 mag. For the Before Gaia scenario, we assume that the mean astrometric accuracy for the Hipparcos members at present is 1 mas and 1 mas yr^{-1}. For the Hipparcos subset, DR1 TGAS-Hip scenario, we update the astrometric accuracies to those specified in [5], and we assume currently spectroscopic data accuracies for stars near the solar neighbourhood to be about 2 km s^{-1}. In the Tycho subset of the release, DR1 TGAS-Tyc, which is fainter than the Hipparcos (about V = 11 mag in mean), we assume that DR1 data will allow us to double the number of members (from 20 to 50). Finally, the Gaia+ scenario assumes the expected end-of-mission astrometric performances and that complementary on-ground follow-up spectroscopic surveys will reach accurate RV ($\sigma_{RV} = 0.5$ km s^{-1}), which will allow us to increase significantly the number of new members in the YLA, with a mean V magnitude of about 13 mag. In this scenario, we assume a mean colour of the YLA members of $\langle (V-I) \rangle = 0.5$ mag, needed to compute the Gaia end-of-mission errors.

	N	$\langle V \rangle$	Astrometric accuracy	σ_{RV} (km s^{-1})
Before Gaia	20	9	Hipparcos	4
DR1 TGAS-Hip	20	9	DR1-Hip	2
DR1 TGAS-Tyc	50	11	DR1-Tycho	2
Gaia+	100	13	end-of-mission	0.5

Table 1: Different scenarios for the astrometric and spectroscopic data of a given YLA.

We present the results of the traceback analysis of a given YLA under two different potentials, first with a bar model and second with a spiral PERLAS-20-i12 model. For simplicity we assume that all the stars of the YLA have born at the same position, with null spatial dispersion, and isotropic velocity dispersion. We consider a YLA with an heliocentric velocity similar to that of TW-Hydra, $(-9.7, -17.1, -4.8)$ km s^{-1}[4], with an integration time of 50 Myr. In Fig. 1 we show the differences between the *Back-in-time* and the *At birth* positions as a function of the Data Scenarios. We can see that the differences using the current available data Before Gaia can be of the order of 1 kpc in positions. These differences are too big to make the method useful for the place of birth or age determination. The situation slightly improves when using the Gaia DR1 TGAS data, both Tycho and Hipparcos subsets, with the Hipparcos subset having smaller differences in the dispersion than the full Tycho. Results using TGAS data are that we can determine the place of birth with an accuracy of a few tens of parsecs. Even though the association has the *At birth* position at about 1 kpc from the Sun, the method recovers the initial positions with an accuracy of ± 20 pc, even if we only have 50 members. Work is in progress but as a preliminary result, we see that only when using the Gaia+ scenario we can recover positions with differences that are of less than 10 pc, thus only under this scenario we would be able to determine the dynamical ages of a YLA as the ones simulated here.

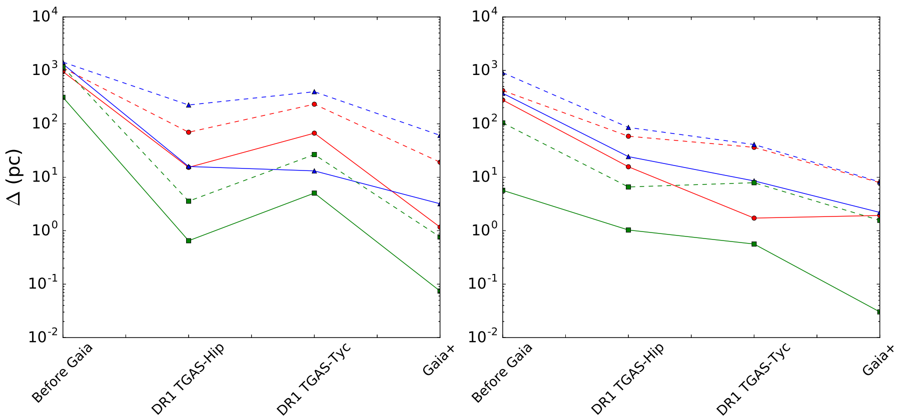

Figure 1: Effect of the different Data Scenarios and the two models considered on the recovery of the imposed mean positions (solid lines) and their dispersion (dashed lines) of a simulated TW Hya YLA. In red, blue and green we show the radial, tangential and vertical components, respectively. Particles have been integrated using the bar (left) and the spiral arm potential (right). Note that the y-axis is in logarithmic scale.

3 Getting ready for GDR2

Using the expected data to be released in GDR2, we can tackle a variety of scientific cases, ranging from the exploration of radial migration to the kinematic detection of the Galactic warp. In Fig. 2 we show the accuracy expected for the GDR2 trigonometric parallax data. We can see how Red Clump stars placed as far as $3-4$ kpc towards the Galactic anticenter will have distance accuracies better than 20%. Red clump stars, giants and supergiants stars, are good trace populations both for both Galactic structure and kinematic studies.

In Fig. 3 we show the orbital trajectory back-in-time of two simulated test particles. On the left we simulate a Red Clump star placed near the Perseus arm and towards the Galactic anticenter with galactocentric coordinates (X,Y) $= (-10.5, 0)$ kpc. Its apparent magnitude is $V \sim 15$. The second particle, on the right, simulates the same target but placed inner to the Sun galactocentric radius with coordinates (X,Y) $= (-6.5, -1.0)$ kpc, that is near the Sagitarius arm, with an apparent magnitude $V \sim 16$. One hundred realizations of each particle have been done assuming a Gaussian distribution of the astrometric proper motions errors as expected from GDR2. We simulate the Gaia observations of these particles using the public Gaia-error code developed by our team, implemented following the specifications of the Gaia Science Performance webpage[3] and using 22 months of Gaia data and assuming 2 km s^{-1} error in the radial velocity for a typical performance of the WEAVE instrument. Orbital evolution back-in-time has been performed using a realistic Galactic potential [9]. In black we show the trajectories of these particles and in red points the final positions of these one hundred realizations after evolving $\Delta t = 1$ Gyr under the Galactic potential. The

[3]Gaia-errors code: https://github.com/mromerog/Gaia-errors; Science Performance webpage: http://www.cosmos.esa.int/web/gaia/science-performance

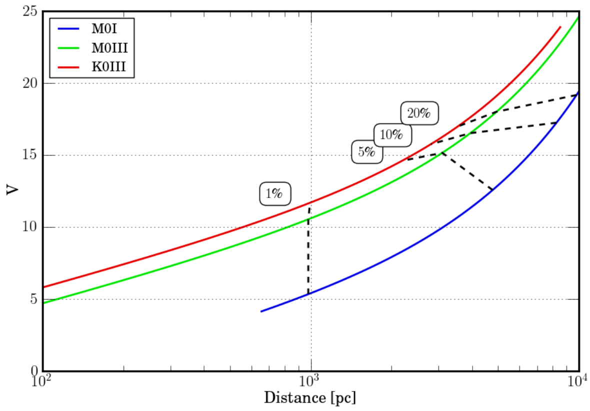

Figure 2: Mean relative parallax accuracy horizons for red giants and supergiants. The plot of visual apparent magnitude versus heliocentric distance has been done assuming an extinction of 1 magnitude per kiloparsec. Dashed lines represents the constant line of mean relative parallax accuracy expected for GDR2 (code courtesy by A. Brown).

dispersion of these points give us an indication of the accuracy we will have when looking, for example, at the at birth position of a particle in the Perseus or in the Sagitarius arm. At about 2 kpc from the Sun towards the anticenter direction, i.e. near the Perseus spiral arm, the dispersion of the particles when integrated back-in-time is much smaller than if we consider a set of particles located near the Sagitarius arm towards the inner part of the Galaxy. As expected, the WEAVE contribution to improve the radial velocity component is crucial for this detailed analysis of the at birth positions of field stars.

With the expected accuracies discussed here and expected to be available in $2-3$ years from now, it will be possible to study the mechanisms explaining the evolution of large scale non-axisymmetric structures such as the Galactic warp, the spiral arms or the bar. For example, analytic models of the Galactic warp predict a maximum of the vertical velocity at the anti-center direction [1]. However, observational works using proper motions from PPMXL detect this maximum at a slightly displaced longitude. Using the Red Clump giants of PPMXL, an impulsive generation of the warp would explain the trend observed in vertical velocities. The problem, though, is at present highly degenerated because a non-symmetric warp could also generate such displacement. Therefore, the results are non conclusive. The use of of GDR2 data will shed new light to this problem. Concerning spiral arms, [2] have quantified the perturbation the spiral arms could produce to the GDR2 tangential velocities. As discussed in that paper, GDR2 data will have enough accuracy to measure differences between the median transverse velocities in symmetric longitudes of about $2-10$ km s^{-1}. Work is ongoing to evaluate if this accuracy will be enough to analyze the nature of spiral arms, possible theories being the Tight Winding Approximation, the Swing Amplification or the Invariant Manifolds. At present we know that both test particle simulations and self-consistent N-body simulations of barred galaxies reproduce well the characteristics of spiral arms trapped in the invariant manifolds [8, 3, 7]. Again, the accuracy expected for kinematic

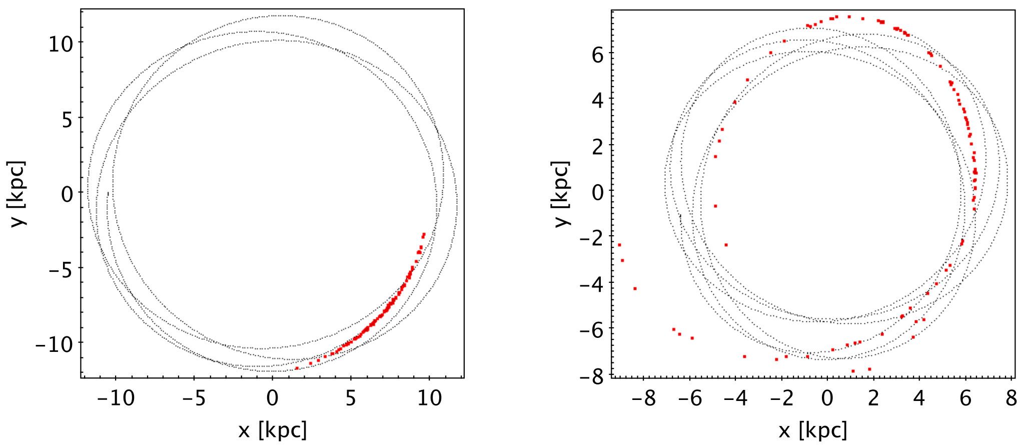

Figure 3: Quantitative evaluation of the Gaia-DR2 plus WEAVE capabilities to derive the at birth position of two hypothetical Red Clump stars. one placed near the Perseus arm toward the anticenter (left) and the other near the Sagitarius arm (right).

tracers such as Red Clumps of GDR2 together with spectroscopic follow up surveys allow to tackle this problem.

Acknowledgments

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