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KINEMATIC IMPRINTS FROM THE BAR AND SPIRAL STRUCTURES IN THE GALATIC DISK

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Abstract. At 140 years of the discovery of the moving groups, these stellar streams are emerging as powerful tools to constrain the models for the spiral arms and the Galactic bar in the Gaia era. From the kinematic-age-metallicity analysis in the solar neighbourhood it is now well established that some of these kinematic structures have a dynamical origin, different from the classical cluster disruption hypothesis. Test particle simulations allow us to definitively establish that these local structures can be created by the dynamical resonances of material spiral arms and not exclusively by the Galactic bar. First studies to evaluate the capabilities of the future Gaia data to detect and characterize moving groups at 2-6 kpc from the solar neighborhood are discussed.

Keywords: Galaxy: kinematics and dynamics, solar neighbourhood, spiral structure, Galactic bar

1 Introduction

In the last two decades the study of the Milky Way (MW) has experienced outstanding progress owing to the advendt of high-quality observations, better models and methods, and the use of powerful computation facilities (e.g. Turon et al. 2008). In particular, the solar neighbourhood has been studied in depth thanks to the stellar positions and velocities from the Hipparcos mission and its complementary photometric and spectroscopic on-ground surveys. The rich kinematics and stellar chemical distribution in the solar neighbourhood may constitute a set of imprints and fossils left after several Galactic processes. The observations have revealed very interesting properties, one of the most intriguing features being what now is usually called moving groups (MG). These are stellar streams, gravitationally unbound, occupying extended regions of the Galaxy which are seen as overdensities in the velocity space. At present, the origin of these kinematic structures is far from being completely understood although it is more than 140 years since they were discovered (see Antoja et al. 2010a, for a historical review).

Several scenarios to understand their origin and evolution have been proposed since then: 1) cluster and star complex disruption; 2) orbital and resonant effects of the non-axisymmetric structure of the MW (spiral arms and bar): periodic orbits, chaos, precession of periodic orbits, transient spiral structure; 3) tidal debris of past accretion events and, 4) external dynamical effects on the disk resulting from interaction events. A combination of some of these options becomes a complex but fascinating scenario. Here we will comment on the work our team has been undertaken in the last five years, that is, the characterization of what we observe in the solar neighbourhood, how test particle simulations show that MGs can be induced by the MW bar and spiral arms and how the Gaia satellite* will see them in the next decade.

2 What we observe

In Antoja et al. (2008) we applied the Waveled Denoising technique to an extensive compendium of stars – more than 24000 – in the solar neighbourhood to characterize MGs in the U-V-age-[Fe/H] space. We confirm that the

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dominant kinematic structures in the U-V plane are the branches of Sirius, Coma Berenices, Hyades-Pleiades and Hercules. They all present a negative slope of $\sim 16°$ in the U-V plane. These branches are present in all spatial regions studied and, although our data was well constrained to the solar neighbourhood, we detected for the first time a slight dependence of the kinematic branches on Galactic position. These studies is being now taken up again with a much more extended sample around the Sun using the recently published 3th release of RAVE radial velocity survey (Antoja et al., in prep.).

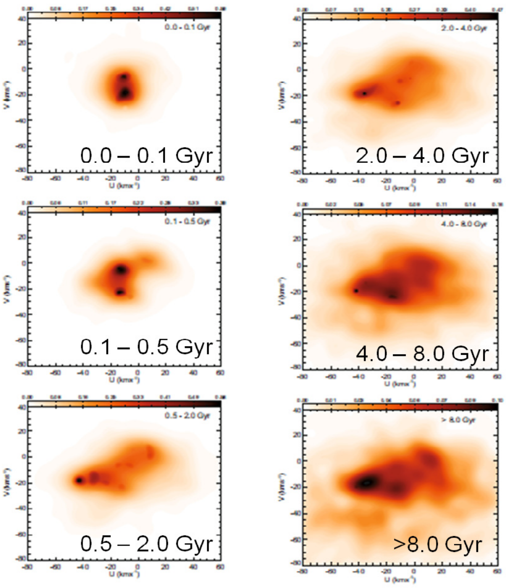

Fig. 1. Velocity distribution for different ages groups. See Antoja et al. (2008) for catalogue compilation.

From the Geneva Copenhagen Survey it is now well stablished that these kinematic branches have an extended age distribution (see Fig. 1). Even more, very promising recent spectroscopic studies have revealed that most groups are chemically inhomogeneuous (Arcturus (Williams et al. 2009); Hercules (Bensby et al. 2007), among others). It is reasonable to think that the four scenarios mentioned above for the origin of MGs can coexist in the solar neighbourhood. HR1614 can be an example of a minor kinematic structure possibly originated from a cluster disruption; it has a low chemical and age scattering and, hence, it does seem to be remnant of a dispersed star-forming event (de Silva et al. 2007). But for sure, the observations available up to now show that many MGs, specially the above mentioned branches, have a large spread in ages and chemical composition indicating that, definitively, we shall rule out those models that propose that these kinematic structures are remnants of disk star clusters.

3 Moving groups induced by MW bar and spiral arms

We have performed numerical integrations of test particle orbits on the Galactic plane (2D), adopting the potential described in Antoja et al. (2011). There we have shown that studies with only spiral arms or only the bar are a valid way to understand the effects of each component in the velocity distribution, and eventually they could be used to constrain the characteristics of the bar and spiral arms.

3.1 Imprints from the Galactic bar

In Antoja et al. (2009) we show how the Galactic prolate bar (Pichardo et al. 2003), with a realistic orientation and density profile, triggers the already known bimodality in the velocity distribution (Kalnajs 1991). This is caused by a thin region of irregular orbits that are probably related to the bar 2:1 OLR. The central node of the bimodality is distorted through positive U. This distortion could be associated with the new observed group found at $(U, V) = (35, -20)$ km/s and with the elongation of the Coma Berenices branch. We also propose that the low angular momentum MGs, including Arcturus, could have two distinct viable origins related to the bar acting on a relatively hot stellar disk: 1) the dynamics of the bar could have a strong influence on the transient kinematic groups at low angular momentum that are products of the ongoing phase mixing in an un-relaxed disk or 2) the bar also creates kinematic structures at low angular momentum that may be associated entirely with its induced resonant effects on the U-V plane. Bar resonances 3:1, 4:1 and 5:1 could be responsible for these kinematic groups at low angular momentum.

3.2 Imprints from the spiral arms

In Antoja et al. (2011) we studied the spiral arm influence on the solar neighbourhood stellar kinematics. We have seen that the spiral arms induce strong kinematic imprints in the solar neighbourhood for pattern speeds $\Omega_p \sim 15 - 19\,\mathrm{km/s/kpc}$, close to the 4:1 inner resonance (see Fig. 2). No substructure is induced close to corotation or higher order resonances (m>6) which, in the solar neighbourhood, corresponds to pattern speeds of $20 - 30$ km/s/kpc.

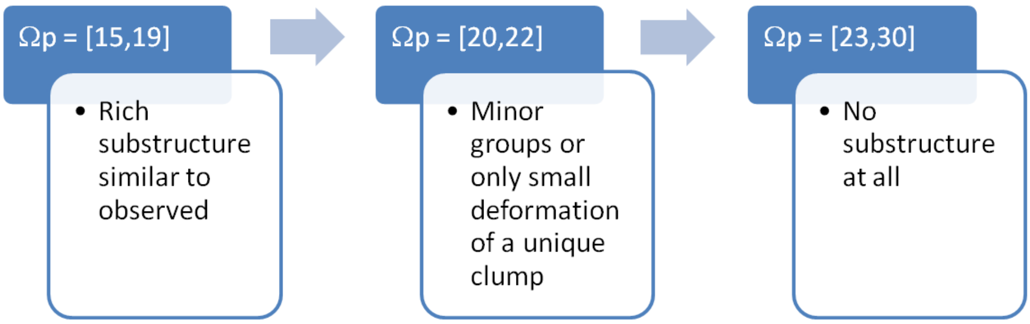

Fig. 2. Scheme of the relation between the MW pattern speed of the spiral arms and the existence of kinematic substructure in the solar neighbourhood.

We have observed that the velocity distribution is less sensitive to the relative spiral phase. More than 2 kpc in galactocentric azimuth are needed to detect a significant change in the velocity space. The strongest effects are detected near the arms. The effects of spiral arm density contrast has been also investigated. We observe that a higher density contrast increases the dispersion but maintains the geometry of the kinematic substructure, so concluding that the strength of the MW spiral pattern will be a parameter difficult to constrain using MGs.

4 Future Gaia capabilities

We can indentify several scientific challenges for the coming years as far as MGs are concerned. A combination of chemical tagging, improved large-scale Galactic dynamics studies and cosmological simulations applied to the MW are required in order to disentangle the origin of the kinematic structures in the Galactic disk. New theoretical and observational strategies to approach the problem are needed in preparation for the upcoming Gaia and complementary surveys. A first attempt to evaluate how far Gaia will go in providing precise 3D velocity distributions was presented in Antoja et al. (2010b). We analized two regions, the Scutum Centarus tangency $(l, b) = (305°, 0°)$ at $\sim 7\,\mathrm{kpc}$ and the Perseus arm at the anticenter direction, at $\sim 2\,\mathrm{kpc}$. Working in the space of the observables we confirm that the unprecedented Gaia accuracy in proper motions will allow to clearly identify the rich kinematic substructure in the Perseus arm at $\sim 2\,\mathrm{kpc}$ from the Sun. That is Gaia errors hardly change or hide the the kinematic structure obtained from our test particle simulations in this region. Concerning the detection of kinematic substructure in the Scutum Centaurus tangency, K giants in this far region will have a relative error in Gaia parallax of $\sim 60\%$, therefore IR photometric distances will be required. Looking again in the observable plane of radial velocities and proper motions, we checked that errors in radial velocity not larger than $2 - 3\,\mathrm{km/s}$ are needed to detect the rich resonant kinematic structure in this region. The study of the phase space in those regions is critical to understand the kinematic behaviour and nature of the spiral pattern.

5 Conclusions

Our analysis of the observational sample and the test particle simulations indicates that it is very feasible that some of the MGs observed in the solar neighbourhood have a dynamical origin related with the effects induced by the spiral arms and the bar. However, several improvements are needed in order to definitively characterize the chemistry and the evolutionary state of the different kinematic groups. This is a statistical study which requires a large number of stars with accurate ages and chemical composition. Data from Multi-Object Spectrographs currently available and/or in preparation are promising for the analysis of chemical inhomogenieties in the kinematic groups. More complex is the derivation of accurate stellar ages, where large errors are present. Future Gaia data will require complementary age determinations from new tools like asteroseismology (Poretti et al. 2011) or stellar chronology with white dwarfs in wide binary systems (Garces et al. 2012), among others.

From our test particle studies we can confirm that MW spiral arms in the range of the observed spiral arms parameters favour the triggering of kinematics groups such us the ones observed in the solar neighbourhood. But can we at present constrain the spiral arms using the MGs? Our analysis demonstrates that groups such as the observed ones in the solar vicinity can be reproduced by different combinations of parameters, i.e. a degeneracy is present. Thus, data from velocity distributions at larger distances are needed for a definitive constraint. Work is in progress to map the evolution of these MGs at large scale on the Galactic disk both from test particle and N-body simulations.

Preliminar analysis of Gaia capabilities confirm that the stellar streams are emerging as powerful tools to constrain the models for the spiral arms and the Galactic bar in the Gaia era. It is mandatory to analyze carefully our modelled velocity distributions at large scale in the Galactic disk so as to find strategic places where the kinematic structures are particularly rich to discriminate among models and to constrain the spiral arm and the Galactic bar parameter space.

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