The General Assembly of Galaxy Halos: Structure,
Origin and Evolution
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The Milky Way evolution under the RAVE perspective

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Abstract. The RAdial Velocity Experiment (RAVE) collected from 2003 to 2013 medium resolution spectra for $5 \cdot 10^5$ low-mass stars of our Galaxy, improving our understanding of the Milky Way evolution and of its properties outside the Solar neighbourhood. This proceeding gives an overview of RAVE results obtained in the last two years.

1. Overview of the survey and of the public catalogue

The *Radial Velocity Experiment* project (Steinmetz *et al.* 2006) used the 6dF instrument mounted on the 1.2 m Schmidt telescope of the Anglo-Australian Observatory, to obtain spectra of 480,000 stars in the magnitude range $8 < I < 12$ mag (up to ~ 3 kpc from the Sun). The fourth data release (DR4 Kordopatis *et al.* 2013a) publishes for these stars the atmospheric parameters, chemical abundances, line-of-sight velocities and distances, as well as cross-correlations with photometric and proper motion catalogues. Typical uncertainties of DR4 are $\sim 150\,K$ for $T_{\rm eff}$, 0.2 dex for $\log g$, and $\sim 0.1 - 0.2$ dex for metallicity and chemical abundances. Distances are derived with errors better than $\sim 20\%$ and radial velocities with mean accuracy of $1.5\,{\rm km\,s^{-1}}$. These uncertainties lead to median errors on 3D Galactocentric velocities of $15\,{\rm km\,s^{-1}}$.

2. Description of the Milky Way morphology: structure and dynamics

Combining *RAVE* with the Geneva-Copenhagen Survey, Sharma *et al.* (2014) constrained the three-component age-velocity dispersion relations, the radial dependence of the velocity dispersions, the Solar peculiar motion ($\mathrm{U}_\odot = 10.96, \mathrm{V}_\odot = 7.53, \mathrm{W}_\odot = 7.54\,{\rm km\,s^{-1}}$), the circular speed at the Sun ($\Theta_0 = 232.8\,{\rm km\,s^{-1}}$), and the fall of mean azimuthal motion with height above the mid-plane. The authors found that the radial scale length of the velocity dispersion profile of the thick disc is smaller than that of the thin disc, in agreement with recent high-resolution spectroscopic studies separating the discs based on their chemical composition (e.g. Kordopatis *et al.* 2015). On a similar topic, Binney *et al.* (2014) studied the velocities of the disc stars and highlighted the non-Gaussianity of the velocity distribution functions. This led to the publication of formulae from which the shape and orientation of the velocity ellipsoid can be determined at any location.

The north-south differences in the stellar kinematics have been studied in Williams *et al.* (2013). Among others, a clear vertical rarefaction-compression pattern up to 2 kpc above the plane has been found, originating either by accretions (e.g. Widrow *et al.* 2014), or by the effect of the spiral arms on the stellar orbits (Faure *et al.* 2014).

The Galactic escape speed has been evaluated by Piffl *et al.* (2014b) to be $V_{\rm esc} = 533^{+54}_{-41}\,{\rm km\,s^{-1}}$. The authors further found that the dark matter and baryon mass interior to three virial radii is $1.3^{+0.4}_{-0.3} \times 10^{12}\mathrm{M}_\odot$, in good agreement with recently independently published mass estimates. In addition, by modelling the kinematics of giant stars up to ~ 1.5 kpc from the Sun, Piffl *et al.* (2014a) found that the dark mass contained within the iso-density surface of the dark halo that passes through the Sun, and the surface density within 0.9 kpc of the plane, are almost independent of the halo's axis ratio q and estimated that the baryonic mass is at most 4.3% of the total Galaxy mass.

Bienaymé *et al.* (2014) estimated the vertical force (K_z) at 1 kpc and 2 kpc from the plane, and found an unexpectedly large amount of dark matter at distances greater than 2 kpc. This could be evidence of either (i) a flattening of the dark halo of the order of 0.8, (ii) a spherical cored dark matter profile whose density does not drop sharply radially or (iii) the presence of a secondary dark component resulting from dark matter accretion.

The chemo-dynamical properties of the high-velocity stars in *RAVE* have been investigated in Hawkins *et al.* (2015). The authors report the discovery of a metal-rich halo star that has likely been dynamically ejected from the thick disc, which could aid in explaining the assembly of the most metal-rich component of the Galactic halo.

Finally, Antoja *et al.* (2014) modelled the observed radial dependence of V_ϕ of the Hercules moving group to determine the pattern speed for the Galactic bar. Then, extending the analysis of the bar's influence to larger distances from the Galactic mid-plane, Antoja *et al.* (2015) found asymmetries in the $V_R - V_\phi$ velocity distributions of the disc stars, which suggest that the nature of reported thick disc substructures might be associated with dynamical resonances rather than to accretion events.

3. Milky Way internal evolution and accretion history

Kos *et al.* (2013, 2014) studied the ISM at the extended Solar neighbourhood by measuring the spatial variations of the strength of the absorption line at 8620 Å, associated to a diffuse interstellar band (DIB). They found that the DIB density follows the interstellar dust spatial distribution, with however a scale height significantly larger. The youngest stellar populations, presumably formed from a similar ISM, have been addressed in Conrad *et al.* (2014), where members of 110 open clusters have been identified, updating the radial velocities and metallicities of present cluster catalogues.

Boeche *et al.* (2013, 2014) derived the chemical gradients in the Galaxy and confirmed that the iron and $\alpha-$elements radial gradients flatten as a function of the distance from the plane. This result suggests a different chemical enrichment history for the thick disc compared to the thin disc.

Kordopatis *et al.* (2013b) investigated the properties of the thick disc, down to metallicities of -2 dex. They identified the typical correlation between metallicity and azimuthal velocity of the canonical thick disc stars (e.g. Kordopatis *et al.* 2011, 2013c), which suggests that radial migration could not have been the main mechanism at the origin of the formation of this structure.

Minchev *et al.* (2014) analysed the velocity dispersion of giant disc stars as a function of chemistry and found that the metal-poor stars having [Mg/Fe] > 0.4 dex (the oldest in the sample) have lower velocity dispersions than same metallicity stars with lower [Mg/Fe] abundances. According to the authors this is a signature of a past merger event in the Galaxy, followed by a quiescent period dominated by radial migration.

First direct evidence of stellar radial migration happening at the co-rotation resonances with the spiral arms has been found in Kordopatis *et al.* (2015a). In that study, the orbital and spatial properties of stars that have [M/H] $\gtrsim +0.2$ are studied. It is found that more than half of these super metal-rich stars have migrated through mechanisms that maintain the circularity of the orbits. Given the spatial distribution of these stars, the authors also put constraints on the history of the spiral arms of the Milky Way, that should have been only few and of large structure at least for the last 6 Gyr.

Finally, two recent works addressed globular clusters in *RAVE*. Using solely radial velocities, Anguiano *et al.* (2015) identified members of NGC 3201, ω Cen and NGC 362, to validate the *RAVE*–DR4 stellar parameter and distances. Kunder *et al.* (2014) investigated the chemo-dynamical properties of the available stars around M 22, NGC 1851 and NGC 3201, and reported some stars belonging to these clusters being at projected distances of $\sim$ 10 degrees away from their respective cores. Furthermore, in the radial velocity histograms of the regions surrounding NGC 1851 and NGC 3201, a peak of stars at 230 $\mathrm{km\,s^{-1}}$ is seen, consistent with extended tidal debris from ω Cen.

4. Perspectives and relation with Gaia

Future RAVE data releases are planned to improve, among others, the calibration of the metal-rich end of the metallicity distribution. This will be achieved thanks to the constant addition of metallicity measurements coming from Gaia-benchmark stars (e.g. Jofré *et al.* 2014) and high-resolution spectra of super-solar metallicity stars (see Kordopatis *et al.* 2015a).

The Gaia satellite will obtain proper motions of exquisite quality and distances derived by parallax, overtaking RAVE's precisions by orders of magnitude. However, Gaia will not publish parameter for its stars before ~2017. Until then, RAVE is one of the most significant samples from which Galactic archaeology is possible.

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