RAVE: RESULTS AND UPDATES FROM DATA RELEASE 4

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Abstract. The RAAdial Velocity Experiment (RAVE) published in November 2013 its fourth data release with the stellar atmospheric parameters, abundances, distances, radial velocities, proper motions and spectral morphological flags for more than \(4 \times 10^5\) targets. With that, a plethora of papers ranging from the mass of the Milky Way to the mapping of the Diffuse Interstellar Band, and from the chemo-dynamical history and properties of the disc to the Galaxy’s bar pattern speed have also been published, therefore preparing the ground for the exploitation of the Gaia catalogs, since RAVE will be the biggest available spectroscopic database in the magnitude range of Gaia. Here, we review some of these results and present some perspectives about the future data releases.

Keywords: Surveys, Stars: kinematics and dynamics, Galaxy: general, Galaxy: stellar content, Galaxy: structure

1 Introduction

The Radial Velocity Experiment \cite{Steinmetz2006} is to this date the largest spectroscopic survey of Milky Way stars available for the community. The project finished its observations in April 2013, obtaining more than half a million spectra of more than 400,000 stars in the magnitude range \(8 < I < 12\) mag. RAVE used the 6dF instrument mounted on the Schmidt telescope of the AAO in Siding Spring, Australia. The targeted spectral region (8410–8794Å), contains the infrared Calcium triplet and is similar to the wavelength chosen for Gaia’s Radial Velocity Spectrometer \cite{Cropper2011}. The effective resolution of \(R \sim 7000\) enables us to measure line-of-sight velocities with a median precision better than 1.5 km s\(^{-1}\). The distribution on the sky of the observed RAVE targets, as of the end of the project (April 2013), is shown in Fig. 1 and covers a large fraction of the sky accessible from the southern hemisphere. One of the major improvements of RAVE fourth data release (noted DR4 hereafter, Kordopatis et al. \citeyear{Kordopatis2013a}), compared to the previous data releases \cite{Zwitter2008, Siebert2011}, is its more thorough metallicity calibration, based on the RAVE observations of cluster stars and the availability of high-resolution spectra of already observed RAVE targets. In this proceeding we therefore focus in summarising the results of RAVE obtained with DR4. Results of the project up to DR3 can be found summarised in \cite{Siebert2012}. Section 2 presents the new algorithms used to obtain the stellar parameters, abundances and distances. Section 3 and Sect. 4 present the main results obtained on the Milky Way structure, dynamics and evolution. Finally, Sect. 5 presents future prospects of the RAVE project.

2 New pipelines used in the fourth data-release

2.1 Obtention of the atmospheric parameters, chemical abundances and detection of chromospheric activity

A new pipeline for spectral automatic parameterisation has been applied on the totality of the RAVE spectra, based on the one presented in Kordopatis et al. \citeyear{Kordopatis2011a}. Compared to previous data-releases, the spectral degeneracies are better taken into account, since the synthetic grid that has been used has a reduced dimensionality of the parameter space, excludes the core of the Calcium triplet lines and takes into account photometric constraints from 2MASS. The effective temperatures, surface gravities and overall metallicities are hence computed...
Fig. 1. Left: RAVE footprint on the sky as in April 2013, in Galactic coordinates. The points are colour-coded according to their measured heliocentric radial velocity. Right: Median metallicities of the stars as a function of the Galactocentric position (taken from Kordopatis et al. 2013b). Assumed Sun’s position is indicated by a “+” sign, at \((R, Z) = (8, 0)\) kpc.

in that frame. In addition, the chemical abundance pipeline presented in Boeche et al. (2011) has been improved, in order to obtain the elemental abundances of six elements, namely the magnesium, aluminium, silicon, titanium, iron, and nickel. In the same way as for the previous data releases, the methods presented in Matijević et al. (2011, 2012), Zerjal et al. (2013) identify and flag, based on the spectral morphology, the spectroscopic binaries and peculiar stars, such for example the ones with chromospheric activity. All the above pipelines allow to obtain all the possible parameters relative to the stellar atmospheres, that will be used as input for the computation of the stellar distances and from there the measurement of the global Galactic chemo-dynamical properties.

2.2 Computation of the line-of-sight distances

RAVE DR4 publishes two different sets of distances, based on different algorithms. The first one, is based on the Zwitter et al. (2010) method, that projects the atmospheric parameters on theoretical isochrones introducing only a mild prior on the evolutionary stage at which the star is expected to belong to. The other method, based on the Bayesian approach of Burnett et al. (2011) assumes a Galactic model, with realistic stellar and velocity distributions for the Galactic discs and halo, to infer the most likely distance modulus, parallax and line-of-sight distance of the targets (Binney et al. 2014a). These distances have been tested on Hipparcos targets (Binney et al. 2014a) and cluster members (Binney et al. 2014a) Anguiano et al. submitted, showing relatively small deviations from true values for the types of stars most commonly observed by RAVE. The probed distances, colour-coded according to the mean metallicity of the stars are illustrated in Fig. 1 (taken from Kordopatis et al. 2013b).

3 Milky Way structure and dynamics

Galactic archaeology and the development of models allowing to disentangle to mechanisms responsible for the evolution of our Galaxy rely on our knowledge of the Milky Way’s structure and kinematics of its stars. Sharma et al. (2014) took advantage of the large size of RAVE to measure and constrain the age-velocity dispersion relation for the three kinematic components, the radial dependence of the velocity dispersions, the solar peculiar motion, the circular speed \(\Theta_0\) at the Sun, and the fall of mean azimuthal motion with height above the mid-plane. They found that the Shu distribution describes the best the kinematic distributions of the stars and that the radial scale length of the velocity dispersion profile of the thick disc is smaller than that of the thin disc. Binney et al. (2014b) also highlights the non-gaussianity of the velocity distribution functions and give formulae from which the shape and orientation of the velocity ellipsoid can be determined at any location.

On the other hand, Williams et al. (2013) studied in detail the stellar kinematics in the solar suburb, concentrating on north-south differences. They find a complex three-dimensional structure of velocity space, with among others a clear vertical rarefaction-compression pattern up to 2 kpc above the plane, suggestive of wave-like behaviour produced by either internal evolution of the Galaxy or external factors such as accretions.
Using a statistical sample ten times larger than the one previously used by Smith et al. (2007) in DR1, the Galactic escape speed has been re-evaluated by Piff et al. (2014b) to $335_{-41}^{+54}$ km s$^{-1}$, confirming previous results and constraining even more the 90% confidence interval. From the escape speed the authors further derived estimates of the mass of the Galaxy using a simple mass model and found that the dark matter and baryon mass interior to $R_{200}$ is $1.3_{-0.3}^{+0.4} \times 10^{12} M_\odot$, in good agreement with recently published mass estimates based on the kinematics of more distant halo stars and the satellite galaxy Leo I.

Bienaymé et al. (2014) used a subsample of $\sim 4500$ red clump stars, and determined the vertical force at two distances from the plane, as well as the local dark matter density $\rho_{DM}(z = 0) = 0.0143 \pm 0.0011 M_\odot$ pc$^{-3}$ and the baryonic surface mass density $\Sigma_{\text{baryons}} = 44.4 \pm 4.1 M_\odot$ pc$^{-2}$. They found evidence for an unexpectedly large amount of dark matter at distances greater than 2 kpc from the plane. On the same topic, Piff et al. (2014a) modelled the kinematics of giant stars that lie within $\sim 1.5$ kpc from the Sun and found that the dark mass contained within the isodensity surface of the dark halo that passes through the Sun $(6 \pm 0.9 \times 10^{10} M_\odot)$, and the surface density within 0.9 kpc of the plane $(69 \pm 10 M_\odot$ pc$^{-2}$) are almost independent of the halo’s axis ratio $q$. They estimated that the baryonic mass is at most 4.3% of the total Galaxy mass.

Finally, Antoja et al. (2014) utilised the moving groups available in the database and found that the azimuthal velocity of the Hercules structure decreases as a function of Galactocentric radius. The authors then modelled this behaviour to impose constraints on the bar’s pattern speed. The combined likelihood function of the bar’s velocity of the Hercules structure decreases as a function of Galactocentric radius. The authors then modelled this behaviour to impose constraints on the bar’s pattern speed. The combined likelihood function of the bar’s velocity of the Hercules structure decreases as a function of Galactocentric radius. The authors then modelled this behaviour to impose constraints on the bar’s pattern speed.

4 Milky Way internal evolution and accretion history

The change in chemical properties of the stars and the interstellar medium as a function of position in the Galaxy and the correlation between the stellar kinematics and their atmospheric abundances hold important information on the formation and evolution of the Galaxy’s structures. Their measurement require large statistical samples spanning volumes of several kiloparsecs wide in order to detect trends and identify rare stellar populations.

An estimation of the amount of interstellar matter in the line-of-sight towards the observed stars can be obtained by analysing the absorption lines in the RAVE spectra, originated from the Diffuse Interstellar Bands (DIBs). Kos et al. (2013, 2014) measured the equivalent width of the DIBs present in the spectra, and produced the first pseudo three-dimensional map of the strength of the DIB at 8620Å, covering the nearest 3 kpc from the Sun. The authors have found that the DIB follows the spatial distribution of extinction by interstellar dust, however with a significantly larger vertical scale height.

Using the fact that DR4 has large statistical sample of stars at different Galactic regions, Boeche et al. (2013, 2014) measured the radial and vertical gradients in metallicity and individual $\alpha$-elements in the Galaxy. They found a radial gradient $\partial [\text{Fe}/H]/\partial R \sim -0.054$ dex kpc$^{-1}$ close to the Galactic plane ($|Z| < 0.4$ kpc) that becomes flatter for larger distances above the plane. Other elements are found to follow the same trend although with some variations from element to element, showing that the thick disc experienced a different chemical enrichment history than the thin disc.

Kordopatis et al. (2013b) selected stars located between 1 and 2 kpc from the Galactic plane in order to investigate the properties of the metal-weak tail of the thick disc. The authors found a kinematic signature of thick disc stars down to metallicities of $-2$ dex, having the suggested correlation between metallicity and azimuthal velocity of the canonical thick disc stars, of $\partial V_z/\partial [\text{M}/\text{H}] \approx -50$ km s$^{-1}$ dex (e.g., Kordopatis et al. 2011b, 2013c; Lee et al. 2011). The authors interpreted this result as evidence that radial migration could not have been the main mechanism at the origin of the formation of the thick disc.

Minchev et al. (2014) focused on stars in the Solar vicinity, and analysed the velocity dispersion of the giant disc stars as a function of metallicity and $\alpha$-abundances. The authors found that the velocity dispersion of the metal-poor stars first show an increase in their velocity dispersion, then a decrease for the most $\alpha$-enhanced stars ([$\text{Mg}/\text{Fe}] > 0.4$ dex). By comparing with their chemo-dynamical evolution models of the Milky Way, the authors suggested that this behaviour was evidence of the merger history of the Galaxy and that the stars responsible for the velocity dispersion decrease are stars that reached the Solar neighbourhood through radial migration from the inner Galaxy. Evidence of radial migration towards the metal-rich end distribution in the thin disc has also been found in Kordopatis et al. (2014), based on the orbits of the super-Solar metallicity stars.

Finally, Kunder et al. (2014) investigated the chemo-dynamical properties of the stars in the RAVE database.
around the globular clusters M 22, NGC 1851 and NGC 3201, to assess whether the brightest clusters in the Galaxy might actually be the remnant nuclei of accreted dwarf spheroidal galaxies. The authors report some stars belonging to these clusters being at projected distances of $\sim 10$ degrees away from the core of these clusters. In addition, in both of the radial velocity histograms of the regions surrounding NGC 1851 and NGC 3201, a peak of stars at 230 km s$^{-1}$ is seen, consistent with extended tidal debris from $\omega$ Centauri.

5 Perspectives and relation with Gaia

Future RAVE data releases are planning, among others, to improve the calibration of the metal-rich end of the metallicity distribution, thanks to the constant addition of metallicity measurements coming from benchmark stars and high-resolution spectra of super-solar metallicity stars (see Kordopatis et al. 2014, submitted). In addition, high-precision APASS photometry will also be included in the pipeline to put more weight on the photometric priors (Munari et al. 2014), and hence reducing even more the spectral degeneracies intrinsic to the Calcium triplet wavelength region, responsible to a high extent for the uncertainties in the stellar parameters. Finally, the spectroscopic distances in the catalogue will also be updated for the most metal-poor stars ([M/H] $< 1$ dex), by including lower-metallicity isochrones.

The Gaia satellite will obtain proper motions of exquisite quality and distances derived by parallax, out-taking RAVE’s precisions by orders of magnitude (Prusti 2012). However, atmospheric parameters and radial velocities for the Gaia stars obtained by the onboard instruments “Blue” and “Red spectro-photometers” and the RVS will not be published before the end of 2016 (Brown 2012). Until then, RAVE will represent the most significant sample in Gaia’s magnitude range, from which Galactic archaeology will be possible.

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