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The evolution history of the extended solar neighbourhood

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Abstract. Our detailed analytic local disc model (JJ-model) quantifies the interrelation between kinematic properties (e.g. velocity dispersions and asymmetric drift), spatial parameters (scale-lengths and vertical density profiles), and properties of stellar sub-populations (age and abundance distributions). We discuss a radial extension of the disc evolution model representing an inside-out growth of the thin disc with constant thickness. Based on metallicity distributions of APOGEE red clump stars we derive the AMR as function of galactrocentric distance and show that mono-abundance as well as mono-age populations are flaring. The predictions of the JJ-model are consistent with the TGAS-RAVE data, which provide a significant improvement of the kinematic data and unbiased distances for more than 250,000 stars.

Keywords. Galaxy: disk, Galaxy: kinematics and dynamics, Galaxy: evolution, Galaxy: solar neighbourhood, Galaxy: abundances

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1. Dynamical disc model

The most elaborate model of the present day Milky Way is the Besançon Galaxy Model (BGM) including extinction, the bar, spiral arms and the warp (Czekaj, Robin, Figueras, *et al.* 2014). Nevertheless there are still open issues to be solved concerning the degeneracy of the SFR and IMF and a consistent chemical abundance model. Our alternative local disc model (JJ-model) based on the kinematics of main sequence stars (Just & Jahreiß 2010), the stellar content in the solar neighbourhood (Rybizki & Just 2015) and Sloan Digital Sky Survey (SDSS) star counts to the north Galactic pole (Just *et al.* 2011) has a significantly higher accuracy compared to the old BGM (Gao *et al.* 2013). In the JJ-model the local SFR, IMF, AVR (age–velocity dispersion relation) are determined self-consistently and it includes a simple chemical enrichment model. With the TGAS data as part of the first Gaia data release DR1 (Gaia Collaboration, Brown, & Vallenari, *et al.* 2016) we have independent and unbiased distances and significantly imroved proper motions for more than a million stars. This allows a sharp test of our local model (see Sect. 3).

In order to extend the JJ-model over the full radial range of the disc, we have used in a first step the Jeans equation for the asymmetric drift to connect local dynamics with the radial scale-lengths of mono-abundance populations (Golubov *et al.* 2013). Based on RAVE (RAdial Velocity Experiment) data we found an increasing scale-length with decreasing metallicity, which is consistent with a negative overall metallicity gradient of the disc. On the other hand Milky Way-like galaxies show a radial colour gradient of the disc to be bluer and younger in the outer part. Combining both observations immediately shows that the chemical enrichment in the inner disc must be faster/larger compared to the outer disc.

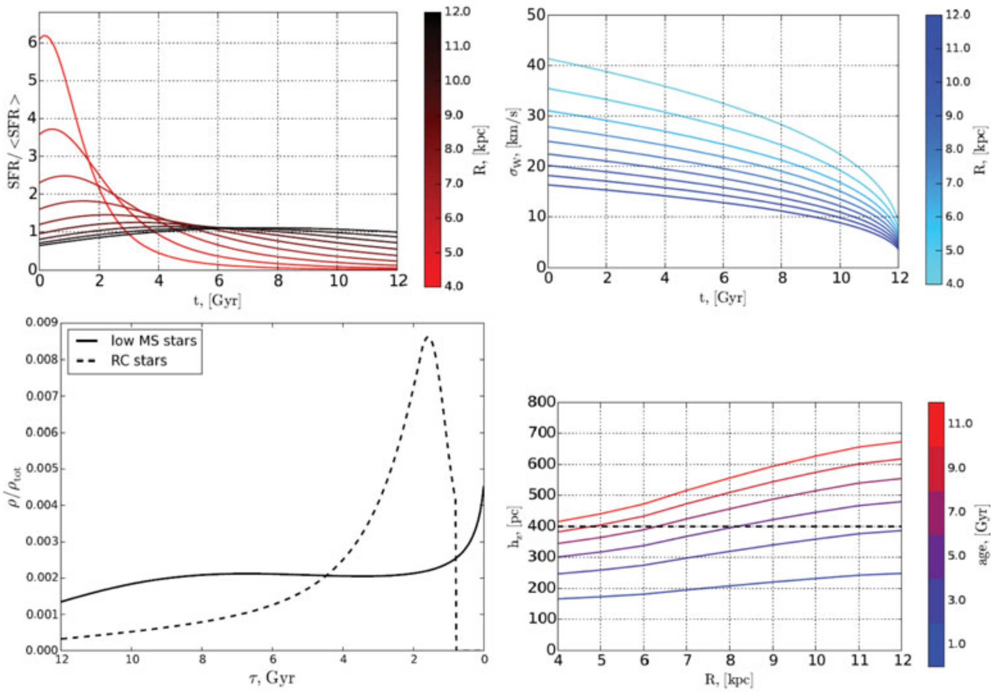

Figure 1. Top left: SFR at different galactrocentric distances R (increasing with declining maximum). Top right: Corresponding AVR. Bottom left: Age distributions of lower MS (full line) and of RC (dashed line) stars in the solar neighbourhood. Bottom right: Thickness profiles of mono-age populations (larger for older ages). The horizontal dashed line shows the thickness of the whole disc.

2. Inner structure of simple discs

Since most observed stellar samples, like main sequence (MS) stars, red clump (RC) stars or mono-abundance populations, are composed by different generations, it is crucial to derive self-consistent age distributions (see bottom left panel of Fig. 1 for lower MS and for RC stars in the solar neighbourhood at $(R, z) = (8\,\mathrm{kpc}, 0\,\mathrm{kpc})$) from the model, which vary strongly with galactrocentric distance R and vertical distance z, in order to derive number densities, velocity or abundance distributions. We are modelling an inside-out growth of the disc by varying the SFR in the range $4\,\mathrm{kpc} < R < 12\,\mathrm{kpc}$ in two models (model A with a strong variation of the SFR and model B with a weaker variation). Here we focus on model A, where the SFR has a strong peak at early times in the inner disc (top left panel of Fig. 1). The SFR is scaled to an exponential disc with a scalelength of 2.5 kpc. The AVR (top right panel of Fig. 1) is scaled in order to achieve a constant thickness $h = 400\,\mathrm{pc}$ of the disc independent of R. Mono-age populations show an exponential radial density profile with increasing scalelength for decreasing age. Another generic consequence of the age shift from predominantly old to younger stars with increasing R combined with the larger thickness of older stars at each R is a flaring of all mono-age populations measured by the (half-)thickness h_z (lower right panel of Fig. 1).

We derive an empirical AMR by identifying the cumulative age distibutions of RC stars at each radius R with the observed cumulative metallicity distributions taken from APOGEE DR12. We find a fast enrichment to supersolar abundances in the inner disc and a much slower early enrichment in the outer disc reaching a lower present day metallicity

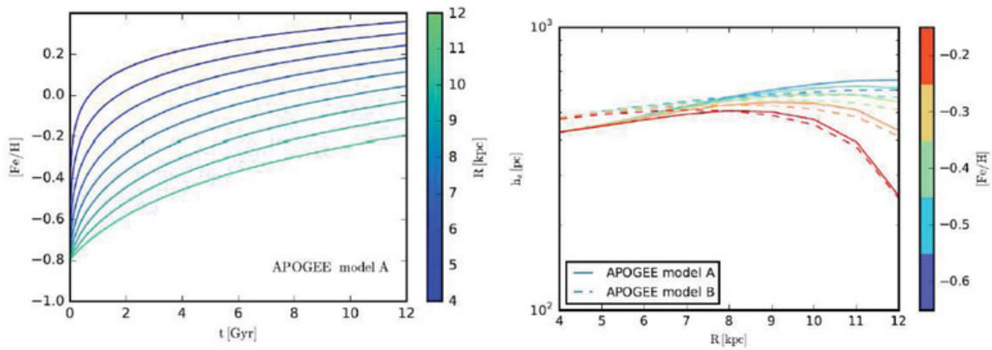

Figure 2. Left: AMR at different galactrocentric distances R (increasing from top to bottom line) derived from the APOGEE metallicity distribution and the RC age distribution of the model. Right: Radial thickness profiles of different metallicity bins.

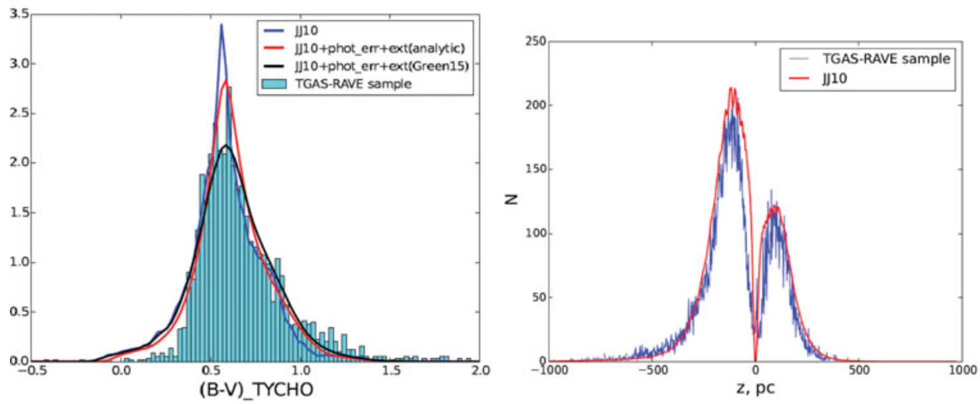

Figure 3. Left: Impact of reddening on the colour distribution (full lines) compared to the TGAS-RAVE sample (histogram). Right: Comparison of star counts in the local cylinder of model and data.

(see left panel of Fig. 2). The combination of the SFR and the AMR leads to the surface density profiles of mono-abundance populations. We find approximately exponential profiles with a scalelength range from 15 kpc to 4.5 kpc with increasing metallicity. Taking into account the self-consistent vertical density profiles, we find also for mono-abundance populations a flaring structure, but with an outer turndown due to the depletion of higher metallicity stars in the outer disc (see right panel of Fig. 2).

3. TGAS-RAVE data

For a detailed test of the local JJ-model we start with the ∼250,000 stars in common of TGAS and RAVE providing improved 6-D phase space information. We select stars in the solar cylinder with radius 300 pc and relative parallax errors smaller than 30% and choose a subsample of 48,000 stars, which are most probably thin disc stars ([Fe/H]<-0.6 and [Mg/Fe]<0.2 dex). We apply the Tycho and RAVE selection functions as well as extinction and reddening to our model predictions. The left panel of Fig. 3 demonstrates the impact of the extinction model on the colour distribution of all stars at $|z| = 100$ pc and shows that the 3-D model based on Pan-STARRS and 2MASS photometry of Green *et al.*(2015) fits very well. No additional TGAS selection function is applied yet. The

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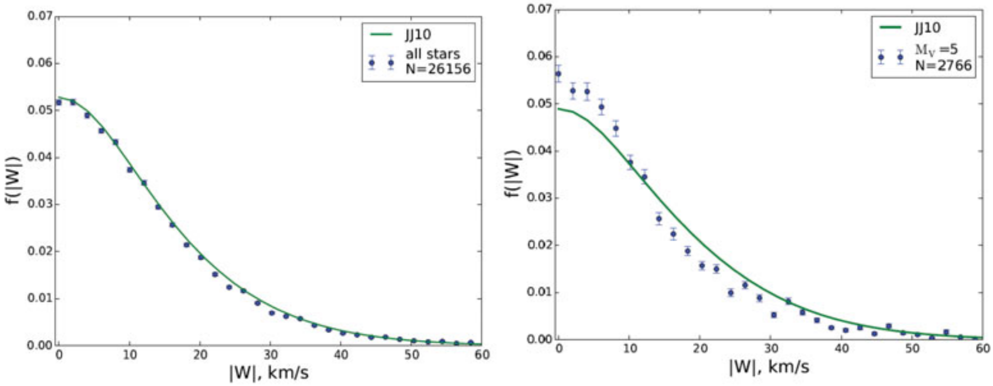

Figure 4. Left: Normalized distribution function of the vertical velocity component $|W|$ of the full sample (points) compared to the model (full line). Right: Similar distribution function for MS stars with $M_V = 5$ mag.

right panel of Fig. 3 shows that the vertical density profile including the asymmetry due to the RAVE selection is well reproduced by the model.

The large sample size and the high quality of the kinematic data allow a detailed test of the vertical component of the velocity distribution functions $f(|W|)$. The left panel of Fig. 4 shows that $f(|W|)$ of our full TGAS-RAVE sample is reproduced extremly well. On the other hand the right panel of Fig. 4 shows that the MS stars with $M_V = 5$ mag seem to have a slightly cooler core compared to our model.

We will use the potential of these new high quality data to improve the JJ-model by combining the number counts and kinematics of slices in z and sub-populations in the colour magnitude diagram.

Acknowledgements

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