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CHARACTERIZATION OF THE THICK DISC PROPERTIES UP TO 8 KPC THROUGH A SPECTROSCOPIC SURVEY

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Abstract. A spectroscopic survey of nearly 600 stars probing the Galactic Thick Disc far from the Solar neighbourhood is performed. The MATISSE (MATrix Inversion for Spectral SynthEsis) algorithm is developed and trained in order to automatically obtain the atmospheric parameters of the stars. The derived effective temperatures, surface gravities and overall metallicities are then combined to stellar evolution isochrones, radial velocities and proper motions to get the distances, kinematics and orbital parameters of the sample stars, up to 8kpc. The Galactic components Thin and Thick discs and Halo are then characterized. The velocity ellipsoid for the old Thin Disc is found at $(\sigma_u, \sigma_v, \sigma_w) = (39, 27, 20)$ km s^{-1} with a mean [M/H] ~ -0.12 dex, whereas the Thick Disc has a mean [M/H] ~ -0.4 dex and a rotational lag of V $\sim$-76 km s^{-1}

Keywords: galaxy: evolution, galaxy: kinematics and dynamics, stars: abundances, methods: observational

1 Introduction

The existence of a Thick Disc for the Milky Way (Gilmore & Reid 1983), and for other disc Galaxies (Yoachim & Dalcanton 2006) is rather clearly established nowadays. Nevertheless, its creation mechanisms still remain a riddle in the paradigm of a cold dark matter dominated Universe. For instance, Abadi *et al.* (2003) propose that the stars forming the Thick Disc mostly come from distrupted satelites, whereas Villalobos & Helmi (2008) predict that the pre-existing Thin Disc has been heated rapidly from successive accretions. On another hand, Brook *et al.* (2004) suggest that a gas rich merger brought the necessary gas to form *in situ* the Thick disc stars, before the gas have had completely settled into a thin disc. Finally, the simulations of Schönrich & Binney (2009) manage to form a Thick Disc without any external stimulus: stars migrate to larger heights from the inner parts of the Galaxy, due to resonances with the spiral arms and the central bar.

Typical F, G and K main sequence stars are particularly useful to study Galactic evolution, since they are both numerous and long-lived, and their atmospheres reflect their initial chemical composition. However, a direct measurement of their spatial distribution requires accurate estimates of stellar distances, which is a delicate step involving (if the parallax is not available) the determination of precise stellar parameters (effective temperatures $T_{\rm eff}$, surface gravities log g, and metal content [M/H]).

In order to put more constraints on the Thick Disc properties, we explore spectroscopically the stellar contents outside the Solar neighbourhood, owing to an extensive use of the Ojha (1994) catalogue in which are published the proper motions and U,B,V colours of several thousand stars. Here, based on the observations of 600 of these stars towards the galactic coordinates l$\sim$ 277°, b$\sim$ 47°, we present a kinematic and chemical characterization of the Galactic components.

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2 The catalogue of stars

The target stars were selected having $14 \leq m_v \leq 18.5$ mag in order to probe the Galactic Thick Disc and have acceptable signal-to-noise ratios (S/N). According to the published values of Ojha (1994), the magnitude precisions range from 0.02 mag for the brightest, to 0.05 mag for the faintest stars. Associated errors for the proper motions are estimated to be 2 mas/year.

Radial velocities have been derived by cross-correlating the spectra with a binary template of a K0 type star, reaching a mean estimated error of 4.7 km s^{-1}. The observations were obtained with VLT/FLAMES feeding the GIRAFFE spectrograph with the LR08 grating (8206-9400 Å, R$\sim$6500). This setup contains the Gaia/RVS wavelength range (8475-8745 Å), and is similar to its low resolution mode. This survey can therefore be used as a complementary study of Recio-Blanco *et al.* (2006), to test with real spectra what information will be possibly retrieved from the Gaia/RVS low resolution mode (or its ground based follow up), with an automatic spectral analysis code such as the MATrix Inversion for Spectral SynthEsis (MATISSE, Recio-Blanco *et al.* 2006).

In that wavelength range, the IR CaII triplet is predominant for most of the spectral types and luminosity classes as well as for very metal poor stars. In addition, these strong features are still detectable even at a low S/N, allowing a good radial velocity ($V_{\rm rad}$) derivation and an overall metallicity estimation. Paschen lines are visible for stars hotter than G3. The MgI (8807 Å) line, which is a useful indicator of surface gravity, is also visible even for low S/N. Finally, molecular lines like TiO and CN can be seen for the cooler stars.

3 The derivation of the atmospheric parameters

We used the MATISSE algorithm to obtain the $T_{\rm eff}$, log g and [M/H] for our sample. MATISSE is a local multi-linear regression method that allows the determination of an atmospheric stellar parameter by a simple projection of an observed spectrum on vectors derived during a learning phase. In order to train MATISSE for the LR08 setup of FLAMES, we computed a library of 2905 synthetic spectra using the MARCS model atmospheres, and a linelist calibrated on the high resolution spectra of the Sun and Arcturus. The parameter ranges for the synthetic library were, $T_{\rm eff}$: [3000, 8000] K, log g: [0, 5] dex and [M/H]: [-5, +1] dex. We assumed a coupling between the overall metallicity and the α-elements abundances*, according to the commonly observed enhancements in the metal-poor Galactic stars.
The method has been tested on a set of 10^3 synthetic spectra not being part of the learning set of MATISSE, in order to establish the relative errors of our algorithm. We found that for an intermediate metallicity dwarf star, at S/N $\sim$ 50 (which is the mean S/N of our spectra), accuracies of $\sim$ 150 K, 0.3 dex and 0.2 dex are achieved for $T_{\rm eff}$, log g and [M/H], respectively. In addition, the algorithm has been applied on two observed stellar librairies, the S^4N and the CFLIB one, showing no particular biases according to the S/N, the spectral type of the star or the metallic content (Kordopatis *et al.* 2010).

4 Characterization of the observed stellar sample

Based on the position of the stars in the H–R diagram and an interpolated set of the Y^2 isochrones, we derived the line-of-sight distances, by assuming the interstellar extinction provided by the Schleggel data. Galactocentric positions† X,Y,Z and velocities U,V,W were derived, using the proper motions of Ojha (1994) and the derived by ourselves $V_{\rm rad}$. Errors have been propagated by running 5.10^3 Monte-Carlo simulations, taking as a final value the mean of the obtained realisations and as an error their dispersions. All the stars having S/N >10, relative errors on the distance less than 40%, and errors on $V_{\rm rad}$ less than 7 km s^{-1} have been selected.

In order to characterize the Galactic components, we made extensive use of the Besançon Model of the Milky Way (Robin *et al.* 2003), which supposes a scale height of 800 pc for the Thick disc. We obtained a catalog of simulated stars towards our line-of-sight and biased it according to our magnitude distribution. According to the model, stars till a Z-height above the plane of 600 pc are dominated (more than 80%) by the Thin Disc. Furthermore, a given star situated between 0.6 kpc and 1.1 kpc, has equal chances to belong to one of the two components. On the other hand, farther than 1.1 kpc, the Thick Disc is predominant and for 1.1 kpc<Z<4 kpc, more than 82 % of the stars should be from the Thick Disc. Farther away than 4 kpc, the inner Halo is no longer negligible, representing more than 40% of the total stars according to the model. Thus, we decided to select as

*The chemical species considered as α-elements are O, Ne, Mg, Si, S, Ar, Ca and Ti.

†We have adopted a right-handed reference frame, with the X axis pointed towards the Galactic centre

Galactic component	N	<U>; σ_U km s^{-1}	<V>; σ_V km s^{-1}	<W>; σ_W km s^{-1}	<[M/H]>; $\sigma_{[\mathrm{M/H}]}$ dex
Thin Disc	108	(−22; 39)	(−12; 27)	(−7; 20)	(−0.12; 0.30)
Thick Disc	215	(−49; 72)	(−76; 57)	(−12; 59)	(−0.41; 0.26)
Inner Halo	30	(−24; 187)	(−257; 89)	(−135; 132)	(−0.66; 0.50)

Table 1. Column (2) shows the number of stars considered in order to characterize each Galactic component. Colums (3) to (6) show the mean values as well as the dispersion for the fitted Gaussians of the velocity and metallicity distributions. The Thin Disc stars have been selected as the ones having Z<600 pc, the Thick disc stars as the ones having $1.1 < Z < 4$ kpc, and the Halo stars the ones having $Z > 4$ kpc and V smaller than -180 km s^{-1} .

Thin Disc members the stars being closer than 600 pc, as Thick Disc stars the targets lying between 1.1 kpc and 4 kpc, and as inner halo members, all the stars above 4 kpc having an almost null rotational velocity (V smaller than -180 km s^{-1}). This selection separates out clearly each Galactic component in a Toomre diagram (see Fig. 1-d).

Gaussians fits have been applied to the velocities and metallicity distributions (see Fig. 1) of the Thin and Thick discs as well as the inner Halo. As summarized in Table 1, we found that the Thin Disc has (<U>; σ_U)=(−22; 39) km s^{-1}, (<V>; σ_V)=(−12; 27) km s^{-1}, (<W>; σ_W)=(−7; 20) km s^{-1} and (<[M/H]>, $\sigma_{[M/H]}$)=(−0.12; 0.30) dex. These values agree with the studies of for example Reddy *et al.* (2006) and Soubiran *et al.* (2003). As far as the Thick Disc is concerned, the Gaussian distributions are characterized by (<U>; σ_U)=(−49; 72) km s^{-1}, (<V>; σ_V)=(−76; 57) km s^{-1}, (<W>; σ_W)=(−12; 59) km s^{-1} and (<[M/H]>, $\sigma_{[M/H]}$)=(−0.41; 0.26) dex. Finally, let us note that the stars selected as belonging to the inner Halo, may still include a non negligible part of Thick Disc members. In addition, they are prone to bigger errors (because of the fact that they are giant stars), as well as to selection biases, since a lot of them might have been rejected due to either their low S/N, or their high relative error on the atmospheric parameters (and hence their distance). Indeed, the rejection of the targets based on their distance accuracies and their S/N, removes most of the metal poor stars, which may introduce a bias against low-metal stars. For the 30 stars selected as being part of the inner Halo, we find a mean [M/H] of ∼ -0.66 dex, but the number of the candidates is rather small to make reliable statitistics.

The eccentricity of the stars was computed by integrating their orbits up to several Galactic revolutions. The Milky Way potential is fixed, and is modelled with a Miyamoto-Nagai disc, a Hernquist bulge and a spherical logarithmic halo. The shape of the eccentricity distribution seems to rule out, according to Sales *et al.* (2009), a pure accretion scenario for the formation of the Thick Disc.

5 Conclusions

Results found for the Thin Disc are in very good agreement with the predictions of the Besançon model, or surveys made in the Solar neighbourhood (Reddy *et al.* 2006; Soubiran *et al.* 2003). On another hand, the rotational lag found for the Thick Disc is higher than the commonly admitted value for the Canonical Thick Disc of ∼-50 km s^{-1}. The issue whether or not this is due to a gradient of the rotational velocity with Z is still an open question.

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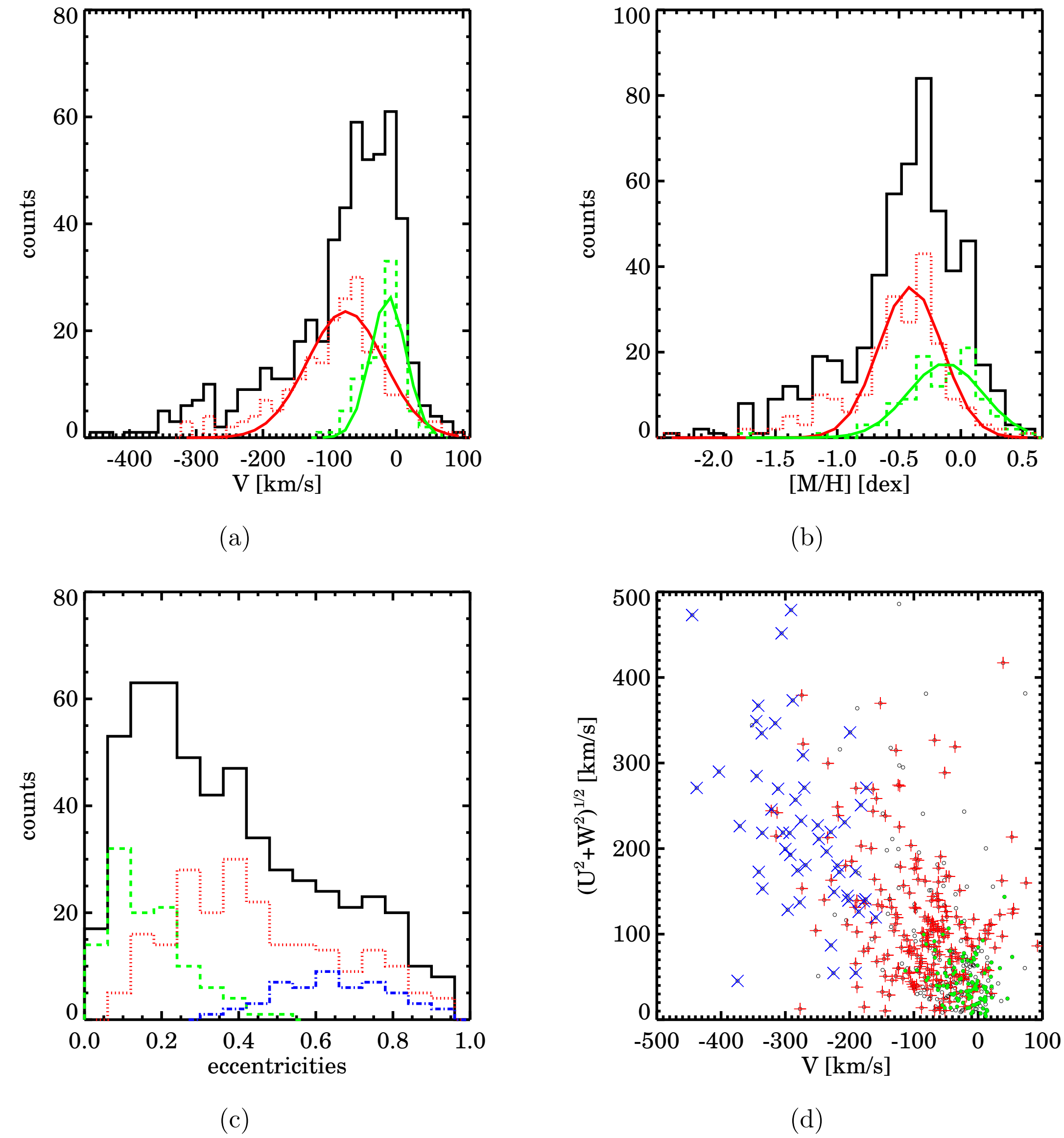

Fig. 1. Pannels (a), (b), (c) refer to the V-velocity, metallicity and eccentricity distributions for all the stars (continuous line), Thin Disc (dashed green line), Thick Disc (dotted red line) and Halo (blue dotted-dashed line). For panels (a) and (b) the halo distribution has not been shown for clarity reasons, since the counts are very few. Finally, pannel (d) shows the Toomre diagram, where each Galactic component separates out clearly. Thin disc stars are represented with filled green dots, Thick Disc stars with red plus signs and Halo stars with blue crosses. Open circles represent stars that could not be affiliated to any of the Galactic components.

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