Kinematic and chemical signatures of the formation processes of the galactic thick disk

A. Spagna[1] , A. Curir[1], M. G. Lattanzi[1], G. Murante[1], P. Re Fiorentin[1,2], R. L. Smart[1]

[1]Osservatorio Astronomico di Torino/INAF, Italy - [2]University of Ljubljana, Slovenia

ABSTRACT

Thick disks have been observed in many disk galaxies and represent the frozen relics of the first phases of disk galaxy formation.

Our Galaxy, the Milky Way, also presents a thick disk whose main spatial, kinematic, and chemical features of this population are well established. However, the origin of this ancient component is still unclear, in spite the many studies carried out and several formation scenarios proposed until now.

For the first time to our knowledge, we found evidence of a kinematics-metallicity correlation, of about 40-50 km/s per dex, amongst thick disk stars at 1 kpc< |z| < 3 kpc and with abundance -1<[Fe/H]<-0.5.

This finding sets important constraints on the origin of the thick disk in the context of CDM hierarchical galaxy formation mechanisms and of secular evolutionary processes in galactic disks.

This result is reported and, preliminary results, based on new N-body high numerical resolution simulations of stellar disks endowed with a bulge inside a dark matter NFW halo, are presented.

Evidence of a rotation-metallicity correlation

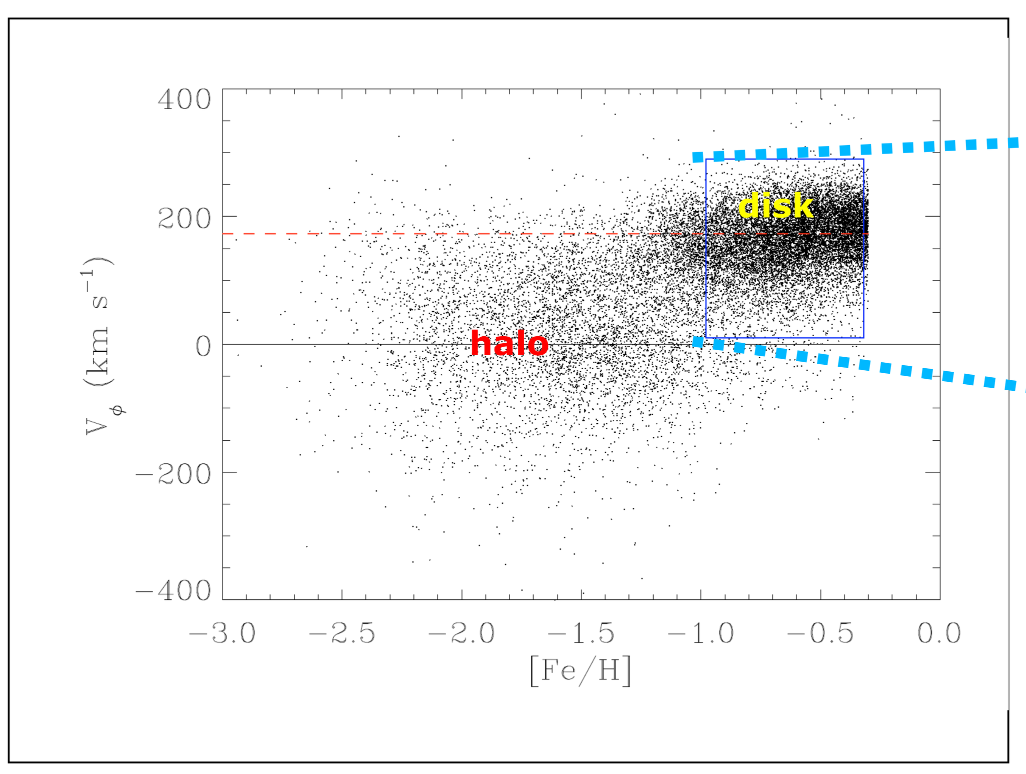


Figure 1. ***The disk and halo populations are apparent in the velocity-metallicity distribution of 20 251 stars with|z| = 1.0–3.0 kpc and [Fe/H] < −0.3.***
The dashed line indicates the thick disk rotation, Vφ = 173 km s−1 at |z| = 1.24 kpc.The box defines the region, shown in Fig. 2, in which the thick disk population dominates.

We analyzed a *new kinematic survey* that includes accurate proper motions derived from SDSS DR7 positions, combined with multiepoch measurements from the GSC-II database (*Lasker et al.* 2008).

By means of the SDSS spectro-photometric data (T_{eff}, log *g*, [Fe/H], and radial velocities), we estimate photometric parallaxes for a sample of 27 000 FGK (sub)dwarfs with [Fe/H] < −0.5, which we adopted as tracers of the 7D space distribution (***X***, ***V***, *[Fe/H]*) of the thick disk and inner halo within a few kiloparsecs of the Sun.

We find evidence of a *kinematics-metallicity correlation*, $\partial V\varphi/\partial$[Fe/H] ≈ 40 ÷ 50 km s^{-1} dex^{-1}, amongst thick disk stars located between 1 kpc and 3 kpc from the plane and with abundance −1 < [Fe/H] < −0.5. No significant correlation is present for [Fe/H] > −0.5 (*Spagna et al.* 2010)

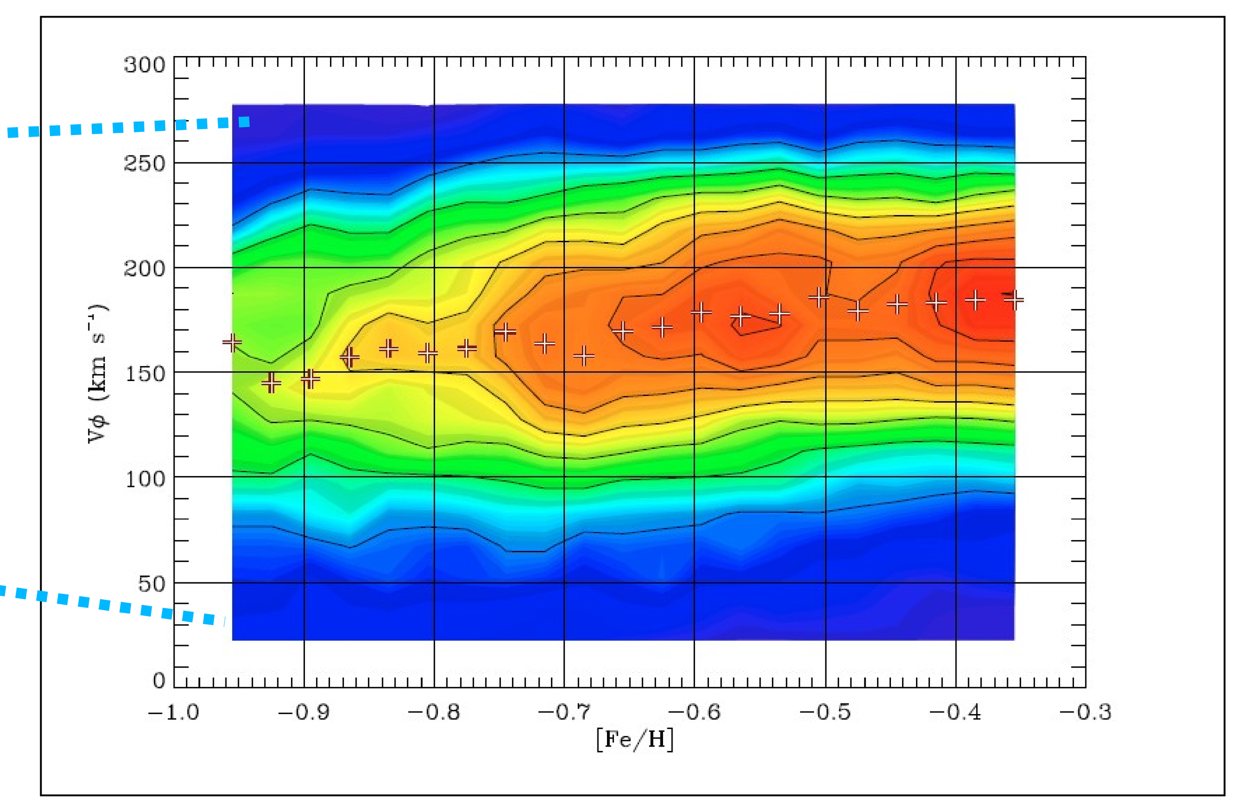


Figure 2. ***Iso-density contours of 13 108 metal-poor stars from the SDSS-GSC-II catalo: −1.0 < [Fe/H] < −0.3 and |z| = 1.0–3.0 kpc. White crosses mark the ridge line of the maximum likelihood Vφ vs. [Fe/H].***

Notice the bimodal distribution with a secondary maximum at [Fe/H]≈−0.55, close to the value of the mean metallicity of the thick disk, and the peak at [Fe/H]−0.38 due to thin disk stars.

As in Bond et al. (2010), no correlation appears in the transition region between the thin and thick disks ([Fe/H] > −0.5). Instead, a shallow but clear slope appears for [Fe/H] < −0.5, which indicates that the metal-rich stars tend to rotate faster than the metal-poor ones.

Comparison with N-body simulations

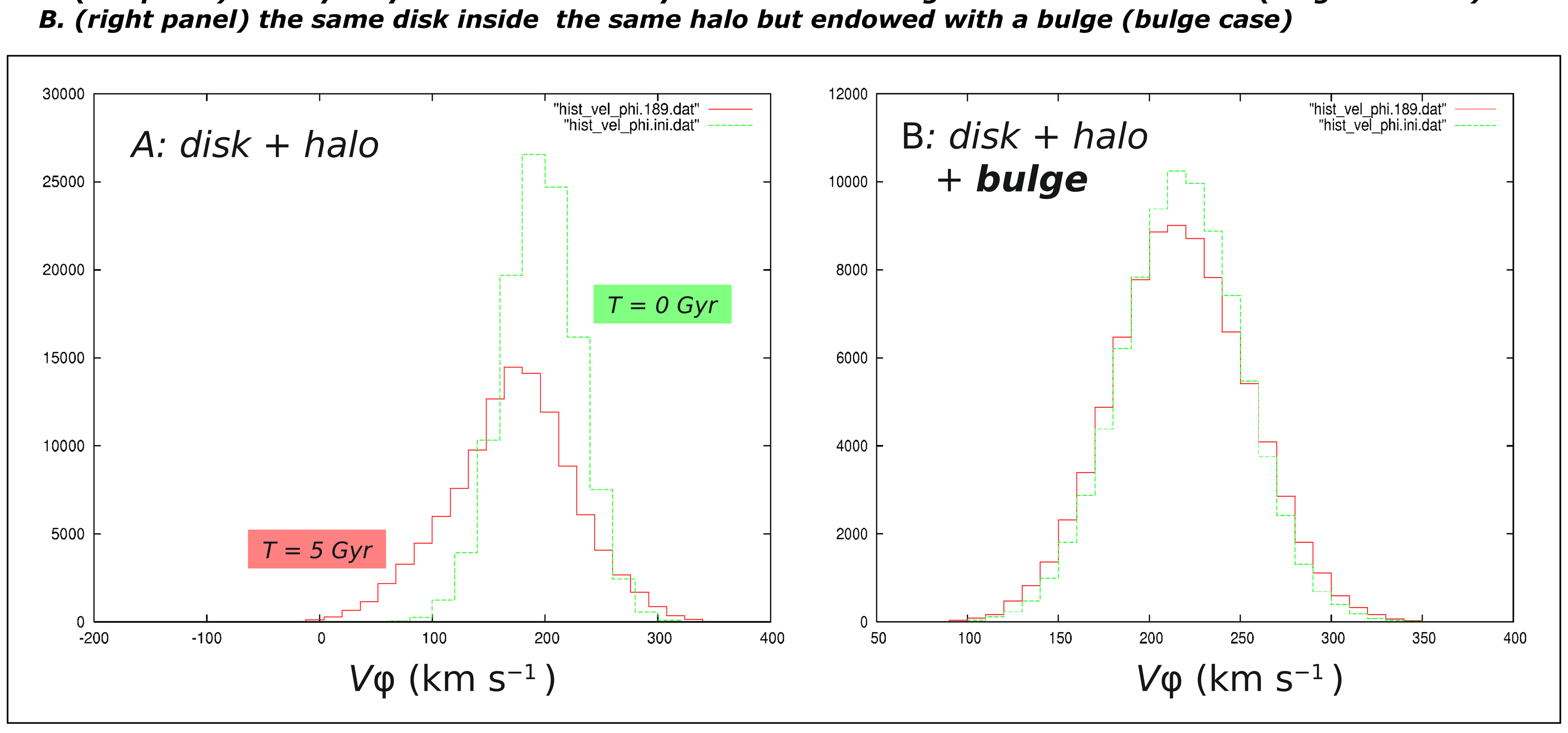
CDM hierarchical galaxy formation models predict that thick disks can be formed by the heating of a pre-existing thin disk through *(a)* a minor merger (e.g. *Villalobos & Helm*i 2008), *(b)* by accretion of stars from disrupted satellites (*Abadi et al.* 2003), or *(c)* by the stars formed in situ from gas-rich chaotic mergers at high redshift (*Brook et al. 2005*). In addition, simulations suggest that thick disks could simply be produced through secular radial migration of stars induced by the spiral arms (*Roškar et al.* 2008; *Schönrich & Binney 2009*).

Here we show preliminary results of N-Body high-resolution simulations (no gas) of a stellar disk endowed with a bulge inside a Dark Matter (DM) halo (cfr. *Curir et al.* 2006).

Model - Milky Way-like central galaxy

- exponential thin disk: M=2 10^{10} M_{sun}/h; scale-length H_R=3 kpc; solar metallicity [Fe/H]=0 at R=8 kpc ; radial gradient d[Fe/H]/dR= -0.058 dex/kpc
- bulge of 10^{10} M_{Sun}/h + NFW halo of 10^{12} M_{Sun}/h.

Figure 3.***Azimuthal velocity, VΦ, distributions of the particles selected in the same initial corona between 8 and 10 kpc inside a disk of 20 Kpc of radius. These histograms are representing the <u>disk</u> particles evolved for <u>5 Gyr</u> in the two cases:***
A. (left panel) a Milky Way disk surrounded by a NFW halo having a concentration c=7.4 (bulgeless case)
B. (right panel) the same disk inside the same halo but endowed with a bulge (bulge case)

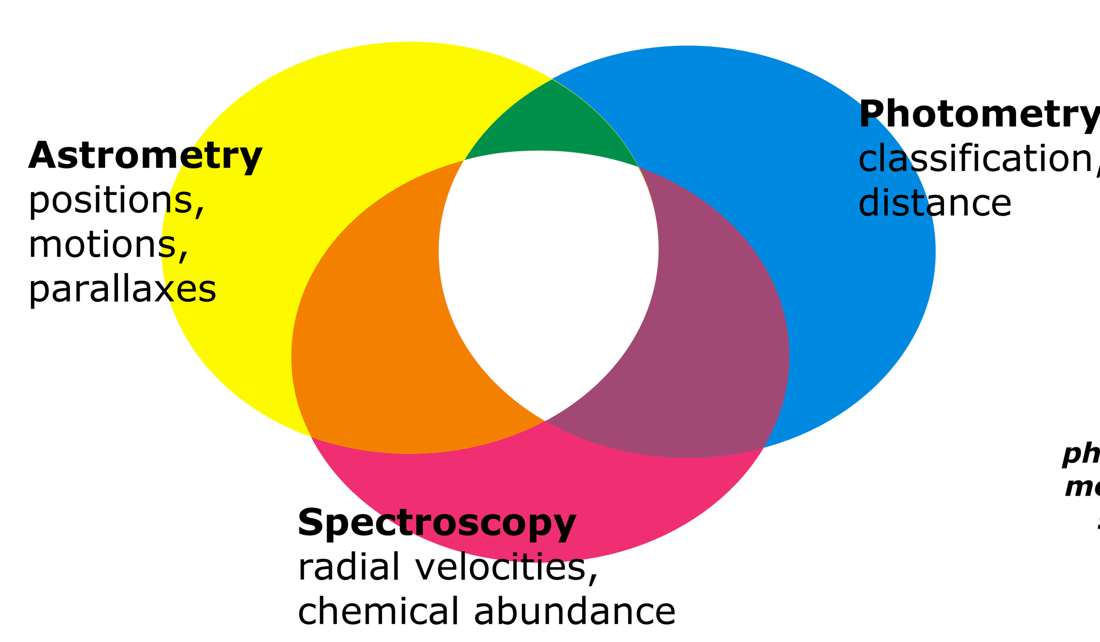


In the first case a <u>strong bar</u> is formed at the end ot the evolution, and this non axisymmetric structure promotes an <u>inner radial migration</u> of disk particles and a disk <u>thickening</u> which are not evident for the case B.

Future

Since the epoch of the studies carried out by *Eggen, Lynden-Bell & Sandage* (1962), the integration of astrometric + photometric + spectroscopic data is the successful "recipe" to understand the mechanisms of galactic formations.

Thus, we expect that our findings will be investigated soon in more details thanks to data provided by the many current all-sky surveys (GSC-II, UCAC, RAVE, SEGUE, LAMOST, 2MASS, ...), and in the long term, by means of Gaia catalogue which will provide much more accurate information for much larger samples of stars spanning a wide range of distances from the Sun.



Ingredients: astrometric, photometric and spectroscopic measurements for statistically significant stellar samples

Tools: stellar evolution, dynamical models, and advanced statistical methods

REFERENCES

- Abadi, M. G., Navarro, J. F., Steinmetz, M., & Eke, V. R. 2003, ApJ, 597, 21
- Bond, N. A., Ivezic, Ž., Sesar, B., et al. 2010, ApJ, 716, 1
- Curir A., Mazzei P., Murante G., 2006, A&A, 447, 453
- Lasker, B. M., Lattanzi, M. G., McLean, B. J., et al. 2008, AJ, 136, 735
- Roškar, R., Debattista, V. P., Stinson, G. S., et al. 2008, ApJ, 675, L65
- Schönrich, R., & Binney, J. 2009, MNRAS, 396, 203
- Spagna, A. et al, 2010, A&A, 510, L4
- Villalobos, Á., & Helmi, A. 2008, MNRAS, 391, 1806