The thick disk rotation-metallicity correlation, comparison with Galactic cosmological simulations

Alessandro Spagna[1], Anna Curir[1], Marco Giammaria[2], Mario G. Lattanzi[1], Paola Re Fiorentin[1]

(1) INAF-Osservatorio Astrofisico di Torino (Italy) (2) Università di Torino (Italy

Abstract

Although the existence of a thick disc in the Milky Way was revealed 35 years ago and its spatial, kinematic, and chemical properties are today better defined, its origin is still matter of debate. Proposed scenarios include the heating of a pre-existing thin disc through a minor merger, accretion of dwarf galaxies stars from disrupted satellites, or stars formed in situ from gas-rich mergers at high redshift.

In order to better understand these processes, we have investigated the chemo-dynamical evolution of a Milky Way-like disk galaxy, as produced by the recent cosmological simulations, integrating a sub-resolution ISM model, published by Murante et al. (2015). In particular, we evidence a global inside-out and top-down disk evolution.

Recently, Re Fiorentin, Lattanzi & Spagna (2019) analysed a new chemo-kinematic catalogue based on Gaia DR2 and APOGEE DR14 and showed evidence that the thick disk rotation-metallicity correlation is persistently positive from R=5 kpc to 13 kpc, in spite of a quasi-flat metallicity gradient.

Our simulation at redshift z=0 shows very similar properties when we look at the “thick disk” stellar particles at 1 kpc <|z| < 3 kpc from the plane and at 6 kpc < R < 8 kpc from the galactic center.

Here we show that similar trends seen in the Milky Way could have resulted from of the chemo-dynamical evolution of the galactic disk, starting from a primordial disk (redshift *z* > 2) with a negative rotation-metallicity correlation associated with a negative radial metallicity gradient (cfr. also Schoenrich & McMillan 2017; Kawata et al. 2018).

Cosmological simulation Aquila C4 (AqC4)

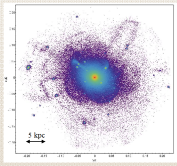


Fig. 1: stellar distribution at z=2.16 (t_{lback}= 10.5 Gyr)

We analyze a ΛCDM cosmological simulation, AqC4, carried out with the GADGET-3 TreePM+SPH code, where star formation, chemical evolution and stellar feedback are described using a sub-grid Multi Phase Particle Integrator (MUPPI) model. The main parameters of this simulation are listed in Table 1. For further details, see *Murante et al.* (2015).

M_{DM} [Mo]	M_{gas} [Mo]	ε [kpc]	M_{vir} [Mo]	R_{vir} [kpc]	N_{DM}	N_{gas}	N_{star}	Ω_m	Ω_Λ	Ω_b	H_0
$2.7 \cdot 10^5$	$5.1 \cdot 10^4$	0.163	$1.49 \cdot 10^{12}$	237.13	5,518, 587	1,348,120	6,919,646	0.25	0.75	0.04	73

Table 1. M_{DM} = mass of DM particles; M_{gas} = initial mass of gas particle; ε = smoothing parameters; M_{vir} and R_{vir} = mass and radius of DM at z=0; $N_{DM,}$ $N_{gas,}$ N_{star} = number of DM particles, gas particles and stellar particles within R_{vir} at z=0; Ω_i = density parameters; H_0 [km/s/Mpc] Hubble constant.

Inside-out galaxy formation

Because of the hierarchical accretion processes, at *z* = 0, the spatial distribution of the oldest stellar populations (left panels of Fig. 2) is more roundish with respect to the thinner and flatter distribution of the younger stellar generations (right panels of Fig. 2). The final structure usually represented by three main components (i.e. bulge/spheroid, thin and thick disk) is the results of the superposition of these stellar generations, whose chemo-dynamical properties depends on the formation history and their evolution due to the internal secular processes and to external perturbations produced by accretion events. Our results are quite consistent with similar studies based on independent cosmological simulations (e.g. *Bird et al.* 2013, *Ma et al.* 2017).

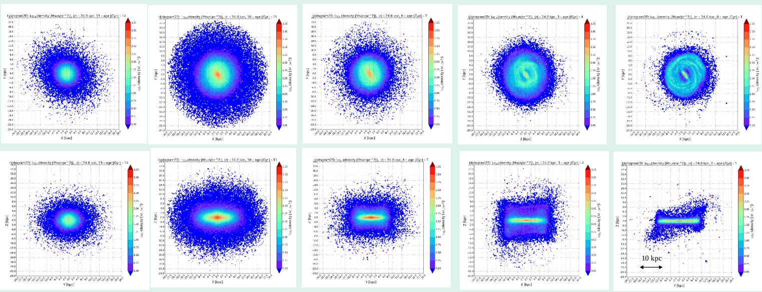


Fig. 2 – Face on (*top panels*) and edge on profiles (*bottom panels*) at *z*=0 of five stellar generations (13-14 Gyr, 10-11 Gyr, 6-7 Gyr, 3-4 Gyr, 0-1 Gyr). Notice the higher vertical scale-heights and shorter radial scale-lengths of the older populations.

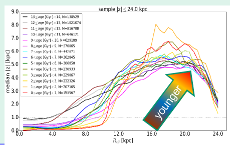


Fig. 3 – Median height |*z*| vs. *R* at *z*=0 of the mono-age-populations (0 < age < 14 Gyr). Here, the shift of the ***flaring*** toward larger radii for the younger population is apparent (cfr. *Minchev et al*. 2012).

Chemo-kinematic evolution of the simulated “thick disk”

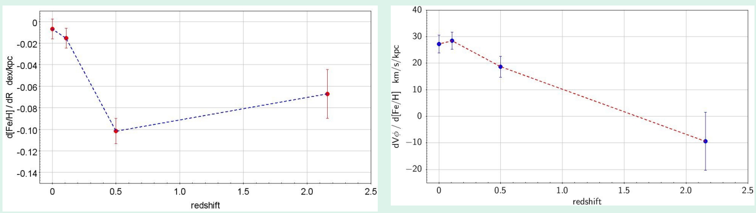


Fig. 6. Evolution of Vϕ – [Fe/H] and d[Fe/H]/dR as a function of time. As in Fig. 5, the values are computed for simulated stellar particles with 6 kpc < R < 8 kpc and 1 kpc < |z| < 3 kpc.

Rotation-metallicity correlation

Thin disk. At redshift z=0, a typical negative metallicity radial gradient is present in the disk of AqC4 (Fig. 4 left panel), while no rotation-metallicity correlation has been detected for whole disk (Fig. 4, right panel)

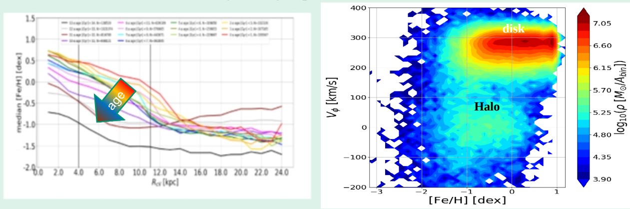
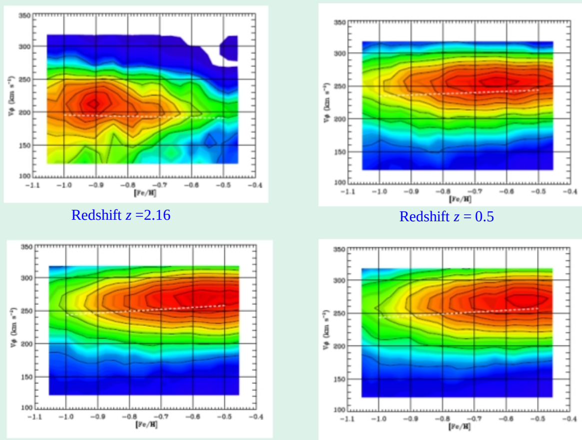


Fig. 4– Left panel. Radial metallicity gradient, [Fe/H] vs. R, at redshift z=0 for various monoage disk populations.
Right panel. Distribution Vϕ – [Fe/H] in the “solar” neighborhood, within 3 kpc from (X,Y,Z) = (+8,0,0) kpc

Thick disk. We investigated the evolution of the chemo-kinematic properties of the “thick disk” by selecting stellar particles at 1 kpc <|z| < 3 kpc from the plane and at 6 kpc < R < 8 kpc from the galactic center.



Redshift *z* =2.16 | Redshift *z* = 0.5 | Redshift *z* = 0.1 | Redshift *z* =0 (today)

Fig. 5. Distribution Vϕ – [Fe/H] of the simulated “thick disk” in the “solar” neighborhood, 6 kpc < R < 8 kpc. The white dashed lines show the resulting linear best fit

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