

# Gaia and the Galactic disk

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GREAT-ESF Workshop

## **Collaborators**

*Anna Curir*

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*Giuseppe Murante*

*Paola Re Fiorentin*

*Richard L. Smart*

*Emanuele Spitoni*

*Alvaro Villalobos*

## ***Expertise***

**Spectro-photometry**

**Galactic dynamics and N-body  
models**

**Chemical models**

**Astrometry, MW structure,  
stellar pop.s**

## Outline

- Introduction (local cosmology and Gaia)
- Problem: *thick disk* formation
- Observed rotation-metallicity correlation (late F, G, K dwarfs sample)
- Results from N-body simulations (chemistry given)
- Conclusions (local cosmology, back to Gaia)

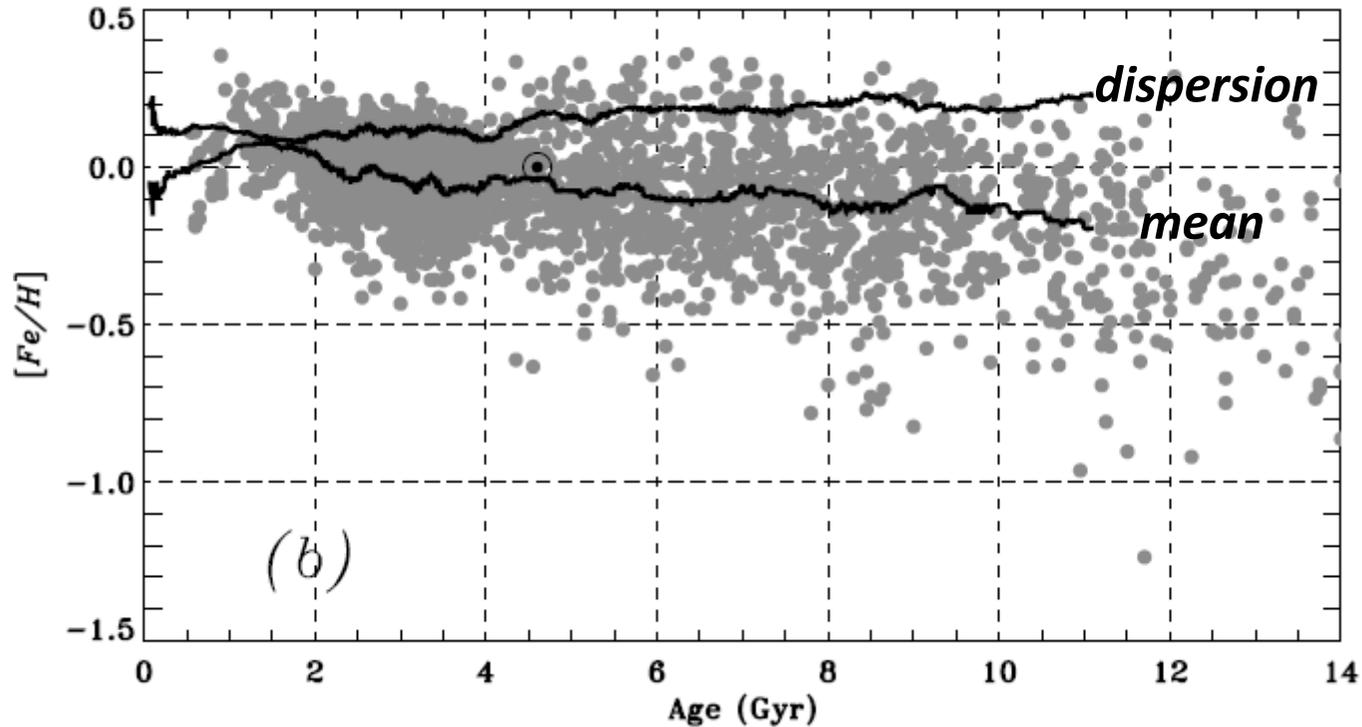
# Introduction

*Local cosmology:* we look for archeological relics of the chemo-dynamical evolution of the Milky Way



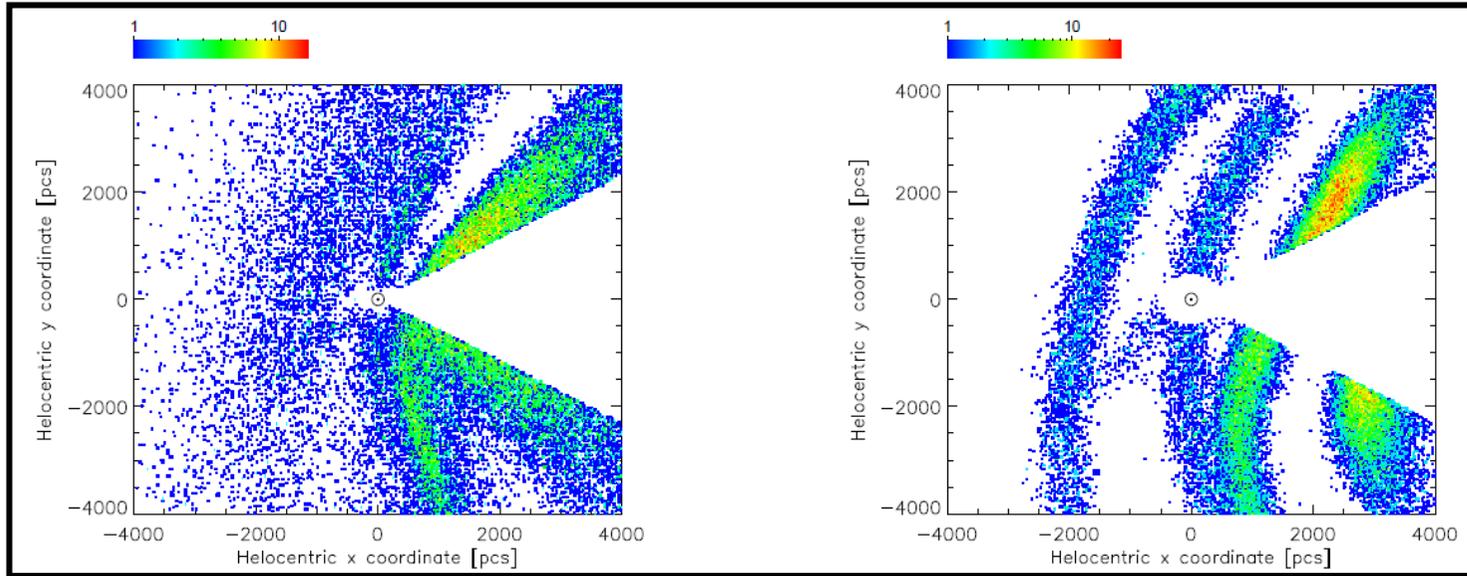
# Age-metallicity relation

As indication of the radial mixing in the galactic disk

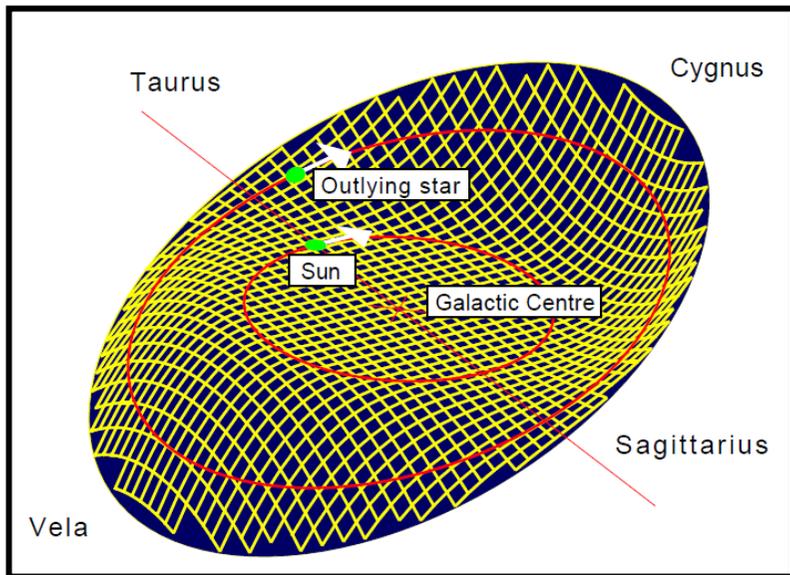


**3300 stars within 75 pc from the Sun**  
(Haywood 2008, MNRAS, 388, 1175)

# Gaia



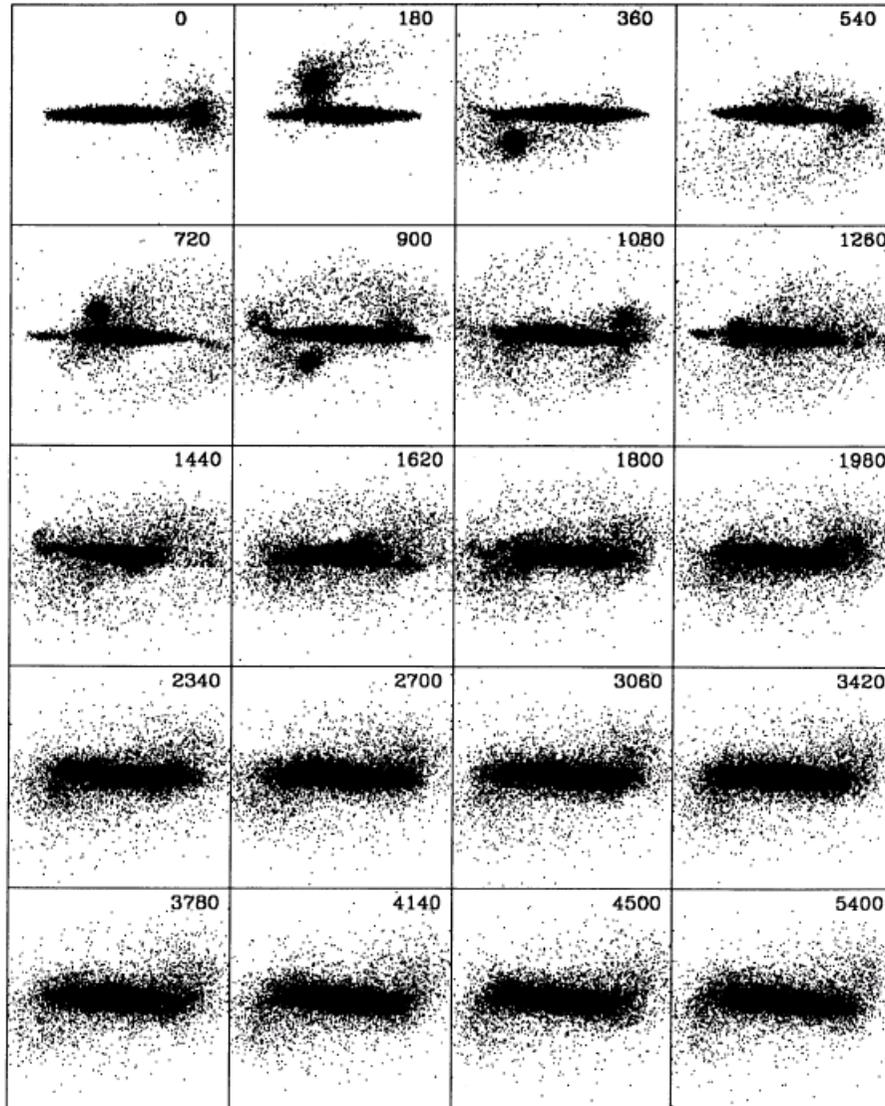
*Distribution in the Galactic plane of a hypothetical spectroscopic and photometric statistically complete survey of 50 000 OB stars with photometric distances (left) and with GAIA parallaxes (right), as generated by a synthetic catalogue generator (from Drimmel, Smart, Mgl 1997).*



*The disk of the Galaxy based on HI observations (from Smart, Drimmel, Mgl, Binney 1998). [The vertical axis is exaggerated by a factor of 10.] The line indicates the locus of zero vertical displacement for the warped disk.*

# The origin of the Thick disk?

## The origin of the Thick disk?



**Heating** of a galactic disk by a merger of a high density small satellite.

N-body simulations by  
*Quinn et al.*  
(1993, ApJ, 403, 74)

## The origin of the Thick disk?

1. kinematical **heating** of a pre-existing old disk via minor mergers (*Quinn et al. 1993, Villalobos & Helmi 2008*)
2. stars formed **in situ** (*Jones & Wise 1983, Chiappini 2009*)
3. Chaotic **mergers of gas-rich systems** and intense star formation (*Brook et al. 2005*)
4. **stellar accretion** of merged satellites (*Abadi et al. 2003*)
5. kinematical heating from **massive star clusters** (Kroupa 2001)
6. **radial migration** due to secular dynamical processes (*Schonrich & Binney 2009*)

# Radial migration in spirals

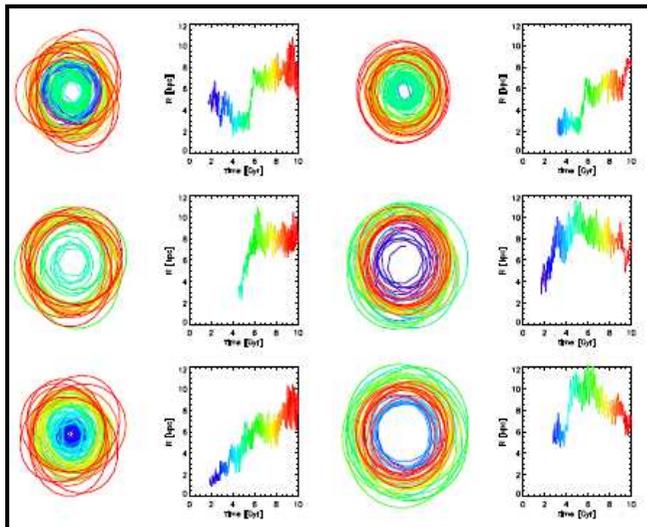
- Stars in disks of spiral galaxies were usually assumed to remain roughly at their birth radii.
- Indeed stars migrate across significant galactocentric distances due to resonant scattering with transient spiral arms, while preserving their circular orbits

*Wielen, R. 1977, A&A, 60, 263*

*Sellwood, J. A., & Binney, J. J. 2002, MNRAS, 336, 785*

*Schonrich, R. & Binney J. 2009, MNRAS, 396, 203*

*Roskar, R et al., 2012, arXiv:1110.4413*

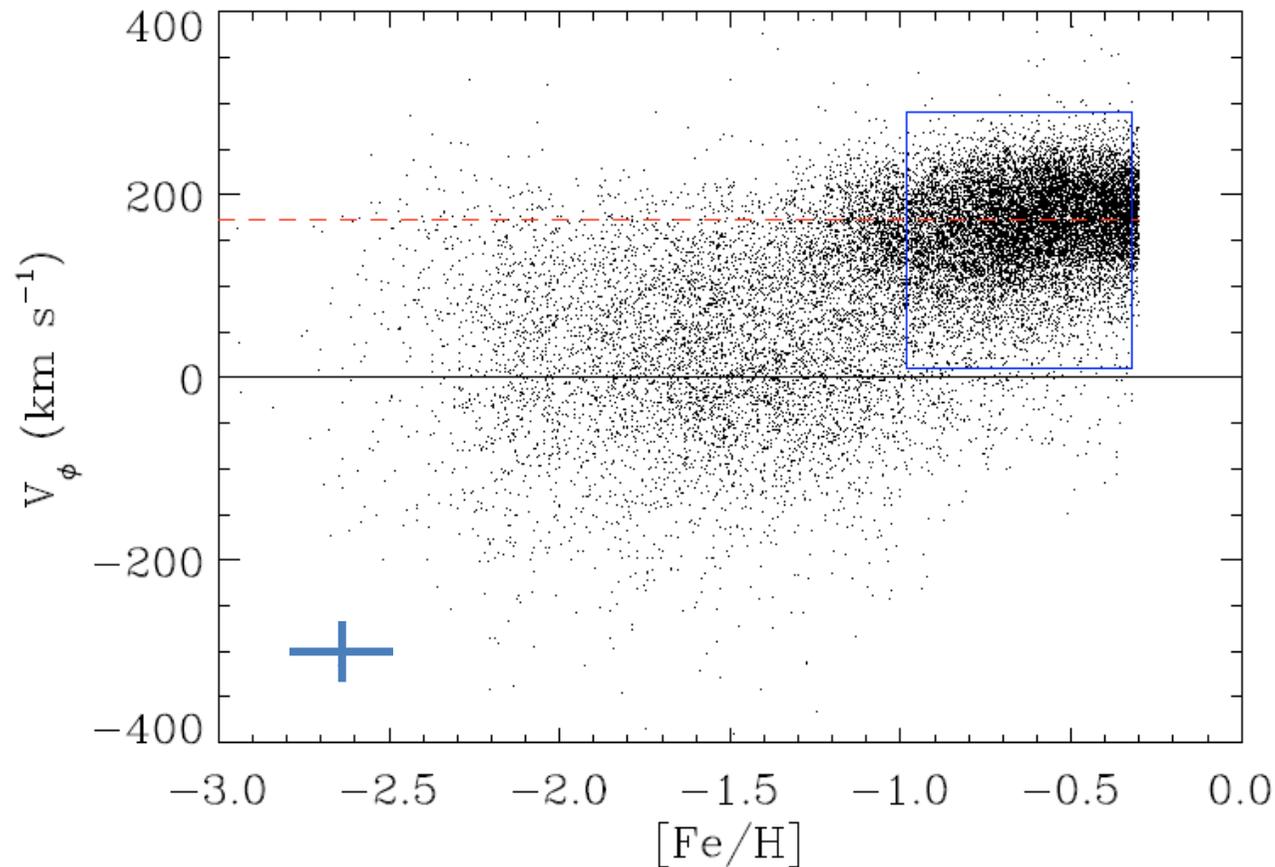


Examples of orbital migration for individual particles (Roskar et al, 2012)

# Evidence of a thick disk rotation–metallicity correlation

A. Spagna<sup>1</sup>, M. G. Lattanzi<sup>1</sup>, P. Re Fiorentin<sup>2</sup>, and R. L. Smart<sup>1</sup>

A&A 510, L4 (2010)



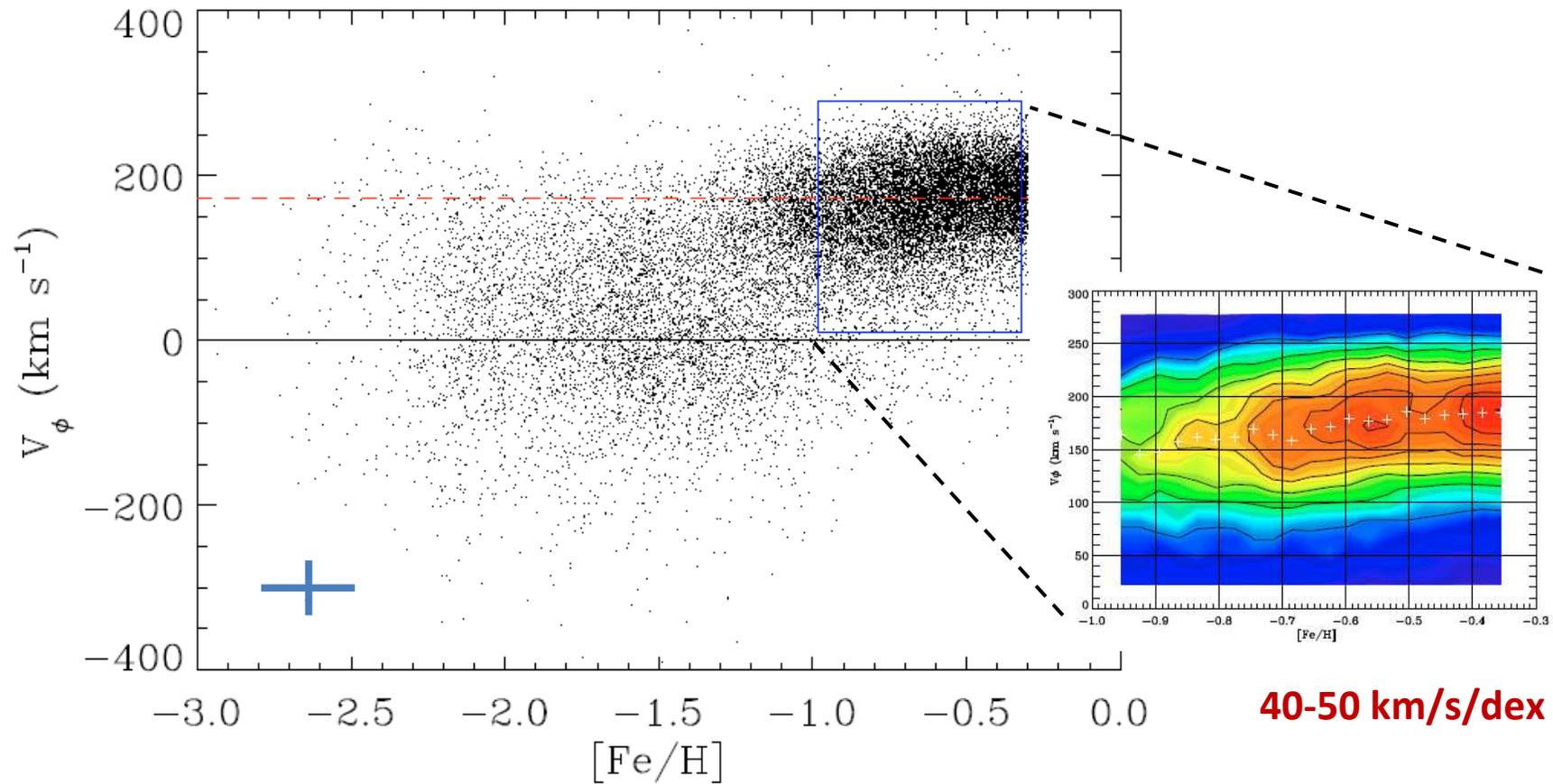
**20,000 FGK  
(sub)dwarfs from  
SDSS-GSC-2 catalog,  
 $1.0 \text{ kpc} < |z| < 3.0 \text{ kpc}$   
and  $[\text{Fe}/\text{H}] < -0.3$**

- $4500 \text{ K} < T_{\text{eff}} < 7500 \text{ K}$
- $\log g > 3.5$ ,
- $g-i > 0.55 \text{ mag}$   
(Klement et al 2009)  
to remove turn-off stars

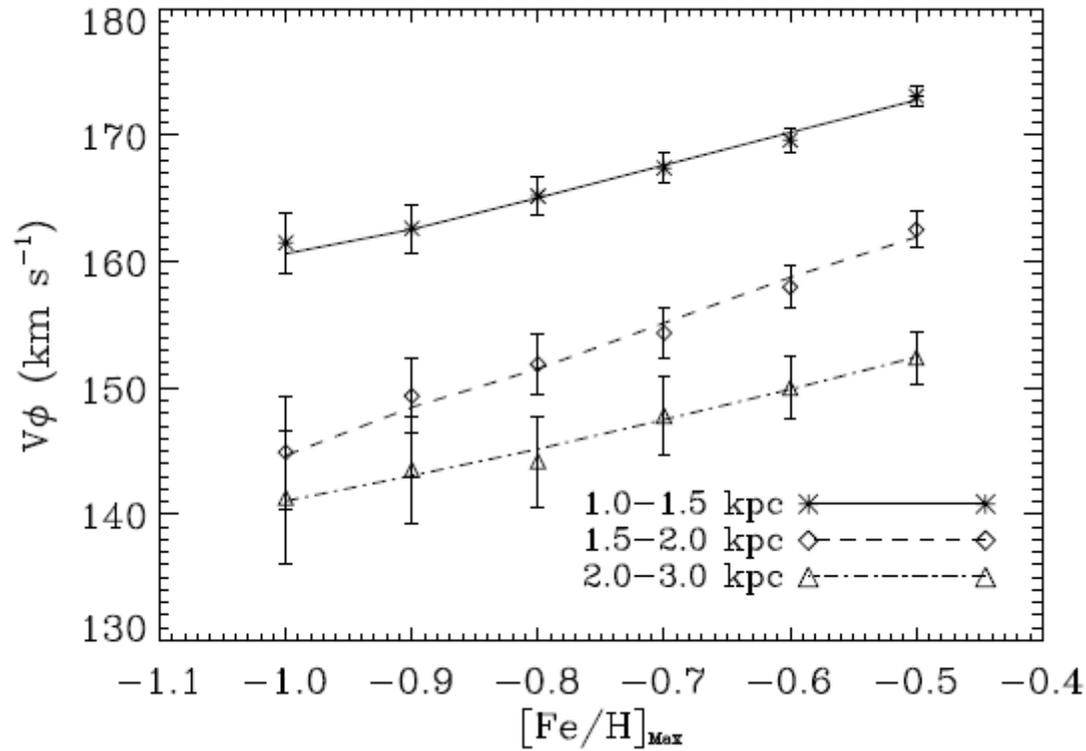
# Evidence of a thick disk rotation–metallicity correlation

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## Thick disk kinematic-metallicity correlation

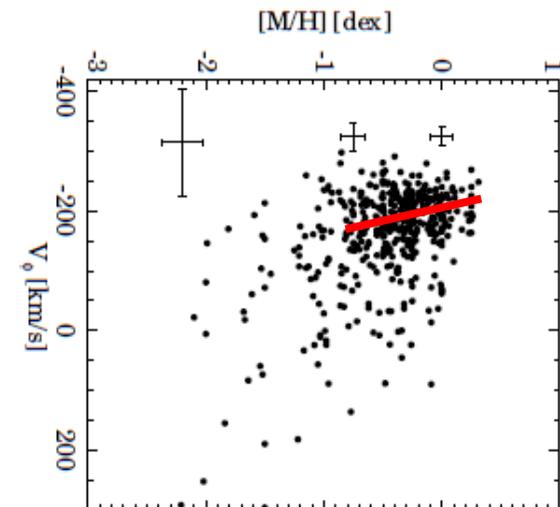
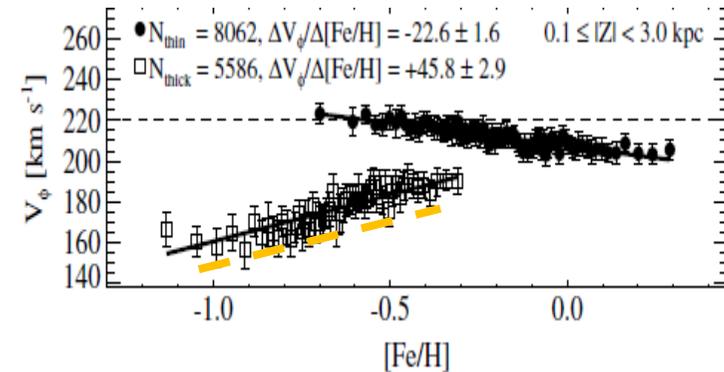


$$\partial\langle V_\phi \rangle / \partial [Fe/H] = (39 \pm 5, 56 \pm 9, 38 \pm 13) \text{ km s}^{-1} \text{ dex}^{-1}$$

*Spagna et al (2010)*

# New observational results on the relation $V_\phi$ vs. $[\text{Fe}/\text{H}]$

- Lee et al (2011) confirm the correlation discovered by Spagna et al using similar SDSS data
- Kordopatis et al. (2011) confirm the correlation using *independent* spectroscopic VLT/FLAMES data



Understanding  
observations

## *Results from specially designed N-body simulations*

- We run 2 N-body simulations (with or without a Bulge) of 20 M particles (public parallel treecode GADGET2 – Springel, 2005 – run on CASPUR@Rome evolving for 10 Gyr) designed to study the dynamical evolution of a stellar disk inside a Dark Matter halo (dimensional and mass properties representative of the MW values).
- Our disk models are conceived in a *non dissipative framework*: we want to evaluate the effect of **pure dynamics** on radial migration (mixing).

## *Disentangling chemistry from dynamics*

- We assume a long-lived stellar population (no star formation, no stellar evolution)
- Each particle in the initial configuration (after dynamical relaxation) is tagged with a  $[\text{Fe}/\text{H}]$  label, according to the initial chemical radial distribution of *Spitoni & Matteucci (2011)* based on *Chiappini et al. (2007)*
- → *we wish to follow the redistribution of the metallicity* inside the disk due to radial mixing.

“Through N-body simulations we studied the dynamical evolution of a stellar disk inside a Dark Matter (DM) halo. Our results evidence how a ‘standard’ -radially decreasing- metallicity gradient produces a negative  $V\phi$  vs.  $[Fe/H]$  correlation, similar to that shown by the **thin disk stars**.....”

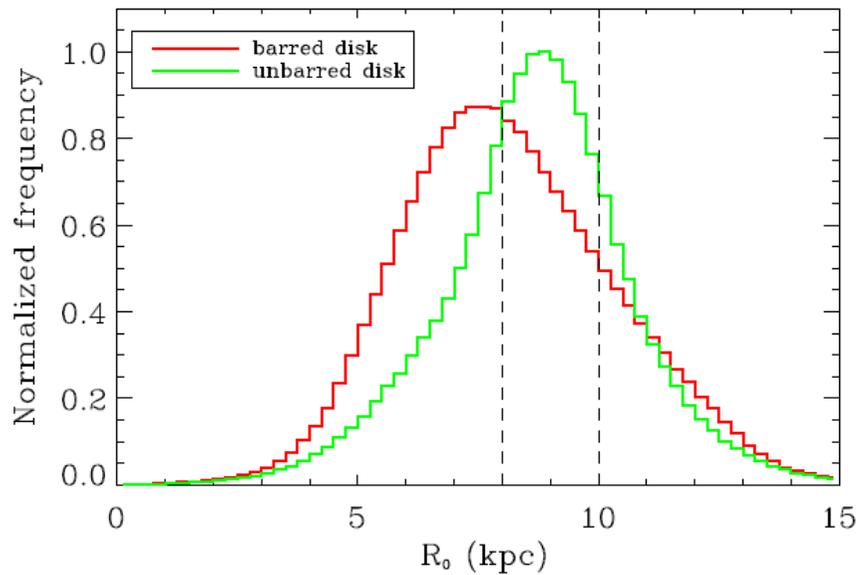
(Curir, et al. 2012)

A quick look at some  
dynamical properties

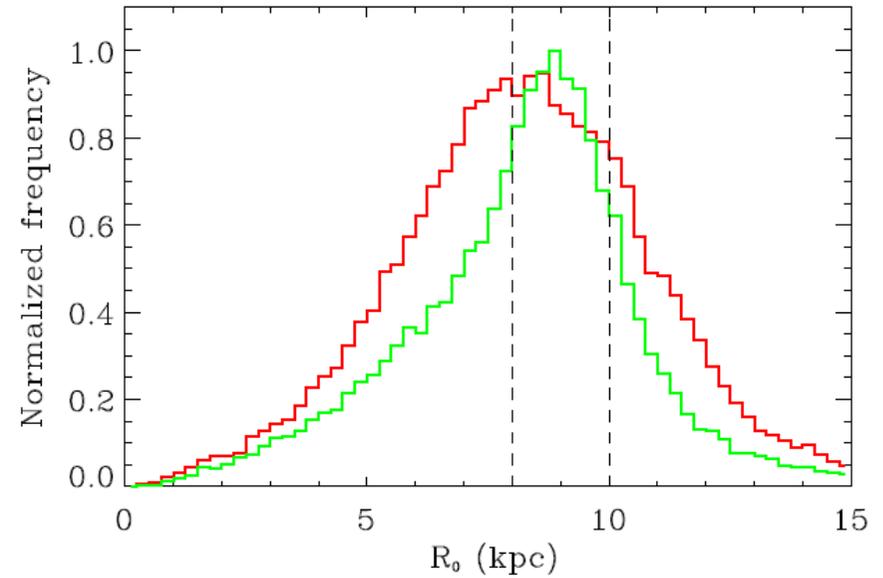
# Where do stars come from?

**$T = 5 \text{ Gyr}$**

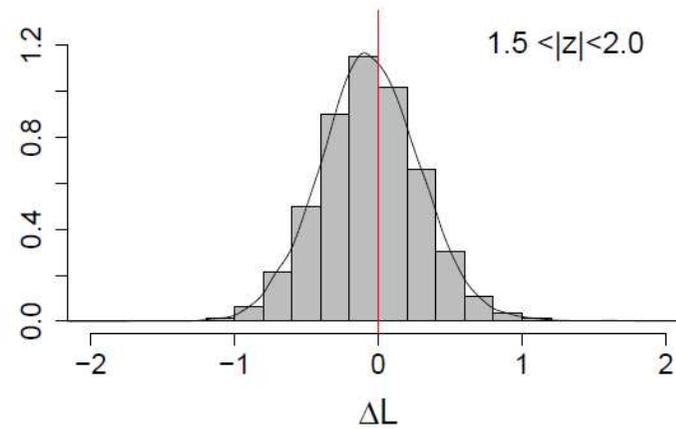
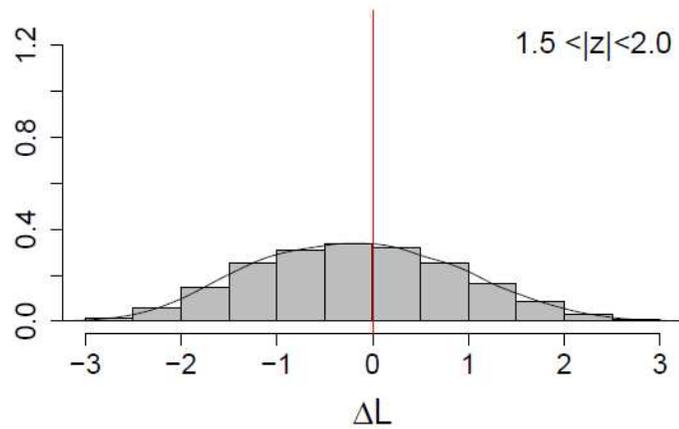
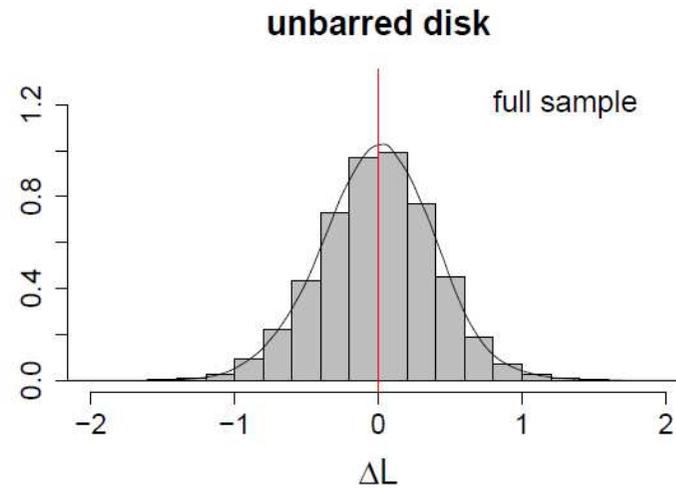
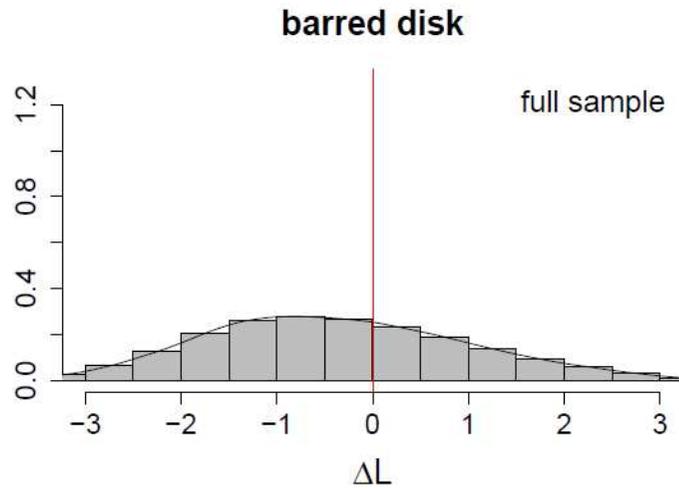
8 kpc <  $R$  < 10 kpc – full sample



8 kpc <  $R$  < 10 kpc –  $1.5 < |z| < 2.0$  kpc



*Inner disk stars move towards the outer regions and populate layers located at higher  $|z|$ , thus forming a thick disk component.*



Histograms of the differences  $L_{ini} - L_f$  in between initial and final total angular momenta (after 5 Gyr) of the particles inside the solar annulus for the barred and unbarred disk (the curves represent a gaussian fit)

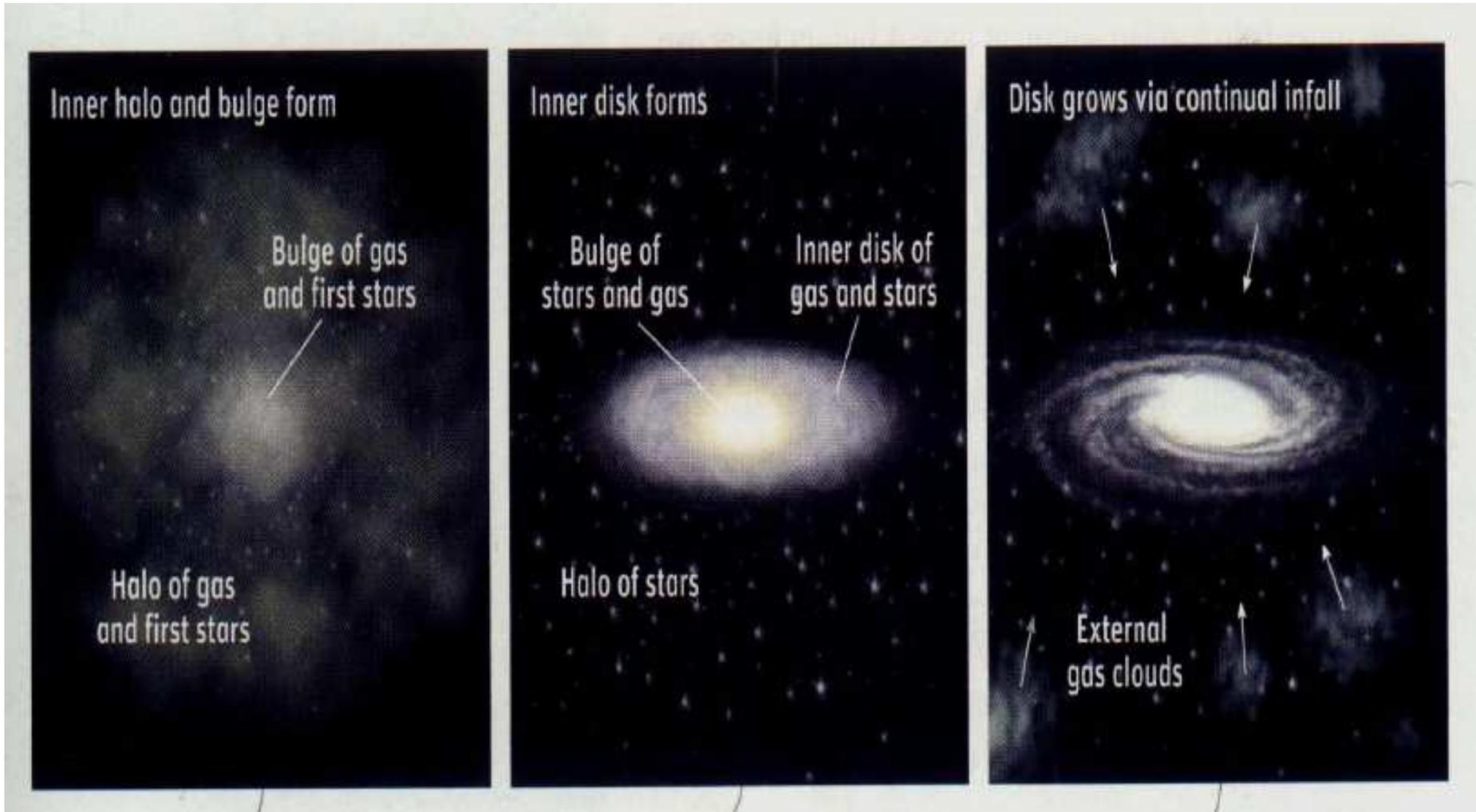
(Curir, MGL, Spagna, Matteucci, et al. 2012, submitted)

## Comparison with SDSS-GSC II Catalog data Velocity distribution (kinematical comparison)

Sample @  $8 \text{ kpc} < R < 10 \text{ kpc} - 1.5 < |z| < 2.0 \text{ kpc}$

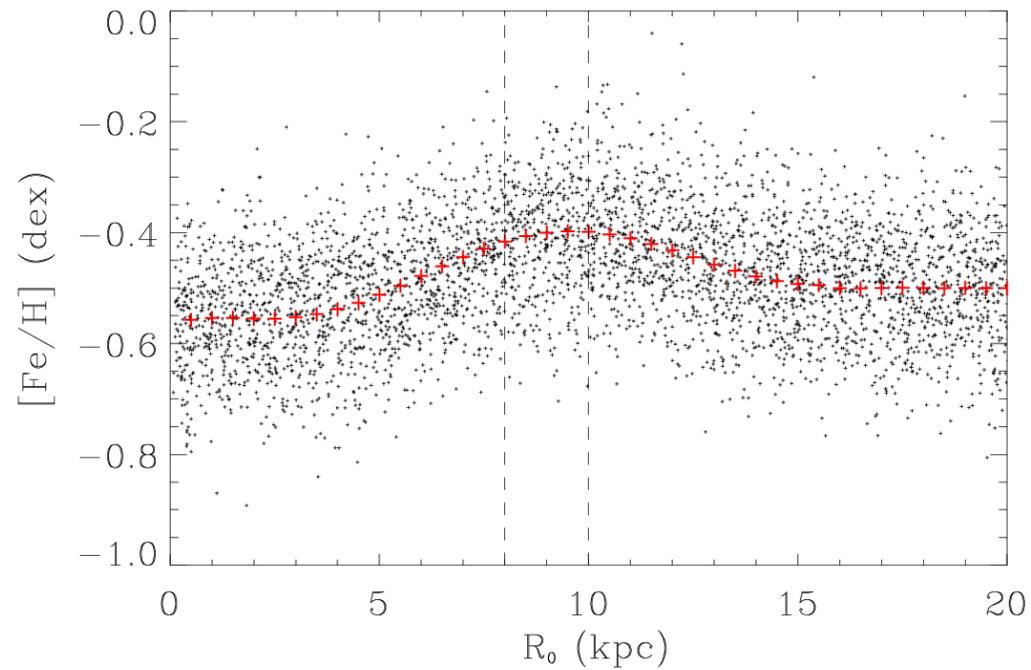
	N-body Model (*) (this work)	Data (Spagna et al., 2010)	
$\langle V_\phi \rangle$ (km/s)	142	159	
$\sigma(V_\phi)$	59	56	
$\sigma(V_R)$	70	62	
(*) After 5 Gyr from injection of radial chemical distribution.			

*Two infall model:  
inside-out disk formation  
(Matteucci et al )*



## «Inverse» chemical radial distribution

Stellar population expected at  $T = 2$  Gyr after star formation



***Spitoni & Matteucci (2011) based on Chiappini et al (2007)***

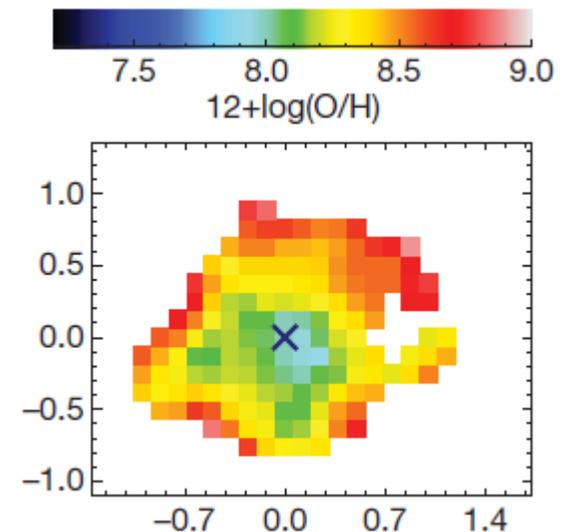
# Inverse chemical gradients observed at high redshift

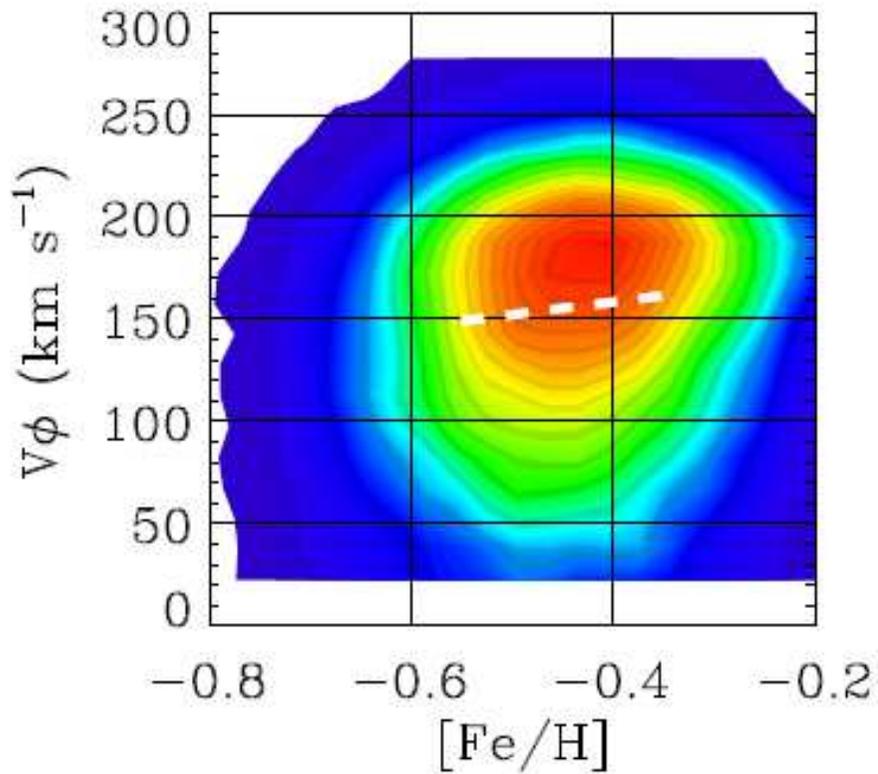
- Negative radial metallicity gradient in local spiral galaxies: the central disk region is more metal-enriched than the outer regions.
- More complex situation in larger samples: even positive “inverted” gradients at  $z \sim 1.5$  in MASSIV (Mass Assembly Survey) galaxies

Thanks to the AMAZE/LSD data: **First metallicity maps at  $z \sim 3$ :**

- Three undisturbed disks
- Well defined regions close to the SF peak are less metal enriched than the disk.

(*Cresci, Maiolino, Mannucci et al 2011*)





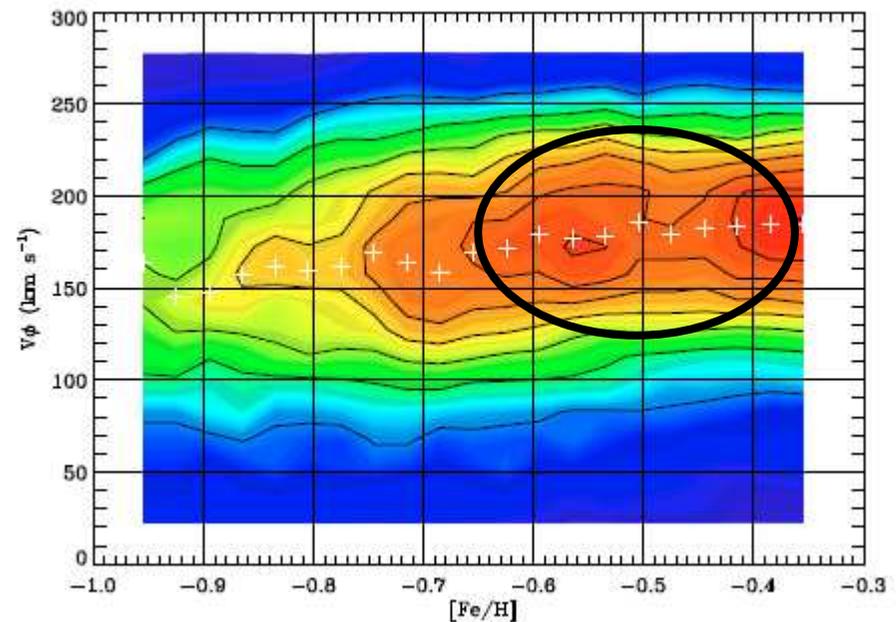
Barred disk simulation (t=5 Gyr)  
 ~60 km/s/dex

$1.5 \text{ kpc} < |z| < 2.0 \text{ kpc}$

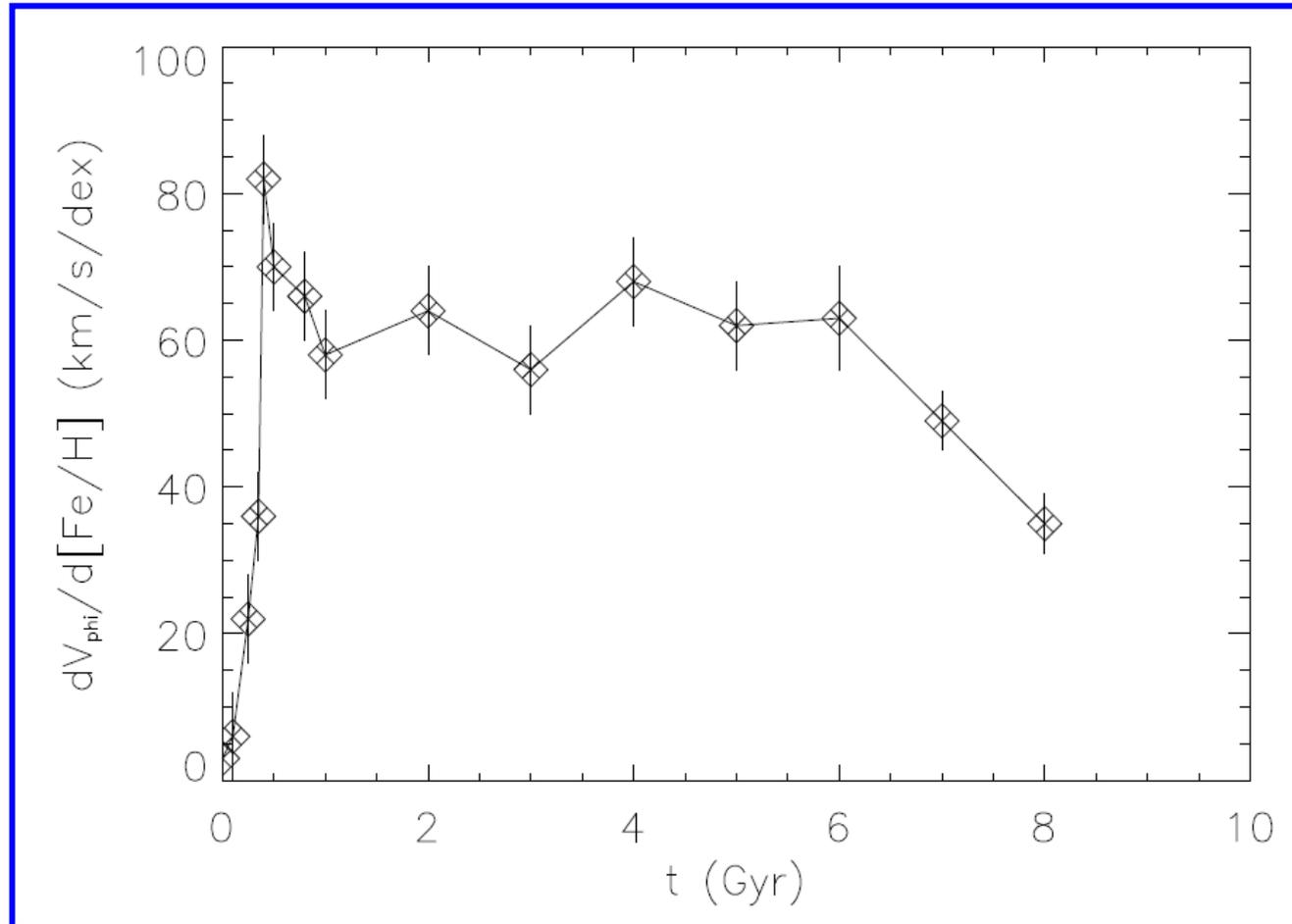
*Curir, Lattanzi, Spagna, Matteucci,  
 Murante, Re Fiorentin, Spitoni &  
 Villalobos  
 (2012, submitted)*

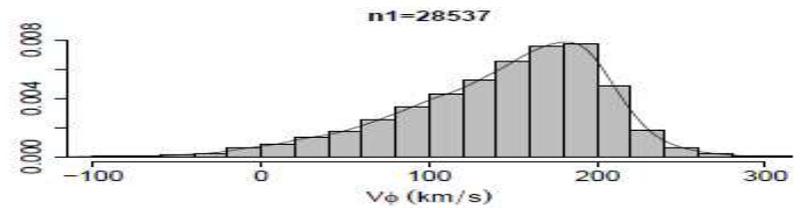
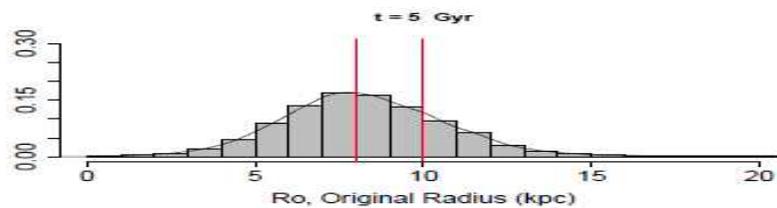
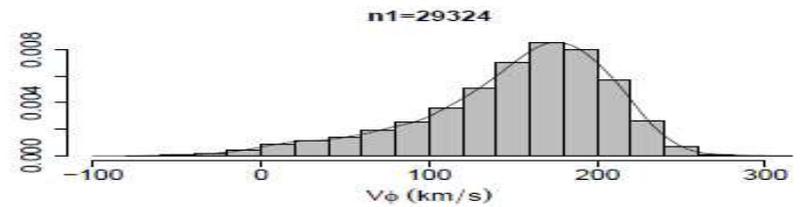
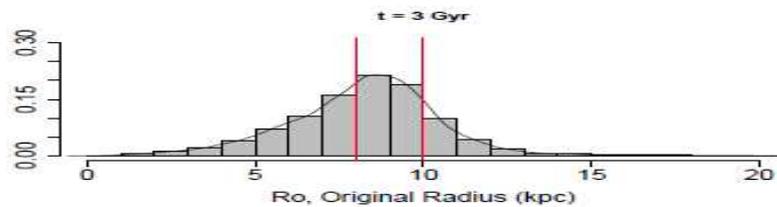
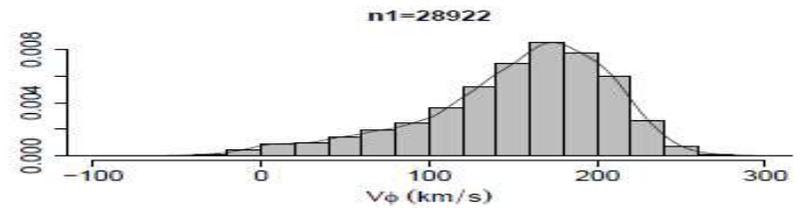
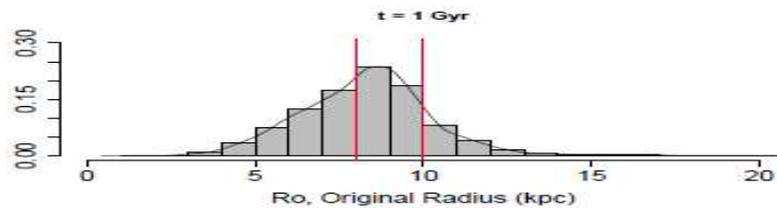
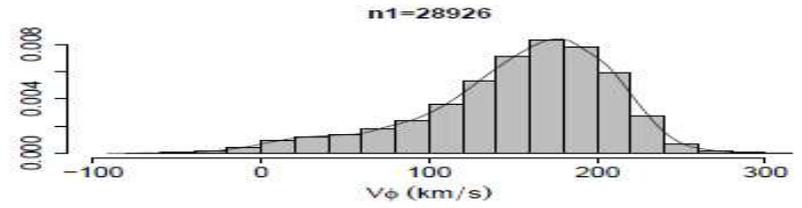
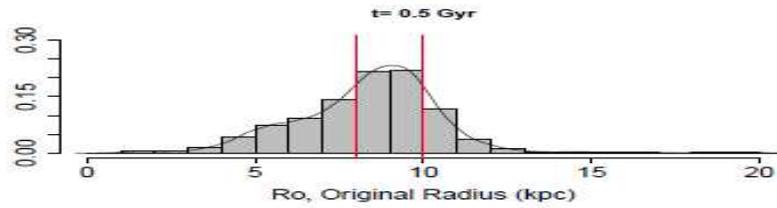
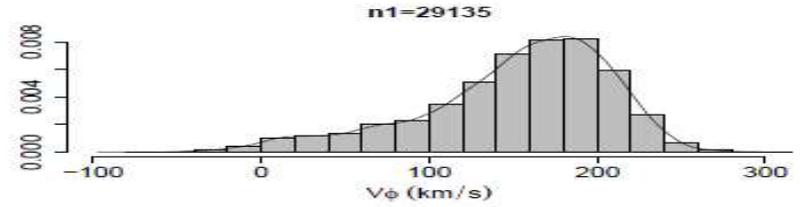
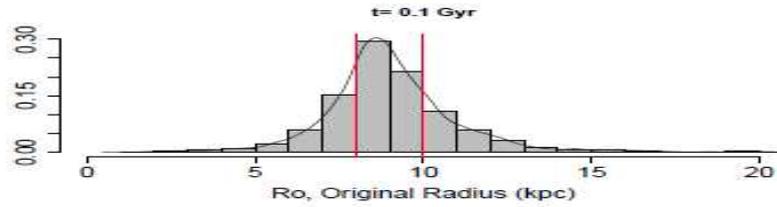
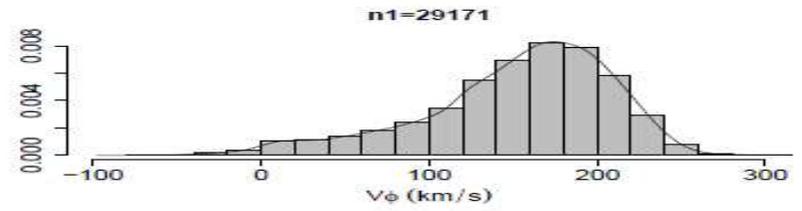
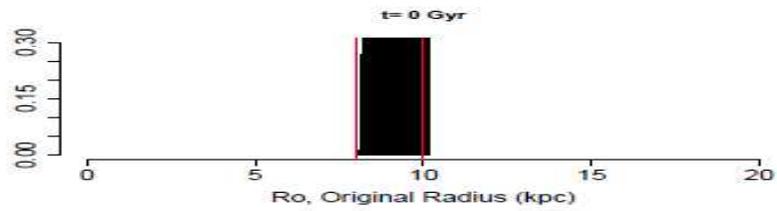
SDSS – GSC-II catalog  
 40-50 km/s/dex

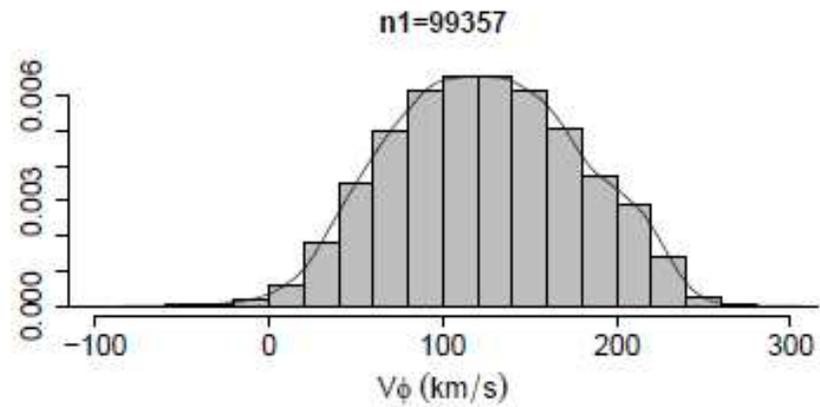
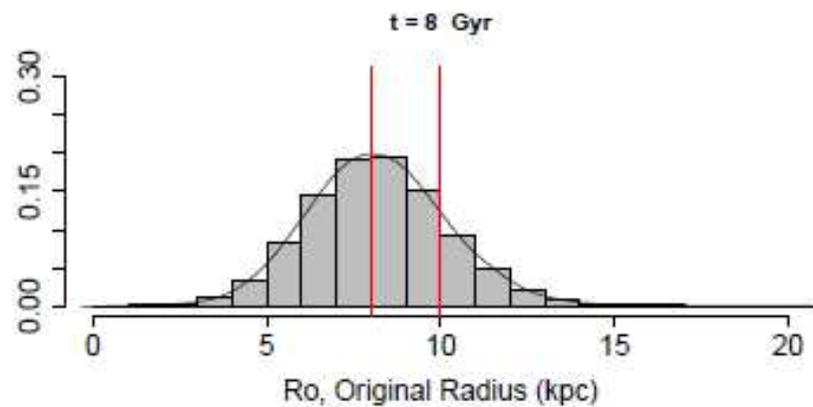
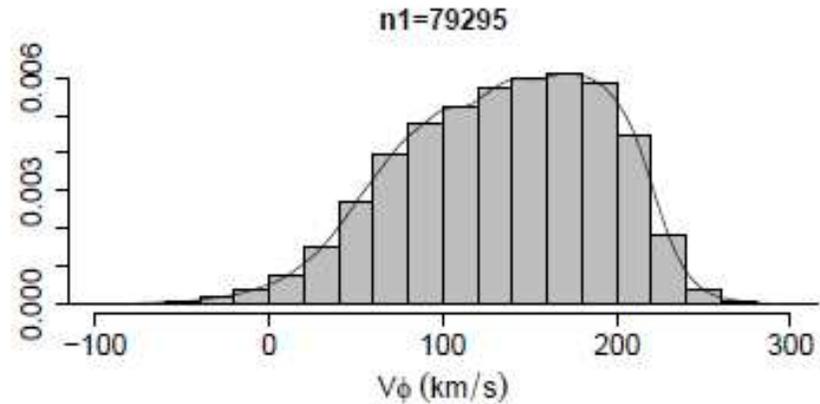
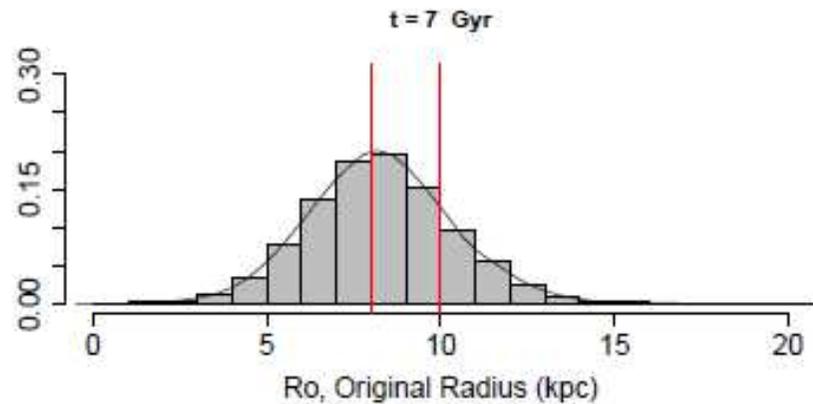
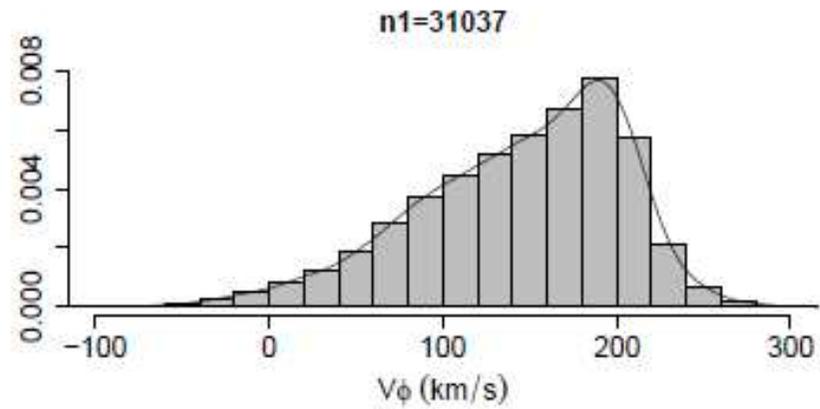
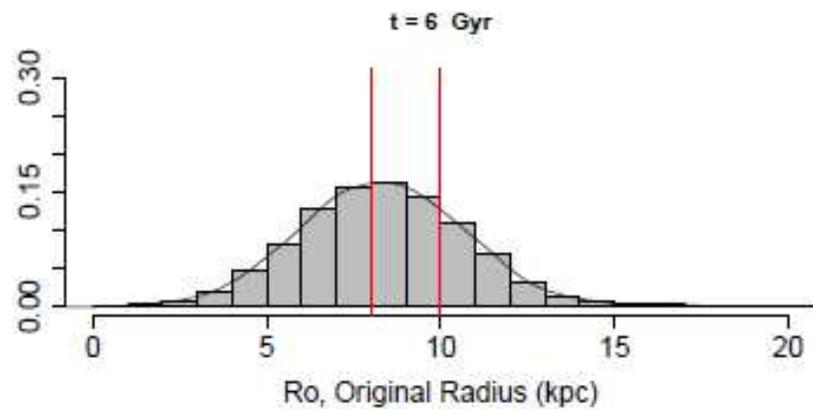
$1.5 \text{ kpc} < |z| < 3.0 \text{ kpc}$



**Evolution of the velocity-metallicity gradient in the 'local' (@  $8 < R < 10$  kpc) thick disk  
( $1.5 < z < 2$  kpc)**







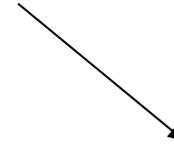
## Conclusions - I

- We have detected a rotation/metallicity correlation in the thick disk population that represents an important signature of the formation processes of the galactic disks
- For the first time, relatively high resolution N-Body models can account for a similar correlation,  $V_{\phi}$ -[Fe/H], as a combination of stellar *radial migration and heating*, if we assume an initial «inverse» chemical gradient in the inner disk
- This scenario, based on local observations, appears consistent with the chemical properties of isolated disk galaxies at high redshift

Sample of FGK dwarfs  $\rightarrow V > 16$

- Mostly in the range 17.5 - 19

**Back to Gaia**

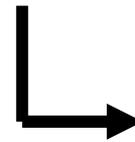


**Gaia's potential**

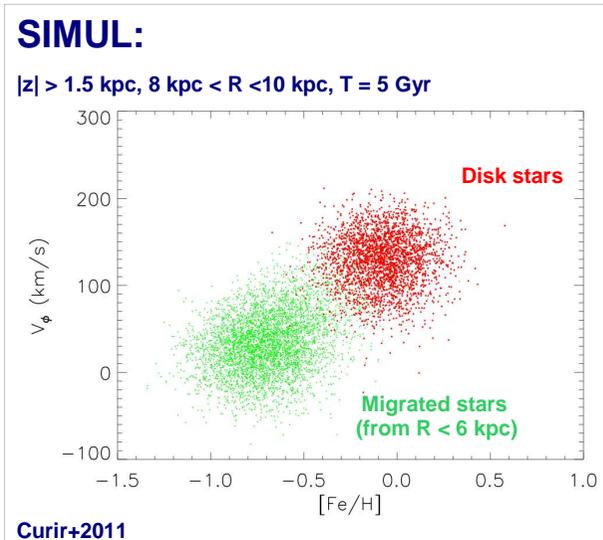
$\sigma_{\pi}/\pi = \sigma_d/d = 0.1 \rightarrow 50$   
 $\mu\text{as @ 2 kpc}$

• Good range for Gaia spectrophotometry (metallicity dispersion)

• Critical range for RVS (3-rd vel. Comp.)



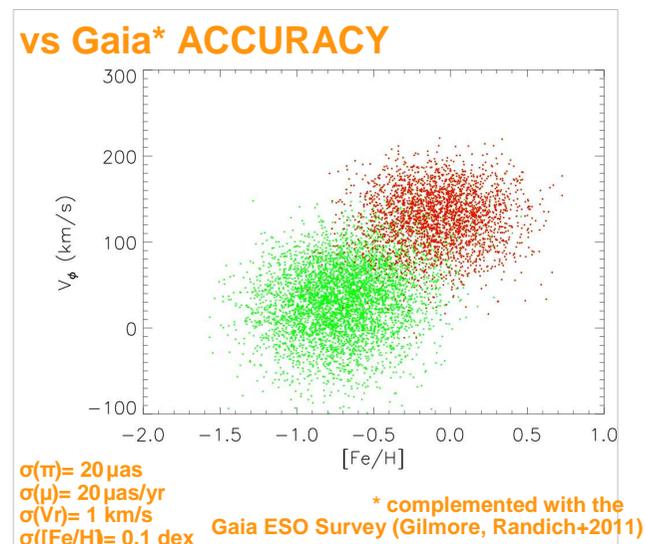
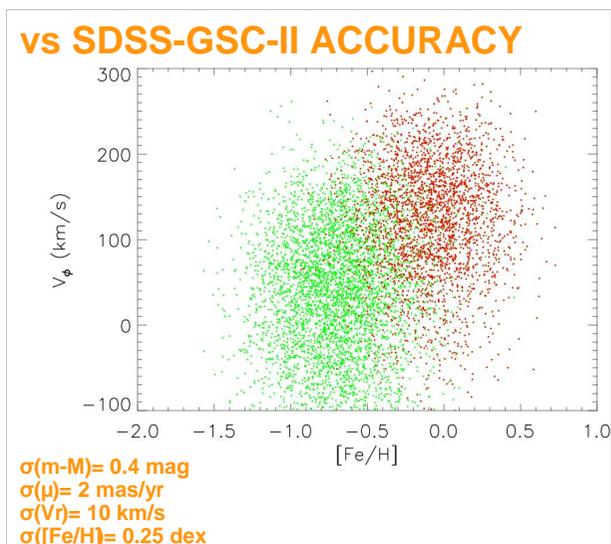
GES



**Back to Gaia**

**Gaia's potential**

Increased dispersion due to observational errors dramatically affects estimation of rotation-metallicity signatures.



# Conclusions - II

## (With Gaia)

•Much improved (through primary recalibrations) independence of distances from spectro-photometric indicators (also, minimization of interstellar extinction):

- Local Thick Disk (up to 2 kpc) → total independence (10% parallaxes), accurate velocity and momenta distributions
- Recalibrations for larger distances but first real possibility to map Thick Disk as function of  $R$  (testing of local cosmology models?). Gaia spectro-photometry crucial, complemented with ground based specifically acquired spectro data (e.g. GES).

•Characterization of Galaxy evolutionary models (velocity gradients as indicator of age)

•Information of early chemical evolution in the MW disk (confirmation of cosmological nature of disk)

Thank You!