Properties of the galactic thick disks inferred from kinematical studies

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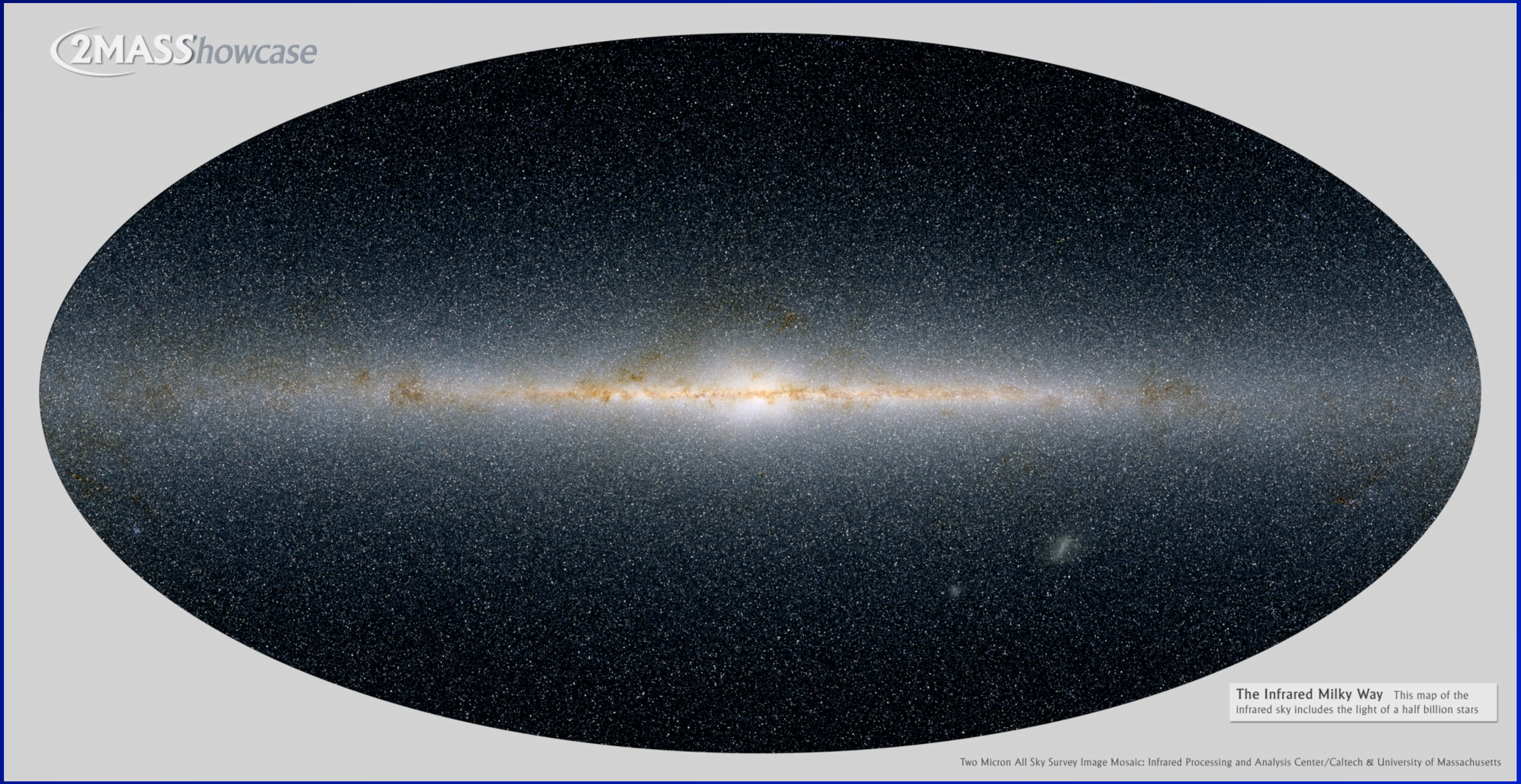

Milky Way disk (2MASS ≈ 5×10^8 stars)

Thick disk of the Milky Way :

- Discovered by star counts (Gilmore and Reid 1983)
- Scale height ≈ 1.3 kpc
- Later determinations: (Robin et al. 1996, Ojha 2001, Chen et al. 2001, Larsen and Humphreys 2003)

Recent determinations

STRUCTURE AND KINEMATICS OF THE STELLAR HALOS AND THICK DISKS OF THE MILKY WAY BASED ON CALIBRATION STARS FROM SDSS DR7

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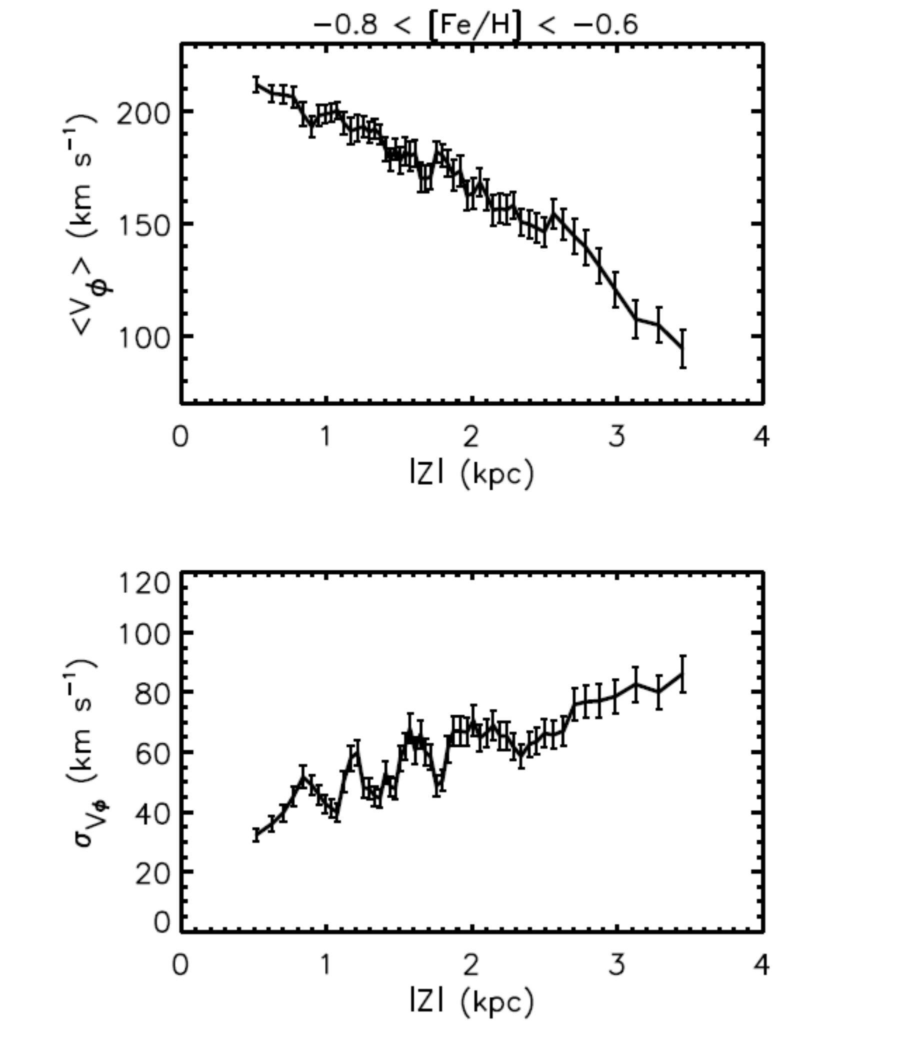
ABSTRACT

The structure and kinematics of the recognized stellar components of the Milky Way are explored, based on well-determined atmospheric parameters and kinematic quantities for 32360 "calibration stars" from the Sloan Digital Sky Survey (SDSS) and its first extension, (SDSS-II), which included the sub-survey SEGUE: Sloan Extension for Galactic Understanding and Exploration. Full space motions for a sub-sample of 16920 stars, exploring a local volume within 4 kpc of the Sun, are used to derive velocity ellipsoids for the inner- and outer-halo components of the Galaxy, as well as for the canonical thick-disk and proposed metal-weak thick-disk populations. This new sample of calibration stars represents an increase of 60% relative to the numbers used in a previous analysis. We first examine the question of whether the data require the presence of at least a two-component halo in order to account for the rotational behavior of likely halo stars in the local volume, and whether more than two components are needed. We also address the question of whether the proposed metal-weak thick disk is kinematically and chemically distinct from the canonical thick disk, and point out that the Galactocentric rotational velocity inferred for the metal-weak thick disk, as well as its mean metallicity, appear quite similar to the values derived previously for the Monoceros stream, suggesting a possible association between these structures. In addition, we consider the fractions of each component required to understand the nature of the observed kinematic behavior of the stellar populations of the Galaxy as a function of distance from the plane. Scale lengths and scale heights for the thick-disk and metal-weak thick-disk components are determined. Spatial density profiles for the inner- and outer-halo populations are inferred from a Jeans Theorem analysis. The full set of calibration stars (including those outside the local volume) is used to test for the expected changes in the observed stellar metallicity distribution function with distance above the Galactic plane *in-situ*, due to the changing contributions from the underlying stellar populations. The above issues are considered, in concert with theoretical and observational constraints from other Milky-Way-like galaxies, in light of modern cold dark matter galaxy formation models.

Subject headings: Galaxy: Evolution, Galaxy: Formation, Galaxy: Halo, Galaxy: Disks, Galaxy: Kinematics, Galaxy: Structure, Methods: Data Analysis, Stars: Abundances, Surveys

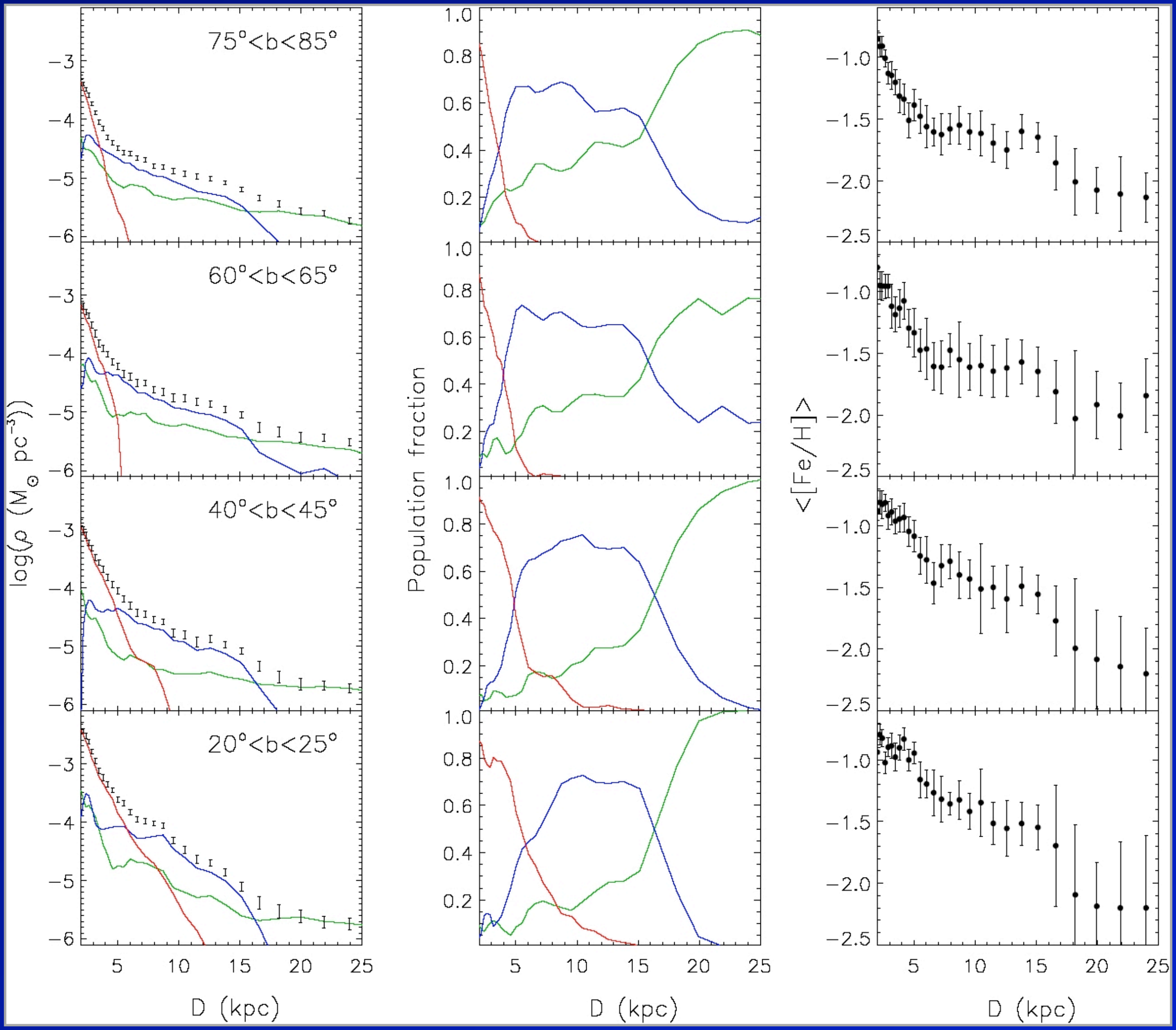
Carollo, Beers et al (2010)

-0.8 < Fe/H < -0.6
1 kpc < Z < 2 kpc



De Jong et al. 2010

Mapping the stellar structure of the Milky Way Thick Disk



Carollo et al. (2008)

$h_R = 2.2 \pm 0.35$ kpc

$h_Z = 0.51 \pm 0.04$ kpc

Assymetric drift $dV/dZ = -36 \pm 1$ km/s/kpc

De Jong et al. (2010) : $h_R = 4.1 \pm 0.4$ kpc $h_Z = 0.75 \pm 0.07$ kpc

Local thick disk density fraction 15 ± 4 %

Stellar density of thin disk should never amount to more than 10% at $|z|>1.5$ kpc

$h_{thick} = 0.75$ kpc $h_{thin} = 0.25$ kpc

$\rho_{thin}/\rho_{thick} \sim 46\%$ at 1 kpc

$\rho_{thin}/\rho_{thick} \sim 12\%$ at 1.5 kpc

Brief sumary

- Thick disk has larger vertical scale compared to the thin disk
- Larger velocity dispersion
- Rotation of the thick disk lags the thin disk
- In solar neighborhood, thick Disk metallicity [Fe/H] from -0.5 to -1.0. However, the tail of distribution extends to [Fe/H] = -2.0.

Thick disk of Galaxy is a separate component that differs by properties from the thin disks.

THE KINEMATICS OF THICK DISKS IN NINE EXTERNAL GALAXIES

Peter Yoachim and Julianne J. Dalcanton, Ap.J, 2008

- Ca triplet absorption lines
- Flat Galaxies Catalog (Karachentsev et al. 1993)
- Thick disks are more prevalent in low-mass galaxies
- In the higher mass galaxies, they have failed to observe off-plane regions with high enough thick disk fraction
- There is a wide range of thick-disk kinematical behaviors, including thick disks with substantial lag and one counter-rotating thick disk.

Thick Disks Origin

a) Thin disk is heated kinematically

b) Stars are born in a “thick” gaseous disk

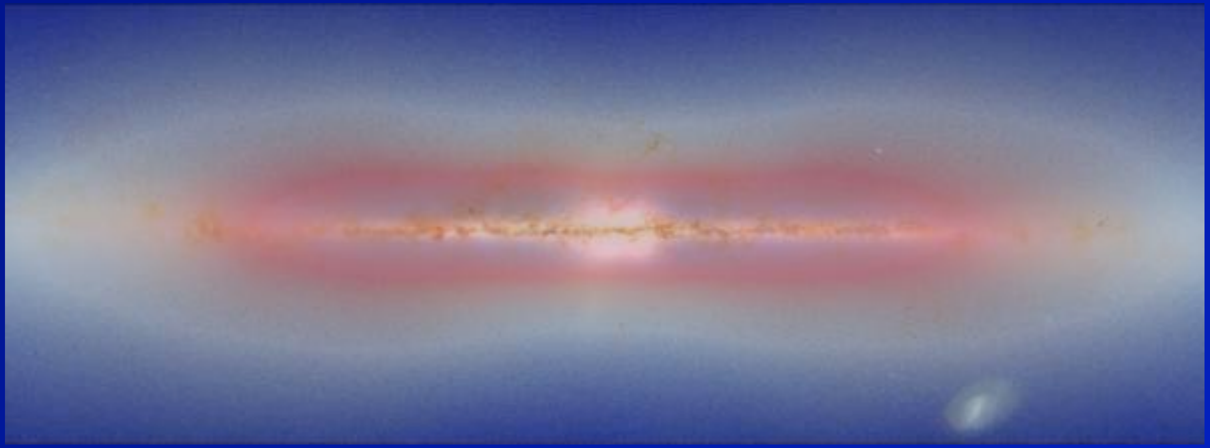
c) Accreted satellites

Joachim and Dalcanton: Difference in kinematical properties of the disks helps to distinguish between these scenarios.

Dark matter in our Galaxy: computer modeling

The Milky Way, contains a disk of "dark matter".

(Read et al. MN 2008)



Based on numerical simulations Λ-CDM model Read et al. find that mass of stellar component in the thick disks 2 – 10 less than mass of the thick disk dark matter.

A bit of theory

We start from Poisson equation in cylindrical coordinates:

$$\frac{1}{R}\frac{\partial}{\partial R}(RF_R) + \frac{\partial F_z}{\partial z} = -4\pi G\rho_{tot}$$

where ρ_{tot} is the total mass density and F_z are the components of the force per unit mass. Integrating we obtain:

$$-4\pi G\Sigma(z) = \int_0^z \frac{1}{R}\frac{\partial}{\partial R}(RF_R)dz + F_z(z)$$

Where $\Sigma(z)$ is the surface mass density at height z.
From Jeans equations, assuming equilibrium (all temporal derivatives set to zero):

$$F_R = -[\frac{1}{\rho}\frac{\partial(\rho\overline{v_R^2})}{\partial R} + \frac{1}{\rho}\frac{\partial(\rho\overline{v_R v_z})}{\partial z} + \frac{\overline{v_R^2} - \overline{v_\theta^2}}{R})]$$

$$F_z = -\frac{1}{\rho}[\frac{\partial(\rho\overline{v_z^2})}{\partial z} + \frac{\rho\overline{v_R v_z}}{R} + \frac{\partial}{\partial R}(\rho\overline{v_R v_z})]$$

We will assume that all dispersions σ_x^2 and the density ρ have an exponential radial dependence of appropriate scale length $h_{R_{\sigma_x}}$ and h_{R_ρ}, and:

$$\overline{v_z^2} = \sigma_z^2$$

$$\overline{v_R^2} = \sigma_R^2$$

$$\overline{v_\theta^2} = \sigma_\theta^2 + \overline{v_\theta}^2$$

Moreover, we will assume a flat rotation curve, i.e. no dependence of $\overline{v_\theta}^2$ on radial coordinate. Hence:

$$RF_R = \frac{R\sigma_R^2}{h_R} - \frac{R}{\rho}\frac{\partial(\rho\overline{v_R v_z})}{\partial z} - \sigma_R^2 + \sigma_\theta^2 + \overline{v_\theta}^2$$

where

$$\frac{1}{h_R} = \frac{1}{h_{R_{\sigma_R}}} + \frac{1}{h_{R,\rho}}$$

Therefore:

$$\frac{1}{R}\frac{\partial}{\partial R}(RF_R) = \sigma_R^2\left(\frac{1}{Rh_R} - \frac{1}{h_R h_{R_{\sigma_R}}} + \frac{1}{Rh_{R,\sigma_R}}\right) - \frac{\sigma_\theta^2}{h_{R_{\sigma_\theta}}R} - \frac{1}{\rho}\left(\frac{1}{R} + \frac{1}{h_{R,\rho}}\right)\frac{\partial(\rho\overline{v_R v_z})}{\partial z} - \frac{1}{\rho}\frac{\partial^2(\rho\overline{v_R v_z})}{\partial z\partial R}$$

Inserting these equations in the Poisson equation, and integrating, we get:

$$-4\pi G\Sigma(z) = k_1\int_0^z \sigma_R^2 dz - k_2\int_0^z \sigma_\theta^2 dz - \frac{1}{\rho}\frac{\partial(\rho\sigma_z^2)}{\partial z} - \frac{\overline{v_R v_z}}{R} - \frac{1}{\rho}\frac{\partial}{\partial R}(\rho\overline{v_R v_z}) -$$

$$-\left(\frac{1}{R}+\frac{1}{h_{R_\rho}}\right)\int_0^z \frac{1}{\rho}\frac{\partial(\rho\overline{v_R v_z})}{\partial z}dz - \int_0^z \frac{1}{\rho}\frac{\partial^2(\rho\overline{v_R v_z})}{\partial z\partial R}dz$$

Where:

$$k_1 = \frac{1}{Rh_R} - \frac{1}{h_R h_{R_{\rho\pi}}} + \frac{1}{Rh_{R_{\rho\pi}}}$$

$$k_2 = \frac{1}{h_{R_{\rho\theta}}R}$$

The last two terms can be integrated per parts:

$$\int_0^z \frac{1}{\rho}\frac{\partial(\rho\overline{v_R v_z})}{\partial z}dz = \overline{v_R v_z}(z) - \overline{v_R v_z}(0) - \int_0^z \frac{\overline{v_R v_z}}{h_{z_\rho}}dz$$

$$\int_0^z \frac{1}{\rho}\frac{\partial^2(\rho\overline{v_R v_z})}{\partial z\partial R}dz = \frac{1}{\rho(z)}\frac{\partial(\rho\overline{v_R v_z})}{\partial R}(z) - \frac{1}{\rho(0)}\frac{\partial(\rho\overline{v_R v_z})}{\partial R}(0) - \int_0^z \frac{1}{\rho h_{z,\rho}}\frac{\partial(\rho\overline{v_R v_z})}{\partial R}dz$$

Finally:

$$\Sigma(z) = -\frac{1}{4\pi G}\Big[k_1\int_0^z \sigma_R^2 dz - k_2\int_0^z \sigma_\theta^2 dz - \frac{1}{\rho}\frac{\partial(\rho\sigma_z^2)}{\partial z} - \frac{2}{\rho}\frac{\partial}{\partial R}(\rho\overline{v_R v_z}) - k_3\overline{v_R v_z} +$$

$$+k_4\left(\overline{v_R v_z}(0) + \int_0^z \frac{\overline{v_R v_z}}{h_{z,\rho}}dz\right) + \frac{1}{\rho(0)}\frac{\partial}{\partial R}(\rho\overline{v_R v_z})(0) + \frac{1}{h_{z_\rho}}\int_0^z \frac{1}{\rho}\frac{\partial}{\partial R}(\rho\overline{v_R v_z})dz\Big]$$

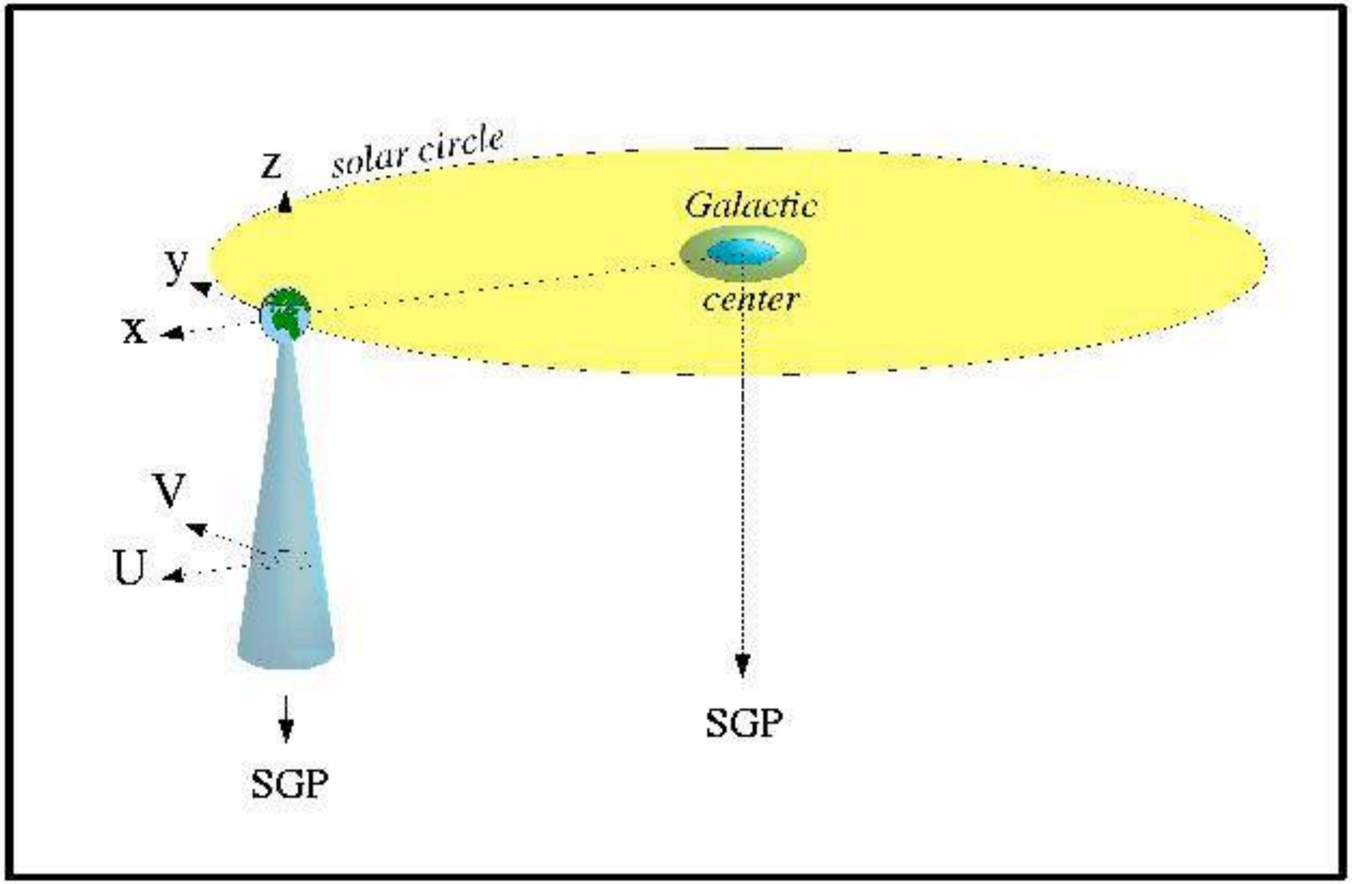
where

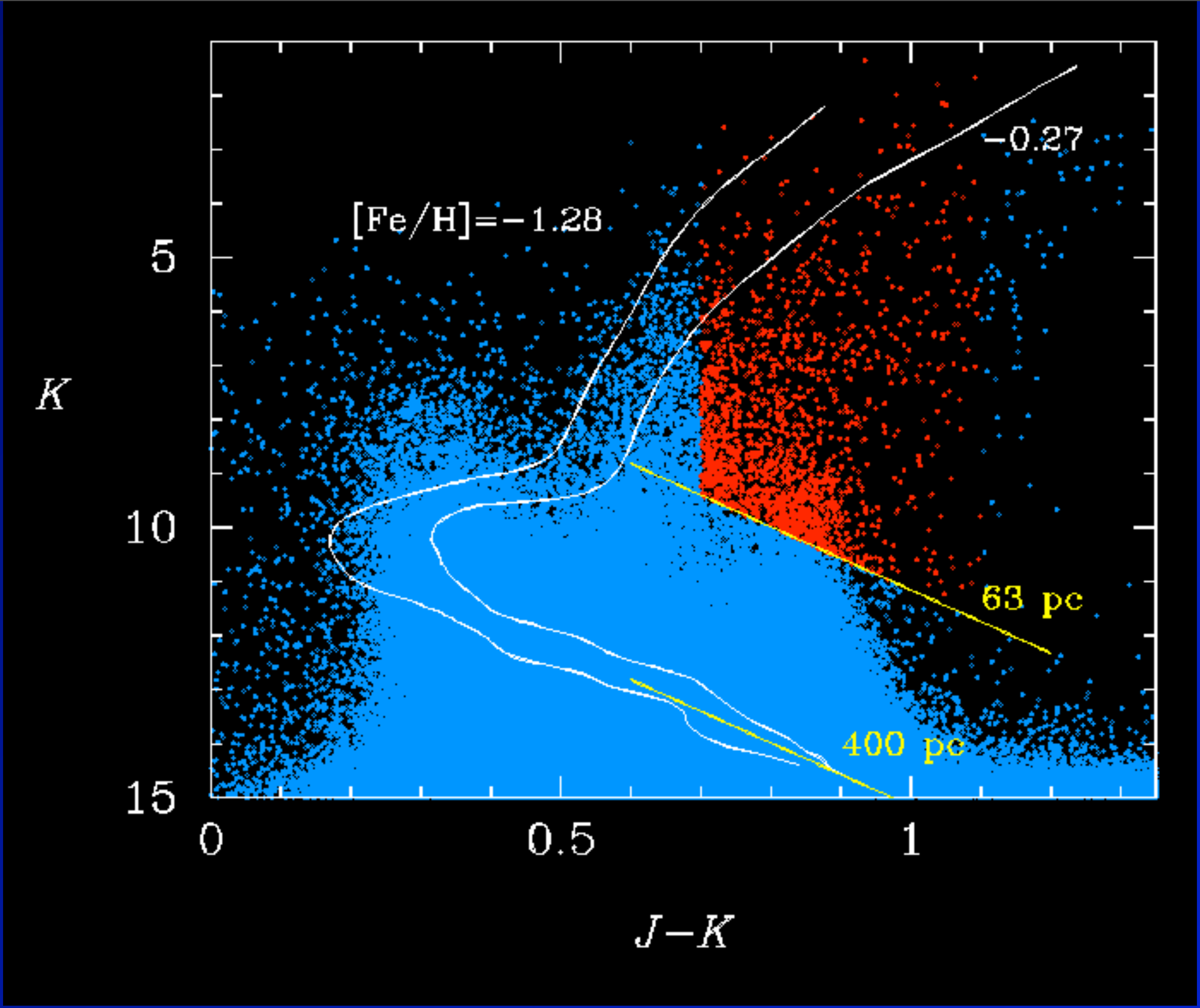
$$k_3 = \frac{2}{R} + \frac{1}{h_{R_\rho}}$$

$$k_4 = \frac{1}{R} + \frac{1}{h_{R_\rho}}$$

From this equation, in order to estimate $\Sigma(z)$ (at $R = 8$ kpc), we need reasonable assumption (or a range of values) for the scale length of ρ, σ_R^2 and σ_θ^2, and for the scale height of the density ($h_{z,\rho}$). From our data we should obtain the vertical profiles of all quantities, i.e. σ_R^2, σ_θ^2, σ_z^2, $\overline{v_R v_z}$ as functions of z (to be inserted in the equation, and integrated/derived where necessary). Finally, we also need some reasonable assumption for the radial dependence of the cross term $\rho\overline{v_R v_z}$, which must be derived with respect to R in the equation.

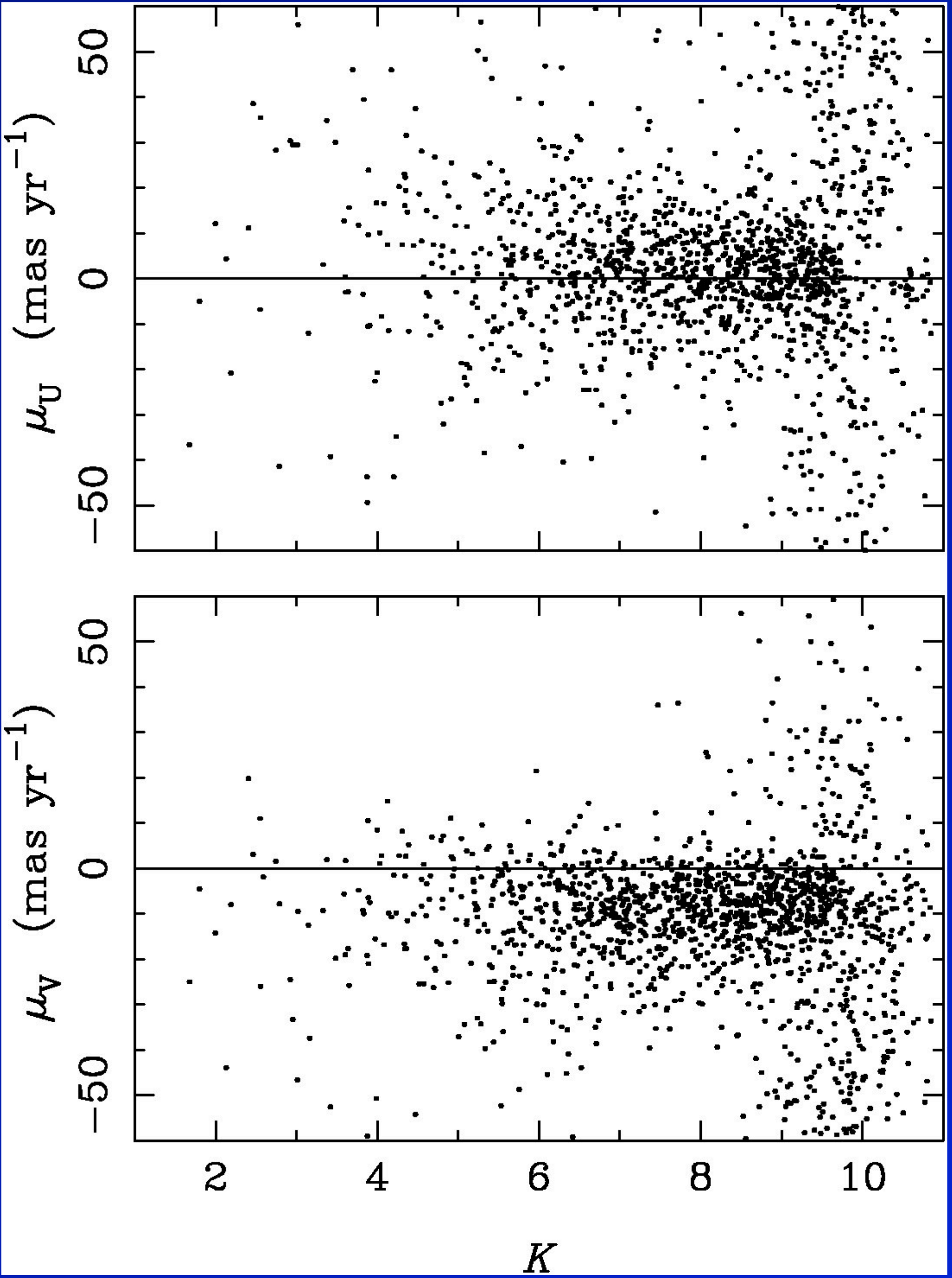
Girard et al. 2006

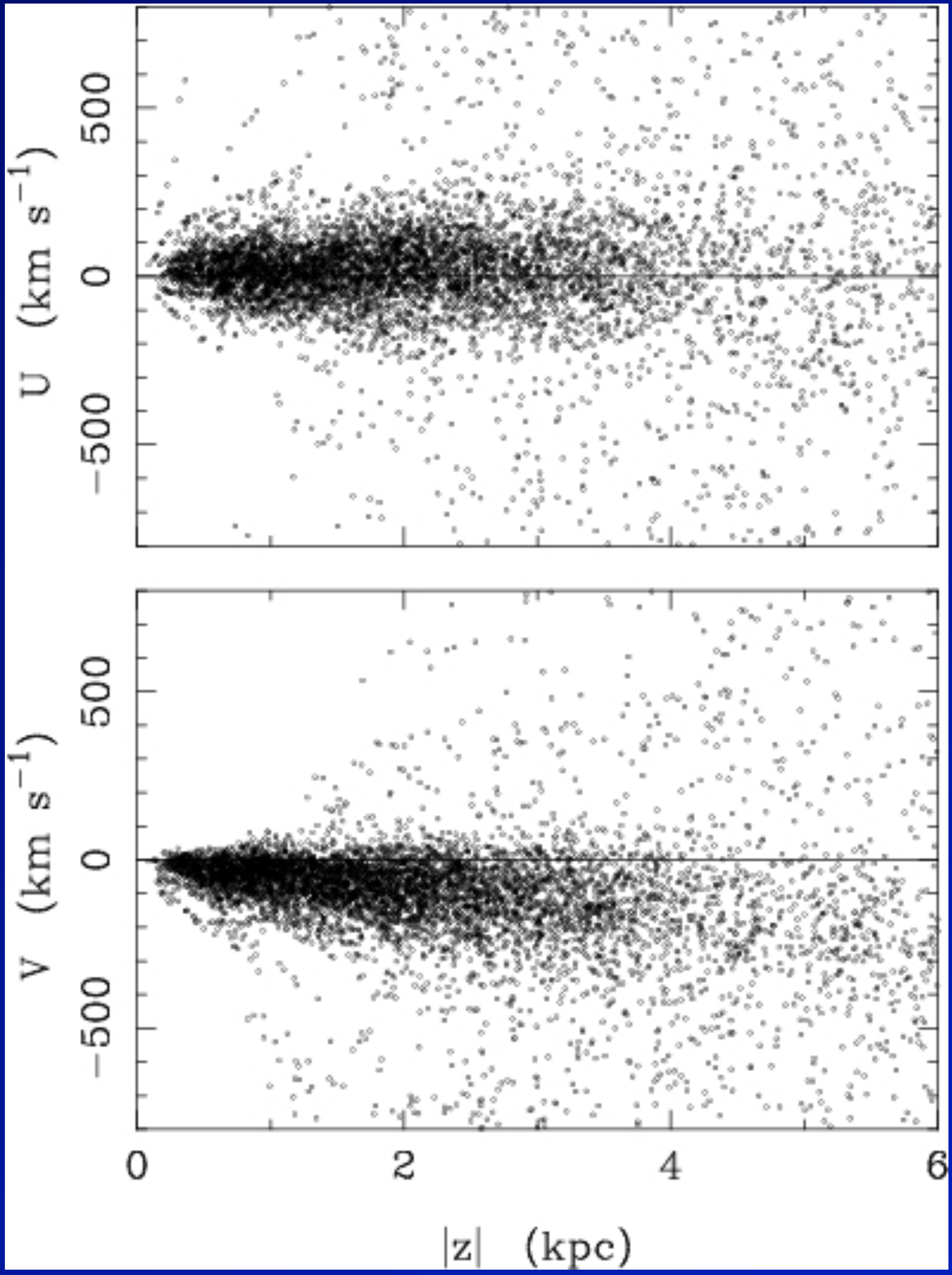




0.7 < J – K < 1.1

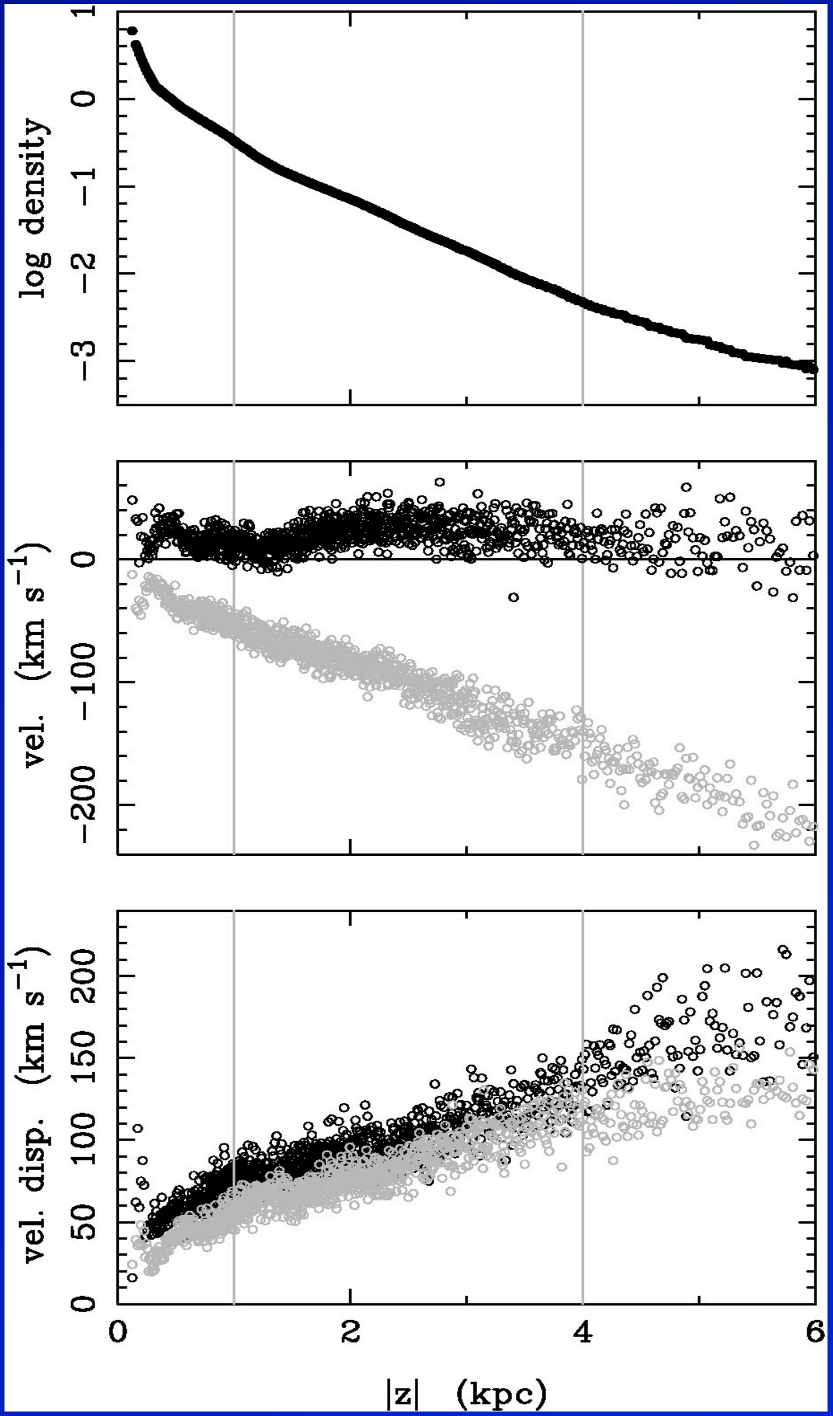
Absolute proper motions of stars as a function of stellar magnitude





Tangential velocities dependences from distance to galactic plane.

Distributions of density, velocity and velocity dispersion in direction which is normal to Galactic disc. Star sample is complete in the range 0.5 – 3 kpc



Properties of the Disks in study:

- Thin disk:

  Radial scale length - 2.5 kpc

  Local surface density - 43 $M_{sun} pc^{-2}$

- Thick disk :

  Radial scale length - 3.5 to 5.0 kpc

  Vertical scale height - 800 to 1200 pc

Properties of the sample of stars

Approximately 1200 red giants in a cone of 15 deg in the direction to the SGP

Vertical and radial velocity dispersions:

σ_w = 27.0 км/s + 6.5 км/s/крс * Z [kpc]
σ_u = 36.4 км/s + 20.8 км/s/крс * Z [kpc]

Non-diagonal component of velocity dispersion tensor:

$< \sigma_u * \sigma_w > \sim 1000$ км^2/s^2

Girard et al. (2006)

$h_Z = 0.78 \pm 0.05$ kpc

Asymmetric drift dV/dZ = -30 ± 3 km/s/kpc

Kinematical properties consistent with dynamical equilibrium of thick disk

Moni Bidin et al. (2010) in preparation

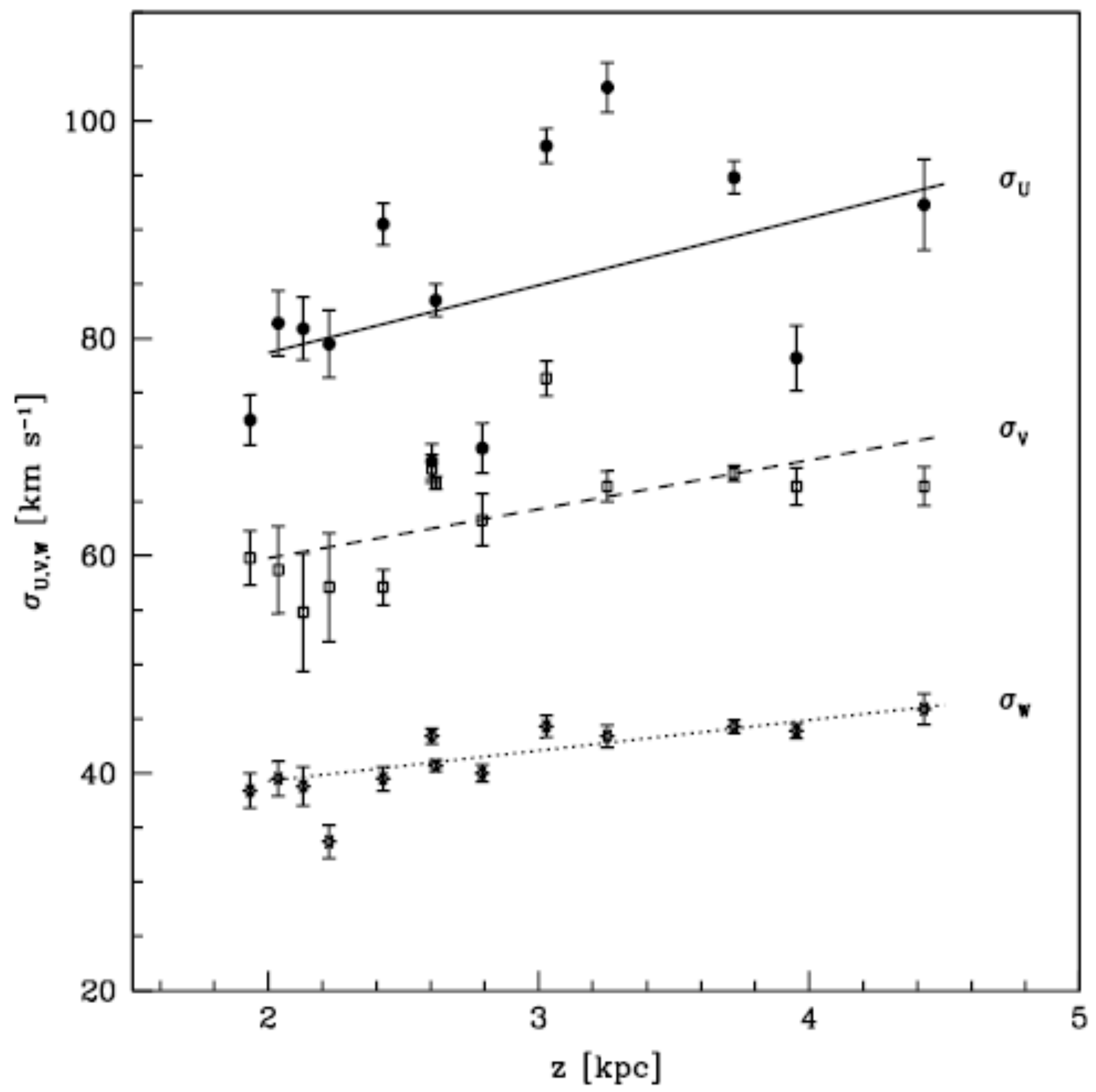
~1200 red giants in a 15 deg cone towards SGP

824 stars with radial velocities

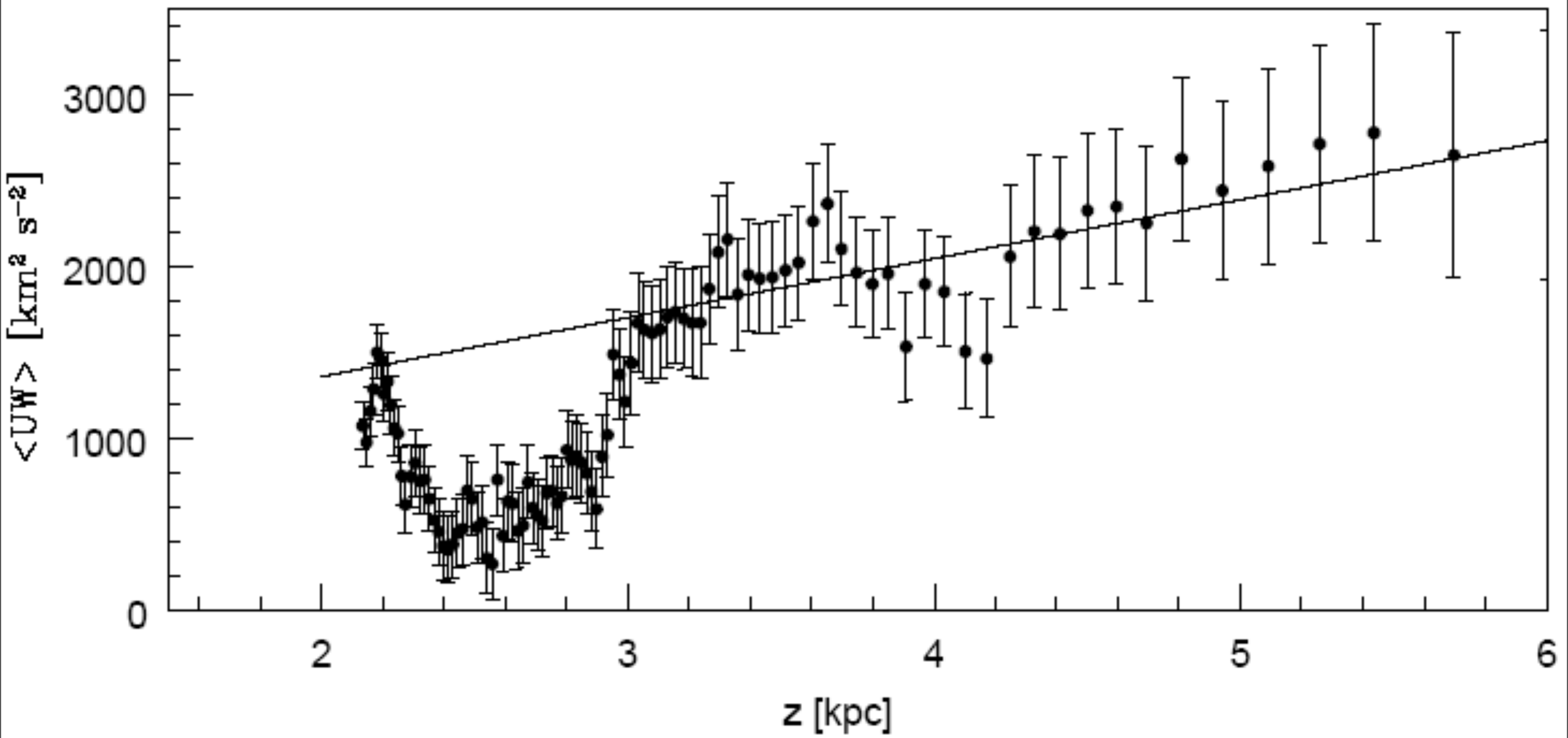
Proper motions from SPM3 catalog

~300 stars selected beyond 2 kpc from Galactic Plane

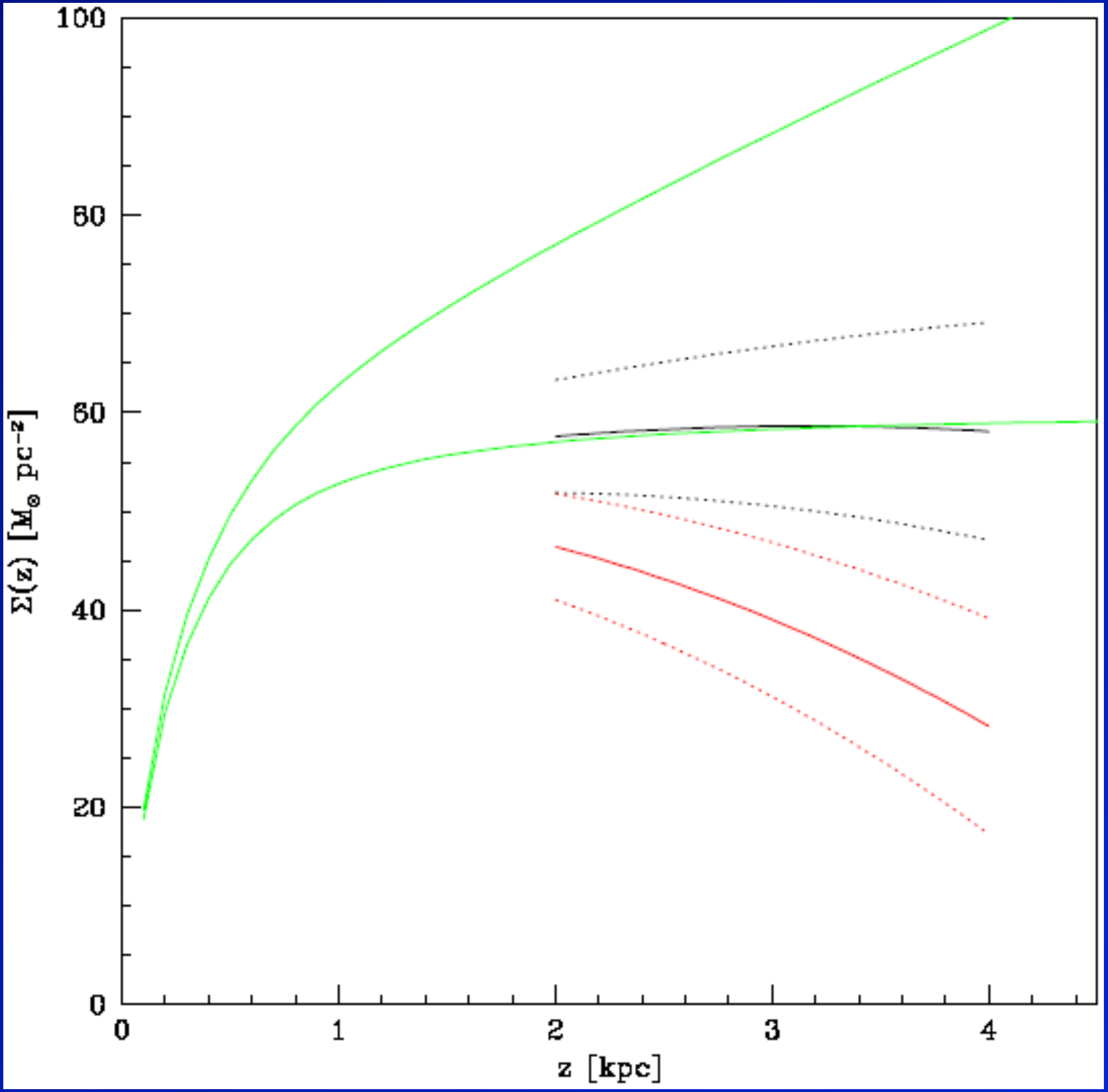
UVW
velocity
dispersions



<UW> cross term



Results on surface density beyond 2 kpc



Surface density of the thick disk (Moni Bidin et al. 2010)

For "standard parameters" of the thick disk

$$h^2_{R\sigma} = h_{R\rho} = 4 \text{ kpc}$$

$$h_{Z\rho} = 1 \text{ kpc}$$

$$R_{sun} = 8 \text{ kpc}$$

The surface density of gravitating matter within 2 kpc (think and thick disks):

$$\Sigma(2 \text{ kpc}) \sim 43\ M_{sun}/pc^2$$

From 2 to 3.5 kpc:

$$\Sigma(2 \div 3.5 \text{ kpc}) \sim 6.6\ M_{sun}/pc^2$$

Predicted «Dark matter disk» – $\rho_{DM} \sim 0.25 - 1\ \rho_{Halo}$ ($0.0025 - 0.01\ M_{sun}/pc^3$)

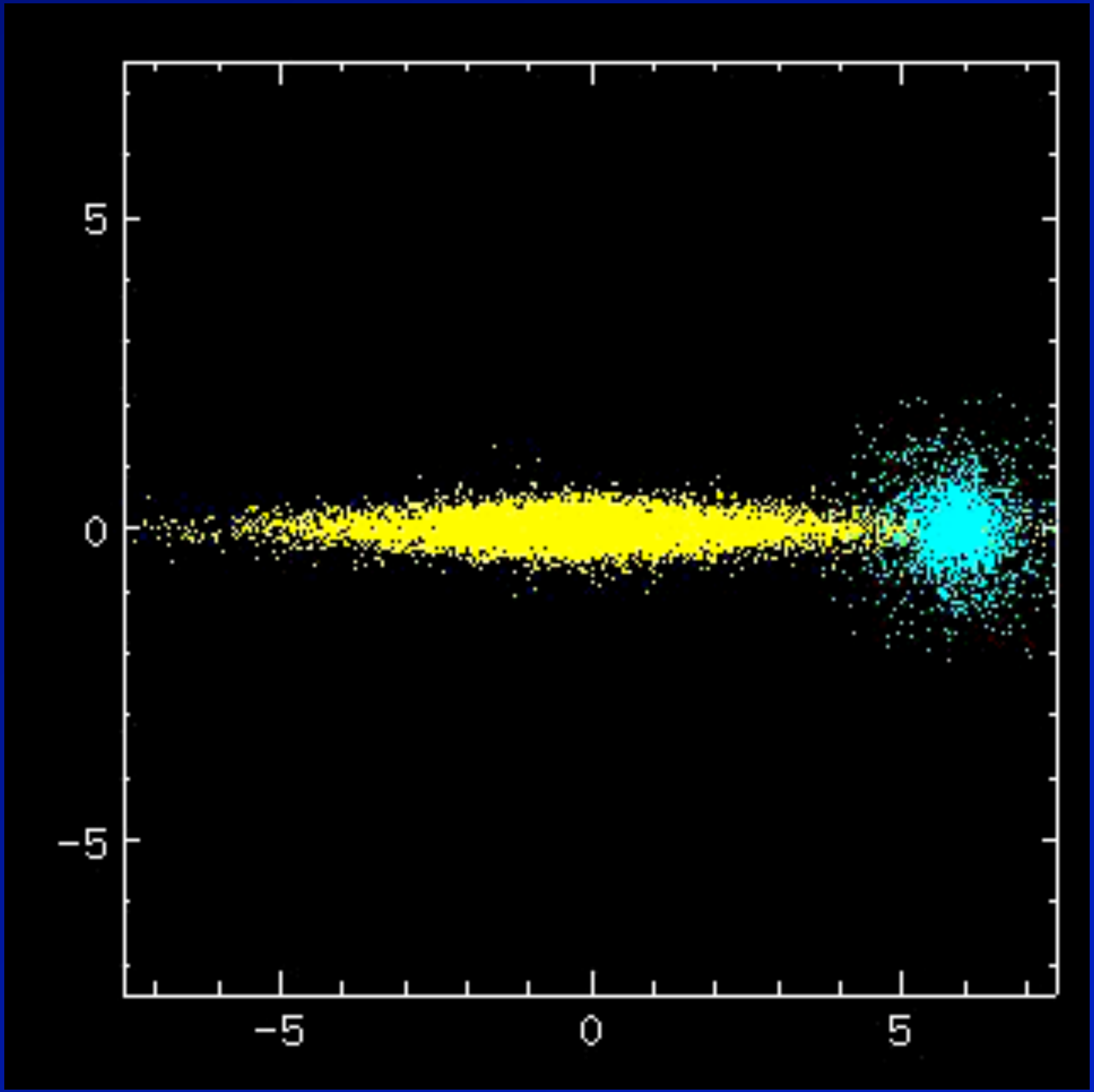
(Read et al. 2008)

This gives the surface density between 2 and 3.5 kpc about 15 M_{sun}/pc^2

The value of dark matter in the thick disk is overestimated by Read et al. by 2-4 times

Chris Mihos (Case Western Reserve University)

http://burro.astr.cwru.edu/models/models.html



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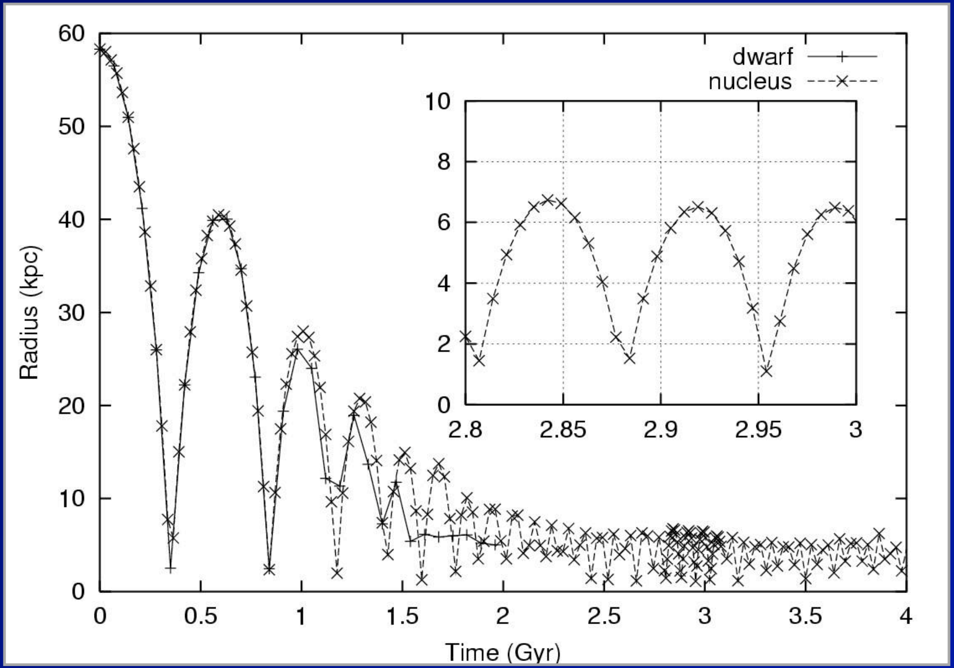
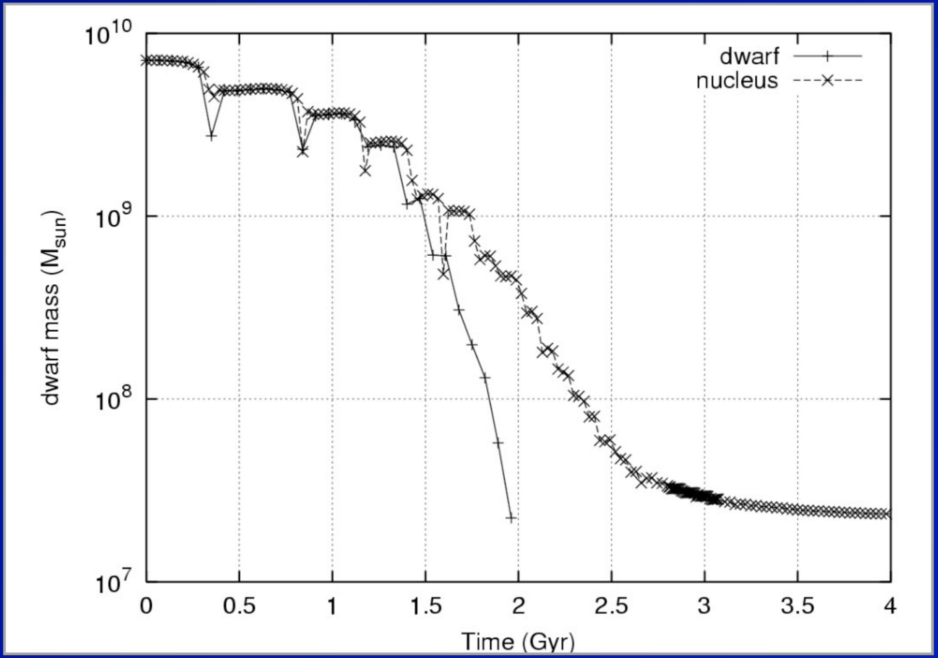
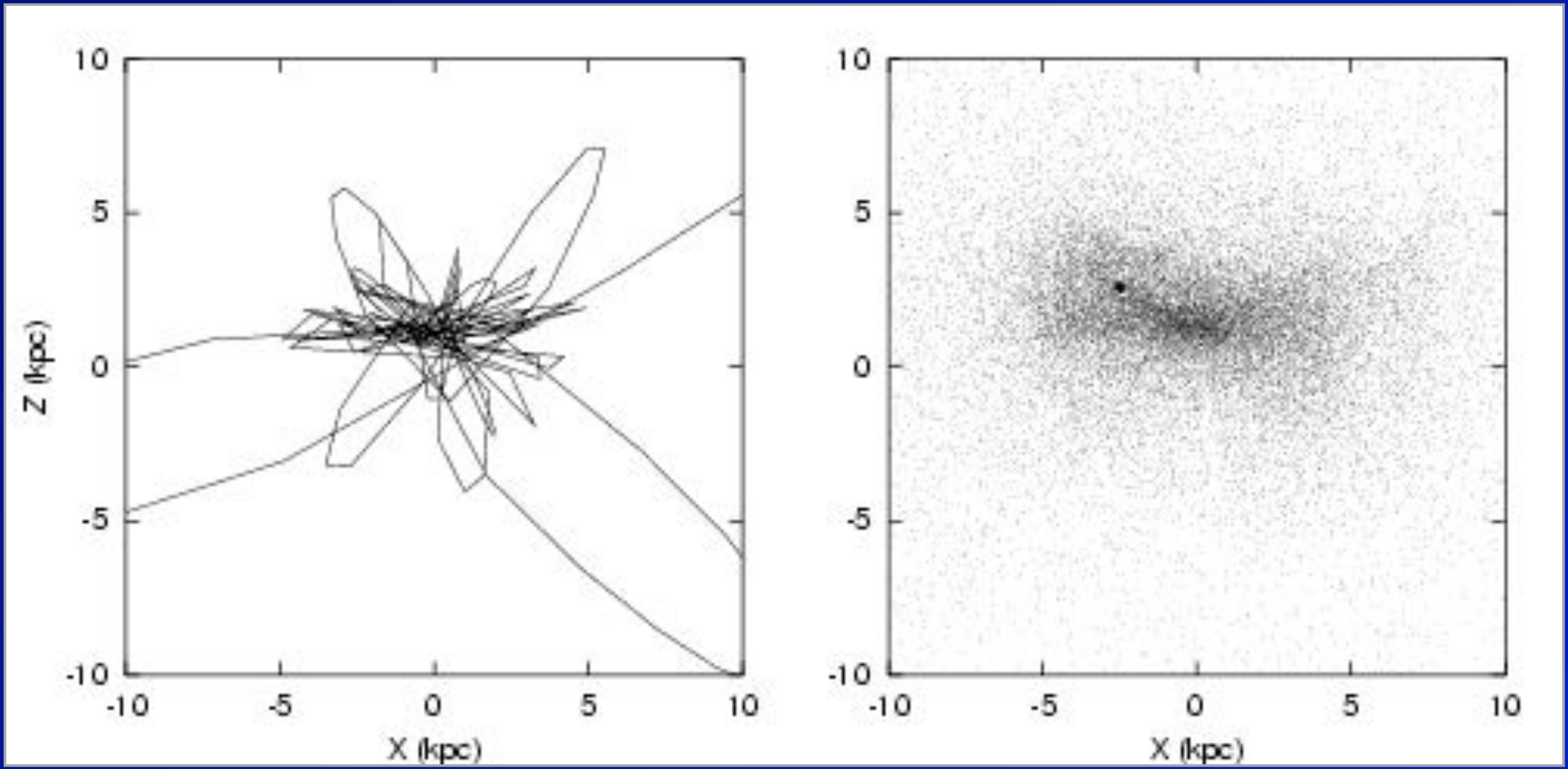




Capture of a proto-ω Cen

Tsuchiya, Dinescu, Korchagin (2003, 2004)



Distribution of debris of proto-ω Cen

after disruption

Conclusions

Distribution of stars in galaxies adn their kinematical properties point at the existence of two physically distinct disk components, the thin and the thick disk

The vertical scale height of the thick disk varies from 0.5 to 1.5 kpc while the radial scale length is estimated from 2 to 5 kpc

The estimate of the surface density of the thick disk of the Galaxy within 2 - 3.5 kpc gives the value of $\Sigma \sim 6.6\ M_{sun}/pc^2$ showing that the mass of dark matter in the thick disk can not dominate the mass of gravitating matter