Dark matter mass density at high distance from the Galactic plane

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Dark matter component

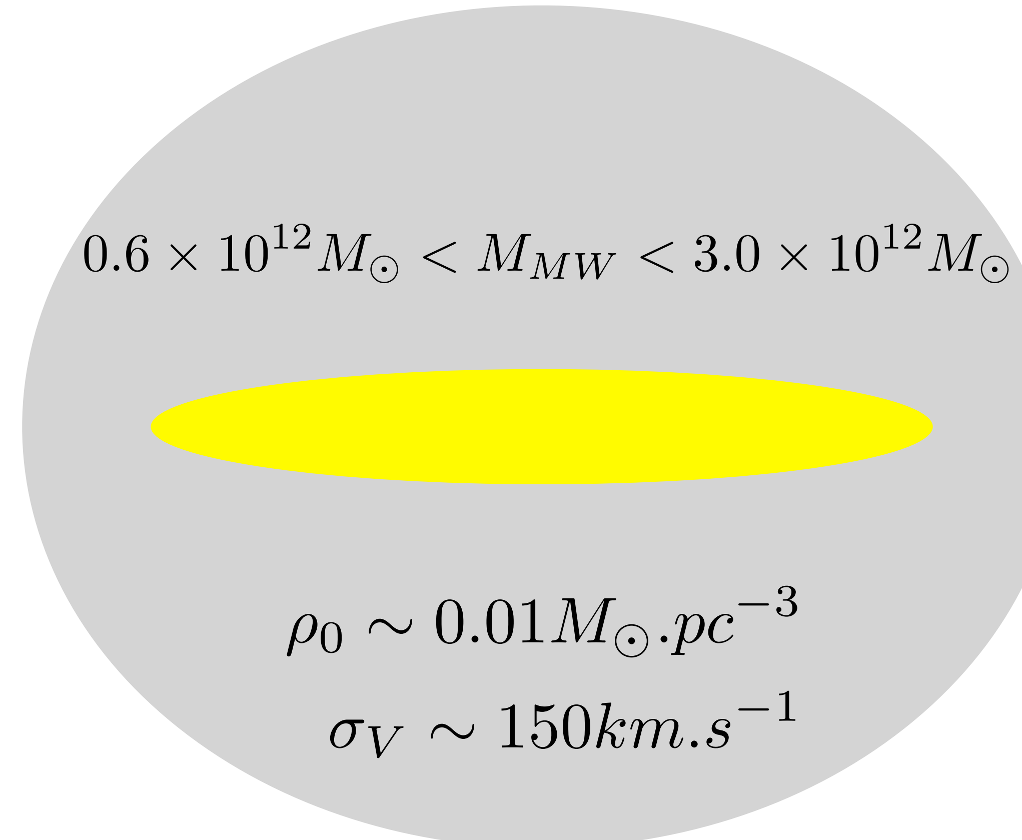
Different methods to derive the properties of dark matter density in the MW, for example:

Using hypotheses of quasi-spherical halo

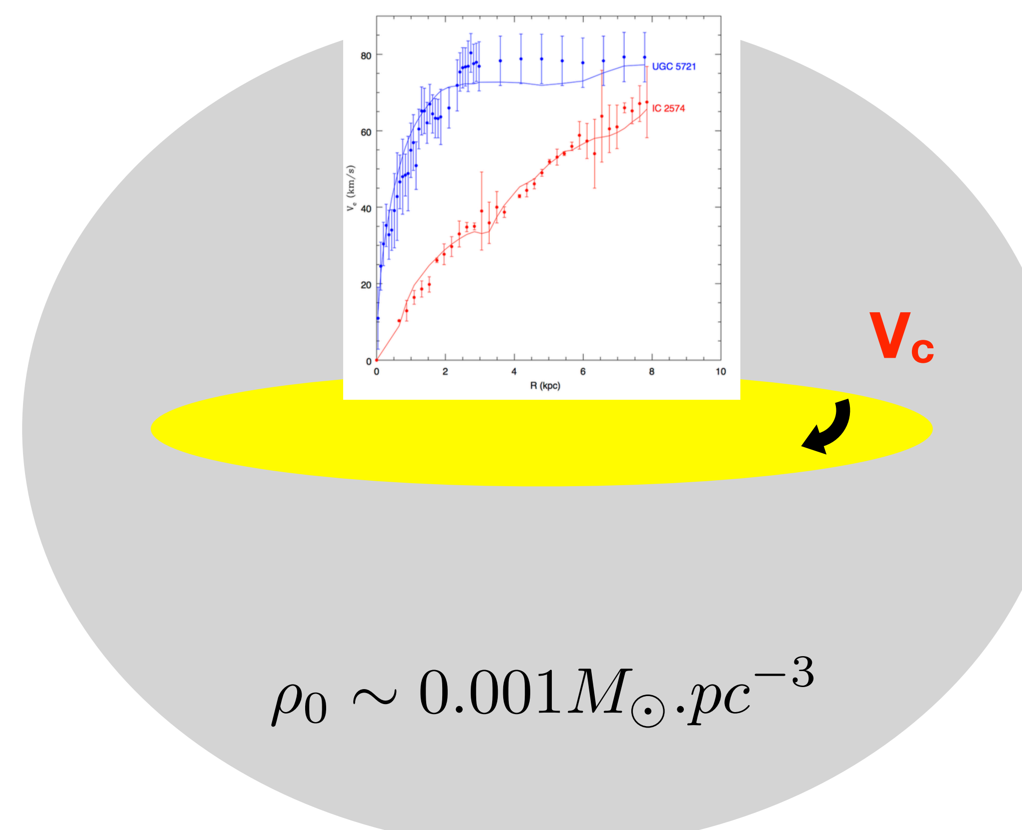
—> timing argument and N-body simulations, DM halo parameters (e.g.: Li & White 2008)

—> local cosmic expansion, DM mass (e.g.: see Guillaume's talk)

—> kinematics of satellites or stellar streams, DM halo parameters (e.g.: Ibata et al., 2013, 2019)



—> study of the disk rotation curve, local DM density
Fitting of a global model to fit a population
(star tracers or HI rotation curve)
(e.g.: Catena & Ullio 2010, Piffl et al. 2014…)



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Dark matter disc component

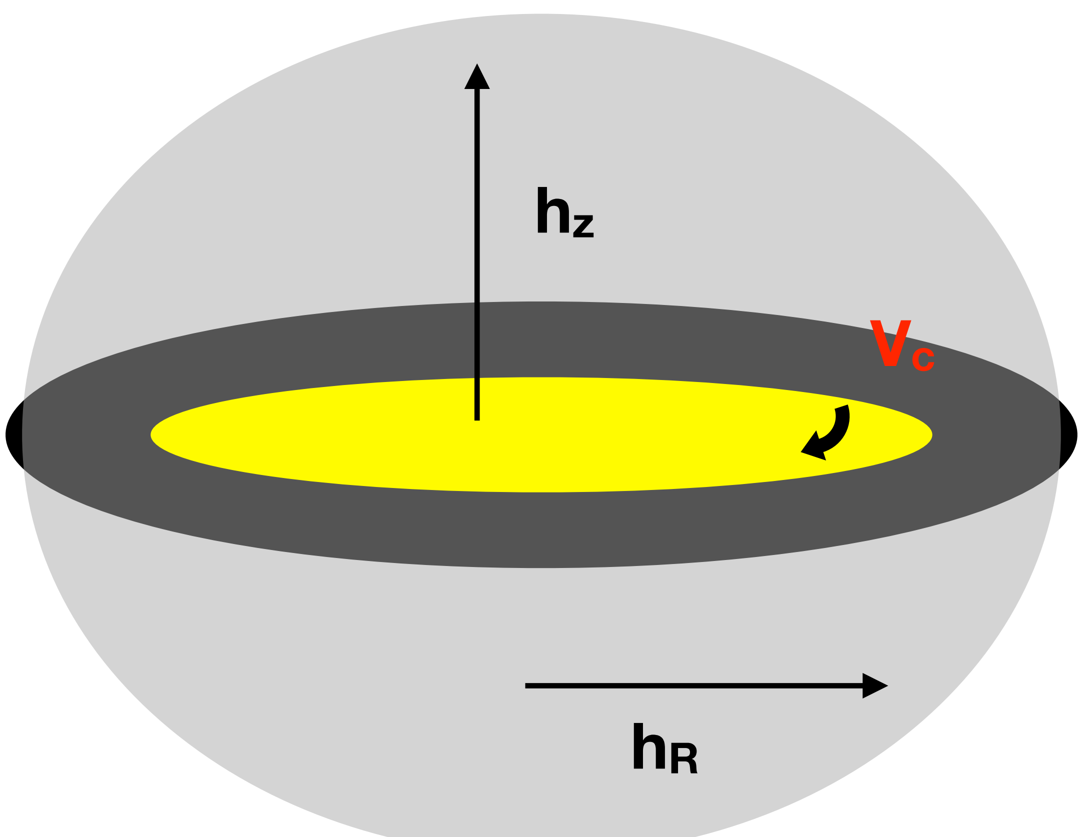
formation history: several formation episode, massive satellite accretion,
adiabatic response of the DM halo to the baryonic component

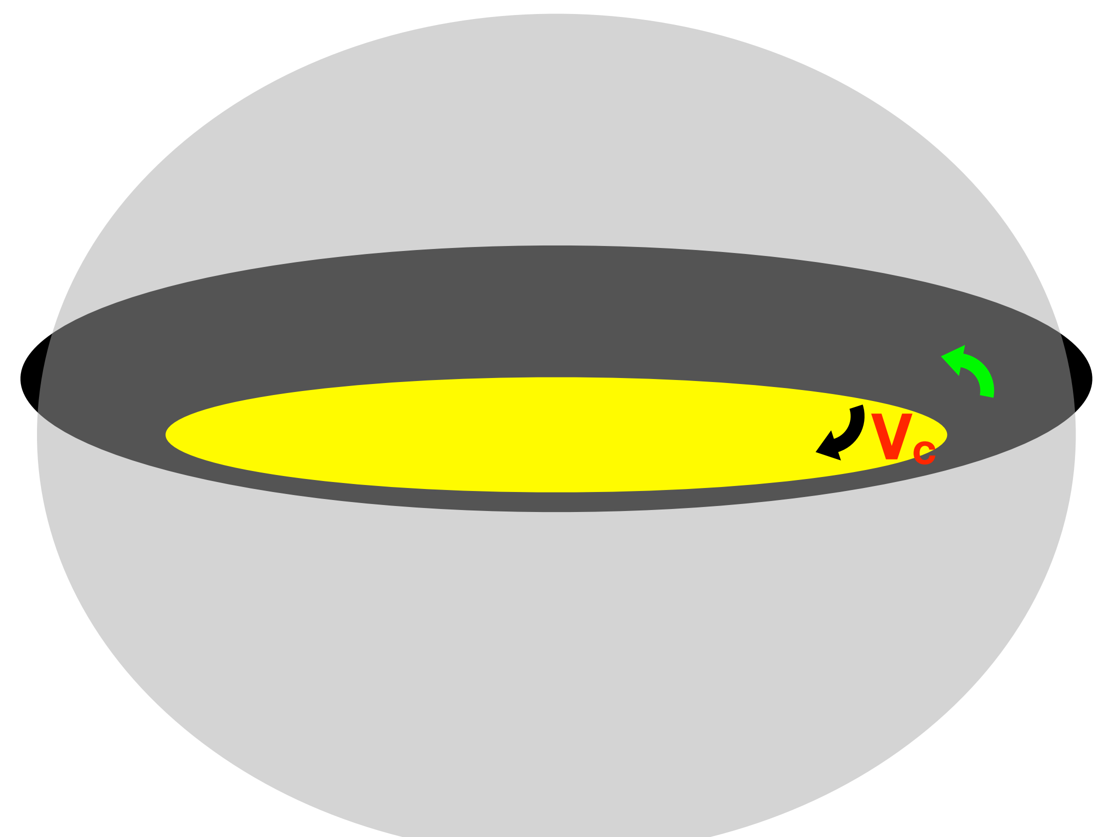
—> dark component could be much more complex like:

. one or several additional dark discs,
. potentially shifted from the baryonic disc,
. possibly in counter rotation. (e.g. Buch et al. 2018)

Especially as we infer DM from non equilibrium baryon distributions:

. Phase-space spiral structure in z-v_z plane (Antoja et al. 2018)
. Rings, Ridge and arches (e.g. Monari et al. 2017)
. Bending and breathing modes, spiral arms, waves… (e.g. DeBattista 2014, Bennett & Bovy 2019)
. Buckling of the bar (Khoperskov et al. 2019)





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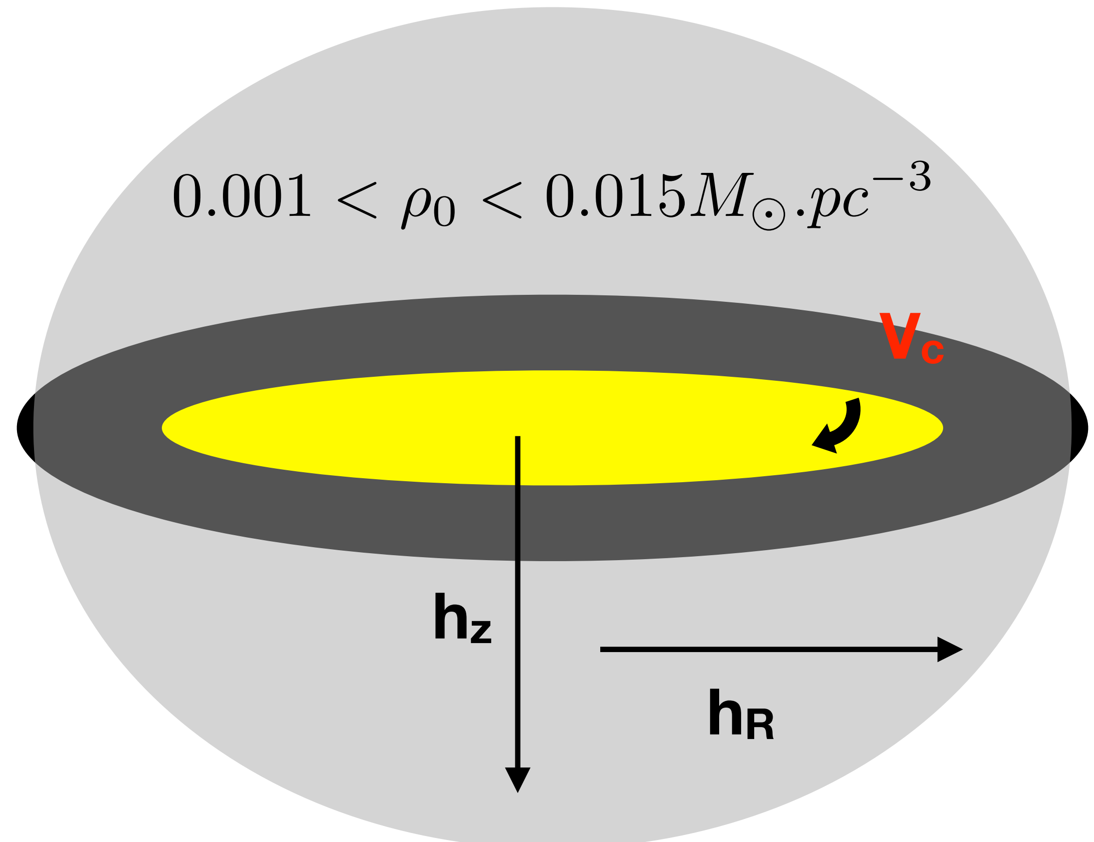
Jeans analysis

—> study of the gravitational potential based on phase-space distribution, local DM density
Equilibrium of a population
Dependance with the population, height considered, disk parameters…
(e.g.: Bovy & Rix 2013, Moni Bidin et al. 2015, Bienaymé et al. 2014, Sanchez-Salcedo et al. 2016…)



Density profile of the disc

$$F_R = \left(\frac{1}{R} - \frac{1}{h_R} - \frac{1}{h_{\sigma_R}}\right)\sigma_R^2 - \frac{1}{R}(\sigma_\theta^2 + \bar{V}_\theta^2) + \frac{\partial \sigma_{Rz}^2}{\partial z} - \frac{\sigma_{Rz}^2}{h_z}$$

$$F_z = \frac{\partial \sigma_z^2}{\partial z} - \frac{\sigma_z^2}{h_z} + \left(\frac{1}{R} - \frac{1}{h_R} - \frac{1}{h_{\sigma_{Rz}}}\right)\sigma_{Rz}^2$$

Poisson equation to link the gravitational forces to DM density

$$4\pi G\rho(R,z) = \frac{\partial F_z}{\partial z} - \frac{1}{R}\frac{\partial}{\partial R}(RF_R)$$

Dynamical surface mass density
Local DM density

Our study:

performing a Jeans analysis with a tracer population consistent and complete from 0.6 kpc to 3 kpc

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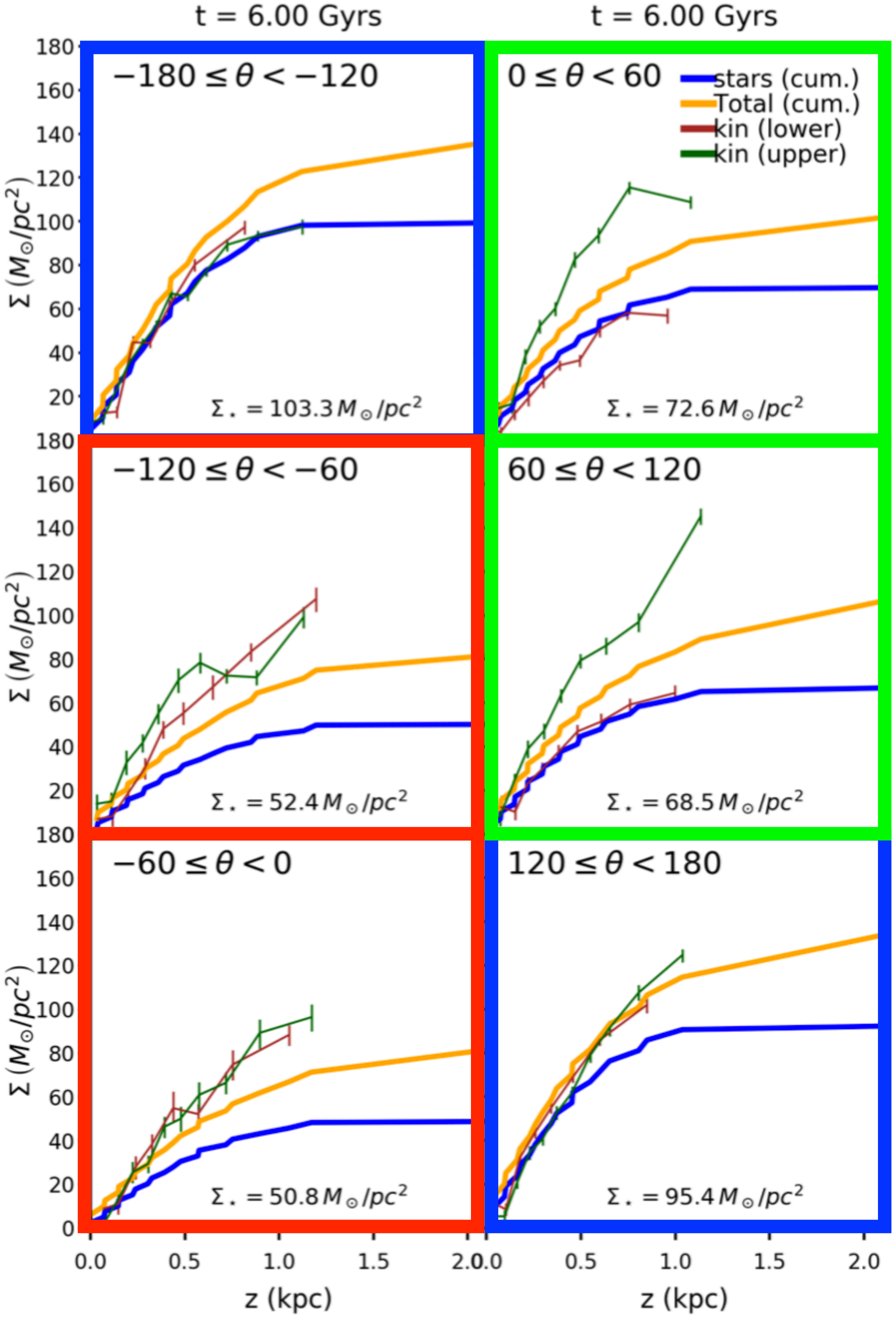
Dark matter component

Specific case of a large perturbation causes by the passage of a massive satellite through the disc

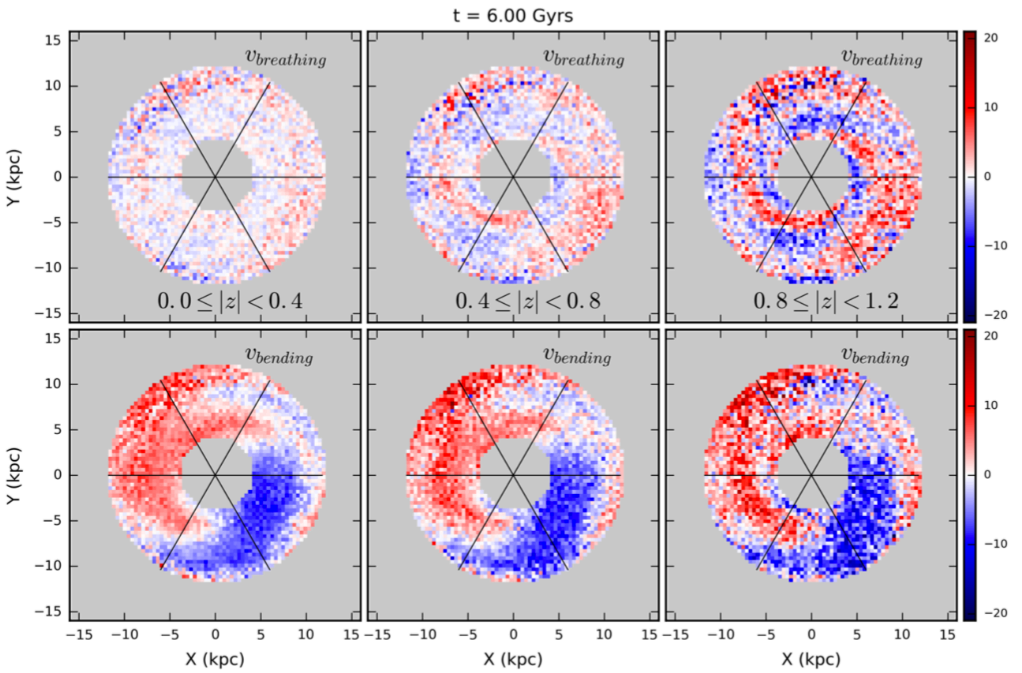
Haines et al. (2019)



good approximation for high density

overestimation for low density

reasonable estimation for medium density if North+South considered



↓

rapid time variations in the potential

↓

bias in the determination of the local DM density in a Jeans approach

Hypotheses: in a first step, simultaneous fitting on the North + South to have a better DM estimation

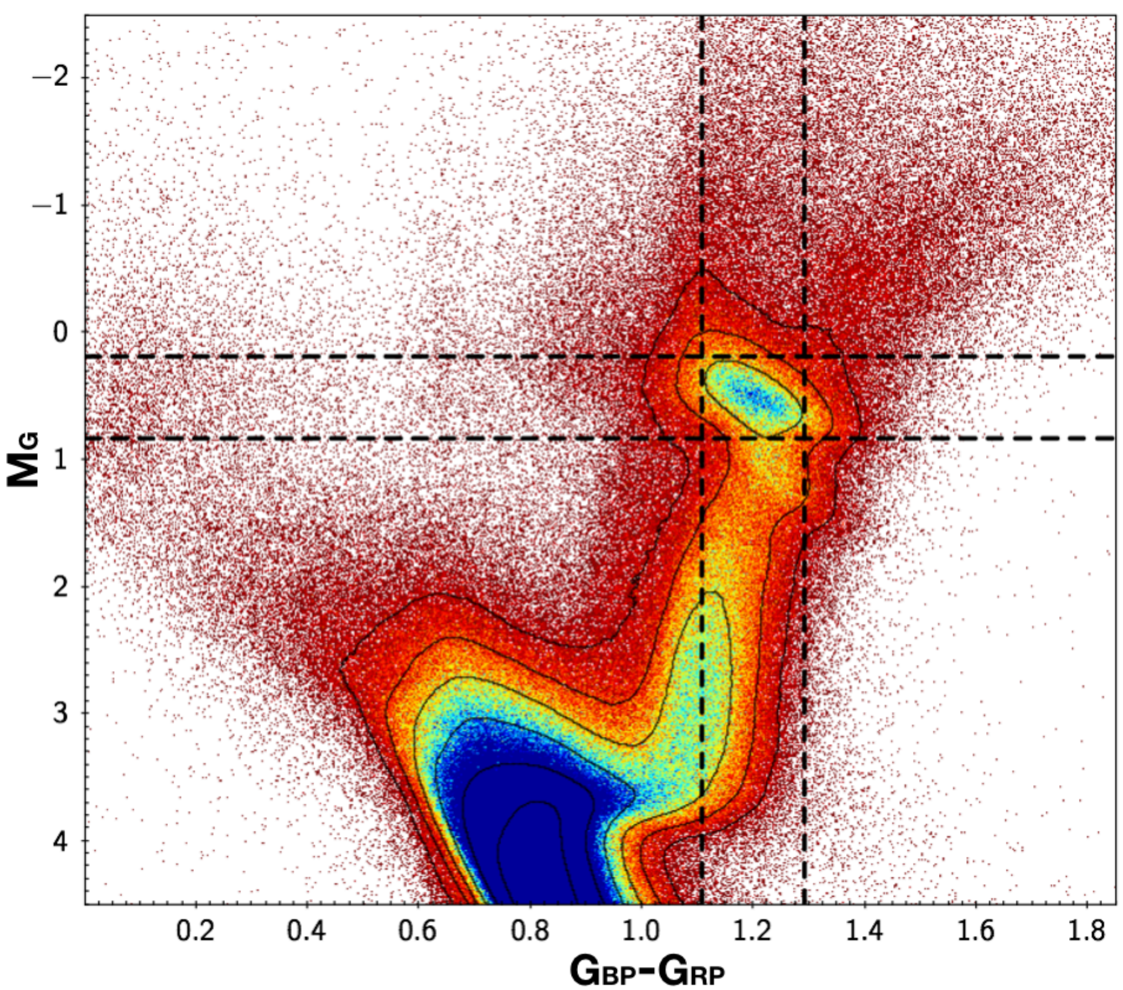
Dark matter mass density at high distance from the Galactic plane

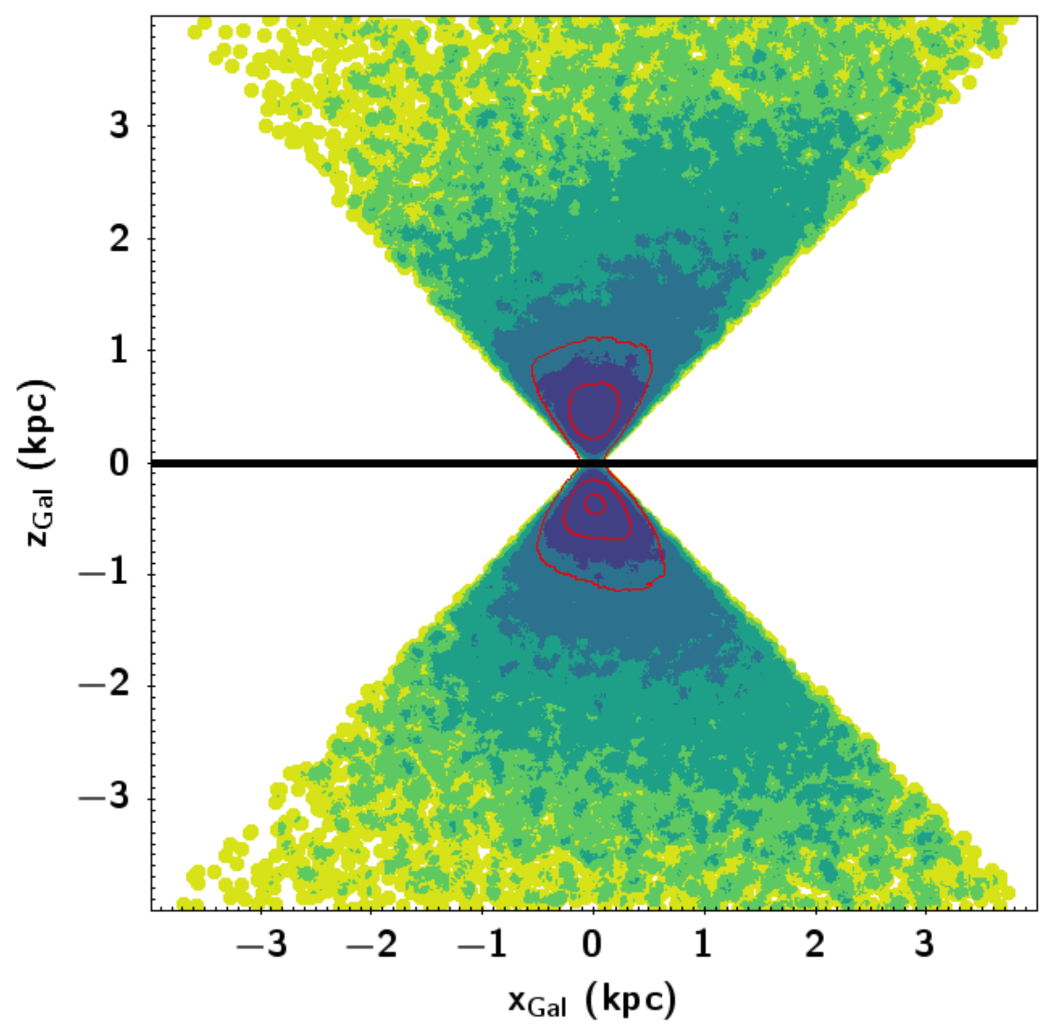
Sample selection from Gaia DR2 catalogue

Strict magnitude cut towards North and South Galactic poles:
- $|b| > 45$ degrees
- $G < 15$

Selection of red clump stars:
- $1.107 < G_{BP} - G_{RP} < 1.291$
- $0.185 < M_G > 0.83$

43589 sources





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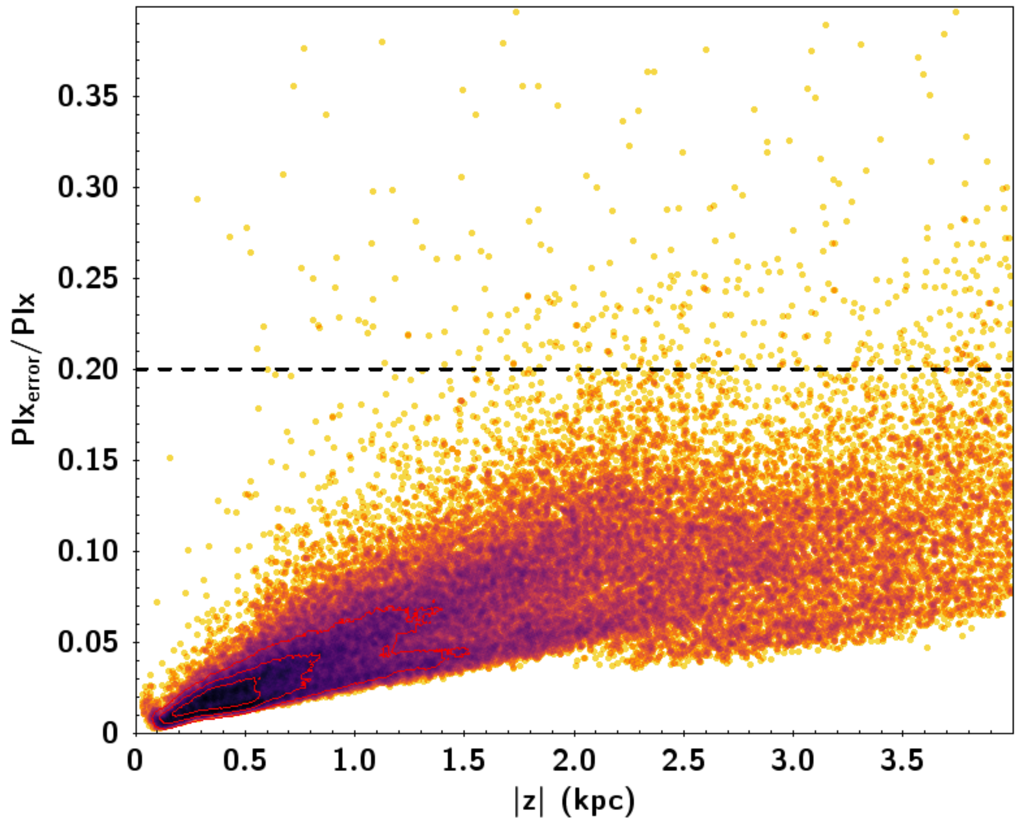
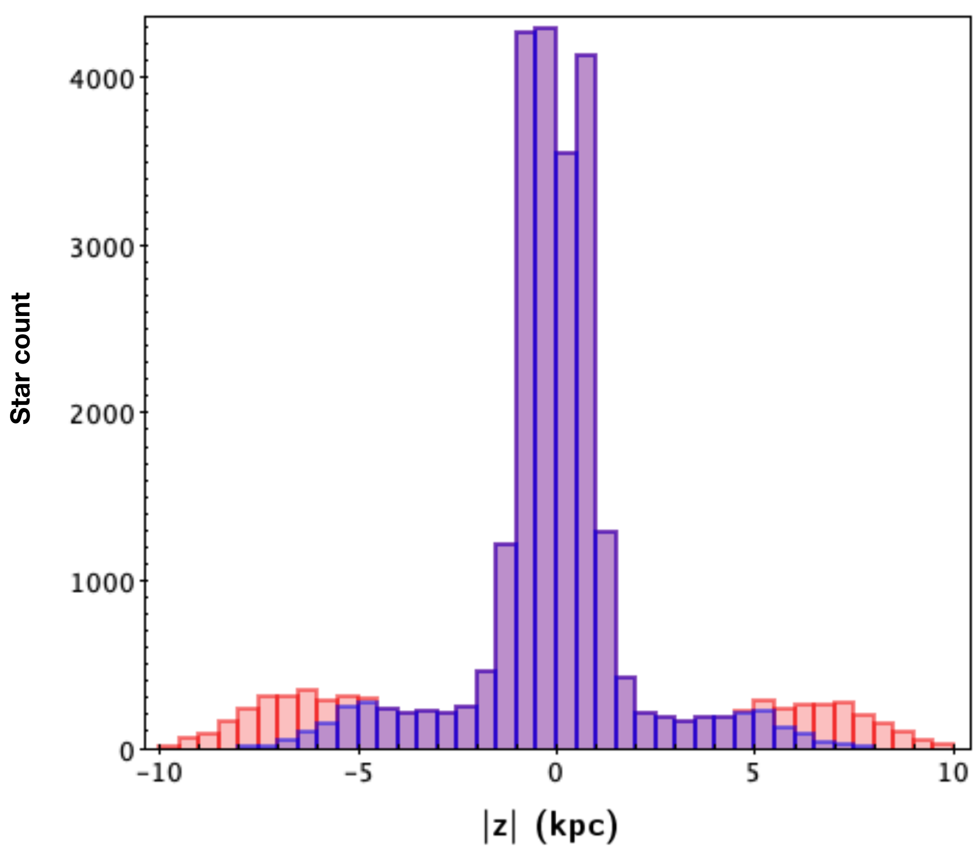
Sample completeness and errors



> 90 % of sample stars with relative error on parallax < 20 % (No need for distance correction)



Comparison with BGM simulations with the same cuts in magnitude and volume —> 100 % of stars up to |z| = 4.5kpc

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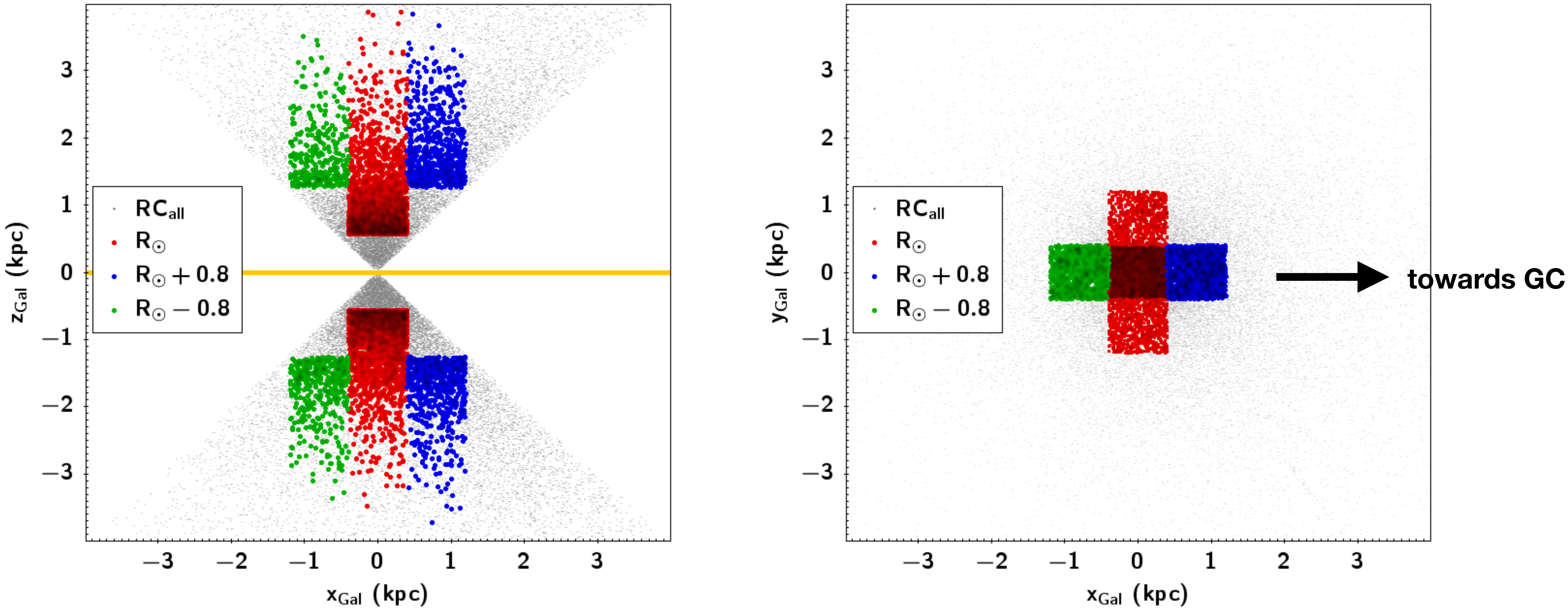
Volume selections



Cuboids along z axis centred on the solar position

Area of the square slices perpendicular to z: 800 pc²

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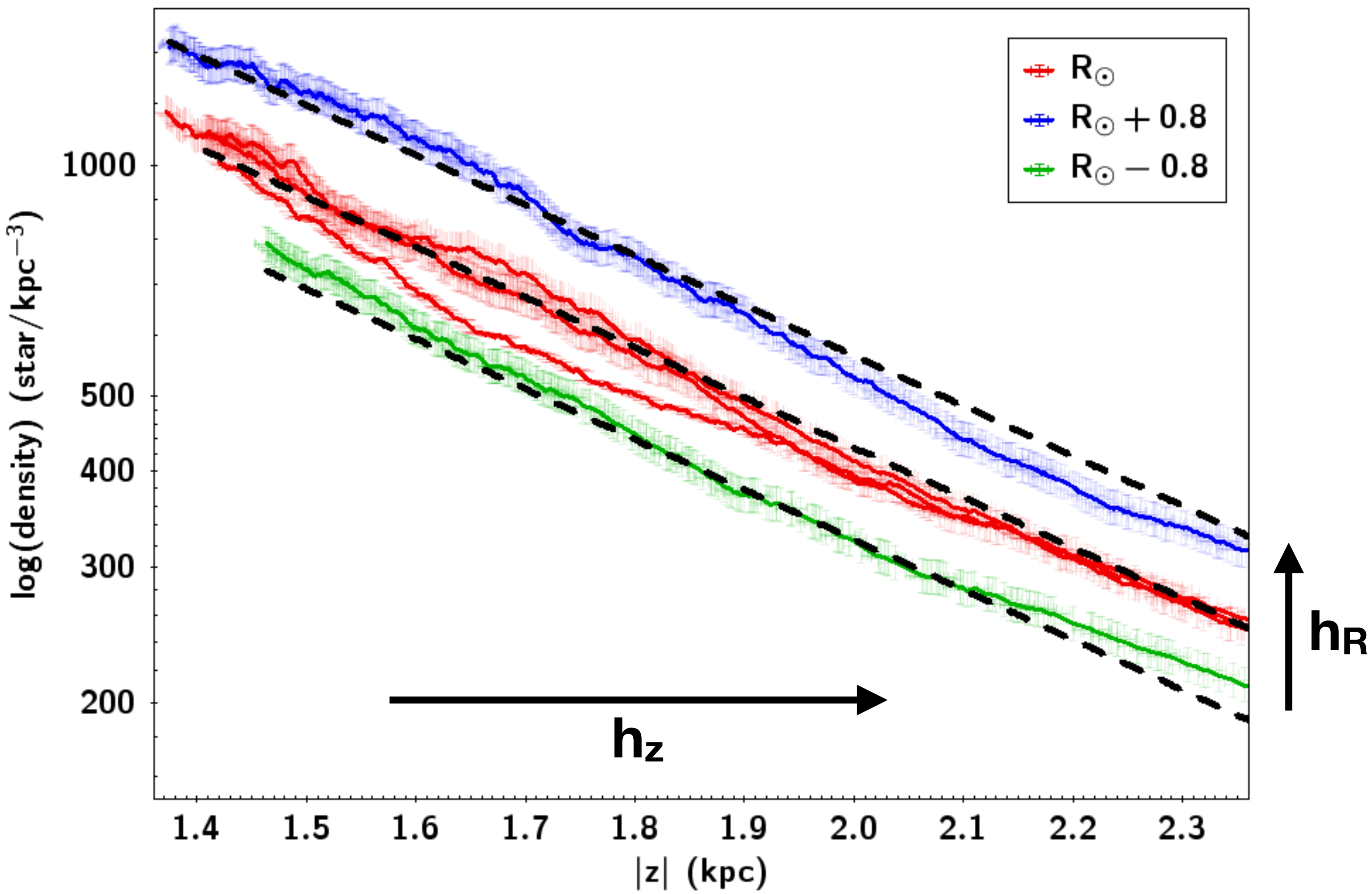
Density Profile

Simultaneous fitting of North + South volumes



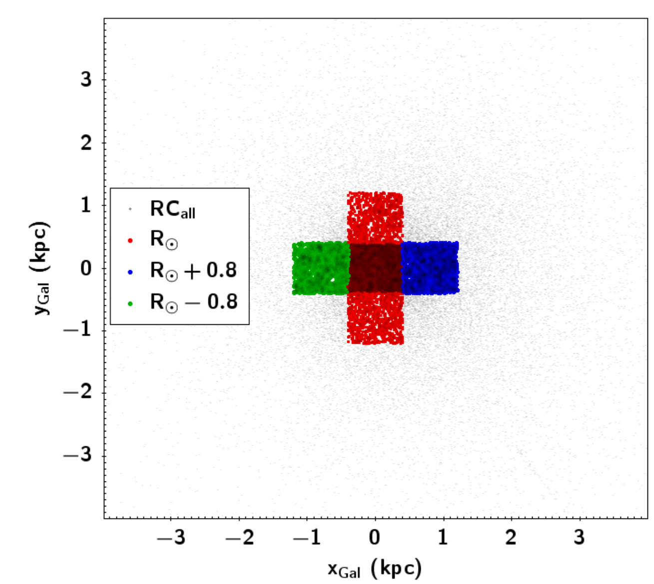
$$\nu(R, z) = \nu_0 \exp\left(-\frac{R - R_\odot}{h_R} - \frac{|z|}{h_z}\right)$$

density profile for:

- **1.35 kpc < |z| < 2.35 kpc**
- **-1.2 kpc < R < 1.2 kpc**

scale length: h_R = 2.9 kpc

scale height: h_z = 0.67 kpc



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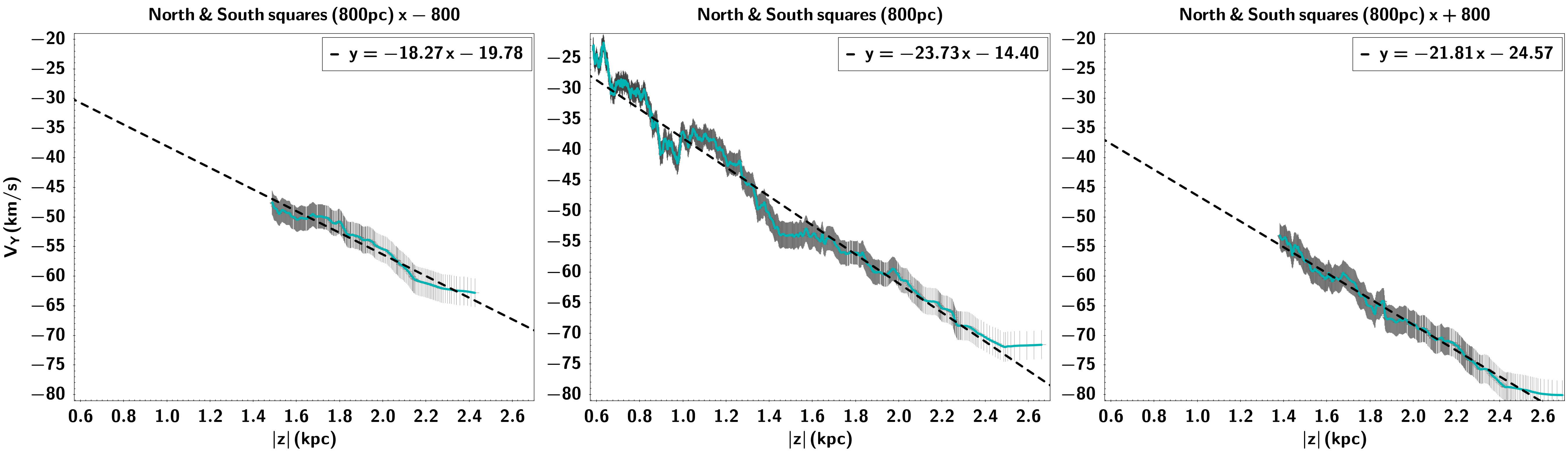
Velocity Profiles



$$\bar{V}_\theta = 237.98 - 23.77|z| km.s^{-1}$$

$$\bar{V}_\theta^2 = 55451.14 - 9551.18|z|$$

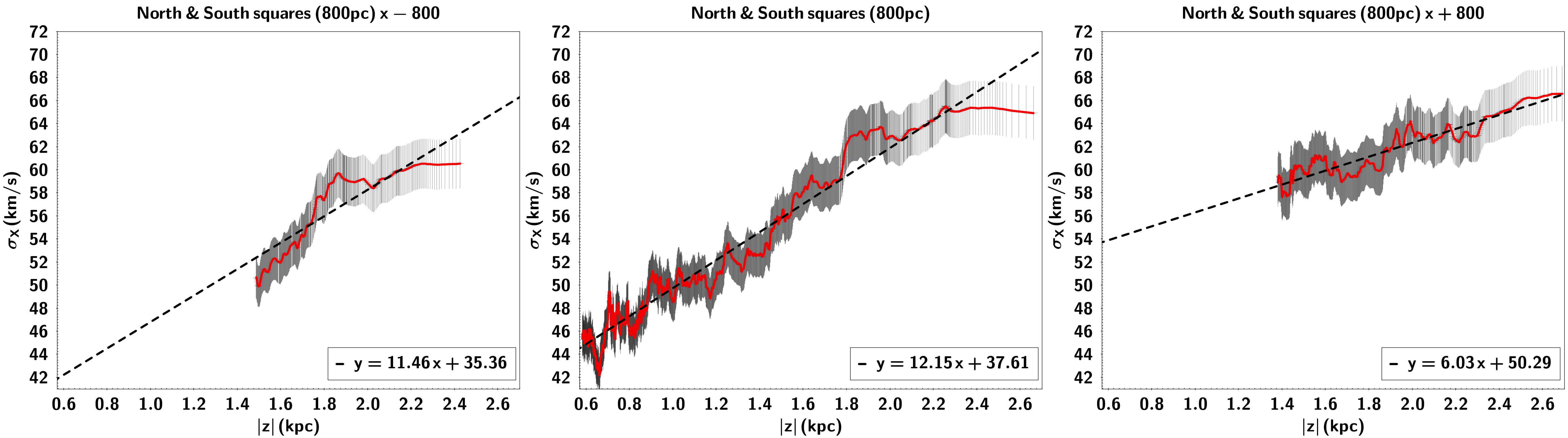
$$\frac{\partial \bar{V}_\theta}{\partial R} = 1.67 + 2.91|z|$$

$$\frac{\partial \bar{V}_\theta^2}{\partial R} = -2613.46 + 650.47|z|$$

Gaining gradient from velocity and dispersion profiles

Dark matter mass density at high distance from the Galactic plane

Dispersion Profiles



$$\sigma_R = 37.62 + 12.17|z|$$
$$\sigma_R^2 = 1132.79 + 1362.18|z|$$

Gaining gradient from velocity and dispersion profiles

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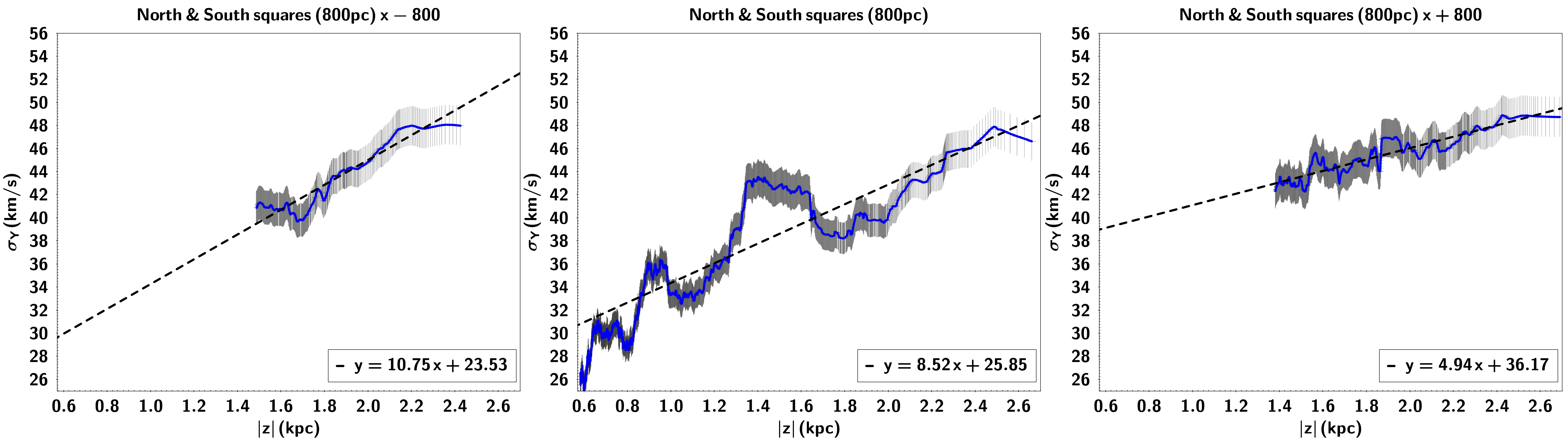
Dispersion Profiles



$$\sigma_\theta = 25.67 + 8.65|z|$$
$$\sigma_\theta^2 = 560.59 + 648.06|z|$$

Gaining gradient from velocity and dispersion profiles

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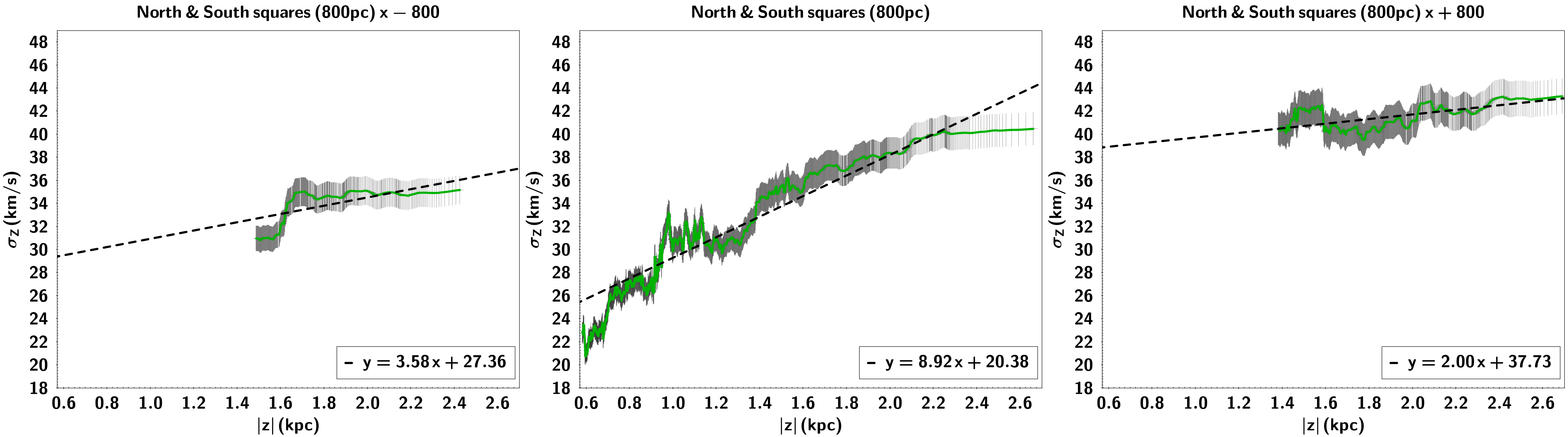
Dispersion Profiles



$$\sigma_z = 20.73 + 8.72|z|$$

$$\sigma_z^2 = 335.48 + 559.85|z|$$

$$\sigma_{Rz}^2 = 595.31 + 370.52|z|$$

Gaining gradient from velocity and dispersion profiles

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First estimation (preliminary results)

Density profile of the disc

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Dynamical surface mass density
Local DM density

Limitations

stationarity of the disc $\bar{V}_R = \bar{V}_z = 0$
axisymmetry
constant scale lengths
strict exponential profile for the disc

$$\frac{dh_z}{dR} = 0$$

$$h_{\sigma_{ij}} = h_{\sigma_i} = h_R$$

Valid at $R = R_\odot$

for |z| > 1.2 kpc

$$\bar{\rho}_0 \approx 0.011 M_\odot.pc^{-3}$$

imply a massive dark disc

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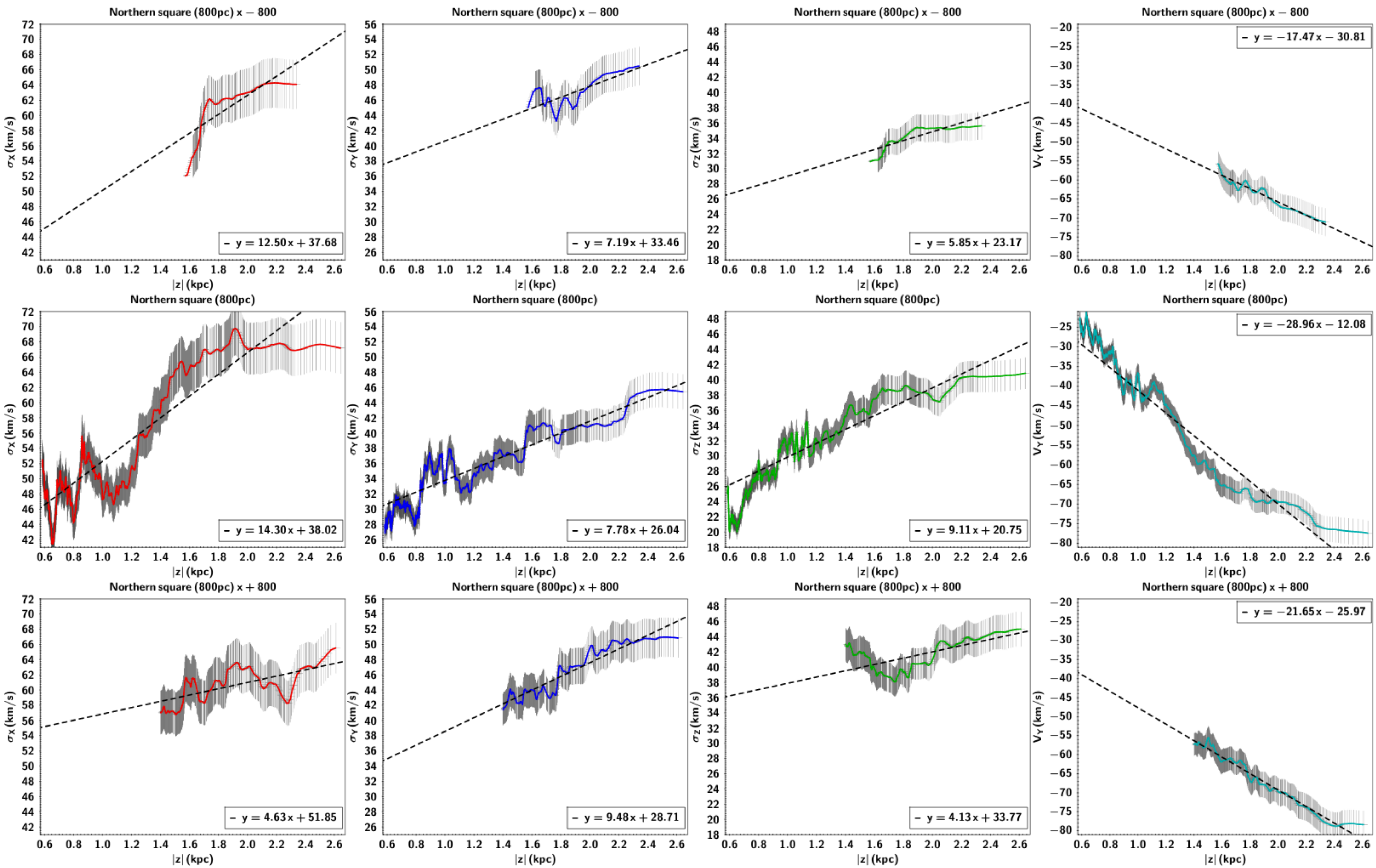
Deviations

North



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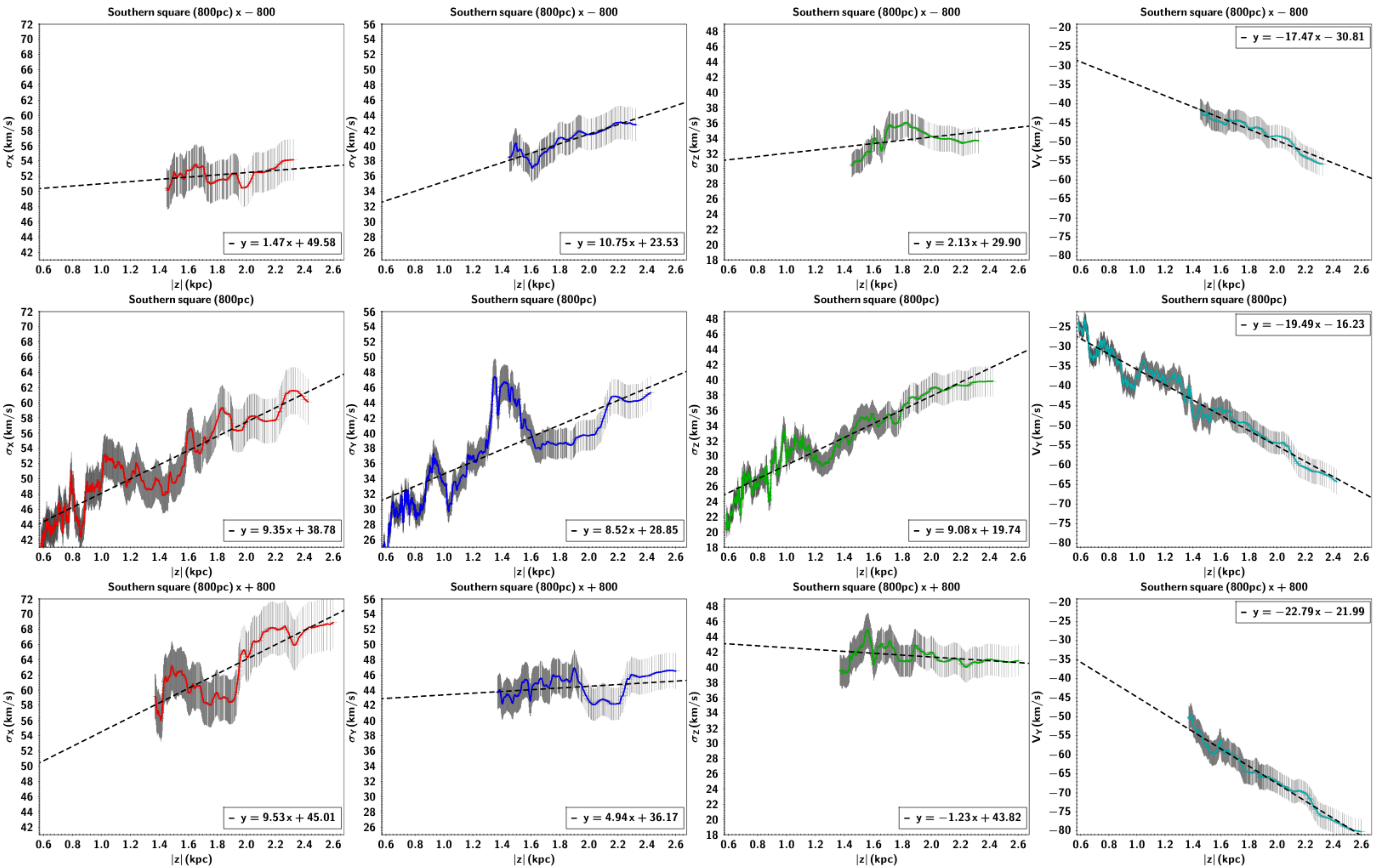
Deviations

South



Conclusions and perpectives

Construction of a consistent, homogeneous and complete sample of tracers up to 3 kpc from the Galactic plane

Fitting of the density with a single exponential disc (1.3 < |z| 2.3 kpc)

Linear approximation for all velocity and dispersion profiles, including cross terms.

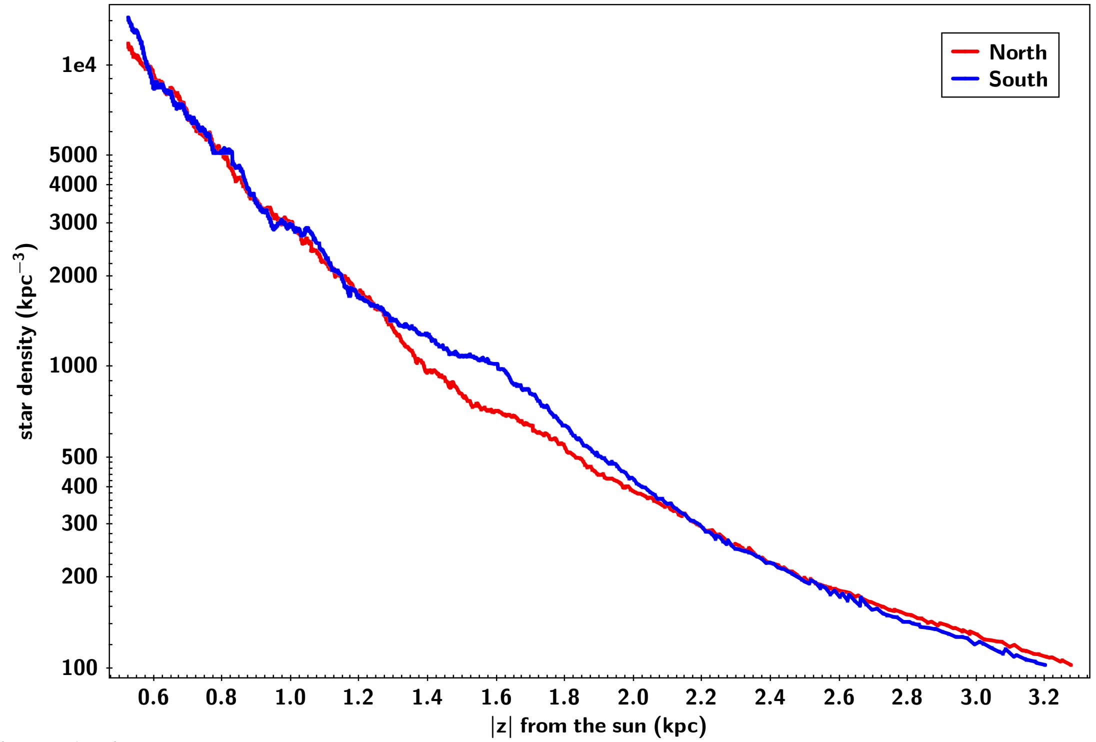
Under many assumptions (axisymmetry, stationarity, constant scale length…) including a North - South “average”, derivation of the DM volume density at the solar radius

……………………………………………………………………………

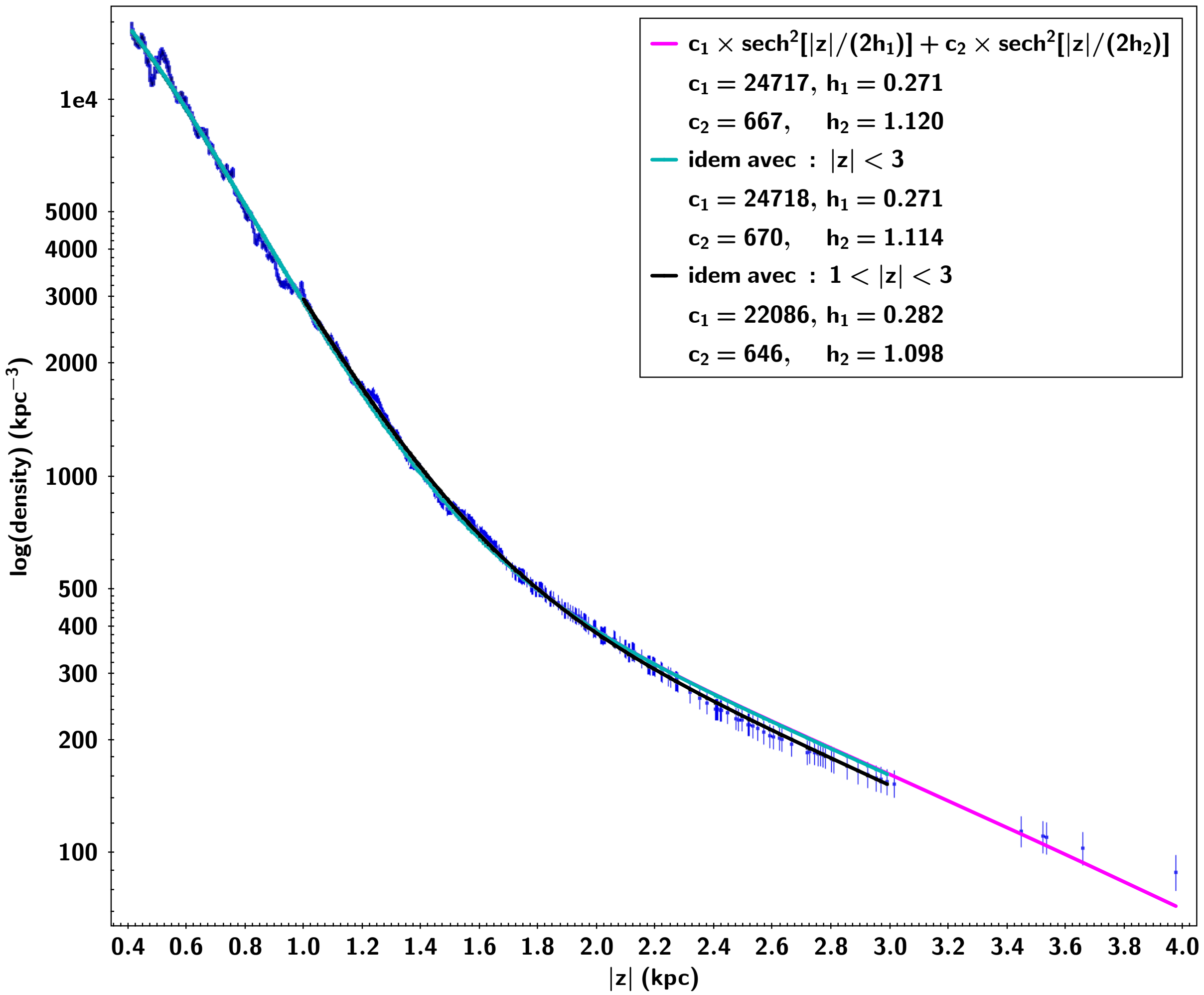
Now, working on individual volumes in order to identify deviations from our assumptions (equilibrium…)

Density profile will be fitted with more parameters

Thank you for your attention



selection cylindre Nord R400 (200st/bin) (ajust. sécante)



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