Stockholm University

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GRAPPA
GRavitation AstroParticle Physics Amsterdam

# The local dark matter density from SDSS data.

Including modeling of the tilt term.

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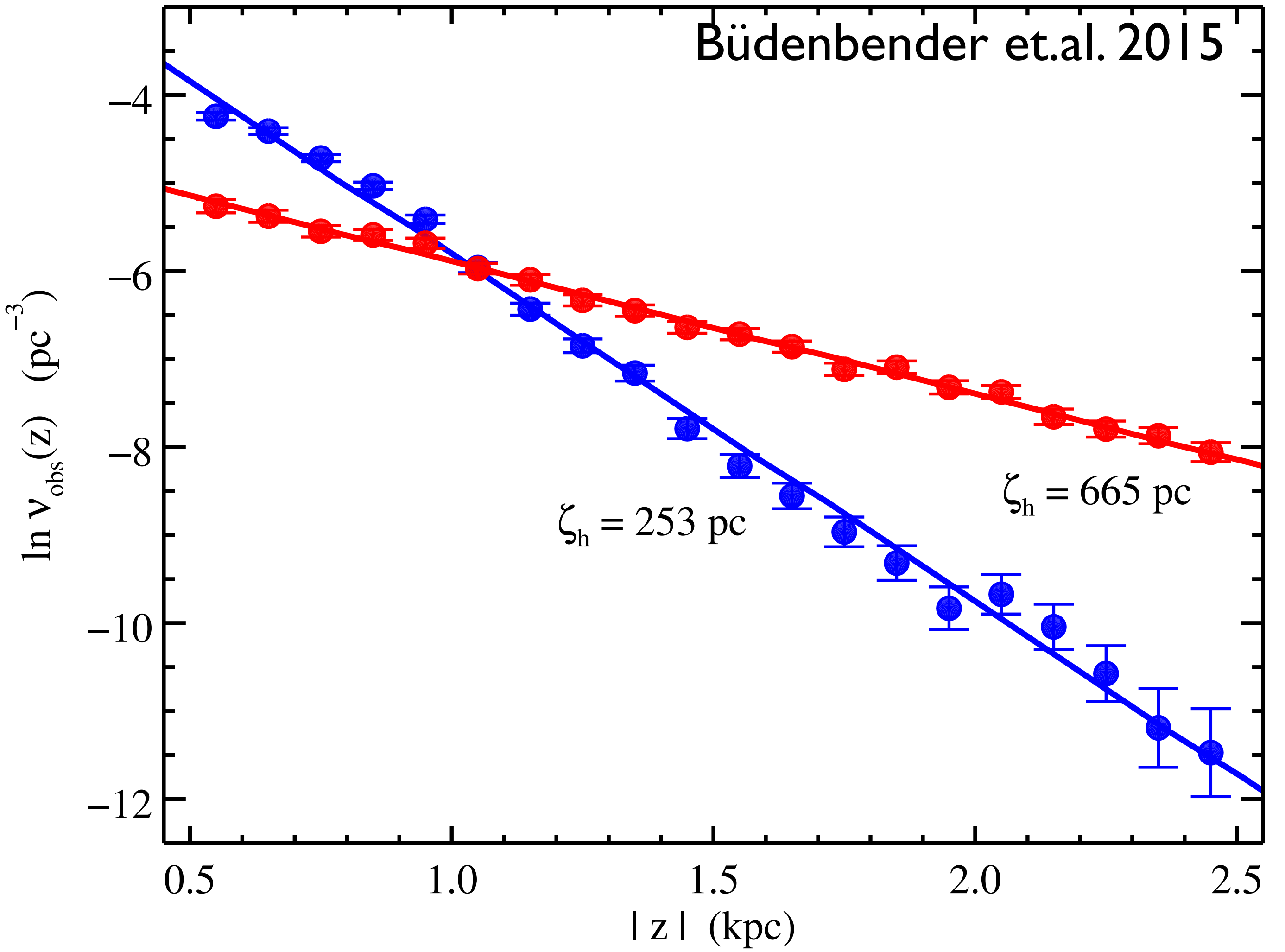
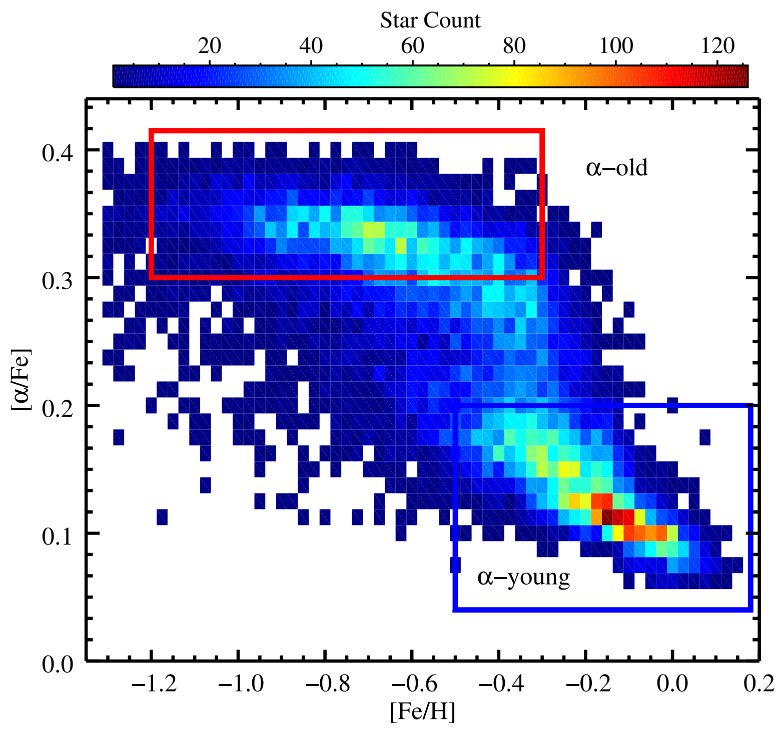
Based on SDSS data from Büdenbender et.al. 2015

# Preliminaries

- 1-D analysis, assuming steady state.
- SDSS data from Büdenbender et.al., giving: $\nu(z)$ $\sigma_z(z)$ & $\sigma_{Rz}(z)$
- 2 populations extracted by metallicity: young (thin) pop and old (thick) pop.
- Assume exponential tracer density profiles.
- Assume constant dark matter density and symmetry above and below the disk plane.



# Our aim: more robust limits on the dark matter density by making less assumptions.

z-Jeans Equation:

$$\underbrace{\frac{1}{R\nu}\frac{\partial}{\partial R}\left(R\nu_i\sigma_{Rz}\right)}_{\text{'tilt' term: }\mathcal{T}}+\frac{1}{\nu}\frac{d}{dz}\left(\nu\sigma_z^2\right)=-\underbrace{\frac{d\Phi}{dz}}$$

Gravitational force

Integrate ↓

$$\sigma_z^2(z)=\frac{\nu(z_0)\sigma_z^2(z_0)}{\nu(z)}-\frac{1}{\nu(z)}\int_{z_0}^{z}\nu(z')\left[2\pi G\Sigma_z(z')+\mathcal{T}(z')\right]\mathrm{d}z$$

Velocity dispersion → $\sigma_z^2(z)$

Tracer number density → $\nu(z')$

Surface density → $\Sigma_z$

Tilt term → $\mathcal{T}$: coupling between radial and vertical stellar motion

↑

Poisson Equation:

$$\nabla^2\Phi=\frac{\partial^2\Phi}{\partial z^2}+\underbrace{\frac{1}{R}\frac{\partial V_c^2(R)}{\partial R}}_{\text{'rotation curve' term: }\mathcal{R}}=4\pi G\rho$$

Absorbed in $\rho$

Use MuliNest to find the dark matter densities which best fit the data.

# Modeling the tilt term

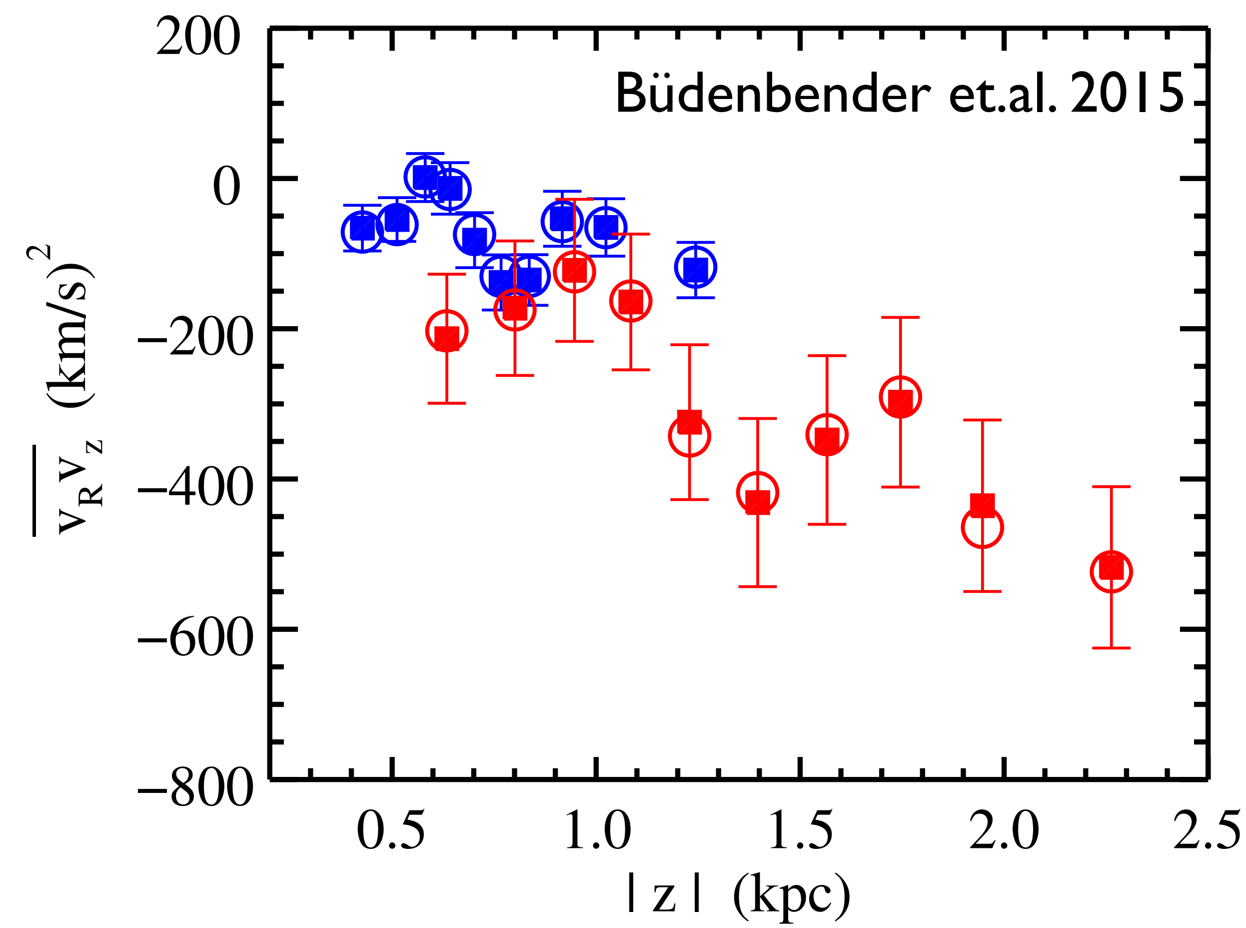
Tracer density distribution (e.g. Bovy et.al. 2016): $\nu(R,z) = \nu(z)\exp(-k_0 R)$

Assume similarly: $\sigma_{Rz}(R,z) = \sigma_{Rz}(z)\exp(-k_1 R)$

Model: $\sigma_{Rz}(z) = Az^n$

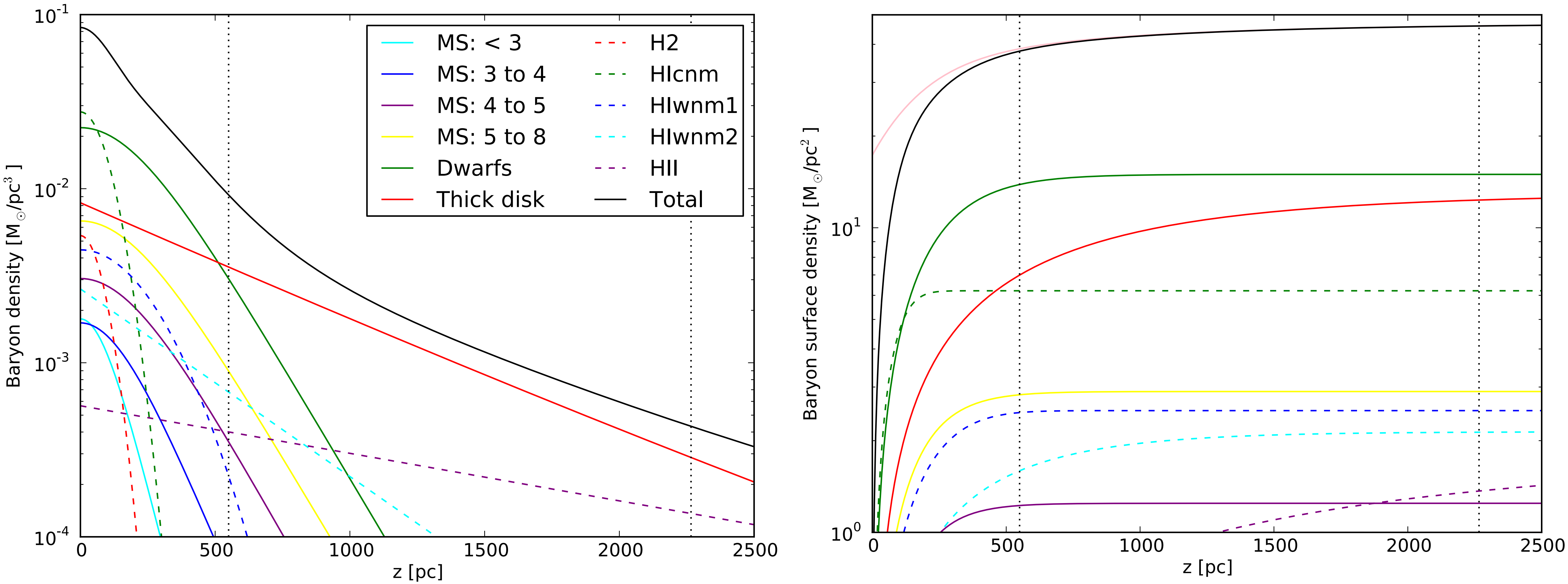
Gives the tilt term:

$$\mathcal{T}(R_\odot, z) = \underbrace{\left(\frac{1}{R_\odot} - k_0 - k_1\right)}_{\text{sign unknown}} Az^n$$



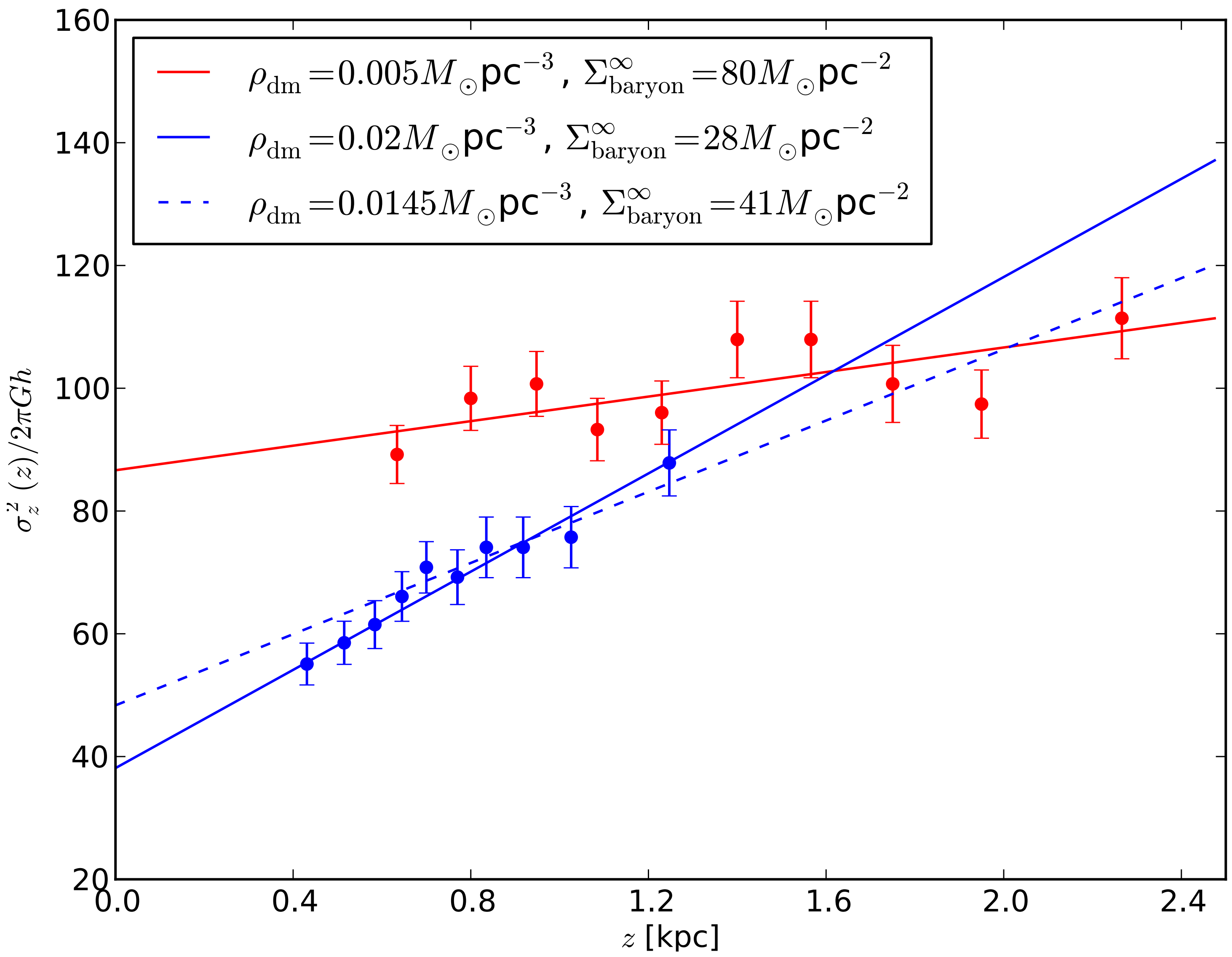

Plot easily fit by $\sigma_{Rz}(z) = Az$, which makes the tilt term look like a constant density term and hence a positive or negative contribution to the dark matter density.

# The baryonic components' contributions to the (surface) density




- Most of the baryonic surface density is located inside the innermost bin (left vertical dashed line).
- Total baryonic surface density: $\Sigma^{\infty}_{\mathrm{baryon}} = 46.95 M_\odot \mathrm{pc}^{-2} \pm 13\%$
- Pink line: simplified modeling of the surface density used in Multinest.

# Simplified modeling: the tracer populations prefer different matter distributions.




Simple modeling without tilt.

Assuming all baryonic matter inside innermost z bin:

$$\frac{\sigma_z^2(z)}{2\pi G h} = \Sigma^\infty_{\rm baryon} + 2\rho_{\rm dm} h + 2\rho_{\rm dm} z$$

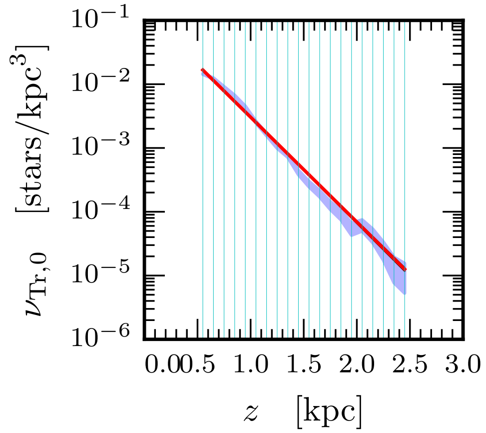
Young pop: scale height h=253 pc

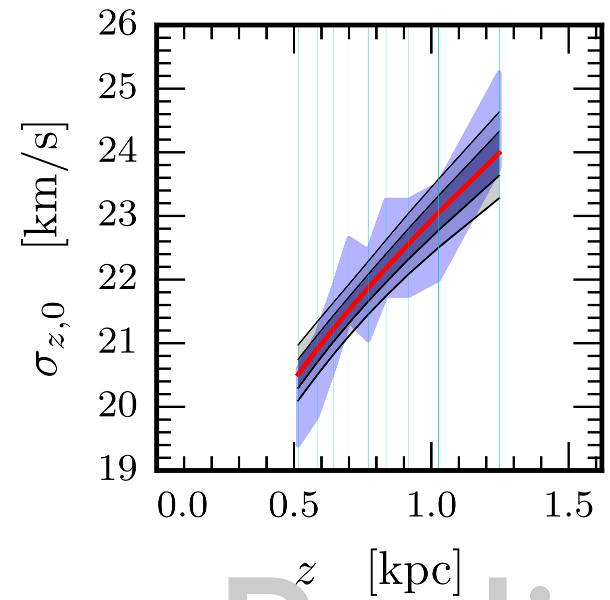
Old pop: scale height h=665 pc

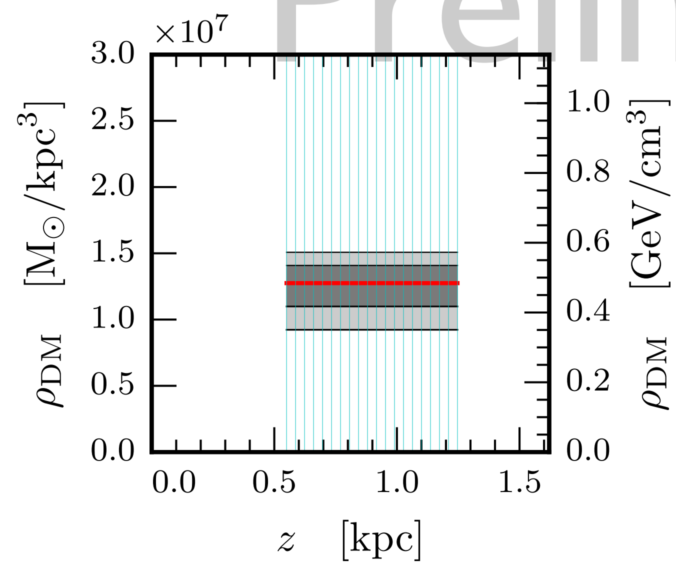
Tilt term is different for the two populations and can easily mimic an extra (pos or neg) DM component.

Hence tilt can resolve the tension on the DM density but it's more difficult to resolve the tension on the baryonic surface density.

# Fitting to the young population



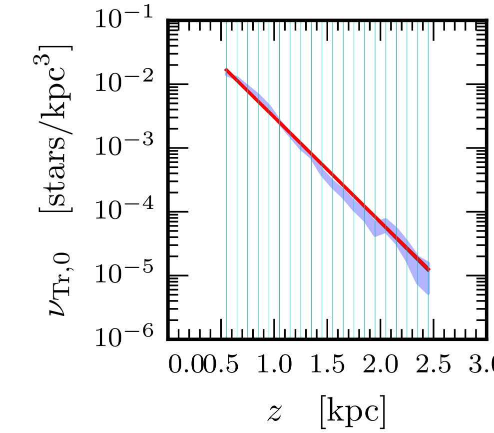



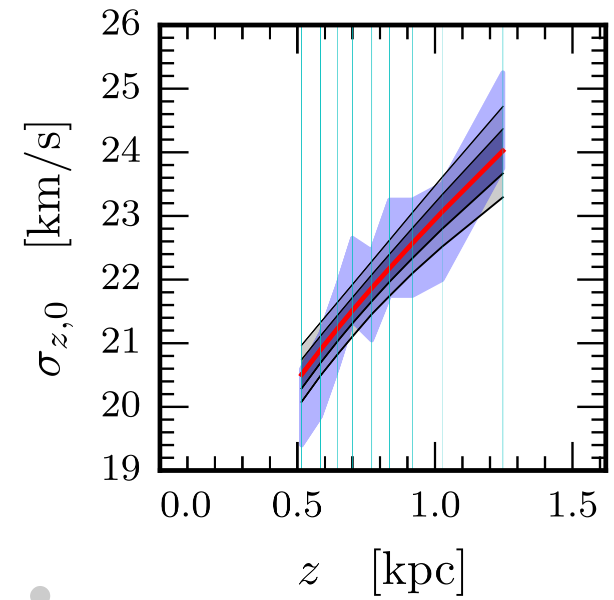



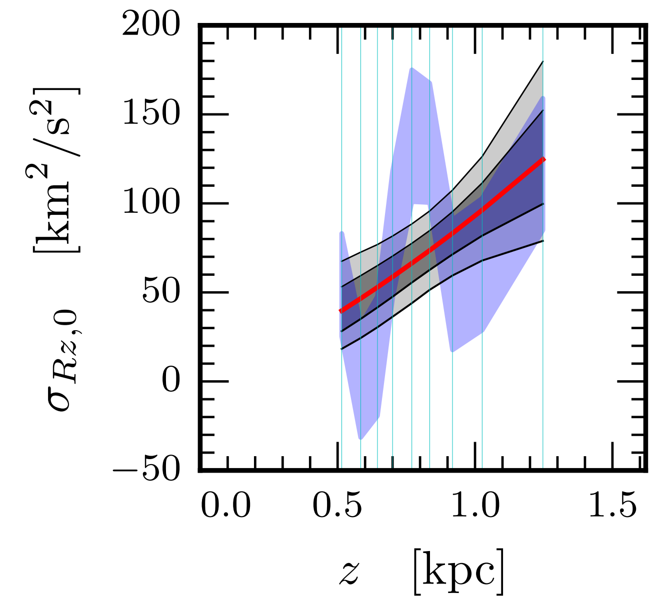


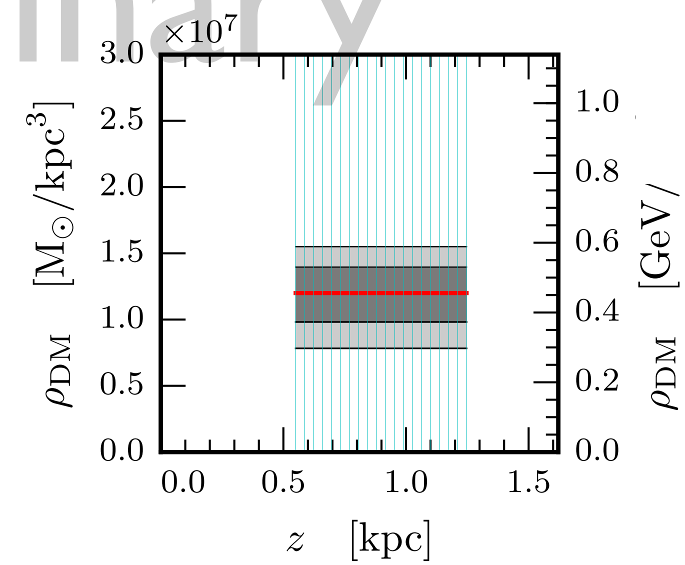

Fit **not** including the tilt term.

Fits the data well.



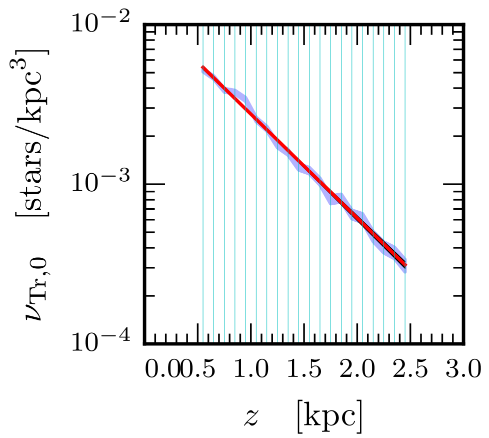



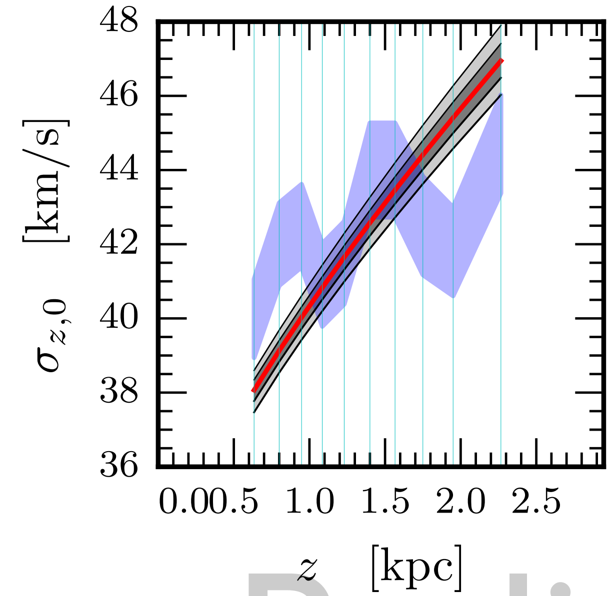



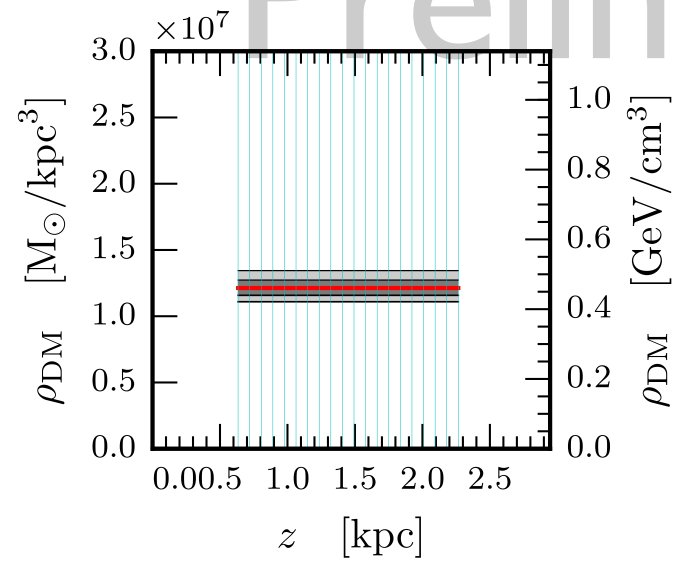

Fit including the tilt term.

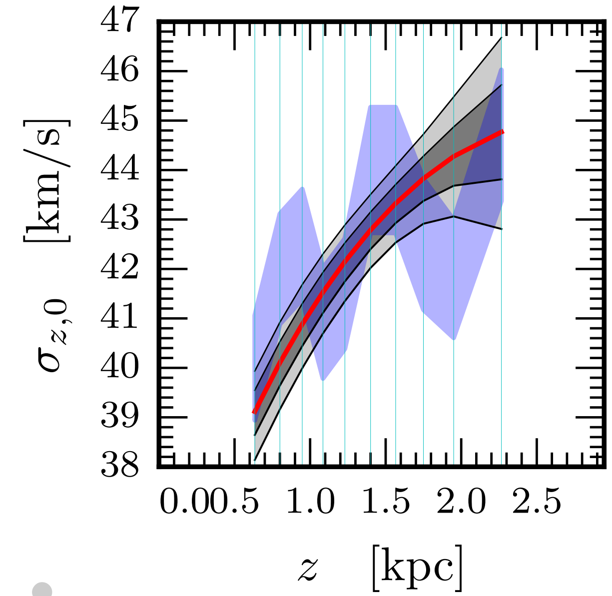
Fits the data well, gives a wider range for the dark matter density.

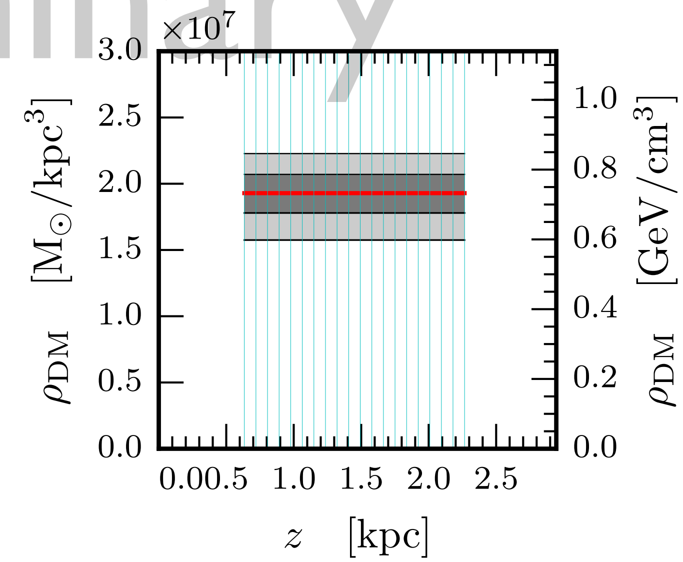
# Fitting to the old population

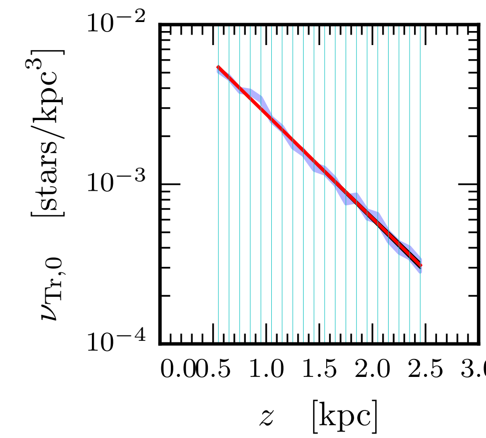


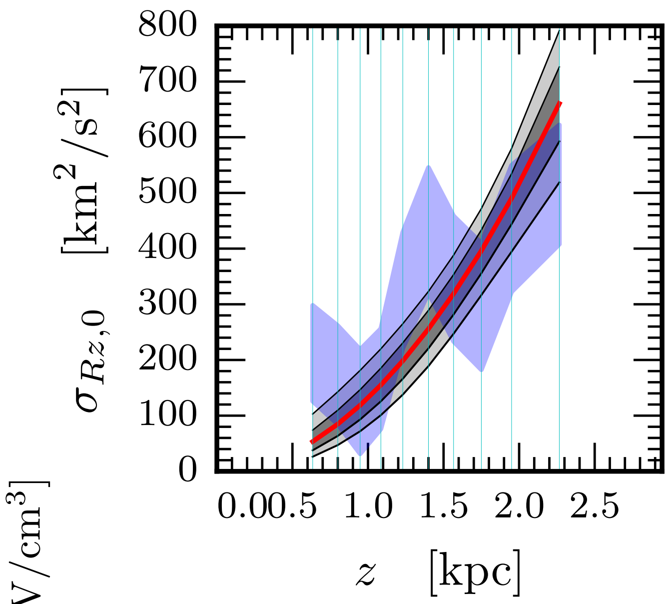




Preliminary

Fit **not** including the tilt term.

Does not fit the velocity data well.

Overly constraining the dark matter density.

Fit including the tilt term.

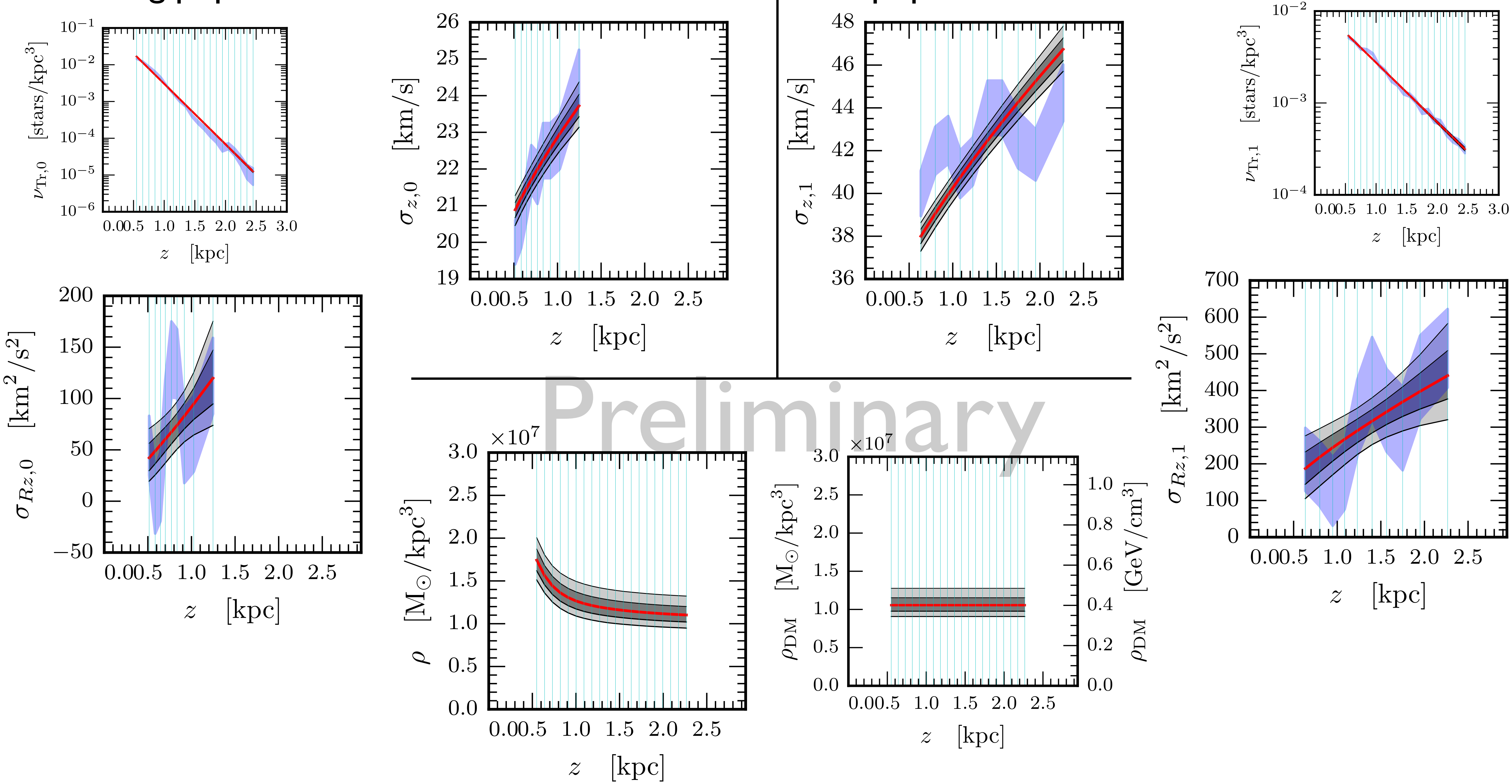
Not so good fits to the velocity data.

Gives a very high dark matter density

# Fitting both populations, including the tilt term.

Young population:

Old population:




Fits the young data well, but not the vertical velocities for the old data.

Resulting dark matter density similar to that from the young population alone.

# Final remarks.

- Joint population analysis driven by the young population data.
- Young pop (with tilt): $\rho_{\rm dm} = 0.46^{+0.13}_{-0.16}\ {\rm GeV/cm^3}$
  Both pop (with tilt): $\rho_{\rm dm} = 0.40^{+0.8}_{-0.6}\ {\rm GeV/cm^3}$
- We have so far not discussed the rotation curve term. Literature compatible with zero rotation curve term, adds an error of ~0.1 Gev/cm^3 (Bovy et.al. 2012).
- Further investigate the old population data. Disequilibrium, breathing mode? (Banik et.al. 2016)
- Gaia data.