The local dark matter density

Gaia data revolution

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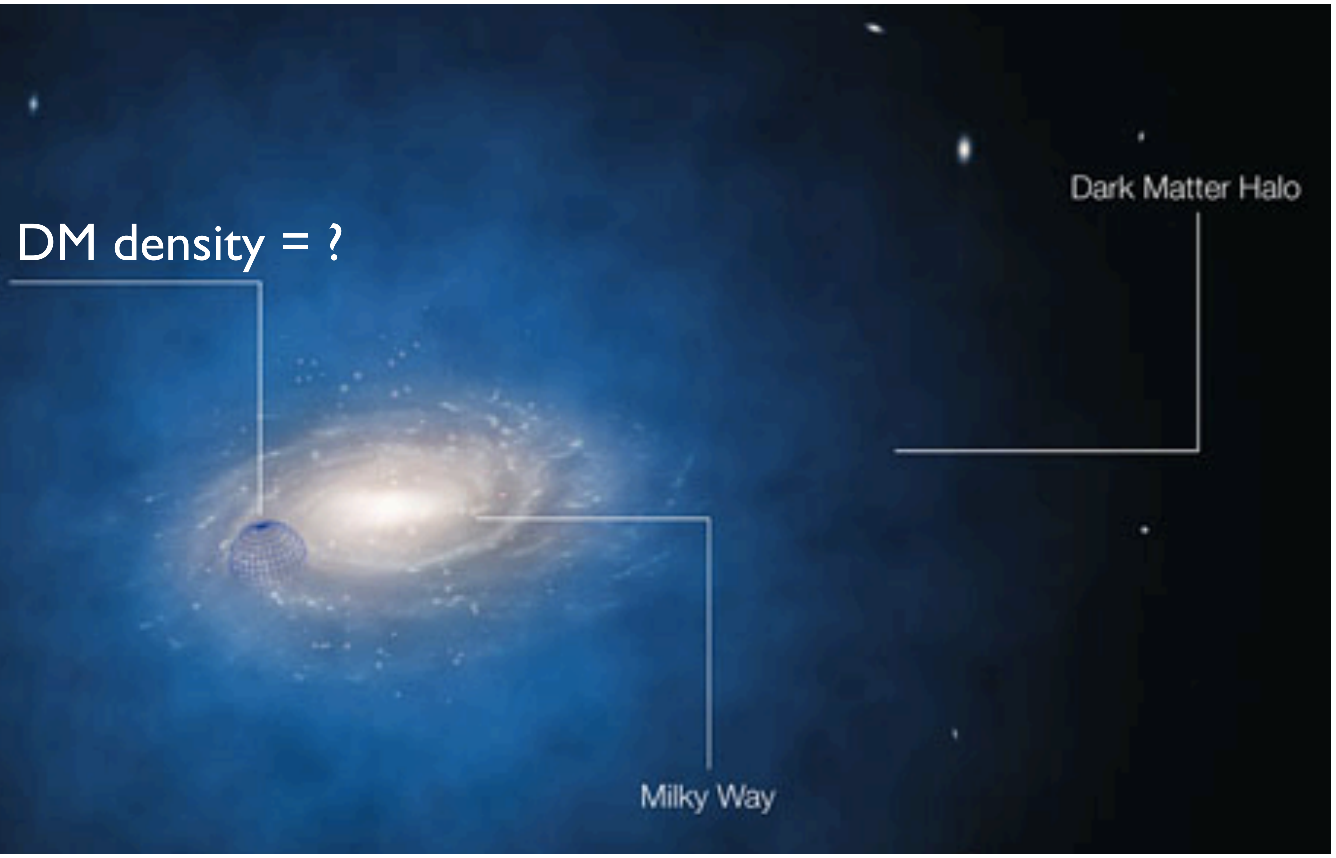
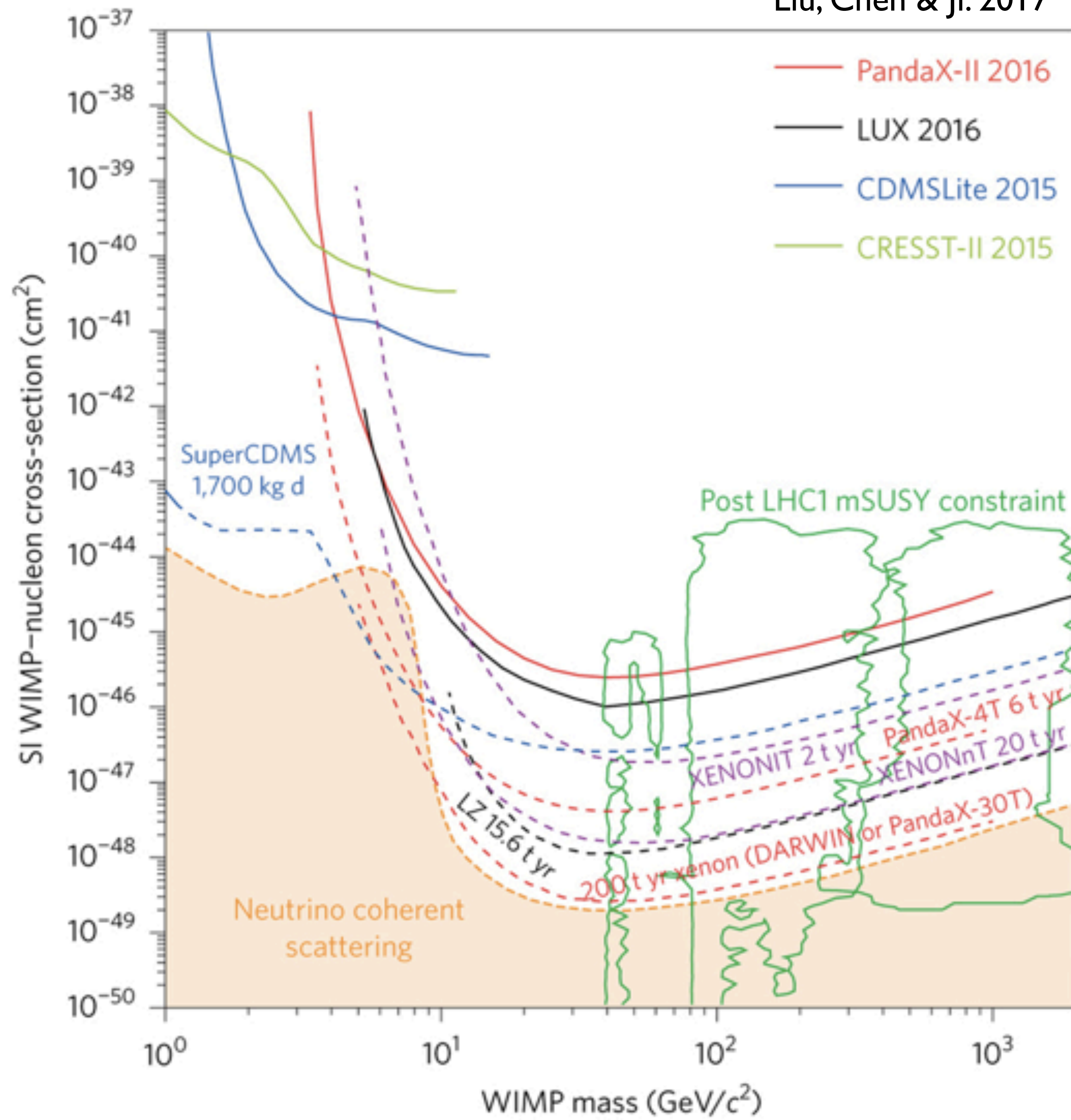
The local dark matter density

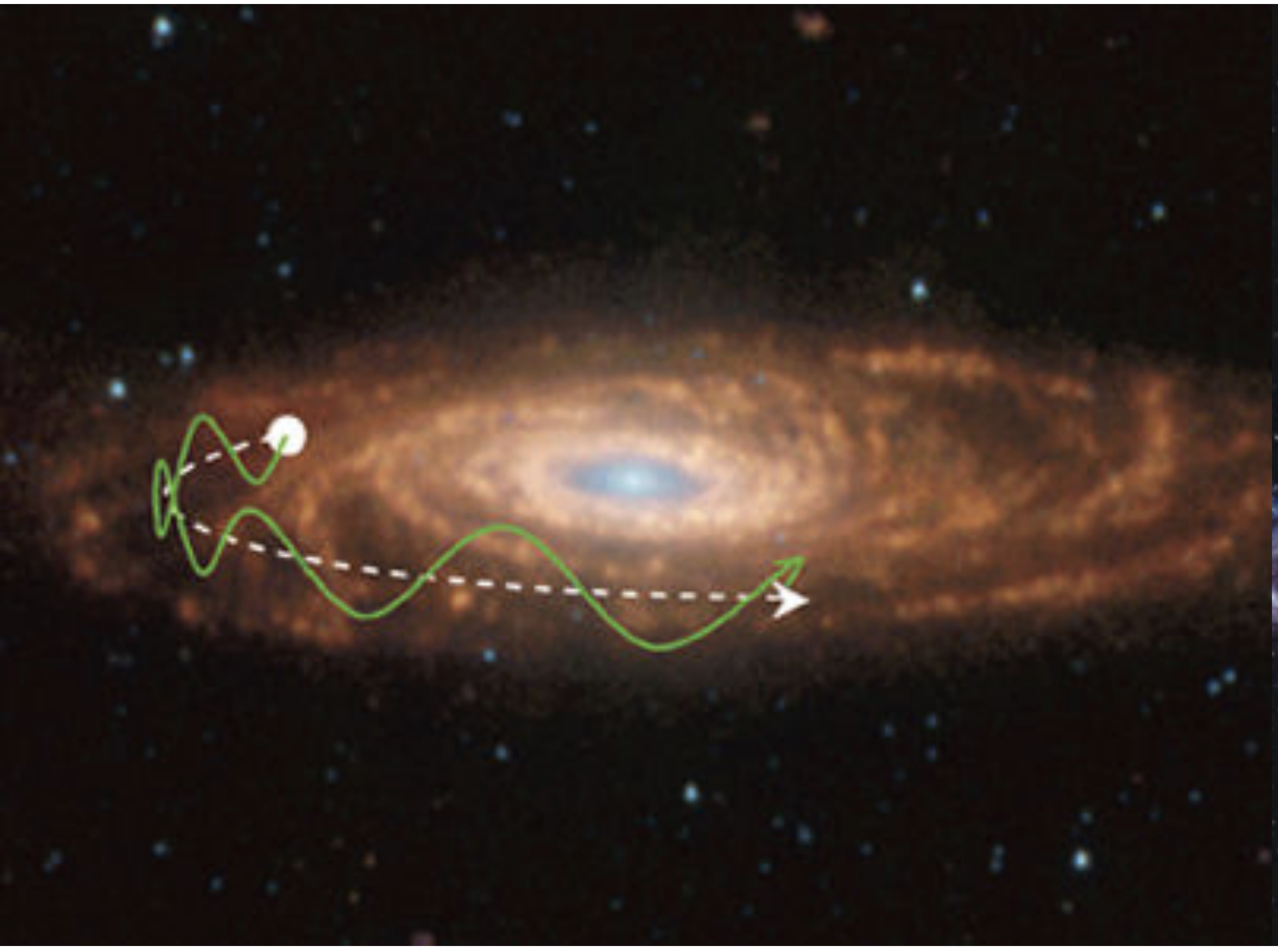


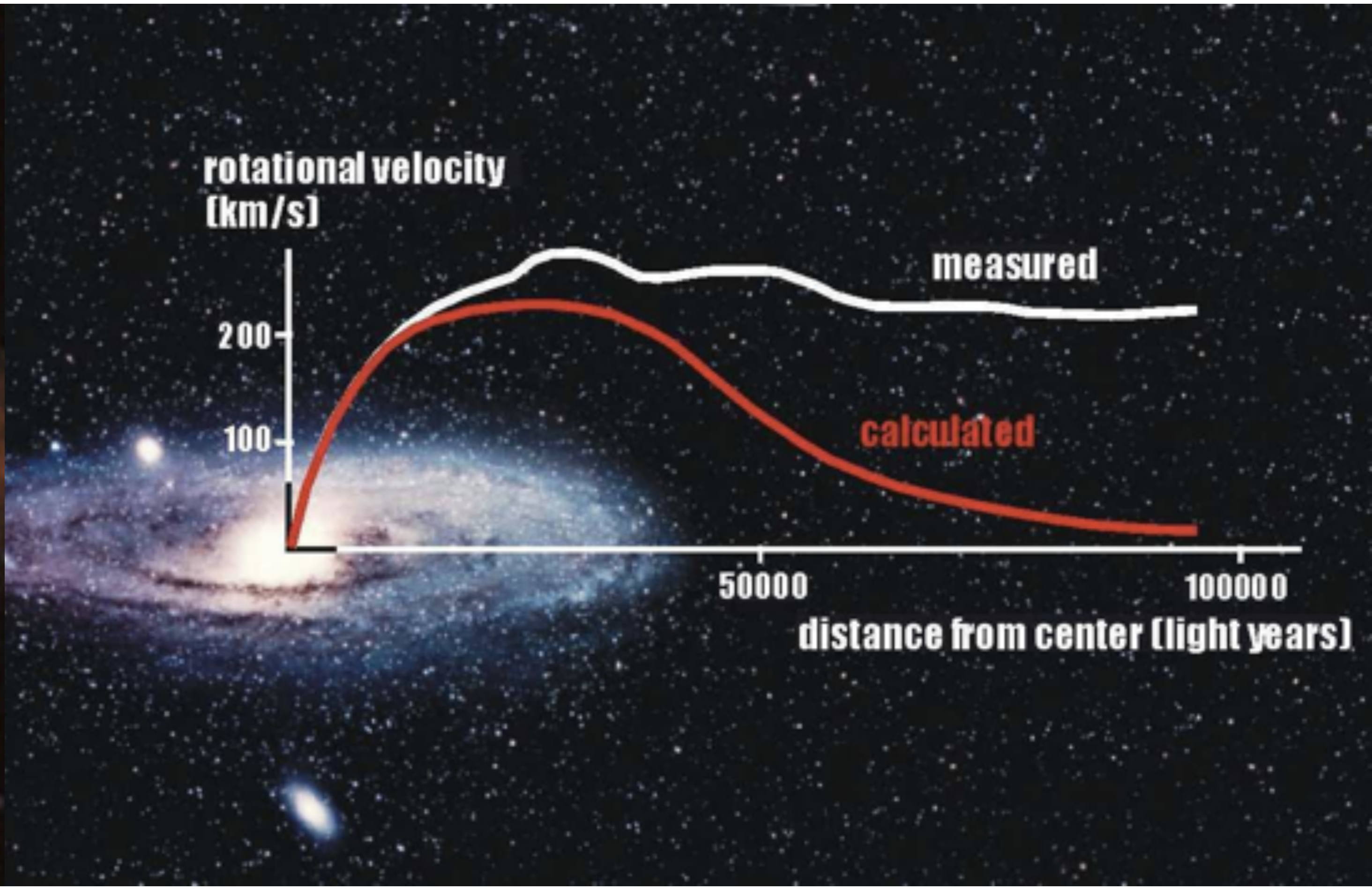
Liu, Chen & Ji. 2017



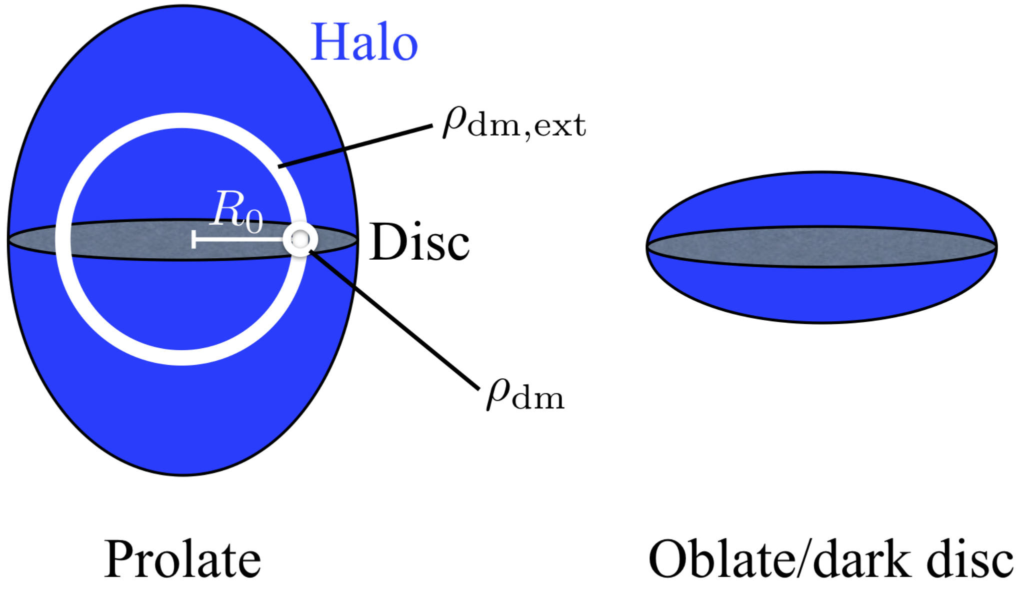
- What is the local dark matter density in our region of the Milky Way?
- Depends on the history of the Milky Way.
- Direct detection limits typically proportional to the local dark matter density.
  (Usually assume 0.3 GeV/cm3)

Local and global density measurements

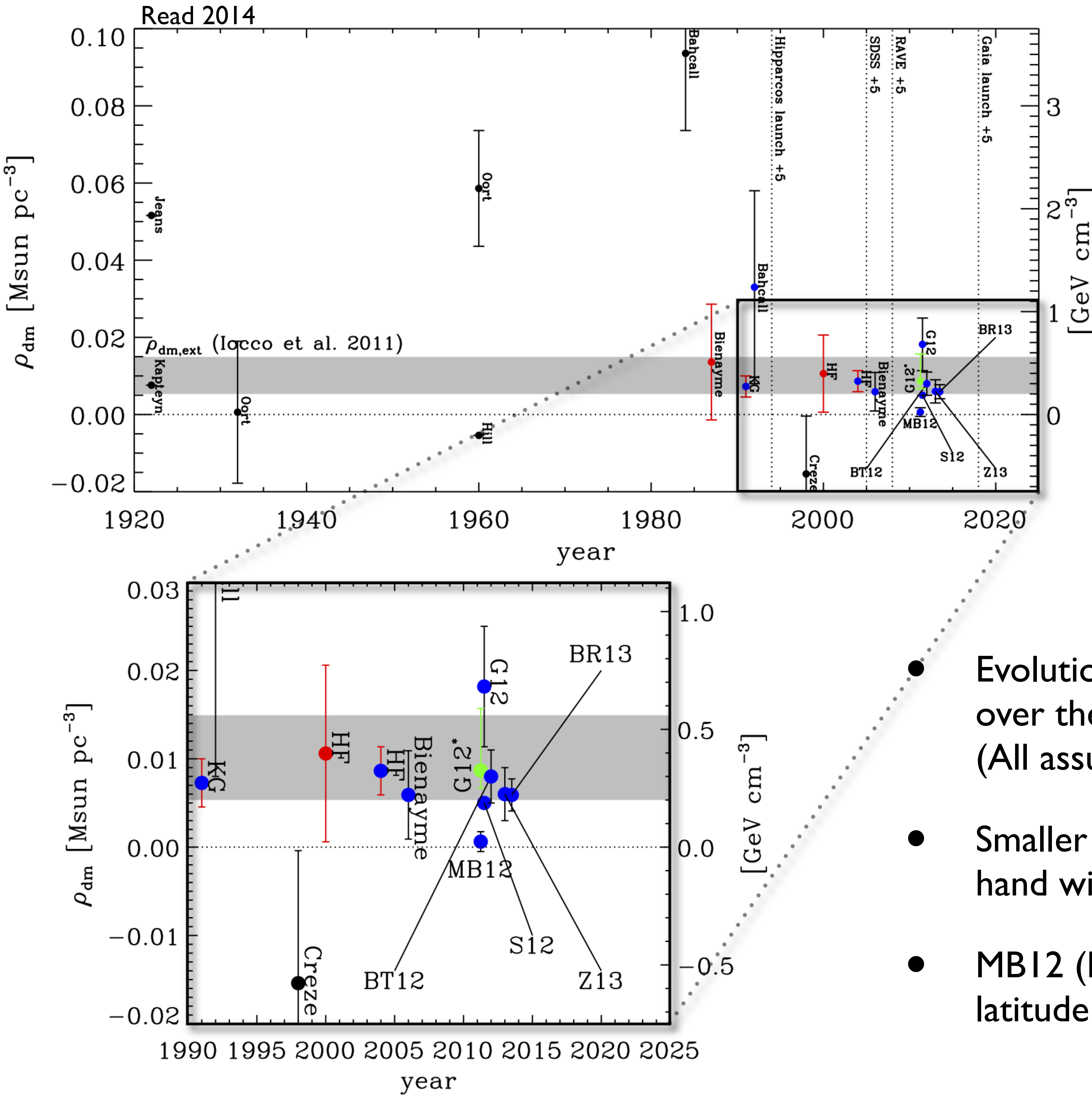




- Local dark matter density from the vertical motion of stars. This work.
- Global density profile by rotational velocities of stars.
- Comparing the results of the two measurements gives some information about the shape of the dark matter halo.



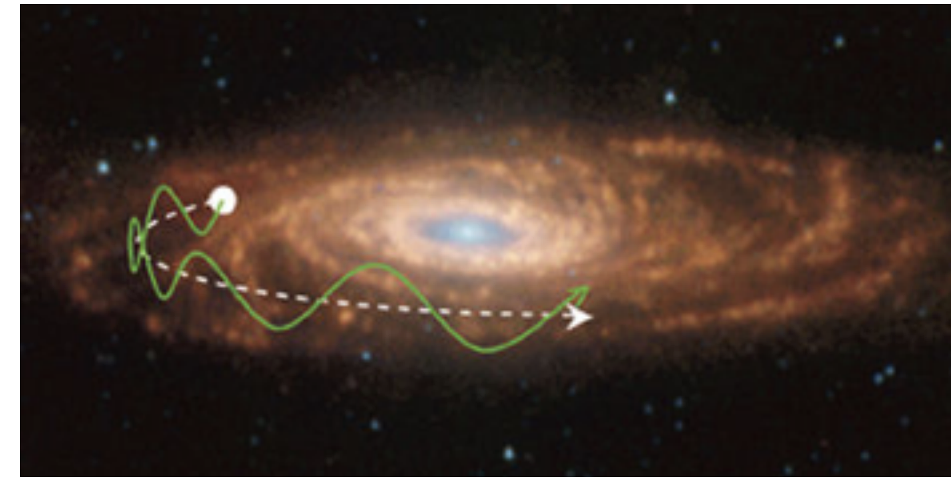
Dark matter density evolution



- Evolution of the dark matter density over the past century. (All assume the same baryonic density.)
- Smaller error bars usually goes hand in hand with more assumptions.
- MB12 (Bidin et.al.) ~500 stars at high latitude (2-4 kpc).

Using Jean's equations, assuming steady state.

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



Integrate

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

Velocity dispersion

Tracer number density

Surface density

Tilt term
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 ρ

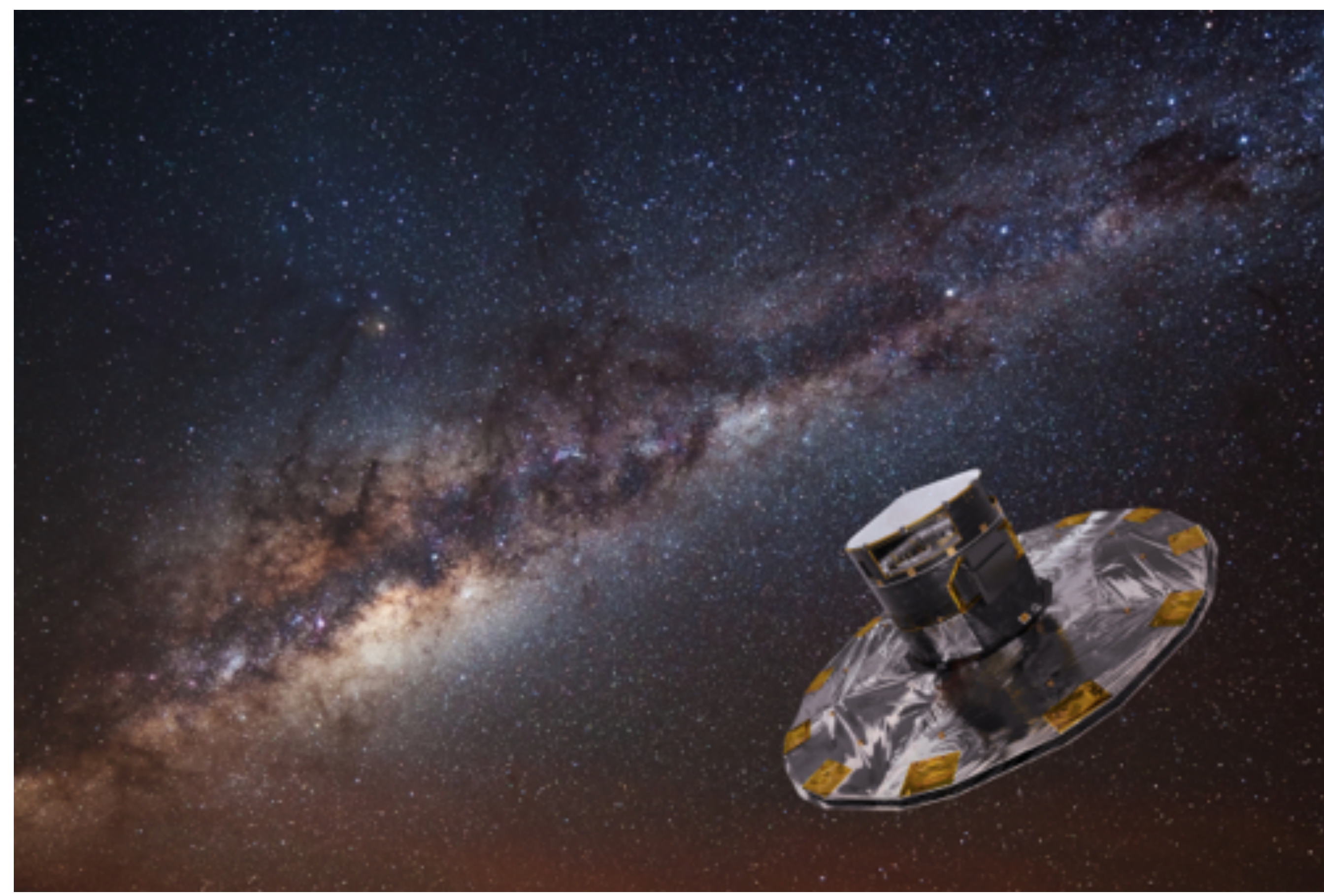
Terms usually neglected, i.e. assumed to be zero.

Subdominant and difficult to measure. Gaia!

Fit to data using Multinest. Less assumptions required.

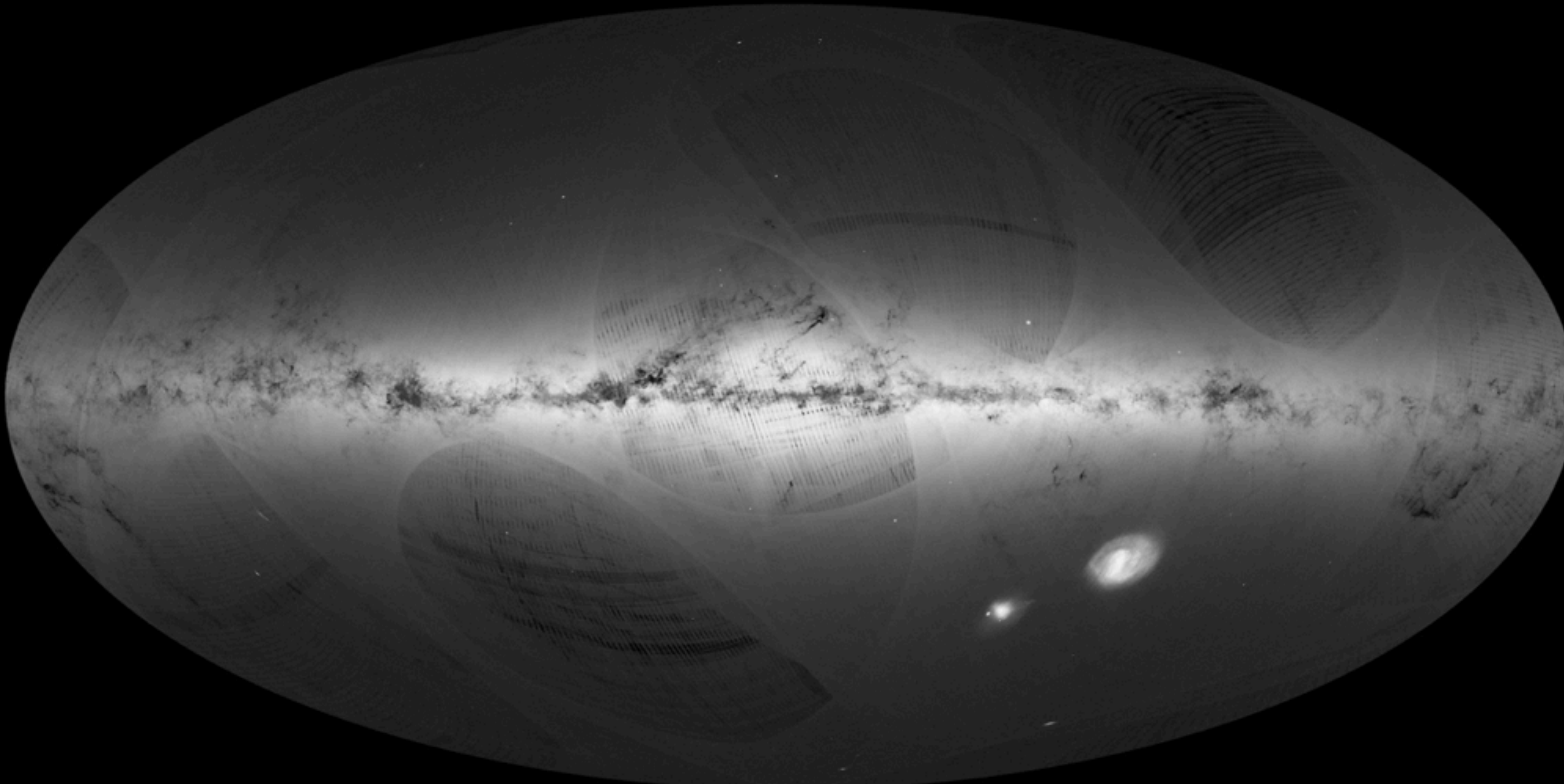
Gaia satellite mission

- Launched 19 December 2013.
- First data release 14 September 2016:
  Position of 1.1 billion single stars with acceptable error.
  Proper motion for stars in common with Tycho-2 catalogue.
  Systematic errors.
- Second release: April 2018.
  Radial and proper motion for bright stars.
- Final release: 2022 (including ground based observations).



→ GAIA'S FIRST SKY MAP

esa



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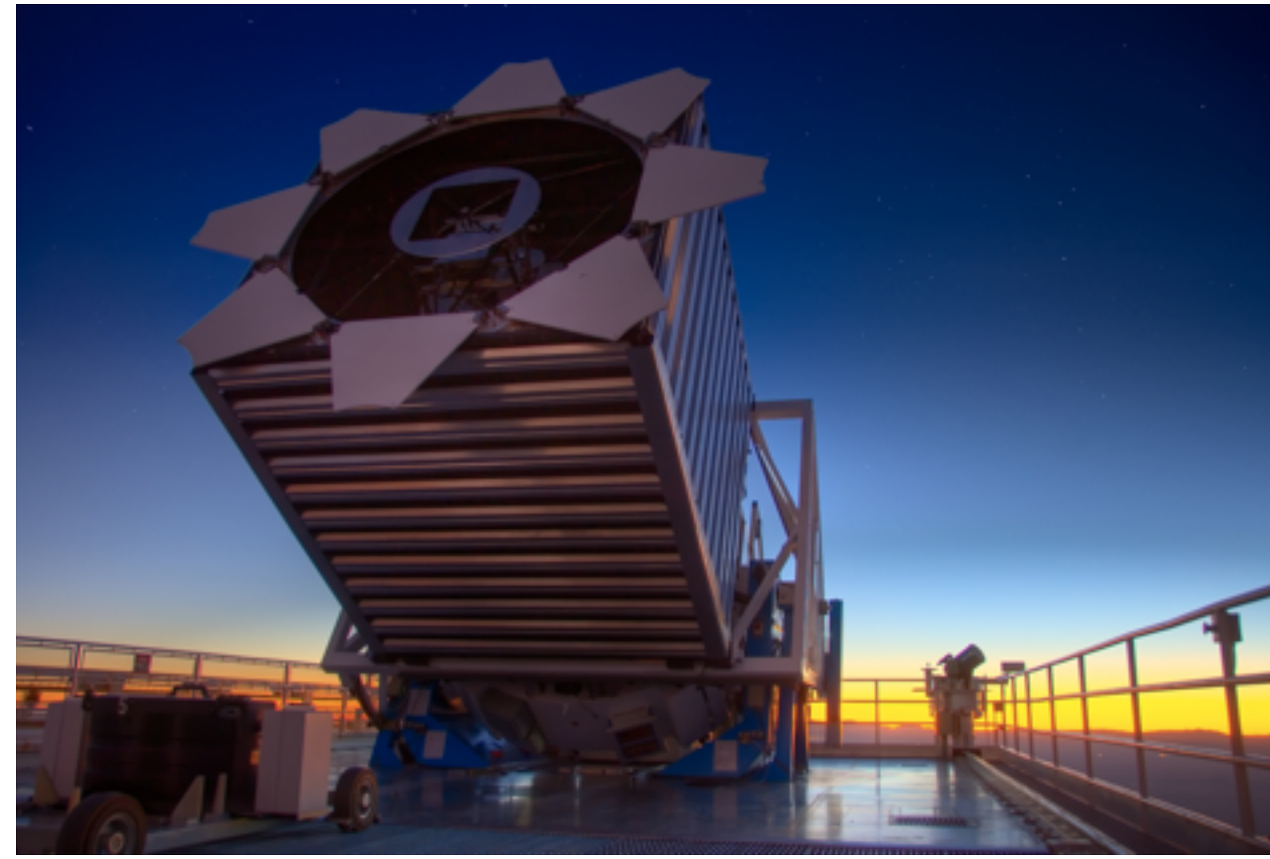
Credit: ESA/Gaia/DPAC

European Space Agency

Method applied on SDSS data, with tilt



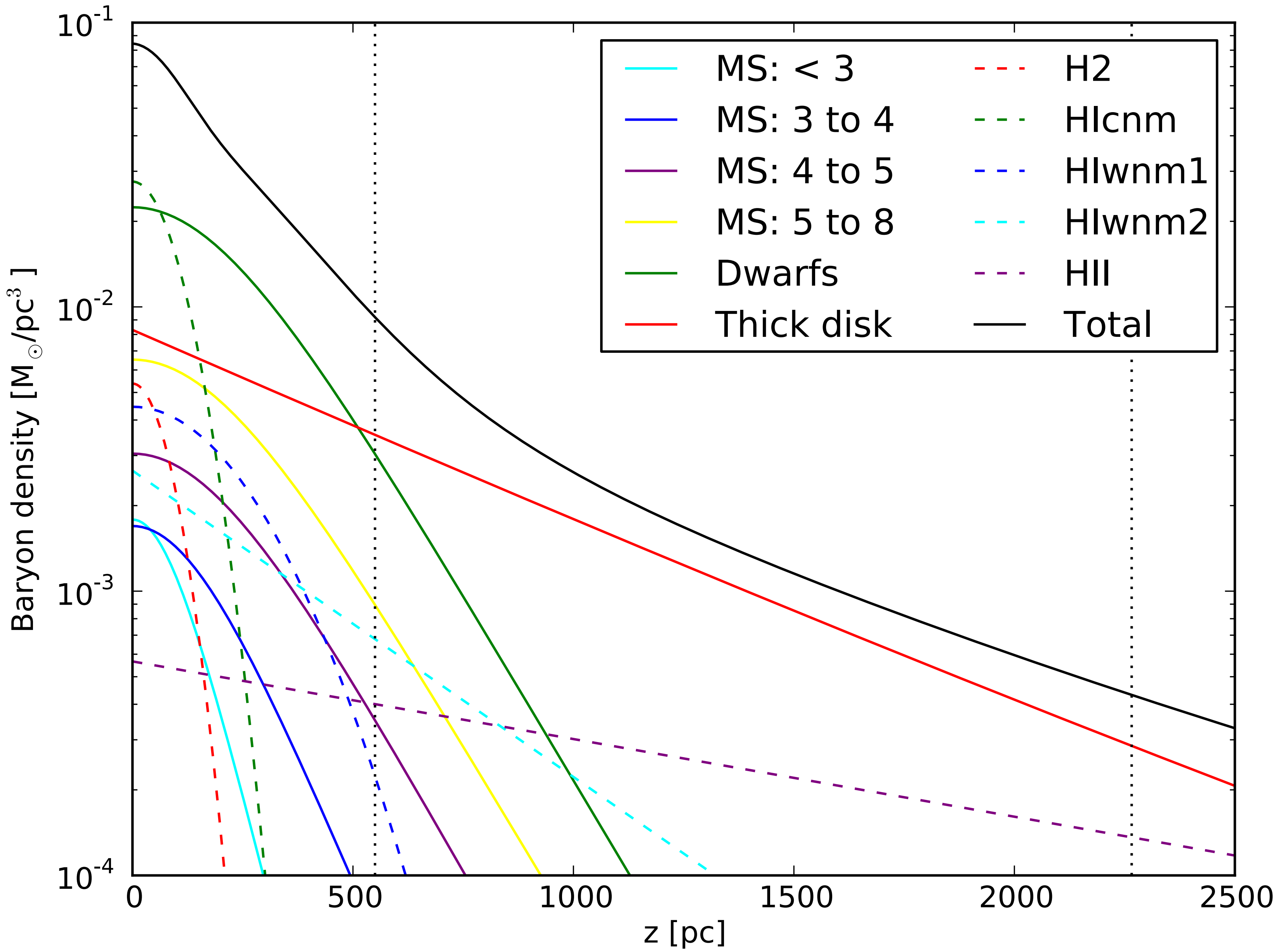
- Applied our method to SDSS data, analyzed by Büdenbender et.al. Awaiting Gaia's second data release.
- Measurement of tilt (although not well constrained).
- Split tracer stars in old and young populations (by metallicity). Young stars more confined to the disk plane.
- Old stars further away, more difficult to measure. We do not manage to find a decent fit to the old tracer stars. (Requires too high baryonic surface density.)
- Present analysis of young tracer population only.

Baryon density profile

NGC 891 - Milky Way analog

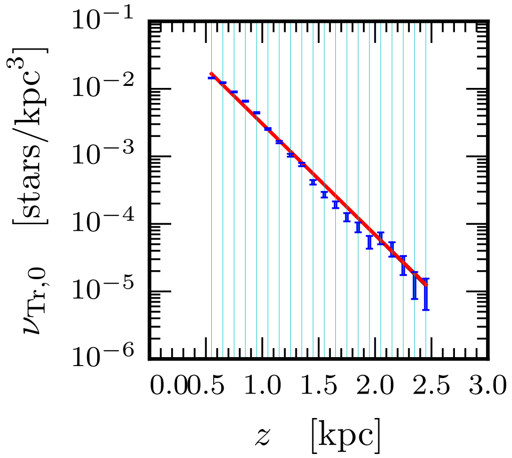
- Baryons dominate close to the disk,
  DM dominate further out.

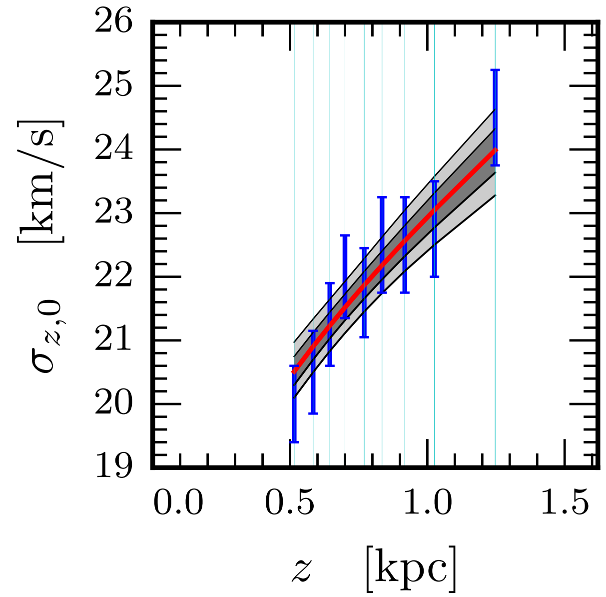
- Far out more complicated:
  fewer tracer stars,
  tilt term more important.

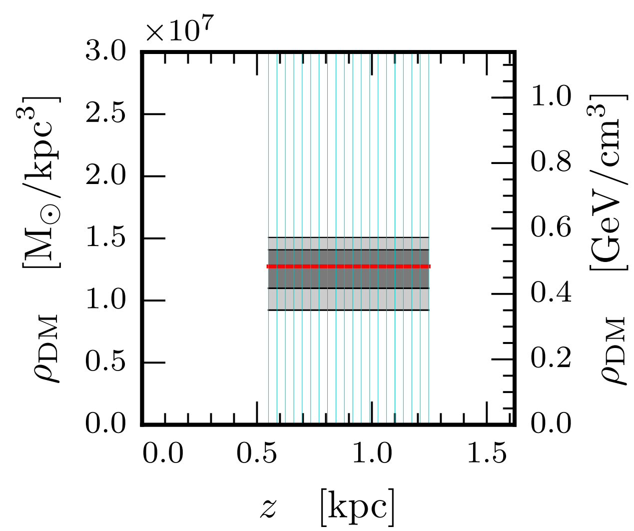


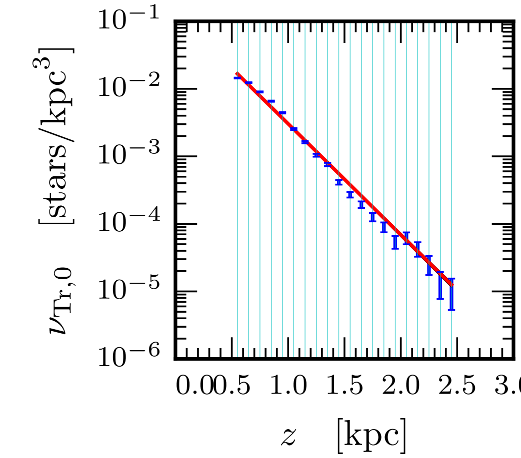
$$0.4\ \mathrm{GeV/cm^3} \simeq 10^{-2} M_\odot/\mathrm{pc}^3$$

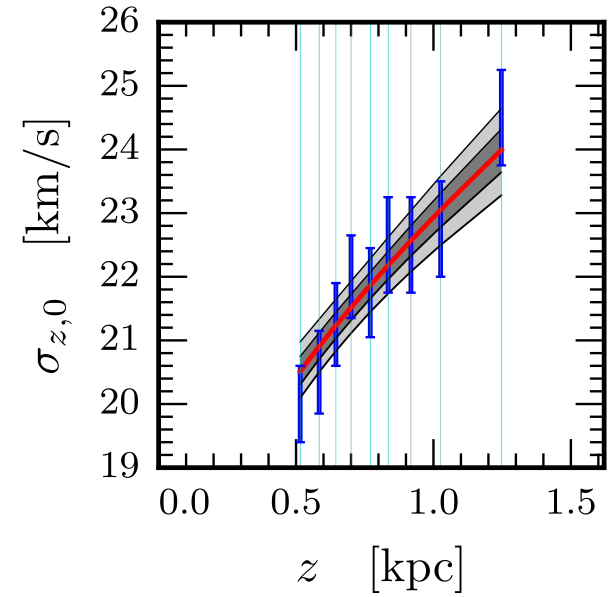
Fitting to the young population

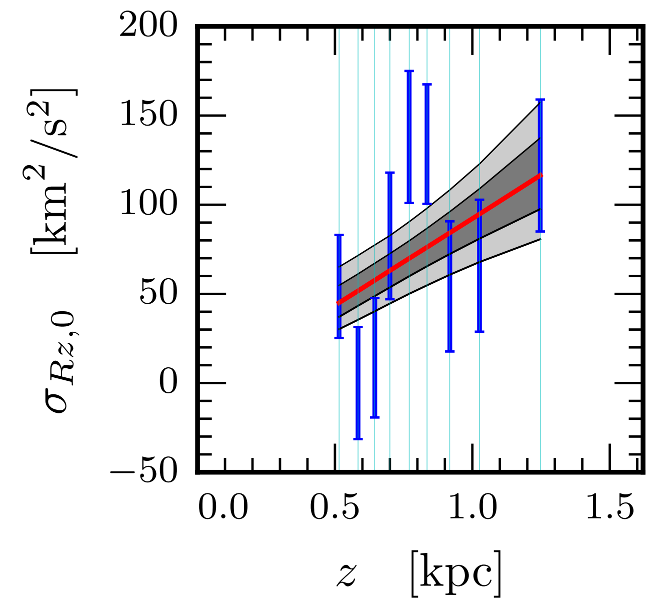


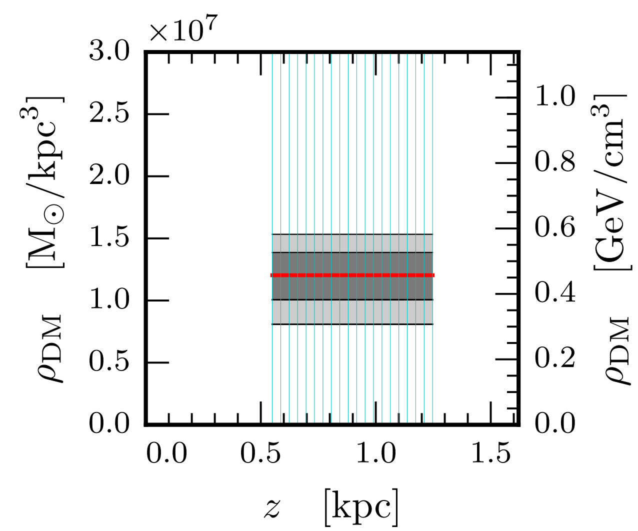












201610201137
0.5<n<1.5
-1.3 < k_young < 1
(-0.5 < k_old < 1.5)

Fit **not** including the tilt term.

Fits the data well.

201606262336

Fit including the tilt term.

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

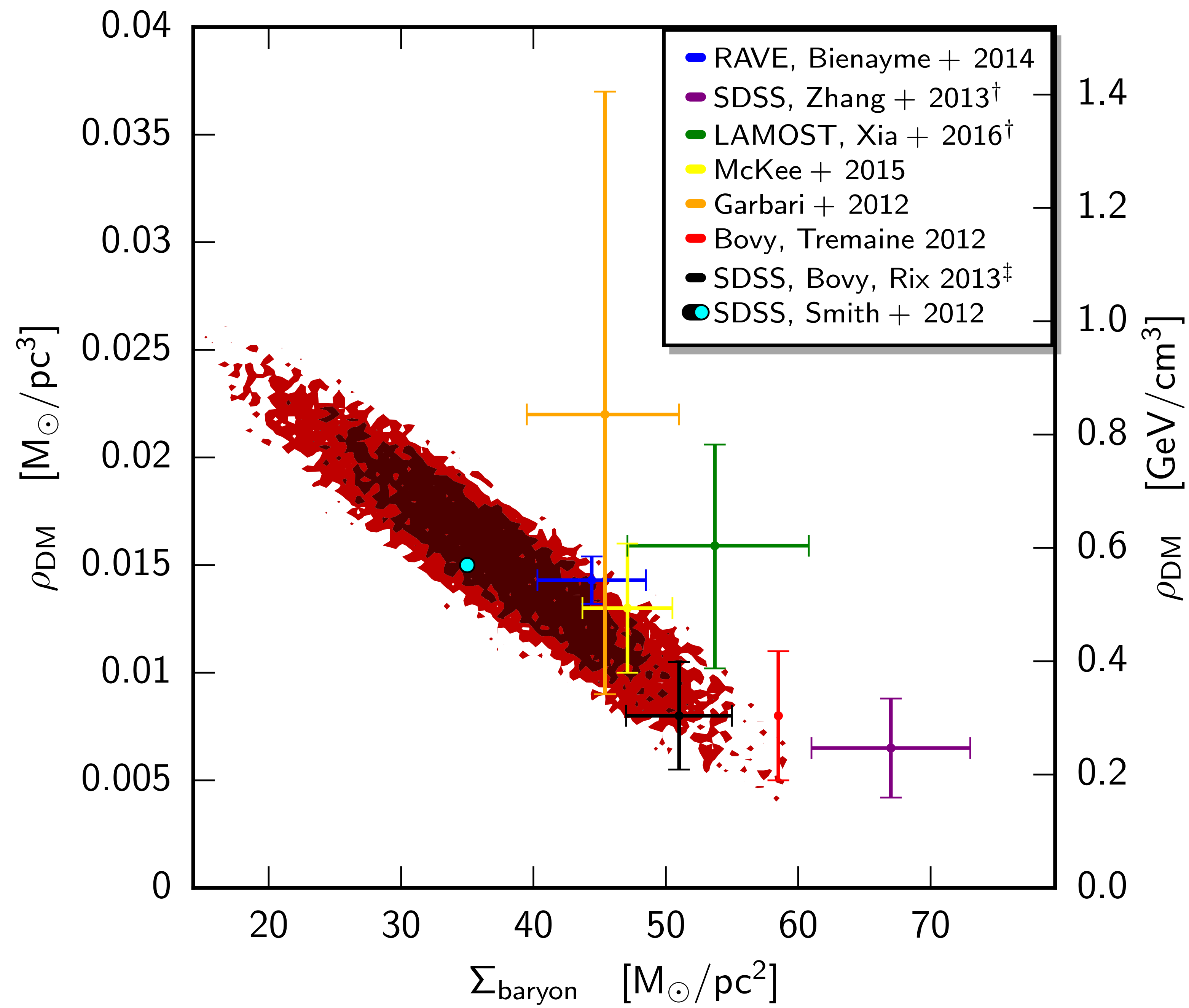
As expected, tilt term not very important for the young stellar population.

Results & outlook

- Young pop (with tilt): $\rho_{\rm dm} = 0.46^{+0.13}_{-0.16}\ {\rm GeV/cm}^3$
- 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).
  Better measurement to come, also dependence on height above disk plane.
- Disequilibrium? No sign of a breathing mode in the data, but there is a small net velocity.
- Gaia data.

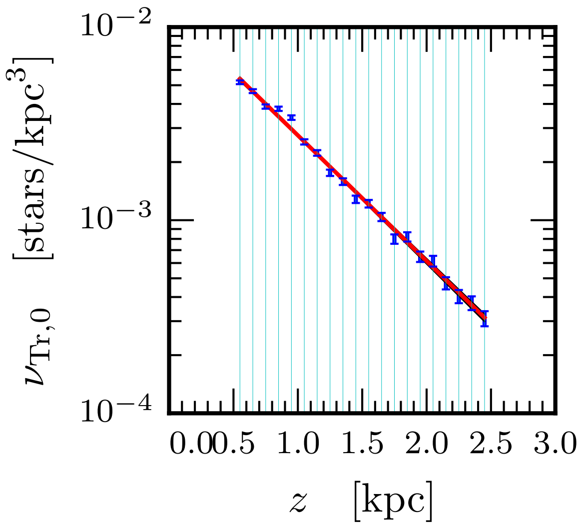
DM baryon degeneracy

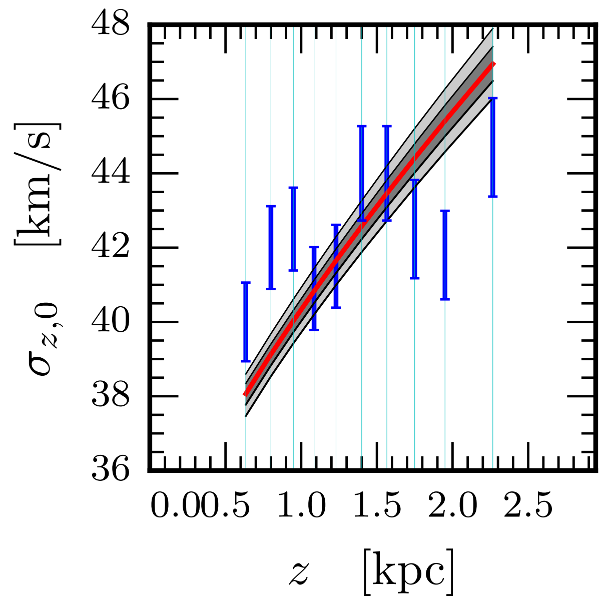
- Red ellipses: Our result (without baryonic prior).
- Degeneracy between DM density & baryonic surface density.
- Important when comparing results.

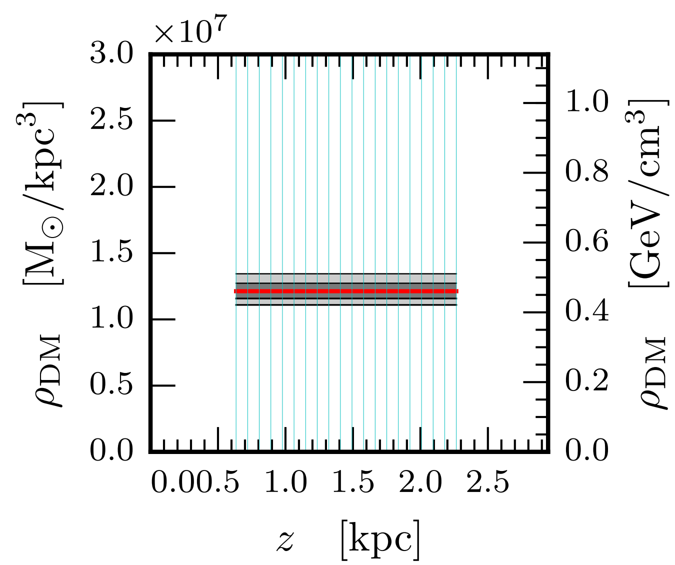


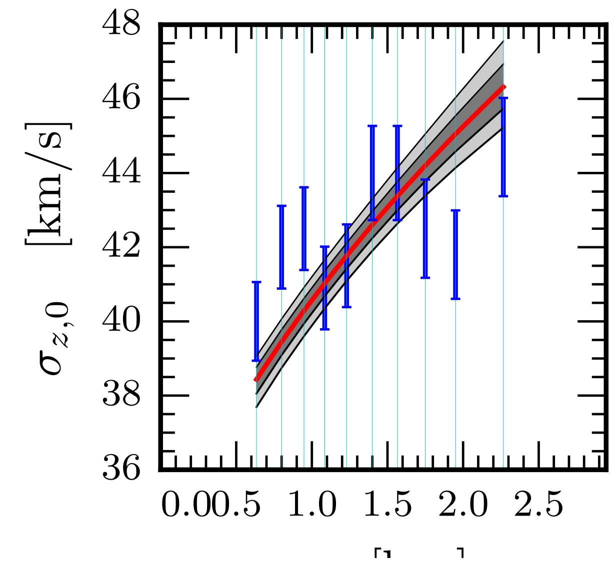
Backup slides

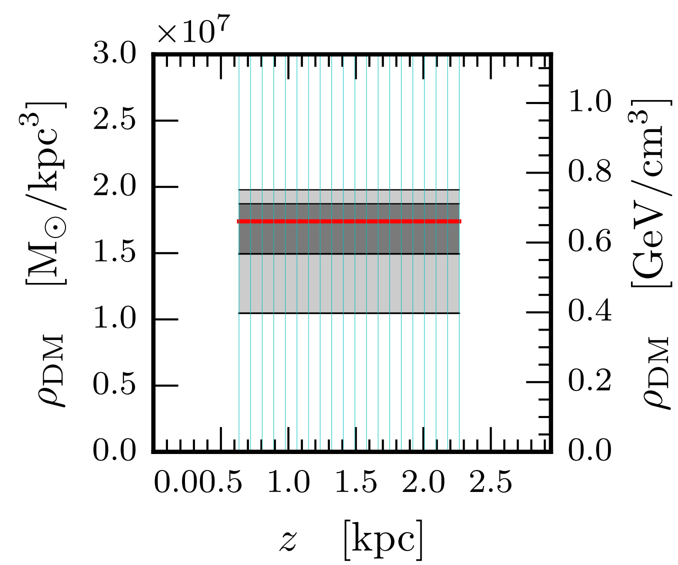
Fitting to the old population

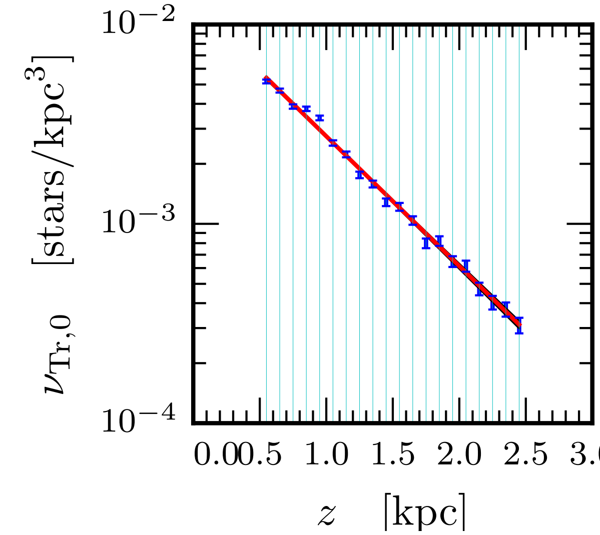


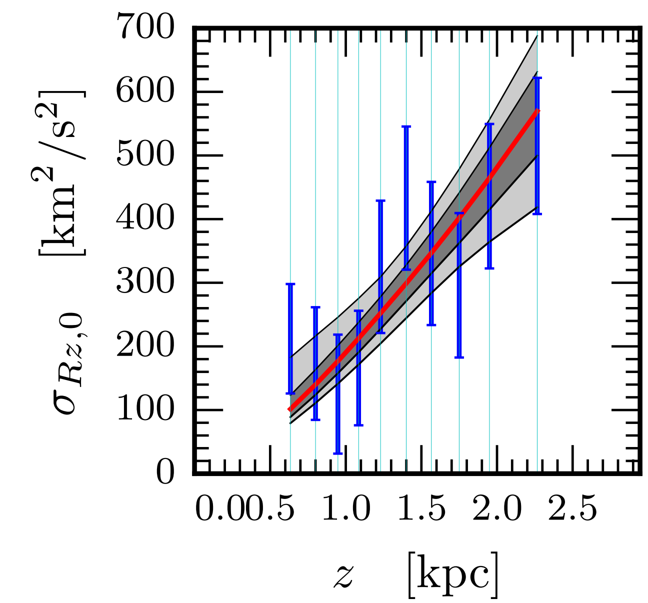












201610201140
0.5<n<1.5 ;
(-1.3 < k_young < 1)
-0.5 < k_old < 1.5

Fit **not** including the tilt term.

Does not fit the velocity data well.

Overly constraining the dark matter density.

201606270022

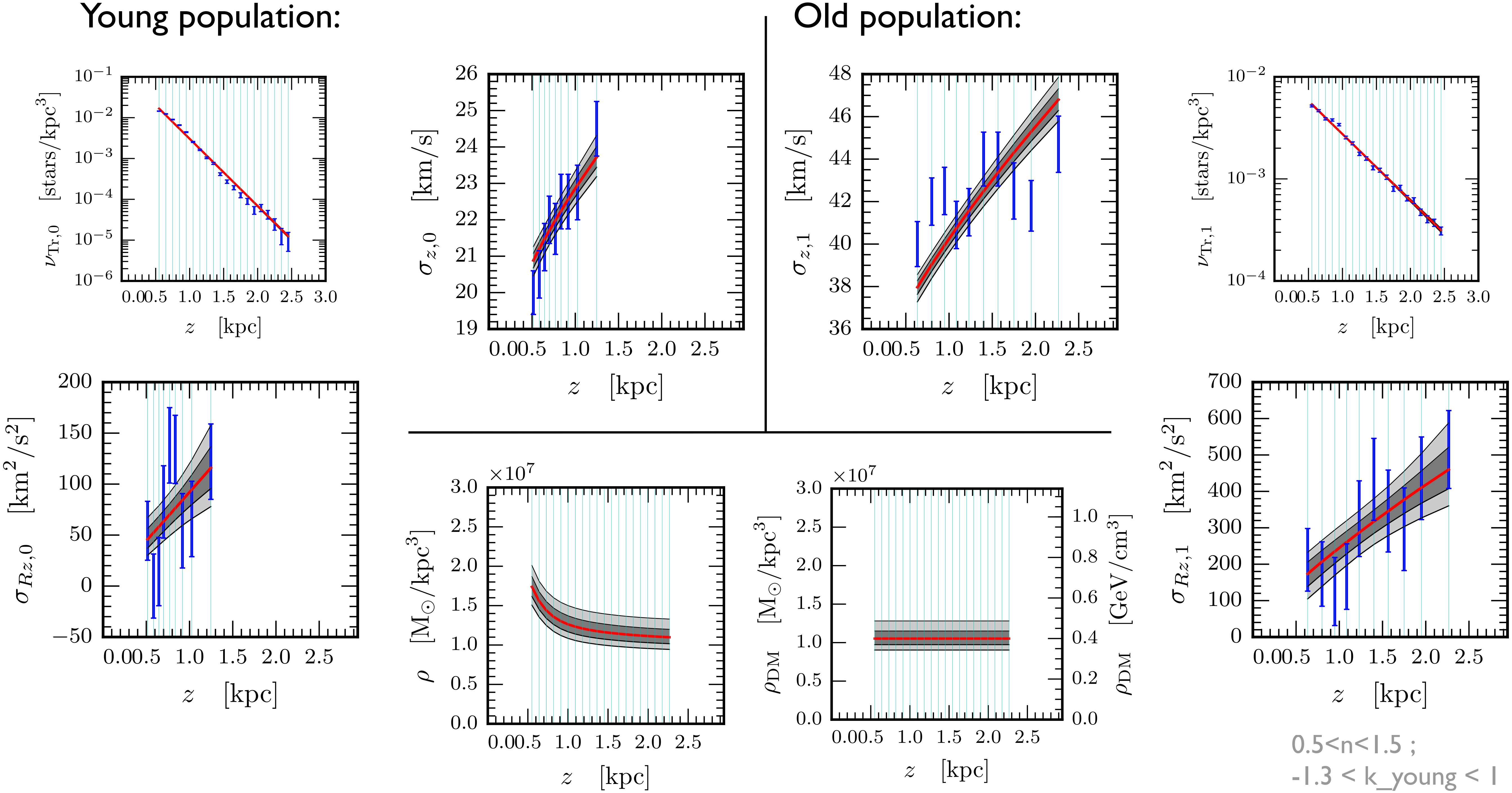
Fit including the tilt term.

To fit the old data would require extra mass at the disk plane, which the tilt term cannot mimic.
(Not seen in young data)

Fitting both populations, including the tilt term.

Young population:

Old population:



0.5<n<1.5 ;
-1.3 < k_young < 1
-0.5 < k_old < 1.5

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 but seemingly overly constrained.