The vertical force in the solar neighbourhood

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credit: NASA, ESA, and T. Brown and J. Tumlinson (STScI)


credit: ESO/L Calçada.

The force-equation

- We explore the vertical force-equation:

$$-\frac{\mathrm{d}\Phi}{\mathrm{d}z} \equiv F_z = \frac{\sigma_z^2}{\nu}\frac{\mathrm{d}\nu}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_z^2}{\mathrm{d}z} + \frac{\mathrm{cov}(v_R, v_z)}{R}\left[1 - \gamma_{\nu,R} - \gamma_{\mathrm{cov}(v_R,v_z),R}\right]$$

where:

$$\gamma_{Q(x),x} = -\frac{x}{Q(x)}\frac{\mathrm{d}Q(x)}{\mathrm{d}x}$$

- The surface mass density is approximated by:

$$\Sigma(z) \approx \frac{|F_z(z)|}{2\pi G}$$

The vertical force equation & dark matter

- Near the mid-plane, the baryonic surface density is expected to be dominant over a possible DM surface density.

- Therefore, to constrain a DM density we need to probe up to sufficiently large galactic heights.

Data

- TGASxRAVE = 6D phase-space information for about 200.000 stars!

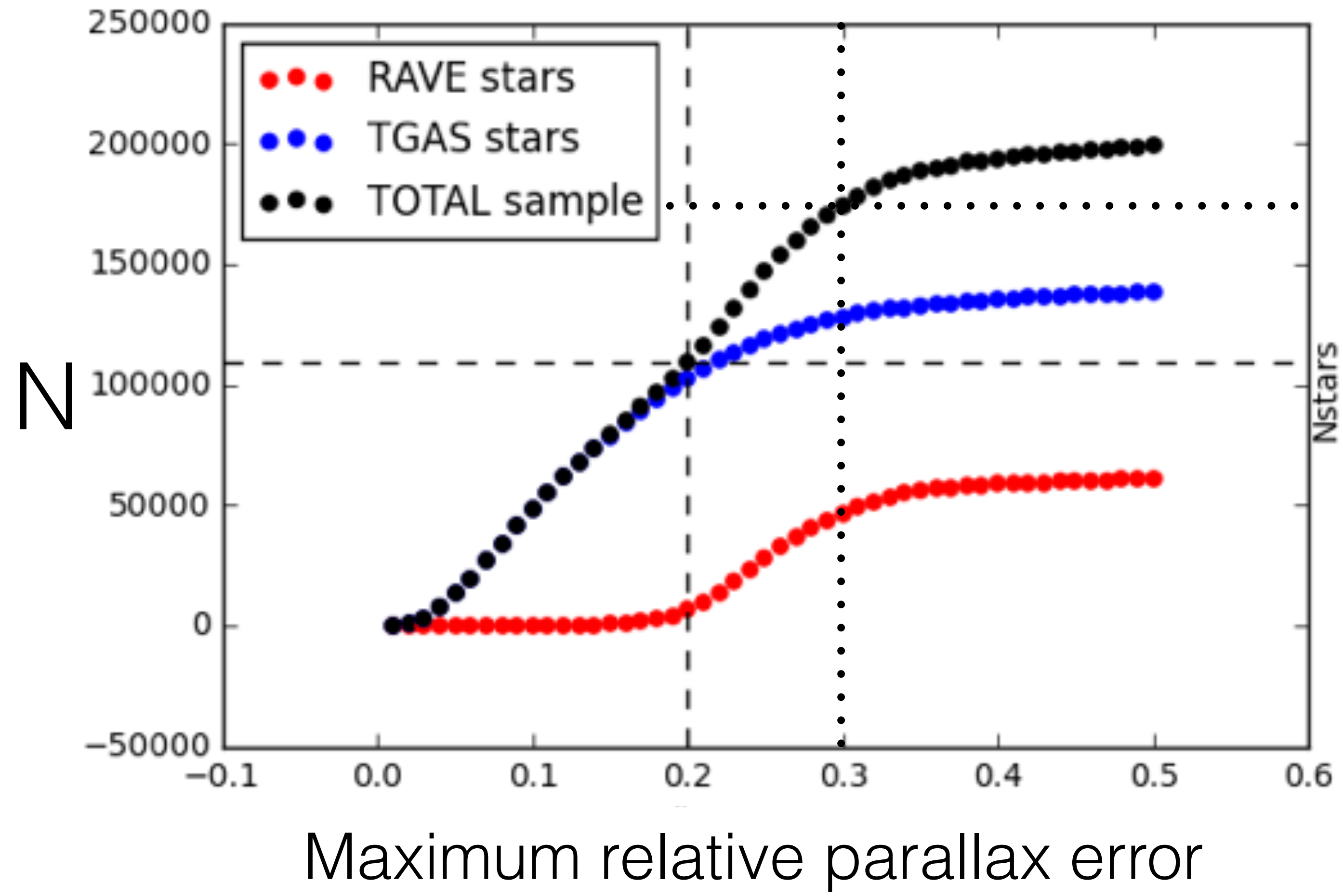
- Selection Criteria:
  parallax > 0
  parallax_error / parallax < 0.2

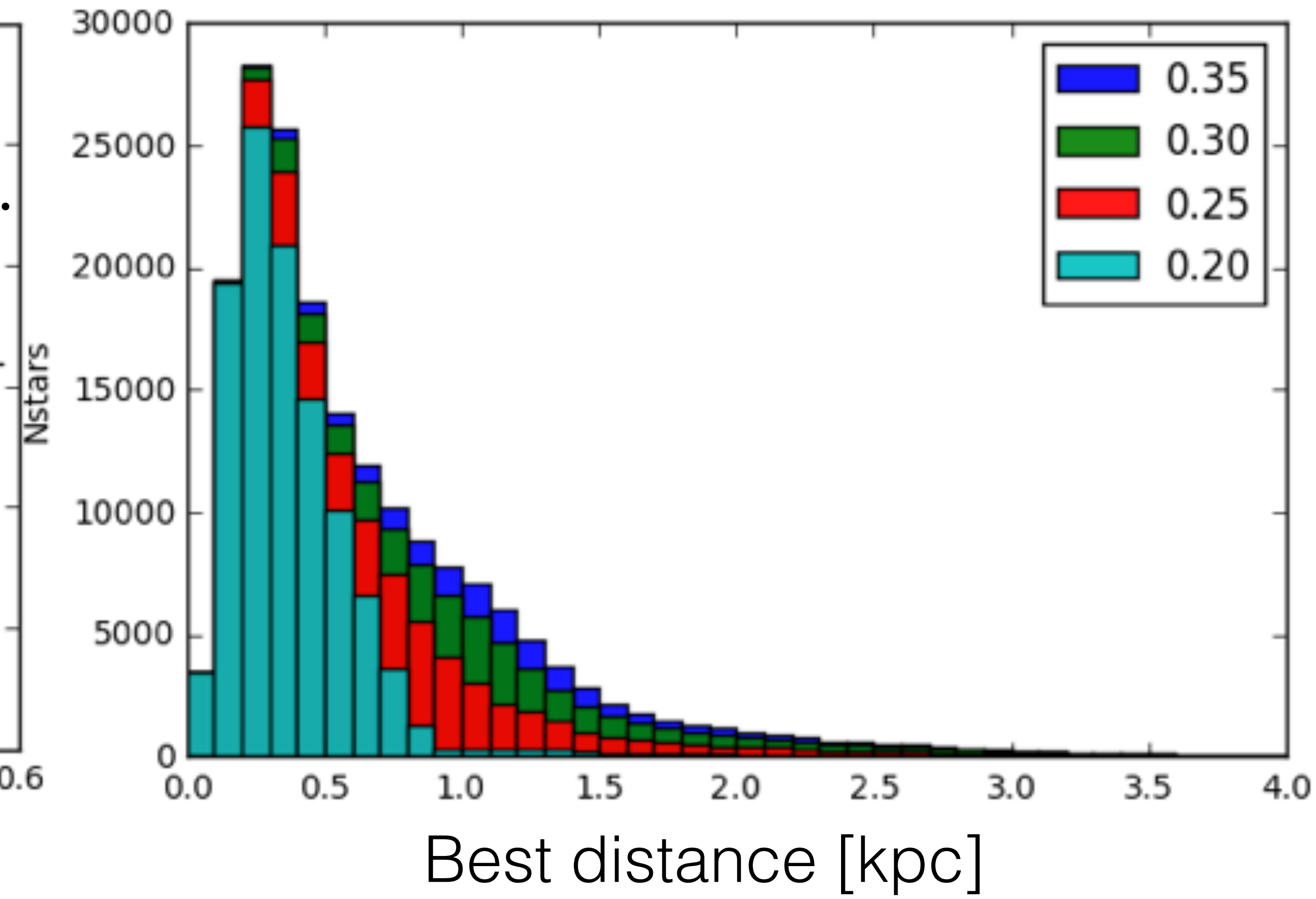
- Parallaxes are either taken from TGAS or from RAVE DR5: the measurement with the best relative error on the parallax is used.

- RAVE radial velocities if:
  eHRV < 8 km/s
  CorrelationCoeff > 10

- RAVE distances only if:
  ALGO_CONV != 1
  SNR > 20

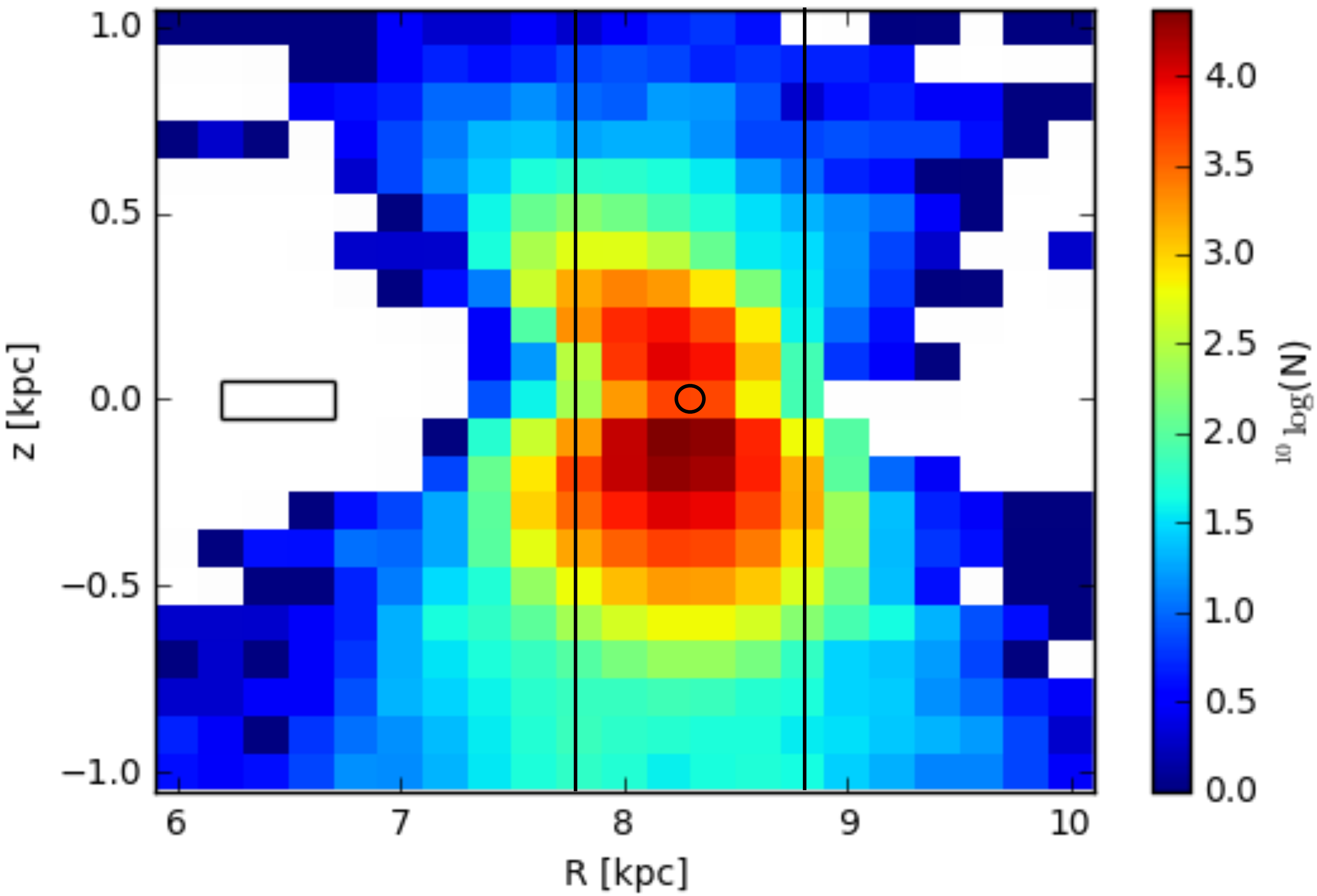
The effect of the maximum relative parallax errors on the sample





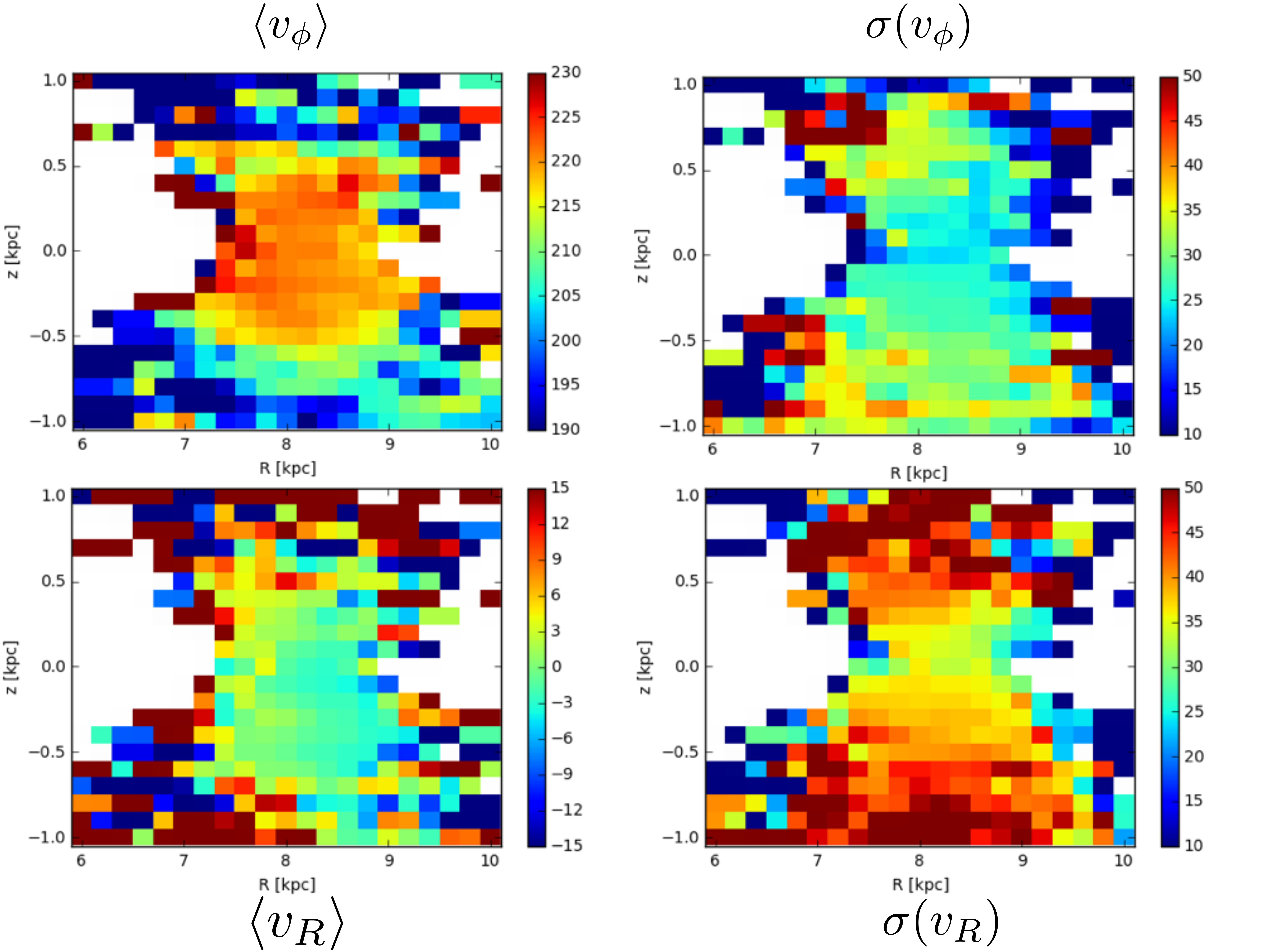
- We choose a maximum of 20% relative distance error

Distribution of stars in our sample



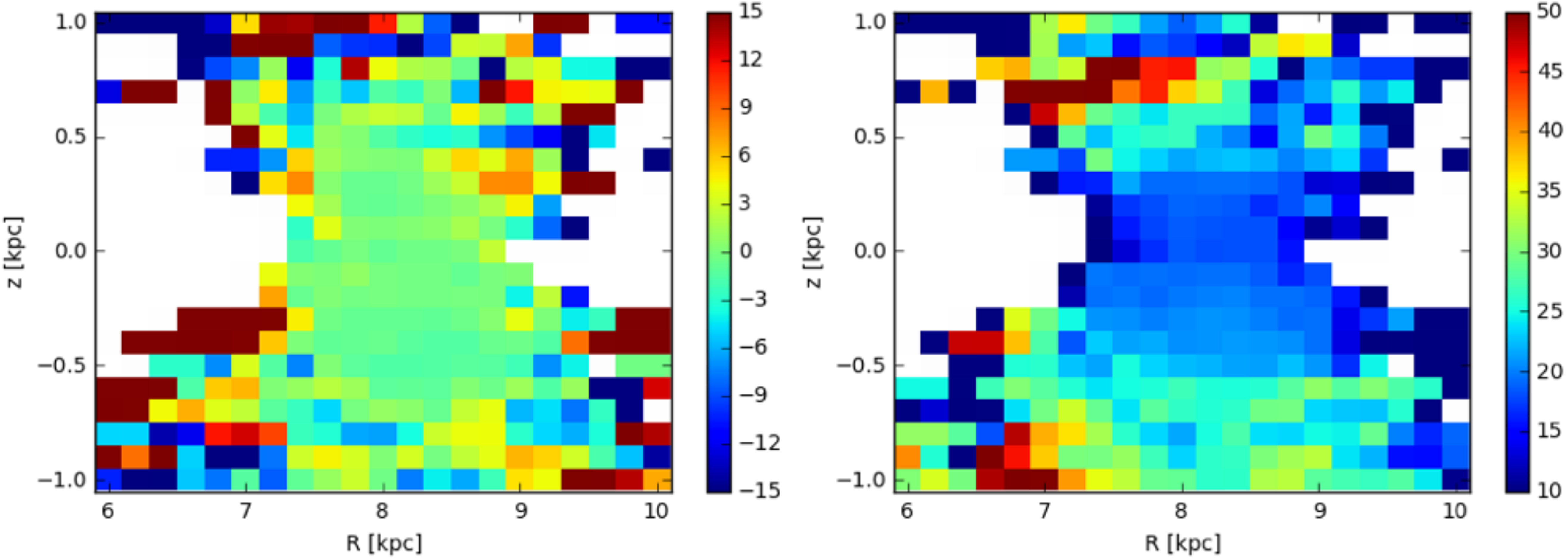
20% parallax error sample: ~110000 stars
30% parallax error sample: ~175000 stars

Sun at R = 8.3 kpc & z=+14 pc
vLSR = 228.5 km/s
(U,V,W) = (11.1, 12.24 ,7.25) km/s



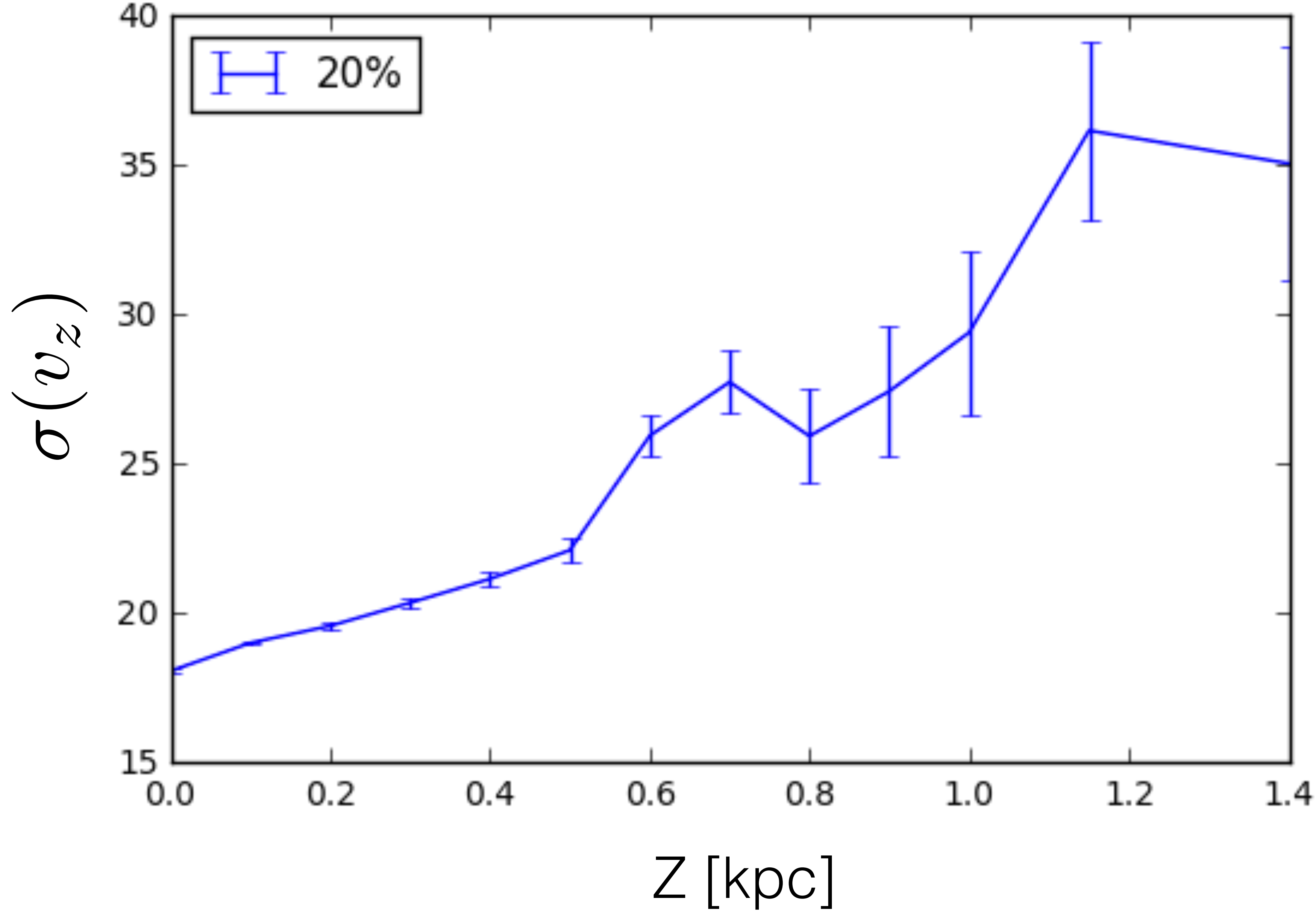
$\langle v_\phi \rangle$
$\sigma(v_\phi)$
$\langle v_R \rangle$
$\sigma(v_R)$
z [kpc]
R [kpc]

$$\langle v_z \rangle \qquad\qquad \sigma(v_z)$$



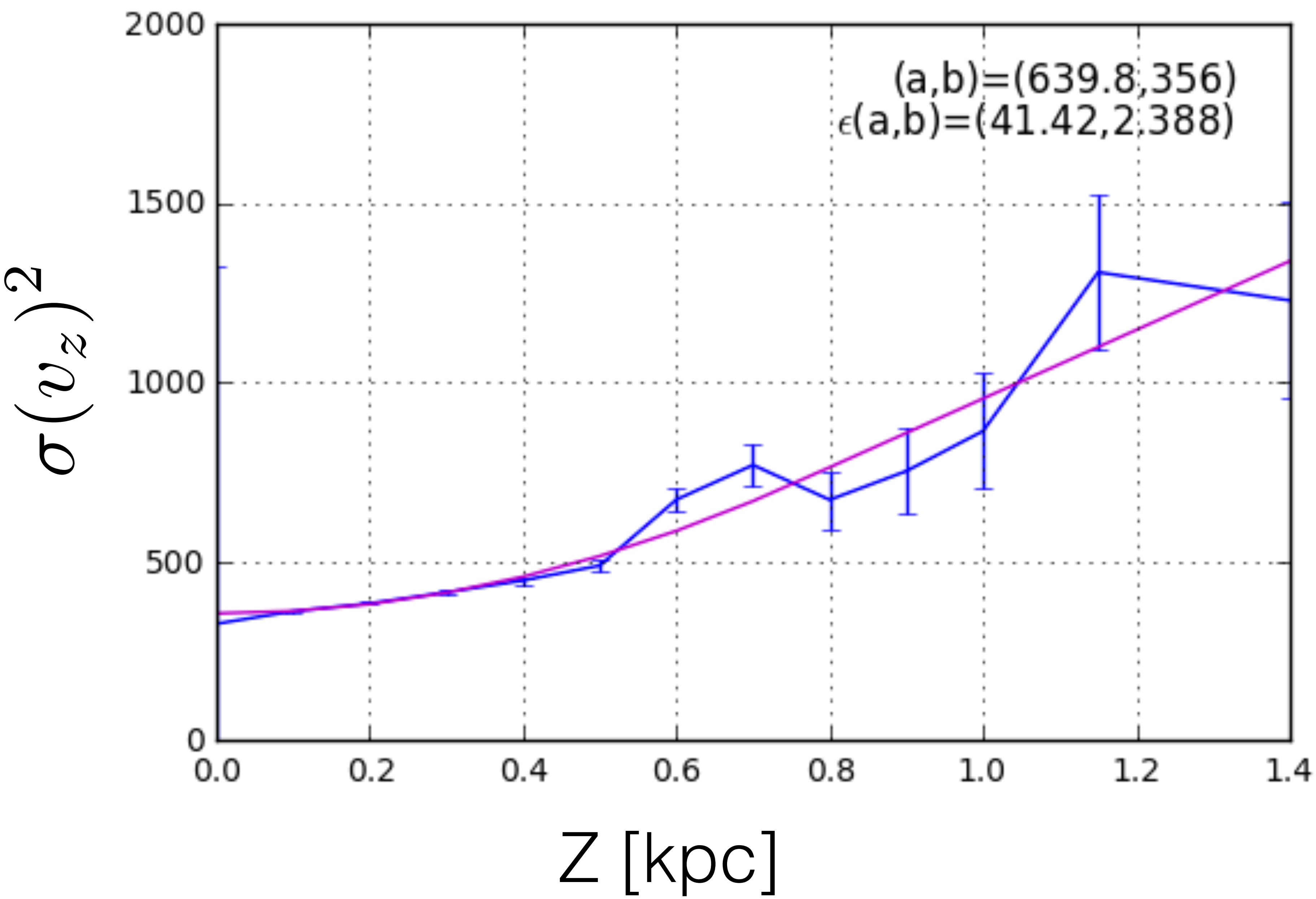
$$-\frac{\mathrm{d}\Phi}{\mathrm{d}z} \equiv F_z = \frac{\sigma_z^2}{\nu}\frac{\mathrm{d}\nu}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_z^2}{\mathrm{d}z} + \frac{\mathrm{cov}(v_R, v_z)}{R}\left[1 - \gamma_{\nu,R} - \gamma_{\mathrm{cov}(v_R,v_z),R}\right]$$

Vertical velocity dispersion at the solar radius.



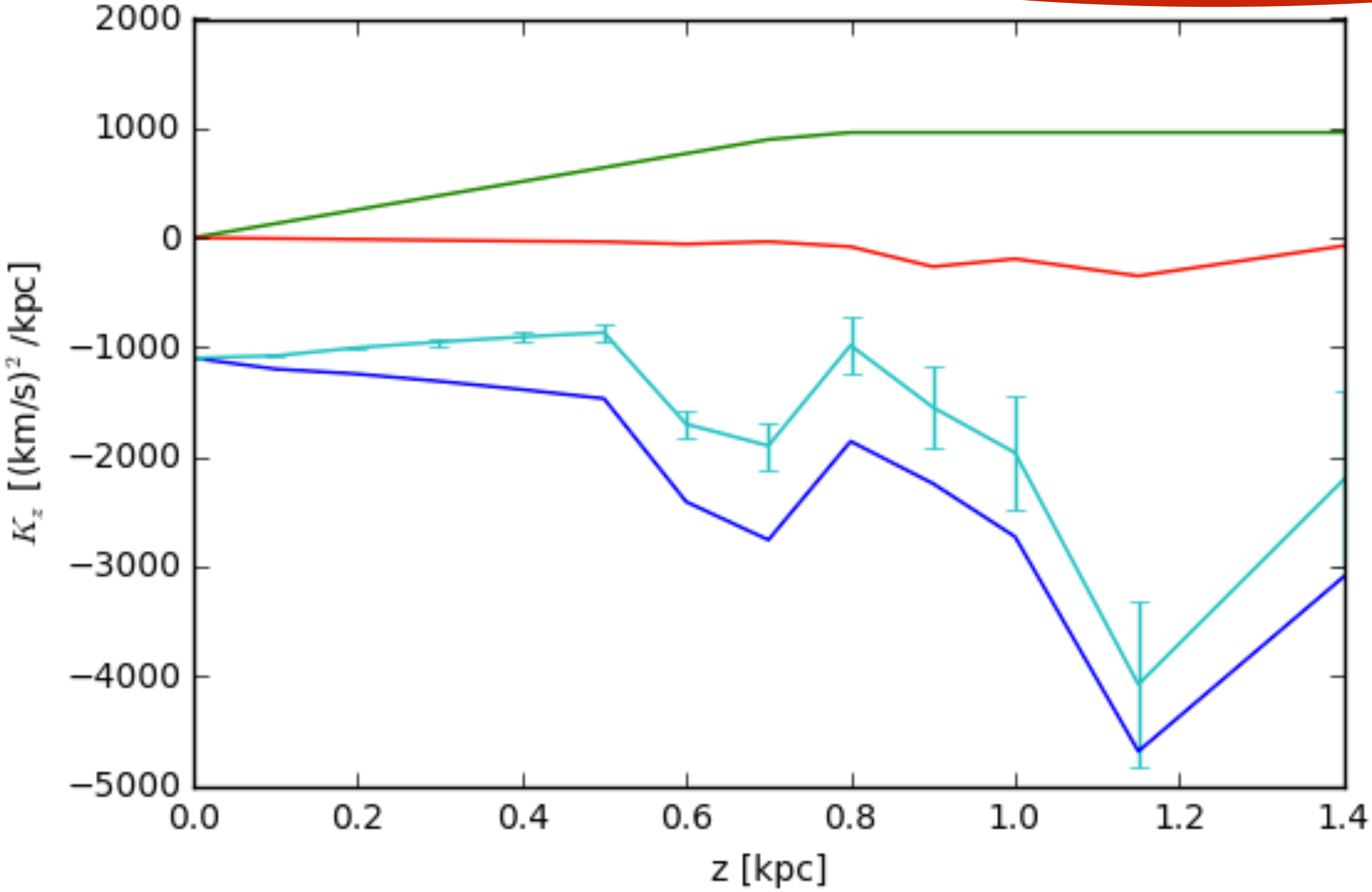
The vertical dispersion profile

$$-\frac{\mathrm{d}\Phi}{\mathrm{d}z} \equiv F_z = \frac{\sigma_z^2}{\nu}\frac{\mathrm{d}\nu}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_z^2}{\mathrm{d}z} + \frac{\mathrm{cov}(v_R, v_z)}{R}\left[1 - \gamma_{\nu,R} - \gamma_{\mathrm{cov}(v_R,v_z),R}\right]$$

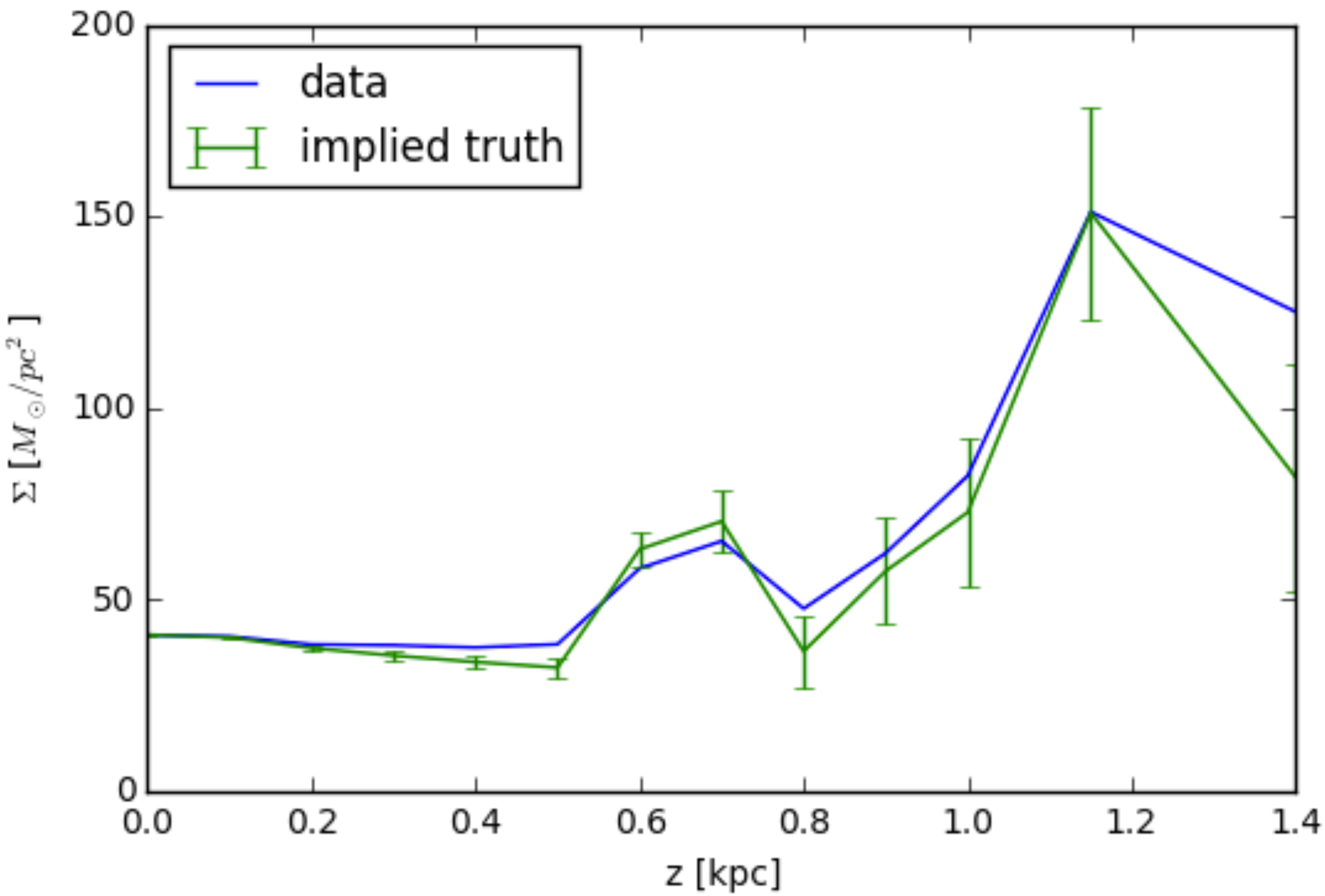


Contribution of the individual terms

$$-\frac{\mathrm{d}\Phi}{\mathrm{d}z} \equiv F_z = \frac{\sigma_z^2}{\nu}\frac{\mathrm{d}\nu}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_z^2}{\mathrm{d}z} + \frac{\mathrm{cov}(v_R, v_z)}{R}\left[1 - \gamma_{\nu,R} - \gamma_{\mathrm{cov}(v_R,v_z),R}\right]$$



The implied surface mass density



$$\Sigma(z) \approx \frac{|F_z(z)|}{2\pi G}$$

Mass model

- We model the stellar contribution in the solar neighbourhood by a single disk:

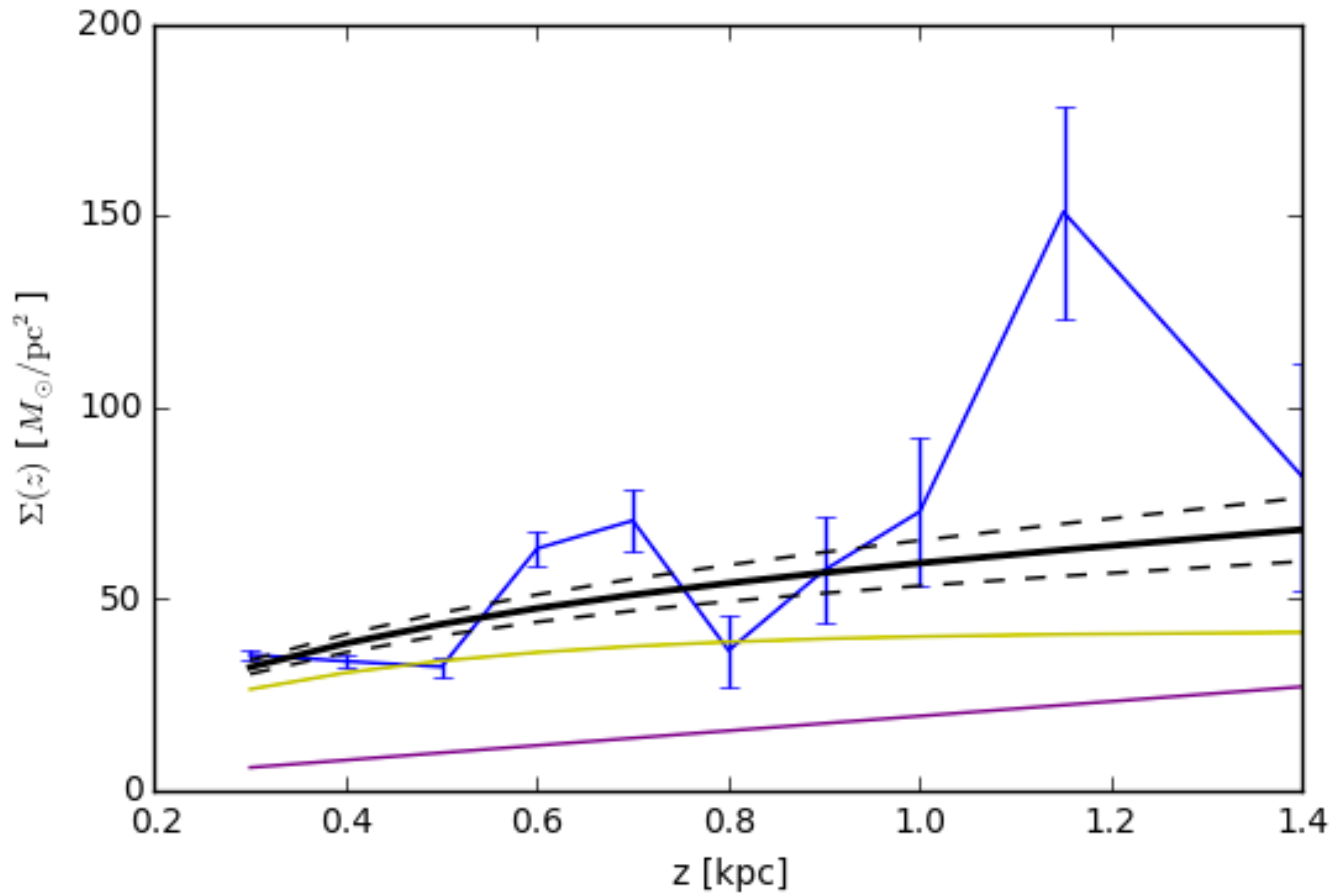
$$M_{\rm disk} = 4.5 \times 10^{10} M_\odot$$

$$h_R = 2.5\,{\rm kpc}$$

$$h_z = 0.3\,{\rm kpc}$$

- We allow for a dark matter component by assuming a constant dark matter density.

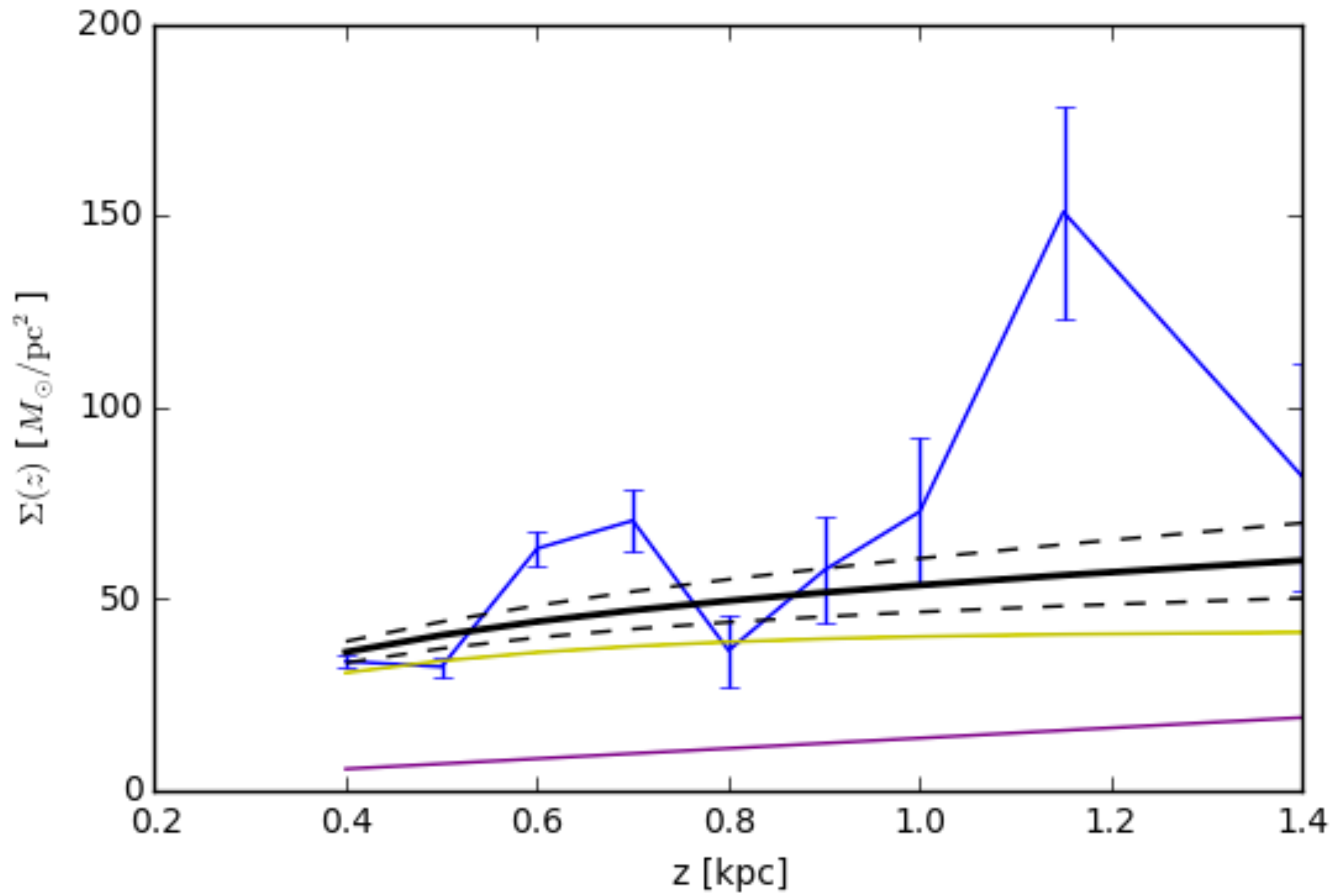
Mass models



$$\rho_{DM}(R = R_\odot, z = 0) = 0.010\, M_\odot/\mathrm{pc}^3$$

$$\mathrm{error}(\rho_{DM,R_\odot}) = 0.003\, M_\odot/\mathrm{pc}^3$$

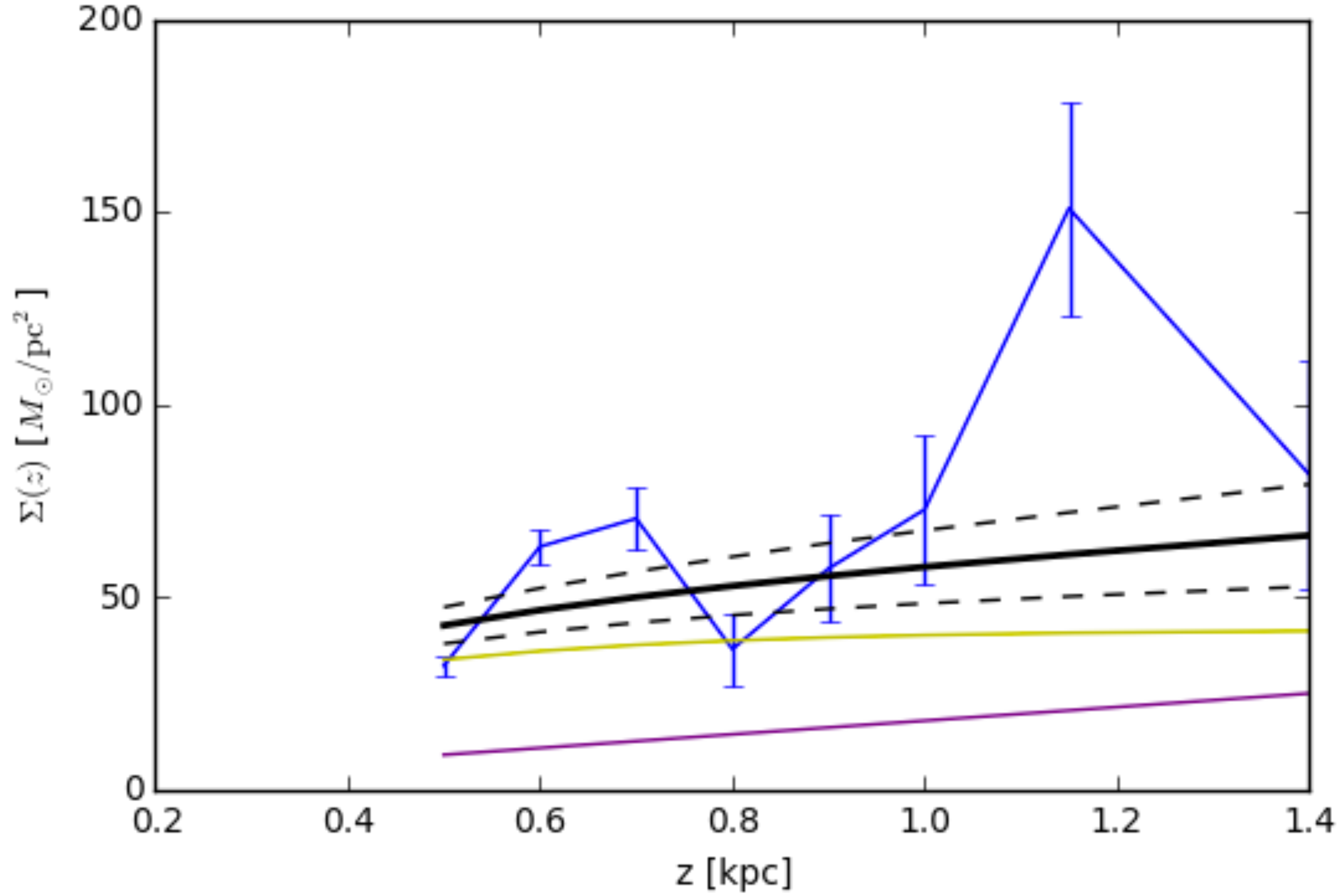
Mass models



$$\rho_{DM}(R = R_\odot, z = 0) = 0.007\, M_\odot/\mathrm{pc}^3$$

$$\mathrm{error}(\rho_{DM,R_\odot}) = 0.003\, M_\odot/\mathrm{pc}^3$$

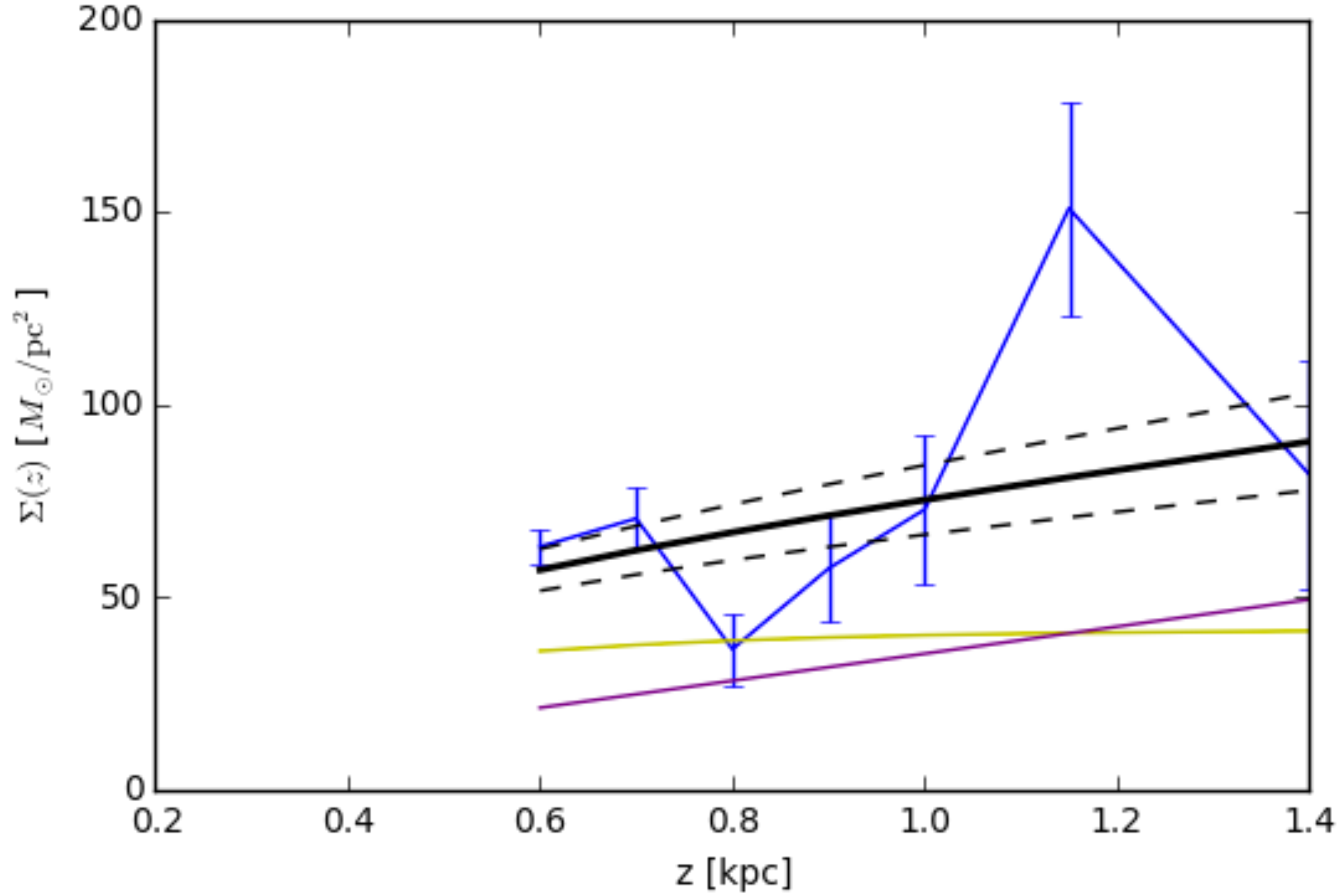
Mass models



$$\rho_{DM}(R = R_\odot, z = 0) = 0.009\, M_\odot/\mathrm{pc}^3$$

$$\mathrm{error}(\rho_{DM,R_\odot}) = 0.005\, M_\odot/\mathrm{pc}^3$$

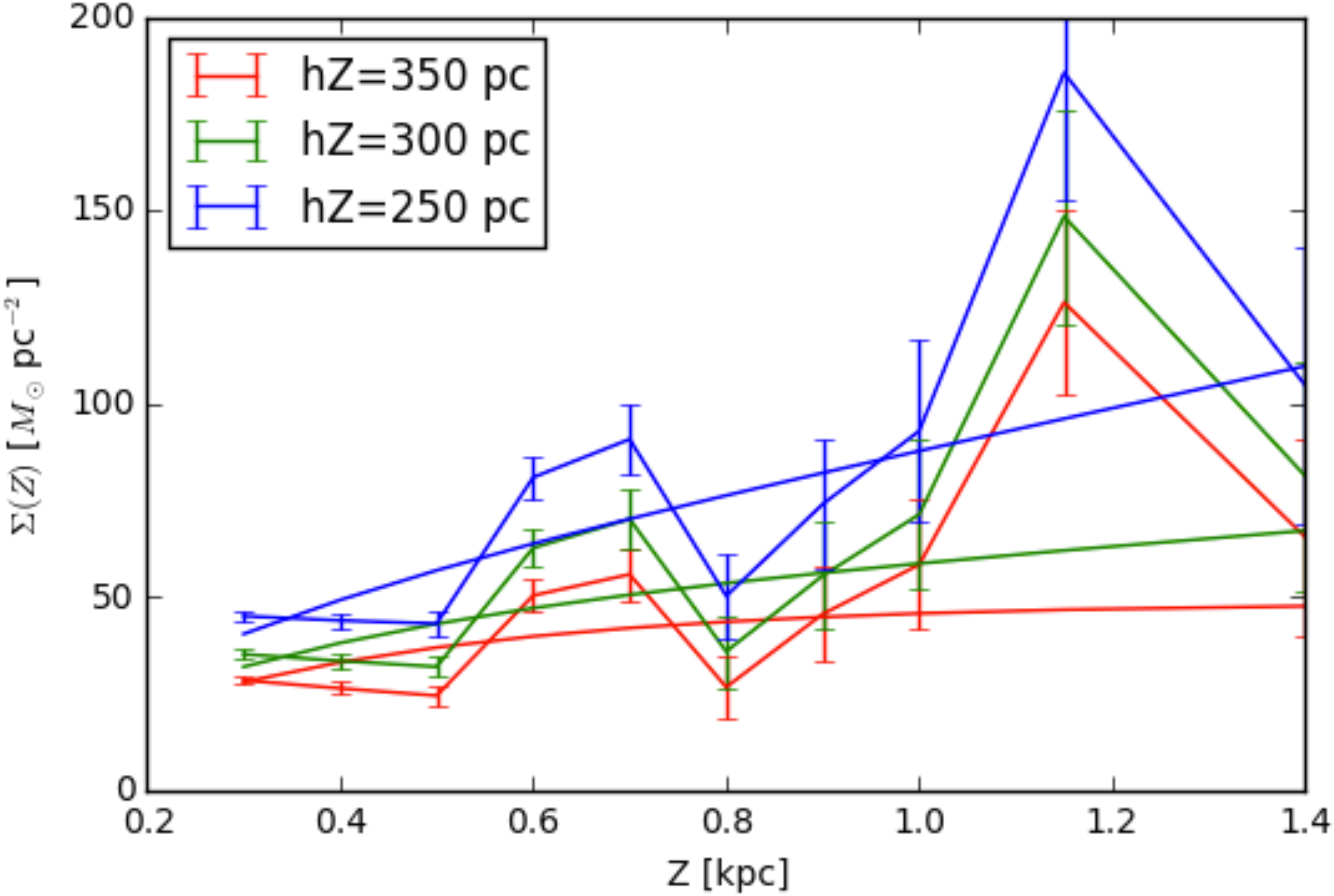
Mass models



$$\rho_{DM}(R = R_\odot, z = 0) = 0.018\, M_\odot/\mathrm{pc}^3$$

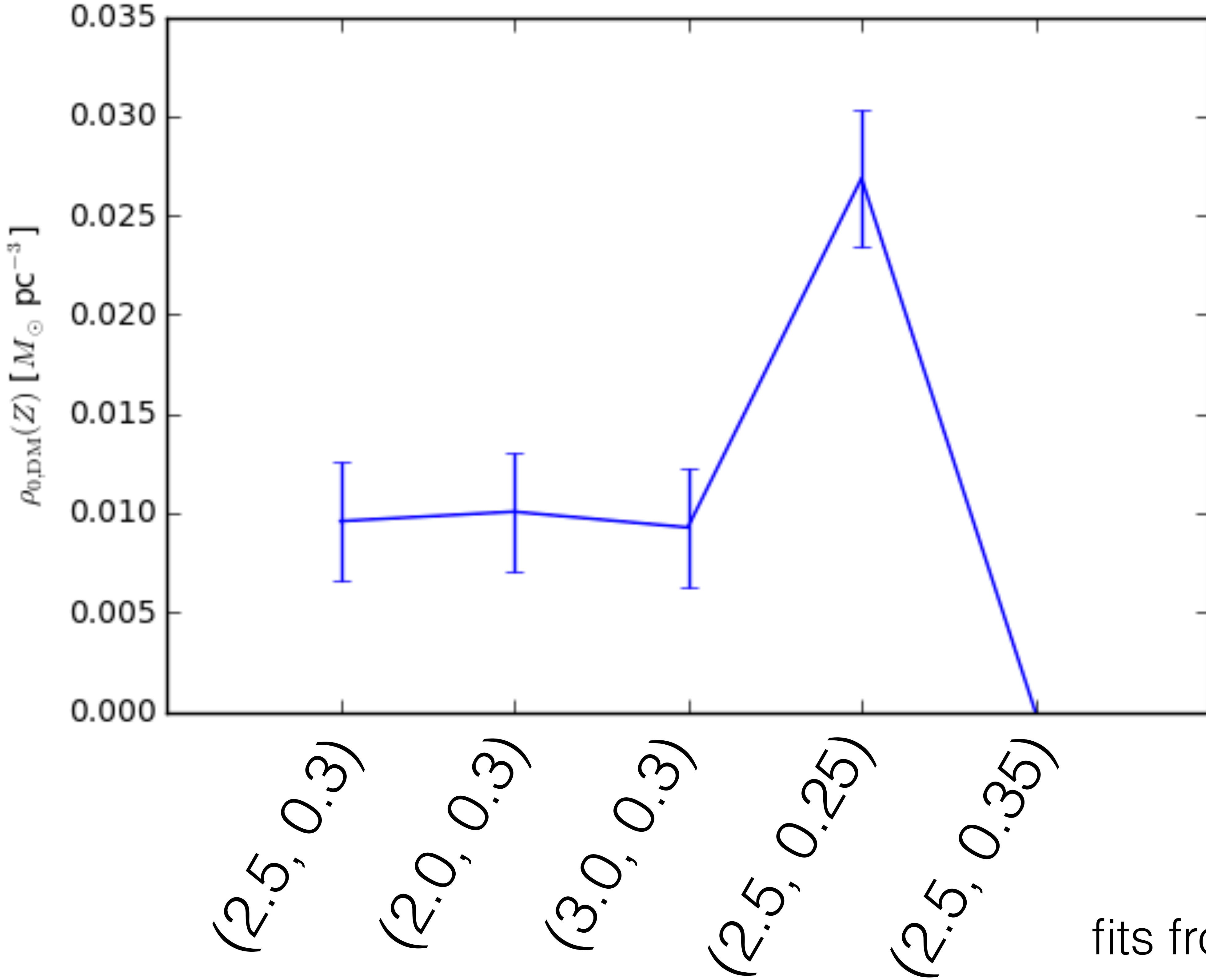
$$\mathrm{error}(\rho_{DM,R_\odot}) = 0.005\, M_\odot/\mathrm{pc}^3$$

Varying hz



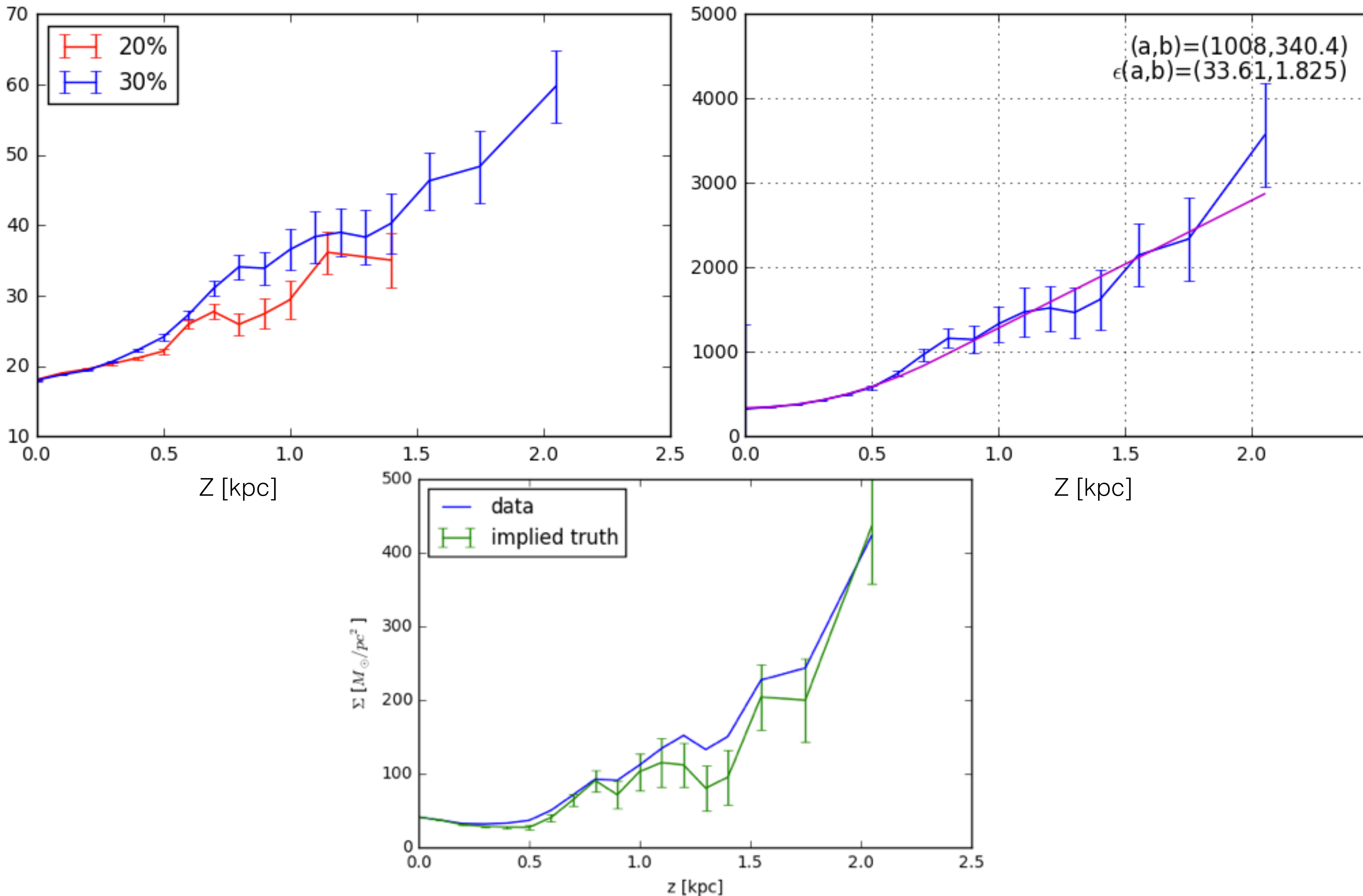
hZ=350 pc
hZ=300 pc
hZ=250 pc
$\Sigma(Z)$ [$M_\odot$ pc^{-2}]
Z [kpc]
0
50
100
150
200
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Varying (h_R, h_z)

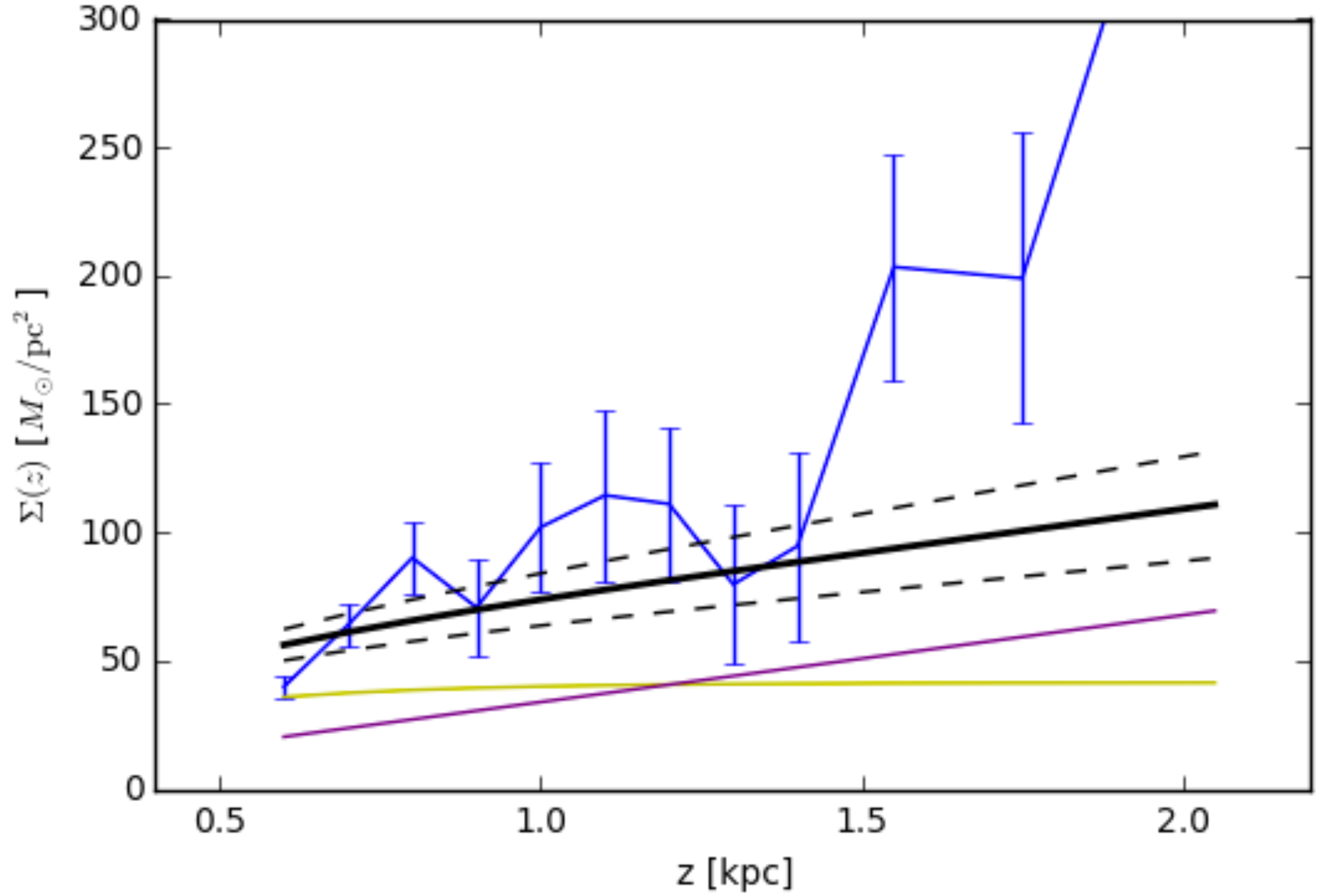


fits from z=0.3 kpc

30% parallax error sample



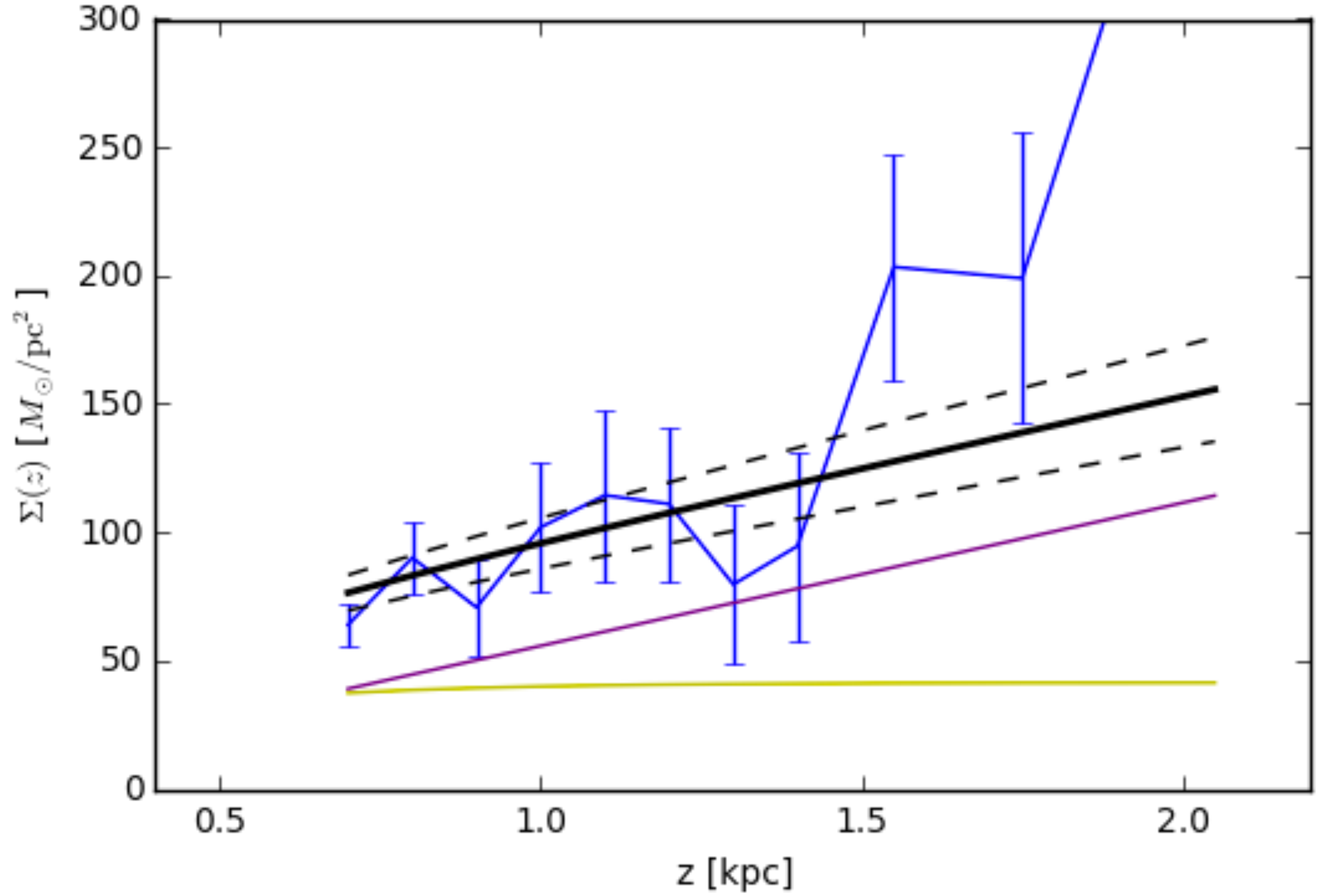
Mass models



$$\rho_{DM}(R = R_\odot, z = 0) = 0.017\, M_\odot/\mathrm{pc}^3$$

$$\mathrm{error}(\rho_{DM,R_\odot}) = 0.005\, M_\odot/\mathrm{pc}^3$$

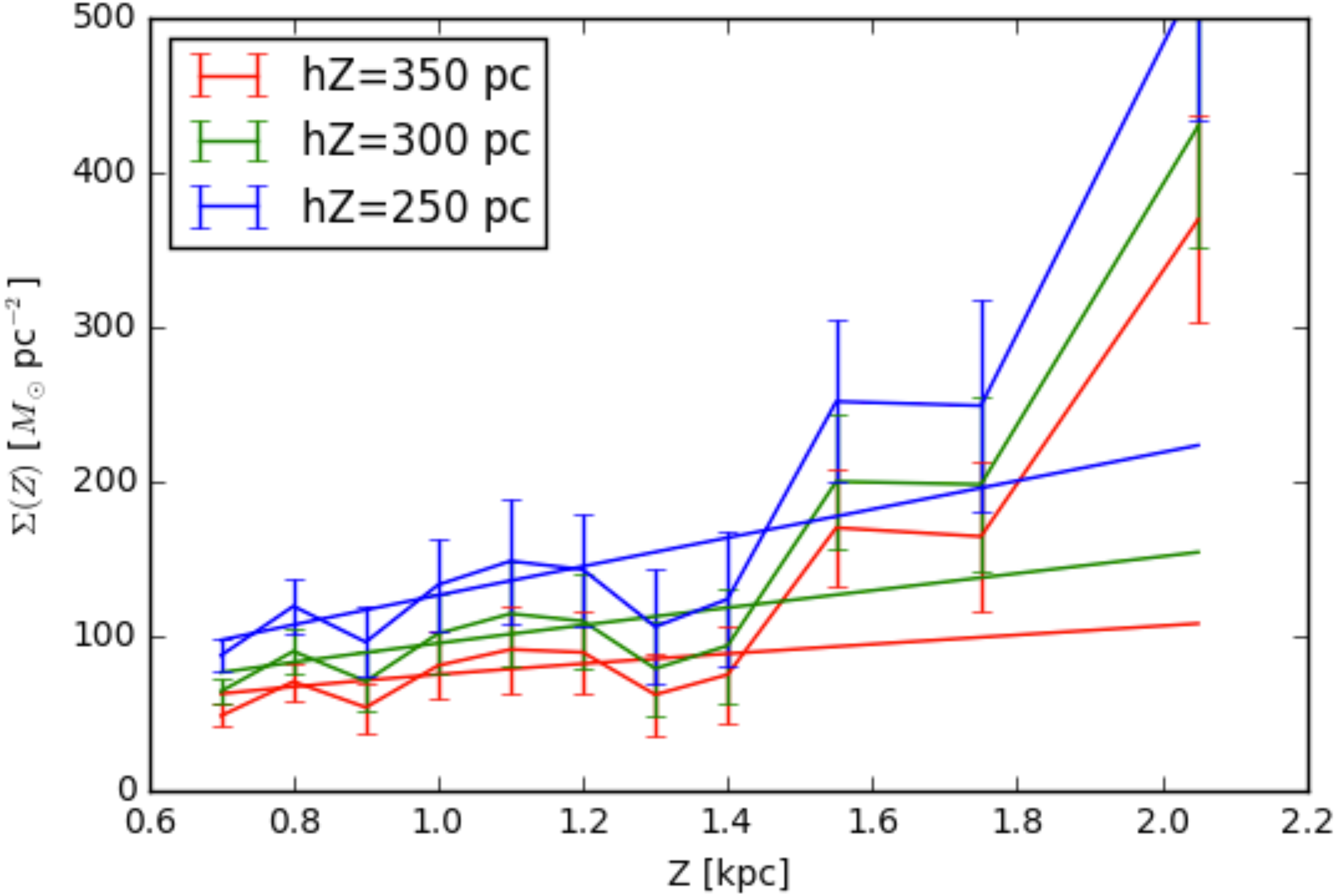
Mass models



$$\rho_{DM}(R = R_\odot, z = 0) = 0.027\, M_\odot/\mathrm{pc}^3$$

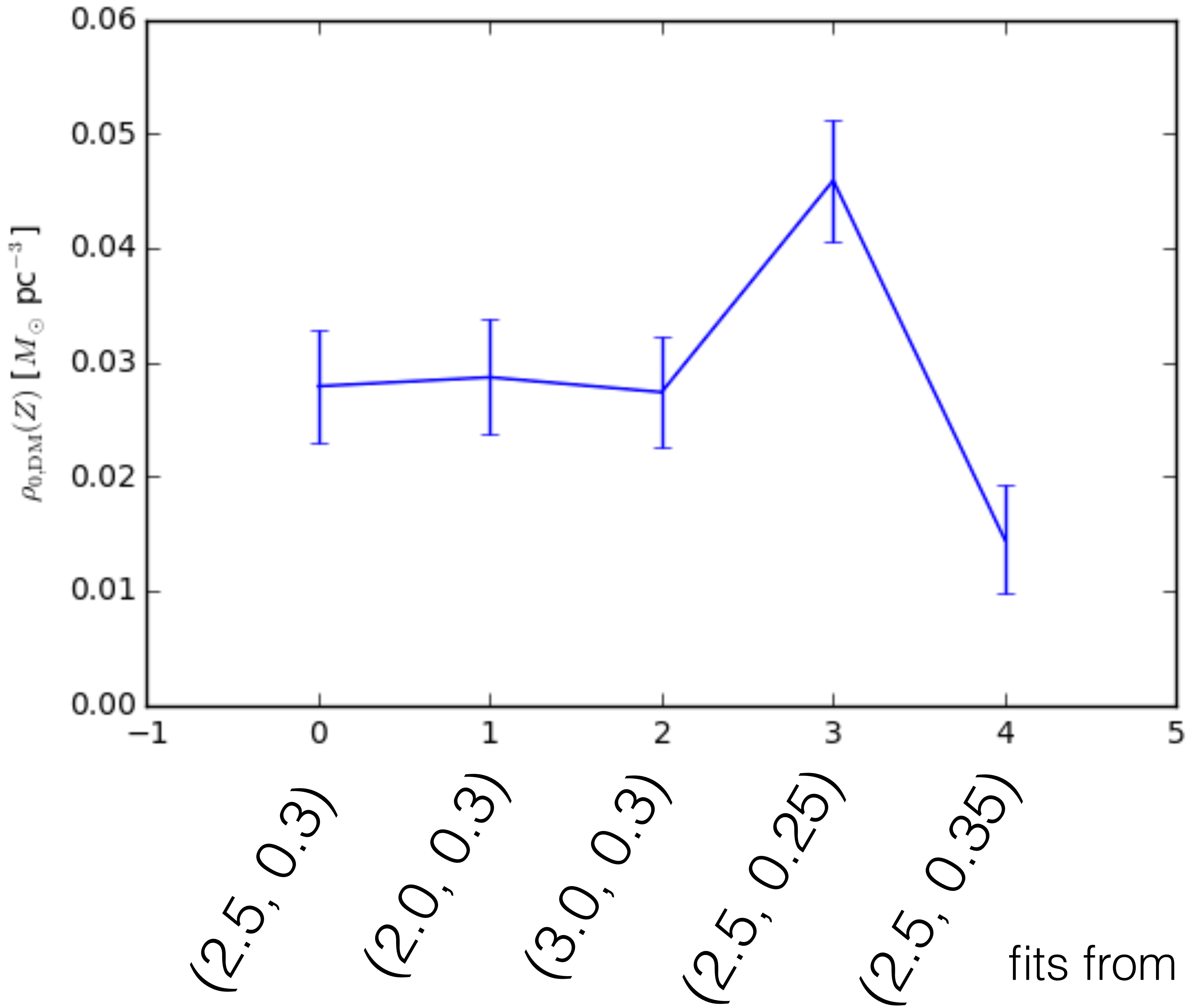
$$\mathrm{error}(\rho_{DM,R_\odot}) = 0.005\, M_\odot/\mathrm{pc}^3$$

Varying hz

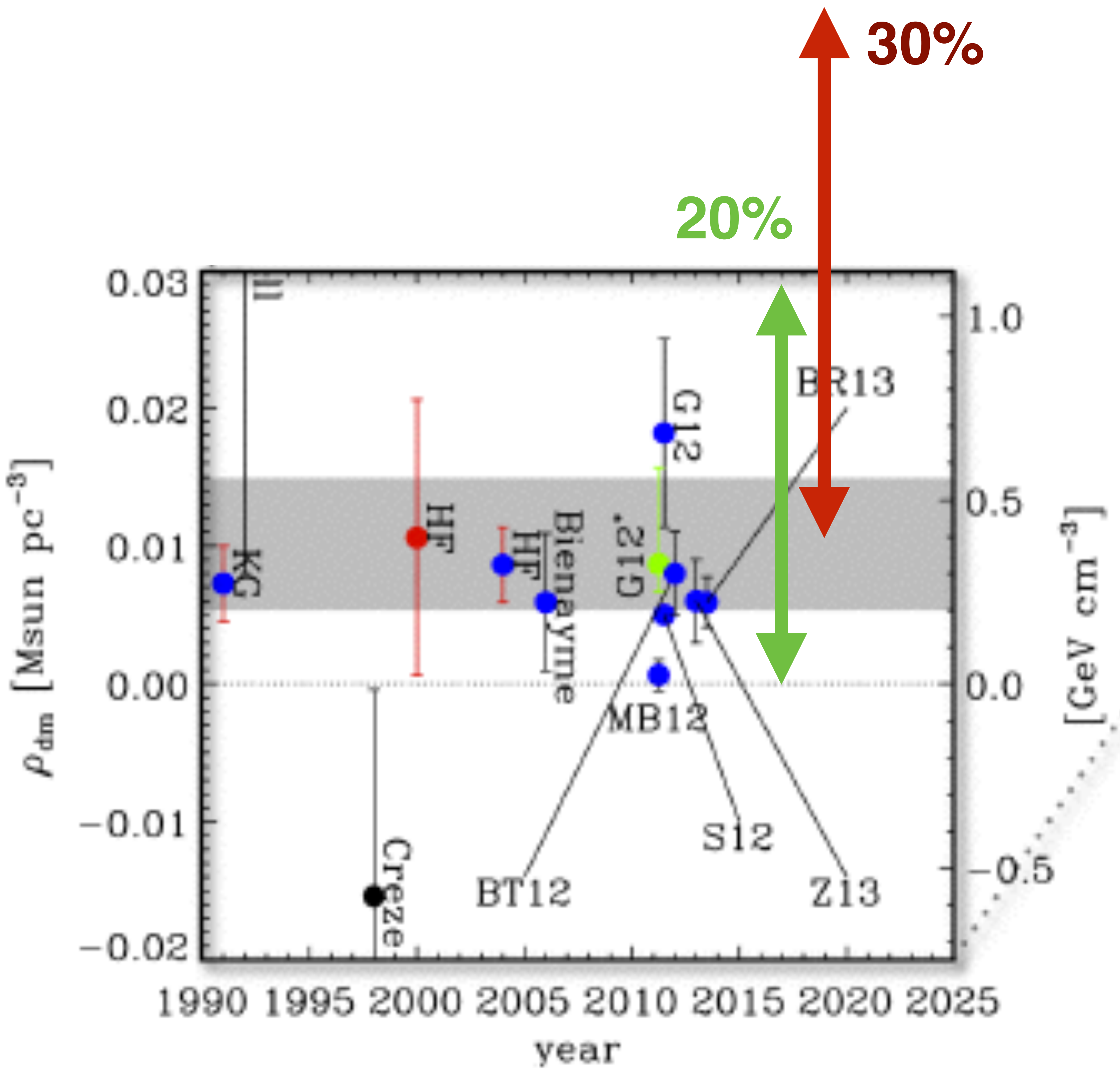


hZ=350 pc
hZ=300 pc
hZ=250 pc
$\Sigma(Z)$ [$M_\odot$ pc^{-2}]
Z [kpc]
0
100
200
300
400
500
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2

Varying (h_R, h_z), 30% sample



fits from z=0.7 kpc



30%
20%
0.03
0.02
0.01
0.00
−0.01
−0.02
1.0
0.5
0.0
−0.5
ρ_{dm} [Msun pc^{-3}]
[GeV cm^{-3}]
1990 1995 2000 2005 2010 2015 2020 2025
year
KG
HF
HF
Bienaymé
G12
G12*
BR13
MB12
S12
BT12
Z13
Creze

Summary

- We attempted to model the DM density by a single disk component.
- We obtain large errors and are looking at the data, to see why we obtain different results.
- Errors on disk parameters can have a significant influence on the implied dark matter density at the solar position.
- Gaia DR2: more & accurate proper motions, distances and radial velocities.

Questions