Universiteit Leiden
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Sterrewacht Leiden

The MW mass profile

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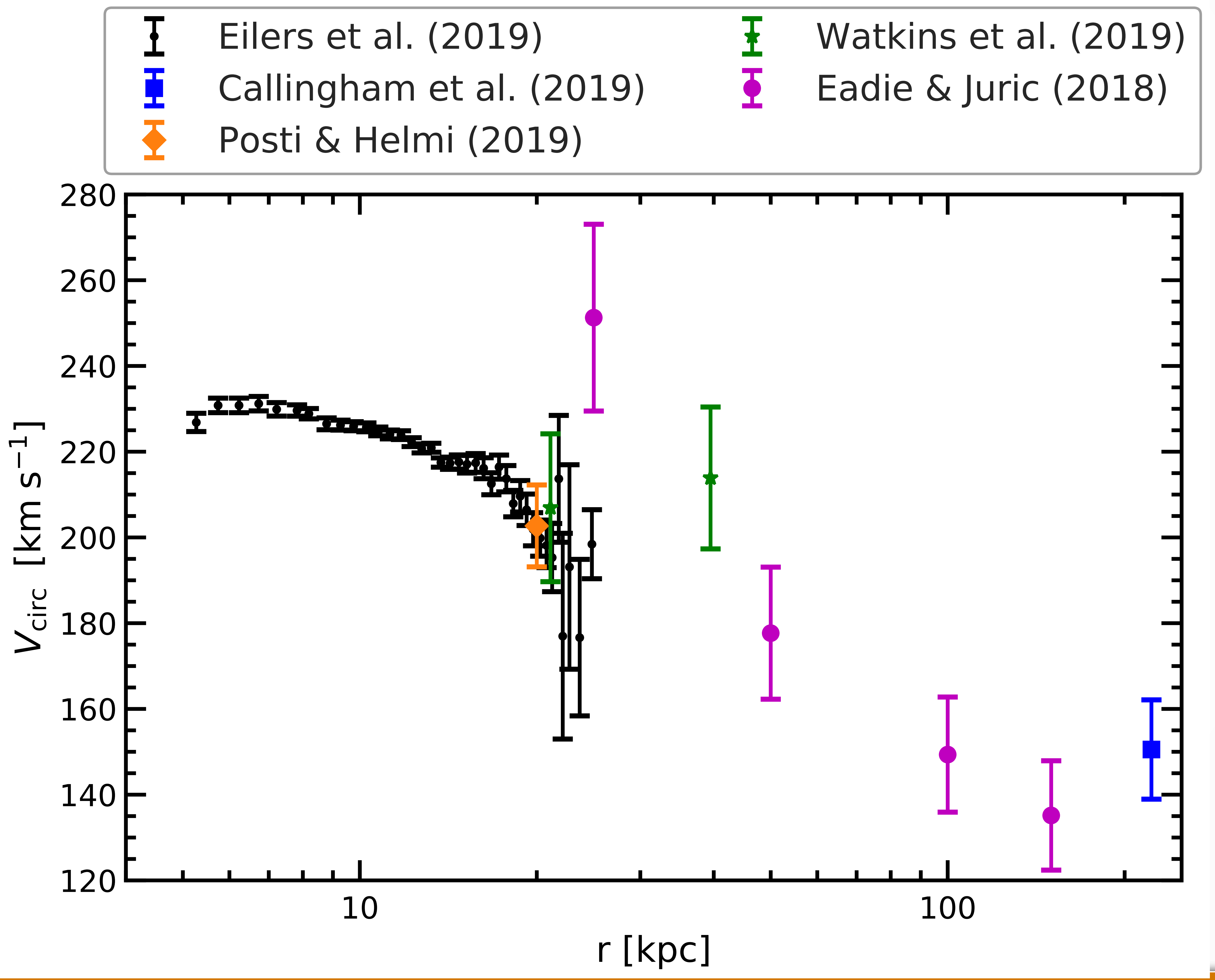
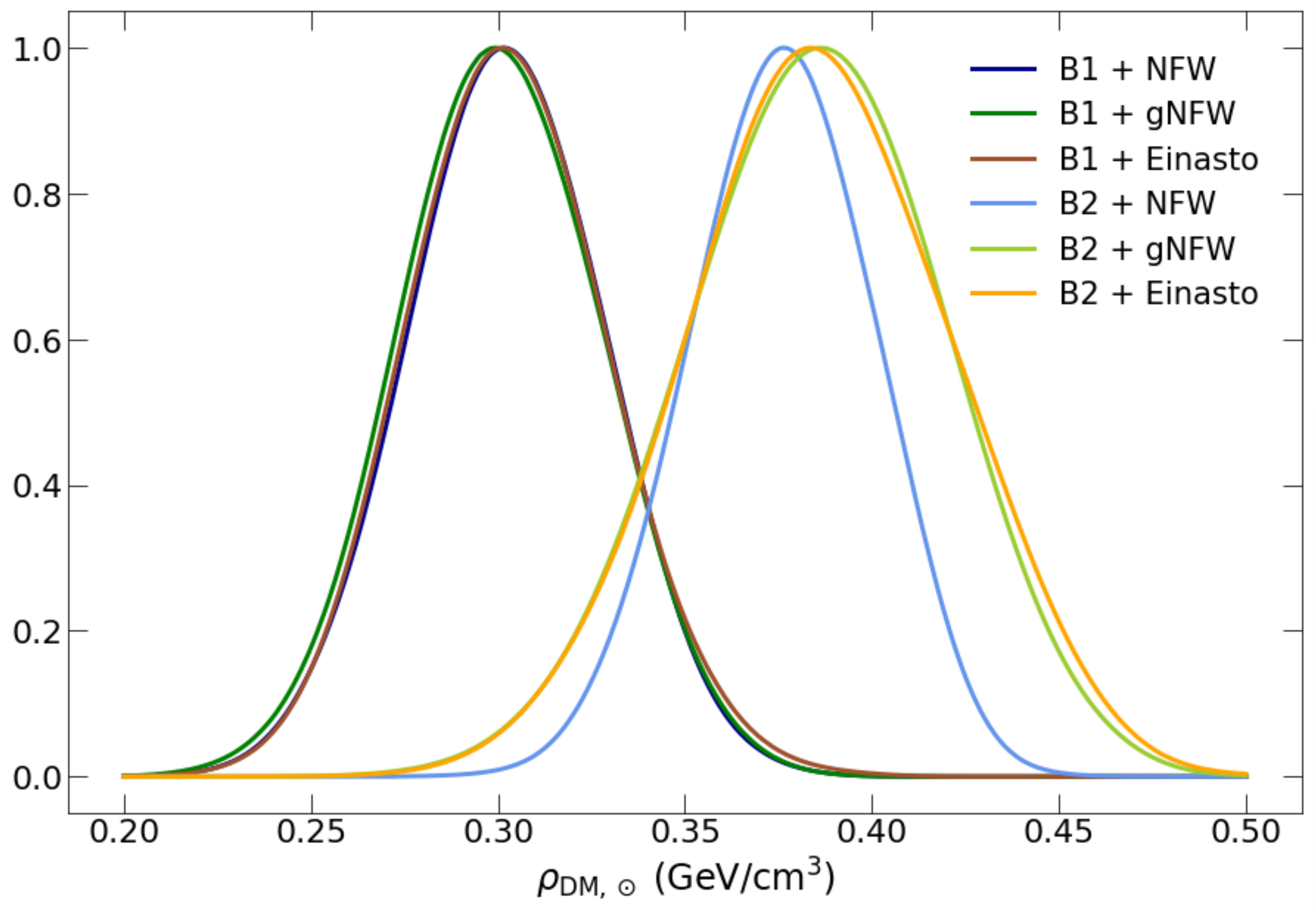
The Local DM Distribution
Durham
03 December 2019

MC+ (2019) – arXiv:1911.04557

The MW rotation curve as inferred from Gaia DR2



The Local DM distribution



	NFW	gNFW	Einasto
M_{200} $[10^{11}\ \mathrm{M}_\odot]$	$5.2^{+2.0}_{-1.1}$	$5.5^{+3.1}_{-1.4}$	$2.8^{+7.7}_{-1.2}$
c_{200}	15^{+5}_{-4}	14 ± 5	12 ± 4
Slope parameter	$\gamma = 1$	$\gamma = 1.2^{+0.3}_{-0.8}$	$\alpha = 0.11^{+0.20}_{-0.05}$
$\rho_{\mathrm{DM},\odot}$ $[\mathrm{GeV/cm^3}]$	$0.301^{+0.028}_{-0.025}$	$0.300^{+0.028}_{-0.027}$	0.301 ± 0.027
r_{200} [kpc]	173^{+19}_{-13}	174^{+29}_{-15}	182^{+43}_{-51}
r_s [kpc]	10^{+5}_{-3}	9^{+12}_{-8}	11^{+10}_{-4}

de Salas+ 2019

MW mass model

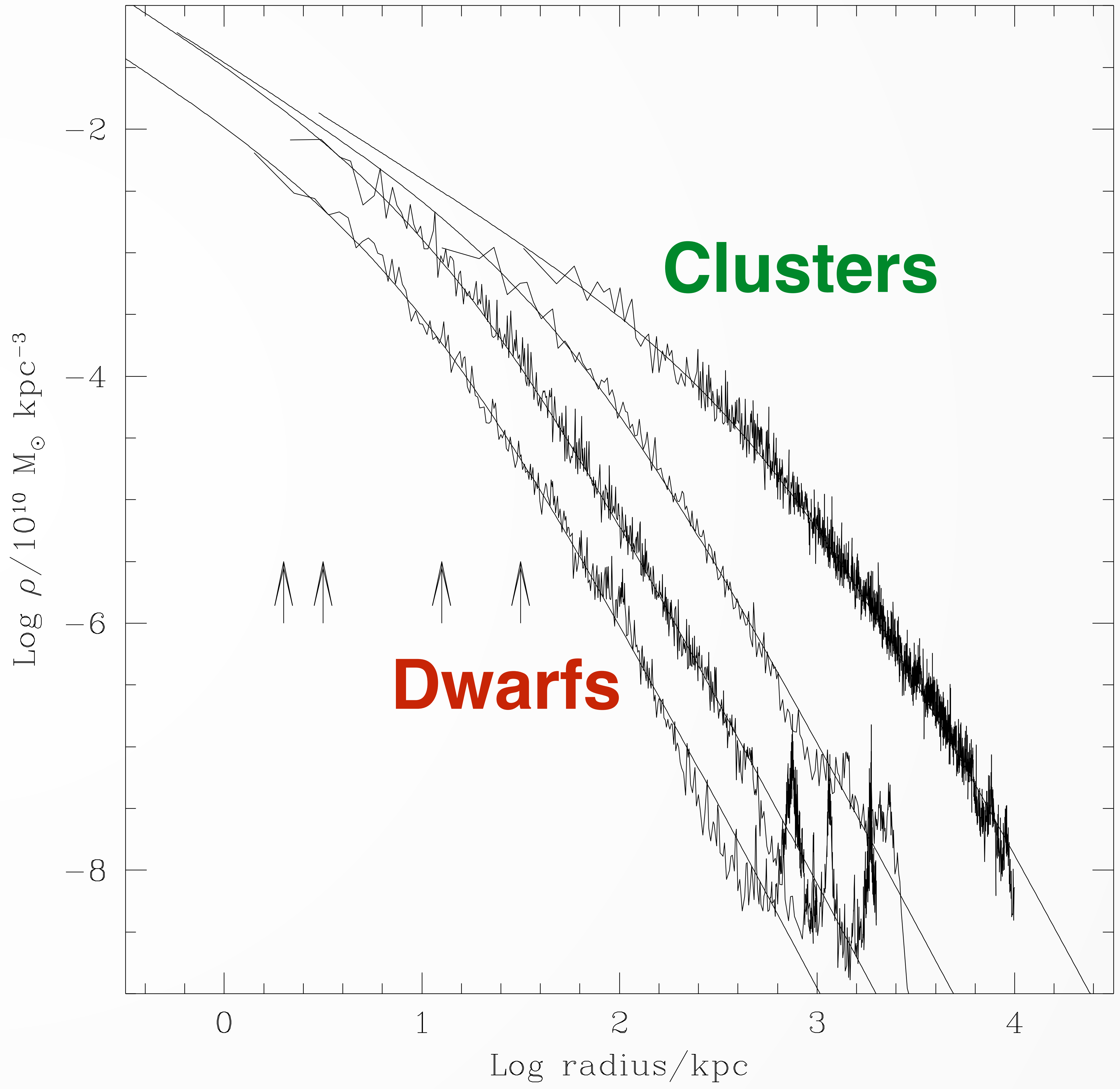
- DM halo
- Stellar bulge
- Thin stellar disc
- Thick stellar disc
- HI and molecular gas discs
- Hot gas (CGM)

How to model the Galactic DM halo

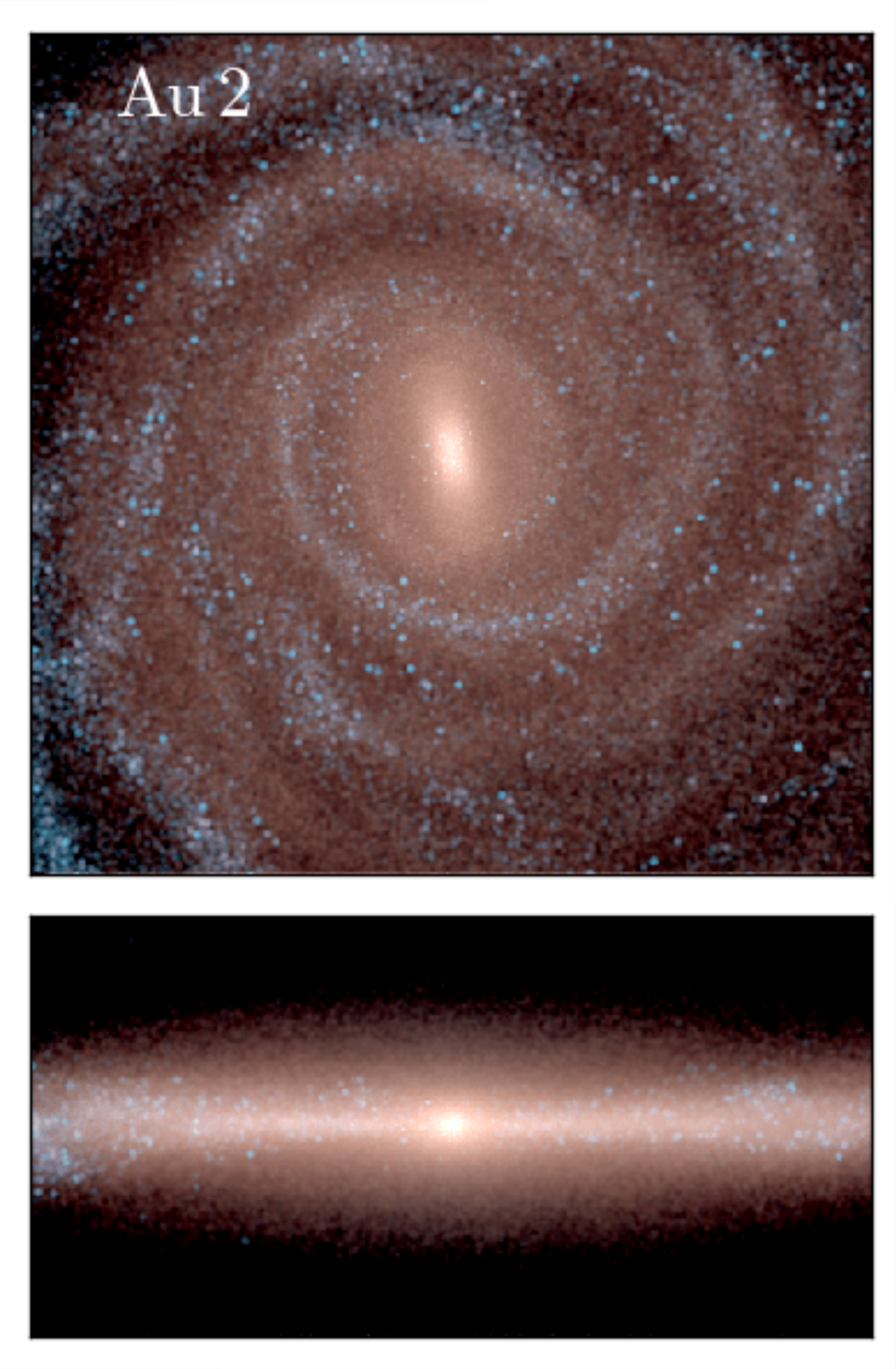
In the absence of baryons, the CDM haloes are well described by a Navarro, Frenk & White (1996) profile:

$$\rho(r) = \frac{\rho_0 R_s^3}{r(r+R_s)^2}$$

(see also Einasto or generalised NFW profiles)



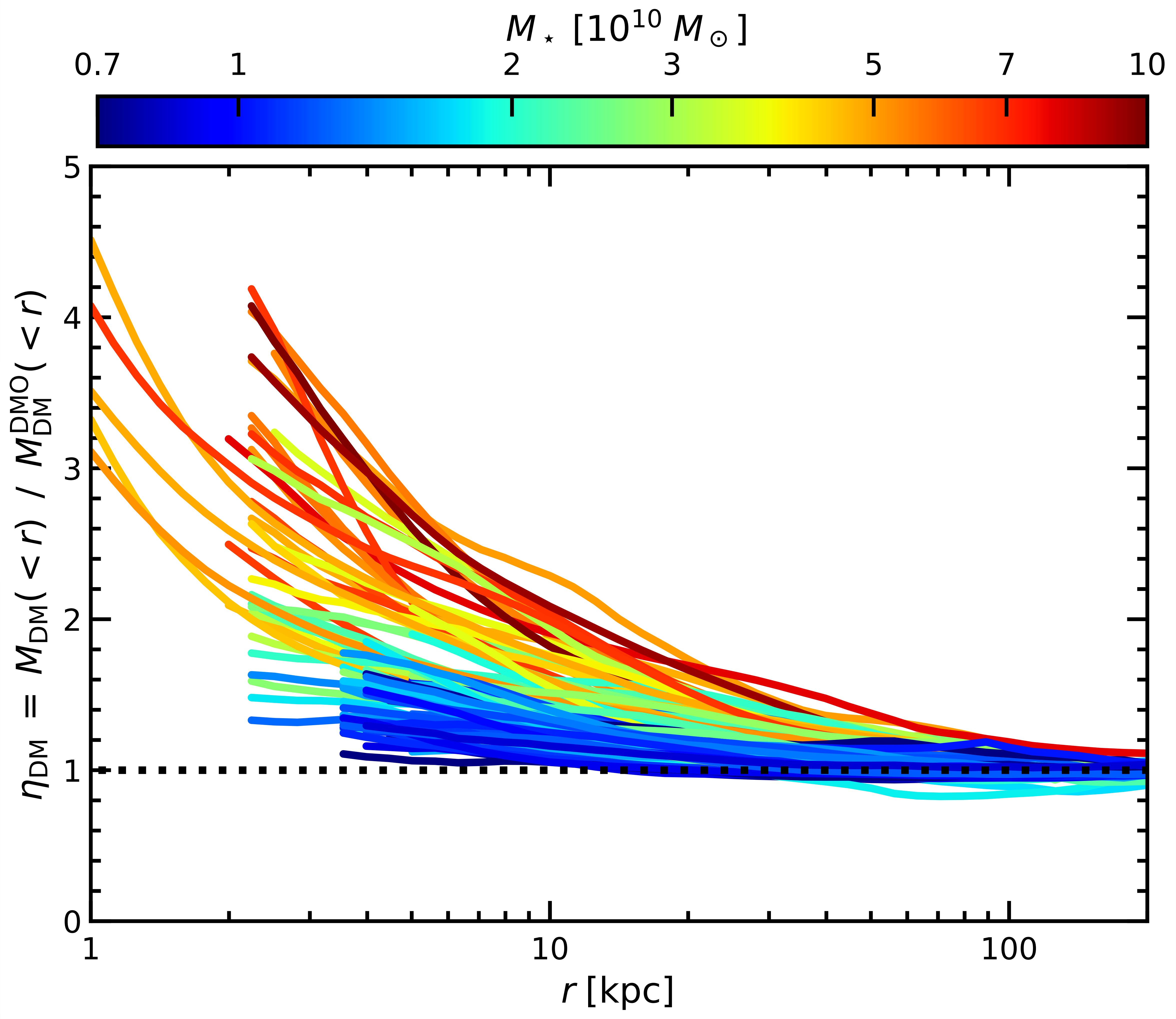
Adding baryons



Grand+ 2017

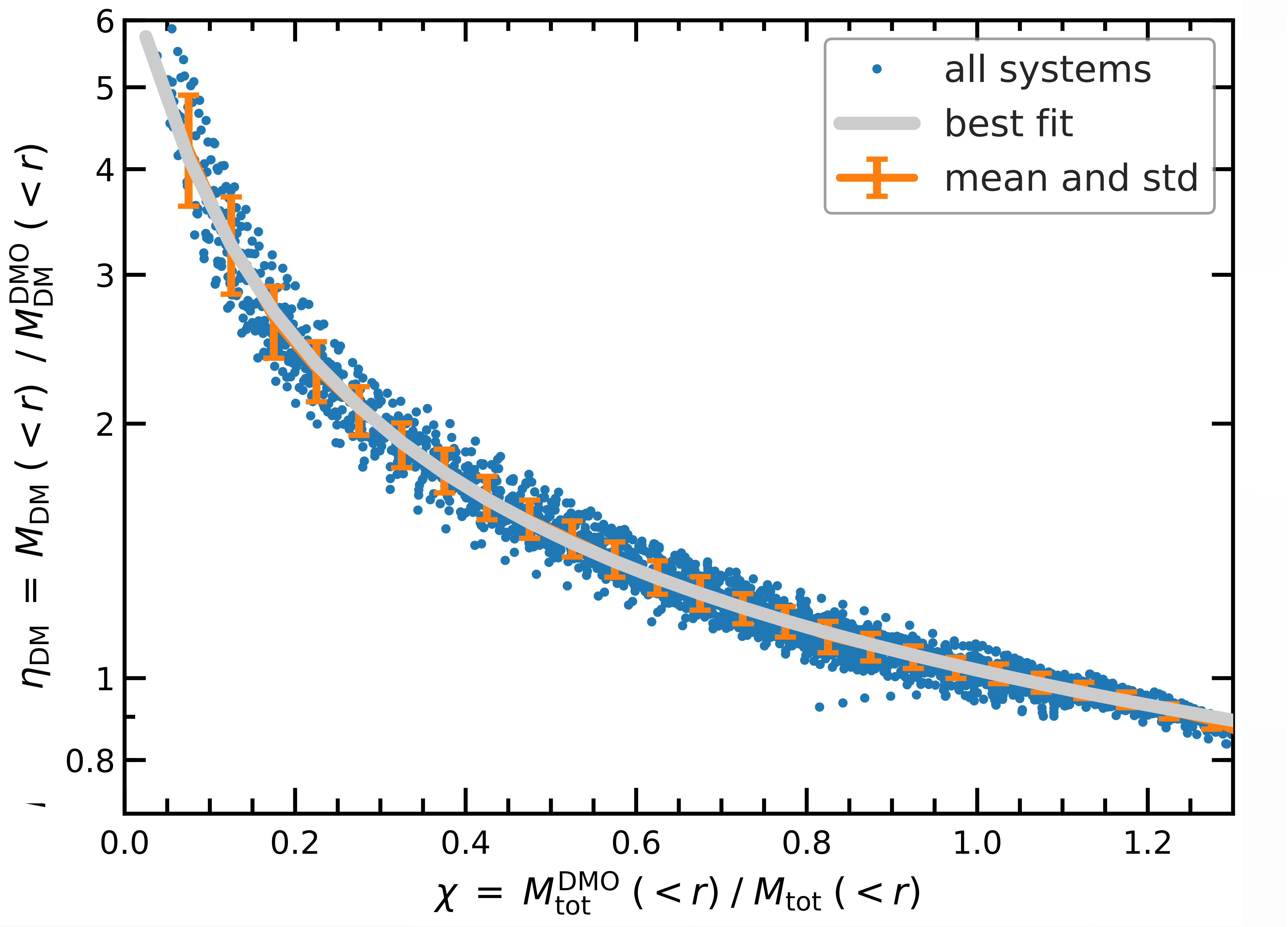
MW-mass haloes in 3 simulations:

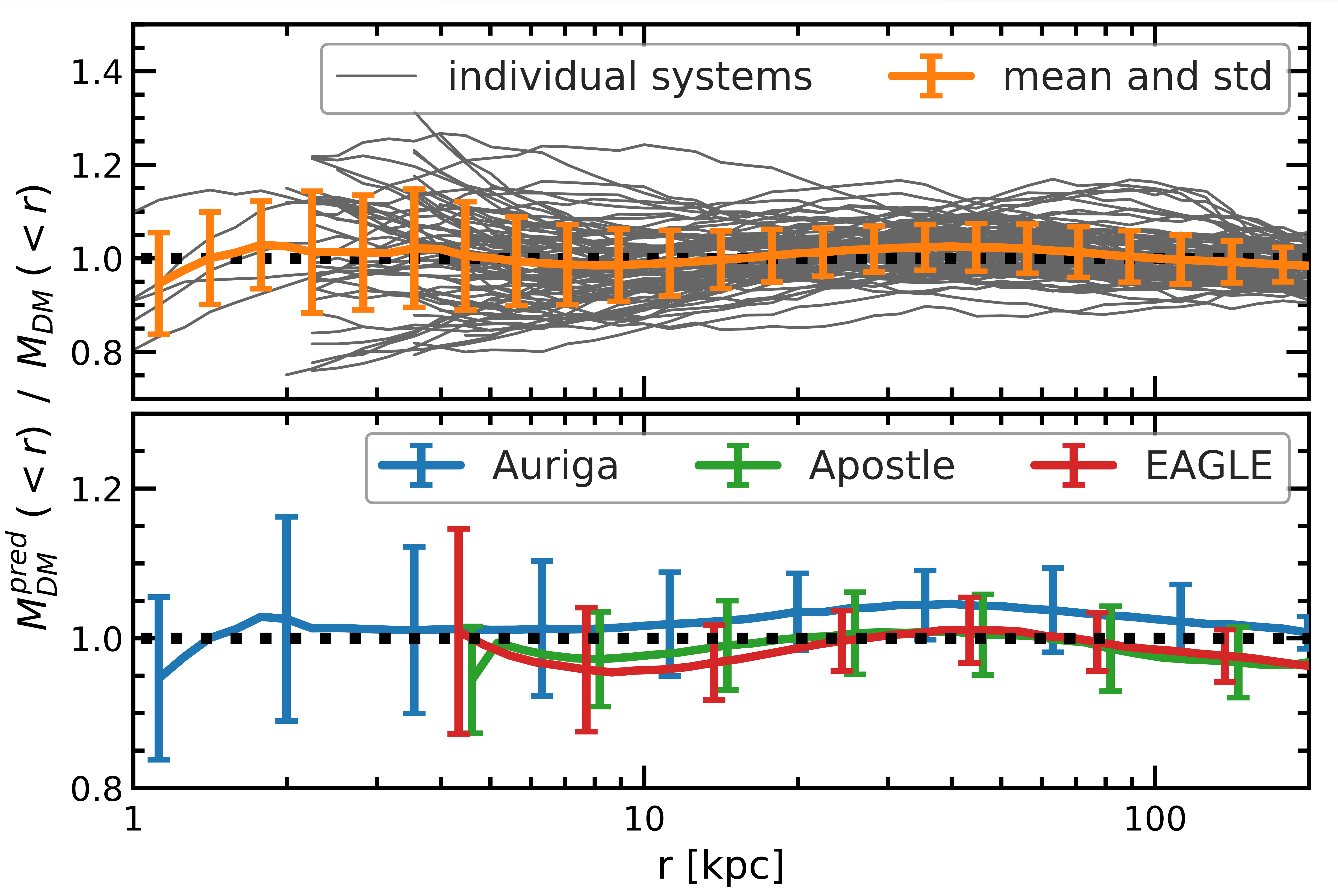
- Auriga
- APOSTLE
- EAGLE.



MC+ 2019

Modelling the DM halo response to baryons





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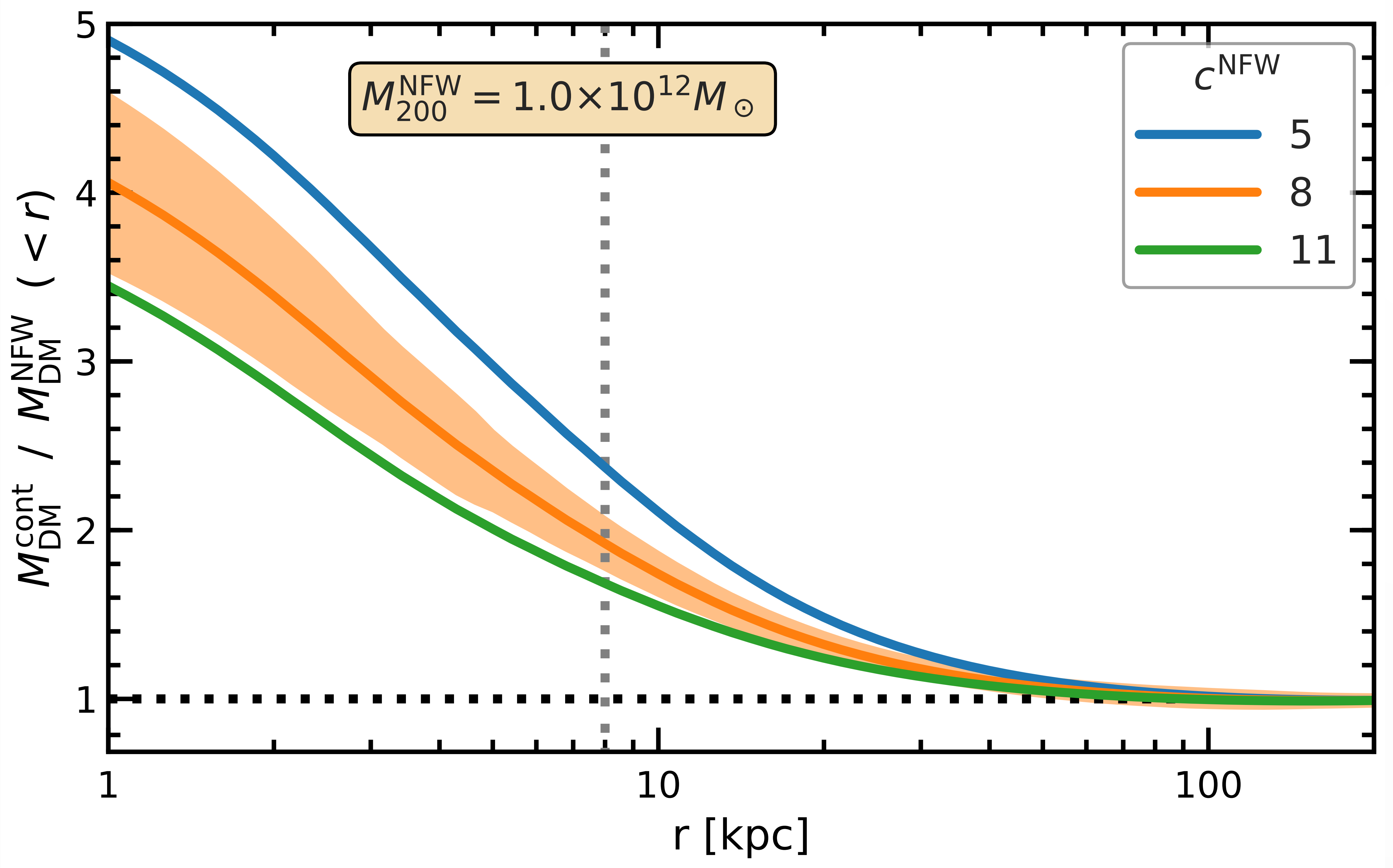
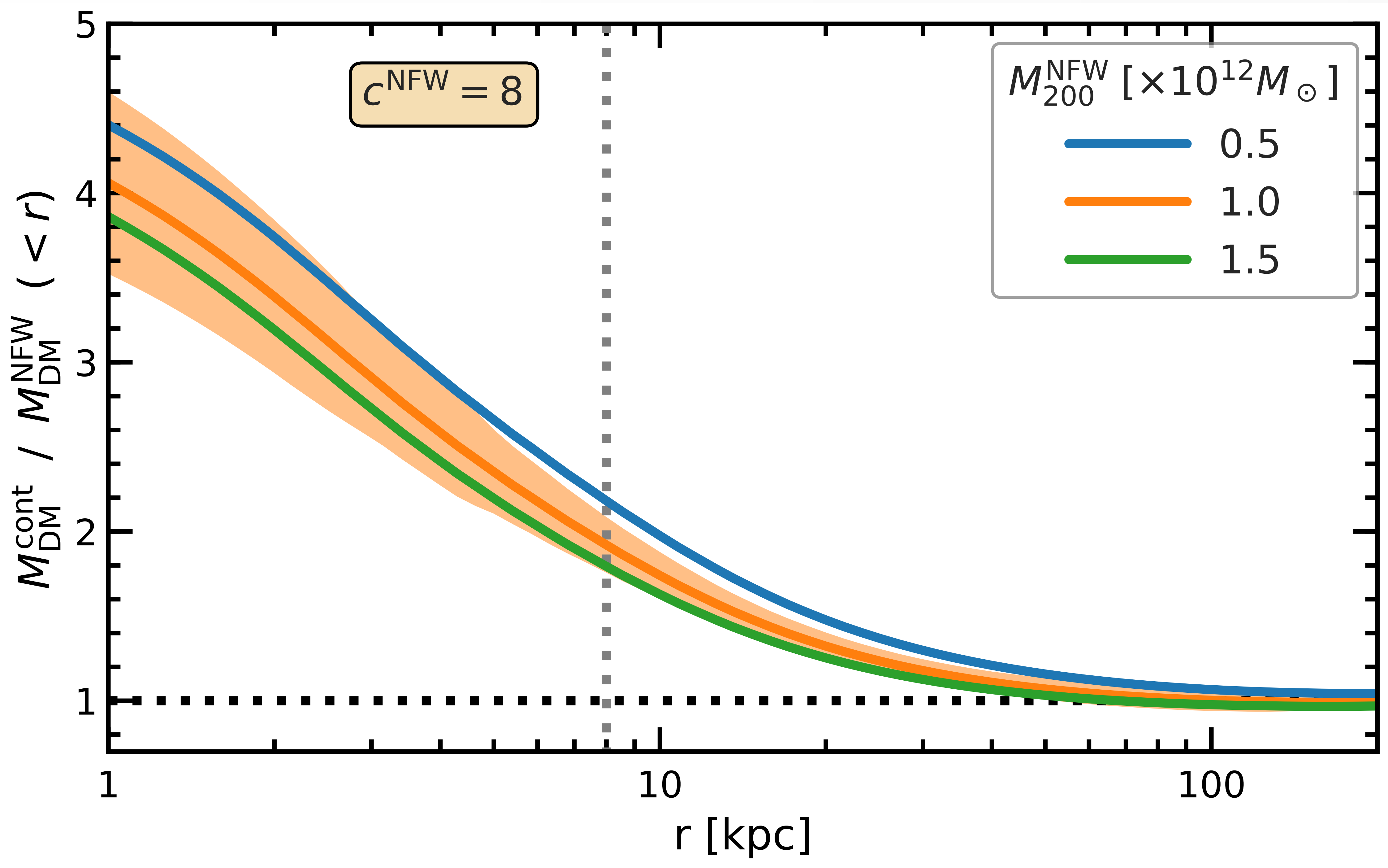
The Galactic DM halo

Taking the MW stellar and gas masses (which I will describe in a few slides):

$$M_\star^{\rm MW} = 5.0 \times 10^{10} M_\odot$$

$$M_{\rm cold\ gas}^{\rm MW} = 1.2 \times 10^{10} M_\odot$$





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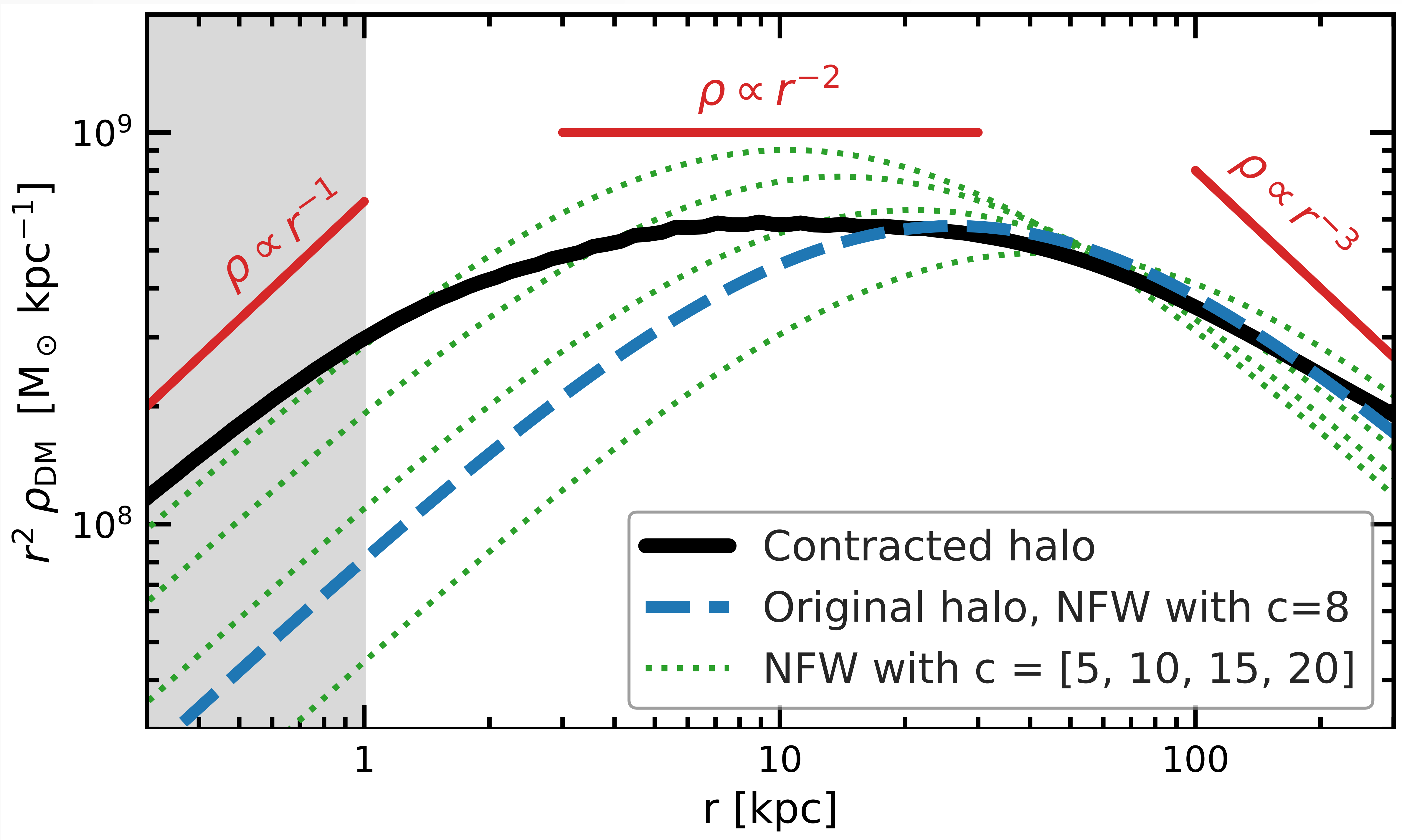
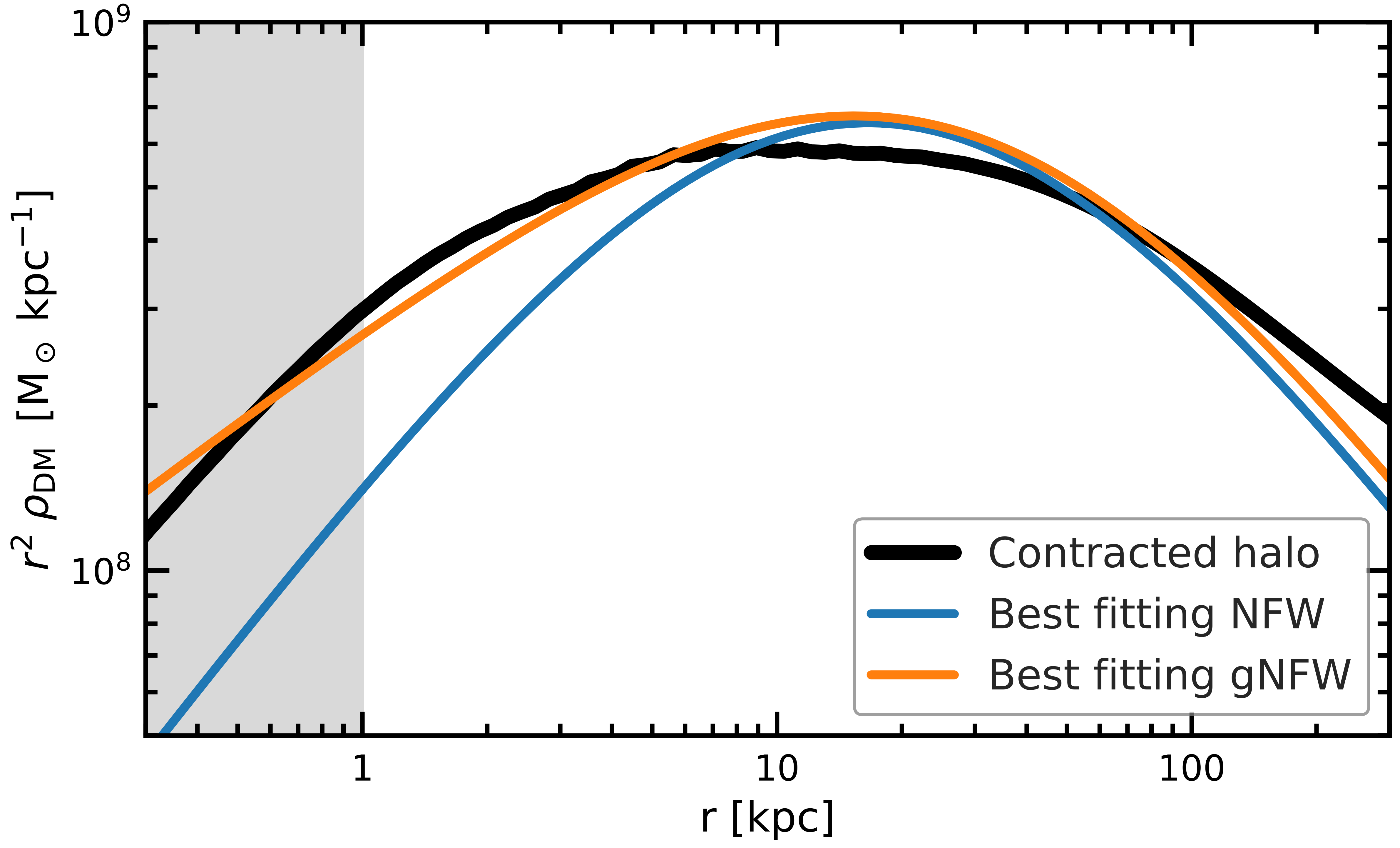
The Galactic DM halo





MC+ 2019

Complete MW mass model

Dehnen & Binney (1998); Klypin+ (2002); McMillan (2011, 2017); Bovy+ (2012); Kafle+ (2014)

MW components	Free parameters
Baryon contracted spherical DM halo	NFW halo before applying baryonic contraction; **Mass & concentration**
Hernquist bulge (Bissantz & Gerhard 2002)	**Mass**
Exponential thin stellar disc	**Mass & scale length**
Exponential thick stellar disc	**Mass & scale length**
HI and molecular gas discs	Fixed from observations (Kalberla & Dedes 2008)
CGM (hot gas)	Fixed from hydrodynamical simulations

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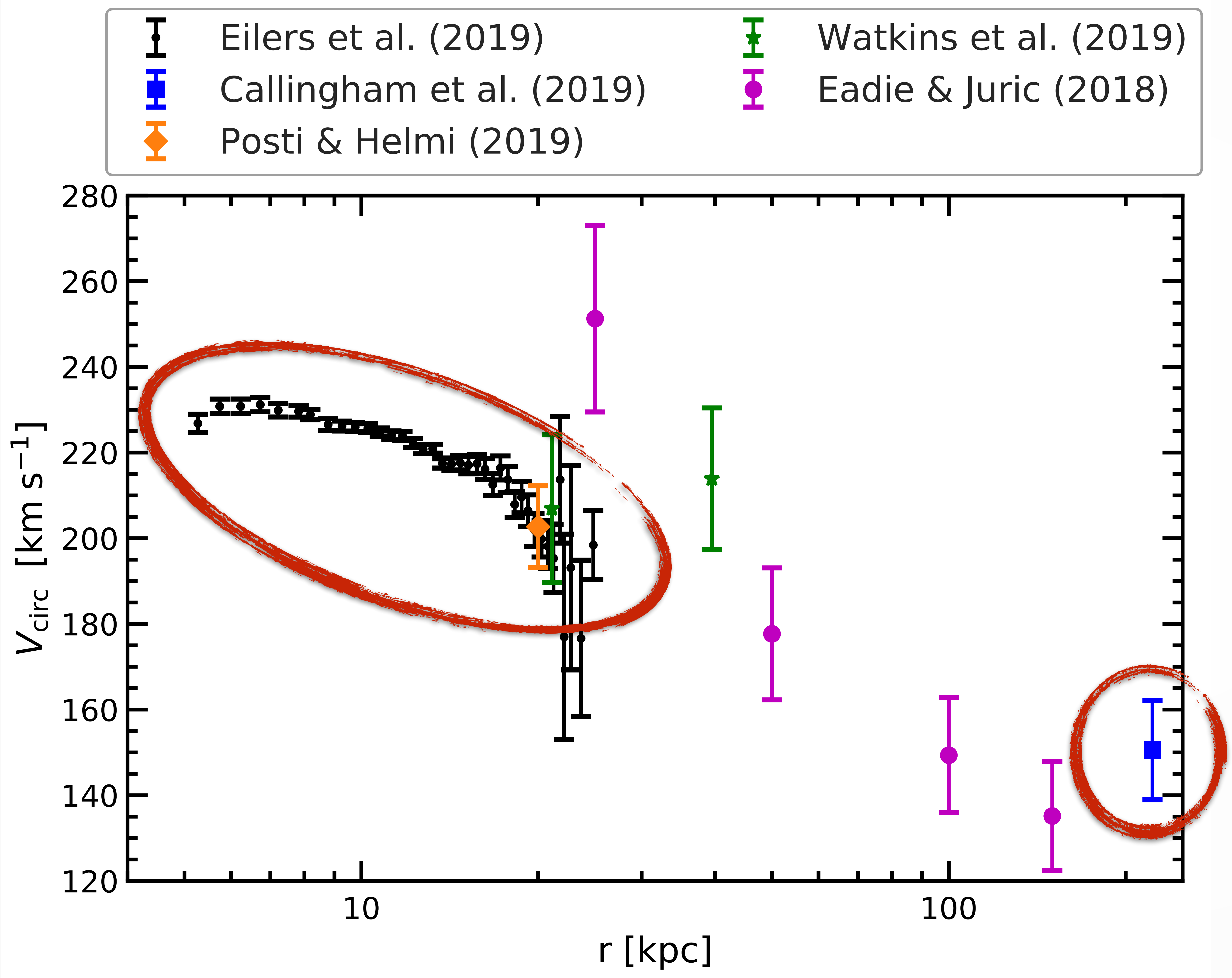
The MW rotation curve



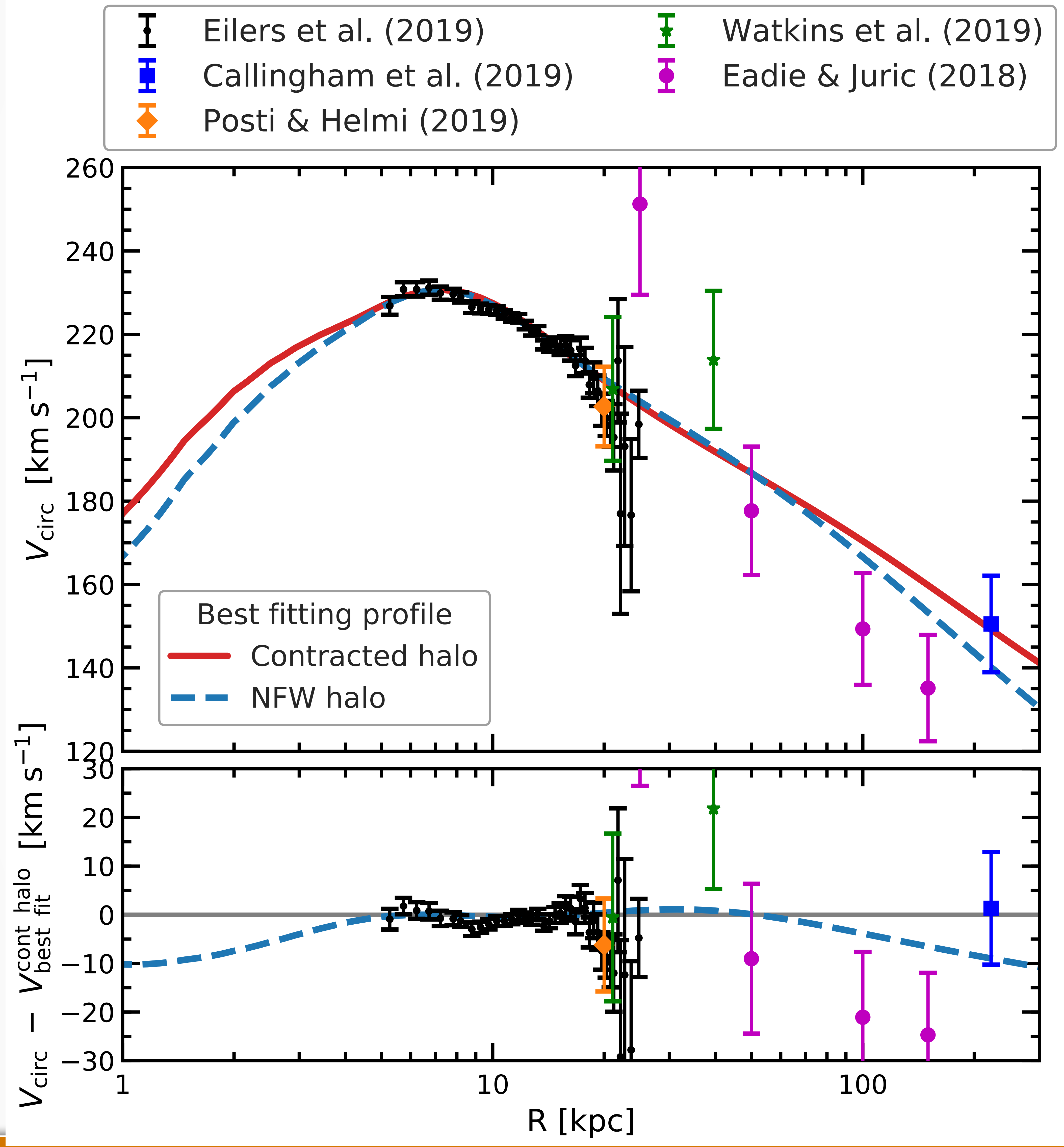
Eilers et al (2019) rotation curve:

- Axisymmetric Jeans modelling of the 6D phase space of ~23,000 red giant stars
- Precise parallaxes obtained from combining Gaia DR2, APOGEE, WISE and 2MASS

Callingham et al (2019) total mass:

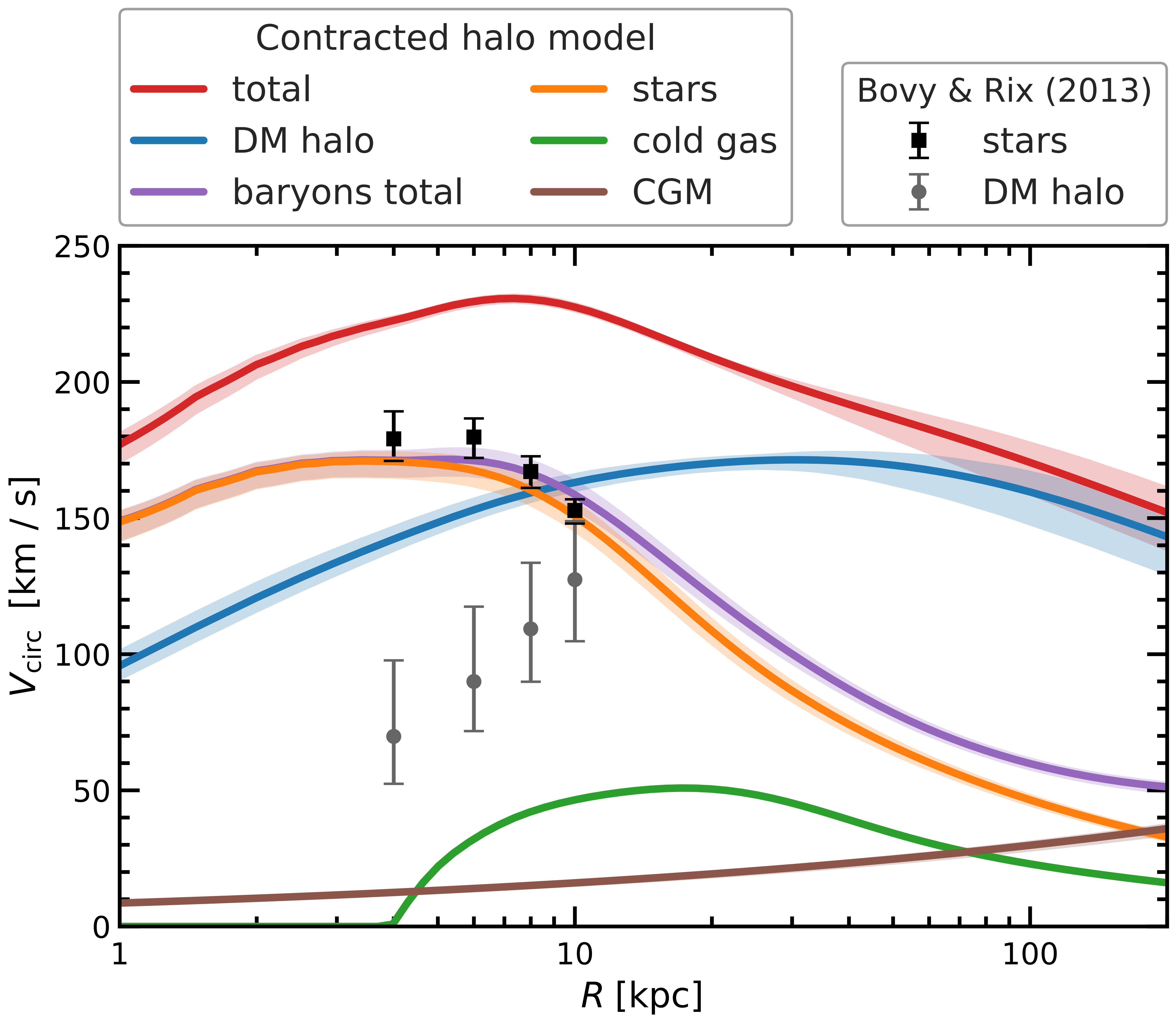
- Obtained from the 6D phase space of the classical MW satellites using Gaia DR2 data

Best fitting MW mass model

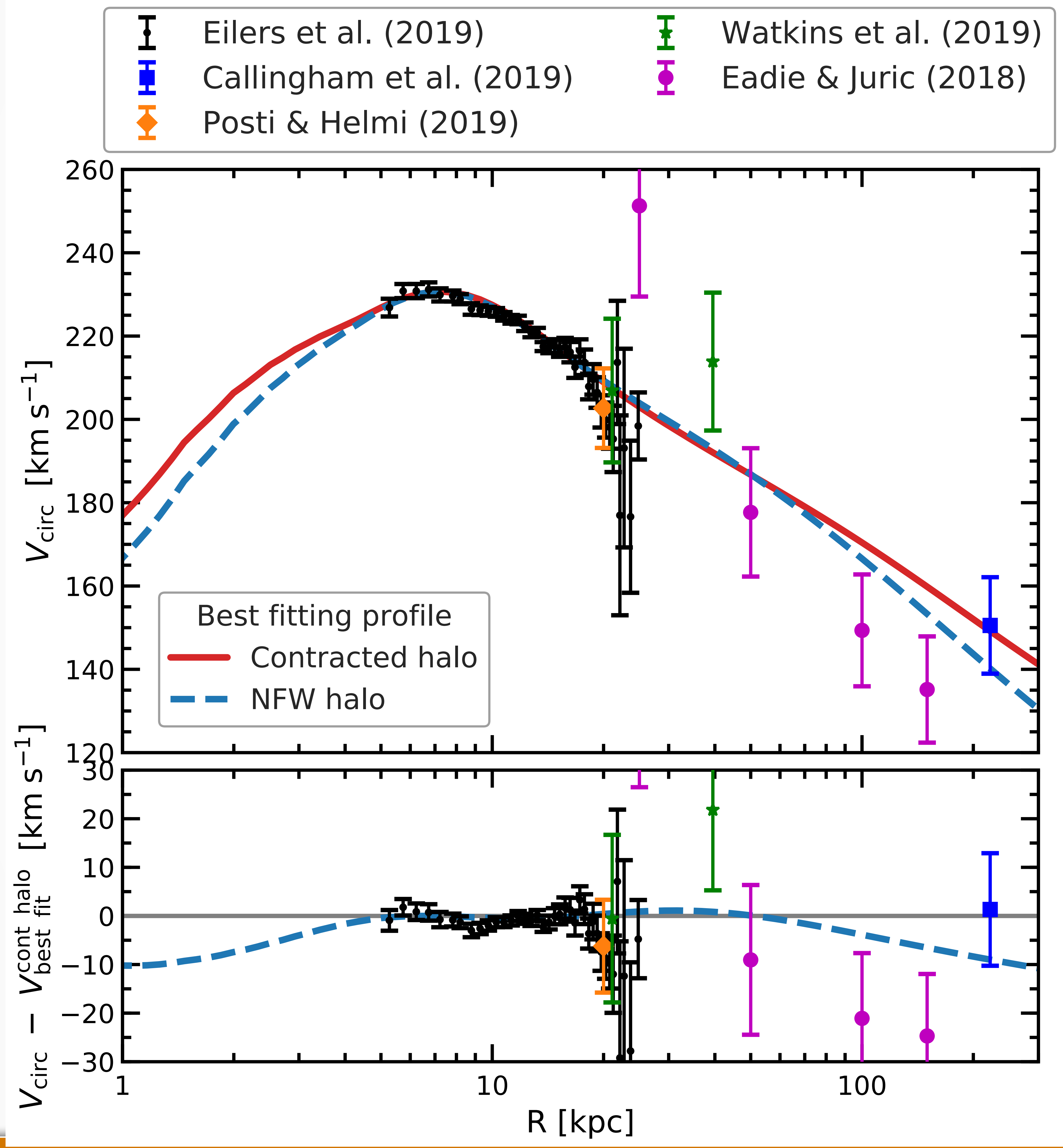


$M_{200}^{\rm DM}$ [$\times 10^{12}\ M_\odot$]	$0.99^{+0.18}_{-0.20}$
$c^{\rm NFW}$	$8.15^{+1.67}_{-1.48}$
$M_{\star\rm thin}$ [$\times 10^{10}\ M_\odot$]	$3.15^{+0.21}_{-0.46}$
$M_{\star\rm thick}$ [$\times 10^{10}\ M_\odot$]	$0.91^{+0.19}_{-0.11}$
$M_{\star\rm bulge}$ [$\times 10^{10}\ M_\odot$]	$0.93^{+0.09}_{-0.08}$
$R_{\rm thin}$ [kpc]	$2.66^{+0.19}_{-0.11}$
$R_{\rm thick}$ [kpc]	$3.99^{+0.31}_{-1.07}$

MW components

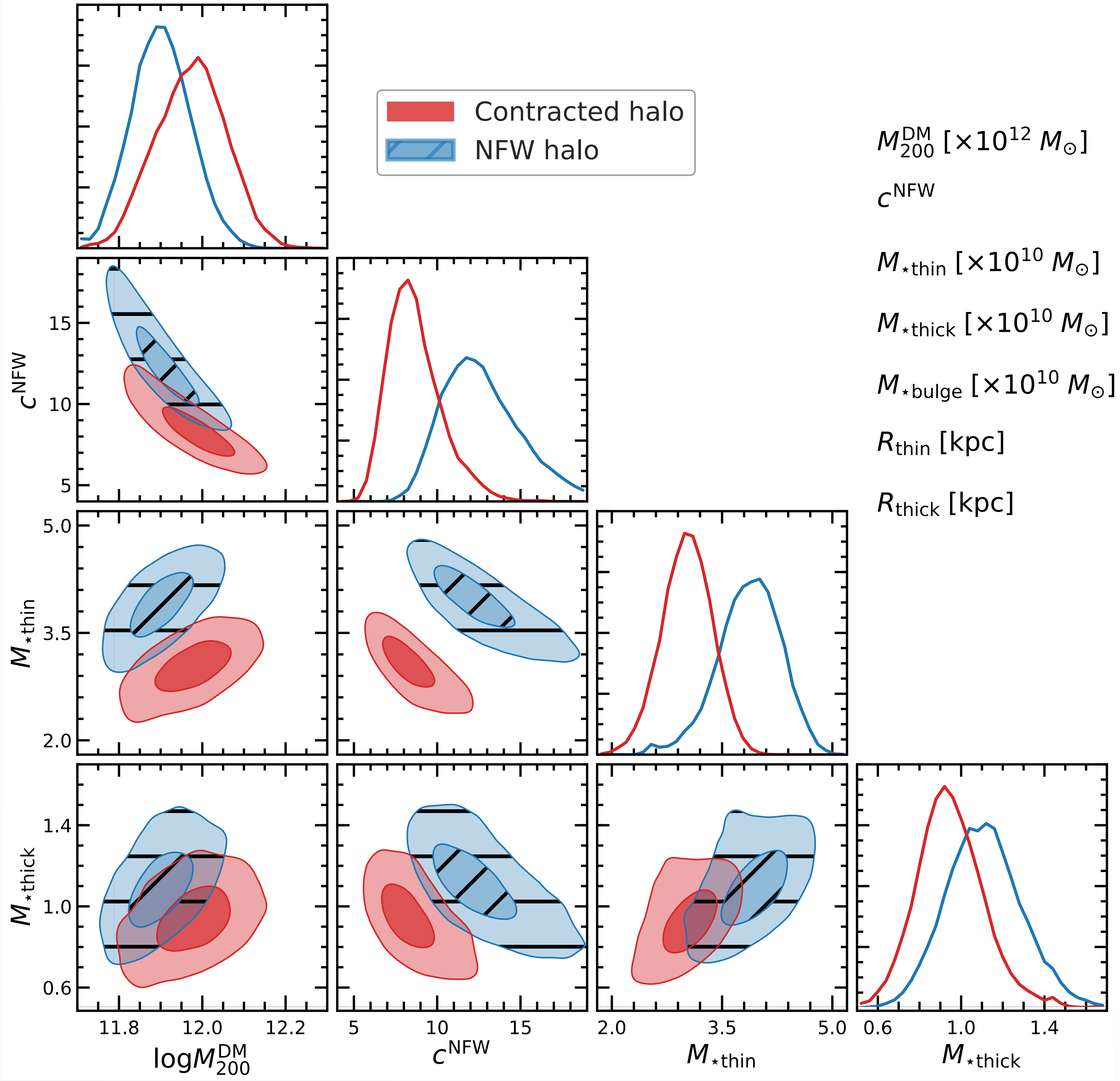


Best fitting MW mass model



	Cont. halo	NFW halo
$M_{200}^{\rm DM}$ [$\times 10^{12}\ M_\odot$]	$0.99^{+0.18}_{-0.20}$	$0.83^{+0.11}_{-0.15}$
$c^{\rm NFW}$	$8.15^{+1.67}_{-1.48}$	$12.03^{+2.59}_{-2.44}$
$M_{\star\rm thin}$ [$\times 10^{10}\ M_\odot$]	$3.15^{+0.21}_{-0.46}$	$4.04^{+0.25}_{-0.59}$
$M_{\star\rm thick}$ [$\times 10^{10}\ M_\odot$]	$0.91^{+0.19}_{-0.11}$	$1.08^{+0.21}_{-0.15}$
$M_{\star\rm bulge}$ [$\times 10^{10}\ M_\odot$]	$0.93^{+0.09}_{-0.08}$	$0.92^{+0.09}_{-0.08}$
$R_{\rm thin}$ [kpc]	$2.66^{+0.19}_{-0.11}$	$2.46^{+0.14}_{-0.08}$
$R_{\rm thick}$ [kpc]	$3.99^{+0.31}_{-1.07}$	$3.80^{+0.44}_{-0.89}$

Best fitting MW mass model



	Cont. halo	NFW halo
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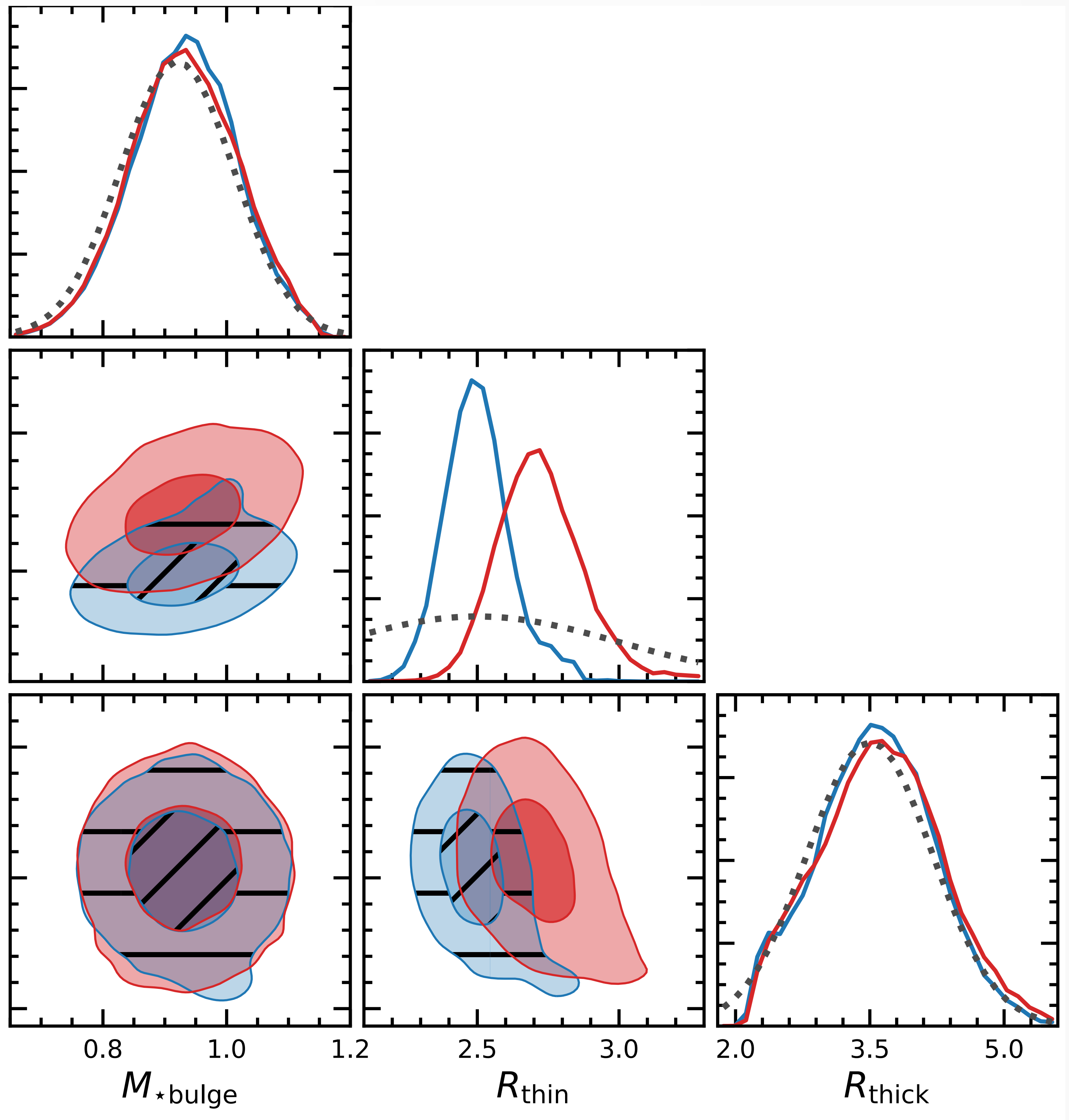
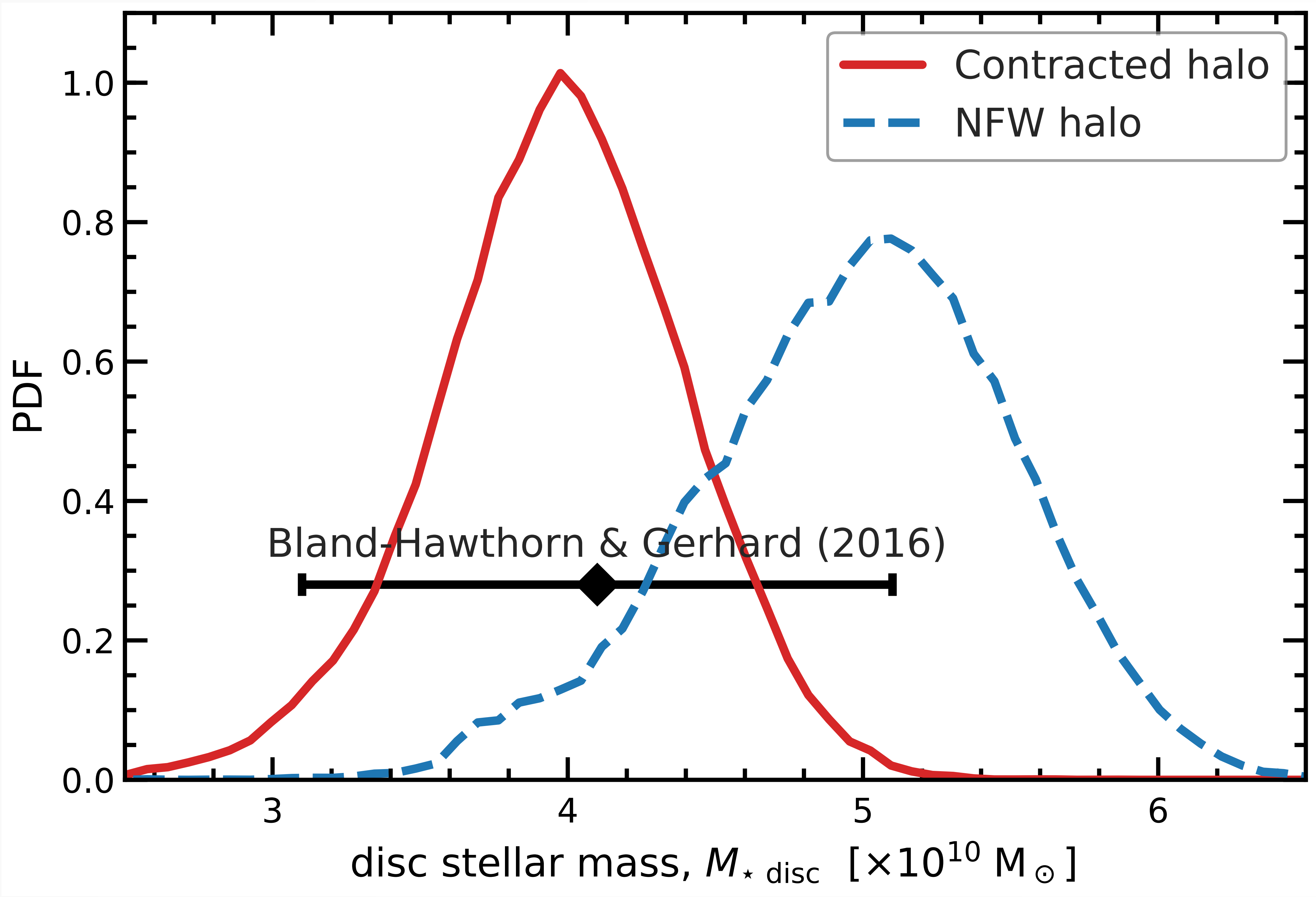
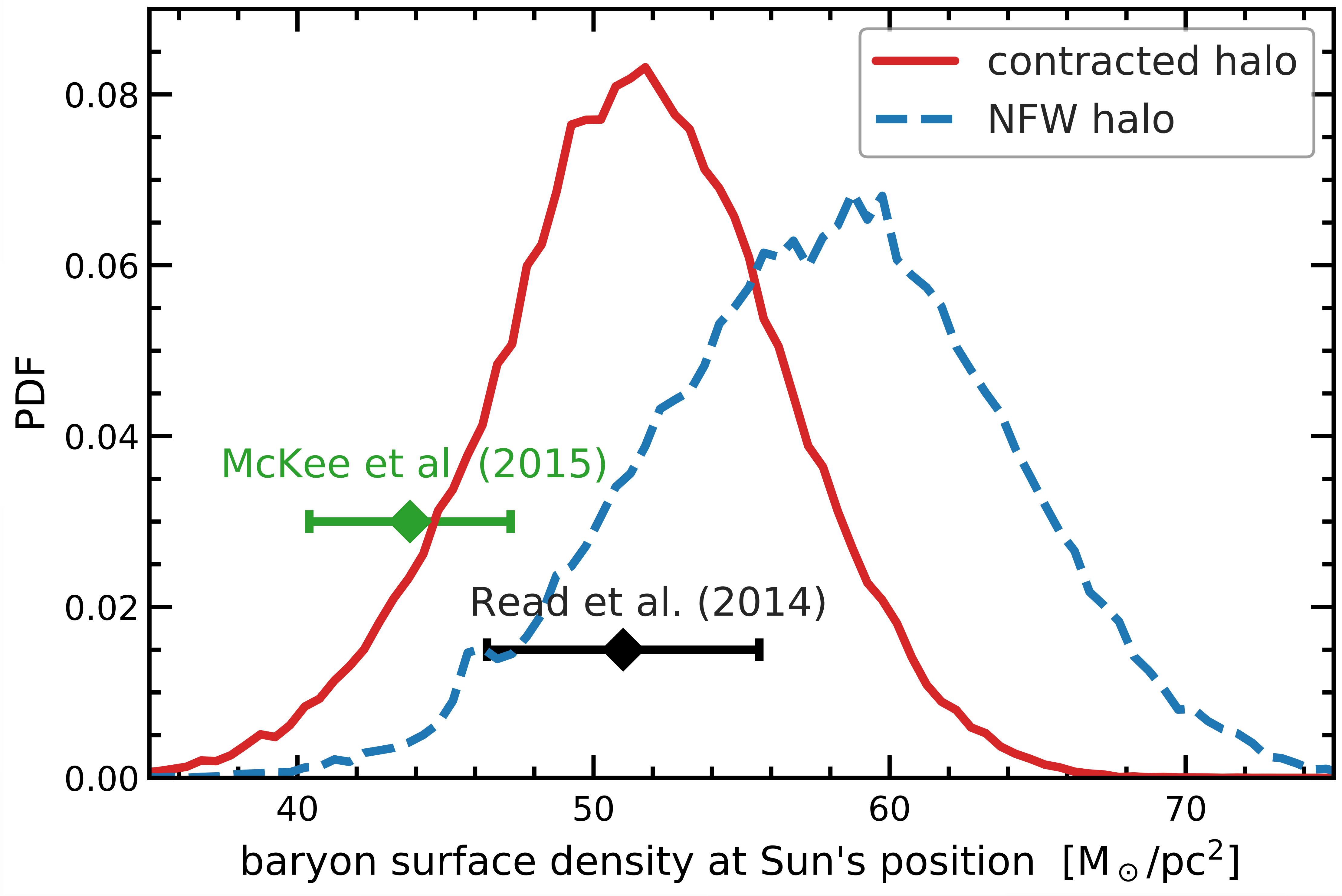


MC+ 2019

MW stellar distribution





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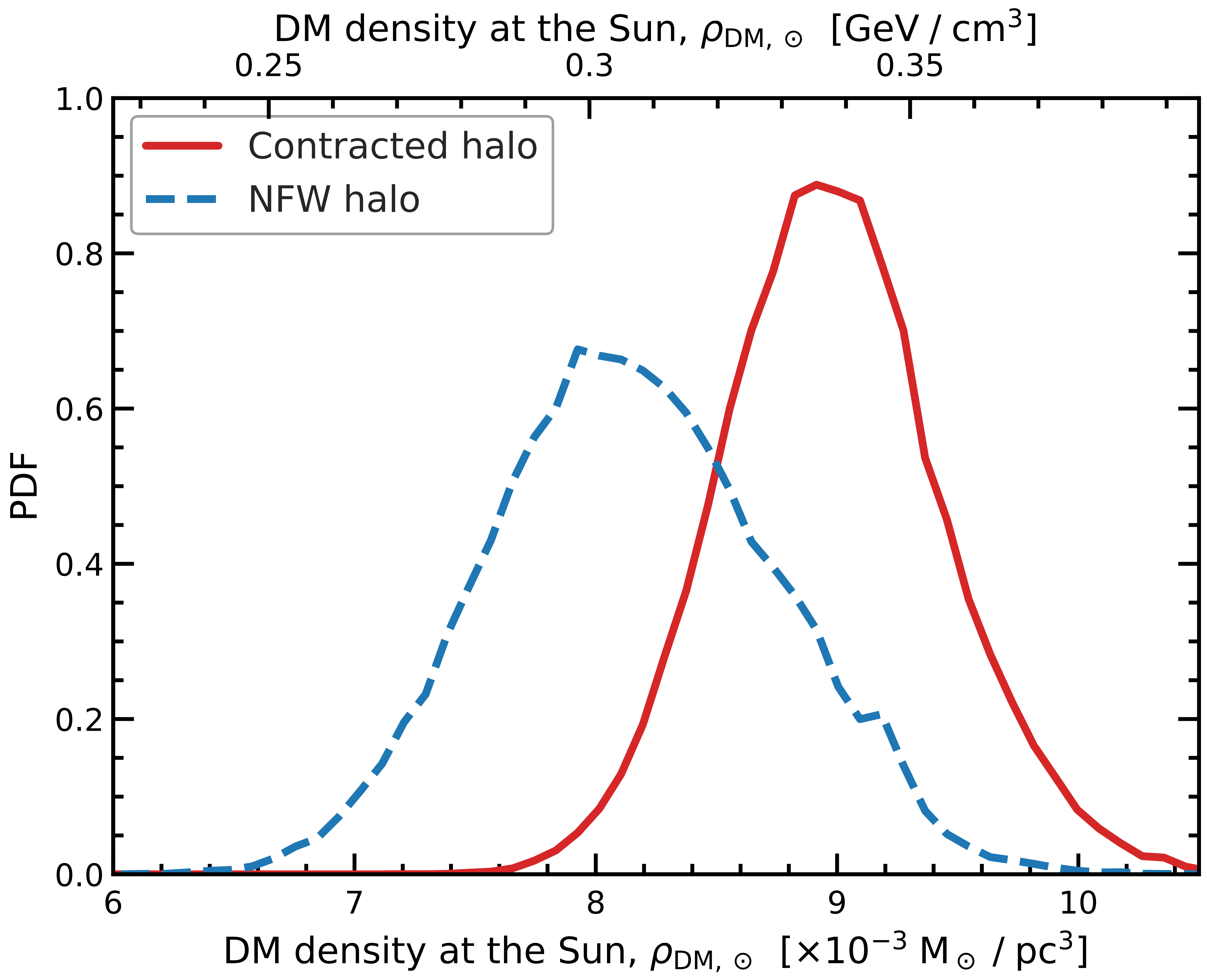
Local DM density



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$$\rho_{\odot}^{\rm DM} = 9.0^{+0.5}_{-0.4} \times 10^{-3} M_{\odot} {\rm pc}^{-3}$$

$$\equiv 0.34^{+0.02}_{-0.02}\ {\rm GeV\ cm}^{-3}$$

Which DM halo model is preferred: a contracted or a NFW profile?

	Contracted halo	NFW halo
Theoretical predictions	✓	
Fit to the MW rotation curve data	✓	
Abundance matching	✓	
Escape velocity at Sun's location	✓	

NFW model has 2 times lower likelihood

In NFW model the MW is a 2 sigma outlier in the M_{star}—M_{halo} relation

NFW model predicts a too low escape velocity

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Which DM halo model is preferred: a contracted or a NFW profile?

Observable	Study	Cont. halo	NFW halo	$\mathcal{L}$ ratio
Theoretical predictions†	–	✓		–
Fit to MW rotation curve	(1)	✓		2.1
Stellar disc mass	(2)	✓		1.4
Abundance matching	(3)	✓		3.2
	(4)	✓		2.0
Baryon surface density	(5)	✓		1.7
at Solar position	(6)	✓		3.5
Escape velocity	(7)	✓		1.2
at Solar position	(8)	✓		1.7

References: (1) this work, (2) Bland-Hawthorn & Gerhard (2016), (3) Moster et al. (2013), (4) Behroozi et al. (2013), (5) Read (2014), (6) McKee et al. (2015), (7) Deason et al. (2019b), (8) Grand et al. (2019b).

† Many hydrodynamical simulations find that the DM halo profile changes in the presence of baryons (e.g. Gnedin et al. 2004; Abadi et al. 2010; Duffy et al. 2010; Schaller et al. 2015; Dutton et al. 2016).

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Summary

- The baryons lead to a contraction in the inner regions of the DM haloes. For the MW, it predicts a **1.3, 2 and 4 times increase** in the DM density at respectively **20, 8 and 1 kpc**.

- The MW rotation curve is well fitted by **a contracted DM halo model** with parameters:

$$M_{200}^{\mathrm{DM}} = 1.0 \pm 0.2 \times 10^{12} M_\odot \qquad c^{\mathrm{DM}} = 8.2 \pm 1.6$$

$$M_{200}^{\mathrm{total}} = 1.1 \pm 0.2 \times 10^{12} M_\odot$$

This is **spot on the LCDM prediction** for the mass—halo concentration.

- An NFW halo model fits the data almost as well, but very different stellar mass estimates for the MW.