Galactic accelerations in different dark matter paradigm

Arpit Arora, Robyn E. Sanderson, and Sukanya Chakrabarti

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(Literally the vertical accelerations around the mid-plane in the solar neighborhood.)

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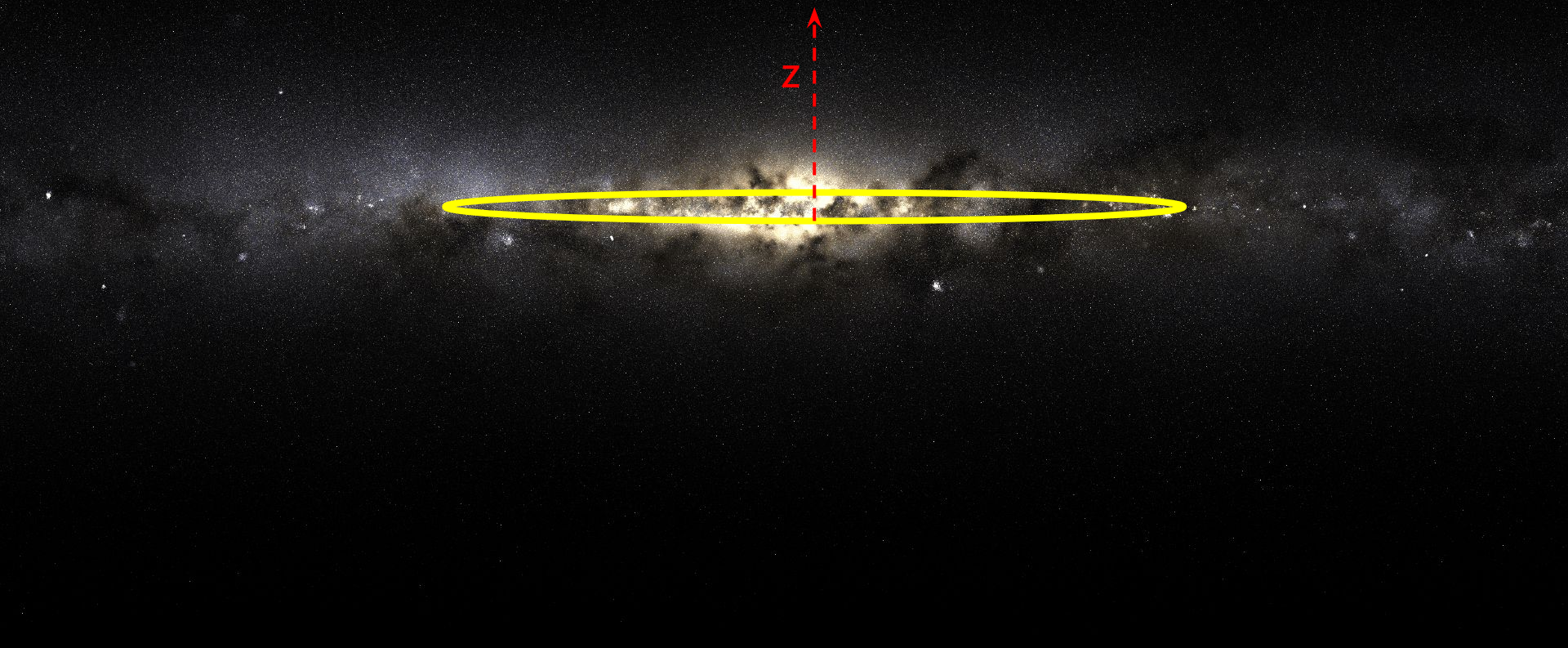

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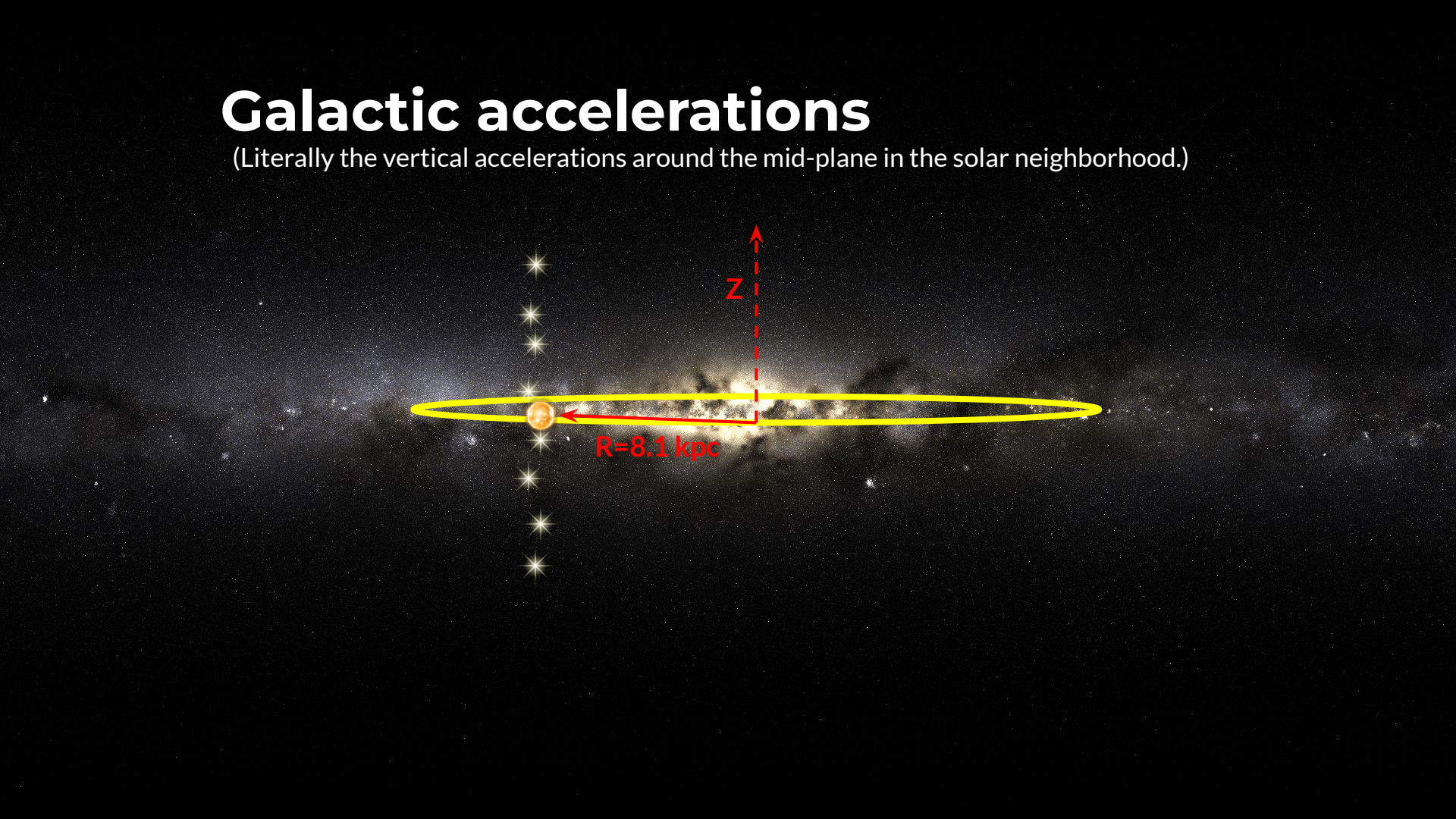
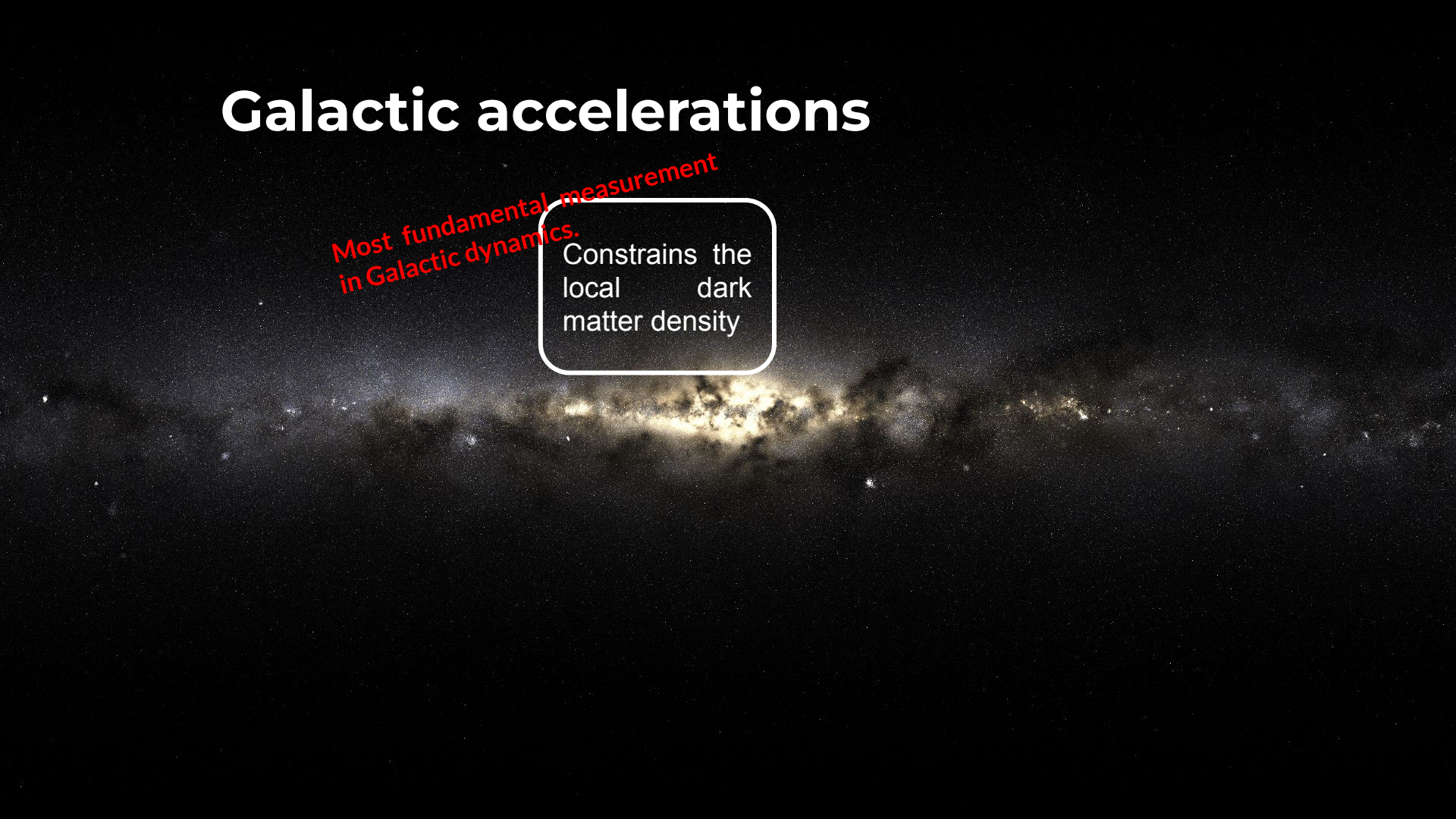


Galactic accelerations

Most fundamental measurement in Galactic dynamics.

Constrains the local dark matter density



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Constrains the local dark matter density

Can be used to determine Milky way halo shape.

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Used in direct detection experiments .

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New measurement technologies!

Galactic accelerations : Measurements

The Astrophysical Journal Letters, 907:L26 (7pp), 2021 February 1 https://doi.org/10.3847/2041-8213/abd635

A Measurement of the Galactic Plane Mass Density from Binary Pulsar Accelerations

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[4] Laboratory for Multiwavelength Astronomy, Rochester Institute of Technology, 84 Lomb Memorial Drive, Rochester, NY 14623, USA
[5] Department of Physics and Astronomy, University of Rochester, USA
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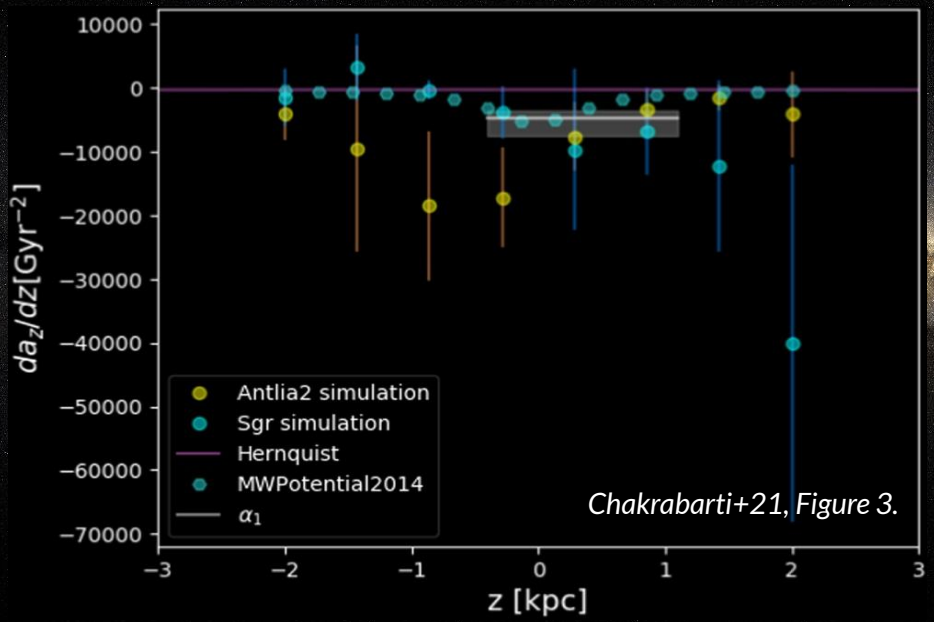
Abstract

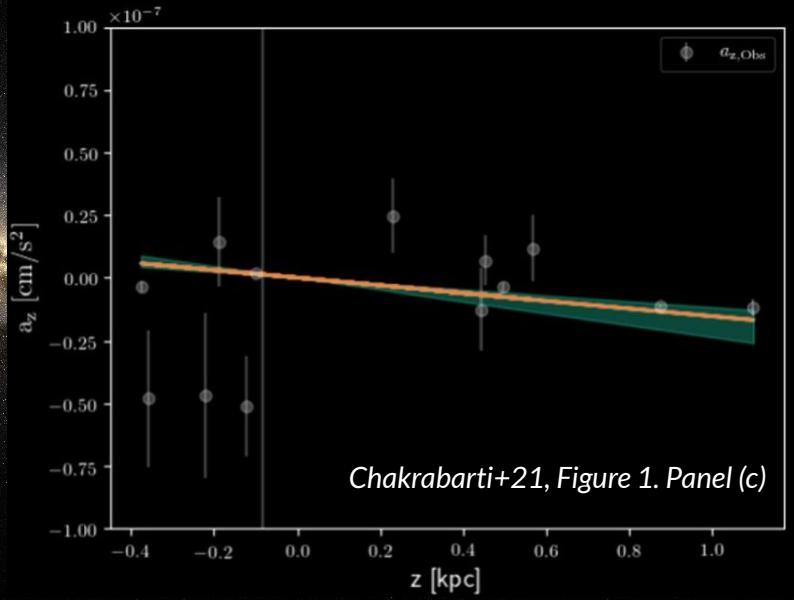
We use compiled high-precision pulsar timing measurements to directly measure the Galactic acceleration of binary pulsars relative to the solar system barycenter. Given the vertical accelerations, we use the Poisson equation to derive the Oort limit, i.e., the total volume mass density in the Galactic mid-plane. Our best-fitting model gives an Oort limit of $0.08^{0.05}_{-0.02} M_\odot\ \mathrm{pc}^{-3}$, which is close to estimates from recent Jeans analyses. Given the accounting of the baryon budget from McKee et al., we obtain a local dark matter density of $-0.004^{0.05}_{-0.02}\ M_\odot\ \mathrm{pc}^{-3}$, which is slightly below other modern estimates but consistent within the current uncertainties of our method. The error bars are currently about five times larger than kinematical estimates, but should improve in the future for this novel dynamical method. We also constrain the oblateness of the potential, finding it consistent with that expected from the disk and inconsistent with a potential dominated by a spherical halo, as is appropriate for our sample that is within a ~kpc of the Sun. We find that current measurements of binary pulsar accelerations lead to large uncertainties in the slope of the rotation curve. We give a fitting function for the vertical acceleration a_z: $a_z = -\alpha_1 z; \log_{10}(\alpha_1/\mathrm{Gyr}^{-2}) = 3.69^{0.19}_{-0.12}$. By analyzing interacting simulations of the Milky Way, we find that large asymmetric variations in da_z/dz as a function of vertical height may be a signature of sub-structure. We end by discussing the power of combining constraints from pulsar timing and high-precision radial velocity measurements toward lines-of-sight near pulsars, to test theories of gravity and constrain dark matter sub-structure.

Unified Astronomy Thesaurus concepts: Dark matter (353); Milky Way dark matter halo (1049); Pulsars (1306); Binary pulsars (153)

Galactic accelerations : Measurements



Chakrabarti+21, Figure 3.

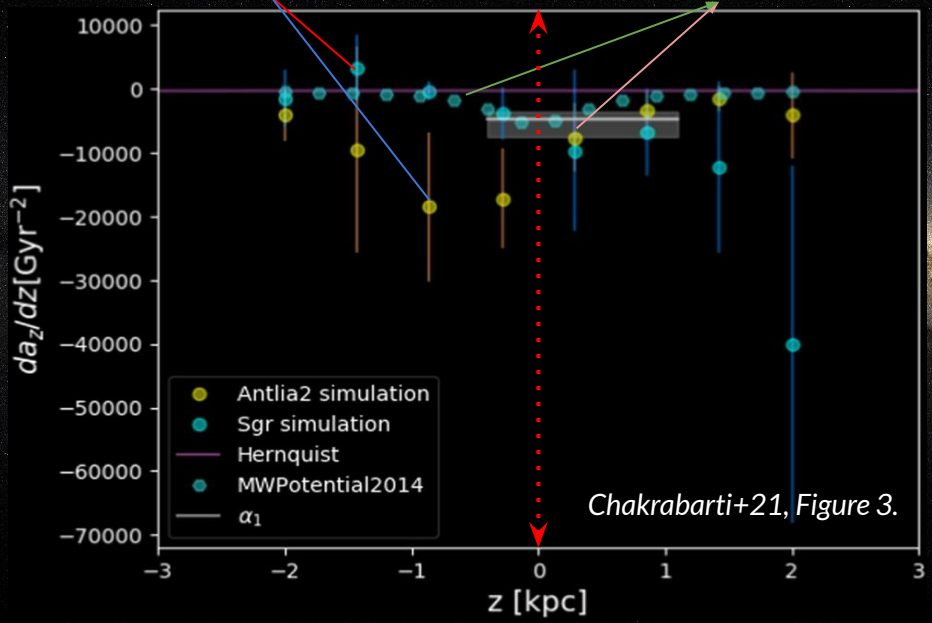


Chakrabarti+21, Figure 1. Panel (c)

Galactic accelerations : Measurements

asymmetric
(interactions)

Symmetric
(static model)



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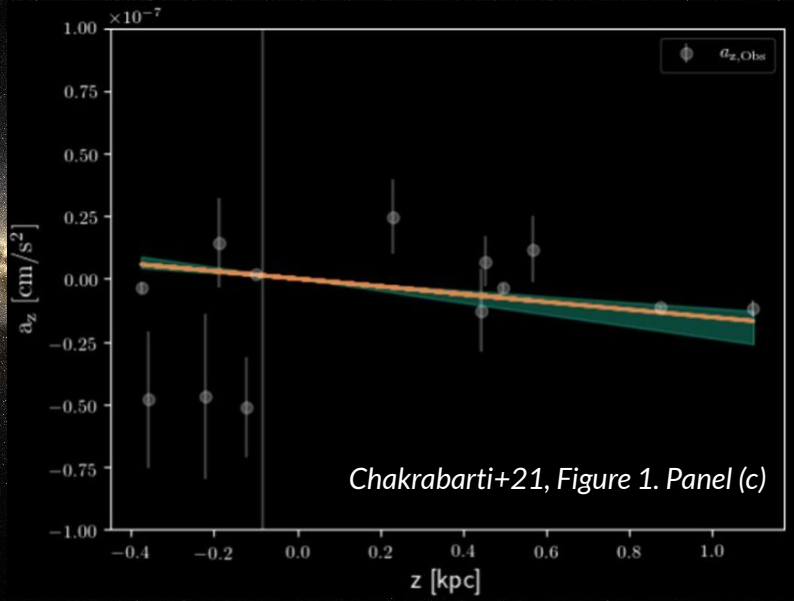

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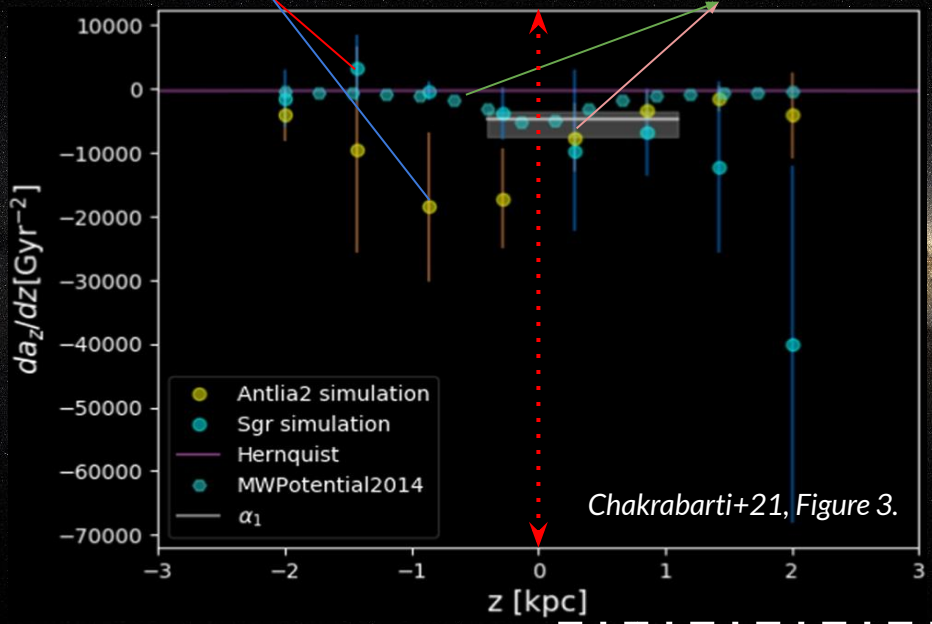

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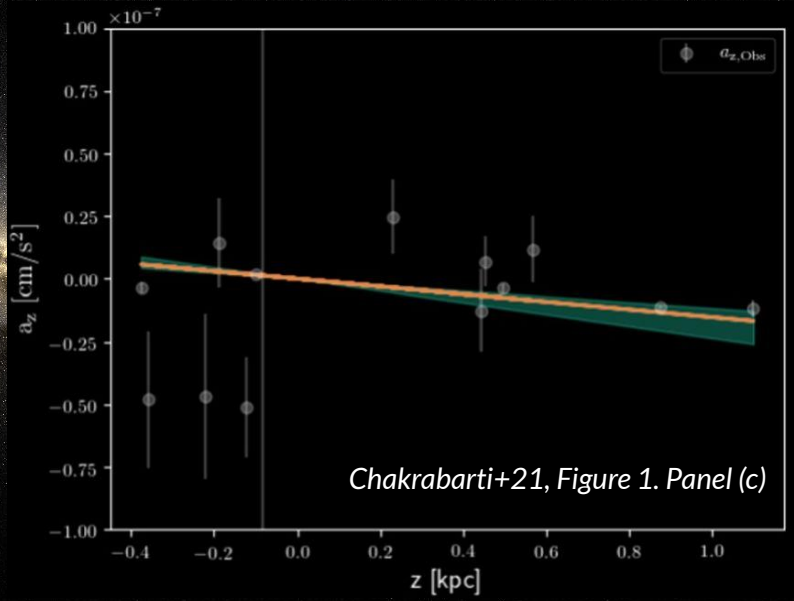
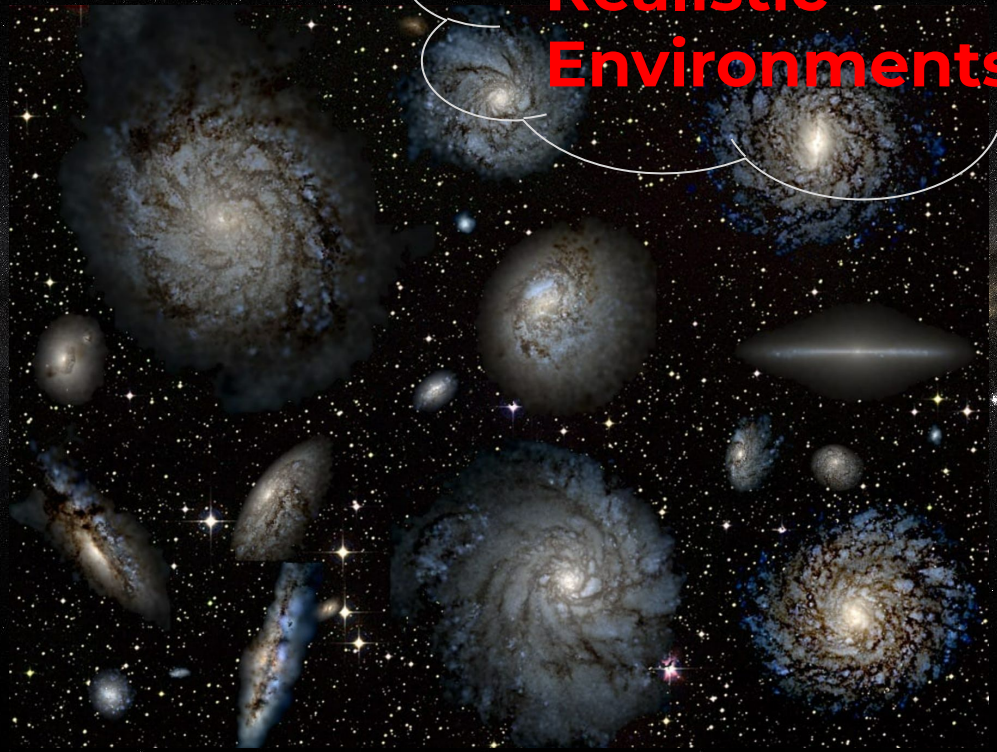
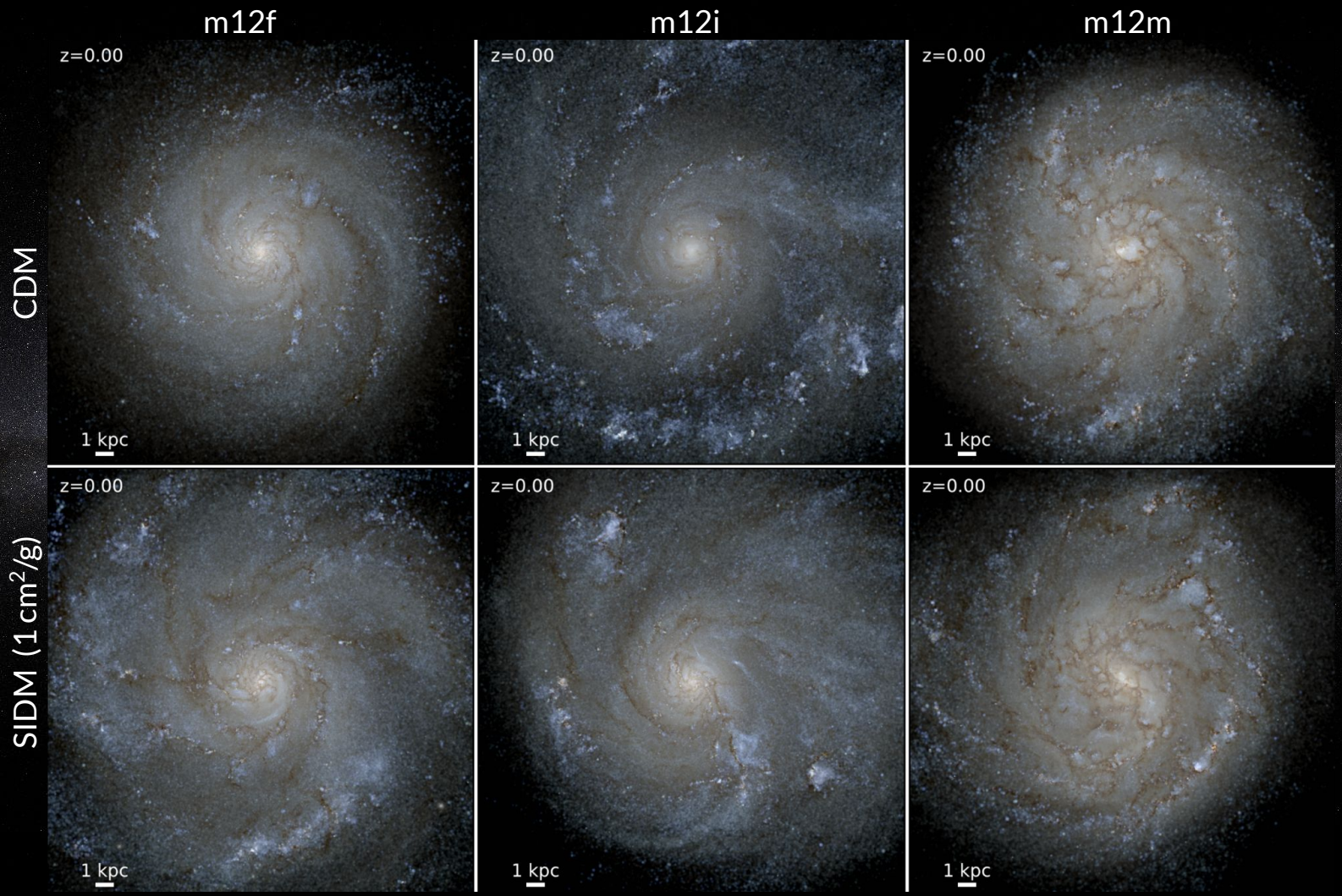


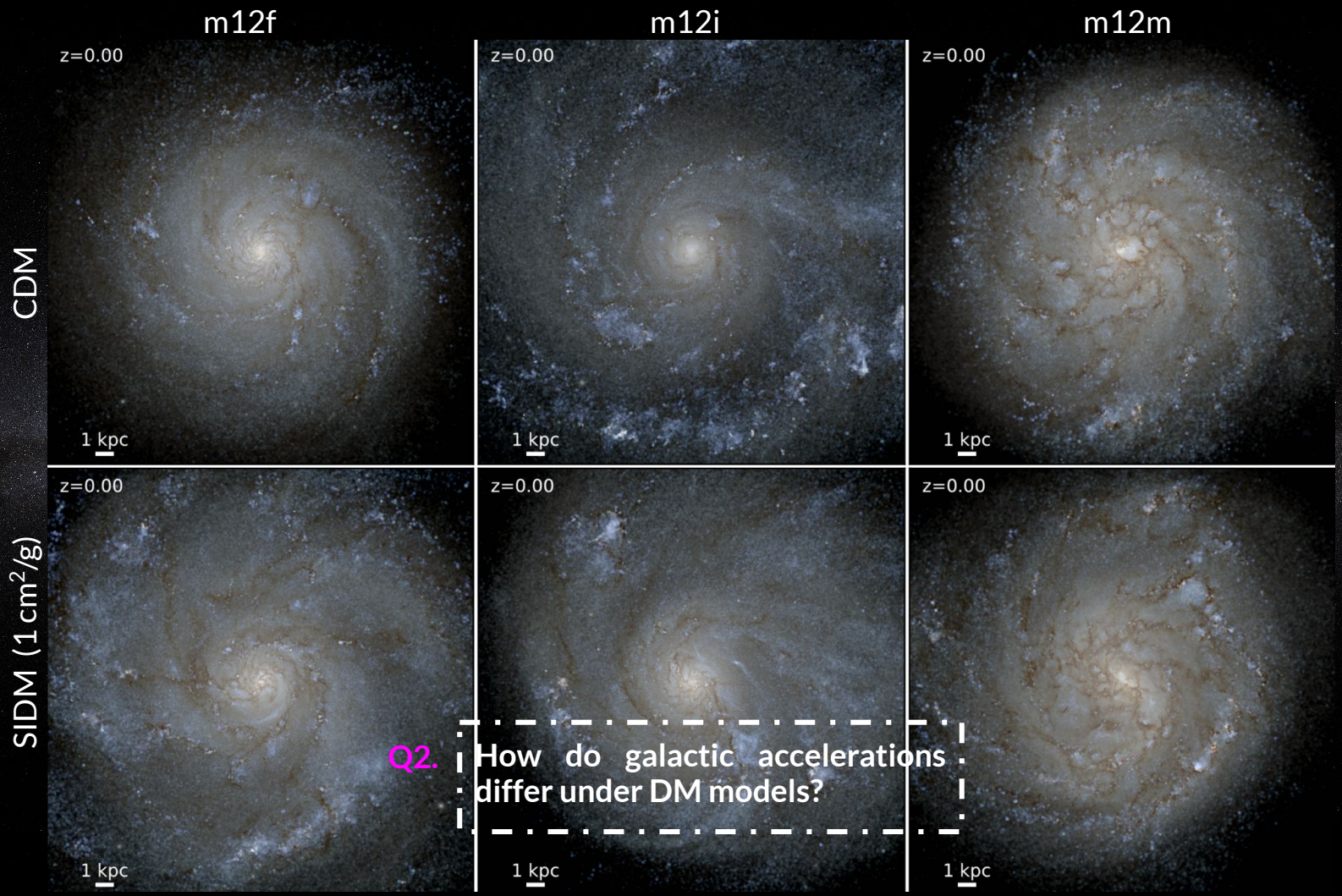
Chakrabarti+21, Figure 1. Panel (c)

Q1. **What happens in simulations with different assembly history?**

FIRE-2: Feedback in Realistic Environments

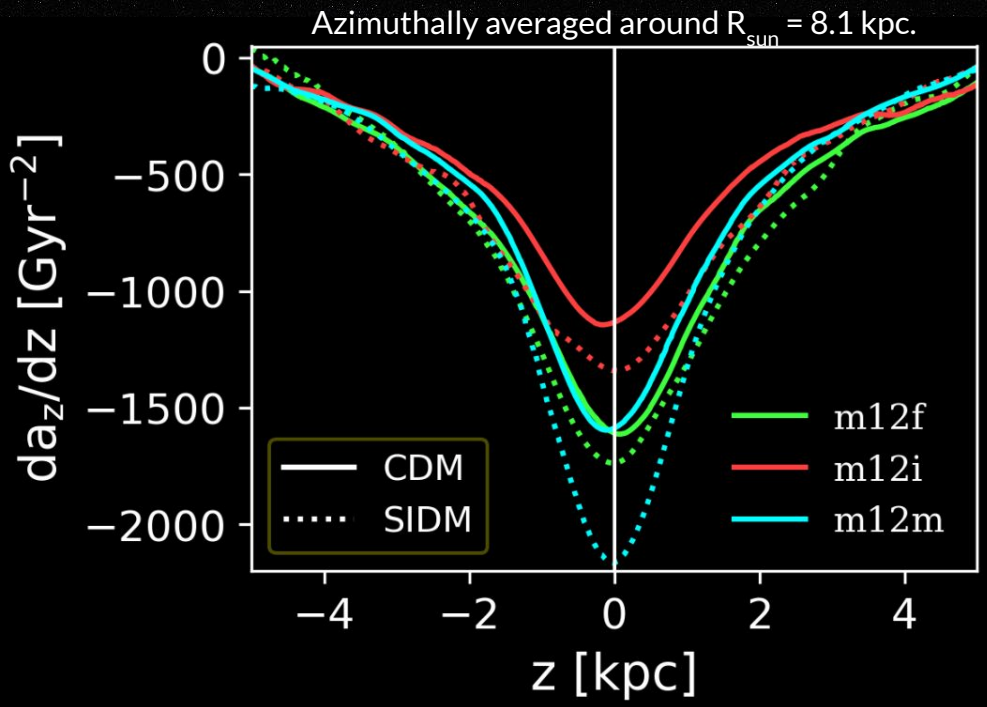



m12f
m12i
m12m
CDM
SIDM (1 cm^2/g)
z=0.00
1 kpc



Q2. How do galactic accelerations differ under DM models?

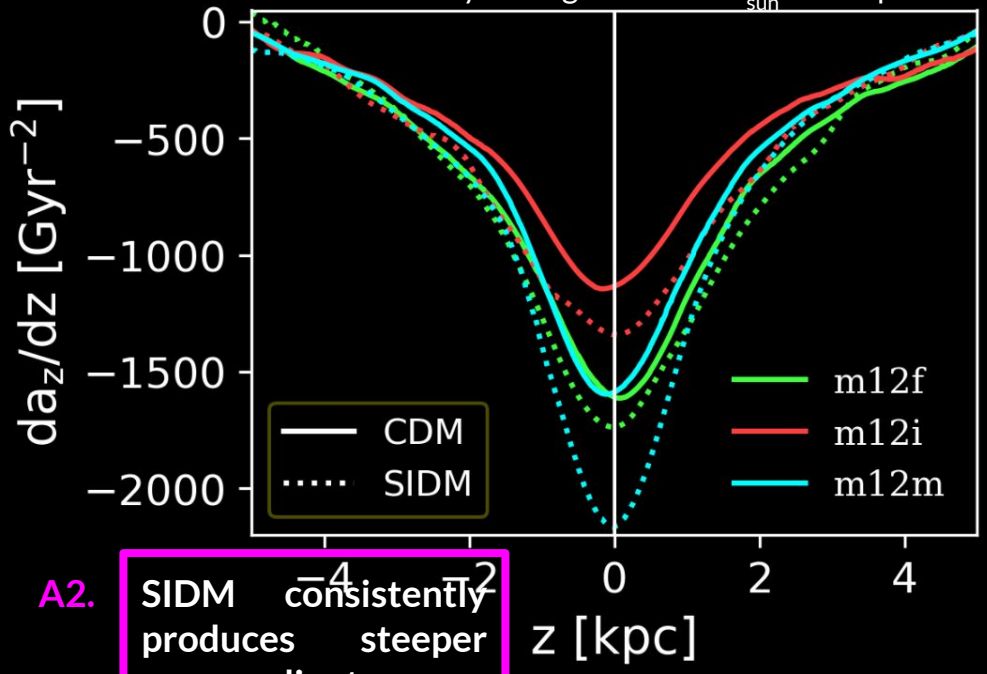
Systematically shallower vertical acceleration gradients.



Chakrabarti et. al. best fit at -5000 Gyr^{-2}

Systematically shallower vertical acceleration gradients.

Azimuthally averaged around R_{sun} = 8.1 kpc.



A2. **SIDM consistently produces steeper acc. gradient**

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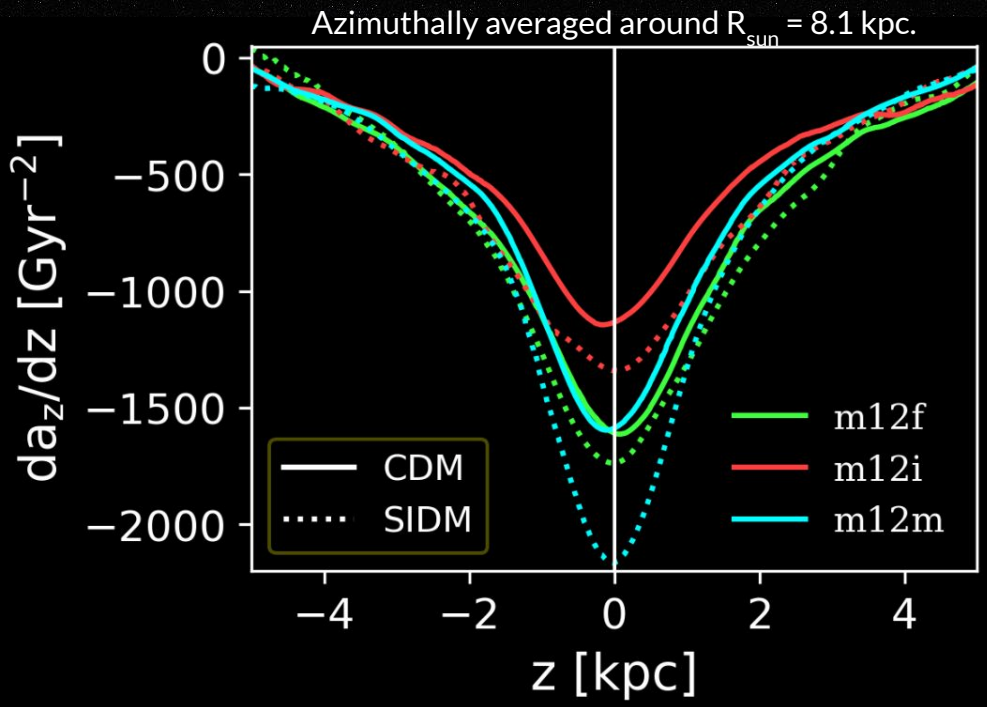


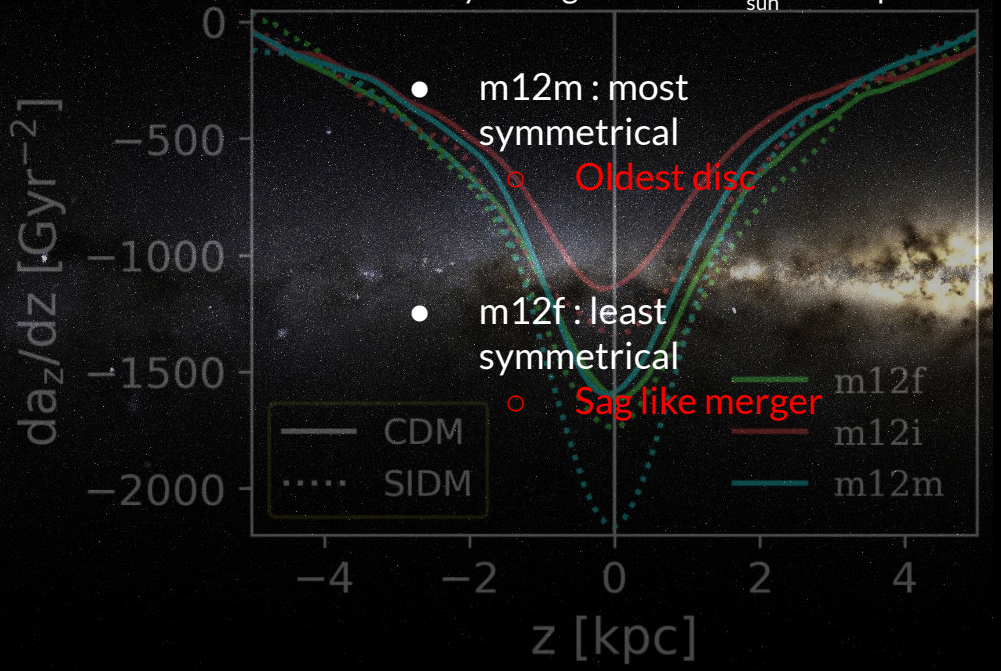
Chakrabarti et. al. best fit at -5000 Gyr^{-2}

We plot the differences!

$$|\Delta da_z/dz| = |\frac{da_z}{dz}(z) - \frac{da_z}{dz}(-z)|$$

Asymmetries around the mid-plane.

Azimuthally averaged around R_{sun} = 8.1 kpc.



- m12m : most symmetrical
  - Oldest disc
- m12f : least symmetrical
  - Sag like merger

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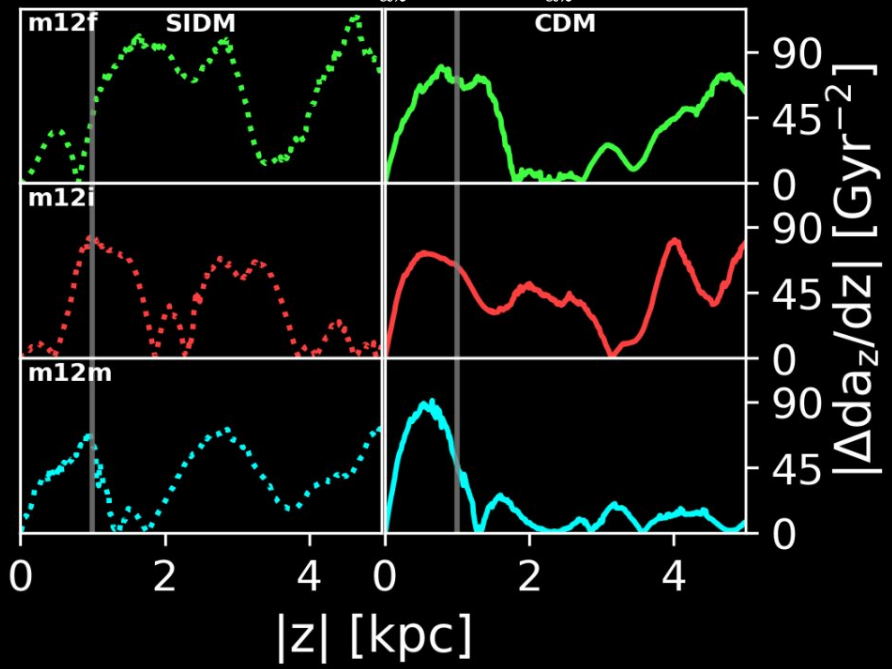

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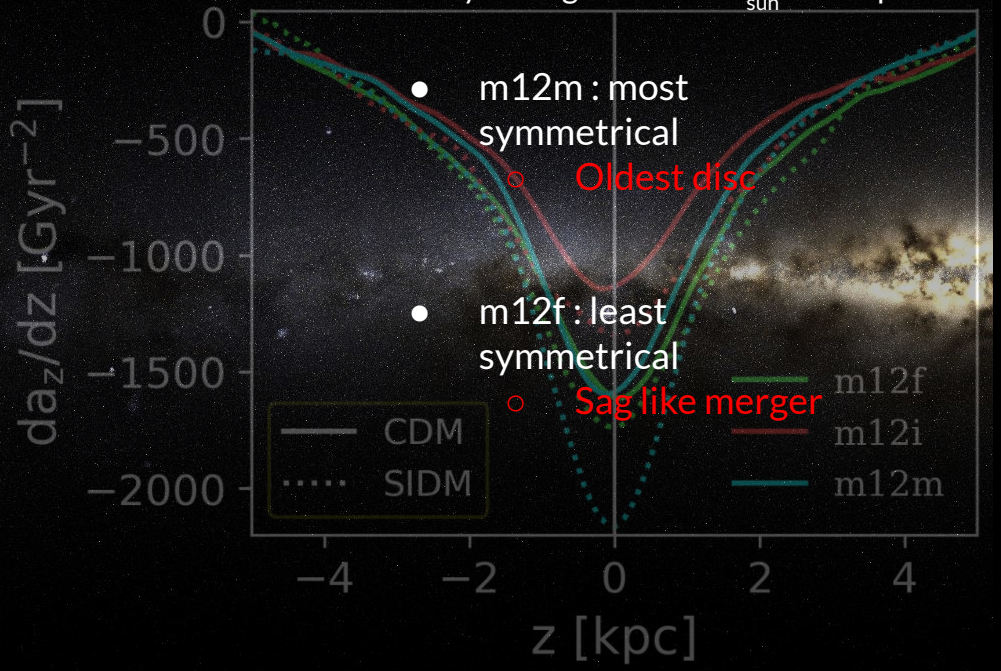

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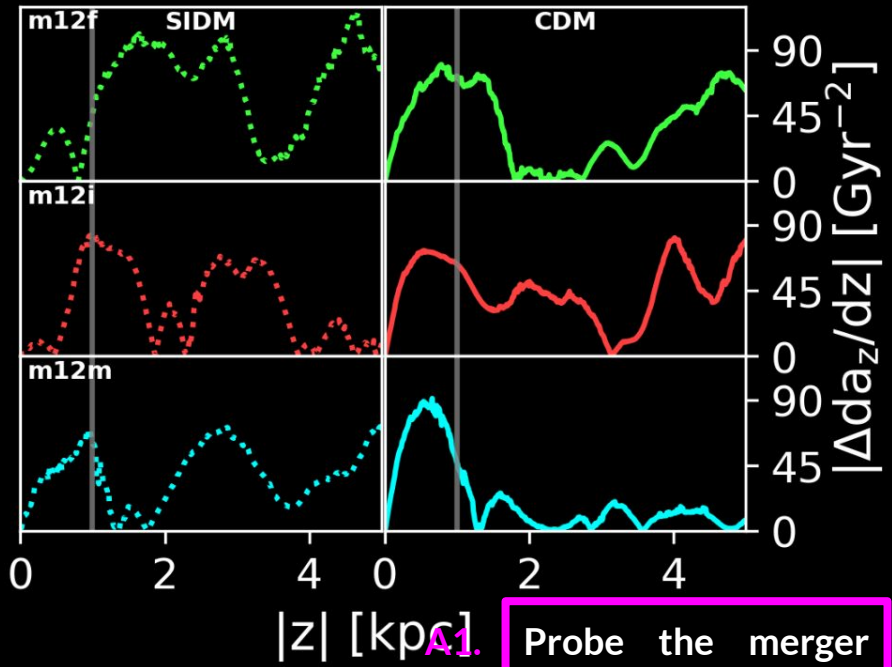

A1.

Chakrabarti et. al. best fit at -5000 Gyr^{-2}

Probe the merger history from the asymmetry!

Systematically shallower vertical acceleration gradients.

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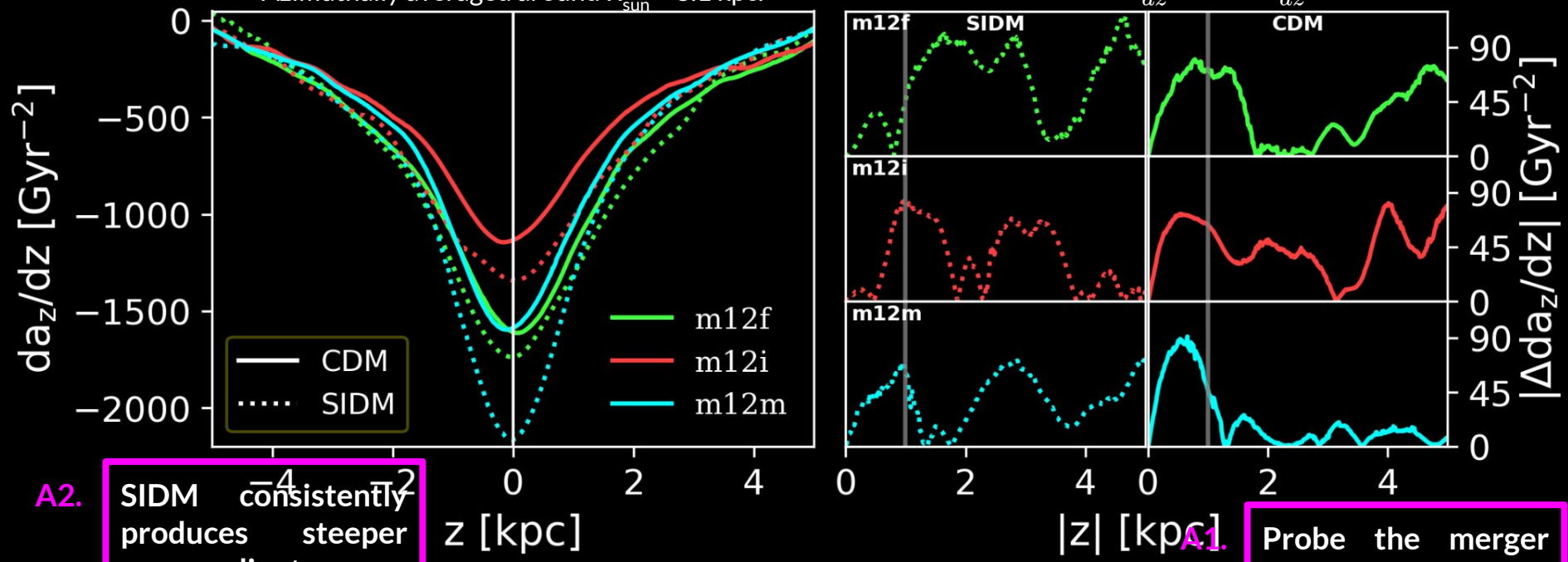

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Chakrabarti et. al. best fit at -5000 Gyr^{-2}

A1. **Probe the merger history from the asymmetry!**

Simulation halo properties:

		surface density $[M_\odot/pc^{-2}]$		volume density[d] $[10^{-3}M_\odot/pc^{-3}]$				scale height [pc]		
Galaxy	**Physics**	total[b]	baryonic[c]	total	stars	gas	DM	stars thin	stars thick	cold* gas
MW[a]		70 ± 5	47 ± 3	99.5 ± 7.2	43 ± 3	46 ± 6	10.5 ± 2.5	300 ± 60	900 ± 180	150
m12i	CDM	44.7	40.1	23.1	7.8	6.6	8.7	566.76	2000†	321.85
	SIDM	54.6	57.2	29.7	11.2	9.5	9.02	411.98	887.1	344.95
m12f	CDM	61.6	62.5	33.6	12.9	10.7	10	391.44	826.06	395.53
	SIDM	67.9	74.0	35.3	16.5	7.4	11.3	455.67	2000†	325.82
m12m	CDM	63.6	64.4	35	16.1	8.1	10.9	142.04	670.13	342.73
	SIDM	87.5	93.6	49.1	24.9	10.7	13.5	274.8	933.67	314.03

Azimuthally averaged properties at solar position, R_{sun} = 8.1 kpc for simulated galaxies.

[a] values from Bland-Hawthorn+2016 unless noted. [b] materials within |z| ≤ 1.1 kpc. [c] materials within |z| ≤ 4 kpc.

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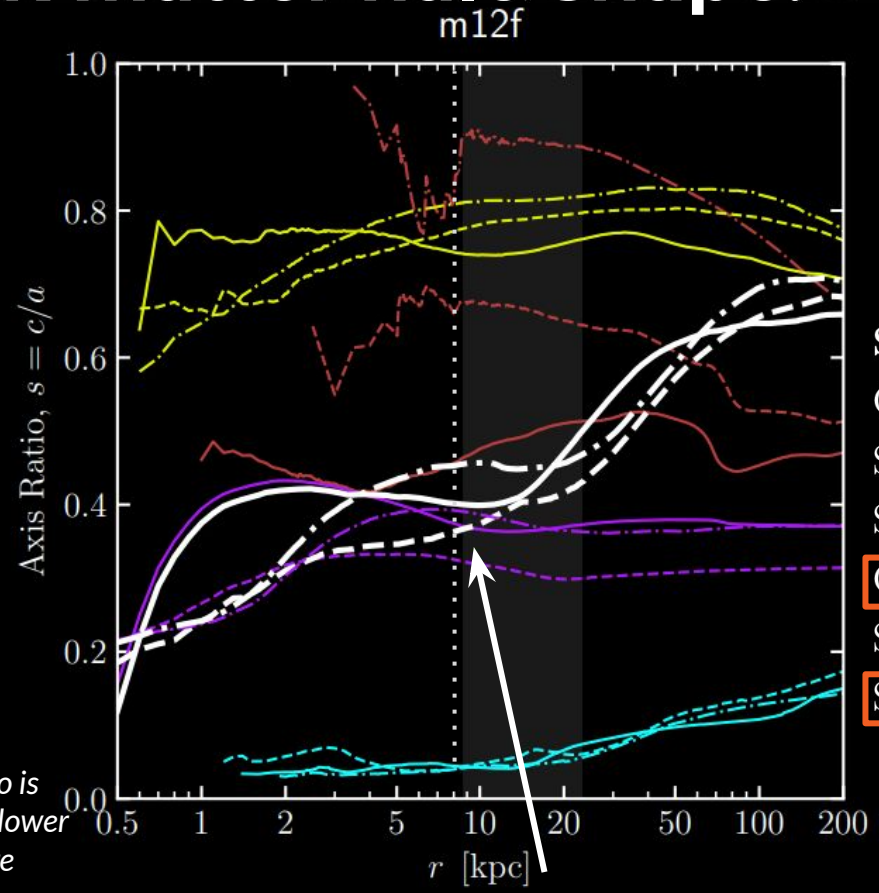
Dark matter halo shape:



Work by Drona Vargya, Penn PhD Dec 2020

Simulations	σ/m	Total	Dark	Stars
CDM-only	0			
SIDM-only	1			
SIDM-only	10			
CDM+Baryon	0			
SIDM+Baryon	0.1			
SIDM+Baryon	1			

SIDM halo is flatter at lower radii, more squashed

DM+baryons combined axis ratio in white.

Simulation halo properties:

Galaxy	Physics	surface density [$M_\odot/pc^{-2}$] total[b]	surface density [$M_\odot/pc^{-2}$] baryonic[c]	volume density[d] [$10^{-3}M_\odot/pc^{-3}$] total	volume density[d] [$10^{-3}M_\odot/pc^{-3}$] stars	volume density[d] [$10^{-3}M_\odot/pc^{-3}$] gas	volume density[d] [$10^{-3}M_\odot/pc^{-3}$] DM	scale height [pc] stars thin	scale height [pc] stars thick	scale height [pc] cold* gas
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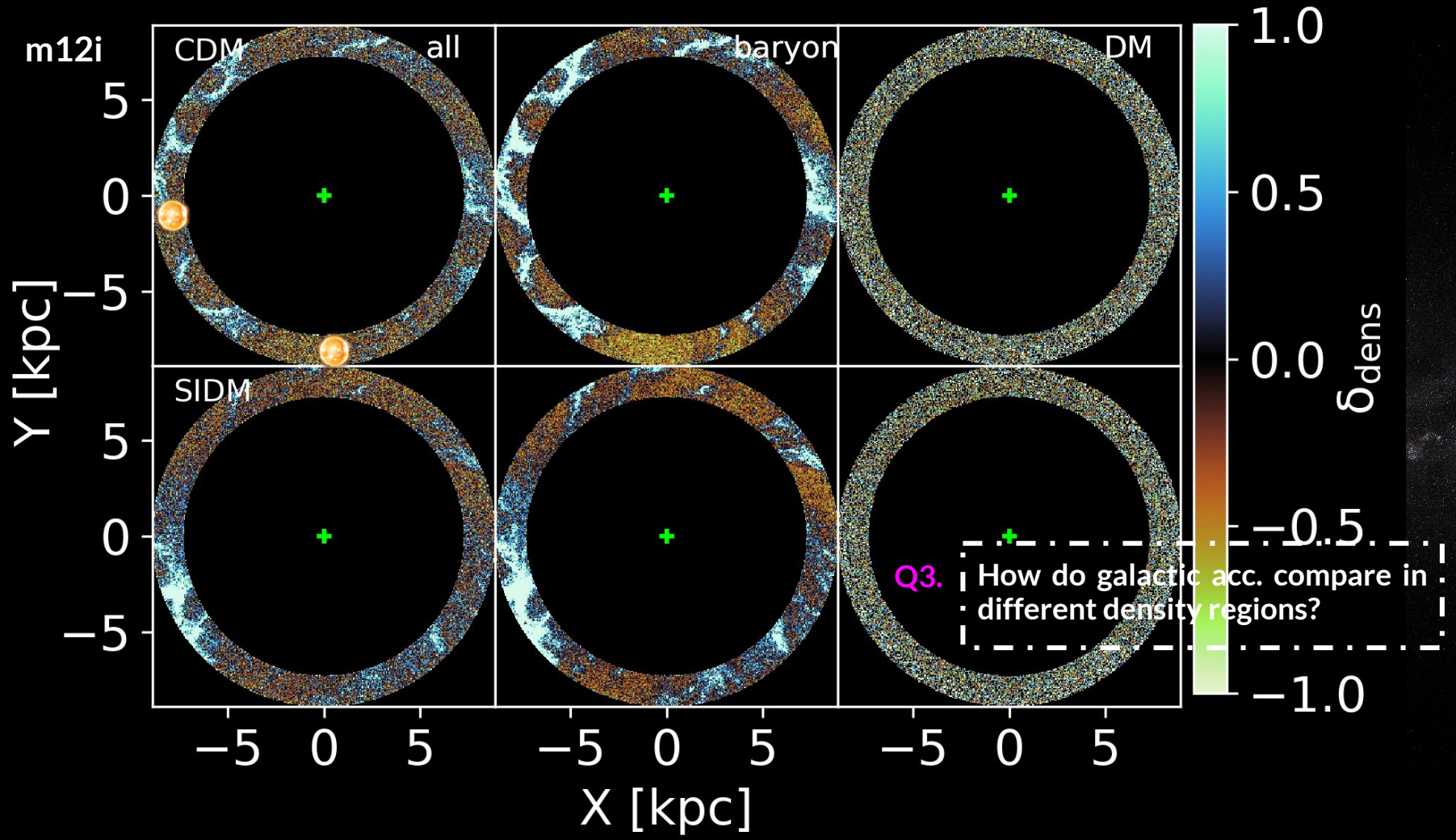
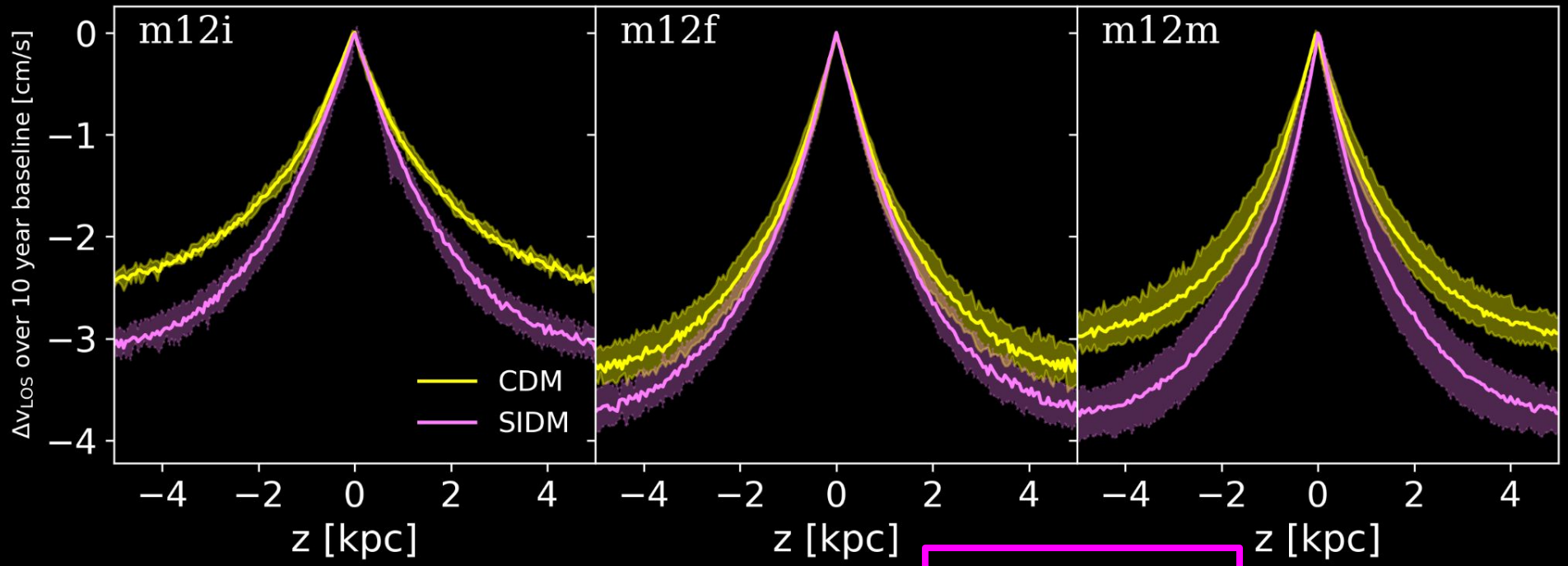
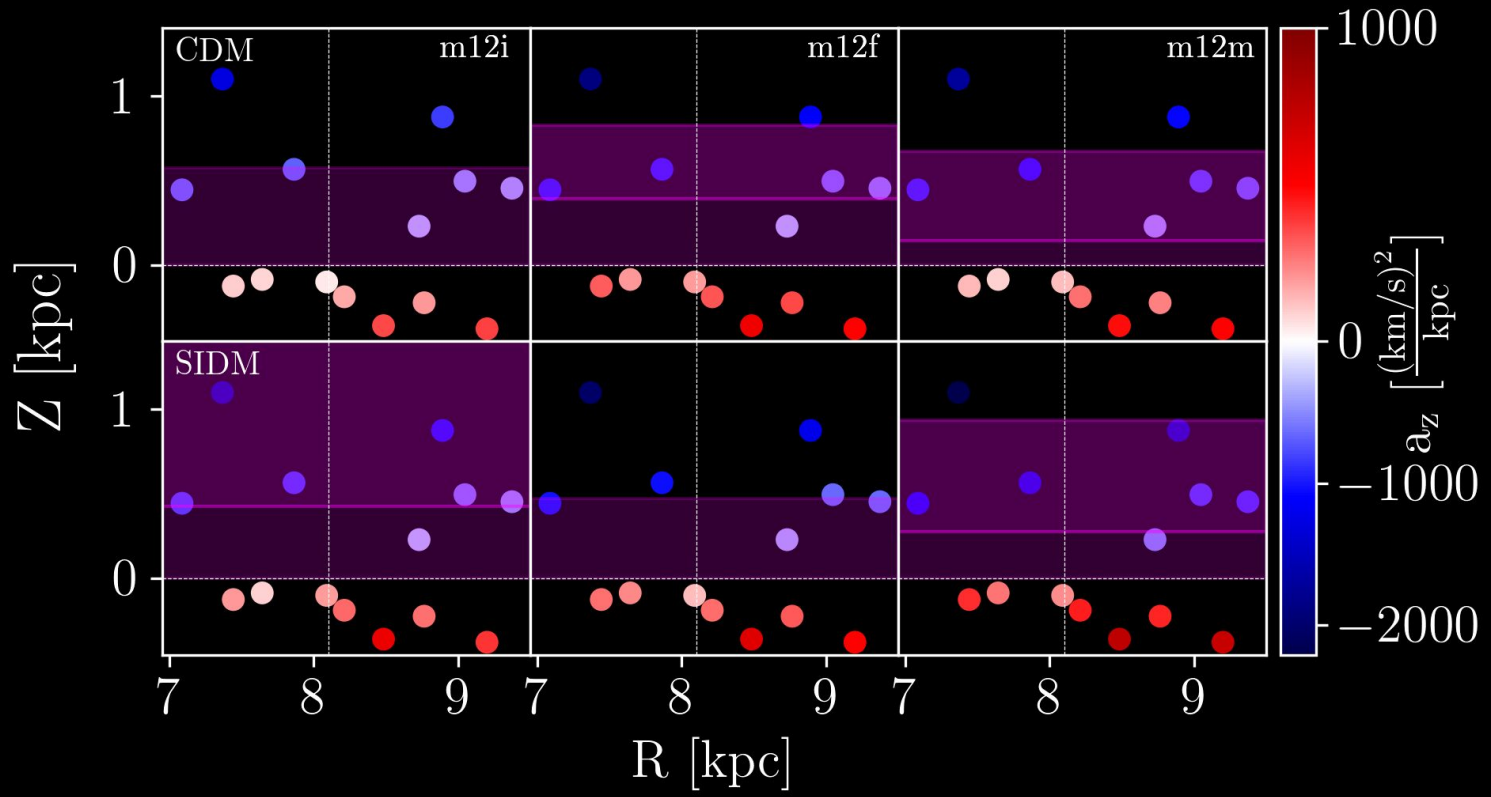

m12i
CDM
all
baryon
DM
SIDM
Y [kpc]
X [kpc]
5
0
−5
1.0
0.5
0.0
−0.5
−1.0
δ_{dens}
Q3.
How do galactic acc. compare in different density regions?

Sun in differently dense regions:



A3. Low dense SIDM produce steeper changes than CDM.

Predictions : 14 binary pulsars



To conclude: Probing dark matter with Galactic accelerations.

Q1. What happens in simulations with different assembly history?

→ Probe the merger history from the asymmetry!

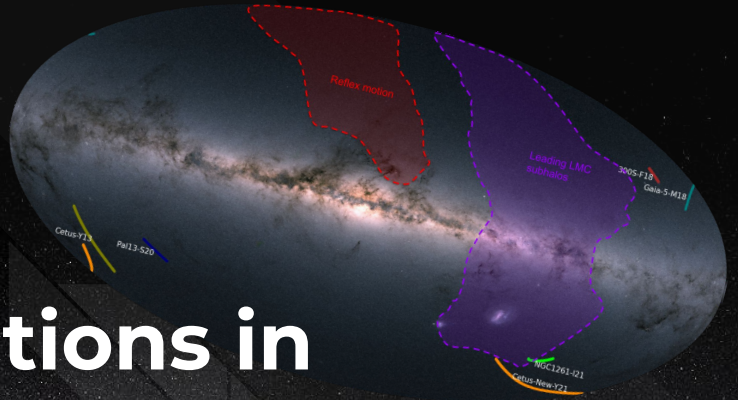
Q2. How do galactic accelerations differ under DM models?

→ SIDM consistently produces steeper acc. gradient

Q3. How do galactic acc. compare in different density regions?

→ Low dense SIDM produce steeper changes than CDM.

Ask me about this:



Subhalo-stream interactions in presence of Massive Satellite.

Arpit Arora[1], Nico Garavito[2], and Robyn Sanderson[1,2]

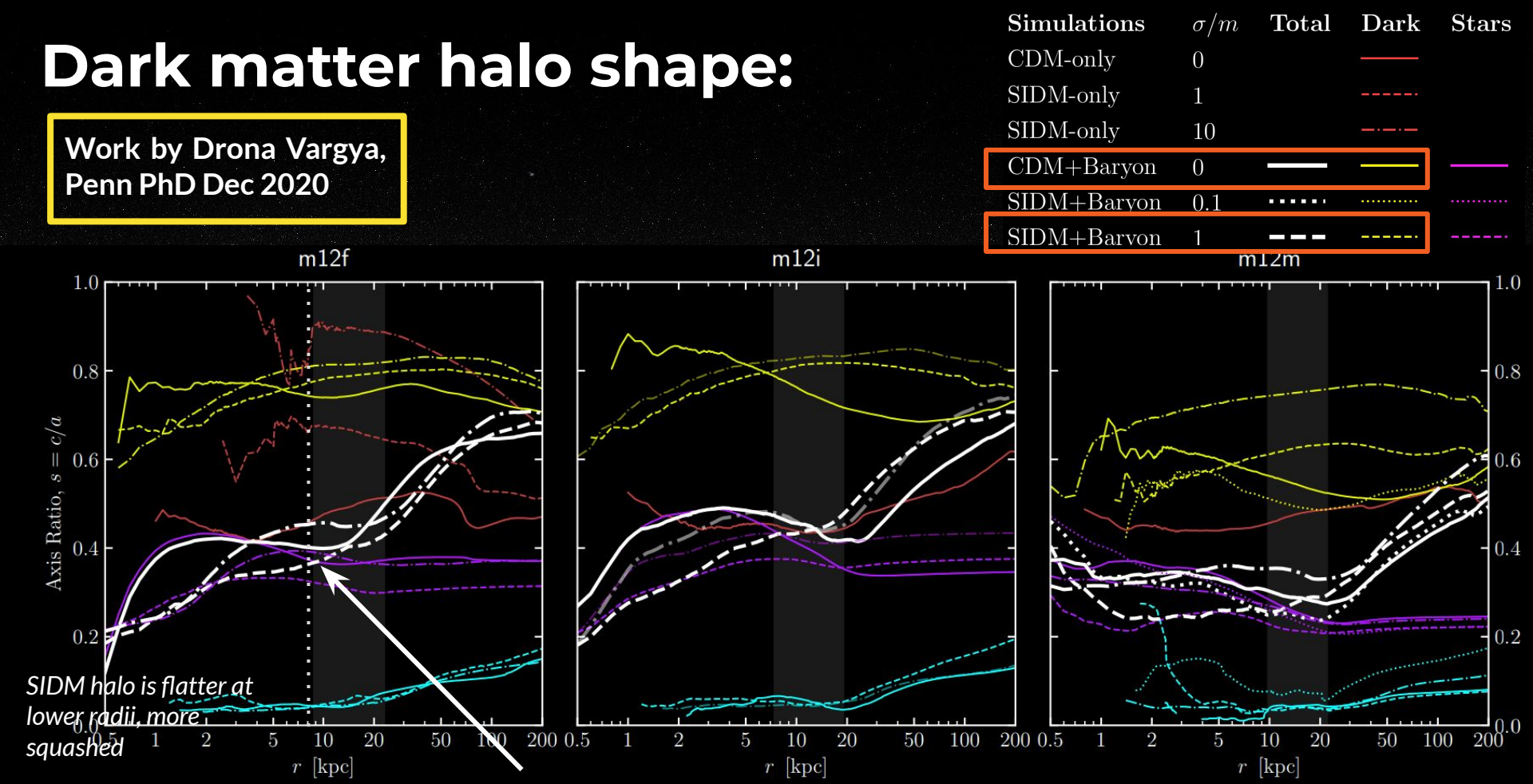
[1] *Department of Physics and Astronomy, University of Pennsylvania.*

[2] *Center for computational astrophysics, Flatiron institute.*

Supplementary slides

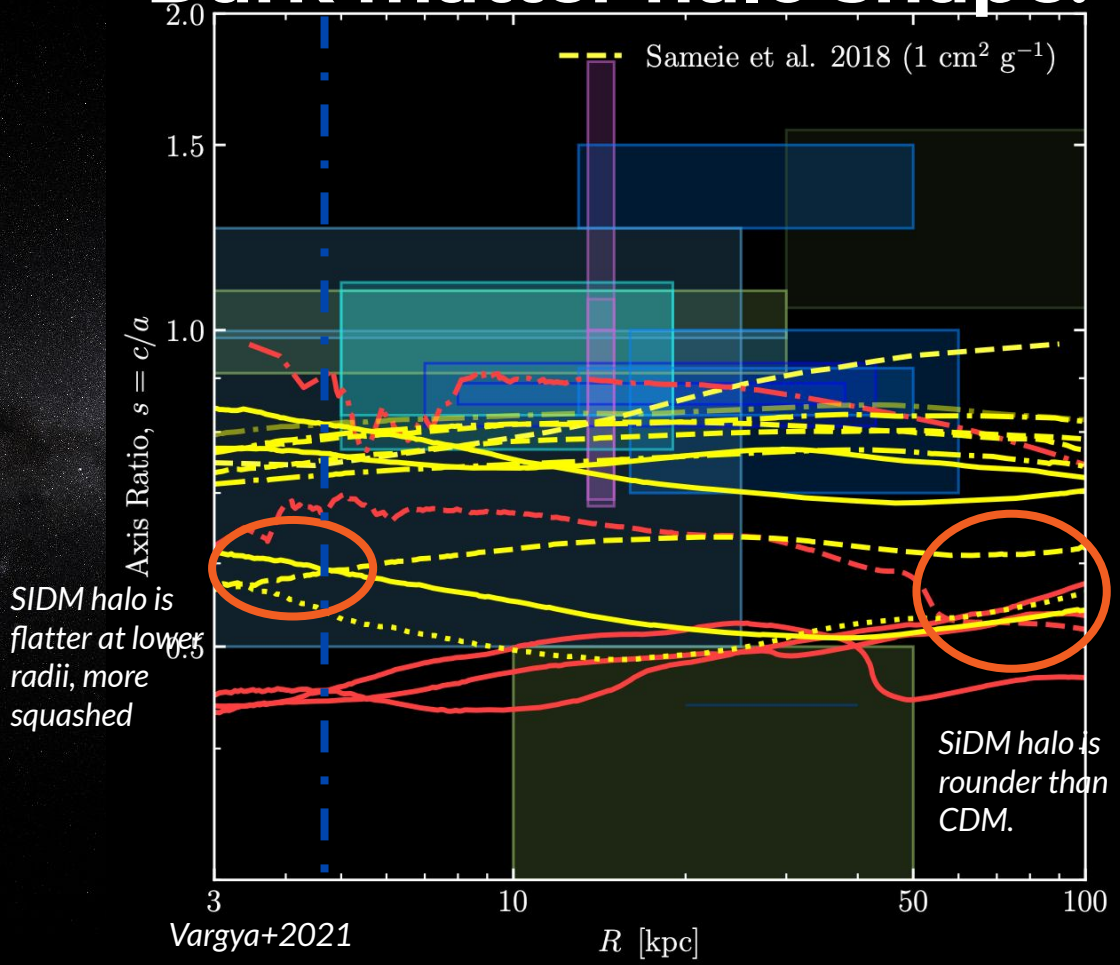
Dark matter halo shape:

Work by Drona Vargya, Penn PhD Dec 2020



DM+baryons combined axis ratio in white.

Dark matter halo shape:



SIDM halo is flatter at lower radii, more squashed

SiDM halo is rounder than CDM.

Vargya+2021

Simulations	σ/m	Dark
CDM-only	0	
SIDM-only	1	
SIDM-only	10	
CDM+Baryon	0	
SIDM+Baryon	0.1	
SIDM+Baryon	1	
SIDM+Baryon	10	

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