Effect of the Large Magellanic Cloud on dark matter direct detection

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Based on arXiv: 2302.04281

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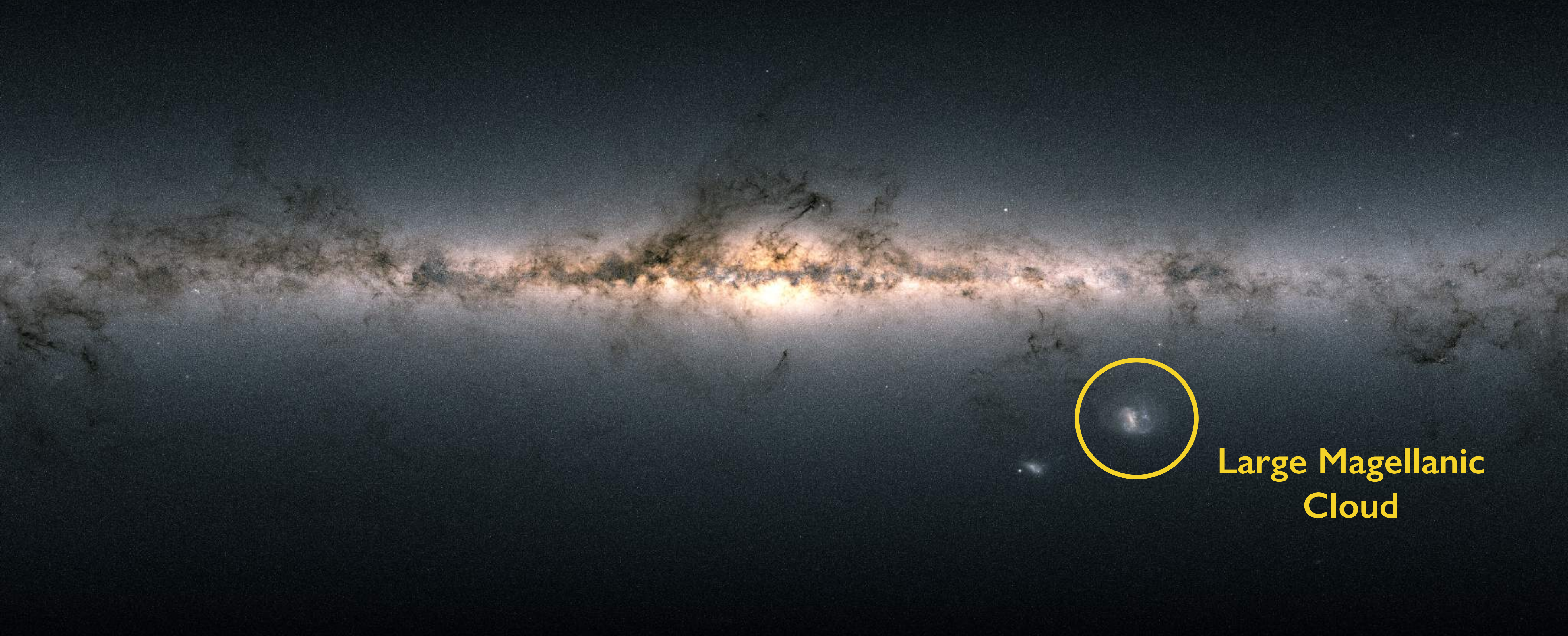
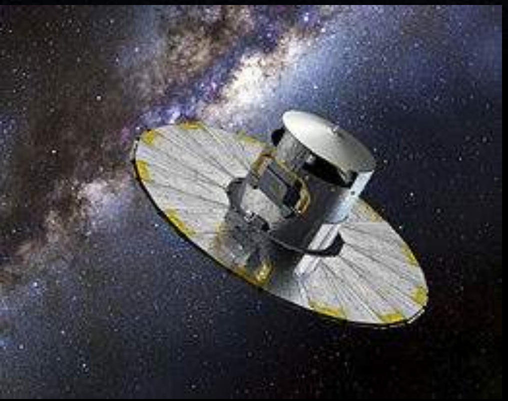
The Large Magellanic Cloud

The **Large Magellanic Cloud (LMC)** is the most massive satellite of the Milky Way and on its first passage around the Galaxy.



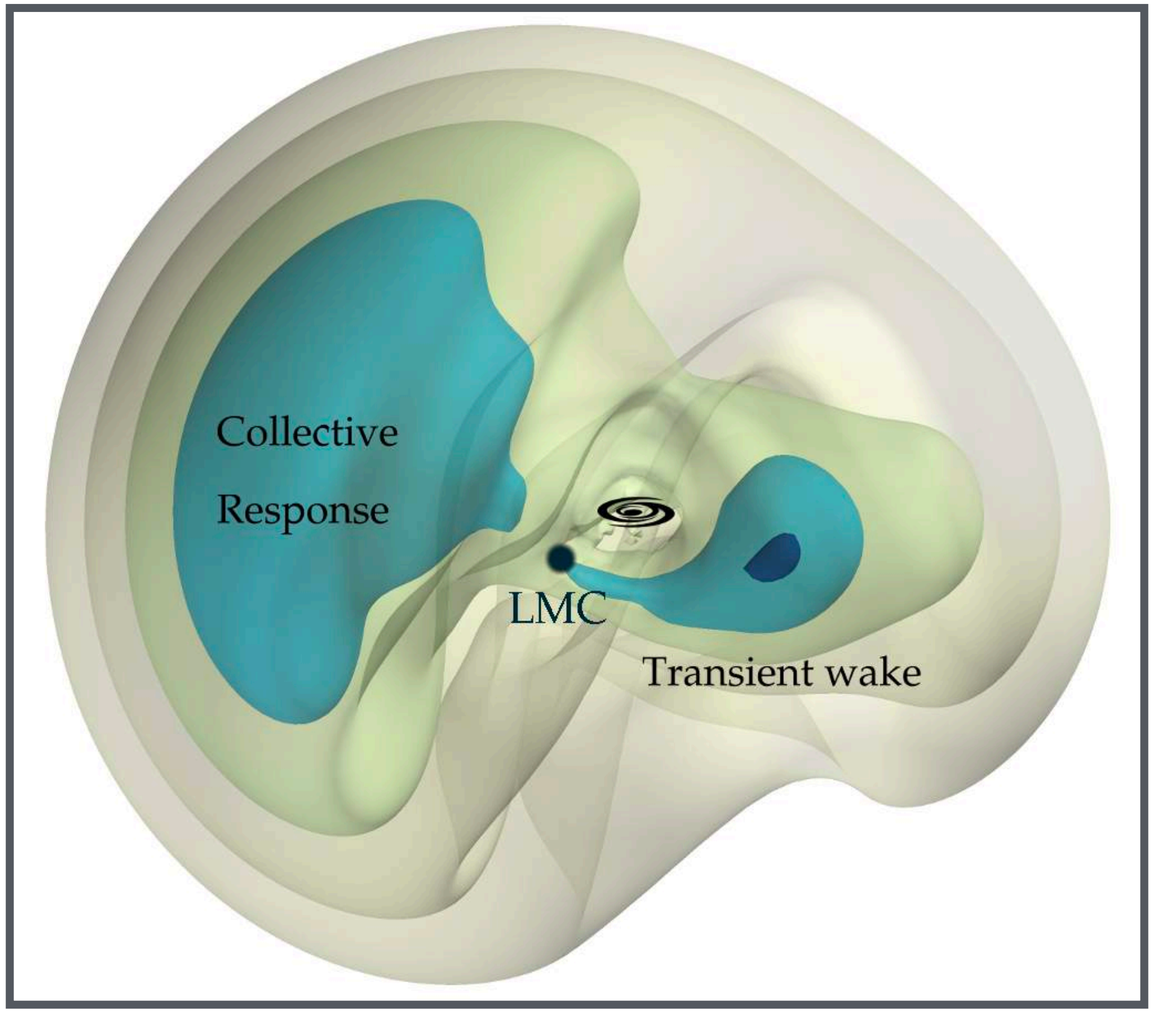


Gaia's EDR3 sky map. *Credit: ESA/Gaia/DPAC*

The effect of the LMC

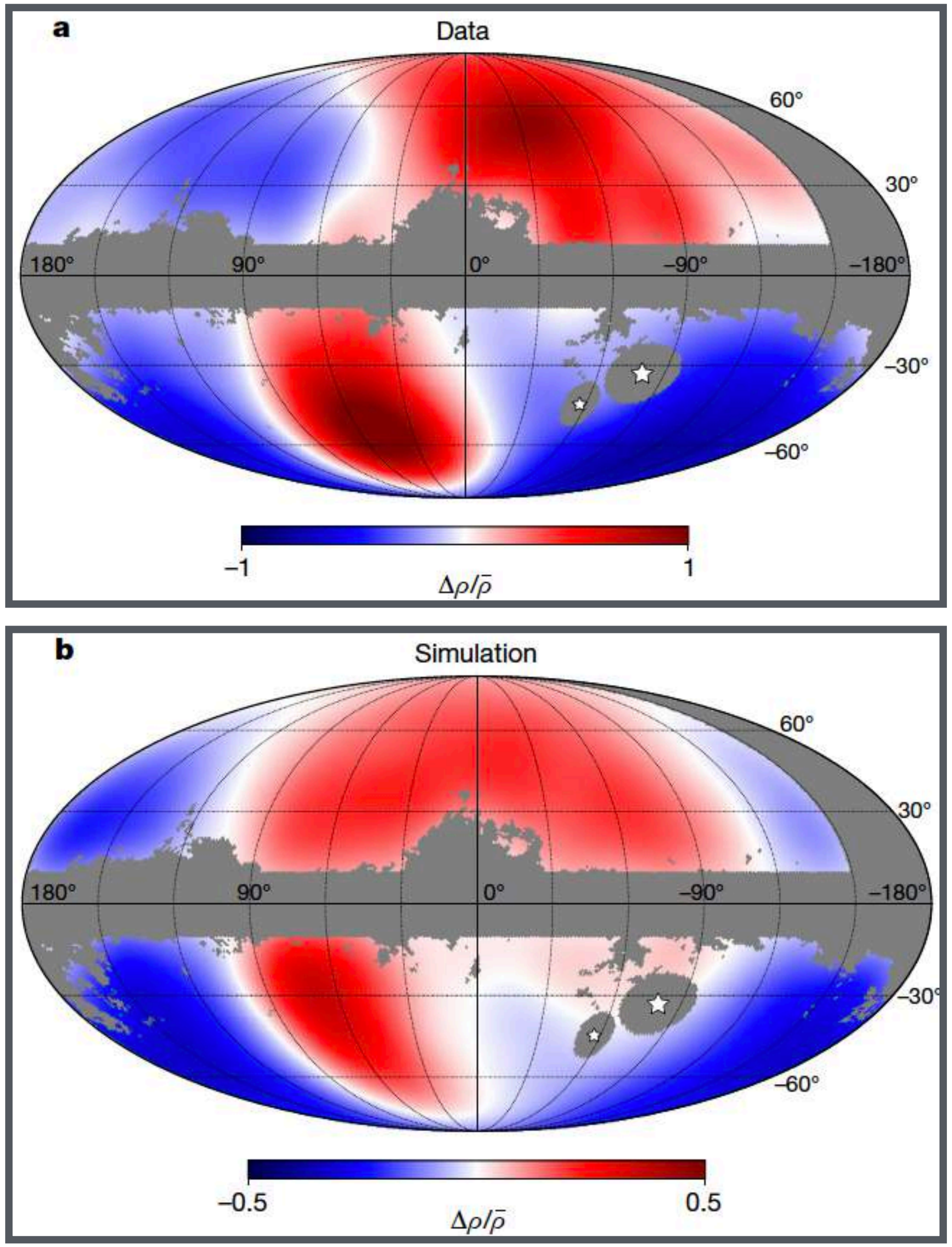
LMC introduces perturbations in the DM and stellar halo.

DM halo



Garavito-Camargo et al, ApJ 919, 2, 109 (2021)
Gravito-Camargo et al, ApJ 884, 51 (2019)

Stellar halo



Conroy et al, Nature 592, 534–536 (2021)

Effect of LMC on direct detection

- The **LMC** could also perturb the high speed tail of the local DM velocity distribution. → ***Affects direct detection implications for low mass DM.***

Besla et al, JCAP 11, 013 (2019)
Donaldson et al, MNRAS 513, 1, 46 (2022)

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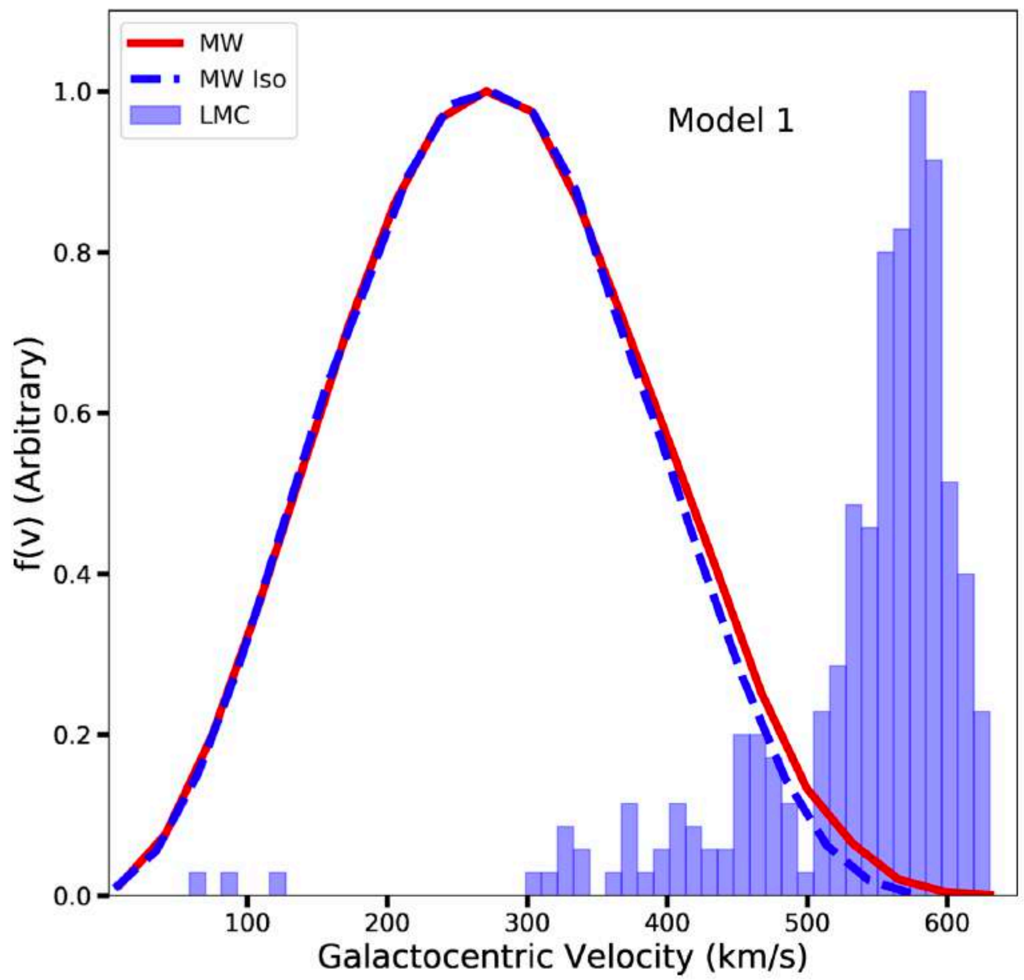

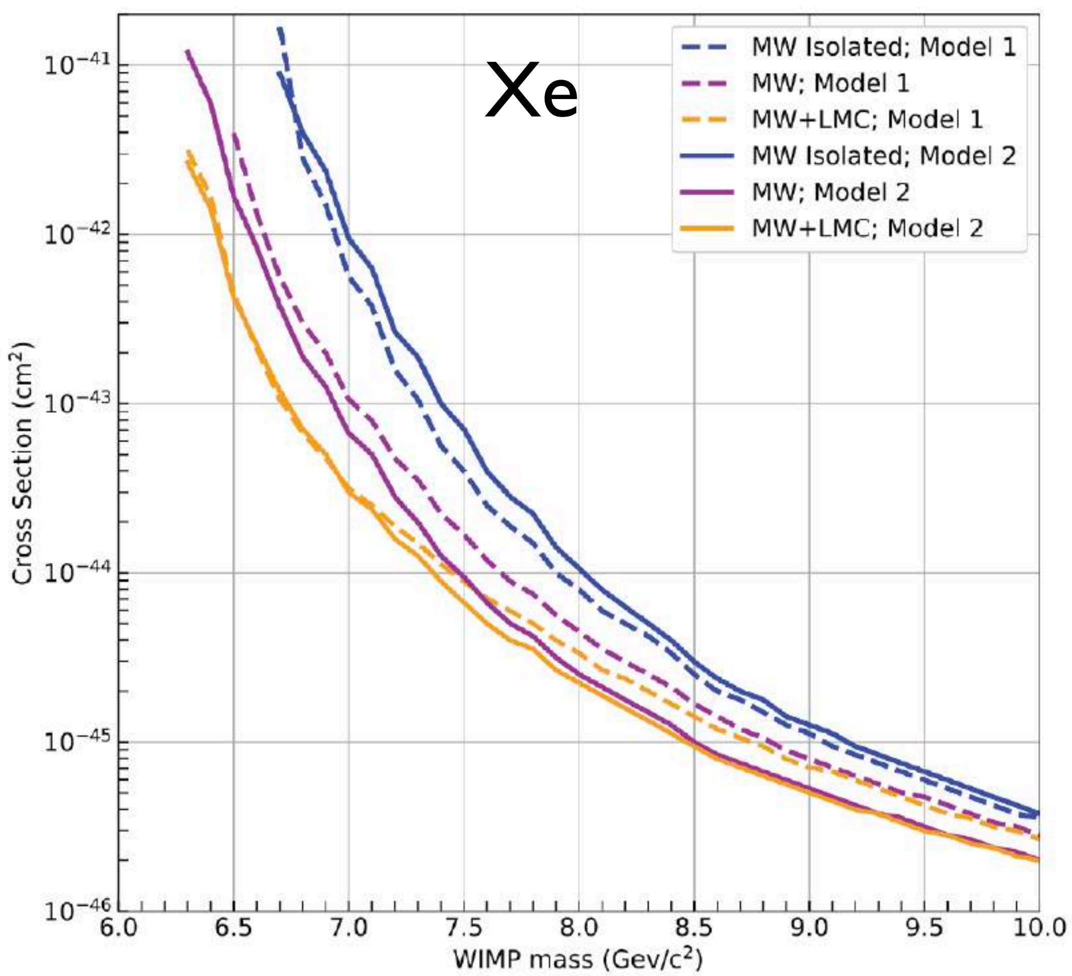

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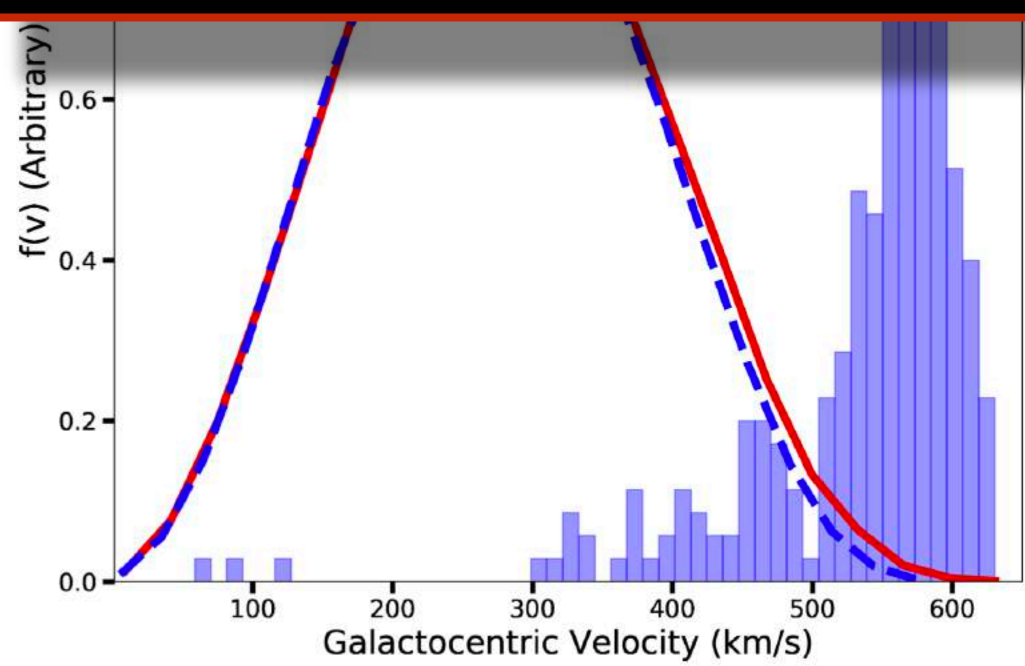
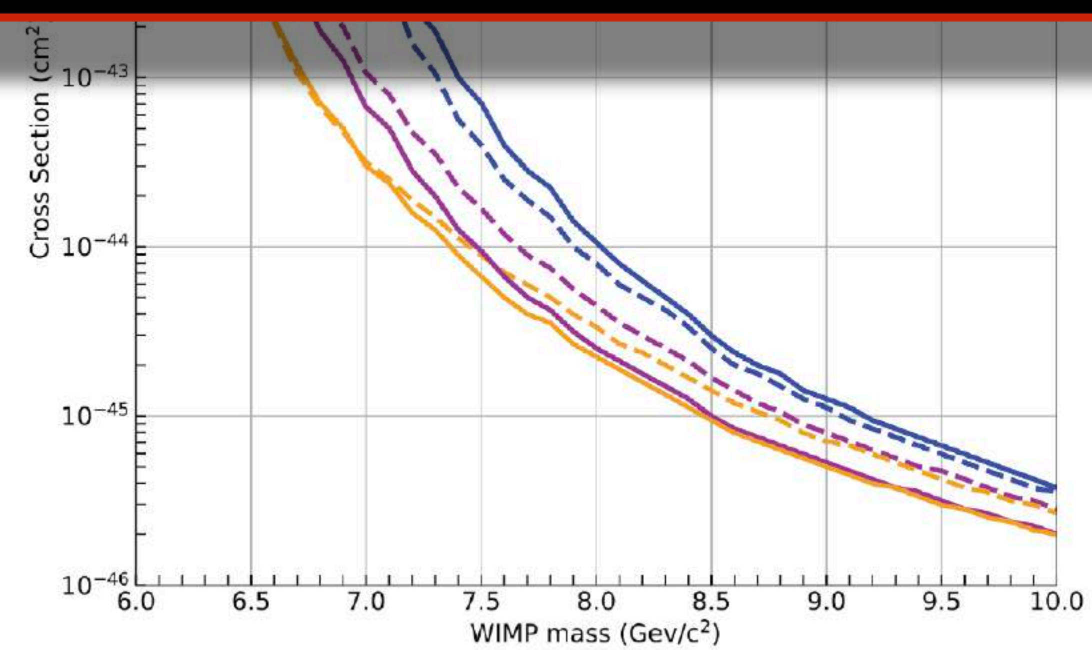
Are these findings valid for fully cosmological halos with multiple accretion events over their formation history?



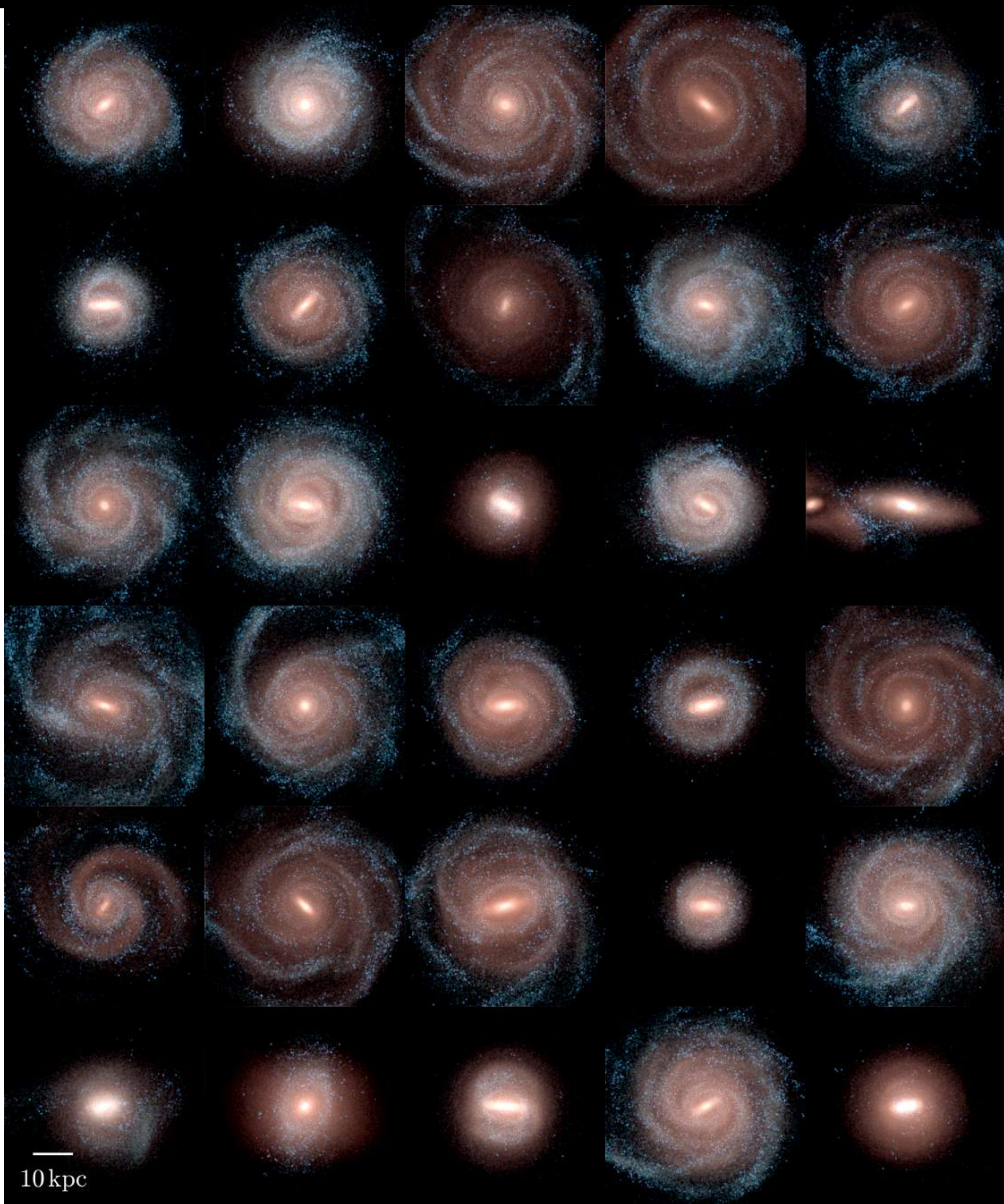


Besla et al, JCAP 11, 013 (2019)

Auriga cosmological simulations

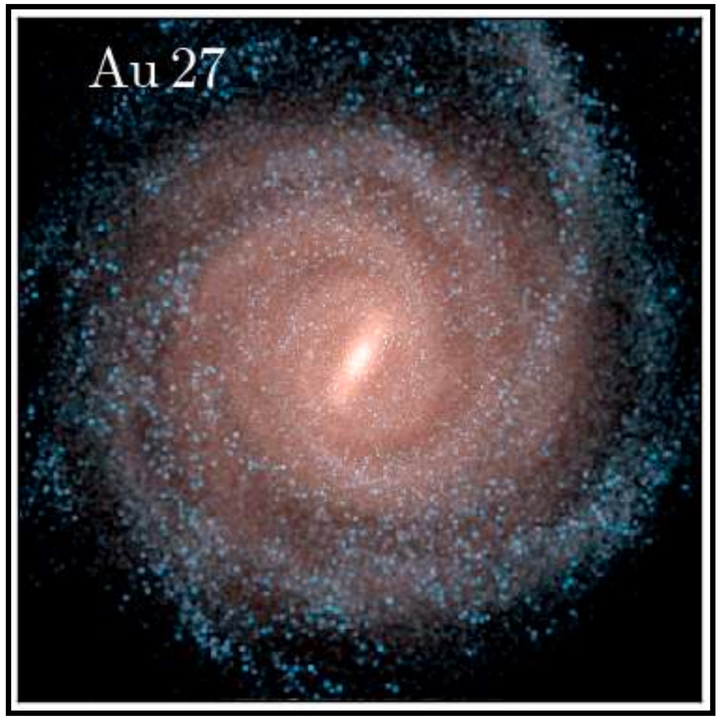
- Study the effect of the LMC in the **Auriga** simulations.
- State-of-the-art cosmological magneto-hydrodynamical zoom-in simulations of Milky Way size halos.
- 30 halos at the standard resolution:

$m_{\rm DM}$ $[{\rm M}_\odot]$	$m_{\rm b}$ $[{\rm M}_\odot]$	ϵ [pc]
3×10^5	5×10^4	369



Auriga cosmological simulations

- Identify **15 Milky Way-LMC analogues** based on **LMC's stellar mass** and **distance from host** at first pericenter approach.



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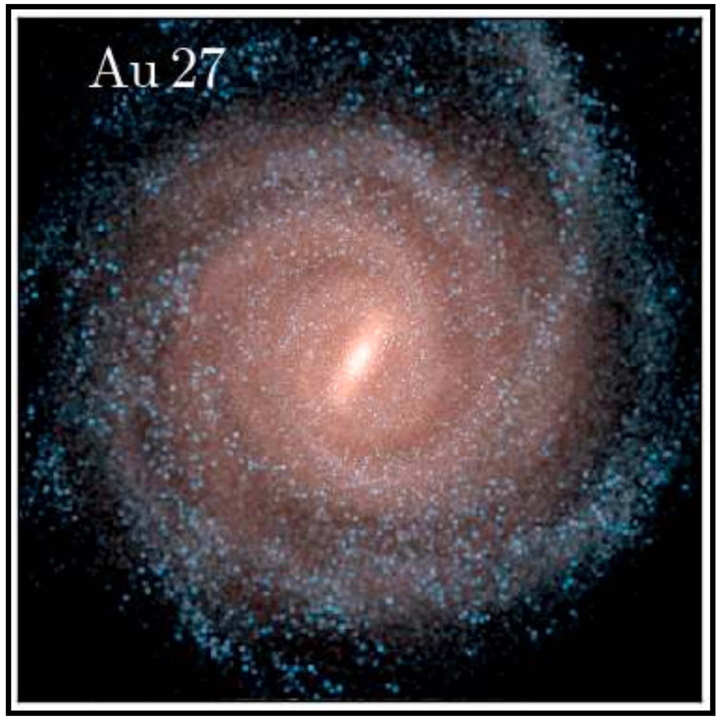
- Focus on one halo and study the impact of the LMC on the local DM distribution at different times (snapshots) in its orbit.



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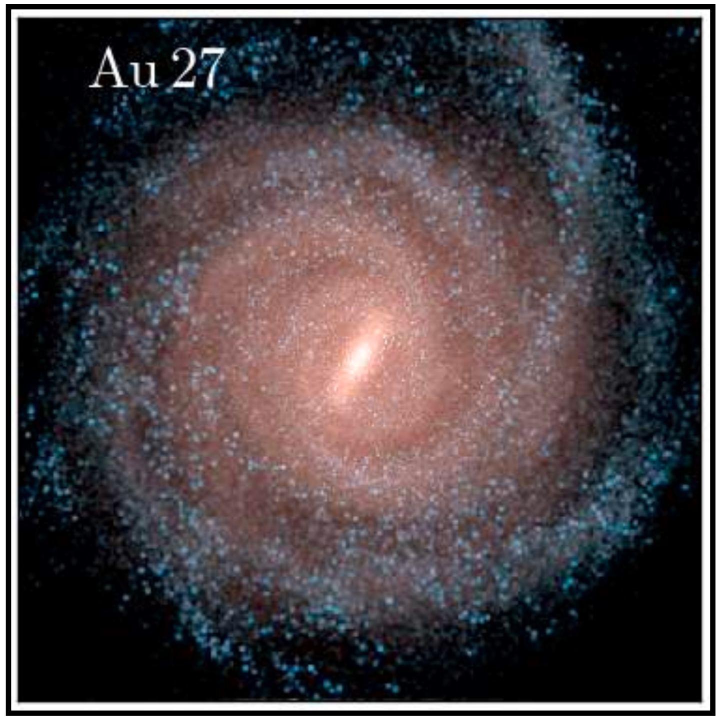
- Focus on one halo and study the impact of the LMC on the local DM distribution at different times (snapshots) in its orbit.

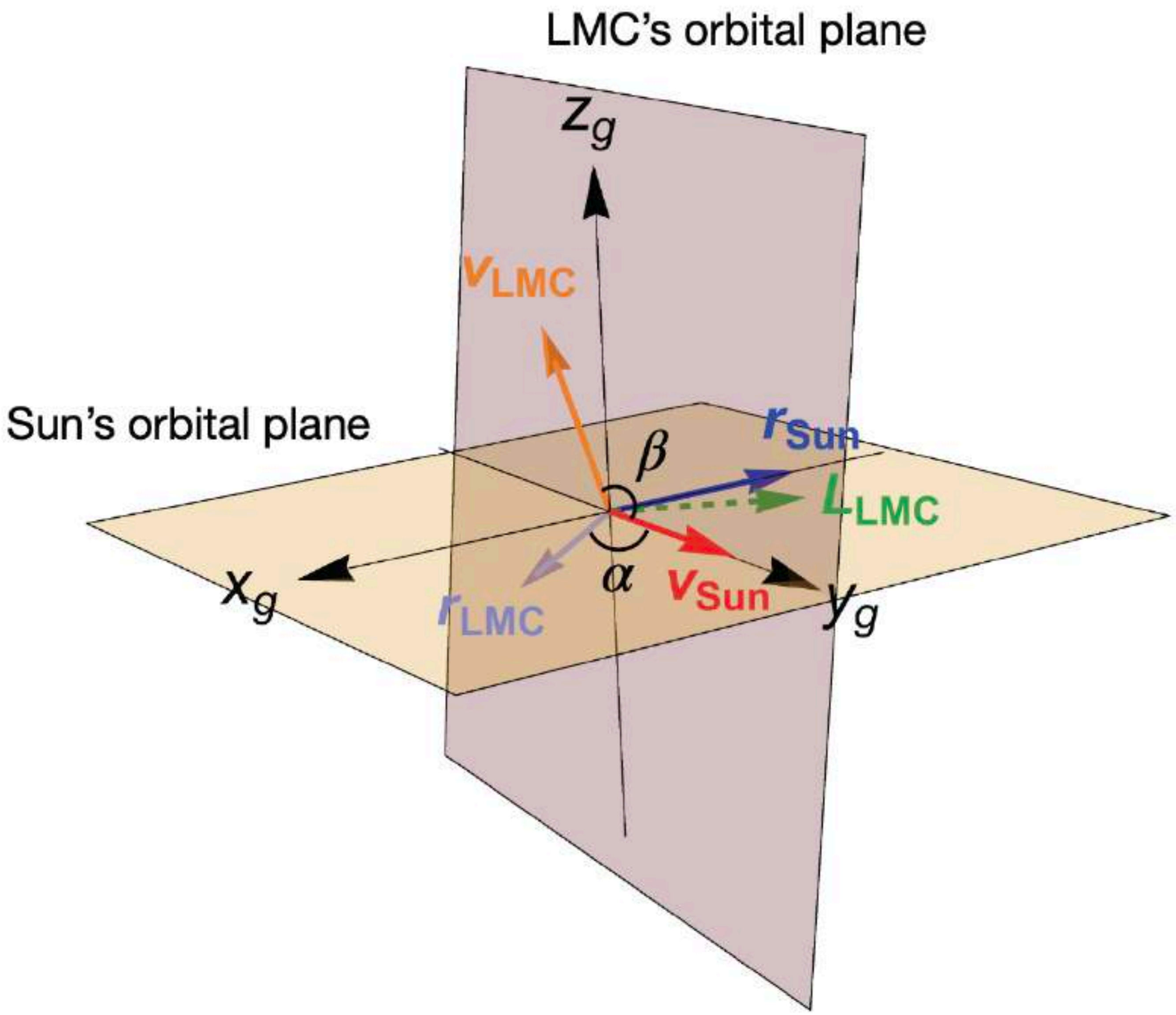
- Consider four representative snapshots:



Snapshot	Description	$t - t_{\text{Pres.}}$ [Gyr]
Iso.	Isolated MW analogue	-2.83
Peri.	LMC's 1st pericenter approach	-0.133
Pres.	Present day MW-LMC analogue	0
Fut.	Future MW-LMC analogue	0.175

Matching the Sun-LMC geometry

- The LMC is predominately moving in the opposite direction of the Solar motion. → Large relative speeds of DM particles originating from the LMC with respect to the sun.



- Choose the position of the Sun in the simulations such that it matches the observed Sun-LMC geometry.

Local dark matter density

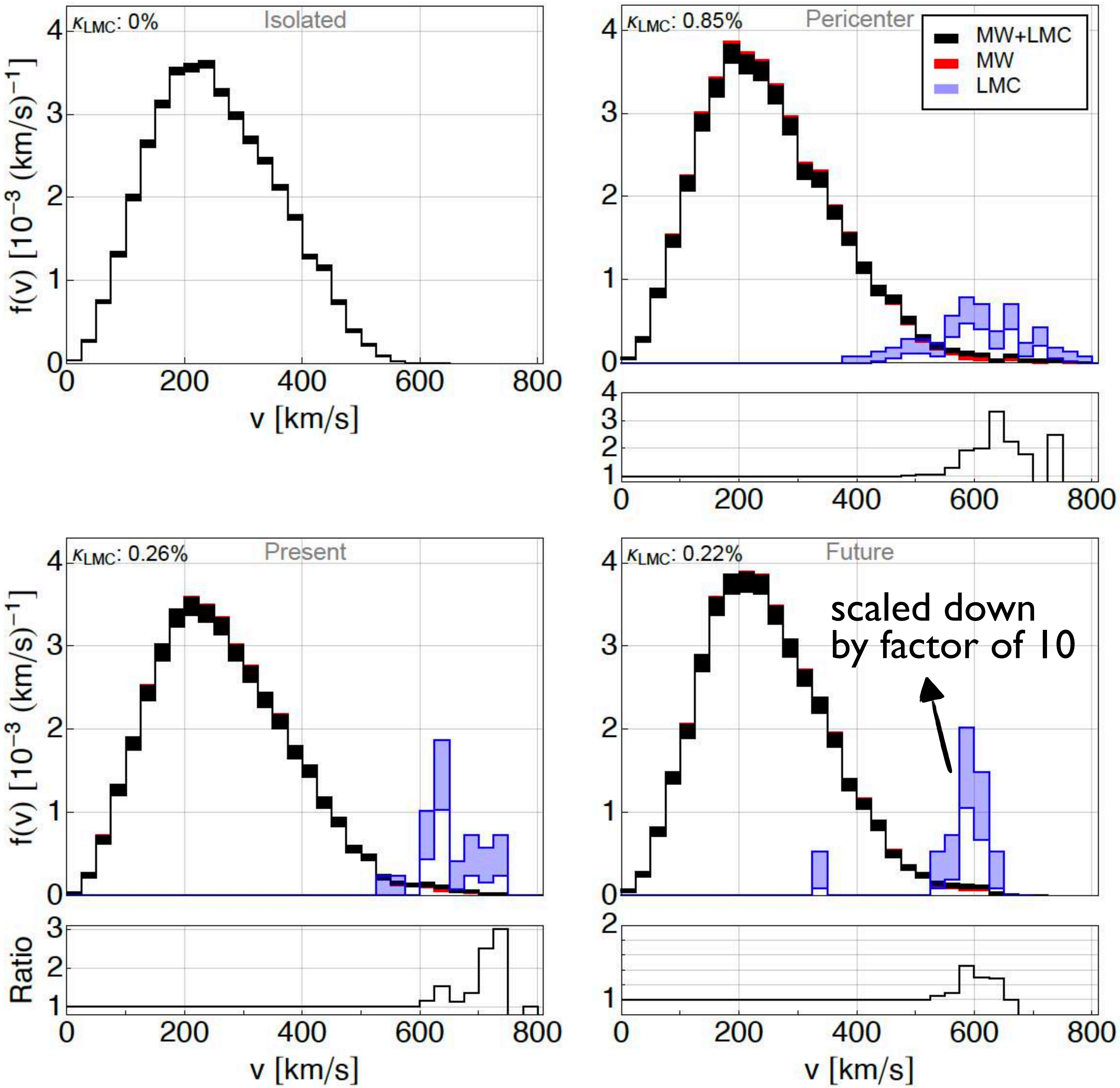
Halo ID	$M_{\rm Infall}^{\rm LMC}$ [10^{11} $M_\odot$]	ρ_χ [GeV/cm^3]	$\kappa_{\rm LMC}$ [%]
1	0.31	0.21	0.14
2	0.31	0.23	0.64
3	0.34	0.35	0.026
4	0.82	0.34	0.096
5	1.84	0.24	1.5
6	1.10	0.38	0.038
7	0.32	0.53	0.032
8	0.36	0.38	0.0077
9	0.73	0.36	0.10
10	3.28	0.39	2.8
11	1.45	0.43	0.028
12	1.43	0.53	0.17
13	3.18	0.34	2.3
14	0.84	0.60	0.26
15	1.15	0.32	1.2

Percentage of DM particles in the Solar region from the LMC

- The percentage of DM particles in the Solar neighborhood originating from the LMC is small.

Local dark matter speed distribution

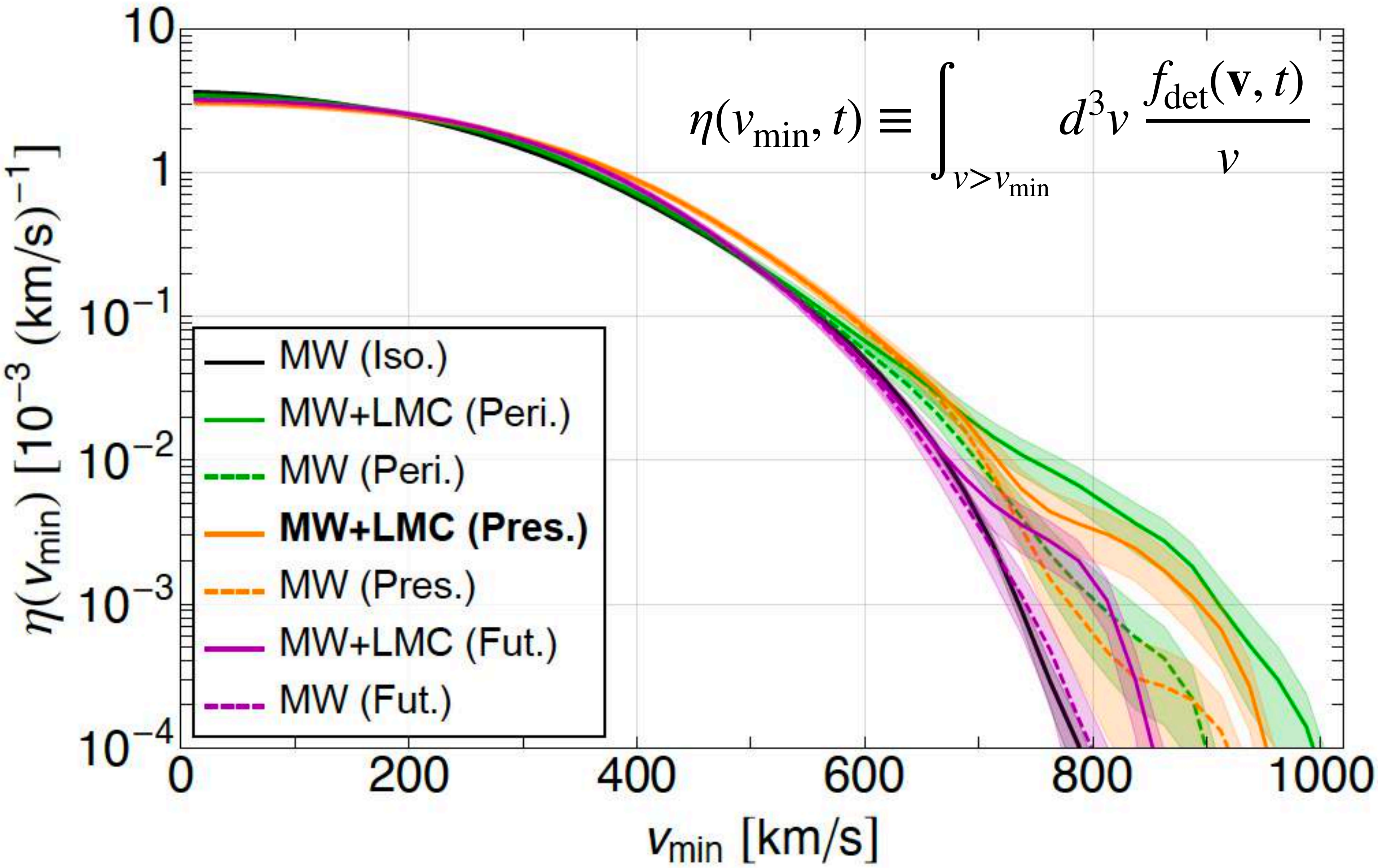
In the galactic rest frame



Smith-Orlik et al., 2302.04281

The LMC impacts the high speed tail of the DM speed distribution not only at its **pericenter approach** and the **present day**, but also up to **~175 Myr after the present day**.

Halo integrals



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Two effects: High speed LMC particles in the Solar region + Milky Way's response to the LMC. → ***Shift of*** > 150 km/s ***in the high speed tail of the halo integrals at the present day.***

Direct detection exclusion limits

- Simulate the signals in 3 idealized near future direct detection experiments that would search for nuclear or electron recoils.

Nuclear recoils

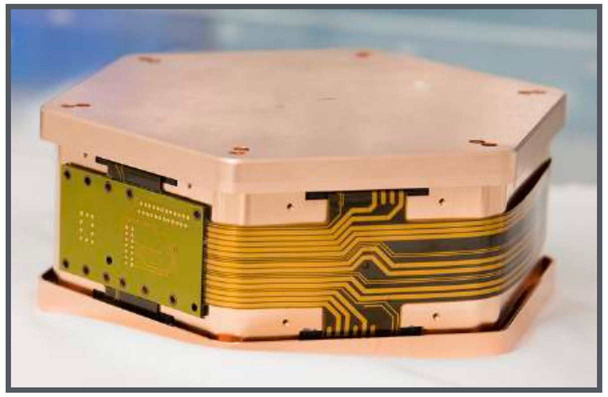
Xenon based

$[2 - 50]$ keV
5.6×10^6 kg days
Based on LZ

Germanium based

- $[40 - 300]$ eV, 1.6×10^4 kg days
- $[3 - 30]$ keV, 2.04×10^4 kg days

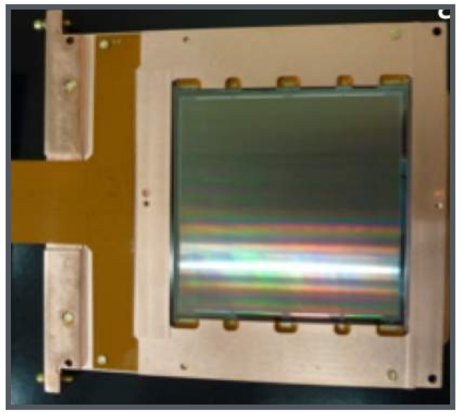
Based on SuperCDMS



Electron recoils

Silicon CCD

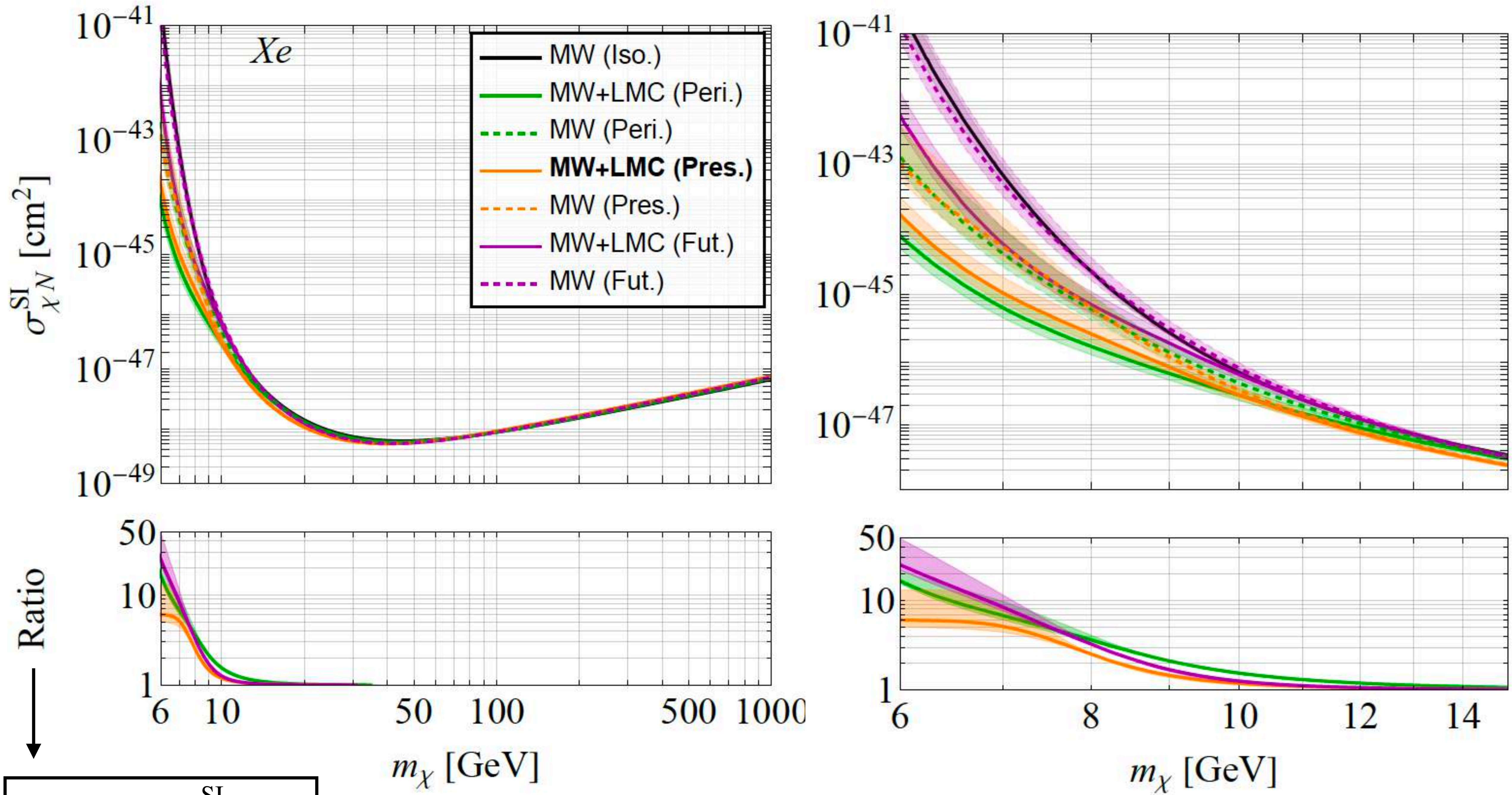
1 electron threshold
1 kg yr
Based on DAMIC



Direct detection: nuclear recoils

Xenon based detector:

Fix $\rho_\chi = 0.3\ \mathrm{GeV/cm^3}$



$$\text{Ratio} = \frac{\sigma^{SI}_{\chi,\mathrm{MW}}}{\sigma^{SI}_{\chi,\mathrm{MW+LMC}}}$$

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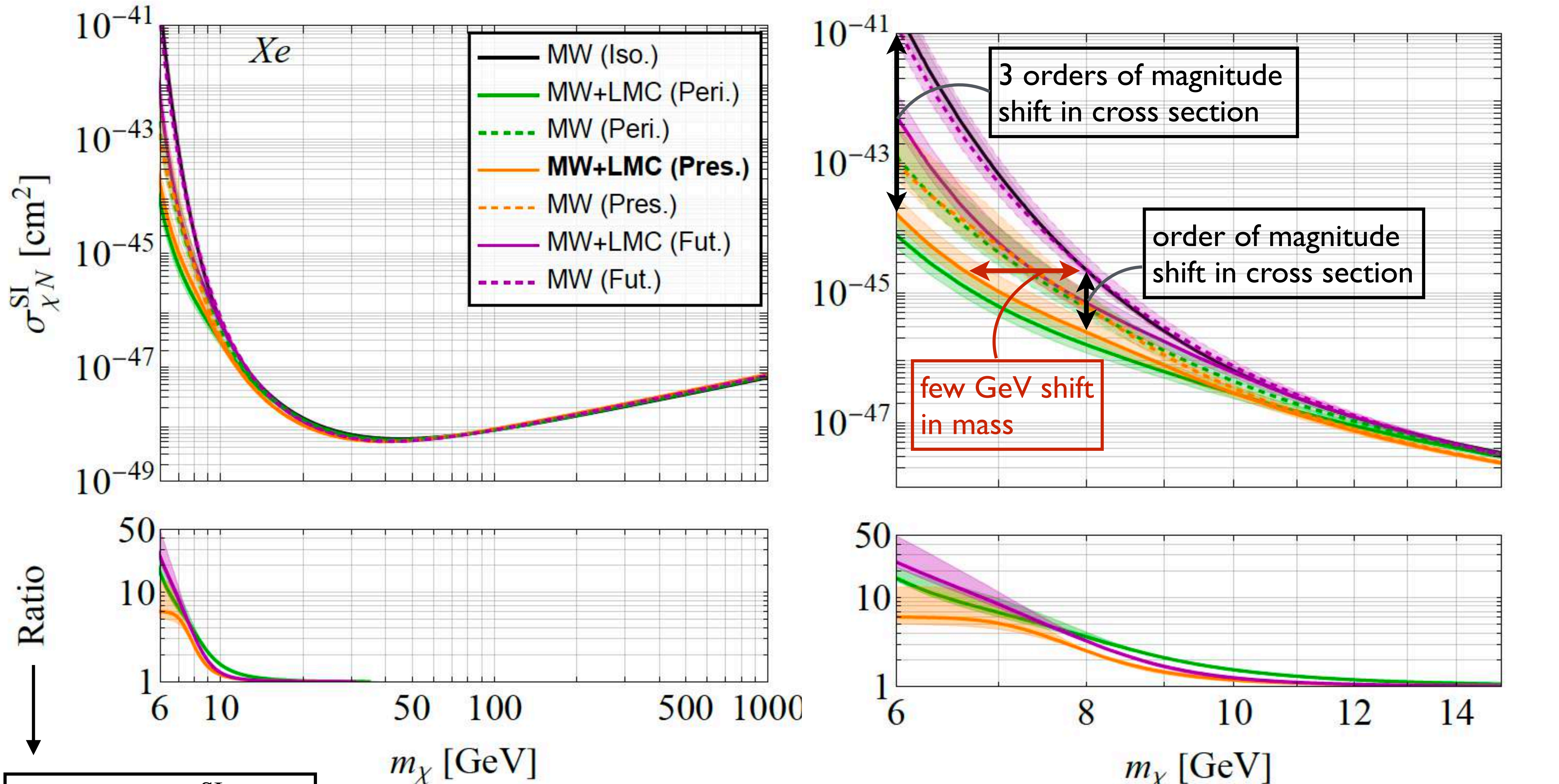

$$\text{Ratio} = \frac{\sigma^{SI}_{\chi,\text{MW}}}{\sigma^{SI}_{\chi,\text{MW+LMC}}}$$

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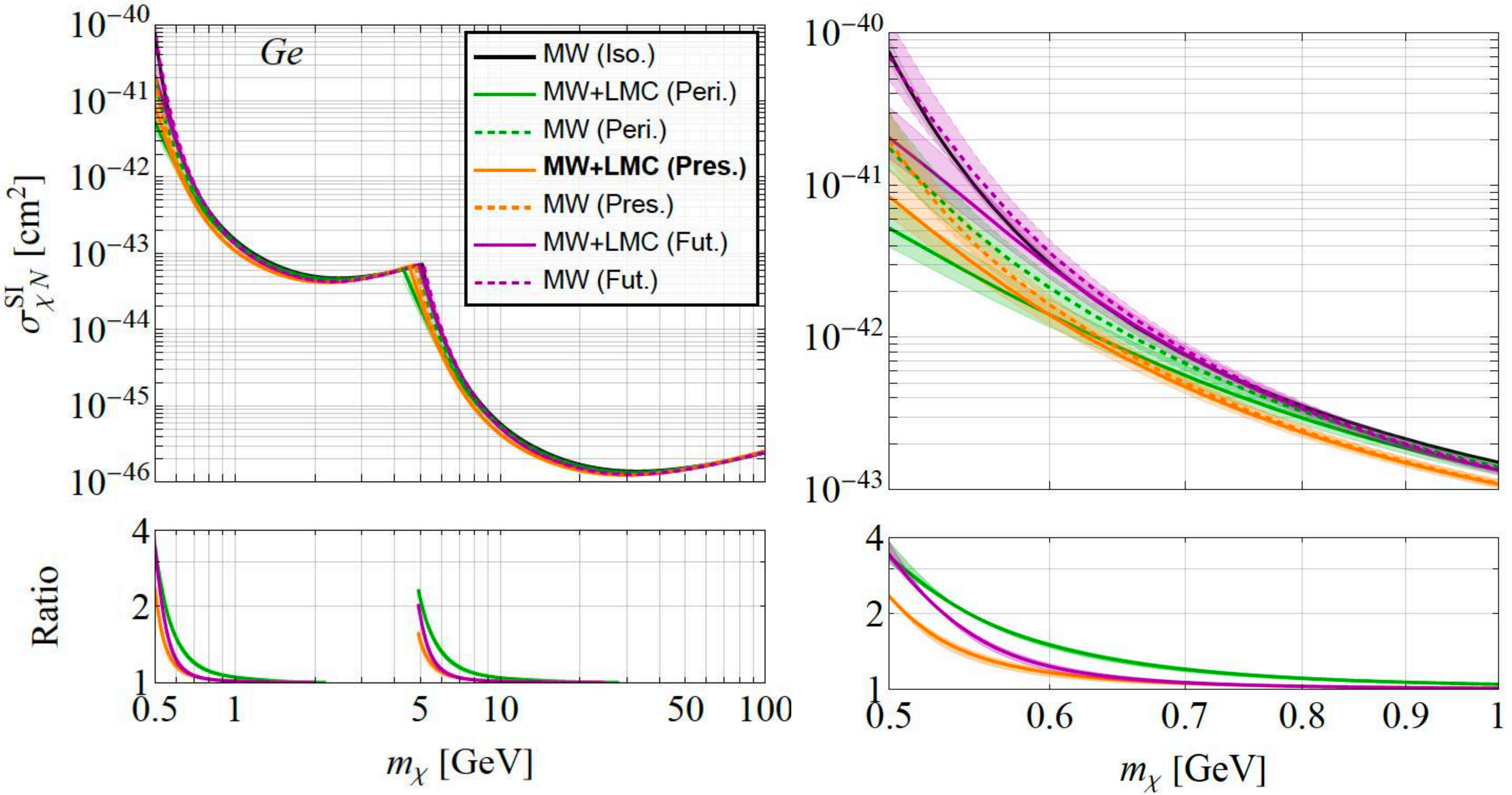
Direct detection: nuclear recoils

Germanium based detector:

Fix $\rho_\chi = 0.3\ \mathrm{GeV/cm^3}$



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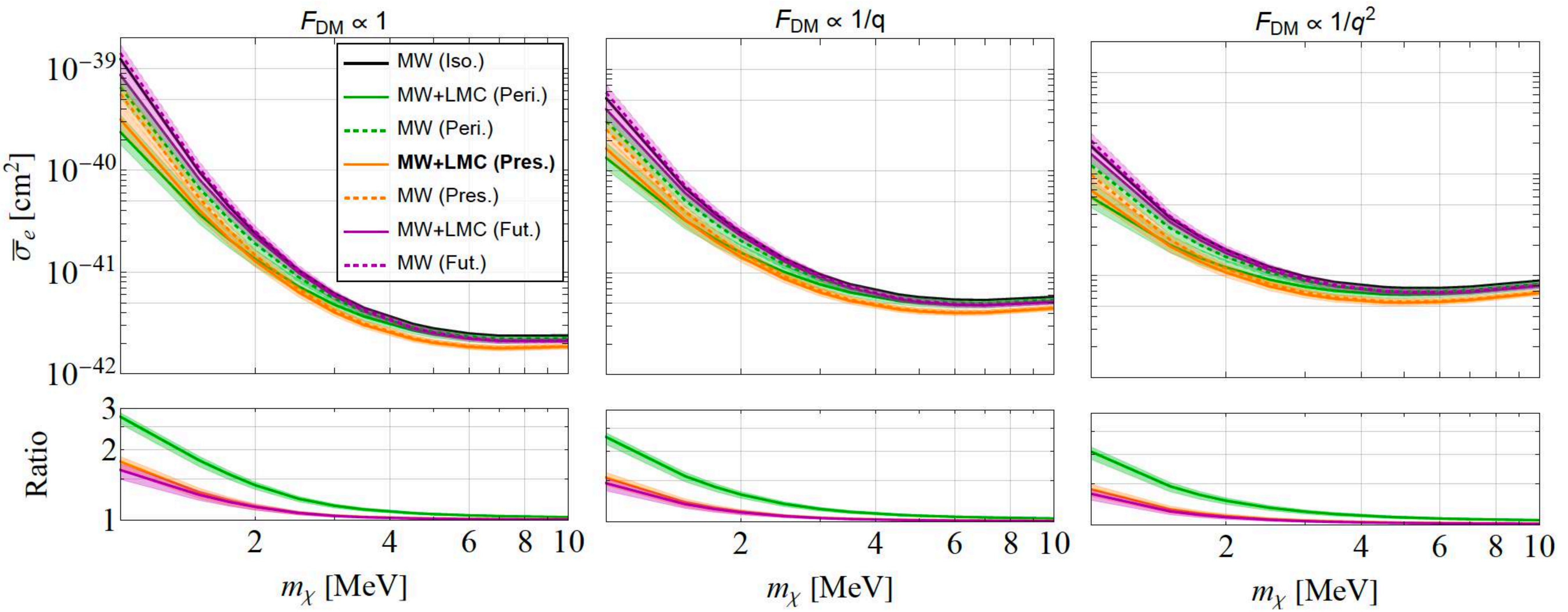
Direct detection: electron recoils

Silicon CCD detector:

Fix $\rho_\chi = 0.3\ \mathrm{GeV/cm^3}$



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Summary

- **LMC's influence on the local DM velocity distribution is significant even in a fully cosmological simulation.**
- Our particular Sun-LMC geometry maximizes LMC's impact.
- **Two effects** cause a boost in the high speed tail of the DM velocity distribution:
  - High speed DM particles from the LMC in the Solar region
  - The response of the Milky Way DM particles to the LMC

  → *Significant shift in direct detection limits towards lower cross sections and smaller DM masses.*

Backup Slides

Matching the Sun-LMC geometry

Steps in matching the Sun-LMC geometry to observations:

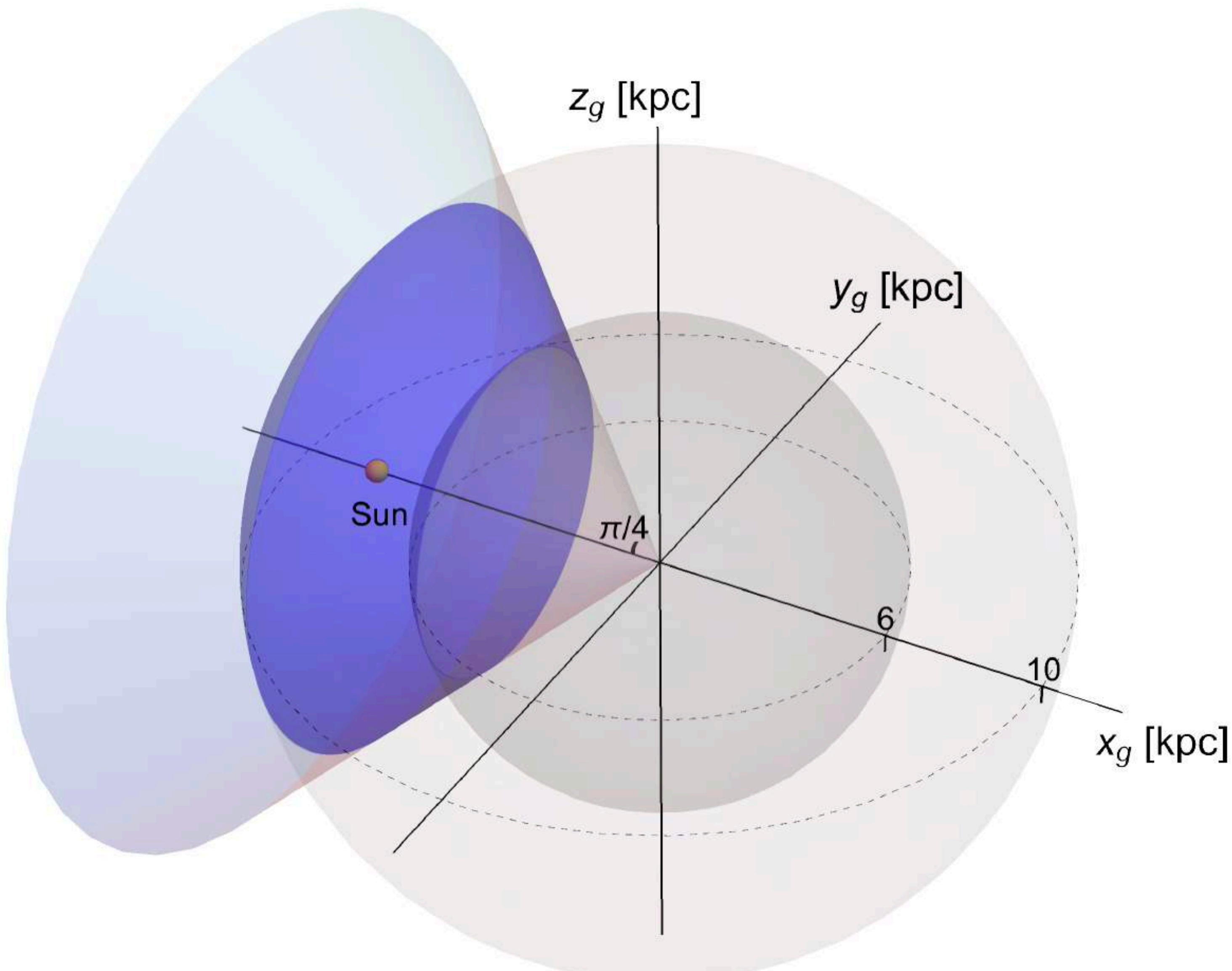
1. Find the stellar disk orientations that make the same angle with the orbital plane of the LMC analogues as in observations.

2. Find the position of the Sun for each allowed disk by matching the angles between the **angular momentum of the LMC** and the **Sun's position** and **velocity** in the simulations to their observed values.

3. The best fit Sun's position is the one that leads to the closest match of the angles between the **Sun’s velocity** and the **LMC's position** and **velocities** with observations.

Solar region

Solar region: overlap of a spherical shell between 6-10 kpc from the Galactic center and a cone with opening angle $\pi/4$ with its axis aligned with the position of the Sun.



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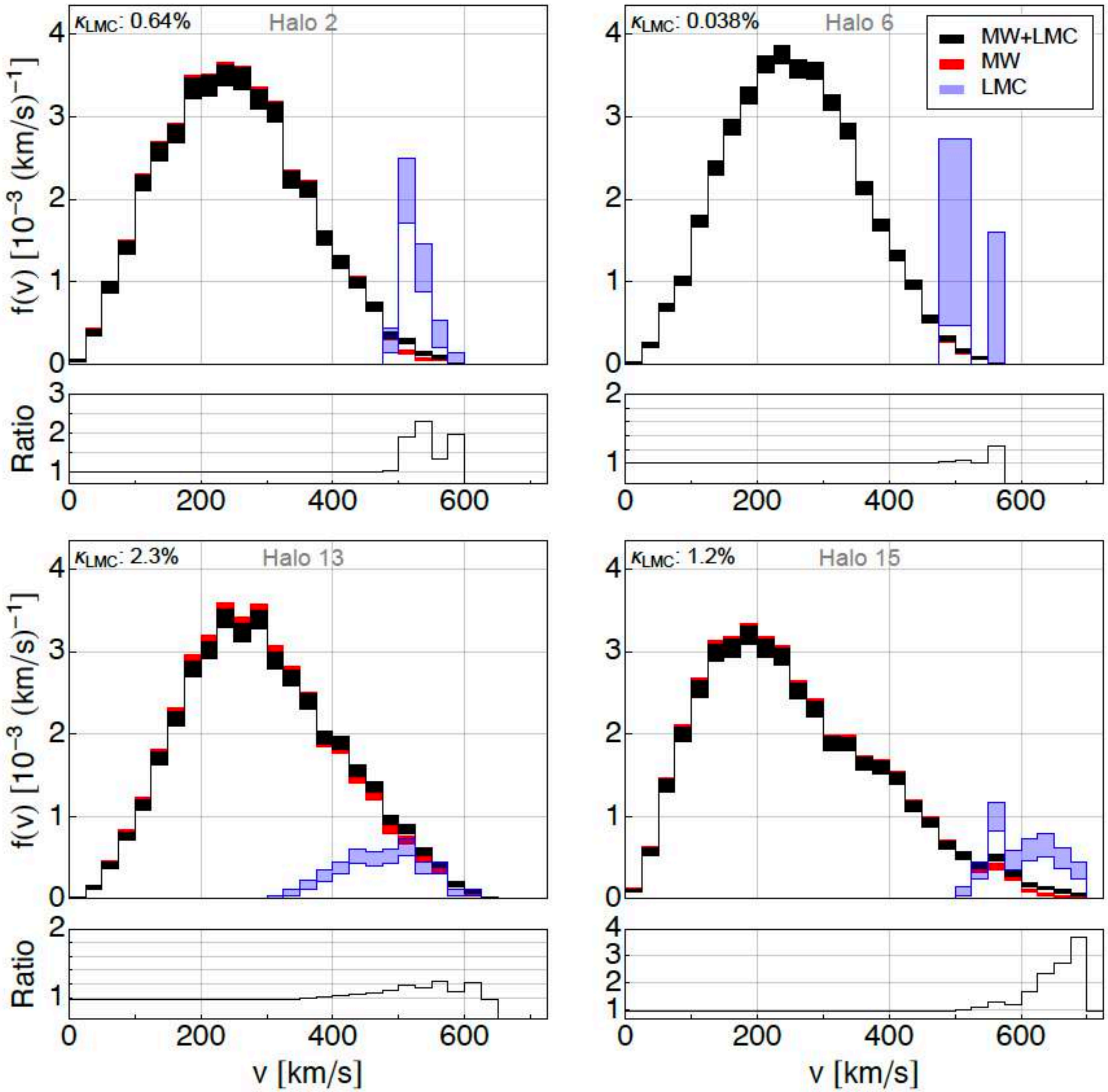
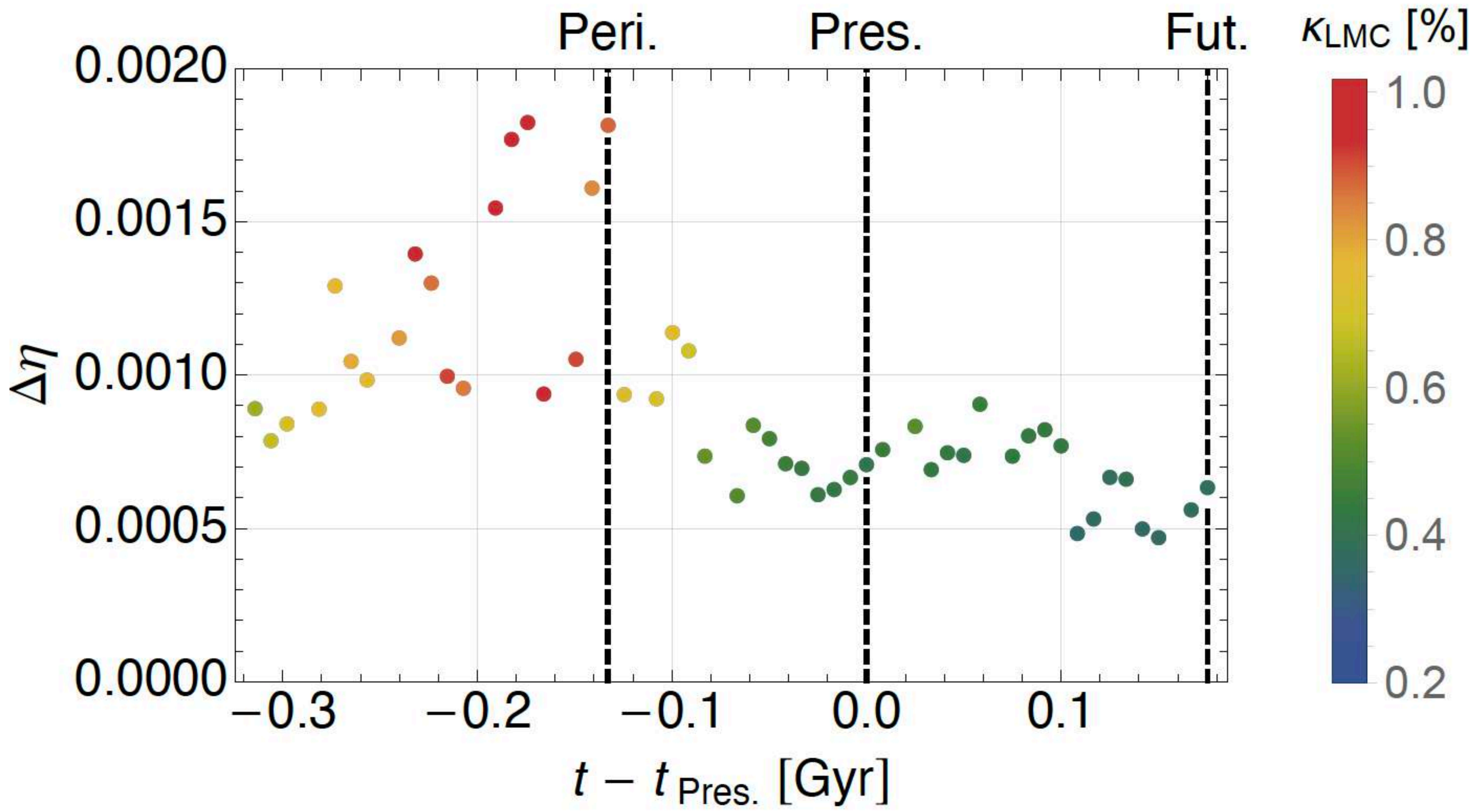


Changes in the halo integrals

- Quantify the changes in the tails of the halo integral by:

$$\Delta\eta = \sum_{v^i_{\rm min} \geq 0.7 v^{\rm det}_{\rm esc}} \left[\eta_{\rm MW+LMC}(v^i_{\rm min}) - \eta_{\rm MW}(v^i_{\rm min})\right] \Delta v_{\rm min}$$



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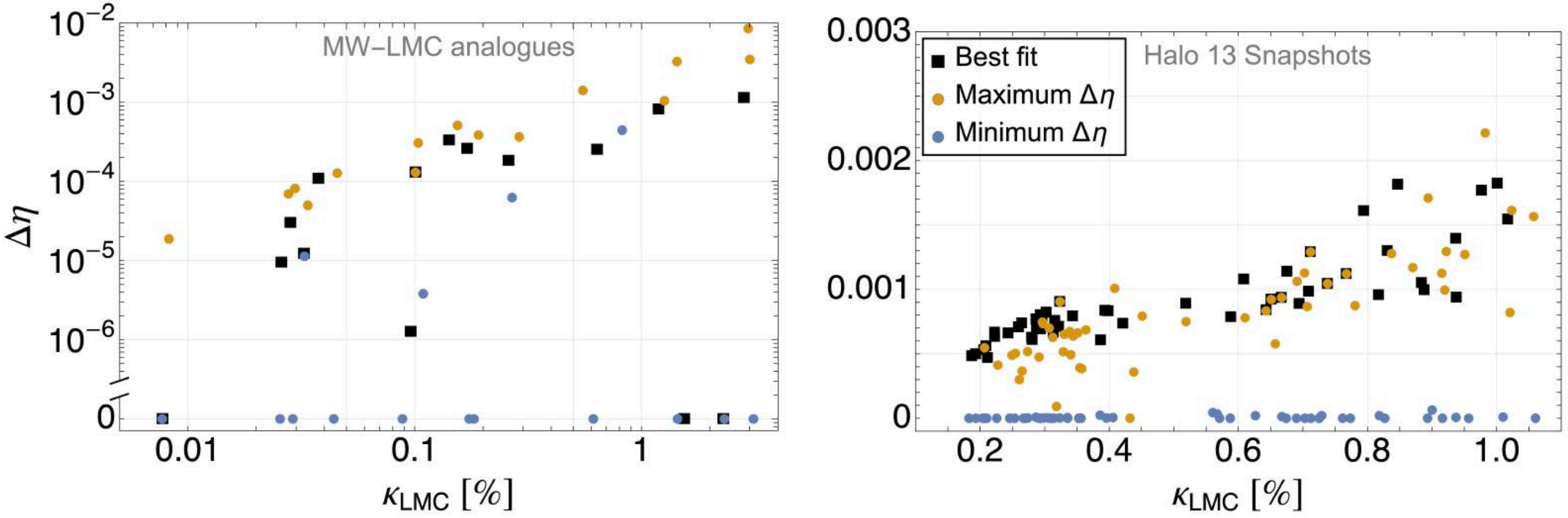

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