# Binary-boosted Dark Matter

## Light Dark World 2026

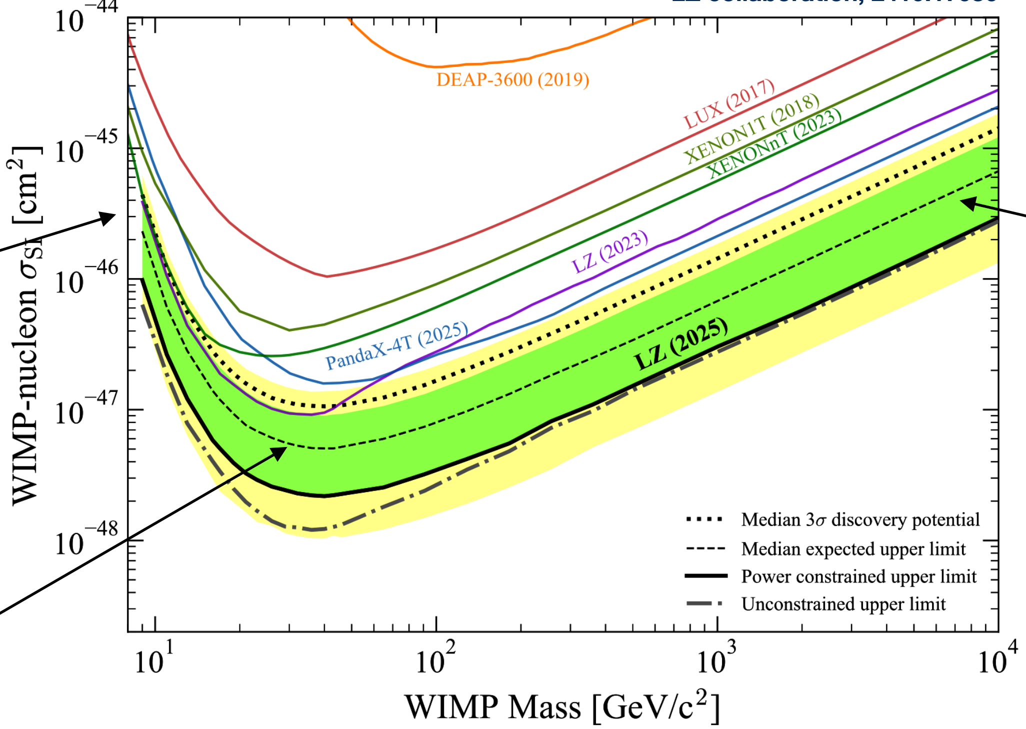
Javier F. Acevedo

Based on: Acevedo & Ritz, 2603.08781
Acevedo & Ritz, 2606.30724

# Introduction

Typical direct detection constraint:

LZ collaboration, 2410.17036




**threshold**

kinematic matching

flux $\propto 1/m_\chi$

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Approaches to scan the sub-GeV regime:

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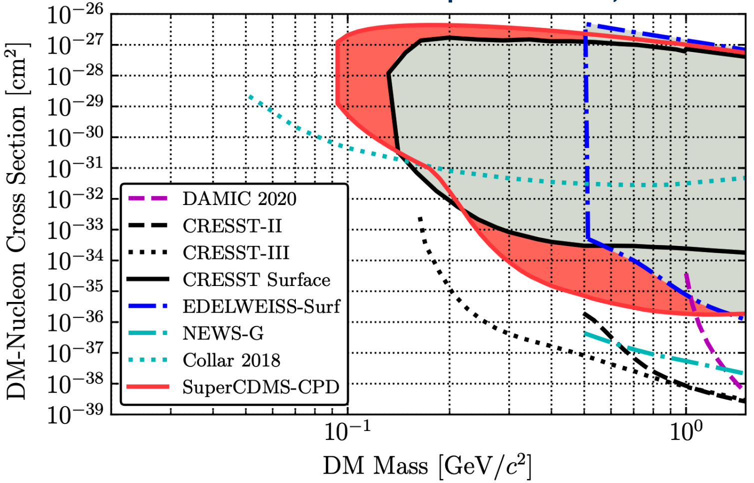
1) Lowering detector threshold

SuperCDMS coll., 2007.14289




(+ Migdal effect, bremsstrahlung, etc.)

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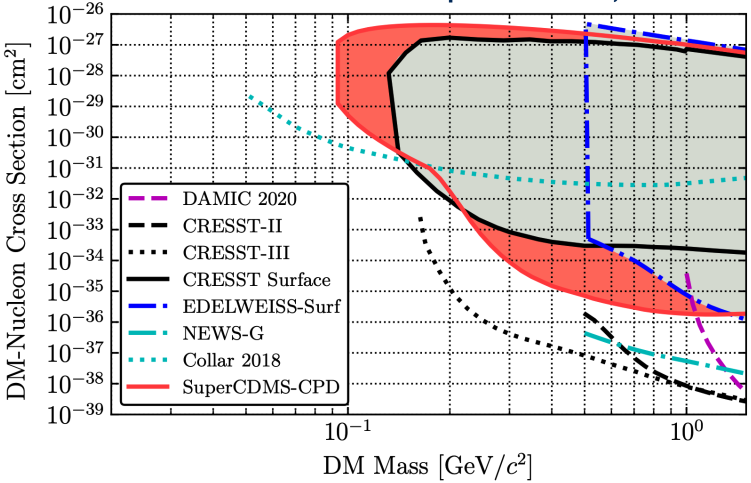
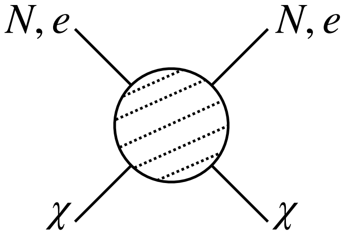
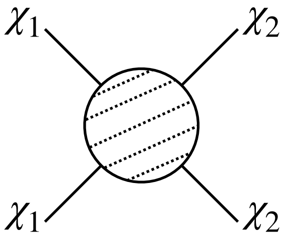



(+ Migdal effect, bremsstrahlung, etc.)

2) Boosting DM energy




e.g. cosmic-rays,
solar reflection, blazars




more complex dark sector dynamics

$$m_{\chi_2} \gg m_{\chi_1}$$

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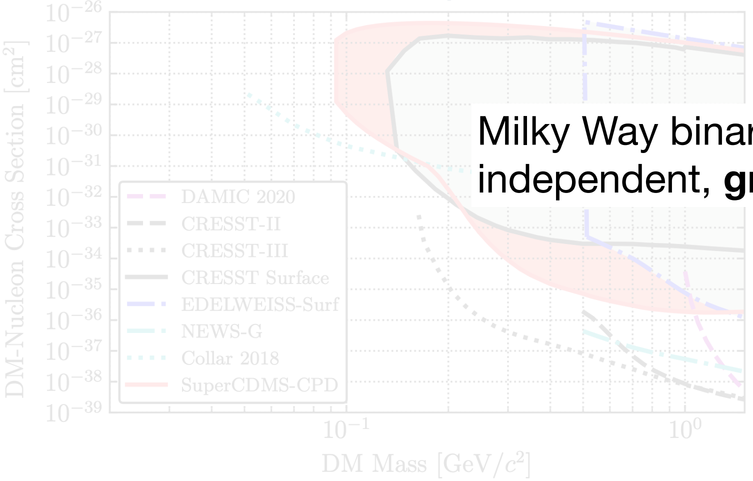



(+ Migdal effect, bremsstrahlung, etc.)

2) Boosting DM energy


e.g. cosmic-rays, solar reflection, blazars

Milky Way binaries provide an independent, **gravitational** boosting channel




more complex dark sector dynamics

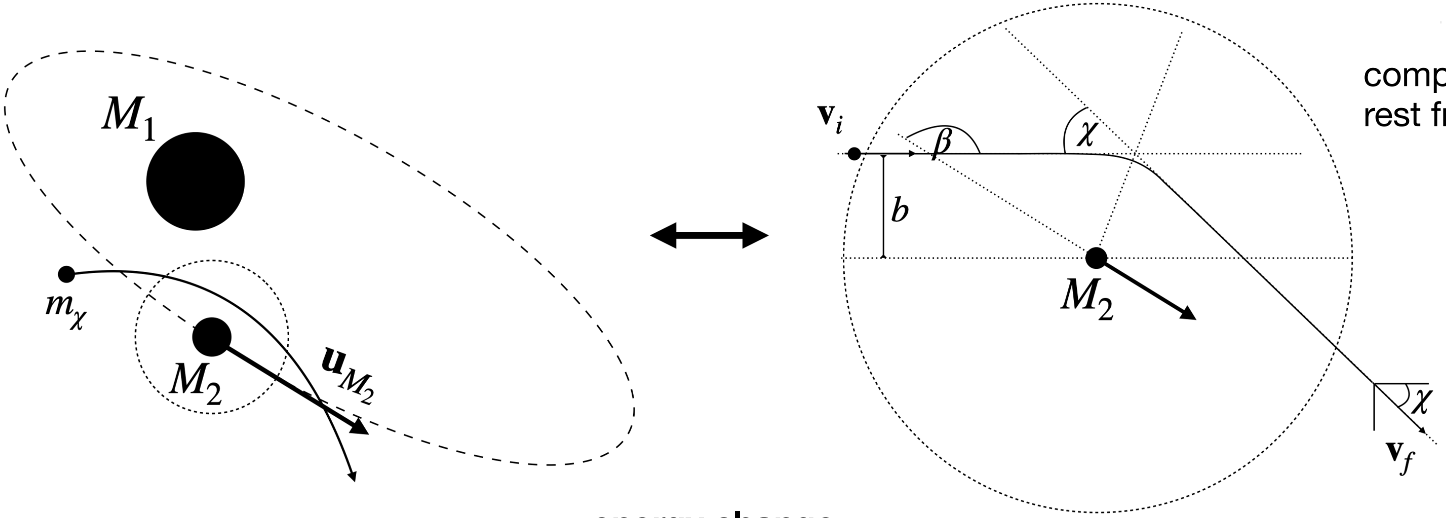
$m_{\chi_2} \gg m_{\chi_1}$

# Boosting DM via gravity

Consider the restricted 3-body problem: $m_\chi \ll M_2 \ll M_1$

barycentric frame

companion rest frame




**energy change:**

$$\Delta\varepsilon = u_{M_2} v_i \left(\cos\beta - \cos(\beta + \chi)\right)$$

$$\tan\left(\frac{\chi}{2}\right) = \frac{GM_2}{b\, v_i^2}$$

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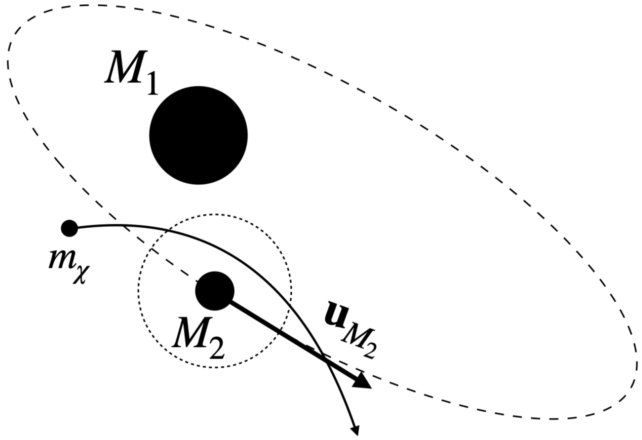
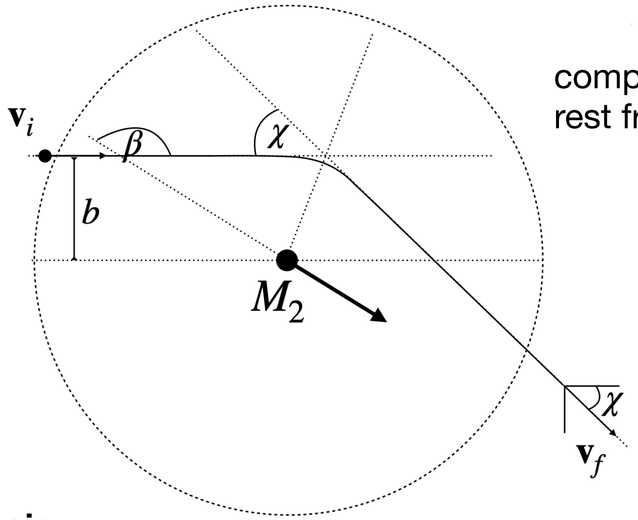


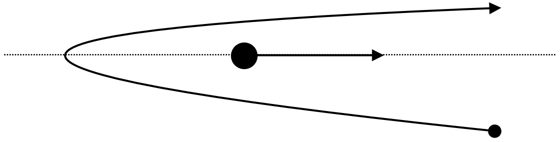

companion rest frame

**max energy gain:**

$$\chi = \pi$$

$$\beta = 0$$

$$\Delta\varepsilon = 2\, u_{M_2} v_i$$

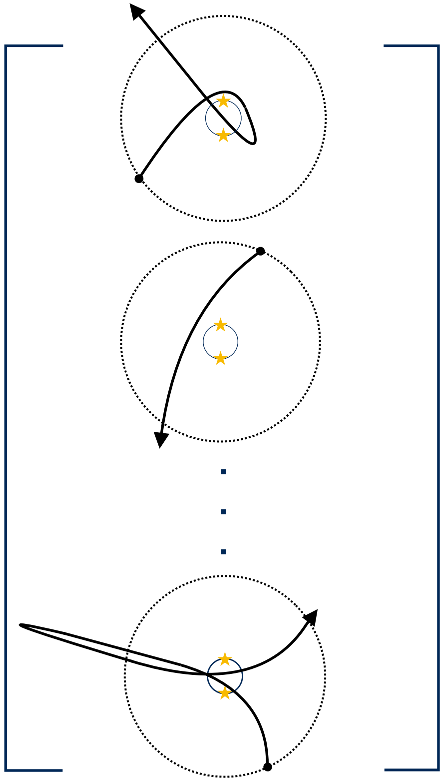


# Simulation

Generate an ensemble of 3-body realizations:

DM velocity distribution + binary parameters

integrate orbital evolution



compute ejection probability: $\boxed{\dfrac{d^2p}{d\epsilon\, d\Omega}}$

physical ejection spectrum:

$$\frac{d^3N_\chi}{d\Omega\, d\epsilon\, dt} = \mathscr{F}_{\rm sim} \times \left(\frac{d^2p}{d\epsilon\, d\Omega}\right)$$

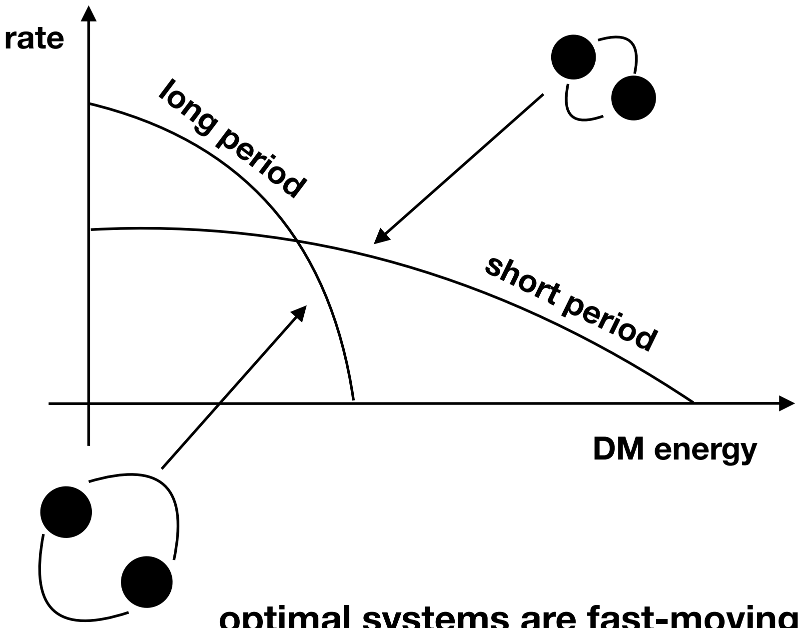
$$\mathscr{F}_{\rm sim} \simeq 4\pi R_{\rm sim}^2\, n_\chi \sqrt{\frac{2}{\pi}}\, \sigma_\chi$$

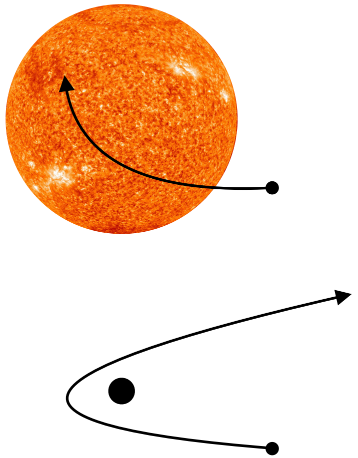
minimal underlying assumptions:

- no sizeable self-interactions
- no wave-like DM
- no binary back-reaction

# Optimal Systems

Ideally: deep gravitational well



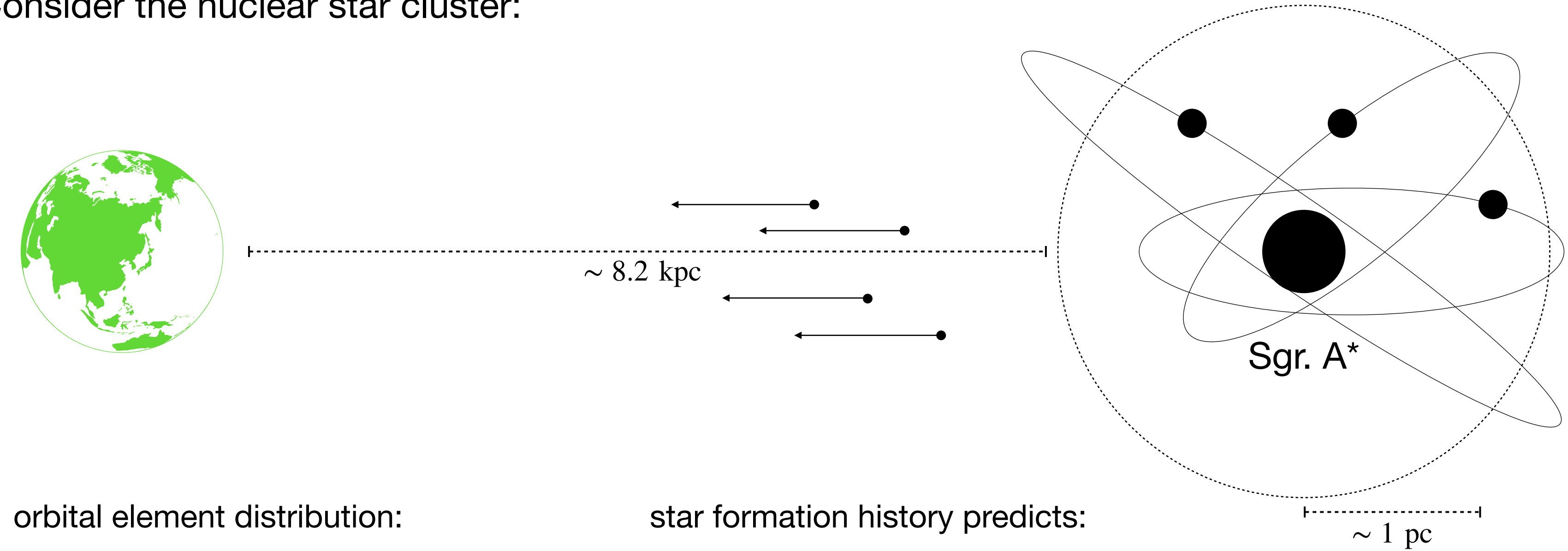
extended objects deviate from 1/r field

compact objects source point-like field

**optimal systems are fast-moving, extended, heavy black hole binaries**

# Target Region

Consider the nuclear star cluster:




orbital element distribution:

$$\frac{d^2 N_{\rm BH}}{da\,de} \propto a^{3/2-p}\, e$$

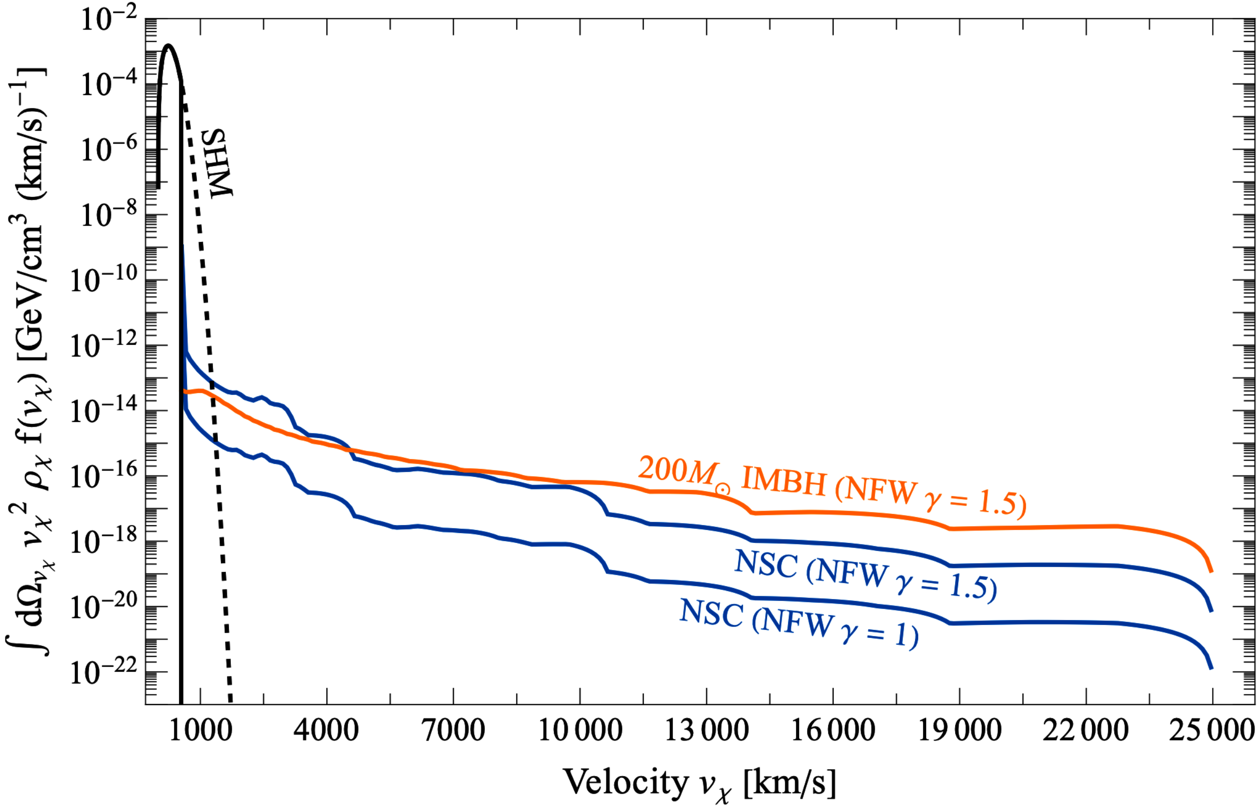
(e.g. Bahcall-Wolf cusp, p = 0.25)

star formation history predicts:

$$N_{\rm BH} \simeq 2.5 \times 10^5 \quad (R \lesssim 1\,{\rm pc})$$

**Chen et. al., 2212.01397**

# Velocity Distribution from Sgr. A*




Acevedo & Ritz, 2606.30724

# Detection Rates

This can be fed into the standard direct detection machinery:

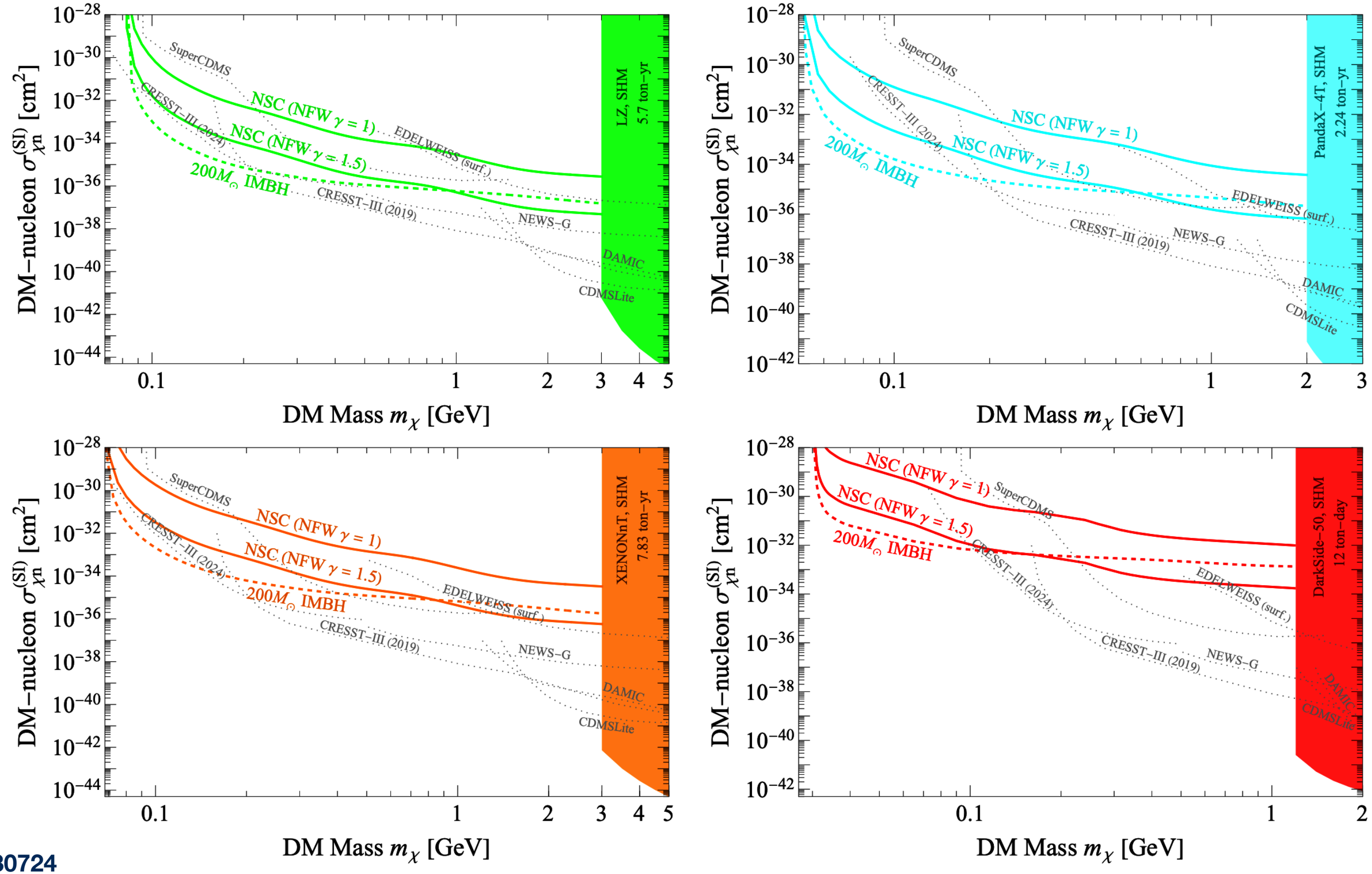
$$\frac{dR}{dE_R} = N_T \int_{v_{\min}(E_R)} \eta(E_R) \frac{d\sigma}{dE_R} v_\chi f(\mathbf{v}_\chi)\, d^3\mathbf{v}_\chi$$

$$N_{\text{events}} = (\text{exposure}) \times \int \frac{dR}{dE_R} dE_R$$

where now the velocity distribution:

$$f(\mathbf{v}_\chi) = \underbrace{n_\chi^{(\text{SHM})} f_{\text{SHM}}\left( |\mathbf{v}_\chi + \mathbf{v}_{\text{det}}| \right)}_{\text{standard halo contribution}} + \underbrace{n_\chi^{(\text{NSC})} f_{\text{NSC}}\left( |\mathbf{v}_\chi + \mathbf{v}_{\text{det}}| \right)}_{\textbf{non-thermal contribution from nuclear star cluster}}$$

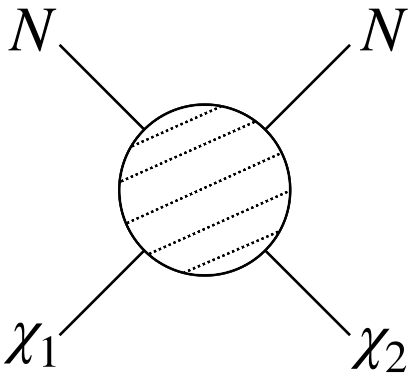
# Extended Sensitivity: Elastic Scattering




Acevedo & Ritz, 2606.30724

# Extended Sensitivity: Inelastic Scattering

Consider inelastic process:



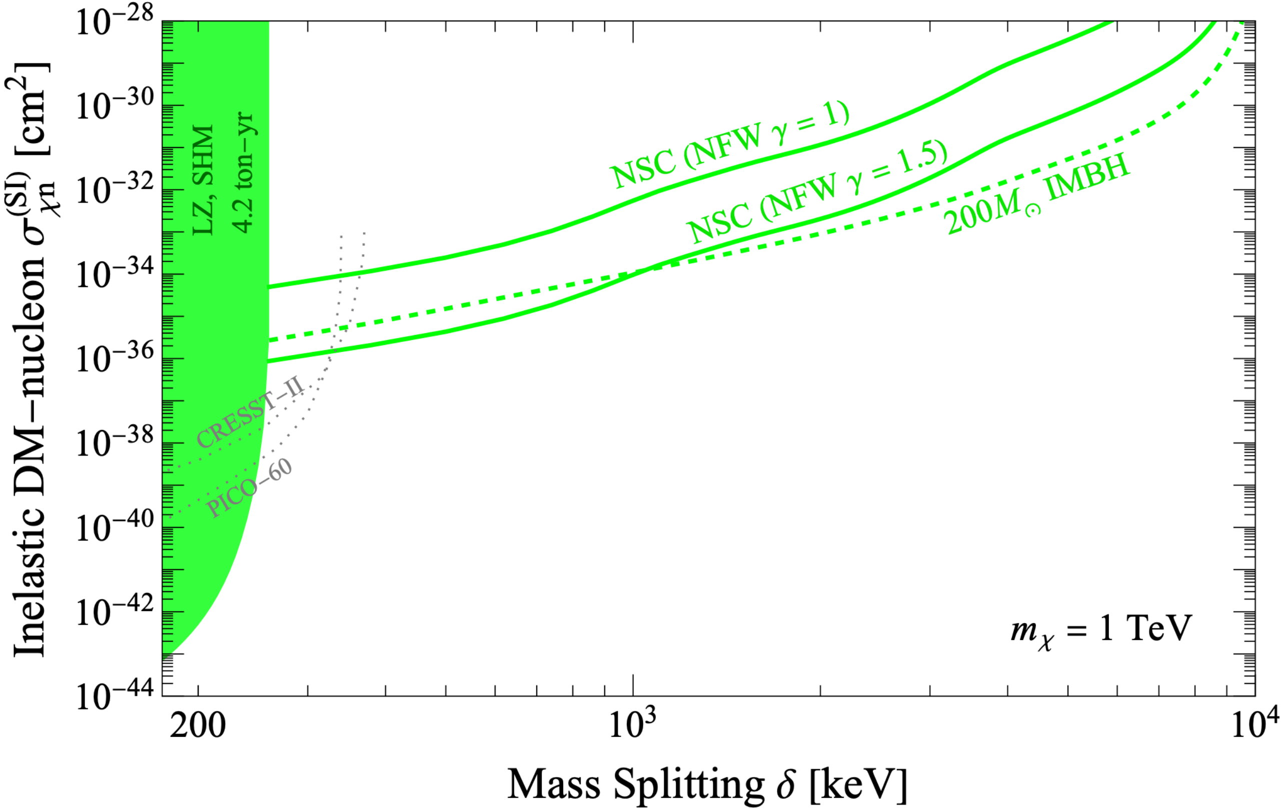

$$\delta = m_{\chi_2} - m_{\chi_1} > 0$$

non-diagonal coupling imposes a kinematic threshold:

$$v_\chi^{(\min)} = \sqrt{\frac{2\delta}{\mu_{\chi N}}}$$

- Standard Halo Model only allows probing ~ 300 keV splittings
- Non-gravitational boosting ineffective for heavy DM.

# Extended Sensitivity: Inelastic Scattering




*unique* feature of gravitational boosting

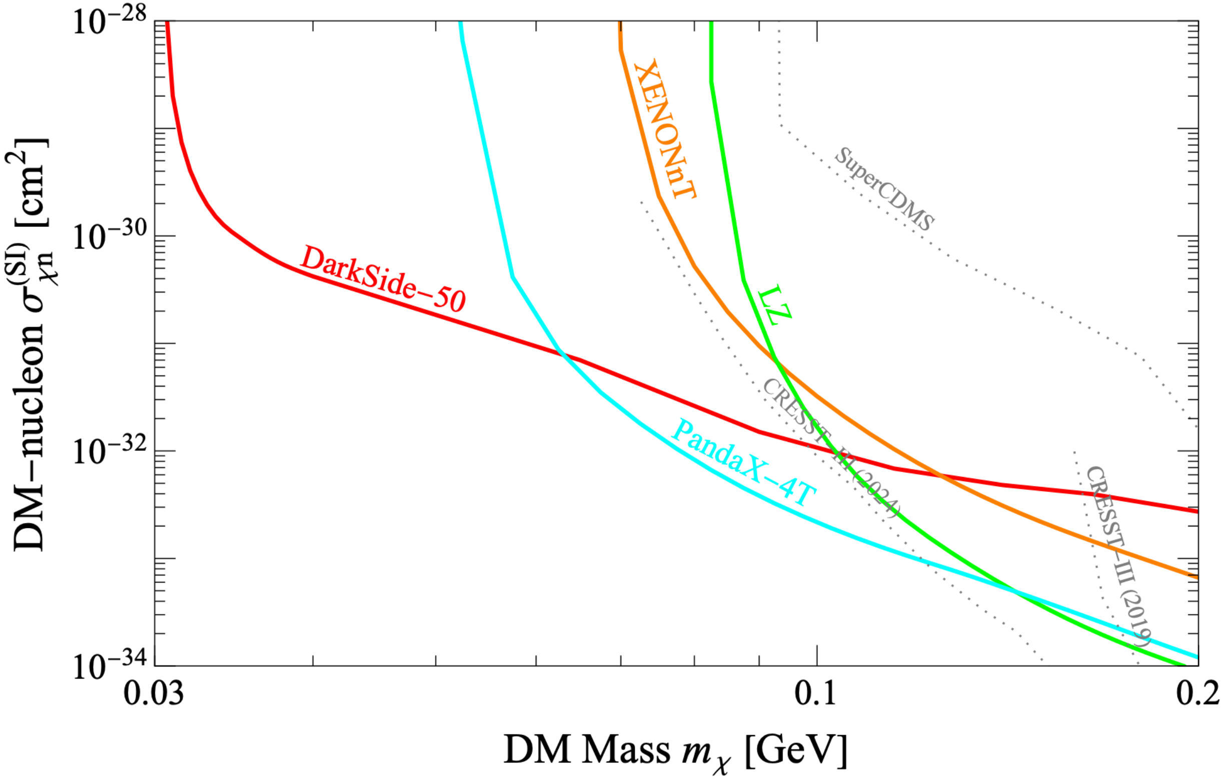
Acevedo & Ritz, 2606.30724

# Summary

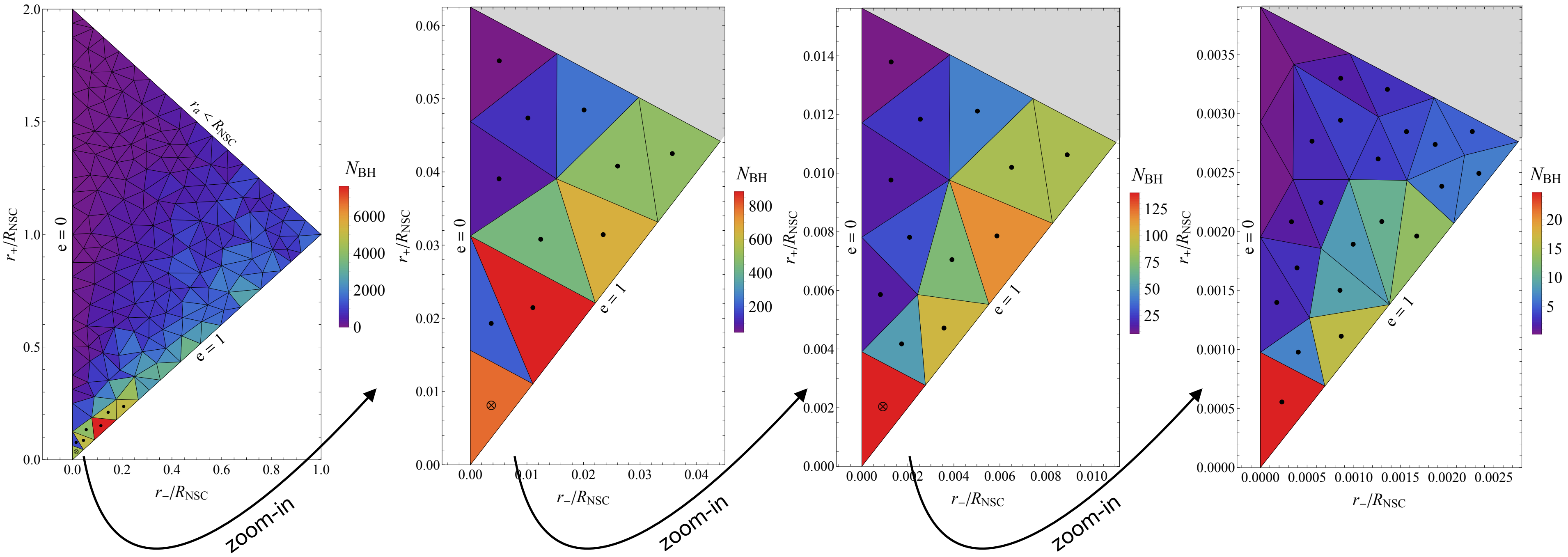
- The nuclear star cluster can accelerate transiting DM particles to substantially higher velocities compared to the halo through gravity alone.
- Its presence offers a nearly model- and mass-independent way of extending the sensitivity of large-volume detectors.
- This mechanism illustrates how astrophysical structures at the smallest scales might be relevant for DM phenomenology.

**Thank you!**

# Extended Sensitivity: Elastic Scattering (zoom-in)



# Backup: Orbital Binning

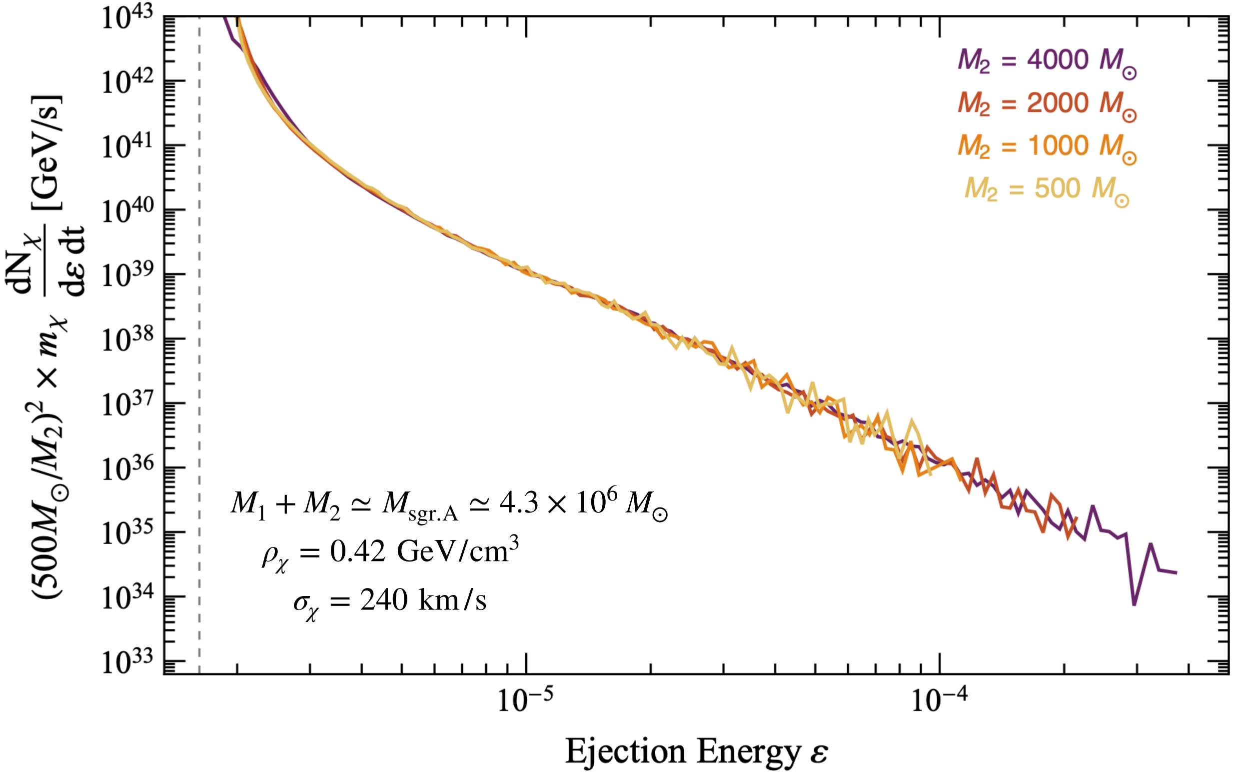



each dot is an independent simulation

$$\frac{d^2N_{BH}}{da\,de} \to \frac{d^2N_{BH}}{dr_+dr_-} \propto r_-\,r_+^{\alpha} \qquad \text{where} \qquad r_\pm = \text{apocenter} \pm \text{pericenter}$$

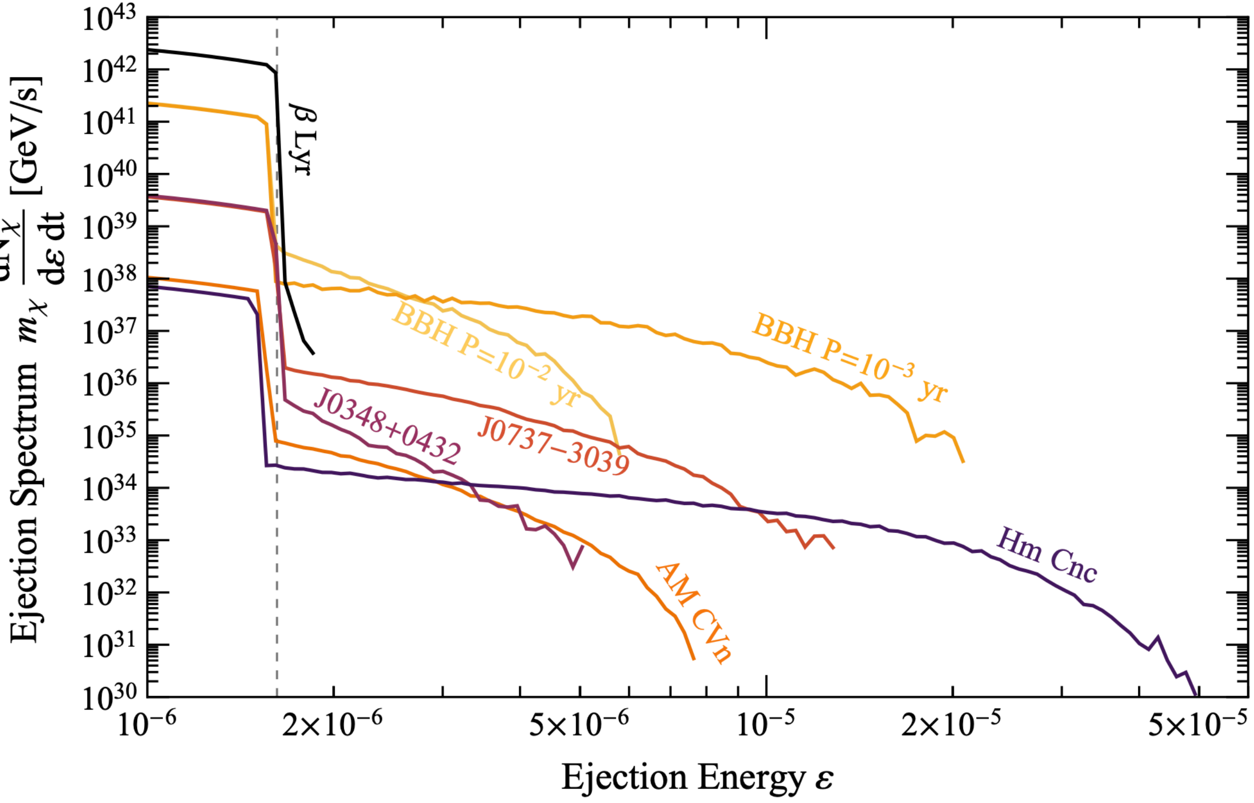
Acevedo & Ritz, 2606.30724

# Backup: Mass Ratio Dependence

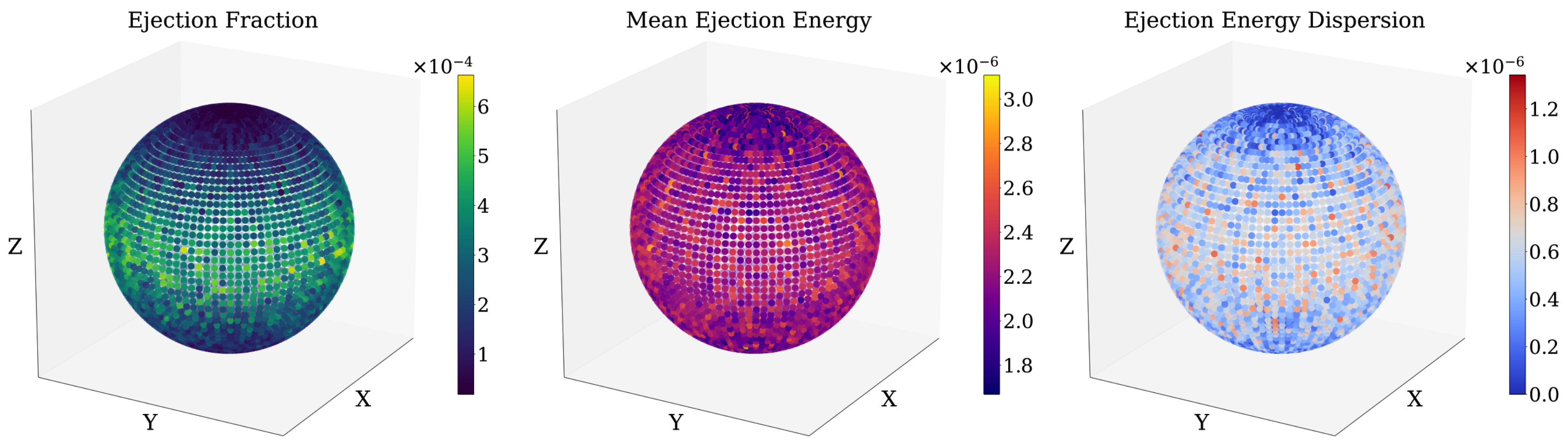



Acevedo & Ritz, 2603.08781

# Backup: Milky Way Binary Sample



# Backup: Ejection Anisotropy

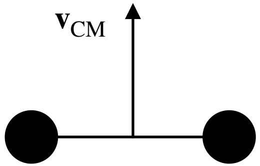


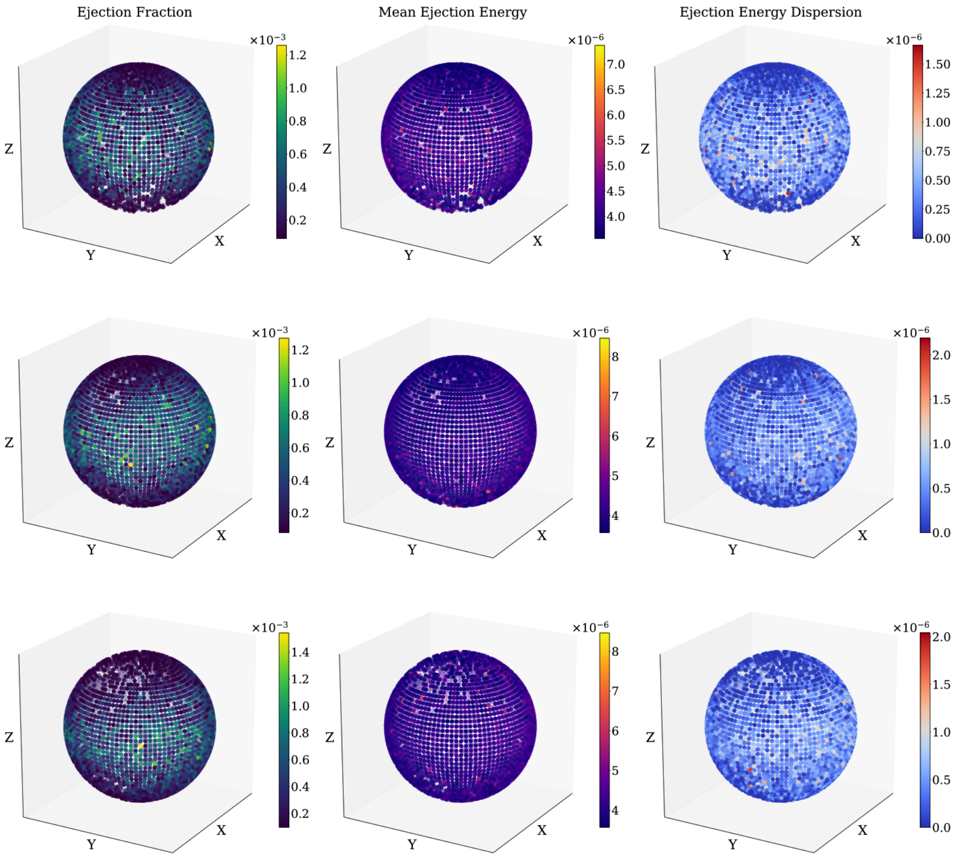

$$f_i = \frac{N_i}{N_{\rm tot}}$$

$$\langle E_i \rangle = \frac{\sum_j N_j^i E_j^i}{N_{\rm tot}^i}$$

$$\sqrt{\langle E^2 \rangle - \langle E \rangle^2}$$

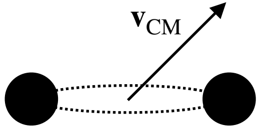
# Backup: Systemic Motion Dependence

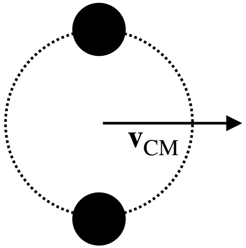



$v_{\rm CM} = 240$ km/s

$\sigma_\chi = 240$ km/s

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