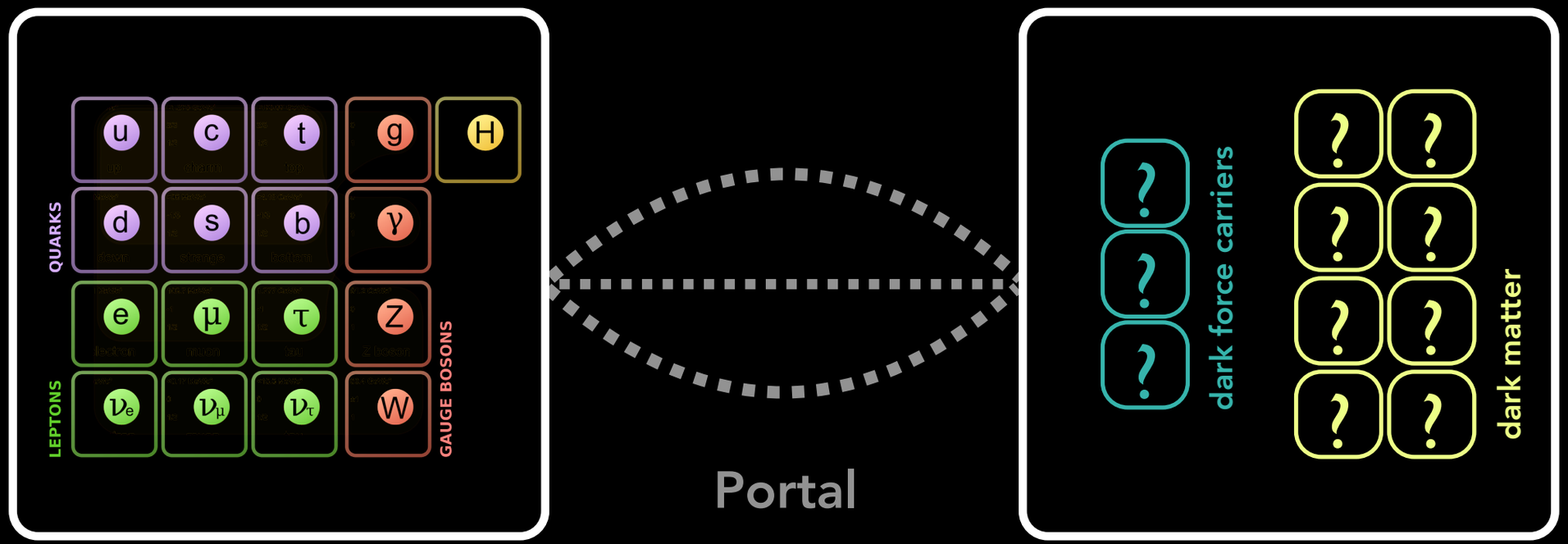
The Imprint of Dark Matter Self Interactions on Cosmic Collisions

Mariangela Lisanti

Princeton University
Flatiron Institute

Image Credit: Ron Miller, Scientific American

Theory of Dark Sectors



What if new forces allow dark matter to interact with itself either elastically or inelastically?

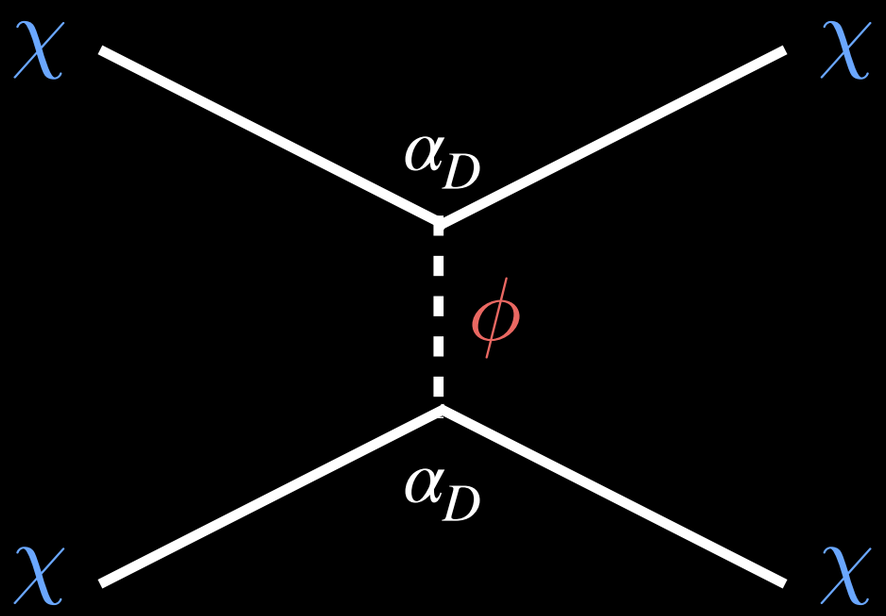
Short-Range Elastic Self Interactions (SIDM)

Inelastic/Dissipative Self Interactions (Atomic Dark Matter)

Long-Range Elastic Self Interactions

Short-Range Elastic Self Interactions

Dark matter particles interact via some new mediator

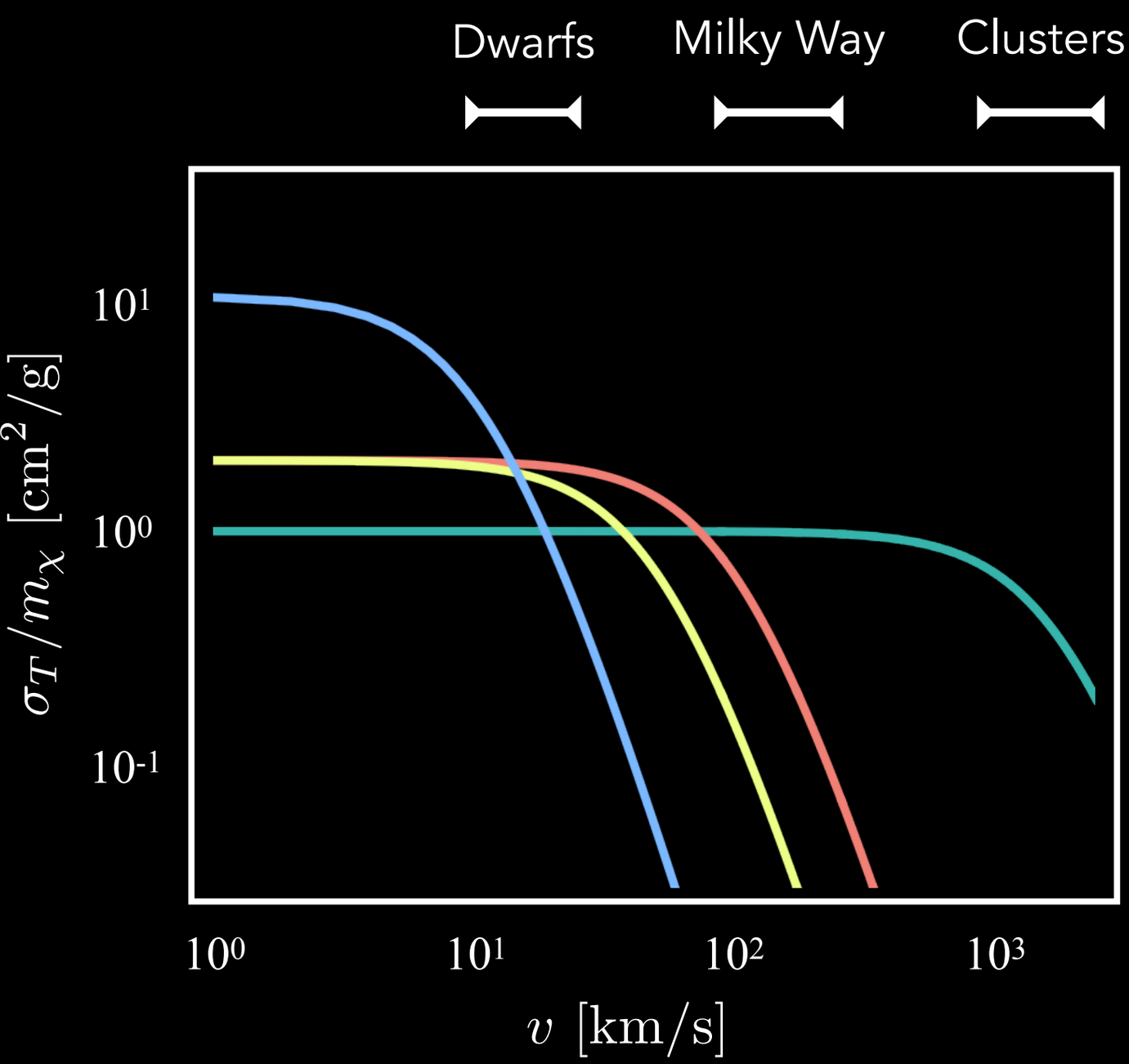


$$L_{\text{int}} = \begin{cases} g_D \bar{\chi} \gamma^\mu \chi \phi_\mu \\ g_D \bar{\chi} \chi \phi \end{cases}$$

Self scattering described by Yukawa potential
in non-relativistic limit

Feng et al. [0905.3039]; Loeb and Weiner [1011.6374]; Kaplinghat, Tulin and Yu [1508.03339]

Short-Range Elastic Self Interactions



Anisotropic, velocity-dependent self scattering

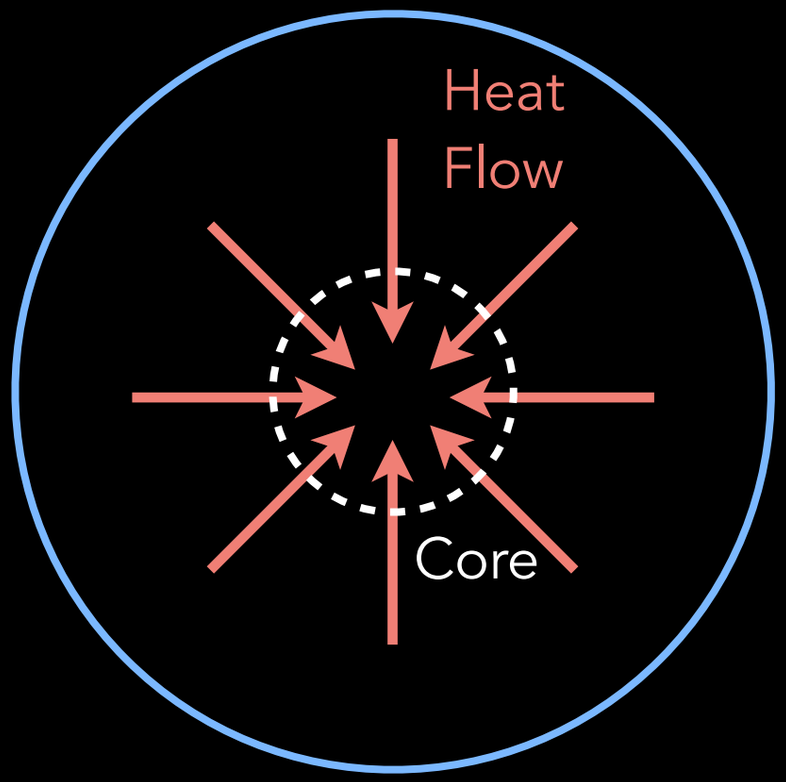
$$\frac{d\sigma}{d\theta} = \frac{\sigma_0 \sin\theta}{2\left[1 + \frac{v^2}{\omega^2}\sin^2\frac{\theta}{2}\right]^2}$$

Two free parameters

$$\sigma_0 \equiv 4\pi\alpha_D^2 m_\chi^2/m_\phi^4$$
$$\omega \equiv m_\phi/m_\chi$$

see Tulin and Yu [1705.02358] for review

SIDM Halo Evolution



Stage 1: Core Formation

Self interactions transfer heat *inwards*

→ Formation of isothermal core

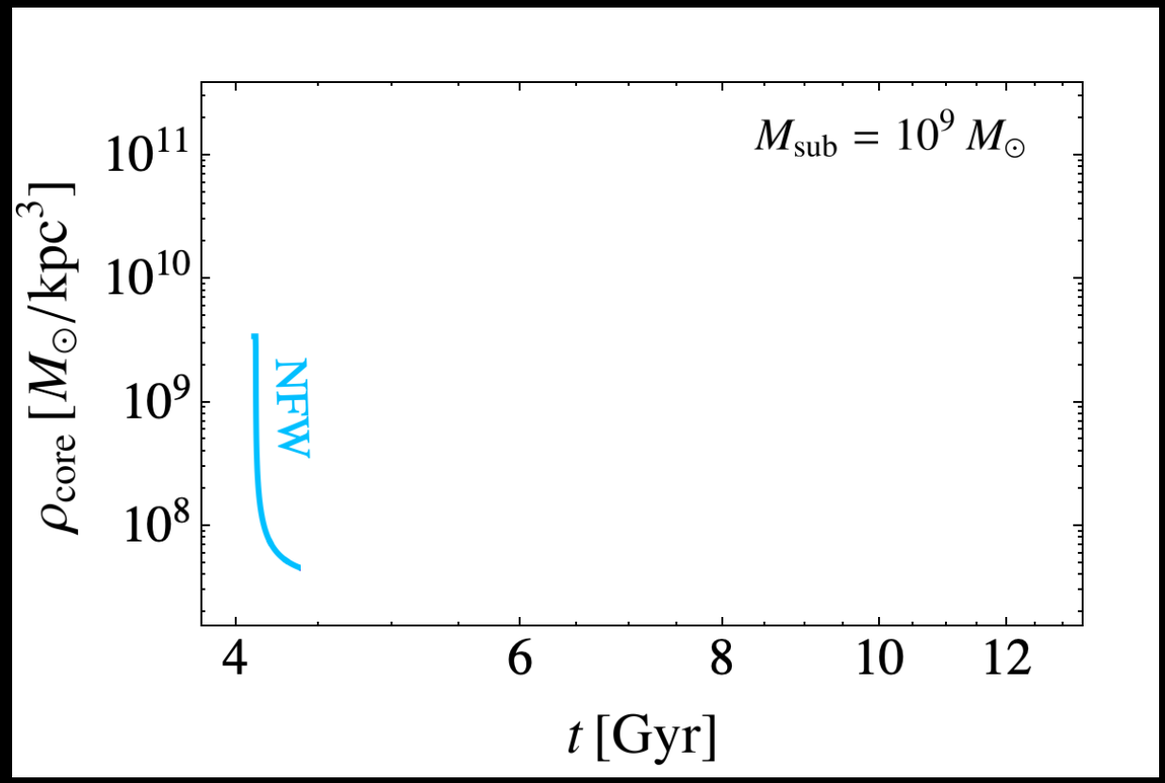
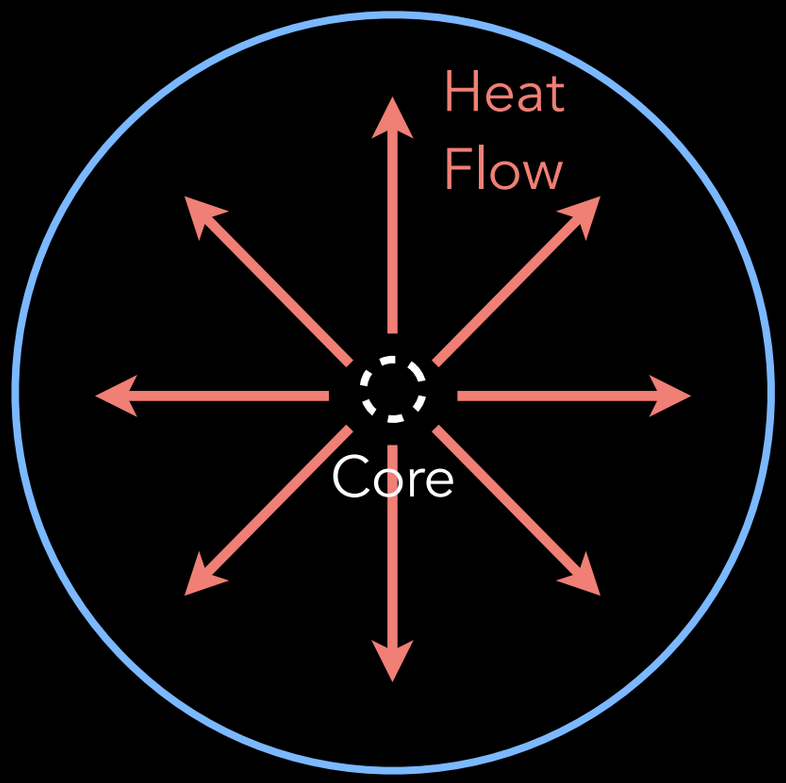


Image Credit: Oren Slone

Vogelsberger et al. [1201.5892]; Zavala et al. [1211.6426]; Robles et al. [1903.01469]; Zavala et al. [1904.09998]

SIDM Halo Evolution



Dark Matter Halo

Stage 2: Core Collapse

Self interactions transfer heat *outwards*

→ Core heats up and shrinks

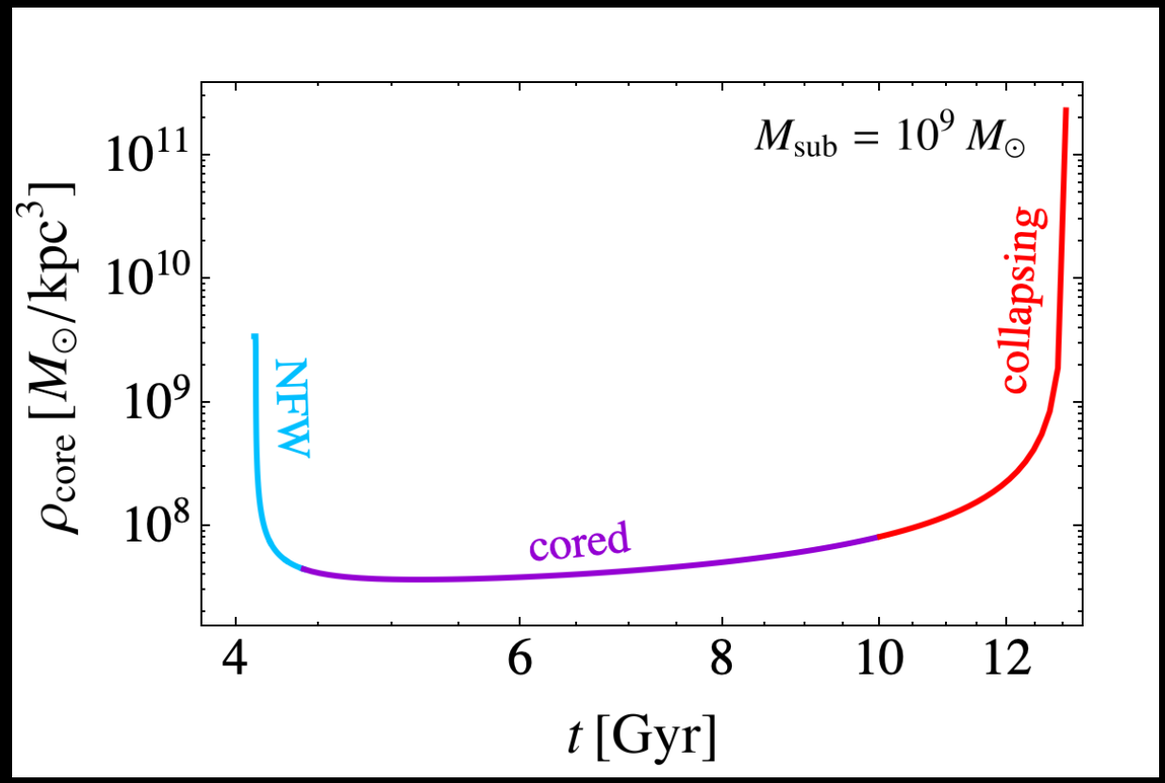


Image Credit: Oren Slone

Balberg et al. [astro-ph/0110561]; Koda and Shapiro [1101.3097]; Elbert et al. [1412.1477];
Essig et al. [1809.01144]; Nishikawa et al. [1901.0049]; Kahlhoefer et al. [1904.10539]; Turner et al. [2010.02924]

SIDM Halo Evolution

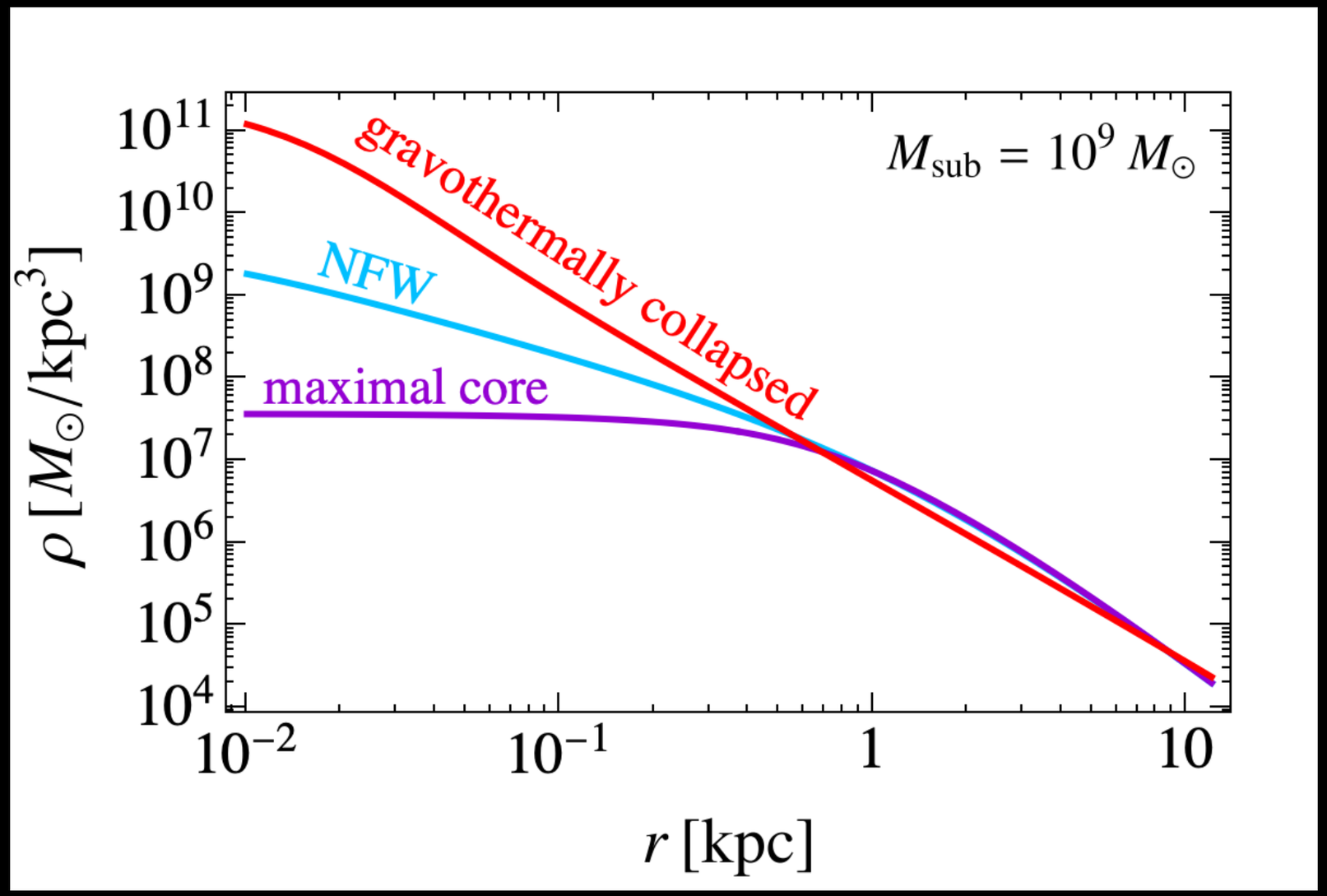
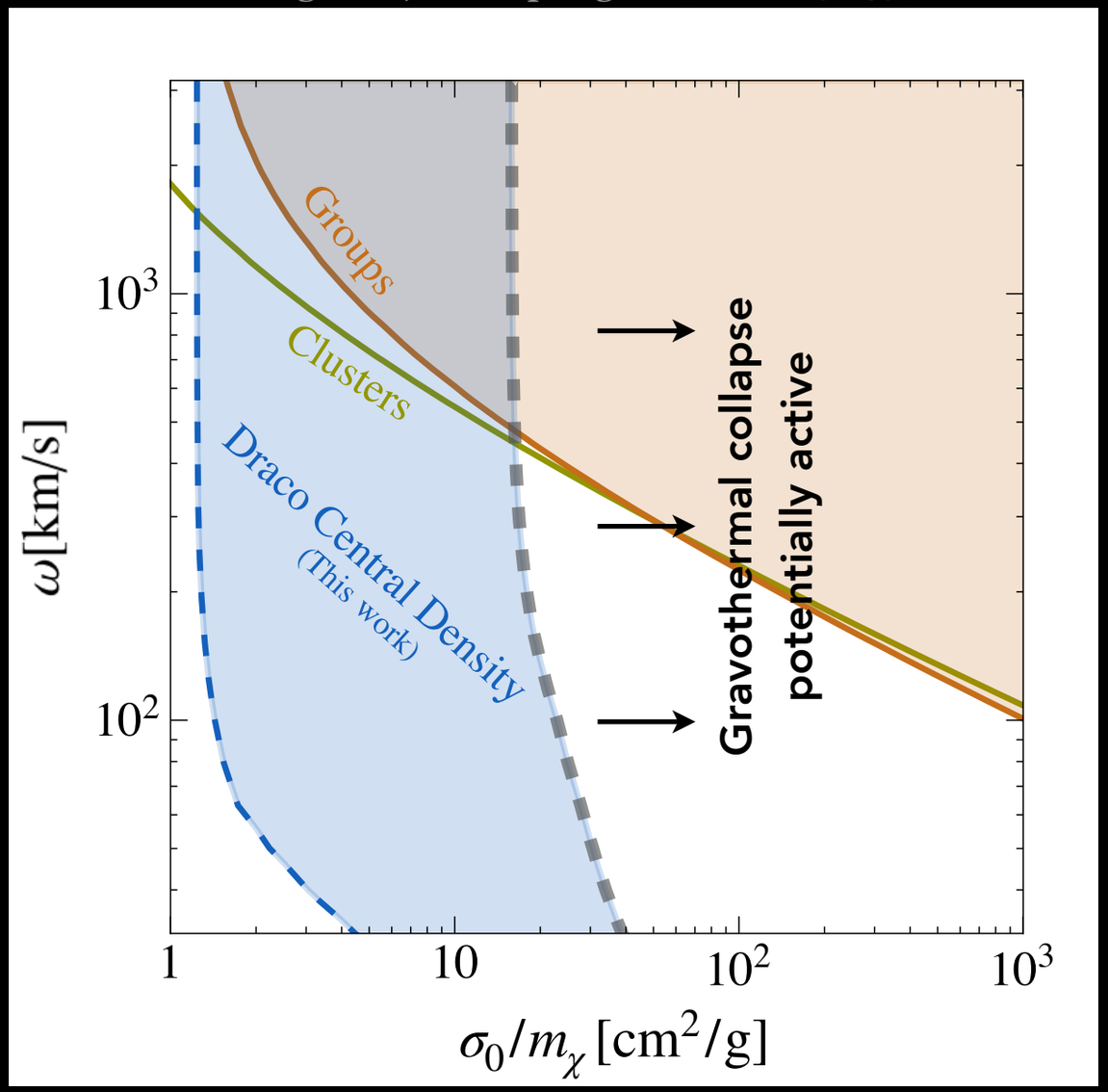


Image Credit: Oren Slone

Oren Slone

Summary of Current Constraints

O. Slone, F. Jiang, **ML**, M. Kaplinghat [2108.03243]



SIDM cross section

Observational Consequences:

SIDM models favor velocity-dependent interactions

Gravothermal collapse must occur for densest dwarf galaxies

$$\frac{d\sigma}{d\theta} = \frac{\sigma_0 \sin\theta}{2\left[1 + \frac{v^2}{\omega^2}\sin^2\frac{\theta}{2}\right]^2}$$

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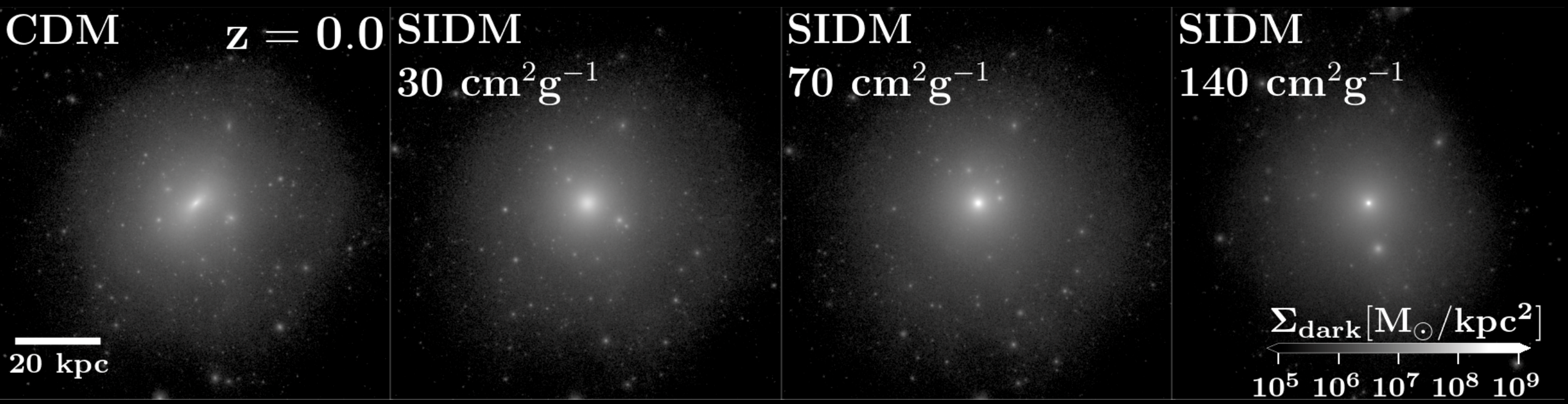
Cosmological SIDM Simulations

New suite of cosmological N-body simulations of field dwarfs (~10^{10} $M_\odot$) in the gravothermal collapse regime



(same initial conditions, different cross sections)

Silverman, Arora, Huseein, Kaplinghat, **ML**, Necib, and Sanderson [in prep]

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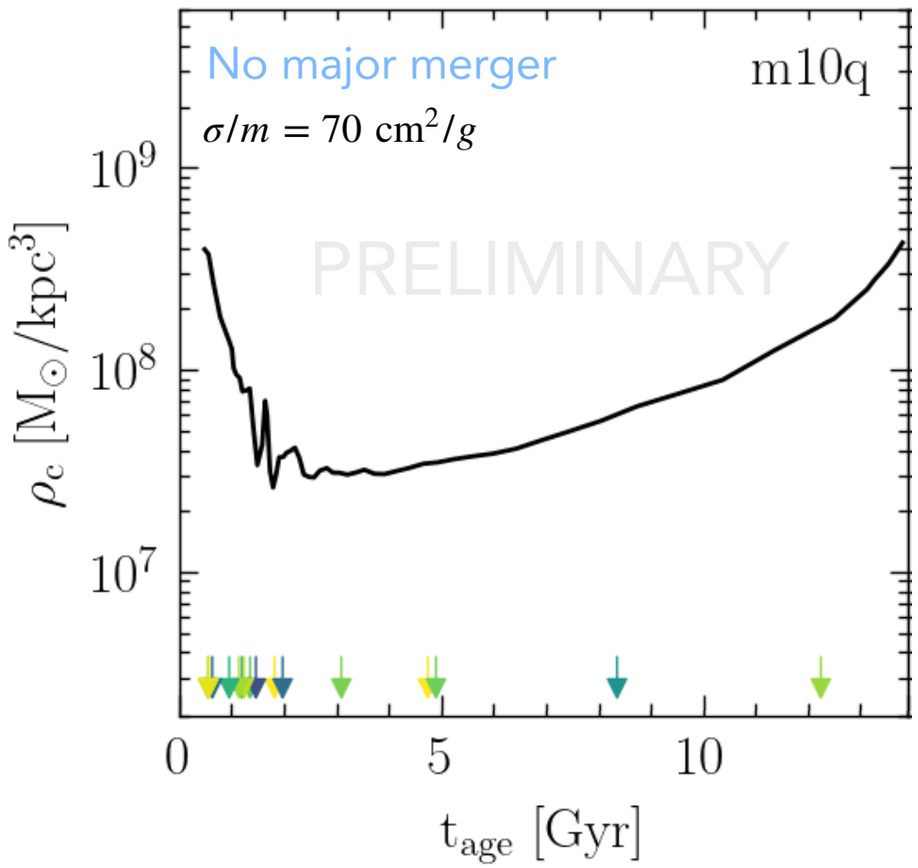
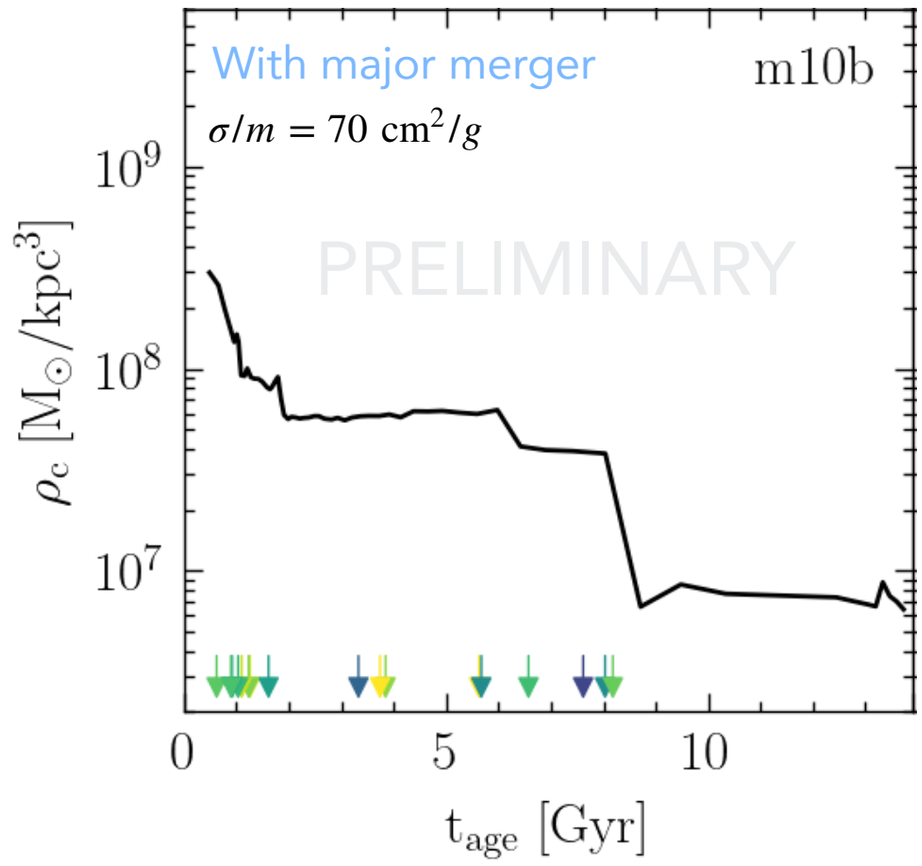
A Complicated Picture Emerging

Significant mergers can turn off the gravothermal collapse process





Silverman, Arora, Huseein, Kaplinghat, **ML**, Necib, and Sanderson [in prep]

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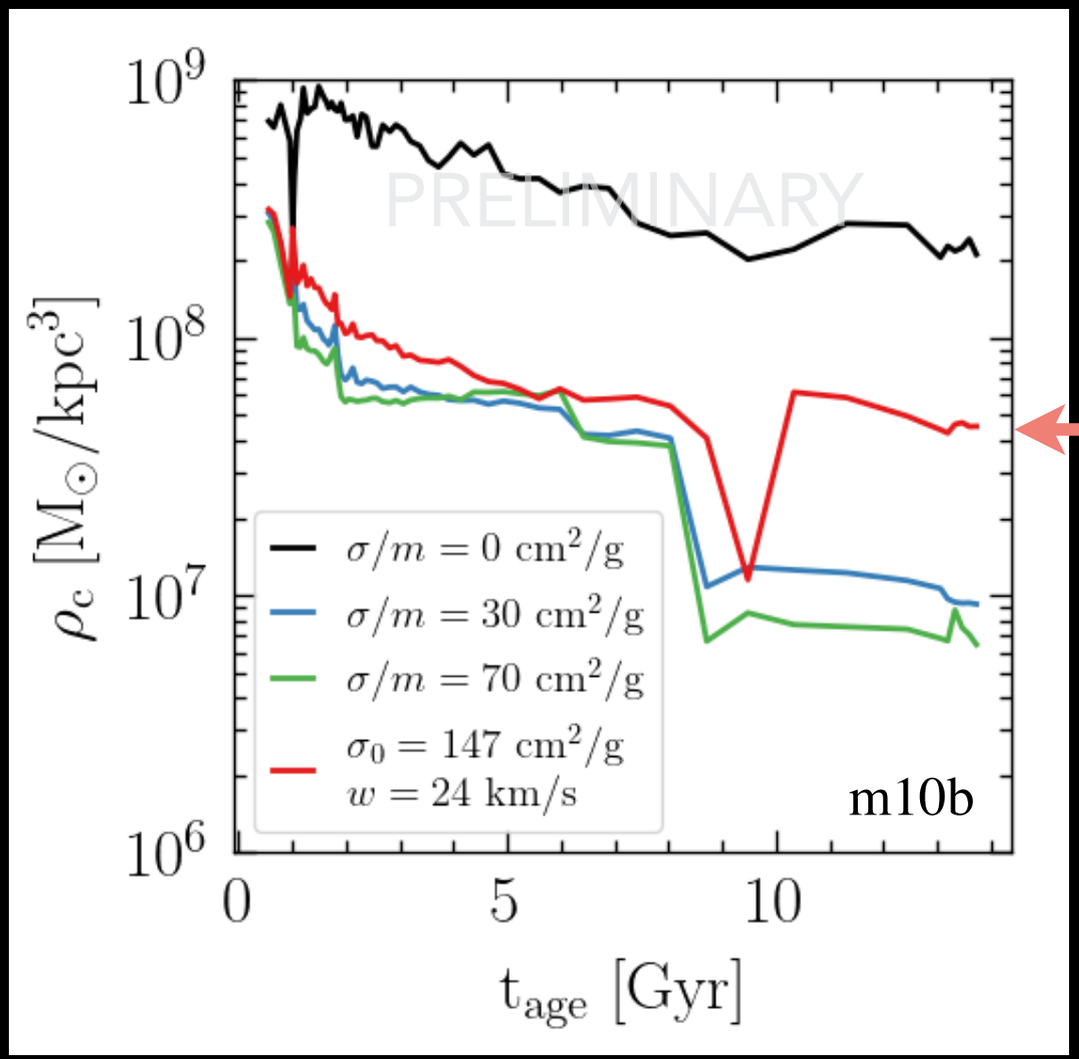
Ram-Pressure Effects

Scattering between dark matter in subhalo and host redistributes energy, potentially cutting off collapse process



This change in cross section suppresses ram pressure, bringing core density back up

Silverman, Arora, Huseein, Kaplinghat, **ML**, Necib, and Sanderson [in prep]

Conclusions

Galaxies can serve as cosmic colliders, opening a window into the dark matter dynamics that impact their formation and evolution

Elastic short-range self interactions affect halo evolution, leading to a diversity of cores and cusps

SIDM halo morphology is highly sensitive to merger history, complicating interpretations from semi-analytic modeling

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