What Does the Bullet Cluster Tell us about Self-Interacting Dark Matter?

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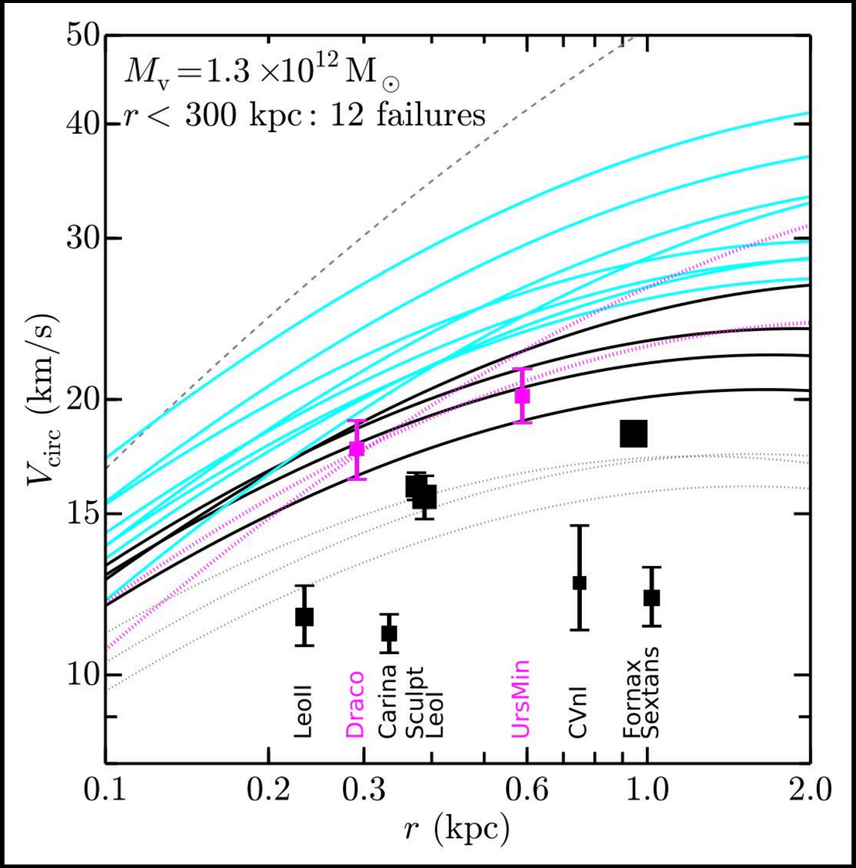
24th November 2016, Dark Matter from aeV to ZeV, Lumley Castle

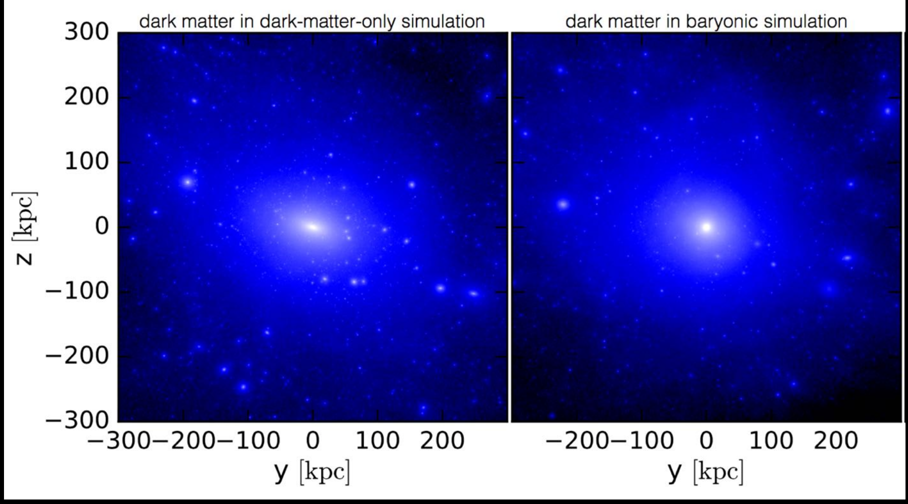
WHY STUDY SELF-INTERACTING DARK MATTER?

- SIDM: Cold Dark Matter with non-gravitational interactions (here elastic scattering)
- Originally proposed to solve missing satellites problem
- But implications for ‘Too Big to Fail’



Garrison-Kimmel+ 2014

“The Chosen Few” – Sawala+ 2014



Wetzel+ 2016

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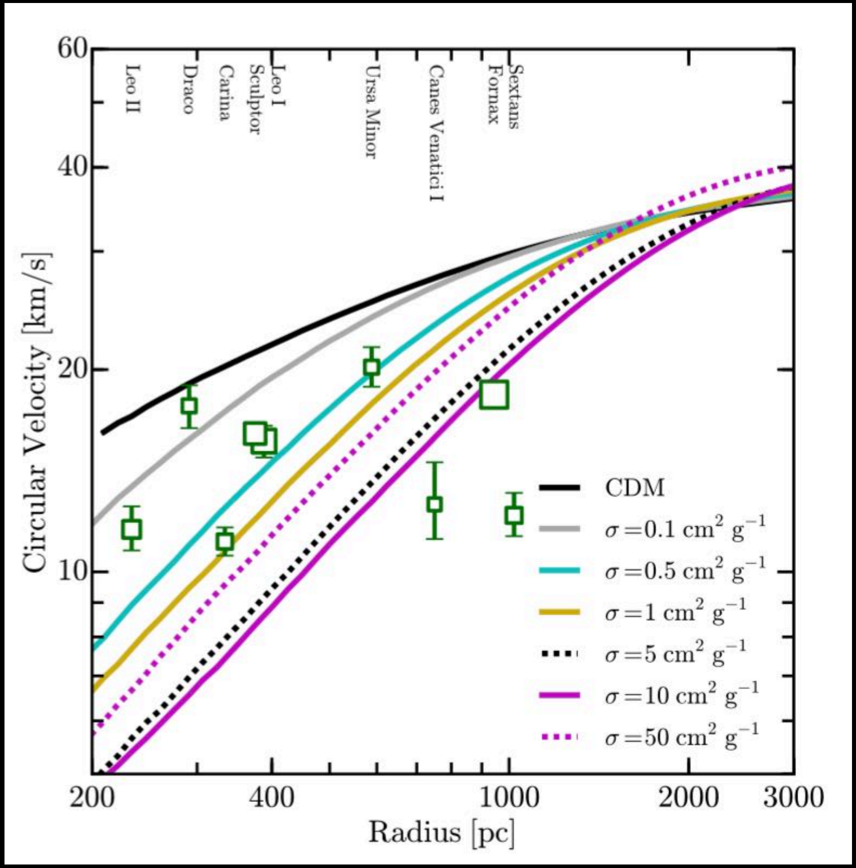

Elbert+ 2016

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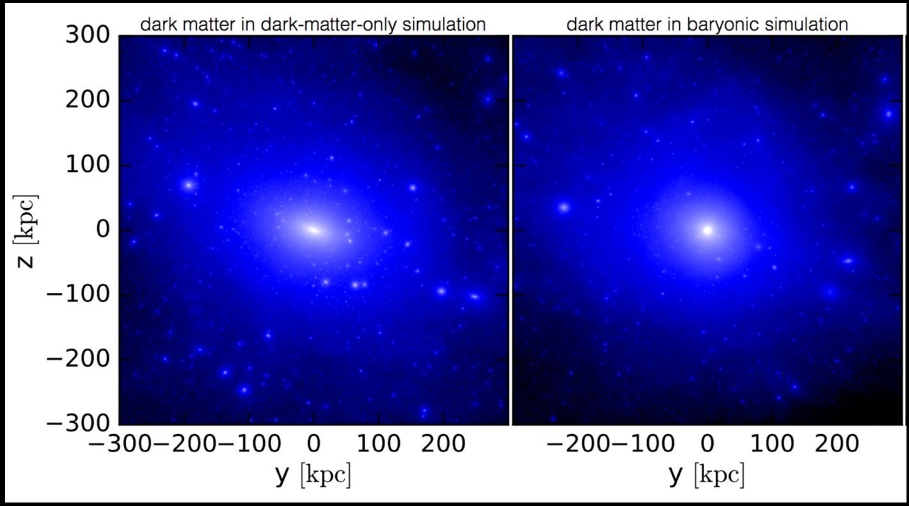
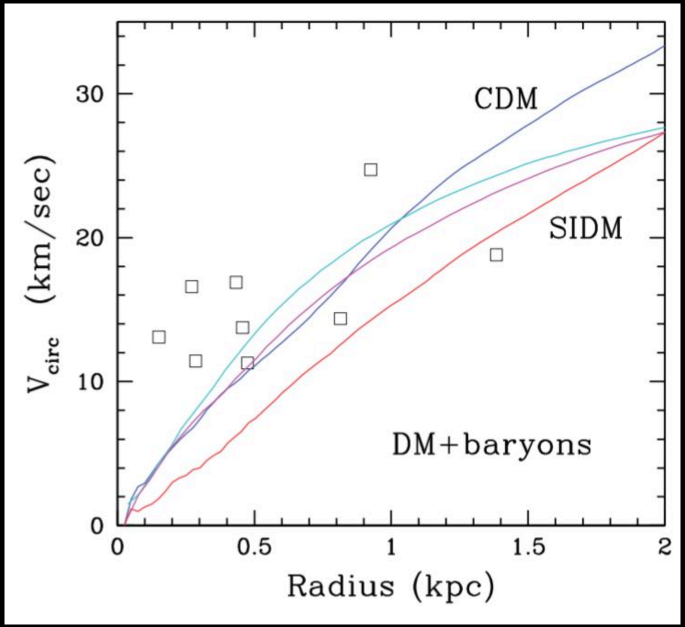


Wetzel+ 2016

WHY LOOK AT GALAXY CLUSTERS?

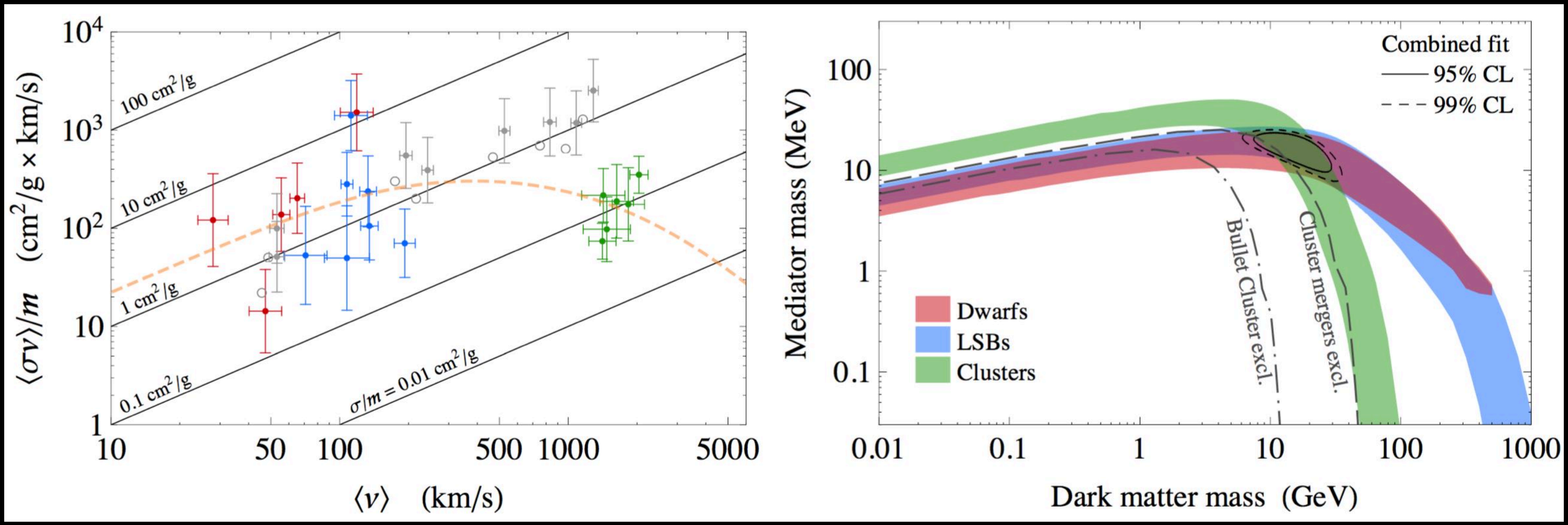
The situation on dwarf galaxy scales in unclear

If DM has a velocity dependent cross-section, then information on DM scattering at different velocities provides complementary information



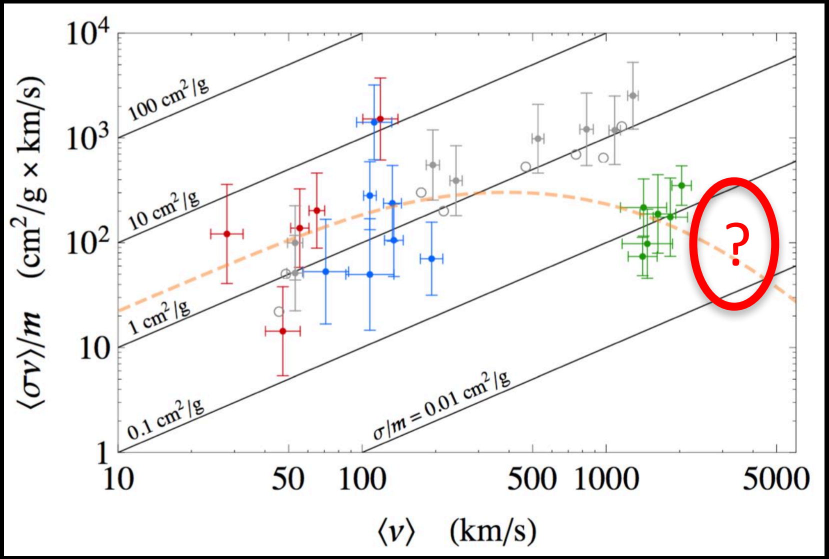
Bastidas Fry+ 2015

Kaplinghat+ 2016



WHY LOOK AT MERGING GALAXY CLUSTERS?

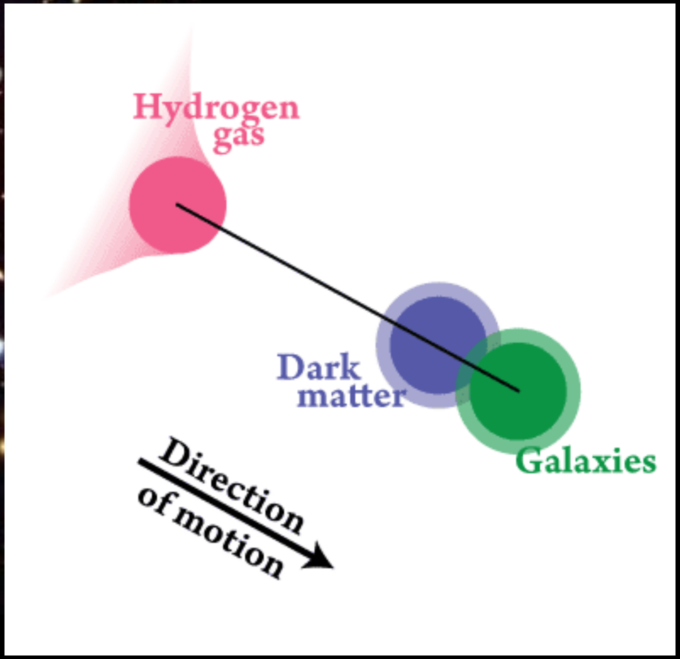
Higher DM-DM velocities than in isolated galaxy clusters



Dark Matter separated from main baryonic component

Particle Collider for Dark Matter!

THE BULLET CLUSTER – A TOY MODEL

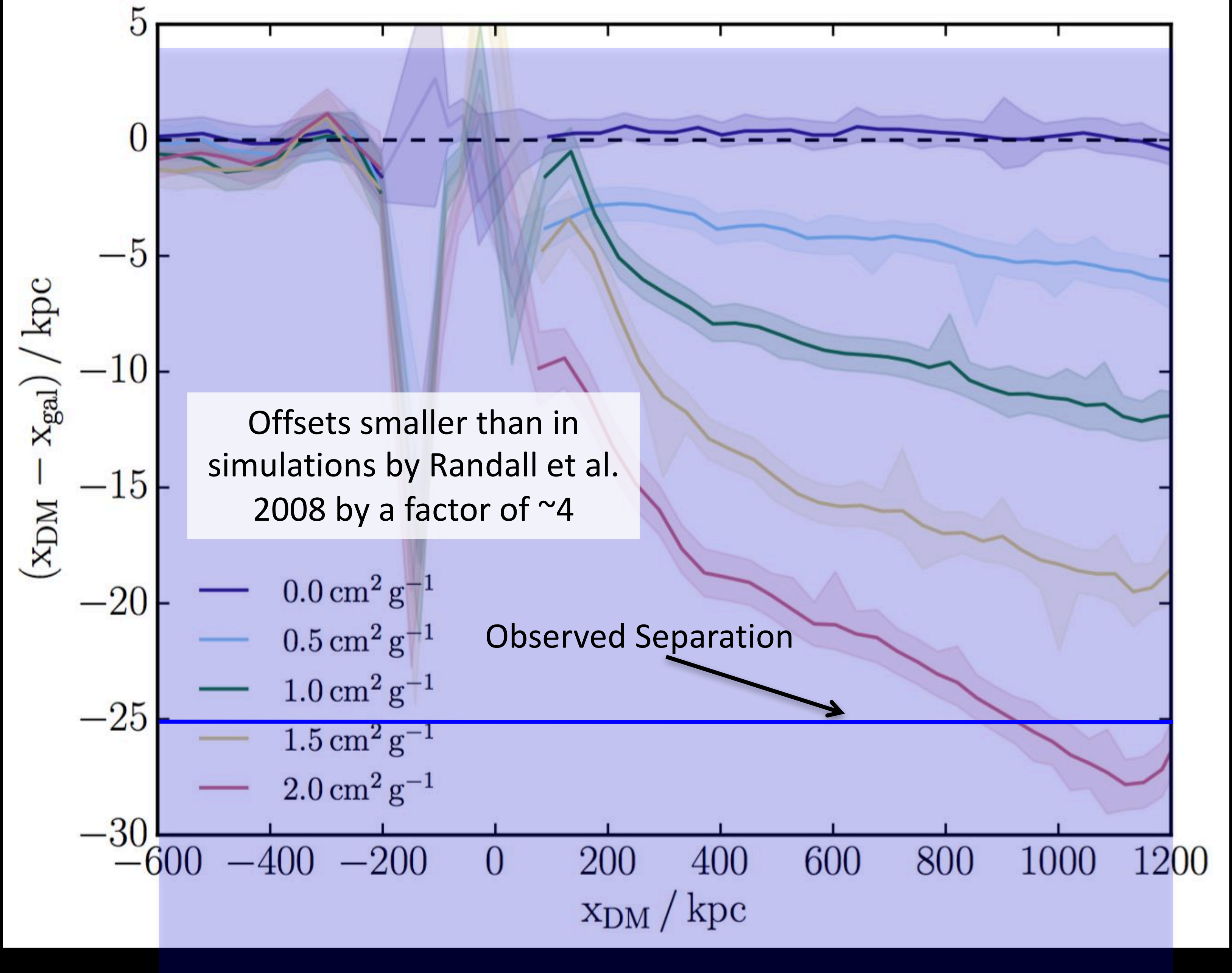


Harvey+ 2014

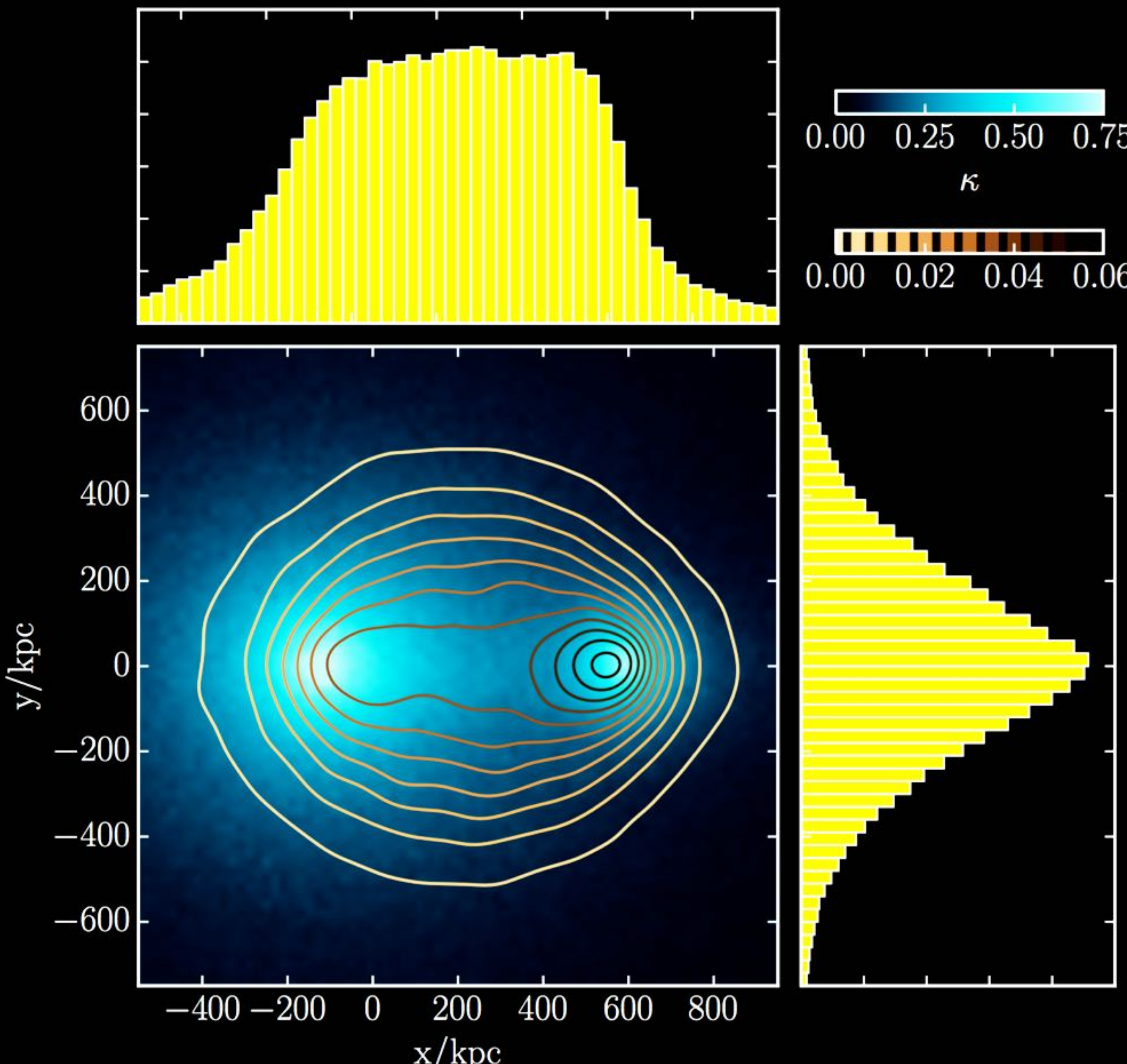
SMASHING CLUSTERS TOGETHER

INCLUDING SIDM WITH A LARGE CROSS-SECTION

DM–GALAXY OFFSETS



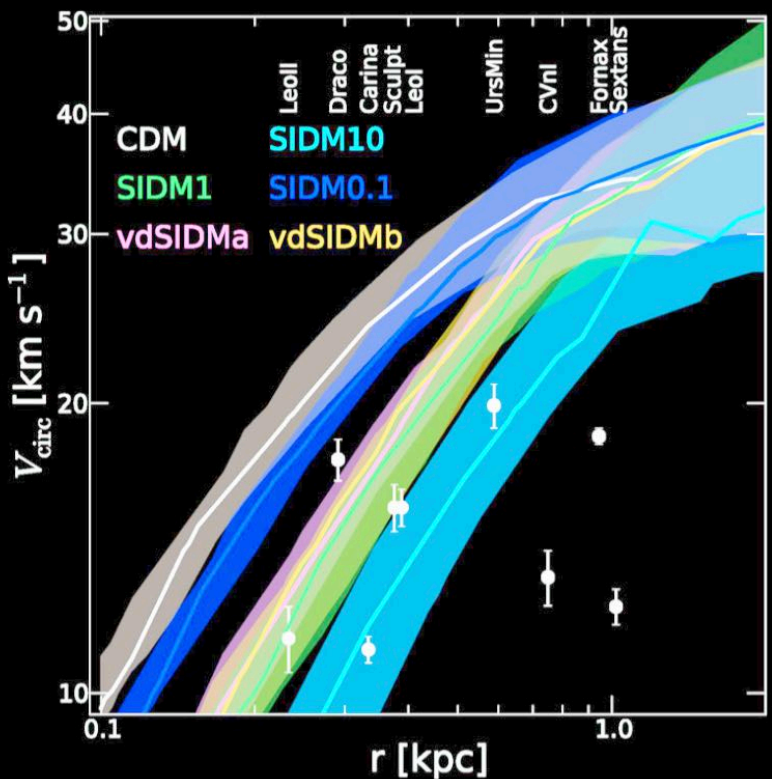
THE DISTRIBUTION OF SCATTERED PARTICLES



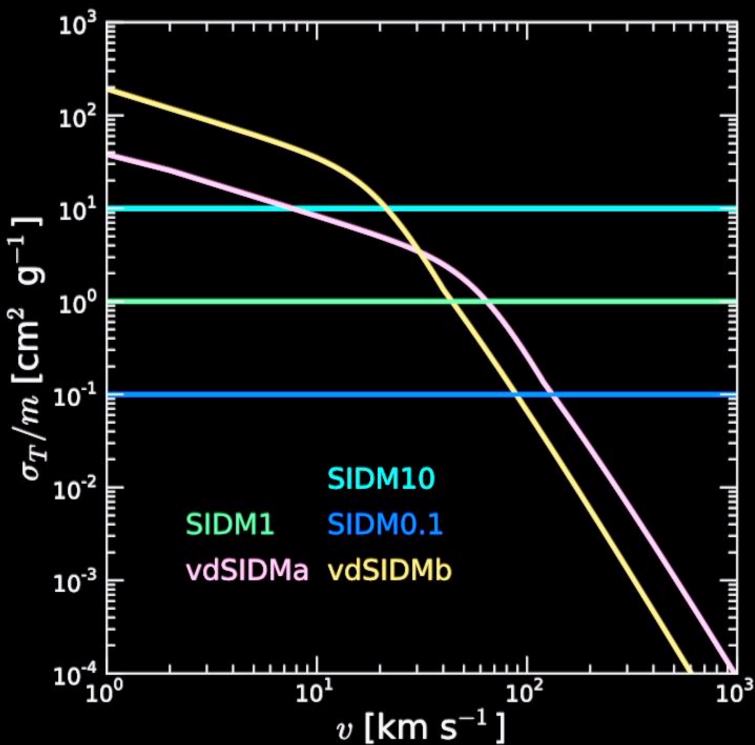
VELOCITY DEPENDENT SIDM

Can have large cross-sections in dwarf galaxies while evading constraints from galaxy clusters

$$\sigma_T \equiv \int (1 - \cos\theta) \frac{d\sigma}{d\Omega} d\Omega.$$



Zavala+ 2013



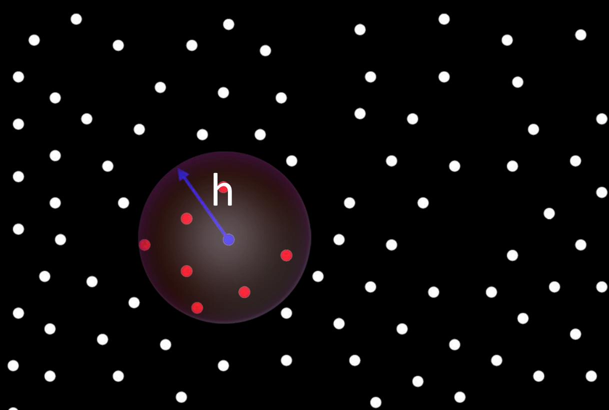
A natural outcome of some SIDM candidate models

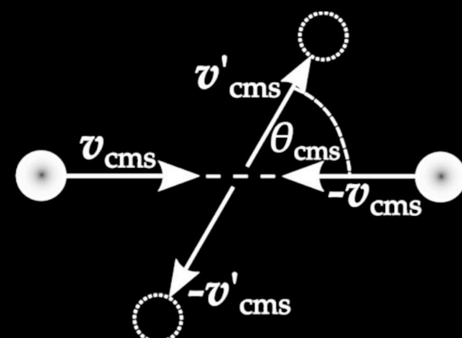
(e.g. mirror DM or atomic DM)

SCATTERING WITH A GENERAL DIFERENTIAL CROSS-SECTION

$$\Gamma = \frac{dn}{dt} = \int f(\mathbf{v_1}) \frac{\rho\,\sigma_\chi}{m_\chi} |\mathbf{v_0} - \mathbf{v_1}|\, d^3\mathbf{v_1}$$

$$P_{ij} = \frac{\sigma_p |\mathbf{v_i} - \mathbf{v_j}| \Delta t}{\frac{4\pi}{3} h^3}$$

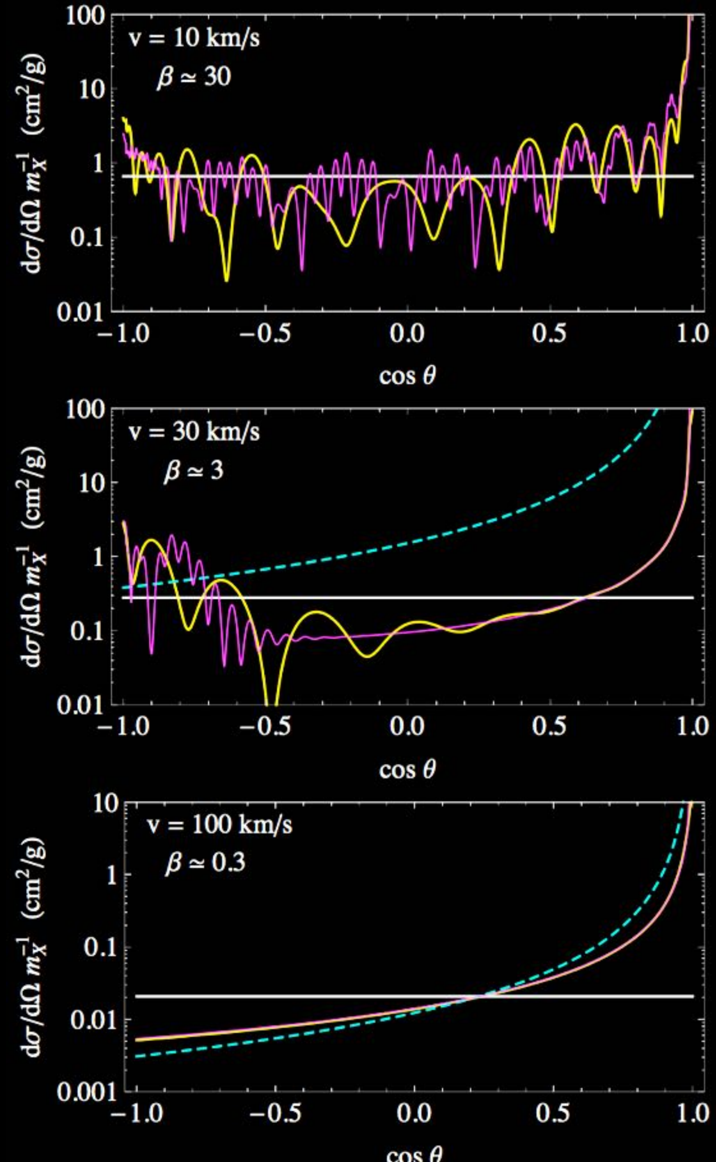




Kahlhoefer+ 2014

When two particles scatter, draw θ from the relevant probability distribution (which can change with relative velocity)

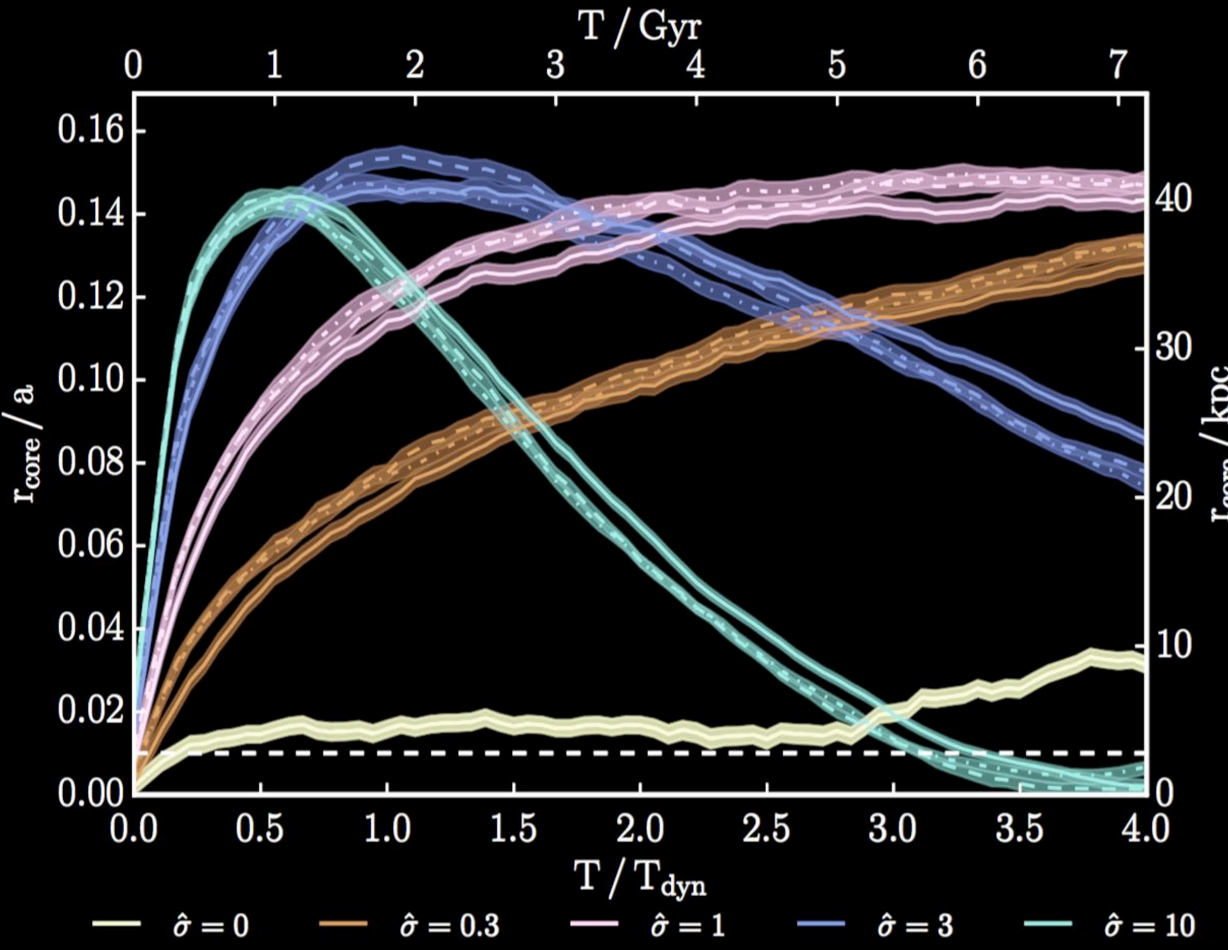
Tulin+ 2013



EFFECTS IN AN ISOLATED HALO

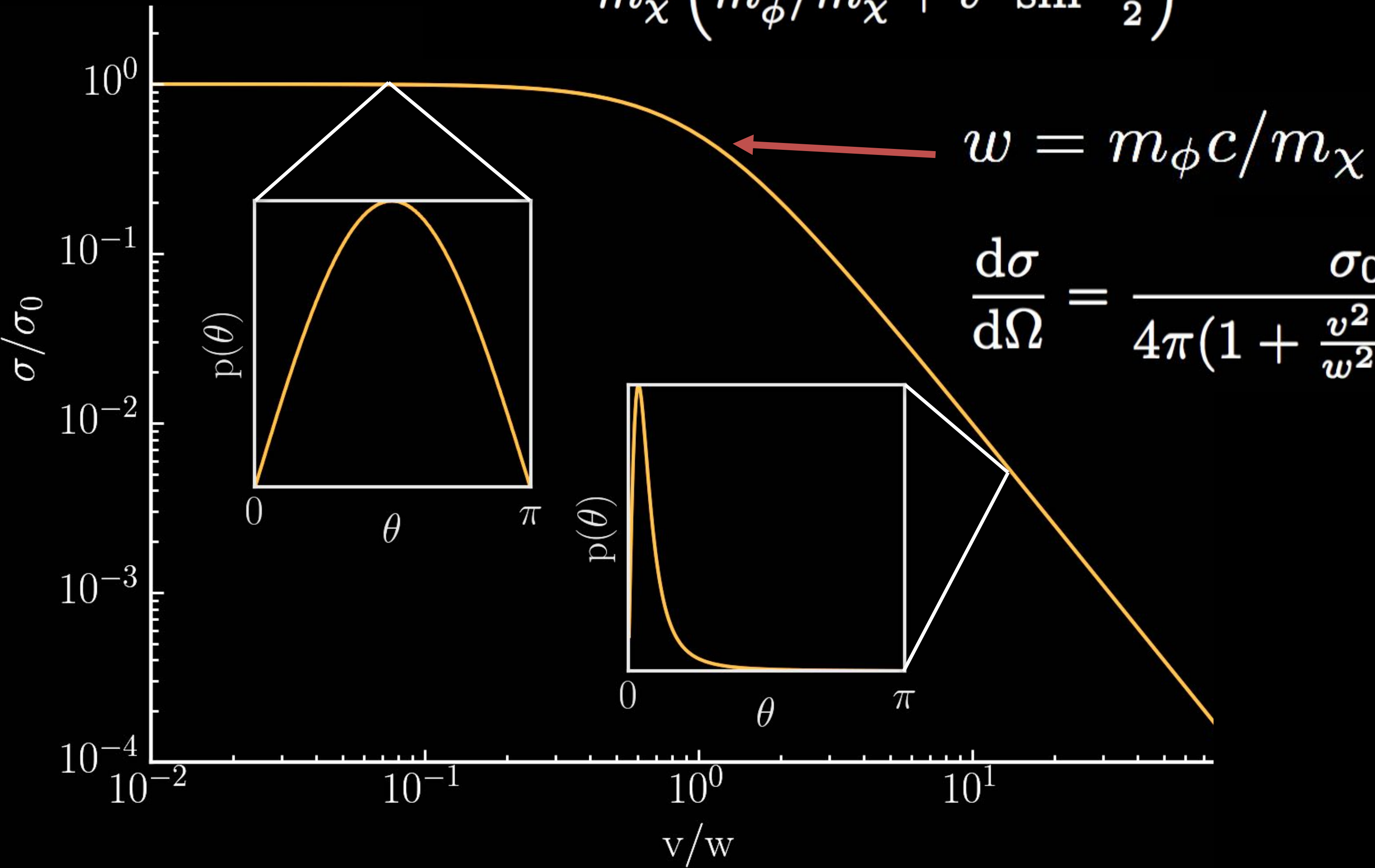
$\sigma_{\tilde{T}}$: The momentum transfer cross-section if we re-label particles that scatter by more than π/2

In an isolated halo (with isotropic velocities) $\sigma_{\tilde{T}}$ captures the evolution of the density profile



AS A FIRST TEST, SIMULATE YUKAWA SCATTERING WITH THE BORN-APPROXIMATION

$$\frac{d\sigma}{d\Omega} = \frac{\alpha_\chi^2}{m_\chi^2\left(m_\phi^2/m_\chi^2 + v^2\sin^2\frac{\theta}{2}\right)^2}$$

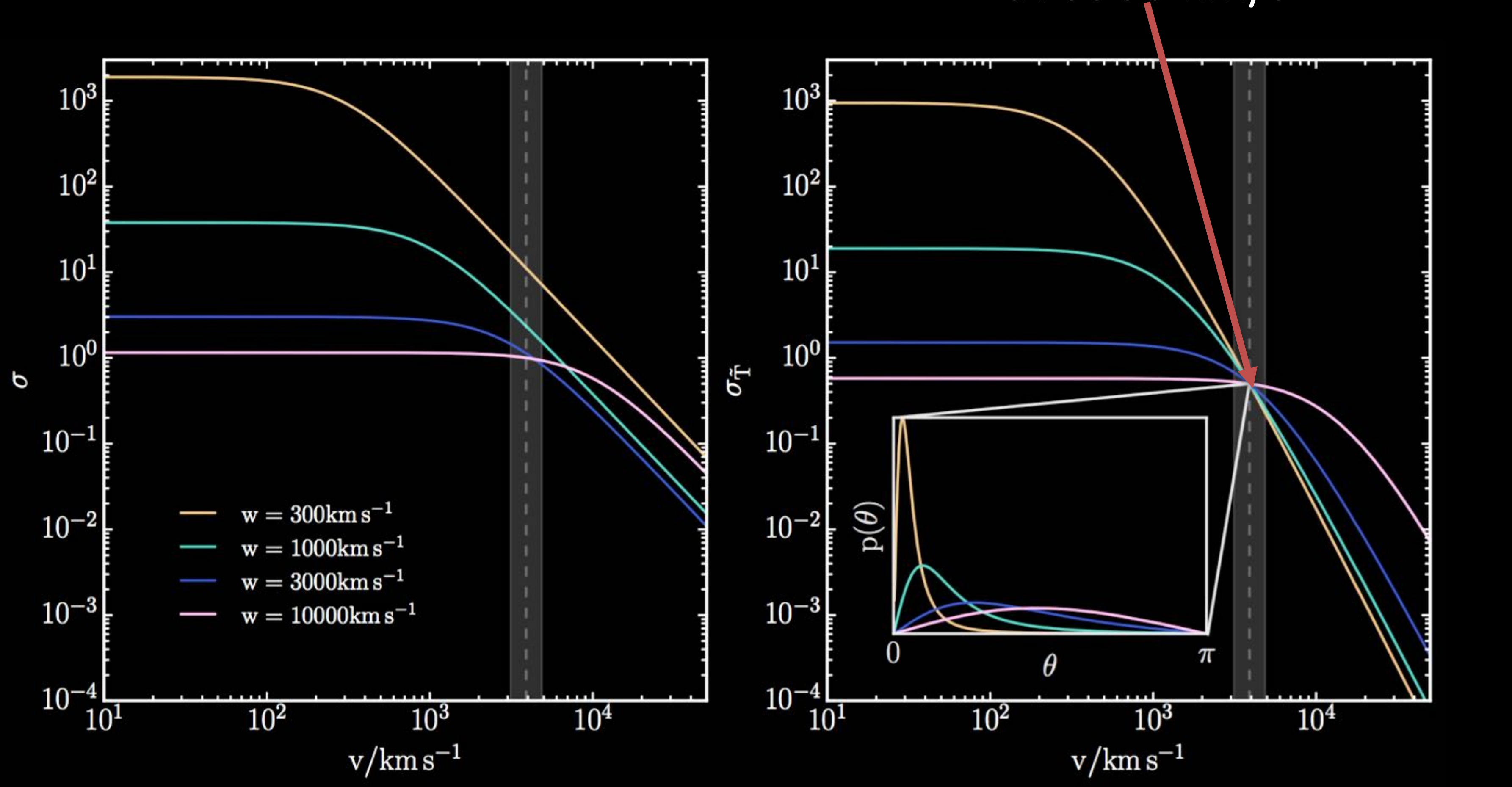


$$\frac{d\sigma}{d\Omega} = \frac{\sigma_0}{4\pi(1+\frac{v^2}{w^2}\sin^2\frac{\theta}{2})^2}$$

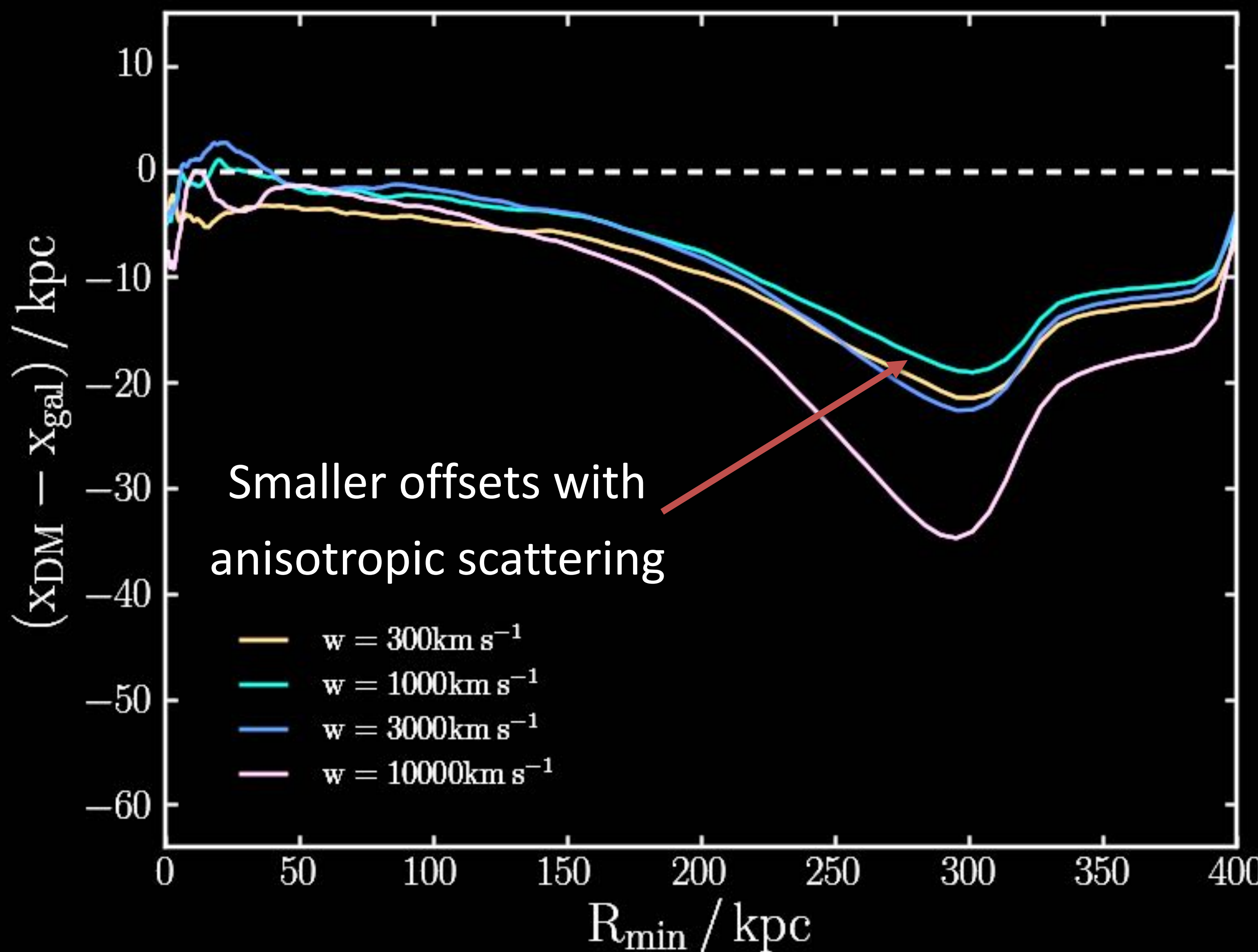
YUKAWA CROSS-SECTIONS FOR BULLET CLUSTER SIMULATIONS

Four different cross-sections, with different 'turn-over' velocities

Matched to have same $\boldsymbol{\sigma}_{\tilde{T}}$ at 3900 km/s

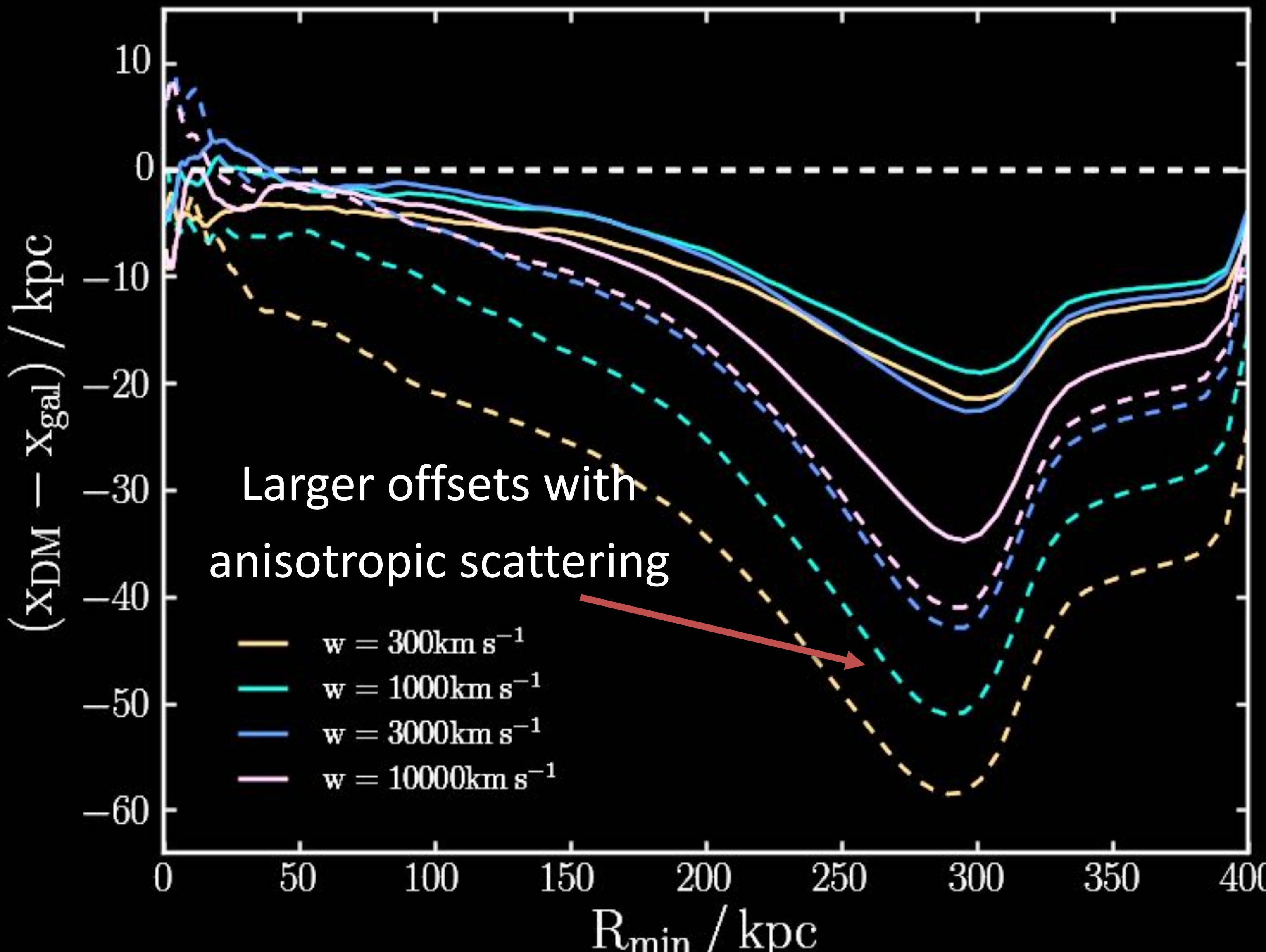


DM-GALAXY OFFSETS

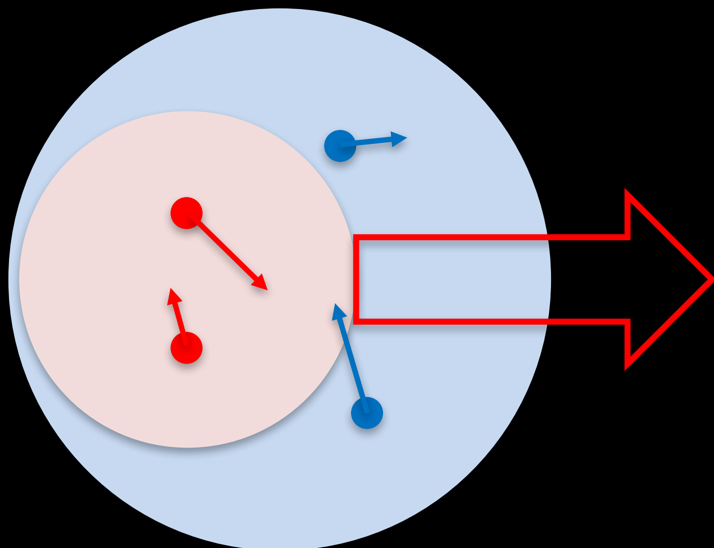


DM-GALAXY OFFSETS

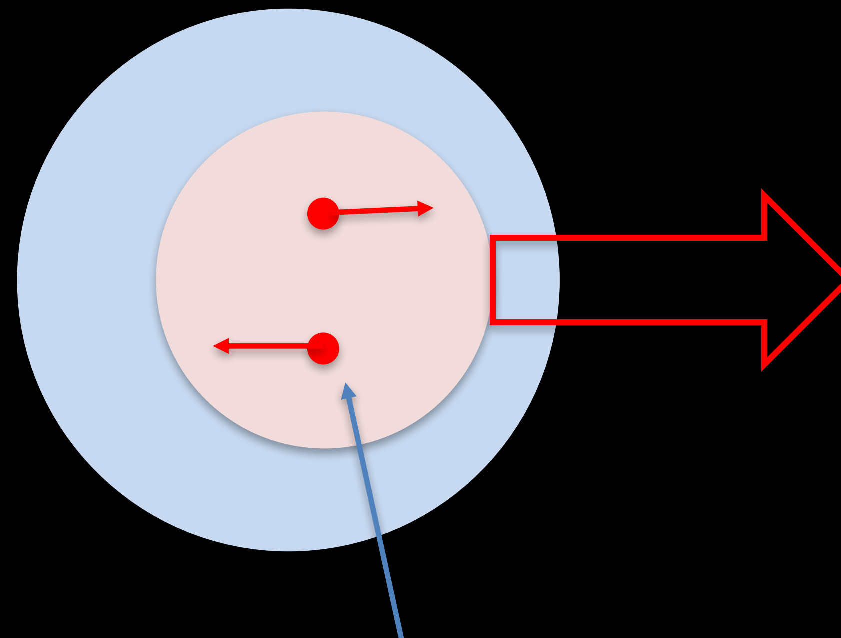
(WITH VELOCITY-DEPENDENCE 'TURNED OFF')



WHY VELOCITY DEPENDENCE REDUCES OFFSETS



The motion of particles within their halos has a component transverse to the collision axis, which increases the average pairwise velocity of particles above the collision velocity of the two haloes



Particles moving ‘backwards’ with respect to their halo’s direction of motion have a lower relative velocity with respect to the main halo – more likely to scatter

SUMMARY

- Colliding galaxy clusters are an interesting place to look for non-gravitational DM interactions
- It is important to consider how your simulation analysis compares to what is done observationally
- Current constraints on SIDM cross-sections from offsets in merging clusters may be over-stated
- For the simplest well-motivated velocity-dependent SIDM, expect only small offsets in merging galaxy clusters

THANKS FOR LISTENING