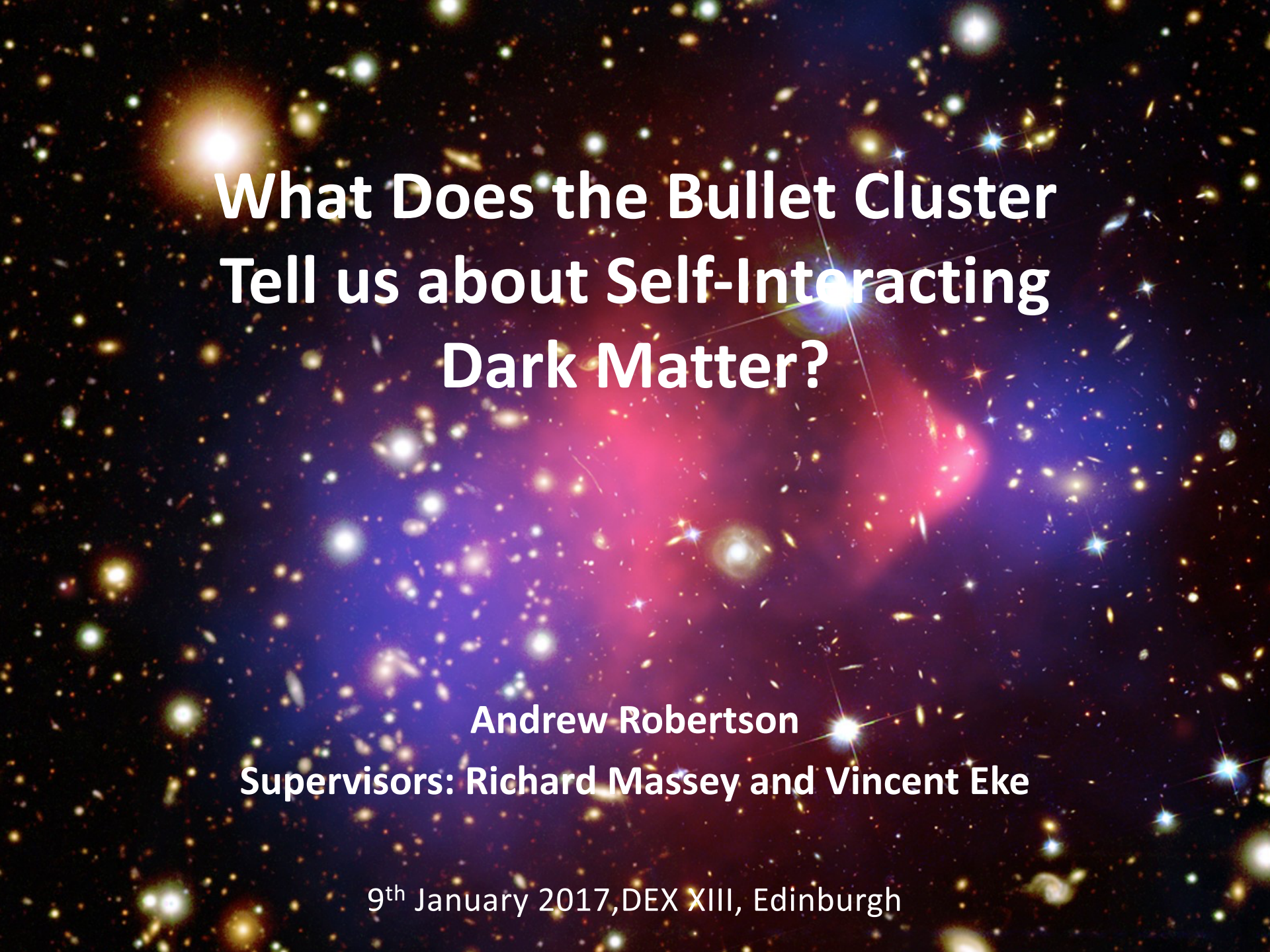
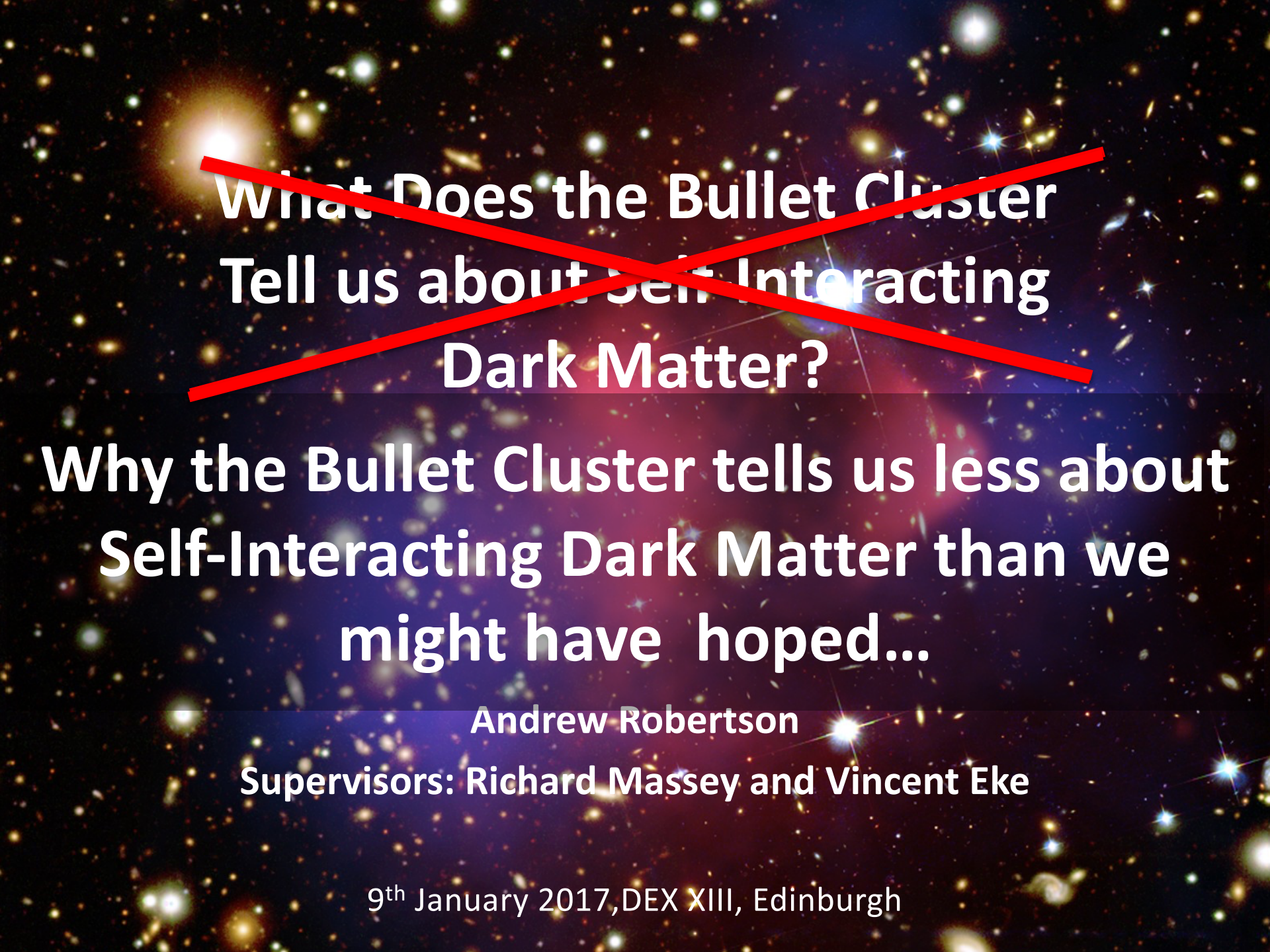


What Does the Bullet Cluster Tell us about Self-Interacting Dark Matter?

Andrew Robertson

Supervisors: Richard Massey and Vincent Eke

9th January 2017, DEX XIII, Edinburgh


What Does the Bullet Cluster
Tell us about Self-Interacting
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Why the Bullet Cluster tells us less about Self-Interacting Dark Matter than we might have hoped…
Andrew Robertson
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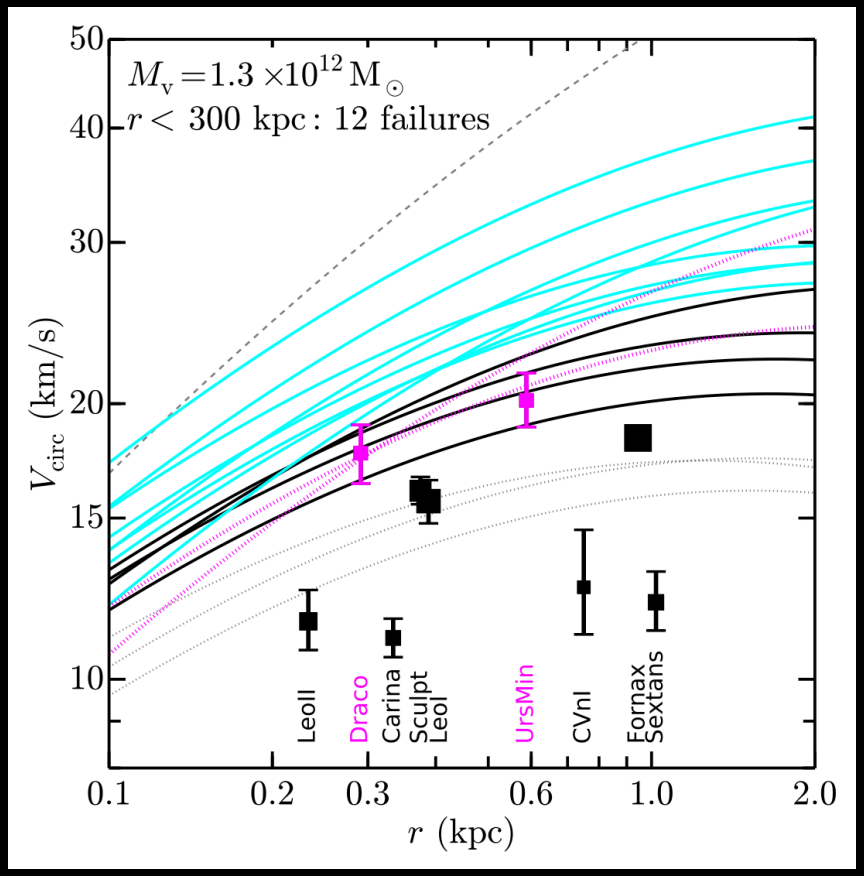
9th January 2017, DEX XIII, Edinburgh

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

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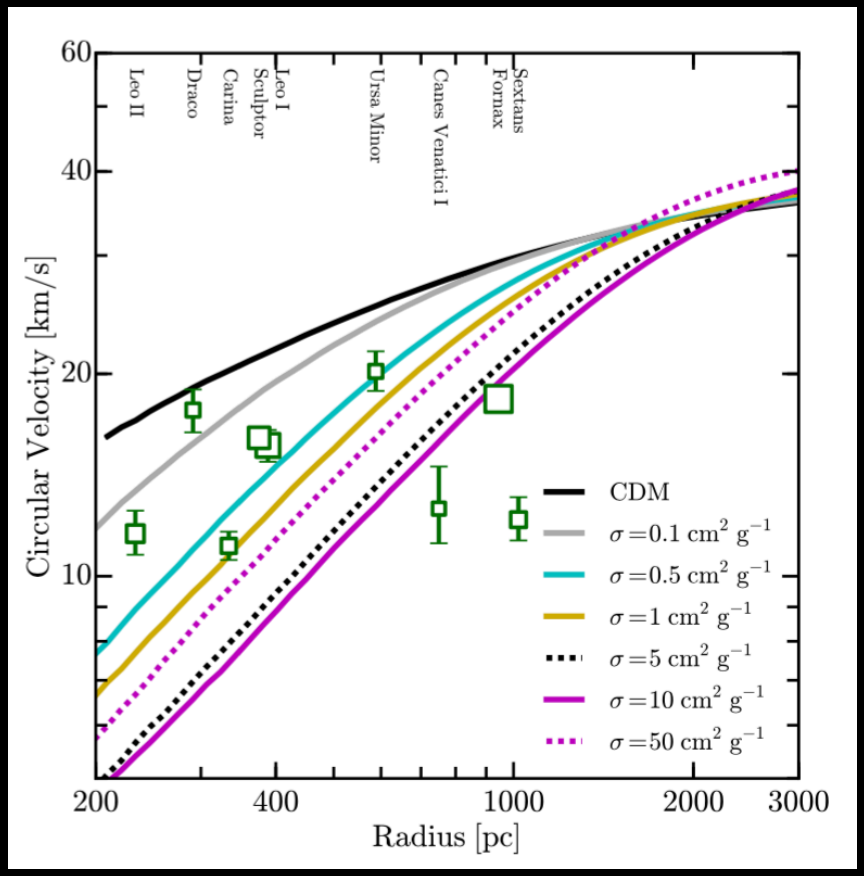

Elbert+ 2016

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WHY STUDY SELF-INTERACTING DARK MATTER?

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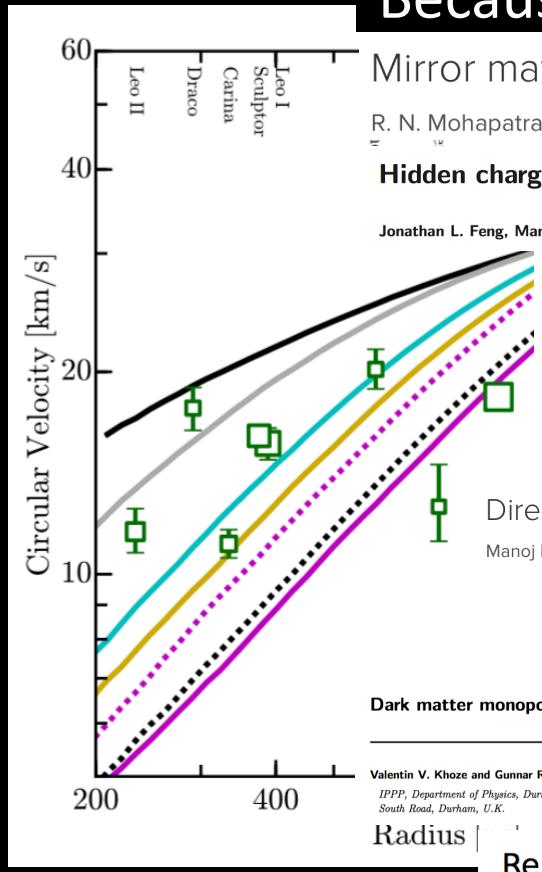
Because particle physicists are interested!



Mirror matter as self-interacting dark matter

R. N. Mohapatra, S. Nussinov, and V. L. Teplitz

Hidden charged dark matter

Jonathan L. Feng, Manoj Kaplinghat, Huitzu Tu and Hai-Bo Yu

Q-Ball Candidates for Self-Interacting Dark Matter

Alexander Kusenko[1,2] and Paul J. Steinhardt[3]

A Parallel World in the Dark

Tetsutaro Higaki[a,*], Kwang Sik Jeong[b,*], Fuminobu Takahashi[b,†]

Higgs-portal Scalar Dark Matter: Scattering Cross Section and Observable Limits

Huayong Han and Sibo Zheng

Department of Physics, Chongqing University, Chongqing 401331, P. R. China

– Sawala+ 2014

Direct detection portals for self-interacting dark matter

Manoj Kaplinghat, Sean Tulin, and Hai-Bo Yu

Composite strongly interacting dark matter

James M. Cline,[1] Zuowei Liu,[1] and Guy D. Moore[1]

[1]*Department of Physics, McGill University, 3600 Rue University, Montréal, Québec, Canada H3A 2T8*

Dark matter monopoles, vectors and photons

Valentin V. Khoze and Gunnar Ro

IPPP, Department of Physics, Durham University, South Road, Durham, U.K.

Self-Interacting Dark Matter with Flavor Mixing

Mikhail V. Medvedev

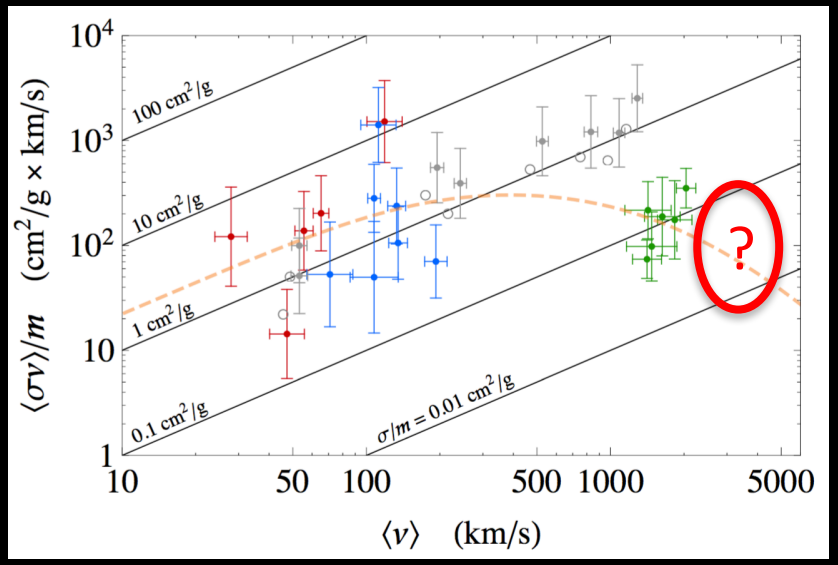
Resonant Dark Forces and Small-Scale Structure

Sean Tulin, Hai-Bo Yu, and Kathryn M. Zurek

Elbert+ 2

WHY LOOK AT MERGING GALAXY CLUSTERS?

Higher DM-DM velocities than in isolated galaxy clusters



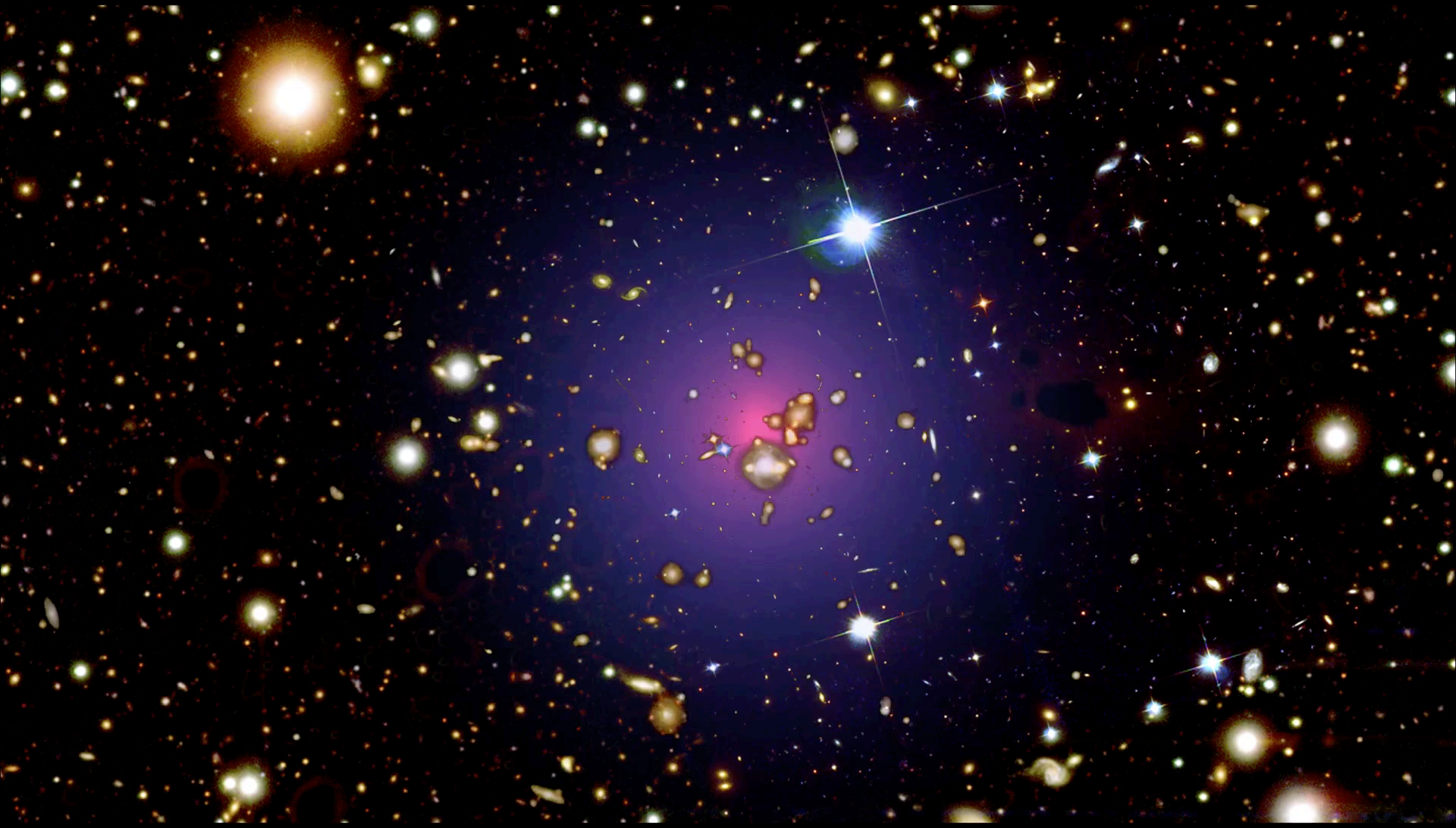
Kaplinghat+ 2016

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

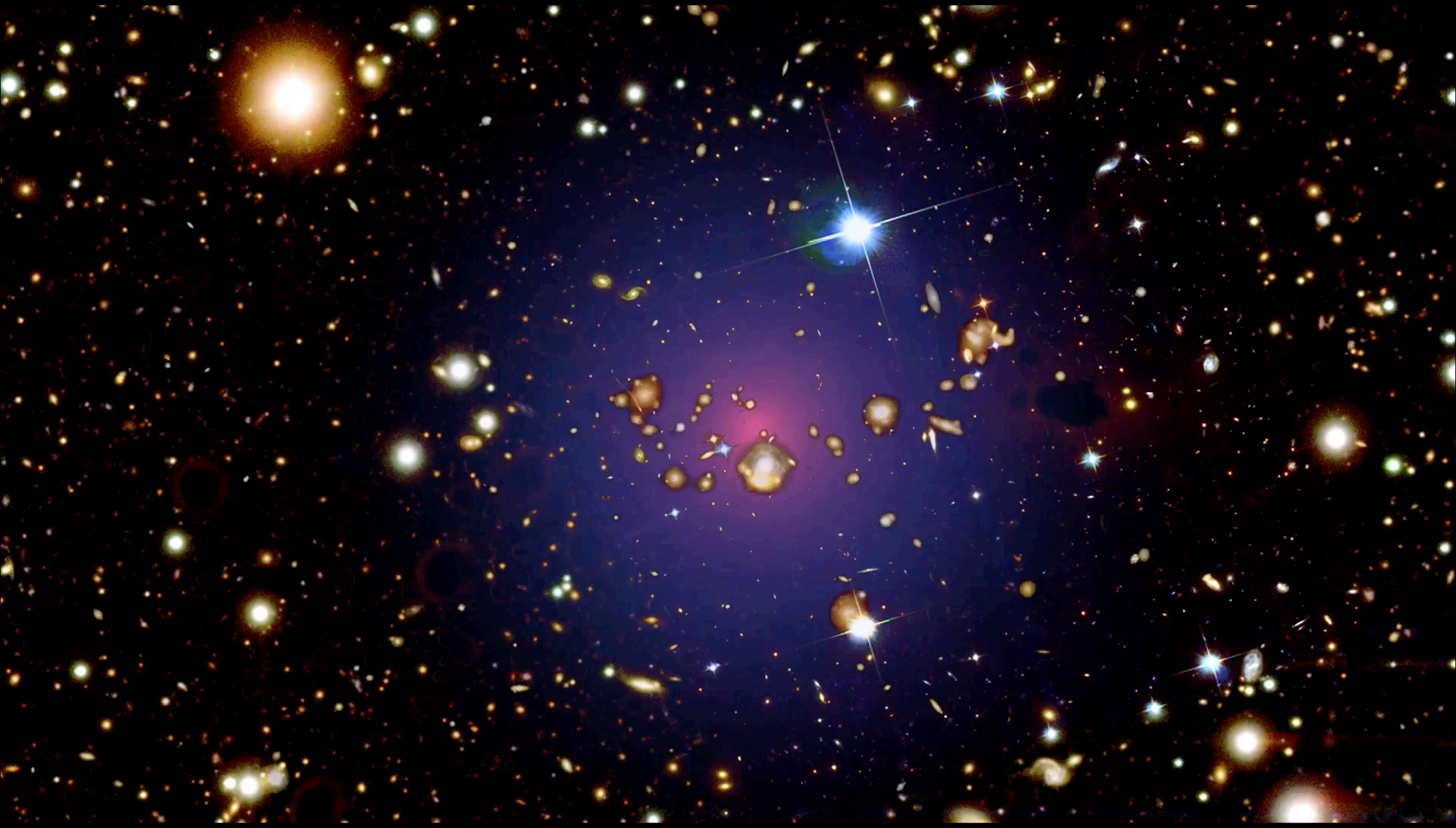
Particle Collider for Dark Matter!

Dark Matter separated from main baryonic component

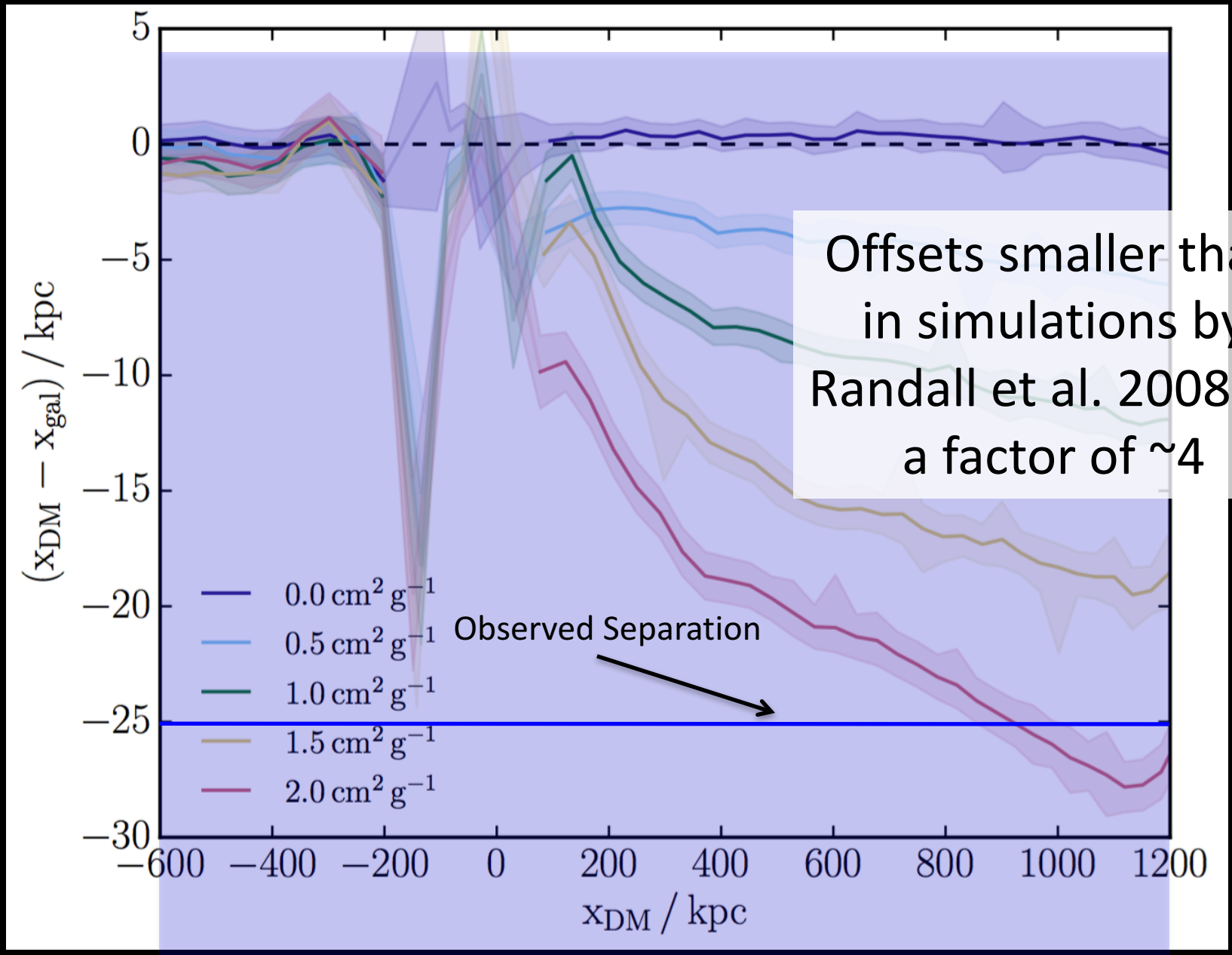
SMASHING CLUSTERS TOGETHER



INCLUDING SIDM WITH A LARGE CROSS-SECTION



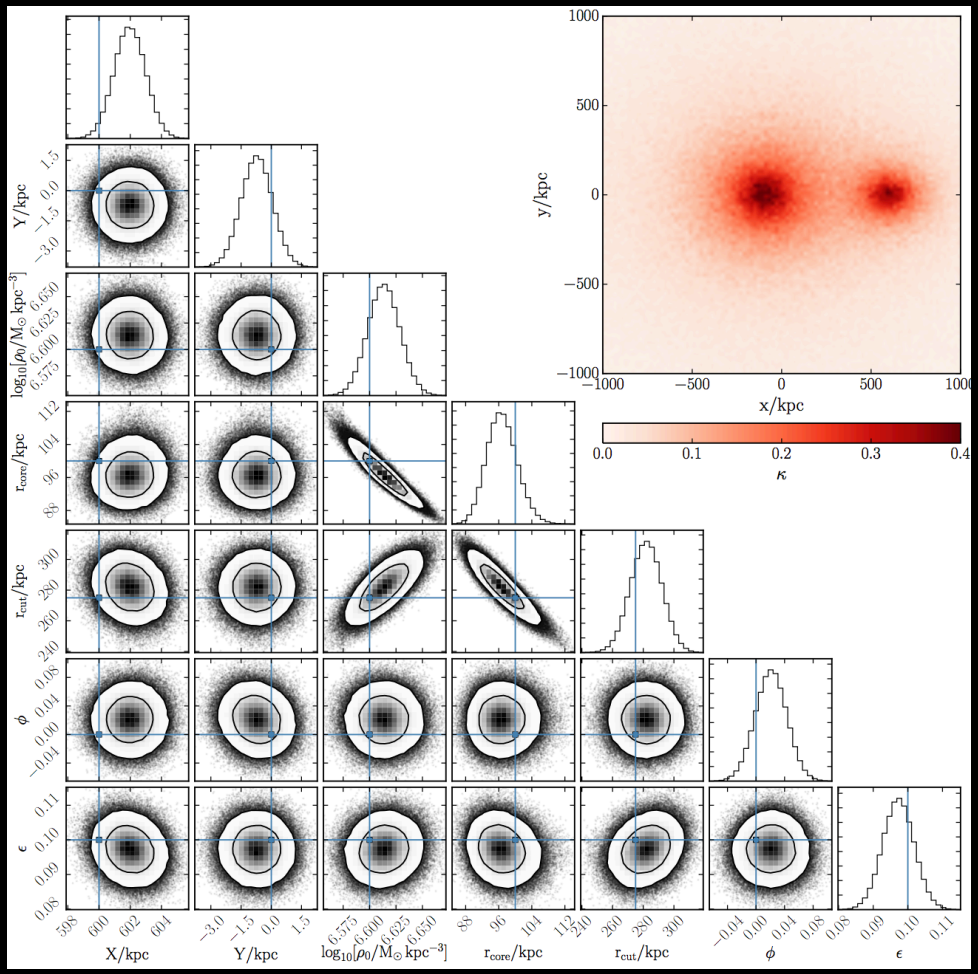
DM–GALAXY OFFSETS



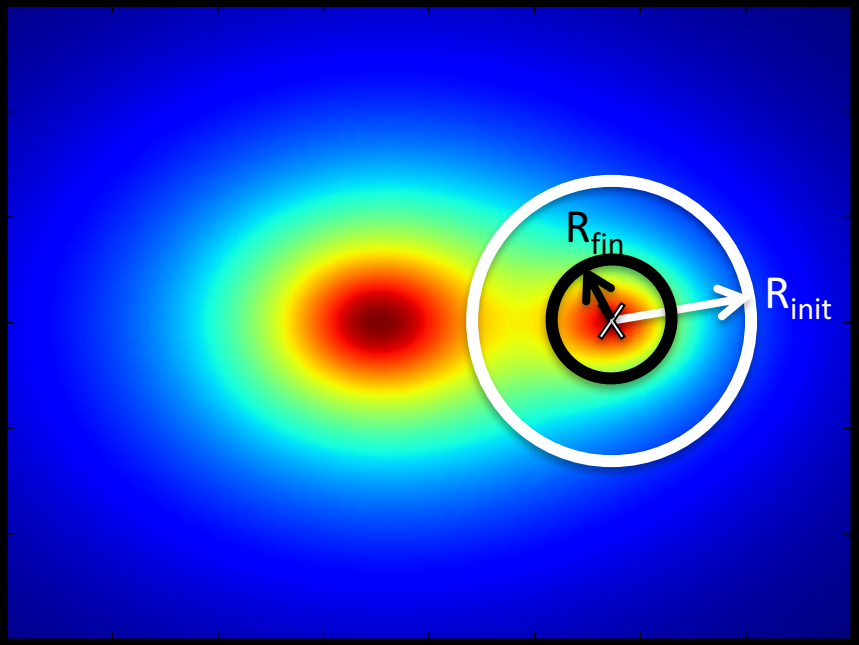
Offsets smaller than in simulations by Randall et al. 2008 by a factor of ~4

MEASURING HALO POSITIONS

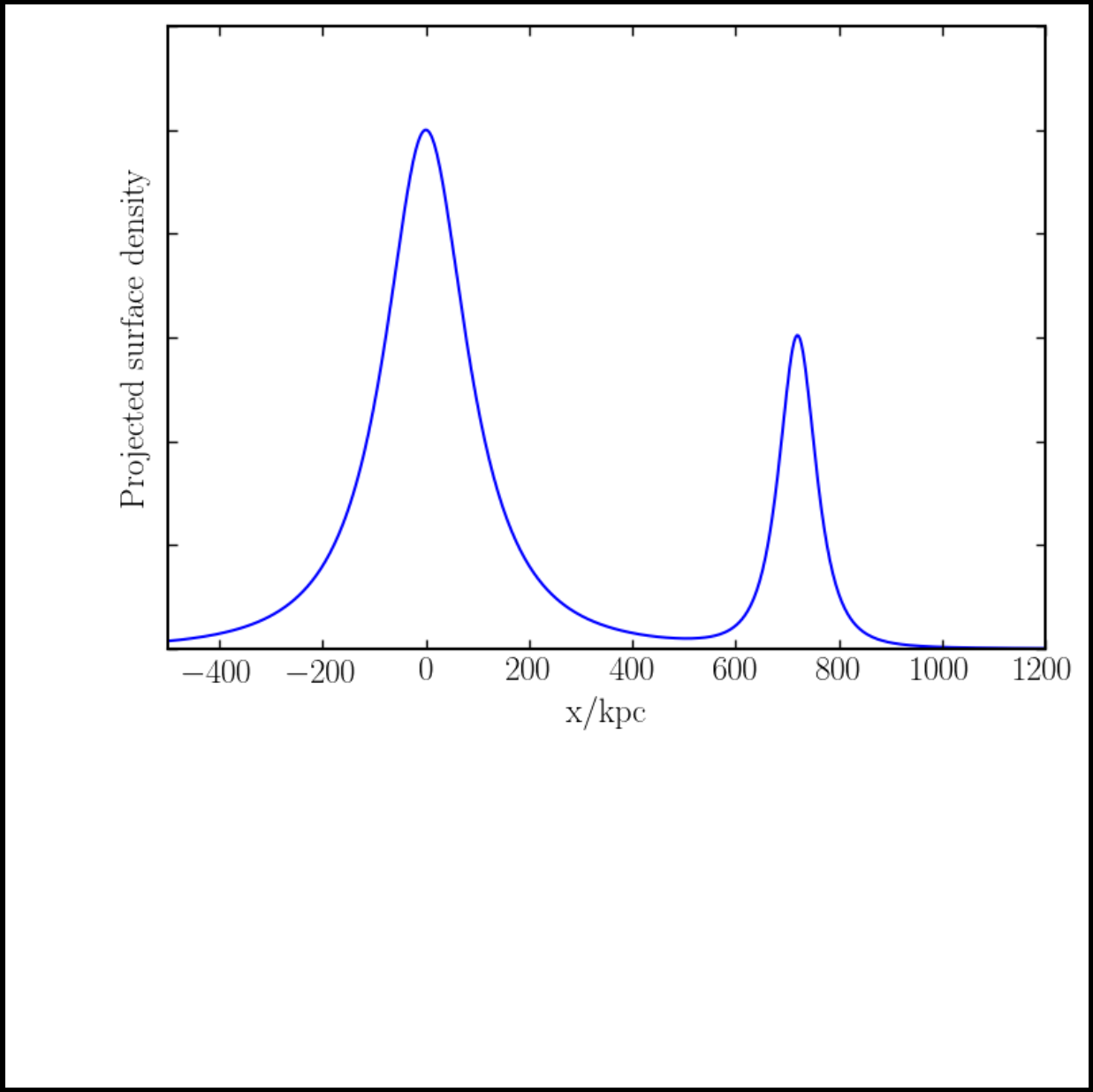
Parametric Model Fitting (what I did)



Shrinking Circles (what Randall did)



TOY MODEL OF SHRINKING CIRCLES



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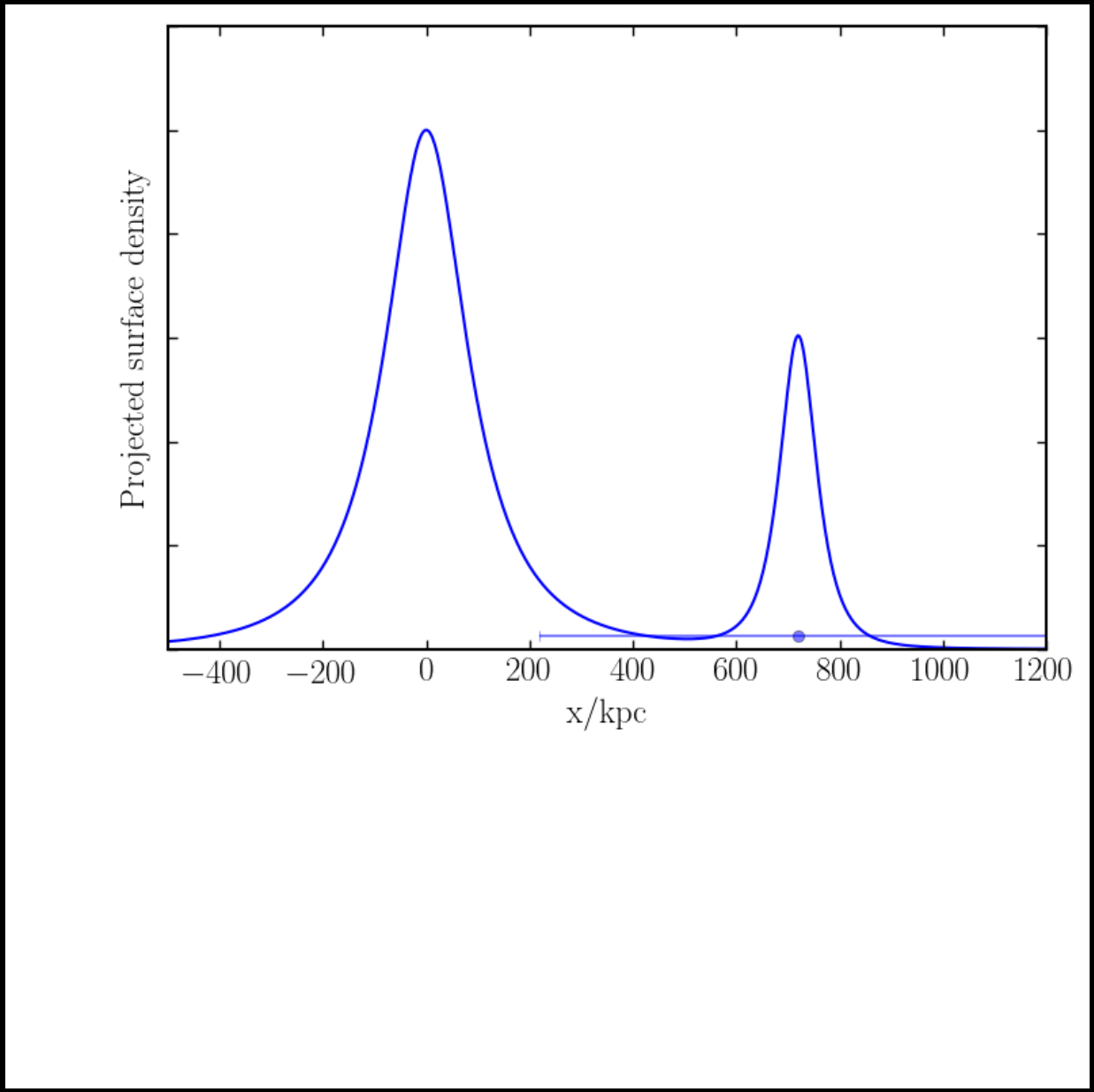

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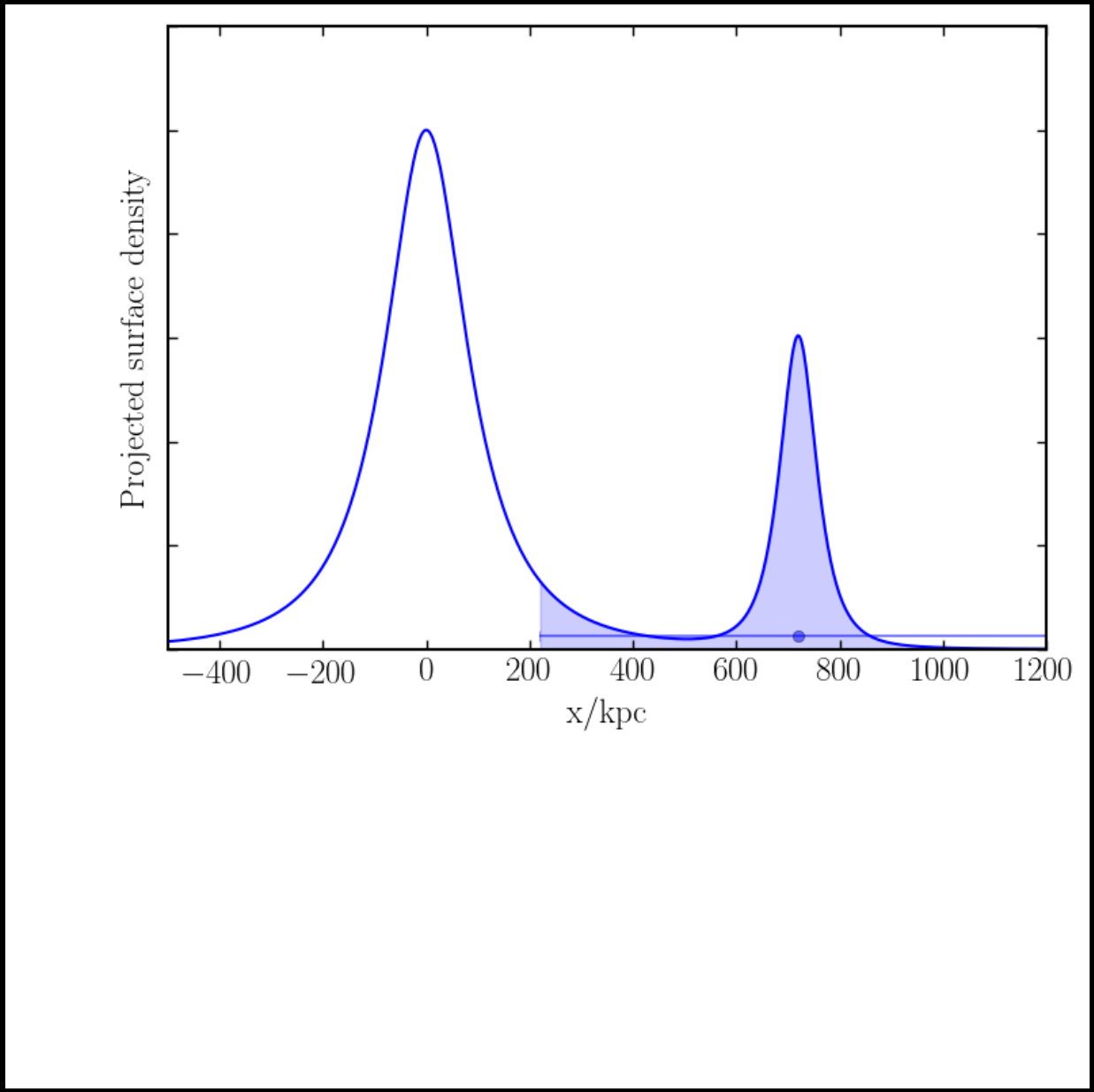

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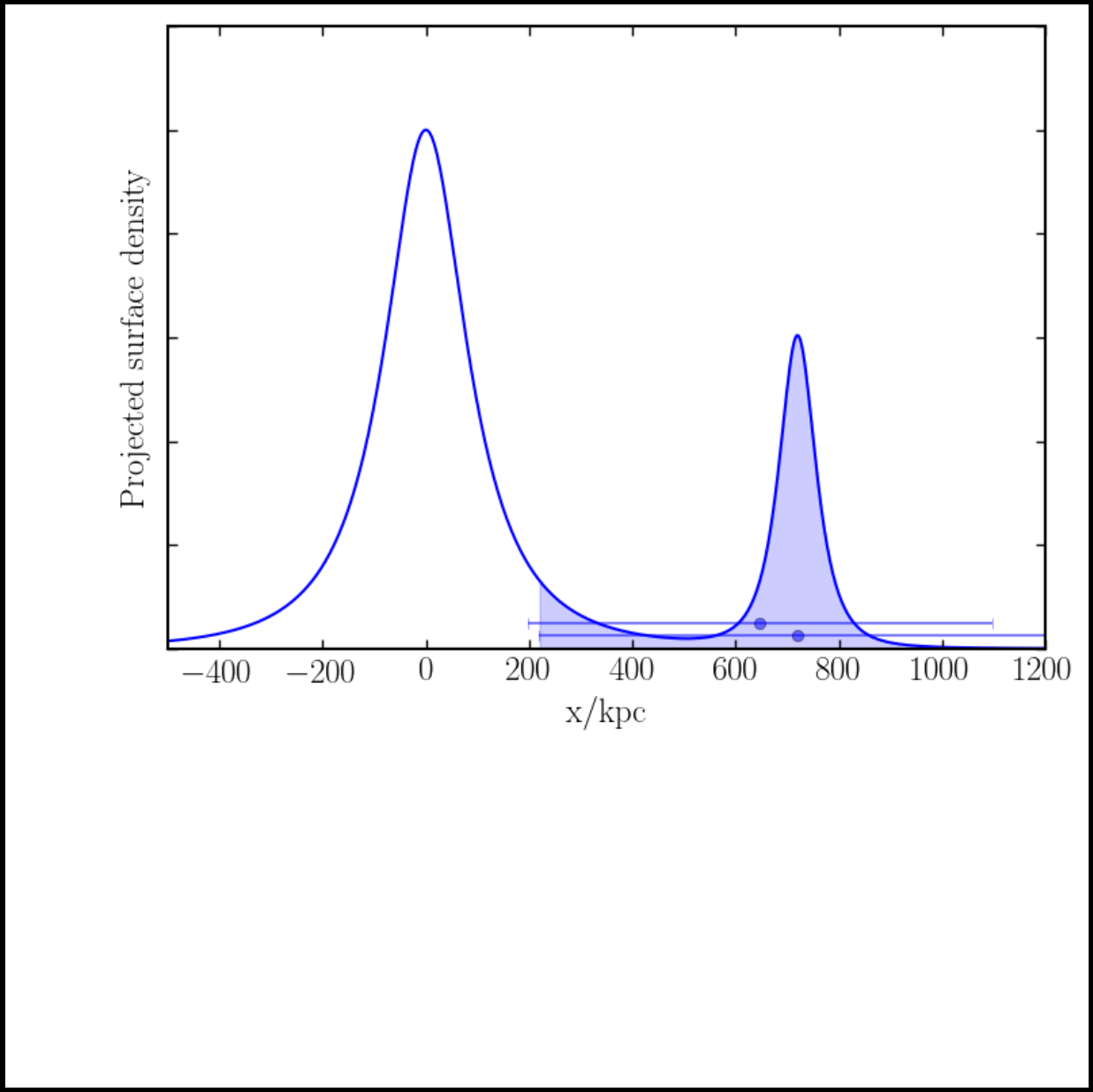

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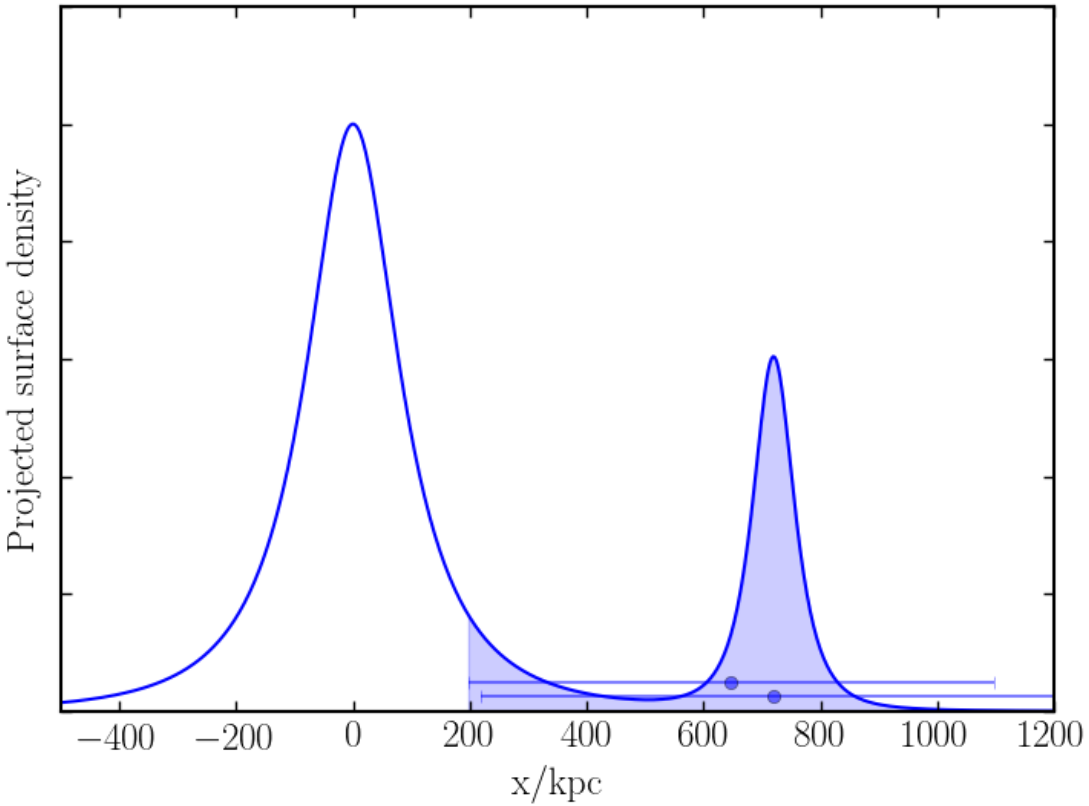

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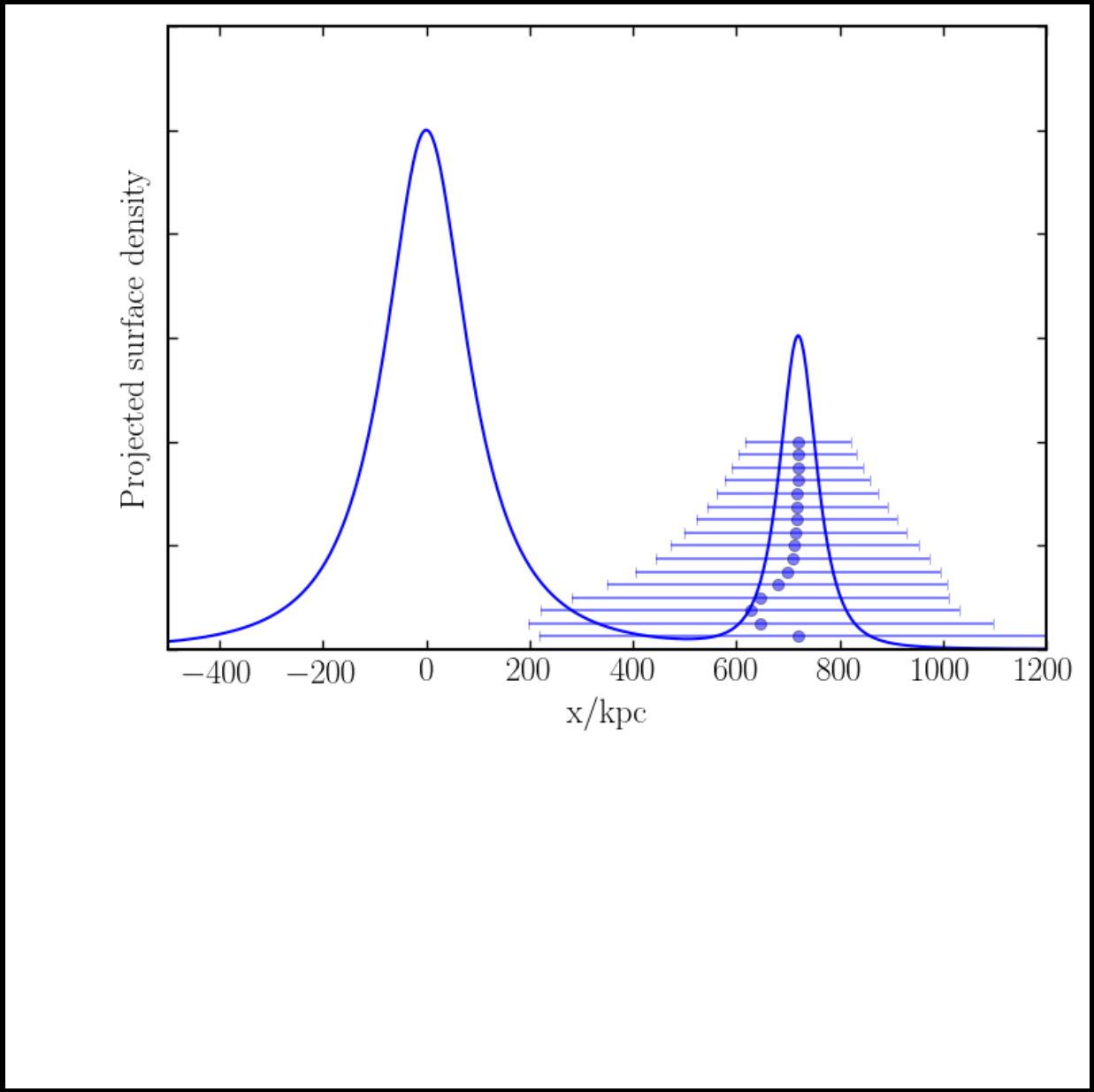

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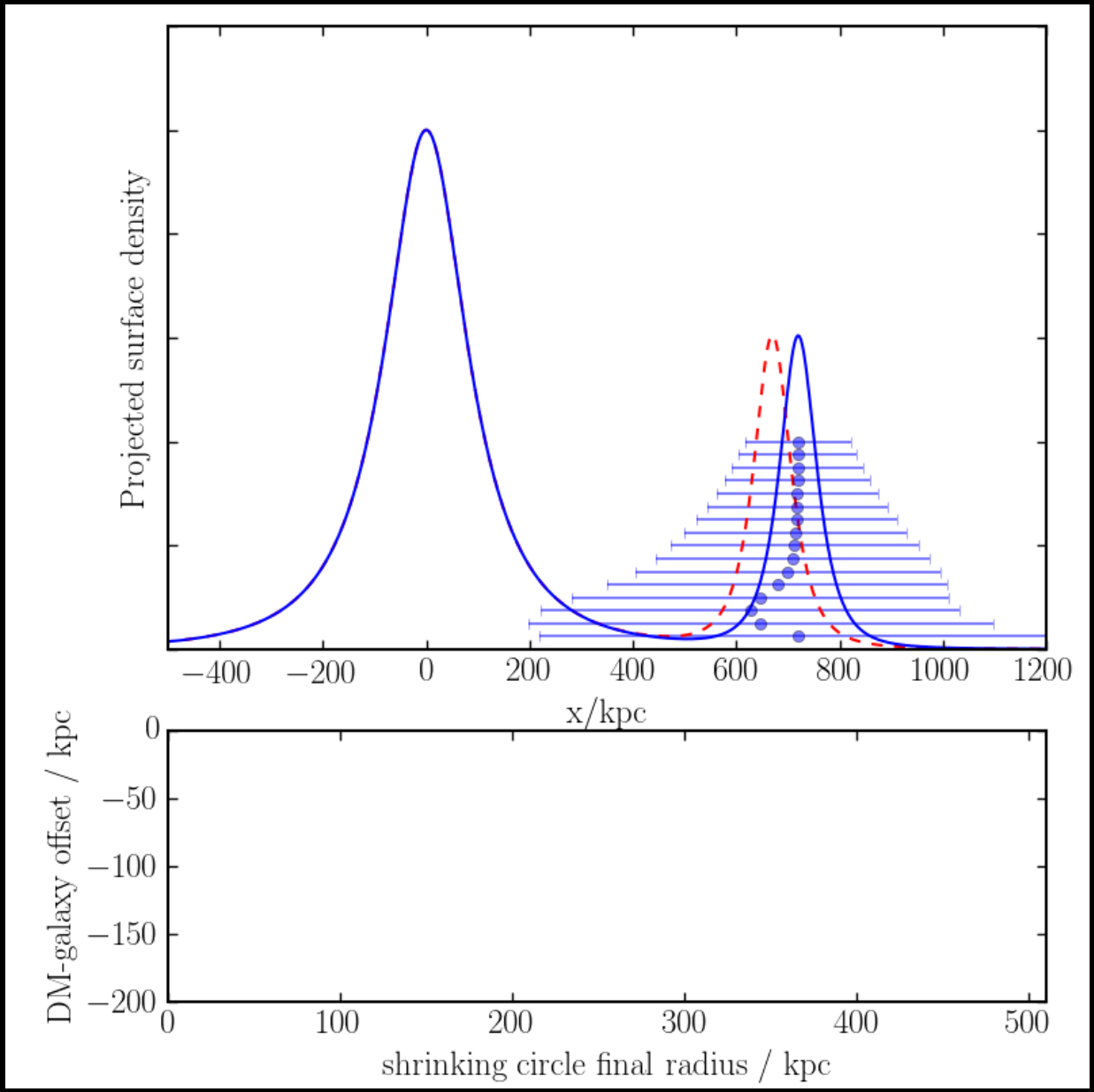

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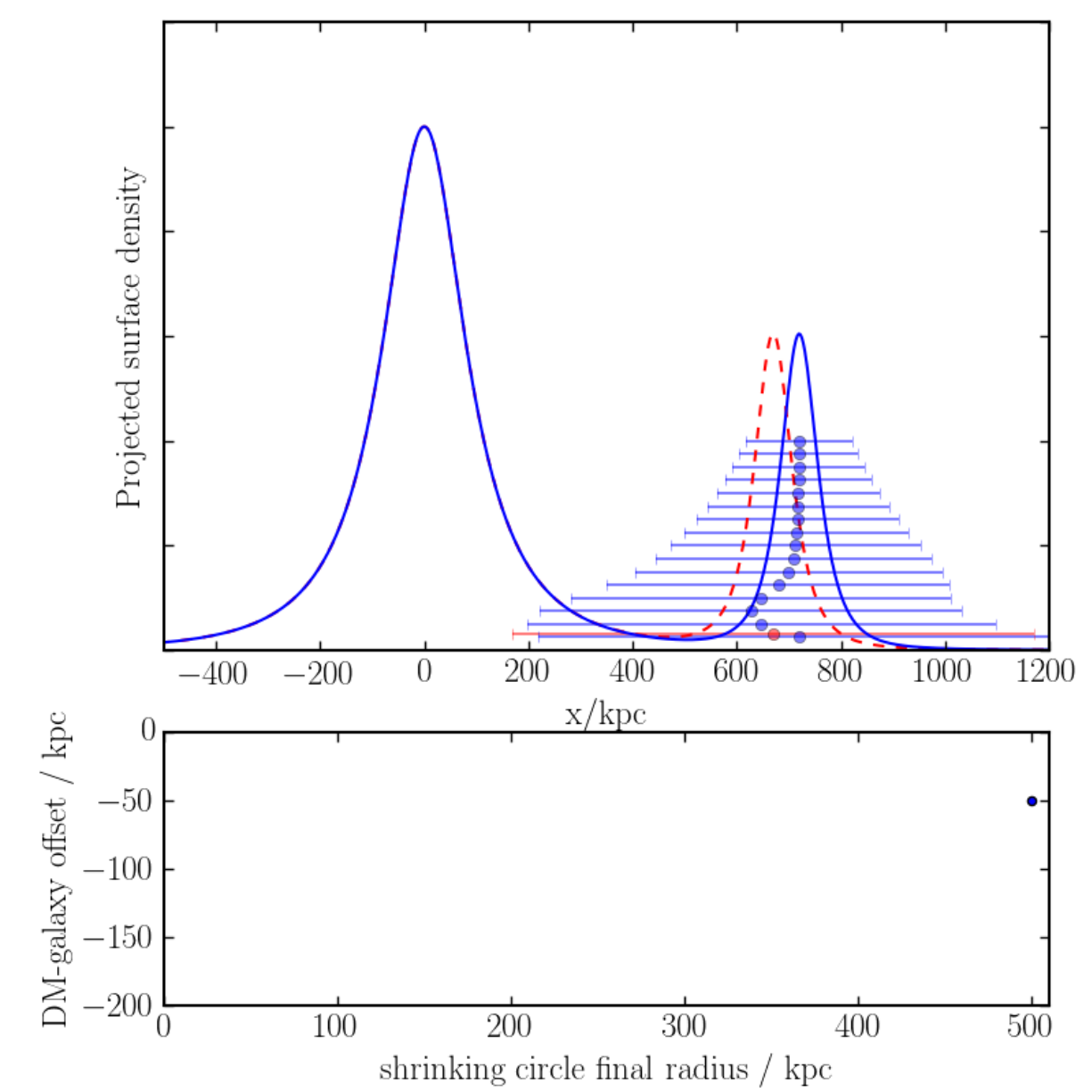

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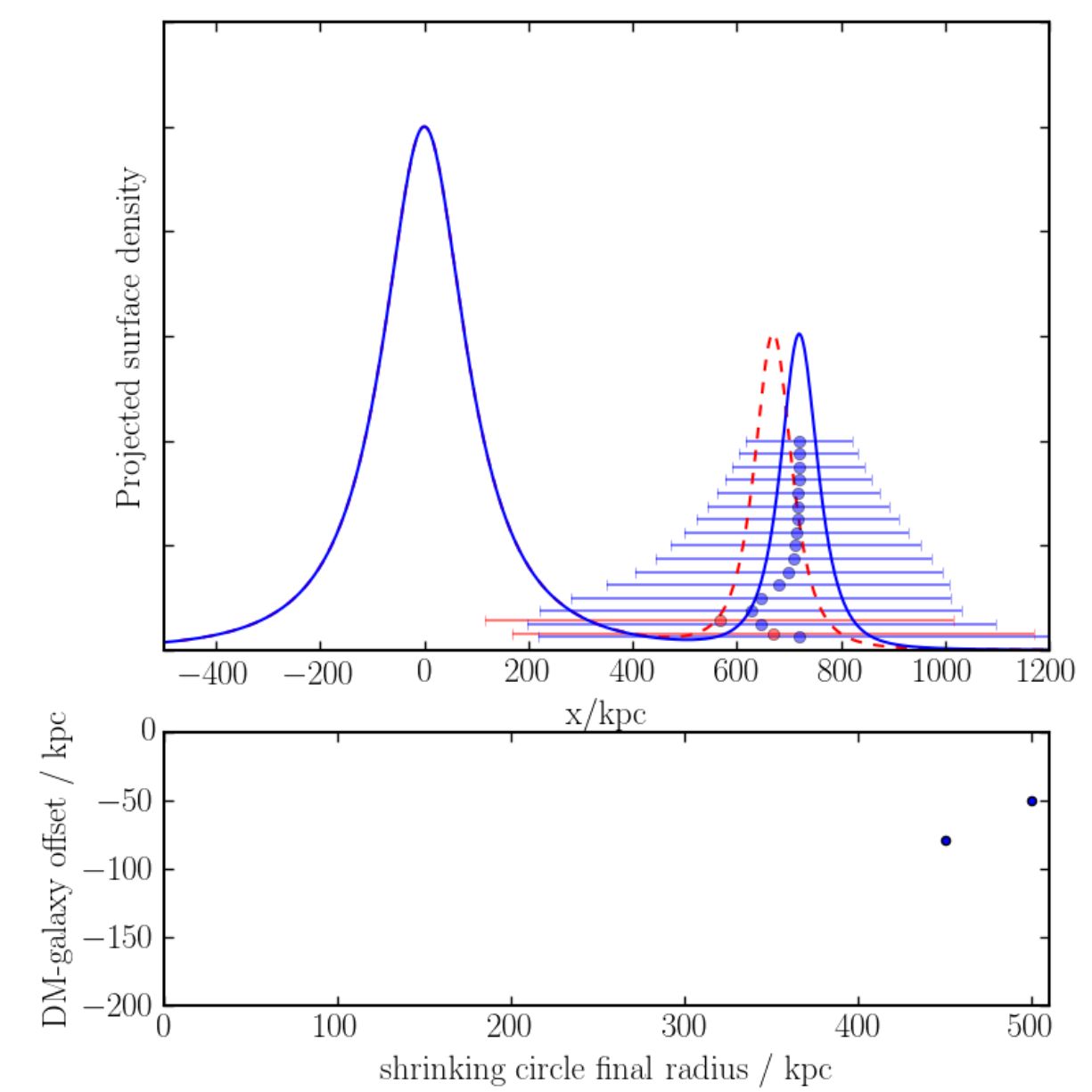

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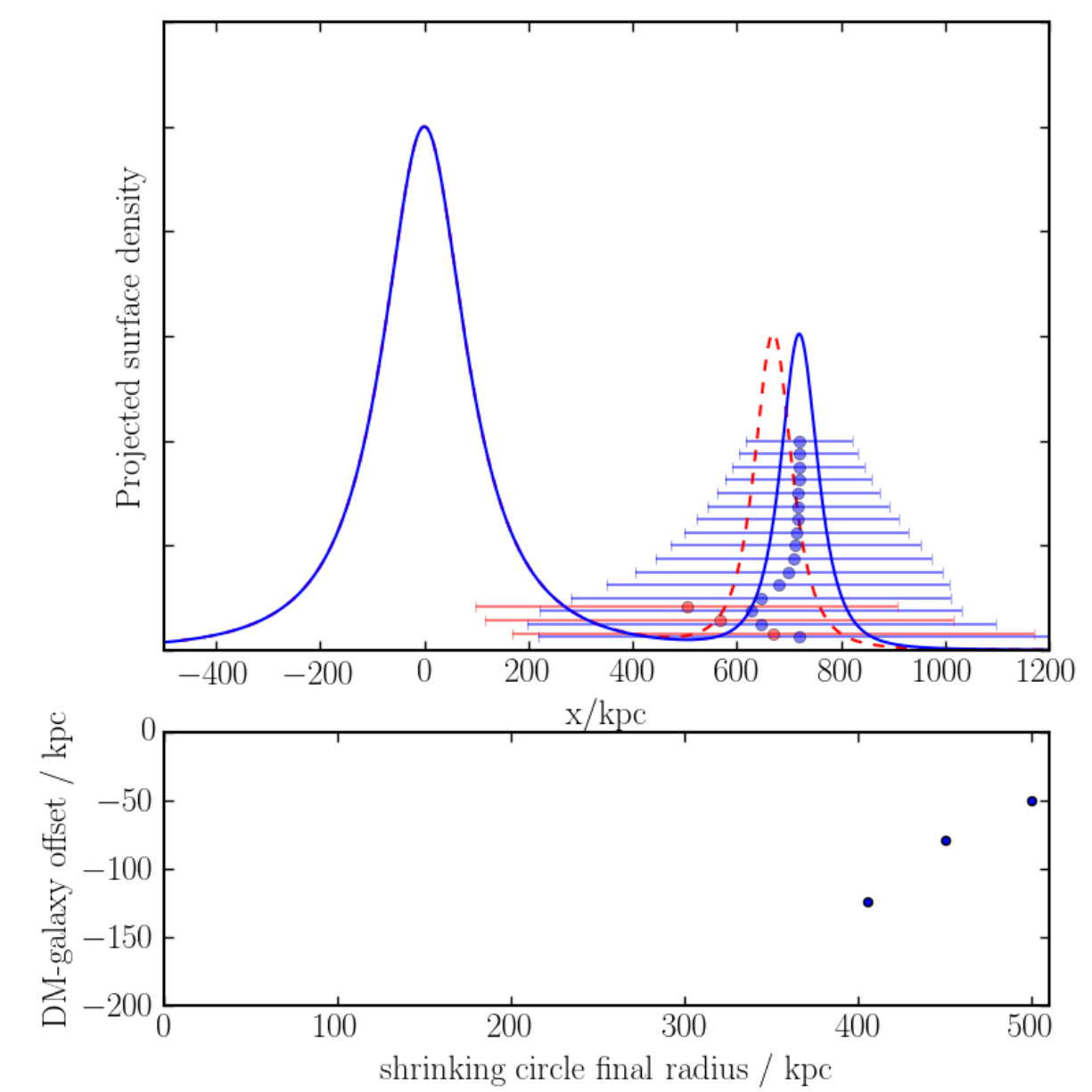

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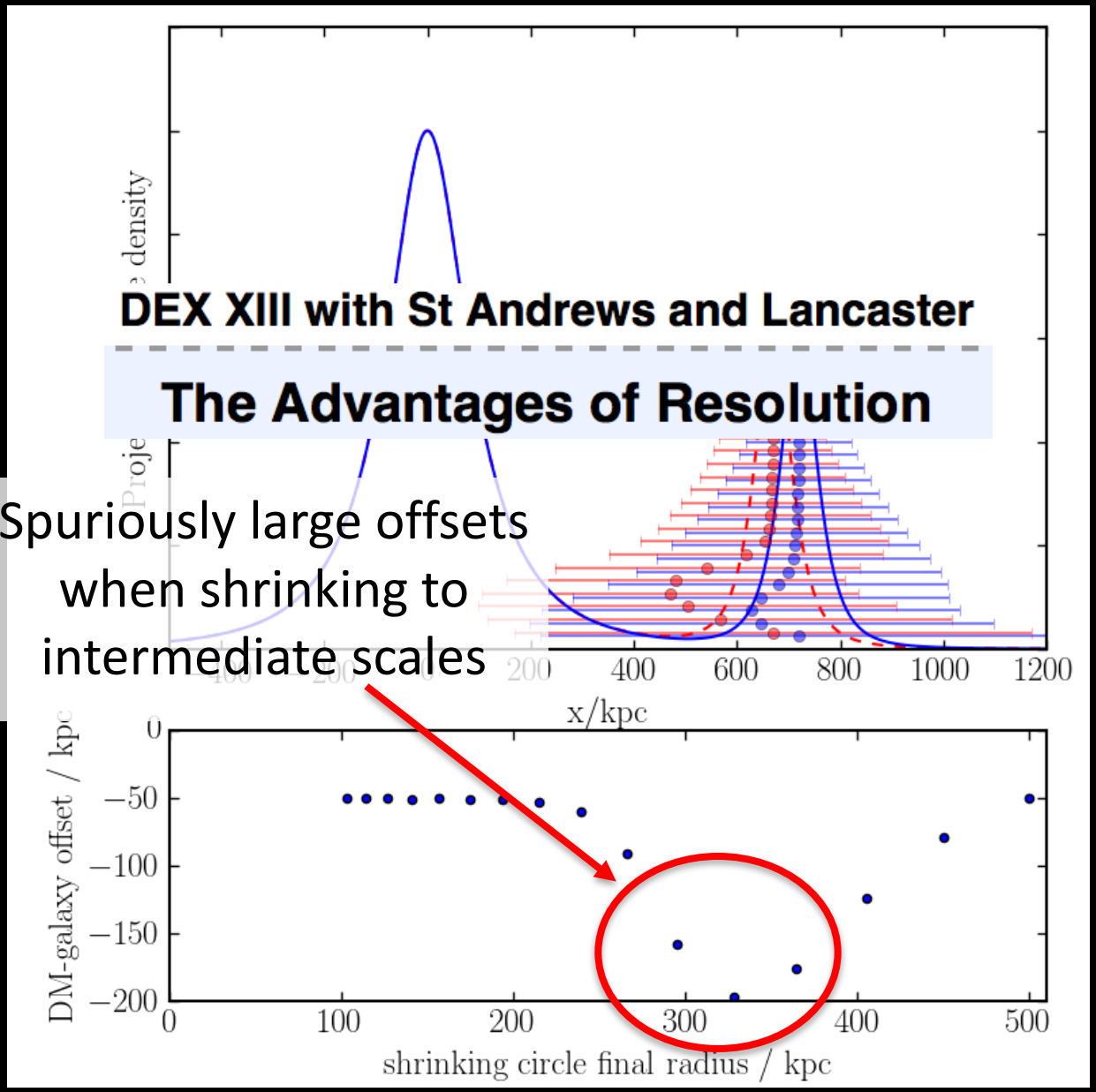
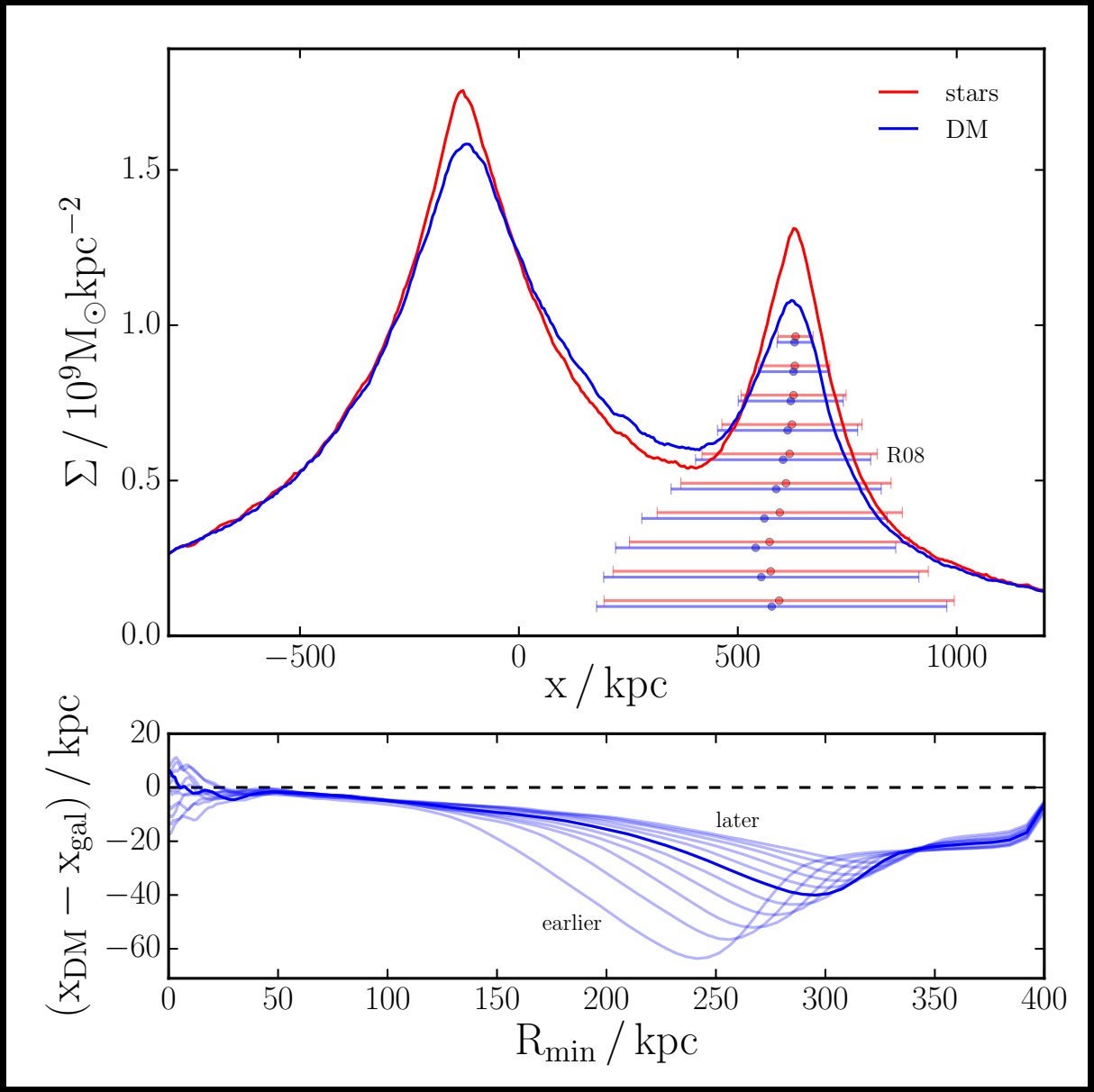


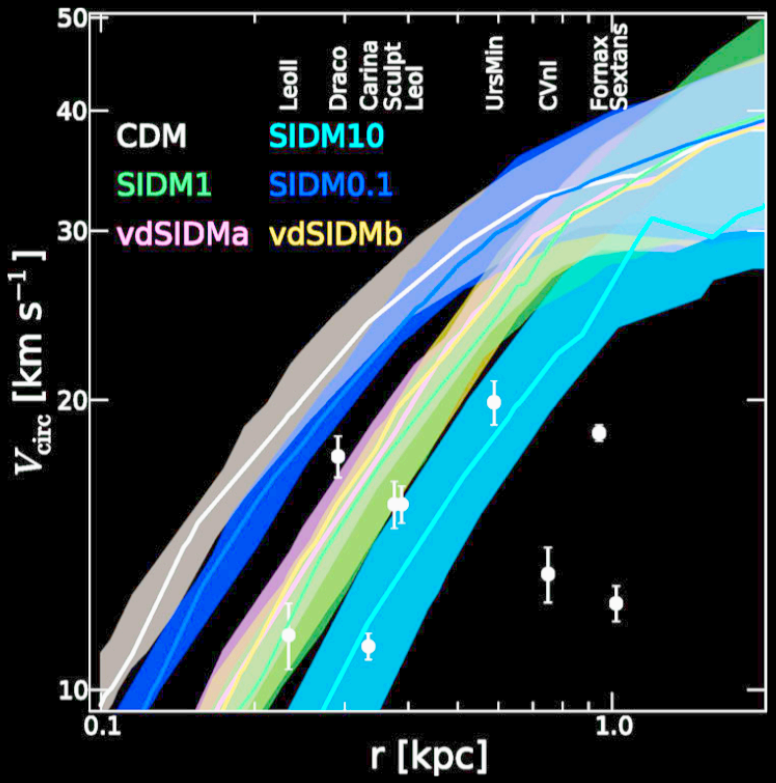
MEASURING HALO POSITIONS

SHRINKING CIRCLES



VELOCITY DEPENDENT SIDM

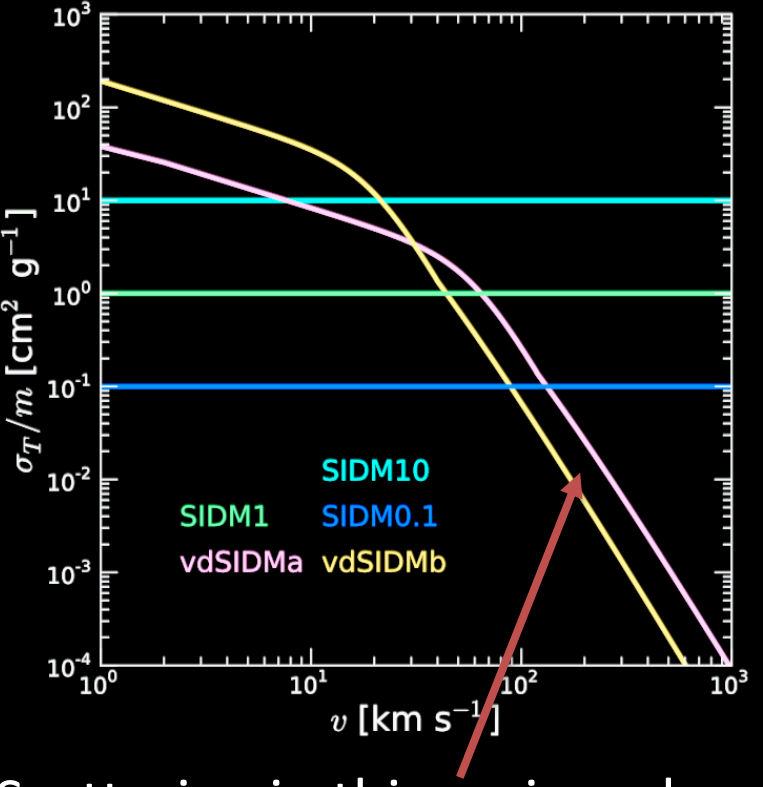
Can have large cross-sections in dwarf galaxies while evading constraints from galaxy clusters



Zavala+ 2013

A natural outcome of some SIDM candidate models

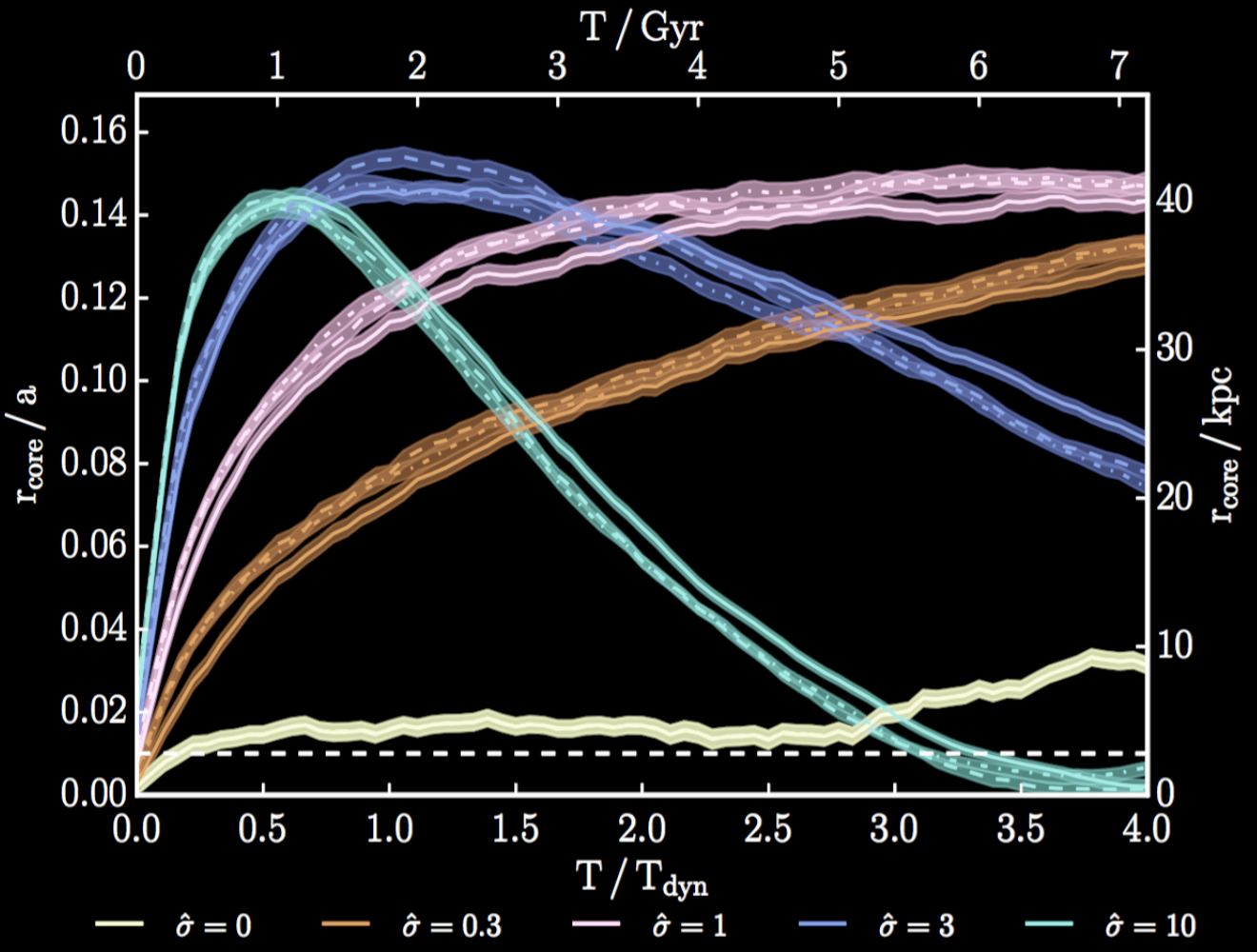
(e.g. mirror DM or atomic DM)



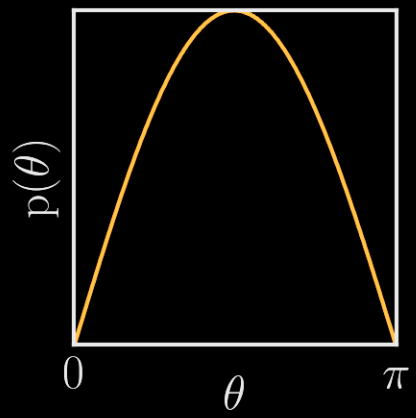
Scattering in this regime should be angularly-dependent

CORE GROWTH IN ISOLATED HALOES

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

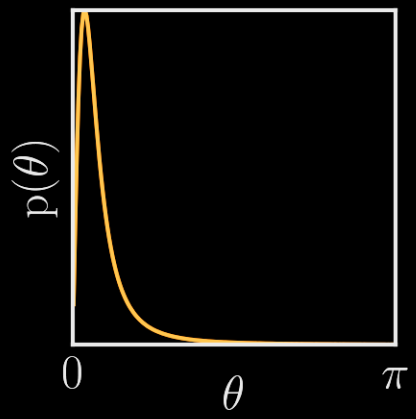


Isotropic scattering

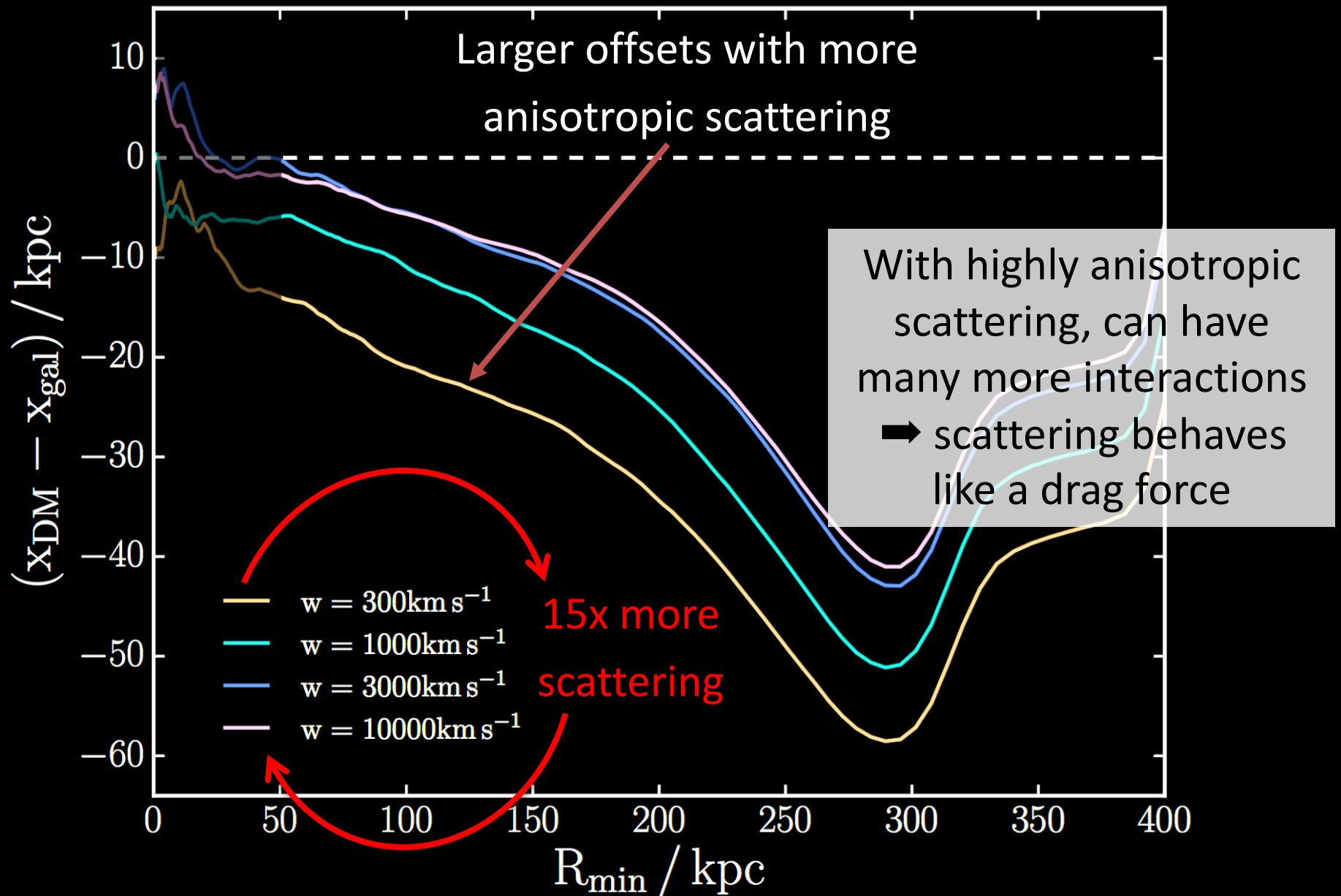


Anisotropic DM

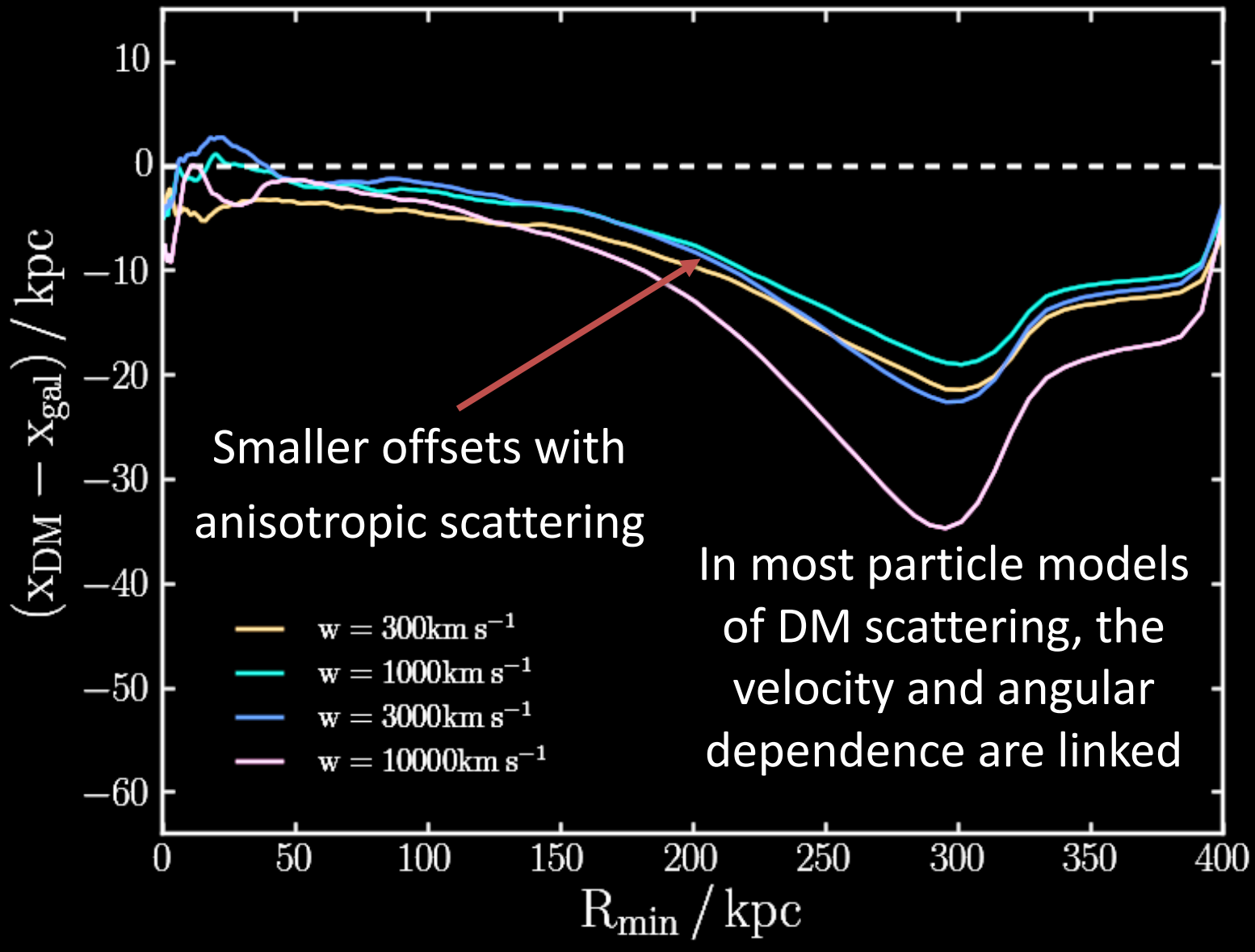
5x more scattering



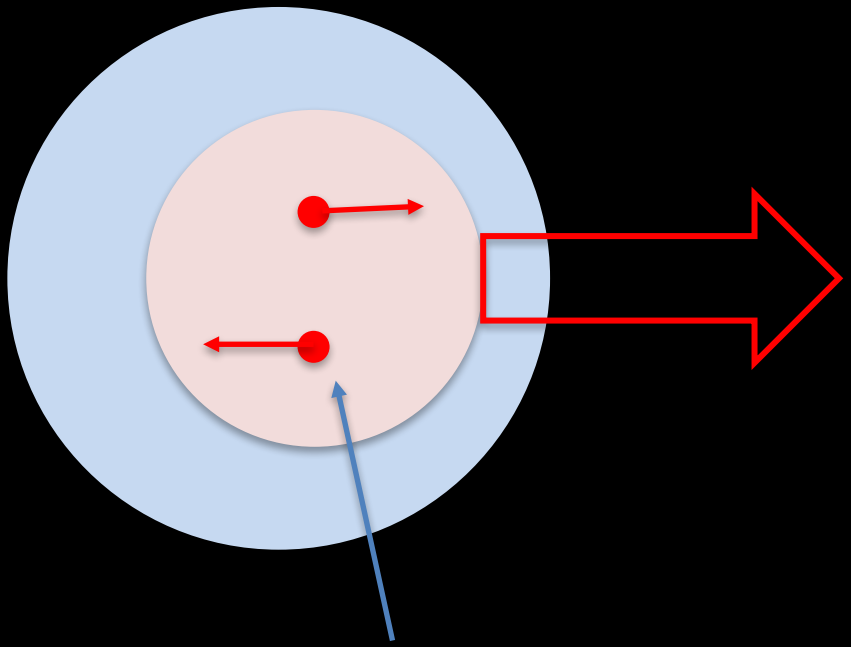
DM-GALAXY OFFSETS WITH ANGULARLY-DEPENDENT SCATTERING



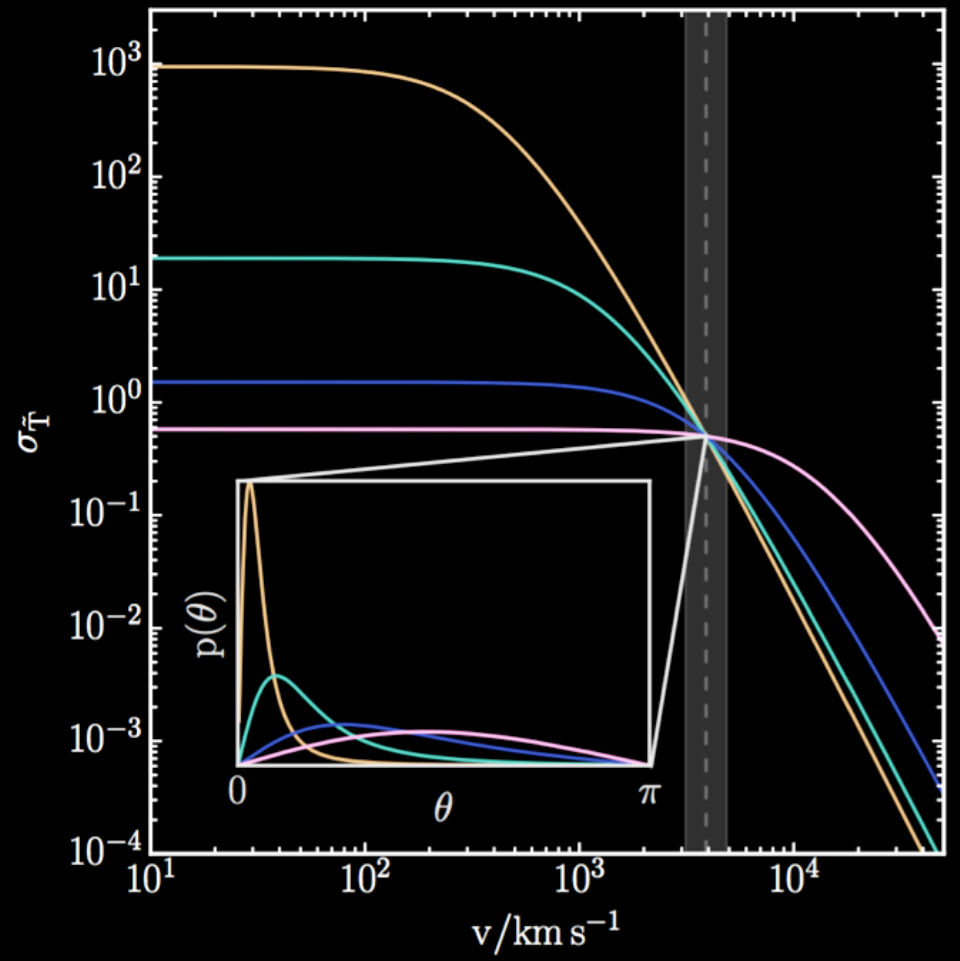
DM-GALAXY OFFSETS WITH REALISTIC (YUKAWA) PARTICLE SCATTERING



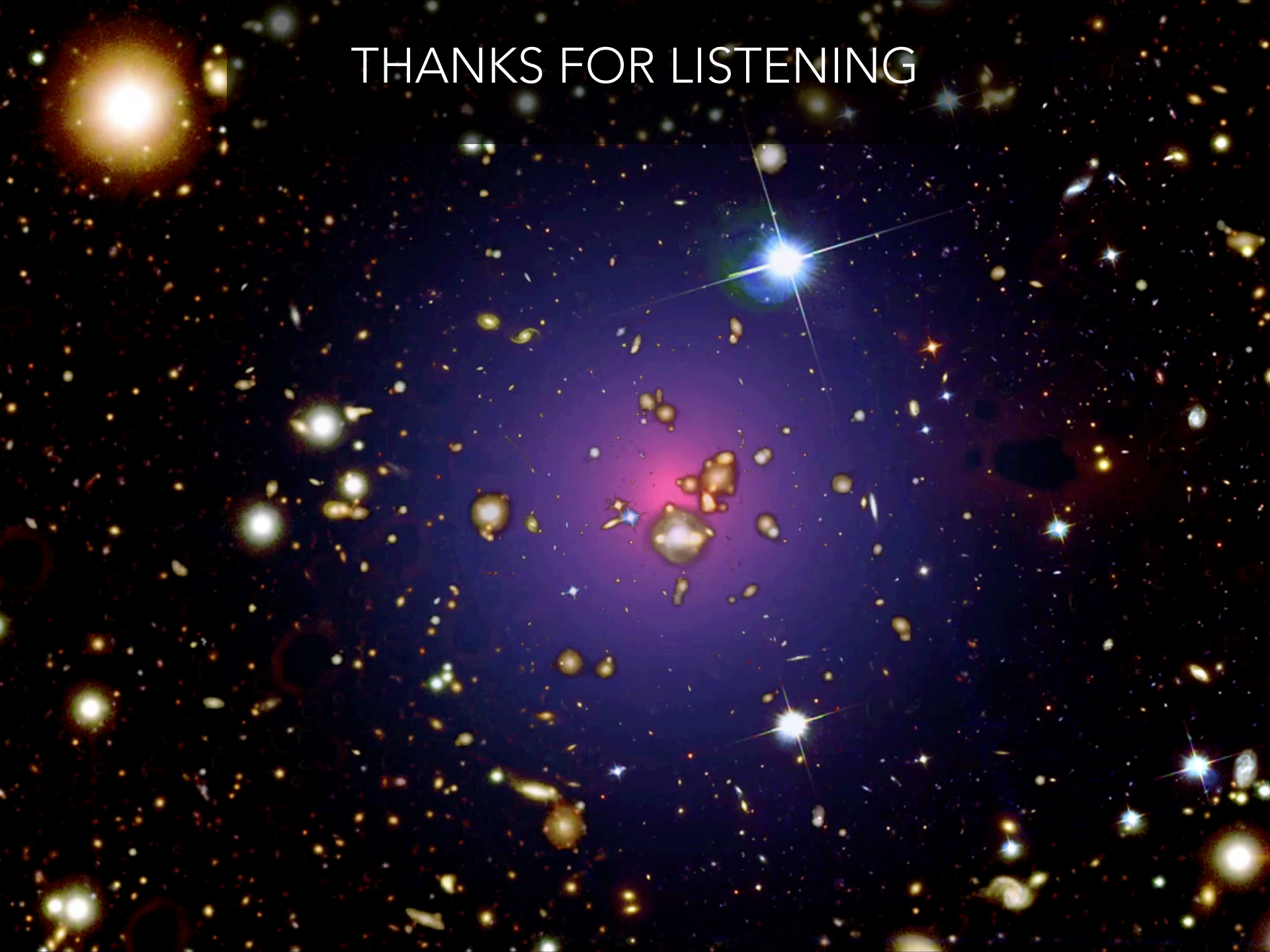
VELOCITY DEPENDENCE REDUCES OFFSETS



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



THANKS FOR LISTENING

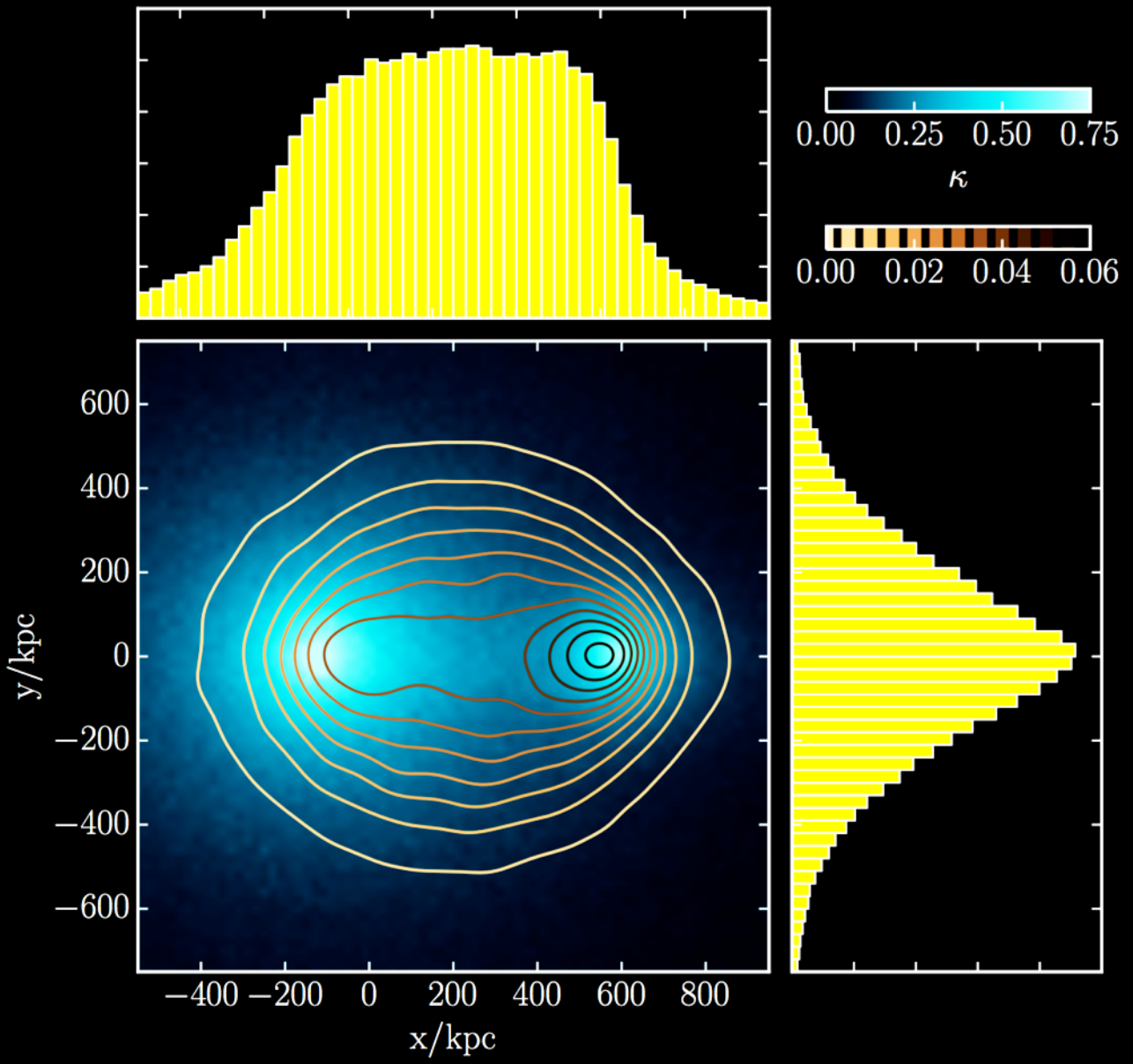


SUMMARY

- Colliding galaxy clusters are an interesting place to look for non-gravitational DM interactions
- Current constraints on SIDM cross-section from offsets in merging clusters have been over-stated
- For the simplest well-motivated velocity-dependent SIDM, expect only small offsets in merging galaxy clusters

THANKS FOR LISTENING

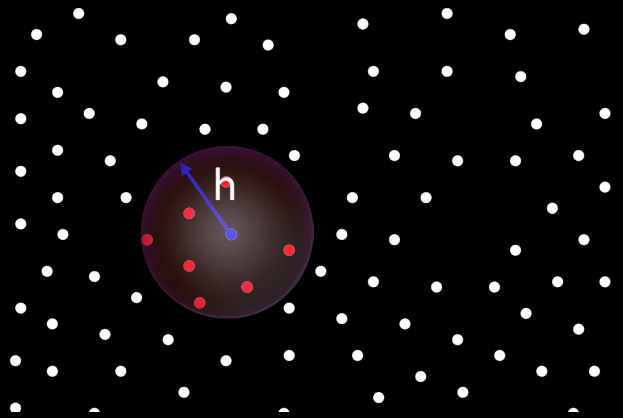
THE DISTRIBUTION OF SCATTERED PARTICLES

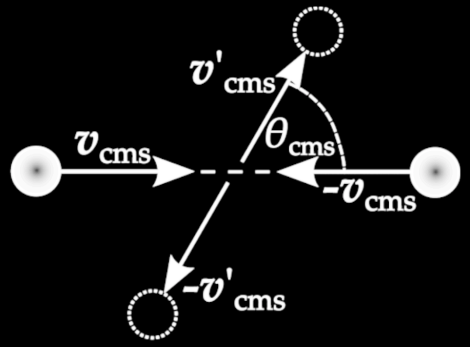


SCATTERING WITH A GENERAL DIFERENTIAL CROSS-SECTION

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

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

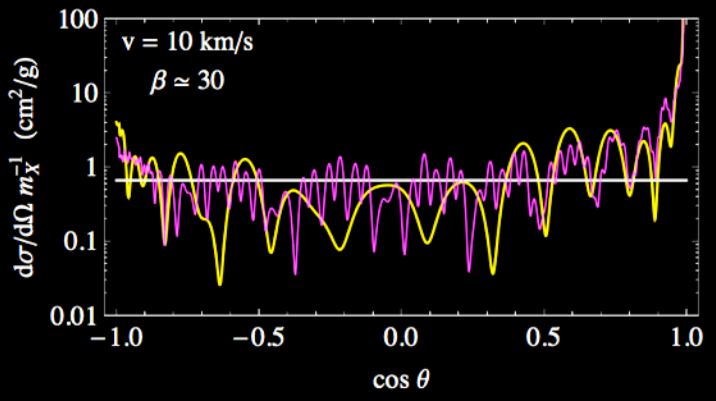


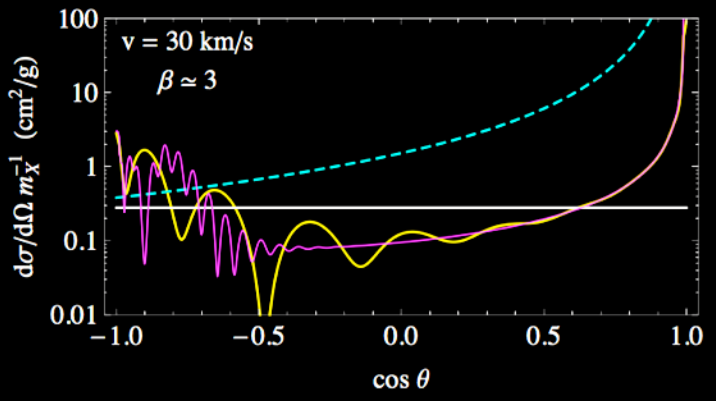


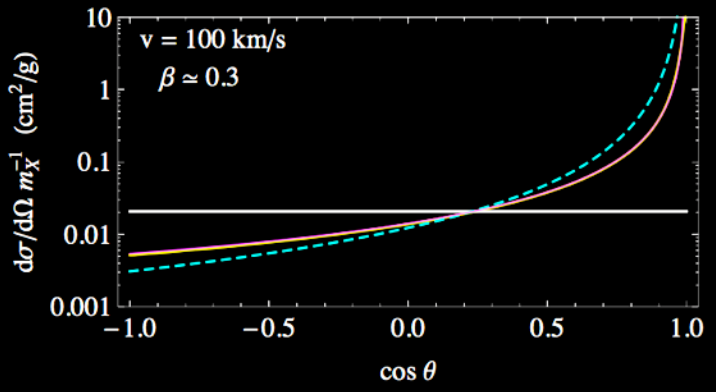
Kahlhoefer+ 2014

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

Tulin+ 2013

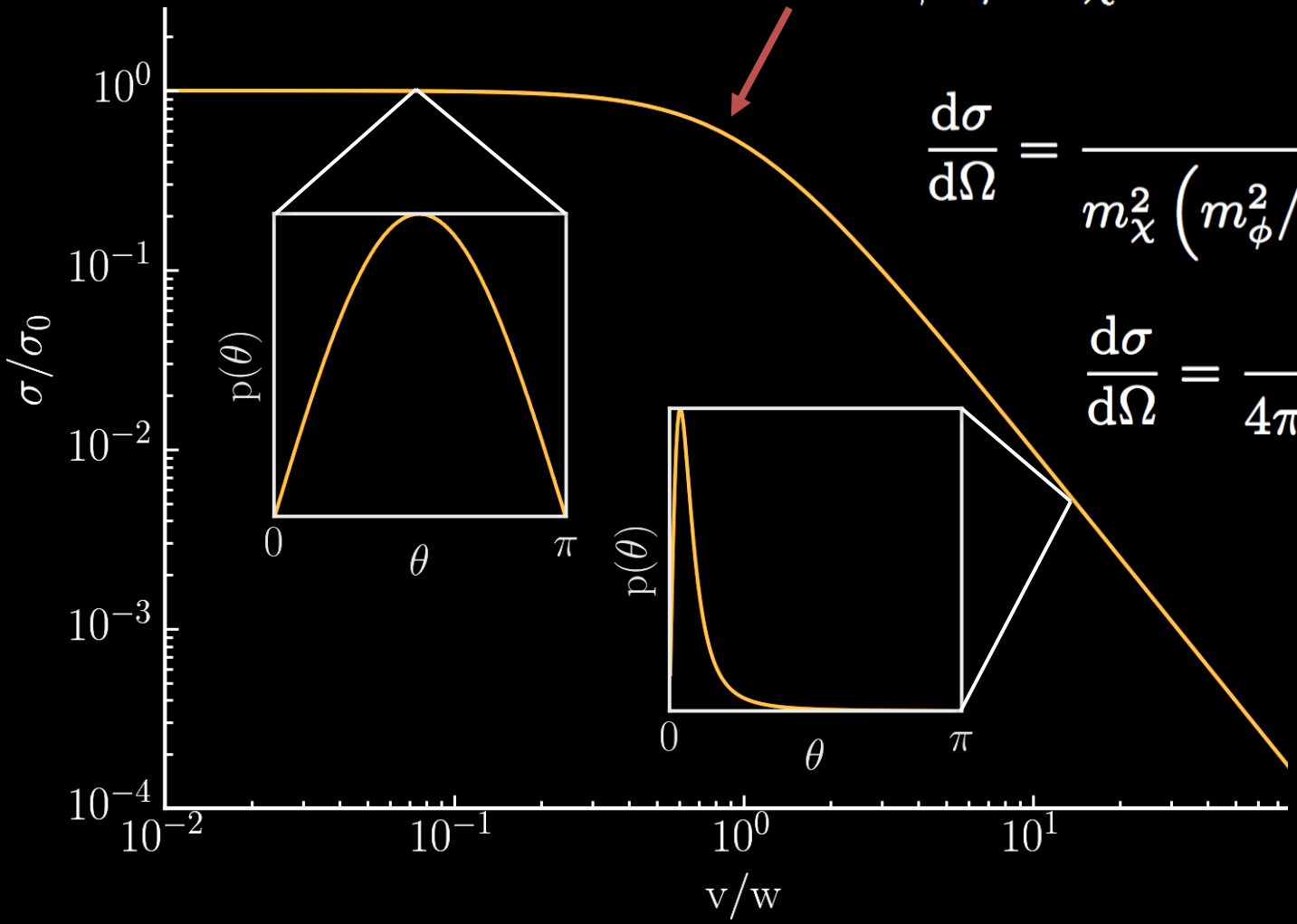






YUKAWA SCATTERING WITH THE BORN-APPROXIMATION

$$w = m_\phi c / m_\chi$$



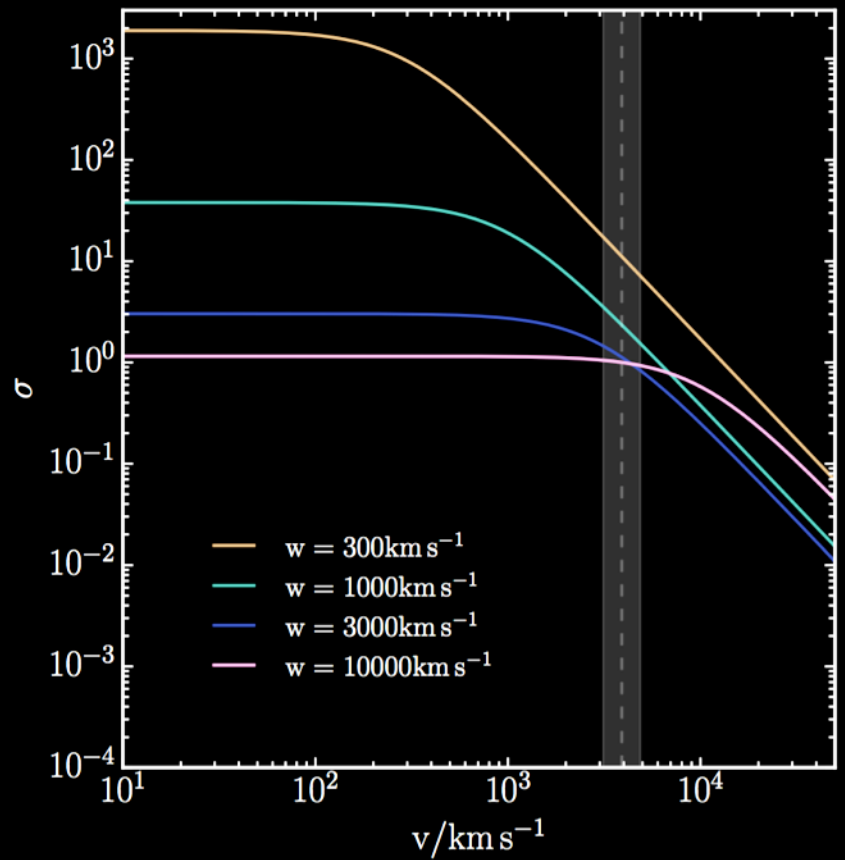
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\alpha_\chi^2}{m_\chi^2 \left(m_\phi^2/m_\chi^2 + v^2 \sin^2 \frac{\theta}{2} \right)^2}$$

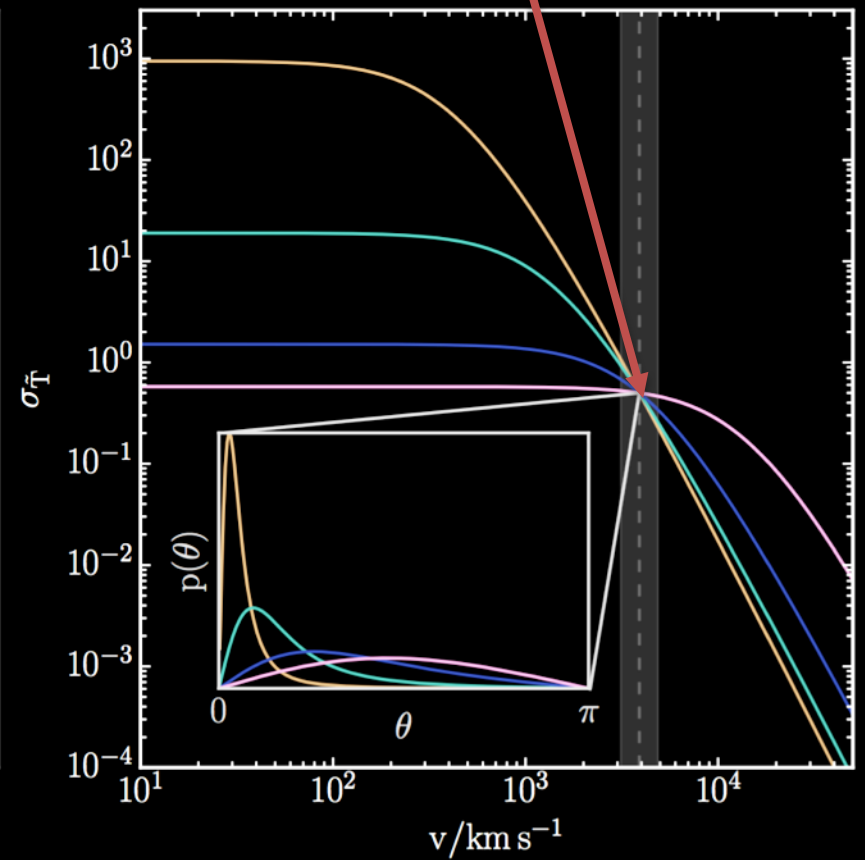
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\sigma_0}{4\pi(1 + \frac{v^2}{w^2} \sin^2 \frac{\theta}{2})^2}$$

YUKAWA CROSS-SECTIONS FOR BULLET CLUSTER SIMULATIONS

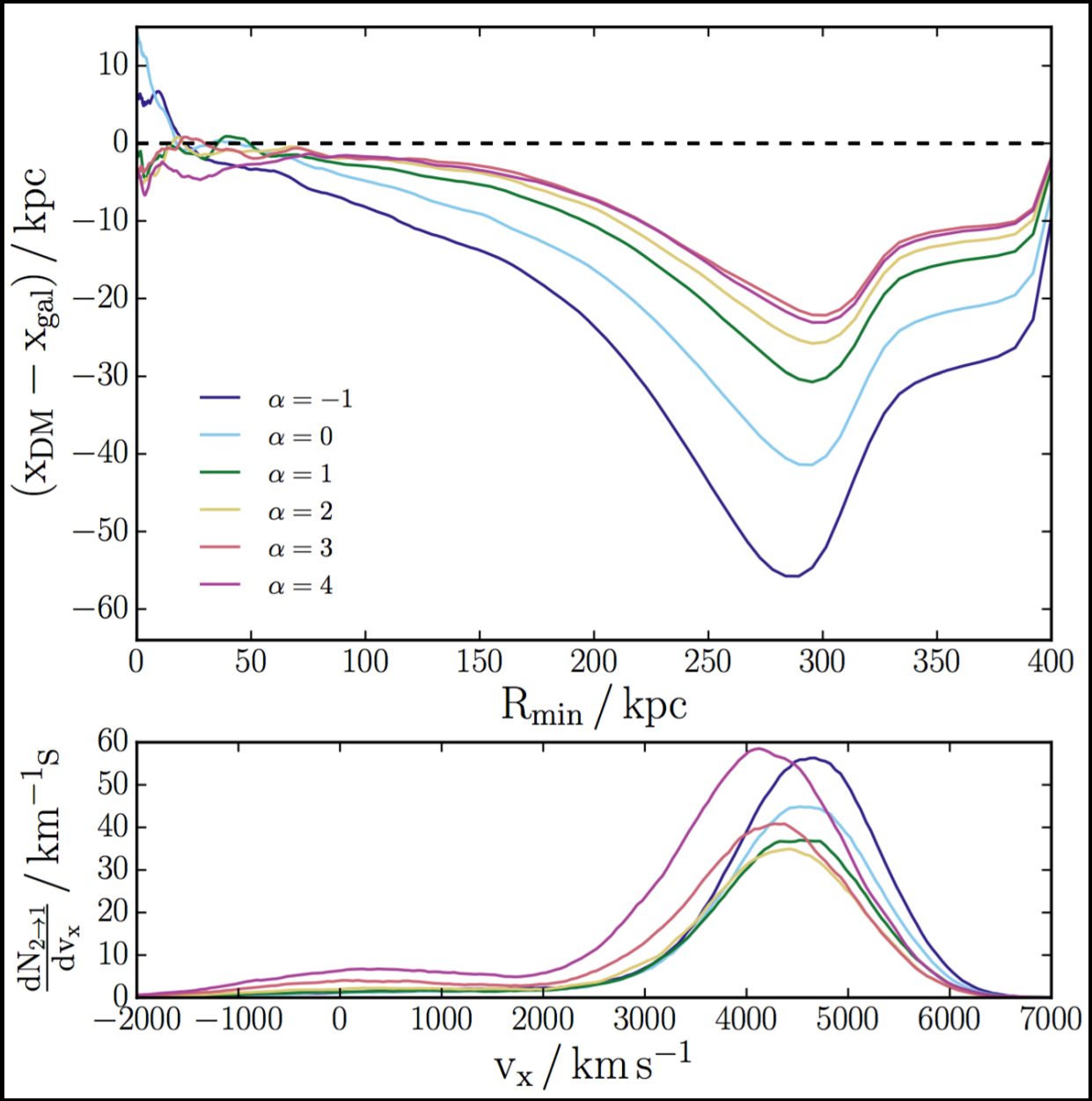
Four different cross-sections, with different ‘turn-over’ velocities

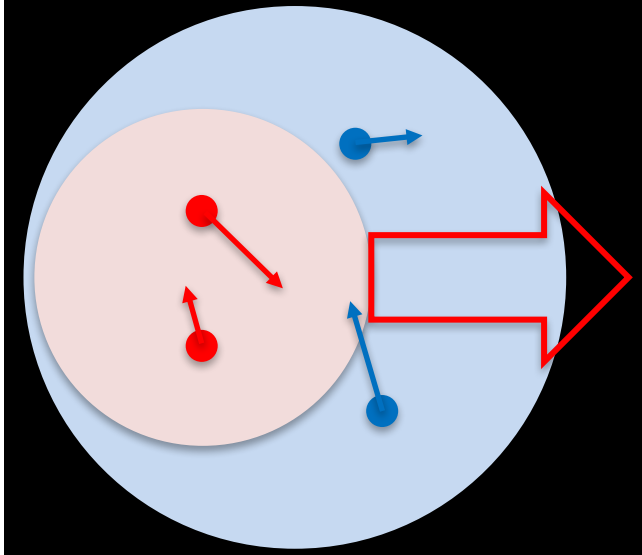
Matched to have same $\sigma_{\tilde{T}}$ at 3900 km/s





THE EFFECTS OF VELOCITY DEPENDENCE





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

$$\frac{\sigma(v)}{m} = \left(\frac{v}{4350\,\mathrm{km\,s^{-1}}}\right)^{-\alpha} \mathrm{cm^2 g^{-1}}$$