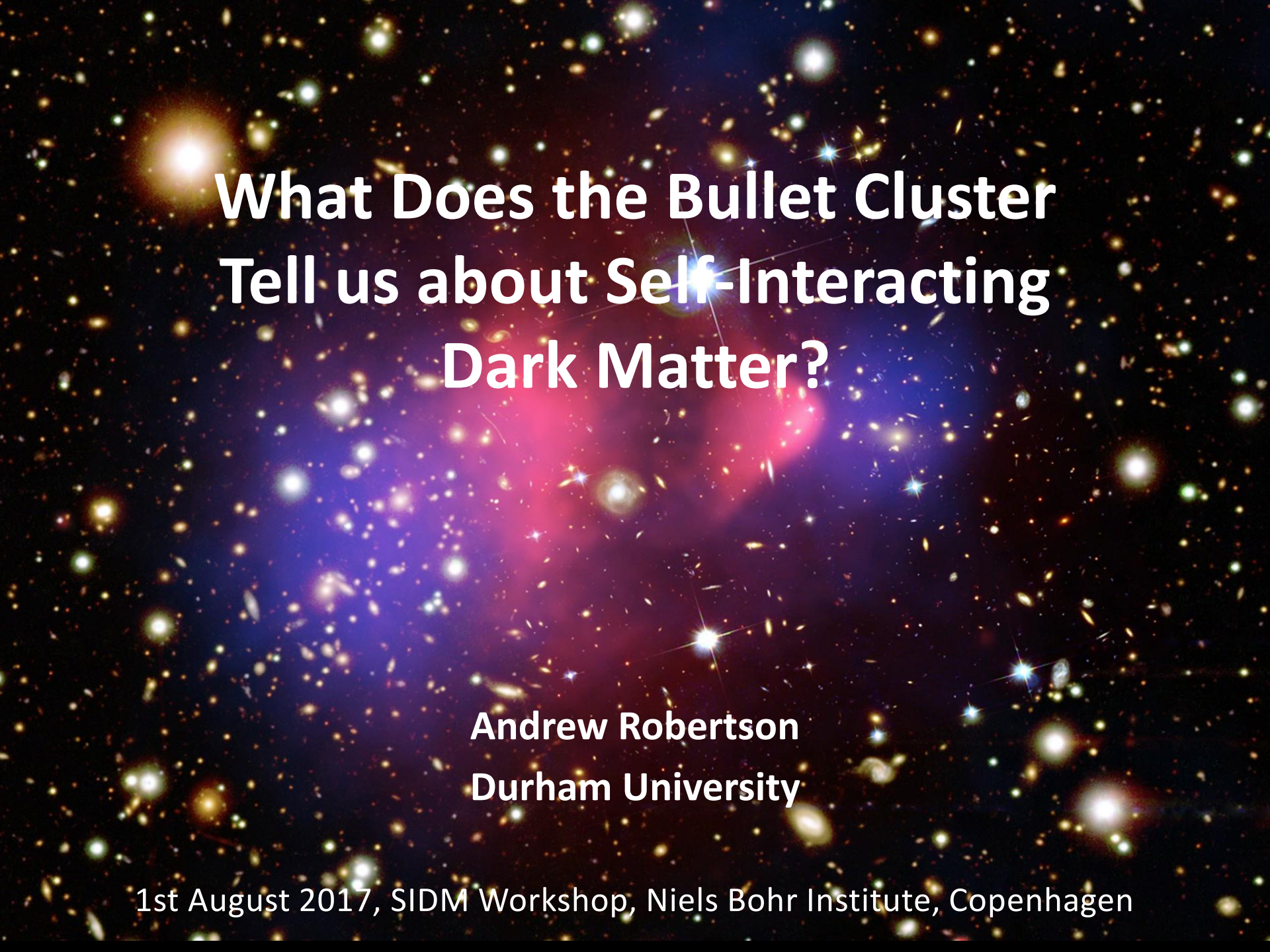
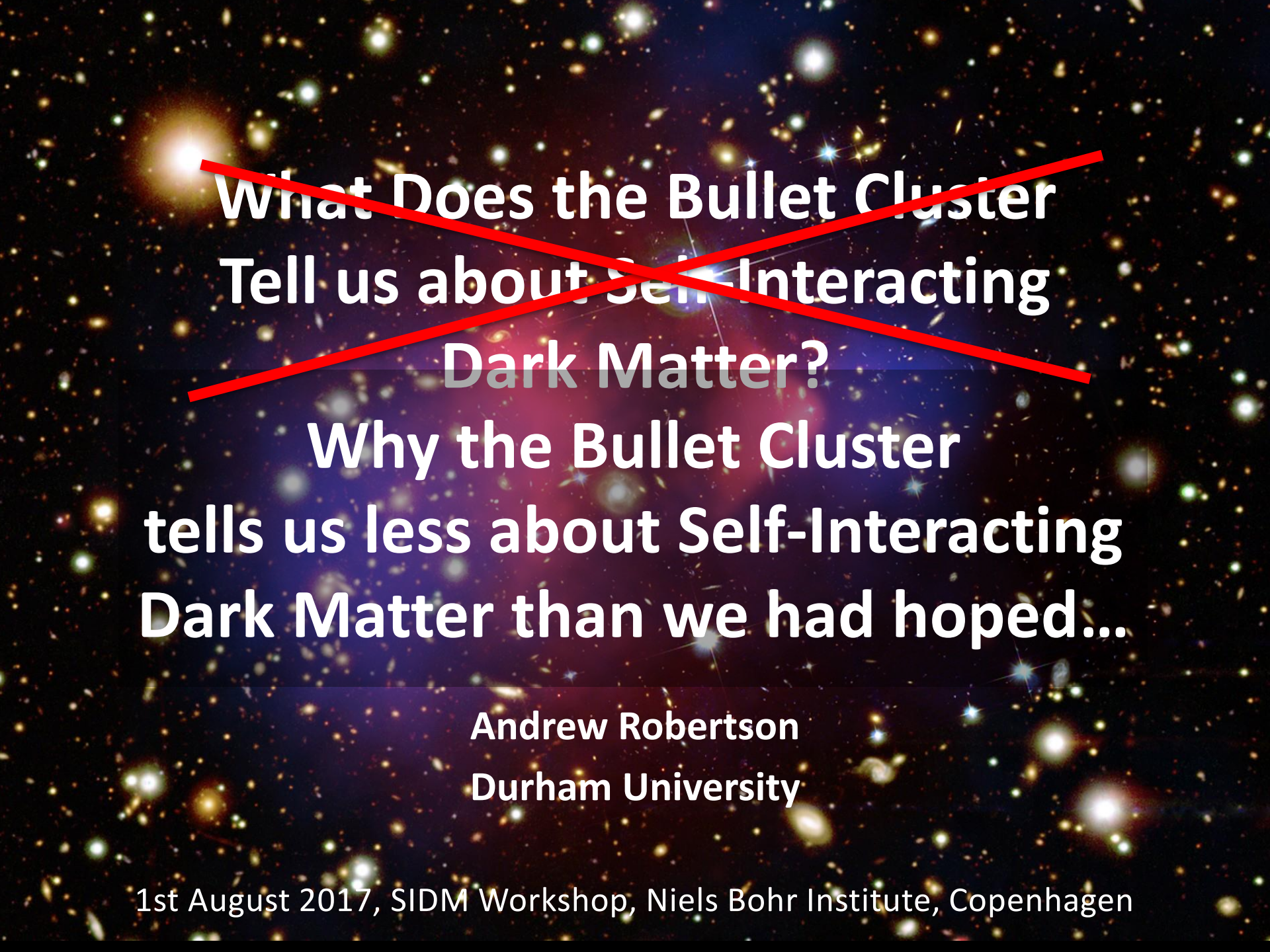


What Does the Bullet Cluster Tell us about Self-Interacting Dark Matter?

Andrew Robertson

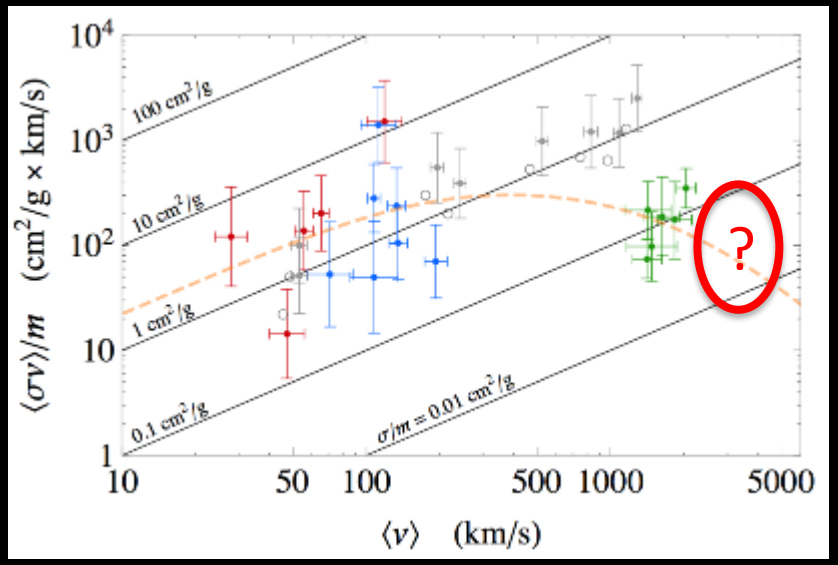
Durham University

1st August 2017, SIDM Workshop, Niels Bohr Institute, Copenhagen


What Does the Bullet Cluster
Tell us about Self-Interacting
Dark Matter?
Why the Bullet Cluster
tells us less about Self-Interacting
Dark Matter than we had hoped…
Andrew Robertson
Durham University
1st August 2017, SIDM Workshop, Niels Bohr Institute, Copenhagen

WHY LOOK AT MERGING GALAXY CLUSTERS?

Higher DM-DM velocities than in isolated galaxy clusters

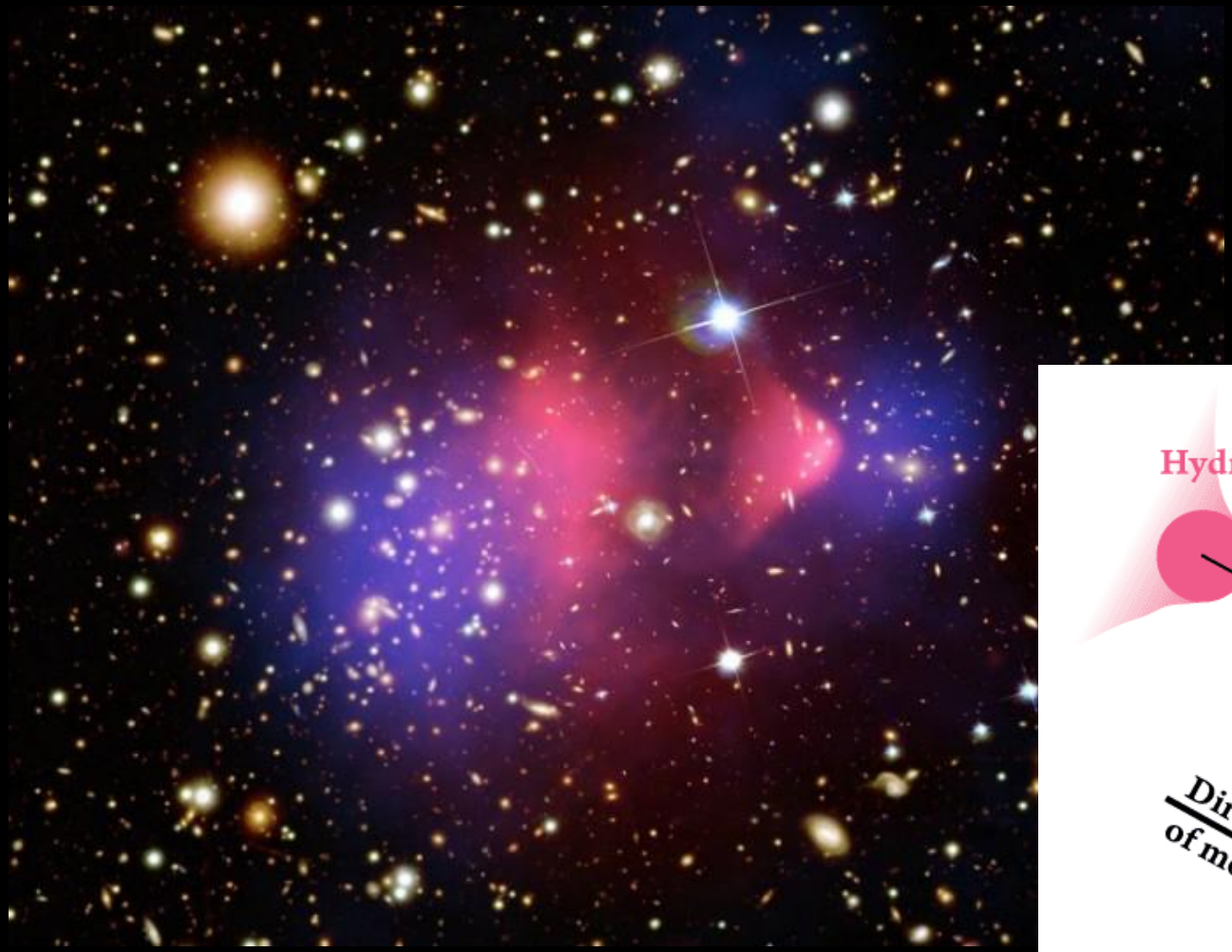


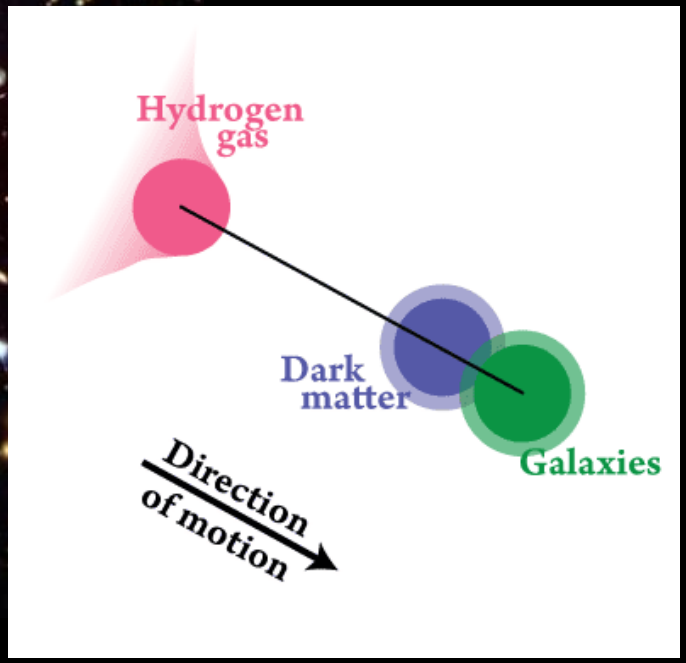
Kaplinghat+ 2016

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

Particle Collider for Dark Matter!

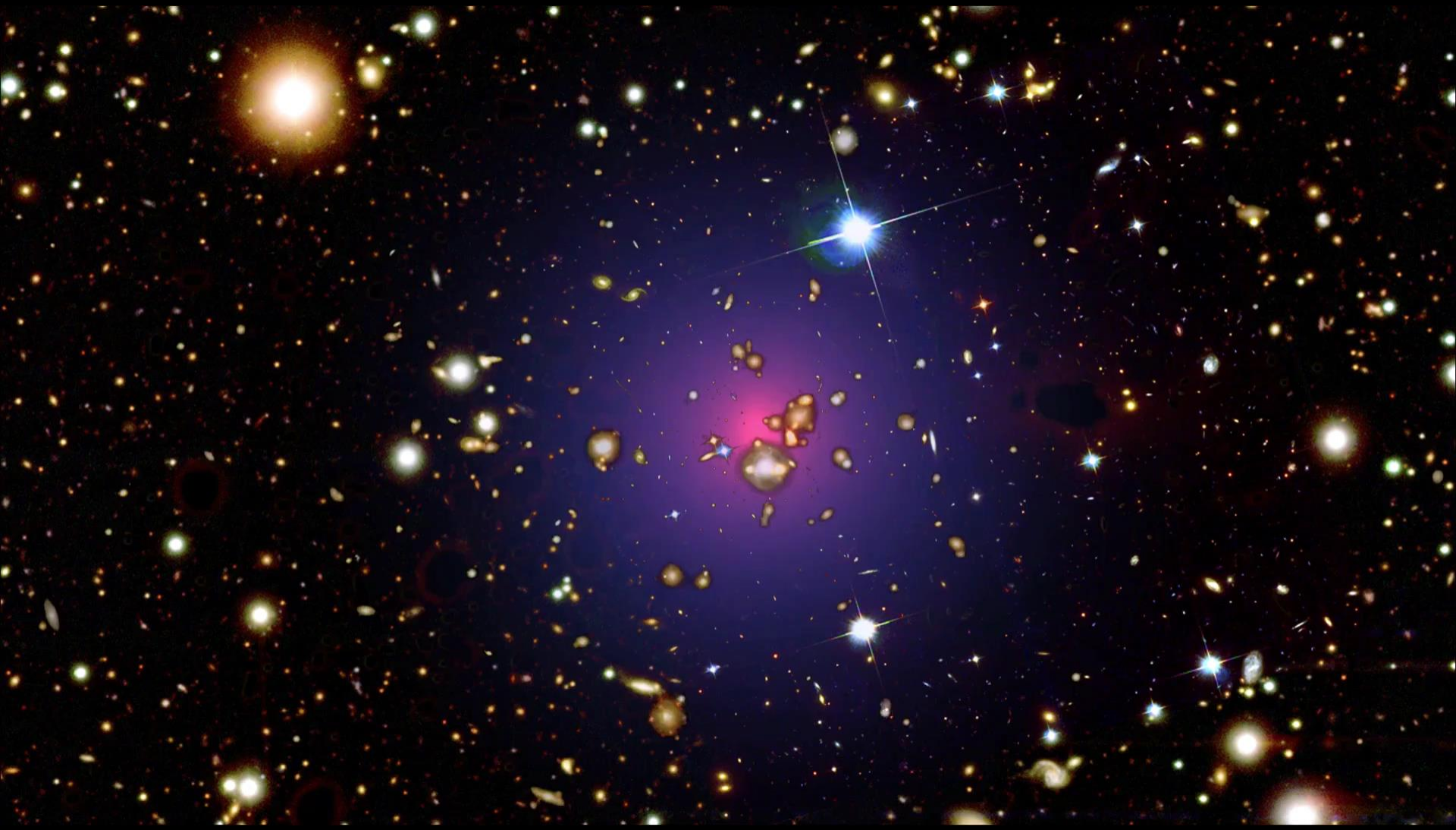
THE BULLET CLUSTER – A TOY MODEL





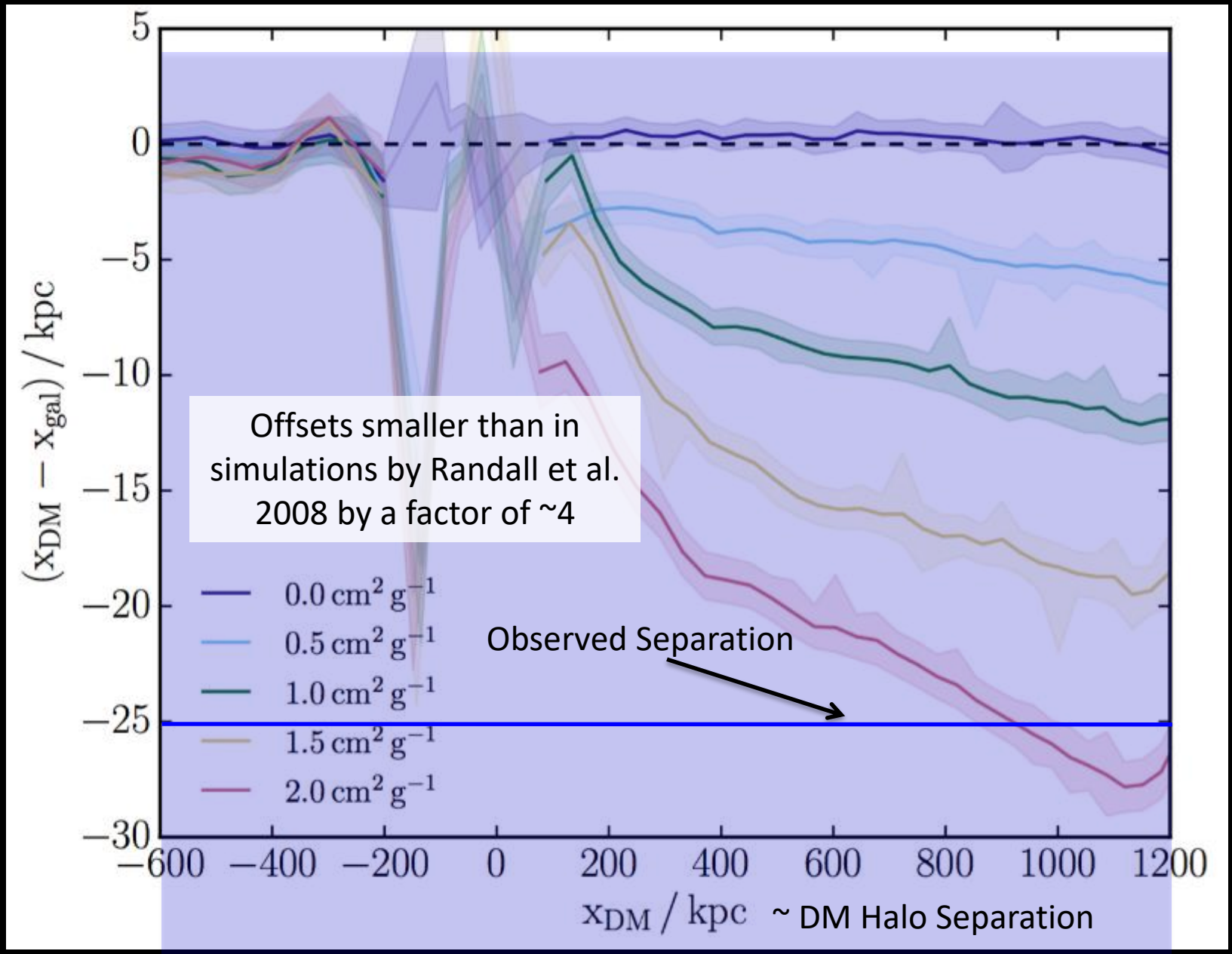
Harvey+ 2014

SMASHING CLUSTERS TOGETHER



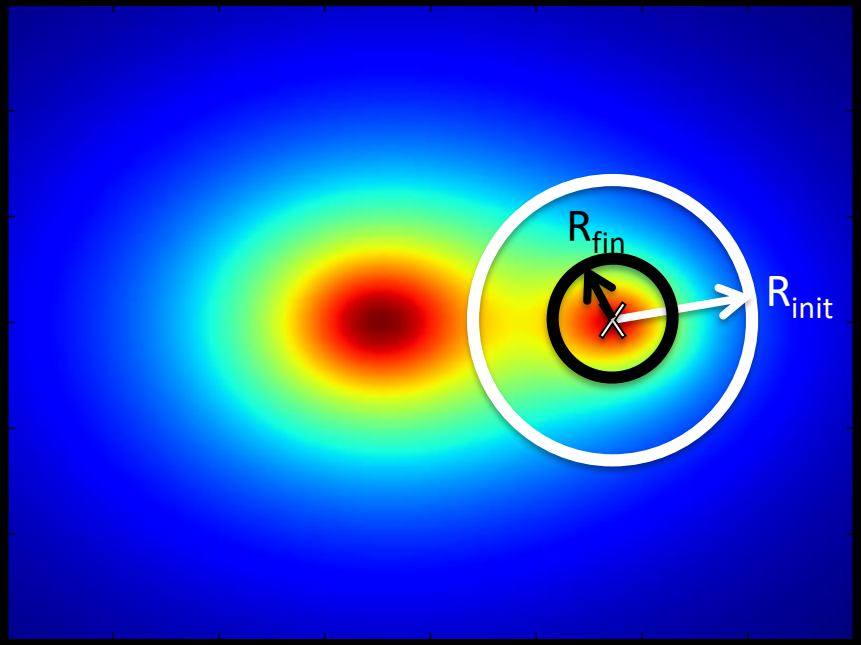
INCLUDING SIDM WITH A LARGE CROSS-SECTION

DM–GALAXY OFFSETS

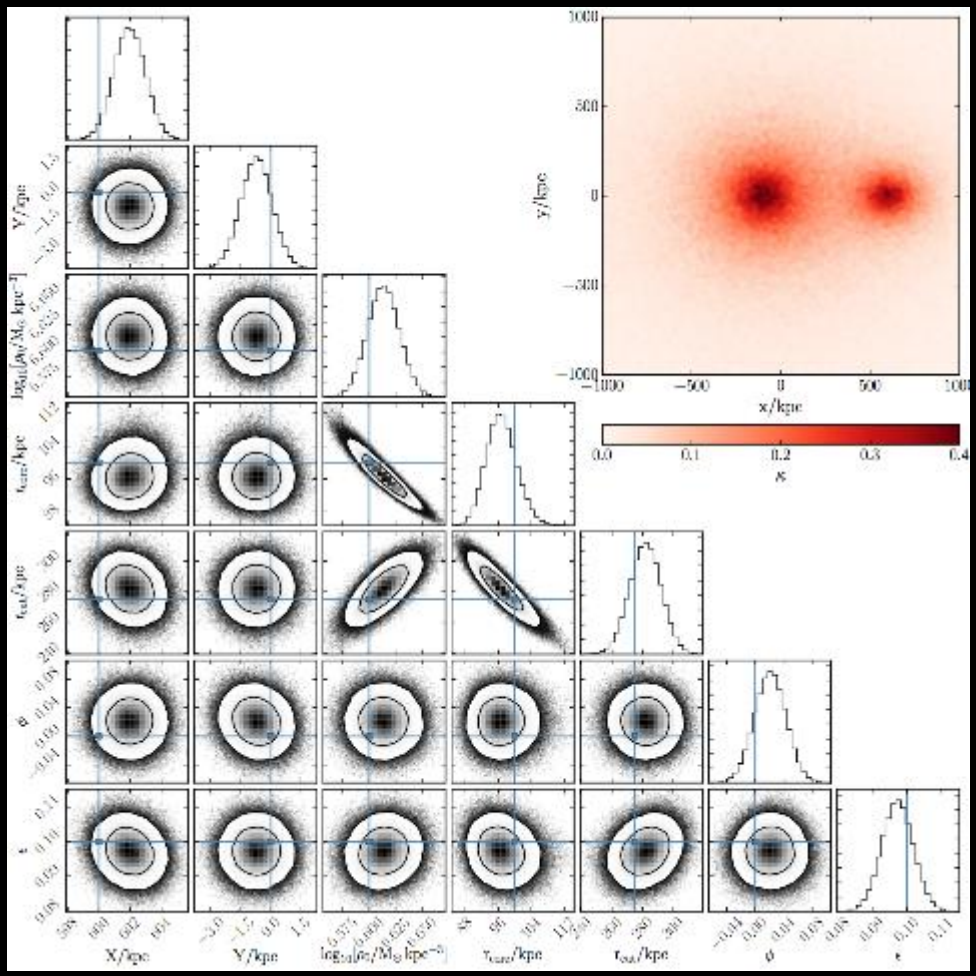


MEASURING HALO POSITIONS

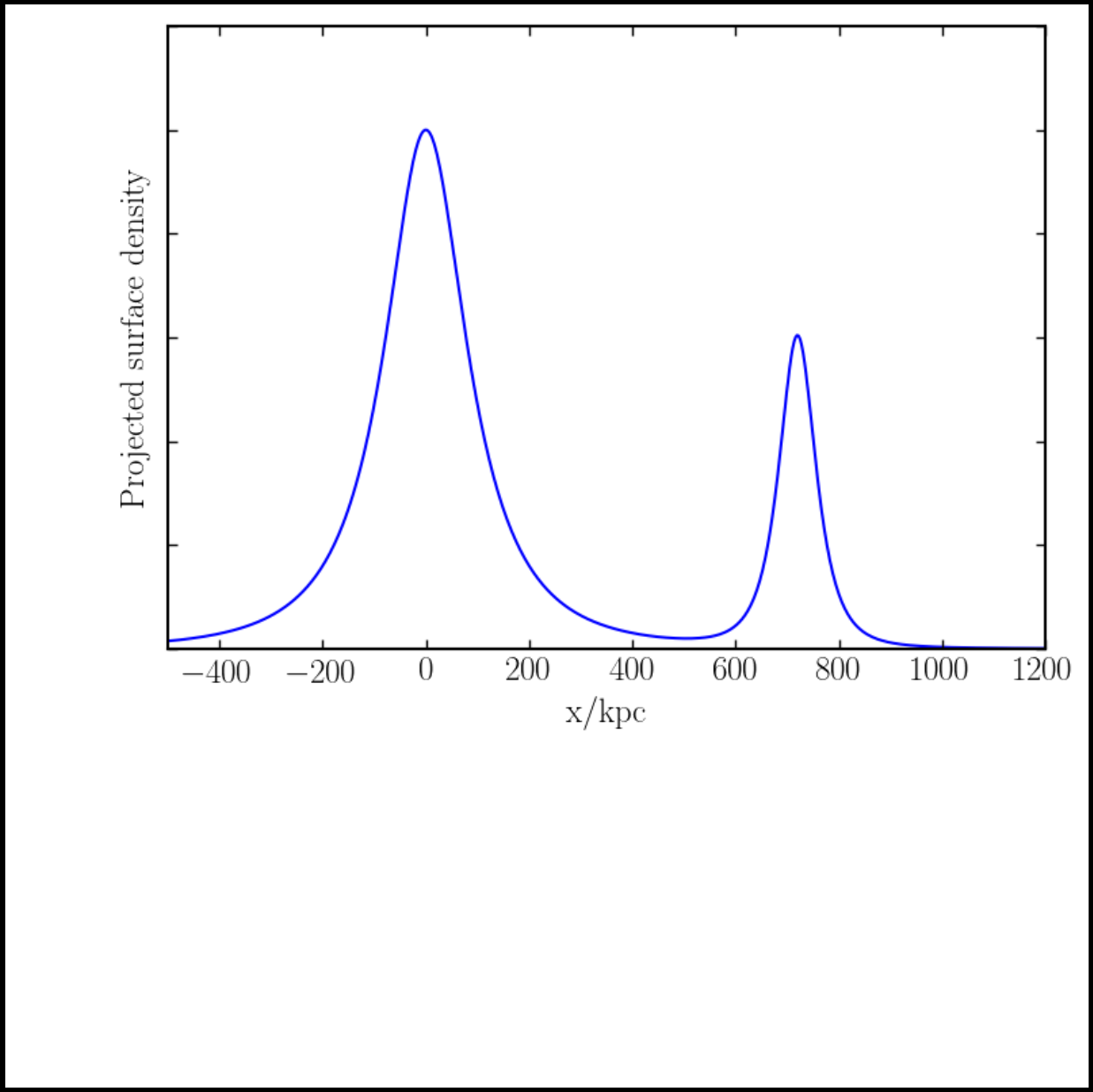
Shrinking Circles
(what Randall+ 08 did)



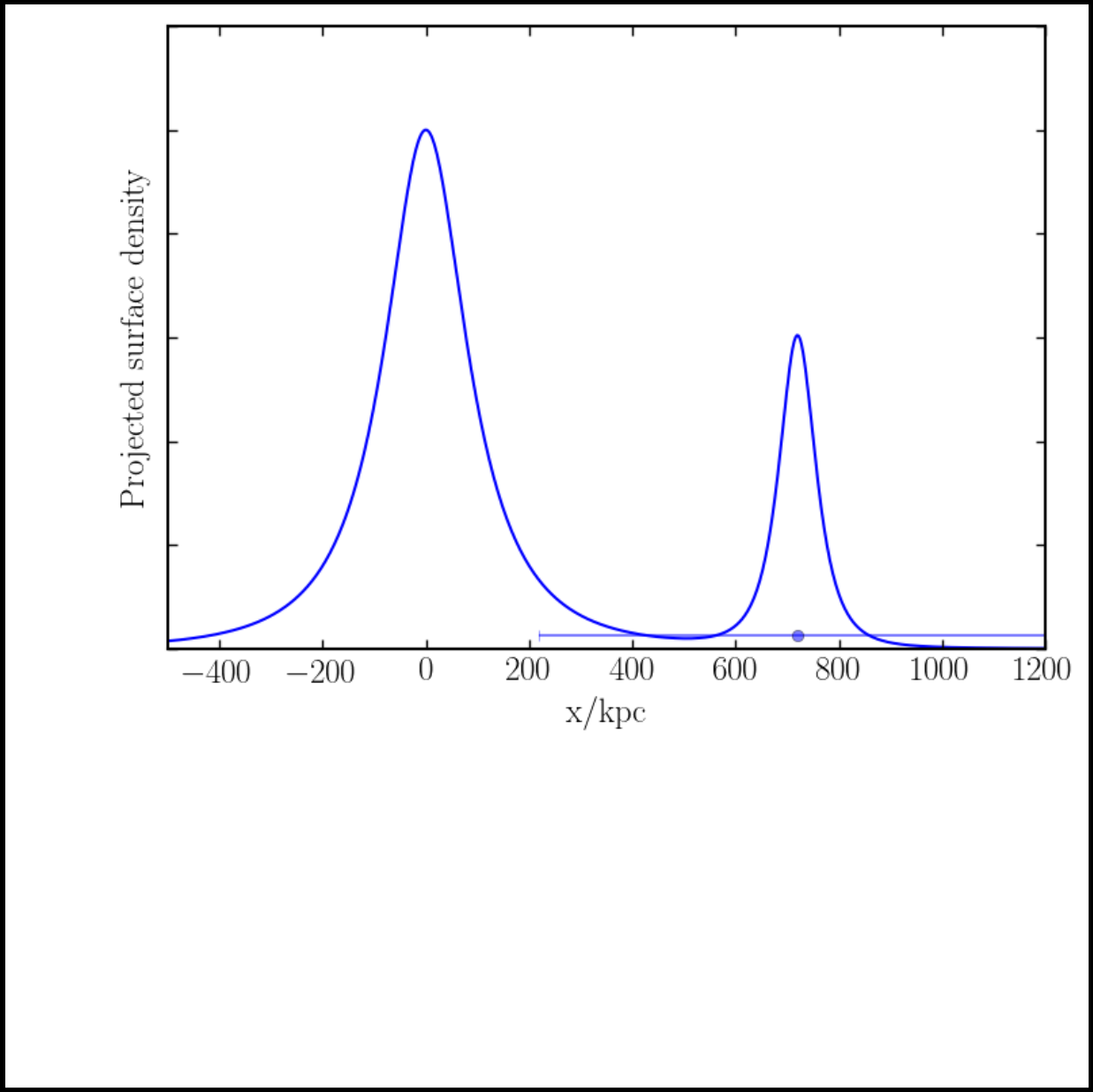
Parametric Model Fitting



TOY MODEL OF SHRINKING CIRCLES



TOY MODEL OF SHRINKING CIRCLES



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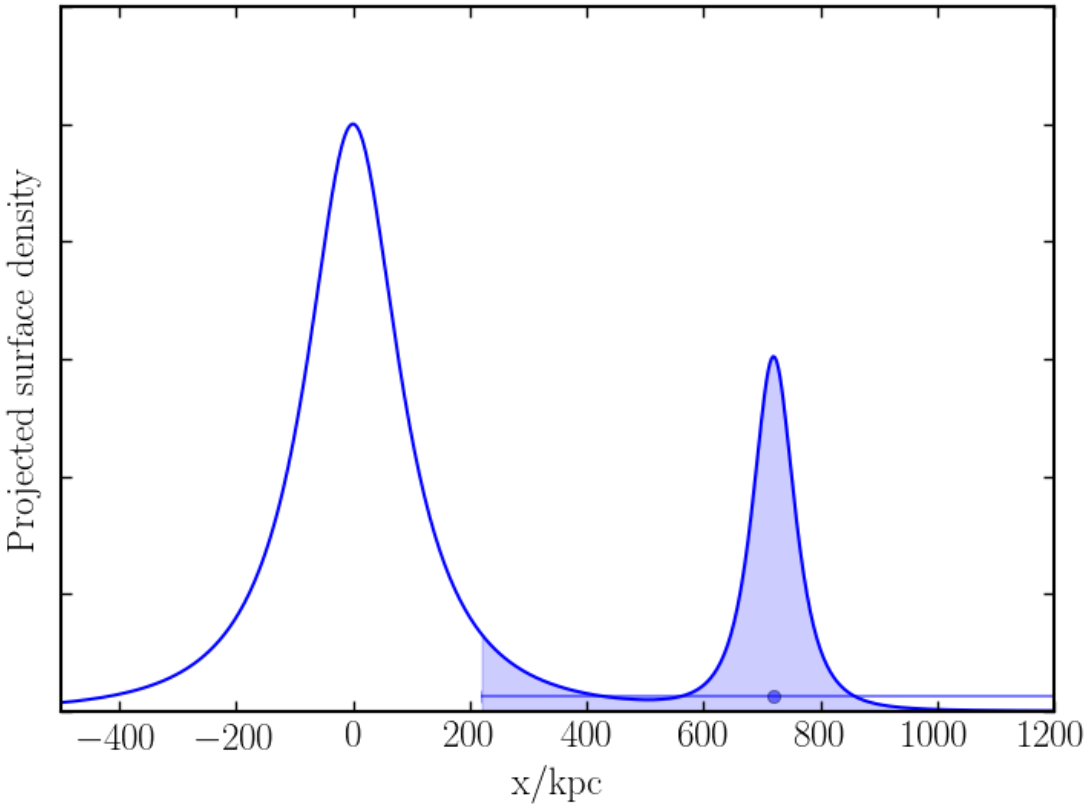

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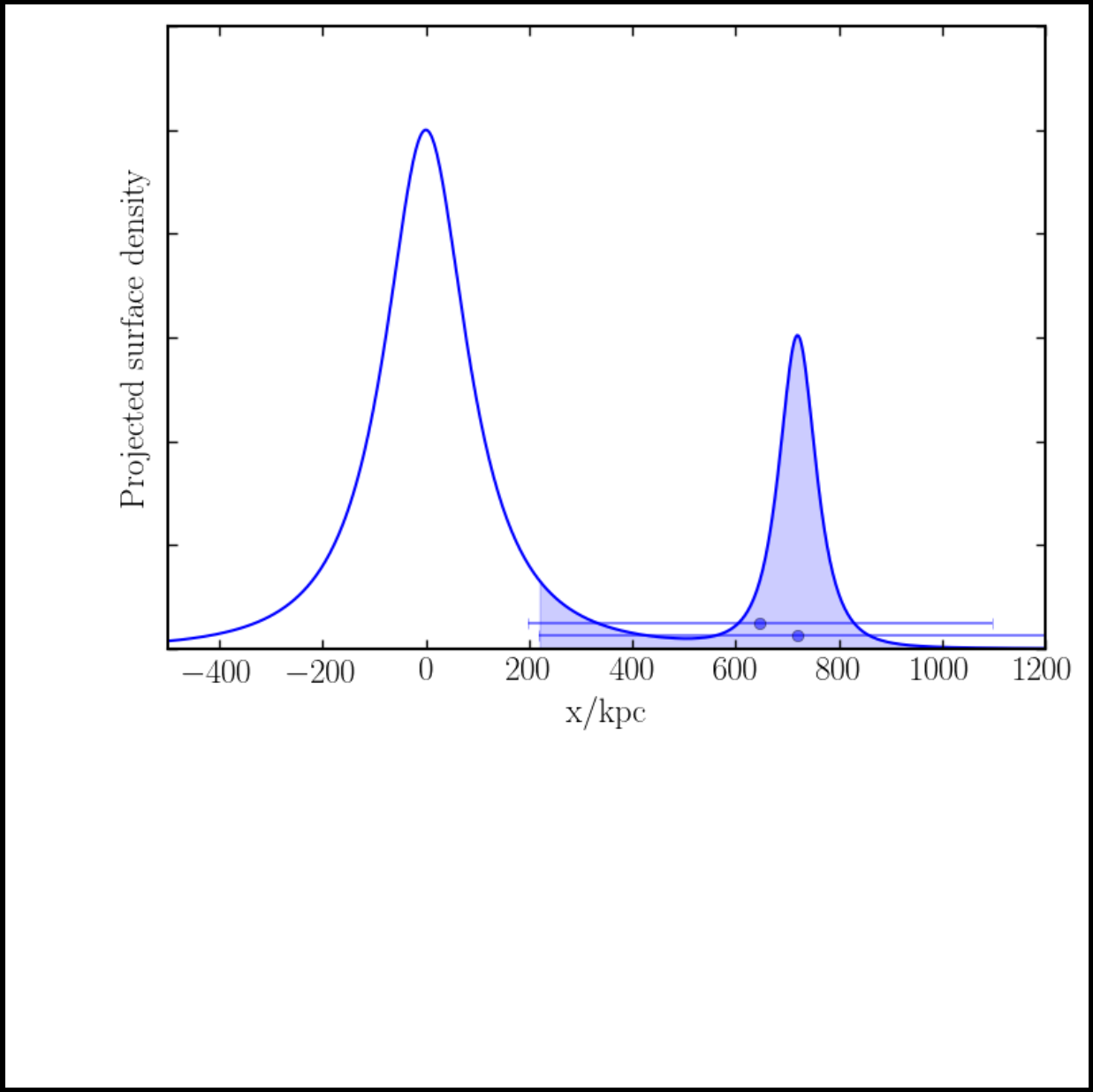

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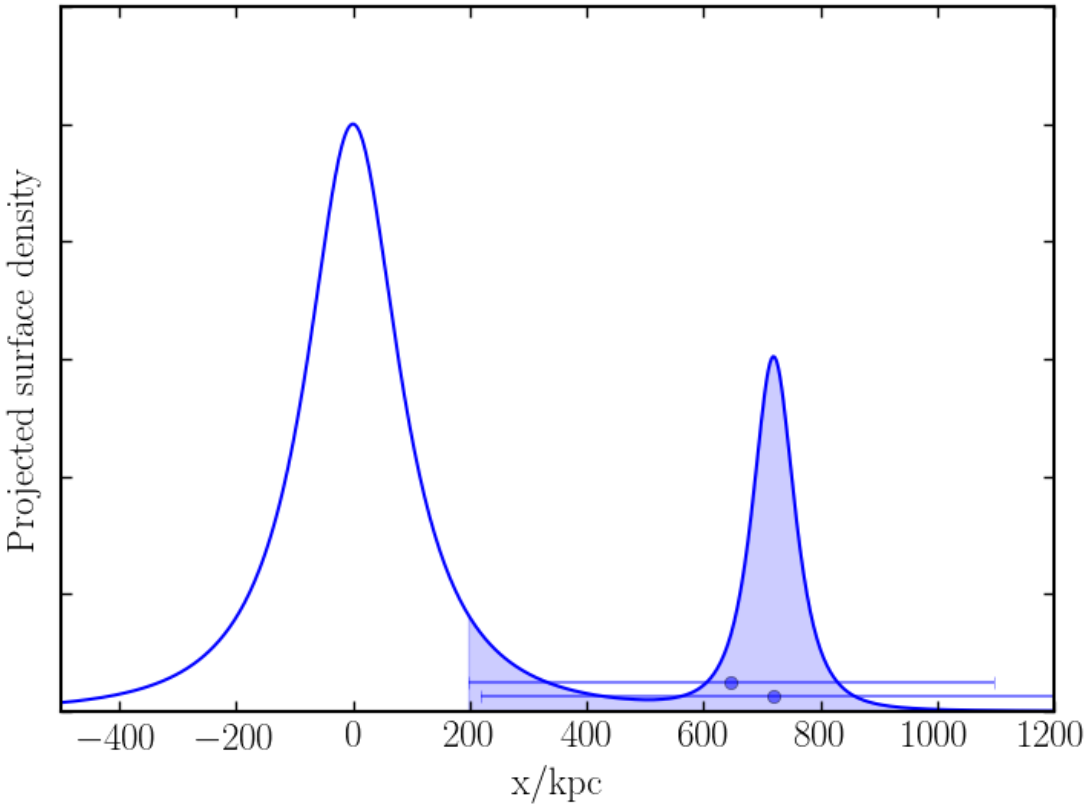

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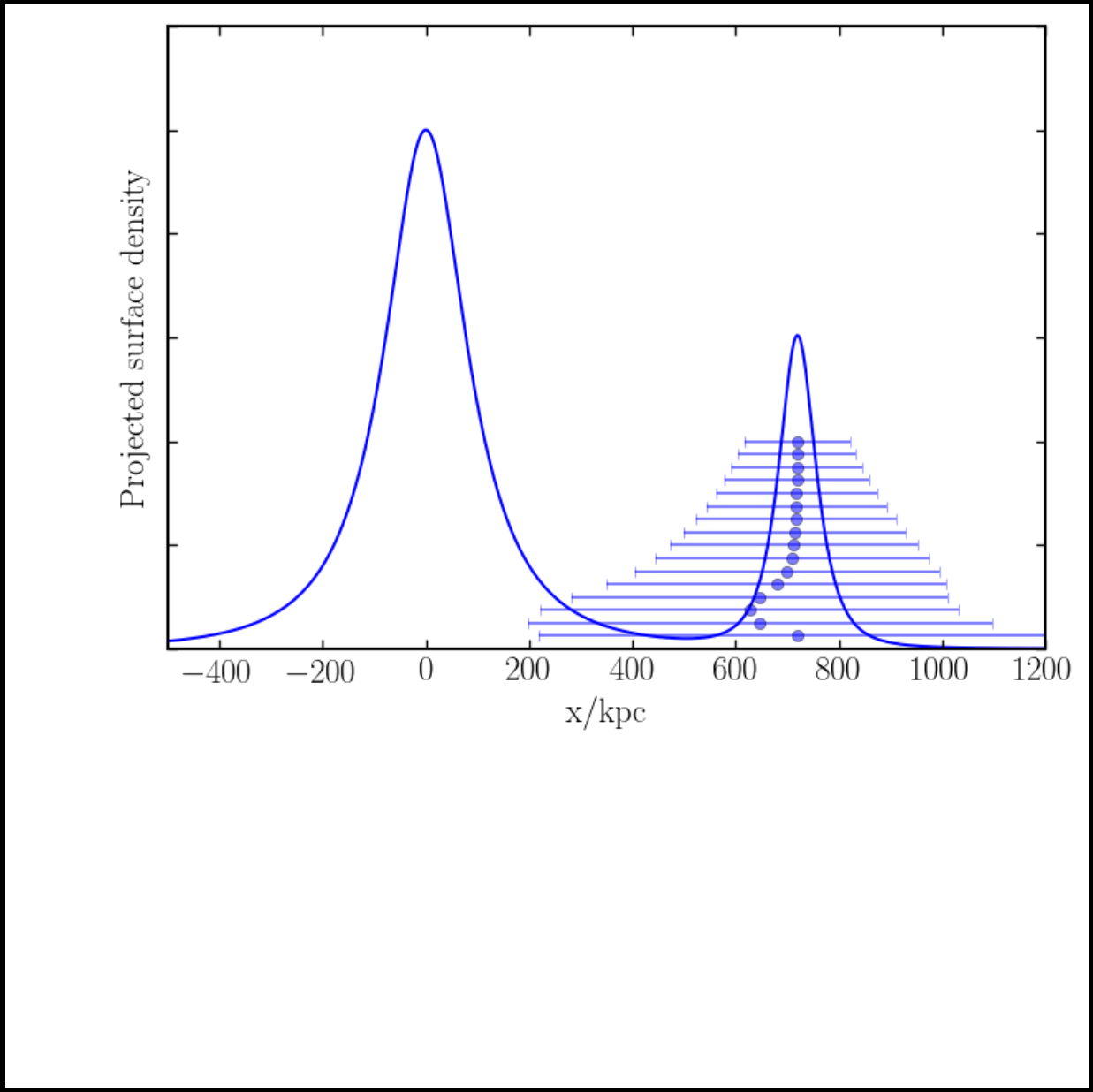

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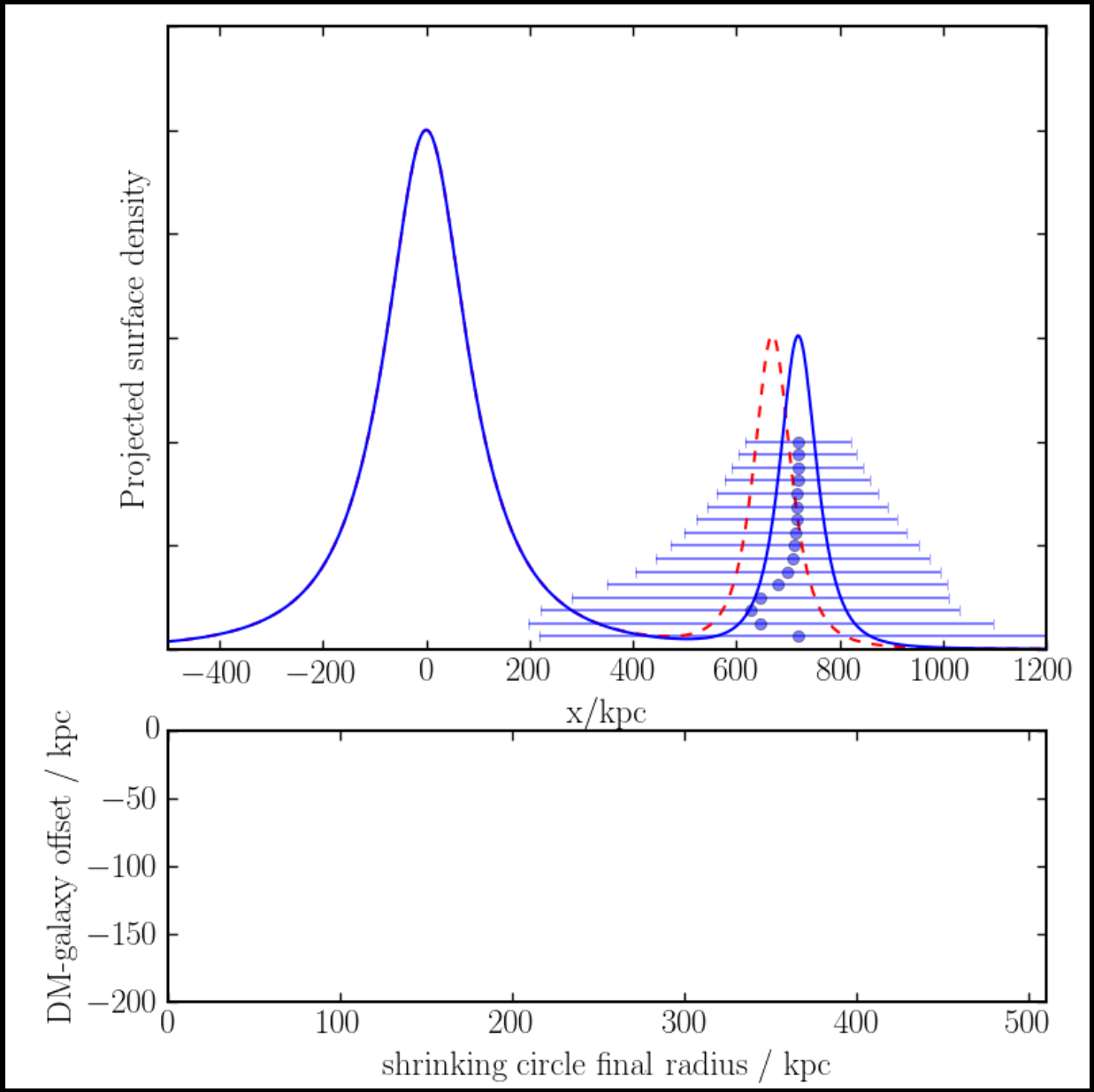
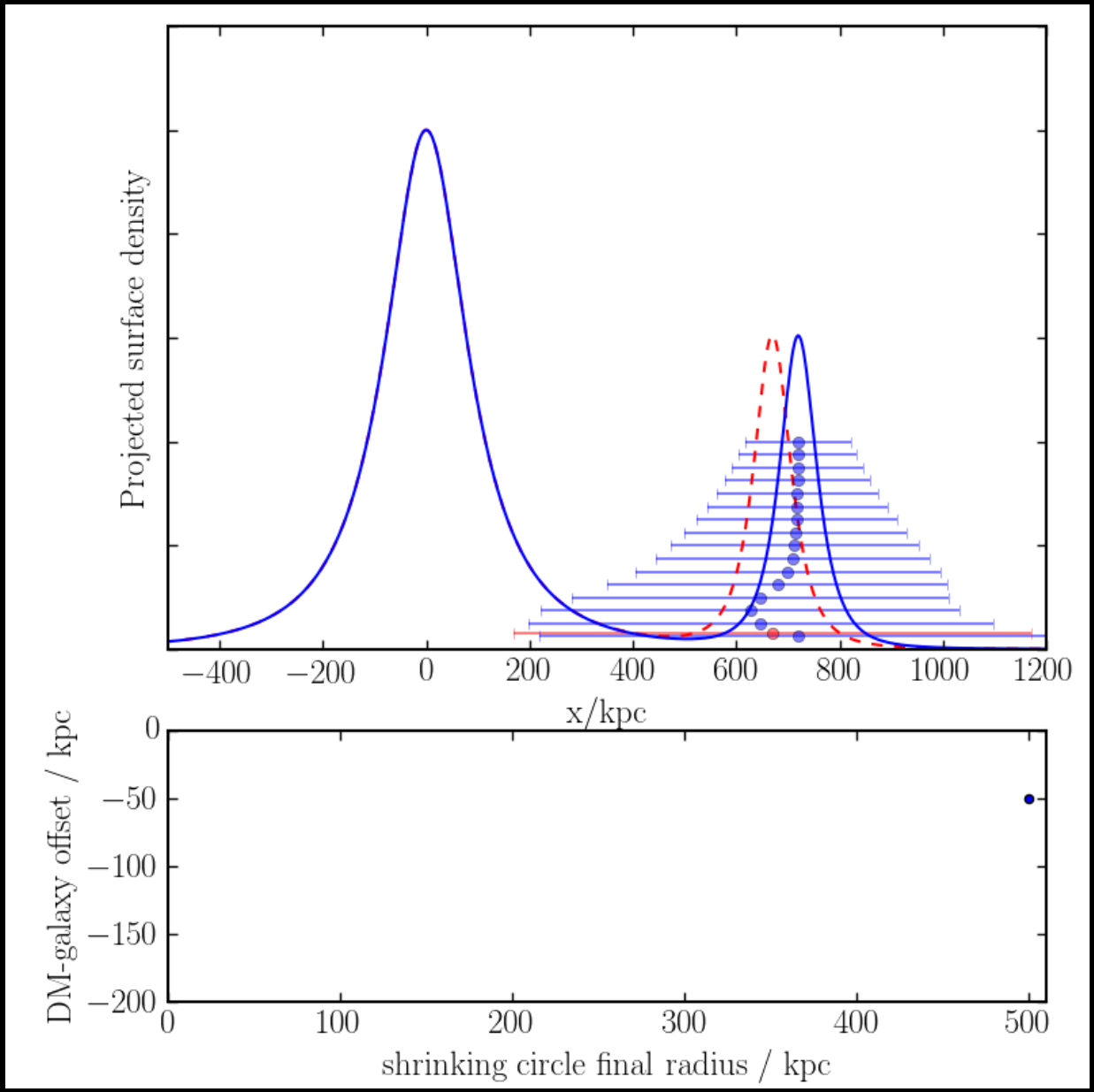


TOY MODEL OF SHRINKING CIRCLES



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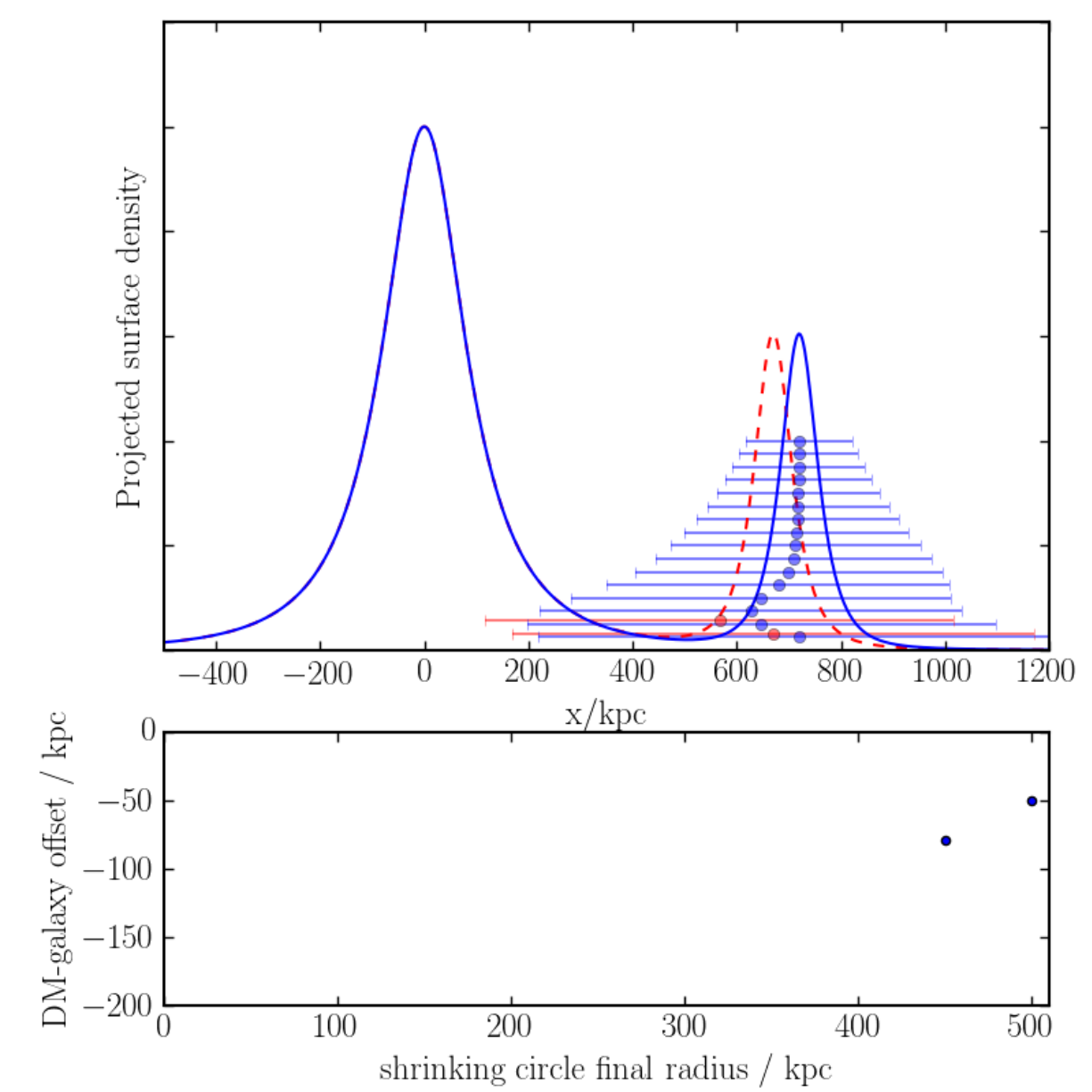
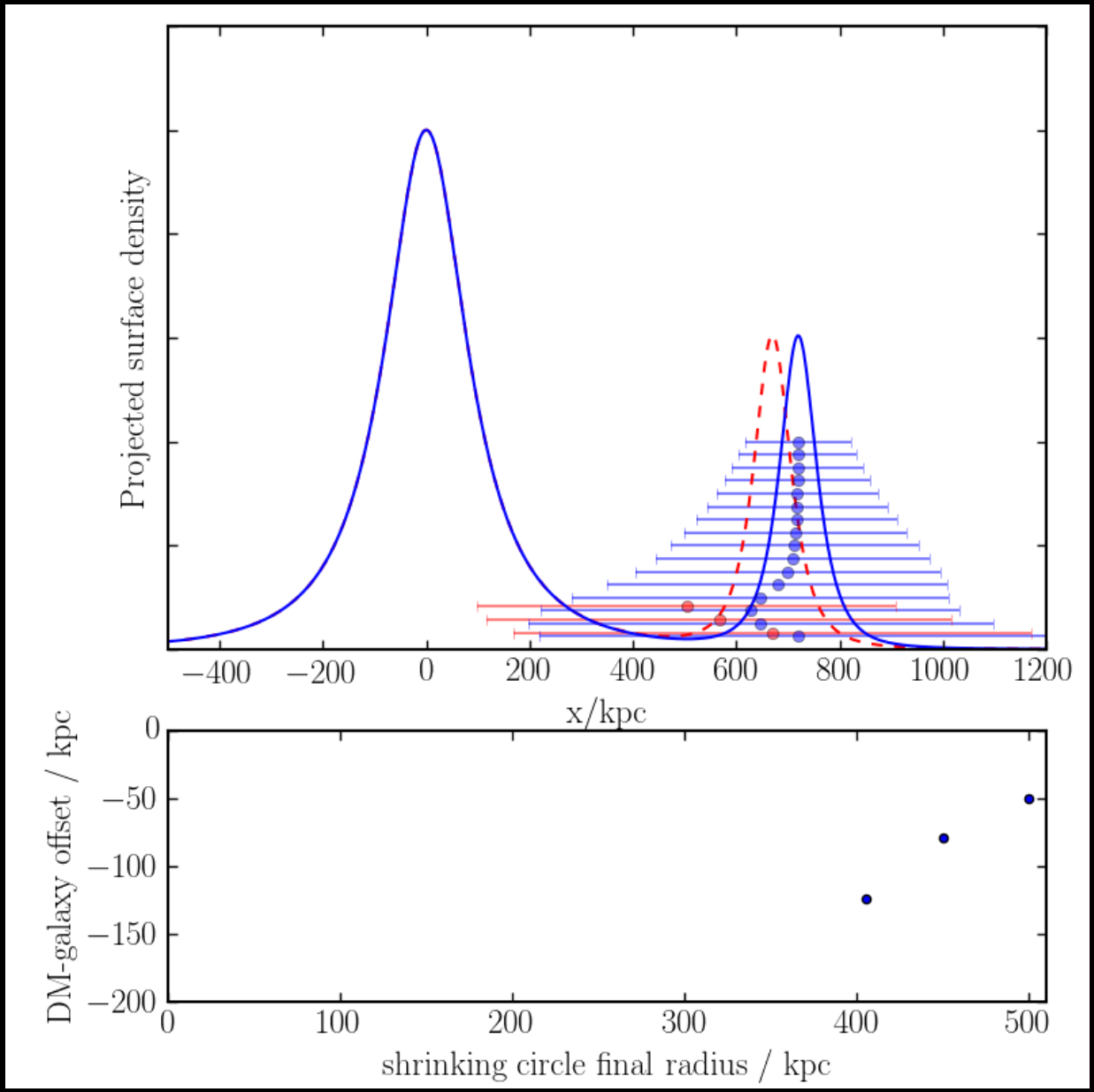
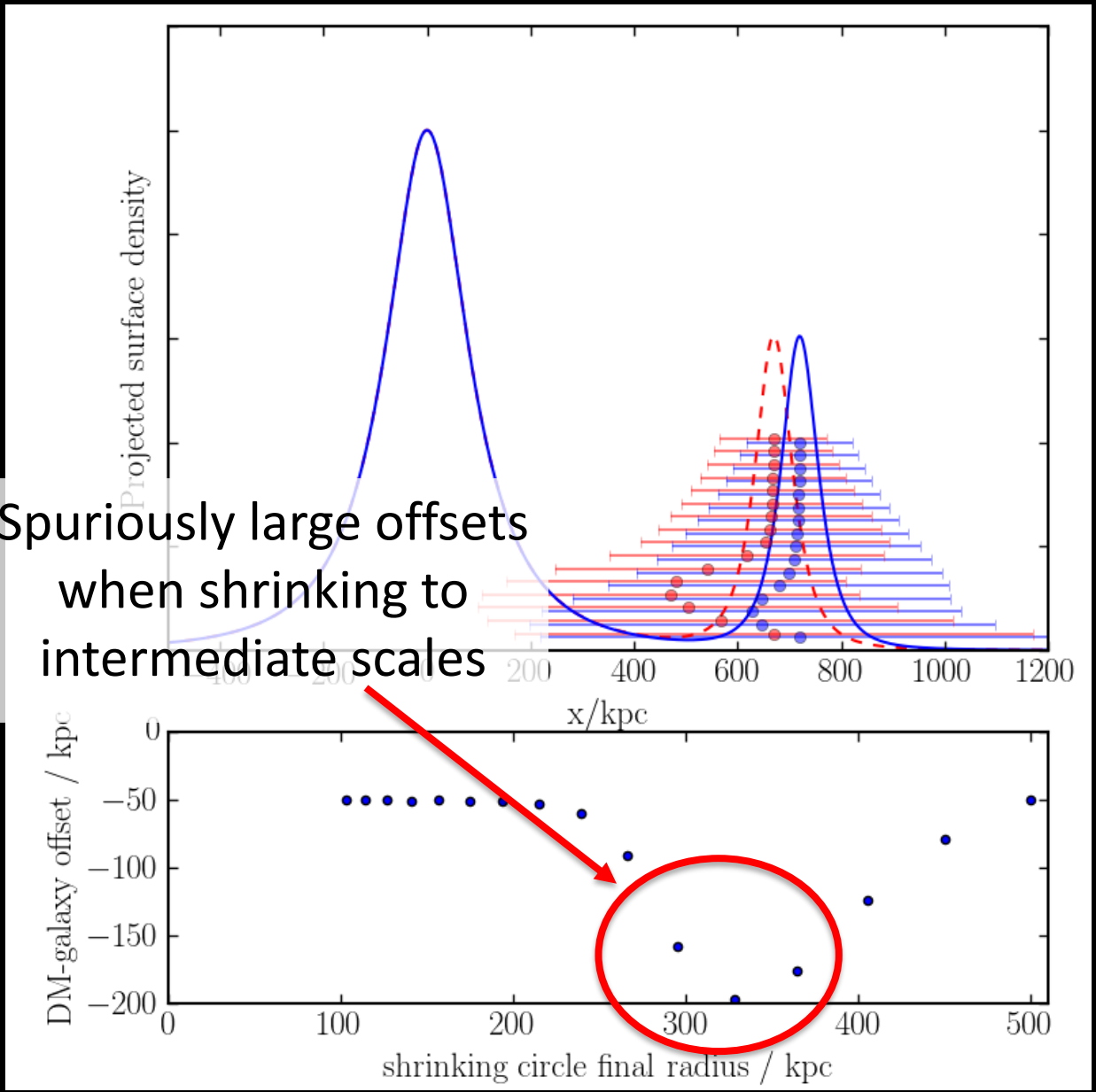


TOY MODEL OF SHRINKING CIRCLES

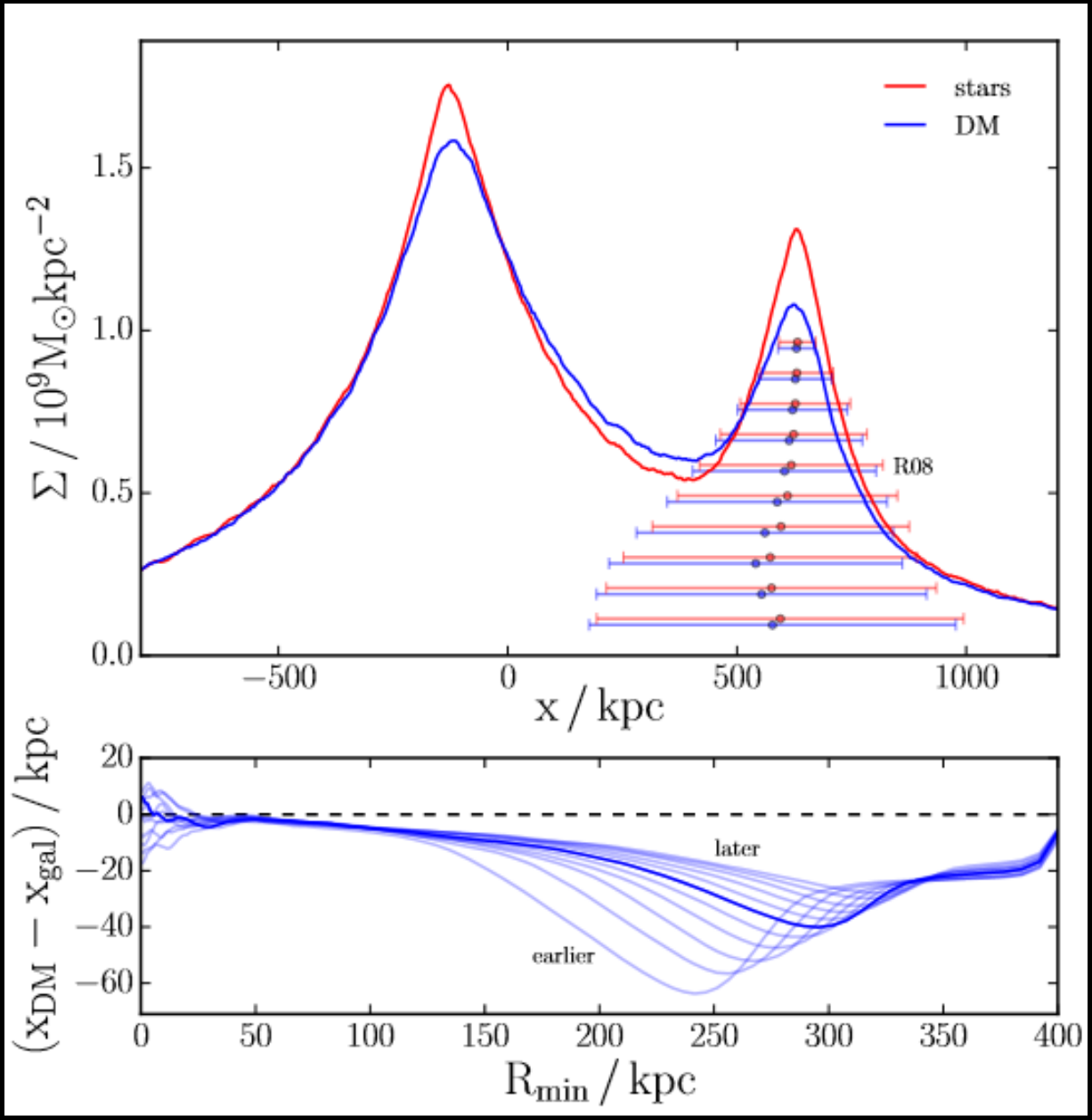


TOY MODEL OF SHRINKING CIRCLES



Spuriously large offsets when shrinking to intermediate scales

THE DISTRIBUTION OF SCATTERED PARTICLES



HALF-TIME CONCLUSION

- DM-galaxy offsets in the Bullet Cluster with isotropic SIDM are significantly smaller than has previously been claimed.
- And including the effects of DM subhaloes decreases these offsets further ☹

MNRAS **000**, 1–13 (2017) Preprint 11 July 2017 Compiled using MNRAS LATEX style file v3.0

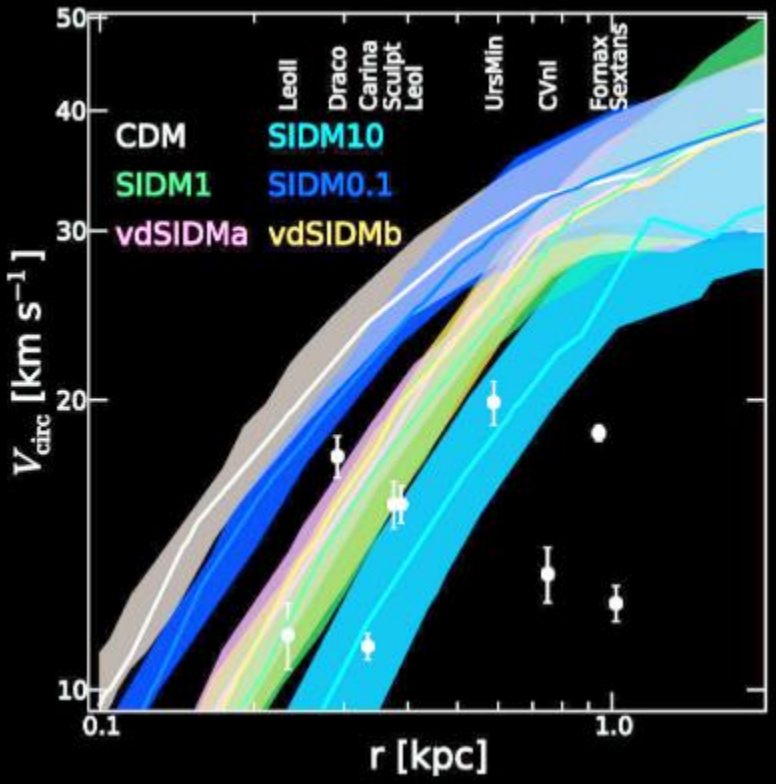
Effective description of dark matter self-interactions in small dark matter haloes*

Janis Kummer[1,2†], Felix Kahlhoefer[1] and Kai Schmidt-Hoberg[1]
[1] *DESY, Notkestrasse 85, D-22607 Hamburg, Germany*
[2] *Hamburger Sternwarte, Gojenbergsweg 112, D-21029 Hamburg, Germany*

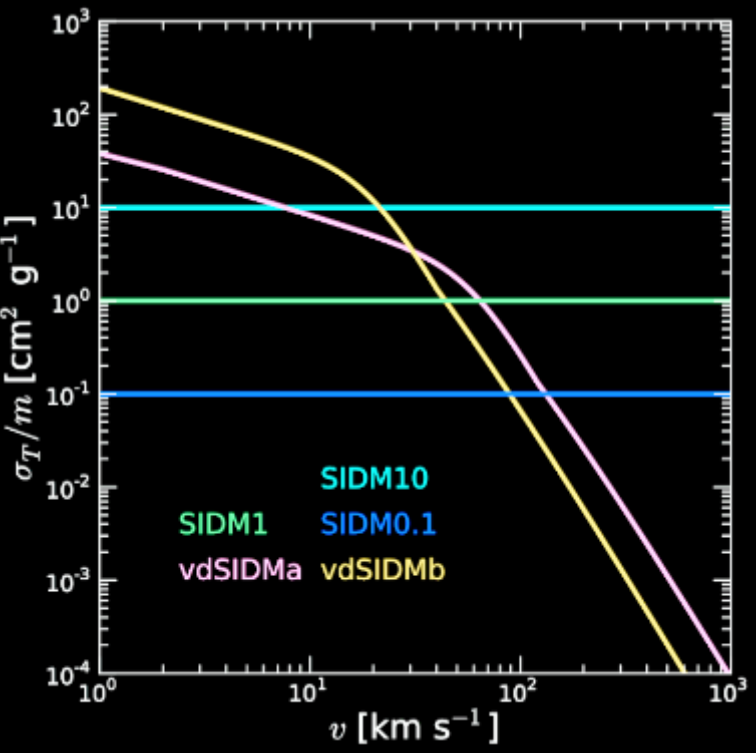
VELOCITY DEPENDENT SIDM

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

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



Zavala+ 2013

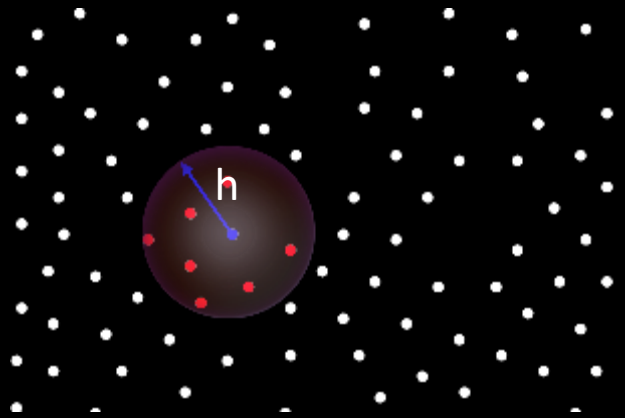


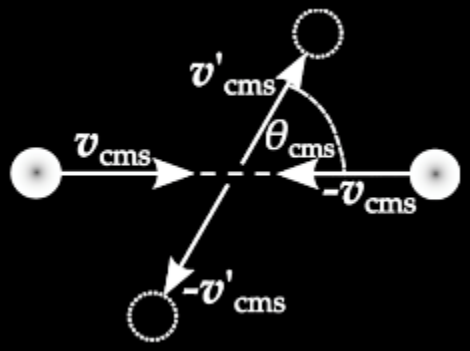
A natural outcome of some SIDM candidate models

(e.g. mirror DM or atomic DM)

SCATTERING WITH A GENERAL DIFERENTIAL CROSS-SECTION

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

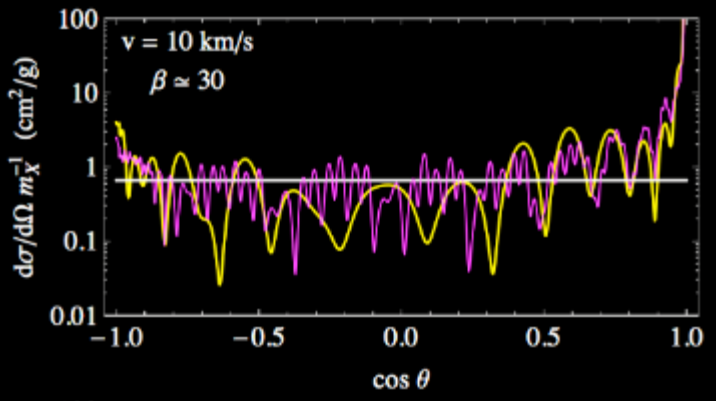


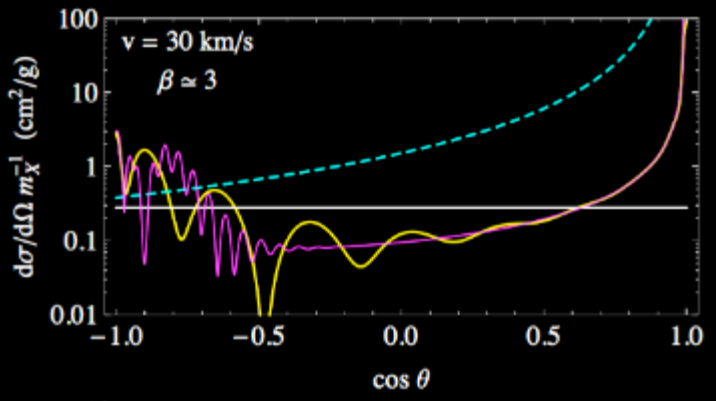


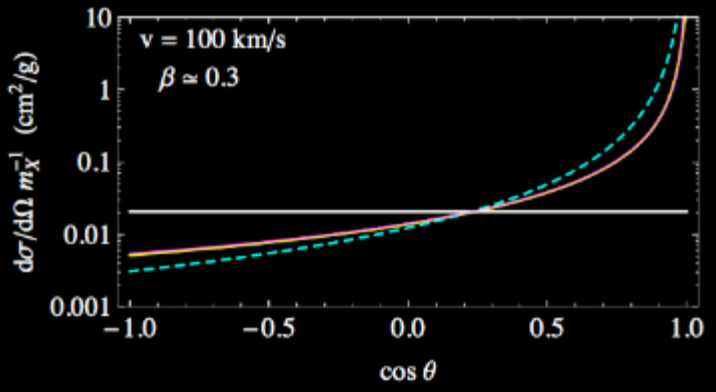
Kahlhoefer+ 2014

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

Tulin+ 2013

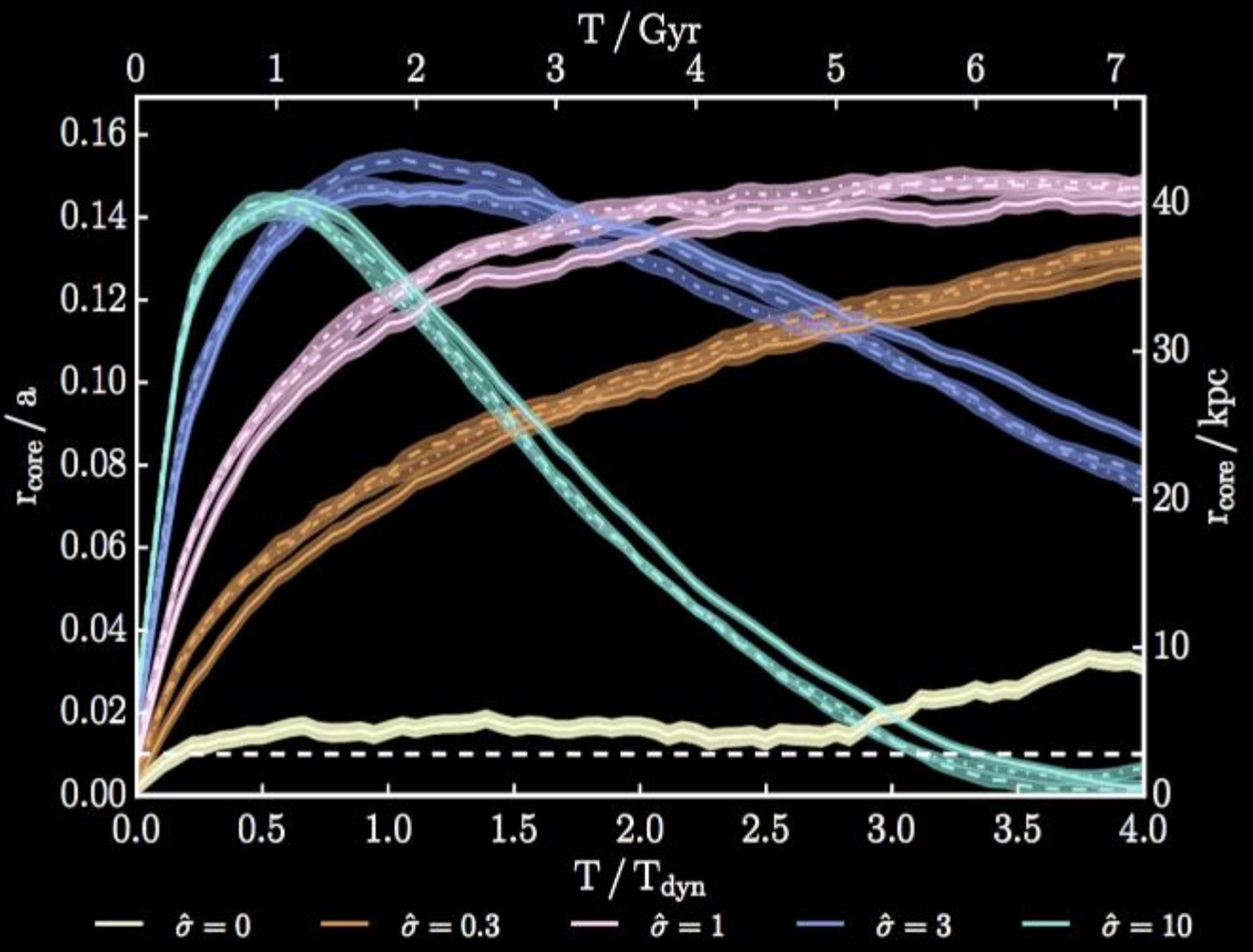




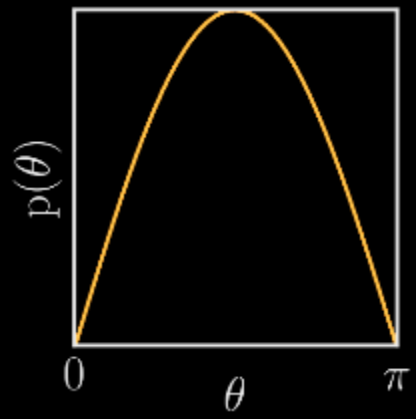


CORE GROWTH IN ISOLATED HALOES

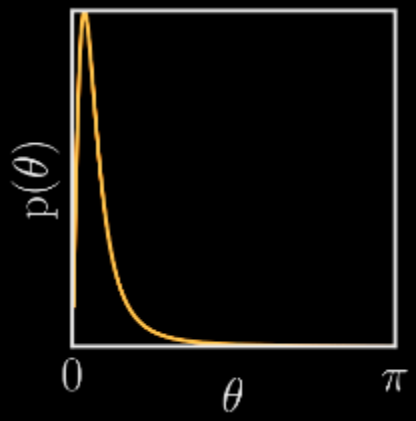
$$\sigma \equiv \int \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\mathrm{d}\Omega \qquad \sigma_{\tilde{T}} \equiv \int (1 - |\cos\theta|)\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\mathrm{d}\Omega$$



——— Isotropic scattering

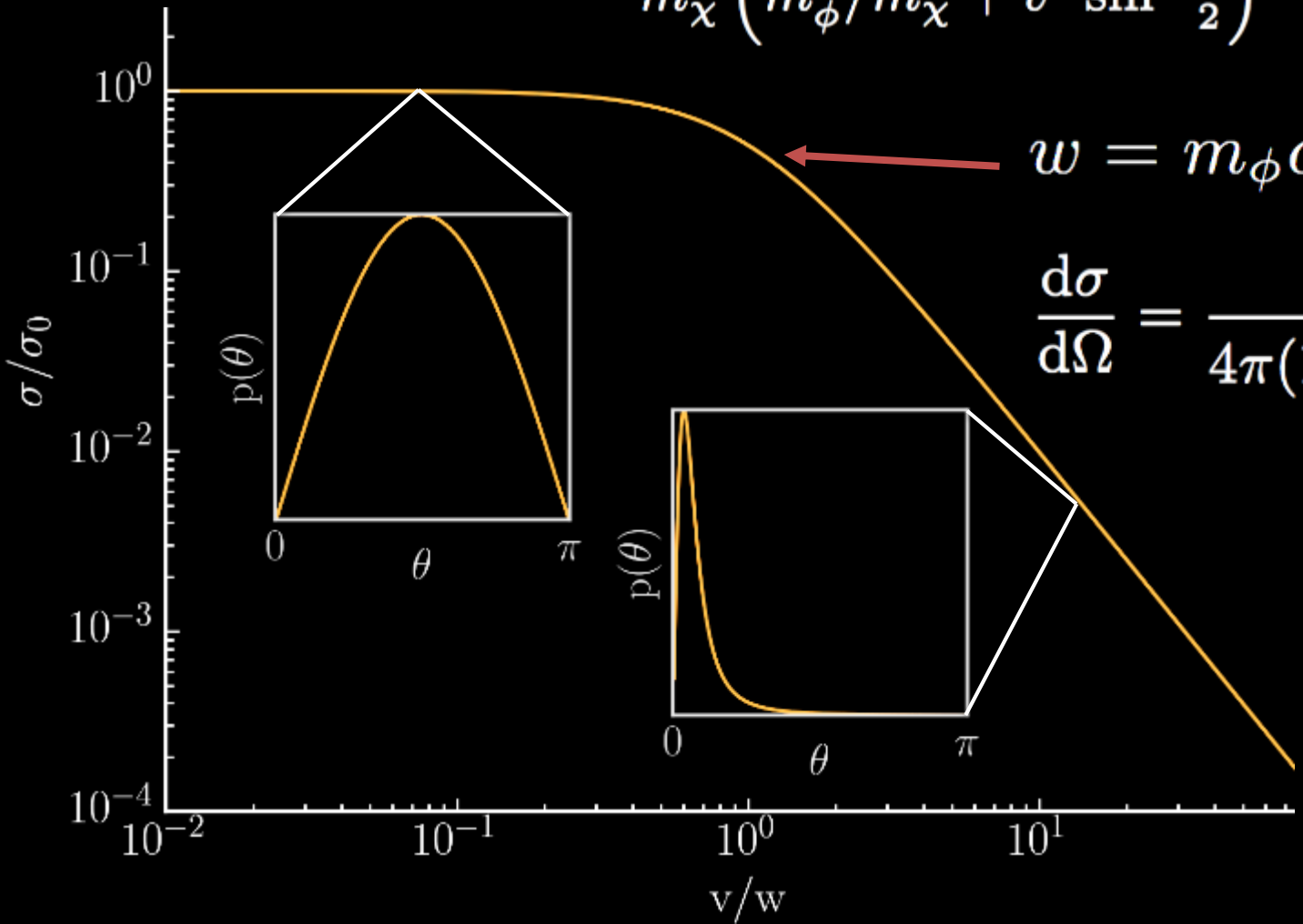


- - - - Anisotropic DM
5x more scattering



YUKAWA SCATTERING UNDER THE BORN-APPROXIMATION

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



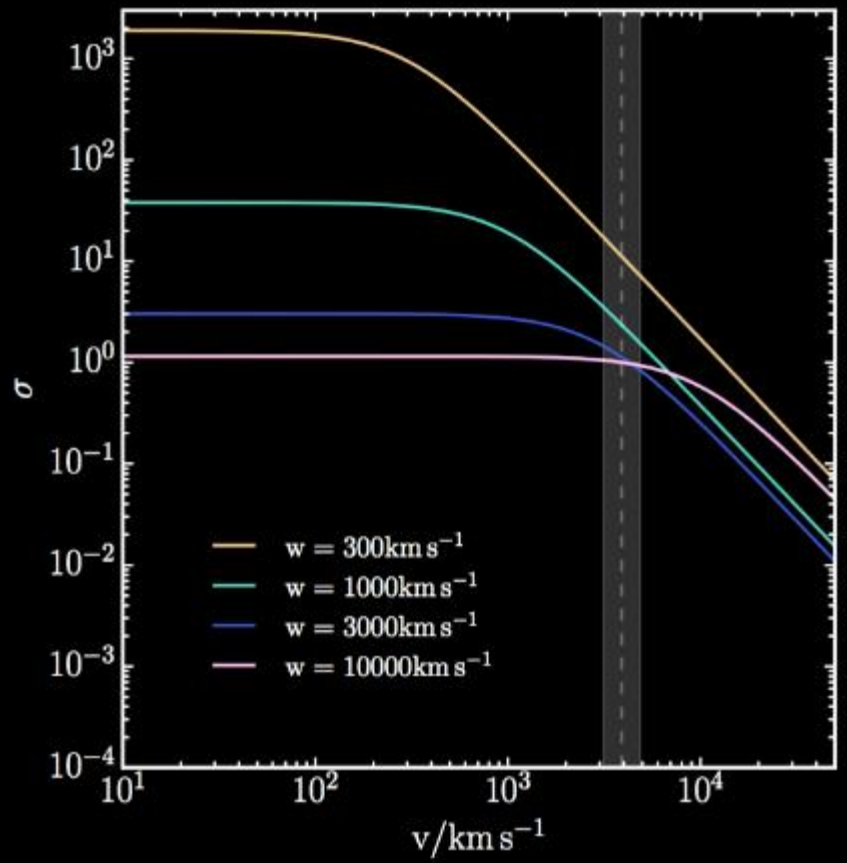
$$w = m_\phi c / m_\chi$$

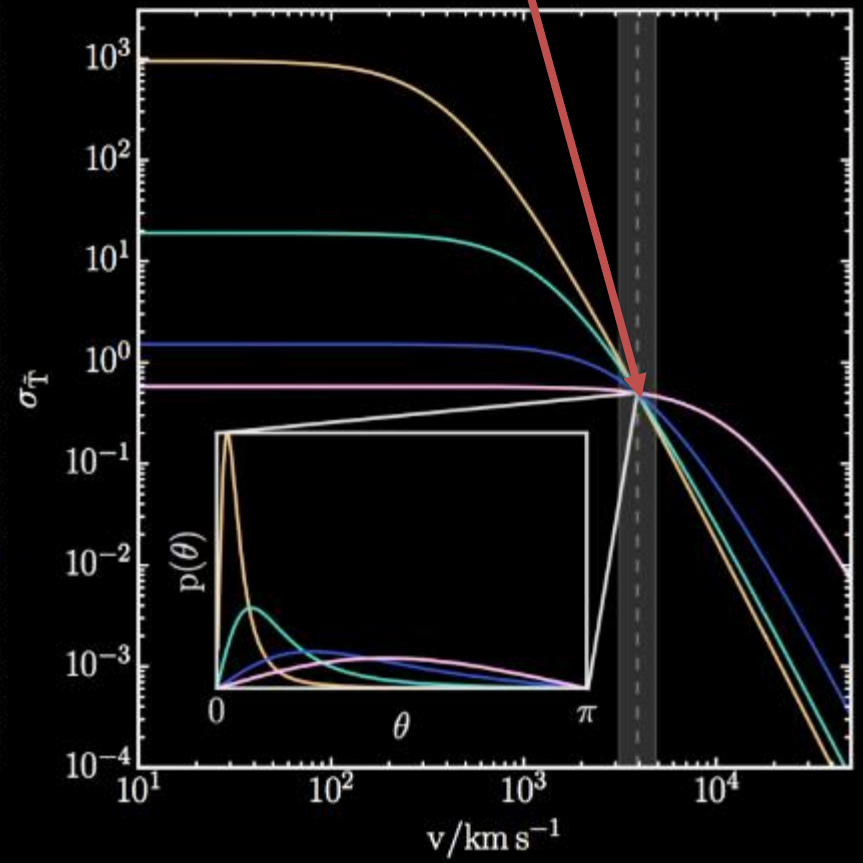
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\sigma_0}{4\pi(1 + \frac{v^2}{w^2} \sin^2 \frac{\theta}{2})^2}$$

YUKAWA CROSS-SECTIONS FOR BULLET CLUSTER SIMULATIONS

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

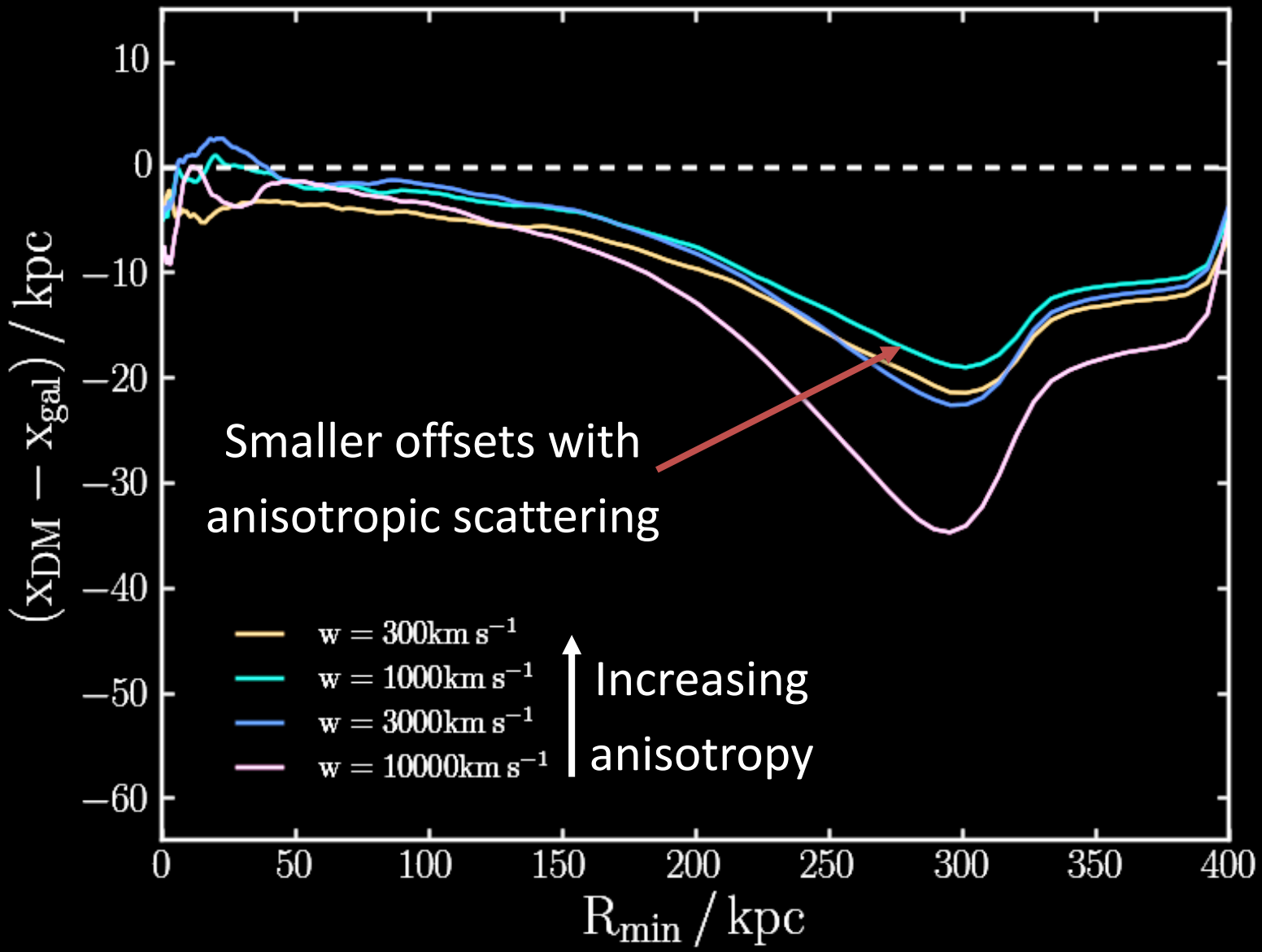
Matched to have same $\sigma_{\tilde{T}}$ at 3900 km/s





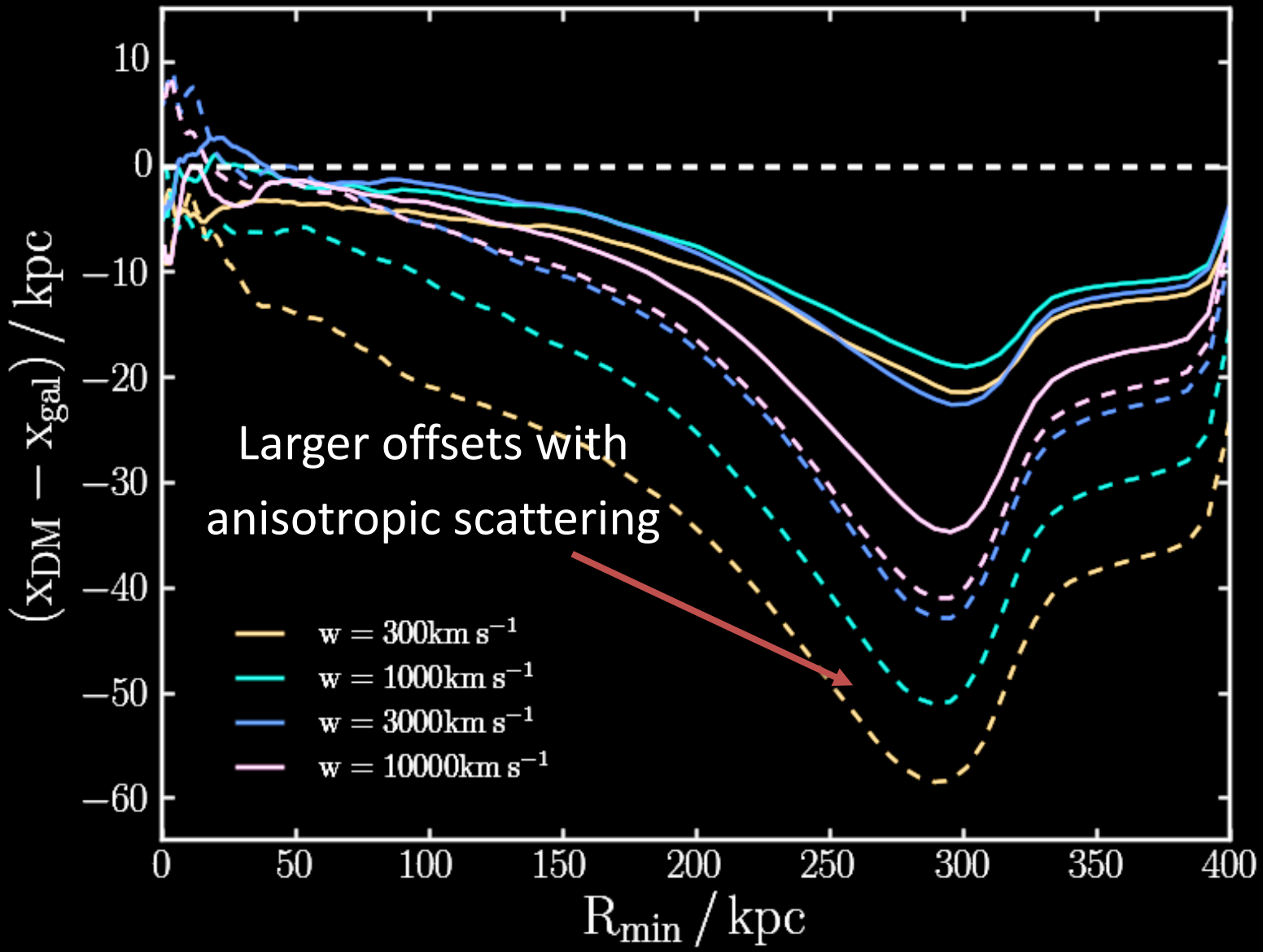
DM-GALAXY OFFSETS

(using the method I just said you shouldn't use!)

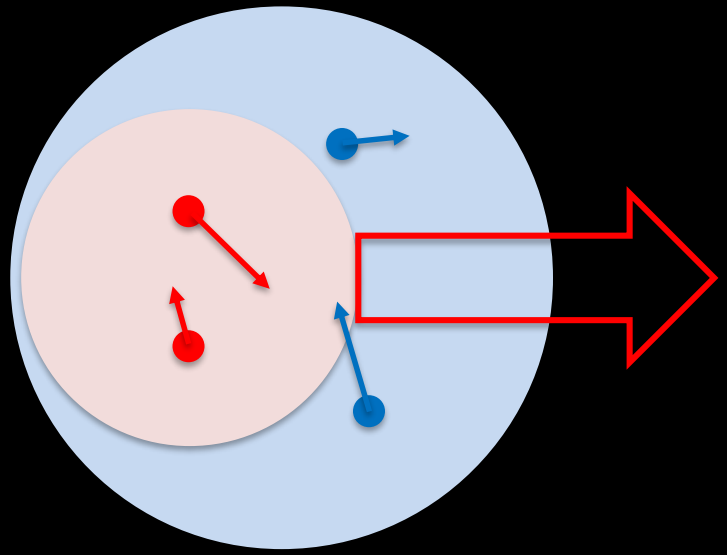


DM-GALAXY OFFSETS

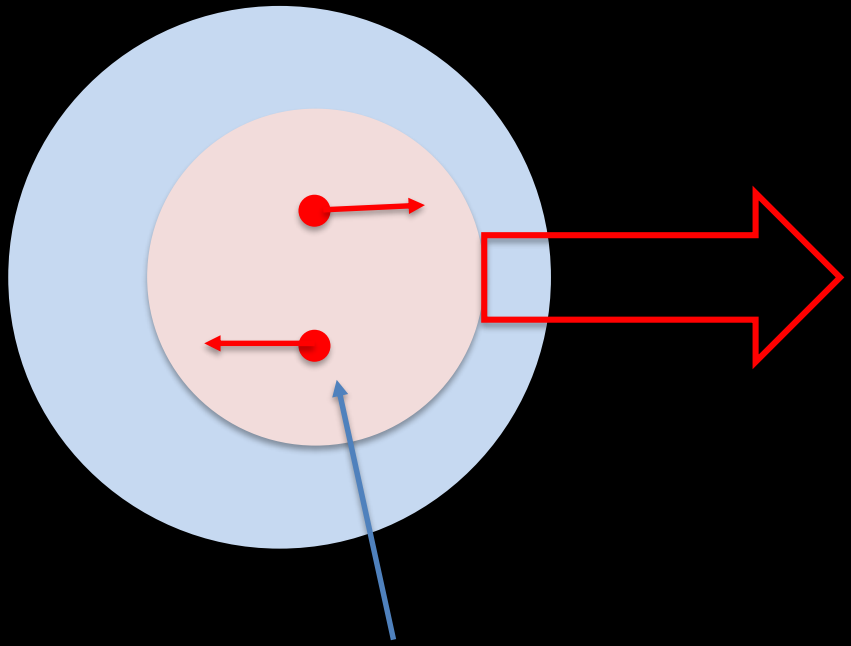
(WITH VELOCITY-DEPENDENCE 'TURNED OFF')



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



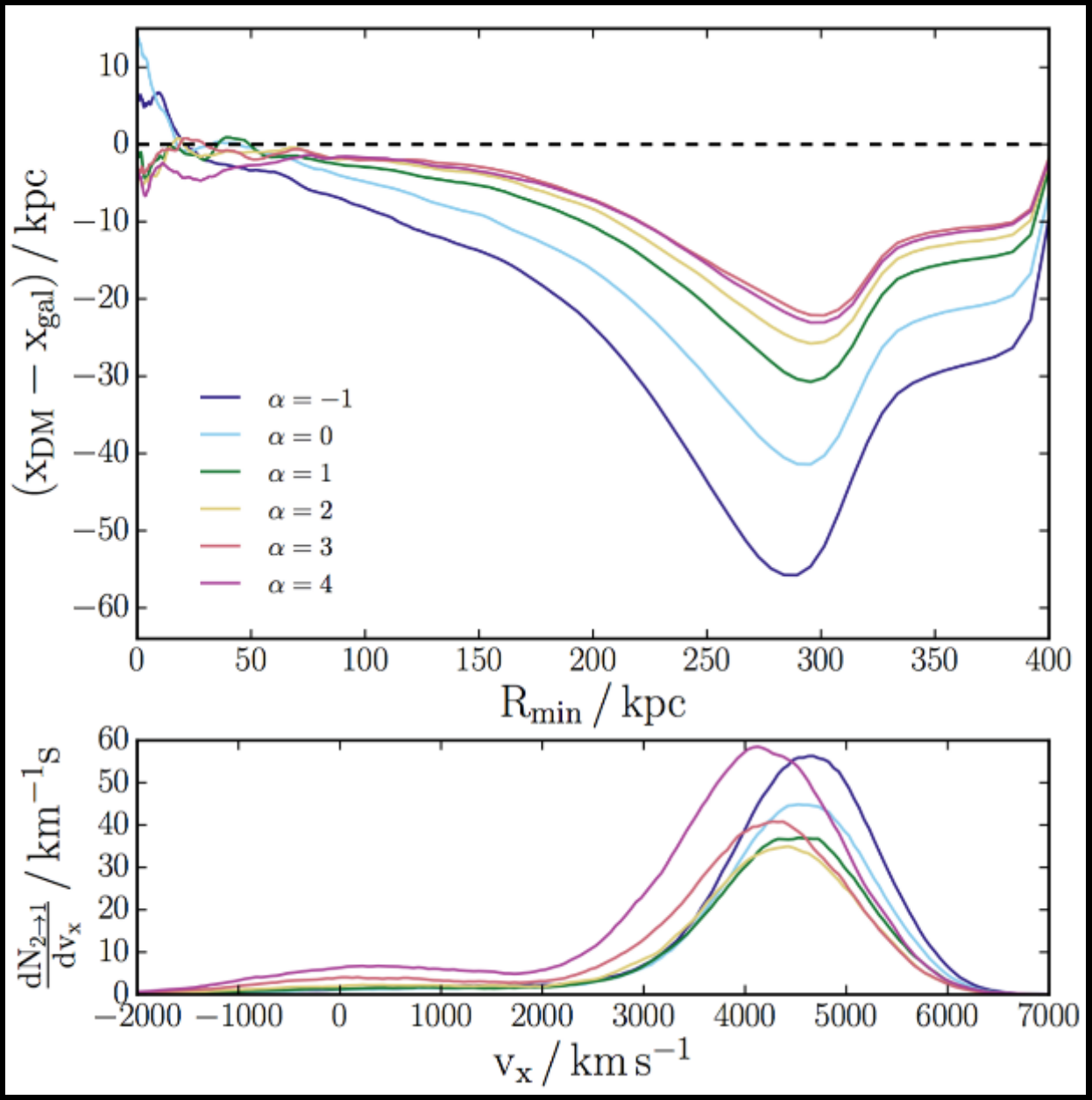
Particles moving ‘backwards’ with respect to their halo’s direction of motion have a lower relative velocity with respect to the other halo – more likely to scatter

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

THE EFFECTS OF VELOCITY DEPENDENCE



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

THE DISTRIBUTION OF SCATTERED PARTICLES