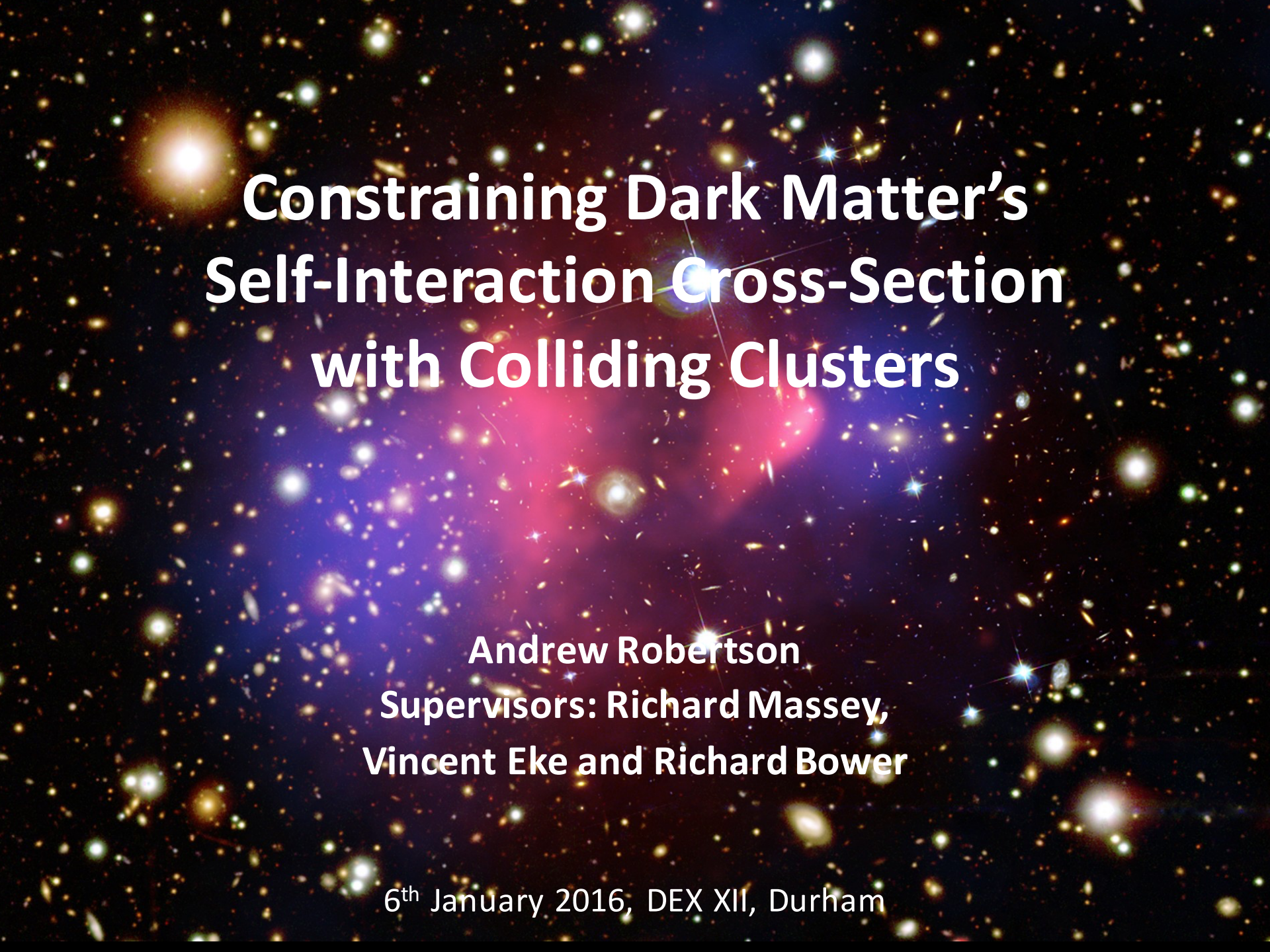

Constraining Dark Matter's Self-Interaction Cross-Section with Colliding Clusters

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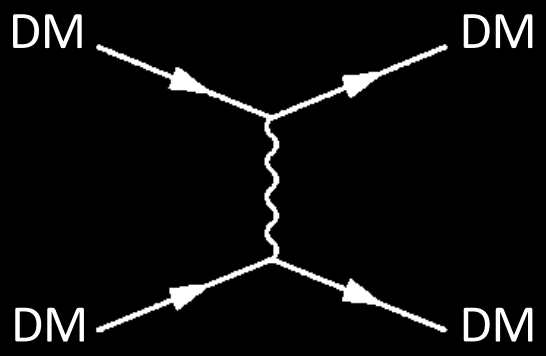
Supervisors: Richard Massey, Vincent Eke and Richard Bower

6th January 2016, DEX XII, Durham

WHY STUDY SELF-INTERACTING DARK MATTER?

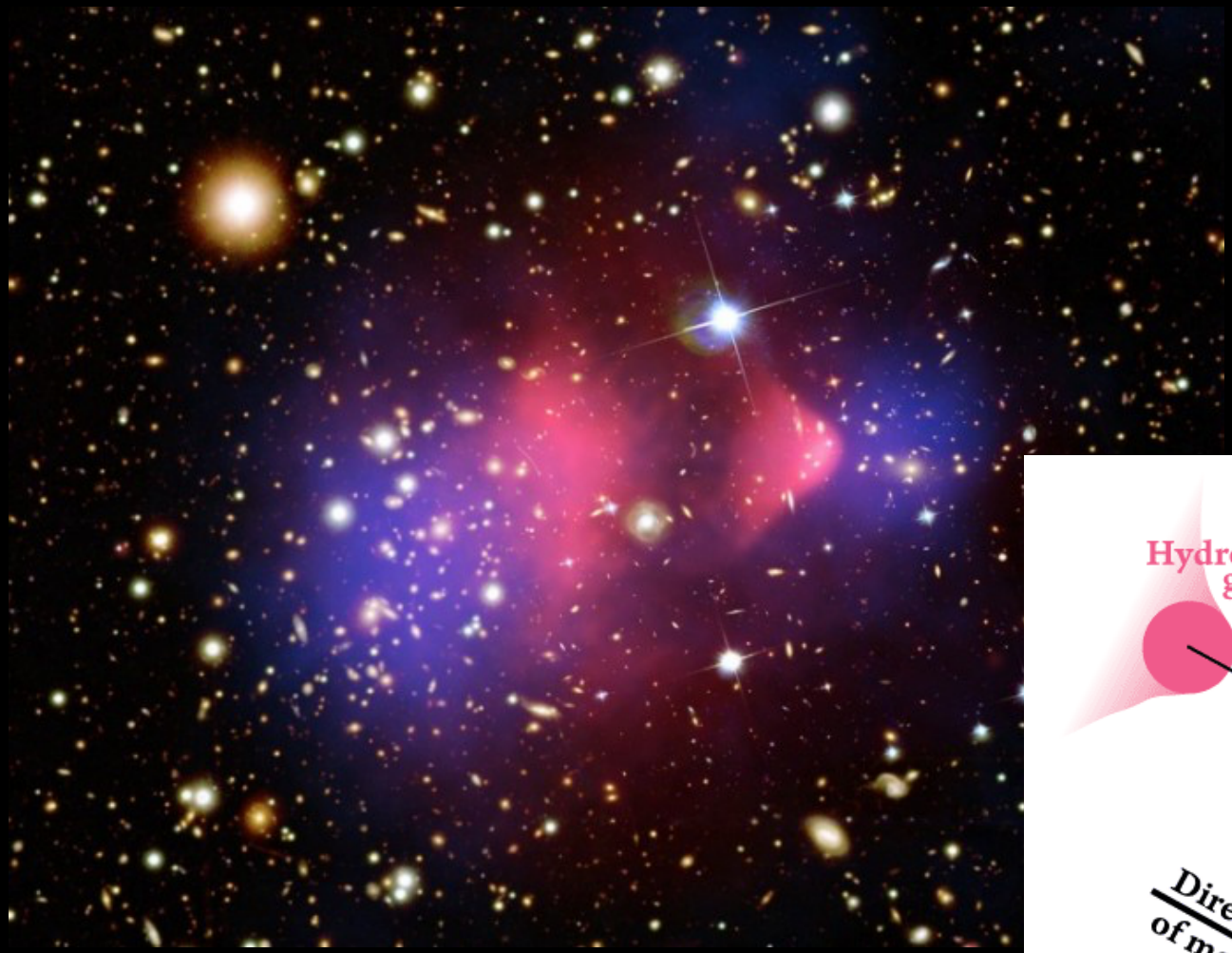
- Probably don't need it to fix Cosmology's "small scale problems" – and small scales are a tricky place to look!

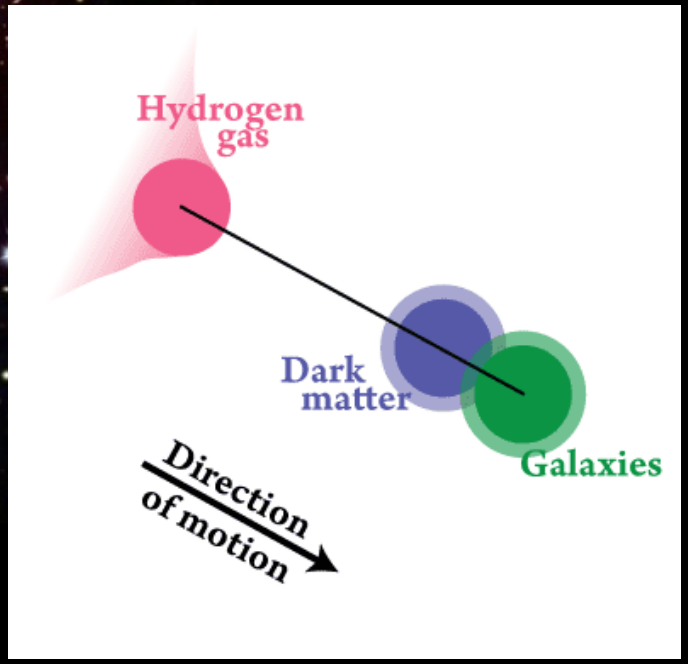
- But there are numerous particle physics models of DM that predict elastic scattering of DM particles. Examples include:
  - "Fluid Dark Matter" (Peebles, 2000)
  - "Q-balls" (Kusenko and Steinhardt, 2001)
  - "Mirror Dark Matter" (Mohapatra+ 2001)
  - "Dark Electromagnetism" (Ackerman+ 2006)
  - "DM with Yukawa Potential" (Loeb and Weiner, 2011)
  - "Light Asymmetric DM" (Frandsen+ 2011)
  - "Composite strongly interacting dark matter" (Cline+ 2014)
  - "Higgs-portal Scalar Dark Matter" (Han and Zheng, 2015)



- Limits on the DM scattering cross-section are useful to constrain these models

THE BULLET CLUSTER – A TOY MODEL





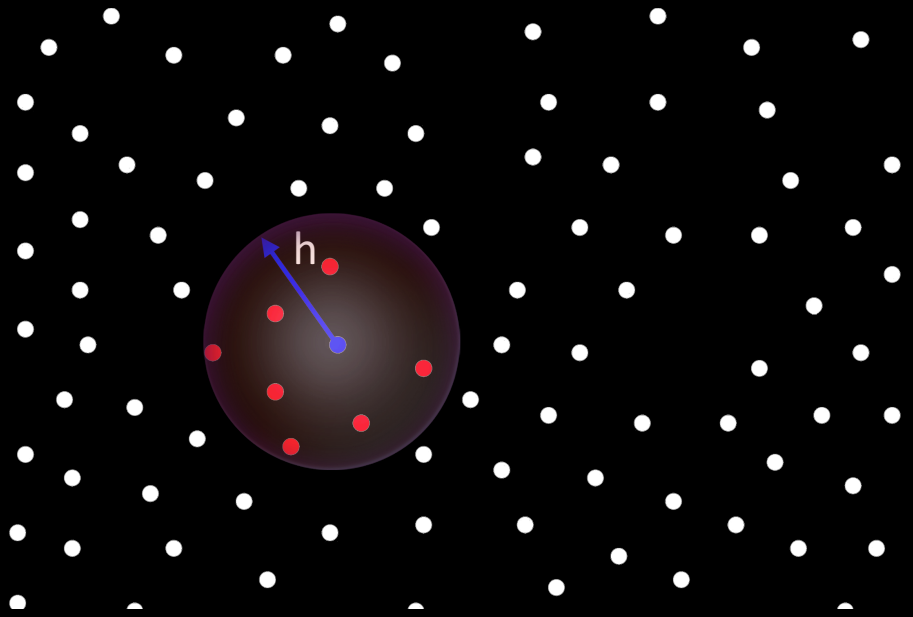
CALCULATING SCATTERING PROBABILITIES

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

Probability of particle i scattering from particle j, in time Δt is:

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

Short Range interactions, with O(1) interaction per particle per Hubble time

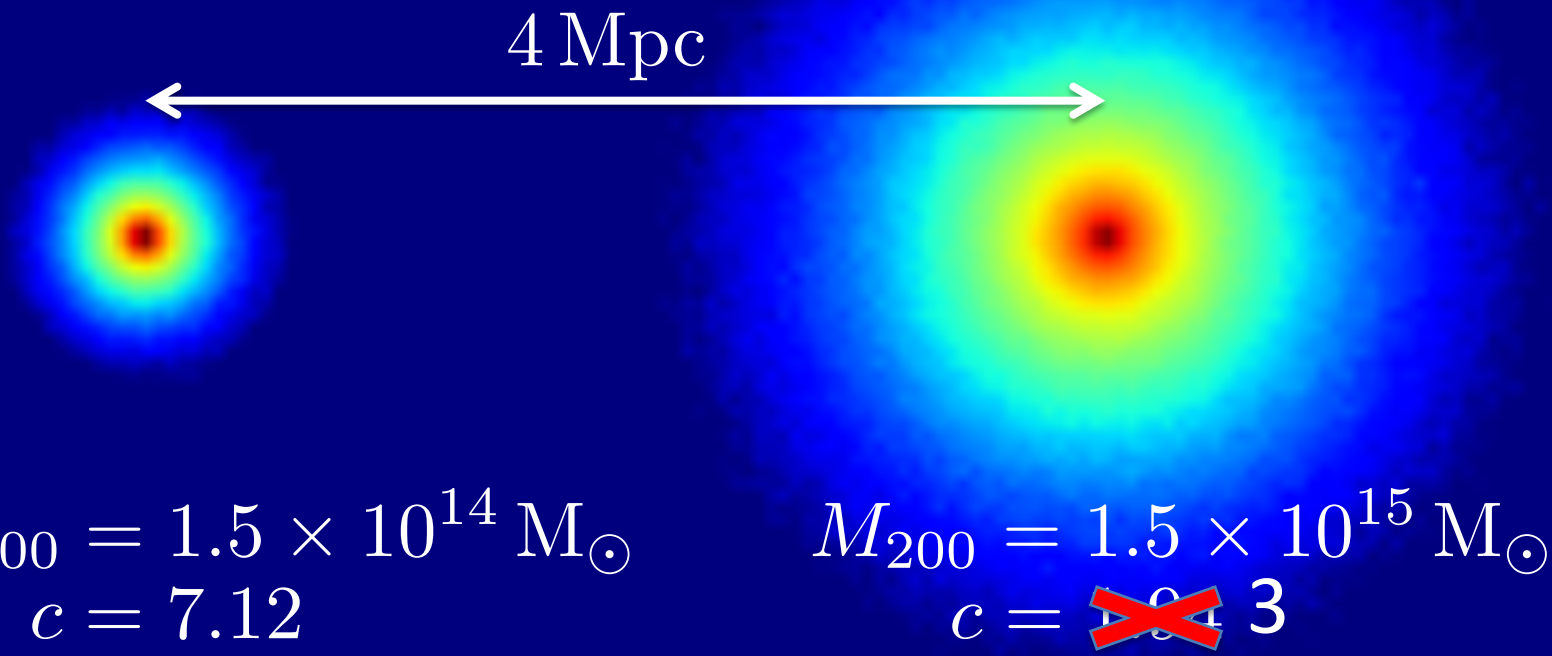


Local quantities estimated from region within 'search radius', h

- Fixed h
- Vary h to encompass a fixed number of neighbours
- Kernel weight

INITIAL CONDITIONS

- Use weak-lensing NFW fit for fiducial model
- Convert NFW haloes to Hernquist haloes
- Gas density follows DM density profile
- Set gas temperatures for hydrostatic equilibrium
- Put in collisionless tracers (galaxies)
- Zero impact parameter

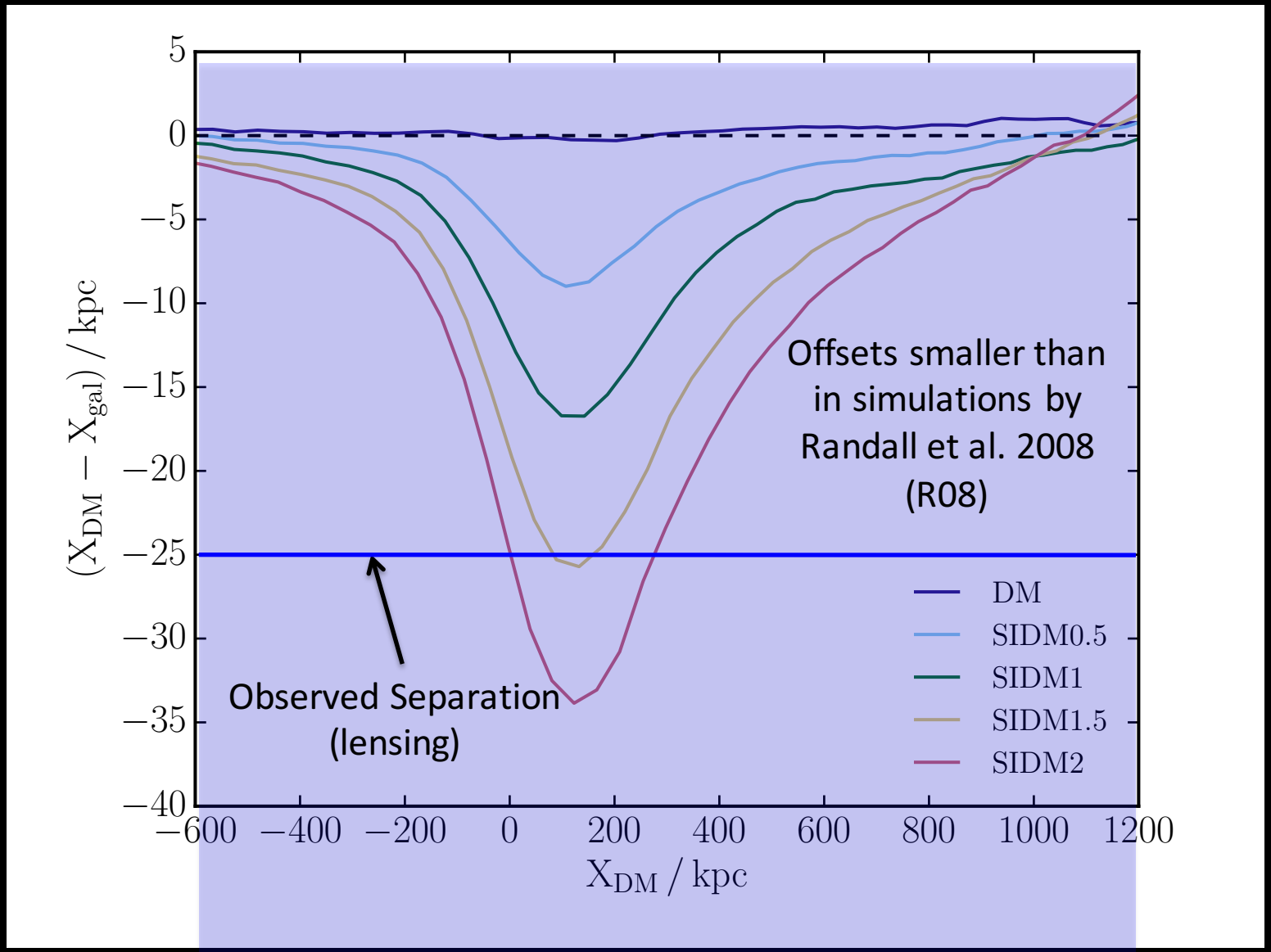


$M_{200} = 1.5 \times 10^{14}\,\mathrm{M}_\odot$
$c = 7.12$

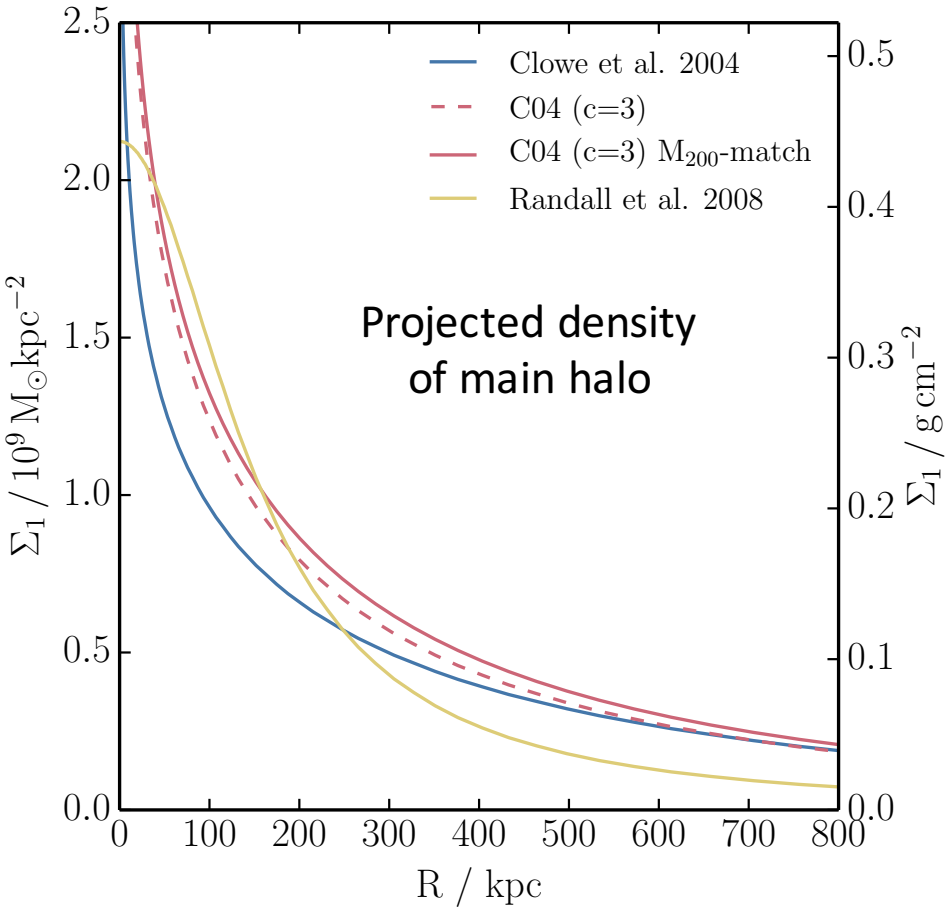
$M_{200} = 1.5 \times 10^{15}\,\mathrm{M}_\odot$
$c =$ ~~4~~ 3

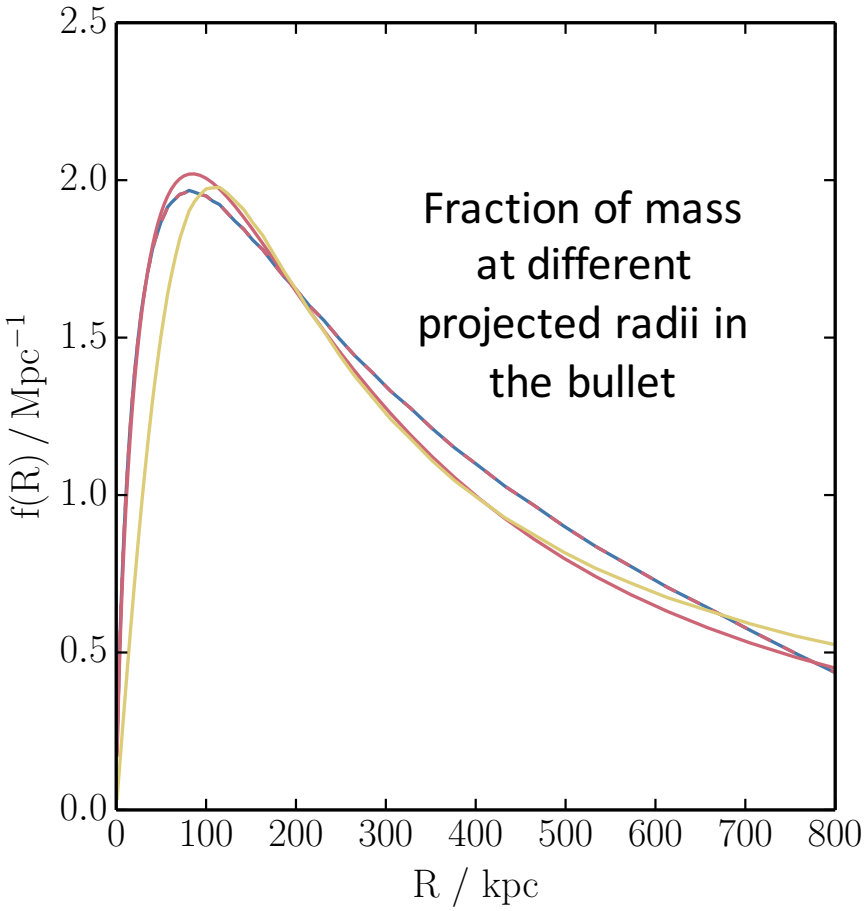
SMASHING THEM TOGETHER (GAS TEMPERATURE MAP)

DM–GALAXY OFFSETS



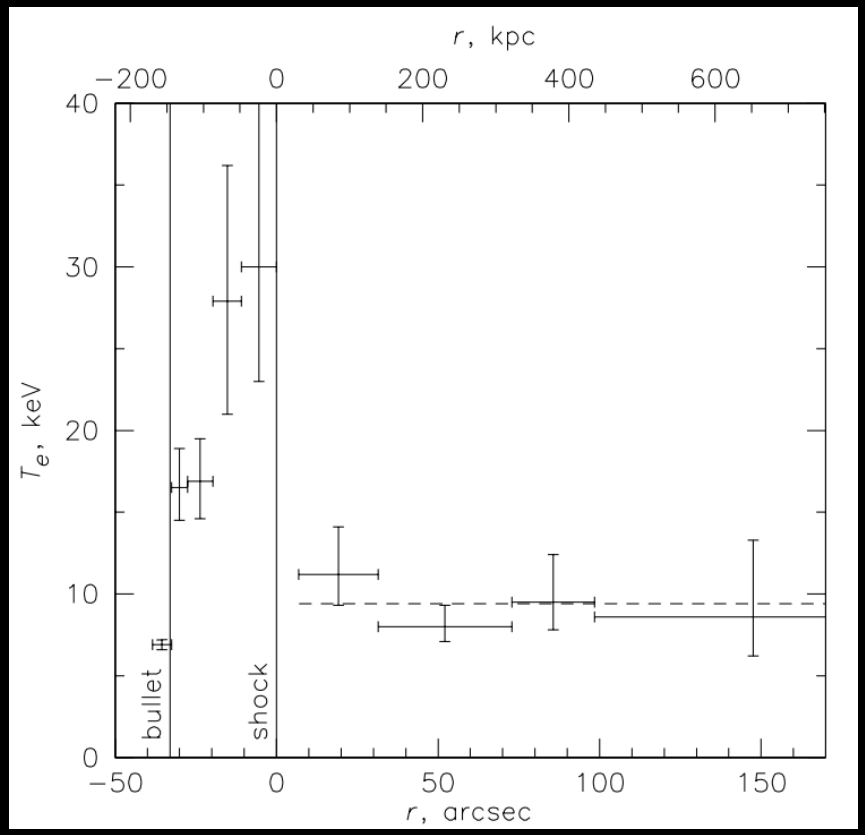
DENSITY PROFILE COMPARISON





Density profiles used suggest a similar fraction of scattered particles in the R08 simulations

THE SHOCK VELOCITY IN THE BULLET CLUSTER



Markevitch 2006

Discontinuity in gas properties across the shock gives Mach number

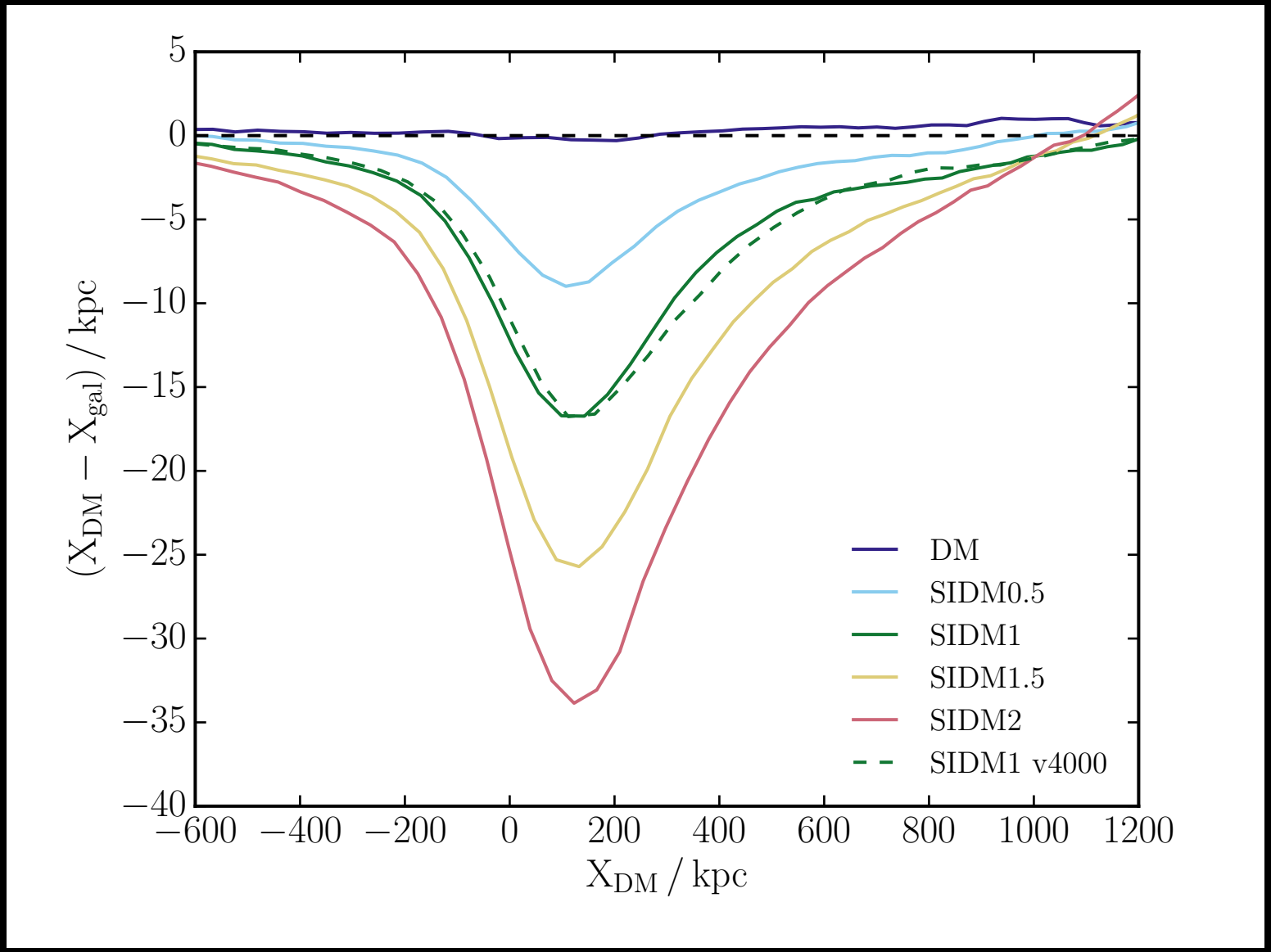
$$\mathcal{M} = 3.0 \pm 0.4$$

Combined with the temperature of the pre-shock gas, this gives a shock velocity

$$v_{\rm s} = 4700 \pm 600\,{\rm km\,s^{-1}}$$

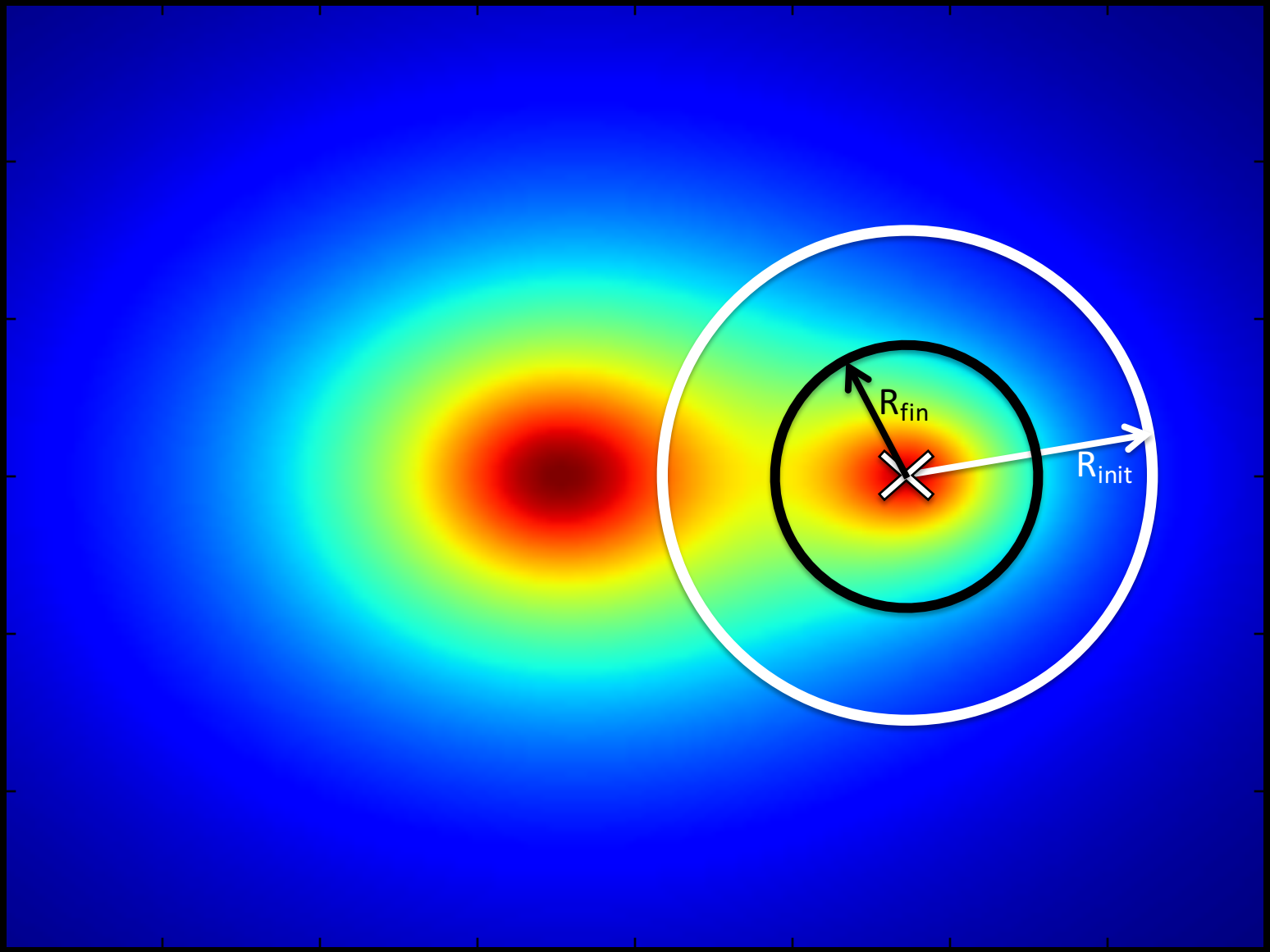
In Randall et al. 2008 this was assumed to be the relative velocity between the two dark matter haloes. But Springel and Farrar 2007 demonstrated that the shock velocity can be matched with a much lower relative velocity between the DM haloes.

THE EFFECT OF MERGER VELOCITY

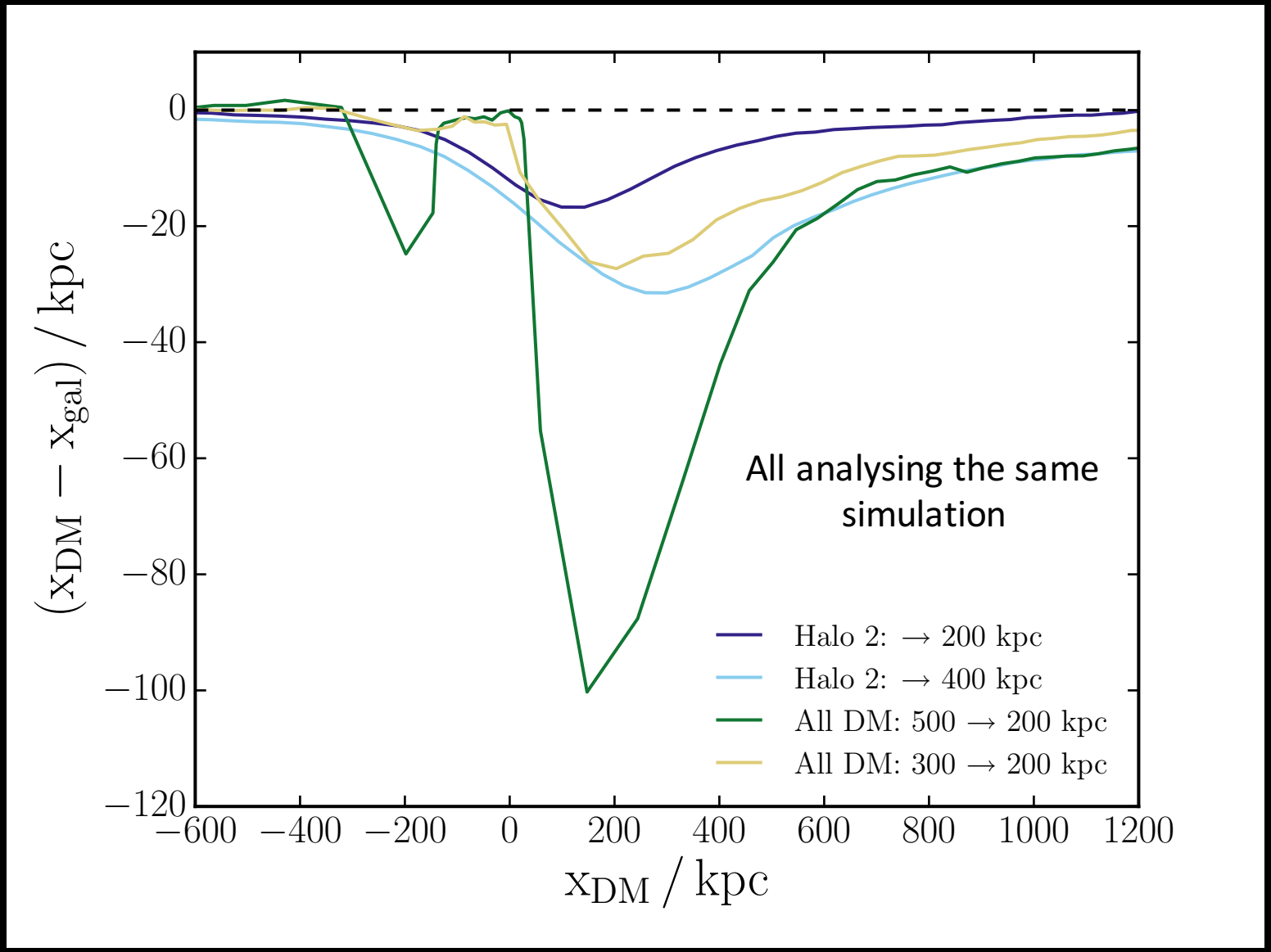


MEASURING HALO POSITIONS

SHRINKING CIRCLES



HOW YOU ANALYSE SIMULATIONS IS IMPORTANT!



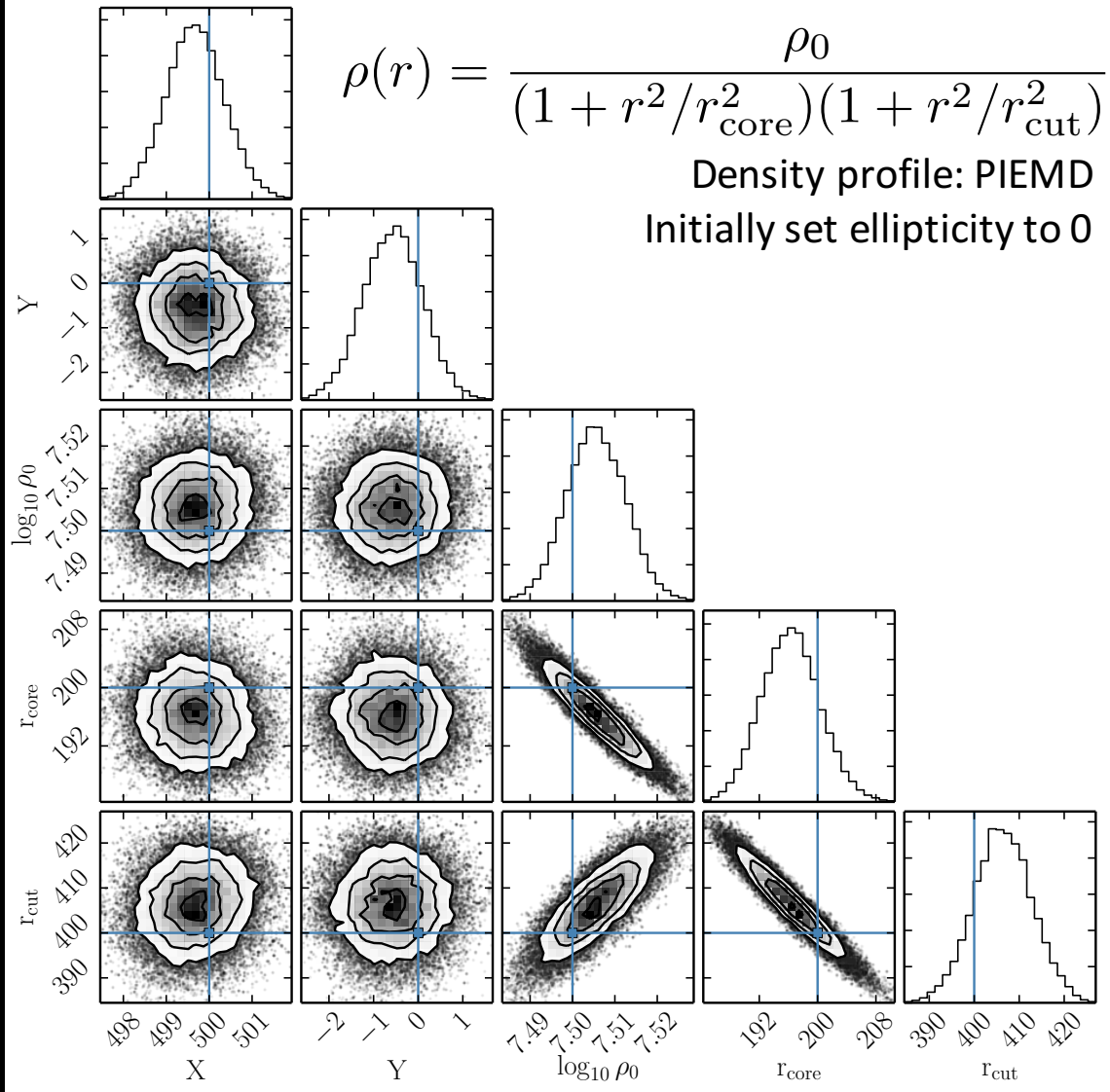
MEASURING HALO POSITIONS

PARAMETRIC FITTING

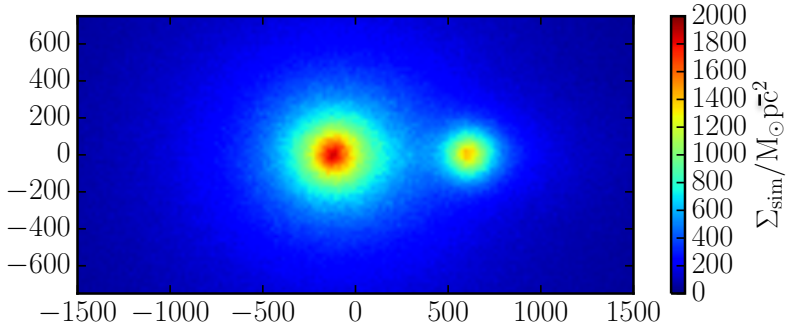
$$\rho(r) = \frac{\rho_0}{(1 + r^2/r_{\rm core}^2)(1 + r^2/r_{\rm cut}^2)}$$

Density profile: PIEMD

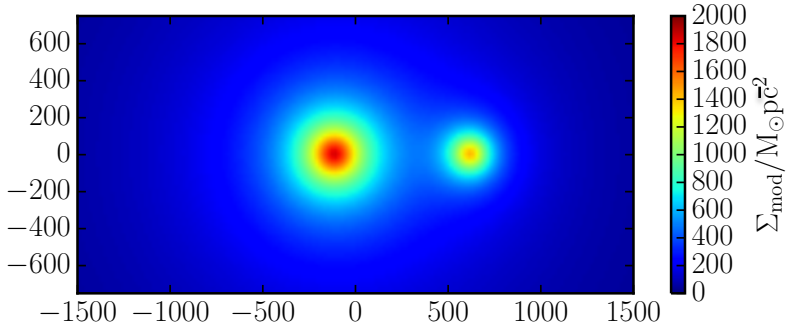
Initially set ellipticity to 0



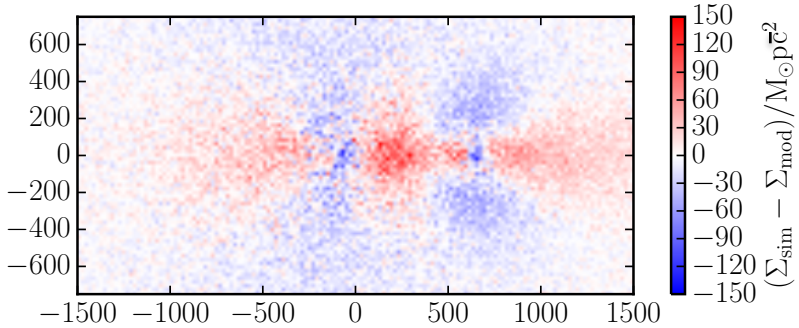
FITTING TO THE SIMULATION SNAPSHOTS



Simulation

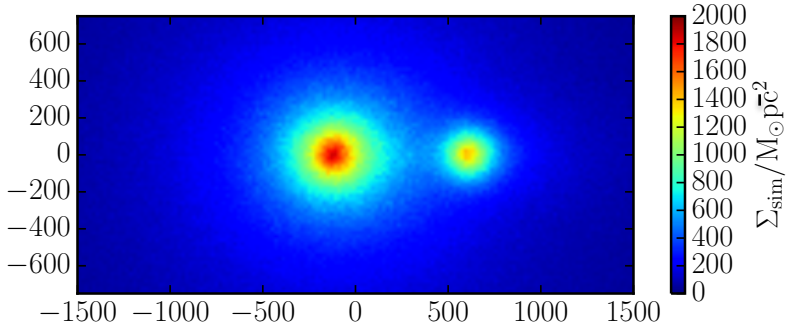


Model

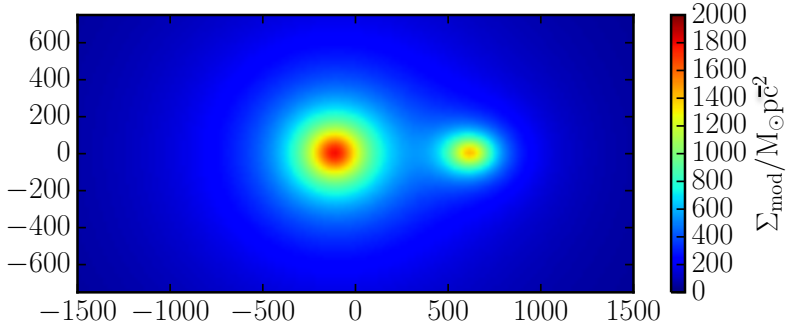


Residuals

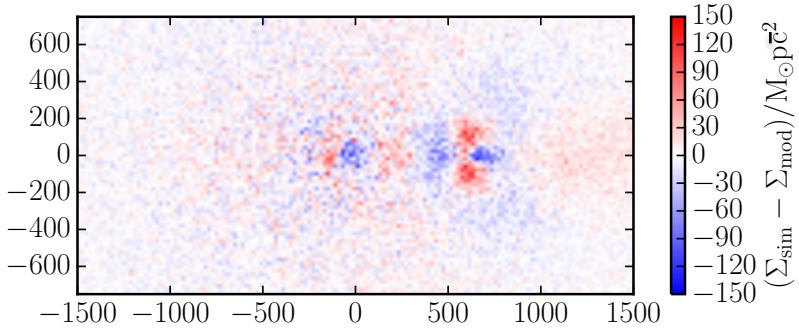
FITTING TO THE SIMULATION SNAPSHOTS



Simulation

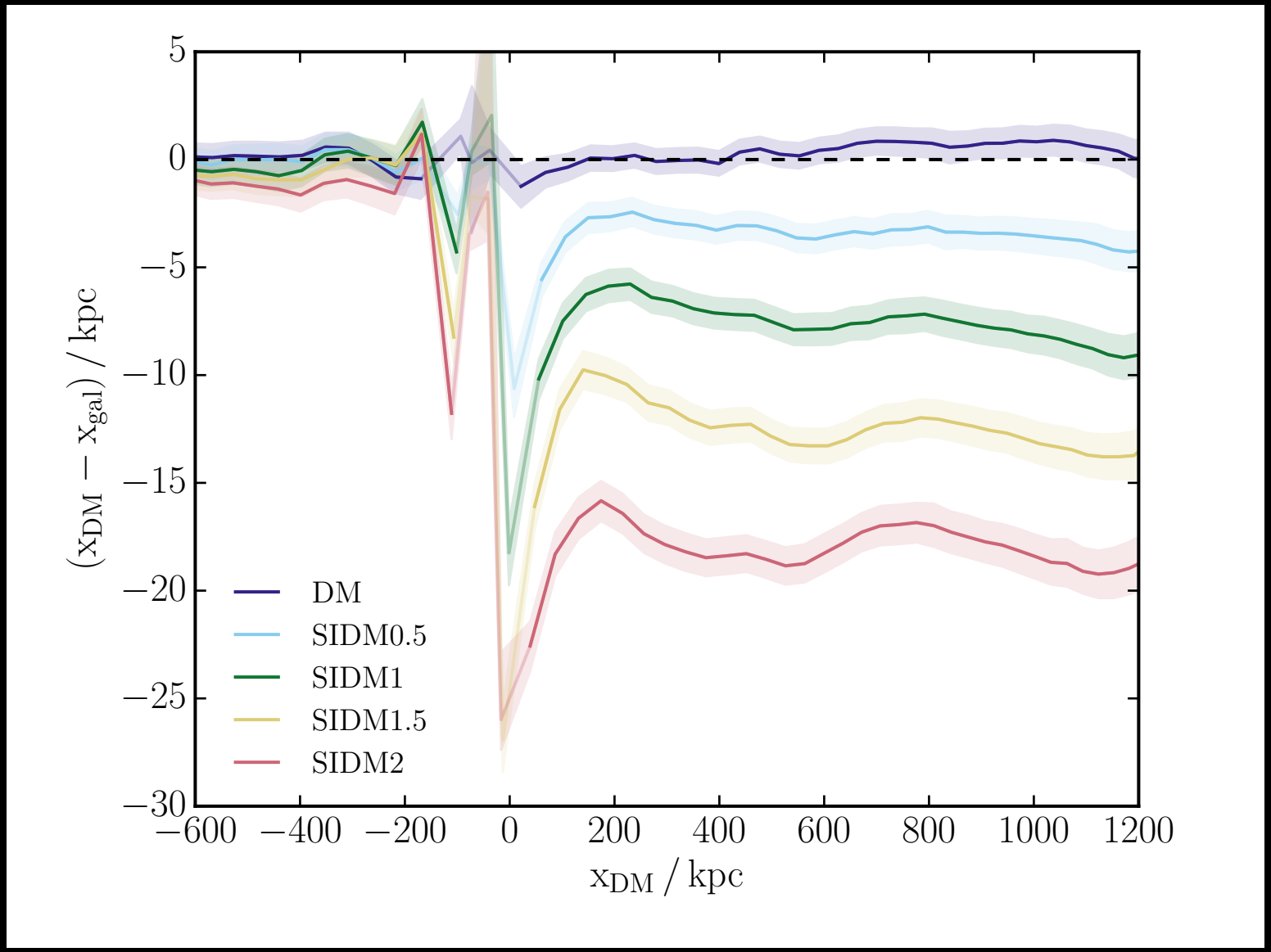


Model

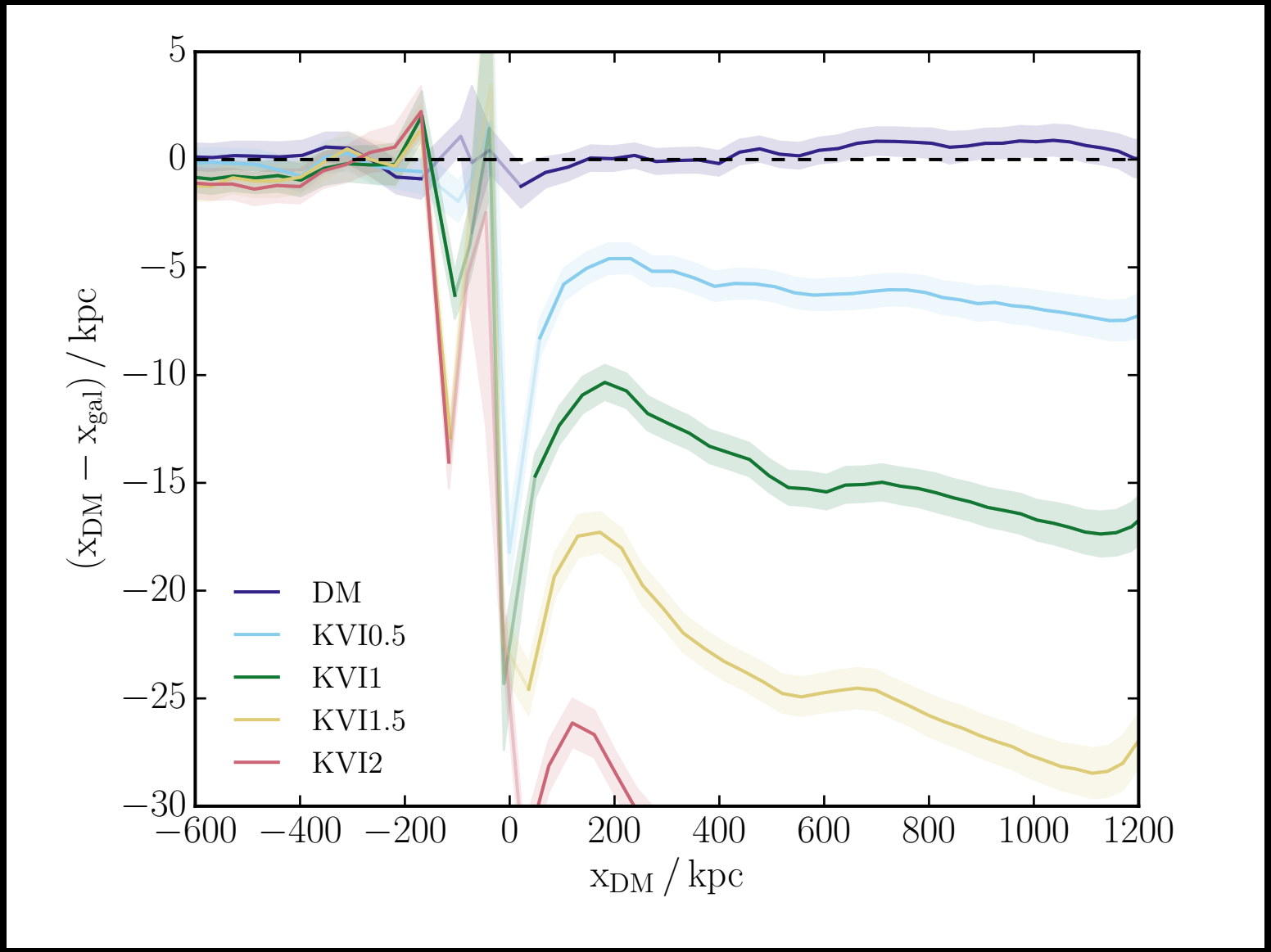


Residuals

DM-GALAXY OFFSETS FROM PARAMETRIC FITS TO PROJECTED DENSITY



OFFSETS WITH AN ANGULAR-DEPENDENT SCATTERING CROSS-SECTION



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
- The current tightest constraint on SIDM cross-sections from merging clusters may not be all that robust

- QUESTION – What is the smoking gun of SIDM?

- QUESTION – Should we worry about modifications to ΛCDM?