Signatures of Self-Interacting Dark Matter on Cluster Density Profile and Subhalo Distributions

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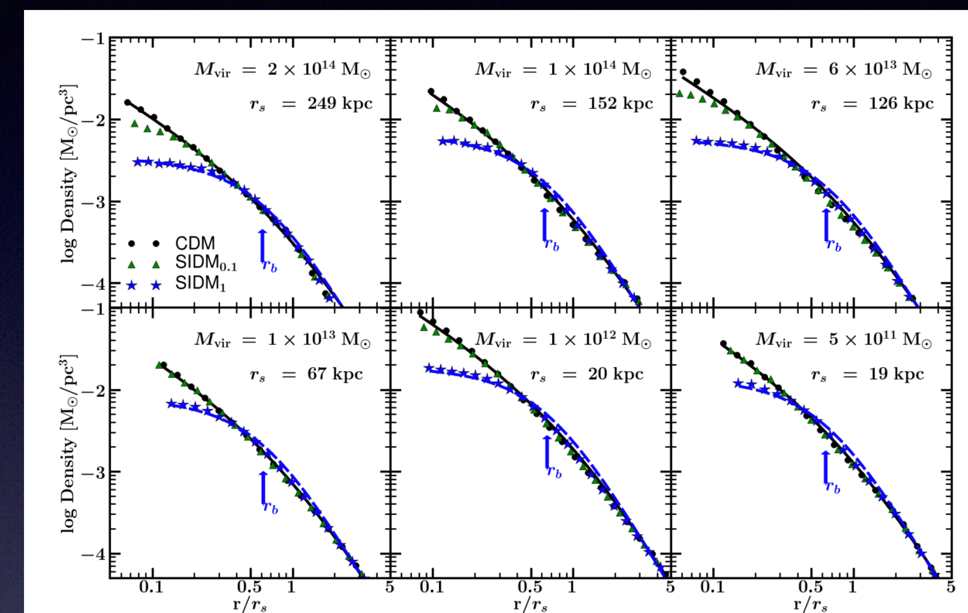
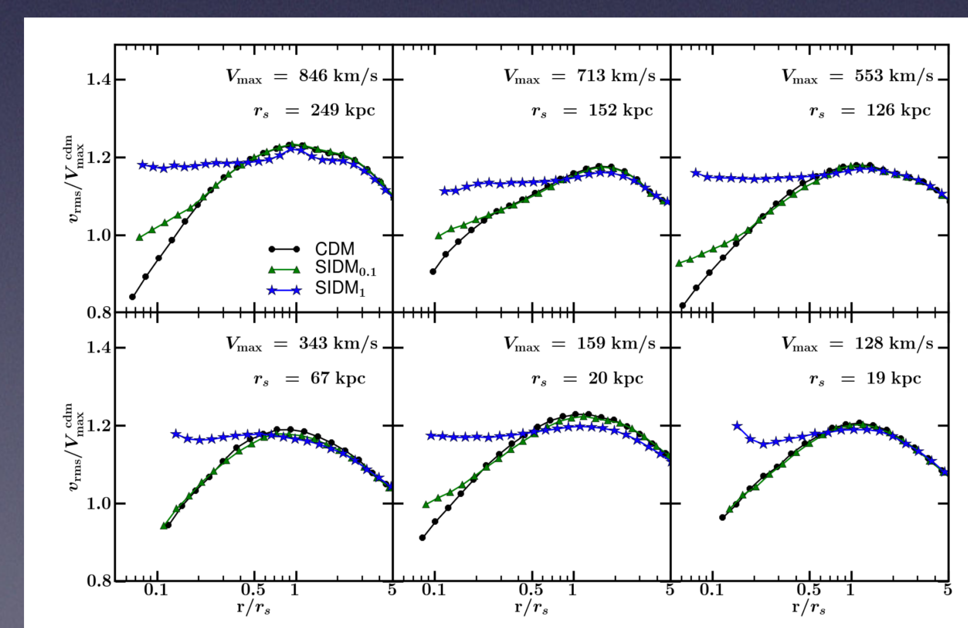
Self Interacting Dark Matter

- CDM paradigm works extremely well to describe clustering of matter and galaxies on large scales, but signs of possible tensions on smaller scales.
- What can these smaller scales tell us about additional interactions of Dark Matter?
- We focus on self-interactions with negligible annihilation and dissipation, but with significant scattering.
- Known to affect halo structure and satellite dynamics.

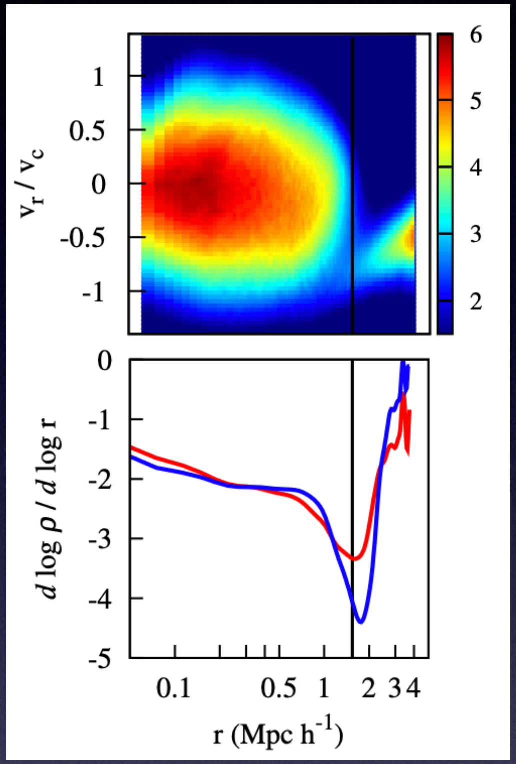




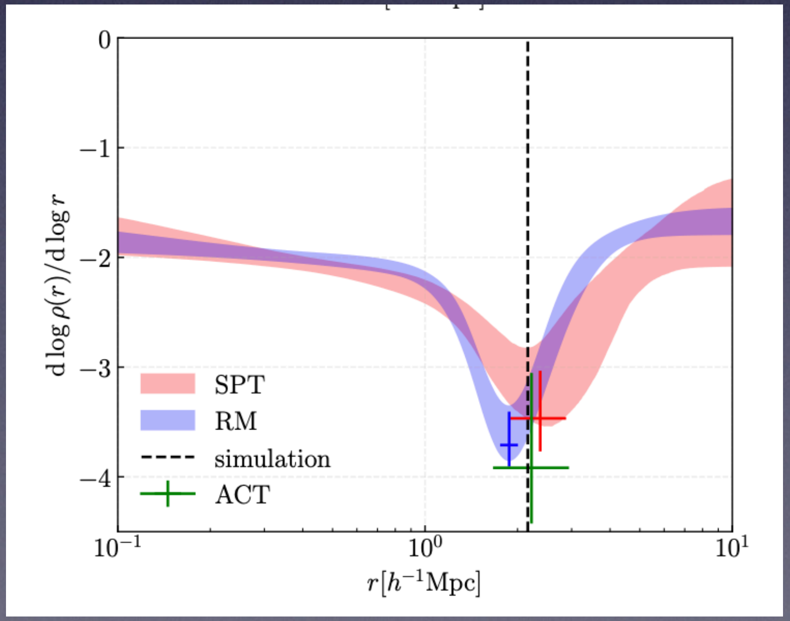
Rocha *et al*, 2012

Connecting to Imaging Surveys

- Individual objects have been studied thoroughly, but can we learn about SIDM by studying density profiles and satellite distributions of populations of objects, specifically galaxy clusters.
- Individual clusters do not have high S/N, but stacking helps improve statistical power.
- Related question: do self-interactions have an effect on the outer boundaries of halos? Specifically, does the splashback radius move in the presence of self-interactions?



Adhikari *et al*, 2014



Shin *et al*, 2018

SIDM Simulations

- We modified the Gadget-2 N-body code to include self-interactions. We considered various scenarios for the differential cross section:
- a) Velocity independent and isotropic.
- b) Velocity independent, but with angular dependence:

$$\frac{d\sigma}{d\Omega} \propto \frac{1+\cos^2\theta}{1-\cos^2\theta}$$

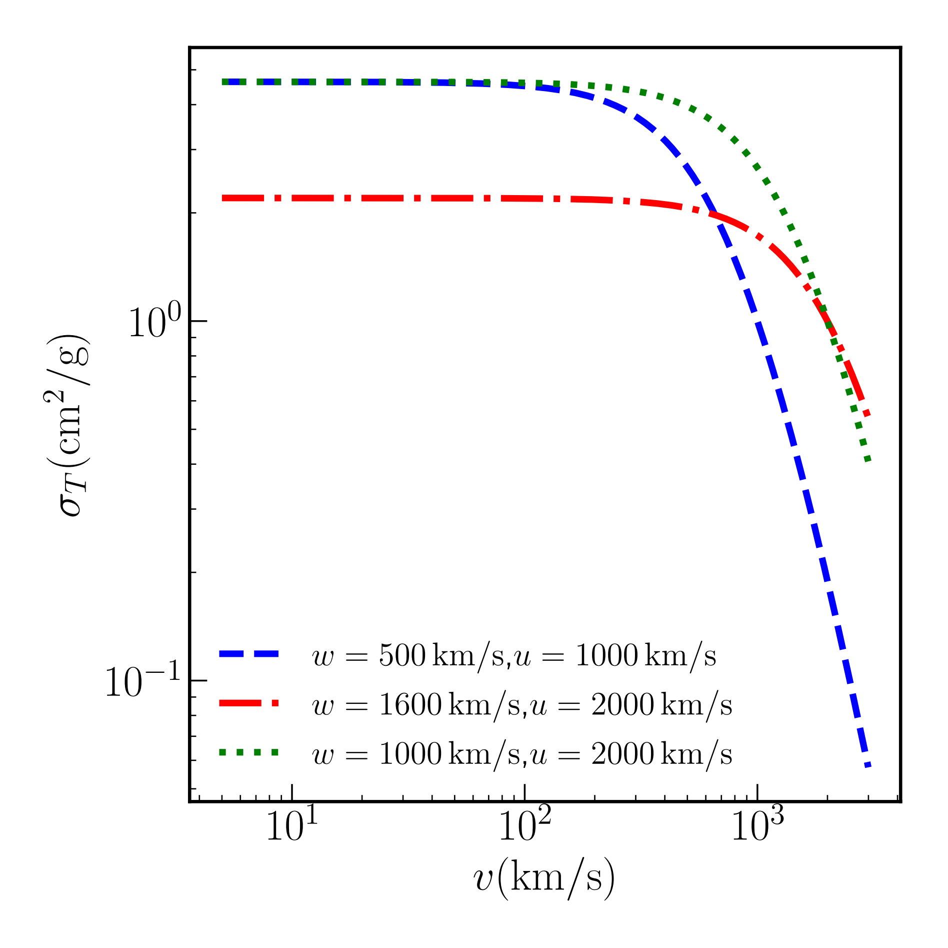
Kahlhoefer *et al,* 2013

- c) Velocity dependent and angle dependent:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\sigma_0}{2\left[1+\frac{v^2}{w^2}\sin^2\left(\frac{\theta}{2}\right)\right]^2}$$

Tulin *et al,* 2017

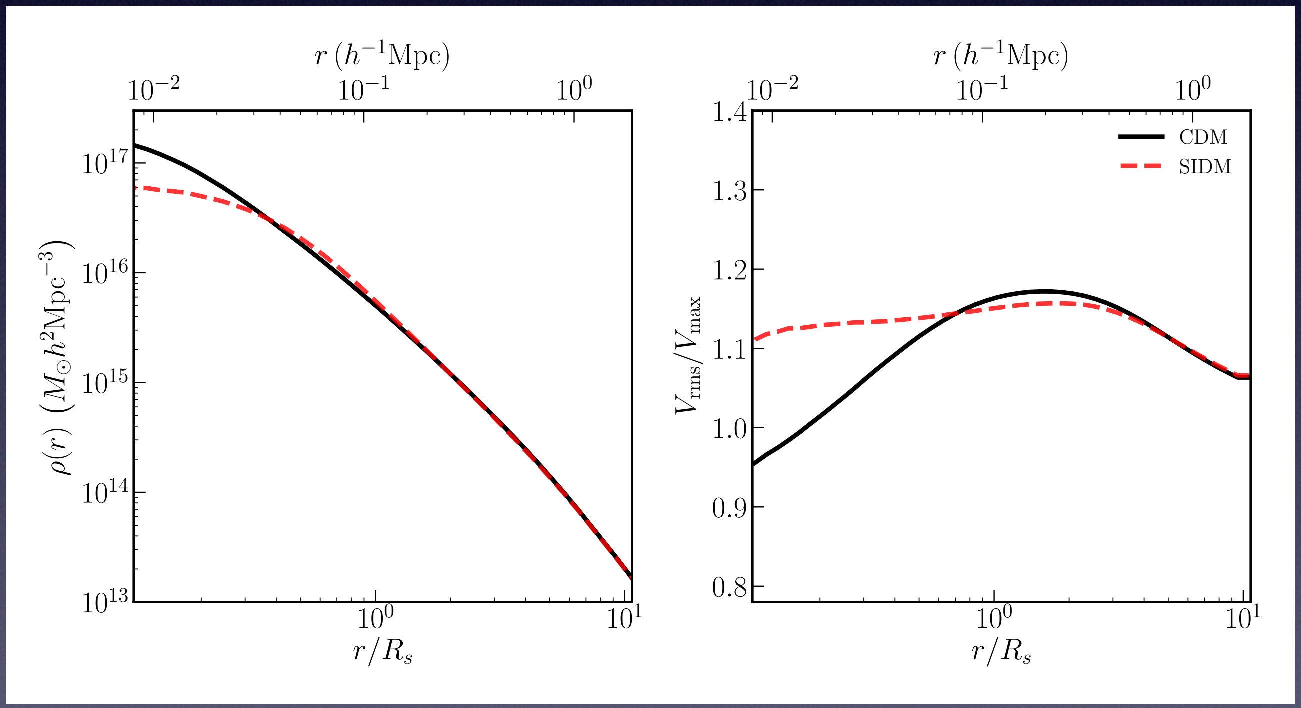
- Ran cosmological sims with volume (1 Gpc/h)^3. Concentrated on halos in the mass range (1e14-2e14) M_{sun}/h. Approximately 20000 objects in each simulation.



Banerjee *et al,* 2019

Reproducing cores and halo thermalization

- One of the most robust predictions of these self-interactions is the formation of a core in the inner regions of the halo. The interactions are also expected to “heat up” the inner regions compared to purely collisionless interactions.
- For the well studied case of $\sigma/m = 1\mathrm{cm}^2/\mathrm{g}$, we check that we match these predictions, but using the full population of halos in the mass range.



Banerjee *et al*, 2019

Effect of angular dependence of interactions

- To compare the effects of velocity-independent isotropic vs. anisotropic interactions, we need to match some physical quantity.
- The total cross section is not well defined for the anisotropic interactions:

$$\sigma = \int \frac{d\sigma}{d\Omega} d\Omega$$

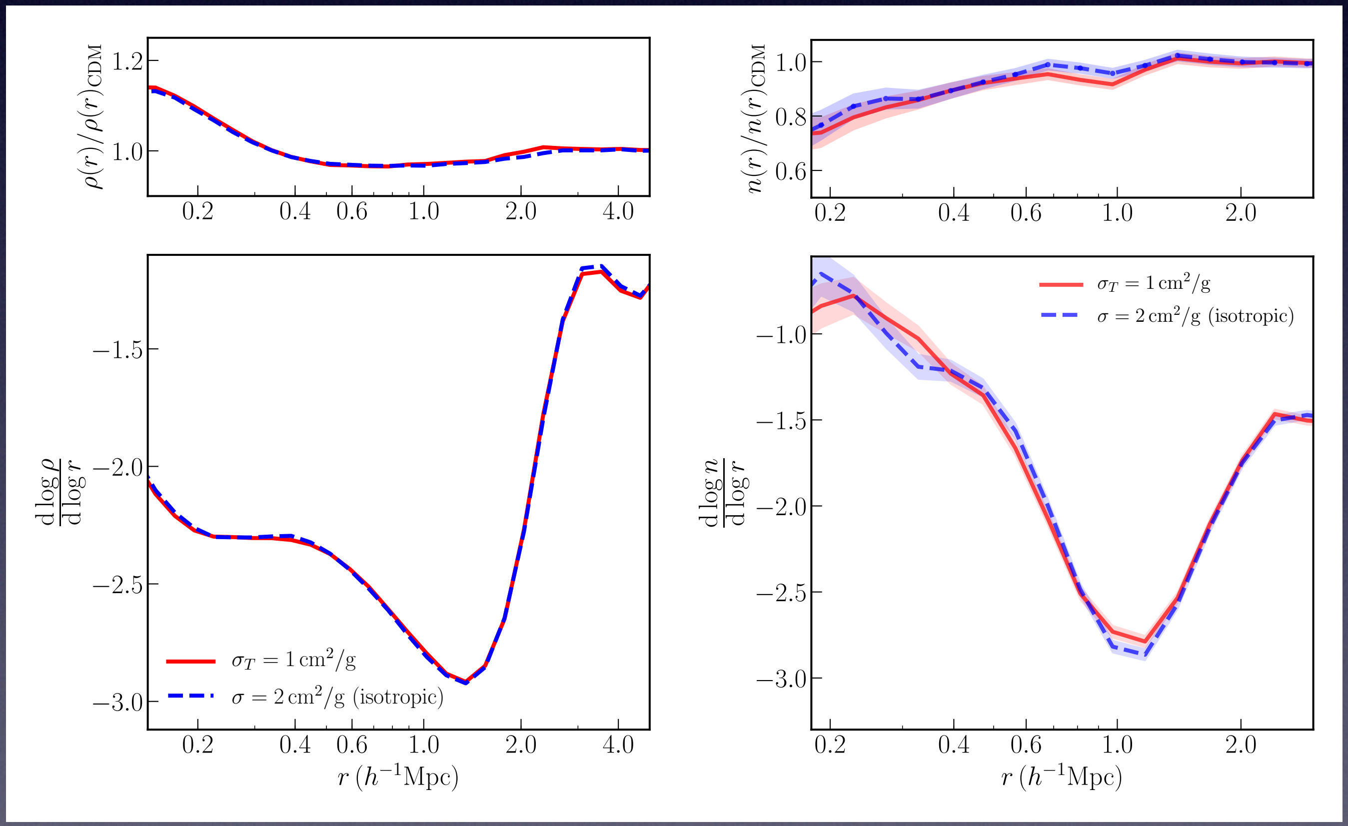
- Instead we match the momentum transfer cross section:

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

- We find no strong evidence that the exact angle-dependence of the differential cross section affects the stacked density or subhalo profiles.

Matter density profile

Subhalo profile

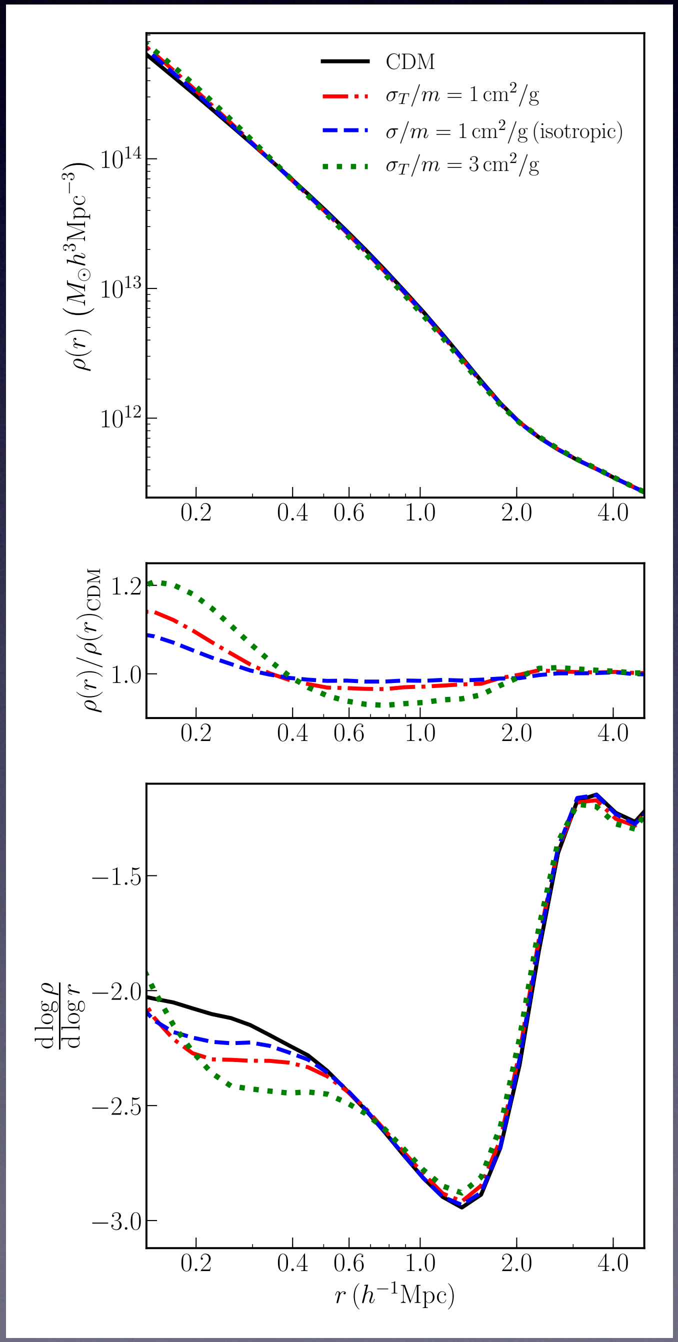


Banerjee *et al*, 2019

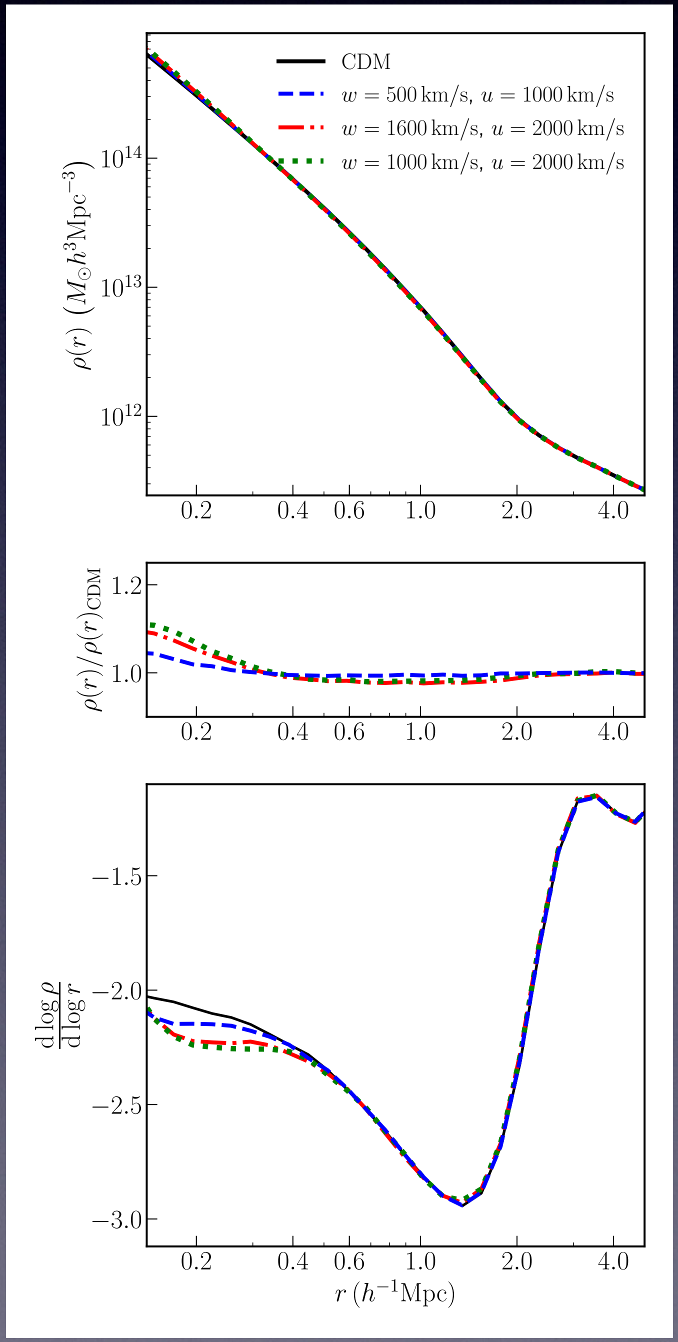
SIDM effects on stacked 3-d density profiles

- Effects of self-interactions persist out to close to the viral radius and are measurable in the stacked density profiles. The effect is qualitatively the same for both velocity independent as well as velocity dependent interactions.
- The splashback radius does not show any significant movement for the full population.

Velocity independent



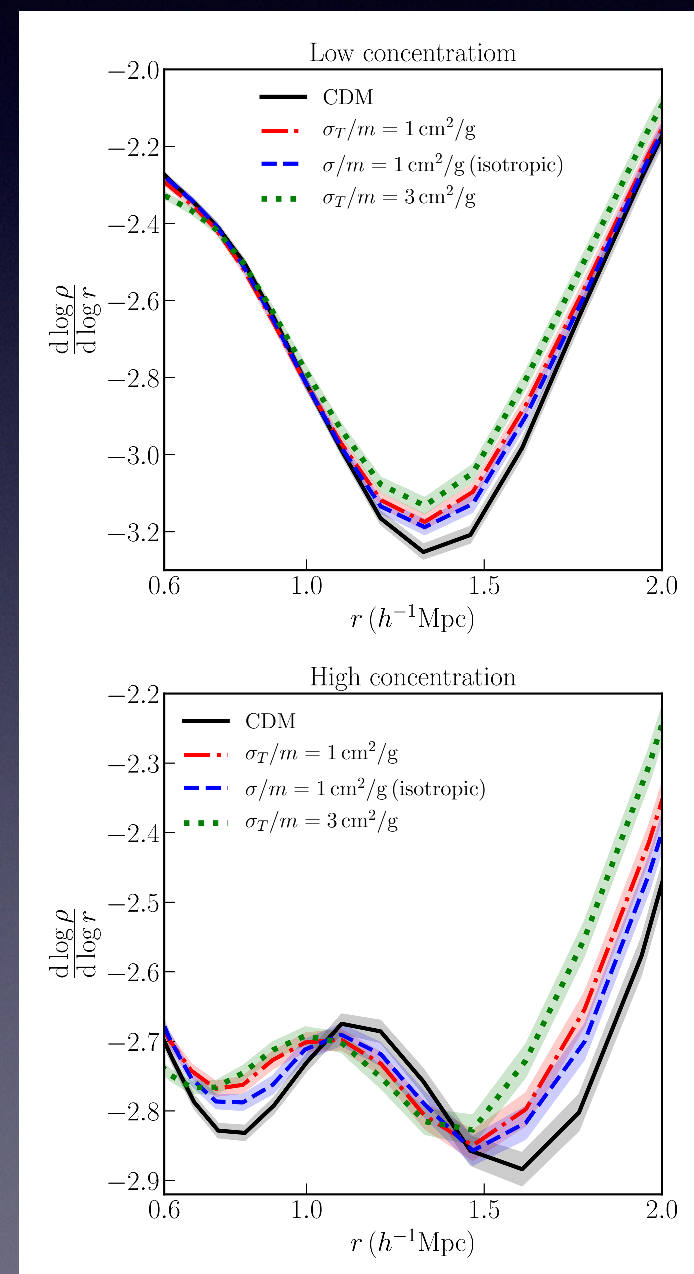
Velocity dependent



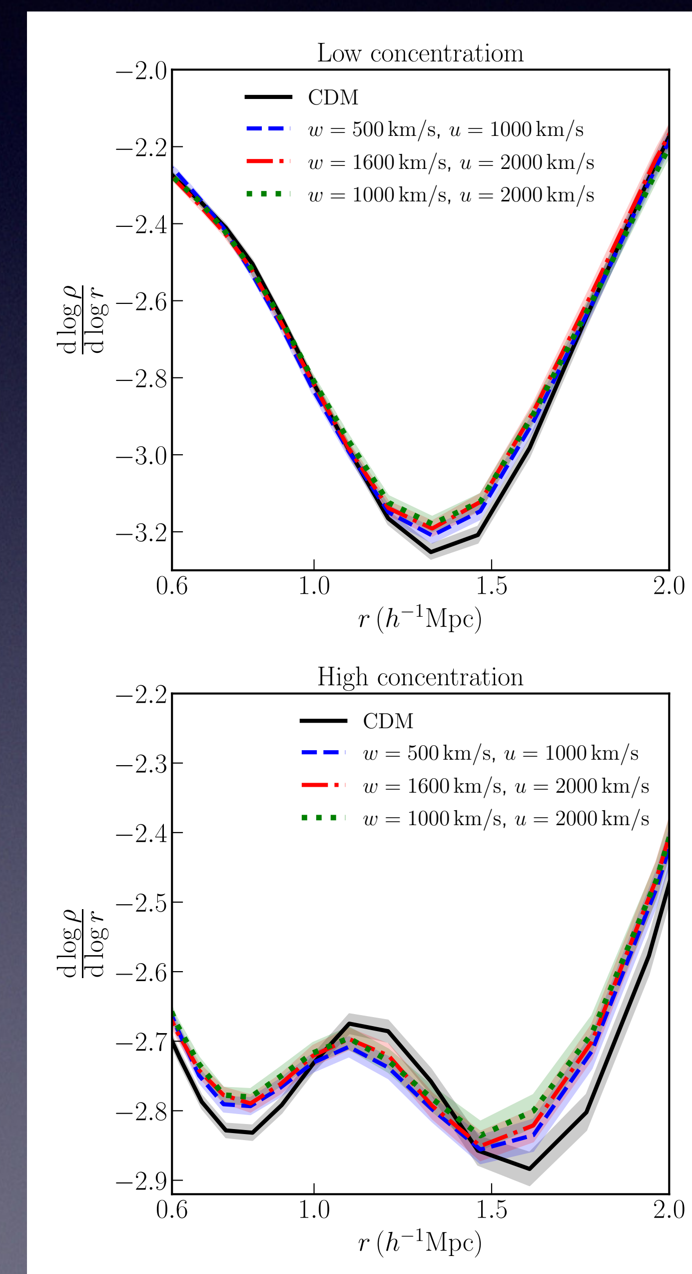
Trends in splashback radius with concentration

- When halos are split on concentration (of the CDM counterpart), self-interactions can change the splash back radius.
- Low concentration (late-forming) halos do not show any movement in the splash back radius.
- High concentration (early-forming) halos clearly show a trend with interaction strength.

Velocity independent



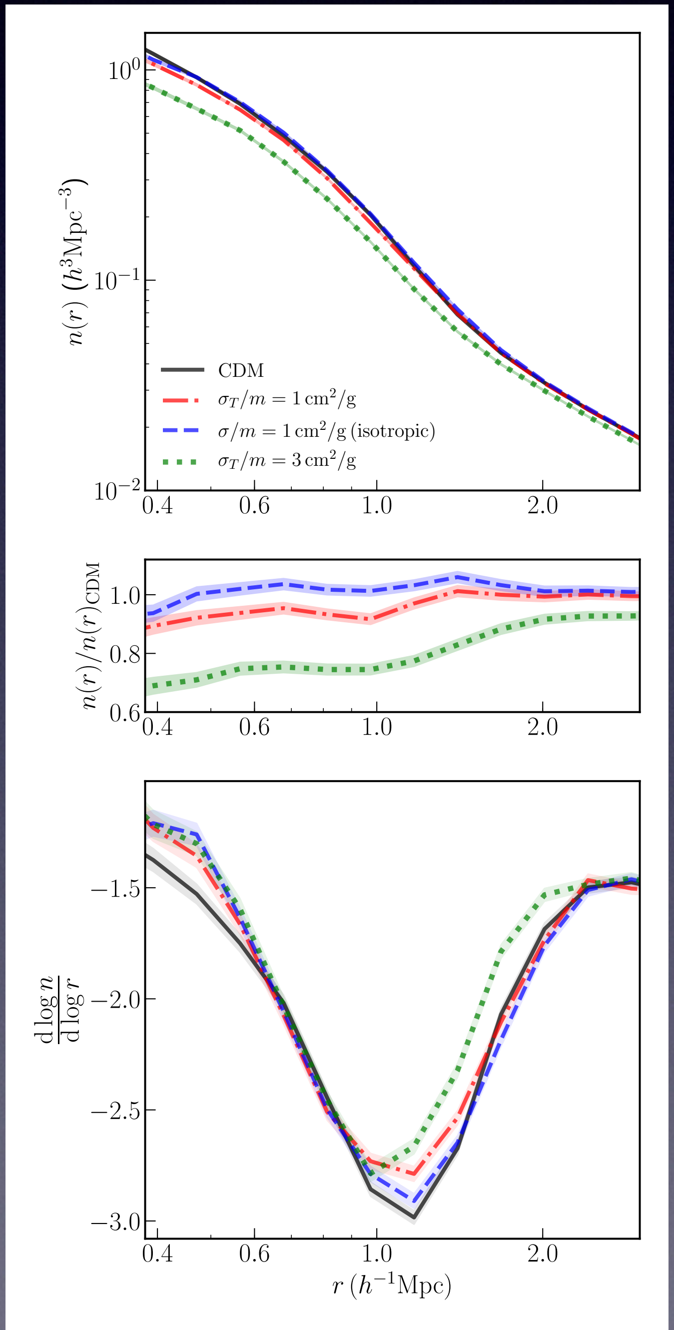
Velocity dependent



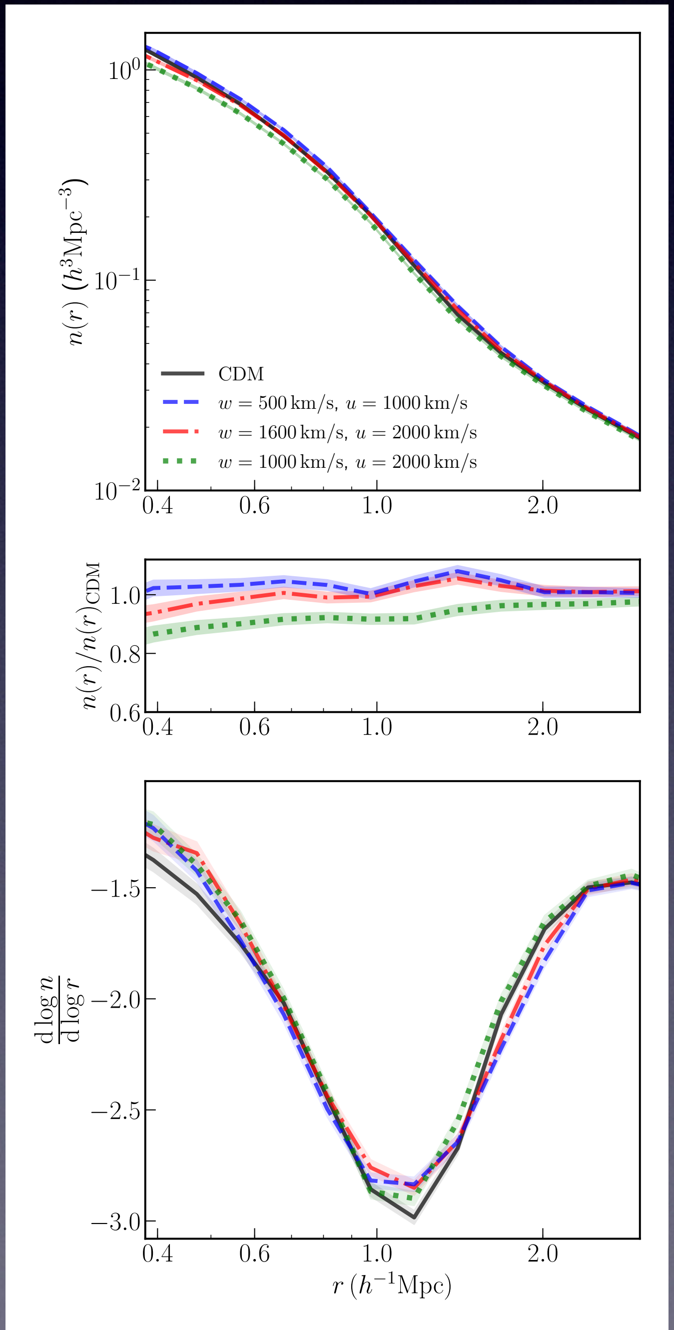
Signatures on subhalo distributions

- Subhalos identified with M_{peak}> 5e12 M_{sun}/h.
- Once again, noticeable effects on the sub halo distributions out to the virial radius.
- Splashback is smaller (in all cases) than in the particles due to dynamical friction.
- For extremely high cross sections, splashback radius shrinks further.

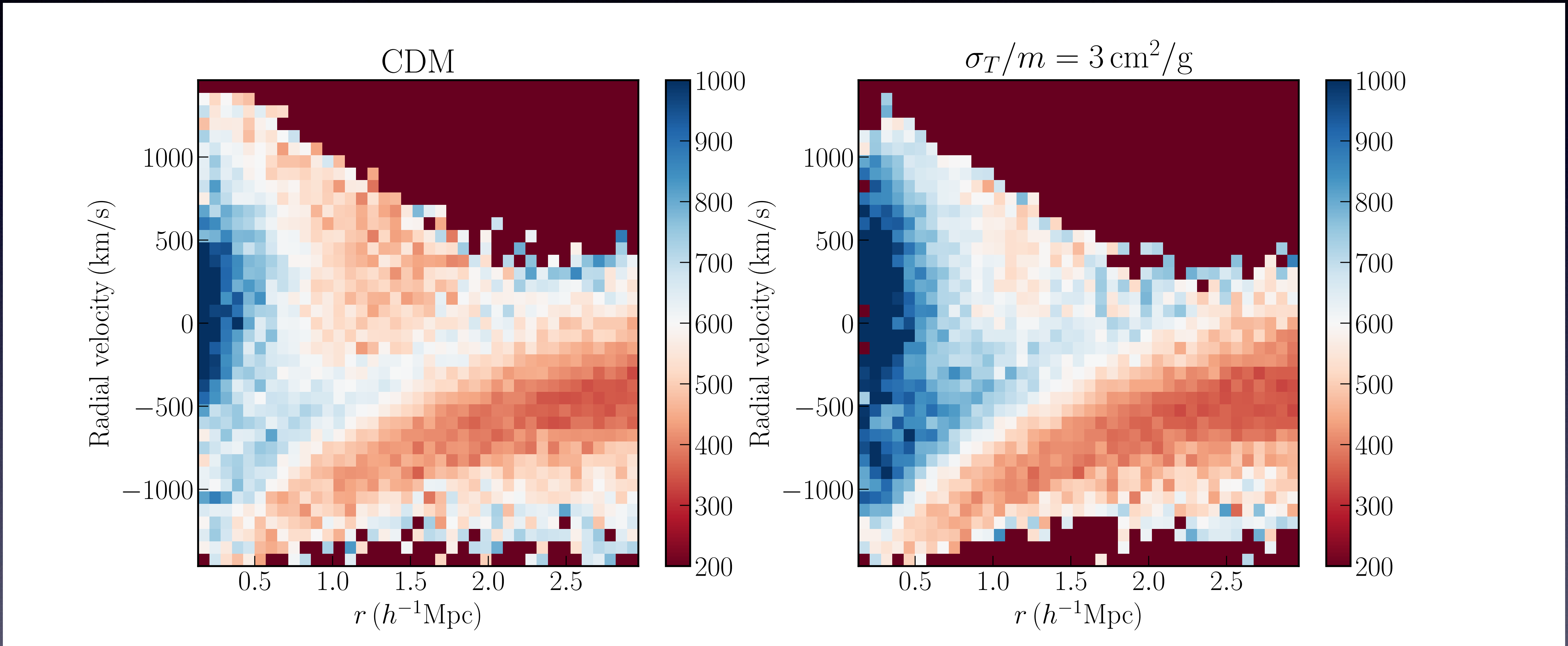
Velocity independent



Velocity dependent



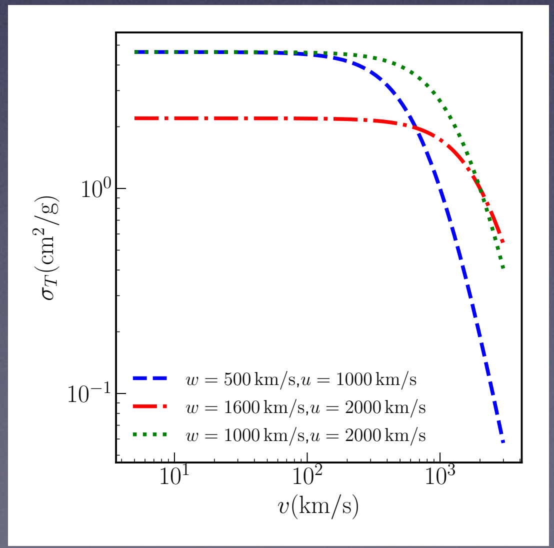
Subhalo splashback at high interaction rates



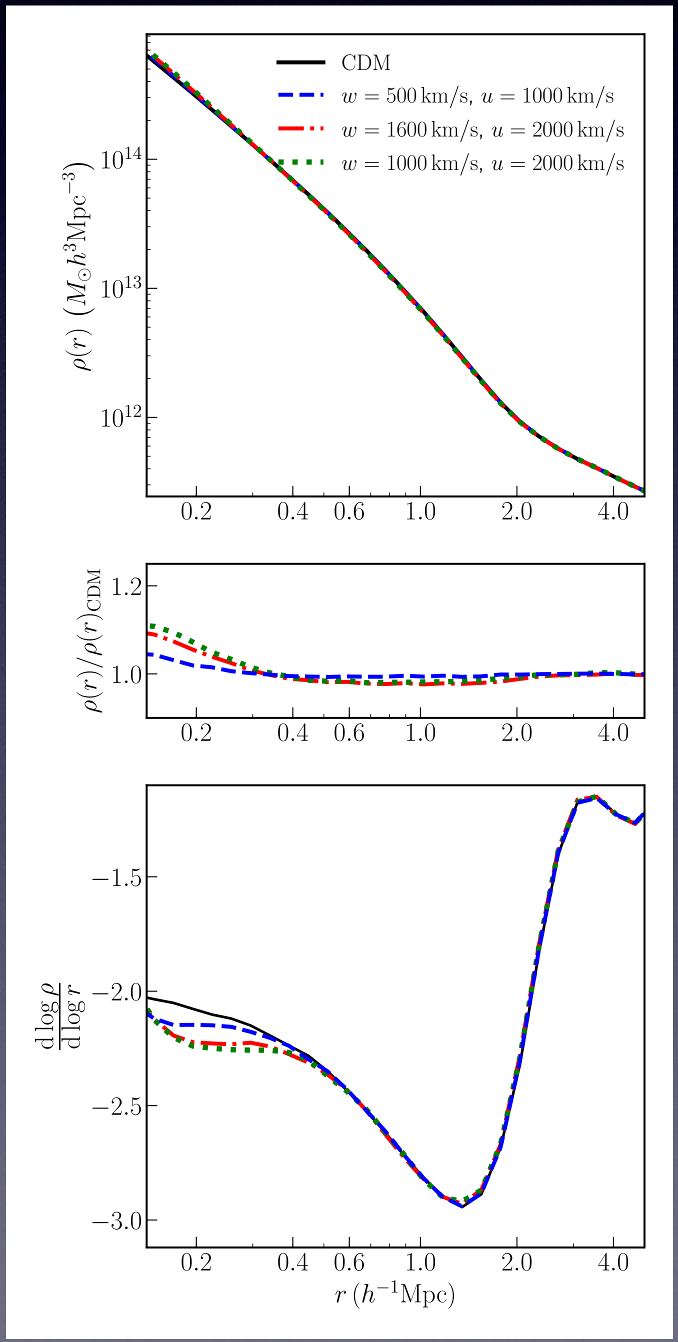
Banerjee *et al*, 2019

Can we test velocity dependence of the cross section?

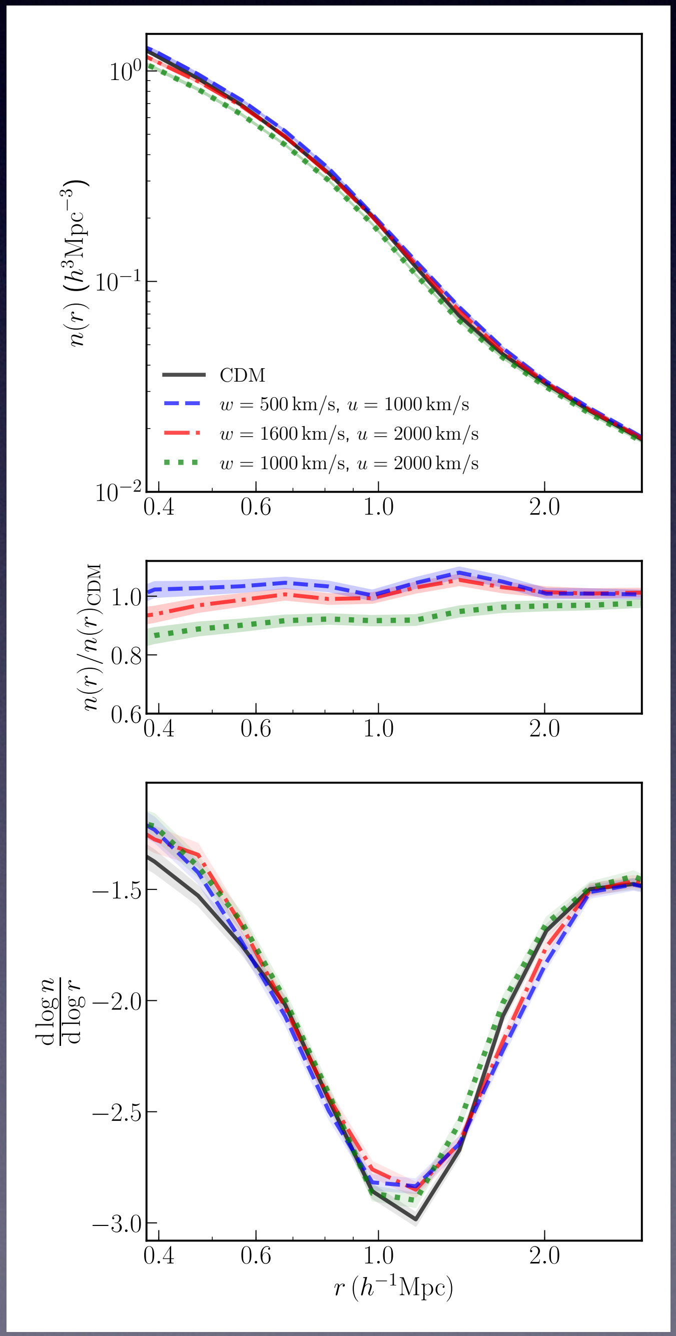
- If subhalos and hosts lie in different regimes of the velocity dependence, the matter profile and subhalo profiles can jointly inform about the turnover scale.



Matter profile



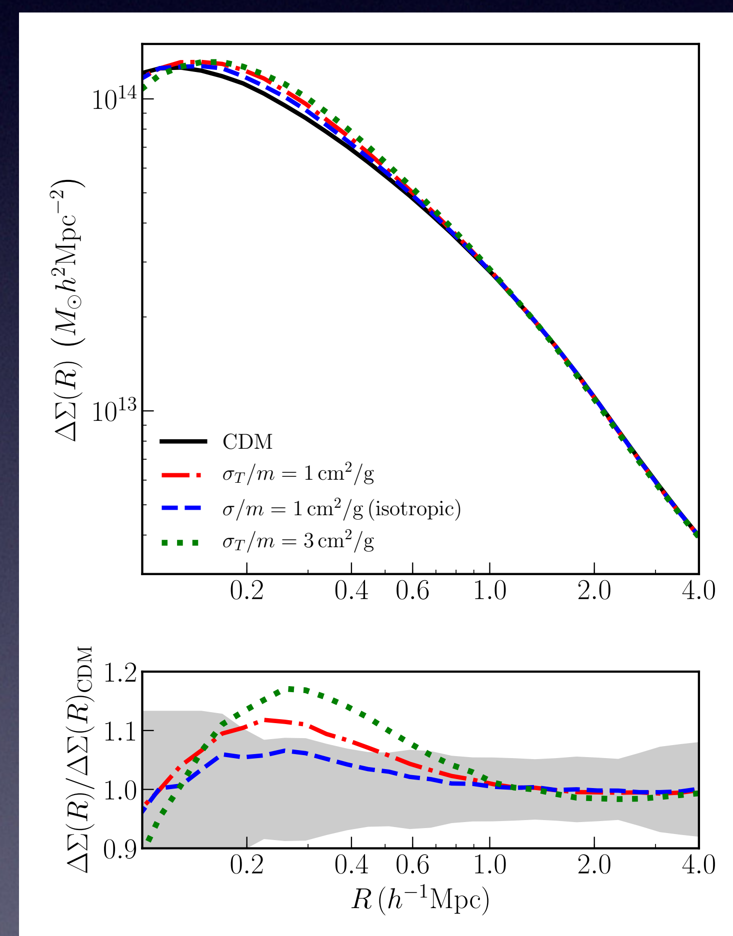
Subhalo profile



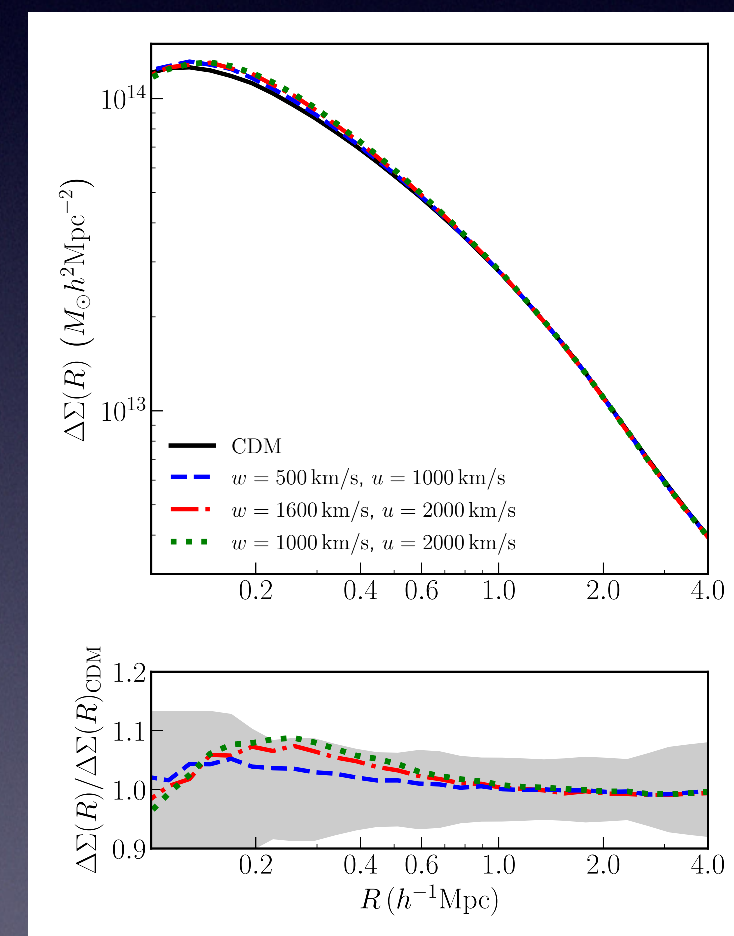
Prospects of constraining SIDM with cluster lensing

- We plot the $\Delta\Sigma(R)$ profiles and overplot the lensing error bars from DES Y1.
- Error bars expected to go down by a factor of $\sqrt{3}$ in Y3 due to increased sky coverage.
- Statistical error bars should be at a level allowing for constraints competitive with those from the Bullet Cluster.
- Possible to use the satellite profiles but larger systematic uncertainties.

Velocity independent



Velocity dependent



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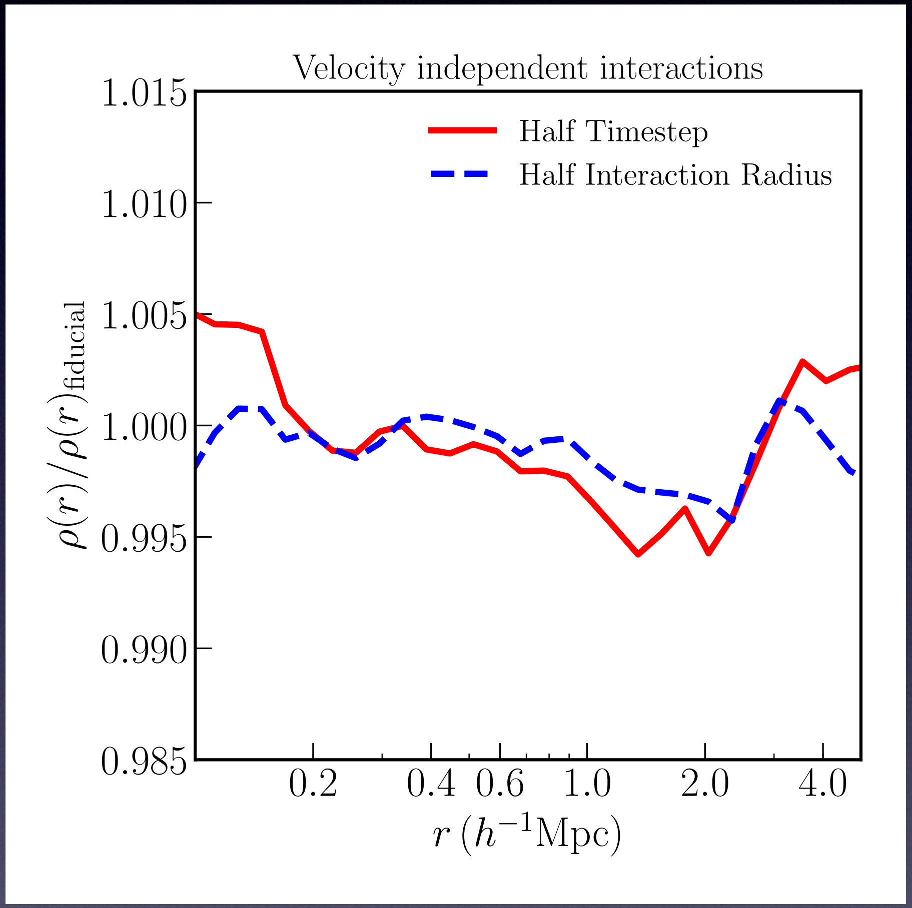
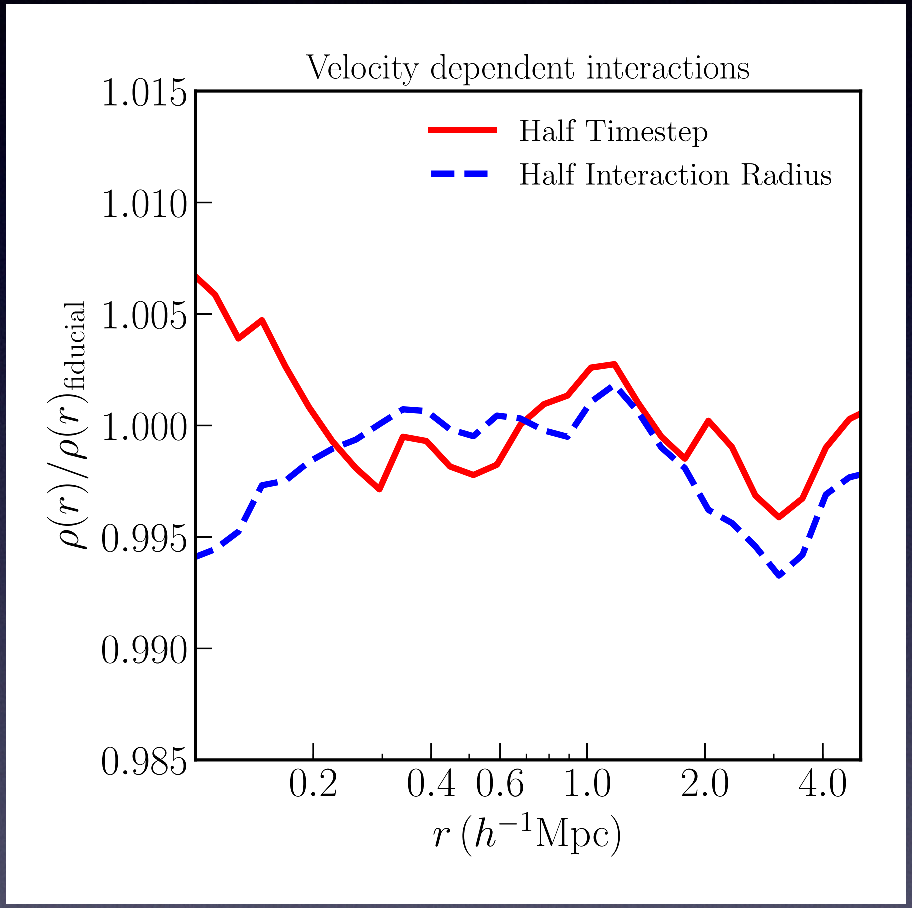
Conclusions

- SIDM can affect cluster density and subhalo profiles out to close to the viral radius, and the effects are not washed away when stacked.
- Angular dependence of the cross section does not seem to play an important role in the stacked profiles. On the other hand, velocity dependence can, in principle, be studied by jointly analyzing the density and subhalo profiles.
- Splashback radius, as defined in matter does not change for a mass-selected population. However, if we split on halo history within the mass bin, splashback is affected by self-interactions.
- The changes in the stacked lensing profiles seems to be a promising avenue to constraining self-interactions at the cluster scale, and has enough statistical power, especially in the era of LSST, to become competitive with other probes of self-interactions at this scale.

Convergence tests





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