Self–Interacting Dark Matter and the Distribution of Matter in Clusters of Galaxies

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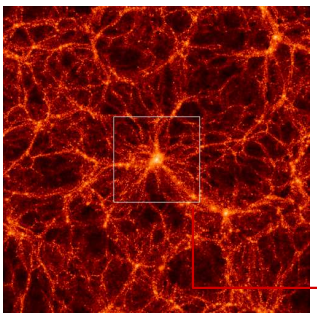
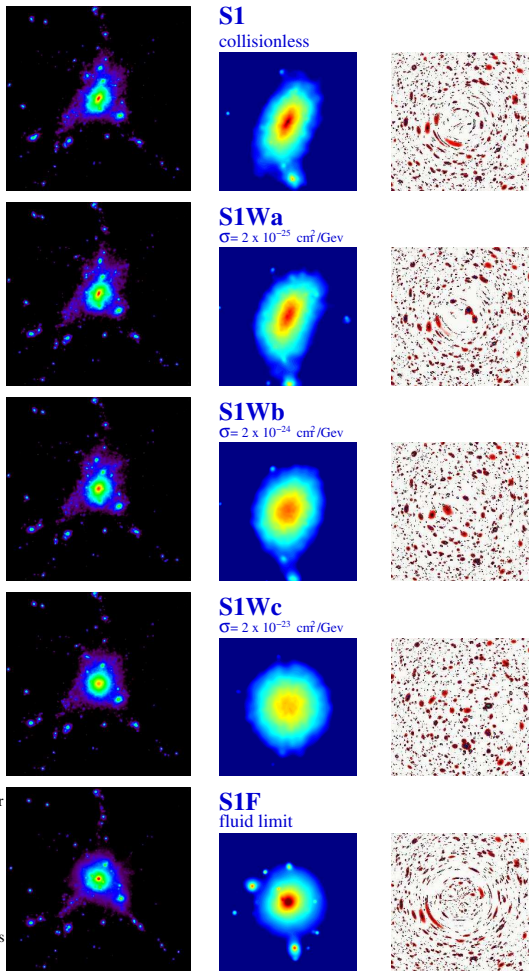


ABSTRACT

We study the formation of dark halos in a universe dominated by Cold Dark Matter with a positive cosmological constant under the assumption that Cold Dark Matter particles have a finite cross–section for elastic collisions. We compare the evolution when dark matter mean free path is comparable to halo sizes, with the collisionless and "fluid" limit. We show that a few collisions per particle per Hubble time at halo centre can substantially affect the central density profile. An order of magnitude larger cross–sections cause sufficient relaxation for massive clusters to develop large cores. Ray–tracing simulations of gravitational lensing show that giant arcs as seen in many clusters can only be produced if dark matter collisions are very rare. We conclude that the scattering cross–section in clusters must be very small, below ~ 10^{-25} cm ^{2}/Gev, to be compatible with the observed ability of clusters to produce both radial and tangential arcs.

Resimulations



Figures (top) Projected mass distribution in the parent simulation box (140 Mpc/h on a side). (Right) Resimulated clusters. Enlargements of the central 2 Mpc/h regions are shown in the middle column. Distorted source images produced by ray–tracing simulations of gravitational lensing are also shown to the right.

METHOD

The simulations were carried out by using the parallel tree N–body code GADGET. All the simulations start from an identical initial condition, and the particle interactions are modelled and implimented in the following manner:

Collisionless limit → N–body (gravity only)
Elastic collisions → Monte Carlo method *
Fluid limit → Smoothed Particle Hydrodynamics

* Elastic collisions of the CDM particles are simulated in a Monte Carlo fashion. We evaluate the scattering probability for a pair of particles as

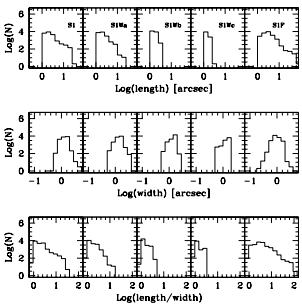
$$P = \rho \sigma V dt$$

where ρ is the local density, σ is the scattering cross–section per unit mass, V is the relative velocity between the collision pair, and dt is the time step width.

RESULT

In the central region of our S1Wa cluster, particles experience a few times collisions over the age of the universe. The corresponding numbers are ~10 for S1Wb, and ~50 for S1Wc. As the picture shows, elastic collisions between dark matter particles do indeed affect the structure of the final cluster –more frequent collisions lead to clusters which are rounder and have weaker central concentrations–.

These effects of the dark matter interaction have an 'undesirable' impact on the ability of clusters to produce large arcs. The assymetries, steep density profiles, and existence of substructures are essential for the ability of galaxy clusters to produce pronounced strong–lensing features. To evaluate the ability, we carry out ray tracing through the clusters. The clusters are put at z=0.28, and background sources are located at z=2.0.



The figure on the left shows histograms of the lensed image lengths (top panels), widths (middle panels), and length–to–width ratios (bottom panels). Each column refers to a different model as indicated in the top panels. Calculation of the lensing cross–section Q, for tangential arcs with l/w > 5, shows the massive impact of the dark matter scattering on the lensing ability. The cross section for S1Wa is an order of magnitude smaller than that for S1 (collisionless case), and the value of Q is 0 for S1Wb, S1Wc ! We investigate whether cluster S1Wb can produce long arcs by rescaling its mass by a factor of 3,5,7, and 10. We found that a cluster with the same density profile as our S1Wb must have a mass of at least ~ 4 x 10^{15}Msun. The number of such clusters is very small in the real universe.

REFERENCES

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