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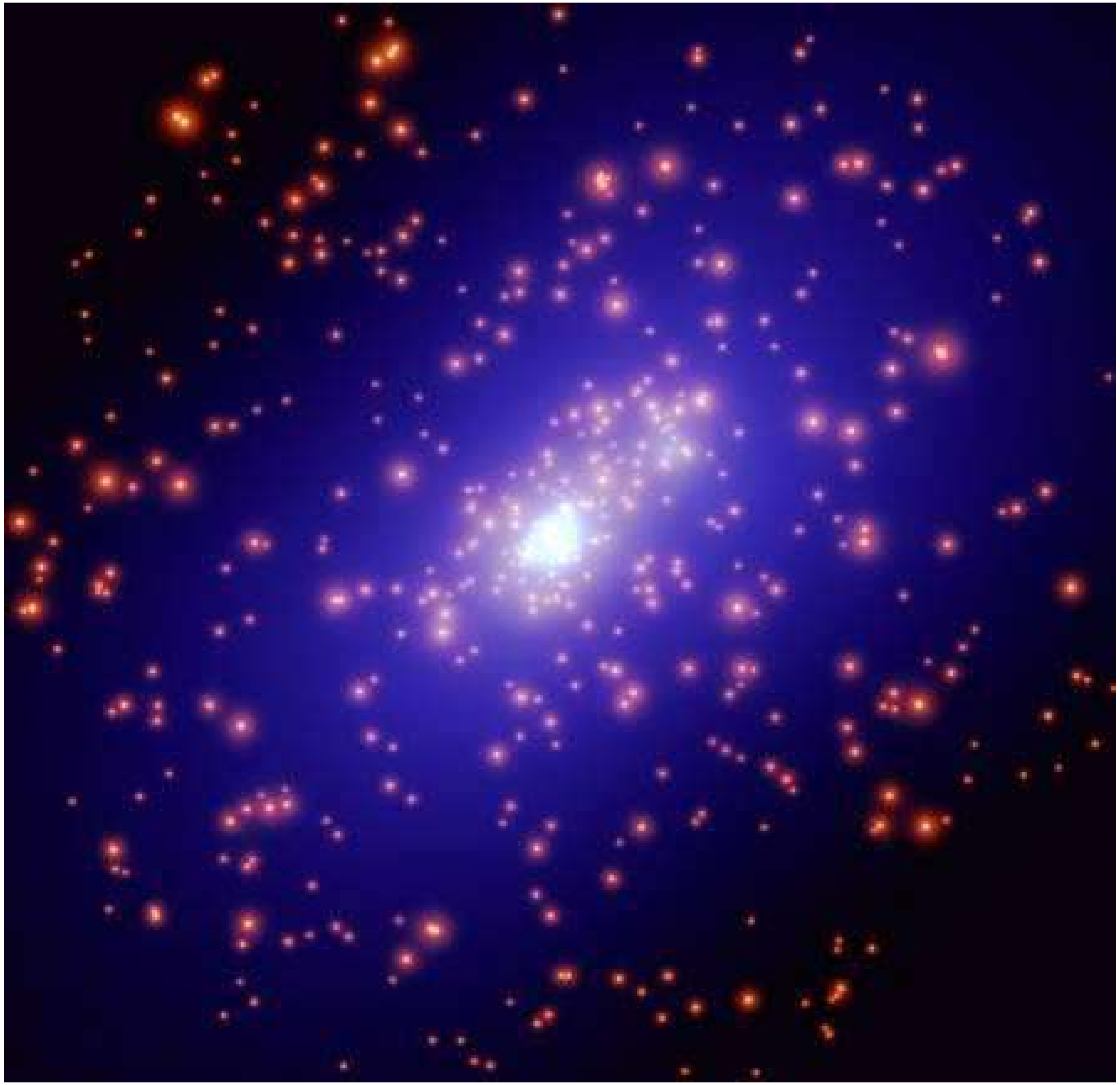
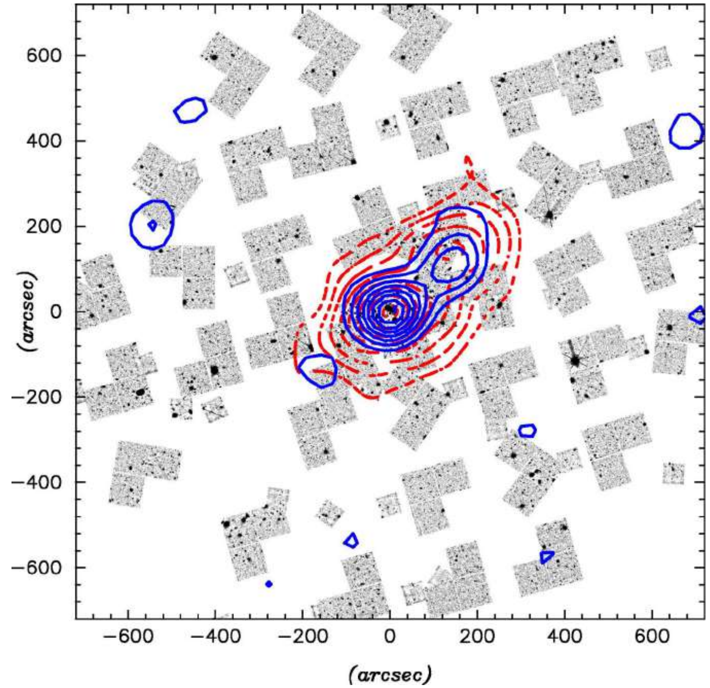
Gareth Conduit

Major Halo Mergers
Investigation of Density Profiles





A cluster of galaxies Cl0024+1654 is shown in red and the associated dark matter halo in blue

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Introduction

- Pt II Physics undergraduate
- Invited to give talk at the BP Institute after being awarded the *BP Prize for Advanced Physics*
- This presentation summarises computer simulations of the merger of two dark matter halos, which were run last summer whilst on the SURE programme

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Outline of Talk

- Review of the SURE programme
- Introduction to dark matter halos, looking both at their necessity for a consistent theory and observational evidence
- An overview of the computer simulations performed
- Scatter plots of a merger of two haloes
- Overview of results of investigation
- The possibilities of further work stemming from this investigation
- Summary of this presentation

SURE Programme

- SURE (Science Undergraduate Research Experience) is a 6 week summer programme supporting undergraduate students
- Students undertake research within the Department of Physics and Astronomy or the Space Research Centre at the University of Leicester
- This project was completed within the Theoretical Astrophysics Group under Dr. Walter Dehnen

Evidence for Dark Matter Halos

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- The dynamics of galaxies within clusters necessitates associating a dark matter halo with the galactic cluster
- The rotation curves of stars orbiting about the galactic centre requires a large amount of non-visible matter to be associated with the galaxy
- Gravitational lensing, light from distant galaxies is deflected by a nearby dark matter halo
- The Wilkinson Microwave Anisotropy Probe examined microwave background radiation from the Big Bang. This allows parameters of the universe to be determined including the amount of dark matter

Actual Dark Matter Halo

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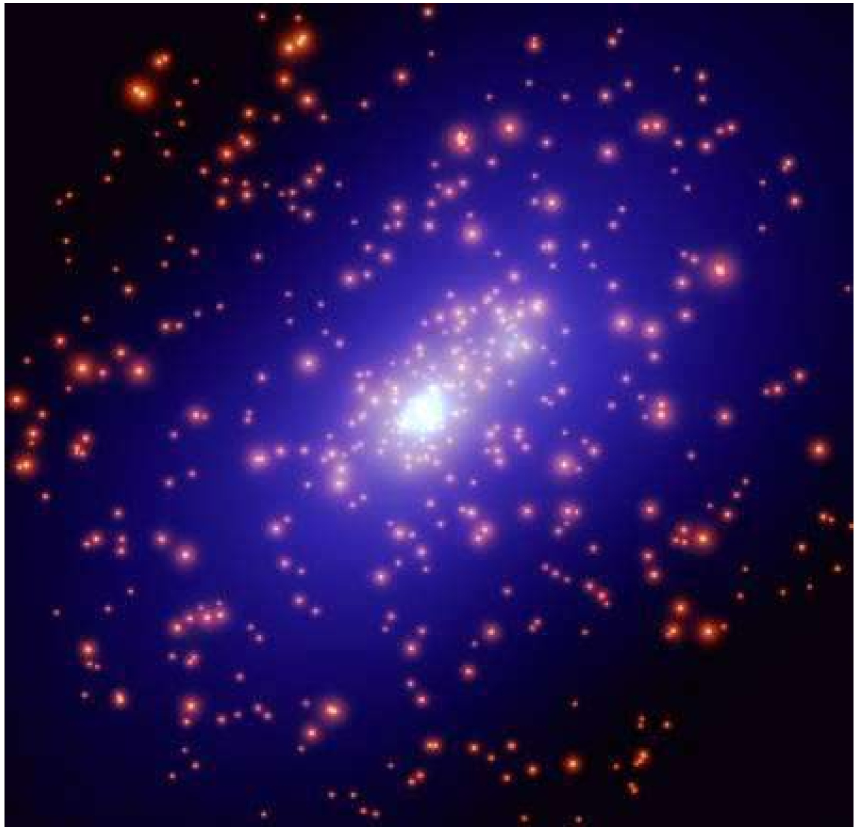
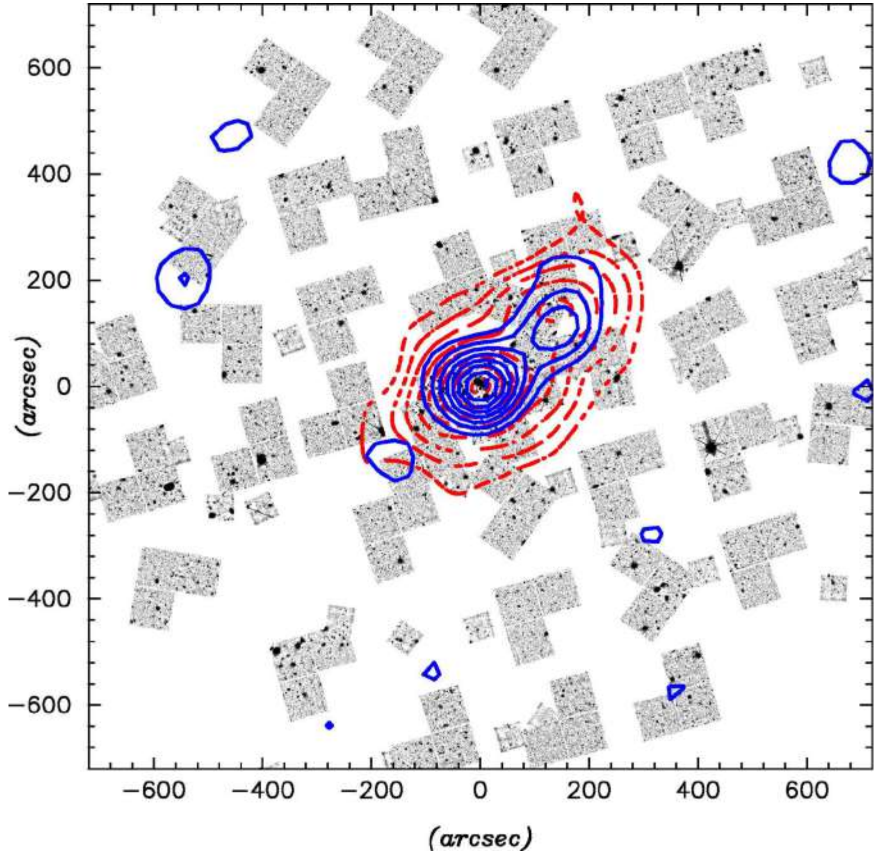
- An image taken by Hubble Space Telescope of cluster of galaxies, shown in red
- Superimposed onto this is the theoretically calculated dark matter halo shown in blue





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Modelling Dark Matter Halos

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- 88% of the mass of a galaxy is the dark matter halo
- To give the correct star rotation curves the halo must have cuspy density profile
- Halo density profile should be stable over time
- Dark matter obeys the collisionless Boltzmann equation (Jeans equation). This is because particles move under the influence of the potential generated by all the other particles within the halo rather than interact just during collisions

Stable Dark Matter Halos

- Following the Big Bang the dark matter in the universe was evenly distributed containing minor perturbations
- Halos formed by the gravitational collapse of this cloud
- Small halos merge forming larger halos hierarchically
- A suitable stable density profile for these halos takes the modified NFW form:

$$\rho(r) = \rho_0 \frac{sech(r/r_t)}{(r/r_s)^{\gamma}(1+r/r_s)^{3-\gamma}}$$

- Scale radius $r_s = 1$
- Truncation radius $r_t = 12$
- Inner logarithmic slope $1 \leq \gamma \leq 1.6$

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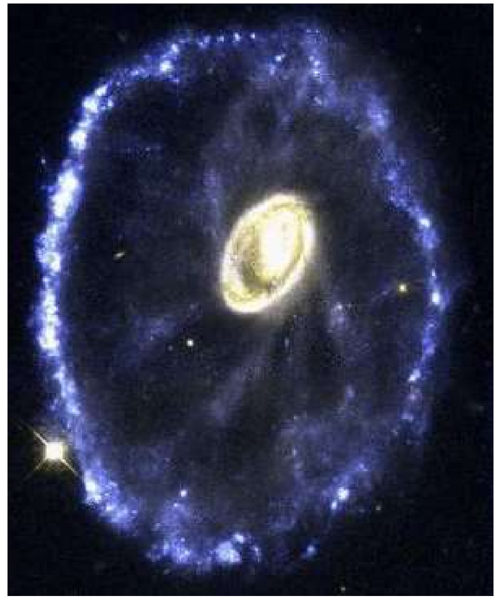
Halo Mergers

- Many features of galaxies can be explained by merger halos e.g. elliptical galaxies, galaxy pairs and tidal tails





- In the investigation the merger of two identical modified NFW profile halos is investigated using a N-body computer simulator, gyrfalcON
- Two strands of investigation were followed, γ and impact parameter were varied

Testing Halo Stability

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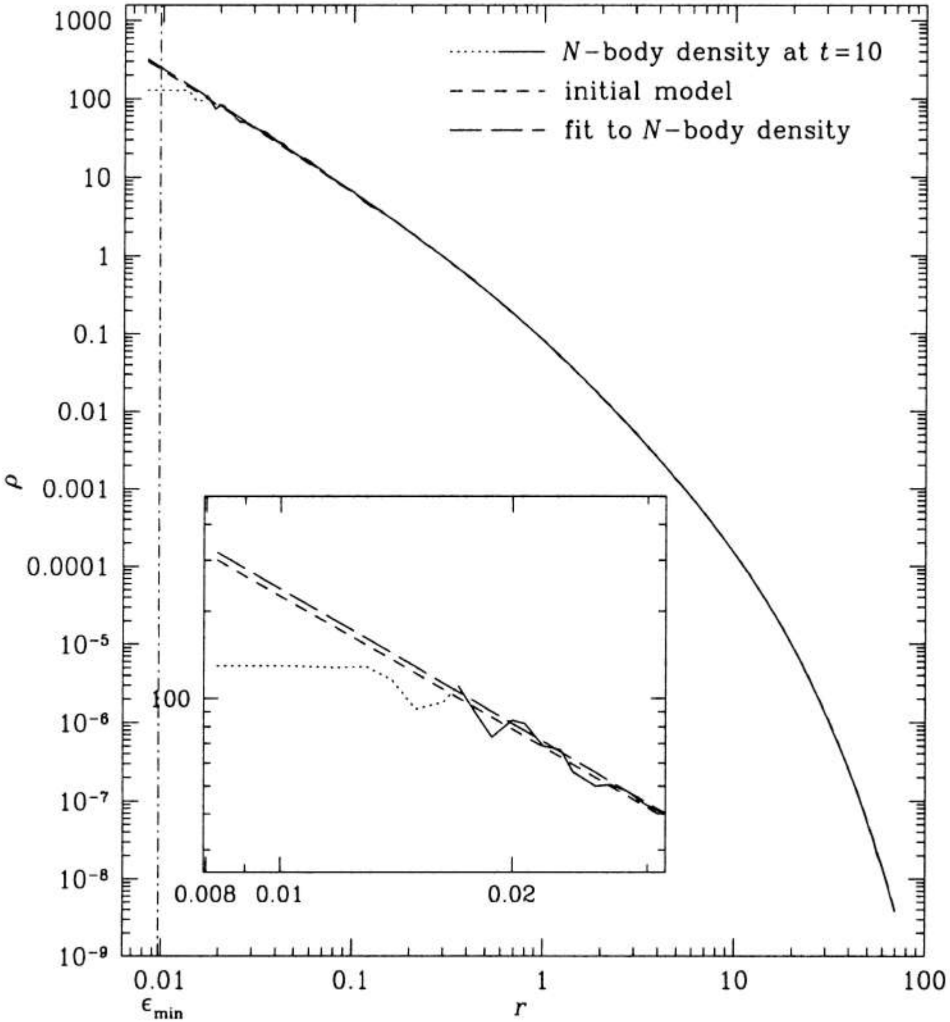
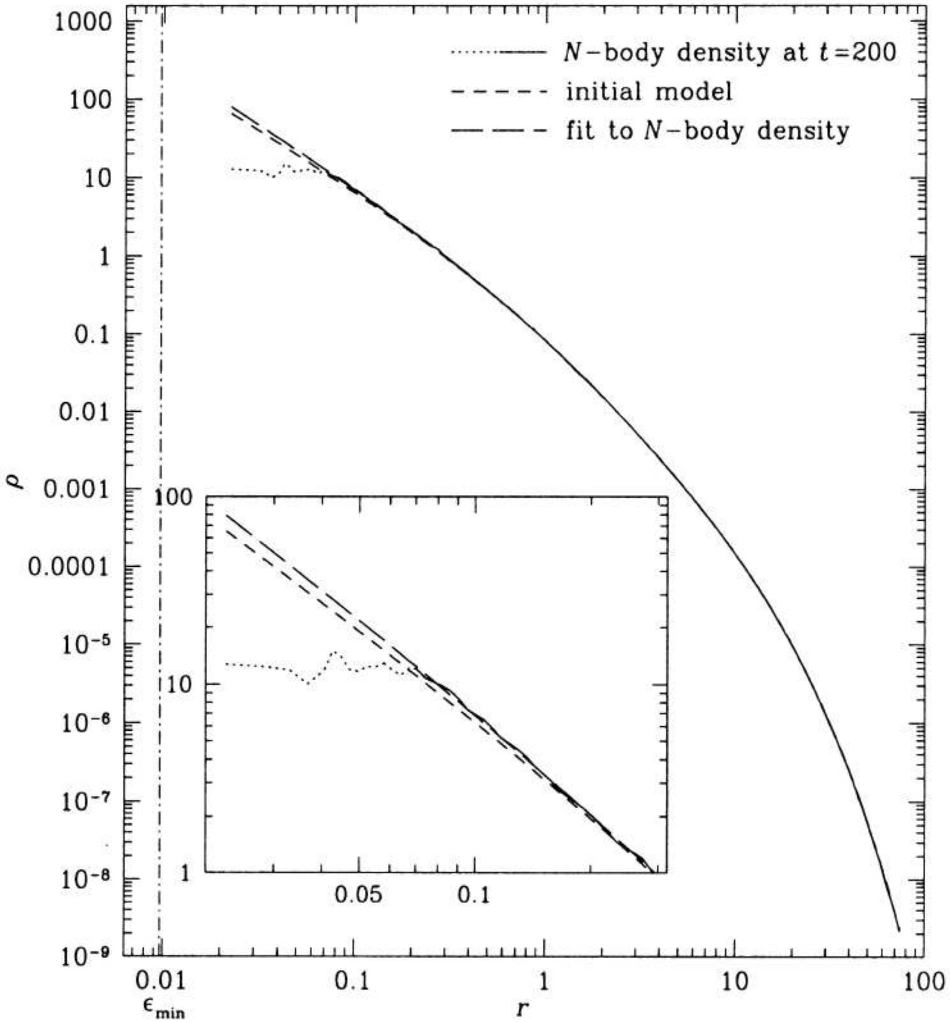
- Test a simulated halo for stability
- Deviation at small radii is due to two body relaxation





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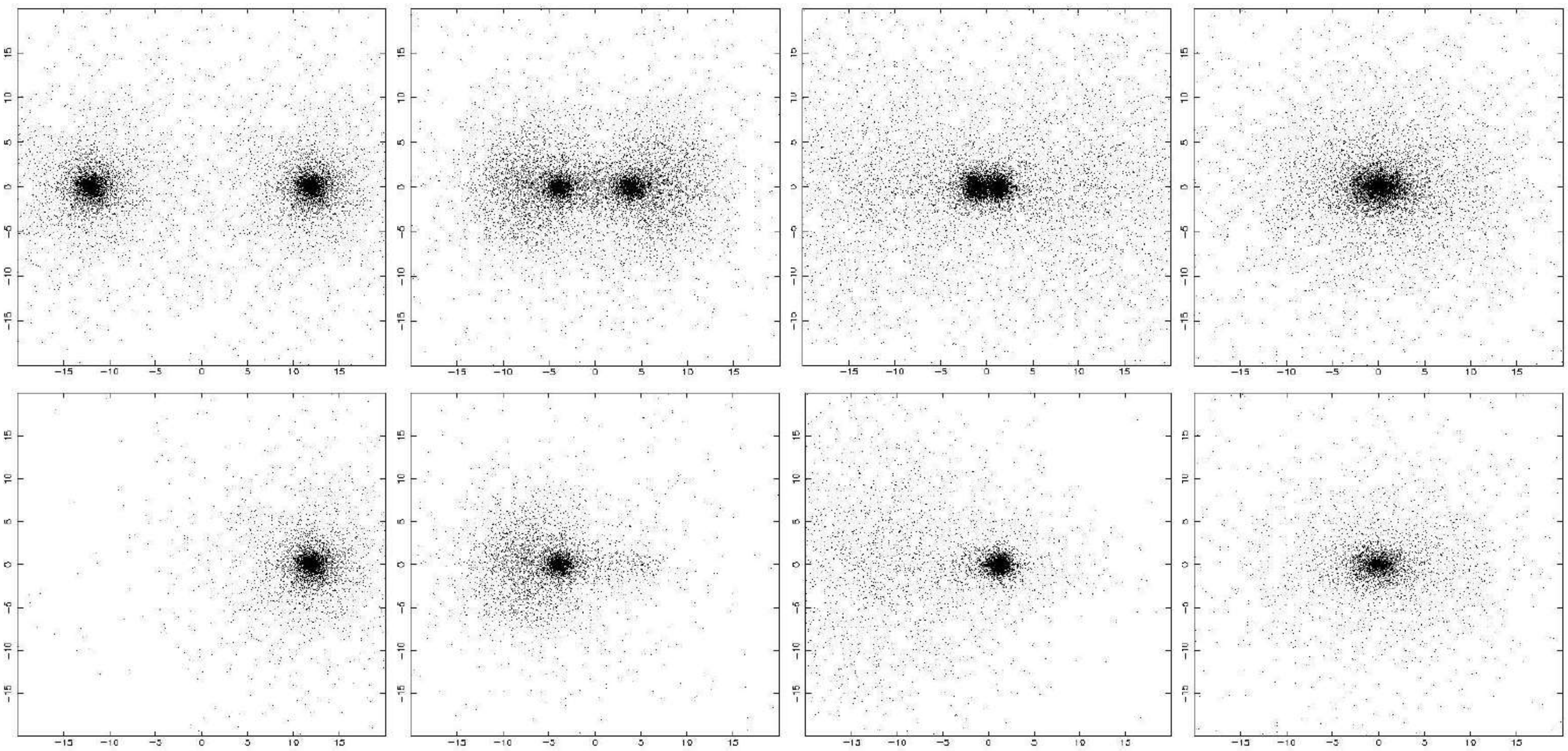
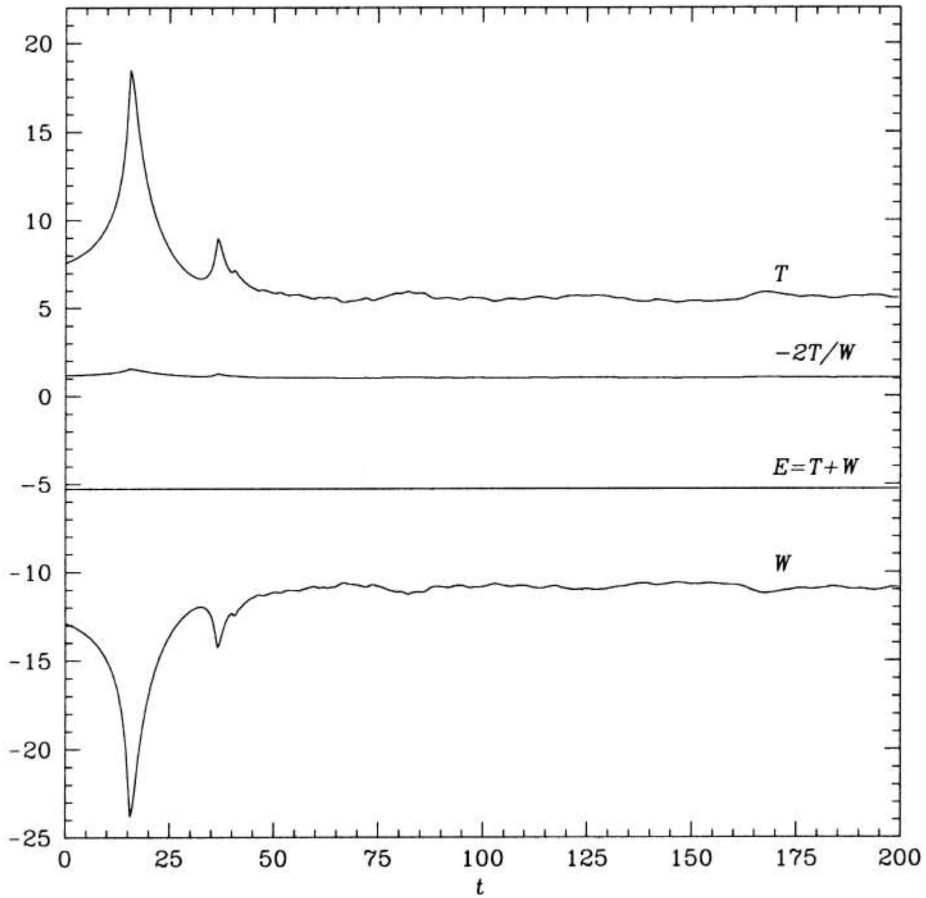
Results of Mergers
Scatter Plot

Start of simulation End of simulation



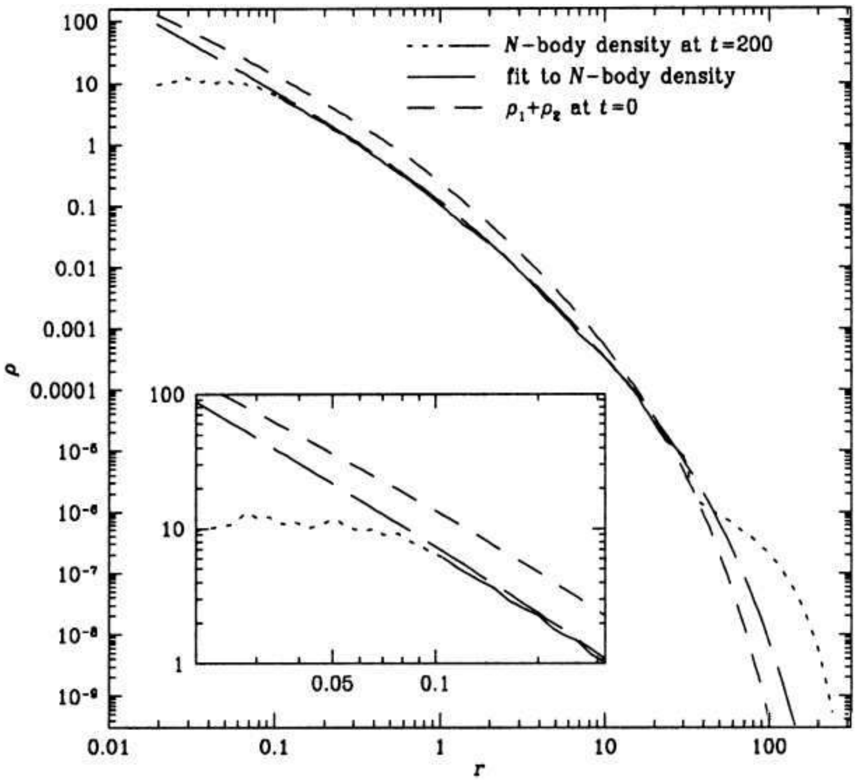
Results from Mergers
Energy Plot

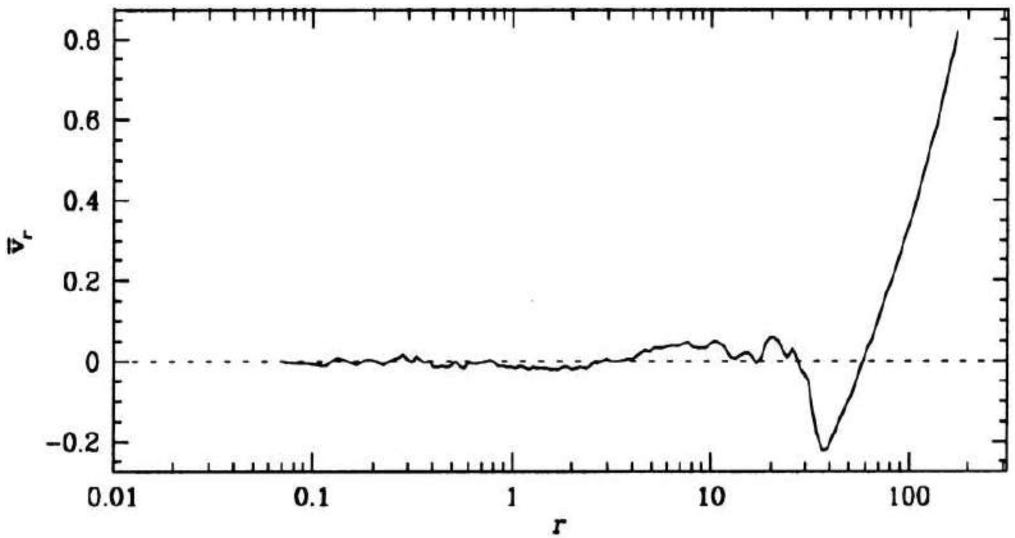
- During the first encounter energy is transferred between particles indicating violent mixing drives to equilibrium
- Following the second encounter phase mixing damps to equilibrium



Results of Mergers
Density Profile and Velocity Profile

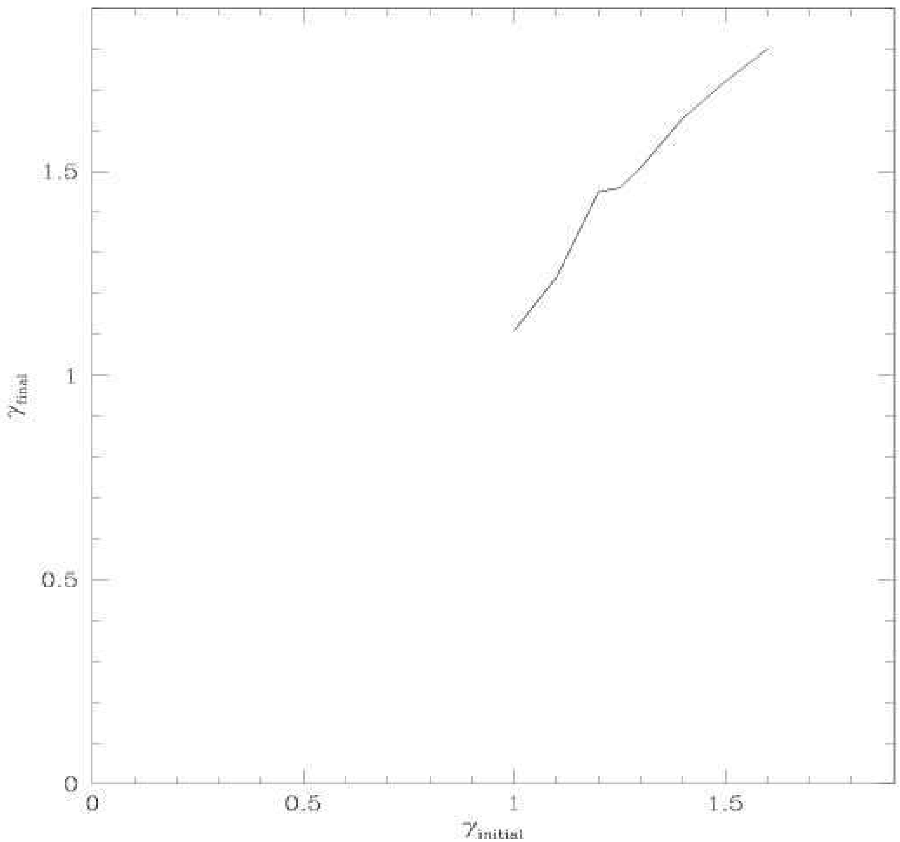
- The modified NFW model fits the density profile following the merger over 3 decades of radius
- Deviation at small radii is due to two body relaxation
- Deviation at large radii is due to unbound particles

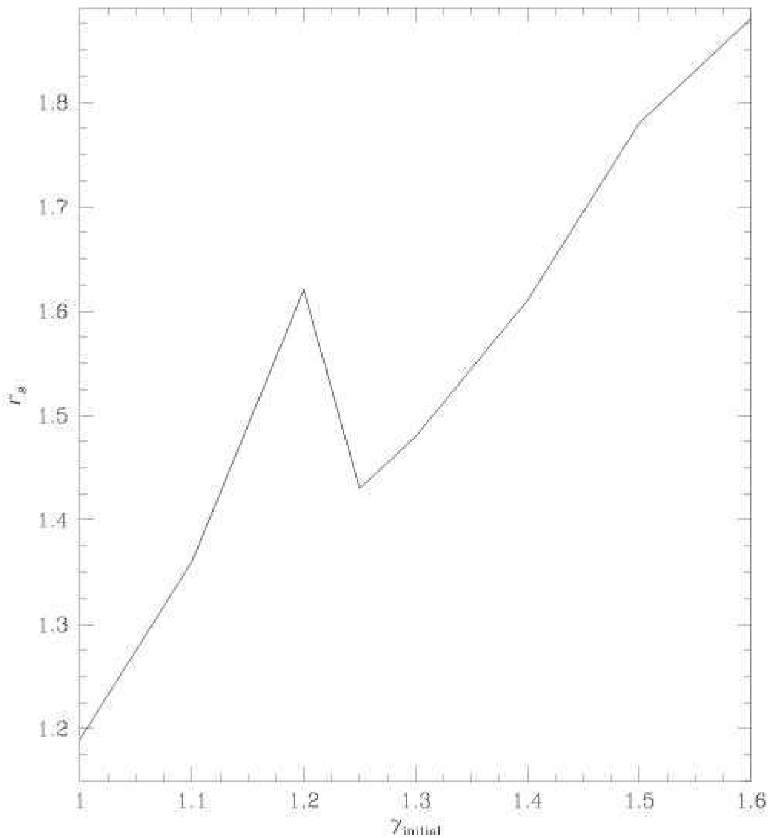




Results of Mergers
Varying Inner Logarithmic Slope γ

- Head on collisions
- Mergers generate halos with steeper cusps and increased scale radius





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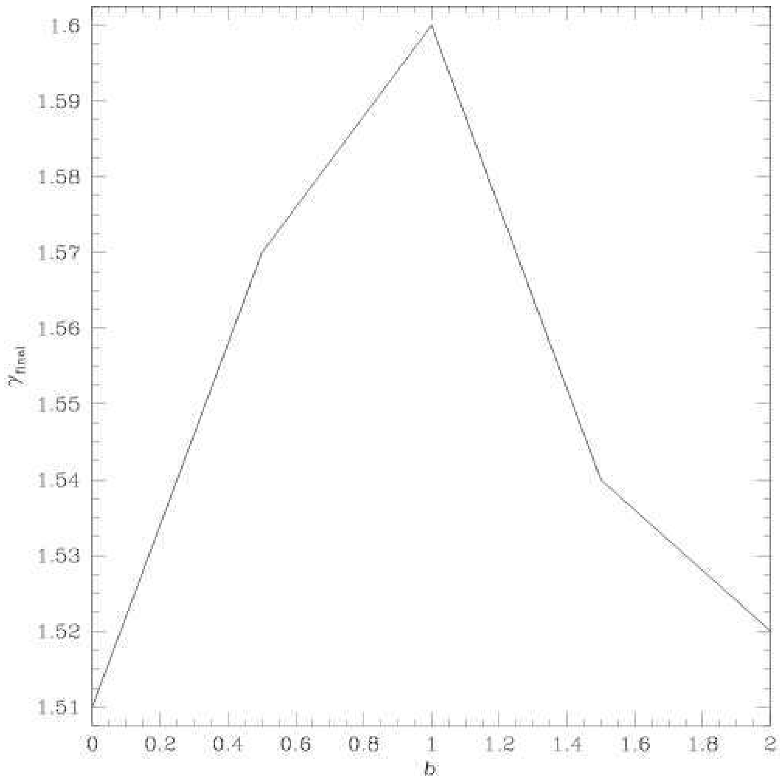
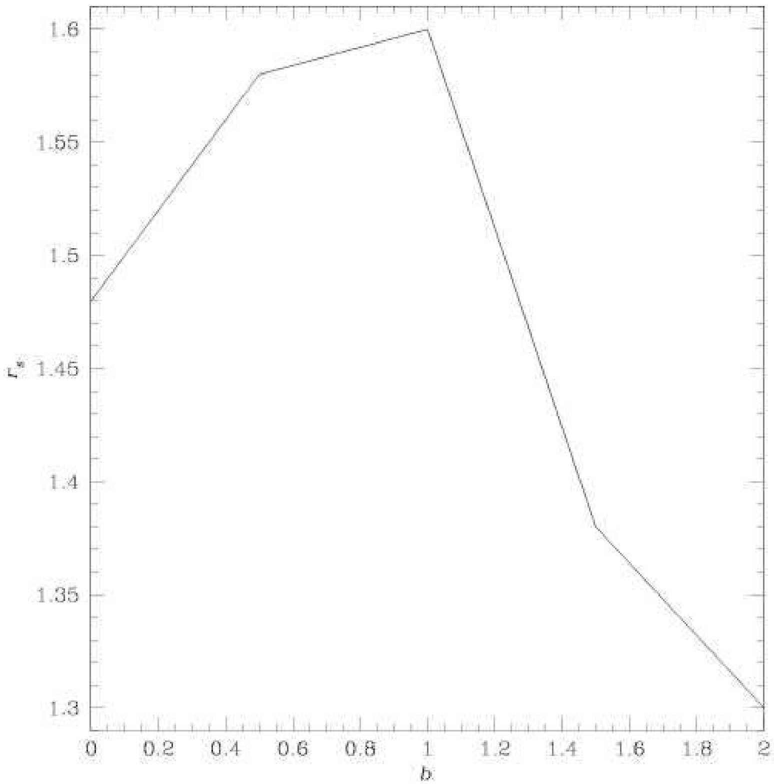
Results of Mergers Varying Impact Parameter

- Initially the halos had inner logarithmic slope $\gamma = 1.3$
- Mergers generate halos with steeper cusps and increased scale radius





Possible Further Work

- Explore relationships found in more detail, using higher resolution and examining non-linearity carefully
- Collisions between halos having different initial parameters (scale radius, truncation radius, mass and inner logarithmic slope)
- Halos having initial angular momentum
- Effects of halo inner structure e.g. bars, satellite halos and continuous accretion of diffuse material
- Alternative density profiles

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Summary

- Reviewed the necessity and evidence for dark matter halos
- Outlined modelling a dark matter halo using a computer simulation
- Reviewed the general properties of a merger by examining scatter plots
- Following a merger the remnant halo density profile always followed a modified NFW form
- Studied how the remnant halo density profile varies with changing inner logarithmic slope of initial halo and impact parameter of the collision.
- Indicated areas of further possible research