Imprints of structure formation history on dark matter halo profiles

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Cosmology miniworkshop – ICTP

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**Dark matter halos**

Result of the growth of initial perturbations influenced by gravity and expansion.

Traced by observable galaxies, lensing effect, X-ray gas...
**A universal profile?**

**Navarro, Frenk and White profile**

Phenomenological density profile from the simulations

\[
\rho(r) = \frac{\rho_s}{\frac{r}{r_s}(1 + \frac{r}{r_s})^2}
\]

concentration: \( c = \frac{r_{200}}{r_s} \)

Navarro, Frenk & White, 1997
Concentration-mass relationship


Linked to the mass-accretion history of the halo.
1. **Dark Energy Universe Simulations**

2. **Agreement to the NFW Profile**

3. **Sparsity: An Alternative Parameter**

4. **Conclusion**
DEUS
NFW profile
Sparsity
Conclusion
Ideal set-up to study imprints of cosmology on non-linear structure formation, and in particular on halo profiles.

see www.deus-consortium.org,
http://www.deus-consortium.org/deuvo/
Cosmological models

Realistic models

- Calibrated on WMAP5 (3,1) and the UNION dataset
- ΛCDM: \( \Omega_\Lambda = 0 \)
- SUCDM: \( w \approx -0.94 + 0.19(1 - a) \)
- RPCDM: \( w \approx -0.87 + 0.08(1 - a) \)

Toy models

- Study of the influence of one single parameter
- SCDM: \( \Omega_\Lambda = 0 \)
- LΛCDM: \( \Omega_\Lambda = 0.9 \)
- LRPCDM: equation of state \( w \)
Halo Finder

**Spherical Overdensity**

Halo: sphere of mean density $\Delta \times \rho_m$

$\Delta = 200$

imposed spherical geometry

From SOD: $M_{200}, r_{200}, \{r_i, \rho_i, \sigma_i\}$
PROFILE FITTING

Fitting procedure: $c$, $\chi^2 = \left( \sum_{i=1}^{n} \frac{(\rho_i^{\text{NFW}} - \rho_i)^2}{2\sigma_i^2} \right) / n$
PROFILE FITTING

Fitting procedure: \( c, \chi^2 = \frac{\sum_{i=1}^{n} (\rho_i^{NFW} - \rho_i)^2 / 2\sigma_i^2)}{n} \)
Numerical effect on $\chi^2$

Renormalization: $\tilde{\chi}^2 = \chi^2 \sqrt{\frac{n_{\text{min}}}{n_{\text{part}}}}$

$\tilde{\chi}^2$ independent of the resolution
In cosmological models with no dark energy, halos are more in agreement with the NFW profile.
HALO GROUPS

Halos fitted to within $1\sigma$: 68%
Halos fitted to within $2\sigma$: 95%
Halos ill-fitted: 5%
**Concentration as a function of mass**

In ill-fitted halos, $c$ has no physical meaning.
Sparsity

\[ S_\Delta = \frac{M_{200}}{M_\Delta} \]

- no fitting required
- probes the outer parts of the halo

\[ \Delta = 200 \\
600 \\
1200 \]
**SPARSITY AS A FUNCTION OF MASS**

The sparsity is not influenced by the profile agreement with NFW.
near mass independence $\Rightarrow$ Consistency relation between $s_{\Delta}$ and the mass functions

$$\int_{M_1}^{M_2} \frac{1}{M_\Delta} \frac{dn}{d \ln M_\Delta} d \ln M_\Delta = s_{\Delta} \int_{s_\Delta M_1}^{s_\Delta M_2} \frac{1}{M_{200}} \frac{dn}{d \ln M_{200}} d \ln M_{200}$$

solid: $z = 0$

dotted: $z = 1$
VARATIONS WITH THE COSMOLOGY
The higher $D_+ (\sigma_8)$, the lower $s_\Delta$
Observational data

22 clusters with measured $M_{112}$ and $M_{500}$ (projected) masses (Local Cluster Substructure Survey)

Okabe et al., 2010
PROOF-OF-CONCEPT

CONCLUSION

- comparison with observations
  investigate possible biases
- 2D sparsity
  projected mass, as measured by weak lensing
- higher masses
  DEUS Full Universe Run
- investigation of the relationship with the mass function