IMPRINTS OF STRUCTURE FORMATION HISTORY ON DARK MATTER HALO PROFILES

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Cosmology miniworkshop – ICTP

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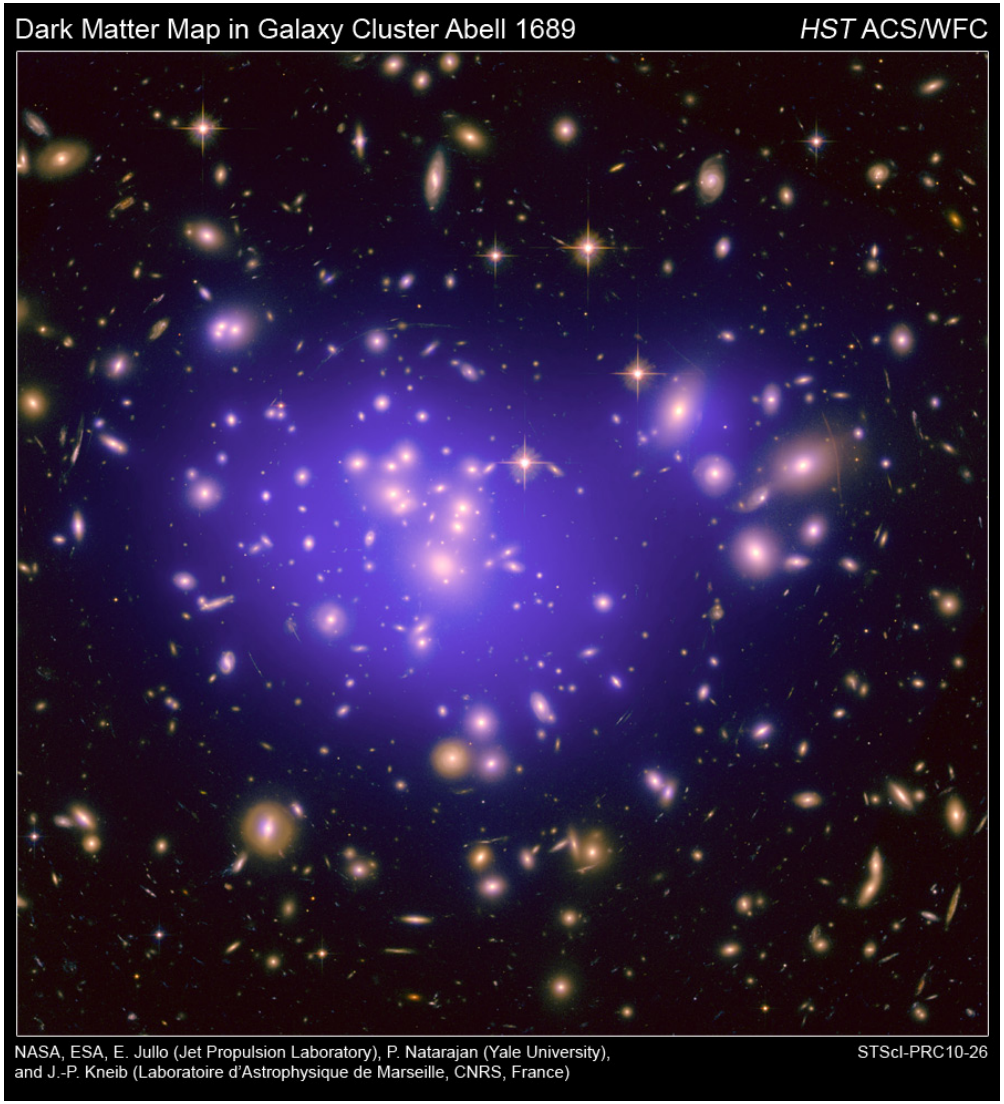
DARK MATTER HALOS

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

Traced by observable galaxies, lensing effect, X-ray gas...



A UNIVERSAL PROFILE?

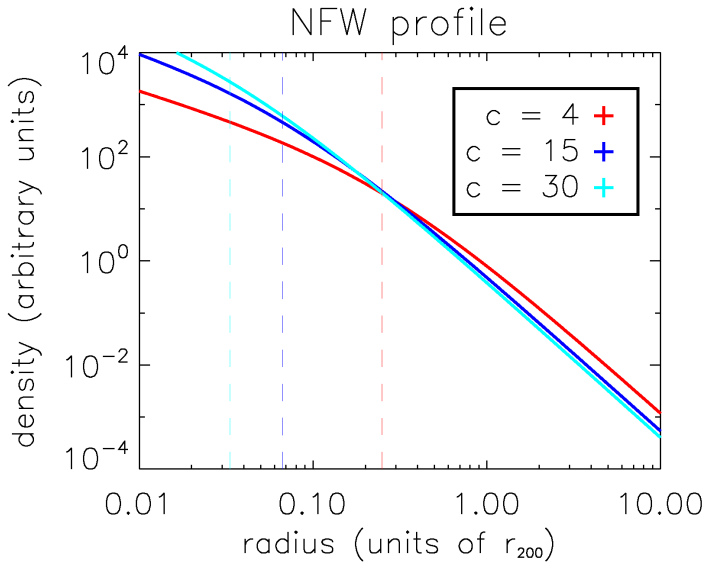
NAVARRO, FRENK AND WHITE PROFILE

Phenomenological density profile from the simulations

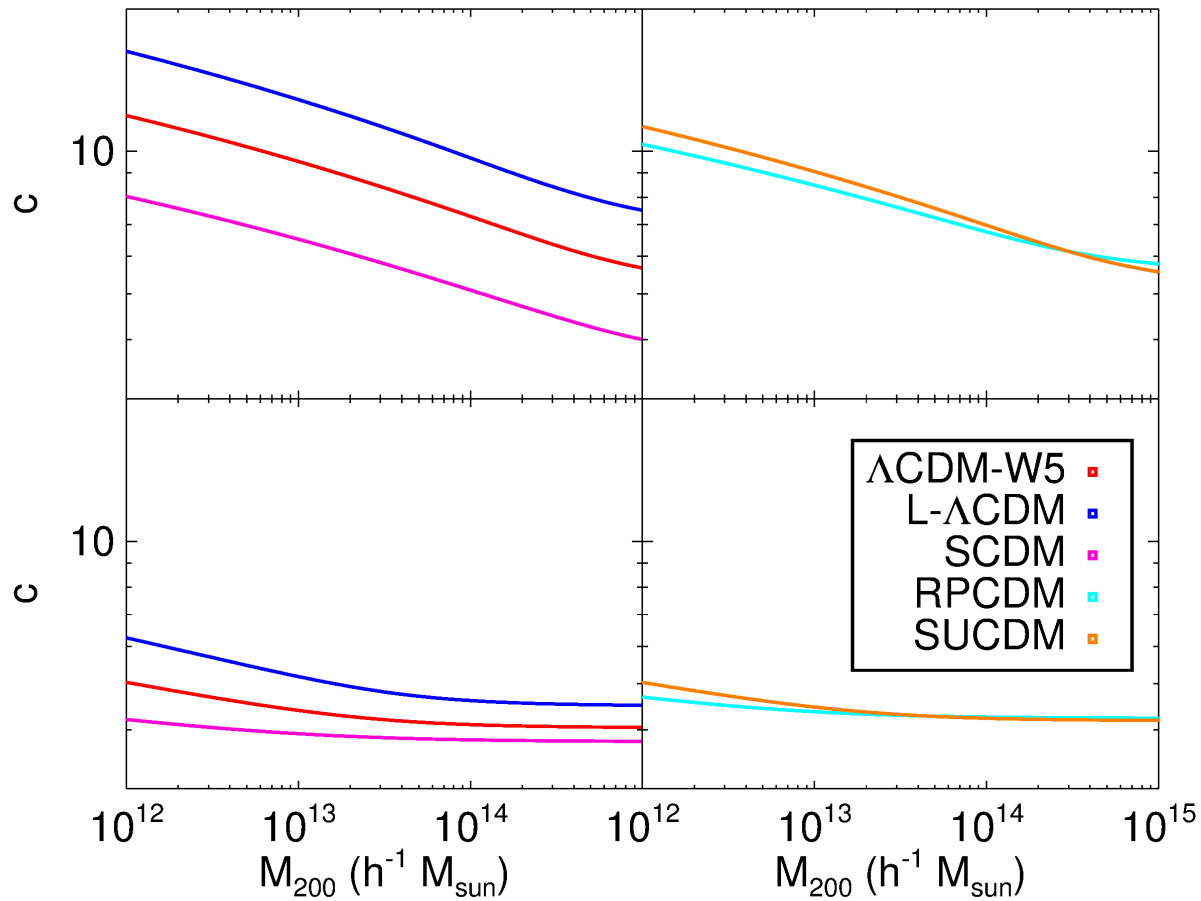
$$\rho(r) = \frac{\rho_s}{\frac{r}{r_s}(1+\frac{r}{r_s})^2}$$

concentration: $c = \frac{r_{200}}{r_s}$

Navarro, Frenk & White, 1997



CONCENTRATION-MASS RELATIONSHIP



Navarro et al. 1997, Bullock et al. 2001, Zhao et al. 2003, 2009, Dolag et al. 2004...

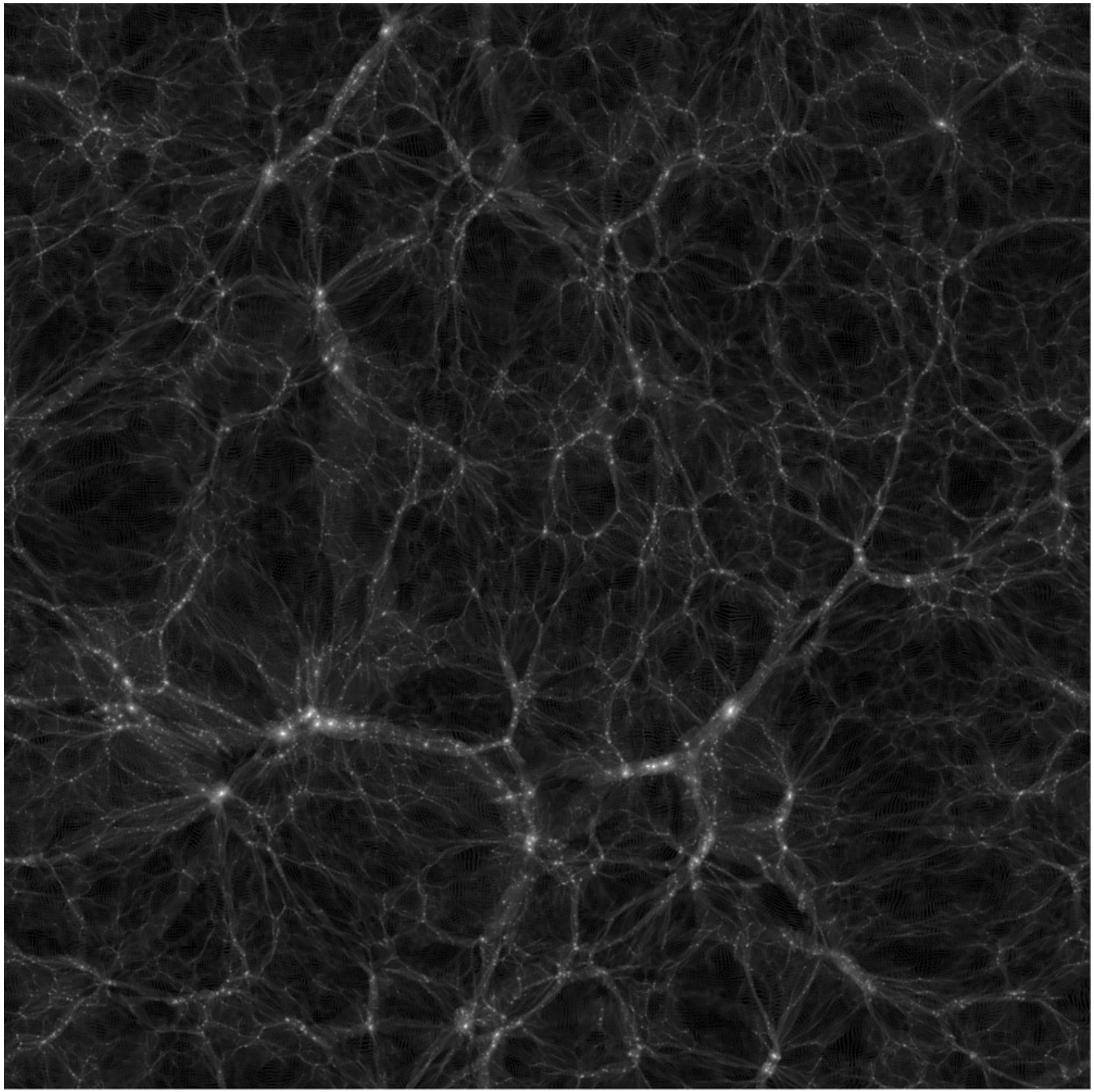
Linked to the mass-accretion history of the halo.

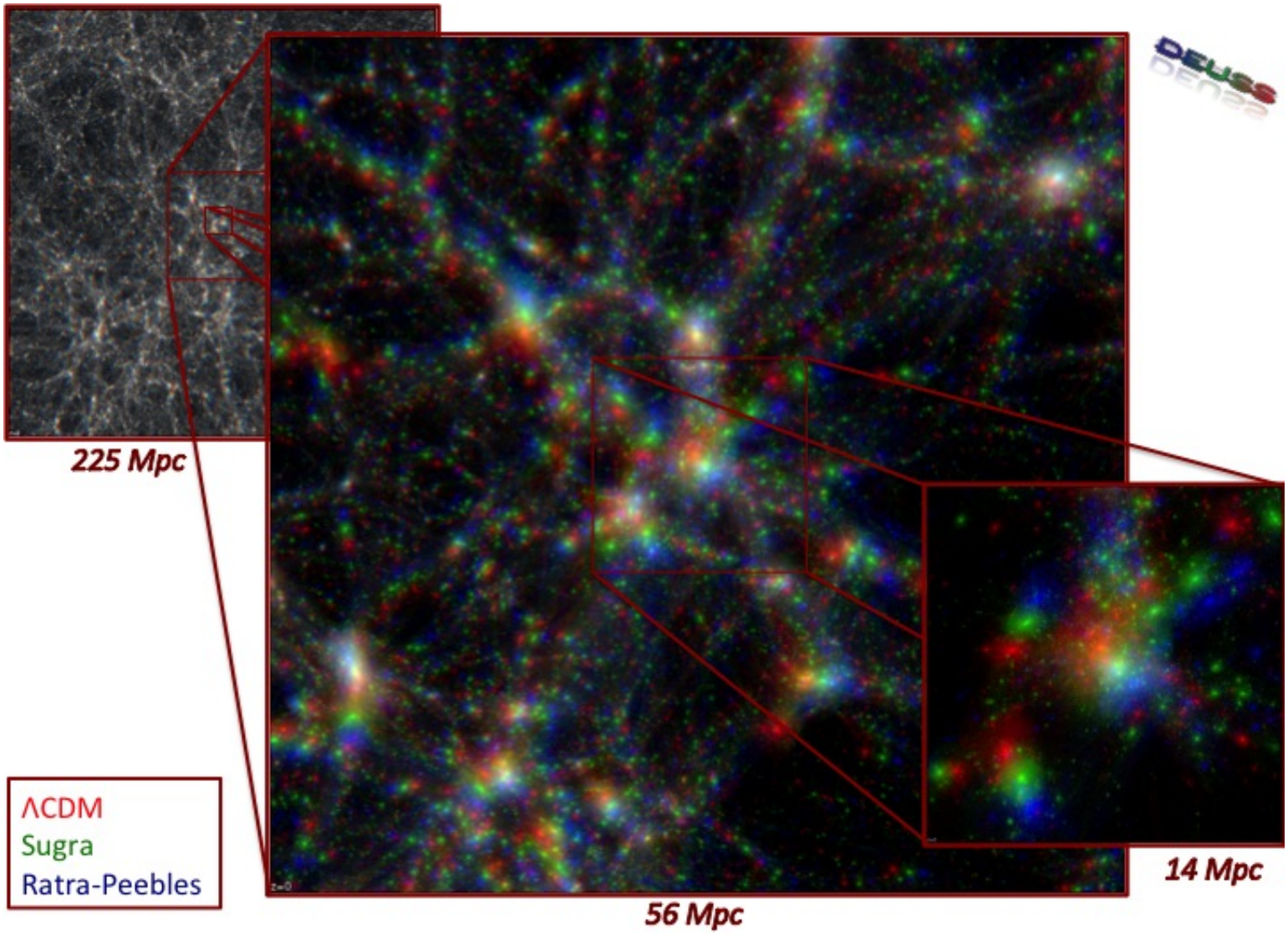
1 DARK ENERGY UNIVERSE SIMULATIONS

2 AGREEMENT TO THE NFW PROFILE

3 SPARSITY: AN ALTERNATIVE PARAMETER

4 CONCLUSION




225 Mpc
56 Mpc
14 Mpc
ΛCDM
Sugra
Ratra-Peebles

LARGE SET OF UNIVERSE VOLUMES (+ 25 SIMULATIONS)
HIGH SPATIAL RESOLUTION AND MASS: 2.5 h^{-1} kpc to 10.4 h^{-1} Gpc, 2.5 10^8 h^{-1} $M_\odot$ to 10^{16} $h^{-1}M_\odot$
INITIAL REDSHIFT DEEP IN LINEAR REGIME

Box Size	Force Resolution	Mass Resolution	Number of Particles	Initial Redshift	Cosmological Models	Supercomputer (Nb of Proc)
162 h^{-1} Mpc	2.5 h^{-1} kpc	~2. 10^9 h^{-1} $M_\odot$	512^3	~90	ΛCDM, SUCDM, RPCDM	Titane (64)
162 h^{-1} Mpc	2.5 h^{-1} kpc	~2.5 10^8 h^{-1} $M_\odot$	1024^3	~130	ΛCDM, SUCDM, RPCDM	Blue Gene/P(4096)
648 h^{-1} Mpc	20 h^{-1} kpc	~1.5 10^{11} h^{-1} $M_\odot$	512^3	~55	ΛCDM, SUCDM, RPCDM	-
648 h^{-1} Mpc	10 h^{-1} kpc	~1.75 10^{10} h^{-1} $M_\odot$	1024^3	~90	ΛCDM, SUCDM, RPCDM	Blue Gene/P(4096)
648 h^{-1} Mpc	5 h^{-1} kpc	~2. 10^9 h^{-1} $M_\odot$	2048^3	~90	ΛCDM, RPCDM	Blue Gene/P(32768)
1296 h^{-1} Mpc	40 h^{-1} kpc	~1. 10^{12} h^{-1} $M_\odot$	512^3	~40	ΛCDM, SUCDM, RPCDM	-
2592 h^{-1} Mpc	40 h^{-1} kpc	~1. 10^{12} h^{-1} $M_\odot$	1024^3	~55	ΛCDM, SUCDM, RPCDM	Blue Gene/P(4096)
2592 h^{-1} Mpc	20 h^{-1} kpc	~1.5 10^{11} h^{-1} $M_\odot$	2048^3	~55	ΛCDM, RPCDM	Blue Gene/P(24576)
5184 h^{-1} Mpc	40 h^{-1} kpc	~1. 10^{12} h^{-1} $M_\odot$	2048^3	~40	ΛCDM, RPCDM	Blue Gene/P(24576)
10368 h^{-1} Mpc	40 h^{-1} kpc	~1. 10^{12} h^{-1} $M_\odot$	4096^3	~40	ΛCDM	Curie Fat Nodes (9728)

DEUS SIMULATIONS

- multiple box-sizes and resolutions
- large mass range
- several cosmological models

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

- ΛCDMW5 (3, 1)
- SUCDM: $w \simeq -0.94 + 0.19(1 - a)$
- RPCDM: $w \simeq -0.87 + 0.08(1 - a)$

TOY MODELS

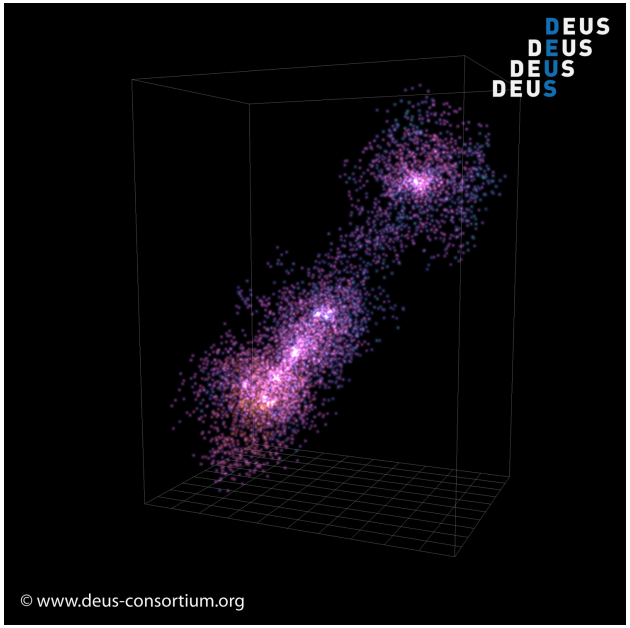
Study of the influence of one single parameter

- SCDM: $\Omega_\Lambda = 0$
- LΛCDM: $\Omega_\Lambda = 0.9$
- LRPCDM: equation of state w

HALO FINDER

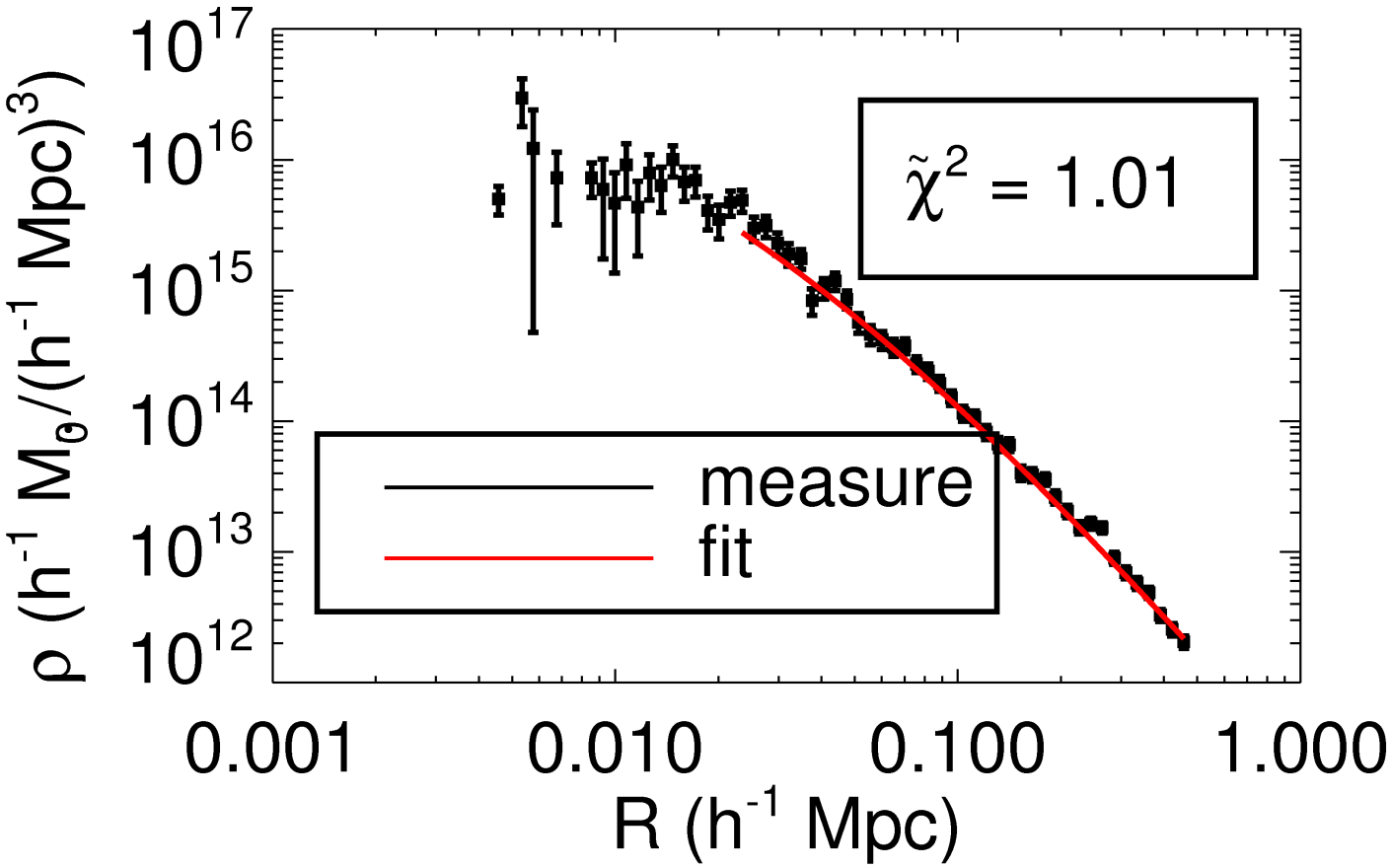
SPHERICAL OVERDENSITY

Halo: sphere of mean density $\Delta \times \rho_m$
$\Delta = 200$
imposed spherical geometry



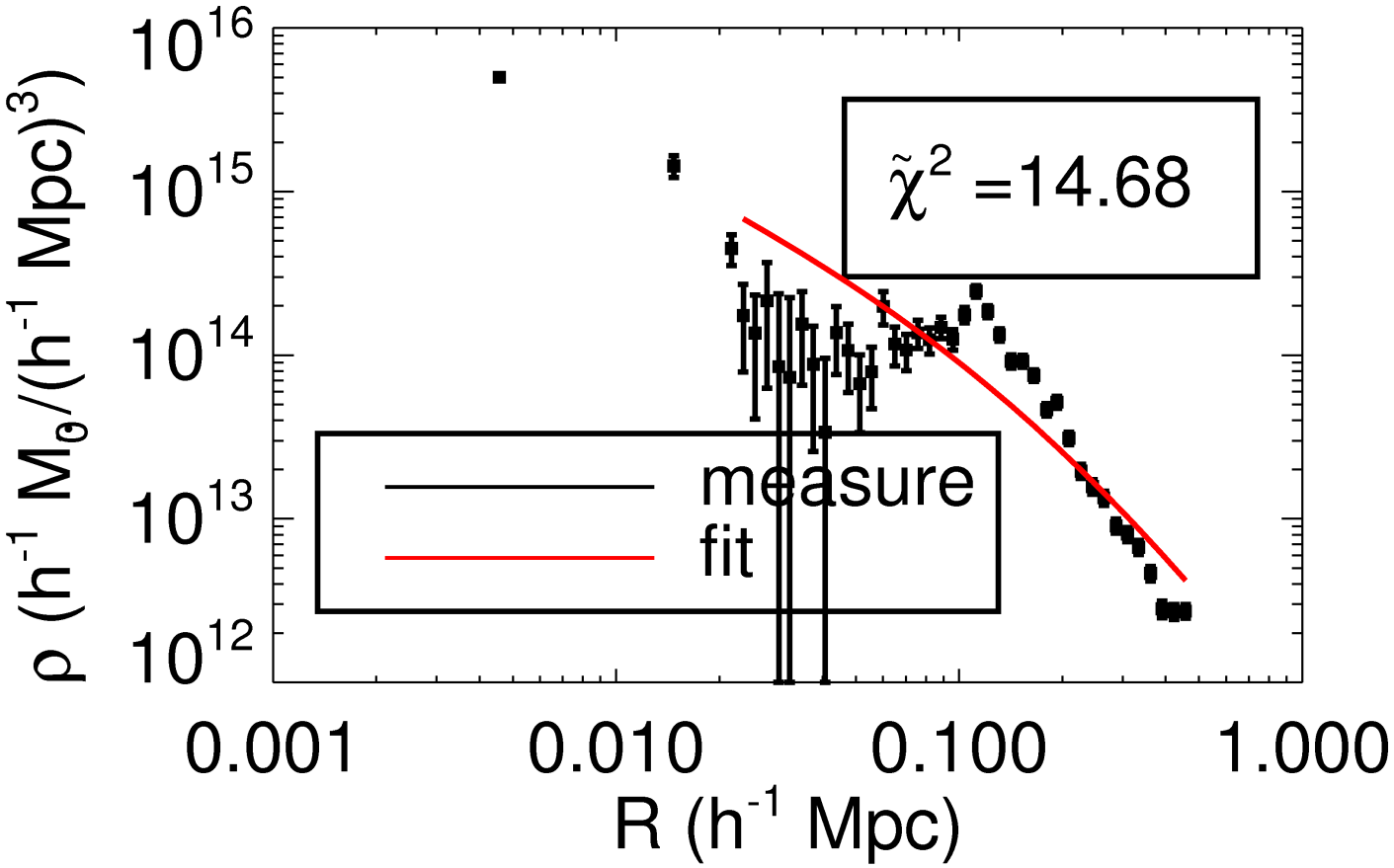
From SOD: M_{200}, r_{200}, $\{r_i,\ \rho_i,\ \sigma_i\}$

PROFILE FITTING



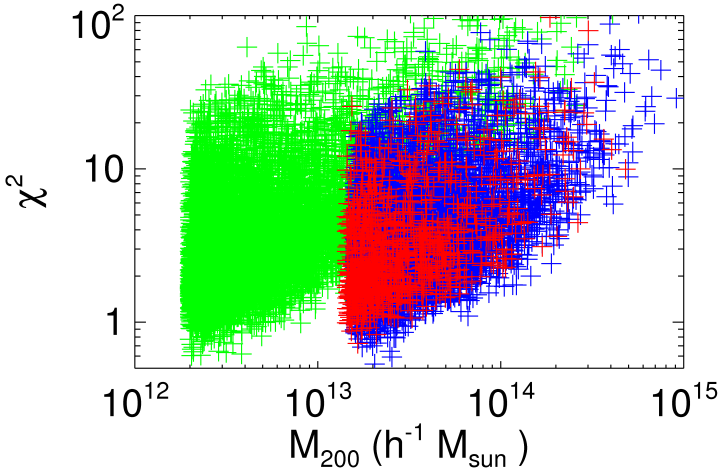
Fitting procedure: c, $\chi^2 = (\sum_{i=1}^{n}(\rho_i^{NFW} - \rho_i)^2/2\sigma_i^2)/n$

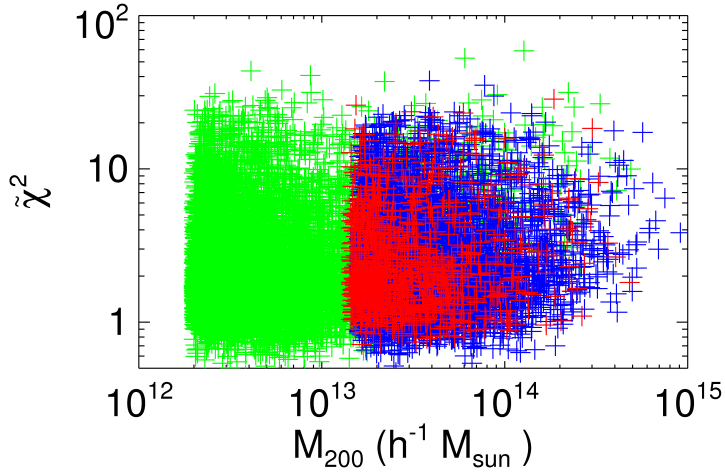
PROFILE FITTING



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

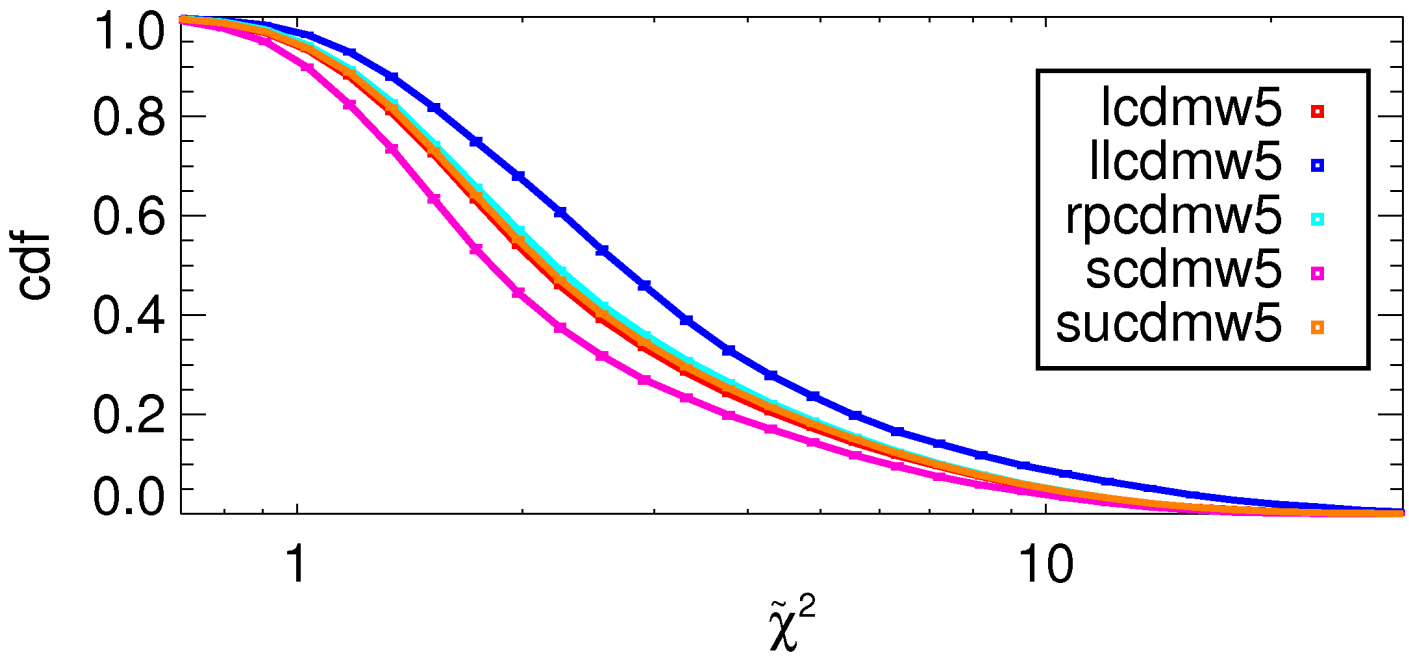
NUMERICAL EFFECT ON χ^2





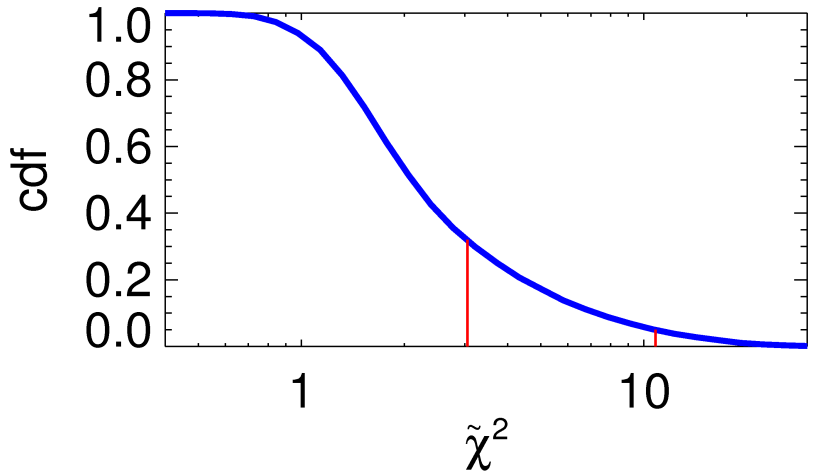
Renormalization: $\tilde{\chi}^2 = \chi^2 \sqrt{n_{min}/n_{part}}$
$\tilde{\chi}^2$ independent of the resolution

AGREEMENT WITH NFW



In cosmological models with no dark energy, halos are more in agreement with the NFW profile.

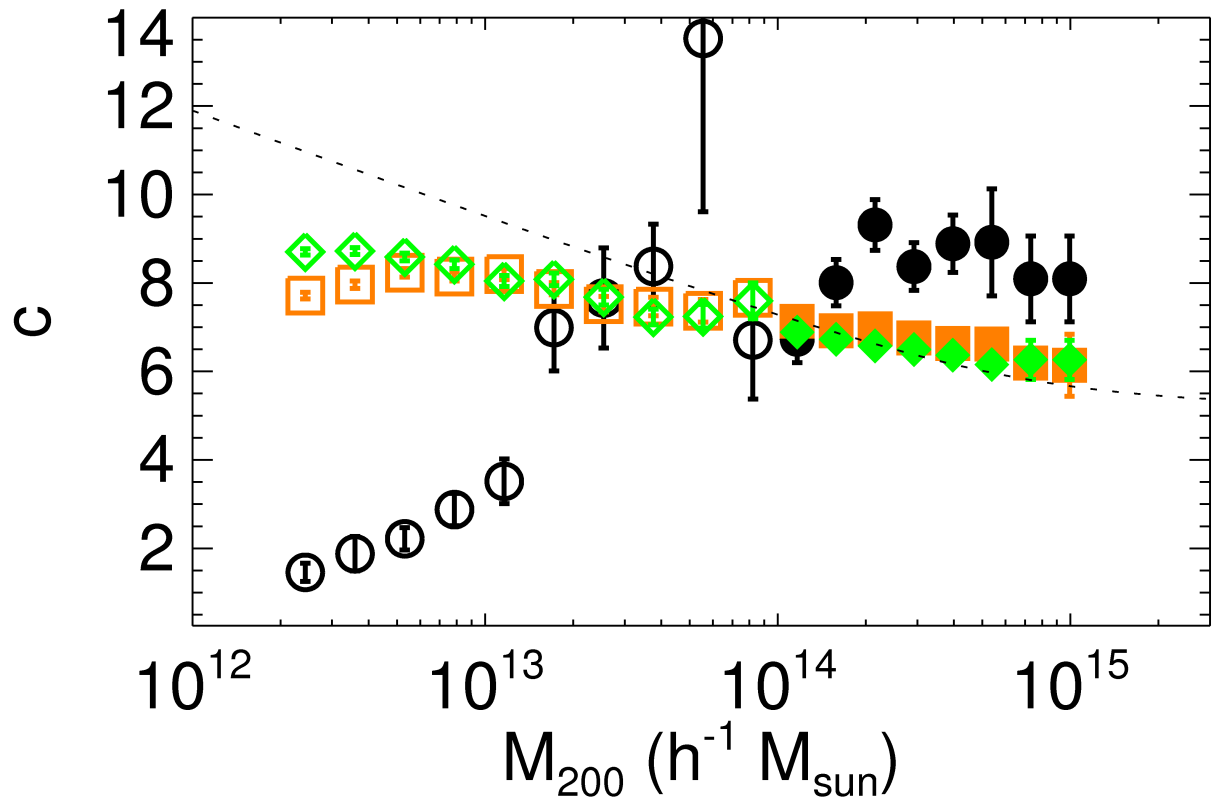
HALO GROUPS



3 HALO GROUPS

- Halos fitted to within 1σ: 68 %
- Halos fitted to within 2σ: 95 %
- Halos ill-fitted: 5%

CONCENTRATION AS A FUNCTION OF MASS

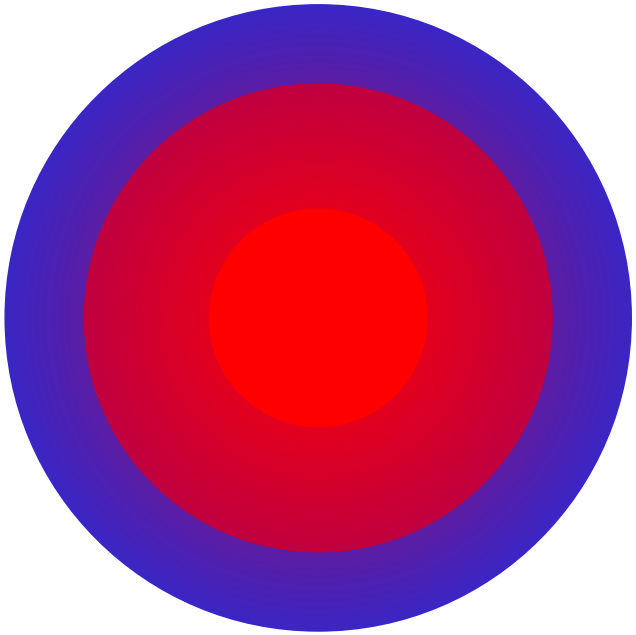


In ill-fitted halos, *c* has no physical meaning.

SPARSITY

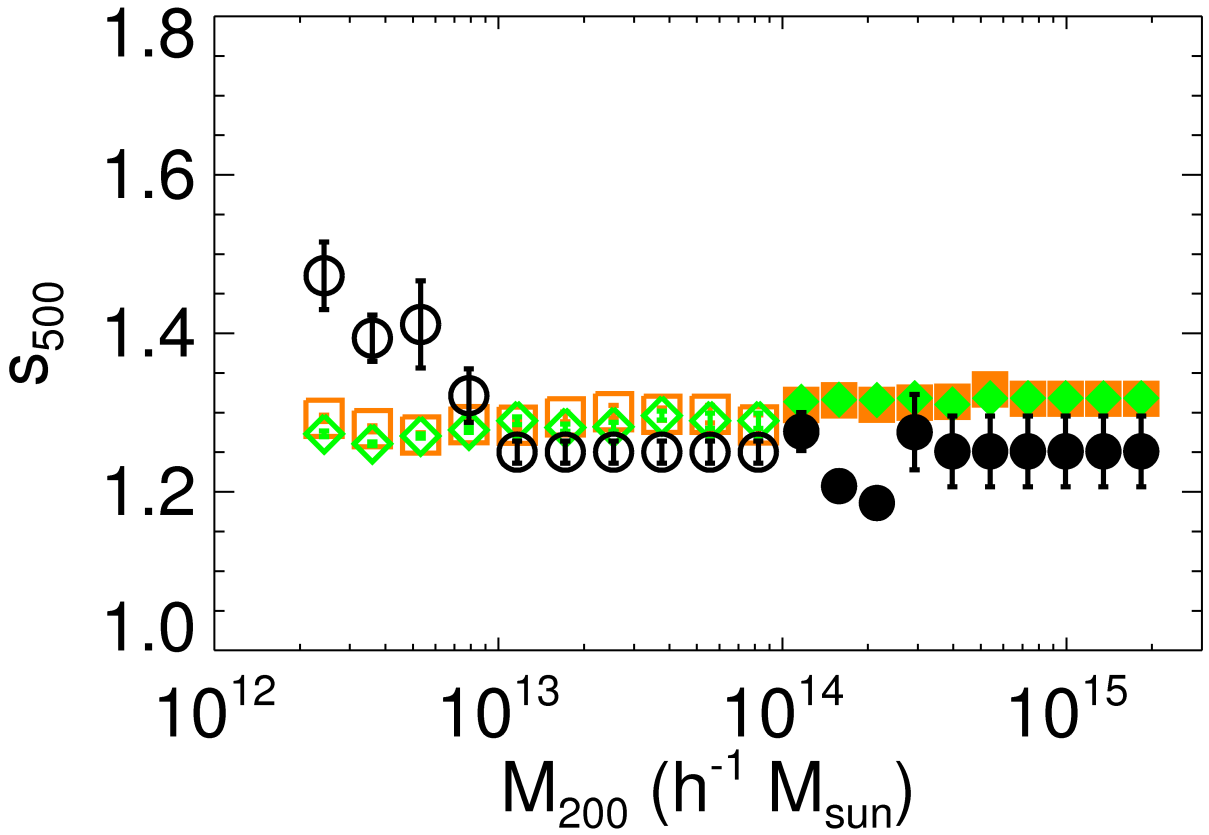
$$s_\Delta = \frac{M_{200}}{M_\Delta}$$

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



$\Delta =$200
600
1200

SPARSITY AS A FUNCTION OF MASS

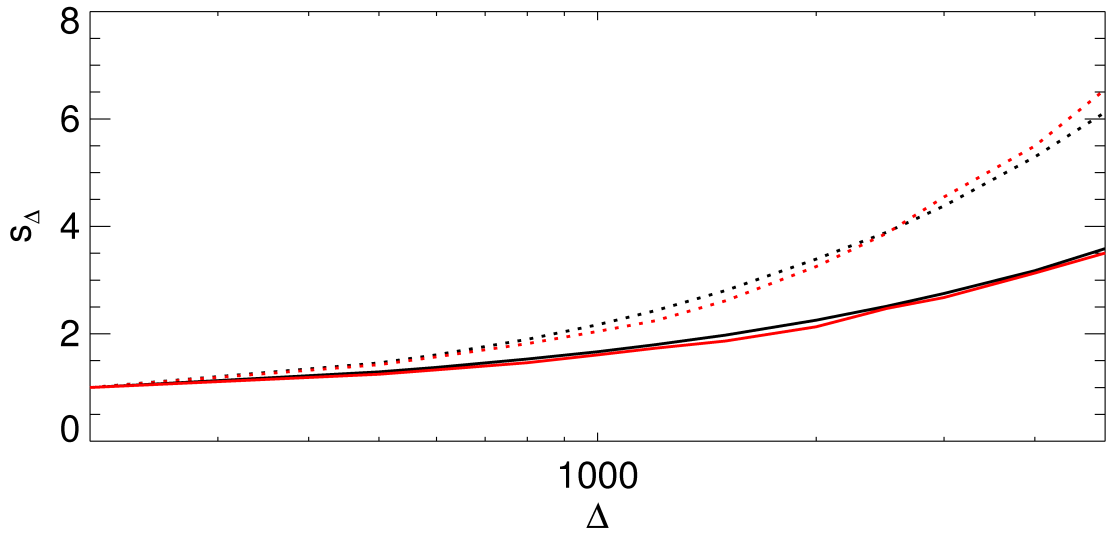


The sparsity is not influenced by the profile agreement with NFW.

CONSISTENCY RELATION

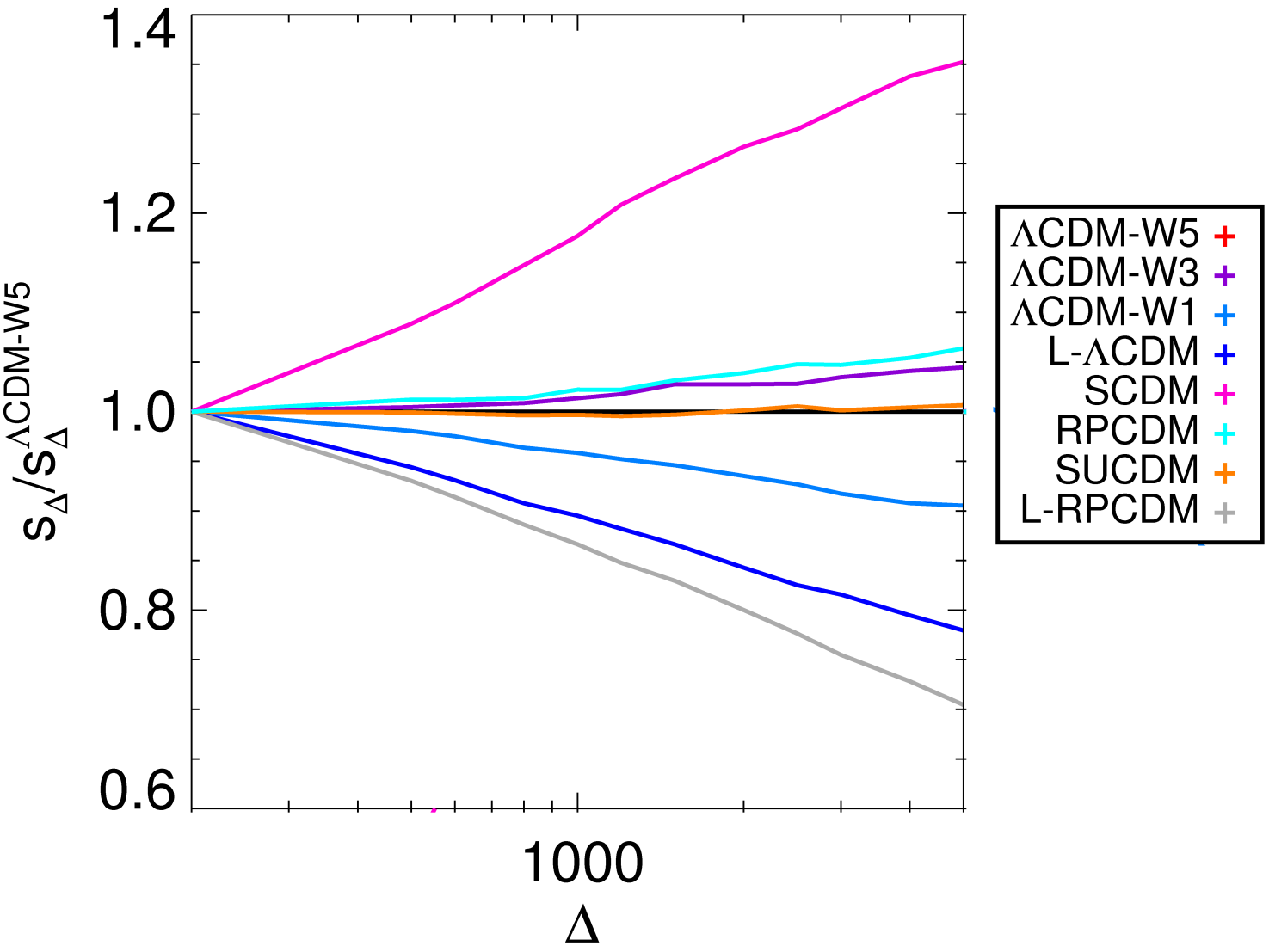
near mass independence $\Rightarrow$ Consistency relation between s_Δ and the mass functions

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

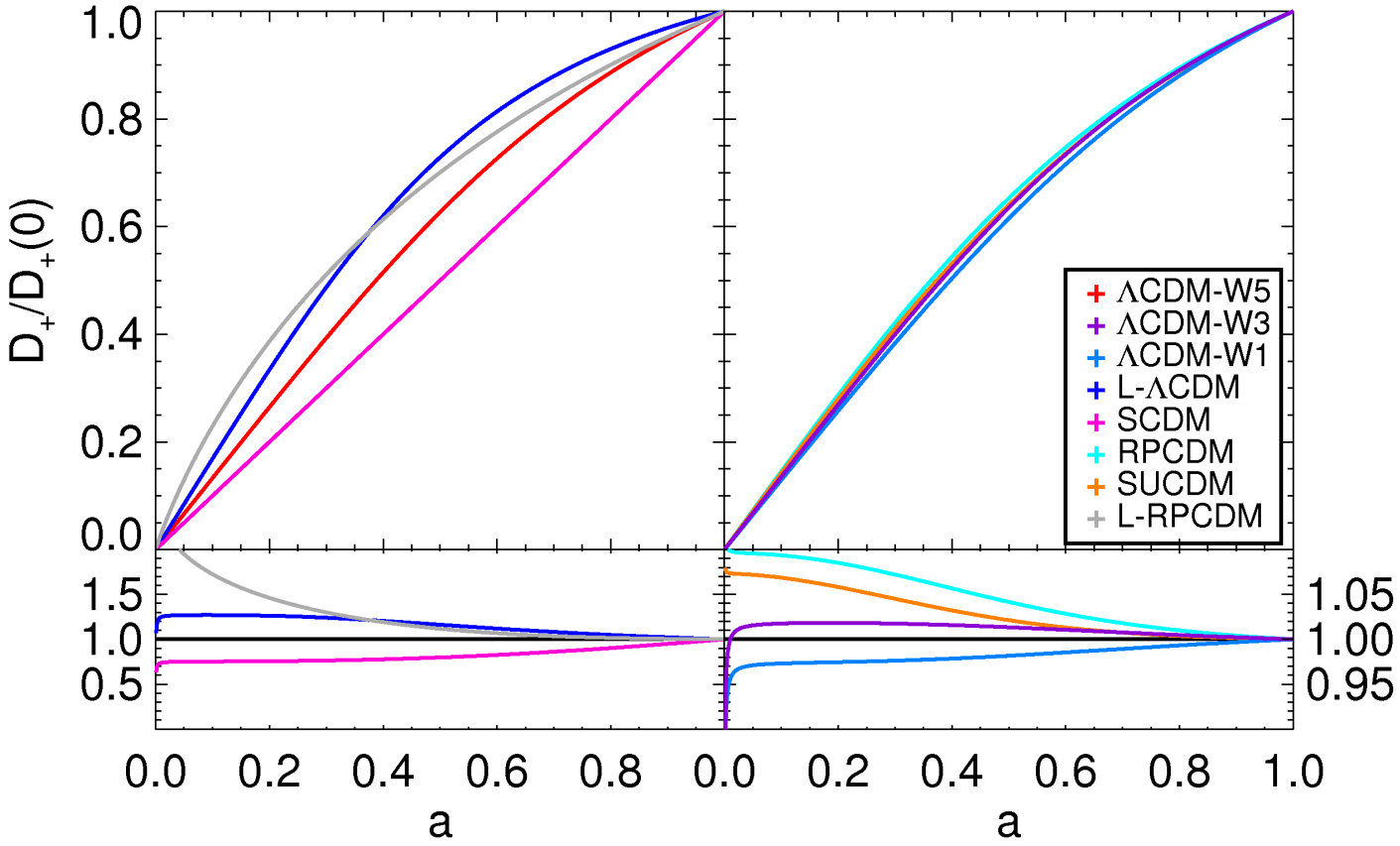


solid:
$z = 0$
dotted:
$z = 1$

VARIATIONS WITH THE COSMOLOGY



ORIGINS OF THE VARIATIONS



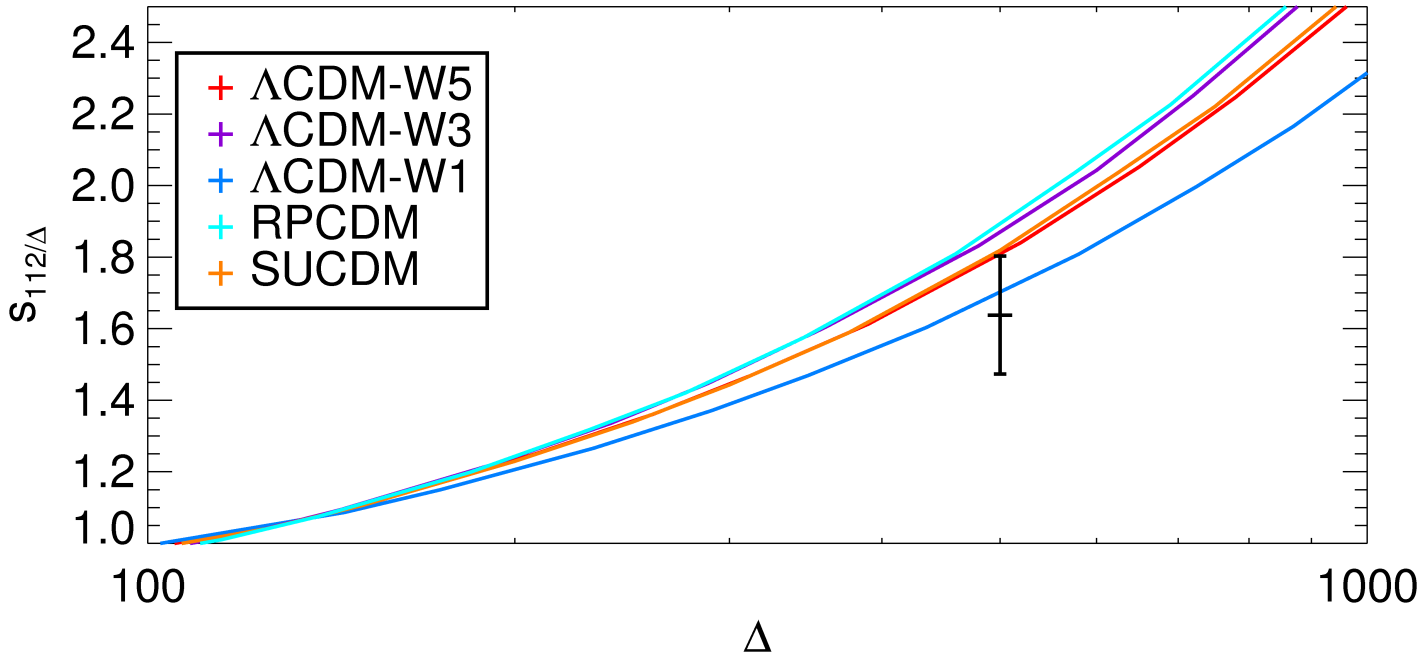
The higher D_+ (σ_8), the lower s_Δ

OBSERVATIONAL DATA

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

Okabe et al., 2010

PROOF-OF-CONCEPT



see Balmès, Rasera, Corasaniti & Alimi, MNRAS, 2014

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