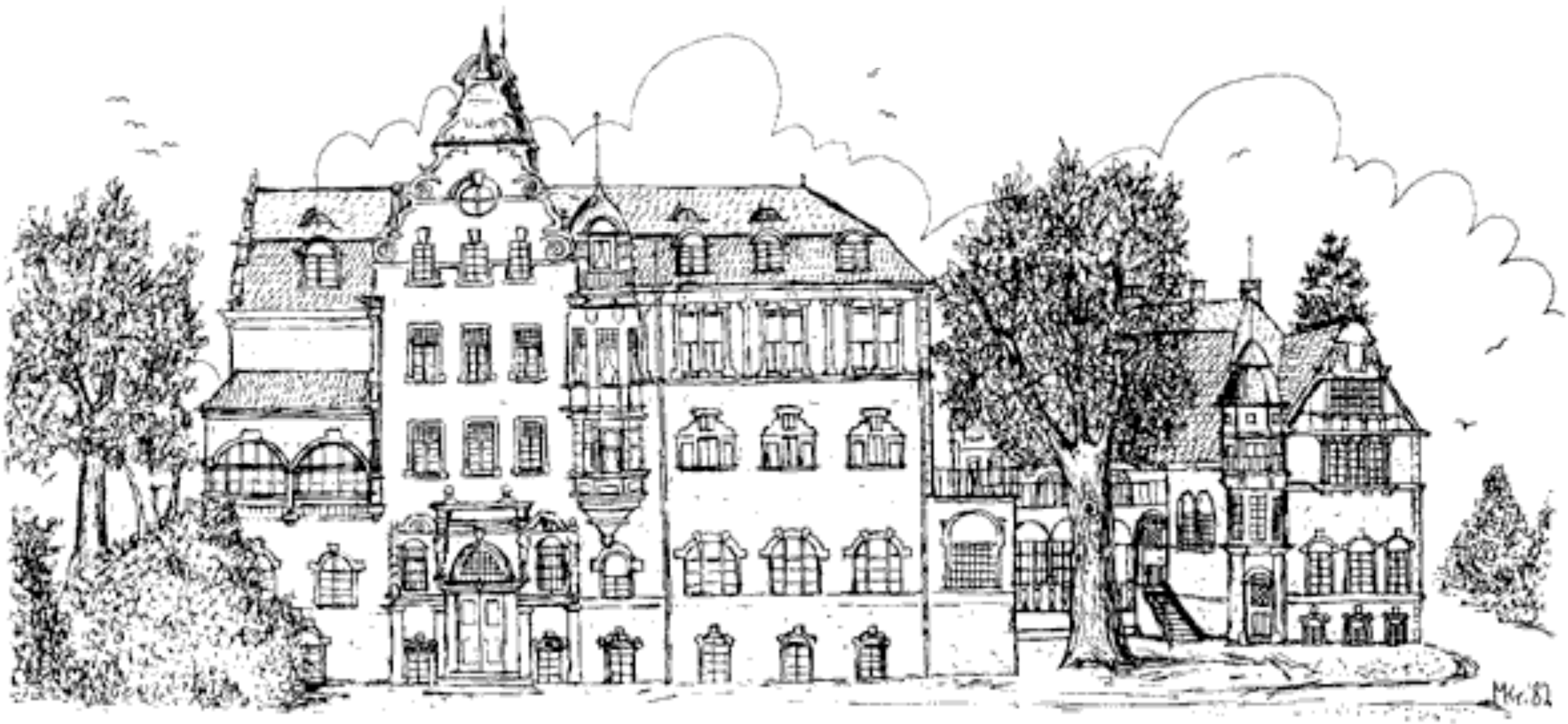
Marco Baldi

Excellence Cluster Universe, Garching

TIME DEPENDENT COUPLINGS IN THE DARK SECTOR



outline

1) Introduction and motivations

2) Dark interactions in general
   2a - constant couplings [MB, V. Pettorino, G. Robbers, V. Springel - MNRAS 2010]
   2b - time dependent couplings [MB - MNRAS 2010]

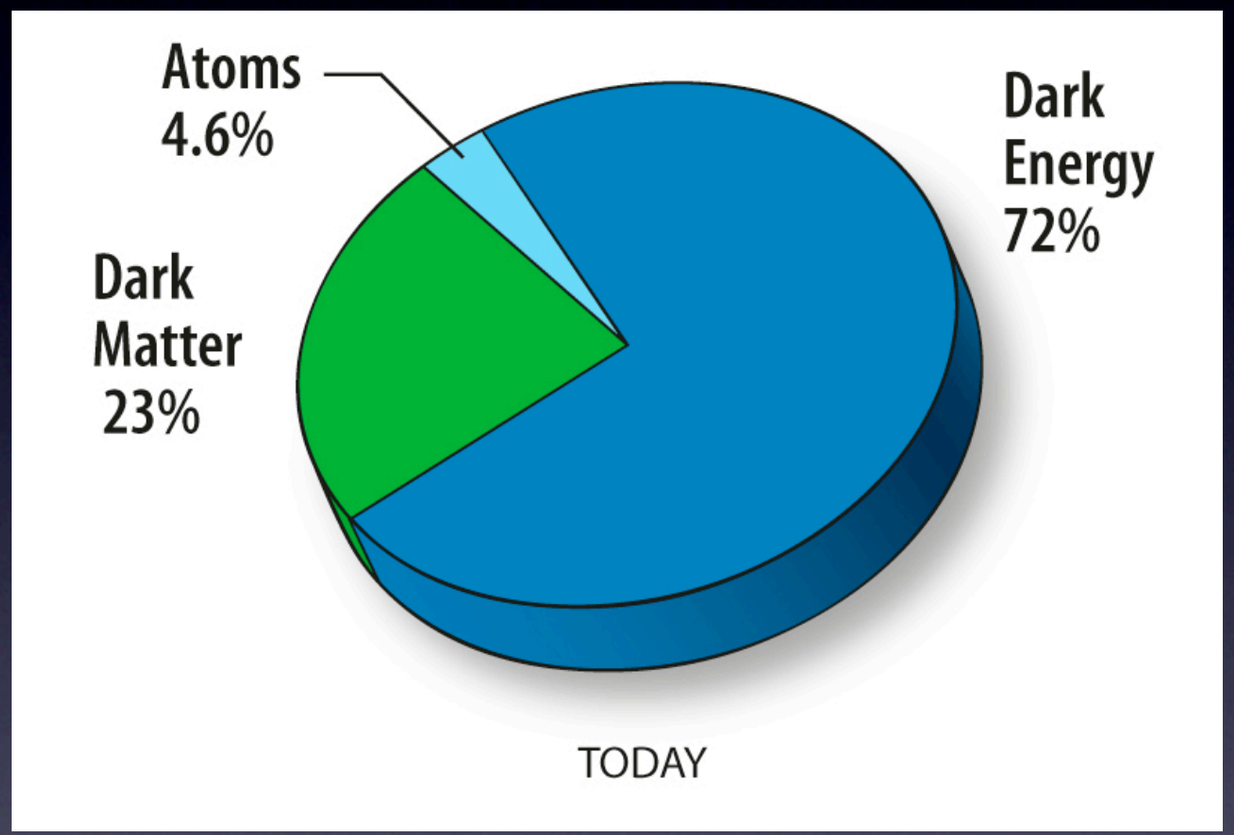
3) Numerical methods for N-body simulations of interacting dark energy
   - assumptions, approximations, and their range of validity

4) Results from high-resolution N-body runs:
   4a - Large Scale Structure: Halo Mass Function [MB, V. Pettorino - 1006.3761]
   4b - Collapsed objects: Density Profiles, Concentrations, Baryon Fraction

5) Conclusions

Introduction and motivations: the standard model

The last decade has provided us with a hardly doubtable evidence of the existence of some accelerating component in the Universe, dubbed Dark Energy



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[APM, 2dF, SDSS, ...]

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[high-z SNS, SN Cosmology Project, ...]

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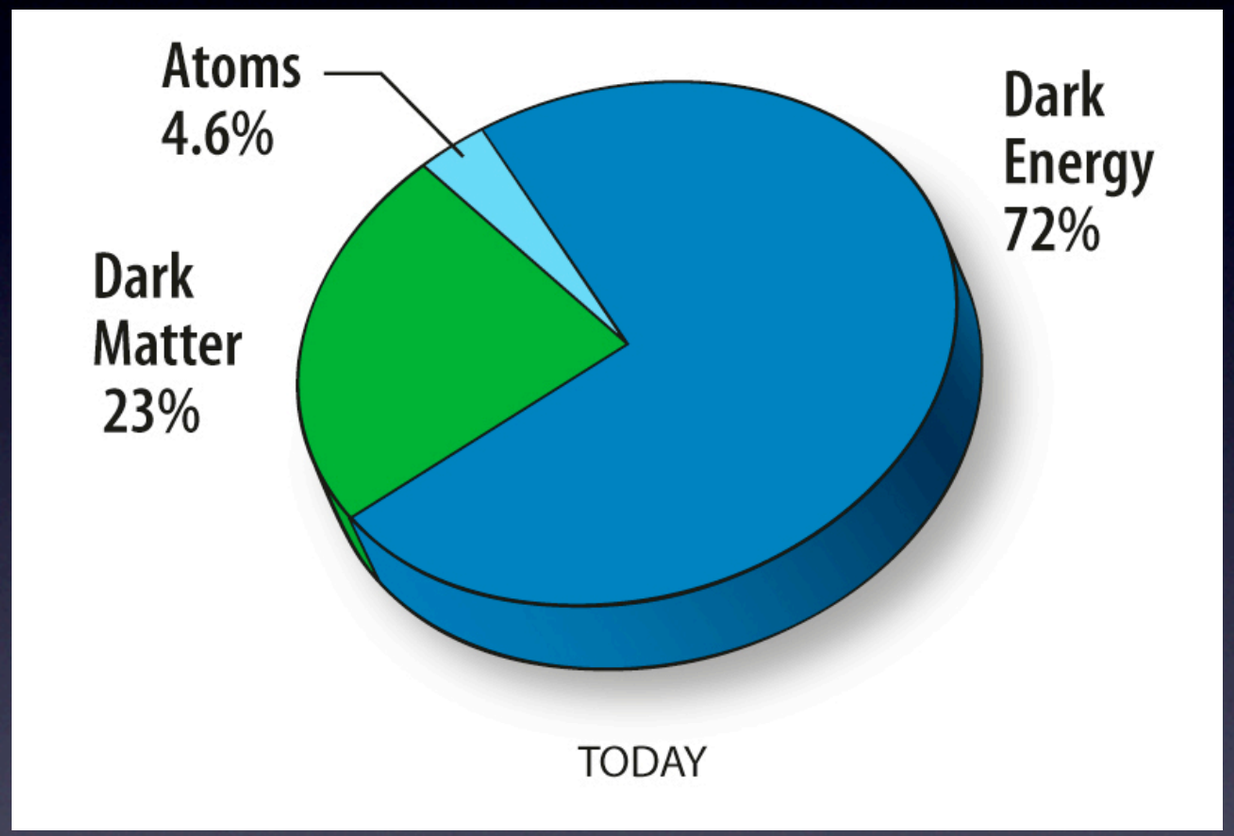

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The theoretical effort to cast all these data into a simple and consistent picture of the Universe has led to the establishment of a STANDARD MODEL...

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Dropping 4) → Dynamic Dark Energy models (Quintessence, k-essence, phantom, ...)

Dropping 4) → Interactions of Dark Energy (Coupled DE, Unified DM, Chaplygin gas, ...)

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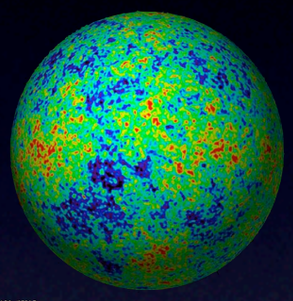

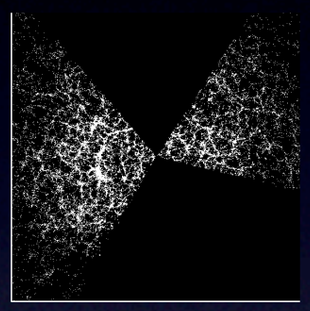

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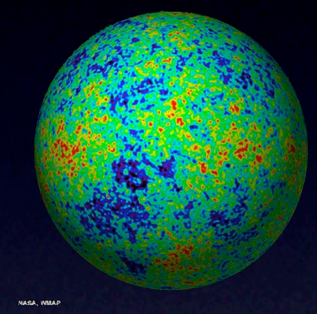

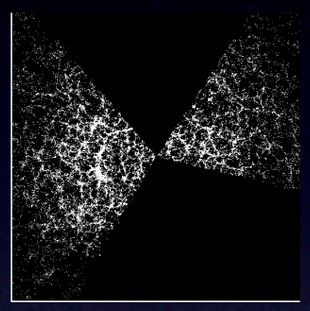

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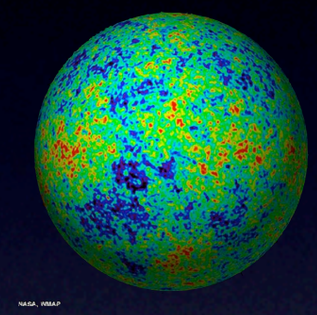

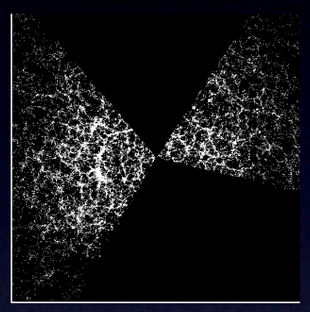

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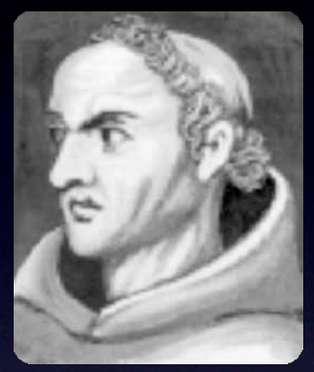

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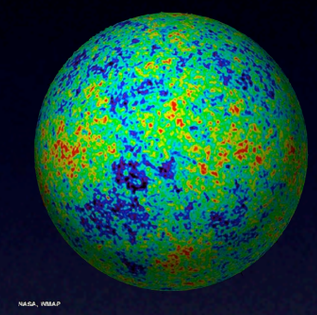

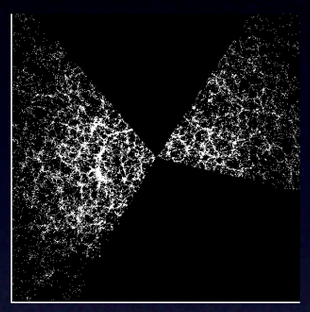

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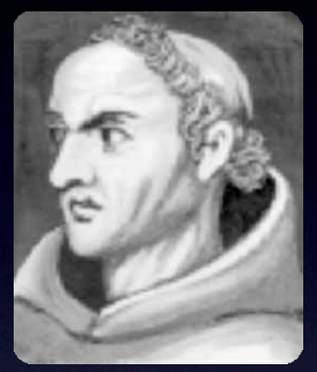

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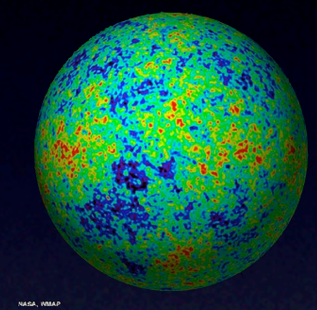

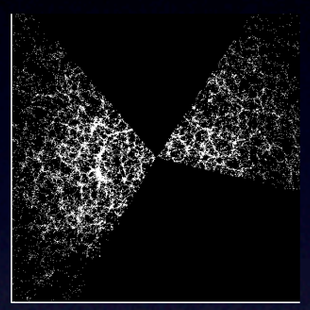

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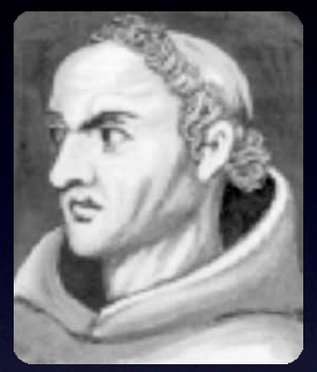

So why looking for something more "exotic"?

Easy BUT highly fine-tuned (cosmological issues):

1) Only one number (Λ) but unnaturally small: FINE TUNING $\frac{\rho_\Lambda}{\rho_{pl}} \sim 10^{-123}$

2) Λ domination is very recent: COINCIDENCE $\frac{\rho_\Lambda}{\rho_m} < 10^{-3}$ for $z > 6$

Why bothering with non-standard models? (II)

NOT everything fits (astrophysical issues):

1) Cusp-Core problem: OBSERVED CDM HALOS SHALLOWER THAN NFW
[e.g. Flores & Primack 1994, Salucci & Burkert 2000, Newman et al. 2009]

2) Satellite Problem: MANY FEWER SATELLITES OBSERVED THAN PREDICTED
[e.g. Klypin et al. 1999, Springel 2008, (but see also e.g Maccio' et al. 2009 MAYBE SOLVED?)]

3) Void Phenomenon: TOO FEW GALAXIES FOUND IN VOIDS
[e.g. Peebles 2000, Peebles & Nusser 2010]

4) Cluster Baryon Fraction: SYSTEMATICALLY LOWER THAN EXPECTED
[e.g. Allen et al. 2006 (but see also Giodini et al 2009!!)]

5) Bulk Flows: TOO LARGE GALAXY VELOCITIES ON LARGE SCALES
[e.g. Watkins et al. 2008, (but see also Erdogdu & Lahav 2009)]

6) High-z massive clusters: VERY UNLIKELY TO FORM IN ΛCDM
[e.g. Jee et al. 2009, Rosati et al 2009]

7) The Bullet Cluster: EXCEEDINGLY RARE OBJECT IN A ΛCDM UNIVERSE
[Lee & Komatsu 2010]

Dynamic and interacting

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✔Dynamic DE (UNCOUPLED):
a scalar field in a self-interaction potential

$$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = 0$$ [Wetterich 1988]

Fundamental problems:
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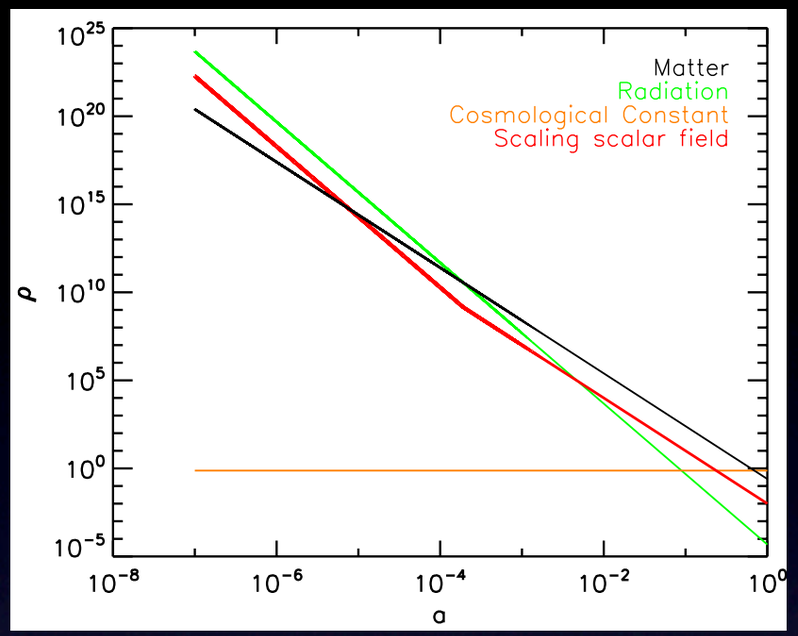

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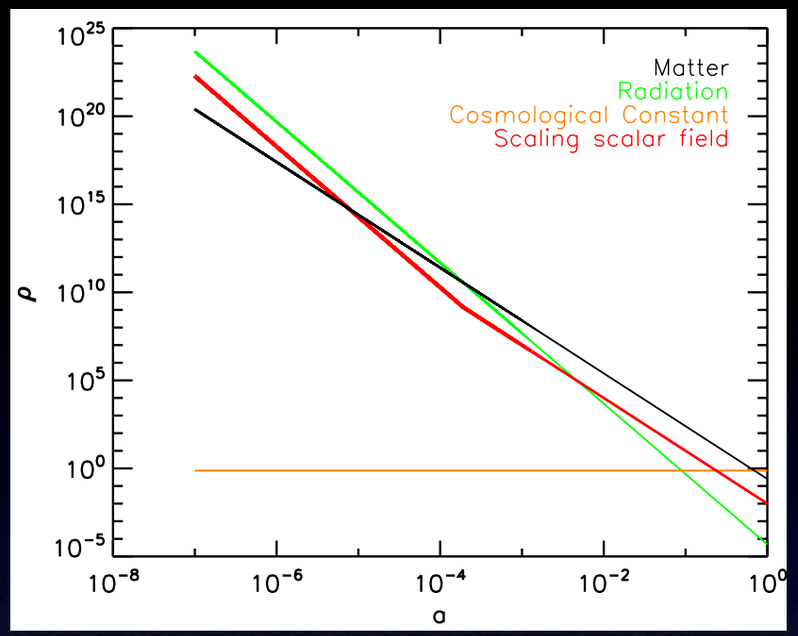

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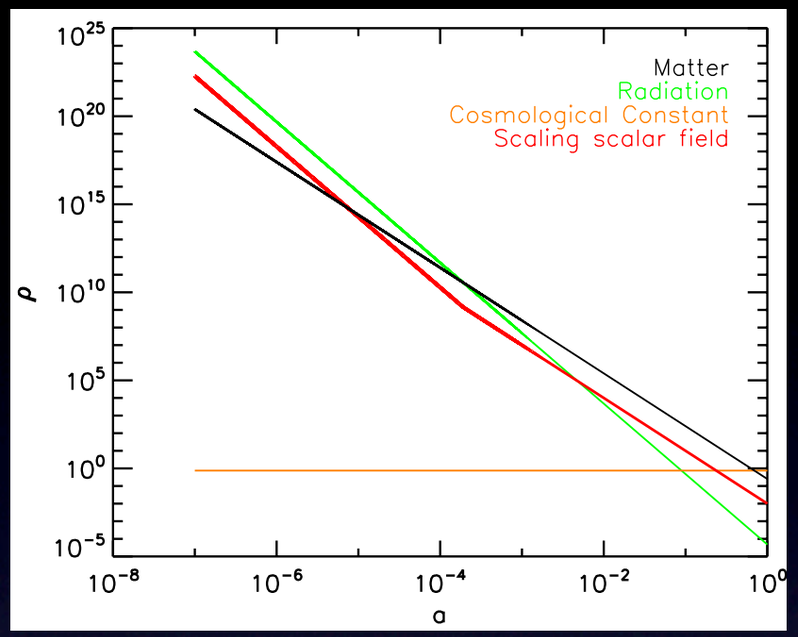

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✔Why consider a time evolution of the coupling?

1) There is no reason why β should be a constant. β(ϕ) is a more natural assumption

2) A varying (growing) β could have stronger effects on astrophysical observables at late times with a weaker impact on CMB and background expansion: INTERESTING.

Time dependent couplings [MB 1005.2188]

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However all of these bounds were derived for a constant coupling. If β grows in time these constraints could be significantly released, allowing for larger values of β during

STRUCTURE FORMATION

Modified Force Law (and its caveats)

$$\dot{\vec{v}}_i = \beta_i(\phi)\frac{\dot{\phi}}{M}\vec{v}_i + \sum_{j\neq i}\frac{m_j\vec{r}_{ij}}{|\vec{r}_{ij}|^3}G[1+2\beta_i\beta_j]$$

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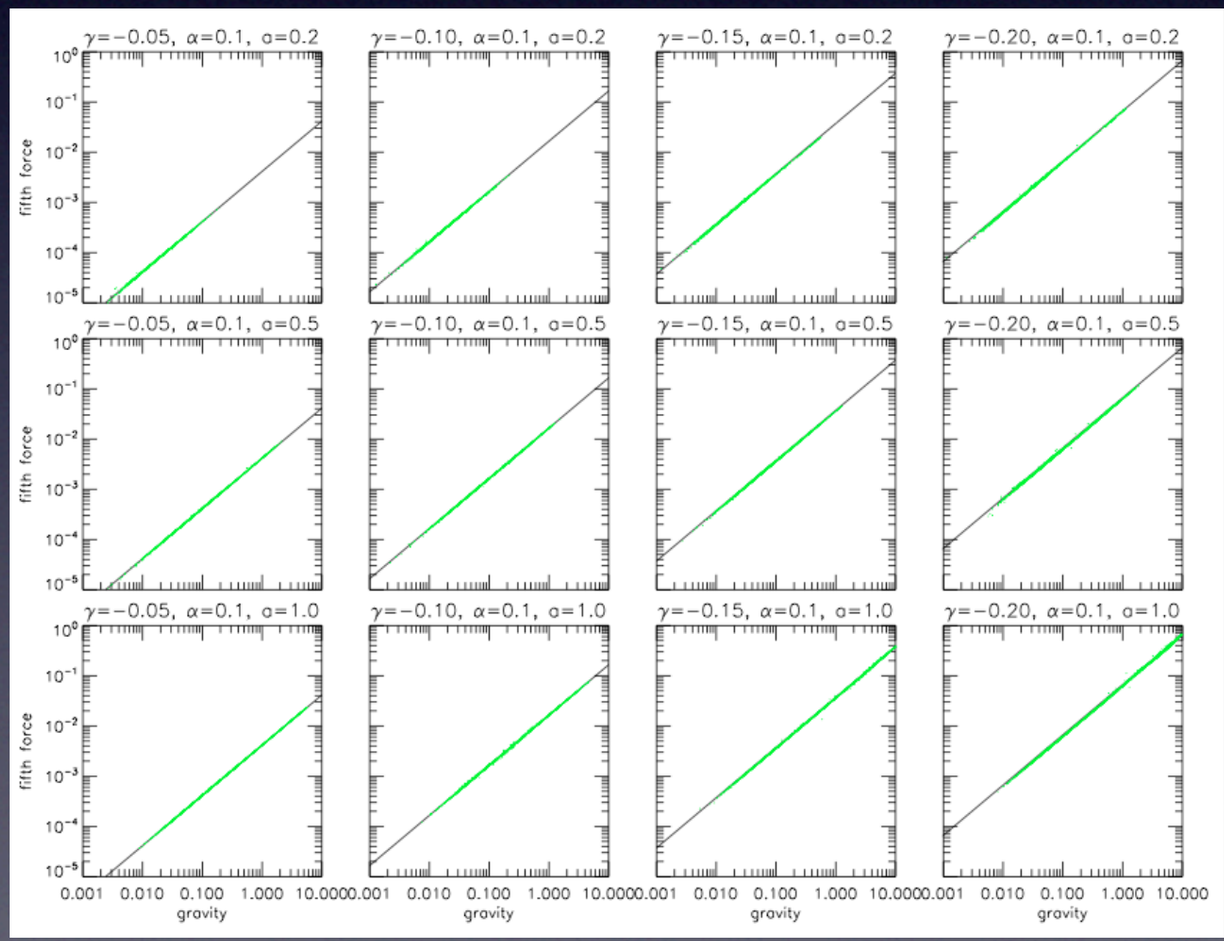
Li & Barrow (1005.42311) provide a direct confirmation of this: for light coupled scalar fields the linear approximation is fully justified. No need to solve directly for the scalar field fluctuations →

FASTER ALGORITHMS



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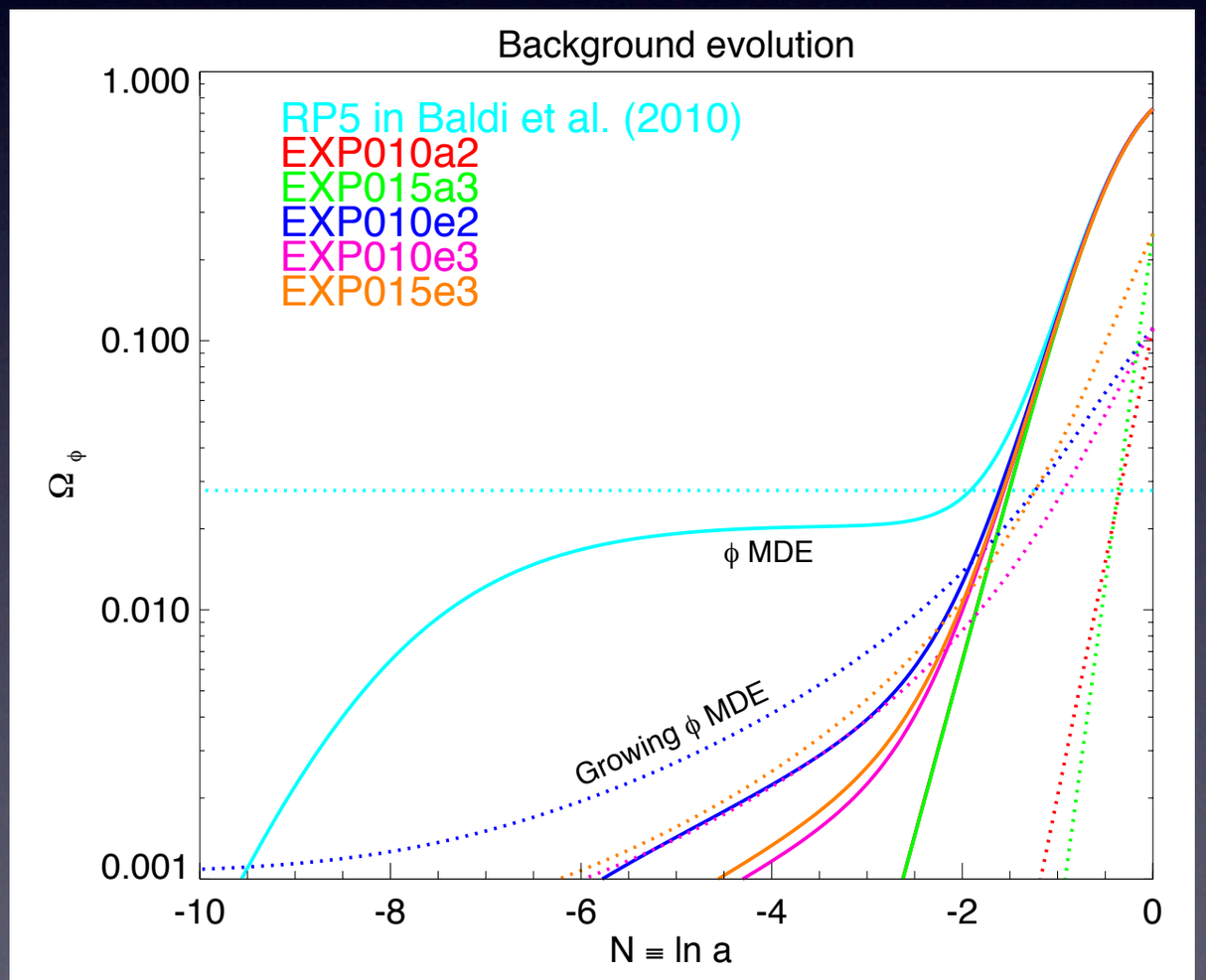

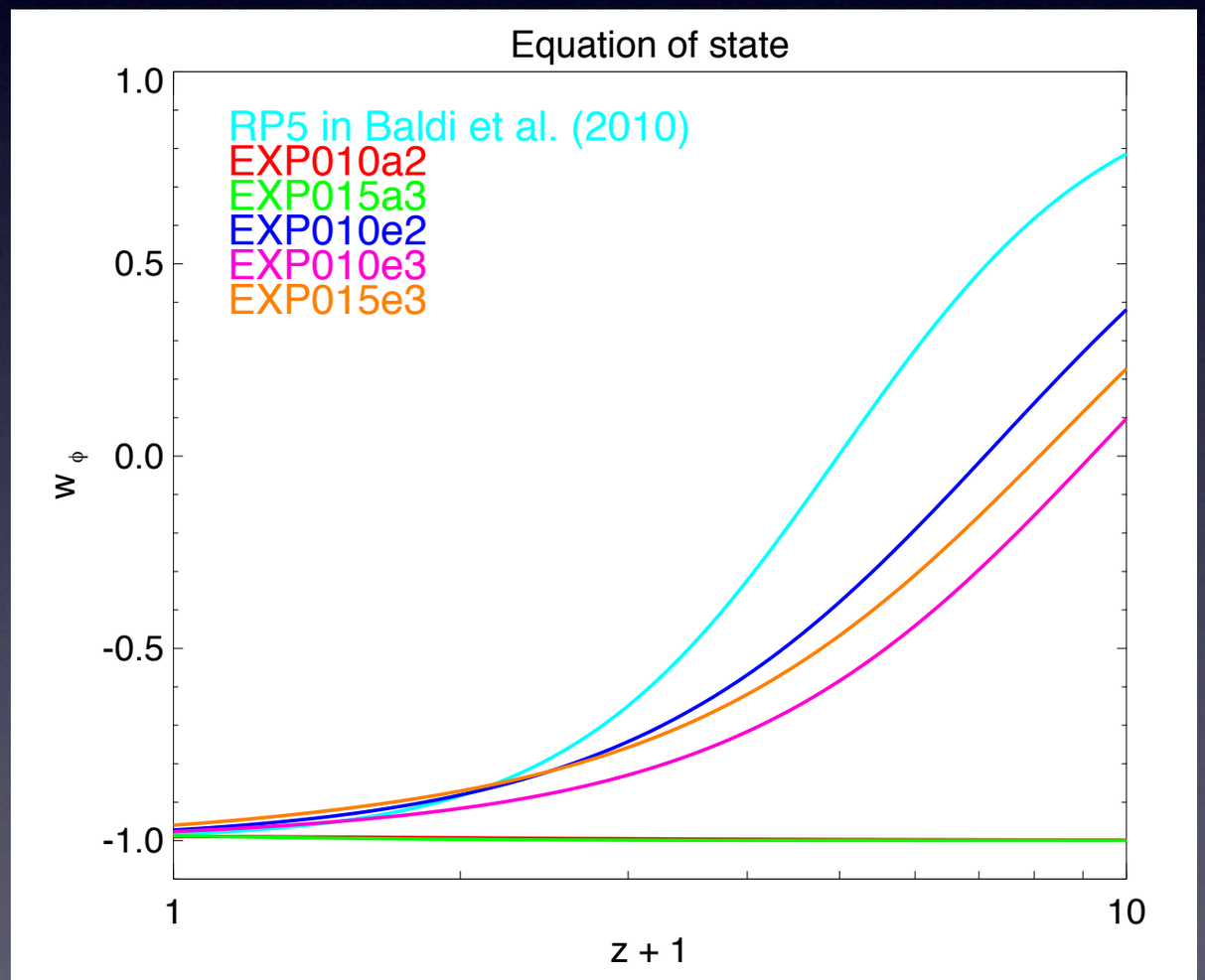

N-body implementation

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+
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=
GADGET-3

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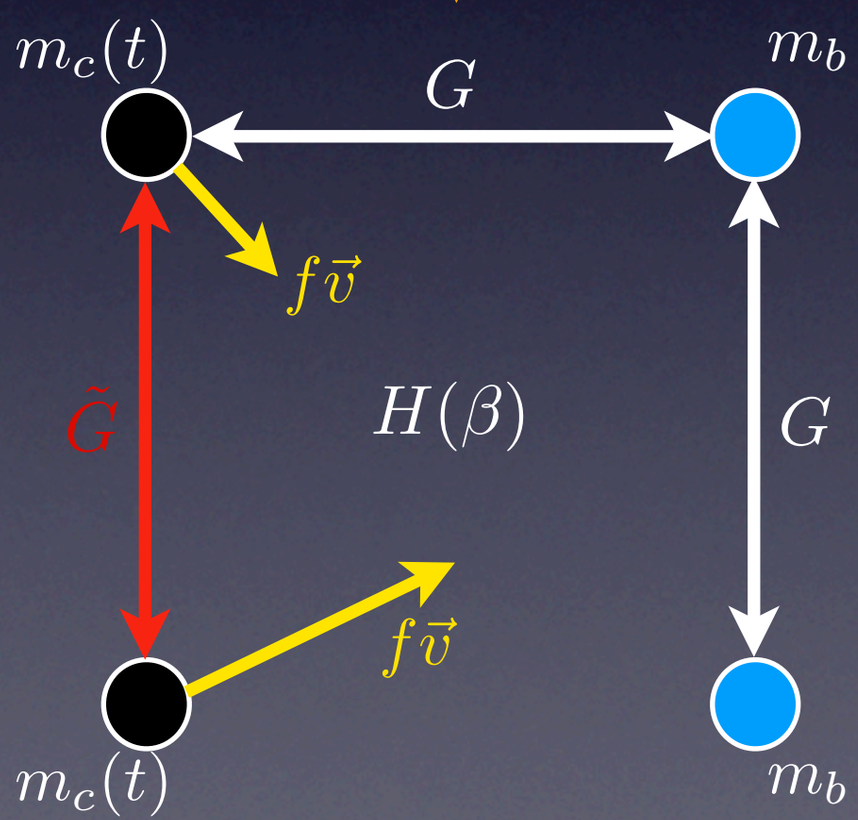
- No need to solve for the spatial SF distribution

- Same Poisson solver as for standard gravity

- Moderate increase of computational time (~2x)



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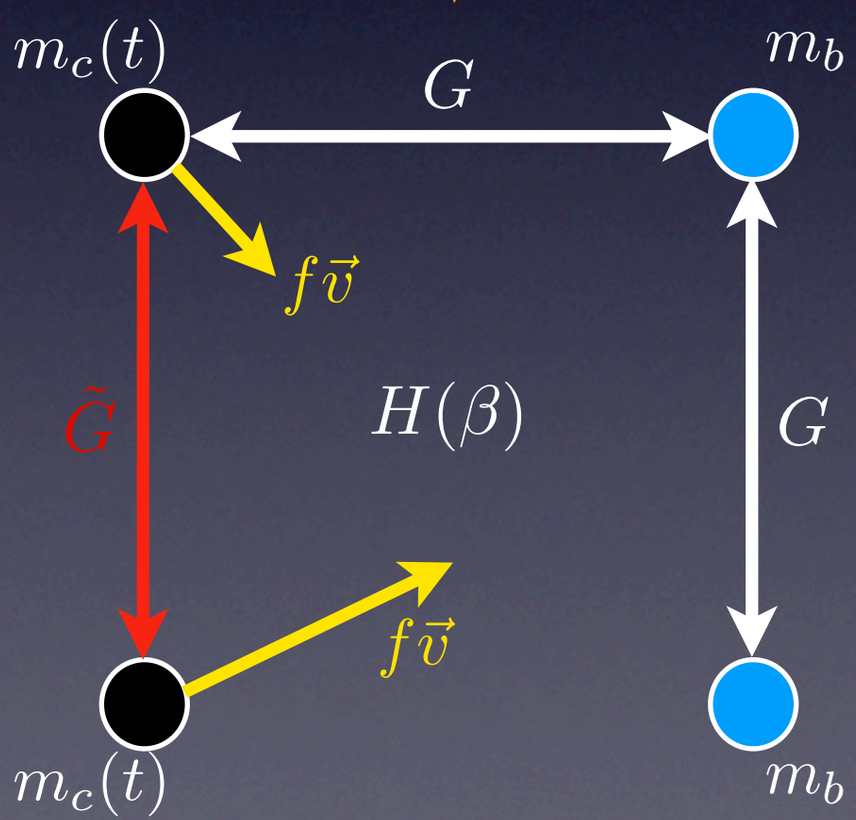

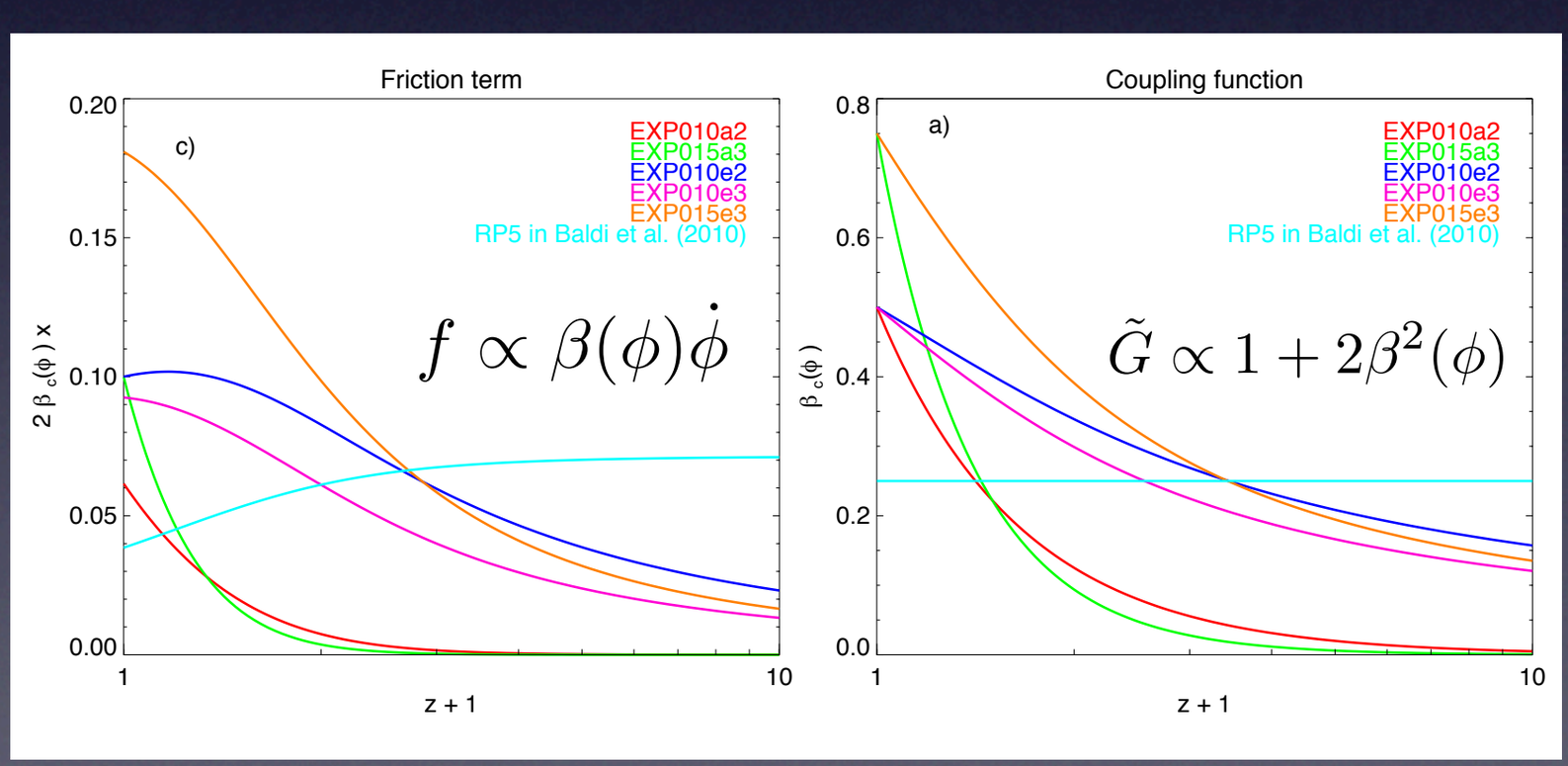

Results (I): halo mass function and cluster counts

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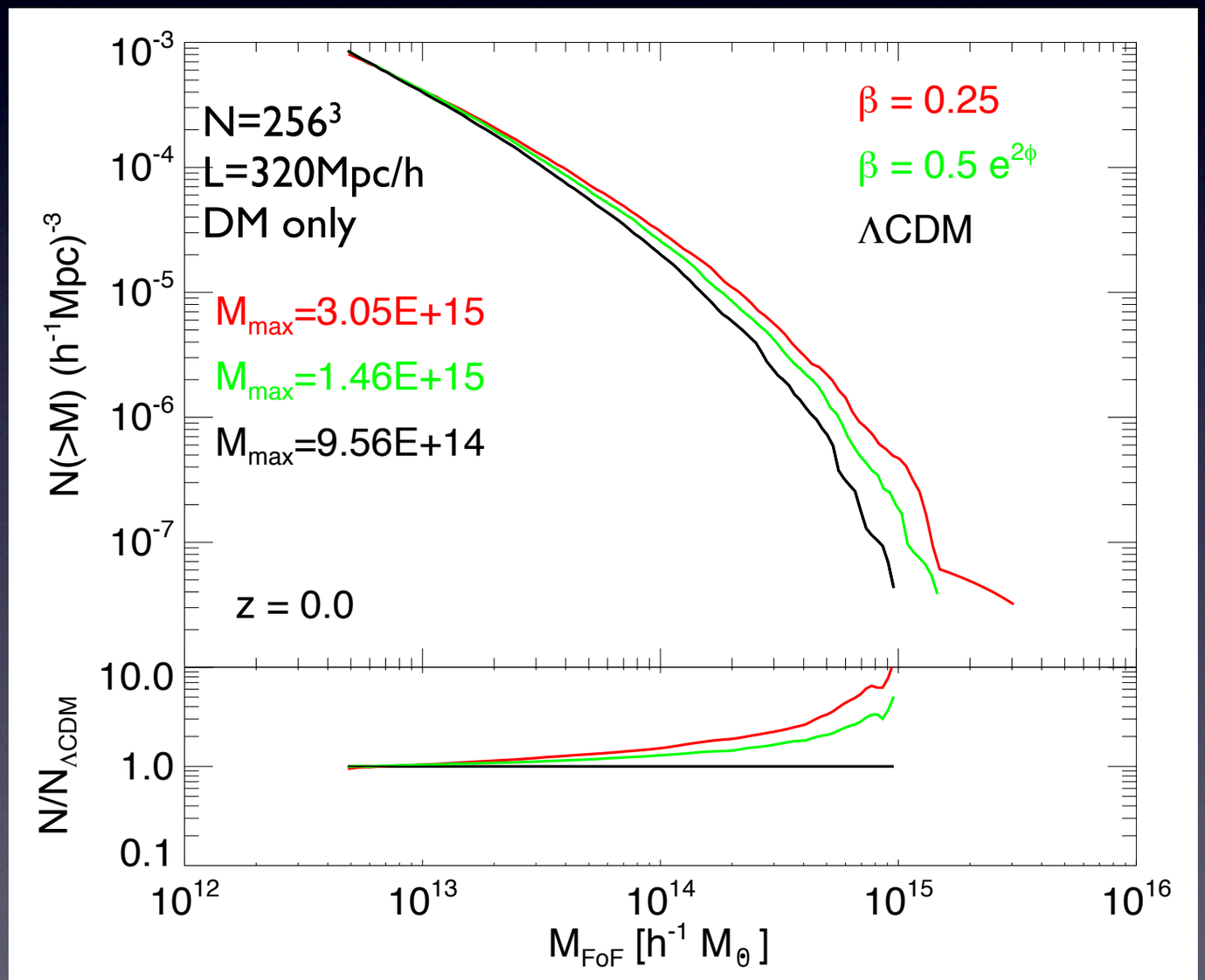

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NEED A LARGE f_{NL}

INTERACTING DE:
The extra force acting between CDM particles and the extra friction term determine a faster growth of density perturbations.

The number density of halos above a given mass M at any redshift z is correspondingly enhanced.

Resuts (II): halo density profiles

The first hydrodynamical high-resolution N-body simulations for a weak DE-CDM CONSTANT interaction: [MB et al., MNRAS 2010]

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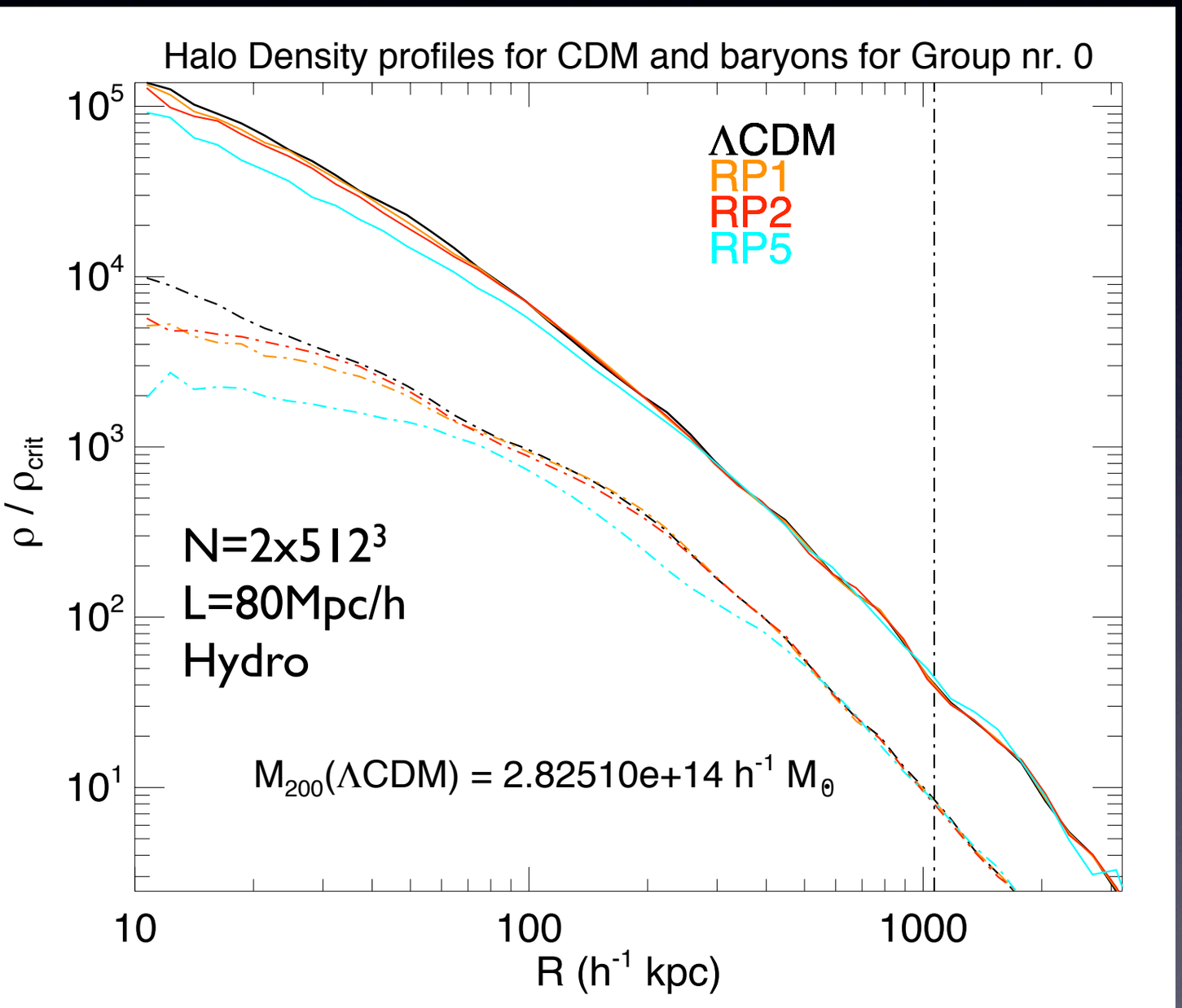


DENSITY PROFILES

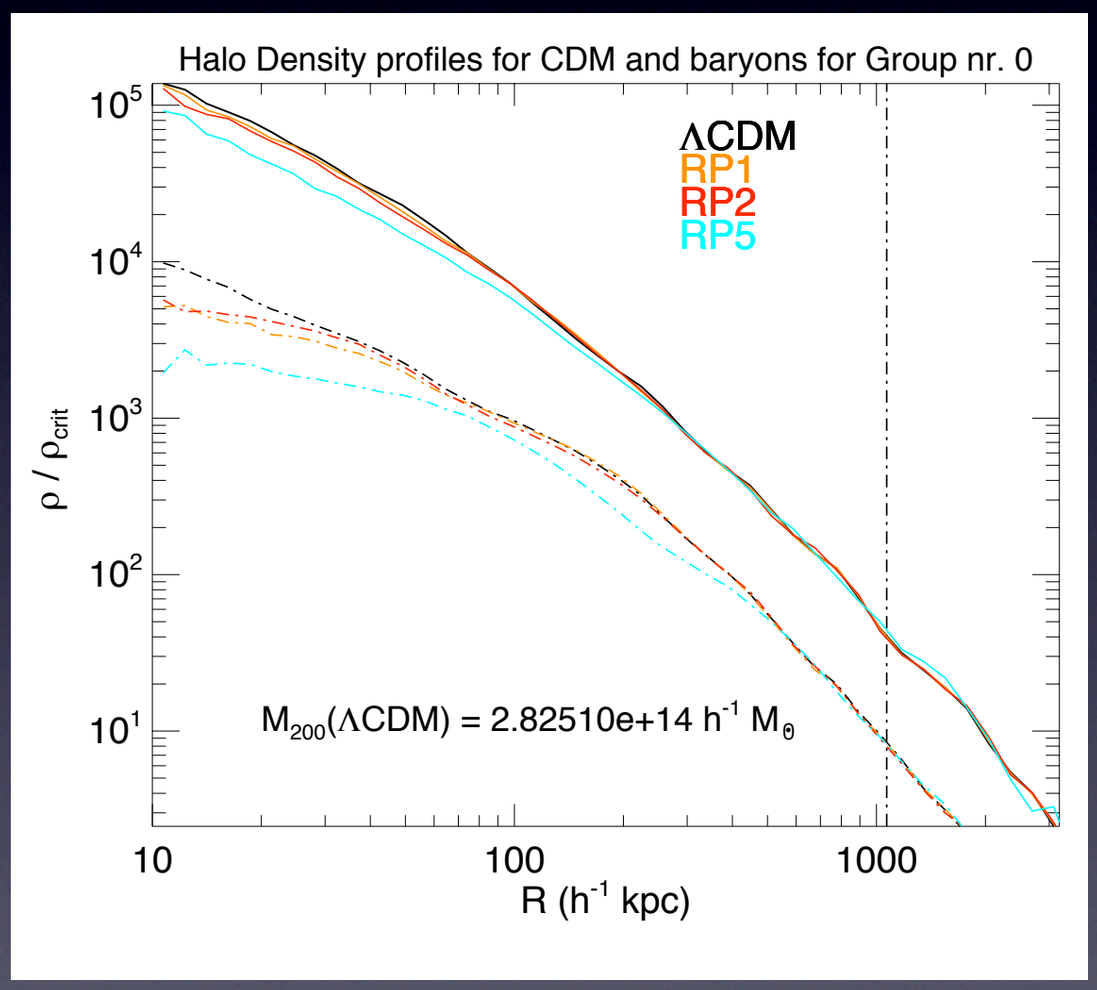
The combination of the friction term and of the mass variation of (coupled) CDM particles affects the virial equiibrium of collapsed objects.

The two effects induce a global increase of the total energy of the systems which slightly expand. This produces shallower density profiles in the inner regions of CDM halos: **RINGS A BELL?**

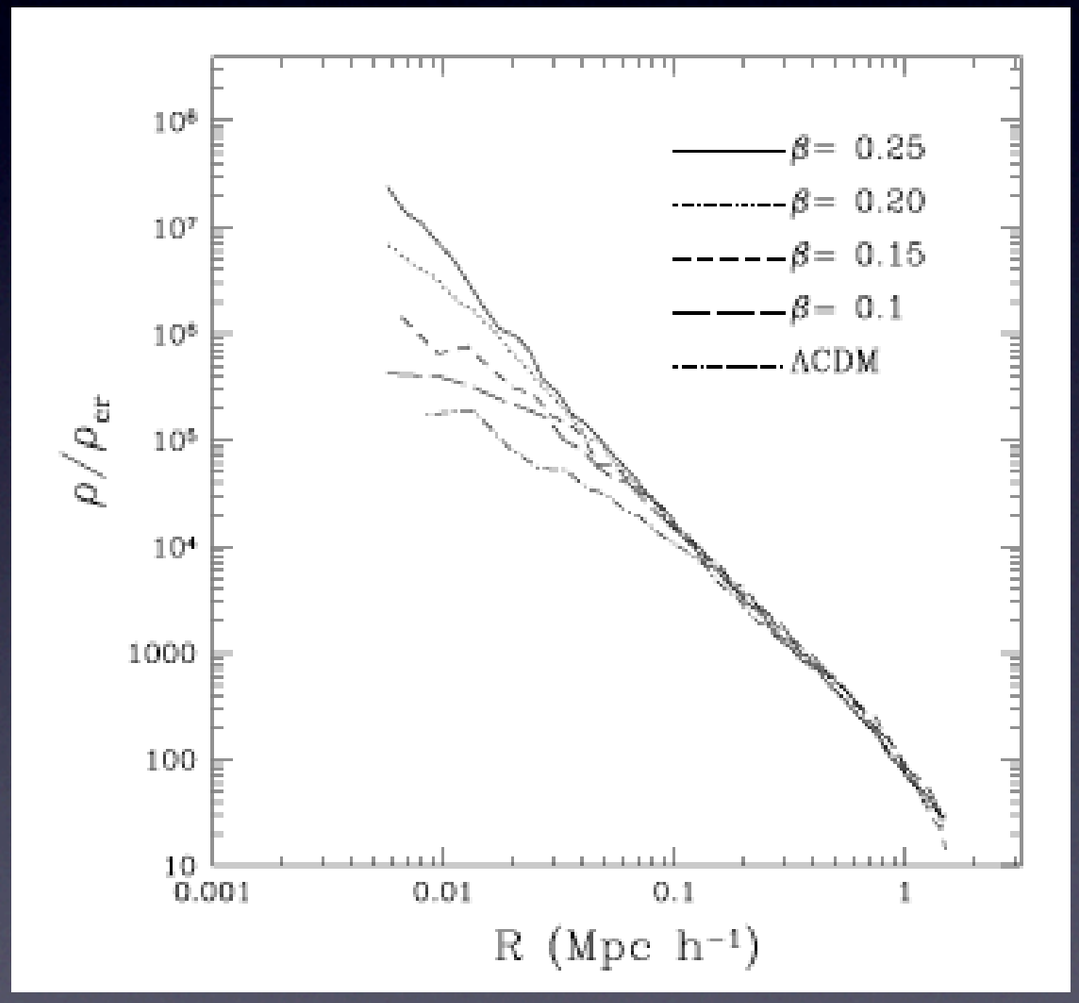
Results (II): halo density profiles

This has been quite controversial for a while, since the result is in stark contrast with previous claims...

MB et al. (submitted in 2008!)



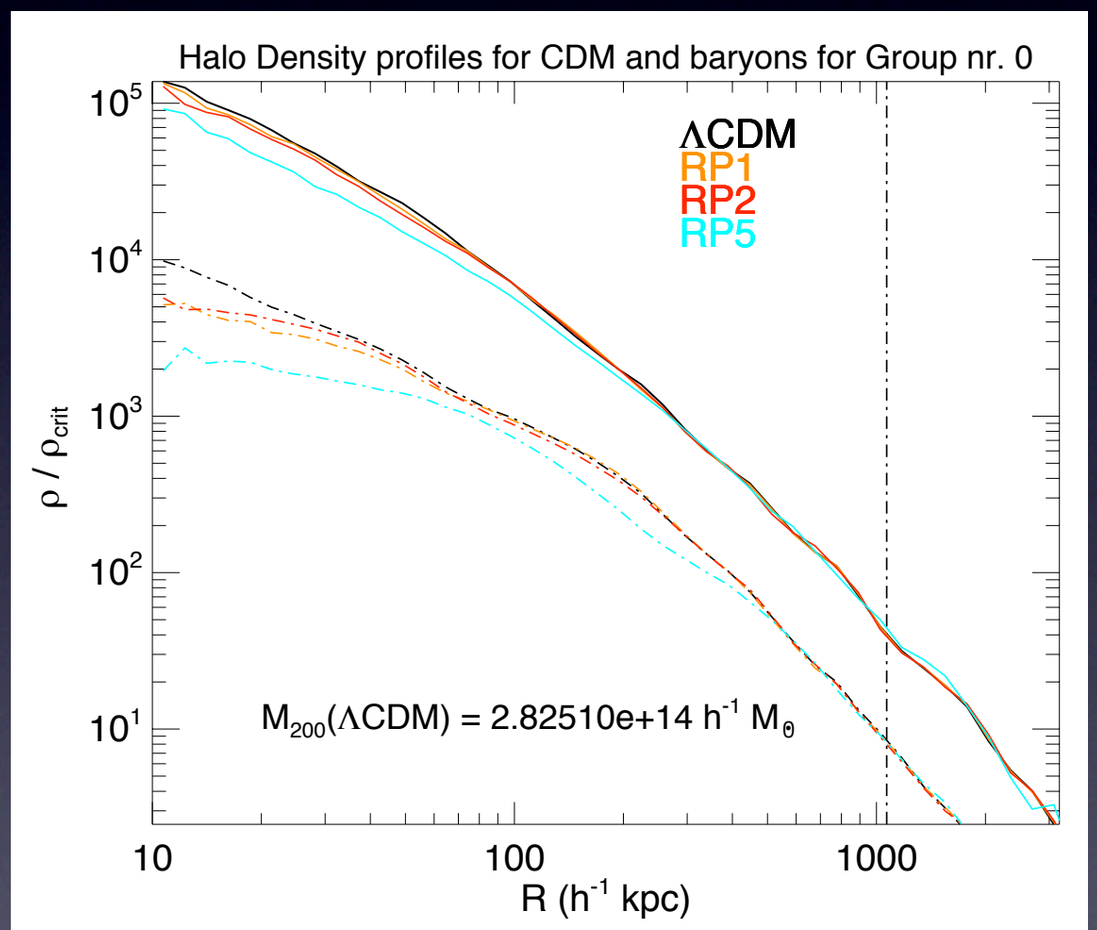
Macciò et al. PRD 2004



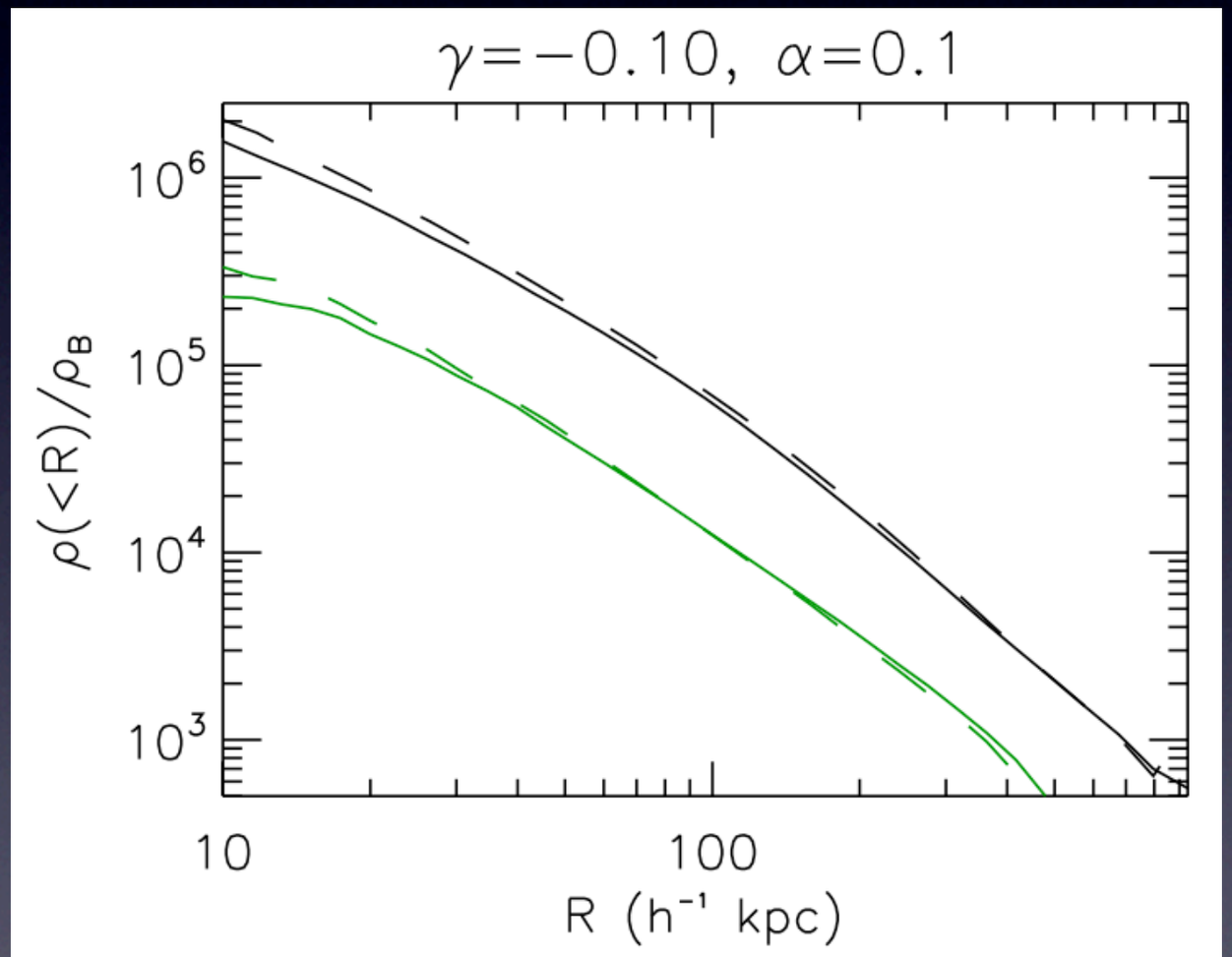
Results (II): halo density profiles

...but now this behavior has been independently confirmed by other numerical works

MB et al. (published in 2010!)

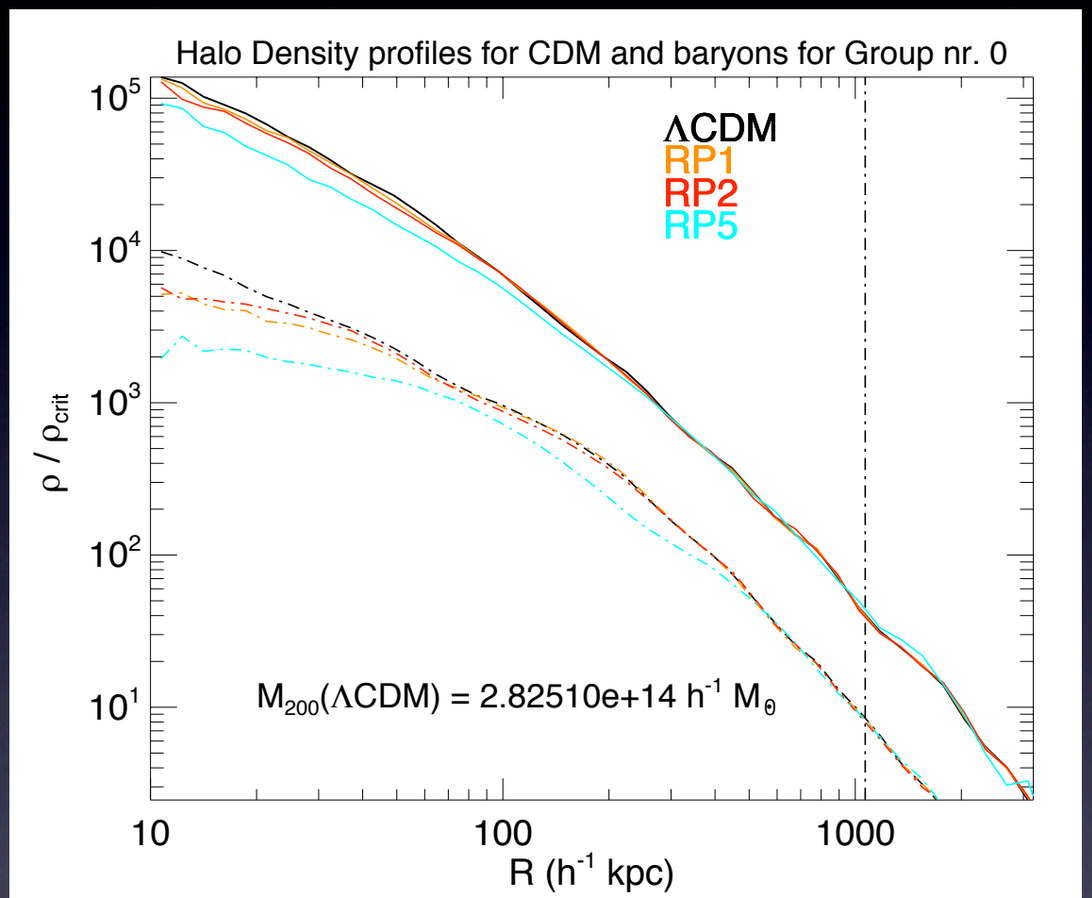


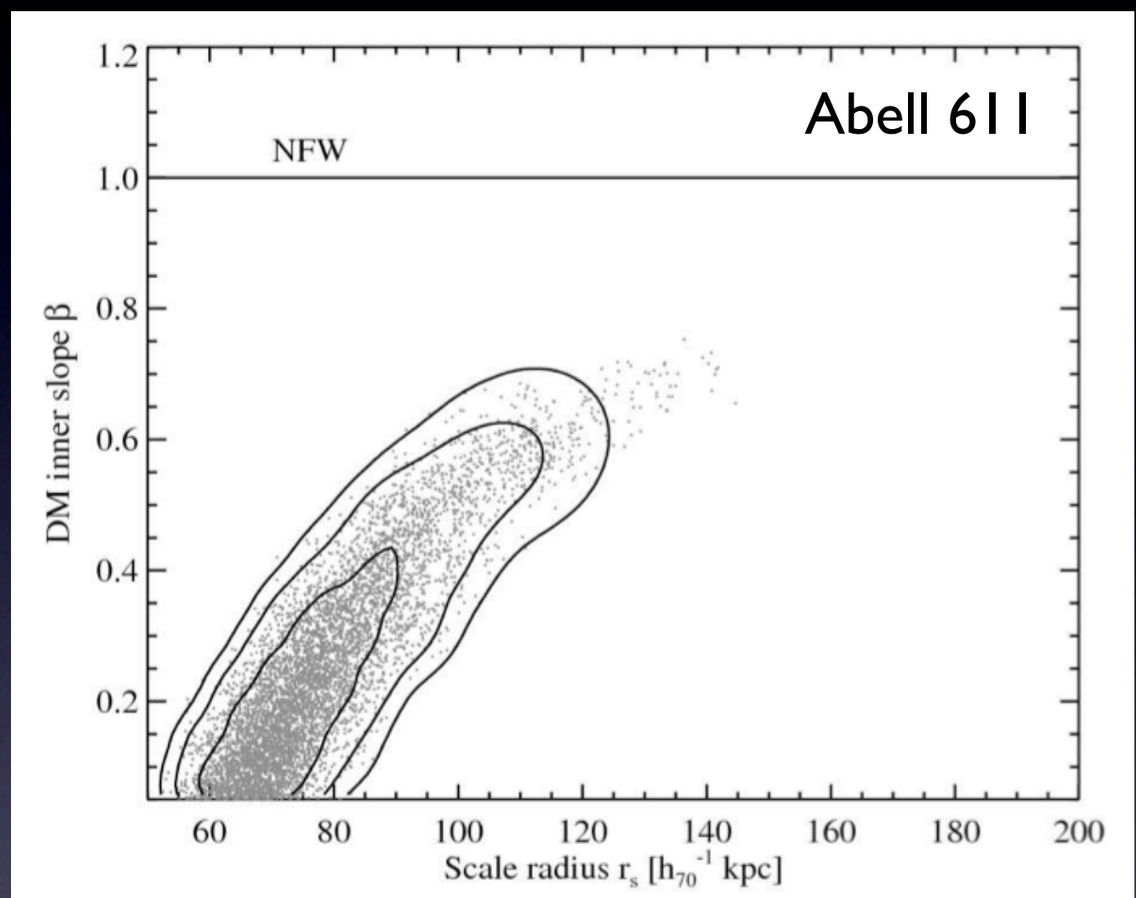
Li & Barrow, 1005. 4231



Resuts (II): halo density profiles

Are NFW density profiles too steep also at cluster scales?

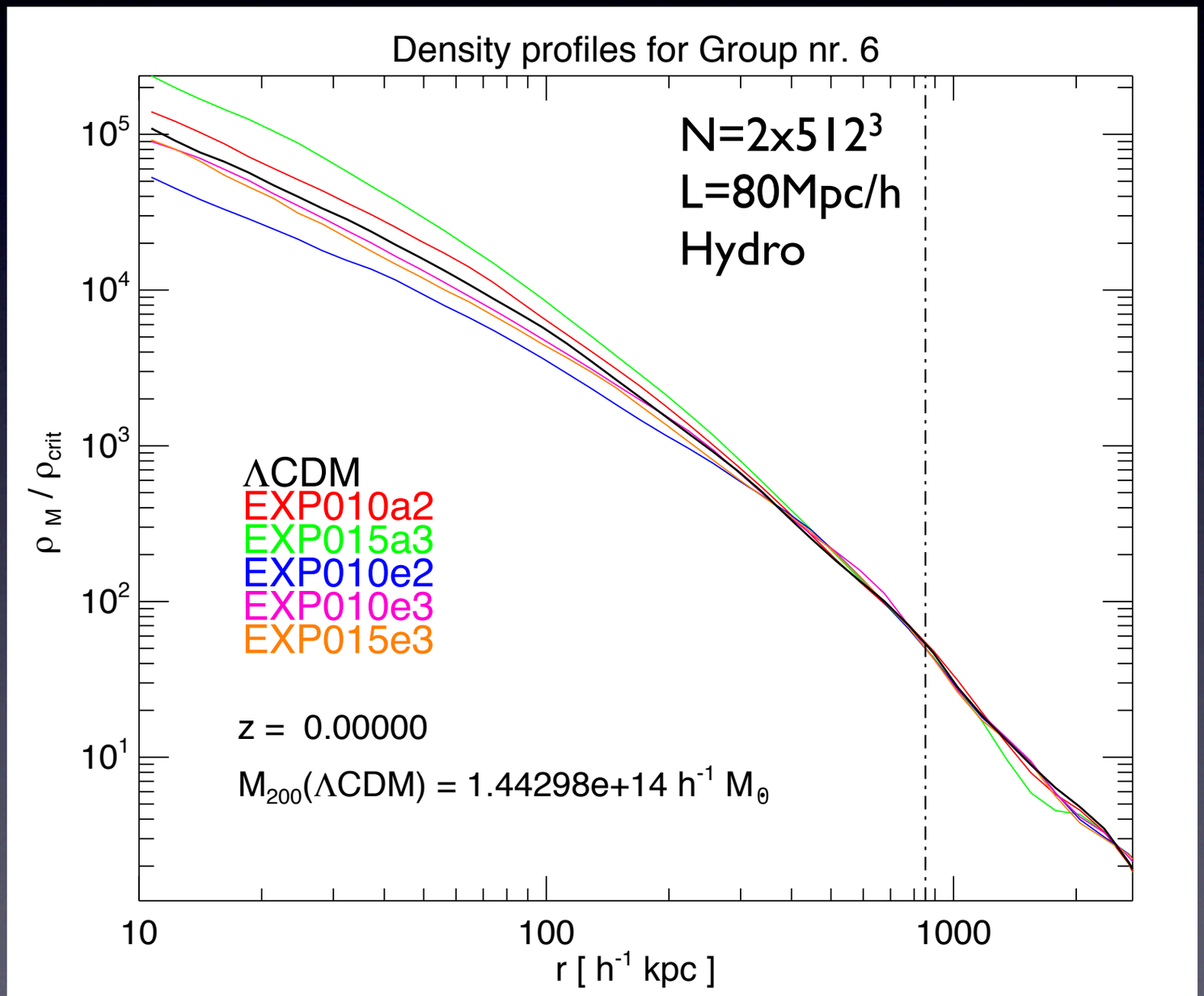




[Newman et al. 2009]

Resuts (II): halo density profiles

The first hydrodynamical high-resolution N-body simulations for a weak DE-CDM VARIABLE interaction: [MB MNRAS 2010 (1005.2188)]



DENSITY PROFILES

The combination of the friction term and of the mass variation of (coupled) CDM particles affects the virial equilibrium of collapsed objects.... BUT:

If the coupling grows in time, there is also a decrease of the gravitational potential energy of halos. Two effects are competing, and can determine both shallower and steeper density profiles depending on the existence of a "Growing ϕMDE" phase.

the highlights

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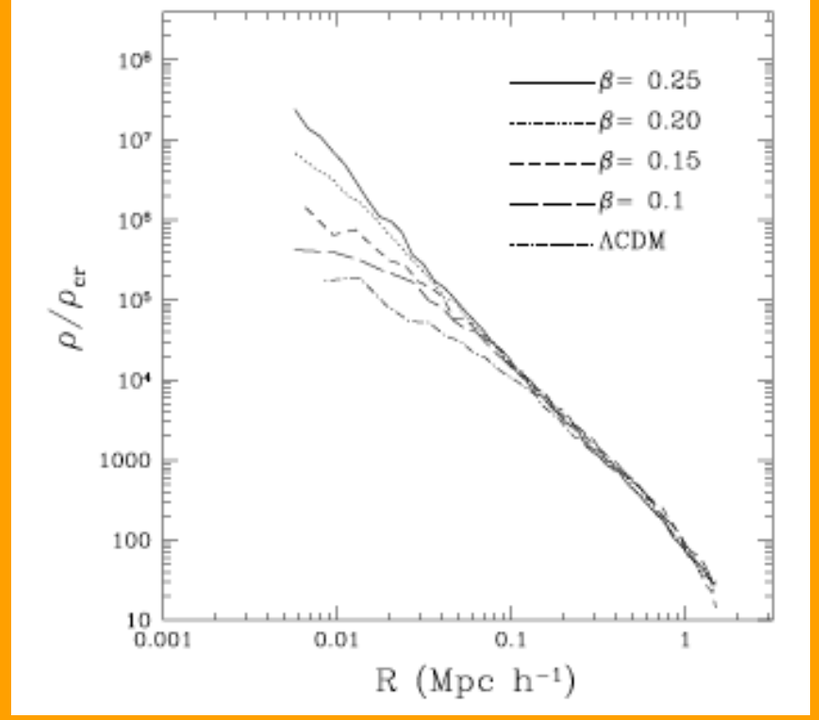
Maccio' et al 2004
Constant β



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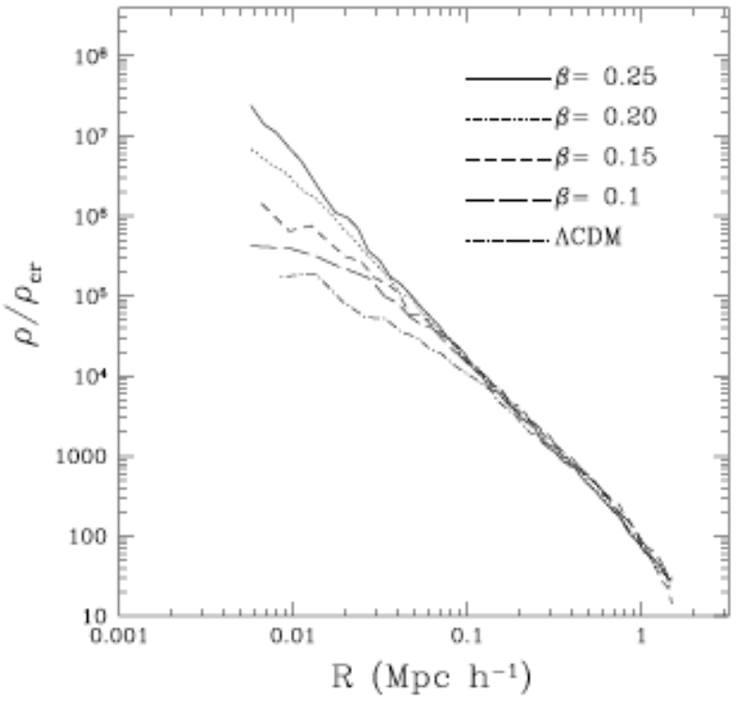

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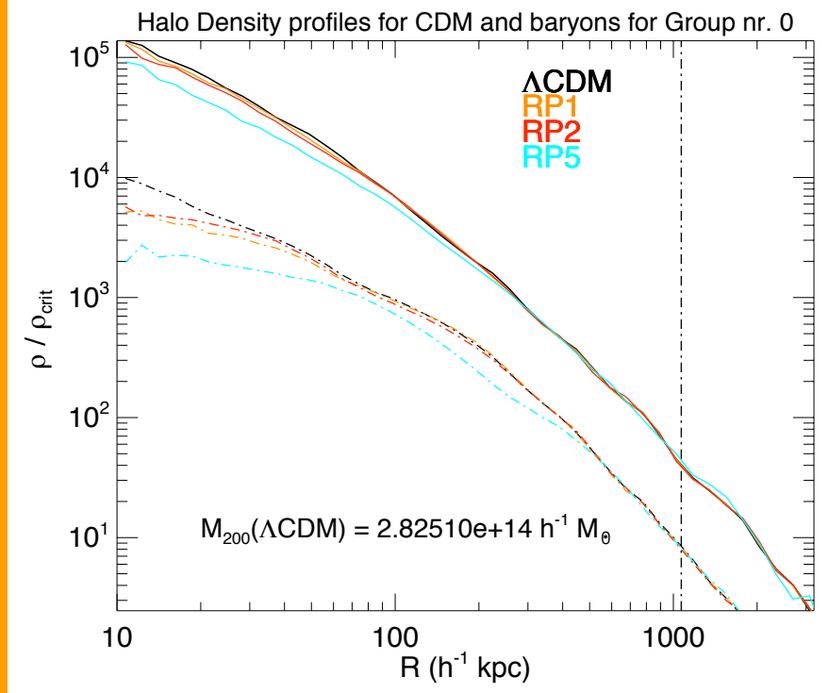

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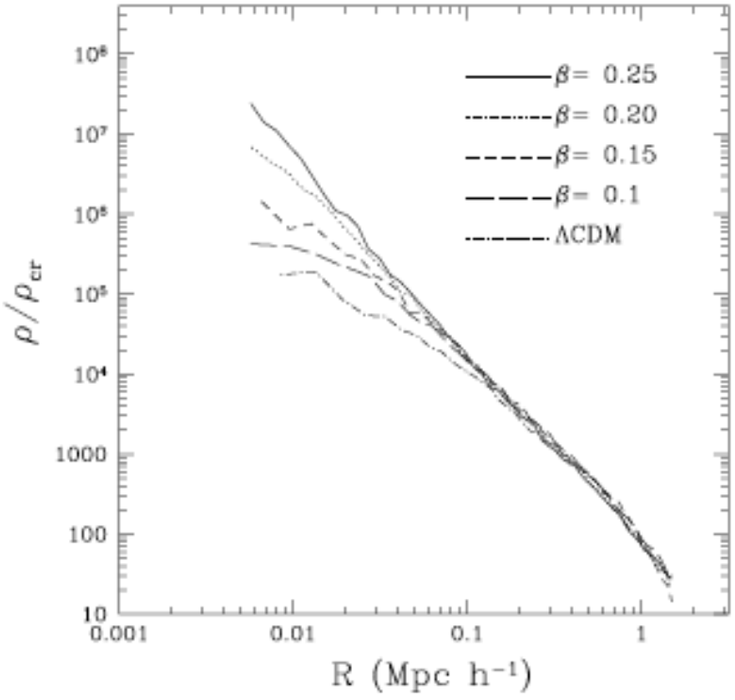

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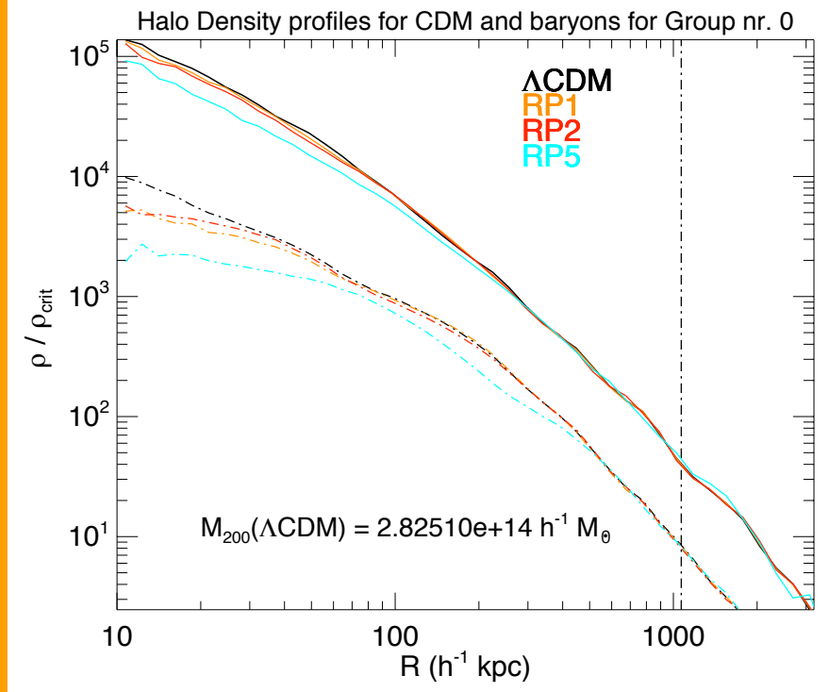
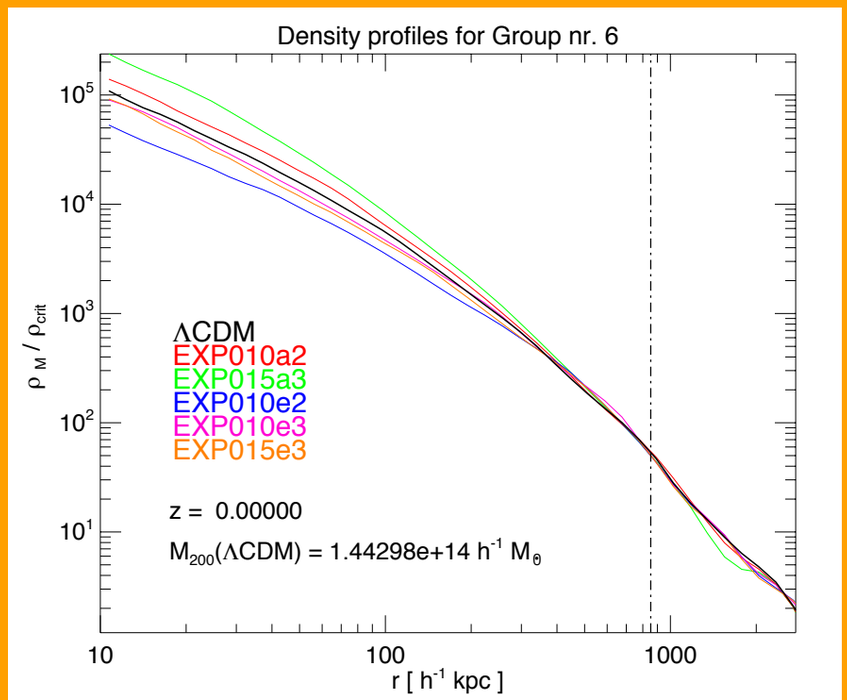


MB 2010 (1005.2188)
Variable β



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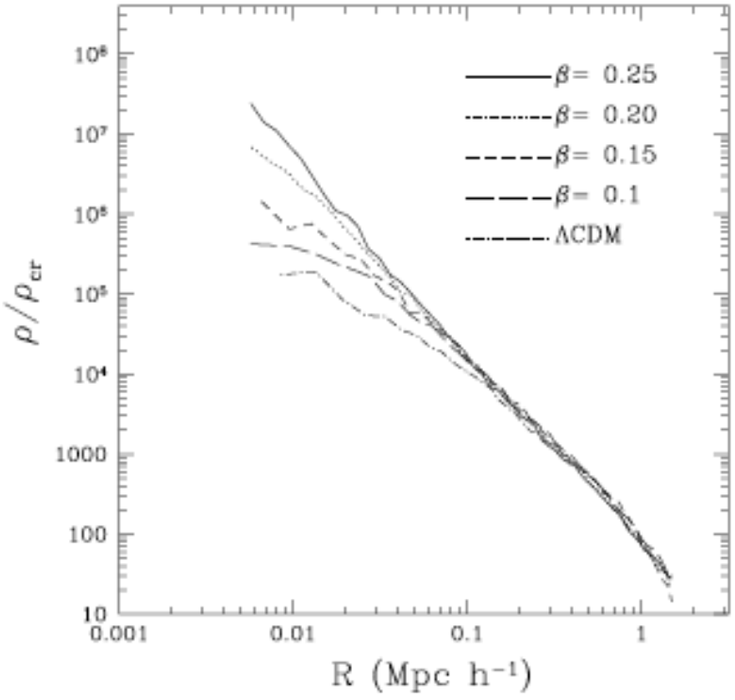

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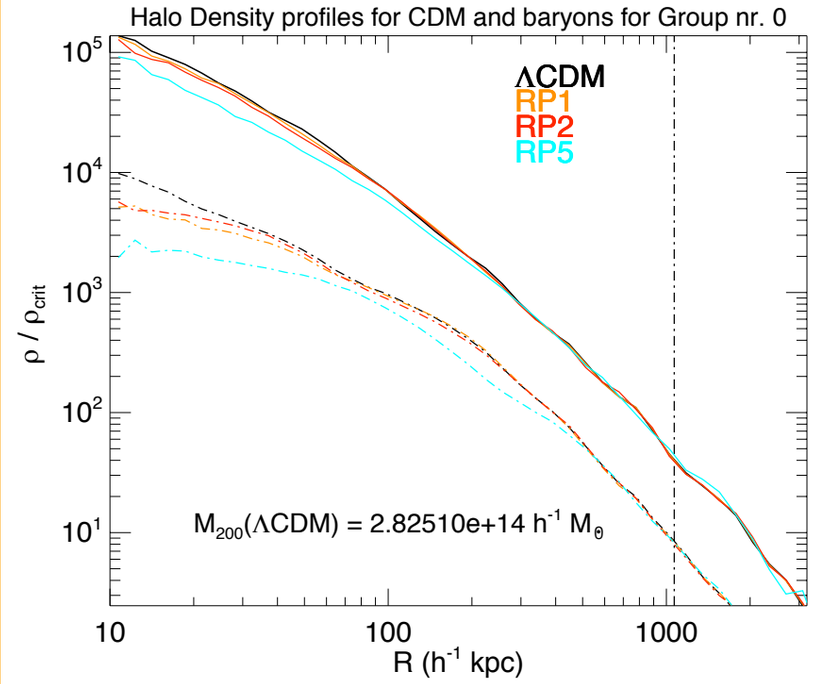

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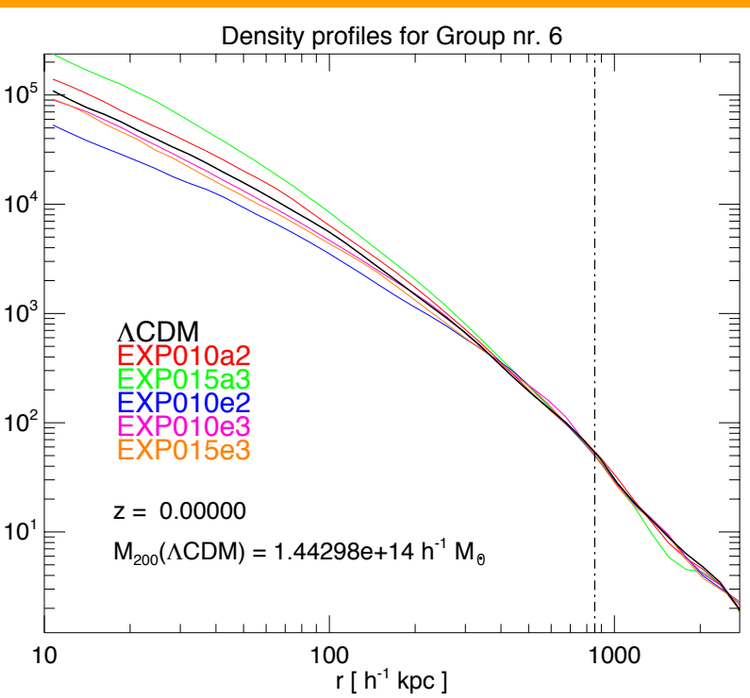

Li & Barrow (1005.4231)
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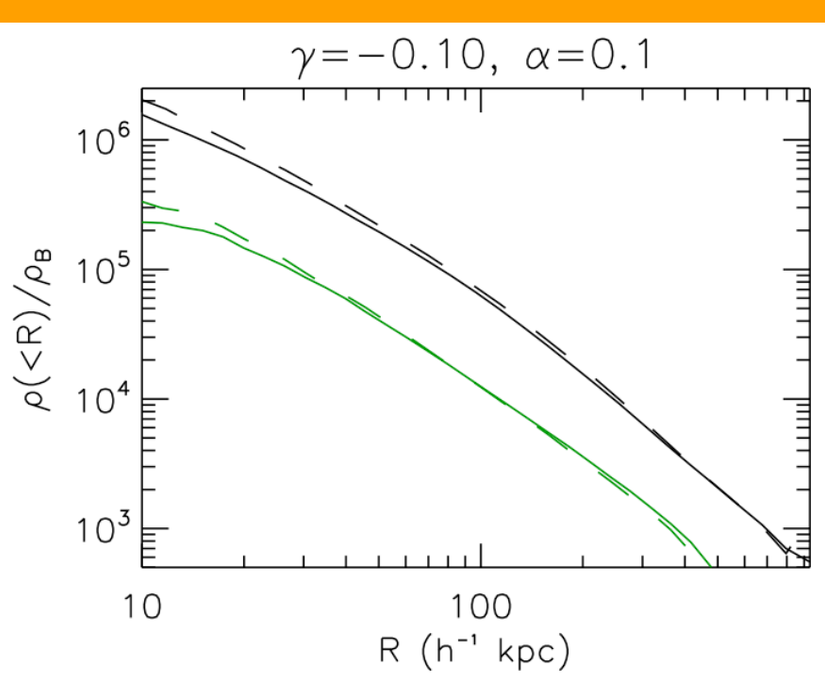

Results (II): baryon fraction

The first hydrodynamical high-resolution N-body simulations for a weak DE-CDM CONSTANT interaction: [Baldi et al., MNRAS 2010]

N=2x512^3, L=80Mpc/h, Hydro

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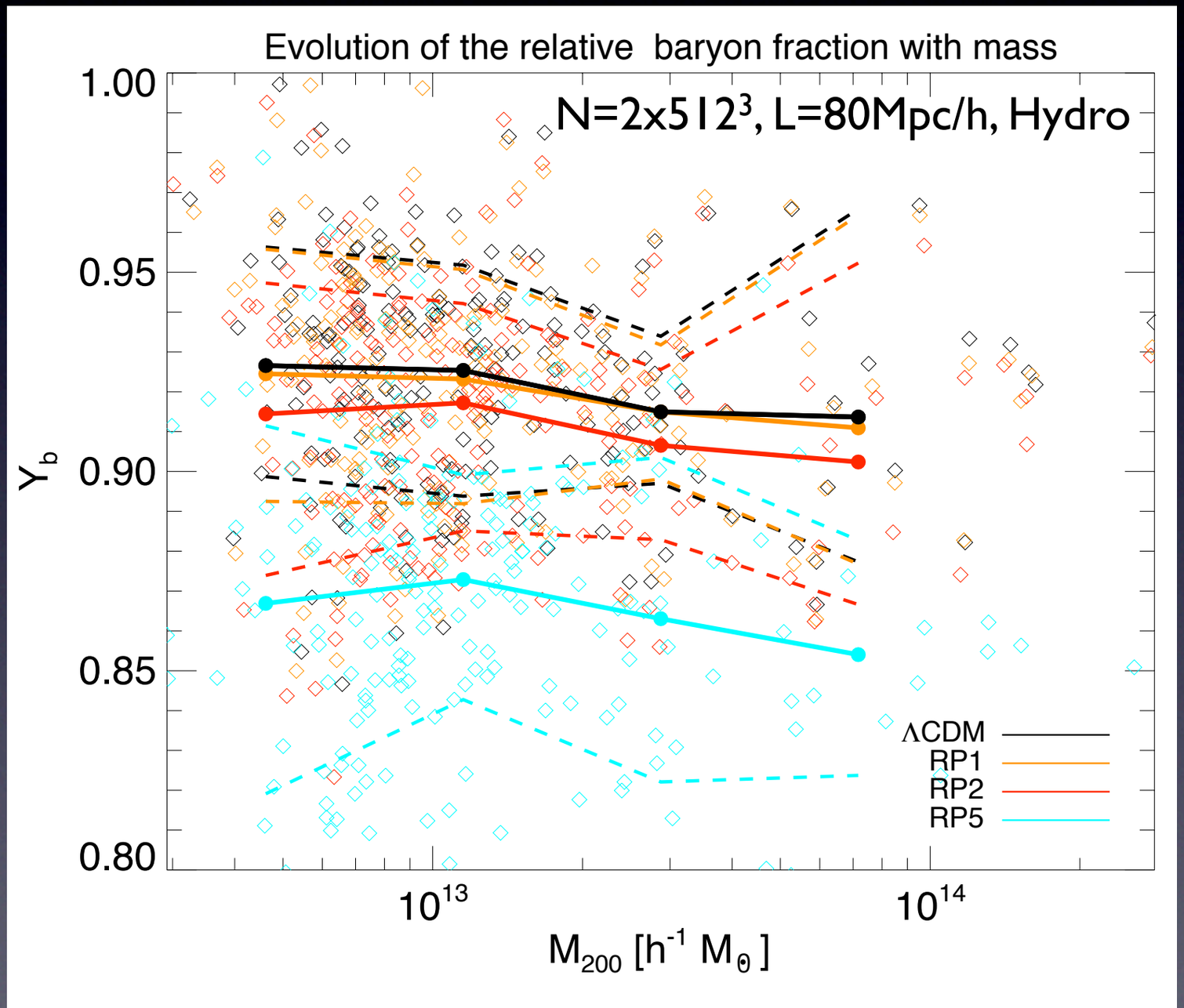

BARYON FRACTION

The different dynamics of (uncoupled) baryons and (coupled) CDM leads to a linear and nonlinear bias between the two species

As a consequence, the baryon fraction of large halos is reduced in proportion to the coupling strength: **RINGS A BELL?**

$$Y_b \equiv \frac{f_b}{\Omega_b/\Omega_M}$$

Results (II): baryon fraction

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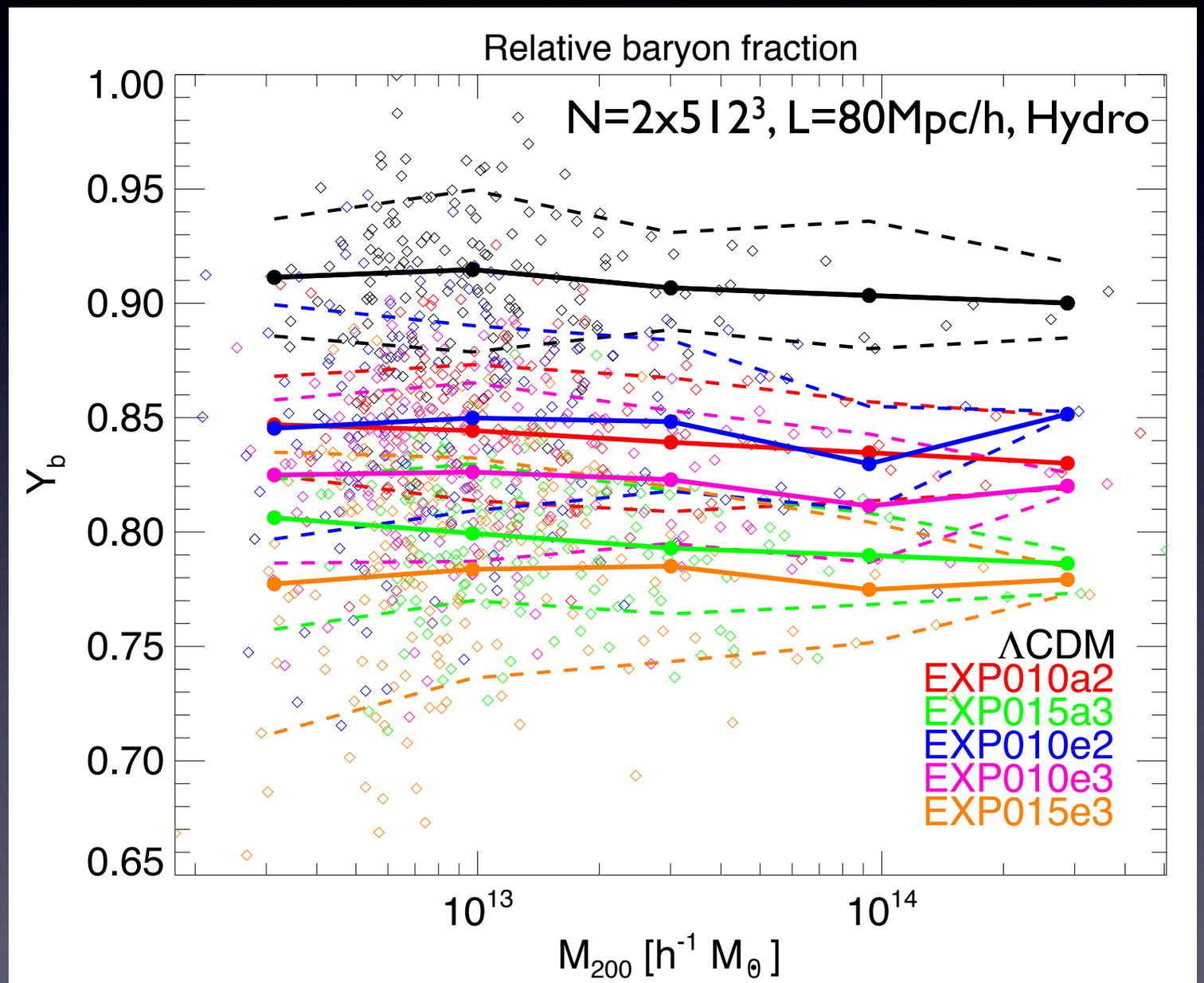

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concluding...


TOURAINE
APPELLATION TOURAINE CONTRÔLÉE
QUINTESSENCE
SELON PATRICIA & BRUNO DENIS
2003
Domaine de La Renaudie
12,5% vol.
PRODUIT DE FRANCE
750 ml.
monroe 102821

concluding...

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The standard cosmological model requires extreme fine tuning and still shows some problems at small scales;

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Scalar field models without a coupling also fail in reproducing the present Universe even at the background level

Coupled dark energy models, with constant or variable couplings, provide possible solutions to both the fine tuning and the small scale problems of ΛCDM...

WORTH EXPLORING FURTHER

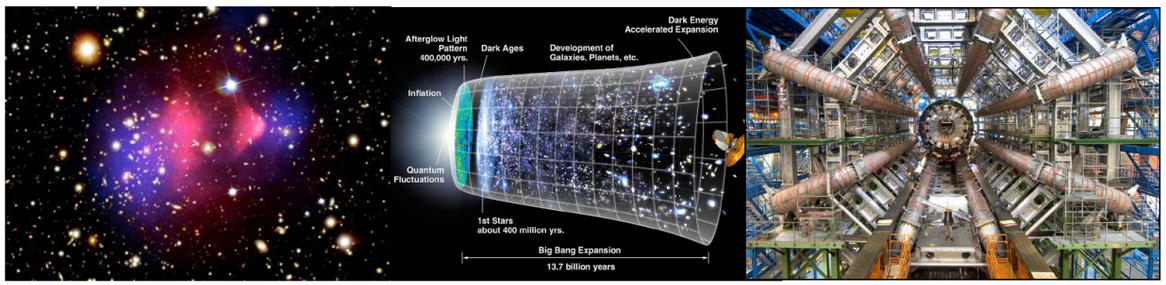
Fourth TRR33 Winter School on Cosmology

Theory for observers
Observations for theorists

5-10 December 2010
Passo del Tonale, Italy

Deadline for registration: November 15th
Deadline for financial support: November 1st

http://darkuniverse.uni-hd.de/winterschool



Overview lecture	Andy Taylor, Royal Observatory, Edinburgh
Inflation and non-Gaussianity	Paul Shellard, DAMTP, Cambridge
LHC physics	Christophe Grojean, CERN, Geneva
Large-scale Structures	Raul Jimenez, University of Barcelona
Weak Lensing	David Bacon, ICG, Portsmouth

4th Transregio Winter School on Cosmology

5-10 December 2010
Passo del Tonale (Italy)

Registration is open!

Registration deadline: 15 November

Financial support deadline 1st November

darkuniverse.uni-hd.de/winterschool

Some first results (IV)

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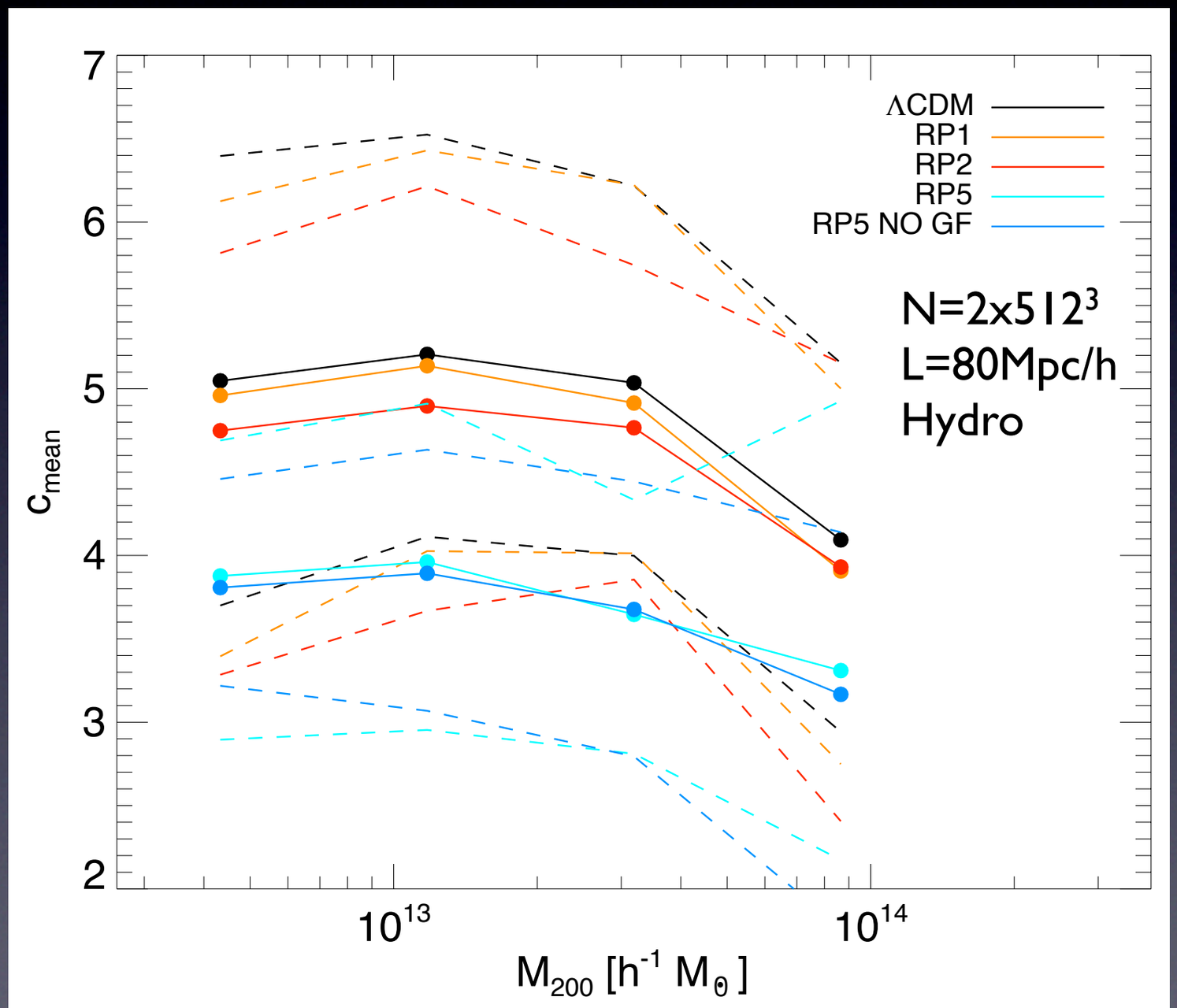

CONCENTRATIONS

Consistently with the results on density profiles, the concentrations of halos are found to be lower in coupled cosmologies with constant couplings than in ΛCMD.

This confirms the picture: mass is moving outwards from the innermost regions of halos due to the extra physics coming from the DE-CDM interaction.

Possible observational effects for strong lensing and galactic dynamics.

Some first results (IV)

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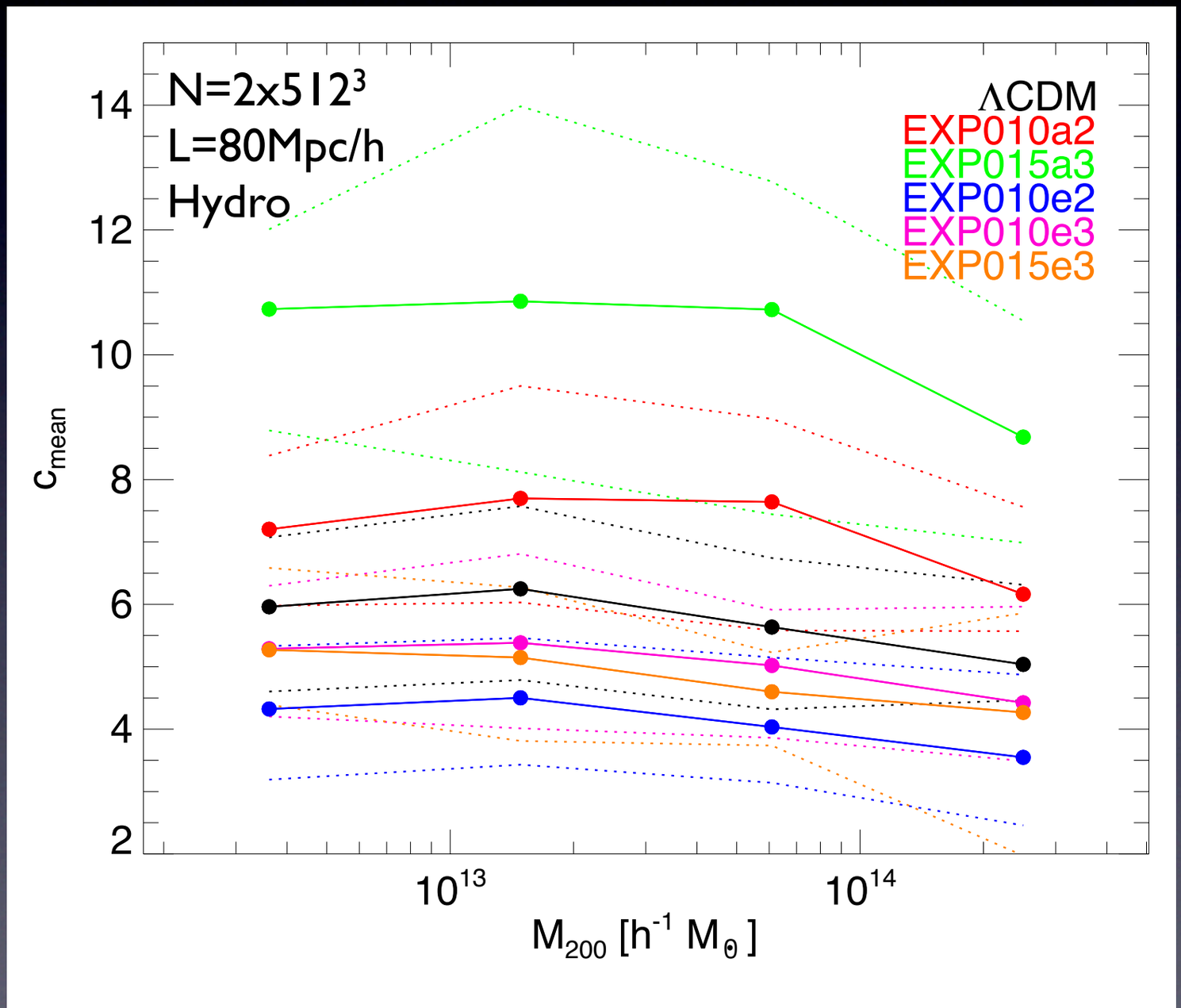


CONCENTRATIONS

Consistently with the results on density profiles, the concentrations of halos are found to be lower or higher in coupled cosmologies than in ΛCMD, according to the presence of a "Growing ϕMDE" phase:

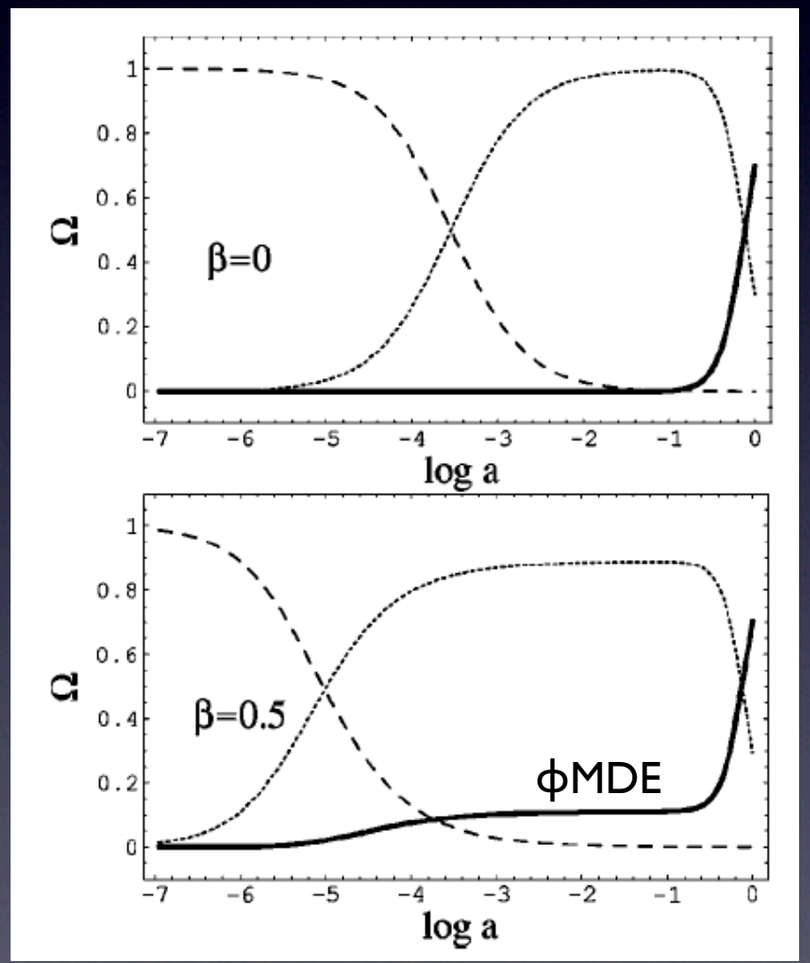
GϕMDE → Friction at work →
→ halo "heating" →
→ lower concentrations

NO GϕMDE → NO friction →
→ Potential energy decreases in time →
higher concentrations

Constant coupling: weak or strong?

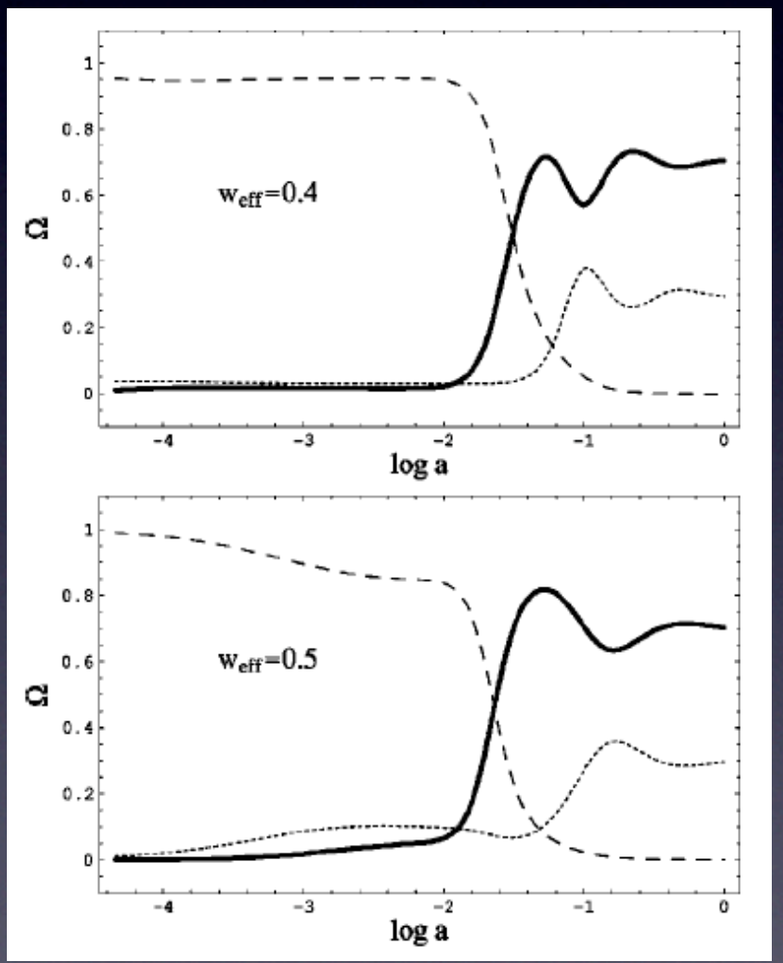
In the case of CONSTANT COUPLINGS [Amendola 2000] there are two very different behaviors of interacting DE depending on the strength of the interaction:

WEAK coupling regime $|\beta| < 1/\sqrt{2}$



+) Late-time accelerated phase
−) Coincidence problem still open

STRONG coupling regime $|\beta| > 1/\sqrt{2}$



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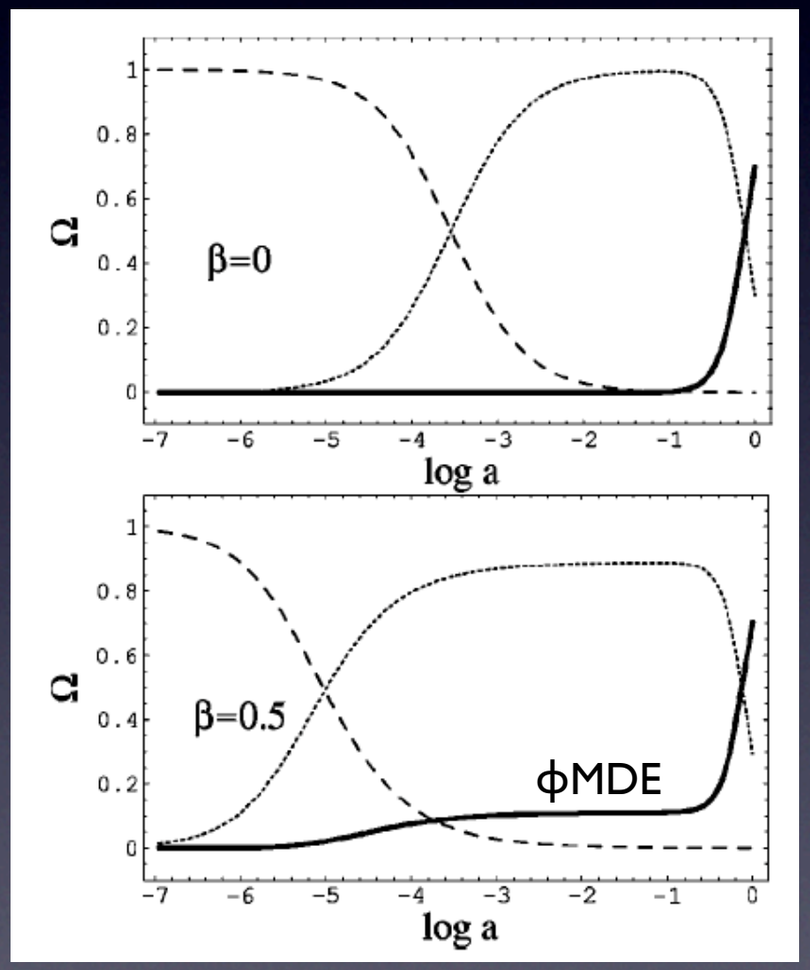

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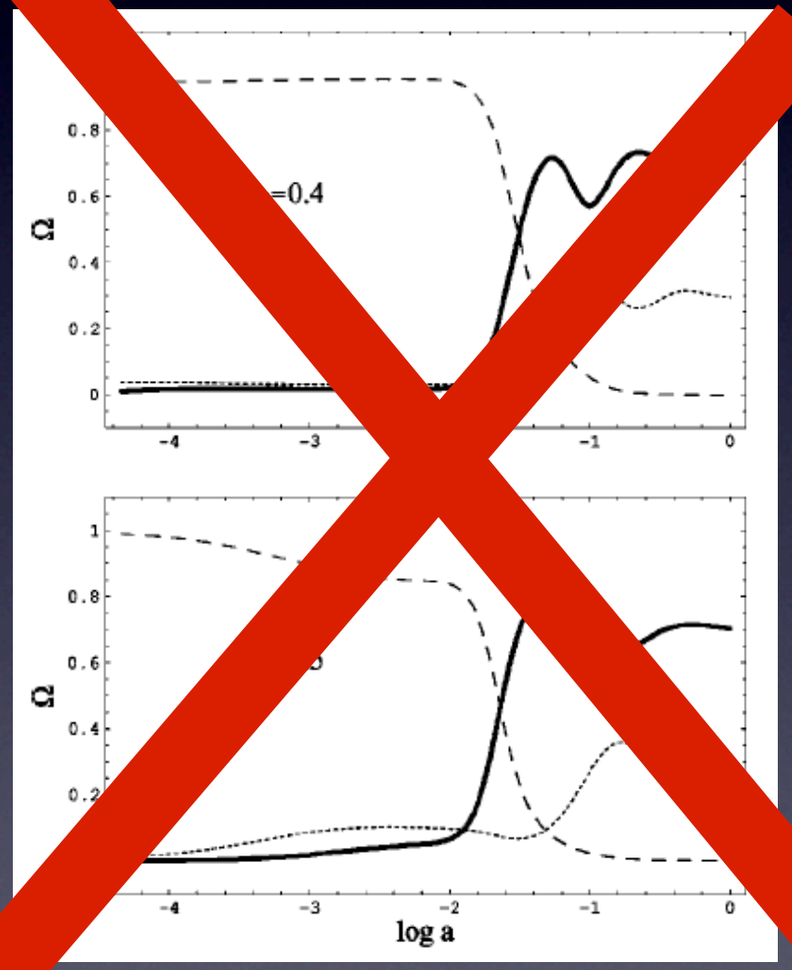

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