Marco Baldi

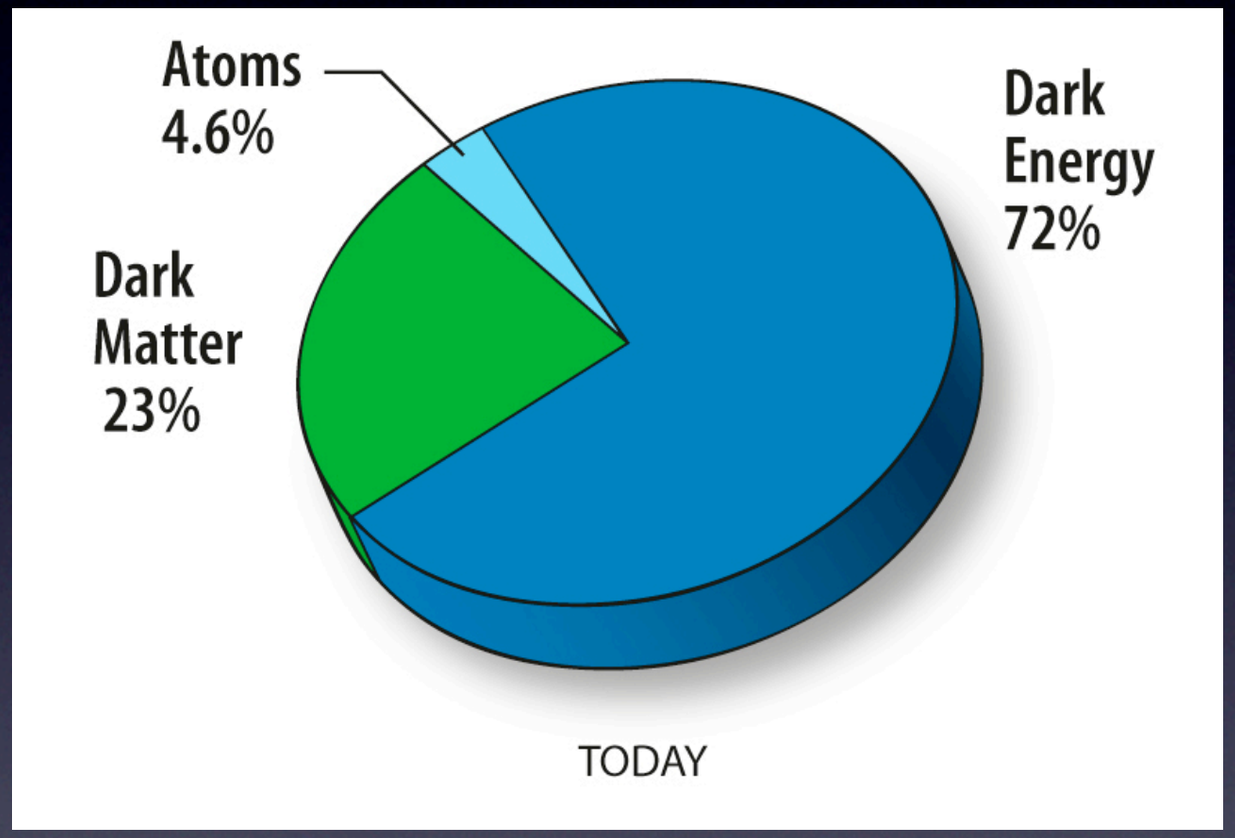
Excellence Cluster Universe, Garching

N-BODY SIMULATIONS OF INTERACTING DARK ENERGY MODELS

Cosmology on the beach - Puerto Vallarta, Mexico - 10 | 2011

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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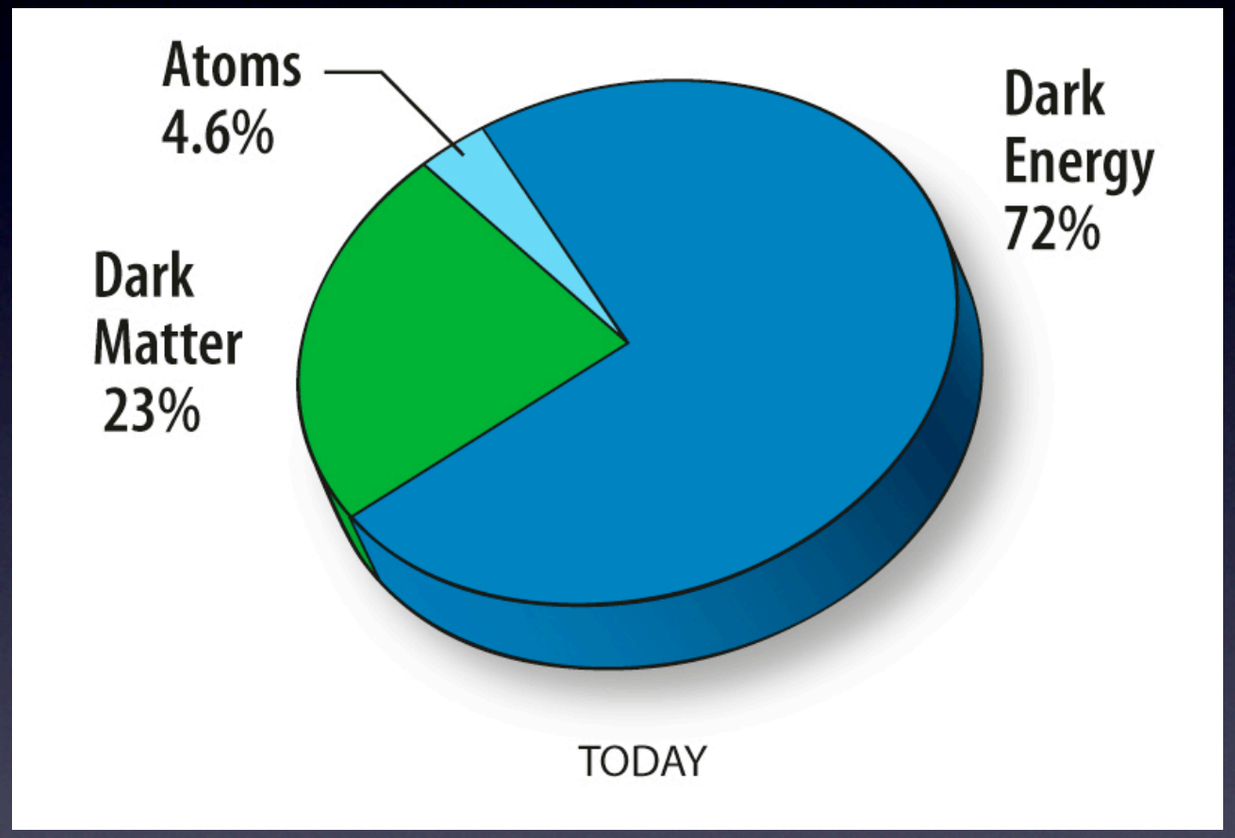

The theoretical effort to cast all these data into a simple and consistent picture of the Universe has led to the establishment of a STANDARD MODEL...

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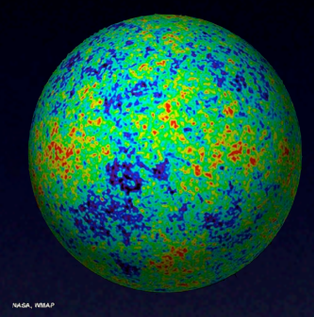

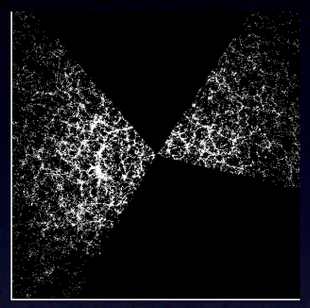

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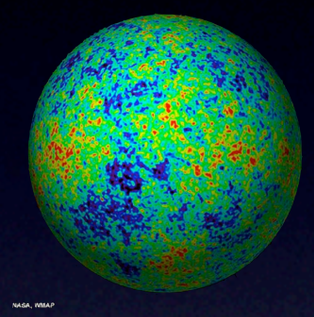

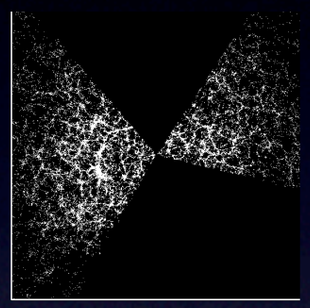

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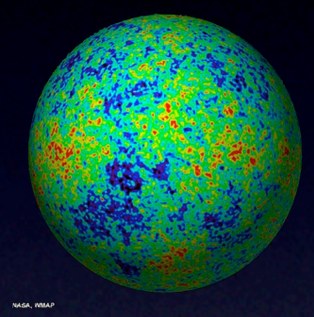

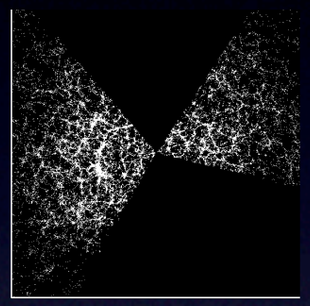

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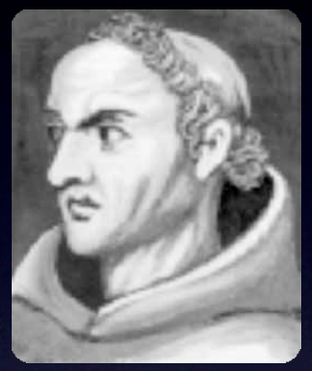

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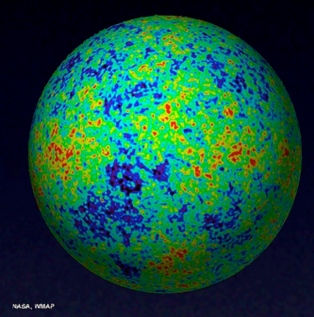

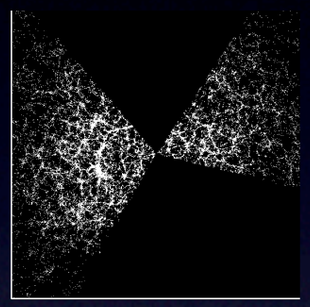

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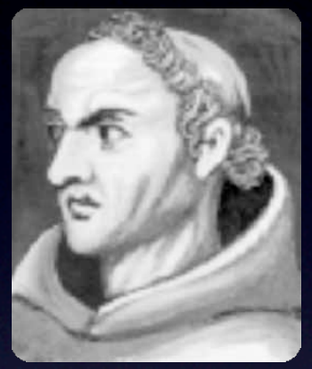

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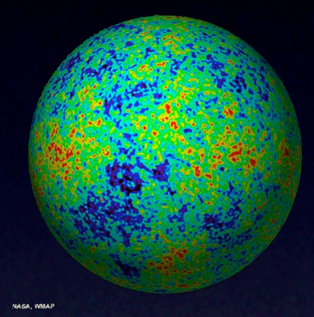

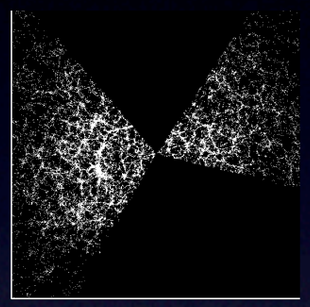

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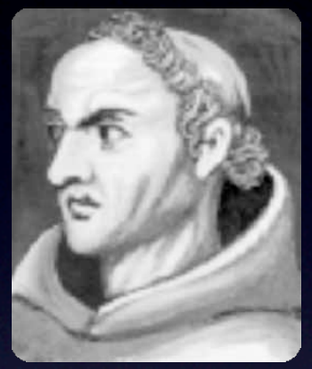

So why looking for something more "exotic"?

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 $\frac{\rho_\Lambda}{\rho_m} < 10^{-3} \text{ for } z > 6$

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]

8) The misalignment of halo satellites: Weaker alignment observed than expected
[Lee 2010; Oguri et al. 2010; MB, Lee & Maccio' 2011]

Dynamic and interacting

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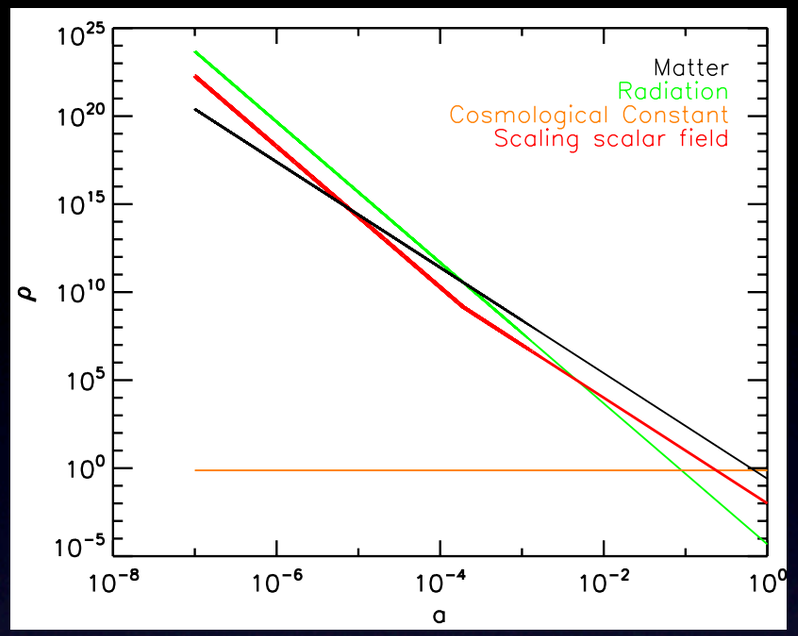
✔Dynamic DE (UNCOUPLED):
a scalar field in a self-interaction potential

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



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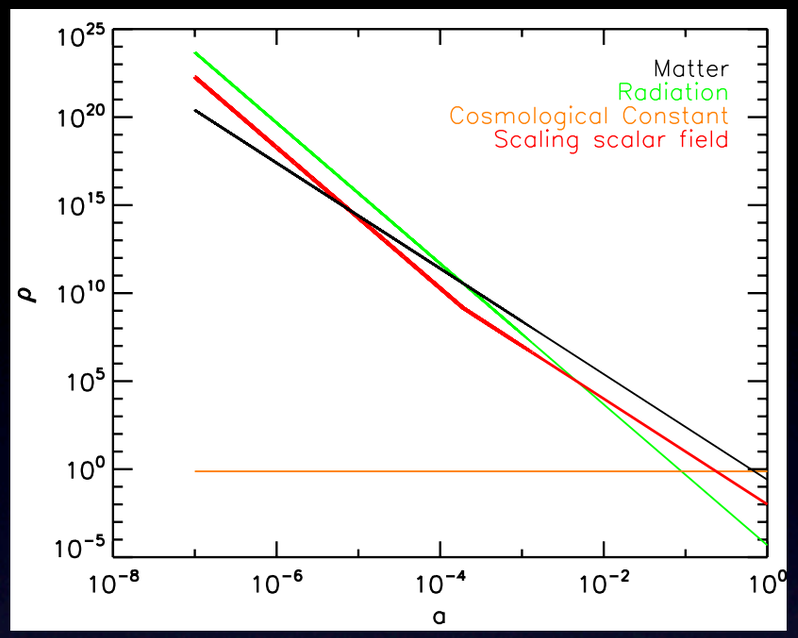

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✔Interacting DE:
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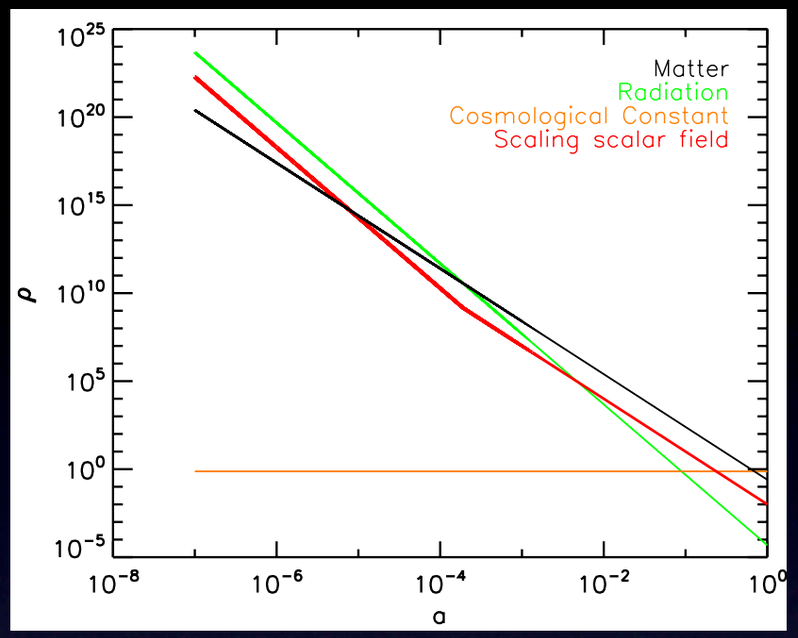

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Consequence: modified gravitational dynamics

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

To study the impact of these models on nonlinear structures we need to include coupled DE into an N-body code

Implementation of coupled DE equations in the Tree-PM code GADGET-2

[MB, V. Pettorino, G. Robbers, V. Springel MNRAS 2010]

Results (I): halo mass function and cluster counts

Number counts in coupled dark energy models: CONSTANT and VARIABLE couplings [MB & V. Pettorino MNRAS-L 2010 (1006.3761)]

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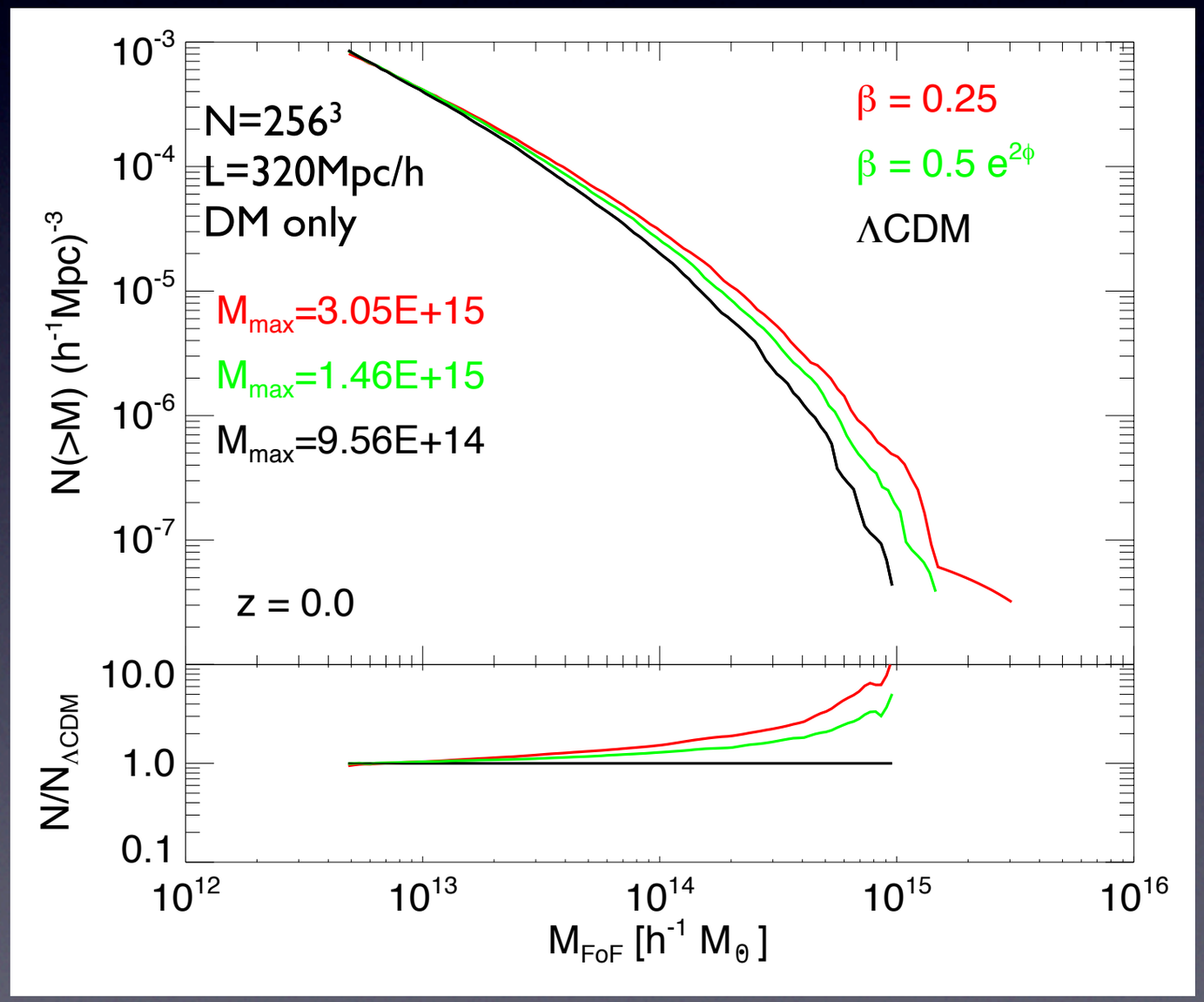

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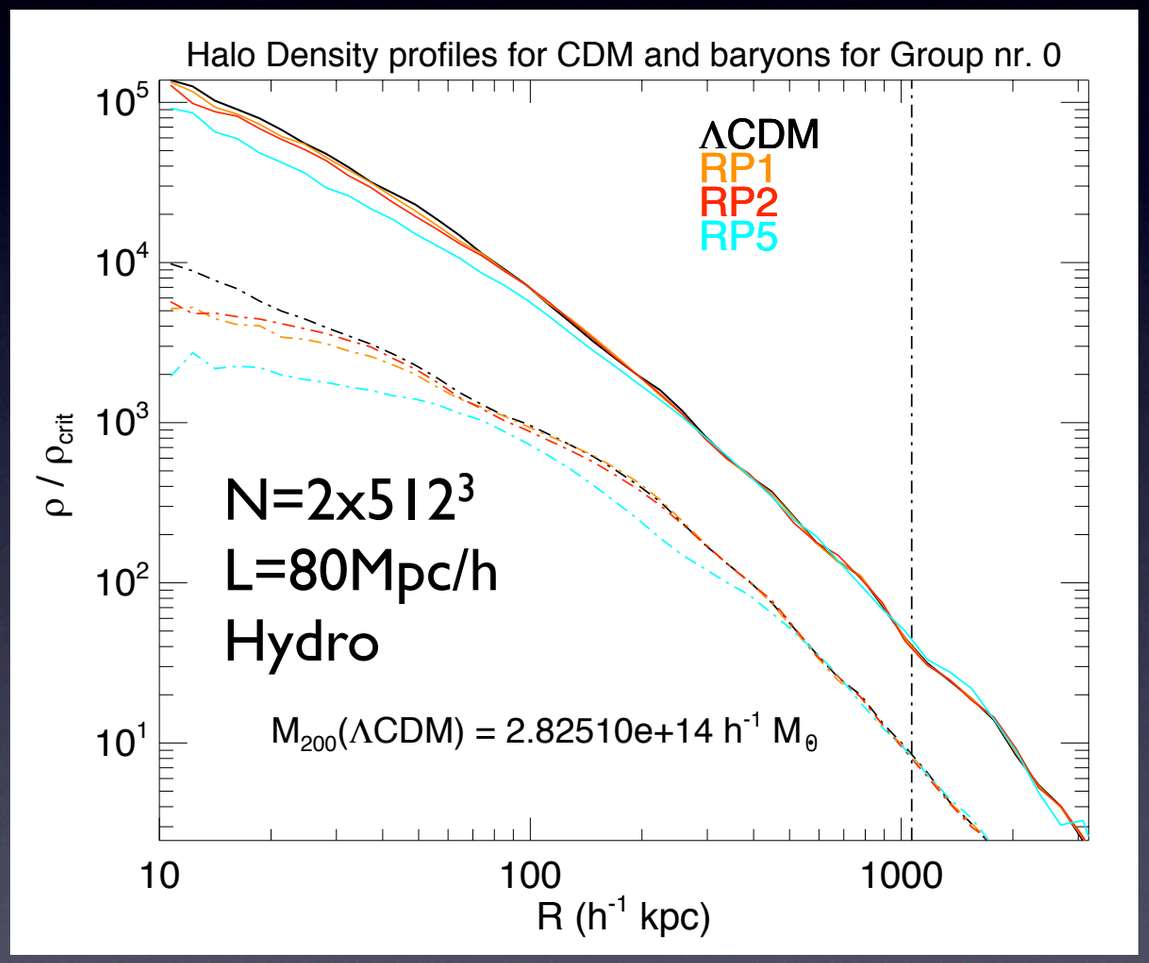
INTERACTING DE:
The extra force acting between CDM particles and the extra friction term determine a faster growth of density perturbations.

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

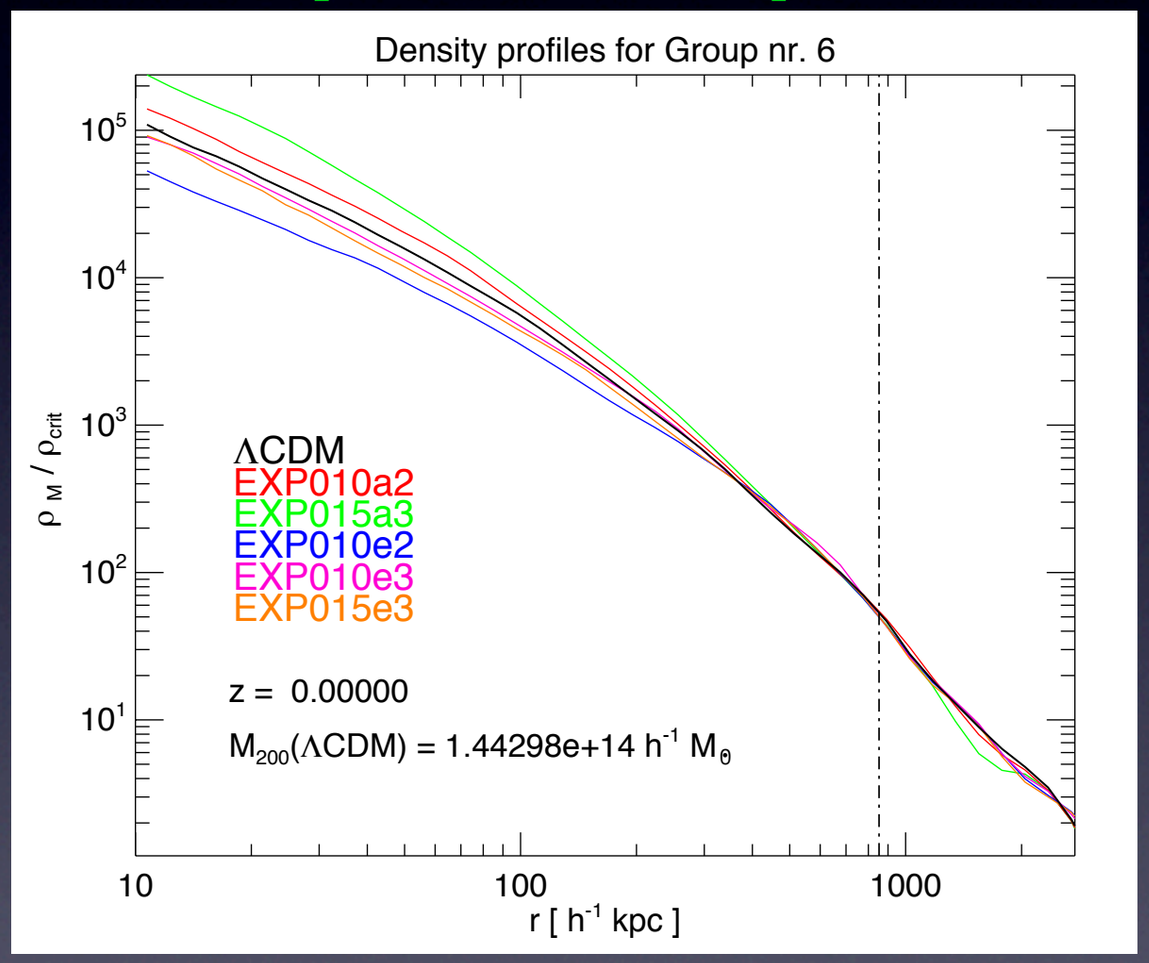
Results (II): halo density profiles

The first hydrodynamical high-resolution N-body simulations for a weak DE-CDM interaction:

Constant coupling
[MB et al., MNRAS 2010]



Variable coupling
[MB, MNRAS 2010]



Possibly detectable by weak/strong lensing and dynamical probes

Results (III): 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

Results (III): baryon fraction

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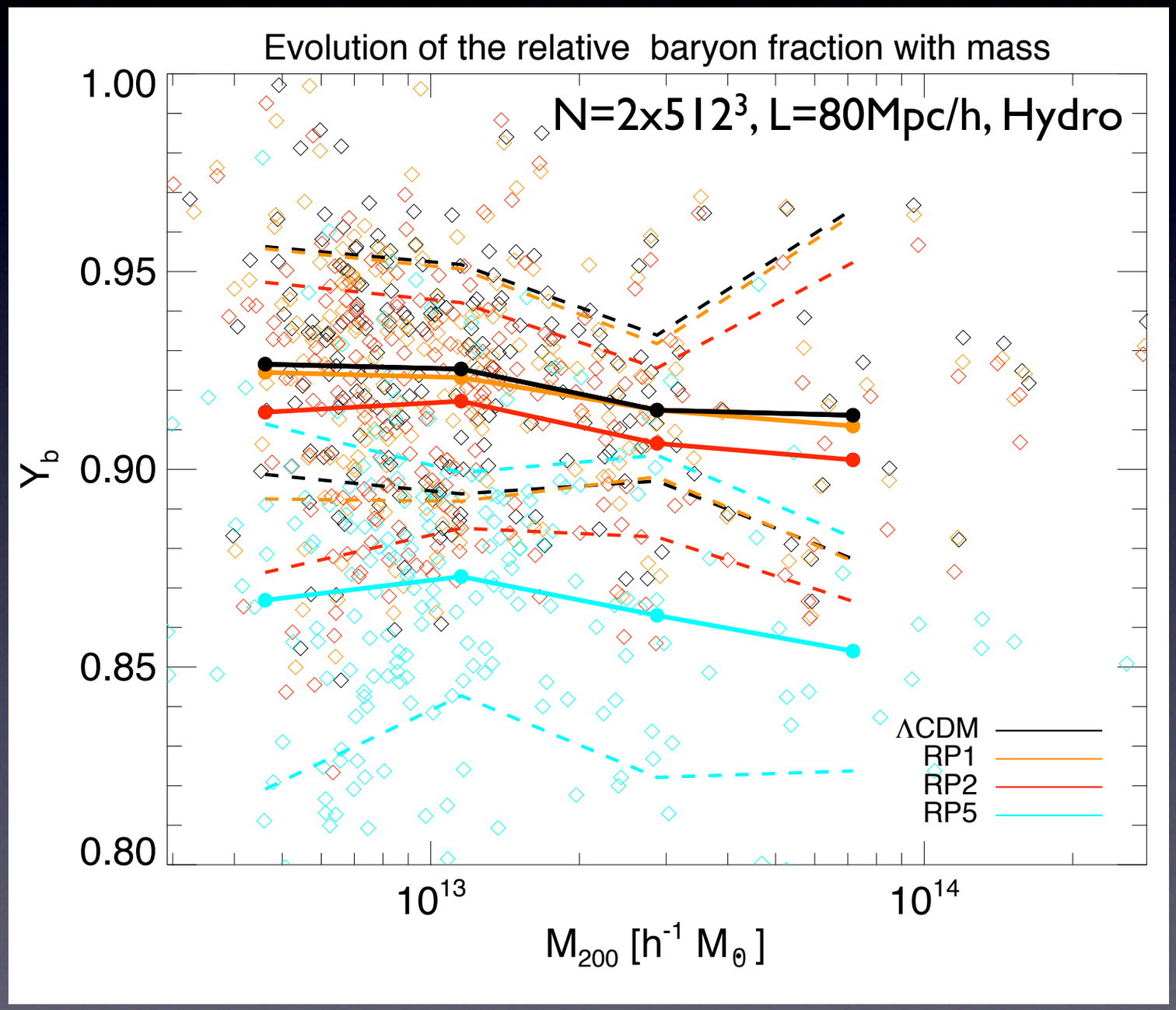


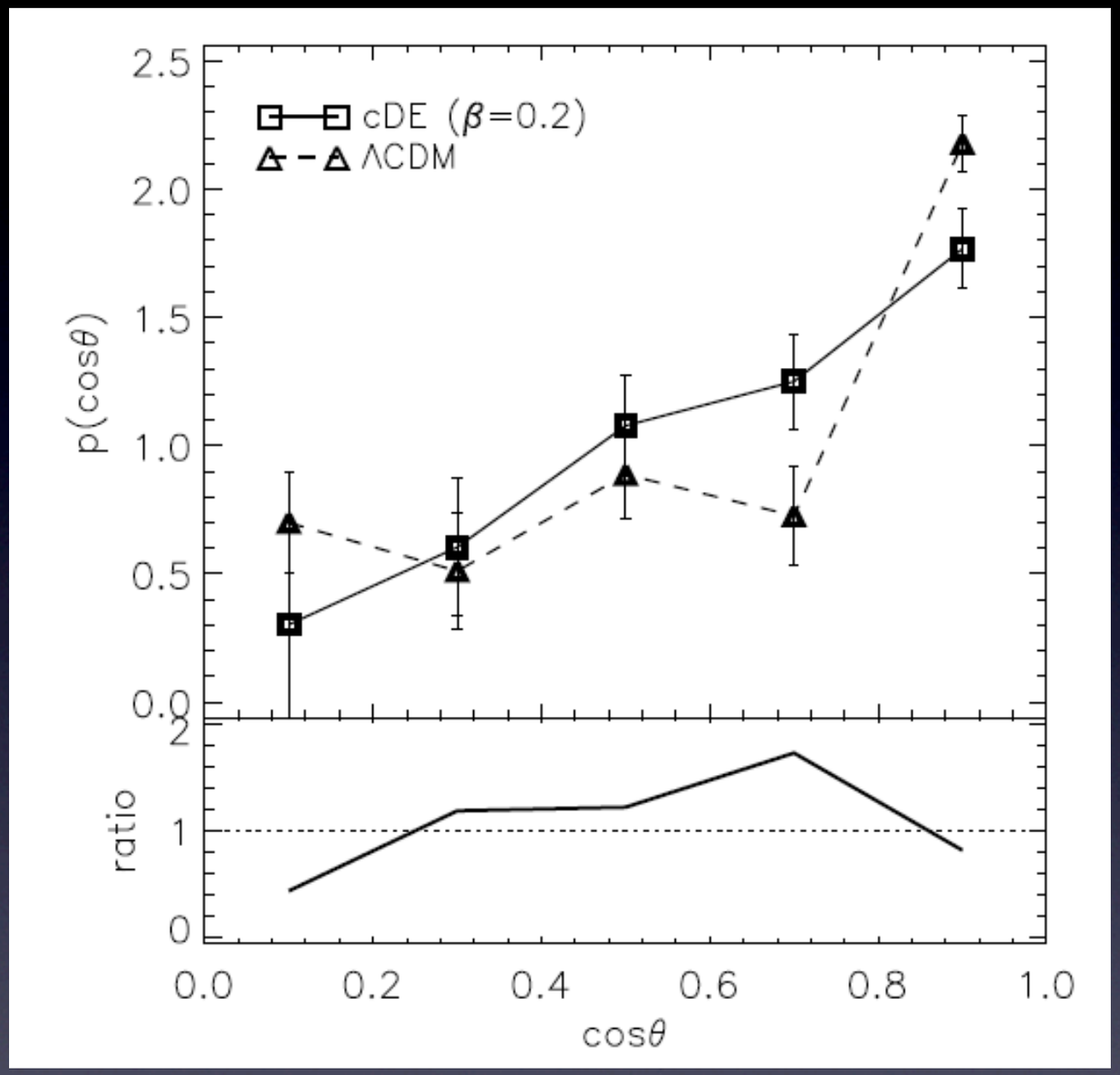
BARYON FRACTION

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 (IV): subhalos misalignment



ΛCDM simulations seem to show a strong alignment between galaxy and CDM distributions in clusters [Lee APJ 2010]

However, recent observations (still a low number of objects, though) have shown a lower degree of alignment [Oguri et al. 2010]

By means of high-resolution N-body simulations we have shown that coupled DE cosmologies predict a weaker alignment between galaxy and CDM distributions [MB, J. Lee, A. Maccio' submitted to APJ Letters]

Need more data to increase statistical significance

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The effects of the DE interactions on nonlinear structure formation could provide unique tools to observationally test coupled DE models