Marco Baldi

Excellence Cluster Universe, Garching

Simulating the impact of Dark Energy interactions on the formation and evolution of cosmic structures

Bologna, 28 IV 2011

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   1a - cosmological and astrophysical problems of the SM

   1b - standard and non-standard models

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5) Conclusions and future developments: the CoDECS project

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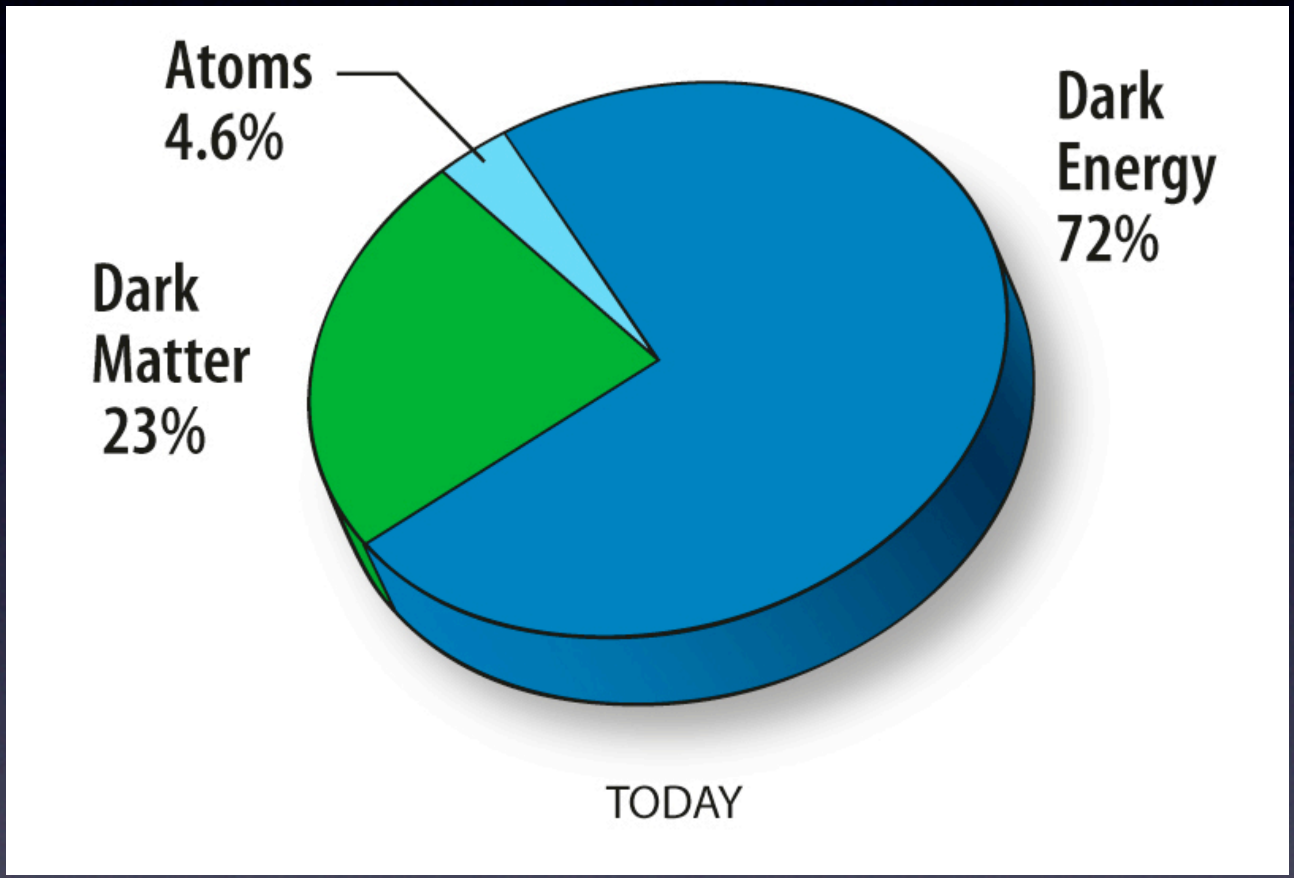

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[APM, 2dF, SDSS, ...]

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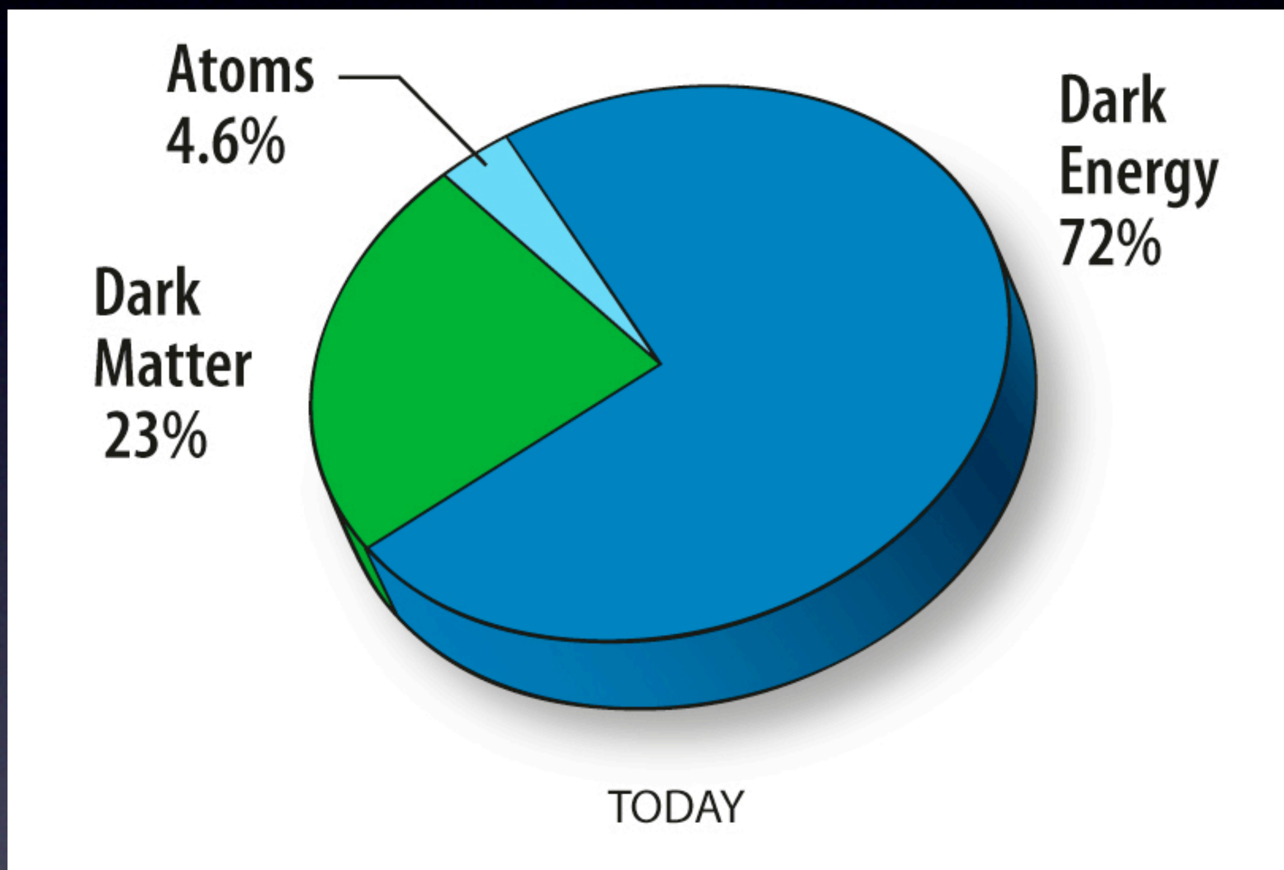

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The theoretical effort to cast all these data into a simple and consistent picture of the Universe has led to the establishment of a STANDARD MODEL...

Standard model and non-standard models

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Dropping 6) Dynamic and Interacting DE models (Quintessence, k-essence, phantom, Coupled DE, Unified DM, Chaplygin gas...)

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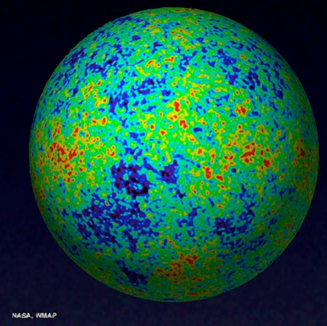

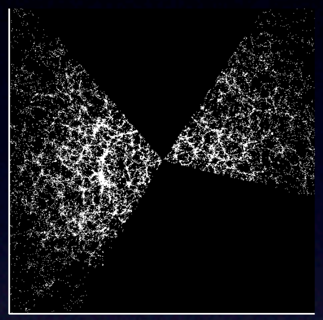

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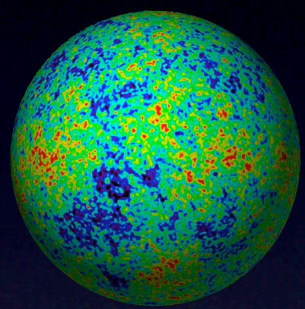
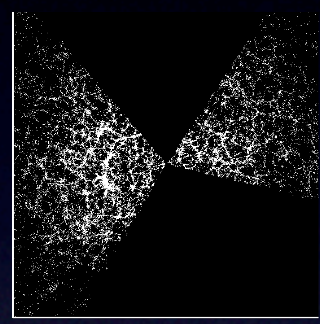


NASA, WMAP



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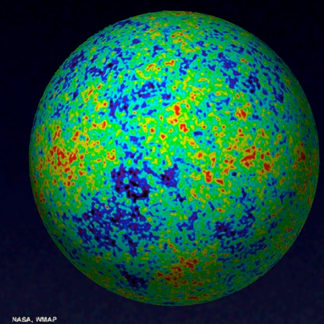

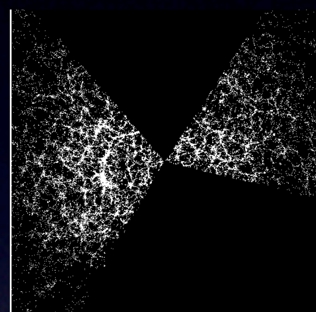

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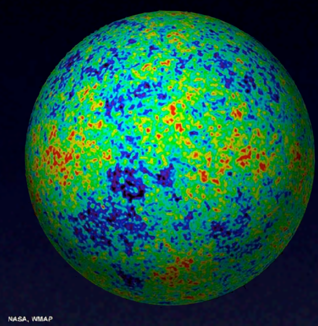

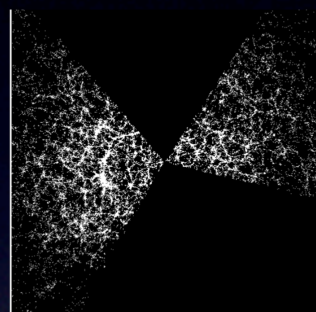

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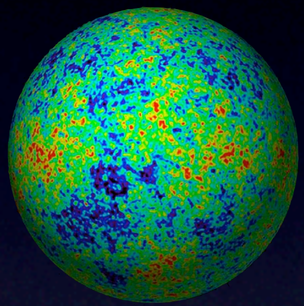

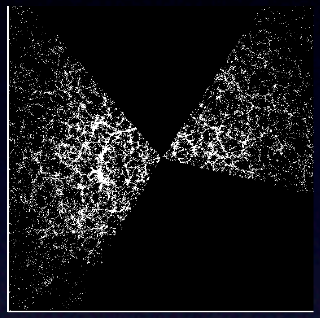

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So why looking for something more "exotic"?

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
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4) Cluster Baryon Fraction: SYSTEMATICALLY LOWER THAN EXPECTED
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7) The Bullet Cluster: EXCEEDINGLY RARE OBJECT IN A ΛCDM UNIVERSE
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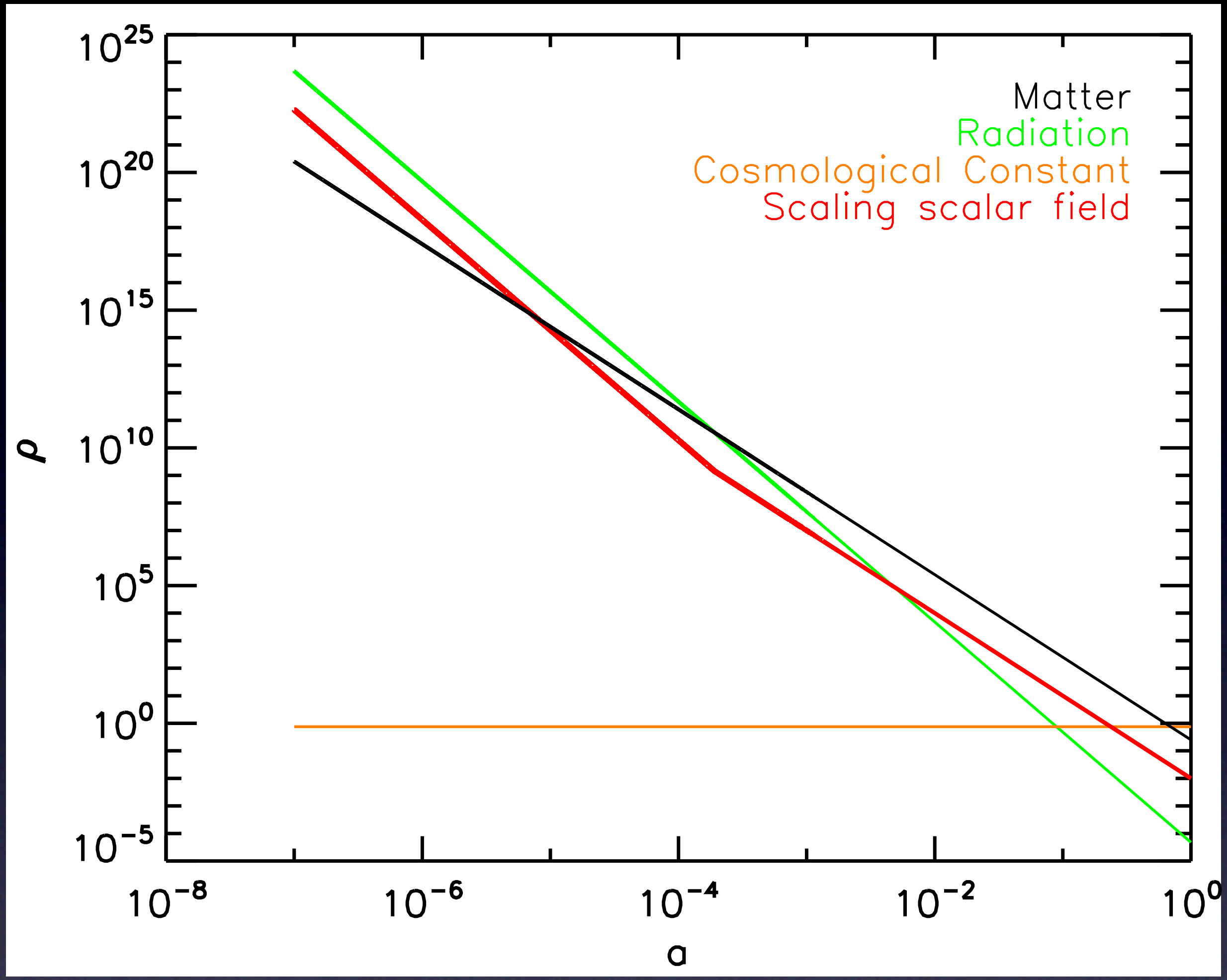

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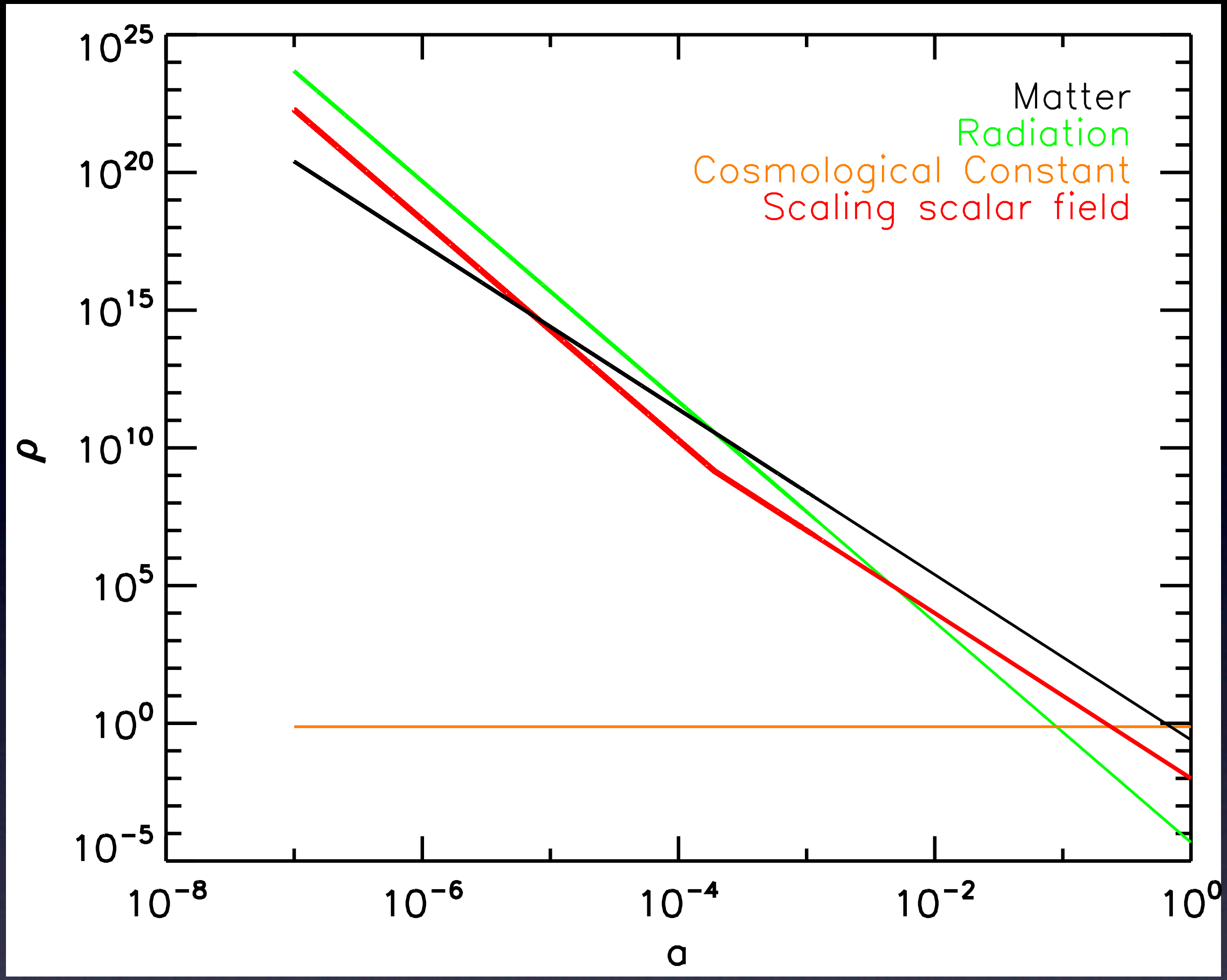

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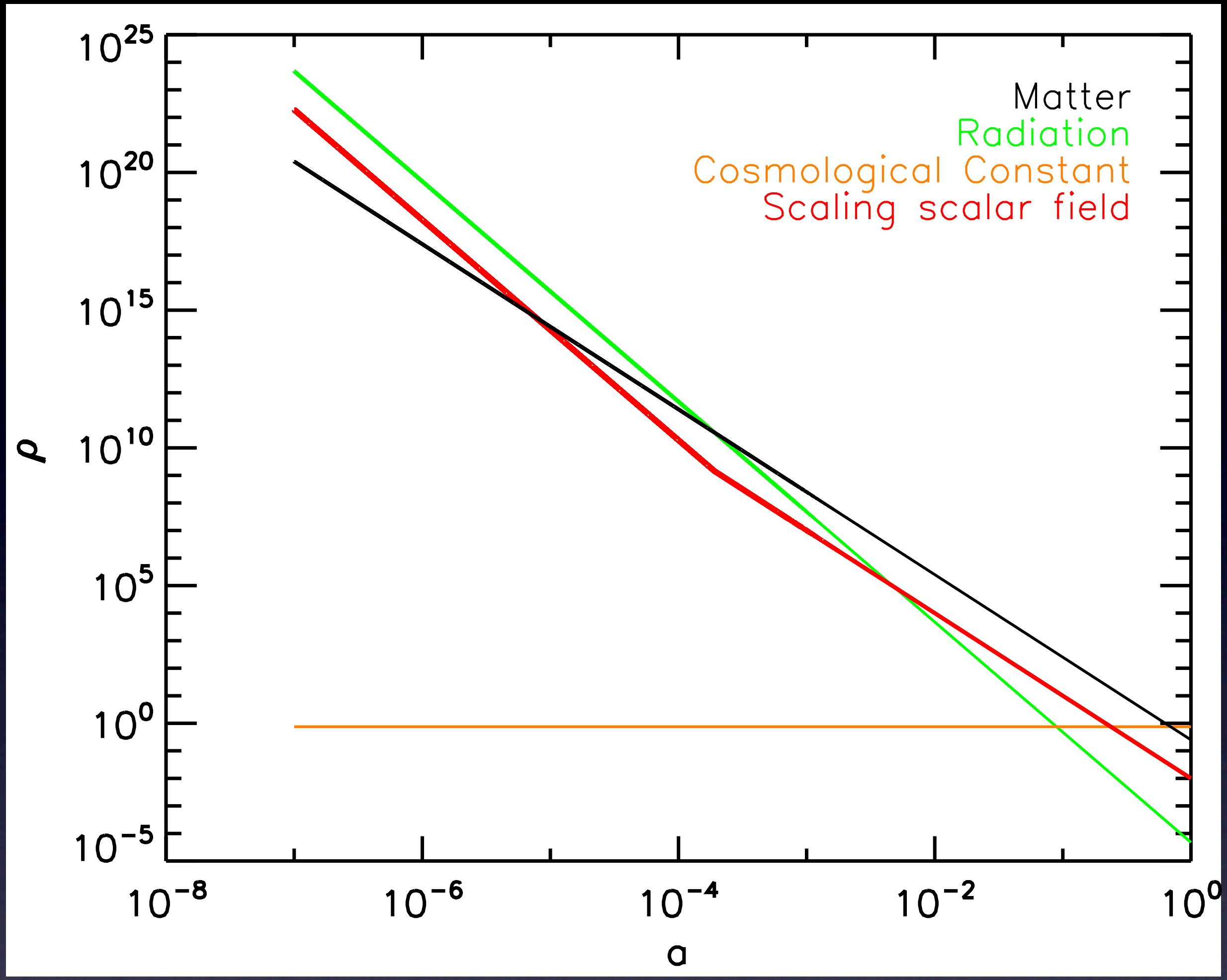

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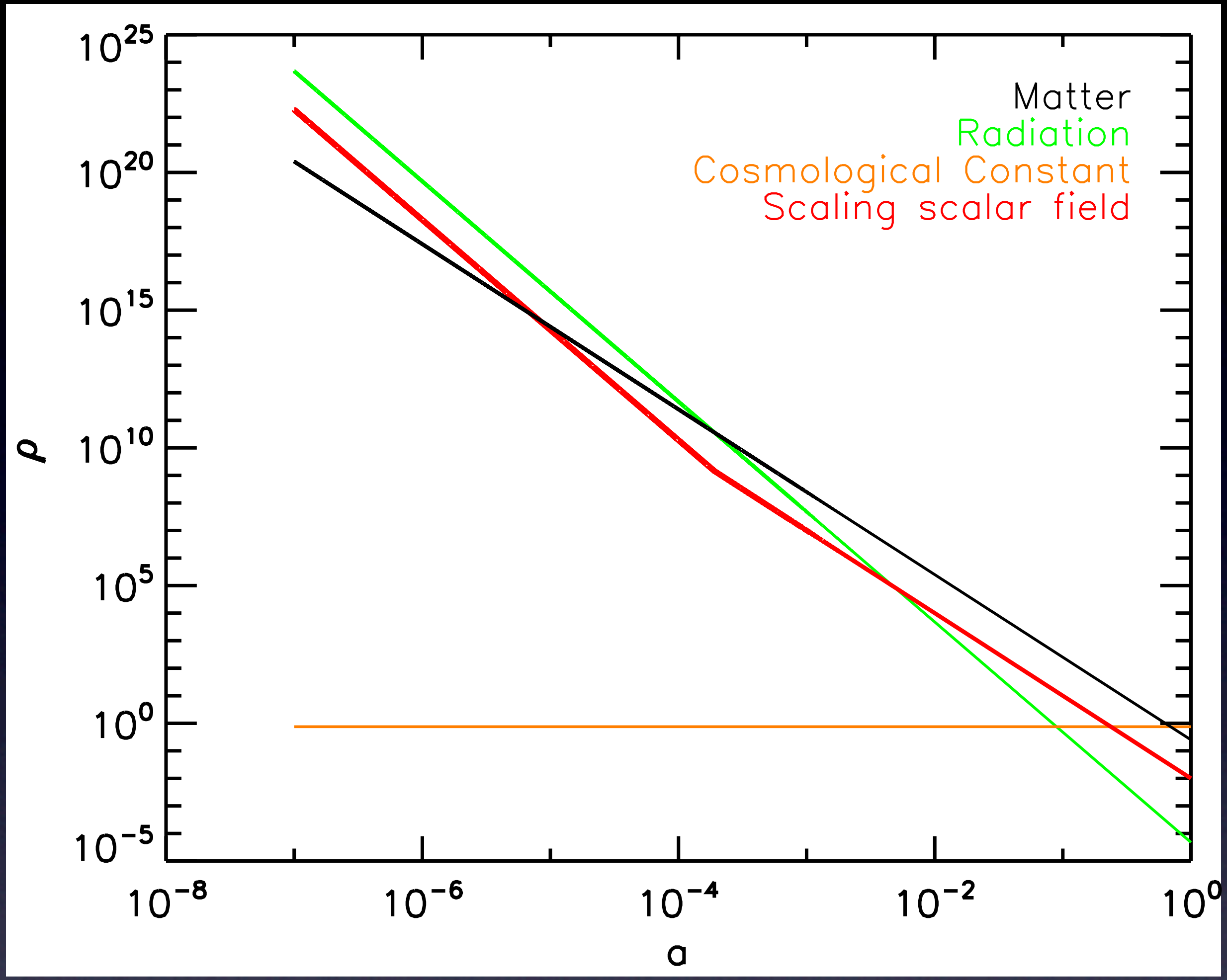

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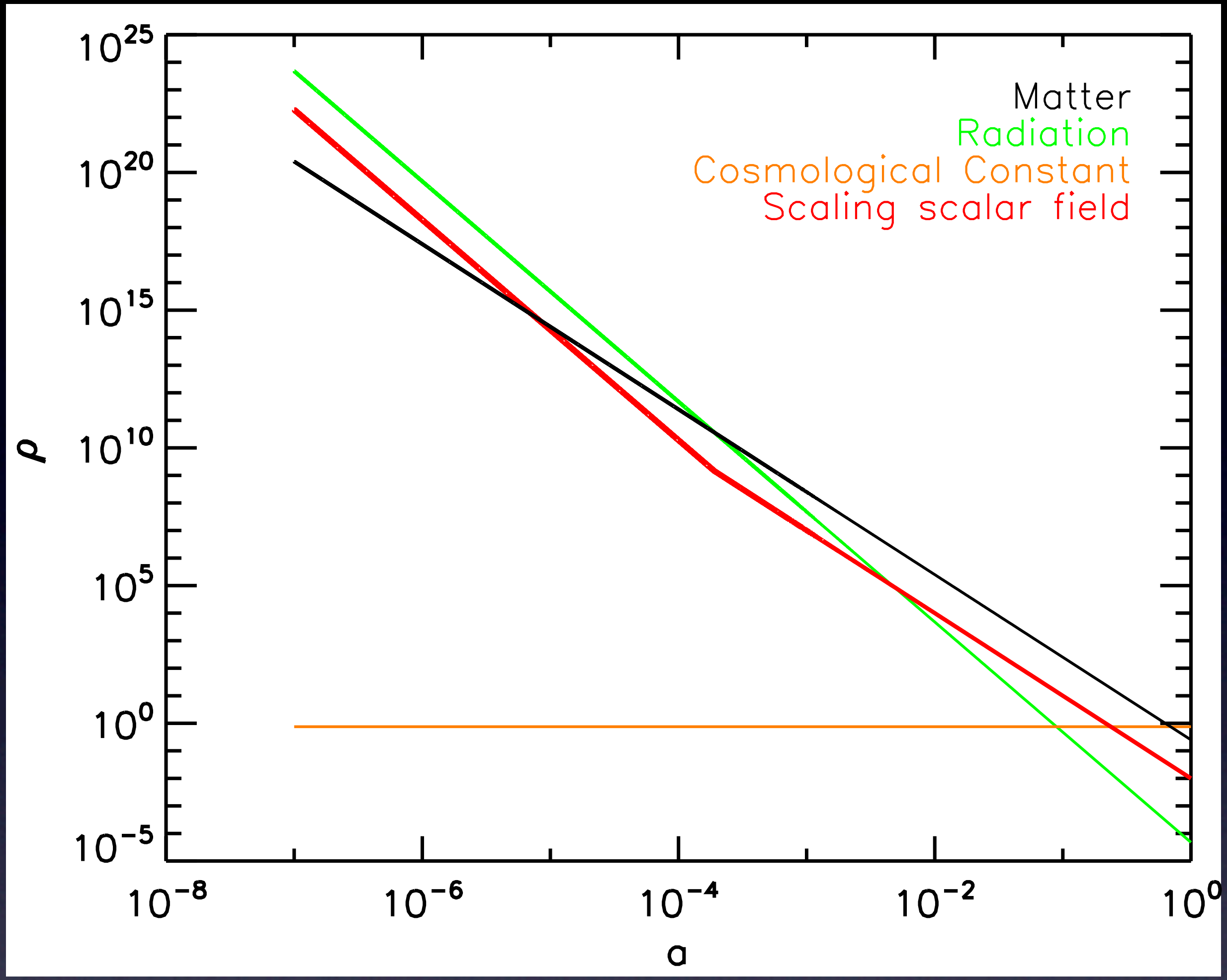

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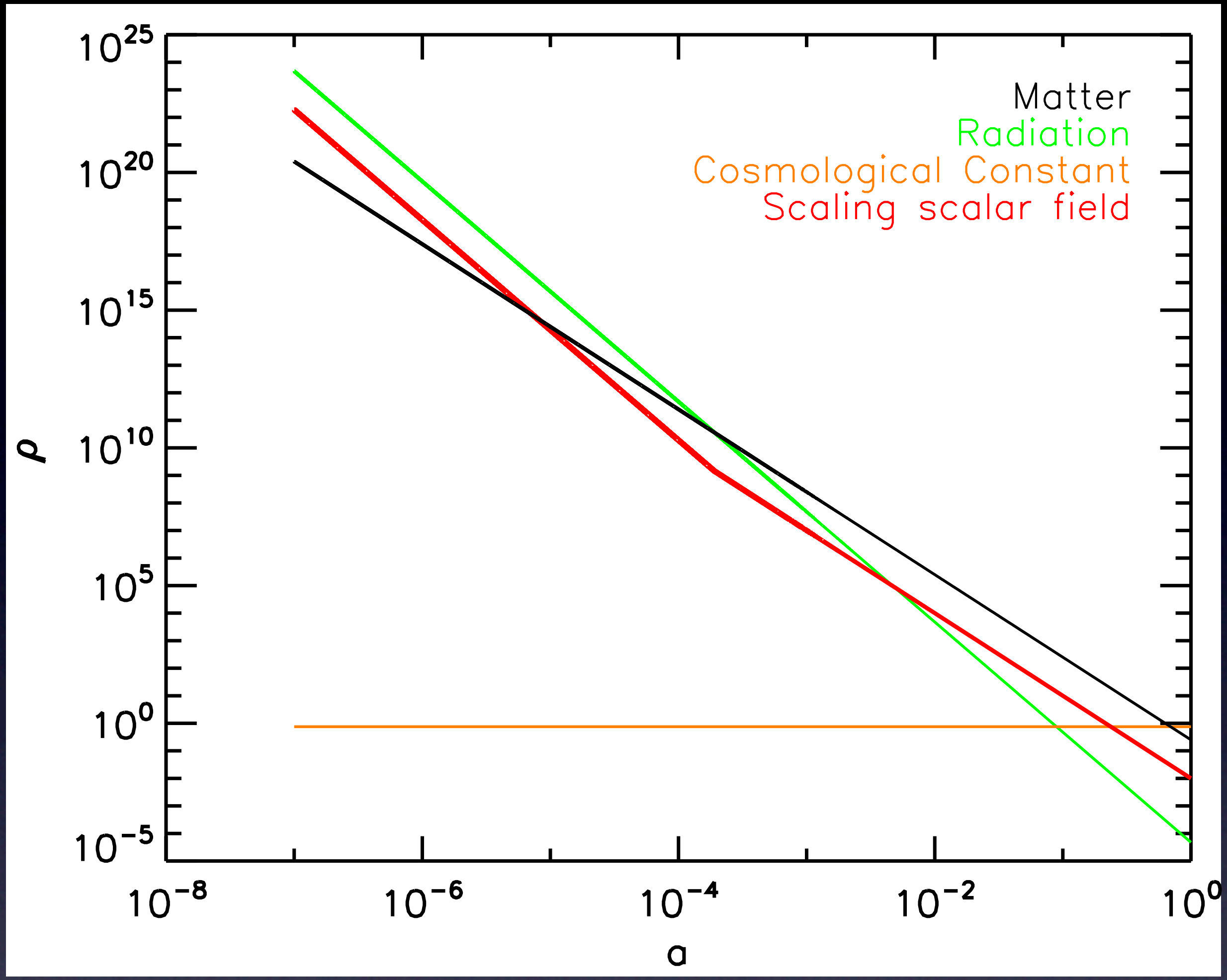

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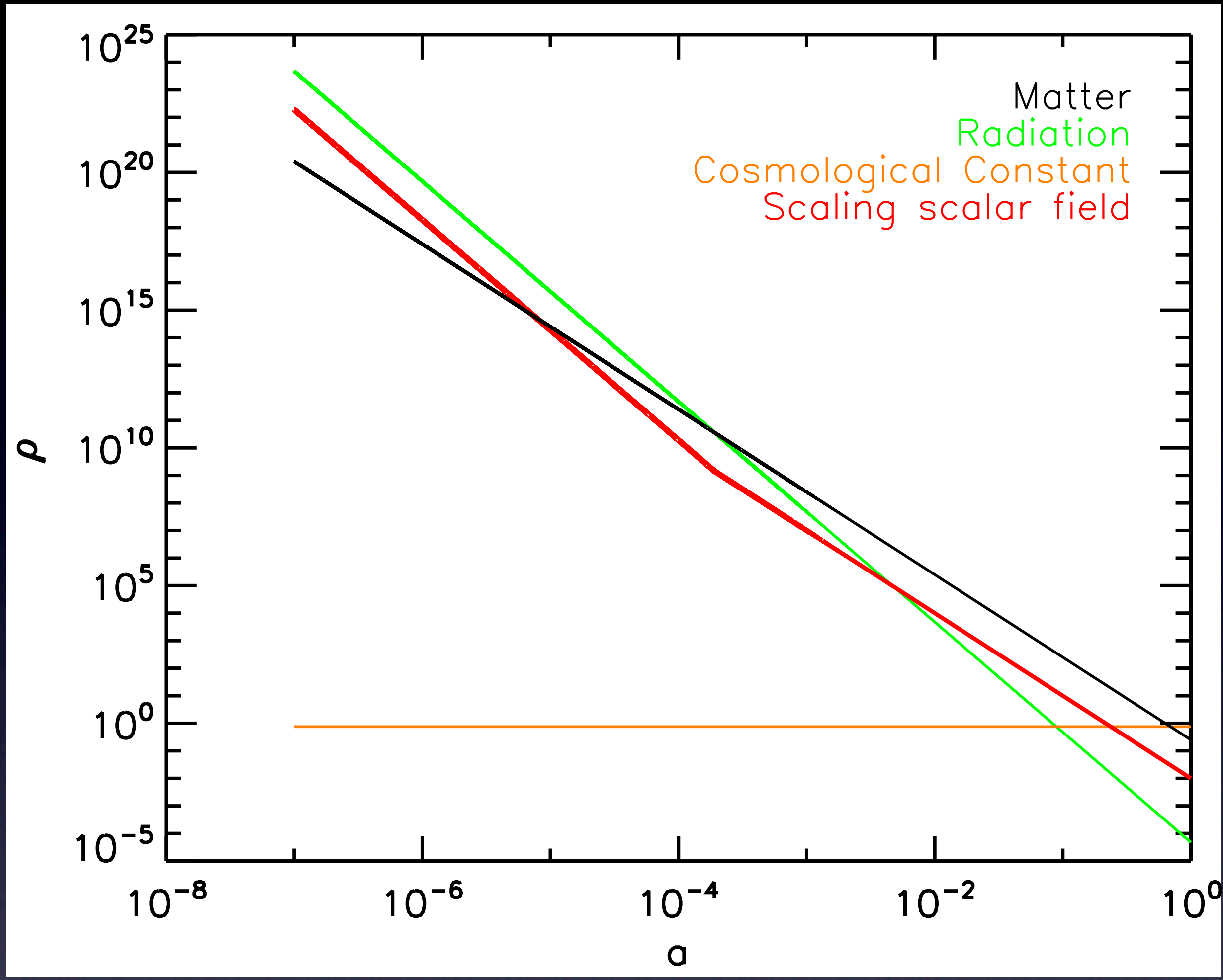

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{++} Scaling solutions with a late-time accelerated attractor: DE domination

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There are two very different behaviors of interacting DE depending on the strength of the interaction:

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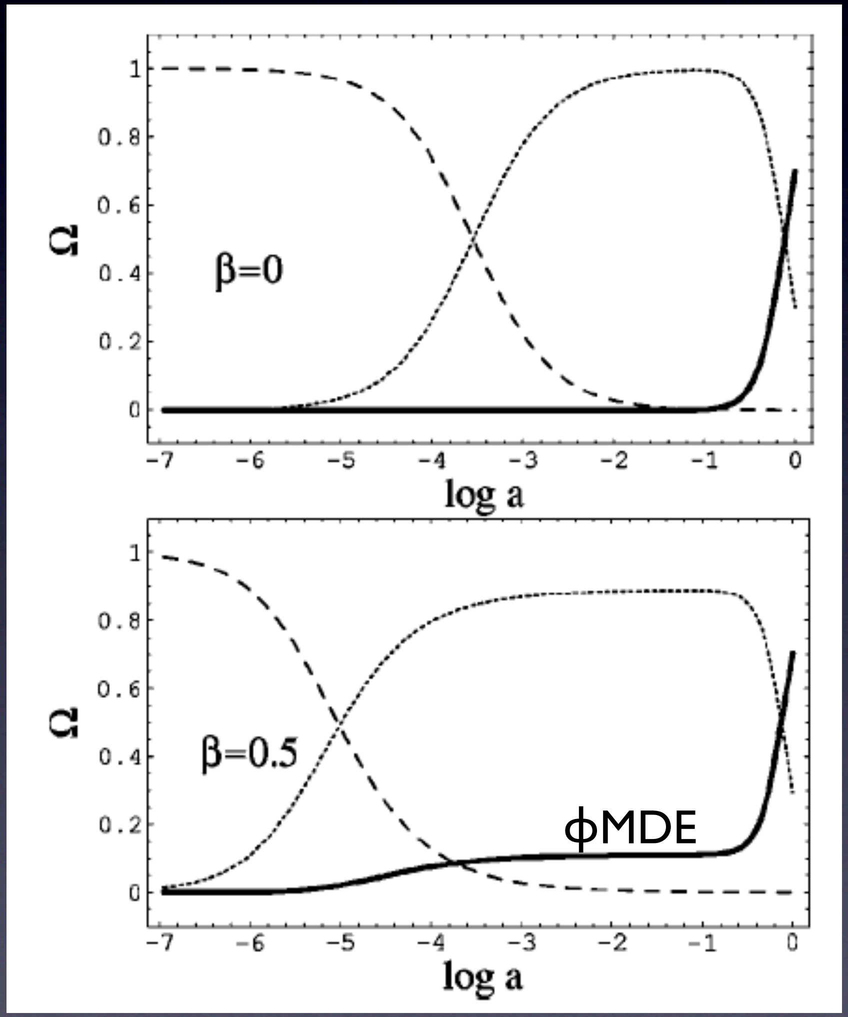

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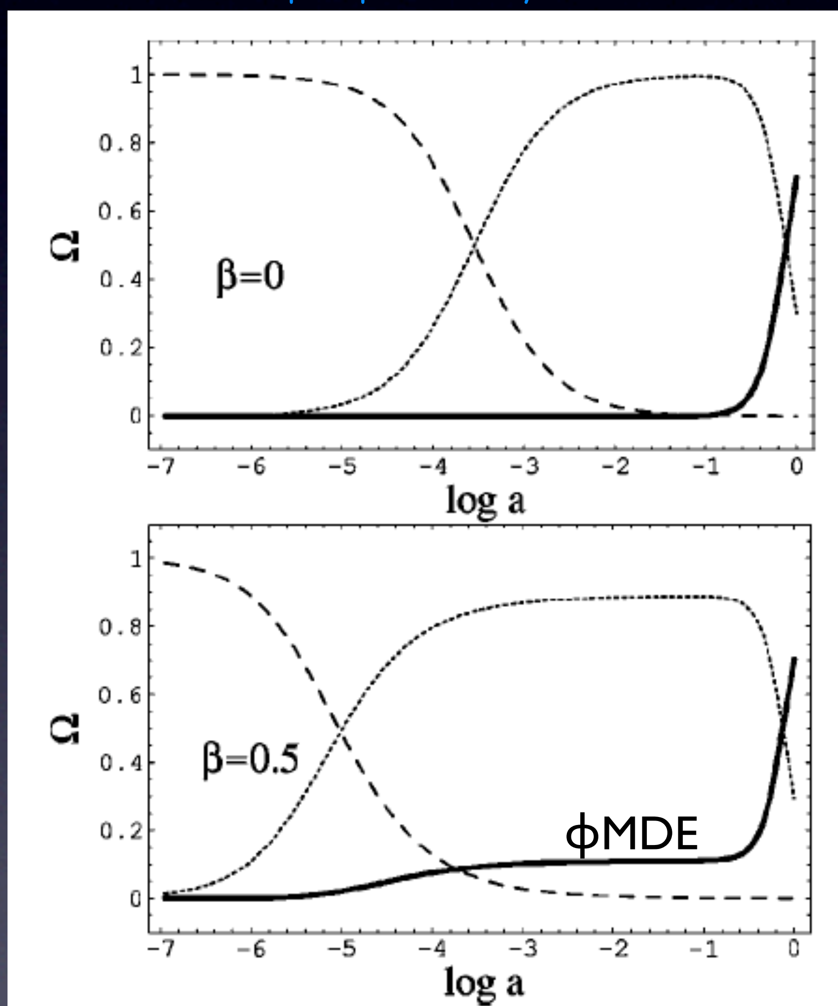

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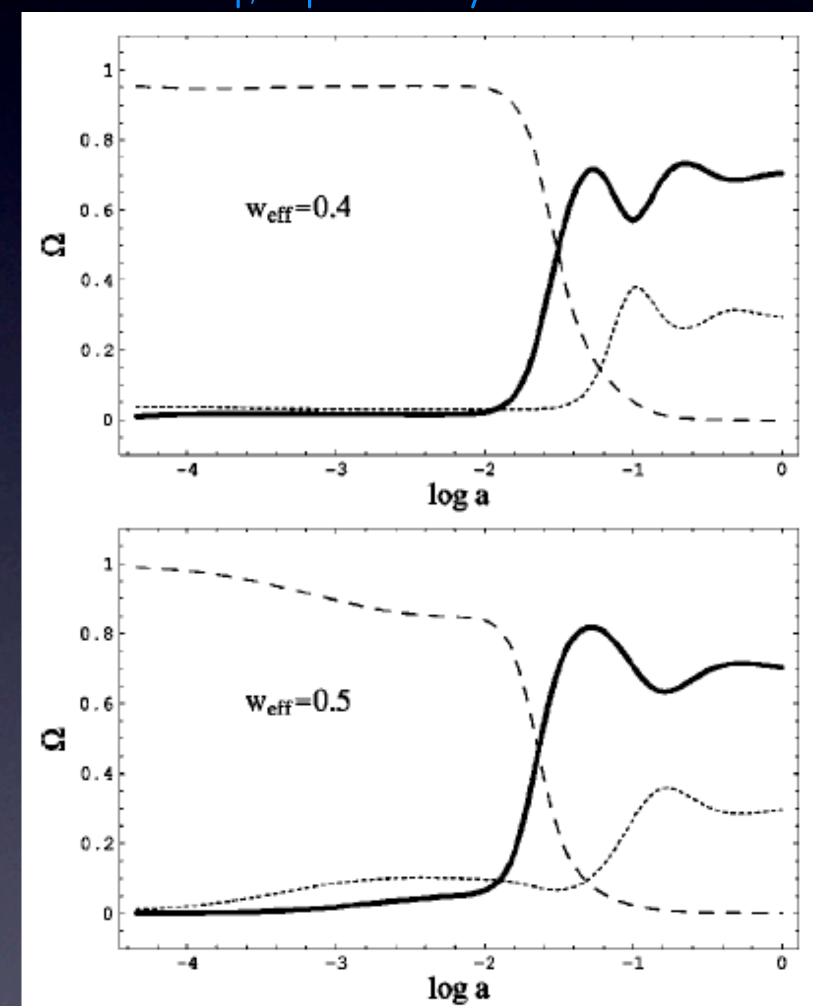

+) Late-time accelerated scaling

−) No Matter Domination ⇒ No Structures

Features of interacting dark energy

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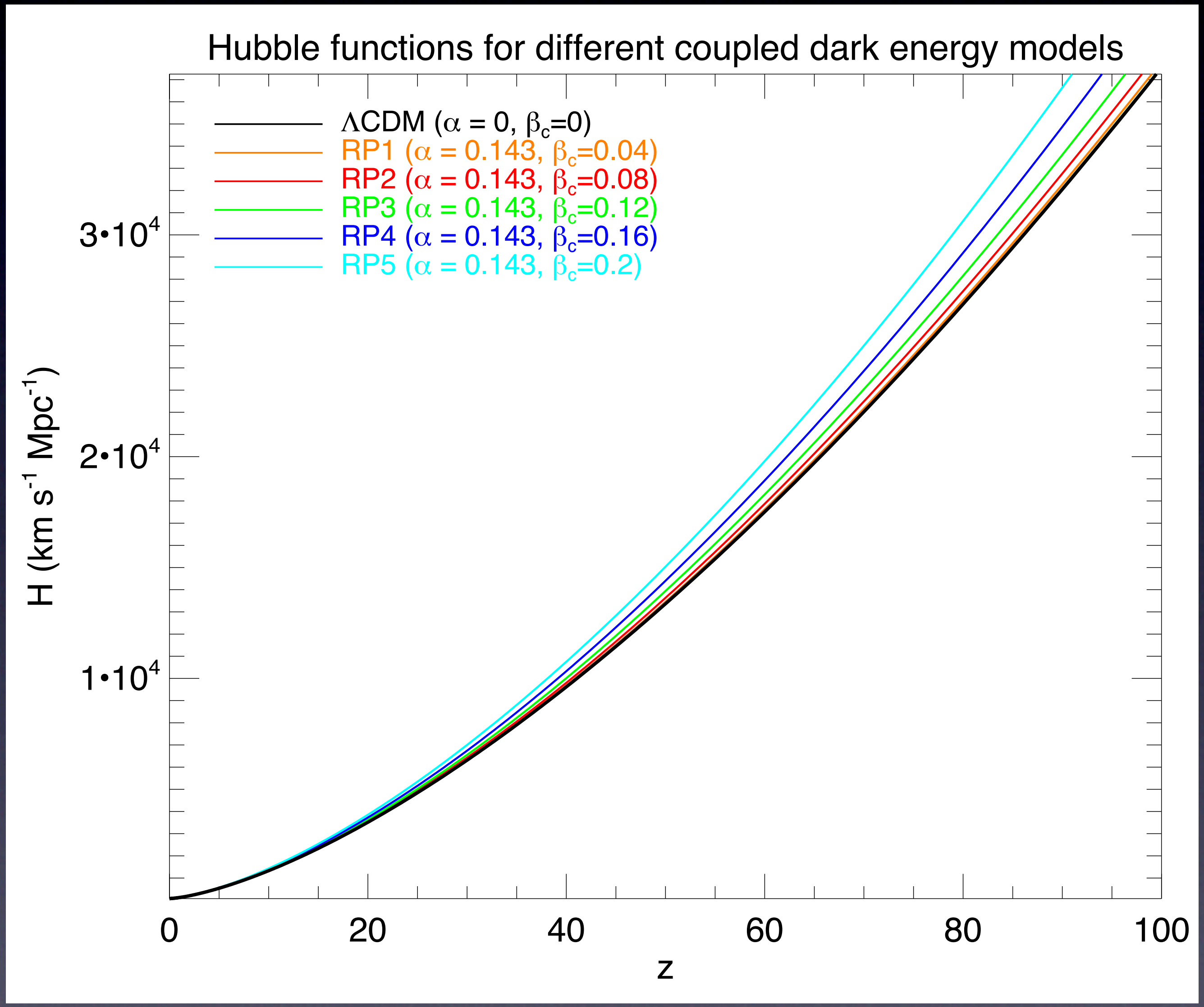
due to the early DE component



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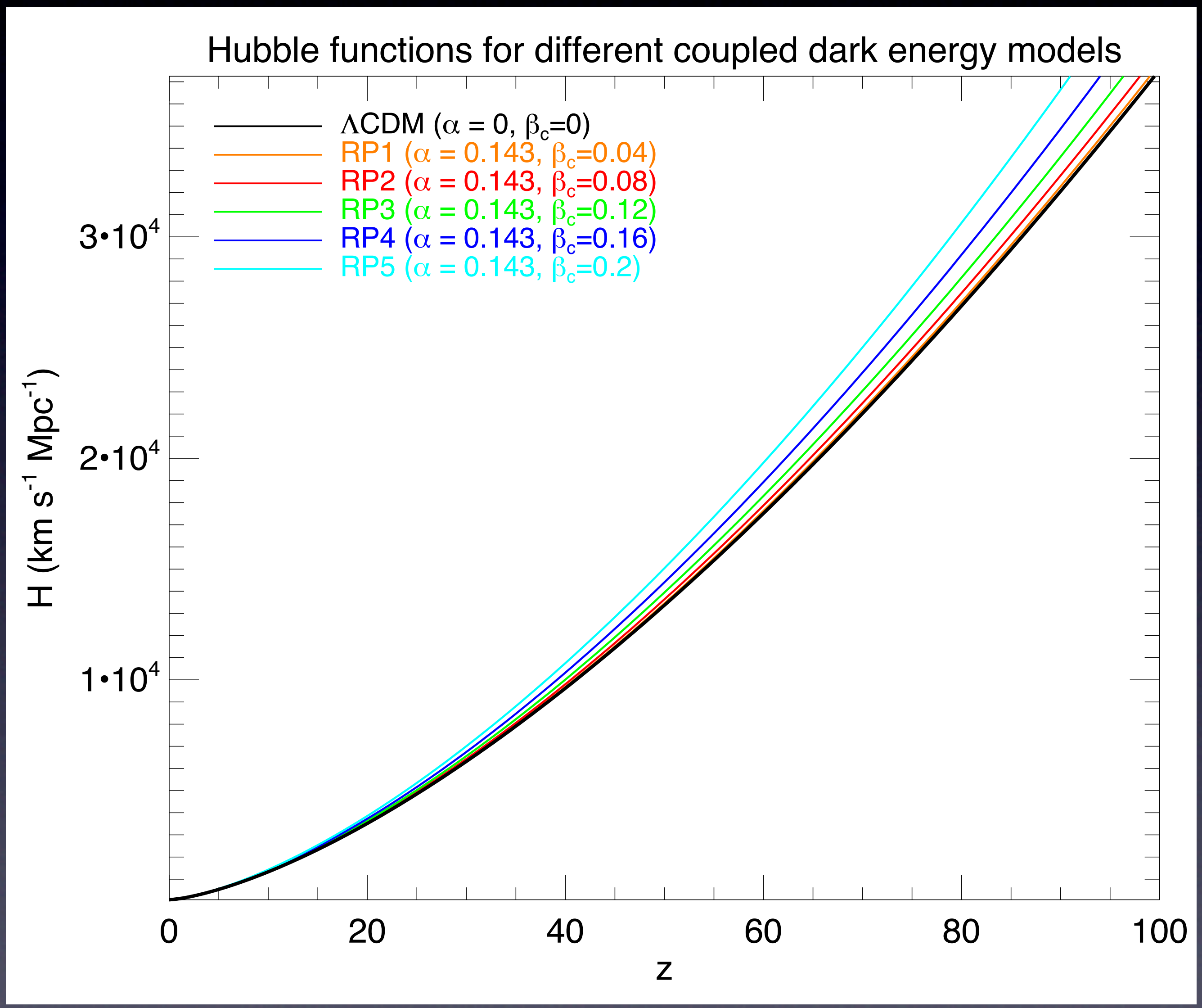

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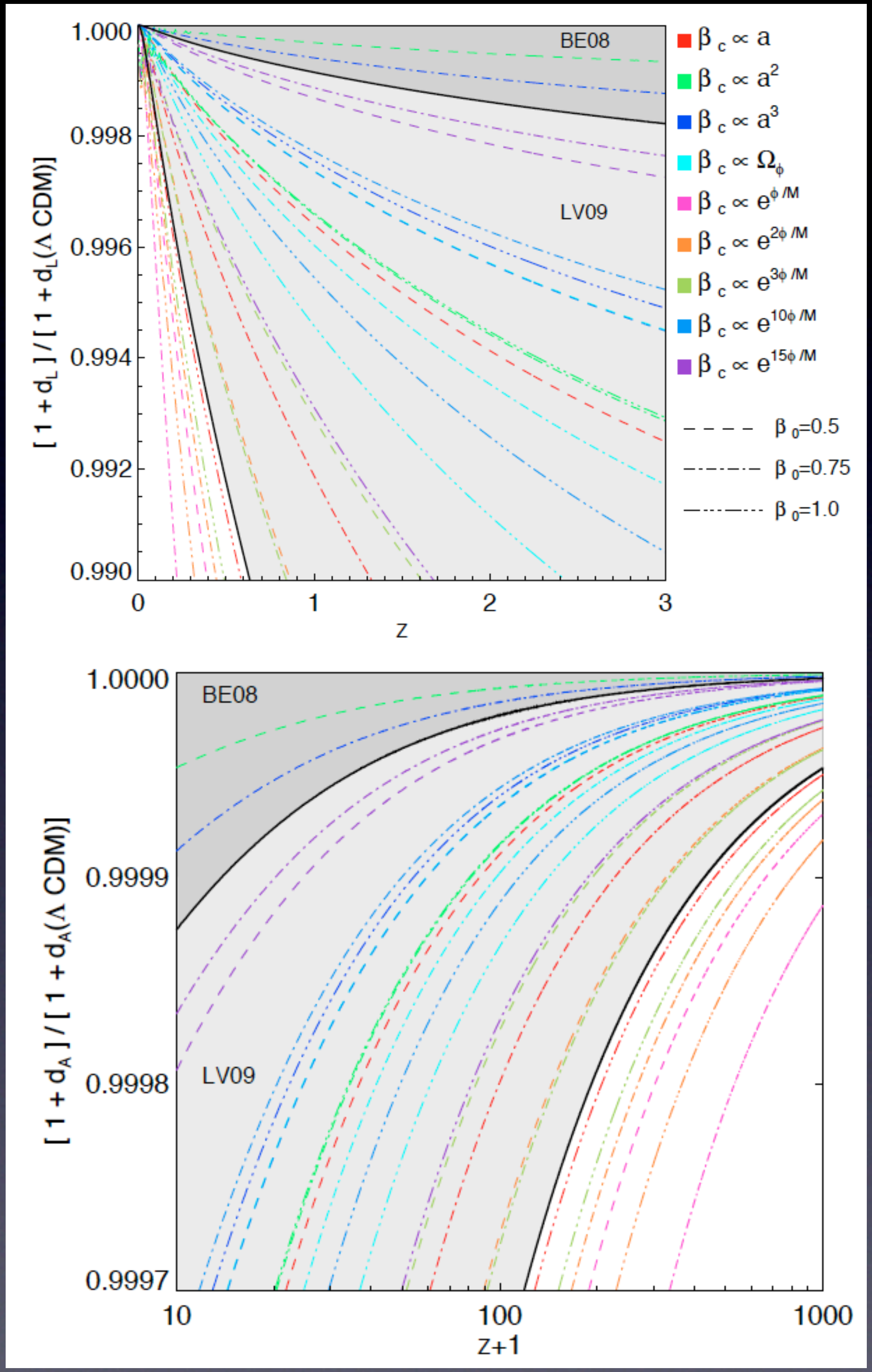

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FEATURES OF INTERACTING DARK ENERGY

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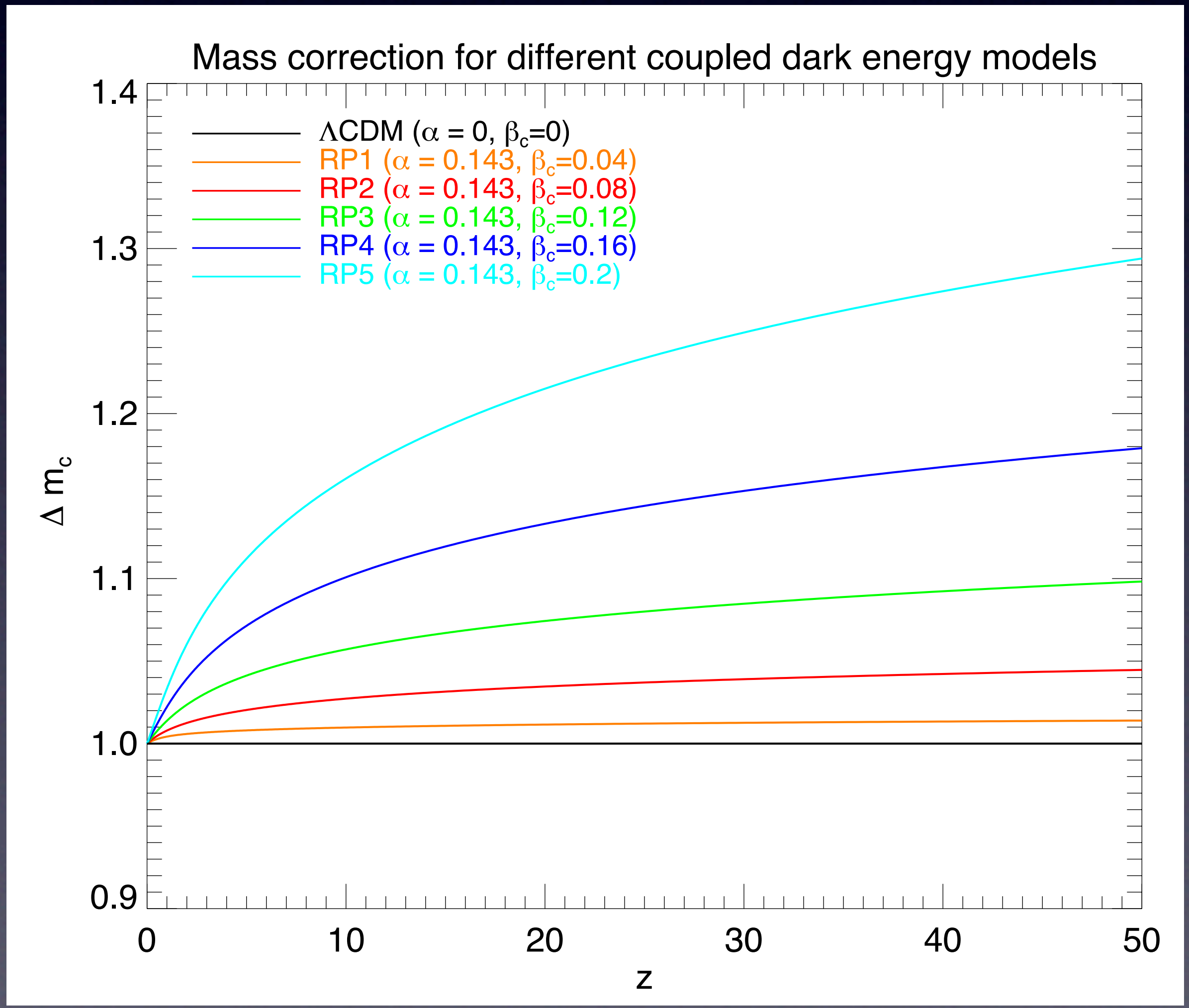

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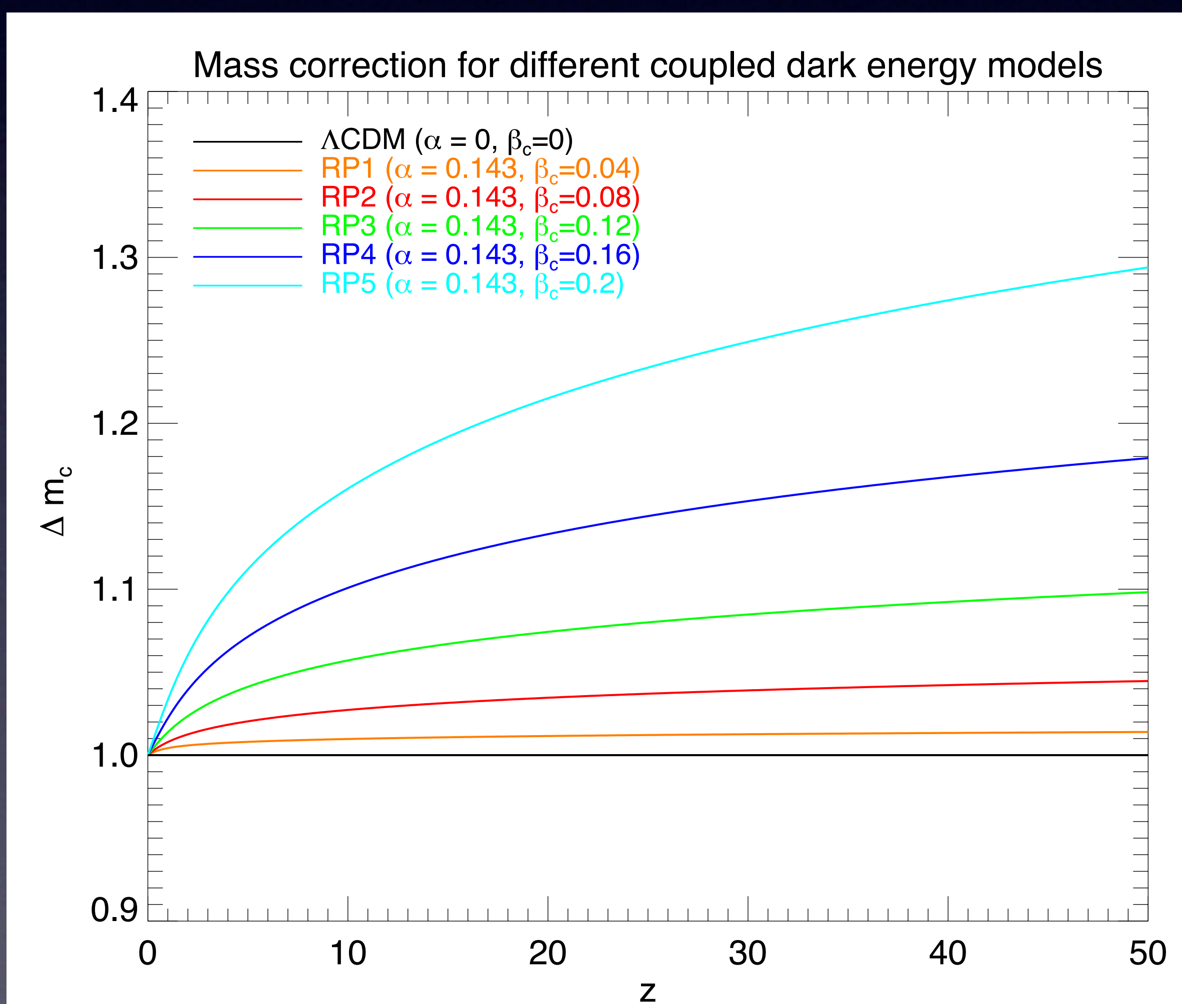
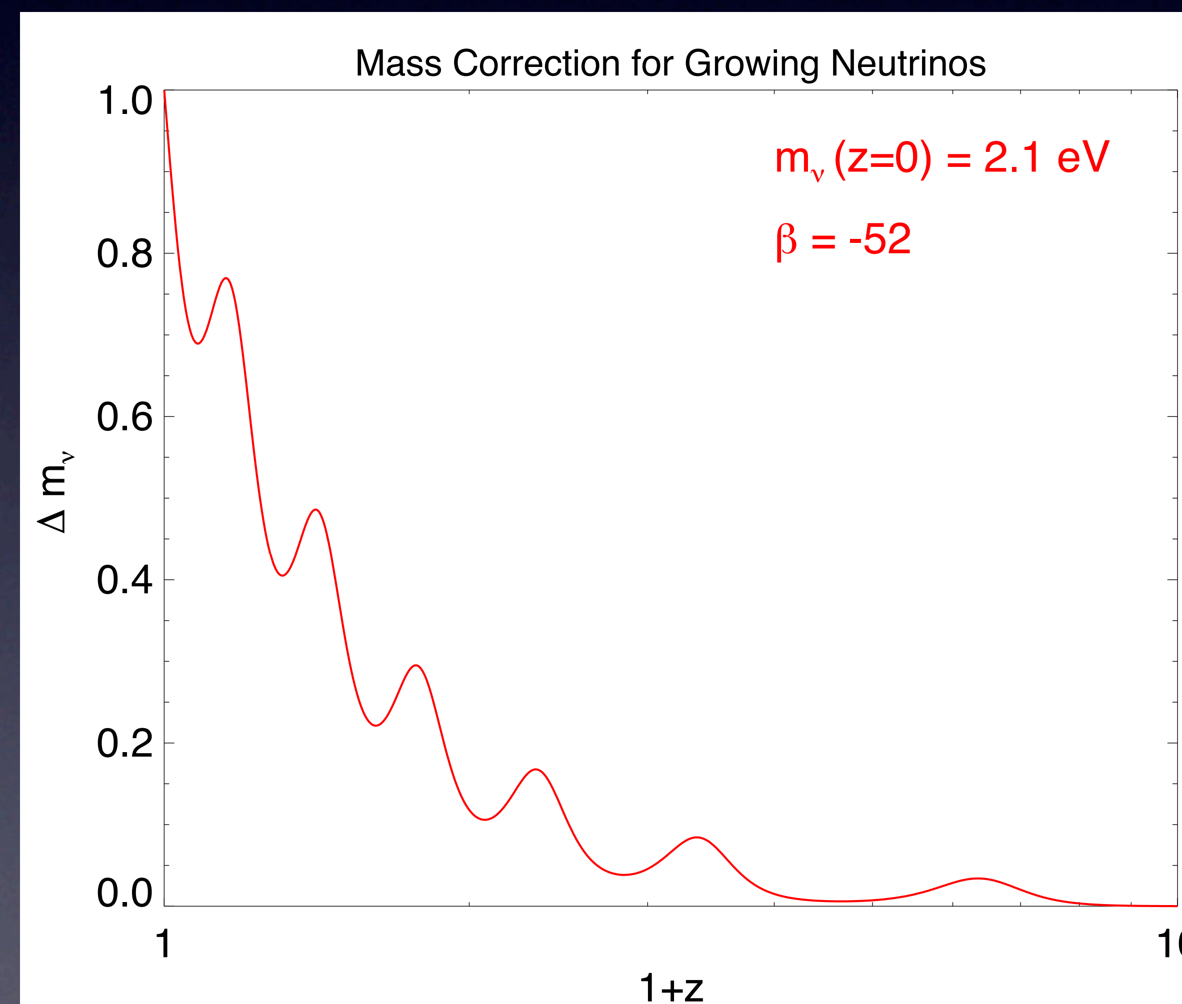


Negative coupling, growing mass
(Growing Neutrinos)



Features of interacting dark energy

3) Modified force law

of coupled matter particles

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

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There are several ways to constrain the magnitude of the coupling based on its impact on the expansion history or on the growth of structures:

Bean et al. 2008 (CMB+BAO+SnIa+LSS) $|\beta| \lesssim 0.07$

La Vacca et al. 2009 (CMB with massive neutrinos) $|\beta| \lesssim 0.17$

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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

What changes with a time dependent coupling?

TIME DEPENDENT COUPLINGS [MB 2010 (1005.2188)]

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Assume some generic forms of coupling evolution and find numerical solutions:

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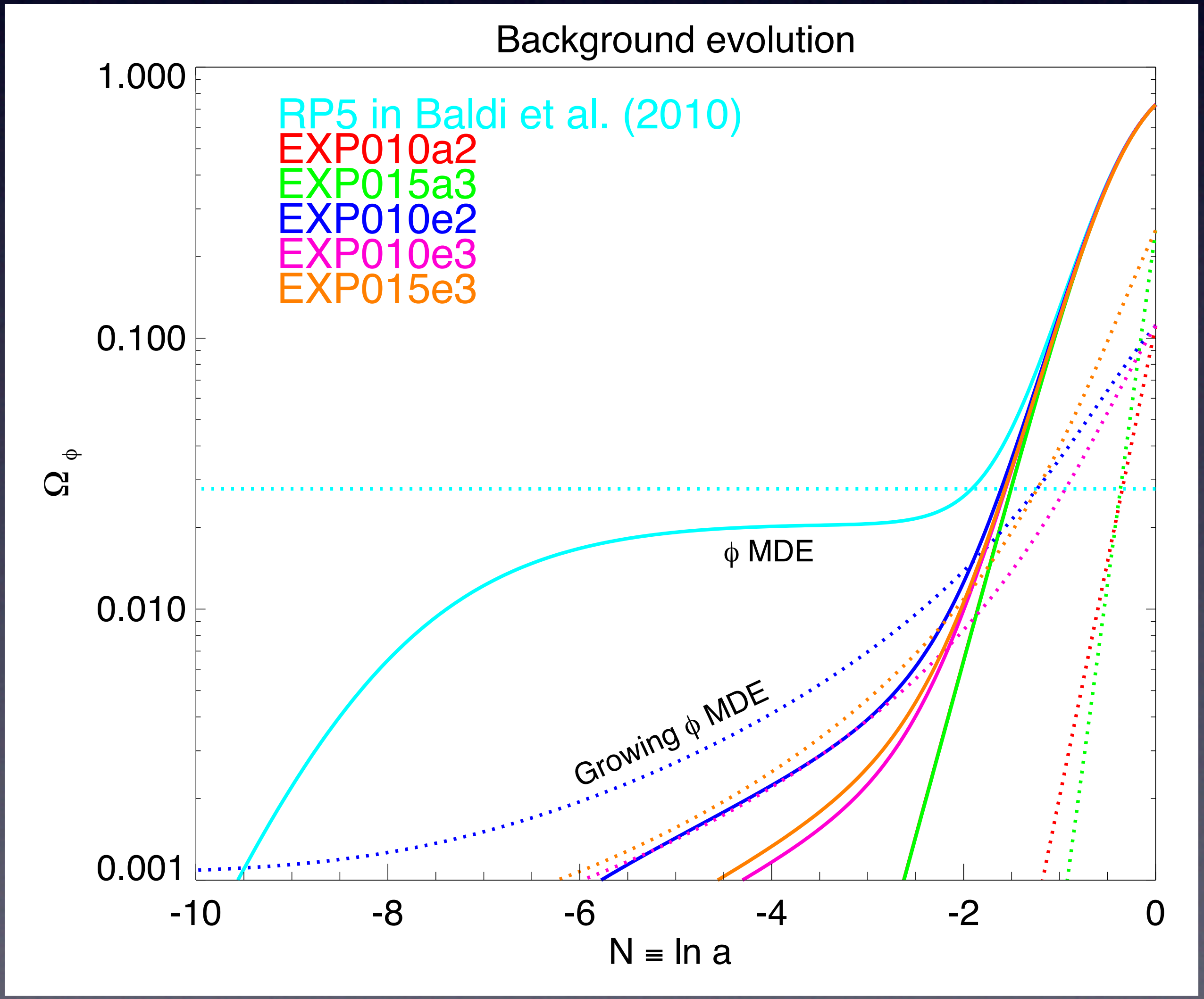

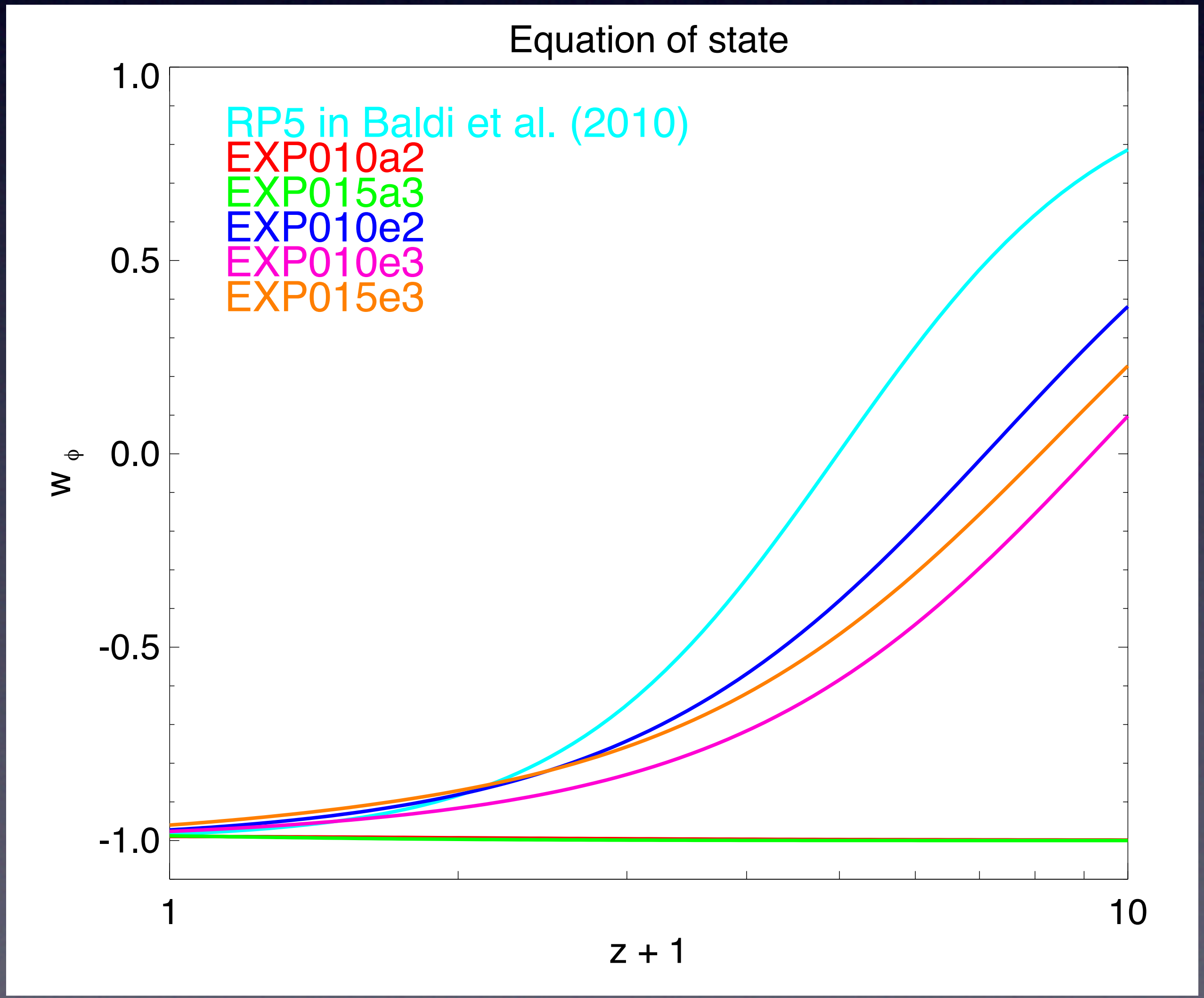

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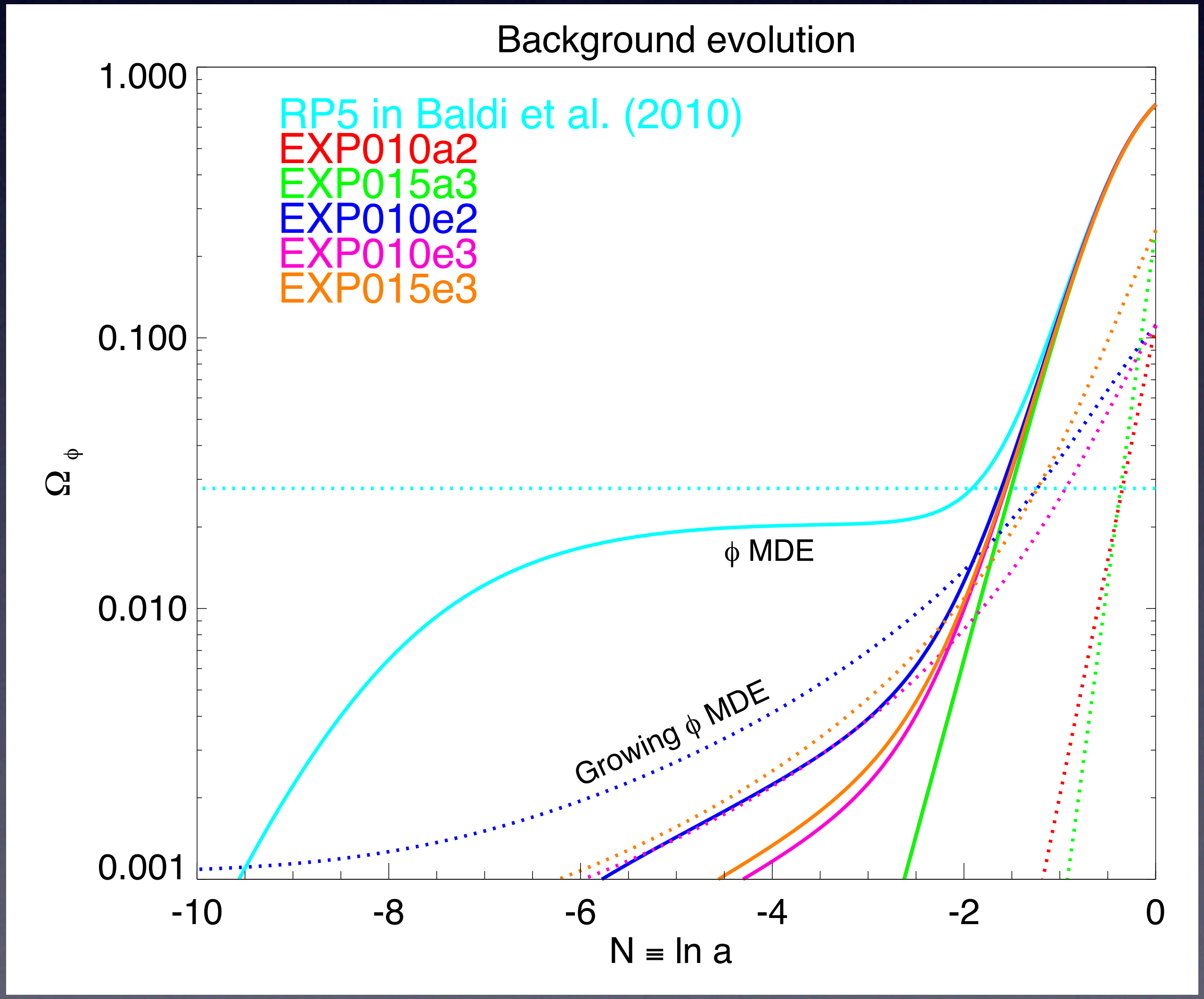

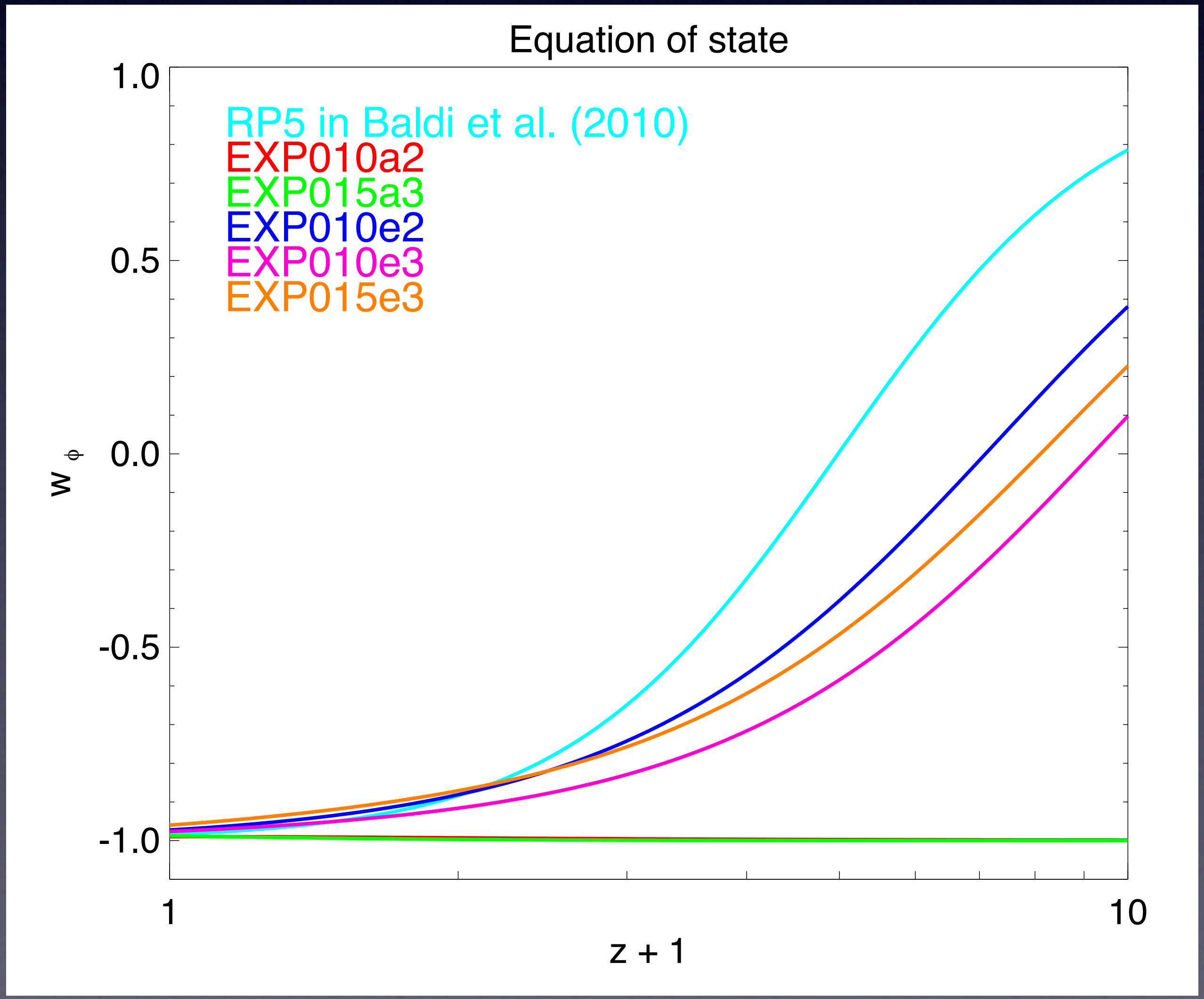

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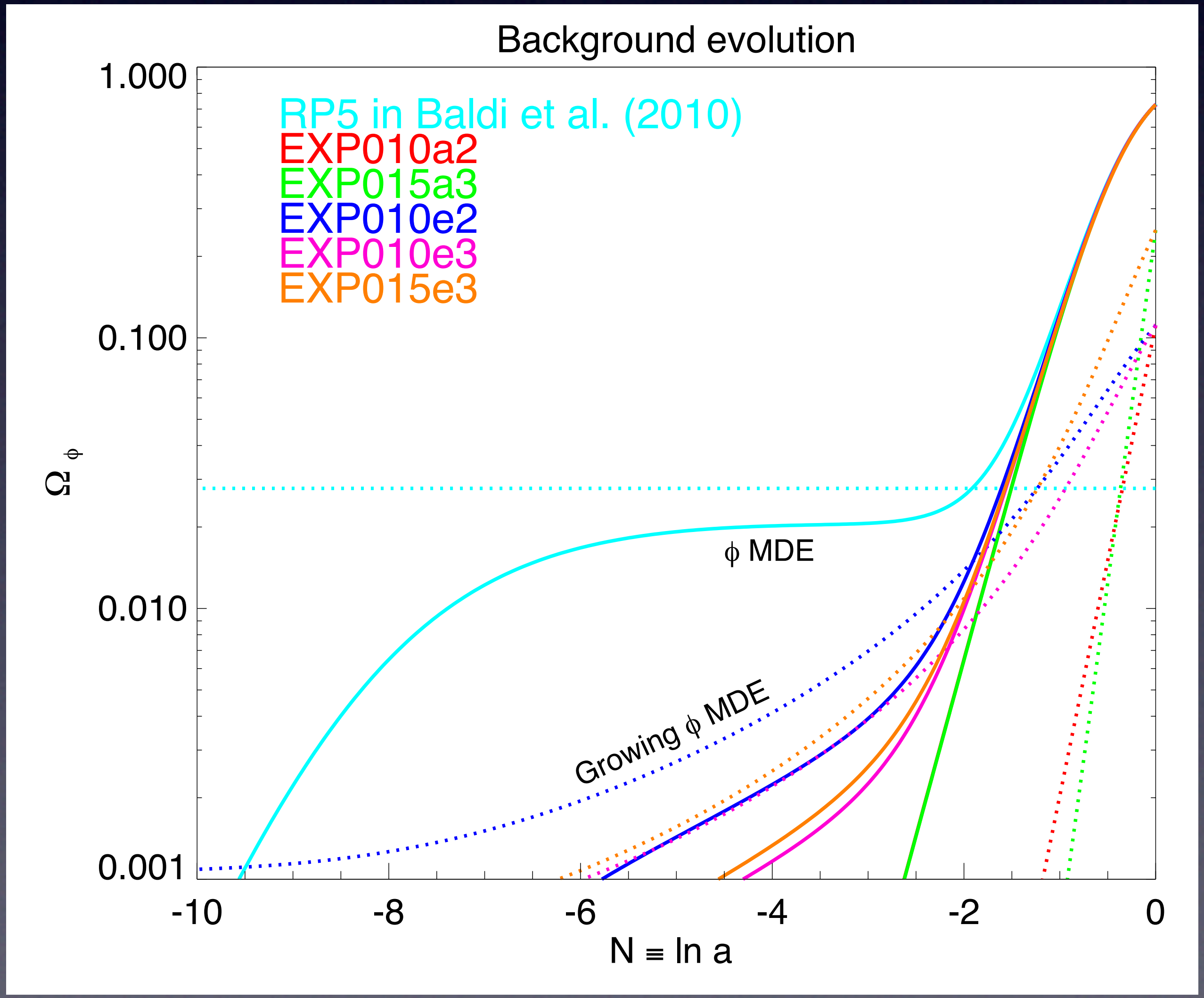

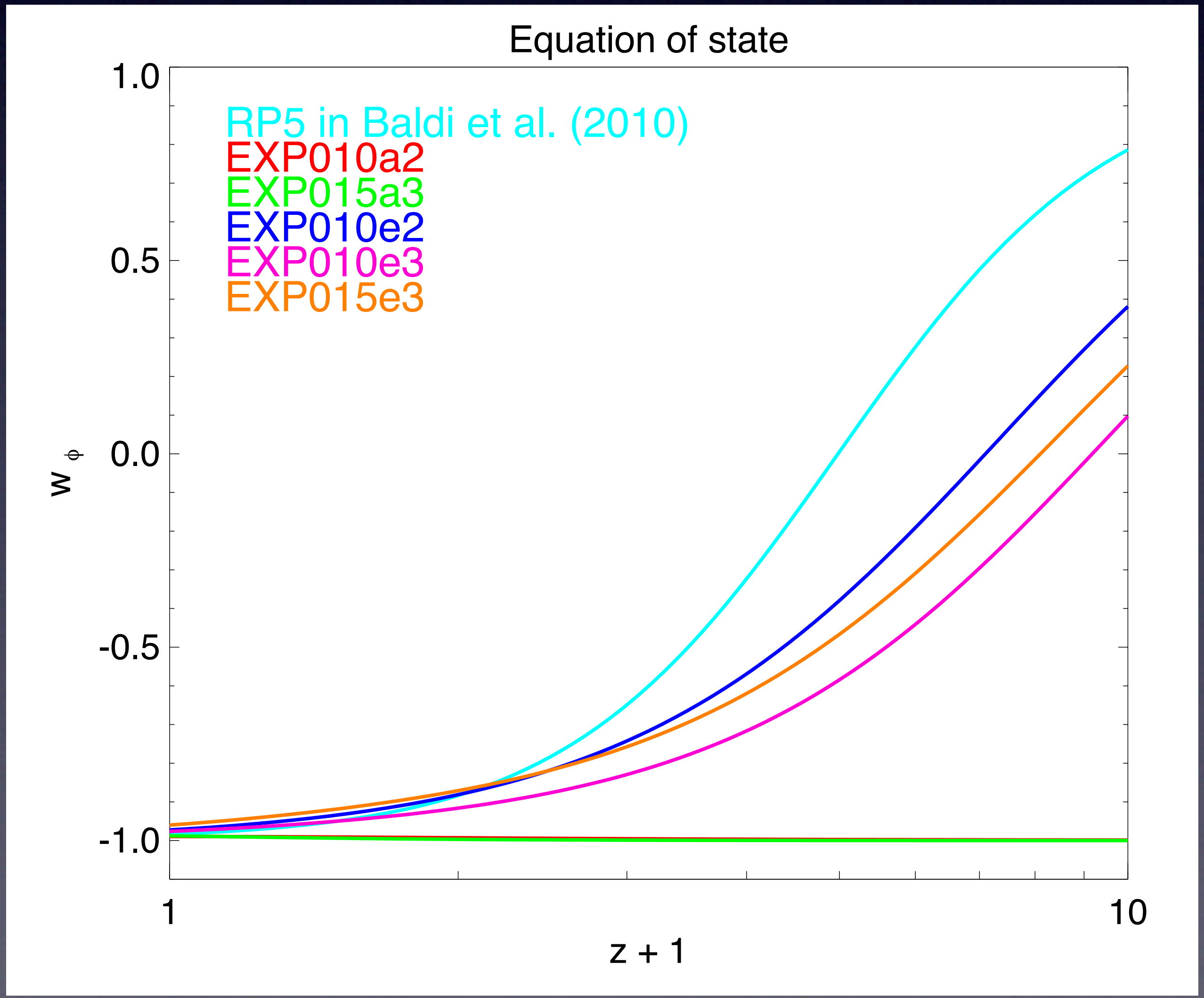

Time dependent effects on sructure formation

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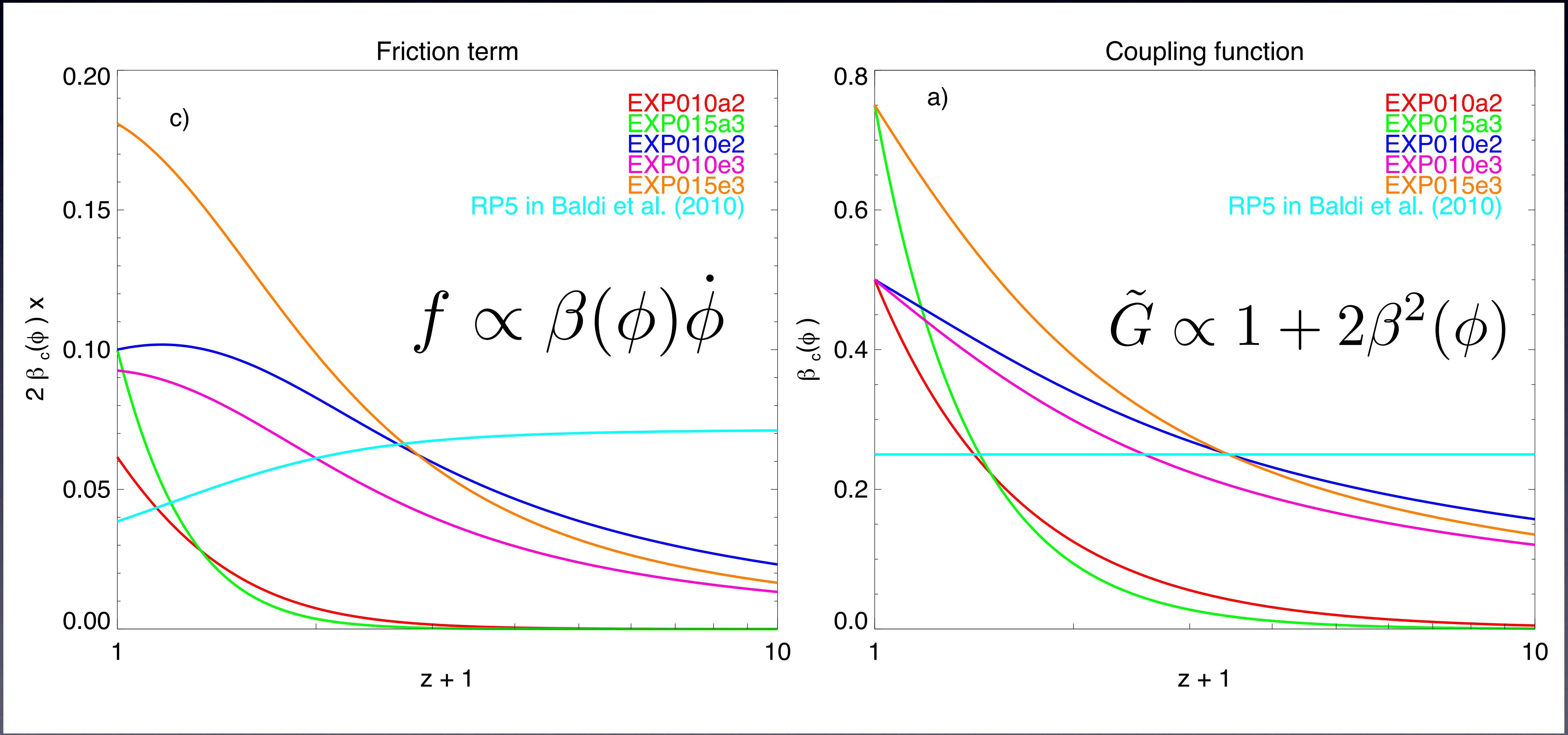

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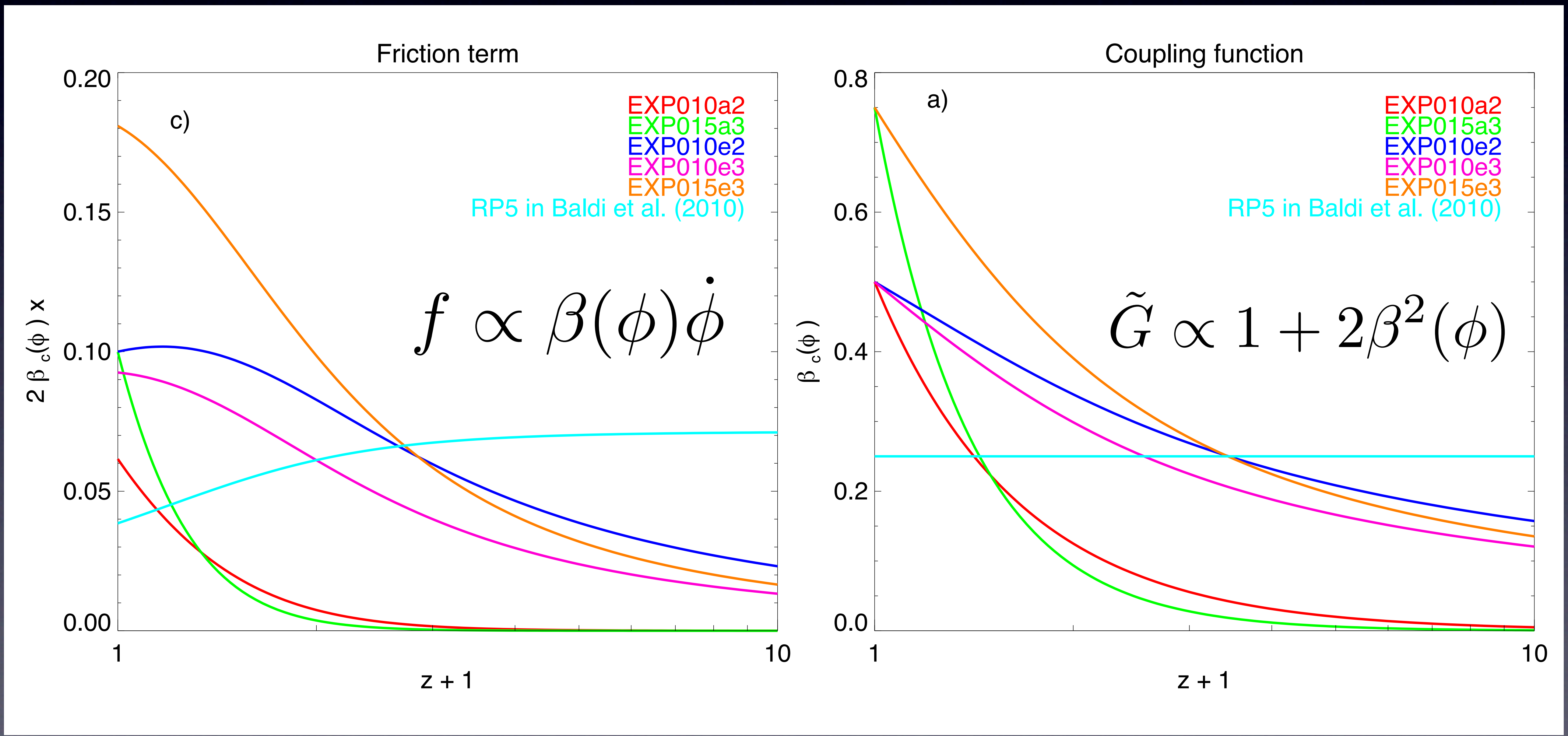

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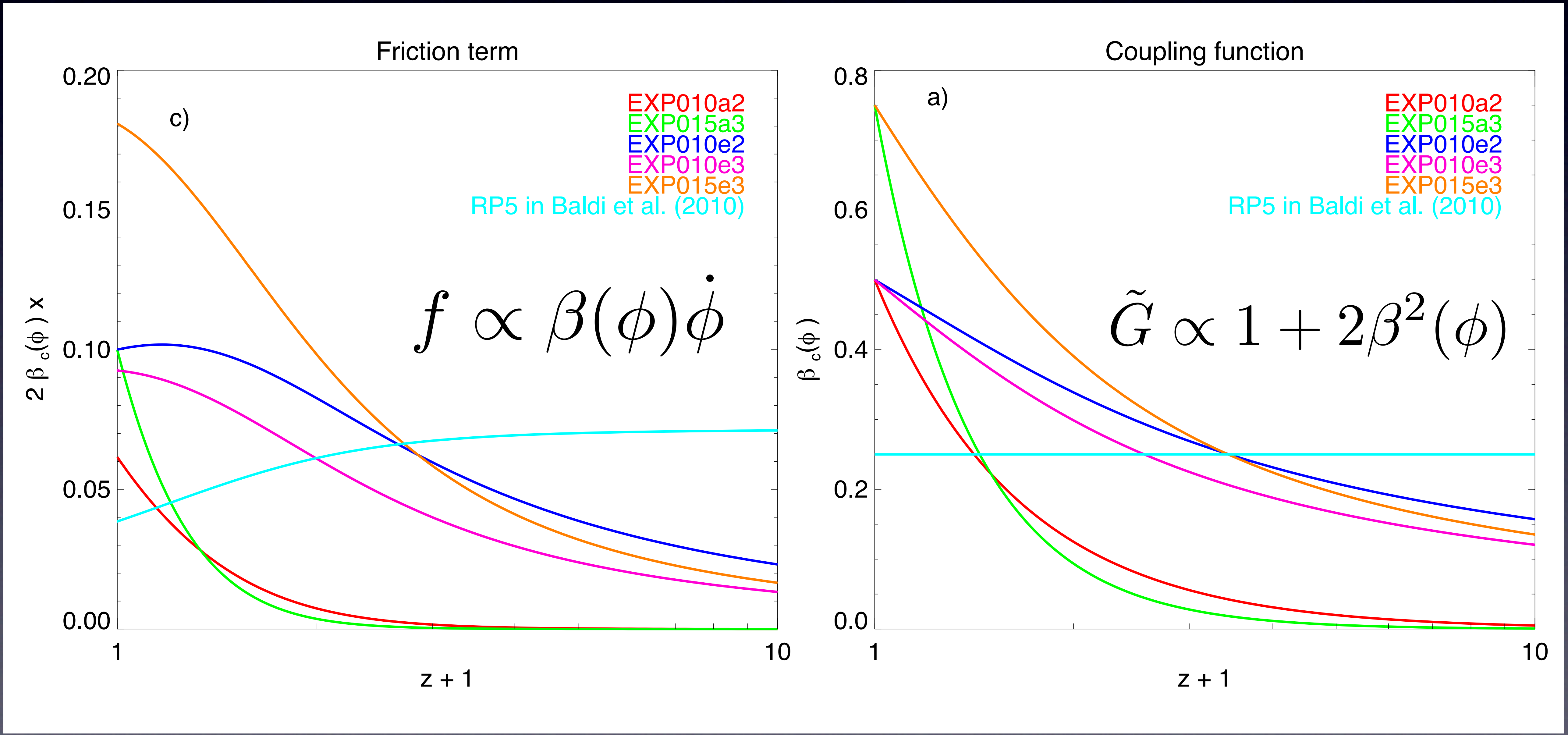
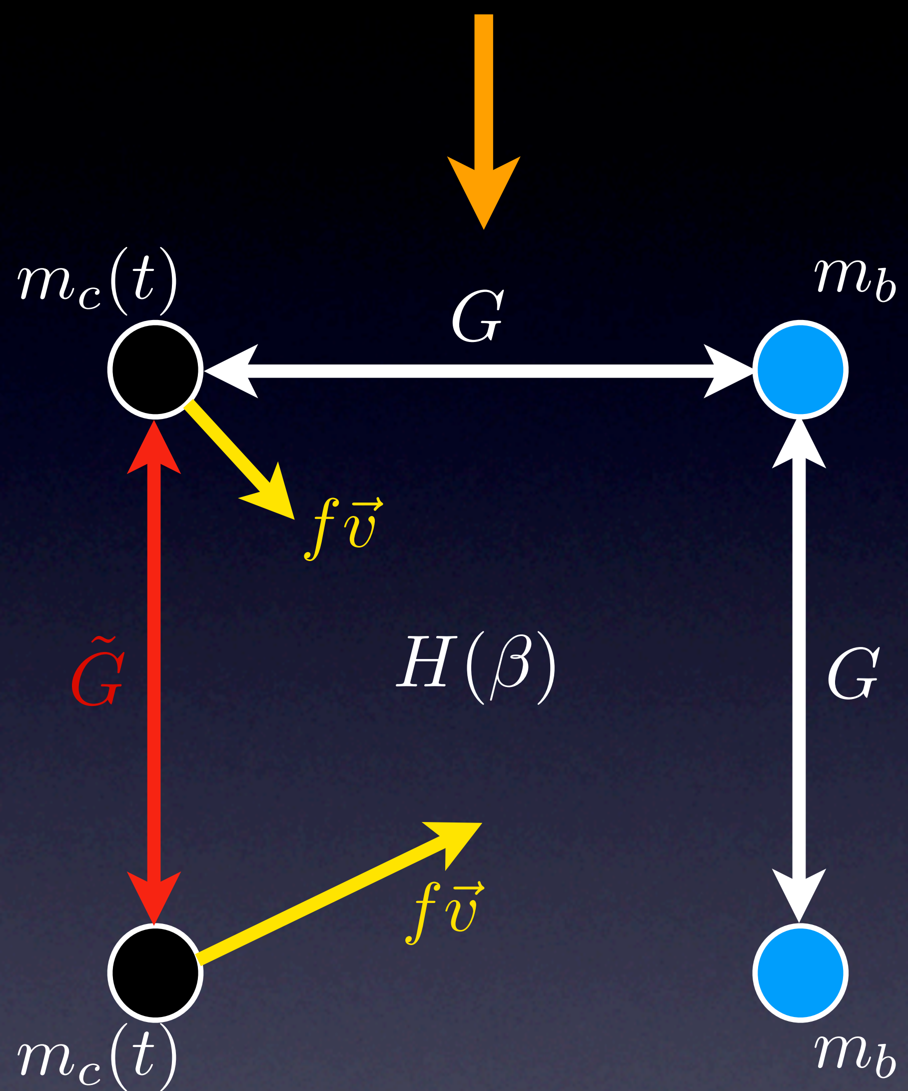
Effectively growing gravitational constant



GADGET-3

N-body implementation

GADGET-3



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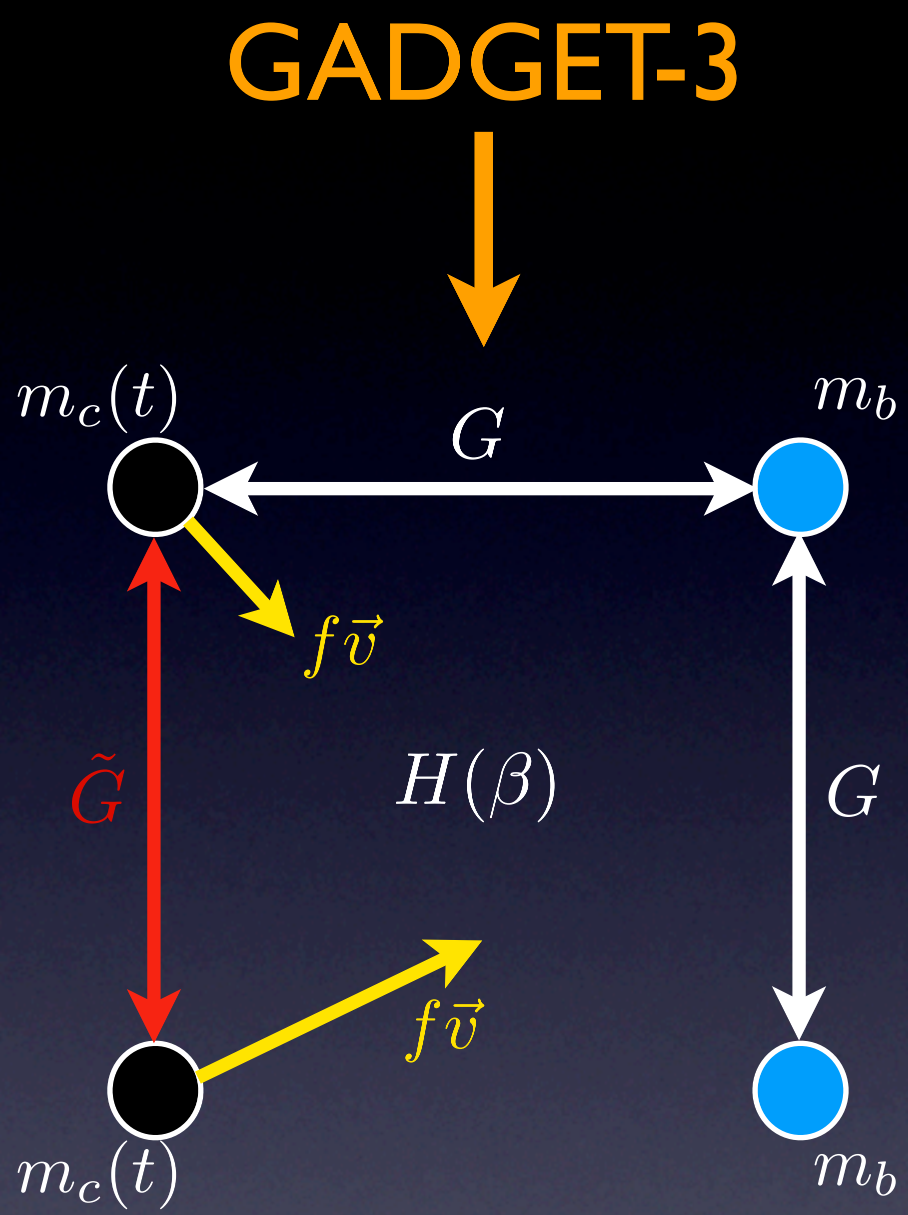

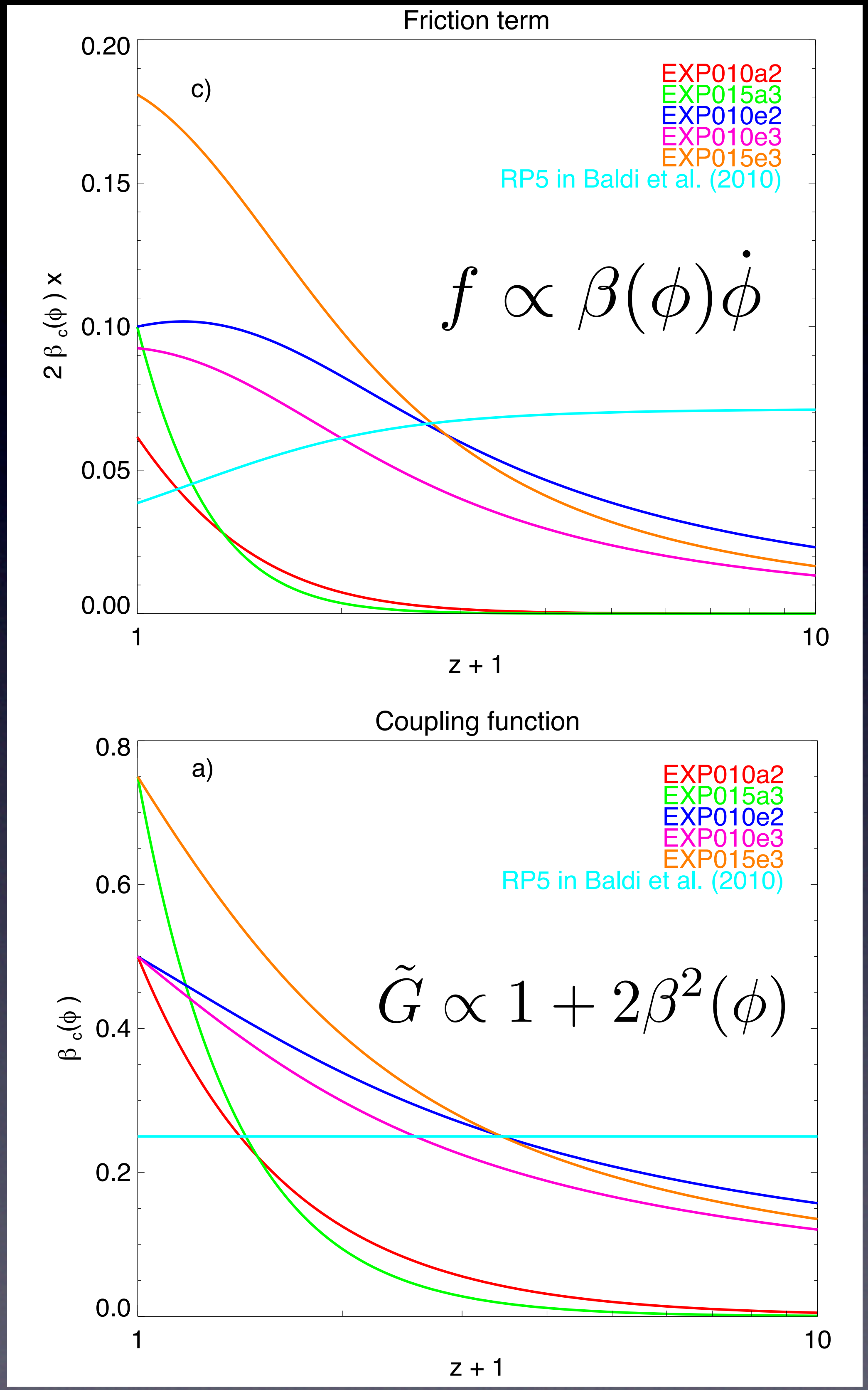

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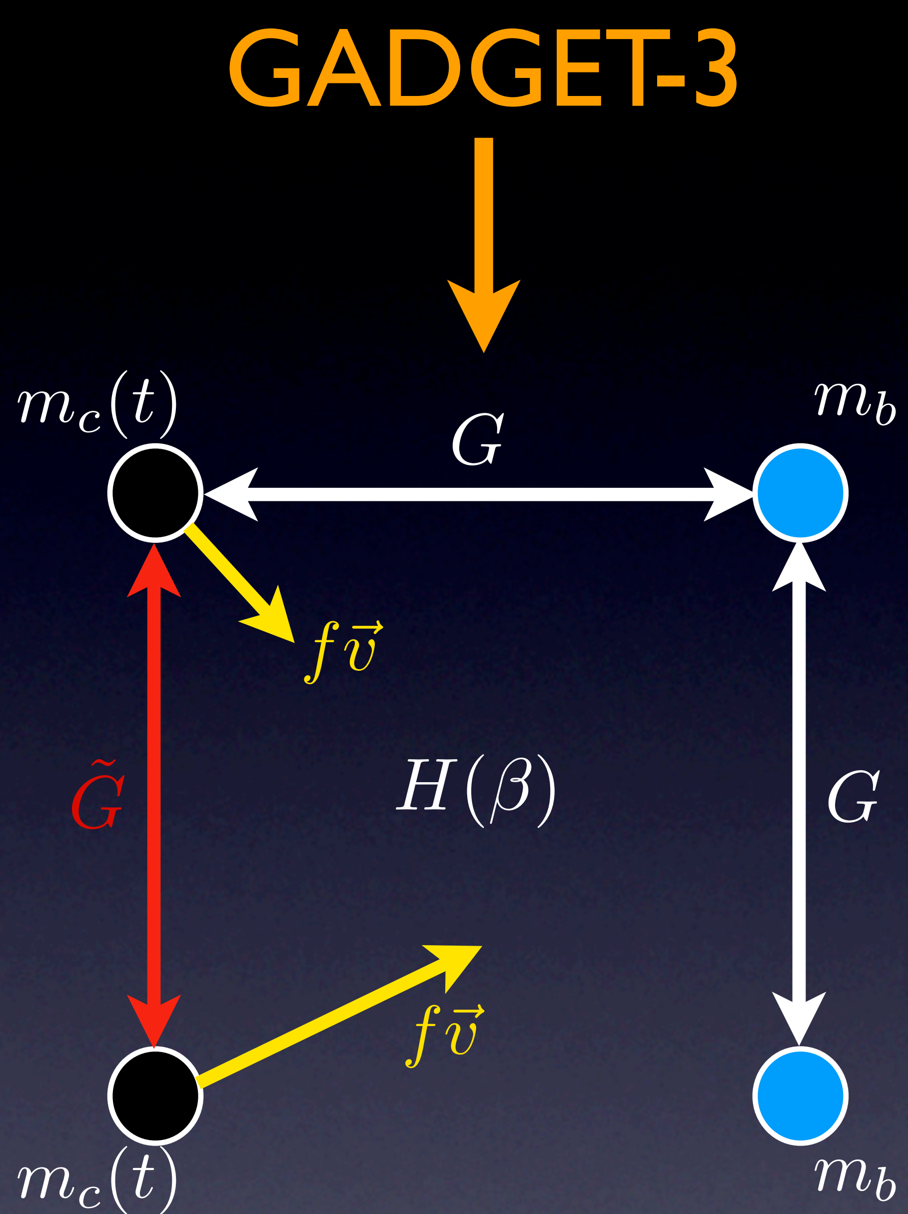

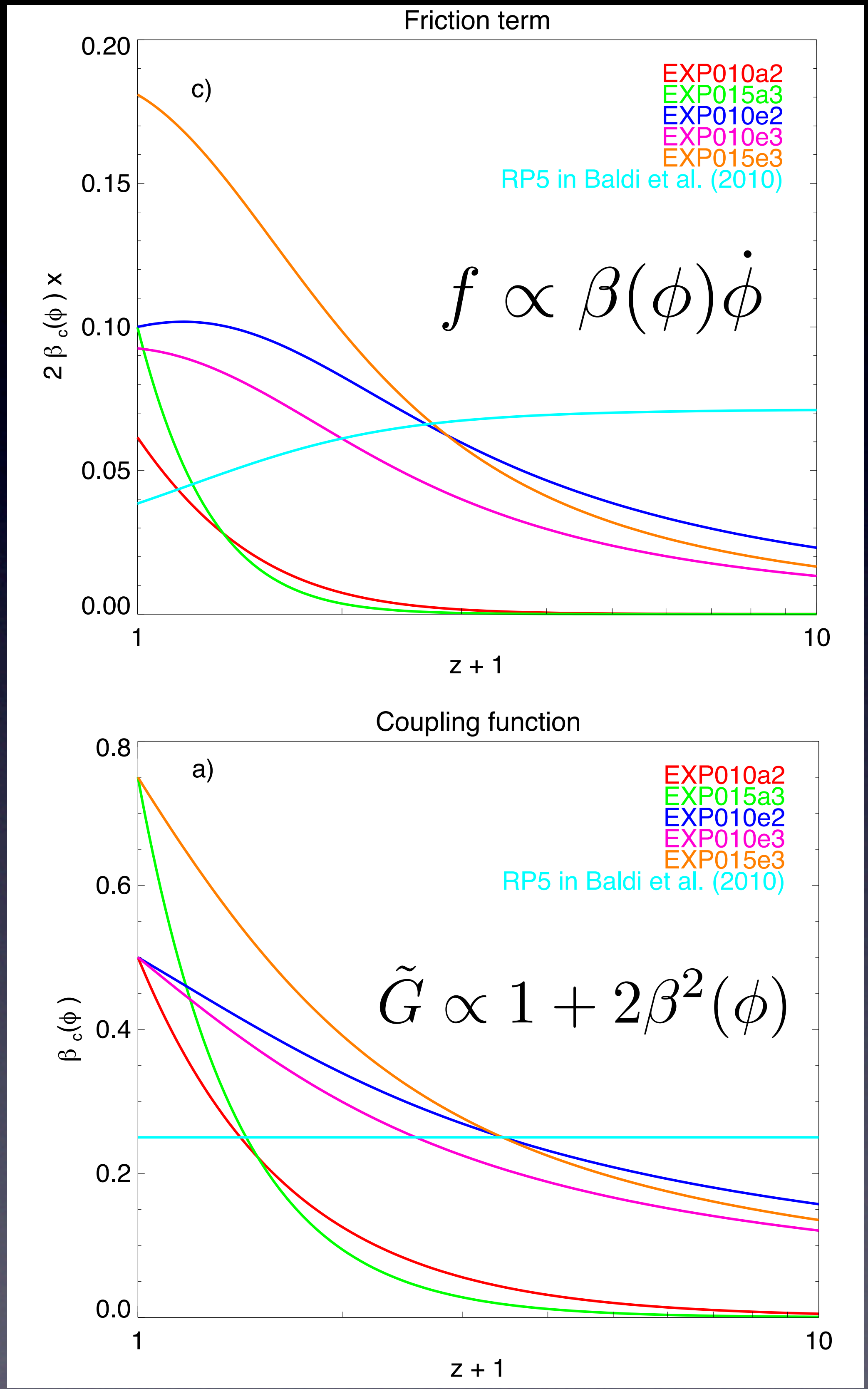

Advantages of the linear approximation algorithm:

- No need to solve for the spatial SF distribution
- Same Poisson solver as for standard gravity
- Moderate increase of computational time (~2x)

Results:
The effects on Structure Formation

Weak coupling regime: Coupled Quintessence

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$$m_{\rm CDM}(z=0) < m_{\rm CDM}(z>0)$$

Results (I): halo mass function and cluster counts

Number counts in coupled dark energy models: CONSTANT and VARIABLE couplings [MB & V. Pettorino 2010]

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[Jimenez&Verde (2009);
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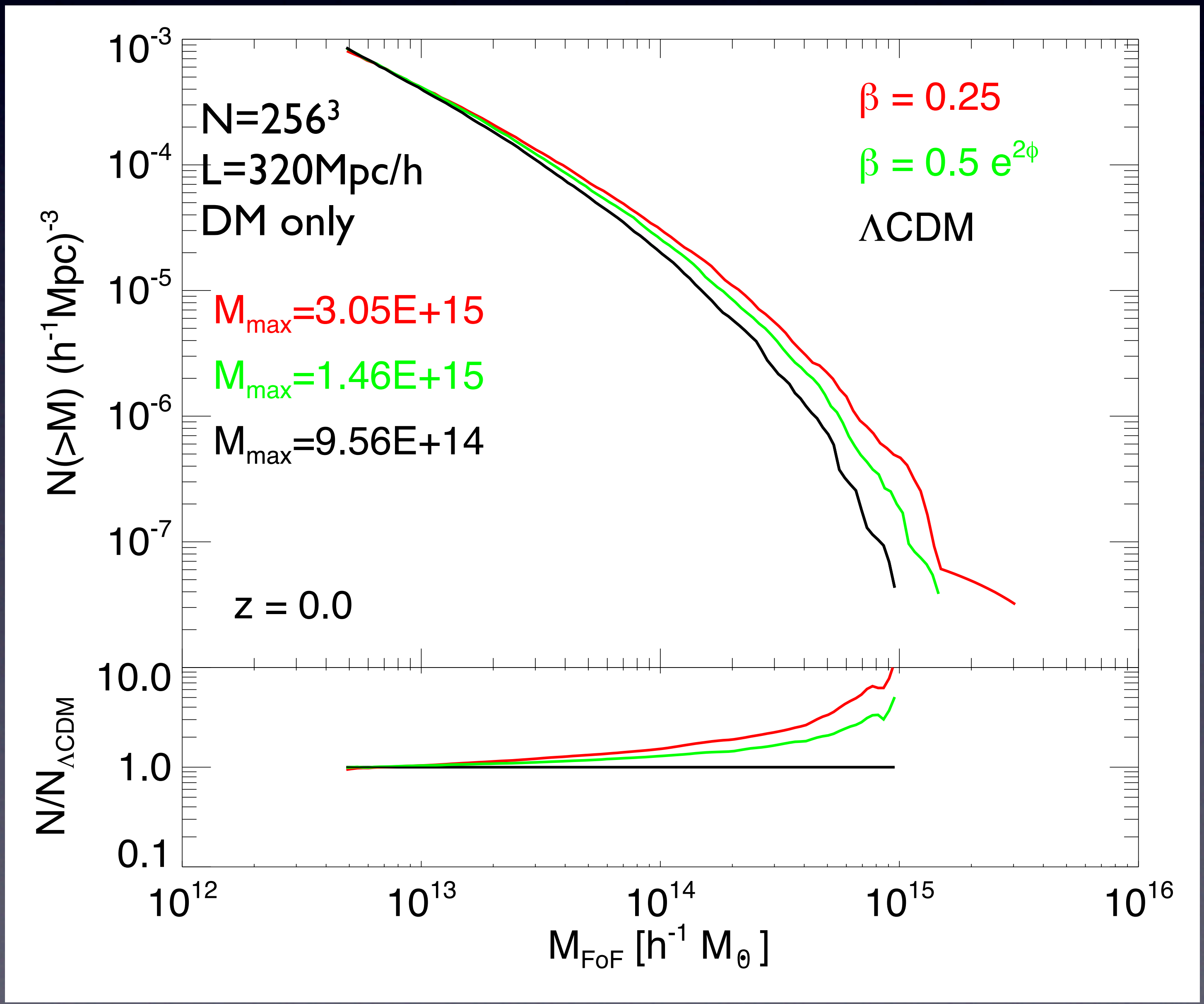

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INTERACTING DE:
The extra force acting between CDM particles and the extra friction term determine a faster growth of density perturbations.

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 CONSTANT interaction: [MB et al., MNRAS 2010]

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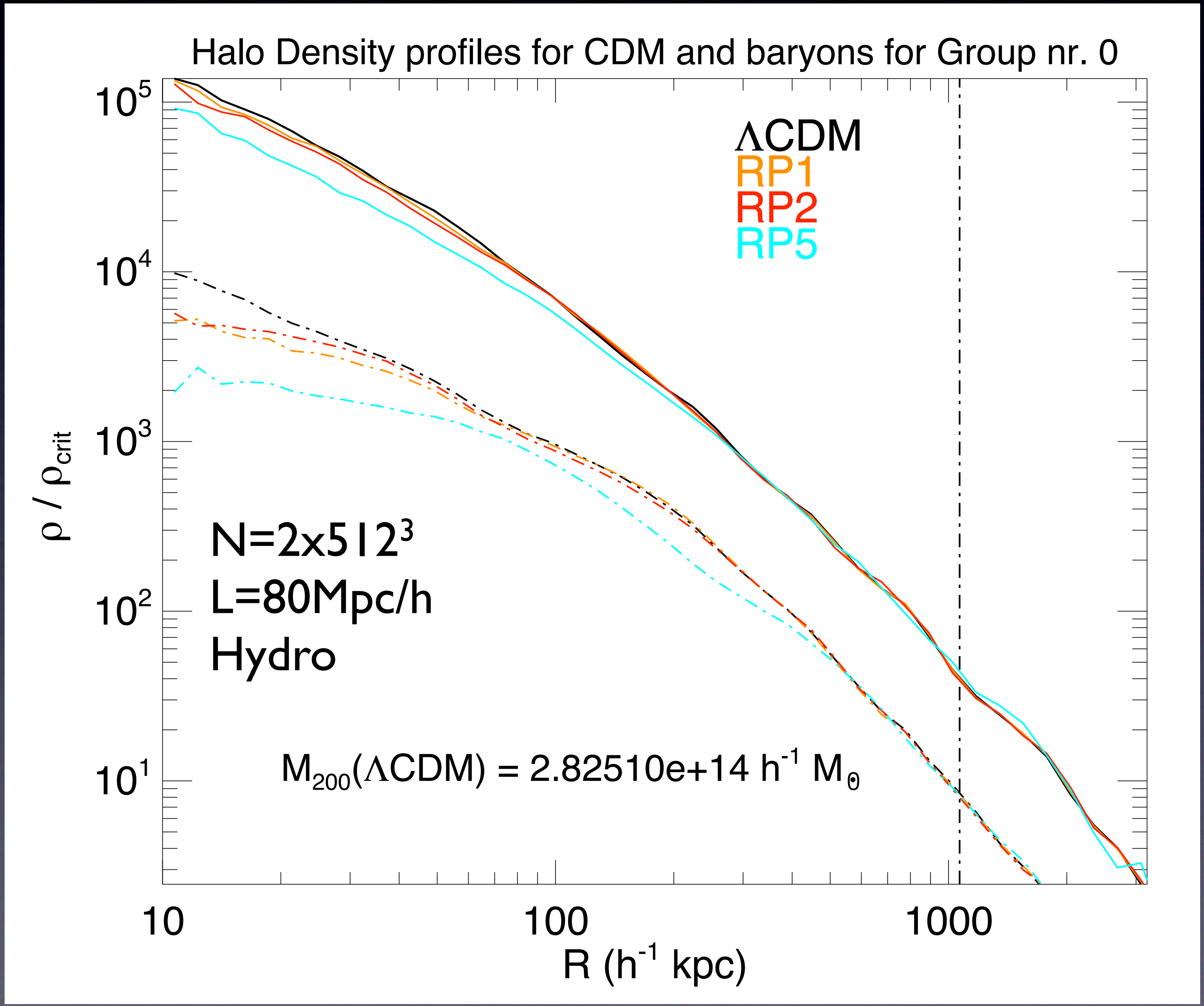
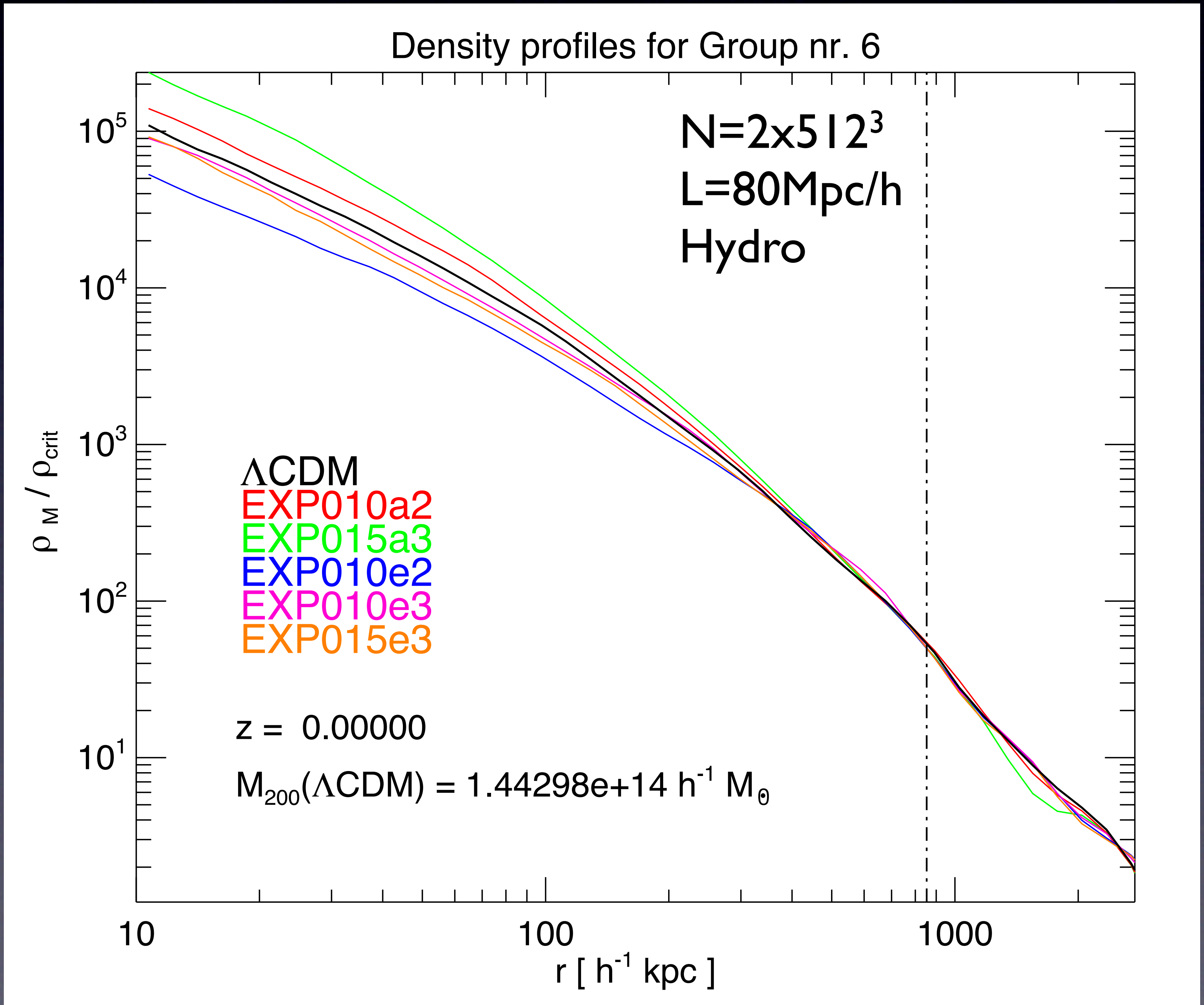


DENSITY PROFILES

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. Might provide a way out of the "cusp-core" problem

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.

Results (III): baryon fraction

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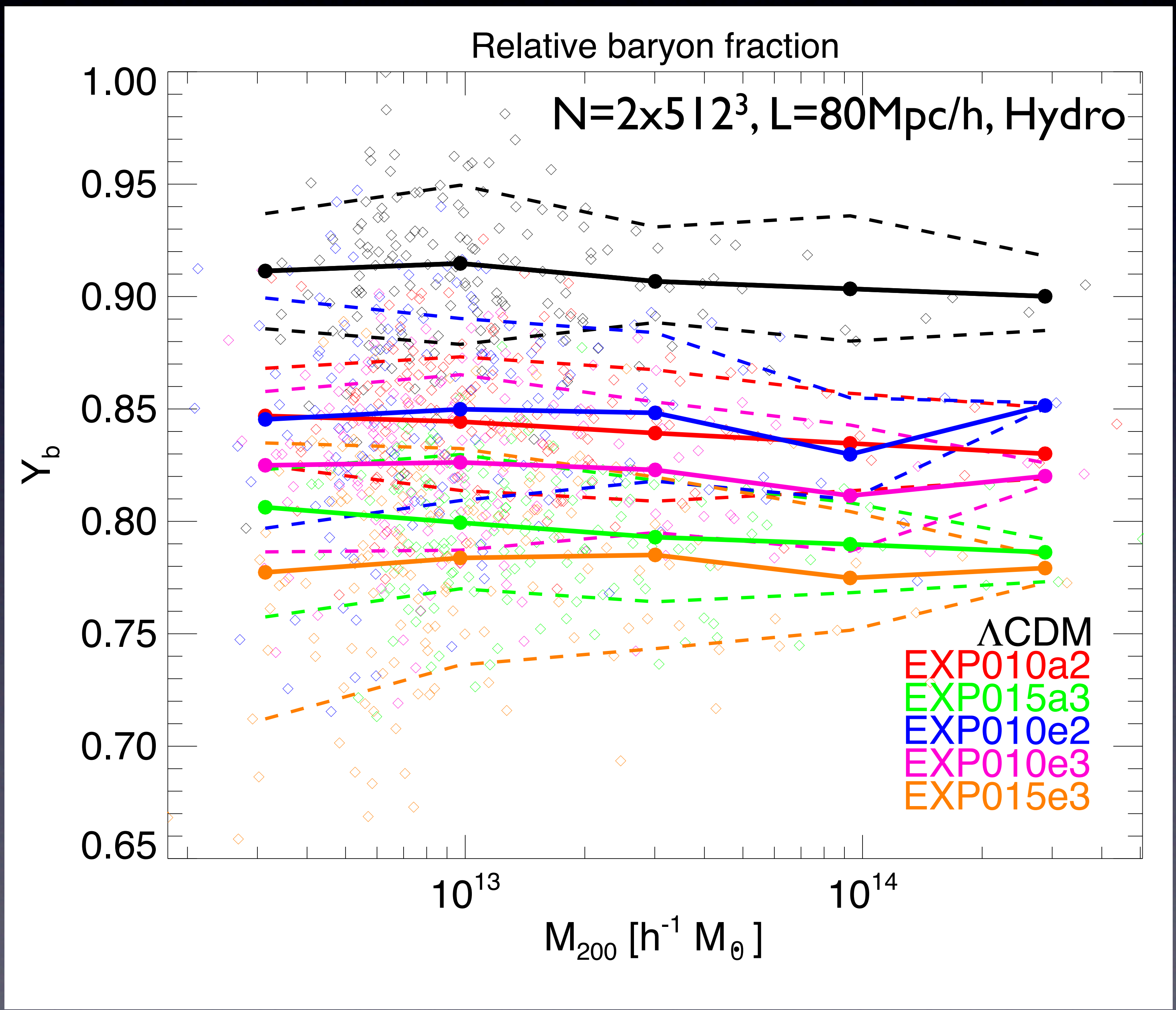

BARYON FRACTION

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.

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

Results (IV): subhalos misalignment

[MB, J. Lee, A. Maccio', ApJ 2011]

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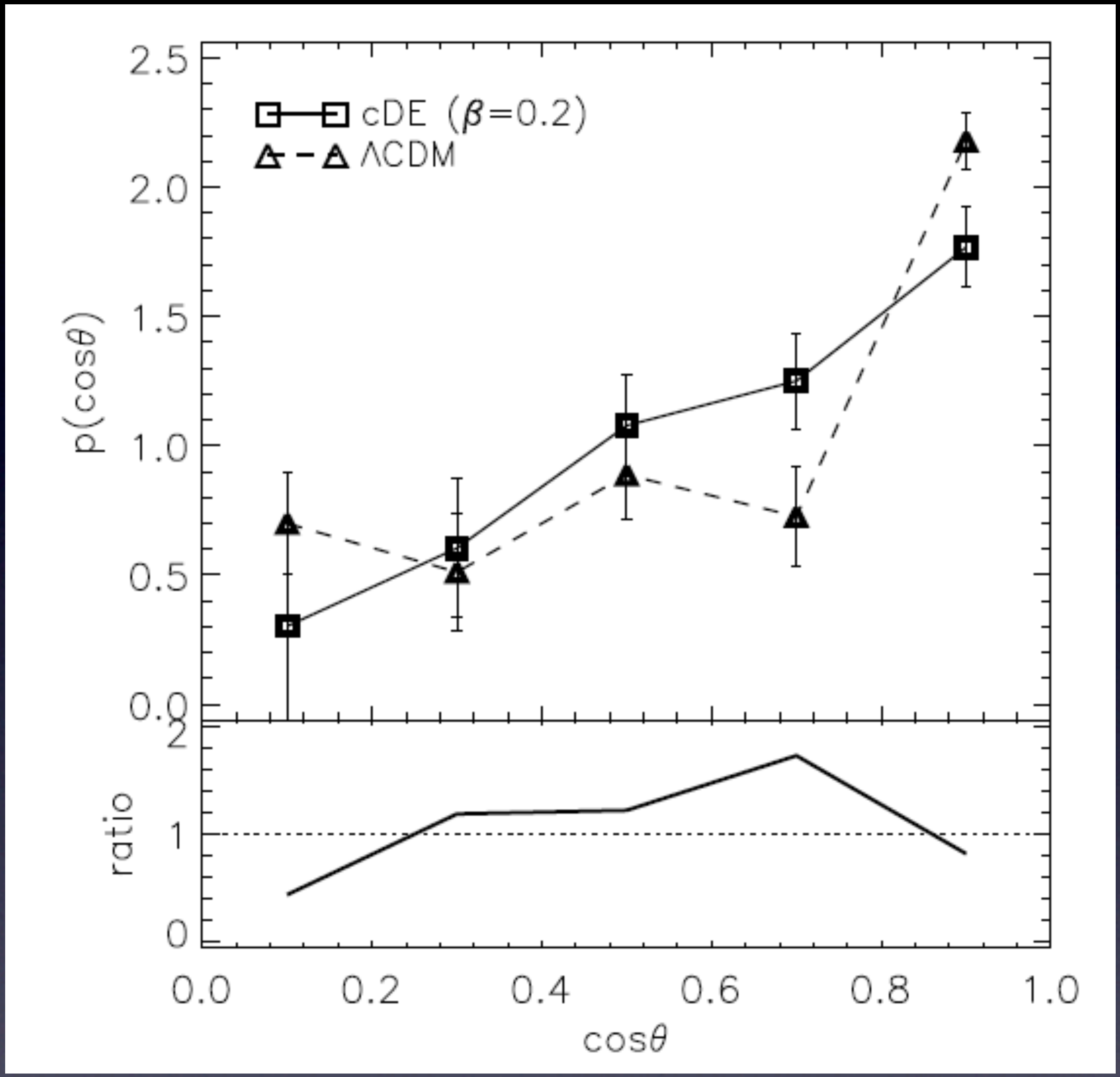

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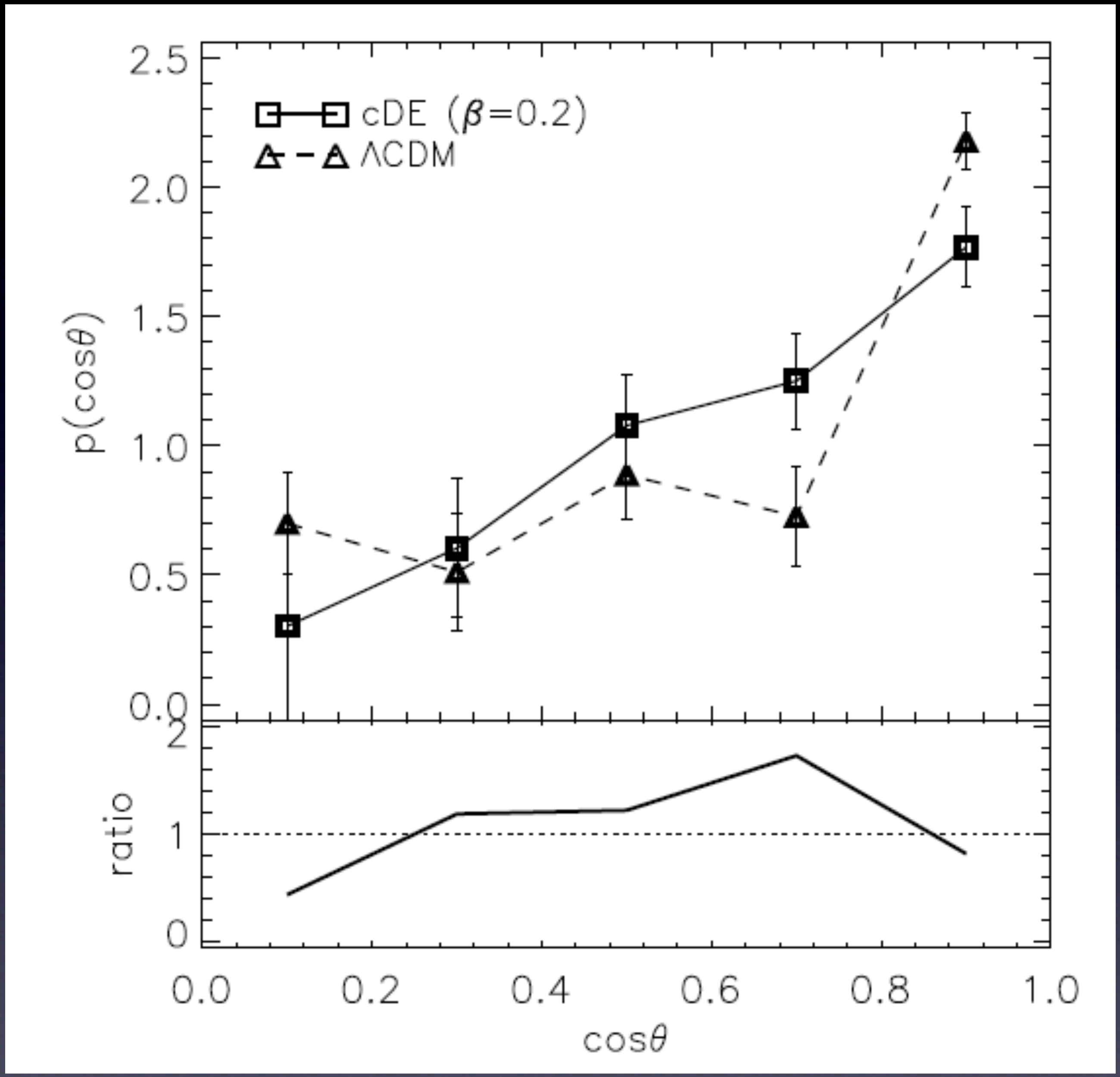

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Need more data to increase statistical significance

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Strong coupling regime: Growing Neutrinos

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$$m_\nu(z=0) \gg m_\nu(z>0)$$

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in pills...

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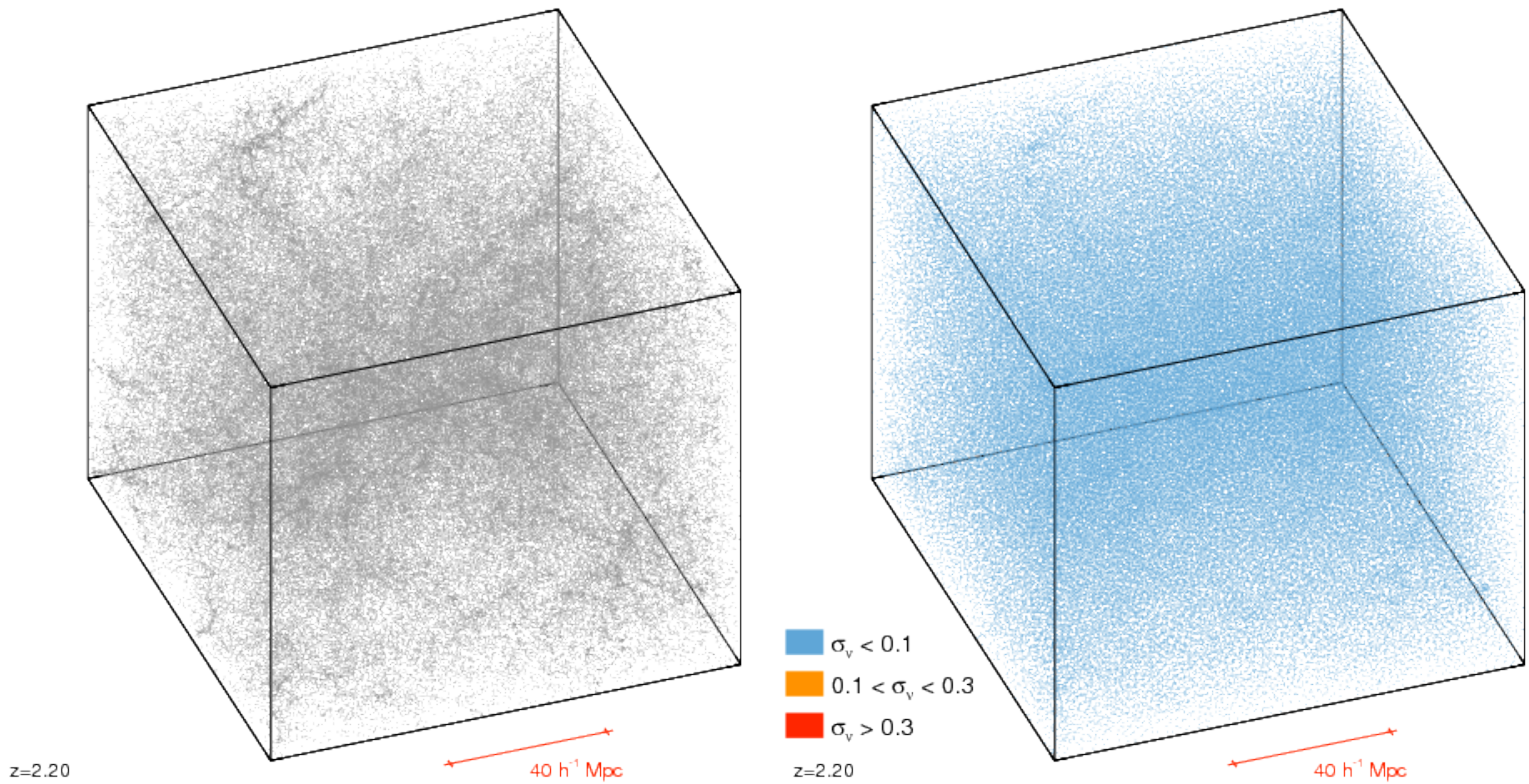
8) Neutrino structures quickly become nonlinear (as predicted by linear perturbations codes, see e.g. Mota et al 2008), need of N-body sims...

The first growing neutrino simulations



[MB, Pettorino, Wetterich, Amendola, in prep.]

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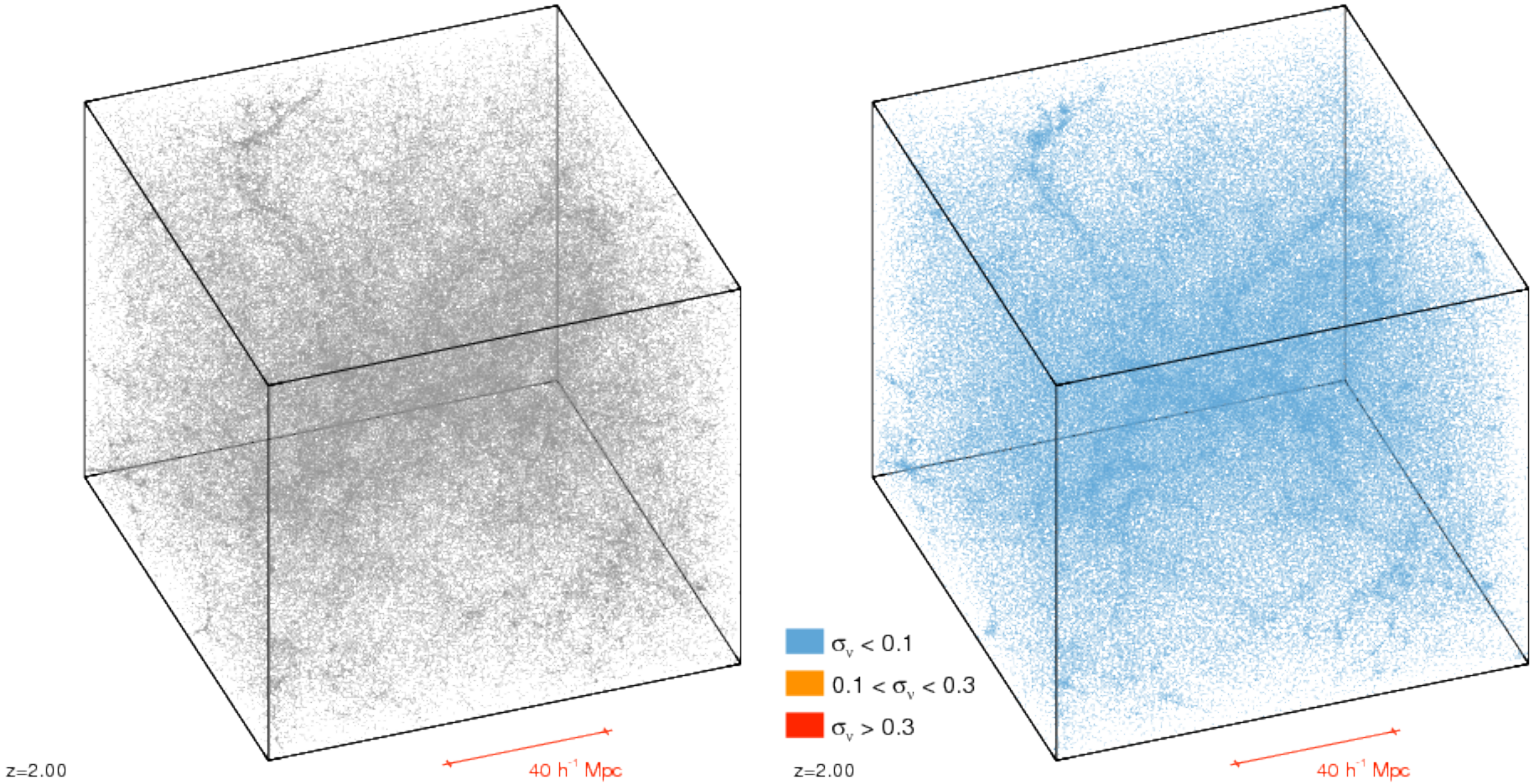

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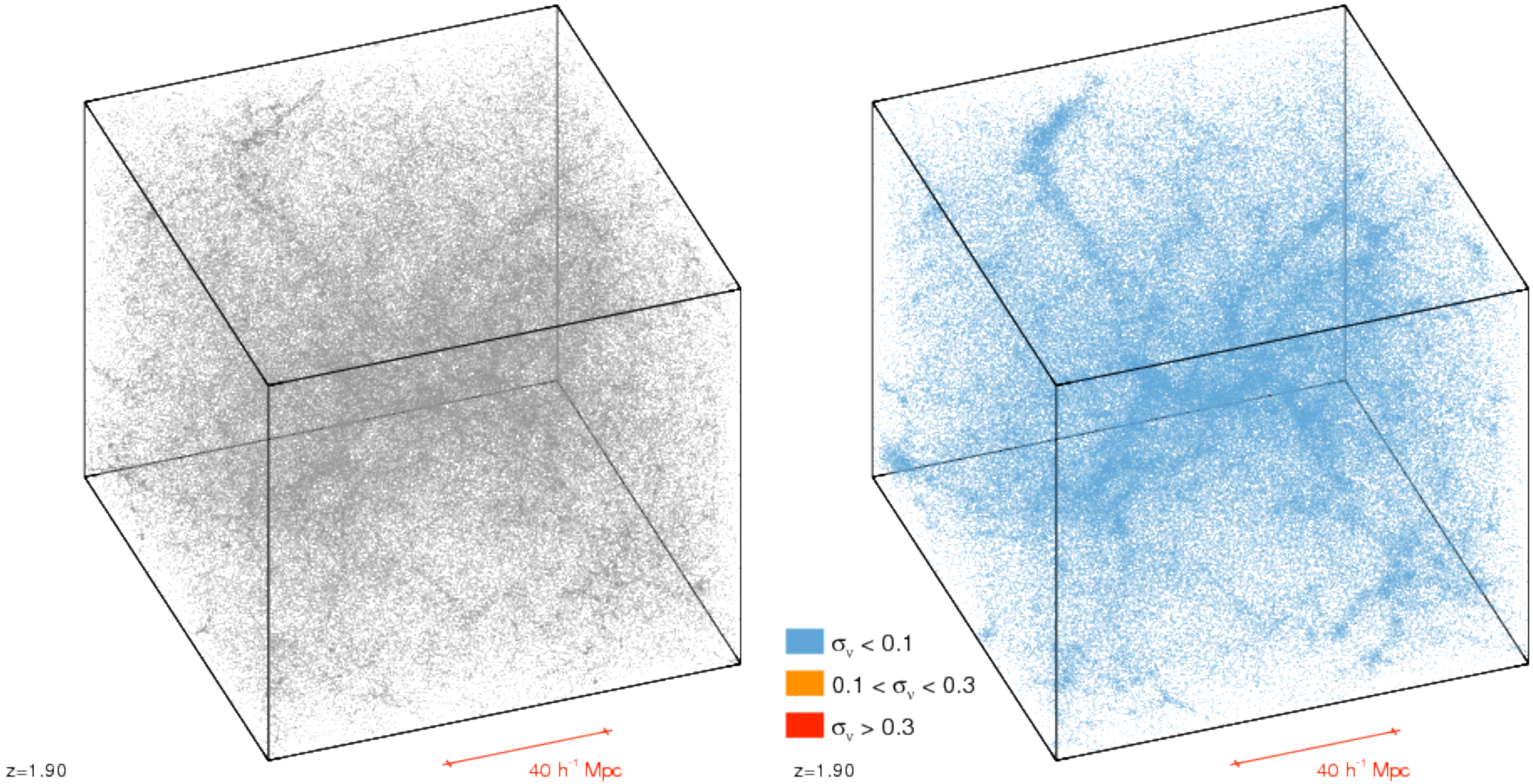

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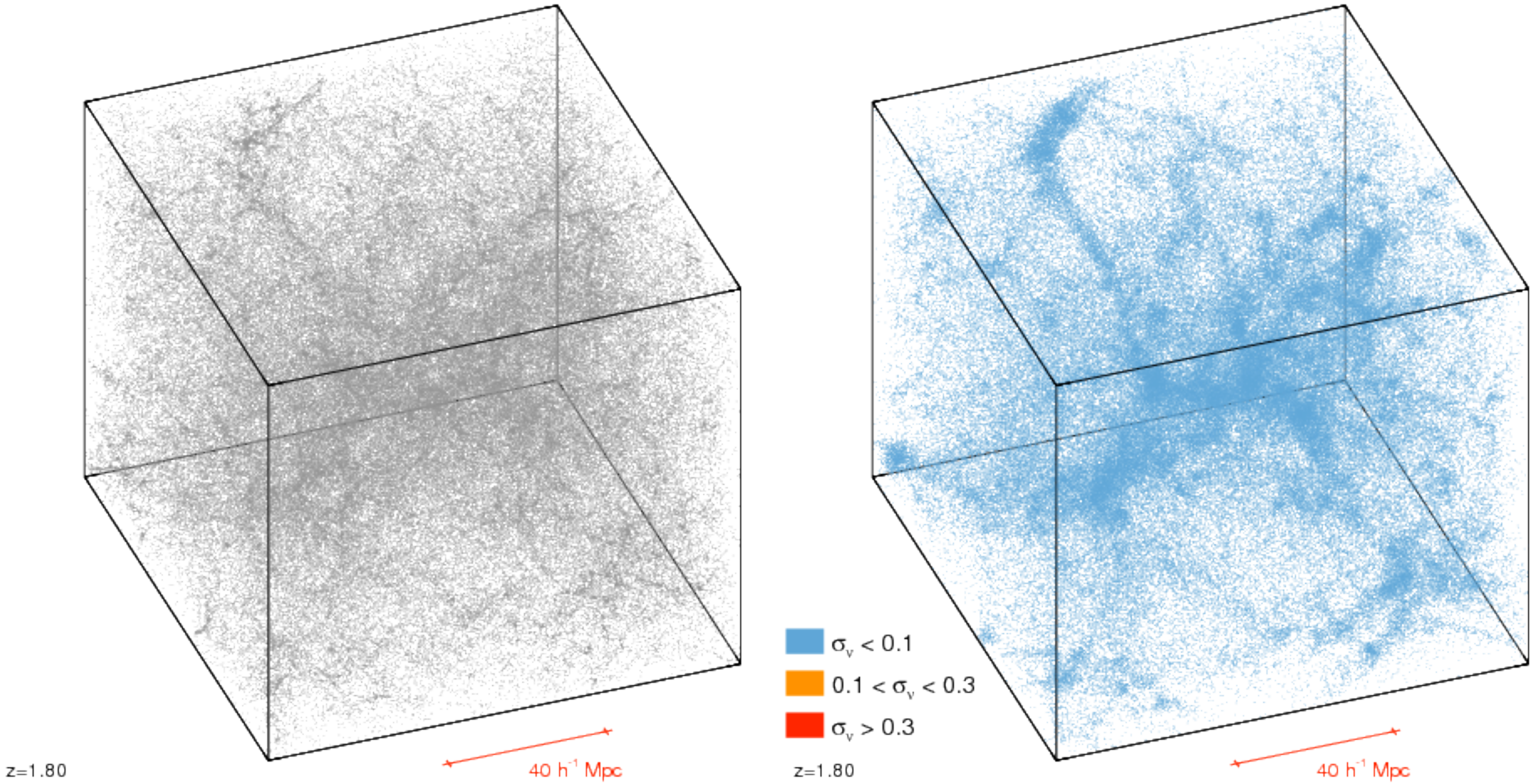

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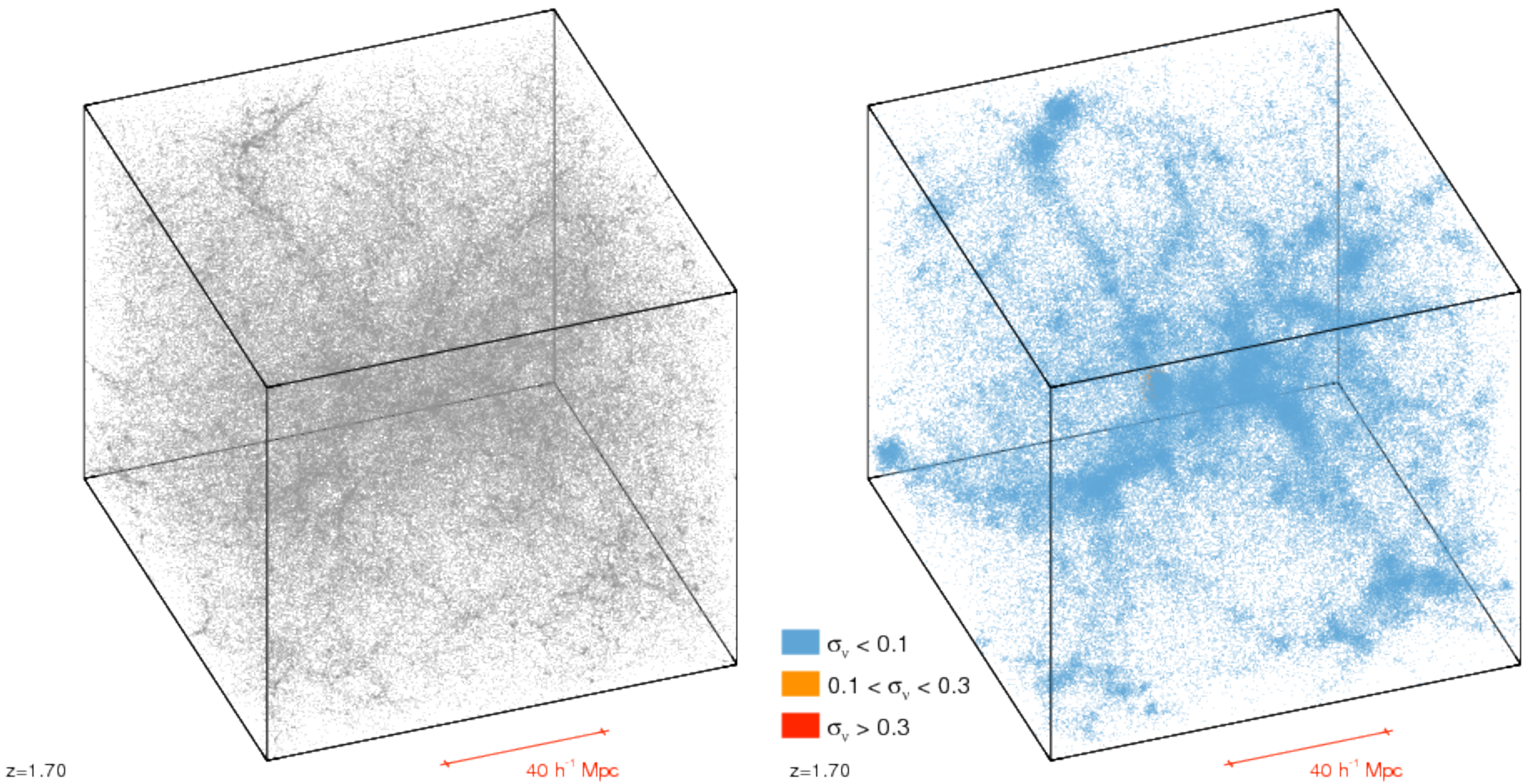

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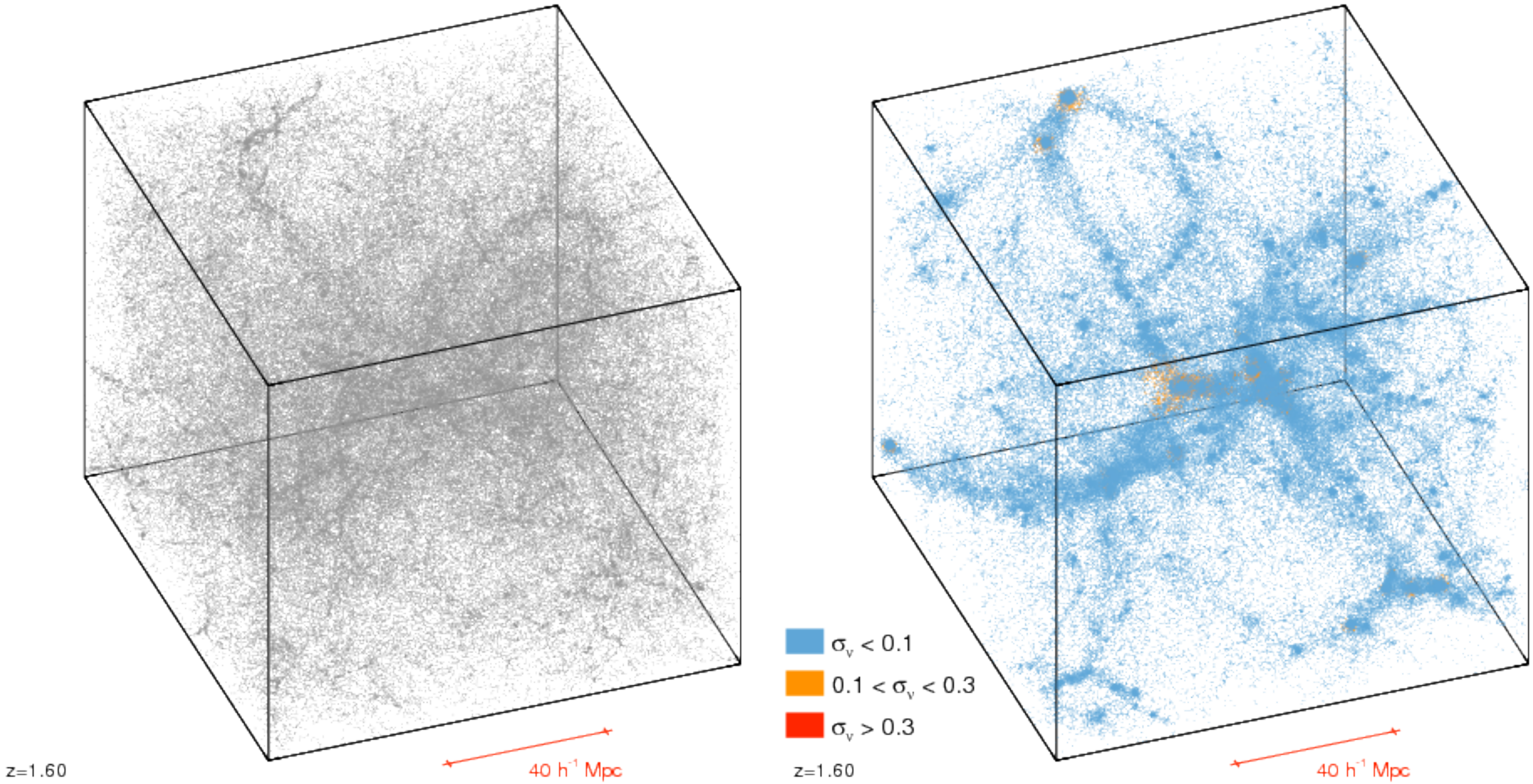
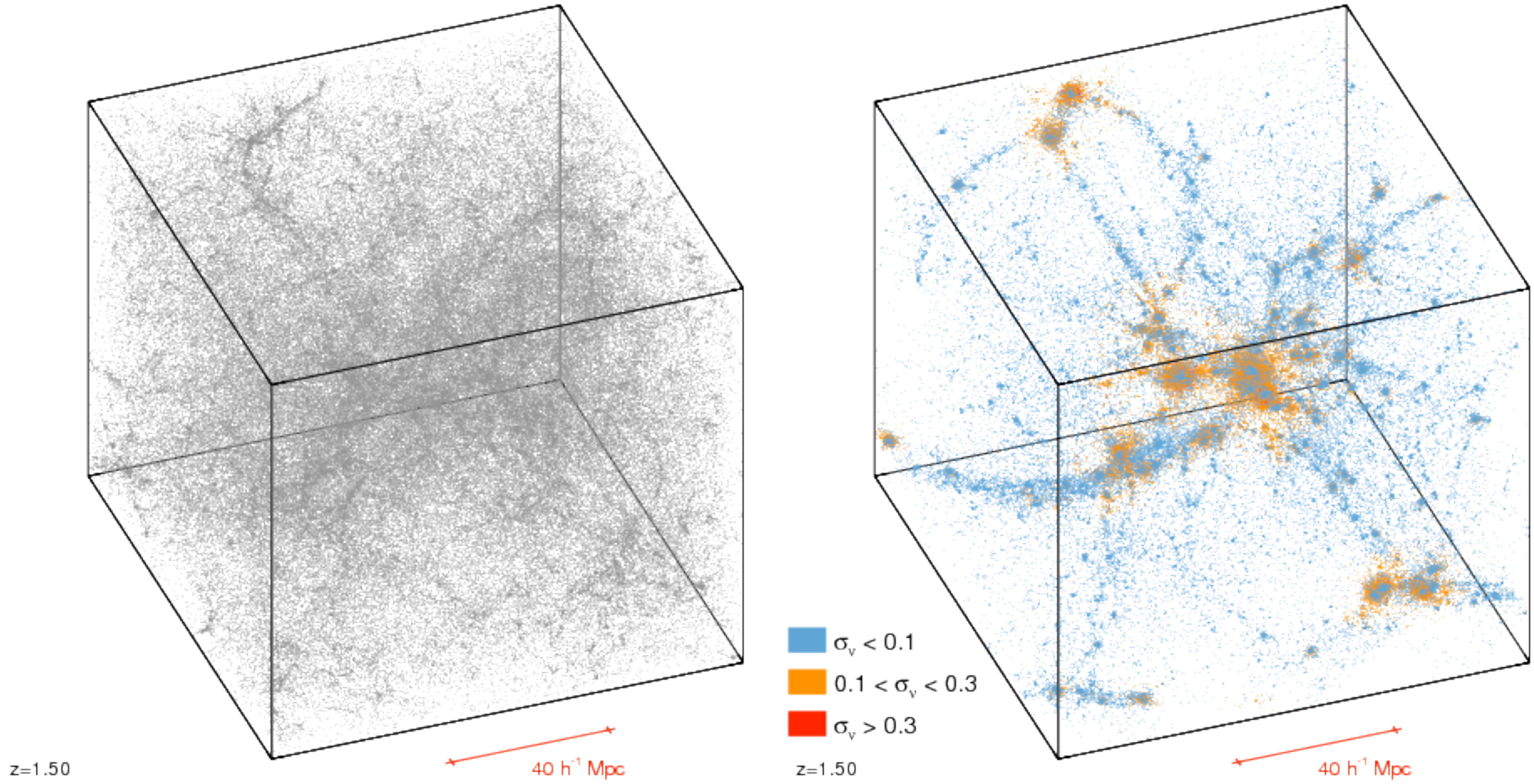


[MB, Pettorino, Wetterich, Amendola, in prep.]

PRELIMINARY THE FIRST GROWING NEUTRINO SIMULATIONS



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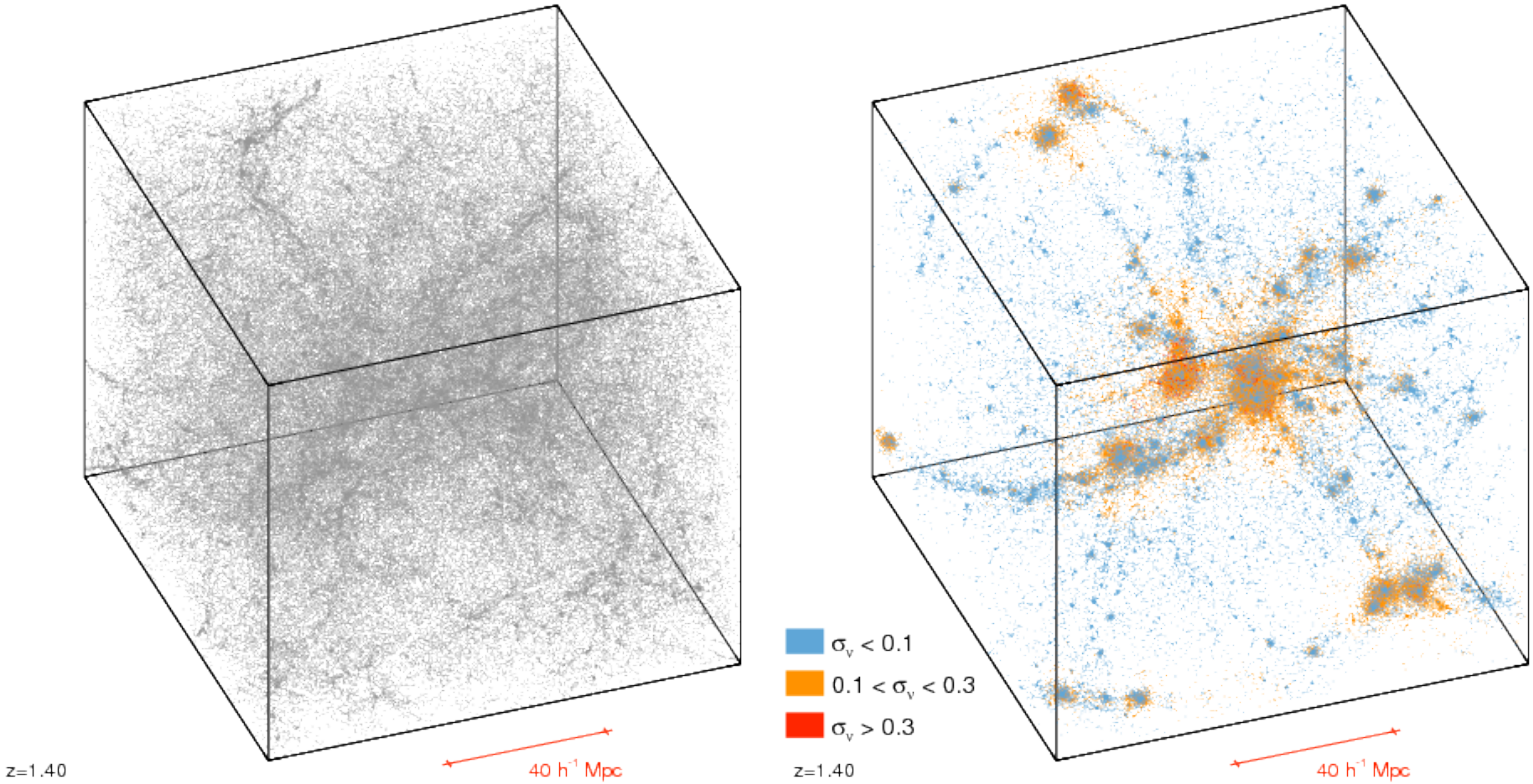

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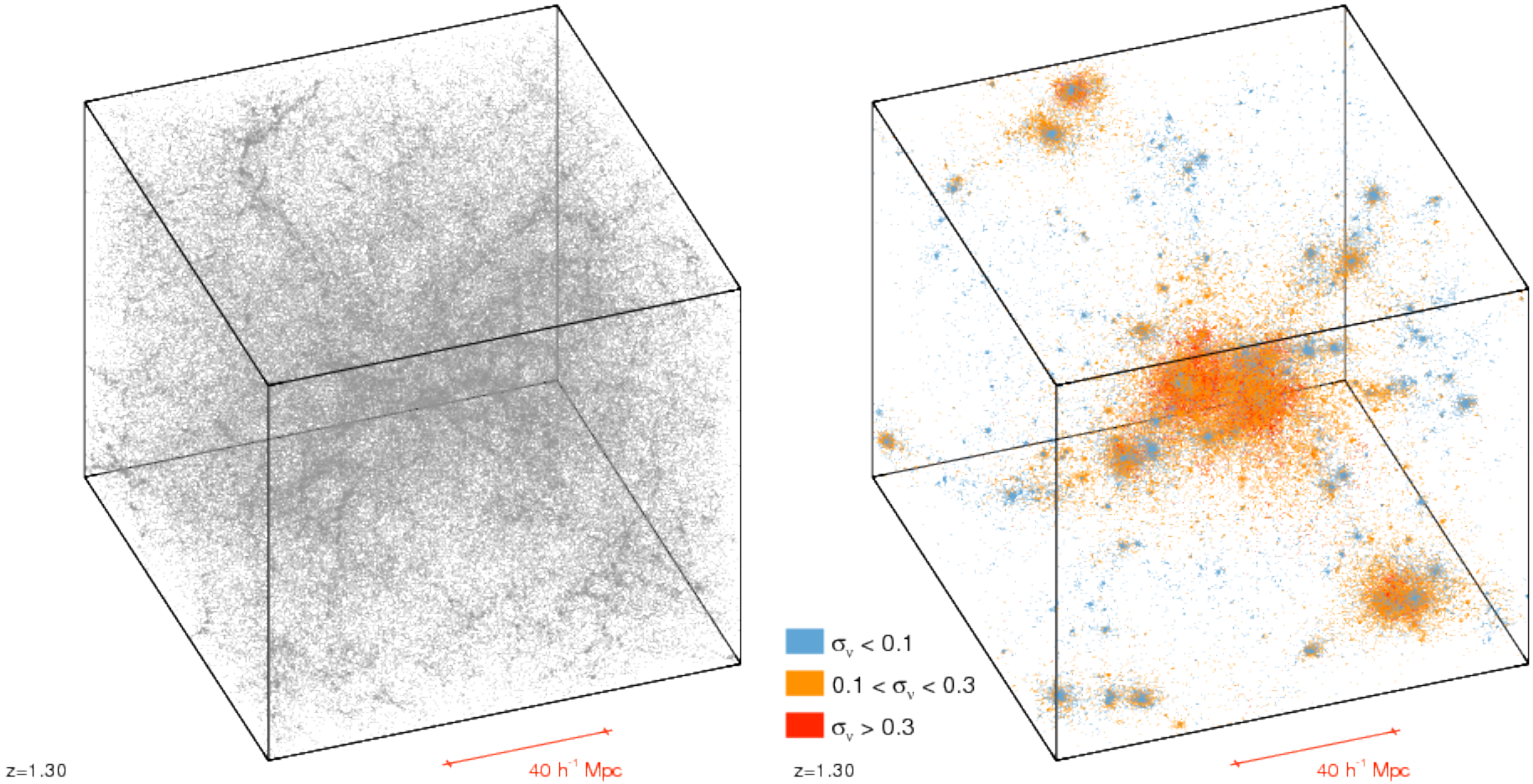

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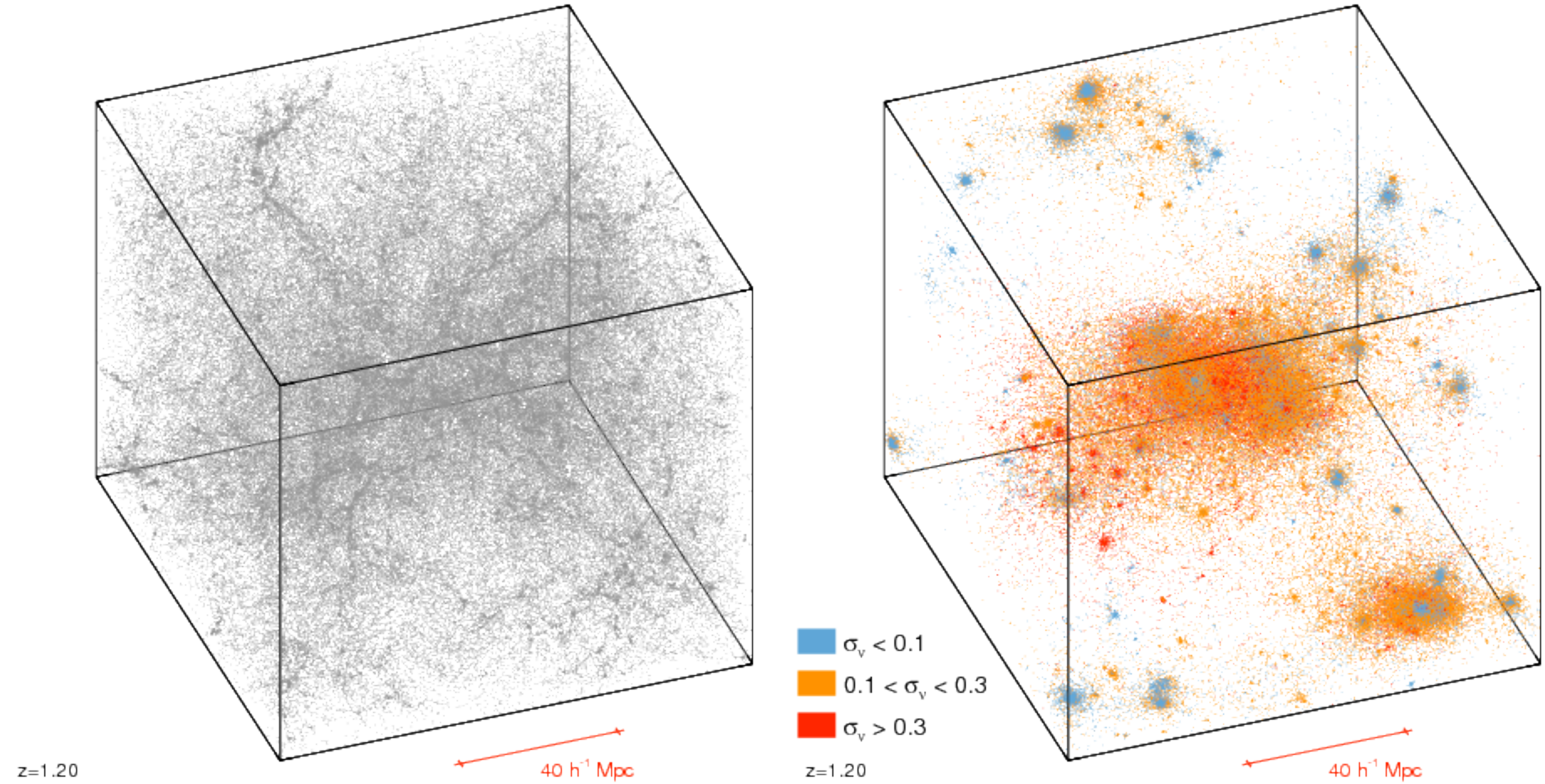

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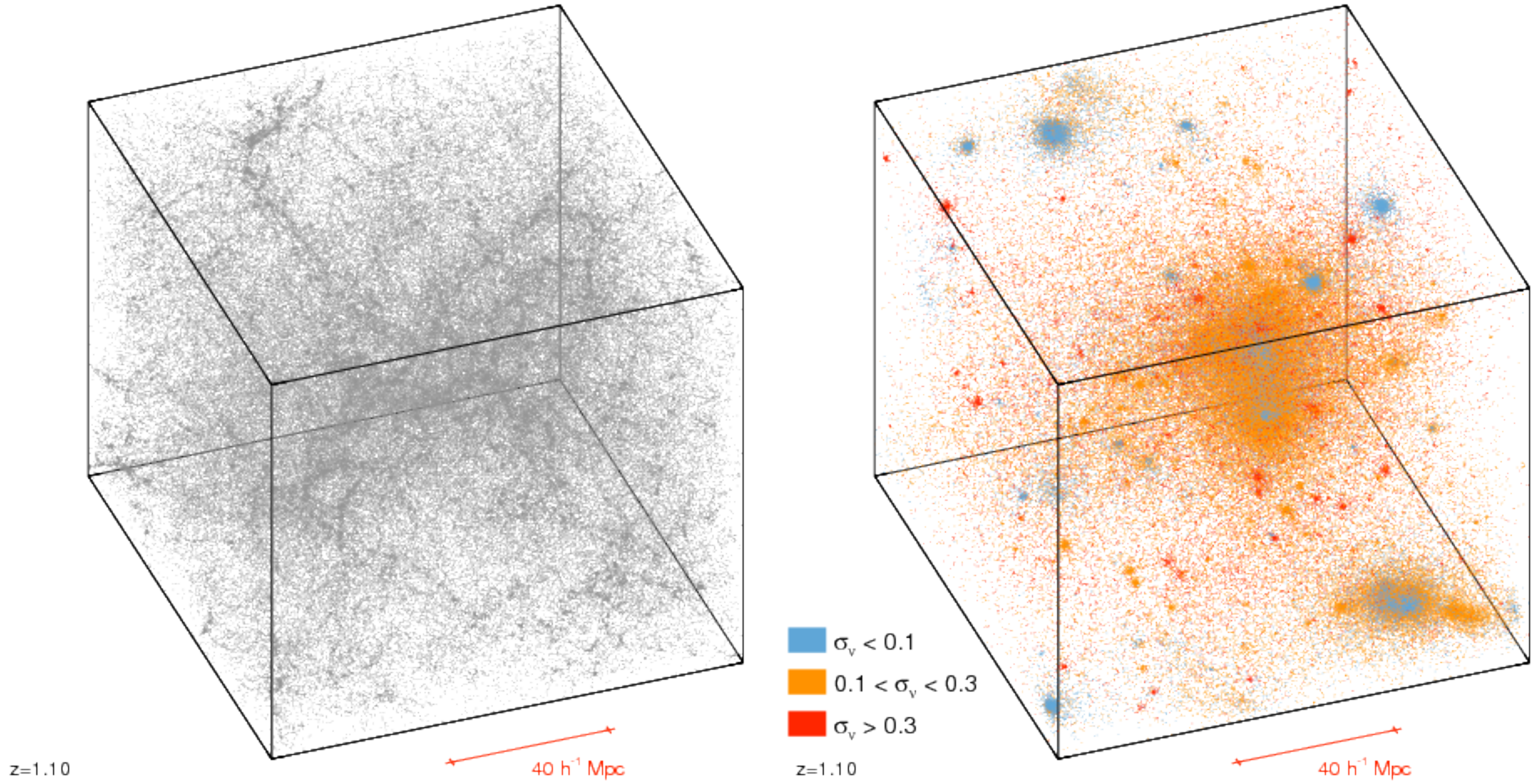

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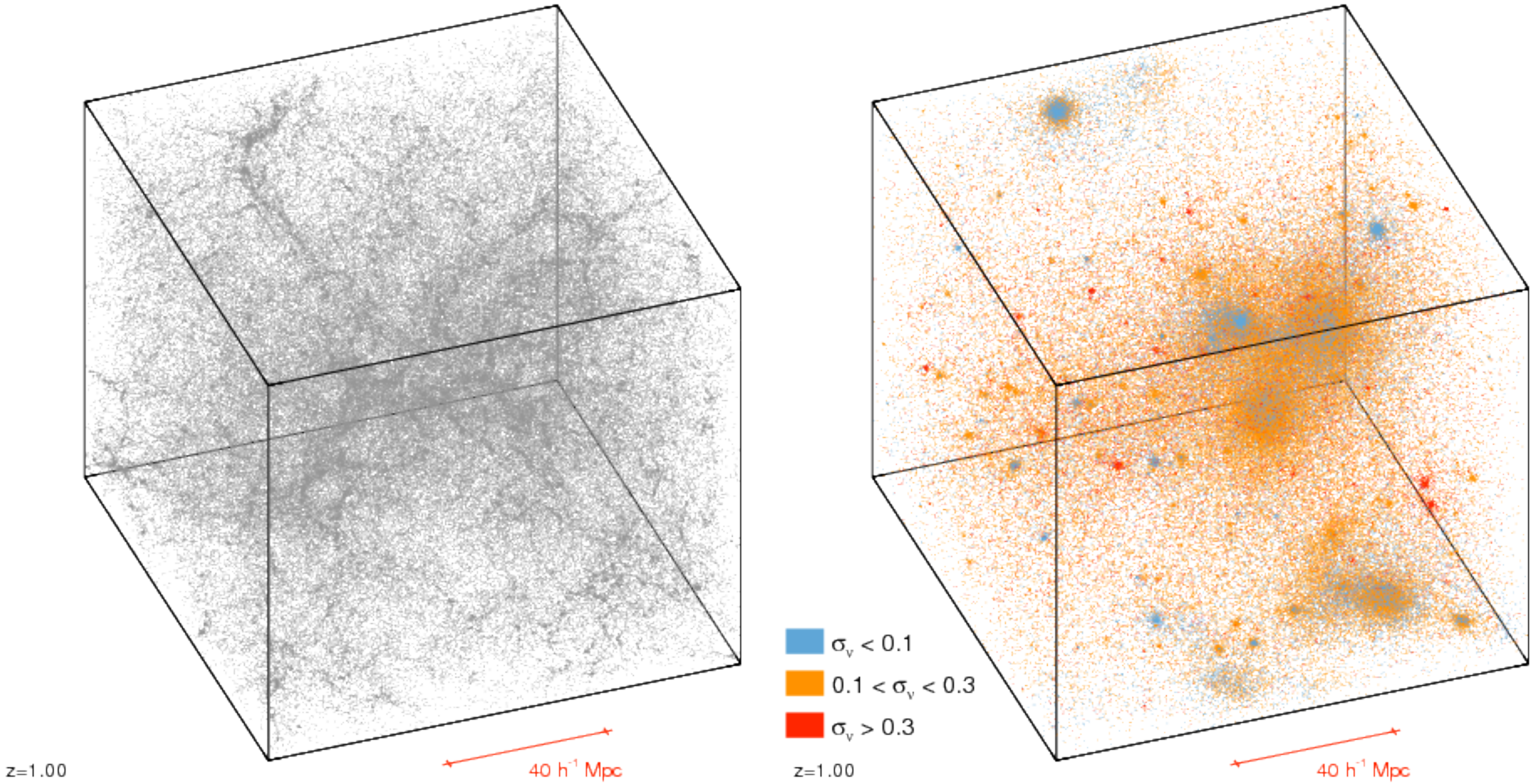

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PRELIMINARY

OSCILLATING STRUCTURE FORMATION

We found that:

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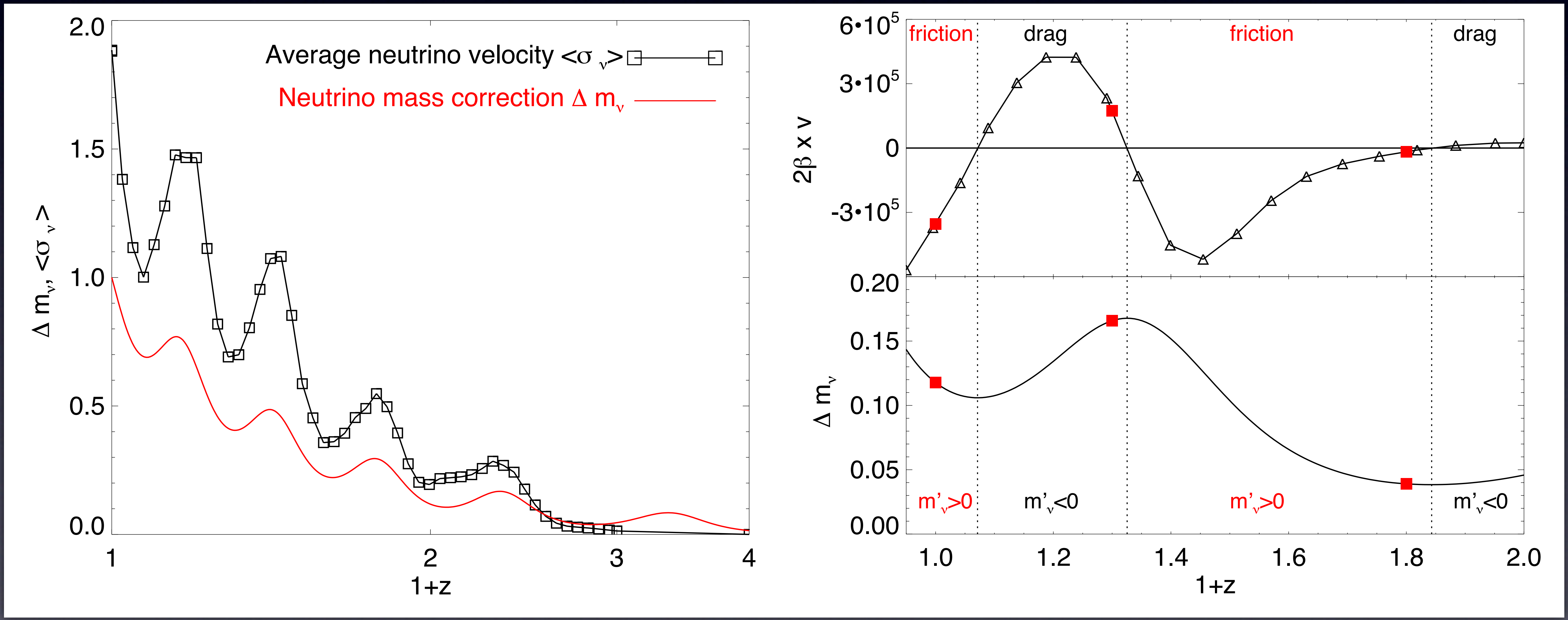
The SF oscillations determine oscillations of the neutrino mass, which in turn determine oscillations of neutrino velocities and an alternation of scalar friction and drag



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WHY IS THIS RELEVANT AT ALL???

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BECAUSE WE MIGHT BE ABLE TO SEE IT!!!

COUPLED QUITESSENECE MIGHT IMPLY:

- A change in the cluster number counts
- A larger normalization of linear perturbations
- A change in the concentration vs. mass relation
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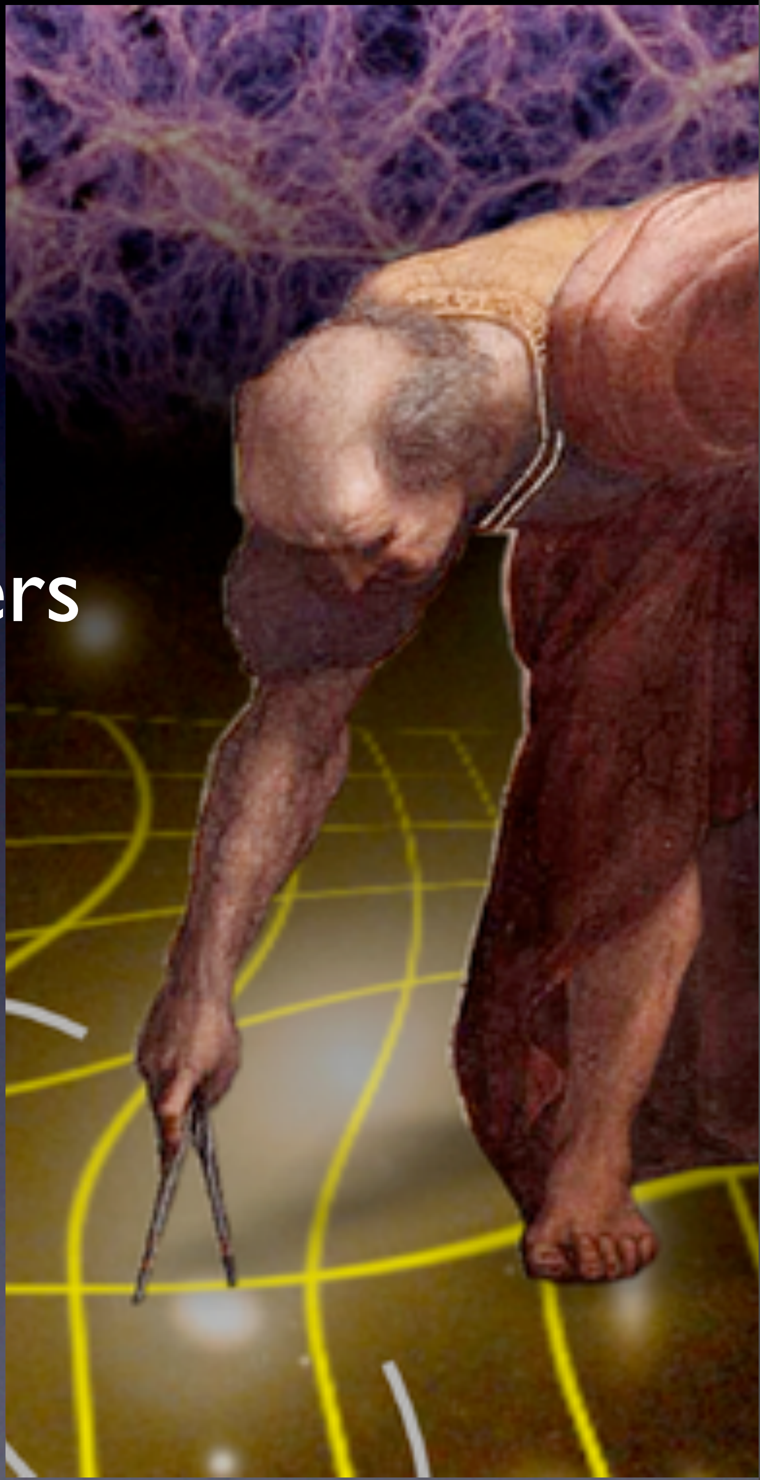

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DES, HETDEX, OR EUCLID
COULD SEE THESE EFFECTS

THE CoDECS PROJECT

(COUPLED DARK ENERGY COSMOLOGICAL SIMULATIONS)

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A publicly available set of cosmological N-body simulations for interacting Dark Energy models, suitable for the scientific goals of EUCLID

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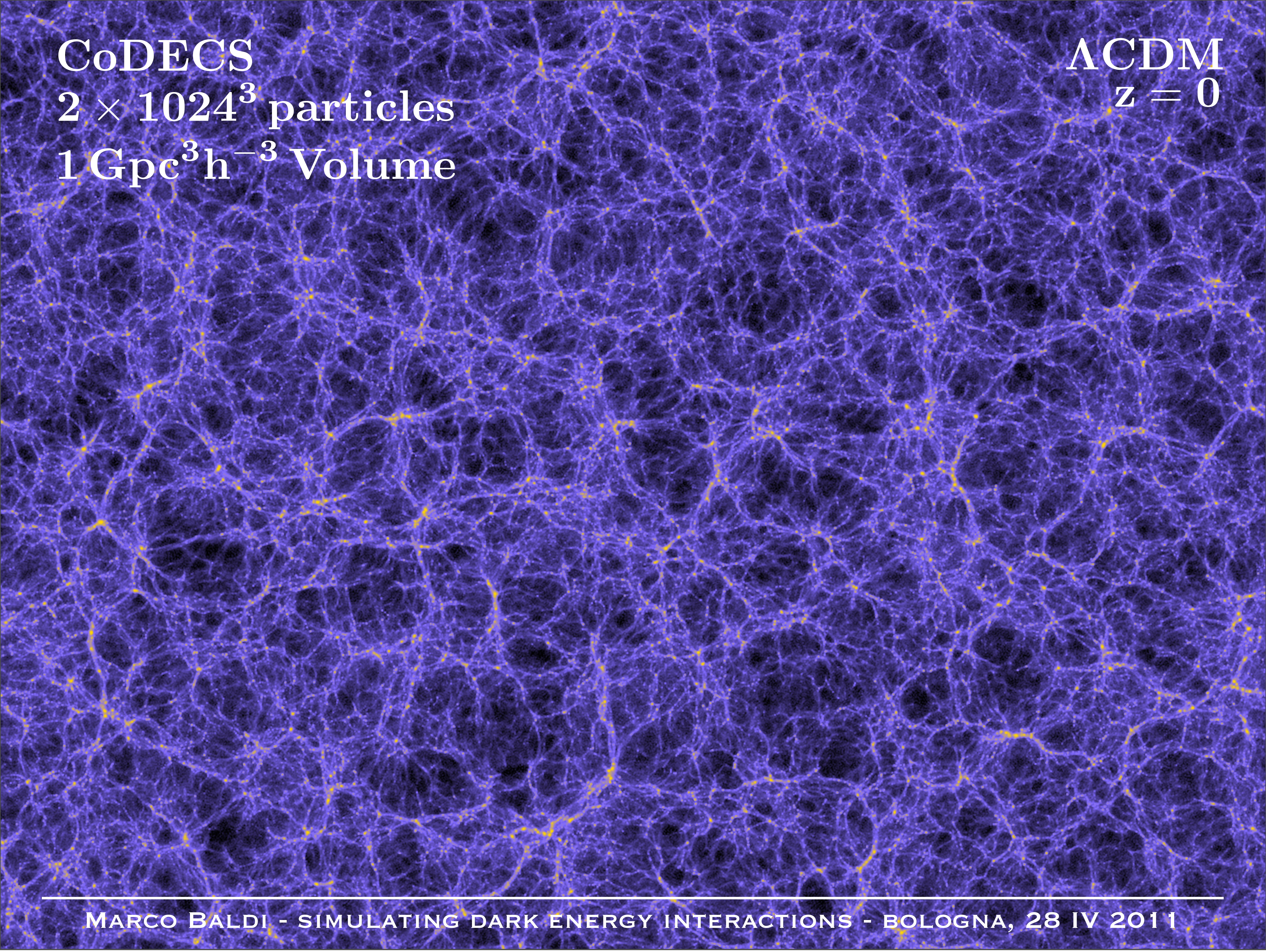
A LOT OF WORK EXPECTED FOR THE NEAR FUTURE IN THE NON-STANDARD COSMOLOGIES SIMULATIONS BUSINESS.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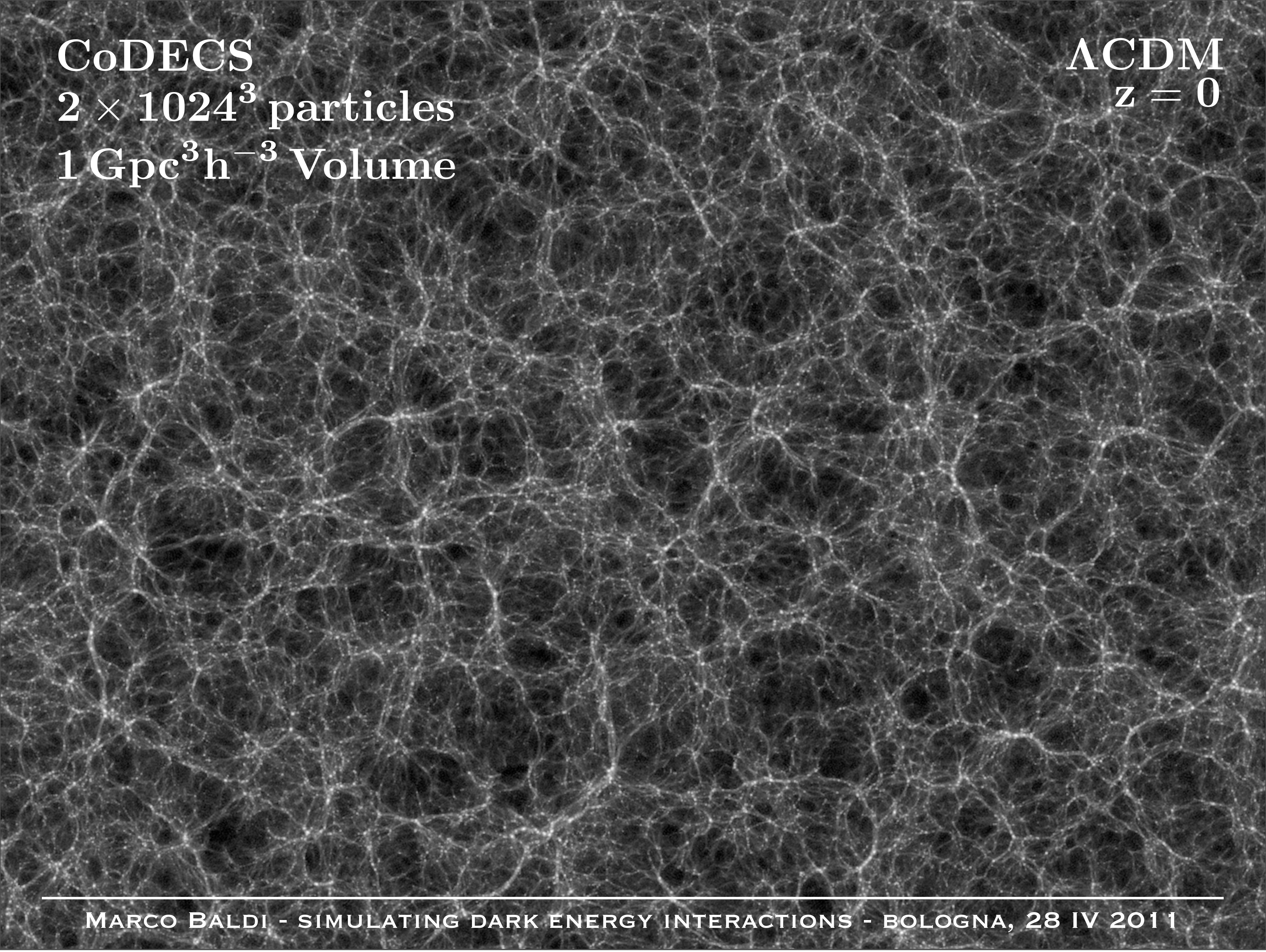
Marco Baldi - simulating dark energy interactions - bologna, 28 IV 2011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