The impact of interacting dark energy on the cosmic web and galaxy clusters

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Quintessence Models

- General SM Lagrangian + dark sector:

$$\mathcal{L} = \mathcal{L}_{SM+DM} + \frac{1}{2}\dot{\phi}^2 + m(\phi)\psi_{DM}\bar{\psi}_{DM} + V(\phi)$$

- Ratra-Peebles potential *(Ratra & Peebles 1988)*:

$$V(\phi) = V_0 \left(\frac{\phi}{M_p}\right)^{\alpha}$$

- Dark matter - dark energy interaction *(Amendola 2000)*:

$$m(\phi) = m_0 \exp\left[-\beta(\phi)\frac{\phi}{M_p}\right]$$

- Parameter constraints (WMAP7, SNe, BAO) ($\beta < 0.1$) *(Pettorino et al. 2012)*
- Effective G for DM particles (ligh ϕ):

$$\tilde{G} = G_N(1 + 2\beta(\phi)^2)$$

N-body Simulations

- Newtonian gravity integrated in co-moving coordinates + hydrodynamical forces acting on baryons
- Probe the deep non-linear regime $\lambda << 25 Mpc$, astrophysical predictions of cosmological models
- Simulated with `GADGET-2` Tree-PM + SPH code *(Springel, 2005)* using modified grav-solver for DM *(Baldi et al., 2010)*, baryons do not interact with ϕ
- Settings: WMAP7 cosmology for all models, 2×1024^3 DM+gas particles in a 250Mpc/h (comoving) box, 5 simulations (ΛCDM, uDE, cDE033, cDE066, cDE099)

The Cosmic Web

- Dynamical identification of the environment using the velocity shear at the grid nodes *((Hoffman et al. 2012))*:

$$\Sigma_{\alpha\beta} = -\frac{1}{2H_0}\left(\frac{\partial v_\alpha}{\partial r_\beta} + \frac{\partial v_\beta}{\partial r_\alpha}\right)$$

- Diagonalize $\Sigma_{\alpha\beta}$ and compute the eigenvalues $\lambda_{1,2,3}$,

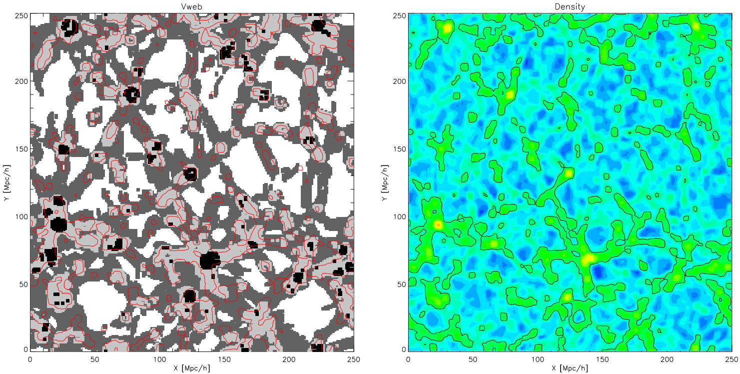
$$Tr(\Sigma_{\alpha\beta}) = \lambda_1 + \lambda_2 + \lambda_3 = -\vec{\nabla} \cdot \vec{V} \propto \delta_m$$

- Set a threshold λ_{th} to classify:

$$\textit{void} \text{ no } \lambda > \lambda_{th}, \; \textit{sheet} \text{ one } \lambda > \lambda_{th}$$
$$\textit{filament} \text{ two } \lambda > \lambda_{th}, \; \textit{knot} \text{ all } \lambda > \lambda_{th}$$

- λ_{th} is a *free parameter*
- Correlations between halo properties and environment ($c - M$, λ, $n(> M)$) *(EC, Knebe, Lewis, Wales, Yepes 2014 I)*

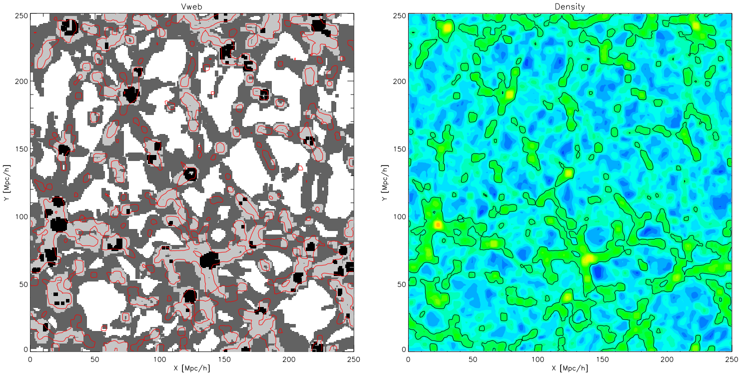
Cosmic web: ΛCDM



Filling fractions:

	void	sheet	filament	knot
Mass	0.103	0.343	0.437	0.115
Volume	0.337	0.461	0.185	0.017

Cosmic web: *cDE*099

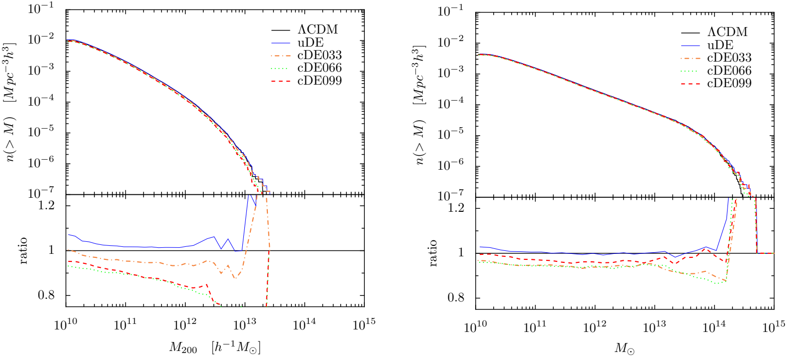


Filling fractions:

	void	sheet	filament	knot
Mass	0.099	0.339	0.443	0.118
Volume	0.335	0.461	0.186	0.017

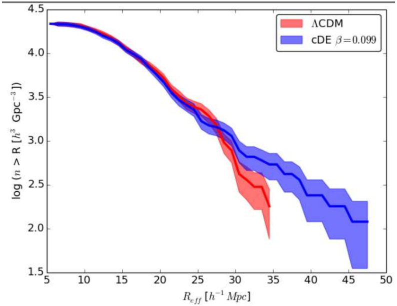
Environment dependence: halo mass function in void and knots

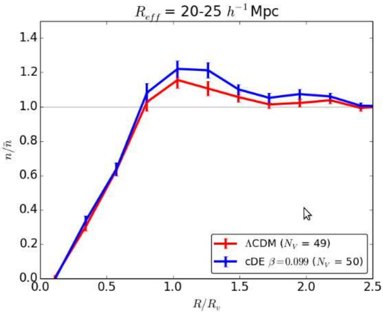
Halo dependence on environment reveals that voids in cDE are less dense: the fifth force pulls matter out of them



Void properties

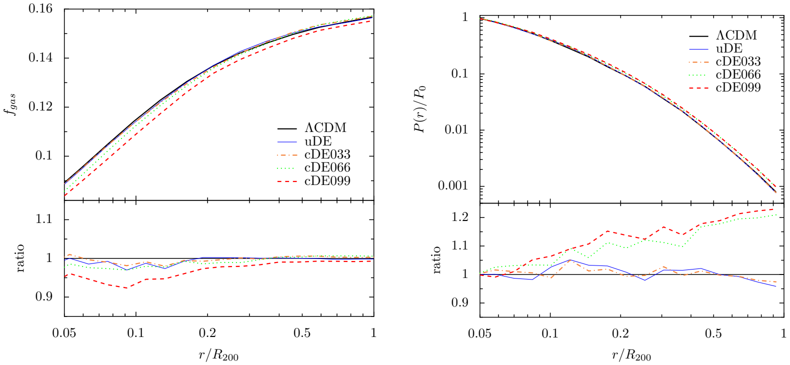
Properties of voids (now identified with Voronoi Tessellation / watershed algorithm) can be used to characterize cDE *(Sutter & EC in prep.)*





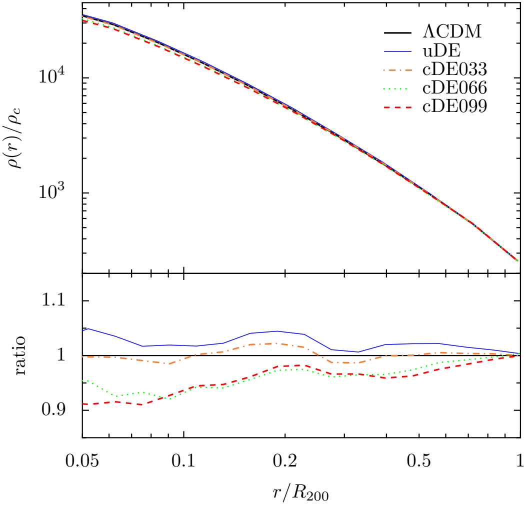
Galaxy clusters

Influence of cDE on gas properties *(EC, Knebe, Lewis, Yepes 2014 II)* look at stacked profiles for clusters' gas fraction and pressure profiles



Gas infall towards the center is comparatively slower than DM: smaller f_{gas} in cDE cluster centers

Dark matter density profile in clusters



Central regions of the haloes are less dense: effective pressure (interaction driven) counteracts gravity

DM detection in clusters

Large galaxy clusters are expected to be detectable sources of γ-ray from DM annihilation. The expected flux at a given direction Ψ_0:

$$F(E_\gamma > E_{th}) = J(\Psi_0) \times f_{part}(E_\gamma > E_{th})$$

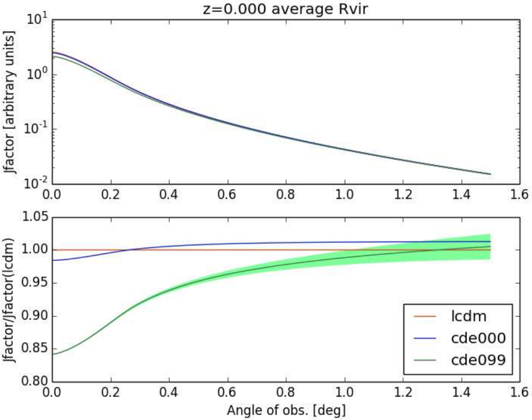
The J factor models the geometry of the problem:

$$J(\Psi_0) \propto \int \rho_{DM}^2(r) d\lambda$$

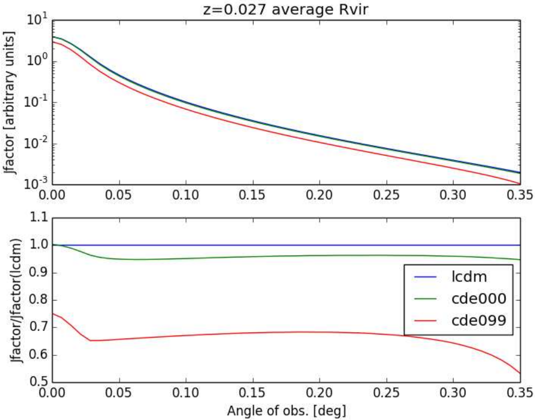
ϕ effect on f_{part} is negligible (DE force is long range),

DM detection in clusters

We compute the $J(\Psi_0)$ for average clusters at different zs to see how this affects observations such as Fermi and CTA (Cherenkov Telescope Array) *(Gomez-Vargas & EC in prep.)*



DM detection in clusters



The cDE suppression of $\rho_{DM}(r)$ has a large effect on J.

Summary

Main effects of cDE can be seen in:

- Halo abundances in underdense regions
- Void properties
- Cluster profiles (gas, DM)
- Affects DM detection in clusters