Simulating the Interaction between Dark Energy and Dark Matter

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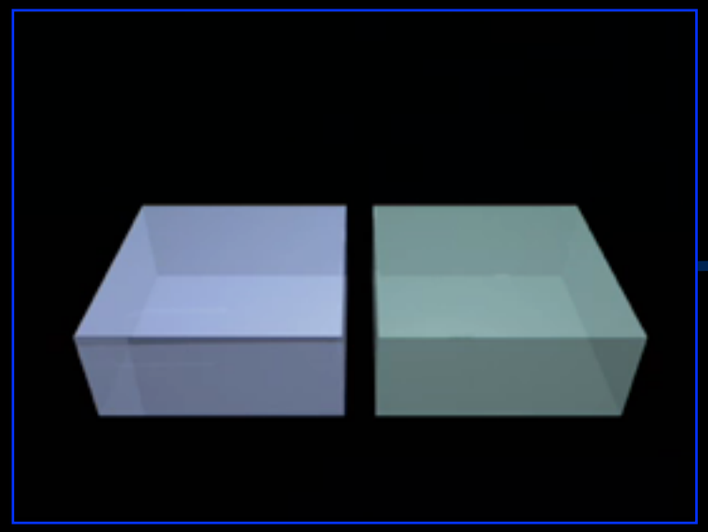
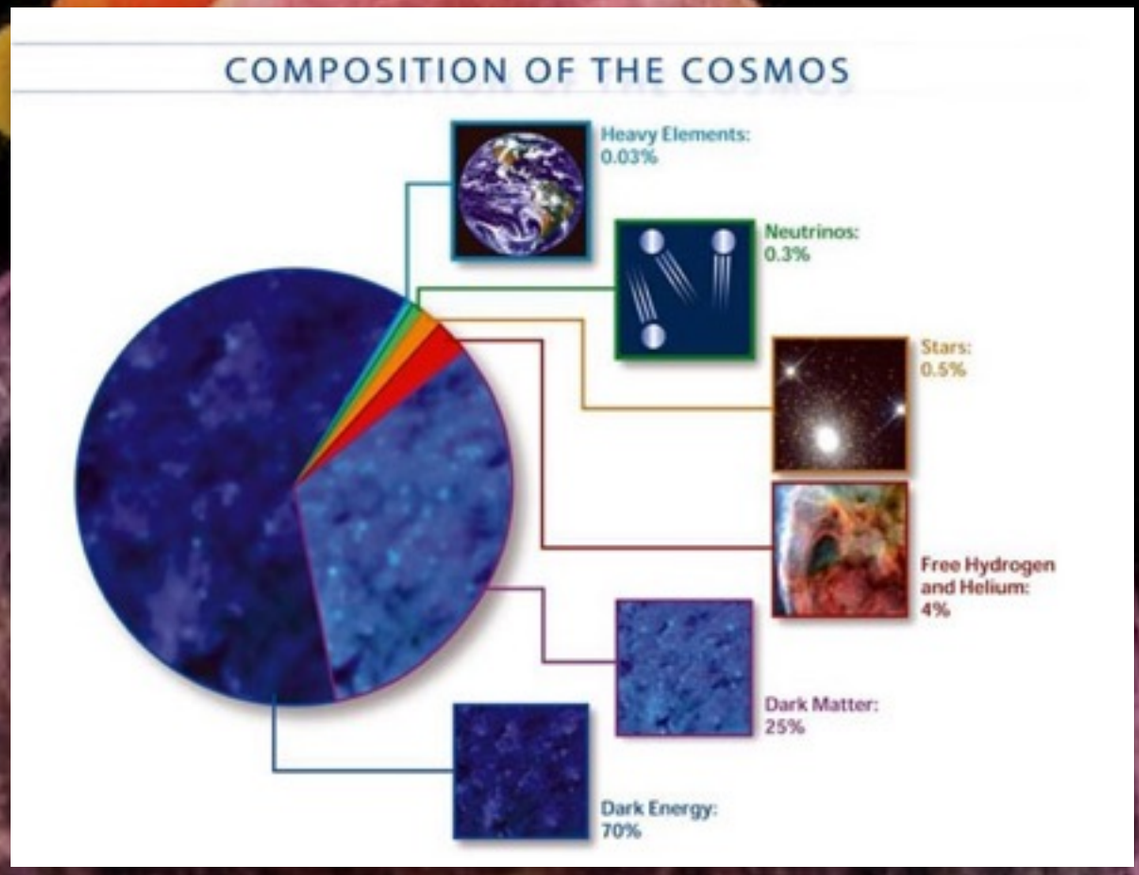
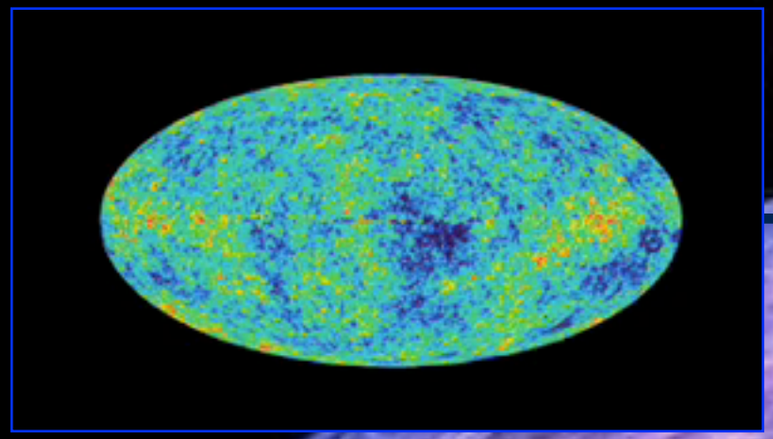
Structure Formation







SKA Era

Radio Continuum Survey

(Total radio emission from galaxies, no redshift information.)

- first large-scale weak lensing survey in radio.
- test isotropy of the universe.
- tight constraints on **non-Gaussianity**.

HI Intensity Mapping Survey

(Individual HI Galaxies NOT detected, only integrated HI emission.)

- precise BAO, RSD up to z~3.
- excellent constraints on **Dark Energy** and curvature.
- probe the largest scales ever – **non-Gaussianity**, modified gravity.

HI Galaxy Redshift Survey

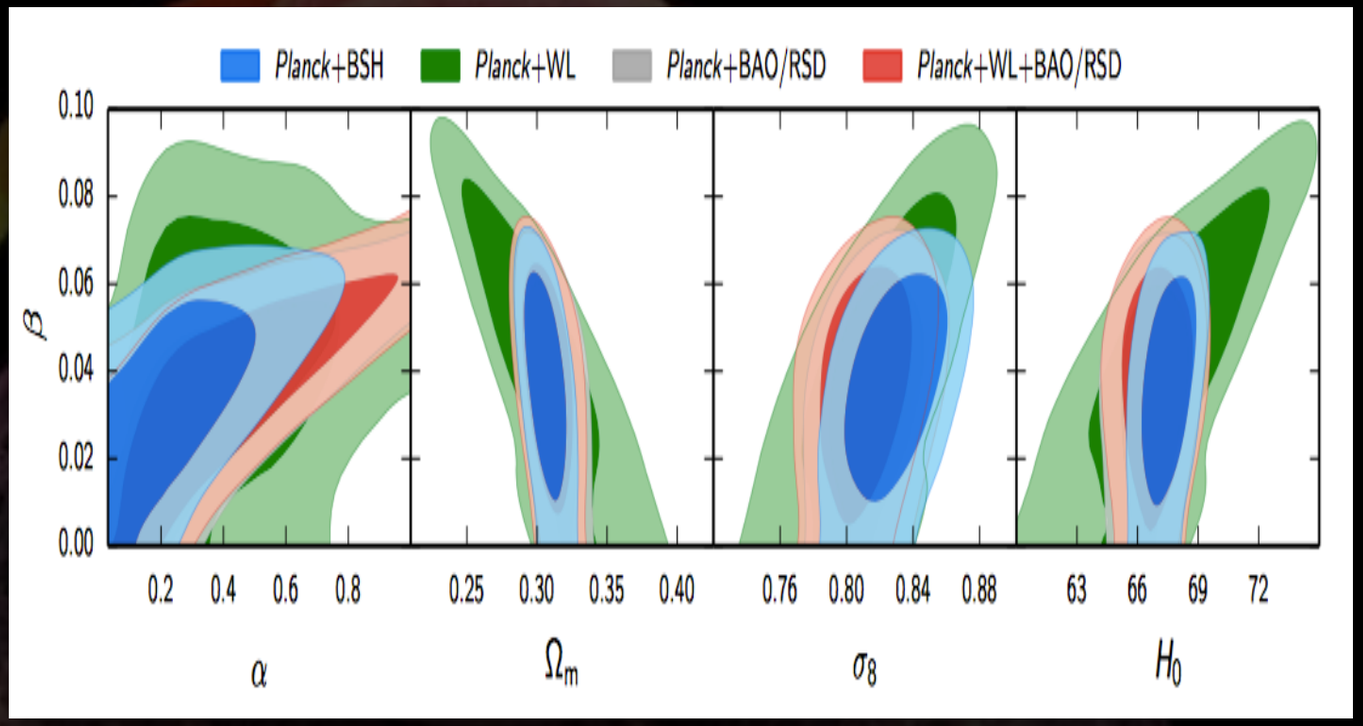
(Individual HI Galaxies detected, very accurate redshift.)

- precise RSD at z<0.5.

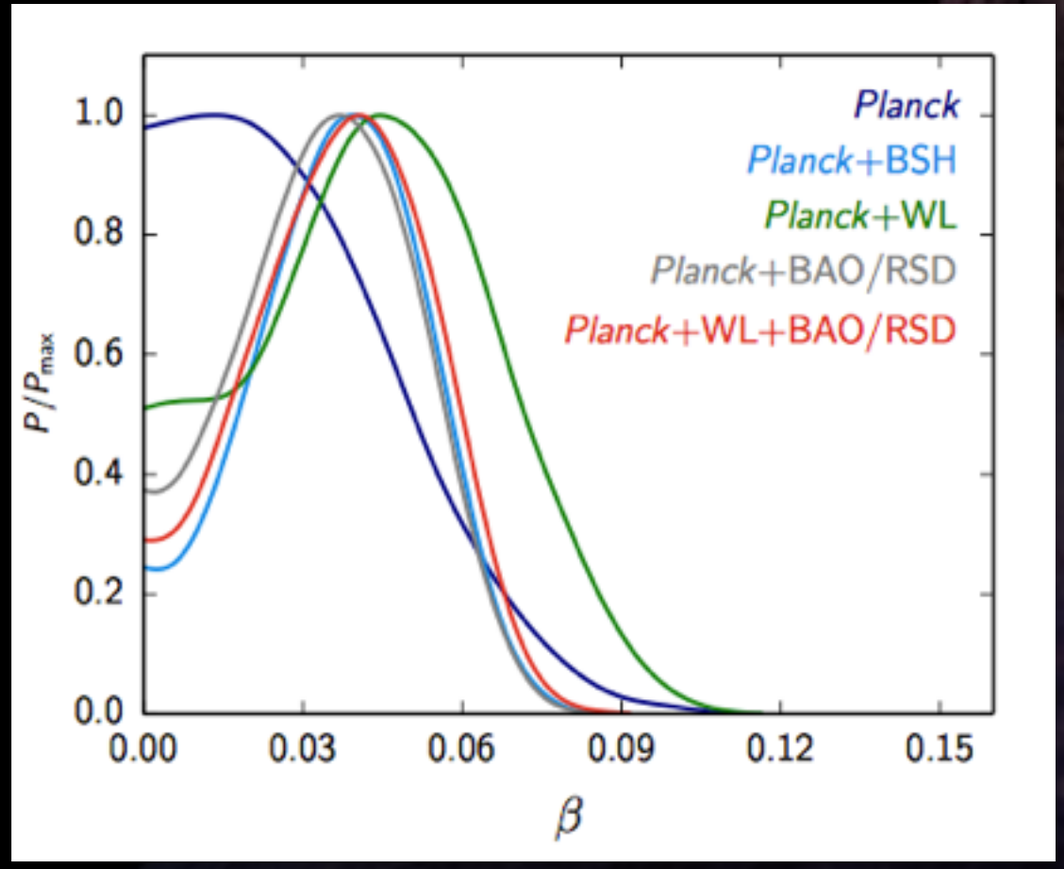
Dark Interaction

Interaction between Dark Energy nd Dark Matter is a theoretical possibility that may help to solve the coincidence problem.

Dark energy and dark matter interact via energy-momentum exchange.



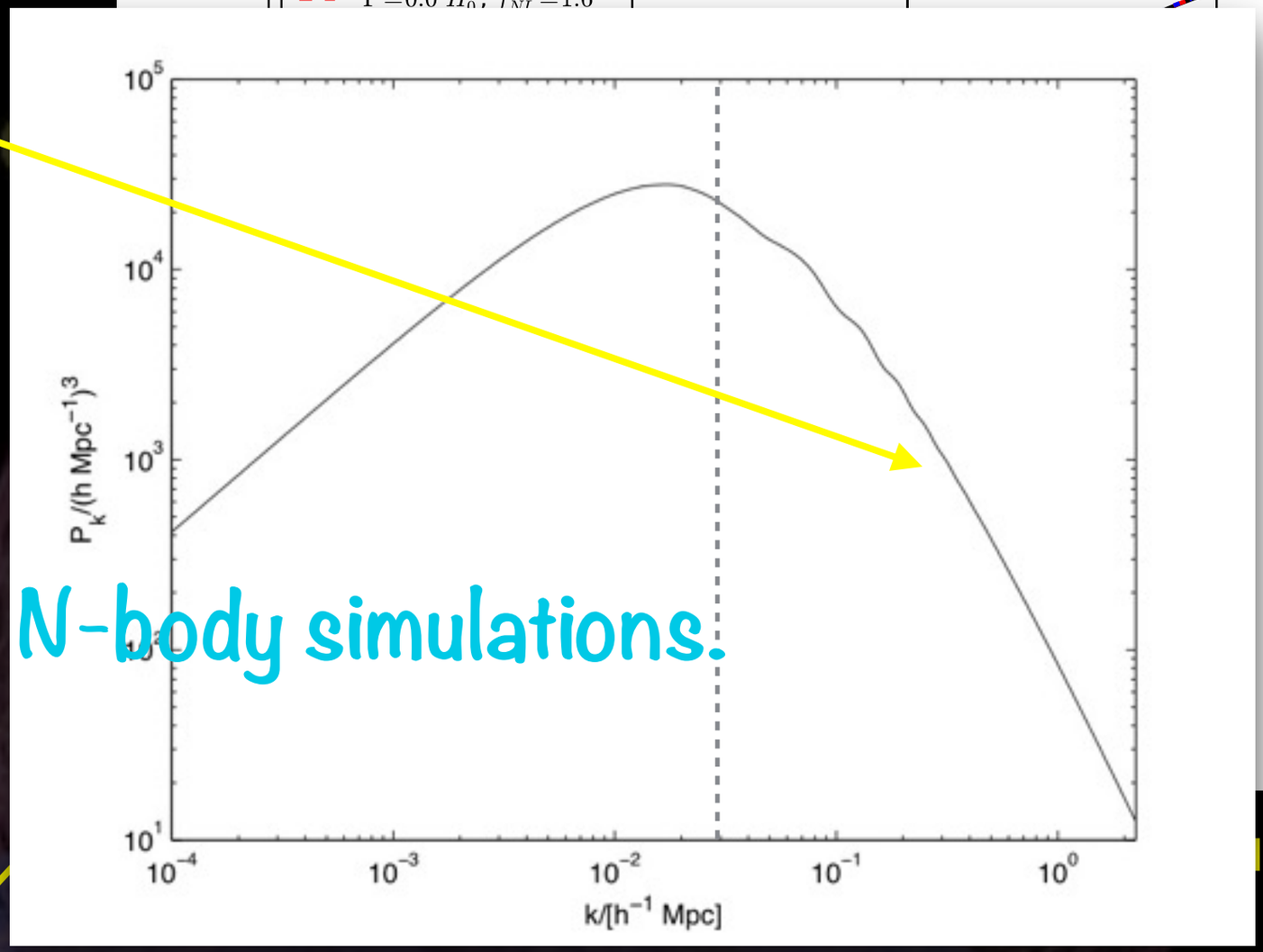
Planck Collaboration 2015 (arXiv:1502.01590)



The transfer of energy-momentum between dark matter and dark energy is not ruled out by current observations.

Dark Interaction

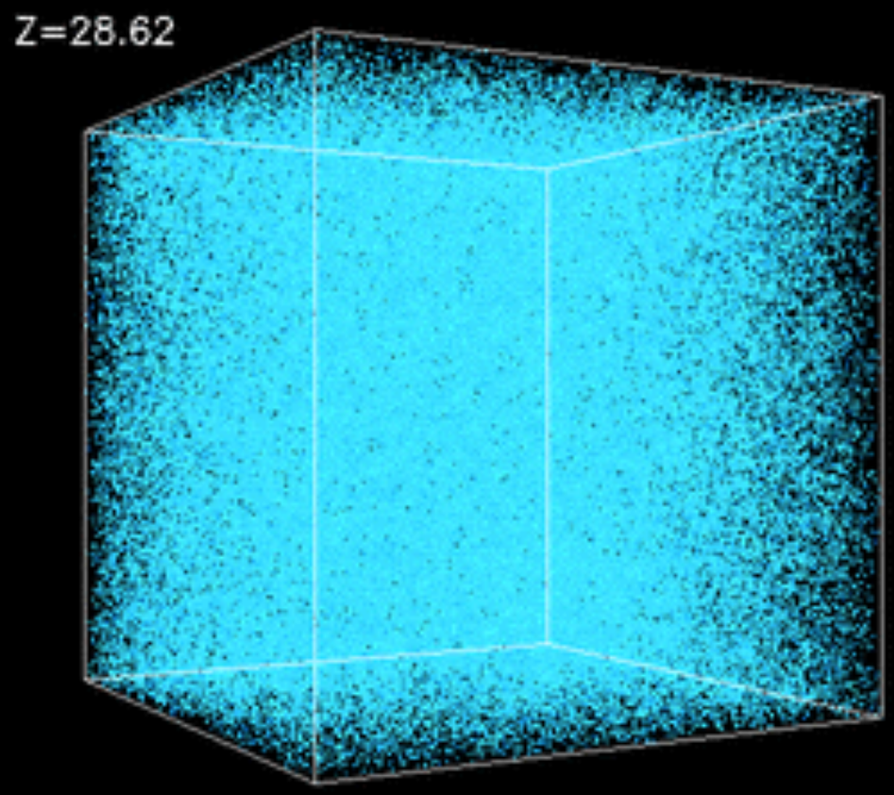
What happens on nonlinear scales?



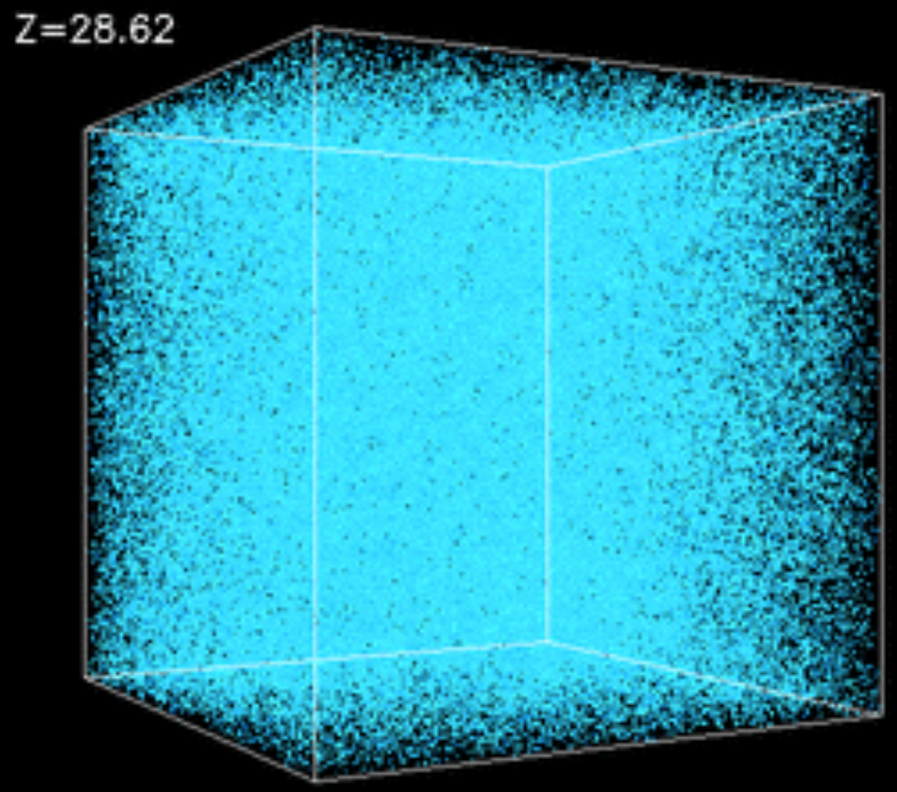
We need to perform N-body simulations.

Perturbation theory shows a change on very large scales due to the interaction that is similar to the effect of PNG in the absence of dark interaction.

N-Body Simulation



N-Body Simulation

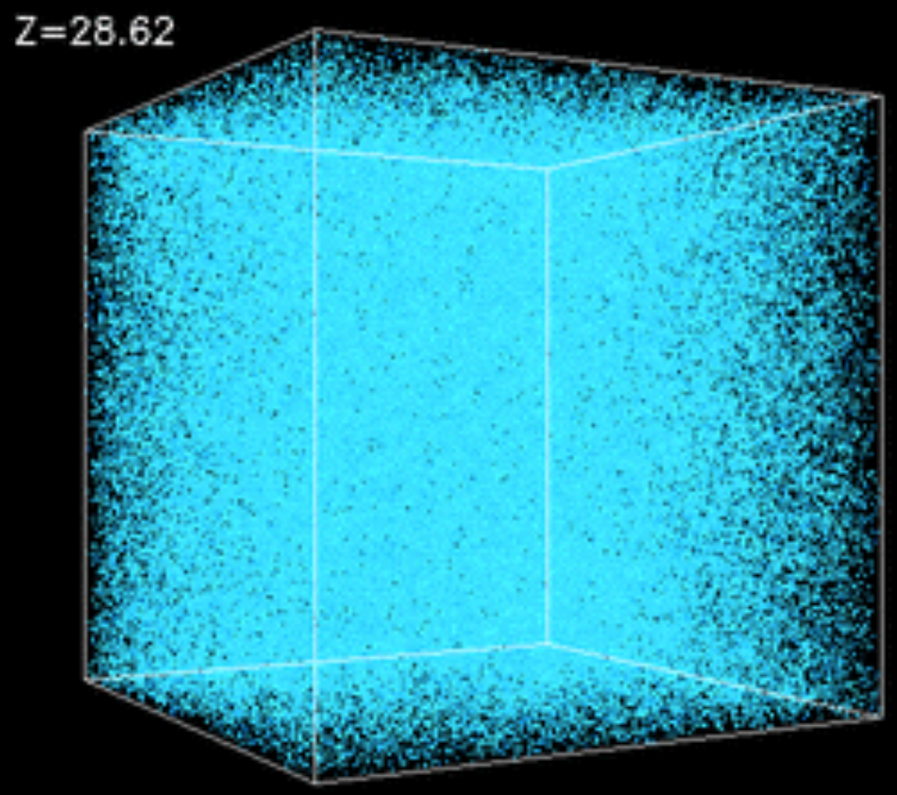


q

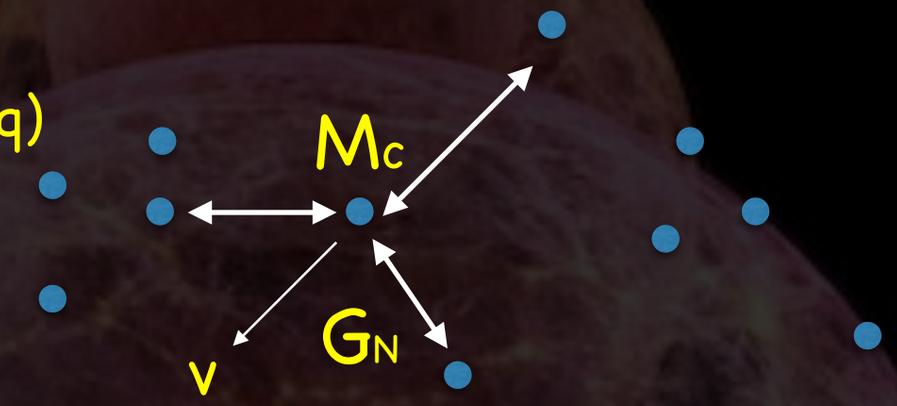
l = B/N^1/3

B

N-Body Simulation

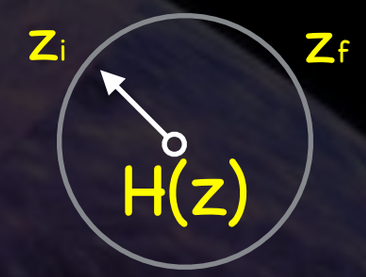


$x = q + S(q)$

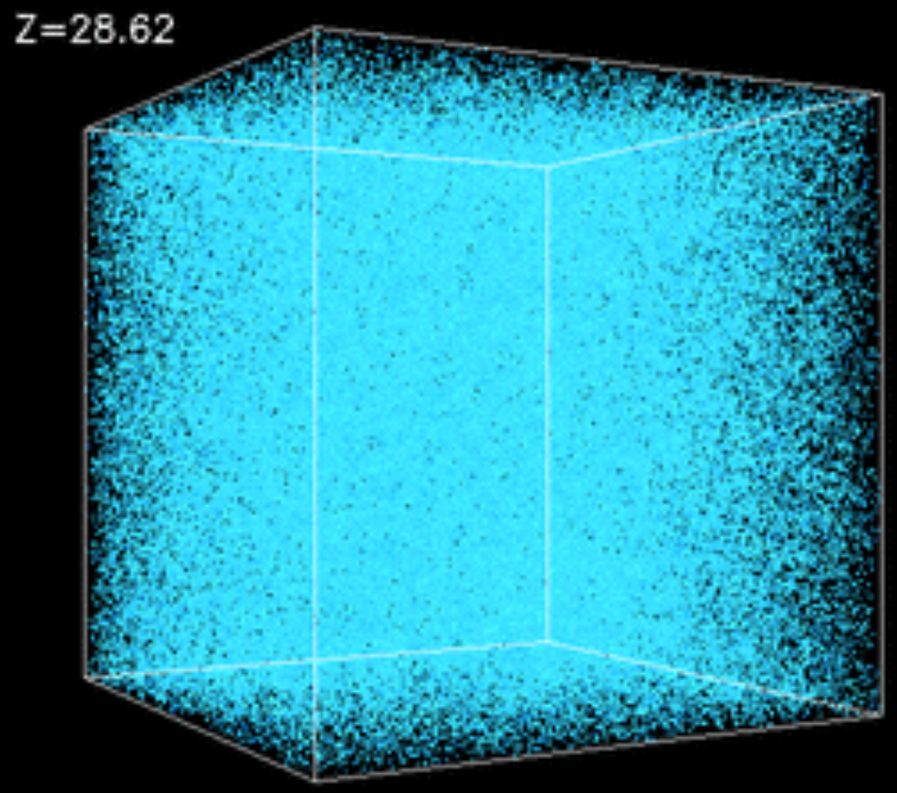


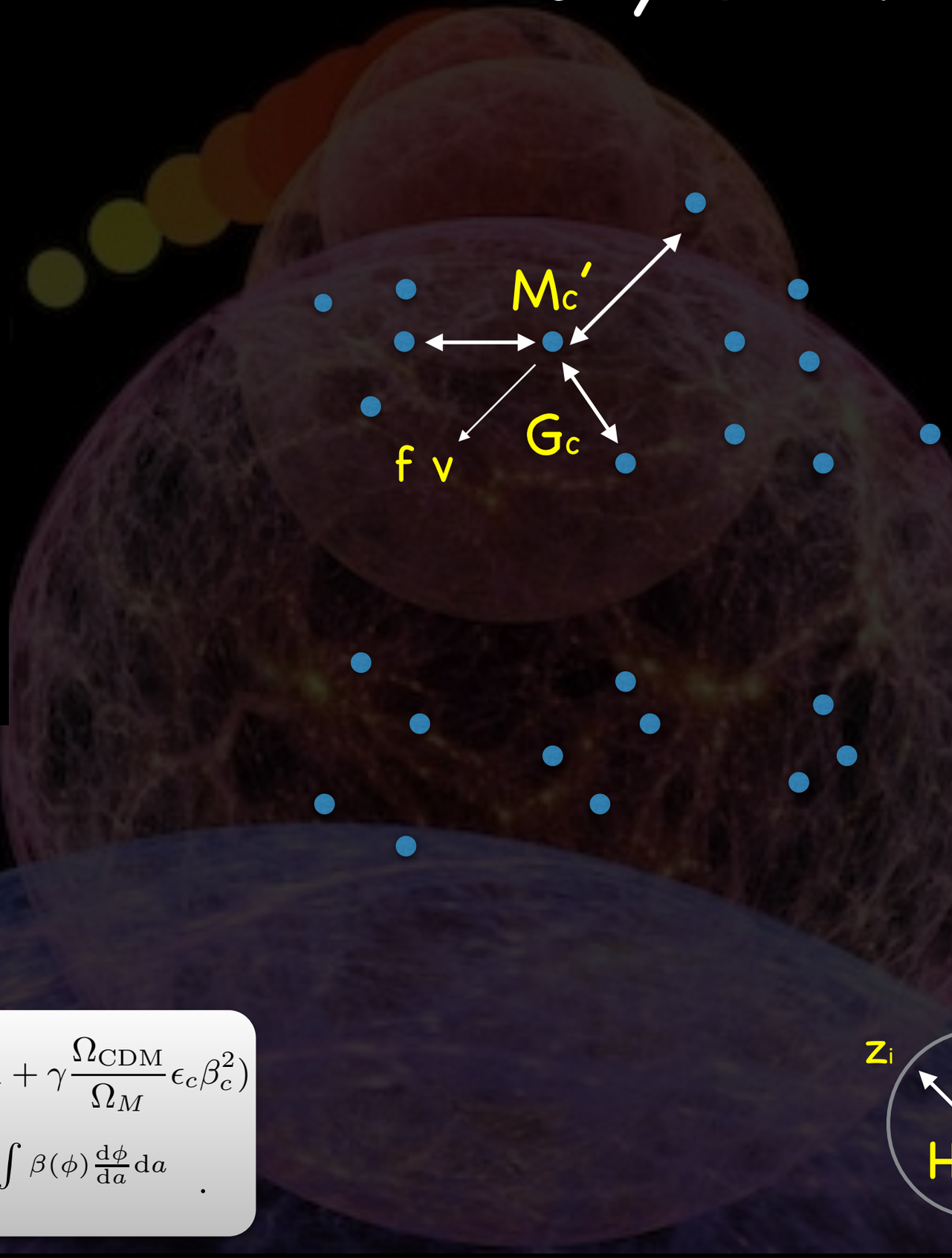
+ ICs (ZA, 2LPT)

$$\boldsymbol{v}(\boldsymbol{k}, a) = if(a)aH\delta(\boldsymbol{k}, a)\frac{\boldsymbol{k}}{k^2}$$



N-Body Simulation



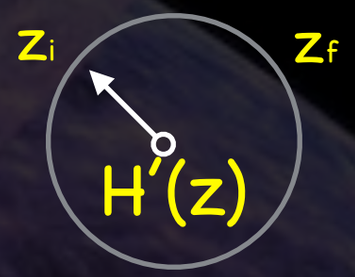


+ ICs (ZA, 2LPT)

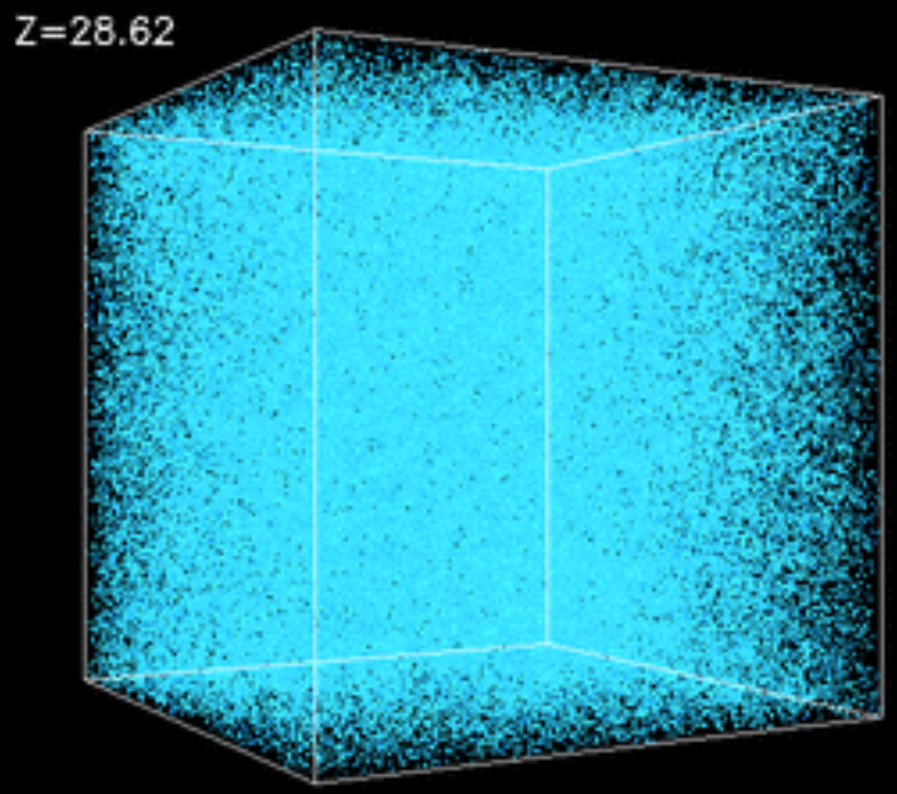
+ Interaction

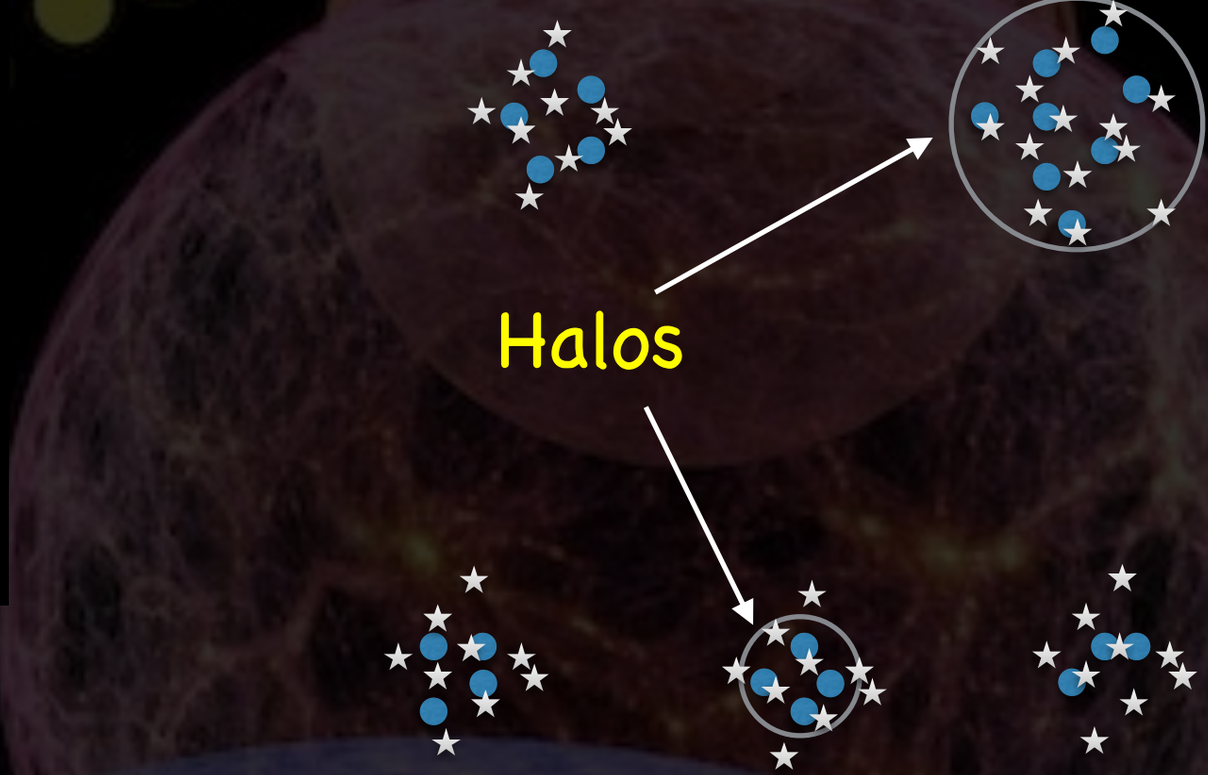
$$\tilde{H} \equiv H\left(1-\frac{\beta(\phi)}{M}\frac{\dot{\phi}}{H}\right) \qquad f(a) \sim \Omega_M^{\gamma}(1+\gamma\frac{\Omega_{\rm CDM}}{\Omega_M}\epsilon_c\beta_c^2)$$

$$\tilde{G}_c = G_N[1+2\beta^2(\phi)], \quad \tilde{M}_c \equiv M_c e^{-\int \beta(\phi)\frac{\mathrm{d}\phi}{\mathrm{d}a}\mathrm{d}a} \quad .$$



N-Body Simulation



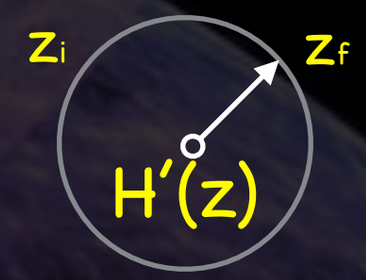


+ ICs (ZA, 2LPT)

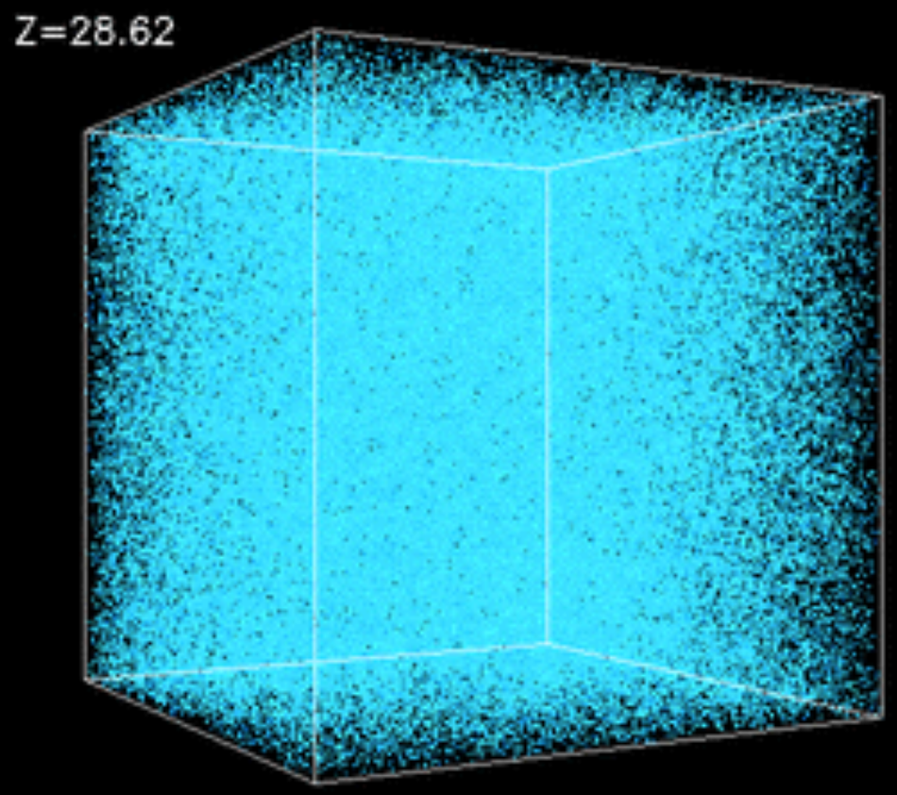
+ Interaction

+ Evolution

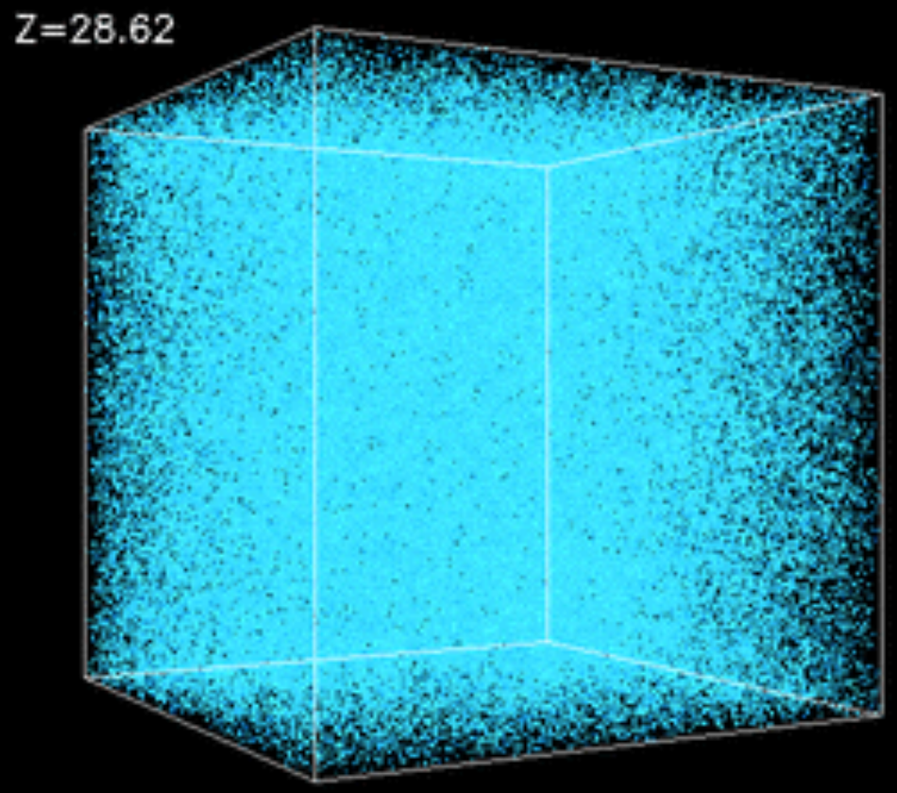
$$\dot{\rho}_c + 3H\rho_c = -\sqrt{\frac{2}{3}}\beta_c(\phi)\frac{\rho_c\dot{\phi}}{M_{\rm Pl}}$$



N-Body Simulation



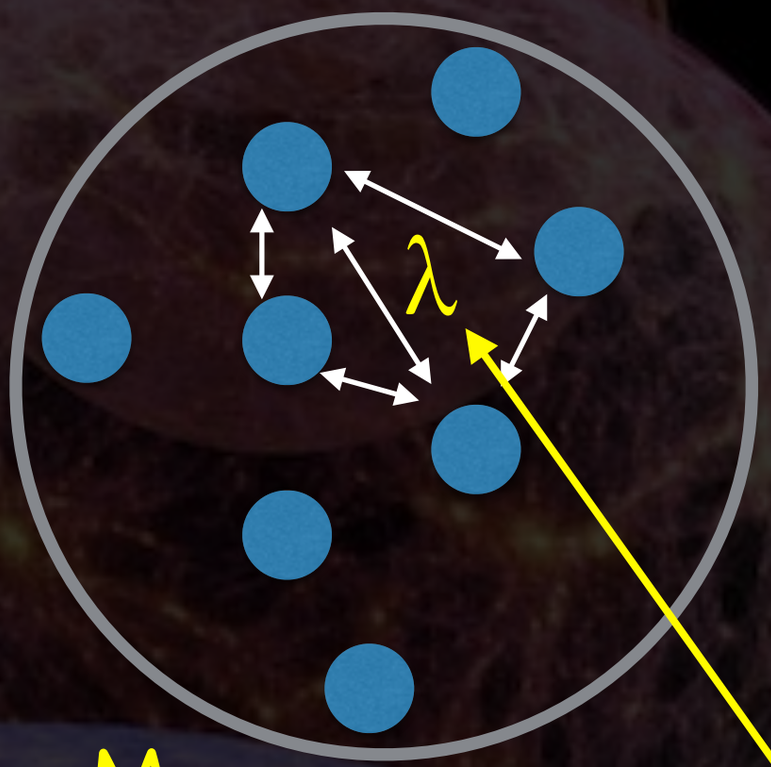
N-Body Simulation



Halos (HMf)

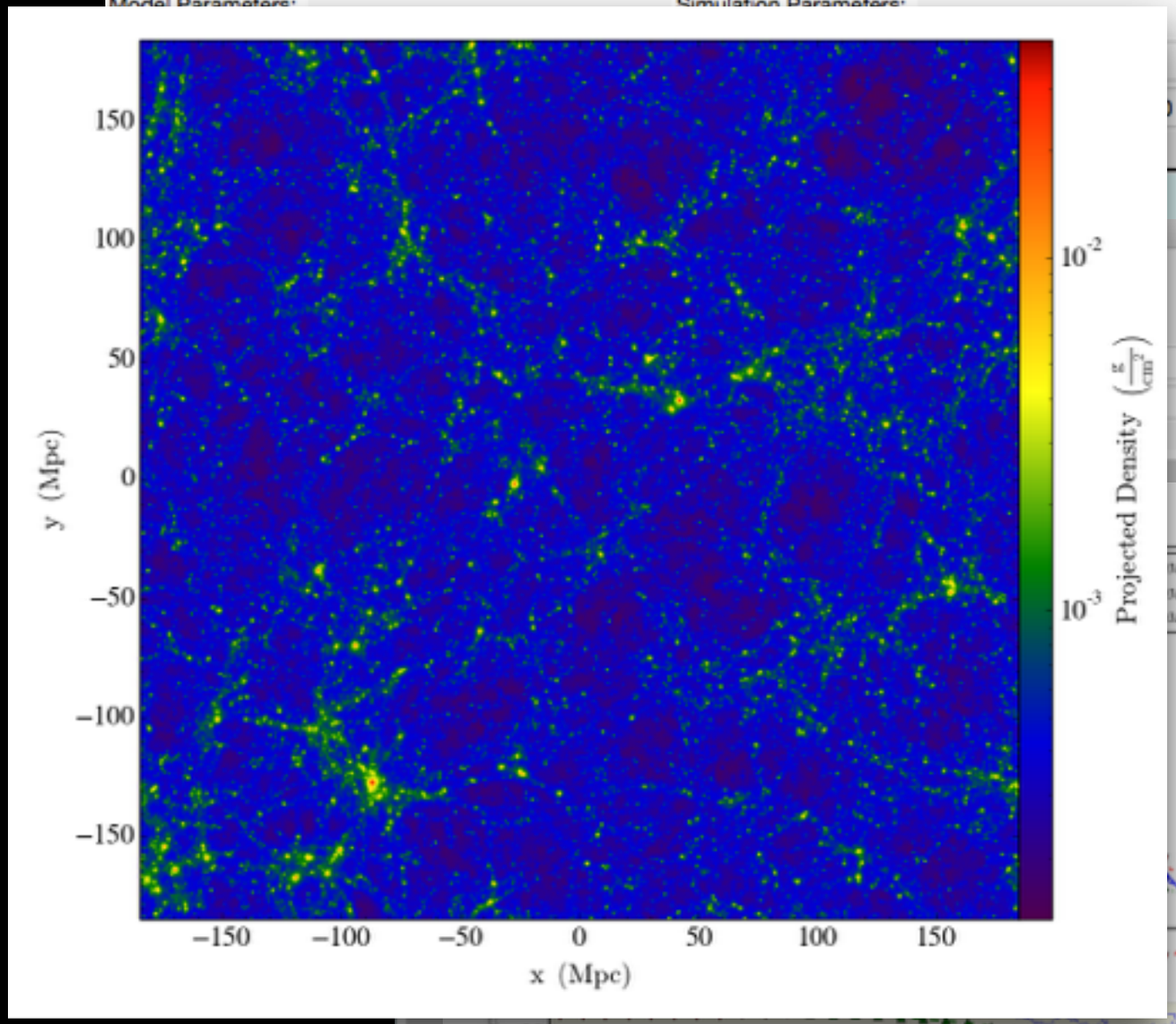
$$\frac{dn}{d\log M} = \frac{M}{L^3}\frac{\Delta N}{\Delta \log M}$$

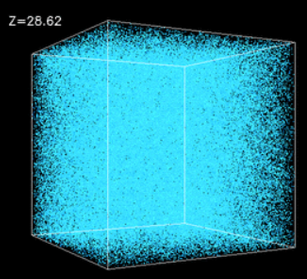
FoF



$\lambda \equiv b \cdot l$

N-Body Simulation

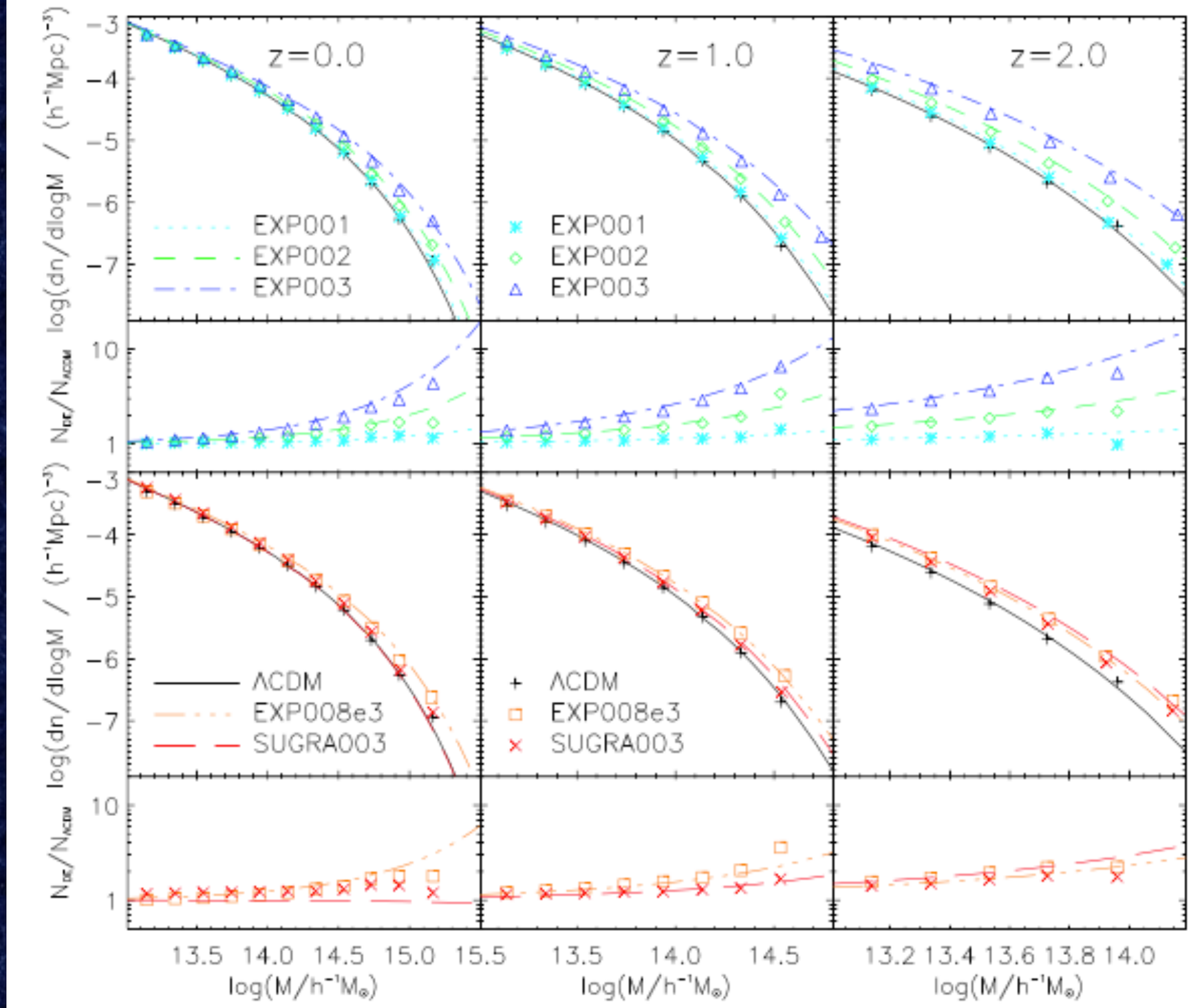


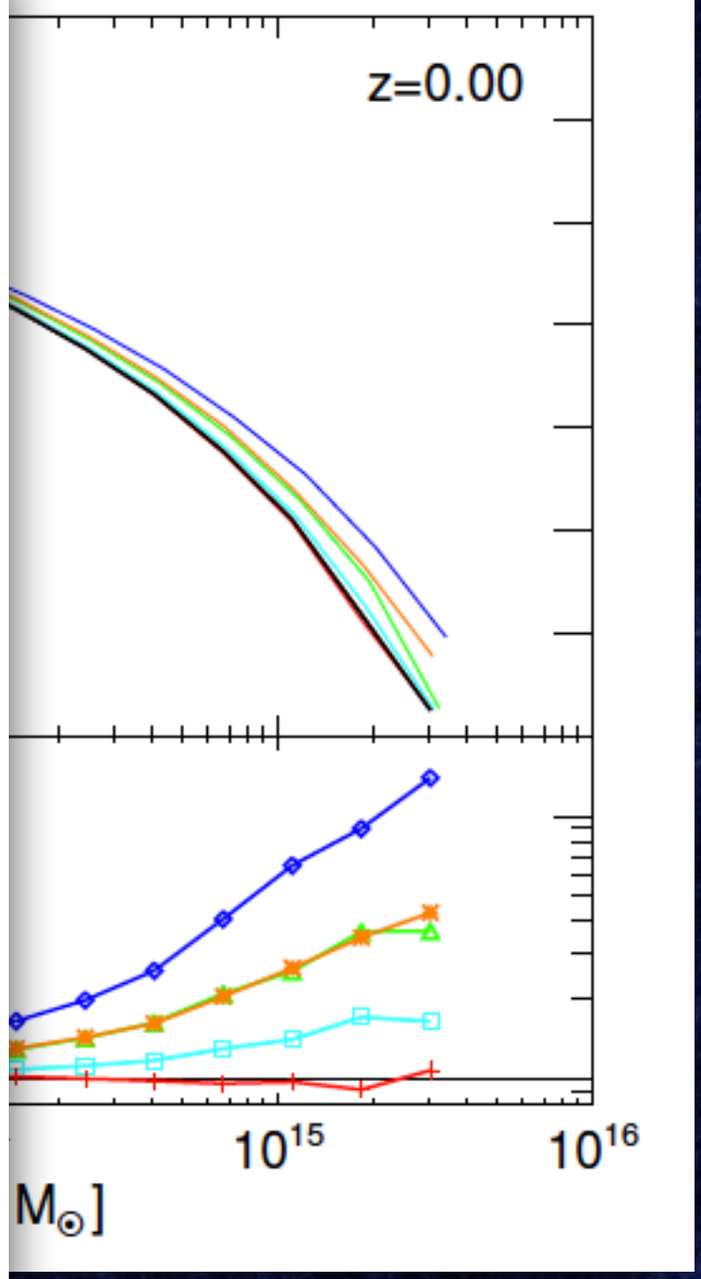


GADGET - 2

A code for cosmological simulations of structure formation

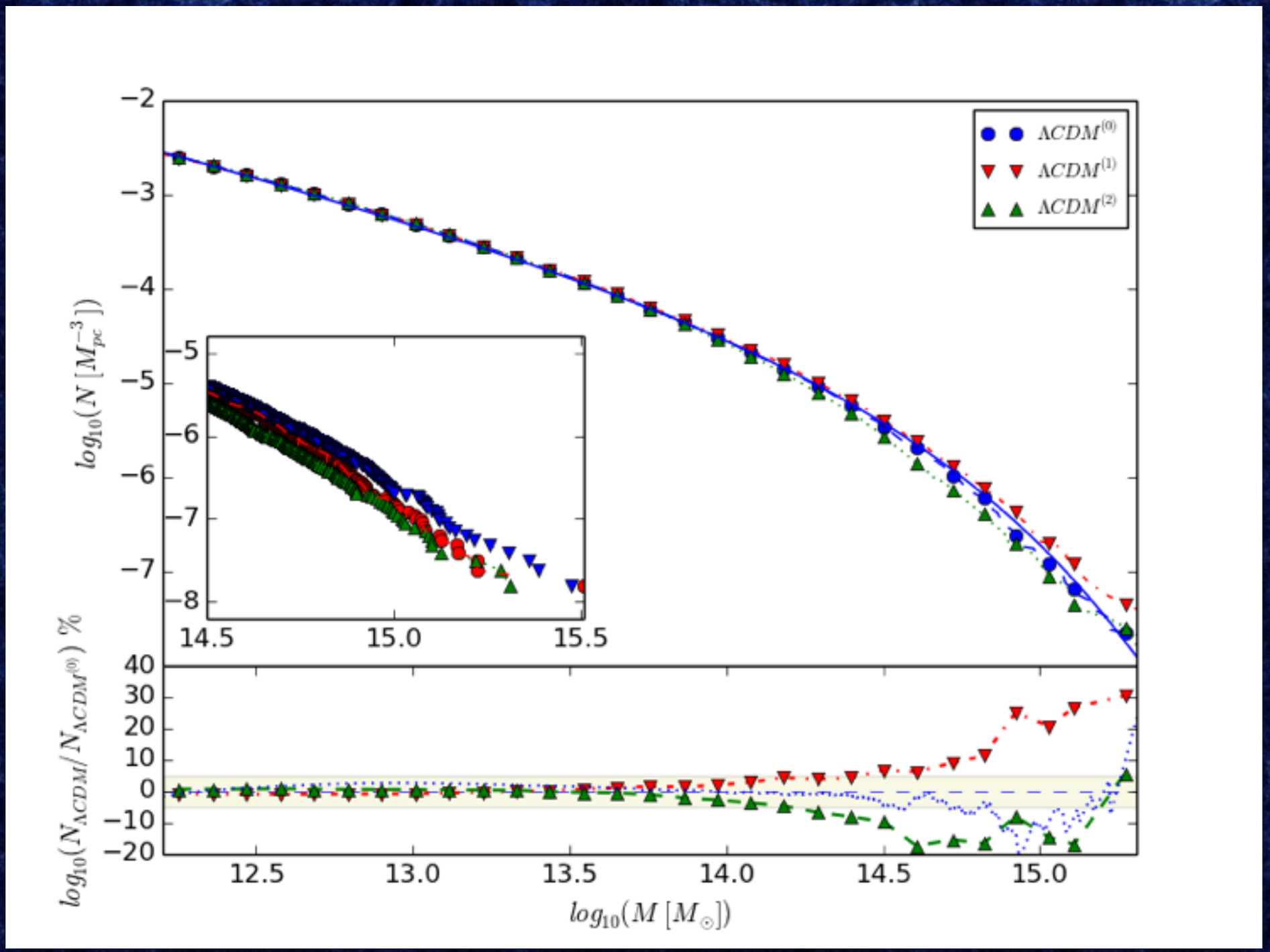
Halo Mass function





Weiguang et al. 2012 (arXiv:1201.3568)

Halo Mass function (non-Gaussian)



Hashim et al, in preparation.

Is it degenerate with Dark Energy Interaction signal ?

Conclusion

- Interaction between dark matter and dark energy is not ruled out by current observations.

- Future galaxy surveys covering huge volumes (SKA) of the universe are needed to constrain interacting Dark Energy models.

- Halo Mass Function from N-Body simulations of interacting dark energy models show enhancement on very large masses.

- Primordial non-Gaussianity show a similar HMF signal which might be degenerate with Dark energy Interaction.