

Simulating the Interaction between Dark Energy and Dark Matter

Mahmoud Hashim

University of the Western Cape

Supervisors: Prof. Roy Maartens (UWC, ICG)

Dr. Chris Clarkson (UCT)

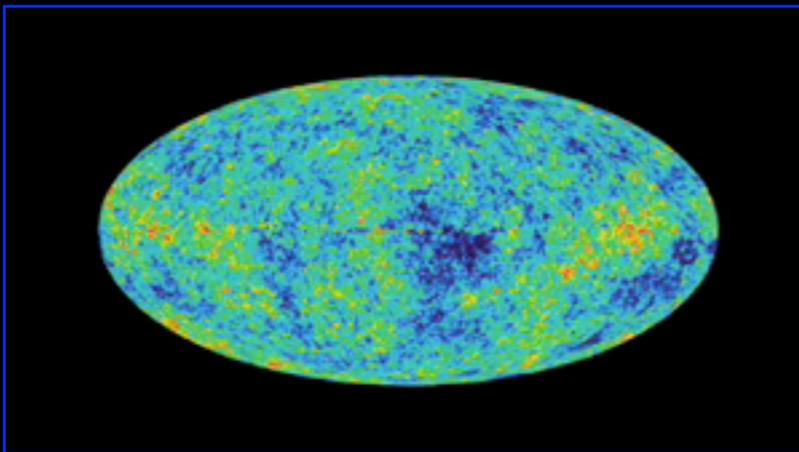
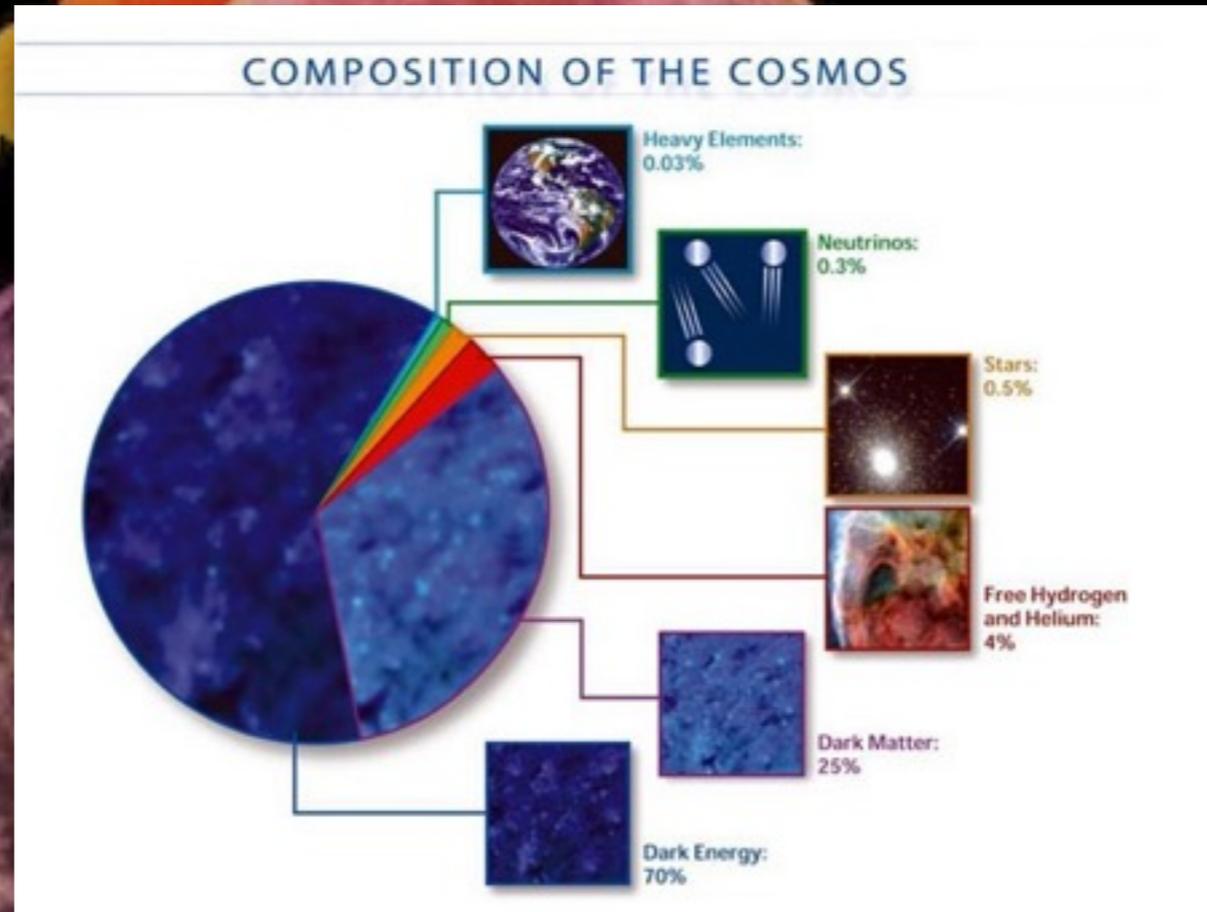
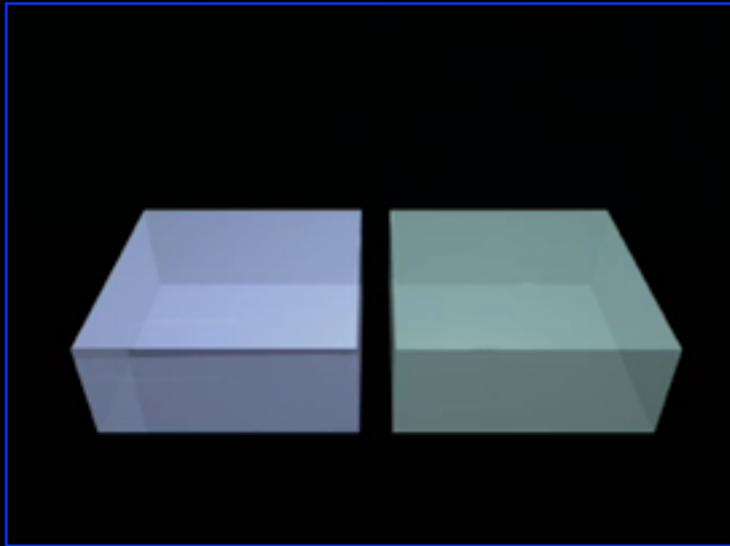
Dr. Daniele Bertacca (BU)



SKA Postgraduate Conference, Stellenbosch, Dec 2015



Structure Formation



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**.

SKA Era

HI Intensity Mapping Survey

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

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

HI Galaxy Redshift Survey

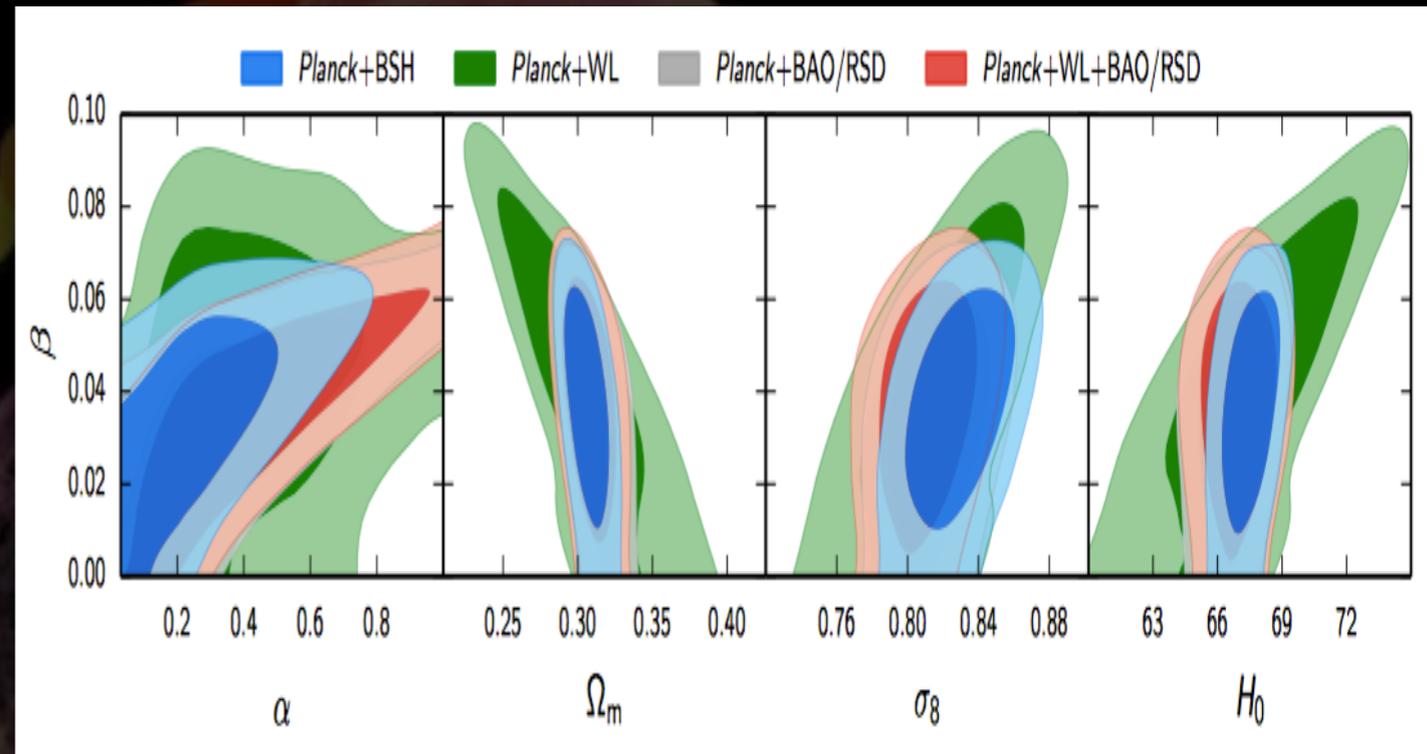
(Individual HI Galaxies detected, very accurate redshift.)

- precise RSD at $z < 0.5$.

Dark Interaction

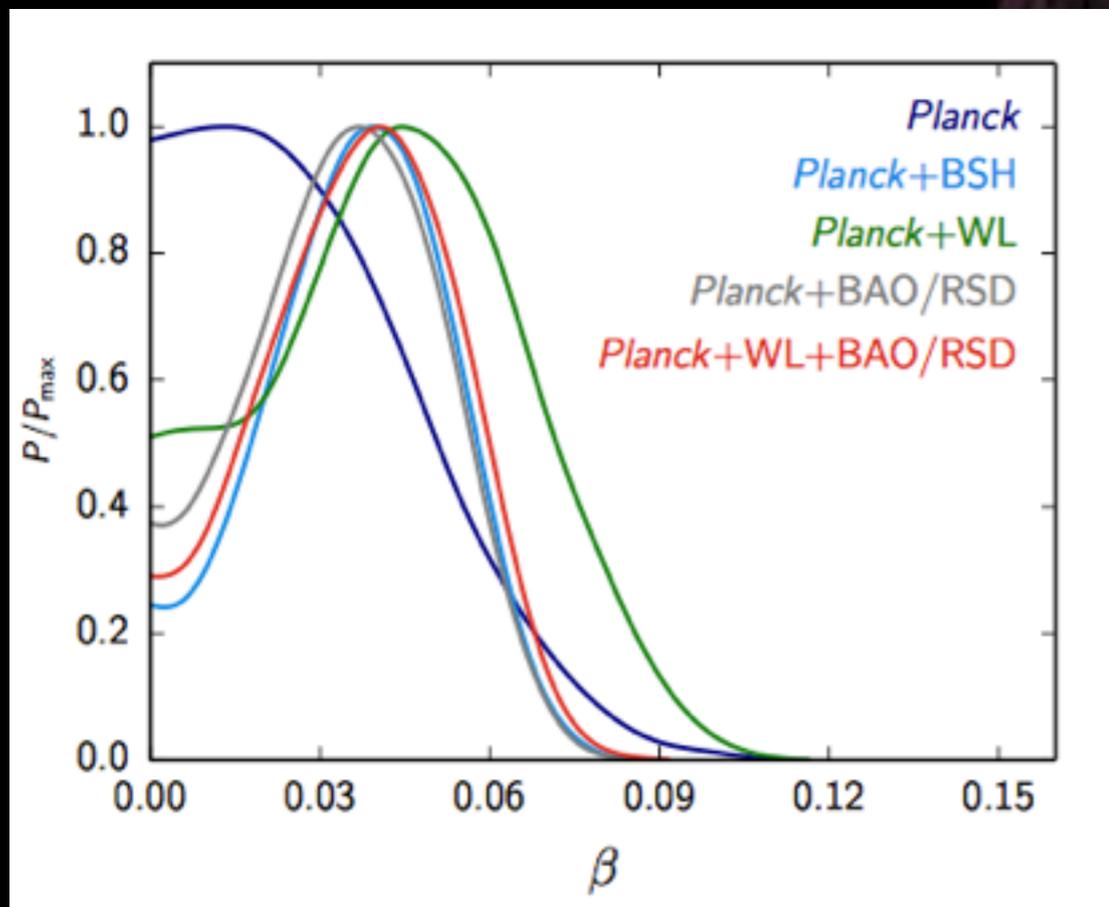
Interaction between Dark Energy and Dark Matter is a theoretical possibility that may help to solve the **coincidence problem**.

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



Planck Collaboration 2015 (arXiv:1502.01590)

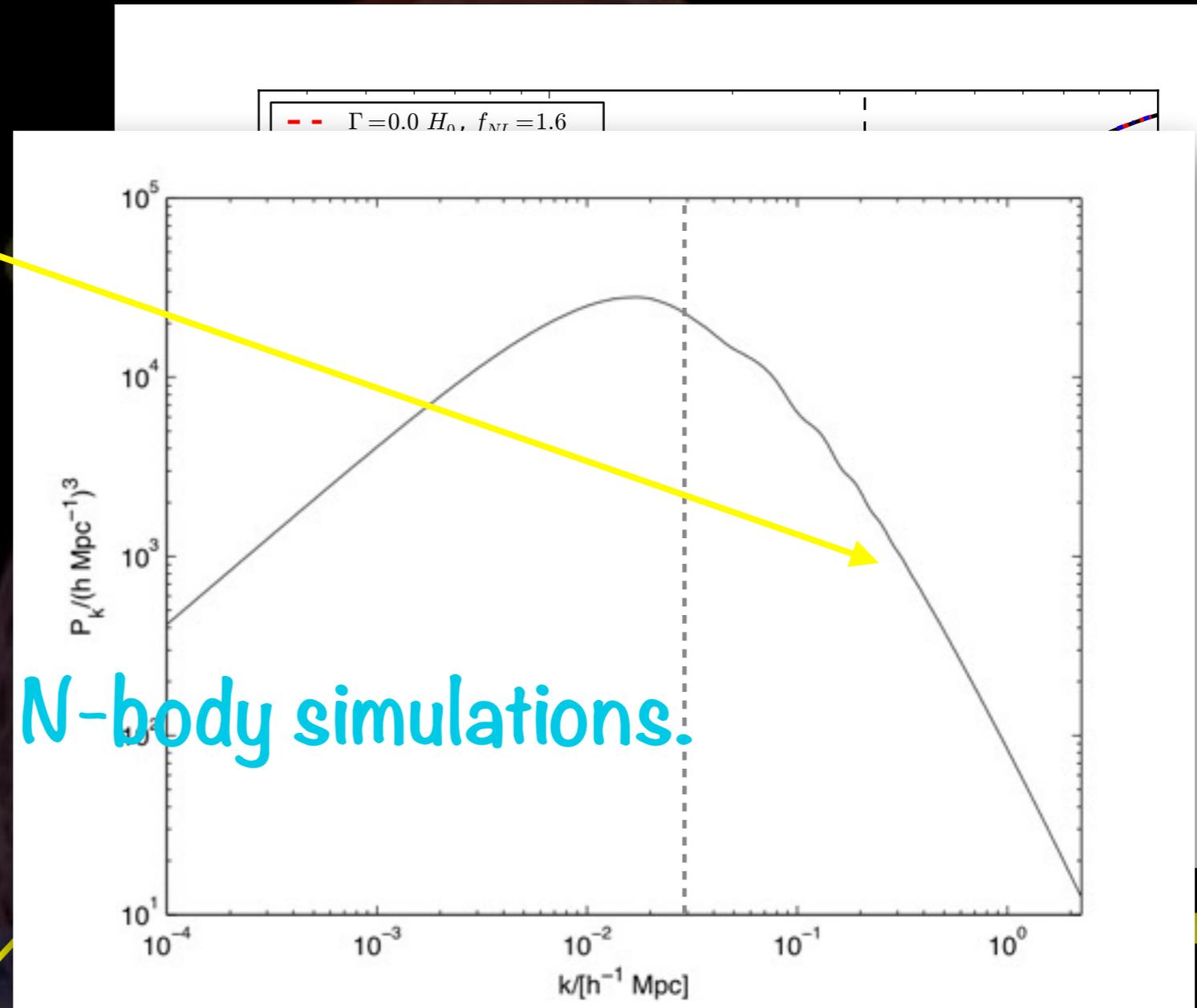
The transfer of energy-momentum between dark matter and dark energy is **not ruled out** by current observations.



Dark Interaction

What happens on nonlinear scales?

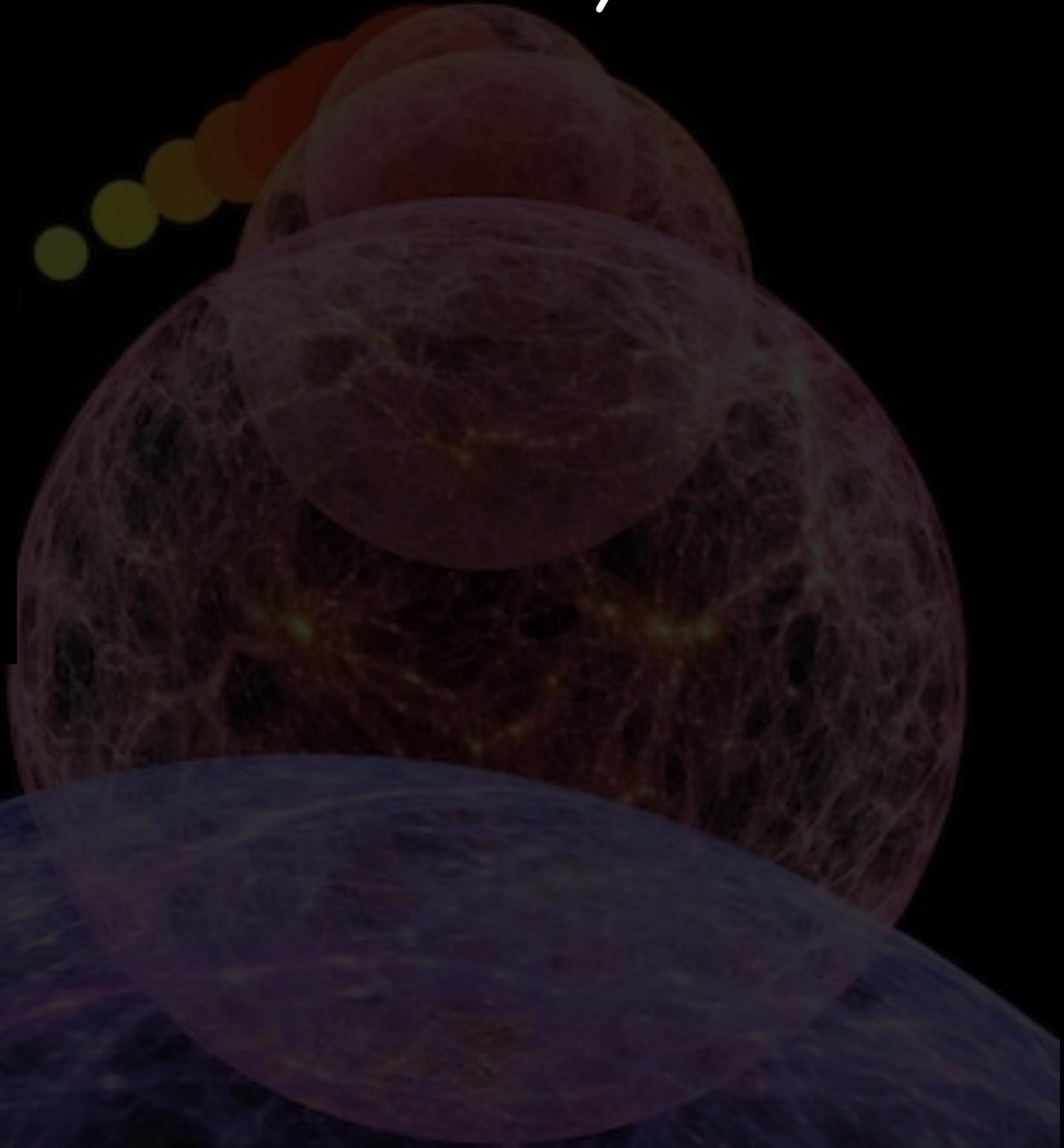
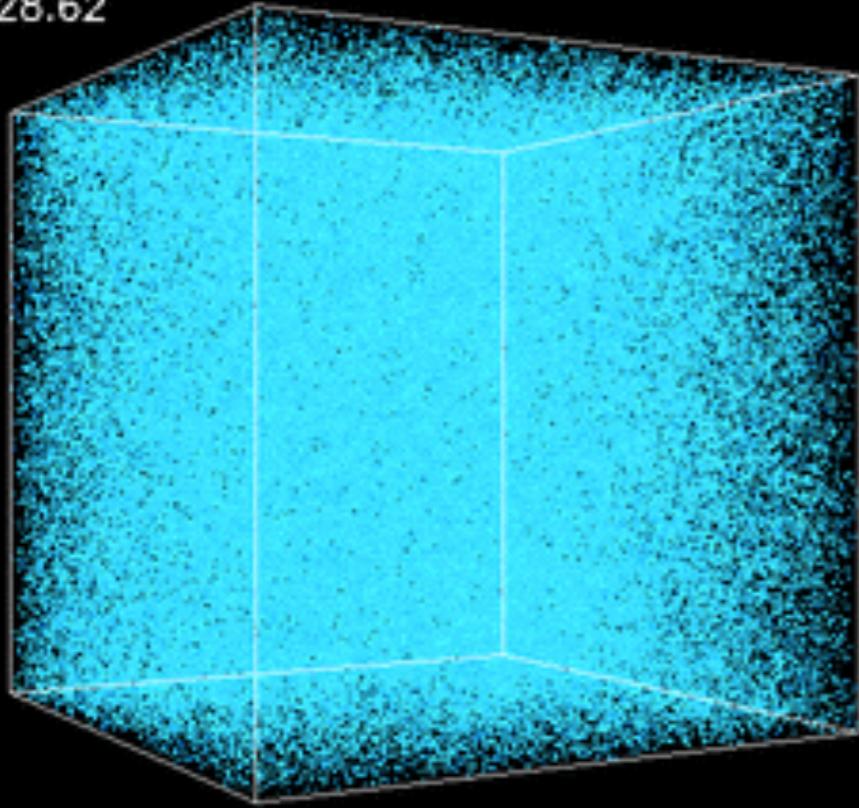
We need to perform N-body simulations.



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.

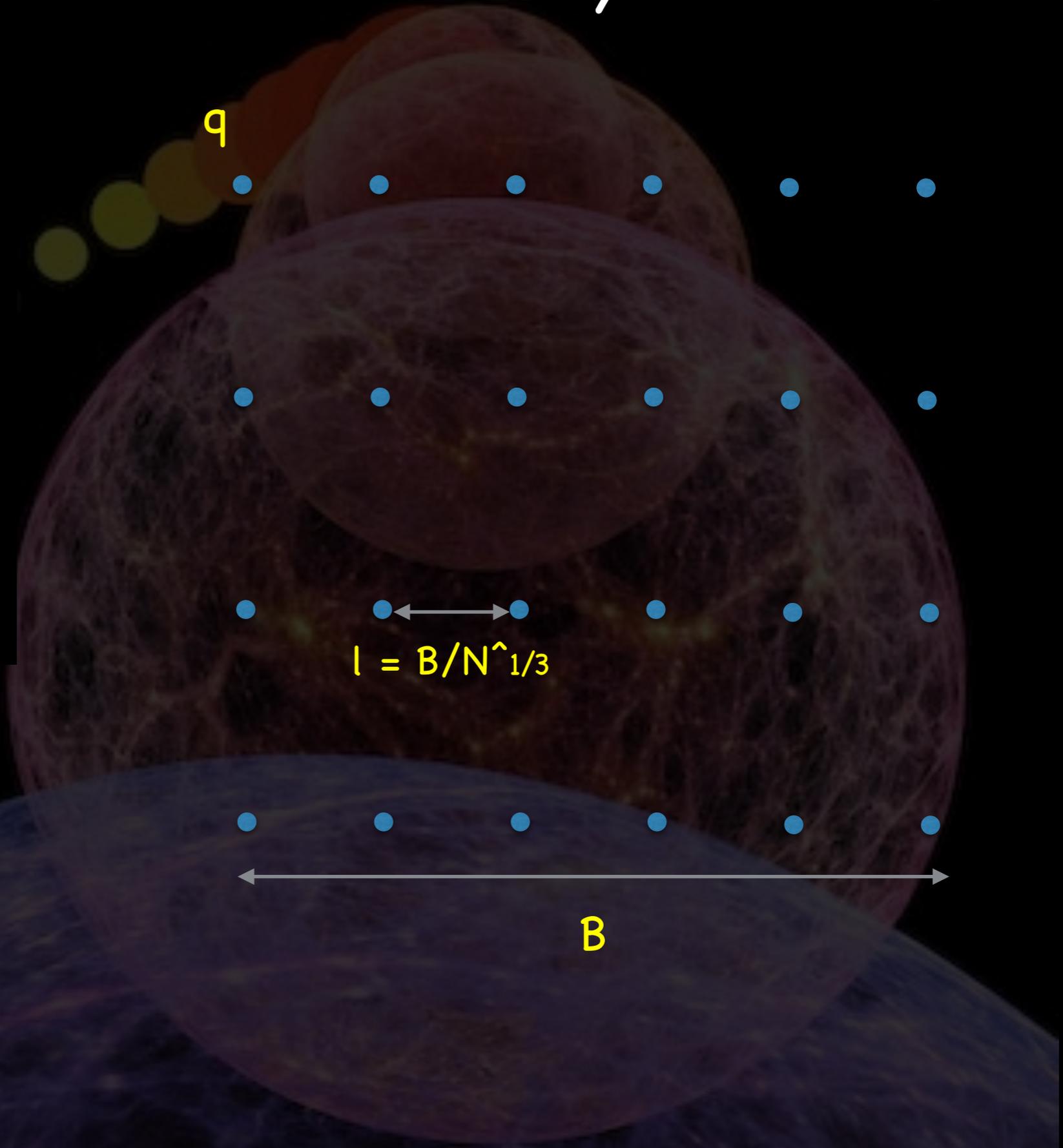
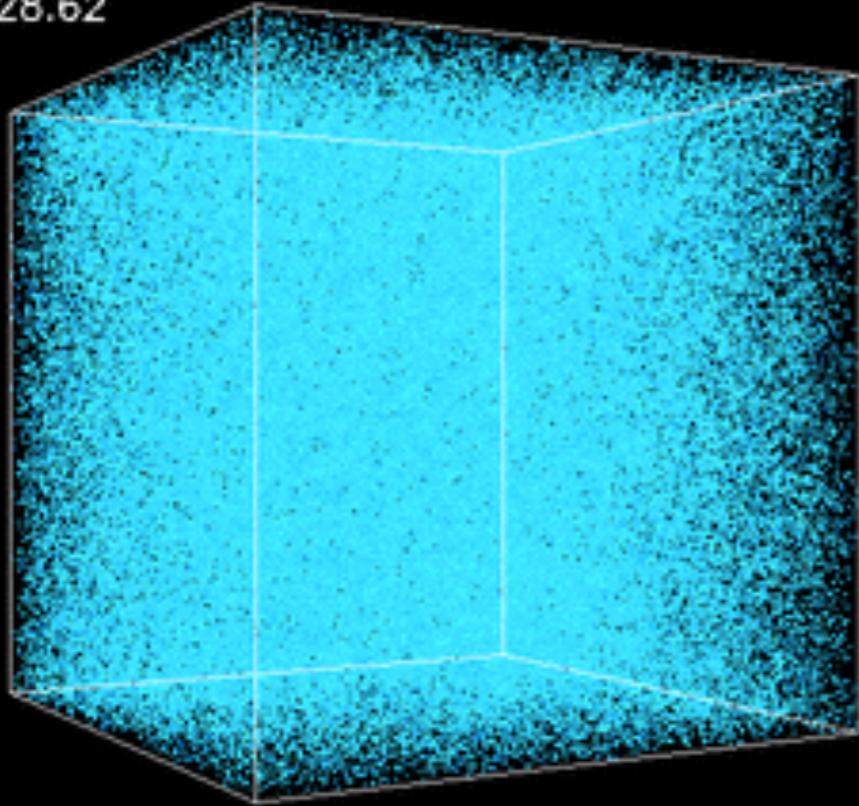
N-Body Simulation

$Z=28.62$



N-Body Simulation

$z=28.62$



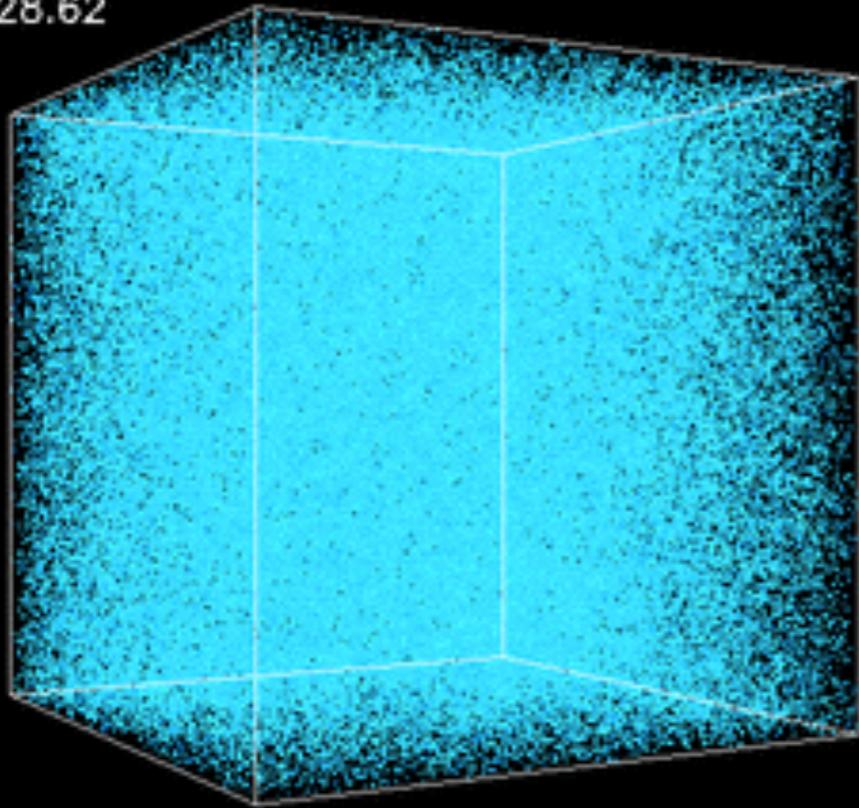
q

$$l = B/N^{1/3}$$

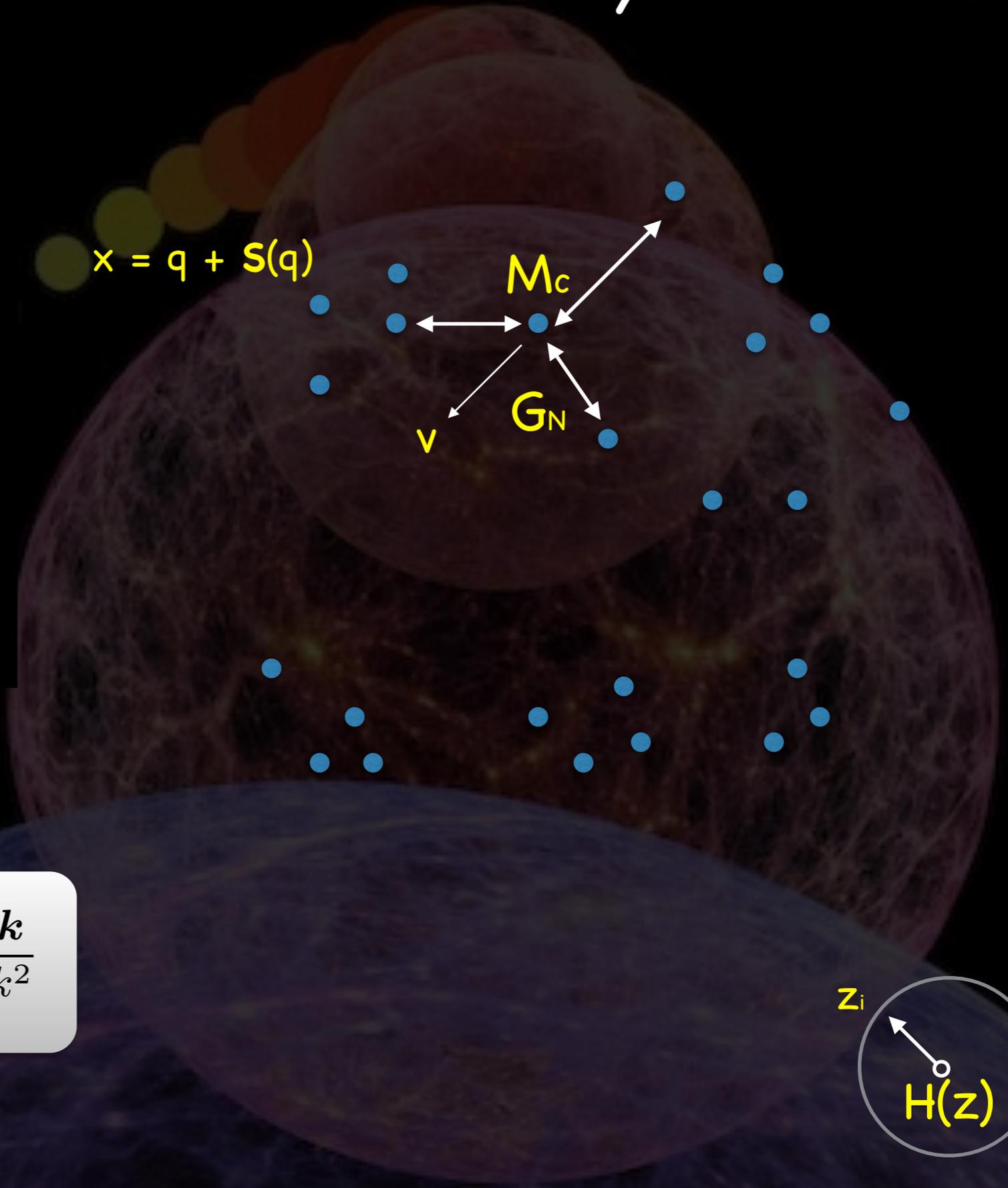
B

N-Body Simulation

$z=28.62$

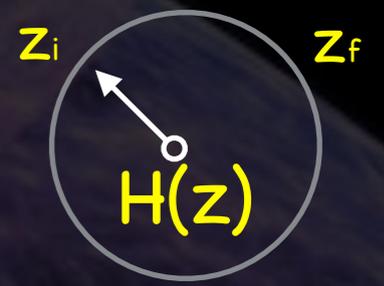


$$\mathbf{x} = \mathbf{q} + \mathbf{S}(\mathbf{q})$$

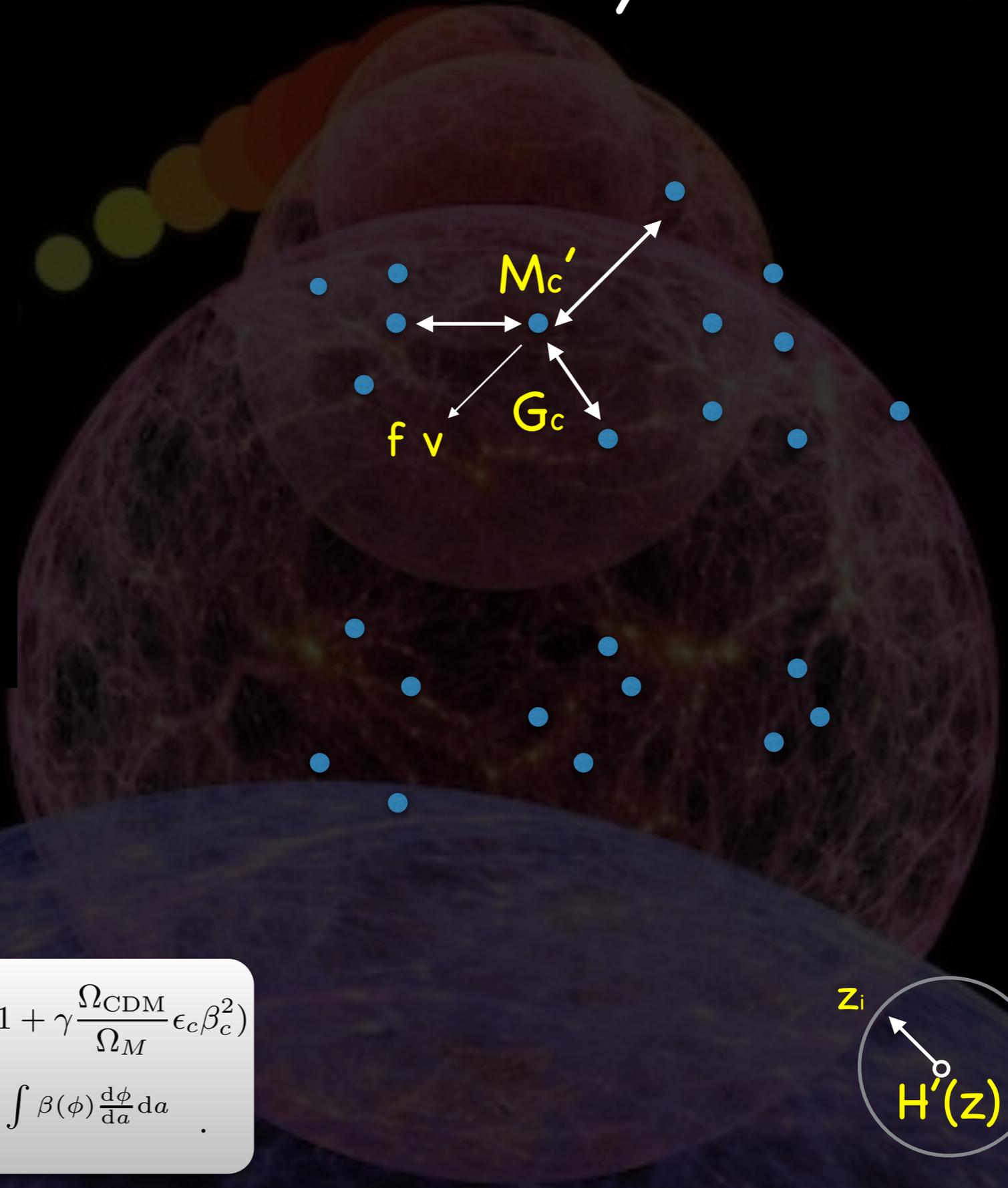
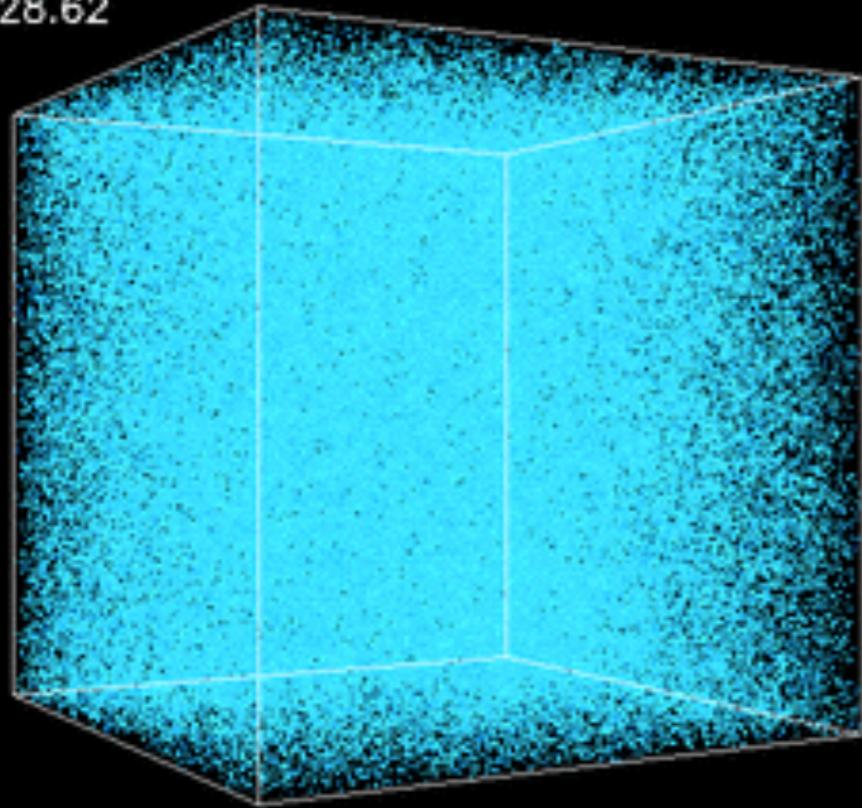


+ ICs (ZA, 2LPT)

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



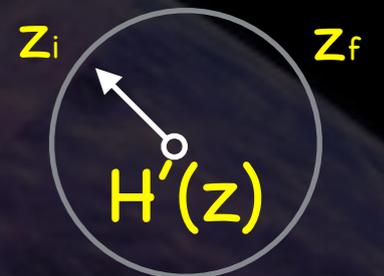
$z=28.62$



+ ICs (ZA, 2LPT)
+ Interaction

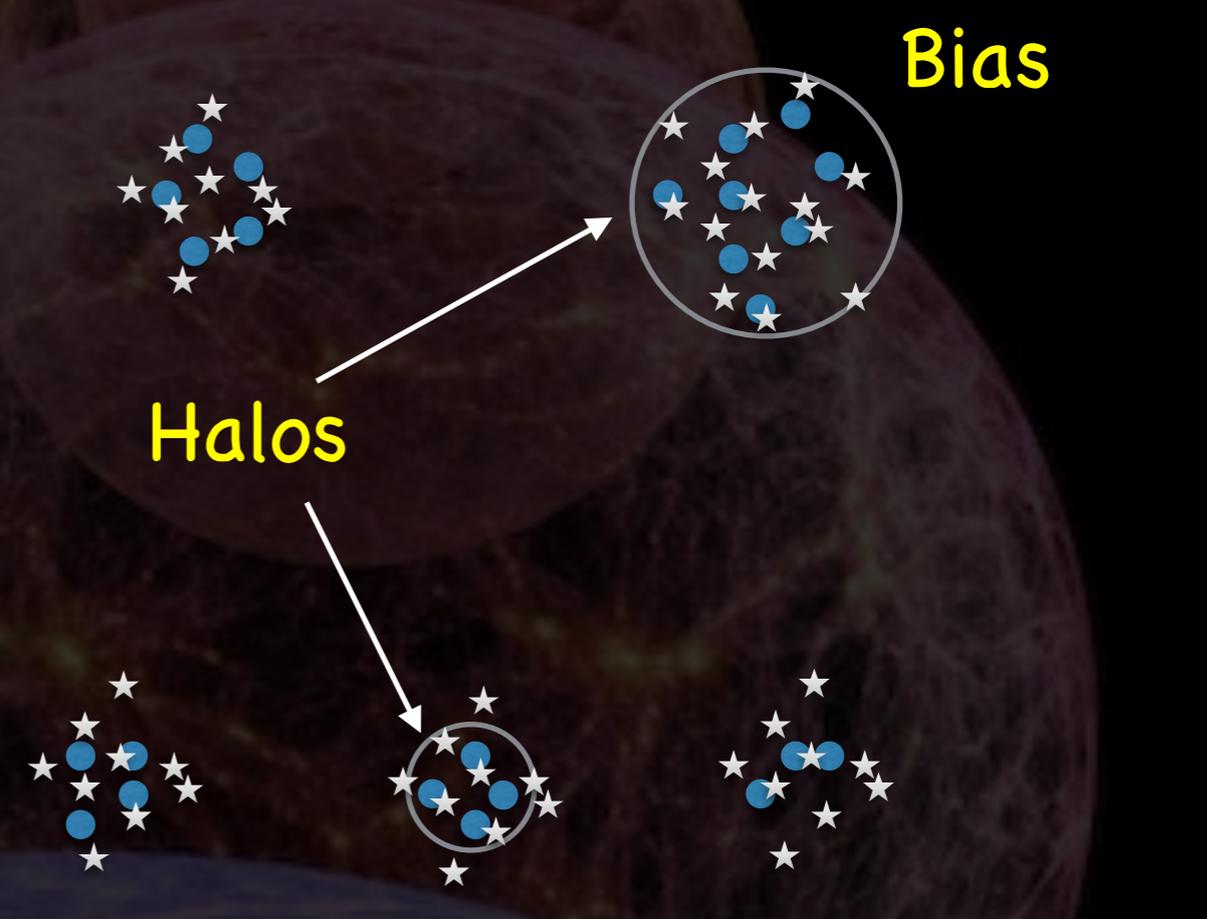
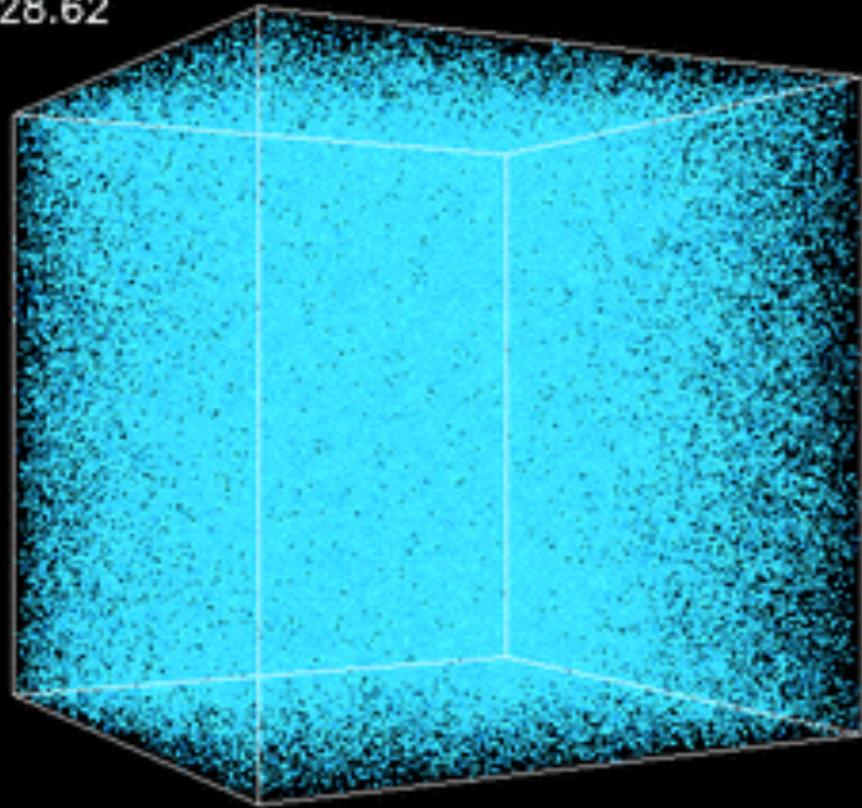
$$\tilde{H} \equiv H \left(1 - \frac{\beta(\phi)}{M} \frac{\dot{\phi}}{H} \right) \quad f(a) \sim \Omega_M^\gamma \left(1 + \gamma \frac{\Omega_{\text{CDM}}}{\Omega_M} \epsilon_c \beta_c^2 \right)$$

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



N-Body Simulation

$z=28.62$

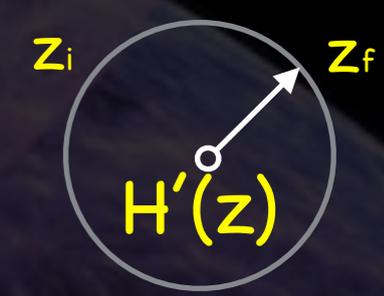


+ ICs (ZA, 2LPT)

+ Interaction

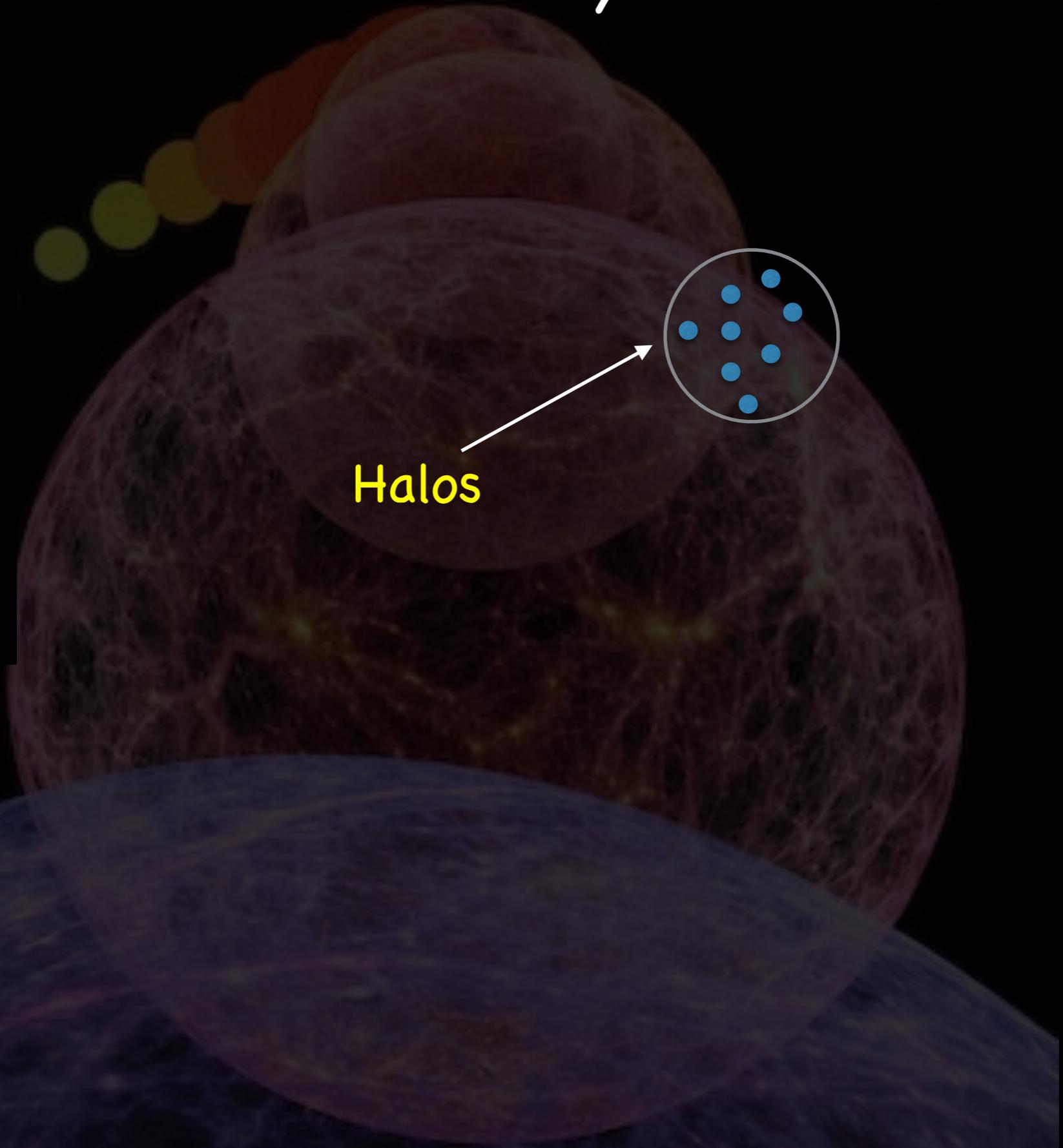
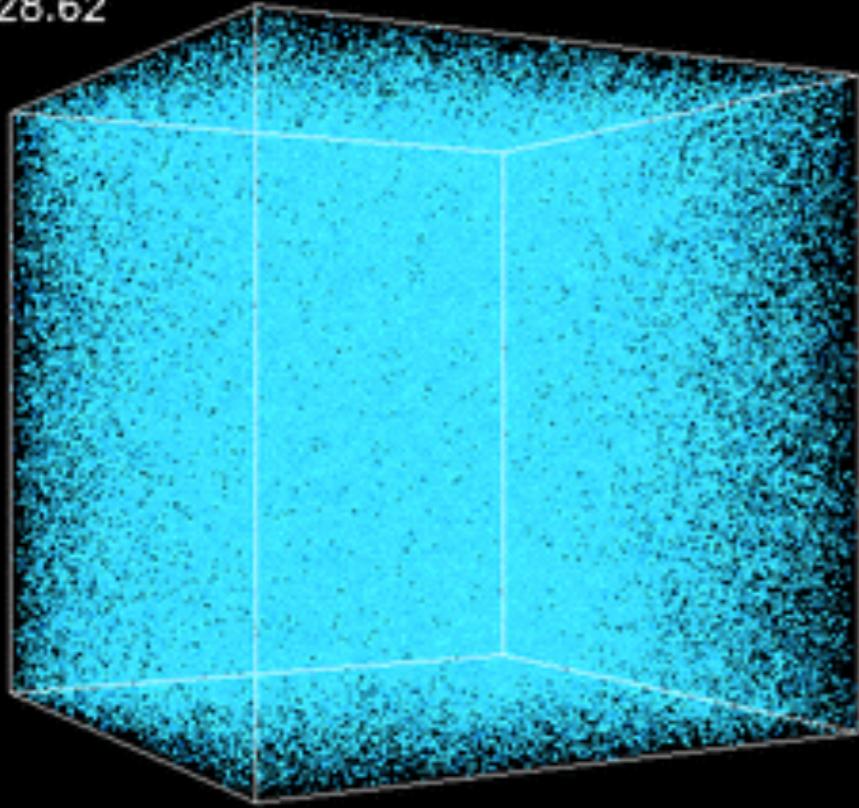
+ Evolution

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



N-Body Simulation

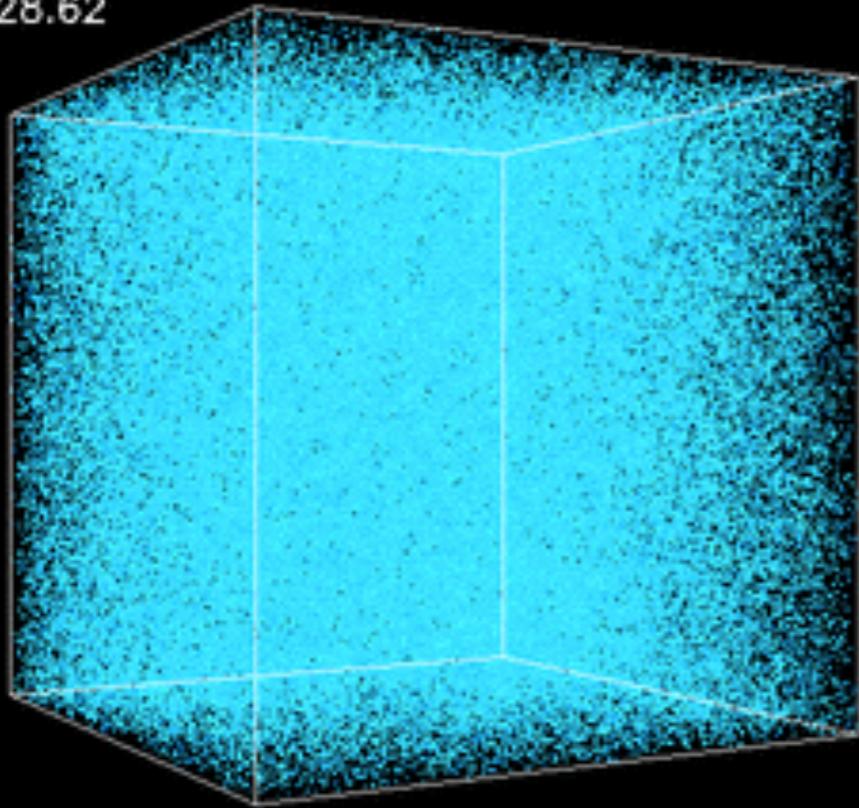
$Z=28.62$



Halos

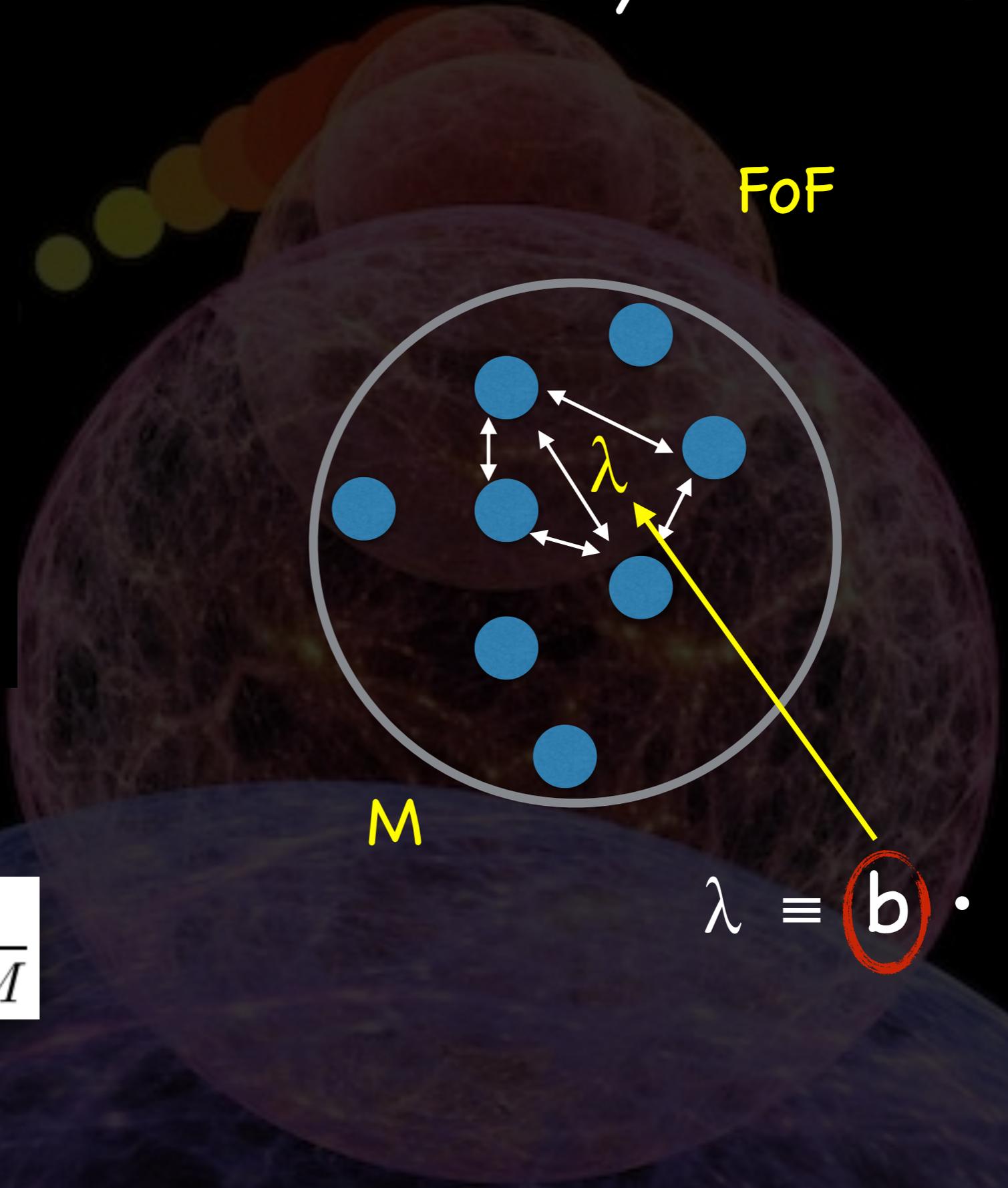
N-Body Simulation

$z=28.62$



Halos (HMF)

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



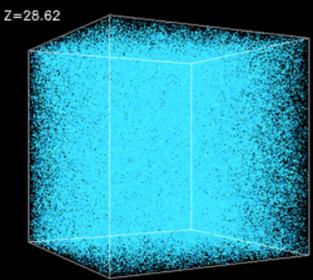
$$\lambda \equiv \text{b} \cdot l$$

The screenshot displays the GADGET 2 GUI interface. On the left, a large 2D density map shows the projected density of particles in a simulation box. The axes are labeled 'x (Mpc)' and 'y (Mpc)', both ranging from -150 to 150. A color bar on the right indicates the projected density in units of $\frac{g}{cm^3}$, with a scale from 10^{-3} to 10^{-2} . The map shows a complex distribution of particles, with higher density regions appearing in yellow and red, and lower density regions in blue and purple.

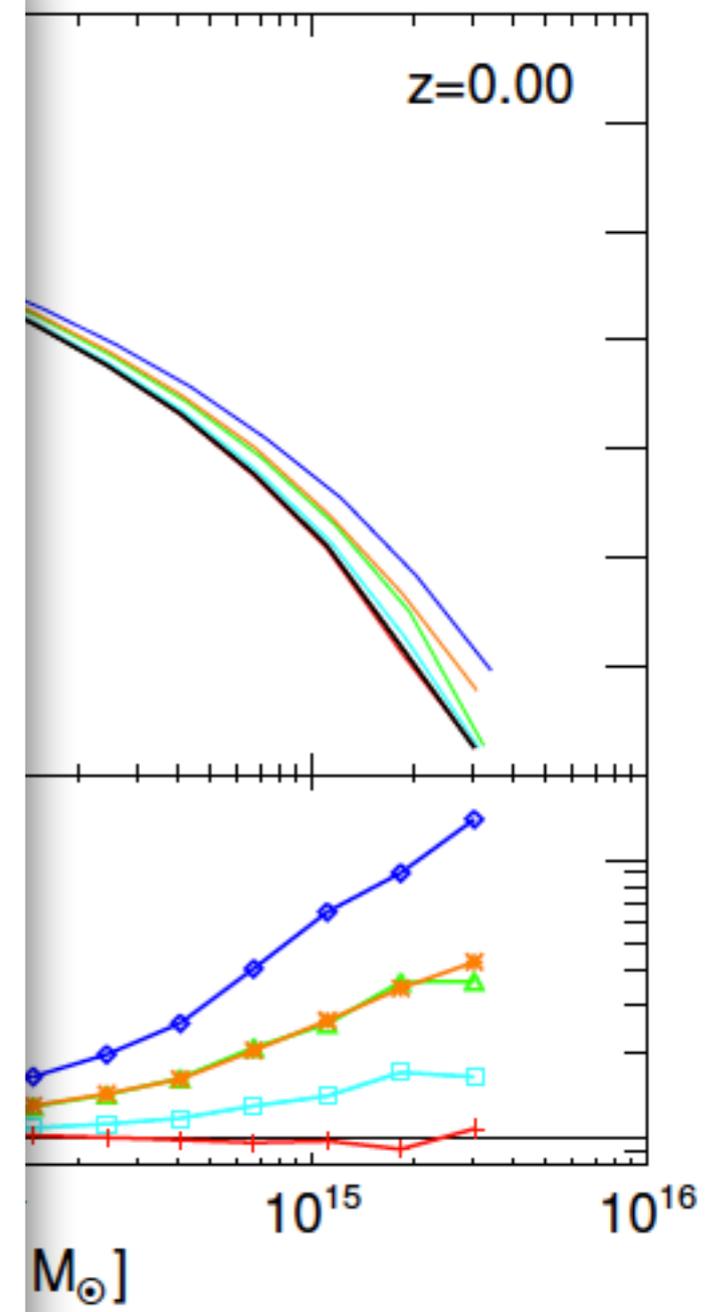
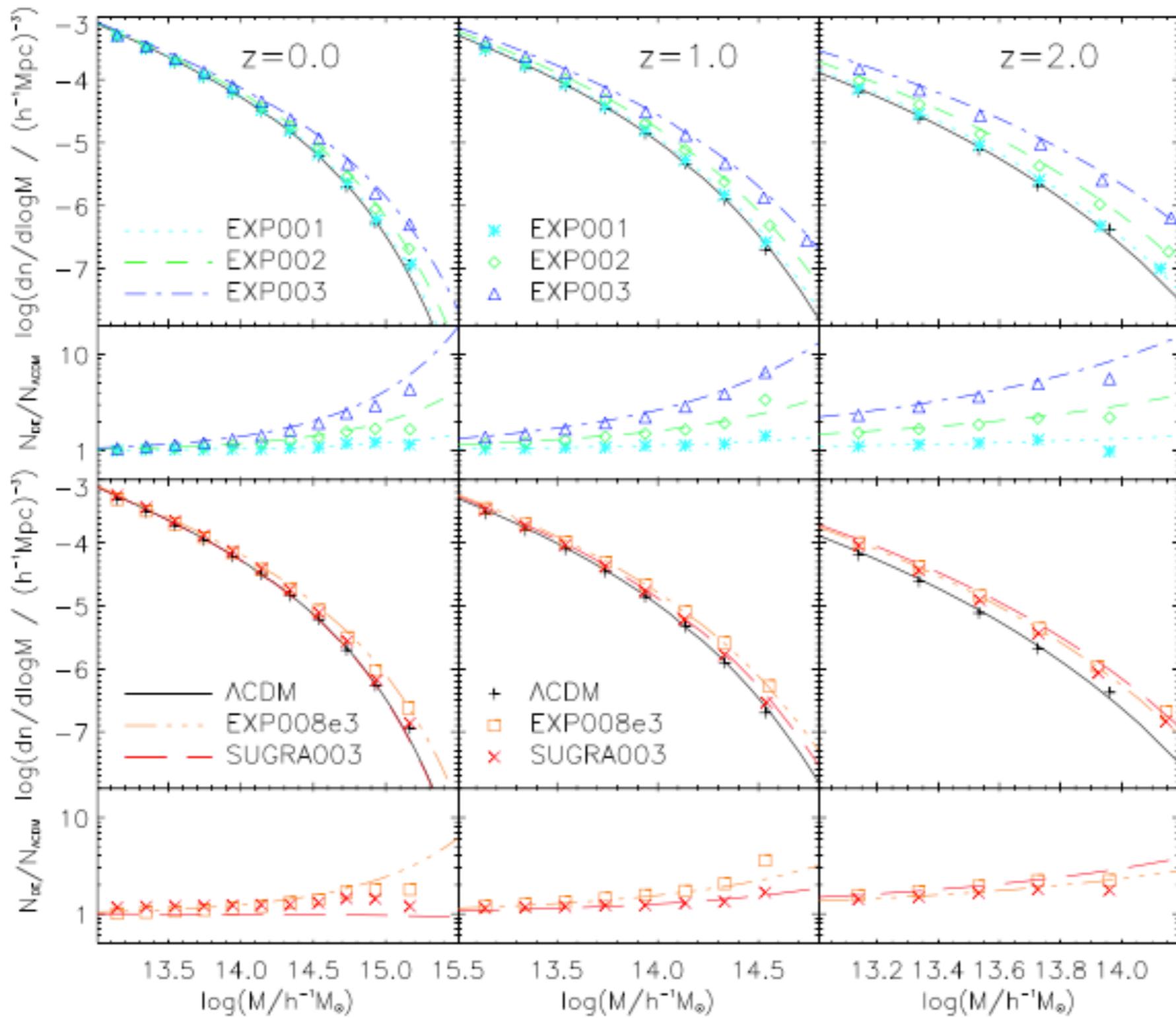
The main GUI area contains several sections for parameter configuration:

- Cosmological Parameters:** Includes a dropdown for 'Planck' and a 'set' button. Below are input fields for Ω_{Λ} (0.692), Ω_m (0.308), σ_8 (0.8149), Ω_b (0.0484), and H_0 (0.6781). There is also an input for n_s (0.9677).
- Initial/Final Redshift:** Both are set to 0.0.
- Simulation Parameters:** Includes 'N_part' (0) and 'eta' (0.0).
- ICs MakeOpts:** Radio buttons for 'ZA' (selected), '2LPT', 'Gauss' (selected), 'Loc', 'Add Gass', 'Orth', and 'Eq'.
- Buttons:** 'Run', 'Gadget2(Only)', 'Results', 'QStat', and 'Quit'.
- Model and Plot Options:** 'Add Model' is set to 'LCDM' and 'Plot_Opts' is set to 'HMF'. There are 'Show Details', 'Refresh', 'Show', and 'Back' buttons.

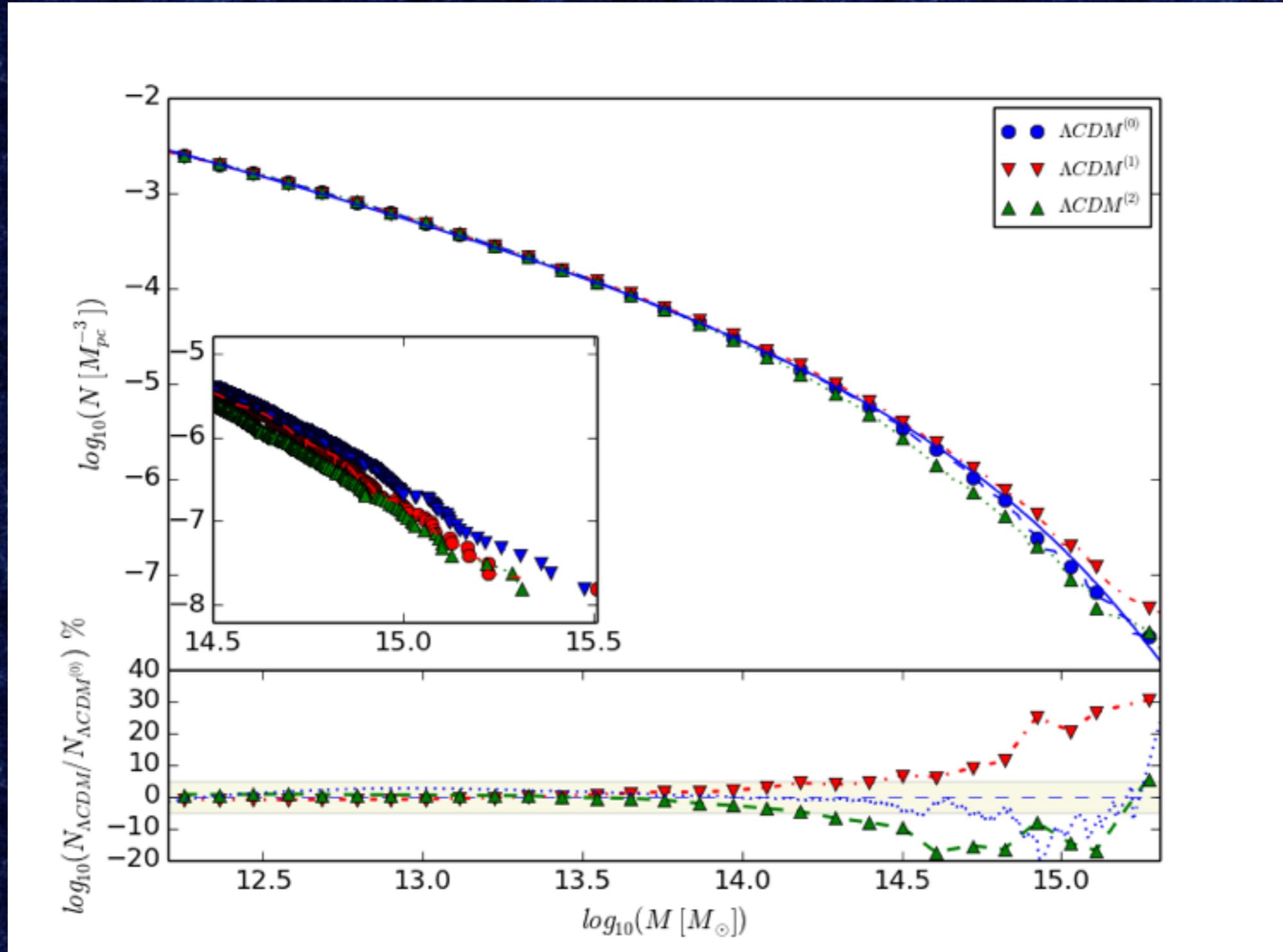
At the bottom of the GUI, there is a toolbar with icons for home, back, forward, zoom in, zoom out, and save. Below the toolbar, the text 'Results from Simulation Run' is visible. The bottom right corner of the GUI area contains the text 'Gadget-2 GUI ©2015'.



Halo Mass function



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.