Generalized Dark Matter in Compact Groups

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1. Introduction

Generalized Dark Matter is an extension of CDM which allows a pressure P and a shear Σ different from zero. This model has three free parameters namely, the equation of state w, sound speed c_s and the viscosity c_{vis}. Choosing these parameter values properly it is possible to reproduce some known scenarios such as

- If $(w, c_s^2, c_{\text{vis}}^2) \to (1/3, 1/3, 1/3)$ we have HDM
- If $(w, c_s^2, c_{\text{vis}}^2) \to (\omega, 1, 0)$ we have SFDM, (Wayne Hu 1998)
- To stay near CDM, then $w, c_s^2, c_{\text{vis}}^2 \ll 1$ (B. Thomas et al., 2020)

Likelihood (PPS+...)	Model (Λ-GDM+...)	$10^2 w$ 95%	$10^2 w$ 99%	$10^6 c_s^2$ (upper bound) 95%	$10^6 c_s^2$ (upper bound) 99%	$10^6 c_{\text{vis}}^2$ (upper bound) 95%	$10^6 c_{\text{vis}}^2$ (upper bound) 99%
		$-0.040^{+0.473}_{-0.468}$	$-0.040^{+0.700}_{-0.701}$	3.31	6.31	5.70	11.3
+ Lens		$0.066^{+0.434}_{-0.427}$	$0.066^{+0.654}_{-0.642}$	1.92	3.44	3.27	5.99
+ Lens + BAO		$0.074^{+0.111}_{-0.110}$	$0.074^{+0.164}_{-0.163}$	1.91	3.21	3.30	6.06
	+ HM	$-0.029^{+0.477}_{-0.481}$	$-0.029^{+0.716}_{-0.690}$	3.11	5.39	5.62	11.1
+ Lens	+ HM	$-0.087^{+0.448}_{-0.461}$	$-0.087^{+0.668}_{-0.649}$	1.92	3.83	3.13	5.79

2. GDM model

Lets consider a perturbated metric in a FRW universe

$$ds^2 = a^2\left(-(1+2\Psi)d\tau^2 - 2\vec{\nabla}_i\zeta d\tau dx^i + \left[\left(1+\frac{1}{3}h\right)\gamma_{ij} + D_{ij}v\right]dx^i dx^j\right) \quad (1)$$

where $D_{ij} = \vec{\nabla}_i\vec{\nabla}_j - \frac{1}{3}\gamma_{ij}\vec{\nabla}^2$, being $\vec{\nabla}$ the covariant derivative. After perturbating the Einstein equation as well as the energy density ρ and the pressure P we can construct the pertubated equations at first order,

$$\dot{\delta}_I = 3H(w_I\delta_I - \Pi_I) - (1+w_I)\left[\frac{k^2}{a}(\theta_I - \zeta) + \frac{1}{2}\dot{h}\right] \quad (2)$$

$$a\dot{\theta}_I = -(1-3c_a^2)aH\theta_I + \frac{\Pi_I}{1+w_I} - \frac{2}{3}k^2\Sigma_I + \Psi \quad (3)$$

For Π_I and Σ_I there are some closure equatinos

$$\Pi_g = c_a^2\delta_g + 3(1+w_I)(c_s^2 - c_a^2)aH\theta_g \quad (4)$$

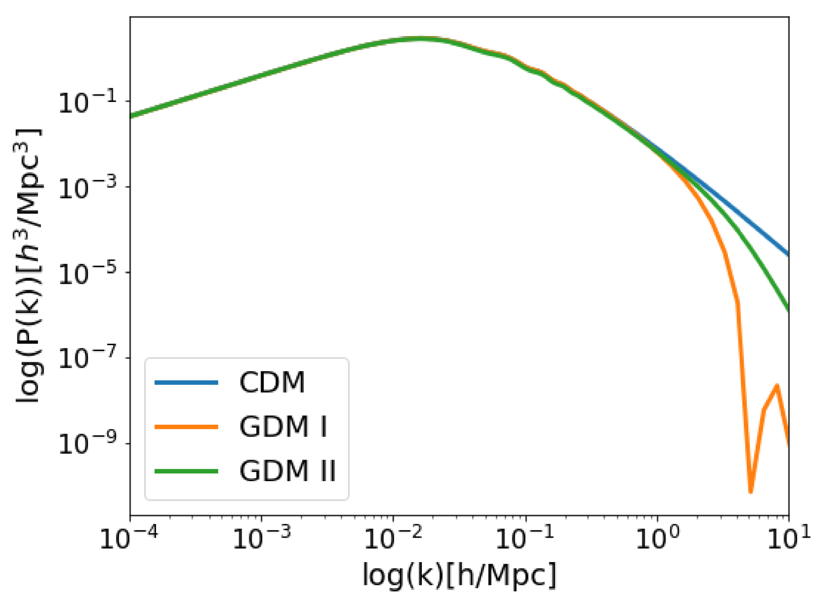
$$\dot{\Sigma}_g = -3H\Sigma_g + \frac{4}{1+w_I}c_{vis}^2\left(\frac{\theta_g}{a} - \frac{1}{2}\dot{v}\right) \quad (5)$$

The first expression corresponds to the perturbated pressure while the second one is related to the shear dynamics.
It is convenient to define some invariant potentials

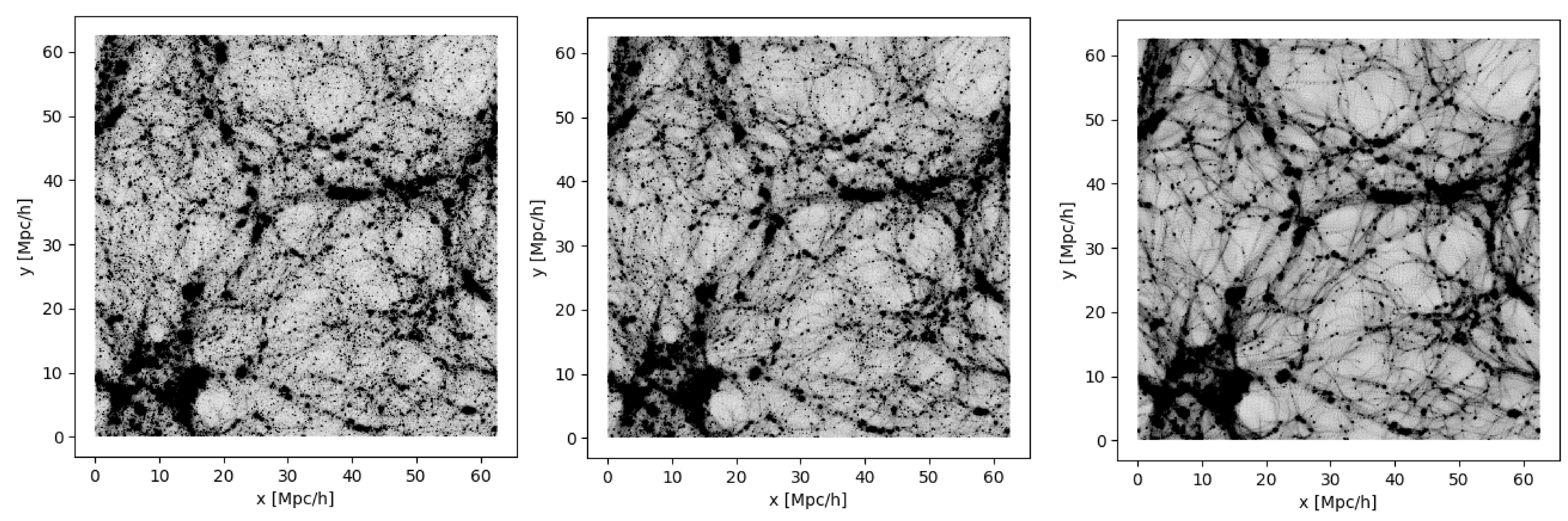
$$\hat{\Phi} \equiv \eta + H\left(\frac{1}{2}\dot{\nu} + \zeta\right) \qquad \hat{\Psi} \equiv \Psi - \frac{1}{a}\partial_\tau\left[a\left(\frac{1}{2}\dot{\nu} + \zeta\right)\right] \quad (6)$$

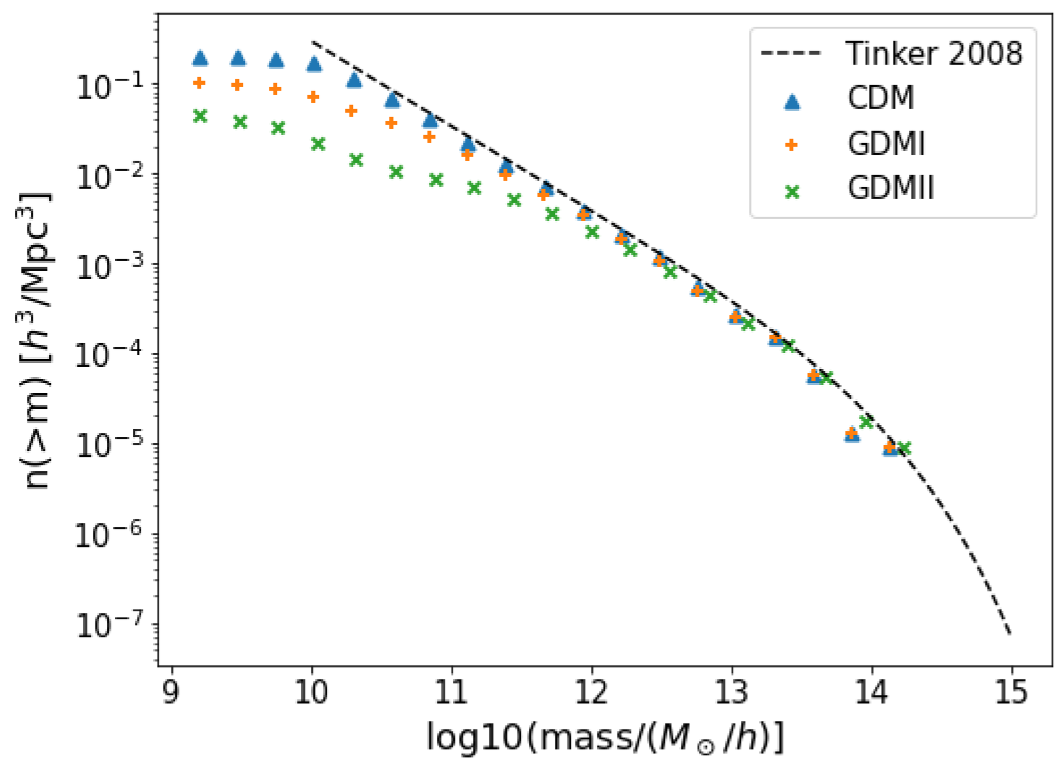
The free parameter values determine the dynamics of the potentials and therefore the CMB and Matter Power Spectrum Behavior.

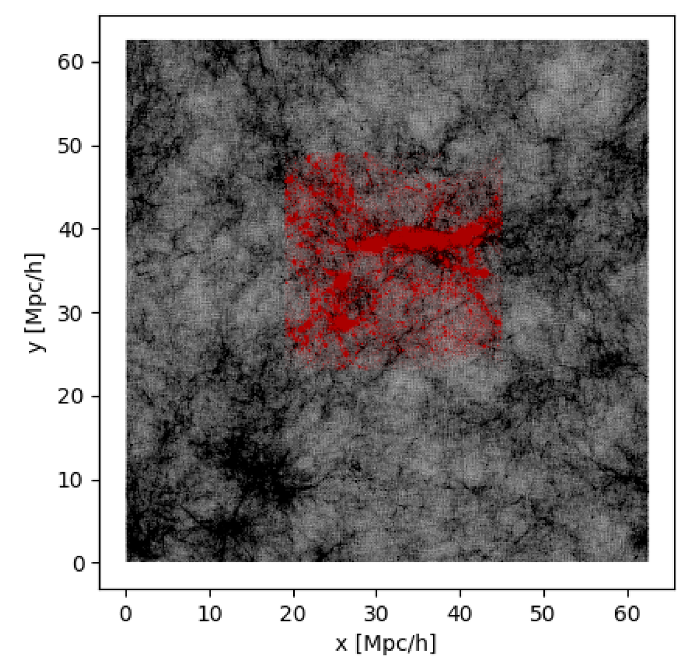
3. Cosmological Simulations



z=127, N=272^3, L=62.5 Mpc/h, ϵ = 0.05 kpc
GDM I: w=-1×10^{-4}, $c_s = 1\times10^{-6}$, $c_{\text{vis}} = 1\times10^{-7}$
GDM II: w=6×10^{-4}, $c_s = 1.92\times10^{-6}$, $c_{\text{vis}} = 1.1\times10^{-7}$







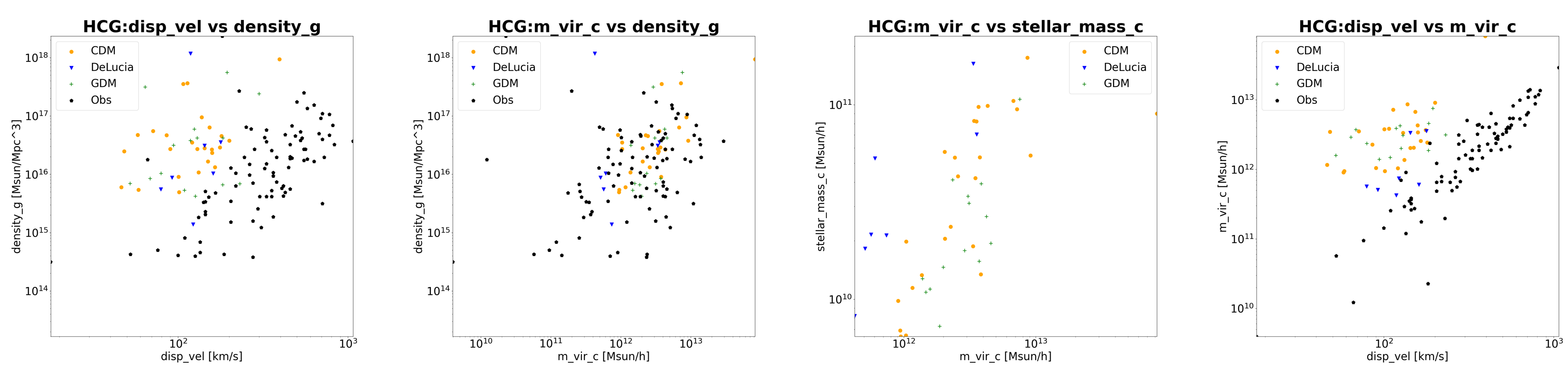
4. Hickson Compact Groups

HCG are believed to be rich in DM and were classified by Paul Hickson in 1984.

- **Population** $N > 4$ in a range of 3 times the magnitud of the most brilliant galaxy.
- **Isolation** $\theta_N \geq 3\theta_G$
  θ_G is the smallest circle containing all the centers
  θ_N is the biggest concentric circle without containing other galaxies
- **Compacticidad** $\bar{\mu}_G < 26.0$
  $\bar{\mu}_G$ is the total magnitude/arcsec^2 averaged over θ_G

We have created the Mock catalogues constructing the mergers trees for each halo at $z = 0$. After that, we have applied a semi-empirical model to obtain galaxy information.

5.Comparing simulations against observational data



6. Conclusions

- We performed dm-only simulations in CDM and different GDM scenarios where changes in small structure are observed.
- We have constructed Mock Catalogues to get information about galaxies in their respective halos using the genealogic tree for each halo at $z = 0$
- Using this catalogues a HCG classification has been applied taking into account the original classification by Paul Hickson.
- It is convenient to implement zoom simulations to study the HCG as well as their environment.