Structure formation in non-minimally coupled dark energy models

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Collaborators

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Outline

Motivations

- Check the validity of N-body simulations
- Study the effect of a varying G on structure formation
- Compare models with the same $w(a)$ but with different physical background
- Compare models with the same $H(a)$ but with constant G
- Can we constrain them?

Models

- ΛCDM model (fiducial model)
- Minimally coupled models (to test the effects of $G(t)$)

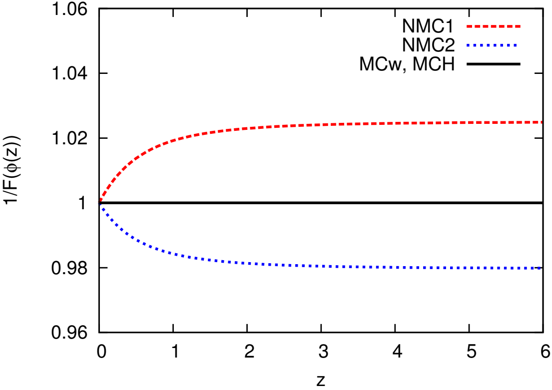
$$
\begin{aligned}
S &= \int d^4x\sqrt{-g}\left(\frac{R}{16\pi G}+\mathcal{L}_\phi+\mathcal{L}_{\rm fl}\right)\\
G_{\mu\nu} &= 8\pi G\left[T^{(\rm fl)}_{\mu\nu}+T^{(\phi)}_{\mu\nu}\right]
\end{aligned}
$$

- Non-minimally coupled models

$$
S = \int d^4x\sqrt{-g}\left(\frac{1}{2}f(\phi,R)+\mathcal{L}_\phi+\mathcal{L}_{\rm fl}\right)
$$

$$
G_{\mu\nu} = 8\pi G T_{\mu\nu} = \frac{1}{f'}\left[T^{(fl)}_{\mu\nu}+T^{(\phi)}_{\mu\nu}+\frac{1}{2}g_{\mu\nu}(f-f'R)+A_{\mu\nu}(f')\right]
$$

$$
f(\phi,R) = \frac{F(\phi)}{8\pi G_*}R\,,\quad F(\phi) = 1+8\pi G_*\xi(\phi^2-\phi_0^2)
$$



1.06
1.04
1.02
1
0.98
0.96
1/F(φ(z))
0
1
2
3
4
5
6
z
NMC1
NMC2
MCw, MCH

Basic equations

Continuity equation

$$\dot{\delta} + (1+\delta)\vec{\nabla}_{\vec{x}} \cdot \vec{u} = 0$$

Euler equation

$$\dot{\vec{u}} + 2H\vec{u} + (\vec{u}\cdot\nabla_{\vec{x}})\vec{u} + \frac{1}{a^2}\nabla_{\vec{x}}\psi = 0$$

Poisson equation

$$\vec{\nabla}^2_{\vec{x}}\phi_{\mathsf{E}} = \frac{4\pi G}{F}a^2\bar{\rho}_{\mathsf{m}}\delta$$

$$\phi_{\mathsf{E}} = \left(1 + \frac{1}{2}\frac{F^2_{,\phi}}{F+F^2_{,\phi}}\right)\phi$$

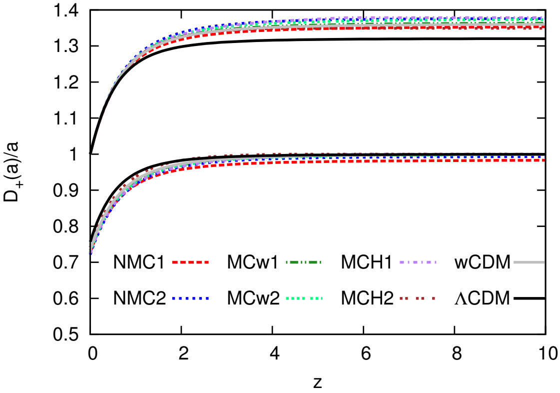
Equations of motion (DM only)

$$\ddot{\delta} + 2H\dot{\delta} - \frac{4}{3}\frac{\dot{\delta}^2}{1+\delta} - 4\pi G_{\rm eff}\bar{\rho}_{\rm m}\delta(1+\delta) = 0$$

$$\ddot{\delta} + 2H\dot{\delta} - 4\pi G_{\rm eff}\bar{\rho}_{\rm m}\delta = 0$$

$$G_{\rm eff} = \frac{G}{F}\frac{2(F + F_{,\phi}^2)}{2F + 3F_{,\phi}^2} \approx \frac{G}{F} \text{ for } \xi \ll 1$$

Growth Factor

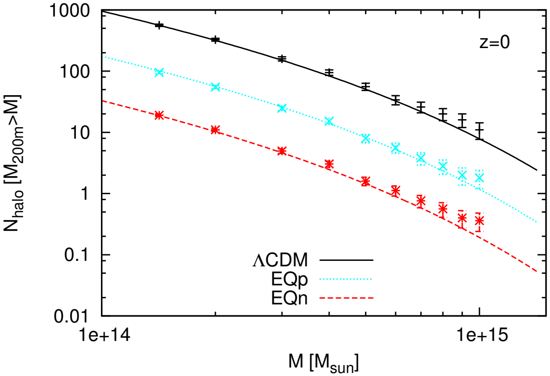


FP et al., 2013

Mass function

- Depends on $\delta_{\rm c}$, $D_+(a)$ and σ_8
- Sensitive to cosmology in the high-mass tail
- Different models
- Here used the Sheth & Tormen formulation

Comparison with simulations



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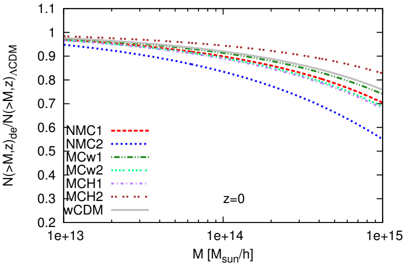


1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
N(>M,z)de/N(>M,z)ΛCDM
NMC1
NMC2
MCw1
MCw2
MCH1
MCH2
wCDM
z=0
z=2
1e+13
1e+14
1e+15
M [Msun/h]

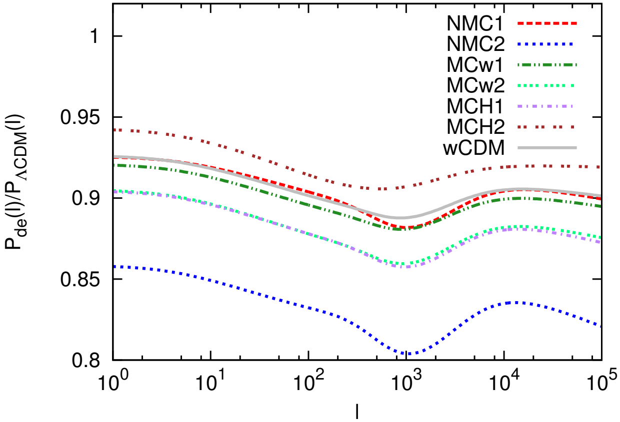
FP et al., 2013

Weak cosmological lensing

- Images of background objects distorted by gravity
- Effect of few percent
- Effective convergence and shear related to matter distribution

$$P_\kappa(\ell) = \frac{9H_0^4\Omega_{\mathrm{m},0}^2}{4c^4}\int_0^{\chi_{\mathrm{H}}} \frac{W^2(\chi)}{a^2(\chi)F^2(a)}P_{\delta_{\mathrm{m}}}\left[\frac{\ell}{f_K(\chi)},\chi\right]d\chi$$

Convergence power spectrum



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Conclusions

- Differences in G of order 2% due to solar system constraints
- Small coupling constant
- Appreciable differences in all observables
- Influence of coupling on cluster concentration
- Possibility to probe these models with future surveys