Spherical collapse in Modified Gravity theories

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supervised by Jean-Michel Alimi

July 5, 2016

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# • accelerated cosmic expansion ! $\ddot{a} > 0$

# Dark Energy

cosmological constant Λ

$$\square p = -\rho$$

dark fluid

• 
$$p = w\rho$$
 and  $w < -1/3$ 

quintessence

• 
$$p = w(a)\rho$$
 with  $w(1) \sim -1$ 

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# 68.3% Dark Energy 4.9% Ordinary Matter

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$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \kappa T_{\mu\nu} \tag{1}$$

modified gravity : modifications of the geometrical term

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \kappa T_{\mu\nu} \tag{2}$$

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$$S = \frac{1}{2\kappa} \int d^4 x \sqrt{-g} R + S_m[\Psi;g] + S_{DE}[\phi,g]$$
(3)

leads to w :

$$\mathbf{w}(\phi) = \frac{\dot{\phi}^2 - 2V(\phi)}{\dot{\phi}^2 + 2V(\phi)} \tag{4}$$

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# Non minimal coupling ? changing

$$S = \frac{1}{2\kappa} \int d^4x \sqrt{-g} R + S_m[\Psi;g] + S_{DE}[\phi,g]$$
(5)

# to a non minimal coupling

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$$G_{\mu\nu} = \kappa \left[ T^m_{\mu\nu} + T_{\mu\nu}(\phi) \right] \rightarrow F(\phi) G_{\mu\nu} = \kappa \left[ T^m_{\mu\nu} + T_{\mu\nu}(\phi) \right]$$
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$$\mathsf{F}(\phi)\mathsf{G}_{\mu\nu} = \kappa \mathsf{T}^{m}_{\mu\nu} + \kappa \mathsf{T}_{\mu\nu}(\phi) \tag{8}$$

FLRW metric  $ds^2 = dt^2 - a^2(t)d\mathbf{x}^2$ ,

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$$ds^{2} = dt^{2}(1+2\Phi) - a^{2}d\mathbf{x}^{2}(1-2\Psi)$$
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1 modified Poisson equation :  $k^2 \Phi = -\mu(a, k)\delta\rho$ 2 in GR,  $\mu(a, k) = G$ 3 modified slip equation :  $\Psi = \gamma(a, k)\Phi$ 4 in GR =  $\gamma = 1$ with  $\mu = \frac{1 + p_3 k^2}{p_4 + p_5 k^2}, \qquad \gamma = \frac{p_1 + p_2 k^2}{1 + p_3 k^2} \qquad (1)$ 

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- perturbed level :
  - Poisson equation :  $k^2 \Phi = -\mu(a,k)\delta\rho$

- Slip equation :  $\Psi = \gamma(a, k)\Phi$
- variable  $G_N$  ,  $G_N o G_N(a,k)$
- decomposed as  $G_1(a)$  + fifth force

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- Collapse applied on Large scale matter profiles

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Simple but powerful approach ! Newtonian spherical motion

$$\ddot{r} = \frac{\ddot{a}}{a}r - \nabla\Phi \tag{15}$$

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With the Poisson equation

$$k^{2}\Phi = -\mu(a,k)\delta\rho \quad \Rightarrow \quad \nabla^{2}\Phi = [\delta\rho * \tilde{\mu}] \tag{16}$$

 $\tilde{\mu}$  can be written :

$$\tilde{\mu}(r) = \tilde{G}\delta_D^{(3)}(r) + (G_0 - \tilde{G})\frac{1}{4\pi R^2 r}e^{-\frac{r}{R}}$$
(17)

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where

$$G_0 = \frac{1}{p_4}, \quad \tilde{G} = \frac{p_3}{p_5}, \quad R^2 = \frac{p_5}{p_4}$$
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**3** small r (Solar system) : Chameleon mechanism (non linearities)  $\Rightarrow G_N = G_0(a)$ 

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### Question

We know the dynamics. We need initial realistic matter profiles

#### ossible answer

Averaged large scale matter profiles around ... Halos and Cosmic Voids !

analytically predicable (Gaussian primordial field)

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- spherically averaged
- suitable for spherical collapse
- observable

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- analytically predicable (Gaussian primordial field)
- spherically averaged
- suitable for spherical collapse
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### Question

We know the dynamics. We need initial realistic matter profiles

## Possible answer

- analytically predicable (Gaussian primordial field)
- spherically averaged
- suitable for spherical collapse
- observable

Spherical collapse in Modified Gravity theories

> Paul de Fromont

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#### Possible answer

Averaged large scale matter profiles around ... Halos and Cosmic Voids !

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Figure : Mass contrast for  $R_1 = 30 h^{-1}Mpc$ 

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#### we have

initial conditions (averaged profiles) the dynamics for every model

#### /e need

A Modified gravity model ! Generic effective model : *f*(*R*) Hu & Sawicki model (2007)

$$S = \frac{1}{2\kappa} \int d^4 x \sqrt{-g} \left( R + f(R) \right) + S_m[\Psi;g] \qquad (20)$$
$$f(R) = f_0 \frac{\gamma + 1}{\gamma + R_0/R} \qquad (21)$$

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## Hu & Sawicki model

- effective  $w(a) \simeq w_0 \frac{8}{3} |f_R^0|(a-1)|$
- scalaron scale  $R(a) \sim |f_R^0| a^{5/2} \times \left(1 + [1 3w(a)] \frac{1 \Omega_m}{\Omega_m}\right)^{-3/2}$ usual  $G_0 = 1$

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## Spherical collapse in Modified Gravity Mass profiles for halos



conclusion

## Spherical collapse in Modified Gravity Mass profiles for Voids



Figure : Mass contrast with various  $f_R^0$  (ACDM for  $f_R^0 o 0$ )

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# Spherical collapse in Modified Gravity Exclusion contour



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# Spherical collapse in Modified Gravity Exclusion contour



Collapse applied on Large scale matter profiles

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Figure : Exclusion region for  $\Omega_m$  and  $f_R^0$ 

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## Conclusion

- $\blacksquare Modified gravity and Quintessence \Rightarrow Dark Energy$
- for background :  $MG \equiv Quintessence$
- Impact on LSS
- Using averaged profiles : new constraints on MG !

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### Thank you for your attention !



"But before we move on, allow me to belabor the point even further..."