

# RESTRICTIONS ON EXTENDED GRAVITY AT GALAXY CLUSTERS SCALES

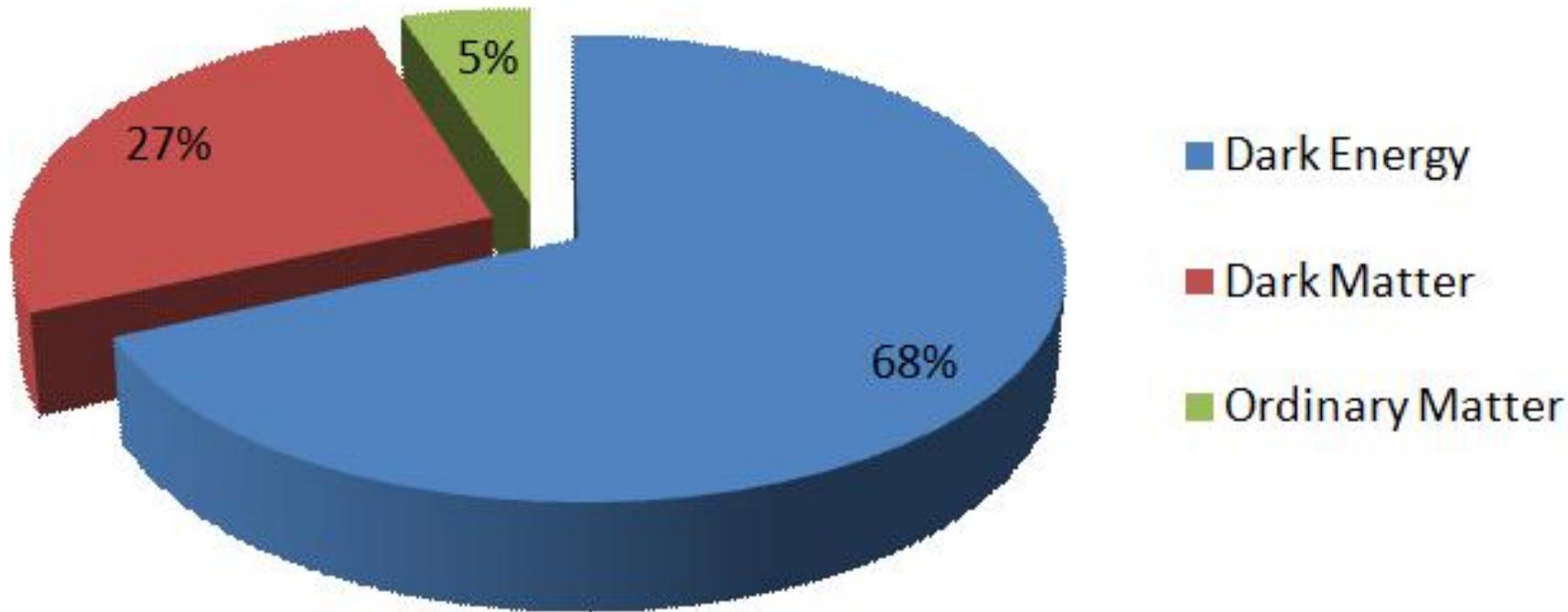
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*S.A., B.Latosh, V.Echeistov, JETP v.125, p.1083 (2017)*

# Fraction of usual General Relativity



# Dark matter, dark energy

## new physics

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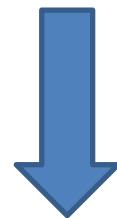


## scalar-tensor gravity

# Dark matter, dark energy

New physics

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Scalar-tensor gravity

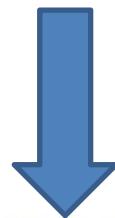
$f(R)$  gravity

Horndesky model

# Dark matter, dark energy

New physics

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Scalar-tensor gravity  
 $f(R)$  gravity  
Horndesky model

*Constraints from GW170817*

# Dark energy + f(R) gravity



## Starobinsky model

$$f(R) = R + \lambda R_0 \left( \left[ 1 + \frac{R^2}{R_0^2} \right]^{-n} - 1 \right)$$



## Observational Data $\rightarrow$ $\Lambda$ -CDM

$$S = \frac{1}{16\pi} \int d^4x \sqrt{-g} (R + \Lambda)$$

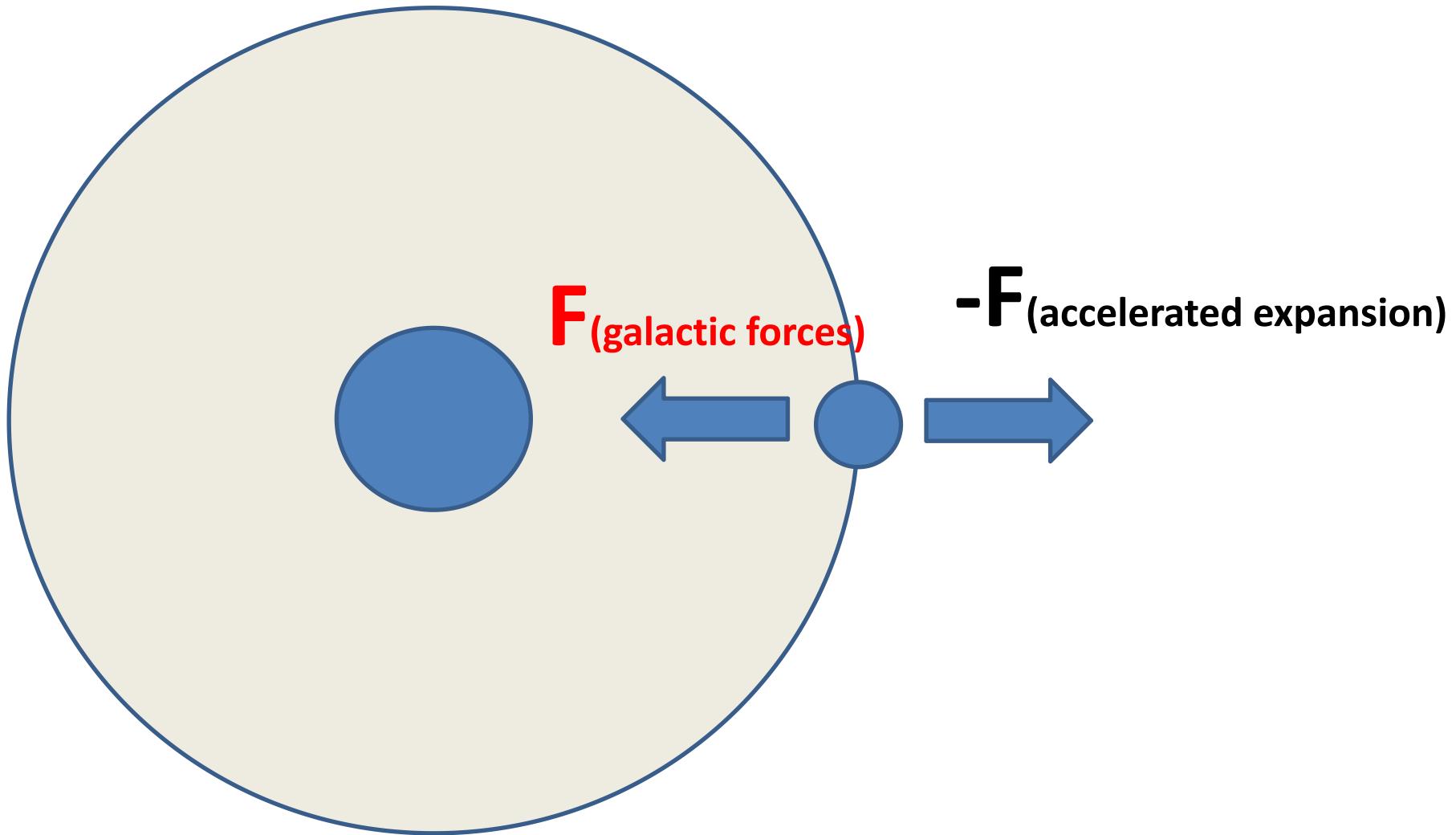
# Starobinsky model

$$f(R) = R + \lambda R_0 \left( \left[ 1 + \frac{R^2}{R_0^2} \right]^{-n} - 1 \right)$$

**$\Lambda$ CDM limit:**  $\Lambda = \frac{\lambda}{2} R_0$

**Solar system:**  $n \geq 2$

# Method\*: cut-off radius calculation



# Cut-off radius calculation

Mass spectra range:

$10^{11} M_{\text{Sun}}$  (**Milky Way**)

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$10^{15} M_{\text{Sun}}$  (**Galaxy clusters**)

**Metrics**  $ds^2 = e^A c^2 dt^2 - e^{-A} dr^2 - r^2 d\Omega.$

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## Field equations\*

$$f'(R)R_{ii} - f(R)\frac{g_{ii}}{2} - (\nabla_i^2 - g_{ii}\square) f'(R) = 0,$$

\*Thomas P. Sotiriou and Valerio Faraoni, Rev. Mod. Phys. 82, p.451 (2010)

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## Field equations\*

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$$\left\{ \begin{array}{l} \frac{dA}{dr} = a, \\ \frac{da}{dr} = e^{-A} \left( R + \frac{2}{r^2} \right) - a^2 - \frac{4a}{r} - \frac{2}{r^2} \\ \frac{dR}{dr} = \frac{f'(R) \cdot R_{00}/g_{00} - f(R)/2}{(e^A(a+2/r)+a/2)f''(R)} \end{array} \right.$$

\*Thomas P. Sotiriou and Valerio Faraoni, Rev. Mod. Phys. 82, p.451 (2010)

- **Gravitational potential**

$$\phi = \frac{c^2}{2} (g_{00} - 1) = \frac{c^2}{2} (e^A - 1)$$

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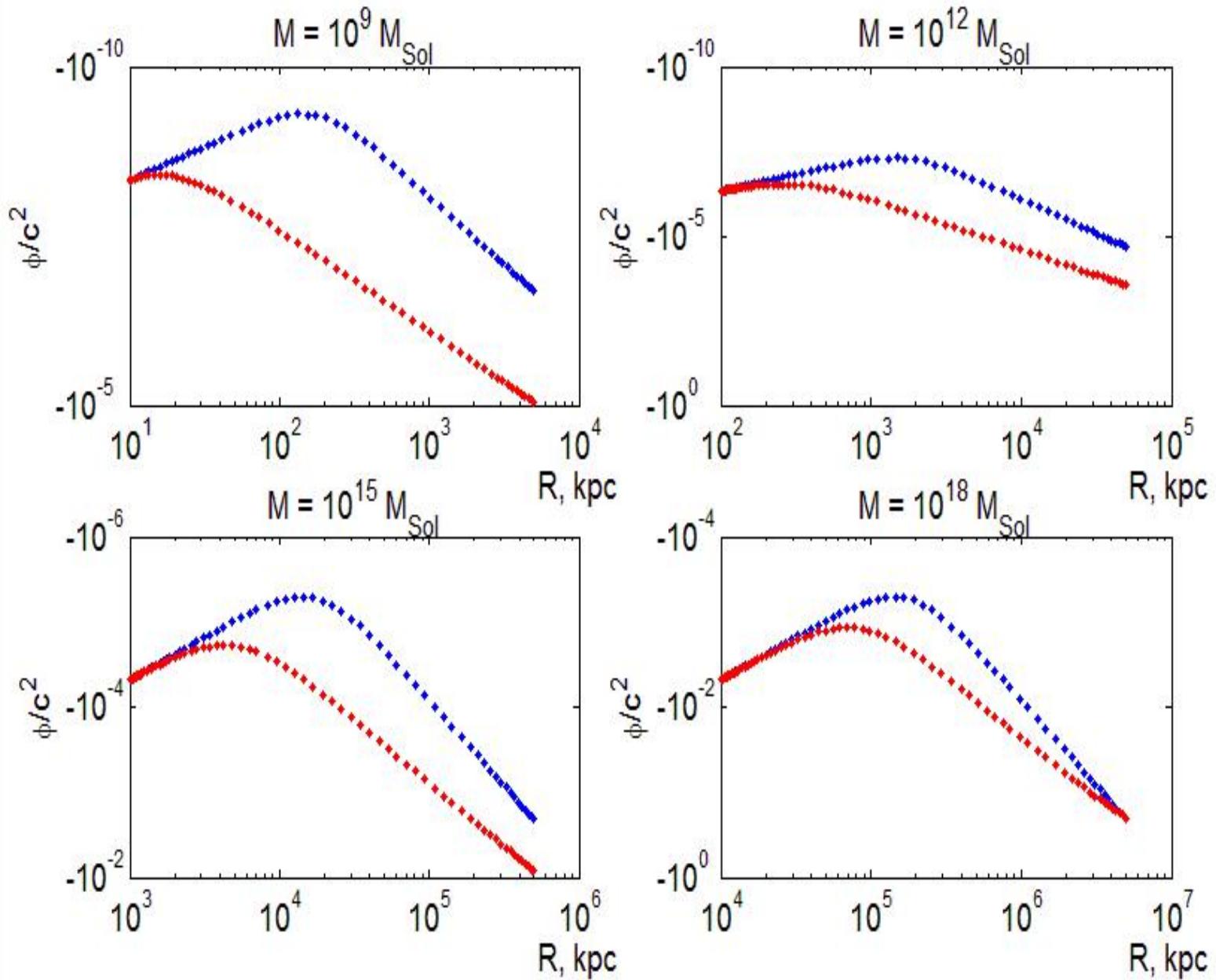
- **Dimensionless gravitational potential**

$$\frac{\phi}{c^2} = \frac{e^A - 1}{2}$$

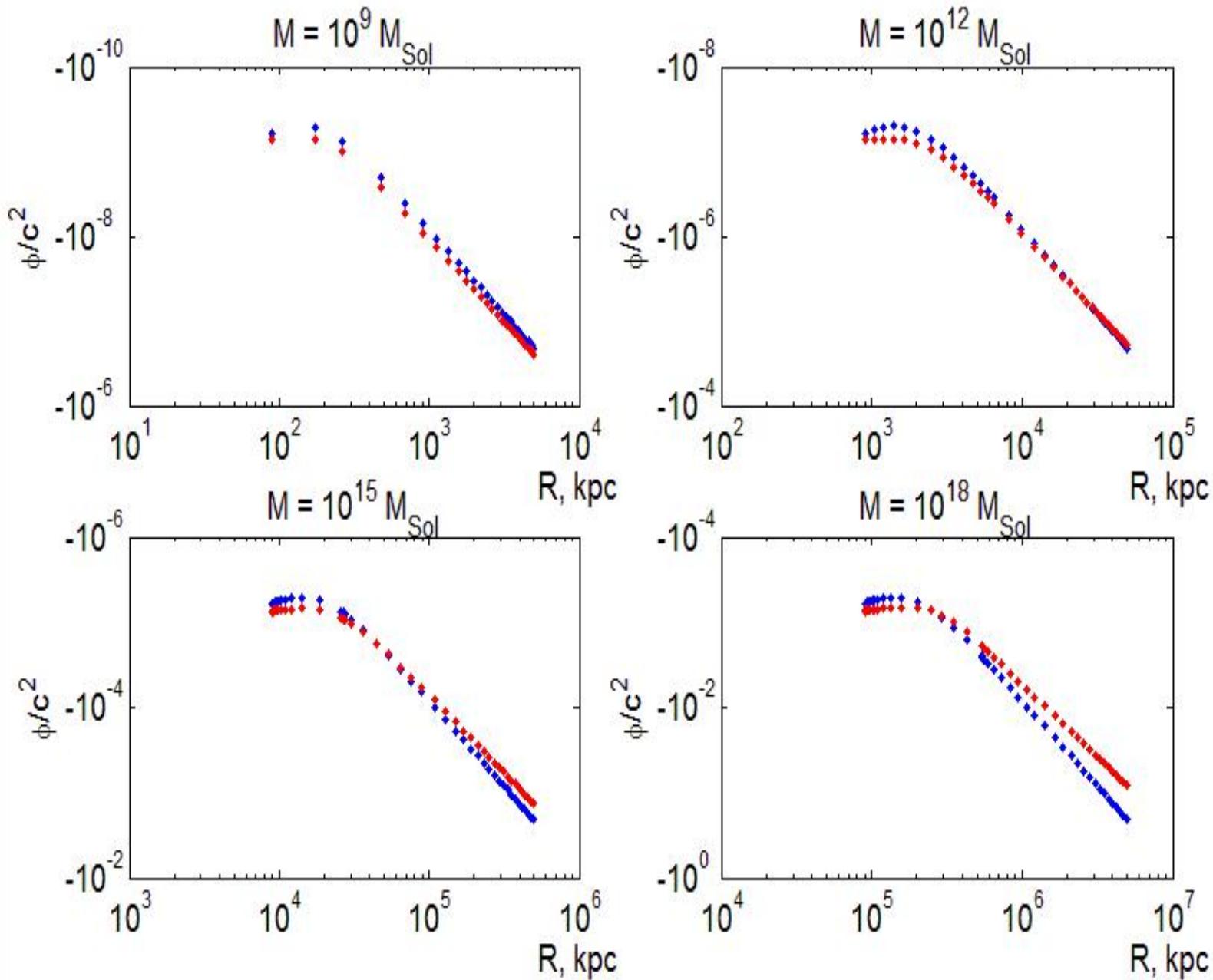
- **At the cut-off radius**

$$\frac{d\phi}{dr} = 0 \Leftrightarrow a = 0$$

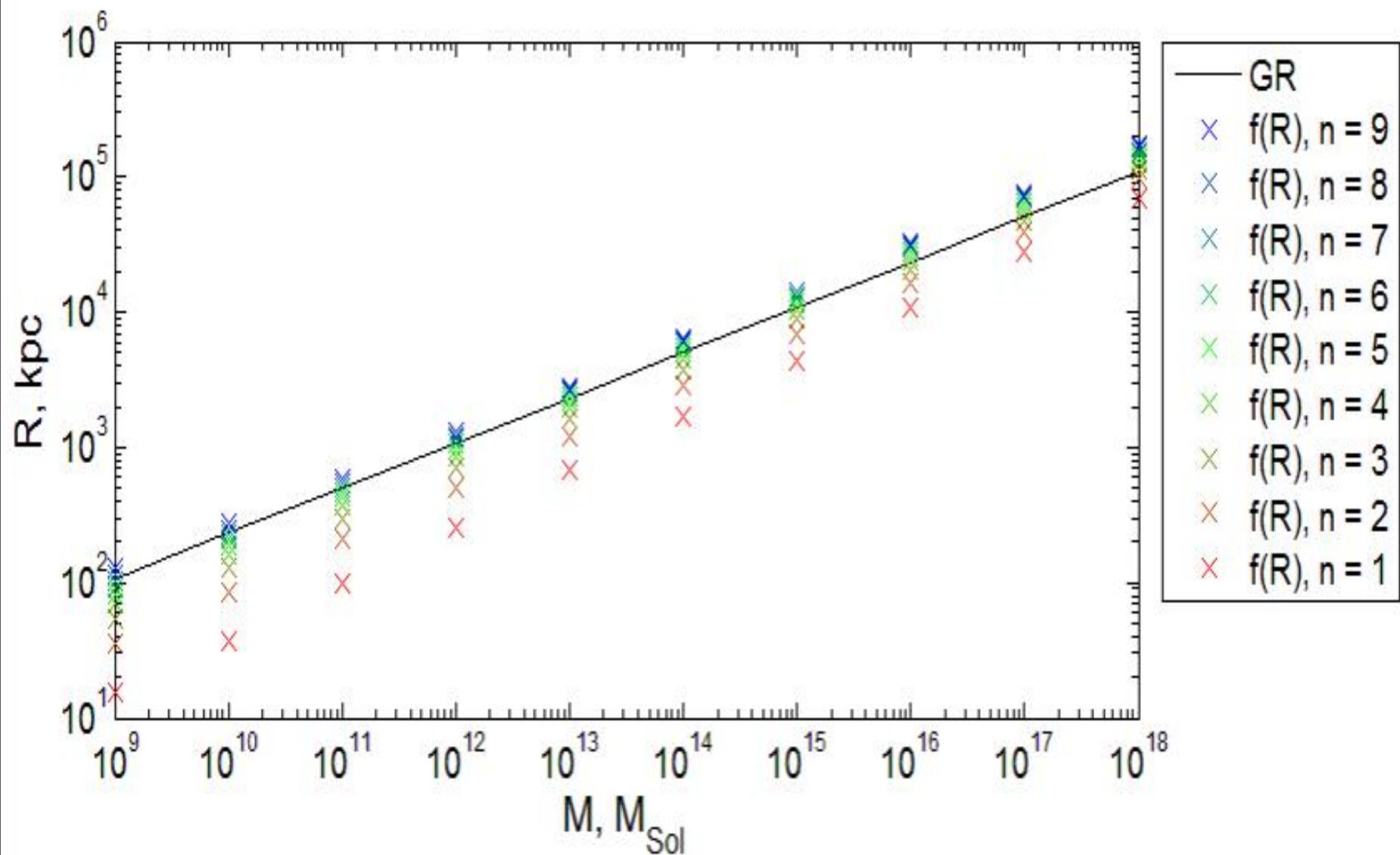
# $\phi/c^2$ , case n=1 (\*\* GR case)



# $\phi/c^2$ , case n=9 (\*\* GR case)



# Cut-off radius vs mass

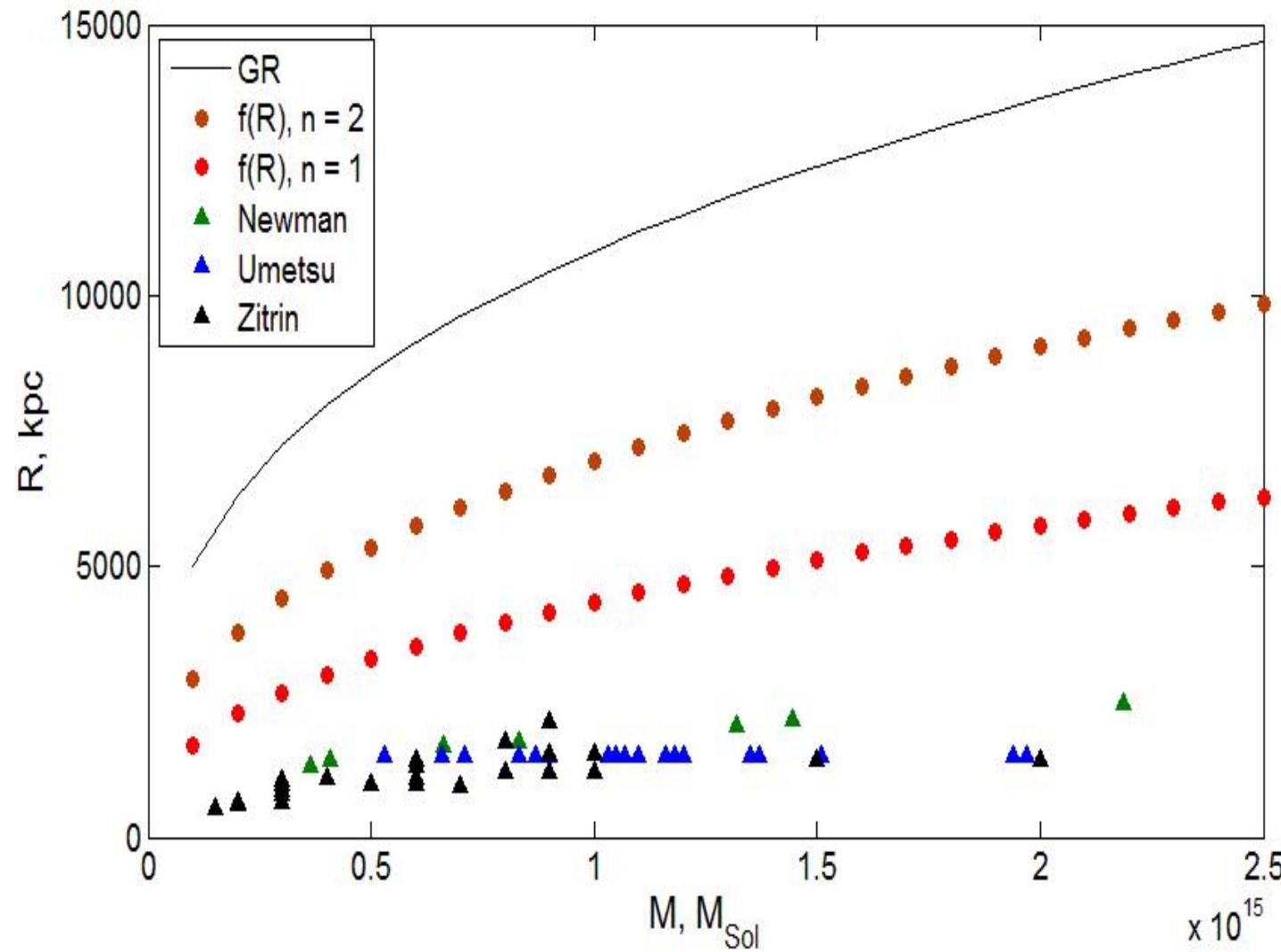


*(Numerically obtained)*  
**coefficients**  
**for n=1..9**

n	$\alpha$	$\beta$
0	0.3333	-0.966
1	0.4084±0.0013	-2.495±0.017
2	0.3807±0.0004	-1.869±0.005
3	0.3683±0.0001	-1.578±0.001
4	0.3617±0.0001	-1.412±0.002
5	0.3577±0.0002	-1.305±0.003
6	0.3552±0.0003	-1.231±0.004
7	0.3528±0.0005	-1.169±0.007
8	0.3486±0.0015	-1.091±0.019
9	0.3428±0.0019	-0.993±0.024

$$\log_{10}(R_{\text{cut-off}}) = \alpha \log_{10}(M) + \beta$$

# Cut-off radius: theory vs observational results



A. B. Newman, T. Treu, R. S. Ellis, D. J. Sand, C. Nipoti, J. Richard, and E. Jullo, *Astrophys. J.* 765, 24 (2013)

K. Umetsu et al., *Astrophys. J.* 795, 163 (2014)

A. Zitrin et al., *Astrophys. J.* 801, 44 (2015)

# Conclusions

The dependence (**cut-off radius vs mass**) for Starobinsky model with vanishing cosmological constant at the current accuracy level has no visible difference from GR one in the wide mass range



The current accuracy value in extra-galactic astronomy does not provide additional constraints on Starobinsky model

THANK YOU  
FOR YOUR ATTENTION !

