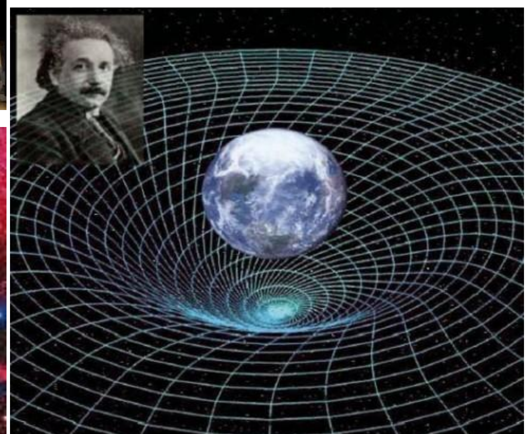
Helmholtz international Summer School “Cosmology, Strings, New Physics”



August 2019, JINR, Dubna

AL ZAHRA UNIVERSITY

Chameleon mechanism in inhomogeneous astrophysical objects

Noshad Khosravi Largani*

M.T Mirtorabi

Y. Akrami

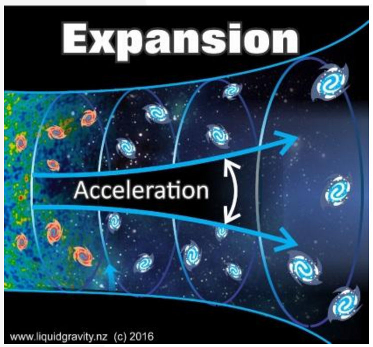
outline

History of MoG

The scalar-Tensor theories and Screening mechanism

The Chameleon Model

Key Questions



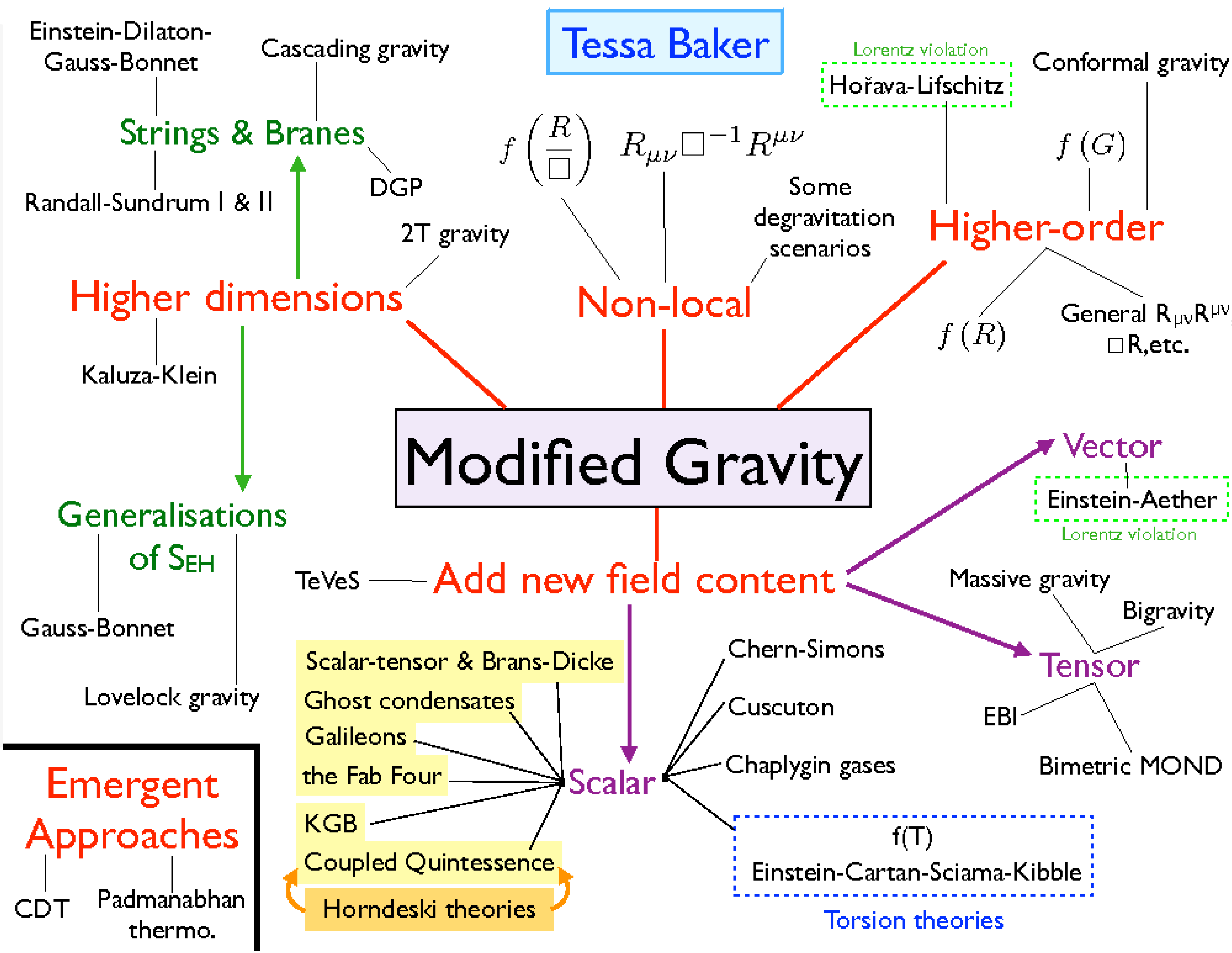
Is there a compelling theory explaining the accelerated expansion of the universe?

What is the difference between the standard model and Scalar-Tensor theories?

Key Questions

- Why screening mechanism is functional?
- Can chameleon reveal the mystery of Dark Energy?
- How would Chameleon behave in homogeneous and inhomogeneous objects?


Once we accept our limits,
we go beyond them.
Albert Einstein
quotefancy



T.Baker et al,Phys.Dark Univ. 12 (2016) 56-99

The standard model

Action:

$$S = \int d^4x\sqrt{-g}[\frac{M_{Pl}^2}{2}(R-2\Lambda)+L_m(g_{\mu\nu},\Psi)]$$

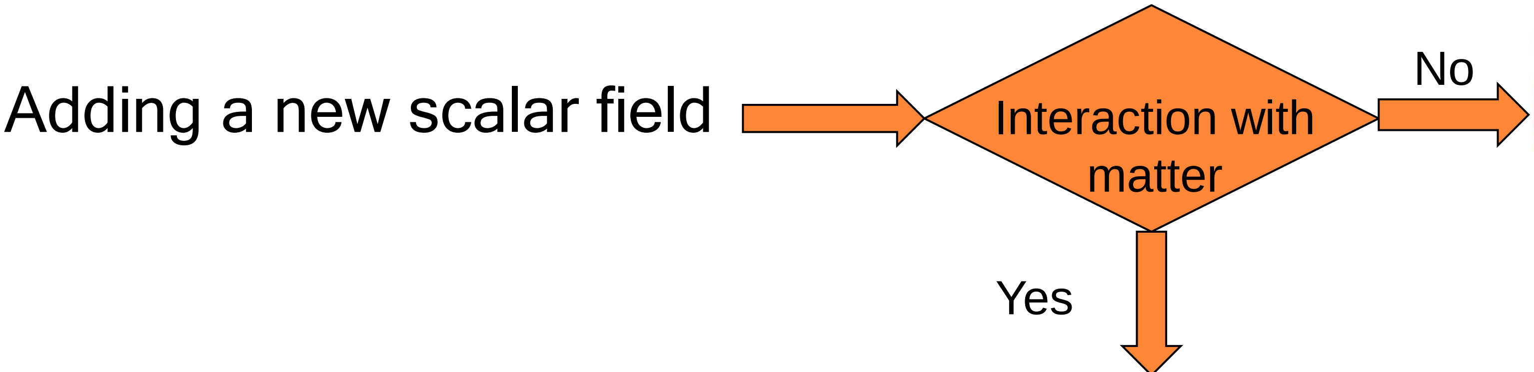
Einstein's Field Equations

$$R_{\mu\nu}-\frac{1}{2}Rg_{\mu\nu}+\Lambda g_{\mu\nu}=8\pi GT_{\mu\nu}$$

Einstein's Tensor

$$G_{\mu\nu}=R_{\mu\nu}-\frac{1}{2}Rg_{\mu\nu}$$

Is it easy to Modify gravity?



Two important challenges:

1: compatibility with Equivalence principle
2: Compatibility with solar system tests of gravity

Brans-Dicke model

Action (in Jordan frame)

$$S_{BD} = \frac{M_{pl}}{2} \int d^4x \sqrt{-g} [\phi R - \frac{\omega_0}{\phi} g^{\mu\nu} \nabla_\mu \phi \nabla_\nu \phi \quad] + S_m(g_{\mu\nu}, \Psi)$$

$$S_m = \int d^4x \sqrt{-g} L_m$$

The screening mechanism

Scalar Tensor Theories

Action in Jordan frame

$$S = \int d^4x \sqrt{-\tilde{g}} \left[\frac{{M_{\rm pl}}^2}{2A^2(\phi)} \tilde{R} - \frac{1}{2} \left[\frac{k^2(\phi)}{A^2(\phi)} - 6 \left(\frac{A'(\phi)}{A} \right)^2 \right] \tilde{\nabla}_\mu \phi \tilde{\nabla}^\mu \phi - \frac{V(\phi)}{A^4(\phi)} \right] + S_{\rm m}[\tilde{g}_{\mu\nu}; \psi_{\rm i}]$$

Action in Einstein's frame

$$S = \int d^4x \sqrt{-g} \left[\frac{{M_{\rm pl}}^2}{2} R - \frac{1}{2} k^2(\phi) \nabla_\mu \phi \nabla^\mu \phi - V(\phi) \right] + S_{\rm m}[A^2(\phi) g_{\mu\nu}; \psi_{\rm i}]$$

Conformal transformation $g_{\mu\nu}^{(i)} = e^{2\beta_i \phi / M_{pl}} g_{\mu\nu}$

Scalar Tensor Theories

In a simpler way...

$$S = \int d^4x\sqrt{-g}[\frac{M_{Pl}^2}{2}f(R,\phi) + L_\phi(g_{\mu\nu},\phi,\partial\phi) + L_m(g_{\mu\nu},\Psi)]$$

$$L_\phi = -\frac{1}{2}\omega(\phi)(\nabla^\alpha\phi)(\nabla_\alpha\phi) - V(\phi)$$

The Chameleon Model

$$F_\phi = \frac{-\beta}{M_{pl}} M \nabla \phi$$

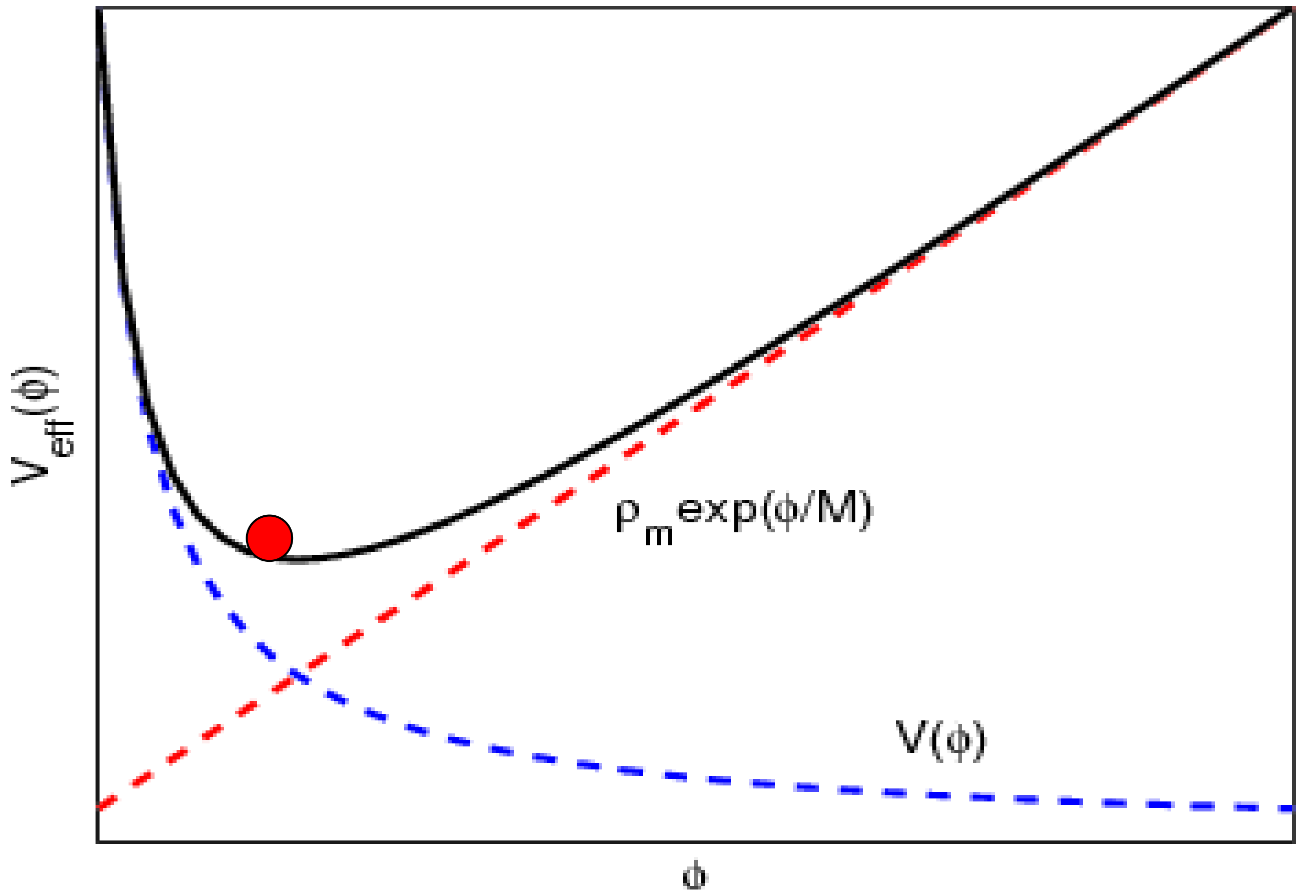
Fifth force

$$S = \int d^4x \sqrt{-g}\,[\frac{M_{Pl}^2}{2} R - \frac{1}{2}(\partial\phi)^2 - V(\phi) + L_m(g_{\mu\nu}^{(i)}, \Psi_m^{(i)})]$$

$$g_{\mu\nu}^{(i)} = e^{2\beta_i \phi / M_{pl}} g_{\mu\nu}$$

Variation with respect to the scalar field turns into this equations of motion:

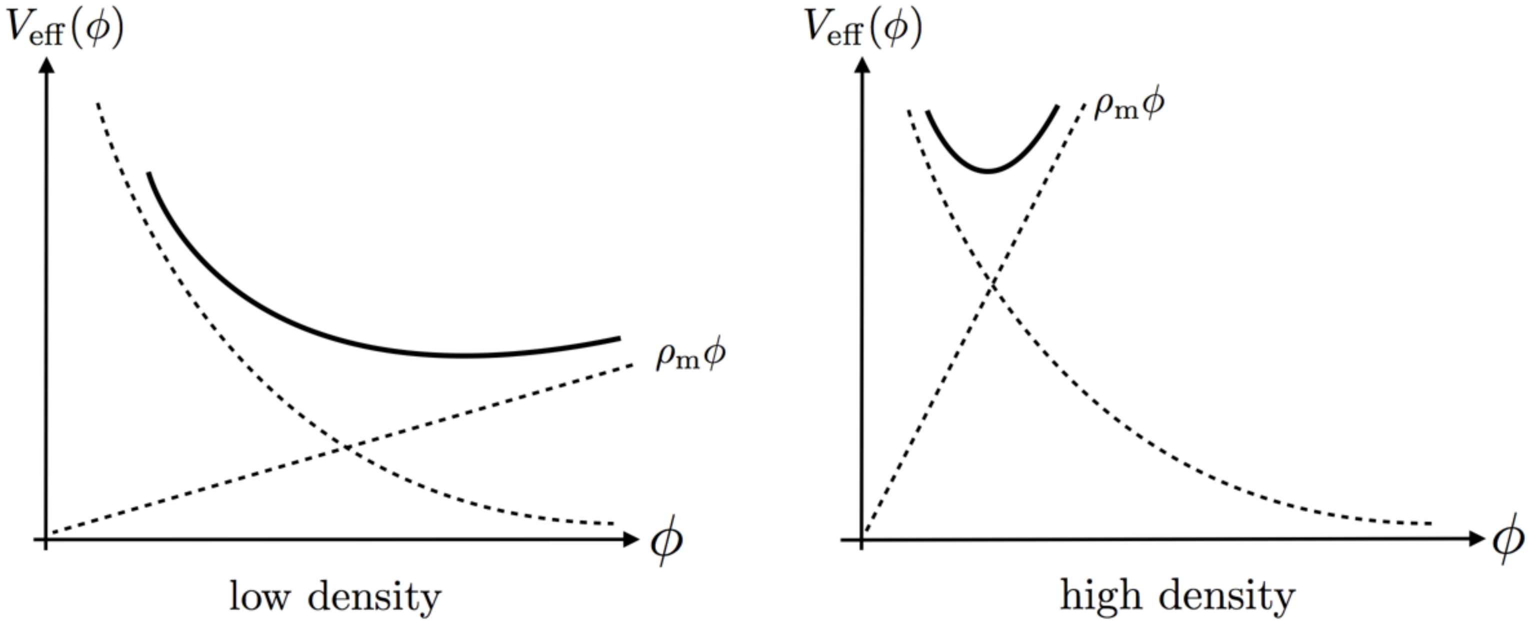
$$\Box\phi = V_{,\phi} + \frac{\beta_i}{M_{pl}} e^{4\beta_i \phi / M_{pl}} g_{(i)}^{\mu\nu} T_{\mu\nu}^{(i)}$$



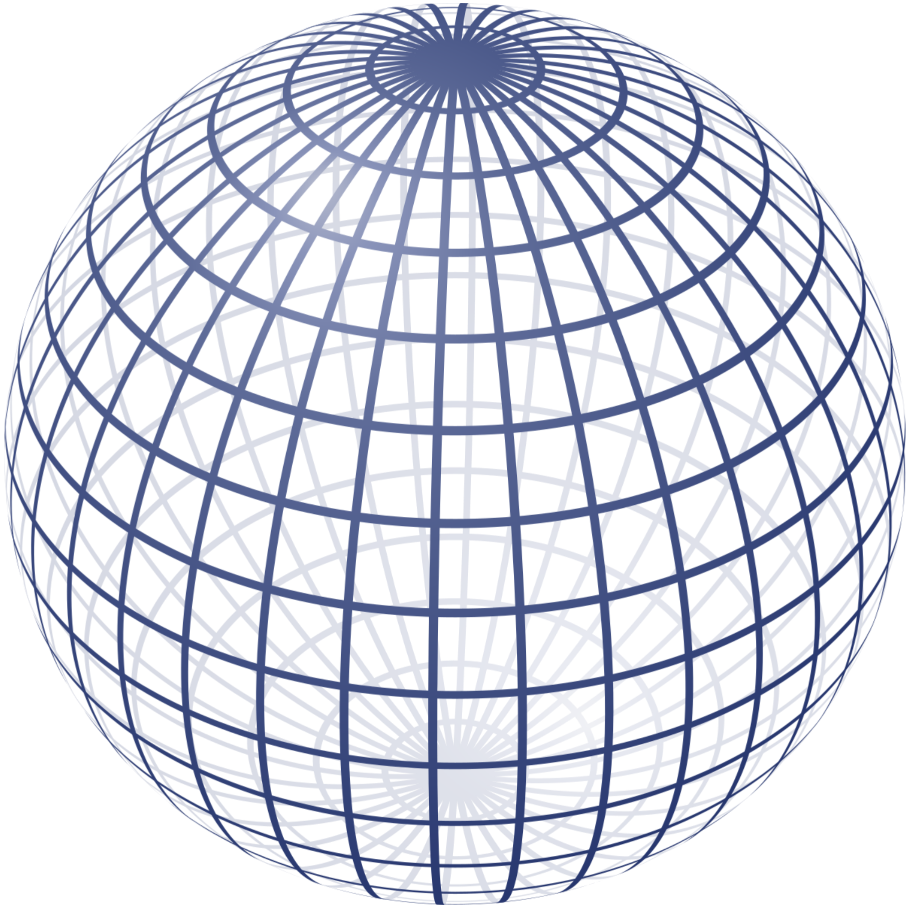
$$V_{eff}(\phi) = V(\phi) + \rho e^{\beta\phi/M_{pl}}$$

The role of mass in Chameleon model

$$m_{eff}^2 \equiv n(n+1)M^{-(\frac{4+n}{n+1})}(\frac{\beta\rho}{nM_{pl}})^{\frac{n+2}{n+1}}$$



The thin-shell and Thick-shell regime

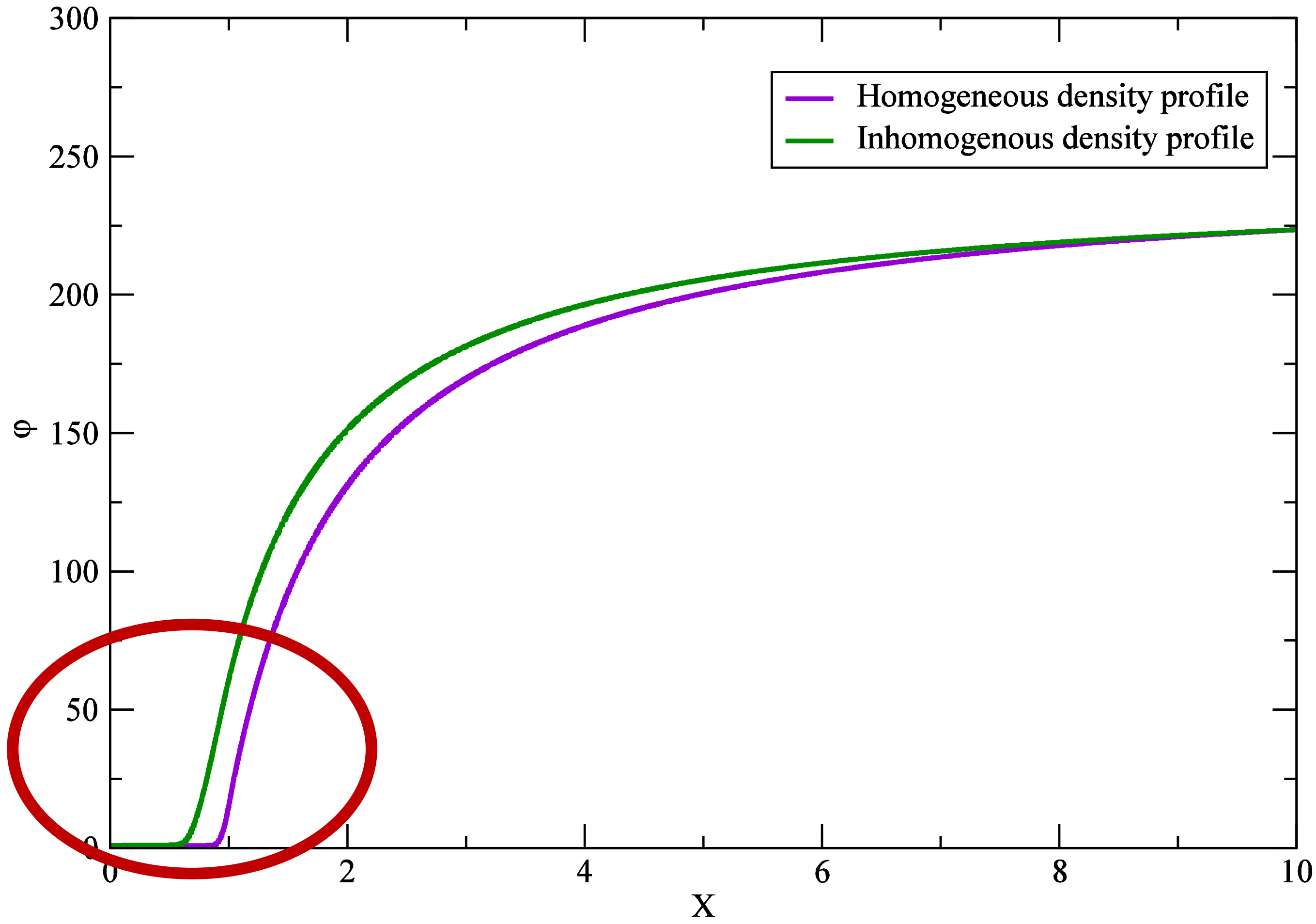


Khoury, Justin et al. Phys.Rev. D69 (2004) 044026 astro-ph/0309411

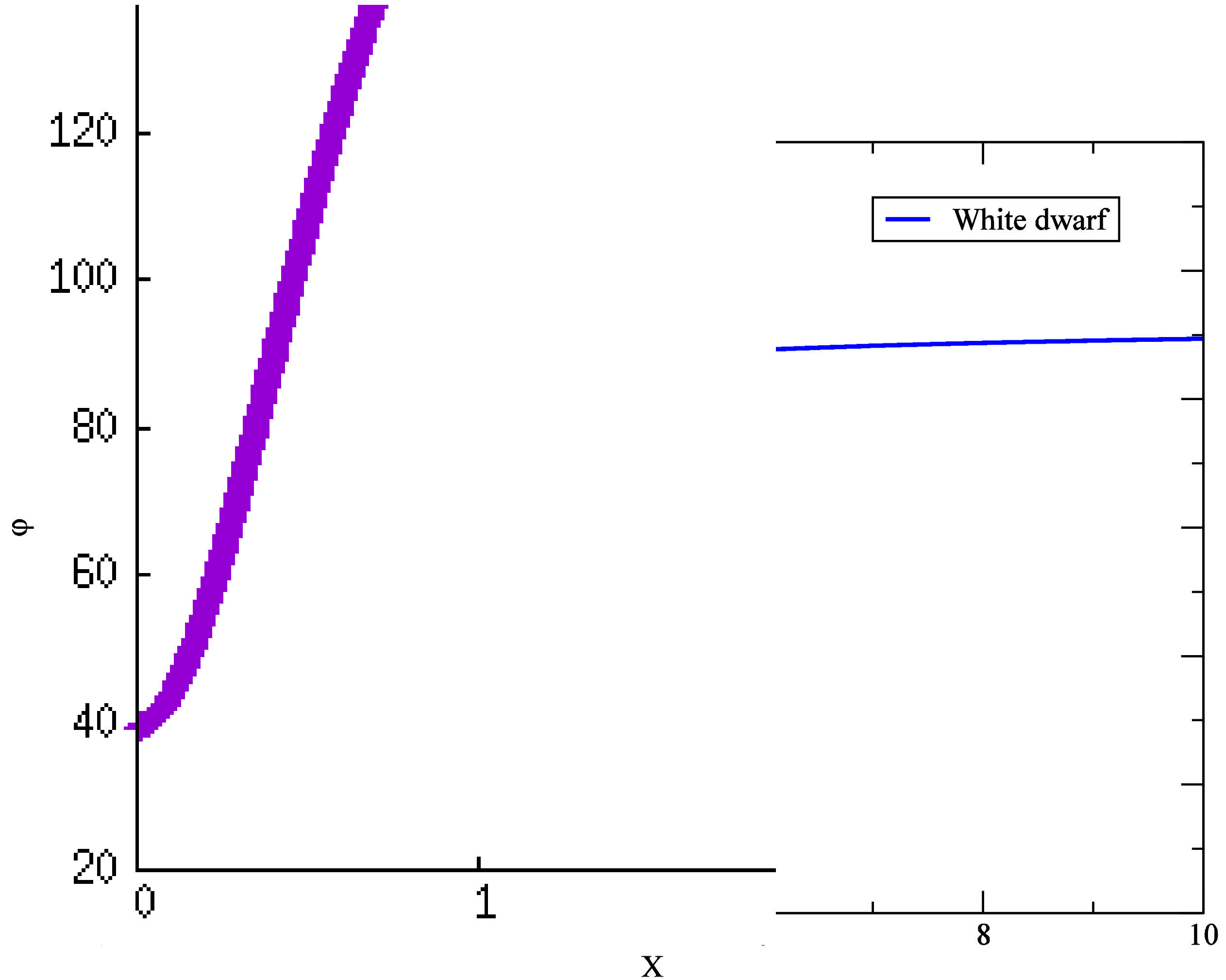
Homogeneous Profile

$$\rho_0(r) = \begin{cases} \rho_c & r < R_c \\ \rho_G & r > R_c \end{cases}$$

$$\frac{d^2\phi}{dx^2} + \frac{2}{x}\frac{d\phi}{dx} = \frac{(m_c R_c)^2}{n+1}[\frac{\rho_0(x)}{\rho_c} - \frac{1}{\phi^{n+1}}]$$


Homogeneous density profile
Inhomogenous density profile
φ
X
0
2
4
6
8
10
50
100
150
200
250
300

White dwarf



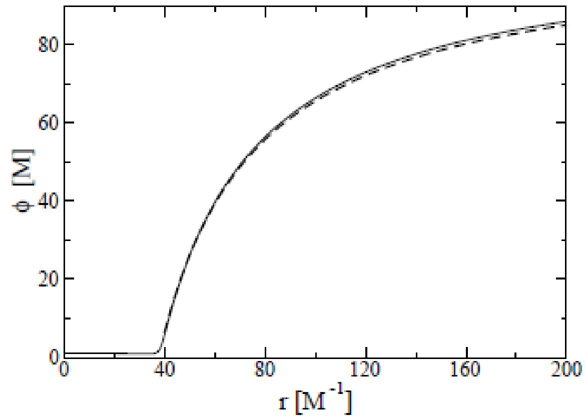


FIG. 2: Example of solution with thin shell.

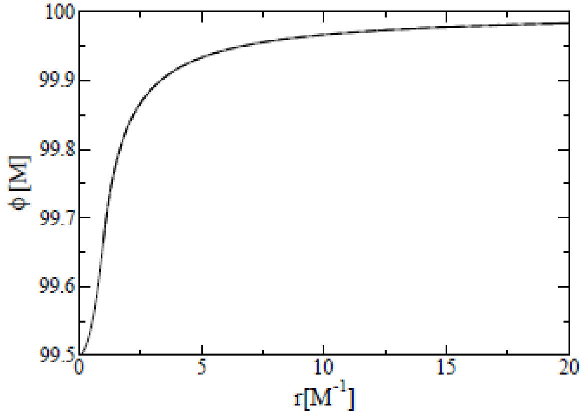
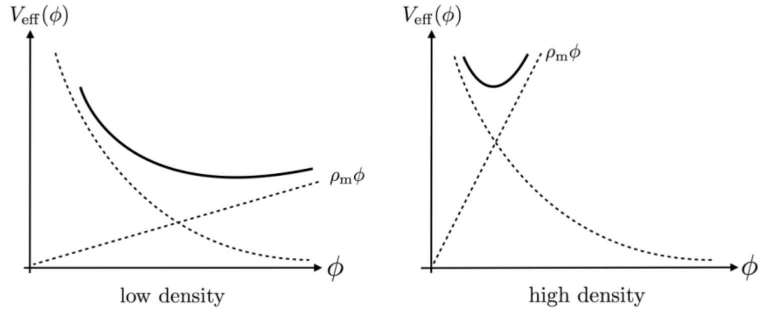
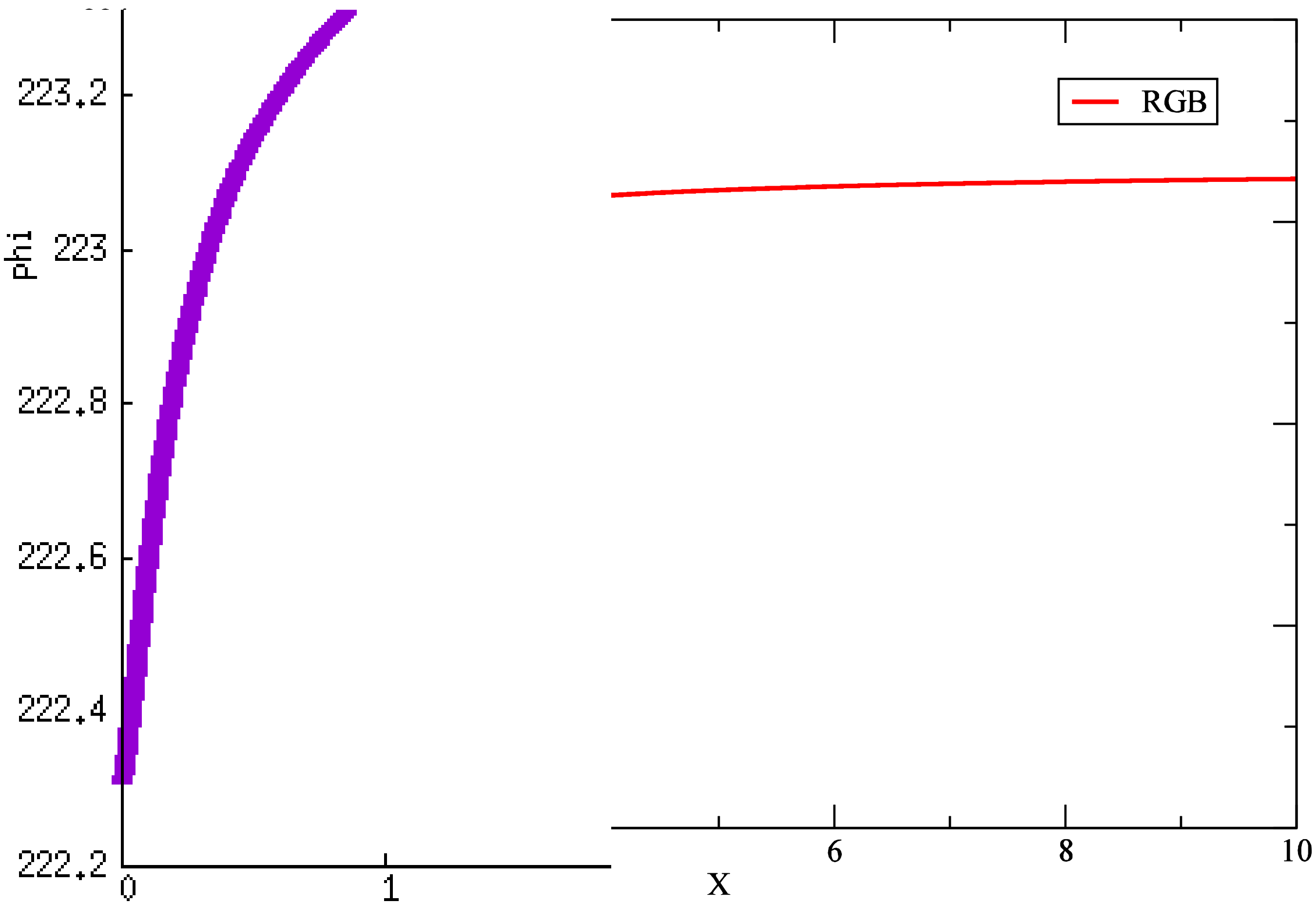


FIG. 3: Example of solution without thin shell.

Khoury, Justin et al. Phys.Rev.Lett. 93 (2004) 171104 astro-ph/0309300

Red Giant star





Outlook and conclusions:

- Screening mechanism is a good method in order to make MoG theories compatible with solar system tests of gravity.
- Although the Chameleon model cannot be a good substitution for Dark Energy, Detecting the fifth force can face GR some new challenges.
- in addition of size, varying density can also result into effects that fall under the thin-shell or thick-shell regime.
- As a following step, inclusion of a time dependent source shall be considered in order to investigate the behavior of the time-dependent chameleon field as well as the effects of inhomogeneous environments.

سپاسگزارم
TERIMA KASIH
GRACIAS
MERCI
K SALAMAT
OBRIGADO
GRAZIE
THANK YOU
DZIĘKUJĘ
감사합니다
DANKIE
TƏŞƏKKÜR
DĚKUJI
СПАСИБО
DANKE
DANK U
ありがとう
MULȚUMESC
TACK
FALEMNDERIT
ÞAKKA ÞÉR