Modified Gravity Makes Galaxies Brighter

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Outline

Why Modify Gravity?

Need to account for unexplained phenomena such as dark energy using extra scalar degrees of freedom.

Why Screen Gravity?

This produces unobserved fifth forces.

All of the constraints on gravity come from local solar system constraints.

The Screening Mechanism (1)

Start with the general scalar-tensor action in the Einstein frame where the field ϕ is minimally coupled to gravity:

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

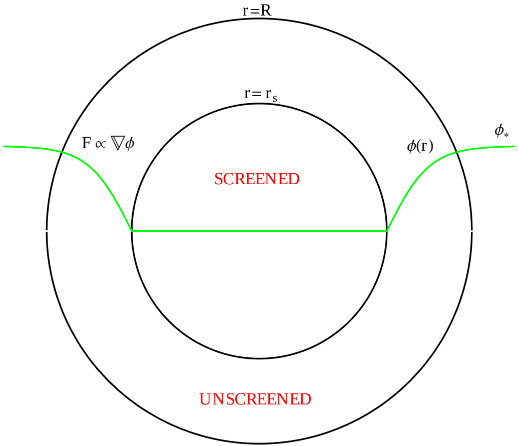
The matter fields Ψ_i couple to the Jordan frame metric $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu}$. $A(\phi)$ is the *coupling function*.

The field feels an effective potential

$$V_{\mathrm{eff}}(\phi) = V(\phi) + \rho A(\phi).$$

The Screening Mechanism (2)

The field profile is:



The Screening Mechanism (3)

There are two parameters controlling the screening, **which depend on the cosmological variables only**:

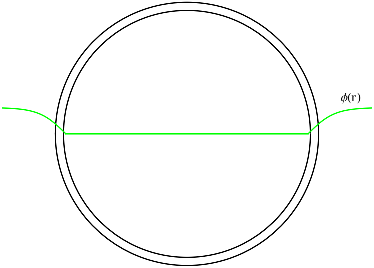
In the unscreened region $G \to G(1+\alpha_{\rm eff}(r))$.

$$\alpha_{\rm eff}(r) = \alpha_\star \left[1 - \frac{m(r_s)}{m(r)}\right].$$

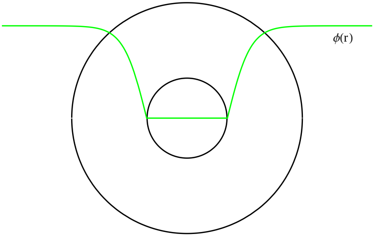
$\alpha_\star$ is typically $\mathcal{O}(1)$ but can be much larger. Here we use $\alpha = 1/3$, corresponding to $f(R)$ gravity.

The Screening Mechanism (4)

The screening radius is determined by $\chi_\star$:



(a) Small $\chi_\star$



(b) Large $\chi_\star$

In general the body will be unscreened if $\chi_\star > \Phi_N$, the surface Newtonian potential.

Basic Idea

Consider two identical stars of equal mass and composition, one screened and the other not. The properties of the unscreened star differ in the following way:

1. The star feels a stronger gravitational force.
2. In order to support itself against this increased gravity the star must burn more fuel per unit time.
3. The star is hence more luminous.
4. The star only has a finite amount of fuel which is deleted at a faster rate.
5. The star's lifetime is therefore shorter.

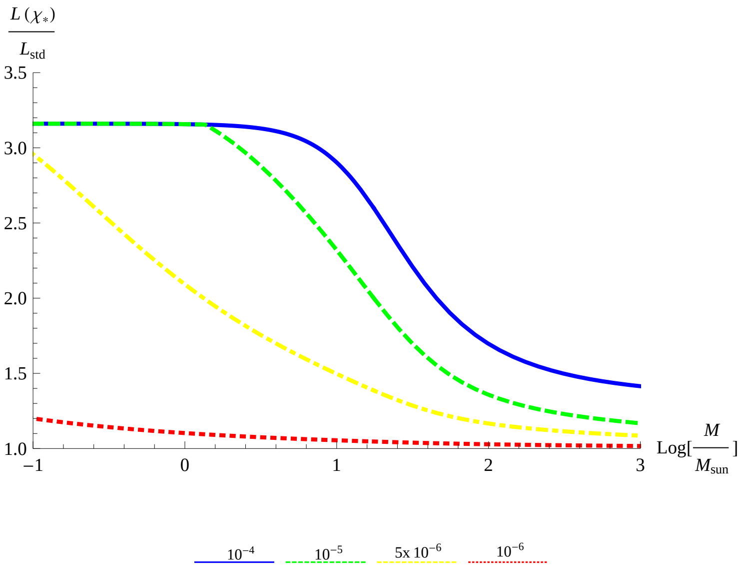
Equations of Stellar Structure

Gravity only appears in the hydrostatic equilibrium equation equation:

$$\frac{\mathrm{d}P}{\mathrm{d}r} = -\frac{G\rho(r)m(r)}{r^2}$$

By replacing G by $G(1+\alpha_{\mathrm{eff}})$ we can solve this with the other equations using Eddington's standard model and a polytropic equation of state ($P \propto \rho^{1/3}$) to find the luminosity increase as a function of mass.

Luminosity Increase



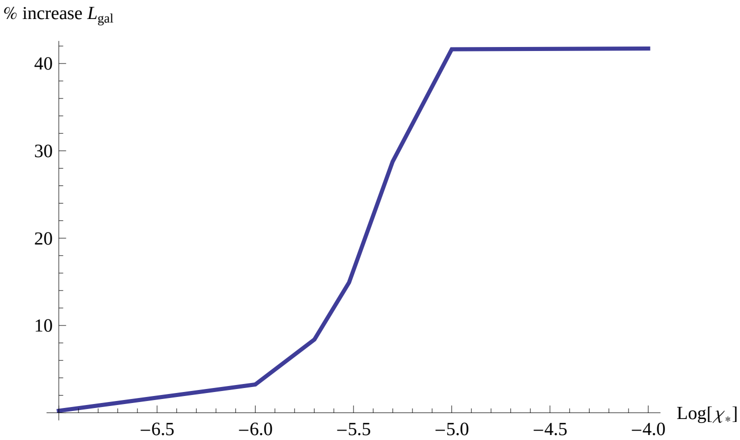
Galactic Luminosity

Dwarf galaxies have $\Phi_N \sim 10^{-7} - 10^{-8}$, at least an order of magnitude below current constraints on $\chi_\star$.

The luminosity of a galaxy is the sum of that due to its constituent stars:

$$L_{\rm gal} = \int_{0.08M_\odot}^{100M_\odot} \mathrm{d}M \, f_0(M, \tau_{\rm age}) L_{\rm star}(M; \chi_\star) \Phi(M) \, .$$

Luminosity Enhancement (1)



Luminosity Enhancement (2)

$\chi_\star$	Luminosity Enhancement
$1\text{x}10^{-4}$	42%
$1\text{x}10^{-5}$	42%
$5\text{x}10^{-6}$	29%
$1\text{x}10^{-6}$	3%

$$\alpha_\star = \frac{1}{3}$$

What Next?

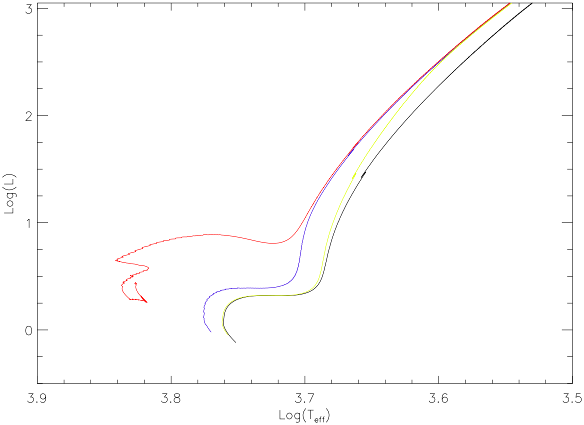
We have modified the publically available code MESA to include the effects of modified gravity.

Using this we can generate isochrones for the entire mass range of the IMF for stars of varying initial metallicity.

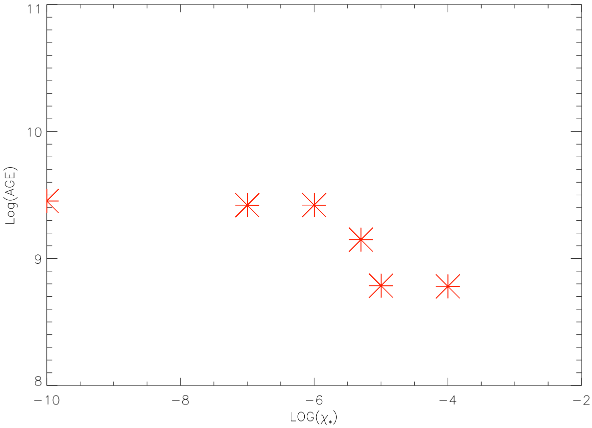
These can then be fed into galaxy synthesisers in order to predict the observational properties:

- spectra
- colour index
- absolute magnitude (luminsoity)
- metallicity

H-R Diagram



Age Vs. $\chi_\star$



Summary

1. Modified gravity with screening mechanisms can account for dark energy whilst still satisfying local constraints on general relativity.
2. Dwarf galaxies are unscreened for certain values of the parameters not yet ruled out by observation.
3. In these galaxies stars that are at least partially unscreened need to burn more fuel per unit time to support themselves against the increased gravity.
4. This has they effect that:
    - They are more luminous.
    - They have a shorter lifetime.
5. The luminosity of these dwarf galaxies is enhanced due to the increase in their constituent stars.
6. This enhancement is significant for values of the parameters an order of magnitude lower than the current bounds.

Thank You!