The Effect of Screening on Galactic Dynamics

Clare Burrage

University of Nottingham

Outline:

Symmetron screening

Radiatively Stable Symmetron

Galactic Dynamics

THE ROYAL SOCIETY

University of Nottingham UK | CHINA | MALAYSIA

LEVERHULME TRUST

Symmetron Screening

Canonical scalar with potential and coupling to matter

$$V(\phi) = \frac{\lambda}{4}\phi^4 - \frac{\mu^2}{2}\phi^2 \qquad \mathcal{L} \supset \frac{\phi^2}{2M^2} T^\mu_\mu$$

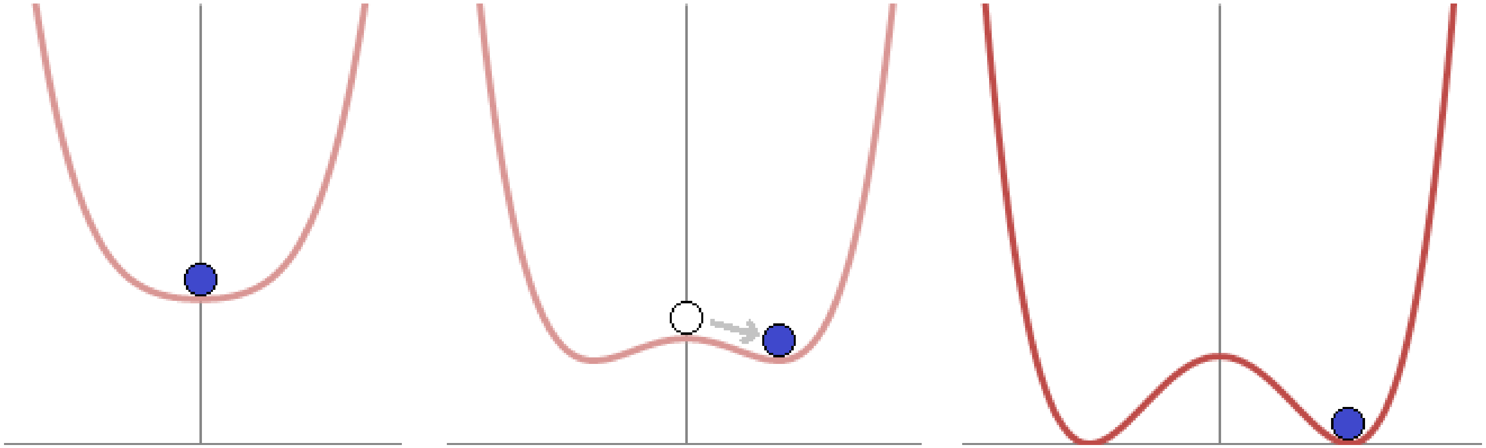
Effective potential

$$V_{\rm eff}(\phi) = \frac{1}{2}\left(\frac{\rho}{M^2} - \mu^2\right)\phi^2 + \frac{1}{4}\lambda\phi^4$$

Symmetry breaking transition occurs as the density is lowered

Hinterbichler, Khoury. (2010).
See also: Pietroni (2005). Olive, Pospelov (2008). Brax et al. (2011).

Symmetron Screening



Force on test particle vanishes when symmetry is restored

$$F = \phi \nabla \phi / M^2$$

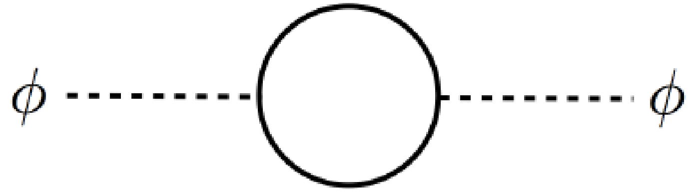
Hinterbichler, Khoury. (2010).

Radiative Stability

Screening mechanisms rely on non-linearities

- Requires the introduction of non-renormalisible operators
- In the absence of a symmetry (e.g. Galileon, DBI), relevance of these terms would indicate break down of EFT

Coupling to matter can also generate large corrections. E.g. standard model loops generate a large scalar mass



Radiatively Stable Symmetron

Start with a scale invariant model

$$S = \int \mathrm{d}^4x \sqrt{-g} \left[\frac{1}{2} F(\phi) \mathcal{R} - \Lambda + \mathcal{L} + \mathcal{L}_m \right]$$

$$-\mathcal{L} = \frac{1}{2} \phi_{,\mu} \phi^{,\mu} + \frac{1}{2} X_{,\mu} X^{,\mu} + \frac{\lambda}{4} \phi^2 X^2 + \frac{\kappa}{4!} X^4$$

Minimally coupled to gravity in the Jordan frame

$$F(\phi) = 1 + \frac{\phi^2}{M^2}$$

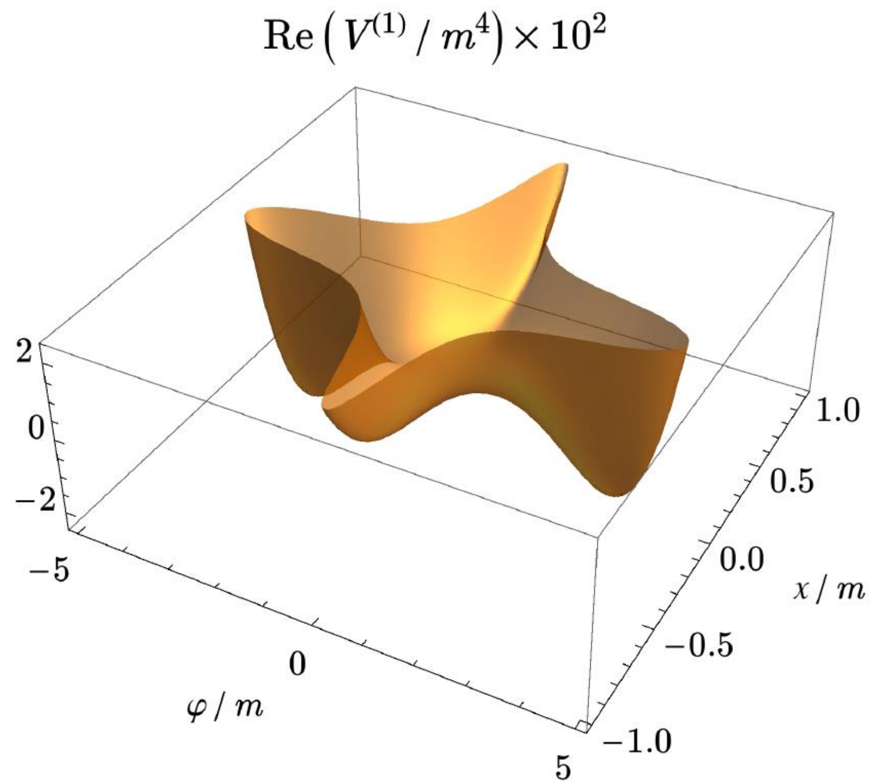
At tree level fields are massless in vacuum

CB, Copeland, Millington (2016).

One loop effective potential

Treat gravity as a classical source

Assume Minkowski background and constant field configurations

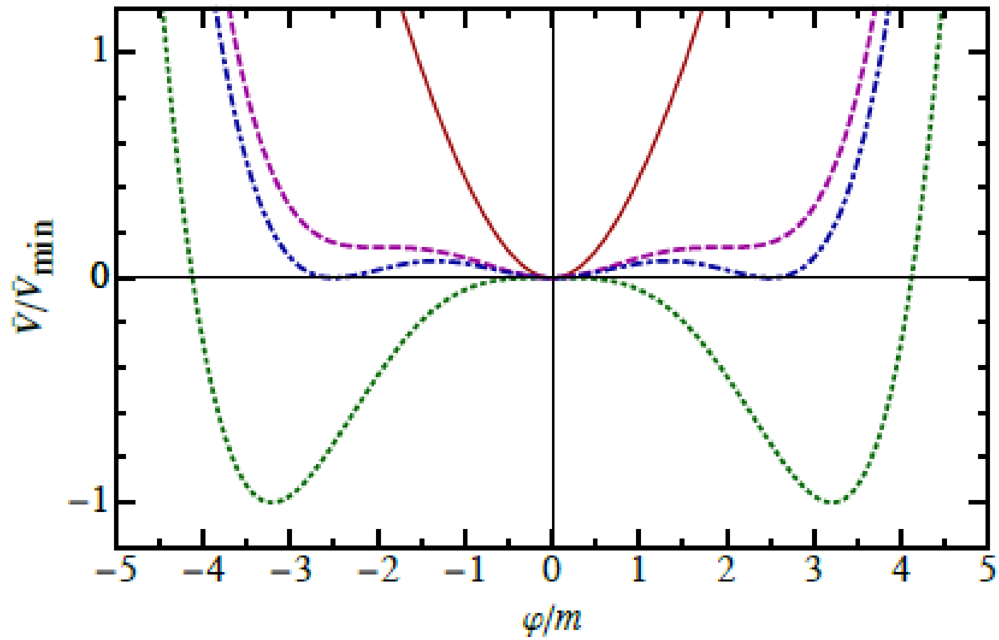


Garbrecht, Milington (2015). CB, Copeland, Millington (2016).

Radiatively Stable Symmetron

One loop potential for 'symmetron' field

$$V^{(1)}(\varphi) = \left(\frac{\lambda}{16\pi}\right)^2 \varphi^4 \left(\ln\frac{\varphi^2}{m^2} - Y\right)$$

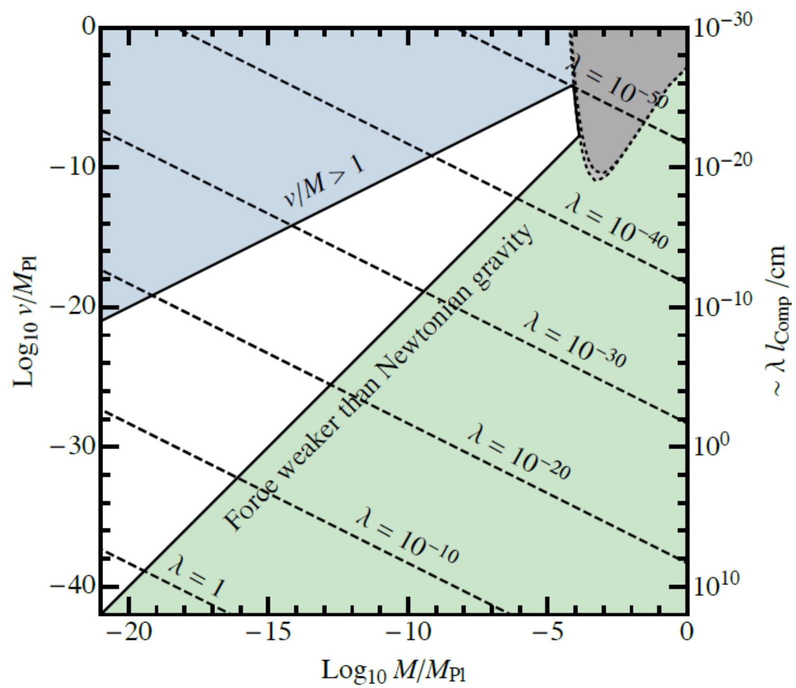


Available Parameter Space

Radiatively stable if

$$\frac{v}{M_{\rm Pl}} < \frac{M}{M_{\rm Pl}} \qquad\qquad \lambda > \left(\frac{v_H}{M}\right)^2$$

Also need to satisfy Eöt-Wash, and be in symmetry broken phase in current cosmological vacuum



Screened Forces in Galaxies

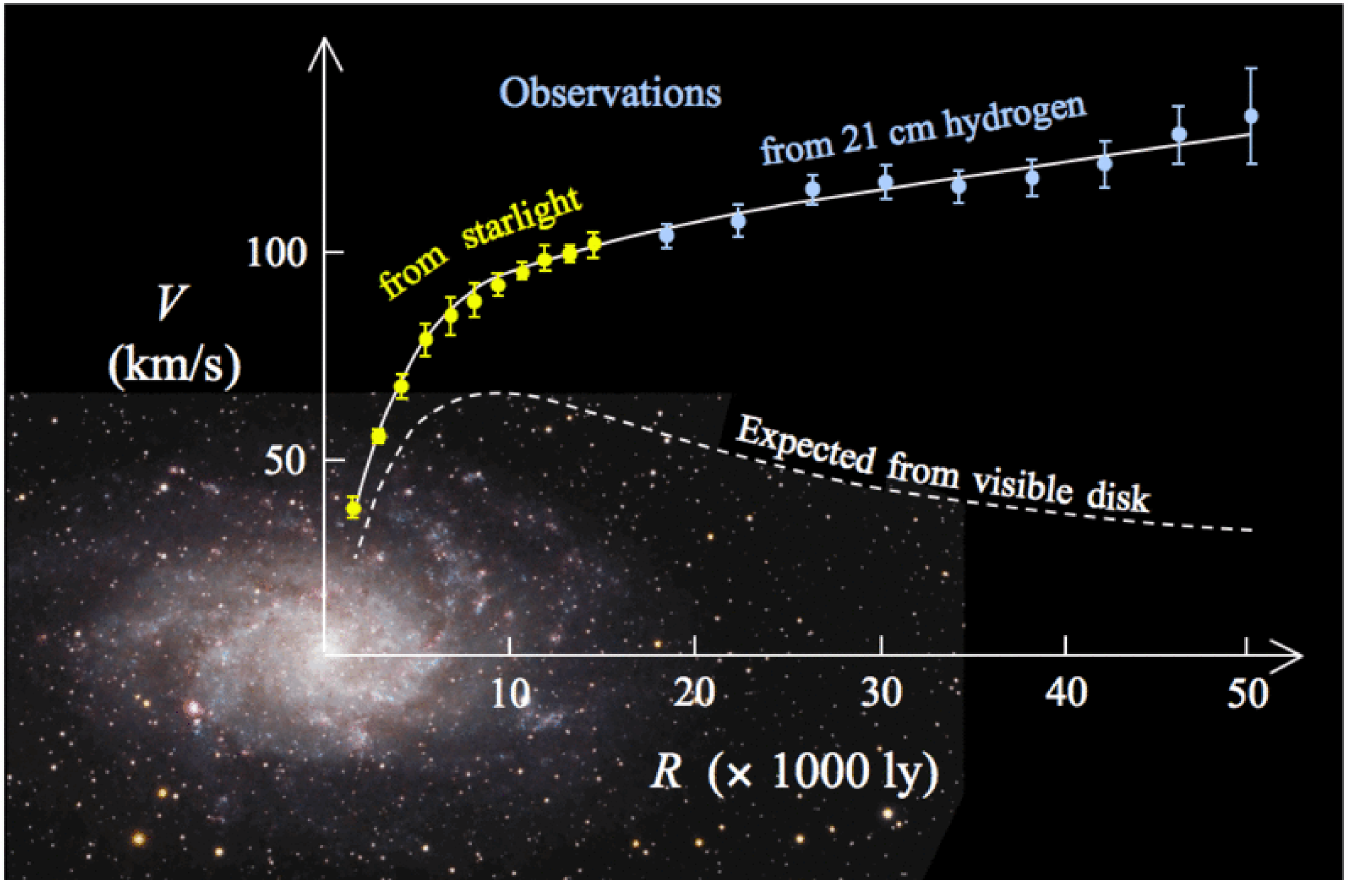
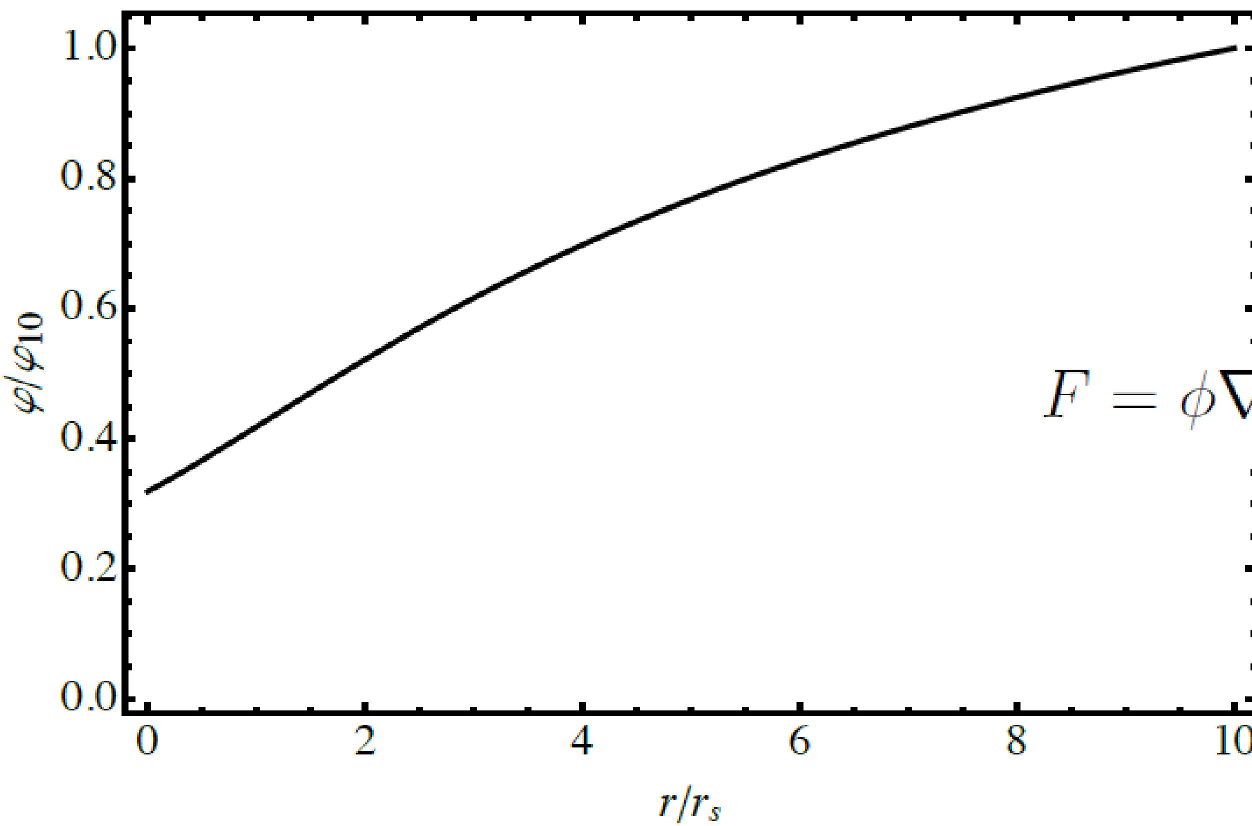


Image Credit: Stefania.deluca

Symmetron Field Profile for a Galaxy

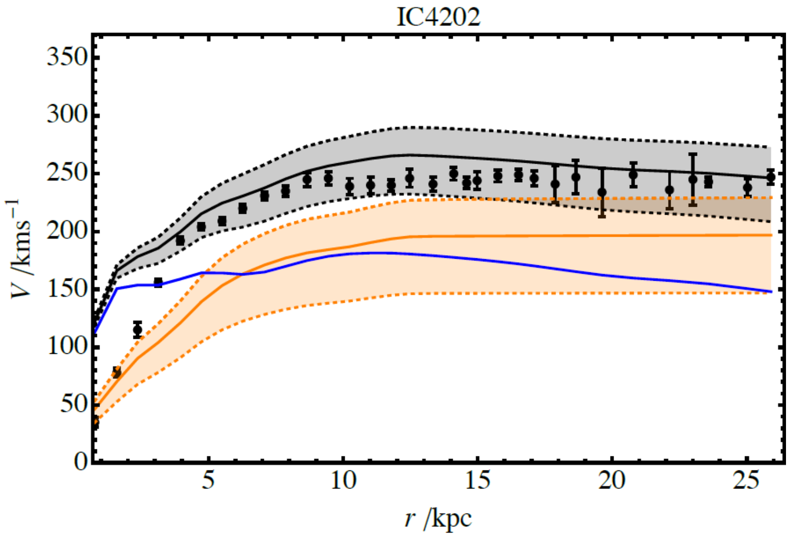
To explain rotation curve of a 'typical' galaxy with only a symmetron force and no dark matter

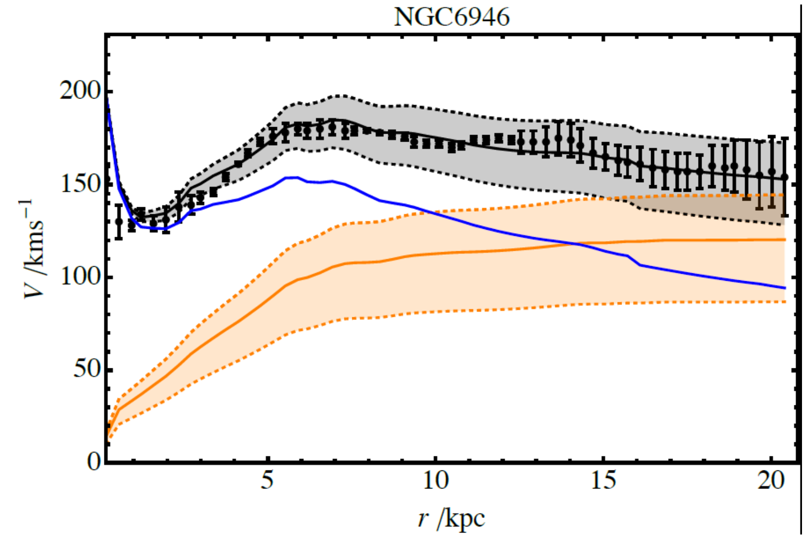


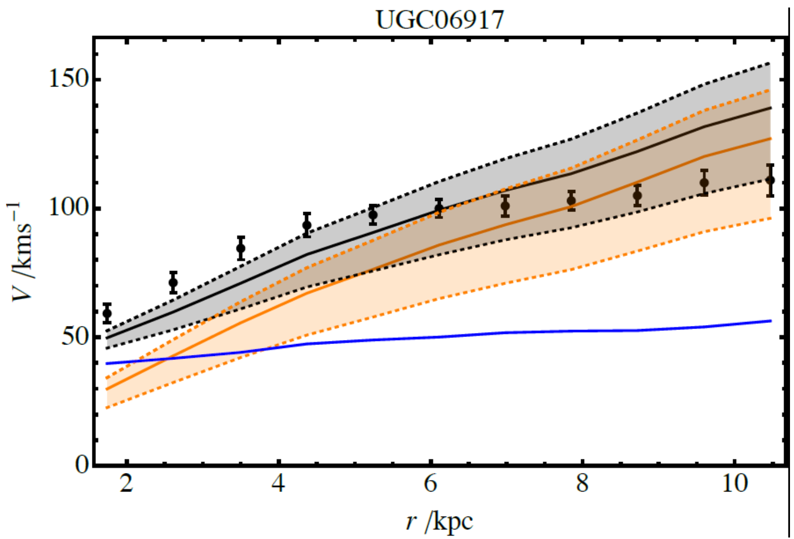
$$F = \phi \nabla \phi / M^2$$

CB, Copeland, Millington (2016)

Galaxy Rotation Curves







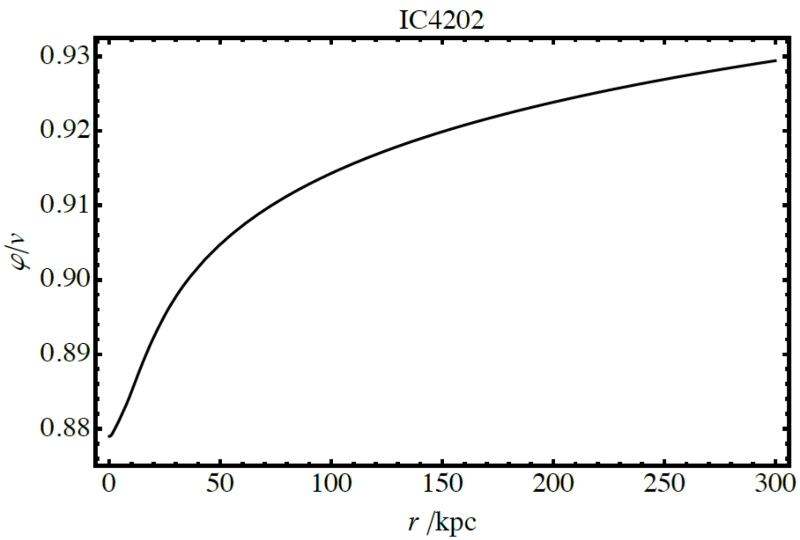
$$\mu = 10^{-40}\ \mathrm{GeV}$$

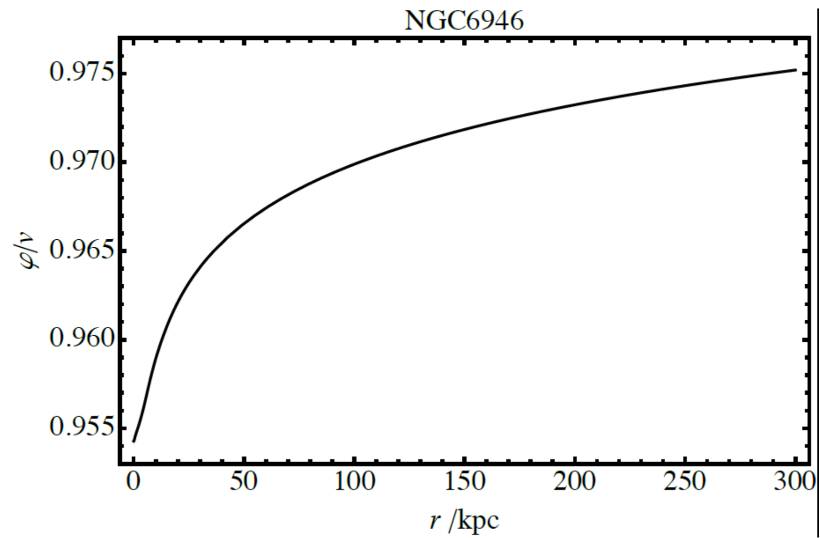
$$M = M_{\mathrm{Pl}}/10$$

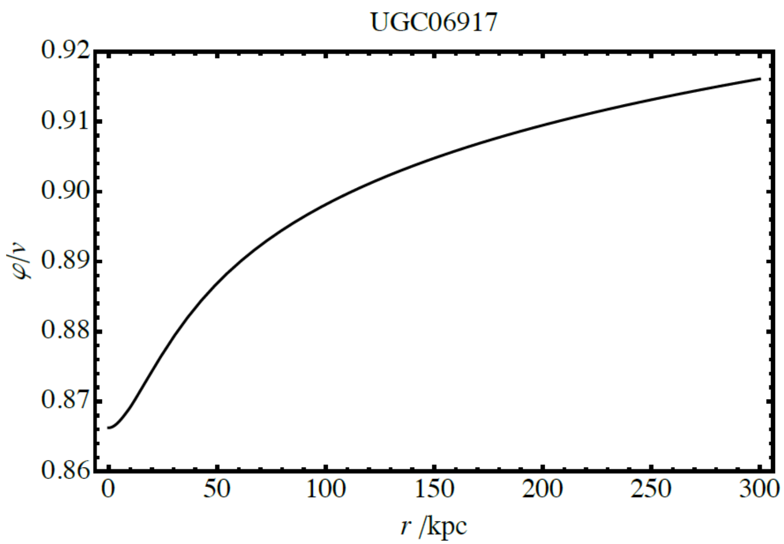
$$v = M/170$$

CB, Copeland, Millington (2016). SPARC data: McGaugh, Lelli, Schombert (2016)

Symmetron Field Profiles







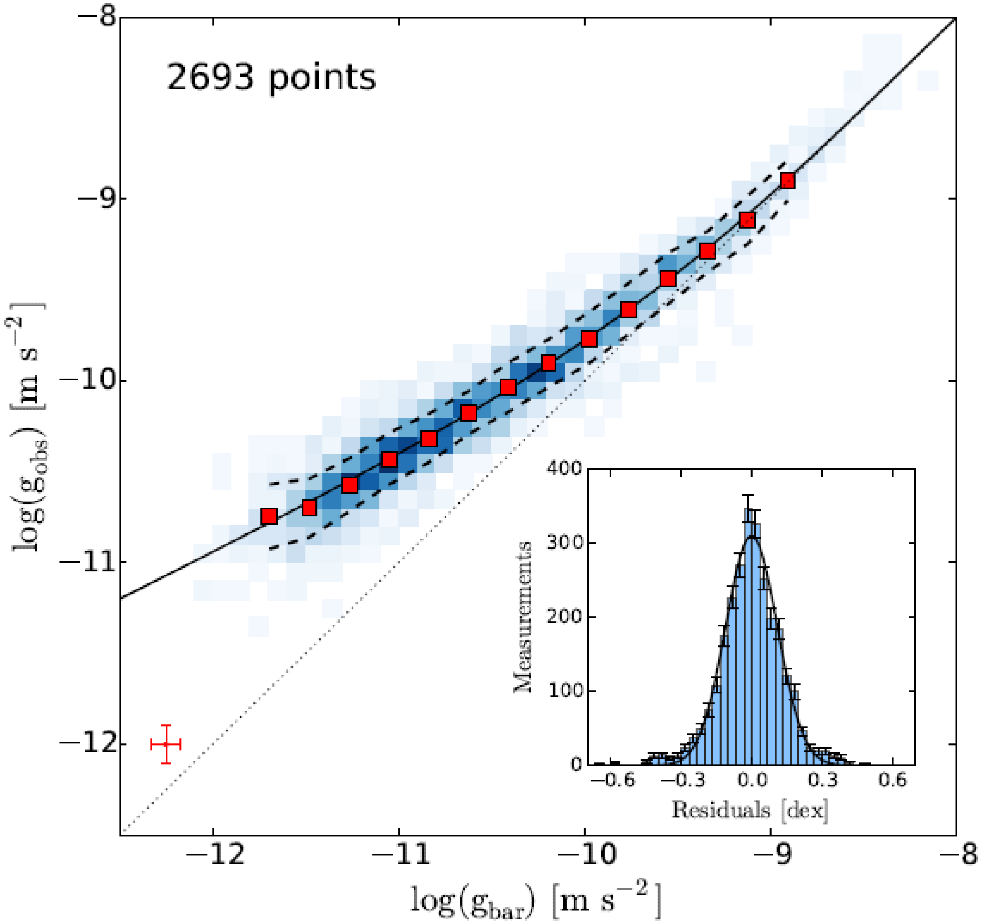
$$\mu = 10^{-40}\ \mathrm{GeV}$$

$$M = M_{\mathrm{Pl}}/10$$

$$v = M/170$$

See also: Gessner (1992).

Radial Acceleration Relation



153 galaxies,

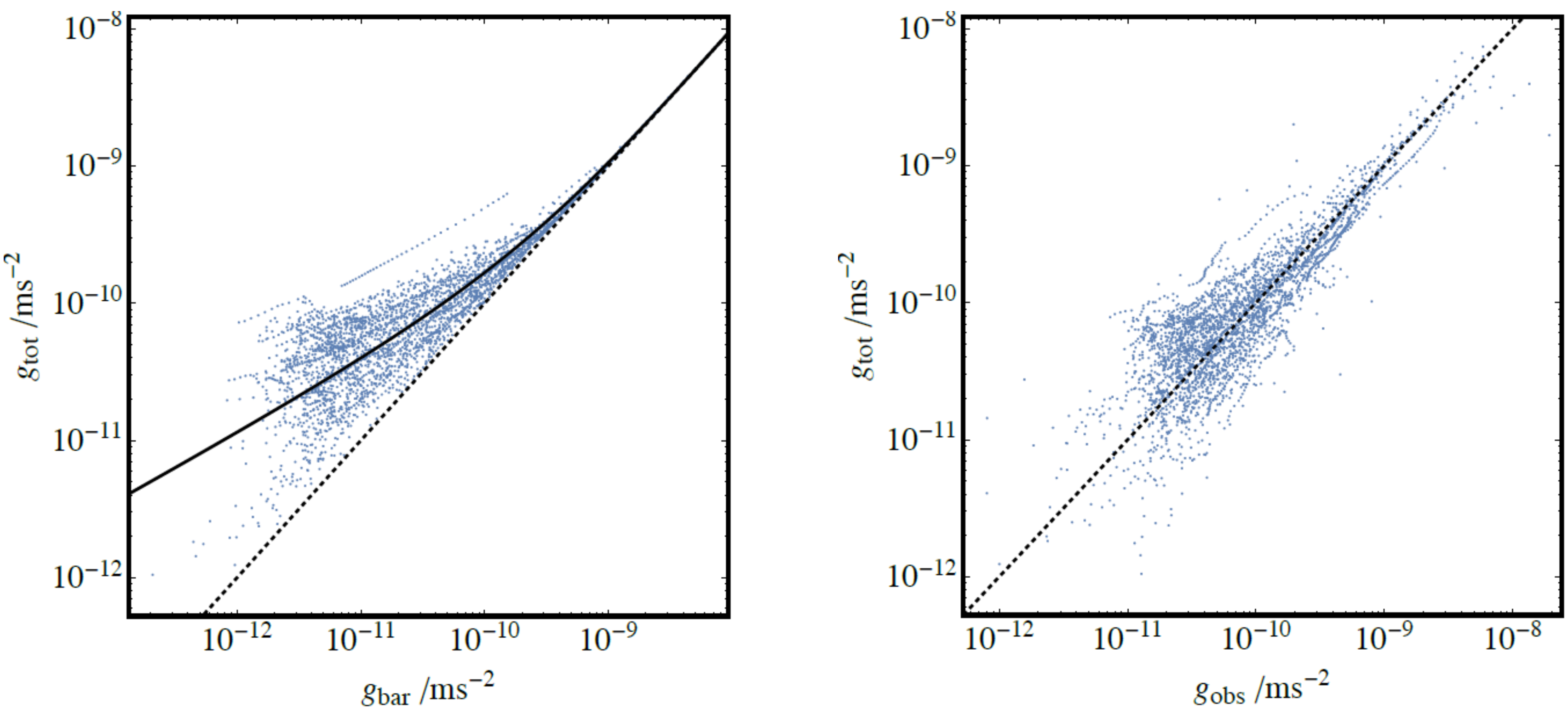
~ 2700 data points

$$g_{obs} = \frac{V^2(R)}{R}$$

$$g_{obs} = \mathcal{F}(g_{bar}) = \frac{g_{bar}}{1 - e^{-\sqrt{g_{bar}/g_{\dagger}}}}$$

McGaugh, Lelli, Schombert (2016). See also: Keller and Wadsley (2016).

Symmetron Acceleration Relation



CB, Copeland, Millington (2016)

What can we conclude from this?

The fifth forces from a canonical scalar can explain galactic rotation curves (and stability)

Lensing & cosmological background evolution requires extending the model
(eg an additional disformally coupled scalar)

If fifth forces are present on galactic scales we may be over estimating dark matter abundances

If dark matter is a light scalar (eg fuzzy dark matter) we should consider non-minimal couplings and the resulting fifth forces.

Summary

The symmetron model can be constructed in a radiatively stable way

Symmetron fifth forces can explain galaxy rotation curves and stability without the need for dark matter

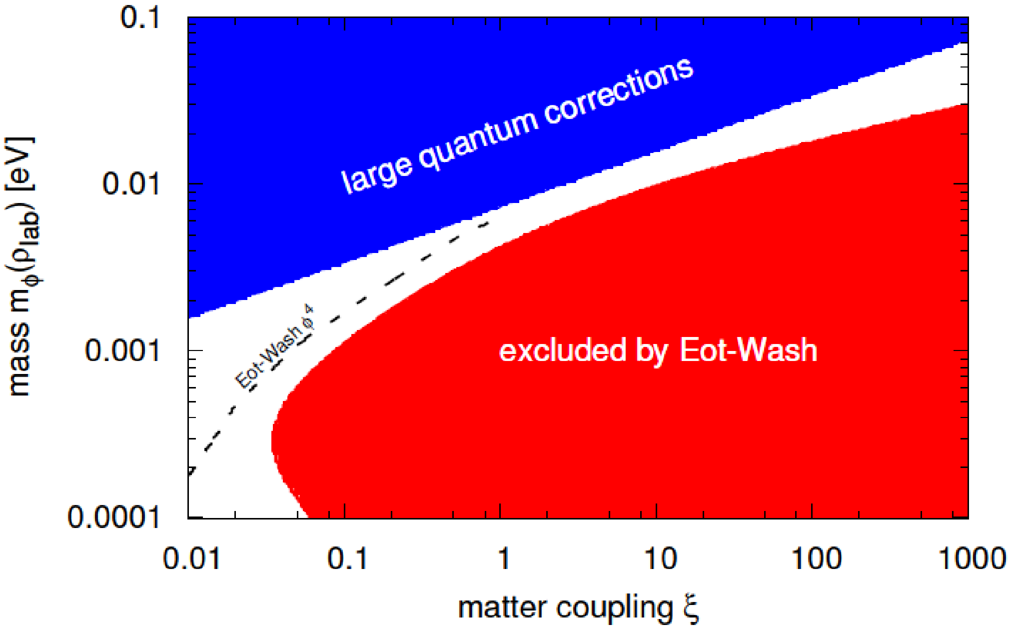
Also explains observed correlations with baryonic components

Chameleon Coleman-Weinberg Corrections

One-loop Coleman-Weinberg

$$\Delta V(\phi) = \frac{m_{\rm eff}^4(\phi)}{64\pi^2} \ln\left(\frac{m_{\rm eff}^2(\phi)}{\mu^2}\right)$$

Corrections become important when mass becomes large – but this is needed for chameleon screening



Upadhye, Hu, Khoury. (2012).

Galaxy Rotation Curve – KK98-251