Chameleons Galore

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Outline

1-Scalars and Cosmic Acceleration?

2-Chameleons and Thin Shell effect

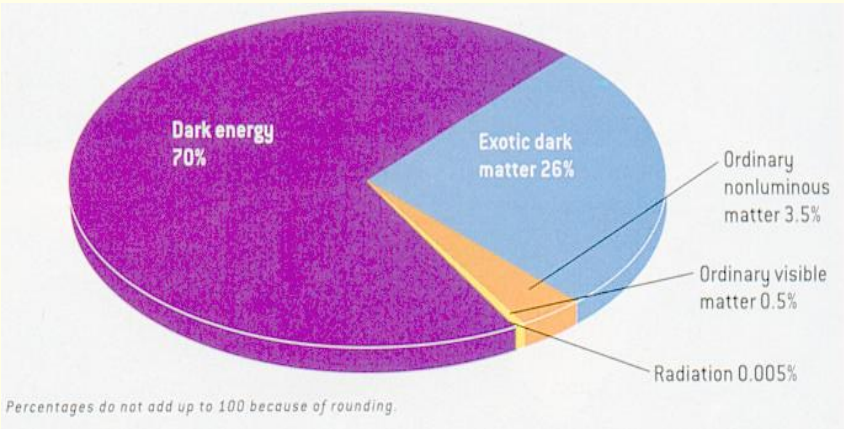
3-The Casimir Effect

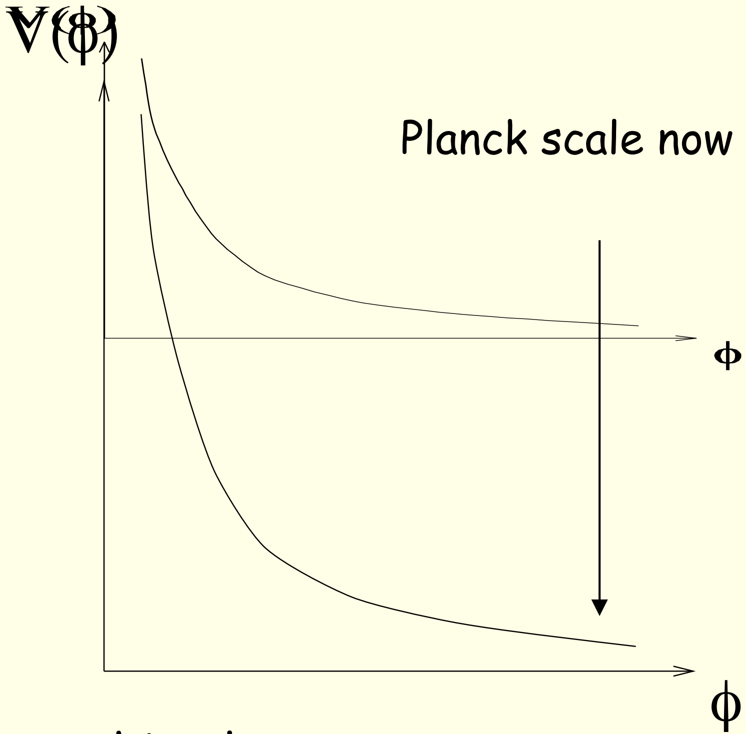
4- Chameleon Optics

5-Modifying gravity at low redshift.

Scalars and Dark Energy

Dark Energy





Field rolling down a runaway potential, reaching large values now (Planck scale)

Extremely flat potential for an almost decoupled field

How Flat?

Energy density and pressure:

$$\rho = \frac{1}{2}\dot{\phi}^2 + V(\phi), \; p = \frac{1}{2}\dot{\phi}^2 - V(\phi)$$

Runaway fields can be classified according to

$$w = \frac{p}{\rho}$$

$m \gg H_0$	very fast roll	$w \approx 1$
$m \ll H_0$	slow roll	$w \approx -1$ (inflation)
$m \approx H_0$	gentle roll	$-1 \leq w < -\frac{1}{3}$ (dark energy)

$H_0 \approx 10^{-43}\text{GeV}$ strong gravitational constraints

Gravitational Tests

Dark energy theories suffer from the potential presence of a fifth force mediated by the scalar field.

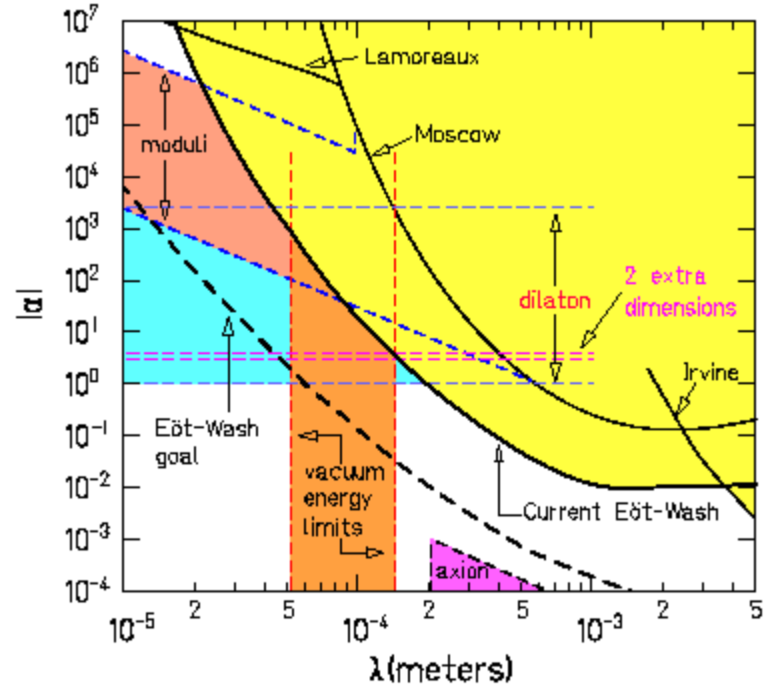
Alternatives:

Non-existent if the scalar field has a mass greater than :

$$m \geq 10^{-3}\ \mathrm{eV}$$

If not, strong bound from Cassini experiments on the gravitational coupling:

$$\alpha^2 \leq 10^{-5}$$



Scalar-Tensor Effective Theory

Effective field theories with gravity and scalars:

$$S=\int d^4x\sqrt{-g}\left(\frac{1}{16\pi G_N}R-\frac{1}{2}(\partial\phi)^2-V(\phi)+\mathcal{L}_m(\psi_m,A^2(\phi)g_{\mu\nu})\right)$$

$$\alpha_\phi = m_{\rm Pl}\frac{d\ln A}{d\phi}$$

Scalars differ from axions (pseudo-scalars) inasmuch as they can couple to matter with non-derivative interactions. All the physics is captured by the function $A(\phi)$.

$$m(\phi)=A(\phi)m_0$$

In the Einstein frame, masses become conformally related to the bare mass.

Gravitational Constraints

- Deviations from Newton's law are tested on macroscopic objects. The gravitational coupling is:

$$\kappa_4 \alpha = \frac{\mathrm{d} \ln m_{\mathrm{atom}}}{\mathrm{d}\phi_n}$$

- The deviation is essentially given by:

$$\alpha \approx [\frac{3}{2}\frac{m_u + m_d}{\Lambda_{QCD}} - \frac{1}{8}\frac{N-Z}{N+Z}\frac{m_u - m_d}{\Lambda_{QCD}}]\alpha_\phi$$

An Example: the radion

The distance between branes in the Randall-Sundrum model:

$$A(\phi) = \cosh \frac{\phi}{\sqrt{6}}$$

where

$$R = \frac{1}{k} \ln \tanh \frac{\phi}{\sqrt{6}}$$

Gravitational coupling:

$$\alpha_\phi = \frac{1}{\sqrt{6}} \tanh(\frac{\phi}{\sqrt{6}})$$

close branes:

$$A(\phi) = \exp \frac{\phi}{\sqrt{6}}$$

constant coupling constant

$$\alpha_\phi = \frac{1}{\sqrt{6}}$$

Example: Moduli coupled to the standard model

The Standard Model fermion masses become moduli dependent

$$m_{\text{u,d}}(\phi) = \lambda e^{\kappa_4^2 K(\phi)/2} m_{\text{u,d}}$$

Scalar-tensor theory

Yukawa

Kahler

$$K = -\frac{n}{\kappa_4^2} \ln \kappa_4(\phi + \bar{\phi})$$

n=1 dilaton, n=3 volume modulus

Gravitational Problems

- Deviations from Newton's law are tested on macroscopic objects. The gravitational coupling is:

$$\kappa_4 \alpha_\phi = \frac{\mathrm{d} \ln m}{\mathrm{d}\phi_n} \quad \longleftarrow \quad d\phi_n = \sqrt{K_{\phi\phi}} d\phi$$

- For moduli fields: $\kappa_4 \partial_{\phi_n} K = \sqrt{2n}$ Too Large !

f(R) gravity

- The simplest modification of General Relativity is f(R) gravity:

$$\frac{1}{16\pi G_N}\int d^4x\sqrt{-g}R \rightarrow \frac{1}{16\pi G_N}\int d^4x\sqrt{-g}f(R)$$

- The function f(R) must be close to R, so f(R)= R+ h(R), h<< R in the solar system.
- f(R) gravity addresses the dark energy issue for certain choices of h(R).

f(R) vs Scalar-Tensor Theories

f(R) totally equivalent to an effective field theory with gravity and scalars

$$S = \int d^4x\sqrt{-g}(\frac{1}{16\pi G_N}R - \frac{1}{2}(\partial\phi)^2 - V(\phi) + \mathcal{L}_m(\psi_m, e^{2\phi/\sqrt{6}m_{\rm Pl}}g_{\mu\nu}))$$

The potential V is directly related to f(R).

$$V(\phi) = m_{\rm Pl}^2 \frac{Rf' - f}{2f'^2}, \quad f' = e^{-2\phi/\sqrt{6}m_{\rm Pl}}$$

Same problems as dark energy: coincidence problem, cosmological constant value etc…

$$\alpha_\phi = \frac{1}{\sqrt{6}}$$

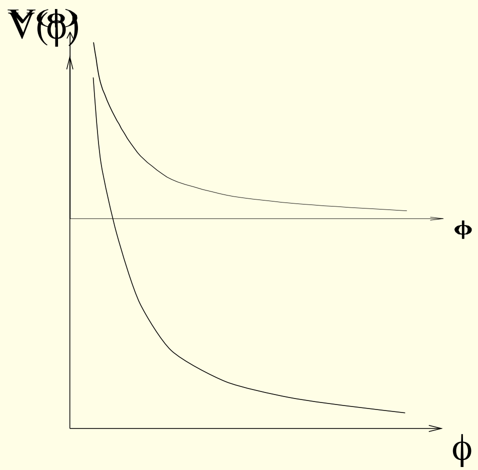
A Few Examples

A large class of models is such that h(R)→ C for large curvatures. This mimics a cosmological constant for large value of ϕ

$$h(R) = \lambda \frac{R}{\frac{\lambda R}{C} + 1}$$

Another class of models leads to a quintessence like behaviour:

$$h(R) \sim \bar{R}(\frac{R}{\bar{\bar{R}}})^{p+1}, \quad V(\phi) \sim \Lambda^4 (\frac{\phi}{\Lambda})^{(p+1)/p}$$



Ratra-Peebles ! n=-(p+1)/p

Chameleons

Chameleons

Chameleon field: field with a matter dependent mass

A way to reconcile gravity tests and cosmology:

Nearly massless field on cosmological scales

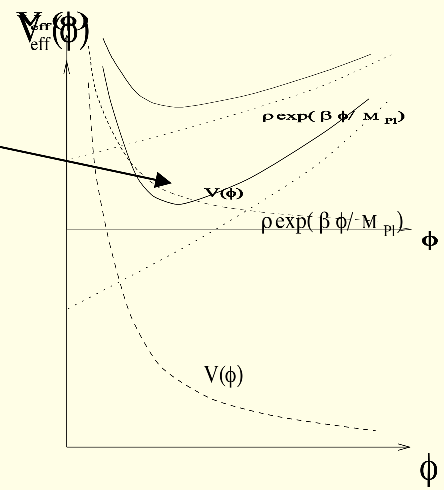
Massive field in the laboratory

The effect of the environment

When coupled to matter, scalar fields have a matter dependent effective potential

$$V_{eff}(\phi) = V(\phi) + \rho_m A(\phi)$$

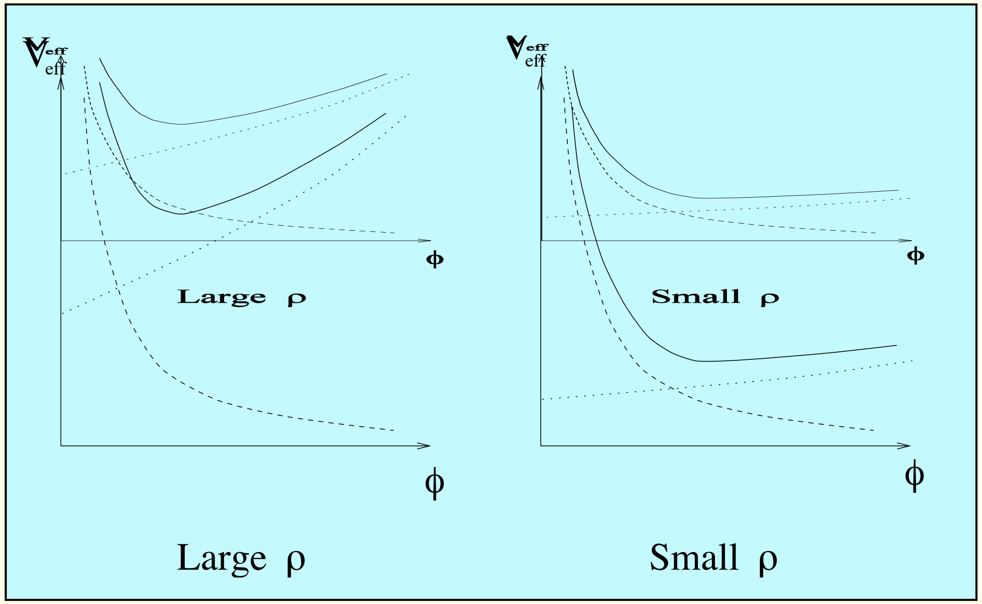
Environment dependent minimum



An Example:

Ratra-Peebles potential $$V(\phi) \sim \frac{\Lambda^{4+n}}{\phi^n}$$

Constant coupling to matter $$A(\phi) = \exp \beta \frac{\phi}{m_{\text{Pl}}}$$



$\beta = \frac{1}{\sqrt{6}}$ for f(R) theories

What is dense enough?

- The environment dependent mass is enough to hide the fifth force in dense media such as the atmosphere, hence no effect on Galileo's Pisa tower experiment!

$$\rho \approx 10^{-4} \mathrm{g/cm^3}$$

- It is not enough to explain why we see no deviations from Newtonian gravity in the lunar ranging experiment

$$\rho \approx 10^{-22} \mathrm{g/cm^3}$$

- It is not enough to explain no deviation in laboratory tests of gravity carried in "vacuum"

$$\rho \approx 10^{-14} \mathrm{g/cm^3}$$

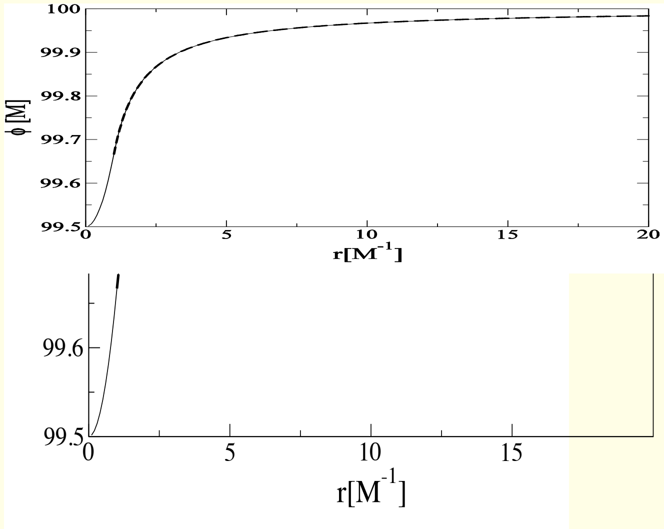
The Thin Shell Effect I

- The force mediated by the chameleon is:

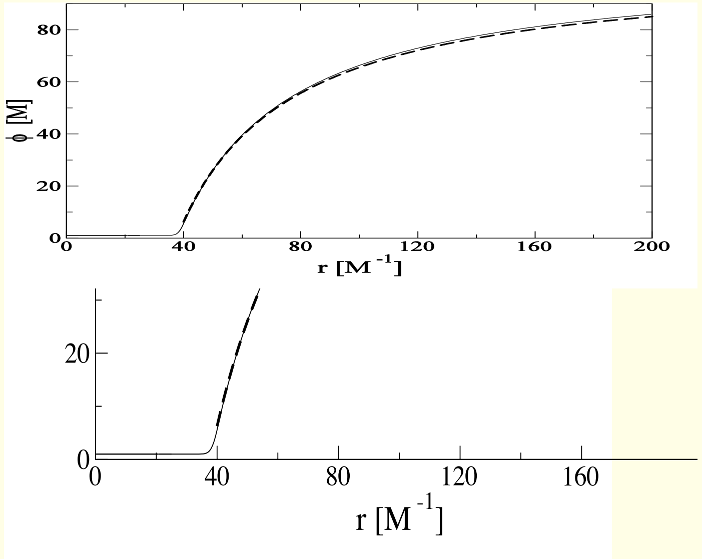
$$F_\phi = -\beta \frac{m}{m_{\mathsf{Pl}}} \nabla \phi, \quad \beta = \frac{m_{\mathsf{Pl}}}{M}$$

- The force due to a compact body of radius R is generated by the gradient of the chameleon field outside the body.
- The field outside a compact body of radius R interpolates between the minimum inside and outside the body
- Inside the solution is nearly constant up to the boundary of the object and jumps over a thin shell ΔR
- Outside the field is given by:

$$\phi \approx \phi_\infty - \frac{\beta}{m_p} \frac{3\Delta R}{R} \frac{M_c}{r}$$



No shell



Thin shell

The Thin Shell Effect II

- The force on a test particle outside a spherical body is shielded:

$$\alpha_\phi = 3\beta \frac{\Delta R}{R}$$

- When the shell is thin, the deviation from Newtonian gravity is small.

- The size of the thin-shell is:

$$\frac{\Delta R}{R} = \frac{\phi_\infty - \phi_c}{6\beta m_p \Phi_N}$$

- Small for large bodies (sun etc..) when Newton's potential at the surface of the body is large enough.

Laboratory tests

- In a typical experiment, one measures the force between two test objects and compare to Newton's law (this is very crude, more about the Eot-wash experiment later…). The test objects are taken to be small and spherical. They are placed in a vacuum chamber of size L.
- In a vacuum chamber, the chameleon "resonates" and the field value adjusts itself according to:

$$m_{\rm vac} L \sim 1$$

- The vacuum is not dense enough to lead to a large chameleon mass, hence the need for a thin shell.

$$\phi_{\rm vac} \leq 10^{-28} m_{\rm Pl}$$

- Typically for masses of order 40 g and radius 1 cm, the thin shell requires for the Ratra-Peebles case:

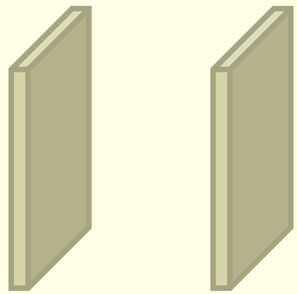
$$\Lambda \leq 10^{3n/(n+4)} 10^{-12}\ \text{GeV}$$

- We will be more precise later….

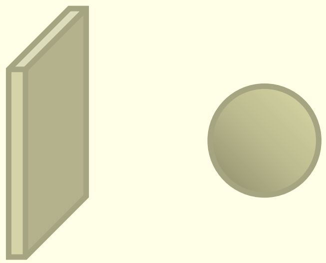
The Casimir Effect

Casimir Force Experiments

- Measure force between
  - Two parallel plates



  - A plate and a sphere



The Casimir Force

- The inter-plate force is in fact the contribution from a chameleon to the Casimir effect. The acceleration due to a chameleon is:

$$a_\phi = -\alpha\kappa_4 \nabla\phi$$

- The attractive force per unit surface area is then:

$$\frac{F_\phi}{A} = -\int_{d/2}^{D+d/2} \alpha\kappa_4\rho_c \frac{d\delta\phi}{dx} = V'(\phi_c)\delta\phi_s$$

where

$$\delta\phi_s = \frac{V(\phi_b) - V(\phi_0) - V'(\phi_b)(\phi_b - \phi_0)}{V'(\phi_c)}$$

is the change of the boundary value of the scalar field due to the presence of the second plate.

The Casimir Force

- We focus on the plate-plate interaction in the range:

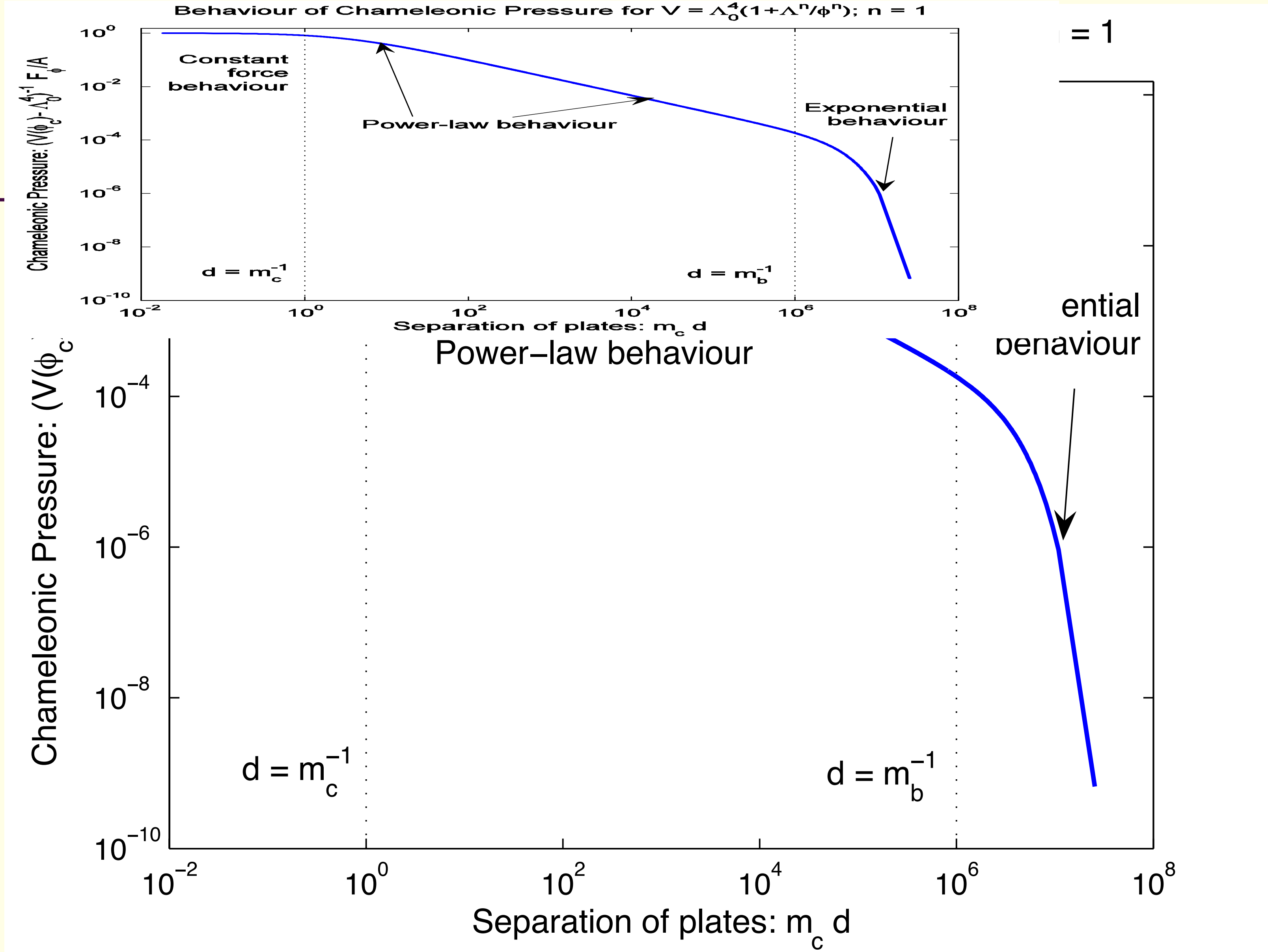
Mass in the plates → $$m_c^{-1} \leq d \leq m_b^{-1}$$ ← Mass in the cavity

- The force is algebraic:

$$\frac{F_\phi}{A} \sim \Lambda^4 (\Lambda d)^{-\frac{2n}{n+2}}$$

- The dark energy scale sets a typical scale:

$$\Lambda^{-1} \sim 82 \mu m$$



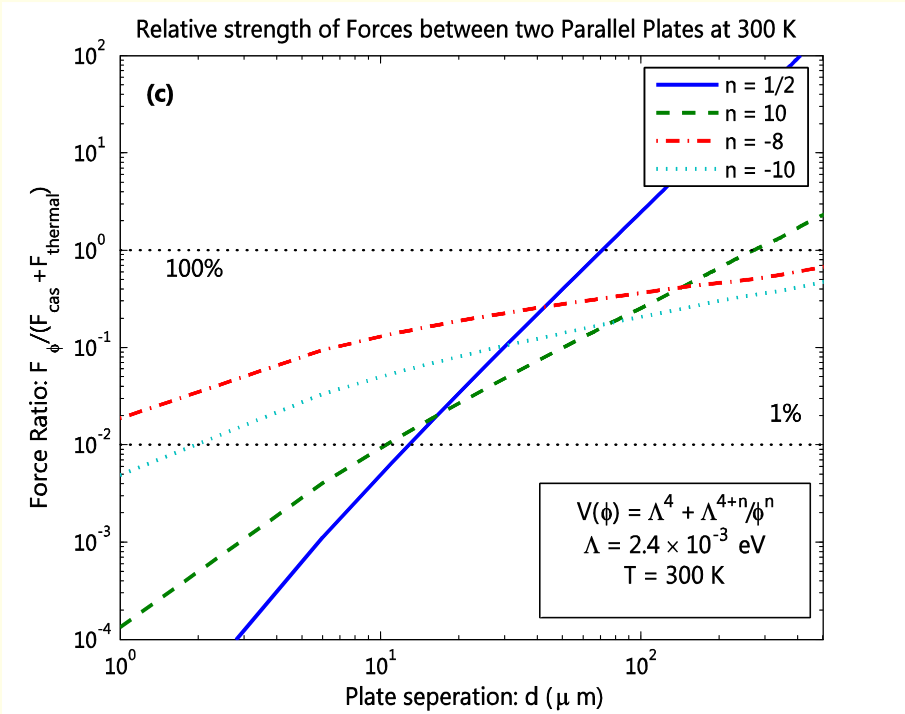
Behaviour of Chameleonic Pressure for V = $\Lambda_0^4(1+\Lambda^n/\phi^n)$; n = 1
Constant force behaviour
Power-law behaviour
Exponential behaviour
d = m_c^{-1}
d = m_b^{-1}
Chameleonic Pressure: $(V(\phi_c)-\Lambda_0^4)^{-1} F_\phi/A$
Separation of plates: m_c d
10^{0} 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10}
10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8}
= 1
ential
behaviour
Power−law behaviour
Chameleonic Pressure: (V(ϕ_c
d = m_c^{-1}
d = m_b^{-1}
Separation of plates: m_c d

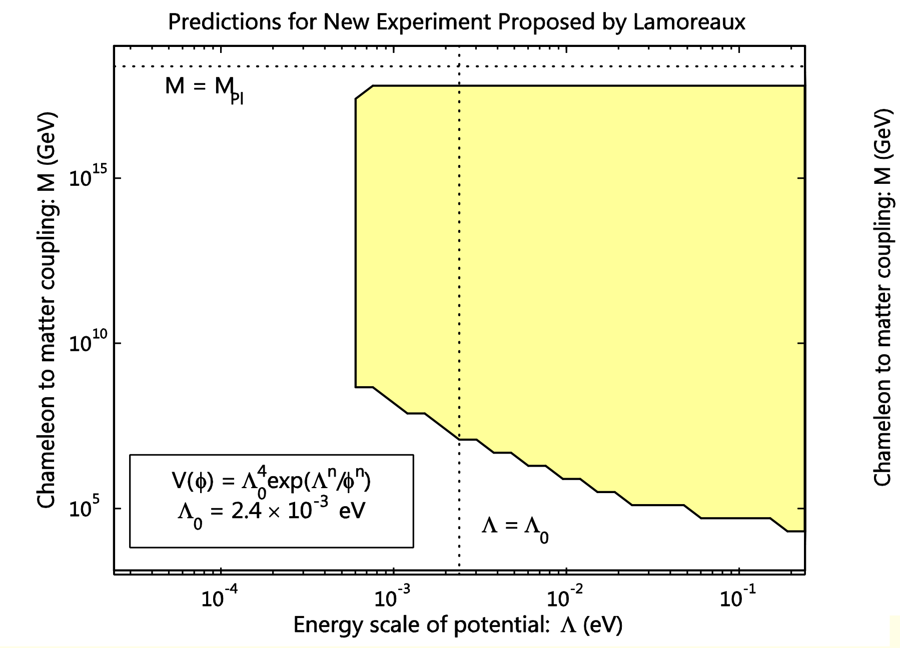
Detectability

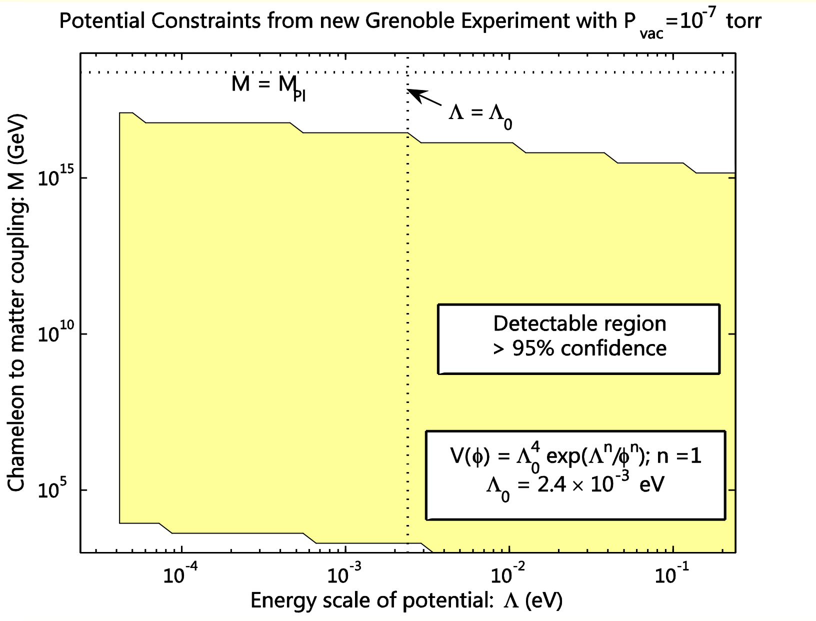
- The Casimir forces is also an algebraic law implying:

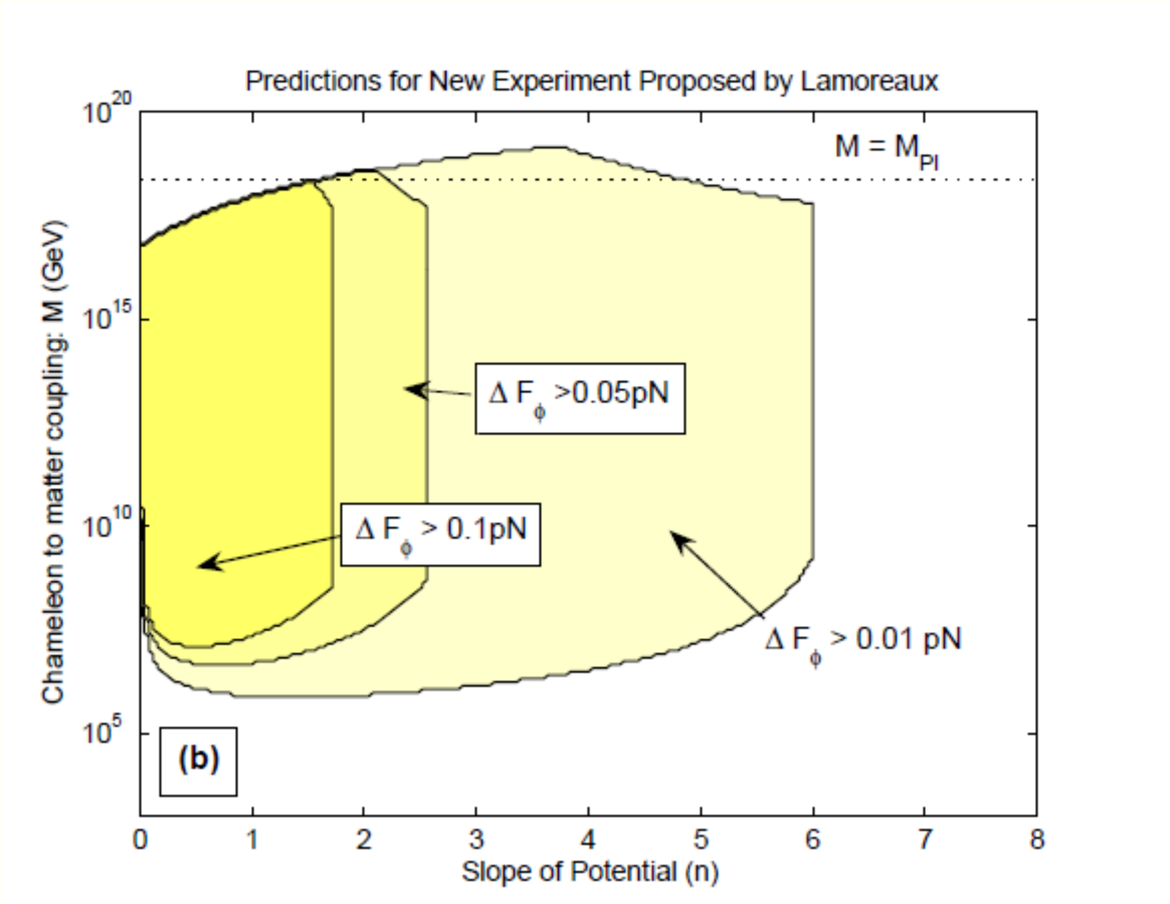
$$\frac{F_\phi}{F_{\text{cas}}} \sim \frac{240}{\pi^2}(\Lambda d)^{\frac{2(n+4)}{n+2}}$$

- This can be a few percent when d=10µm and would be 100% for d=30 µm




Predictions for New Experiment Proposed by Lamoreaux
M = M_Pl
Λ = Λ_0
V(ϕ) = Λ_0^4 exp(Λ^n/ϕ^n)
Λ_0 = 2.4 × 10^-3 eV
Chameleon to matter coupling: M (GeV)
Energy scale of potential: Λ (eV)
10^5
10^10
10^15
10^-4
10^-3
10^-2
10^-1


Potential Constraints from new Grenoble Experiment with P_vac =10^-7 torr
M = M_Pl
Λ = Λ_0
Detectable region
> 95% confidence
V(ϕ) = Λ_0^4 exp(Λ^n/ϕ^n); n =1
Λ_0 = 2.4 × 10^-3 eV
Chameleon to matter coupling: M (GeV)
Energy scale of potential: Λ (eV)
10^5
10^10
10^15
10^-4
10^-3
10^-2
10^-1



Predictions for New Experiment Proposed by Lamoreaux
M = M_Pl
ΔF_φ >0.05pN
ΔF_φ > 0.1pN
ΔF_φ > 0.01 pN
(b)
Chameleon to matter coupling: M (GeV)
Slope of Potential (n)
10^20
10^15
10^10
10^5
0
1
2
3
4
5
6
7
8

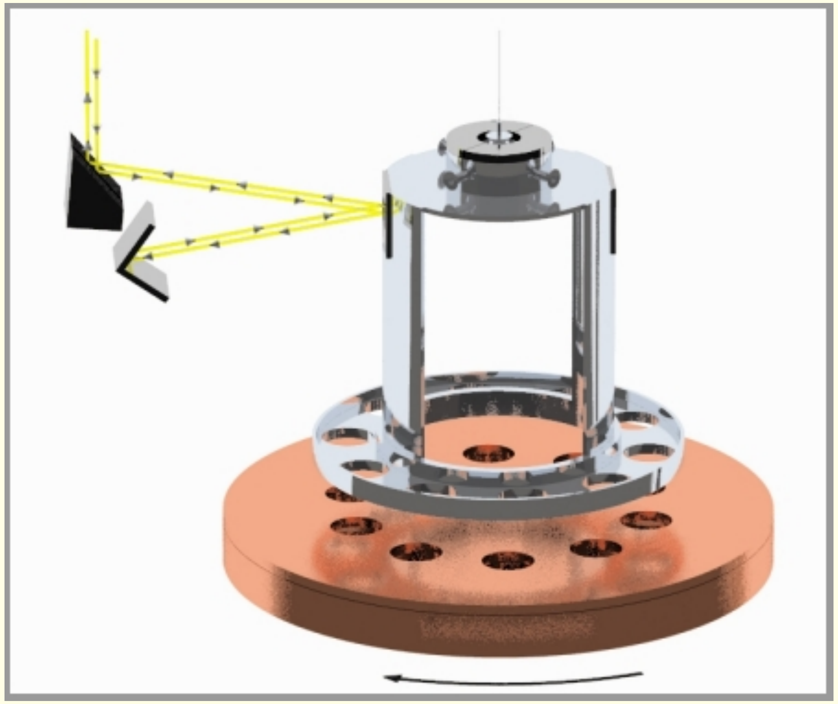
Eot Wash Experiment

- Measurement of the torque between two plaques with holes (no effect for Newtonian forces)
- The potential energy of the system due to a chameleon force between the plates is

$$V_T = A \int_d^\infty \frac{F_\phi}{A} ds$$

- The force per unit surface area can be approximated by the force between two plates, the torque becomes:

$$T \approx a_T \int_d^\infty \frac{F_\phi}{A} ds$$



$$\int_{55\mu\text{m}}^\infty \frac{F_\phi}{A} ds \le 7.0 \; 10^{-37} \; \text{GeV}^3$$

$$a_T = \frac{dA}{d\theta}$$

Power Law Example

- Power law:

$$h(R) \sim \bar{R}\left(\frac{R}{\bar{R}}\right)^{p+1}$$

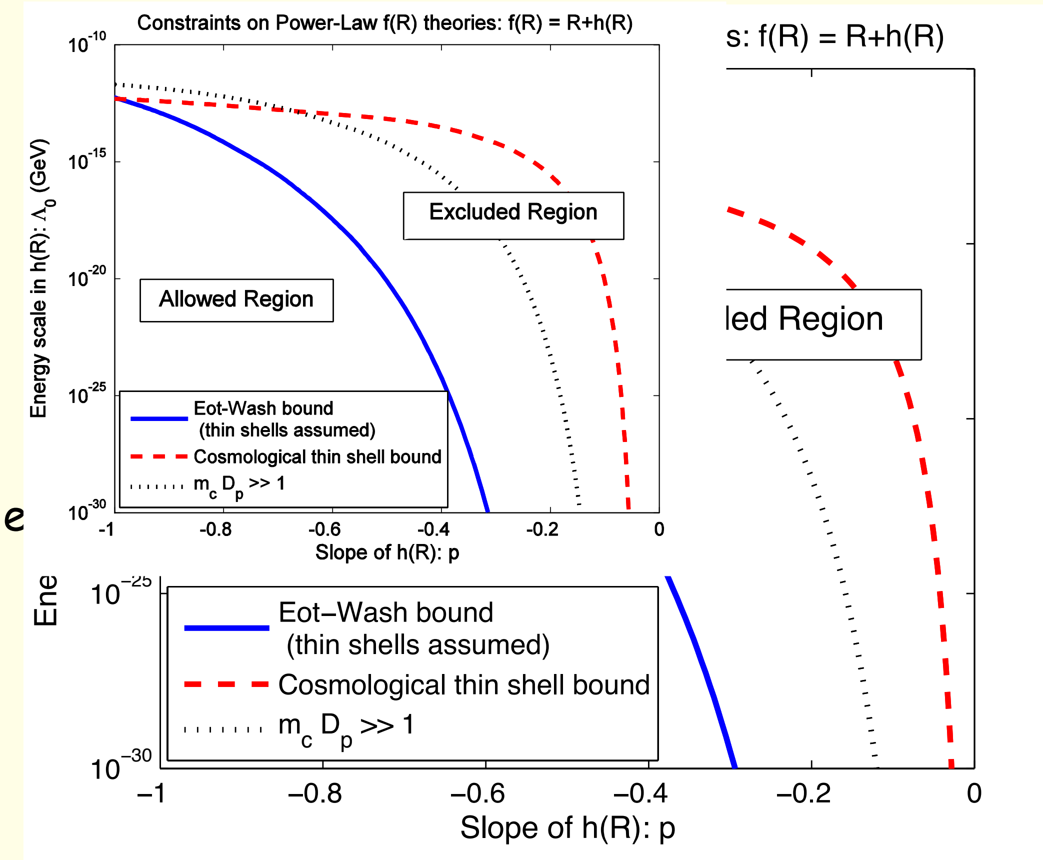
- Integrating the field equations between the plates:

$$R_0 \sim \bar{R}(\bar{R}d^2)^{\frac{1}{p-1}}$$

- We find constraints on the scale

$$\bar{R} = \frac{\Lambda_0^4}{m_{\mathrm{Pl}}^2}$$

$$\Lambda^{n+4} \sim \Lambda_0^4 m_{\mathrm{Pl}}^n$$



Chameleon Optics

Induced Coupling

$$L_{\text{eff}} = \frac{e^2}{3(4\pi)^2 M_{\text{matter}}} \phi F_{ab} F^{ab}$$

$$\alpha_\phi = \frac{m_{\text{Pl}}}{M_{\text{matter}}}$$

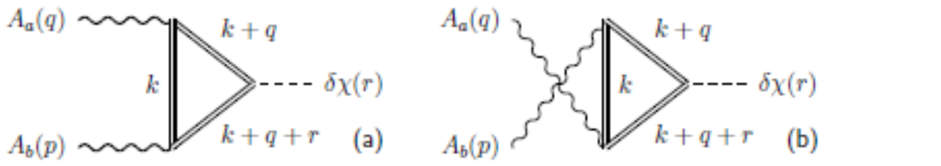


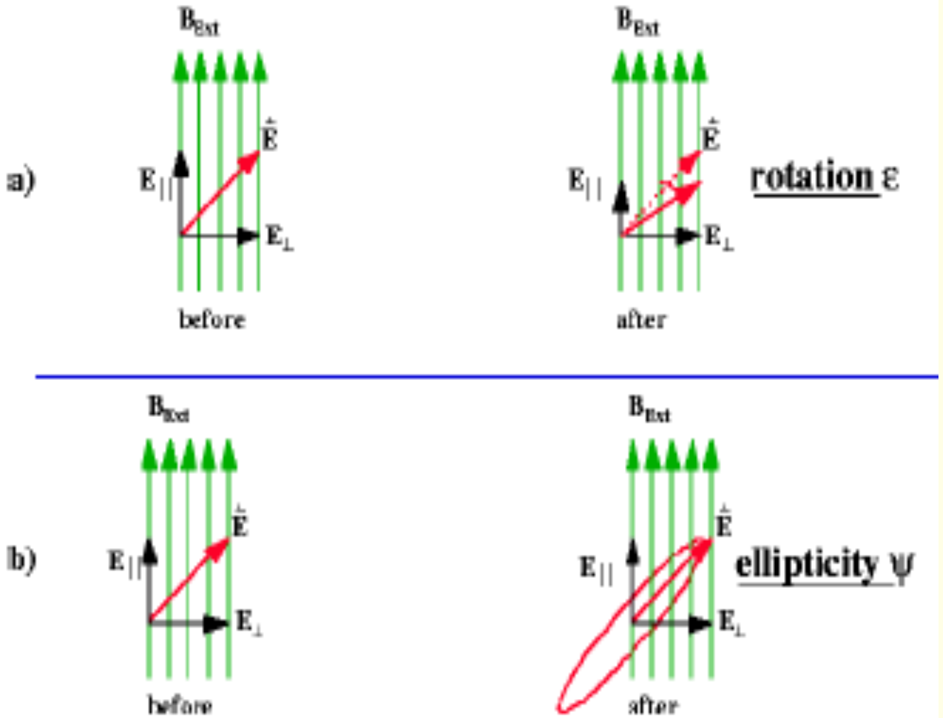
Figure 1. Diagrams contributing to the leading interaction between dark energy and the electroweak gauge bosons, which determine an effective operator acting on $A_a(q)A_b(p)\chi(r)$. Note that the momentum carried by χ is taken to flow into the diagram. Double lines represent a species of heavy fermion charged under SU(2)×U(1).

When the coupling to matter is universal, and heavy fermions are integrated out, a photon coupling is induced.

$$M_\gamma = \frac{3(4\pi)^2}{e^2} M_{\text{matter}}$$

1. Vacuum Magnetic Dichroism and Birefringence

- Send linearly polarized laser beam through transverse magnetic field ⇒ measure changes in polarization state:
  - rotation (dichroism)
  - ellipticity (birefringence)

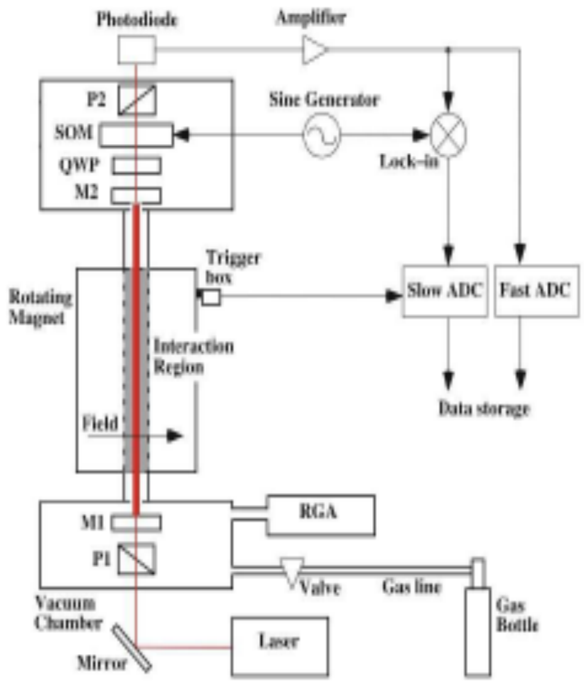


[Brandi *et al.* '01]

Experimental Setup

PVLAS experiment: [Zavattini,... PRL '06]

$B = 5\ \mathrm{T}, \ell = 1\ \mathrm{m}, \omega = 1.2\ \mathrm{eV}, N_{\mathrm{pass}} = 44000$



name	place	magnet (field length)	laser wavelength power	P_{PVLAS}	photon flux at detector
ALPS	DESY	5 T 4.21 m	1064 nm 200 W cw	$\approx 10^{-19}$	10/s
BMV	LULI	11T 0.25 m	1053 nm 500 W 4 pulses/day	$\approx 10^{-21}$	10/pulse
LIPSS	Jefferson Laboratory	1.7 T 1.0 m	900 nm 10 kW cw	$\approx 10^{-23.5}$	0.1/s
OSQAR (preliminary phase)	CERN	9.5T 1.0 m 9.5T 3.3 m	540 nm 1 kW cw	$\approx 10^{-20}$	10/s
PVLAS (regeneration)	INFN Legnaro	5 T 1 m 2.2T 0.5 m	1064 nm 0.8W cw Npass= 5×10^5	$\approx 10^{-23}$	10/s CERN Courier

Chameleons Coupled to Photons

- Chameleons may couple to electromagnetism:

$$\mathcal{L}_{\text{optics}} = \frac{e^{\phi/M_\gamma}}{g^2} F_{\mu\nu} F^{\mu\nu}$$

- Cavity experiments in the presence of a constant magnetic field may reveal the existence of chameleons. The chameleon mixes with the polarisation orthogonal to the magnetic field and oscillations occur (like neutrino oscillations)

- The coherence length $z_{\text{coh}} = \frac{2\omega}{m^2}$

  depends on the mass in the optical cavity and therefore becomes pressure and magnetic field dependent:

$$\rho = \rho_m + \frac{B^2}{2}$$

- The mixing angle between chameleons and photons is:

$$\theta = \frac{B\omega}{M_\gamma m^2}$$

Ellipticity and Rotation

- Photons remain N passes in the cavity. The perpendicular photon polarisation after N passes and taking into account the chameleon mixing becomes:

$$\psi(z) = N(1-\frac{1}{N}\sum_{n=0}^{N-1} a_n(z))\cos(\omega z+\frac{1}{N}\sum_{n=0}^{N-1}\delta_n(z))$$

- The phase shifts and attenuations are given by:

$$a_n(z) = 2\theta^2 \sin^2\frac{m^2(z+nL)}{4\omega},\ \delta_n(z) = \frac{m^2\theta^2}{2\omega}(z+nL)-\theta^2\sin\frac{m^2(z+nL)}{2\omega}$$

identified with the phase shift and attenuation after one pass of length nL.

- At the end of the cavity z=L, this can be easily identified for commensurate cavities whose lengths corresponds to P coherence lengths

Rotation → $$a_T = \theta^2,\ \delta_T = \pi\frac{N}{P}\theta^2$$ ← ellipticity

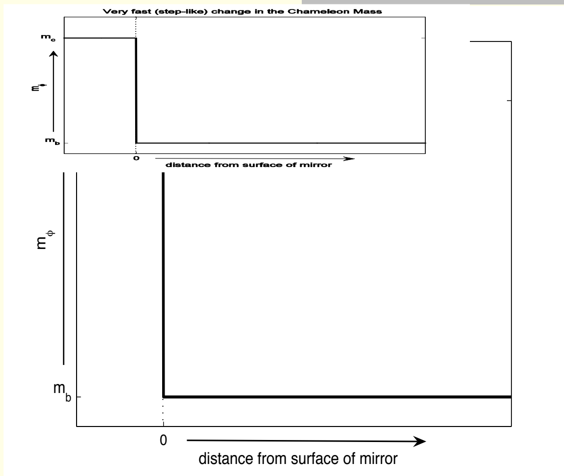
Realistic Chameleon Optics

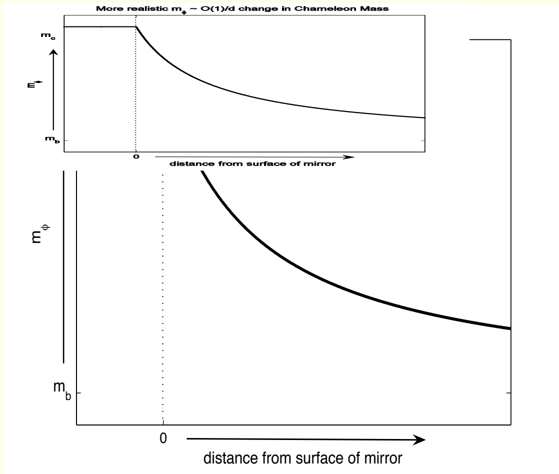
- Must take other effects into account.
- Chameleons never leave the cavity (outside mass too large, no tunnelling)
- Chameleons do not reflect simultaneously with photons.

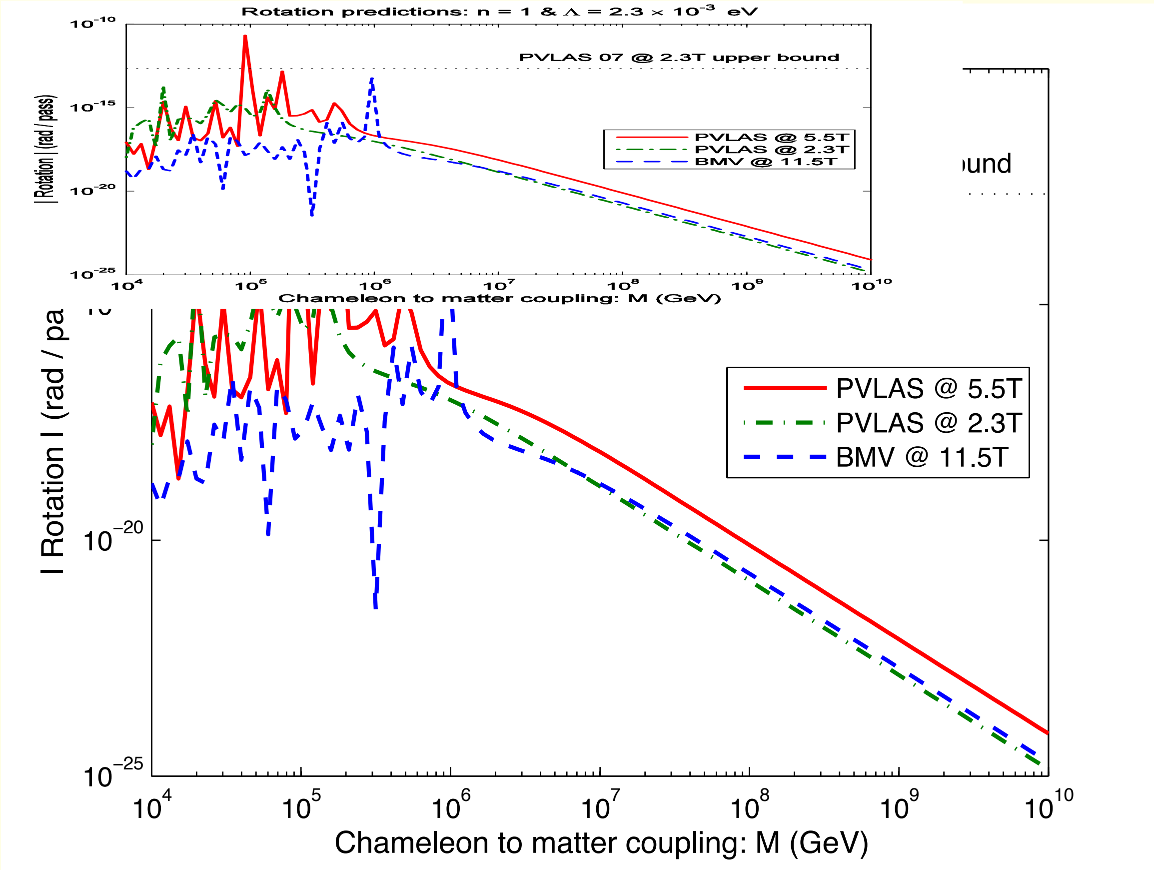
$$\Delta_r = \frac{\pi n}{n+2}$$

- Chameleons propagate slower in the no-field zone within the cavity

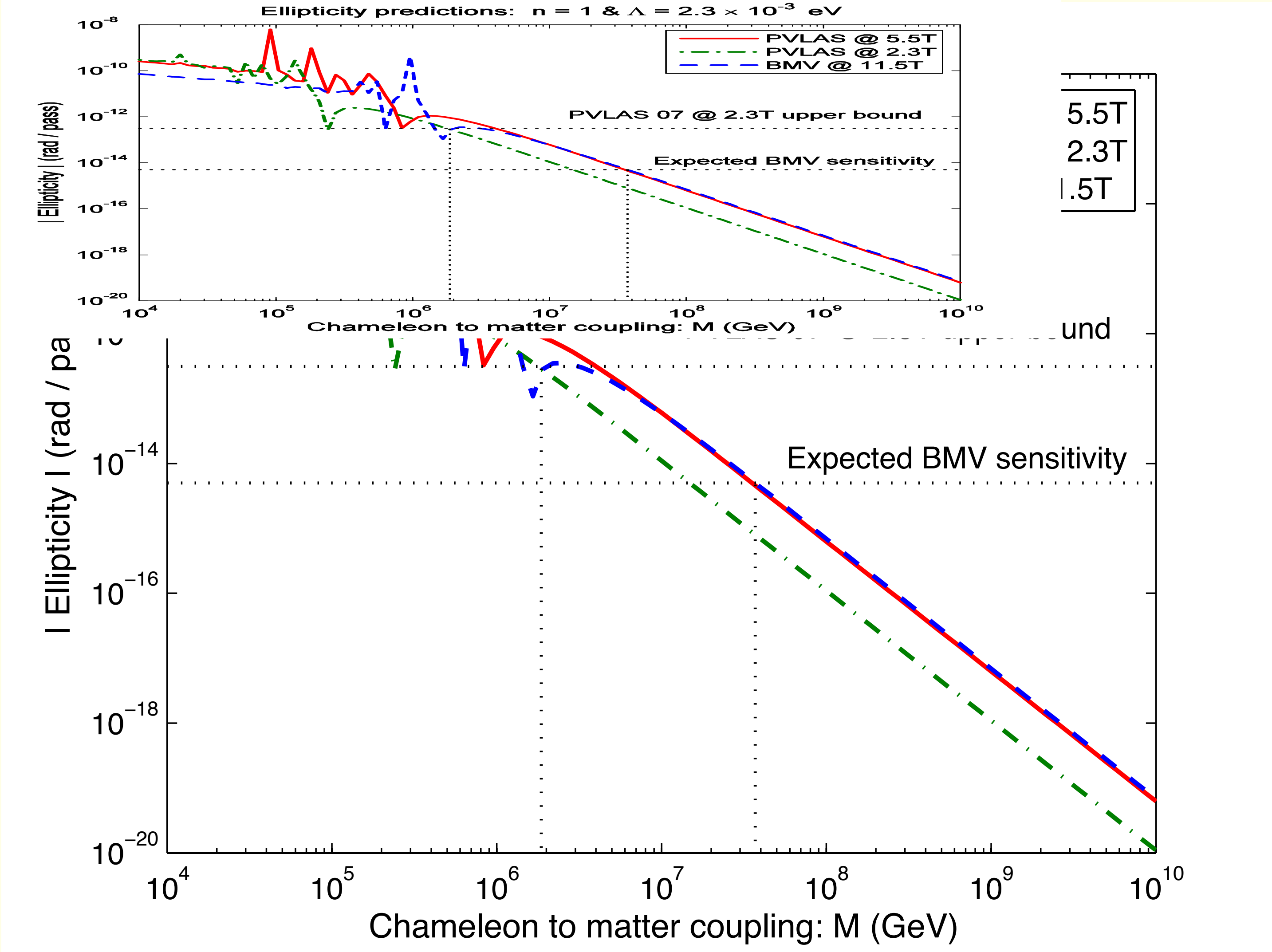
$$\Delta_d = \frac{m_\phi^2 d}{\omega}$$







Rotation predictions: n = 1 & Λ = 2.3 × 10⁻³ eV
PVLAS 07 @ 2.3T upper bound
PVLAS @ 5.5T
PVLAS @ 2.3T
BMV @ 11.5T
|Rotation| (rad / pass)
Chameleon to matter coupling: M (GeV)


Ellipticity predictions: n = 1 & Λ = 2.3 × 10^-3 eV
PVLAS @ 5.5T
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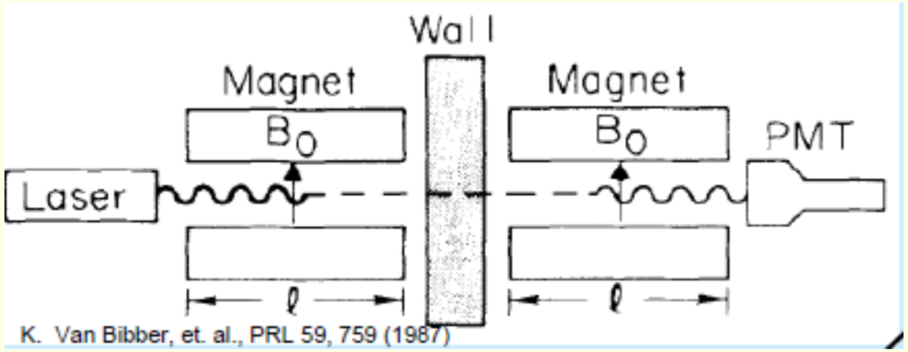
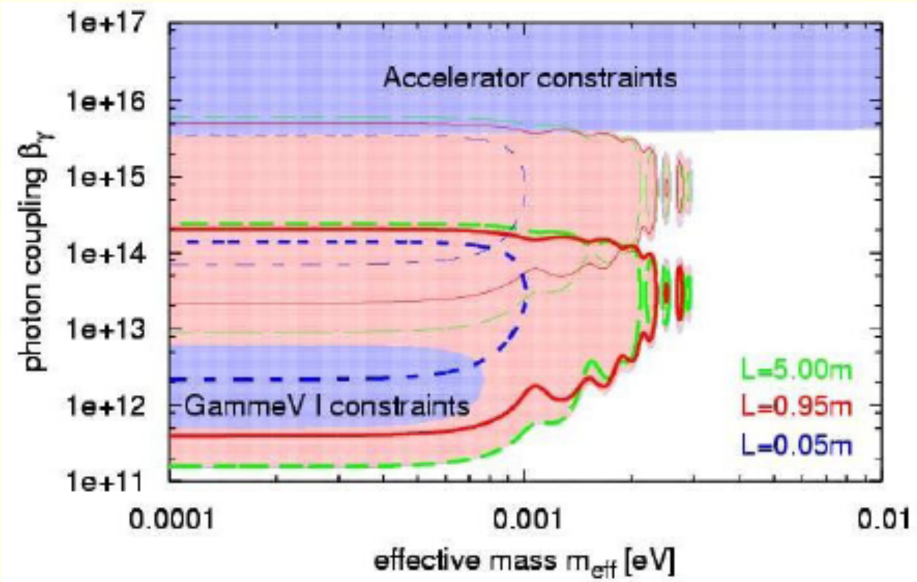
Expected BMV sensitivity
|Ellipticity| (rad / pass)
Chameleon to matter coupling: M (GeV)
Expected BMV sensitivity
Chameleon to matter coupling: M (GeV)

Light Shining through a Wall



Axion-like particles, once generated can go through the wall and then regenerate photons on the other side.

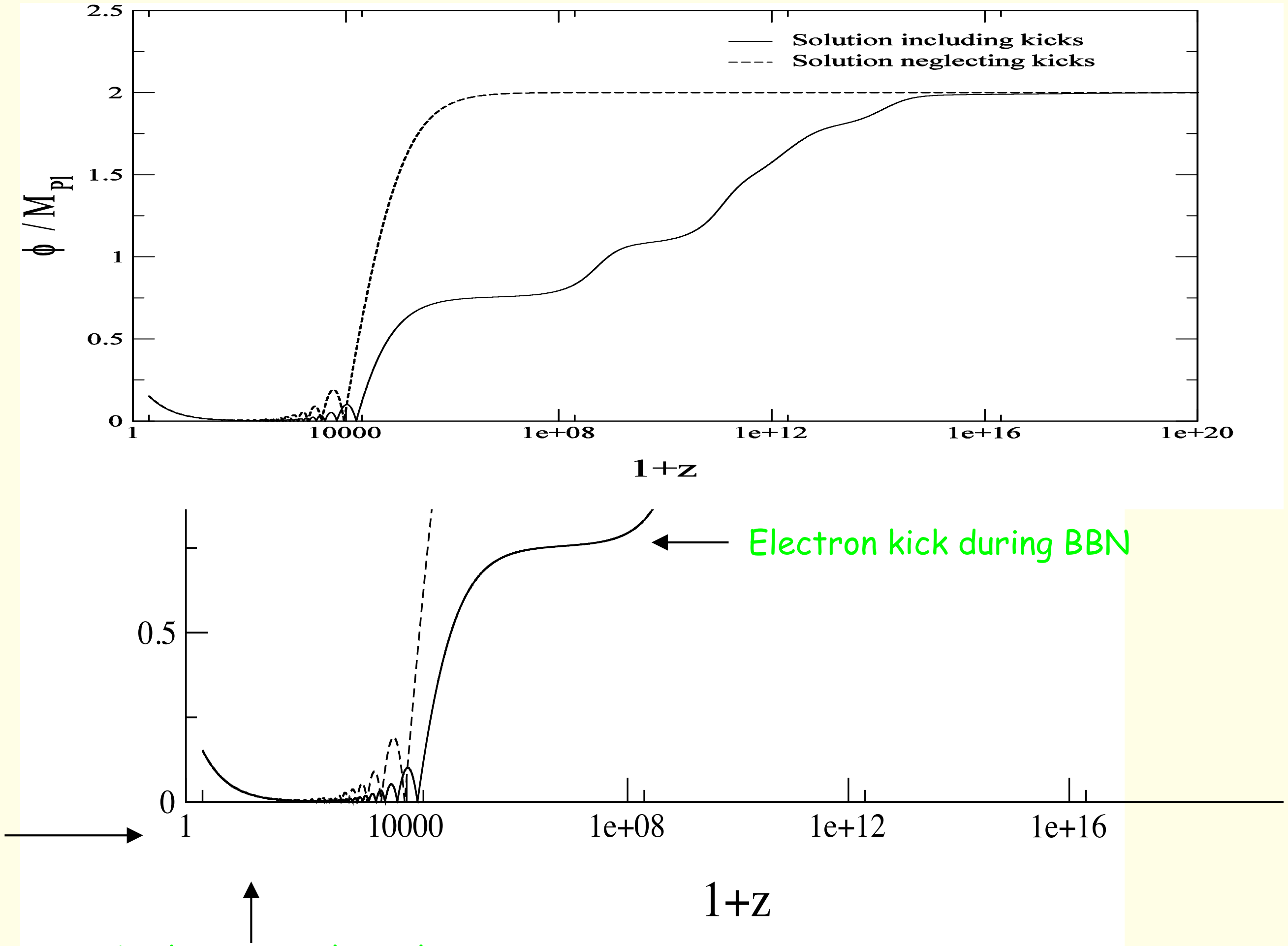
Chameleons cannot go through but can stay in a jar once the laser has been turned off and then regenerate photons.



GammeV (Fermilab) and ADMX (Seattle) will cover a large part of the parameter space.

Modifying gravity at low z

Chameleon Cosmology



Late time acceleration

Possibility of variation of constants

Lurking cosmological constant

Modified Gravity at low z ?

- Gravity is well tested in the solar system. For larger scales, gravity may be modified. A test of modified gravity can be obtained by studying the growth of structures at low redshift (in the linear regime):

$$ds^2 = -a^2(1+2\psi)d\tau^2 + a^2(1-2\phi_N)dx^2$$

- This is most sensitive to the behaviour of the growth factor on sub-horizon scales and the ratio of the Newton potentials

$$f = \frac{d\ln\delta}{d\ln a} \quad \gamma = \frac{d\ln f}{d\ln\Omega_m} \qquad \eta = \frac{\phi_N}{\psi}$$

- In general relativity, the slip function and the growth index are know to be:

$$\gamma \approx 0.55, \;\; \eta = 1$$

- Recently, Rachel Bean found some « evidence » in favour of a modification of gravity at low redshift.
- When scalars couple to matter, not a unique definition of « a » slip function.

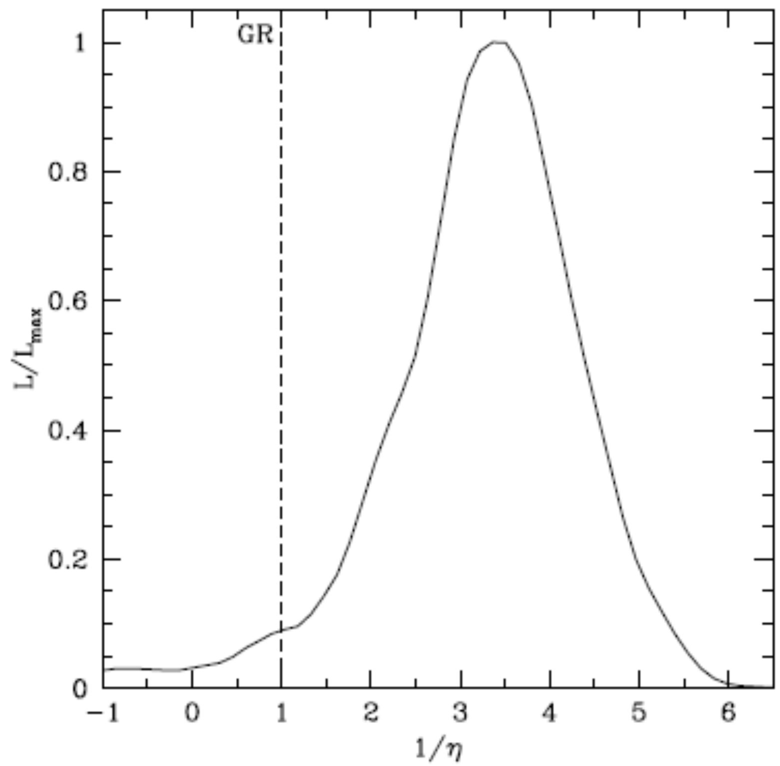


FIG. 1: 1D marginalized constraints for $1/\eta$ for the scenarios in which $1/\eta$ can vary at $1 < z < 2$. The results disfavor GR (the dashed line) at the 98% significance level (p-value=0.02).

Linear Growth factor

At the perturbation level, the growth factor evolves like:

$$\delta'' + \mathcal{H}\delta' - \frac{3}{2}H^2(1 + \frac{2\beta^2}{1 + \frac{m^2a^2}{k^2}})\delta = 0$$

The new factor in the brackets is due to a modification of gravity depending on the comoving scale k. Here the coupling is constant.

Everything depends on the comoving Compton length:

$$\lambda_c = \frac{1}{ma}$$

Gravity acts in an usual way for scales larger than the Compton length

$$\delta \sim a$$

Gravity is modified inside the Compton length with a growth:

$$\delta \sim a^{\frac{\nu}{2}}, \quad \nu = \frac{-1 + \sqrt{1 + 24(1 + 2\beta^2)}}{2}$$

Everything depends on the time dependence of m(a). If m is a constant then the Compton length diminishes with time. So a scale inside the Compton length will eventually leave the Compton length

Modified gravity → General Relativity

z=z*

On the other hand, for chameleons the Compton length increases implying that scales enter the Compton length.

General Relativity → Modified gravity

z=z*

General Framework

We will generalise the previous models and work with a different coupling for each species. The Einstein equation and the Bianchi identity are satisfied with:

$$T_{\mu\nu} = \sum_A e^{\beta_A \chi/m_{\rm Pl}} \rho_A u_\mu^{(A)} u_\nu^{(A)} + D_\mu \chi D_\nu \chi - \frac{1}{2} g_{\mu\nu}((D\chi)^2 + m^2\chi^2)$$

The Klein-Gordon equation becomes:

$$D^2\chi = m^2\chi + \sum_A \beta_A \frac{\rho_A}{m_{\rm Pl}} e^{\beta_a \chi/m_{\rm Pl}}$$

The metric is specified by two potentials:

$$ds^2 = -a^2(\tau)(1+2\psi)d\tau^2 + a^2(\tau)(1-2\phi_N)dx^2$$

At late times, in the absence of anisotropic stress, the Poisson equation is satisfied:

$$\psi = \phi_N, \quad \Delta\phi_N = 4\pi G a^2 \sum_A \rho_A \delta_A$$

Growth of structures

The density contrast of each species satisfies:

$$\delta_A'' + \mathcal{H}\delta_A' - \frac{3}{2}\mathcal{H}^2 \sum_B \Omega_B \delta_B (1 + \alpha_{AB}(x)) = 0$$

Gravity is modified because the coupling constants depend on time:

$$\alpha_{AB}(x) = \frac{2\beta_A \beta_B}{1 + x^2}, \qquad x = \frac{am}{k}$$

In the following: A=baryons, B=CDM. As long as a scale does not cross the Compton length:

$$\delta_A = (1 + \xi(x))\delta_B, \qquad 1 + \xi(x) = \frac{1 + \alpha_{AB}(x)}{1 + \alpha_{BB}(x)}$$

After crossing the Compton length, the relation changes:

$$\delta_A = (1 + \xi_{\text{eff}})\delta_B$$

Growth index

Modified gravity implies that the growth is altered:

$$f(\ln a, k) = (1 + g_B(\ln a)) f_0(\ln a), \qquad f_0 \sim \Omega_m^{0.55}$$

The deformation is a slowly varying function:

$$g_B \approx -\frac{5}{4} + \sqrt{\frac{25}{16} + \frac{3}{2}\alpha_{BB}(x)}$$

B=CDM
A=baryons

$$\alpha_{BB}(x) = \frac{2\beta_B^2}{1 + \frac{m^2 a^2}{k^2}}$$

Slip function I

Weak lensing which is sensitive to the total Newton potential

$$\psi + \phi_N \equiv 2\phi_N$$

Reconstructing the effective Newton potential from the Poisson law assuming that baryons track CDM as in General Relativity leads to:

$$\Delta\phi_A \approx 4\pi G\rho_B\delta_A \approx (1+\xi_{eff})\Delta\phi_N$$

Our first slip function compares this potential to weak lensing:

$$1+\eta_\delta^{-1} = \frac{\phi_N+\psi}{\phi_A}$$

Slip function II

Another slip function can be obtained by correlating the ISW effect and galaxies:

$$1+\eta_I^{-1}=\frac{\dot{\phi}_N+\dot{\psi}}{\dot{\phi}_A}$$

This one is sensitive to the growth index and differs from one even if the couplings are equal:

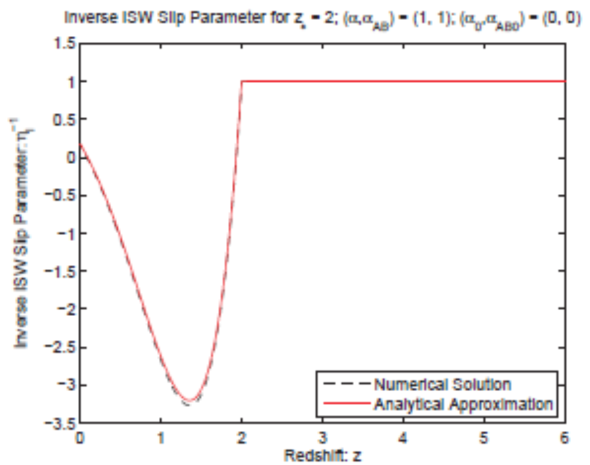
$$1+\eta_I^{-1}=(1+\eta_\delta^{-1})\left(\frac{\Omega_m^{\gamma_B}-1}{\Omega_m^{0.55}-1}\right)$$

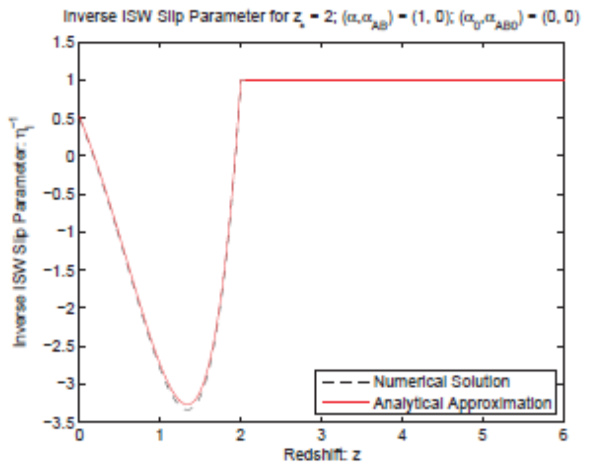
ISW slip function

Despite the large uncertainty, this slip function gives the tightest constraints on the couplings when no coupling to baryons is present.

Coupling Turns On			
$\beta_A = \beta_B$		$\beta_A = 0$	
z_*	$\alpha_{\max}$	z_*	$\alpha_{\max}$
1	1.58	1	1.61
2	0.26	2	0.28
3	0.13	3	0.13
4	0.10	4	0.11
16	0.083	8	0.090

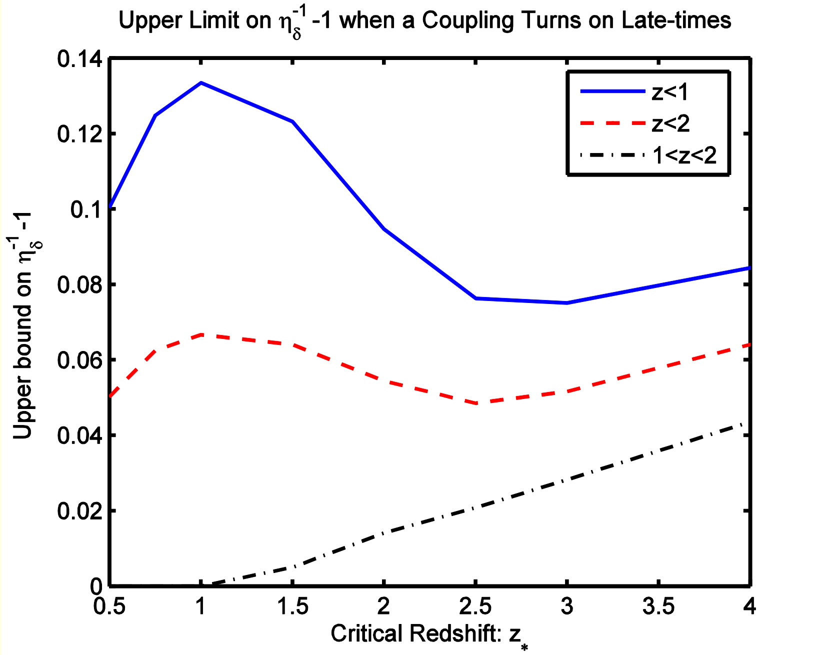
When the coupling is universal, this is equivalent to the baryonic growth index.





Combining the slip functions

If the crossing of the Compton length is around z*=4, one could expect at most and at the 1-sigma level a discrepancy with General Relativity to be of order 0.13. If the crossing is at z*=2, this reduces to 0.067.



The Dilaton

String theory in the strong coupling regime suggests that the dilaton has a potential:

$$V(\phi) = V_0 e^{-\phi} + \ldots$$

Damour and Polyakov suggested that the coupling should have a minimum:

$$A(\phi) \approx 1 + \frac{A_2}{2}(\phi - \phi_0)^2 + \ldots$$

The coupling to matter becomes:

$$\alpha_\phi \approx A_2(\phi - \phi_0)$$

In the presence of matter, the minimum plays the role of an attractor:

$$\phi - \phi_0 \approx \frac{1}{1 + A_2 \frac{\rho}{V_0}}$$

The coupling becomes:

$$\alpha_\phi \approx \frac{A_2}{1 + A_2 \frac{\rho}{V_0}}$$

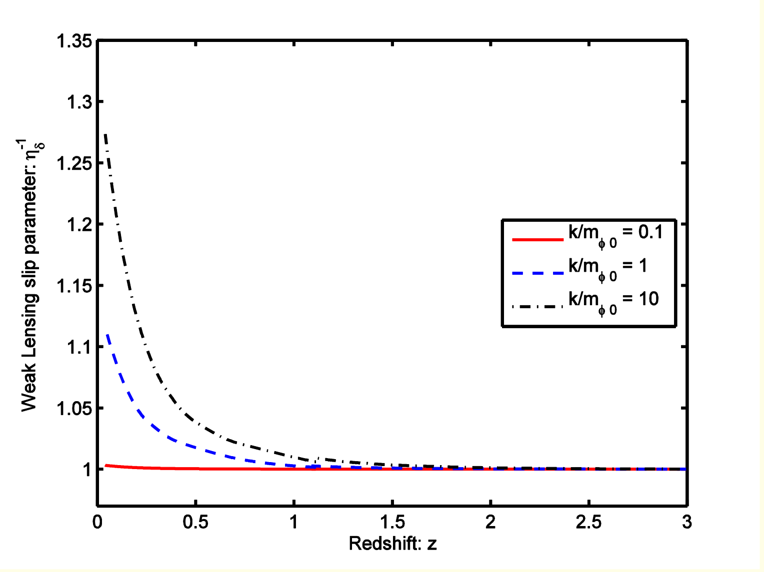
Three regimes:

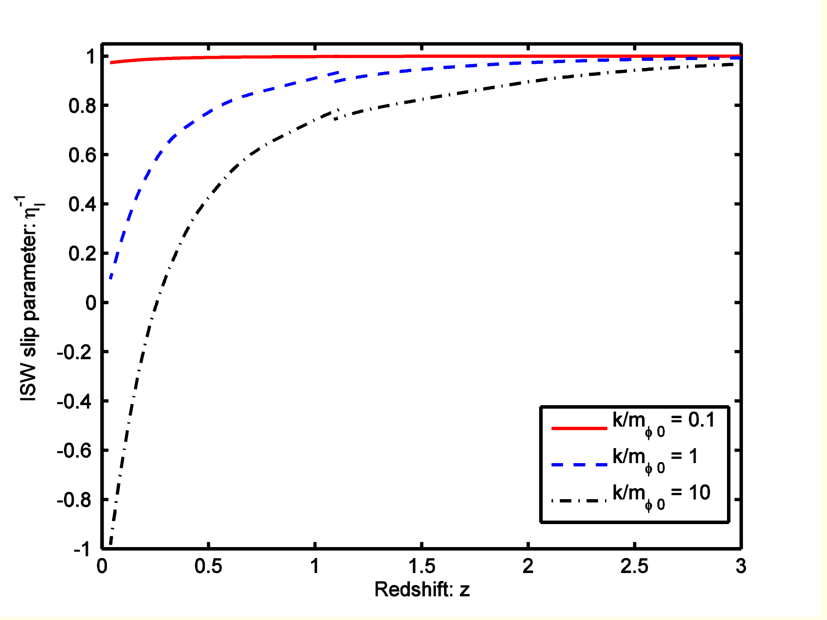
i) early in the universe, large density: small coupling.

ii) recent cosmological past: large scale modification of gravity.

iii) collapsed objects: small coupling.

The Dilatonic case





Conclusions

- Chameleons could be around if scalar fields are the reason behind cosmic acceleration
- Light scalars are under experimental scrutiny (Casimir, optics)
- Weak lensing surveys could give a hint about late time deviations from General Relativity