Looking for chameleons

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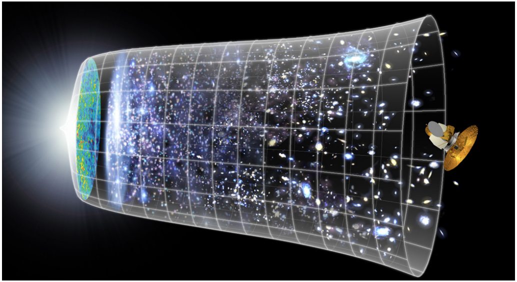
2014-08-12

ArmarisFraino



NASA/WMAP Science Team

Acceleration & the Cosmological Constant

Einsteins biggest blunder?

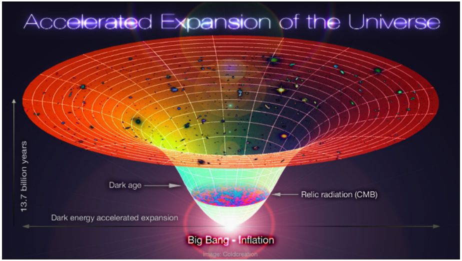
$$G_{\mu\nu} = 8\pi G T_{\mu\nu} - \Lambda g_{\mu\nu}$$

Deceleration Parameter

$$q \equiv -\frac{\ddot{a}a}{\dot{a}^2} < 0$$

⇒ need substance w/ "negative pressure"

$$w = p/\rho < -\frac{1}{3}$$



A cosmological constant works (at least till now), but why is it so small?
What does it mean?
Is there a better explanation? Quintessence: A scalar field...

Playing with General Relativity

Scalar-tensor Gravity

$$S = \int d^4x \sqrt{-g} \left(\frac{\mathcal{R}}{16\pi G} - \frac{1}{2} (\partial\phi)^2 - V(\phi) \right) + S_m \left[g^J \right]$$

with a gravitationally coupled scalar field ϕ and conformal transformation $g^J_{\mu\nu} = A^2(\phi)\, g_{\mu\nu}$.

Equation of motion:

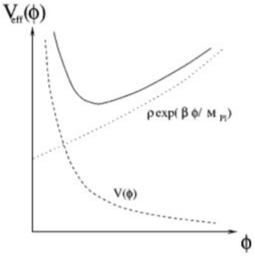
$$\partial^2\phi = V_{,\phi}(\phi) + A_{,\phi}(\phi)\,\rho$$

An effective potential

$$V_{\text{eff}}(\phi) \equiv V(\phi) + A(\phi)\,\rho$$

w/ a local minimum depending on local energy density $\phi_{\text{min}} = \phi_{\text{min}}(\rho)$ renders effective mass

$$m^2_{\phi,\text{eff}} = V_{\text{eff},\phi\phi} = V_{,\phi\phi}(\phi_{\text{min}}) + A_{,\phi\phi}(\phi_{\text{min}})\,\rho,$$



Phys. Rev. D 69, 044026 (2004)

Chameleons: J. Khoury & A. Weltmann '07

Take a potential $V(\phi) = \Lambda^4 \left(1 + \frac{\Lambda^n}{\phi^n}\right)$ & matter coupling $A(\phi) = e^{\frac{\beta_m}{M_{Pl}}\phi}\rho$

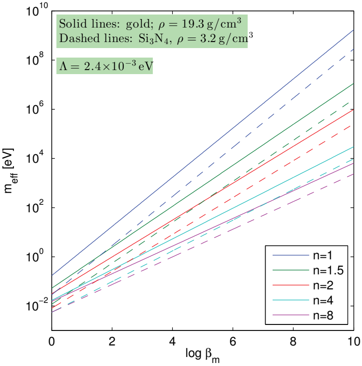
to get an effective potential

$$V_{\text{eff}}(\phi) = \Lambda^4 \left(1 + \frac{\Lambda^n}{\phi^n}\right) + e^{\frac{\beta_m}{M_{Pl}}\phi}\rho_m + e^{\frac{\beta_\gamma}{M_{Pl}}\phi}\rho_\gamma$$

and an effective mass

$$m_{\text{eff}}^2 = (n+1)\,\frac{\beta_m \rho_m}{M_{Pl}}\,\frac{1}{\phi_{\text{min}}}$$

where $\phi_{\text{min}} = \left(\frac{n\Lambda^{4+n}\beta_m}{M_{Pl}\rho_m}\right)^{\frac{1}{n+1}}$

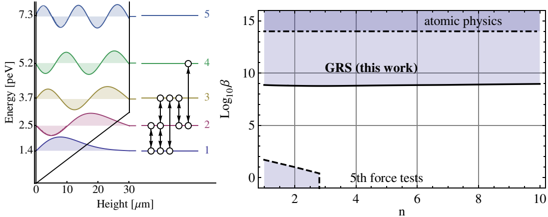


Let's bounce some UCNs!

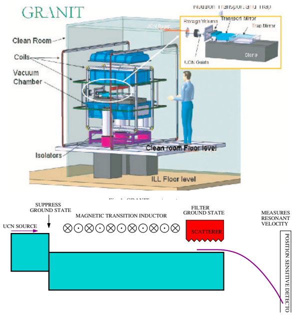
UCN in grav. bound states

- Ultracold Neutrons ($T < 10\,\mu$K) can bounce on a "mirror", e.g. glass w/ $V_{\text{fermi}} \sim 100\,$neV
- states in the gravitational field become quantized w/ $\Delta E \sim$ peV
- Rabi-Oscillations $P(t) = \frac{\sin^2\left(\sqrt{(\omega-\omega_0)^2+\Omega^2}\,\frac{t}{2}\right)}{1+\left(\frac{\omega-\omega_0}{\Omega}\right)^2}$

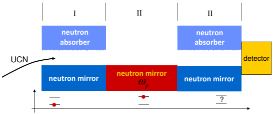
qBounce14: PRL 112, 151105



GRANIT @ ILL (Grenoble)



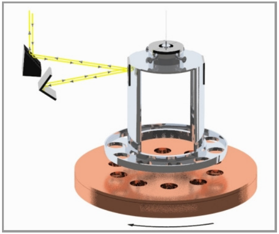
qBounce @ TU Wien/ILL

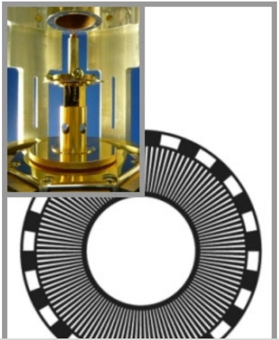


Or turn some disks?

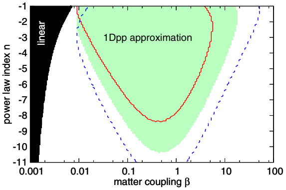
Eöt-Wash @ U of Wash.

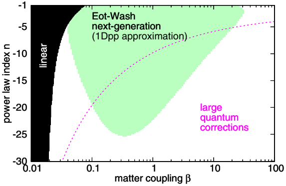
- Test Newton's $F \propto r^{-2}$ with a torsion pendulum on short scales $\sim 100\,\mu$m
- Since chameleon screening reduces the force this is sensitive to weakly coupled chameleons.
- Problem: shielding membrane between disks





present constraints (left) & future projections (right)





Phys. Rev. D 86, 102003 (2012)

Ad Break. Axions & CAST

strong CP-Problem

$$\mathcal{L}_{\mathrm{QCD}} \supset \frac{\alpha_s}{8\pi} \theta G^a_{\mu\nu} \tilde{G}^{a,\mu\nu}$$

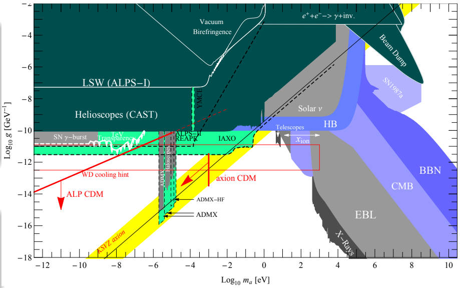
but: $|\theta| < 10^{-10}$!

Solution (?): PQ-Axion

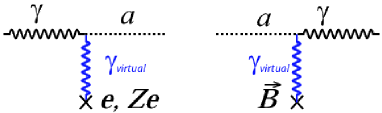
introduce U(1) & break it

$$\mathcal{L} \supset \frac{\alpha_s}{8\pi} \left(\theta - \frac{\phi_A}{f_A} \right) G^a_{\mu\nu} \tilde{G}^{a,\mu\nu}$$

non-pertubative QCD induces the potential to have a minimum at $\phi_A = \theta f_A$
$\rightarrow$ the CP-violating term is dynamically pulled to 0!



adapted and updated from arXiv:1205:2671v1



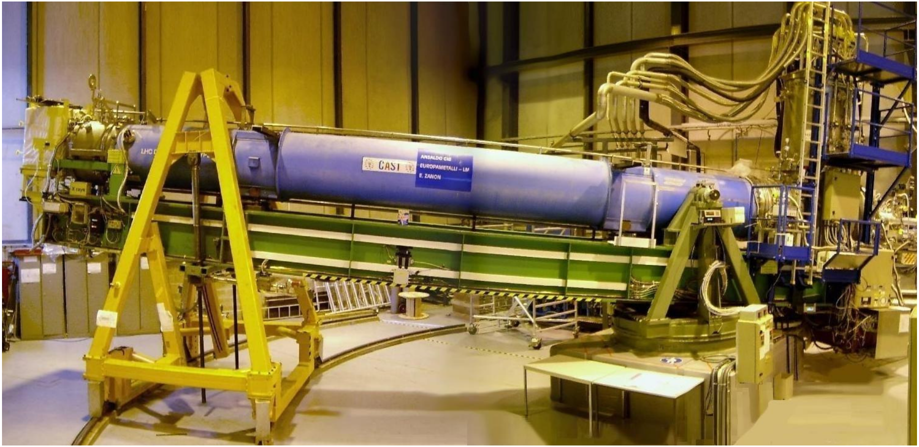
New J.Phys. 11 (2009) 105020

P. Sikivie had a great idea:

Let's point a magnet at the sun...

...and look for X-Rays!

Ad Break: Axions & CAST

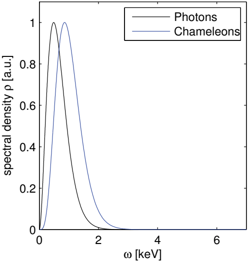


Ad Break: Axions & CAST

Chameleons from the sun

In a region of strong magnetic field photons effectively mix with chameleons (Primakoff)
$\rightarrow$ Tachocline: $B \approx 30\,\mathrm{T}$, $T = 2 \times 10^6\,\mathrm{K}$

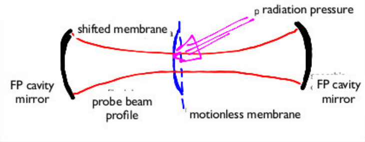
$$P(\omega) = 2\left(\frac{\omega B \beta_\gamma}{M_{\mathrm{Pl}}\left(m_{\mathrm{eff}}^2 - \omega_{\mathrm{Pl}}^2\right)}\right)^2$$

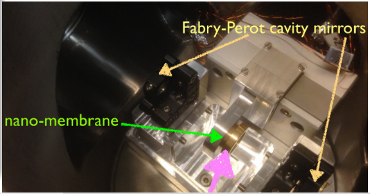


Radiation pressure from Chameleons

Chameleons can only propagate when $\omega > m_{\mathrm{eff}}$
$\rightarrow$ one can deflect them with a dense medium!
KWISP: $5{\times}5\,\mathrm{mm}^2$ micromembrane in FP-cavity

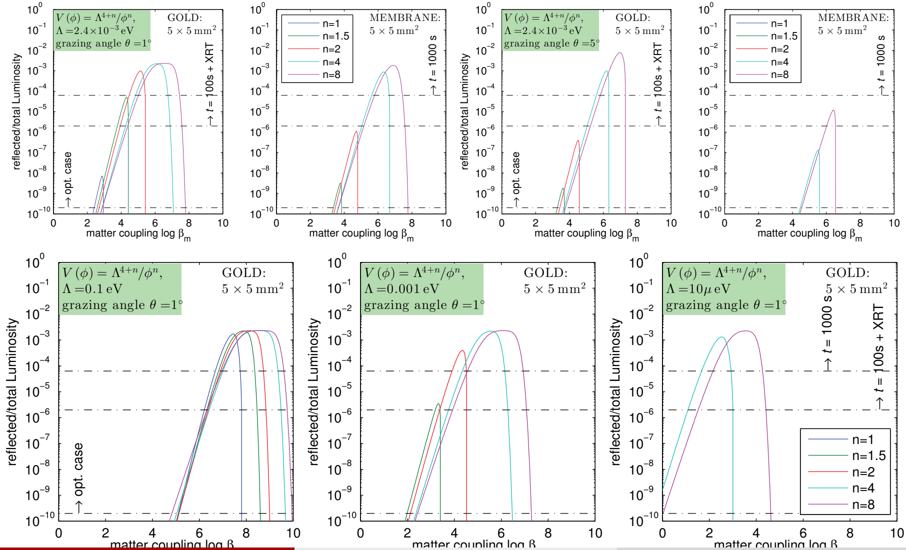
$$\frac{\Phi_{\mathrm{reflected}}}{\Phi_{\mathrm{chameleon}}} = (\cos\theta)^{3/2}\,\frac{\int_0^{m_{\mathrm{eff}}/\cos\theta} \rho_{\mathrm{chameleon}}(\omega)\, d\omega}{\int_0^{\infty} \rho_{\mathrm{chameleon}}(\omega)\, d\omega}$$





KWISP @ CAST: Sensitivity forecast

KWISP: $F/\sqrt{t_{\text{meas}}} = 5 \times 10^{-14}\,\text{N}/\sqrt{\text{Hz}}$, $\Phi_{\text{cham}} = 10\% \times \phi_{\text{sol}} = 136\,\text{W/m}^2$



Conclusion & Outlook

- If we want a coupled scalar field as Dark Energy, we need some sort of screening mechanism
- Chameleon-mechanism "works", maybe the best DE-model out there! $\rightarrow$ investigate it!
- (direct) searches: fifth-force, WEP, afterglow, RADIATION PRESSURE, ...
- CAST is looking for new things to do $\rightarrow$ why not look for chameleons?