Solar Chameleons

Collaboration with K. Zioutas

"Patras 2010" workshop
Zurich July 2010

Outline

1-Producing Chameleons.

2-Solar Chameleons.

Producing 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

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

Induced Coupling

$$L_{\text{eff}} = \frac{1}{M_\gamma}\phi F_{ab}F^{ab}$$

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

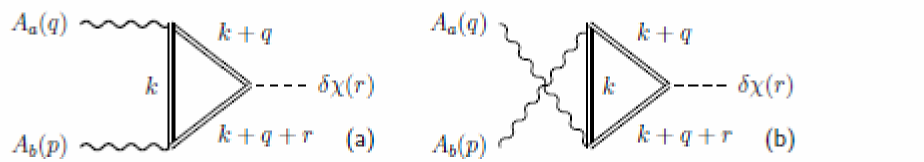


Figure 1. Diagrams contributing to the leading interaction between dark energy and the electroweak gauge bosons, which determine an effective operator acting on $A_a(q)A_b(p)\chi(r)$. Note that the momentum carried by χ is taken to flow into the diagram. Double lines represent a species of heavy fermion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

When the coupling to matter is universal, and heavy fermions are integrated out, a photon coupling is induced. Other contributions from conformal anomaly.

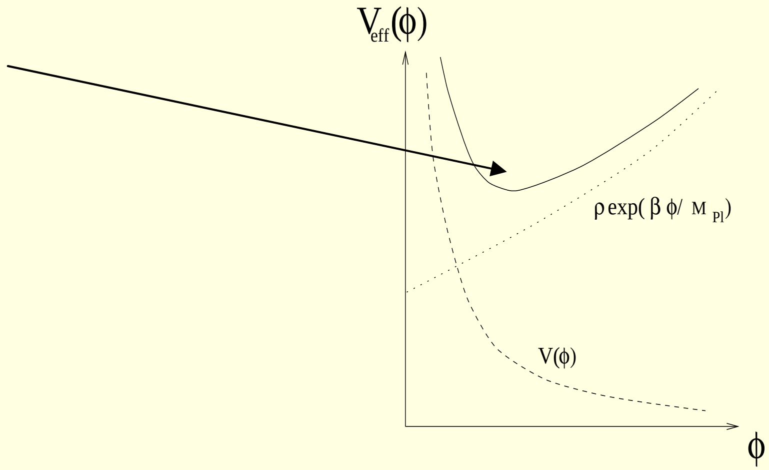
$$M_\gamma = \frac{3(4\pi)^2}{e^2}M_{\text{matter}}$$

The effect of the environment

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

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

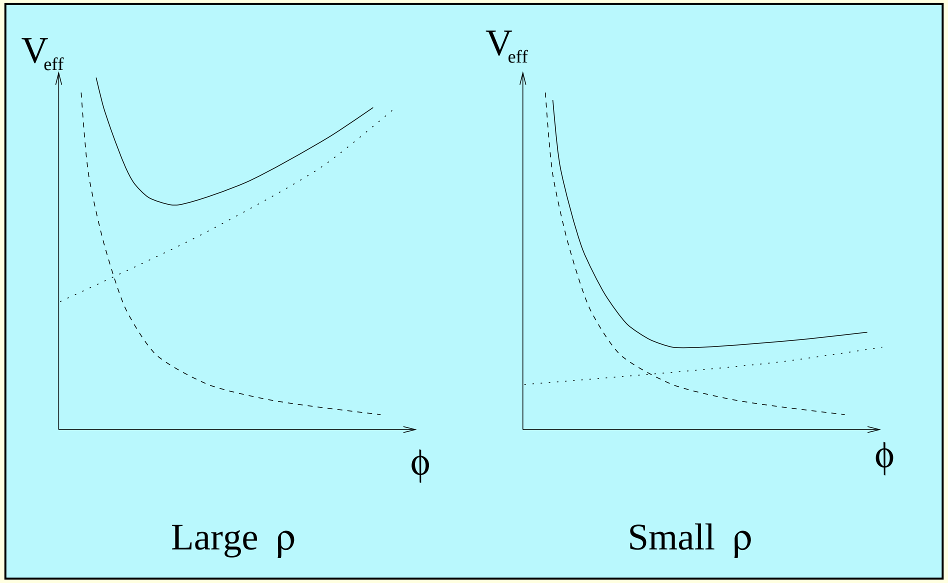
Environment dependent minimum



An Example:

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

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



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

Chameleons Coupled to Photons

- The chameleon mixes with the polarisation orthogonal to the magnetic field and oscillations occur. Mixing happens when the chameleon is not tachyonic:

$$k^2(\omega) = \omega^2 - (m^2 - \frac{B^2}{M_\gamma^2} - \omega_{\mathrm{Pl}}^2)(\frac{\cos\theta + 1}{2\cos\theta})$$

- The mixing angle between chameleons and photons is:

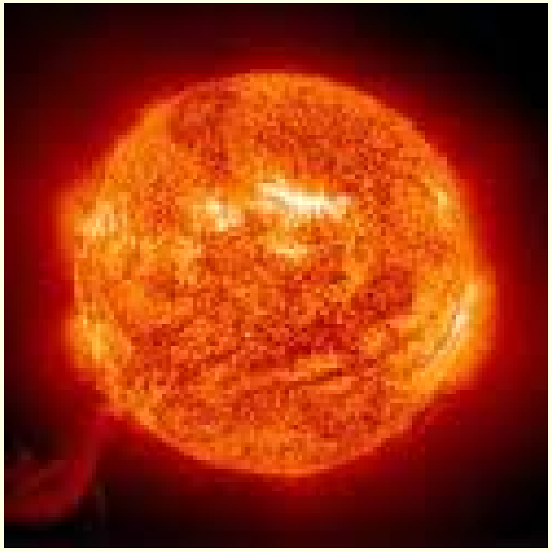
$$\tan 2\theta = \frac{2\omega B}{M_\gamma(m^2 - \frac{B^2}{M_\gamma^2} - \omega_{\mathrm{Pl}}^2)}$$

- The transition probability is:

$$P_{\mathrm{chameleon}} = \sin^2\theta < \sin^2(\frac{\Delta}{\cos 2\theta}) > \approx \frac{\theta^2}{2}$$

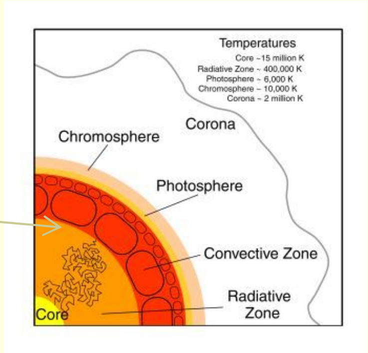
$$\Delta = \frac{(m^2 - \frac{B^2}{M_\gamma^2} - \omega_{\mathrm{Pl}}^2)L}{4\omega}$$

Solar Chameleons



Chameleons can be produced in the tachocline region at a radius 0.7 Rs. The magnetic field is 20-50 T. The mean free path is about 10 cm. The photons have a temperature of 200 eV and the photon flux is $n_\gamma \sim 10^{21} s^{-1} cm^{-2}$. These thermal photons create chameleons.

tachocline



Most chameleons escape the sun, a tiny fraction are back-converted to photons in the outer sun (the photosphere) over magnetic regions of about 10-100 km where the magnetic field is 0.2 T. The photons perform a random walk and lose their directionality.

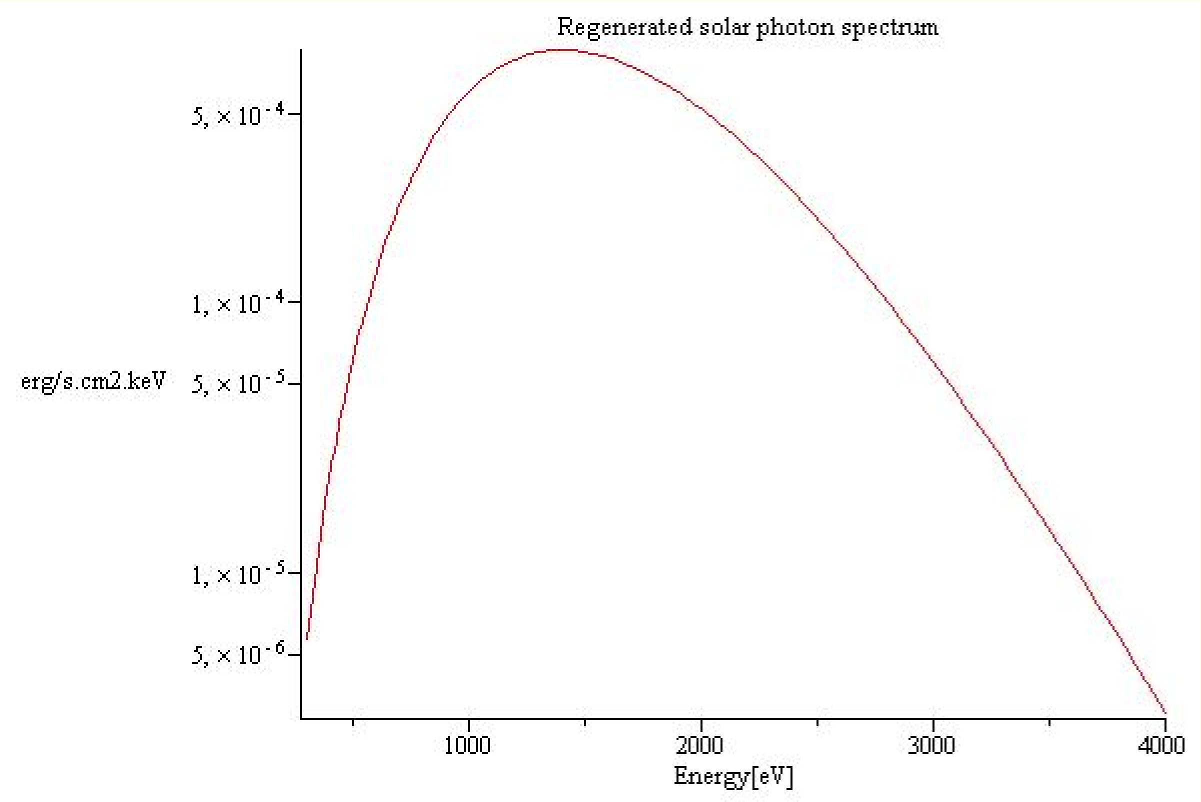
The back converted photons can saturate the Sphinx bound for the solar luminosity in the soft X-ray region:

$$\Phi \sim 10^{-3} \mathrm{erg/s.cm^2}, \ k \geq 1 \ \mathrm{keV}$$

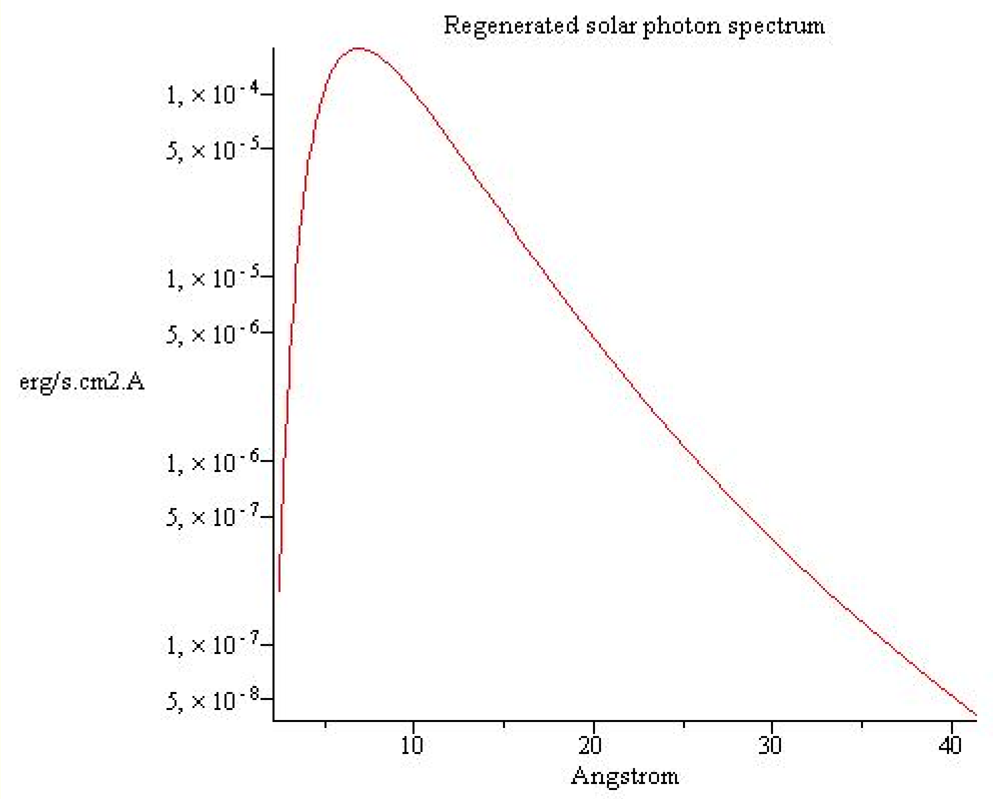
This can only happen if the chameleon mass is resonantly close to the plasma frequency in the outer sun.

The emitted chameleons can penetrate the CAST experiment and would lead to too many regenerated photons.

These two competing effects lead to a drastic reduction of the chameleon parameter scale. In particular, the photon coupling must be small enough to evade the CAST bound and large enough to allow for a resonant production of photons.

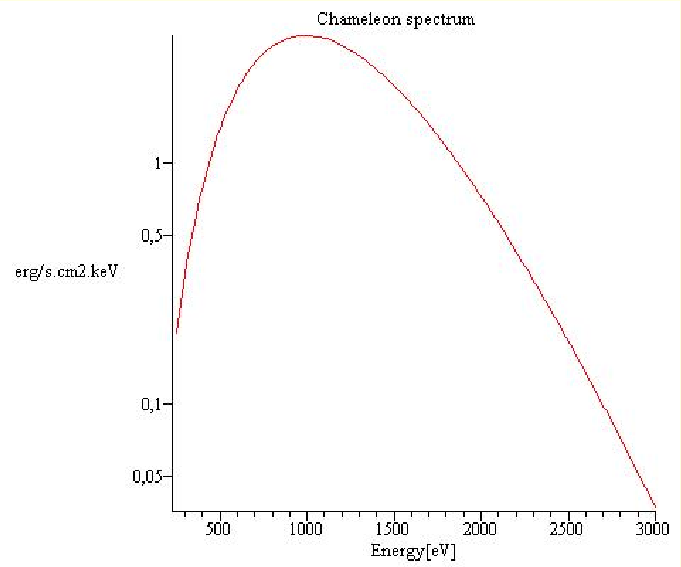


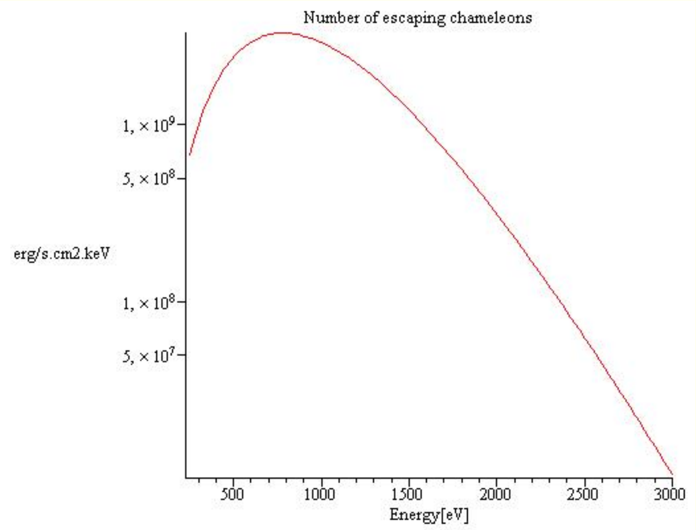
$M_\gamma = 10^{5.8}$ GeV, $\beta = 10^{7.09}$ $n = 8.7$



In the photosphere:

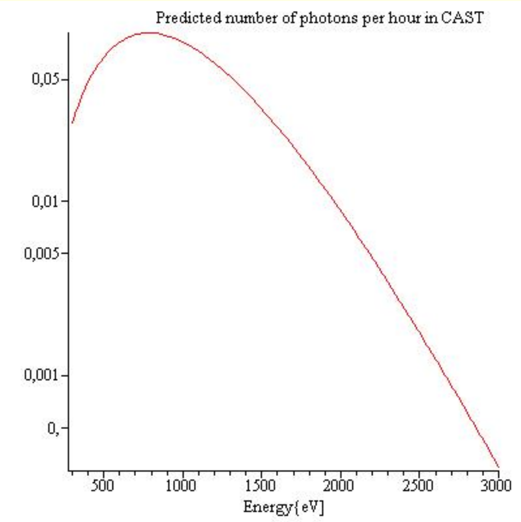
$$m_{\text{chameleon}} \approx 8.9 \ \text{meV}$$

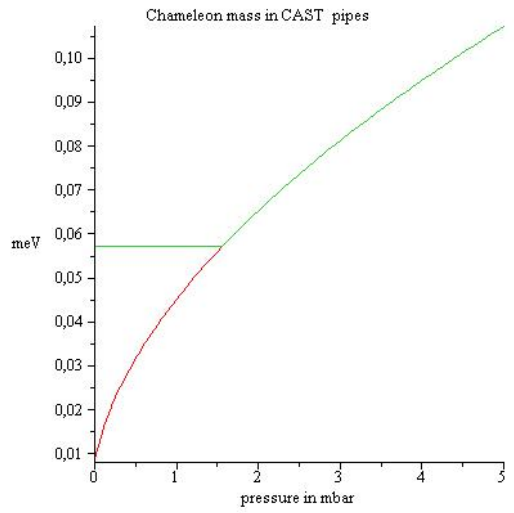




$$L_{\text{chameleon}} \approx 4 \text{ erg/s.cm}^2 \ll L_\gamma \approx 10^{11} \text{ erg/s.cm}^2$$

$$L = 9.26m,\ \ B = 9T, d = 43mm$$





$$N_\gamma \approx 0.04$$

With a noise of 0.13 photons per hour and 200 hours of observation, it is only a 1.5 standard deviation.

With a pipe length L=15m, B=6 T and an aperture 0.15 m2, a 5 standard deviation in 3 hours for a noise of 4 photons per hour.

Conclusions

- The quiet sun luminosity in the soft X-ray region can be generated by the back-converted photons produced from chameleons inside the photosphere.
- Most chameleons escape the sun and could regenerate photons in the CAST pipes. Detection rate low for present CAST.
- Regenerated photons detectable with upgraded CAST specifications.