LIGHT PARTICLES COUPLED TO PHOTONS

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Motivation: The Axion Model

Consequence of Peccei-Quinn solution to strong CP-problem

- ★ Axion mass m and breaking scale f related

$$m = \frac{f_\pi m_\pi}{f} \frac{\sqrt{m_u m_d}}{m_u + m_d} = 0.6 \text{ eV } \frac{10^7 \text{ GeV}}{f}$$

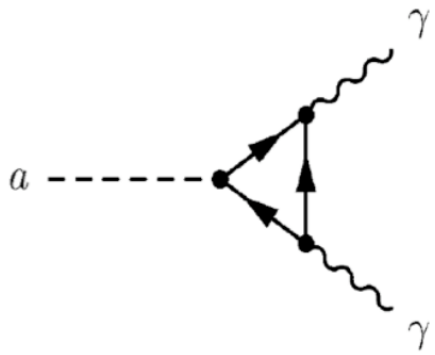
- ★ Couplings to matter ($i = p, n, e, etc.$)

$$\mathcal{L}_{a\Psi\Psi} = \sum_i c_i \frac{1}{2f} (\bar{\Psi}_i \gamma^\mu \gamma_5 \Psi_i)(\partial_\mu a)$$

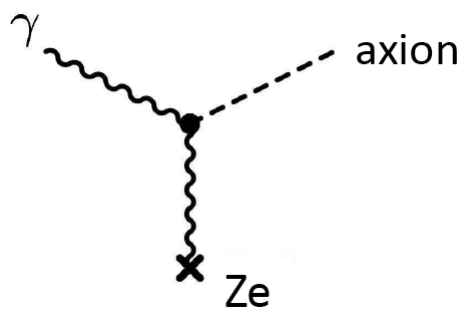
Axion Coupling to Two Photons

Axion searches use $a\gamma\gamma$ coupling

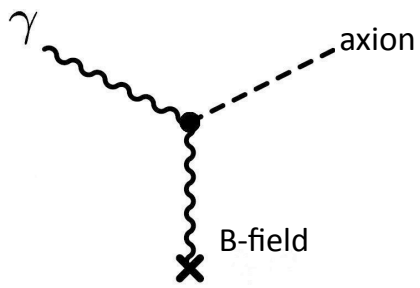
$$\begin{aligned}\mathcal{L}_{a\gamma\gamma} &= c_\gamma \frac{\alpha}{\pi f} F \cdot \tilde{F}\, a \\ &= -g_{a\gamma\gamma}\, \vec{E}\vec{B}\, a\end{aligned}$$



★ Example:
axion production
Primakoff-like process



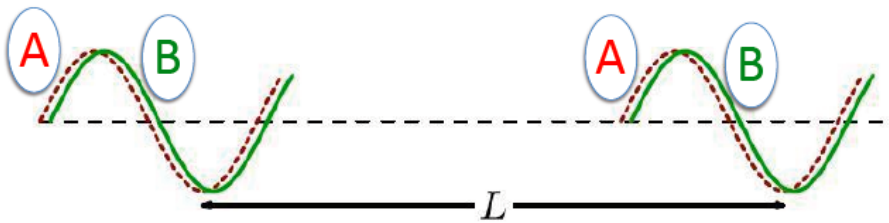
Axion-Photon Mixing in a Magnetic Field



Interaction states different from propagation states:

$$|a'> = \cos\varphi\,|a> - \sin\varphi\,|\gamma>$$
$$|\gamma'> = \sin\varphi\,|a> + \cos\varphi\,|\gamma>$$

Coherent effect among ***A***, ***B***



$$|k_A - k_B|L \ll 2\pi \qquad \text{(coherence)}$$

Axion-Photon Coherence

Propagation of a photon beam (energy E) traveling distance L

Conversion to axions:

$$Lm^2/E < 1 \qquad (\text{coherence})$$

Probability (in vacuum)

$$P(\gamma \to a) = \frac{1}{4}\, g_{a\gamma\gamma}^2\, B_T^2\, L^2$$

Other (light) particles coupled to photons

Most experiments looking for axions use the fact that:

- the mass is small

- it couples to two photons

$\Rightarrow$ Experiments are sensitive
to other particles with these properties

Other (light) particles coupled to photons

- Predicted in BSM models and/or needed

- Scalar particles

- quintessence fields in cosmology

- light spin 2 particles

- Axion has $f_a m_a \sim f_\pi m_\pi$

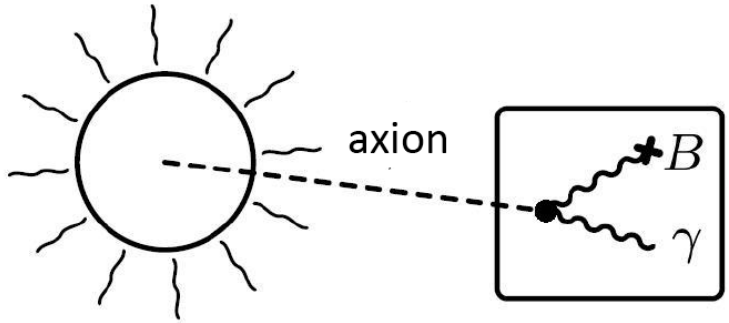
But for other particles consider f and m independent parameters

- Name:

Axion Like Particles (ALPs)

or Weakly Interacting Sub-eV Particles (WISPs)

ALPs from the Sun



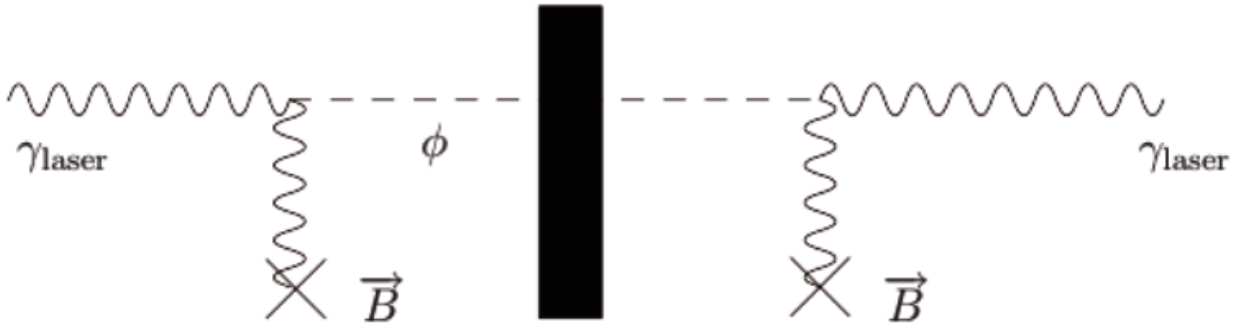
- Produce X-ray photons
- Valid for axion masses where conversion would be coherent
- CAST limit: $g_{a\gamma\gamma} < 2.2 \times 10^{-10}\ \mathrm{GeV}^{-1}$ (95 % CL, $m < 0.4\,\mathrm{eV}$)
- Caveat:

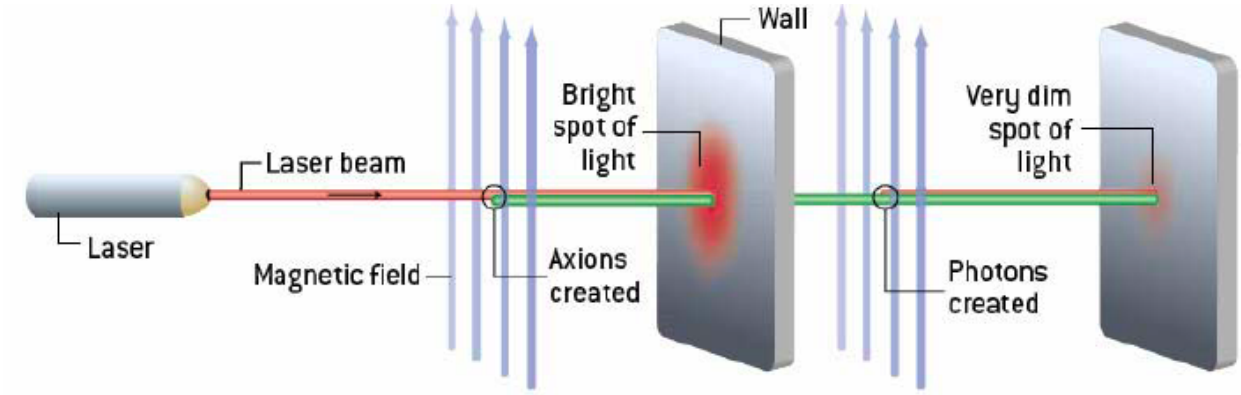
  Models where axion production suppressed at high T

  Need of Lab exps. (complementary to astro-constraints)

ALPs in the Laboratory

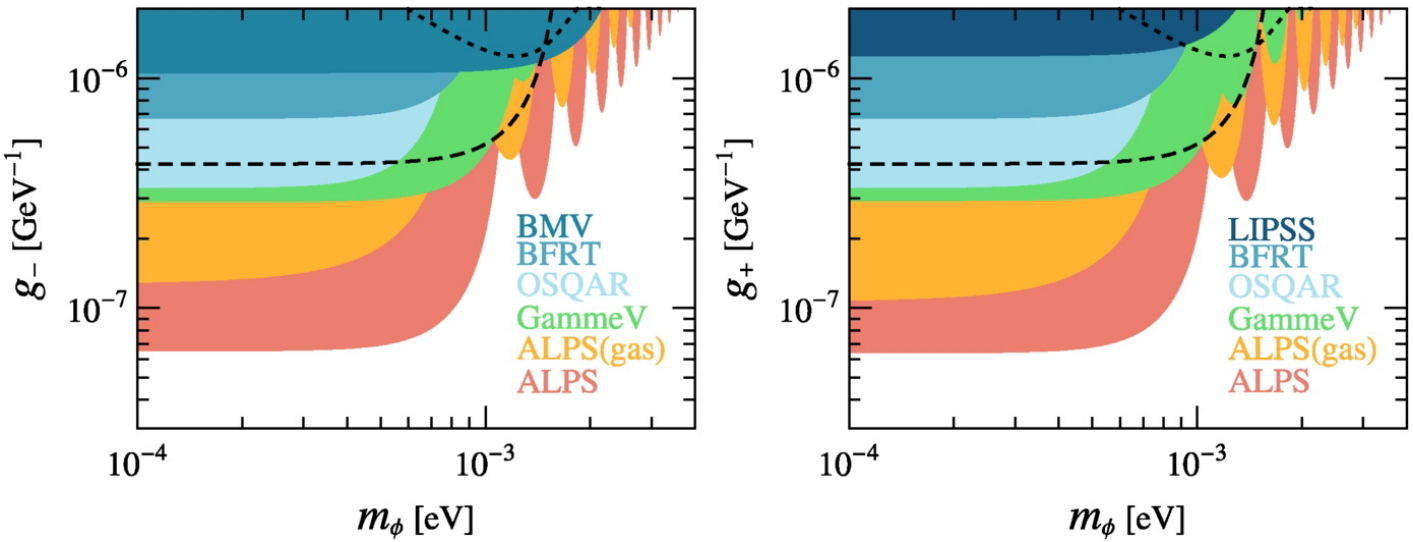
Light-Shining-through-a-Wall (LSW)





Experimental State of the Art

Results from the ALPS collaboration at DESY



New Forces

Light bosons of mass mediate forces with range $\lambda = \text{mass}^{-1}$

$$m \sim 10^{-5}\ \text{eV} \ \leftrightarrow \lambda \sim 2\ \text{cm}$$

Boson can be a Scalars or a Pseudoscalars

- Scalar-mediated force among 1 and 2

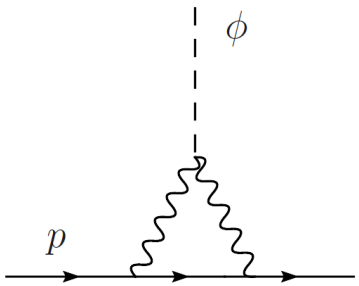
$$V_{ss}(r) = \frac{g_s^{(1)} g_s^{(2)}}{4\pi r} e^{-mr}$$

At a distances $r \sim m^{-1}$

$$\frac{V_{ss}}{V_{grav}} \sim (g_s^{(N)})^2 \frac{M_P^2}{m_N^2}$$

Equivalence principle restrict g_N to very tiny values

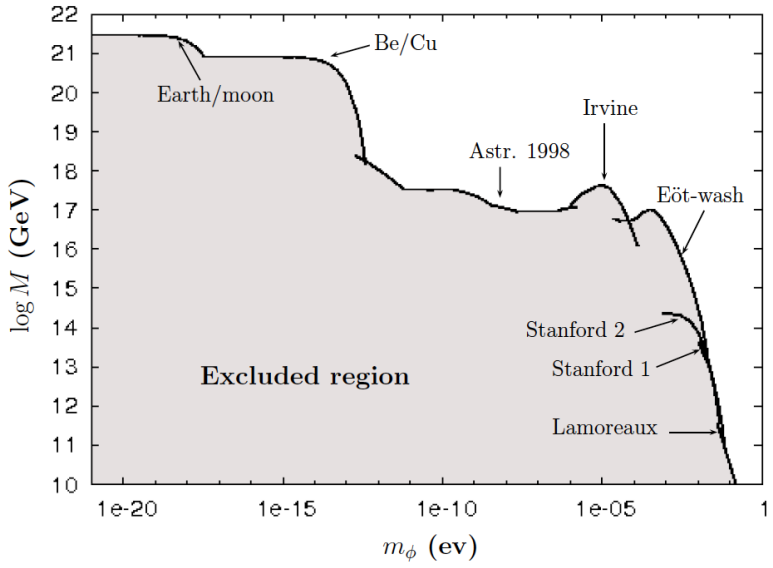
Scalar-photon couplings and Equivalence Principle



Coupling to protons but not to neutrons

$\Downarrow$

equivalence principle violation



$(g = 1/M)$

New Forces

However, for pseudoscalar-exchange there is coupling to spin which weakens very much the new force

$$\frac{V_{pp}}{V_{grav}} \sim (g_p^{(N)})^2 \frac{M_P^2}{m_N^2} F$$

$$F = \sum_{spins} \left[7(\vec{\sigma_1} \cdot \vec{n})(\vec{\sigma_2} \cdot \vec{n}) - 2(\vec{\sigma_1} \cdot \vec{\sigma_2}) \right]$$

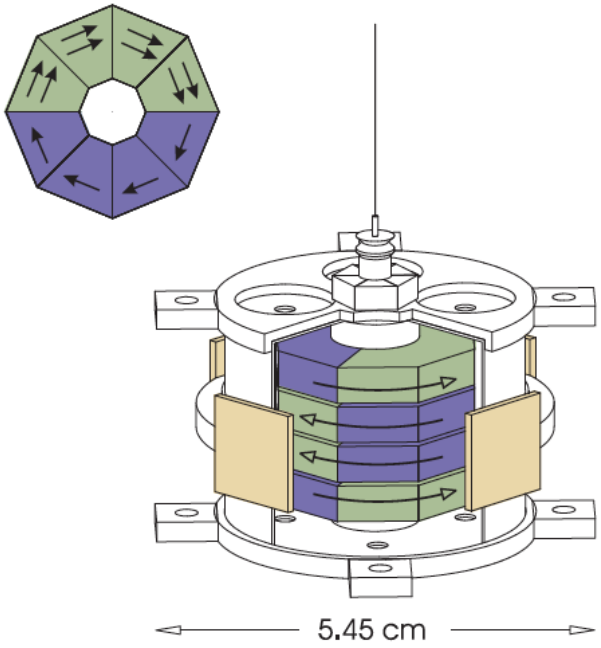
For unpolarized bodies, $F \to 0$.

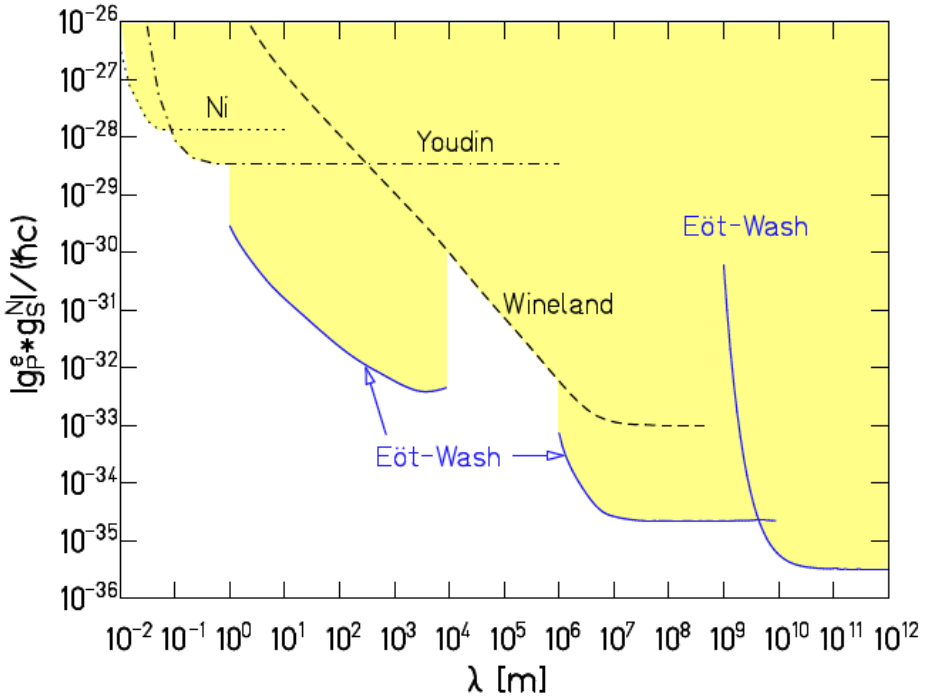
- In general, pheno point of view,

- S$\times$S $\quad g_s g_s$
- P$\times$P $\quad g_s g_p$
- S$\times$P $\quad g_p g_s$

New Observational Constraints on New Forces

torsion pendulum containing 9×10^{22} polarized electrons





hep-ph/0606218

Quantum states of neutrons in the Earth's gravitational field

- Bound states exist for neutrons trapped in the Earth's gravitational field.
- Quantum mechanical expectation verified experimentally
- OK without additional forces,
  $\Rightarrow$ get constraints on additional forces.
- proposal of exp. with polarized neutrons, $\lambda = 1 - 200\ \mu$m

nucl-ex/0902.3139

Chamaleons

- Light scalar particles as quintessence
- Induce new force; impact in gravity experiments

The chamaleon idea:

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

$A(\phi)$ arbitrary function, ρ_m ambient matter density

Particle mass / interaction range depend on ρ_m

$\Rightarrow$ Escape fifth-force constraints

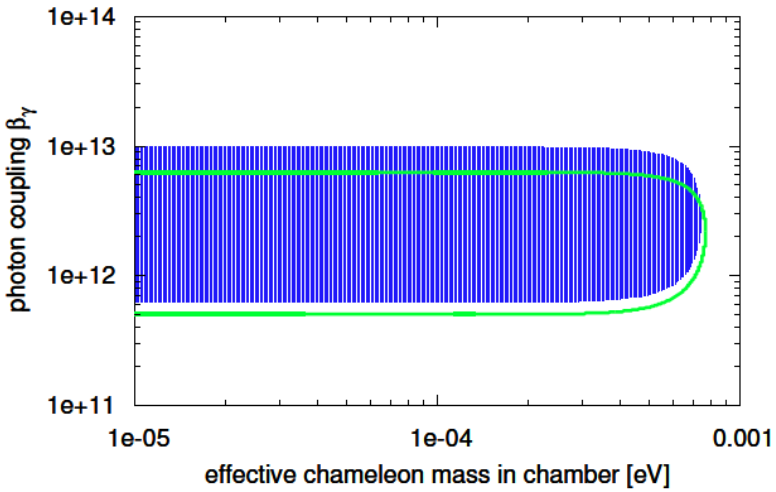
Chamaleons in the laboratory

Chameleons have generic coupling to photons $\beta_\gamma = M_{Planck}/M$

Idea of detection:

1) Produce chamaleons in a magnetic field

2) Wait for desintegration into photons



We are testing
models of Dark Energy
in the lab !

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Conclusions

- Many ideas in the subject
  of light particles coupled to photons
- New experiments undergoing
- The low-energy frontier of New Physics