Unveiling the Dark Universe with the Sun

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Outline

Introduction to screened scalars

Chameleons; symmetrons

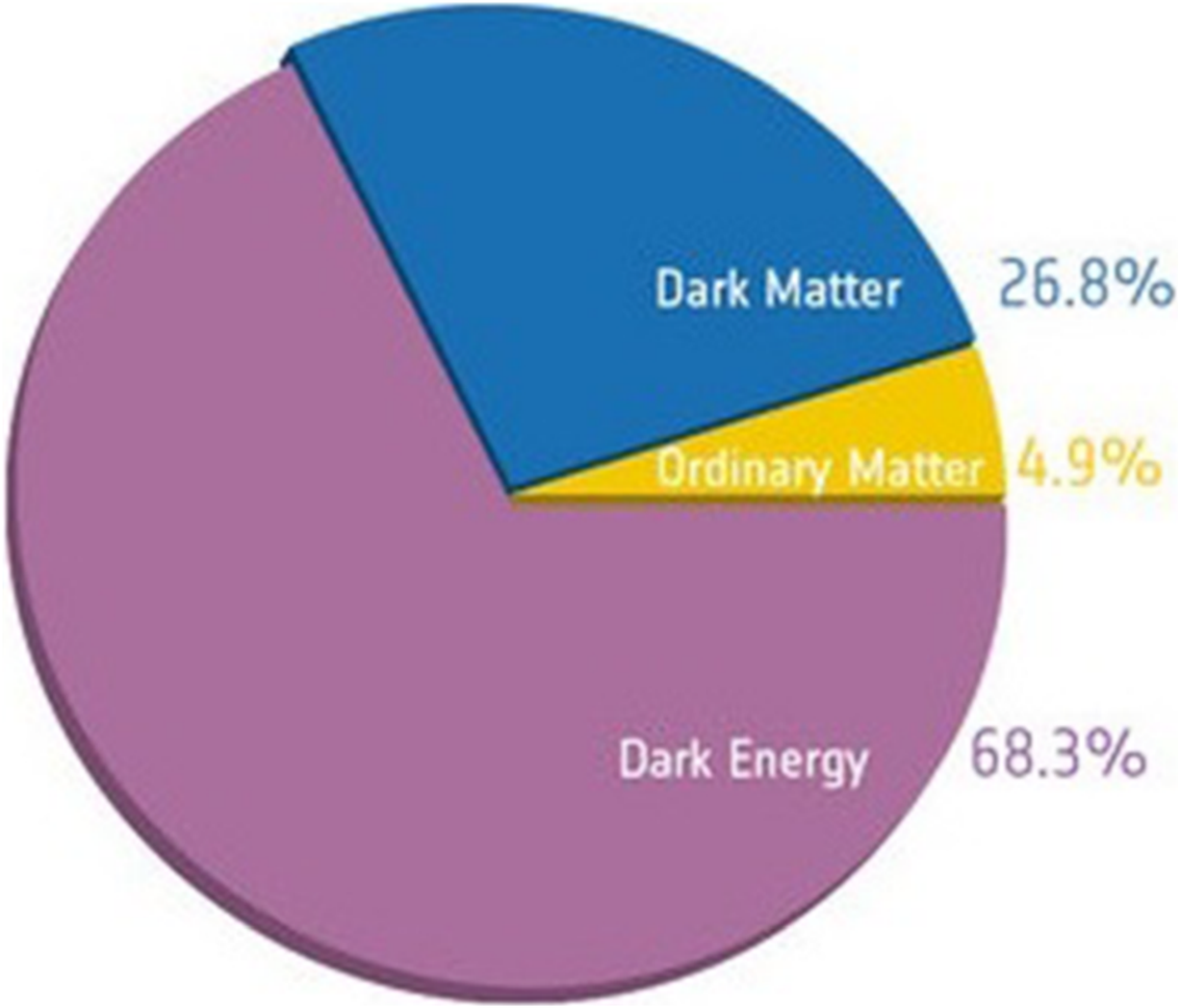
Solar Production

Luminosity constraints; O'Shea, ACD, Giannotti, Vagnozzi, Visinelli, Vogel 2406.01691; G-Y Yaun, ACD, Giannotti, Vagnozzi, Visinelli, Vogel 2511.01655; Banks, ACD, Visinelli 2604.09283

Direct Detection Vagnozzi, Visinelli, Brax, ACD, Sakstein 2103.15834; Yaun et al; Banks et al

The Future

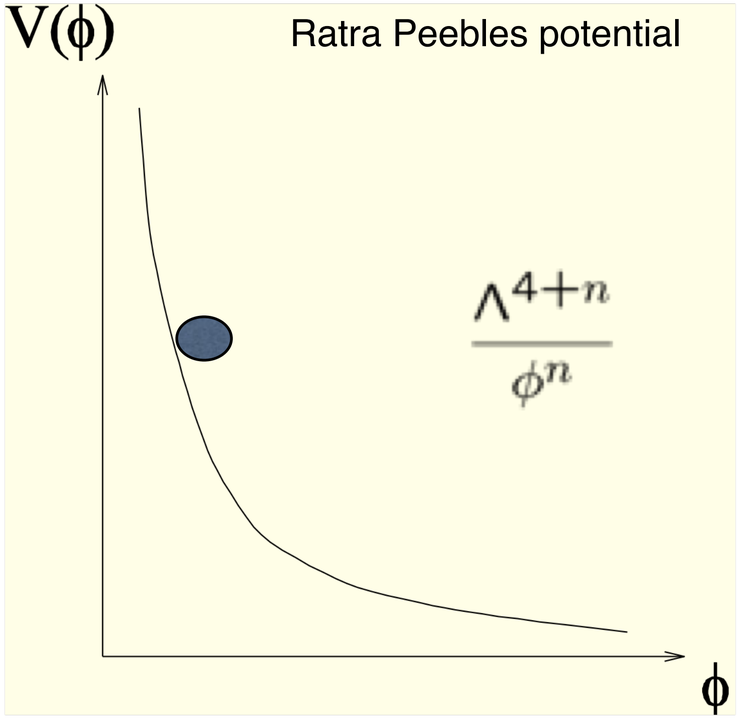
Dark Energy



A scalar field could act a dark energy provided its mass today

$$m_\phi < H_0 \approx 10^{-33} eV$$

We only know dark energy dominates today



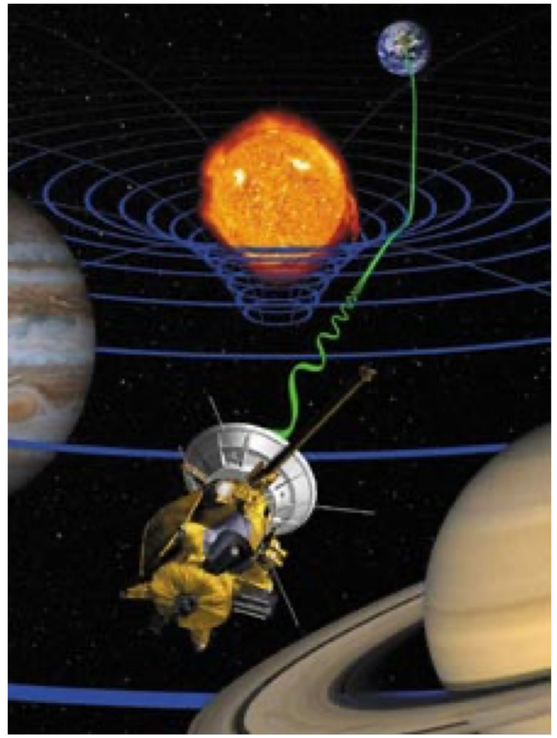
Deviations from Newton's Laws parametrised by

$$\Phi_N = -G_N/r(1 + 2\beta^2 e^{-r/\lambda})$$

tightest constraint from Cassini

$$\beta^2 \leq 4 \cdot 10^{-5}$$

Fifth Force must be screened



The Chameleon Mechanism

Khoury and Weltman astro-ph/0309300

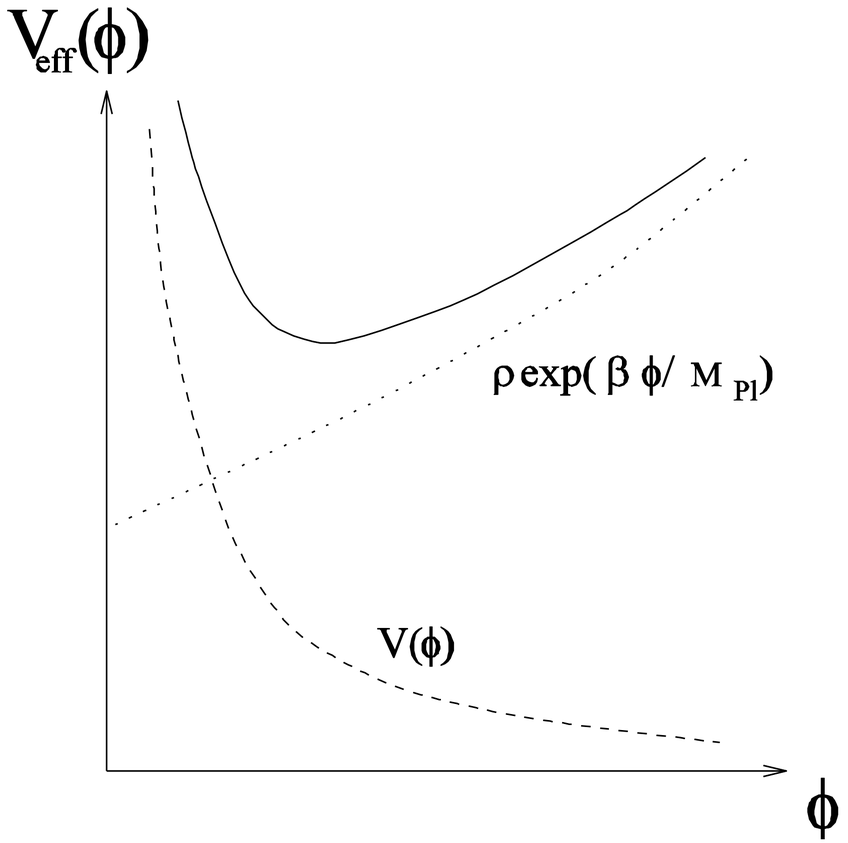
consider the action

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

gives the effective potential

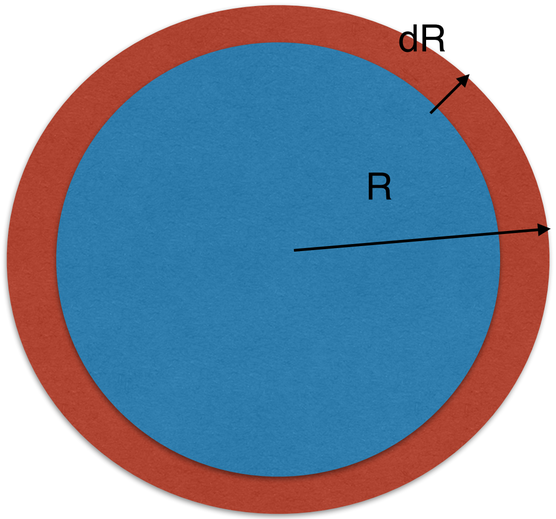
$$V_{\text{eff}}(\phi) = V(\phi) - (A(\phi) - 1)T$$

There is an environmental effect: when coupled to matter the potential depends on the ambient matter density as well



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

To screen fifth forces in the solar system one needs the thin shell effect.



The fifth force is proportional to the size of the thin shell where the field varies

$$F_\phi \approx \frac{\Delta R}{R\Phi_N}$$

Symmetrons

Khoury&Hinterbichler, 1001.4525

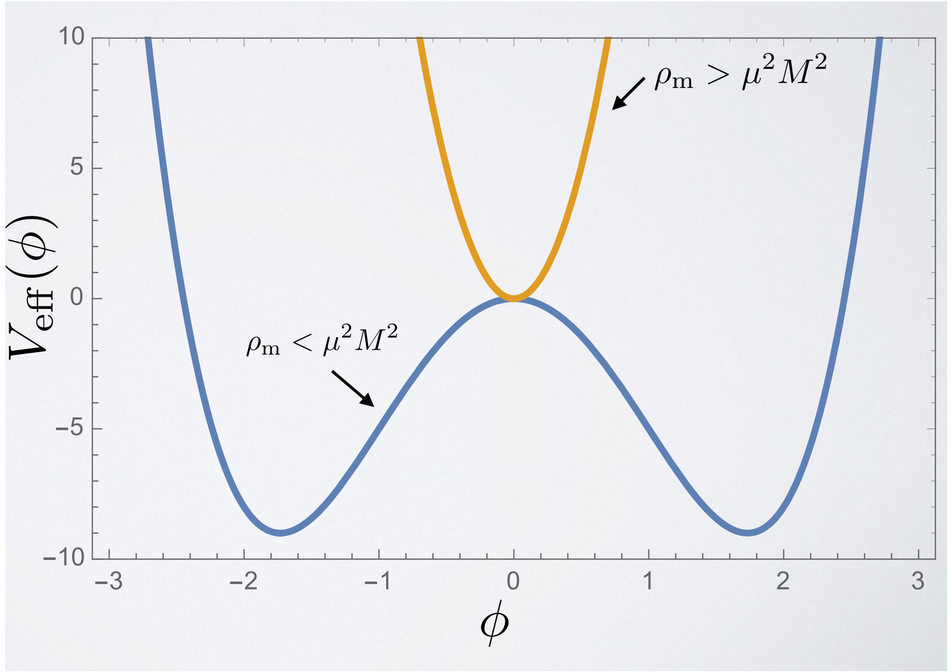
This has potential

$$V(\phi) = V_0 + \frac{\lambda}{4}\phi^4 - \frac{\mu^2}{2}\phi^2$$

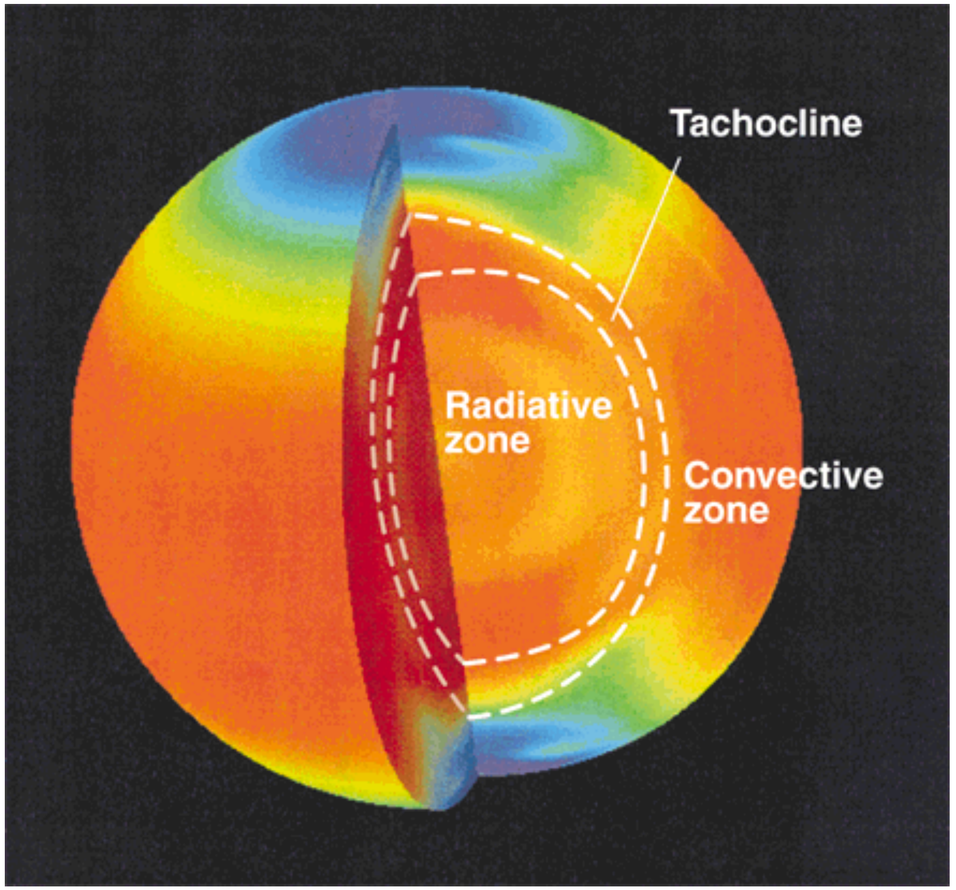
with Z_2 symmetry and coupling function

$$A(\phi) = 1 + \frac{\beta_\star}{2\phi_\star m_{\rm Pl}}\phi^2$$

In a dense environment the field is at the origin whilst in a sparser one the field is at the minimum of the potential with the transition happening at density ρ_*



The Sun



we originally considered production of chameleons in the tachocline where the B field is 50T. In our work we consider production in all regions of the sun, taking into account the density dependent mass of the chameleon. In the radiative zone where the magnetic field is $3 \times 10^3 T$

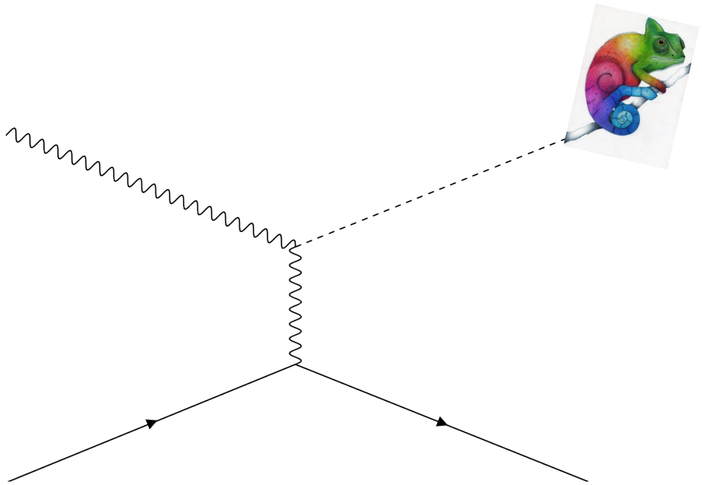
Hence we consider the bulk magnetic field with production of chameleons via the Primakoff effect. We consider Primakoff production in the electric field of the electrons and ions. This is a new channel.

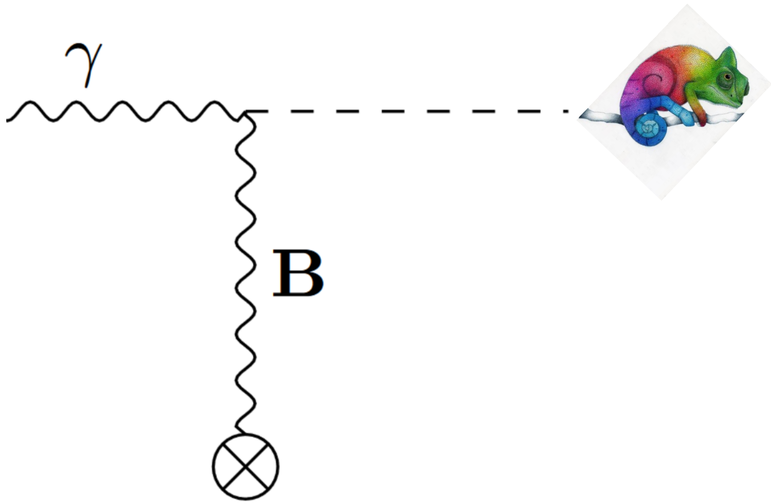
We used thermal field theory techniques to evaluate the Feynman diagrams. Since the coupling is

$$\phi F_{\mu\nu} F^{\mu\nu} \propto \phi(B^2 - E^2)$$

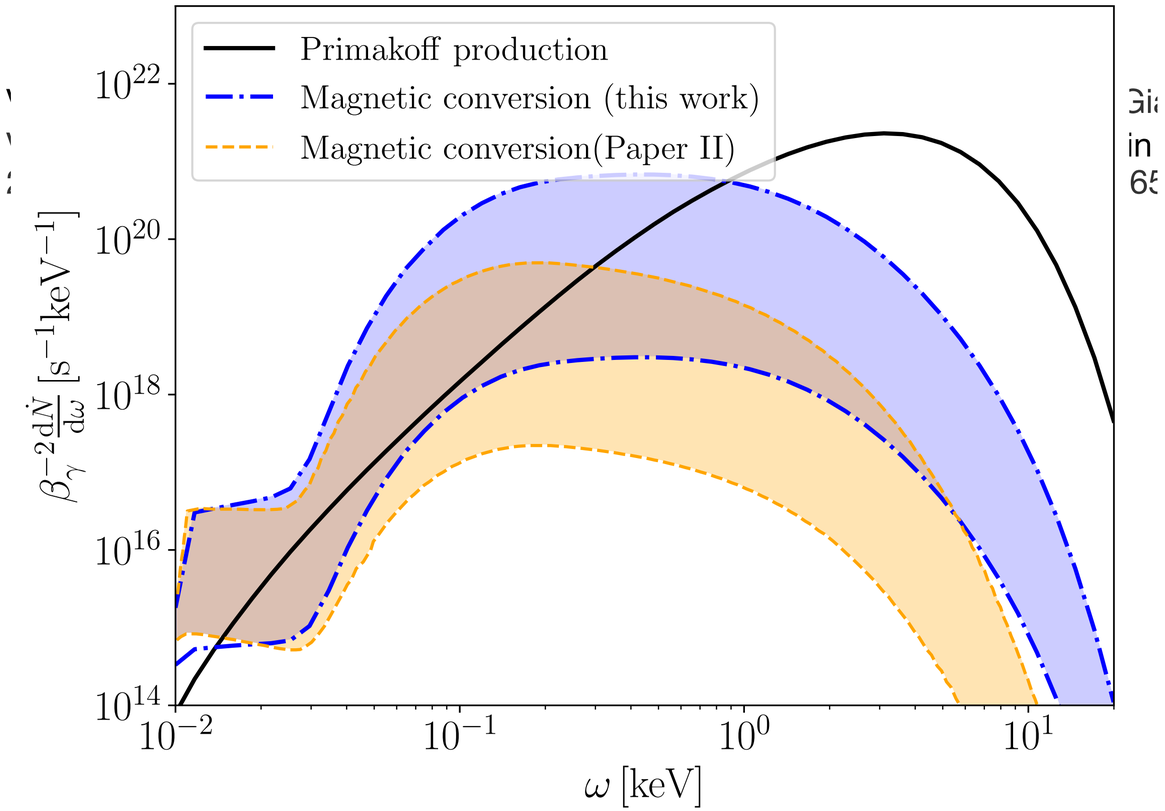
The B field gives the scalar photon coupling whilst the E field gives the scalar coupling with the photon and plasmon. This gives rise to TT, TL and LL modes unlike the case for axions where the L modes are forbidden. We used a model for the solar magnetic field and considered the three sections of the core, the tachycline and the outer region.

Solar Production

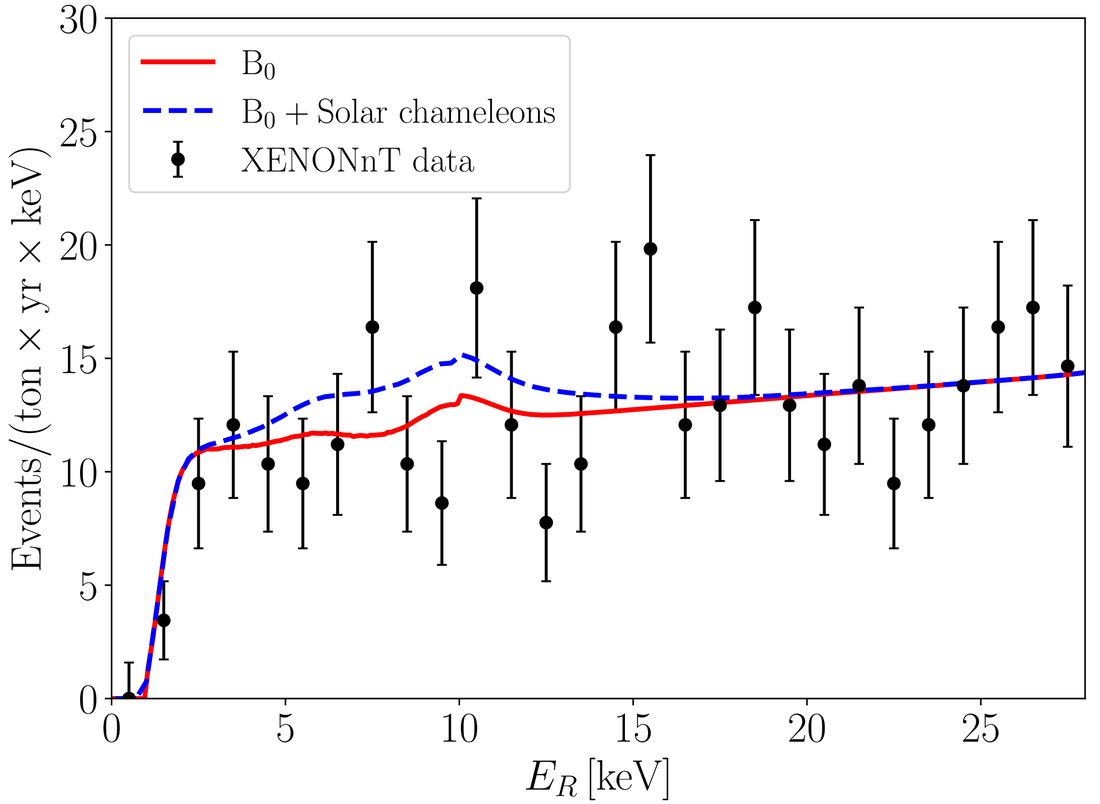




Spectrum



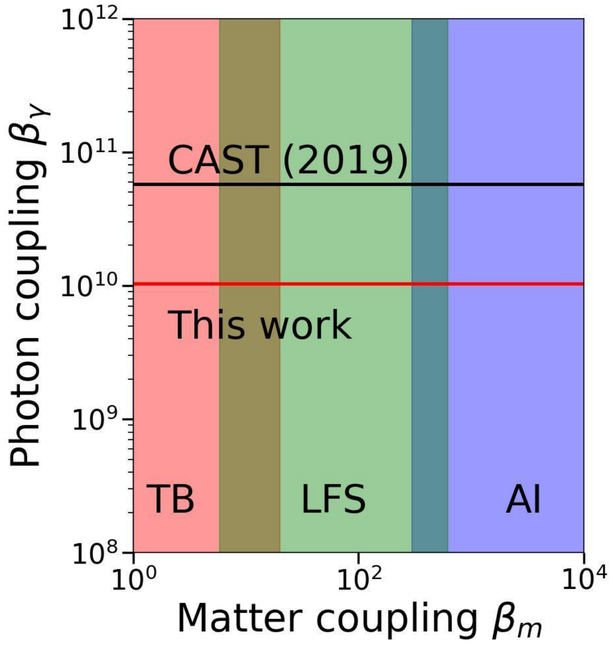
XENONnT



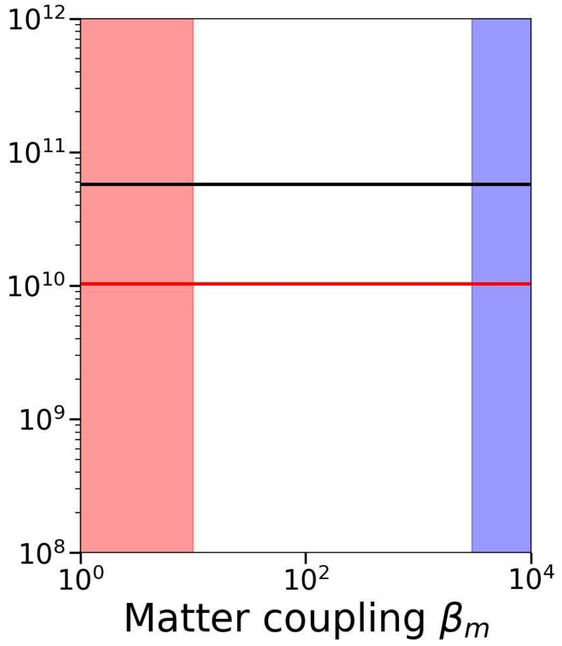
G-Y Yaun, ACD, et al 2511.01655;

This follows Vagnozzi, ACD,et al 2103.15834 ; O'Shea, ACD, et al 2406.01691

Solar Energy Loss Bounds

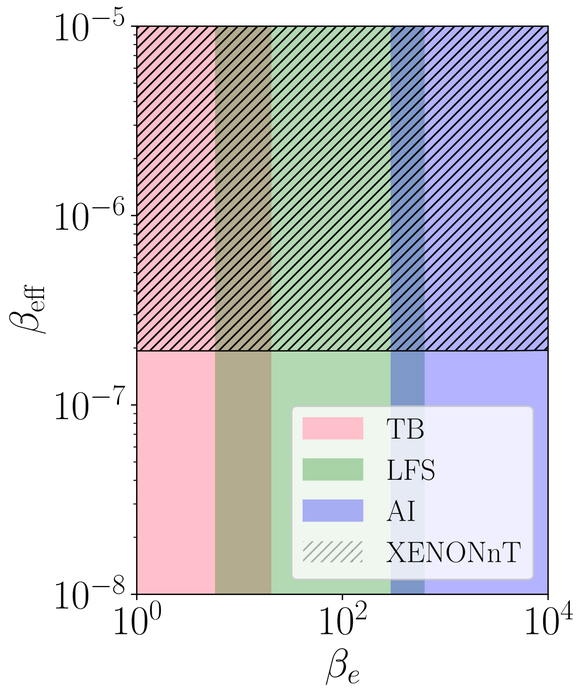


n=1

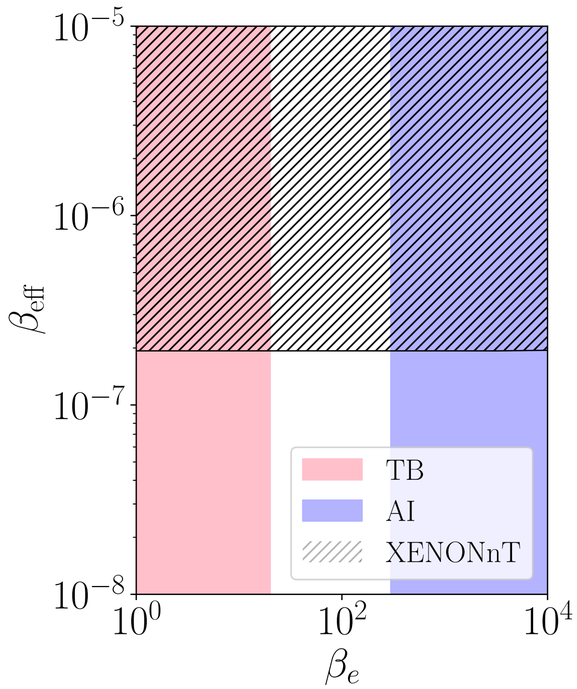


n=4

XENONnT



n=1

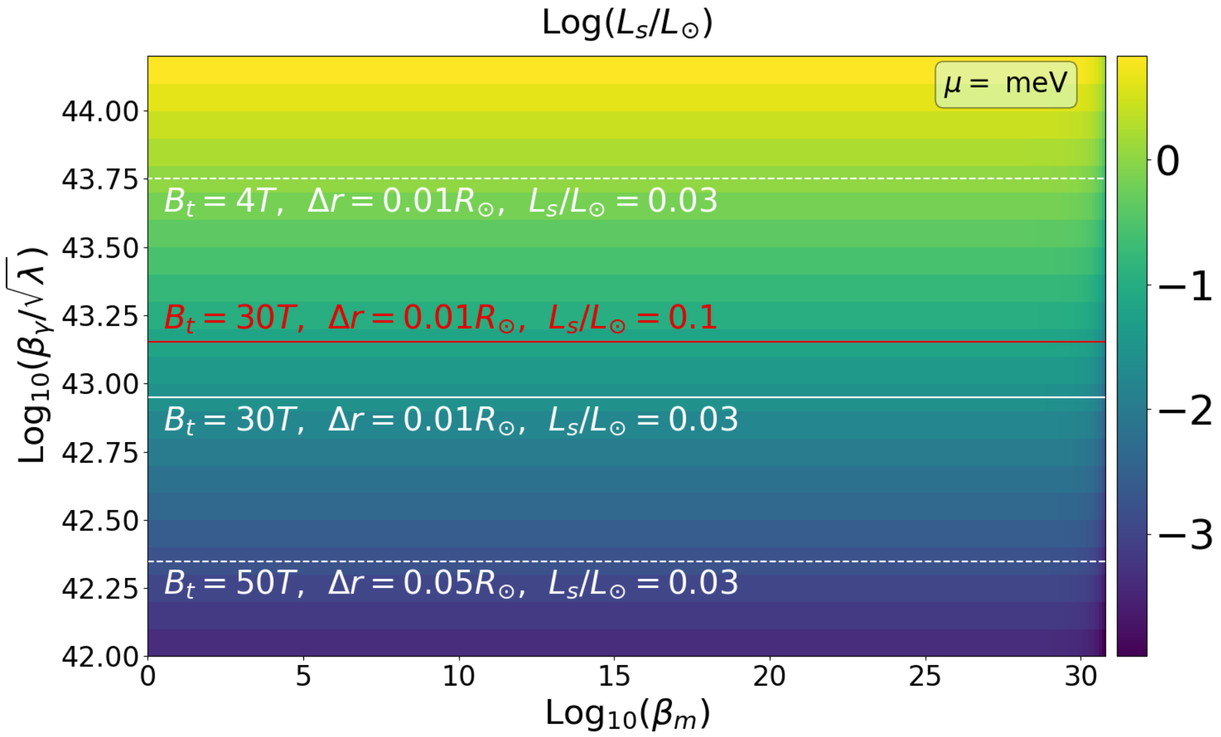


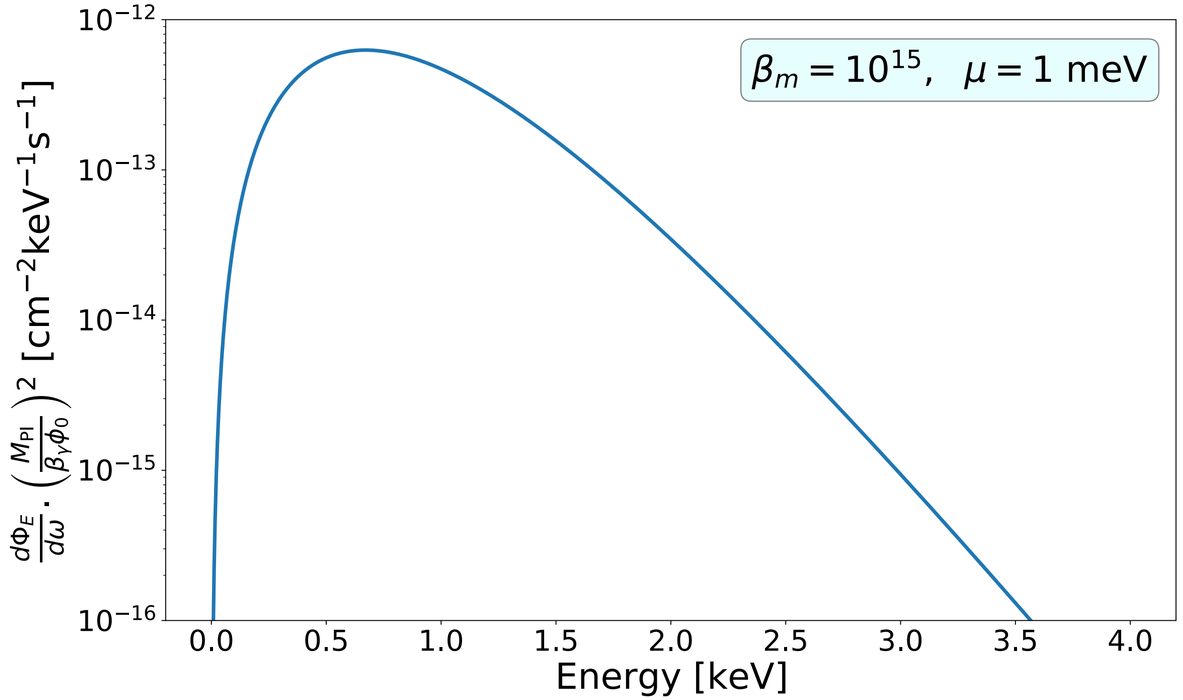
n=4

G-Y Yaun, ACD, Giannotti, Vagnozzi, Visinelli, Vogel 2511.01655;

Symmetrons

Due to the nature or the model they are only likely to be in the symmetry breaking phase, where the scalar field can couple to matter, in the tachocline. In the tachocline the magnetic contribution dominates over the Primakoff, so only this is considered. The coupling in this case is $\phi^2 F_{\mu\nu} F^{\mu\nu}$





Banks, ACD, Visinelli 2604.09283

The Future

Include Longitudinal Modes (not entirely straightforward) for production in the solar core

One can do something similar with dark matter scalars

NuStar Predictions and Constraints

Helioscope Predictions —- IAXO

In progress