New method for setting a bound on the product $g_{an}g_{a\gamma\gamma}$ from 14.4 keV solar axions

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Axions: What are they and how do they solve all our problems?

Initially proposed by Peccei and Quinn to solve the strong CP problem

Possible candidate for Dark Matter $\Omega_a \sim \left(\frac{5\mu eV}{m_a}\right)^{7/6}$

Possible explanation for the presence of very high energy(TeV) photons in the cosmic rays

Important implications for stellar evolution

Coupling of axions to other things

- Photon $\mathcal{L}_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} \phi$
- Electron $\mathcal{L}_{ae} = \frac{1}{2} g_{ae} \overline{\psi}_e \gamma_5 \gamma^\mu \partial_\mu \phi \psi_e$
- Nucleon $\mathcal{L}_{aN} = i \overline{\psi}_N \gamma_5 (g_{aN}^0 + g_{aN}^3 \tau_3) \phi \psi_N$

Axion mass $$m_a \approx 0.6\,\mathrm{meV}\left(\frac{10^{10}\,\mathrm{GeV}}{f_a}\right)$$

Coupling to EM field $$g_{a\gamma} = \frac{\alpha}{2\pi f_a}\left(\frac{E}{N} - \frac{2}{3}\frac{4+z}{1+z}\right) \approx \begin{cases} 8.4\times 10^{-4}/f_a & \mathrm{DFSZ} \\ 2.3\times 10^{-3}/f_a & \mathrm{KFSZ} \end{cases}$$

Coupling to electrons $$g_{ae} = \frac{C_e m_e}{f_a}$$ KSFZ tree level

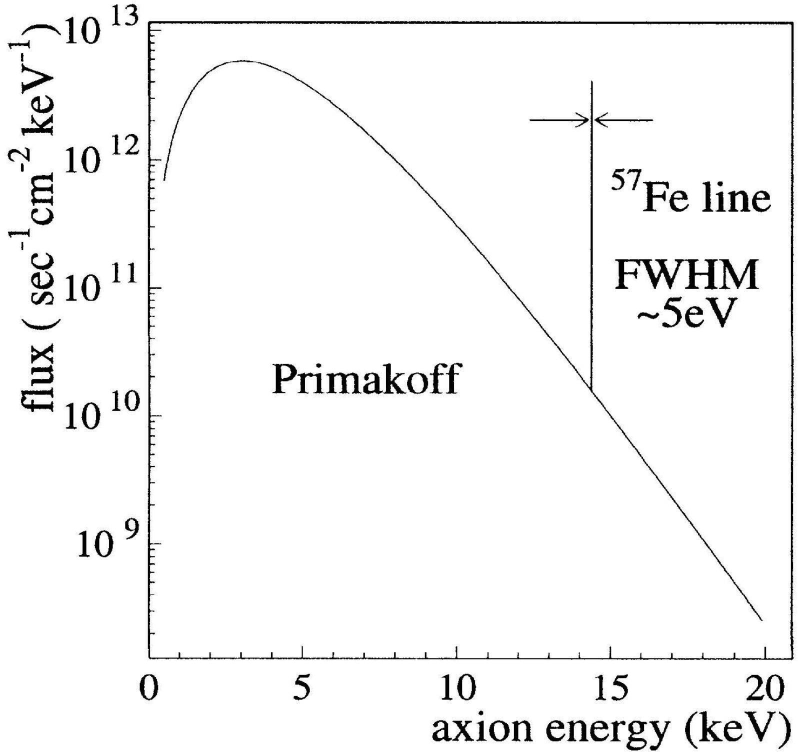
Coupling to nucleons

$$g_{aN}^{0} = -0.27\frac{\mathrm{GeV}}{f_a} \quad \text{isoscalar}$$

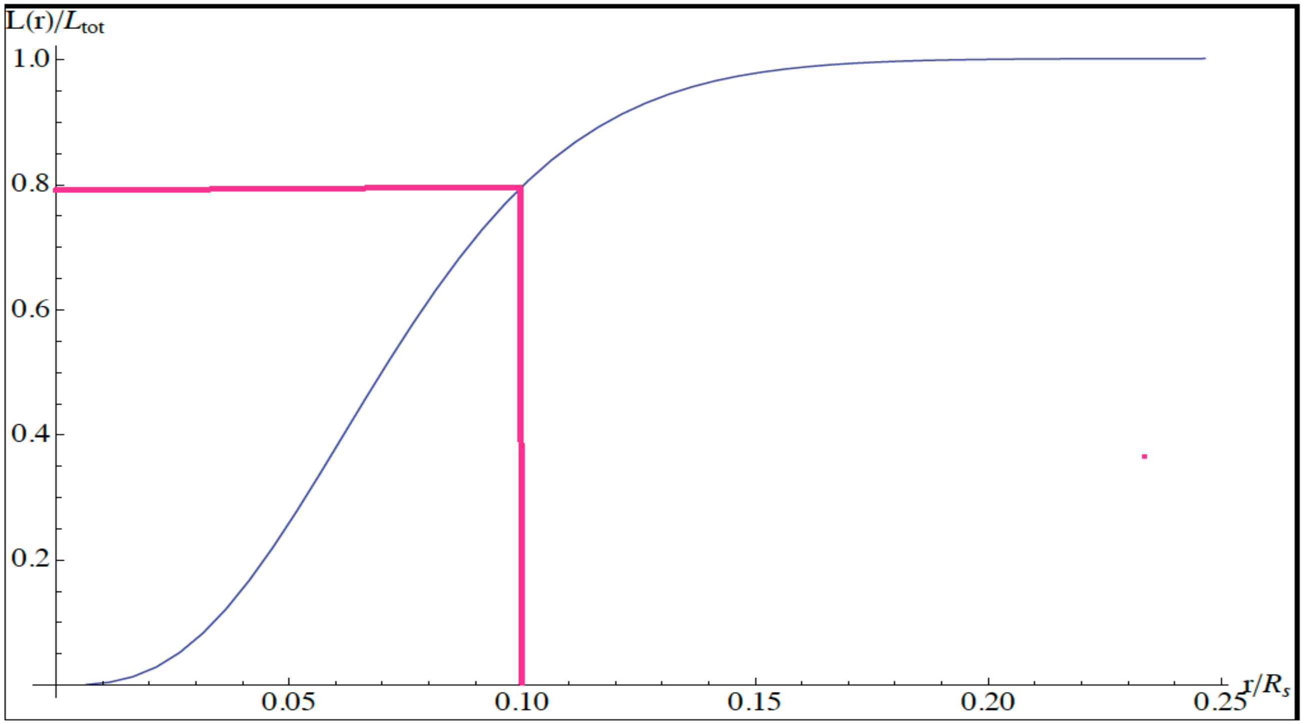
$$g_{aN}^{3} = -0.16\frac{\mathrm{GeV}}{f_a} \quad \text{isotriplet}$$

$$g_{aN}^{(eff)} = \beta g_{aN}^{0} + g_{aN}^{3} \quad \beta = -1.19 \quad \text{for } ^{57}Fe$$

Solar Axion Fluxes



Primakoff and Fe-57 14.4 keV axions fluxes for f_a=10^6 GeV S. Moriyama PRL **75,** 3222 (1995)



Partial axion luminosity in the solar core.

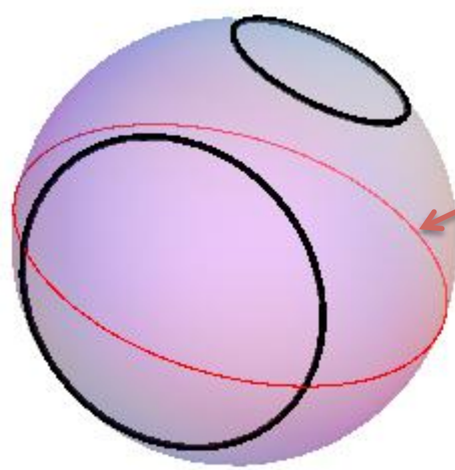
Coherent Bragg-Primakoff Conversion

Bragg Condition: $2\hat{\mathbf{p}}(t)\cdot\mathbf{G} = \dfrac{\hbar c G^2}{E_\gamma}$

Photon energy

Unit vector to the Sun

Reciprocal lattice vector



Path of the Sun

Bragg circles for 40 reciprocal vectors

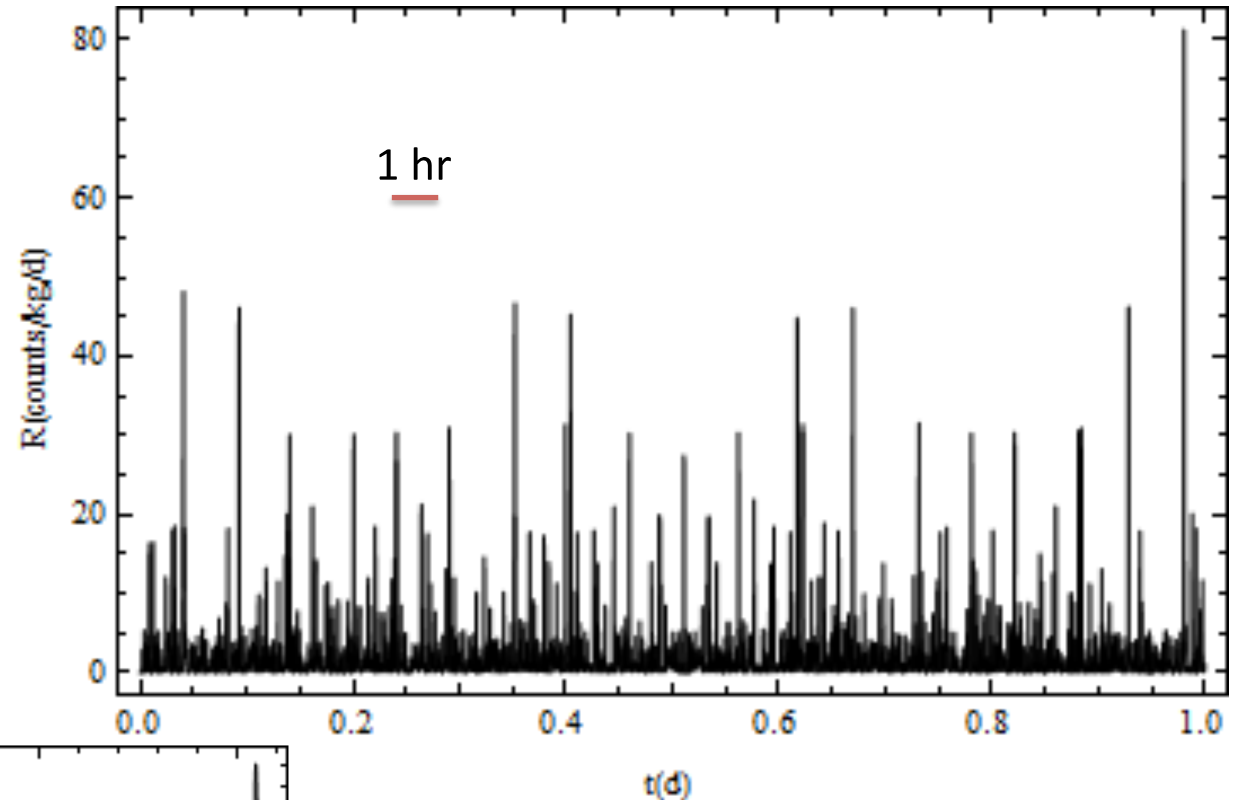
Solar core ~0.1R_S~0.025deg

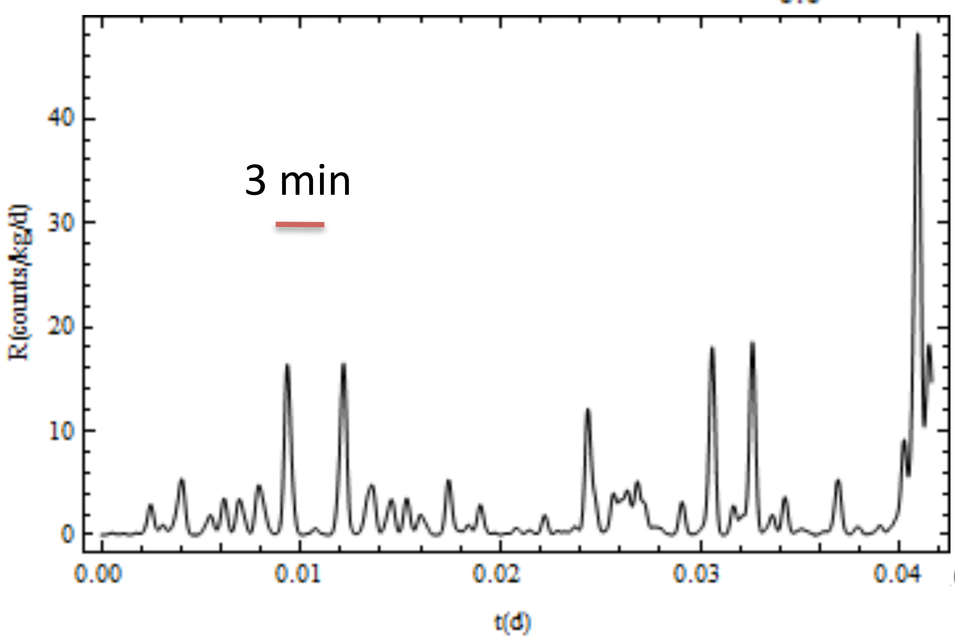
Sun moves at 0.25 deg/m

Time to cross one Bragg circle ~0.2 min (12s)

Counts/kg/d for one Day (TeO_2)

$g_{a\gamma} g_{an}^{eff} = 10^{-16}\,\mathrm{GeV}^{-1}$





Counts/kg/day over the first hour

Time Correlation Function

$$\chi = \sum_{i=1}^{N} w(t_i) n(t_i)$$

$$\langle n(t_i) \rangle = \left(\lambda R_0(t_i) + B \right) \Delta t$$

theoretical counting rate

$$g_{a\gamma} g_{an}^{eff} = 10^{-16}\,\mathrm{GeV}^{-1}$$

The "best" weighting function is $w(t) = R_0(t) - \overline{R}_0$

$$\langle \chi \rangle = \lambda \int_0^T dt\, w^2(t)$$

$$\Delta\chi^2 \cong B \int_0^T dt\, w^2(t)$$

$$\frac{\langle \chi \rangle}{\Delta\chi} = \lambda \sqrt{\frac{\int_0^T dt\, w^2(t)}{B}}$$

$$\lambda < \sqrt{\frac{B}{\int_0^T dt\, w^2(t)}}$$

CAST (2009) $g_{a\gamma} g_{an}^{eff} < 1.36 \times 10^{-16}\,\mathrm{GeV}^{-1}$

CUORE:
B~1.0c/kg/d
M=741 kg TeO_2
T=365 d

$g_{a\gamma} g_{an}^{eff} < 2.76 \times 10^{-18}\,\mathrm{GeV}^{-1}$