LHC Science with AGN
or
Warm Converters

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Have you seen this?

If so then...

an absorption-like feature: not a line not an edge
The Nobel Prize in Physics 2020

“for the discovery of pseudo-scalars and for solving of the strong-CP problem of QCD and the dark matter problem of cosmology“

Jelle Kaastra  1/3 of the prize  
Helen Quinn   1/3 of the prize  
Roberto Peccei  1/3 of the prize
The strong-CP problem

- $C$: CP
- $P$: CP (1956/7)
- $T$: CP (1964)
- $CPT$: weak

Landau

- weak (1956/7)
- weak (1964)

- weak
The QCD Lagrangian

\[ \mathcal{L} = - \frac{1}{4} \text{tr} F_{\mu\nu} F^{\mu\nu} - \theta \frac{n_f g^2}{32\pi} \text{tr} F_{\mu\nu} \tilde{F}^{\mu\nu} + \bar{\psi} \left( i\gamma^\mu D_\mu - m e^{i\theta' \gamma_5} \right) \psi \]

strong obeys CP \[ \theta \ll 10^{-10} \]

Fine tuning!!!
The Peccei-Quinn solution

θ naturally relaxed to zero!!!

Wilczek: “... for cleaning the strong CP problem...”

pseudo-scalar
(spin-0, boson)
Axions as DM particles

(very) early universe

QCD phase transition
The EM+axion Lagrangian

\[ \mathcal{L}_{EM} = \mathcal{L}_{EM}^{\text{free}} + g \vec{B} \vec{E} a \]
Current limits

\[ m_a > 10^{-6} \text{ eV} \]

\[ g < 10^{-10} \text{ GeV}^{-1} \]

main limitation:

\[ P_{a \rightarrow \gamma} \sim g^2 B^2 R^2 \]

\[ \left( \frac{B_{\text{quasar}}}{B_{\text{CAST}}} \frac{R_{\text{quasar}}}{R_{\text{CAST}}} \right)^2 \sim 10^{20} \]

One could do better w/AGN
photon-axion conversion

\[
\begin{align*}
\mathbf{k}^2 |\mathbf{k}\omega|^{2} - |\omega|^{2} + \frac{m_{\gamma}^{2}n_{\gamma}^{2}}{-gB||\omega||} \left(\frac{0}{m_{a}^{2}n_{a}^{2}}\right) \left(\frac{\gamma}{a}\right) = 0 = 0
\end{align*}
\]

**Resonance energy:** \(m_{\gamma}(\omega) \simeq m_{a}\)

dependence on plasma density and temperature, and magnetic field value.

(NO DEPENDENCE ON ATOMIC DATA)

“Feature” depth:
non-linear dependence on the magnetic field and the system’s size

(VERY DIFFERENT CURVE OF GROWTH)

“Feature” width:
depends primarily on the stratification of the magnetic field and density, and,
to a lesser extent, on the system size.

(NO DEPENDENCE ON TEMPERATURE)
10^{-3} < W_{\gamma \rightarrow a} < 10 \text{ Å}
0.1 \text{ keV} < E_{\gamma \rightarrow a} < 100 \text{ keV}
In this case, lies in the part of the spectrum close to the iron with the specific oscillation feature considered here. Thus far we have considered pseudo-scalar particles such as axions and bosonic dark matter. The higher sensitivity (assuming 5% detection threshold) of current methods to these particles, such as CAST/HB stars, also depends on assumptions concerning the density of the magnetosphere in magnetars; see figure 20 and is compared to the regions that can now be probed by studying the spectra of compact objects which is unreachable by laboratory means. As such, the approach proposed in this paper may allow us to probe a considerably larger parameter range than is accessible by other methods. We further show that the proof-of-concept limits obtained by other currently used methods such as laser experiments, microwave cavity detectors, solar axion telescopes, and indirect ap-
Summary

• Axions provide a solution to the strong-CP problem and dark matter problems. Their detection may also help to establish string theory and could shed light on quintessence fields (cosmological constant).

• Detailed spectral predictions of photon-axion oscillations were calculated.

• Features are expected to show up in the soft to hard X-ray band and require high-res grating spectra to be securely detected.

• Observations of AGN (and also magnetars and pulsars in the IR band) are several orders of magnitude more sensitive to axions compared to current terrestrial experiments.