

A COSMIC AXION DETECTOR*

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AXION PROPERTIES

The axion¹ is a hypothetical particle which was introduced to solve the strong CP problem. Peccei and Quinn proposed a U(1)-symmetry to explain the absence of CP violations in QCD, manifested in the upper limit on the neutron electric dipole moment. At low energies the symmetry is spontaneously broken and the associated pseudo-Nambu-Goldstone boson is the axion. Massless at the classical level, it acquires a small mass due to instanton effects. The theory does not predict its mass and couplings to quarks, electrons and photons, though they are related to the symmetry breaking scale f_a :

$$m_a \simeq \frac{0.62 \times 10^{-5} \text{ eV}}{(f_a/10^{12} \text{ GeV})} = \frac{2\pi \cdot 1.5 \text{ GHz}}{(f_a/10^{12} \text{ GeV})} \quad (1)$$

The coupling of the axion field a to the electromagnetic field is given by

$$L_{a\gamma\gamma} \simeq -8.4 \times 10^{-4} \frac{a}{f_a} \vec{E} \cdot \vec{B} \quad (2)$$

Laboratory searches have eliminated axions which have $f_a < 10^3 \text{ GeV}$, while astrophysical and cosmological considerations have narrowed the possible mass range to $10^{-6} \text{ eV} < m_a < 10^{-3} \text{ eV}$. Axions of this mass have important cosmological consequences. In the early universe at $T \simeq 1 \text{ GeV}$, the axion mass 'turns on' due to quantum effects and the axion field starts to oscillate. These oscillations correspond to a highly degenerate zero-momentum Bose condensate. Relic axions are still around today and contribute to the present energy density of our universe :

$$\Omega_a \simeq 0.85 \cdot (m_a/10^{-5} \text{ eV})^{-1.18} \quad (3)$$

If axions close the universe then they are likely to form the dark halo around our galaxy which is known to have a density of $\rho_{\text{halo}} \simeq 0.3 \text{ GeV} \cdot \text{cm}^{-3}$.

AXION DETECTION

Our detector makes use of the electromagnetic coupling of the axion, which allows for a decay of one axion into one photon in the presence of a static background field B_0 . Axion to photon conversion is greatly enhanced in a microwave cavity resonating at the axion energy ($\omega = m_a \cdot (1 + O(10^{-6}))$), where the $O(10^{-6})$ spread comes from the axion kinetic energy.

The power in mode nl is given by ($\vec{B}_0 = B_0 \hat{z}$)

$$P_{nl} \simeq 2 \times 10^{-20} \text{ W} \left(\frac{V}{500 \ell} \right) \left(\frac{B_0}{8 \text{ T}} \right)^2 C_{nl} \left(\frac{\rho_a}{\rho_{\text{halo}}} \right) \left(\frac{m_a}{2\pi \cdot 1.5 \text{ GHz}} \right) Q_{nl} \quad (4)$$

where V is the cavity volume, Q_{nl} is the loaded quality factor of the cavity and

$$C_{nl} = \frac{|\int_V d^3x E_{z,nl}|^2}{V \cdot \int_V d^3x \epsilon(x) |E_{z,nl}|^2} \quad (5)$$

Because the axion mass is only known in order of magnitude the cavity has to be tunable and a wide range of frequencies has to be scanned. The search rate for given signal to noise ratio s/n is determined by V, B_0, Q_{wall} and system noise temperature T_n .

RESULTS

$$T_n = T_{bath} + T_{amp} = 2\text{ K} + 3\text{ K} = 5\text{ K} \quad @ 1.2 - 1.6\text{ GHz}$$

$$Q_{wall} \simeq 10^5$$

$$B_0 = 8.5\text{ T}$$

$$V \simeq 6\text{ l}$$

Frequencies covered : 1.48 – 1.50 GHz with $s/n = 1/300$

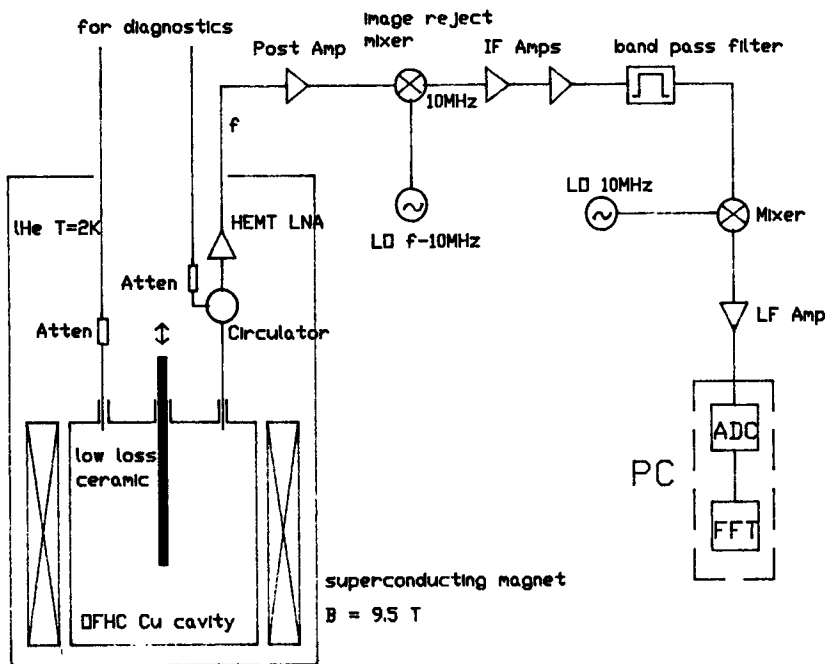


Fig.1: schematic diagram of axion detector.

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REFERENCES

1. J.E. Kim Phys.Rep. **150** (1987) and references quoted therein