

First results from the CAST experiment

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Abstract. The CAST Experiment commenced its first phase of solar axion-searching in 2003, and ran successfully for two years. In the transverse field of a decommissioned Large Hadron Collider (LHC) test magnet (9.26 m, 9 T), the CERN Axion Solar Telescope intends to transform axions -that would be produced in the sun- into X-rays with energies of a few keV. The first results from the analysis of the data taken in 2003 show no signature of axions, implying an upper

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limit to the axion-photon coupling $g_{a\gamma} \leq 1.16 \times 10^{-10} \text{ GeV}^{-1}$ at 95% C.L. for $m_a < 0.02 \text{ eV}$, already a factor 100 better than previous searches. In Phase I the twin bores of the magnet were kept in vacuum. In Phase II (due to start in November 2005) the bores of the magnet will be filled with a buffer gas, which will allow CAST to explore the region of higher axion masses.

1. The CAST experiment: motivation, description

CAST [1] is an axion helioscope; it is searching for axions coming from the sun. Axions are hypothetical light pseudoscalar particles. They emerge from the breaking of a symmetry introduced by Peccei-Quinn, a symmetry that proposed an elegant solution to the strong CP-problem [2]. The most interesting property of axions, the two-photon interaction, allows them to transform into photons in the presence of suitable external electric or magnetic fields[3], a conversion known as the Primakoff effect. Consequently, this conversion could take place in the electromagnetic fluctuations of the stellar plasma, making stars continuous sources of axions. The sun is a source of axions of the most interest, being the closest to the earth. At the earth, the expected flux of low-energy axions generated in the sun via the Primakoff effect is $\Phi_a = g_{10}^2 3.67 \times 10^{11} \text{ cm}^{-2} \text{ s}^{-1}$ (where $g_{10} \equiv g_{a\gamma} 10^{10} \text{ GeV}$) and has a distribution in the range of $1 - 10 \text{ keV}$ with a peak at 3 keV and mean energy of $\sim 4.2 \text{ keV}$.

The Primakoff effect also works inversely: the axions generated in the sun by thermal photons, can be re-converted to photons of the X-ray region, if a magnetic field is provided in the laboratory[4]. This is the concept on which CAST is based. In the presence of a magnetic field of intensity B and length L in vacuum, the axion-to-photon conversion probability [4] is calculated as $P_{a \rightarrow \gamma} = (B g_{a\gamma}/2)^2 2L^2 [1 - \cos^2(qL)]/(qL)^2$, where $q = m_a^2/2E_a$ indicates the momentum transfer between the axion and the X-ray photon. The conversion probability is maximum when the axion and photon fields remain in phase over the length of the magnetic field, or else when $qL \leq 1$, in which case the X-ray flux is $\Phi_\gamma = 0.51 \text{ cm}^{-2} \text{ d}^{-1} g_{10}^4 (L/9.26 \text{ m})(B/9 \text{ T})$.

There are two main features that make CAST significantly different from other similar searches. The most important is the strong magnetic field; it is provided by a straight-bore, twin-aperture magnet, originally an LHC test prototype. This magnet reaches 9 T extended at 9.26 m, making CAST the most sensitive of the helioscopes constructed until now. The magnet is sitting in a movable platform which enables it to align with the center of the sun for a period of approximately 100 min twice a day; once during sunrise and another during sunset. Three different types of X-ray detectors have been developed for CAST: looking at axions during the sunset, a Time Projection Chamber is occupying two bores of the magnet, while on the other bores a Micromegas detector and a Charge Coupled Device (CCD) are assigned to the sunrise axions. The CCD is combined with an X-ray focusing mirror system, the second important feature of CAST, which improves greatly the signal-to-noise ratio.

2. First results of CAST

The end of November 2004 signalled the completion of CAST Phase I. The data of the first year of data taking (2003) have been analyzed and are presented here. During that year CAST took data for approximately six months. The data are separated in two sets, one labeled as “tracking data” and the other as “background data”. The tracking data are data taken when the magnet was aligned with the center of the sun, while background data are the data taken in between trackings. The expected signal would be seen as an excess of X-rays appearing only in the tracking data and remaining after the background data are subtracted. The analysis of the data has shown no excess in the spectra of all three detectors. The absence of a signal restricts the value of the axion-photon coupling constant, for axion masses up to $m_a \leq 0.02 \text{ eV}$ to $g_{a\gamma} \leq 1.16 \times 10^{-10} \text{ GeV}^{-1}$ at a 95% confidence level (C.L.) [5]. Figure 1 shows the 95%

exclusion line of CAST, a factor at least 5 more restrictive in comparison to previous solar axion searches.

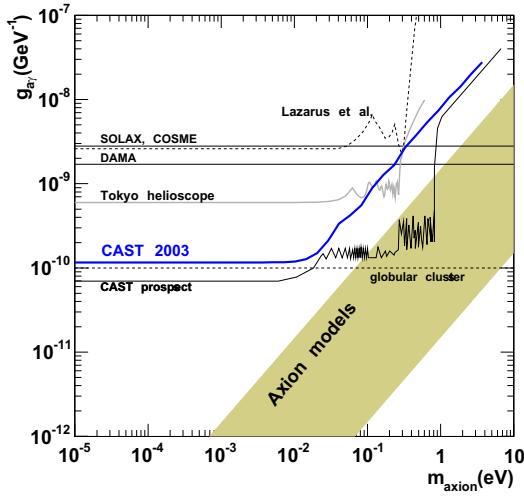


Figure 1. Exclusion limit at 95% C.L. from the CAST data of 2003 compared with other contributions. This limit is comparable to the limit from stellar energy-loss arguments and considerably more restrictive than any previous experiment. The shaded area represents typical theoretical models [5]. The sensitivity CAST is foreseen to reach [1] is also shown.

3. Summary and Prospects

CAST is the most recent and most sensitive of the axion helioscopes. The analysis of only part of the data taken during Phase I has shown no signature of axions. However it has provided the most restrictive (upper) limit on the coupling of axions to photons, of $g_{a\gamma} \leq 1.16 \times 10^{-10} \text{ GeV}^{-1}$ at a 95% C.L. for axion masses of up to 0.02 eV. The analysis of the rest of the data for Phase I is underway and is expected to increase the sensitivity of the experiment, especially after the exploitation of the full potential of the x-ray telescope.

The next step, CAST Phase II, is to fill the magnet bores with a buffer gas (first ${}^4\text{He}$, later ${}^3\text{He}$) which will help restore the coherence –and therefore the sensitivity of the experiment– for higher axion masses (up to ~ 1 eV). In order to be sensitive to different axion masses the gas pressure has to be systematically changed and a gas system has been built for that purpose. In addition, to contain the helium in the isothermal region of the cold bores, cold windows have been installed inside the cryostat. A first run under the new conditions is foreseen in November 2005. Another improvement of the setup, scheduled for the 2006-2007 data taking, is the implementation of x-ray optics for the Micromegas. This upgrade is expected to improve notably the performance of the detector, in combination with the addition of a shielding for the detector, and at the same time, to increase the detection probability of the experiment.

With Phase II CAST will be the first experiment to investigate in the axion mass region the most favourable by axion models.

References

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