THE CAST EXPERIMENT: STATUS AND PERSPECTIVES

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CAST (CERN Axion Solar Telescope) is looking for axions coming from the Sun, using an LHC decommissioned prototype dipole magnet as a converter of axions into detectable x-rays. The experiment started data-taking in 2002 and has used different configurations, keeping the magnet bores under vacuum and using ^{4}He as buffer gas. It has put the most restrictive limits of the axion-to-photon coupling constant of $g_{a\gamma} < 8.8 \times 11^{-11}\,\mathrm{GeV}^{-1}$ for axion masses up to $m_a \sim 0.02\,\mathrm{eV/c^2}$ and $g_{a\gamma} < 2.2 \times 10^{-10}\,\mathrm{GeV}^{-1}$, for masses between $0.02\,\mathrm{eV} < m_a < 0.39\,\mathrm{eV}$. CAST is sensitive for the first time to realistic QCD-axion models at the sub-eV scale. Since 2008, ^{3}He has been used inside the magnet, intending to reach even higher axion masses. Here we present the current status of the experiment as well as a short discussion on the future prospects of the helioscope technique.

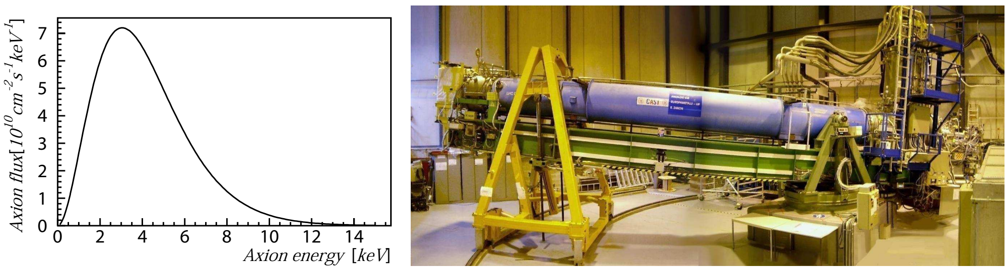
1 Introduction

Axions are hypothetical particles which give an elegant solution to the strong-CP problem. They could have been produced in early stages of the Universe, which makes them good candidates for the Dark Matter. One of the processed they could have been produced is the so-called misalignment (or re-alignment) effect. These relic axions could be the main component of the Cold Dark Matter, if their masses fall in the $10^{-6}\,\mathrm{eV}$ to $10^{-3}\,\mathrm{eV}$ range. Microwave cavity experiments are the most sensitive to these axions, like the Axion Dark Matter Experiment (ADMX)[1], which is scanning this low axion mass range. Axions could also have been thermally produced and therefore could be part of the Hot Dark Matter. In any case their mass should should not exceed 1 eV, in order to be compatible with the latest CMB data.[2]

Axions couple to gluons, and thus couple to nucleons and mix with pions. However the cornerstone of all experimental efforts to look for axions so far, has been their coupling to photons, (present as well in all QCD-axion models). This property allows for an axion-to-photon conversion (and viceversa) in the presence of an electromagnetic field, also known as the Primakoff effect. Therefore, axions could be produced in the core of stars like the Sun, through the conversion of the blackbody photons in the solar plasma. In 1983, Sikivie [3] suggested that the inverse effect could take place; if we provided the axions with an appropriate magnetic field as they are streaming out of the Sun, so as to reconvert them to photons, which should be easily detectable. This introduced the *helioscope* concept. CAST has been the third helioscope built so far and the most sensitive one.[4] It was preceded by the pioneering experiment of the Rochester, Brookhaven, Florida collaboration [5,6] and by Sumico [7].

2 The CERN Axion Solar Telescope

The CERN Axion Solar Telescope (CAST) is looking for axions produced in the center of the Sun (Figure 1(b)). In order to re-convert the axions to photons, it is using a decommissioned LHC prototype dipole magnet which can reach 9 T along its 10 m-length. The magnet has two bores, with an aperture of 14.5 cm^2 each, and is sitting on a moving platform allowing it to align itself with the center of the Sun for approximately 1.5 h during sunrise and 1.5 h during sunset. The energy range of the expected signal is between 1 and 10 keV (Figure 1(a)), and its rate is dependent on the very weak axion-photon coupling. Therefore, low background x-ray detectors are necessary in order to have a high sensitivity.



(a) (b)

Figure 1: a) The solar axion flux as expected on the earth. It spans between 1 and 10 keV with a mean energy of 4.2 keV. b) A photograph of the CAST Experiment.

Phase I of the physics program of CAST started in 2002, when data were taken keeping the magnet bores under vacuum. At the time, three different types of detectors were covering the ends of the magnet looking for axions. A multiwire TPC was occupying the two bores looking for 'sunset' axions,[8] while a micromegas detector[9] and a CCD were looking for 'sunrise' axions. The CCD is coupled to an x-ray focusing device, forming part of an x-ray telescope prepared for x-ray astronomy space missions, and which increases significantly the signal-to-background ratio.[10] In the absence of an axion signal, the experiment published the most restrictive limit on the axion-to-photon coupling constant to $g_{a\gamma} < 8.8\times 11^{-11} GeV^{-1}$ for axion masses up to $m_a \sim 0.02\, eV/c^2$.[11]

In 2005, the experiment passed to its second phase, when a buffer gas was introduced in appropriate steps inside the magnet bores in order to restore coherence and therefore sensitivity for specific axion masses, higher than those reached in the previous configuration. During 2006, ^4He was used as buffer gas and it took approximately 160 discrete pressure steps for CAST to scan the axion-mass region up to $0.39\, eV/c^2$, supplying an upper limit for the axion-to-photon coupling constant of $g_{a\gamma} < 2.2\times 10^{-10} GeV^{-1}$.[12] CAST entered for the first time in the QCD-favoured axion model band. Because ^4He condensates in higher pressures (and thus masses), in order to continue with the scanning of higher masses ^3He had to be employed. During 2007 the gas system was being adapted to using the new gas. At the same time, several upgrades of different parts of the setup were made. One of them regarded the detectors: the TPC was replaced by two, new generation, micromegas detectors, which have shown very low background levels.[13]

Data-taking with ^3He started in 2008. Until the end of 2009, CAST had scanned the axion masses up to $0.85 eV/c^2$. Recently the experiment restarted data taking, aiming at reaching $m_a \sim 1.1 eV/c^2$ by the end of 2010. In Figure 2 the results of the experiment so far are summarised.

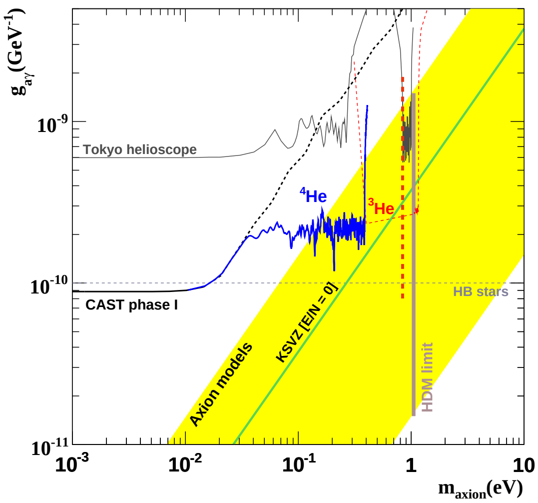


Figure 2: A combined exclusion line at 95% CL with CAST data both of phase I (black line), [11] when the magnet bores were in vacuum and the ^{4}He run (red line).[12] For comparison, other laboratory limits such as the Tokyo helioscope [?,?] as well as the cosmological upper limit on the axion. [2] The yellow-shaded area indicates the region of theoretical preference for QCD axion models. The thin dashed line in red, indicates the sensitivity expected to be reached in the ^{3}He phase. The thick vertical dashed line in orange indicates approximately the progress of CAST data taking with ^{3}He until the end of 2009.

3 Towards a new generation of helioscopes

CAST is the most sensitive helioscope built so far. The main advantages it presents with respect to the previous two are its powerful magnet and the x-ray telescope system. The Collaboration has already started active discussions regarding the future generation of axion helioscopes. Eq. 1

$$g \propto (BL)^{\frac{1}{2}} A^{\frac{1}{4}} (b^{\frac{1}{8}}/t^{\frac{1}{8}}) \tag{1}$$

shows the parameters on which the sensitivity of such devices depends. It can be easily seen that the domains which one could aim to improve are three: the exposure time, considering, for example, a platform that could increase the movement span of the magnet; detectors with zero background and the use of focusing devices, in order to enhance signal sensitivity and efficiency; and a new, powerful magnet with a big aperture. From the contribution of the three parameters in the equation, the effect of a new magnet is evidently the strongest one.

CAST has been actively discussing the near, middle and long-term future, based on the present and near-future technology innovations regarding magnets. An effort has been invested on the understanding of the current detectors used in the experiment, which have shown background levels compatible with zero, as well as the possibility to employ another x-ray focusing device apart from the x-ray telescope. The discussions so far point at encouraging prospects, as shown in figure 3 [a]. Moreover, the combination of Helioscope experiments and Dark matter axion searches (namely ADMX), would lead to the exploration of large parts of the model region for QCD axions in the coming decade.

4 Conclusions

CAST is the most sensitive axion helioscope built so far. Although axions may still elude direct detection, the results of the experiment have put the most stringent constraints on the coupling

[a] This has been discussed in detail in the presentation of T. Papaevangelou in [14]

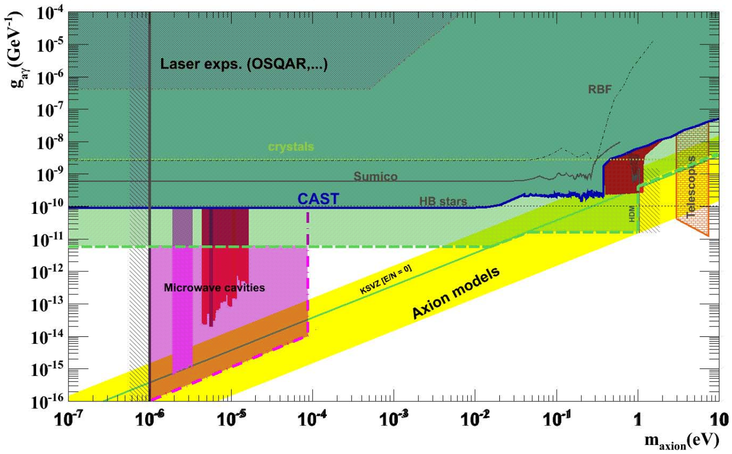


Figure 3: A global view of the Axion and axion-like particles map. The current limits set by CAST and other experiments (helioscopes, laser experiments, microwave cavity experiments) are shown. The limits of the mass set by the CMB data, astrophysical limits (HB stars) and cosmological limits (Overclosure) are presented as well. Also depicted are the prospects of the next generation helioscopes (dashed green line and gren-shaded area), a simulation result of the prospects for a new magnet in the near future, with the current detectors of CAST. The sensitivity is enhanced by one order of magnitude over the whole mass range, entering well in the yellow band of the most favoured axion models. Furthermore, the future of the microwave cavity experiments (dashed purple line and purple-shaded area). One can see that in the next decade the bulk of the yellow area, denoting the region of theoretical preference for axion models, could be explored.

constant of axions to photons, reaching for the first time sensitivities at the QCD-favoured axion models level. Currently the experiment it taking data at the higher end of axion rest masses, with the aim to cover the range up to $1.02\,\mathrm{eV/c^2}$. At the same time, CAST is exploring the possibility to bring build a helioscope of the next generation, with the help of a powerful and higher aperture magnet, which would push the sensitivity of the experiment at least one order of magnitude.

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Dark Energy Probes