IAXO-the Future Axion Helioscope

B. Lakić[1], *F. T. Avignone*[2], *M. Betz*[3], *P. Brax*[4], *P. Brun*[5], *G. Cantatore*[6], *J. M. Carmona*[7], *G. P. Carosi*[8], *F. Caspers*[3], *S. Caspi*[9], *S. A. Cetin*[10], *D. Chelouche*[11], *F. E. Christensen*[12], *A. Dael*[5], *T. Dafni*[7], *M. Davenport*[3], *A. V. Derbin*[13], *K. Desch*[14], *A. Diago*[7], *B. Döbrich*[15], *I. Dratchnev*[13], *A. Dudarev*[3], *C. Eleftheriadis*[16], *G. Fanourakis*[17], *E. Ferrer-Ribas*[5], *J. Galán*[5], *J. A. García*[7], *J. G. Garza*[7], *T. Geralis*[17], *B. Gimeno*[18], *I. Giomataris*[5], *S. Gninenko*[19], *H. Gómez*[7], *D. González-Díaz*[7], *E. Guendelman*[20], *C. J. Hailey*[21], *T. Hiramatsu*[22], *D. H. H. Hoffmann*[23], *D. Horns*[24], *F. J. Iguaz*[7], *I. G. Irastorza*[7], *J. Isern*[25], *K. Imai*[26], *A. C. Jakobsen*[12], *J. Jaeckel*[27], *K. Jakovčić*[1], *J. Kaminski*[14], *M. Kawasaki*[28], *M. Karuza*[29], *M. Krčmar*[1], *K. Kousouris*[3], *C. Krieger*[14], *O. Limousin*[5], *A. Lindner*[15], *A. Liolios*[16], *G. Luzón*[7], *S. Matsuki*[30], *V. N. Muratova*[13], *C. Nones*[5], *I. Ortega*[7], *T. Papaevangelou*[5], *M. J. Pivovaroff*[8], *G. Raffelt*[31], *J. Redondo*[31], *A. Ringwald*[15], *S. Russenschuck*[3], *J. Ruz*[8], *K. Saikawa*[32], *I. Savvidis*[16], *T. Sekiguchi*[28], *Y. K. Semertzidis*[33], *I. Shilon*[3], *P. Sikivie*[34], *H. Silva*[3], *H. ten Kate*[3], *A. Tomas*[7], *S. Troitsky*[19], *T. Vafeiadis*[3], *K. van Bibber*[35], *P. Vedrine*[5], *J. A. Villar*[7], *J. K. Vogel*[8], *L. Walckiers*[3], *A. Weltman*[36], *W. Wester*[37], *S. C. Yildiz*[10], *K. Zioutas*[38] *(IAXO Collaboration)*

[1]Rudjer Bošković Institute, Zagreb, Croatia
[2]Physics Department, University of South Carolina, Columbia, SC, USA
[3]European Organization for Nuclear Research (CERN), Genève, Switzerland
[4]IPHT, Centre d'Études de Saclay (CEA-Saclay), Gif-sur-Yvette, France
[5]CEA Irfu, Centre de Saclay, Gif-sur-Yvette, France
[6]INFN, Sezione di Trieste and Università di Trieste, Trieste, Italy
[7]Laboratorio de Física Nuclear y Altas Energías, Universidad de Zaragoza, Zaragoza, Spain
[8]Lawrence Livermore National Laboratory, Livermore, CA, USA
[9]Lawrence Berkley National Laboratory, USA
[10]Dogus University, Istanbul, Turkey
[11]Physics Department, University of Haifa, Haifa, Israel
[12]Technical University of Denmark, DTU Space Kgs. Lyngby, Denmark
[13]St. Petersburg Nuclear Physics Institute, St. Petersburg, Russia
[14]Physikalisches Institut der Universität Bonn, Bonn, Germany
[15]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany
[16]Aristotle University of Thessaloniki, Thessaloniki, Greece
[17]National Center for Scientific Research *Demokritos*, Athens, Greece
[18]Instituto de Ciencias de las Materiales, Universidad de Valencia, Valencia, Spain
[19]Institute for Nuclear Research (INR), Russian Academy of Sciences, Moscow, Russia
[20]Physics department, Ben Gurion University, Beer Sheva, Israel
[21]Columbia Astrophysics Laboratory, New York, USA
[22]Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan
[23]Technische Universität Darmstadt, IKP, Darmstadt, Germany
[24]Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
[25]Institut de Ciències de l'Espai (CSIC-IEEC), Facultat de Ciències, Bellaterra, Spain
[26]Advanced Sci. Research Center, Japan Atomic En. Agency, Tokai-mura, Ibaraki-ken, Japan
[27]Institut für theoretische Physik, Universität Heidelberg, Heidelberg, Germany

[28]Institute for Cosmic Ray Research, University of Tokyo, Tokyo, Japan
[29]University of Rijeka, Rijeka, Croatia
[30]Research Center for Low Temperature and Material Sciences, Kyoto University, Kyoto, Japan
[31]Max-Planck-Institut für Physik, Munich, Germany
[32]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[33]Physics Department, Brookhaven National Lab, Upton, NY, USA
[34]Department of Physics, University of Florida, Gainesville, FL, USA
[35]Department of Nuclear Engineering, University of California Berkley, Berkley, CA, USA
[36]ACGC, Department of Math. and Applied Math., University of Cape Town, South Africa
[37]Fermi National Accelerator Laboratory, Batavia, IL, USA
[38]Physics Department, University of Patras, Patras, Greece

DOI: http://dx.doi.org/10.3204/DESY-PROC-2013-04/lakic_biljana_IAXO

International Axion Observatory (IAXO) is a new generation axion helioscope aiming to search for axions and axion-like particles with a sensitivity to the axion-photon coupling that is 1 to 1.5 orders of magnitude beyond the one achieved by currently the most sensitive axion helioscope, CAST. IAXO relies on large improvements in magnetic field volume, X-ray focusing optics and detector backgrounds with respect to CAST. Additional IAXO searches would include electron-coupled axions, relic axions, and other more generic axion-like particles.

1 Introduction

Axions are neutral pseudoscalar particles that may solve the strong CP problem. They arise as pseudo-Nambu-Goldstone bosons of the $U(1)$ Peccei-Quinn symmetry [1] which is spontaneously broken at a large energy scale. The spontaneous breaking of other global symmetries is predicted in many extensions of the standard model (including string theory) and can give rise to light axion-like scalar or pseudoscalar particles, called ALPs. Axions and ALPs are candidates for the dark matter (DM) of the universe and can explain a variety of astrophysical observations.

Most of the axion experimental searches are based on the axion interaction with two photons. As a consequence of this interaction, axions could transform into photons and vice versa in external electric and magnetic fields. A promising experimental approach is based on the axion helioscope technique [2] where a dipole magnet is oriented towards the Sun. Axions could be produced in the solar plasma by converting thermal photons in the Coulomb fields of nuclei and electrons - the Primakoff process, and back-converted into photons in a laboratory transverse magnetic field.

Currently the most sensitive heliscope experiment CAST [3, 4, 5, 6] has been taking data since 2003. No signal over background has been observed so far and CAST set the best experimental limit on the axion-photon coupling constant $g_{a\gamma}$ over a broad range of axion masses. IAXO (International AXion Observatory) is a new generation axion helioscope [7], currently at the level of the Conceptual Design. IAXO relies on known technologies, there is no need for development. It will also benefit from the expertise and knowledge gained from the successful operation of CAST.

2 Experimental setup

IAXO concept relies on a dedicated magnet capable to track the Sun for about 12 hours each day, focusing X-ray optics to minimize detector area, and low background X-ray detectors optimized for operation in $0.5 - 10$ keV energy range.

The magnet, inspired by the toroidal ATLAS-like magnet geometry, is being designed at CERN [8]. The new toroid will have eight, 60 cm diameter and 21 m long, magnet bores at room temperature. It is designed to realize a peak magnetic field of 5.4 T. The magnet system will be decoupled from the optical system, which greatly simplifies the system integration. The magnet design opens the way for the sensitivity improvement, with respect to CAST, mainly through a large cross-sectional area.

Each of the eight magnet bores will be equipped with X-ray optics. CAST has successfully used optics, but only for one magnet bore of area ~ 15 cm^2. IAXO relies on focusing from much larger bore areas of $\sim$ m^2 down to spot of ~ 0.2 cm^2. The challenge is the availability of cost-effective X-ray optics of the required size. For IAXO, the baseline fabrication approach is segmented, slumped glass optics. This technology has been successfully used, most recently for the NuSTAR satellite mission.

The baseline technology for the low background detectors are small gaseous detectors with a pixelated Micromegas readout, manufactured with the microbulk technique. This kind of detector has already been used in CAST. The latest generation of Micromegas detecors in CAST are acheiving background levels of around 10^{-6} counts keV^{-1} cm^{-2} s^{-1}, a factor of more than 100 better than the levels at the beginning of CAST data taking. The goal for IAXO is to reduce the background level down to 10^{-7} counts keV^{-1} cm^{-2} s^{-1} or even lower.

3 Expected sensitivity

The primary physics goal of IAXO will be to search for axions and ALPs produced in the solar core via the Primakoff conversion of the solar plasma photons. The goal is to achieve 5 orders of magnitude better sensitivity than CAST, which translates into a factor of about 20 in terms of the axion-photon coupling constant $g_{a\gamma}$. That is, IAXO will reach the few $\times 10^{-12}$ GeV^{-1} level for a wide range of axion masses up to about 0.25 eV. Since IAXO will cover a big part of the unexplored parameter space, it has potential for the discovery of axions and ALPs. At high masses, the experiment would explore a range of realistic axion models related to the Peccei-Quinn solution to the strong CP problem. At low masses (below 10^{-7} eV), IAXO would test the hypothesis in which ALPs explain the transparency of the universe to very high energy photons [9]. Most of the region at reach by IAXO contains possible DM candidates. Figure 1 shows the expected IAXO sensitivity on $g_{a\gamma}$ as a function of the axion mass.

Another important physics goal for IAXO will be to search for solar axions produced in the processes based on the axion-electron coupling g_{ae}. An astrophysical observation shows that axions with g_{ae} of few $\times 10^{-13}$ could solve the anomalous cooling observed in white dwarfs [11]. IAXO is the first axion helioscope with sufficient sensitivity to g_{ae} to test this hypothesis.

Additional physics cases include searches for other proposed particles at the low energy frontier, like hidden photons or chameleons [12]. Also, the IAXO magnet has been designed to easily accomodate new equipment (e.g., microwave cavities or antennas). This provides an intriguing possibility to search in parallel for solar axions and also for relic axions in the galactic halo that could have been produced in the early universe.

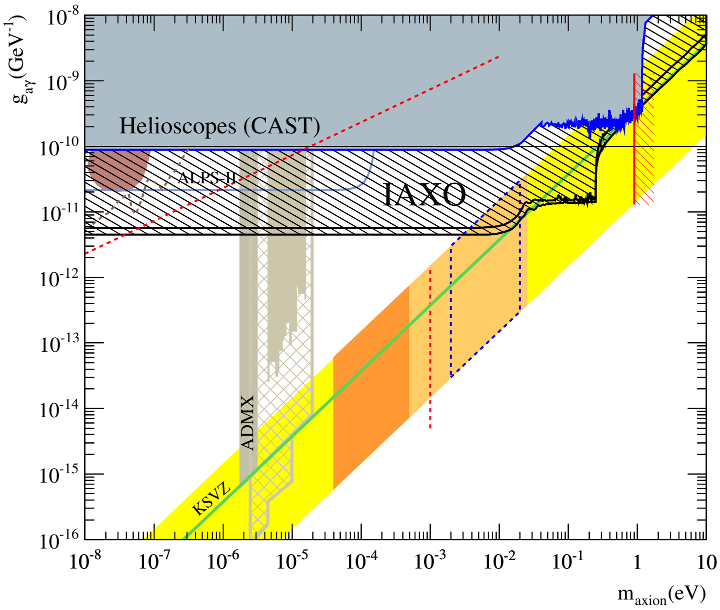

Figure 1: Expected IAXO sensitivity on $g_{a\gamma}$ as a function of m_a, compared with current bounds (solid) and future prospects (dashed) of other experiments (CAST, ADMX, ALPS-II). The region below the red dashed line is viable ALP DM parameter space. The region at low m_a above the dashed grey line is the one invoked in the context of the transparency of the universe while the solid brown region is excluded by H.E.S.S. data [10]. The yellow band represents the range of realistic axion models where the green line refers to the benchmark KSVZ model.

Acknowledgments

We acknowledge support from MSES (Croatia) under grant no. 098-0982887-2872.

References

[1] R. D. Peccei, Lect. Notes Phys. **741**, 3 (2008) [hep-ph/0607268].

[2] P. Sikivie, Phys. Rev. Lett. **51**, 1415 (1983) [Erratum-ibid. **52**, 695 (1984)].

[3] K. Zioutas *et al.* [CAST Collaboration], Phys. Rev. Lett. **94**, 121301 (2005) [hep-ex/0411033].

[4] S. Andriamonje *et al.* [CAST Collaboration], JCAP **0704**, 010 (2007) [hep-ex/0702006].

[5] E. Arik *et al.* [CAST Collaboration], JCAP **0902**, 008 (2009) [arXiv:0810.4482 [hep-ex]].

[6] M. Arik *et al.* [CAST Collaboration], Phys. Rev. Lett. **107**, 261302 (2011) [arXiv:1106.3919 [hep-ex]].

[7] I. G. Irastorza *et al.*, JCAP **1106**, 013 (2011) [arXiv:1103.5334 [hep-ex]].

[8] I. Shilon, A. Dudarev, H. Silva, U. Wagner and H. H. J. t. Kate, arXiv:1308.2526 [physics.ins-det].

[9] M. Meyer, D. Horns and M. Raue, Phys. Rev. D **87**, 035027 (2013) [arXiv:1302.1208 [astro-ph.HE]].

[10] P. Brun, D. Wouters (for the H.E.S.S. collaboration), proceedings of the 33rd ICRC, 2013, Rio de Janeiro

[11] J. Isern *et al.*, Astronomy and Astrophysics **512**, A86 (2010) [arXiv:1001.5248 [astro-ph.SR]].

[12] J. Jaeckel and A. Ringwald, Ann. Rev. Nucl. Part. Sci. **60**, 405 (2010) [arXiv:1002.0329 [hep-ph]].