The International Axion Observatory (IAXO)

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On behalf of the IAXO collaboration
Overview

- Solar Axion Searches
- The International Axion Observatory (IAXO)
  - Magnet
  - X-ray optics for IAXO
  - Low-background detectors for IAXO
  - Prototype Testing
- IAXO Prospects
  - Sensitivity Prospects
  - Collaboration and Schedule
- Conclusions

Irastorza et al. JCAP 06 (2011) 013
Solar Axion Searches

- Astrophysical hints for ALPs
- CDM "anthropic window"
- CDM "classical window" Vacuum mis. + defects
- CDM Defects dominate hep-ph/1202-5851
- Axions as HDM
- White Dwarfs
IAXO – The new generation helioscope

→ 1st generation: Brookhaven Experiment
→ 2nd generation: Tokyo Helioscope
→ 3rd generation: CAST

- IAXO = 4th generation axion helioscope
- Based on the more than a decade CAST experience!!
- CAST is established as a reference result in experimental axion physics
- No other technique can realistically improve CAST in such a wide mass range.
- No miracle needed! IAXO builds on CAST innovations to improve the helioscope technique…
IAXO – How to improve sensitivity

\[ g_{\alpha\gamma}^4 \propto b^{1/2} \varepsilon^{-1} \times s^{1/2} \varepsilon_0^{-1} \times (BL)^{-2} A^{-1} \times t^{-1/2} \]

- **detectors**
  - \( b = \) background
  - \( \varepsilon = \) efficiency

- **optics**
  - \( s = \) spot size
  - \( \varepsilon_0 = \) efficiency

- **magnet**
  - \( B = \) magnetic field
  - \( L = \) magnet length
  - \( A = \) cross-sectional area

- **exposure**
  - \( t = \) time
# IAXO – How to improve sensitivity

## Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>CAST-I</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
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<tr>
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IAXO – The new generation helioscope
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Randy Hill, LLNL
IAXO – The new generation helioscope

Randy Hill, LLNL
Magnet for IAXO

- CAST has one of the best existing magnets than one can “recycle” for axion physics (LHC test magnet)
- Only way to make a step further is to build a new magnet, specifically for axions
- Work ongoing, but best option up to now seems to be a **toroidal configuration** (similar to ATLAS):
  - Much bigger aperture than CAST: ~0.5-1 m per bore
  - Relatively light (no iron yoke)
  - Bores possibly at room temperature

→ A magnet that looks like a detector magnet with the behavior of an accelerator magnet (little stress, strong field,...)
Magnet for IAXO

- Current IAXO design favors bores between coils
  - FOM
  - More flexibility
- Scenario 2 conservative, better than scenario 3 is possible → Work on further optimization ongoing

- Total Radius = 2 m
- Bore diameter = 600 mm
- Number of bores = 8
- Peak field = 6 T
- Stored Energy = 500 MJ
- MFOM = 300
X-ray Optics

- X-ray community put lots of money and effort into development of reflective x-ray optics:
  - HighTech, expensive, unique
  - Excellent imaging capabilities

- Innovations include:
  - Nested designs (i.e. Wolter telescopes)
  - Low-cost substrates
  - Highly reflective coatings

- IAXO optics requirements:
  - Exquisite imaging not needed
  - Need to cover large area:
    → IAXO requires dedicated but cost-effective optics
  - Good throughput (0.3 – 0.5)
  - Small focal point (~1 cm²)
X-ray Optics

- **Most favored IAXO solution:** thermally-formed glass substrates optics
  - Successfully used for NuSTAR
  - Leverage of existing infrastructure → Minimize costs & risks
  - Allows for optimization of the reflective coating (multilayers or thin metal films) of each layer

- **NuSTAR launched 13 June 2012**
  - Specialized tooling to mirror production and telescope assembly now available
  - Hardware can be easily configured to make optics with a variety of designs and sizes

- **Key institutes of NuSTAR optics team**
  Columbia, DTU Space, LLNL → All in IAXO!

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W Craig et al., Proc SPIE, 8147, (2011)
Low-background detectors

- **Goal**
  - Micromegas detectors with at least $10^{-7}$ cts/(keV×cm$^2$×s)
  - If possible go down to $10^{-8}$ cts/(keV×cm$^2$×s)

- **Work ongoing**
  - Experimental tests with current micromegas detectors at CERN, Saclay & Zaragoza
  - Underground setup at Canfranc
  - Simulation works to build up a background model
  - Design a new detector with improvements implemented
Low-background detectors

- **Latest Micromegas:** Background improved by factor 20
  - Shielding
  - Radiopurity & new manufacturing technique (microbulk readouts)
  - More powerful offline cuts

- **Tests in controlled conditions underground at Canfranc:**
  - Better shielding coverage
  - Thicker shielding

### History of background improvement of Micromegas detectors at CAST

- Backgrounds around $2 \times 10^{-7}$ cts/keV/s/cm$^2$ with improved shielding
  - ~30× better than CAST

Recent upgrade of shielding at CAST improves background further towards IAXO!
Pathfinder detector+optics for IAXO

- Small x-ray optics
  - Fabricated purposely using thermally-formed glass substrates (NuSTAR-like)

- Micromegas low background detector:
  - Apply lessons learned from R&D: compactness, better shielding, radiopurity,…
  - Aim for background of $10^{-7} \text{ cts/(keV}\times\text{cm}^2\times\text{s}}$ or lower

- Collaboration of key groups:
  Saclay, Zaragoza, LLNL, DTU, Columbia

  → Operation at CAST in 2013
  → Tests of techniques and acquisition of know-how for IAXO
IAXO sensitivity prospects

- **Hadronic axion models**
  - Improvements of **factor 8-30** in $g_{a\gamma}$
    $(4 \times 10^3 - 1 \times 10^6$ in signal strength!!)
  - QCD axions at masses of $\sim$meV seem out of reach even for an improved axion helioscope...

  But...

- **Non-hadronic axion models** provide extra axion emission from the Sun through axion-electron Compton and bremsstrahlung processes

IAXO could improve current CAST sensitivity to non-hadronic axions by about **3 orders of magnitude**
IAXO sensitivity prospects

Exploration of very extended QCD axion region

Laser exps.

Solar (CAST)

Microwave cavities (ADMX)

Astrophysical hints for ALPs

ALP hints

IAXO

IAXO complements ADMX measurements

Axion models
- Proto-collaboration formed
  - Most CAST groups
  - New groups + extended expertise (magnet, optics,…)
  - Open for interested groups
- Conceptual design report in preparation, LoI to be submitted to CERN soon
- 4th generation helioscope supported in latest draft of ASPERA roadmap 2011

Notional plan

- **Phase III**
- **Phase IV**
- **Phase V ??**
- **detector + optic R&D**
- **Build IAXO**
- **Commission IAXO**
- **IAXO science operations**
Conclusions

- **CAST** is established as a reference result in experimental axion physics
  - CAST PRL2004 most cited experimental paper in axion physics
  - Expertise gathered in magnet, optics, low background detectors, gas systems
  - No other technique can realistically improve CAST in such wide mass range.

- **IAXO** is the new generation helioscope (4th generation) to search for axions
  - Good prospects to improve CAST by 1-1.5 orders of magnitude in sensitivity
  - First solid steps towards conceptual design
  - Together IAXO and haloscopes (ADMX) could explore a big part of the QCD axion model region in the next decade
  - Potential for other physics (White Dwarfs, ALPs, …)
Thank you!