Physics case, prospects and status of the International AXion Observatory IAXO

Igor G. Irastorza (U. Zaragoza)
on behalf of the IAXO collaboration
Beyond Colliders, CERN, September 7th 2016
Why to search for axions?

• Most compelling solution to the **Strong CP problem** of the SM

• Axion-like particles (ALPs) **predicted by many extensions** of the SM (e.g. string theory)

• Axions, like WIMPs, may **solve the DM problem for free.** (i.e. not *ad hoc* solution to DM)

• **Astrophysical hints** for axion/ALPs?
  – Transparency of the Universe to UHE gammas
  – Anomalous cooling of different types of star

• Relevant axion/ALP parameter space at **reach of current and near-future experiments**

• Still too little experimental effort devoted to axions when compared to WIMPs
IAXO in the axion landscape

<table>
<thead>
<tr>
<th>Source</th>
<th>Experiments</th>
<th>Model &amp; Cosmology dependency</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relic axions</td>
<td>ADMX, ADMX-HF, Casper, CAPP, ...</td>
<td>High</td>
<td>New ideas emerging, Active R&amp;D going on,...</td>
</tr>
<tr>
<td>Lab axions</td>
<td>ALPS, OSQAR, fifth force exps,...</td>
<td>Very low</td>
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<tr>
<td>Solar axions</td>
<td>SUMICO, CAST, IAXO</td>
<td>Low</td>
<td>Ready for large scale experiment</td>
</tr>
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</table>

- Helioscopes → do not rely on the axion being the dominant DM component. Solar axion emission robust prediction
- Helioscopes → No R&D needed. Technology mature enough for a large scale experiment (IAXO)
- Large complementarity with other detection strategies
Axion/ALP parameter space

Laboratory experiments (ALPS)

Helioscopes (CAST)

Transparency of the Universe

Stellar cooling hints

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Solar Axions

- Solar axions produced by photon-to-axion conversion of the solar plasma photons in the solar core

“Primakoff” Solar axion flux at Earth

*JCAP 04(2007)010*
Solar Axions

- Solar axions produced by photon-to-axion conversion of the solar plasma photons in the solar core

* if the axion couples with the electron ($g_{ae}$) (non hadronic axion)

Non-hadronic “ABC” Solar axion flux at Earth

$JCAP\ 1312\ 008$
Helioscopes

Axion helioscope concept
P. Sikivie, 1983

(use of buffer gas)

\[
P_{a\gamma} = 2.6 \times 10^{-17} \left( \frac{B}{10 \, T} \right)^2 \left( \frac{L}{10 \, m} \right)^2 \left( g_{a\gamma} \times 10^{10} \, \text{GeV} \right)^2 \mathcal{F}
\]
CAST experiment @ CERN

- Decommissioned LHC test magnet (L=10m, B=9 T)
- Moving platform ±8°V ±40°H (to allow up to 50 days / year of alignment)
- 4 magnet bores to look for X rays
- 2 X ray telescopes to increase signal/noise ratio.
IAXO – Concept


4+ orders of magnitude better SNR than CAST (JCAP 1106:013)
IAXO – Conceptual Design

- Large toroidal 8-coil magnet $L \approx 20$ m
- 8 bores: 600 mm diameter each
- 8 x-ray telescopes + 8 detection systems
- Rotating platform with services
IAXO technologies – Baseline

**IAXO magnet**
- Superconducting “detector” magnet.
- Toroidal geometry (8 coils)
- Based on ATLAS toroid technical solutions.
- CERN+CEA expertise
- 8 bores / 20 m long / 60 cm Ø per bore

**Baseline developed at:**
- IAXO Letter of Intent: CERN-SPSC-2013-022

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**IAXO telescopes**
- Slumped glass technology with multilayers
- Cost-effective to cover large areas
- Based on NuSTAR developments
- Focal length ~5 m
- 60-70% efficiency
- LLNL+UC+DTU + MIT + INAF
IAXO technologies – Baseline

**IAXO detectors**
- **Micromegas** gaseous detectors
- Radiopure components + shielding
- Discrimination from event topology in gas
- Long trajectory in CAST
- Zaragoza + CEA + Bonn + others expertise

Optics+detector IAXO pathfinder system (in operation in CAST during 2014-5)

**IAXO detectors**

- **Ingrid detectors**
  - Better threshold
  - U. Bonn

**MMC (Magnetic Metallic Calorimeters)**
- TES (Transition Edge Sensors)
  - Very good E resolution & threshold
  - Heidelberg + CEA + CNSMS

**Low noise CCDs**

- Solar axion spectroscopy: Axion-electron ABC spectrum
- Axion mass determination

Calibration photons (source 14 m away) focused onto the Micromegas

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Few meV scale QCD axion accessible to IAXO & anomaly cooling hints

Transparency ALP hints accessible to IAXO & ALPS-II

Axion/ALP parameter space

Helioscopes (CAST)

IAXO

ALPS-II

Haloscopes

ALP CDM

KSVZ

ADMX

m_{axion}(eV)
Axion-electron coupling

ABC-produced solar axions

Sensitive to $g_{ae}$ values down to $\sim 10^{-13}$

And more…
- Dark Matter Axions (→ use of IAXO magnet with cavities / RF antennas)
- ALPs from Dark Radiation
- ALPs from nearby Supernova (connection with SNEWS) → MeV photon detector at the other end
- …
IAXO status of project

• 2011: First studies concluded (JCAP 1106:013,2011)
  – Most activity carried out up to now ancillary to other group’s projects (e.g. CAST)
• August 2013: Letter of Intent submitted to the CERN SPSC
  – LoI: [CERN-SPSC-2013-022]
  – Presentation in the open session in October 2013:
• January 2014: Positive recommendations from SPSC.
  – Acknowledge physics case + encourage proceed to TDR

• 2014-15: Transition phase towards TDR (technical design)
  – Some IAXO preparatory activity already going on as part of CAST near term program: IAXO pathfinder system in CAST in 2014-15
  – Preparation of a MoU to carry out TDR work.
  – Strengthen collaboration, awareness actions, meetings, coordinated funding applications
  – First discussion on long-term plan to construction
TDR in progress

- **IAXO-T0**: demonstration coil magnet
- **IAXO-X0**: prototype x-ray optics
- **IAXO-D0**: prototype low background detector setup testing different technologies for detector
- Studies to refine IAXO physics case
- Additional physics potential
- Site studies
- Consolidate and structure collaboration
IAXO proto-collaboration

- Big effort to strengthen collaboration → large consortium involved in a number of funding applications, covering all TDR needs

(*) Only shown groups for which formal activity is ongoing or under discussion/preparation. Potential interest in more groups than shown.
Conclusions

- **IAXO**: best use of technologies (magnet, optics, detectors) and past trajectory of CAST at CERN
- **IAXO** will probe deep into unexplored axion+ALP parameter space:
  - QCD axions at the few meV scale → not at reach of any other technique
  - ALPs at the $g_{a\gamma}\sim10^{-12}$ GeV⁻¹ scale
  - ALPs at the $g_{ae}\sim10^{-13}$ scale
- **IAXO** as a generic “axion/ALP facility”

- First steps towards TDR after the positive recommendation from CERN SPSC.
- Large community now endorsing the project.
- Longer-term strategy towards construction under discussion. Site: CERN but also DESY or LNF
- Looking forward to Study Group process
Backup slides...
An ALP with $g_{a\gamma} \sim 10^{-11-12}$ GeV$^{-1}$

- Well beyond current upper bounds on the $g_{a\gamma}$ coupling (CAST & HB stars $\sim 10^{-10}$ GeV$^{-1}$)
- String theory ALPs
- Invoked to explain the anomalous transparency of the Universe to UHE gammas
- Could explain some anomalous stellar cooling observations
The multi-meV axion

- Is compatible with all current axion bounds.
- Is invoked in several anomalous stellar cooling scenarios
- Can be the cold DM in some models
  - with NDW>1 and bias term to break the discrete symmetry (Kawasaki et al. PRD91 (2015), Ringwald et al. arXiv:1512.06436)
  - or it can be a subdominant DM component
- Very hard to detect (→ IAXO!)
- SN axion background
  - Raffelt et al. PRD84 (11)
Astrophysical hints for axions

- Gama ray telescopes like MAGIC or HESS observe HE photons from very distant sources...

\[ g_{a\gamma} \sim 10^{-12} - 10^{-10} \text{ GeV}^{-1} \]

\[ m_a \lesssim 10^{-10 - 7} \text{ eV} \]
Astrophysical hints for axions (II)

- Most stellar systems seem to cool down faster than expected.
- Presence of axions/ALPs offer a good joint explanation (Giannotti et al. JCAP05(2016)057 [arXiv:1512.08108])
- Parameters at reach of IAXO

\[
\begin{align*}
\Gamma_{g\gamma} & \quad \text{HB} \quad \text{RG} \\
& \quad \text{WDLF (M_{\text{bol}}\sim9)} \\
& \quad \text{PG 1351} \quad \text{R 548} \quad \text{G117–B15A} \\
\Gamma_{g\epsilon} & \quad \text{NS}
\end{align*}
\]

\[\Delta L/L_{\text{st}}\]

- Ayala et. al. (2014), Straniero (proc. of XI Patras Workshop)
- Viaux et. al. (2013), Arceo-Daz et. al. (2015)
- Bertolami (2014)
- Corsico et. al., (2012)
- Kepler et. al., (1991) + many others
- Shternin et. al. (2011)
Buffer gas for higher masses

Coherence condition \((qL \ll 1)\) is recovered for a narrow mass range around \(m_\gamma\)

\[
|q| = \frac{m_a^2 - m_\gamma^2}{2E}
\]

\[m_\gamma \approx \sqrt{\frac{4\pi\alpha N_e}{m_e}} = 28.9 \sqrt{\frac{Z}{A\rho}} \text{ eV}\]

\(N_e\): number of electrons/cm\(^3\)
\(r\): gas density (g/cm\(^3\))

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CAST results (solar axions)

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003 – 2004</td>
<td>CAST phase I</td>
</tr>
<tr>
<td></td>
<td>• vacuum in the magnet bores</td>
</tr>
<tr>
<td>2006</td>
<td>CAST phase II - $^4$He Run</td>
</tr>
<tr>
<td></td>
<td>• axion masses explored up to 0.39 eV (160 P-steps)</td>
</tr>
<tr>
<td>2007</td>
<td>$^3$He Gas system implementation</td>
</tr>
<tr>
<td>2008 - 2011</td>
<td>CAST phase II - $^3$He Run</td>
</tr>
<tr>
<td></td>
<td>• axion masses explored up to 1.17 eV</td>
</tr>
<tr>
<td></td>
<td>• bridging the dark matter limit</td>
</tr>
<tr>
<td>2012</td>
<td>• Revisit 4He Run with improved detectors</td>
</tr>
<tr>
<td>2013-2015</td>
<td>• Revisit vacuum phase with improved detectors</td>
</tr>
<tr>
<td></td>
<td>• Analysis ongoing.</td>
</tr>
<tr>
<td></td>
<td>• New result soon available</td>
</tr>
</tbody>
</table>
IAXO sensitivity prospects

Helioscopes - CAST

Much larger QCD axion region explored

Astrophysical hints for ALPs

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CERN SPSC recommendations

SPSC Draft minutes [Jan 2014]

The Committee recognises the physics motivation of an International Axion Observatory as described in the Letter of Intent SPSC-I-242, and considers that the proposed setup makes appropriate use of state-of-the-art technologies i.e. magnets, x-ray optics and low-background detectors. The Committee encourages the collaboration to take the next steps towards a Technical Design Report. The Committee recommends that, in the process of preparing the TDR, the possibility to extend the physics reach with additional detectors compared to the baseline goal should be investigated. The collaboration should be further strengthened. Considering the required funding, the SPSC recommends that the R&D for the TDR should be pursuit within an MOU involving all interested parties.

This was endorsed by the Research Board in March2014

Minutes of the 206th CERN Research Board held on March2014:
https://cds.cern.ch/record/1695812/files/M-207.pdf
Mid term plans (+4 years) towards IAXO construction

• Site:
  – CERN is Plan A, but alternatives under consideration: it may affect funding strategies. Some preliminary interest from a number of institutions.

• Magnet:
  – Magnet construction → main resources challenge
  – Plan A: Form international consortium, coordinated by CERN (+CEA?) to collectively support the magnet construction, by means of inkind contributions to the effort.
  – Plan B: Large investment by host institution (IAXO being hosted outside CERN)

• X-ray optics:
  – Construction efforts distributed among groups pushing x-ray technologies for IAXO: US (LLNL, UC, MIT) + Europe (DTU, INAF-Milano)

• Detectors:
  – Efforts distributed among groups pushing each detector technology (actual decisions taken after TDR):
    • Micromegas: Zaragoza, CEA
    • Ingrid: Bonn
    • CCD: FNAL?, LPNHE?
    • MMCs/TES: Heidelberg, Orsay, CEA
## IAXO costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (MCHF)</th>
<th>Subtotals (MCHF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet</td>
<td>31.3</td>
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<tr>
<td>Eight coils based assembled toroid</td>
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<td></td>
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<td>Magnet services</td>
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<td><strong>Optics</strong></td>
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<td>16.0</td>
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<tr>
<td>Prototype Optic: Design, Fabrication, Calibration, Analysis</td>
<td>1.0</td>
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<tr>
<td>IAXO telescopes (8 + 1 spare)</td>
<td>8.0</td>
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<td>Calibration</td>
<td>2.0</td>
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<td>Integration and alignment</td>
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<td><strong>Detectors</strong></td>
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<td>Shielding &amp; mechanics</td>
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<td>Calibration systems</td>
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<td>Gas &amp; vacuum</td>
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<td>Dome, base, services building and integration</td>
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<tr>
<td><strong>Sum</strong></td>
<td></td>
<td><strong>56.8</strong></td>
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Table 5: Estimated costs of the IAXO setup: magnet, optics and detectors. It does not include laboratory engineering, as well as maintenance & operation and physics exploitation of the experiment.

Comments/caveats:

- Costs are for construction, and do not include operations and science support
- Costs based on initial estimates that need to be confirmed at TDR
- Labor for engineering, maintenance & operations not included
- Estimates do not include contingencies
IAXO timeline

~18 months -> TDR + preparatory activities
~3.5 years construction
~2.5 years integration + commissioning

<table>
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<tr>
<th>Years</th>
<th>Months</th>
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<th>3</th>
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<td>Installation &amp; commissioning</td>
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</table>
IAXO-DM configurations?

- ADMX has proved haloscope concept competitive at $m_a \sim 1-10$ $\mu$eV. Big motivation to explore higher masses.
- Many new ideas being put forward. R&D needed.
- Various possible arrangements in IAXO. Leverage the huge magnetic volume available:
  1. Single large cavity tuned to low masses
  2. Thin long cavities tuned to mid-high masses. Possibility for directionality. Add several coherently?
  3. Dish antenna focusing photons to the center. Not tuned. Broadband search. Competitive at higher masses?
- Initial stages of exploring and developing concepts.
IAXO low background detectors

- 8 detector systems
- Small gas chamber with Micromegas readouts for low-background x-ray detection
- Shielding
IAXO low background MM detectors

- Small Micromegas-TPC chambers:
  - Shielding
  - Radiopure components
  - Offline discrimination

- Goal background level for IAXO:
  - $10^{-7} - 10^{-8}$ c keV$^{-1}$ cm$^{-2}$ s$^{-1}$

- Already demonstrated:
  - $\sim 8 \times 10^{-7}$ c keV$^{-1}$ cm$^{-2}$ s$^{-1}$
    (in CAST 2014 result)
  - $10^{-7}$ c keV$^{-1}$ cm$^{-2}$ s$^{-1}$
    (underground at LSC)

- Active program of development

Clear roadmap for improvement

See arXiv:1310.3391

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IAXO low background detectors
Optics+detector pathfinder system in CAST

- IAXO optics+detector joint system
  - First time x-ray optics built specifically “for axions”.
  - First time low background + focusing in the same system
- Installed & operated in CAST 2014-15

Calibration photons (source 14 m away) focused onto the Micromegas
Optics+detector IAXO pathfinder system (in operation in CAST during 2014-5)
X-ray optics specifically built for axions
Low background Micromegas

JCAP12 (2015) 008
JCAP01 (2016) 034
Additional detector technologies

Ingrid detectors (U. Bonn):

- Micromegas on top of a CMOS chip (Timepix)
- Very low threshold (tens of eV)
- Tested in CAST
**Additional detector technologies**

**MMC detectors (U. Heidelberg):**

- Extremely low threshold and energy resolution (~eV scale)
- Low background capabilities under study

**See Loredana Gastaldo’s talk next week**

**Low noise CCDs**

- Developed for low mass WIMP experiments (DAMIC)
IAXO technologies – Baseline

IAXO magnet
- Superconducting “detector” magnet.
- Toroidal geometry (8 coils)
- Based on ATLAS toroid technical solutions.
- CERN+CEA expertise
- 8 bores / 20 m long / 60 cm Ø per bore

Baseline developed at:
IAXO Letter of Intent: CERN-SPSC-2013-022
IAXO x-ray optics

- X-rays are focused by means of grazing angle reflection (usually 2)
- Many techniques developed in the x-ray astronomy field. But usually costly due to exquisite imaging requirements
IAXO x-ray optics

IAXO optics conceptual design

Beyond Colliders, CERN, Sept-16

Igor G. Irastorza / Universidad de Zaragoza

Optimal focal length ~5 m

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<th>Parameter</th>
<th>Value</th>
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<td>Telescopes</td>
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<td>N. Layers (or shells) per telescope</td>
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<td>Segments per telescope</td>
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<td>Geometric area of glass per telescope</td>
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<td>Focal length</td>
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<td>Inner radius</td>
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<td>Outer Radius</td>
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<td>Minimum graze angle</td>
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<td>Maximum graze angle</td>
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<td>Pass band</td>
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<td>IAXO Nominal, 50% EEF (HPD)</td>
<td>0.29 mrad</td>
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<td>IAXO Enhanced, 50% EEF (HPD)</td>
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<td>IAXO Enhanced, 90% EEF</td>
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<td>FOV</td>
<td>2.9 mrad</td>
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IAXO x-ray optics

- Each bore equipped with an x-ray optics
- Exquisite imaging not required
- BUT need cost-effective way to build 8 optics of 600 mm diameter each.
IAXO x-ray optics

- Technique of choice for IAXO: optics made of slumped glass substrates coated to enhance reflectivity in the energy regions for axions.
- Same technique successfully used in NuSTAR mission, recently launched.
- The specialized tooling to shape the substrates and assemble the optics is now available.
- Hardware can be easily configured to make optics with a variety of designs and sizes.
- Key institutions in NuSTAR optics: LLNL, U. Columbia, DTU Denmark.
IAXO magnet

TOROIDAL CONFIGURATION specifically built for axion physics

Each conversion bore (between coils) 600 mm diameter

Magnetic length 20 m Total cryostat length 25 m

Bores go through cryostat
Other types of helioscope

• Instead of magnetic field, one can use the electromagnetic field of crystals…

• « Primakoff-Bragg » effect

• WIMP-like experiments provide limit to axions: SOLAX, COSME, DAMA, EDELWEISS, CDMS, etc…

• Characteristic temporal pattern:
Other types of helioscope

- « TPC in a magnetic field »: conversion and absorption happening in the gas
- Competitive only for high axion mass
- Old idea recently studied

Galán et al, JCAP 1512 (2015) 012
Axions as Dark Matter?

- **Axions are produced** in the early Universe by a number of processes:
  - Axion realignment
  - Decay of axion strings
  - Decay of axion walls

- Axion mass giving the right CDM density? Depends on cosmological assumptions:
  - Post-inflation scenario ("classical window") \( \sim 10^{-5} \– 10^{-3} \text{ eV} \)
  - Pre-inflation scenario ("anthropic window") \( \sim \) lower masses possible
  - Higher masses \( \rightarrow \) subdominant CDM / non-standard scenarios

- Thermal production

- Axion masses \( m_a > \sim 0.9 \text{ eV} \) gives densities too much in excess to be compatible with latest CMB data

Astrophysical hints for axions (?)

Gama ray telescopes like MAGIC or HESS observe HE photons from very distant sources...

However, diverse evidence of anomalous cooling has been observed in a number of stars...

Complex situation, but generally compatible with QCD axions with masses at the 10 meV scale...

**ALP:**

\[ g_{a\gamma} \sim 10^{-12} - 10^{-10} \text{ GeV}^{-1} \]

\[ m_a \lesssim 10^{-\left(10^{-7}\right)} \text{ eV} \]
InGrid Detectors

- Micromegas built on top of a CMOS ASIC
- Bump bond pads of the ASIC are used as charge collection pads
- Mesh made of thin aluminum foil
- One hole per readout pixel
  → well aligned
  → each primary electron can be seen as one hit on a pixel

Cosmic ray track

2 X-ray photons of a $^{55}$Fe source
Background Suppression

Knowledge of individual primary electrons gives detailed information on signal shape.

Different event shape variables can be used to distinguish background events (tracks) from signal events (photons).

First likelihood ratio-based analysis reached a background suppression of 120.

Threshold of detector is dominated by transmission of entrance window.

Good energy resolution with pixel counting eliminating contribution of gas amplification.

Efficiency vs. background rejection

**Spectrum of a $^{55}$Fe source**
AXION theory motivation

- Axion: introduced to solve the strong CP problem

In QCD, nothing prevents from adding a term like that to the lagrangian:

\[ \mathcal{L}_{CP} = \theta \frac{\alpha_s}{8\pi} G \tilde{G} \]

In fact, two known facts may induce such kind of term:
- The structure of the QCD vacuum (U(1)_A problem)
- EW quark mixing

2 contributions of very different origin...

\[ \theta = \bar{\theta} + \arg \det M. \]
AXION theory motivation

Axion: introduced to solve the strong CP problem

\[ \mathcal{L}_{CP} = \theta \frac{\alpha_s}{8\pi} G\tilde{G} \]

This term is CP violating. But strong interactions are not observed to violate CP

In particular, this term would predict an electric dipole moment for the neutron of a magnitude:

\[ |d_n| = A|\theta| \times 10^{-15} e \times cm \quad (A = 0.04 - 2.0) \]
AXION theory motivation

- But experiment says...

\[ |d_n| < 2.9 \times 10^{-26} \text{ ecm}. \]

So,

\[ |\theta| < 0.7 \times 10^{-11} \]

• Why so small?

• High fine-tunning of two different contributions required

Peccei-Quinn (1977) propose an elegant solution to this problem. \( \theta \) not anymore a constant, but a field \( \rightarrow \) the axion \( a(x) \). Fine-tunning reached naturally, dinamically.
**AXION as Dark Matter?**

- Can not be baryonic
- Can not be relativistic (CDM)
- Can not be standard (neutrinos)
- Need to go **beyond the SM** →

**Cosmological scale**

- Dark energy ~68.3%
- Dark Matter ~26.8%
- Baryonic < 5%
- Visible < 1%
- Non baryonic

**Galactic scale**

**Beyond Colliders, CERN, Sept-16**

Igor G. Irastorza / Universidad de Zaragoza
Axion DM after BICEP2

Quite an impact... (a few preprints)
- Marsh et al. arXiv:1403.4216
- L. Visinelli, P. Gondolo arXiv:1403.4594
- Chun. arXiv:1404.4284
among others...

In summary:
if “high inflation scale” interpretation of BICEP2 results is right... “classical window” (high mass) scenario is favored.
IAXO in astroparticle roadmaps

- **ASPERA/APPEC Roadmap** acknowledges axion physics, CAST, and recommends progress towards IAXO.

  "...A CAST follow-up is discussed as part of CERN's physics landscape (new magnets, new cryogenic and X-ray devices). The Science Advisory Committee supports R&D on this follow up, as well as smaller ongoing activities on the search for axions and axion-like particles."

- Important community input in the **European Strategy for Particle Physics**
- Presence in the Briefing Book of the ESPP, which reflects also APPEC roadmap recommendations.
- **ESPP recomends CERN to follow APPEC recomendations.**
- Important effort in relation with US roadmapping (Snowmass, and P5 process). **Snowmass reports speak very favourably of axion physics and IAXO.**
Detecting DM axions: “haloscopes”

- Resonant cavities (Sikivie, 1983)
  - Primakoff conversion inside a “tunable” resonant cavity
  - Energy of photon = $m_a c^2 + O(\beta^2)$

Primakoff conversion of DM axions into microwave photons inside cavity

$$P_0 = g_{a\gamma}^2 V B^2 C \frac{\rho_a}{m_a} Q$$

Axion DM field
Non-relativistic
Frequency $\leftarrow$ axion mass

If cavity tuned to the axion frequency, conversion is “boosted” by resonant factor (Q quality factor)

Cavity dimensions smaller than de Broglie wavelength of axions
Haloscopes - AMDX

- Leading experiment: ADMX @ U. Washington
  - Many years of R&D
  - high Q cavity (1 m x 60 cm Ø)
  - 8 T superconducting solenoid
  - Low noise receivers based on SQUIDs
  - Sensitivity to few μeV proven
  - New program ADMX-HF to go to higher frequencies
Detecting DM axions with IAXO?

- All ideas have in common: big magnets needed

**Long thin cavities in dipole magnets**

**Large spherical mirror**

PRD85 (2012) 035018
Directional effect:
JCAP 1210 (2012) 022

JCAP 1304 (2013) 016
Directional effect:
arXiv:1307.7181
IAXO-DM configurations?

• Prospects under study. Very motivated (encouraged by CERN SPSC)
• Needed new know-how (cavities, low noise microwave detectors...)
• Various possible arrangements in IAXO. Profit the huge magnetic volume available:
  1. Single large cavity tuned to low masses
  2. Thin long cavities tuned to mid-high masses. Possibility for directionality. Add several coherently?
  3. Dish antenna focusing photons to the center. Not tuned. Broadband search. Competitive at higher masses?
IAXO Lol authorlist

Letter of Intent to the CERN SPSC

The International Axion Observatory

IAXO

**Expertise**

**Needed know-how well covered:**
- Axion theory & phenomenolgy
- Axion Cosmology & Astrophysics
- Axion detection phenomenology
- X-ray detectors
- Low background techniques
- X-ray optics
- Superconducting magnets and technology

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<th>Axion theory and phenomenology</th>
<th>Axion cosmology and astrophysics</th>
<th>Axion detection phenomenology</th>
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