

Helioscopes: CAST & the IAXO project

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On behalf of the CAST & IAXO collaborations

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Outline

Axions, ALPs and Helioscopes

CAST: the most sensitive helioscope

IAXO: the future

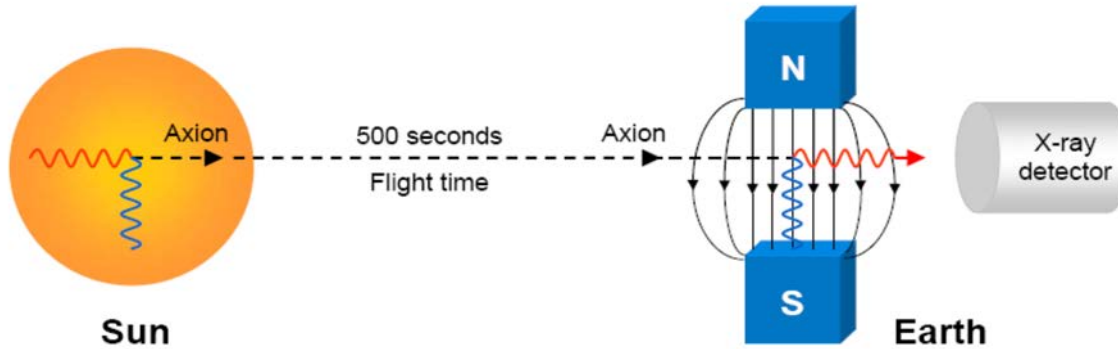
Conclusions

Axions and ALPs

- ✓ Axions are **the most elegant solution to the Strong CP problem** (why QCD does not seem to break the CP symmetry):
 - **pseudoscalar particles, neutral, practically stable**
 - phenomenology driven by the scale f_a , m_a and g_{ai} correlated
- ✓ Candidates for both **cold** and **hot dark matter**
- ✓ Axion-like particles (ALPs) or WISPs (Weakly Interacting Slim Particles) share the axion phenomenology but m_{ALP} and g_{ALPi} not correlated
- ✓ Axions and ALPs are predicted by many **extensions of the standard model**
- ✓ New theory scenarios: **string theory** predicts axions/ALPs with detectable parameters
- ✓ **Axions in astrophysics:**
 - produced in the core of stars can drain energy from them and alter their lifetime
 - decay to two gammas may produce gamma lines in the emission from places (eg. galactic centre).
 - **Hints** for axion/ALPs?
 - transparency of the Universe to UHE gammas
 - white dwarf cooling anomaly → point to few meV axions
 - ...

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

Helioscope technique



Signal: excess of x-rays during alignment over background

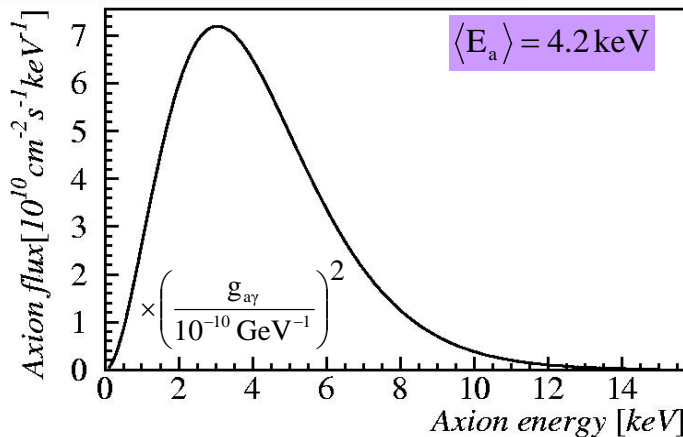
Expected number of Photons:

$$N_\gamma = \int \frac{d\Phi_a}{dE_a} \cdot P_{a \rightarrow \gamma} \cdot S \cdot t \cdot dE_a$$

Production: Primakoff effect
Thermal photons interacting with solar nuclei produce Axions.

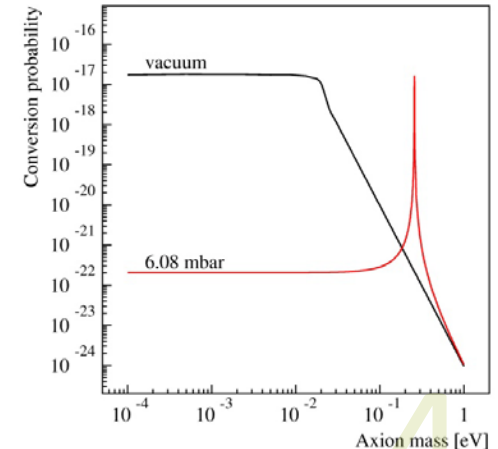
Detection Inverse Primakoff:
axion interacting with a very strong magnetic field converts to a photon
P. Sikivie, PRL 51 (1983)1415;Err. ibid. 52 (1984) 695

Differential axion flux on Earth

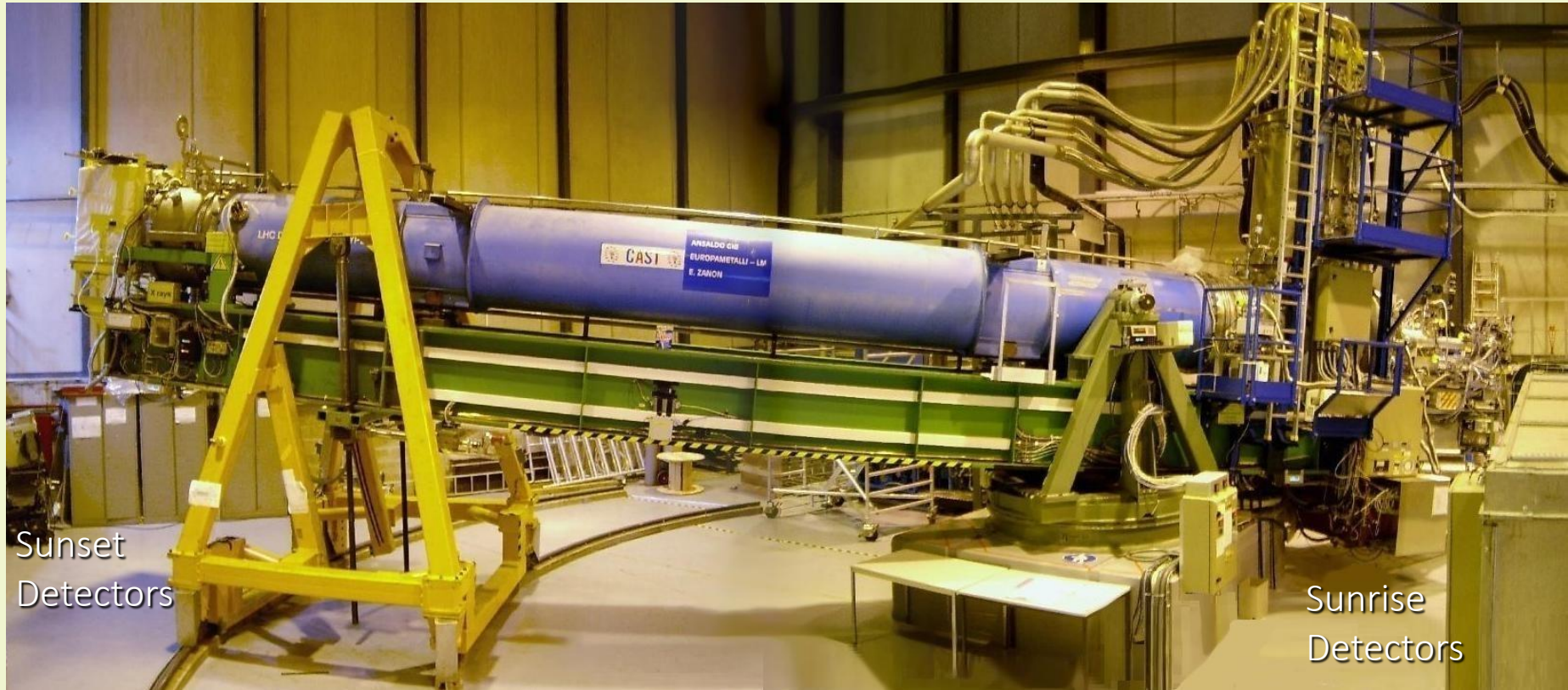


- o Conversion probability depends on medium, $(BL)^2$
- o Coherence can be restored: different mass ranges can be covered in different media and densities

Conversion Probability



CAST: the CERN Axion Solar Telescope



Sunset
Detectors

Sunrise
Detectors

Decommissioned
prototype LHC dipole magnet.

Rotating platform
(Vertical: $\pm 8^\circ$, Horizontal: $\pm 40^\circ$)

Magnetic field: $B=9\text{ T}$

2x1.5h solar tracking/day

Length: $L=9.26\text{ m}$

Sunrise: X-ray Focusing Device/Ingrid + 1 Micromegas

Sunset: 2 Micromegas

CAST Physics program

✓ CAST Phase I, Vacuum

$$m_a < 0.02 \text{ eV}$$

PRL 94 (2005) 121301

JCAP04(2007)020

✓ CAST Phase II, ^4He

$P < 13.4 \text{ mbar (1.8K), 160 steps}$

$$0.02 \text{ eV} < m_a < 0.39 \text{ eV}$$

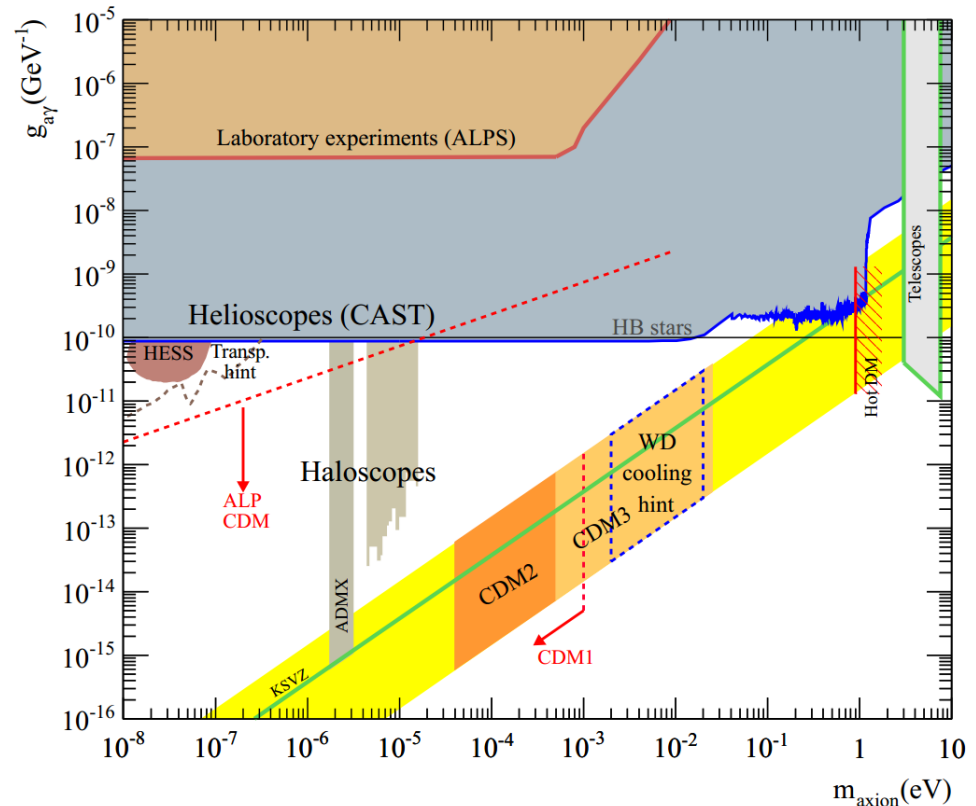
JCAP02(2009)008

✓ CAST Phase II, ^3He

$P < 120 \text{ mbar (1.8K)}$

$$0.39 \text{ eV} < m_a < 0.64 \text{ eV}$$

PRL 107 (2011) 261302



Parallel searches:

- Constraints on the axion-electron coupling g_{ae} : *JCAP 1305 (2013) 010*
- High energy axions *JCAP 1003:032,2010*
- 14.4keV axions from M1 transitions *JCAP 0912:002, 2009*
- Low energy axions
- In preparation: bounds on solar chameleons (data taken with an SDD)

CAST Physics program

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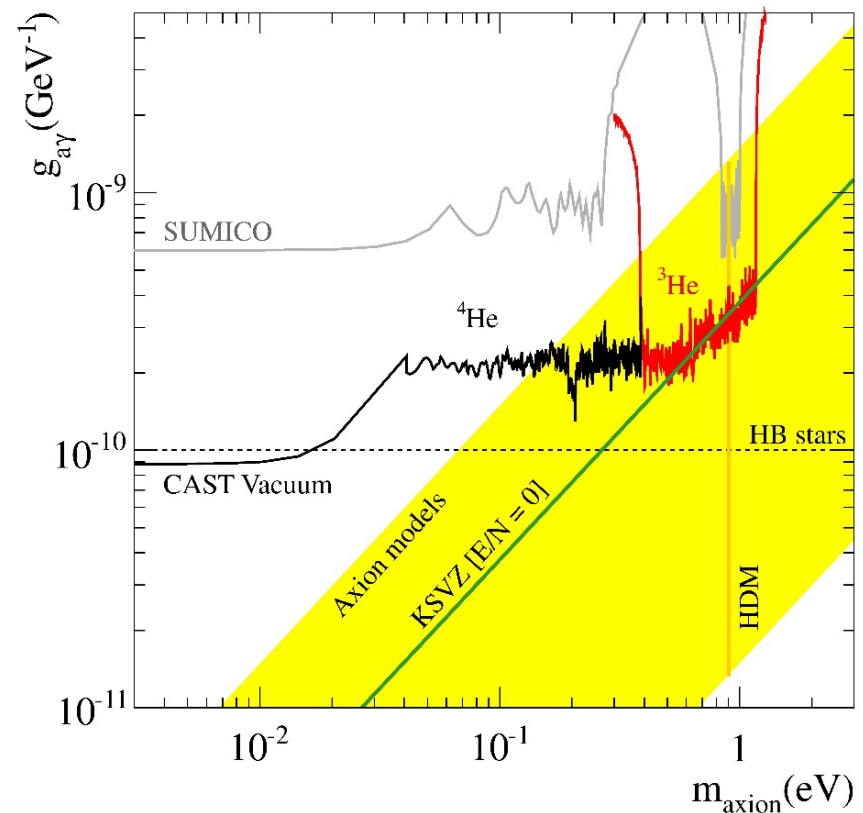
JCAP02(2009)008

✓ CAST Phase II, ^3He

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PRL 107 (2011) 261302



Latest results:

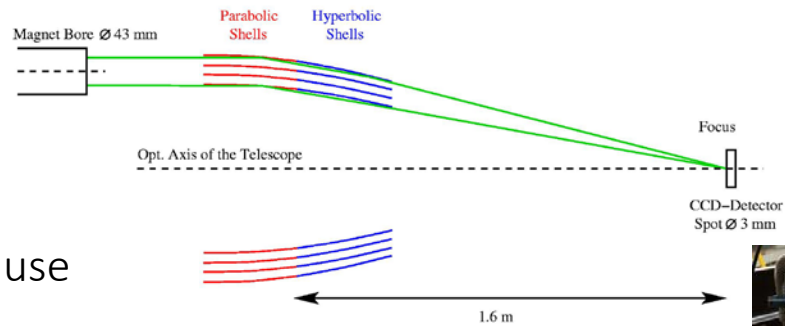
^3He phase results for $0.64 \text{ eV} < m_a < 1.17 \text{ eV}$ (*mM only*)

Excluded down to $g_{ay} < 0.88 \times 10^{-10} \text{ GeV}^{-1}$ *PRL 112 (2014) 091302*

In preparation: paper on the simulations on the gas dynamics inside the magnet

CAST Detectors

X-ray telescope from the ABRIXAS mission
coupled to
a CCD (2002-2013)
an InGrid (2014...)



S/N increased by a factor ~ 150 because
of the focusing



Typical Rates

MM (2-10 keV)

~ 0.5 cts/h

CCD (1-7 keV)

~ 0.2 cts/h

3 microbulk Micromegas

Also: Barbe (PMT in a parasitic line) for low energy axions in the visible

CAST detectors: microbulk

Low intrinsic radioactivity

Light mass, radiopure materials

Signal topology, offline analysis

2D readout pattern, time information

Shielding

archeological lead, inner Cu, N₂ flushing, muon veto

New electronics

lowering noise and threshold, analysis in z

New detector design

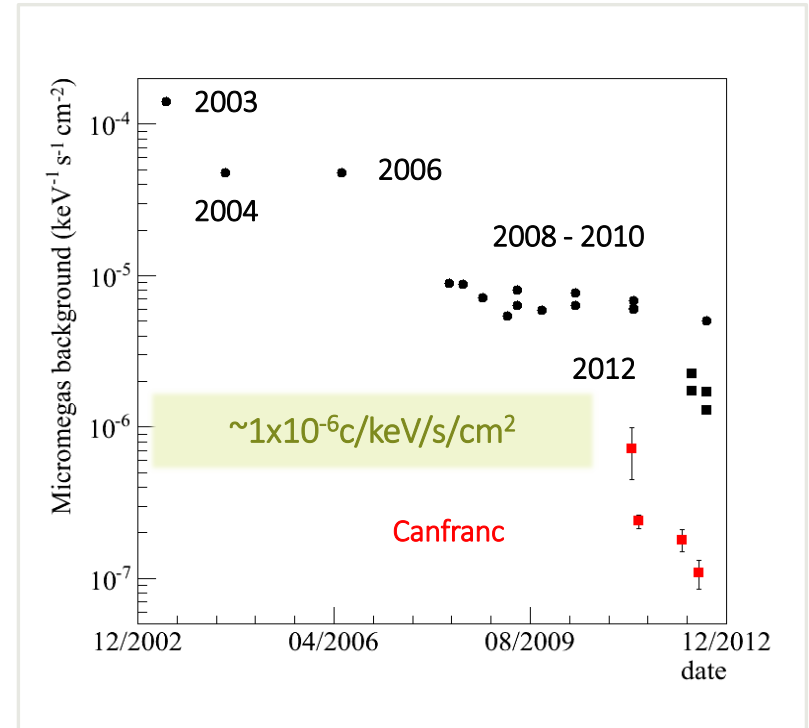
Active experimental program and simulations

- Experimental tests with current detectors at CERN, Zaragoza, Saclay
- Underground setup at Canfranc
- Simulation works to build a detailed background model

Reduction of ~100x since the beginning!

S. Aune, 2014 JINST 9 P01001

Background Level evolution at CAST



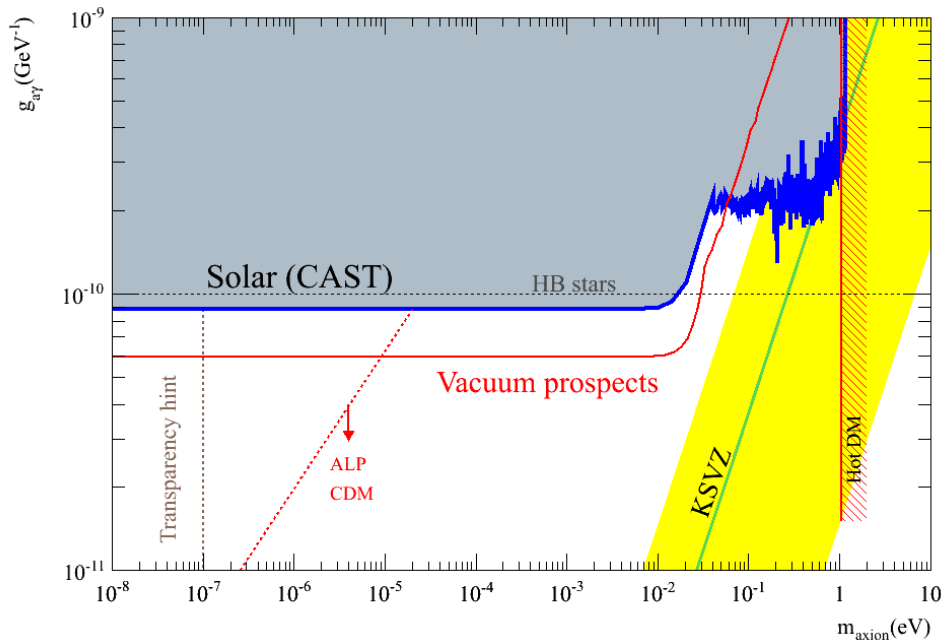
Goal: $<10^{-7} \text{ c/keV/cm}^2/\text{s}$ (down to 10^{-8} if possible)

10

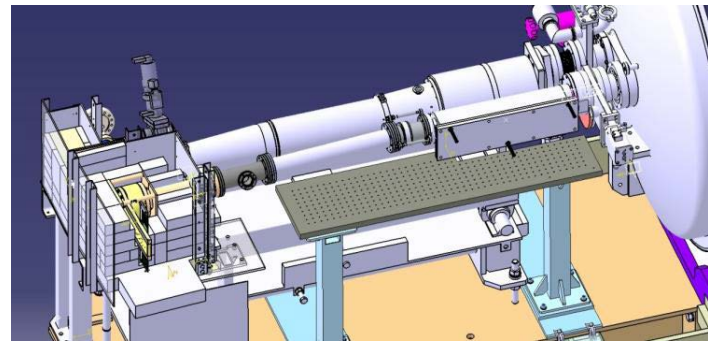
Current activities at CAST

Revisiting the vacuum phase :

Three high performance microbulk detectors, increase sensitivity
an InGRID detector substitutes the CCD behind the telescope



preparation of an x-ray optics for the sunrise one, boost discovery potential.



But also other exotica:

chameleons (publication in progress with a Silicon Drift Detector (SDD) data),
paraphotons, *low energy axions (visible)*

which require: low background, low threshold

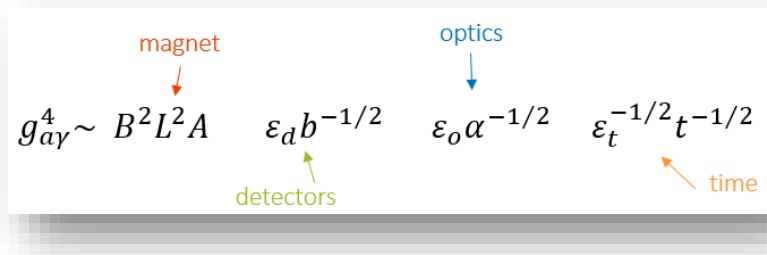
The International AXion Observatory

Letter of Intent already presented to CERN (SPSC-2013-022):
 SPSC recognised the physics case and recommended to
 proceed with the TDR.

I. G. Irastorza, JCAP 06 (2011) 013

In roadmaps of Europe & USA (ASPERA/APPEC, ESPP, Snowmass)

IAXO will improve on all the helioscope-relevant
 parameters



more than 4 orders of magnitude in S/N better than CAST
 More than 1 order of magnitude in $g_{a\gamma}$

Can be converted in an all-purpose axion observatory:
 non-hadronic axions, WISPs
 non-standard axion production scenarios

And even relic axions:
 with long thin cavities, dish antennas

JCAP 10 (2012) 022

JCAP 04 (2013) 016

Journal of Cosmology and Astroparticle Physics
 An IOP and SISSA journal

Towards a new generation axion helioscope

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 and K. Zioutasⁿ

E. Armengaud, 2014 JINST 9 T05002

Conceptual design of the International Axion Observatory (IAXO)

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 W. Wester,^{ak} S.C. Yildiz^{al} and K. Zioutas^{al}

IAXO

All developments based on known technologies

Cryostat

Flexible Lines

Telescopes

Inclination System

Support Frame

Rotating Disk

Services

Rotation System

Magnet structure length: ~25m
Magnet structure diameter: ~5m
Total mass ~ 250ton

8 bores with 60cm diameter
8 focusing devices
8 low-background x-ray detectors

Rotating platform
following the Sun for
12h a day

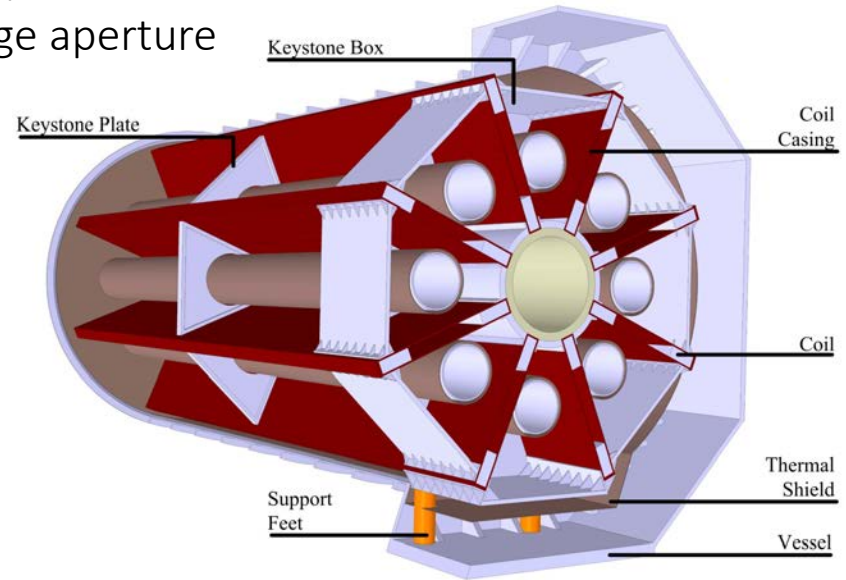
The IAXO magnet

Important change from the previous helioscopes:
a dedicated magnet with high field and large aperture

Toroidal design (ATLAS-inspired)
8 bores

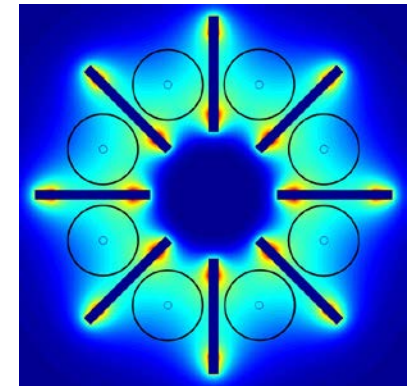
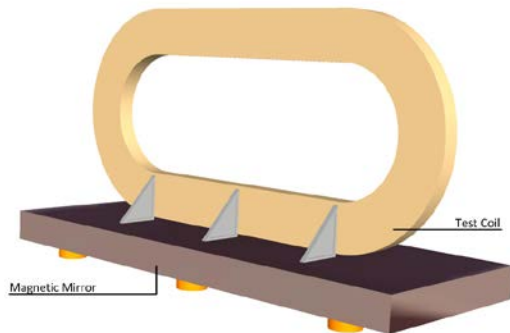
Main characteristics:

length: 20m
bore diameter: 60cm
cross section: 2.3m²
field peak: 5-6T



IAXO T0 Project

Preparing to build a test-coil



IEEE Trans. Appl. Supercond. 23 (ASC 2012)
Adv. Cryo. Eng. (CEC/ICMC 2013)

The optics of IAXO

Using known technology: NuSTAR/HEFT project
Coated thin glass substrates optimized for:
axion energies
focusing power efficiency

Main characteristics:

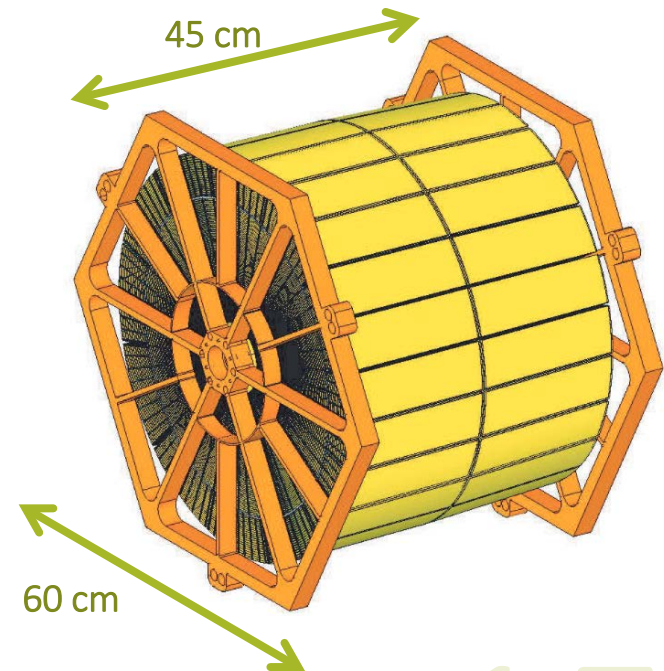
Focal length: $\sim 5\text{m}$
Focusing spot: $\sim 0.2\text{cm}^2$

IAXO X0 Project

Dummy optics of the final size to be built

Telescopes	= 8
Layers per telescope	= 123
Mirrors per telescope	≈ 2200
Focal length	= 5 m
Coatings	= W/B ₄ C multilayers
Pass band	= 1–10 keV
Half-power diameter	= 60 arcsec

NuSTAR telescope



AC Jacobsen et al., Proc SPIE 8861 2013

~~CAST~~ IAXO detectors: microbulk

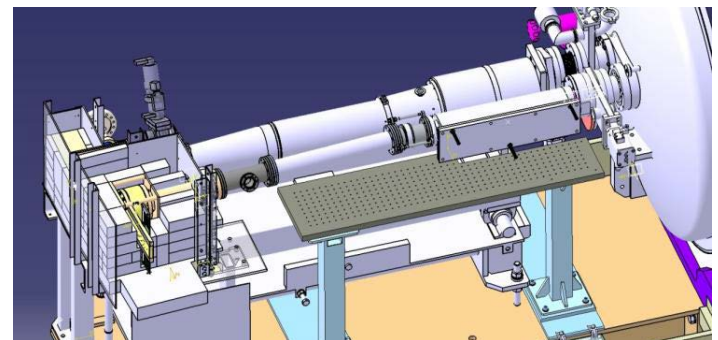
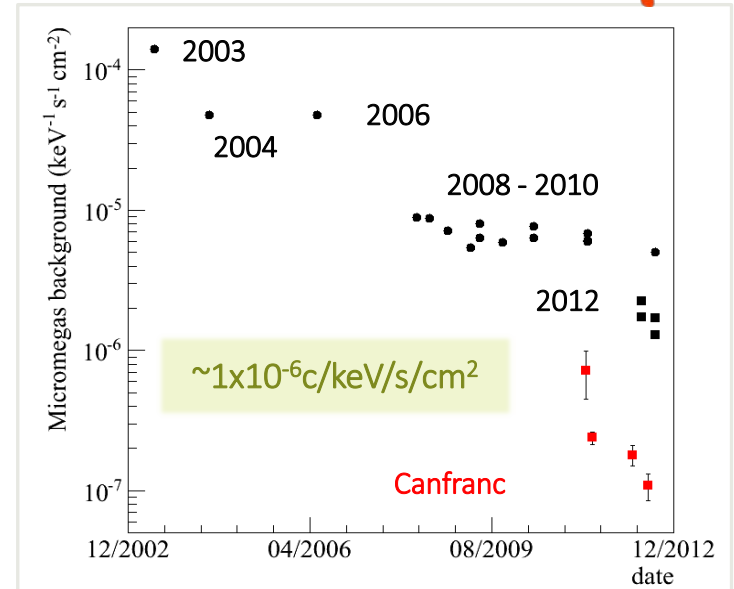
REMINDER

- Low intrinsic radioactivity
- Signal topology, offline analysis
- Shielding
- New electronics
- New detector design
- Active experimental program and simulations

Goal: $<10^{-7}$ c/keV/cm²/s (down to 10^{-8} if possible)

IAXO Pathfinder Project

Building a small optics to couple to the Sunrise mM of CAST: smaller scale but same techniques



Summary and conclusions

- **Axions** and **ALPs** are of great interest in the rare-event searches field and are continuously called in to solve puzzles of physics
- The **helioscope technique** is one of the most promising in order to look for them
- **CAST**
 - *is the most sensitive and most experienced axion helioscope built so far, a reference in axion physics, having restricted a wide m_a - $g_{a\gamma}$ range*
 - *is currently improving its results in vacuum while being sensitive to other exotica such as solar chameleons*
 - *it also serves as an R&D facility for the development of IAXO*
- The **IAXO** project will push the helioscope technique to its limits:
 - *enhance all relevant aspects: magnet, optics and detectors*
 - *improve CAST results by ~ 1 order of magnitude*
 - *can become a general axion facility with a good discovery potential*CDR already published and base projects are ongoing

Large parts of the QCD-favoured parameter space could be explored in the coming decade

