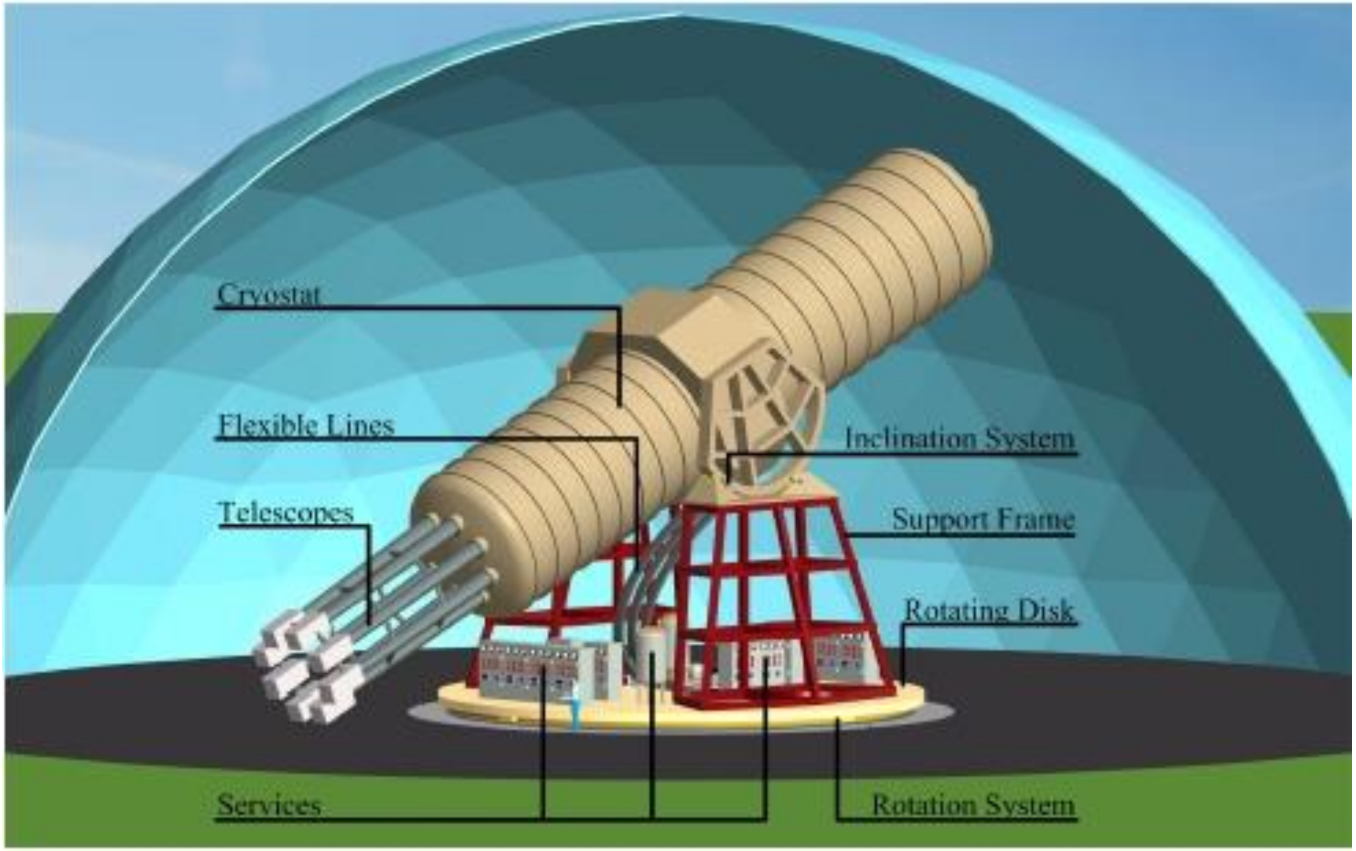
The IAXO (*I*nternational ***Ax***ion ***O***bservatory) Helioscope



Esther Ferrer Ribas, IRFU/SEDI

Irfu
Institut de recherche
sur les lois fondamentales
de l'Univers

Axion Mini Workshop, IPHT, 10-12 Juin 2015

Outline

- **Axion searches, bounds**
- **Helioscope principle**
- **CAST**
- **IAXO concept and ingredients**
- **Sensitivity**
- **Status and plans**
- **Conclusions**

Axion motivations in brief

- **Most elegant solution to the strong CP problem**

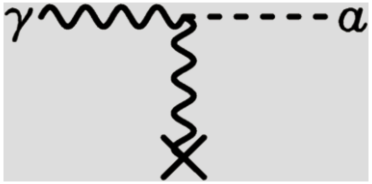
- Axion-like particles predicted by many extensions of the SM (string theory)

- Axions may solve the DM problem

- Hints for axions/ALPS:
    - Transparency of the Universe
    - Anomalous cooling of different types of star

Axion properties

- Neutral Pseudoscalar
- Pratically stable
- Very low mass $m_a \simeq 0.6 \text{ eV} \frac{10^7 \text{GeV}}{f_a}$
- Very low cross-section
- Coupling to photons



$$L_{a\gamma} = g_{a\gamma} (\vec{E} \cdot \vec{B}) a$$

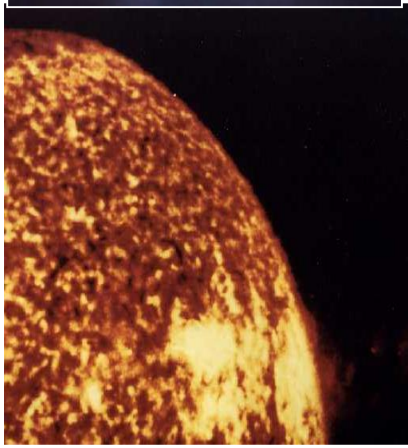
$$g_{a\gamma} \propto 1/f_a$$

$$g_{a\gamma} \propto m_a$$

Axion searches

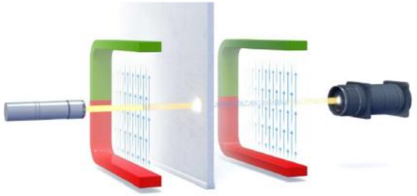
- Relic Axions
  - Axions that are part of galactic dark matter halo:
    - Axion Haloscopes (ADMX)

Direct detection searches for axion dark matter, Gray Rybka *et al*, 2014 *Physics of the Dark Universe* **4**



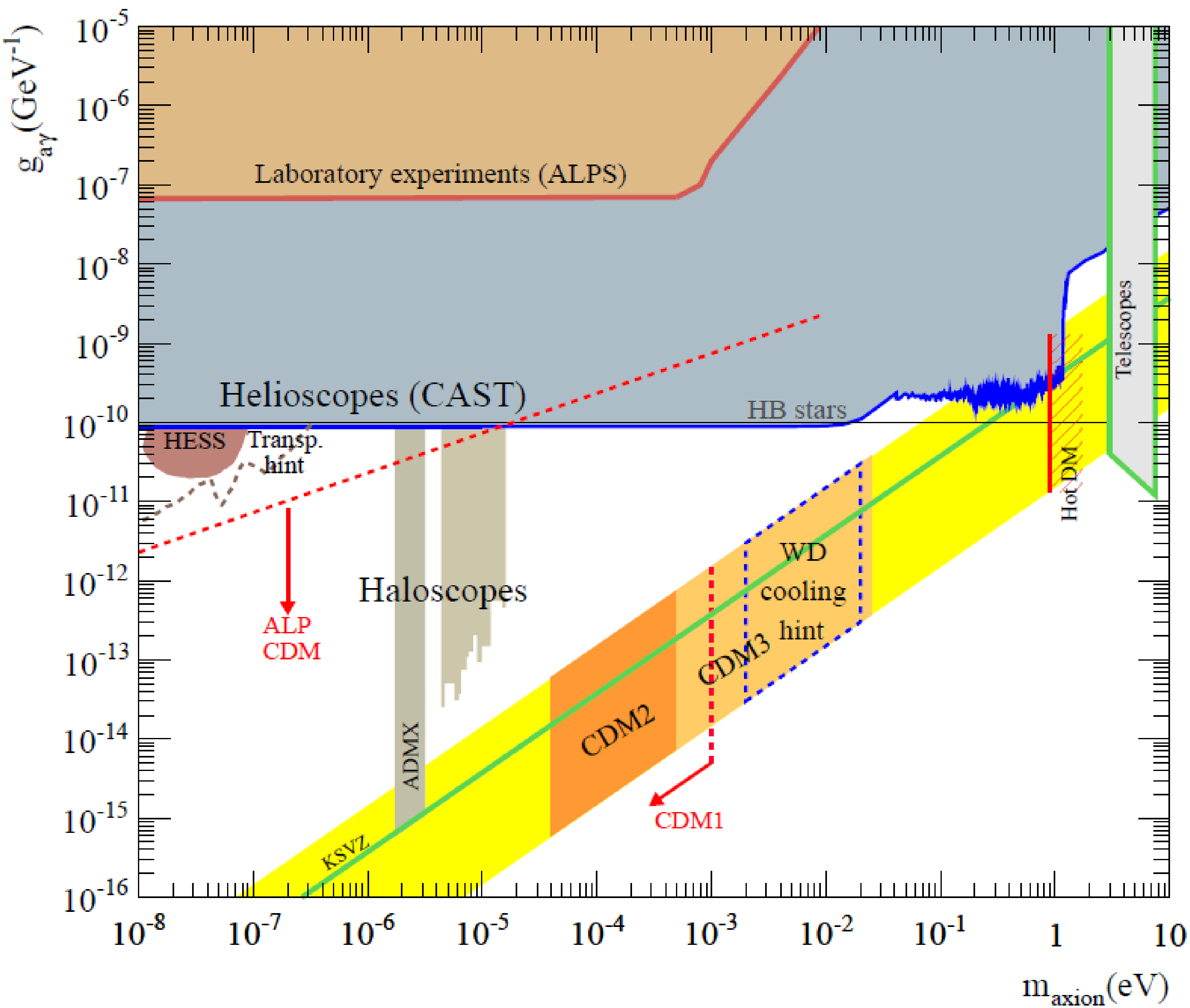
- Solar Axions
  - Emitted by the solar core.
    - Axion Helioscopes (SUMICO, CAST, IAXO)

- Axions in the laboratory
    - "Light shinning through wall" experiments (ALPS, OSQAR…)

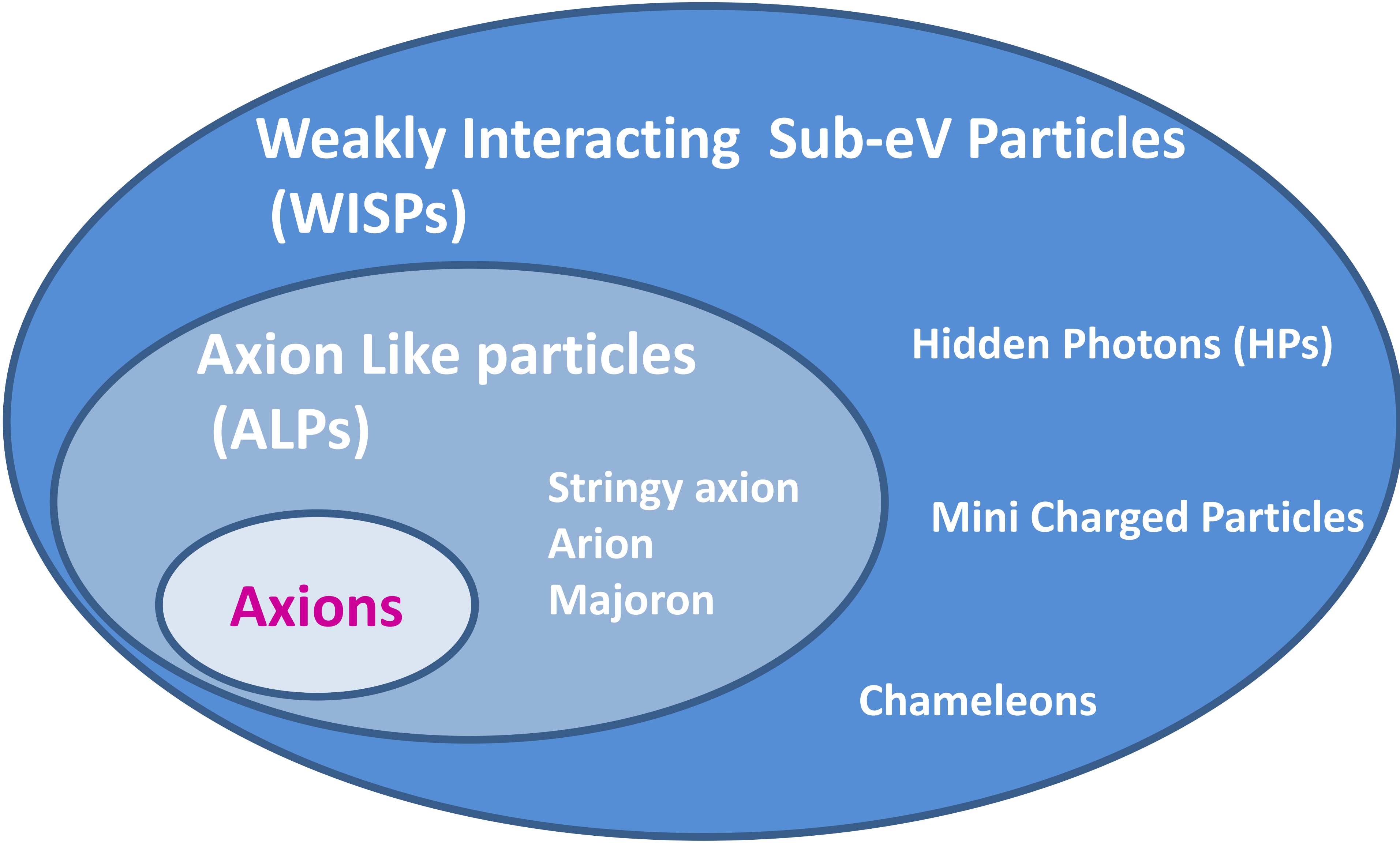


Any light particle search II — Technical Design Report R Bähre *et al* 2013 *JINST* **8** T09001

Bounds: experimental, astrophysical, cosmological



The WISPs zoo



$g_{a\gamma}$ and m_a are two independent "phenomenological" parameters

Helioscope physics

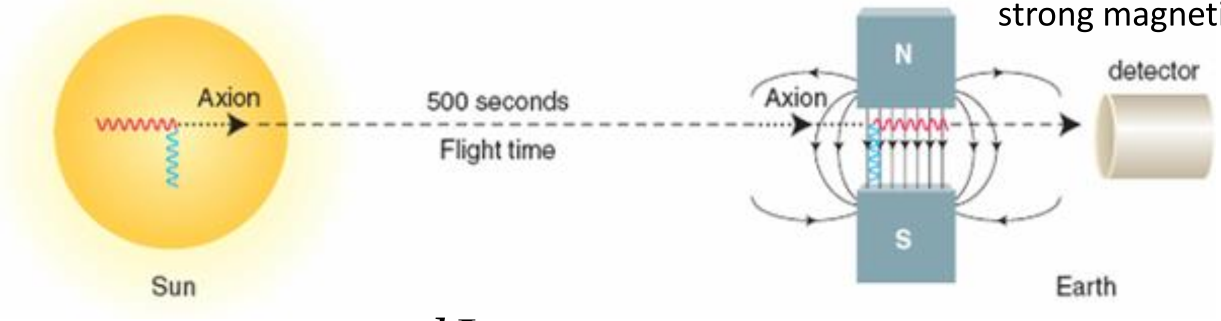
Concept by P. Sikivie 1983

Production in the Sun

Conversion of thermal photons into axions via Primakoff effect in the solar core

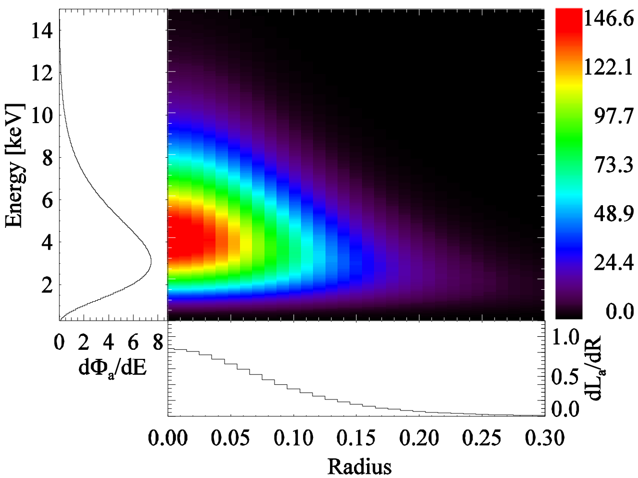
Detection in CAST

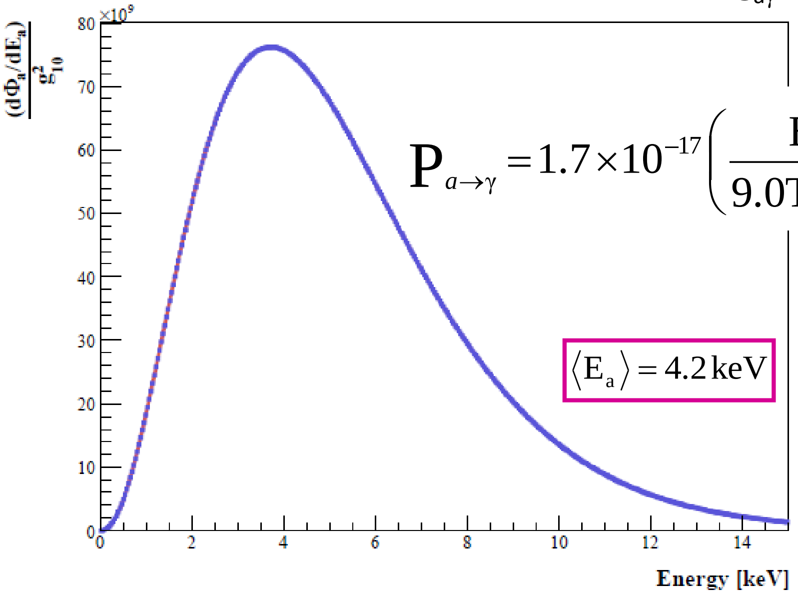
Conversion of axions into photons via the inverse Primakoff effect in a strong magnetic field



Expected number of photons: $$N_\gamma = \int \frac{d\Phi_a}{dE_a} \cdot P_{a\to\gamma} \cdot S \cdot t \cdot dE_a$$ ≈0.3 evts/hour

with $g_{a\gamma} = 10^{-10}$ GeV^{-1} and A = 14 cm^2



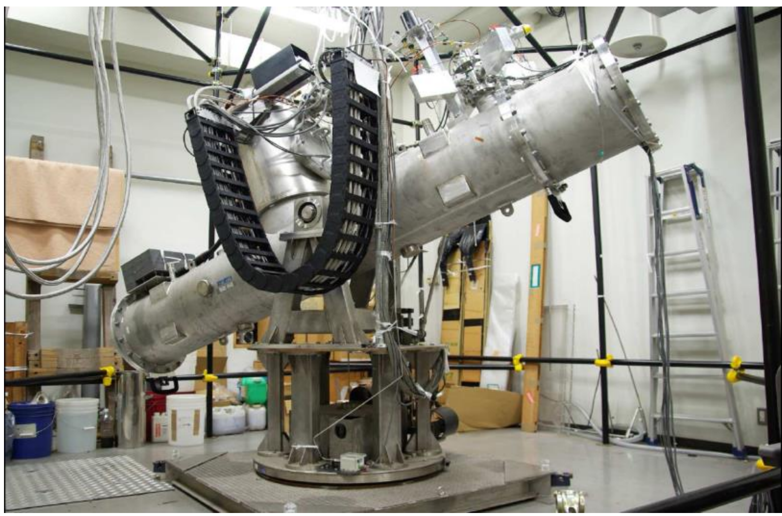


$$P_{a\to\gamma} = 1.7\times10^{-17}\left(\frac{B\cdot L}{9.0T\cdot 9.3m}\right)^2\left(\frac{g_{a\gamma}}{10^{-10}\,GeV^{-1}}\right)^2$$

$$\langle E_a \rangle = 4.2\,keV$$

Helioscopes

- Brookhaven (a few hours of data): Lazarus et al. PRL 69 (92)
- Tokyo Helioscope (SUMICO): 2.3 m long 4 T magnet

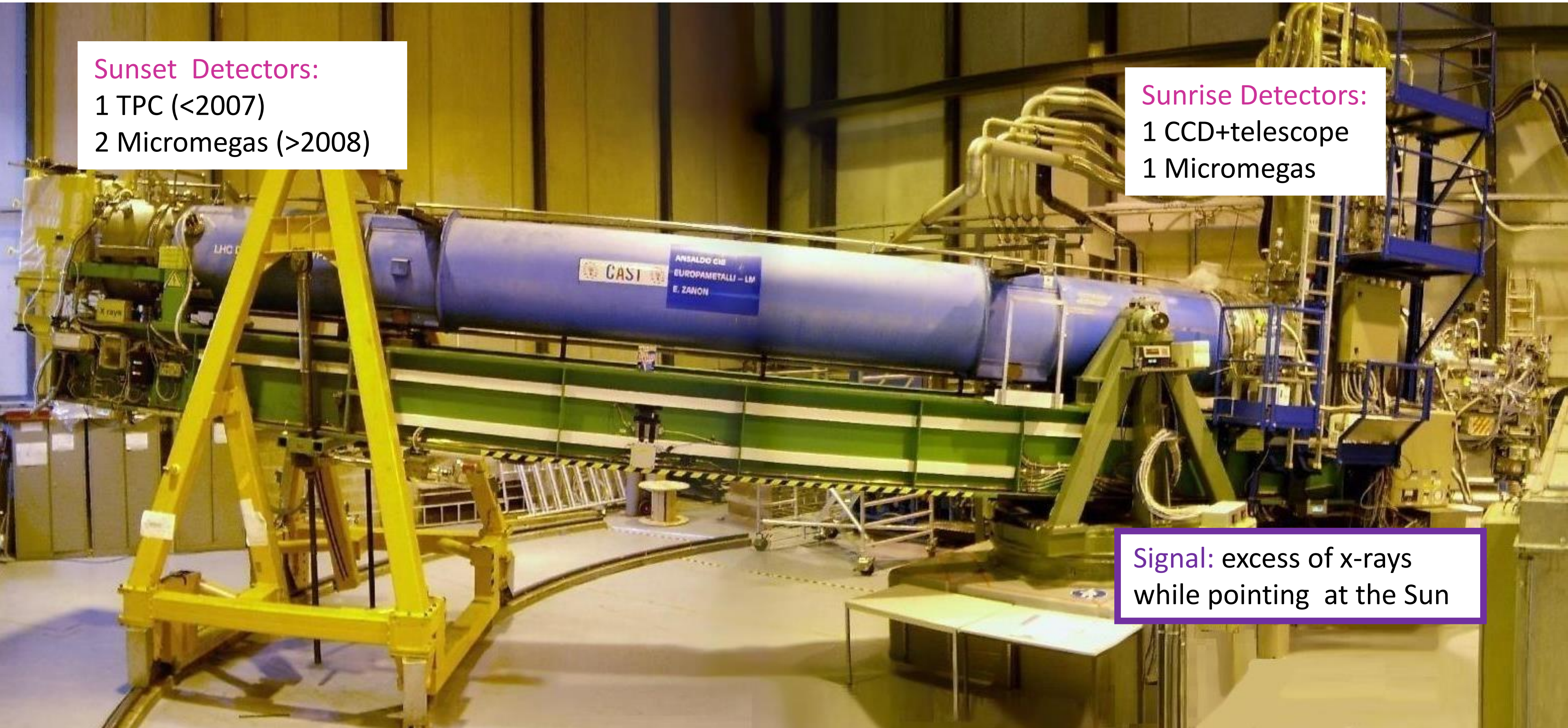


No Liq. He
B=4T, L=2.3m
268A persistent current
16 PIN photodiodes
Altazimuth:Horiz. 360°,
vert.±28°

Inoue et al. **Phys.Lett.B668:93-97,2008**.

Presently running: CERN Axion Solar Telescope (CAST)

CAST (CERN Axion Solar Telescope)



Sunset Detectors:
1 TPC (<2007)
2 Micromegas (>2008)

Sunrise Detectors:
1 CCD+telescope
1 Micromegas

Signal: excess of x-rays while pointing at the Sun

LHC dipole : L = 9.3 m, B = 9 T

Rotating platform : vertical movement 16°

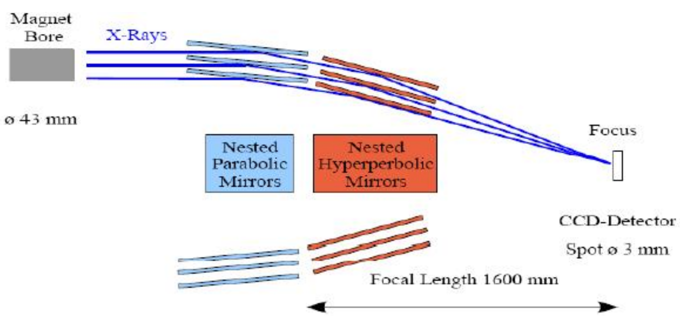
horizontal movement 100°

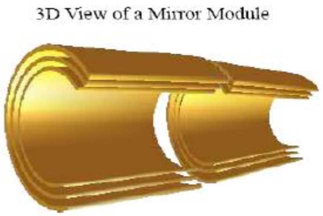
Solar « Tracking » ~3 h/day, background data rest of the day

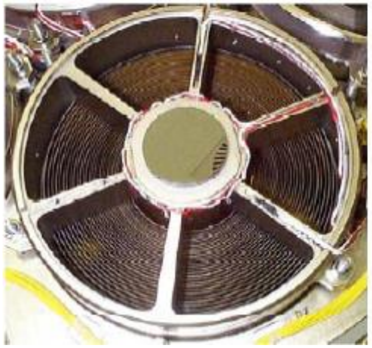
4 X-rays detectors

Originalities of CAST

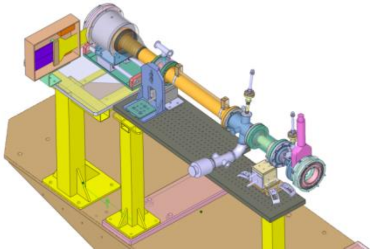
- Use of X-ray telescope ➔ increase S/B noise➔ sensitivity improved by a factor 150 by focusing a ø43 mm x-ray beam to ø3mm

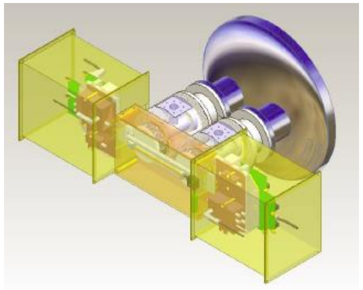


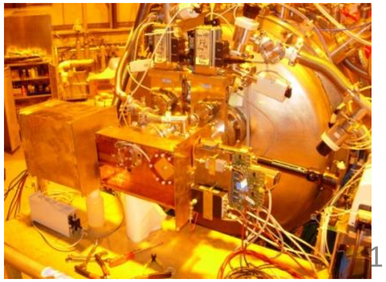




- Low background techniques➔ shieldings, low radioactive materials, simulation and modeling of backgrounds….







CAST results

CAST Physics program

1) CAST Phase I, Vacuum
- $m_a < 0.02$ eV; $g_{a\gamma\gamma}$ **< 0.88·10^{-10} GeV^{-1}**.

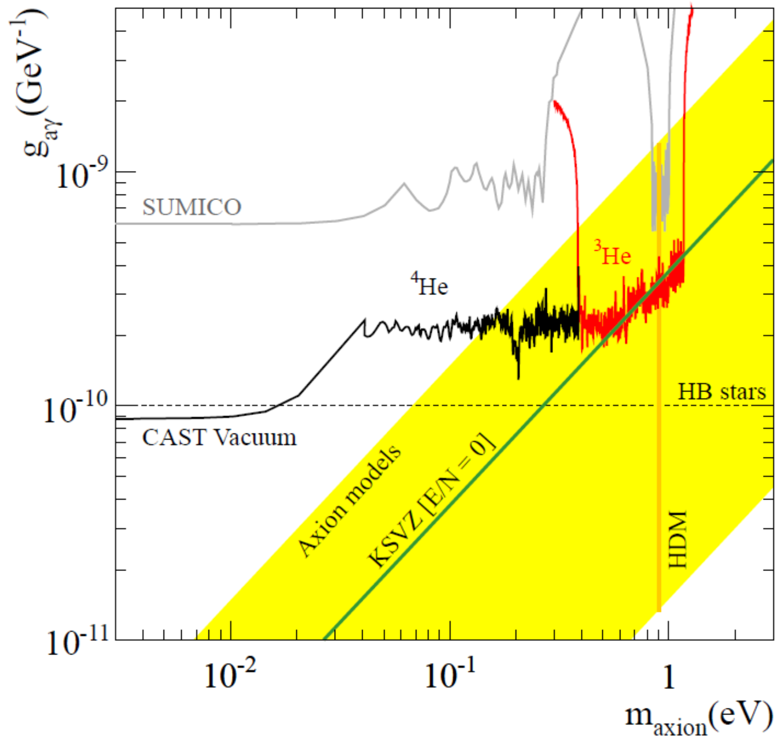
PRL94 (2005) 121301 & JCAP04(2007)020.

2) CAST Phase II, ^{4}He
- P < 13.4 mbar (1.8K), 160 steps
- $0.02 < m_a < 0.39$ eV; $g_{a\gamma\gamma}$ **< 2.2·10^{-10} GeV^{-1}**

JCAP02 (2009) 008

3) CAST Phase II, ^{3}He
- P < 120 mbar (1.8K), 160 steps
- $0.39 < m_a < 1.17$ eV; $g_{a\gamma\gamma}$ **< 3.3·10^{-10} GeV^{-1}**

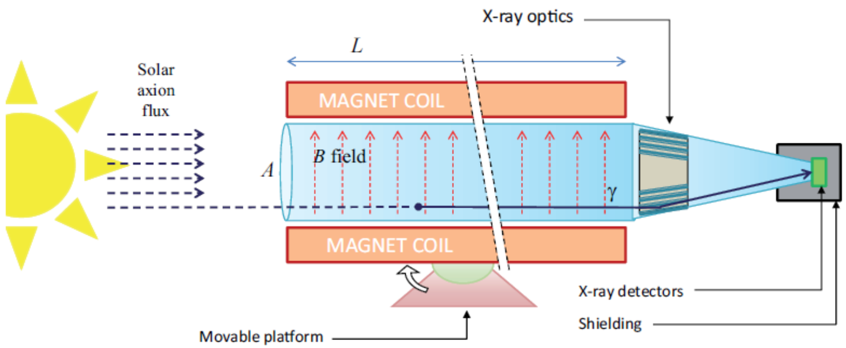
PRL 107 (2011) 261302 & PRL 112 (2014) 091302



Current activities

- Revisiting the vacuum phase (2013-2015) with more sensitive detectors.
- Looking for non-hadronic axions and other WISPs (chamaleons, paraphotons, etc.)

IAXO concept



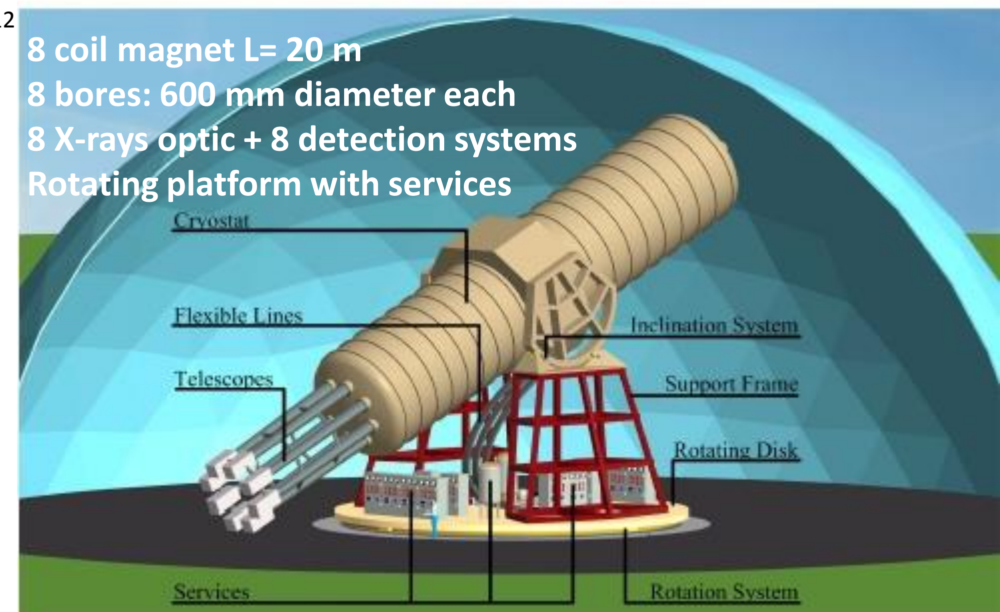
JCAP 06 (2011) 013

No technology challenge (built on CAST experience)

✓New dedicated superconducting magnet
✓Use of X-ray focalisation over ~m^2 area
✓Low background detectors (improve bck by 1-2 orders of magnitude)

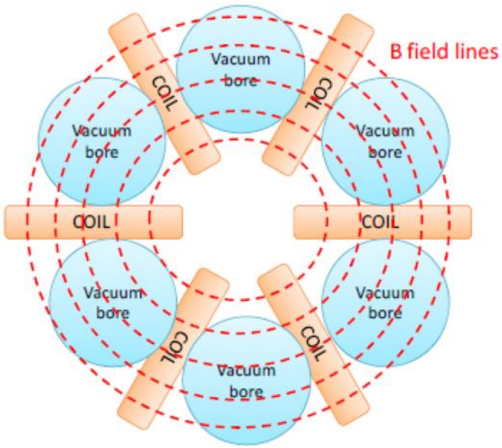
Goal: in terms of signal to background ratio **4-5 orders of magnitude** more sensitive in than CAST, which means sensitivity to axion-photon couplings down to a few ×10^{-12} GeV^{-1}

$$g^4_{a\gamma} \propto \underbrace{b^{1/2}\epsilon^{-1}}_{\text{detectors}} \times \underbrace{a^{1/2}\epsilon_o^{-1}}_{\text{optics}} \times \underbrace{(BL)^{-2}A^{-1}}_{\text{magnet}} \times \underbrace{t^{-1/2}}_{\text{exposure}}$$

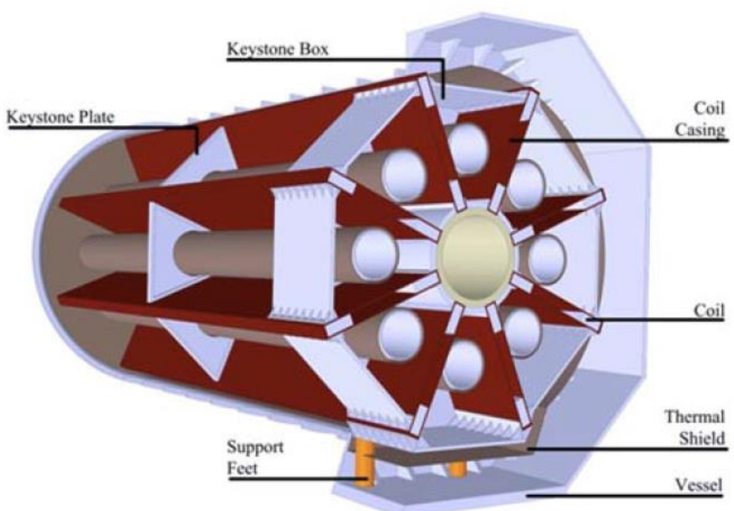


IAXO magnet

Optimised configuration: TOROIDAL with 8 bores
25 m long, 5 m diameter and a peak field of 5.4 T



Property		*Value*
Cryostat dimensions:	Overall length (m)	25
	Outer diameter (m)	5.2
	Cryostat volume (m^3)	~ 530
Toroid size:	Inner radius, R_{in} (m)	1.0
	Outer radius, R_{out} (m)	2.0
	Inner axial length (m)	21.0
	Outer axial length (m)	21.8
Mass:	Conductor (tons)	65
	Cold Mass (tons)	130
	Cryostat (tons)	35
	Total assembly (tons)	~ 250
Coils:	Number of racetrack coils	8
	Winding pack width (mm)	384
	Winding pack height (mm)	144
	Turns/coil	180
	Nominal current, I_{op} (kA)	12.0
	Stored energy, E (MJ)	500
	Inductance (H)	6.9
	Peak magnetic field, B_p (T)	5.4
	Average field in the bores (T)	2.5
Conductor:	Overall size (mm^2)	35 × 8
	Number of strands	40
	Strand diameter (mm)	1.3
	Critical current @ 5 T, I_c (kA)	58
	Operating temperature, T_{op} (K)	4.5
	Operational margin	40%
	Temperature margin @ 5.4 T (K)	1.9
Heat Load:	at 4.5 K (W)	~150
	at 60-80 K (kW)	~1.6



(ATLAS toroid 26 m long, 20 m diameter, peak field 3.9 T)

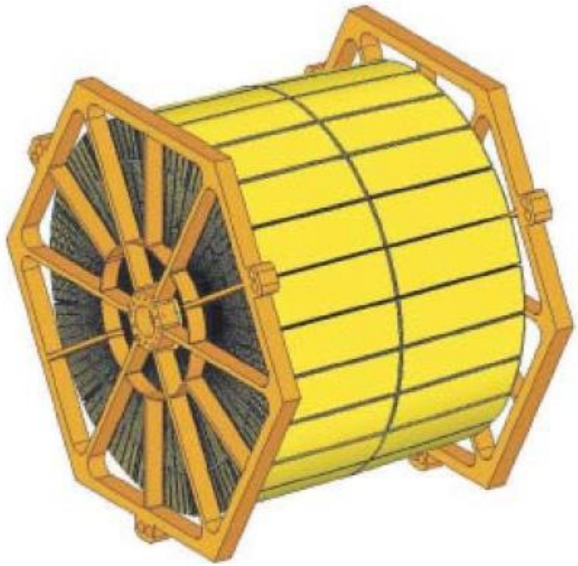
IAXO x-ray optics

Each bore equipped with an X-ray optics
8 systems of 600 mm diameter each

Baseline : X-ray optics for NUSTAR satellite

Specifications:

- •Refined imaging not needed
- •Need to cover large area (cost-effective)
- •Good throughput (0.3-0.5)
- •Small focal point (~1 cm^2)



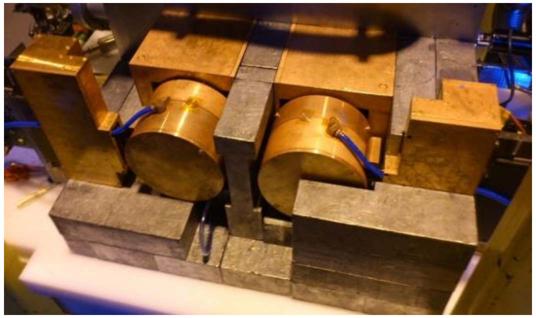
Telescopes	8
N, Layers (or shells) per telescope	123
Segments per telescope	2172
Geometric area of glass per telescope	0.38 m^2
Focal length	5.0 m
Inner radius	50 mm
Outer Radius	300 mm
Minimum graze angle	2.63 mrad
Maximum graze angle	15.0 mrad
Coatings	W/B_4C multilayers
Pass band	1 – 10 keV
IAXO Nominal, 50% EEF (HPD)	0.29 mrad
IAXO Enhanced, 50% EEF (HPD)	0.23 mrad
IAXO Nominal, 80% EEF	0.58 mrad
IAXO Enhanced, 90% EEF	0.58 mrad
FOV	2.9 mrad

IAXO low background detectors

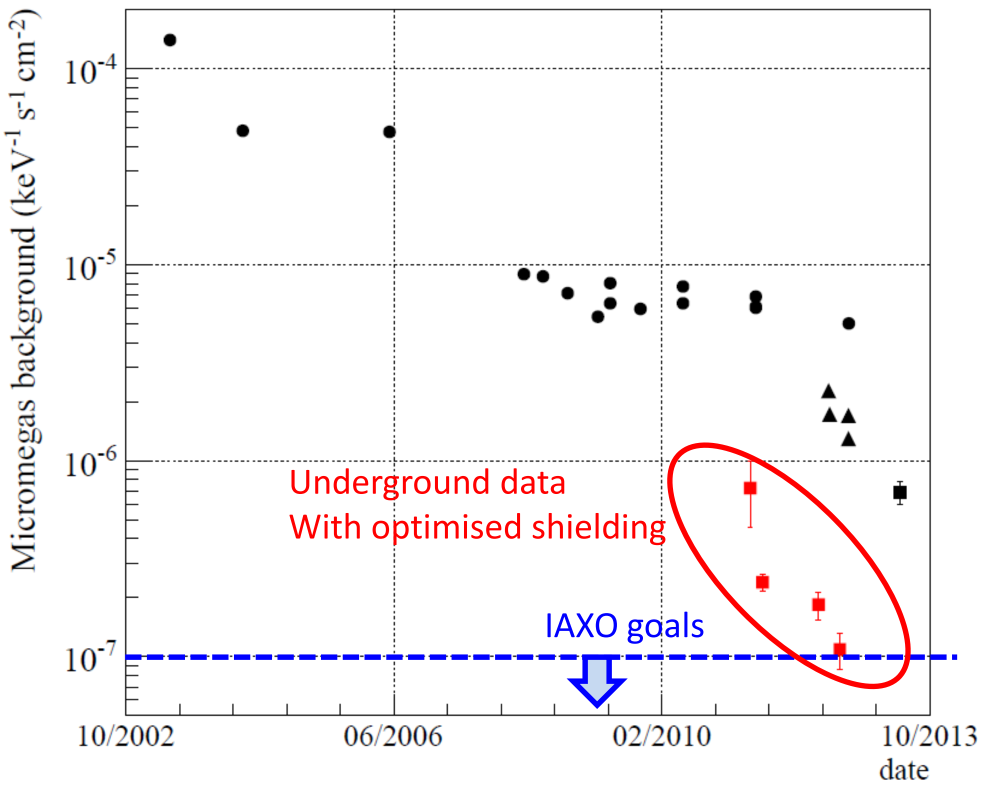
Baseline: gaseous detectors (Micromegas)

Goal: below 10^{-7} c/keV/s/cm^2

Key elements:
- Radiopure components
- Shielding
- Offline discrimination



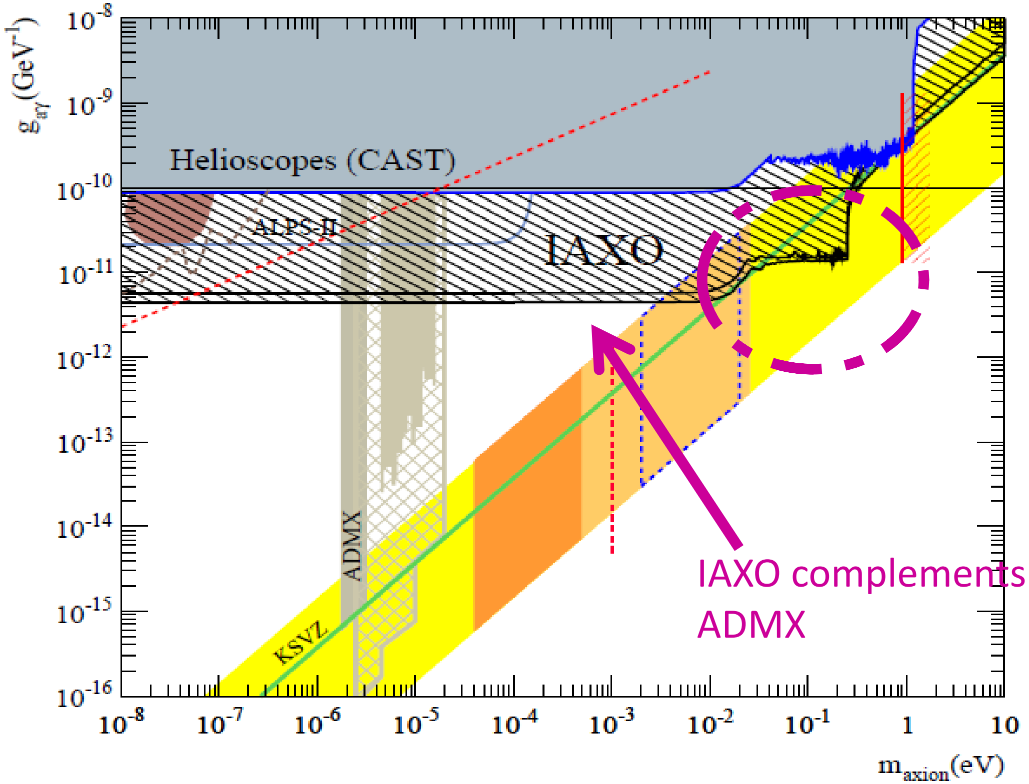
Evolution of Micromegas CAST background



Pathfinder system running in CAST:
last generation of Microbulk detectors + optimised shielding + Xray telescope

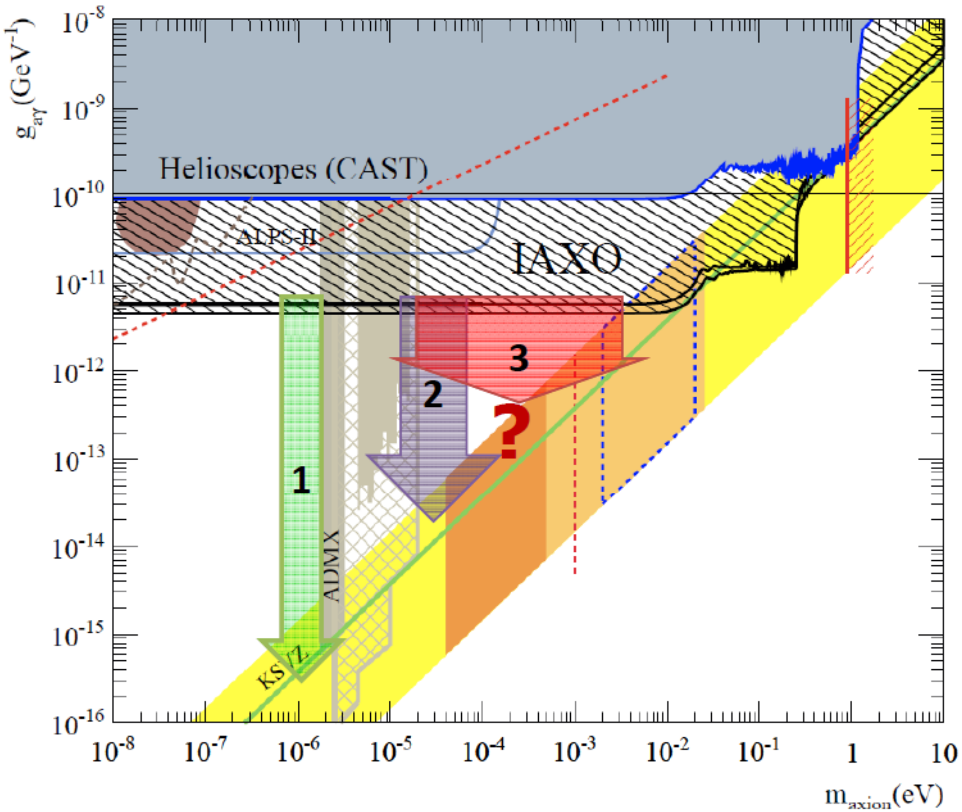
➔ CASTMM 2014 : 0.85 x 10^{-6} c/keV/s/cm^2

IAXO sensitivity prospects



Exploration of very extended QCD axion region

Additional physics cases



IAXO would improve the sensitivity to g_{ae}

Extending ensitivity to other ALP or WISP models at the low energy frontier: paraphotons, chameleons…

Extend the sensitivity to dark matter halo axions by the use of microwave cavities or dish antennas : **IAXO-DM**

➔**IAXO as a « generic axion/ALP facility »**

IAXO-DM

Lots of new ideas, prospects under study

- Precession of nuclear spins (CASPERs): PRD 84, 055013 (2011) and arXiv:1306.6089
- Long thin cavities in dipole fields: PRD85 (2012) 035018
- Directional effect in long thin cavities: JCAP 1210 (2012) 022
- Dish antenna: JCAP 1304 (2013) 016
- Directional effect in dish antenna: arXiv:1307.7181
- LC circuit in B field: PRL 112, 131301 (2014)
- Active resonators: arXiv:1403.6720
- Cavitiy with wires: arXiv:1403.3121 (also old Sikivie paper)

IAXO status of project

•2011: First studies ***Irtastorza et al. JCAP (2011) 1106:013***

•ASPERA/APPEC Roadmap acknowledges axion physics, CAST and recommends progress towards IAXO (C. Spiering Krakow 2012)

•IAXO is also present in US roadmapping (Snowmass and P5 process) (december 2013)

•2013: Conceptual Design: ***Armengaud et al. JINST 9 (2014) T05002***

•August 2013: Letter of Intent submitted to the **CERN SPSC [CERN-SPSC-2013-022]**

•January 2014: Recommendations of SPSC

> 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.

IAXO Collaboration

JINST

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *January 15, 2014*
ACCEPTED: *February 17, 2014*
PUBLISHED: *May 12, 2014*

TECHNICAL REPORT

Conceptual design of the International Axion Observatory (IAXO)

E. Armengaud,[a] F.T. Avignone,[b] M. Betz,[c] P. Brax,[d] P. Brun,[a] G. Cantatore,[e] J.M. Carmona,[f] G.P. Carosi,[g] F. Caspers,[c] S. Caspi,[h] S.A. Cetin,[i] D. Chelouche,[j] F.E. Christensen,[k] A. Dael,[a] T. Dafni,[f] M. Davenport,[c] A.V. Derbin,[l] K. Desch,[m] A. Diago,[f] B. Döbrich,[n] I. Dratchnev,[l] A. Dudarev,[c] C. Eleftheriadis,[o] G. Fanourakis,[p] E. Ferrer-Ribas,[a] J. Galán,[a] J.A. Garcia,[f] J.G. Garza,[f] T. Geralis,[p] B. Gimeno,[q] I. Giomataris,[a] S. Gninenko,[r] H. Gómez,[f] D. González-Diaz,[f] E. Guendelman,[s] C.J. Hailey,[t] T. Hiramatsu,[u] D.H.H. Hoffmann,[v] D. Horns,[w] F.J. Iguaz,[f] I.G. Irastorza,[f,1] J. Isern,[x] K. Imai,[y] A.C. Jakobsen,[k] J. Jaeckel,[z] K. Jakovčić,[aa] J. Kaminski,[m] M. Kawasaki,[ab] M. Karuza,[ac] M. Krčmar,[aa] K. Kousouris,[c] C. Krieger,[m] B. Lakić,[aa] O. Limousin,[a] A. Lindner,[n] A. Liolios,[o] G. Luzón,[f] S. Matsuki,[ad] V.N. Muratova,[l] C. Nones,[a] I. Ortega,[f] T. Papaevangelou,[a] M.J. Pivovaroff,[g] G. Raffelt,[ae] J. Redondo,[ae] A. Ringwald,[n] S. Russenschuck,[c] J. Ruz,[g] K. Saikawa,[af] I. Savvidis,[o] T. Sekiguchi,[ab] Y.K. Semertzidis,[ag] I. Shilon,[c] P. Sikivie,[ah] H. Silva,[c] H. ten Kate,[c] A. Tomas,[f] S. Troitsky,[r] T. Vafeiadis,[c] K. van Bibber,[ai] P. Vedrine,[a] J.A. Villar,[f] J.K. Vogel,[g] L. Walckiers,[c] A. Weltman,[aj] W. Wester,[ak] S.C. Yildiz[i] and K. Zioutas[al]

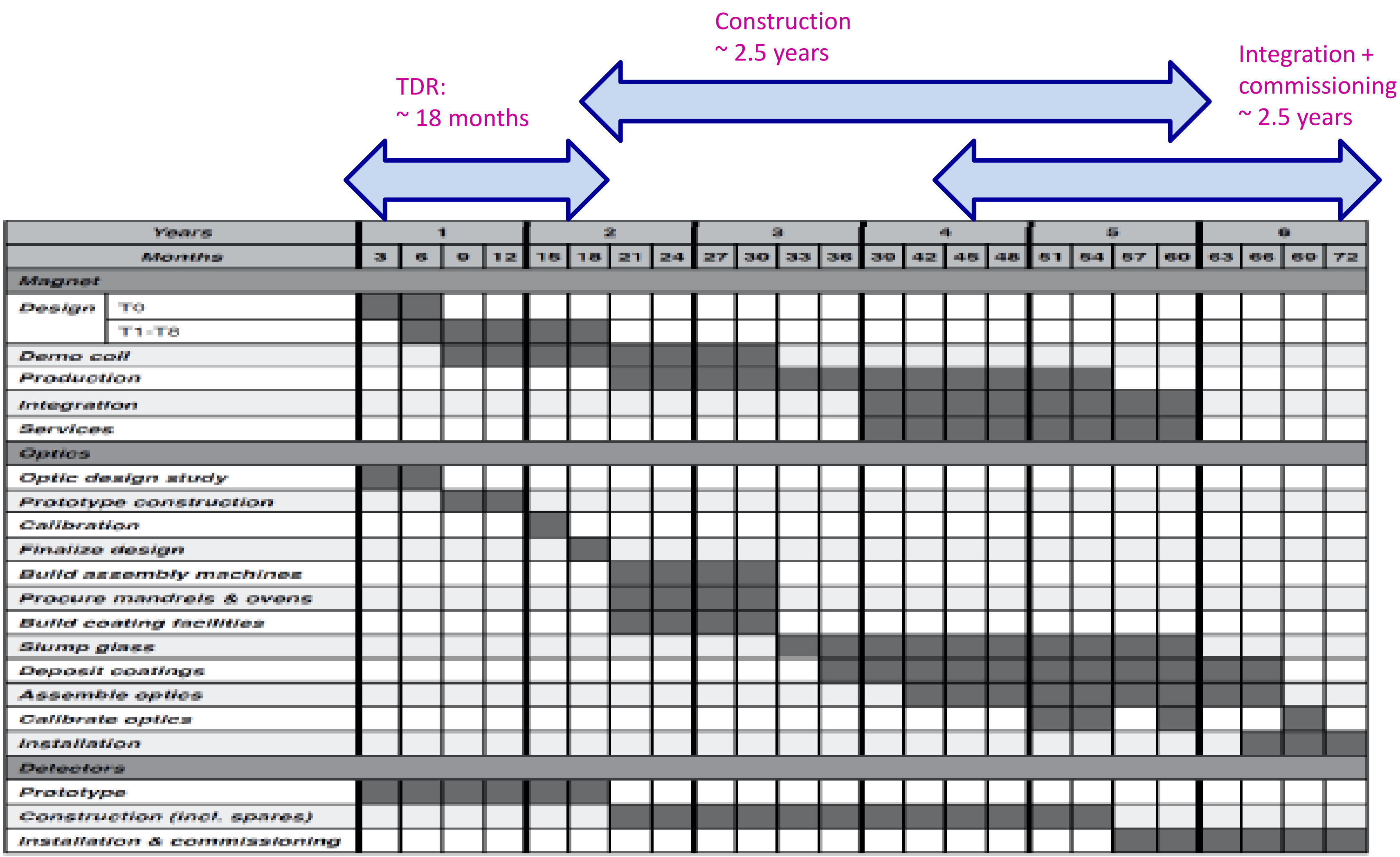
[a]*CEA Irfu, Centre de Saclay, F-91191 Gif-sur-Yvette, France*
[b]*Physics Department, University of South Carolina, Columbia, SC, U.S.A.*
[c]*European Organization for Nuclear Research (CERN), Genève, Switzerland*
[d]*IPHT, Centre d'Études de Saclay (CEA-Saclay), Gif-sur-Yvette, France*
[e]*Instituto Nazionale di Fisica Nucleare (INFN), Sezione di Trieste and Università di Trieste, Trieste, Italy*
[f]*Laboratorio de Física Nuclear y Altas Energías, Universidad de Zaragoza, Zaragoza, Spain*
[g]*Lawrence Livermore National Laboratory, Livermore, CA, U.S.A.*
[h]*Lawrence Berkeley National Laboratory, U.S.A.*
[i]*Dogus University, Istanbul, Turkey*
[j]*Physics Department, University of Haifa, Haifa, 31905 Israel*
[k]*Technical University of Denmark, DTU Space Kgs. Lyngby, Denmark*

[1]Corresponding author.

2014 JINST 9 T05002

~80 authors

IAXO timeline



Short term plans

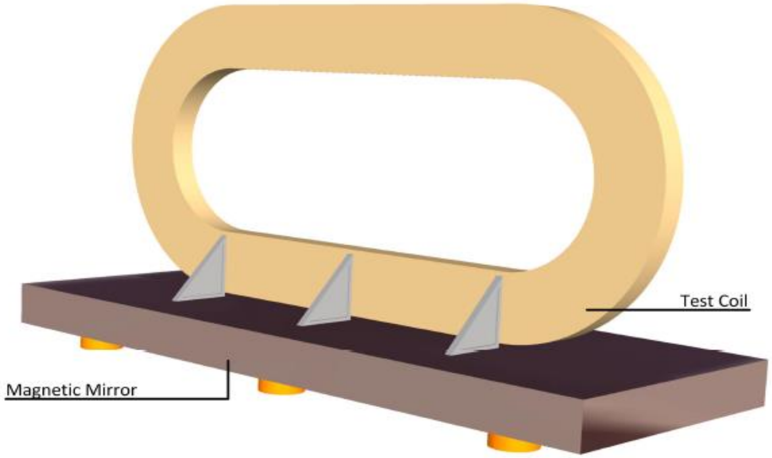
Complete a Technical Design Report:

- Construction of a demonstration coil IAXO-TO
- Constructiuon of a prototype x-rays optics IAXO-X0
- Construction of a low background detector IAXO-D0
- Study and validate alternative detector technologies
- Feasability for IAXO-DM

Site studies

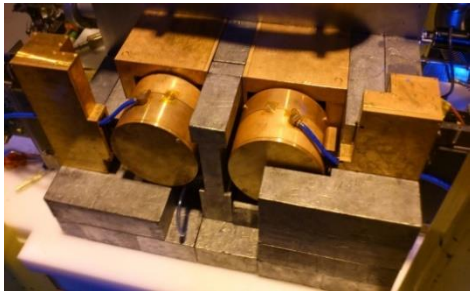
Enlarge the collaboration

IAXO-T0



IAXO-X0

IAXO-D0



Conclusions and next steps

Axion searches→ strong physics case

Increasing experimental effort in the different axion searches strategies: solar axions, relic axions, laboratory axions…

CAST has been a very important milestone in axion research during the last decade

IAXO can probe deep into unexplored axion-ALP parameter space

IAXO could become next large project & a **generic axion facility with discovery protential in the next decade**

Need to continue with TDR & preparatory activities, formal endorsement & resources finding

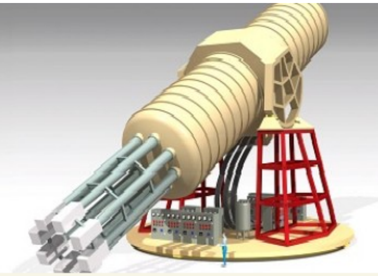
- Construction of demonstration coil IAXO-T0
- Construction of a prototype x-ray optics IAXO-X0
- Construction of a prototype low background detector IAXO-D0
- Refine and update physics case
- Feasability studies for IAXO-DM

Exciting work in front us: join us!

http://iaxo.web.cern.ch/iaxo/

IAXO

The International Axion Observatory



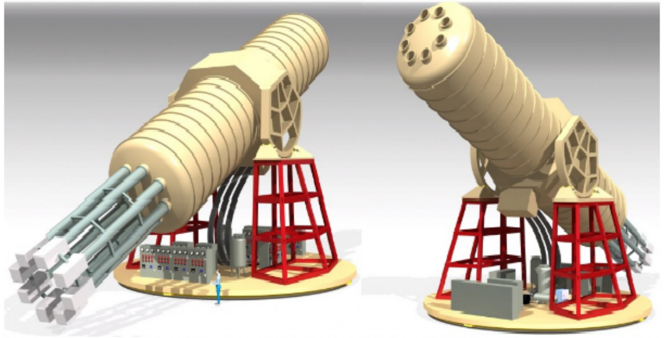
Home | The Experiment | Collaboration | Publications and conferences | Outreach | News

Home

Welcome to the home page of the IAXO project!

The International Axion Observatory (IAXO) is a proposed fourth generation axion helioscope. It aims at a sensitivity much improved with respect to past and current axion searches, with real discovery potential.

The conceptual design of the experiment has been finished and a Letter of Intent submitted to CERN. Recently, the SPSC has recognised the physics case of IAXO and has recommended to proceed with a Technical Design Report.



Views of the conceptual design of IAXO

Search …

Recent Posts

IAXO in the CERN Courier

SPSC recommends IAXO

Letter of Intent to CERN submitted

Categories

General

News

Outreach

Publications

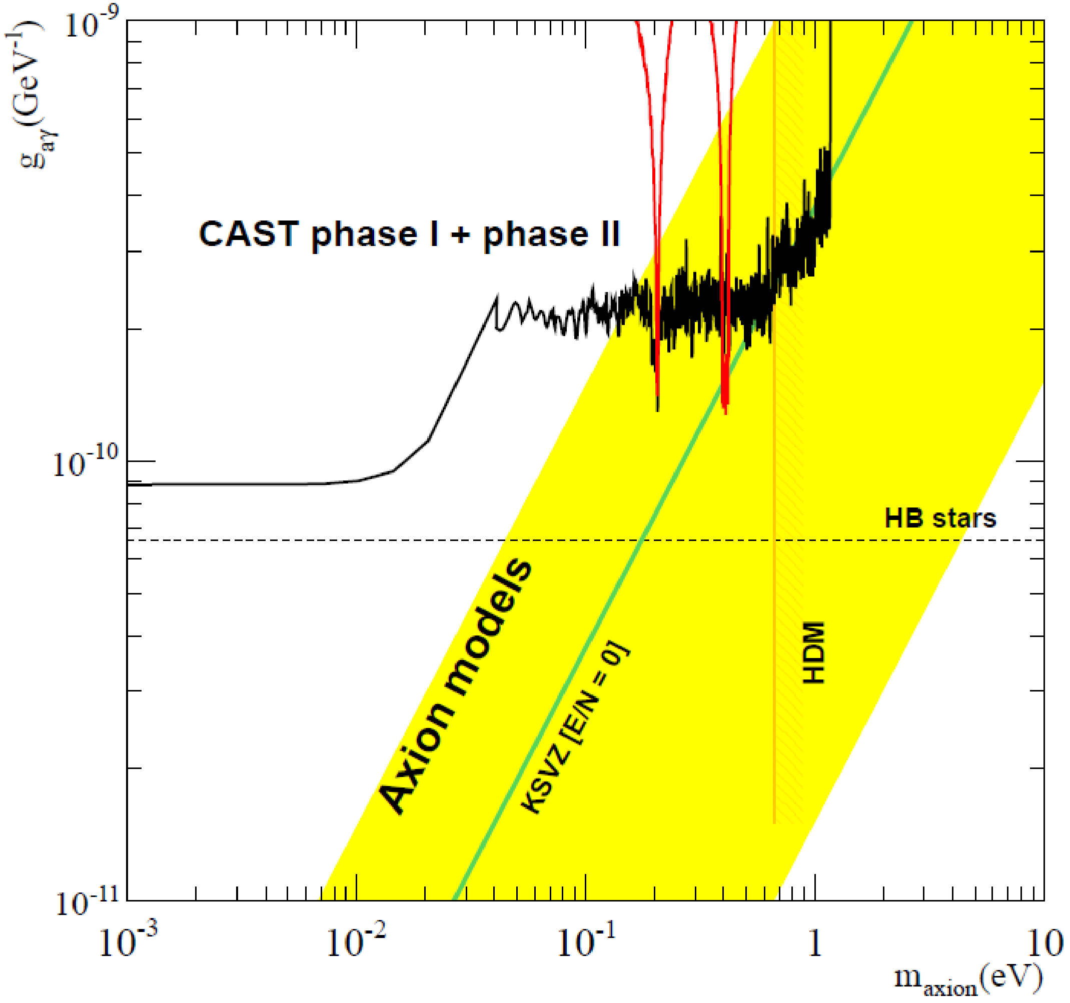
Meta

Log in

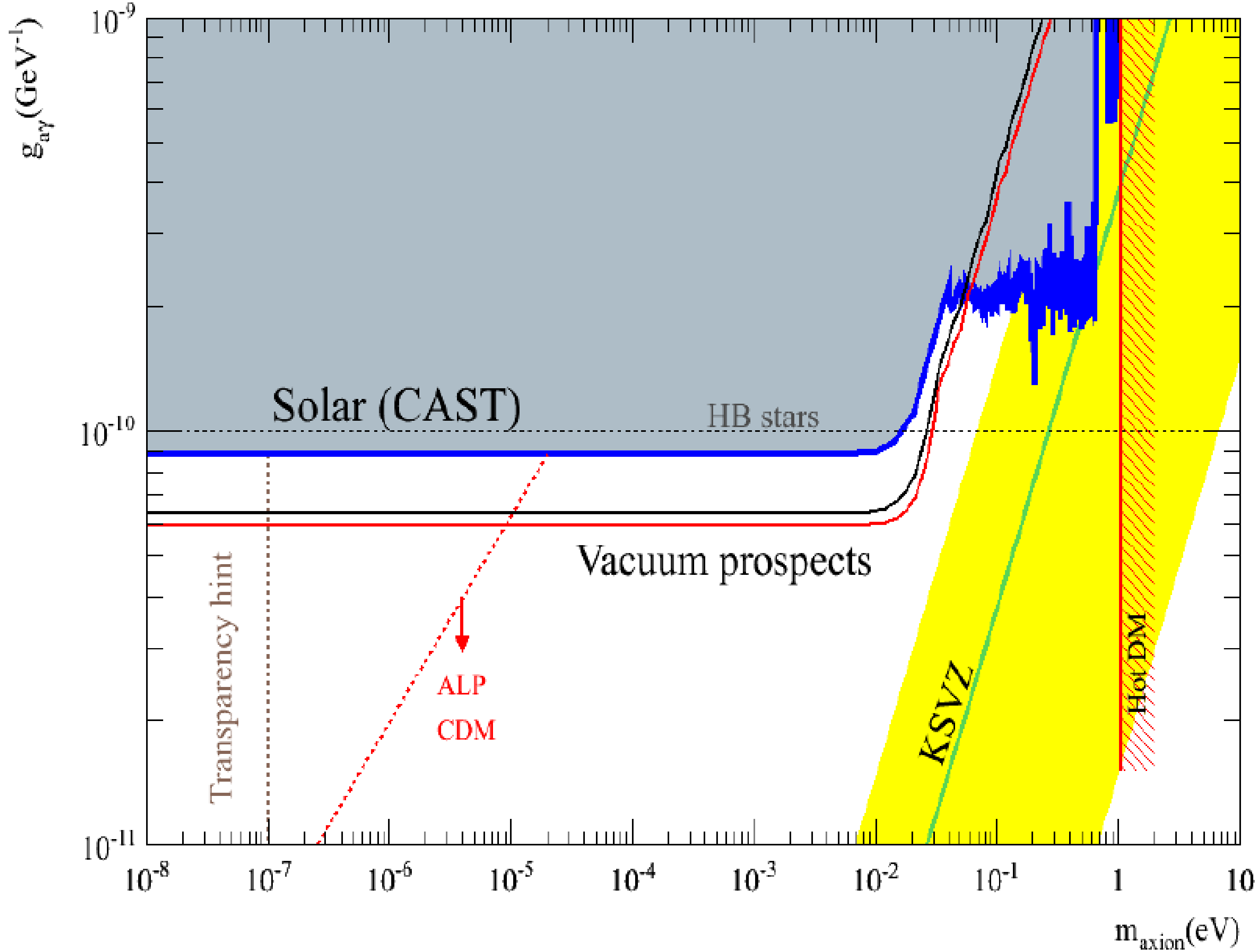
Entries RSS

Comments RSS

BACK UP



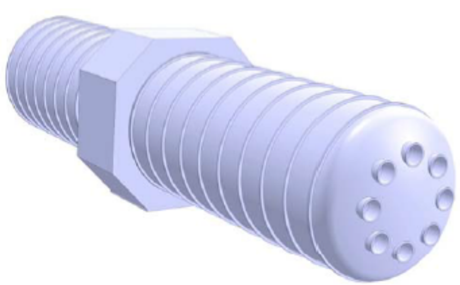
New solar axion search in CAST with ^{4}He Filling, Arik et al. Submitted to PRL
arXiv:1503.00610 [hep-ex]

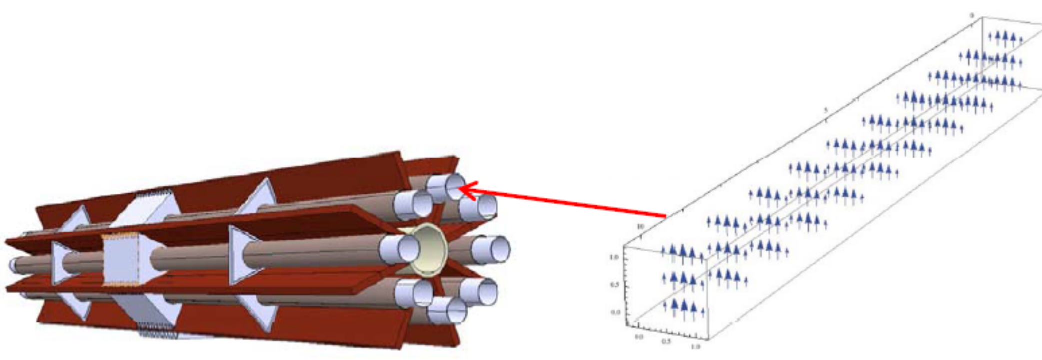


$g_{a\gamma}$ (GeV^{-1})
10^{-9}
10^{-10}
10^{-11}
Solar (CAST)
HB stars
Vacuum prospects
Transparency hint
ALP
CDM
KSVZ
Hot DM
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
m_{axion}(eV)

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?



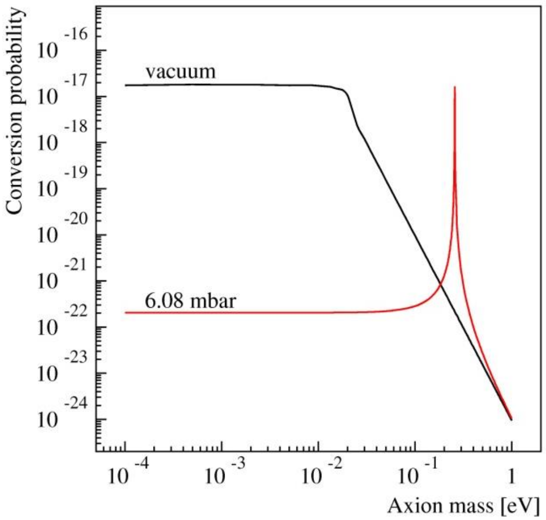


Extending sensitivity to higher masses

Axion to photon conversion probability:

$$P_{a\to\gamma} = \left(\frac{Bg_{a\gamma}}{2}\right)^2 \frac{1}{q^2+\Gamma^2/4}\left[1+e^{-\Gamma L}-2e^{-\Gamma L/2}\cos(qL)\right]$$

Vacuum:
$\Gamma=0$, $m_\gamma=0$



with $$q = \left|\frac{m_\gamma^2 - m_a^2}{2E_a}\right| \qquad m_\gamma(\mathrm{eV}) = \sqrt{\frac{4\pi\alpha N_e}{m_e}} \approx 28.9\sqrt{\frac{Z}{A}\rho\left(\frac{\mathrm{kg}}{\mathrm{m}^3}\right)}$$

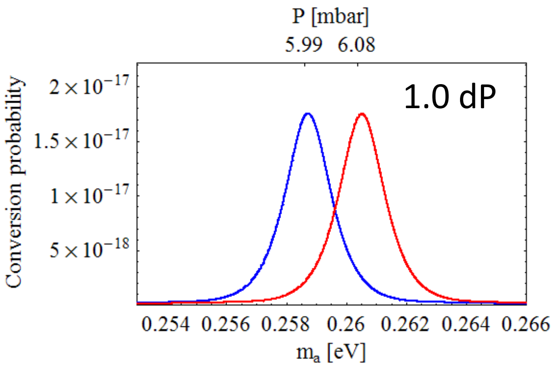
Coherence condition: $qL < \pi$

For CAST phase I conditions (vacuum), **coherence is lost for $m_a > 0.02$ eV**

With the presence of a **buffer gas** it can be **restored** for a narrow mass range:

$$qL < \pi \Rightarrow \sqrt{m_\gamma^2 - \frac{2\pi E_a}{L}} < m_a < \sqrt{m_\gamma^2 + \frac{2\pi E_a}{L}}$$

e.g. for 50 mbar $\Delta m_a \sim 10^{-3}$ eV



IAXO costs

Item	Cost (MCHF)	Subtotals (MCHF)
Magnet		31.3
Eight coils based assembled toroid	28	
Magnet services	3.3	
Optics		16.0
Prototype Optic: Design, Fabrication, Calibration, Analysis	1.0	
IAXO telescopes (8 + 1 spare)	8.0	
Calibration	2.0	
Integration and alignment	5.0	
Detectors		5.8
Shielding & mechanics	2.1	
Readouts, DAQ electronics & computing	0.8	
Calibration systems	1.5	
Gas & vacuum	1.4	
Dome, base, services building and integration		3.7
Sum		**56.8**

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.