baby-IAXO

Prospects on future solar axion searches with the International AXion Observatory

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LDMA 2019, 20-22 November, Venize

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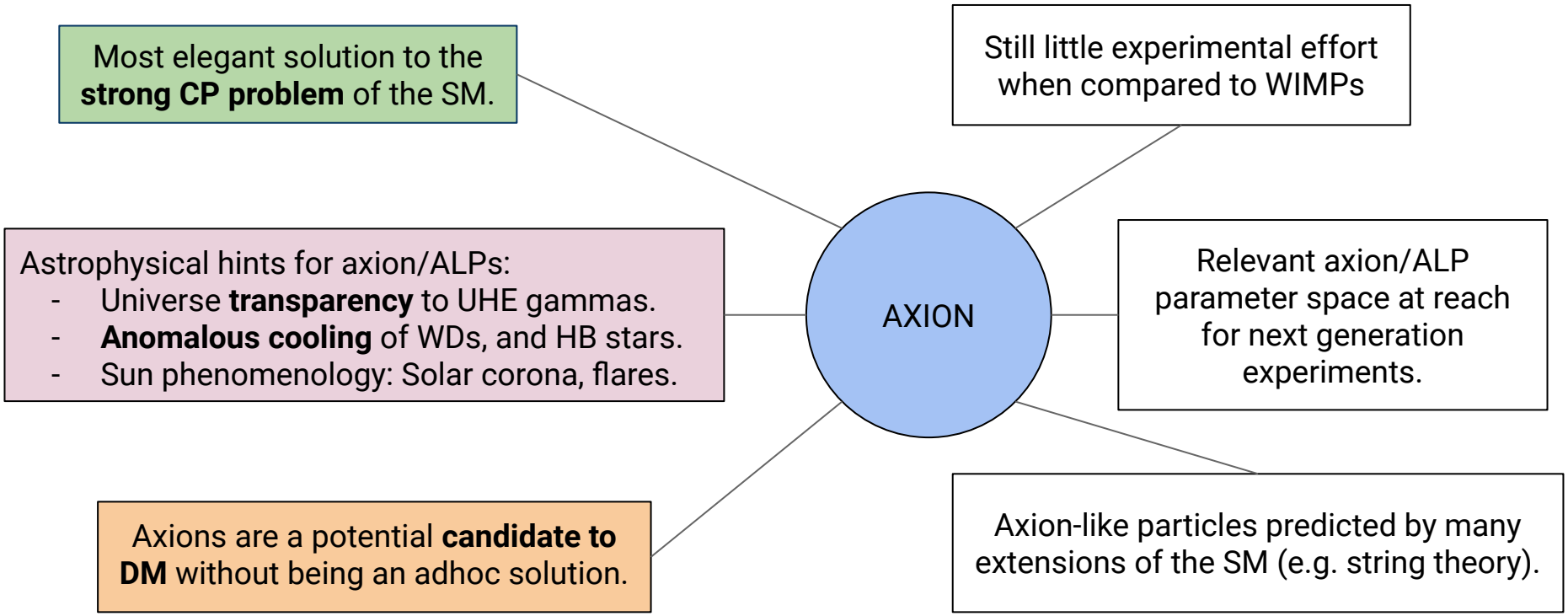
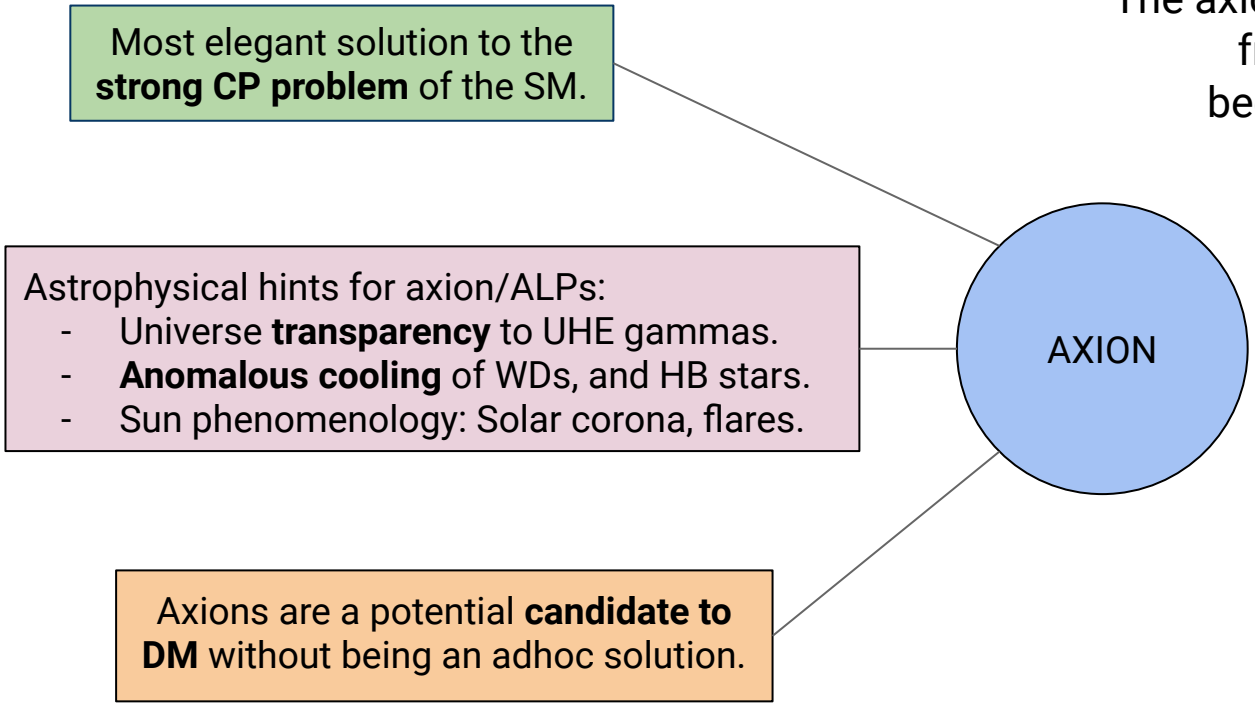
Axion search motivation



Axion search motivation



The axion is a very attractive particle from a theoretical perspective because it would bring together

Particle Physics

Astrophysics

and Cosmology

in a natural way.

Axion detection techniques

Due to its interaction with light it is a **very attractive particle from the experimental point of view**.
Many ideas leading to different detection techniques.

Axion detection technique	Experiments	Model and cosmology dependency	Technology
Haloscope	ADMX, HAYSATC, CASPer, CULTASK, CAST-CAPP, MADMAX, ORGAN, RADES, QUAX, ...	High	New ideas emerging, Active R&D going on, ...
Laser/Interferometry	ALPS, OSQAR, CROWS, ARIADNE	Very Low	Ready for large scale experiment
Helioscope	SUMICO, CAST, (NuSTAR), IAXO & baby-IAXO	Low	Ready for large scale experiment

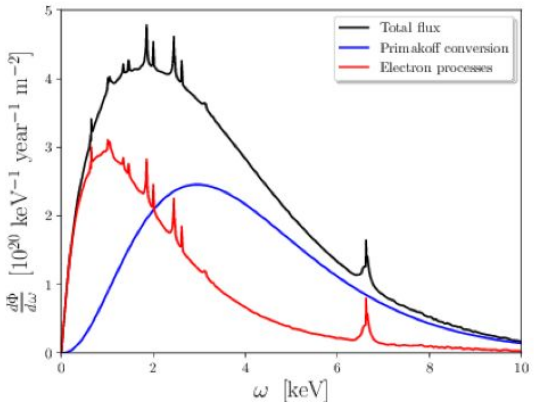
Helioscope technique does not require axions to be a dominant component of dark matter.

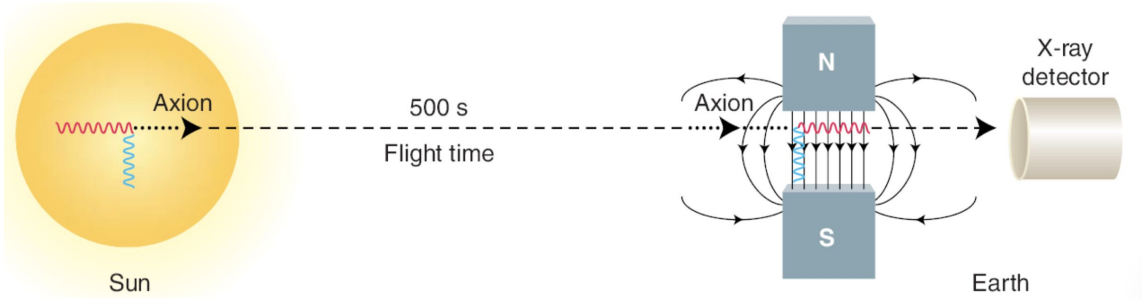
Solar Axion Detection principle

Axion helioscope idea was proposed by P. Sikivie

Sikivie PRL 51:1415 (1983)

- Blackbody photons (keV) in solar core are converted into axions in the dense stellar plasma.
- Reconversions of axions into x-ray photons possible in strong laboratory magnetic field





Idea refined by K. van Bibber, Raffelt et al. by using buffer gas to restore coherence over long magnetic field

Van Bibber et al. Phys.Rev. D 39:2089 (1989)

Helioscope generations

Today we are living in the 3rd helioscope generation

1st generation helioscope: Brookhaven

- Just a few hours of data
- Lazarus et at. PRL 69 (92)

2nd generation: Tokyo Helioscope (SUMICO)

- 2.3 m long, 4 T magnet

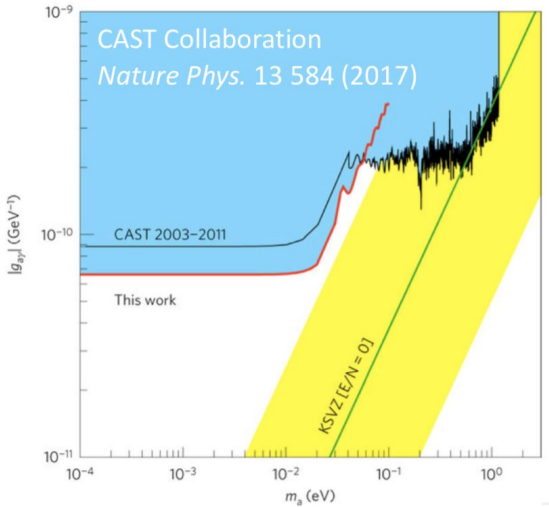
3rd generation: CERN Axion Solar Telescope (CAST)

- Most sensitive axion helioscope to date (10 m, 9 T) - No axions detected yet

- Best experimental limit on axion-photon coupling over broad axion mass range

$$g_{a\gamma} < 0.66 \times 10^{-10}\ \text{GeV}^{-1}\ (95\%\ \text{C.L.})$$

- Latest CAST results have been provided by IAXO-pathfinder. Discussed later.



IAXO. A 4th Generation helioscope

2011

Studies with experience gained pointed to a potential increase on sensitivity by building a new dedicated helioscope

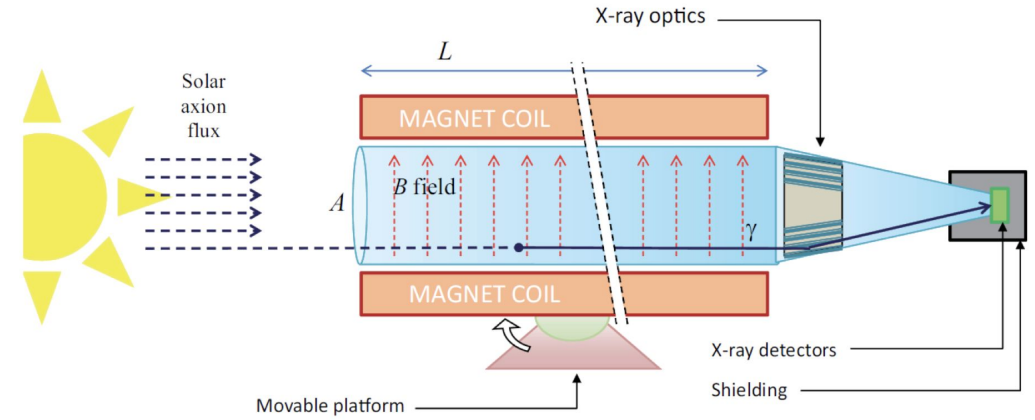
JCAP 1106, 013 (2011)

Sensitivity to g_{ag} coupling.

IAXO Figure Of Merit (FOM).

A factor 10,000 to 20,000 improvement over CAST.

Enhanced axion helioscope prospects by increasing each of the helioscope components



$$g_{a\gamma}^4 \propto \underbrace{(BL)^{-2} A^{-1}}_{\textbf{magnet}} \times \underbrace{t^{-1/2}}_{\textbf{exposure}} \times \underbrace{s^{1/2} \varepsilon_0^{-1}}_{\textbf{optics}} \times \underbrace{b^{1/2} \varepsilon^{-1}}_{\textbf{detectors}}$$

B = magnetic field, *L* = magnet length, *A* = cross-sectional area

t = time

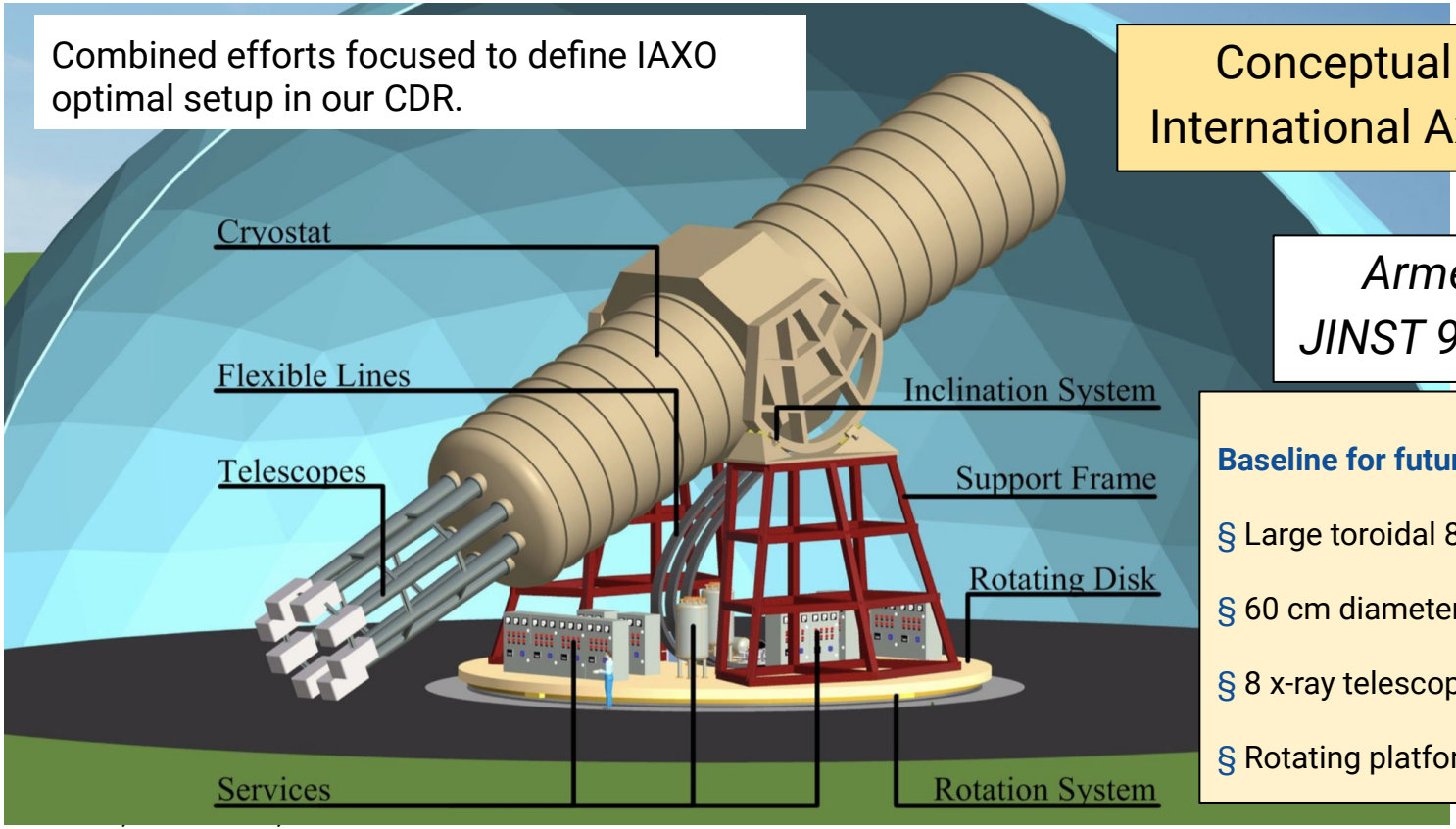
s = spot size, ε_0 = efficiency

b = background, ε = efficiency

IAXO Conceptual Design

2014

Combined efforts focused to define IAXO optimal setup in our CDR.



Conceptual Design of the International Axion Observatory

Armengaud et al. JINST 9 T05002 (2014)

Baseline for future IAXO

§ Large toroidal 8-coil magnet L ≃ 20 m

§ 60 cm diameter each bore

§ 8 x-ray telescopes + 8 detection systems

§ Rotating platform with services

IAXO Pathfinder. Optics and detectors in CAST

2014-15

IAXO Pathfinder supports the testing new systems, R&D for IAXO

§ **Small x-ray optics**

• Fabricated purposely using thermally-formed glass substrates (NuSTAR-like)

§ **Micromegas low background detector**

• Applied lessons learned from R&D: compactness, better shielding, radiopurity,...

§ **Data acquisition at CAST (2014/15)**

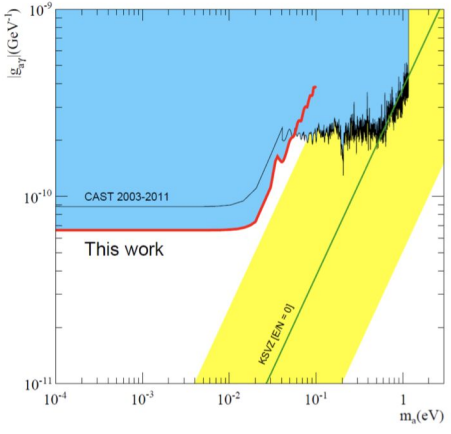
• Background level ~ 0.003 counts/hour

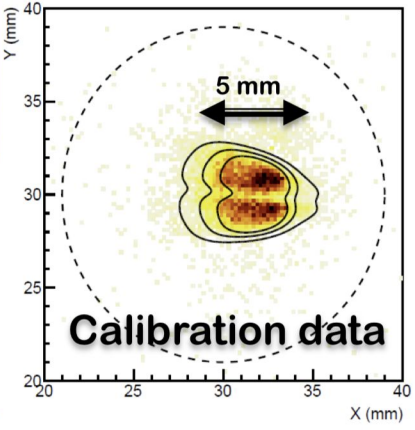
Sensitivity increase for CAST

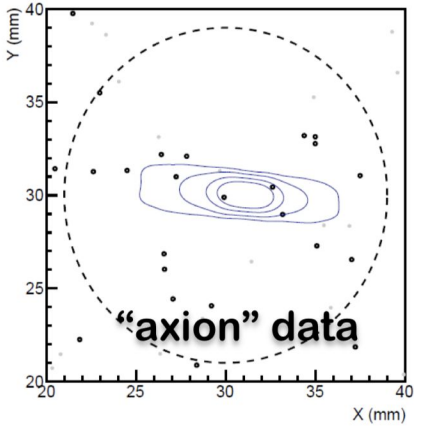
and

Testbench for IAXO

Anastassopoulos et al. Nature Phys. ***13*** *(2017) 584-590*







Baby-IAXO. A prototype with physics reach.

2019

BabyIAXO = Intermediate experimental stage before IAXO

§ Performance verification for IAXO and **significant science return** simultaneously

§ Conceptual design finished (Presented to DESY Oct 2018)

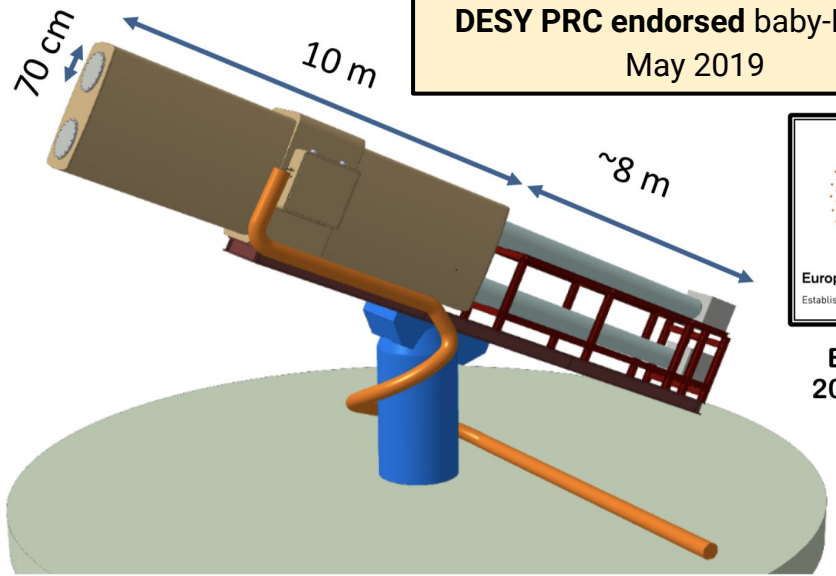
§ Two bores of dimensions similar to final IAXO bores

Aperture/diameter [m]	2 x 0.7
Magnetic field length [m]	10
Average field intensity [T]	~2-3
Peak field [T]	4.1

~10x CAST B^2L^2A

ERC advanced grant by I. Irastorza to support the development of baby-IAXO and enhance future IAXO prospects.

DESY PRC endorsed baby-IAXO in May 2019

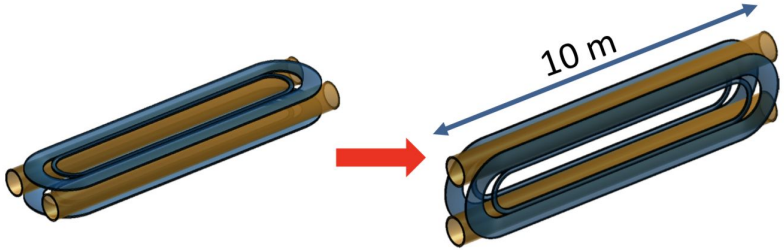


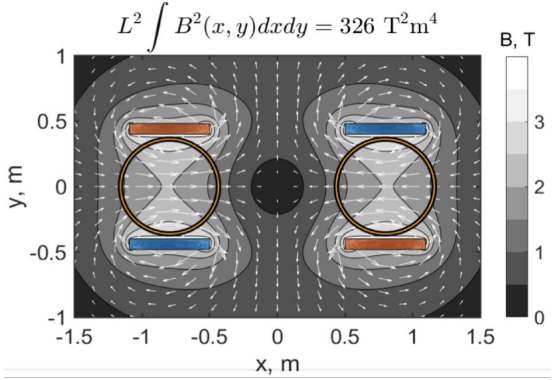
erc
European Research Council
Established by the European Commission

ERC-AvG 2017 IAXO+

Baby-IAXO magnet design

Baby-IAXO magnet : “Common coil” configuration chosen.
Minimal construction risk with existing infrastructure

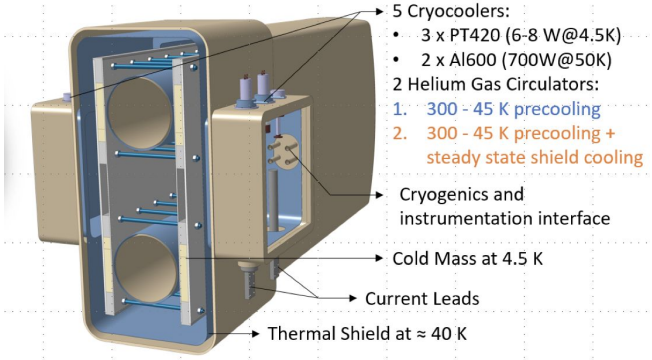




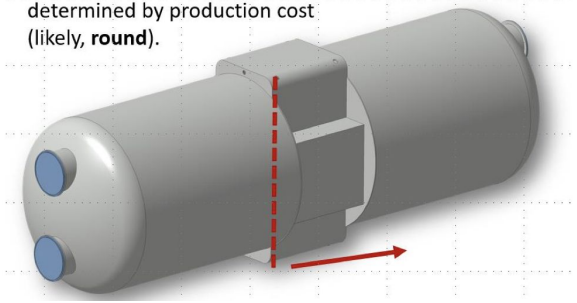
Much larger aperture magnet compared to CAST.

Magnetic profile not uniform, is not a requirement for axion searches, as opposed to accelerator physics.

Magnet conception & design moving towards **construction** design.



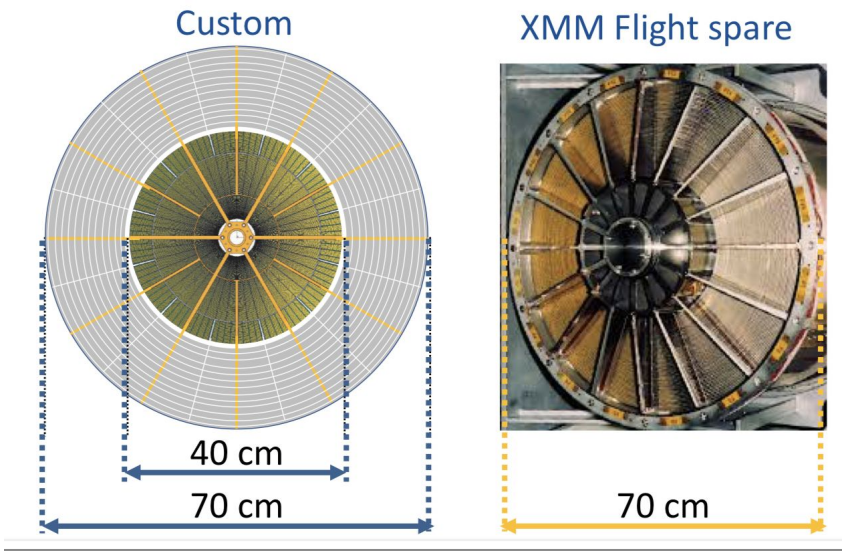
* shape of cryostat **end-caps** will be determined by production cost (likely, **round**).



J. Galan, LDMA2019, 22/Nov/2019

Baby-IAXO optics

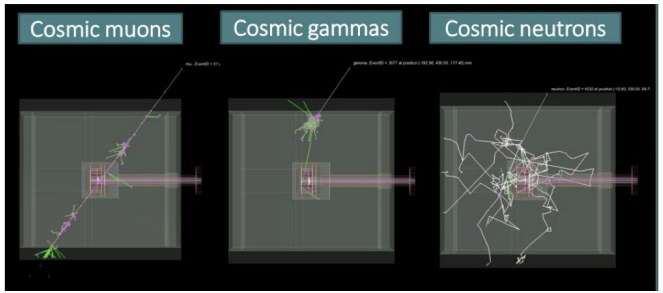
Optics



baby-IAXO will use:
- One custom IAXO optic (multilayer-coated, segmented- glass Wolter-I) to be built.
- and one existing flight spare XMM telescope from ESA.

– Minimal risk to the project
  a. In one hand, XMM optics specs very close to IAXO optics design
  b. In the other, we gain experience on the production of segmented segmented-glass optics for future IAXO (x8 optics)

Low background detectors for baby-IAXO



R&D program to understand the nature of the background and identify dominant components.

Many years expertise developed at Univ. of Zaragoza.

MonteCarlo
+
experimental data

Studies based on RESTSoft (Rare Event Searches with TPCs) Framework for data analysis and Geant4 MonteCarlo simulation.

Set-up optimization.

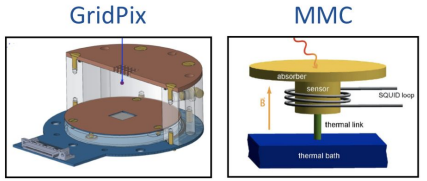
Combining active + passive shielding

Detectors

– Baseline option:

2 Micromegas setups

– In addition: an R&D generic platform to improve and tests all other detection technologies



Baby-IAXO and IAXO Physics reach

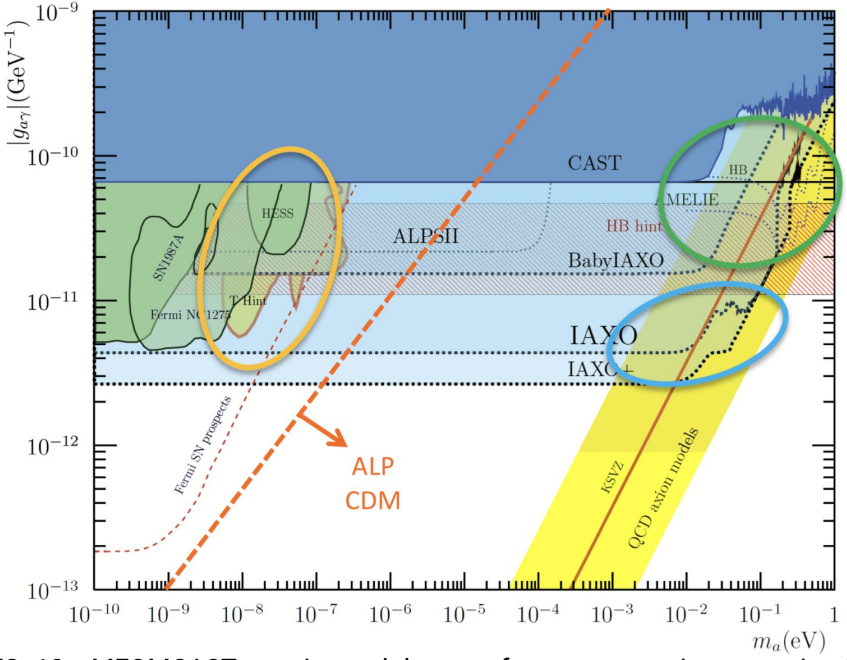
IAXO will probe large parts of QCD axion model space (KSVZ, DFSZ) including viable DM models

"ALP miracle" region: ALPs solving both DM & inflation Daido et al. 2017 arXiv:1710.11107

Large fraction of the axion & ALP models invoked in the "stellar cooling anomaly" (*gae* particularly interesting for this)

IAXO will fully explore ALP models invoked to solve the "transparency hint"

IAXO will also be able to probe large parameter space for CDM ALPs



Baby-IAXO: 10 x MFOMCAST + optics and detector from conservative scenario of LoI

IAXO: > 300 x MFOMCAST +optics and detector improvements

IAXO+: Enhanced scenario with x 10 (x4) higher FOM (MFOM) with respect LoI

Review on Physics potential of IAXO

A deep review on axion theory, axion hints and the physics reach of the future IAXO helioscope was recently published.

E. Armengaud et al., JCAP (2019) 06 047

Important reference for axion searches in general, 82 pages review.

Physics potential of the International Axion Observatory (IAXO)

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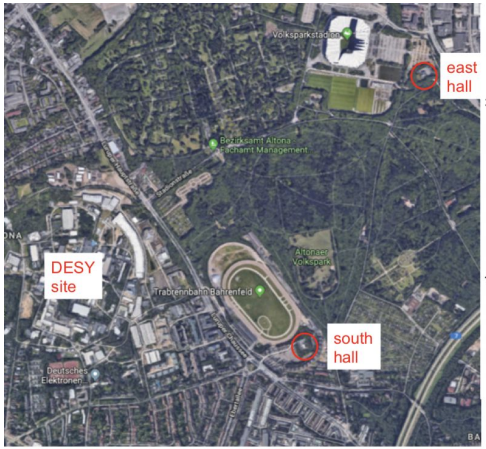
Baby-IAXO will be installed @ DESY

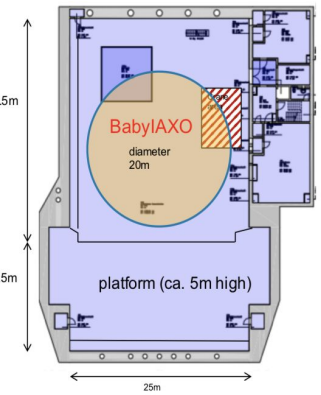
§ DESY HERA South and East Halls being considered as Baby-IAXO sites

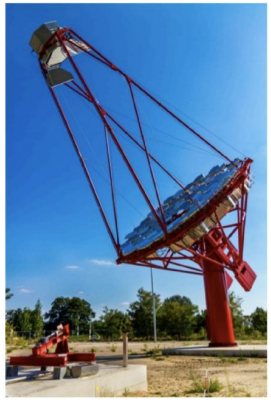
§ Infrastructure at DESY & good expertise very well suited to host IAXO

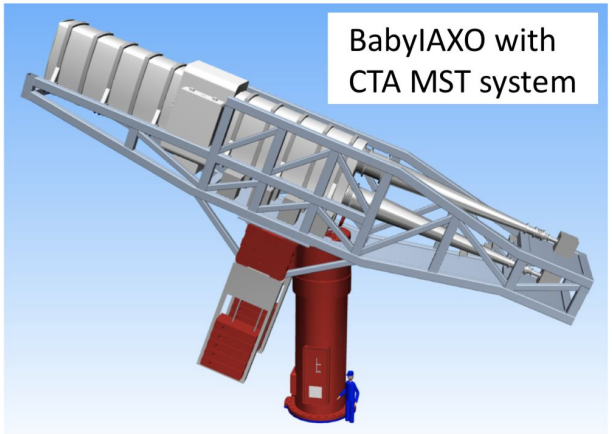
§ CTA MST prototype, support and drive system could be used for Baby-IAXO

Baby-IAXO Sun Tracking capabilities ~ 18 hours per day.



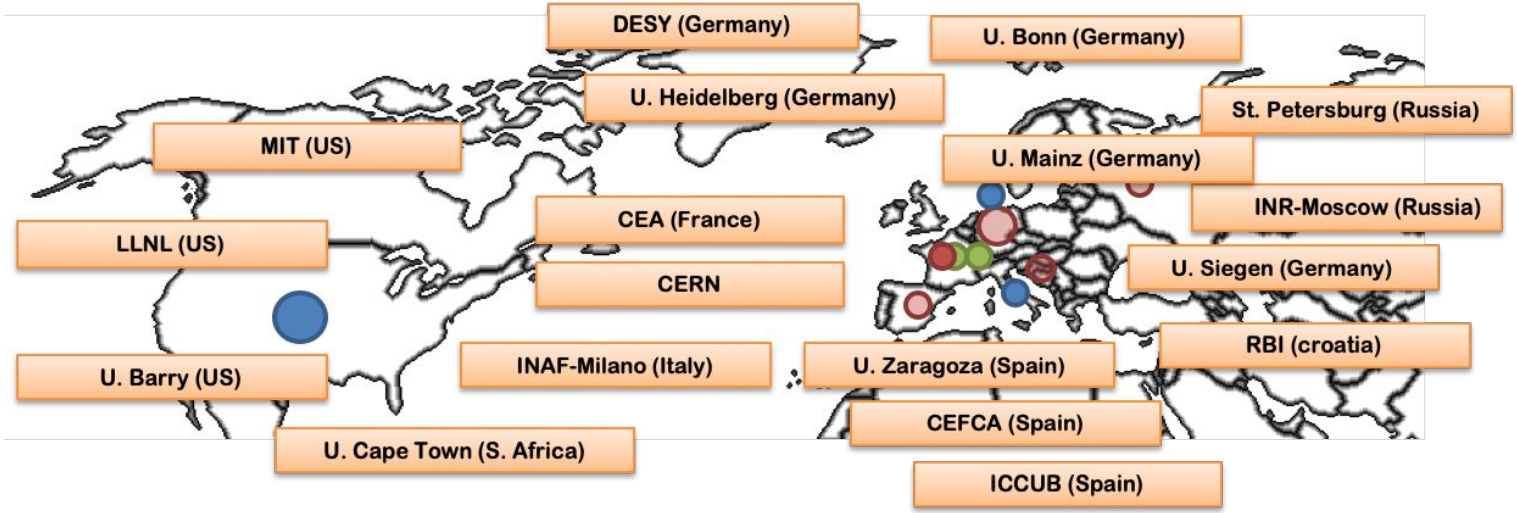






IAXO Collaboration

18 institutions from Germany, Spain, US, Italy, France, Russia, Croatia, S. Africa, CERN.



- DESY as host site for BabyIAXO
- ERC Advanced Grant for magnet development, detector platform and science reach exploration
- Always open to new partners. Very exciting time to join. From design to reality.

Summary on IAXO & Baby-IAXO Roadmap

2011 First concept studies date back to

2014 Positive CERN SPSC review

2016+ IAXO part of “Physics Beyond Colliders” process at CERN and the European Strategy for Particle Physics (ESPP)

- Summary Report of Physics Beyond Colliders at CERN (https://arxiv.org/abs/1902.00260)
- PBC at CERN: Beyond the Standard Model WG Report (http://arxiv.org/abs/arXiv:1901.09966)
- A European Strategy Towards Finding Axions and Other WISPs(https://indico.cern.ch/event/765096/contributions/3295758/)
- IAXO input to ESPP (https://indico.cern.ch/event/765096/contributions/3295553/)

2017 IAXO Collaboration formally established (18 institutions to date)

2018+ Near term goal defined for the collaboration: BabyIAXO

- BabyIAXO Magnet under design at CERN (Applied fellow)
- Important support decisions obtained recently: ERC AdG grant (Spain) and other preparatory IAXO projects granted in Germany, Croatia, Spain, US....
- First BabyIAXO physics expected as early as 2023
- Preparations for IAXO ongoing in parallel

Conclusions

§ Helioscopes can search for axions and ALPs from the Sun over wide mass range

§ IAXO/BabyIAXO simultaneously sensitive to QCD axions, addressing the dark matter problem and probing astrophysical hints

§ BabyIAXO envisioned to reach a few 10^{-11} GeV^{-1} in $g_{a\gamma}$

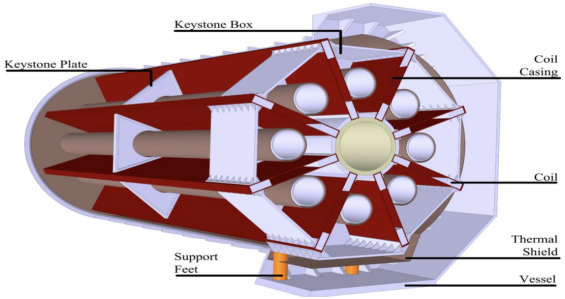
§ IAXO & IAXO+ will reach a few 10^{-12} GeV^{-1} in $g_{a\gamma}$ (>1 order of magnitude improvement in $g_{a\gamma}$ and > 4 Orders of Magnitude in S/N over CAST)

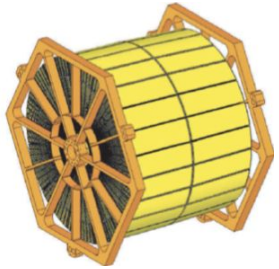
§ Diverse Physics reach:
QCD axions, ALPs, astrophysical hints, dark radiation, dark energy, ...

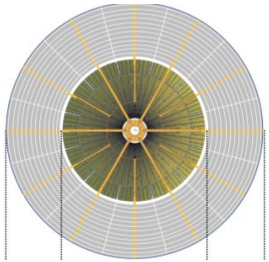
IAXO magnet, optics and detectors

IAXO magnet

- Superconducting “detector” magnet
- Toroidal geometry (8 coils)
- Based on ATLAS toroid technical solutions. 8 bores & 20m long.







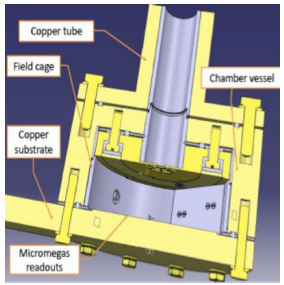
IAXO telescopes. IAXO Dedicated R&D

- Segmented-glass, multi-layer-coated optics
- Cost-effective to cover large areas
- Based on NuSTAR technology
- Focal length ≈ 5m
- 8 optics with 123+ layers each

IAXO detectors

- Micromegas gaseous detectors
- Radiopure components+ shielding
- Event topology in gas for discrimination
- Bgrd ≤10-7/(keV×cm2×s) through fabrication, radiopurity, shielding and event pattern recognition.

Other detector technologies

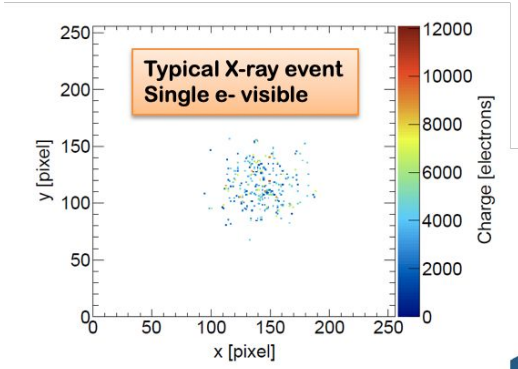


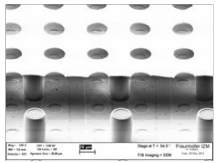
- GRIDPix low-threshold detector
- Magnetic Metallic Calorimeter (MMC) for better energy threshold and resolution.

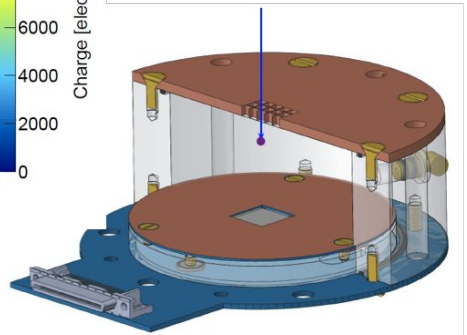
Additional detector technologies for IAXO

GridPix detectors (U. Bonn):

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

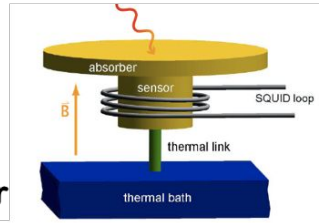


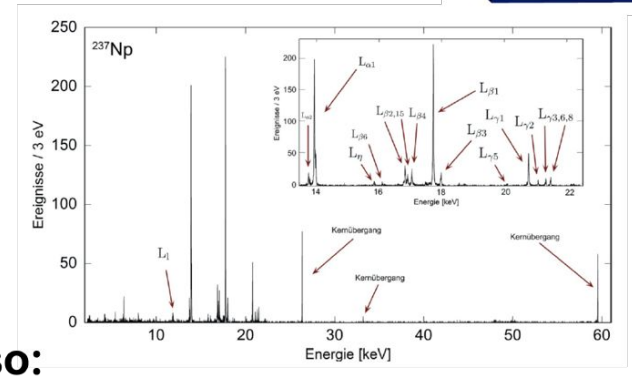




MMC detectors (U. Heidelberg):

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



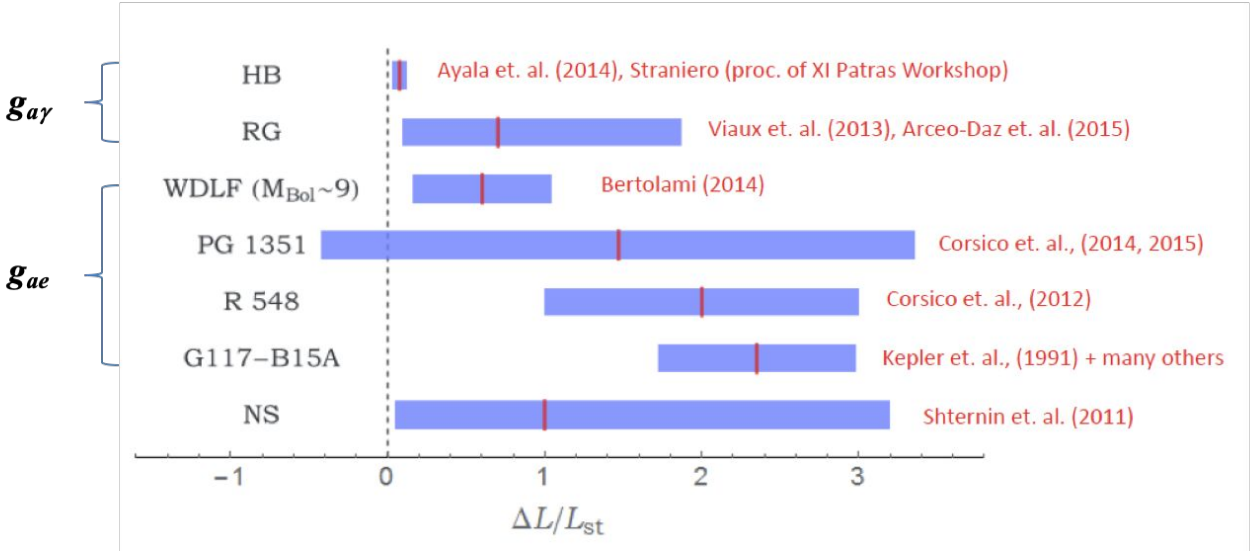


Also:

- Transition Edge Sensors (TES)
- Silicon Drift Detectors (SDD)

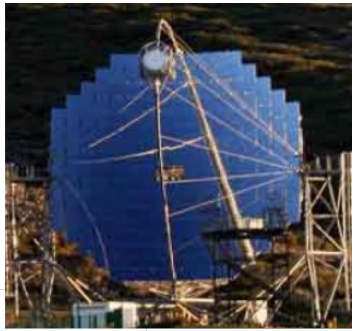
Astrophysical hints for axions

- **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**



Astrophysical hints for axions

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



ALP: $g_{a\gamma} \sim 10^{-12}\text{–}10^{-10}\ \text{GeV}^{-1}$

$m_a \lesssim 10^{-(10-7)}\ \text{eV}$