Axion and ALP Dark Matter Search with the International Axion Observatory (IAXO)

TeVPA 2017, Columbus, Ohio

Julia K. Vogel (Lawrence Livermore National Laboratory)
for the IAXO Collaboration

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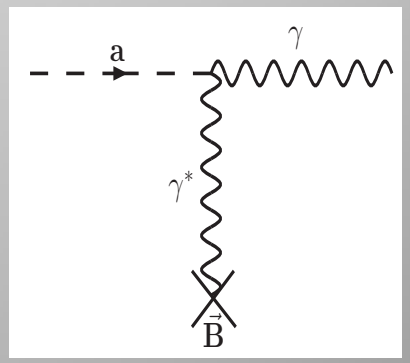
Lawrence Livermore National Laboratory

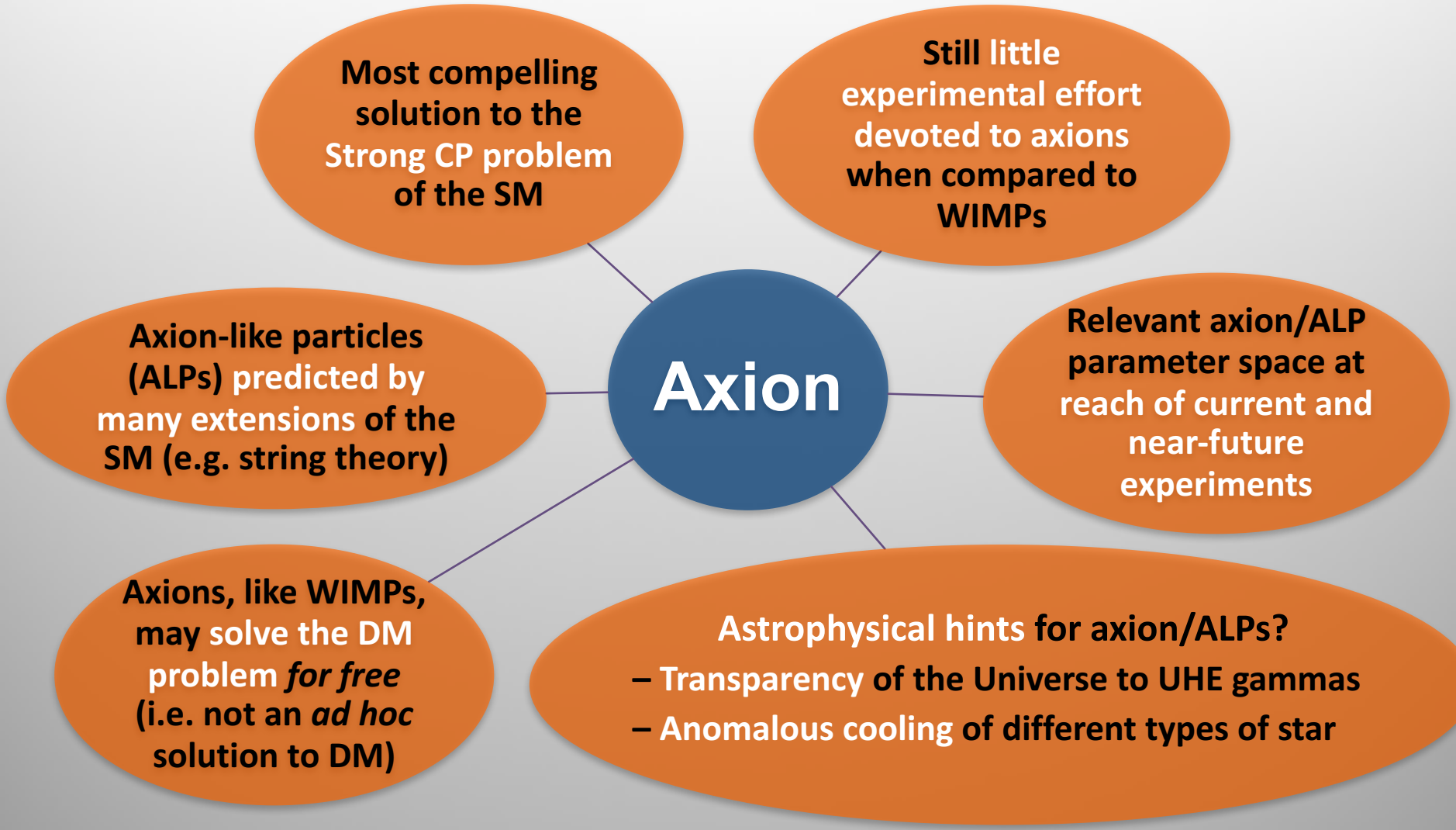
What is an axion? (in 70 words or less)

- **Strong CP problem**
  - CP violation expected in QCD, but not observed experimentally (q, nEDM)
- **Axion**
  - Pseudo Goldstone-Boson results if this new global symmetry (PQ solution) is spontaneously broken at yet unknown scale f_a
- **Axion-like particles (ALPs)**
  - Predicted by various extensions to the Standard Model, notably string theory
- **Properties of this potential DM candidate**
  - Extremely weakly-coupled fundamental pseudoscalar
  - Generic coupling to two photons
  - Mass unknown $m_a \propto g_{a\gamma}$, Astrophysics: $g_{a\gamma} < 10^{-10}$ GeV^{-1}

  → **Dark matter candidate**



Axion motivation

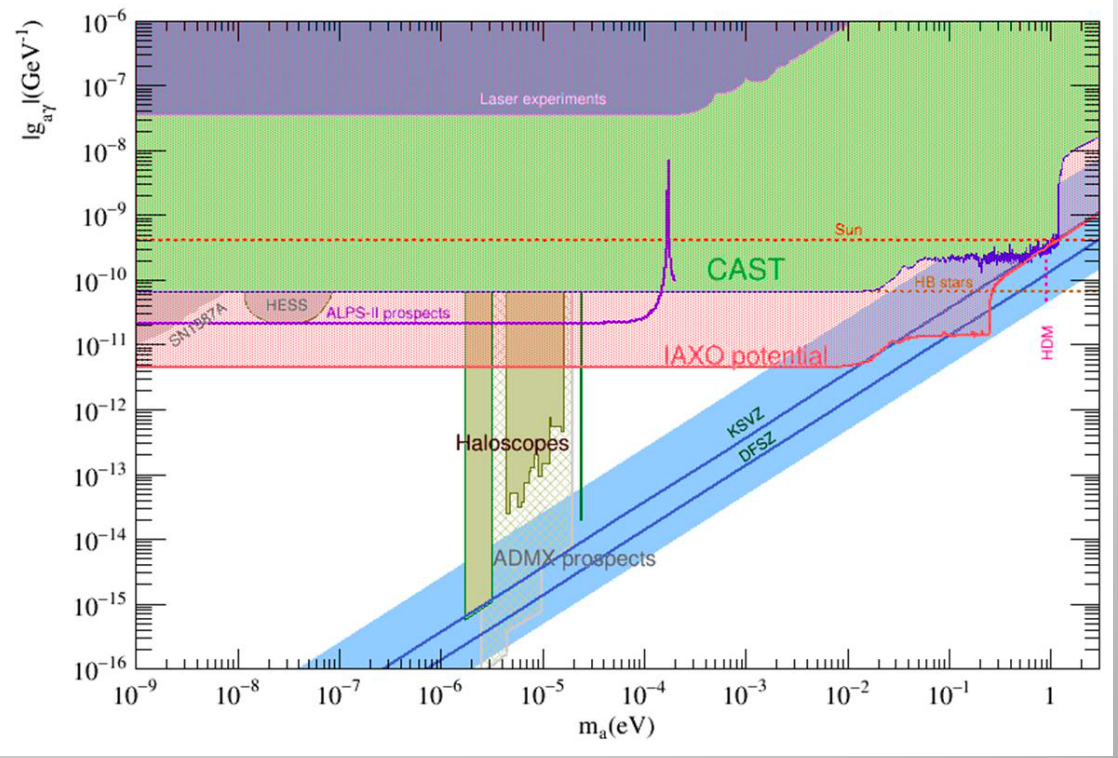


IAXO in the axion landscape

Laser/Lab axion experiments:
Search for ALPs in Light-shining-through-Wall experiments (ALPS, OSQAR, PVLAS, ARIADNE…)

Axion haloscopes:
Search for relic dark matter axions (ADMX, HAYSTAC, CAPP, Casper, MADMAX,…)

Axion helioscopes:
Search for solar axions and ALPs (Sumico, NuSTAR, **CAST**, **IAXO**)



Helioscopes technique:

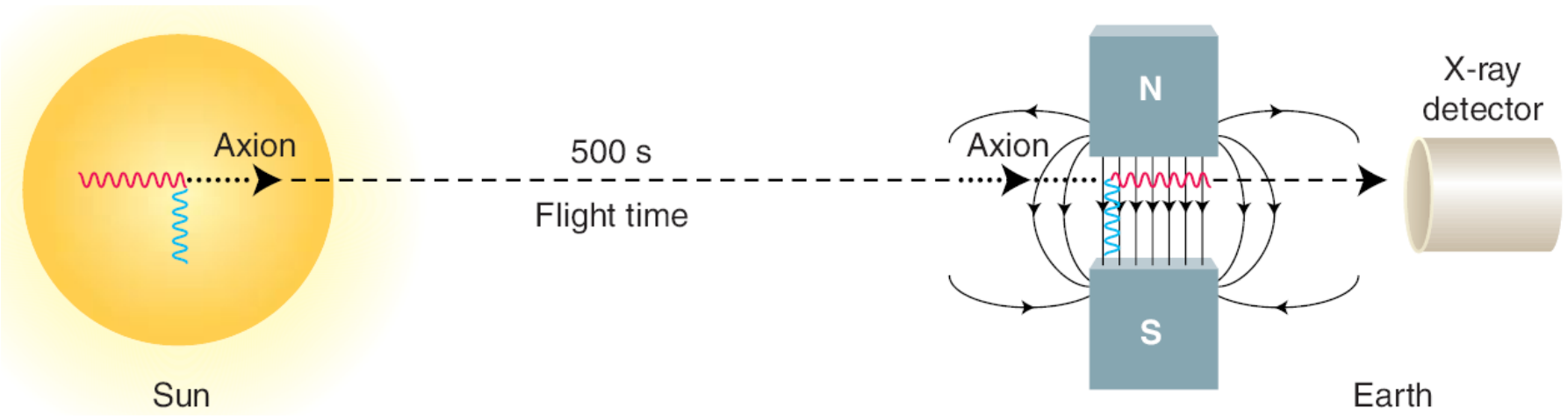
- Does not require axions to be dominant DM component
- Large complementarity with other strategies
- Technology mature enough for a large scale experiment (IAXO)

IAXO – Physics

- First axion helioscope proposed by P. Sikivie

Sikivie *PRL* 51:1415 (1983)

  - Blackbody photons (keV) in solar core can be converted into axions in the presence of strong electromagentic fields in the plasma
  - Reconversions of axions into x-ray photons possible in strong laboratory magnetic field



- Idea refined by K. van Bibber by using buffer gas to restore coherence over long magnetic field

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

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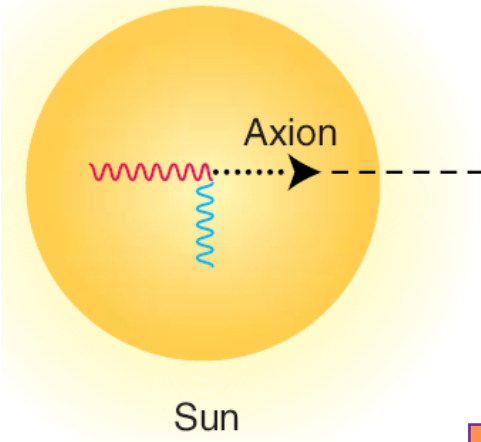

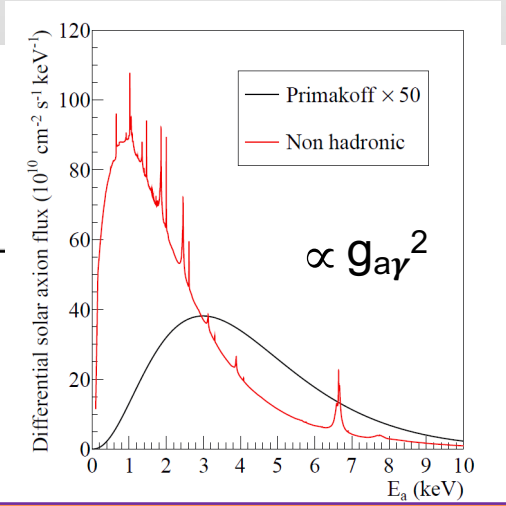

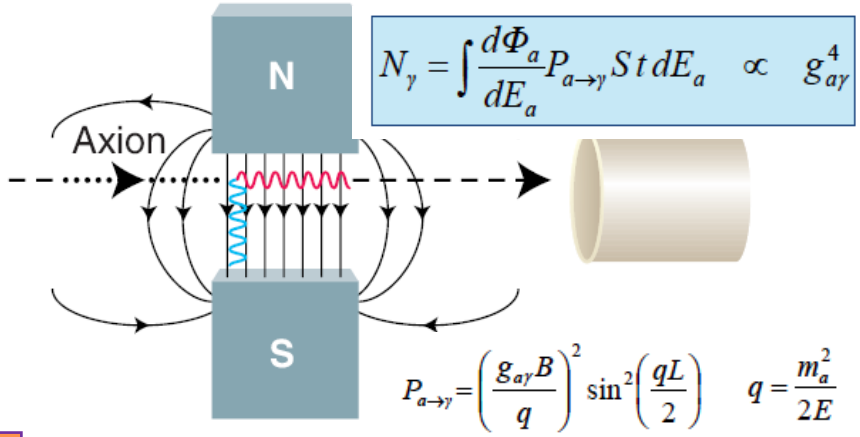

Redondo JCAP 1312 008 (2013)

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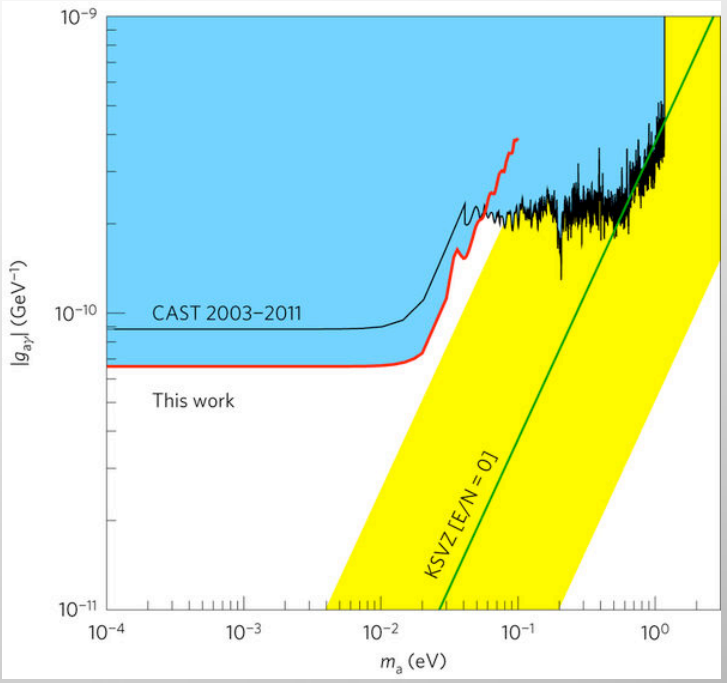
IAXO – Physics

CAST Collaboration
Nature Phys. 13 584 (2017)

3rd generation helioscope: CAST

- Most sensitive axion helioscope to date
- No axions detected yet
- Best experimental limit on axion-photon coupling over broad axion mass range
  $g_{a\gamma} < 0.66 \times 10^{-10}$ GeV^{-1} (95% C.L.)
- Latest results enabled by IAXO-pathfinder:
  NuSTAR-like x-ray optic coupled to low-background Micromegas



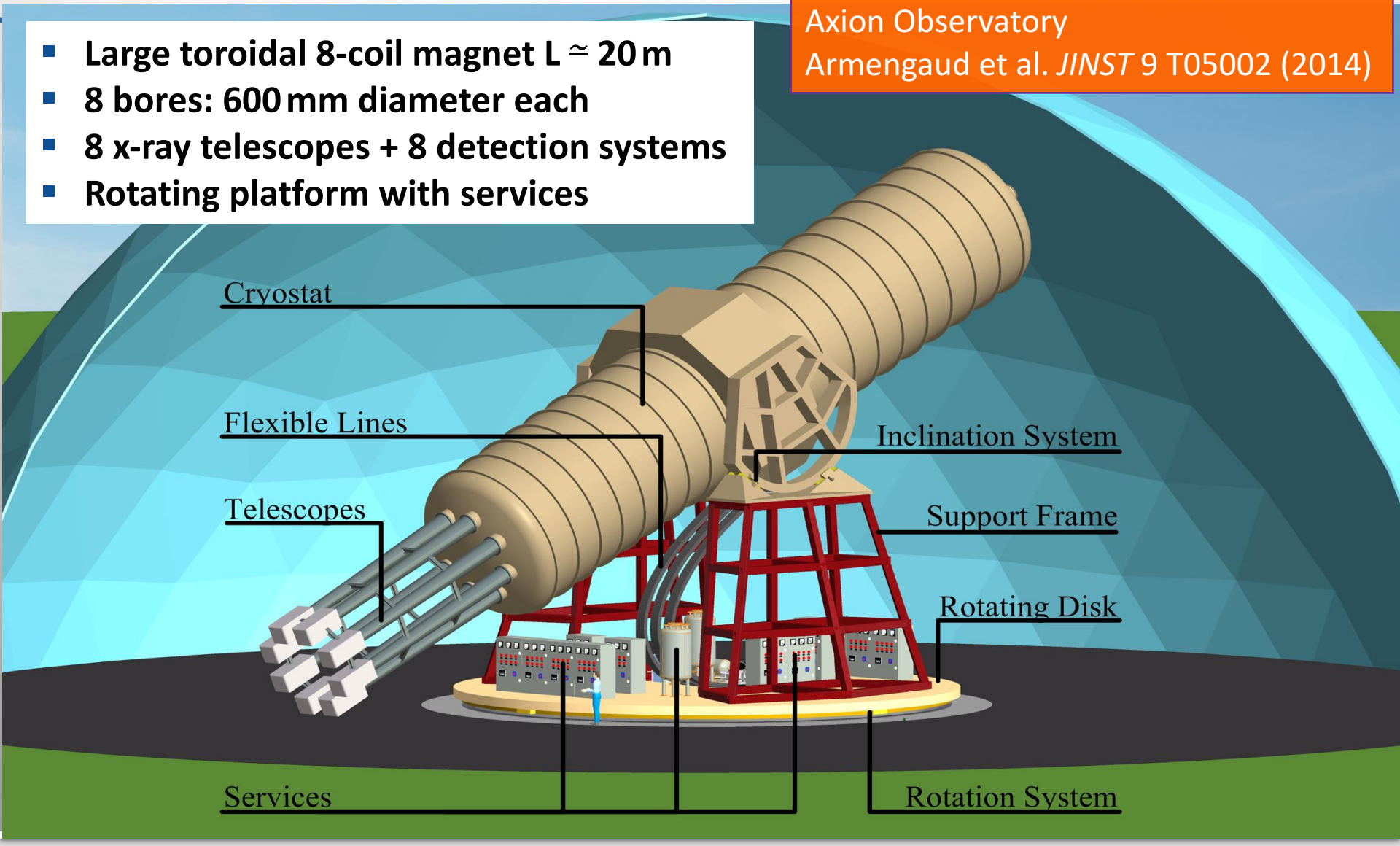
Next generation helioscope: IAXO

- Excellent prospects to improve over CAST by **1–1.5 orders of magnitude in sensitivity to $g_{a\gamma}$** (> 4 orders of magnitude in signal-to-noise)
- Plan to achieve this goal with
  - Purpose-designed magnet
  - Custom-built optics
  - Very low background detectors

IAXO – Conceptual design

- **Large toroidal 8-coil magnet L ≃ 20 m**
- **8 bores: 600 mm diameter each**
- **8 x-ray telescopes + 8 detection systems**
- **Rotating platform with services**

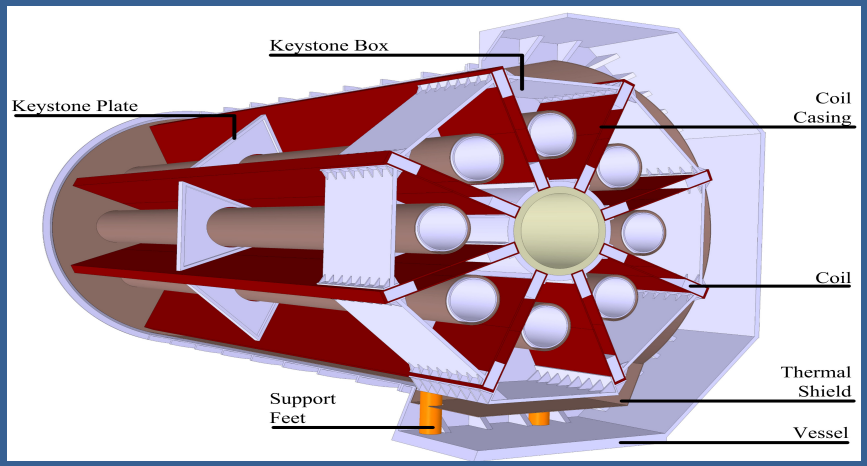
Conceptual Design of the Interantional Axion Observatory
Armengaud et al. *JINST* 9 T05002 (2014)



IAXO – Conceptual design

IAXO magnet

- Superconducting “detector” magnet
- Toroidal geometry (8 coils)
- Based on ATLAS toroid technical solutions
- 8 bores|20m long|60cm ⌀ per bore|5.4/2.5 T



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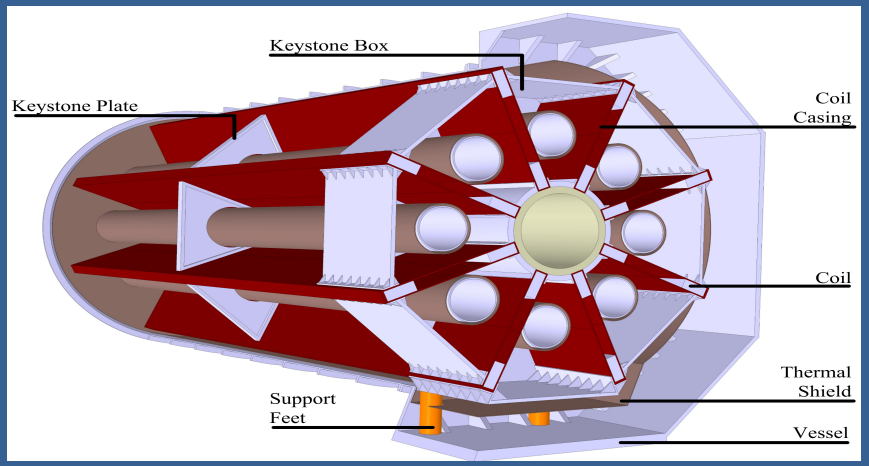
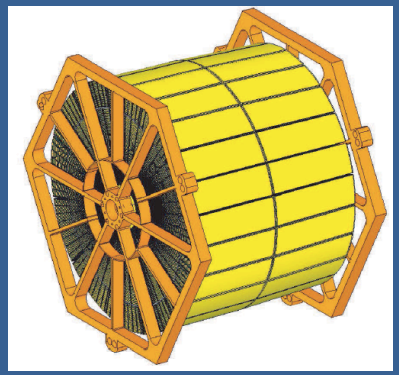


IAXO telescopes

- Slumped glass technology with MLs
- Cost-effective to cover large areas
- Based on NuSTAR technology
- Focal length ≃ 5m
- 8 optics with 123 layers each



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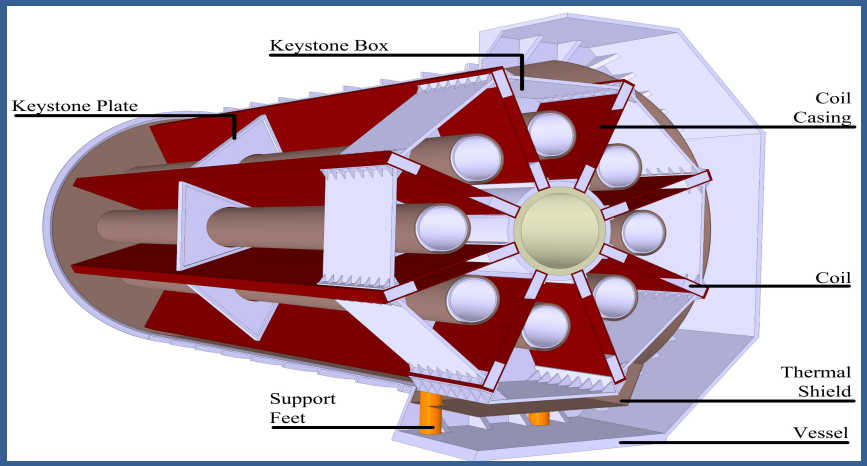

Other detector technologies

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

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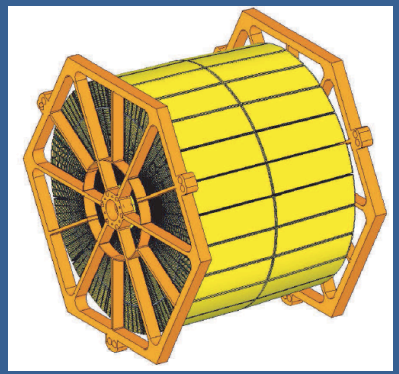
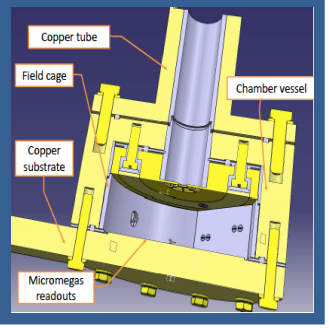


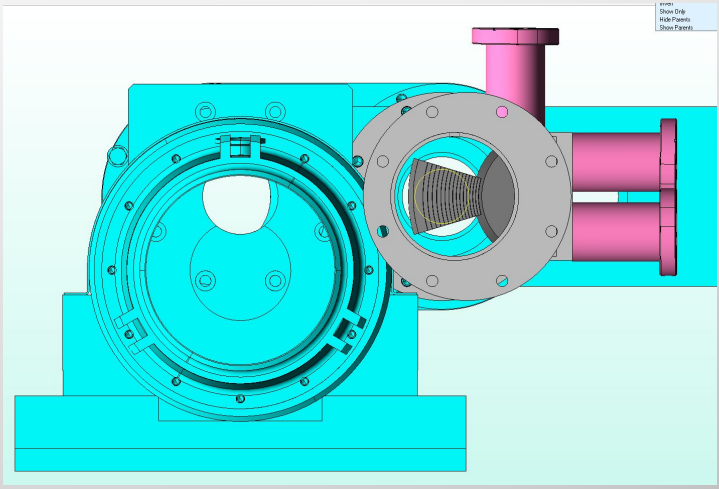
IAXO detectors

- Micromegas gaseous detectors
- Radiopure components+ shielding
- Event topology in gas for discrimination
- Bgrd $\leq 10^{-7}/(\text{keV}\times\text{cm}^2\times\text{s})$ through fabrication, radiopurity,shielding and simulations



IAXO – Pathfinder

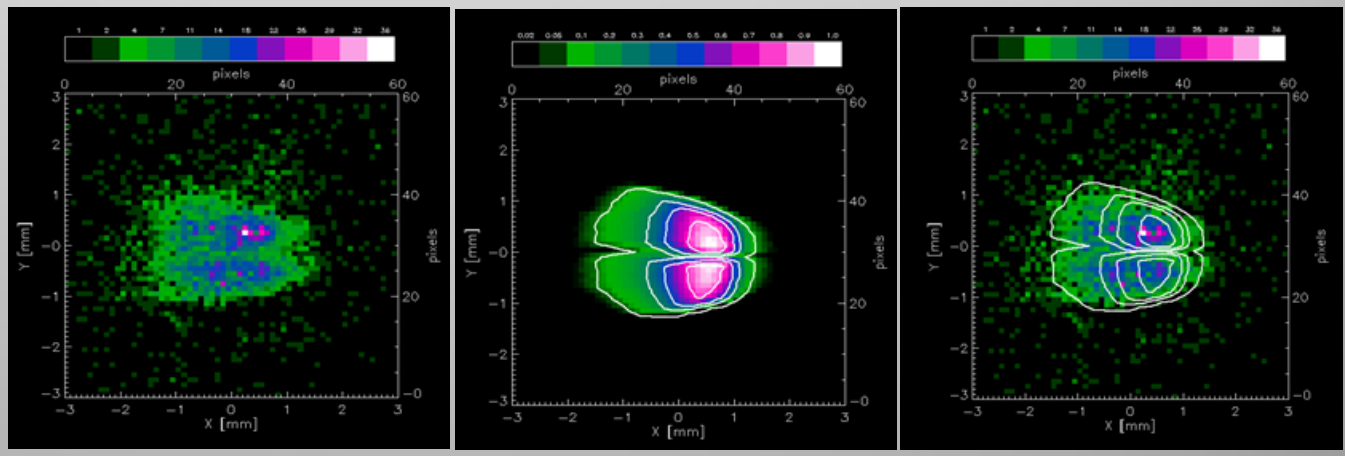
- **Small x-ray optics**
  - Fabricated purposely using thermally-formed glass substrates (NuSTAR-like)
- **Micromegas low background detector**
  - Applied lessons learned from R&D: compactness, better shielding, radiopurity,…
- **Data acquisition during CAST 2014/15 run**
  - Background level ~ 0.003 counts/hour



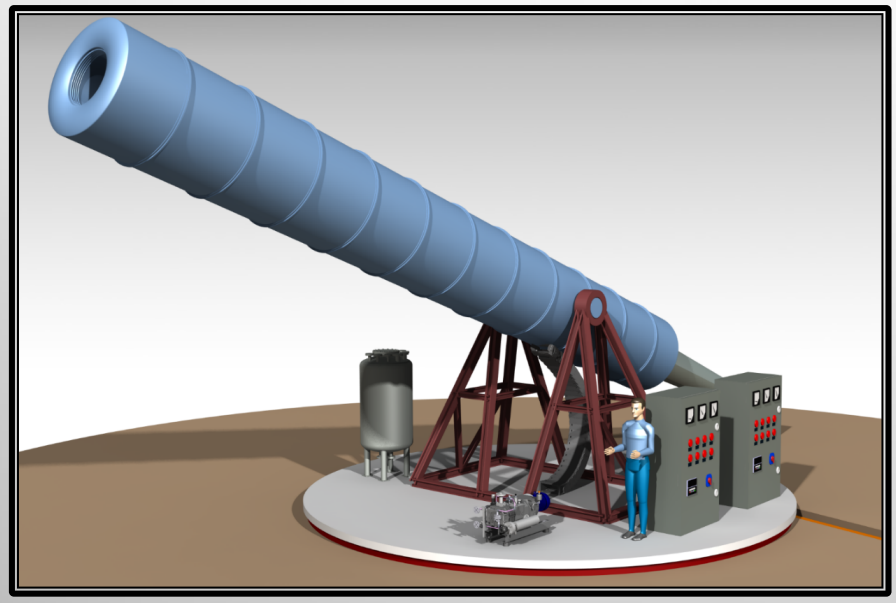
Sensitivity increase for CAST

and simultaneously

Testbench for IAXO



Mini-IAXO/Baby-IAXO



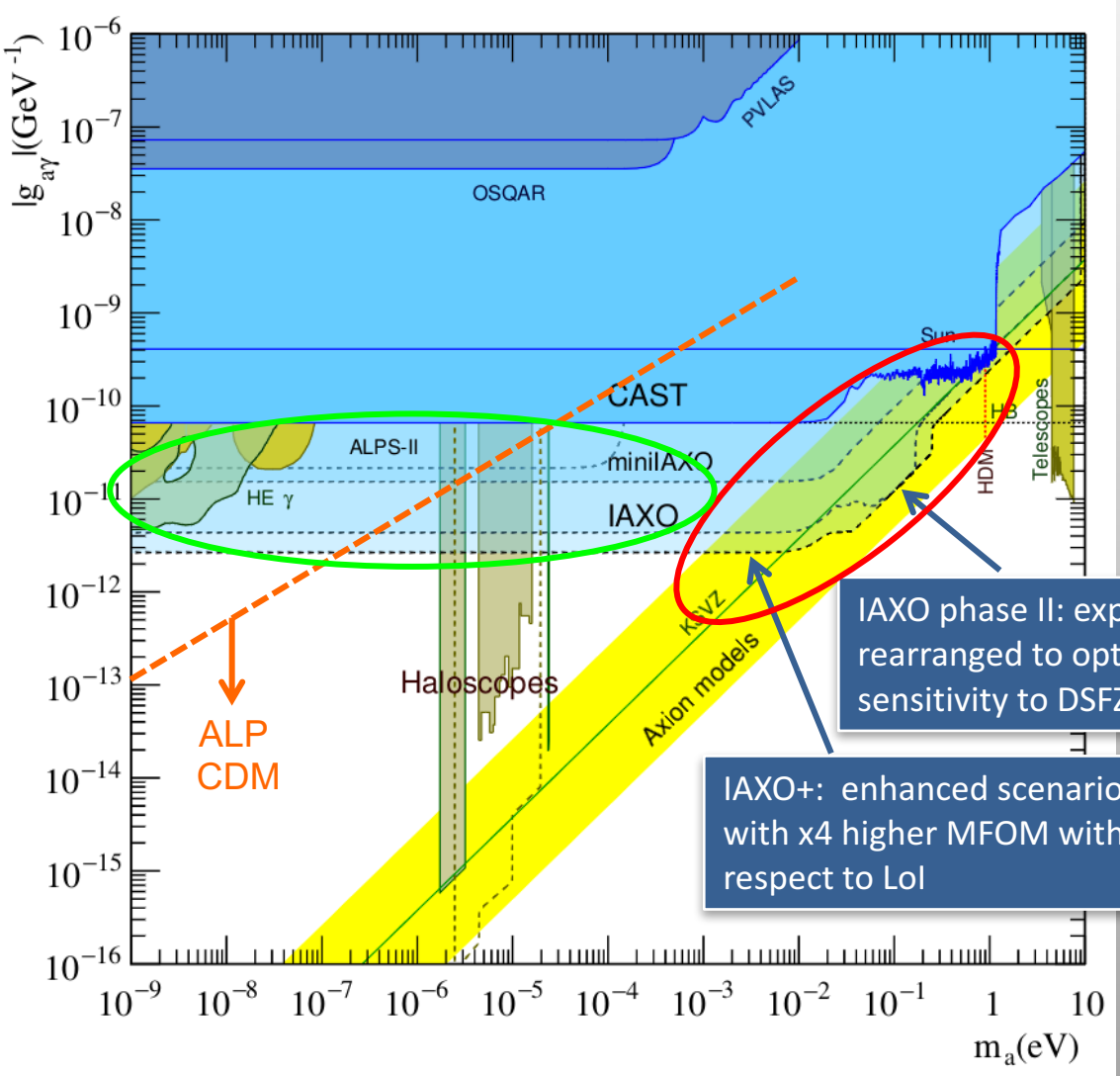
Property	Value
Free bore [m]	0.6
Magnetic length [m]	10
Field in bore [T]	2.5
Stored energy [MJ]	27
Peak field [T]	4.1

- **Original TDR baseline**
  - Single prototype magnet coil (IAXO-T0)
  - Prototype x-ray optics (IAXO-X0)
  - Prototype low-bgrd detector (IAXO-D0)
- **Extention of the TDR (mini-IAXO)**
  - Higher-risk magnet design
  - 1 bore: full diameter, half of full length
  - Full-scale optics and detector
    - > **Testbench for optics/detectors**
    - > **Relevant physics at intermediate level (FOM: 10 × CAST)**
    - > **Helps increase interest in science community and facilitates funding**

IAXO – Sensitivity prospects

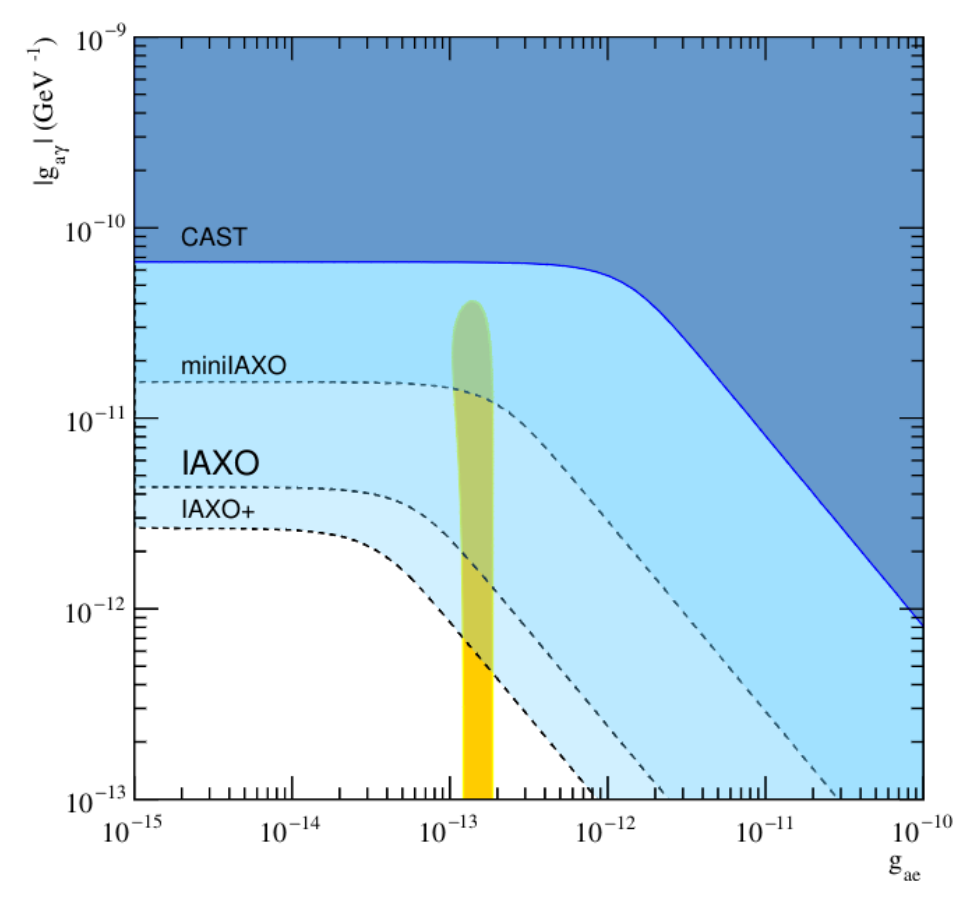
IAXO sensitivity region (for axion–photon coupling) includes:

- Large part of region relevant for QCD axions
- Share of region relevant for cold and hot dark matter
- Parameter space relevant for ALPs & inflation
- Some unexplained astrophysical observations:
  - Transparency of the Universe to UHE gammas
  - Anomalous cooling of stars



IAXO – Sensitivity prospects

IAXO sensitivity region for axion–electron coupling



Additional IAXO physics cases

- Relic axions:
  IAXO magnet with microwave cavities/RF antennas installed
- Search for other exotic particles such as paraphotons, chameleons …
- … and others

IAXO – Status and Conclusions

- **IAXO** is a new generation axion helioscope aiming to
  - **improve CAST sensitivity to axion-photon coupling by over 1 order of magnitude**
  - address **additional physics cases** including axion-electron coupling, relic axions, …
- **Status**
  - Conceptual Design completed (2013)
  - Letter of Intent submitted to the CERN SPSC (2013): received positive recommendations acknowledging physics case + encouraging to proceed to TDR
  - Transition phase towards TDR (2014-16): IAXO pathfinder system at CAST, coordinated funding applications, …
- **Most recent developments**
  - Mini-IAXO concept:
    Intermediate experiment + enhancement of final FOM for IAXO
  - Formal founding of IAXO collaboration at recent meeting (DESY July 3/4, 2017):
    - Initial set of 17 institutions from all over the world
    - Bylaws document (setting up collaboration rules) approved
    - Mini-IAXO to be most likely located at DESY
    - http://iaxo.web.cern.ch and https://indico.cern.ch/event/622974/