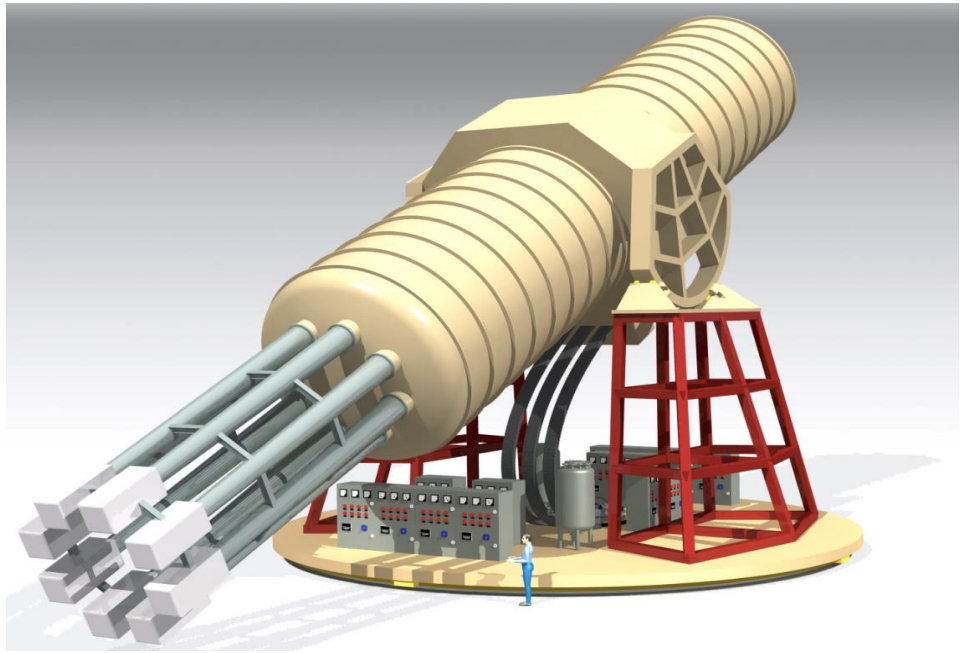
International AXion Observatory (IAXO)
status of project

Igor G. Irastorza (U. Zaragoza)
on behalf of the IAXO collaboration

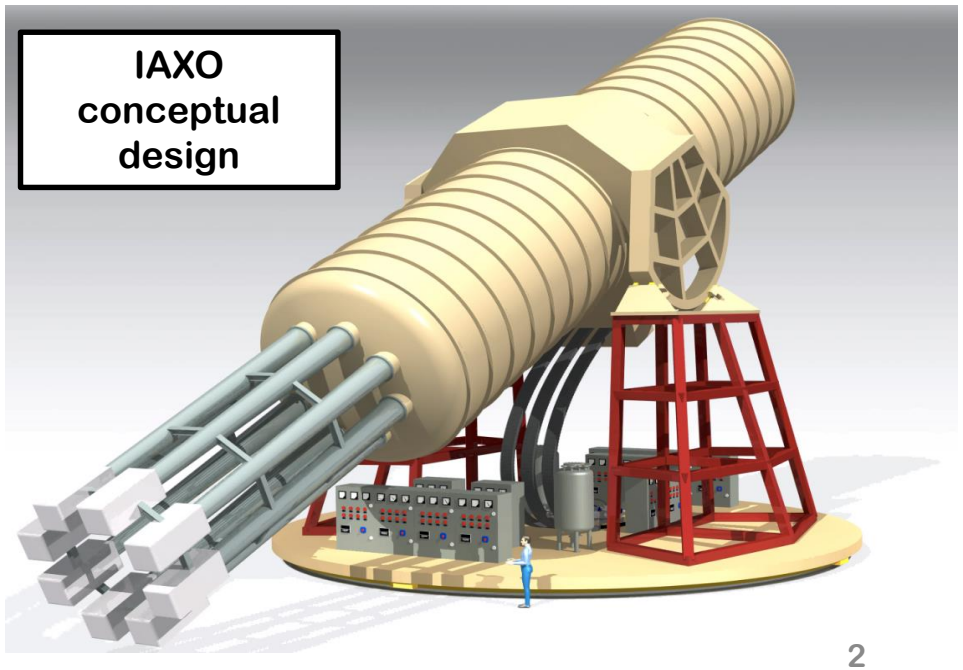
Physics Beyond Colliders, CERN, January 16, 2019



IAXO experiment summary

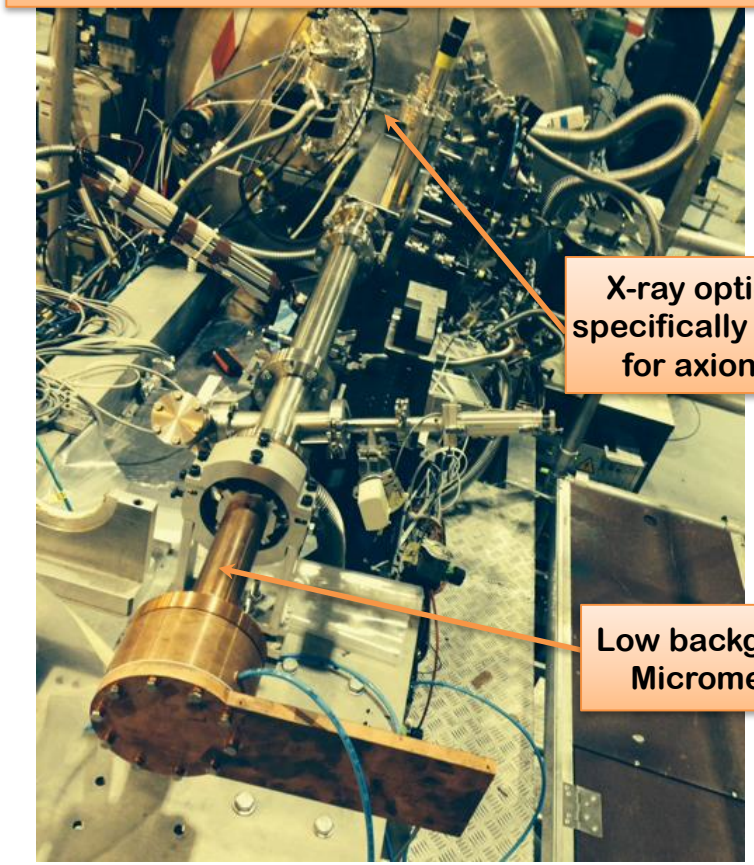
- Next generation “axion helioscope” after CAST
- Purpose-built large-scale magnet
  - >300 times larger B^2L^2A than CAST magnet
  - Toroid geometry
  - 8 conversion bores of 60 cm Ø, ~20 m long
- Detection systems (XRT+detectors)
  - Scaled-up versions based on experience in CAST
  - Low-background techniques for detectors
  - Optics based on slumped-glass technique used in NuStar
- ~50% Sun-tracking time

- Large magnetic volume available for additional “axion” physics (e.g. DM setups)



IAXO pathfinder at CAST

- First MM+XRT combined system
- First XRT built for axions
- Anticipates IAXO technologies

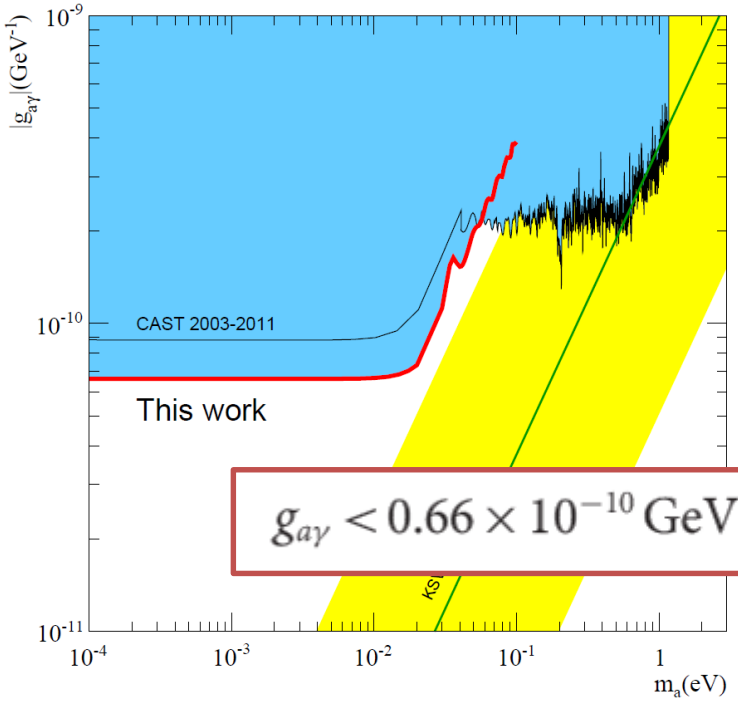


nature physics
ARTICLES
PUBLISHED ONLINE: 1 MAY 2017 | DOI: 10.1038/NPHYS4109
OPEN

New CAST limit on the axion–photon interaction

CAST Collaboration†

Hypothetical low-mass particles, such as axions, provide a compelling explanation for the dark matter in the universe. Such particles are expected to emerge abundantly from the hot interior of stars. To test this prediction, the CERN Axion Solar Telescope (CAST) uses a 9 T refurbished Large Hadron Collider test magnet directed towards the Sun. In the strong magnetic ray photons which can be recorded by X-ray detectors. In the 2013–2015 run, thanks X-ray telescope, the signal-to-noise ratio was increased by about a factor of three. ion–photon coupling strength (0.66×10^{-10} GeV^{-1} at 95% confidence level) set by the most restrictive astrophysical bounds.



$$g_{a\gamma} < 0.66 \times 10^{-10}\,\mathrm{GeV}^{-1} \text{ at } 95\%\ \mathrm{CL}$$

IAXO pathfinder system at CAST (in operation in 2014-15)
Last CAST results published in Nature Physics May-2017
Nature Phys. 13 (2017) 584-590

Progress in 2018

- **Funding & collaboration:**
  - Important funding grants obtained: **ERC-AdG**
    (But also BMBF, US, Spain, Croatia, etc.)
  - Collaboration consolidated, and management fully operative

- **BabyIAXO:**
  - Magnet conceptual design defined. Detailed design ongoing
  - BabyIAXO infrastructure needs being defined.
  - Detector & optics for BabyIAXO: plans defined. Work started in all fronts.

- **Letter of Intent to DESY:**
  - LoI submitted to PRC last October.
  - Full proposal expected in April

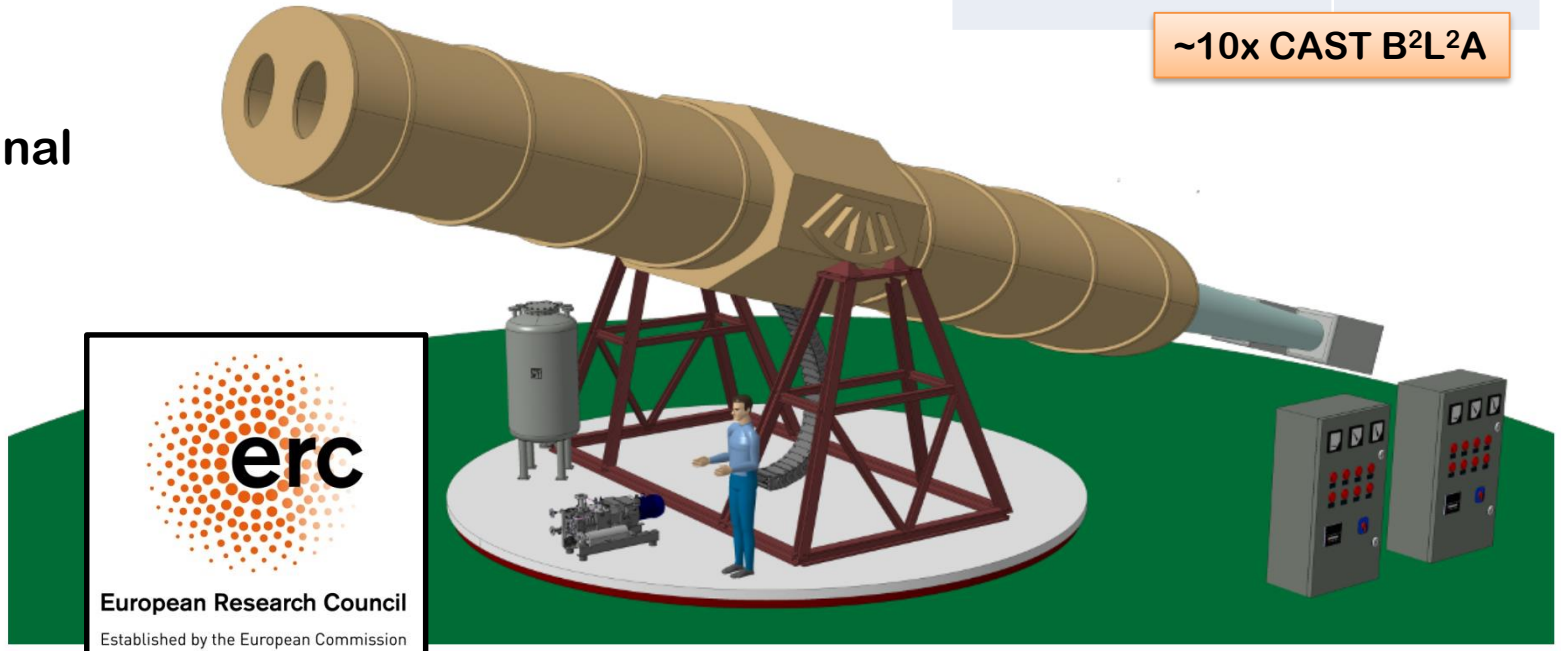
BabyIAXO

- Intermediate experimental stage before IAXO
- Conceptual design finished. Presented to DESY LoI last october
- Now work ongoing towards detailed TDR

Free bore [m]	2 x 0.7
Magnetic length [m]	10
Field in bore [T]	~2-3
Stored energy [MJ]	40-50
Peak field [T]	4.1

~10x CAST B^2L^2A

- Two bores of dimensions similar to final IAXO bores → detection lines representative of final ones.
- Test & improve all systems. Risk mitigation for full IAXO
- Will produce relevant physics
- Move earlier to "experiment mode"

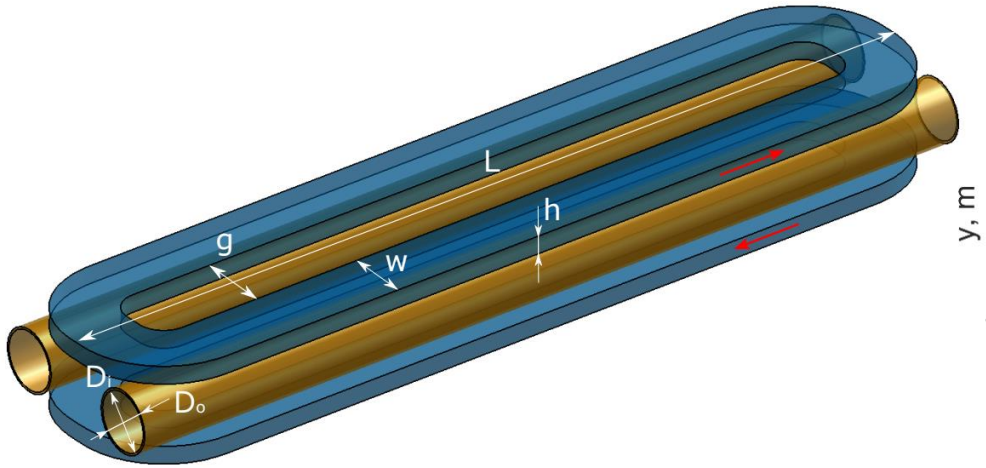


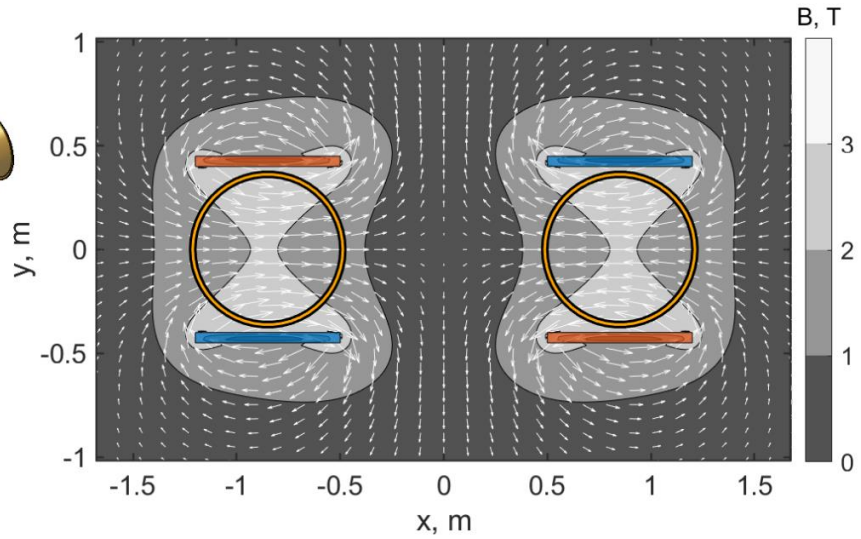
European Research Council
Established by the European Commission

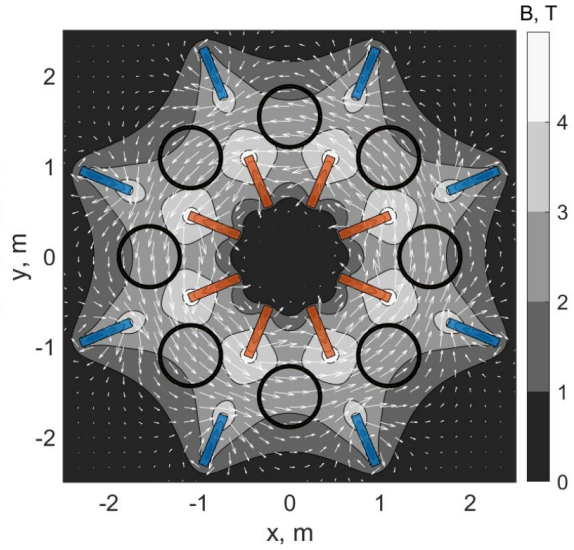
ERC-AvG 2017 IAXO+

BabyIAXO magnet

- After some comparative study between several possible magnet layout for BabyIAXO, the collaboration finally chose a “common coil” configuration last September:
  - Minimal construction risk: move to construction asap
  - Cost-effective: Best use of existing infrastructure (tooling) at CERN
  - Winding layout very close to current IAXO toroidal design.







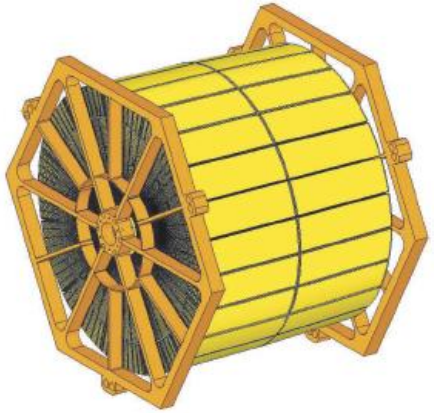
- Work now ongoing at CERN to produce technical design & detailed WBS

X-ray optics for BabyIAXO

- **Two 70-cm Ø bores to cover. Baseline option:**
  - **1 Segmented-glass optics. To be built (similar to the ones proposed for IAXO). Preparatory actions started.**
  - **1 flight spare XMM optics from ESA. 2 such optics exist already. Steps to formally request to ESA started.**
  - **Minimal risk to the project**

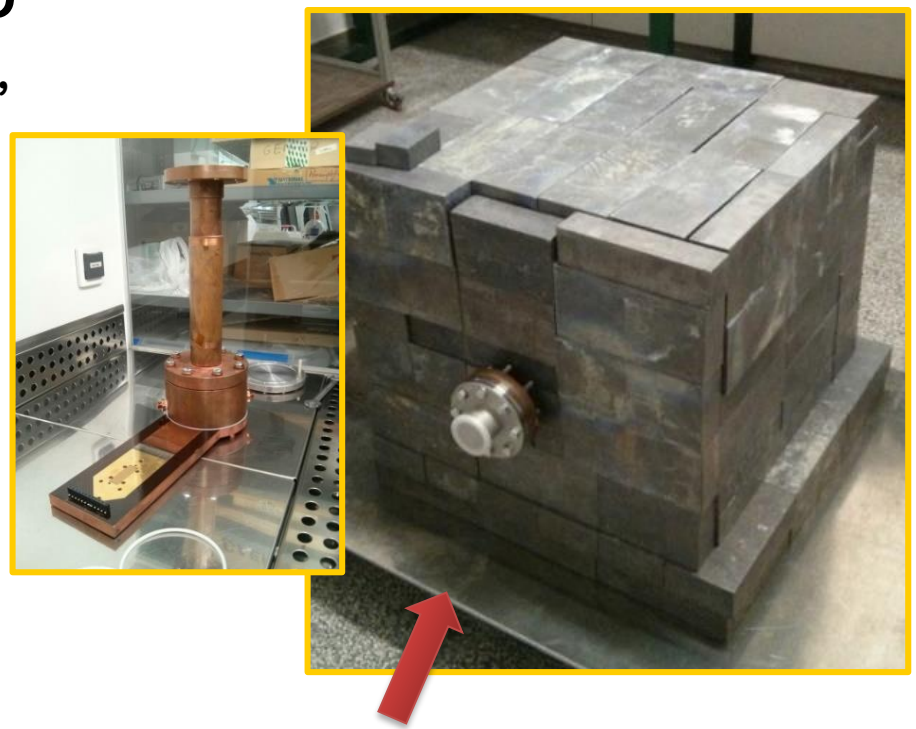
XMM optics specs very close to IAXO optics design

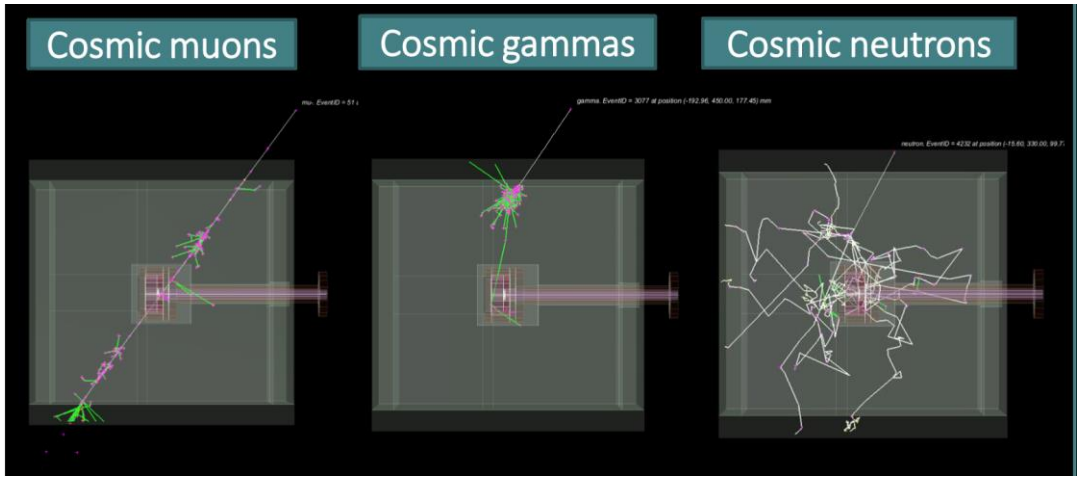
Risk reduction for final IAXO segmented-glass optics



IAXO detector platform

- To prepare the 2 detectors that will go to BabyIAXO
  - Baseline is Micromegas. But also Ingrid, MMCs, TES, SSDs under consideration.
- To assess and if possible improve background levels of detectors for IAXO
- Goal is: 10^{-7} – 10^{-8} c keV^{-1} cm^{-2} s^{-1}
- Also simulation work to build background models





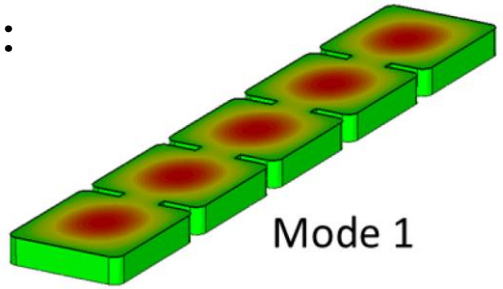
- IAXO-D0 setup already built and taking first data at UNIZAR with a Micromegas detector
- Starting point for the IAXO detector platform

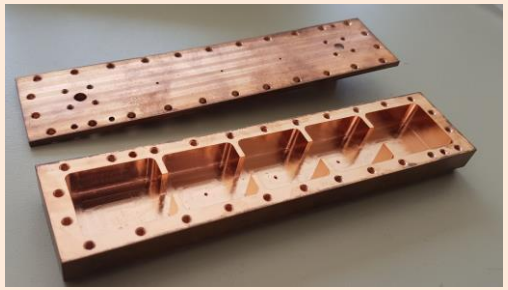
Additional physics: DM searches

- Use of (Baby)IAXO large magnetic volume for axion DM setups.
- RADES R&D exploring new concept to fill large V with high-frequency cavities.
  - Evolved from concept to serious experimental effort in the last ~3 years
  - Proof-of-concept at small scale successful tested in CAST
  - Technological connection with CERN

- Aim: to become the seed of a program to implement DM searches in BabyIAXO.

RADES concept: array of small cavities interconnected with irises:



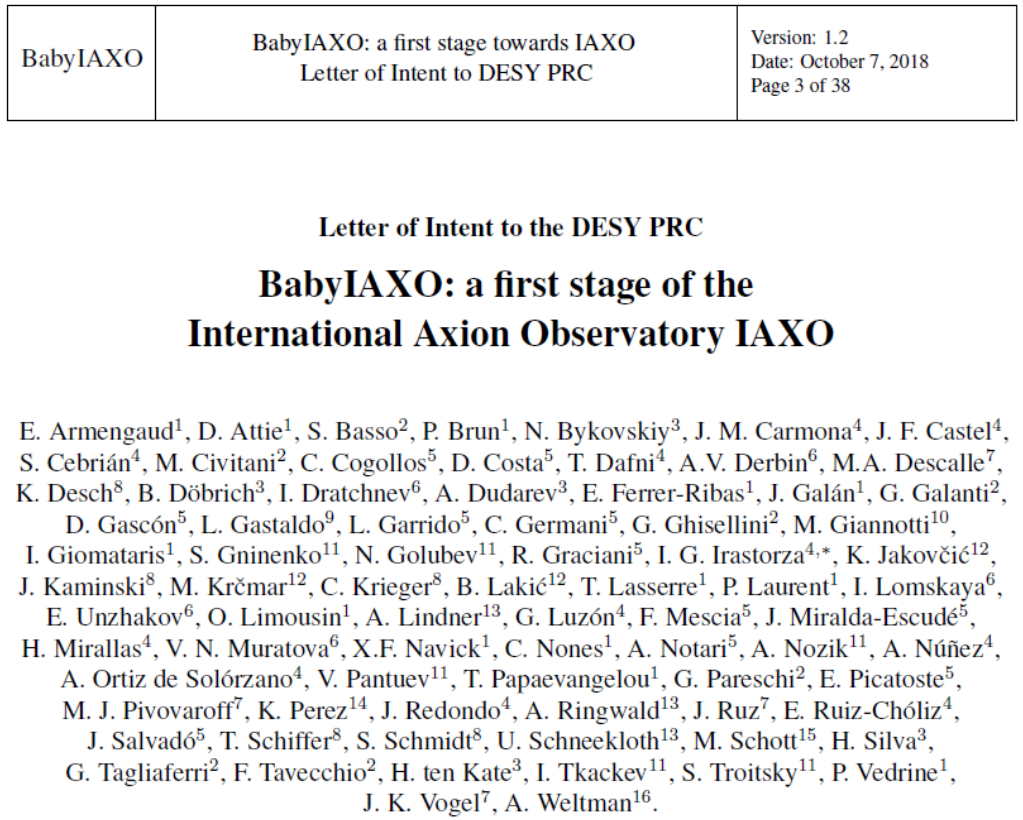


Part of ERC-StG (2018)
B. Döbrich/CERN

Proposal to DESY

- **LoI submitted to DESY PRC last october and well received**

- **Full detailed proposal expected for April, in-depth review prepared in the next PRC meeting in May.**



BabyIAXO	BabyIAXO: a first stage towards IAXO Letter of Intent to DESY PRC	Version: 1.2 Date: October 7, 2018 Page 3 of 38

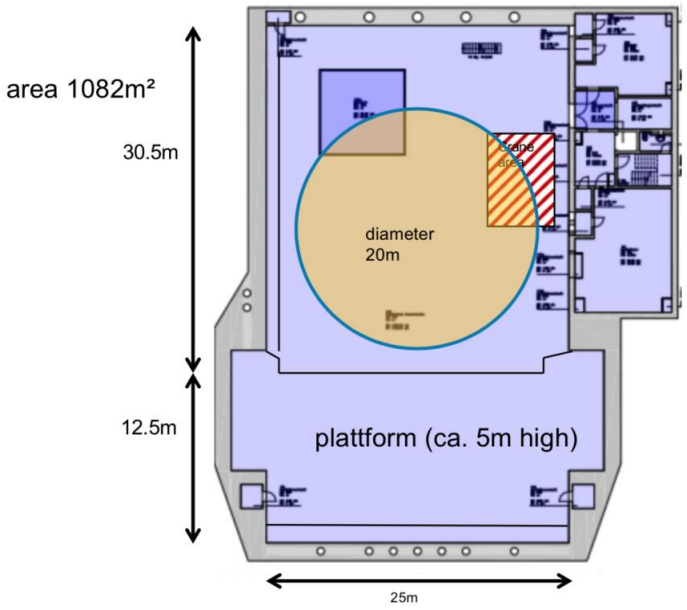
Letter of Intent to the DESY PRC

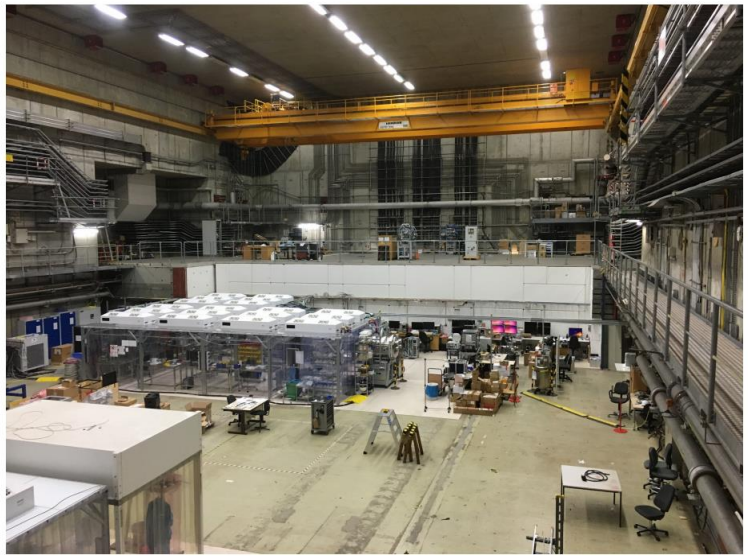
BabyIAXO: a first stage of the International Axion Observatory IAXO

E. Armengaud[1], D. Attie[1], S. Basso[2], P. Brun[1], N. Bykovskiy[3], J. M. Carmona[4], J. F. Castel[4], S. Cebrián[4], M. Civitani[2], C. Cogollos[5], D. Costa[5], T. Dafni[4], A.V. Derbin[6], M.A. Descalle[7], K. Desch[8], B. Döbrich[3], I. Dratchnev[6], A. Dudarev[3], E. Ferrer-Ribas[1], J. Galán[1], G. Galanti[2], D. Gascón[5], L. Gastaldo[9], L. Garrido[5], C. Germani[5], G. Ghisellini[2], M. Giannotti[10], I. Giomataris[1], S. Gninenko[11], N. Golubev[11], R. Graciani[5], I. G. Irastorza[4,*], K. Jakovčić[12], J. Kaminski[8], M. Krčmar[12], C. Krieger[8], B. Lakić[12], T. Lasserre[1], P. Laurent[1], I. Lomskaya[6], E. Unzhakov[6], O. Limousin[1], A. Lindner[13], G. Luzón[4], F. Mescia[5], J. Miralda-Escudé[5], H. Mirallas[4], V. N. Muratova[6], X.F. Navick[1], C. Nones[1], A. Notari[5], A. Nozik[11], A. Núñez[4], A. Ortiz de Solórzano[4], V. Pantuev[11], T. Papaevangelou[1], G. Pareschi[2], E. Picatoste[5], M. J. Pivovaroff[7], K. Perez[14], J. Redondo[4], A. Ringwald[13], J. Ruz[7], E. Ruiz-Chóliz[4], J. Salvadó[5], T. Schiffer[8], S. Schmidt[8], U. Schneekloth[13], M. Schott[15], H. Silva[3], G. Tagliaferri[2], F. Tavecchio[2], H. ten Kate[3], I. Tkackev[11], S. Troitsky[11], P. Vedrine[1], J. K. Vogel[7], A. Weltman[16].

BabyIAXO @ DESY

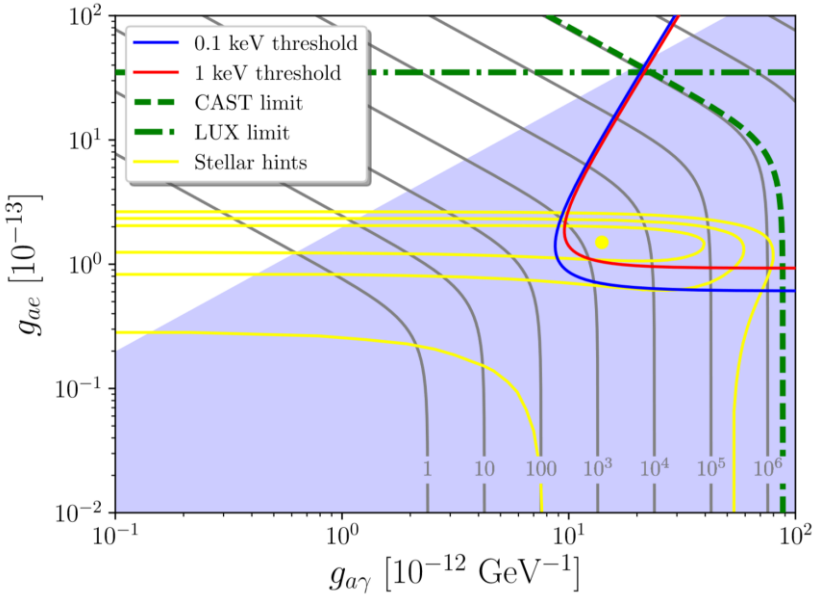
- **HERA South hall: preferred site for BabyIAXO**
- **DESY infrastructure & expertises very well suited to IAXO**



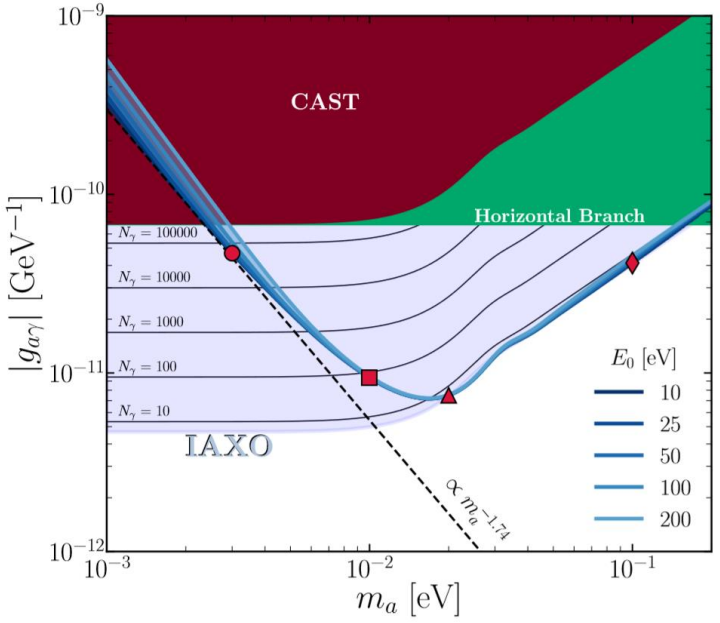


IAXO physics case grows…

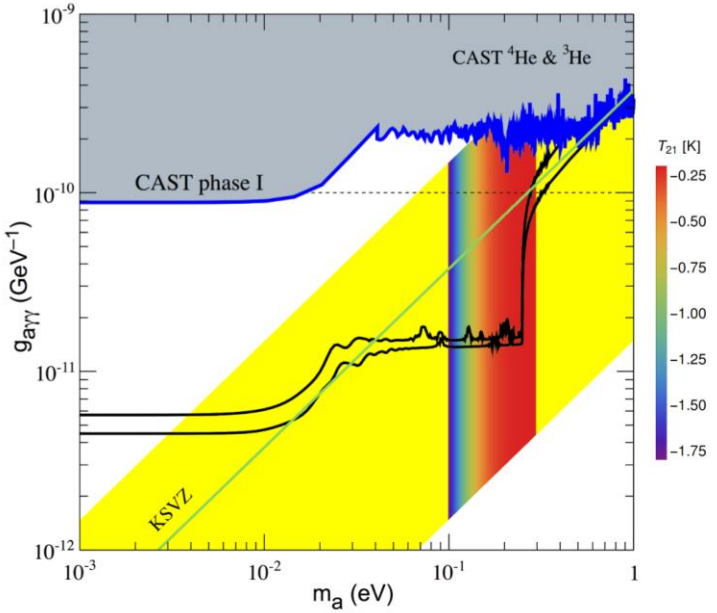
Distinguishing axion models with IAXO
Jaeckel et al. arXiv:1811.09278



"Weighing" the solar axion
Dafni et al. arXiv:1811.09278

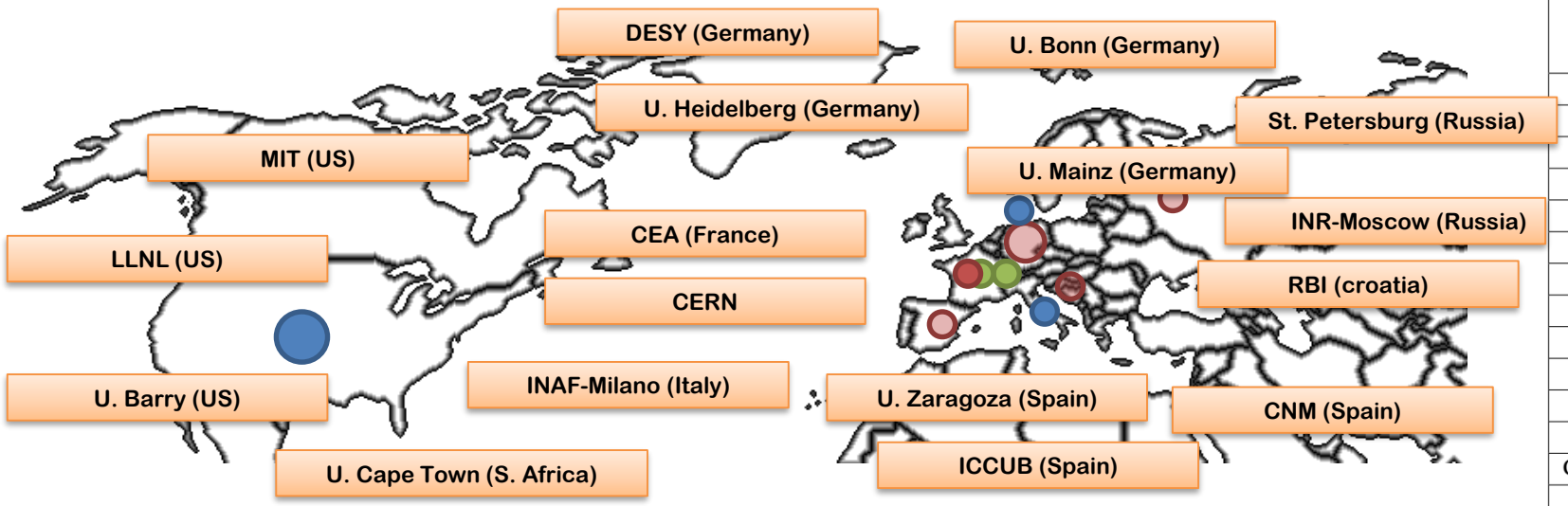


Axion-DM explanation of EDGES 21 cm observation
Houston et al. arXiv:1812.03931



IAXO collaboration

17 institutions from Germany, Spain, US, France, Russia, Croatia, S. Africa, CERN.
Know-how portfolio nicely emcompasses IAXO needs:



Institution	Superconducting magnets	X-ray optics	Detector & electronics	Axion phenomenology	Low background techniques	General infrastructures & engineering
Barry U. (USA)				x		
Irfu/CEA-Saclay (France)	x		x	x	x	x
U. Cape Town (S. Africa)				x		
ICCUB Barcelona (Spain)			x			
LLNL (USA)		x		x		
St. Petersburg NPI (Russia)				x		
Heidelberg U. (Germany)			x		x	
U. of Zaragoza (Spain)			x	x	x	
MIT (USA)		x				
INR Moscow (Russia)	x			x		
RBI Zagreb (Croatia)				x		
U. Bonn (Germany)			x			
CNM-IMB Barcelona (Spain)			x			
JGU Mainz (Germany)			x			
INAF - Brera (Italy)		x				
DESY (Germany)				x	x	x
CERN (Switzerland)	x					x

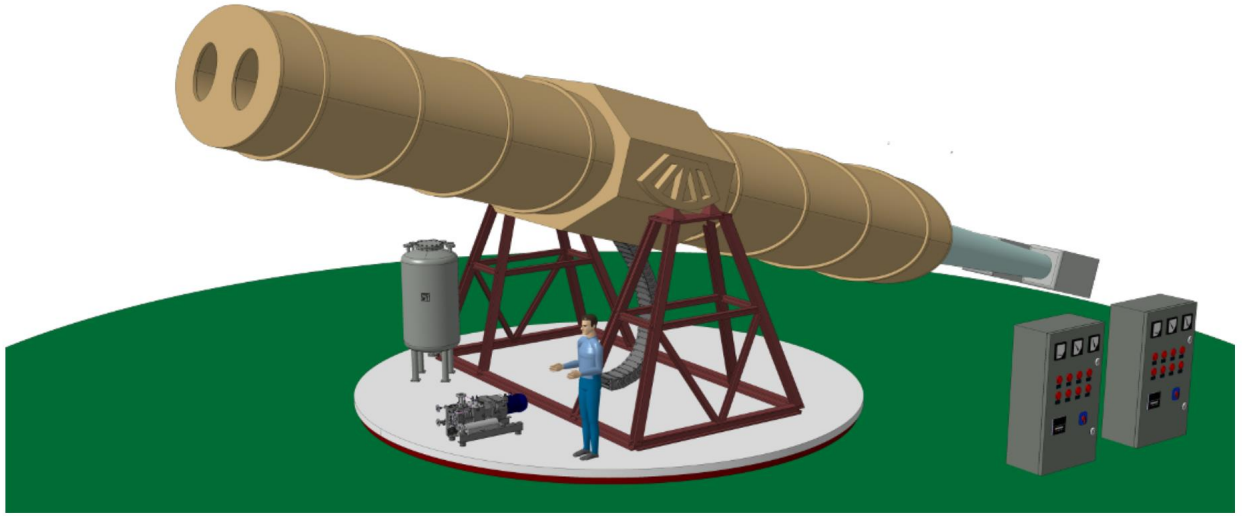
- **Likely to grow in the future, more groups showing interest…**

(2 new groups has sent formal expression of interest, now under consideration at the board)

Conclusions

- 2018 a very important year for IAXO, relevant milestones achieved:
  - Relevant funding coming along
  - Colaboration consolidated
  - Project on solid track to build BabyIAXO

- We want to thank PBC for the support during the process



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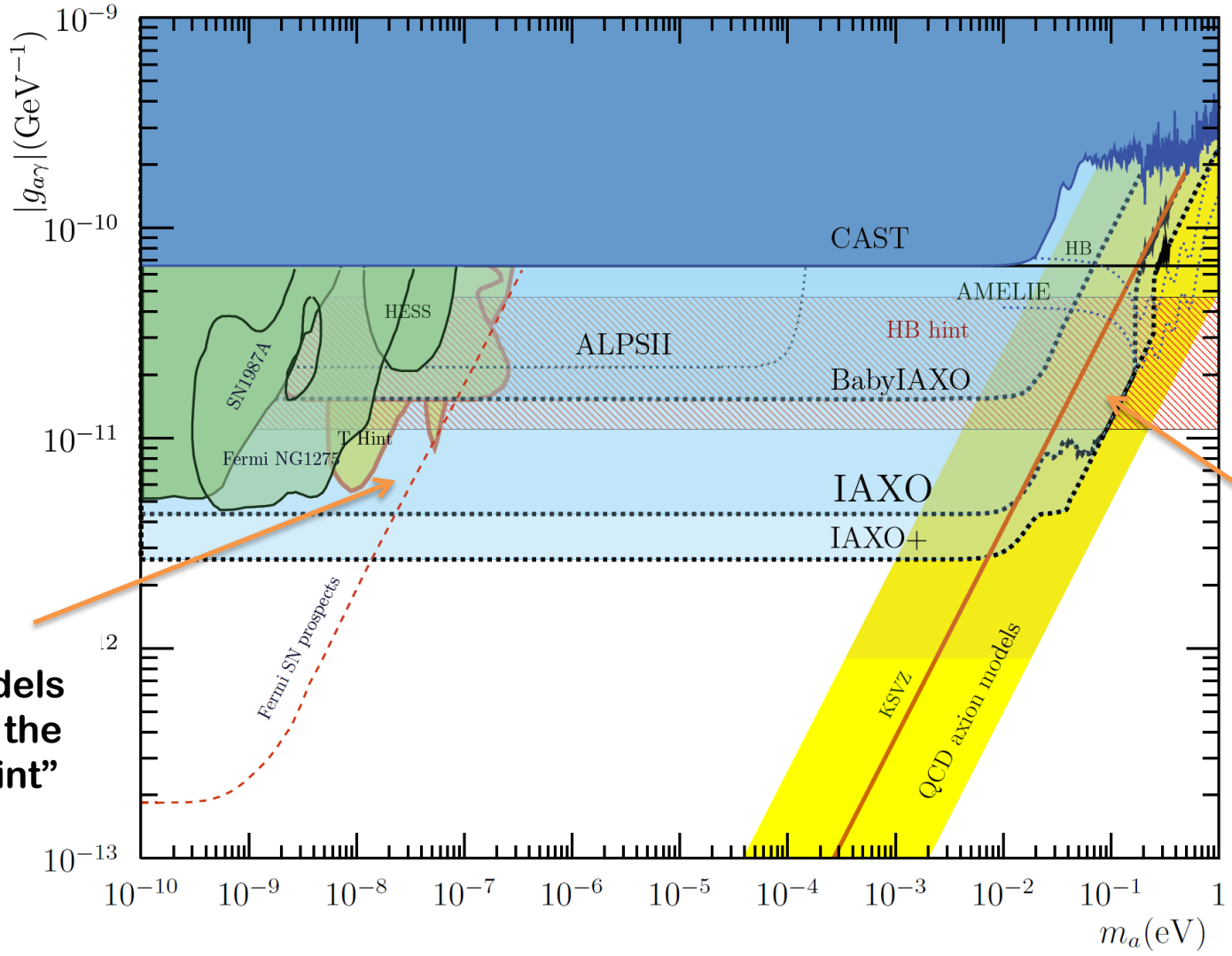
BabyIAXO & IAXO physics reach

BabyIAXO prospects: 10xMFOM + optics and detector from conservative scenario of LoI



IAXO+: enhanced scenario with x10 (x4) higher FOM (MFOM) with respect LoI

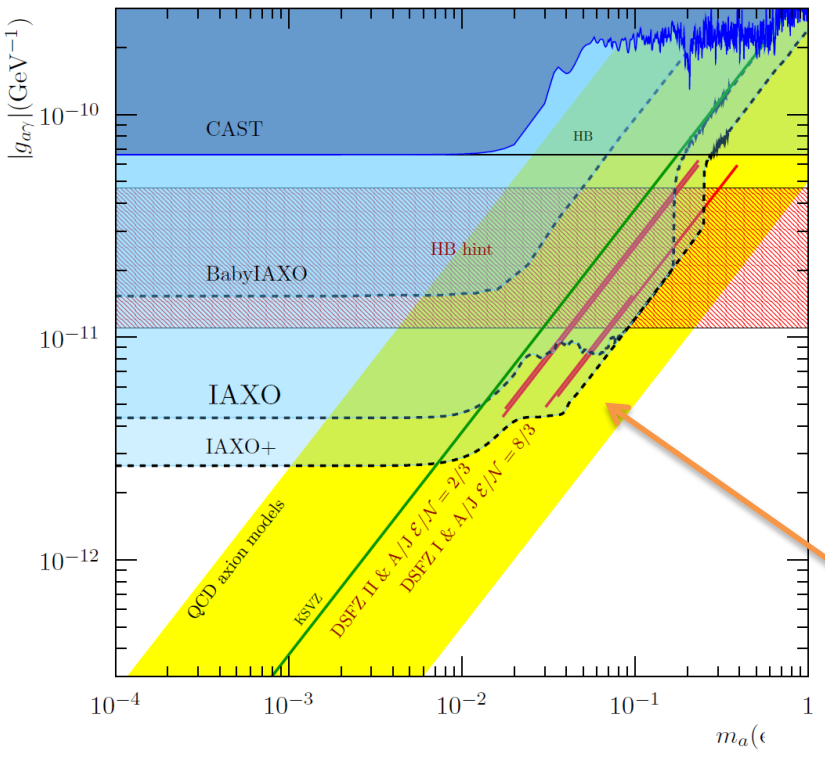
IAXO will fully explore ALP models invoked to solve the "transparency hint"

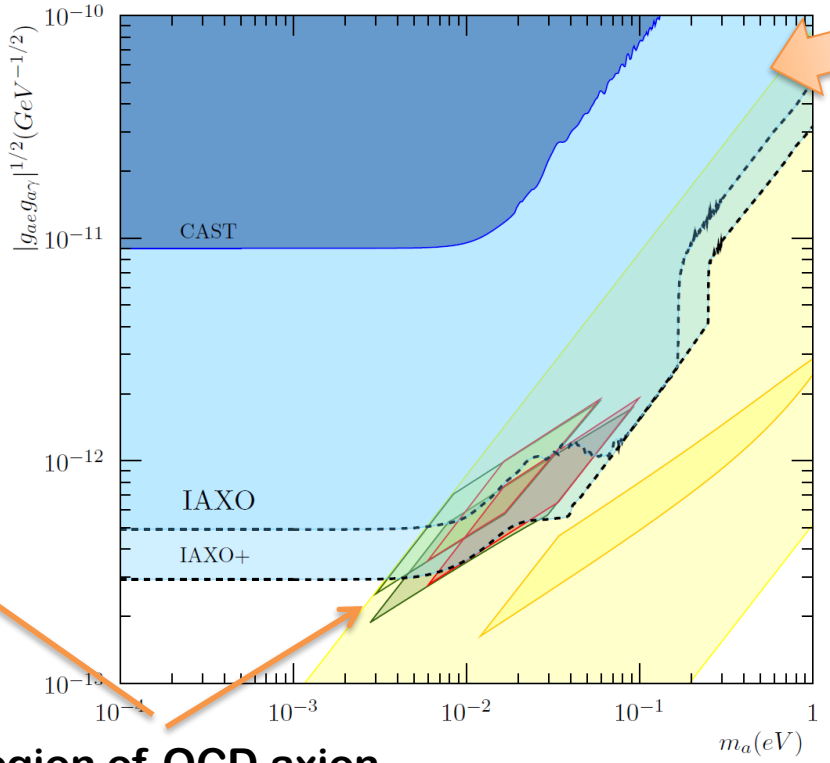
… as well as a large fraction of the axion & ALP models invoked in the "stellar cooling anomaly"
But for this the g_{ae} is particularly interesting

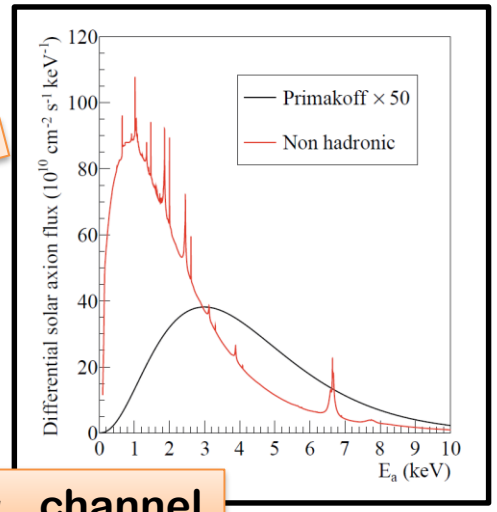
MFOM = Magnet FOM

IAXO & stellar cooling

- **Multiple stellar anomalies (HB, RG, WD, NS,..). Overall 3σ effect.**







g_{ae} **channel**

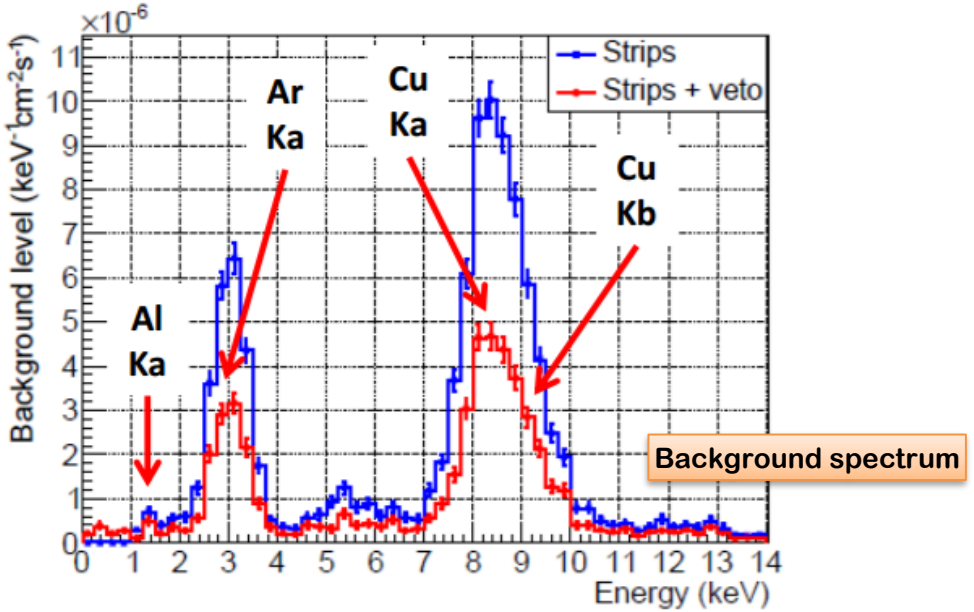
Region of QCD axion models that solve the stellar anomaly

M. Giannotti et al. JCAP 1710 (2017) 010 arXiv:1708.02111

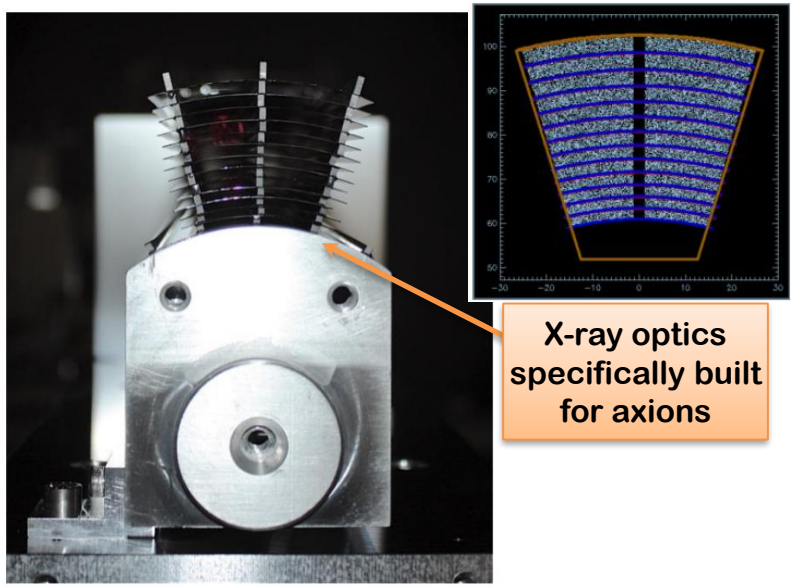
- **IAXO will explore most of the relevant models (especially with IAXO+)**
- **Only experiment with such capability**

IAXO pathfinder system in CAST

Test MM detector + slumped-glass x-ray optics together

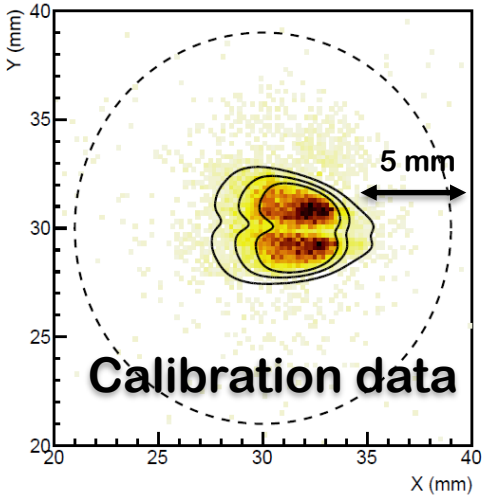


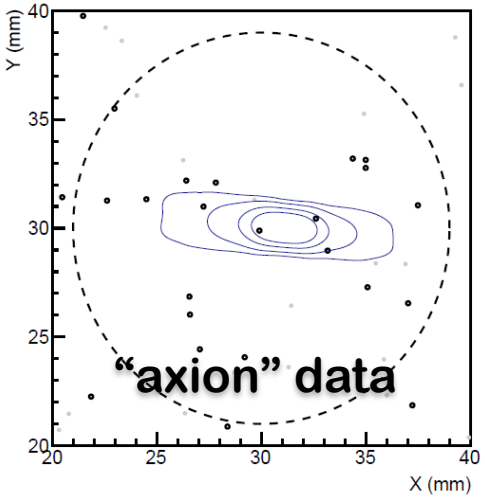
Background spectrum



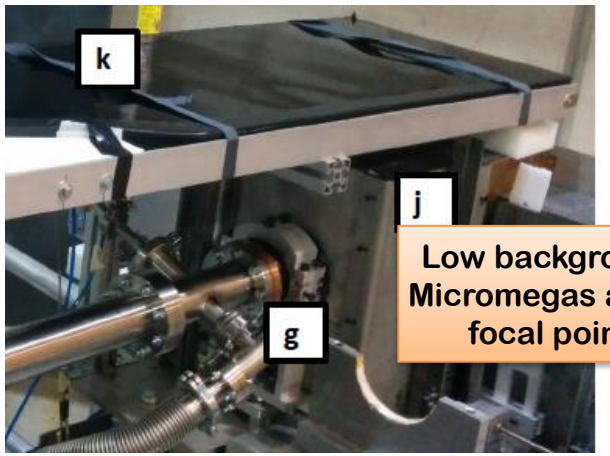
X-ray optics specifically built for axions

Detector: JCAP12 (2015)
Physics: Nature Physics (10.1038/nphys4109)



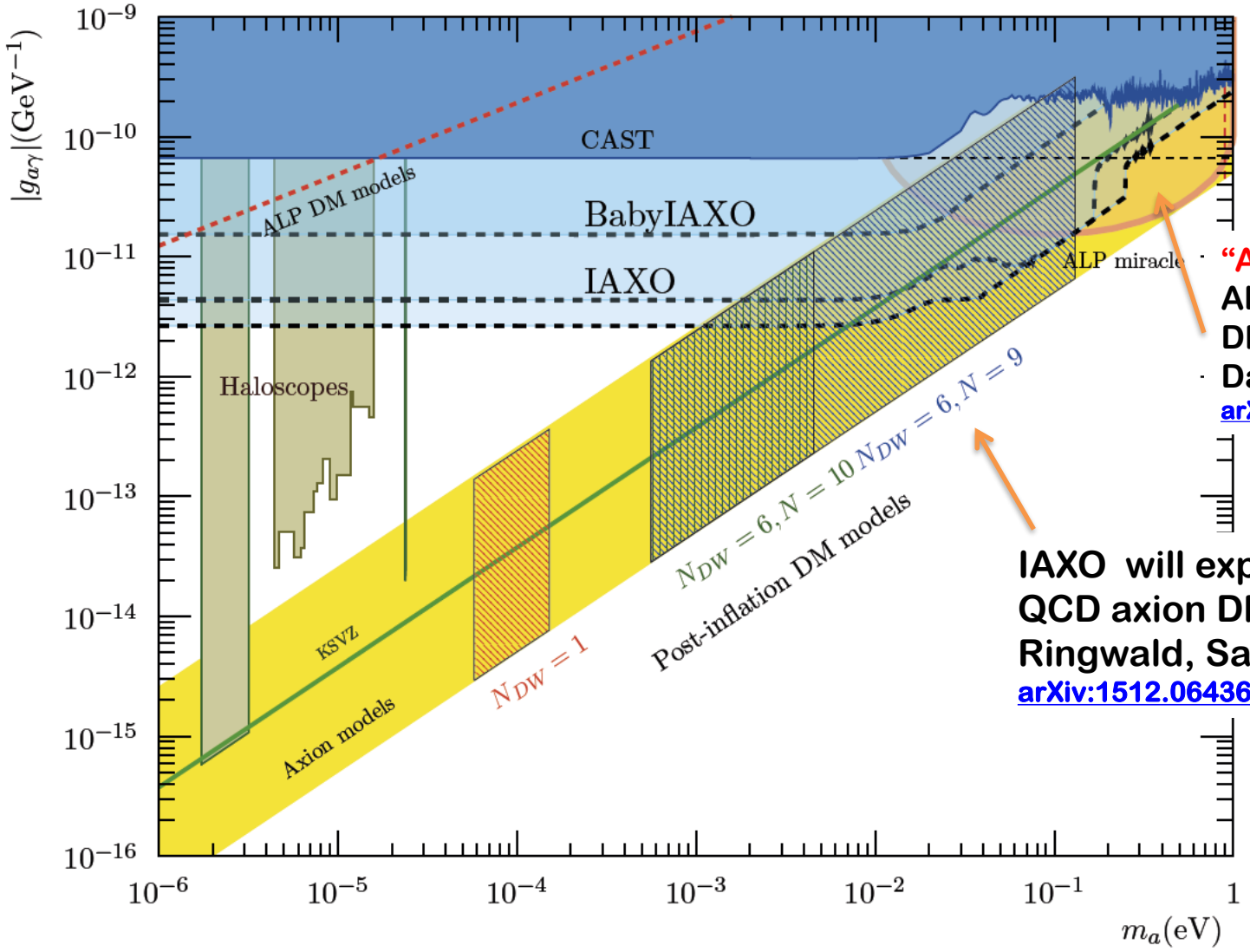


- Best SNR of any previous detector
- 290 tracking hour acquired (6.5 months operation)
- 3 counts observed in RoI (1 expected)



Low background Micromegas at the focal point

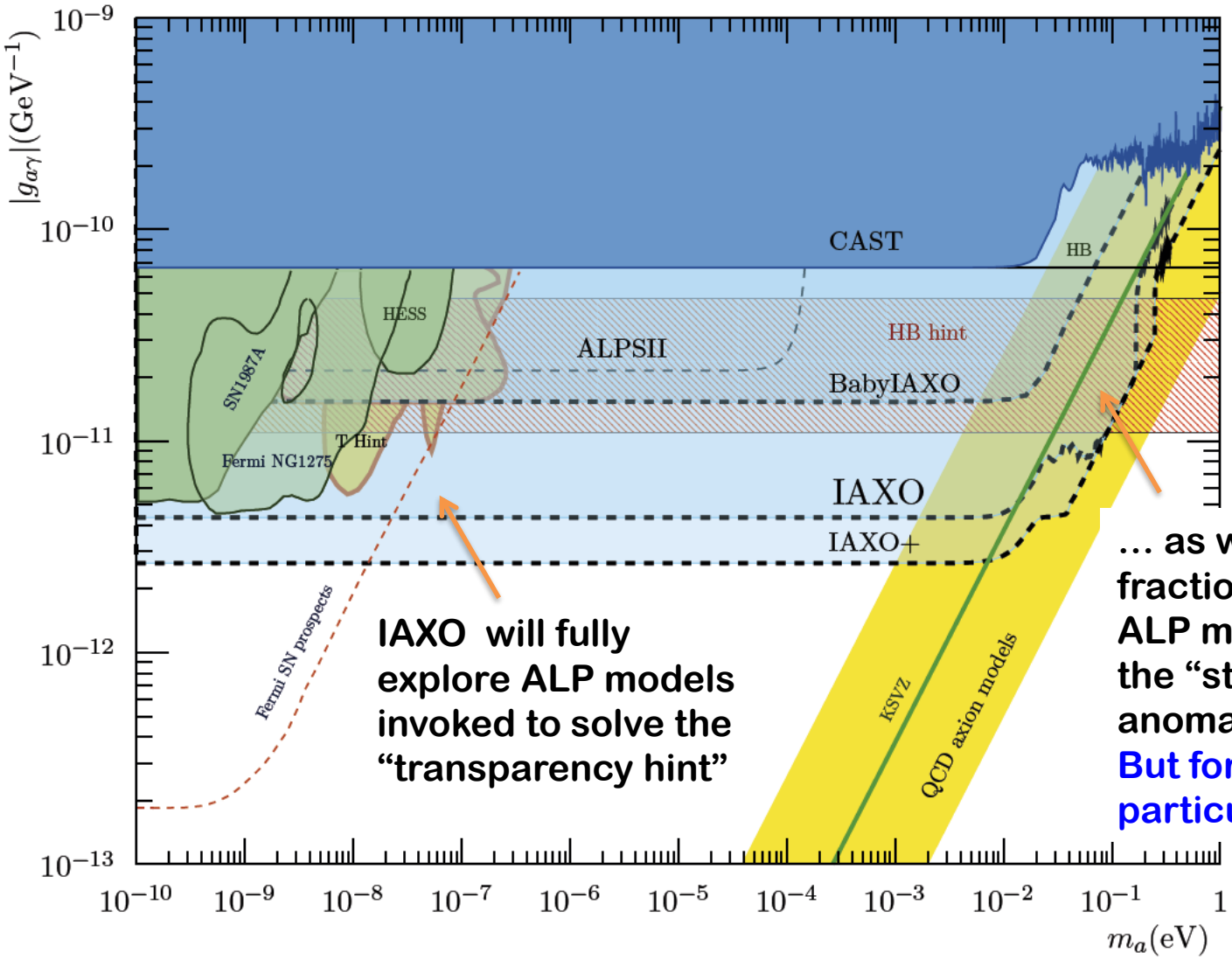
IAXO & meV axion cosmology



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

IAXO will explore viable QCD axion DM models
Ringwald, Saikawa 2016
arXiv:1512.06436

IAXO & astrophysics hints



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

… as well as a large fraction of the axion & ALP models invoked in the "stellar cooling anomaly"

But for this the g_{ae} is particularly interesting

IAXO physics reach in short

- IAXO will improve the experimental "helioscope frontier" by more than 1 order of magnitude in sensitivity to $g_{a\gamma\gamma}$

  (= by more than 10000 in terms of signal to noise ratio)
- IAXO will probe a large fraction of QCD axion models in the meV to eV mass band.
- No other proposed technique can probe QCD axions in this region.

  ← Uniqueness of IAXO.
- IAXO will fully probe the ALP region invoked to solve the transparency anomaly
- IAXO will largely probe the axion region invoked to solve the stellar cooling anomaly
- IAXO will partially explore viable QCD axion DM models, and largely probe the "ALP miracle" models solving both DM and inflation.
- IAXO will probe a large unexplored ALP parameter space, also generically motivated dark radiation, string theory,…
- All this, independent of the axion-as-DM hypothesis.
- Large complementarity with other detection strategies