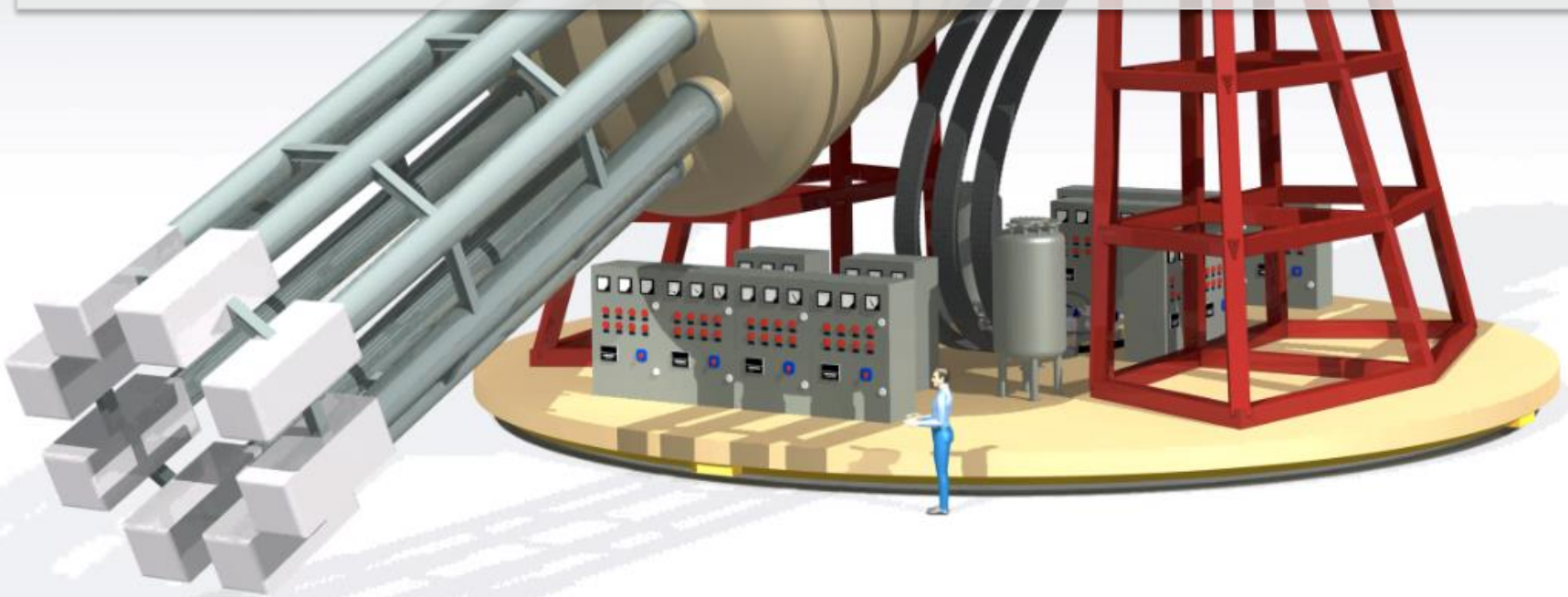
Physics case, prospects and status of the International AXion Observatory IAXO

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

Beyond Colliders, CERN, September 7th 2016



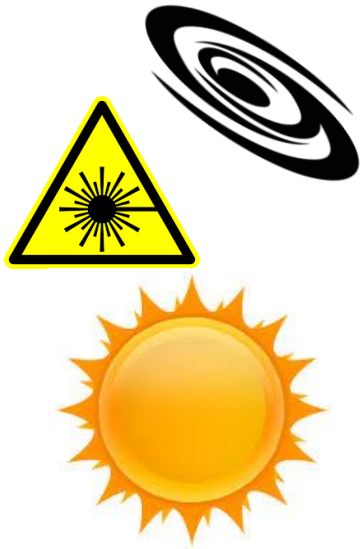
Why to search for axions?

- Most compelling solution to the **Strong CP problem** of the SM

- Axion-like particles (ALPs) **predicted by many extensions** of the SM (e.g. string theory)
- Axions, like WIMPs, may **solve the DM problem** *for free*. (i.e. not *ad hoc* solution to DM)
- **Astrophysical hints** for axion/ALPs?
  - Transparency of the Universe to UHE gammas
  - Anomalous cooling of different types of star

- Relevant axion/ALP parameter space at **reach of current and near-future experiments**
- Still too little experimental effort devoted to axions when compared to WIMPs

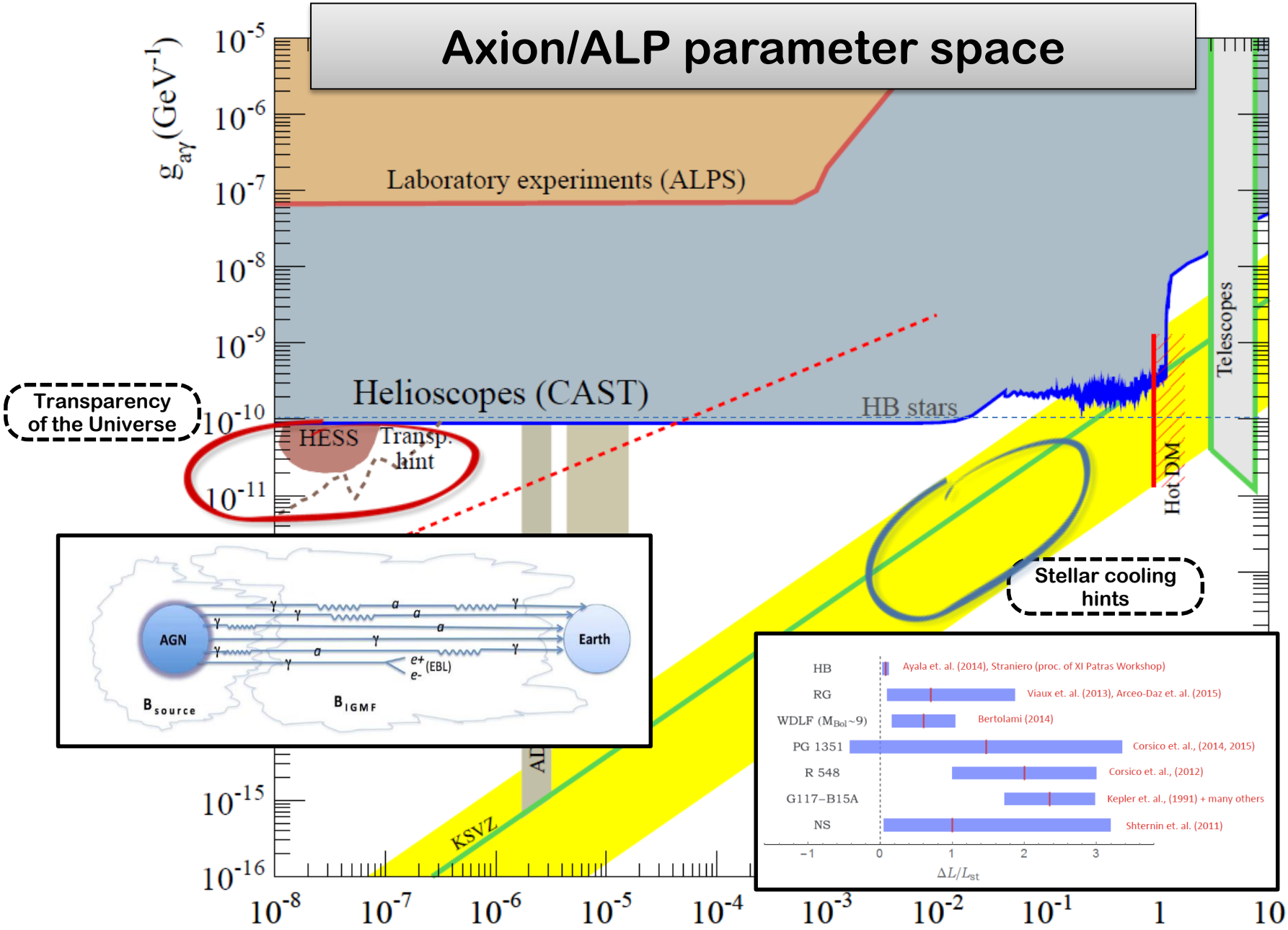
IAXO in the axion landscape



Source	Experiments	Model & Cosmology dependency	Technology
Relic axions	ADMX, ADMX-HF, Casper, CAPP, …	High	New ideas emerging, Active R&D going on,…
Lab axions	ALPS, OSQAR, fifth force exps,…	Very low	
Solar axions	SUMICO, CAST, IAXO	Low	Ready for large scale experiment

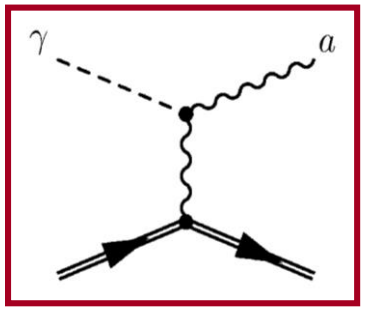
- Helioscopes → do not rely on the axion being the dominant DM component. Solar axion emission robust prediction
- Helioscopes → No R&D needed. Technology mature enough for a large scale experiment (IAXO)
- Large complementarity with other detection strategies

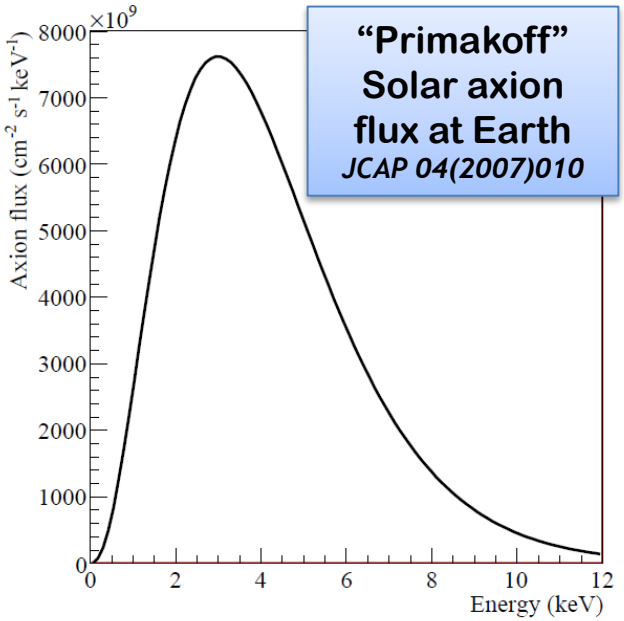
Axion/ALP parameter space

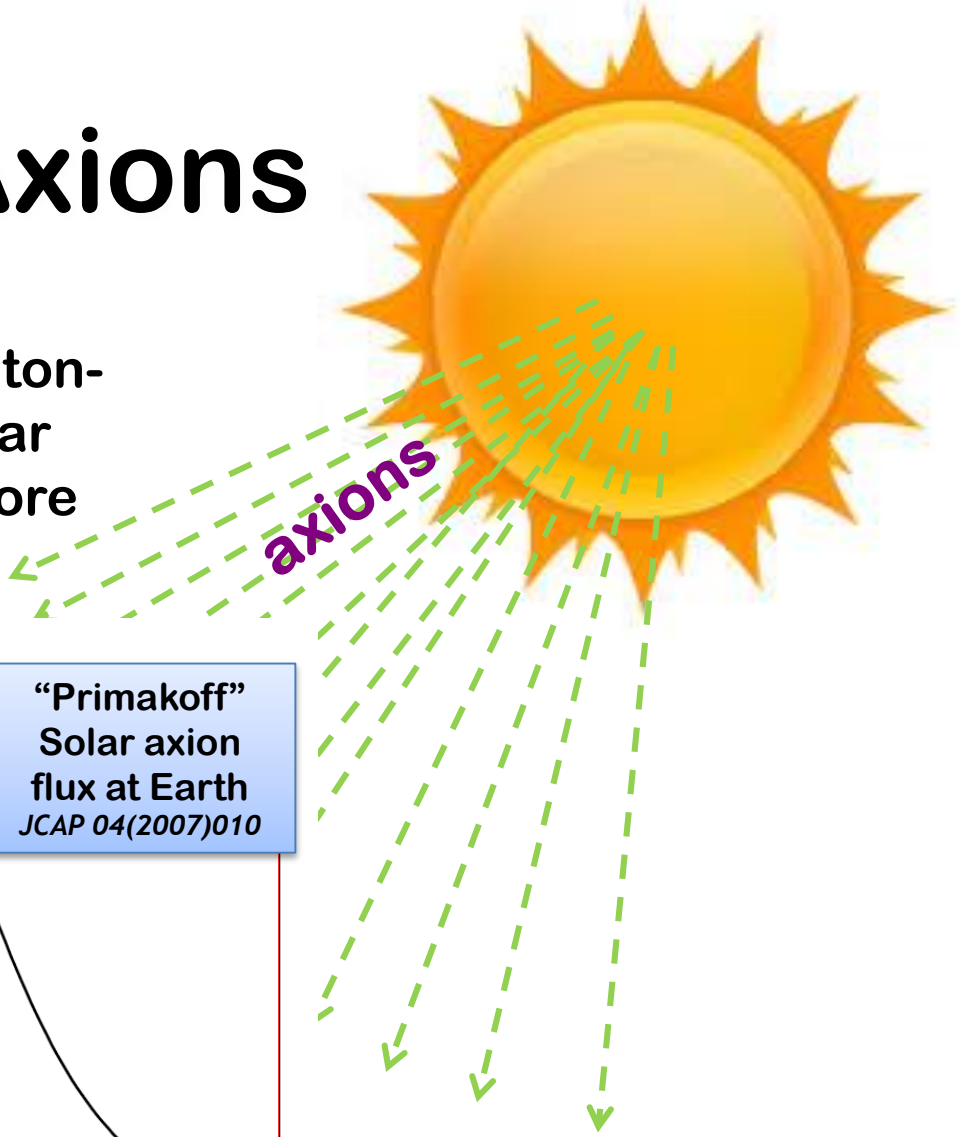


Solar Axions

- Solar axions produced by photon-to-axion conversion of the solar plasma photons in the solar core

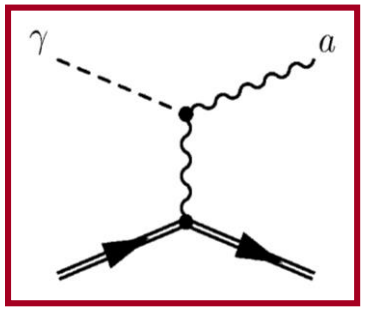


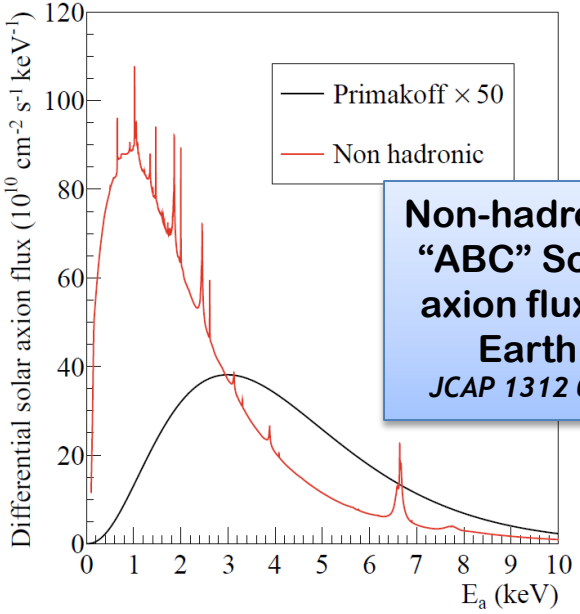




Solar Axions

- **Solar axions produced by photon-to-axion conversion of the solar plasma photons in the solar core**





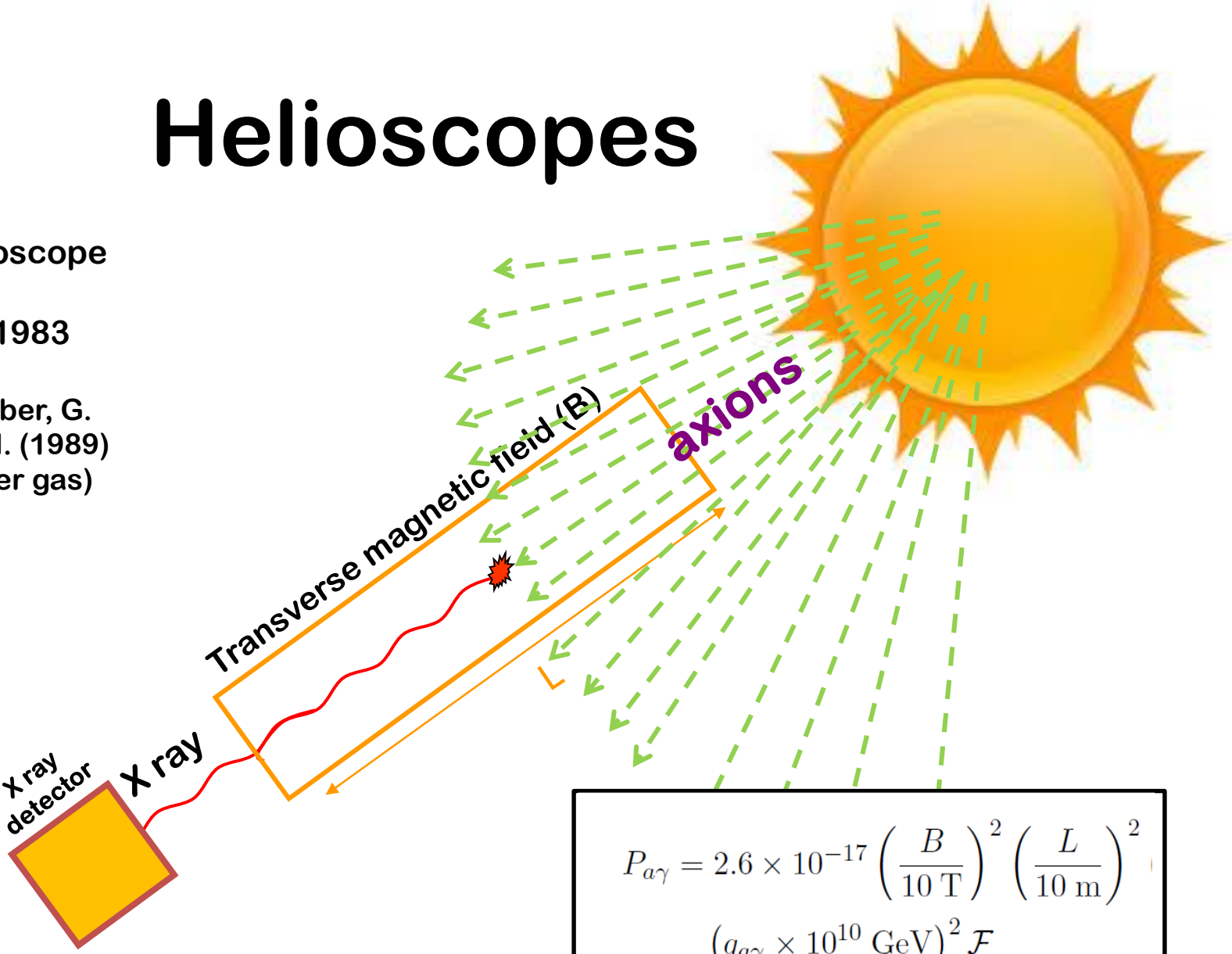
Non-hadronic "ABC" Solar axion flux at Earth
JCAP 1312 008

*** if the axion couples with the electron (g_{ae})**
(non hadronic axion)

Helioscopes

Axion helioscope concept
P. Sikivie, 1983

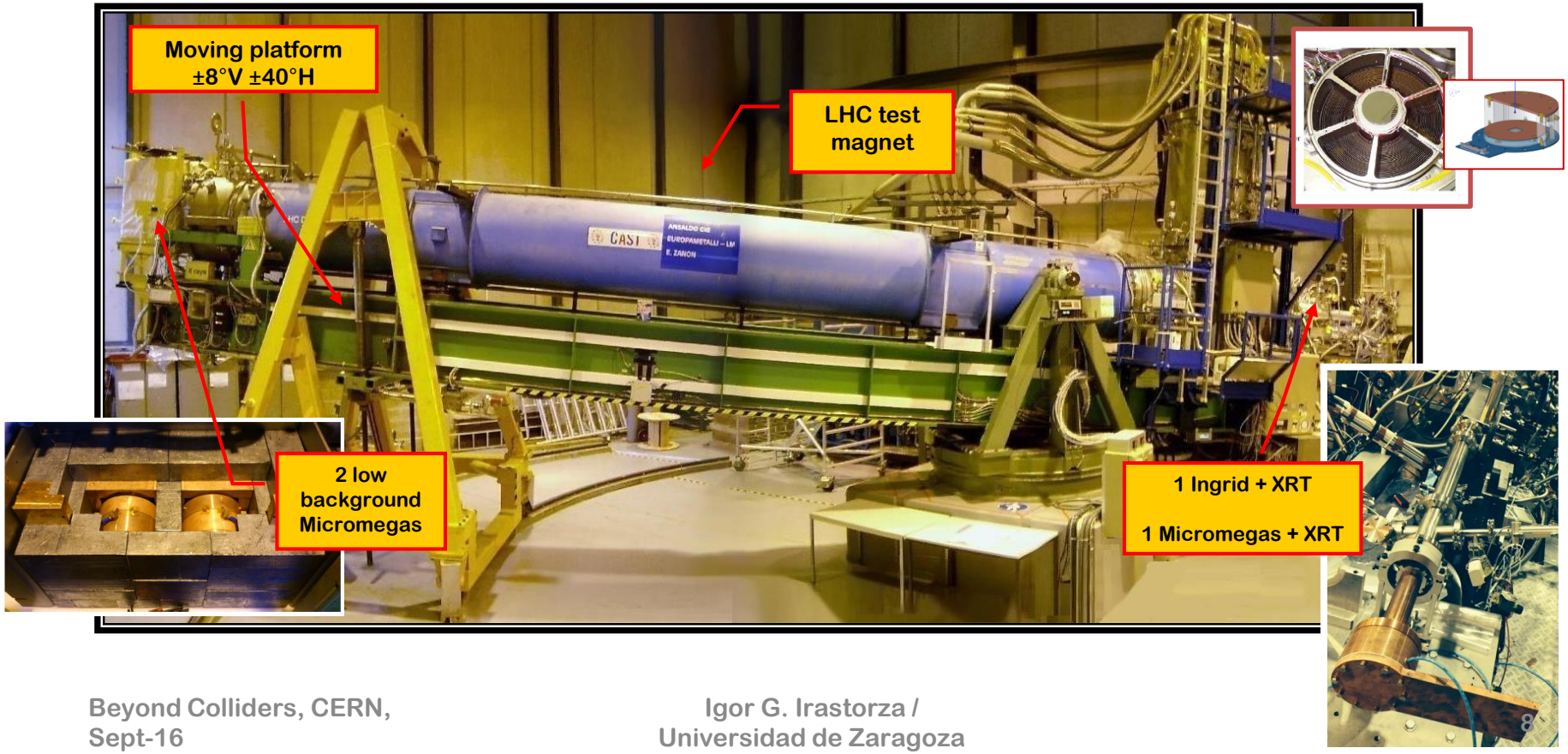
+ K. van Bibber, G. Raffelt, et al. (1989) (use of buffer gas)



$$P_{a\gamma} = 2.6 \times 10^{-17} \left(\frac{B}{10\ \mathrm{T}}\right)^2 \left(\frac{L}{10\ \mathrm{m}}\right)^2 \left(g_{a\gamma} \times 10^{10}\ \mathrm{GeV}\right)^2 \mathcal{F}$$

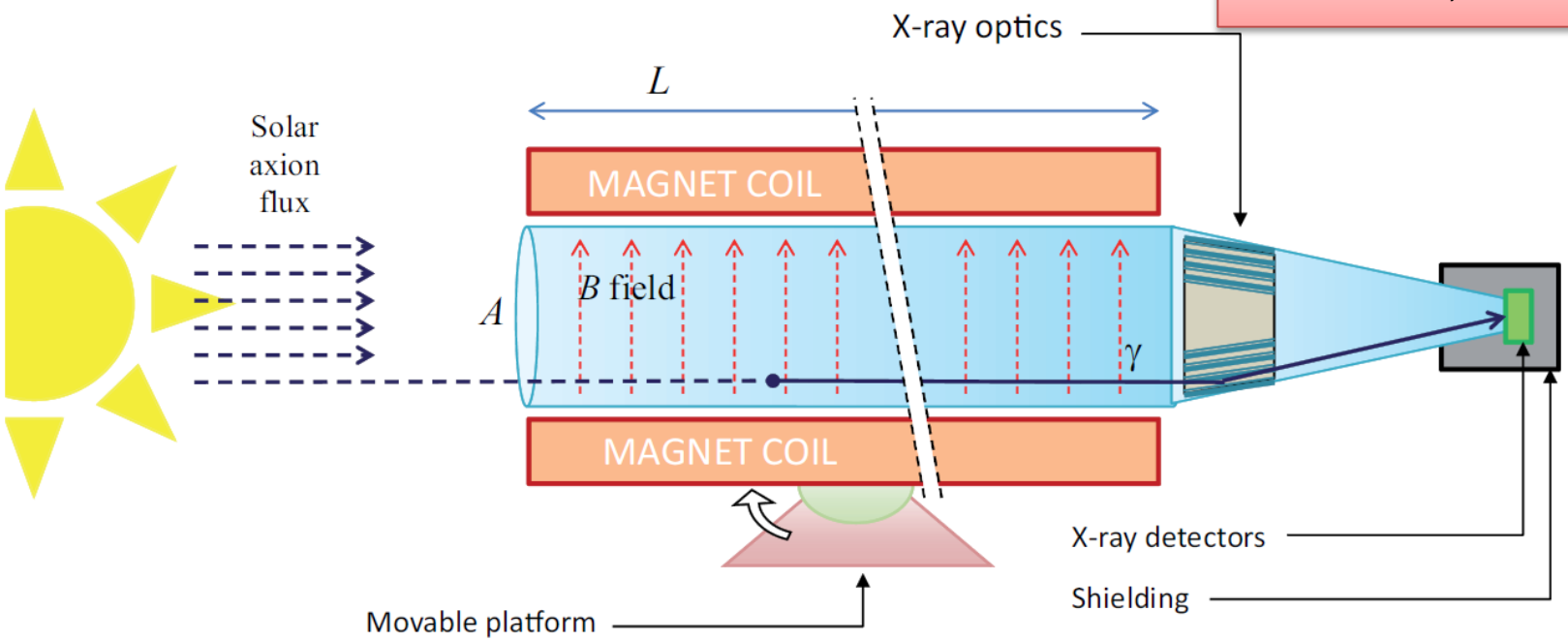
CAST experiment @ CERN

- Decommissioned LHC test magnet (L=10m, B=9 T)
- Moving platform ±8°V ±40°H (to allow up to 50 days / year of alignment)
- 4 magnet bores to look for X rays
- 2 X ray telescopes to increase signal/noise ratio.



IAXO – Concept

Enhanced axion helioscope:
JCAP 1106:013,2011

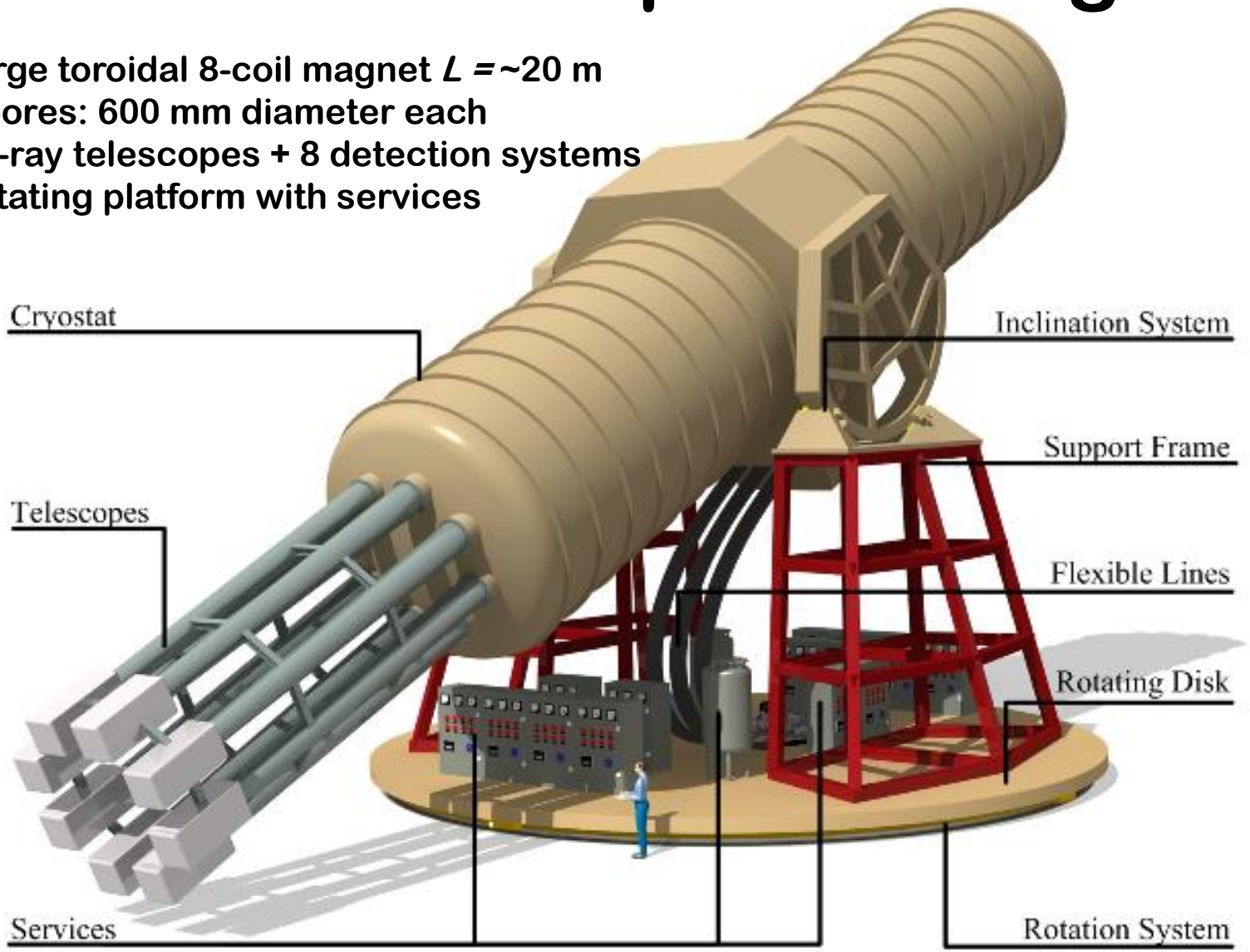


$$g_{a\gamma}^4 \propto \underbrace{b^{1/2}\epsilon^{-1}}_{\text{detectors}} \times \underbrace{a^{1/2}\epsilon_o^{-1}}_{\text{optics}} \times \underbrace{(BL)^{-2}A^{-1}}_{\text{magnet}} \times \underbrace{t^{-1/2}}_{\text{exposure}}$$

4+ orders of magnitude better SNR that CAST (JCAP 1106:013)

IAXO – Conceptual Design

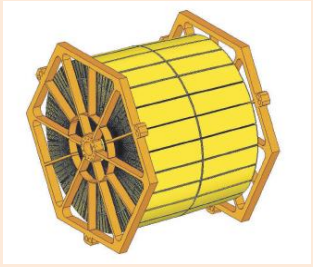
- **Large toroidal 8-coil magnet L =~20 m**
- **8 bores: 600 mm diameter each**
- **8 x-ray telescopes + 8 detection systems**
- **Rotating platform with services**

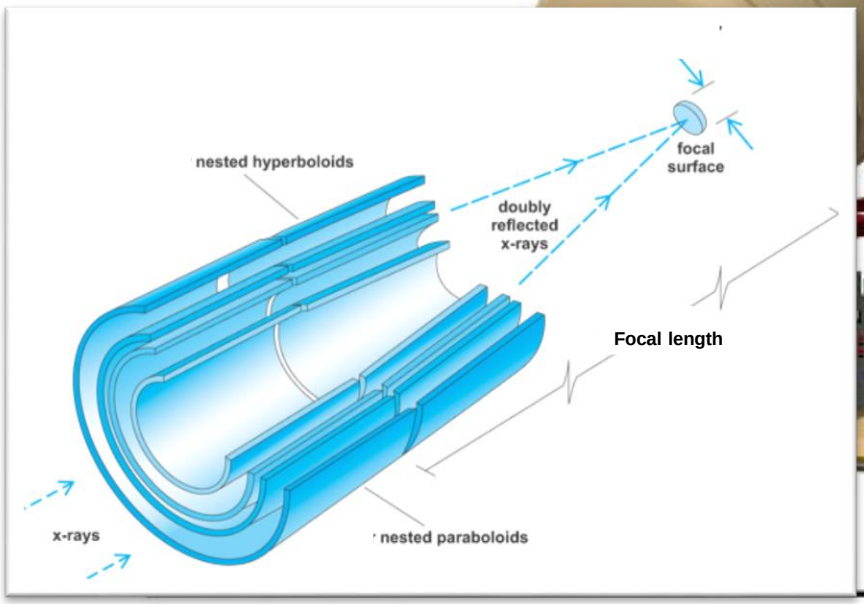


IAXO technologies – Baseline

IAXO telescopes

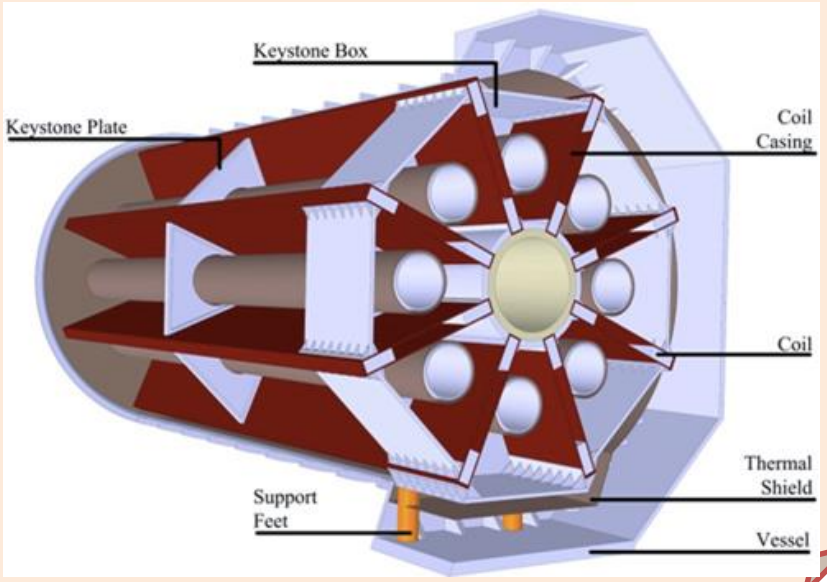
- Slumped glass technology with multilayers
- Cost-effective to cover large areas
- Based on NuSTAR developments
- Focal length ~5 m
- 60-70% efficiency
- LLNL+UC+DTU + MIT + INAF





IAXO magnet

- Superconducting "detector" magnet.
- Toriodal geometry (8 coils)
- Based on ATLAS toroid technical solutions.
- CERN+CEA expertise
- 8 bores / 20 m long / 60 cm Ø per bore



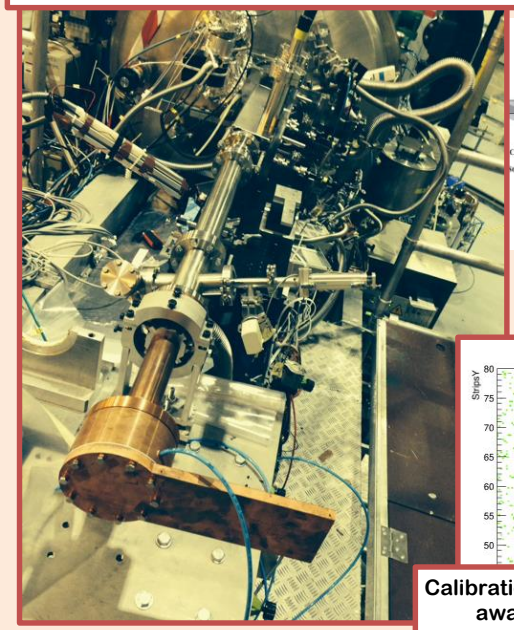
Baseline developed at:
IAXO Letter of Intent: CERN-SPSC-2013-022
IAXO Conceptual Design: JINST 9 (2014) T05002 (arXiv:1401.3233)

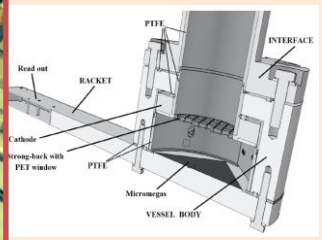
IAXO technologies – Baseline

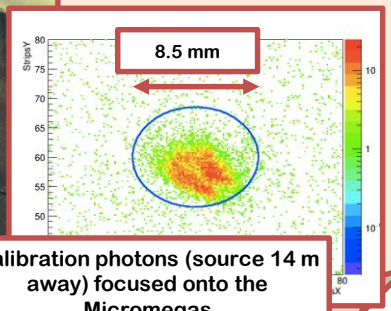
IAXO detectors

- **Micromegas** gaseous detectors
- Radiopure components + shielding
- Discrimination from event topology in gas
- Long trajectory in CAST
- Zaragoza + CEA + Bonn + others expertise

Optics+detector IAXO pathfinder system (in operation in CAST during 2014-5)





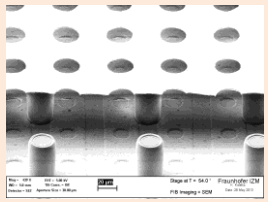


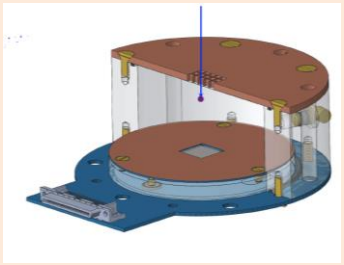
Calibration photons (source 14 m away) focused onto the Micromegas

IAXO detectors

Ingrid detectors

- Better threshold
- U. Bonn

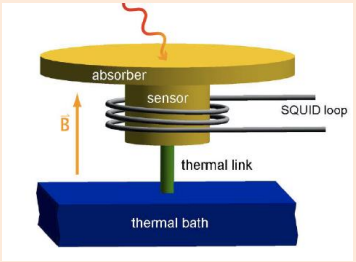




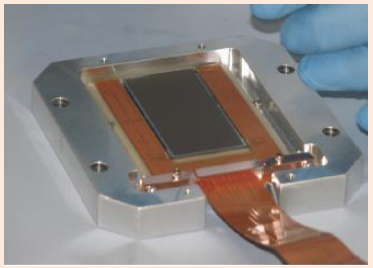
MMC (Magnetic Metallic Calorimeters)
TES (Transition Edge Sensors)

- Very good E resolution & threshold
- Heidelberg + CEA + CNSMS

Solar axion spectroscopy:
Axion-electron ABC spectrum
Axion mass determination

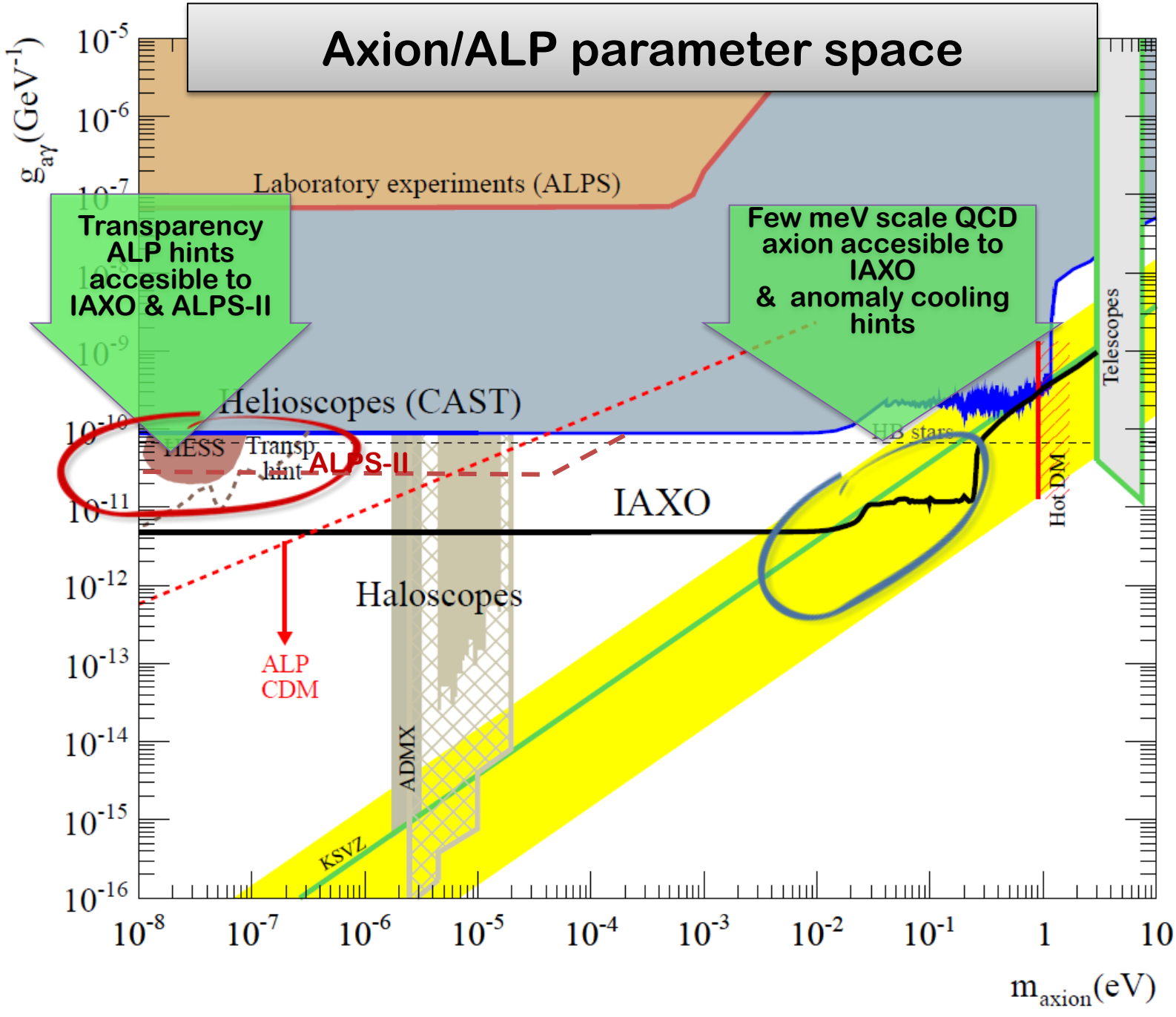


Low noise **CCDs**



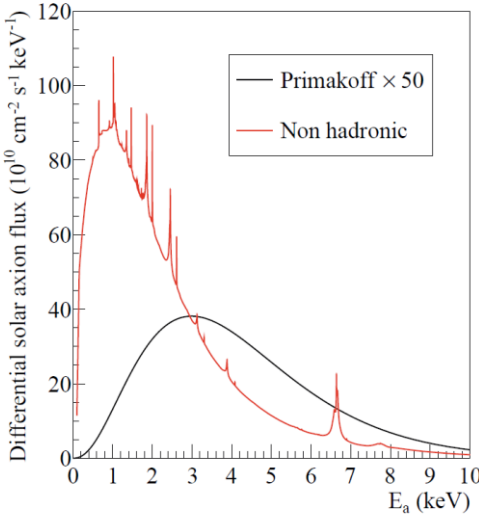
Services

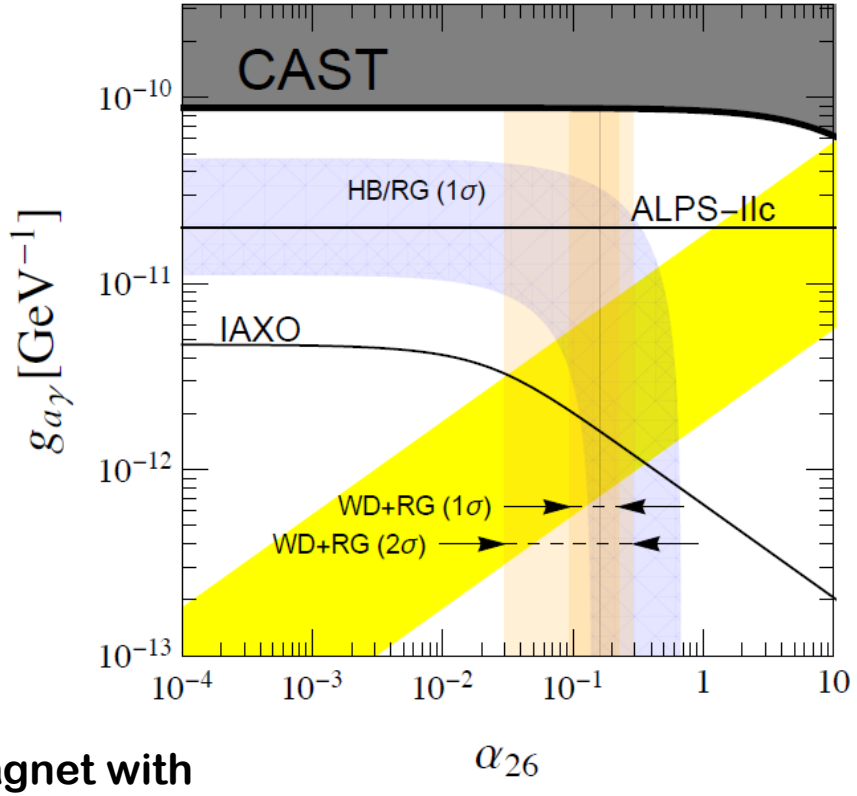
Rotation System


Axion/ALP parameter space
Laboratory experiments (ALPS)
Transparency ALP hints accesible to IAXO & ALPS-II
Few meV scale QCD axion accesible to IAXO & anomaly cooling hints
Helioscopes (CAST)
HESS
Transp hint
ALPS-II
IAXO
HB stars
Hot DM
Telescopes
Haloscopes
ALP CDM
ADMX
KSVZ
$g_{a\gamma}$(GeV^{-1})
m_{axion}(eV)
10^{-5}
10^{-6}
10^{-7}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10

Axion-electron coupling

ABC-produced solar axions





Sensitive to g_{ae} values down to ~10^{-13}

And more…

- **Dark Matter Axions (→ use of IAXO magnet with cavities / RF antennas)**
- **ALPs from Dark Radiation**
- **ALPs from nearby Supernova (connection with SNEWS) → MeV photon detector at the other end**
- **…**

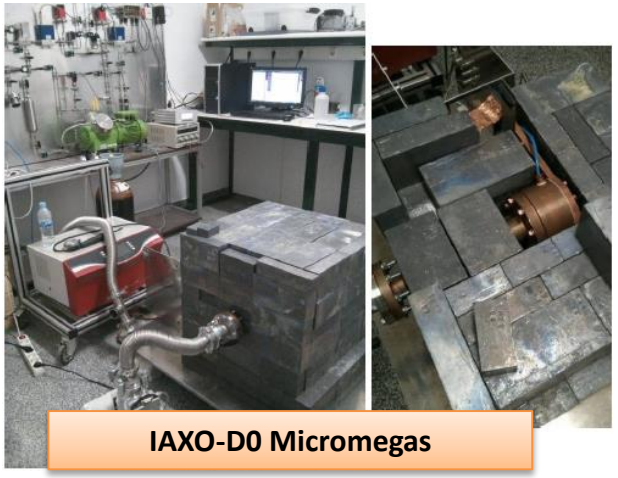
IAXO status of project

- **2011: First studies concluded (JCAP 1106:013,2011)**
- **2013: Conceptual Design finished (arXiv:1401.3233).**
  - **Most activity carried out up to now ancillary to other group's projects (e.g. CAST)**
- **August 2013: Letter of Intent submitted to the CERN SPSC**
  - **LoI: [CERN-SPSC-2013-022]**
  - **Presentation in the open session in October 2013:**
- **January 2014: Positive recommendations from SPSC.**
  - **Ackowledge physics case + encourage proceed to TDR**

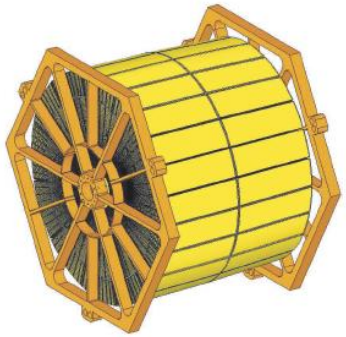
- **2014-15: Transition phase towards TDR (technical design)**
  - **Some IAXO preparatory activity already going on as part of CAST near term program: IAXO pathfinder system in CAST in 2014-15**
  - **Preparation of a MoU to carry out TDR work.**
  - **Strengthen collaboration, awareness actions, meetings, coordinated funding applications**
  - **First discussion on long-term plan to construction**

TDR in progress

- **IAXO-T0**: demonstration coil magnet
- **IAXO-X0**: prototype x-ray optics
- **IAXO-D0**: prototype low background detector setup testing different technologies for detector
- Studies to refine IAXO physics case
- Additional physics potential
- Site studies
- Consolidate and structure collaboration

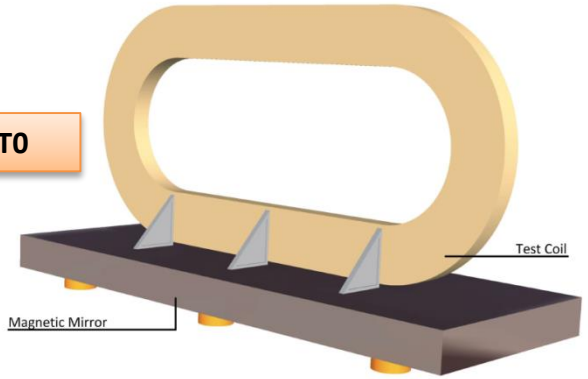


IAXO-D0 Micromegas



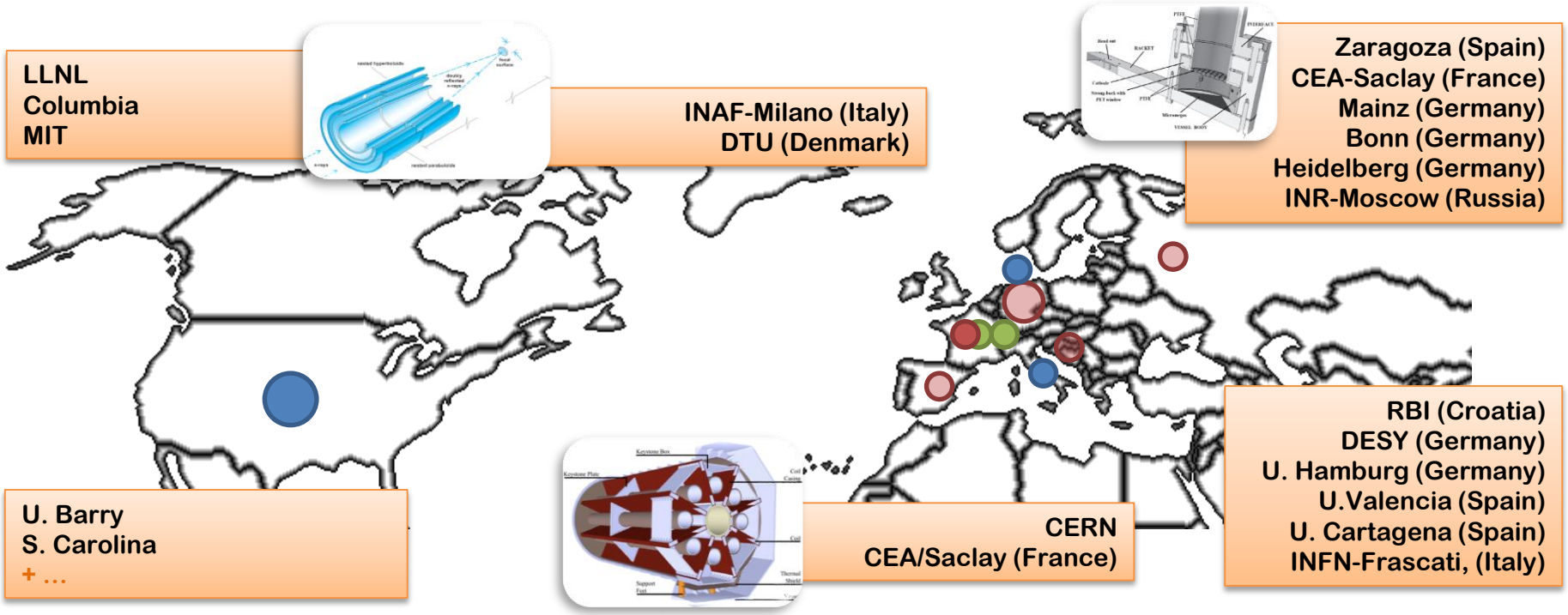
IAXO-X0

IAXO-T0



IAXO proto-collaboration

- **Big effort to strengthen collaboration → large consortium involved in a number of funding applications, covering all TDR needs**

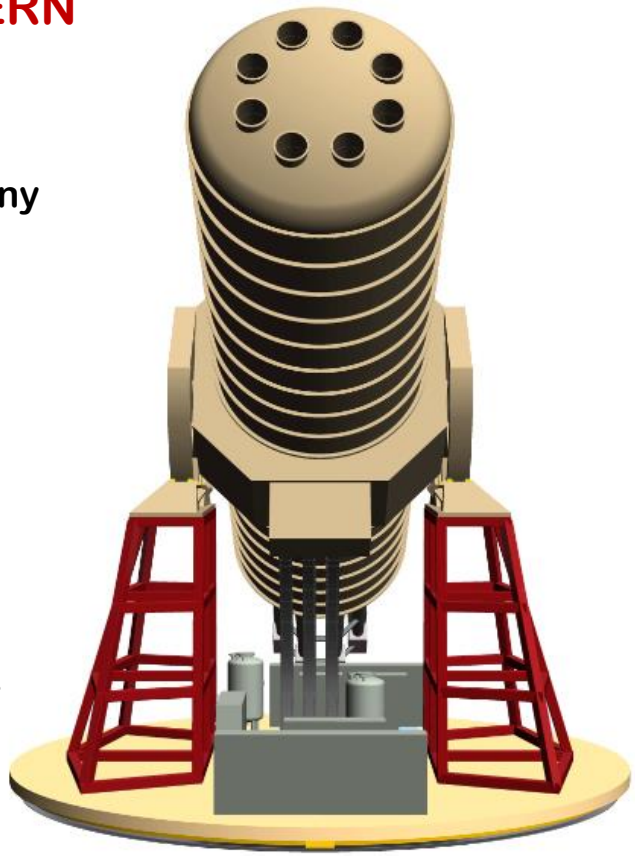


New partners welcome…

(*) Only shown groups for which formal activity is ongoing or under discussion/preparation.
Potentiaal interest in more groups than shown

Conclusions

- **IAXO: best use of technologies (magnet, optics, detectors) and past trajectory of CAST at CERN**
- **IAXO will probe deep into unexplored axion+ALP parameter space:**
  - **QCD axions** at the few meV scale → not at reach of any other technique
  - ALPs at the $g_{a\gamma\gamma}$ ~10^{-12} GeV^{-1} scale
  - ALPs at the g_{ae} ~10^{-13} scale
- **IAXO as a generic "axion/ALP facility"**

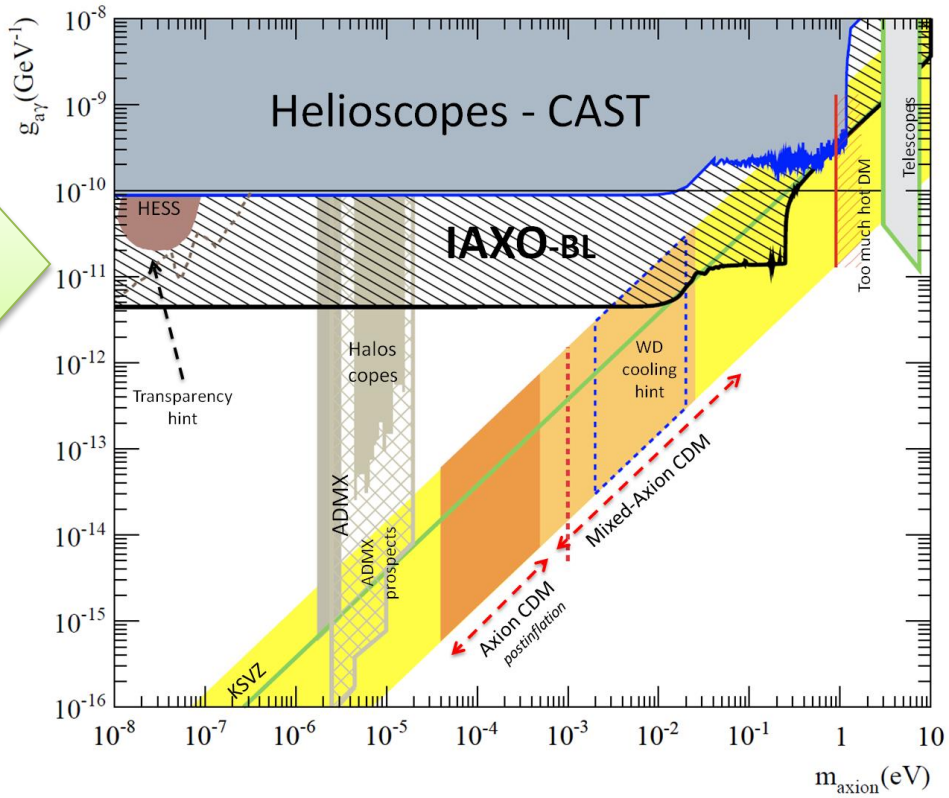


- **First steps towards TDR after the positive recommendation from CERN SPSC.**
- **Large community now endorsing the project.**
- **Longer-term strategy towards construction under discussion. Site: CERN but also DESY or LNF**
- **Looking forward to Study Group process**

Backup slides…

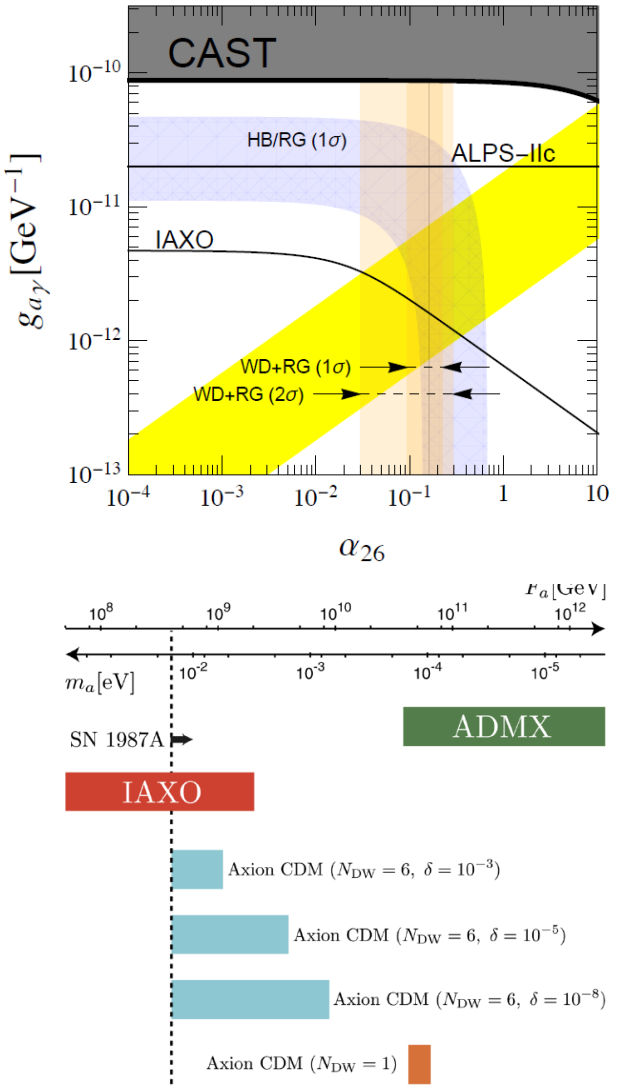
An ALP with $g_{a\gamma}$~ $10^{-11\text{-}12}$ GeV^{-1}

- Well beyond current upper bounds on the $g_{a\gamma}$ coupling (CAST & HB stars ~ 10^{-10} GeV^{-1})
- String theory ALPs
- Invoked to explain the anomanlous transparency of the Universe to UHE gammas
- Could explain some anomalous stellar cooling observations



The multi-meV axion

- Is compatible with all current axion bounds.
- Is invoked in several anomalous stellar cooling scenarios
  - Gianotti et al. JCAP1605 (2016) 057 [arXiv:1512.08108]
- Can be the cold DM in some models
  - with NDW>1 and bias term to break the discrete symmetry (Kawasaki et al. PRD91 (2015), Ringwald et al. arXiv:1512.06436)
  - or it can be a subdominant DM component
- Very hard to detect (→ IAXO!)
- SN axion background
  - Raffelt et al. PRD84 (11)

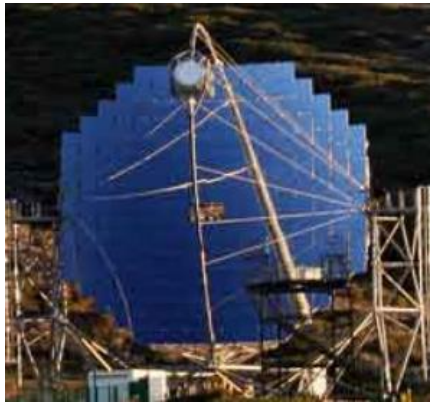


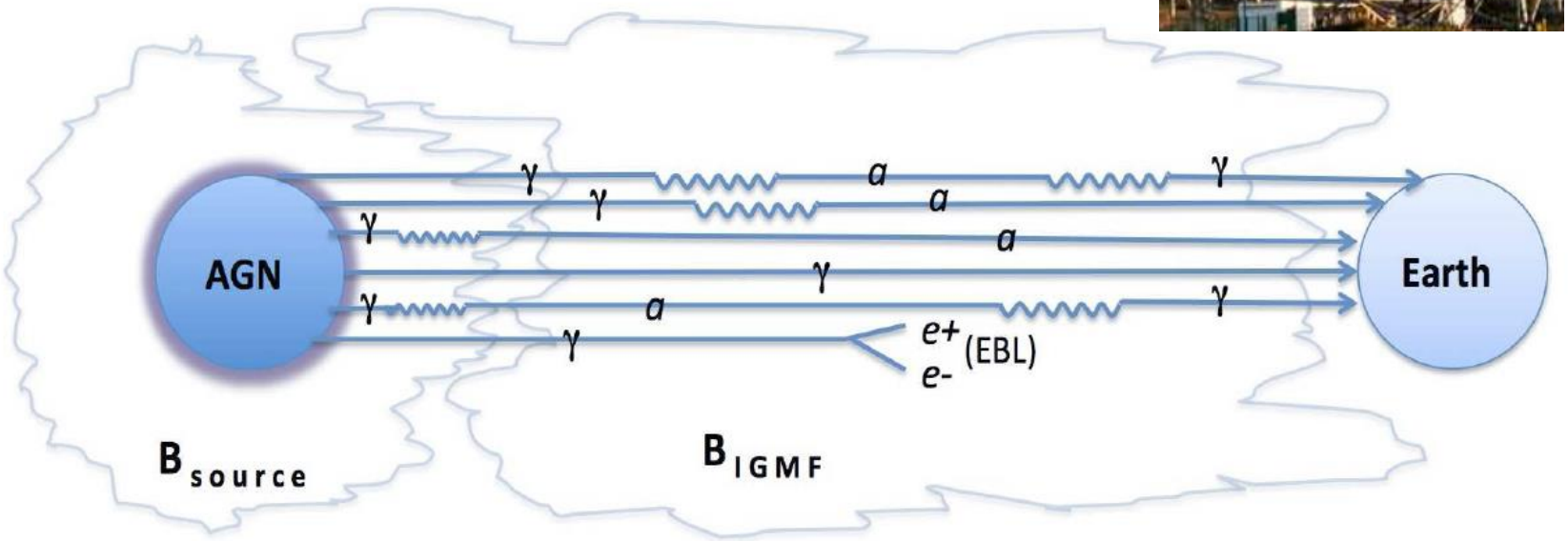
Astrophysical hints for axions

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

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

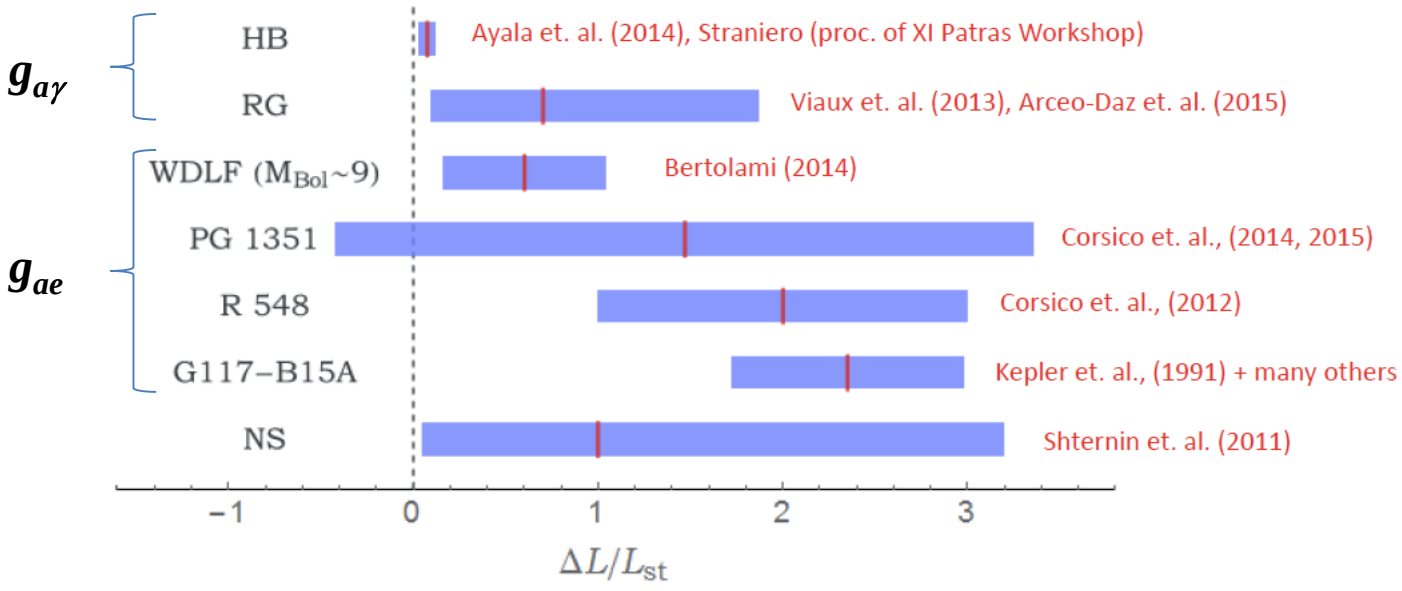
$m_a \lesssim 10^{-(10-7)}\ \mathrm{eV}$





Astrophysical hints for axions (II)

- **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**



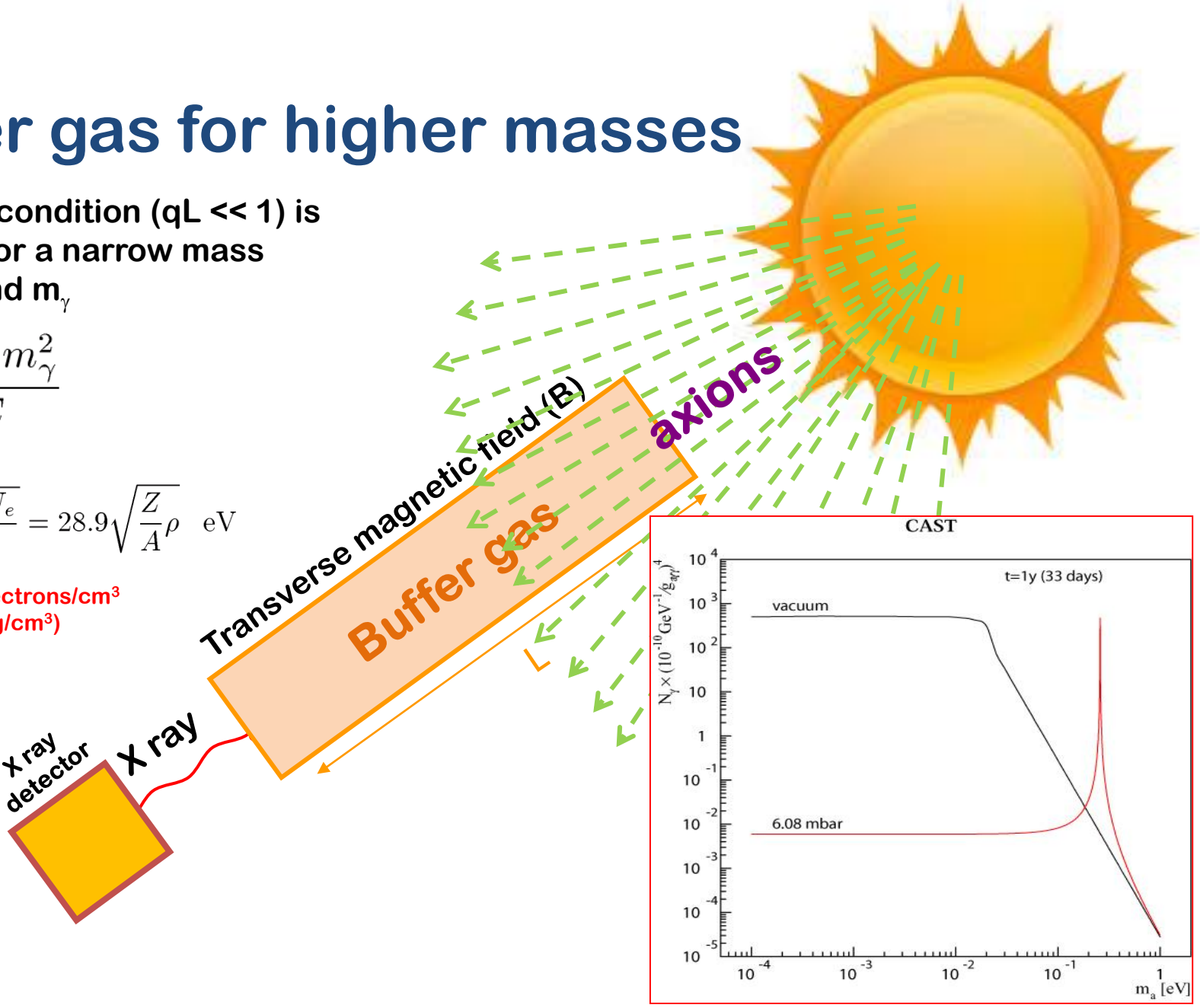
Buffer gas for higher masses

Coherence condition (qL << 1) is recovered for a narrow mass range around m_γ

$$|q| = \frac{m_a^2 - m_\gamma^2}{2E}$$

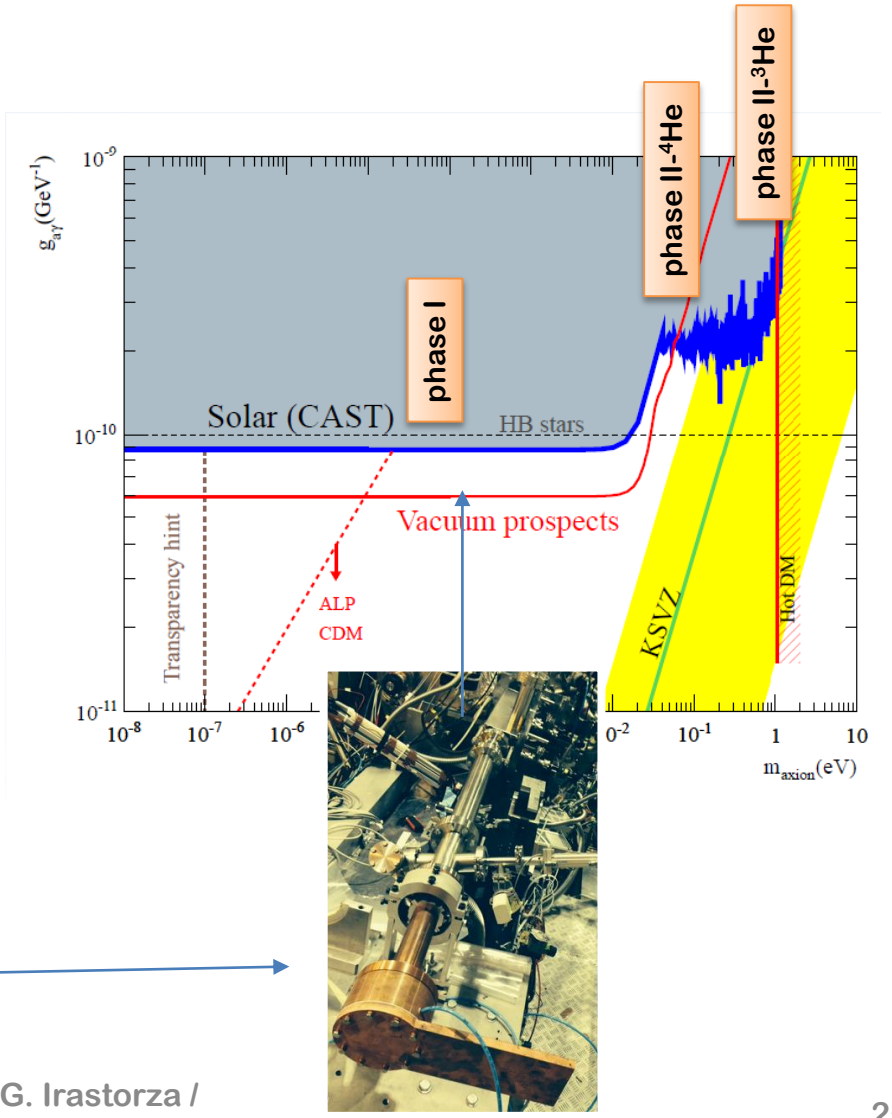
$$m_\gamma \approx \sqrt{\frac{4\pi\alpha N_e}{m_e}} = 28.9\sqrt{\frac{Z}{A}\rho} \quad \text{eV}$$

N_e: number of electrons/cm^3
r: gas density (g/cm^3)

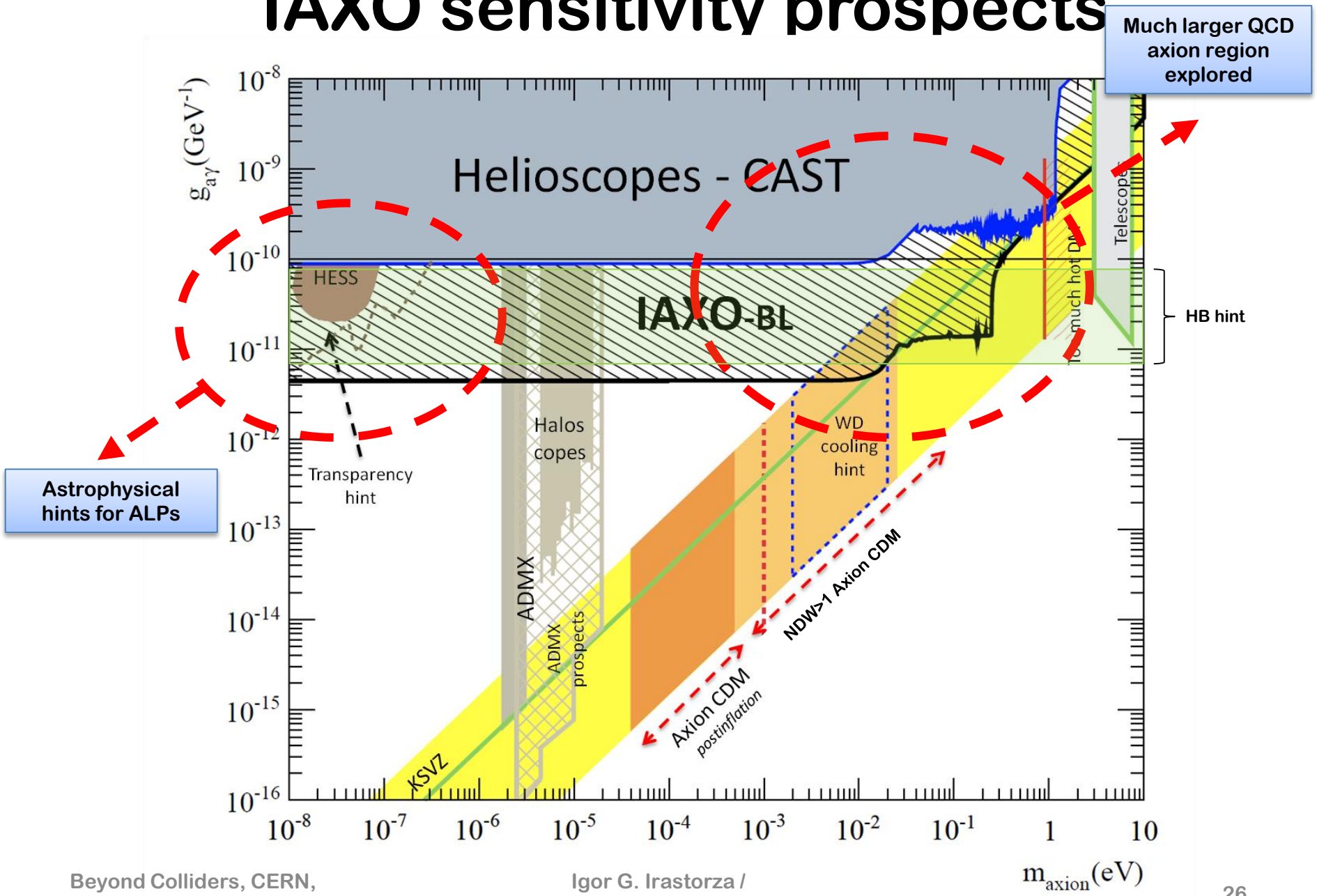


CAST results (solar axions)

2003 – 2004	**CAST phase I** • vacuum in the magnet bores
2006	**CAST phase II - ^{4}He Run** • axion masses explored up to 0.39 eV (160 P-steps)
2007	**^{3}He Gas system implementation**
2008 - 2011	**CAST phase II - ^{3}He Run** • axion masses explored up to 1.17 eV • bridging the dark matter limit
2012	•Revisit 4He Run with improved detecors
2013-2015	•Revisit vacuum phase with improved detectors •**Analisis ongoing.** •**New result soon available**



IAXO sensitivity prospects



CERN SPSC recommendations

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.

This was endorsed by the Research Board in March2014

Minutes of the 206th CERN Research Board held on March2014:
https://cds.cern.ch/record/1695812/files/M-207.pdf

Mid term plans (+4 years)
towards IAXO construction

- **Site:**
  - CERN is Plan A, but alternatives under consideration: it may affect funding strategies. Some preliminary interest from a number of institutions.
- **Magnet:**
  - Magnet construction → main resources challenge
  - Plan A: Form international consortium, coordinated by CERN (+CEA?) to collectively support the magnet construction, by means of inkind contributions to the effort.
  - Plan B: Large investment by host institution (IAXO being hosted outside CERN)
- **X-ray optics:**
  - Construction efforts distributed among groups pushing x-ray technologies for IAXO: US (LLNL, UC, MIT) + Europe (DTU, INAF-Milano)
- **Detectors:**
  - Efforts distributed among groups pushing each detector technology (actual decisions taken after TDR):
    - Micromegas: Zaragoza, CEA
    - Ingrid: Bonn
    - CCD: FNAL?, LPNHE?
    - MMCs/TES: Heidelberg, Orsay, CEA

IAXO costs

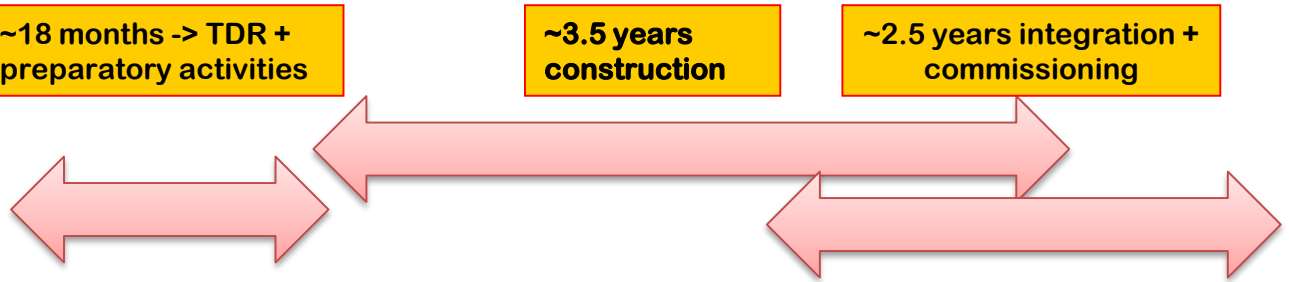
Item	Cost (MCHF)	Subtotals (MCHF)
Magnet		31.3
Eight coils based assembled toroid	28	
Magnet services	3.3	
Optics		16.0
Prototype Optic: Design, Fabrication, Calibration, Analysis	1.0	
IAXO telescopes (8 + 1 spare)	8.0	
Calibration	2.0	
Integration and alignment	5.0	
Detectors		5.8
Shielding & mechanics	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.

Comments/caveats:

- **Costs are for construction, and do not include operations and science support**
- **Costs based on initial estimates that need to be confirmed at TDR**
- **Labor for engineering, maintenance & operations not included**
- **Estimates do not include contingencies**

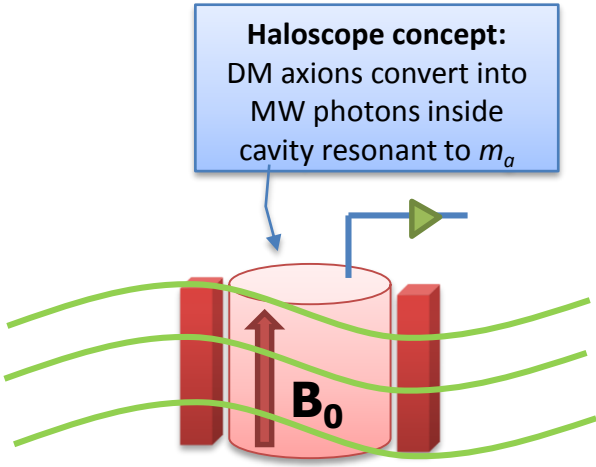
IAXO timeline

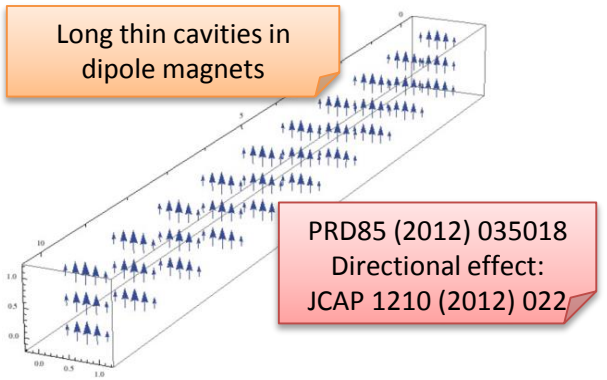


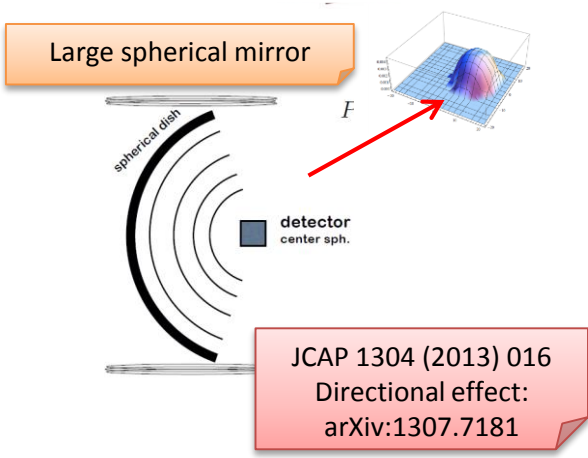
Years		1				2				3				4				5				6			
Months		3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
Magnet																									
Design	T0																								
	T1-T8																								
Demo coil																									
Production																									
Integration																									
Services																									
Optics																									
Optic design study																									
Prototype construction																									
Calibration																									
Finalize design																									
Build assembly machines																									
Procure mandrels & ovens																									
Build coating facilities																									
Slump glass																									
Deposit coatings																									
Assemble optics																									
Calibrate optics																									
Installation																									
Detectors																									
Prototype																									
Construction (incl. spares)																									
Installation & commissioning																									

IAXO-DM configurations?

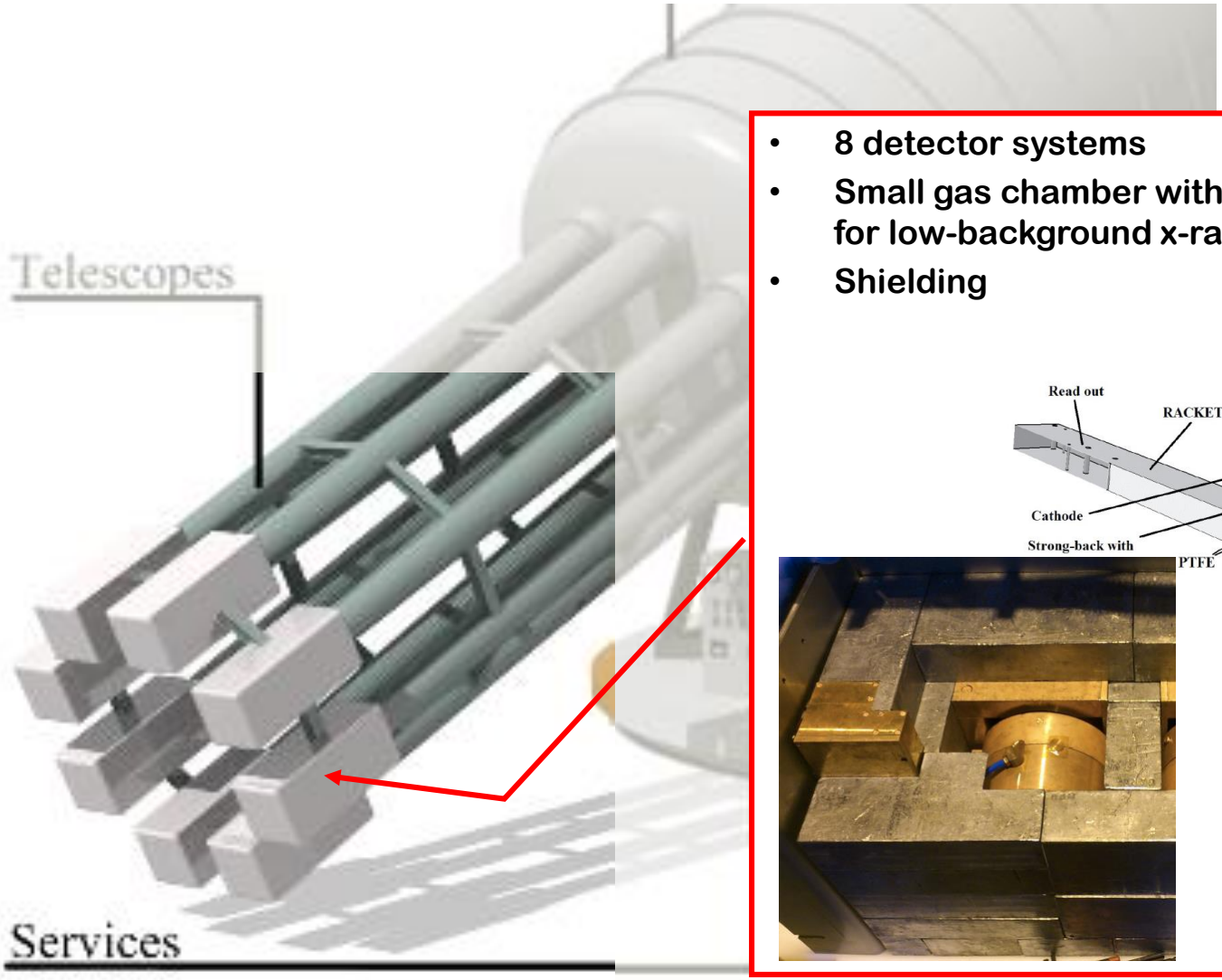
- ADMX has proved halosocope concept competitive at m_a~1-10 μeV. Big motivation to explore higher masses.
- Many new ideas being put forward. R&D needed.
- Various possible arrangements in IAXO. Leverage the huge magnetic volume available:
  1. Single large cavity tuned to low masses
  2. Thin long 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?
- Initial stages of exploring and developing concepts.



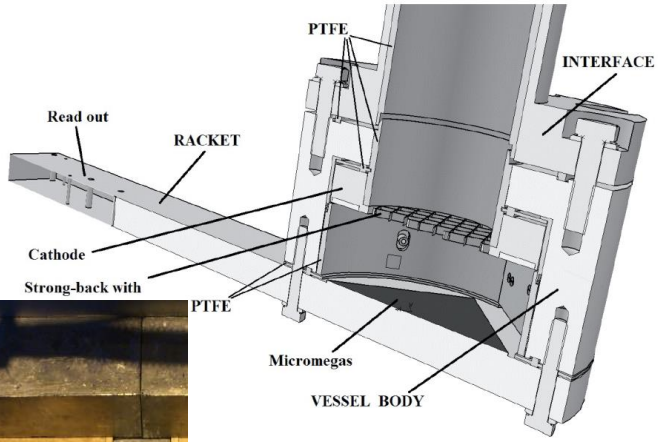




IAXO low background detectors



- 8 detector systems
- Small gas chamber with Micromegas readouts for low-background x-ray detection
- Shielding

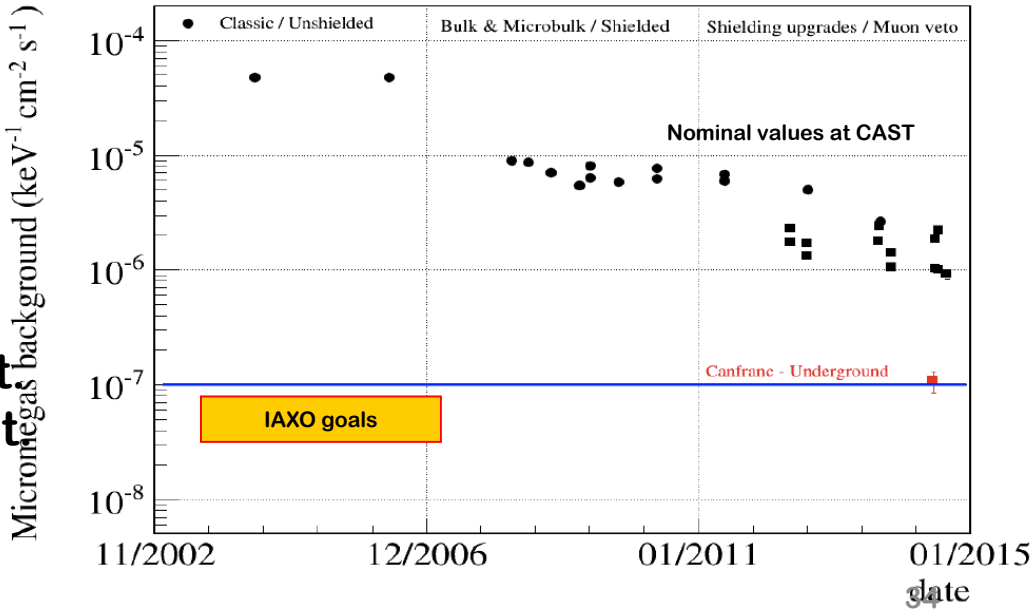


IAXO low background MM detectors

- Small Micromegas-TPC chambers:
  - Shielding
  - Radiopure components
  - Offline discrimination

History of background improvement of Micromegas detectors at CAST

- Goal background level for IAXO:
  - $10^{-7} – 10^{-8}$ c keV^{-1} cm^{-2} s^{-1}
- Already demonstrated:
  - ~8×10^{-7} c keV^{-1} cm^{-2} s^{-1} (in CAST 2014 result)
  - 10^{-7} c keV^{-1} cm^{-2} s^{-1} (underground at LSC)
- Active program of development. Clear roadmap for improvement

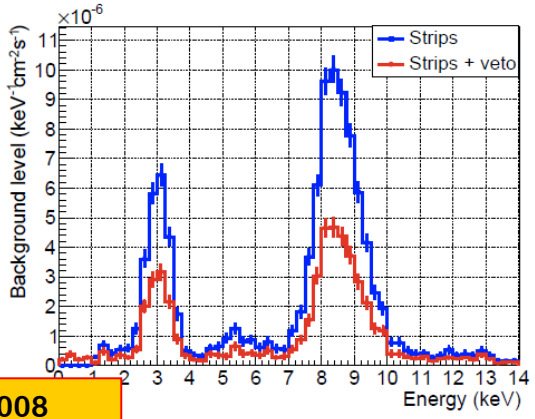


See arXiv:1310.3391

IAXO low background detectors

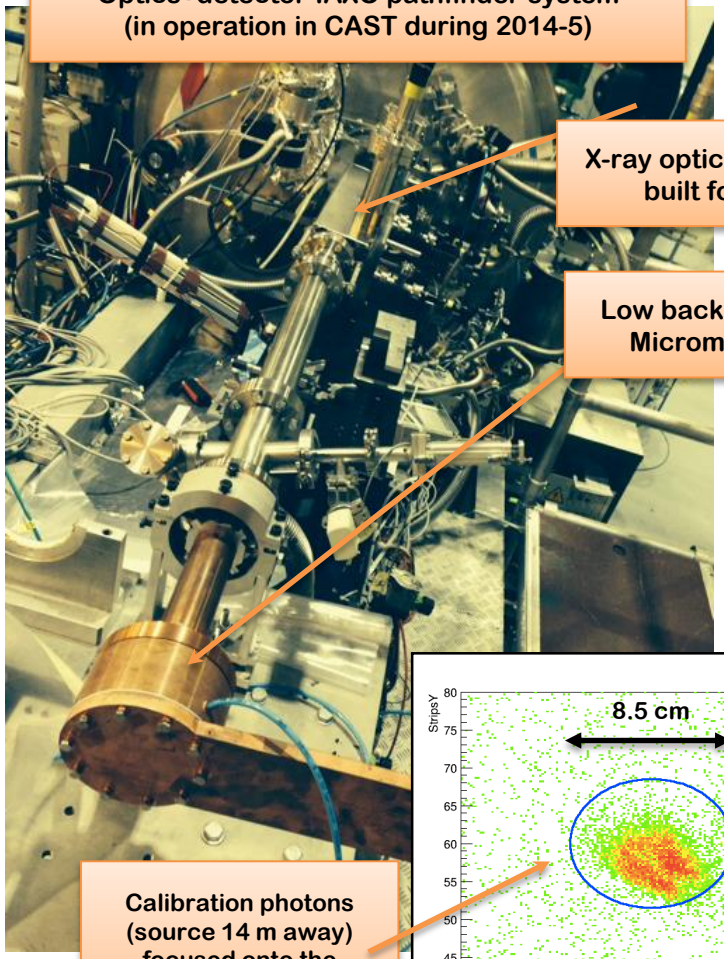
Optics+detector pathfinder system in CAST

- IAXO optics+detector joint system
  - First time x-ray optics built specifically “for axions”.
  - First time low background + focusing in the same system
  - Installed & operated in CAST 2014-15



JCAP12 (2015) 008
JCAP01 (2016) 034

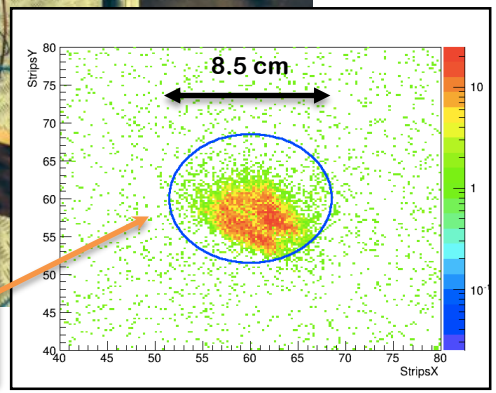
Optics+detector IAXO pathfinder system (in operation in CAST during 2014-5)



X-ray optics specifically built for axions

Low background Micromegas

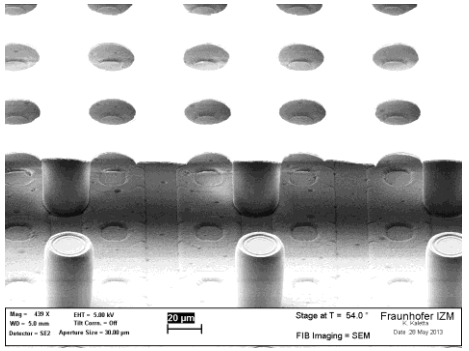
Calibration photons (source 14 m away) focused onto the Micromegas

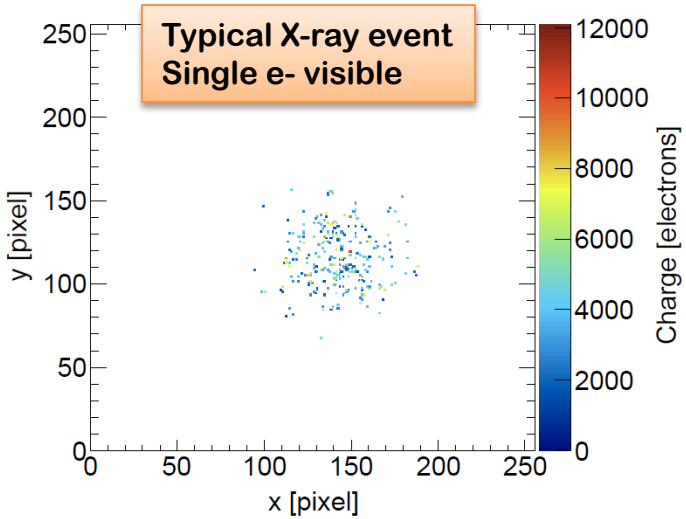


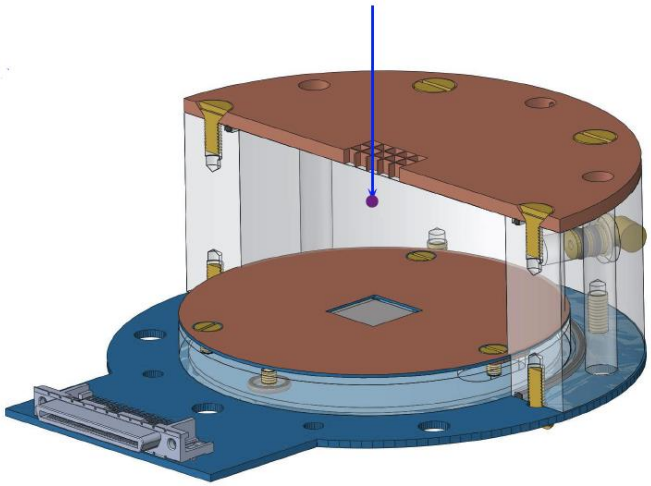
Additional detector technologies

Ingrid detectors (U. Bonn):

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





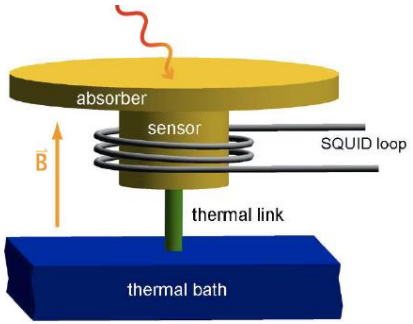


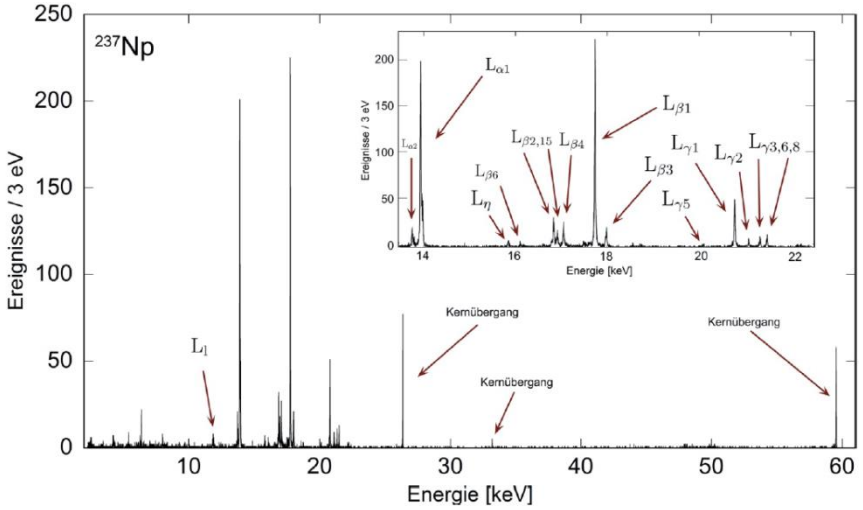
Additional detector technologies

MMC detectors (U. Heidelberg):

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

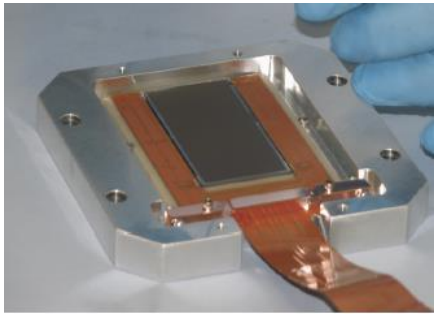
See Loredana Gastaldo's talk next week





Low noise CCDs

- Developed for low mass WIMP experiments (DAMIC)

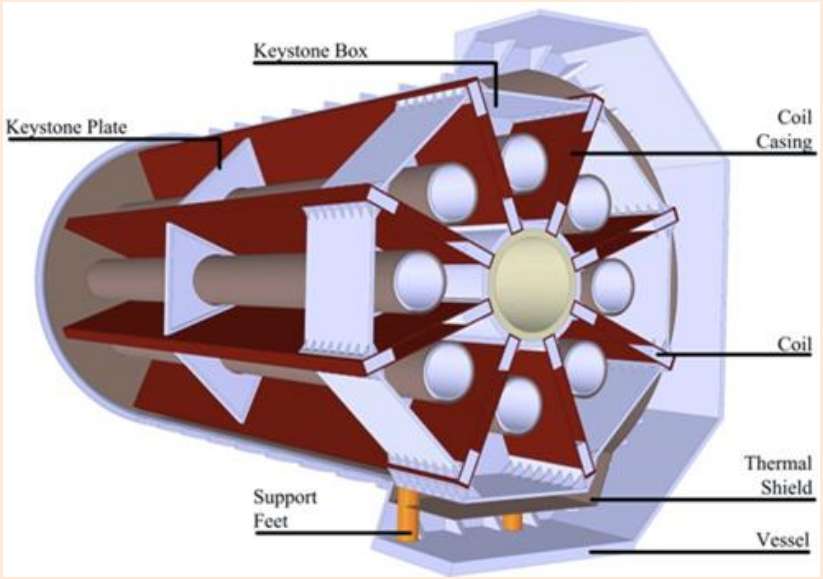


IAXO technologies – Baseline

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

IAXO magnet

- Superconducting "detector" magnet.
- Toriodal geometry (8 coils)
- Based on ATLAS toroid technical solutions.
- CERN+CEA expertise
- 8 bores / 20 m long / 60 cm Ø per bore



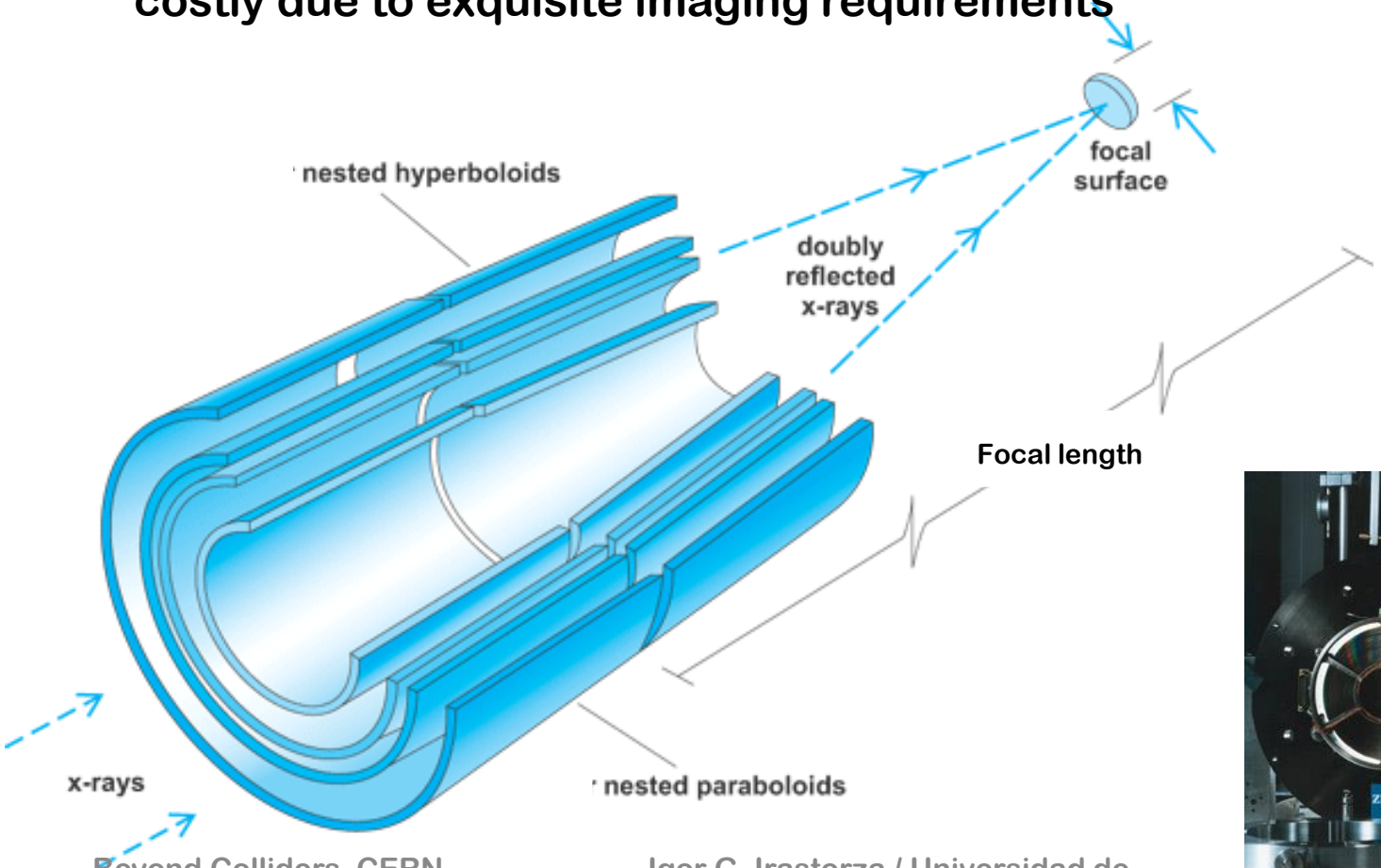
Baseline developed at:
IAXO Letter of Intent: CERN-SPSC-2013-022
IAXO Conceptual Design: JINST 9 (2014) T05002 (arXiv:1401.3233)

Services

Rotation System

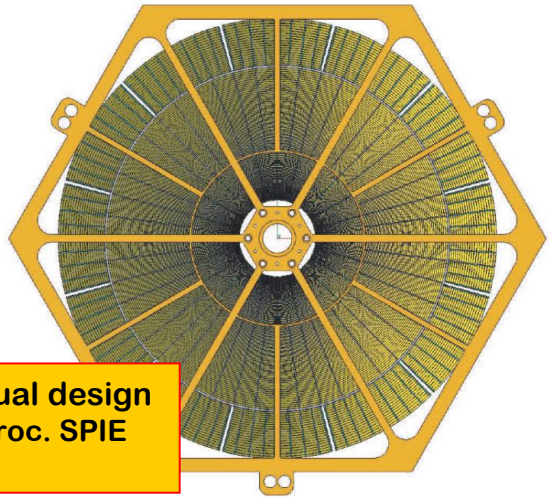
IAXO x-ray optics

- X-rays are focused by means of grazing angle reflection (usually 2)
- Many techniques developed in the x-ray astronomy field. But usually costly due to exquisite imaging requirements

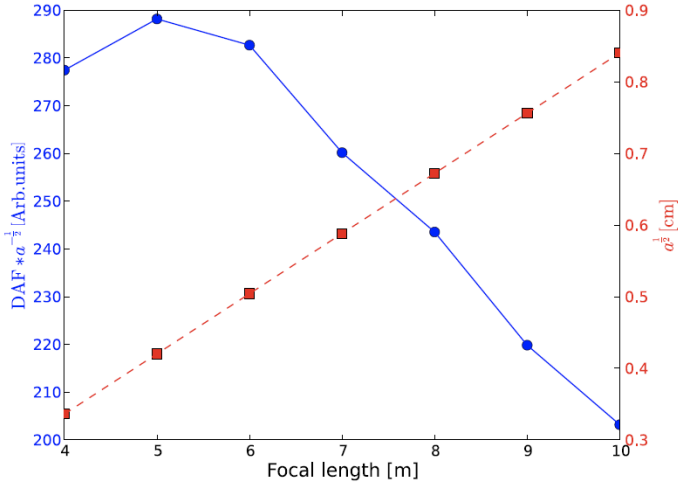


ABRIXAS spare telescope, in use in one of the 4 bores of CAST (pioneer use of x-ray optics in axion research)

IAXO x-ray optics



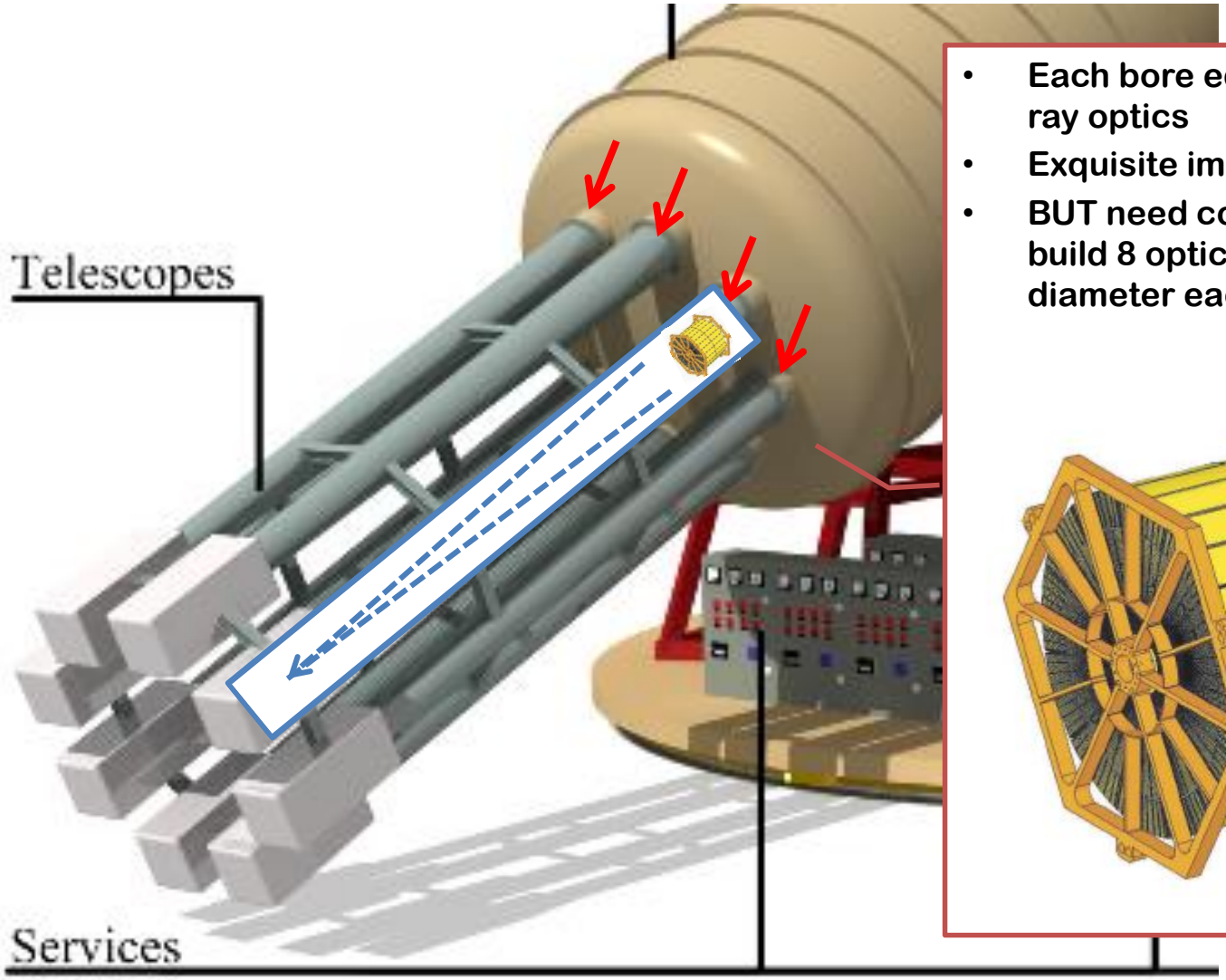
IAXO optics conceptual design
AC Jakobsen et al, Proc. SPIE 8861 (2013)



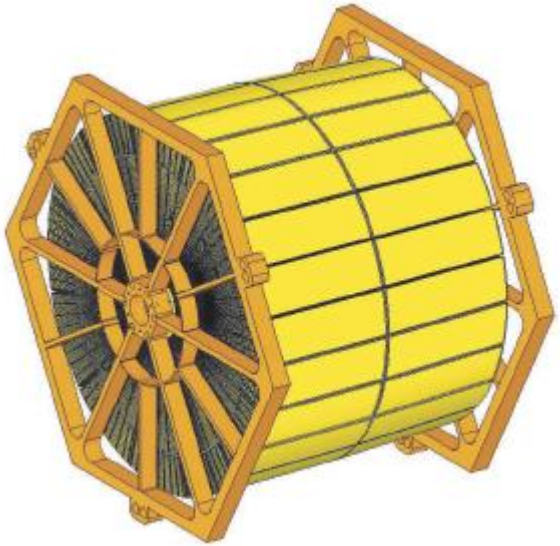
Optimal focal length ~5 m

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 x-ray optics

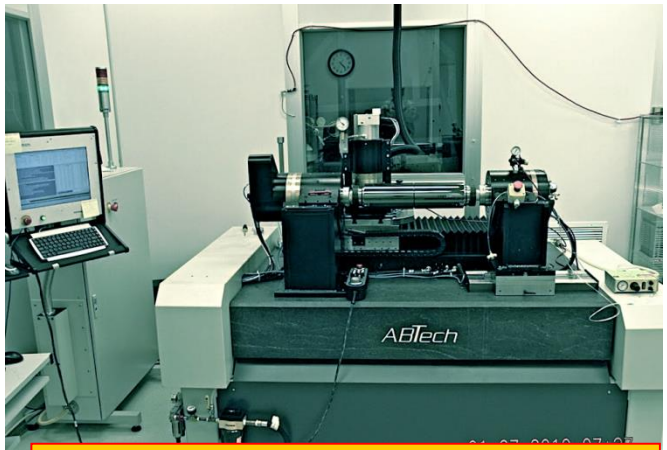


- Each bore equipped with an x-ray optics
- Exquisite imaging not required
- BUT need cost-effective way to build 8 optics of 600 mm diameter each.



IAXO x-ray optics

- Technique of choice for IAXO: optics made of slumped glass substrates coated to enhance reflectivity in the energy regions for axions.
- Same technique successfully used in NuSTAR mission, recently launched



NuSTAR optics assembly machine

- The specialized tooling to shape the substrates and assemble the optics is now available
- Hardware can be easily configured to make optics with a variety of designs and sizes

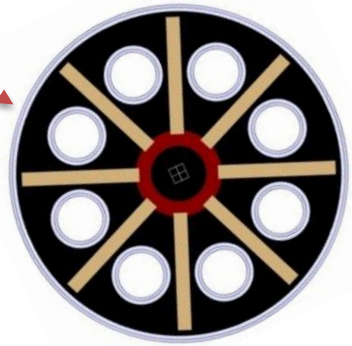
NuSTAR telescope ~400 mm Ø

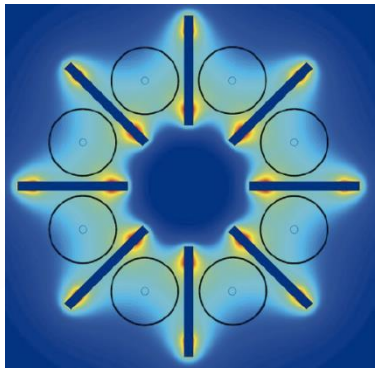
- Key institutions in NuSTAR optics: LLNL, U. Columbia, DTU Denmark.

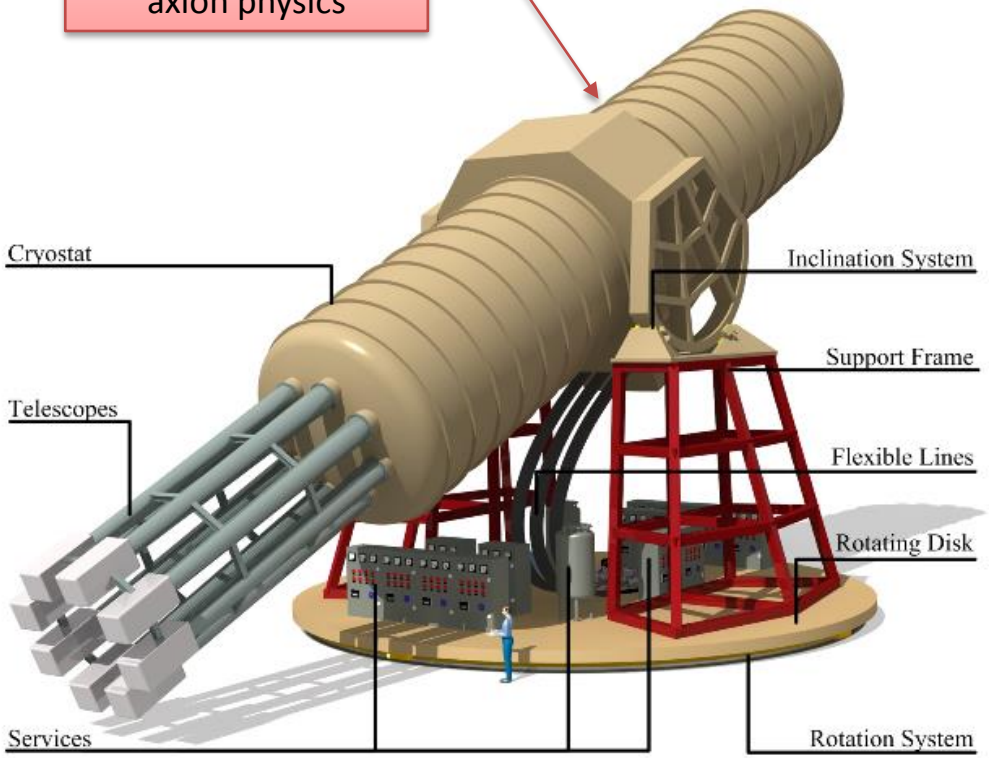
IAXO magnet

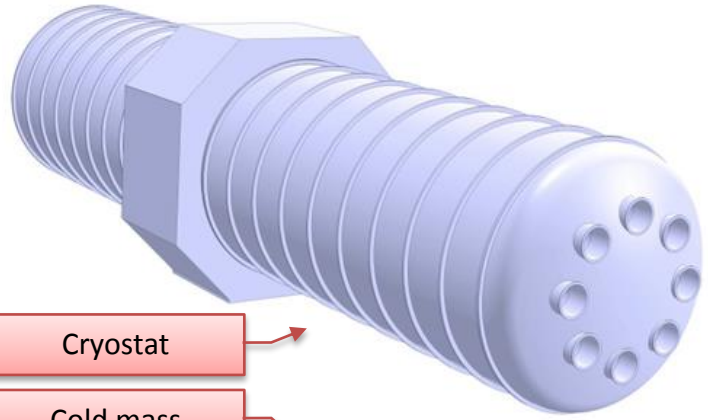
TOROIDAL CONFIGURATION specifically built for axion physics

Each conversion bore (between coils) 600 mm diameter



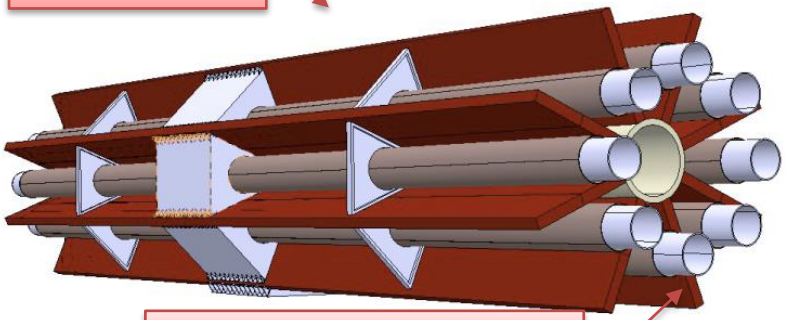






Cryostat

Cold mass

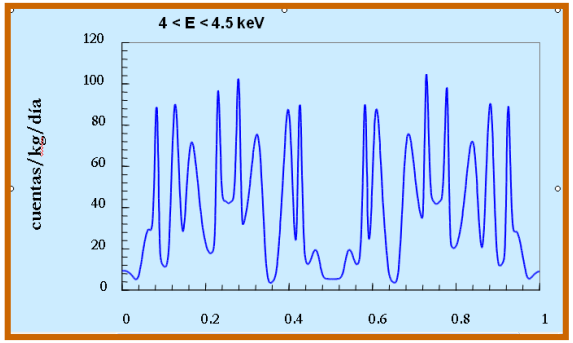


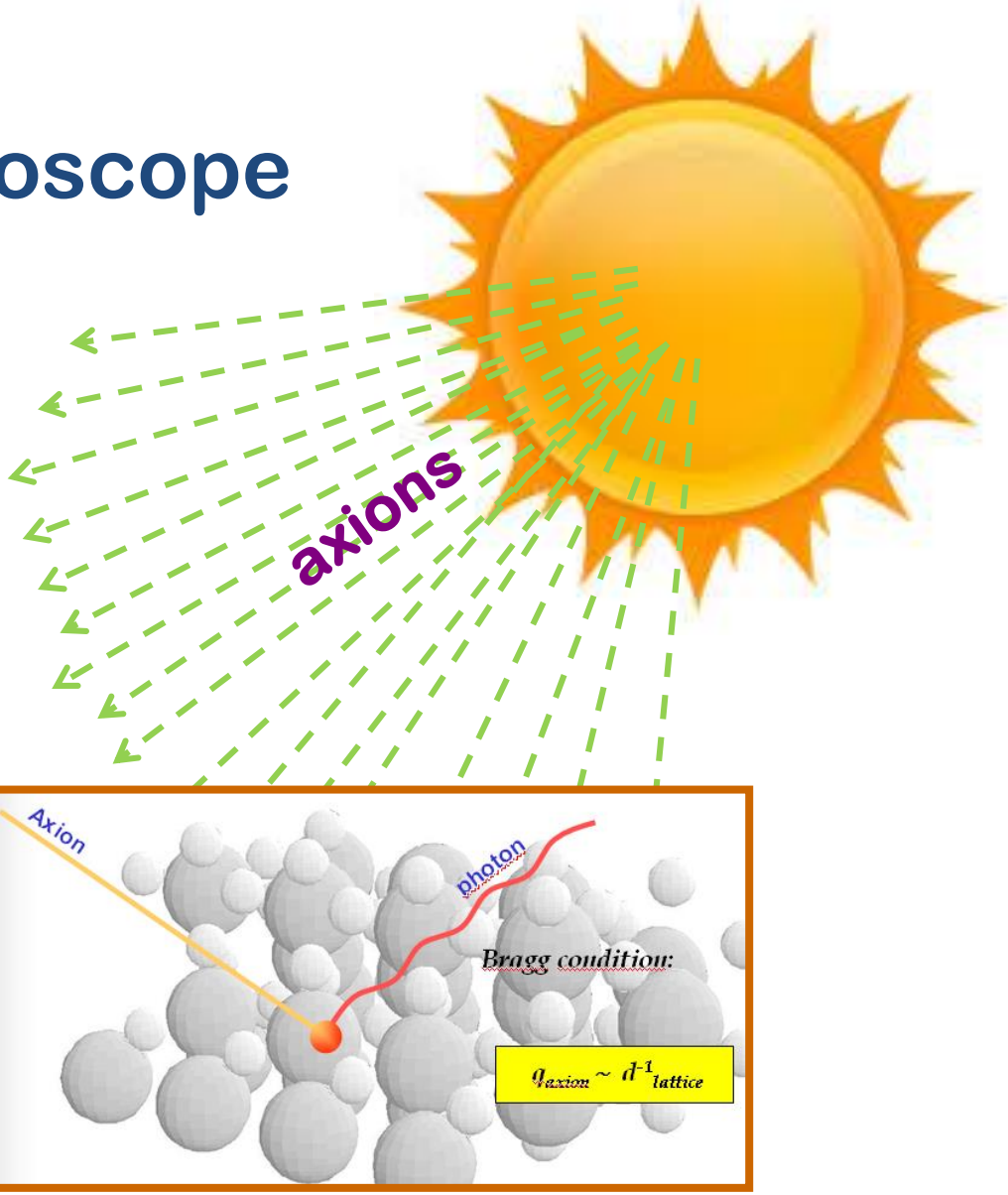
Bores go through cryostat

Magnetic length 20 m Total cryostat length 25 m

Other types of helioscope

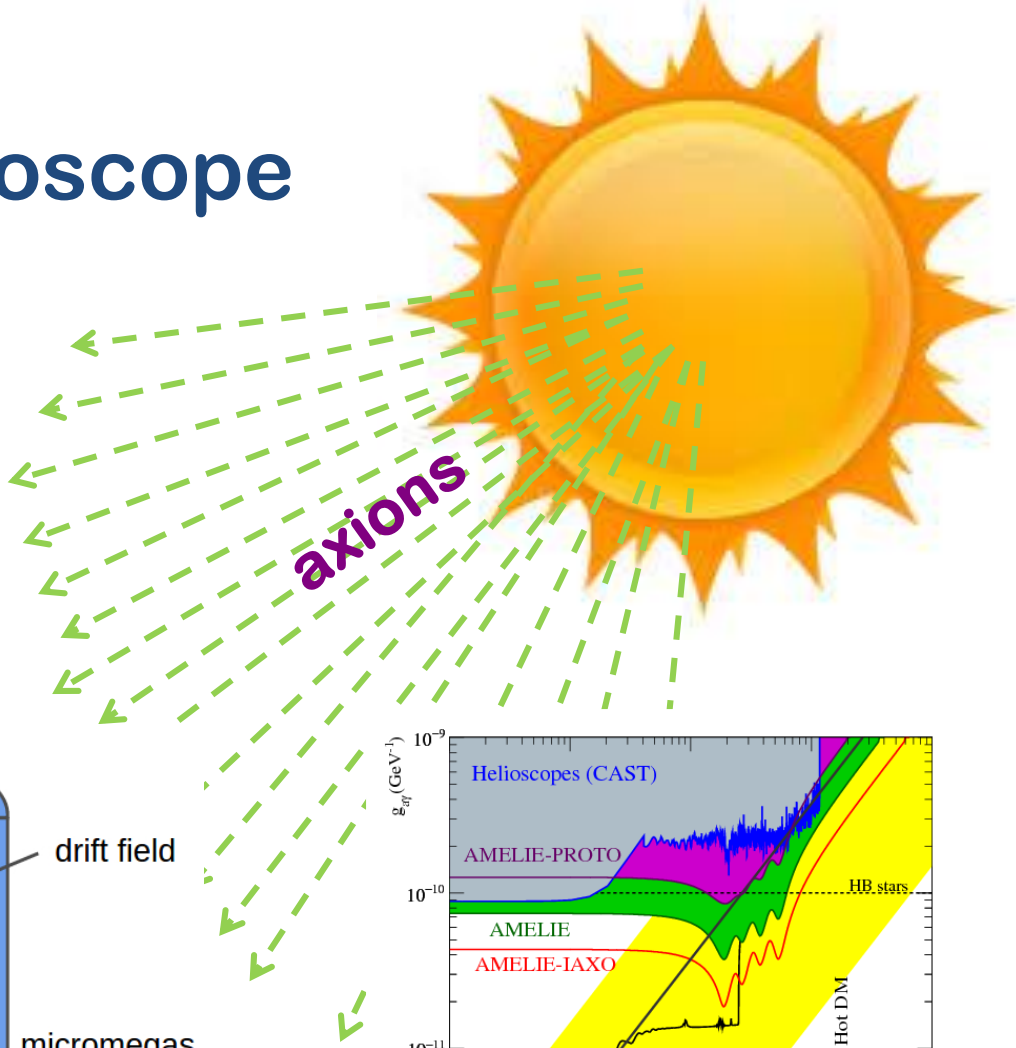
- Instead of magnetic field, one can use the electromagnetic field of crystals…
- « Primakoff-Bragg » effect
- WIMP-like experiments provide limit to axions: SOLAX, COSME, DAMA, EDELWEISS, CDMS, etc…
- Characteristic temporal pattern:

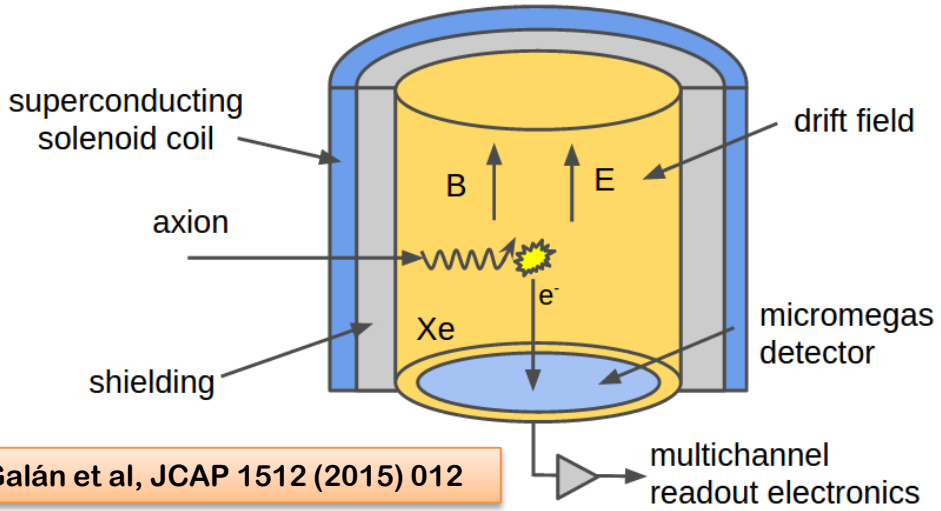




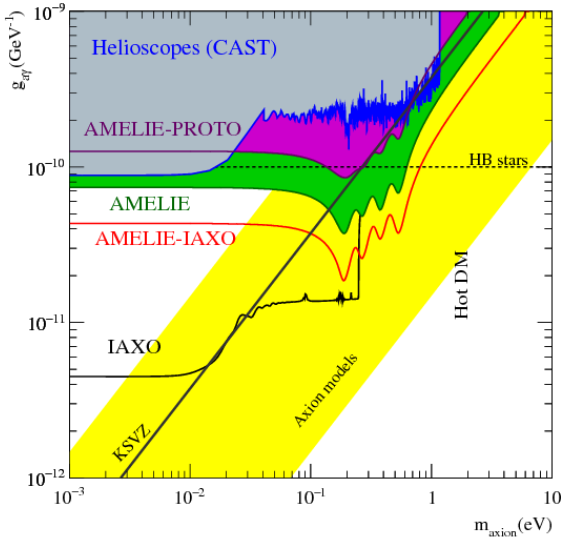
Other types of helioscope

- « TPC in a magnetic field »: conversion and absorption happening in the gas
- Competitive only for high axion mass
- Old idea recently studied





Galán et al, JCAP 1512 (2015) 012



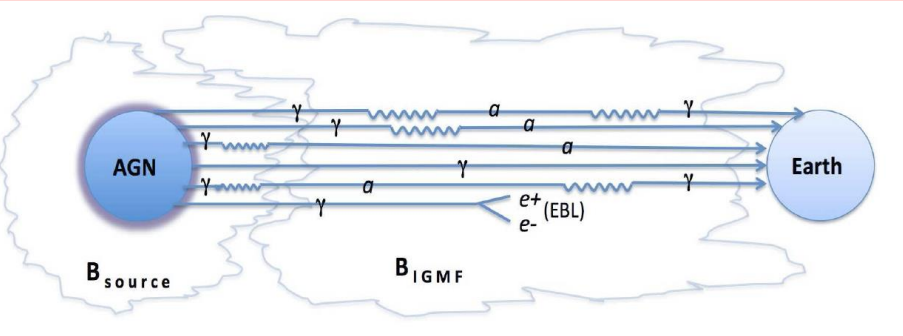
Axions as Dark Matter?

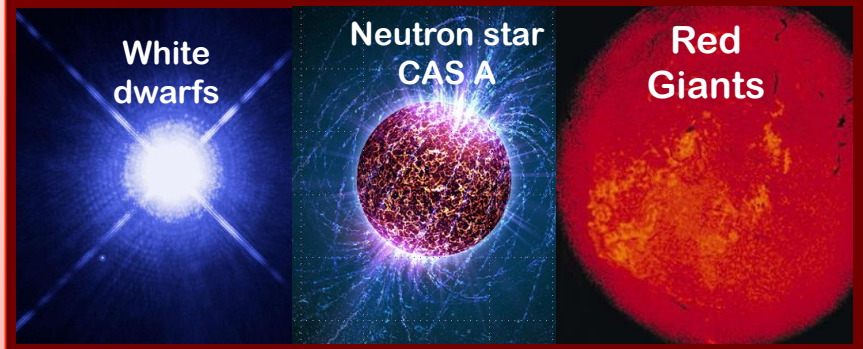
- **Axions are produced** in the early Universe by a number of processes:
  - Axion realignment
  - Decay of axion strings
  - Decay of axion walls

  → **NON-RELATIVISTIC (COLD) AXIONS**
  - Axion mass giving the right CDM density? Depends on cosmological assumptions:
    - Post-inflation scenario ("classical window") **~10^{-5} – 10^{-3} eV**
    - Pre-inflation scenario ("anthropic window") ~ lower masses possible
    - Higher masses→ subdominant CDM / non-standard scenarios
  - Thermal production → **RELATIVISTIC (HOT) AXIONS**
- Axion masses ma > ~0.9 eV gives densities too much in excess to be compatible with latest CMB data

Hannestad et al, JCAP 08 (2010) 001 (arXiv:1004.0695)

Astrophysical hints for axions(?)





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

However, diverse evidence of anomalous cooling has been observed in a number of stars…

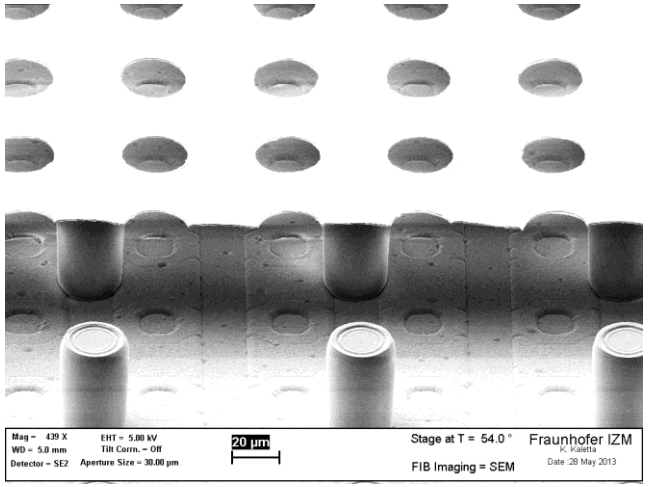
Complex situation, but generally compatible with QCD axions with masses at the 10 meV scale…

ALP:

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

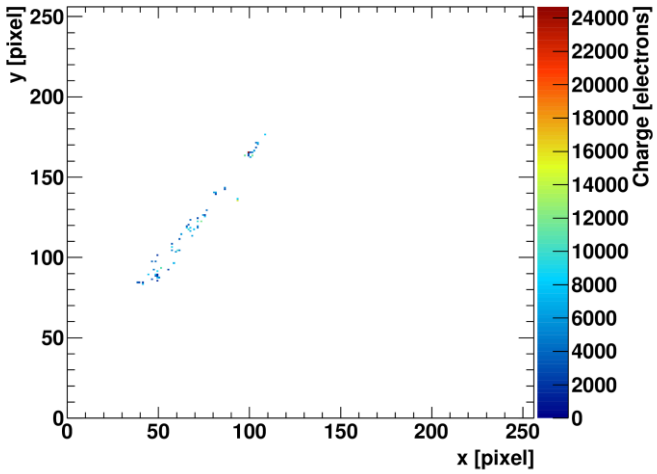
$$m_a \lesssim 10^{-(10-7)}\ \text{eV}$$

InGrid Detectors

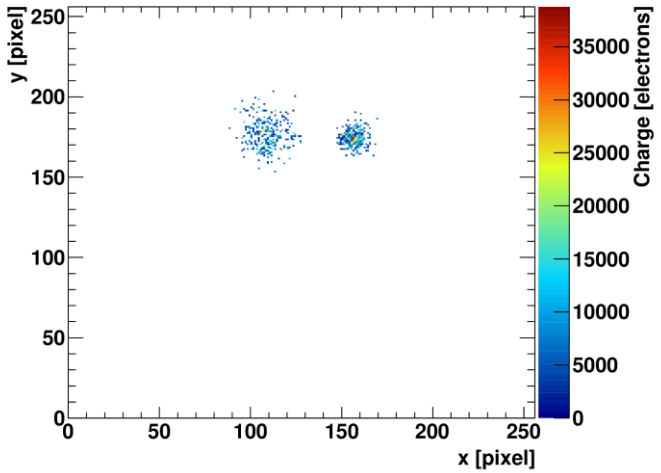


- Micromegas built on top of a CMOS ASIC
- Bump bond pads of the ASIC are used as charge collection pads
- Mesh made of thin aluminum foil
- One hole per readout pixel
  → well aligned
  → each primary electron can be seen as one hit on a pixel

Cosmic ray track



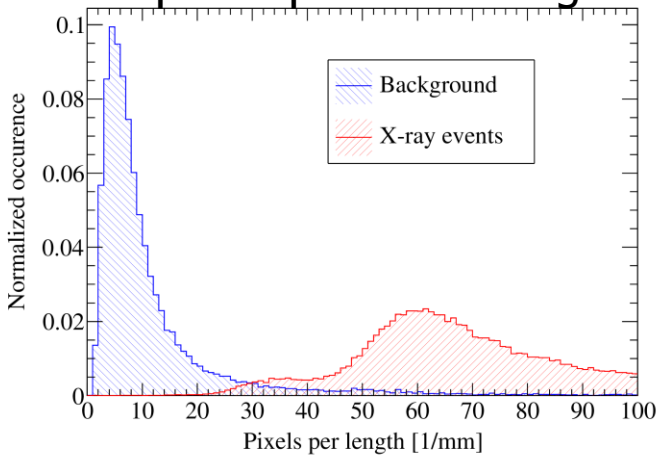
2 X-ray photons of a ^{55}Fe source



Background Suppression

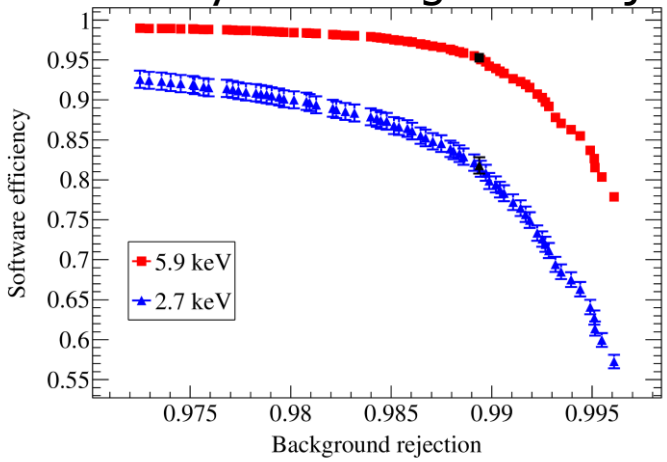
Detailed desciption in: C. Krieger, J. Kaminski and K. Desch, *InGrid-based X-ray detector for low background searches*, NIM A729 (2013) 905–909

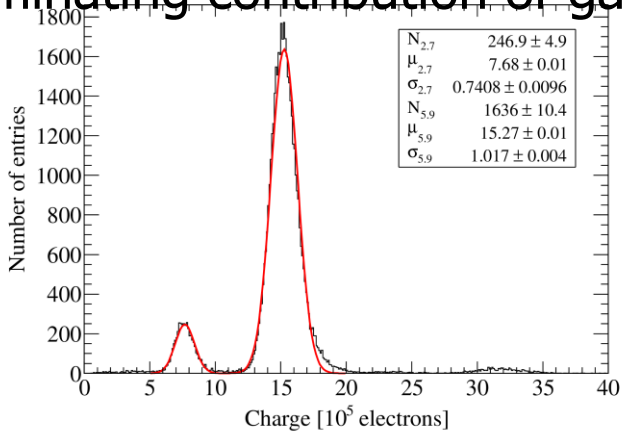
pixels per track length



- Knowledge of individual primary electrons gives detailed information on signal shape
- Different event shape variables can be used to distinguish background events (tracks) from signal events (photons)
- First likelihood ratio-based analysis reached a background suppression of 120
- Threshold of detector is dominated by transmission of entrance window
- Good energy resolution with pixel counting eliminating contribution of gas amplification

Efficiency vs. background rejection





Spectrum of a ^{55}Fe source

AXION theory motivation

- Axion: introduced to solve the **strong CP problem**

In QCD, nothing prevents from adding a term like that to the lagrangian:

$$\mathcal{L}_{CP} = \theta \frac{\alpha_s}{8\pi} G\tilde{G}$$

($\tilde{G}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma}G^{\rho\sigma}$)

In fact, two known facts may induce such kind of term:

- The structure of the QCD vacuum ($U(1)_A$ problem)
- EW quark mixing

2 contributions of very different origin…

$$\theta = \bar{\theta} + \arg\det M \ .$$

AXION theory motivation

- Axion: introduced to solve the **strong CP problem**

$$\mathcal{L}_{CP} = \theta \frac{\alpha_s}{8\pi} G\tilde{G}$$

This term is **CP violating**. But strong interactions are not observed to violate CP

In particular, this term would predict an electric dipole moment for the neutron of a magnitude:

$$|d_n| = A|\theta| \times 10^{-15} e \times cm$$ (A = 0.04 – 2.0)

AXION theory motivation

- But experiment says…

$$|d_n| < 2.9 \times 10^{-26} e\text{cm}$$

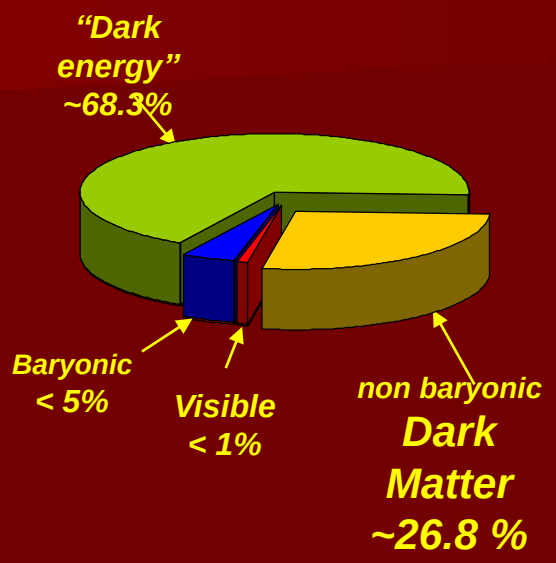
So,

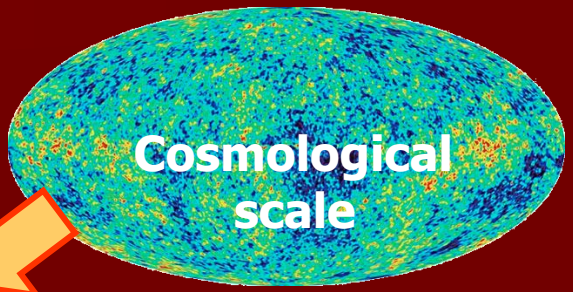
$$|\bar{\theta}| < 0.7 \times 10^{-11}$$

- **Why so small?**
- **High fine-tunning of two different contributions required**

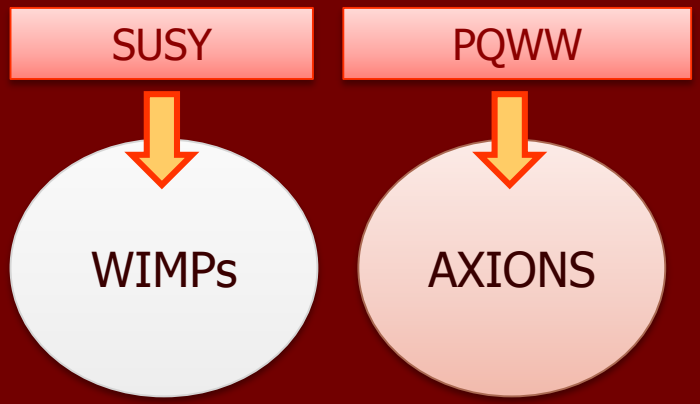
Peccei-Quinn (1977) propose an elegant solution to this problem.
θ not anymore a constant, but a field → the axion a(x).
Fine-tunning reached naturally, dinamically.

AXION as Dark Matter?





- Can not be baryonic
- Can not be relativistic (CDM)
- Can not be standard (neutrinos)
- Need to go **beyond the SM →**



Axion DM after BICEP2

- Quite an impact… (a few preprints)
  - Marsh et al. **arXiv:1403.4216**
  - L. Visinelli, P. Gondolo **arXiv:1403.4594**
  - Choi el al.**arXiv:1404.38803**.
  - Chun. **arXiv:1404.4284**
  - E. Di Valentino et al. Mena. **arXiv:1405.1860**

  among others…

In summary:

if "high inflation scale" interpretation of BICEP2 results is right… **"classical window" (high mass) scenario is favored.**

IAXO in astroparticle roadmaps

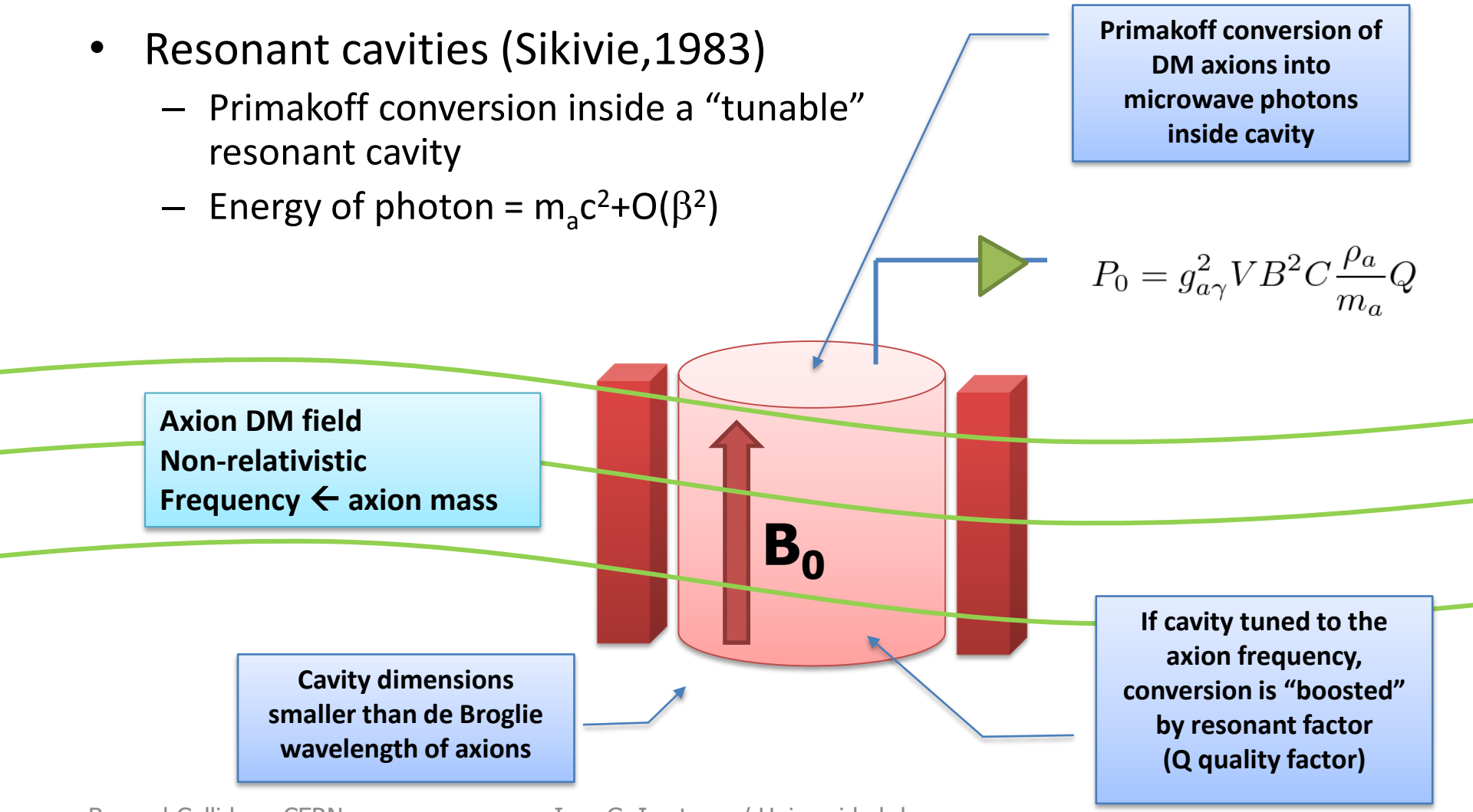
- **ASPERA/APPEC Roadmap** acknowledges axion physics, CAST, and **recommends** progress towards IAXO.

> "...A CAST follow-up is discussed as part of CERN's physics landscape (new magnets, new cryogenic and X-ray devices). The Science Advisory Committee **supports** R&D on this follow up, as well as smaller ongoing activities on the search for axions and axion-like particles."
>
> C. Spiering, ESPP Krakow

- Important community input in the **European Strategy for Particle Physics**
- Presence in the Briefing Book of the ESPP, which reflects also APPEC roadmap recommendations.
- **ESPP recomends CERN to follow APPEC recomendatons**.
- Important effort in relation with US roadmapping (Snowmass, and P5 process). **Snowmass reports speak very favourably of axion physics and IAXO**.

Detecting DM axions: "haloscopes"

- Resonant cavities (Sikivie,1983)
  - Primakoff conversion inside a "tunable" resonant cavity
  - Energy of photon = $m_a c^2 + O(\beta^2)$



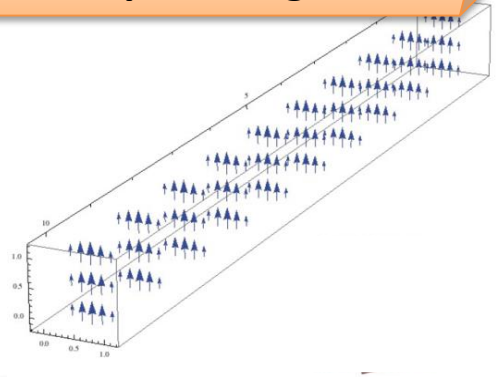
Haloscopes - AMDX

- Leading experiment: ADMX @ U. Washington
  - Many years of R&D
  - high Q cavity (1 m x 60 cm Ø)
  - 8 T superconducting solenoid
  - Low noise receivers based on SQUIDs
  - Sensitivity to few μeV proven
  - New program ADMX-HF to go to higher frequencies

Detecting DM axions with IAXO?

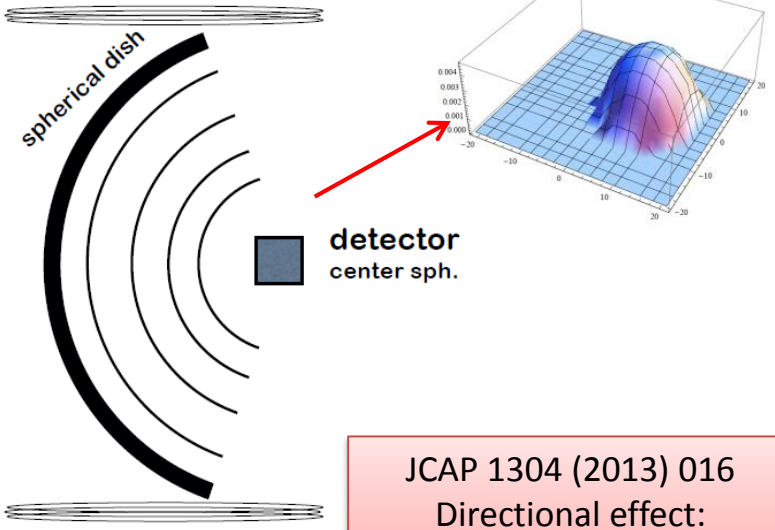
- All ideas have in common: big magnets needed

Long thin cavities in dipole magnets



PRD85 (2012) 035018
Directional effect:
JCAP 1210 (2012) 022

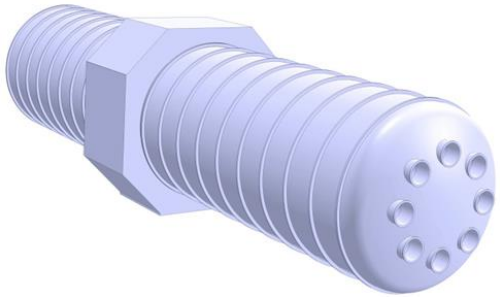
Large spherical mirror

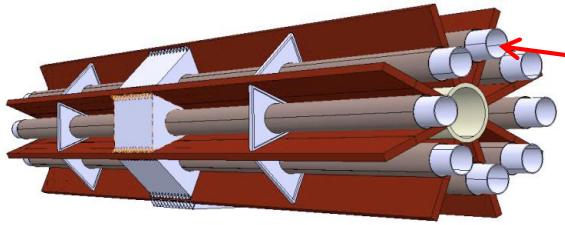


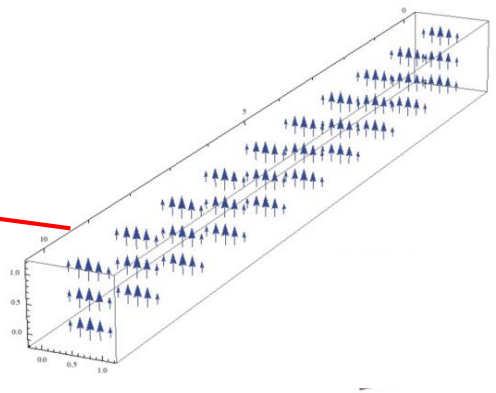
JCAP 1304 (2013) 016
Directional effect:
arXiv:1307.7181

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?







IAXO LoI authorlist

Letter of Intent to the CERN SPSC

The International Axion Observatory IAXO

90 signatures
38 institutions

E. Armengaud[1], F. T. Avignone[2], M. Betz[3], P. Brax[4], P. Brun[1], G. Cantatore[5], J. M. Carmona[6], G. P. Carosi[7], F. Caspers[3], S. Caspi[8], S. A. Cetin[9], D. Chelouche[10], F. E. Christensen[11], A. Dael[1], T. Dafni[6], M. Davenport[3], A.V. Derbin[12], K. Desch[13], A. Diago[6], B. Döbrich[14], I. Dratchnev[12], A. Dudarev[3], C. Eleftheriadis[15], G. Fanourakis[16], E. Ferrer-Ribas[1], J. Galán[1], J. A. García[6], J. G. Garza[6], T. Geralis[16], B. Gimeno[17], I. Giomataris[1], S. Gninenko[18], H. Gómez[6], D. González-Díaz[6], E. Guendelman[19], C. J. Hailey[20], T. Hiramatsu[21], D. H. H. Hoffmann[22], D. Horns[23], F. J. Iguaz[6], I. G. Irastorza[6,*], J. Isern[24], K. Imai[25], A. C. Jakobsen[11], J. Jaeckel[26], K. Jakovčić[27], J. Kaminski[13], M. Kawasaki[28], M. Karuza[29], M. Krčmar[27], K. Kousouris[3], C. Krieger[13], B. Lakić[27], O. Limousin[1], A. Lindner[14], A. Liolios[15], G. Luzón[6], S. Matsuki[30], V. N. Muratova[12], C. Nones[1], I. Ortega[6], T. Papaevangelou[1], M. J. Pivovaroff[7], G. Raffelt[31], J. Redondo[31], A. Ringwald[14], S. Russenschuck[3], J. Ruz[7], K. Saikawa[32], I. Savvidis[15], T. Sekiguchi[28], Y. K. Semertzidis[33], I. Shilon[3], P. Sikivie[34], H. Silva[3], H. ten Kate[3], A. Tomas[6], S. Troitsky[18], T. Vafeiadis[3], K. van Bibber[35], P. Vedrine[1], J. A. Villar[6], J. K. Vogel[7], L. Walckiers[3], A. Weltman[36], W. Wester[37], S. C. Yildiz[9], K. Zioutas[38]

Expertise

Needed know-how well covered:

- Axion theory & phenomenolgy
- Axion Cosmology & Astrophysics
- Axion detection phenomenology
- X-ray detectors
- Low background techniques
- X-ray optics
- Superconducting magnets and technology

Group	(*)	Axion theory and phenomenology	Axion cosmology and astrophysics	Axion detection phenomenology	X-ray detectors	Low background techniques	X-ray optics	SC magnets and technology
South Carolina (US)	2	x		x				
CERN (Switzerland)	3			x				x
IPHT CEA/Saclay (France)	4	x	x					
IRFU CEA/Saclay (France)	1		x	x	x			x
U. Trieste (Italy)	5			x	x			
U. Zaragoza (Spain)	6			x	x	x		
LLNL (US)	7			x			x	
LBNL (US)	8			x				x
Dogus U. (Turkey)	9			x				
U. Haifa (Israel)	10		x					
DTU-Space (Denmark)	11						x	
St. Petersburg NPI (Russia)	12	x		x				
U. Bonn (Germany)	13				x			
DESY Hamburg (Germany)	14	x		x		x	x	x
U. Thessaloniki (Greece)	15			x				
RCLTMS Kyoto U. (Japan)	30			x				
NCSR Demokritos (Greece)	16			x	x			
U. Valencia (Spain)	17							
INR Moscow (Russia)	18	x		x				
Ben Gurion U. (Israel)	19	x						
Columbia Astrophysics Lab (US)	20						x	
Kyoto U. (Japan)	21	x	x					
TU-Darmstadt (Germany)	22			x	x			
ICE Barcelona (Spain)	24		x					
JAEA (Japan)	25			x				
U. Hamburg (Germany)	23		x					
U. Heidelberg (Germany)	26	x						
RBI Zagreb (Croatia)	27	x		x				
U. Tokyo (Japan)	28		x	x				
U. Rijeka (Croatia)	29			x	x			
MPI Munich (Germany)	31	x	x					
Tokyo I.T. (Japan)	32		x	x				
BNL (US)	33			x				
U. Florida (US)	34	x	x					
Berkeley (US)	35			x				x
Cape Town U. (South Africa)	36	x						
FNAL (US)	37			x	x			x
U. Patras (Greece)	38	x		x				