

International Axion Observatory (IAXO)

TAUP 2015

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and the IAXO Collaboration

10 September 2015



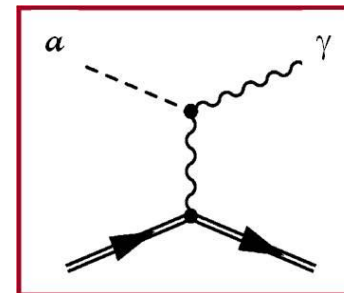
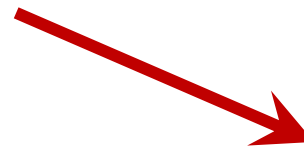
- Physics motivation
- Experimental design
 - Magnet
 - X-ray optics
 - X-ray detectors
- Science potential
- Current status

- **Peccei-Quinn solution** to the strong CP problem
 - New U(1) symmetry introduced. The axion appears as the spontaneous Peccei-Quinn symmetry breaking
 - Axion-photon conversion in the presence of electromagnetic field (Primakoff effect)

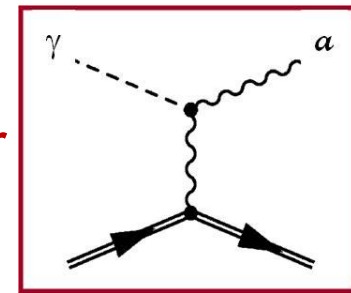
Axion Lagrangian

$$\mathcal{L}_a = \frac{1}{2}(\partial_\mu a)^2 - \frac{\alpha_s}{8\pi f_a} a G \tilde{G}$$

- $\theta = a/f_a$ relaxes to 0 in dynamic fashion, preserving CP
- θ absorbed in the definition of a



or



This EM field can be:

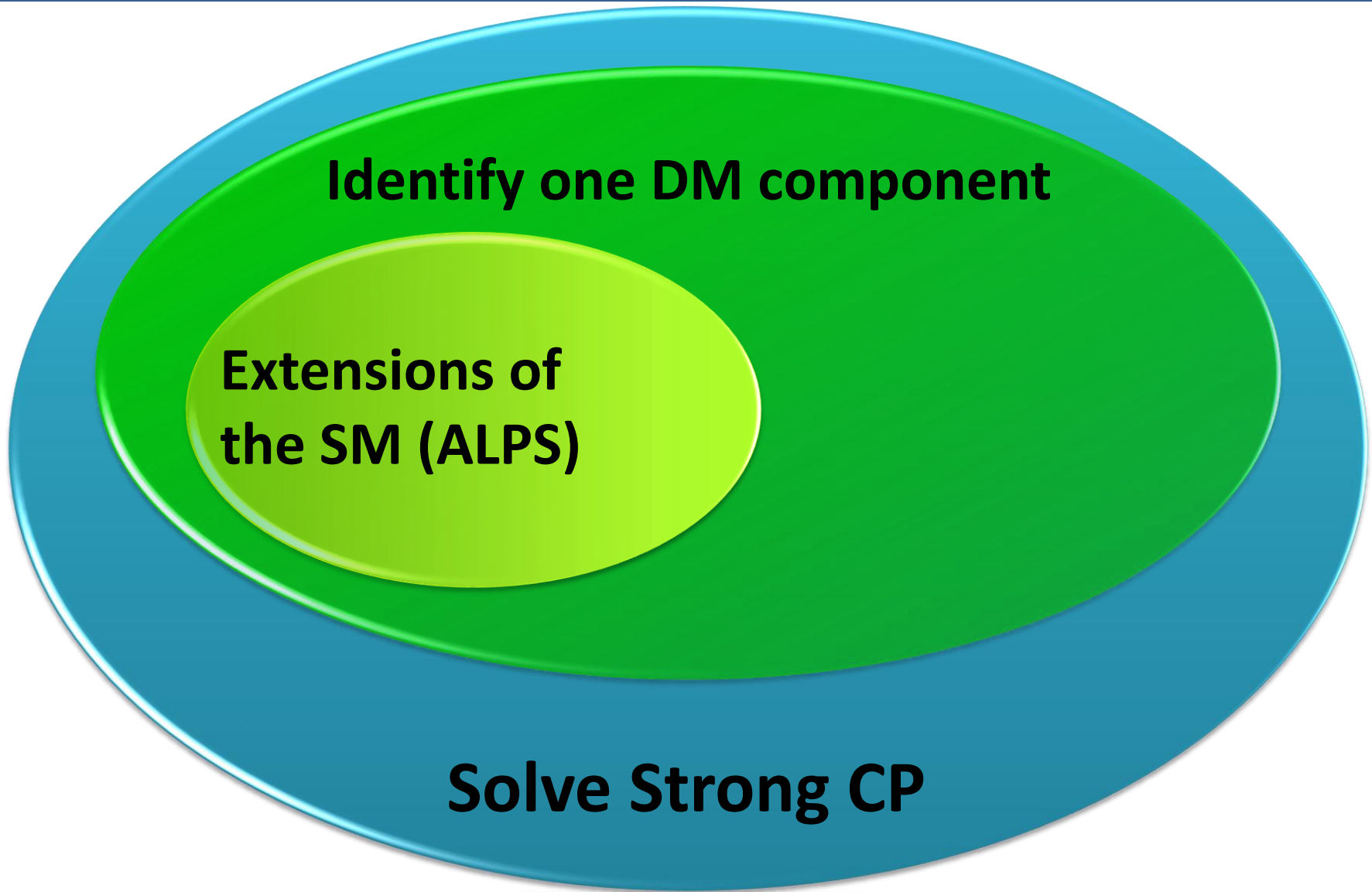
- (Laboratory) B field
- Plasma field in stellar interior
- E field of a crystalline structure
- others ...

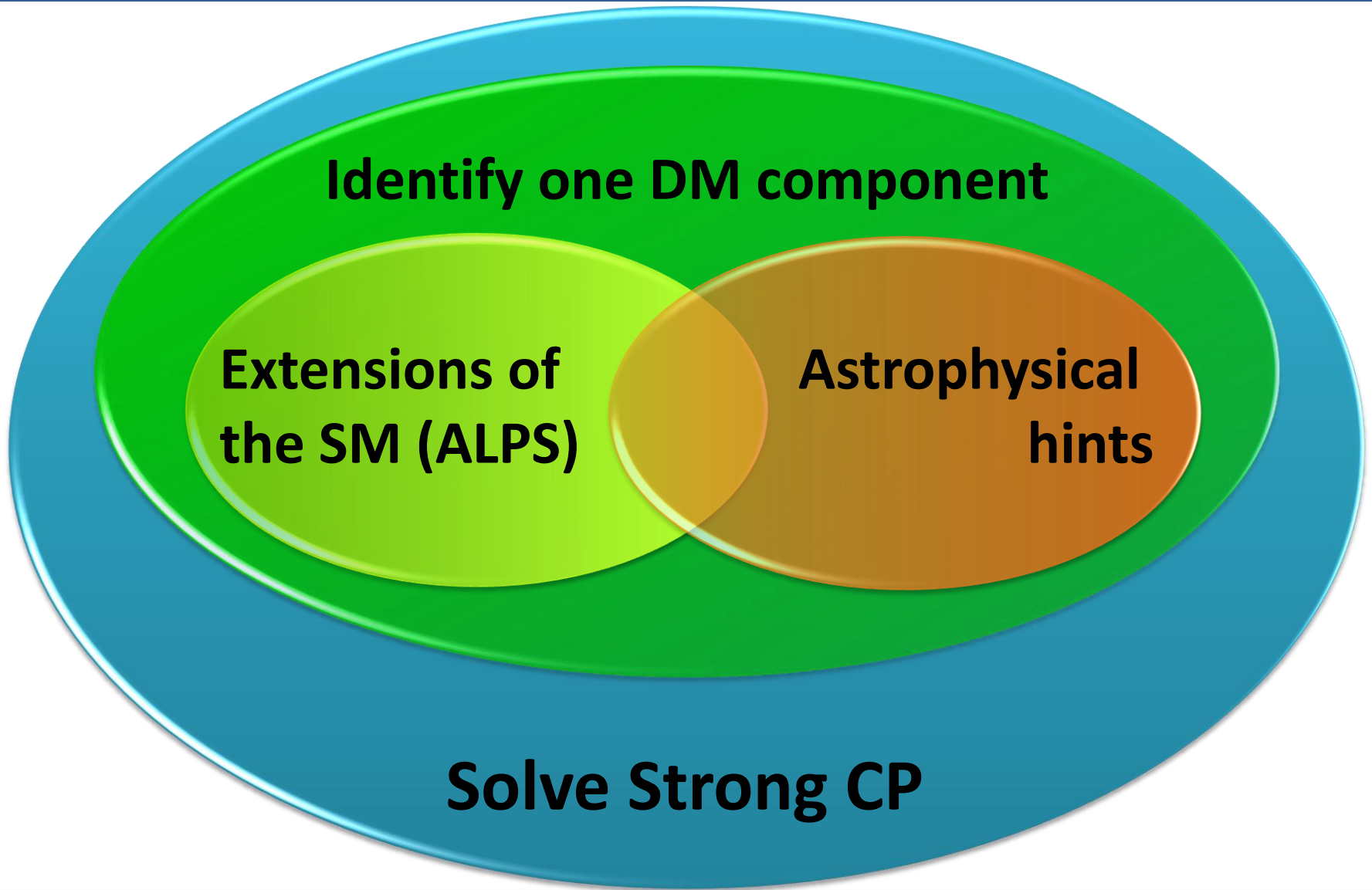
Solve Strong CP



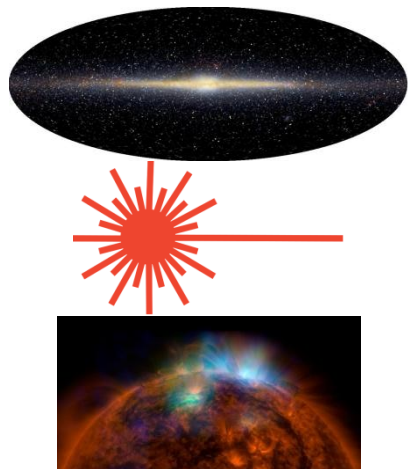
Identify one DM component

Solve Strong CP





IAXO in the axion experiment landscape



Source	Experiments	Model dependence	Scalability & improved reach
Relic Axions	ADMX, ADMX-HF, Casper, CAPP, ...	High	Active R&D
Lab Axions	ALPS, OSQAR, 5 th -force exps, ...	Very low	Concepts
Solar Axions	SUMICO, CAST, IAXO	Low	Ready for large scale project

- Current axion experiments compliment each other well
- Need to actively keep working on all fronts (R&D)
- Technologies needed for helioscopes are now and can support a large scale experiment today → **IAXO**

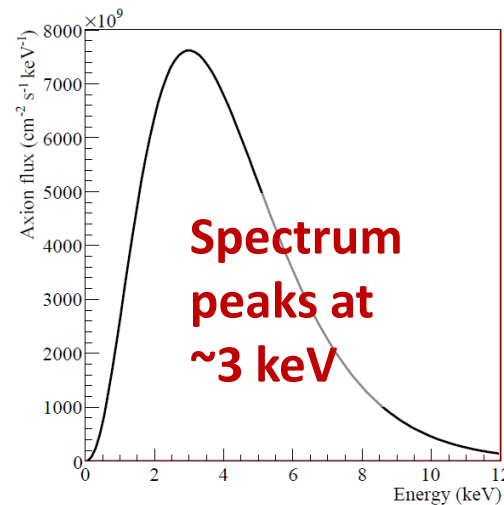
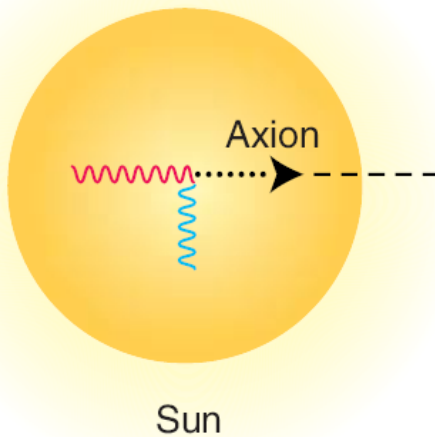
Axion – Production and detection mechanism

- First axion helioscope proposed by P. Sikivie

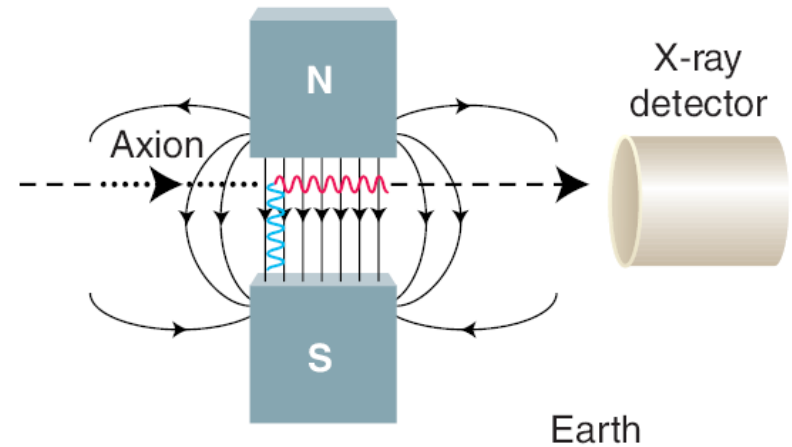
Sikivie *PRL* **51**:1415 (1983)

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

Primakoff effect



Primakoff effect



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

Van Bibber et al. *PhysRevD* **39**:2089 (1989)

The sensitivity of a helioscope

MAGNET & TRACKING

X-RAY OPTICS

X-RAY DETECTORS

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

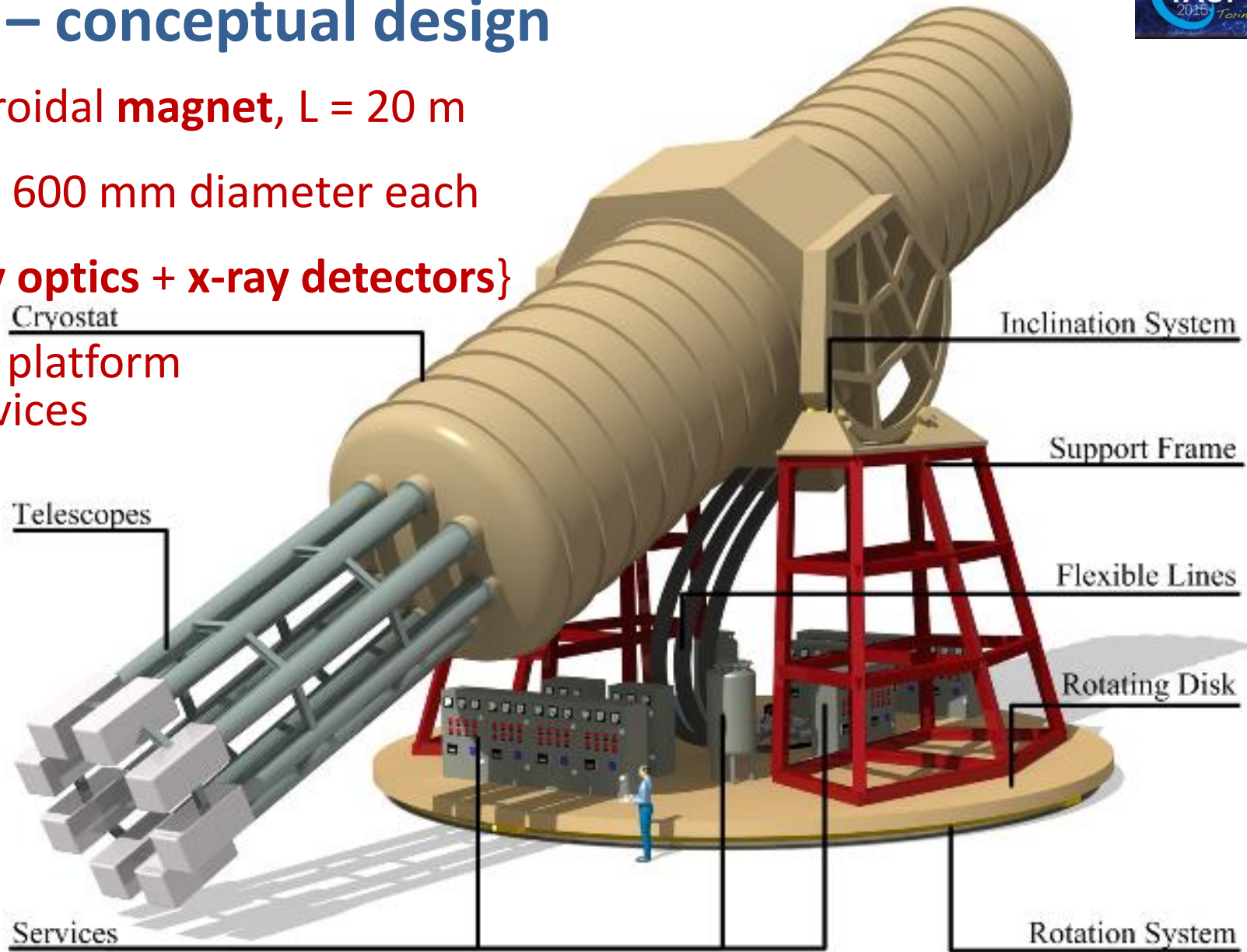
B = magnetic field t = time
 L = magnet length
 A = cross-sectional area
 s = spot size
 ε_0 = efficiency
 b = background
 ε = efficiency

IAXO, relative to CAST:

$\geq 1050 \times$ better
 $1.4 \times$ better
 $14 \times$ better
 $S/N = g_{\text{ay}}^4 \geq 20000$ $g_{\text{ay}} \geq 12 \times$ better

IAXO – conceptual design

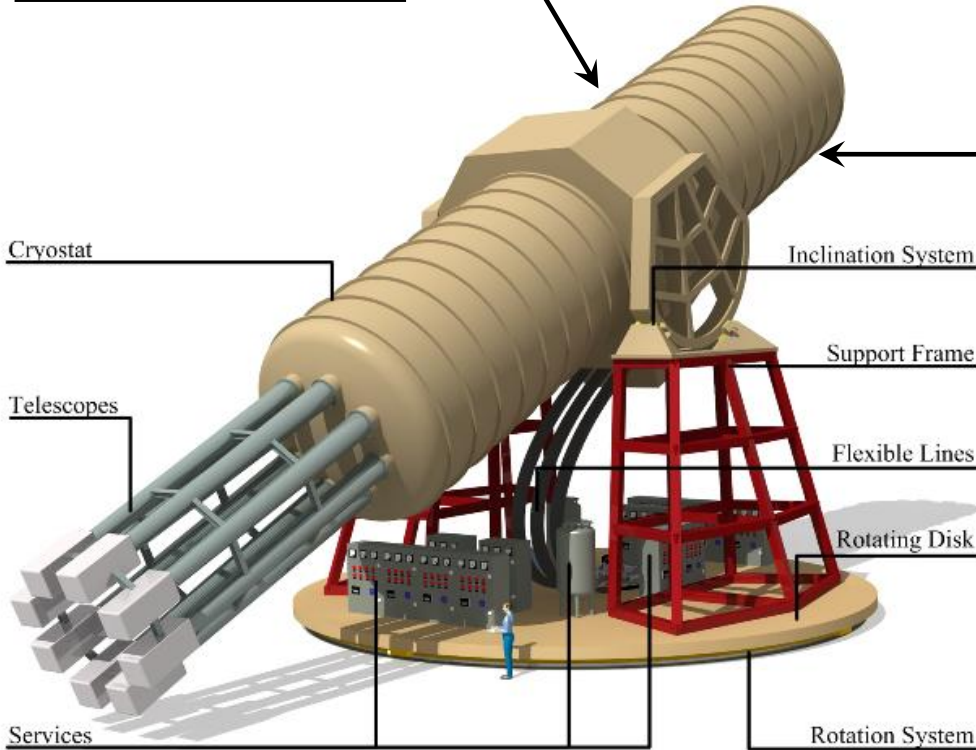
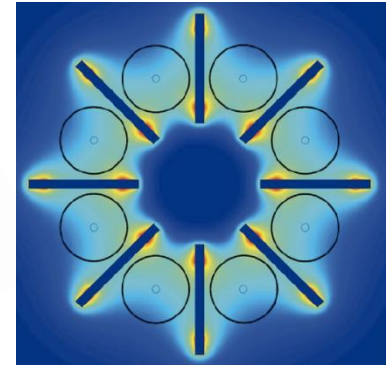
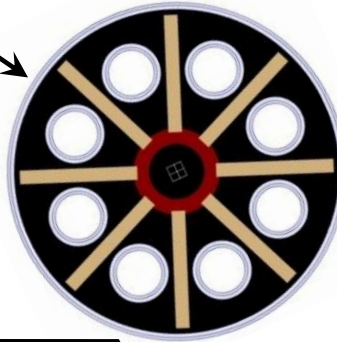
- Large toroidal magnet, $L = 20$ m
- 8 bores: 600 mm diameter each
- 8× {x-ray optics + x-ray detectors}
- Rotating platform with services



IAXO magnet

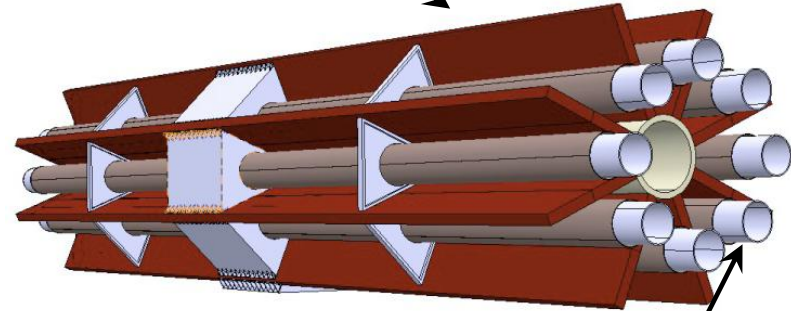
TOROIDAL CONFIGURATION specifically built for axion physics

Each conversion bore (between coils) 600 mm diameter



Cryostat

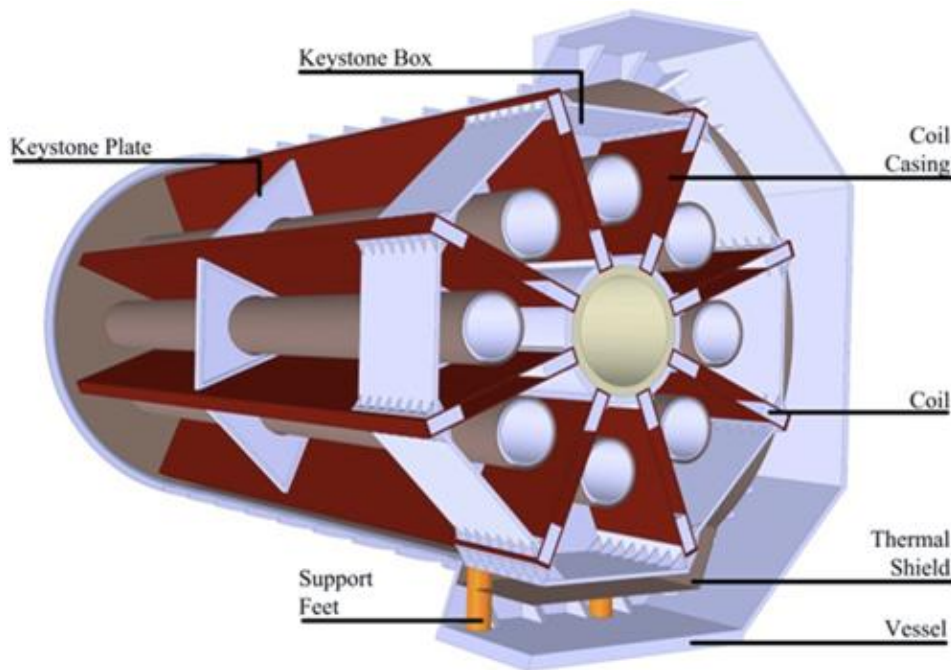
Cold mass



Bores go through cryostat

Magnetic length 20 m Total cryostat length 25 m

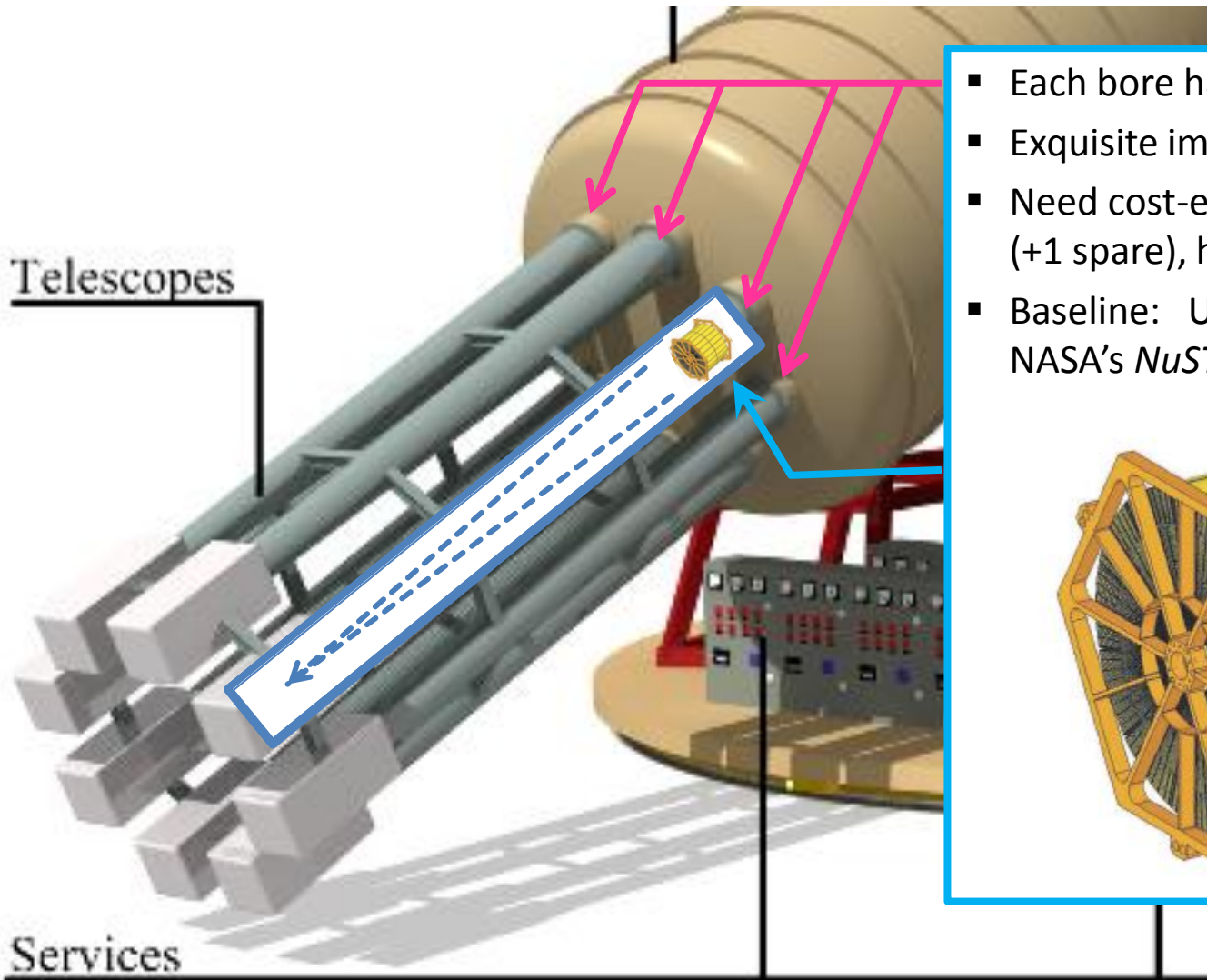
IAXO magnet (2)



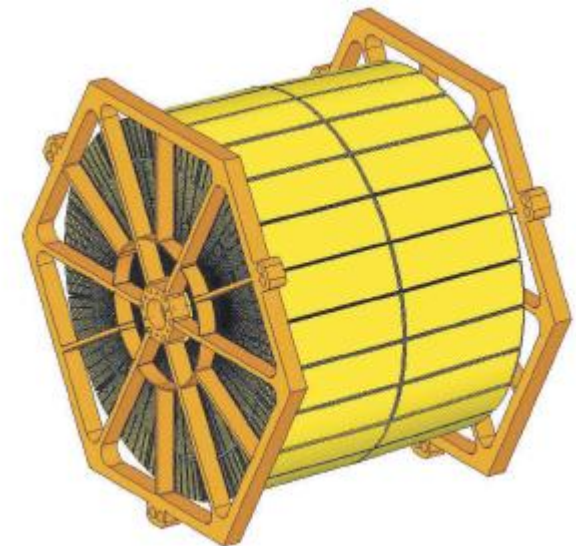
Shilon et al. *IEEE T. Ap. SupCond* **23**:4500604 (2013)
 Shilon et al. *AIP Conf. Proc.* **1573**:1574 (2014)
 Shilon et al. *IEEE T. Ap. SupCond* **24**:4500104 (2014)

<i>Property</i>	<i>Value</i>		
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	
Conductor:	Average field in the bores (T)	2.5	
	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 x-ray optics

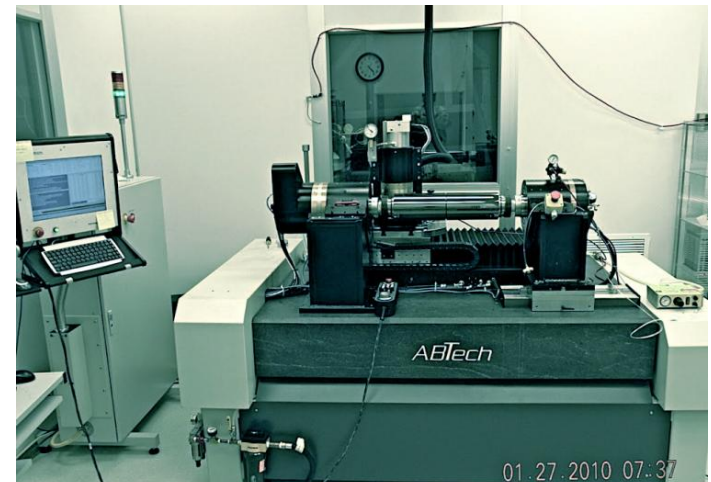


- Each bore has an x-ray telescope
- Exquisite imaging not required
- Need cost-effective way to build 8 (+1 spare), highly nested optics
- Baseline: Use approach from NASA's *NuSTAR* satellite



IAXO x-ray optics (2)

- Technique of choice for IAXO:
 - Slumped glass optics with multilayer coatings
 - Same technique successfully used for *NuSTAR* (launched in 2012)
- The specialized tooling to fabricate substrates and assemble IAXO prototype optics is now available
- Hardware can be easily configured to make optics with a variety of designs and sizes
- Key institutions for NuSTAR optics—LLNL, Columbia U., DTU-Space—all in IAXO
 - Initial studies performed



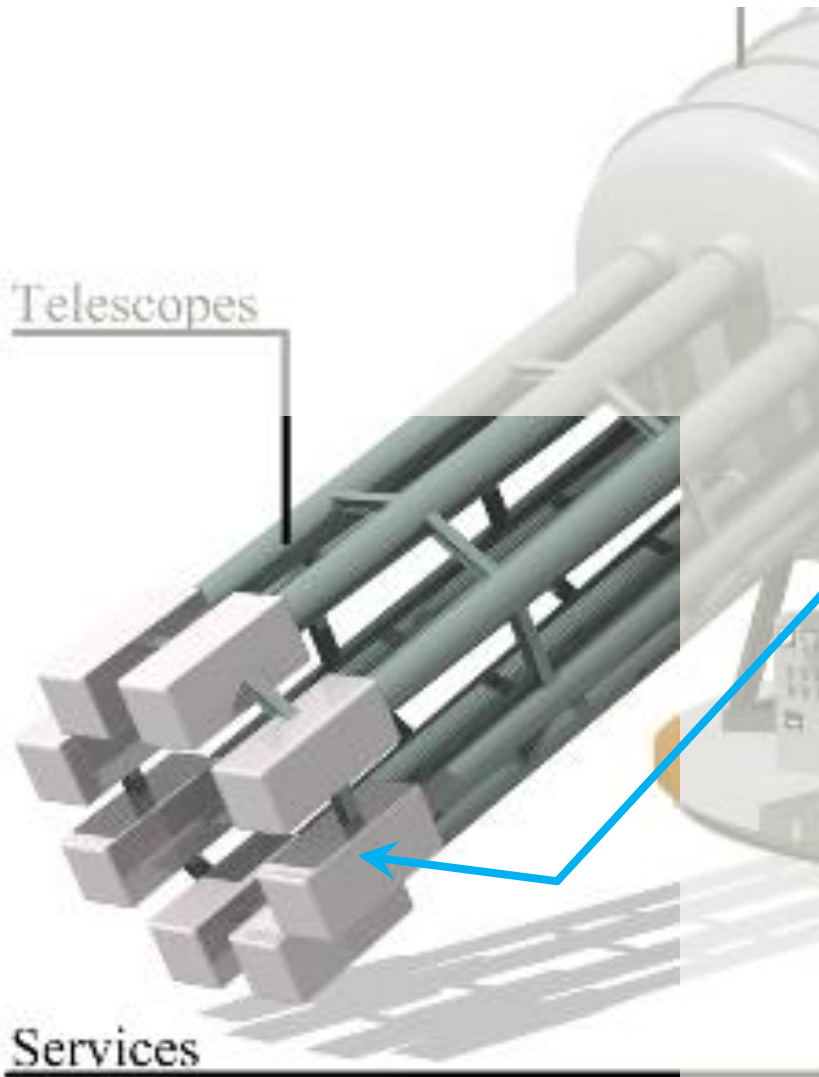
NuSTAR optics assembly machine



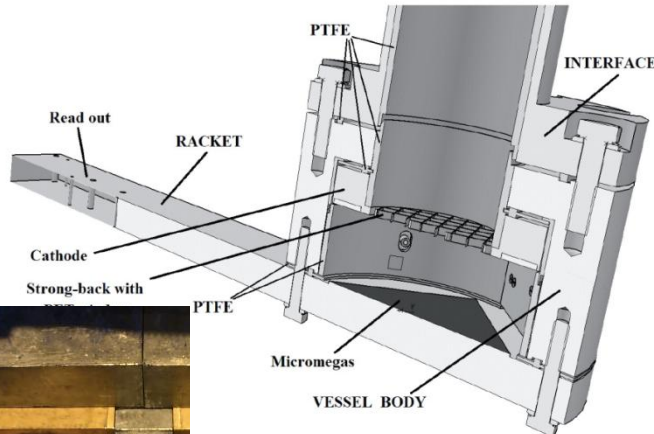
NuSTAR telescope ~38 cm \varnothing

Jakobsen et al. *Proc SPIE* **8861**:886113 (2013)

IAXO low-background x-ray detectors



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



Read out

RACKET

Cathode

Strong-back with

PTFE

Micromegas

VESSEL BODY

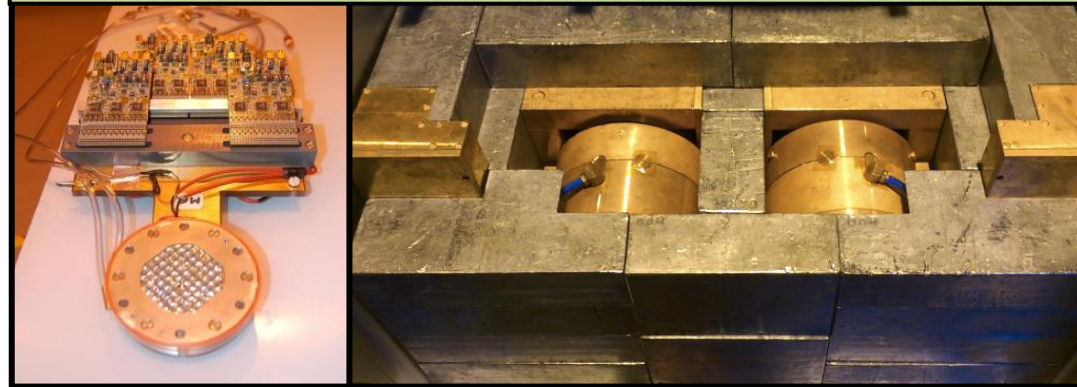
PTFE

INTERFACE

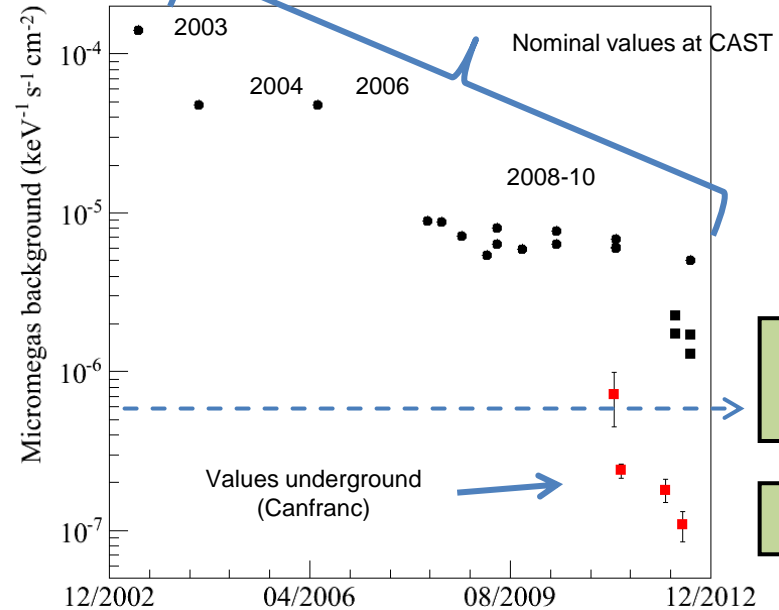
A cross-section diagram of a detector system, showing a central Micromegas detector within a VESSEL BODY. The diagram is labeled with various components: Read out, RACKET, Cathode, Strong-back with, PTFE, Micromegas, VESSEL BODY, and INTERFACE. A photograph below the diagram shows the physical detector assembly, which is a cylindrical component mounted within a complex metal structure.

IAXO low-background x-ray detectors (2)

Mircomegas (MM) detectors in operation at CAST



Improving MM background levels at CAST



- Small Micromegas-TPC chambers:

- Shielding
- Radiopure components
- Offline discrimination

- Background level for IAXO:

- $10^{-7} - 10^{-8} \text{ c keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$

- Already demonstrated:

- $8 \times 10^{-7} \text{ c keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$
(CAST during 2013)
- $1 \times 10^{-7} \text{ c keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$
(underground at Canfranc)

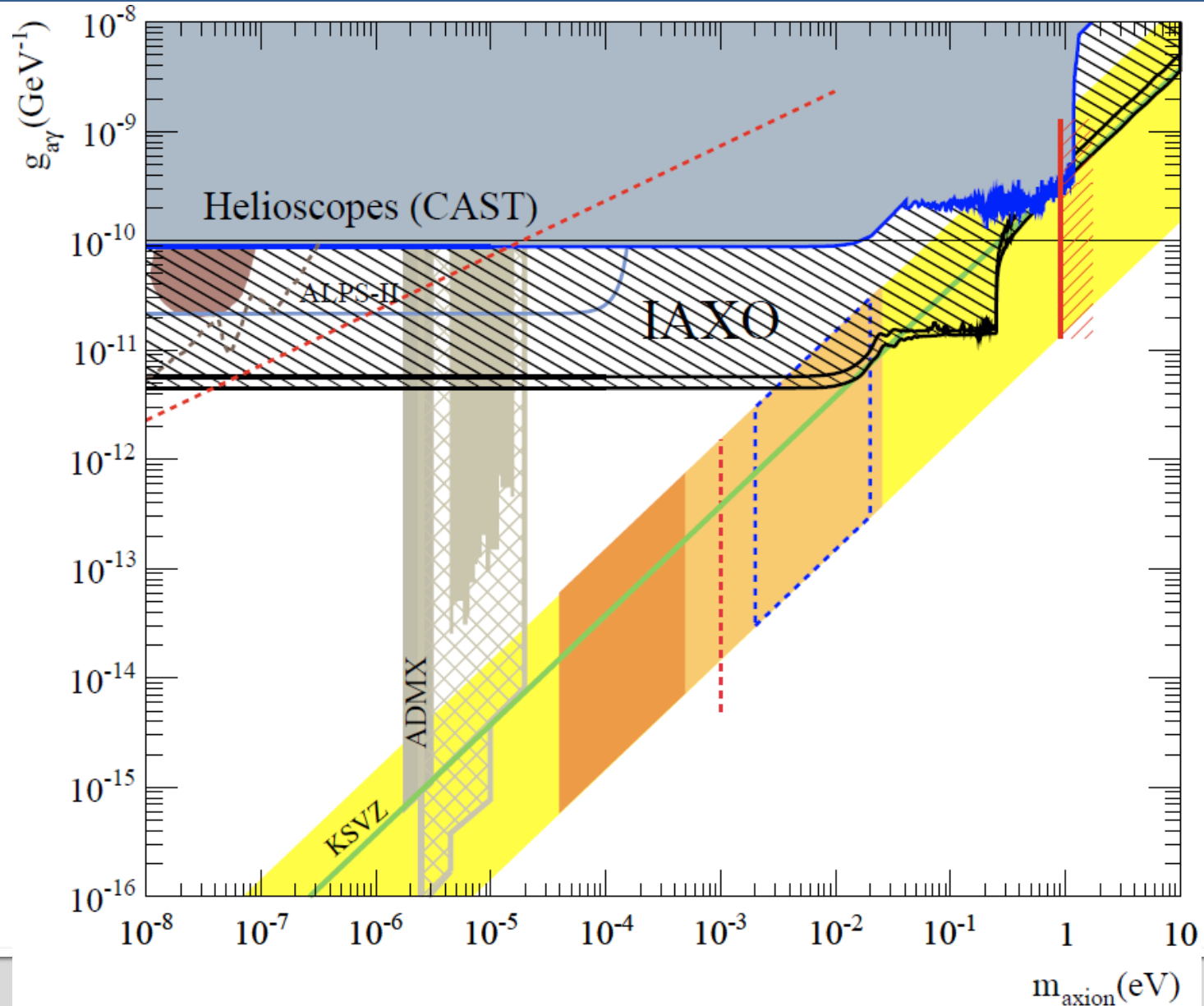
- Active program of development; clear roadmap for improvement

Aune et al. *JINST* 9:P01001 (2014)

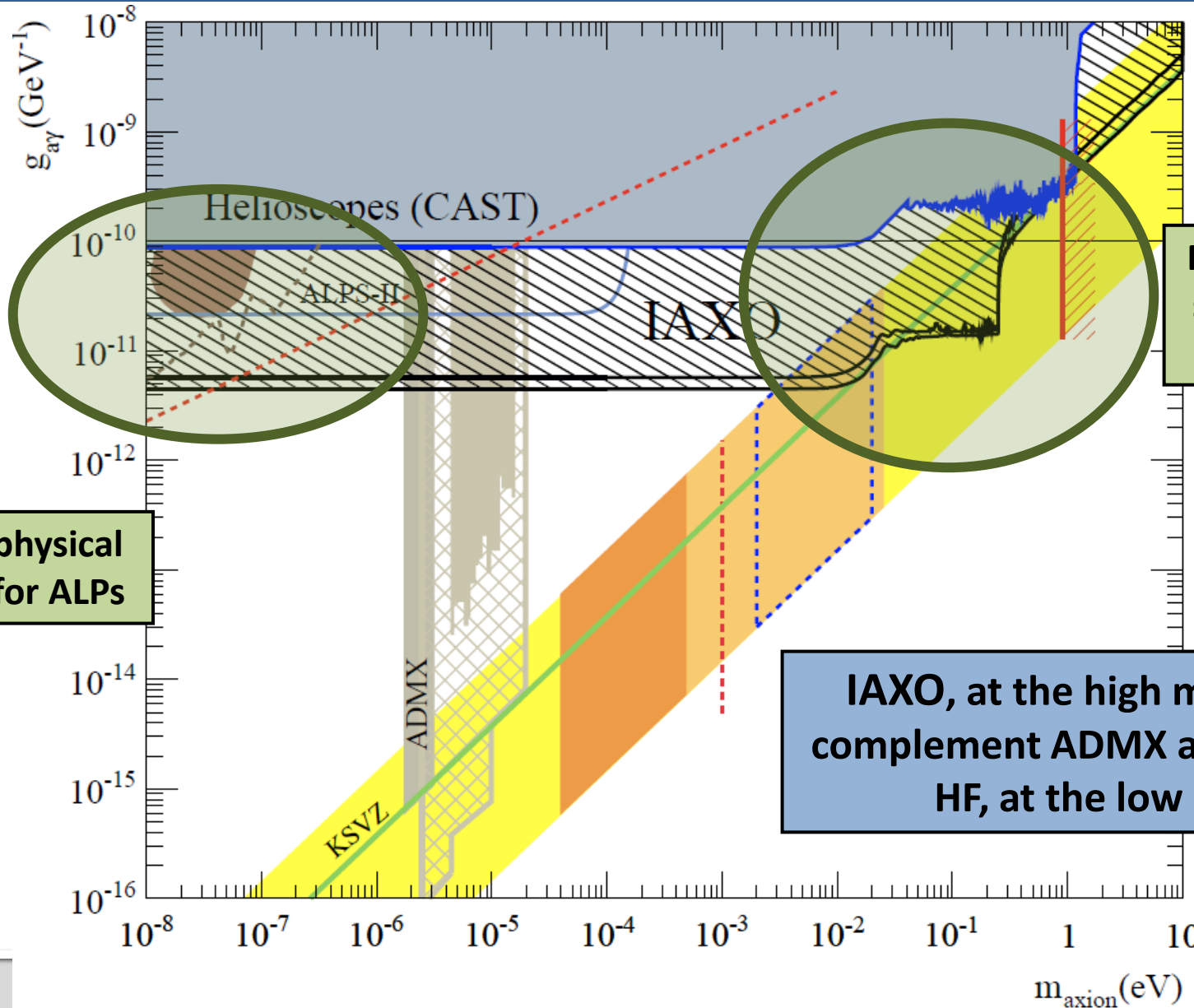
CAST MM
2013 levels

IAXO goals

IAXO sensitivity prospects



IAXO sensitivity prospects



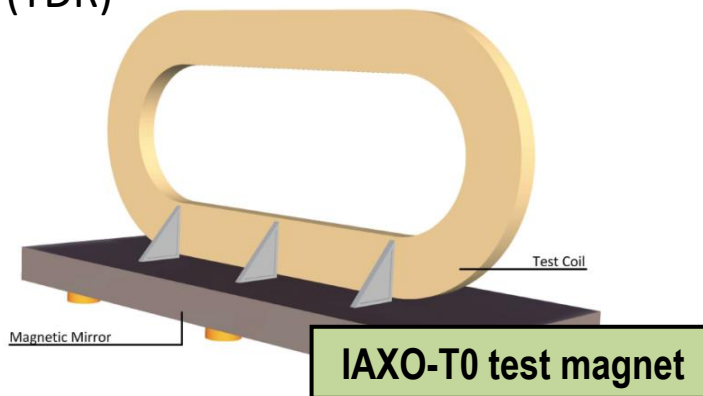
Much greater sensitivity to QCD axions

Astrophysical hints for ALPs

IAXO, at the high mass, will complement ADMX and ADMX-HF, at the low end

During the last 5 years

- **2011:** First studies concluded (*JCAP* 1106:013, 2011)
- **2013:** Conceptual Design finished (*JINST* 9:T05002, 2014)
- **Aug '13:** Letter of Intent submitted to the CERN SPSC (~40 institutions)
 - Lol: [CERN-SPSC-2013-022]
 - **Oct '13:** presentation at open session
- **Jan '14:** SPSC issued positive feedback— requests we complete a Technical Design Report (TDR)



Next steps

- Engage with funding agencies
- Execute the TDR :
 - Construct a demonstration coil [IAXO-T0]
 - Complete pathfinder project {detector+optic} with CAST
 - Construct a prototype x-ray telescope [IAXO-X0] and detector [IAXO-D0]
 - Construct additional detectors to validate alternative technologies
 - Study feasibility of microwave-cavity searches
- Draft and sign the MOU
- Perform site studies
- **Grow the collaboration !**

