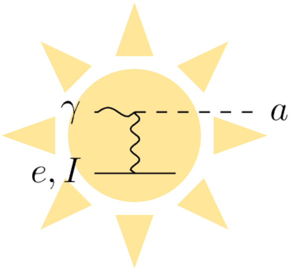
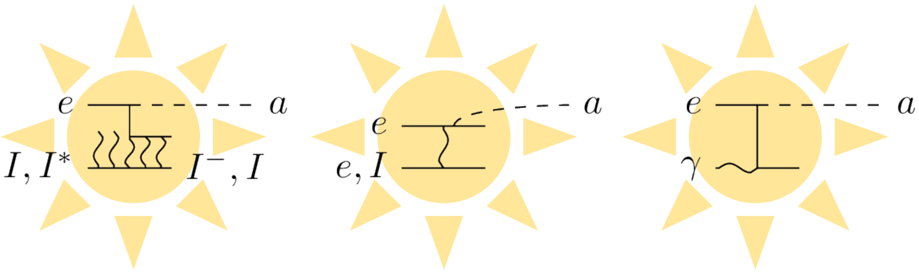
IAXO - *The next generation axion helioscope*

Christoph Wiesinger for the IAXO collaboration, Technical University of Munich (TUM),
Rencontres du Vietnam, 05.08.2024

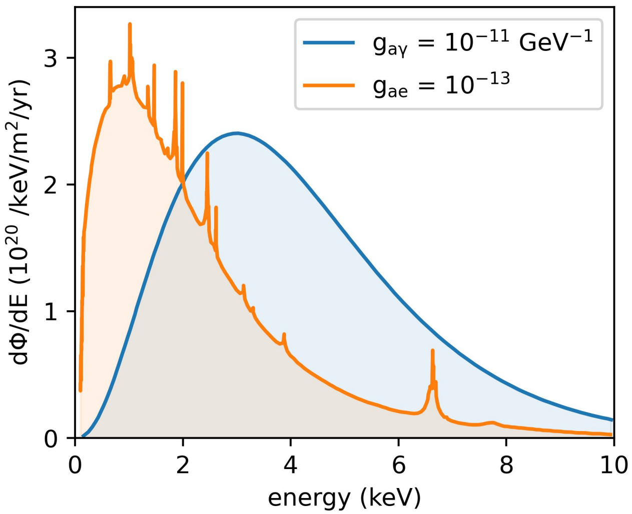
Solar axions



- **Primakoff conversion** of thermal photons, axion-photon coupling $g_{a\gamma}$
- atomic recombination/deexcitation, Bremsstrahlung and Compton scattering (**ABC**), axion-electron coupling g_{ae}
  [Redondo, JCAP 12 (2013) 008]



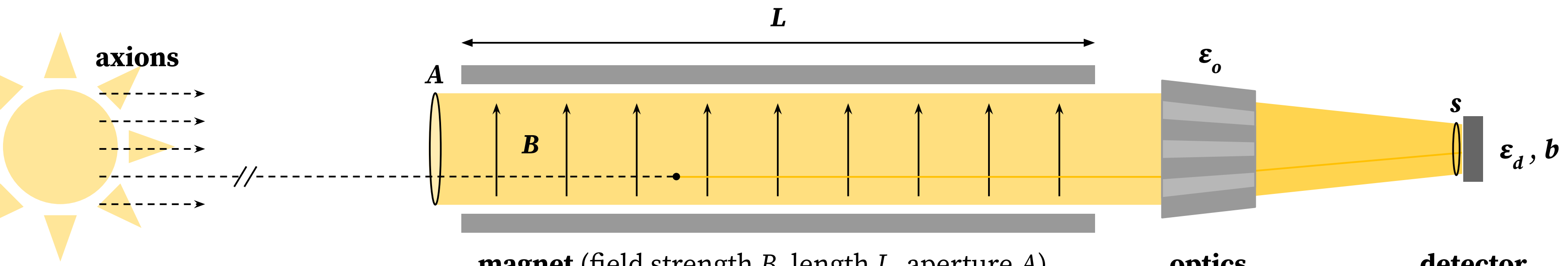
[Dafni et al., PRD 99 (2019) 3, 035037]



- **nuclear transitions**, axion-nucleon coupling g_{aN}, e.g. 14.4 keV from ^{57}Fe M1 transition

Helioscope concept

- **reconversion** of solar axions into **X-ray photons** in magnetic field
  [Sikivie, PRL 51 (1983) 1415-1417]



magnet (field strength *B*, length *L*, aperture *A*)

optics (efficiency ε_o , spot size *s*)

detector (efficiency ε_d , background *b*)

➔ (background dom.) **sensitivity** $g_{a\gamma}^{-4} \propto (BL)^2 A \cdot \varepsilon_o / s^{1/2} \cdot \varepsilon_d / b^{1/2} \cdot t^{1/2}$

- conversion over macroscopic length, **loss of coherence** for axion masses above O(0.01) eV

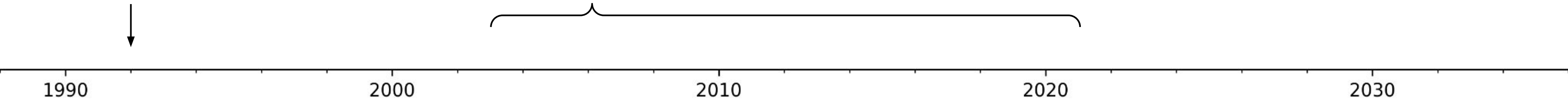
➔ **buffer gas**, refractive photon mass, **restore coherence**, access to larger axion masses [van Bibber et al., PRD 39 (1989) 2089]

Helioscopes

CAST at CERN
X-ray focusing optics, low-background techniques, buffer gas operation
[Anastassopoulos et al., Nature Phys. 13 (2017) 584-590]

➔ **new result,** $g_{a\gamma} < 5.7 \cdot 10^{-11}\ \mathrm{GeV}^{-1}$ (95% CL)
[Altenmüller et al., arXiv:2406.16840]

Brookhaven
stationary magnet
[Lazarus et al., PRL 69 (1992) 2333-2336]



SUMICO at Tokyo University
sun tracking
[Inoue et al., PLB 668 (2008) 93-97]

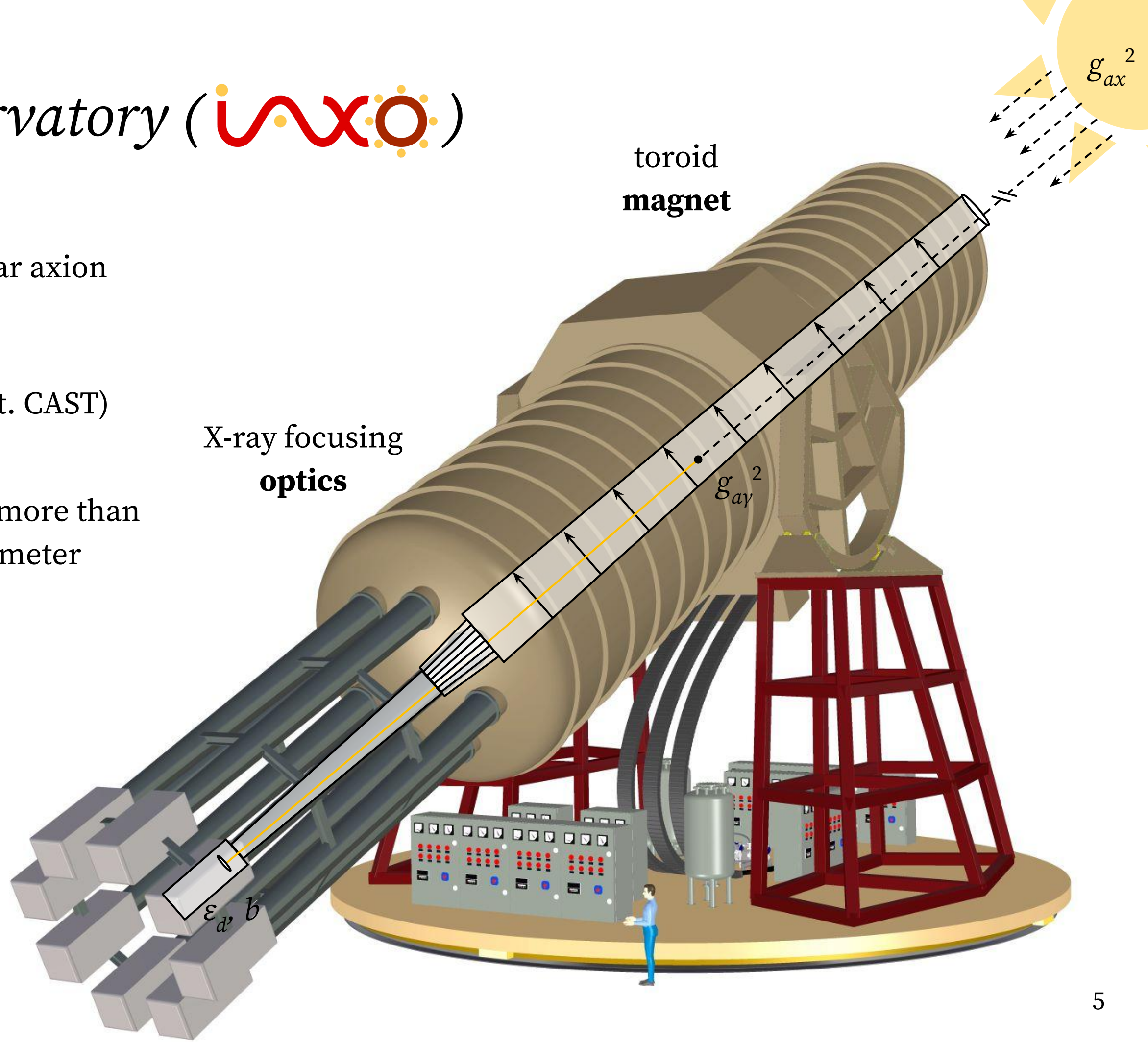
(Baby)IAXO at DESY ⇒
[Armengaud et al., JINST 9 (2014) T05002]

International Axion Observatory (IAXO)

- **next generation** helioscope, expand solar axion search by > 1 order of magnitude
  [Armengaud et al., JINST 9 (2014) T05002]

➔ **> 10^4 signal-to-noise** improvement (w.r.t. CAST)

- **purpose-built magnet**, up to 5.4 T over more than 20 m, 8 conversion bores with 60 cm diameter
- high-efficiency **X-ray focusing optics**, focal spot smaller than 0.2 cm^2
- high-efficiency **ultra-low background X-ray detectors**, background less than 10^{-8} cts/keV/cm^2/s
- 50% sun tracking time



Baby IAXO

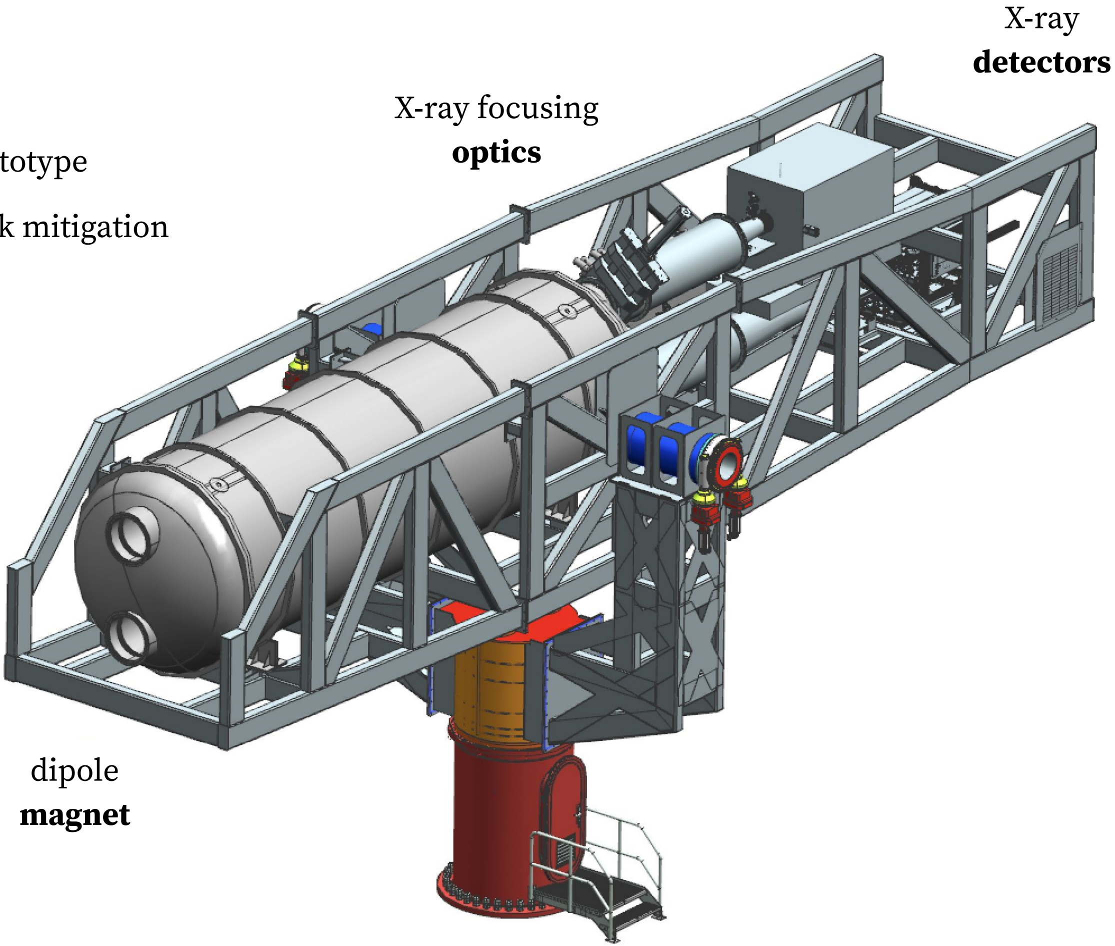
- **intermediate stage**, technological prototype

➔ **inform IAXO** design, optimization, risk mitigation

- fully fledged helioscope, > 10^2 **signal-to-noise** improvement (w.r.t. CAST)

➔ relevant **physics results**

- **DESY** HERA south hall



Baby IAXO magnet

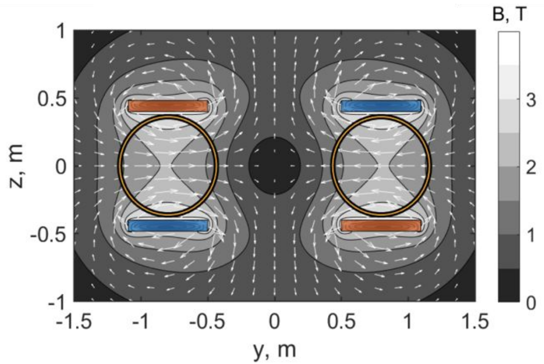
- common-coil **dipole**, racetrack configuration, counter-flowing currents

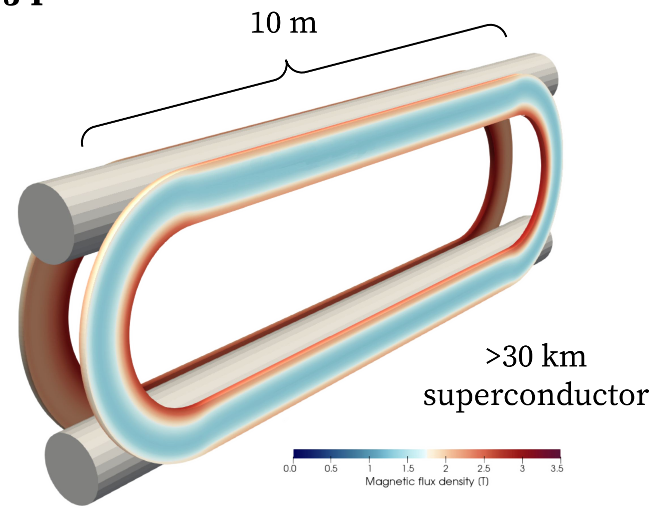
➔ winding layout **similar to IAXO** toroid

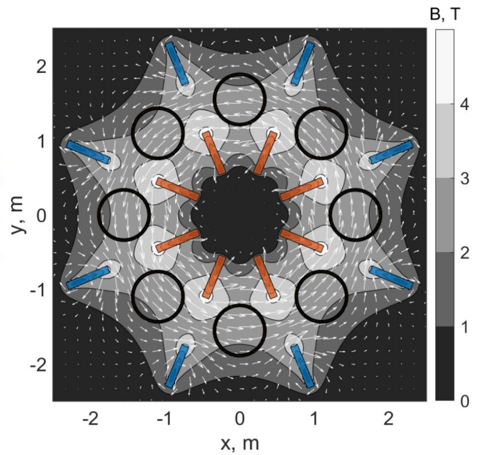
- **two bores** with 70 cm diameter, **2-3 T** average magnetic field strength

- Al-stabilized **Nb-Ti-based superconductor**

➔ cost-effective, but delays due to **cable availability**



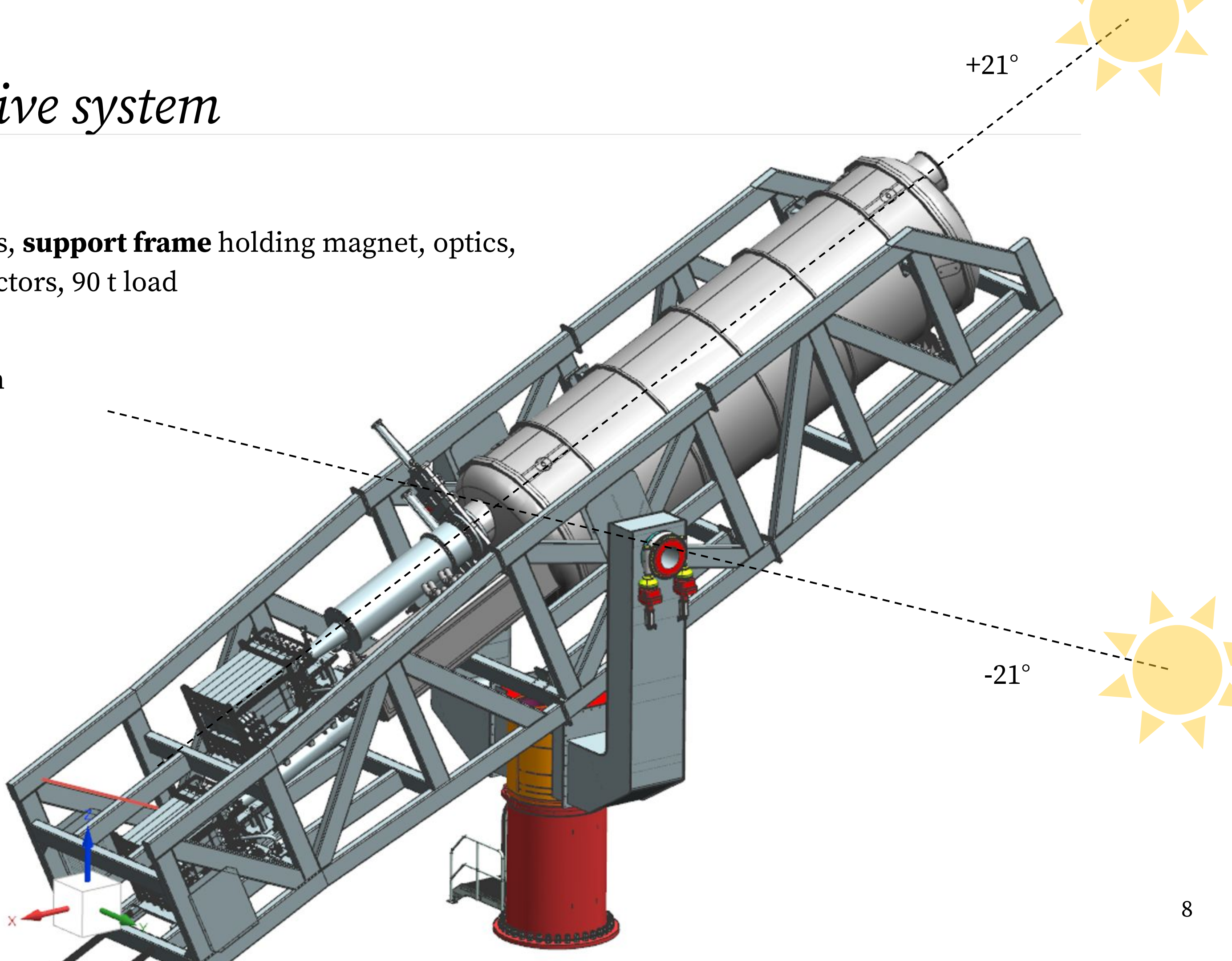


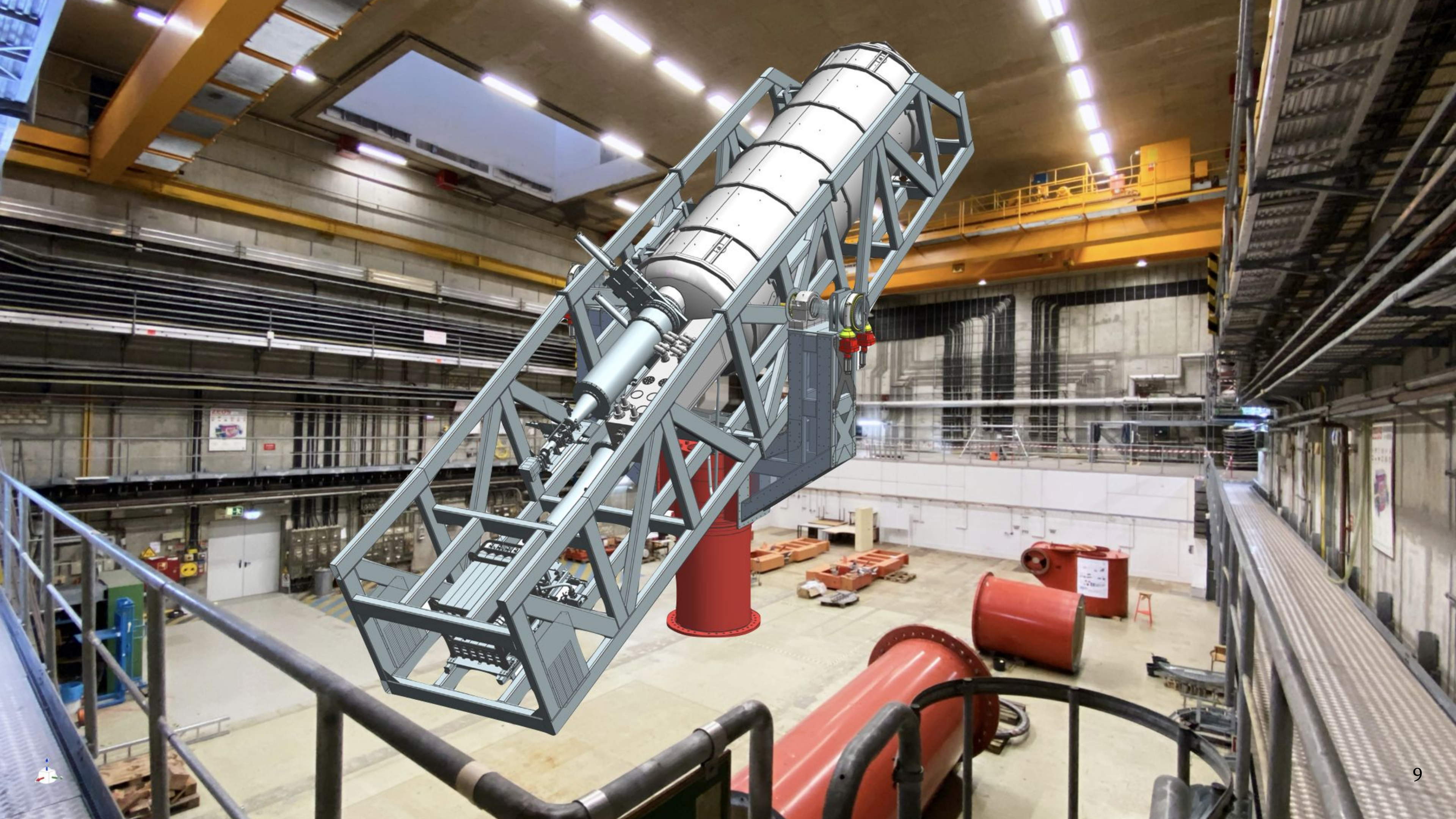


Baby IAXO drive system

- **CTA MST prototype** parts, **support frame** holding magnet, optics, vacuum system and detectors, 90 t load

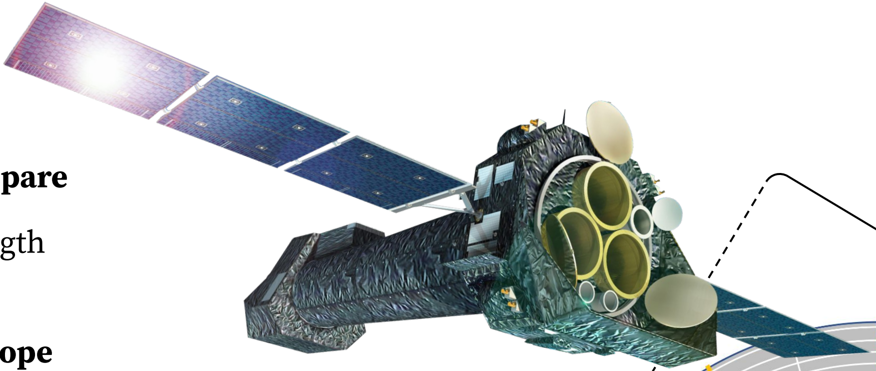
➔ **50% sun-tracking** time,
< 0.01° pointing precision

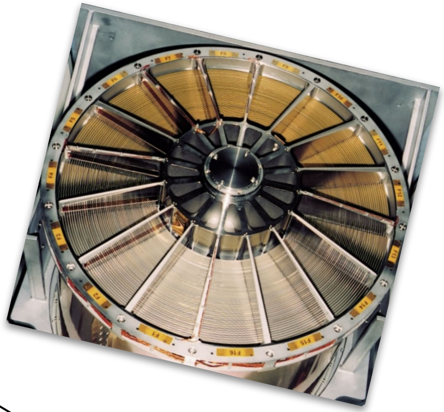


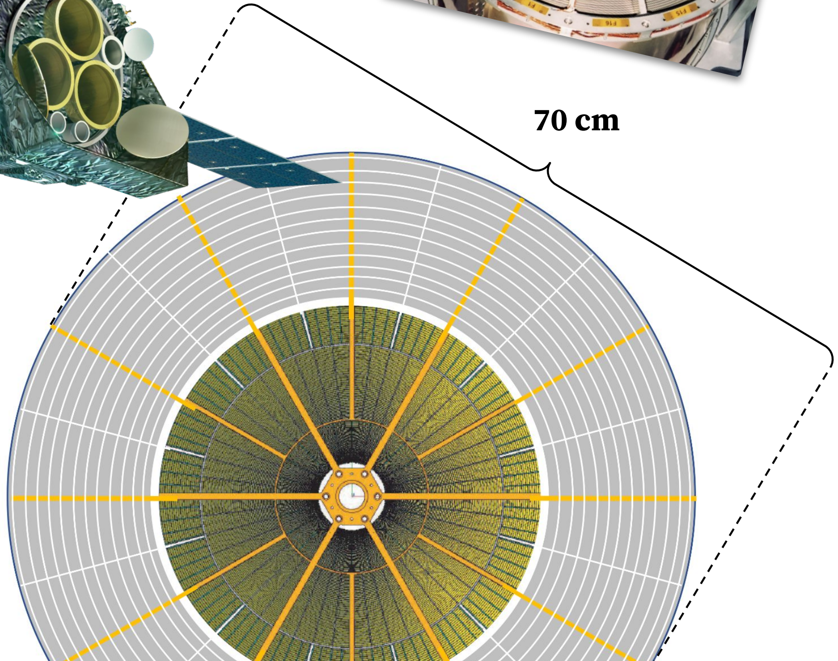


Baby IAXO X-ray optics

- profit from **space instruments**
- **XMM Newton flight spare**
  - 7.5 m focal length
- custom **hybrid telescope**
  - **inner** optics based on NuSTAR/XRISM experience
  - **outer** optics from cold-slumped Willow-glass
  - 5 m focal length





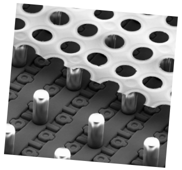


Baby IAXO X-ray detectors

priority

- sufficient **energy resolution** and **threshold**
- high X-ray **detection efficiency**
- ultra-low **background,** background goal $< 10^{-7}$ cts/keV/cm^2/s, **limited overburden**

➔ different **detector technologies**



gaseous

“miniature TPC”

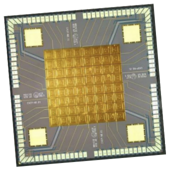
Micromegas

- **O(10^{-7}) cts/keV/cm^2/s** achieved, proven in CAST

➔ **baseline technology**

GridPix

- excellent **spatial resolution**



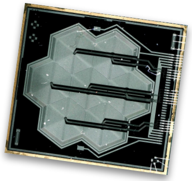
cryogenic

- excellent **energy resolution** and threshold

➔ axion spectroscopy

metallic micro calorimeters (**MMC**)

transition edge sensors (**TES**)



semiconductor

⇒

Silicon drift detectors

- tiny read-out electrode, low capacitance

➔ good **energy resolution**, O(100) eV

➔ low energy threshold, < 1 keV

- thin deadlayer, **no entrance window** needed
  [Mertens et al., J.Phys.G 48 (2020) 1, 015008]

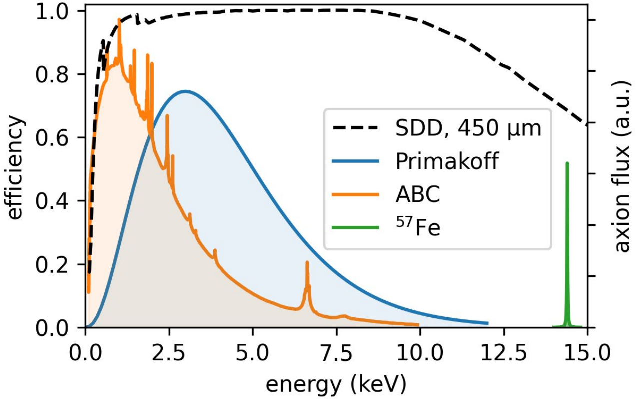
➔ high X-ray **detection efficiency**

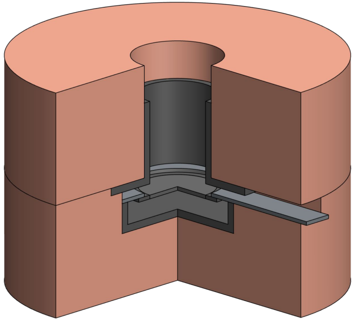
- pure materials, little auxiliaries

➔ great, yet unproven, potential for **low background** applications, O(10^{-6}) cts/keV/cm^2/s achieved

➔ **alternative technology** to Micromegas

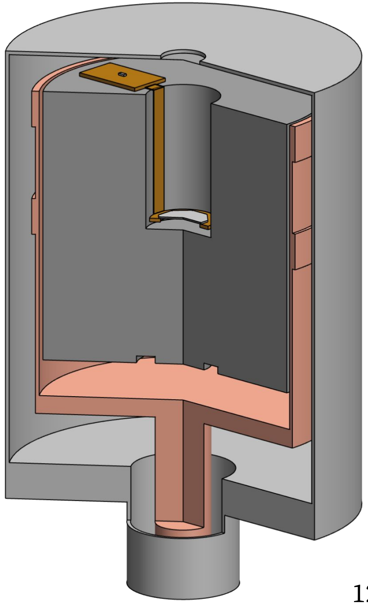
[Schlosser et al., NIM A 624 (2010) 270-276;
Dafni et al., PRD 99 (2019) 3, 035037]





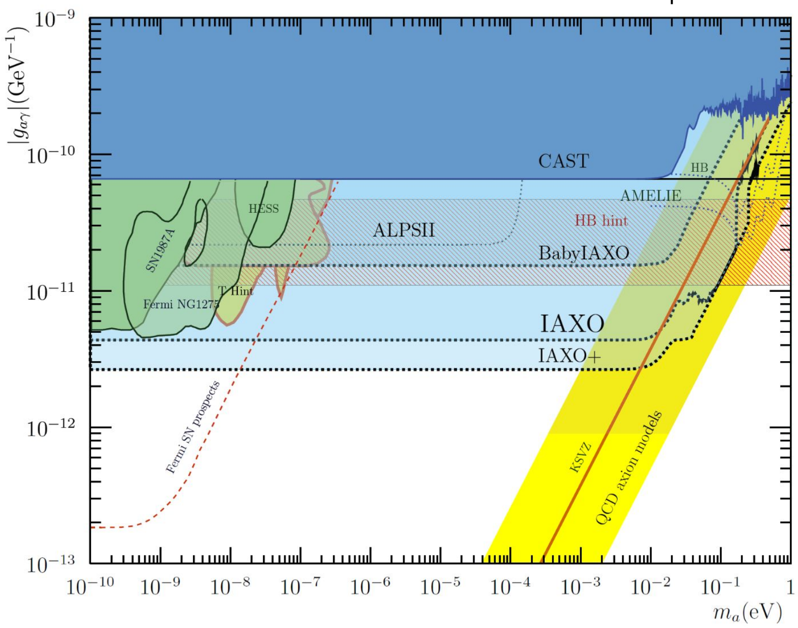
passive-shield SDD design

active-shield
SDD-in-HPGe concept



Physics case

vacuum phase ← - - → **gas** phase



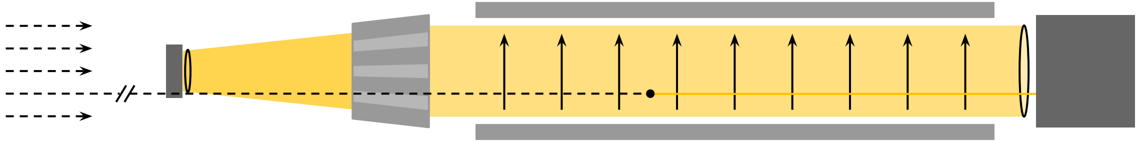
- wide **unexplored ALP parameter space,** $g_{a\gamma}$ down to few 10^{-12} GeV^{-1}, g_{ae} down to few 10^{-13}
- test **astrophysically hinted regions,** transparency, stellar cooling
- **QCD axions** in the meV to eV range, buffer gas phase

➔ independent of dark-matter hypothesis

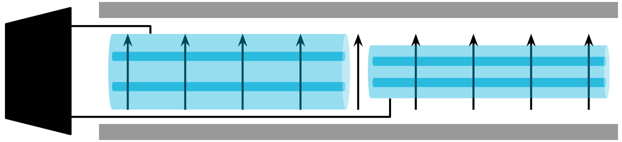
- **post-discovery** opportunities
  - **axion spectroscopy**, detection of Primakoff ($g_{a\gamma}$) and ABC (g_{ae}) flux to distinguish axion mass and models
    [Jaeckel, Thormaehlen, JCAP 03 (2019) 039]
  - **solar magnetometry**, sub-keV axions from longitudinal plasmons, information about magnetic field profile
    [O'Hare, PRD 102 (2020) 4, 043019]

Non-solar axions

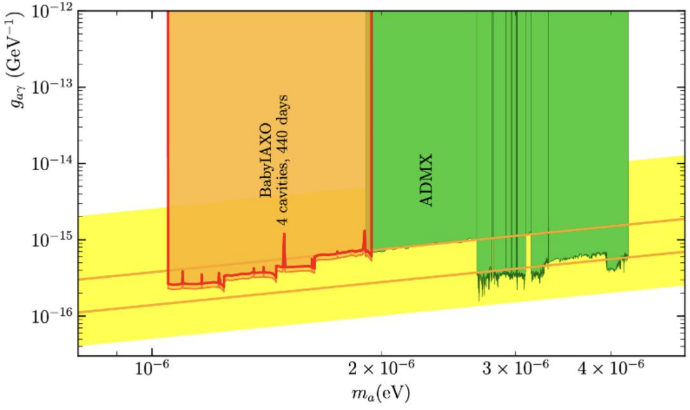
- **supernova axions**, high energy photon detector, O(10) MeV, supernovascope
  [Ge et al., JCAP 11 (2020) 059]



- **relic axions**, large magnetic field volume, haloscope setups, **RADES**
  [Alvarez Melcon et al., JCAP 05 (2018) 040]



[Ahyoune et al., Annalen Phys. 535 (2023) 12, 2300326]

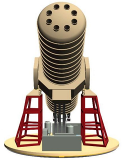


- **exotic WISPs**, e.g. dark photons, chameleons

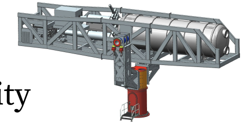
- high-frequency **gravitational waves**, inverse Gertsenshtein effect
  [Franciolini, PRD 106 (2022) 10, 103520]

Conclusions

- solar axions searches able to **probe large ALP parameter space**
- **new result by CAST**, $g_{a\gamma} < 5.7 \cdot 10^{-11}\ \mathrm{GeV}^{-1}$ (95% CL) for $m_a \lesssim 0.02$ eV
  [Altenmüller et al., arXiv:2406.16840]
- **IAXO is next generation helioscope**,
  expand solar axion search by > 1 order of magnitude



- **BabyIAXO is intermediate stage**,
  technological prototype, physics sensitivity



- various **physics cases beyond standard Primakoff flux**, ABC flux, ..

Backup