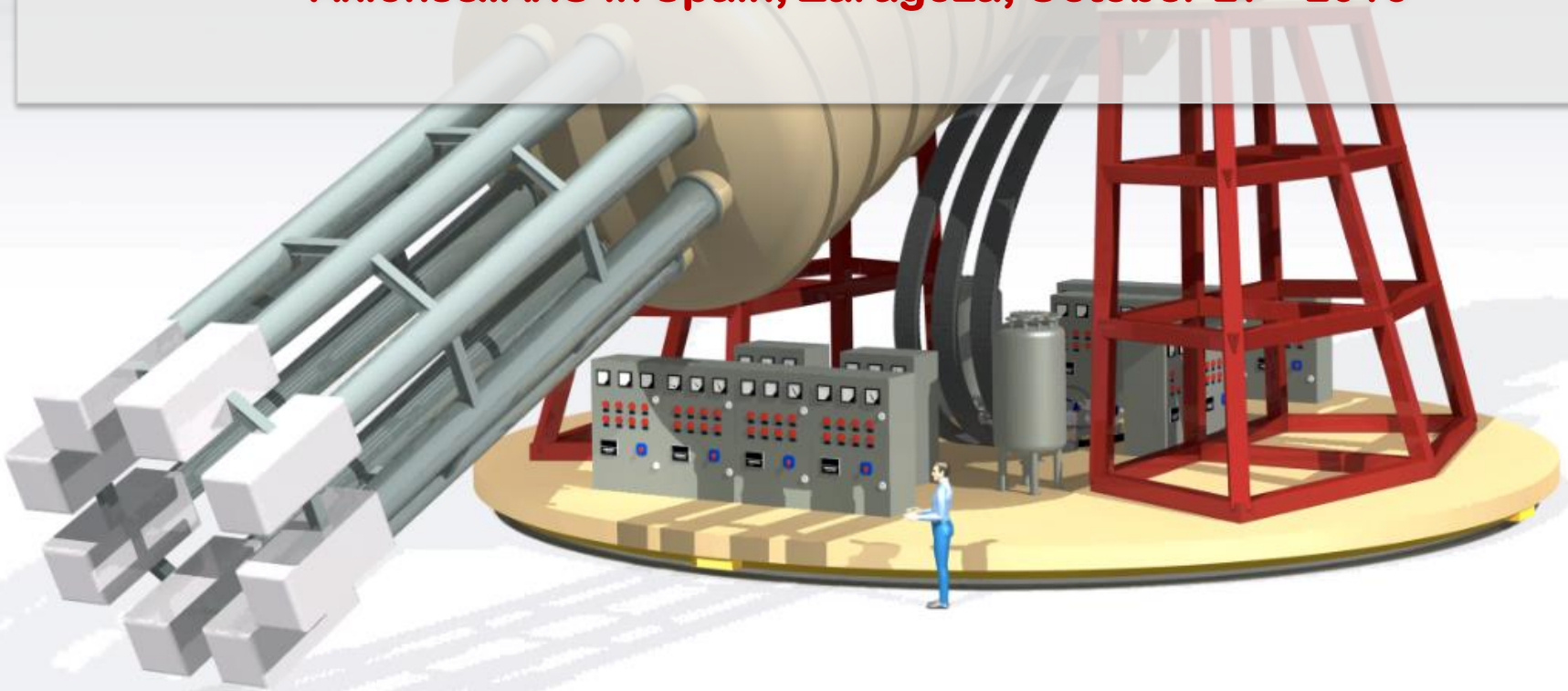
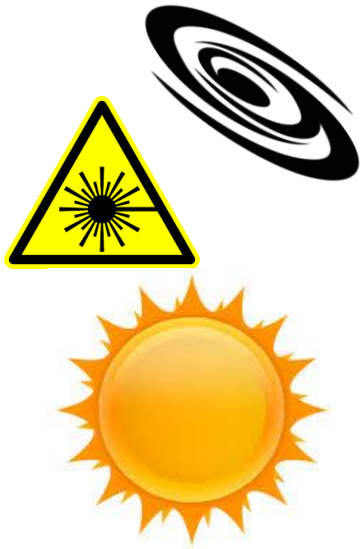
Physics case, prospects and status of the International AXion Observatory IAXO

Igor G. Irastorza (U. Zaragoza)

Axions&IAXO in Spain, Zaragoza, October 27th 2016



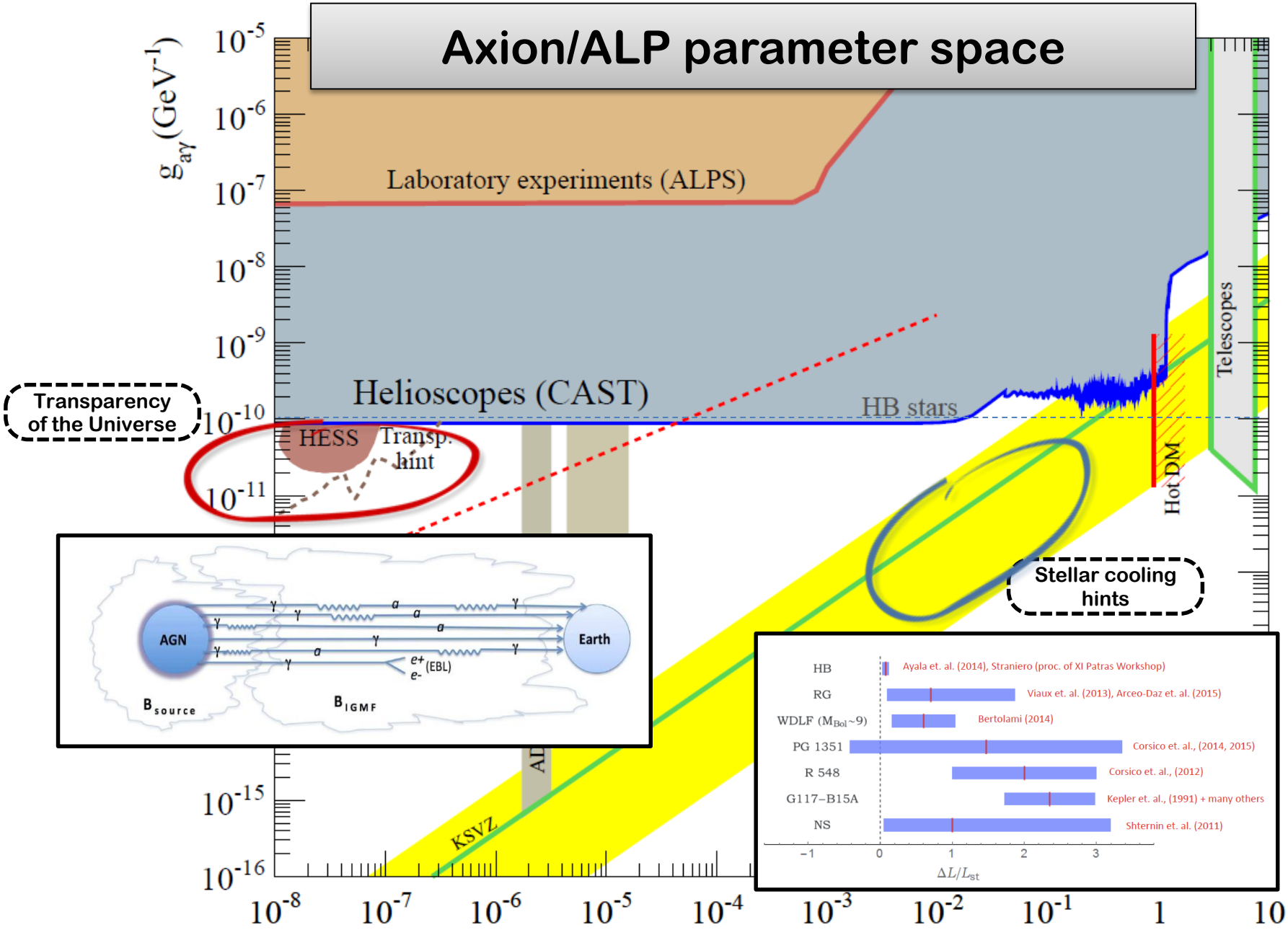
IAXO in the axion landscape



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

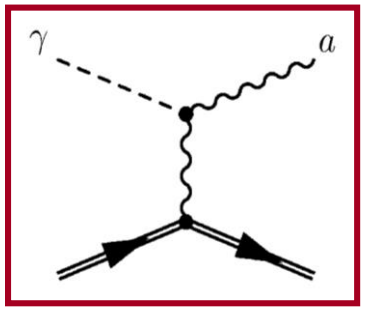
- Helioscopes → do not rely on the axion being the dominant DM component. Solar axion emission robust prediction
- Helioscopes → No R&D needed. Technology mature enough for a large scale experiment (IAXO)
- Large complementarity with other detection strategies

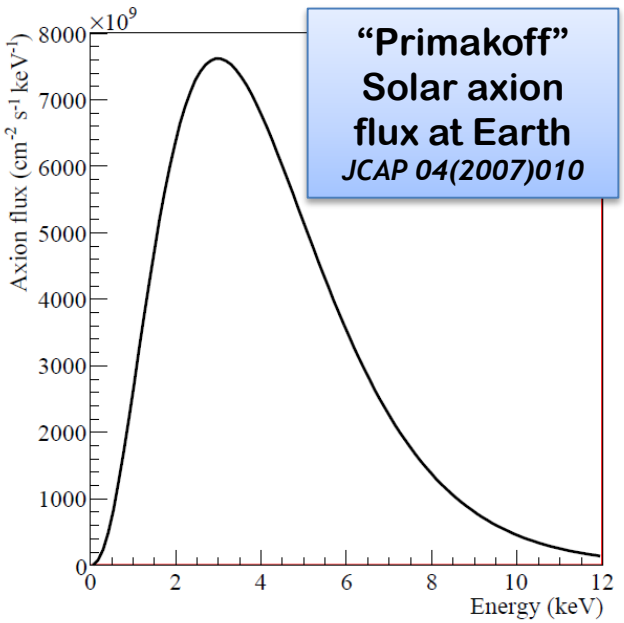
Axion/ALP parameter space

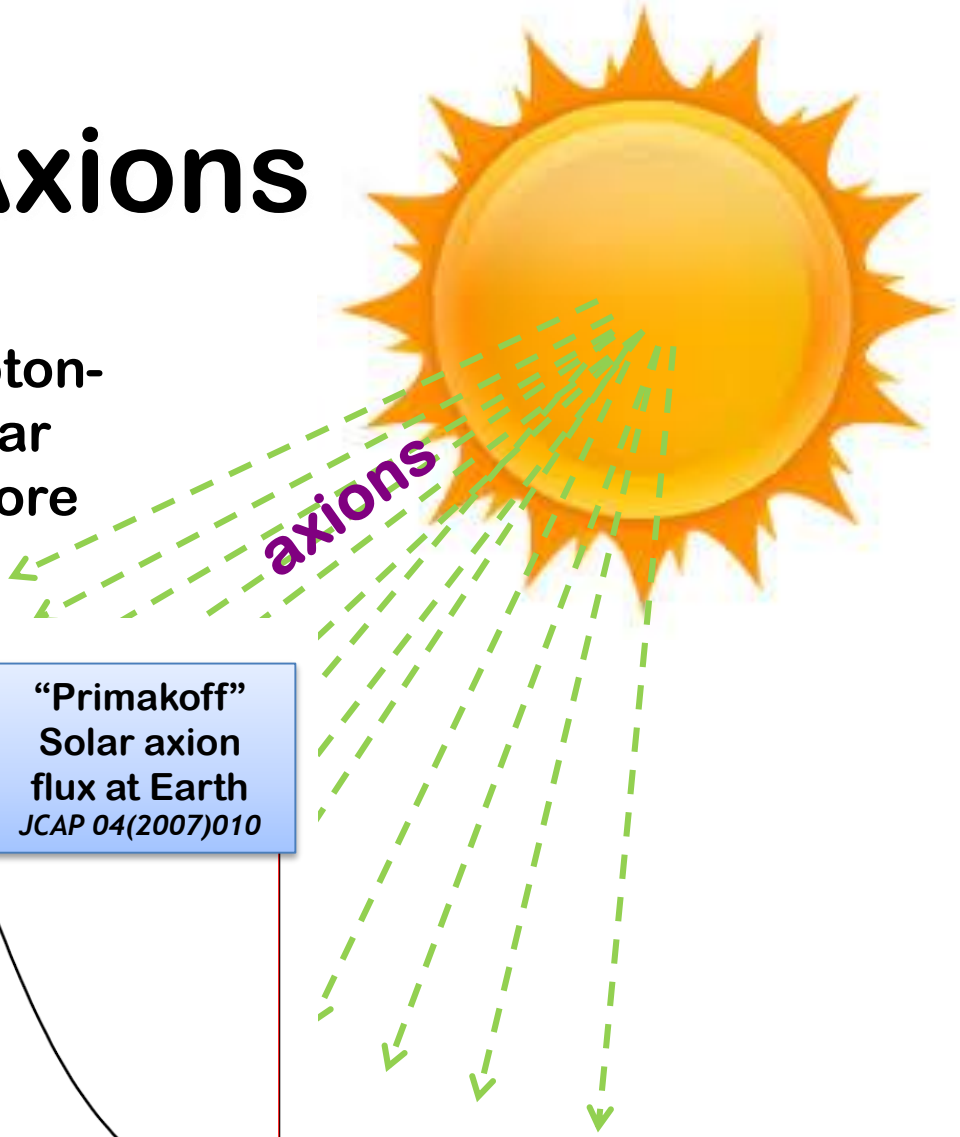


Solar Axions

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

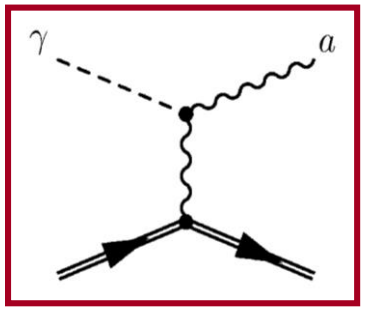


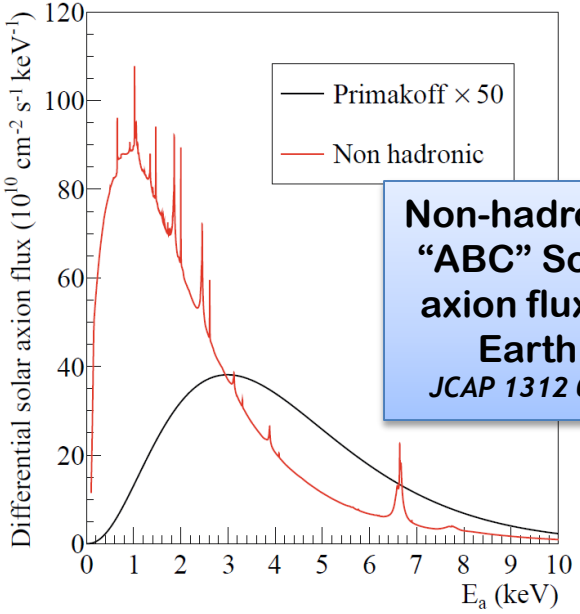




Solar Axions

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





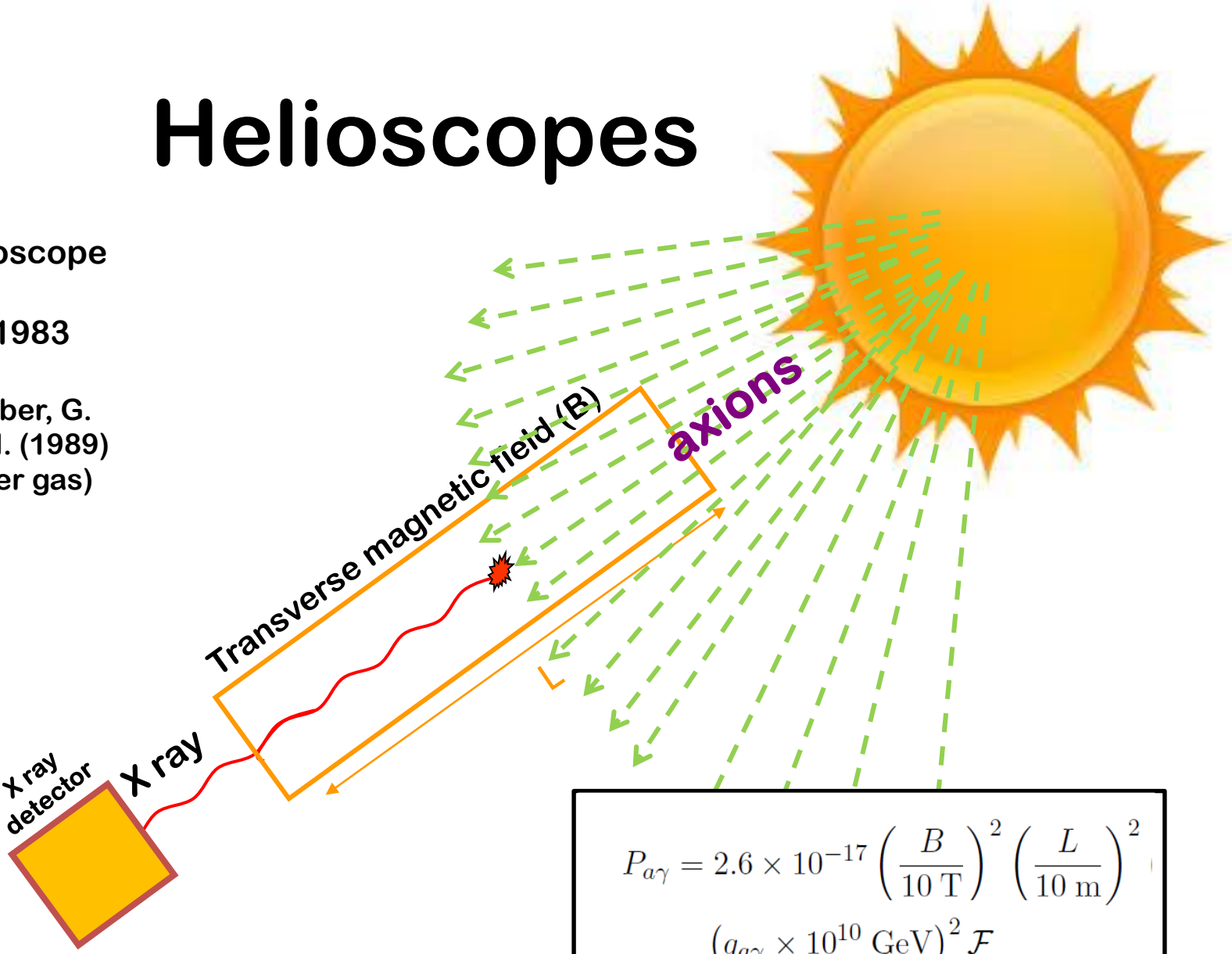
Non-hadronic "ABC" Solar axion flux at Earth
JCAP 1312 008

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

Helioscopes

Axion helioscope concept
P. Sikivie, 1983

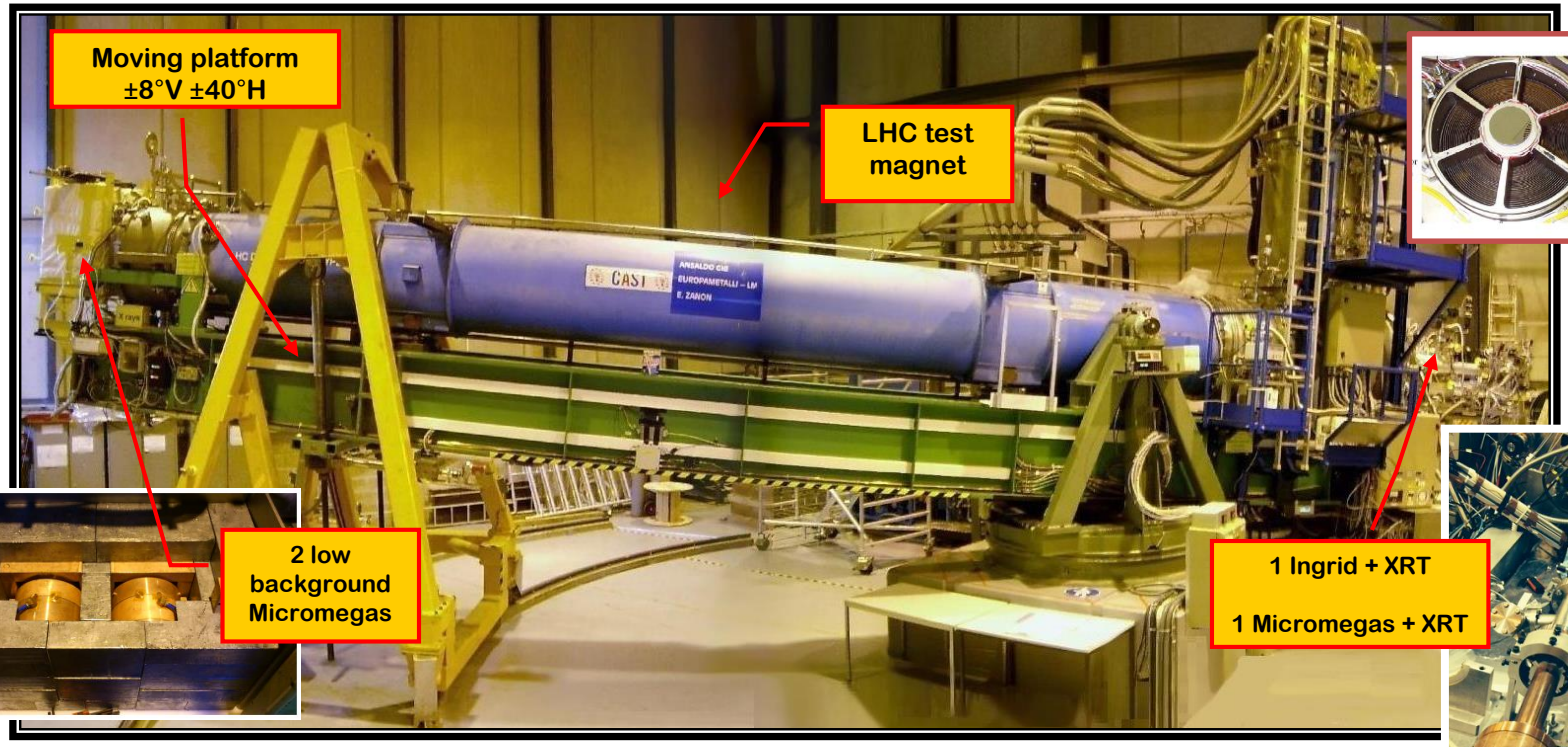
+ K. van Bibber, G. Raffelt, et al. (1989) (use of buffer gas)



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

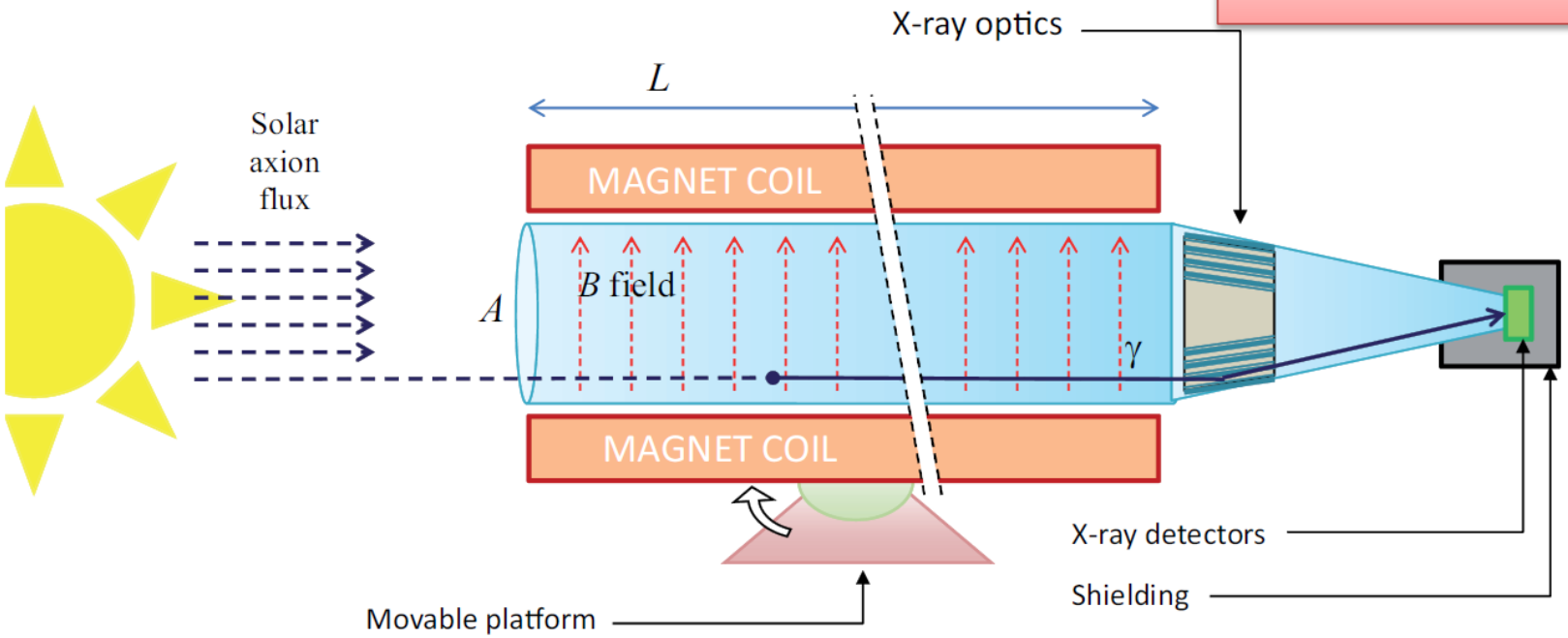
CAST experiment @ CERN

- 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

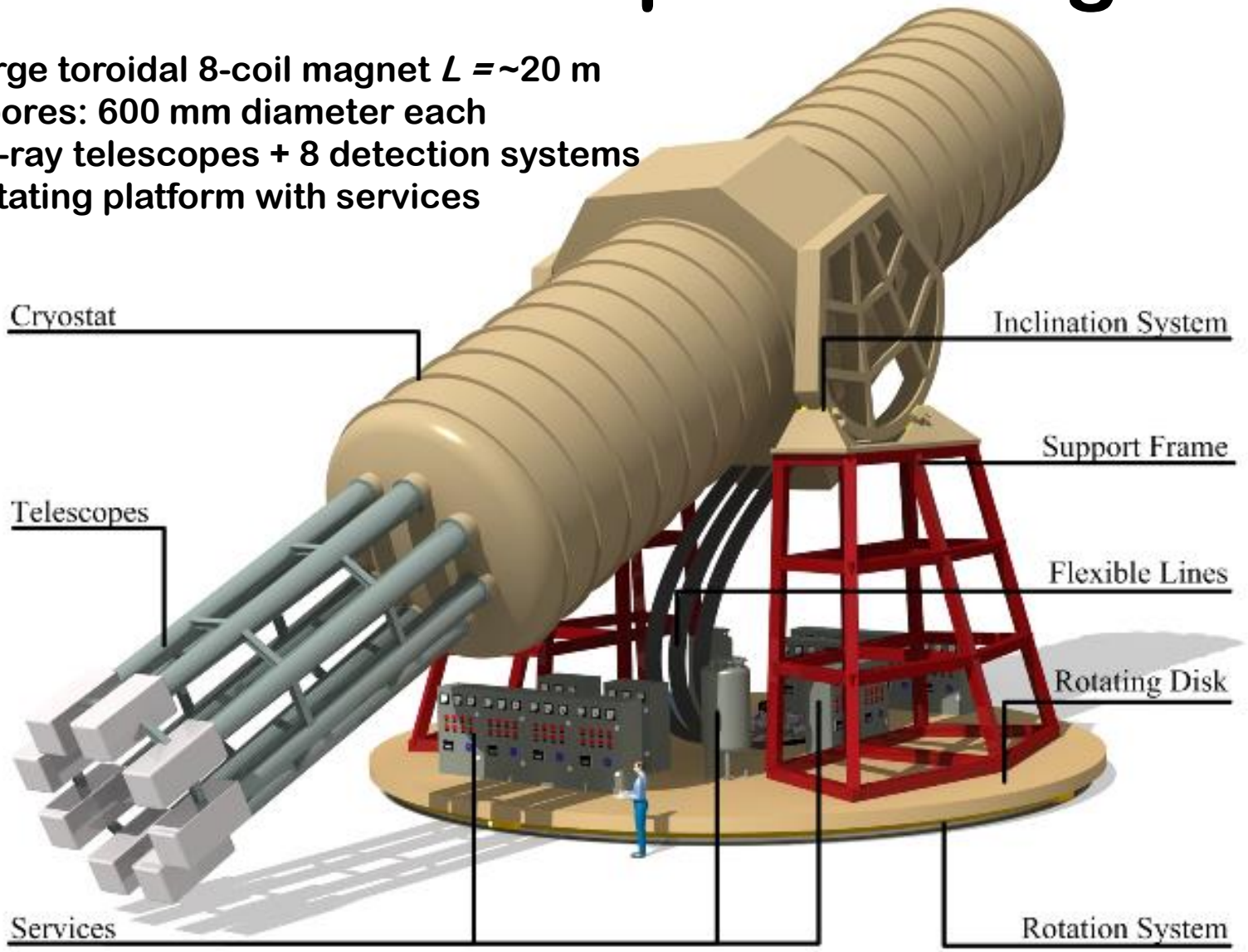


$$g_{a\gamma}^4 \propto \underbrace{b^{1/2}\epsilon^{-1}}_{\text{detectors}} \times \underbrace{a^{1/2}\epsilon_o^{-1}}_{\text{optics}} \times \underbrace{(BL)^{-2}A^{-1}}_{\text{magnet}} \times \underbrace{t^{-1/2}}_{\text{exposure}}$$

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

IAXO – Conceptual Design

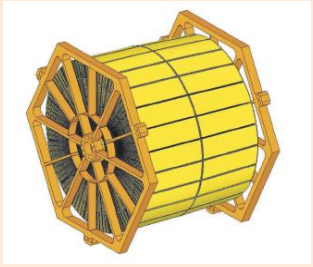
- **Large toroidal 8-coil magnet *L* =~20 m**
- **8 bores: 600 mm diameter each**
- **8 x-ray telescopes + 8 detection systems**
- **Rotating platform with services**

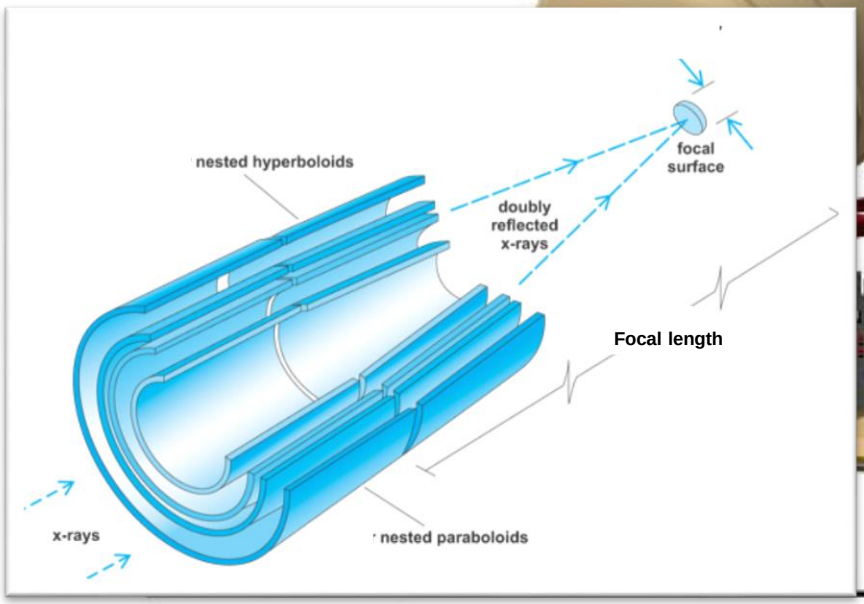


IAXO technologies – Baseline

IAXO telescopes

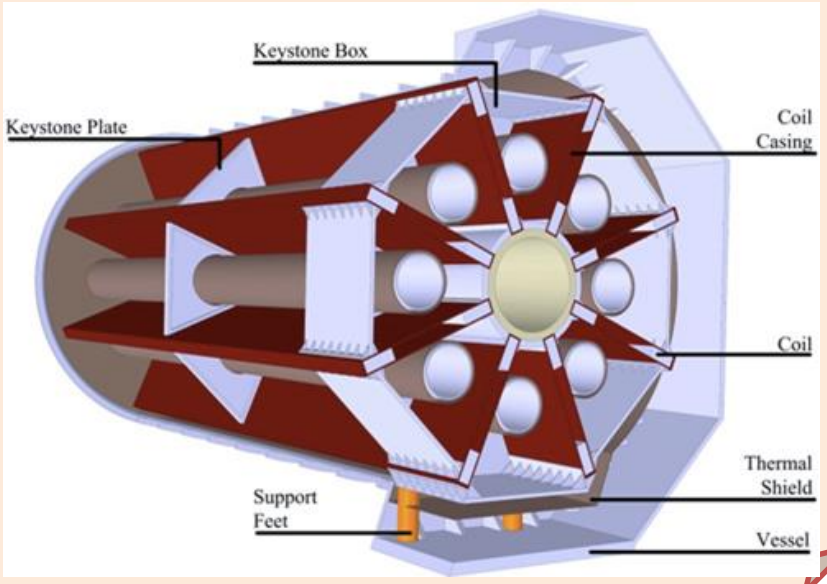
- Slumped glass technology with multilayers
- Cost-effective to cover large areas
- Based on NuSTAR developments
- Focal length ~5 m
- 60-70% efficiency
- LLNL+UC+DTU + MIT + INAF





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



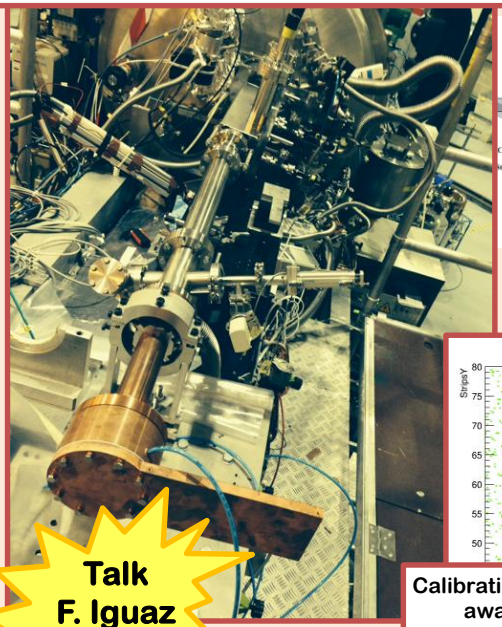
Baseline developed at:
IAXO Letter of Intent: CERN-SPSC-2013-022
IAXO Conceptual Design: JINST 9 (2014) T05002 (arXiv:1401.3233)

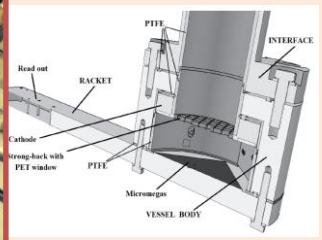
IAXO technologies – Baseline

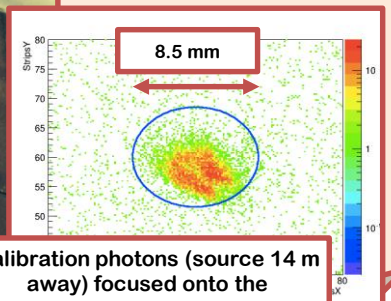
IAXO detectors

- **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)





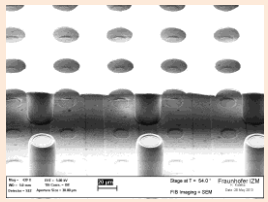


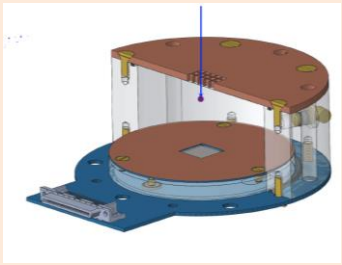
Calibration photons (source 14 m away) focused onto the Micromegas

Talk F. Iguaz

IAXO detectors

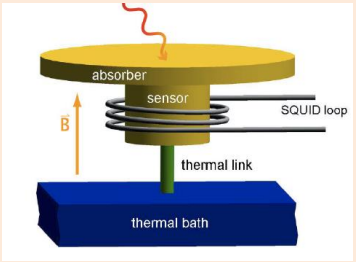
Ingrid detectors
- Better threshold
- U. Bonn

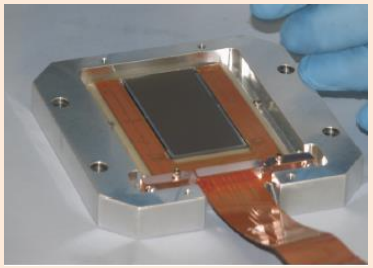




MMC (Magnetic Metallic Calorimeters)
TES (Transition Edge Sensors)
- Very good E resolution & threshold
- Heidelberg + CEA + CNSMS

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

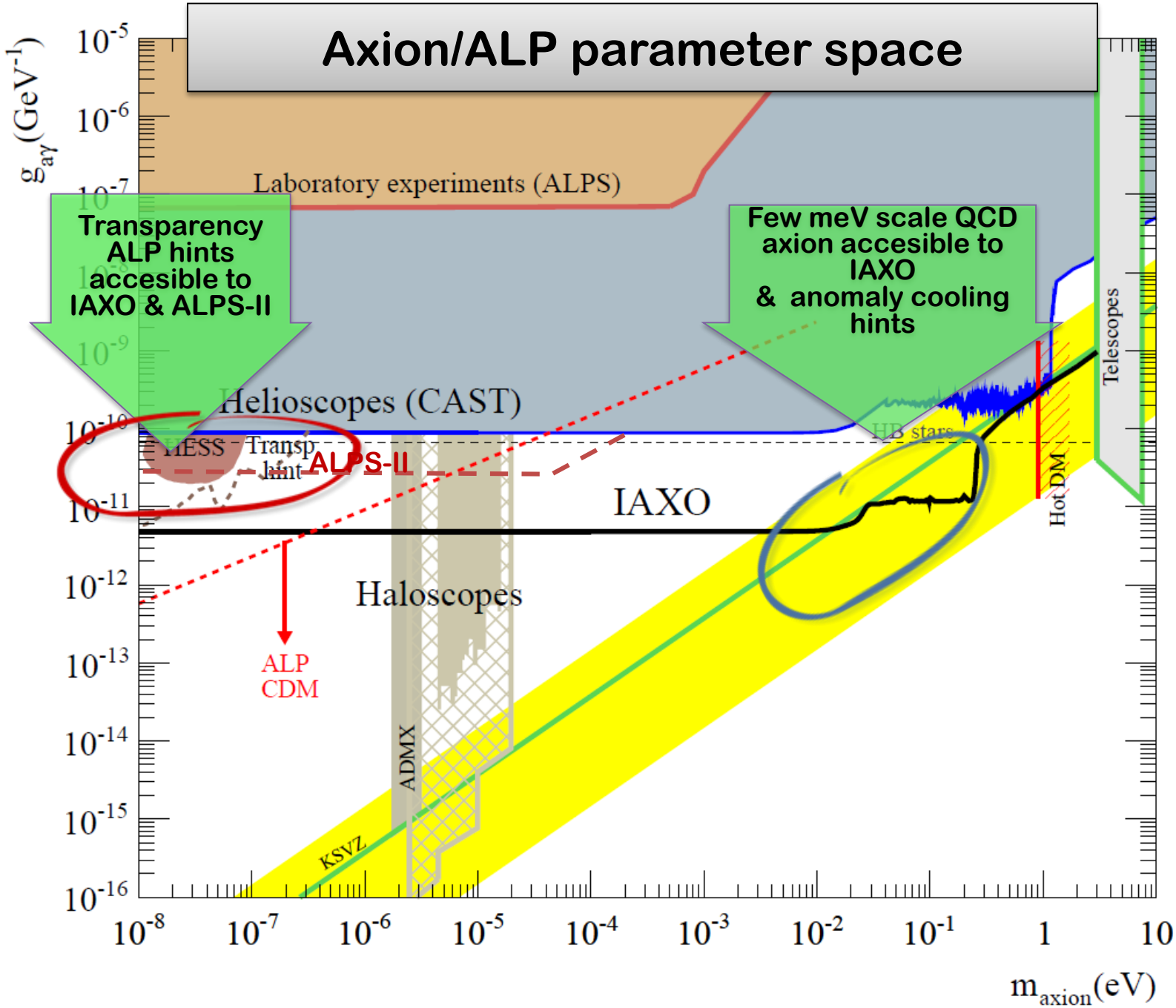




Low noise **CCDs**

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}
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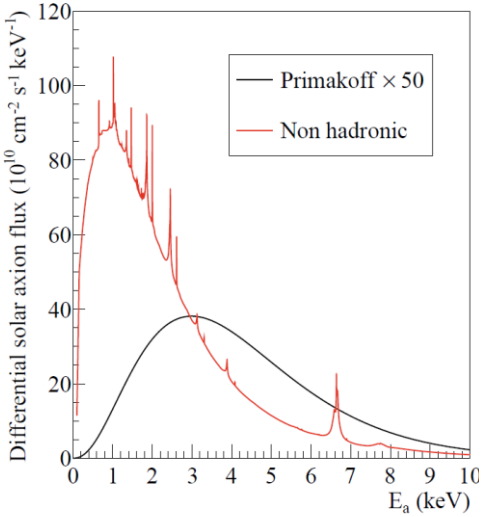
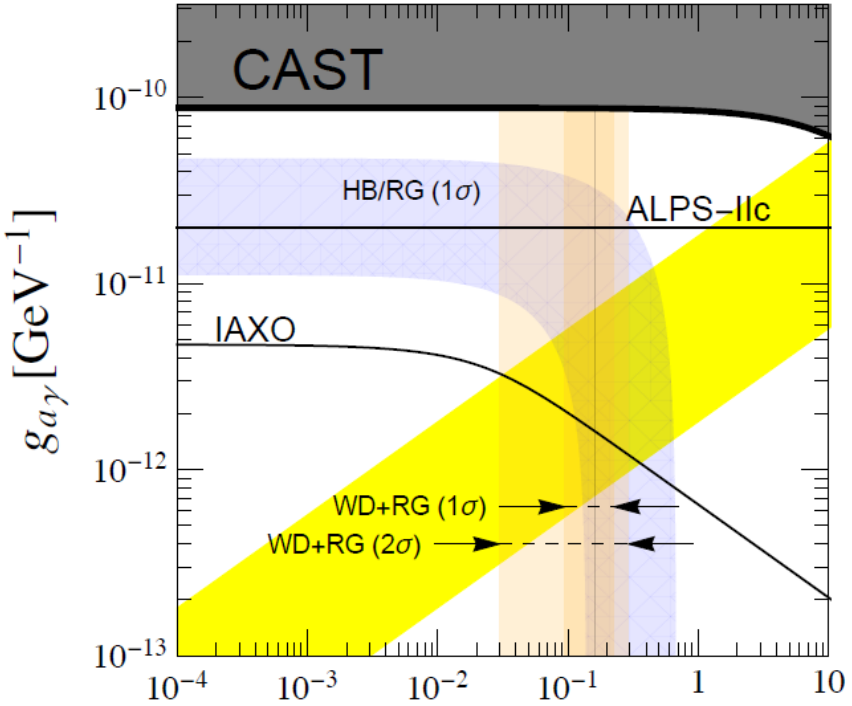
1
10

Axion-electron coupling

ABC-produced solar axions





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

ALSO…

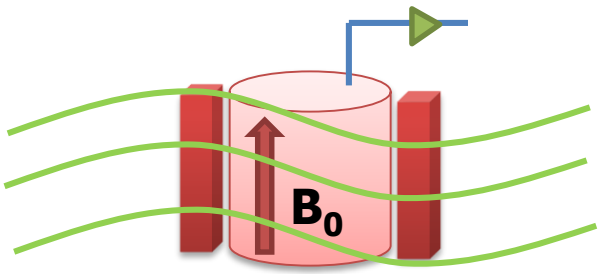
- **Dark Matter Axions (→ use of IAXO magnet with cavities / RF antennas)**
- **ALPs from Dark Radiation**
- **ALPs from nearby Supernova (connection with SNEWS) → MeV photon detector at the other end**
- **…**

α_{26}

Talk J. Carmona

Dark Matter with IAXO

- Motivation to perform “ADMX-like” searches in other mass ranges.
- 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 (ADMX-like but larger)
  2. Thin long cavities tuned to mid-high masses. Possibility for directionality. Add several coherently? (RADES?)
  3. Dish antenna focusing photons to the center. Broadband(?) search. Competitive at higher masses? (MADMAX like?)
  4. “DM-radio” idea?
- Initial stages of exploring and developing concepts.



Talk
J. Redondo

Talk
A. Alvarez &
A. Lozano

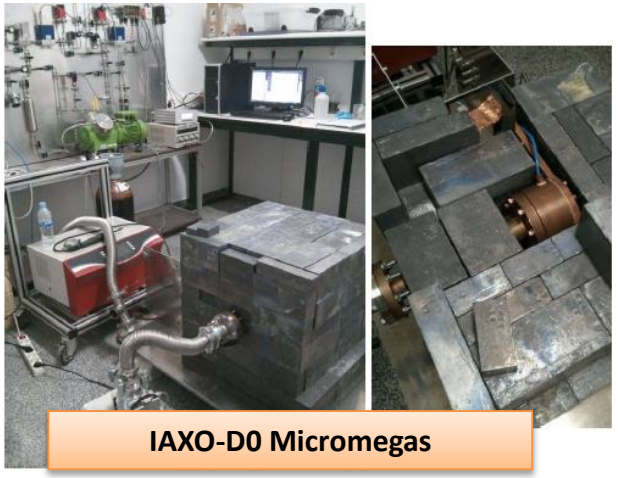
IAXO status of project

- **2011: First feasibility 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.**
  - **Acknowledge physics case + encourage proceed to TDR**

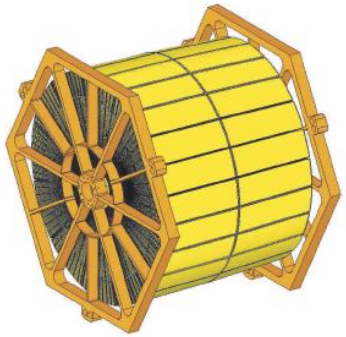
- **2014-15: Transition phase towards TDR (technical design)**
  - **Some IAXO preparatory activity already going on as part of CAST near term program: IAXO pathfinder system in CAST in 2014-15**
  - **Preparation of a MoU to carry out TDR work + formal establishment of collaboration**
  - **Strengthen 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

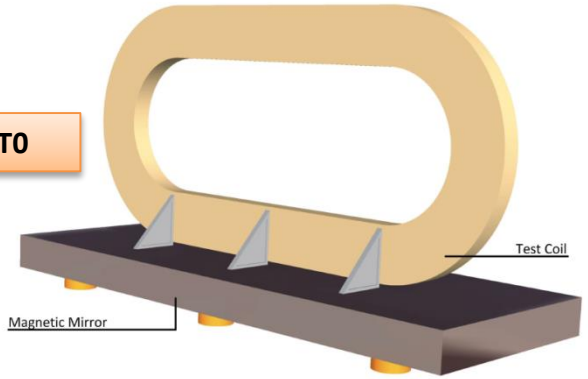


IAXO-D0 Micromegas



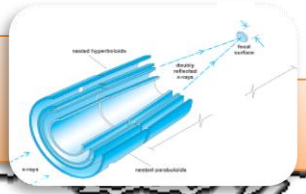
IAXO-X0

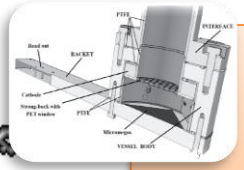
IAXO-T0

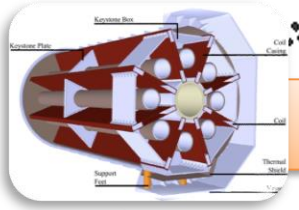


IAXO proto-collaboration

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







LLNL
Columbia
MIT

INAF-Milano (Italy)
DTU (Denmark)

Zaragoza (Spain)
CEA-Saclay (France)
Mainz (Germany)
Bonn (Germany)
Heidelberg (Germany)
INR-Moscow (Russia)

U. Barry
S. Carolina
+ …

CERN
CEA/Saclay (France)

RBI (Croatia)
DESY (Germany)
U. Hamburg (Germany)
U.Valencia (Spain)
U. Cartagena (Spain)
INFN-Frascati, (Italy)

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**