Status and perspectives of the CAST experiment

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for the

CAST Collaboration

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CAST: CERN Axion Solar Telescope

Outline:

- Axions
- The CAST experiment
  - Physics
  - Magnet, detectors
  - Results and prospects

Axions

Axion: pseudoscalar, neutral, practically stable, candidate for dark matter

The strong CP problem:

$$\mathcal{L}_{\mathrm{strongCP}} = \bar{\theta}\frac{\alpha_s}{8\pi} G_a^{\mu\nu}\tilde{G}_{a\mu\nu}$$

$$\bar{\theta} = \theta + \mathrm{Arg}\det M$$

(QCD vacuum + EW quark mixing)

⇩

- experimental bound on the neutron electric dipole moment requires $\bar{\theta} \le 10^{-9}$

Peccei-Quinn solution:

- new global chiral $U(1)_{PQ}$ symmetry spontaneously broken at scale f_a
- associated pseudo Nambu-Goldstone boson: axion !

$$\mathcal{L}_a = \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{\alpha_s}{8\pi f_a} a G_a^{\mu\nu}\tilde{G}_{a\mu\nu}$$

$\Rightarrow$ $\bar{\theta}$ absorbed in the definition of a

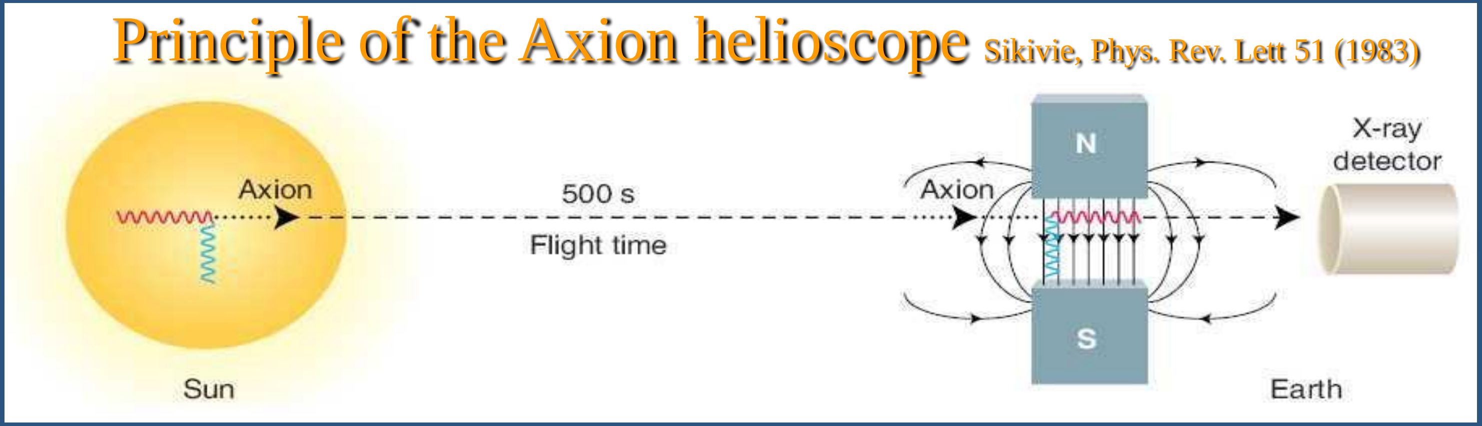
axion mass:

$$m_a = 6\,\mathrm{eV}\frac{10^6\,\mathrm{GeV}}{f_a}$$

axion-photon coupling:

$$g_{a\gamma} = \frac{\alpha}{2\pi f_a}\left[\frac{E}{N} - 1.92 \pm 0.08\right]$$

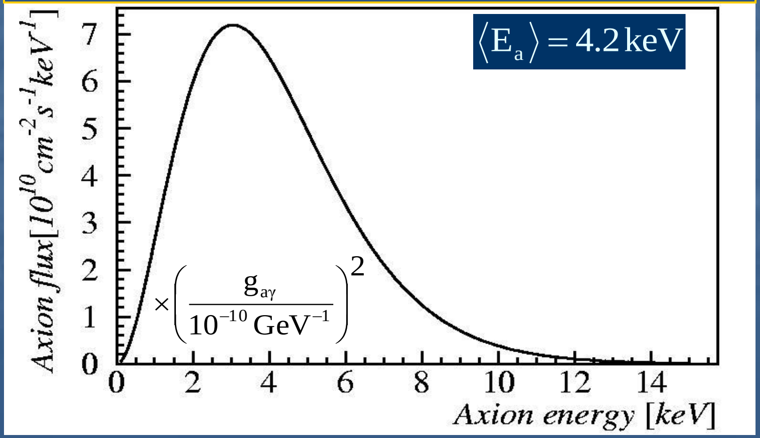
CAST: Physics



Sun: a thermal photon converts into an axion via Primakoff process in the solar plasma

Earth: an axion converts into a photon in a strong transverse magnetic field

- differential axion flux at the Earth:



-expected number of photons

$$N_\gamma = \int \frac{d\Phi_a}{dE_a} P_{a\rightarrow\gamma} S\, t\, dE_a$$

CAST: Physics

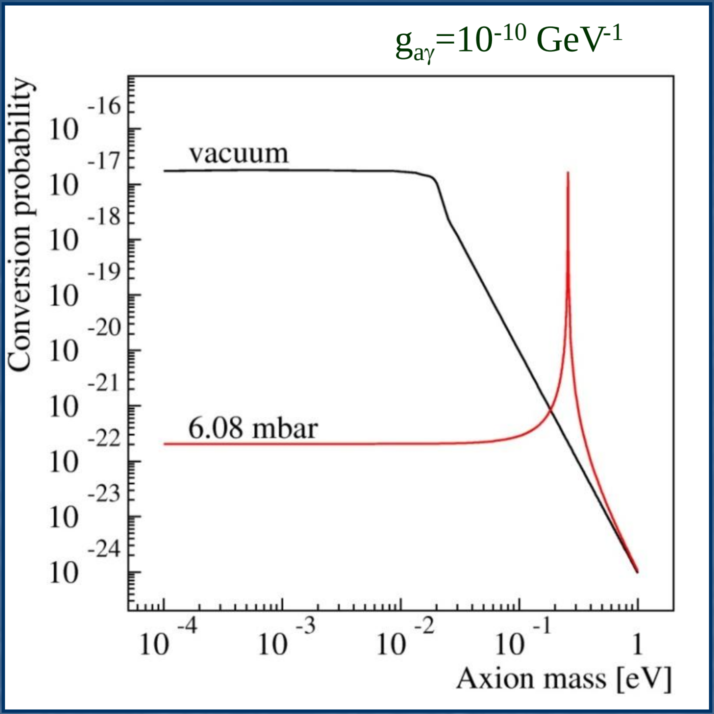
- conversion probability in gas (in vacuum: $\Gamma = 0$, $m_\gamma = 0$):

$$P_{a\to\gamma} = \left(\frac{B g_{a\gamma}}{2}\right)^2 \frac{1}{q^2 + \Gamma^2/4}\left[1 + e^{-\Gamma L} - 2e^{-\Gamma L/2}\cos(qL)\right]$$

L=magnet length, Γ=absorption coeff.

$$q = \left|\frac{m_\gamma^2 - m_a^2}{2E_a}\right|$$ axion-photon momentum transfer

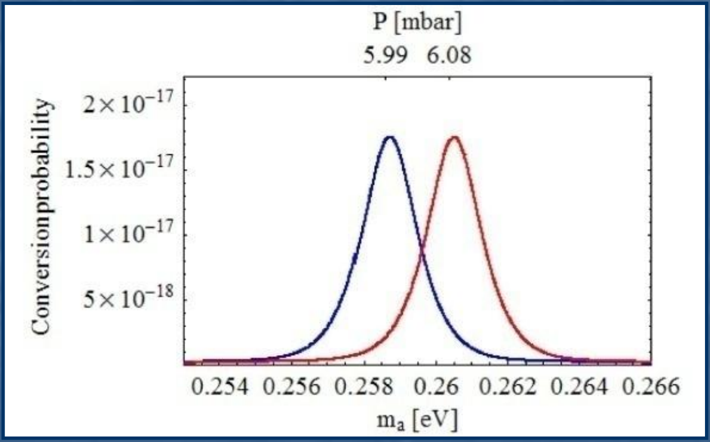
$$m_\gamma(\mathrm{eV}) \approx \sqrt{0.02\,\frac{P(\mathrm{mbar})}{T(\mathrm{K})}}$$ effective photon mass (T=1.8 K)



- coherence condition for $a \to \gamma$ conversion

$$qL < \pi \quad \Rightarrow \quad \sqrt{m_\gamma^2 - \frac{2\pi E_a}{L}} < m_a < \sqrt{m_\gamma^2 + \frac{2\pi E_a}{L}}$$

In case of vacuum, coherence is lost for $m_a > 0.02$ eV. It can be restored with the presence of a buffer gas, but only for a narrow mass range.



CAST: Physics

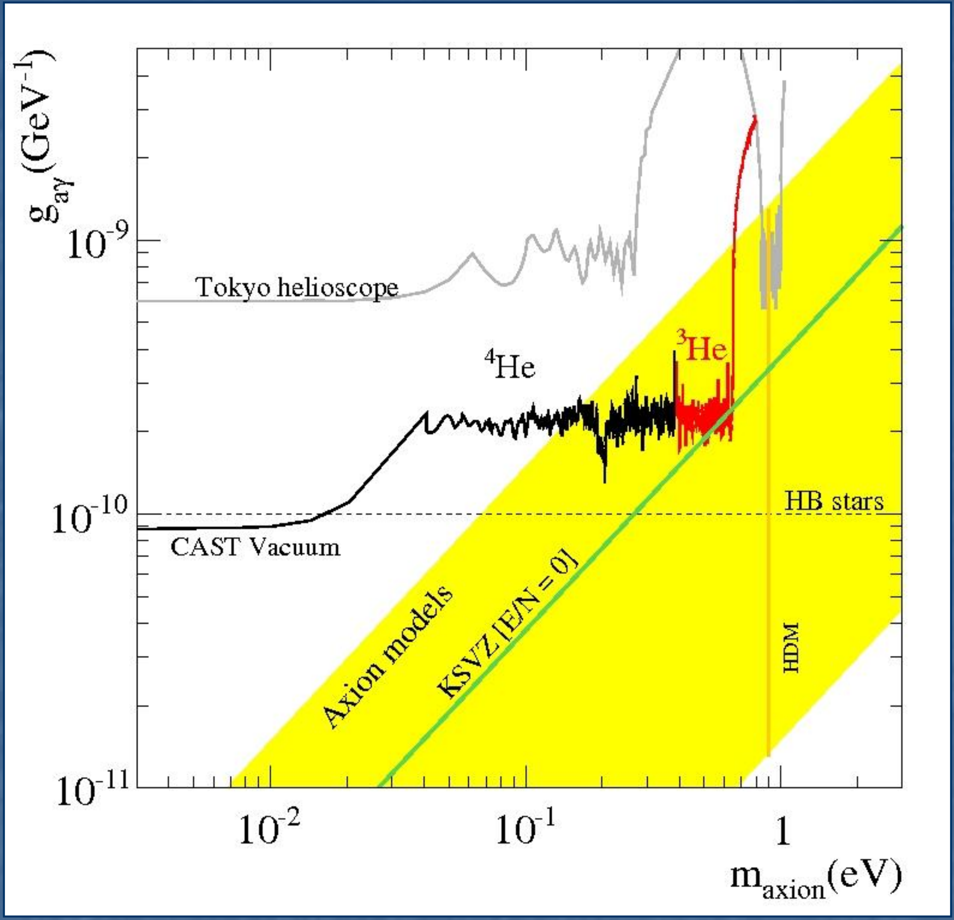
CAST program and main results:

Phase I

- Vacuum in the magnet bores: $m_a < 2.3\times10^{-2}$ eV (during 2003 and 2004)

Phase II

- ^{4}He run: 0.02 eV < m_a < 0.39 eV (during 2005 and 2006)
- ^{3}He run: 0.39 eV < m_a < 1.17 eV (2008 – 2011)
- ^{4}He run: 0.39 eV < m_a < 0.42 eV (2012) → COMPLETED



CAST: Physics

CAST physics program and results:

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For $m_a < 0.02$ eV

$g_{a\gamma} < 0.88 \times 10^{-10}$ GeV^{-1}

Phys.Rev.Lett. 94 (2005) 121301

JCAP 0704 (2007) 010

For $m_a < 0.39$ eV typical upper limit

$g_{a\gamma} < 2.2 \times 10^{-10}$ GeV^{-1}

JCAP 0902 (2009) 008

For 0.39 eV $< m_a < 0.64$ eV typical limit

$g_{a\gamma} < 2.1 \times 10^{-10}$ GeV^{-1}

Phys.Rev.Lett. 107 (2011) 261302

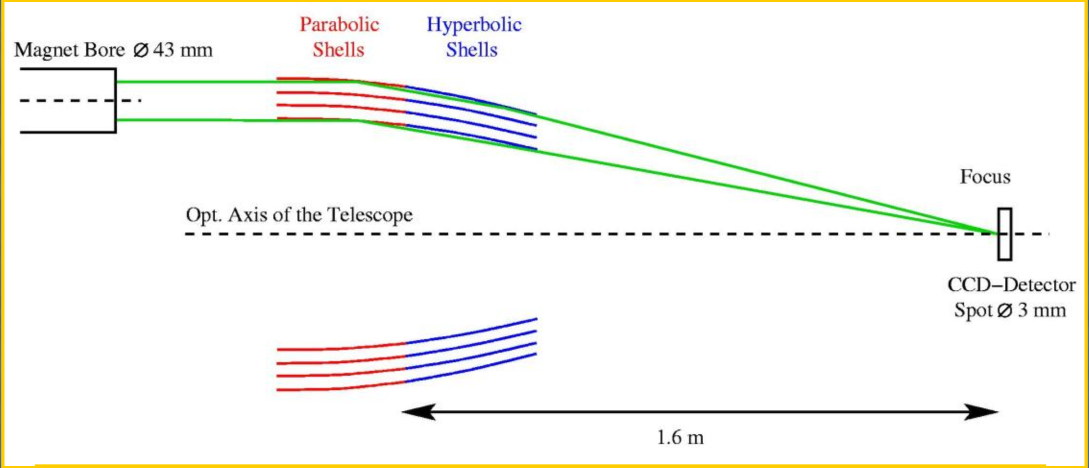
CAST: Setup

- LHC test magnet (B=9 T, L=9.26 m)
- Rotating platform (hor. ±40°, ver. ±8°)
- X-ray detectors
- X-ray Focusing Device

Exposure time:
2×1.5h per day

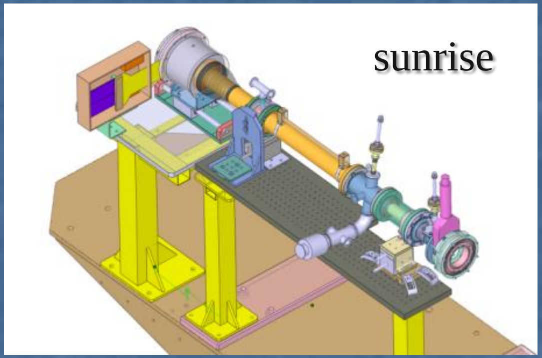
CAST: Detectors

- Sunrise side: X-ray telescope + CCD & shielded Microbulk Micromegas



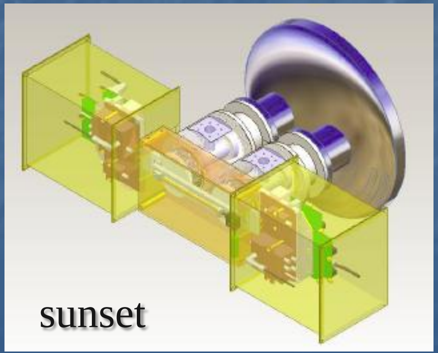
- from 43 mm Ø (LHC magnet aperture) to ~3 mm Ø
- signal-to-noise improvement (up to 200!)

Microbulk: new technique, high radio-purity materials, very low background



MM	~1 count/h (2-10 keV)
CCD	0.2 count/h (1-7 keV)

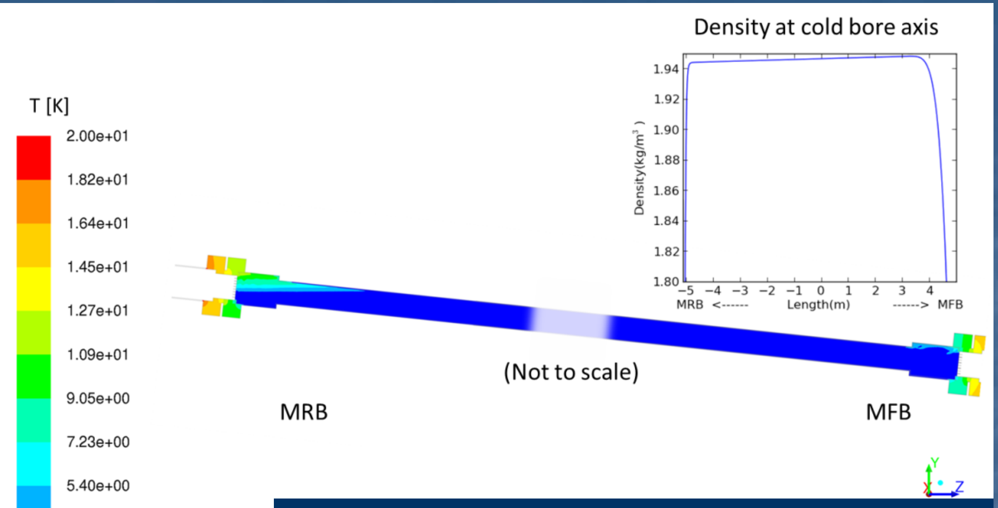
- Sunset side: 2 shielded Microbulk Micromegas



5th line for low energy axions (BaRBE): aluminized Mylar foil (transparent to X-rays) on the sunrise MM line to deflect visible photons on an angle of 90°, towards the PMT

CAST: CFD simulations

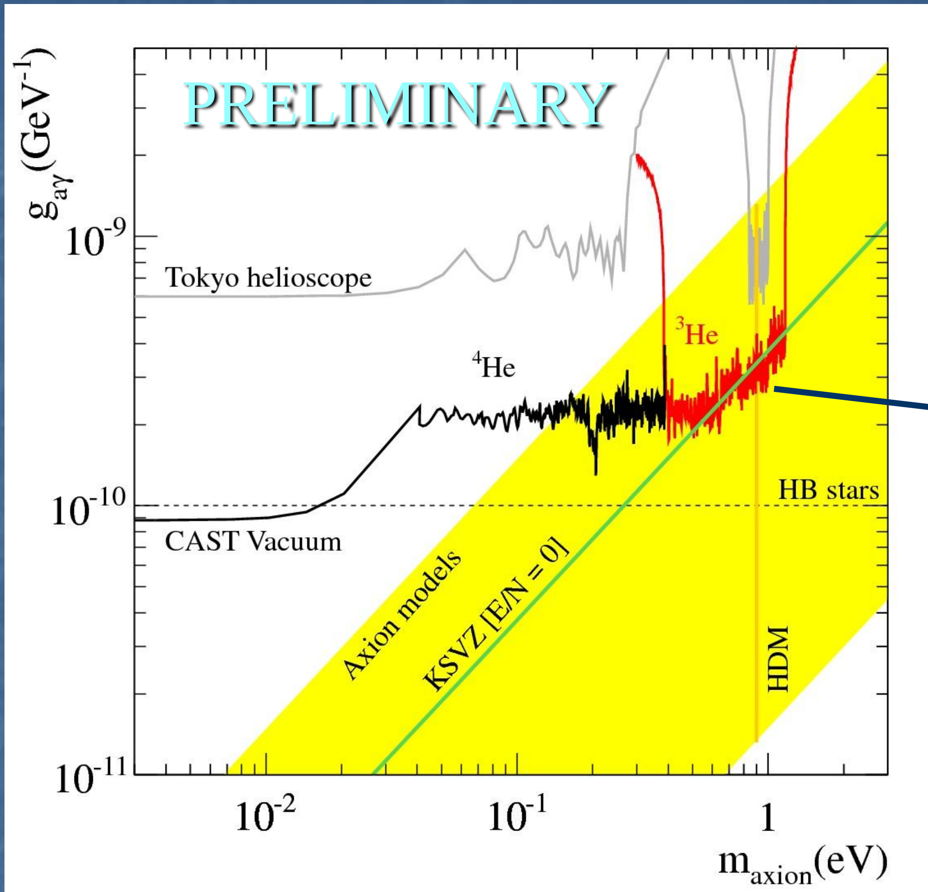
- Precise knowledge and reproducibility of each pressure setting is essential
- Density profile (needed for data analysis) can not be measured directly

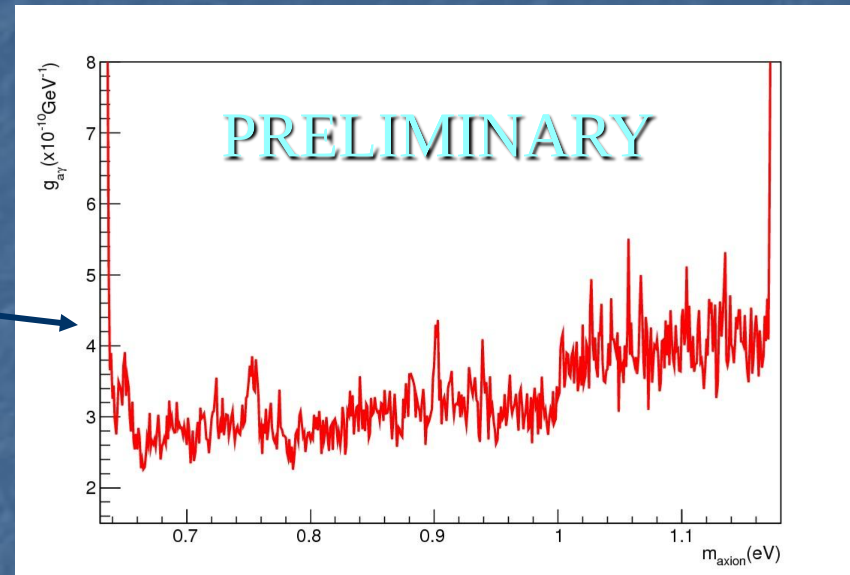


Temperature and density distribution along the magnet for 83 mbar of ^3He and tilt of +6°

- Computational Fluid Dynamics (CFD) simulations are required to describe the complex gas dynamics
- Experimental pressure variation on tilting is a key indicator which the CFD simulations must reproduce. Complex model created:
  - Couples a turbulent solution in one part of a bore with a laminar solution in the other part
  - Predicted pressure variations are in satisfactory agreement with experimentally measured when tilting

CAST: Final ³He data analysis





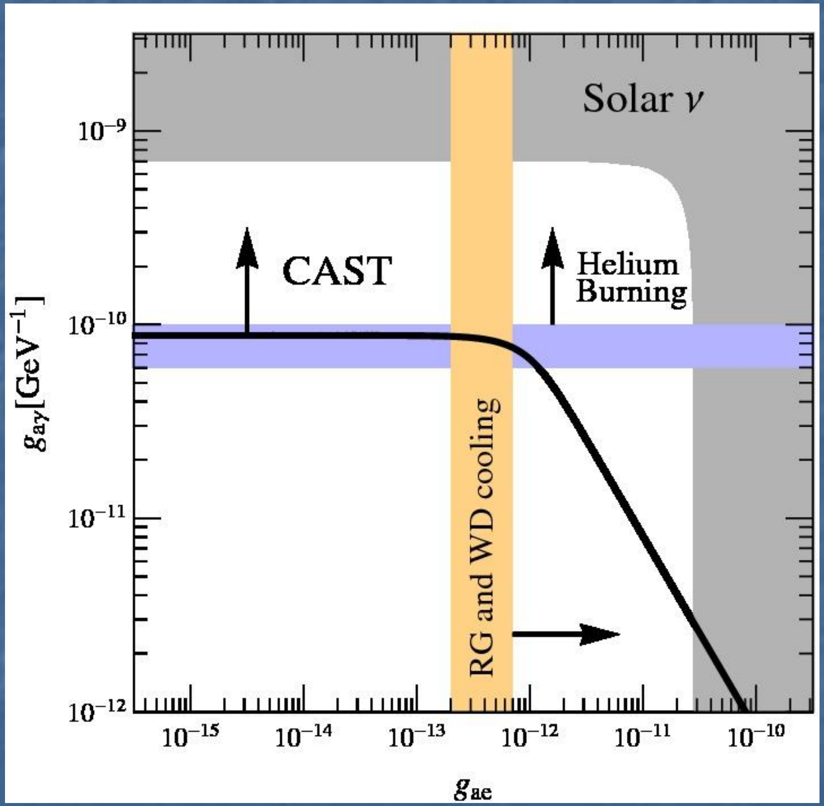
- data taken by 3 MM detectors have been analysed for $0.64\ eV < m_a < 1.17\ eV$
- no signal over background observed → soon to be submitted for publication

CAST: Physics

CAST byproducts:

- High energy axions: data taking with a HE calorimeter (JCAP 1003 (2010) 032)
- 14.4 keV axions: vaccum phase TPC data (JCAP 0912 (2009) 002)
- Low energy (visible) axions: data taking with a PMT/APD (arXiv:0809.4581)
- New: CAST constraints on the axion – electron coupling (JCAP 1305 (2013) 010)
- In preparation: bounds on solar hidden photons → G. Cantatore's talk

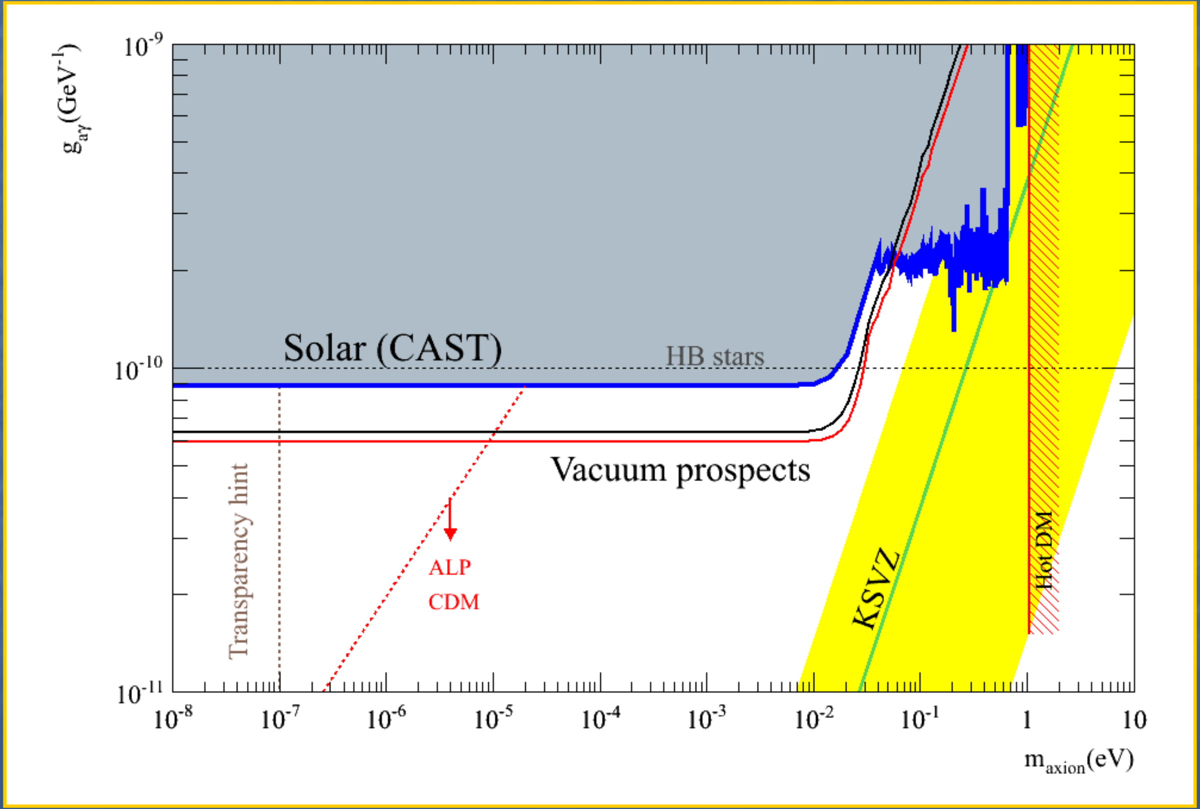
CAST constraints on g_{ae} and $g_{a\gamma}$ for $m_a < 10$ meV

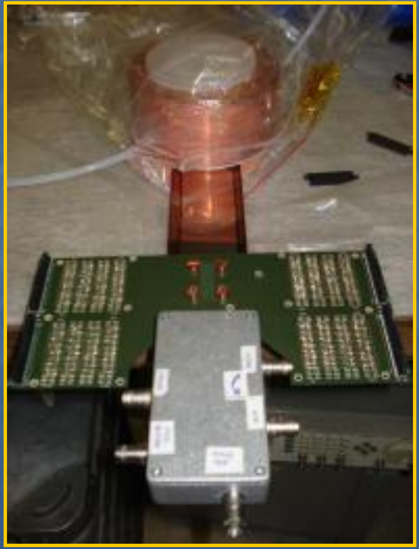


CAST plans 2013 - 2014

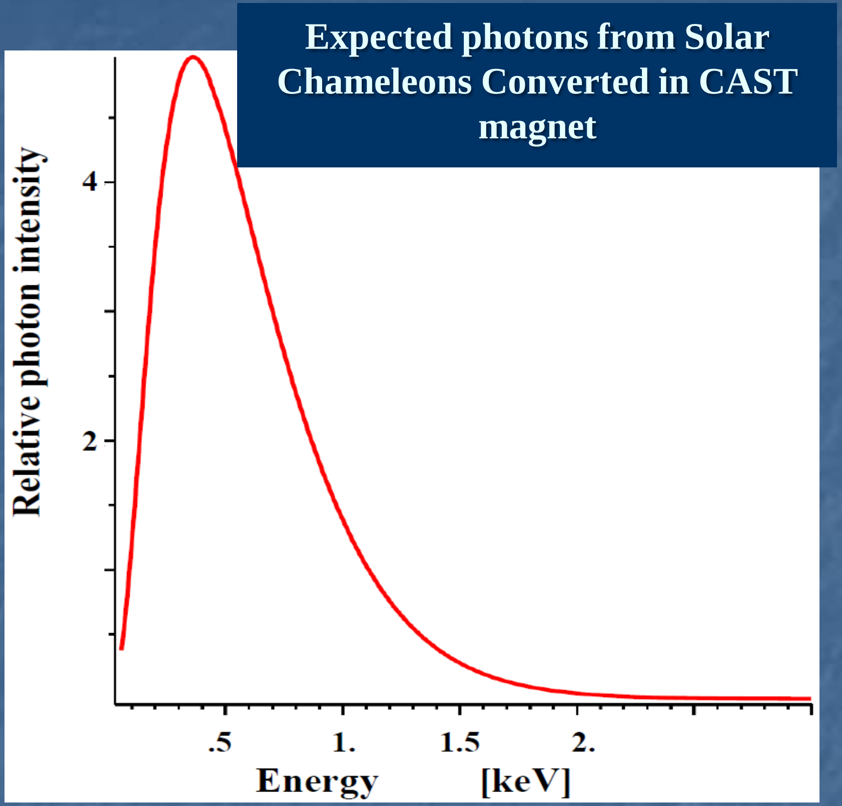
Improved vacuum phase to search for axion-like particles (ALPs)

- Why: ALPs appear in extensions of the standard model, in string theories, as dark matter candidates, as a possible solution to some unexplained astrophysical observations
- How: very-low background (~ 1×10^{-6} s^{-1} cm^{-2} keV^{-1}) Micromegas detectors & new X-ray optics for sunrise Micromegas





CAST plans 2013 - 2014



Other possibilities in vacuum:

- Search for chameleons, paraphotons, low energy axions
- Requirements:
  - Low background detectors
  - Low threshold detectors:
    - InGrid Micromegas detector (to replace CCD): a gas-amplification grid mounted on a pixel-readout chip
    - SDD (Silicon Drift Detector)

Conclusions

- CAST provides the best experimental limit on axion-photon coupling constant over a broad range of axion masses.
- After completing the original program, CAST is looking to improve the vacuuum results, and study other exotica.
- CAST Collaboration has gained a lot of experience in axion helioscope searches.
- Future helioscope experiments (IAXO) and Microwave cavity searches (ADMX) could cover a big part of QCD axion model region in the next decade.