CAST

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on behalf of the CAST Collaboration

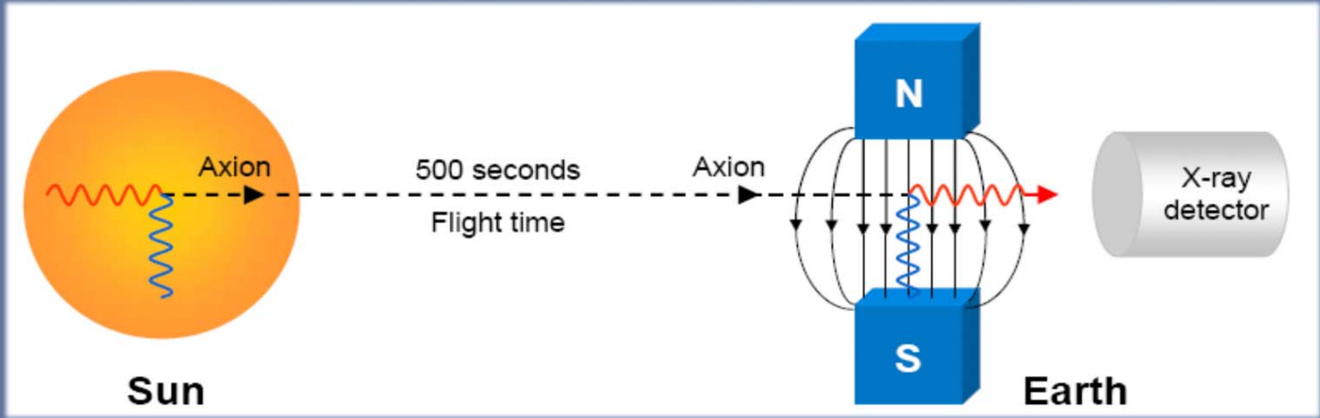
7th Axion Workshop ,26 June-01 July 2011, Mykonos

Outline

CAST Physics
The experiment
Latest results
The future: immediate and long-term
Conclusions

CERN Axion Solar Telescope:
QCD Axions or Axion Like Particles (ALPs)

CAST Physics

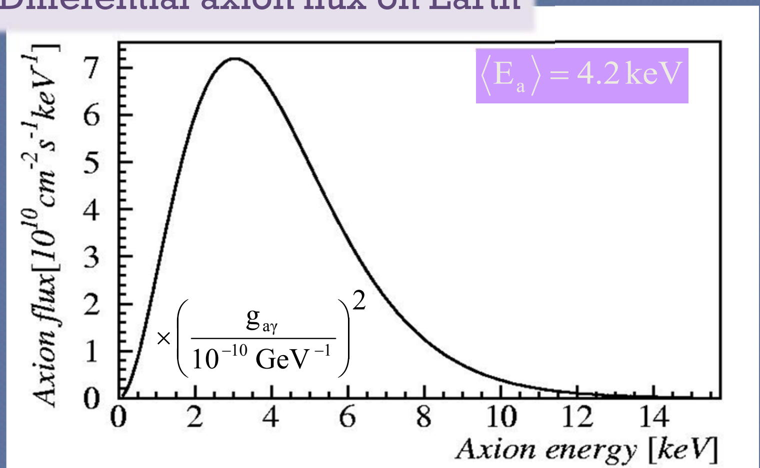


Signal: excess of x-rays during alignment over background

Production: Primakoff effect
Thermal photons interacting with solar nuclei produce Axions.

Detection (Sikivie 1983) Inverse Primakoff: axion interacting with a very strong magnetic field converts to a photon

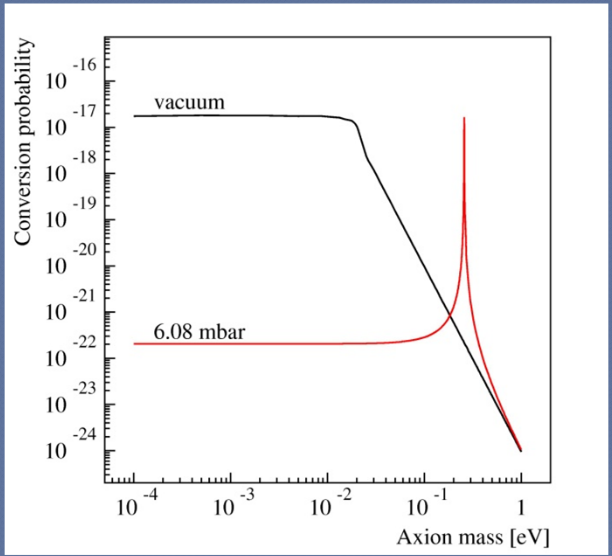
Differential axion flux on Earth



Expected number of Photons:

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

CAST Physics



Conversion Probability in gas

(In vacuum $m_\gamma = 0, \Gamma=0$)

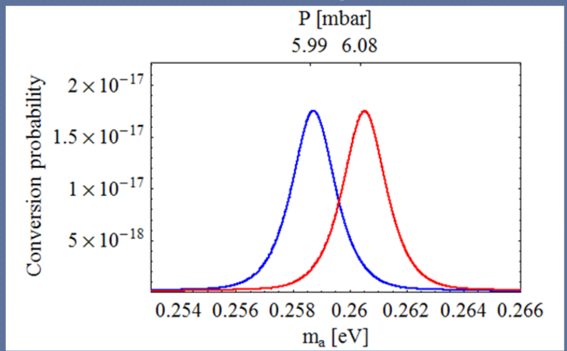
$$P_{a\to\gamma} = \left(\frac{Bg_{a\gamma}}{2}\right)^2 \frac{1}{q^2+\Gamma^2/4}\left[1+e^{-\Gamma L/2}-2e^{-\Gamma L/2}\cos(qL)\right]$$

L= magnet length, Γ =absorption coefficient

In CAST phase I (vacuum), coherence was lost for $m_a > 0.02$ eV.
With the presence of a buffer gas it can be restored for a narrow mass range:

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

Two consecutive gas injections



where

$$m_\gamma(eV) = \sqrt{\frac{4\pi\alpha N_e}{m_e}} \approx 28.9\sqrt{\frac{Z}{A}\rho} \approx \sqrt{0.02\cdot\frac{P(mbar)}{T(K)}}$$

CAST

- Decommissioned prototype LHC dipole magnet.
- Magnetic field: **B=9 T**
- Length: **L=9.26 m**

- Rotating platform
- (Vertical: ±8°, Horizontal: ±40°)

2x90 min solar tracking/day

Sunrise: X-ray Focusing Device coupled to a CCD + 1 Micromegas

Sunset: 2 Micromegas

CAST Physics Program

✓CAST Phase I, Vacuum

- m_a<0.02eV
- **Completed, (2003-2004)**
- PRL94(2005)121301
- JCAP04(2007)020

✓CAST Phase II, ^{4}He

- P< 13.4mbar (1.8K), 160steps
- 0.02<m_a<0.39eV
- **Completed(2005-2006)**
- JCAP02(2009)008

✓CAST Phase II, ^{3}He

- P< 120 mbar (1.8K)
- 0.39<m_a<1.16eV
- Started in 2008
- **Will finish in 2011**

Publication submitted to PRL *Preprint:* 1106.3919

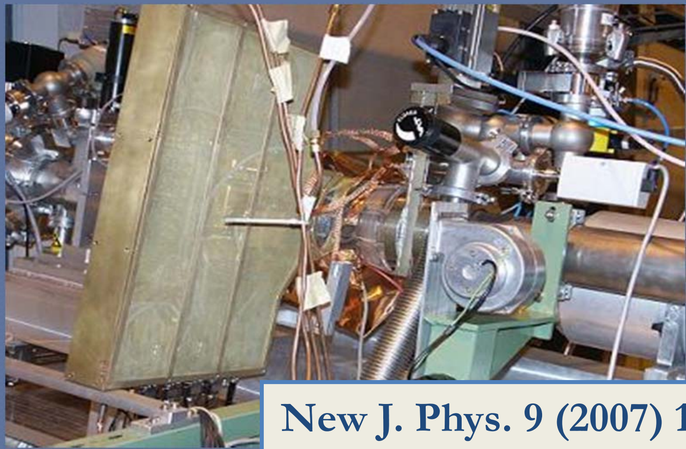
Parallel searches:

- High Energy Axions:
  Data taking with a HE calorimeter
  JCAP 1003:032,2010
- 14.4 keV Axions:
  TPC data
  JCAP 0912:002,2009
- Low Energy (visible) Axions:
  Data taking with a PMT/APD
  arXiv: 0809.4581

CAST detectors, Phase I & Phase II-^{4}He

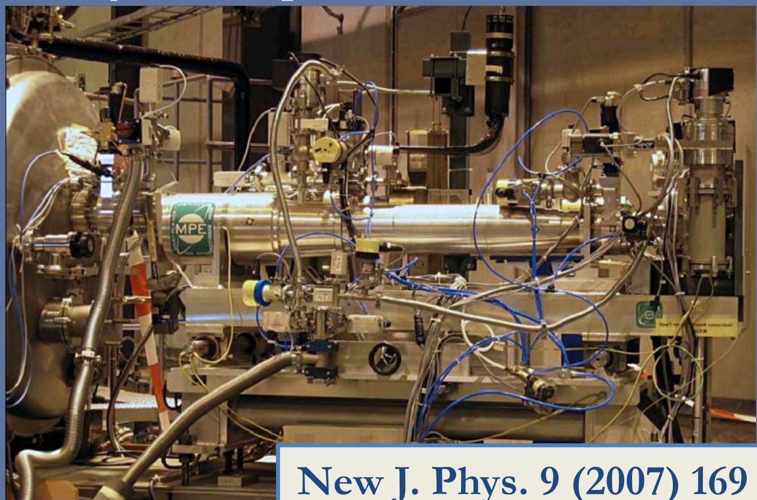
Sunrise detectors

unshielded MICROMEGAS



New J. Phys. 9 (2007) 170

X-ray telescope + CCD



New J. Phys. 9 (2007) 169

	Typical Rates
TPC	85 counts/h (2-12 keV)
MM	25 counts/h (2-10 keV)
CCD	0.18 counts/h (1-7 keV)

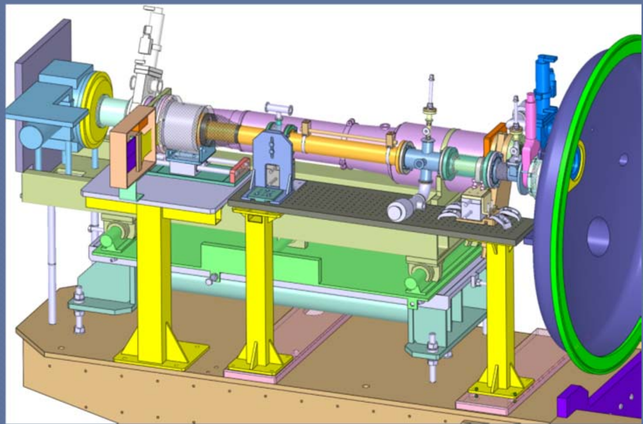
Sunset detector
(covering two bores)

TPC

New J. Phys. 9 (2007) 171

CAST detectors, Phase II-^{3}He

New generation Micromegas



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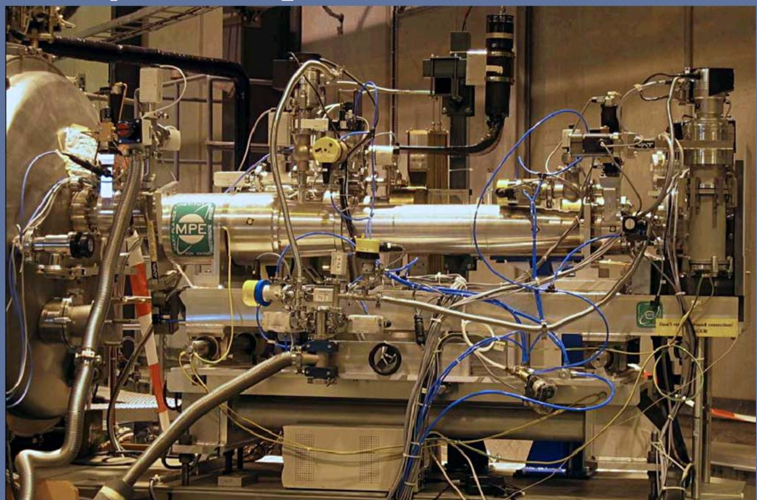
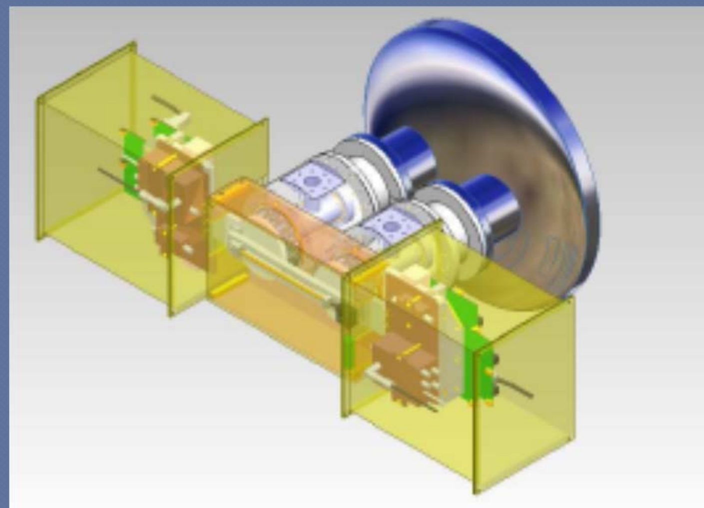


Sunrise detectors

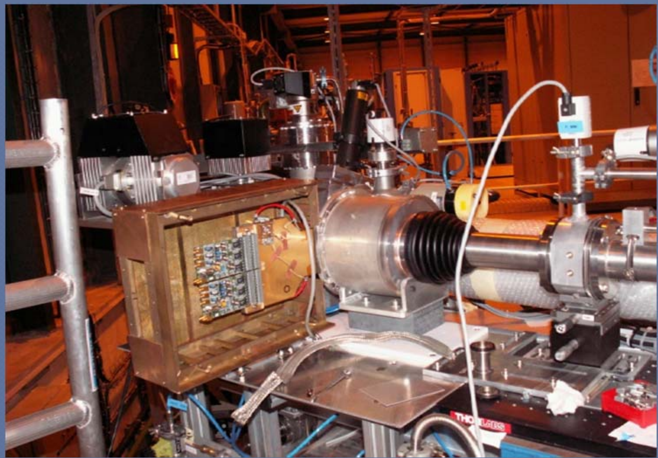
	Typical Rates
MM	3 cts/h (2-10 keV)
CCD	0.18 cts/h (1-7 keV)

Sunset detectors
(2 new Micromegas)

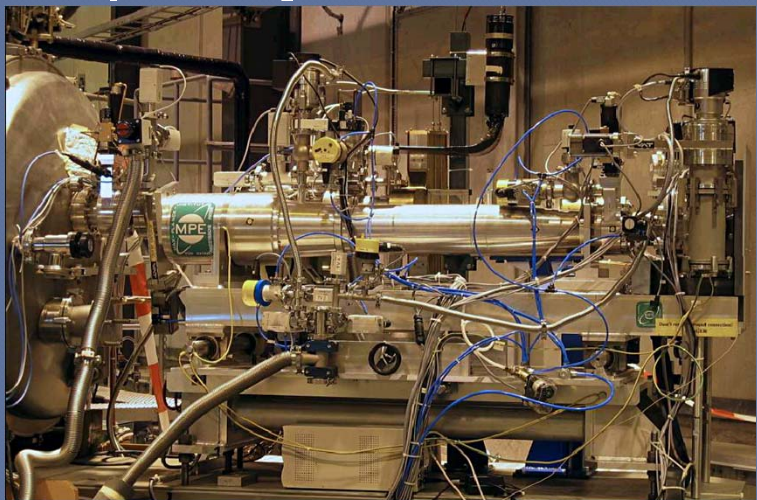


CAST detectors, Phase II-3He

New generation Micromegas



X-ray telescope + CCD



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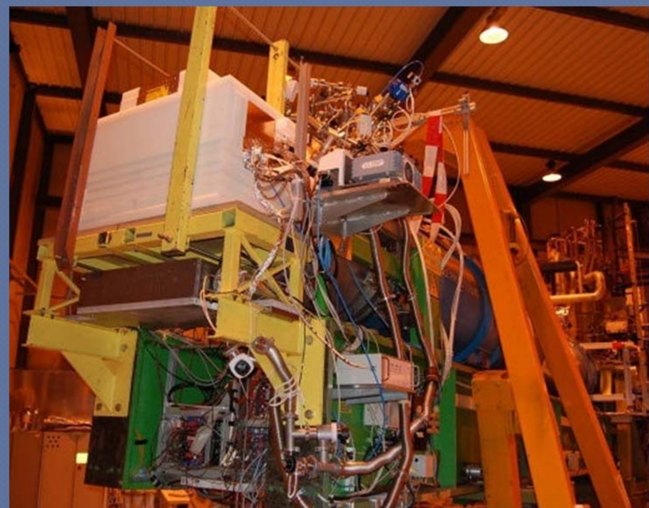


X-ray telescope + CCD system

X-ray focusing device

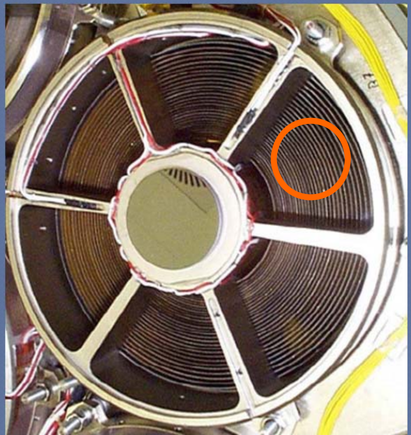
- Wolter-I-type telescope (Prototype of ABRIXAS mission)
- 27 nested, gold-coated mirror shells
- Only one sector of telescope illuminated at CAST

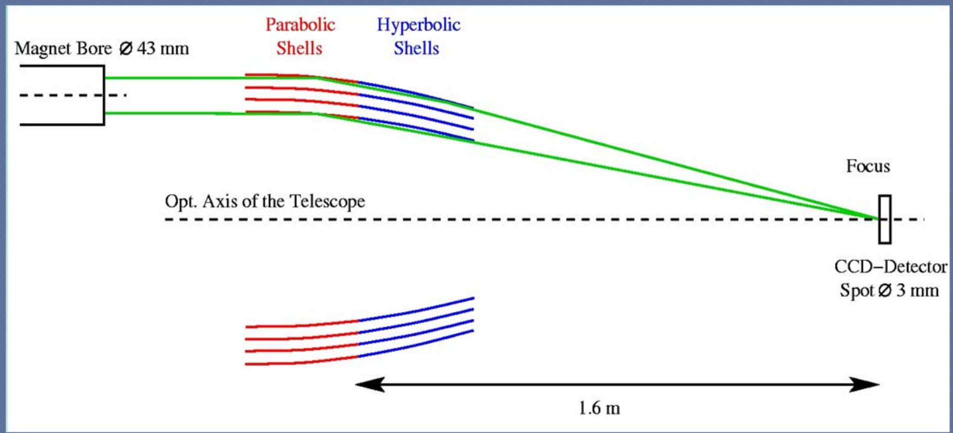
pn-CCD (Prototype of XMM-Newton mission)

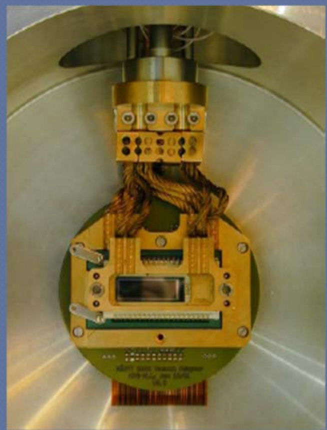
- Very good spatial and energy resolution
- Simultaneous measurement of signal and background

CCD detector

S/B improvement of ~150!

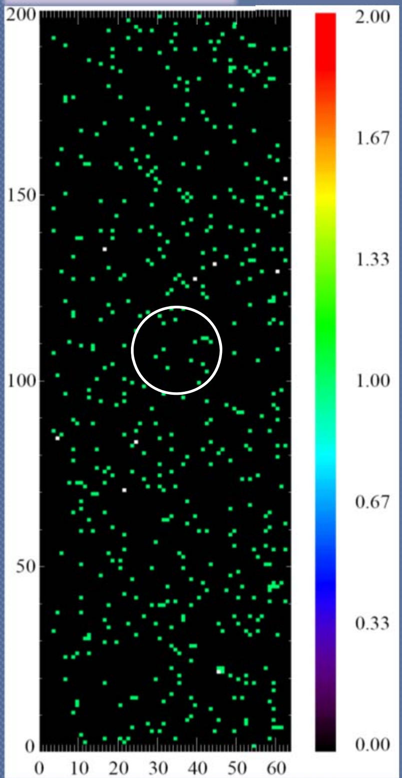




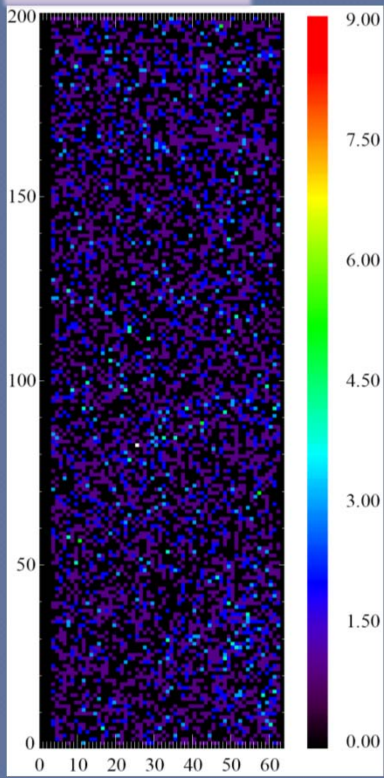


Telescope system

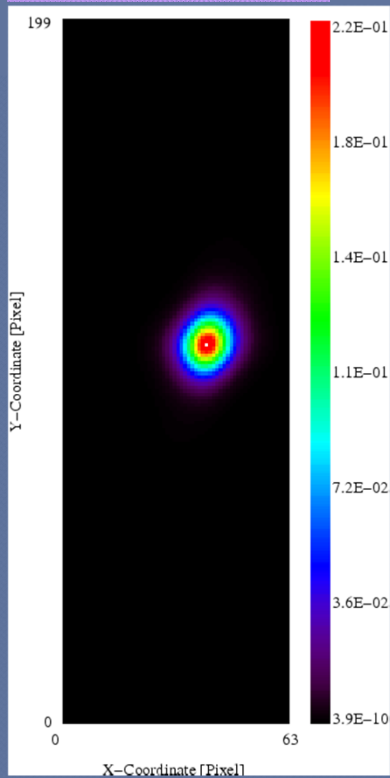
Tracking



Background



Signal simulation

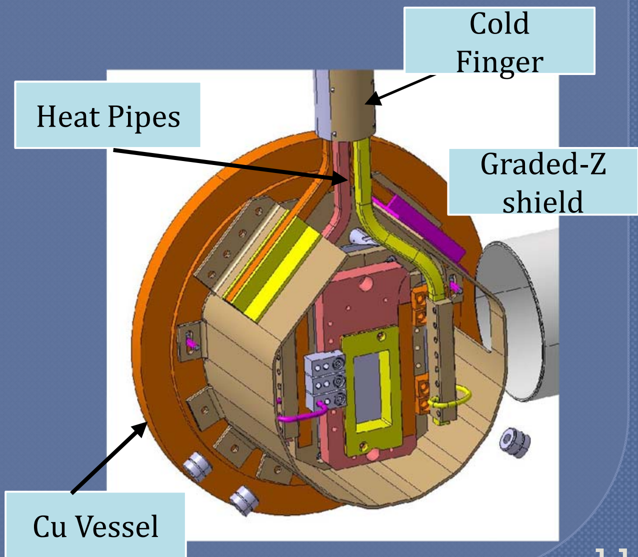


Spot position well determined
Full sensitivity of telescope exploited
Low Energy threshold (no window)

Typical new rate: ~0.25 c/h

Mean background rate (1-7keV)

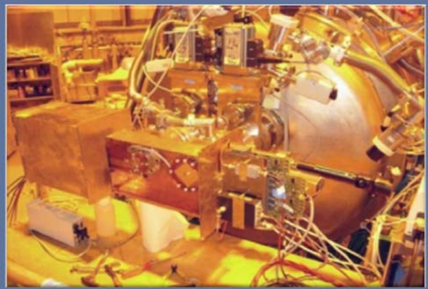
$\sim 8\text{x}10^{-5}$cts keV^{-1}cm^{-2}s^{-1}



understudy

- Lower background (better selection of materials)
- Lower threshold (~200 eV)
- Better E resolution (<160 eV (FWHM) @ 6 keV)
- State of the art technology

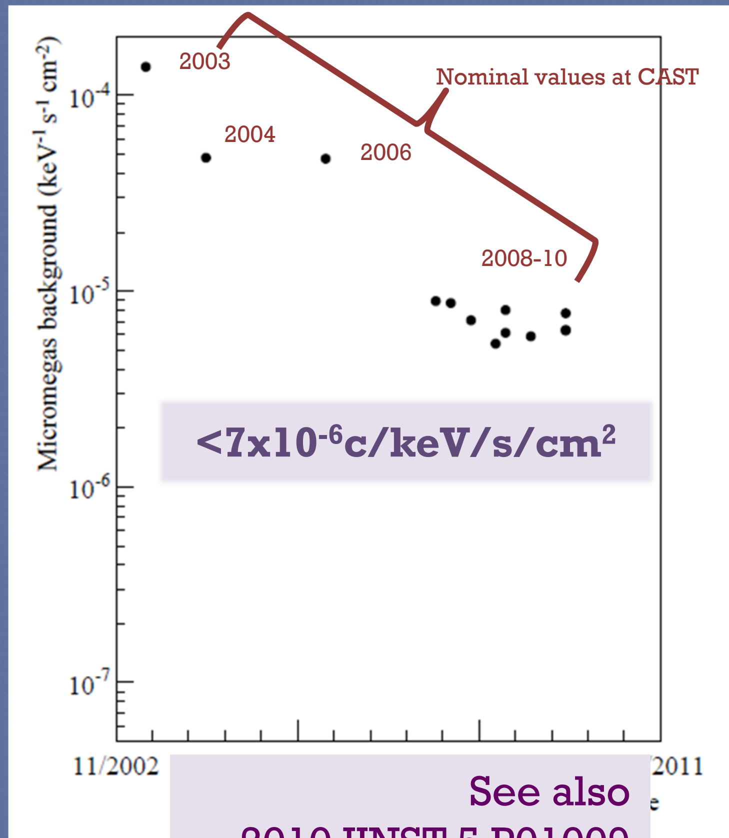
Microbulk Micromegas



Sunset:2 microbulks

Sunrise: 1 microbulk

Background Level history at CAST



See also
2010 JINST 5 P01009
2010 JINST 5 P02001

Low intrinsic radioactivity

- Light mass, clean materials

Signal topology, offline analysis

- 2D readout pattern, Time information

Shielding

- archeological lead, inner Cu, N_2 flushing.

potential for very-low background rates

Typical new rate: <2 c/h

Working with a buffer gas

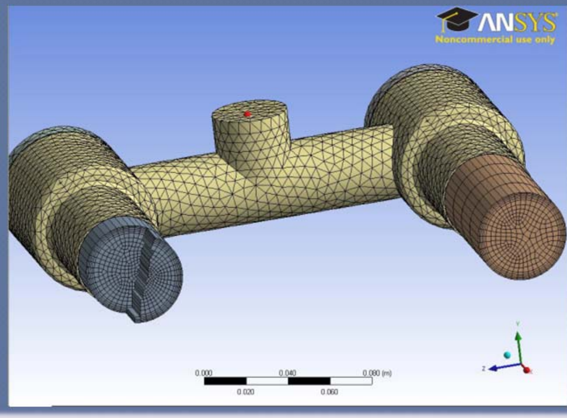
$$m_\gamma(eV) = \sqrt{\frac{4\pi\alpha N_e}{m_e}} \approx 28.9\sqrt{\frac{Z}{A}\rho} \approx \sqrt{0.02 \cdot \frac{P(mbar)}{T(K)}}$$

Precise knowledge and **reproducibility** of each pressure setting is essential
Gas **density homogeneity** along the magnet bore during tracking is critical
To face that situation we:

- Measure precisely the amount of **gas ejected** into the magnet!
- Several **temperature and pressure sensors** are placed in several points of the magnet and the gas system

Extensive simulations for a most detailed model of the system under the different configurations
•A series of Finite Element Analysis (ANSYS) with the sensors' data as bounding conditions was started (Static case, magnet movement)

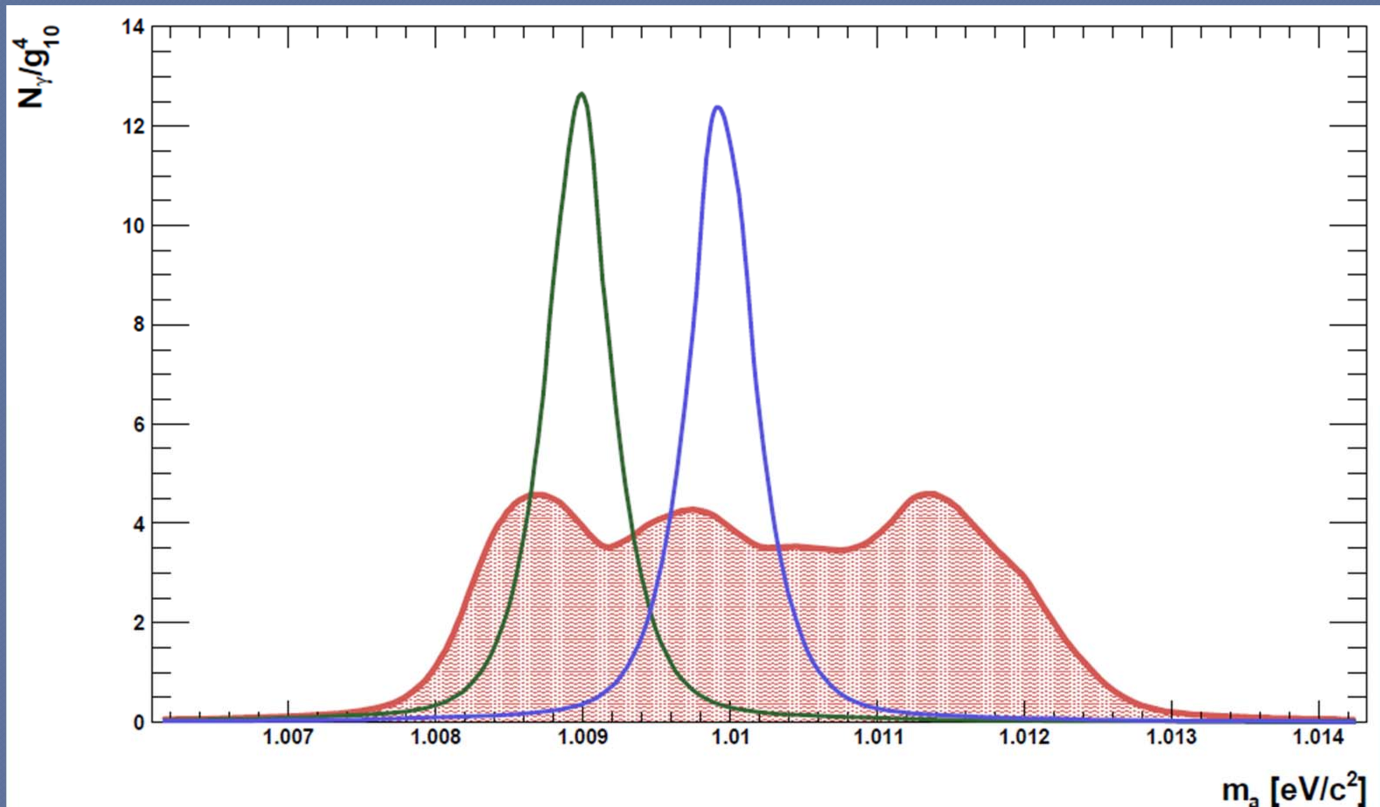
•An analytic calculation approach



Geometry parameterization

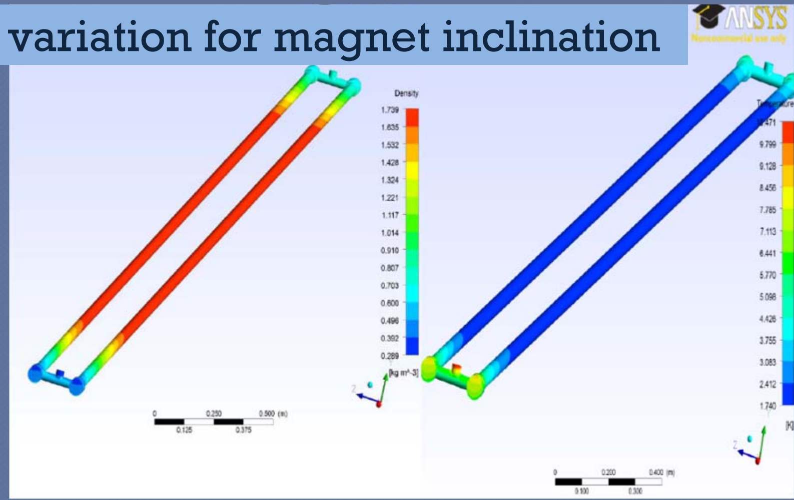
Understanding ^{3}He

What two consecutive steps-gas injections actually look like



Understanding ^{3}He

Density and temperature variation for magnet inclination

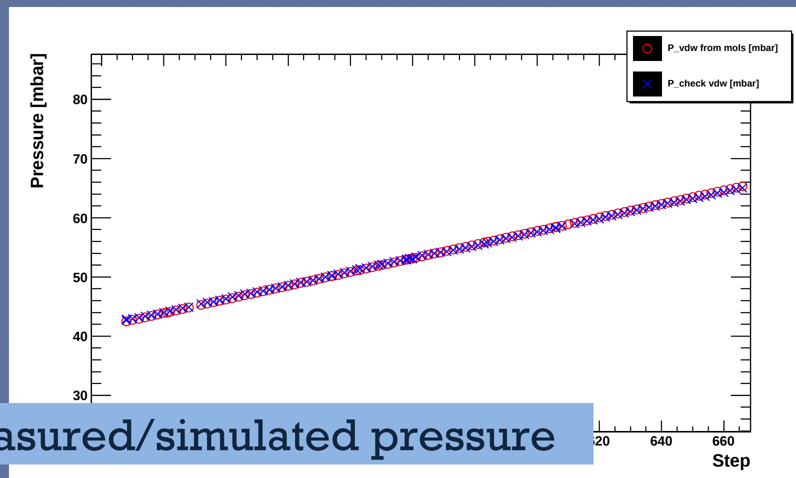


A key point : ^{3}He above some density is not an ideal gas (Van der Waals forces)

Knowledge of gas density / setting reproducibility possible

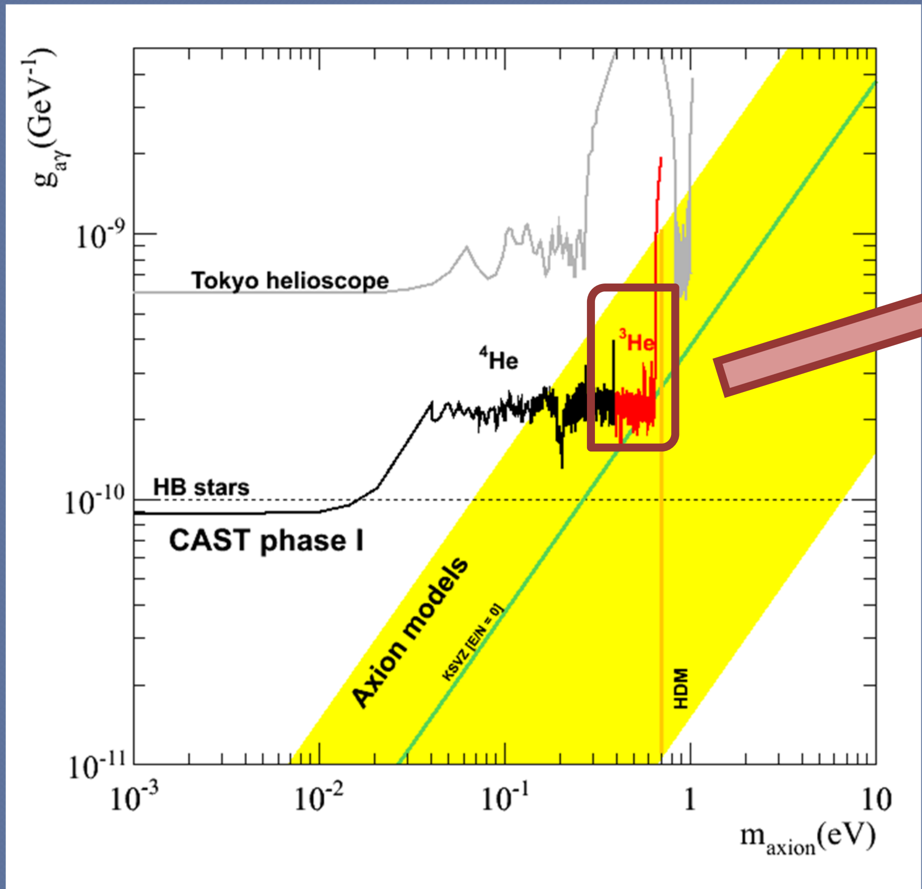
Variation During tracking, but

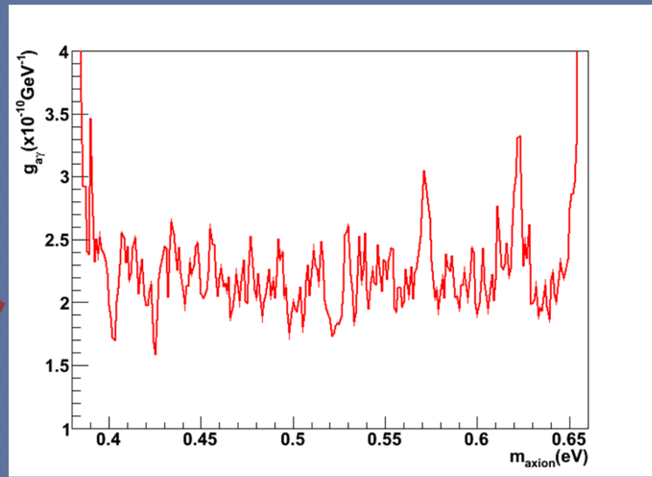
gas density still homogeneous



Agreement between measured/simulated pressure

Preliminary ^{3}He results





First results from the ^{3}He phase

Axion mass 0.39 – 0.65 eV excluded down to
~2-2.5 x 10^{-10} GeV^{-1}

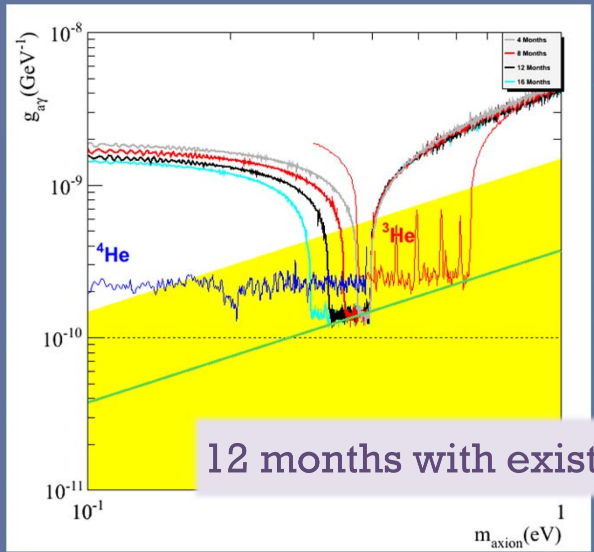
Publication submitted to PRL:
Preprint: 1106.3919

The immediate to mid-term future

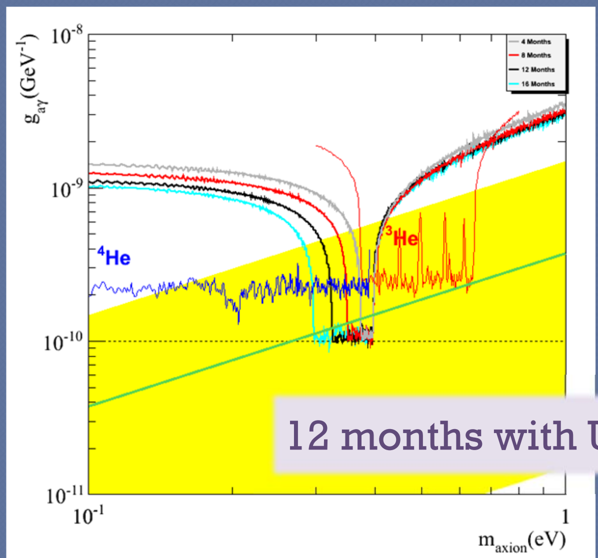
Re-visit ^{4}He and vacuum phases
Exotica:
- Paraphotons
- Chameleons

Detectors for Low energy axions
A possibility:
- Relic axions

Revisit ^{4}He phase



12 months with existing micromegas



12 months with ULB micromegas

CAST could revisit the ^{4}He masses in view of the 3 high performance detectors

Periods with very low background level ($\sim 2 \times 10^{-7}$ s^{-1} cm^{-2} keV^{-1}) : additional sensitivity

Possibility to probe the KSVZ line and below

Preparation of new detectors for a future experiment

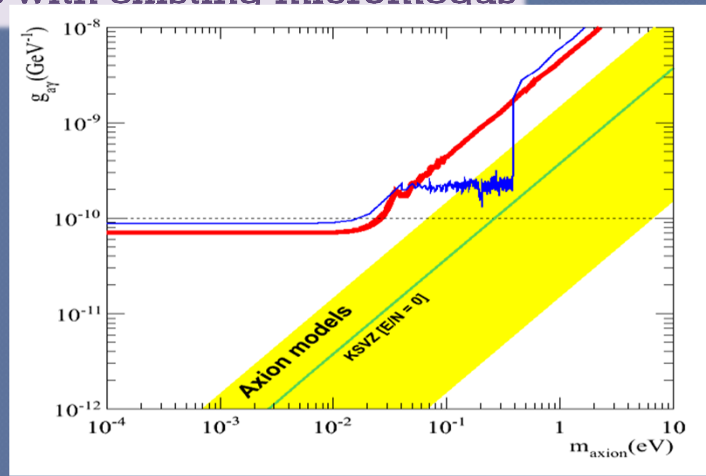
Revisit vacuum phase

CAST phase I limit determined by X-Ray telescope

Now, 3 high performance mibrobulk detectors

Modest improvement with normal background levels

12 months with existing micromegas



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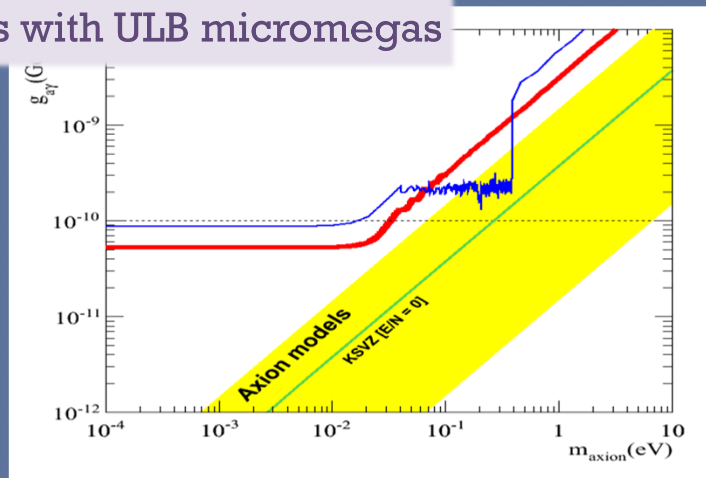


Periods with very low background level ($\sim 2 \times 10^{-7}$ s^{-1} cm^{-2} keV^{-1}) : additional sensitivity and therefore significant improvement

Preparation of new detectors for a future experiment

Other possibilities in vacuum…

More options

Paraphotons

`hidden sector' photons are thought to be massive, although very light in the sub-eV range, and able to kinetically mix with the standard photon:

oscillations between photon - hidden sector photon

Hidden photons produced in the Sun could be detected by the inverse conversion in a Helioscope like CAST.

No magnetic field needed. CAST in a vacuum phase, off-pointing…

Solar Chameleons

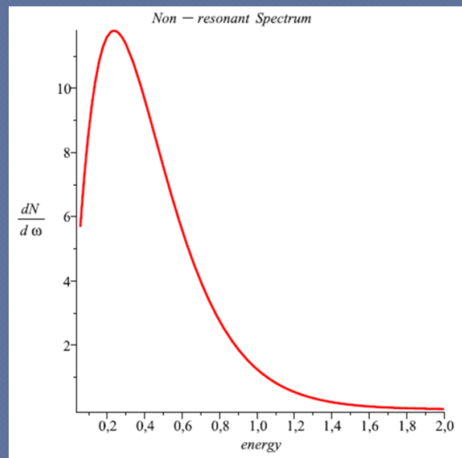
Chameleons are DE candidates:

could explain the acceleration of the Universe.

Created in a strong magnetic field via the Primakoff effect, e.g. in the Sun

Reconverted into x-rays inside the CAST magnet.

Spectrum peaks at much lower energies than axions.



Both require detectors with low background and low Energy Threshold

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Several talks tomorrow afternoon

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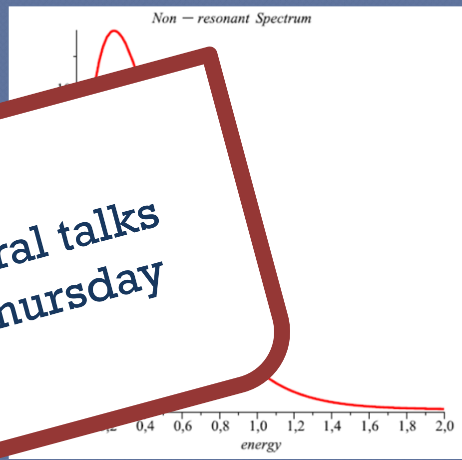


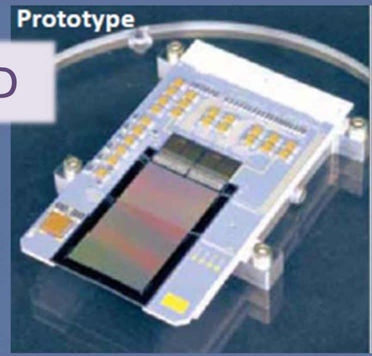
Several talks on thursday

Both require detectors with low background and low Energy Threshold

Detector Development

Detector background level plays an important role for the sensitivity reached.
For the parallel searches, Low Thresholds are another requirement.

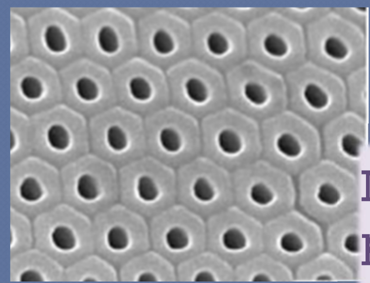
CAST groups in R&D towards such detectors:



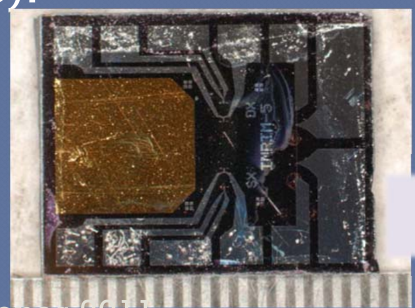
FS CCD

- Development of a Frame store CCD attached to the Telescope

- Studies with Microbulk micromegas :
  - Adjust operation parameters (gas, pressure)
  - Develop transparent windows

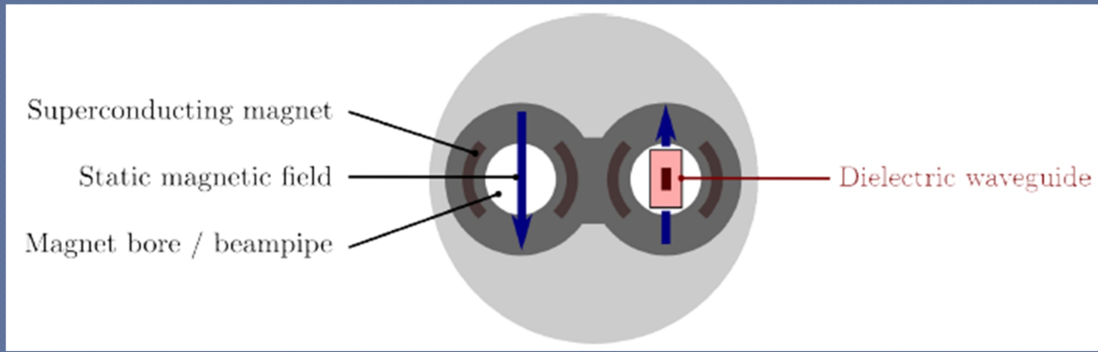

Nanotube porous membrane

- Studies with Transition Edge Sensors (TDS):
  - Very low background but
  - Very small area, cryogenic operation


TES array

Relic axions?

Insert a dielectric waveguide in 1 bore of CAST.
Could act like an 'antenna' where axions could be converted into microwave photons



Still a lot to determine, a feasibility study is underway

In the long-term: A New Generation of Axion Helioscopes

See talk by I. Irastorza tomorrow on the Next Generation Axion Helioscope

A new generation of helioscopes

CAST has gained valuable expertise on the helioscope technique along these years

Future improvement:

More flexible movement, new low background detectors, x-ray focusing devices, new, more powerful magnet.

Detectors
Very low bkg and/or
x-ray focusing optics

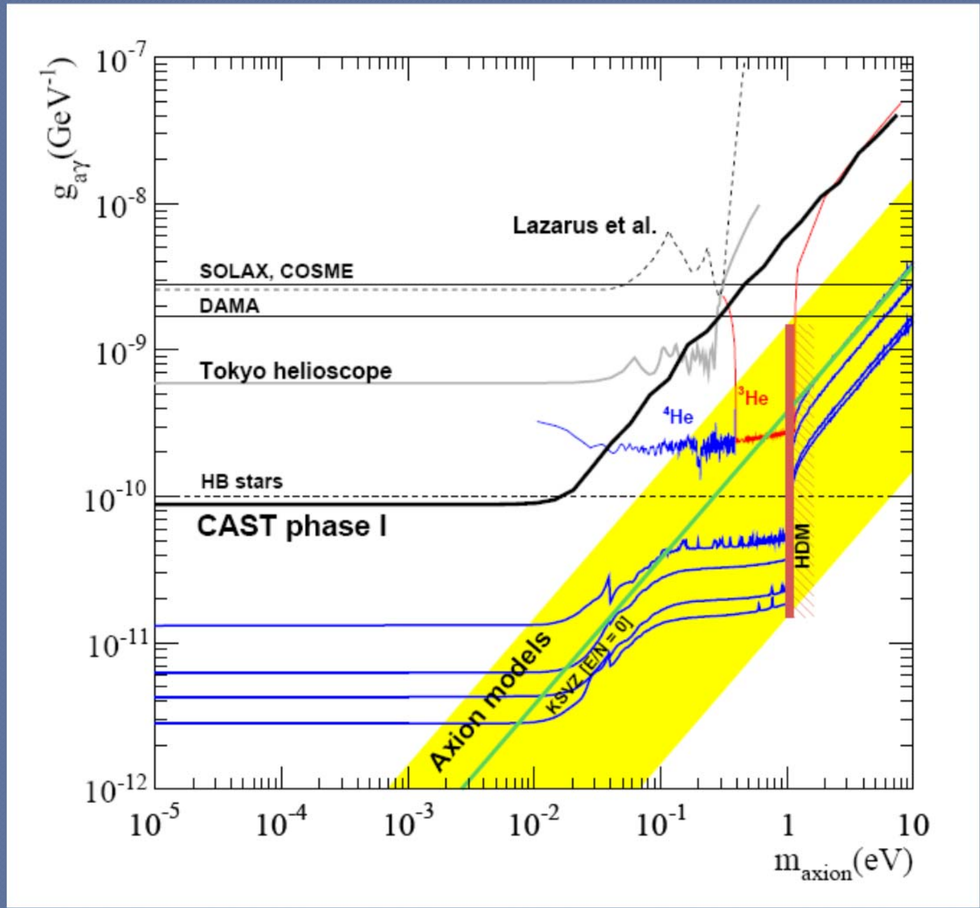
$$g_{a\gamma\gamma} \propto (B\,L)^{-1/2}\, A^{-1/4}\, (b^{1/8} / t^{1/8})$$

Magnet
Stronger field,
bigger area

Movement
Extension of
observation time

A new generation of helioscopes

Large parts of the model region for QCD axions could be explored in the coming decade



Summary

CAST, in these 11 years:

- has put the strictest limit on axion searches for a wide m_a range
- Is scanning the region most favoured by QCD models, first result presented:

  $$g_{a\gamma\gamma} \leq 2.5 \times 10^{-10}\ GeV^{-1}\ (95\%\ C.L)\ \ for\ 0.39 < m_a < 0.65\ eV$$

- has studied by-products in parallel to the main physics:

  HE axions, 14.4keV axions from nuclear transitions, LE axions (visible)
- has gained much experience on Helioscope Axion Searches
- is established as a reference result in axion physics.

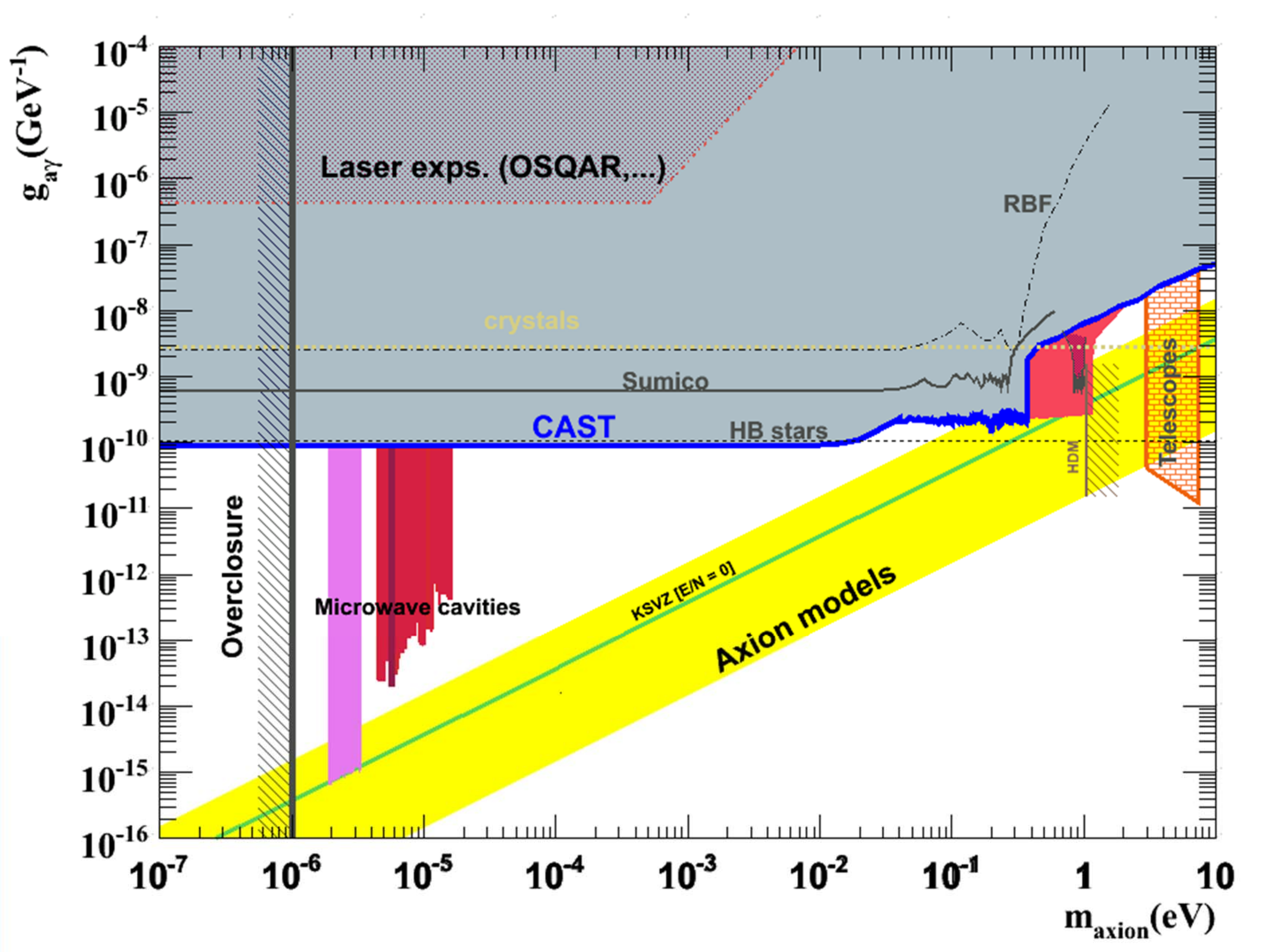
at present is looking to:

- improve the ^4He and vacuum results of the experiment
- explore the possibilities to study other exotica: paraphotons, solar chameleons, improve the LE setup and relic axions
- Working on the development of detectors that would increase the sensitivity

But also looking in the future towards

the new generation of Axion Helioscopes

CAST in the Axion (ALP) MAP



end

Thank you for your attention