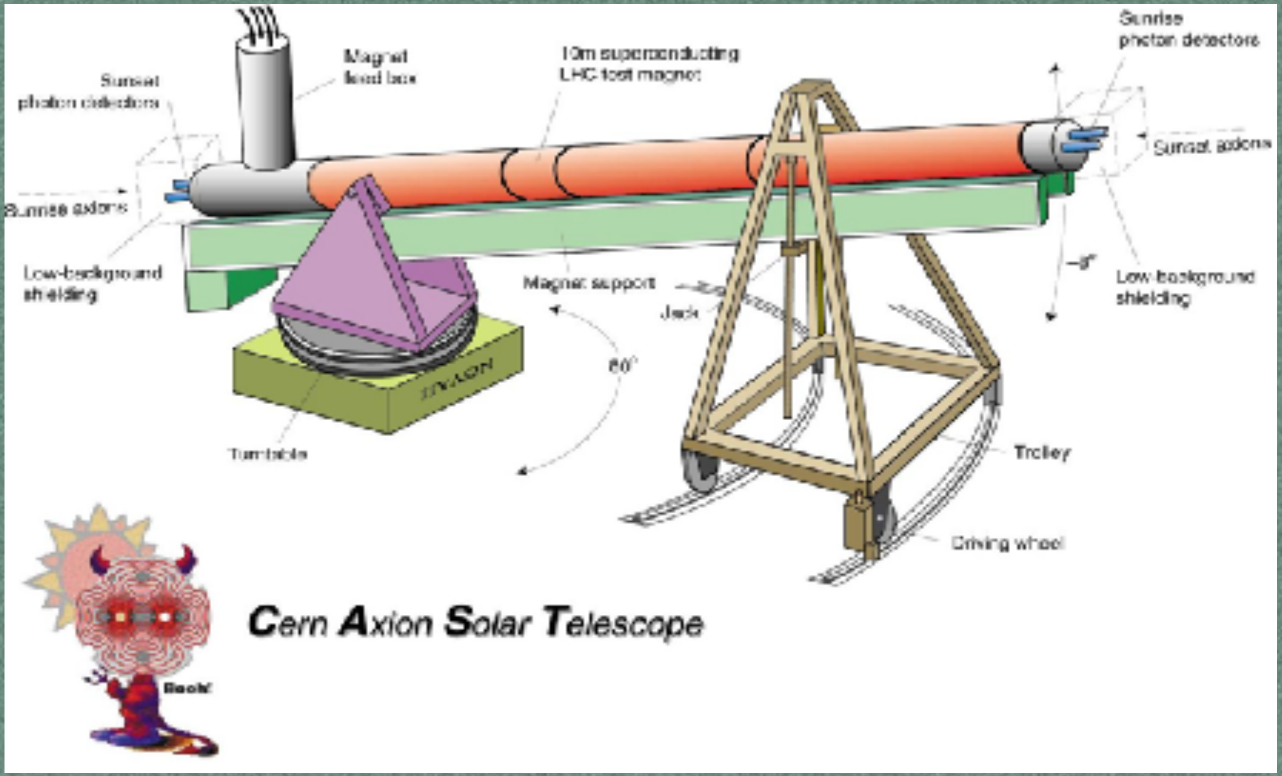
Axion (and other) searches at CAST

M. Karuza, University of Rijeka and INFN Trieste
on behalf the CAST Collaboration

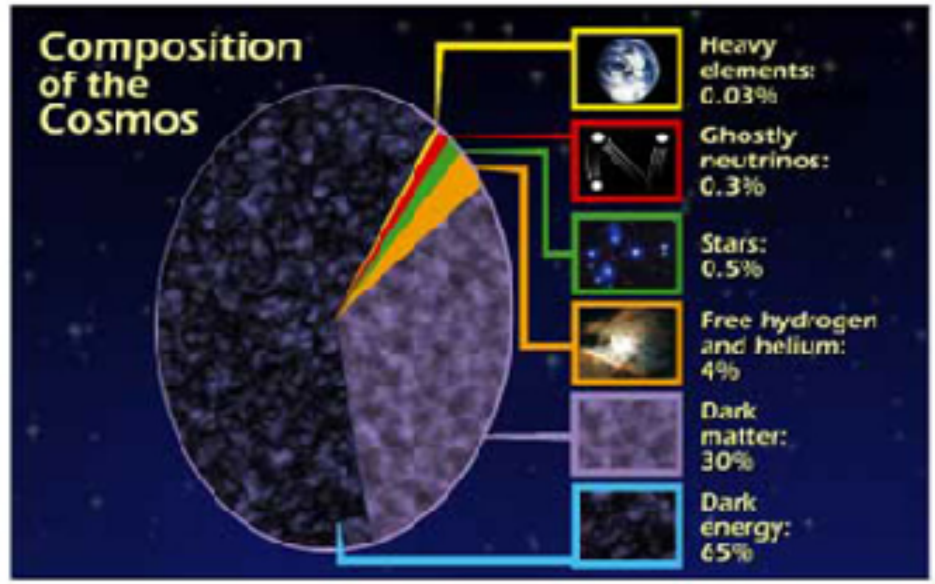
Overview

- Introduction
- History
- Future
- Conclusion



Introduction

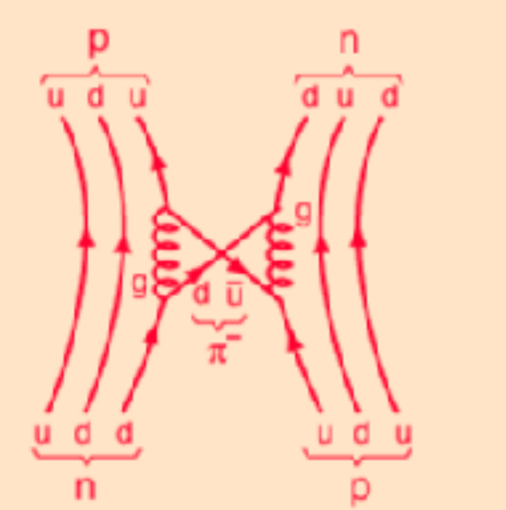
95% Universe is dark.



Ann Feild (STScI)

Strong CP problem.

QCD does not break CP symmetry



http://hyperphysics.phy-astr.gsu.edu/

The answer

Tackles both problems
Dark Matter constituent.
Solves the strong CP problem through Peccei Quinn mechanism.

Where to look

Solar evolution constrains the total exotica flux to less than 10%

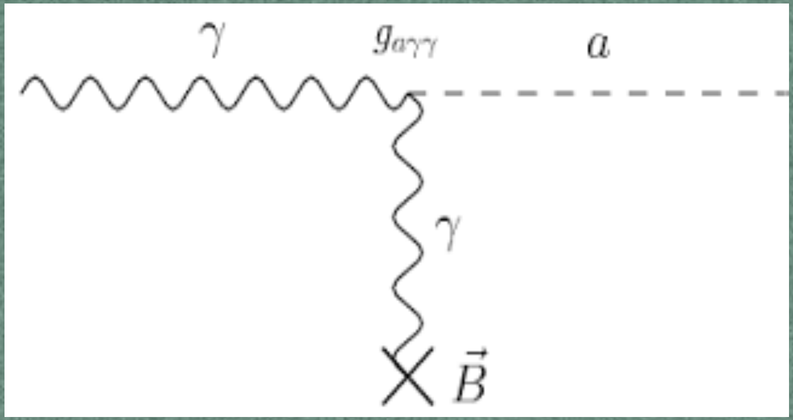
Why?

From two photons!

- Primakoff effect
- directly

- Examples:
- Axion
- Chameleon
- ....

Primakoff effect



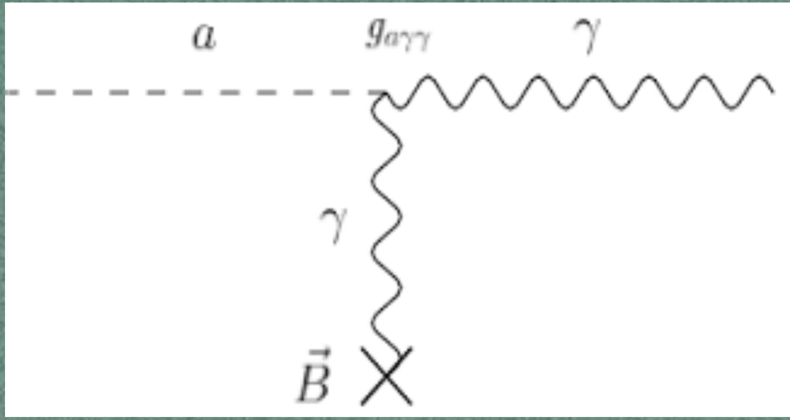
How are exotic particles detected?

Pierre Sikivie 1983

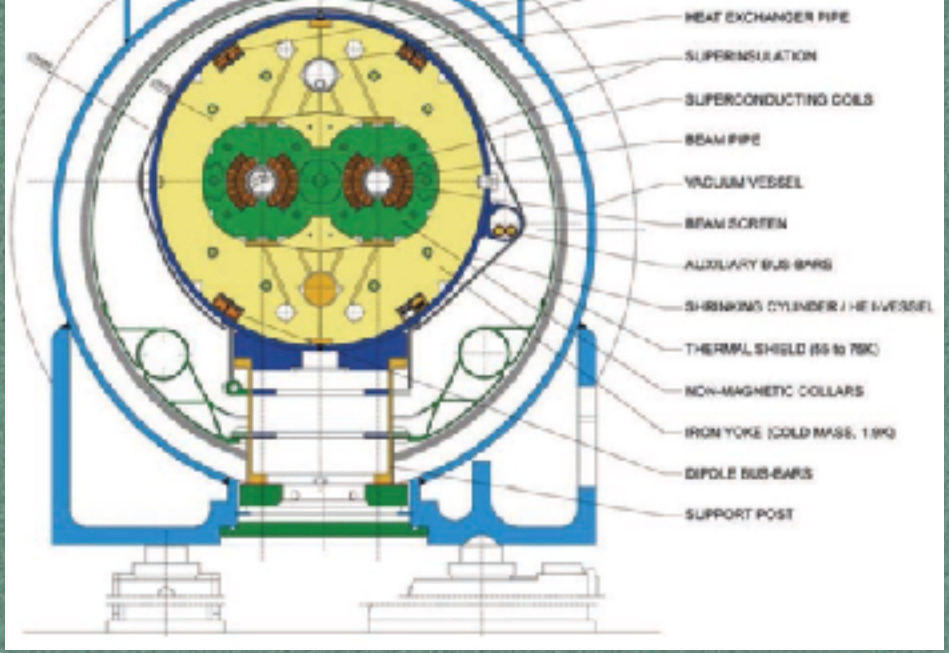
WISP – Weakly Interacting Slim Particles
--> weak or non existent interaction with matter

- best chance by converting them back to photons
- a photon has to be provided (electric or magnetic field)

Inverse Primakoff effect



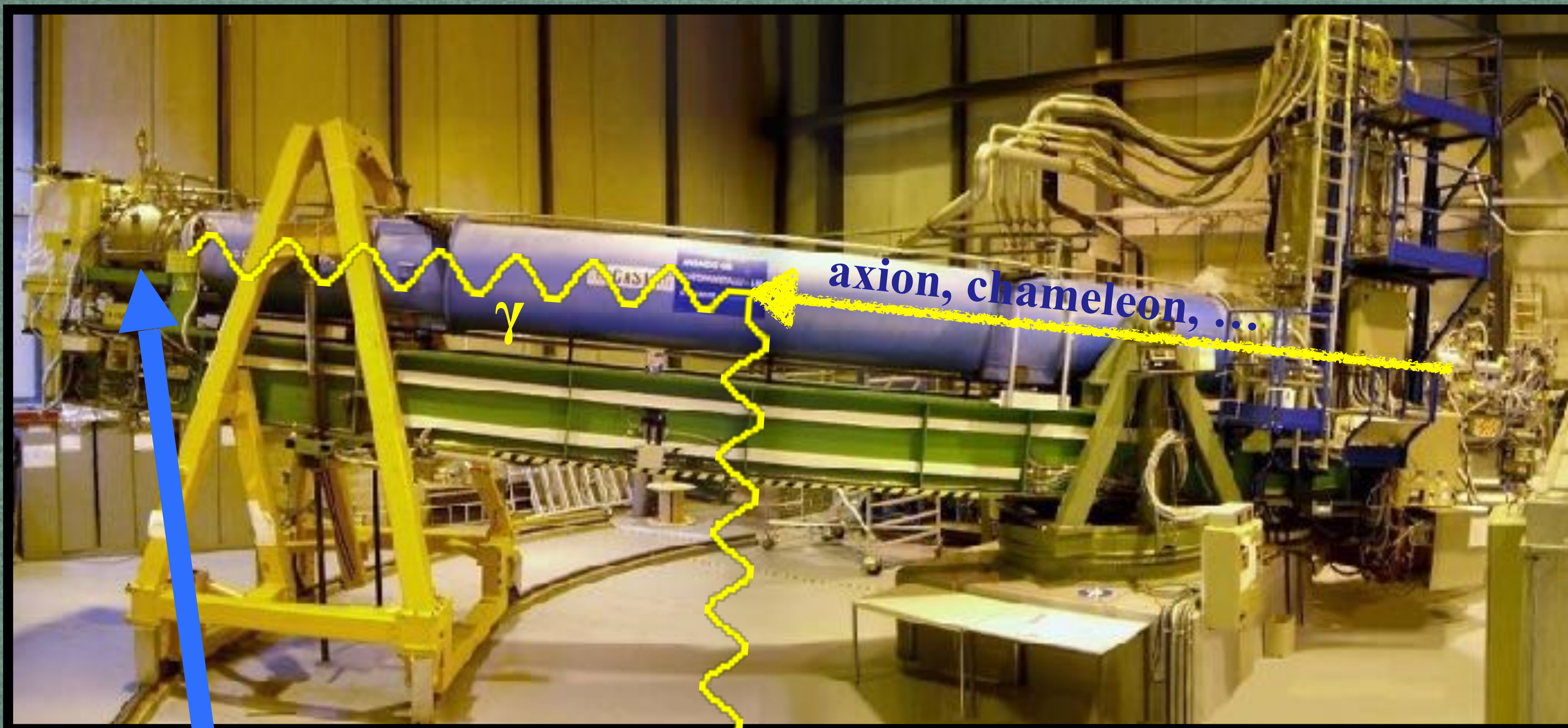
Reconversion: Virtual photon



- a photon has to be provided
- choice: magnetic field

- --> spare LHC magnet
    - 45 mm bore diameter
    - ~10 m long
    - B ~ 9 T

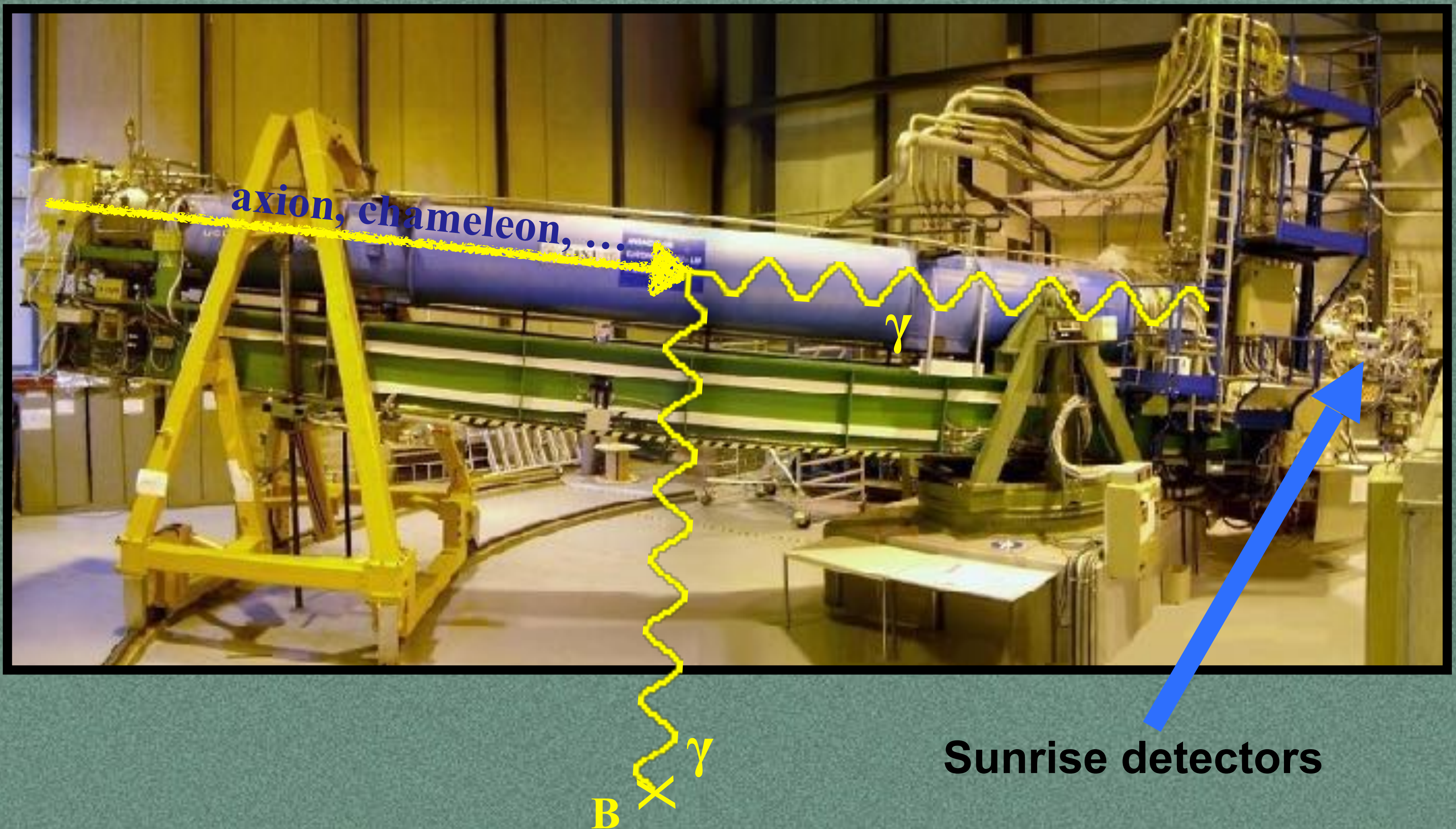
The Cern Axion Solar Telescope



Sunset detectors

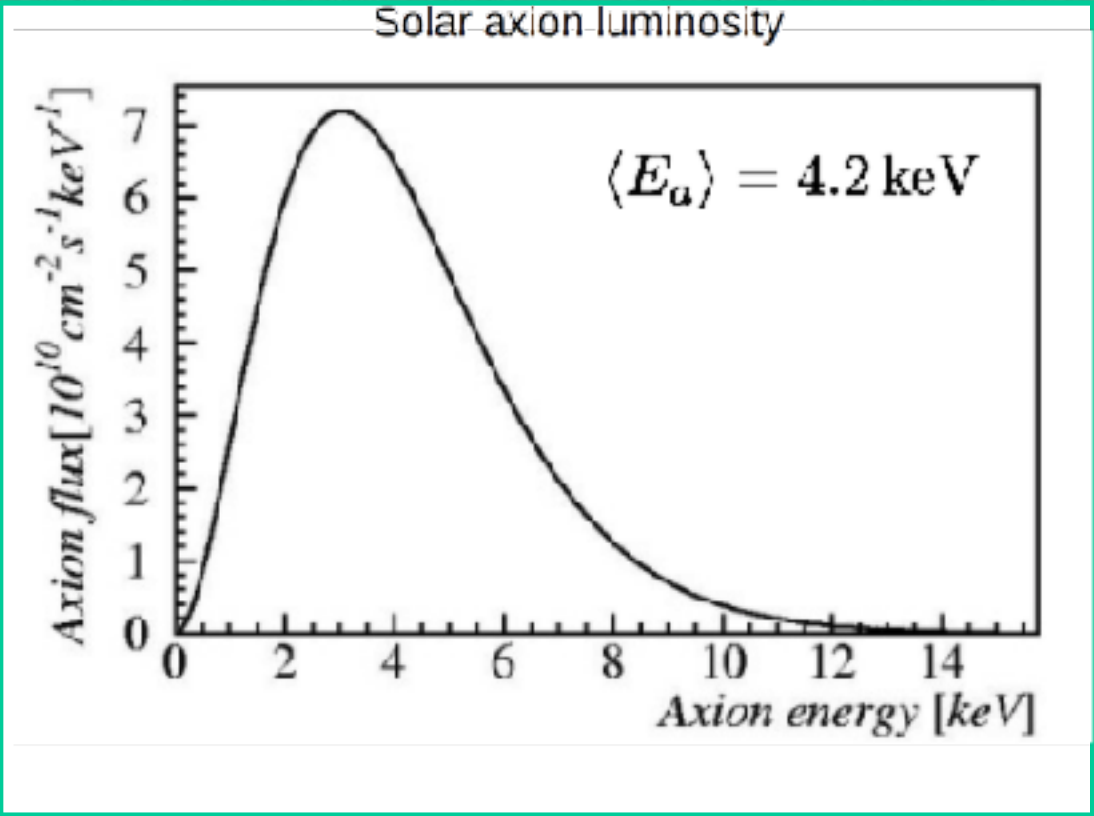
2 MicroMegas
Detectors

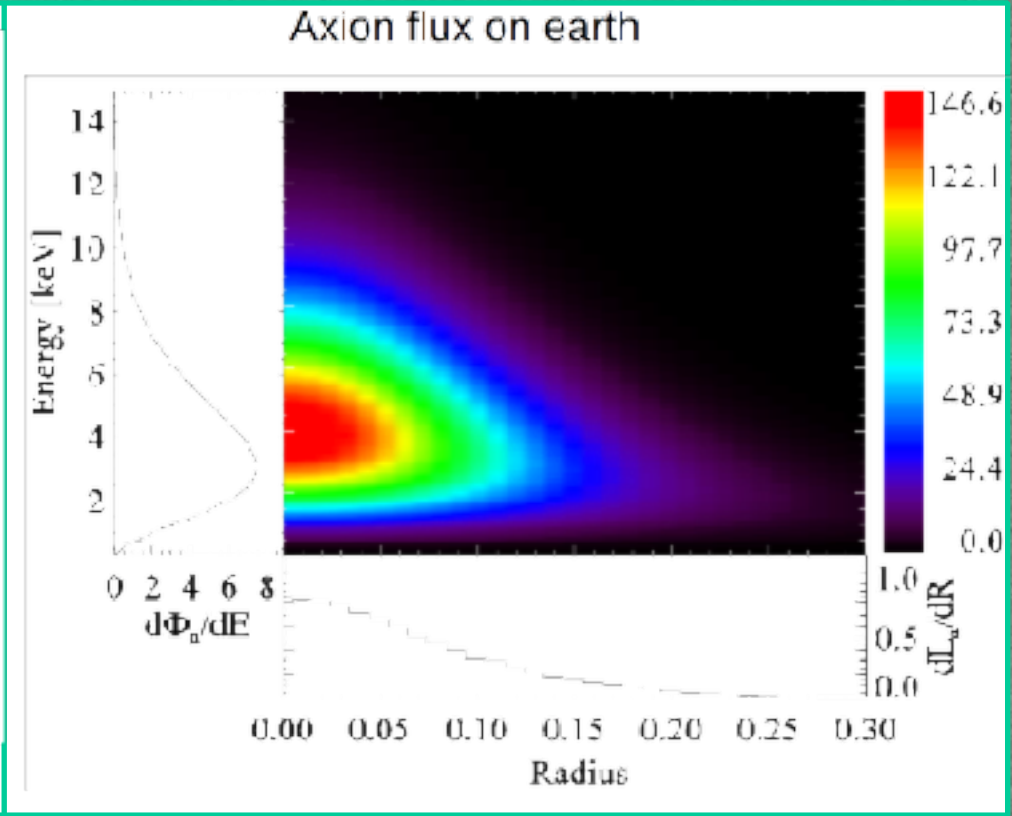
The Cern Axion Solar Telescope



Up to 2013: MicroMegas, CCD & MPE XRT
Since 2014: **MicroMegas & LLNL XRT***,
InGrid & MPE XRT

History





Expected number of photons (1-10 keV) and A = 14.5 cm²

$$N_\gamma = \Phi_a \cdot A \cdot P_{a\to\gamma}$$

$$P_{a\to\gamma} = 1.7\cdot 10^{-17}\left(\frac{B\cdot L}{9.0\mathrm{T}\cdot 9.3\mathrm{m}}\right)^2\left(\frac{g_{a\gamma\gamma}}{10^{-10}\mathrm{GeV}^{-1}}\right)^2$$

0.3 counts/hour for $g_{a\gamma\gamma} = 10^{-10}\,\mathrm{GeV}^{-1}$

History

nature physics

ARTICLES

PUBLISHED ONLINE: 1 MAY 2017 | DOI: 10.1038/NPHYS4109

OPEN

New CAST limit on the axion–photon interaction

CAST Collaboration†

Hypothetical low-mass particles, such as axions, provide a compelling explanation for the dark matter in the universe. Such particles are expected to emerge abundantly from the hot interior of stars. To test this prediction, the CERN Axion Solar Telescope (CAST) uses a 9 T refurbished Large Hadron Collider test magnet directed towards the Sun. In the strong magnetic field, solar axions can be converted to X-ray photons which can be recorded by X-ray detectors. In the 2013-2015 run, thanks to low-background detectors and a new X-ray telescope, the signal-to-noise ratio was increased by about a factor of three. Here, we report the best limit on the axion–photon coupling strength (0.66×10^{-10} GeV^{-1} at 95% confidence level) set by CAST, which now reaches similar levels to the most restrictive astrophysical bounds.

nature physics ARTICLES
PUBLISHED ONLINE: 1 MAY 2017 | DOI: 10.1038/NPHYS4109
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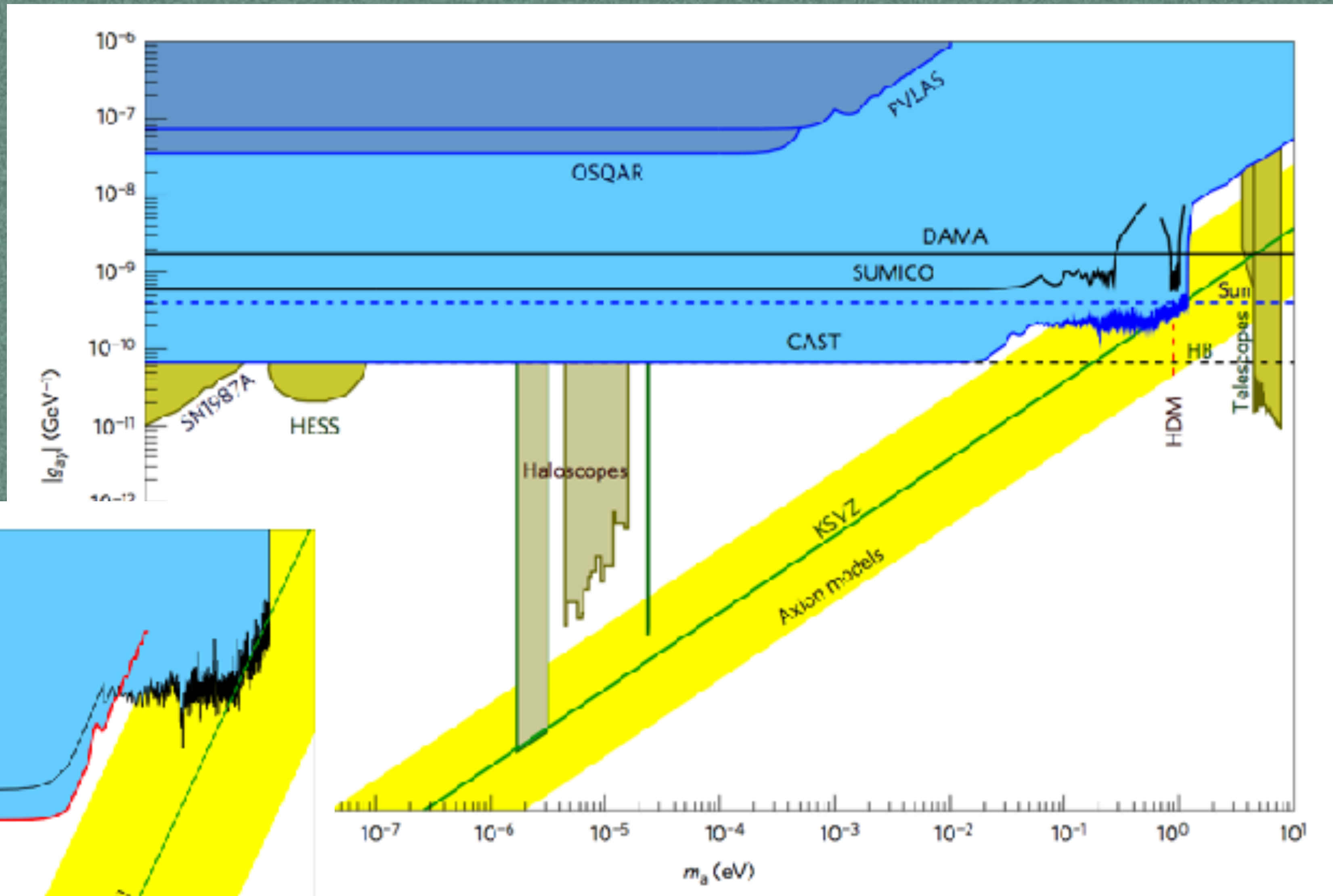
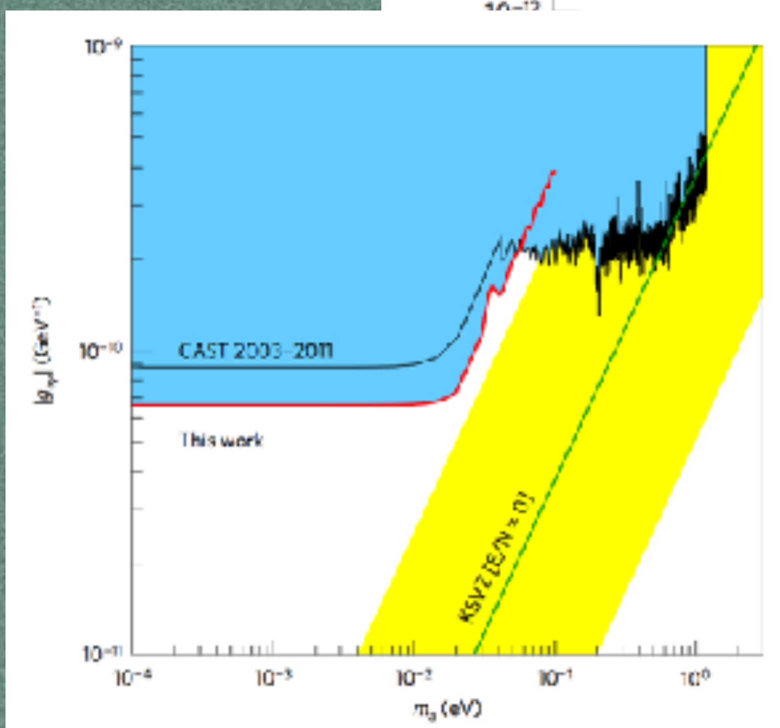
History





$g_{a\gamma}$<0.66 x 10^{-10} GeV^{-1} at 95% CL

Future

- Dark Matter - streaming dark matter
  - relic axions

- Dark Energy - chameleons

Coupling to matter

Coupling to photons

$$V_{\rm eff}(\phi) = \frac{\Lambda^{4+n}}{\phi^n} + e^{\frac{\beta_m}{M_{\rm Pl}}\phi}\rho_m + e^{\frac{\beta_\gamma}{M_{\rm Pl}}\phi}\rho_\gamma$$

- chameleons do not couple only to photons β_γ but also to matter β_m
- measure β_m independently

matter density (local)

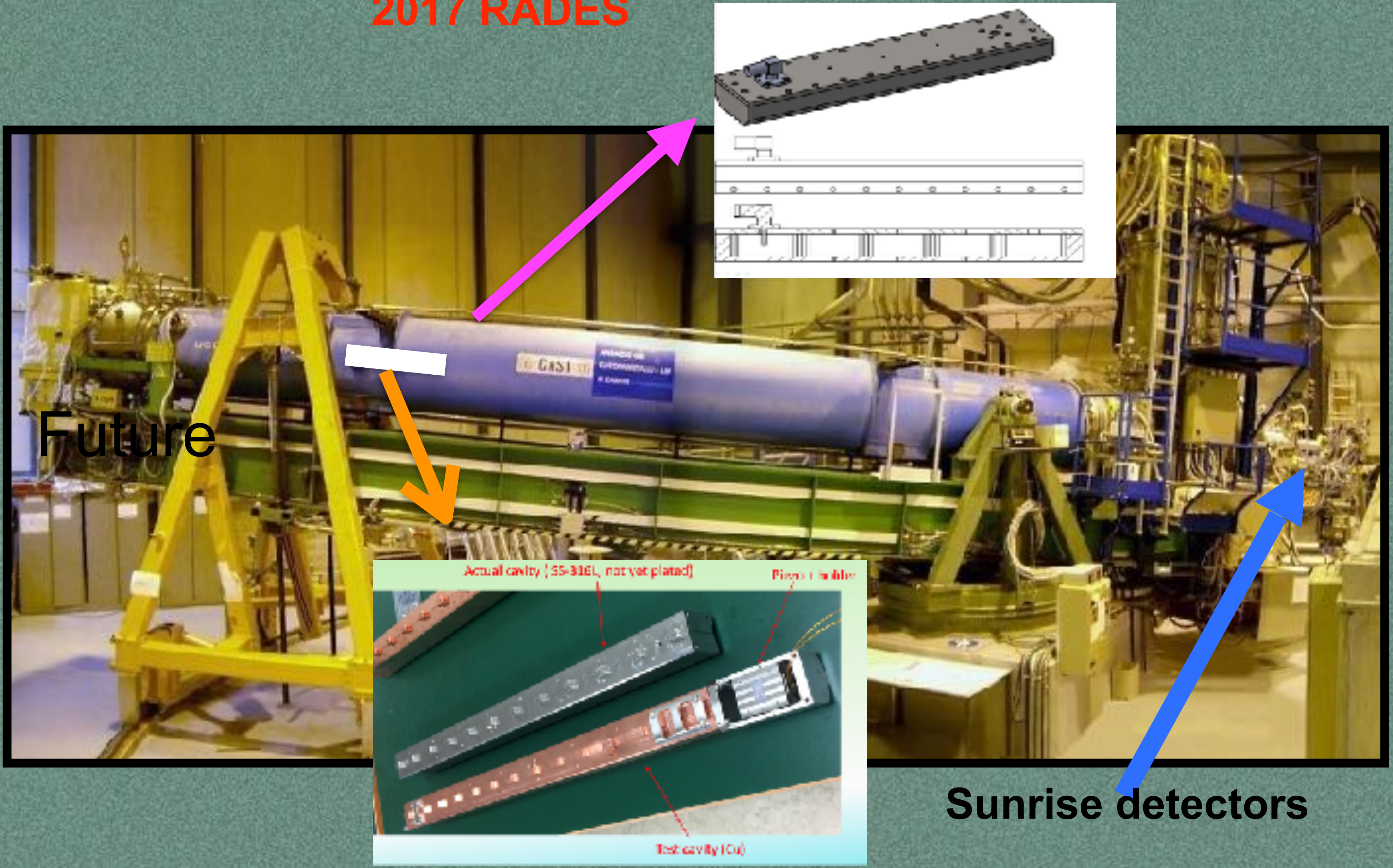
Physics Letters B

Volume 749, 7 October 2015, Pages 172–180

Search for chameleons with CAST

$$m_{\rm eff}^2 = (n+1)\,\frac{\beta_m \rho_m}{M_{\rm Pl}}\,\frac{1}{\phi_{\rm min}}$$

2017 RADES



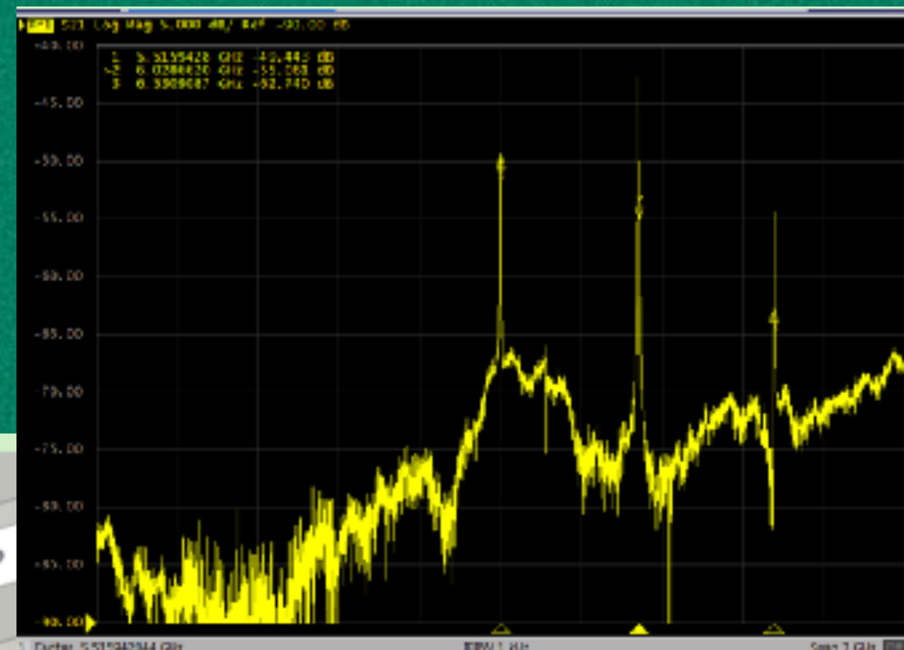
2016 CAST/CAPP

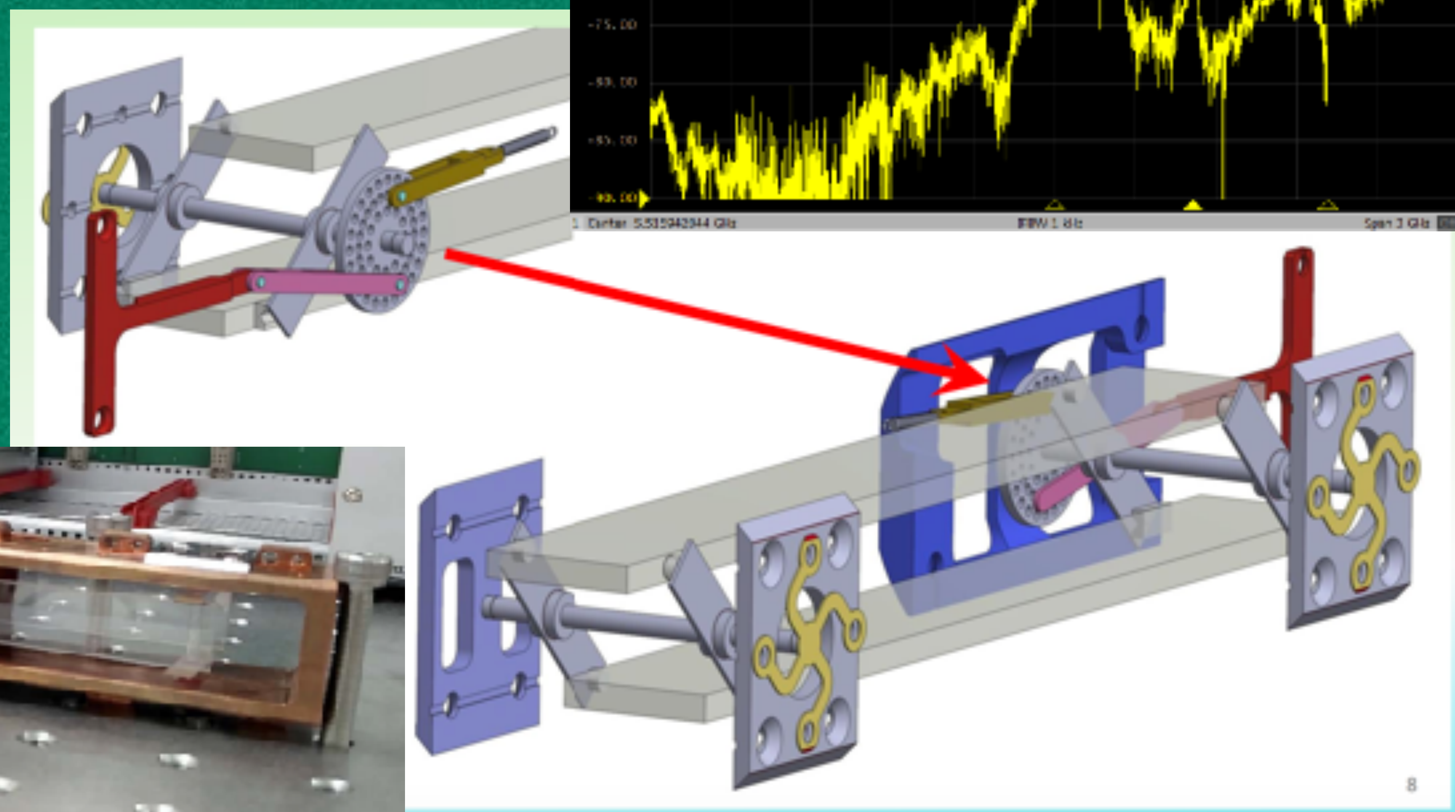
2016 InGrid & MPE XRT

2016 KWISP & MPE XRT

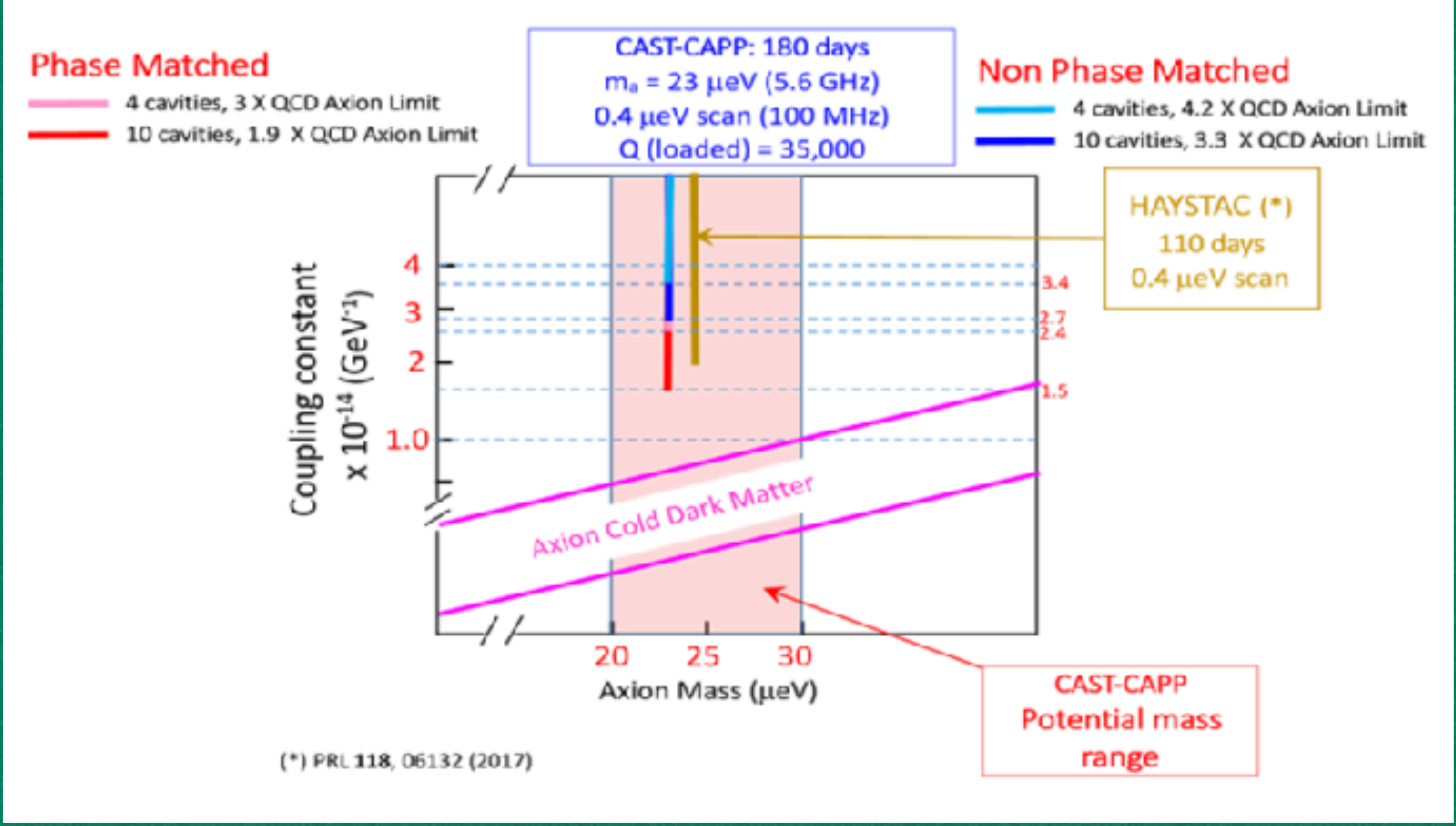
CAST - CAPP

- tuning - 1 GHz
- haloscope



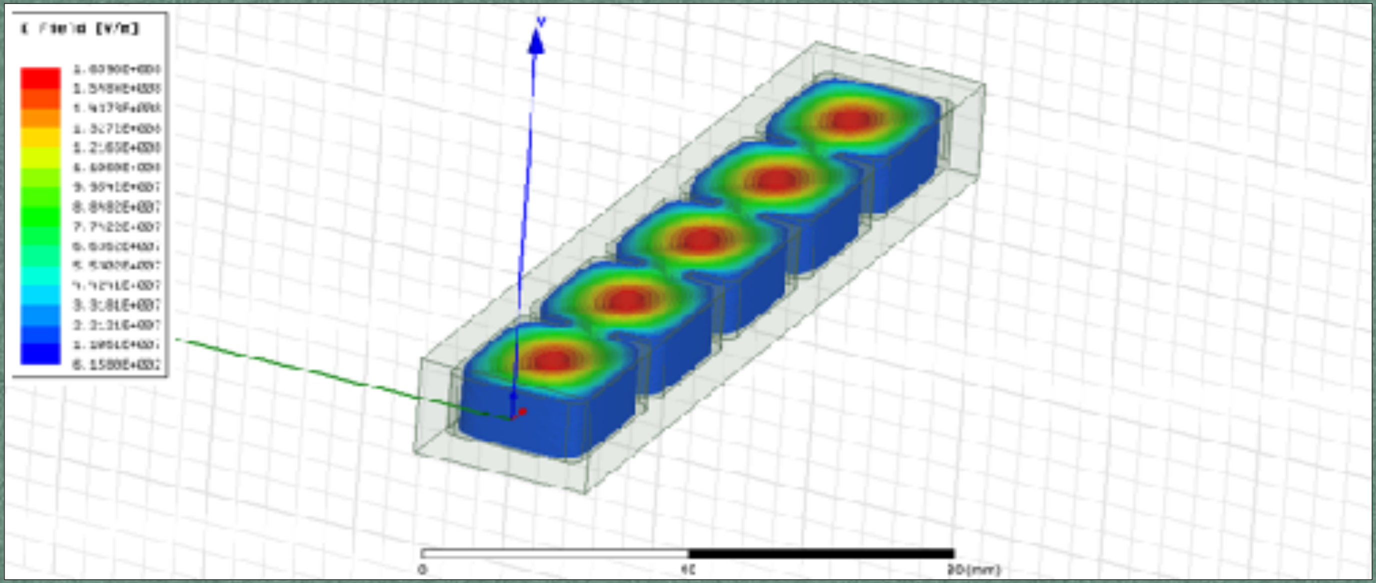


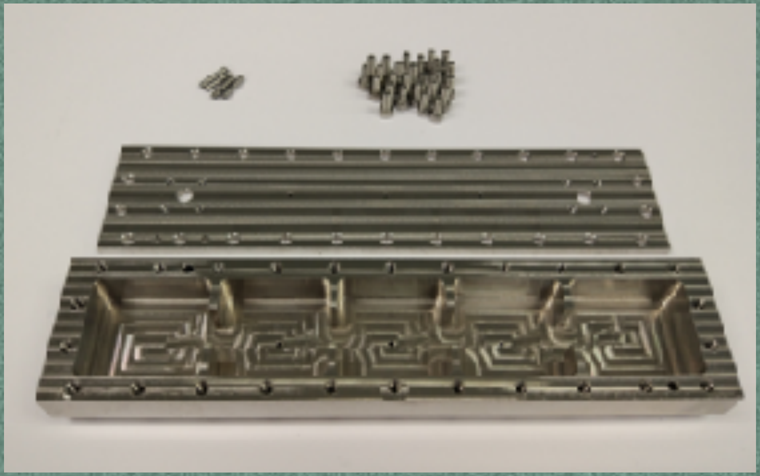
CAST - CAPP



Phase Matched
4 cavities, 3 X QCD Axion Limit
10 cavities, 1.9 X QCD Axion Limit
CAST-CAPP: 180 days
m_a = 23 μeV (5.6 GHz)
0.4 μeV scan (100 MHz)
Q (loaded) = 35,000
Non Phase Matched
4 cavities, 4.2 X QCD Axion Limit
10 cavities, 3.3 X QCD Axion Limit
HAYSTAC (*)
110 days
0.4 μeV scan
Coupling constant
x 10^-14 (GeV^-1)
4
3
2
1.0
3.4
2.7
2.4
1.5
Axion Cold Dark Matter
20
25
30
Axion Mass (μeV)
CAST-CAPP
Potential mass
range
(*) PRL 118, 06132 (2017)

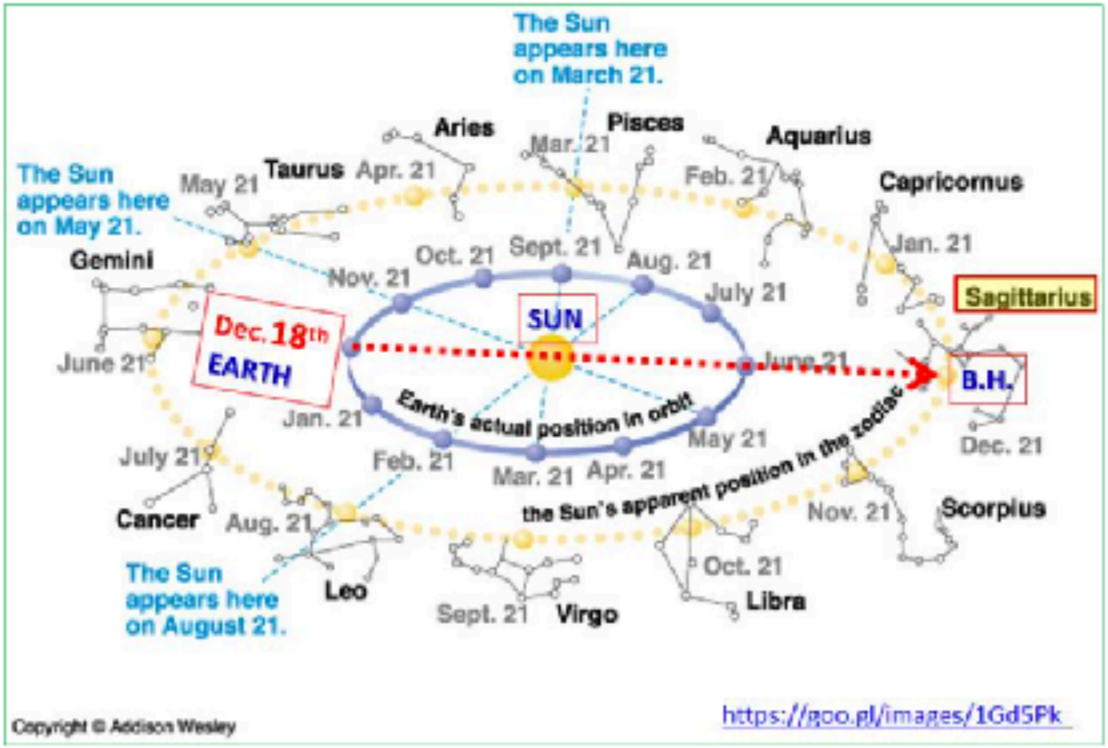
Relic Axion Detector Exploratory Setup (RADES)





- First non-tunable prototype with 5 subcavities/poles just built .
- To be installed and operated this year in CAST magnet
- Next steps:
  - Tunning
  - Larger volumes

Streaming dark matter



First related work:

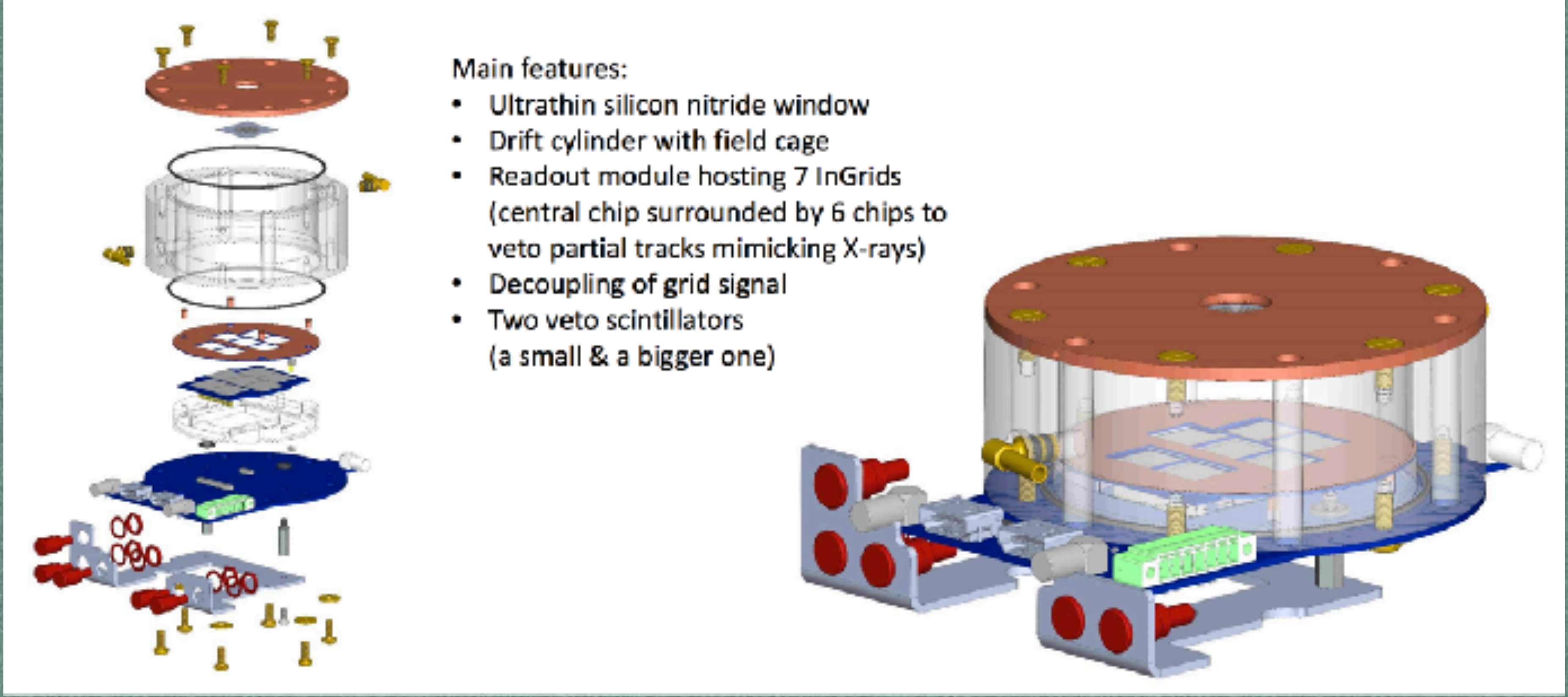
Gravitational lensing by the Sun of non-relativistic penetrating particles
D. Hoffmann, J. Jacoby, K. Z., Astropart. Phys. 20 (**2003**) 73; http://dx.doi.org/10.1016/S0927-6505(03)00138-5
Flux Enhancement of Slow-moving Particles by Sun or Jupiter: Can they be detected?
B.R. Patla, R.J. Nemiroff, D. Hoffmann, K. Z., ApJ. 780 (**2014**) 158;
https://arxiv.org/abs/1305.2454

V. Anastassopoulos, S. Bertolucci, G. Cantatore, S. Cetin, H. Fischer, W. Funk, D. Hoffmann, S. Hofmann, M. Karuza, M. Maroudas, Y. Semertzidis, I. Tkatchev , K. Zioutas
Search for axions in streaming dark matter (https://arxiv.org/abs/1703.01436)

H. Fischer, Y. Semertzidis, K. Zioutas, *Search for axions in streaming dark matter*, https://ep-news.web.cern.ch/content/search-axions-streaming-dark-matter.
See also http://cerncourier.com/cws/article/cern/69886

InGrid

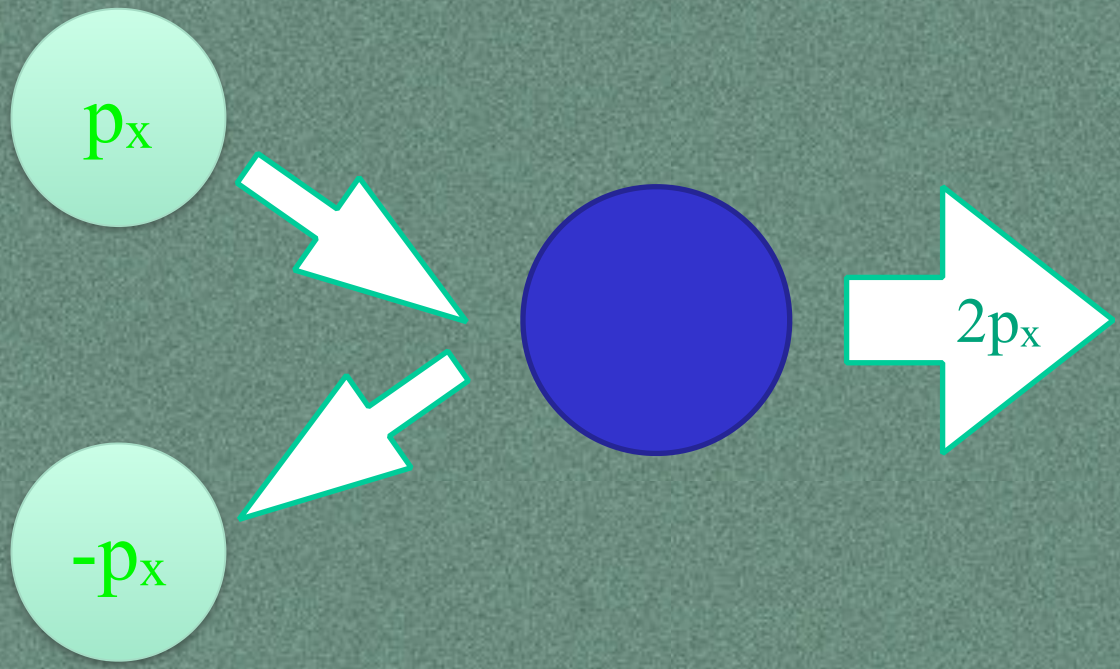
- board with seven modules,
- background rejection
- Silicon nitride windows - 300 nm thick
- Ready for data taking in 2017



KWISP
Dark Energy

- Chameleons leaving the Sun will travel to the detector unperturbed provided that their energy is greater than their effective mass in whichever medium they propagate.
- The densest medium is the vacuum chamber housing the sensor

In a dense medium chameleons get large effective mass. If their total energy is smaller than their effective mass in a medium they try to penetrate, they will get reflected, resulting in the equivalent of radiation pressure.

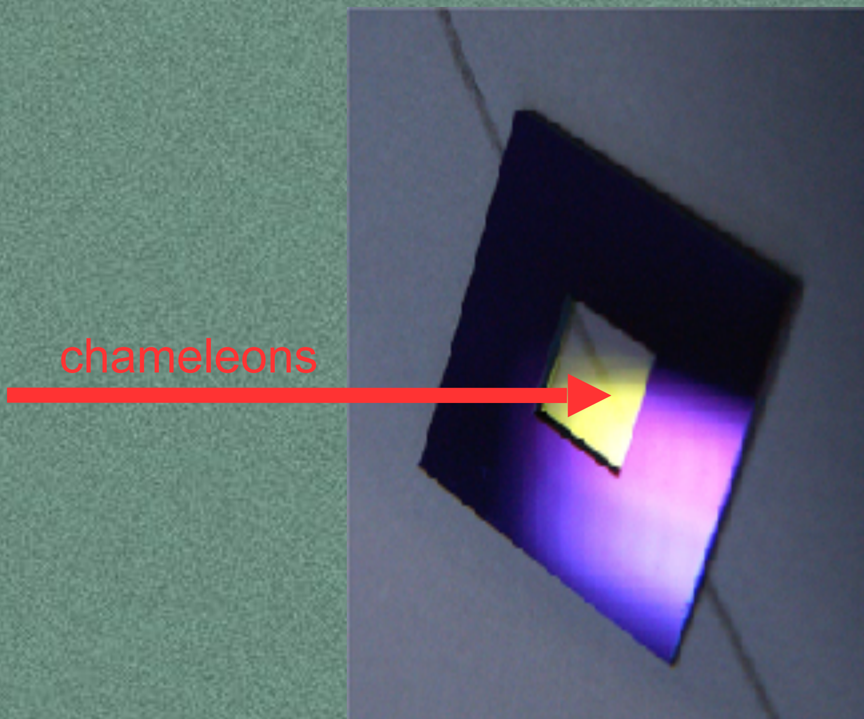


KWISP
Sensor

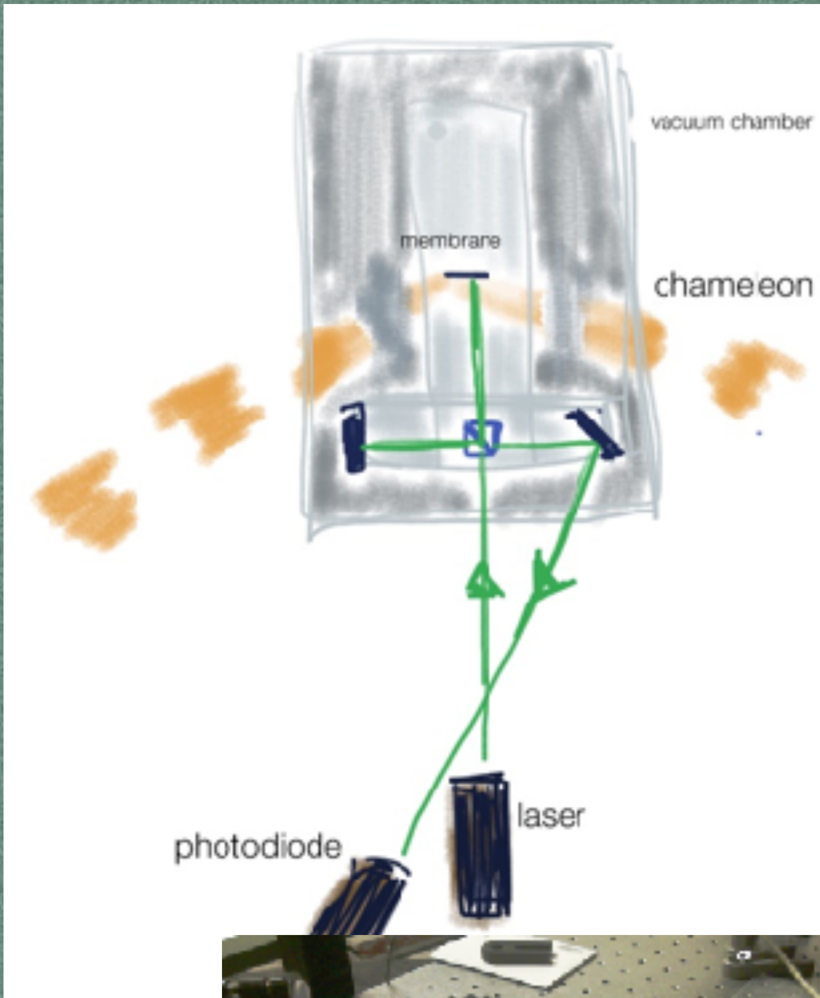
- Unfortunately chameleon flux too small for such an experiment!
- More sensitive experiment needed.

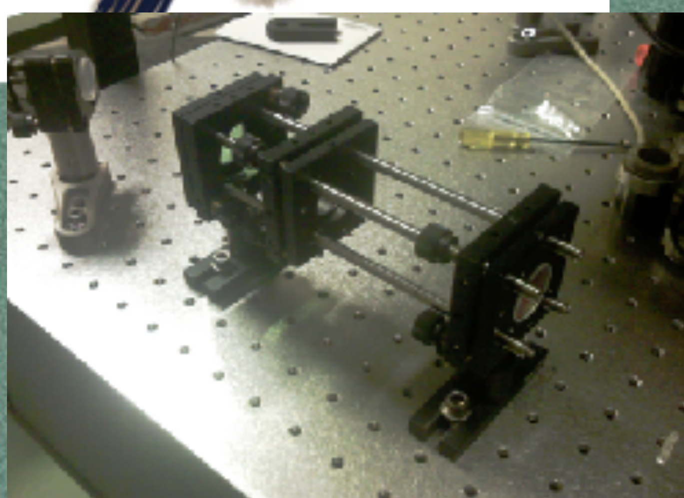
KWISP

Sensor



- Use thin stoichiometric silicon nitride membrane as a sensing element
- Commercially available
- "large" area, up to 5x5 mm
- Transparent @1064 nm
- Density ~ 3 g/cm^3
- Can be coated with metal
- High stress
- High resonant frequency
- High mechanical Q ~ 10^6



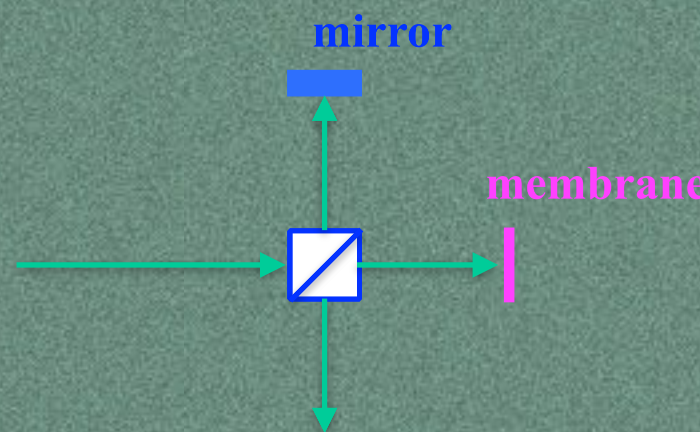


KWISP

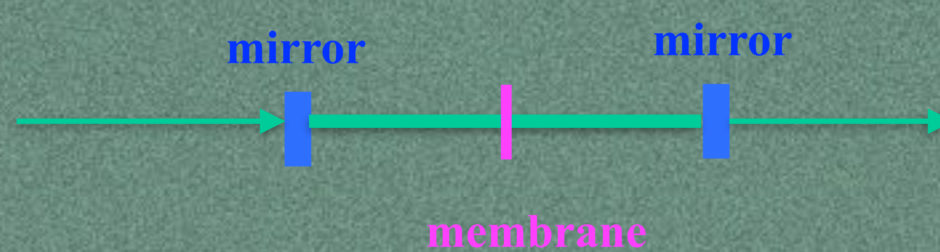
detector readout

Information on membrane position

- **Michelson interferometer**
- **KWISP ver 1.0**
- **KWISP ver 1.5 -> 10^{-13} m/√(Hz)**



- **Fabry – Perot cavity**
- **ver 2.0 -> better than 10^{-15} m/√(Hz)**



Conclusion

- **helioscopes**
- the experiment has reached the ultimate sensitivity
- result will remain as reference for some time
- scale TASTE, babyIAXO, IAXO

- **haloscopes**
- ADMX, CAST/CAPP, RADES, MADMAX, HAYSTAC

- **lab based**
- light shining through the wall
- ALPS, OSQAR