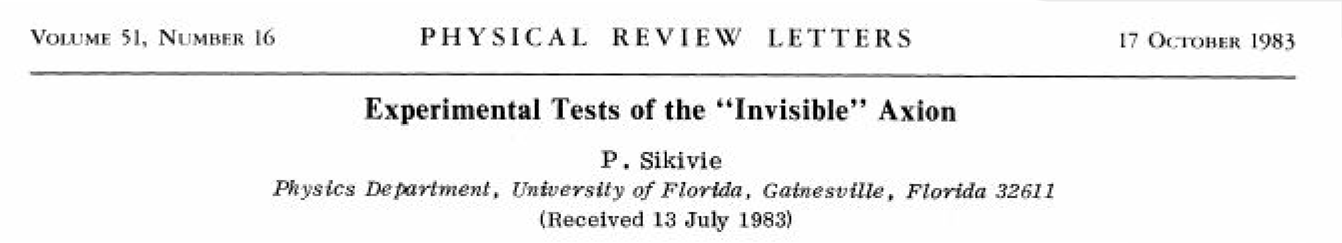
A non-tracking axion helioscope

J. Galan (SJTU)
Axions & IAXO in Spain
27-28 October 2016

Helioscope seminal papers



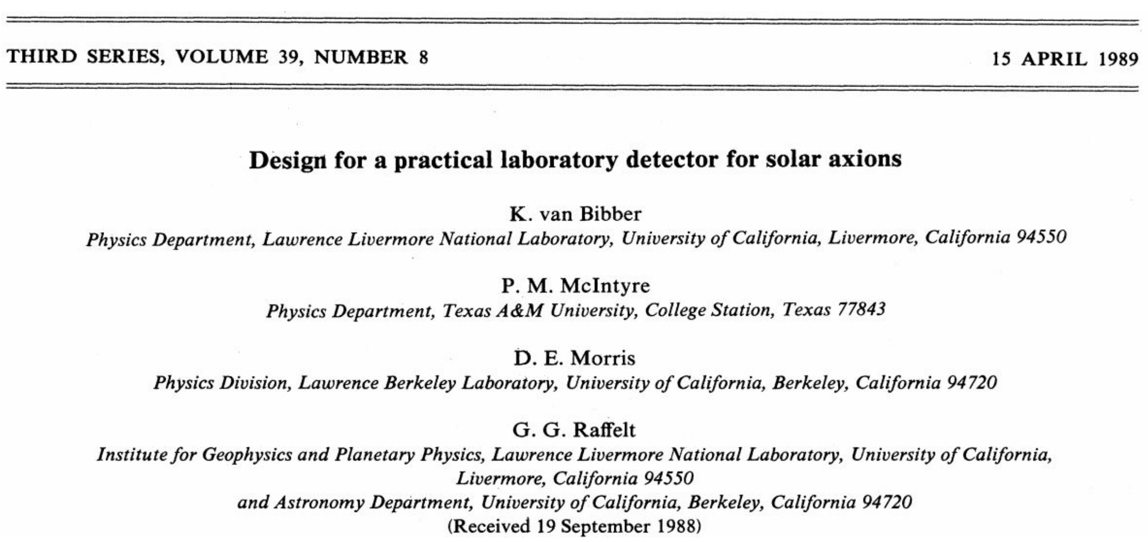
VOLUME 51, NUMBER 16 PHYSICAL REVIEW LETTERS 17 OCTOBER 1983

Experimental Tests of the "Invisible" Axion

P. Sikivie
Physics Department, University of Florida, Gainesville, Florida 32611

(Received 13 July 1983)

1983



THIRD SERIES, VOLUME 39, NUMBER 8 15 APRIL 1989

Design for a practical laboratory detector for solar axions

K. van Bibber
Physics Department, Lawrence Livermore National Laboratory, University of California, Livermore, California 94550

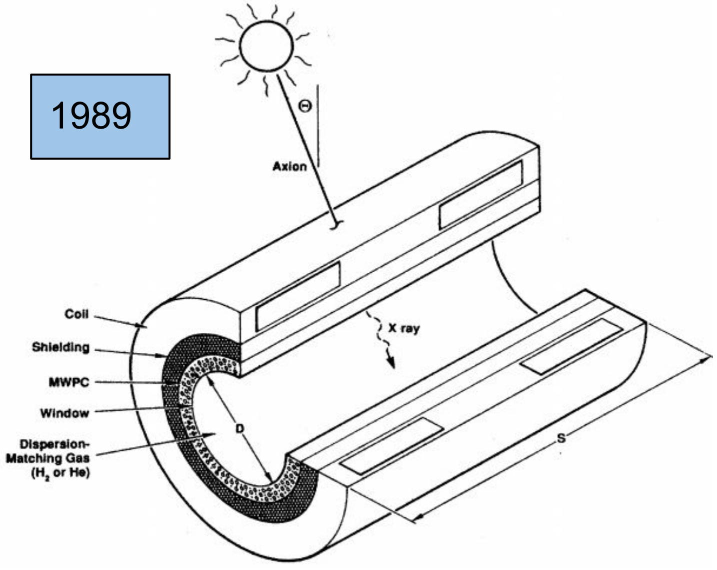
P. M. McIntyre
Physics Department, Texas A&M University, College Station, Texas 77843

D. E. Morris
Physics Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

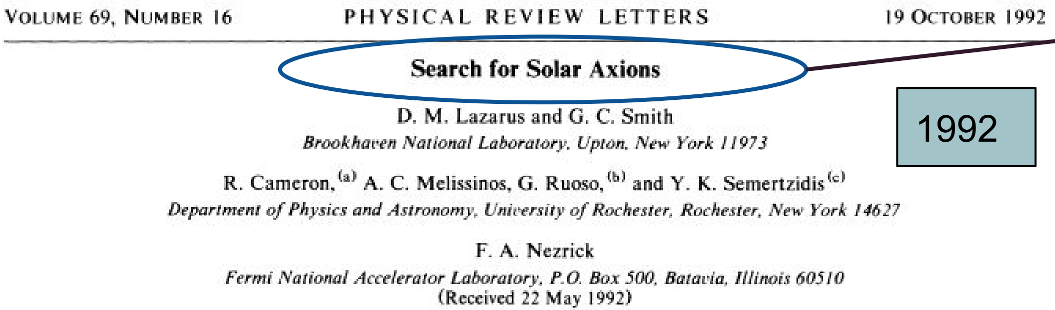
G. G. Raffelt
Institute for Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, University of California, Livermore, California 94550
and Astronomy Department, University of California, Berkeley, California 94720

(Received 19 September 1988)

1989



Pionering helioscope searches using non-tracking helioscopes



VOLUME 69, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1992

Search for Solar Axions

D. M. Lazarus and G. C. Smith
Brookhaven National Laboratory, Upton, New York 11973

R. Cameron,(a) A. C. Melissinos, G. Ruoso,(b) and Y. K. Semertzidis(c)
Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

F. A. Nezrick
Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510
(Received 22 May 1992)

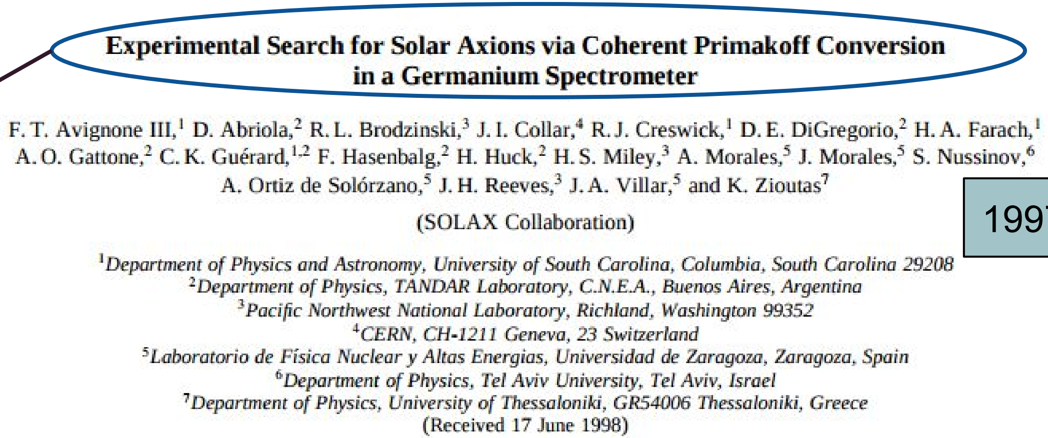
1992

First helioscope

A non-tracking helioscope (a la Sikivie)
Taking data when magnet pipe is on Sun field of view.

$g_{ag} < 3.6 \times 10^{-9}$ GeV^{-1} for $m_a < 30$meV

Also running using low pressure buffer gas



Experimental Search for Solar Axions via Coherent Primakoff Conversion in a Germanium Spectrometer

F. T. Avignone III,[1] D. Abriola,[2] R. L. Brodzinski,[3] J. I. Collar,[4] R. J. Creswick,[1] D. E. DiGregorio,[2] H. A. Farach,[1] A. O. Gattone,[2] C. K. Guérard,[1,2] F. Hasenbalg,[2] H. Huck,[2] H. S. Miley,[3] A. Morales,[5] J. Morales,[5] S. Nussinov,[6] A. Ortiz de Solórzano,[5] J. H. Reeves,[3] J. A. Villar,[5] and K. Zioutas[7]

(SOLAX Collaboration)

[1]*Department of Physics and Astronomy, University of South Carolina, Columbia, South Carolina 29208*
[2]*Department of Physics, TANDAR Laboratory, C.N.E.A., Buenos Aires, Argentina*
[3]*Pacific Northwest National Laboratory, Richland, Washington 99352*
[4]*CERN, CH-1211 Geneva, 23 Switzerland*
[5]*Laboratorio de Física Nuclear y Altas Energias, Universidad de Zaragoza, Zaragoza, Spain*
[6]*Department of Physics, Tel Aviv University, Tel Aviv, Israel*
[7]*Department of Physics, University of Thessaloniki, GR54006 Thessaloniki, Greece*
(Received 17 June 1998)

1997

First Underground helioscopes

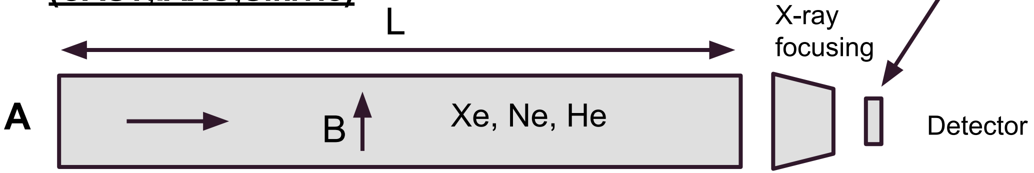
COSME, SOLAX, CDMS, DAMA
These experiments give similar upper limits for the coupling

$g_{ag} < 1.7\text{-}2.7 \times 10^{-9}$ GeV^{-1} $m_a < 1$keV

Two helioscope techniques for axion detection

Photons detected **at the end** of magnet bore

Tracking Helioscope - Photon transmission (CAST,IAXO,Sikivie)

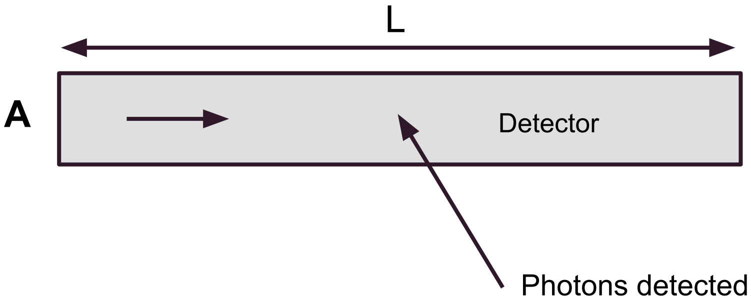


Number of photons found at a distance L

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

Starts to be competitive for higher masses ~eV

Non-tracking helioscope - Photon absorption



Number of photons absorbed along a distance L

$$P_\gamma = \frac{(B/2M)^2}{q^2+\Gamma^2/4}\Gamma L$$

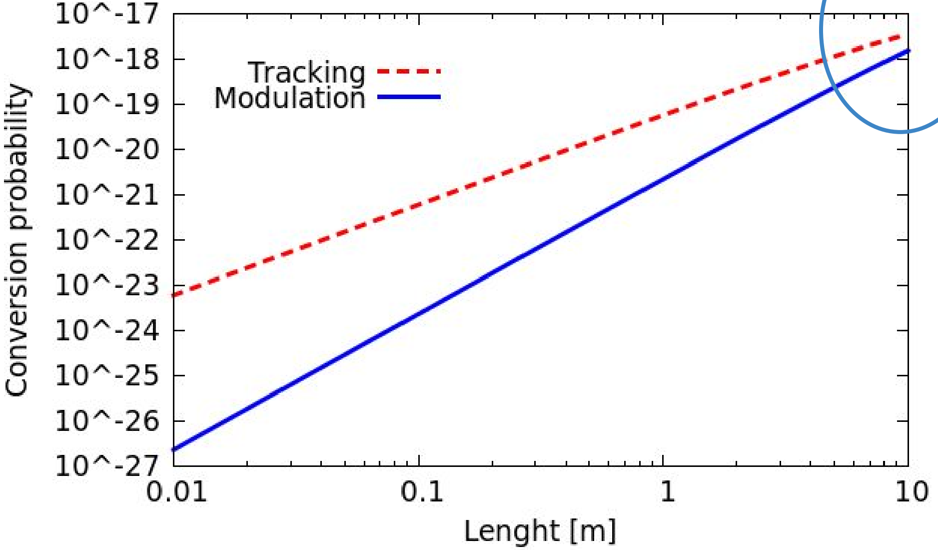
Photons detected **inside** the magnet bore

Absorbed or transmitted photon component

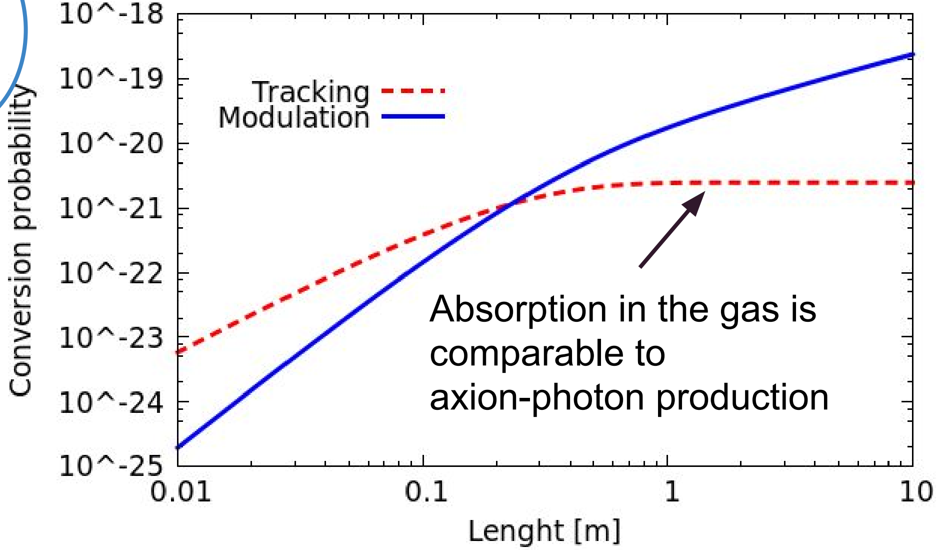
Corresponding to latest CAST pressure settings

Pressures at enviroment temperature ...

Helium at 10 bar (ma ~ 0.85 eV)



Xenon at 100 mbar (ma ~ 0.4 eV)



Absorption in the gas is comparable to axion-photon production

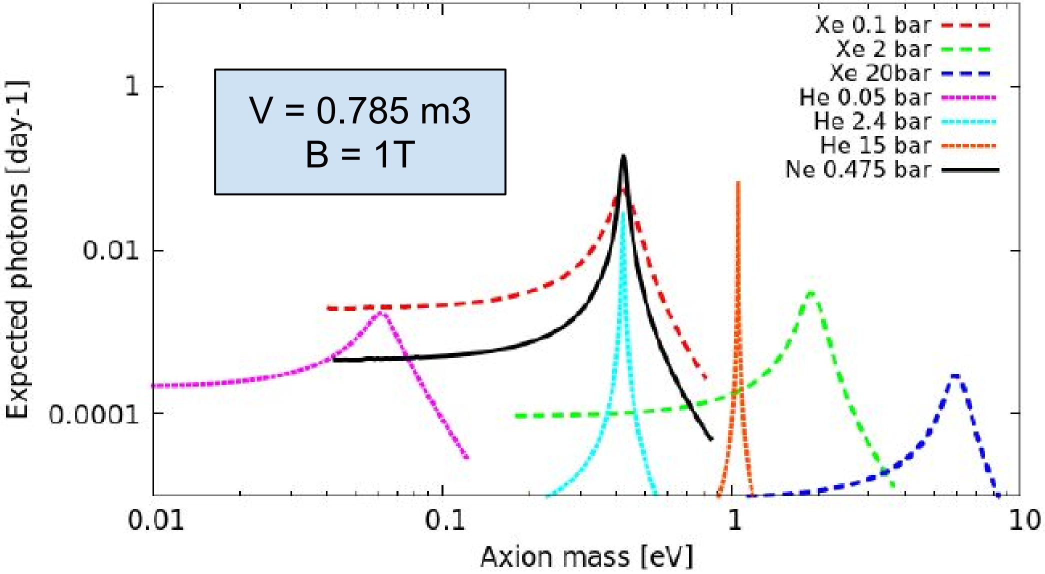
Conversion probability as a function of the axion mass

Helium	Neon	Argon	Xenon
100 mbar - 10 bar	20 mbar - 10 bar	4 mbar - 10 bar	4 mbar - 10 bar
86 meV - 0.86 eV	137 meV - 1.94 eV	51 meV - 2.57 eV	79 meV - 4.05 eV

Conversion probability resonances at different gases and mixtures

Effective axion mass related to gas conditions

$$m_\gamma^2 = 4\pi r_o (N_A / A m_u) \rho f_1$$



A magnetic TPC for helioscope searches

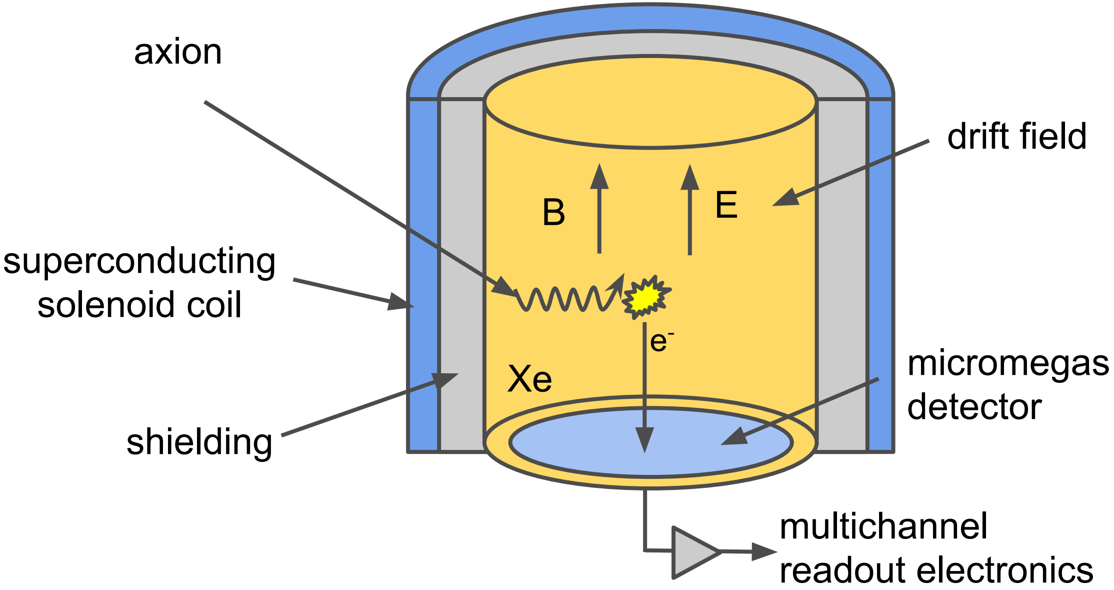
The **transmitted photon component** goes typically as L^2, thus **a long pipe is usually the best suitable geometry**.

However, for the axion-photon **component absorbed** is just proportional to L, thus (for high Γ) we can use **any volume geometry**

$$P_\gamma = \frac{(B/2M)^2}{q^2 + \Gamma^2/4}\Gamma L$$

This technique is especially interesting if
ΓL >> 1.
High Z gases

A possible conceptual TPC-magnet design



axion

superconducting solenoid coil

shielding

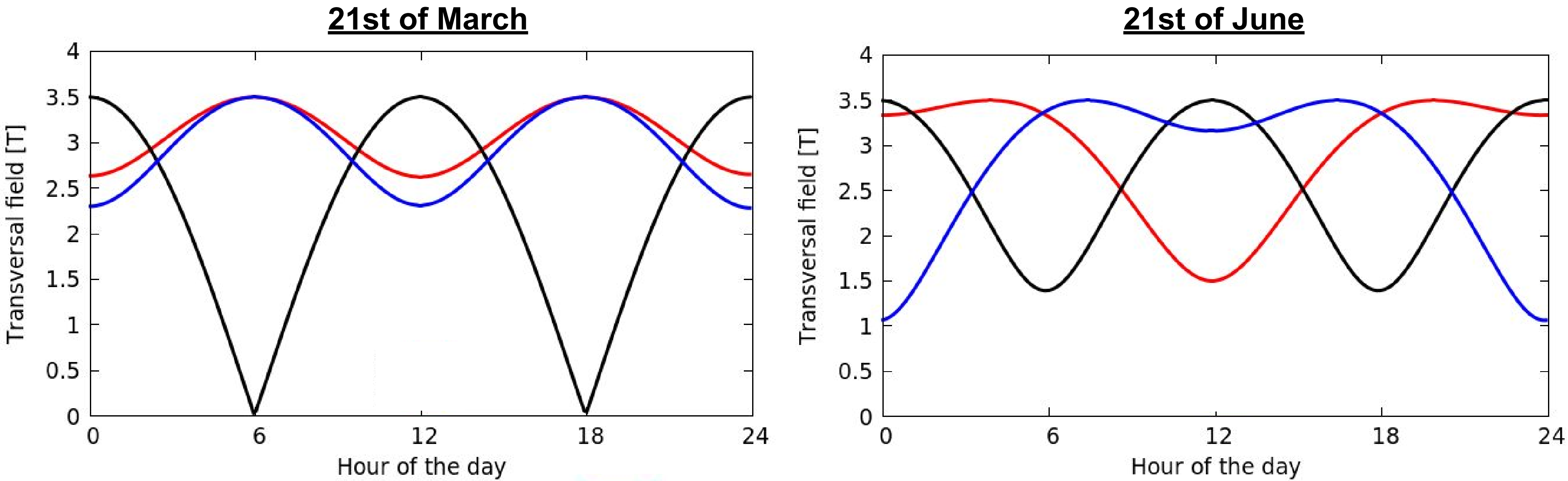
drift field

micromegas detector

multichannel readout electronics

Daily modulation due to Earth rotation

The effective magnetic field for axion-photon conversion modulates.
We must consider only the transversal component to the axion propagation direction that changes along the day.

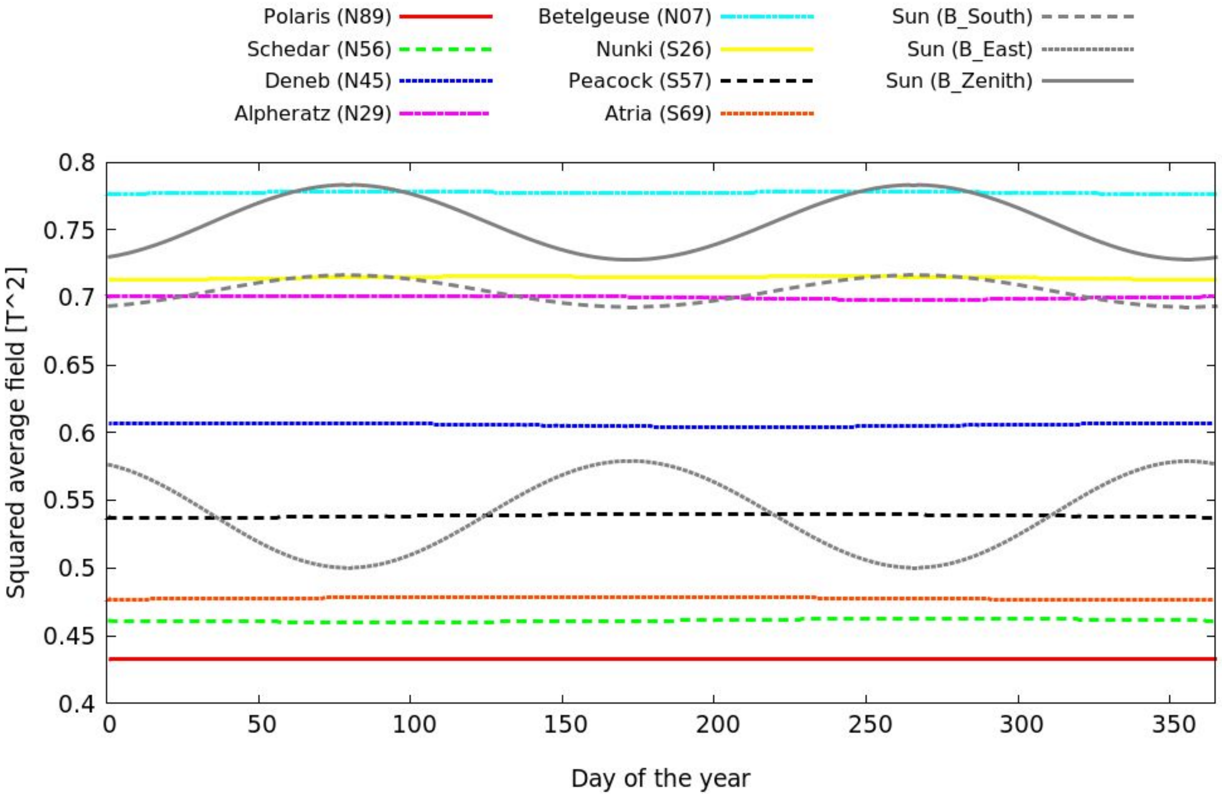


21st of March

21st of June

🟥 **Towards Zenith**
⬛ **Towards East**
🟦 **Towards South**

Annual solar axion modulation (daily averaged)



3 Different TPC magnetic field orientations are shown for Solar axions.

Effective field **~0.75 B^2** for a <u>field perpendicular to the ground.</u>
<u>24h taking data = 18h tracking</u>

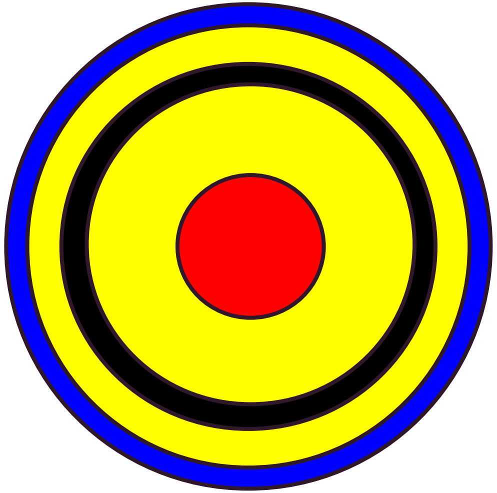
Different sky positions are also shown. Negligible effect on annual modulation.

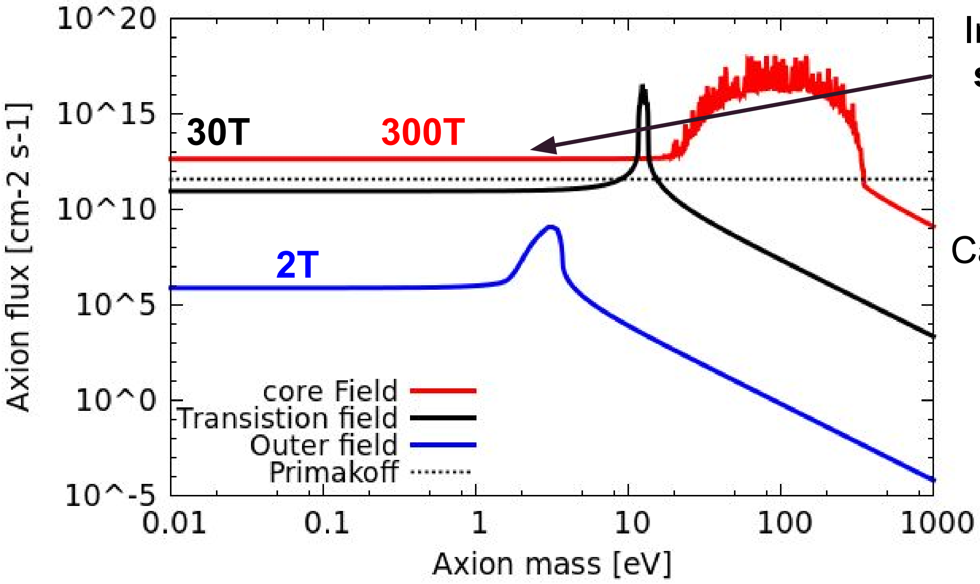
The **Annual** modulation pattern is <u>exclusive of the Sun.</u>

Full angular acceptance (4π)

S.Couvidat, S. Turck-Chieze, A. Kosovichev, APJ 599, 1434 (2003) → Magnetic fields

The Sun magnetic fields





In the core **3000T are still allowed** without effect on Solar observables.

Calculation considering factor 10 reduction

300T

J. Galan, 28th-October-2016

Axions & IAXO in Spain

Solar axion production within the Sun magnetic fields

S.Couvidat, S. Turck-Chieze, A. Kosovichev, APJ 599, 1434 (2003)

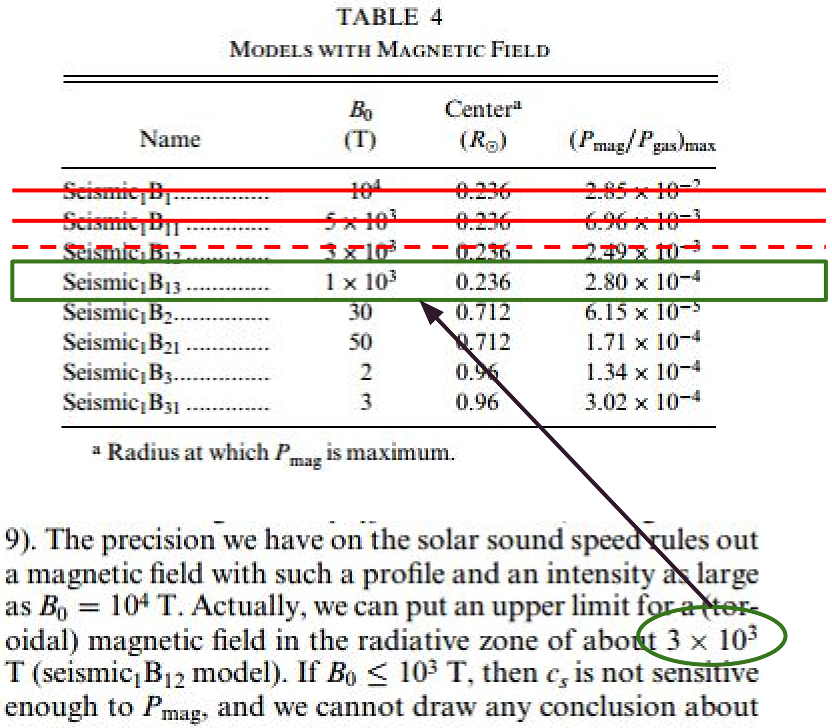


TABLE 4

MODELS WITH MAGNETIC FIELD

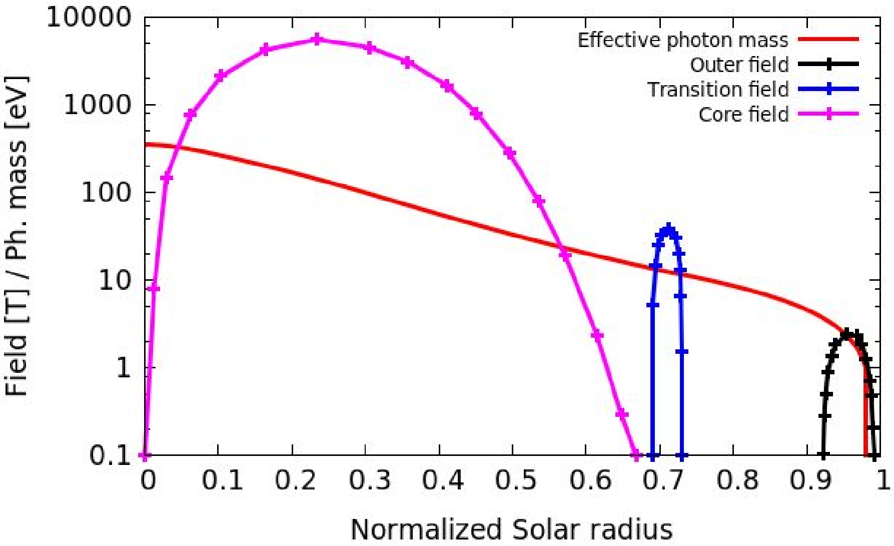
Name	B_0 (T)	Center[a] ($R_\odot$)	$(P_{\rm mag}/P_{\rm gas})_{\rm max}$
~~Seismic$_1$B$_1$..............~~	~~10^4~~	~~0.236~~	~~2.85×10^{-2}~~
~~Seismic$_1$B$_{11}$ ....~~	~~5×10^3~~	~~0.236~~	~~6.96×10^{-3}~~
~~Seismic$_1$B$_{12}$ ....~~	~~3×10^3~~	~~0.236~~	~~2.49×10^{-3}~~
Seismic$_1$B$_{13}$	1×10^3	0.236	2.80×10^{-4}
Seismic$_1$B$_2$..............	30	0.712	6.15×10^{-5}
Seismic$_1$B$_{21}$	50	0.712	1.71×10^{-4}
Seismic$_1$B$_3$..............	2	0.96	1.34×10^{-4}
Seismic$_1$B$_{31}$	3	0.96	3.02×10^{-4}

[a] Radius at which $P_{\rm mag}$ is maximum.

9). The precision we have on the solar sound speed rules out a magnetic field with such a profile and an intensity as large as $B_0 = 10^4$ T. Actually, we can put an upper limit for a (toroidal) magnetic field in the radiative zone of about 3×10^3 T (seismic$_1$B$_{12}$ model). If $B_0 \leq 10^3$ T, then c_s is not sensitive enough to $P_{\rm mag}$, and we cannot draw any conclusion about

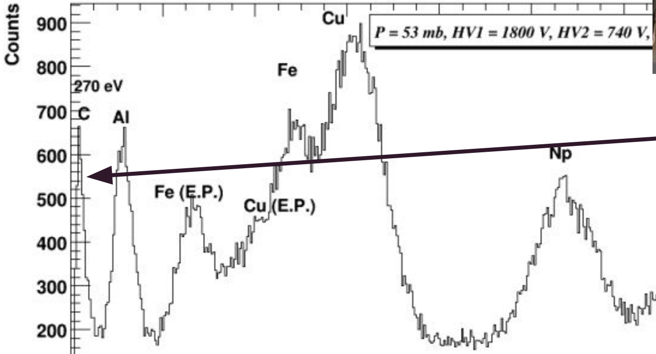
Assuming scattering factor for H $f_1 = 1$ and a purely Hydrogen Sun composition

$$m_\gamma \simeq 28.77\sqrt{\rho(r)[\mathrm{g/cm^3}]}\,\mathrm{eV}$$



Large volume TPCs for rare event searches

SEDINE spherical TPC
running at LSM
Record background levels actually
around 10 cpd/m^3/keV



Ultra low energy threshold TPC
270 eV C peak

Low energy investigations and applications with the spherical TPC

E Bougamont[1], P Colas[1], J Derre[1], I Giomataris[1], G Gerbier[1], M Gros[1], P Magnier[1], X F Navick[1], P Salin[3], I Savvidis[2] Show full author list

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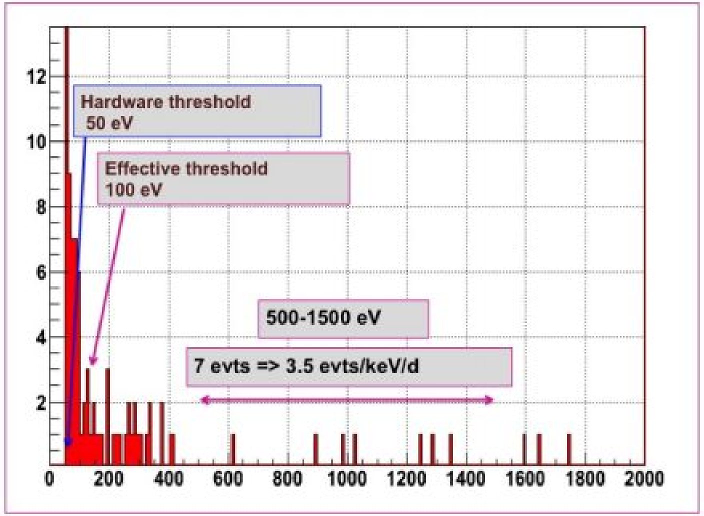
Journal of Physics: Conference Series, Volume 309, Number 1

Simplest TPC, low intrinsic radiopurity.
Single channel
Field cage and vessel same entity

arXiv:1412.0161 [astro-ph.IM]



TREX-DM

Gaseous time projection chambers for rare event detection: results from the T-REX project. II. Dark matter

I.G. Irastorza, F. Aznar, J. Castel, S. Cebrián, T. Dafni, J. Galán, J.A. Garcia, J.G. Garza, H. Gómez, D.C. Herrera Show full author list

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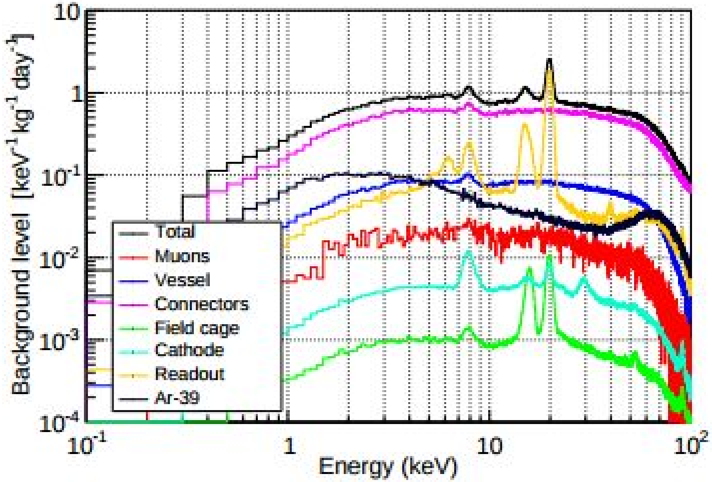
Journal of Cosmology and Astroparticle Physics, Volume 2016, January 2016

TREX-DM to be installed at LSC next year

Simulated background considering the radiopurity of different detector components



Existing magnet facilities

PC-MAG facility at DESY

“Portable” light weigth magnet.

(R=40cm L=1m) 1T solenoid magnet

(R=1.7m L=1.06m) 1.6 T magnet

Goliath magnet at CERN

SEHT test station at CEA Saclay (France)

21 T^2m^3

+10cm shielding
8 T^2m^3

AMELIE Search sensitivity prospects

1-year data taking
75 days per pressure setting

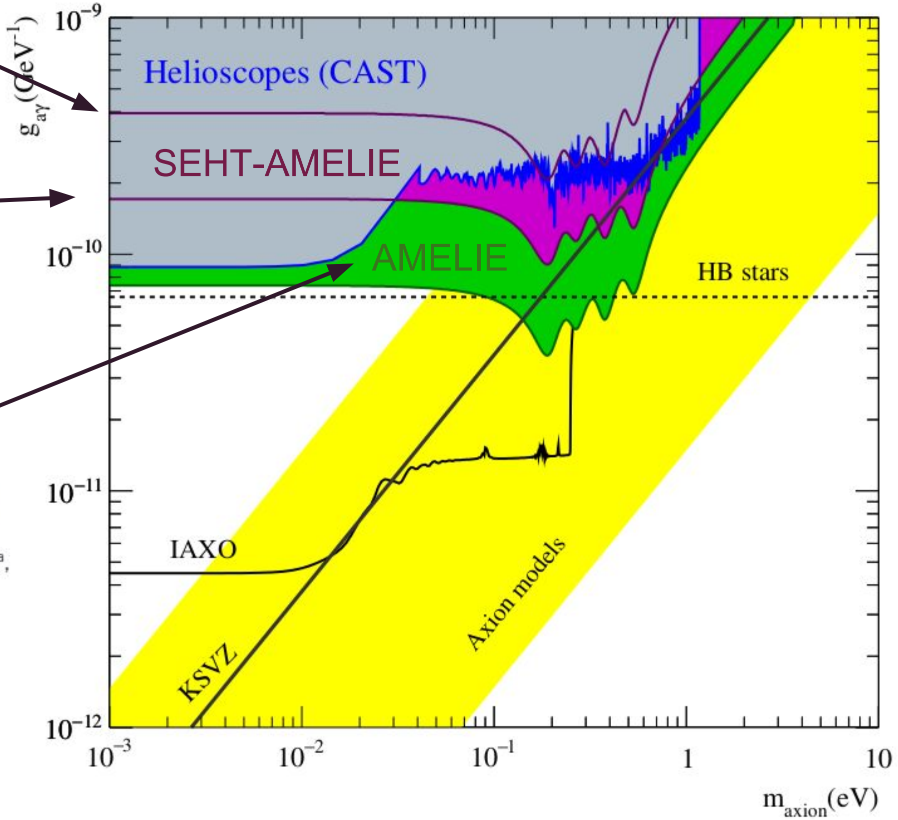
1000 cpd m^3 keV^{-1}

7.7 T^2 m^3

Level reachable underground 1 cpd m^3 keV^{-1}

10-year data taking program 0.1 cpd m^3 keV^{-1}

20 T^{2}m^3



Exploring 0.1 – 10 eV axions with a new helioscope concept

J. Galán[a], T. Dafni[a], E. Ferrer-Ribas[b], I. Giomataris[b], F.J. Iguaz[a], I.G. Irastorza[a], J.A. García[a], J.G. Garza[a], G. Luzon[a], T. Papaevangelou[b] Show full author list

Published 4 December 2015 • © 2015 IOP Publishing Ltd and Sissa Medialab srl

Journal of Cosmology and Astroparticle Physics, Volume 2015, December 2015

2.5T average field, R=30cm L=20m
1-magnet bore IAXO = 35 T^{2}m^3

Conclusions

- An independent technique for solar axion searches competitive with running experiments.
- Full angular sensitivity (allows to observe the full solar disk + CAB?). And not high accuracy alignment required.
- Improved gas density stability and broader axion mass coverage with a single setting. Longer data taking periods.
- Enables searches to very low energies (few ~200eV). Since detector and conversion volume are the same entity.
- Synergies with existing Rare event searches underground, TREX-DM.

Backup Slides

Production probability in a magnetic gas

$$i\partial_z \begin{pmatrix} A(z) \\ a(z) \end{pmatrix} = \begin{pmatrix} E_a - m_\gamma^2/2E_a - i\Gamma/2 & B' \\ B' & E_a - m_a^2/2E_a \end{pmatrix} \begin{pmatrix} A(z) \\ a(z) \end{pmatrix}$$

$$P_a(z) = |a(z)|^2 = \frac{B'^2}{q^2 + \Gamma^2/4}\left[1 + e^{-\Gamma z} - 2e^{-\Gamma z/2}\cos(qz)\right]$$

$$P_\gamma(z) = |A(z)|^2 = e^{-\Gamma z}\left\{1 - \cancelto{0}{\frac{B'^2}{q^2 + \Gamma^2/4} e^{\Gamma z/2}\cos(qz)} + \cancelto{0}{\mathcal{O}(B'^4)}\right\}$$

Photon in the dense plasma will be quickly absorbed.

The coherence length will depend on the mean free path of the photon.

Mean probability to convert a photon into axion

In practice we just integrate the probability of a photon to reach a distance z by the conversion probability at z

$$P_{\gamma a} = \int_0^\infty P_\gamma(z) P_a(z)\, dz \longrightarrow \boxed{P_{\gamma a} = \frac{1}{6}\, \frac{B'^2}{q^2 + \Gamma^2/4}}$$

Solar axion flux integration

Considering only the transversal component
we obtain the mean conversion probability
per photon integrated to 4**π**

$$P_{\gamma a} = \frac{1}{6} \; \frac{{B'_{\perp}}^{2}}{q^2 + \Gamma^2/4} = \frac{\pi^2}{96} \; \frac{{B'_{o}}^{2}}{q^2 + \Gamma^2/4}$$

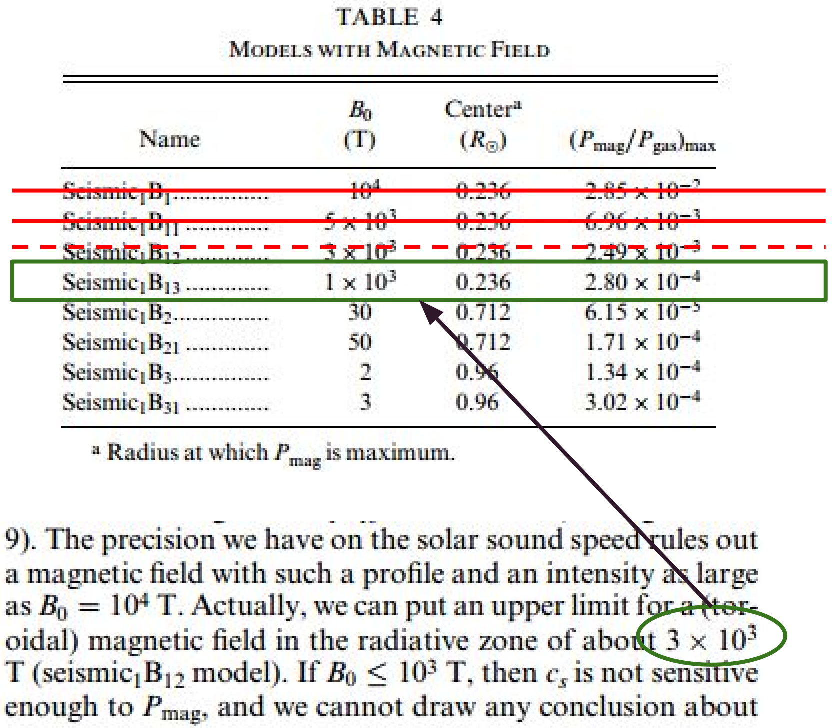
photon irradiance in thermal equilibrium

$$\frac{d\phi_a}{dE} = \frac{1}{4\pi d_{\odot}^2} \int_{V_{Sun}} P_{\gamma a} \, d^3\mathbf{r} \, \frac{1}{(2\pi)^2} \frac{E^3}{e^{E/T} - 1}$$

Flux in
cm^{-2} s^{-1} keV^{-1}

Solar axion production in the Sun inner magnetic fields

S.Couvidat, S. Turck-Chieze, A. Kosovichev, APJ 599, 1434 (2003)



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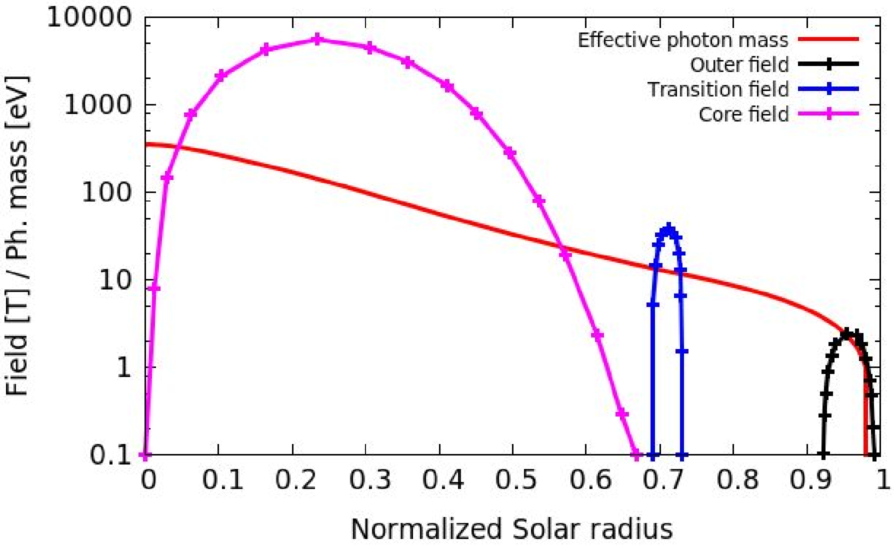
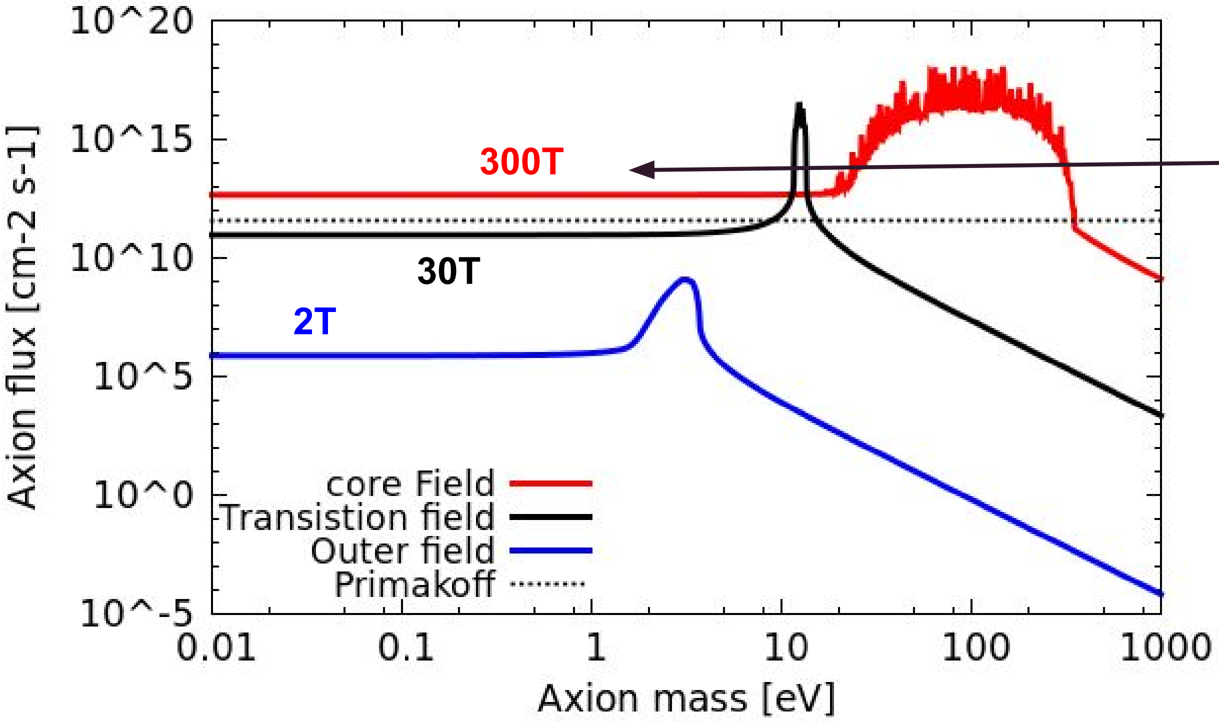


Solar axion production in the Sun inner magnetic fields

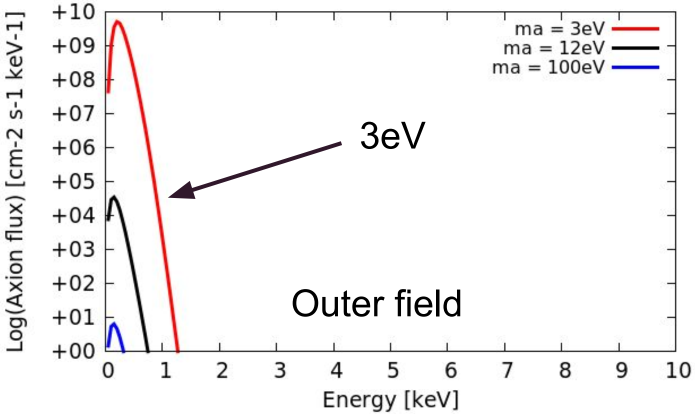


In the core **3000T are still allowed** without effect on Solar observables.

Calculation considering factor 10 reduction

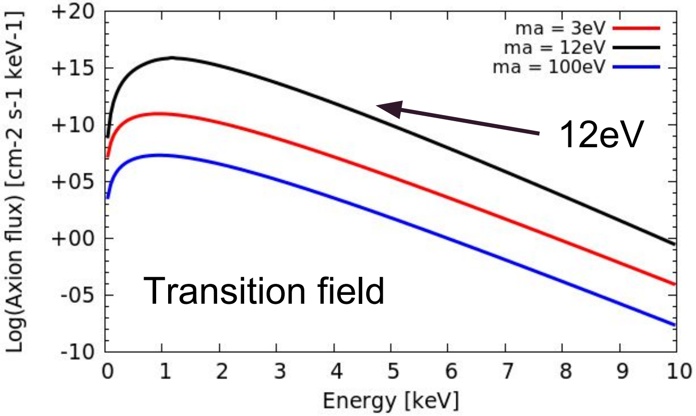
300T

Solar axion spectrum generated by the different magnetic regions



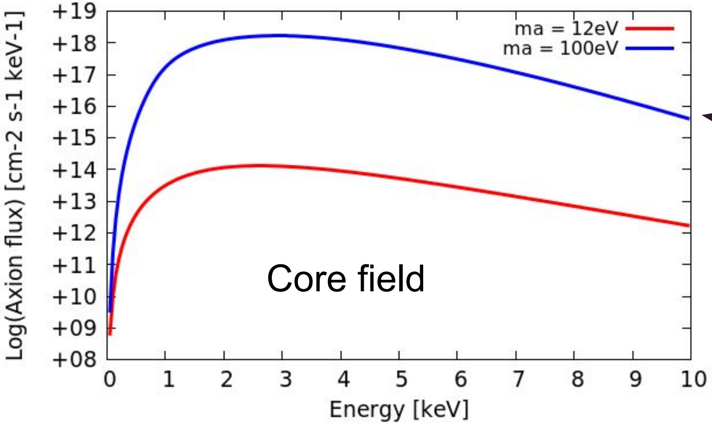
3eV

Outer field



12eV

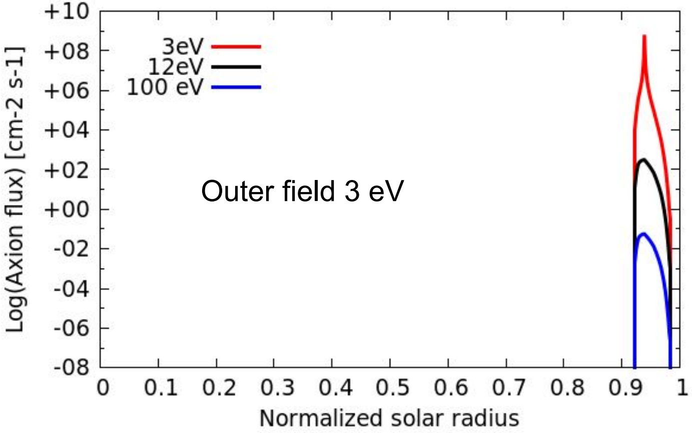
Transition field

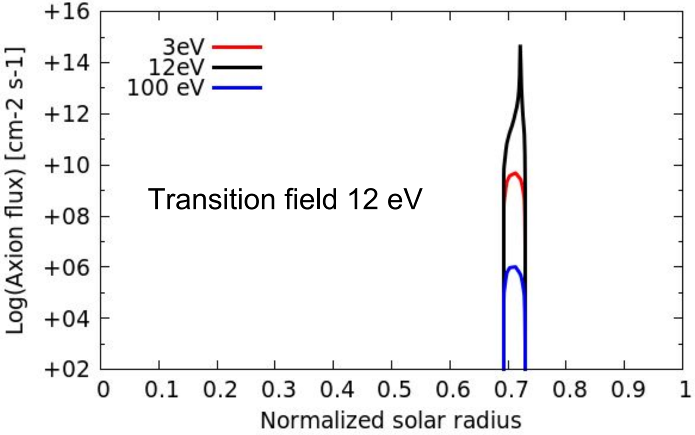


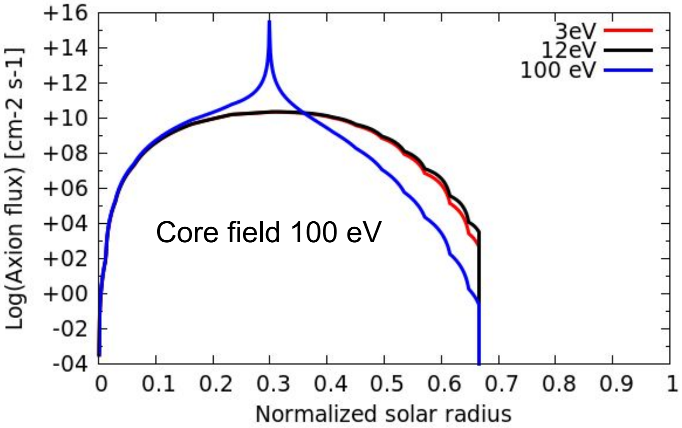
100eV

Core field

Differential axion flux production as a function of R



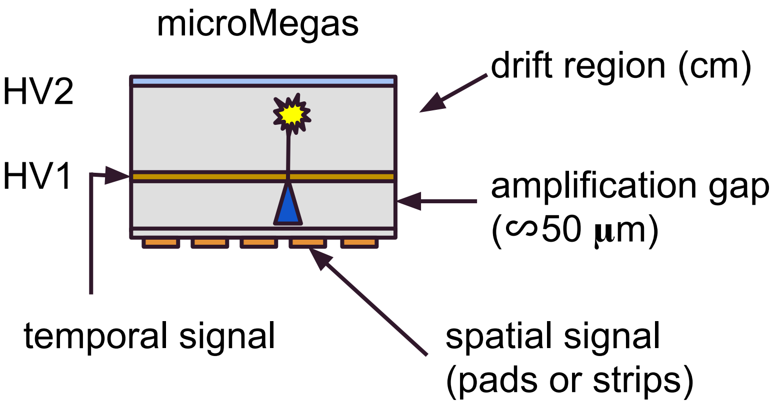




Spherical TPC Detection principle

Micromegas : Best results in terms of energy resolution and spatial resolution (few um)

Main advantage of micromegas is that amplification takes place in a **short amplification gap**



microMegas

HV2

HV1

drift region (cm)

amplification gap ($\backsim$50 μm)

temporal signal

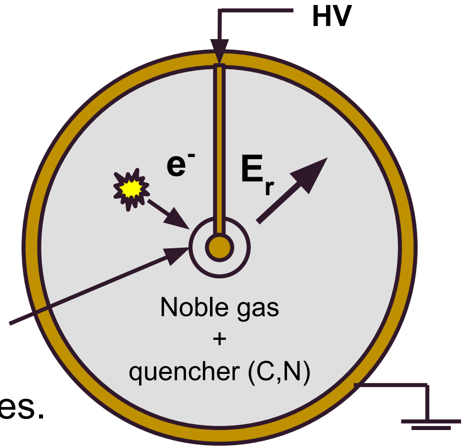
spatial signal (pads or strips)

Micromegas : Amplification given by (HV1-HV2)/d

Spherical TPC : Amplification given by HV and Rsensor. Definition of amplification gap and drift region relays on **strong field variation near the sensor**.

Low noise (few eV)
Spherical geometry

Simplified read-out
price for decreased spatial resolution



Intense field.
Enough to produce avalanche processes.

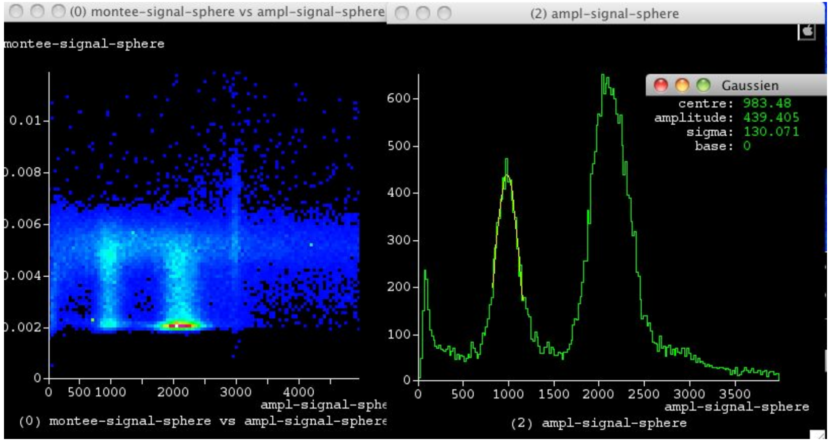
A spherical TPC for particle physics (neutrons, neutrinos, DM, ...)

Existing spheres running in ground and underground laboratories
(NEWS collaboration)

- **Large volume**
- Simplified read-out
- **Gas pressure flexibility** : from few mbar to several bar
- Good energy resolution
- **Low energy threshold**
- Field cage and vessel are one single entity.

Home made Ar-37 source: irradiating Ca-40 powder with fast neutrons 7x10^6neutrons/s

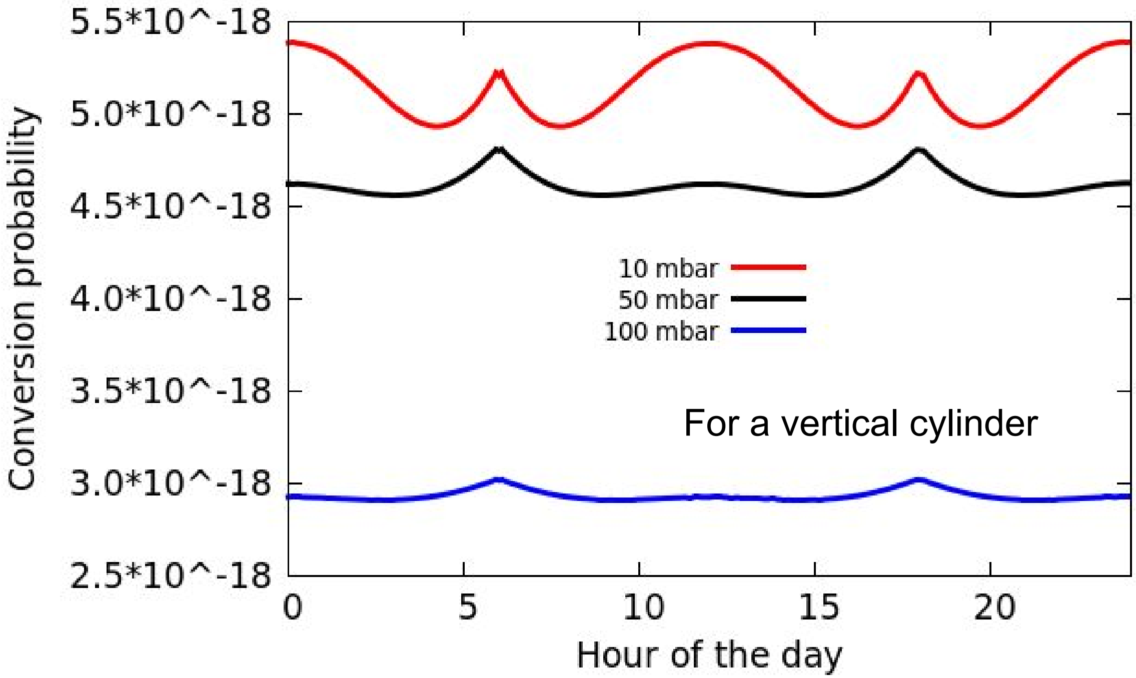
Irradiation time 14 days. Ar-37 emits K(2.6 keV) and L(260 eV) X-rays (35 d decay time)



```
   centre: 983.48
amplitude: 439.405
    sigma: 130.071
     base: 0
```

Effective conversion probability (Geometrical factor)

There is a geometrical factor to consider due to the different coherence lengths traversing the chamber.



For a vertical cylinder

Conversion probability is reduced when ΓL is not >> 1. And this relation does not apply

$$P_\gamma = \frac{(B/2M)^2}{q^2 + \Gamma^2/4}\Gamma L$$

Efficiency loss in Xenon

10 mbar	21.5%
50 mbar	11.9%
100 mbar	6.9%
500 mbar	1.4%
5 bar	0.13%

Small diurnal effect and negligible annual variations