Quantum Universe Kick-Off Meeting
DM 2.1

Light Dark Matter Searches With Haloscope Experiments

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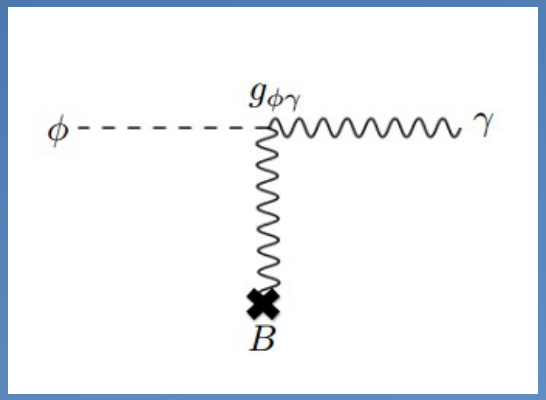
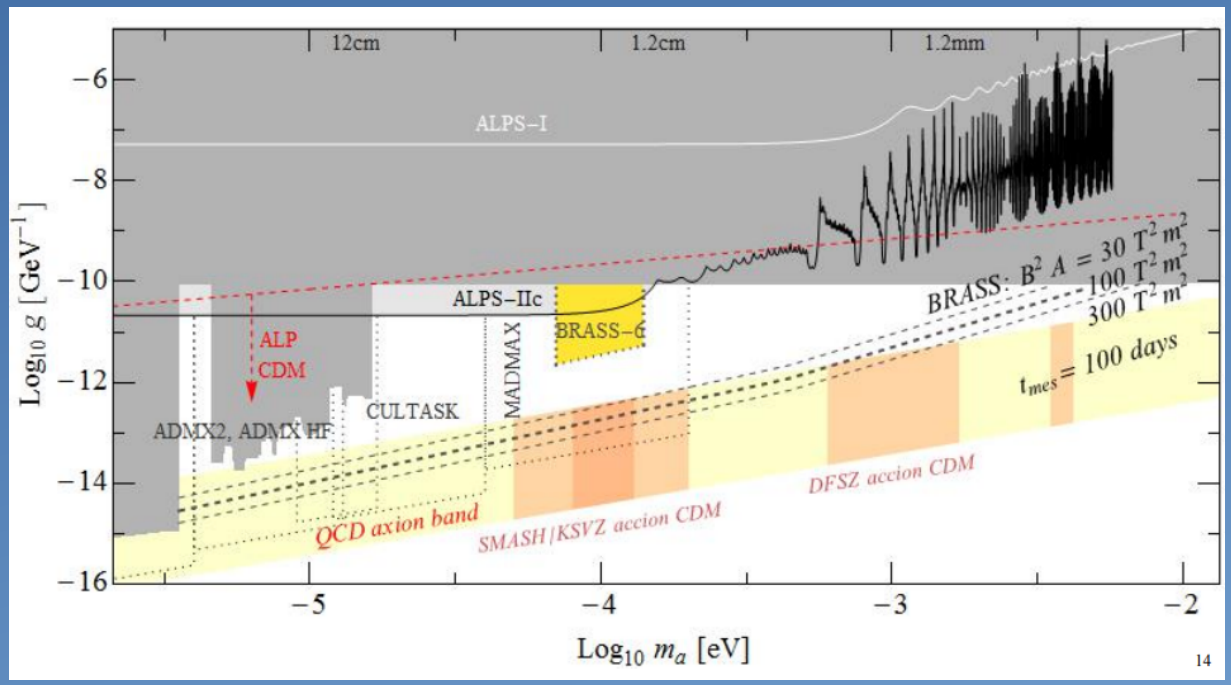
WISPs: Axion and ALPs

- The Peccei-Quinn solution to CP violation of strong interaction (d_n is too small) results in an axion.
- In the early universe, cold axion populations arise from vacuum realignment and string decay.
- ALPs are predicted by several string theory motivated extensions of SM.

$$\mathcal{L} \supset -\frac{1}{4} g_{\phi\gamma} F_{\mu\nu} F^{\mu\nu} \phi = g_{\phi\gamma} \vec{E} \cdot \vec{B} \phi$$

Axion-photon conversion requires the magnetic field [1,2]





From Andrei's talk in Patras18

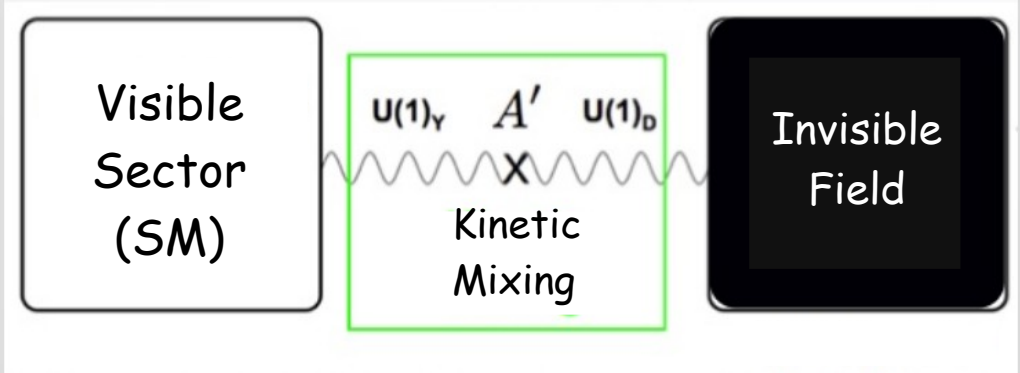
WISPs: Hidden Photon

- Hidden Photon (HP) as an additional gauge field U (1) which kinetically mixes with the SM's U(1).
- Mediator particle between invisible field and the observable field (SM).
- HP can convert to photon without the magnetic field.

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{\chi}{2}F_{\mu\nu}X^{\mu\nu} + \frac{m_X^2}{2}X_\mu X^\mu + ej_\mu A^\mu.$$

Mixing term between two U(1)s

Mass term of the hidden U(1)



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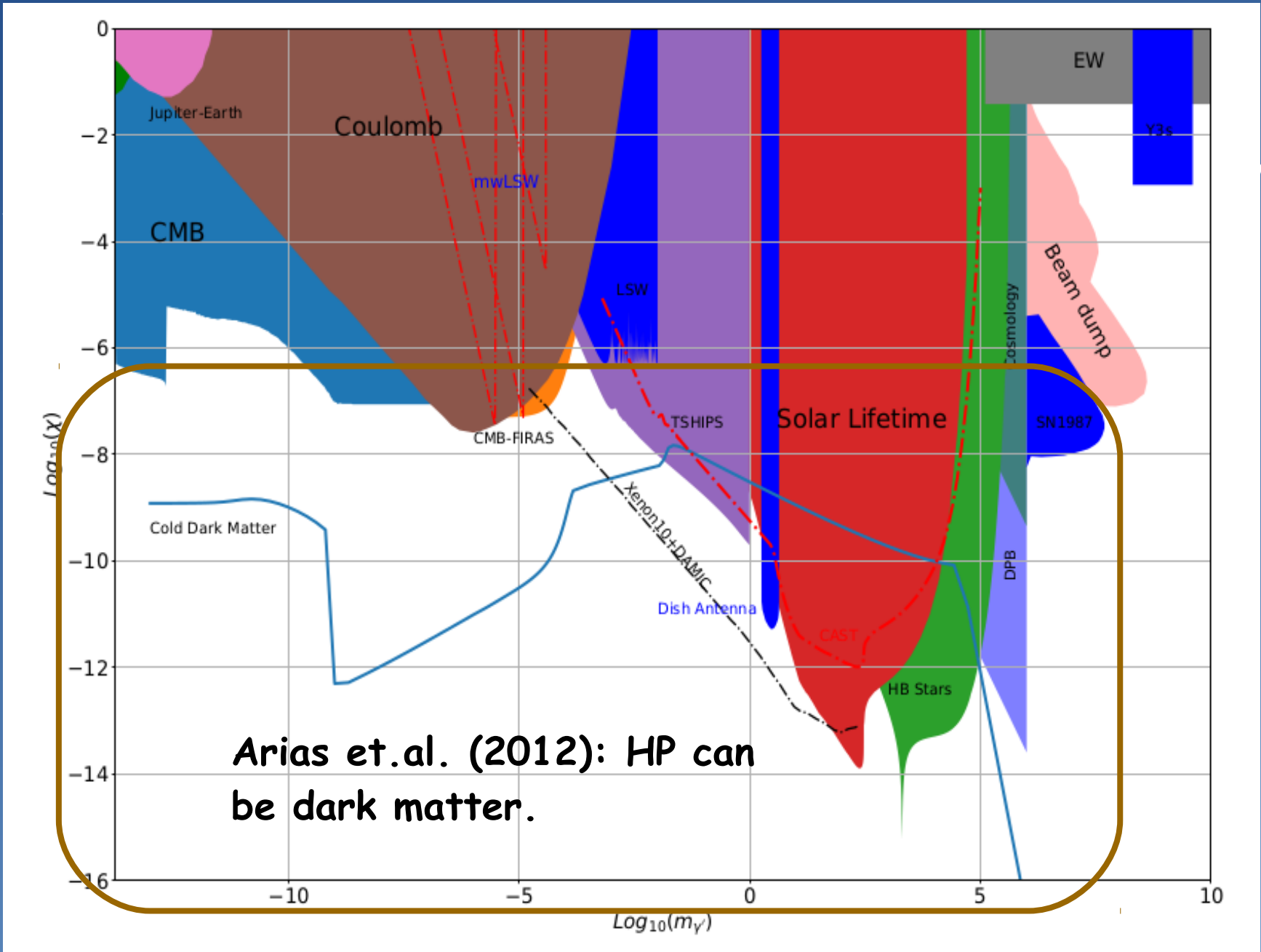

Jupiter-Earth
Coulomb
mwLSW
CMB
LSW
EW
Y3s
Beam dump
Cosmology
CMB-FIRAS
TSHIPS
Solar Lifetime
SN1987
Cold Dark Matter
Xenon10+DAMIC
Dish Antenna
DPB
CAST
HB Stars
Arias et.al. (2012): HP can be dark matter.
$Log_{10}(\chi)$
$Log_{10}(m_{\gamma'})$
0
−2
−4
−6
−8
−10
−12
−14
−16
−10
−5
0
5
10

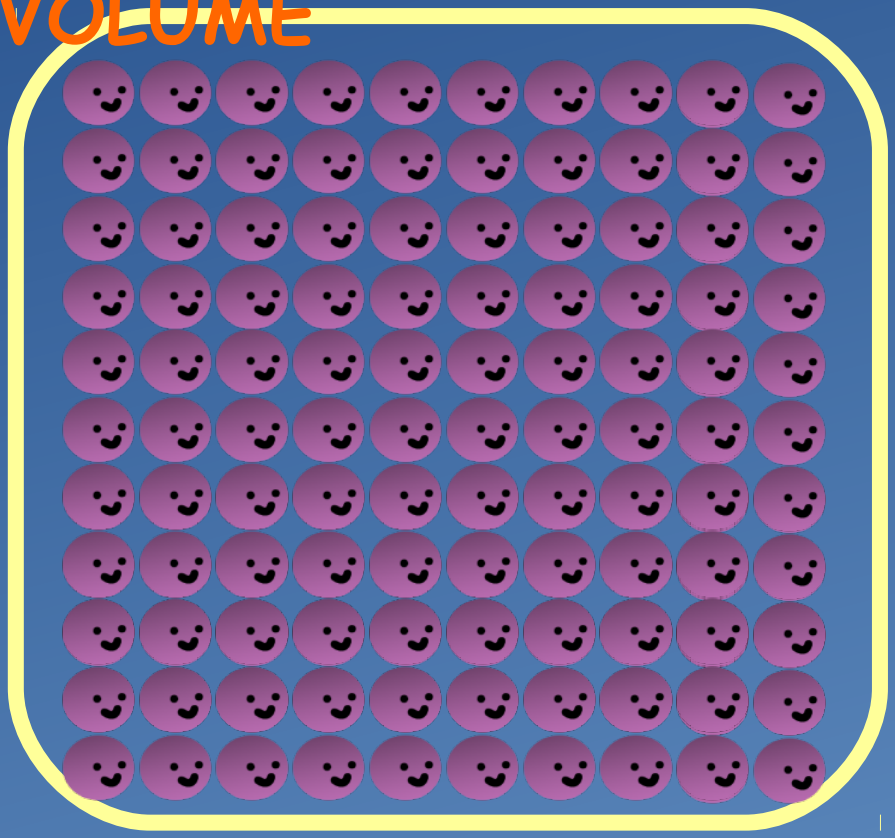
Haloscope Type Experiment

WISPs is everywhere

FIXED SPACE

VOLUME

$$\rho_{\mathrm{CDM}} = 0.39\ \mathrm{GeV/cm^3}$$



$\mathrm{Mass}_{\mathrm{WISP}} \sim 10^{-7} - 10^{-2}\mathrm{eV}$

WISPs DM particle could be everywhere at a high density.

Haloscope Type Experiment

WISPs is everywhere

FIXED SPACE VOLUME

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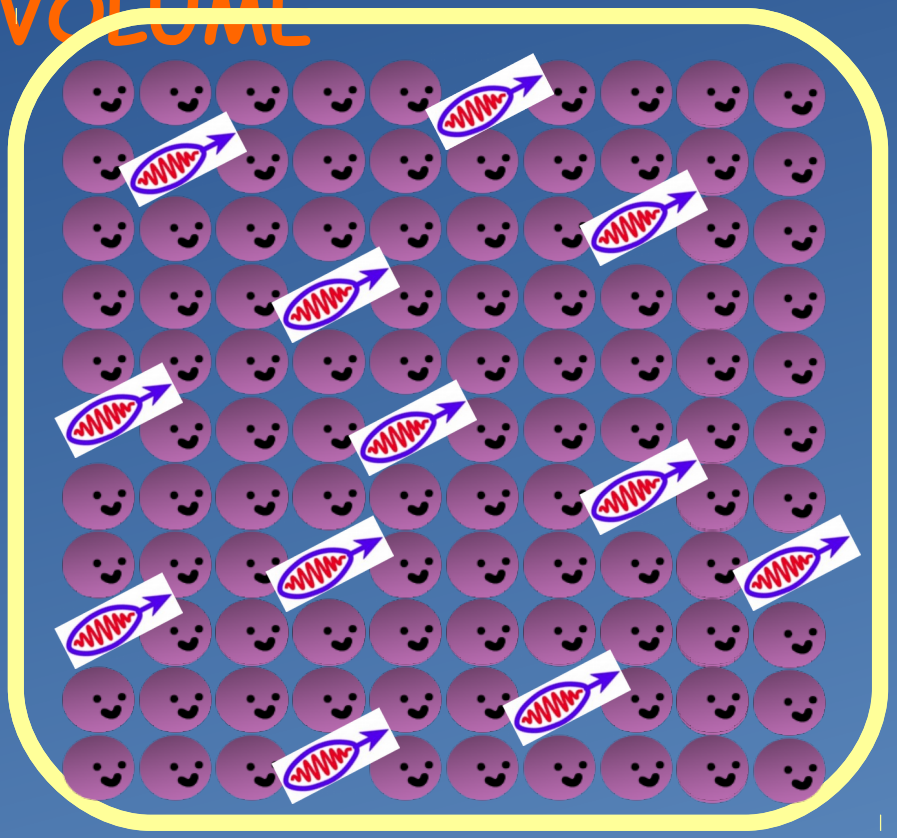

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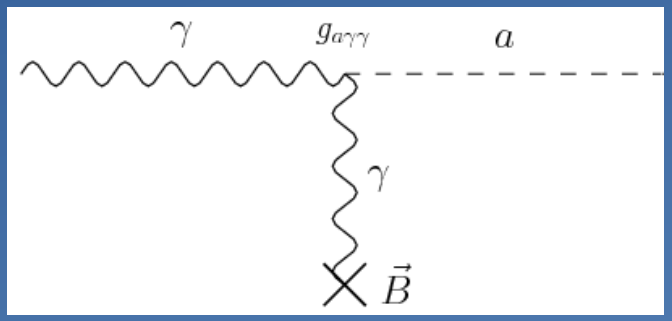
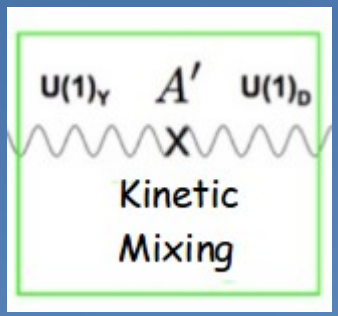


Primakoff effect for axion and ALPs

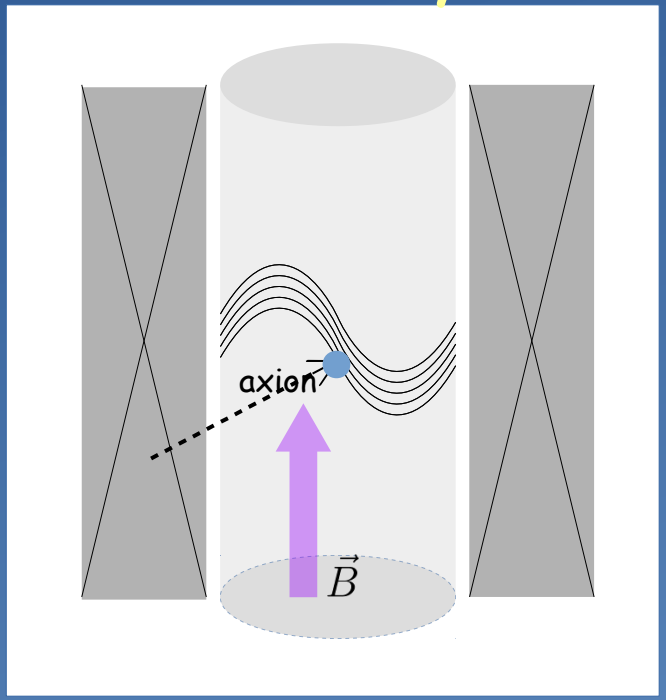


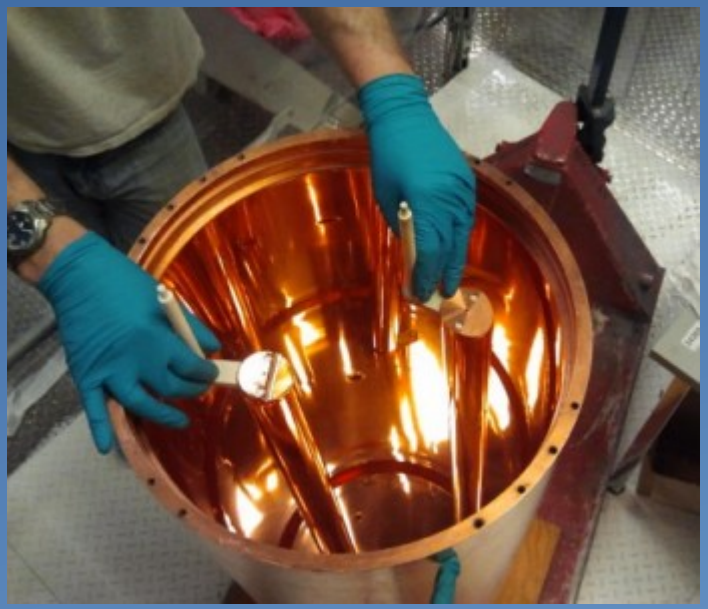
Kinetic mixing for Hidden Photon.

Traces of WISPs can be tracked by searching for their signal in the form of the electromagnetic wave.

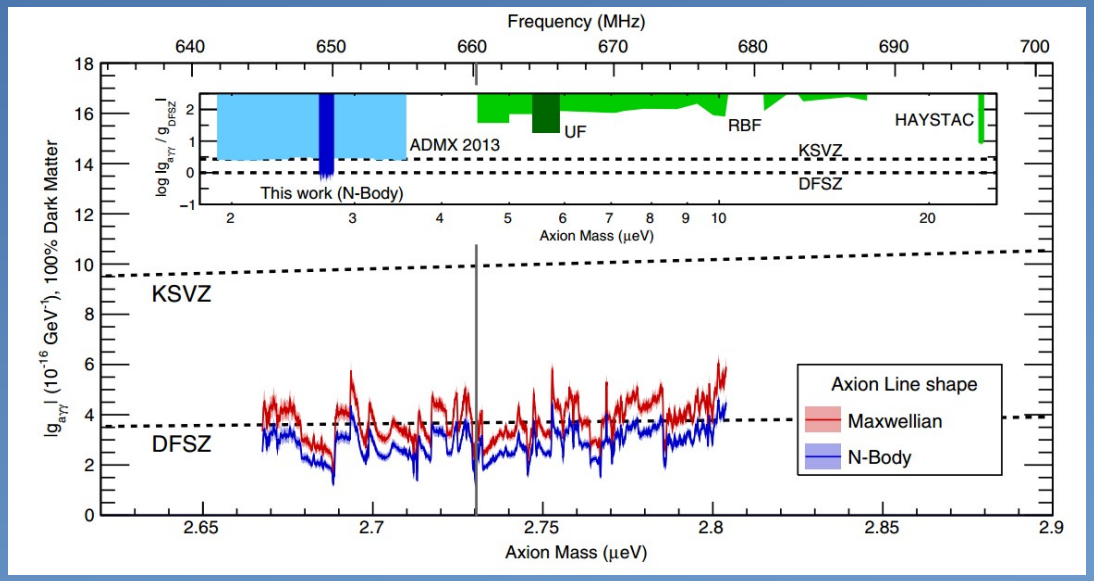
WISPs search with Resonant Cavity

- Proposed by Sikivie (1983).
- A well-known techniques in search for the axion CDM.
- Search for resonant frequency is narrowed in a single resonant mode (tunable).
- ADMX, CULTASK, HAYSTACK are focus on the axion DM.





From [6]



From [7]

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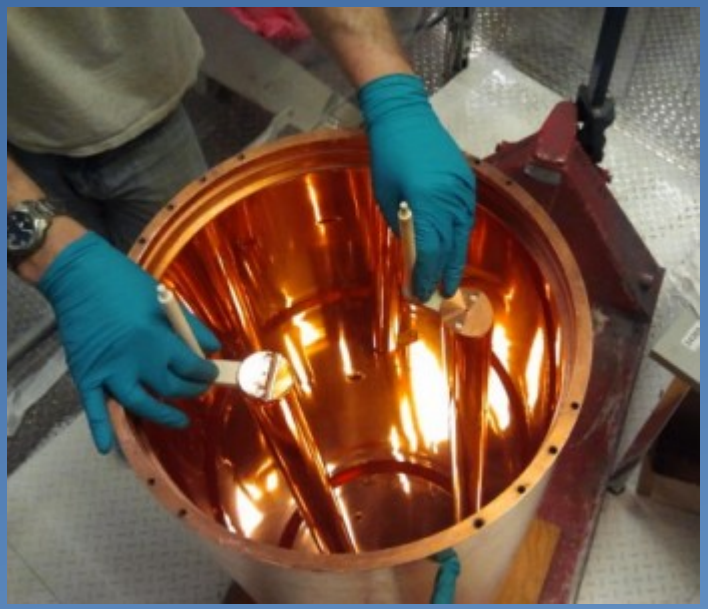
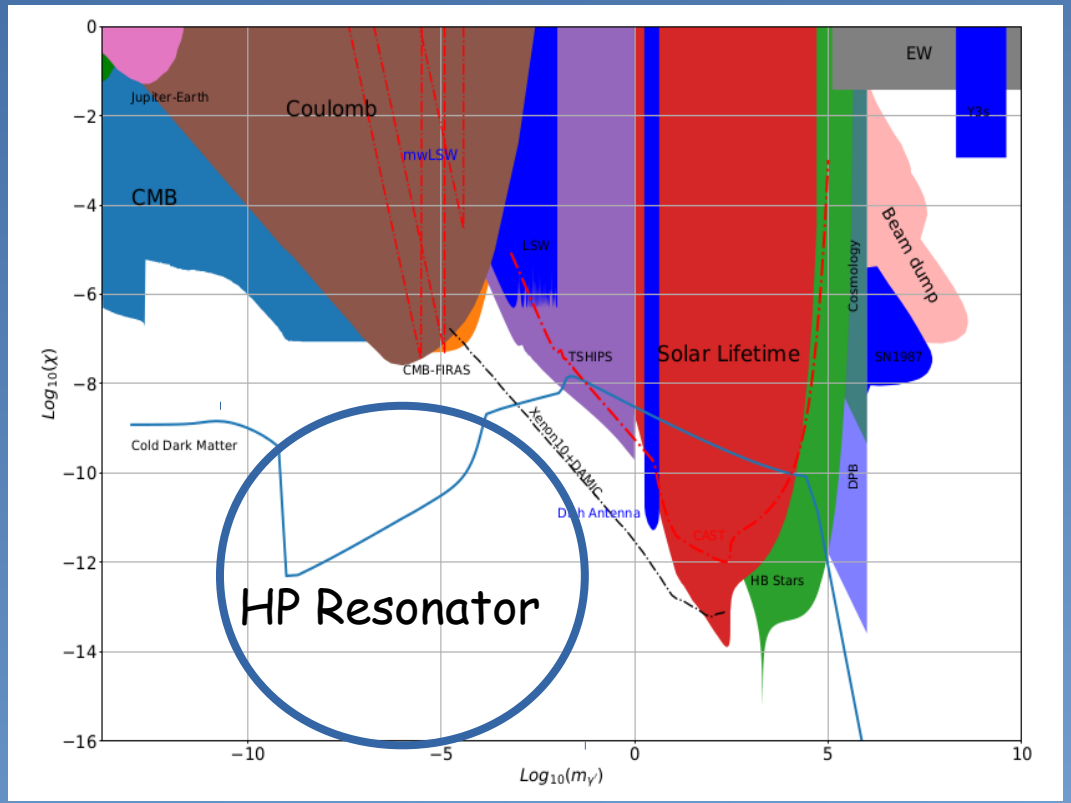
Arias et.al. (2012) shows that resonant cavity also sensitive to HP CDM.

$$P_{\rm out} = \kappa \chi^2 m_{\gamma'} \rho_{\rm CDM} Q V \mathcal{G}.$$



From [6]

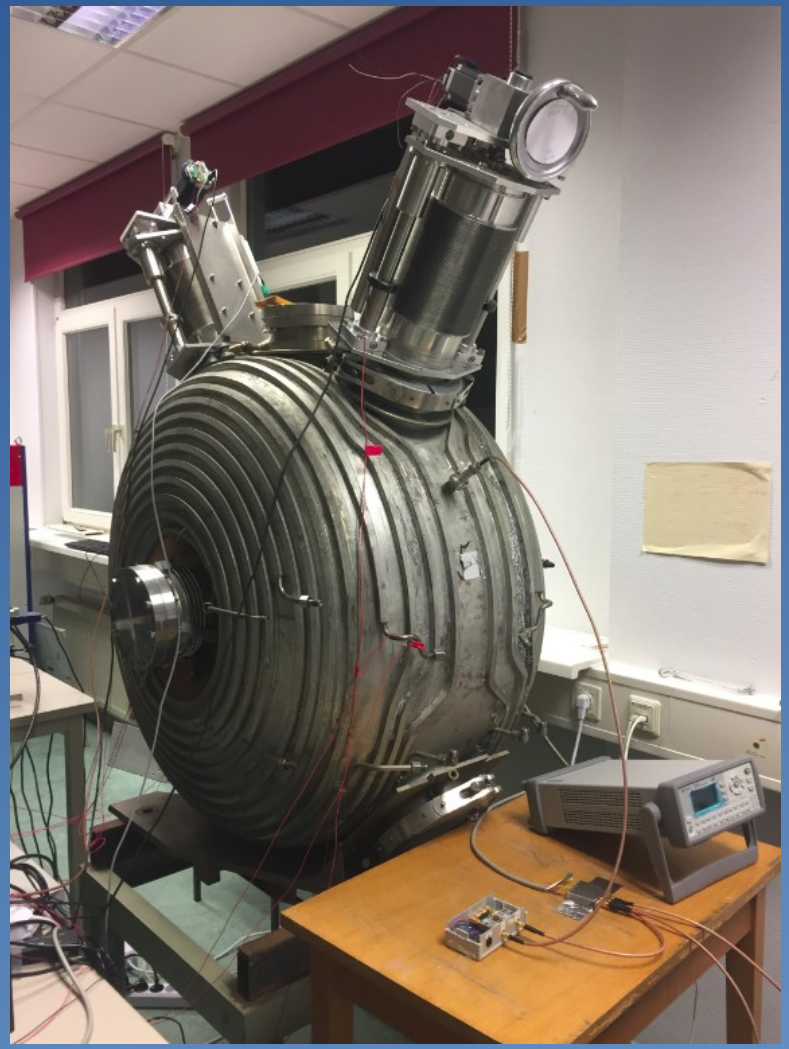


WISPs search with Resonant Cavity

Experiments, R&D in University of Hamburg

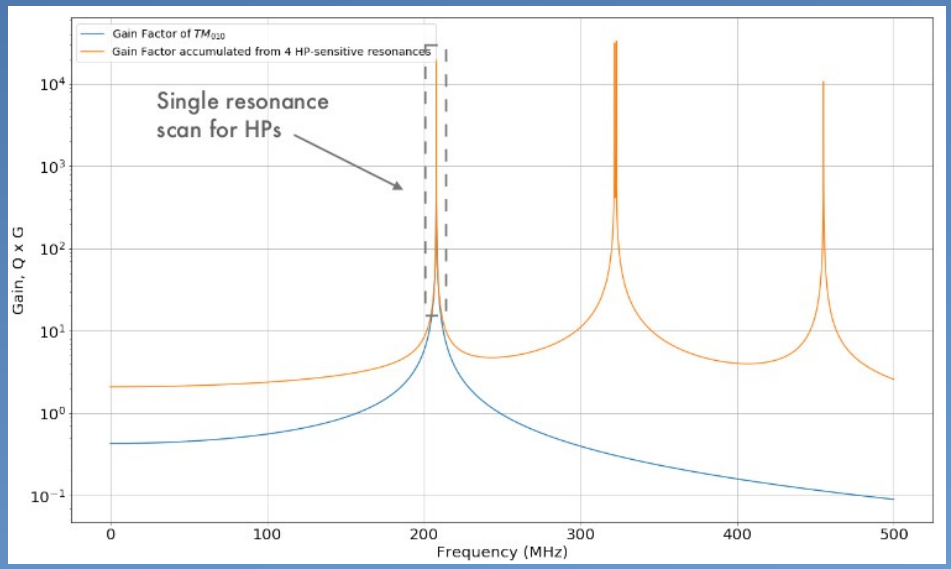
WISP Dark Matter eXperiment
(WISPDMX)

Supported by DESY and MPIfR - Bonn



$$\chi = 2.9 \cdot 10^{-15} \sqrt{\mathrm{SNR}} \left(\frac{t}{1\mathrm{s}}\right)^{-1/4} \left(\frac{T}{100\mathrm{K}}\right)^{1/2} \cdot \left(\frac{\kappa}{0.1} \frac{Q}{50000} \frac{V}{447\ \mathrm{liter}} \frac{\mathcal{G}_{\gamma'}}{0.3} \frac{m_{\gamma'}}{\mu eV} \frac{\rho_0}{\mathrm{GeV/cm}^3}\right)^{-1/2}$$

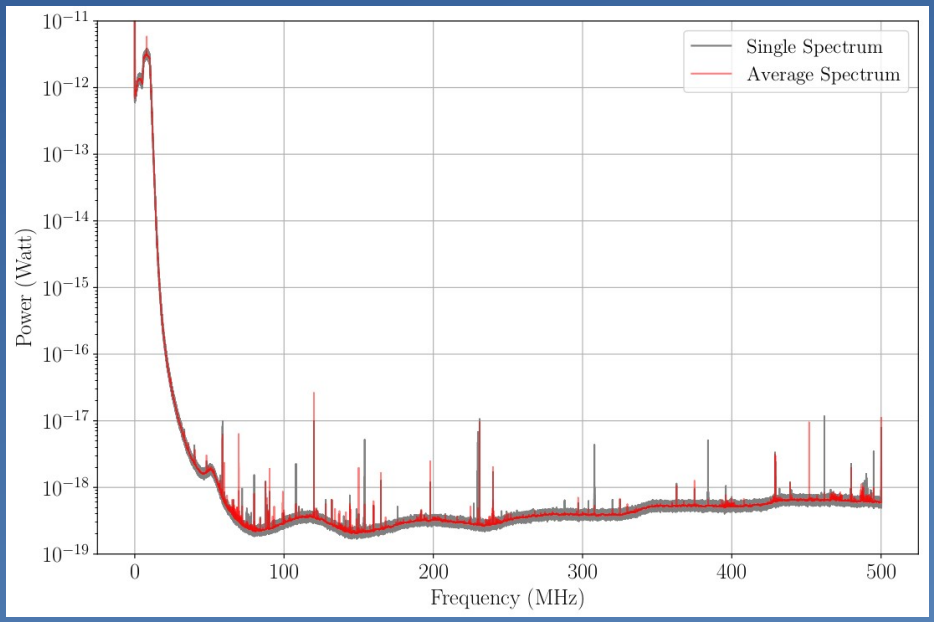
- DAQ allows WISPDMX take broadband spectrum of 500 MHz with high resolution.
- Broadband gain covers the large mass range of HP.



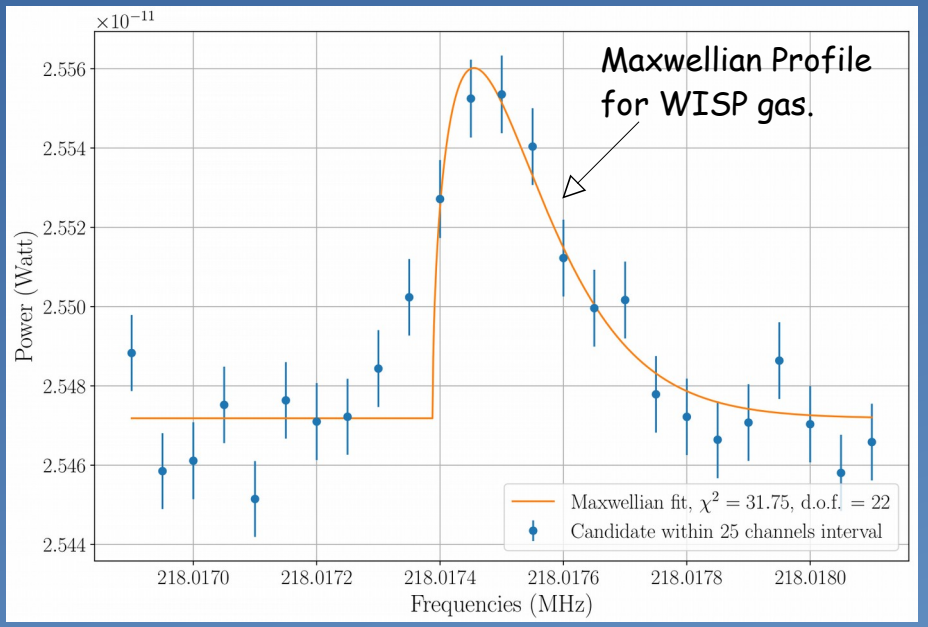
WISPs search with Resonant Cavity

Experiment, R&D in University of Hamburg

Result from the WISPDMX's First Science Run: 61.5 Hours of Data



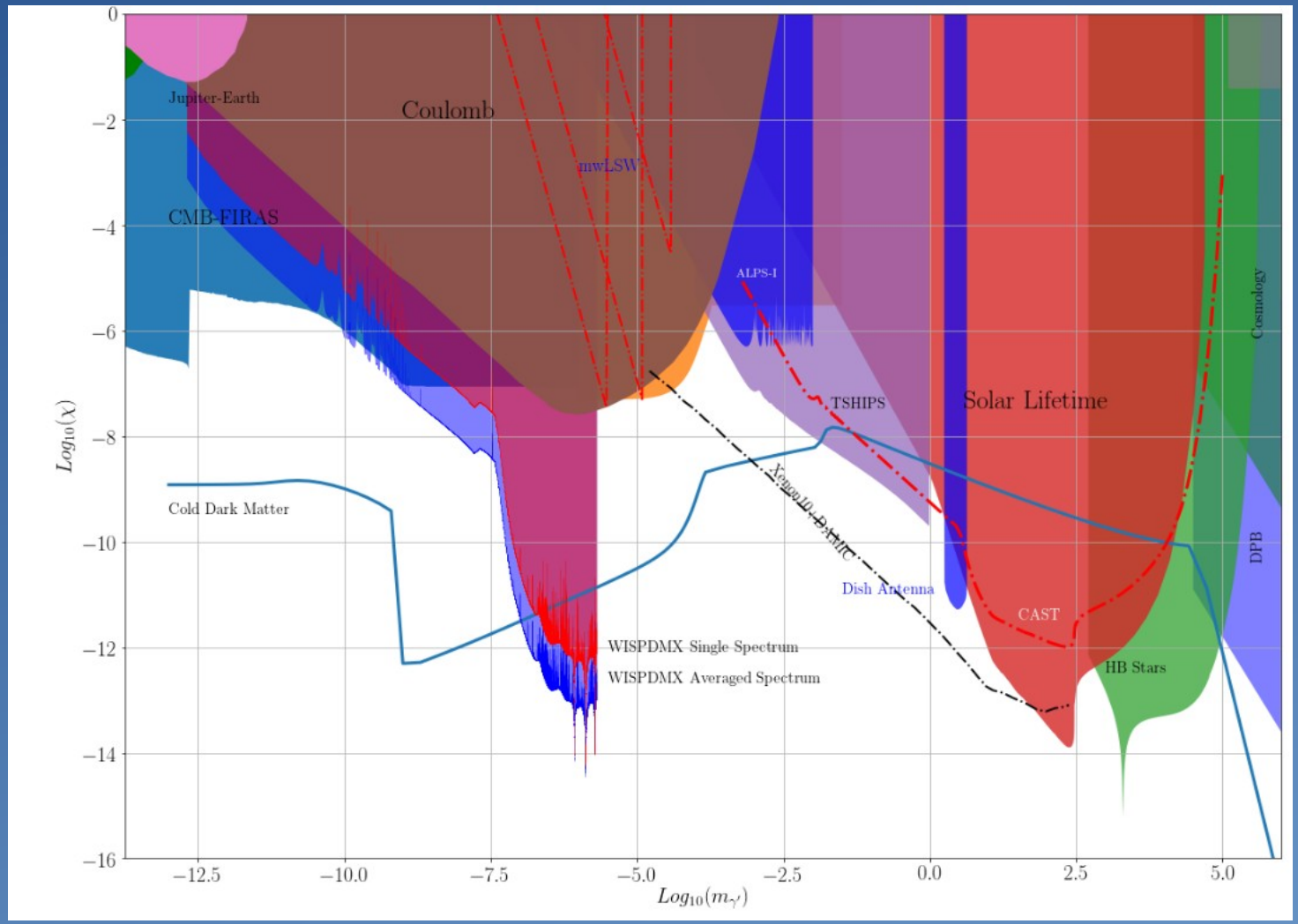
Lowest Power Detectable by WISPDMX run I



The best candidate from the run I

WISPs search with Resonant Cavity

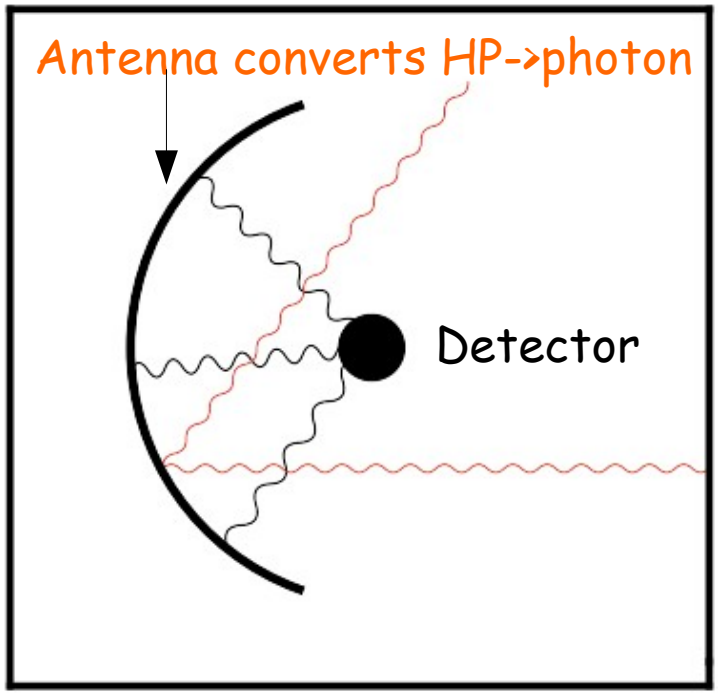
Experiment, R&D in University of Hamburg



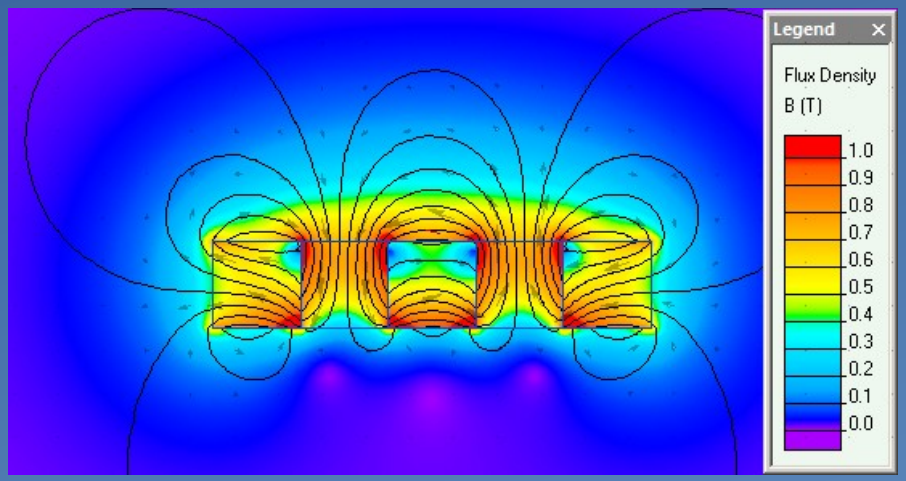
The exclusion limit of the mixing constant χ to the mass of hidden photon.

B.R.A.S.S.

Broadband Radiometric Axion Searches



"Searching for WISPy Cold Dark Matter with a Dish Antenna" [arXiv:1212.2970]



Halbach Array as Conversion Surface

Hidden Photon

$$\chi_{\rm sens} = 4.5 \times 10^{-14} \left(\frac{P_{\rm det}}{10^{-23}\,{\rm W}}\right)^{\frac{1}{2}} \left(\frac{0.3\,{\rm GeV/cm^3}}{\rho_{\rm CDM,halo}}\right)^{\frac{1}{2}} \left(\frac{1\,{\rm m^2}}{A_{\rm dish}}\right)^{\frac{1}{2}} \left(\frac{\sqrt{2/3}}{\alpha}\right).$$

Axion and ALPs

$$g_{\phi\gamma\gamma,\,\rm sens} = \frac{3.6 \times 10^{-8}}{\rm GeV} \left(\frac{5\,{\rm T}}{\sqrt{\langle |\mathbf{B}_{||}|^2 \rangle}}\right) \left(\frac{P_{\rm det}}{10^{-23}\,{\rm W}}\right)^{\frac{1}{2}} \left(\frac{m_\phi}{\rm eV}\right) \left(\frac{0.3\,{\rm GeV/cm^3}}{\rho_{\rm DM,halo}}\right)^{\frac{1}{2}} \left(\frac{1\,{\rm m^2}}{A_{\rm dish}}\right)^{\frac{1}{2}}$$

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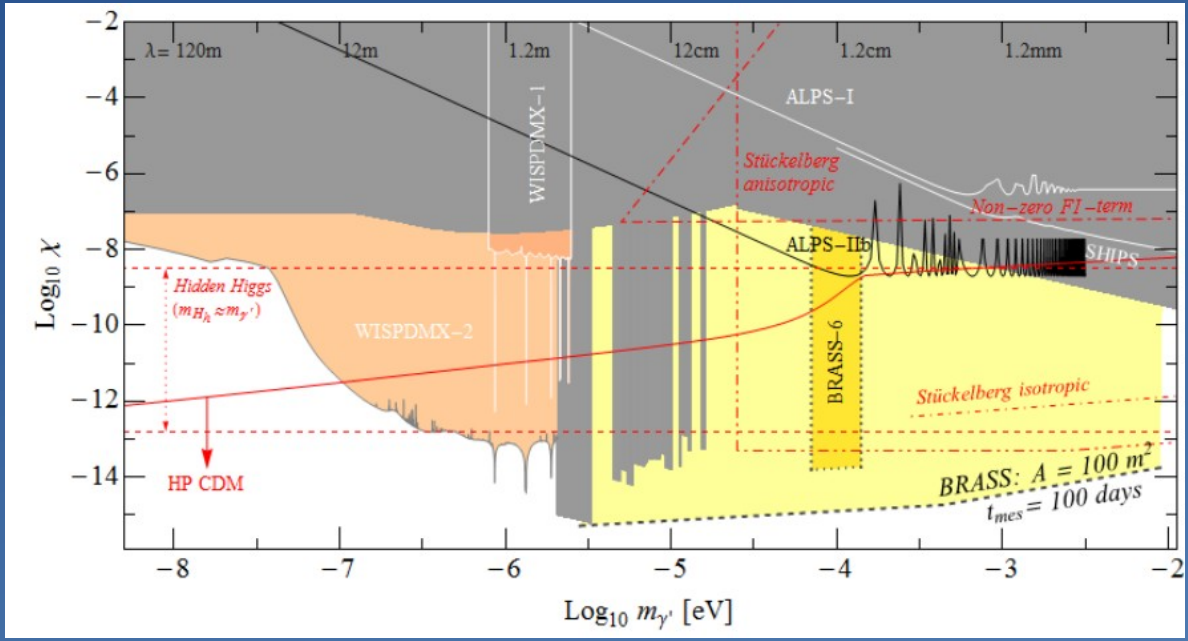
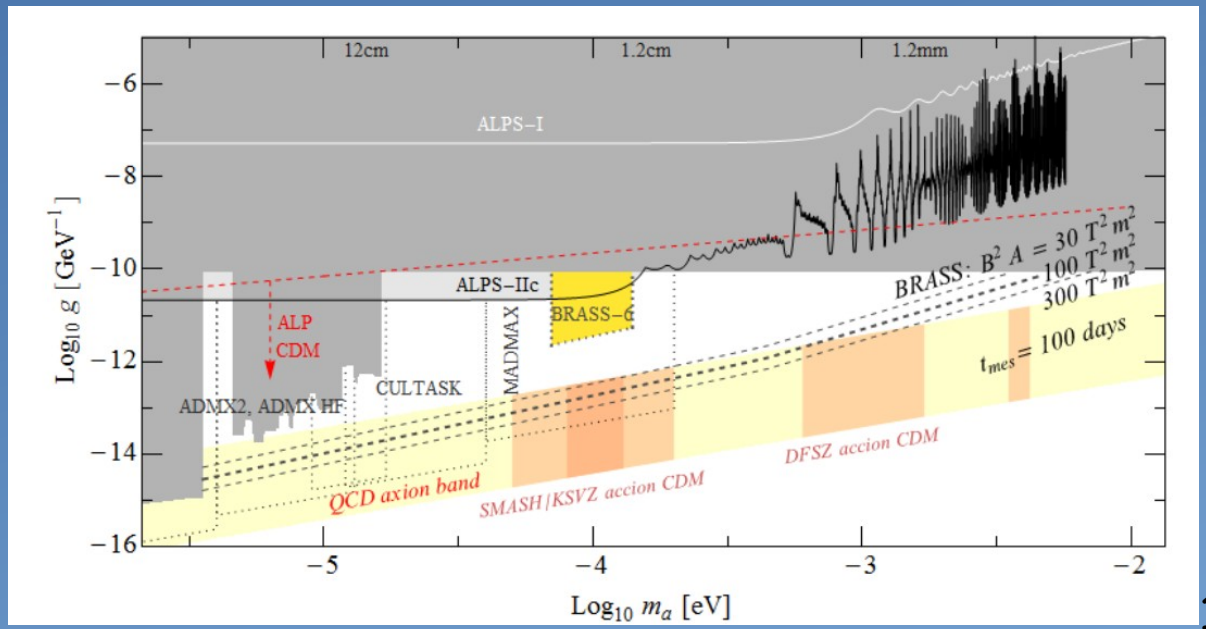
Broadband Radiometric Axion Searches

Hidden Photon



Axion and ALPs



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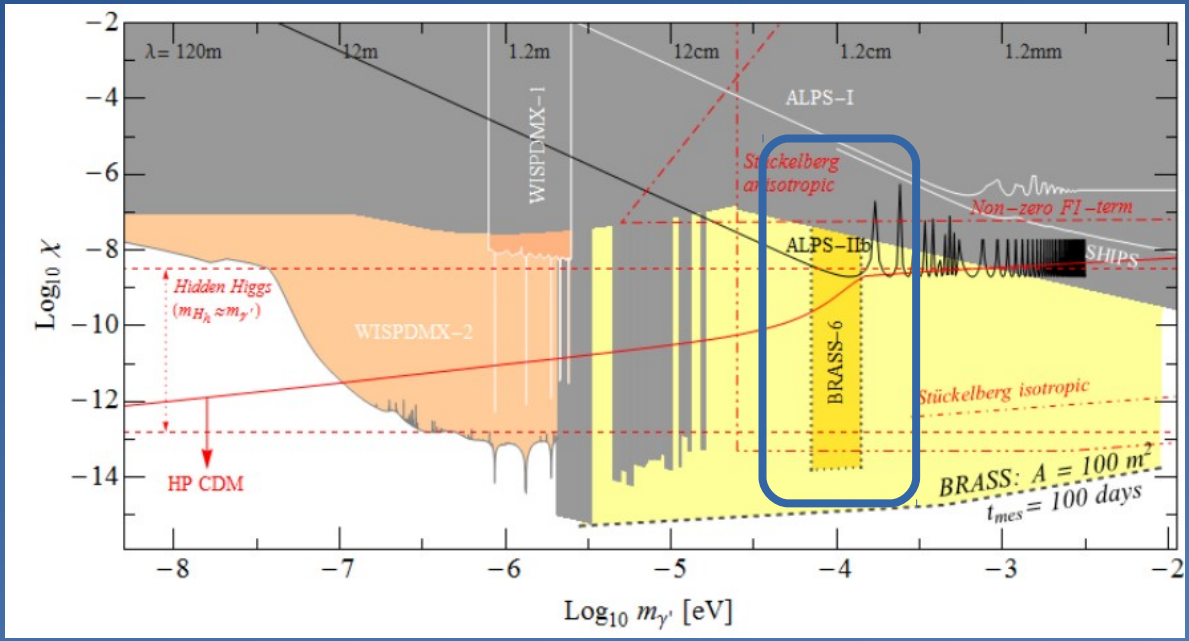
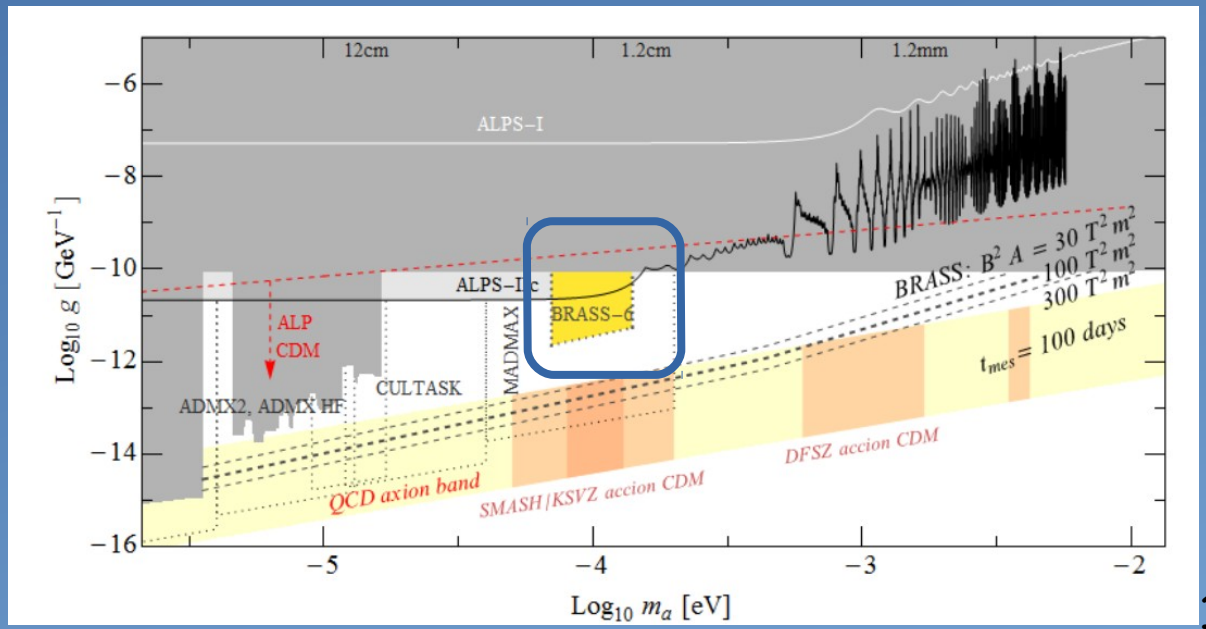
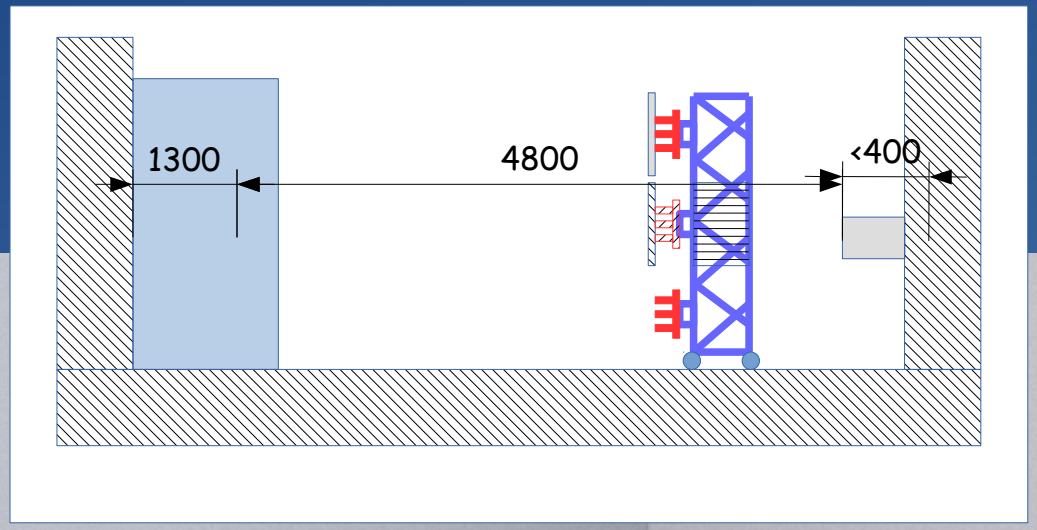


Hidden Photon



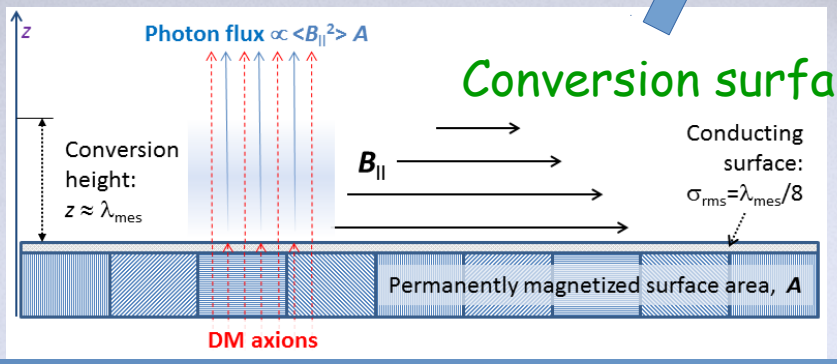
Axion and ALPs



axion

Broadband Receiver

Reflector (d = 2.5m)



Conversion surface

Thank you for attention.

1) P. Sikivie, "Experimental tests of the 'invisible' axion," Physical Review Letters, vol. 51, pp. 1415–1417, Oct. 1983.

2) G. Raffelt and L. Stodolsky, "Mixing of the photon with low-mass particles," Phys Rev D., vol. 37, pp. 1237–1249, Mar. 1988.

3) Paola Arias, Davide Cadamuro, Mark Goodsell, Joerg Jaeckel, Javier Redondo, and Andreas Ringwald. WISPy Cold Dark Matter. JCAP, 1206:013, 2012. doi: 10.1088/1475-7516/2012/06/013.

4) Leanne D. Duffy and Karl van Bibber. Axions as Dark Matter Particles. New J. Phys., 11:105008, 2009. doi: 10.1088/1367-2630/11/10/105008.

5) Principal properties of the velocity distribution of dark matter particles near the Solar System, Anton N Baushev 2012 J. Phys.: Conf. Ser. 375 012048

6) http://www.ectstar.eu/sites/www.ectstar.eu/files/talks/2017Rybka_Trento_ADMX.pdf

7) Search for Invisible Axion Dark Matter with the Axion Dark Matter Experiment N. Du et al. (ADMX Collaboration) Phys. Rev. Lett. 120, 151301 – Published 9 April 2018

8) http://people.roma2.infn.it/~dama/pdf/bernabei_staralesna_web.pdf