Terrestrial tests of the axiverse.

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(DESY)

The Beecroft Institute Workshop on the Axiverse,
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11 January 2013

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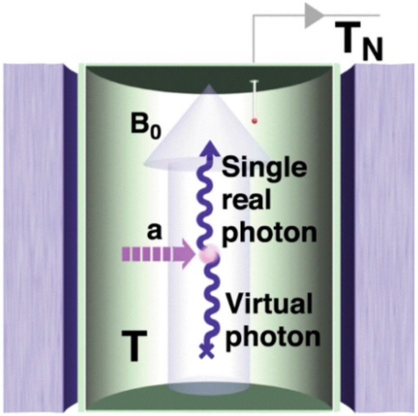
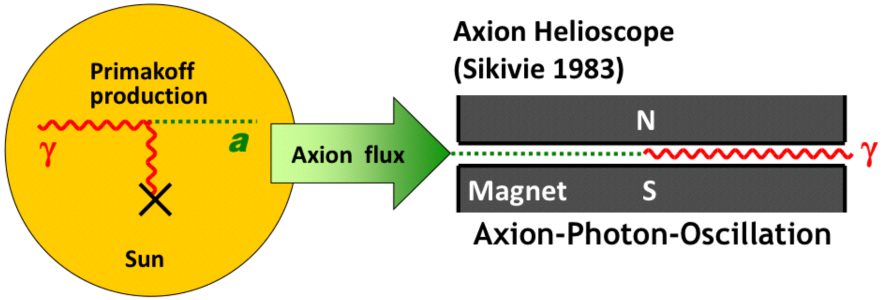
DESY

Terrestrial searches for axions and axion-like particles

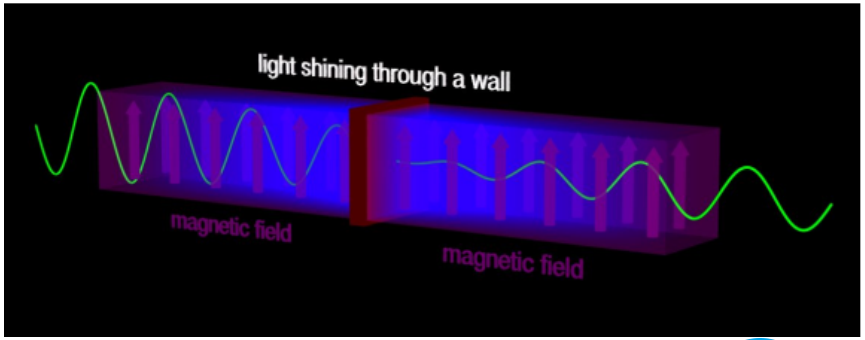
- Direct detection of dark matter axions or axion-like particles (ALPs) (haloscopes)



- Indirect detection of solar axions and ALPs (helioscopes)



- Direct production and detection of ALPs (light shining through walls experiments)

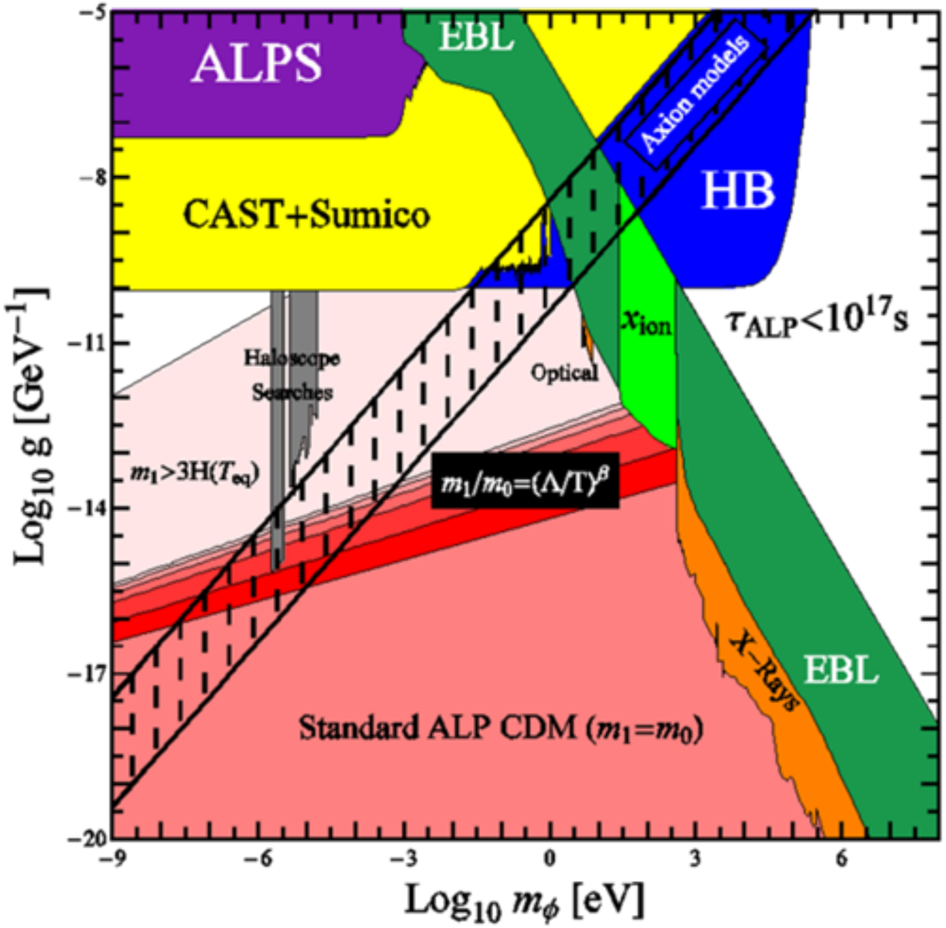


Direct detection of axion or ALP dark matter

- Axions and axion-like particles (ALPs) may be produced non-thermally via vacuum realignment in form of classical, spatially coherent field oscillations = coherent state of extremely non-relativistic dark matter
  (Preskill et al 83; Abbott,Sikivie 83; Dine,Fischler 83; Cadamuro et al 12)
  - Axion and ALPs can contribute significantly to cold dark matter for $f_a \gtrsim 10^9\ \mathrm{GeV}$
  - $g_{a\gamma} \lesssim 10^{-12}\ \mathrm{GeV}^{-1}$, in terms of axion or ALP coupling to two photons,

$$\mathcal{L} \supset -\frac{1}{4} \underbrace{\frac{\alpha}{2\pi} \frac{C_{a\gamma}}{f_a}}_{g_{a\gamma}}\ a\, F_{\mu\nu}\tilde{F}^{\mu\nu}$$

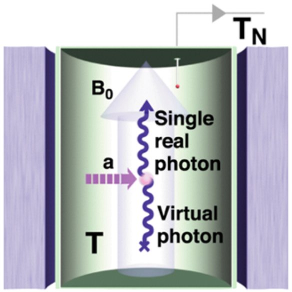
$$= g_{a\gamma}\ a\ \mathbf{E}\cdot\mathbf{B}$$



(Cadamuro et al. 12)

Direct detection of axion or ALP dark matter: Cavities

- Axion or ALP DM -> photon conversion in electromagnetic cavity placed in a magnetic field Sikivie `83



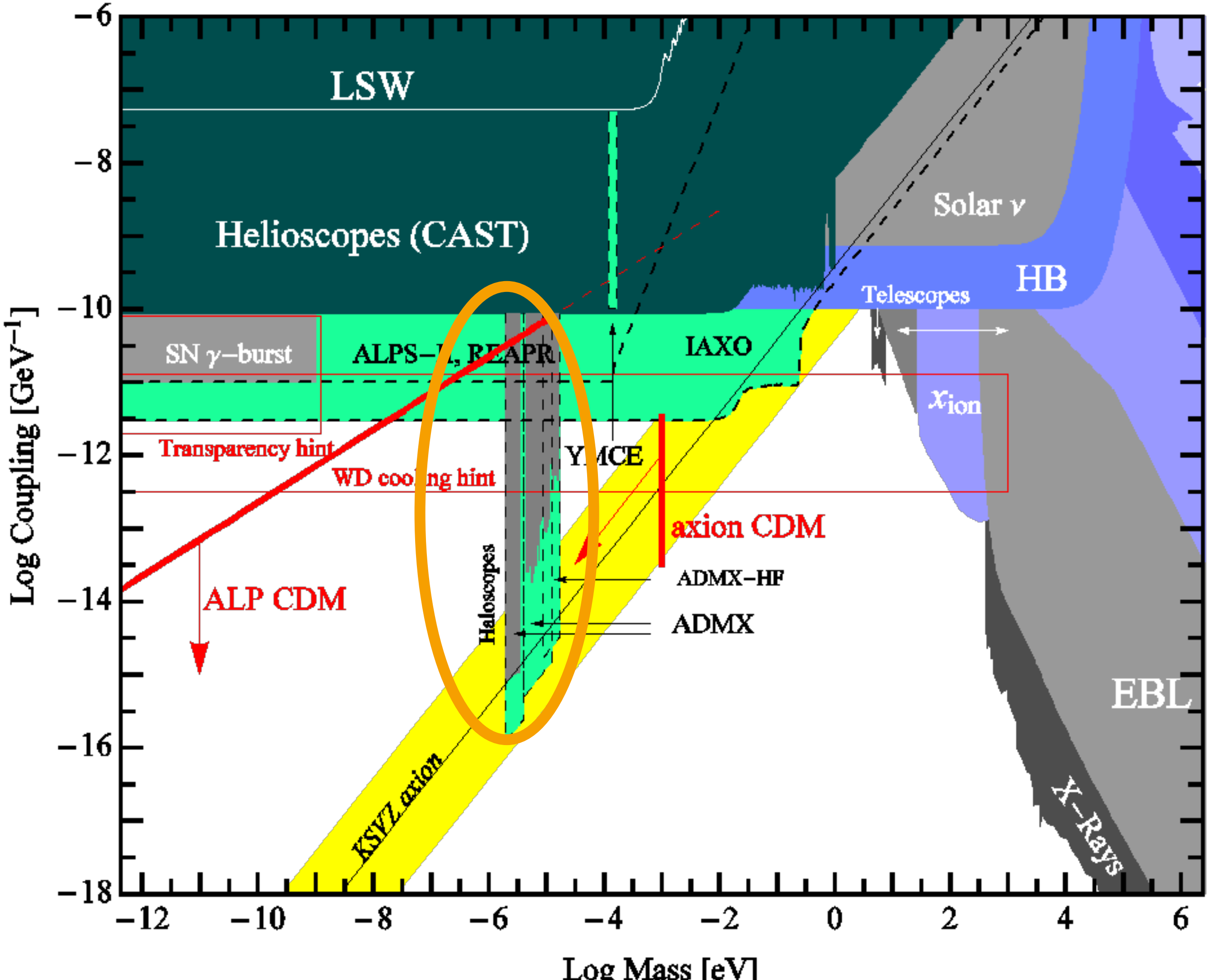
- Best sensitivity : mass = reso-nance frequency

$$m_a = 2\pi\nu \sim 4\ \mu\mathrm{eV}\left(\frac{\nu}{\mathrm{GHz}}\right)$$

$$P_{\rm out} \sim g^2 \mid \mathbf{B}_0 \mid^2 \rho_{\rm DM} V Q / m_a$$

- Ongoing: ADMX (Seattle), takes decade for mass scan over two orders of magnitude

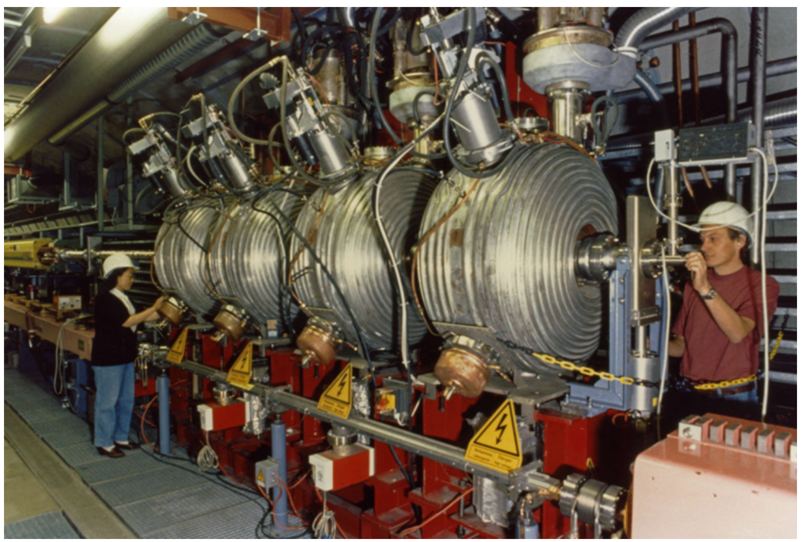
Direct detection of axion or ALP dark matter: Cavities

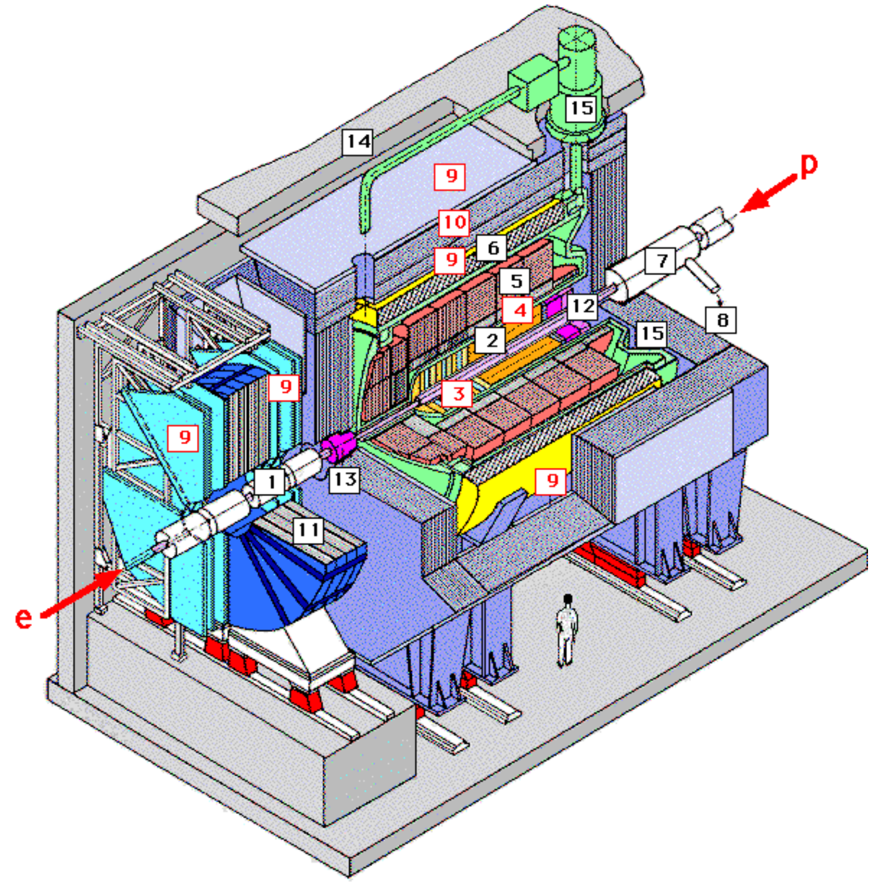


(Hewett et al 12)

Direct detection of axion or ALP dark matter: Cavities

- Available building blocks (DESY)
  - HERA proton ring accelerator cavity
  - H1 superconducting solenoid
- Interested partner institute (MPIfR)
  - Receiver, amplifier, FFT, …

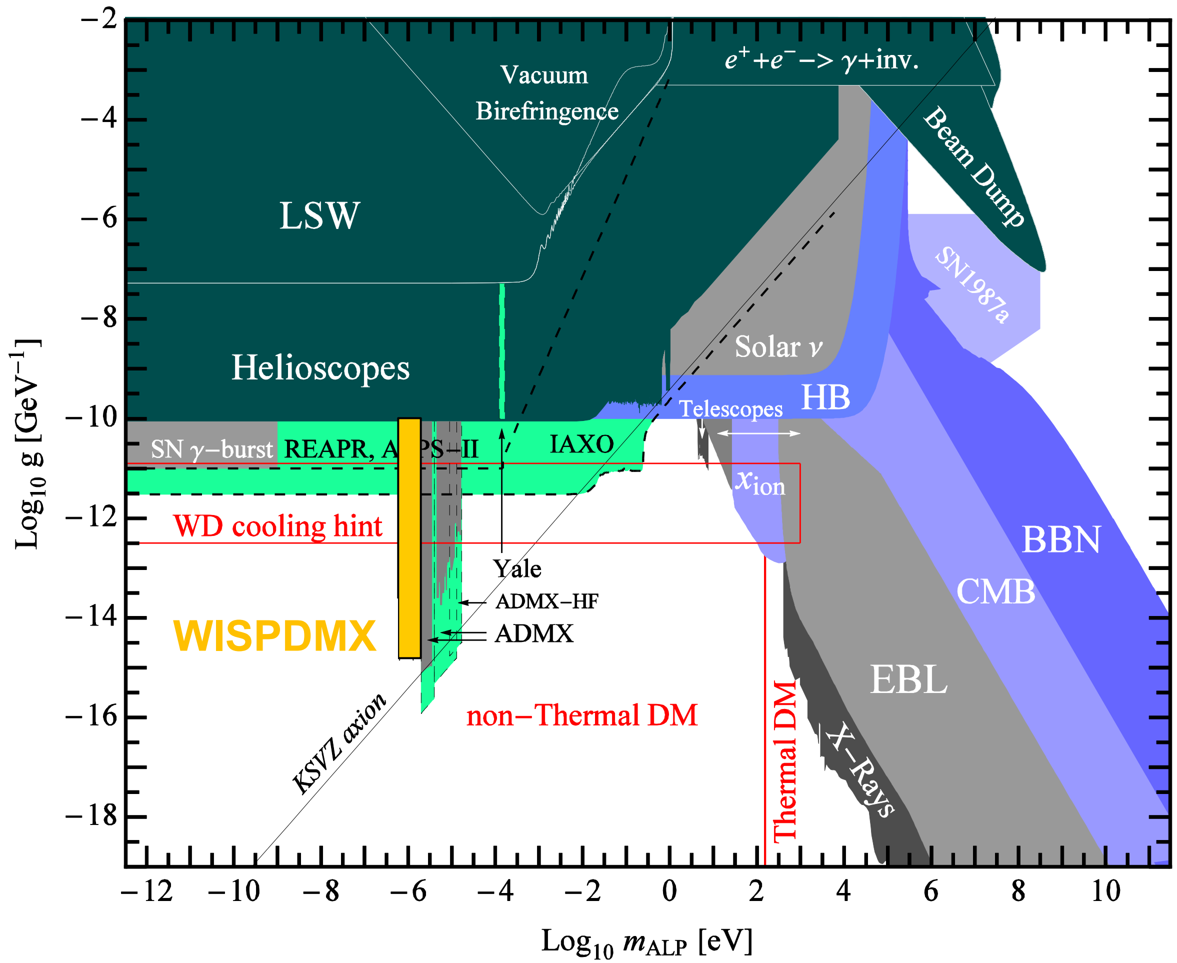




- Ongoing pilot study for WISPDMX

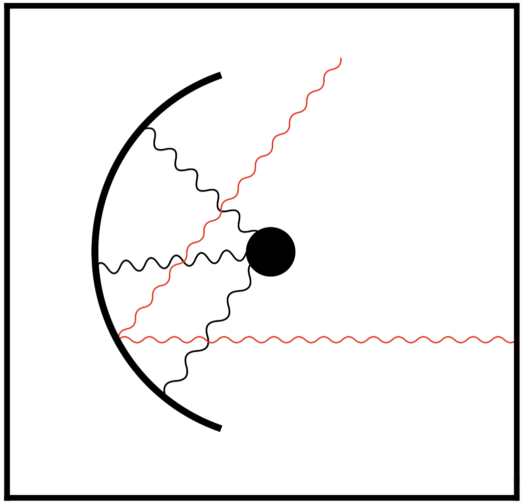
Direct detection of axion or ALP dark matter: Cavities

> WISPDMX may probe mass region below ADMX:
[Horns,Jaeckel,Lindner,Lobanov,Möller,AR,Sekutowicz,Trines,Westphal]

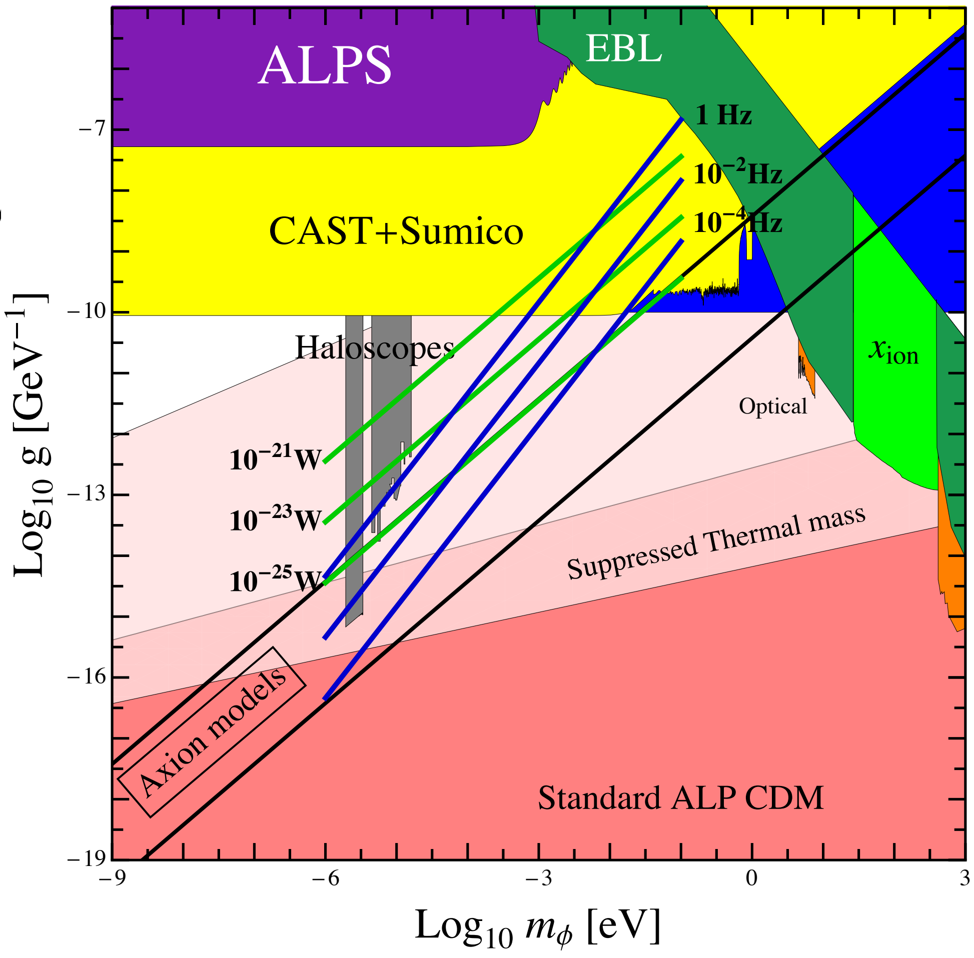


Direct detection of axion or ALP DM: Dish Antenna

- Proposed broadband search method, based on
  - radiation emitted by conducting surfaces when excited by axionic DM
  - focussed into detector by using spherically shaped surface (dish antenna)



$$P_{\rm center} \sim g^2 \mid \mathbf{B}_0 \mid^2 \rho_{\rm DM} A_{\rm dish}/m_a^2$$



(Horns et al 12)

Direct detection of axion DM: Molecular interferometry

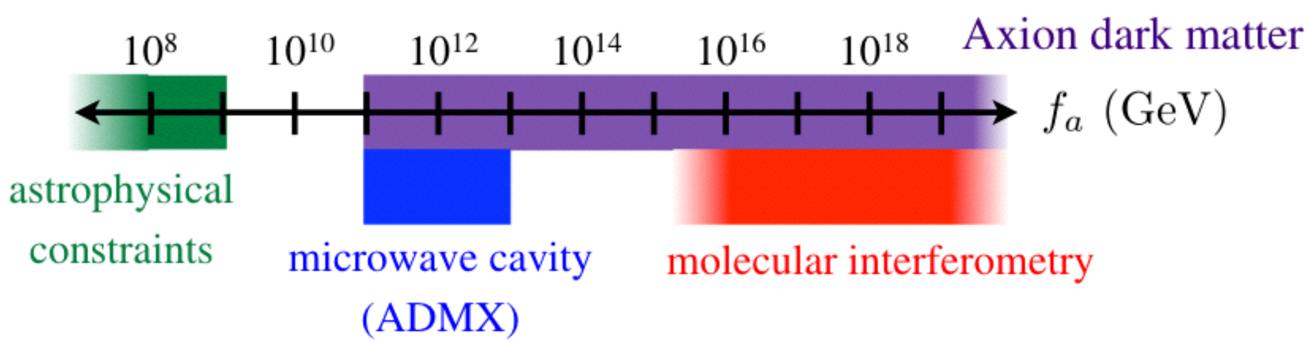
> Axion DM: all nucleons have a rapidly oscillating electric dipole moment

$$d_N \sim e \frac{m_u m_d}{(m_u + m_d) m_N^2} \theta_{\rm eff}(t) \sim 10^{-16}\, \theta_{\rm eff}(t)\, e\, {\rm cm}$$

$$\theta_{\rm eff}(t) \sim \frac{a(t)}{f_a} \sim \frac{\sqrt{\rho_{\rm DM}}}{m_a f_a} \cos(m_a t) \sim \frac{\sqrt{\rho_{\rm DM}}}{m_\pi f_\pi} \cos(m_a t) \sim 10^{-19} \cos(m_a t)$$

- Window of opportunity for $m_a \sim m_\pi f_\pi / f_a \sim {\rm MHz}\, (10^{16}\, {\rm GeV}/f_a)$:
- Molecular interferometric search for oscillating shifts of atomic energy levels due to the coupling between internal atomic fields and time varying CP-odd nuclear moments,

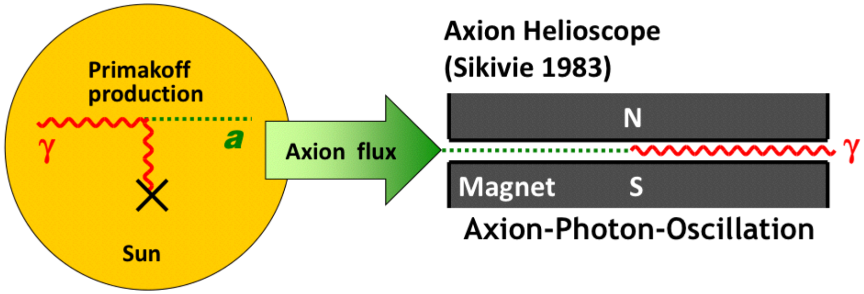
$\delta E \sim E_{\rm int} d_N \sim 10^{-24}$ eV



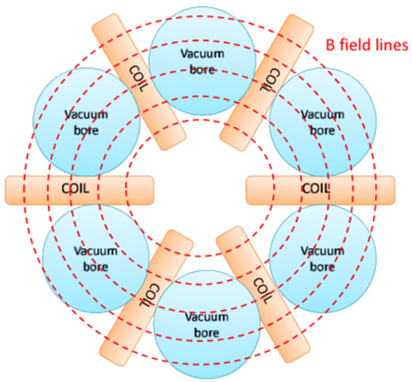
(Graham, Rajendran 11)

Indirect detection of solar axions and ALPs: Helioscopes

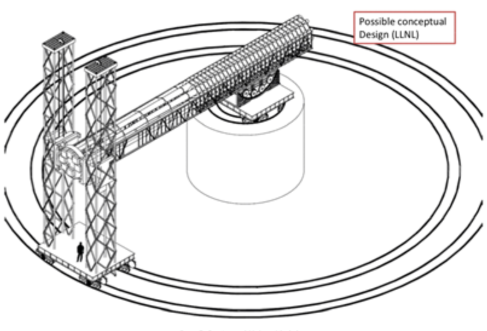
- Sun strong source of axions and ALPs
- Helioscope searches for axions and ALPs



$$P(a \leftrightarrow \gamma) = 4\frac{(g_{a\gamma}\omega B)^2}{m_a^4}\sin^2\left(\frac{m_a^2}{4\omega}L_B\right)$$

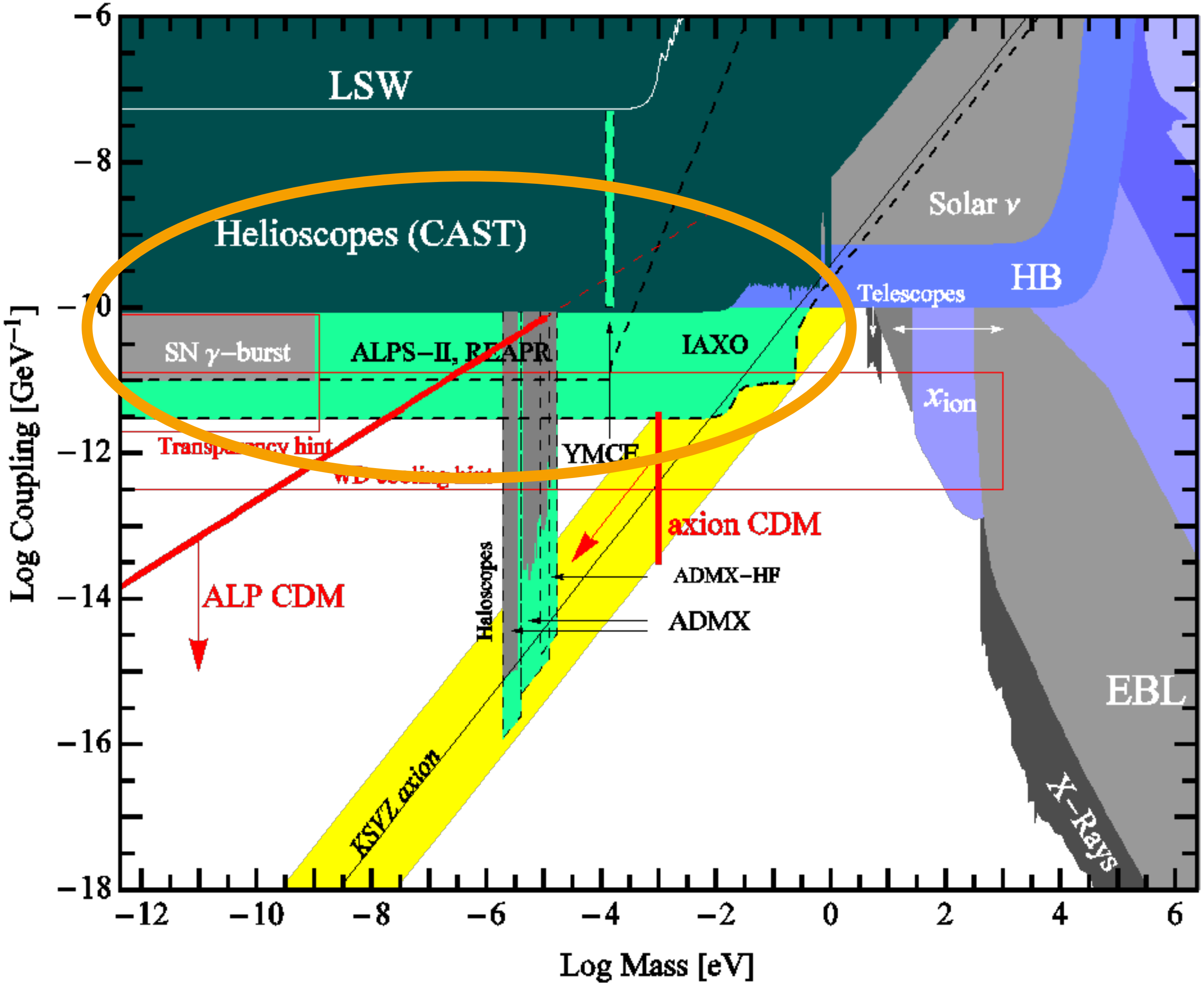


  - Ongoing: CAST … CERN Axion Solar Telescope



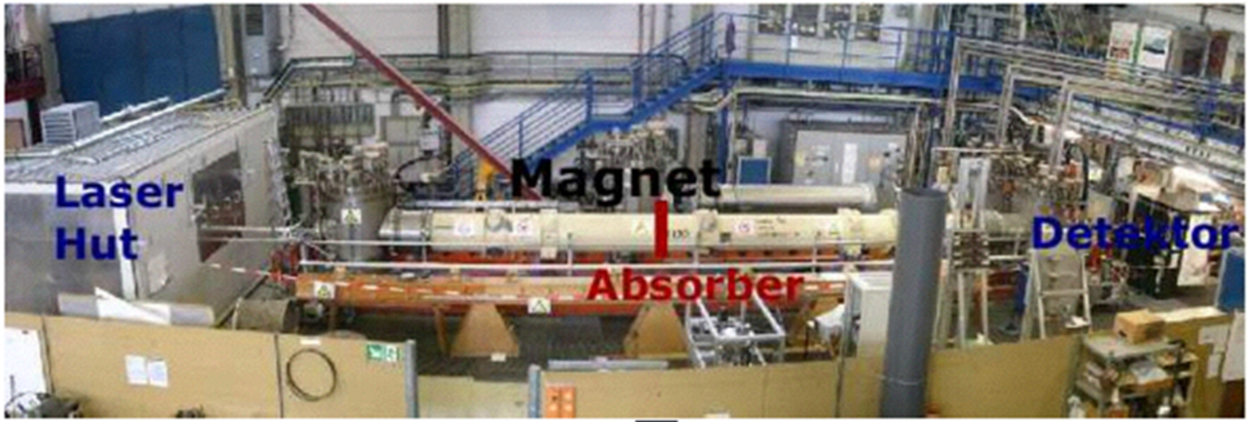
  - LoI: IAXO … International Axion Observatory

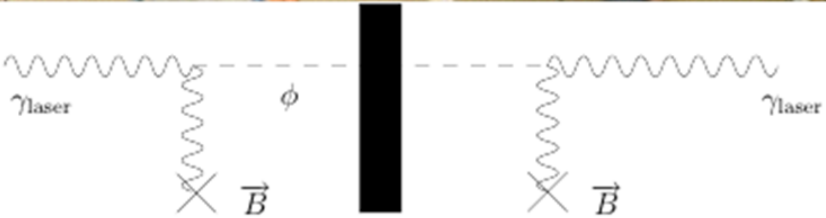
Indirect detection of solar axions and ALPs: Helioscopes



Direct production and detection of ALPs: LSW

- ALPs can pass walls
- Light-shining-through-walls experiments: (here ALPS (@DESY)):





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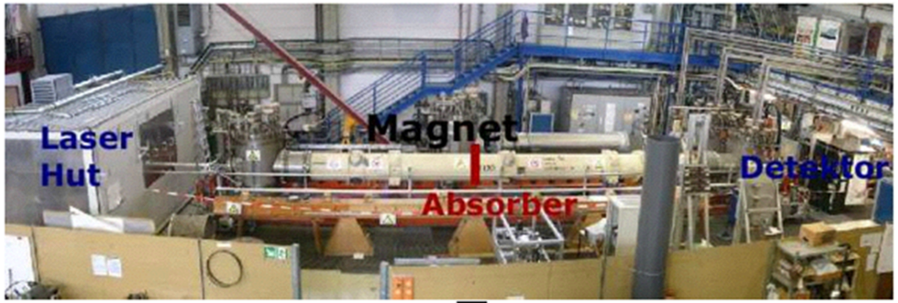
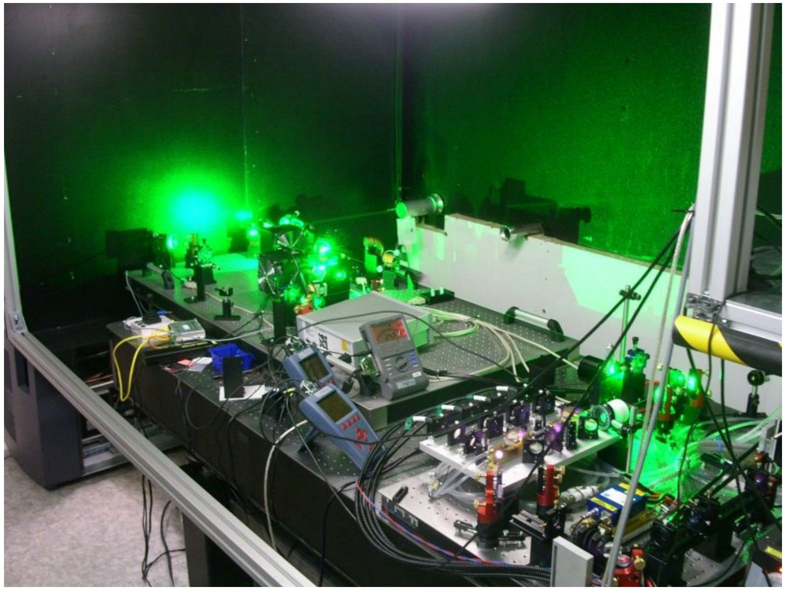
Direct production and detection of ALPs: LSW

- ALPS:
  - HERA dipole (8.4 m, 5 T)
  - Primary laser: enhanced LIGO laser (1064 nm, 35 W)
  - Frequency doubled: 523 nm
  - 300-fold power build-up in cavity





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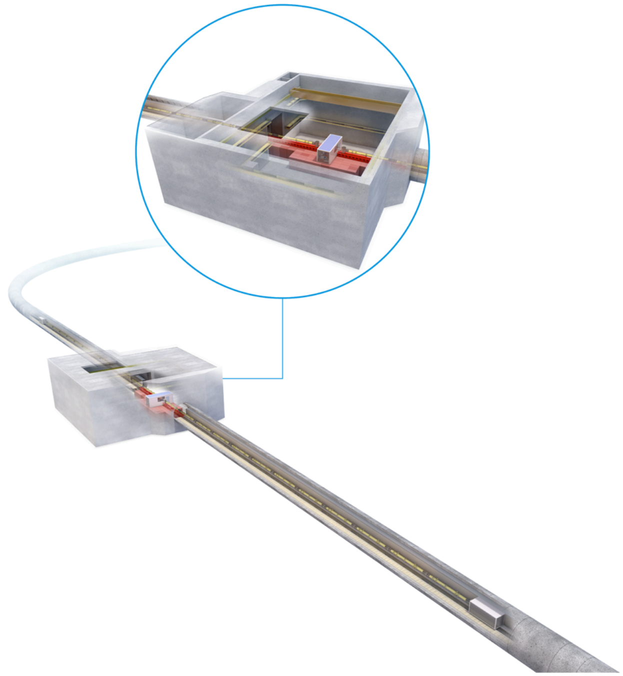
> ALPS-II (2017):

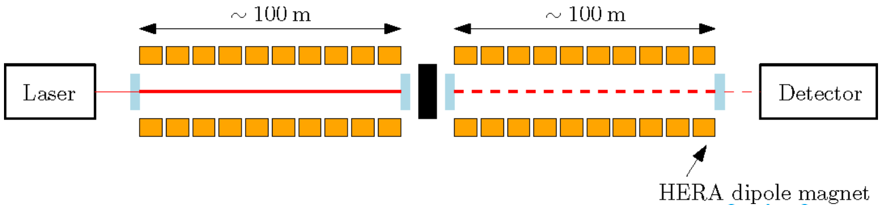
- 12 + 12 HERA dipoles
- 5000-fold power build-up in cavity
- cavity also on regeneration part with 40000-fold power build-up

> Similar plans also at Fermilab (REAPR)

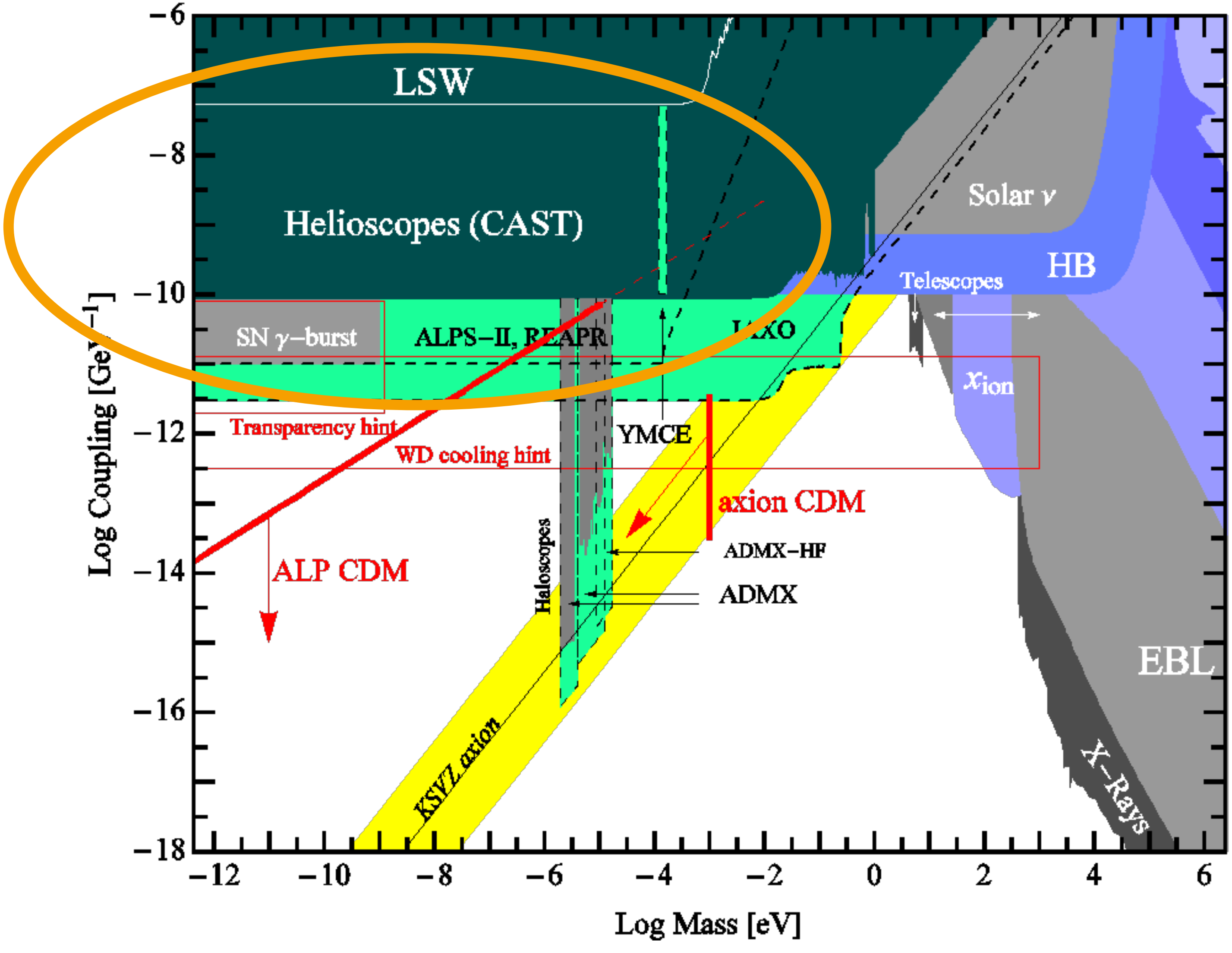
> Next-to-next generation: sensitiv-ity improvement by another order of magnitude in coupling

(ALP-II TDR 12)





Direct production and detection of ALPs: LSW



Summary and conclusions

- Axiverse models that exhibit a QCD axion with an intermediate-scale decay constant $f_a \sim M_s \sim M_P/\sqrt{\mathcal{V}} \sim (M_P m_{3/2}/W_0)^{1/2} \sim 10^{9\div 12}\,\mathrm{GeV}$ and additional even lighter axion-like particles having the same decay constant and coupling to the photon, such as they occur in the LARGE Volume Scenario of IIB string compactifications, can
  - explain astrophysical anomalies (anomalous transparency of the universe for TeV photons and anomalous white dwarf energy loss)
  - be tested with current technology by haloscopes, helioscopes and next-to-next generation of light-shining-through-walls experiments
- Axiverse models with a QCD axion having a GUT to Planck-scale decay constant
  - can not be tested by terrestrial means by currently available experimental techniques
  - most promising: haloscope based on molecular interferometry, technique needs improvement by more than two orders of magnitude