Light shining through walls

Sai Neha Santpur
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Trivial right?

Trivial right?

- Depends on what we define as light and a wall

What are axions?

- Hypothetical particles predicted by some Beyond Standard Model theories
- Proposed to explain
  - Strong CP problem
  - Dark matter existence

Strong CP problem

- CP is violated in weak interactions, but what about strong?
- Strong interaction lagrangian allows the term:

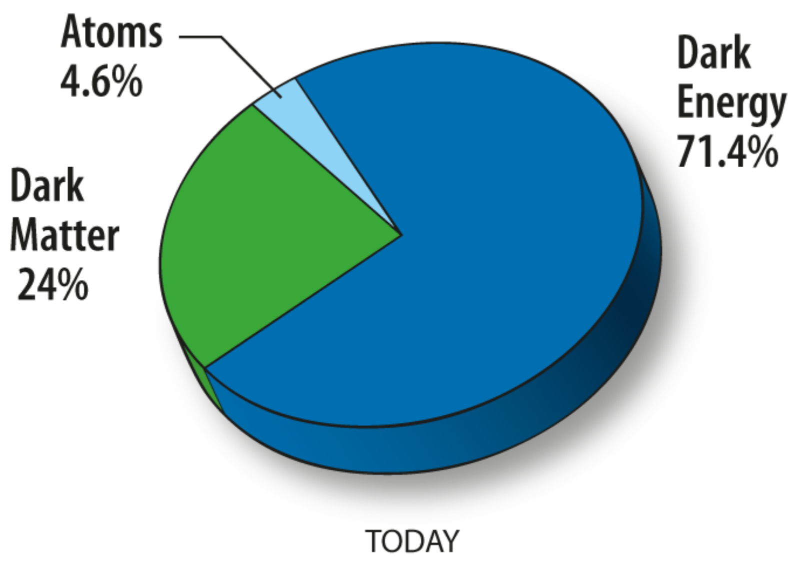
$$\mathcal{L} = \theta \frac{1}{16\pi^2} F^a_{\mu\nu} \tilde{F}^{\mu\nu a} \quad \text{where} \quad \tilde{F}^a_{\mu\nu\rho\sigma} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma} F^{\rho\sigma a}$$

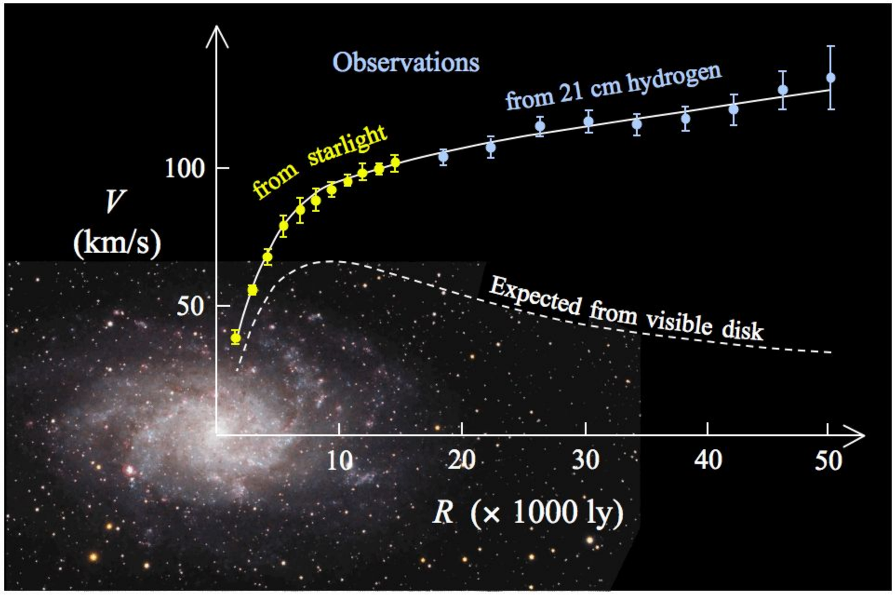
- CP violated when θ≠0 and quark mass phase≠0
- This terms contribute to neutron electric dipole moment (d_n) → O(10^{18} e.m)
- Experimental observation: $|d_n| \sim 10^{-33}$ e·m
- This in turn limits CP violation in strong force to <10^{-9}
- Good reference: TASI lectures on strong CP problem here

Strong CP problem

- In Peccei-Quinn theory:
  - Replace θ by a dynamical field
  - Axion is the particle associated with this new field
  - The term in the Lagrangian that describes this field leads to cancellation of the earlier CP violating terms, making the CP phase ~0

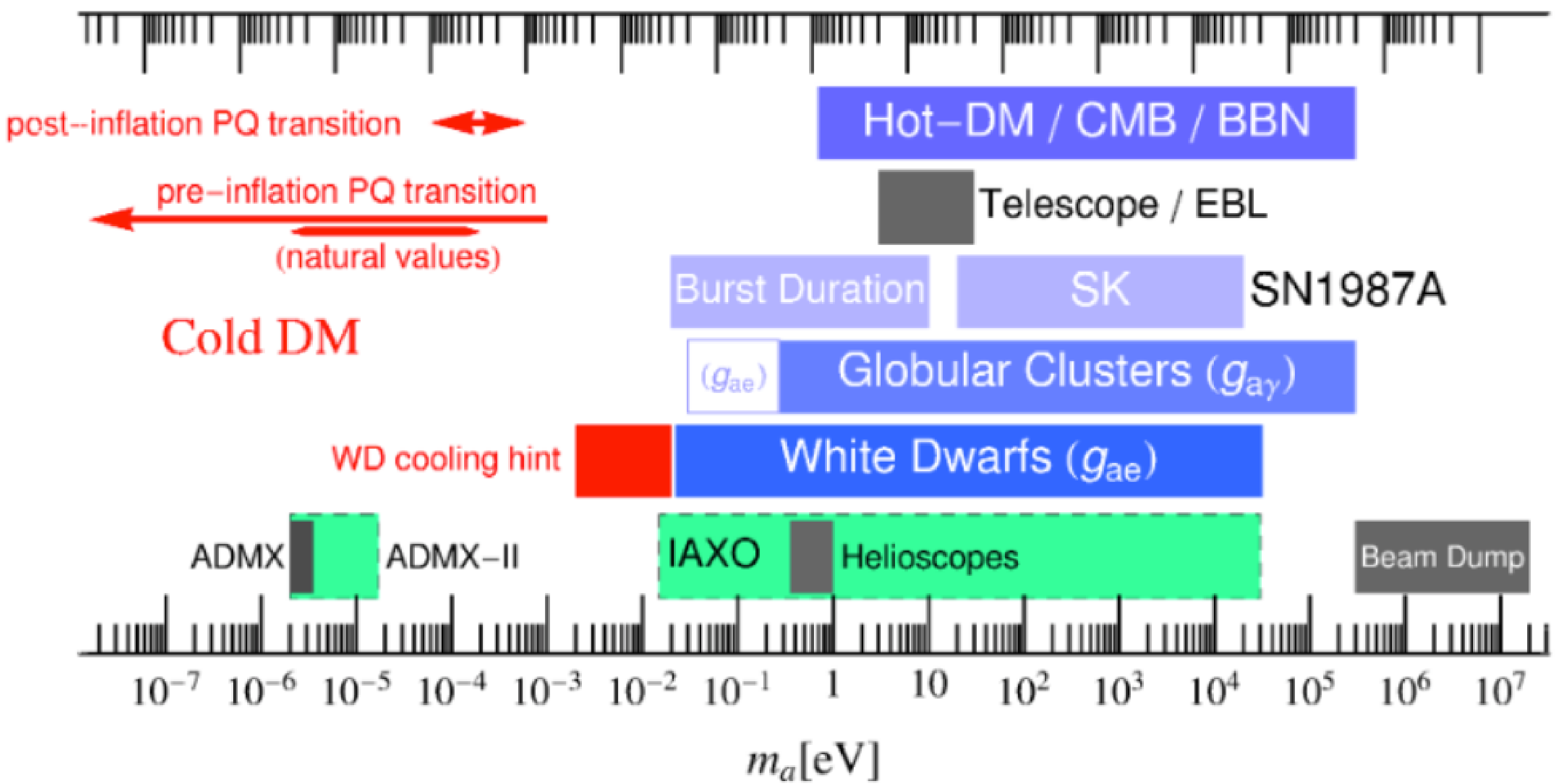
Dark matter





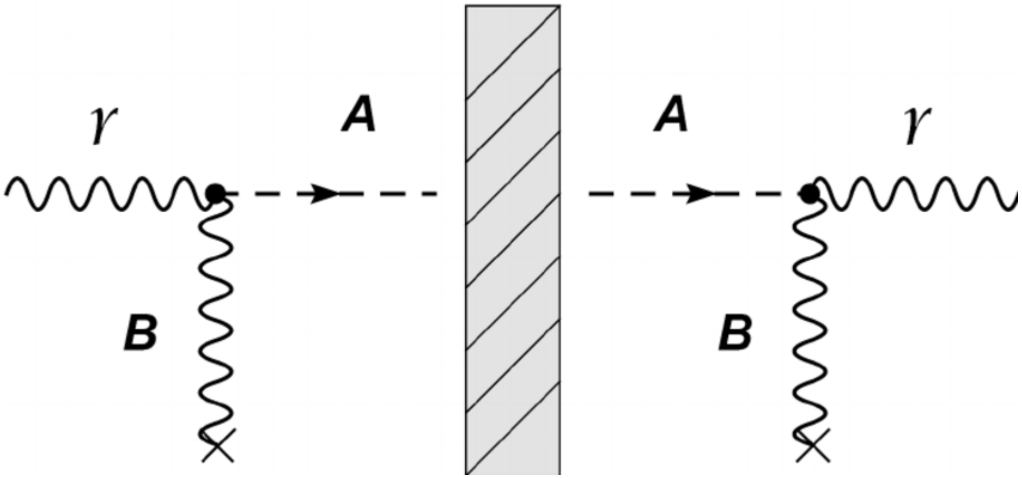
- With right mass, axions can be the dark matter

What masses are we talking about?

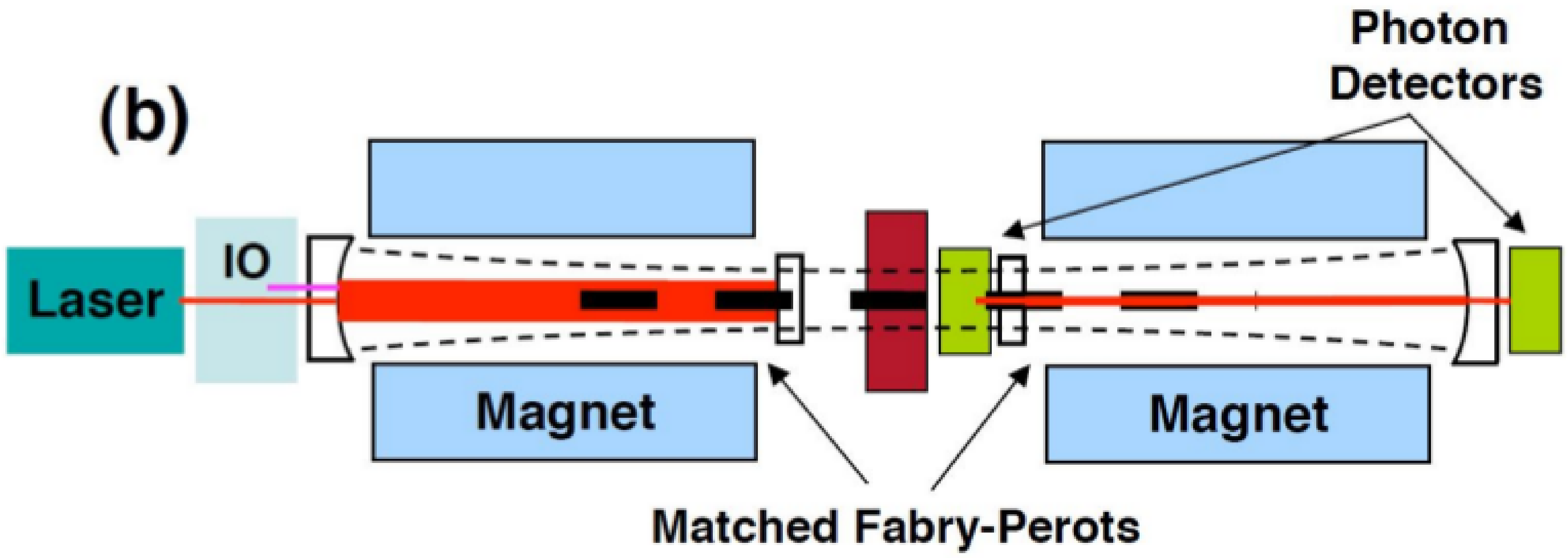


Light shining through walls

- Idea:
  - Shine photons at a wall and see how many of them come out the other side
  - If photons do couple to axions, then there is probability associated with photon-axion oscillations
  - Can look for axions, dark photons and other WISP (weakly Interacting Slim Particles)



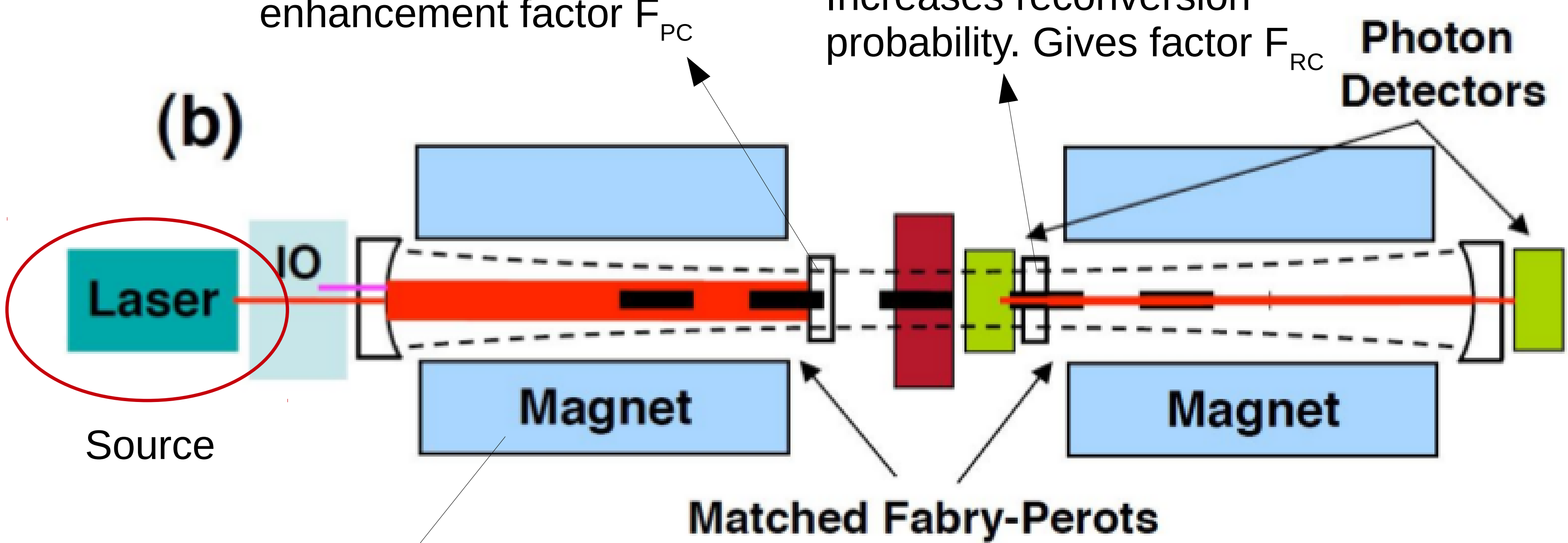
Experimental setup



Experimental setup

Increases light power. Gives enhancement factor F_{PC}

Increases reconversion probability. Gives factor F_{RC}



Magnets may be needed for axions not for other WISPs. Doesn't hurt to have it

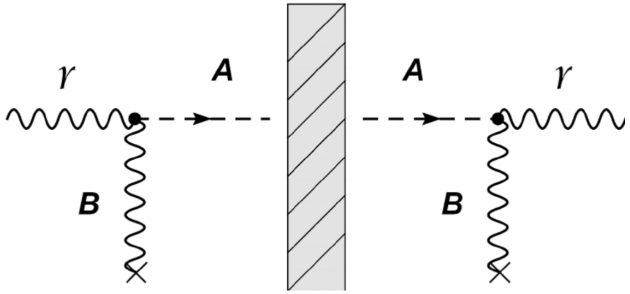
Oscillation probability

- Probability is given by

$$P_{\gamma\to\phi\to\gamma} = |C_{wisp}|^4 \cdot |G|^2 \cdot \mathcal{F}_{PC} \cdot \mathcal{F}_{RC}$$

γγϕ coupling

Form factor to take into account resonant modes



Oscillation probability

- In terms of measured quantities

$$P_{\gamma\to\phi\to\gamma} = \frac{\omega}{\sqrt{\omega^2 - m_\phi^2}} \cdot |C_{wisp}|^4 \cdot \mathcal{F}_{PC} \cdot \mathcal{F}_{RC} \cdot \sin^4\left(\frac{q \cdot l}{2}\right)$$

Length of the experiment

$$q = |n \cdot \omega - \sqrt{\omega^2 - m_\phi^2}|$$

where n is the refractive index

- For dark photon and axion like particles,

$$|C_{hp}|^2 = 4\chi^2 \cdot \frac{m_\phi^4}{\left(m_\phi^2 + 2\omega^2(n-1)\right)^2}; \; |C_{alp}|^2 = 4 \cdot \frac{(g_{a\gamma\gamma}\omega B)^2}{\left(m_\phi^2 + 2\omega^2(n-1)\right)^2}$$

Oscillation probability

- In terms of measured quantities

$$P_{\gamma\to\phi\to\gamma} = \frac{\omega}{\sqrt{\omega^2 - m_\phi^2}} \cdot |C_{wisp}|^4 \cdot \mathcal{F}_{PC} \cdot \mathcal{F}_{RC} \cdot \sin^4\left(\frac{q \cdot l}{2}\right)$$

Length of the experiment

$$q = |n \cdot \omega - \sqrt{\omega^2 - m_\phi^2}|$$

where n is the refractive index

- Making some approximations,

$$P_{\gamma\to\phi\to\gamma} = \frac{1}{16} \cdot \mathcal{F}_{PC}\mathcal{F}_{RC} \cdot (g_{a\gamma\gamma}Bl)^4 = 6 \cdot 10^{-38} \cdot \mathcal{F}_{PC}\mathcal{F}_{RC} \cdot \left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}} \frac{B}{1\,T} \frac{l}{10m}\right)^4$$

LSW experiments

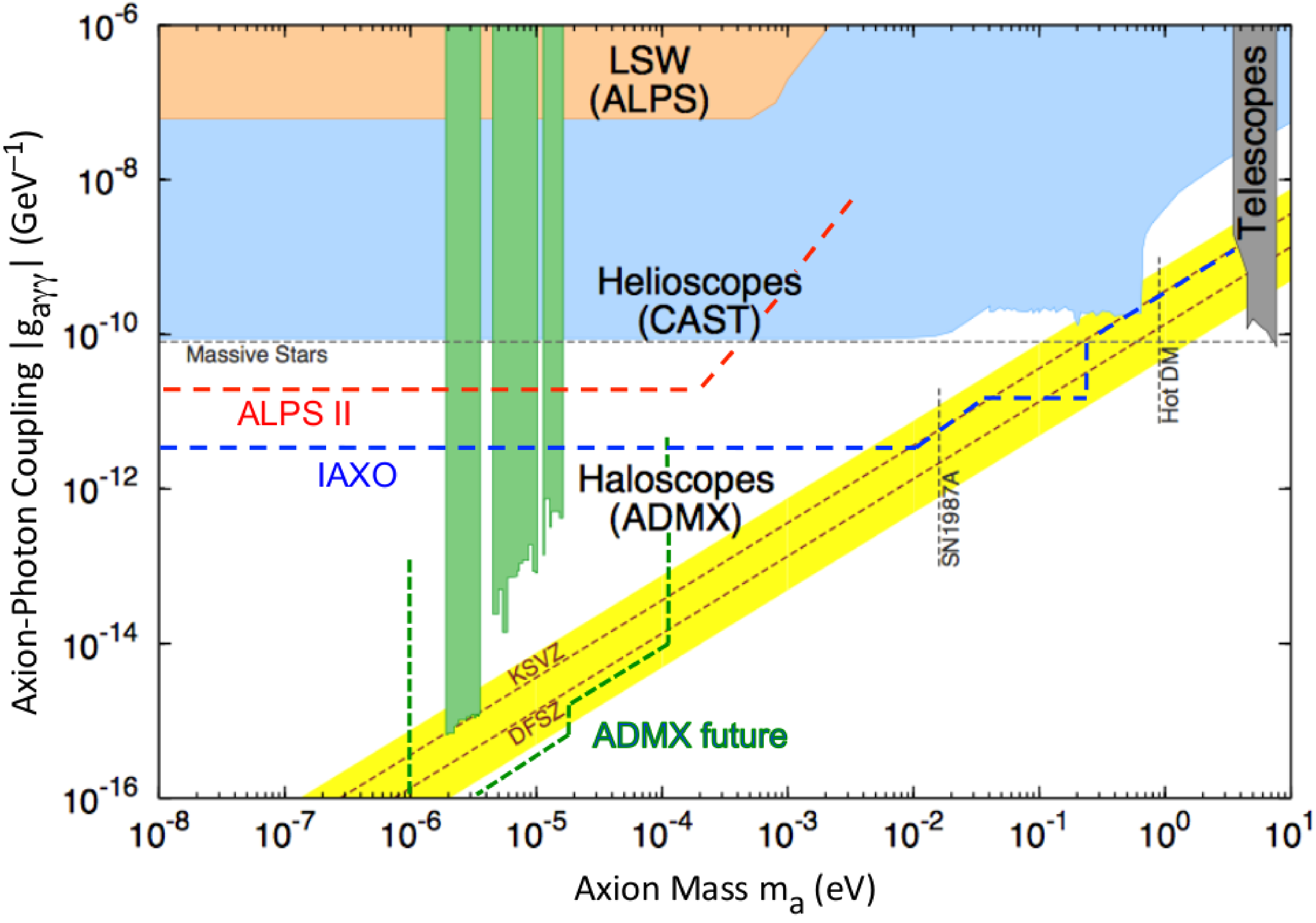
Experiment	ω	P_g	β_g	Magnets
ALPS (DESY) [61, 62]	2.33 eV	4 W	300	$B_g = B_r = 5$ T $L_g = L_r = 4.21$ m
BFRT (Brookhaven) [64, 65]	2.47 eV	3 W	100	$B_g = B_r = 3.7$ T $L_g = L_r = 4.4$ m
BMV (LULI) [66, 67]	1.17 eV	$8 \times 10^{21}\ \frac{\gamma}{\text{pulse}}$ (14 pulses)	1	$B_g = B_r = 12.3$ T $L_g = L_r = 0.4$ m
GammeV (Fermilab) [68]	2.33 eV	$4 \times 10^{17}\ \frac{\gamma}{\text{pulse}}$ (3600 pulses)	1	$B_g = B_r = 5$ T $L_g = L_r = 3$ m
LIPSS (JLab) [69, 70]	1.03 eV	180 W	1	$B_g = B_r = 1.7$ T $L_g = L_r = 1$ m
OSQAR (CERN) [71, 72]	2.5 eV	15 W	1	$B_g = B_r = 9$ T $L_g = L_r = 7$ m
BMV (ESRF) [73]	50/90 keV	10/0.5 mW	1	$B_g = B_r = 3$ T $L_g = 1.5, L_r \sim 1$ m

Current limits and future

- Current limits on photon-axion coupling is: g < 5*10E-8 /GeV
- Mass sensitivity: m<0.001ω
- Future experiments:
  - ALPS II, JURA
  - Future sensitivity upto g~10E-11 /GeV → expected to outperform astrophysics limits

Parameter	Sensitivity	ALPS I	ALPS II	JURA
Effective laser power P_{laser}	$g_{a\gamma\gamma} \propto P_{laser}^{-1/4}$	1 kW	150 kW	1000 kW
$\mathcal{F}_{RC}$	$g_{a\gamma\gamma} \propto \mathcal{F}_{RC}^{-1/4}$	1	40,000	100,000
Length (B field) l	$g_{a\gamma\gamma} \propto (l)^{-1}$	4.4 m	88 m	286 m
Magnetic field B	$g_{a\gamma\gamma} \propto (B)^{-1}$	5.0 T	5.3 T	13 T

Future projections



Summary

- Light Shining through Walls experiments can be used to probe photon-axion (WISP) coupling
- Probe large phase space of axion masses and couplings
- Future LSW experiments are expected to out do the astrophysics limits
- Very exciting times ahead!

- References: Annual Review of Nuclear and Particle Science, Vol. 65: 485-514 (2015)