Searches For Astrophysical and Cosmological Axions

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Presented by AJ Richards

History of the Axion

- Arose as a solution to the strong-CP problem
  - Absence of an electric dipole moment for the neutron
- $\overline{\Theta}$ term represents strong-CP violation
  - Input for particle SM
  - Why is $\overline{\Theta}$ so small?

Enter Peccei and Quinn…

- 1977: they propose a solution
- Think of $\overline{\Theta}$ as a dynamic field, rather than a constant
- This implies the existence of a new particle
  - From spontaneous symmetry-breaking of new field
- New particle dubbed the axion

Properties of the Axion

- Electrically neutral
- Spin 0 boson
- Mass $10^{-6} \leq m_A \leq 10^{-3}$ eV/c^2
  - Mass, coupling strengths of axion fell due to theoretical restrictions
  - However, this *increases* the total mass of the axions in the universe

$$m_A, g_{Aii} \propto f_A^{-1} \qquad \Omega_A \propto f_A^{7/6}$$

Allowable Mass Range

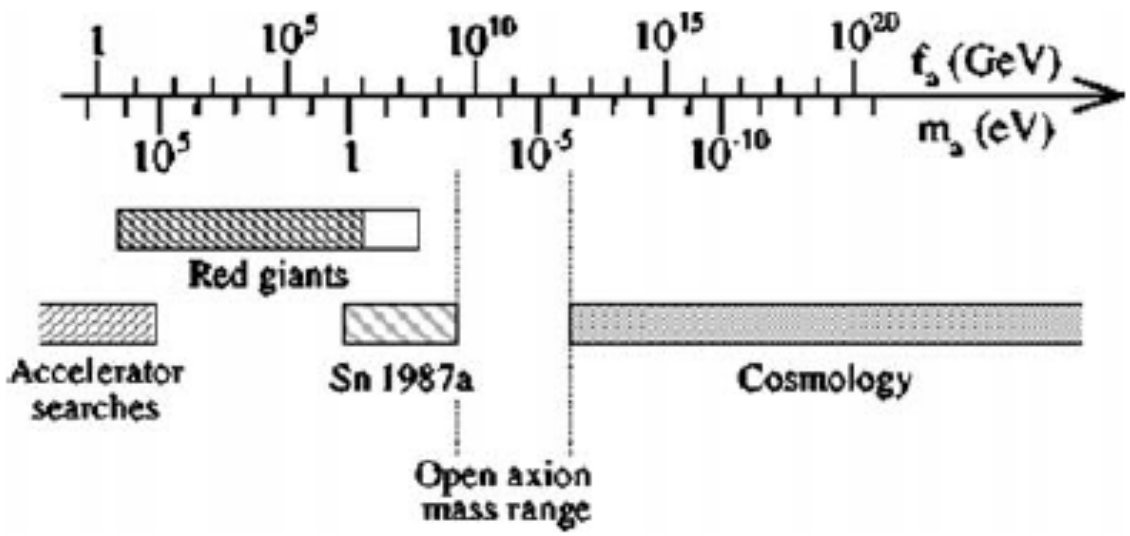


Figure 2 The allowed axion mass range, bounded from below by the requirement that axions should not overclose the universe and from above by accelerator searches and stellar evolution.

Two Types of Axions

Thermal Axions

$$g + g \longrightarrow g + A$$

$$q + g \longrightarrow q + A$$

Relativistic, on order of 1K

Too hot to account for much of dark matter

Nonthermal Axions

- Condensed from spontaneous symmetry-breaking
- $\overline{\Theta}$ field "rolls down" towards zero-point and oscillates
- When field freezes out, $m_A \neq 0$

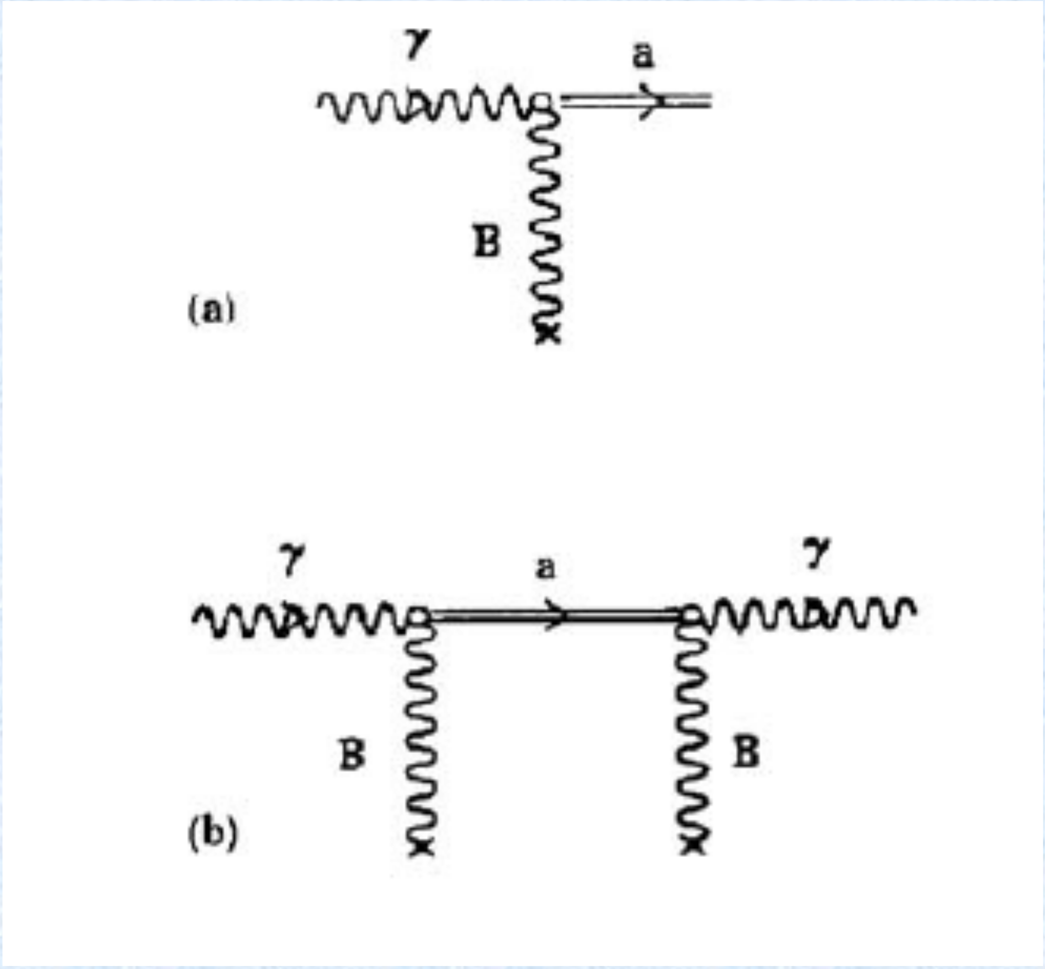
Axion-Photon Mixing

- Axions can mix with photons in the presence of an external electromagnetic field

$$L_{\text{int}} = g_{A\gamma\gamma} A \, \mathbf{E} \bullet \mathbf{B}$$

- Photons can oscillate into an axion and vice-versa

Primakoff Effect



ADMX

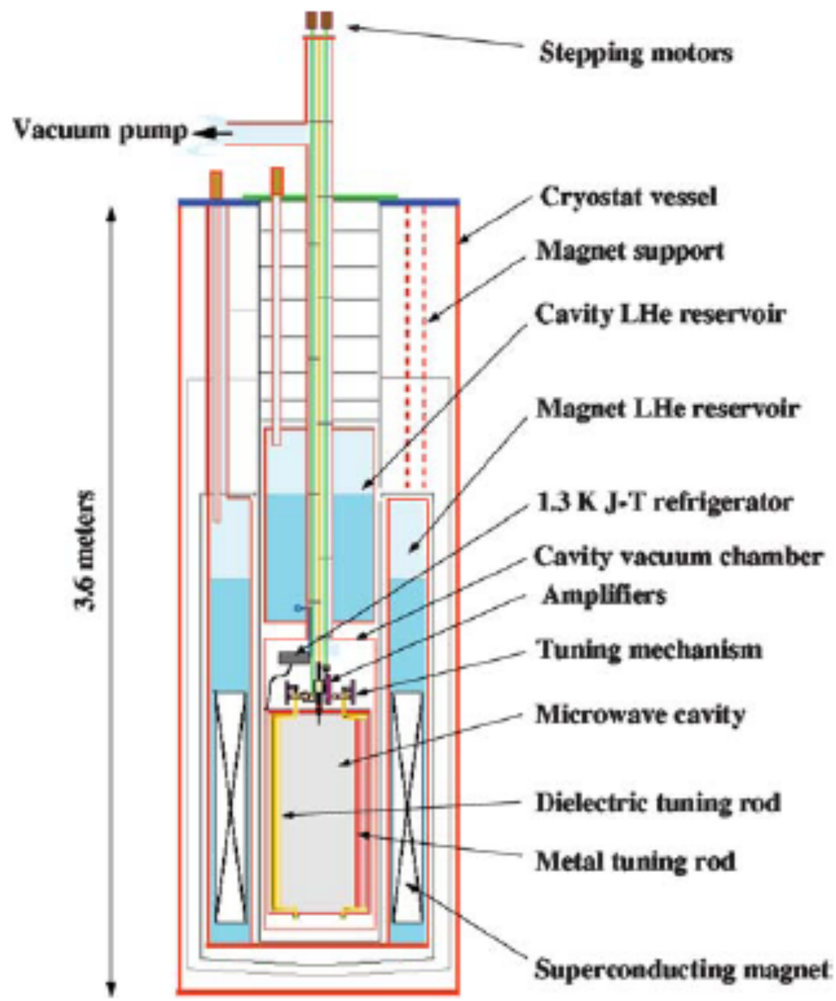
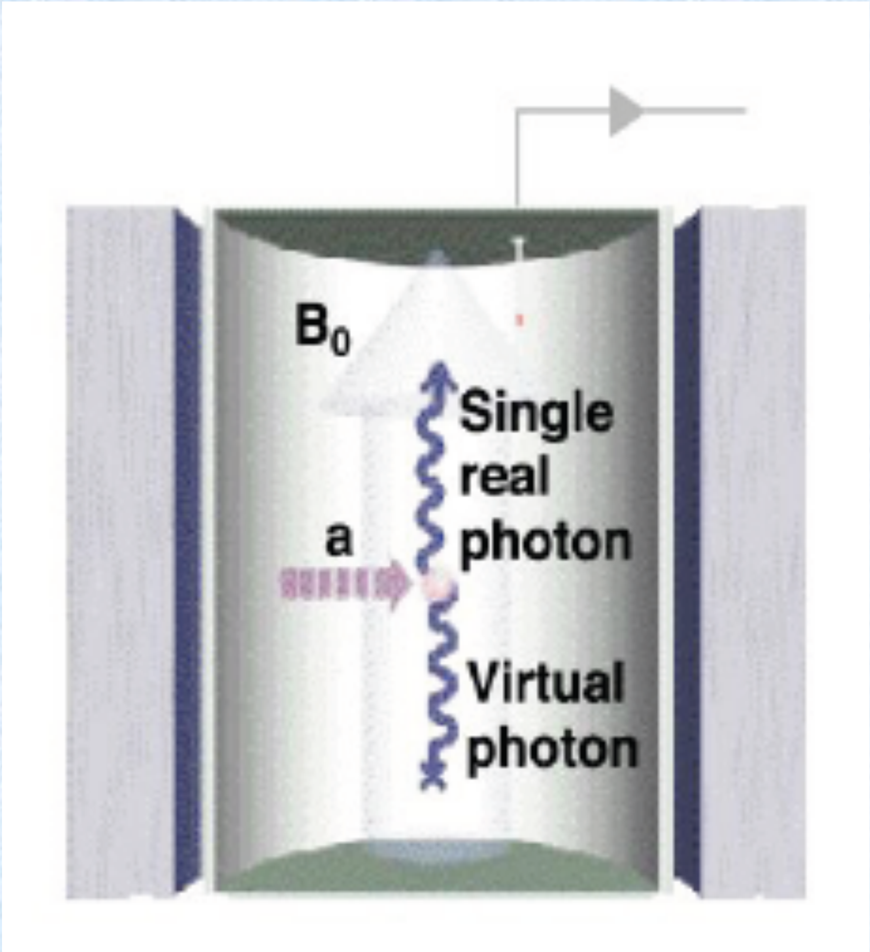


Figure 8 Schematic of the Axion Dark Matter eXperiment (67, 68).

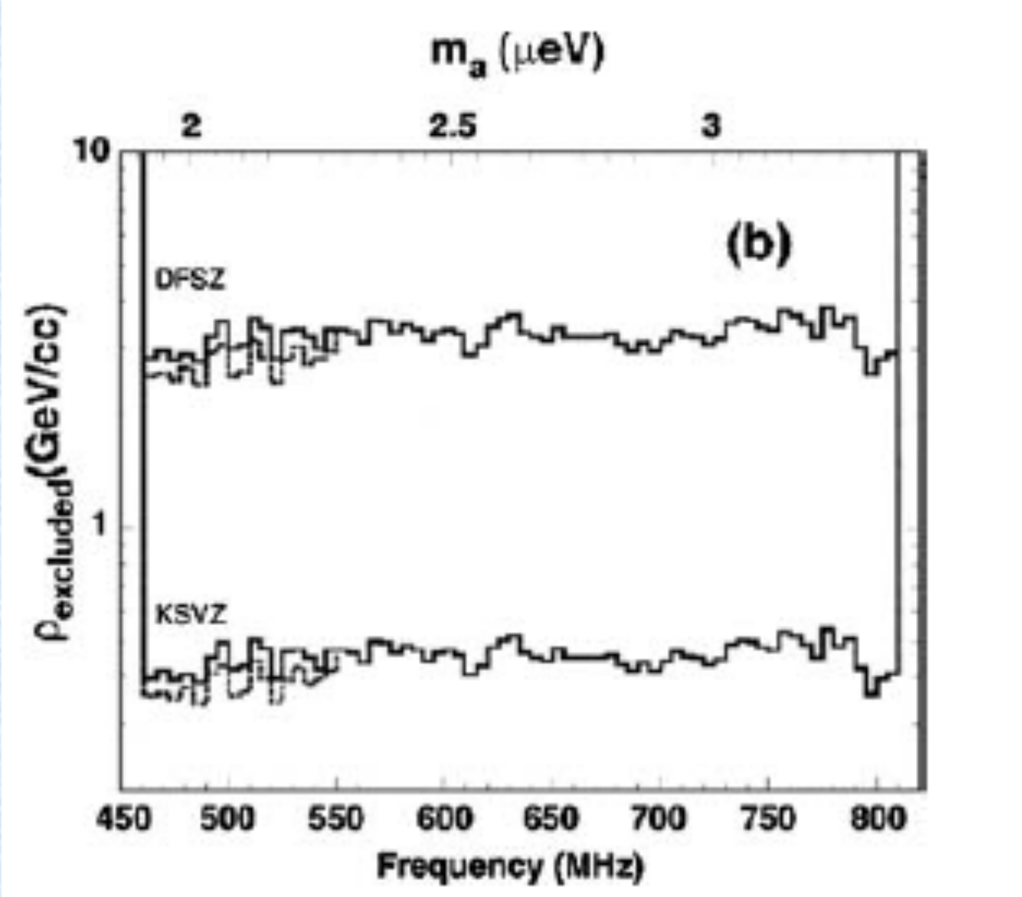
ADMX



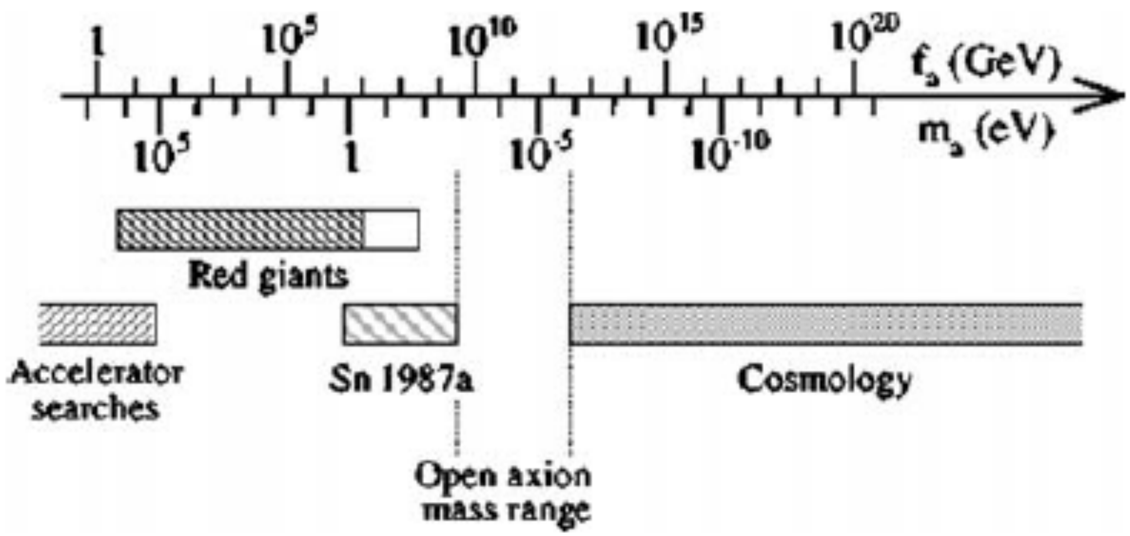
Axions interact with virtual photons in the B-field to produce real photons (microwave range)

ADMX Results

- KSVZ axions excluded at 90% CL



Allowable Mass Range



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Solar Axions

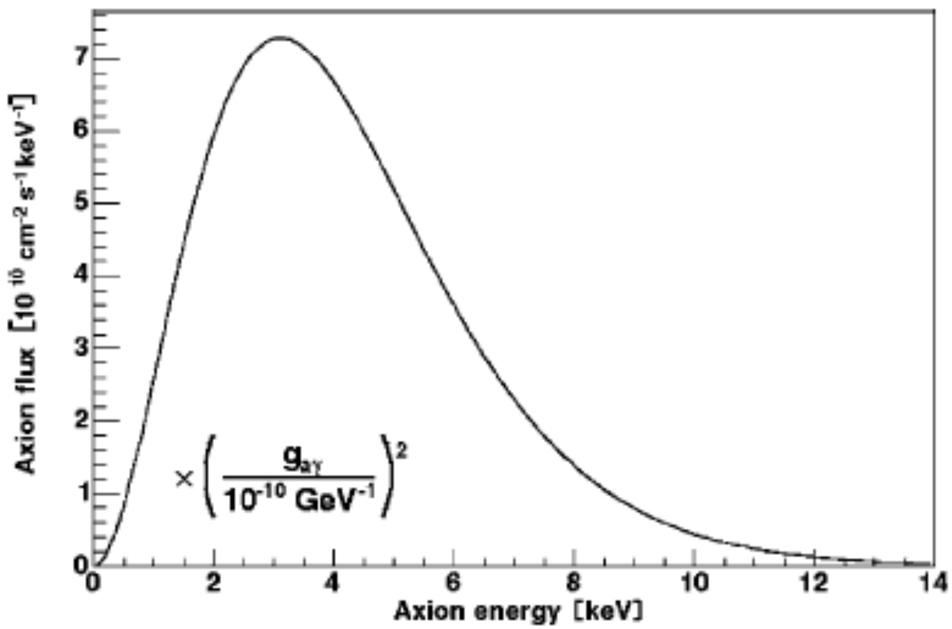
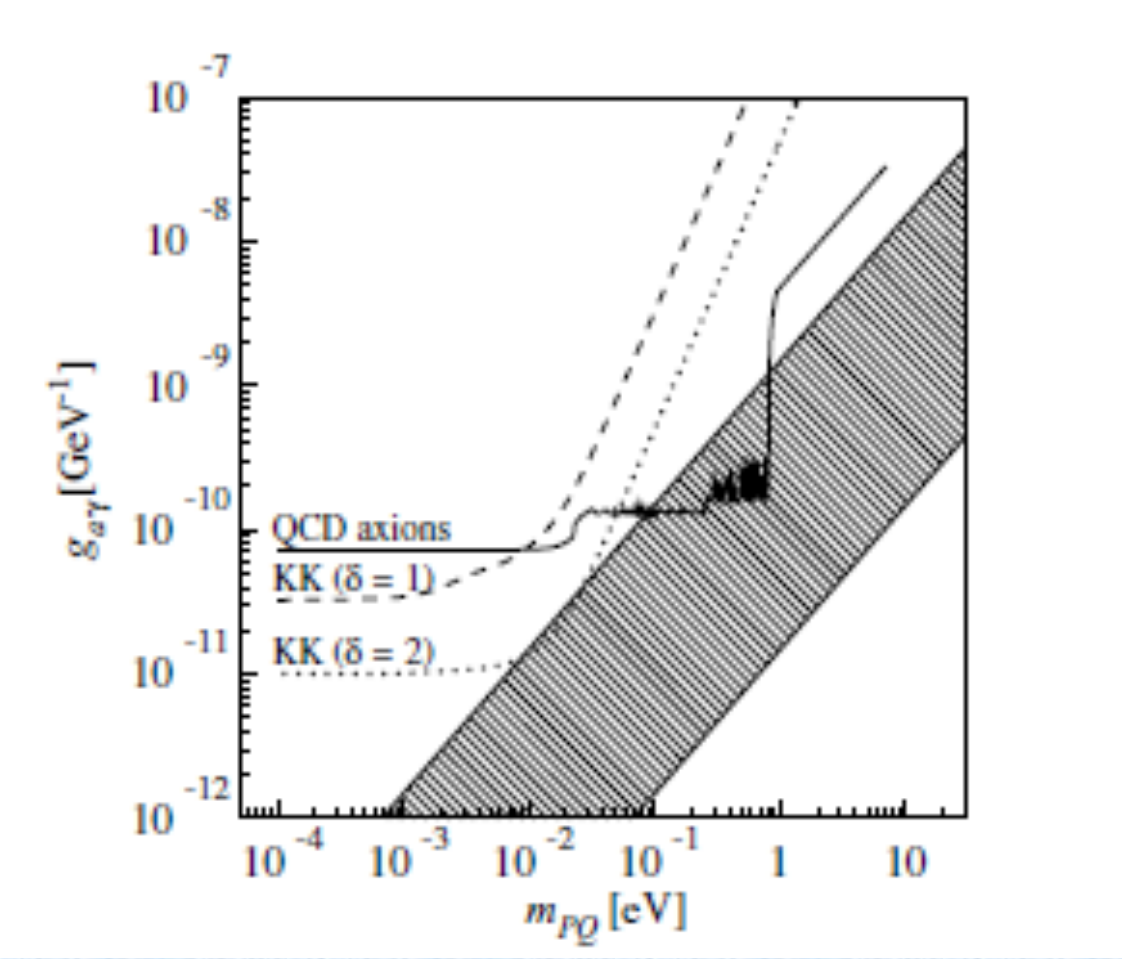


Figure 14 The solar axion flux spectrum at Earth (85).

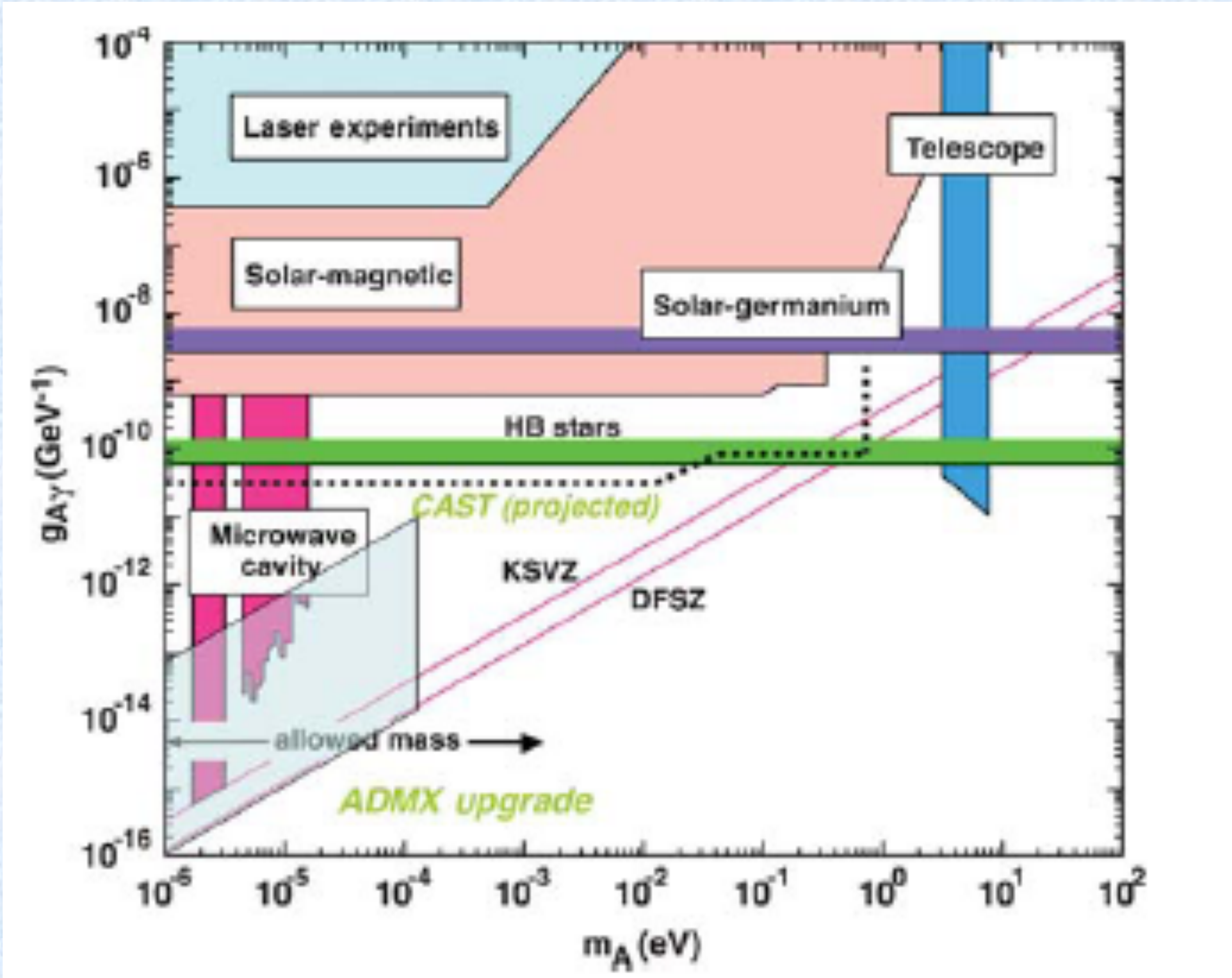
Primakoff: $$A + \gamma_{virtual} \rightarrow \gamma$$

$$P_{A\rightarrow\gamma} \approx \frac{1}{4}(g_{A\gamma\gamma}BL)^2$$

Solar Axion Searches



Summary



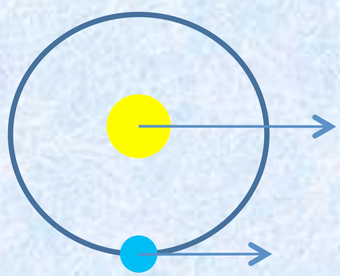
Laser experiments
Telescope
Solar-magnetic
Solar-germanium
HB stars
CAST (projected)
Microwave cavity
KSVZ
DFSZ
allowed mass
ADMX upgrade
$g_{A\gamma}$ (GeV^{-1})
m_A (eV)
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

Search for WIMP Annual Modulation Signature

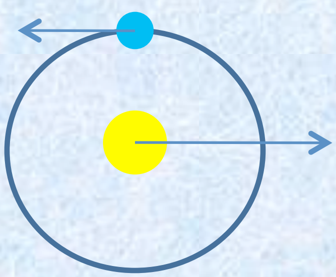
R. Bernabei, et al.

WIMP Wind

- If WIMPs make up a portion of the galactic halo, they should create a “wind” as the Earth plows through them
- This wind will vary with time as the Earth moves through the Galaxy



June



December

WIMP Modulation

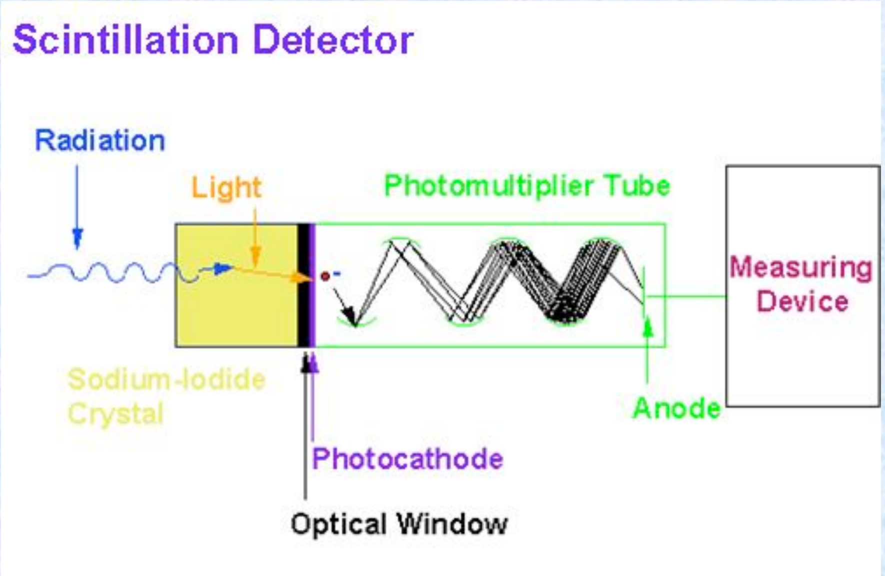
- 6 criteria for WIMP counts:
  - “Single-hit” counts must modulate
  - Events must be in a well-defined, low-energy region
  - Modulation behaves like cosine function
  - Period of modulation equals 1 year
  - Phase must be $t_0 \approx$ June 2
  - Modulation amplitude must be small

The Winner Is…

- The neutralino!
  - Lightest supersymmetric partner
  - Spin-independent interactions with baryonic matter

Interactions

- WIMP particles strike atoms of scintillator detector (NaI)
- NaI produces flash of light which goes to PMT for amplification and measuring



Safeguards

- Detectors shielded from environmental background radiation
- Contained in sealed box, filled with N_2 at overpressure
- Temperature held constant by climate control
- Any background signals (e.g. radon) should not modulate in time, and will be rejected

Data Analysis

- Use a maximum-likelihood function, which we can then solve for M_W.
- M_W must be greater than 30 GeV from accelerator searches for neutralinos
- The maximum-likelihood function analysis yields:

DAMA/NaI-3

$$M_W = (56^{+18}_{-26})\,\mathrm{GeV}$$

DAMA/NaI-4

$$M_W = (44^{+32}_{-14})\,\mathrm{GeV}$$

Modulation

- Modulation is present at 98.3% CL and 92.8% CL for DAMA/NaI-3 and -4, respectively