Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Searching for Axions and Dark Photons w/ Superconducting RF Cavities

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5 minutes 5 slides

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Axions and Dark Photons as Candidates for Dark Matter

Dark Matter

- Dark matter is observed to be translucent, and weakly interacting with visible matter.
- Various phenomena cannot be explained by visible matter.
  - Gravitation Lensing (Einstein rings)
  - Galactic Rotation Curves
  - Cosmic Microwave Background
  - Bullet Cluster

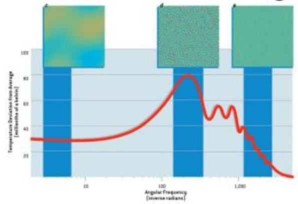
Axions/Dark Photons

- Theoretical framework of dark photons and axions makes them excellent dark matter candidates.

Gravitational Lensing

Credit: *NASA*

Cosmic Microwave Background

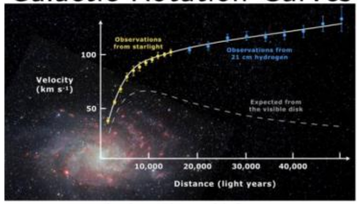


Credit: *Wayne Hu*

Bullet Cluster

Credit: *NASA*

Galactic Rotation Curves

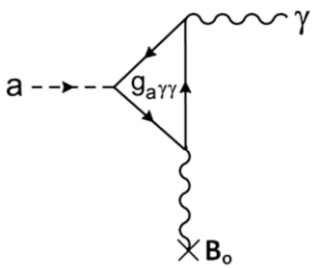


Credit: *Mario de Leo*

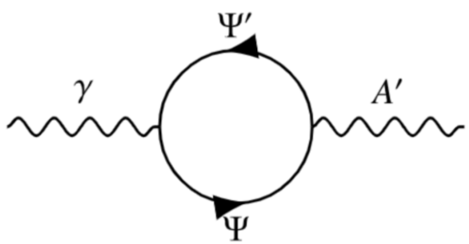
How Are They Detected?

$$\mathcal{L}_{int} = g_{a\gamma\gamma} a \mathbf{E} \cdot \mathbf{B}$$ → Axion/photon interaction

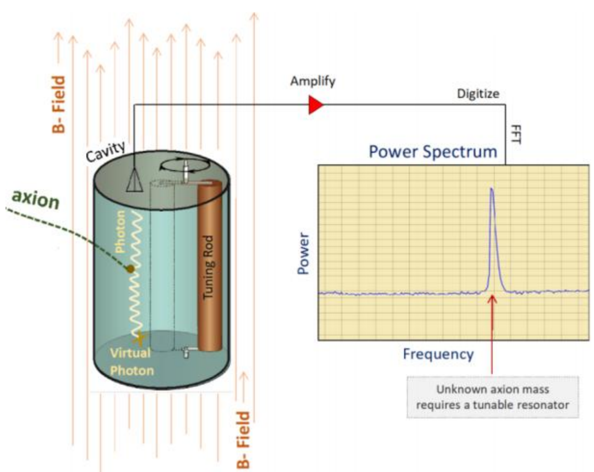
$$\mathcal{L}_{int} = \frac{1}{2} \chi F_1^{\mu\nu} F_{2\mu\nu}$$ → Dark photon/photon interaction



Credit: I. Stern



Credit: A. Filippi



Credit: C. Boutan

- Axions weakly interact with photons in the presence of a magnetic field whereas dark photons interact through kinetic mixing

- The axion and dark photon can be detected using tunable cavity resonators.
  - We are using superconducting cavities which will make the search more sensitive to dark photon/axions.
  - Axion/dark photon mass is not known.
  - A typical search involves scanning over a range of resonant frequencies that may correspond to the mass of the dark matter candidates.
  - The converted photon signal will be resonantly enhanced if the resonator is tuned to the appropriate frequency.

- The signal detected as a power excess over the cavity noise. The signal to noise ratio (SNR) is the key figure of merit for axion and dark photon detection.

Power Spectrum Analysis

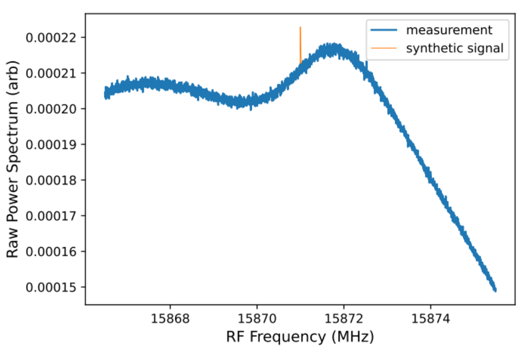
- We process the measured power spectrum to search for spectrally narrow signals with significant SNR.

- The system noise is gaussian; this can be used to place 90% confidence limit for axion/dark photon parameter space when the signal is non-statistical.

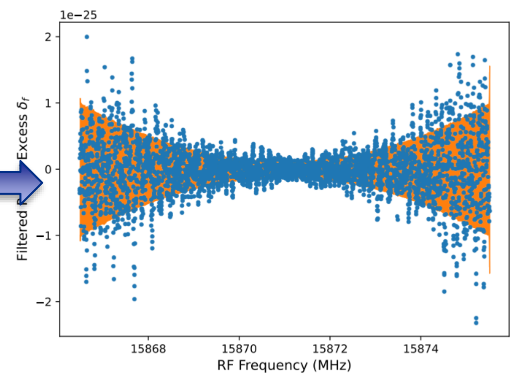
$$\mathrm{SNR} = P_S/\sigma_{P_n}$$

$$\implies \mathrm{SNR} = (P_S/P_n)\sqrt{b\Delta t}$$

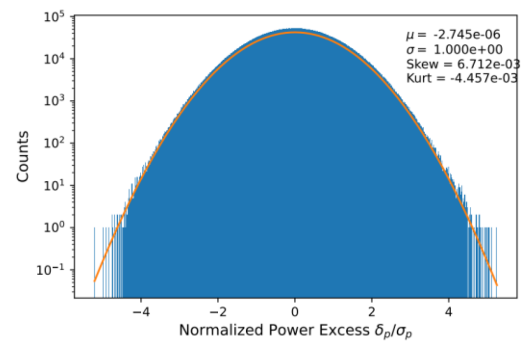
$$\delta_s = \delta_p \frac{k_b b T_n}{P_s}$$ → Rescaled power excess



Credit: R. Cervantes

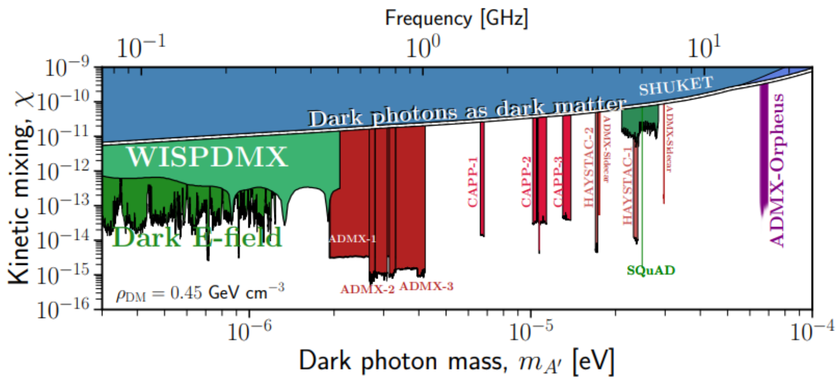


Credit: R. Cervantes

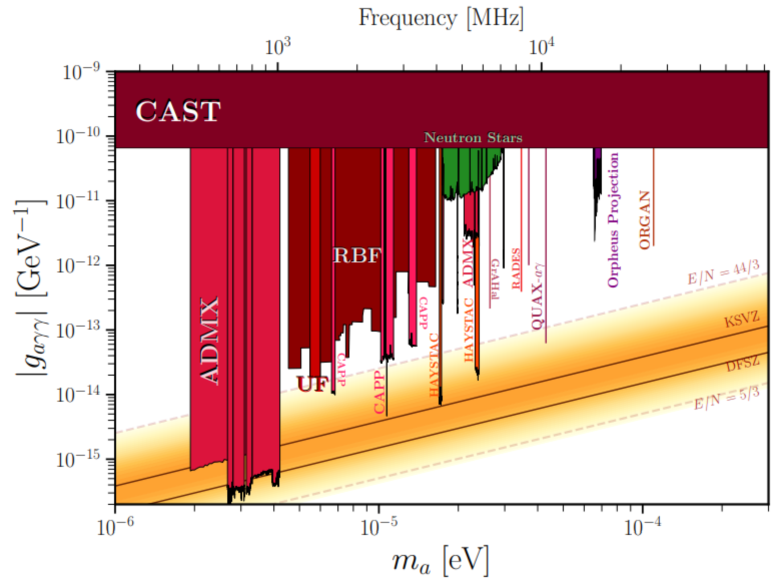


Credit: R. Cervantes

Search Exclusions



Credit: R. Cervantes



Credit: R. Cervantes

- The shaded regions indicates the parameter space that has been searched by various experiments
- Dark photon/axions are said to not exist within the searched parameter space with 90% confidence.

Objectives

- Simulate noise at various cavity temperatures and run it against the analysis strategy.
- Create a synthetic signal in the raw spectrum to observe the effectiveness of the analysis for detection.

$$\mathcal{F}(f) = \frac{2}{\sqrt{\pi}}\sqrt{f - f_a}\left(\frac{3}{f_a\left\langle\beta\right\rangle}\right)^{3/2}\exp\frac{-3(f-f_a)}{f_a\left\langle\beta^2\right\rangle}$$

Axion/dark photon energy distribution

$$P_{synthetic} = \mathrm{SNR} \times \frac{\mathcal{F}(f)}{\max\mathcal{F}(f)\sigma_P P_n}$$

Synthetic signal power