STAX. Axion-like particle searches with sub-THz photons

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Summary

- Dark matter particles: indications
- Axions and axion-like particles (ALPs)
- Light-Shining-Through-Wall (LSW) experiments
- Search for ALPs at STAX
- STAX: exclusion limits for ALPs

Dark matter. Indications

- **Energy density of the Universe**

  $\Omega = \Omega_M\,(0.32) + \Omega_R\,(\mathrm{H}\,0) + \Omega_\Lambda\,(0.68)\,\mathrm{H}\,1$

  Planck Collaboration, arXiv:1502.01589

  $\Omega_M = \Omega_{BM}\,(0.05) + \Omega_{DM}\,(0.27)$

  Big Bag nucleosynthesis predictions on Ω_{BM}

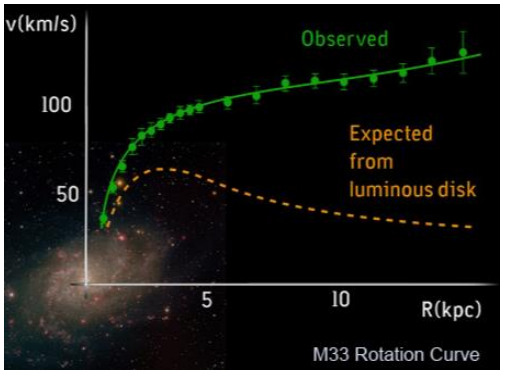
  S. Sarkar, Rep. Prog. Phys. **59**, 1493 (1996)

- **Galactic rotation curves**

  Discrepancies between calculated and observed rotational velocity profiles of galaxies

- **Gravitational lensing**

  Reconstruct dark matter distribution of extended objects via gravitational lensing



Axions & axion-like particles (ALPs)

- Axions and WIMPs are the leading DM particle candidates
- Axions are light neutral scalar or pseudoscalar bosons ($m_a \approx$ μeV - meV)
- Coupled to e.m. field tensor with strength G

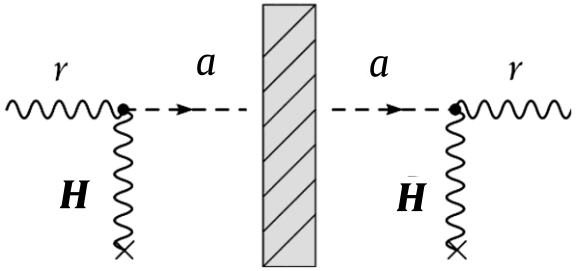
$$\mathcal{L}_{\mathrm{I}} = \frac{1}{4} G a F^{\mu\nu} \tilde{F}_{\mu\nu}$$

- In QCD axion models (DFSZ and KSVZ), G related to m_a. One free parameter, G
- In axion-like particle (ALPs) searches, parameter space is extended: G and m_a

Light-Shining-Through-Wall (LSW)

Photon-axion & axion-photon conversion

P. Sikivie, Phys. Rev. Lett. **51**, 1415 (1983)



- Axion-photon interaction: $\mathcal{L}_I = \frac{1}{4} G\, a\, F^{\mu\nu} \tilde{F}_{\mu\nu} = G\, a\, \boldsymbol{H} \cdot \partial_0 \boldsymbol{A}$

  G = axion-photon coupling constant, a = axion field, $\boldsymbol{A}$ = photon field, $\boldsymbol{H}$ = external magnetic field
- Photon converts into axion in ext. static magn. field via exchange of virtual photon
- External magnetic field uniform in the volume $L_x L_y L_z = L_x S$, **x** = dir. of photon beam
- Photon exchanges 3-momentum **q** with **H**, energy is conserved
- Conversion probability: $P_{\gamma\to a} = P_{a\to\gamma} = G^2 H^2 \frac{\sin^2(q_x L_x/2)}{q_x^2} \frac{\epsilon_\gamma}{1/L_x + \sqrt{\epsilon_\gamma^2 - m_a^2}}$
- Rate: $\frac{\mathrm{d}N_\gamma}{\mathrm{d}t} = \Phi_\gamma \eta P_{\gamma\to a}^2$

  Φ_γ = photon flux (s^{-1}), η = detector efficiency
- The rate can be increased introducing a Fabry-Perot cavity in the magnetic field area before the wall by a factor of Q (quality factor of the cavity)

Search for ALPs at STAX

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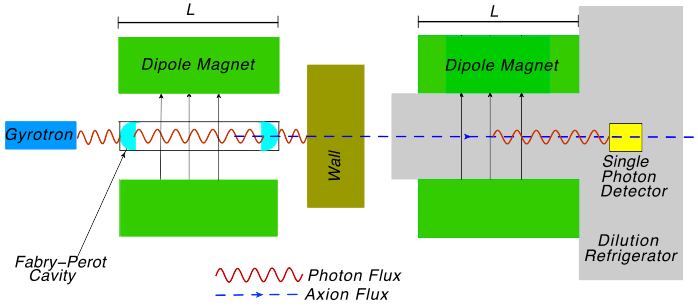
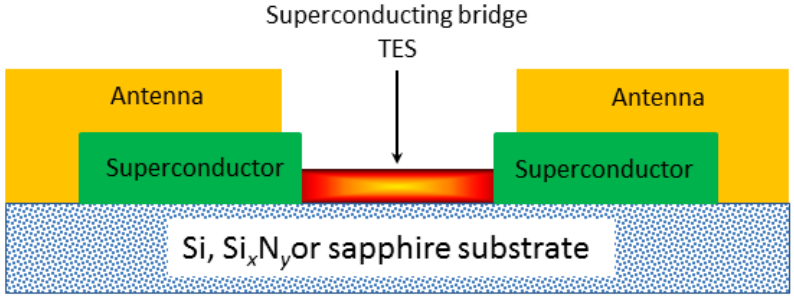
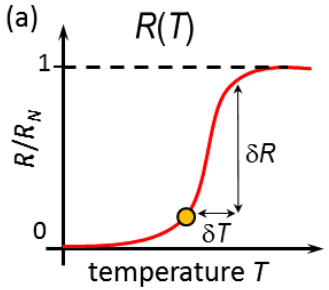


- Up to $m_a \approx 0.1\ \varepsilon_\gamma$, photon-axion conversion probability depends on luminosity, not on photon energy $\Rightarrow$ sub-THz photons
- Magnetic field: H = 15 T, L = 0.5 m
- Photon source: gyrotron; $P \approx 100$ kW, $\Phi_\gamma = 10^{27}$ s^{-1}, $\varepsilon_\gamma = 118$ μeV ($\nu \approx 30$ GHz)
- Fabry-Perot cavity: $Q \approx 10^4$
- Exposure time: 1 month
- Sub-THz single-photon detector: based on TES technology, $\eta \approx 1$

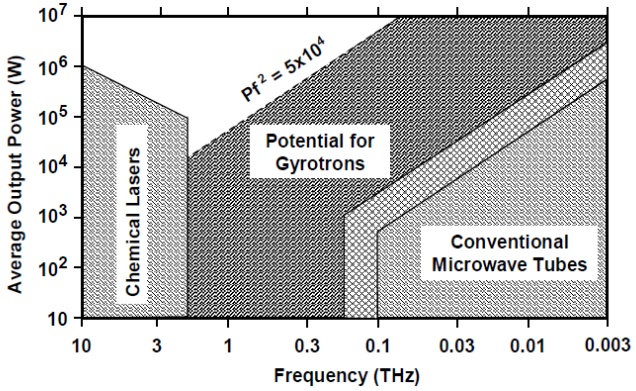
STAX. Single photon detector





- Transition Edge Sensor (TES): low critical temperature superconductor between two superconducting electrodes. TES coupled to antenna.
- TES operated within its superconducting transition. DC bias voltage applied. When TES absorbs an incoming photon, it heats up above critical temperature Tc. Change of resistance and current flowing in the circuit, measured by a SQUID.
- STAX will use α-tungsten (or titanium nitride) for implementation of TES with $T_C \approx 15$ mK. Efficient log-periodic spiral antennas will be designed and integrated.

STAX. Gyrotron

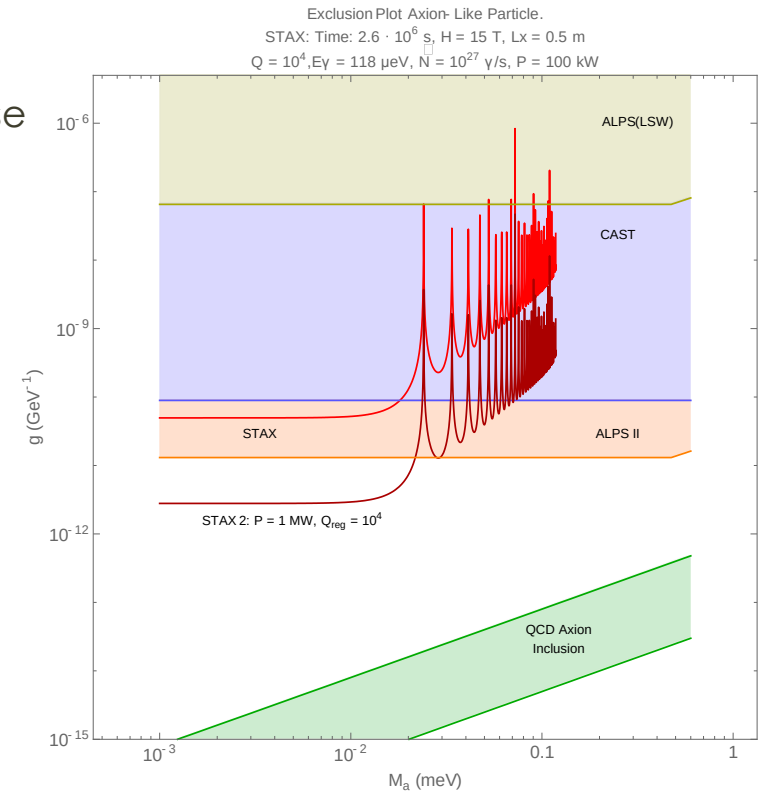


- Klystrons and gyrotrons emit radiation in the 30-100 GHz range.
- Powers exceeding 1 MW in this frequency range.
- Luminosity up to 10^{28}-10^{29} γ/s.
  To be compared with luminosity of lasers (optical regime), commonly used in LSW experiments, of the order of 10^{19} γ/s.

STAX. Exclusion limits

L.M. Capparelli *et al.*, Phys. Dark Univ. **12**, 37 (2016)

- Exclusion limits STAX may achieve in case of null result
- **STAX** limits compared to
  - **ALPS LSW** results
    Phys. Lett. B **689**, 149 (2010)
  - **CAST** results
    Phys. Rev. D **92**, 021101 (2015)
  - Calculated limits of **ALPS II**
    JINST **8**, T09001 (2013)
    arXiv:1309.3965
  - **QCD Axion models** predictions
    (Inclusion limits)



Conclusion

- Axions (and ALPs) are between leading DM candidates
- Light-Shining-Through-Wall (LSW) experiments for ALPs searches
- LSW experiments' exclusion limits may be extended substituting optical lasers with sub-THz photon sources
- Search for ALPs at STAX with sub-THz photons
- STAX: exclusion limits for ALPs

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STAX. Axion-like particle searches with sub-THz photons

Thank you for your attention

STAX II

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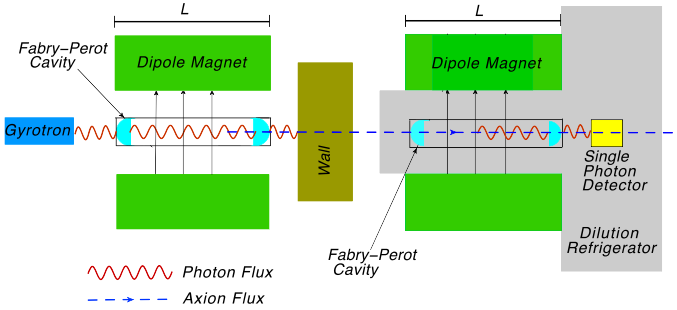

- A second cavity is installed in the magnetic field region behind the wall. A coherent axion beam may excite the cavity electromagnetic modes → enhanced axion-photon conversion. P. Sikivie, D.B. Tanner and K. Van Bibber, Phys. Rev. Lett. **98**, 172002 (2007)
- With a second cavity with quality factor Q = 10^4, STAX exclusion limit on $G_{a\gamma\gamma}$ extended by an order of magnitude.