Cavity Search for Axion

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Outline

- Motivation
- Axion properties
- Axion detection
- Cavity Search for Axions
- Results
- Upgrades
- Conclusions

Strong CP problem (motivation 1)

- *CP* violation in QCD would induce large electric dipole moment for the neutron with discrepancy ~10^9 with experimental results.

- *CP* symmetry is not violated in QCD

- Peccei & Quinn postulated a global symmetry that is spontaneously broken in QCD.

⇨ A new particle is produced (axion).
The CP violating parameter in the lagrangian is allowed to relax to zero.

In theory the Strong CP Problem is solved!!!!

Some Properties

- The existence of an axion is the signature of he *PQ* solution to the *CP* problem.
- Axion mass

$$m_a \approx 6\mu eV \frac{10^{12} GeV}{f_a}$$

- Axion-Photon conversion; Lagrangian; interaction term

$$L_{a\gamma\gamma} = g_\gamma \frac{\alpha}{\pi} \frac{a(x)}{f_a} \vec{E} \cdot \vec{B}$$

$a(x)$ Axion field

$\vec{E}$ Electric field

$\vec{B}$ Magnetic field

α Fine structure constant

g_γ Model dependent coefficient

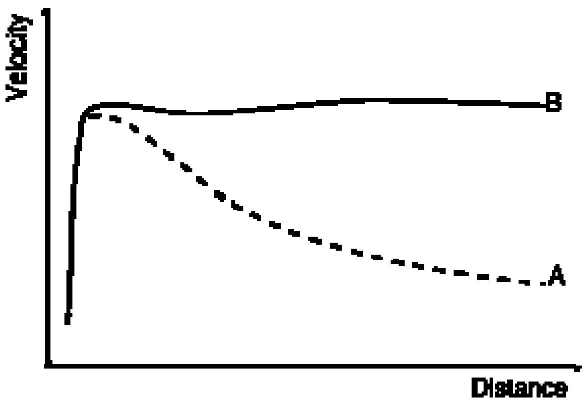
f_a Axion decay constant

$$g_{a\gamma\gamma} = \frac{\alpha g_\gamma}{\pi f_a};\ g_\gamma = \begin{cases} -0.97\ KSVZ \\ 0.36\ DFSZ \end{cases}$$

Axion from Galaxy halo (motivation 2)

- Rotation curve of most spiral galaxies remains flat far beyond the visible matter.
- Dark matter can explain the velocity curve having a "flat" appearance out to large radii.
- It could test GR.
- The axion is a candidate to cold dark matter CDM.
- <u>Two different kinds of axions</u>
  In the halo
  Just fallen into the halo

- Dark matter halo



Rotation curve of a typical spiral galaxy: predicted (**A**) and observed (**B**).

$$v \sim 1/\sqrt{r}$$

Experiments: Why Cavity search?

The Axion Dark Matter Experiment ADMX, (Livermore California).

- It is able to test axions in the range of interest for theoretical models and predictions for the mass of the axion $10^{-6}<m_a<10^{-3}$ eV.
- Enough sensitivity to prove real axion models.
- Level of confidence ~90%.
- Currently running.

Microwave search cavity

- Find axions via conversion into microwave photons in a tunable microwave cavity.
- Stimulate this conversion using a strong static magnetic field.
- Use low-noise detection system to detect the excess in power at the resonance frequency above thermal noise.
- This excess in power constitutes the candidates for detected axions.

Axion Detection

- **Mass window**

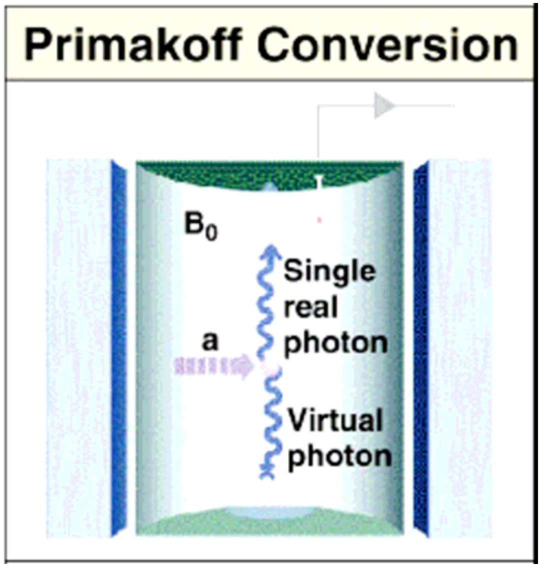
  Astrophysical constraints m_a <10^{-3} eV
  Cosmological constraints m_a >10^{-6} eV

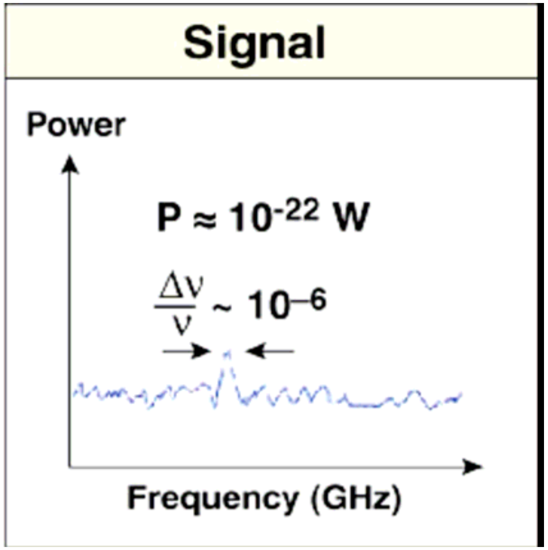
- **Expected signals**
  - Axions through galactic halo

    $\Delta E/E \sim 10^{-6}$

  - Capture of extra-galactic axions by the gravitational potential of the galaxy

    $\Delta E/E \sim 10^{-11}$





Power From Axion-Photon Conversion

$$P = \left(\frac{\alpha g_\gamma}{\pi f_a} \right)^2 \frac{V B_0^2 \rho_a C}{m_a} \min(Q, Q_a)$$

- Large superconducting Magnet
- RF cavity with high *Q* factor
- Big Microwave cavity?
- Low noise receivers and detectors
- Good data analysis

- V volume of the cavity
- B_0 magnetic field at the center of the cavity
- ρ_a density of galactic halo axions at Earth
- f cavity resonance frequency
- C mode dependent form factor ~0.69
- $Q_{(a)}$ quality factor of the cavity (axion signal)

Experiment

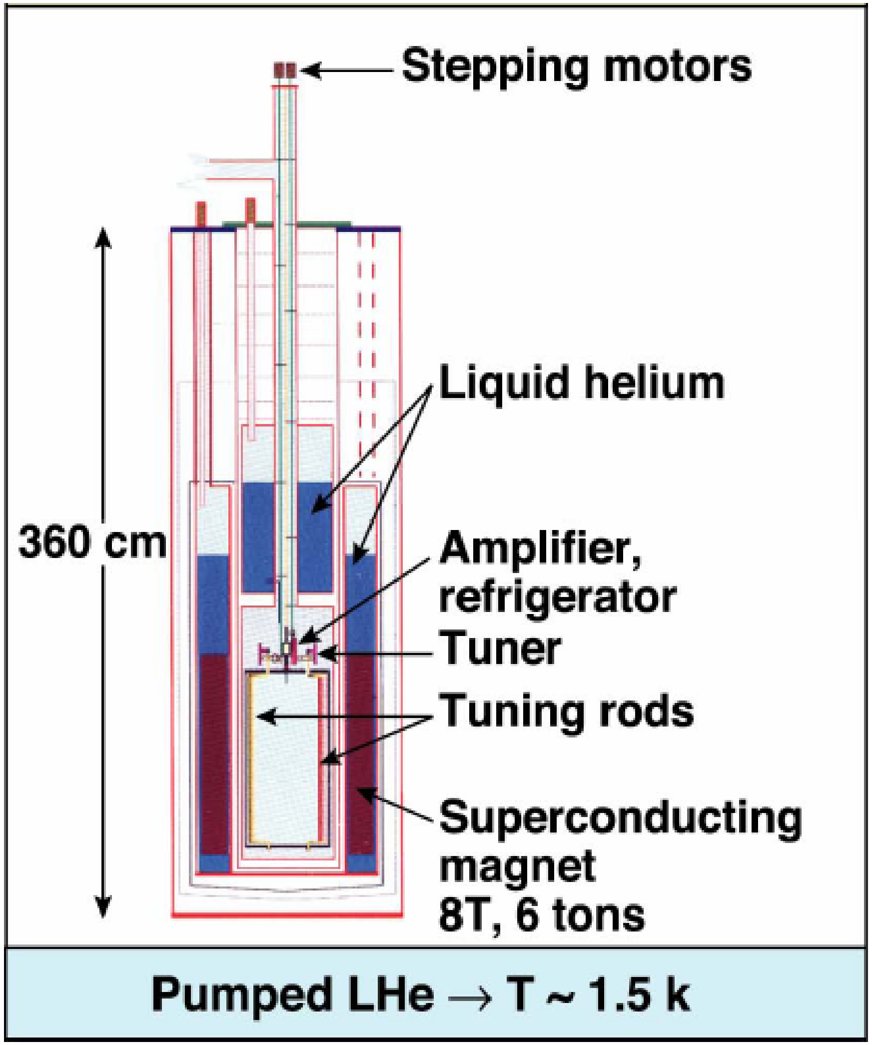
- Tunable Cavity
  Cylindrical RF cavity cooled to reduce thermal noise.

- Superconducting Magnet
  Solenoid surrounding the cavity
  B_0=7.2 T

- Low noise electronics
  Cavity EM field is coupled through an electro-field probe to ultra-low-noise receiver electronics.

- System noise temperature

$$T_s = T_c + T_a$$



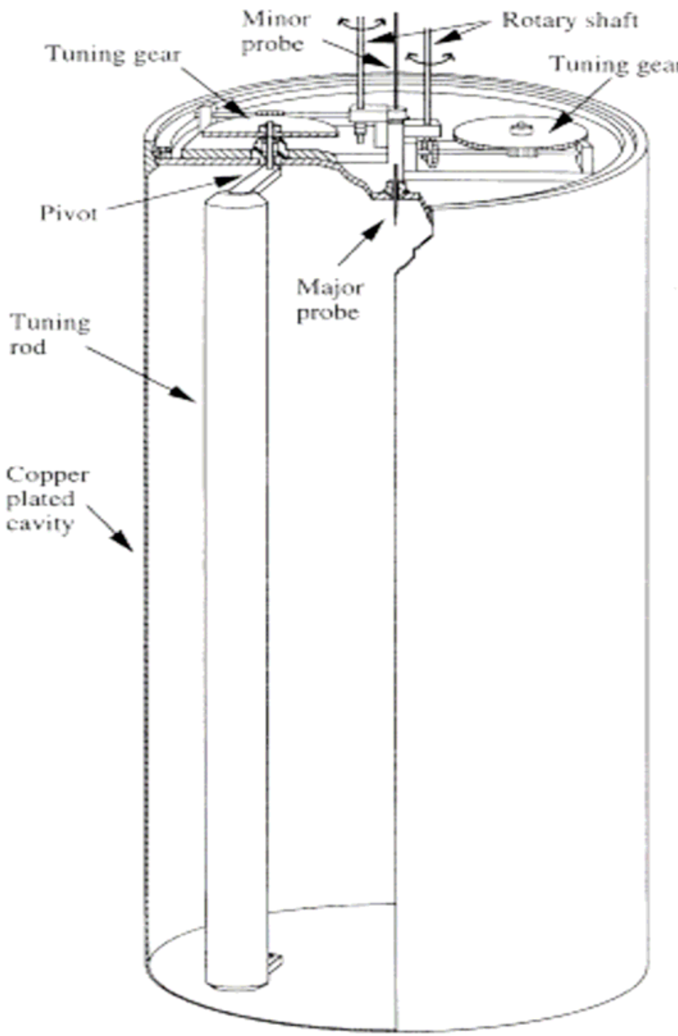
Cavity 1

- <u>Resonant frequency</u>: 300-800 MHz.
  - T~1.3 K
  - V~200 l

<u>Power in the cavity</u>

- Minor port: coupes power into the cavity.
  - Cavity transmission
  - Resonance frequency

- Major port: couples power from the cavity to the preamplifier.



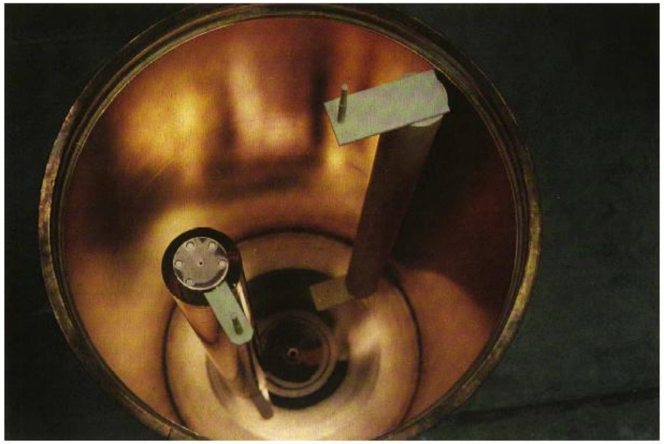
Cavity 2

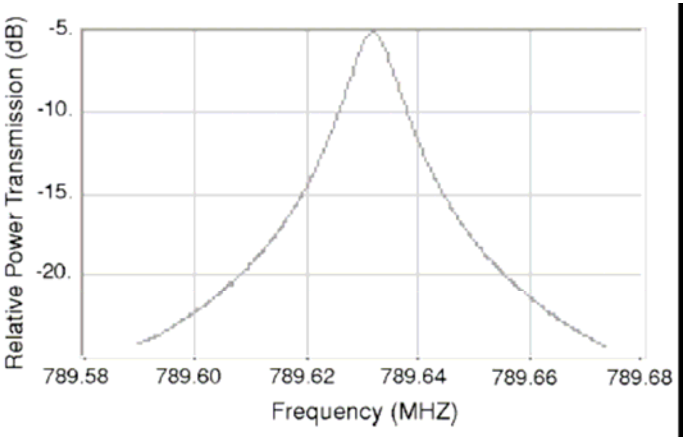
- Tuning the frequency; radial displacement of two rods.

Copper road towards the center:
shifts the frequency up.

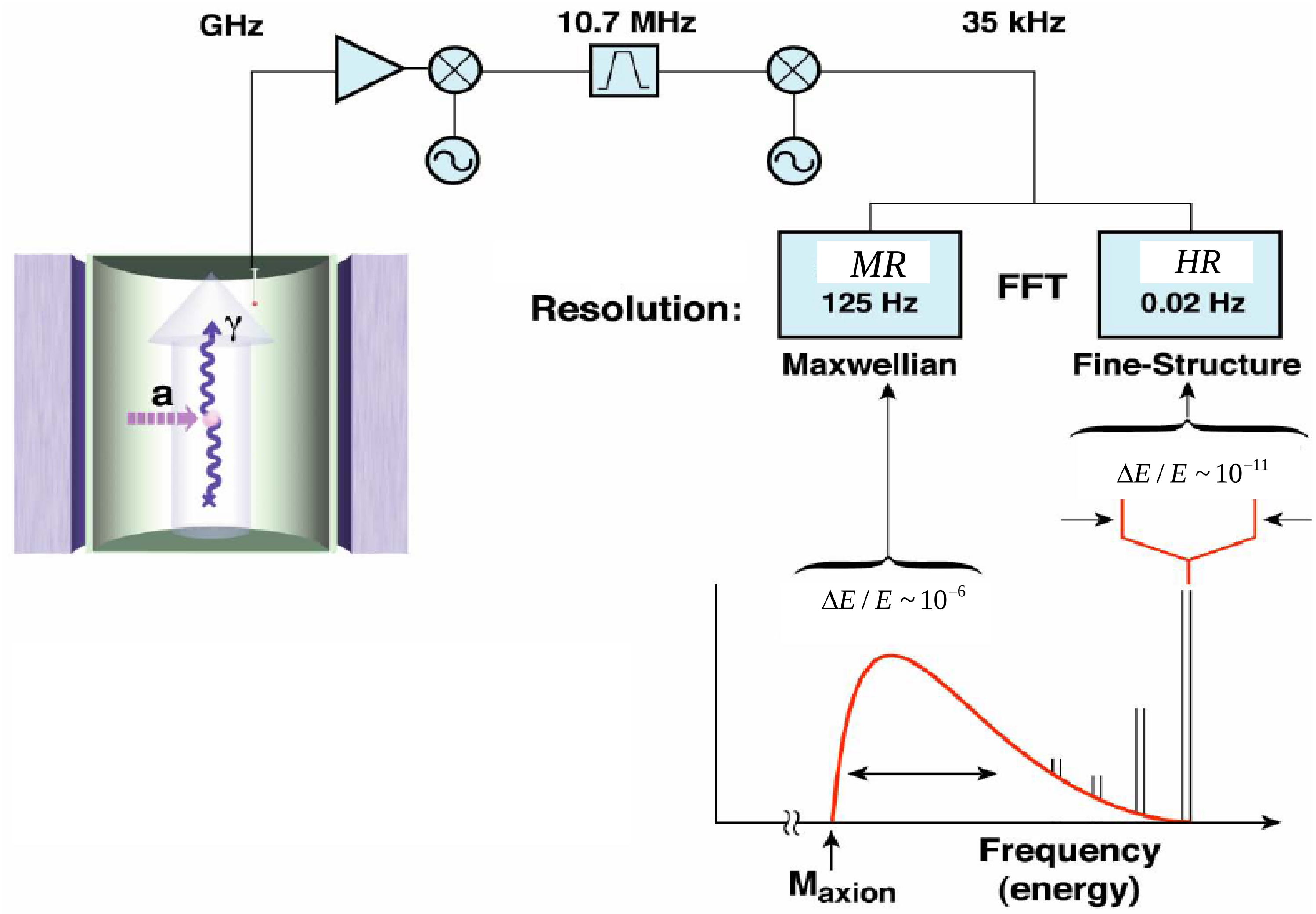
Alumina rod in the same direction:
shifts the frequency down.

Extra frequency shift can be obtained by changing the form factor of the cavity.





Microwave Electronics 1



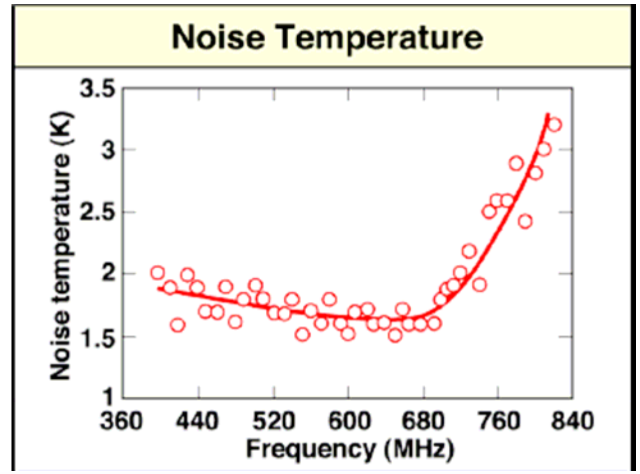
Microwave Electronics 2

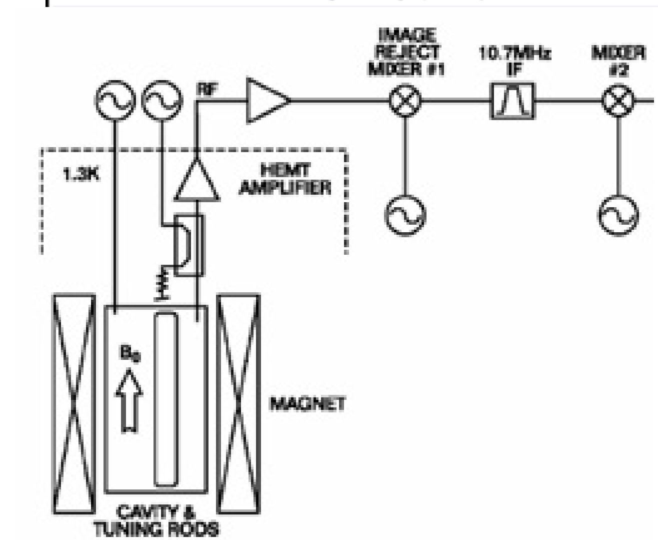
- Dominant background noise: Thermal Noise from cavity and electronics.

- Power from the cavity is coupled to a cryogenic preamplifier through the major port
  - Noise temperature ~2 K
  - Gain~15 dB

Microwave Power Spectrum:

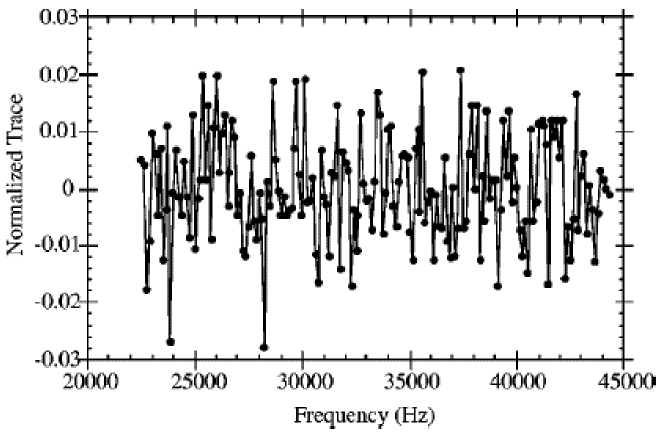
- averaged,
- filtered and
- recorded with all experimental parameters to be analyzed.





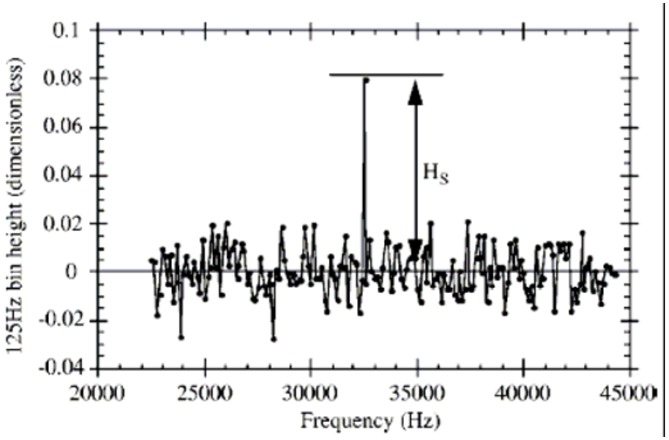
Analysis; Confidence Level

- The confidence level is obtained by injecting a fake signal.
- The traces of the spectral density of the cavity are normalized and corrected from the receiver response.



- Dimensionless fluctuations ~ zero δ.
- Cuts in SD's.

$$\sigma = \sqrt{\sum_i^n \frac{\delta_i^2}{n}}$$

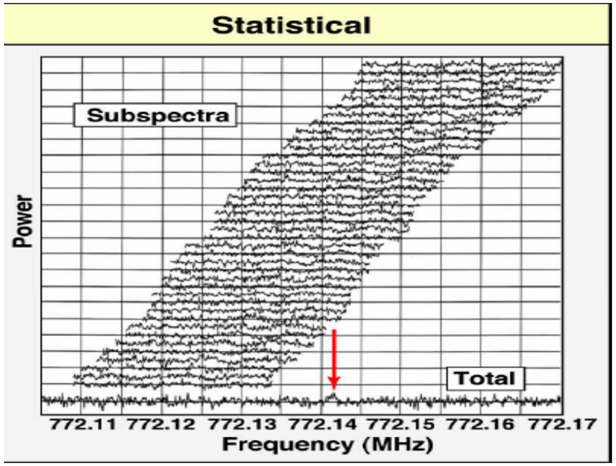


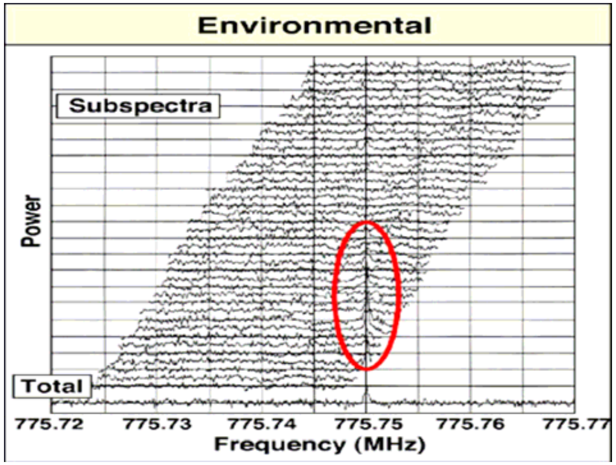
Candidate Exclusion Process

- **Stages**

1. *Several scans* are performed over every frequency region. Required CL=90%.
2. *Rescan*. Candidates are rescaned with required CL~98%.
3. *Persistent Scan*. CL to the cut set above 99%.
4. Terminating the minor and major ports where radio signals can couple to the cavity and preamplifier.
5. Ramping down B field. Look for

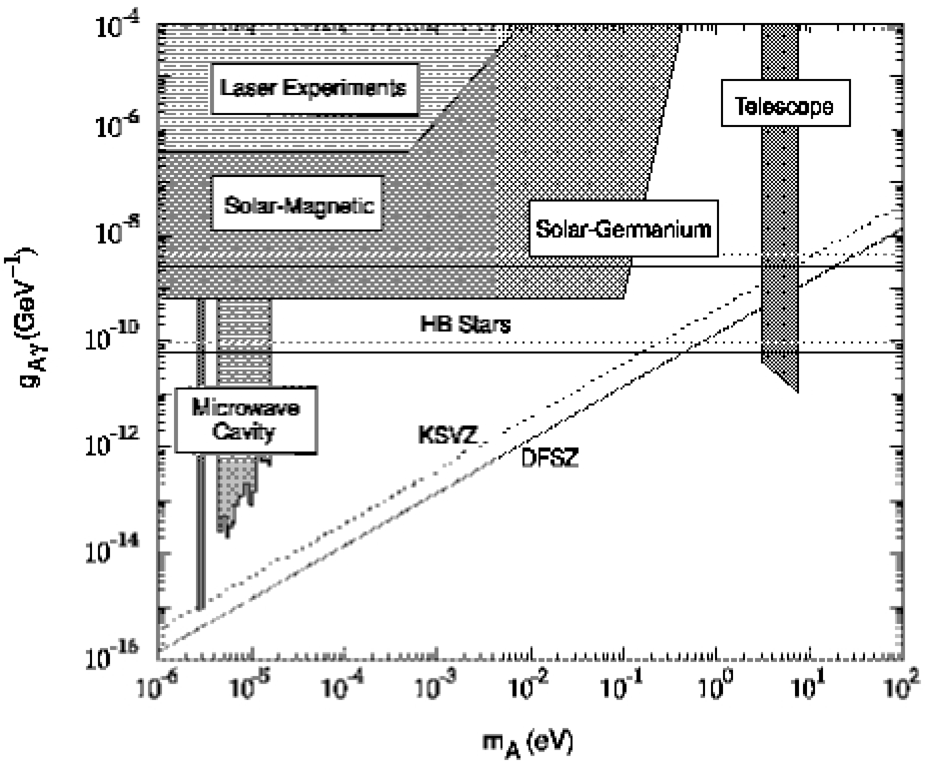
   a behavior: $P \sim B^2$.

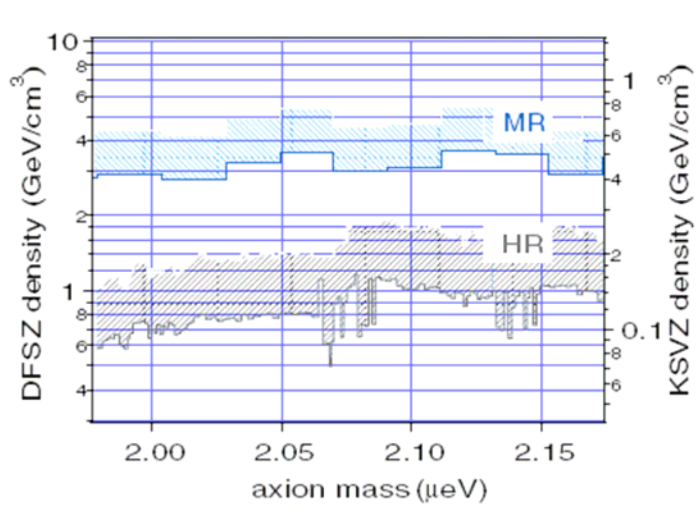




Some Results

Some results from different analysis and experiments





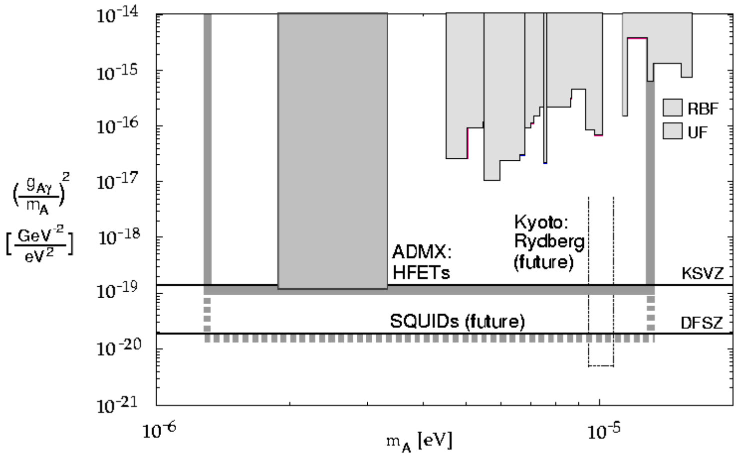
Future

Improve experimental sentsitivity

- SQUID replace the HEMT
  - Noise Temperature ~ 0.2 K
  - S/N 10 times bigger

- Search for higher axion masses
  - Four-cavity array
  - 20 cm in diameter and 1 m tall.

- Piezo drive for the rods
  - Improving thermal insulation



Conclusions

- Search for axions via photon conversion in a microwave tunable cavity.
- Microwave cavity axion detection is able to probe realistic dark matter axion models with sufficient sensitivity.
- Upgrades will permit the search for weaker coupled axion models and over all the axion mass window.
- MW Cavity experiment could probe the solution to the Strong CP Problem.

References

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