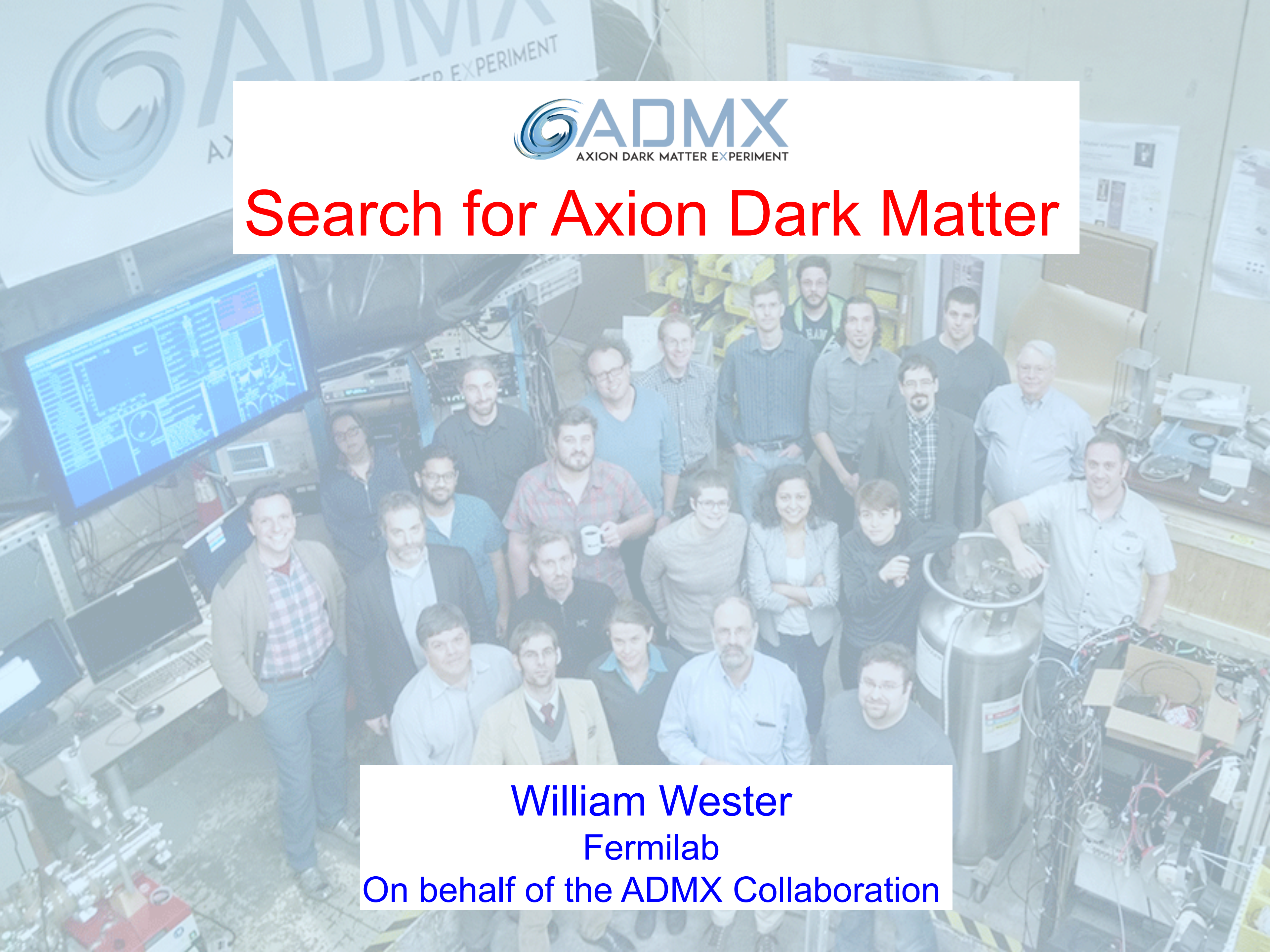
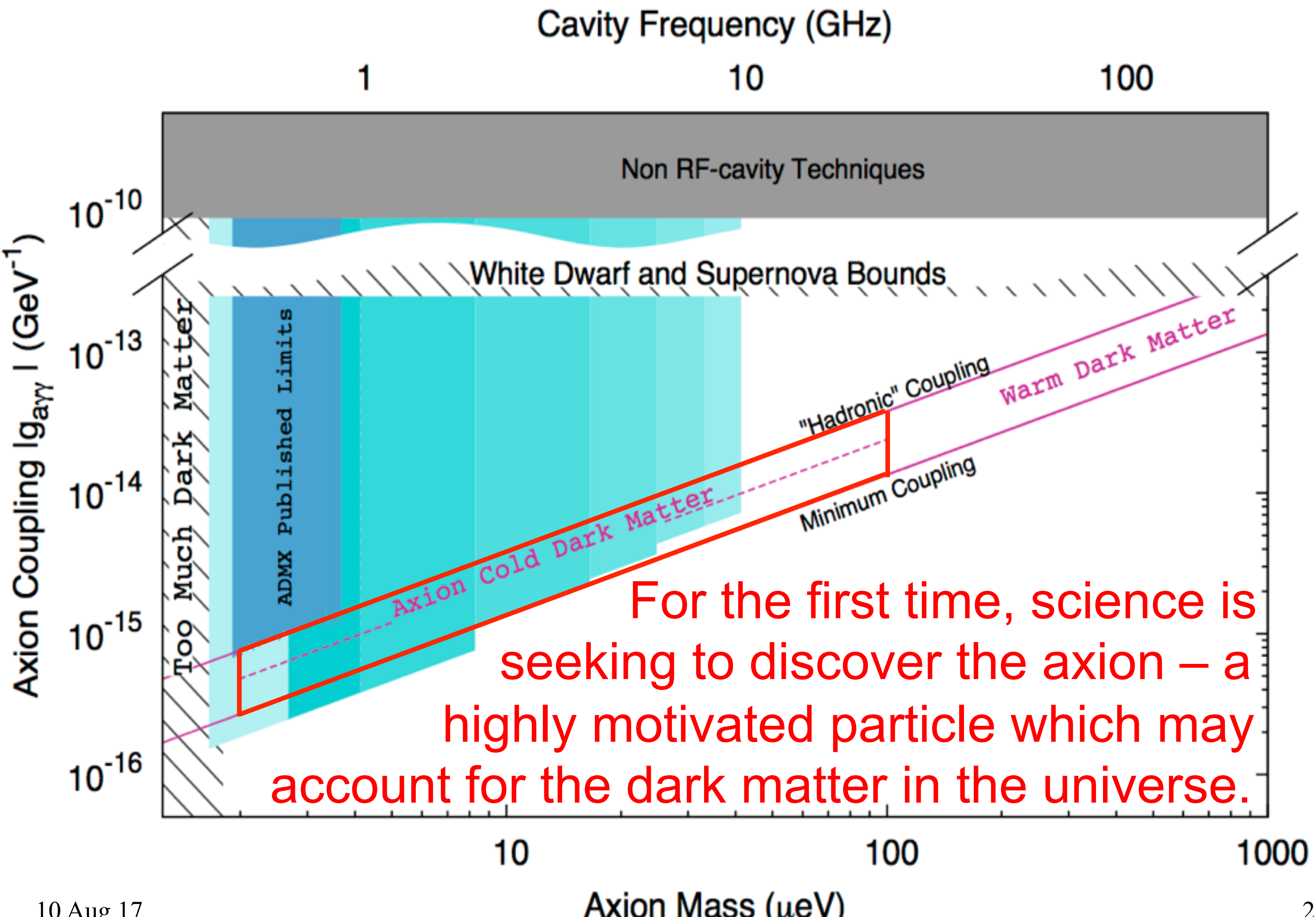
ADMX
AXION DARK MATTER EXPERIMENT

Search for Axion Dark Matter



William Wester
Fermilab
On behalf of the ADMX Collaboration

Gen 2 ADMX Projected Sensitivity



For the first time, science is seeking to discover the axion – a highly motivated particle which may account for the dark matter in the universe.

Axions

- Postulated in the late 1970s as a consequence of not observing CP violation in the strong interaction.

$$L_{CP} = -\frac{\alpha_s}{8\pi}\underbrace{(\Theta - \arg\det M_q)}_{0\leq\bar{\Theta}\leq 2\pi}\,\mathrm{Tr}\,\tilde{G}_{\mu\nu}G^{\mu\nu}$$

Raffelt

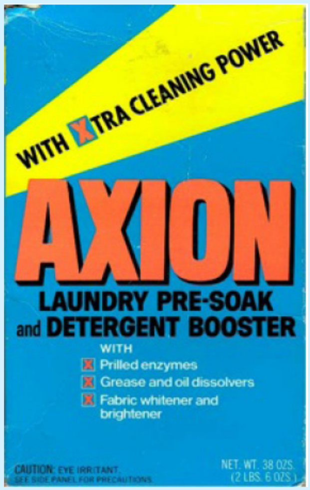
- The measurement of the electric dipole of the neutron implies $\bar{\Theta} < \sim 10^{-10}$. => Strong CP Problem of QCD
  - This is very much on the same order of an issue with the Standard Model as the hierarchy problem that motivates supersymmetry.
  - Axions originate from a new broken symmetry that explains small $\bar{\Theta}$

Bjorken "Axions are just as viable a candidate for dark matter as sparticles"
Wilczek "If not axions, please tell me how to solve the Strong-CP problem"
Witten "Axions may be intrinsic to the structure of string theory"

WW+KvB

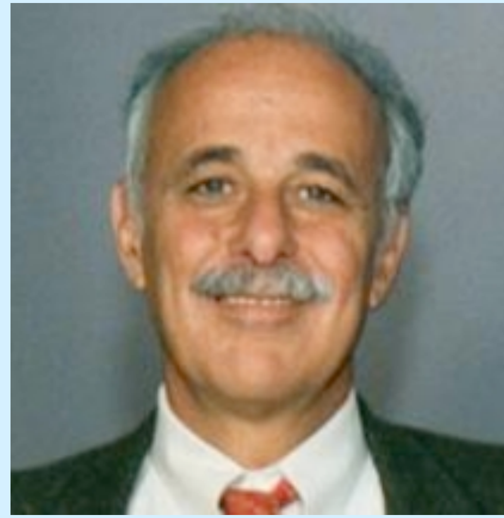
Axions

- Axions "clean-up"



the strong-CP problem!

$\bar{\Theta}$ is near zero due to the breaking of a new symmetry where the axion field relaxes to a minimum



Roberto Peccei

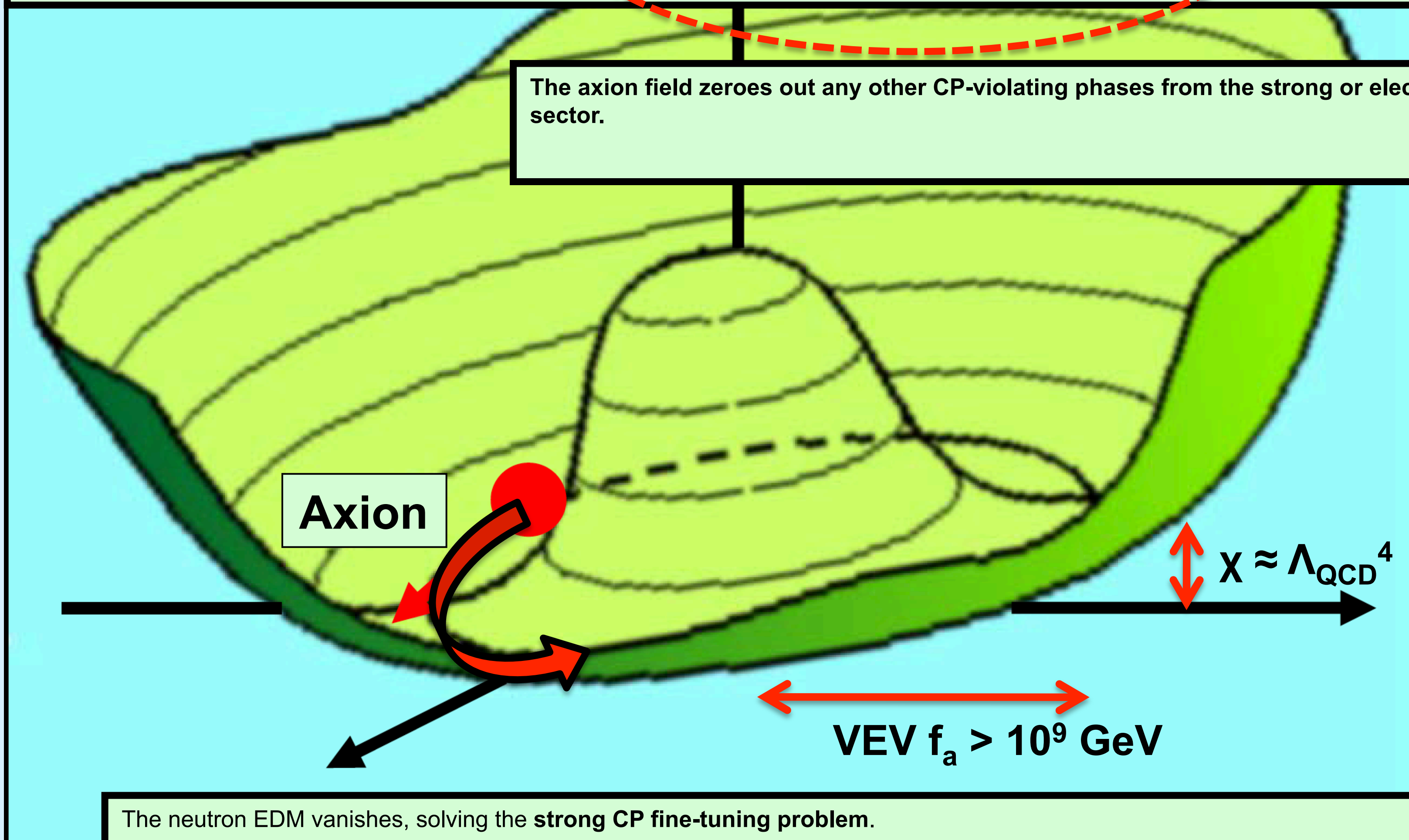
Helen Quinn

2013 JJ Sakuri Prize

Peccei – Quinn Symmetry

Explaining the vanishing neutron EDM

$$V(A) = -f_a^2 A^2 + \frac{\lambda}{4!} A^4 + \left(\frac{g^2}{32\pi^2} \arg(A) - \frac{\alpha_s}{8\pi} \left(\theta_{QCD} + \theta_{quark} \right) \right) \langle G\tilde{G} \rangle$$

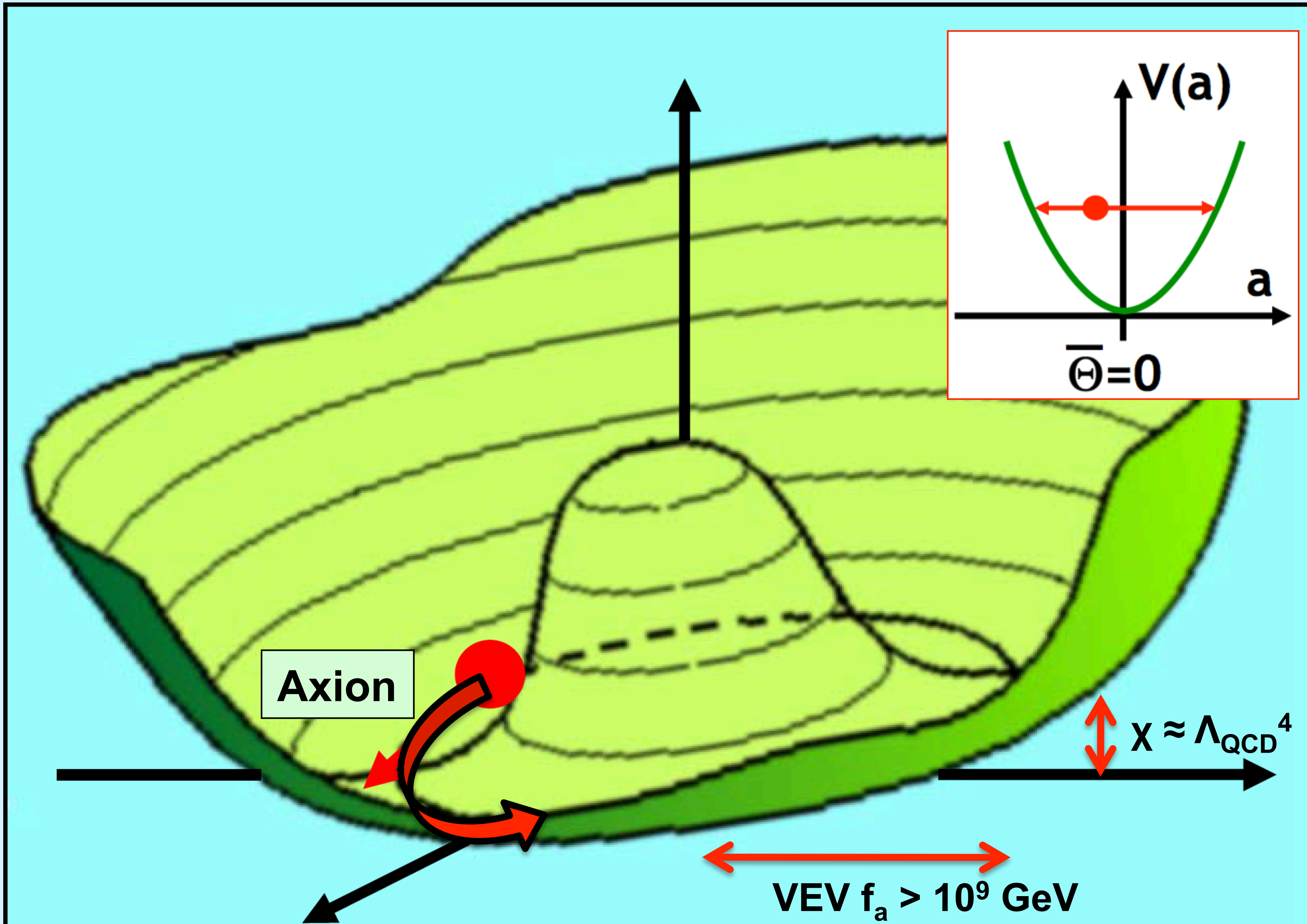


The axion field zeroes out any other CP-violating phases from the strong or electroweak quark sector.

The neutron EDM vanishes, solving the **strong CP fine-tuning problem**.

A. Chou

Axion mass = harmonic oscillator frequency



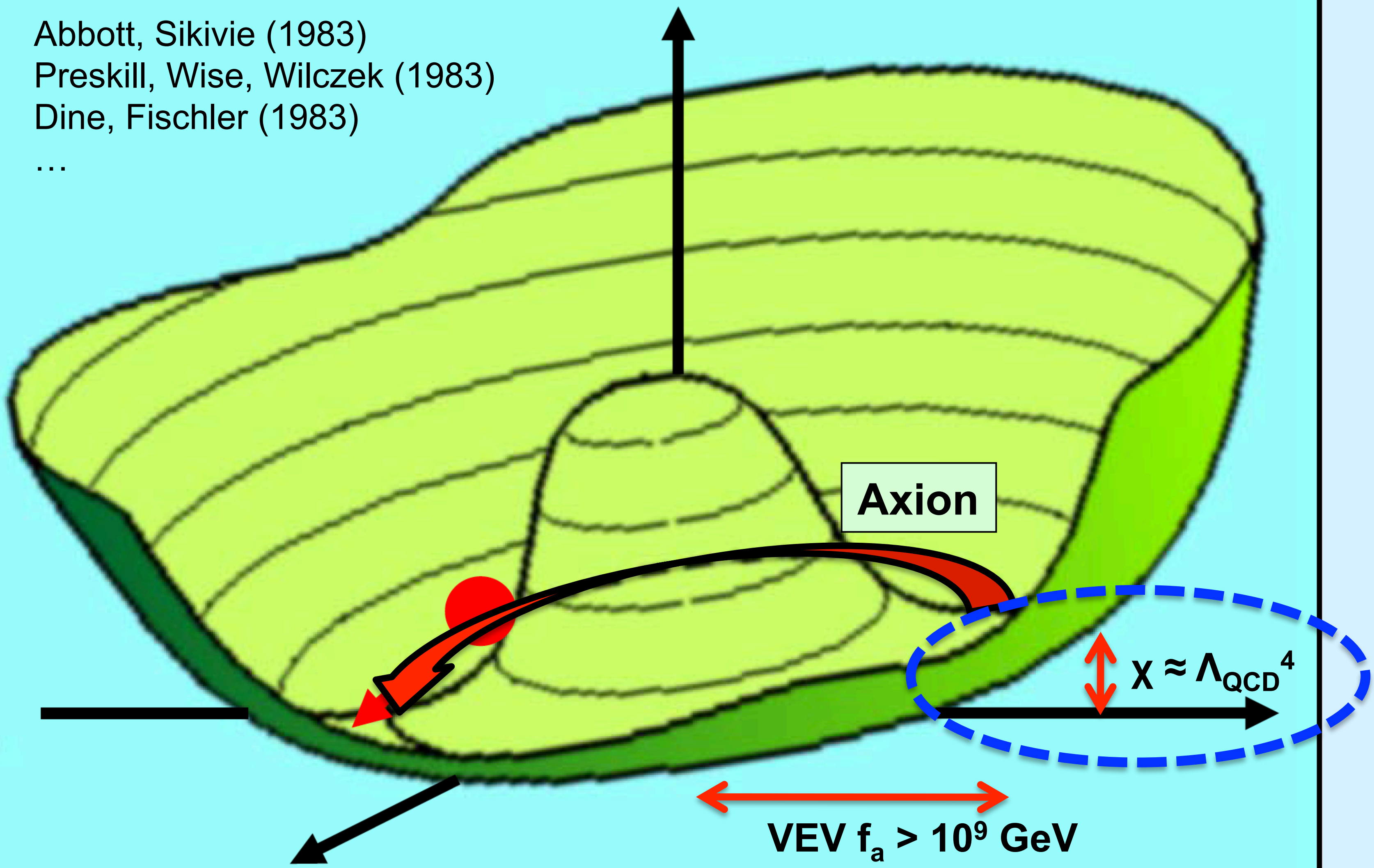
$m_a \approx \Lambda_{QCD}^2 / f_a < 10^{-3}$ eV

Single parameter model for axions

A. Chou

The initial potential energy density is released as ultracold dark matter

Abbott, Sikivie (1983)
Preskill, Wise, Wilczek (1983)
Dine, Fischler (1983)
…



Initial axial **theta angle θ_0**, determines the available potential energy to be converted into axion dark matter.

A. Chou

Axion mass + γ coupling

The axion, an excitation of the field, acquires a mass inversely proportional to the Peccei-Quinn symmetry breaking scale.

$$m_A = \frac{z^{1/2}}{1+z}\frac{f_\pi m_\pi}{f_A} = \frac{0.60\ \text{meV}}{f_A/10^{10}\,\text{GeV}}$$

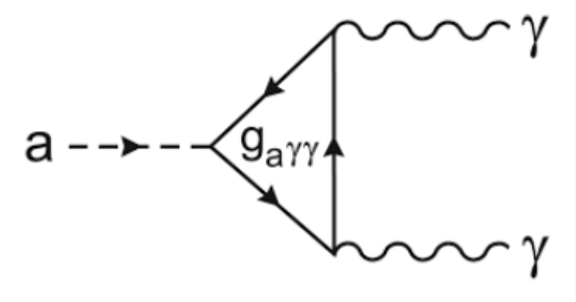
where $z = m_u/m_d$

Gives rise to diagonal relationship the limit plot mass vs coupling constant. Note: small << 1eV masses and large > 10^{10} GeV scales

Photon coupling

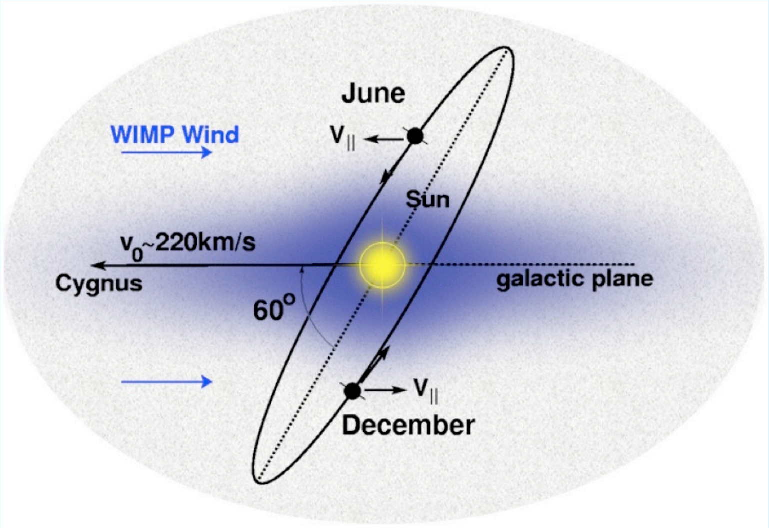
$$L_{a\gamma} = -\frac{g_{a\gamma}}{4}F\tilde{F}a = g_{a\gamma}\vec{E}\cdot\vec{B}a$$

$$g_{a\gamma} = \frac{\alpha}{2\pi f_a}\left(\frac{E}{N} - 1.92\right)$$



E/N is related to the E&M and color anomalies and is model dependent giving a band of allowed values in the diagonal relationship. A model involving Heavy Quarks (KSVZ) and a model involving Higges (DSFZ) help define the region of interest.

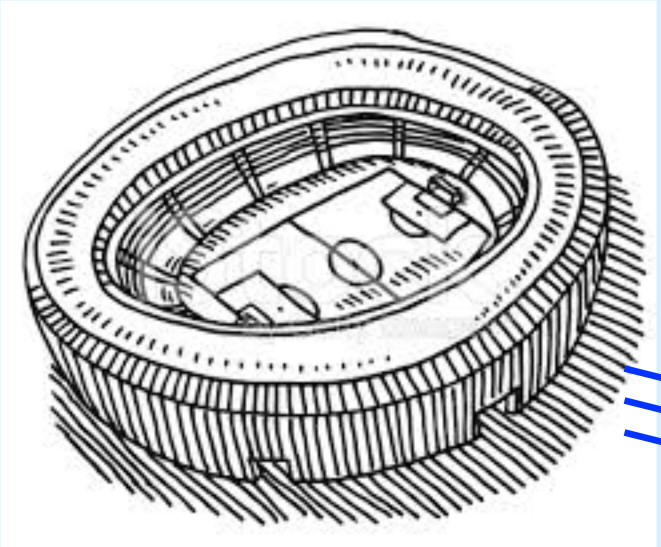
CDM Direct Detection



Solar system is moving at ~200km/s through a dark matter halo with a density of ~ 0.45 GeV/cm^3.

Axion searches look for the axion field coherently interacting with a sensitive apparatus

Suppressing backgrounds such as electronic and thermal noise is key in having sensitivity.

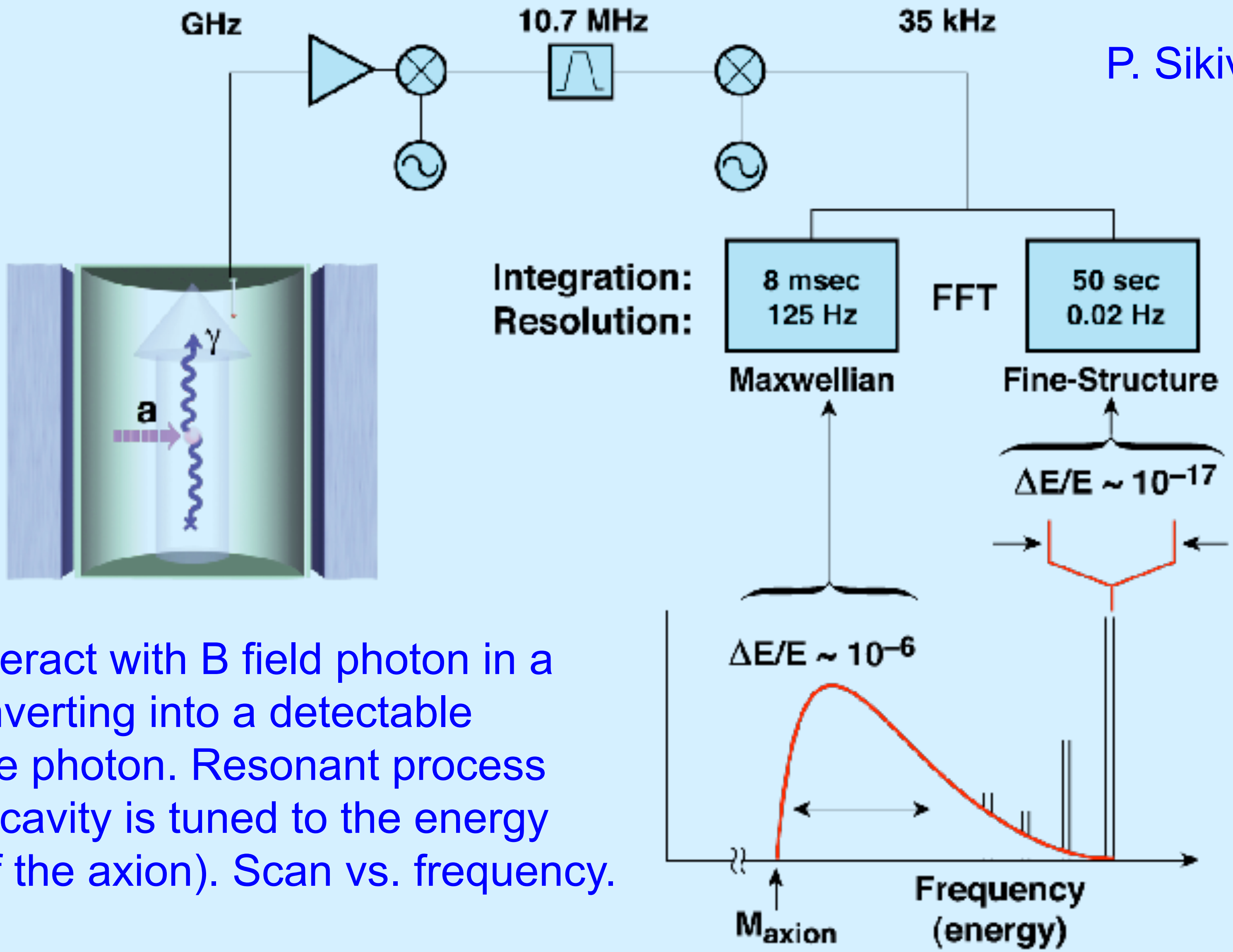


ADMX

Phase coherent over 10^{-3}s or 100s of meters

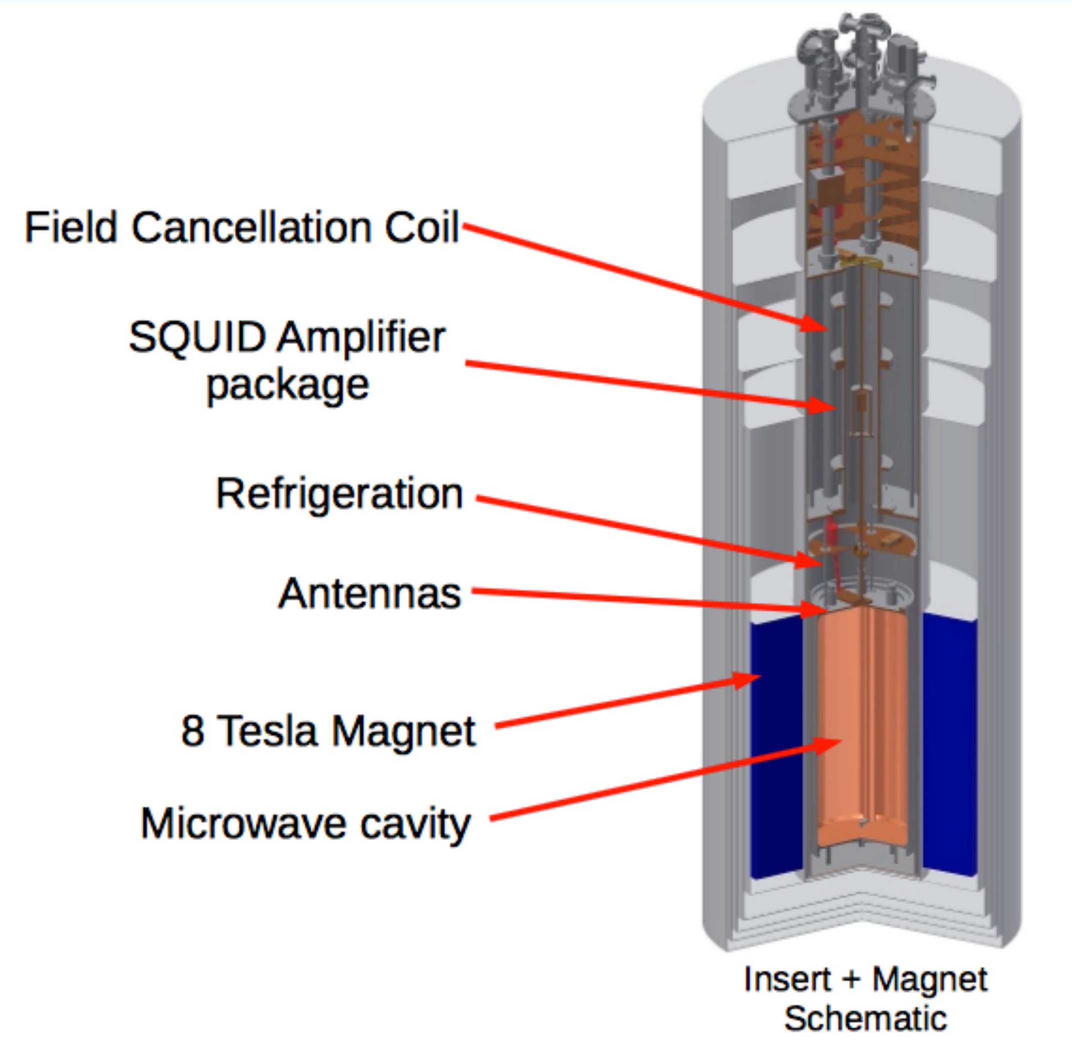
Axion Haloscope

P. Sikivie



Axions interact with B field photon in a cavity converting into a detectable microwave photon. Resonant process when the cavity is tuned to the energy (i.e. KE of the axion). Scan vs. frequency.

ADMX Experiment

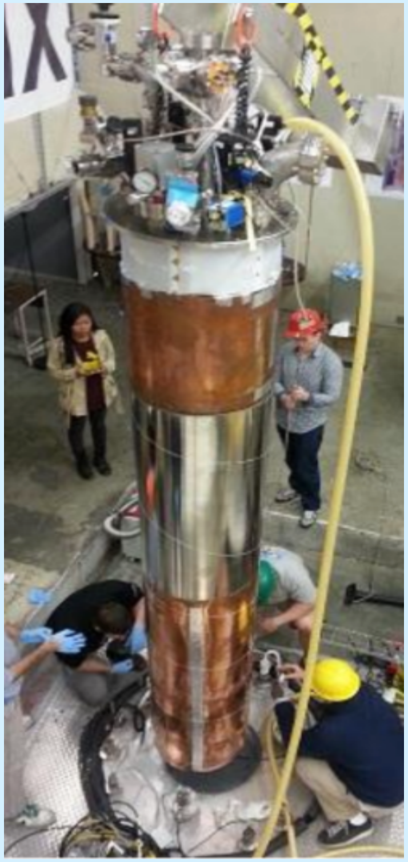


Magnet …
Superconducting with 8 Tesla field

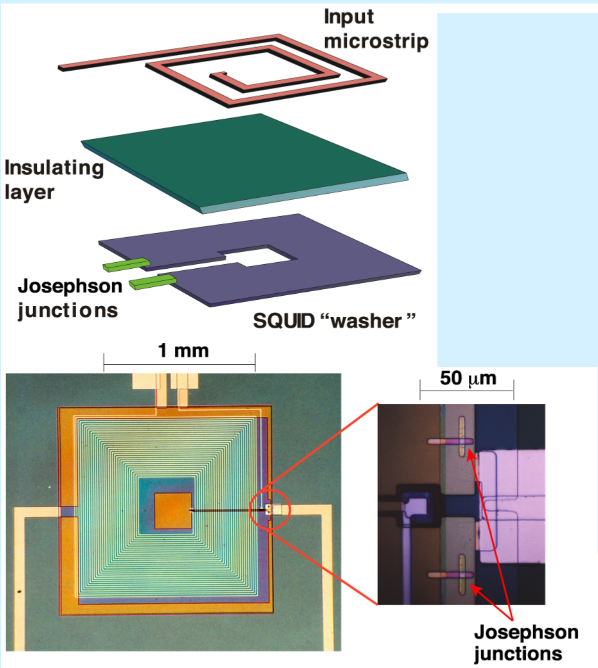
Cavity …
Copper with actuated tuning rods

ADMX Experiment

- Tunable microwave cavity in B field looking for dark matter axions converting into a detectable photons.
- Very small signal … needs the world's most sensitive "radio"

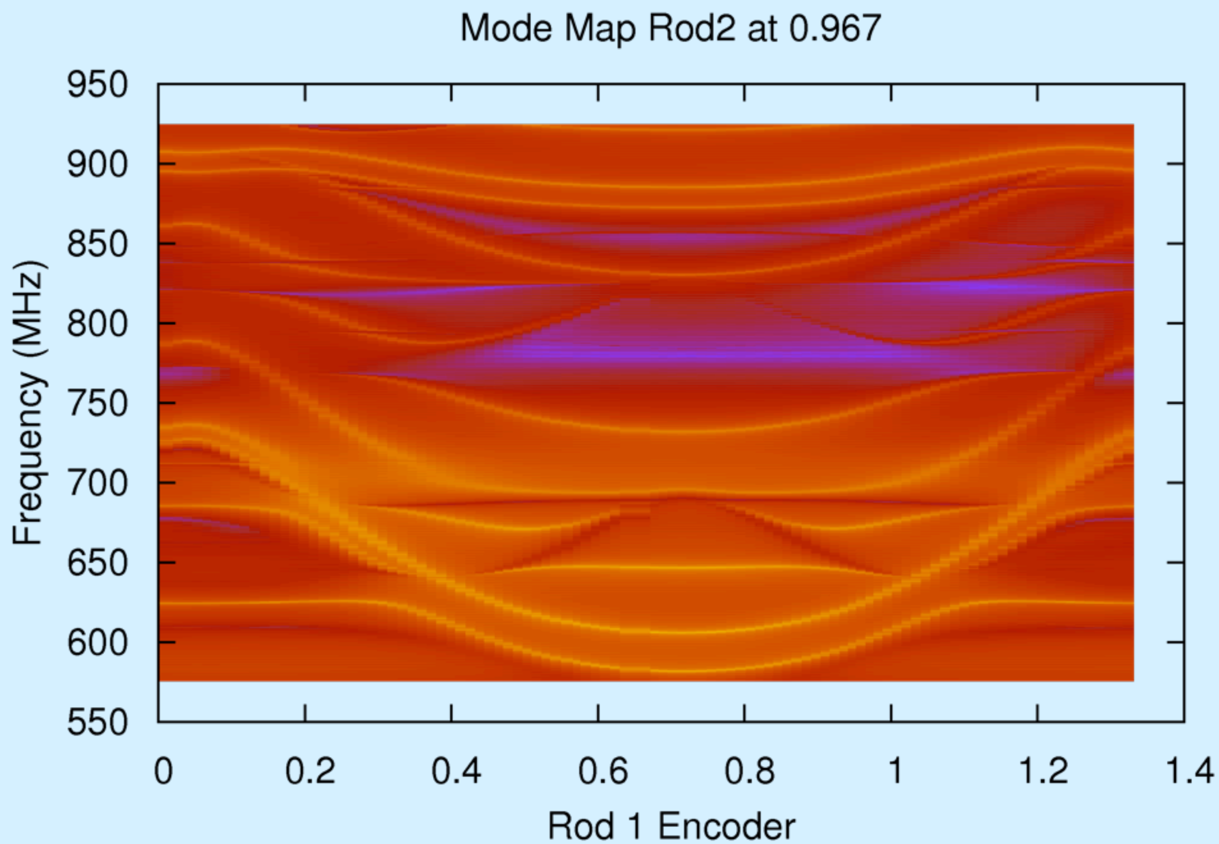


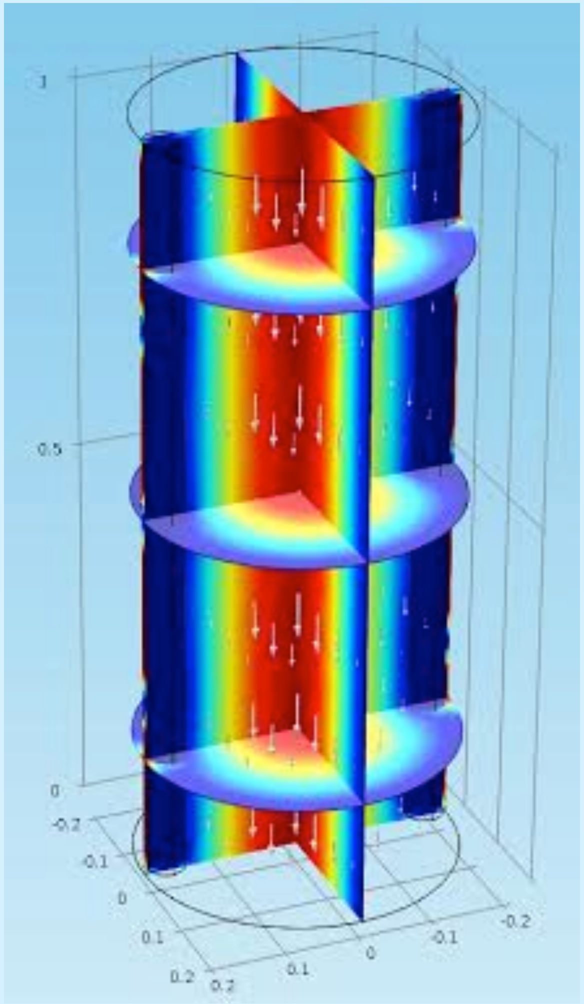
High Q cavity, magnet, dilution refrigerator (new)



SQUID for receiver

Cavity tuning





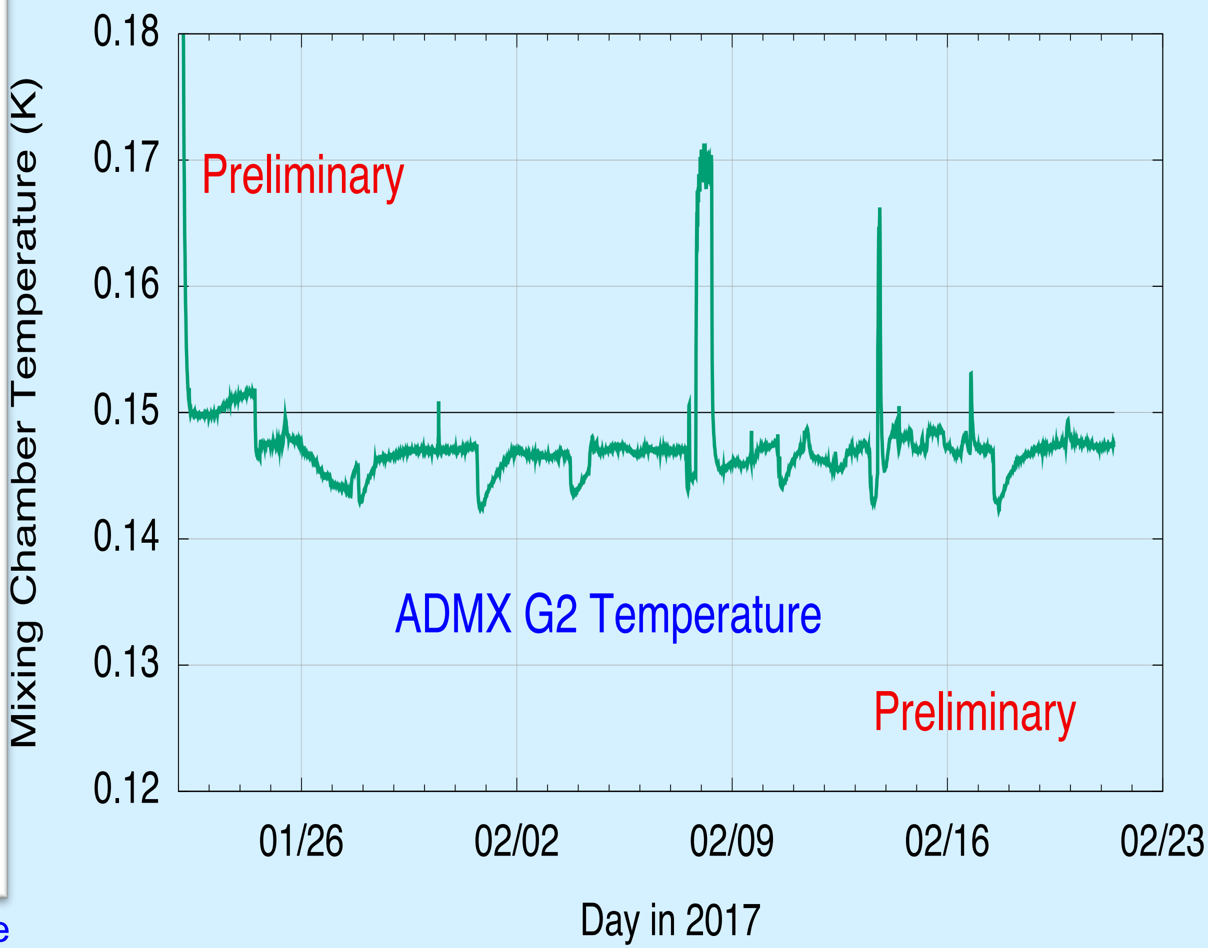
Signal depends on the form factor (i.e. effective volume allowing for E • B … TM_{010} mode)

Mode crossings are a definite complication

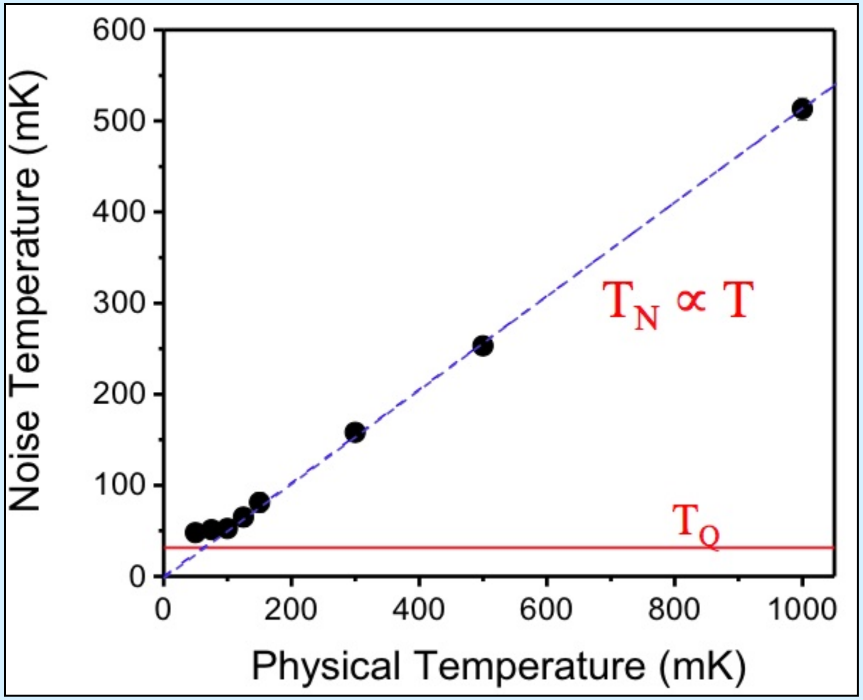
Cryogenics

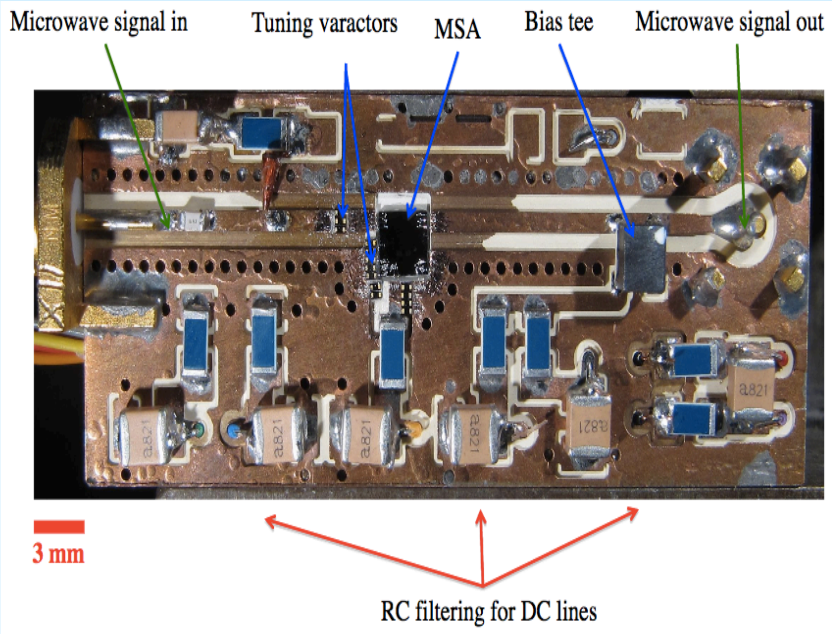
Dilution Refrigerator installed above ADMX Cavity

Cavity and electronics cooled with Dilution Refrigerator to minimize noise



Enabling technology: SQUID amplifiers





Sean O'Kelley, Clarke Group, Berkeley

Scan Rate:

$$\frac{df}{dt} \approx 1.68\ \mathrm{GHz/year}\ \left(\frac{g_\gamma}{0.36}\right)^4 \left(\frac{f}{1\ \mathrm{GHz}}\right)^2 \left(\frac{\rho_0}{0.45\ \mathrm{GeV/cc}}\right)^2 \cdot \left(\frac{5}{SNR}\right)^2 \left(\frac{B_0}{8\ \mathrm{T}}\right)^4 \left(\frac{V}{100\mathrm{l}}\right)^2 \left(\frac{Q_L}{10^5}\right) \left(\frac{C_{010}}{0.5}\right)^2 \left(\frac{0.2\ K}{T_{sys}}\right)^2$$

Operations

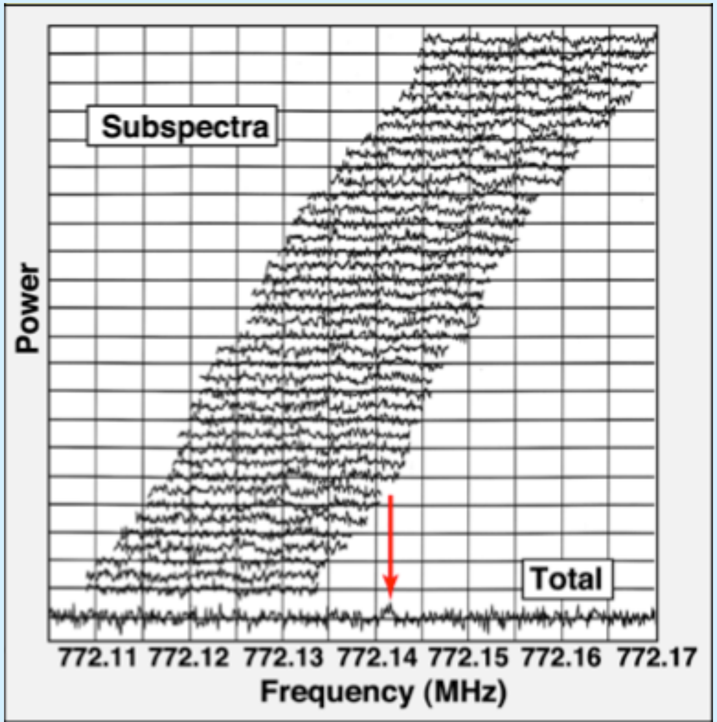
The cavity frequency is scanned over a region until the desired SNR is achieved

We then examine the combined power spectrum for signs of excess

Excess power regions can be statistical fluctuations, *synthetically injected signals*, RF interference, or axions

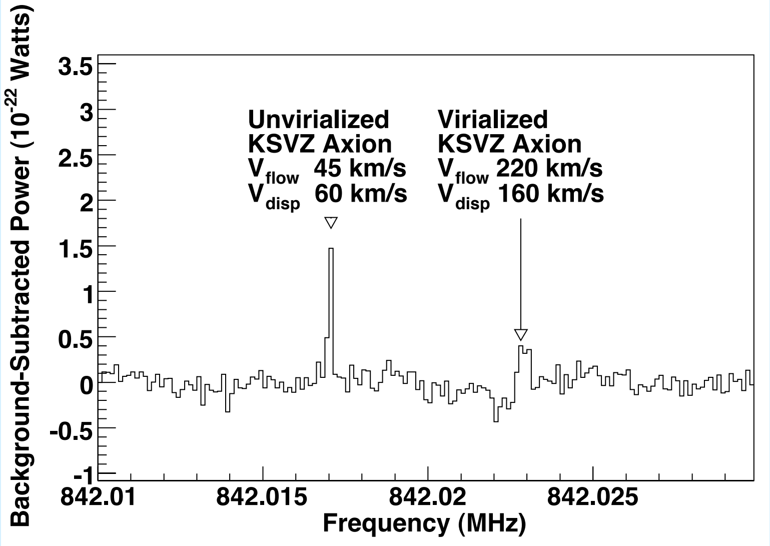
Excess power regions are rescanned to see if they persist

Persistent candidates are subjected to a variety of confirmation tests: for example: magnet field changes or probing with other cavity modes



Signal distributed over many sub-spectra: a good threshold candidate (but did not persist in rescan)

After a persistent signal

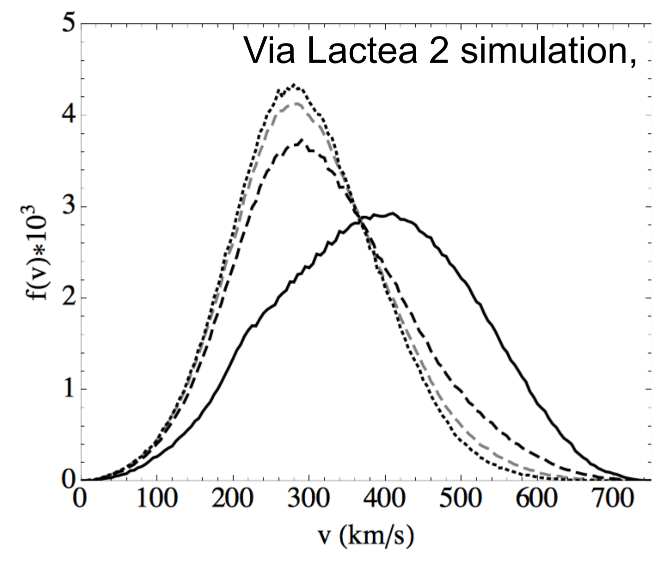


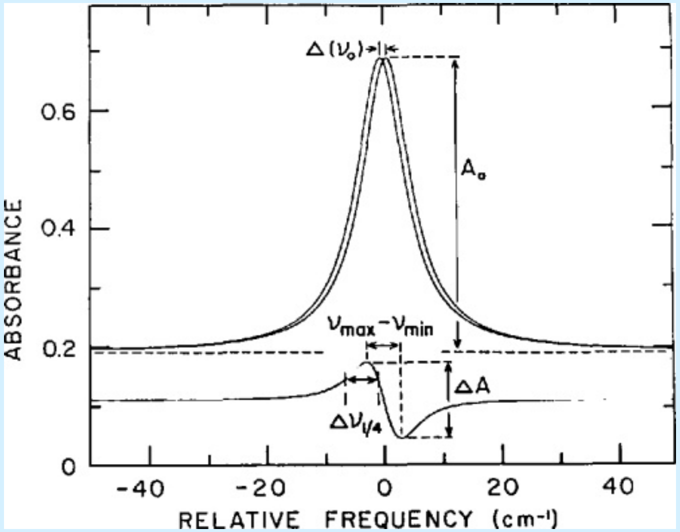
Confirmation (~minutes):

Does it behave as expected vs B^2
Rule out all other sources

Axion Astronomy

Velocity and broadening of the line
Look for structure like infalls etc.
Annual modulation (~hr integration)





Current Status

I can report that since the run started in January, ADMX is scanning at DFSZ sensitivites!

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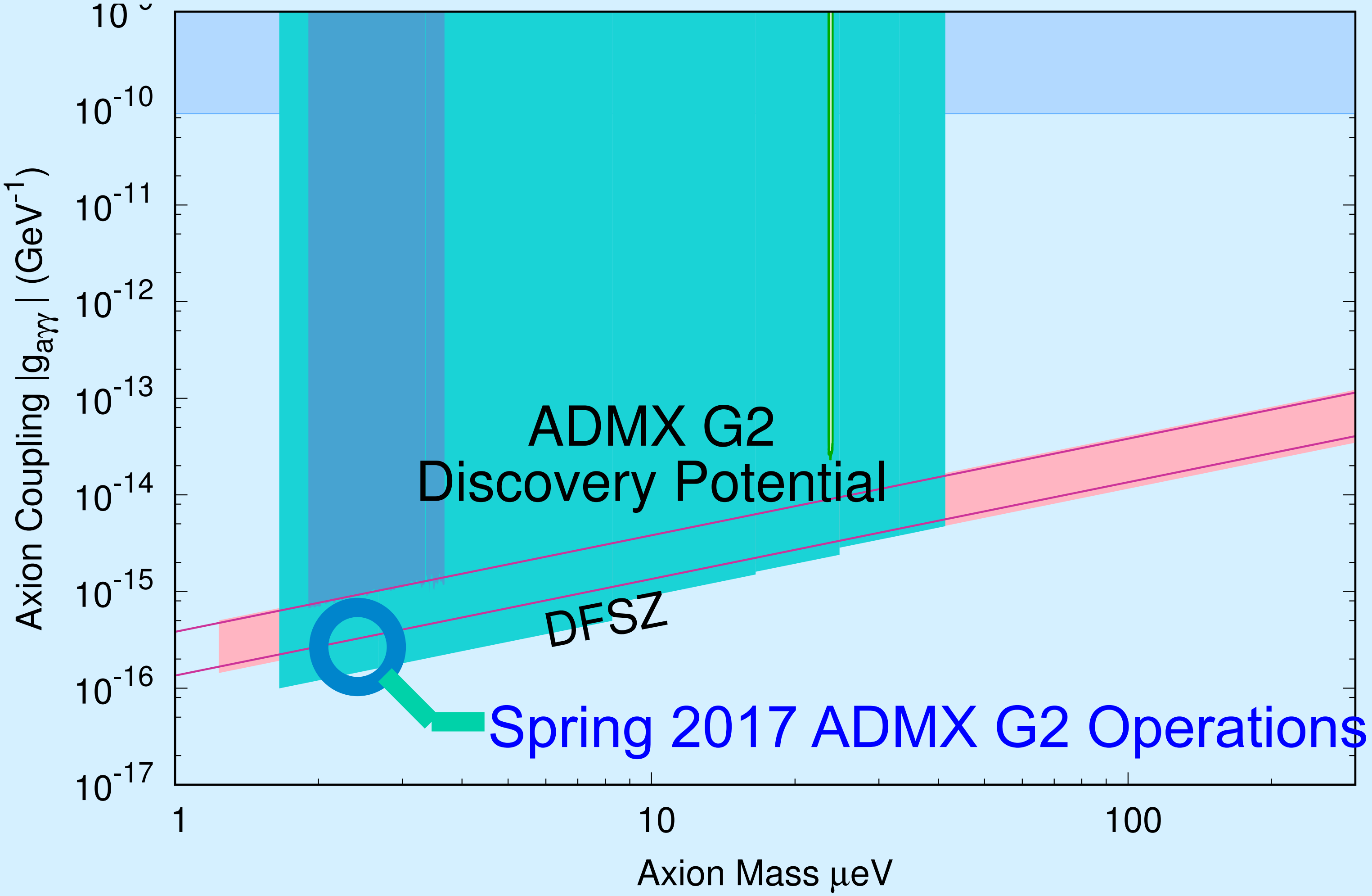
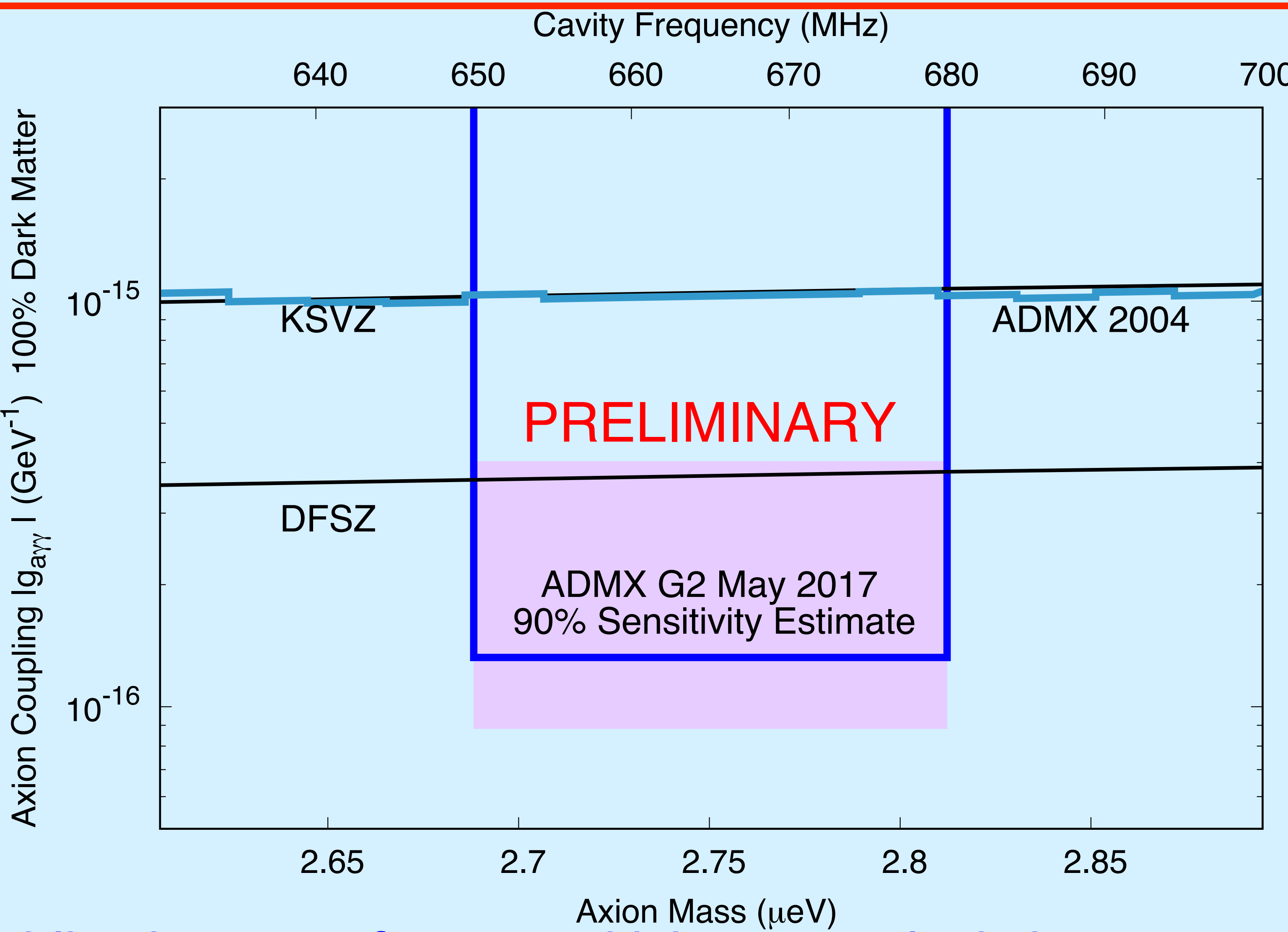
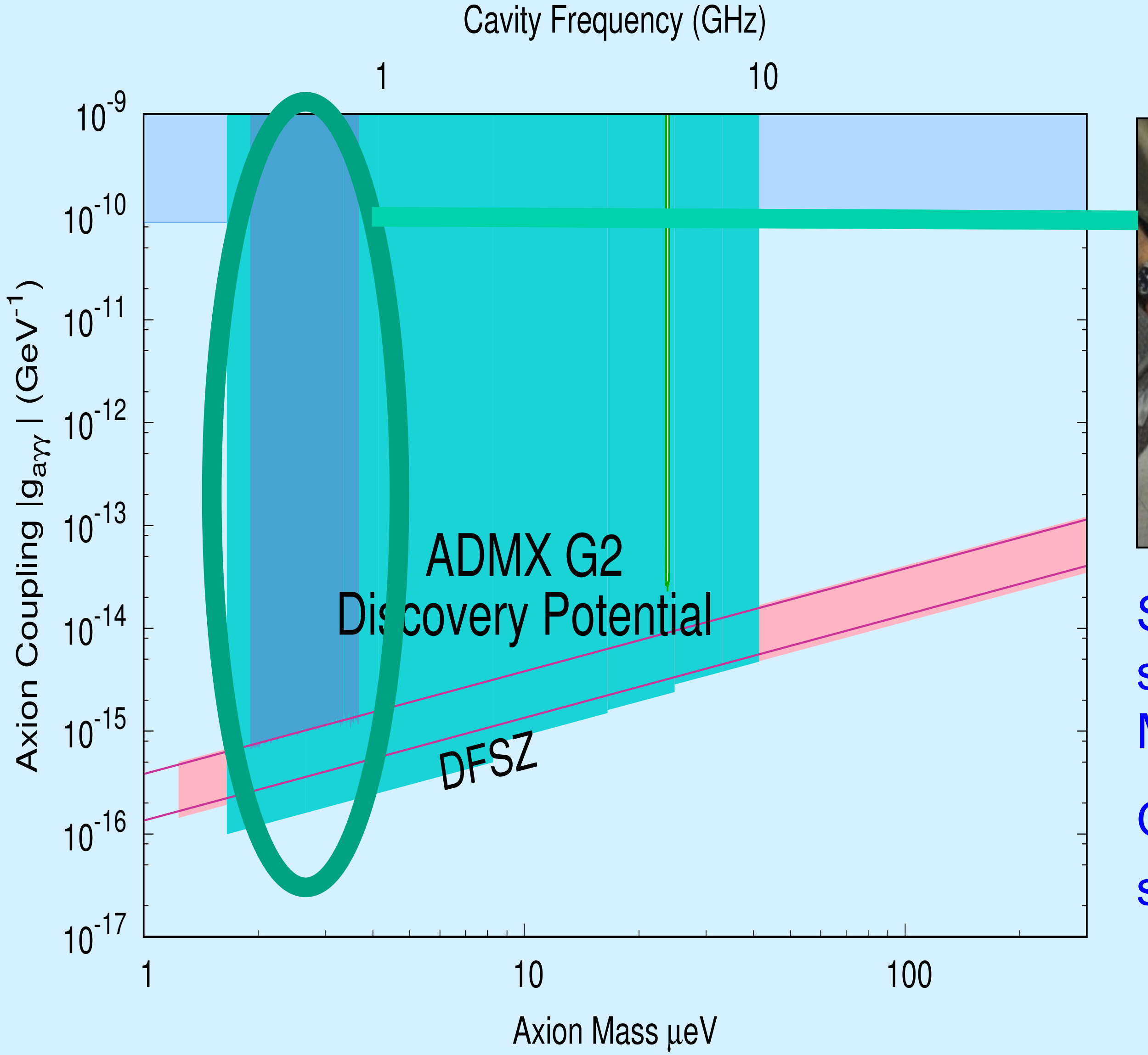


Preliminary Results



Publication to go from sensitivity -> results is in progress

Near term plans

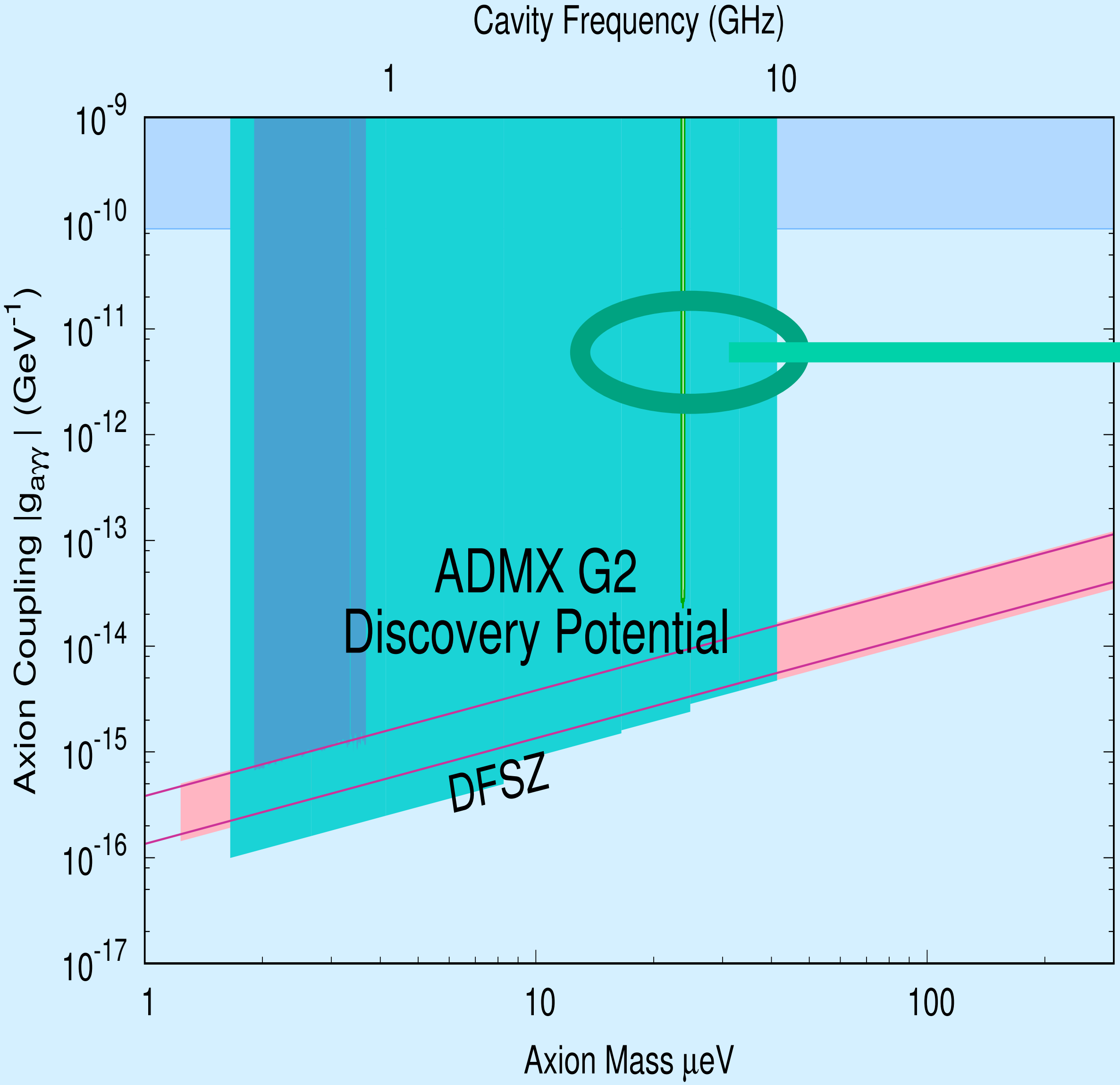


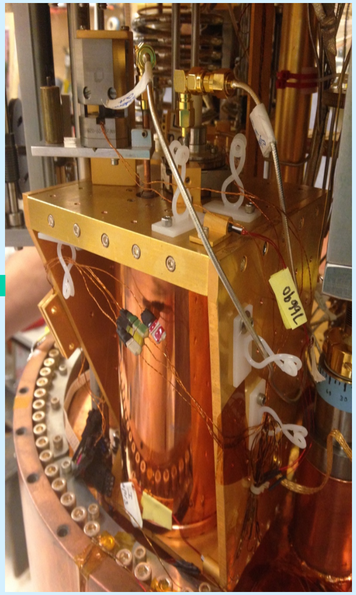
Single cavity system up to 500 MHz – 1 GHz

Operating at DFSZ sensitivity **Now!**

ADMX Prototype for Multicavity Systems

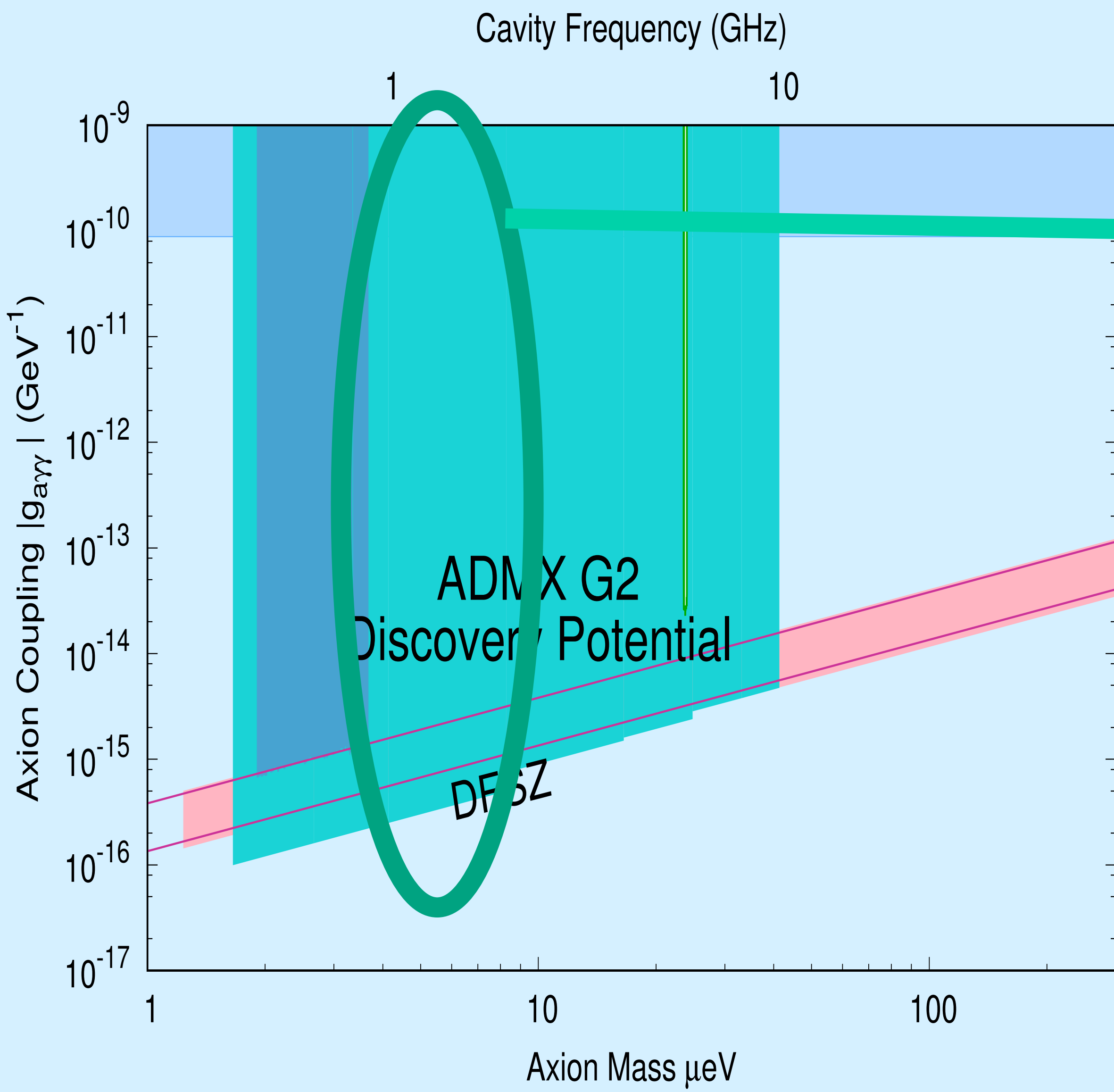
ADMX
AXION DARK MATTER EXPERIMENT

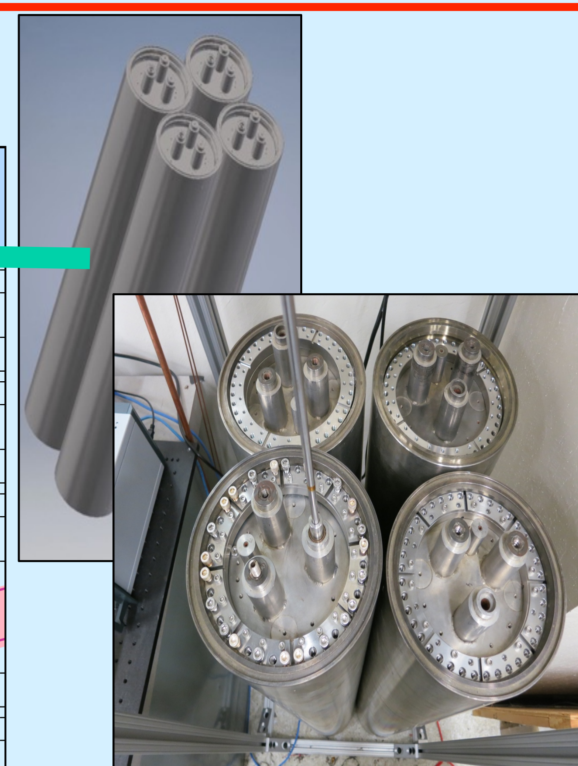




Small cavity prototype "sidecar" taking data 5-7 GHz **now.** First thesis on the 5 GHz data completed. JPA's.

ADMX G2
Multicavity Systems



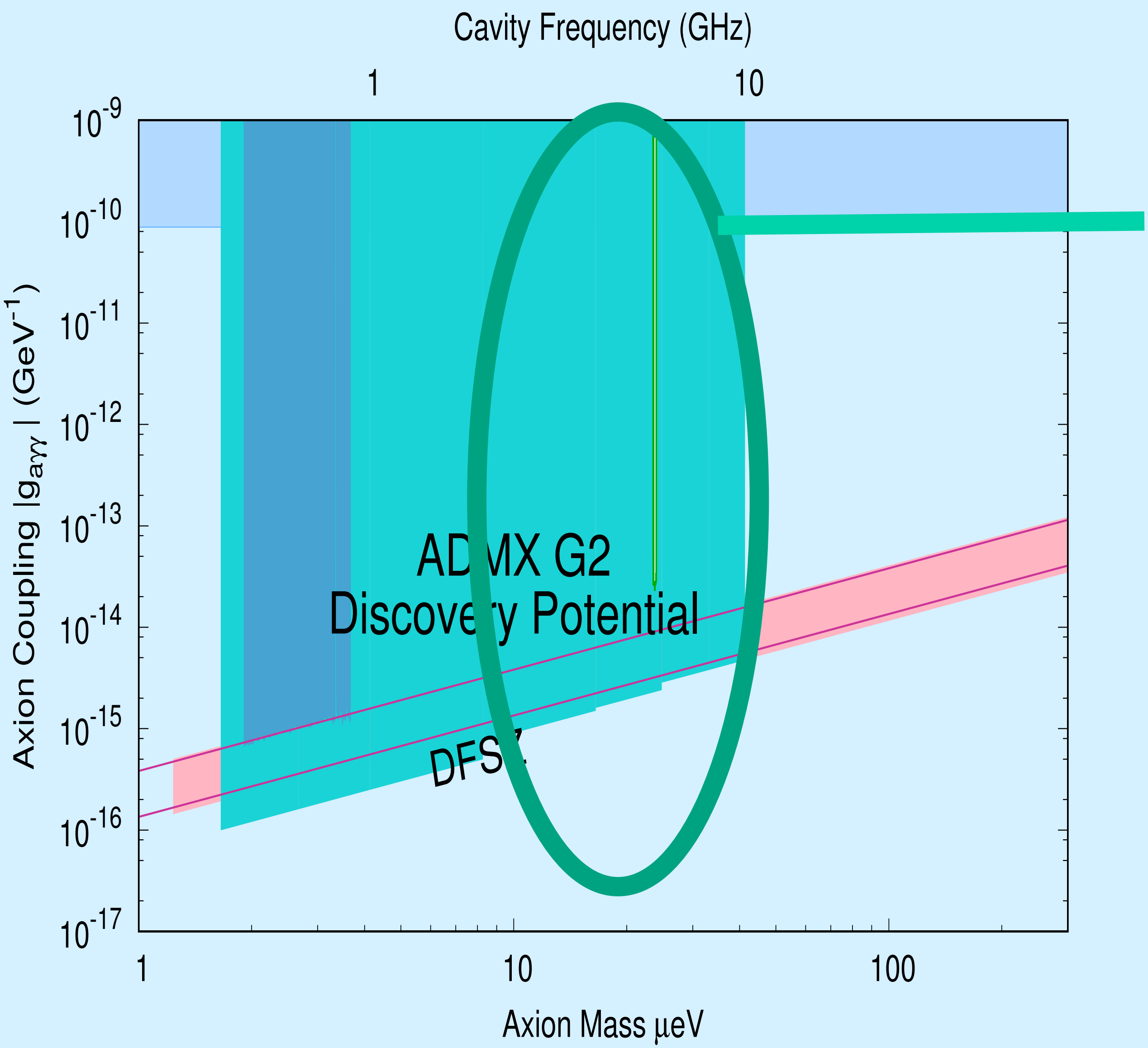


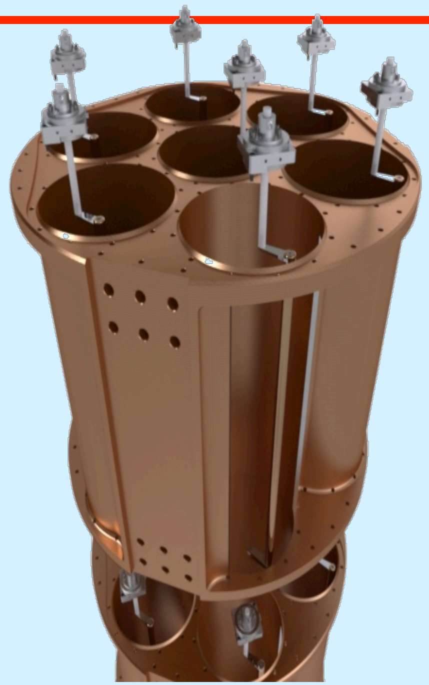
Multicavity system
1-2 GHz

Prototype fabricated, in testing. R&D to combine coherently.

ADMX G2, next steps Multicavity Systems

ADMX
AXION DARK MATTER EXPERIMENT



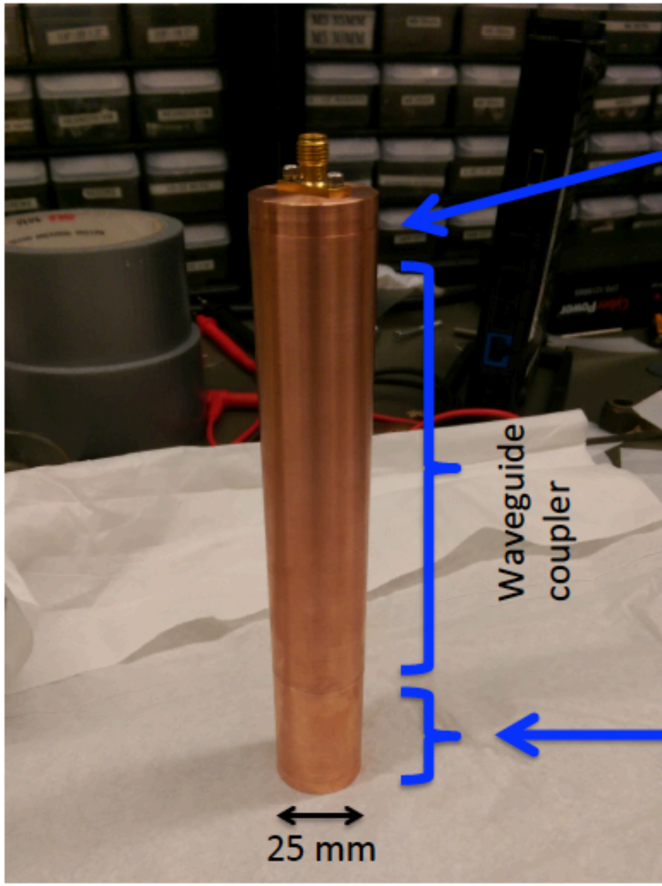


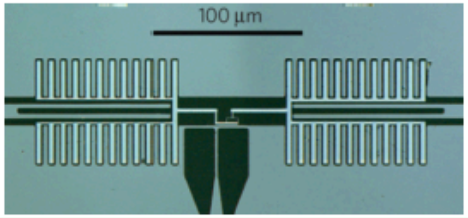
Multicavity systems for 2-4 GHz designs being finalized.

4-8 GHz resonators in design.

Beyond 10 GHz: Quantum Computing Technology

Prototype for 10 GHz axion QND detector





Superconducting qubit in field-free bucking coil region acts as an amplitude→frequency transducer for QND measurements.

Qubit frequency shifts by 10 MHz per photon deposited in axion cavity. **Successful "spin-flip" of qubit confirms presence of cavity photon.**

Axion scattering cavity dipped into high B-field region

Akash Dixit, Aaron Chou, David Schuster (UC), R&D in progress

Aaron S. Chou, NU Seminar 10/3/16 41

Conclusions

ADMX for the first time has the necessary components to probe the QCD axion that would solve the strong-CP problem and could account for most of the dark matter in the universe

ADMX is now taking data at DSFZ sensitivity

ADMX is part of the DOE gen 2 dark matter program. Current funding cycle allows probe up to about 2 GHz. Work with multiple cavities to cover 2-4 GHz and perhaps up to 10 GHz

Above 10 GHz, new technologies such as those enabled by quantum computing and high field magnets may result in a definitive yes-no program on the existence of the axion

ADMX
AXION DARK MATTER EXPERIMENT

ADMX Collaboration: U. Washington, U. Florida, LLNL, UC-Berkeley, PNNL, LANL, NRAO, Washington U., Sheffield U., FNAL

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