Axion Dark Matter eXperiment

(ADMX)

Status & Plans

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U.C. Berkeley

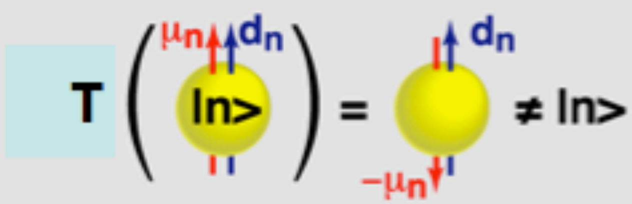
A sign of maturity of a venerable experiment ...

…The next crop of incoming grad students will not have been born when ADMX began construction!

The Standard Model is *still* not complete!

The Strong-CP Problem

- $\mathscr{L}_{QCD} = \ldots + \frac{\theta}{32\pi^2} G\tilde{G}$
  - Explicitly CP-violating
- But neutron e.d.m. $|d_n| < 10^{-25}$ e · cm
  - $\bar{\theta} < 10^{-10}$
  - Strong-CP preserving



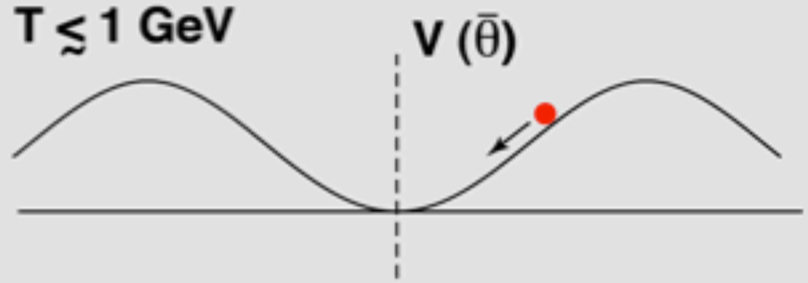
$\not{T} \longrightarrow \not{CP}$

- Why?

Peccei-Quinn / Weinberg-Wilczek

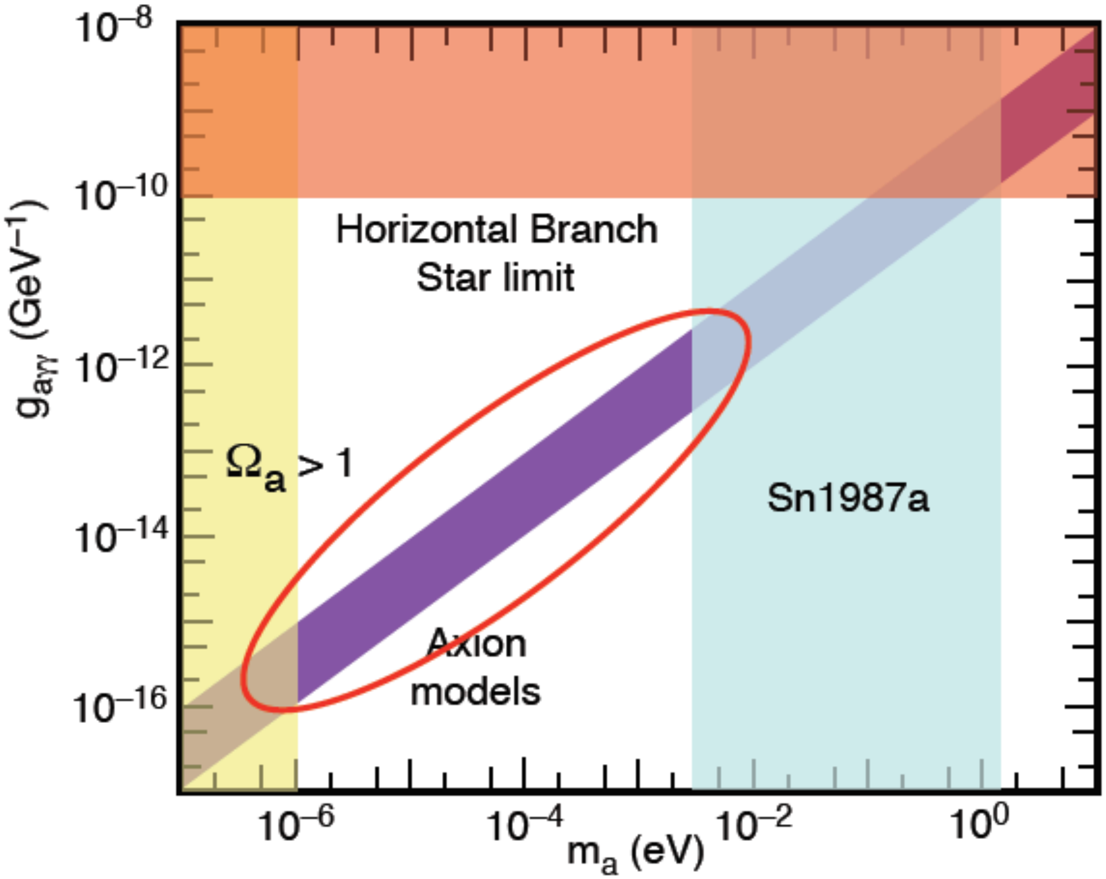
- θ a dynamical variable
- T = f_a spontaneous symmetry breaking

- T $\lesssim$ 1 GeV

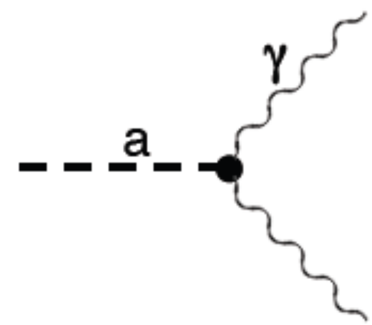


  - $\bar{\theta}$ dynamically → 0
  - Remnant oscillation = Axion

Axion basics



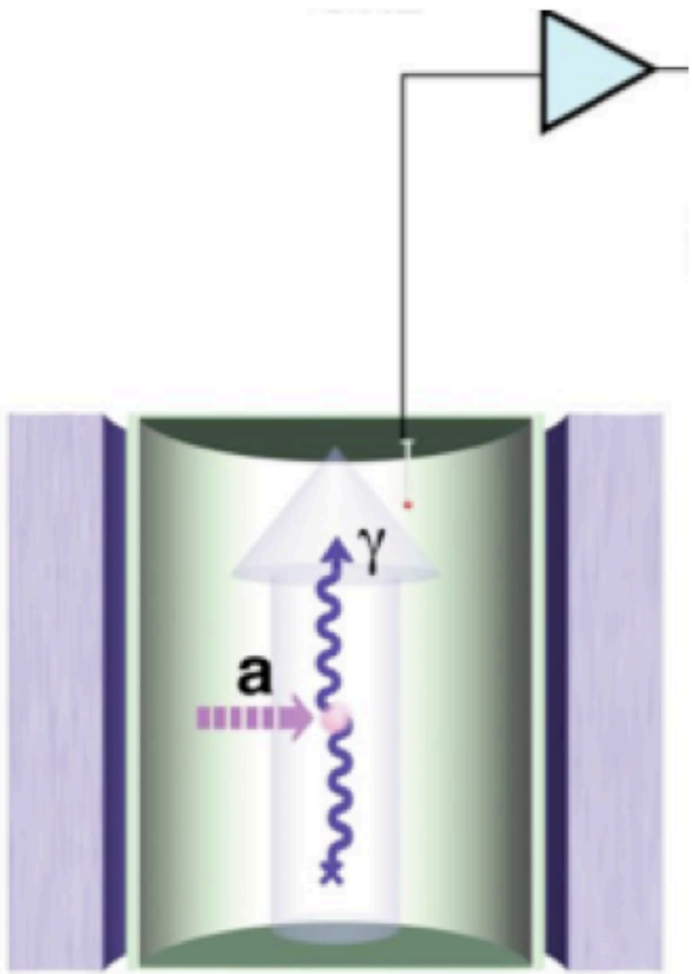
Light cousin of π^0: $J^\pi = 0^-$

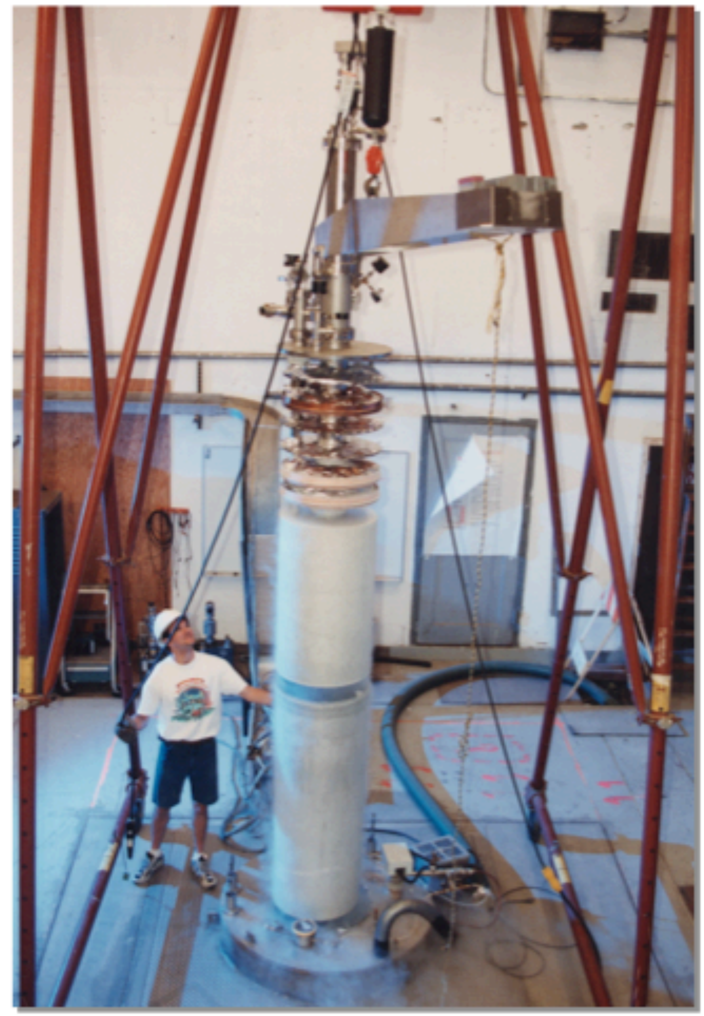


m_a , $g_{aii} \propto f_a^{-1}$ ∴ $g_{a\gamma\gamma} \propto m_a$

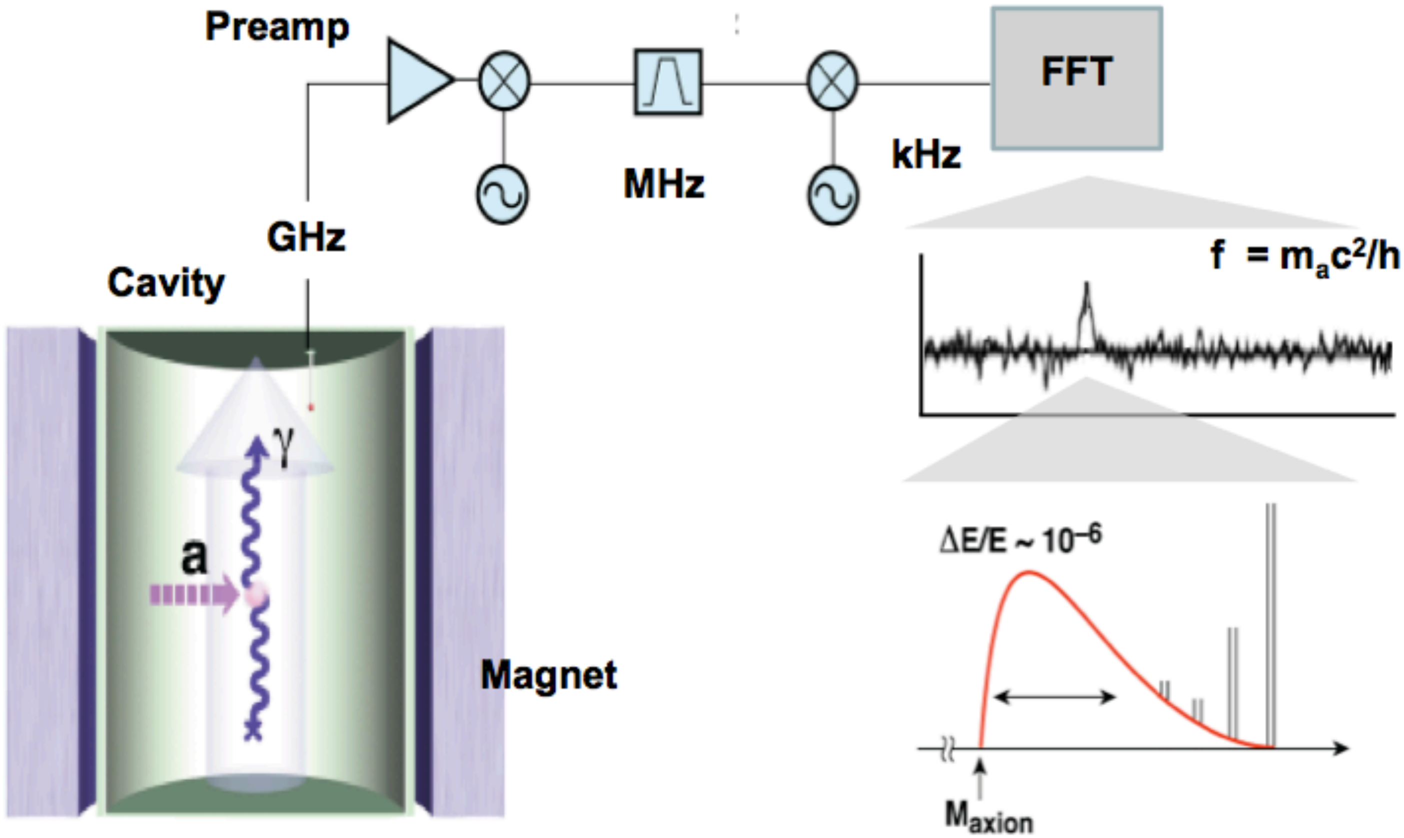
$\Omega_a \propto f_a^{7/6} \rightarrow m_a > 1\ \mu\text{eV}$

The microwave cavity experiment *(Sikivie, 1983)*



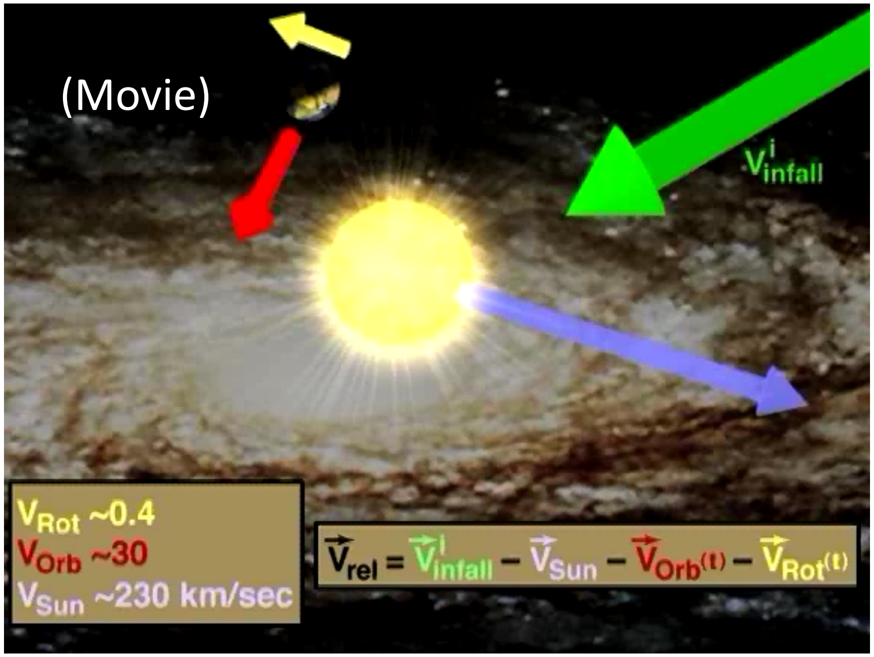


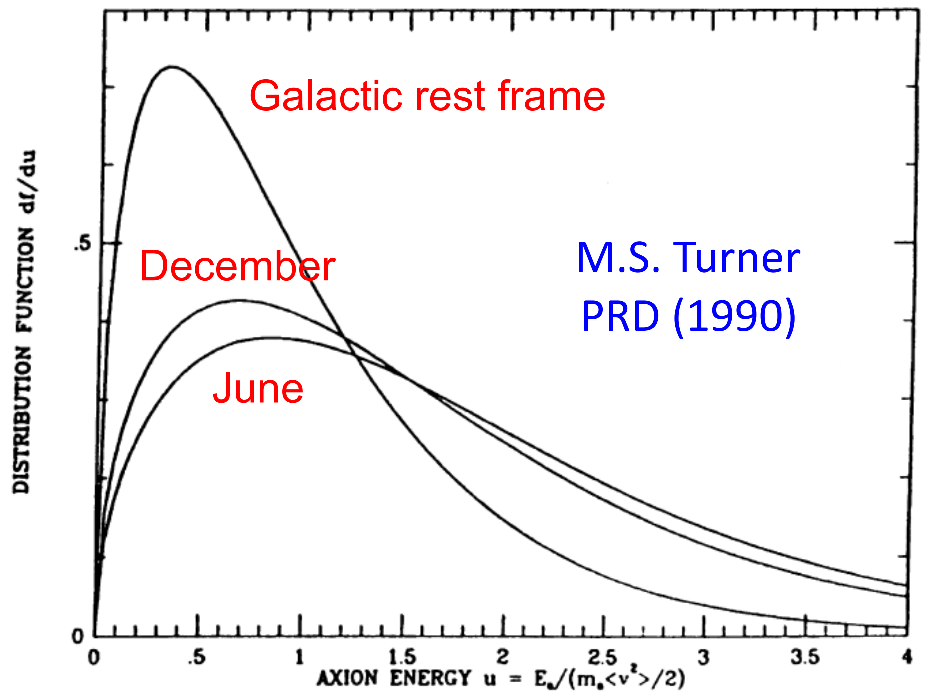
The full ADMX receiver

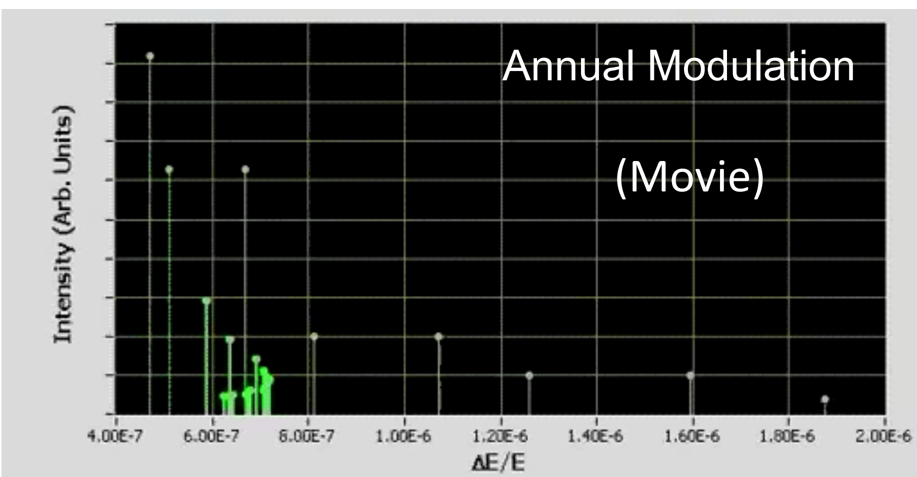


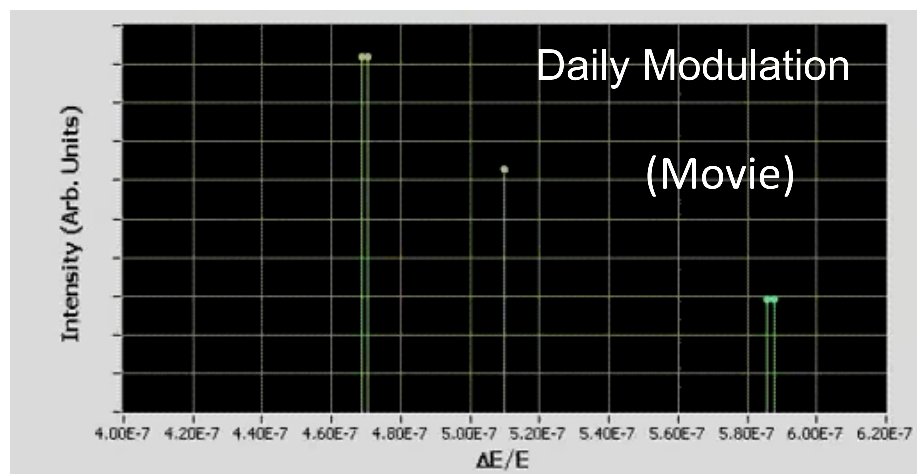
$$P_{sig} \propto (B^2 V Q_{cav})(g^2 m_a \rho_a) \sim 10^{-23}\, W \qquad s/n = \frac{P_{sig}}{kT_{sys}}\sqrt{\frac{t}{\Delta\nu}}$$

ADMX measures the *full energy* (rest mass + kinetic) of the axion signal.
This has important consequences, i.e. diurnal & sidereal modulation

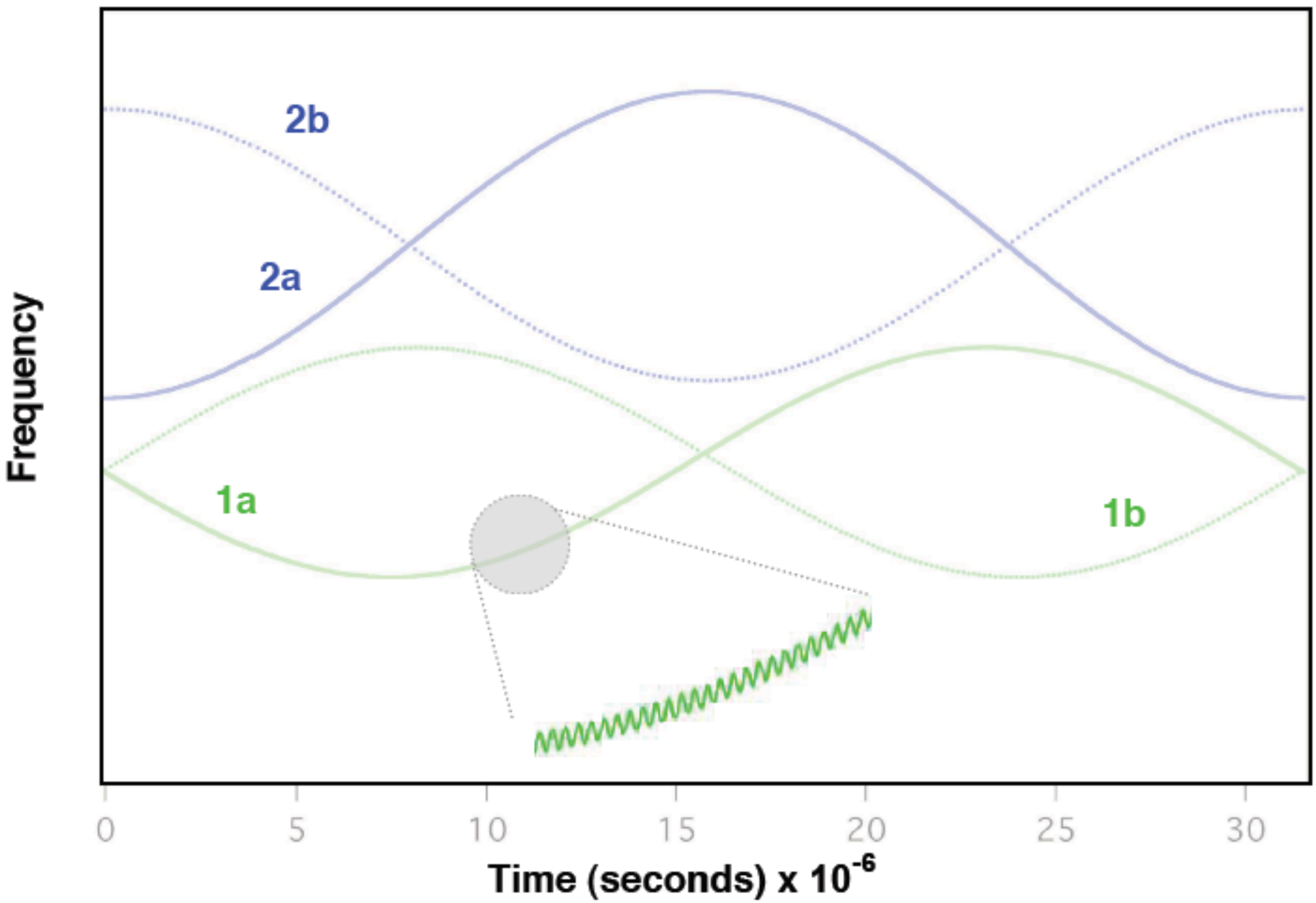




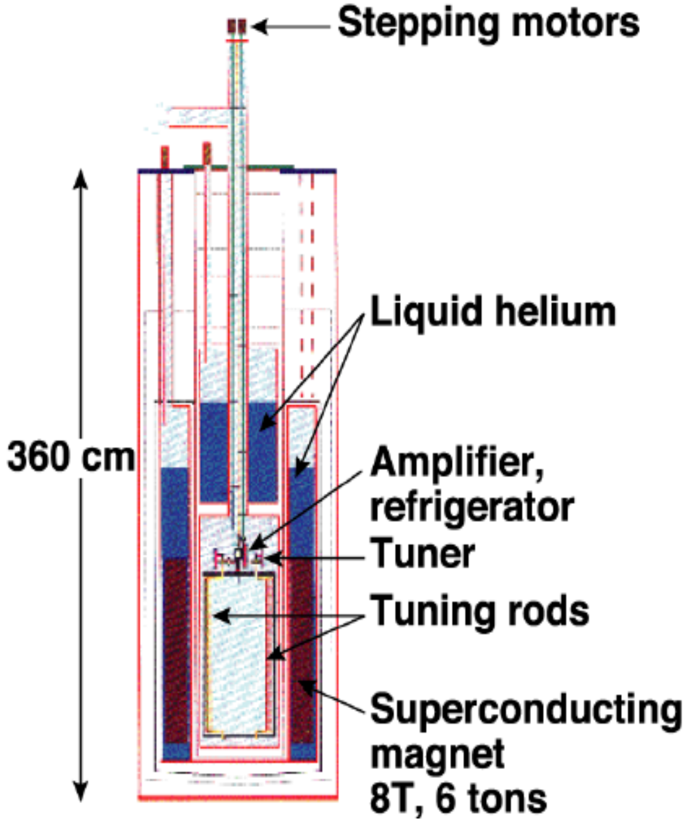


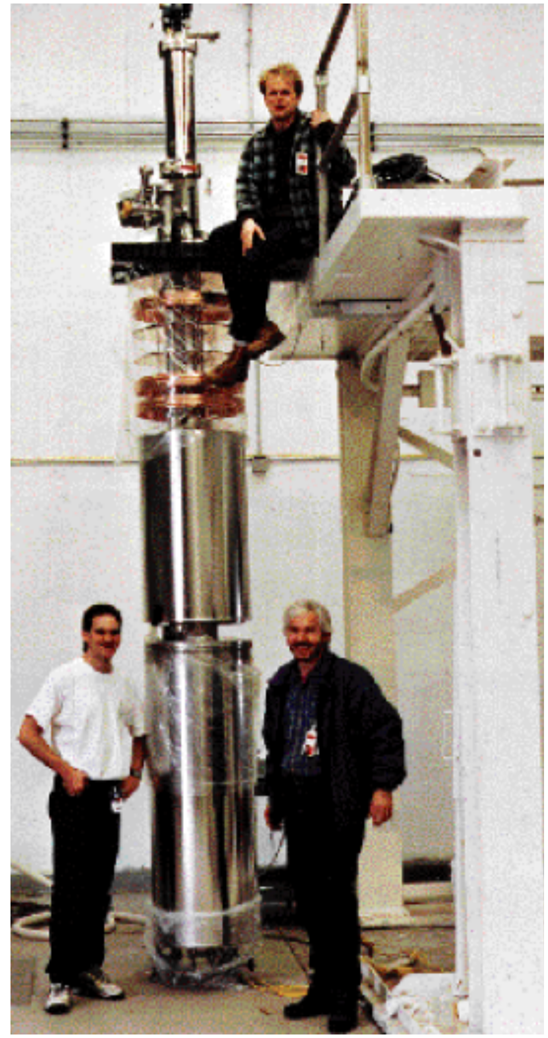


Sufficiently narrow fine-structure would display dramatic modulation, revealing the full vector directionality of the flows

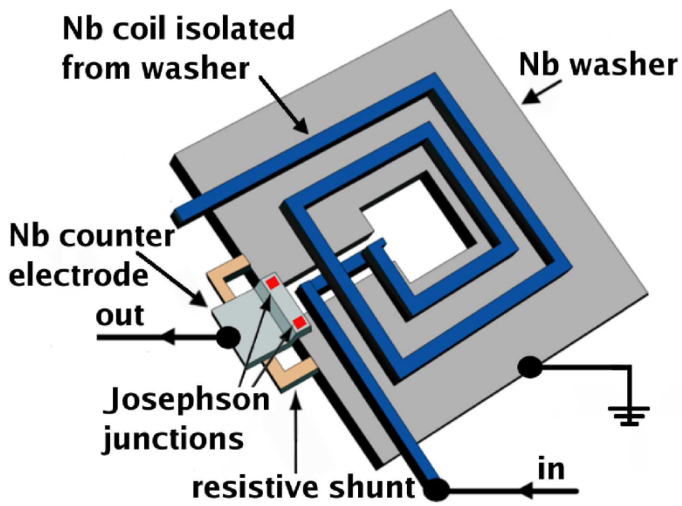


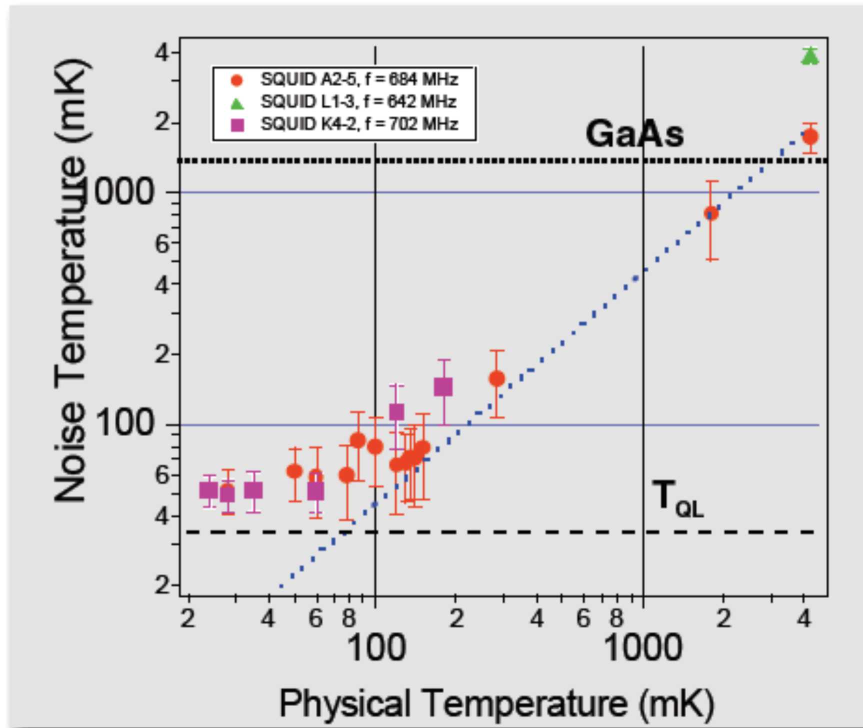
ADMX Hardware

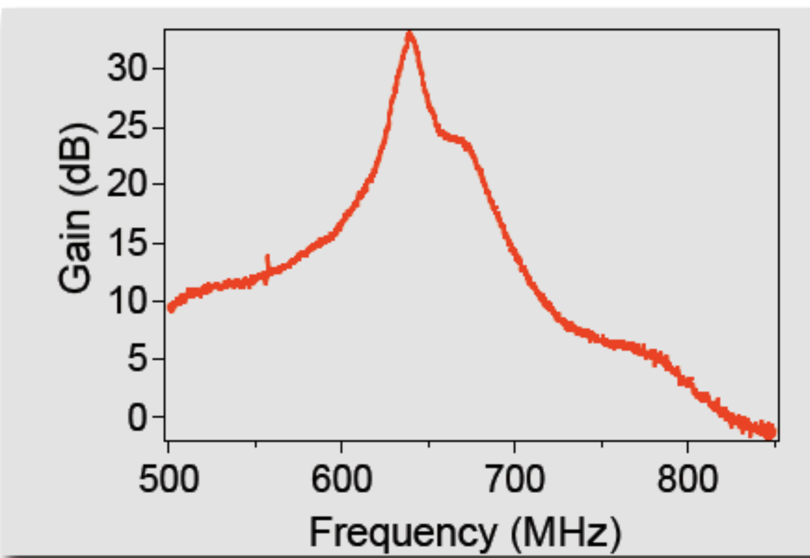




Microstrip SQUID amplifiers *(John Clarke, UC Berkeley)*

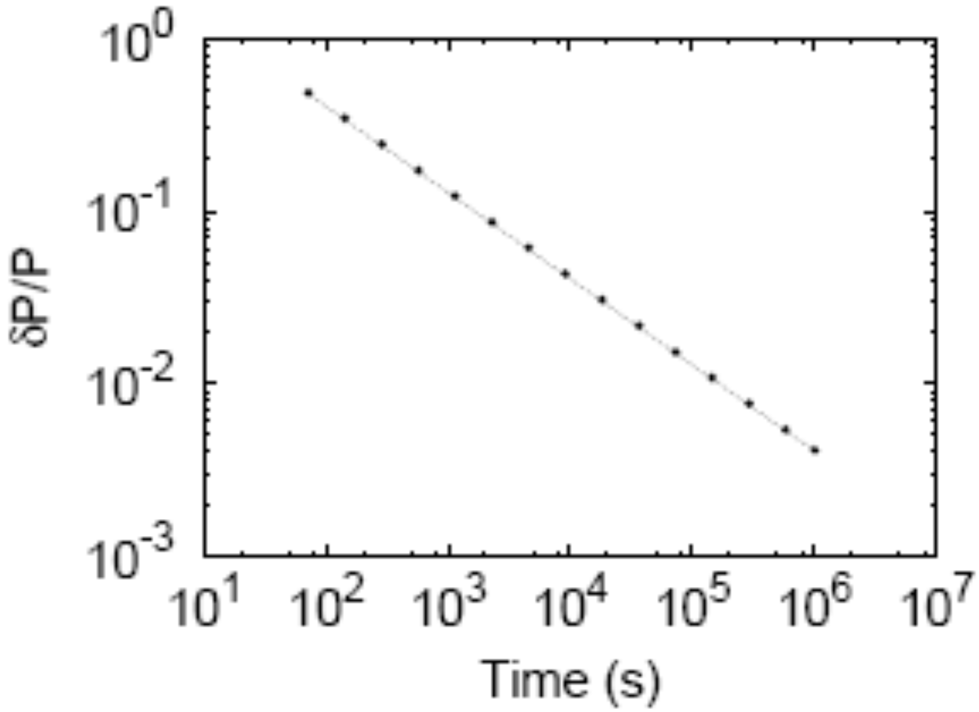






More than an order of magnitude quieter than current GaAs HFET amplifier

ADMX is the world's quietest spectral receiver

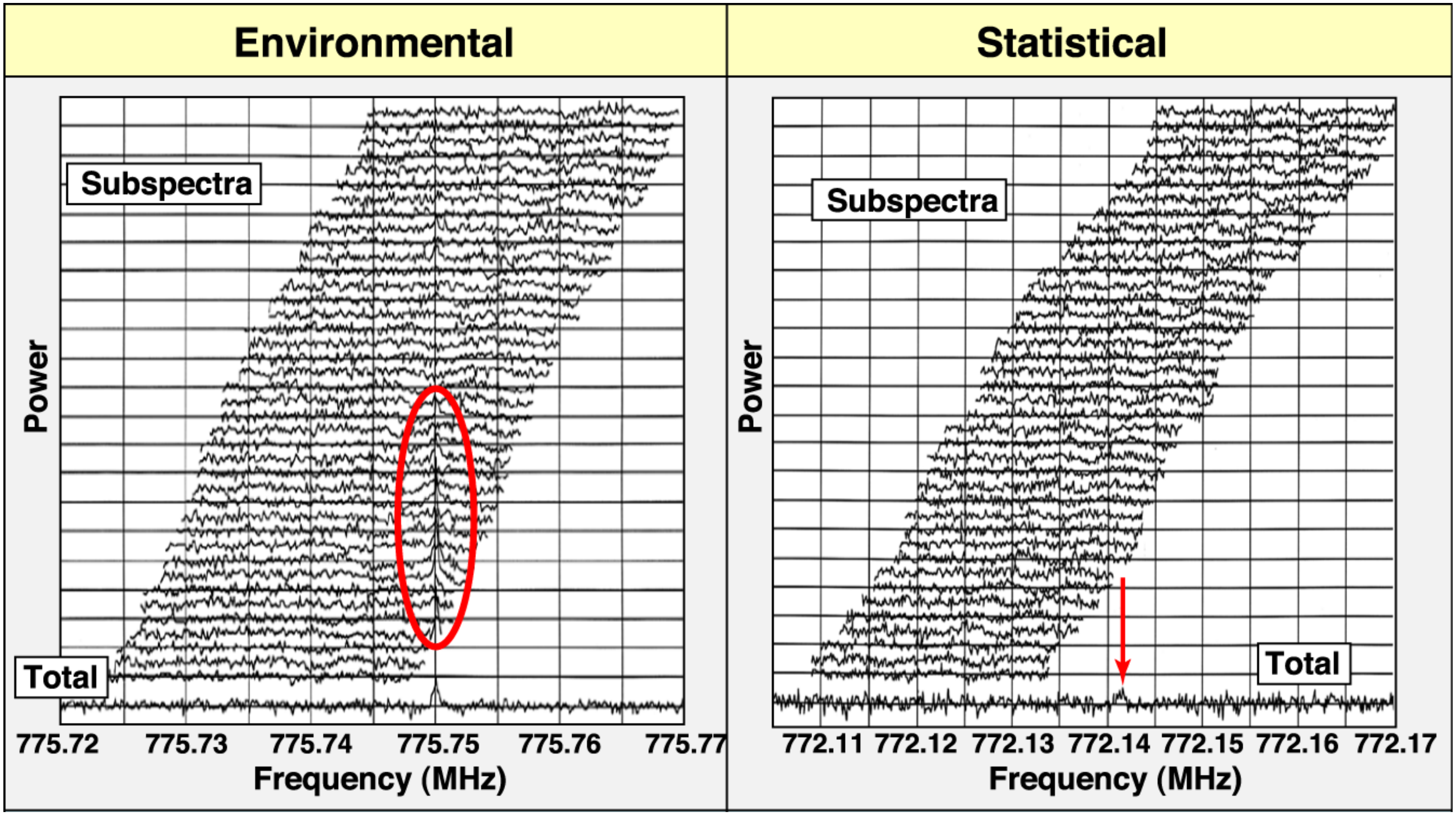


Dicke Radiometer equation:

$$\frac{s}{n} = \frac{P_s}{kT_n}\sqrt{\frac{t}{\Delta\nu}}$$

Systematics-limited for signals of 10^{-26} W – 10^{-3} of DFSZ axion power.
Last signal received from Pioneer 10 (6 billion miles away) ~ 10^{-21} W.

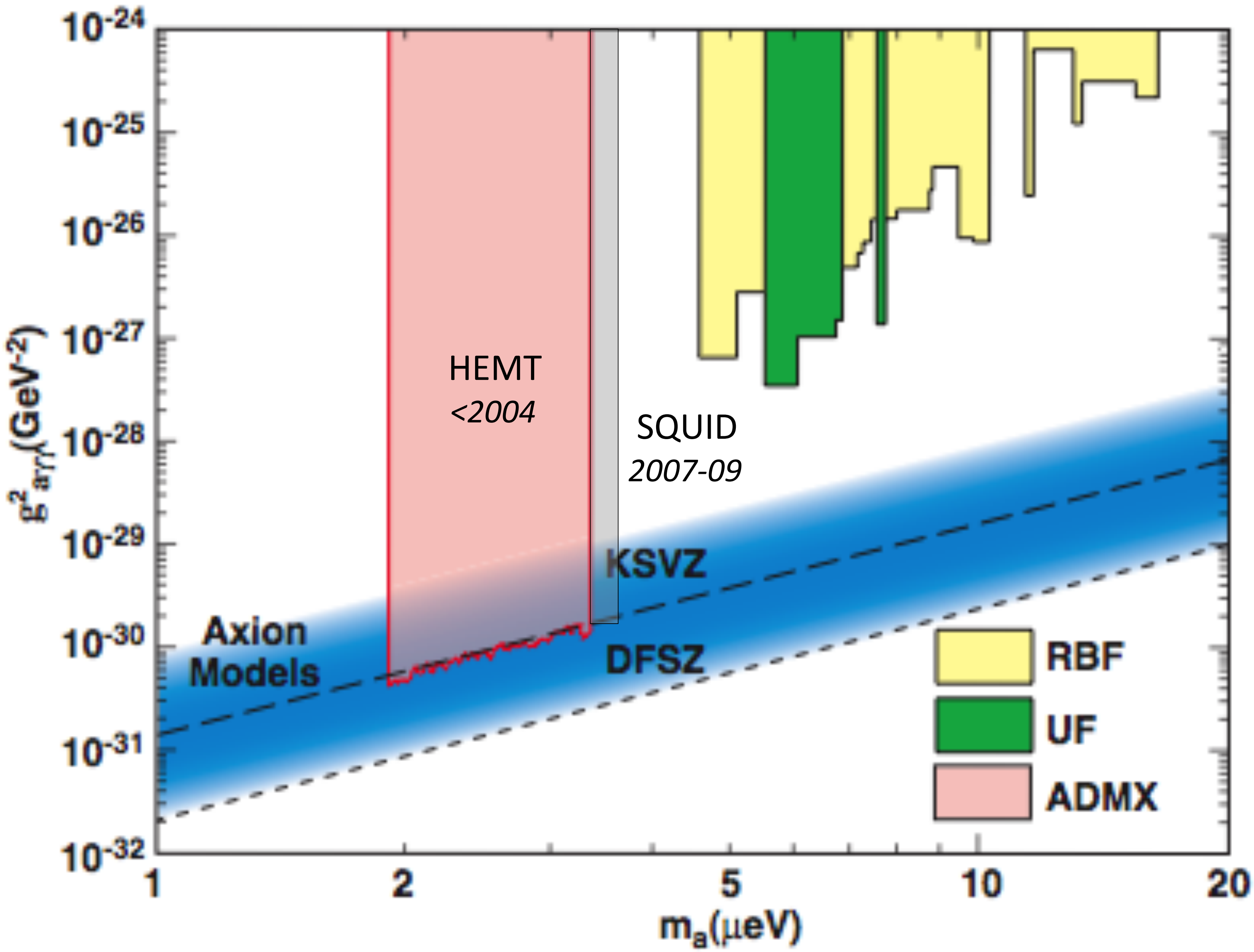
Sample data and candidates



Signal maximizes in the wings, and furthermore is episodic → Radio peak

Distributed over many subspectra, but didn't repeat → Statistical peak

To date, no axion over an octave in mass *(1.9 - 3.6 μeV)*



ADMX is pursuing a complete strategy two fronts

Reduce System Temperature

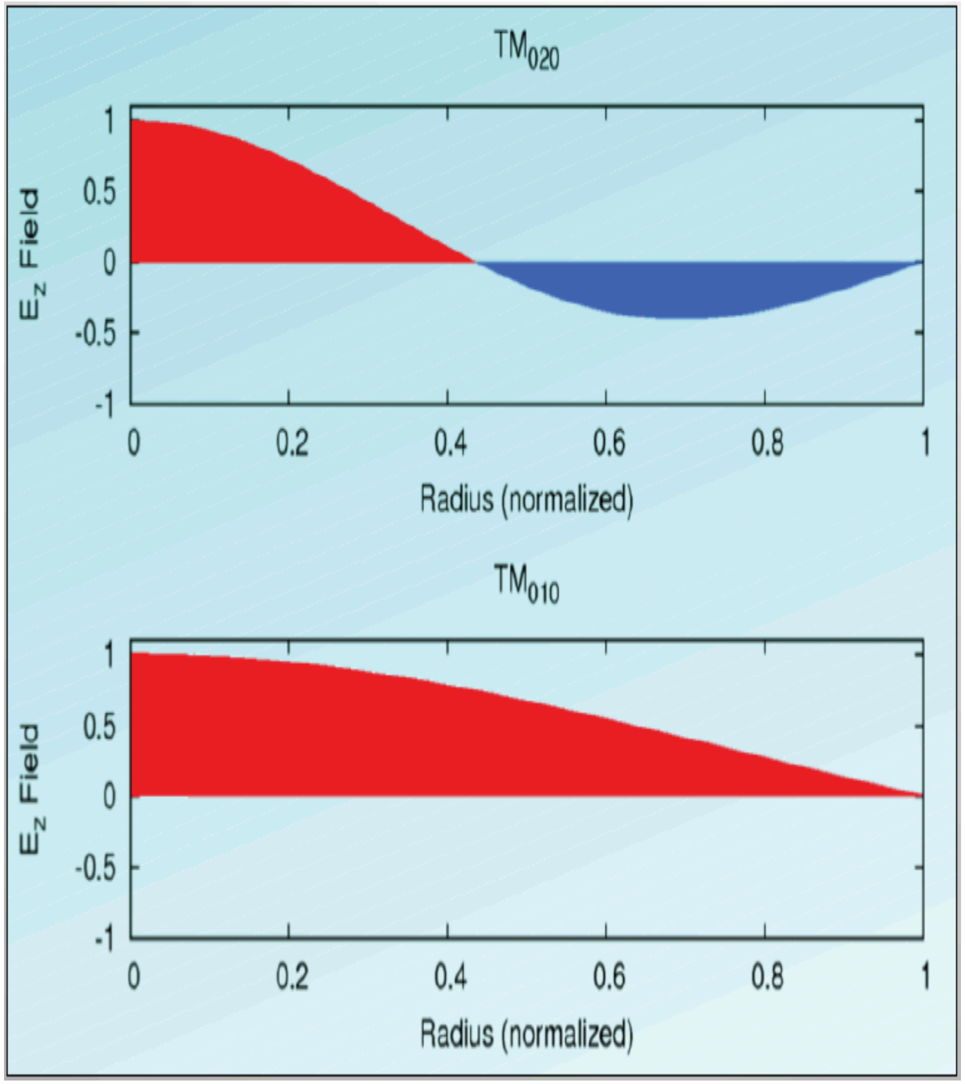
➡ ADMX Phase II a,b: ^3He fridge; Dilution fridge

Go up in Frequency (& down if possible)

➡ Higher harmonic ports (TM_{020}, TM_{030})
ADMX-HF (High Frequency) at Yale

$$T_{Sys} = T + T_N \quad , \quad T_N^{Squid} \propto T$$

Higher-harmonic ports in ADMX Phase II

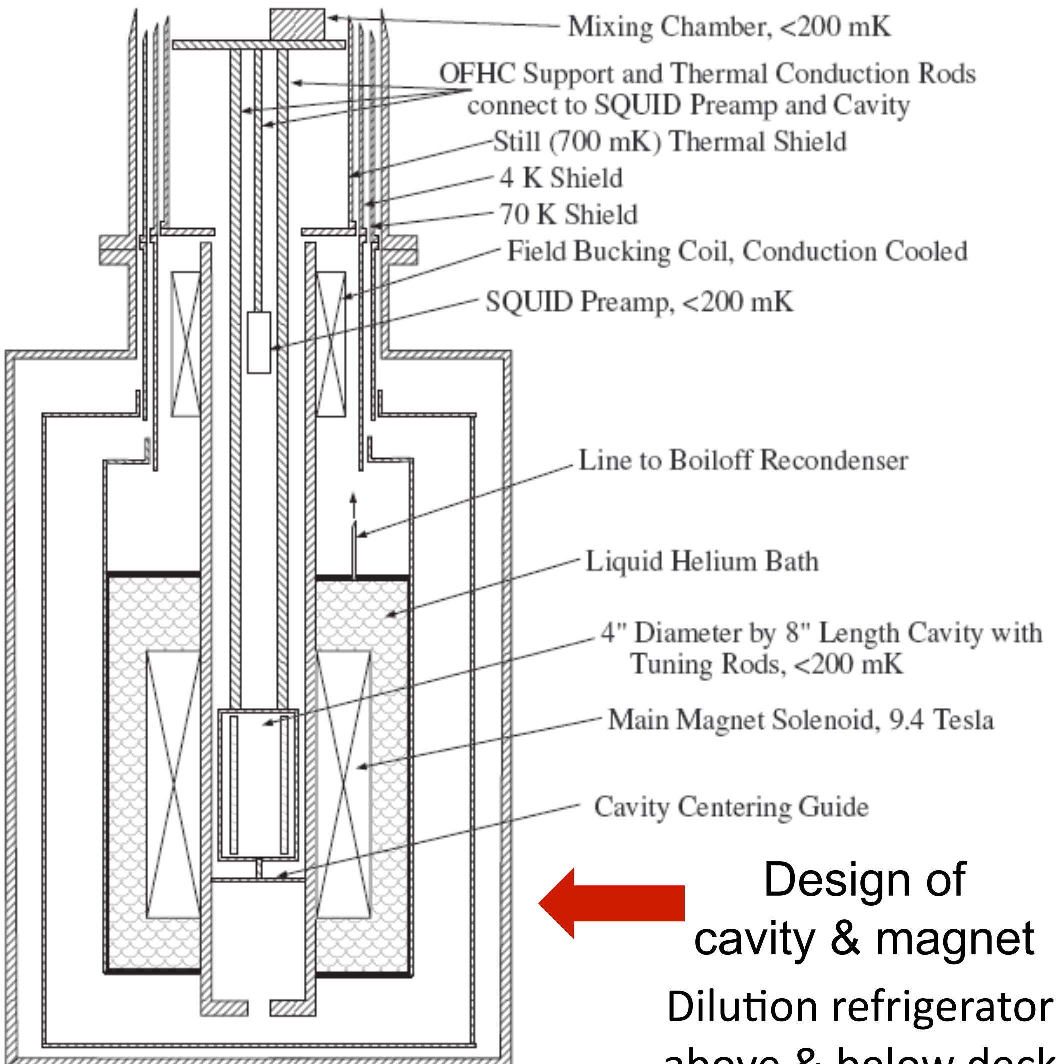


TM_{020} :
920 – 2300 MHz
Rel. power = 0.41

TM_{010} :
400 – 900 MHz
Rel. power = 1

ADMX-HF @ Yale will be a pathfinder & innovation testbed

(Steve Lamoreaux, PI)

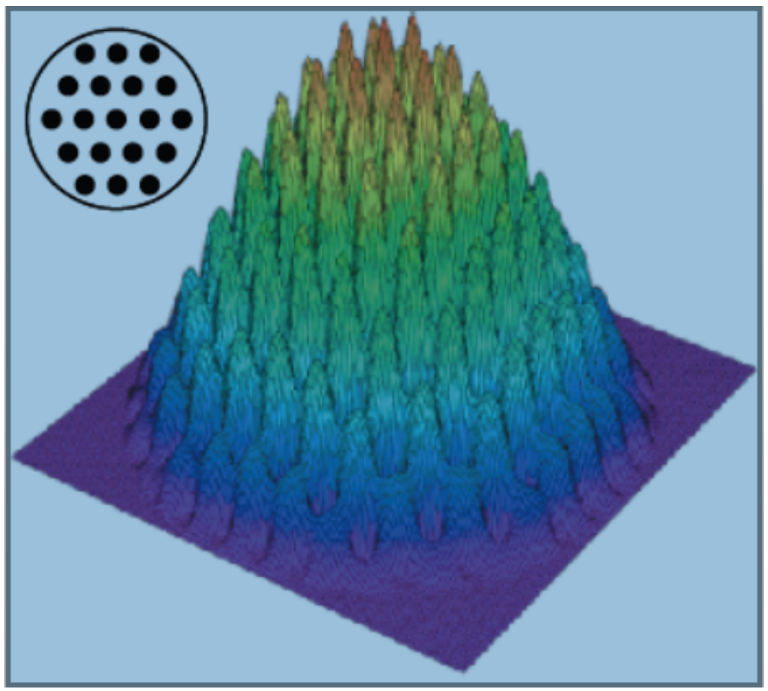


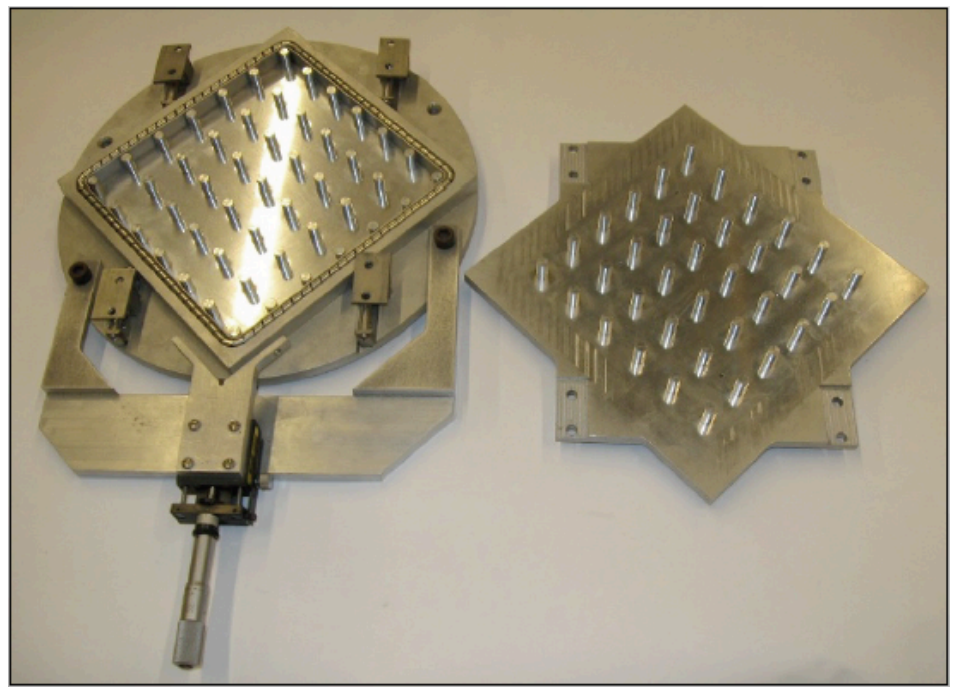
Design of cavity & magnet

Dilution refrigerator above & below deck

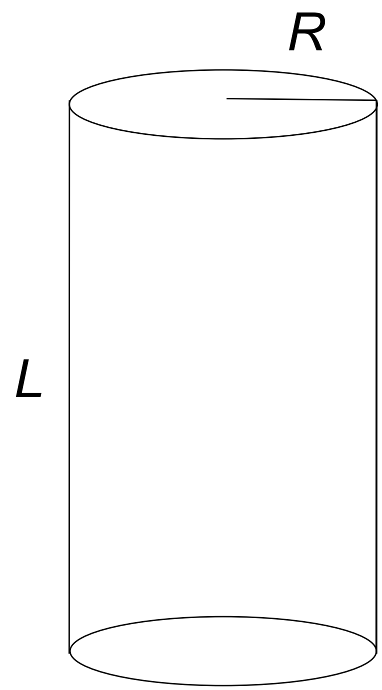
R&D towards much higher frequency arrays

Photonic bandgap resonators ("lattice arrays")



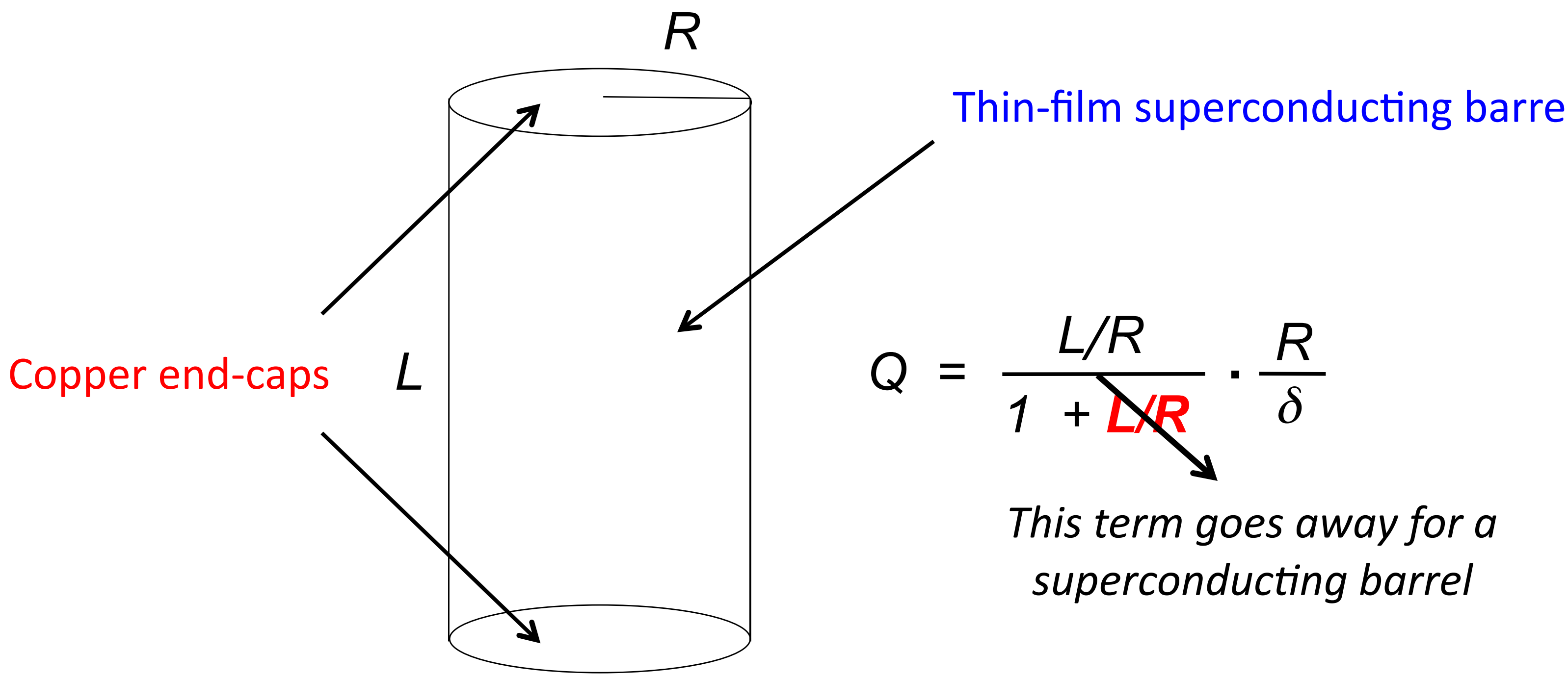


Q of the TM_{010} mode for a conventional Cu cavity:



$$Q = \frac{L/R}{1 + \mathbf{L/R}} \cdot \frac{R}{\delta}$$

The concept of a hybrid superconducting cavity:



$$Q = \frac{L/R}{1 + L/R} \cdot \frac{R}{\delta}$$

This term goes away for a superconducting barrel

$$Q_{hybrid} = (1 + L/R) \cdot Q_{cu}$$

For typical ADMX cavity, L/R = 5, enhancement factor = 6

Thin-film Type-II superconductors appear promising

PRL 105, 257006 (2010) PHYSICAL REVIEW LETTERS week ending 17 DECEMBER 2010

Far-Infrared Conductivity Measurements of Pair Breaking in Superconducting $Nb_{0.5}Ti_{0.5}N$ Thin Films Induced by an External Magnetic Field

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We report the complex optical conductivity of a superconducting thin film of $Nb_{0.5}Ti_{0.5}N$ in an external magnetic field. The field was applied parallel to the film surface and the conductivity extracted from far-infrared transmission and reflection measurements. The real part shows the superconducting gap, which we observe to be suppressed by the applied magnetic field. We compare our results with the pair-breaking theory of Abrikosov and Gor'kov and confirm directly the theory's validity for the optical conductivity.

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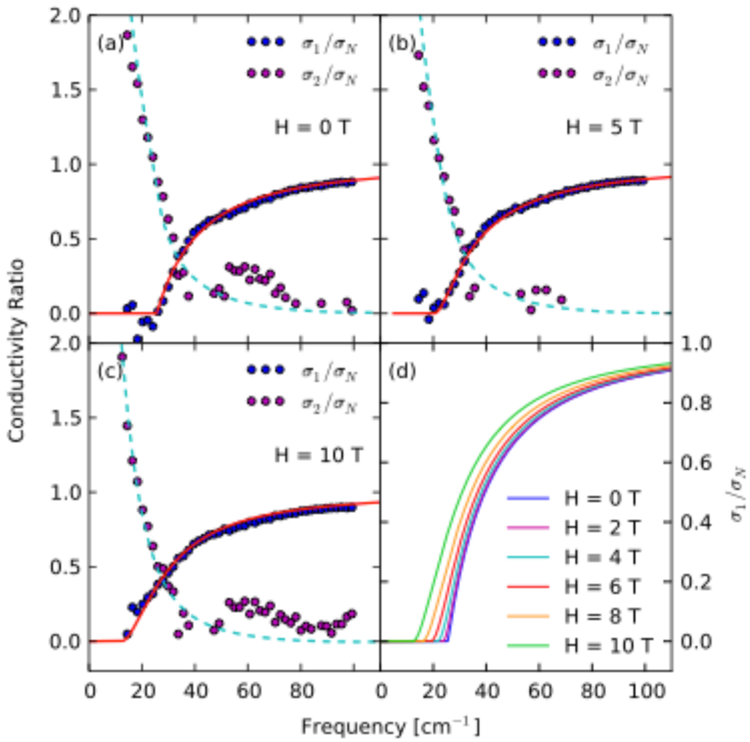
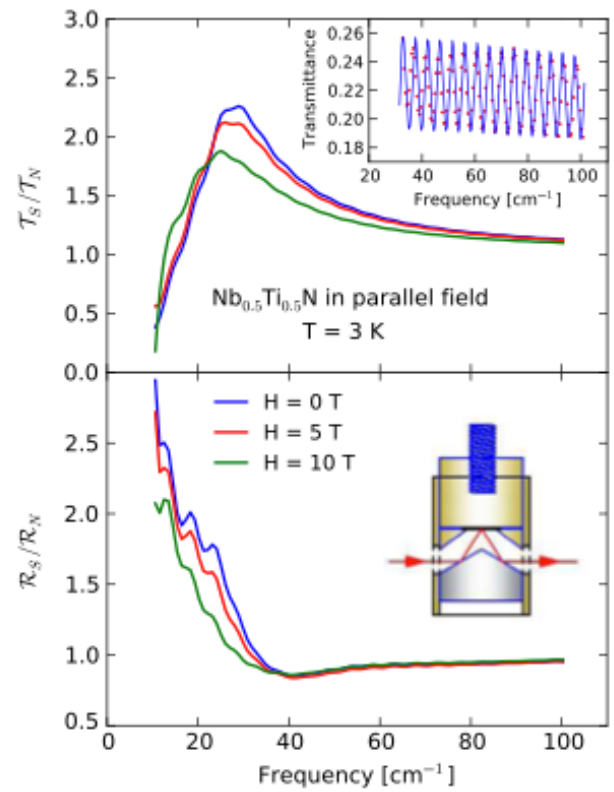
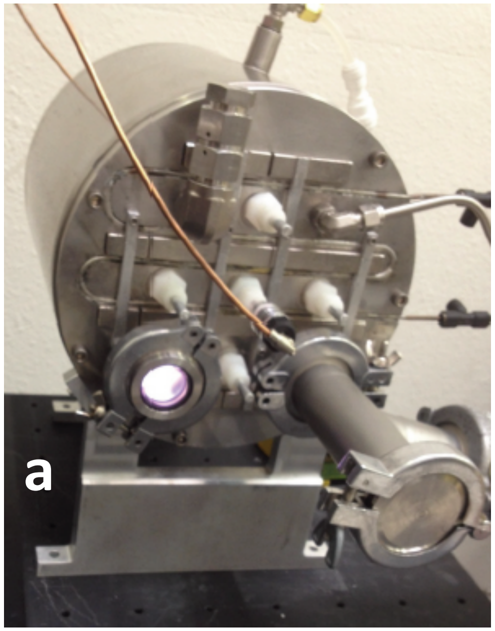


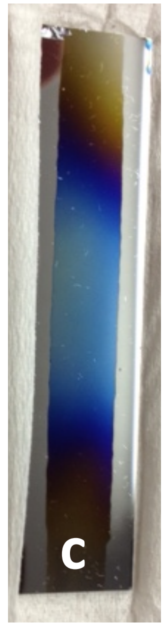


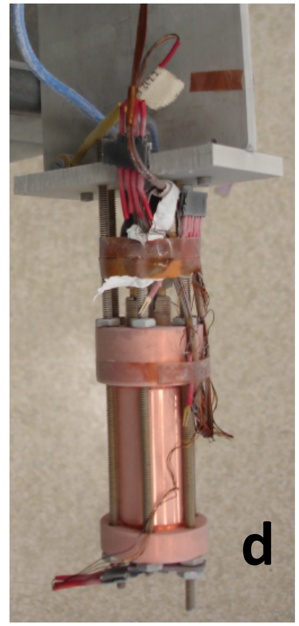
10 nm $Nb_{0.5}Ti_{0.5}N$ is perfect

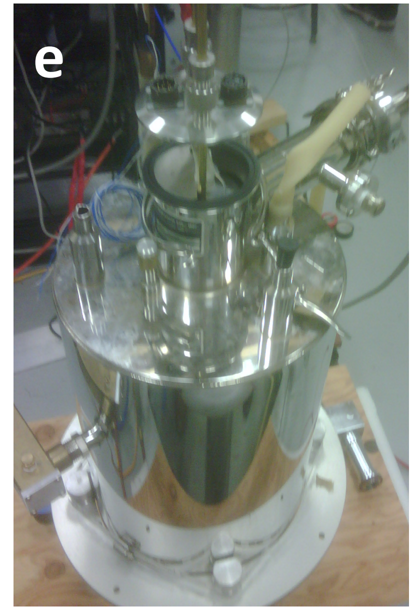
Supports $B_{||}$ up to 10 Tesla

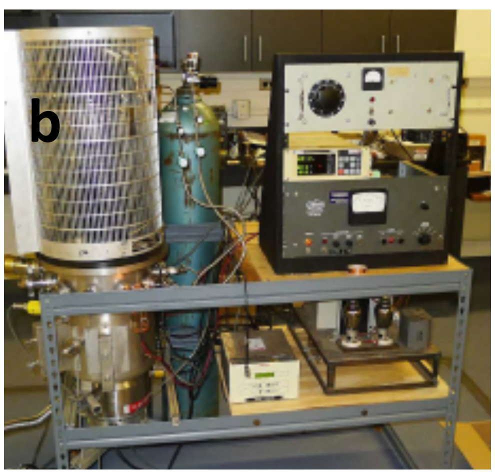
Hybrid superconducting cavity R&D program



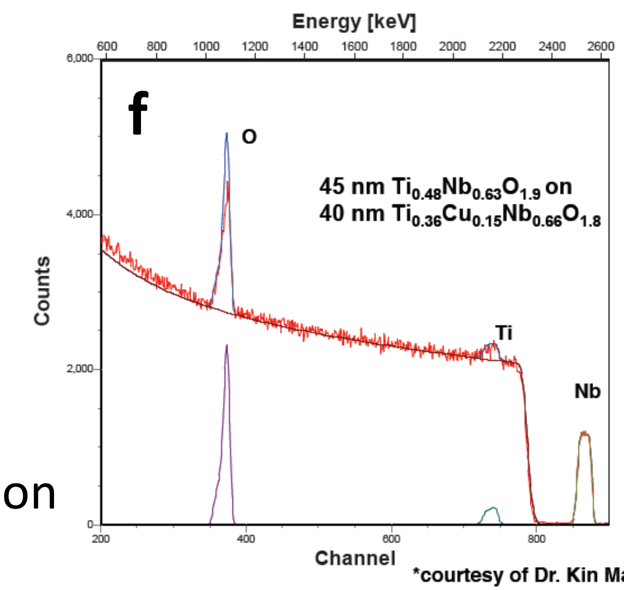


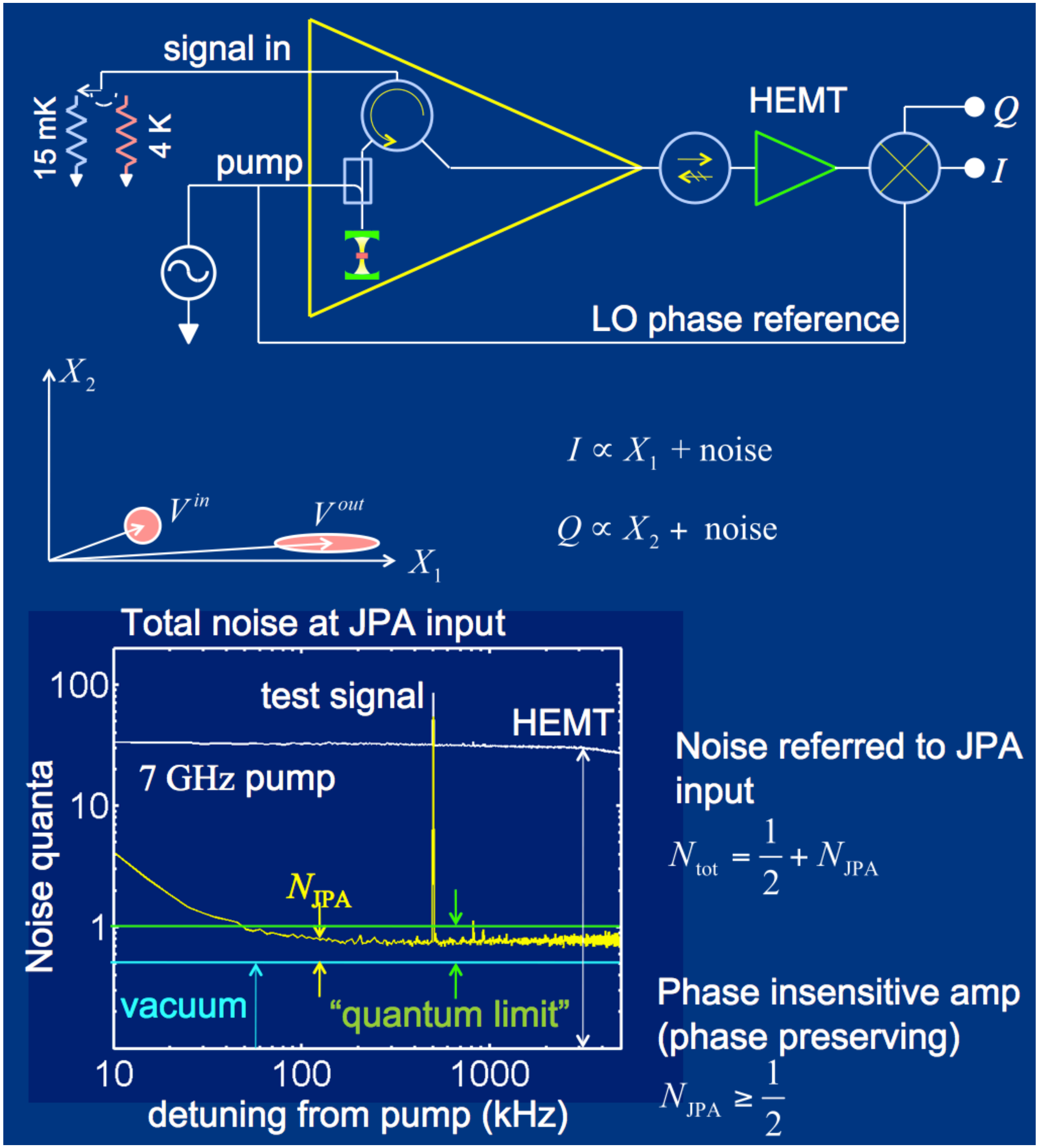






a. Sputtering (UCB-LLNL)
b. Sputtering (Yale)
c. Si strip witness tests
d. Prototype cavity tests
e. NMR magnet testing
f. RBS stoichiometry & thickness characterization



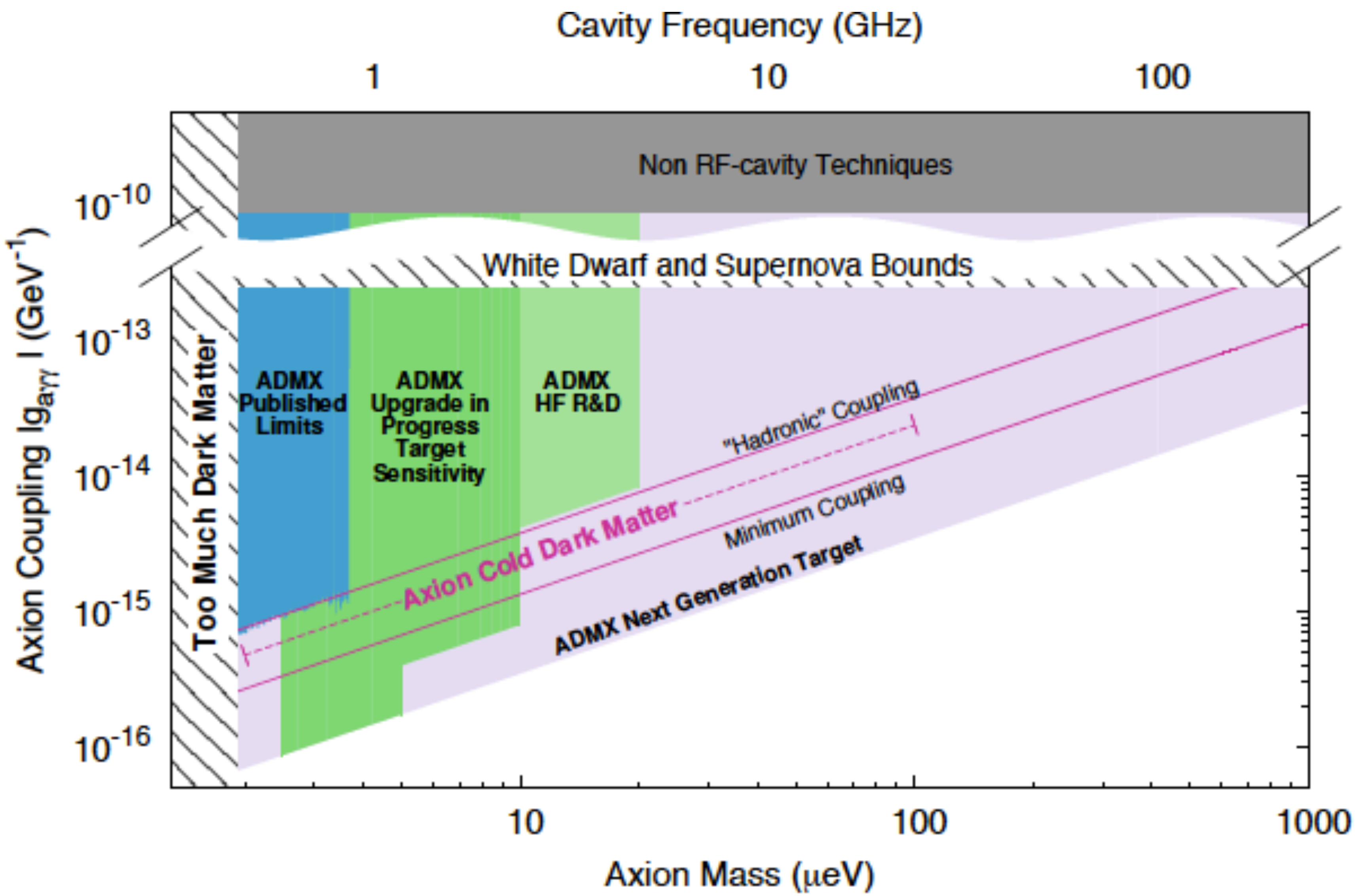


Josephson Parametric Amplifiers (JPA)

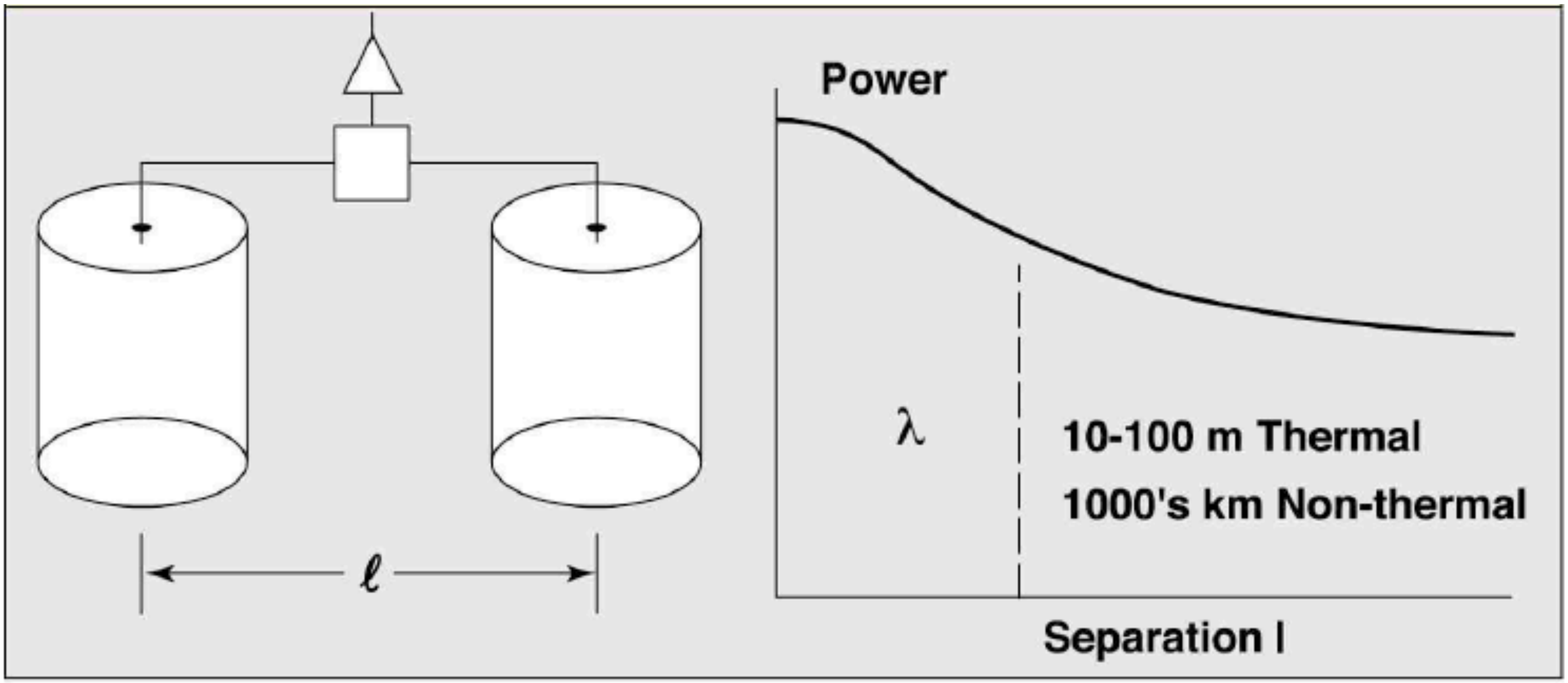
Konrad Lehnert, JILA/CU

- Natural for higher frequencies
- Broadly & easily tunable
- Operates at the SQL or below (squeezing)
- ADMX-HF will initially utilize an existing and proven system design
  - 4-8 GHz
  - Quantum-limited T

Projected coverage in next few years



A unique quantum system for study

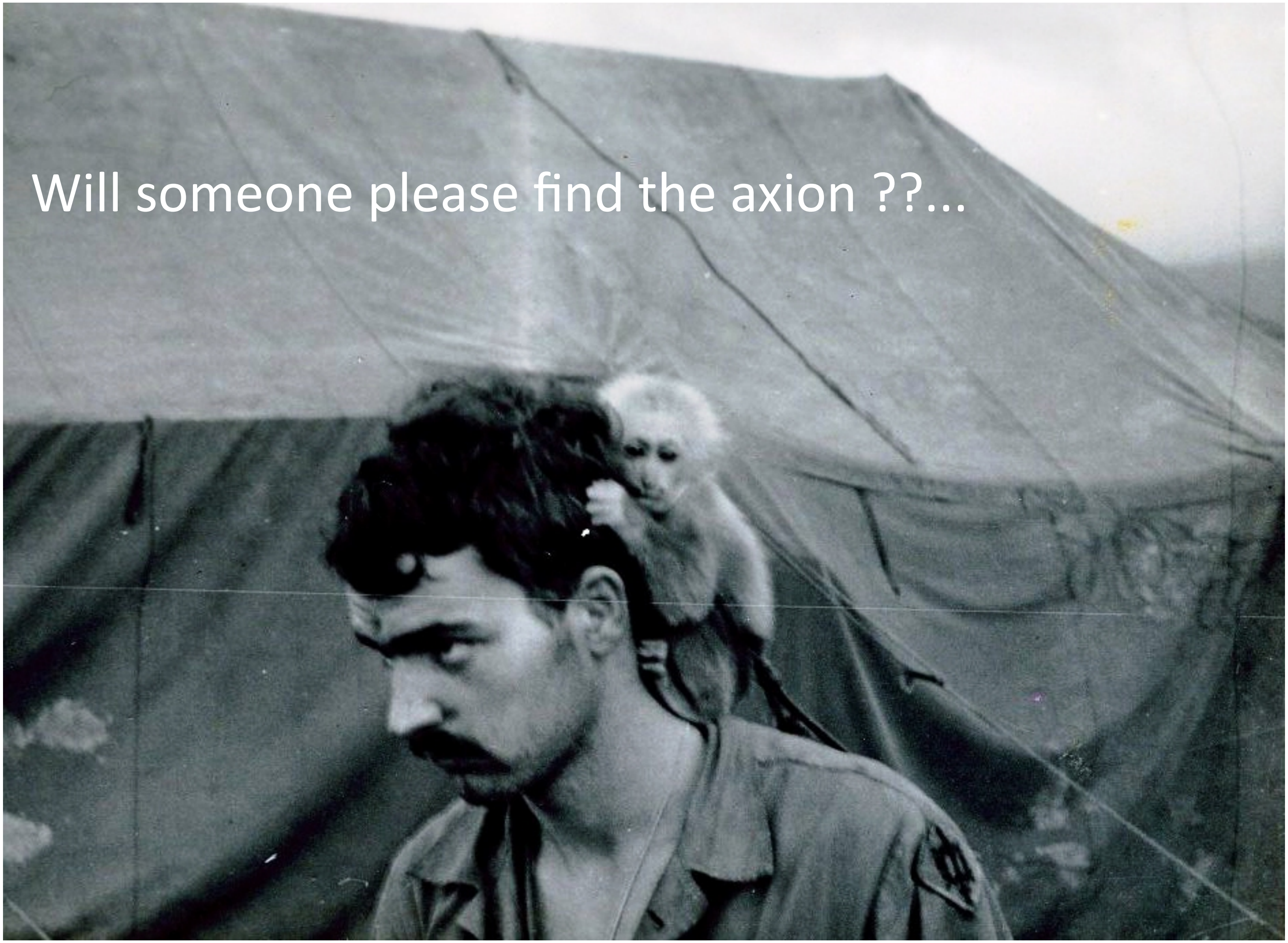


Summary & Outlook

- ADMX is well-positioned to make good progress in exploring most of the 'axion window' as we know it
  - The experimental sensitivity is basically well in hand now
  - Efficiently covering mass range is more challenging, but the pace should accelerate rapidly now

- ADMX/ADMX-HF as "one experiment, two sites" is a good model for pulling together a community, pooling R&D and know-how, and covering ground cost-effectively
  - Thank you DOE & NSF!
  - New cavity microwave experiments (e.g. YMCA) further enrich the field & will accelerate progress

- Should the axionic DM be found, it would open up a unique Bose quantum system for study (& axion astronomy?)



…So I can get this monkey off my back !!