Axion Search with ADMX Gen-2

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The identification of the missing dark matter in galactic halos and clusters remains one of the most pressing and important problems in astrophysics. I shall describe the ongoing search for the QCD axion, an alternative dark matter candidate, with the ADMX2 detector in Seattle. After an introduction to the phenomenology of axions and a description of the experiment, I shall summarise recent results and suggest methods to enhance ADMX2 that may be adopted in the future.

The Strong CP problem

Standard model symmetry group is $SU(3) \times SU(2) \times U(1)$

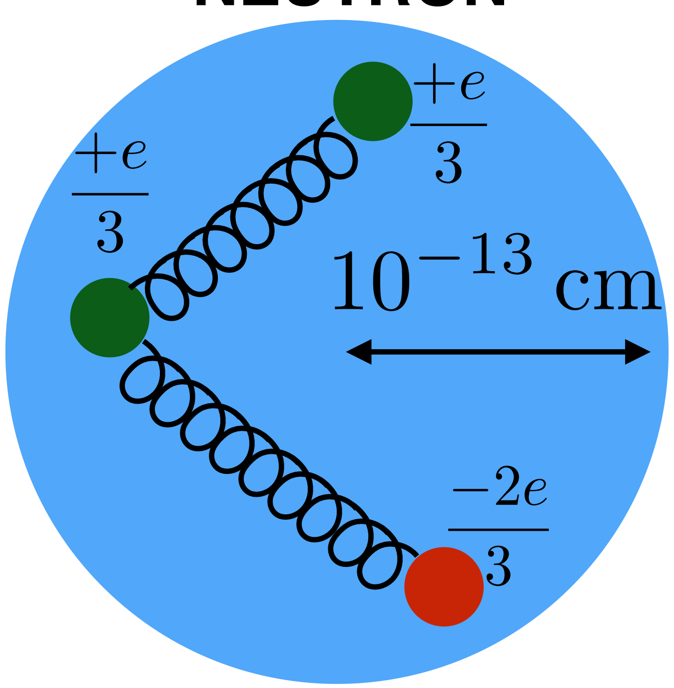
$SU(3)$	$SU(2)$	$U(1)$
NON-ABELIAN	NON-ABELIAN	ABELIAN
CP CONSERVING!	CP VIOLATING	CP CONSERVING

$$\mathcal{L}_{\mathrm{CPV}} = \frac{(\Theta + \arg\det M)}{32\pi^2}\vec{E}_{\mathrm{QCD}} \cdot \vec{B}_{\mathrm{QCD}}$$

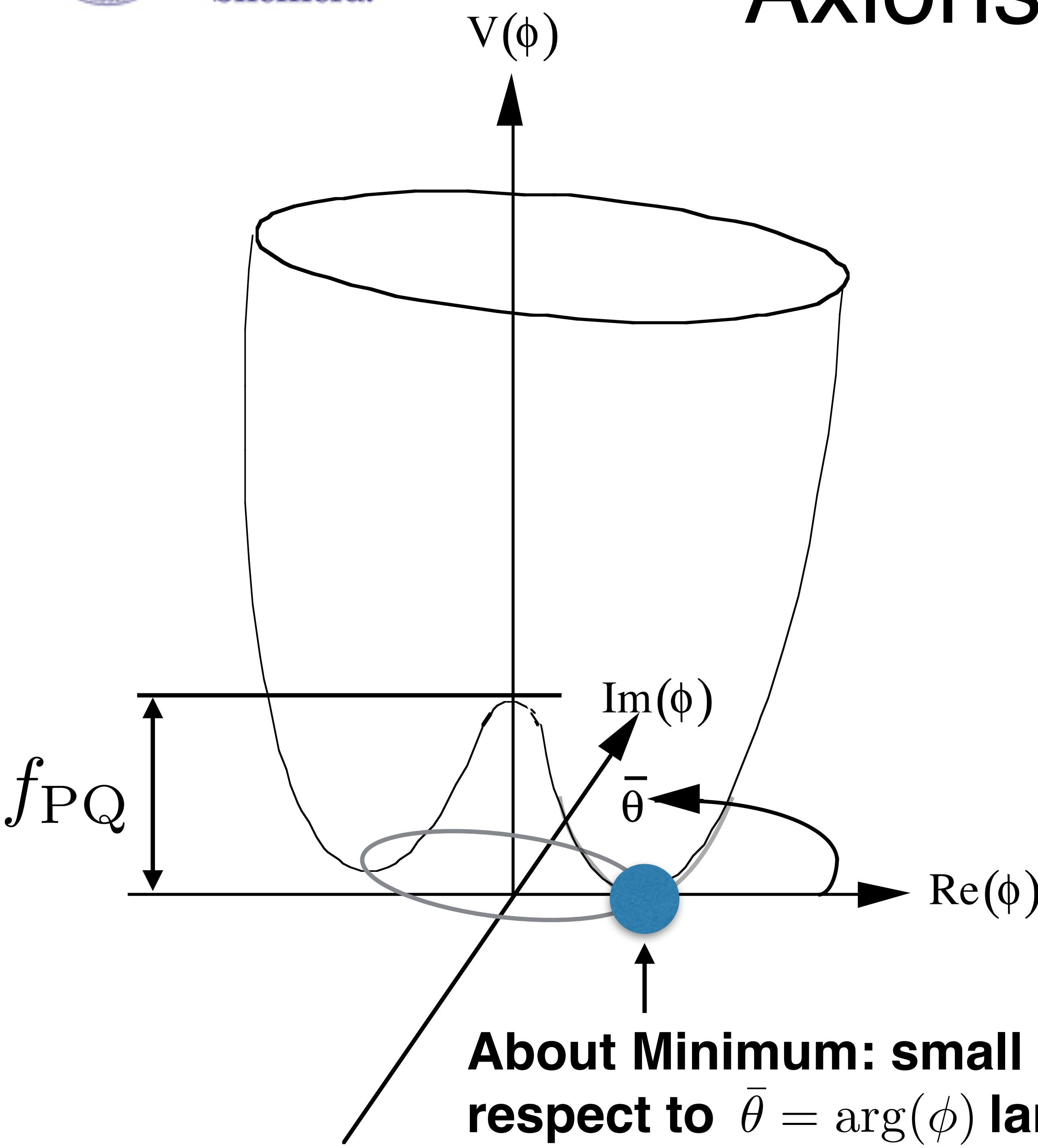
Evidence for CP conservation in the SU(3) strong interactions from multiple measurements of neutron and nuclear electric dipole moments. For example, neutron EDM < 10^{-26} e-cm.

Even simple dimensional arguments show that this is unexpected. Why do the intricate SU(3) QCD interactions conserve CP when the less intricate SU(2) QED interactions do not? This is the strong CP problem.

NEUTRON



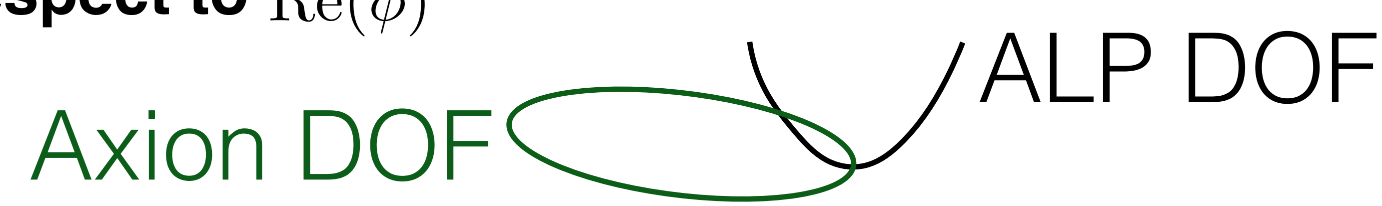
The Peccei Quinn Mechanism
Axions and ALPs



$$\mathcal{L}_{CPV} = \overline{\Theta}\mathbf{E.B}$$

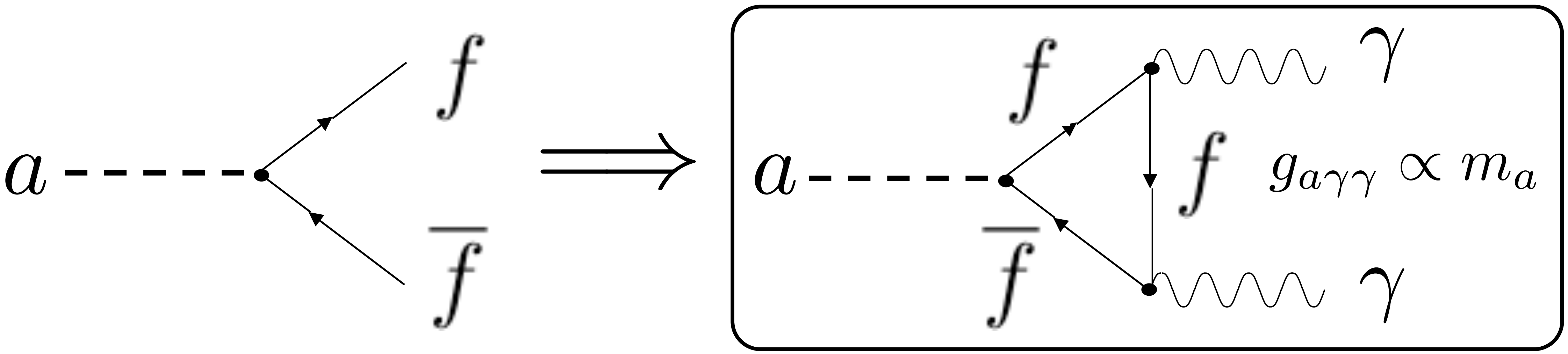
$$\overline{\Theta} = 0$$

About Minimum: small curvature (hence small mass) with respect to $\bar{\theta} = \arg(\phi)$ **large curvature (hence large mass) with respect to** $\mathrm{Re}(\phi)$



Axion Phenomenology

The axion is a pseudoscalar; has the same quantum numbers as the π^0, and the same interactions, but with strengths scaled to the axion mass



$$f_{PQ} \propto \frac{1}{m_a} \qquad \Omega_{PQ} \propto \frac{1}{m_a^{\frac{7}{6}}}$$

Axion Sources for Lab Searches

LAB

PVLAS
ALPS/ALPS2*
OSQAR
CASCADE*
ARIADNE*

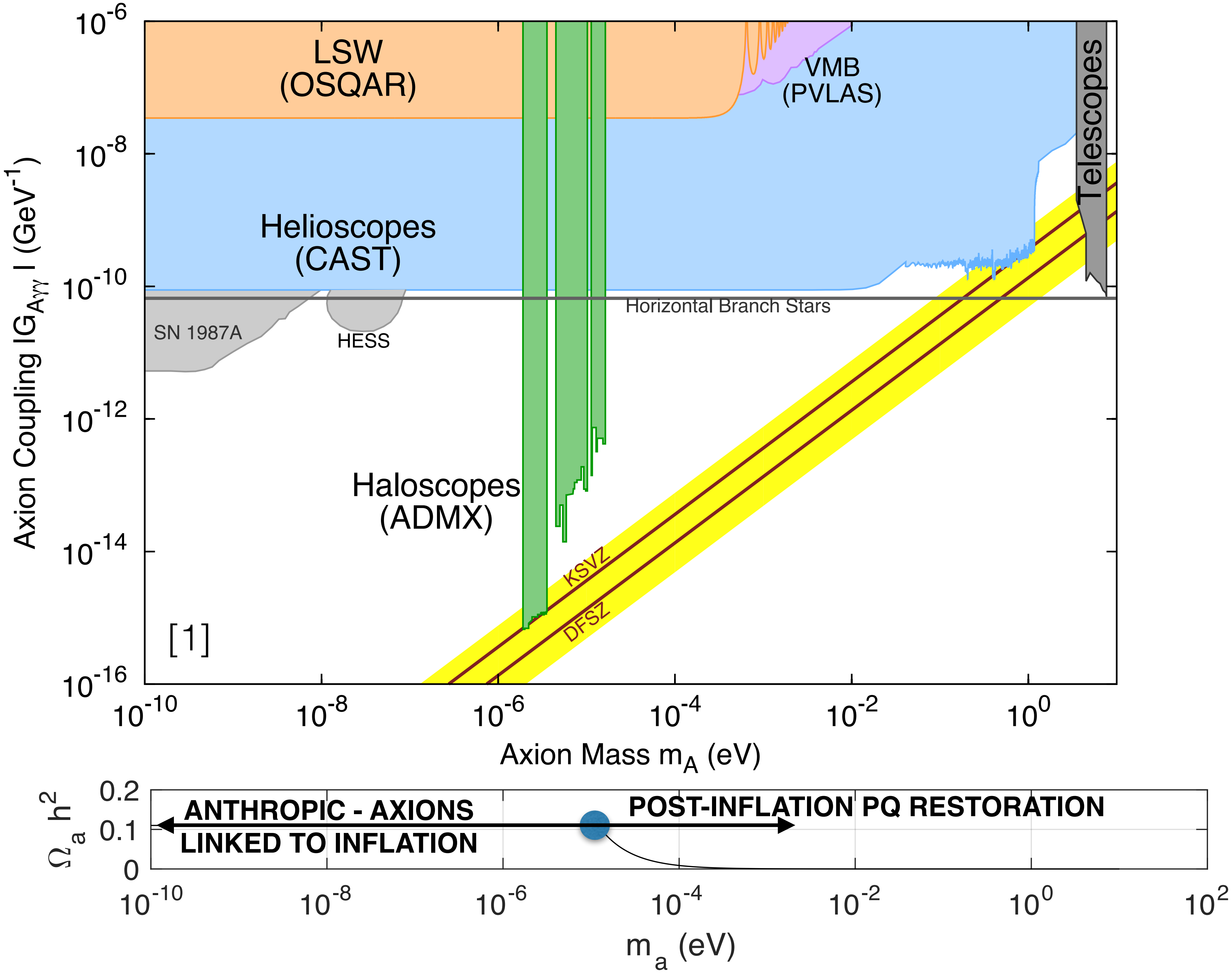
HALO

ADMX*
X3*
CAPP/CULTASK*
CASPER
FUNKY
MADMAX

SUN

CAST
IAXO*

$g_{a\gamma\gamma}$ vs. m_a parameter space



[1] K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014) and 2015 update
2016 revision by A. Ringwald, L. Rosenberg, G. Rybka,

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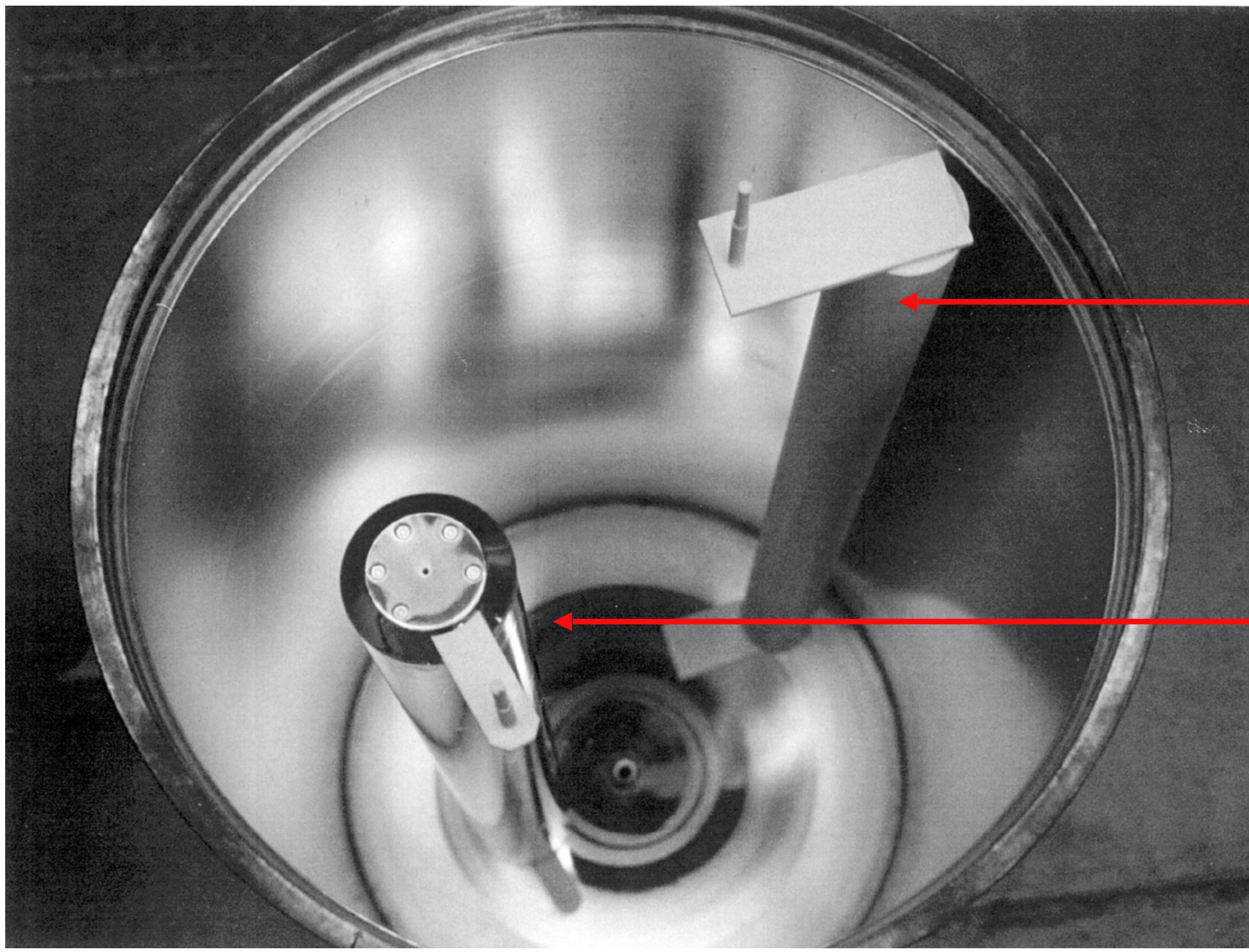
ADMX

Resonant Cavity Detectors



50cm

alumina tuning rod

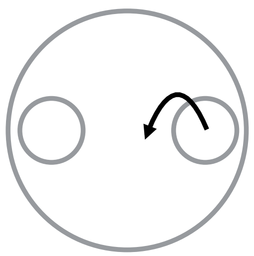
(a dielectric)

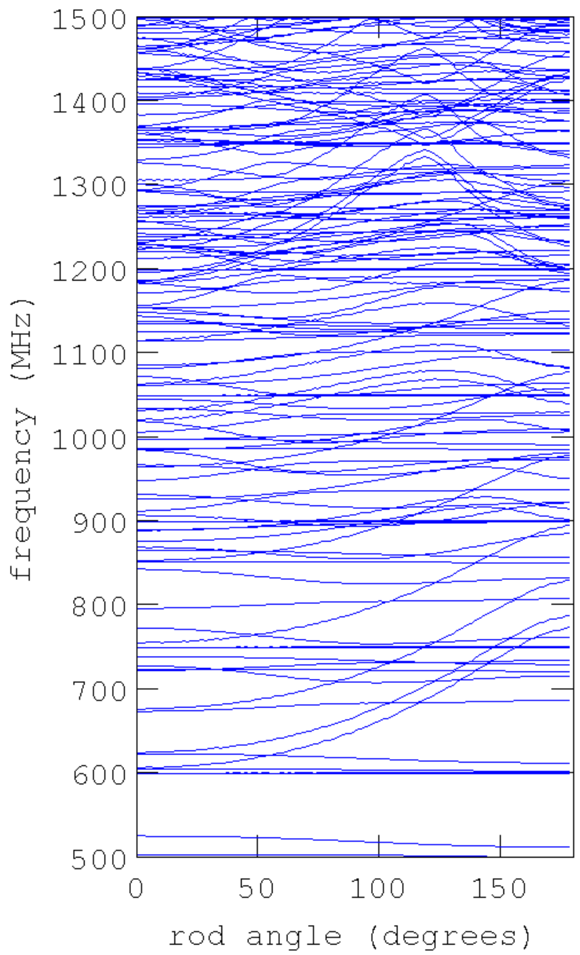
copper coated stainless steel

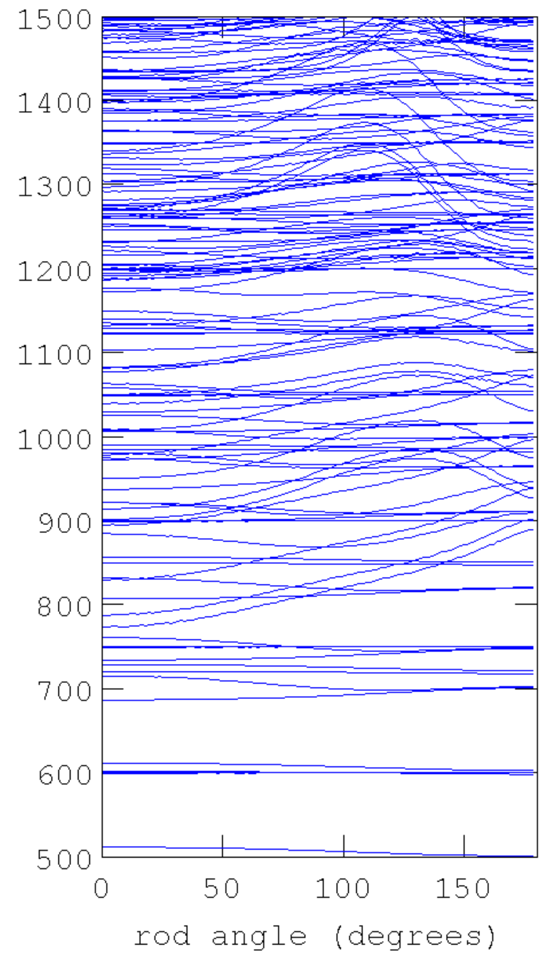
(a metal)

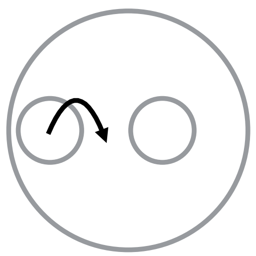
from above with lid removed.
Depth is 1m.

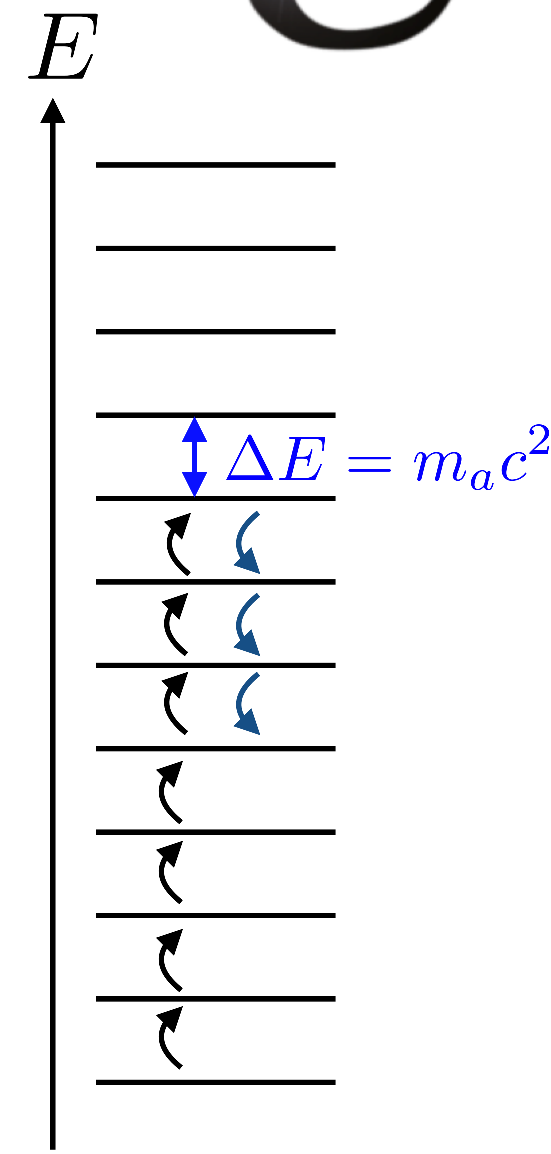
Modes of a Resonant Cavity



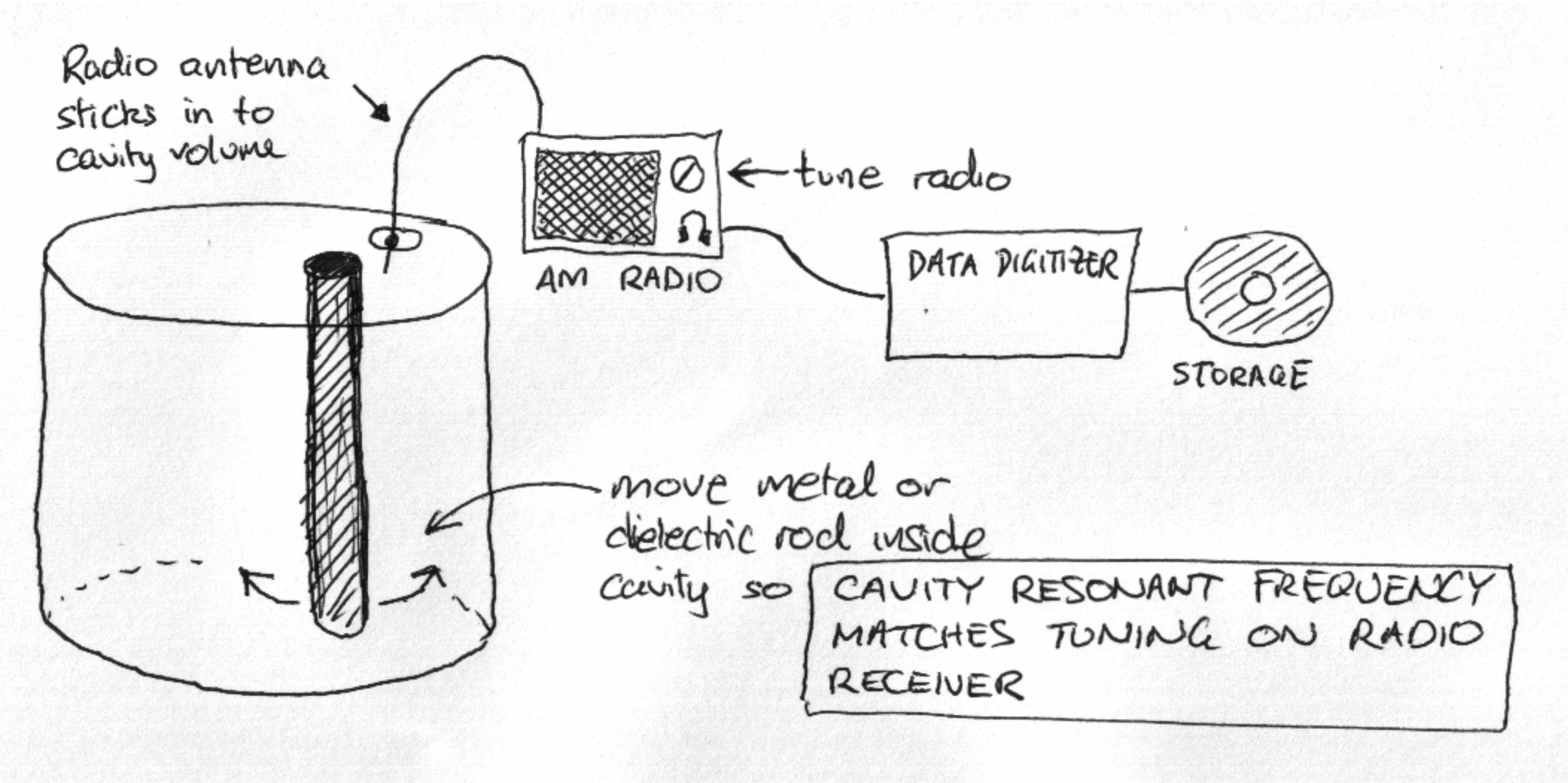








Incoming axions convert into quanta of excitation of TM modes of the cavity. Equilibrium between axion-stimulated excitation of the mode and spontaneous de-excitation due to thermal relaxation. Equilibrium population controlled by axion conversion rate, cavity Q


Radio antenna
sticks in to
cavity volume
tune radio
AM RADIO
DATA DIGITIZER
STORAGE
move metal or
dielectric rod inside
cavity so
CAVITY RESONANT FREQUENCY
MATCHES TUNING ON RADIO
RECEIVER

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ADMX

Anticipated Signal Strength

$$P_\gamma = \left(\frac{g_{a\gamma\gamma}^2 \rho_a \hbar^2}{m_a^2 c}\right) 2\pi c^2 \varepsilon_0 B_0^2 V f_{010} \nu_a Q$$

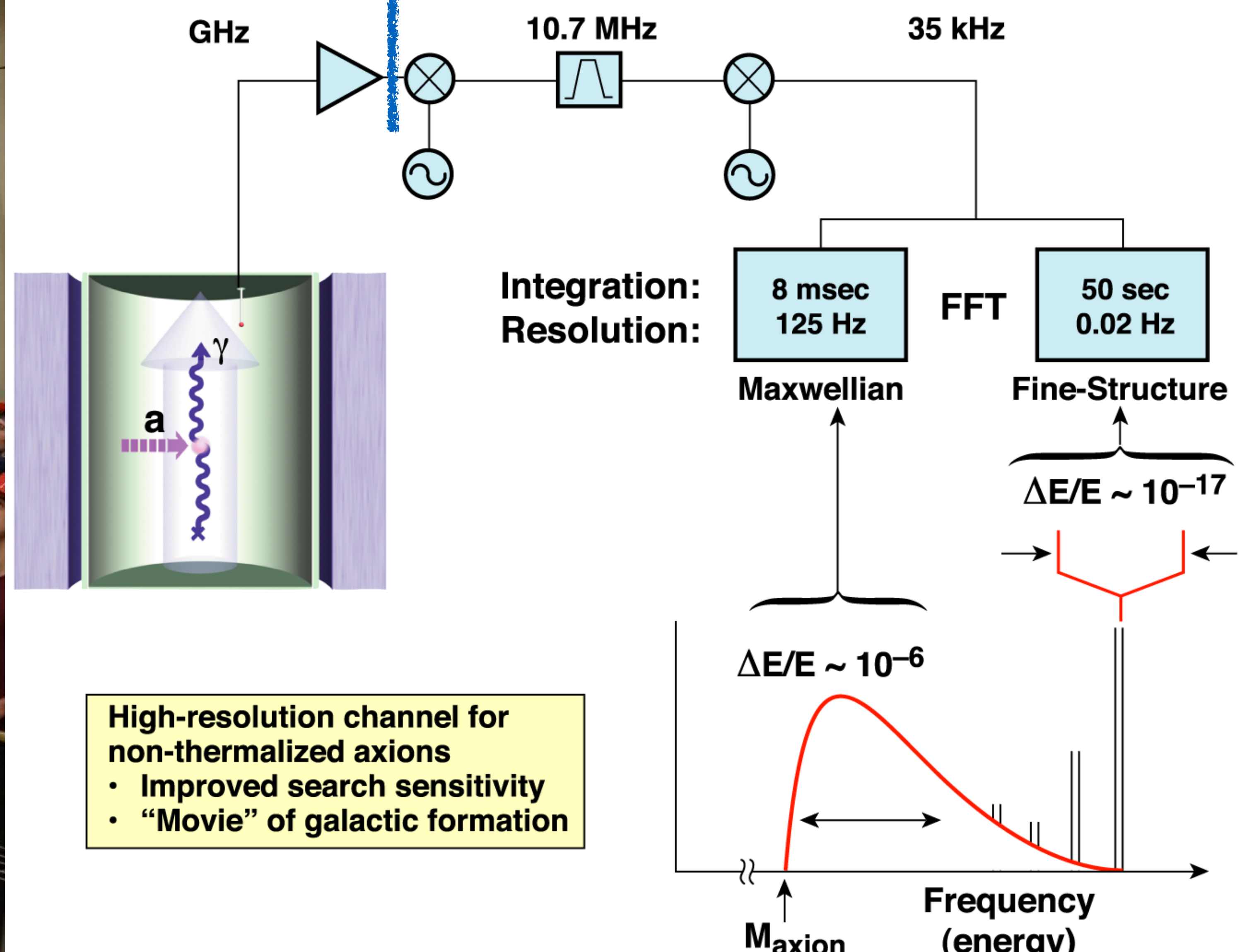
- Square of axion to photon coupling amplitude
- Axion mass
- Density of axions in local galactic halo
- Magnetic field strength
- Cavity volume
- Cavity mode form factor, frequency, quality factor

Expected signal power ~ $10^{-22}\,\mathrm{W}$

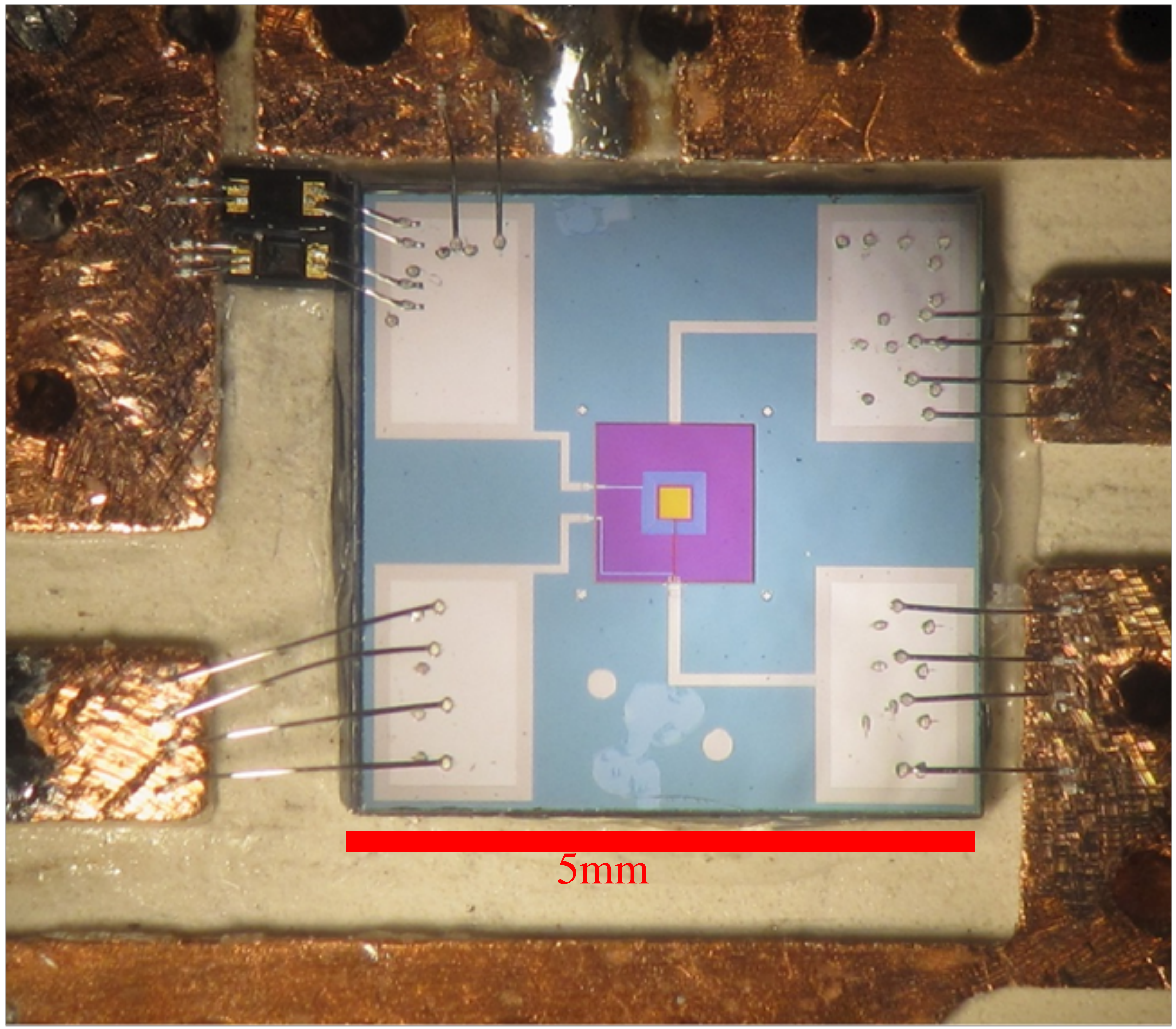
The ADMX detector

Cryogenic | Warm

AM Radio =
Double Heterodyne Receiver

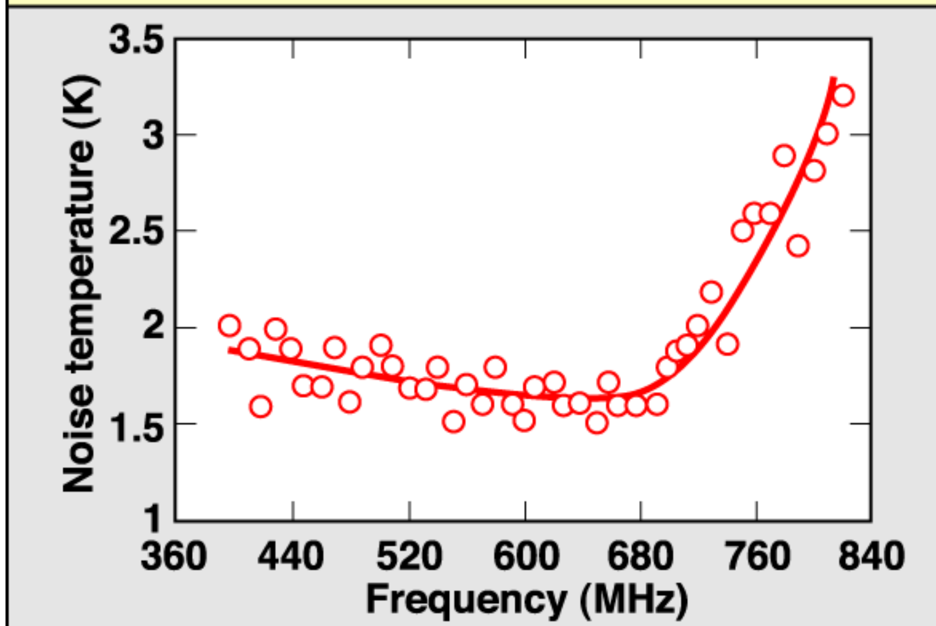


Cold Low-Noise Amplification
1st Stage: RF SQUID
2nd Stage: Balanced HFET amplifier

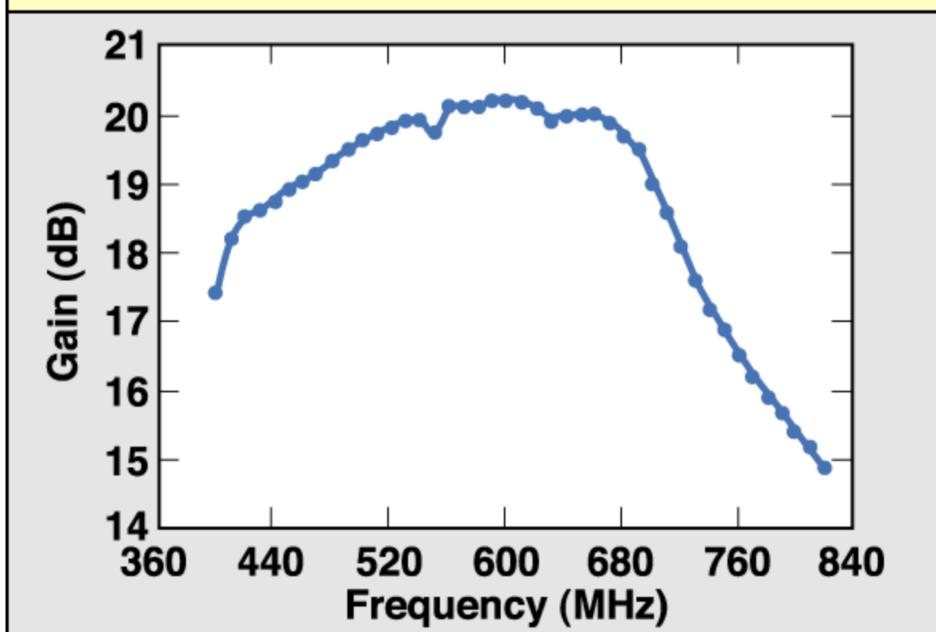


Noise Performance

HFET Noise Temperature

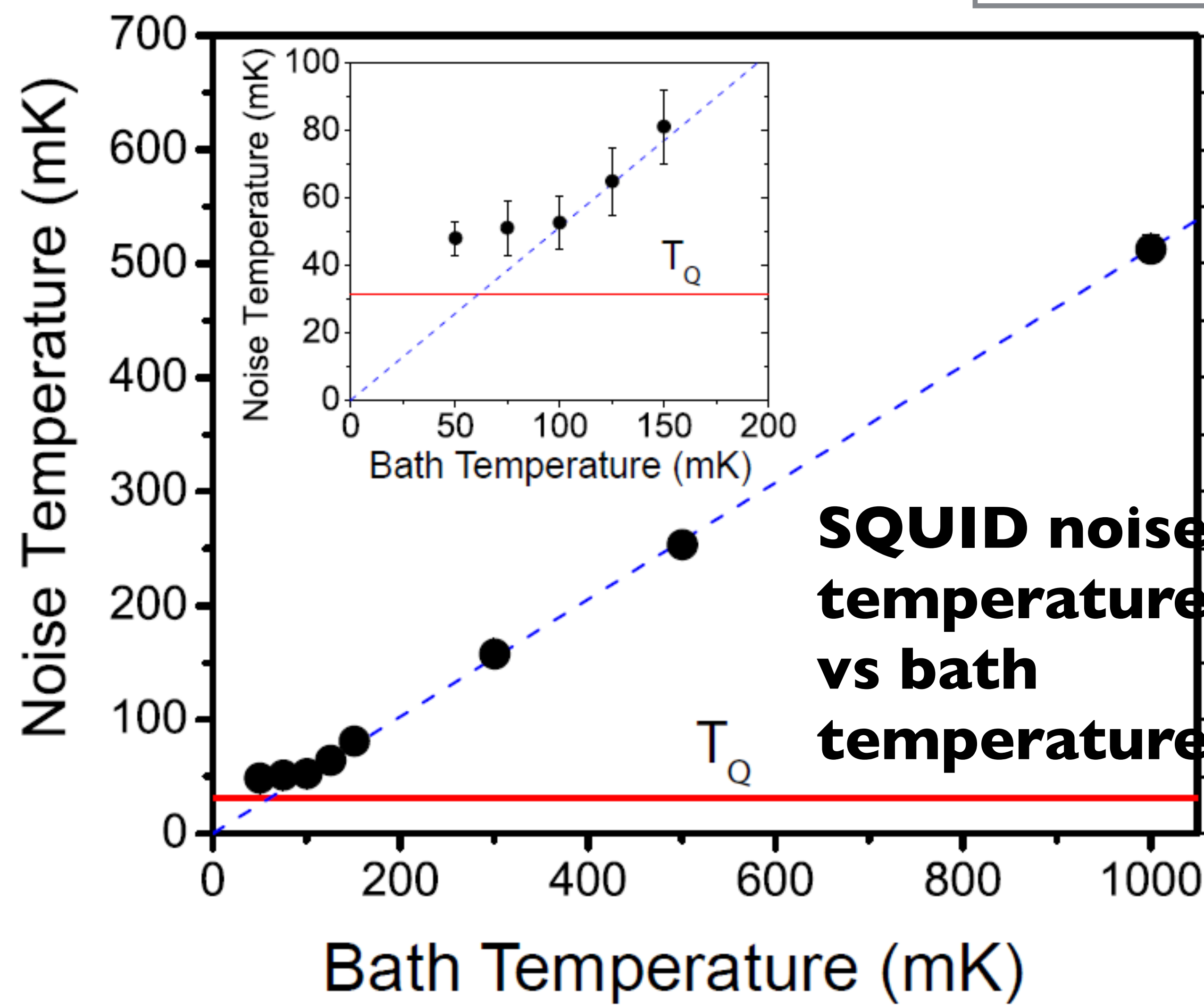


HFET Gain

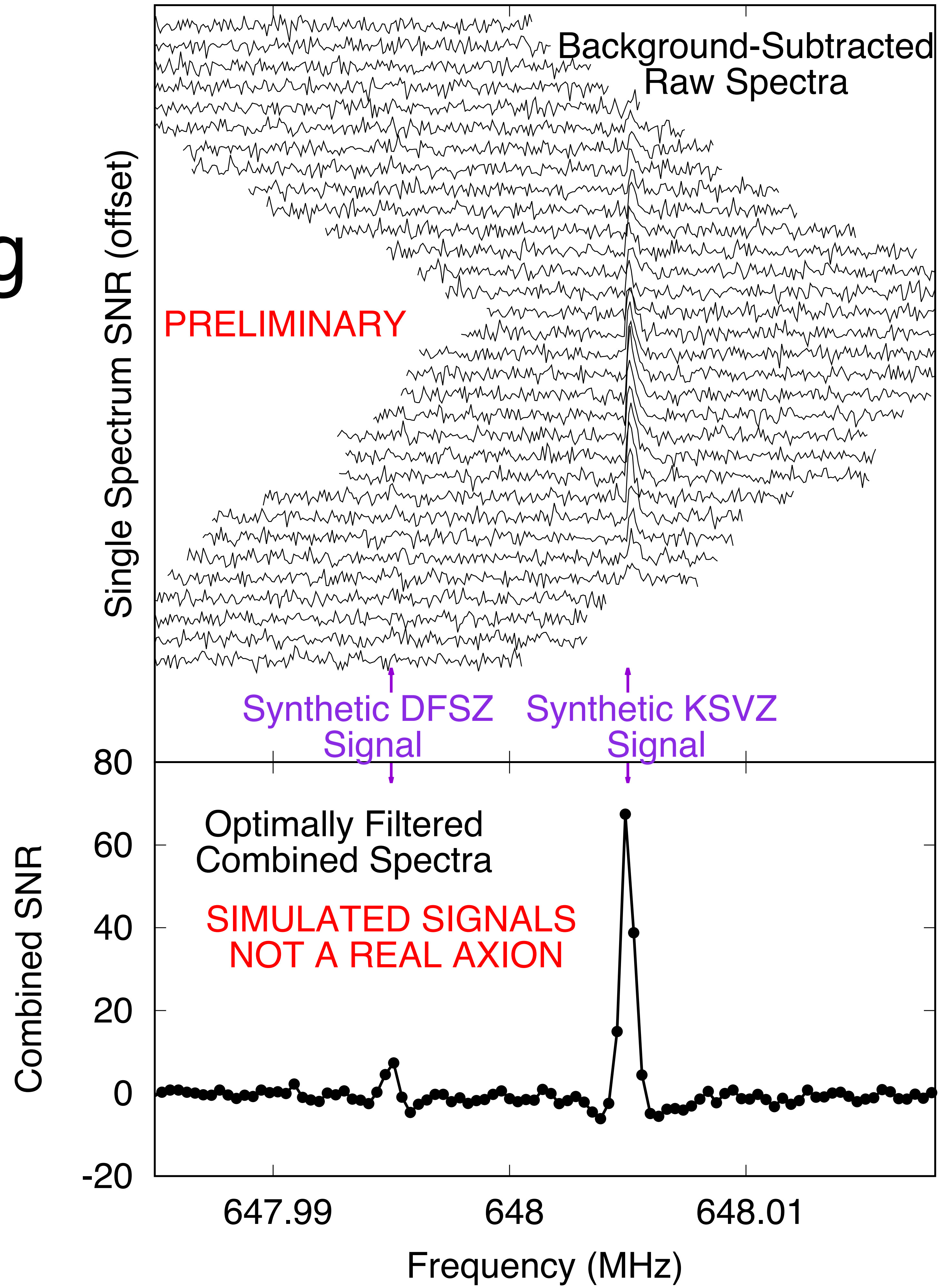


- **Currently HFET amplifiers (Heterojunction Field-Effect Transistor)**
  - **A.k.a. HEMT™ (High Electron Mobility Transistor)**
  - **Workhorse of radio astronomy, military communications, etc.**

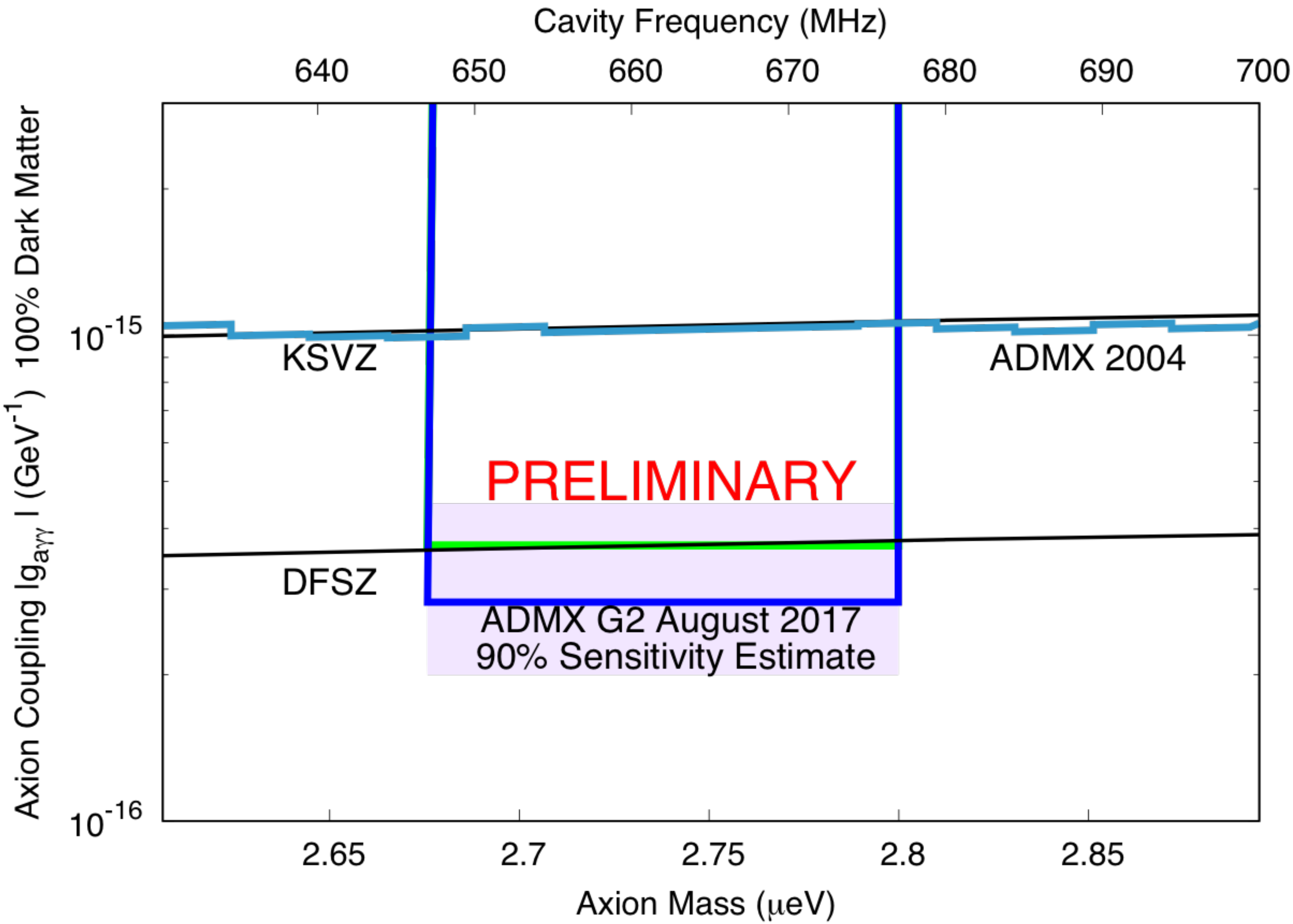
$$\left(\frac{1.5}{0.06}\right)^2 = 625$$



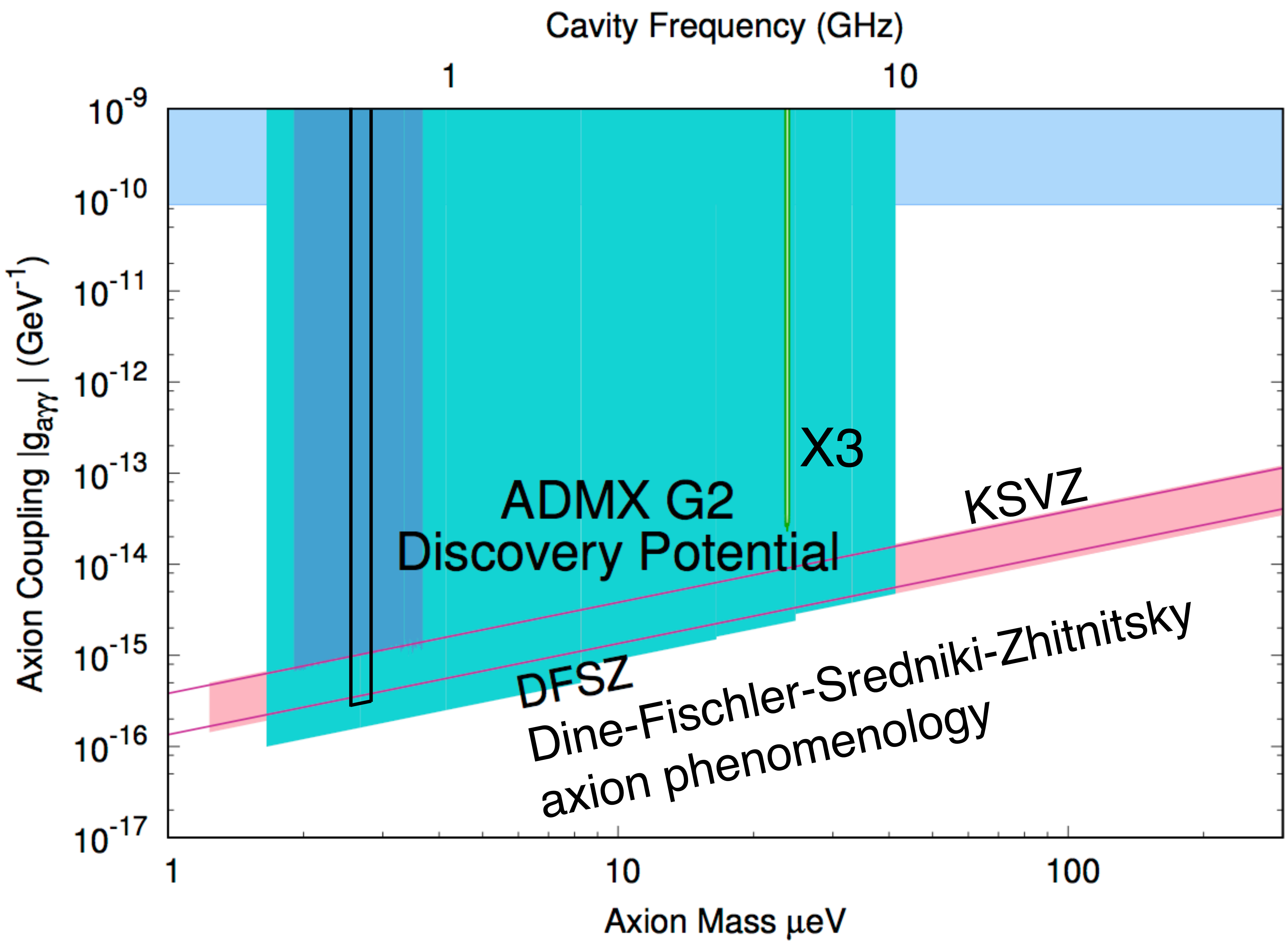
Combining Power Spectra



Sensitivity level in submitted first-results paper



Projected Sensitivity in First Data

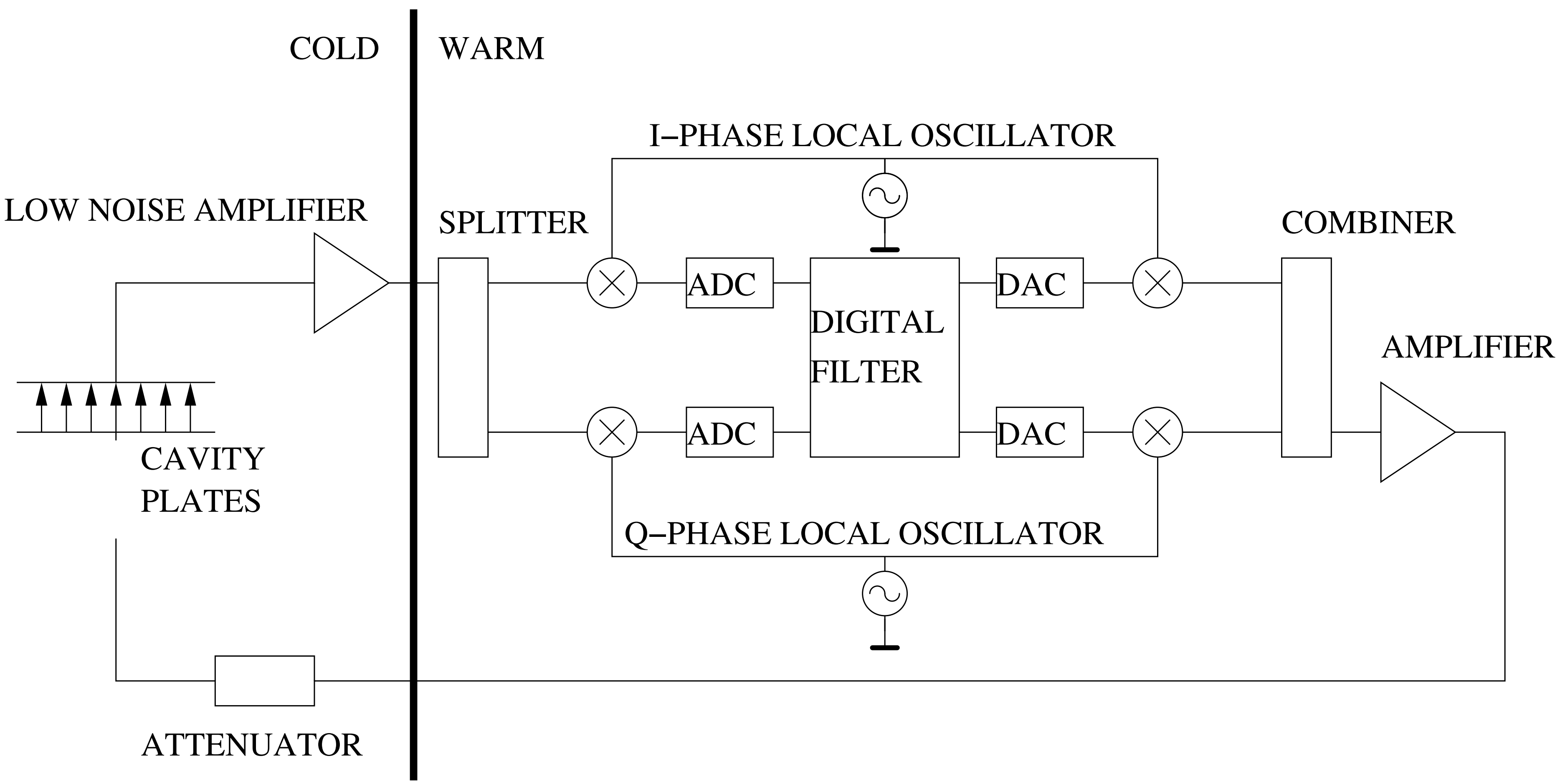


First Probe of sub-DFSZ coupling halo axions!

New approach: Digital Resonant feedback

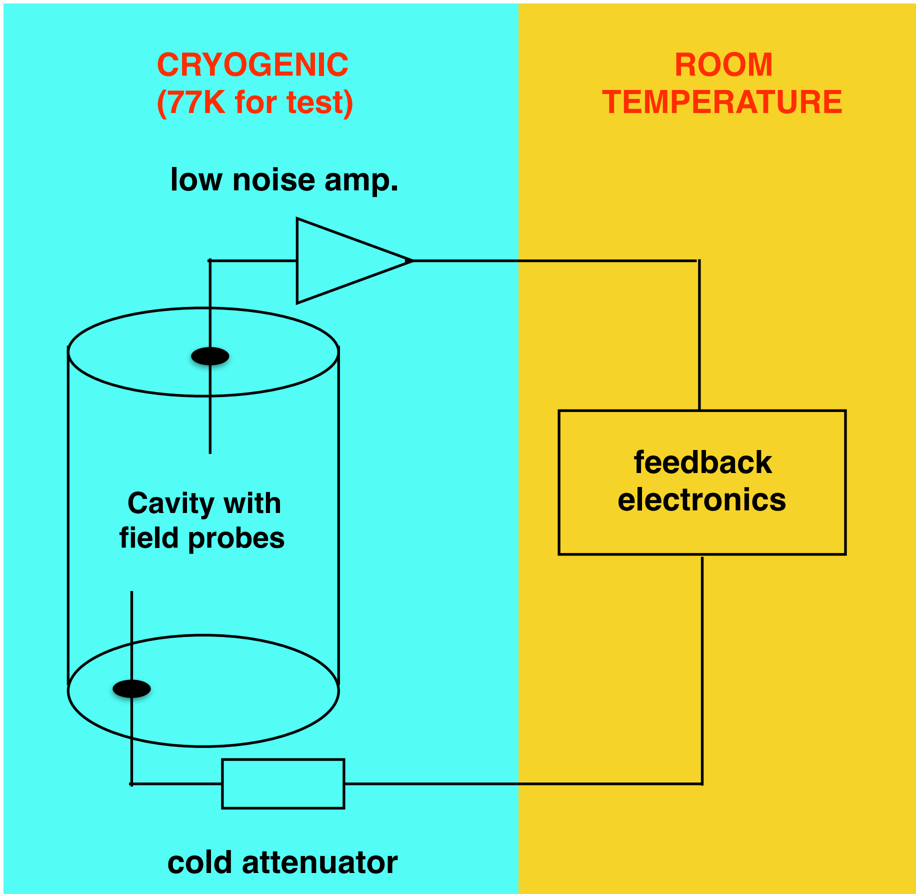
Maybe the resonant structure doesn't have to be in the cavity.

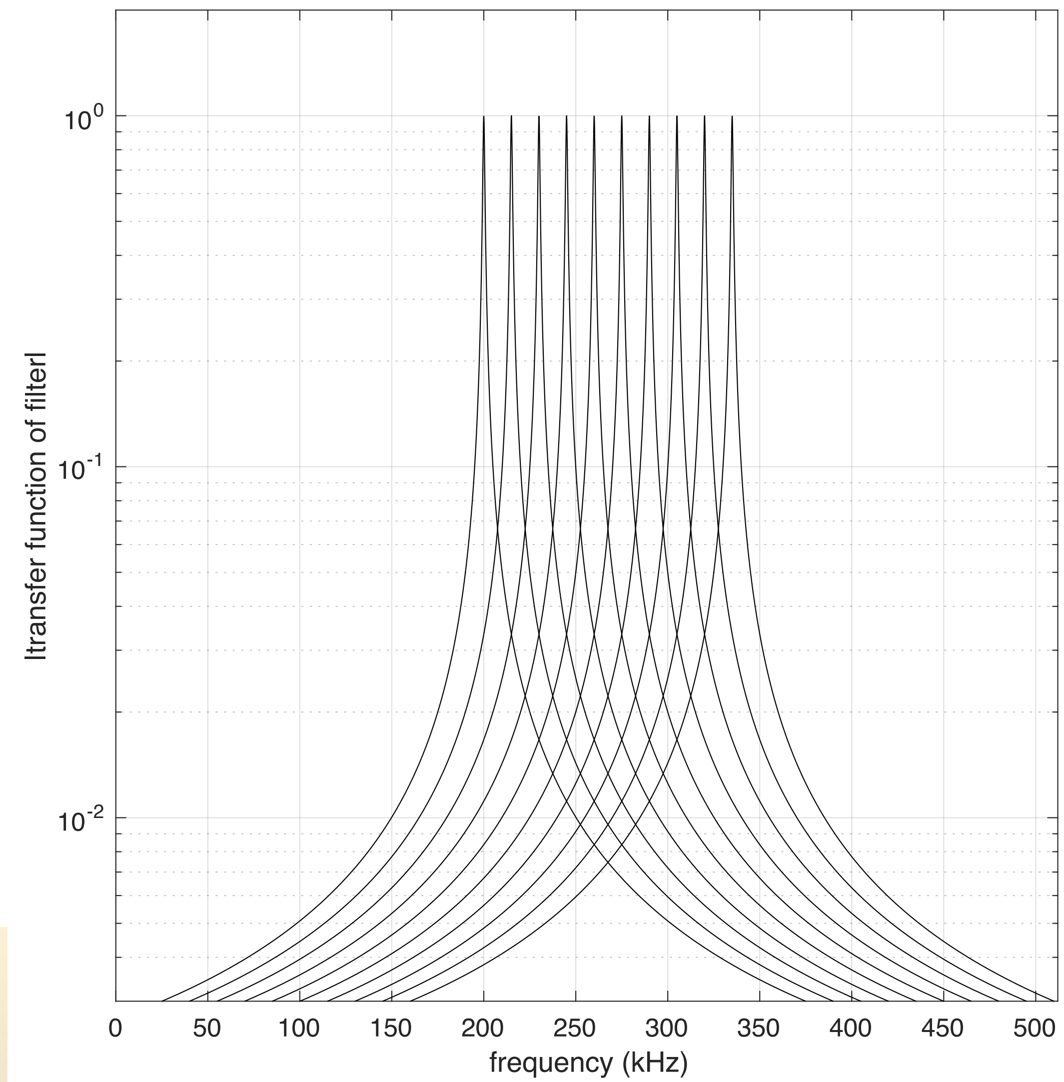
RF structure operated off-resonance



For high Q, but without oscillation, need servo control of the open loop gain so that it is marginally less than 1. Advantage of this method is that many resonators can run in parallel.

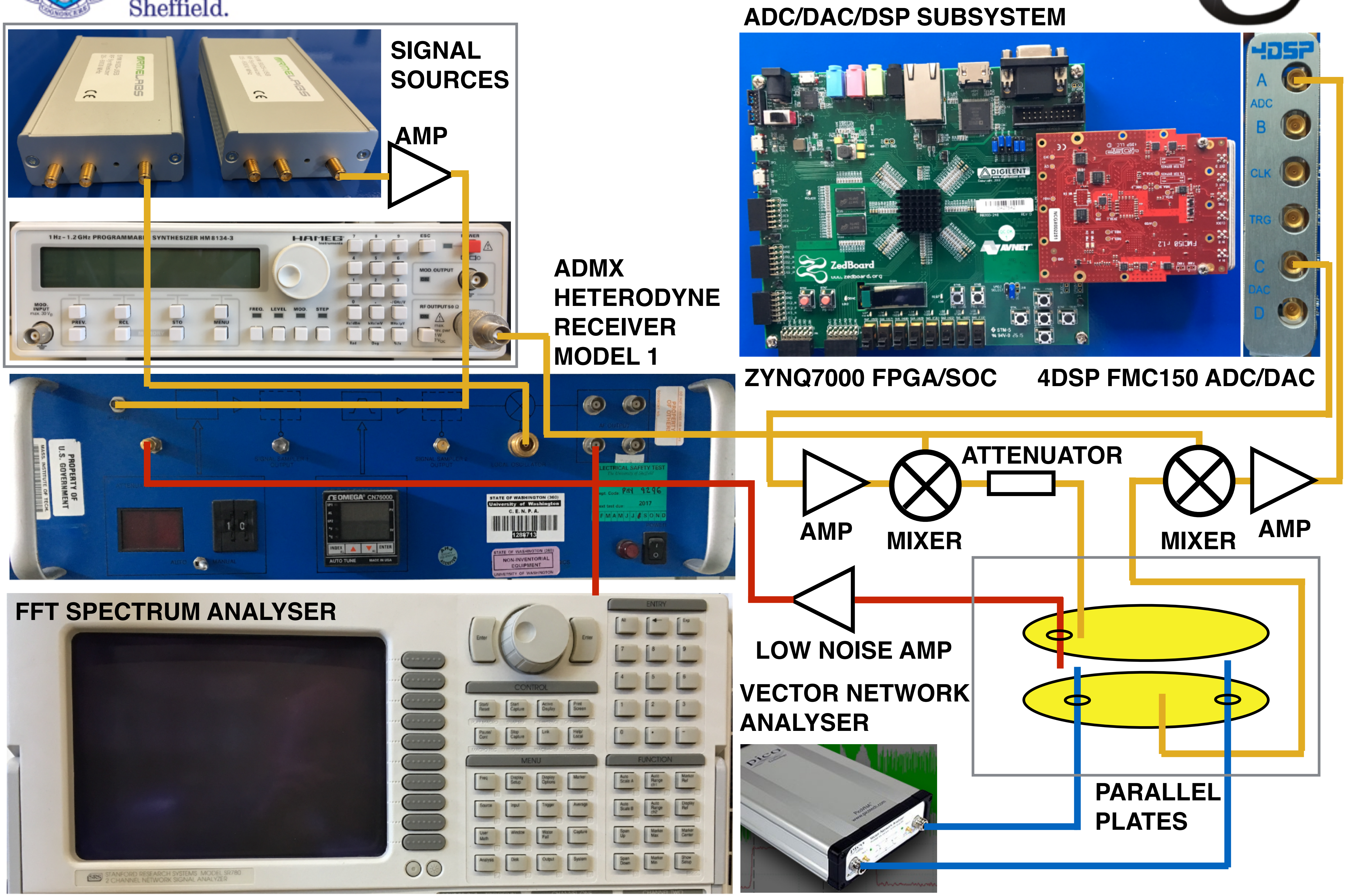
Hurrying it Along





Mitch Perry (Sheffield B.Sc. 2017) at Sheffield.

UKARC Experiment 2



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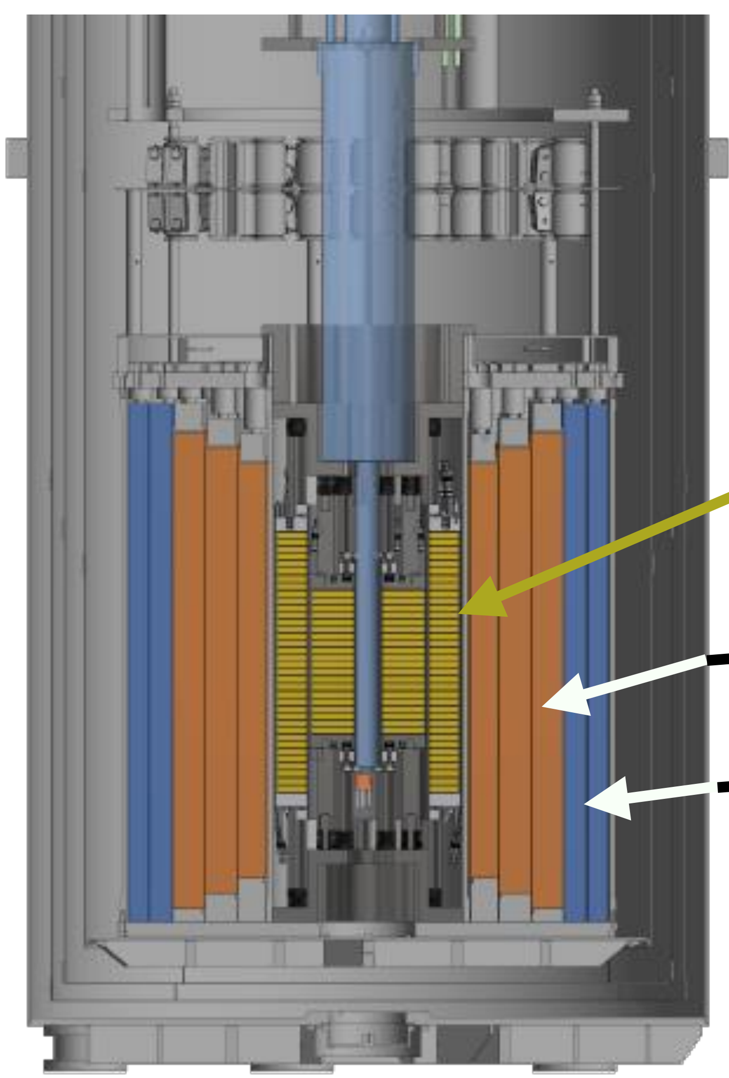
Future Magnet

NATIONAL HIGH MAGNETIC FIELD LABORATORY

[Florida]

Bore of 16cm in diameter - sensitivity to higher mass axions. 24T static field.

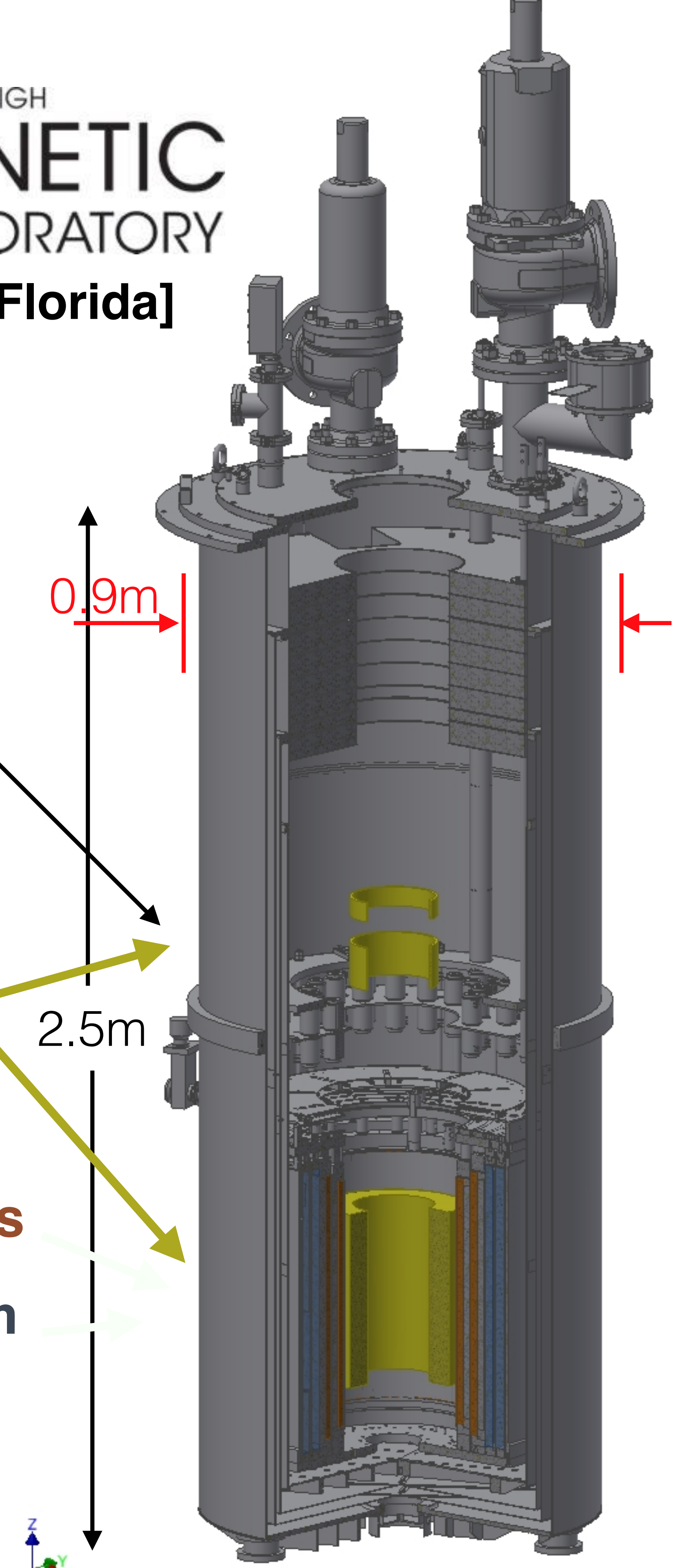
Bucking coils for field free region 60cm above the main magnet



High Temperature Superconductor Coils: 44 modules of YBCO tape

Niobium Tin (Nb_3Sn) coils

Niobium Titanium (NbTi) coils



Conclusions

- Axion dark matter is well motivated.
- ADMX is probing DFSZ halo axions already!
- Coverage of the full plausible mass range challenging. Bigger magnet would help, but £££.
- Resonant feedback offers a potential solution.
- Proposed UK contribution [Daw, Bailey]:

★ **Build and test a prototype resonant feedback system.**
★ **Model the resonant structure, assess form factor.**
★ **Deliver the prototype for testing with the ADMX cavity.**

- Seedcorn money from UofS is getting this started.
- Lots to get involved with! RF, software, FEM
- Sheffield, Lancaster (Ian Bailey) already working.
- Maybe we will detect axions! I certainly hope so.