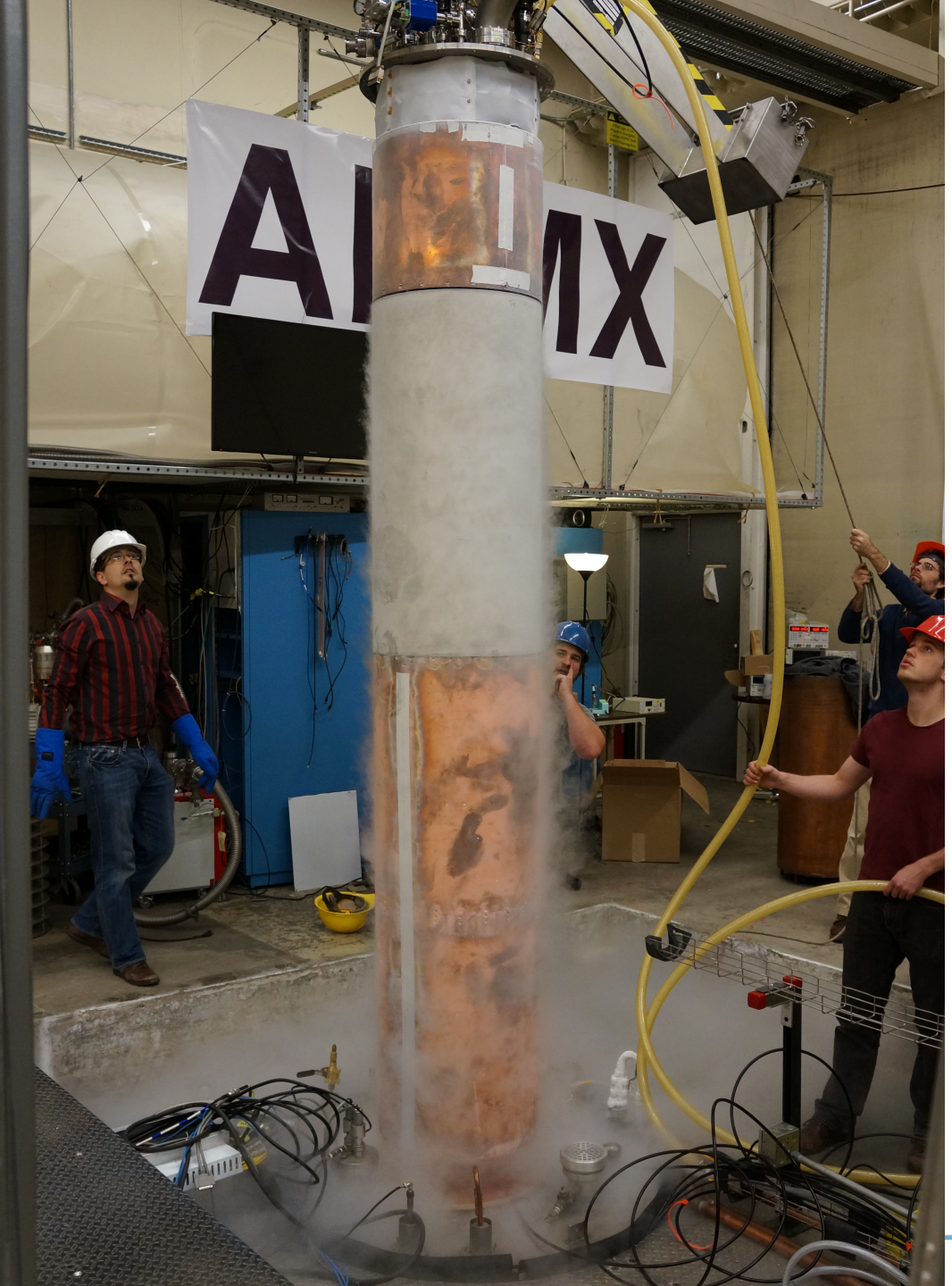

DOE/HEP PI Meeting
Washington, D.C.

Axion Dark-Matter Experiment (ADMX)

Leslie J Rosenberg
University of Washington

June 16, 2014

What constitutes dark matter?

FIRST ATTEMPT AT A THEORY OF THE ARRANGEMENT AND MOTION OF THE SIDEREAL SYSTEM[1]

By J. C. KAPTEYN[2]

ABSTRACT

First attempt at a general theory of the distribution of masses, forces, and velocities in the stellar system.—(1) *Distribution of stars.* Observations are fairly well represented, at least up to galactic lat. 70°, if we *assume that the equidensity surfaces are similar ellipsoids of revolution*, with axial ratio 5.1, and this enables us to compute quite readily (2) *the gravitational acceleration at various points due to such a system*, by summing up the effects of each of ten ellipsoidal shells, in terms of the acceleration due to the average star at a distance of a parsec. The *total number of stars* is taken as 47.4×10^9. (3) *Random and rotational velocities.* The nature of the equidensity surfaces is such that the stellar system cannot be in a steady state unless there is a general rotational motion around the galactic polar axis, in addition to a random motion analogous to the thermal agitation of a gas. In the neighborhood of the axis, however, there is no rotation, and the behavior is assumed to be like that of a gas at uniform temperature, but with a gravitational acceleration ($G\eta$) decreasing with the distance ρ. Therefore the density Δ is assumed to obey the barometric law: $G\eta = -\bar{u}^2(\delta\Delta/\delta\rho)/\Delta$; and taking the mean random velocity $\bar{u}$ as 10.3 km/sec., the author finds that (4) *the mean mass of the stars* decreases from 2.2 (sun = 1) for shell II to 1.4 for shell X (the outer shell), the average being close to 1.6, which is the value independently found for the average mass of both components of visual binaries. In the galactic plane the resultant acceleration—gravitational minus centrifugal—is again put equal to $-\bar{u}^2(\delta\Delta/\delta\rho)/\Delta$, $\bar{u}$ is taken to be constant and the average mass is assumed to decrease from shell to shell as in the direction of the pole. The angular velocities then come out such as to make the linear rotational velocities about constant and equal to 19.5 km/sec. beyond the third shell. If now we suppose that part of the stars are rotating one way and part the other, the relative velocity being 39 km/sec., we have a quantitative explanation of the phenomenon of star-streaming, where the relative velocity is also in the plane of the Milky Way and about 40 km/sec. It is incidentally suggested that when the theory is perfected it may be possible to determine *the amount of dark matter* from its gravitational effect. (5) The *chief defects of the theory* are: That the equidensity surfaces assumed do not agree with the actual surfaces, which tend to become spherical for the shorter distances; that the *position of the center of the system* is not the sun, as assumed, but is probably located at a point some 650 parsecs away in the direction galactic long. 77°, lat. −3°; that the average mass of the stars was assumed to be the same in all shells in deriving the formula for the variation of $G\eta$ with ρ on the basis of which the variation of average mass from shell to shell and the constancy of the rotational velocity were derived—hence either the assumption or the conclusions are wrong; and that no distinction has been made between stars of different types.

1. *Equidensity surfaces supposed to be similar ellipsoids.*—In *Mount Wilson Contribution* No. 188[3] a provisional derivation was given of the star-density in the stellar system. The question was there raised whether the inflection appearing near the pole in the

[1] *Contributions from the Mount Wilson Observatory*, No. 230.

[2] Research Associate of the Mount Wilson Observatory.

[3] *Astrophysical Journal*, **52**, 23, 1920.

Kapetyn 1922

as to the distribution of dark matter. It would appear from the comparison that the dark mass must be relatively more frequent near the galactic plane than far from it, but the data are too uncertain to derive numerical results. A similar conclusion was reached by KAPTEYN in the investigation quoted above.

Recognized by Oort 1932

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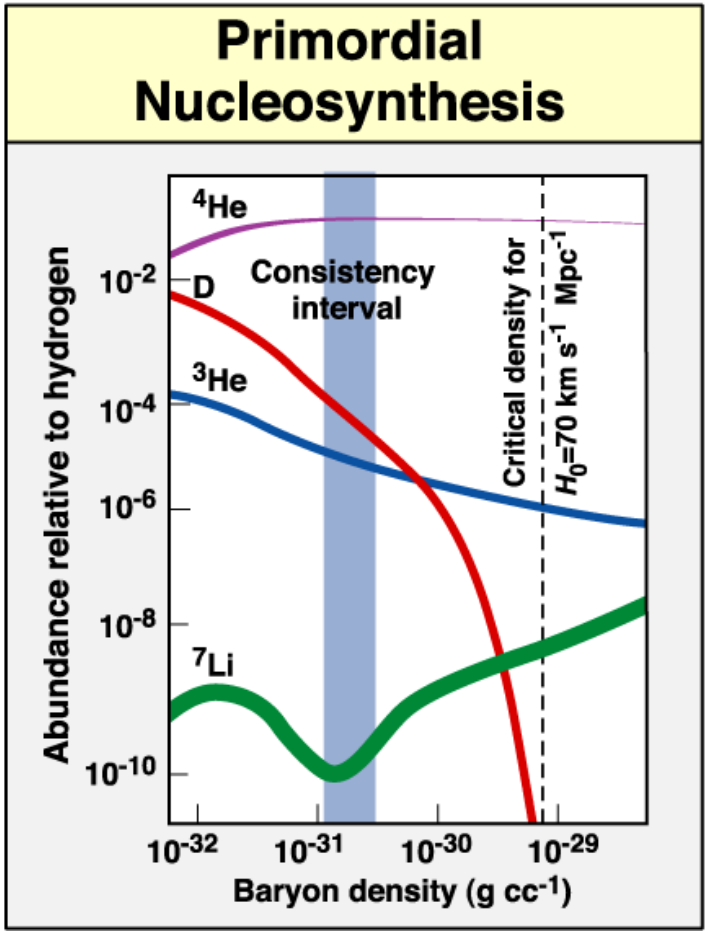
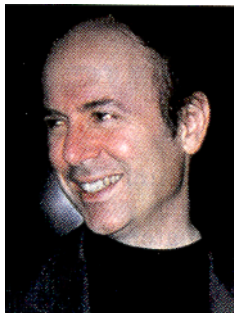
It's been long appreciated that the light axion is a good dark-matter candidate

(1) From light element abundance:
Dark matter probably isn't bowling balls or anything else made of baryons.



(2) Is dark matter made of, e.g., light neutrinos?
Probably not: fast moving neutrinos would have washed-out structure.
Dark matter is substantially "cold".

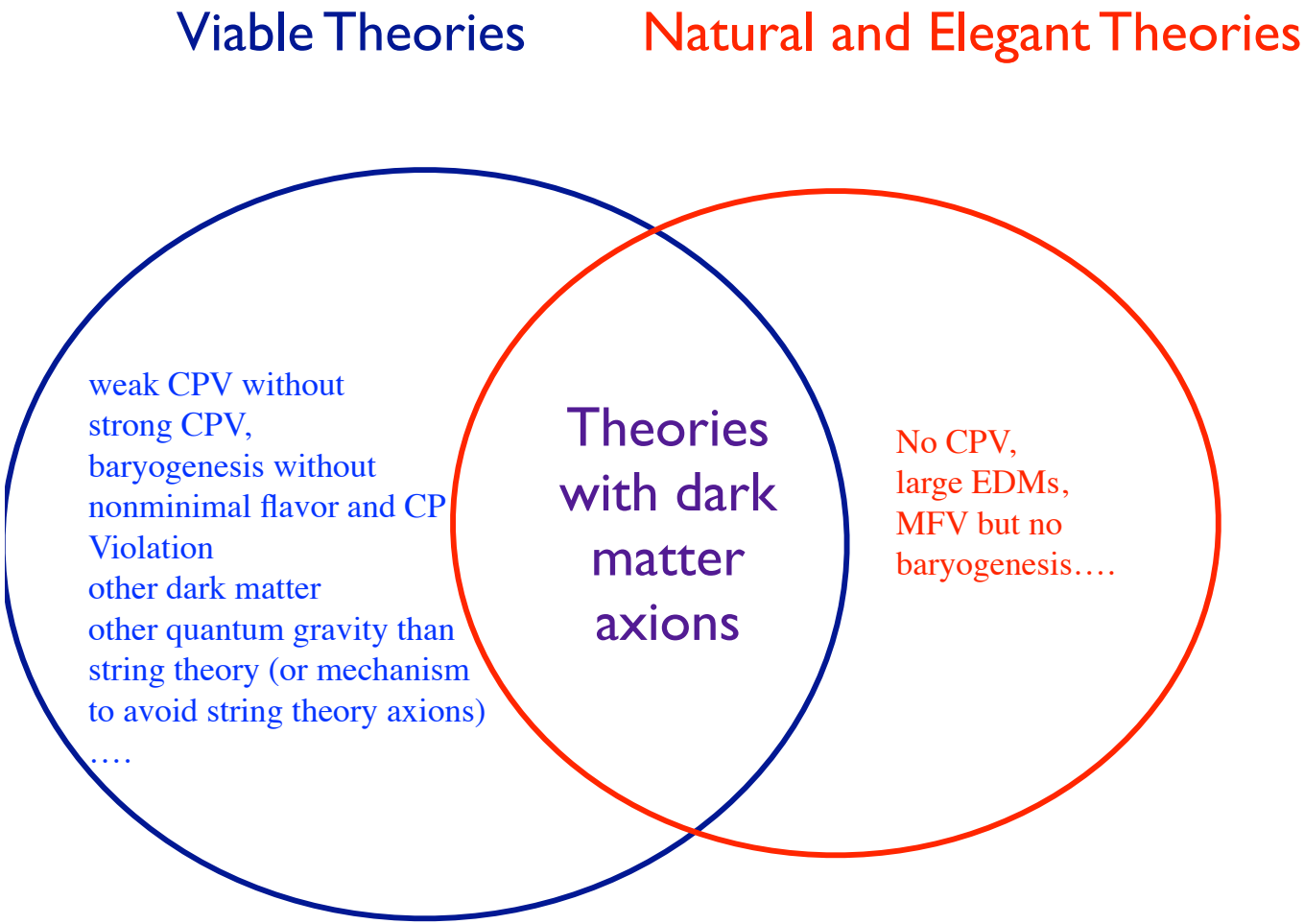


(3) "Dark matter: I'm much more optimistic about the dark matter problem. Here we have the unusual situation that two good ideas exist…"

Frank Wilczek in Physics Today

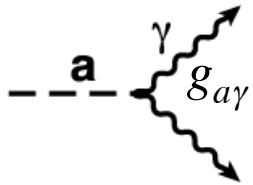
Frank's referring to WIMPS and Axions

From A. Nelson



Pierre Sikivie's RF-cavity idea (1983): Axion and electromagnetic fields exchange energy

The axion-photon coupling…



…is a source term in Maxwell's Equations

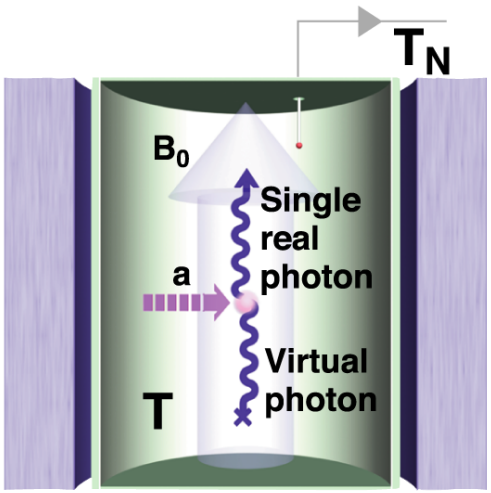
$$\frac{\partial\left(\mathbf{E}^2/2\right)}{\partial t} - \mathbf{E}\cdot\left(\nabla\times\mathbf{B}\right) = g_{a\gamma}\dot{a}\left(\mathbf{E}\cdot\mathbf{B}\right)$$

So imposing a strong external magnetic field B transfers axion field energy into cavity electromagnetic energy.

(Inverse Primakov conversion of axion to photon.)

Some experimental details of the RF-cavity technique

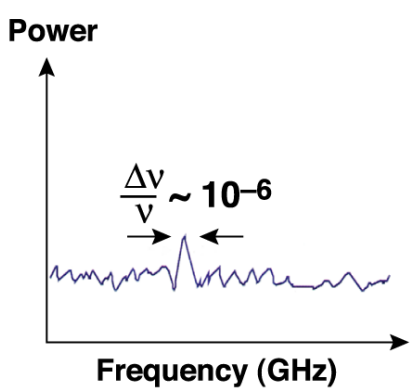
Primakoff Conversion



- **The conversion is resonant, i.e. the frequency must equal the mass + K. E.**
- **The total system noise temperature $T_S = T + T_N$ is the critical factor**

The search speed is quadratic in 1/Ts

Signal



Scaling Laws

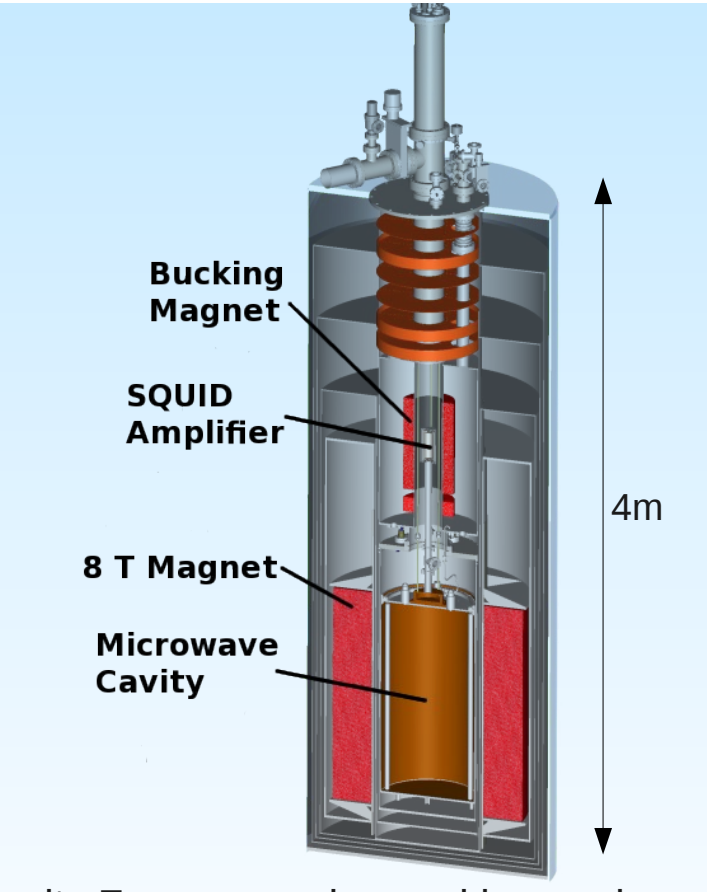
$\frac{d\nu}{dt} \propto B^4 V^2 \cdot \frac{1}{T_S^2}$	$g_\gamma^2 \propto \left(B^2 V \cdot \frac{1}{T_S}\right)^{-1}$
For fixed model g^2	For fixed scan rate $\frac{d\nu}{dt}$

RF-cavity experiments obey the radiometer equation

ADMX: Axion Dark-Matter eXperiment

U. Washington, LLNL, U. Florida, U.C. Berkeley, National Radio Astronomy Observatory, Sheffield U., Yale U., U. of Colorado

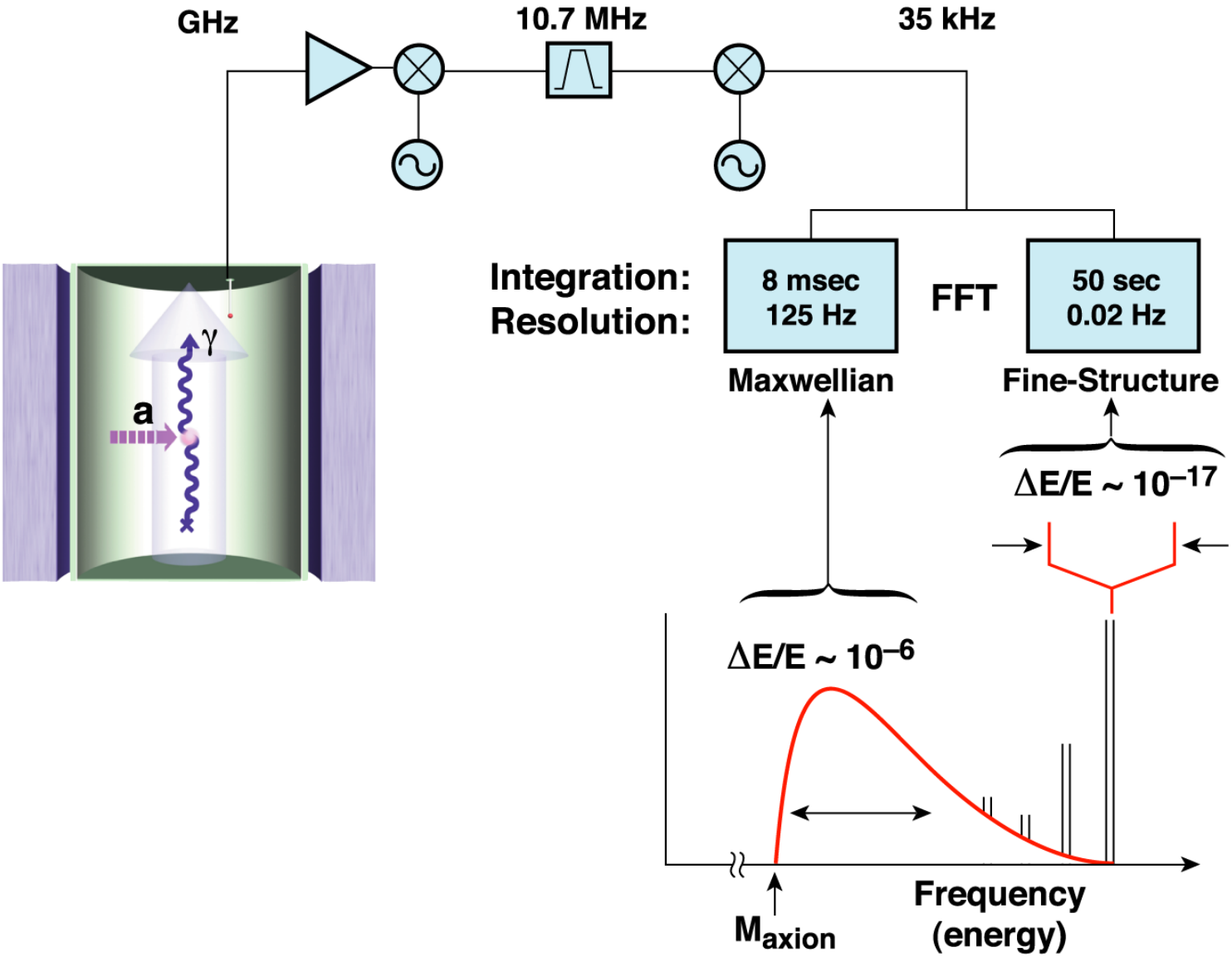
Magnet with insert



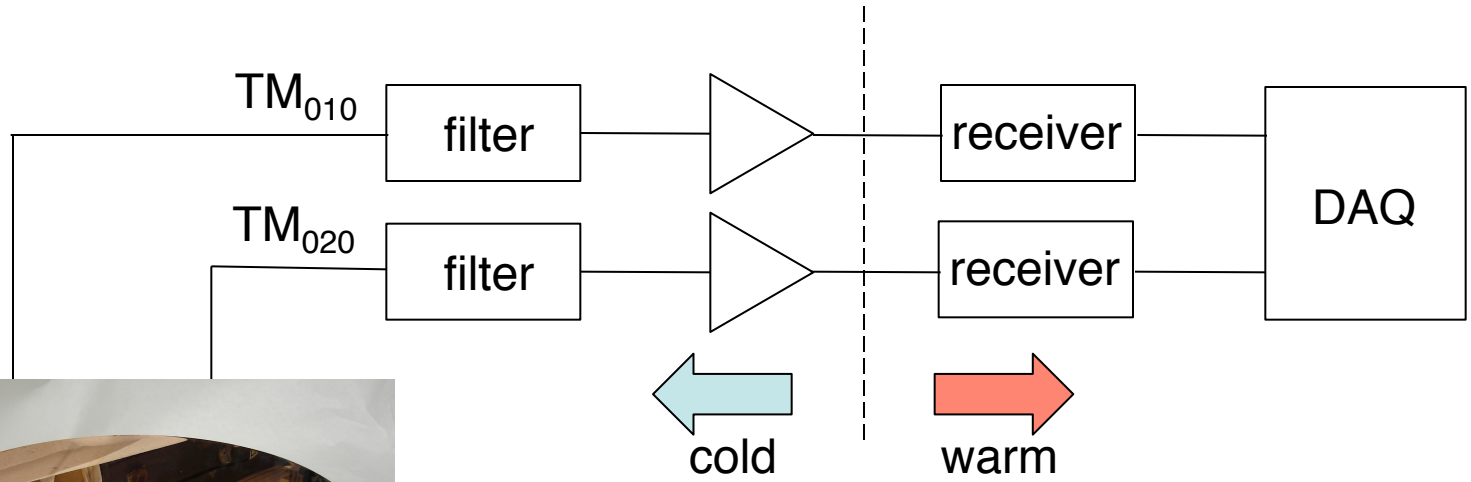
Magnet cryostat

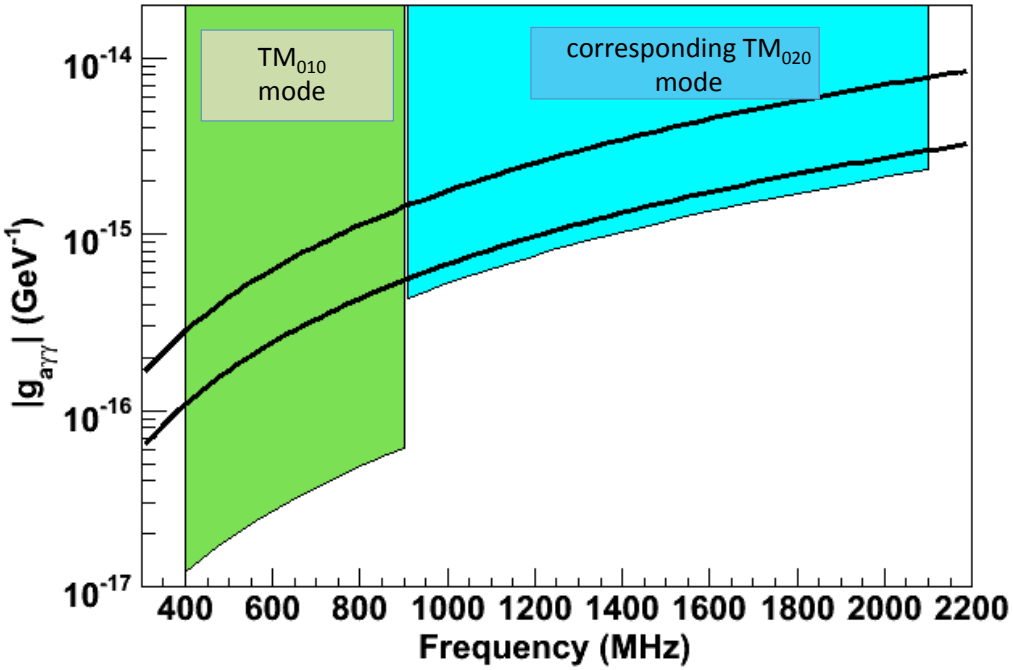
Mostly DOE-HEP supported

ADMX hardware: receiver

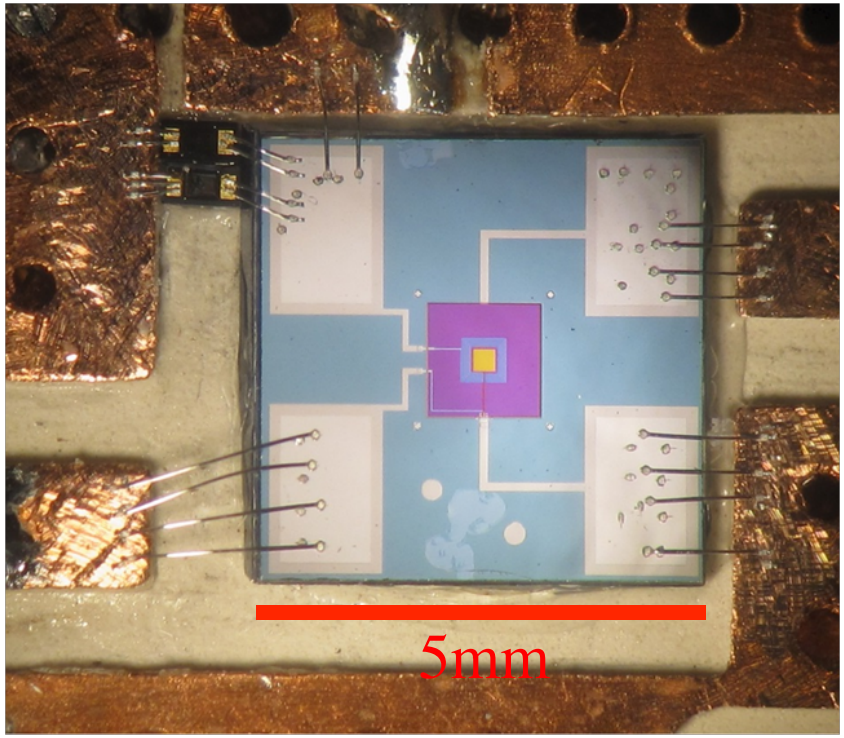


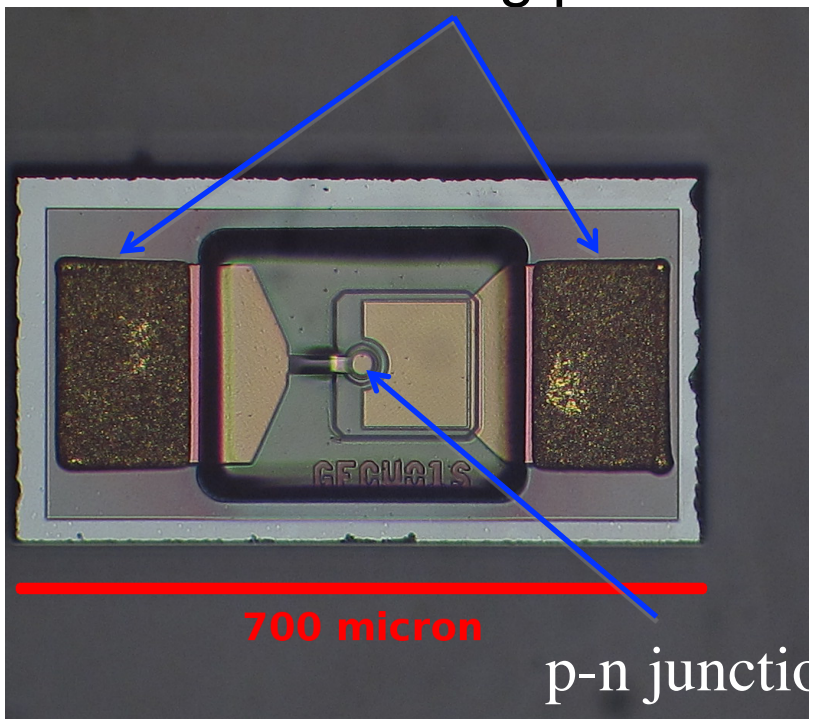
ADMX hardware: multi-mode readout





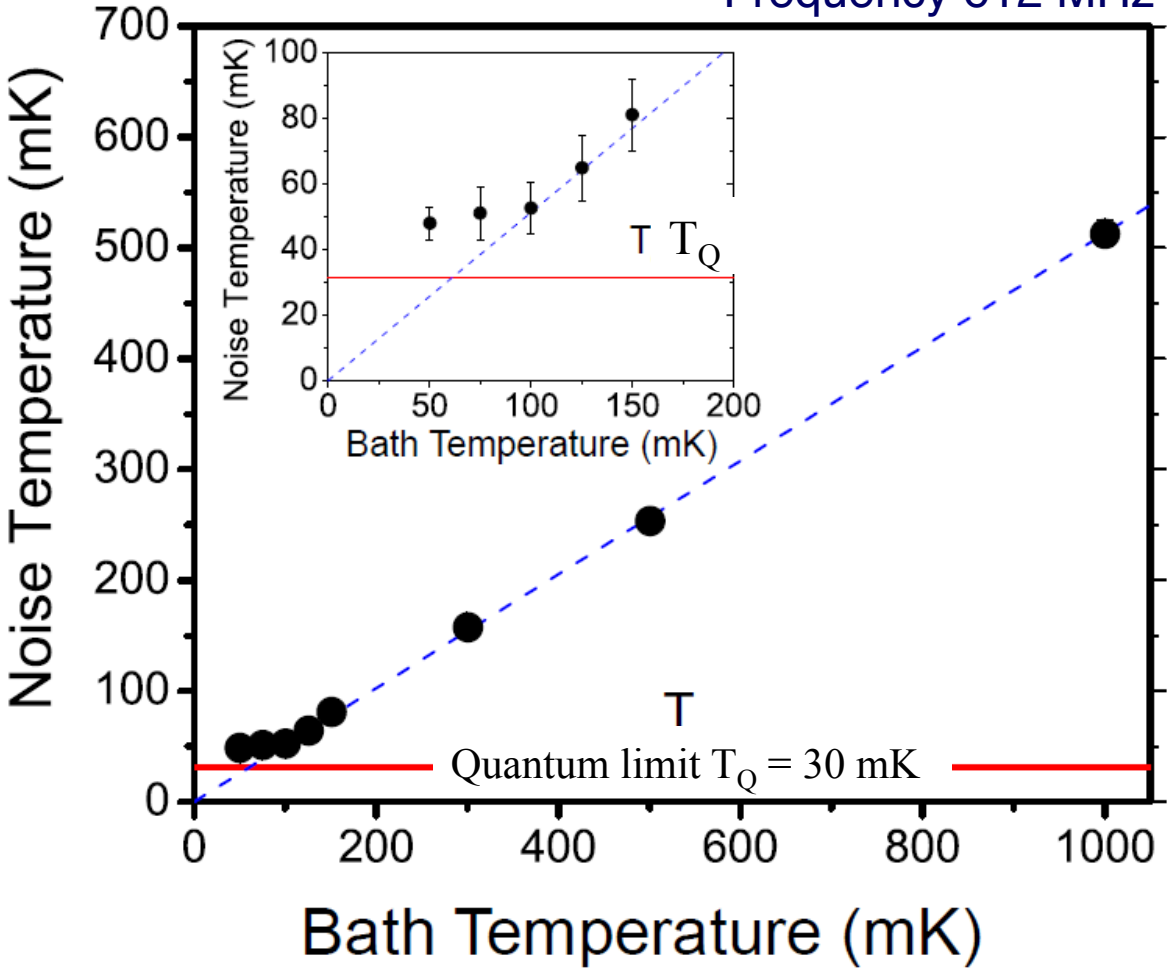
ADMX hardware:
microstrip SQUID amplifiers with varactor tuning





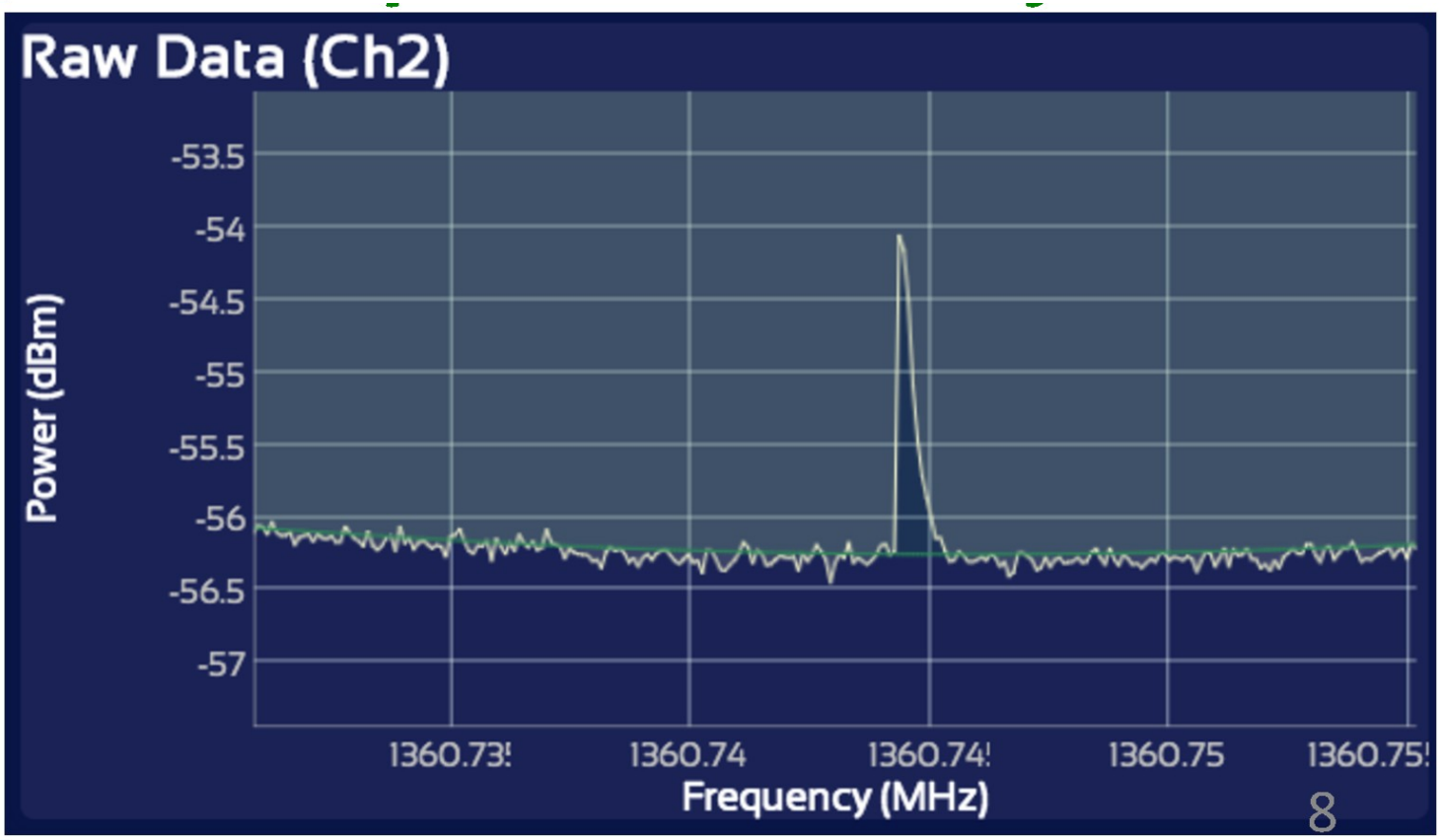
SQUID amplifiers yield quantum-limited noise

Gain = 20 dB
Frequency 612 MHz



Gives speed-up of ×10,000

Raw data plus hardware synthetic axion (×100)



Our confidence limit is our confidence limit

Building the new ADMX infrastructure

July 2011

September 2011

June 2012

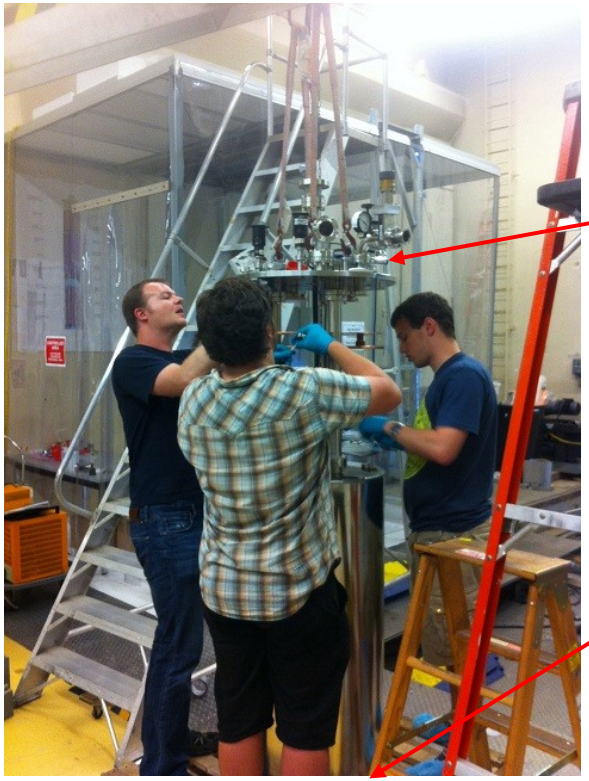
September 2012

April 2013

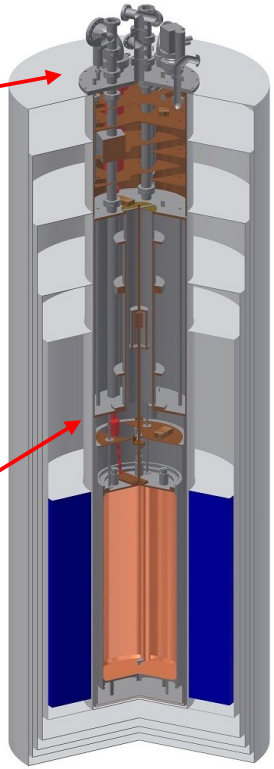
April 2014

Assembling the experiment insert

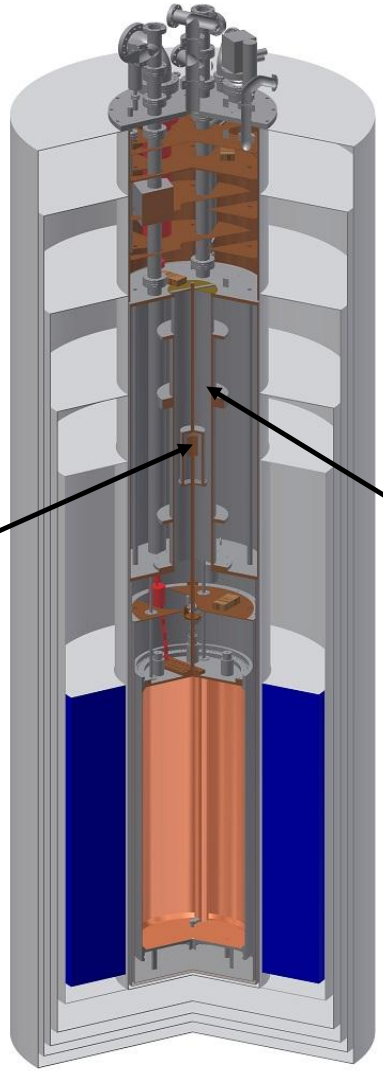
Installation of bucking coil



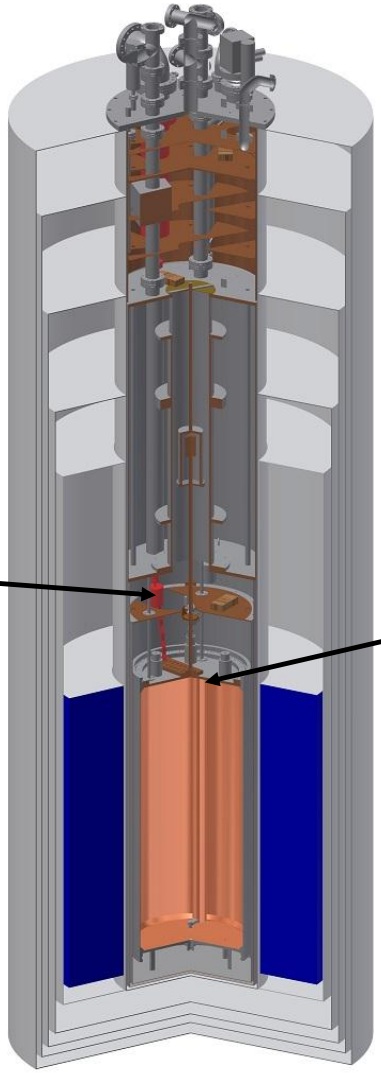
Assembly of top half of insert



Quantum-electronics in a bucking coil

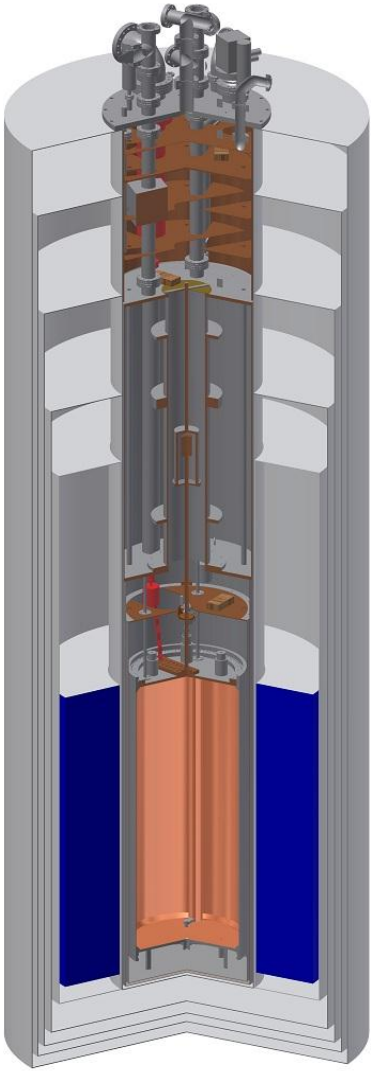


Cavity, tuning and coupling

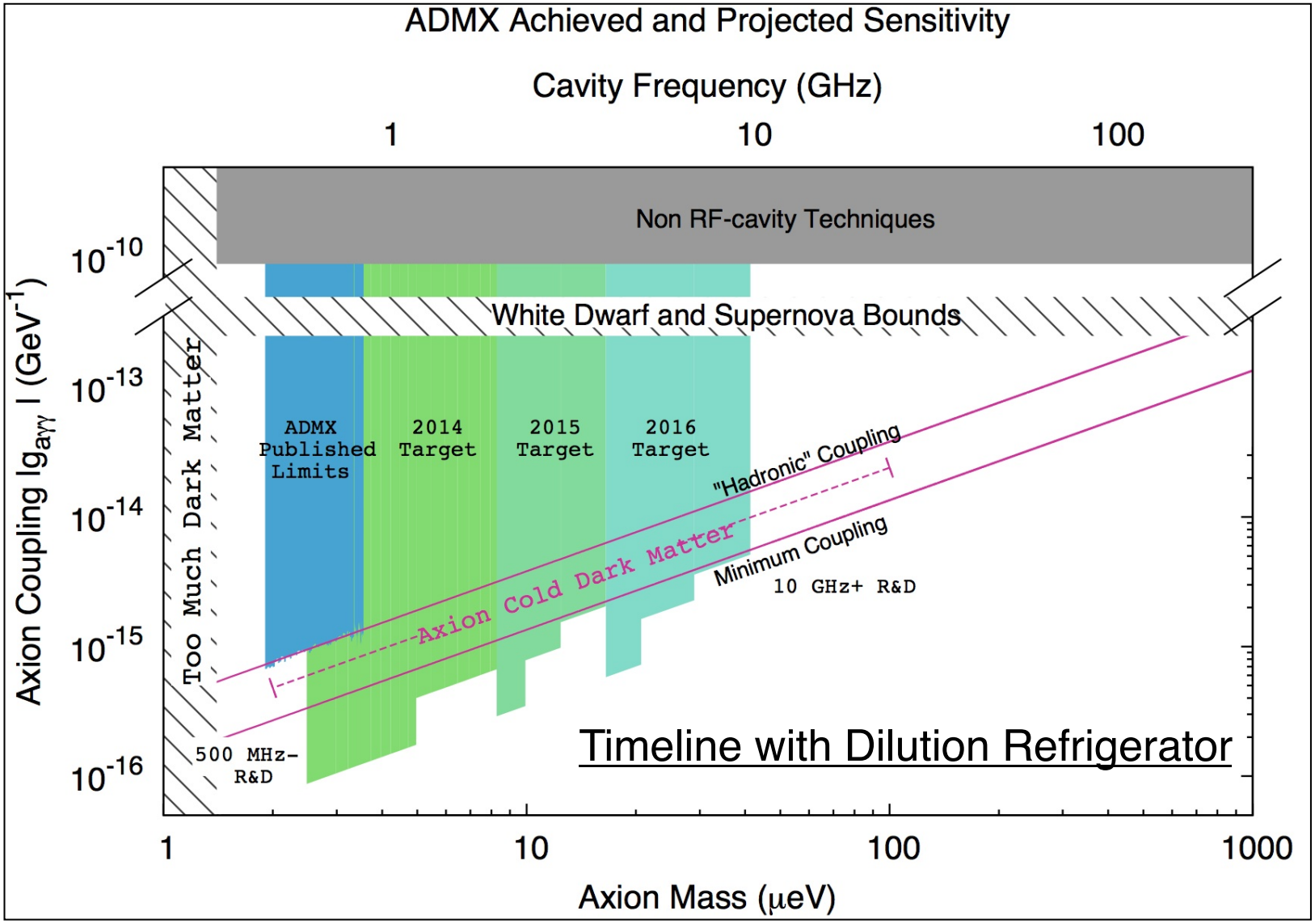


ADMX insert going into and out the magnet bore

Science, Nov. 2013, 552 - 555



ADMX Gen 2: Science Prospects



ADMX challenges and needs

Year 1 (to few GHz): In progress.
Year 2 (few GHz to 5 GHz GHz):
- Amplifiers & receivers get easier (JPA's)
- Need suitable RF structures (cavities)

Year 3 (5 GHz to 10's of GHz):
- Amplifiers & receivers under control (JPA's)
- Need suitable RF structures (cavities)

Each year, ADMX executes 3 parallel phases:
- Operations (year 1)
- Finish design & cut steel (for year 2)
- R&D (for year 3).

ADMX personnel are strained to execute these parallel phases

Gen 3: Over 10's of GHz:
- At some point, likely transition to bolometric receivers of some kind
- Need radically new RF structures.

Who's working on dark-matter QCD axion searches (broadly considered)?

ADMX (started data-taking January 2014)

ADMX-Ouroboros (R&D confocal resonator, high frequency)

ADMX-HF (high frequency, small-bore high-field magnet)

KAIST/Korea (Formulating their research program)

DESY/Germany & UFlorida (R&D lumped LR resonators,
below 1 μeV-mass anthropic axion)

CERN (R&D confocal resonators, below 1 μeV-mass anthropic axion)

Stanford & Maintz (R&D on NMR EDM, below 1 μeV-mass anthropic axion)