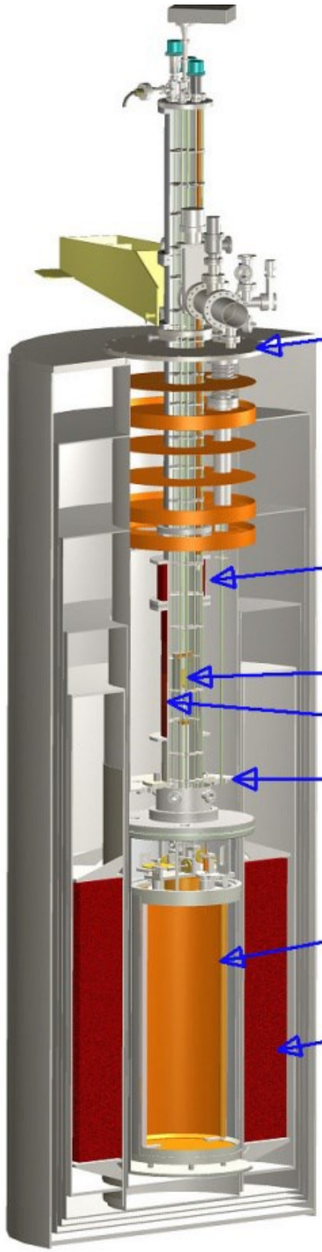
ADMX enters its second generation

David B. Tanner
(presented by Pierre Sikivie)

University of Florida

for the ADMX collaboration*



*Supported by DOE Grants DE-FG02-97ER41029, DE-FG02-96ER40956, DE-AC52-07NA27344, DE-AC03-76SF00098, NSF Grant PHY-1067242, and the Livermore LDRD program

Outline

- Review of ADMX past and present
- Gen 2: dil fridge and higher order modes
- Dil Fridge ITN
- Beyond gen 2

ADMX collaboration (at least a good portion of us)

The axion

- Peccei-Quinn mechanism for strong CP problem -> a
- Decays by two-photon emission $a \rightarrow \gamma\gamma$ (but $\tau > \tau_{universe}$)
- Light axions very weakly coupled: $g_{a\gamma\gamma} \sim m_a$
- Mass limits: $10^{-6} < m_a < 10^{-(2-3)}$ eV

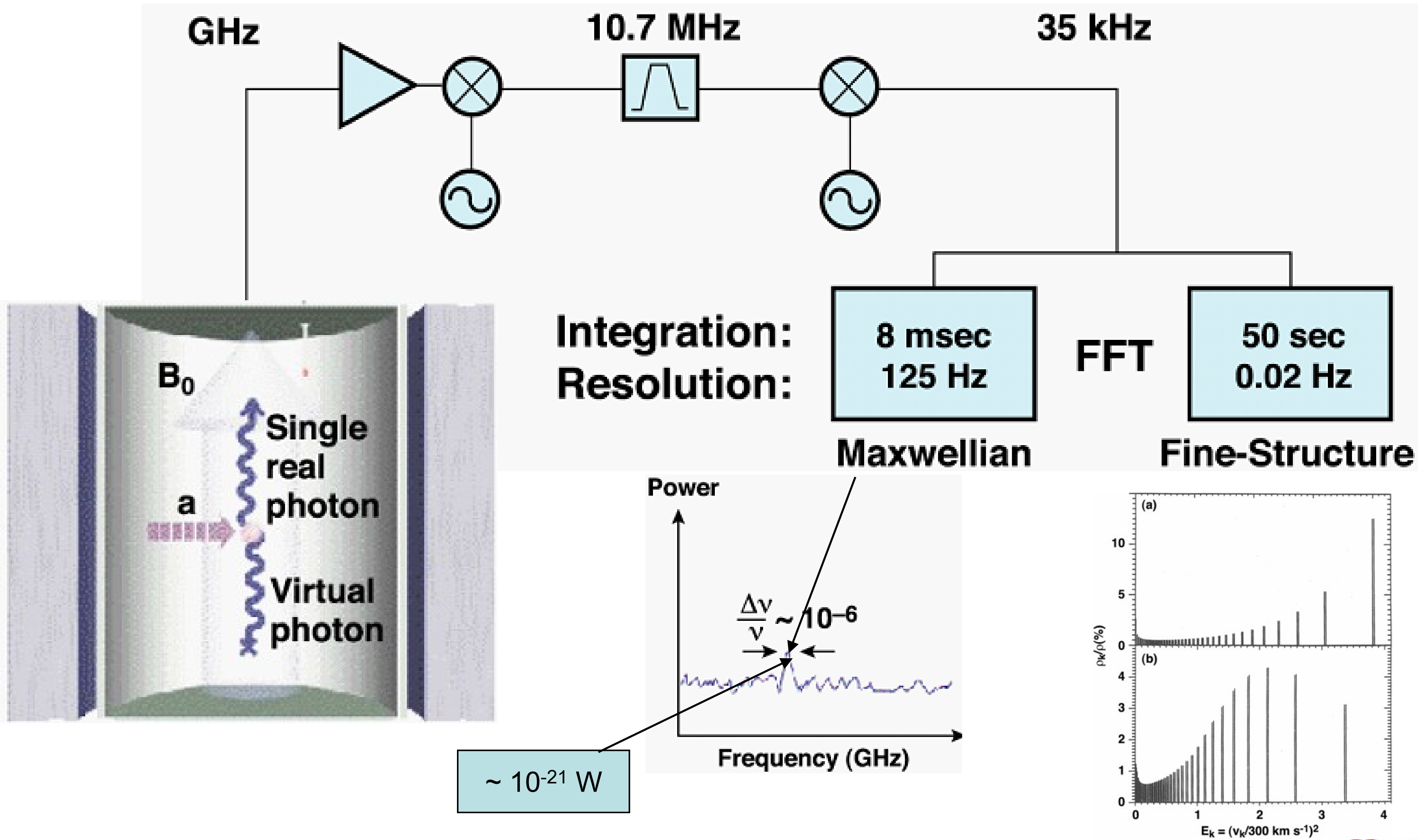
  (overclosure) *(SN1987a)*

- Galactic halos may consist of axions
- At the Earth, ρ_{halo} = 0.45 geV/cm^3 ~ 72 μJ/m^3

  ~10^{14} axions/cm^3

- Recent ideas (Bose condensation, caustics) make the case for axions even stronger

Cavity axion detector (Sikivie, 1983)



ADMX

The signals are very weak

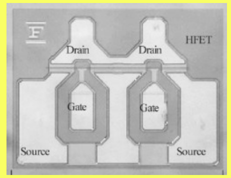
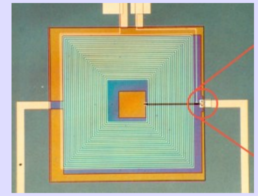
- Power from the cavity is

$$P = 2.3 \cdot 10^{-26}\mathrm{Watt}\left(\frac{V}{200\ell}\right)\left(\frac{B_0}{8\mathrm{Tesla}}\right)^2 C_{nl}\left(\frac{g_\gamma}{0.97}\right)^2 \cdot \left(\frac{\rho_\mathrm{a}}{0.5\cdot 10^{24}\mathrm{g/cm}^3}\right)\left(\frac{m_\mathrm{a}}{2\pi\mathrm{GHz}}\right)\min(Q_\mathrm{L}, Q_\mathrm{a})$$

- Q_L ~ 70000 (GHz/f)$^{2/3}$ (ASE) and Q_a ~10^6

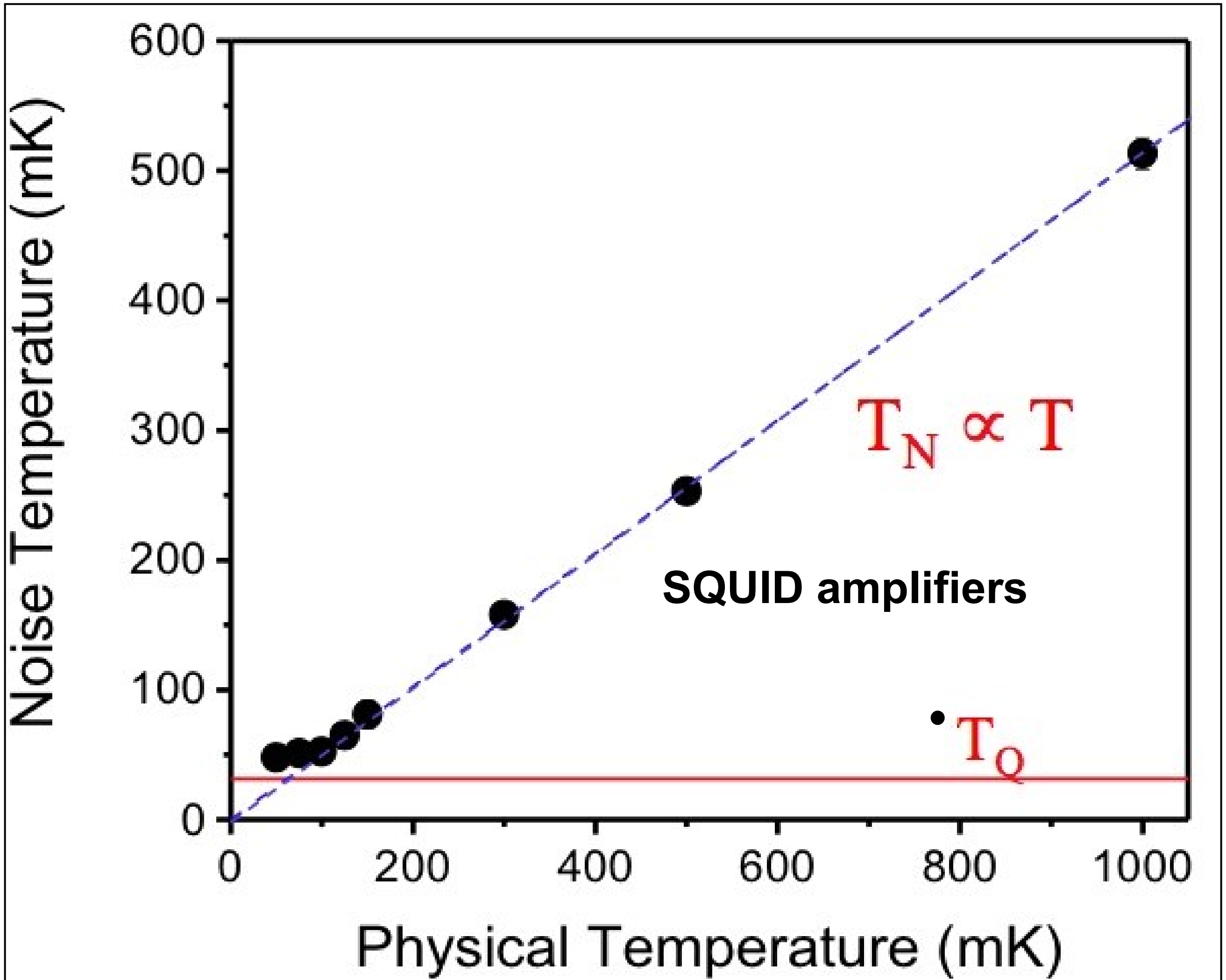
- g_γ ~ 0.97 (KSVZ)
- g_γ ~ 0.36 (DFSZ)

The Axion Dark Matter eXperiment (ADMX)

Stage	**Phase 0**	**Phase I**	**Phase II**
Technology	HEMT; Pumped LHe 	Replace w. SQUID 	Add Dilution Fridge 
T_{phys}	2 K	2 K	100 mK
T_N	2 K	1 K	100 mK
$T_{sys} = T_{phys} + T_N$	4 K	3 K	200 mK
Scan Rate $\propto (T_{sys})^{-2}$	1 @ KSVZ	1.75 @ KSVZ	5 @ DFSZ
		OR	*AND !*
Sensitivity Reach $g^2 \propto T_{sys}$	KSVZ	0.75 x KSVZ	DFSZ

ADMX

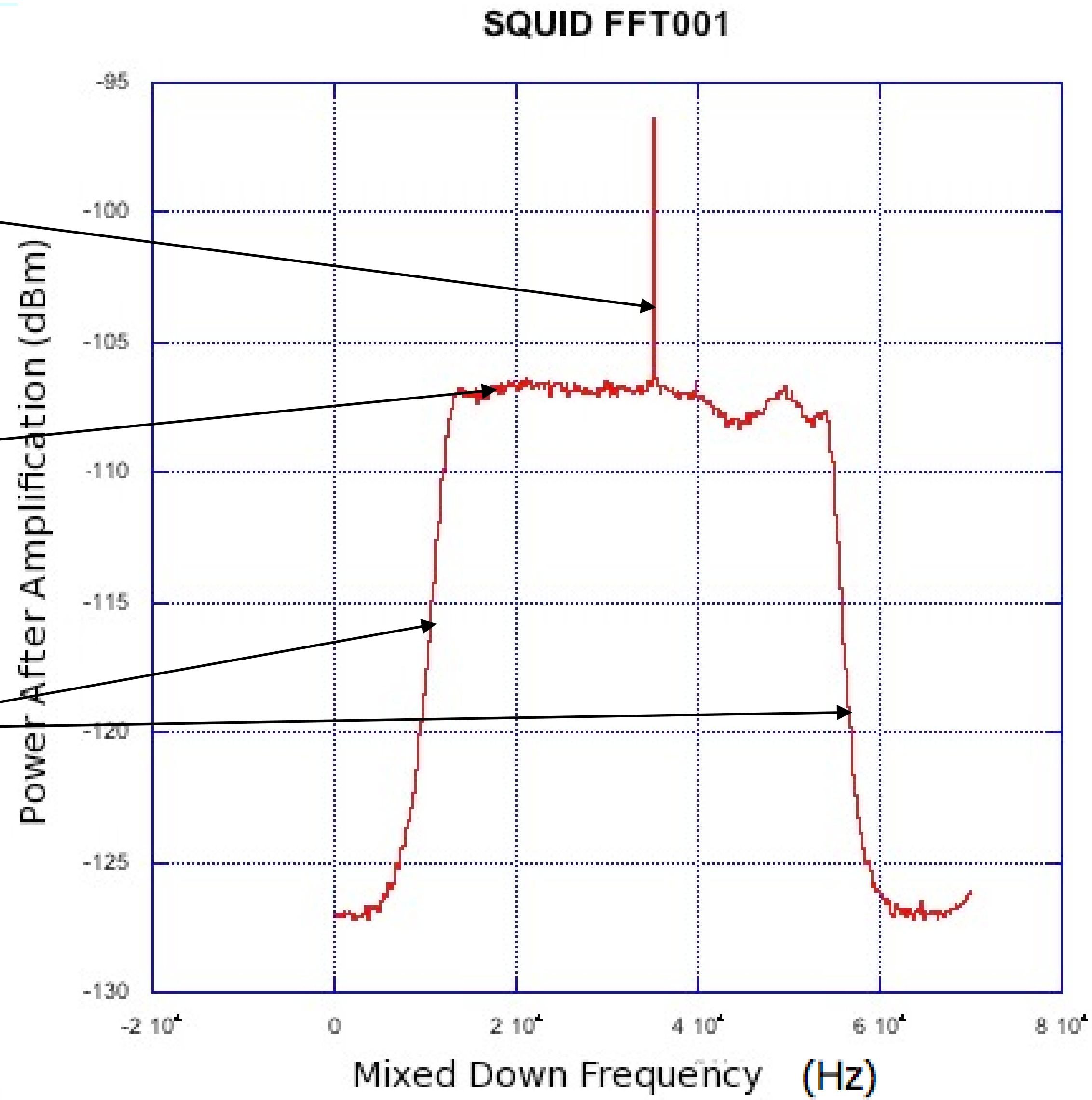
Quantum-limited SQUID-based amplification



- SQUIDs have been measured with $T_N \sim 50$ mK
- Compared to ~ 2 K for HFET amplifiers
- Near quantum– limited noise
- Provides an enormous increase in ADMX sensitivity

Example of injected signal into SQUID amplifier

- Injected Power
- Noise floor
- IF crystal filter



Phase I operations: Science data

PRL **104,** 041301 (2010) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2010

SQUID-Based Microwave Cavity Search for Dark-Matter Axions

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(Received 27 October 2009; published 28 January 2010)

PRL **105,** 051801 (2010) PHYSICAL REVIEW LETTERS week ending 30 JULY 2010

Search for Chameleon Scalar Fields with the Axion Dark Matter Experiment

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PRL **105,** 171801 (2010) PHYSICAL REVIEW LETTERS week ending 22 OCTOBER 2010

Search for Hidden Sector Photons with the ADMX Detector

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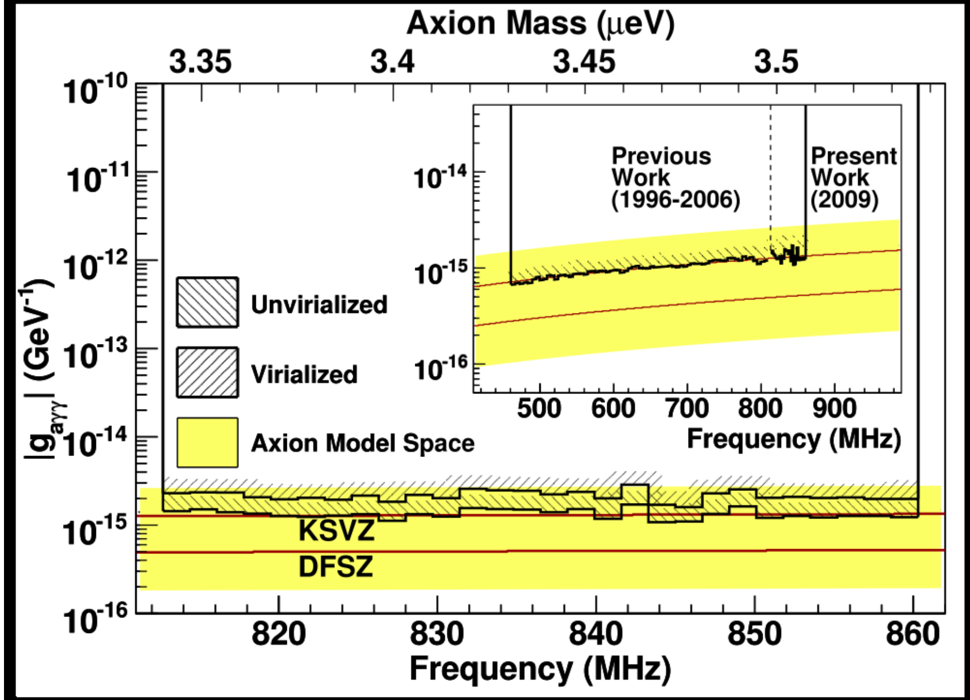
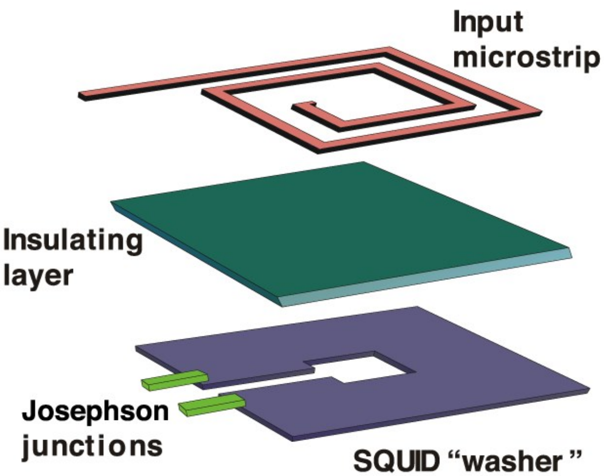


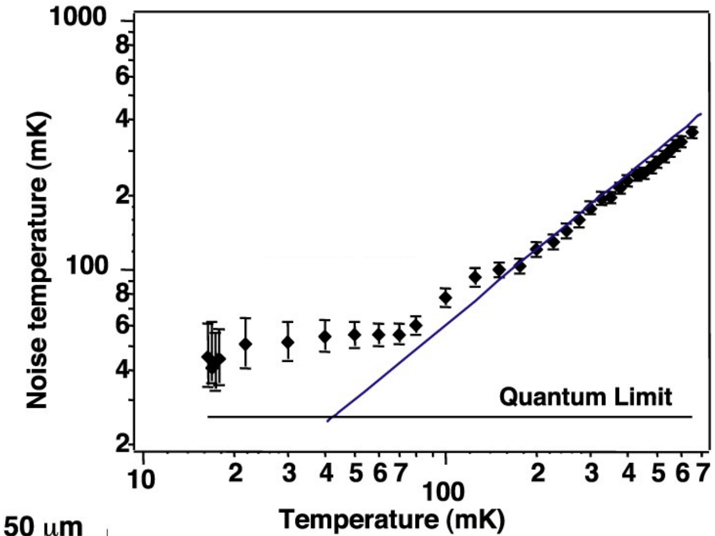
ADMX

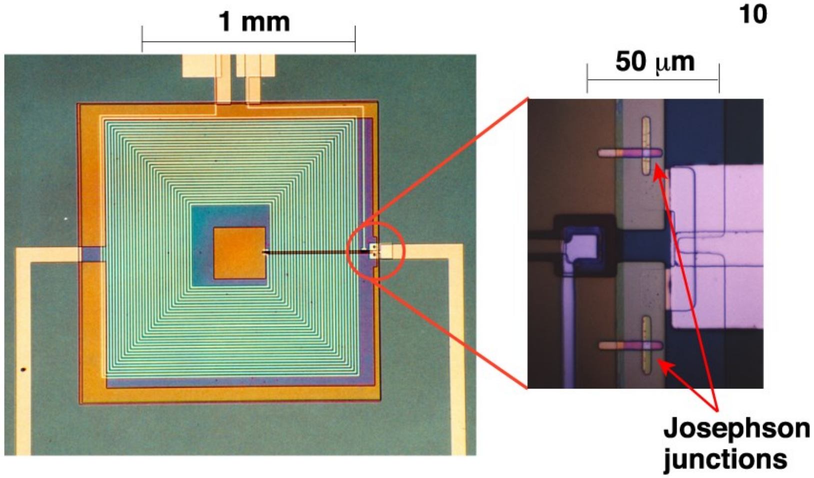
ADMX was moved to the University of Washington

Summer 2010.
Magnet has been cooled and energized.

To exploit SQUID amplifiers: Cool to low temperatures



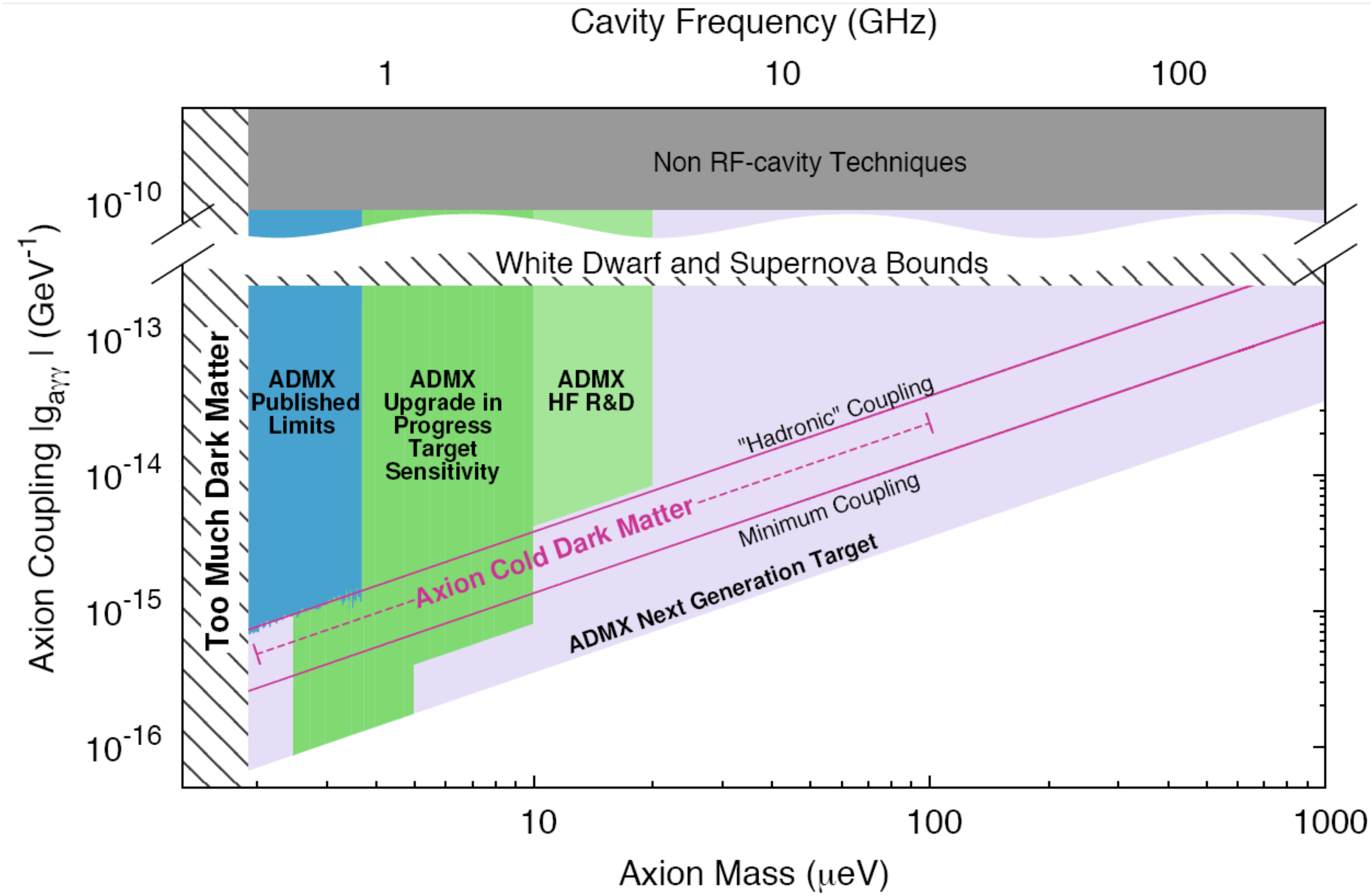




(J. Clarke *et al.*, U.C. Berkeley)

- At least to 100 mK
- Must reduce cavity physical temperature to below 100 mK also.

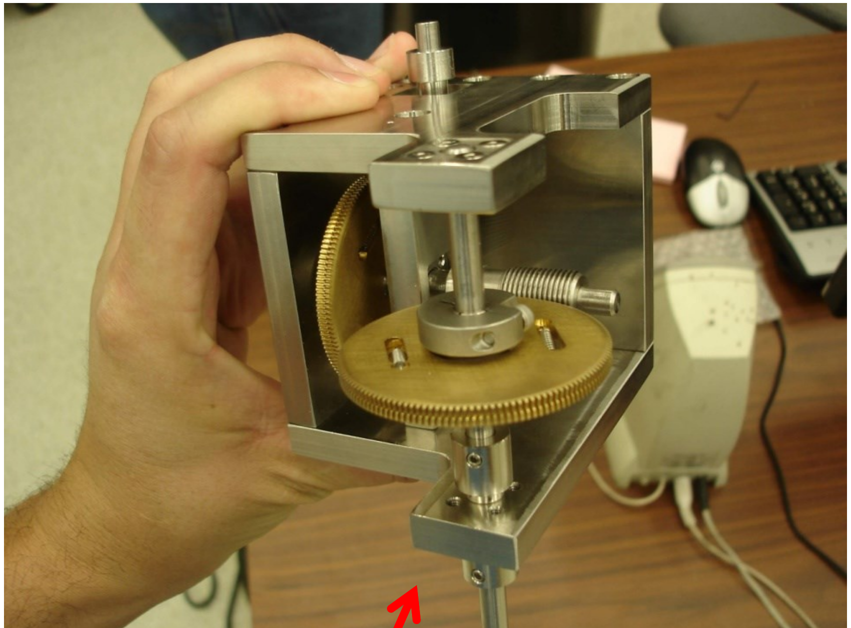
Gen 2 ADMX: Coverage of ~2.5-10 μeV (0.4-2.1 GHz)

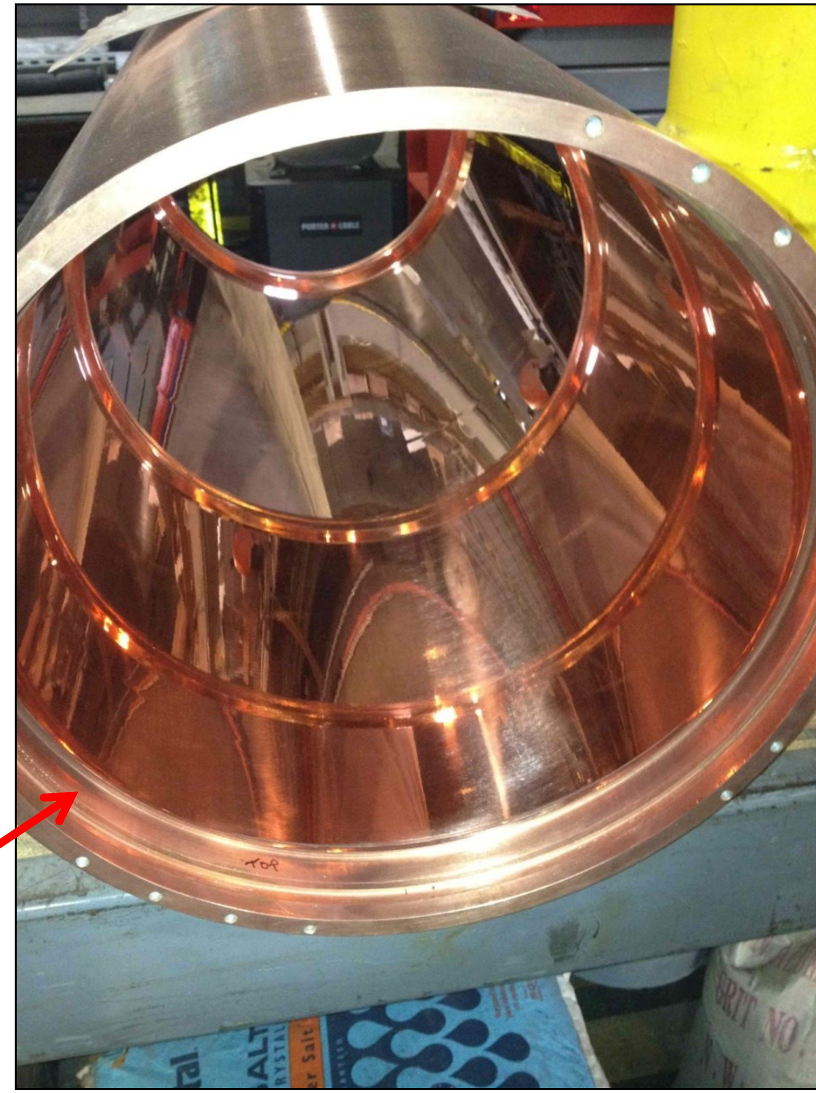


Will scan the lower-mass decade at or below DFSZ sensitivity

ADMX

ADMX Phase II construction well underway!





New modular gear systems
(19600:1 reduction)

Newly plated microwave cavity

ADMX

Typical dilution refrigerator "cold stage"

- Base temperature: < 20 mK
- Cooling power at 50 mK: 700 μW
- Dimensions: 5.625" diam, 14.3" long
- Thermometers: 3x
- Heaters: 2x
- Wiring: to micro-d connector

Invitation to Negotiate issued June 14

- June 14: issued
- June 28: inquiries due
- July 8: responses circulated
- July 26: 3 pm proposals opened
- Aug 13: UF selects vendor; negotiations begin
- Aug 28: 72 hour posting period ends

UF UNIVERSITY of FLORIDA

PURCHASING SERVICES

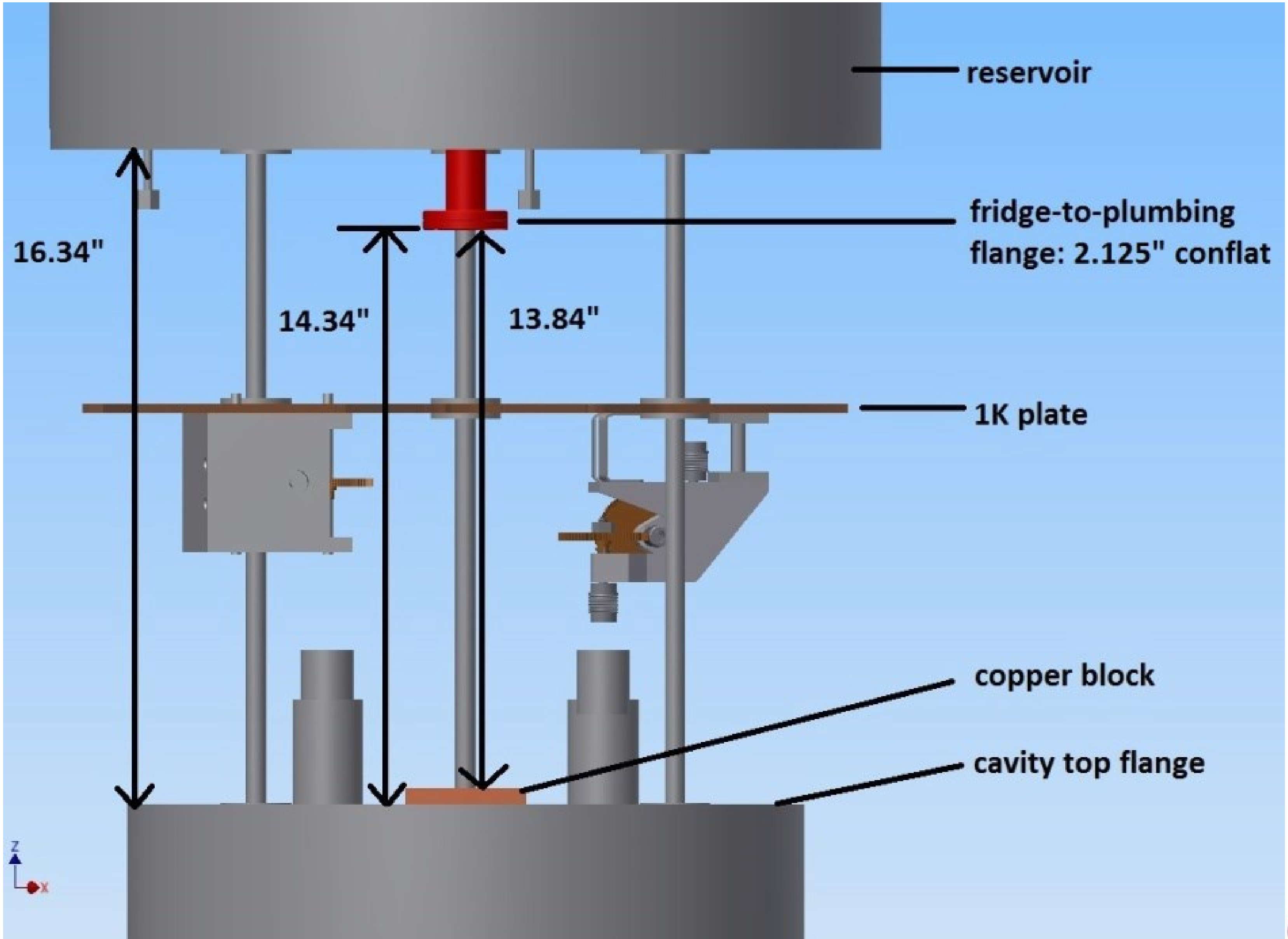
Invitation to Negotiate for

Dilution Refrigerator

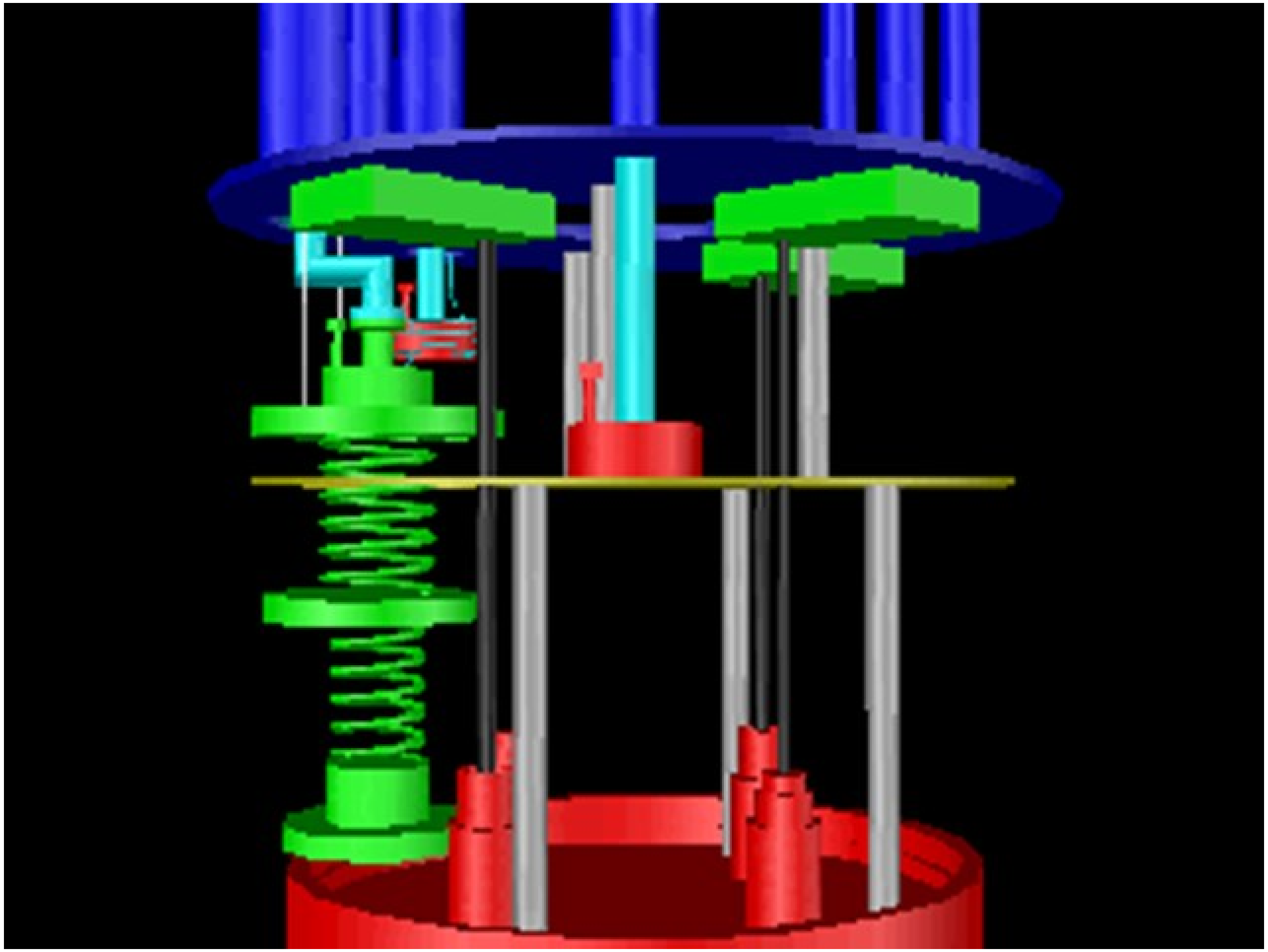
Please mark all proposal submission envelopes with the following information:

ITN14NH102 – Dilution Refrigerator
Opening July/26/2013

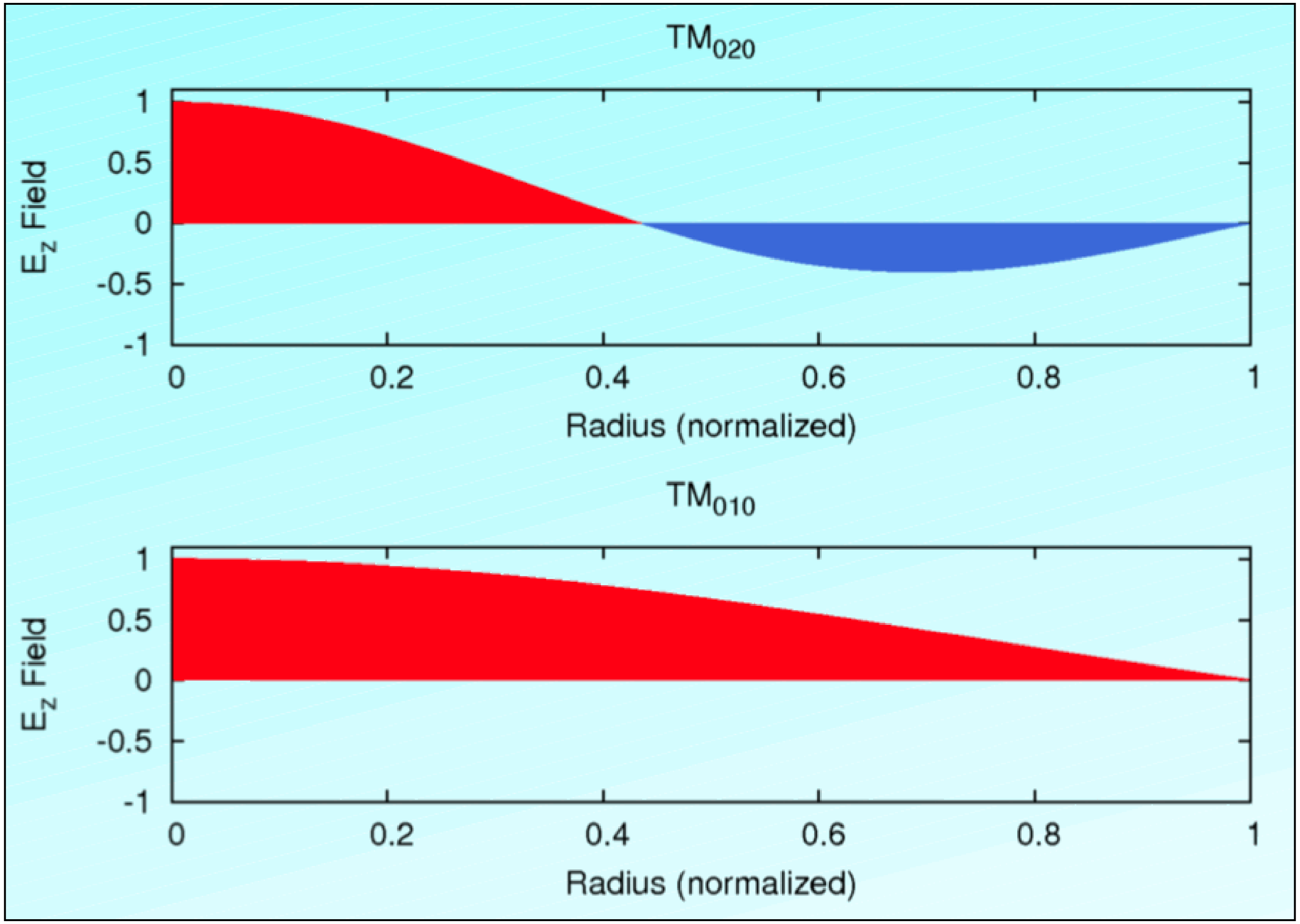
Space for dilution refrigerator, right above cavity



Preliminary design of dil fridge placement



ADMX Phase II: Instrument the TM_{010} & TM_{020} modes



TM_{020} Mode
Relative Frequency
2.3

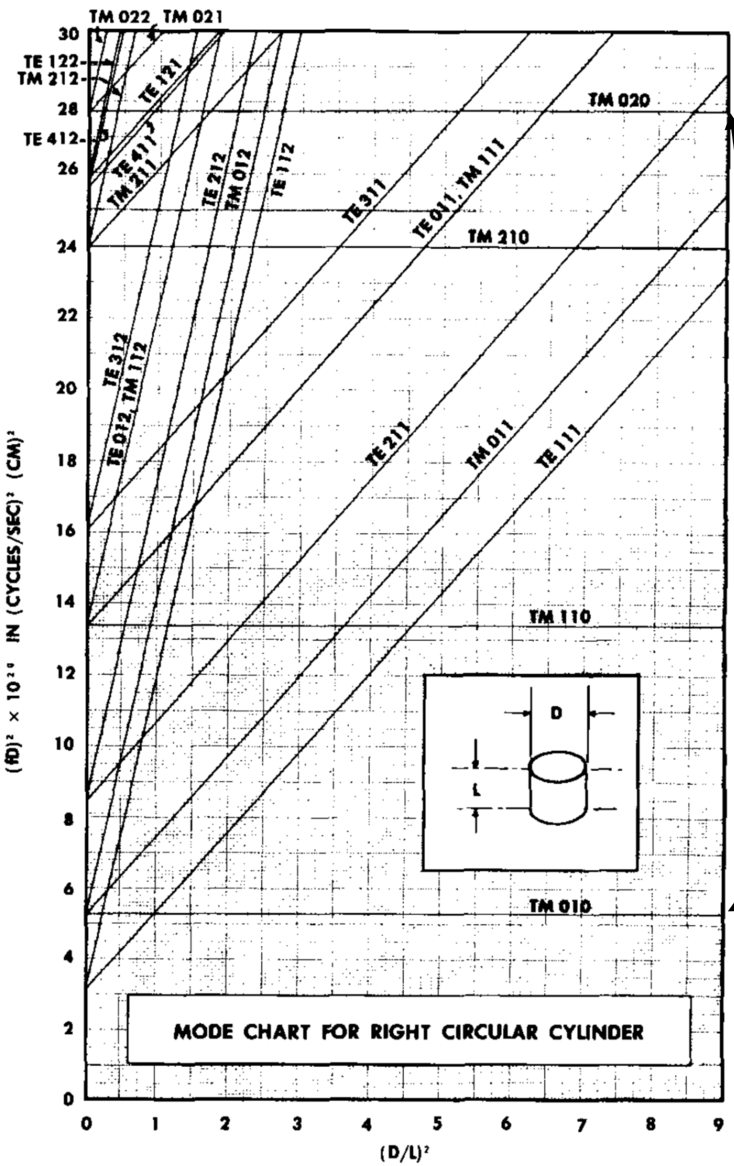
Tuning Range
920-2,100 MHz

Relative Power
0.41

TM_{010} Mode
Relative Frequency
1.0

Tuning Range
400-900 MHz

Why TM_{020}?



The TM_{010} and TM_{020} modes tune together: data from both modes are taken in parallel.

The TM_{020} mode has acceptable "form factor."

Complementary frequency coverage.

For open cylinder

mode	Relative frequency	Tuning range (MHz)	relative power
TM_{010}	1	400-900	1
TM_{020}	2.3	920-2,100	0.41

ADMX

Beyond Generation 2

- Improved magnet
  - $P \sim B^2 V$
  - V is easier than B
  - Increase V and mass range that is easy to scan moves to lower mass
  - Increase B and one can have DFSZ sensitivity at higher frequencies and smaller V

- Complex cavity structures
  - Multiple cavities in parallel
  - Periodic arrays of posts/vanes

Solenoids Present & Future (Mark Bird, MagLab)

CICC = Cable-In-Conduit Conductor. SRC = Stab ilized Rutherford-Cable, Mono = Monolithic Conductor
Pers = persistent. Ti = NbTi, Sn = Nb_3Sn HTS = High temperature superconductor

B_0^2V (T^2m^3)	Magnet	Application/ Technology	Location	Field (T)	Bore (m)	Len (m)	Energy (MJ)	Cost ($M)
12000	*ITER CS*	*Fusion/Sn CICC*	*Cadarache*	*13*	*2.6*	*13*	*6400*	*>500*
5300	CMS	Detector/Ti SRC	CERN	3.8	6	13	2660	>458[1]
650	Tore Supra	Fusion/Ti Mono Ventilated	Cadarache	9	1.8	3	600	
500	*20 T, 1m*	*Axion/HTS CIC*	*?*	*20*	*1*	*2*	*>600*	
430	*Iseult*	*MRI/Ti SRC*	*CEA*	*11.75*	*1*	*4*	*338*	
320	ITER CSMC	Fusion/Sn CICC	JAEA	13	1.1	2	640	>50[2]
290	*60 T out*	*HF/HTS CICC*	*MagLab*	*42*	*0.4*	*1.5*	*1100*	
250	*Magnex*	*MRI/Mono Pers*	*Minnesota*	*10.5*	*0.88*	*3*	*286*	*7.8*
190	Magnex	MRI/Mono Pers	Juelich	9.4	0.9	3	190	
70	45 T out	HF/Sn CICC	MagLab	14	0.7	1	100	14
12	ADMX	Axion/Ti mono/SRC	U Wash	7	0.5	1.1	14	0.4
5	900 mod	NMR/Sn mono	MagLab	21.1	0.11	0.6	40	15

[1]Materials only per BBC/CERN.
[2]US inner module $50M per Minervini

Italics indicates a magnet not yet operational

ADMX

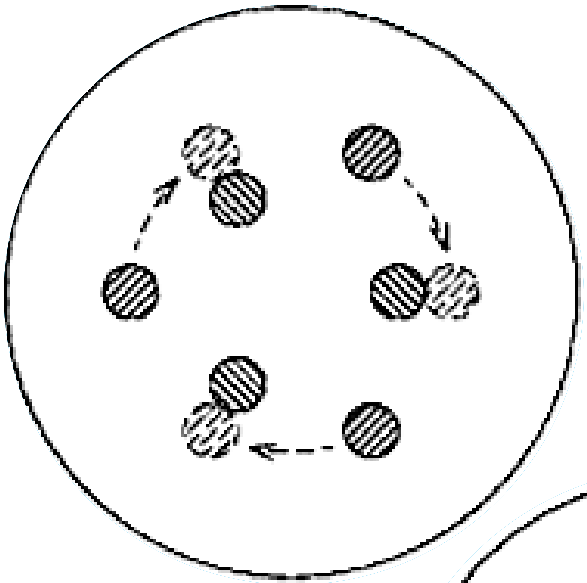
Magnet landscape

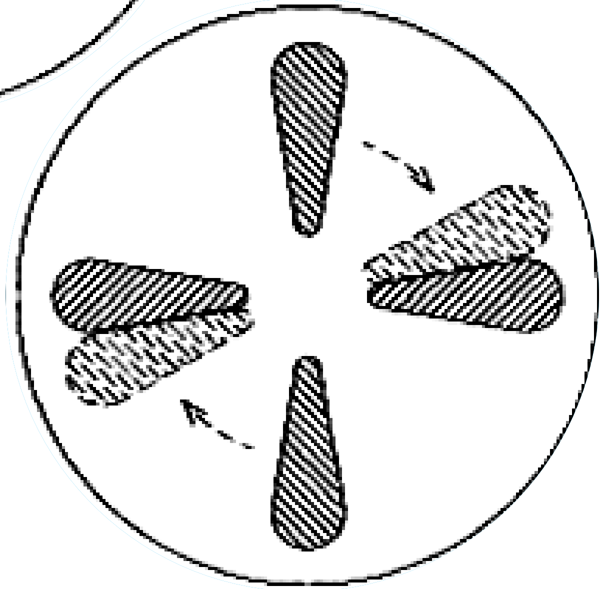
- There are 3 interesting plateaux:

  - 42 T and 0.42 m (HTS, hypothetical): 24x ADMX Gen 2
  - 14 T and 0.7 m (maglab, exists): 5.8x ADMX Gen 2
  - 21 T and 0.11 m (maglab exists): 0.42x ADMX Gen 2
    - *But:* 4.5x higher frequency band, probably worth a factor of 2 in cavity contribution to sensitivity, because SQUID amplifiers have such good noise performance.

Cavity Design Study

- Objective
  - Frequency tuning range
    2 – 3x simple cavity
  - Maximize sensitivity
    ($\propto C^2 Q$)



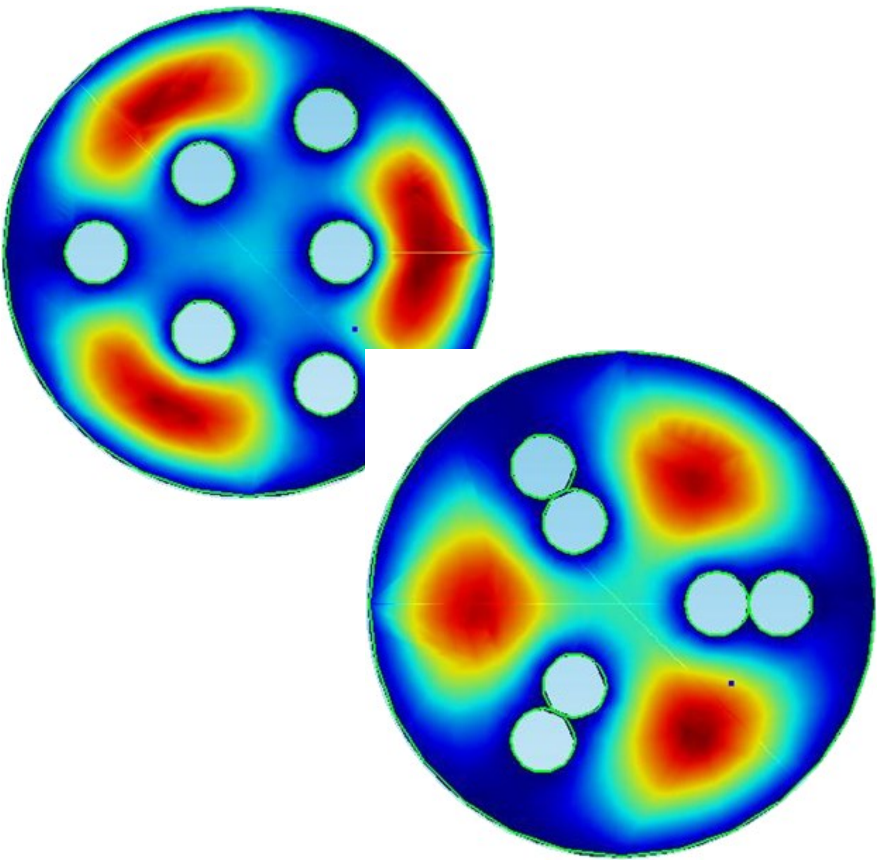


- Designs
  - photonic band-gap &
  - multi-vane designs
  - Evaluated superconducting hybrids

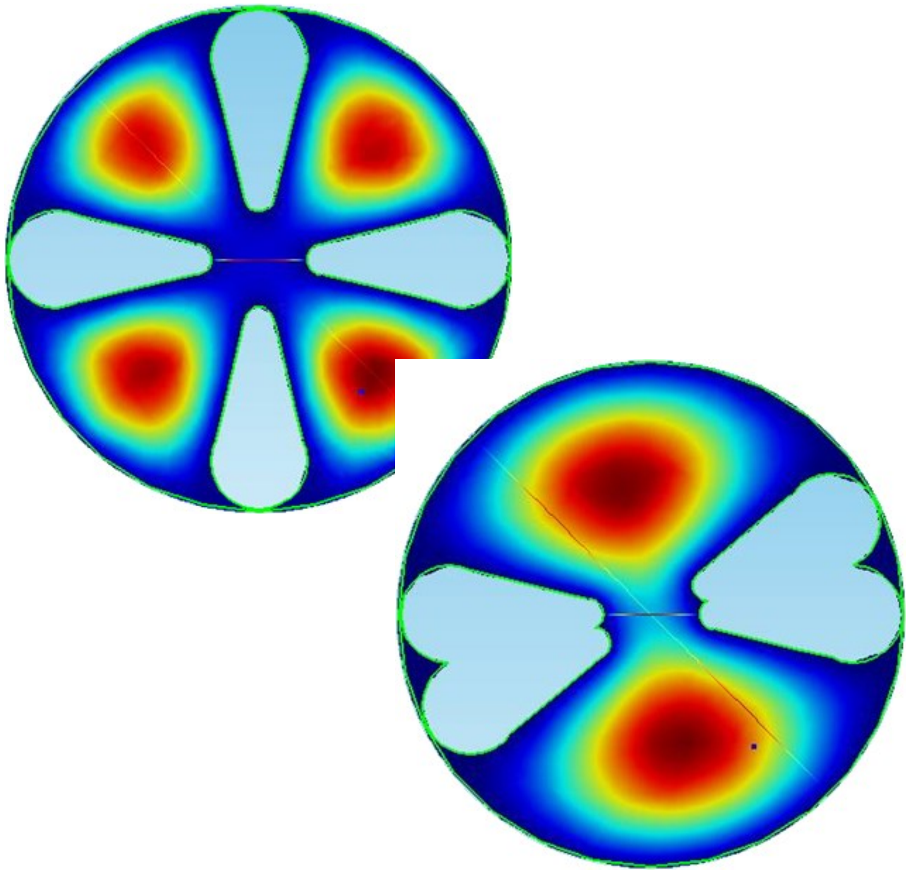
-- Put thin superconducting film on walls; parallel field does not induce vortices.

Cavity Design Study

Manipulated Photonic Band-Gap



Multi-Vane Regulator



Compared with simple cylinder: frequencies 3x higher. Tuning range ~1.3x.

C^2Q better than small cylinder *at same frequency*.

Conclusions

- ADMX Generation 2 aims to have DFSZ sensitivity over 2-10 μeV (0.4 to 2.1 Ghz)
- Insert coming together. We will have an engineering/science run in late 2013 using a ^{3}He refrigerator
  - Will allow commissioning of new insert
  - Will give good data on heat loads in operational conditions
- Dilution refrigerator delivery date requirement: January 2014
  - Acceptance testing inspring; installation/commissioning summer
- 2015 goal is to be operational at 50–100 mK
- It is not too soon to start design/optimization of what comes next