ADMX Phase II+

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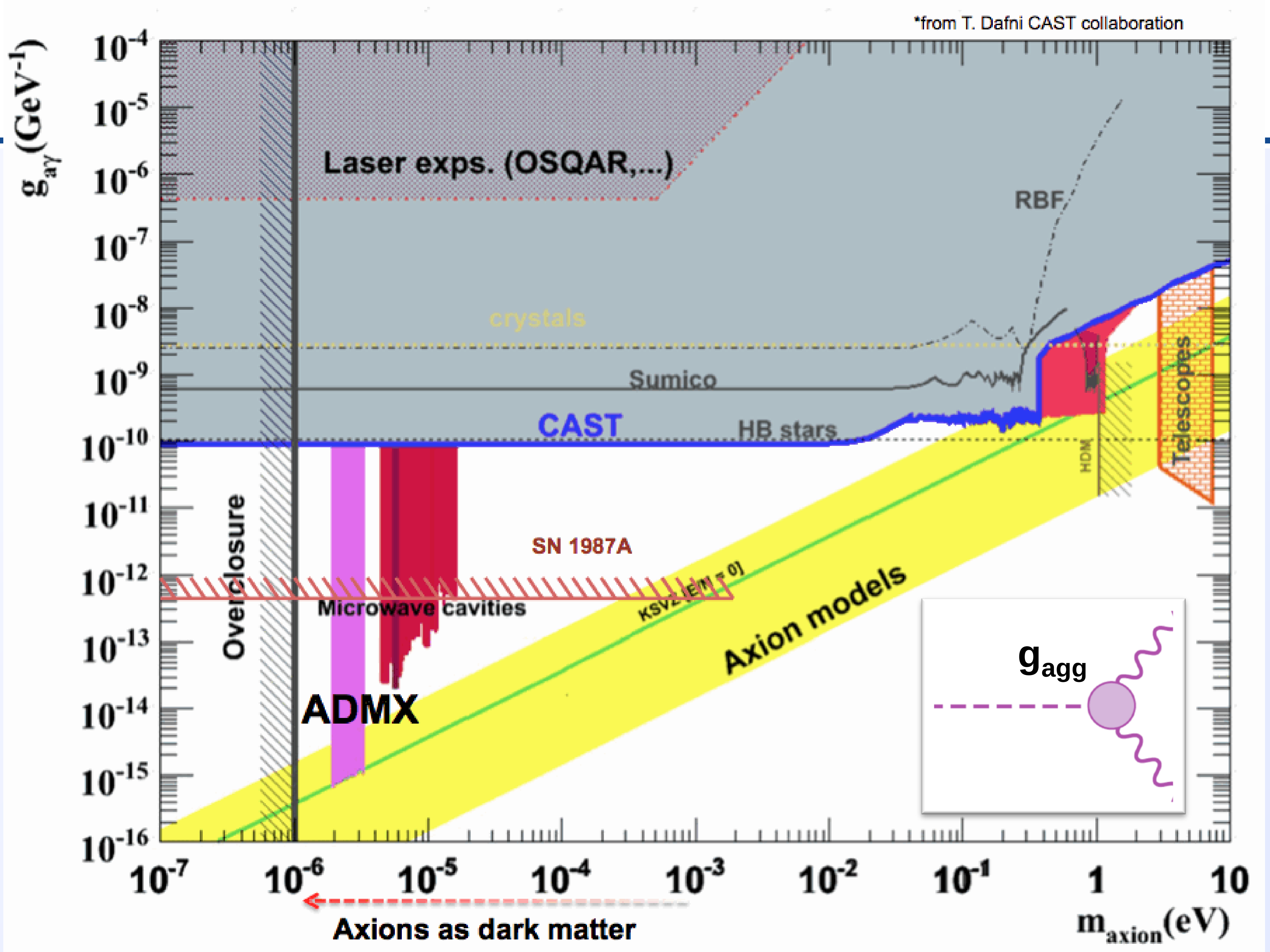
USA

ADMX Collaboration

Vistas in Axion Physics

04/24/2012

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.



*from T. Dafni CAST collaboration
$g_{a\gamma}$ (GeV^{-1})
Laser exps. (OSQAR,...)
RBF
crystals
Sumico
CAST
HB stars
HDM
Telescopes
SN 1987A
KSVZ [E/N = 0]
Axion models
Overclosure
Microwave cavities
ADMX
g_{agg}
m_{axion} (eV)
Axions as dark matter

ADMX collaboration

- University of Washington
- Leslie Rosenberg*spokesman, Gray Rybka, Michael Hotz, Andrew Wagner, Doug Will,
- Dmitry Lyapustin, Christian Boutan
- University of Florida
- David Tanner, Pierre Sikivie, Neil Sullivan, Jeff Hoskins, Jungseek Hwang,
- Catlin Martin, Ian Stern
- Lawrence Livermore National Laboratory
- Gianpaolo Carosi (PI @ LLNL), Darrell Carter, Chris Hagmann, Darin Kinion, Wolfgang Stoeffl, Karl van Bibber currently @ UC Berkeley, Nuclear Engineering Dept, CA
- National Radio Astronomy Observatory
- Richard Bradley
- University of California, Berkeley
- John Clarke
- Yale University
- Steve Lamoreaux
- Sheffield University
- Edward Daw

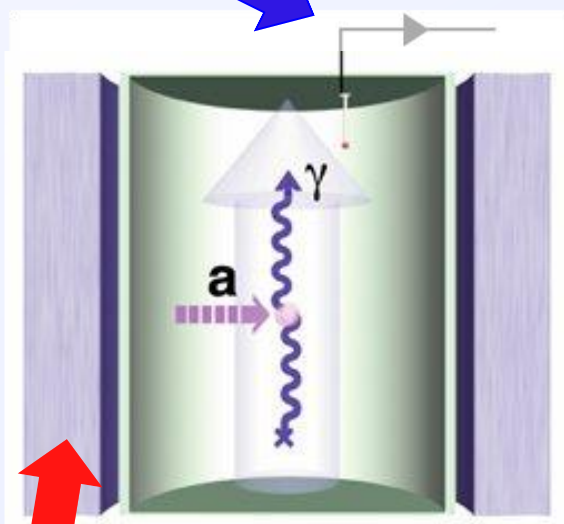
ADMX collaboration (at least a good portion of us)

The radiometer eqn.* dictates the strategy

$$\frac{s}{n} = \frac{P_{sig}}{kT_S} \cdot \sqrt{\frac{t}{\Delta\nu}}$$

But integration time limited to ~ 100 sec

** Dicke, 1946*



System noise temp. now

$T_S = T + T_N \sim 1.5 + 1.5\ K$

But $T_{Quant} \sim 30\ mK$

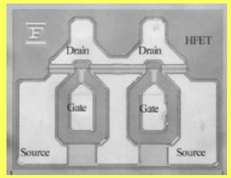
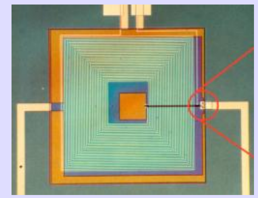
INVEST HERE!

$$P_{sig} \sim (B^2V\ Q_{cav})(g^2 m_a \rho_a)$$

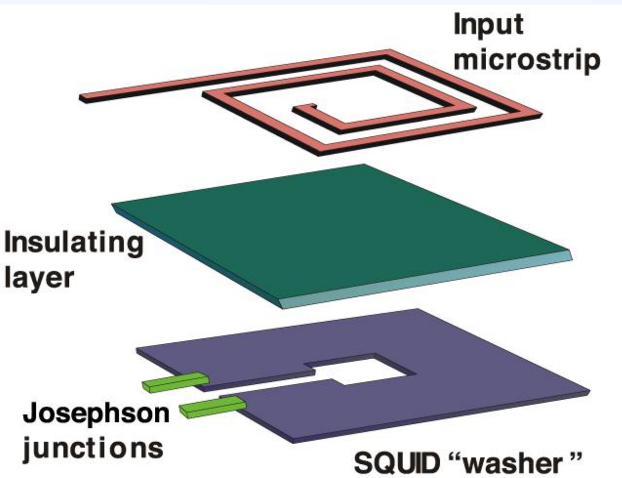
$$\sim 10^{-23}\ \text{watts}$$

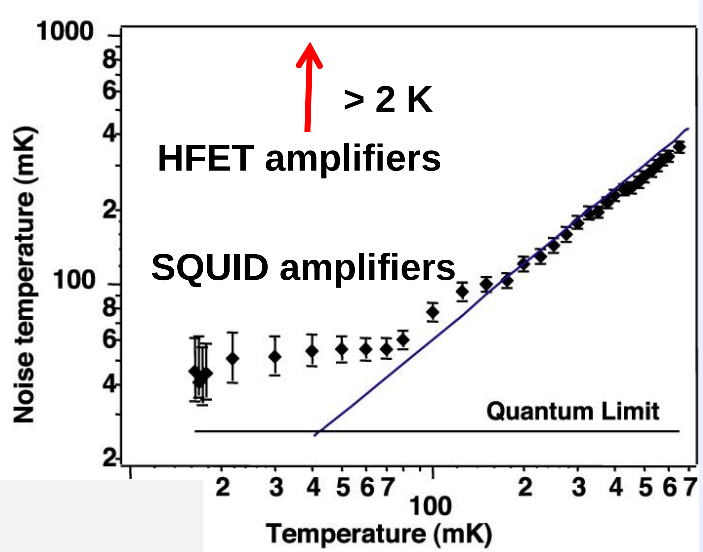
But magnet size, strength B^2V ~ $

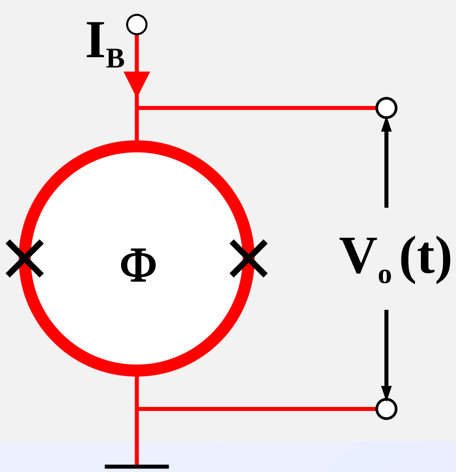
The Axion Dark Matter eXperiment

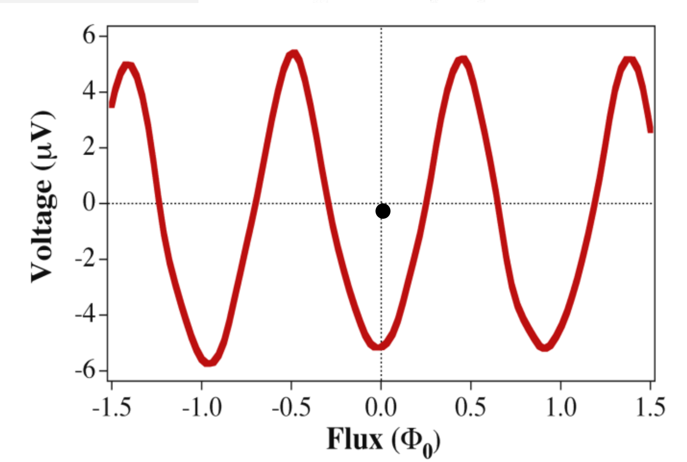
Stage	**Phase 0**	**Phase I**	**Phase II**
Technology	HEMT; Pumped LHe 	Replace w. SQUID 	Add Dilution Fridge 
T_{phys}	2 K	2 K	100 mK
T_{amp}	2 K	1 K	100 mK
$T_{sys} = T_{phys} + T_{amp}$	4 K	3 K	200 mK
Scan Rate $\propto (T_{sys})^{-2}$	1 @ KSVZ	1.75 @ KSVZ	5 @ DFSZ
		OR	***AND !***
Sensitivity Reach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

Phase I & II Upgrade path:
Quantum-limited SQUID-based amplification



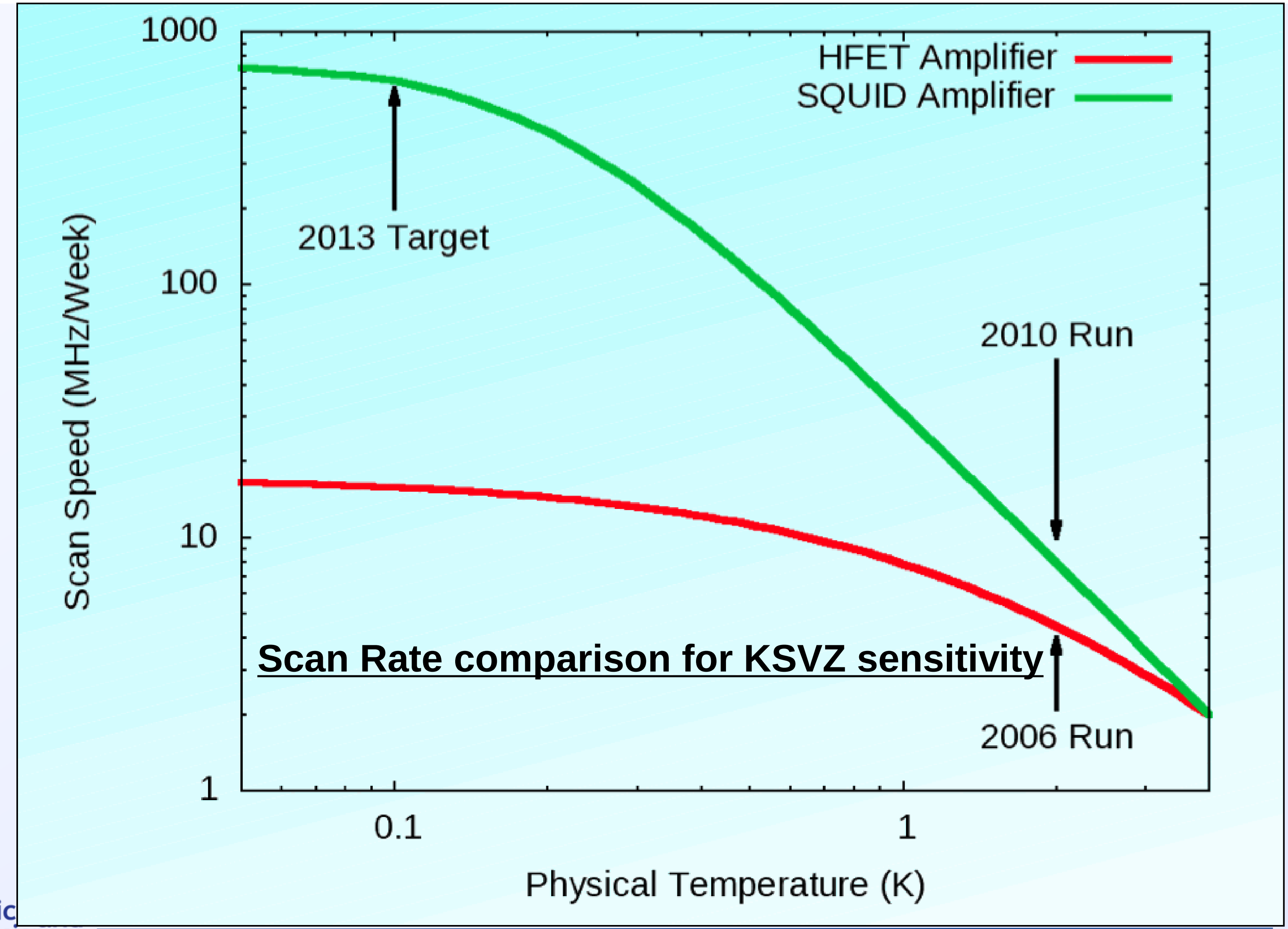






- SQUIDs have been measured with T_N ~50 mK
- Near quantum–limited noise
- This provides an enormous increase in ADMX sensitivity
- See Prof Clarke’s talk earlier

Cooling with SQUID amplifiers greatly increases scan rate

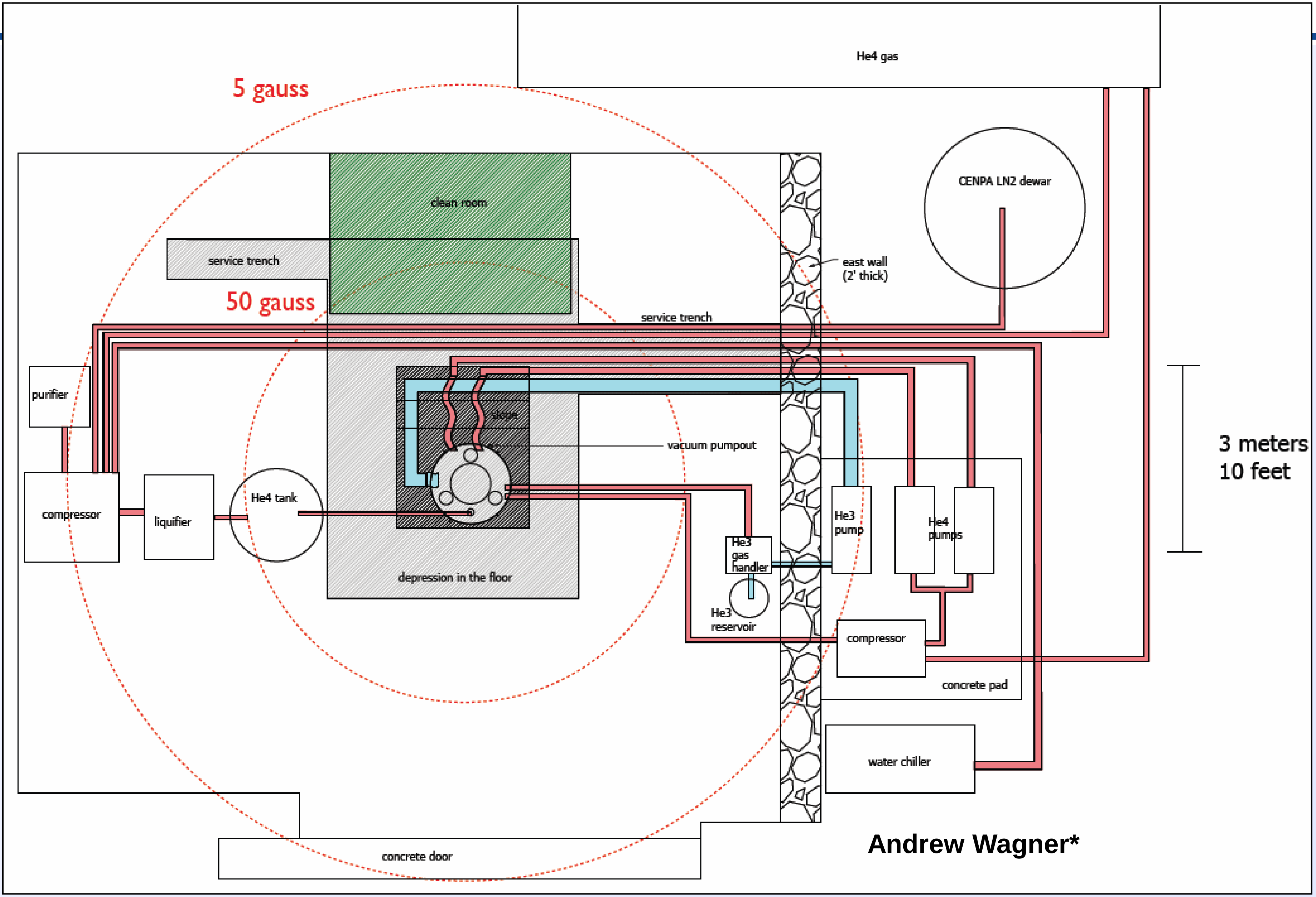


ADMX Phase II:
Moved ADMX main magnet and insert to the U. of Washington

Moved Main Magnet at LN2 temperatures Summer 2010

ADMX Main Magnet installed at CENPA, U.W.

Site Layout at CENPA: Lots of legacy infrastructure

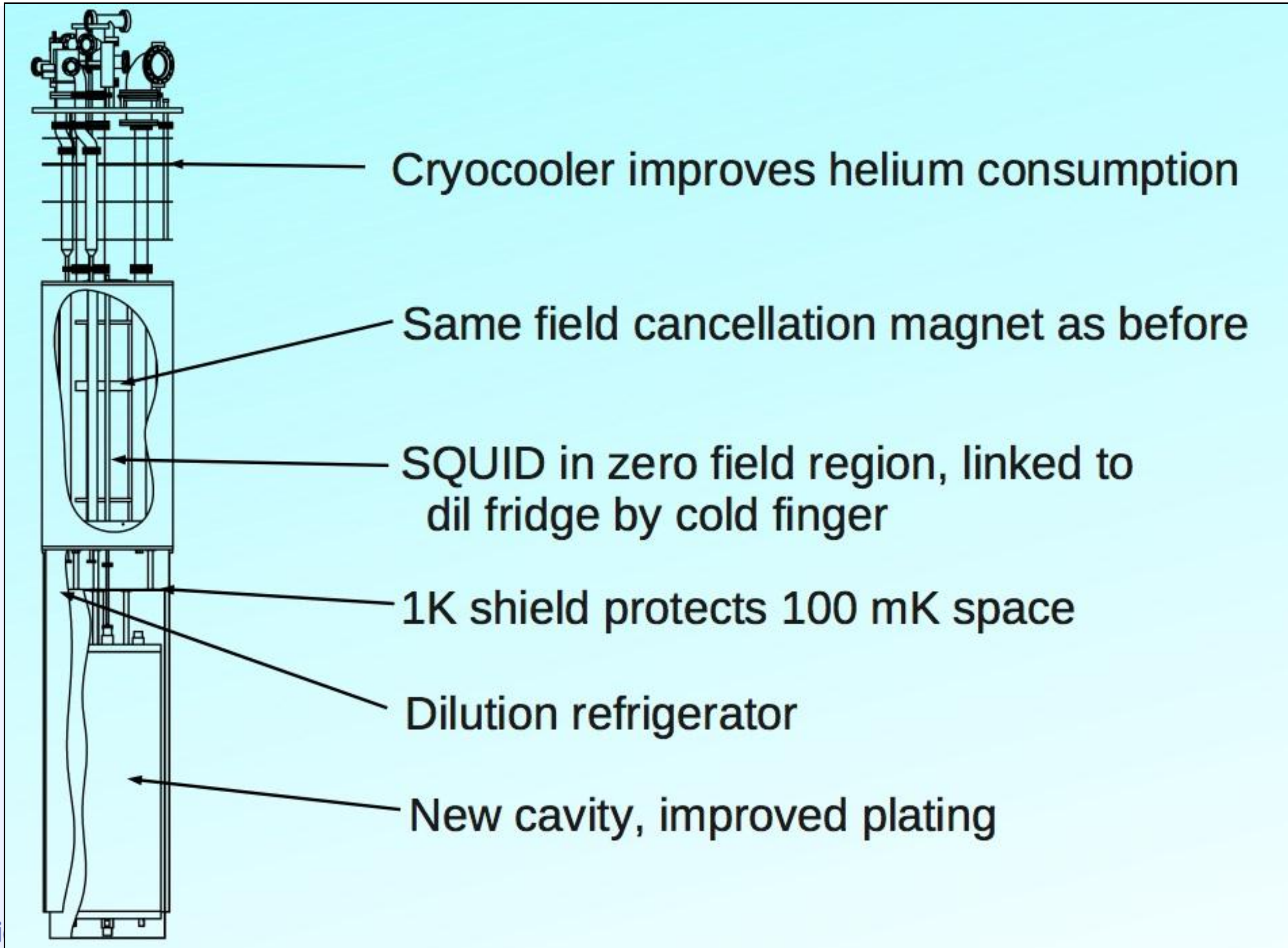


Andrew Wagner*

ADMX Phase II: Large amount of Technical Upgrades!

- Helium Liquifier
- Improved Cryogenics
- Piezoelectric Rod Motion
- Rod location Tracking
- Improved Thermometry
- Real-Time Analysis
- Clean assembly Area
- Better Cavity Modeling
- New Paint Job
- HFET Bias Monitor
- Dynamic SQUID Gain Monitoring
- In-Situ Noise Calibration Suite
- Tunable SQUIDs
- Improved Receiver Chain
- Digital Filtering
- Better Timing Standard
- Cavity Plating Upgrade
- All High Resolution Time Series Data
- New Magnet Leads

ADMX Phase II: Experimental Insert completely redesigned.

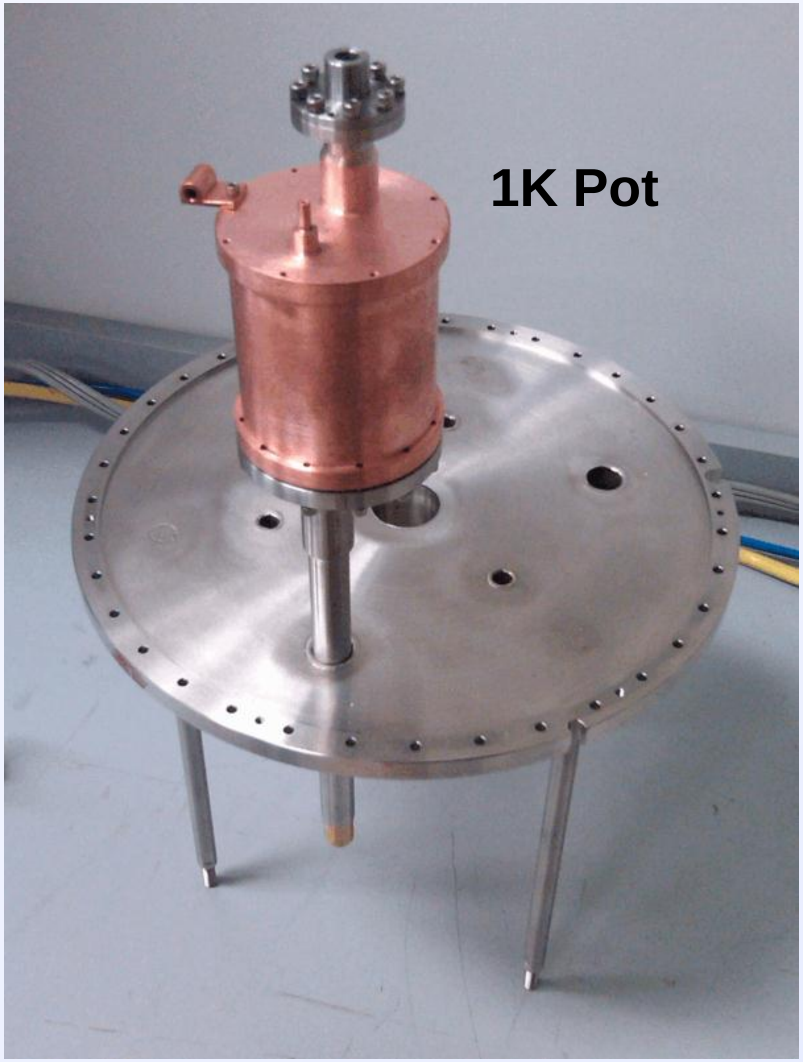


ADMX Phase II construction well underway!

Top Plate has been welded and is being leak tested.

Bucking magnet installed in new reservoir

ADMX Phase II: Cryogenics being design by U. of Florida (N. Sullivan)



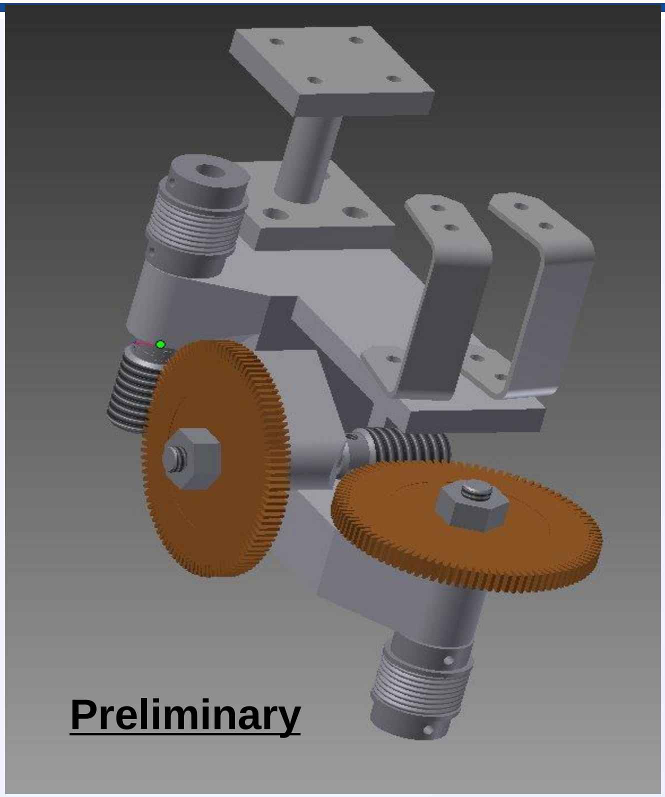
Have been approved for 50 liters STP He^3.

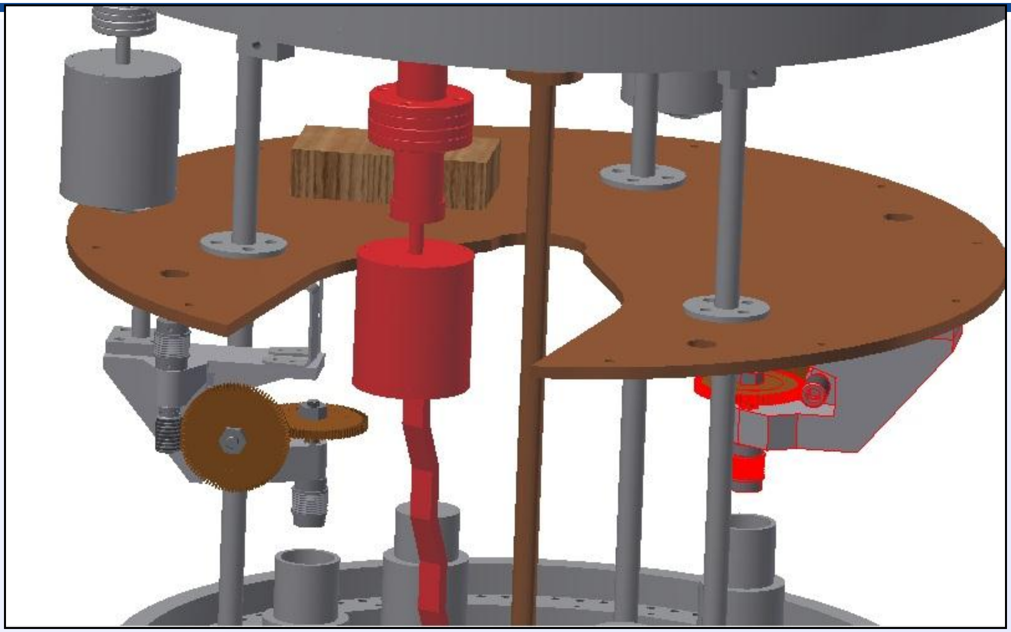
Initially data run with pumped He^3 pot to ~ 300 mK while awaiting dilution refrigerator.

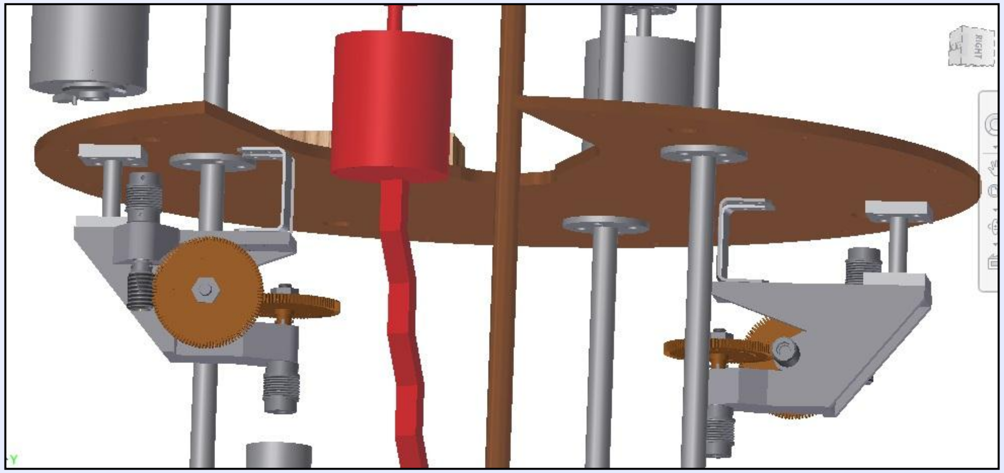
Much of the same infrastructure will be used for dilution fridge ~ 100 mK.

Dilution Refrigerator based on Janis 750 model

Motion Control for Tuning Rods (attached to 1k stage).





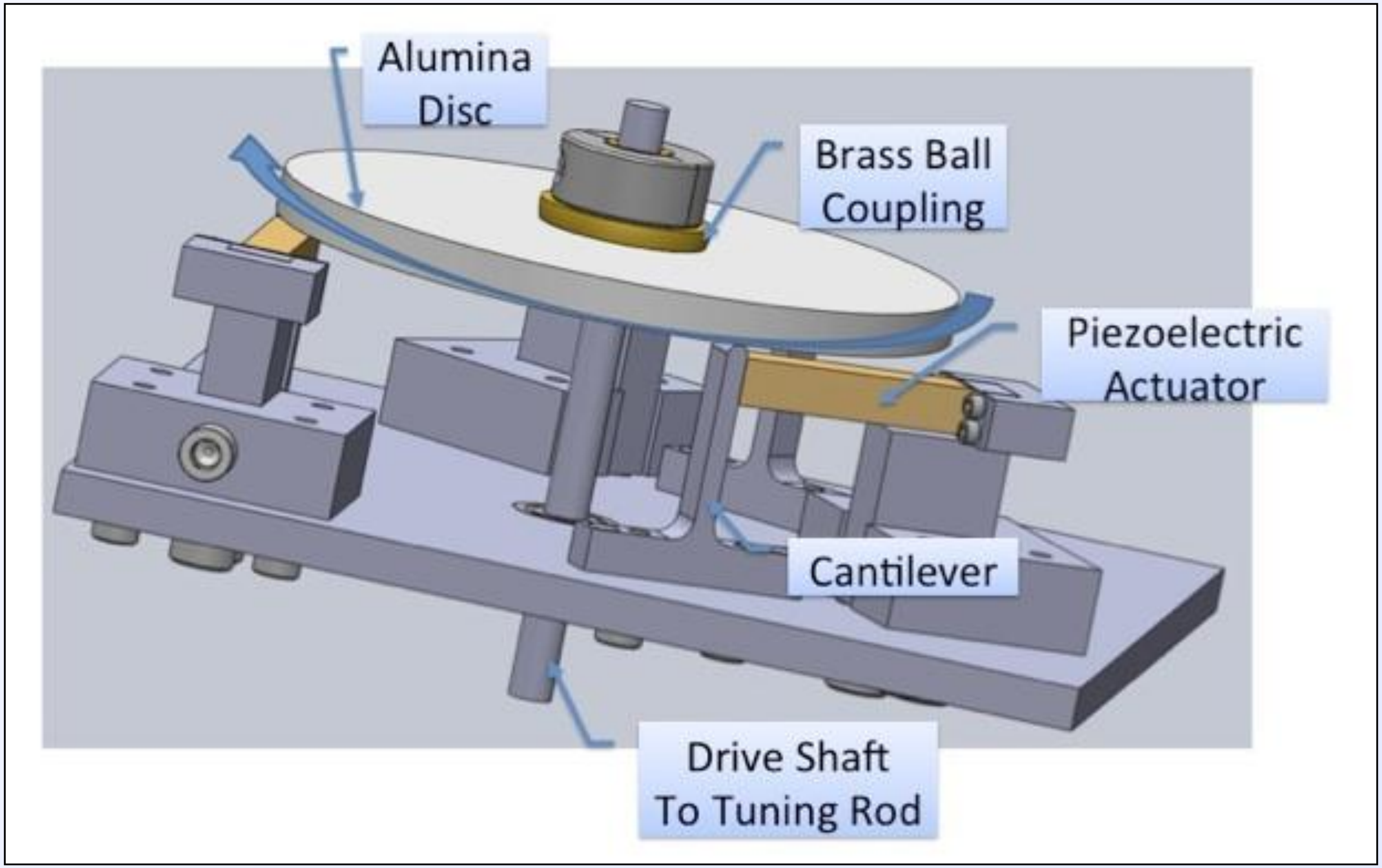


19600:1 gear reduction

Heat budget: ~ 1 mW continuous running (factor of 100 lower for 10 mHz cadence)

Continued R&D effort to potentially use Piezo-electric rotary drive

Stick-slip design with piezo stacks from Physik Instruments.

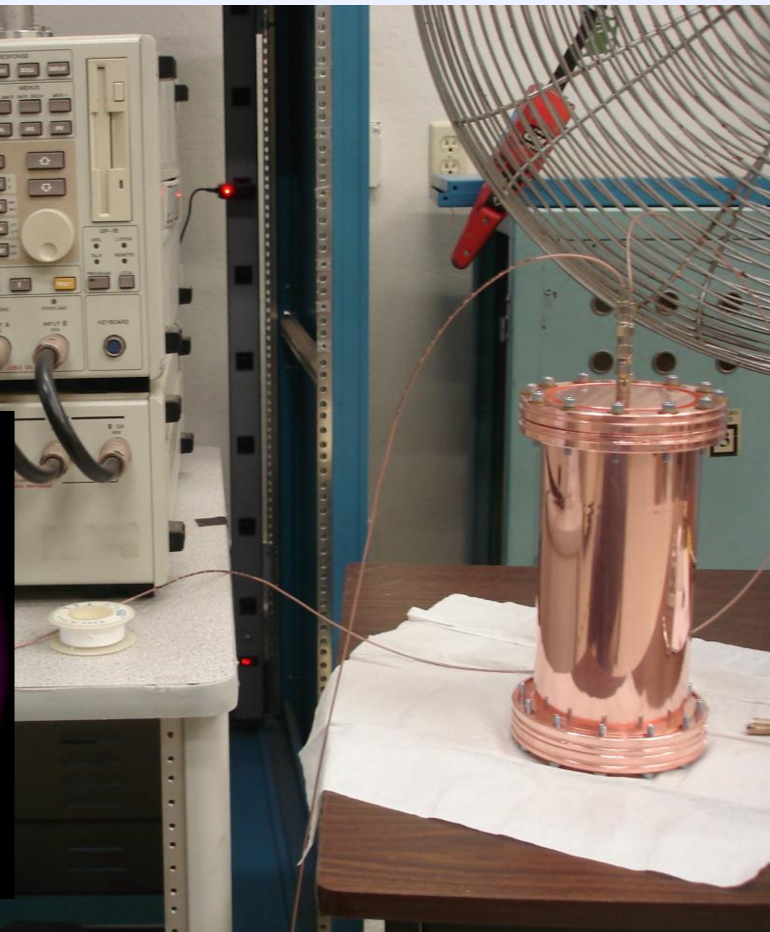


Harvey Mudd College Clinic Team designed & constructed prototype

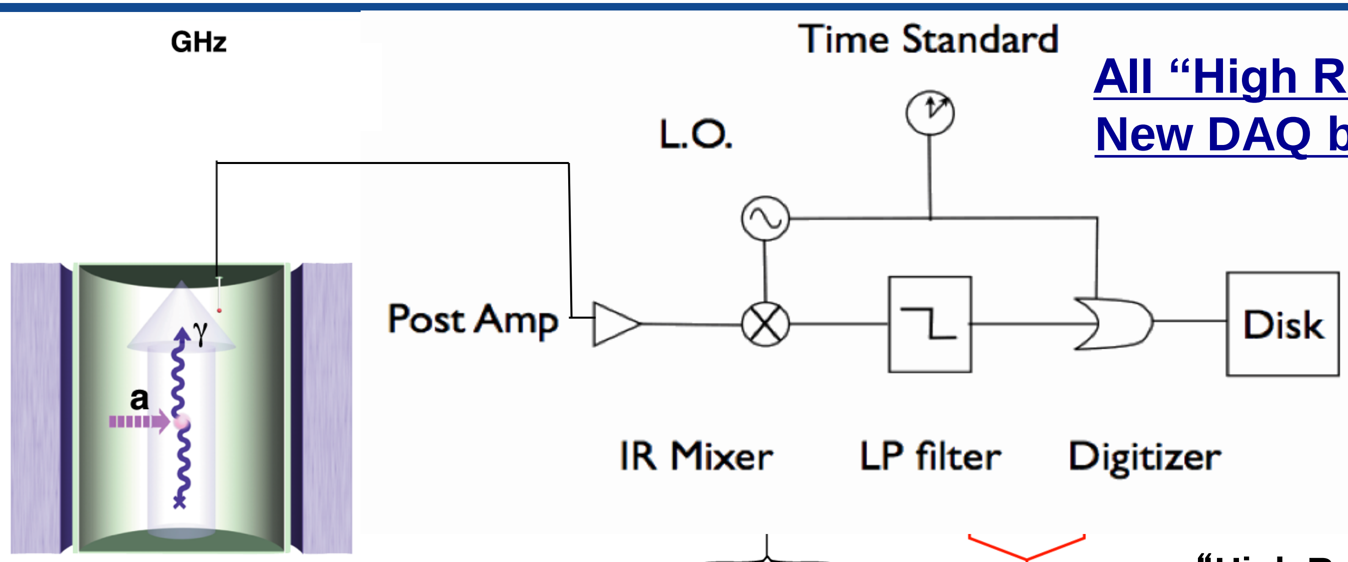
ADMX Phase II: New Microwave cavity and tuning rod plating

- Cavity and Tuning rods: Stainless steel plated with high quality copper.
  - Q near that given by cryogenic anomalous skin depth.
  - Expected unloaded Q of ~ 200,000.

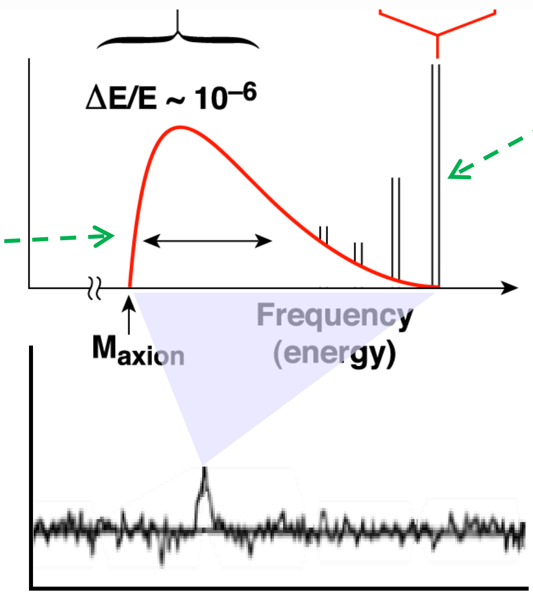
- Main cavity to be delivered to U.W. late summer.
- Continued R&D to improve quality factor and form factor.



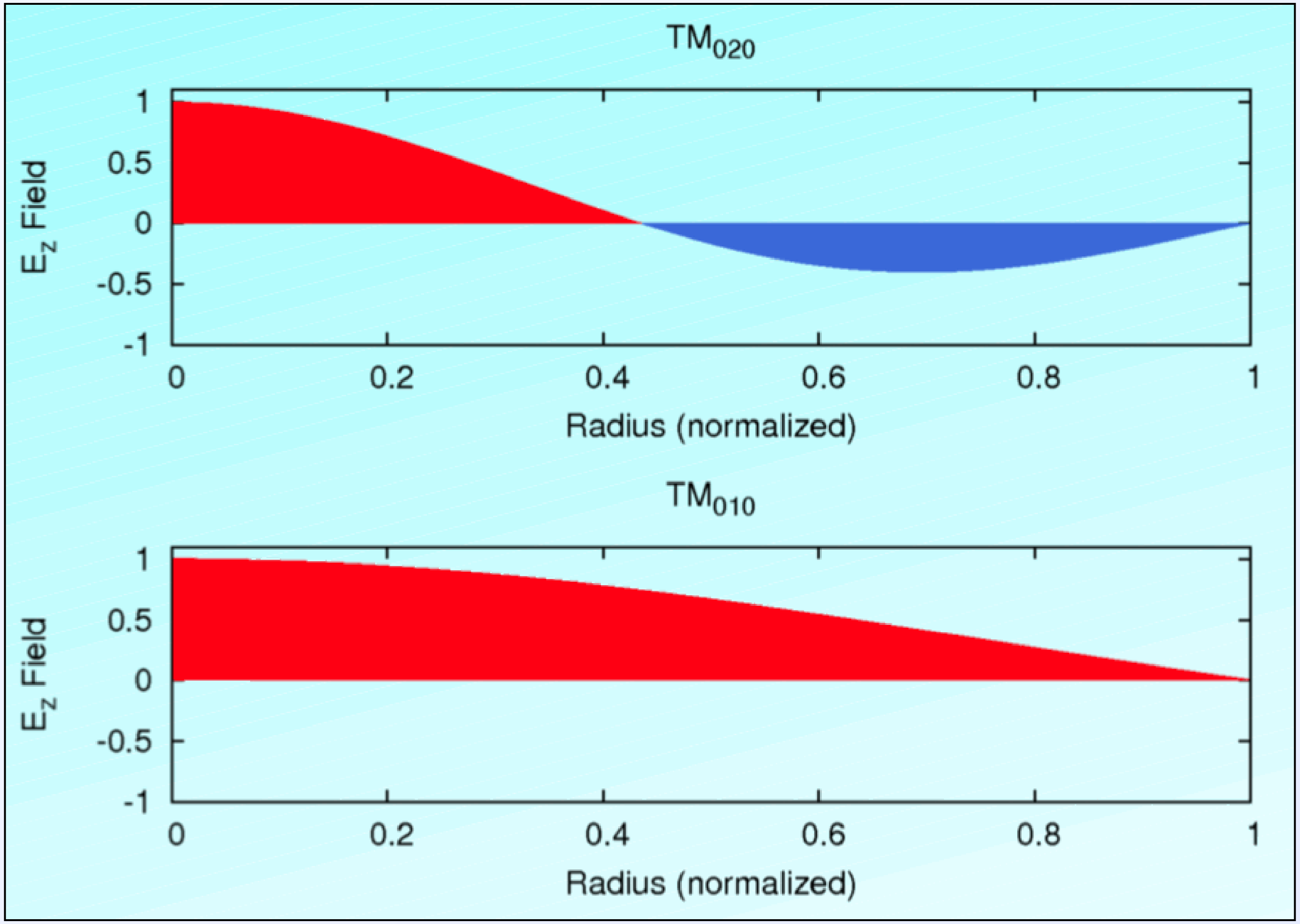
Revamped Receiver Chain: Take advantage of digital electronics



All "High Resolution" data
New DAQ based on EPICS



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

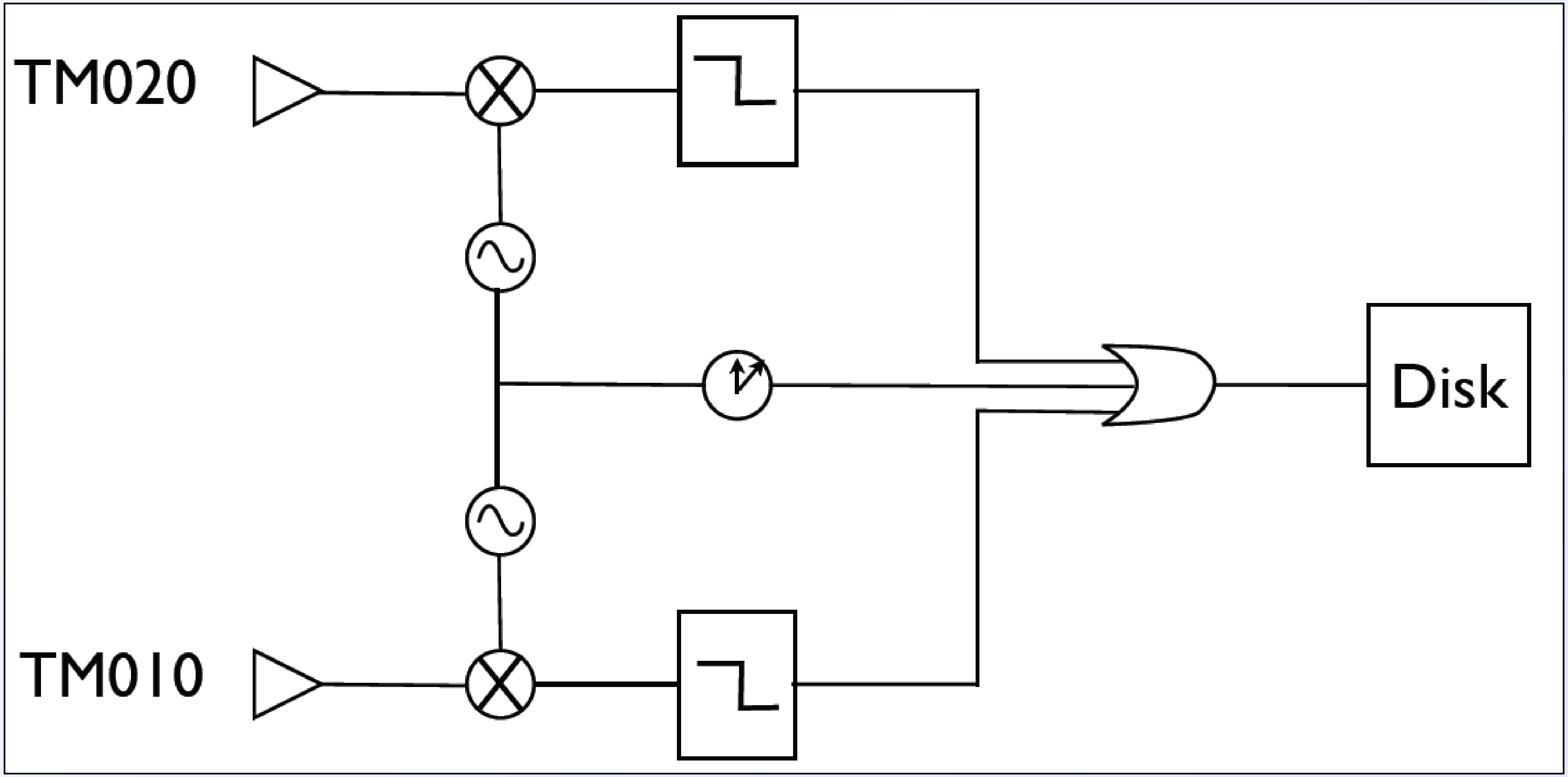
Relative Frequency

1.0

Tuning Range

400-900 MHz

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

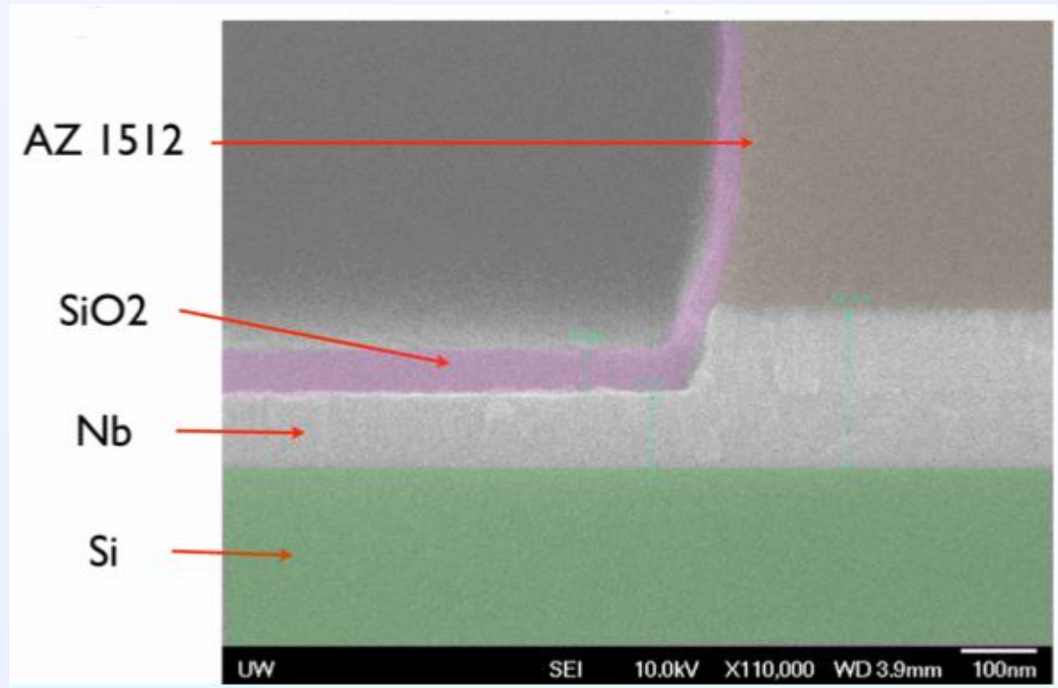


Receiver chain now requires 2 parallel sets of 1^{st} stage amplifiers and antennas and modest amount of filtering.

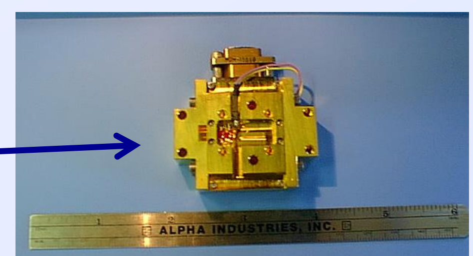
Amplifiers: Steady stream of SQUID and HFET amps

John Clarke's group at UC Berkeley providing baseline SQUID amplifiers

Andrew Wagner coming up to speed to be local (UW) SQUID manufacturer



Richard Bradley at NRAO onboard to provide 2nd stage HFET amps



Current Schedule

Summer 2011 Funding for Phase II arrived!

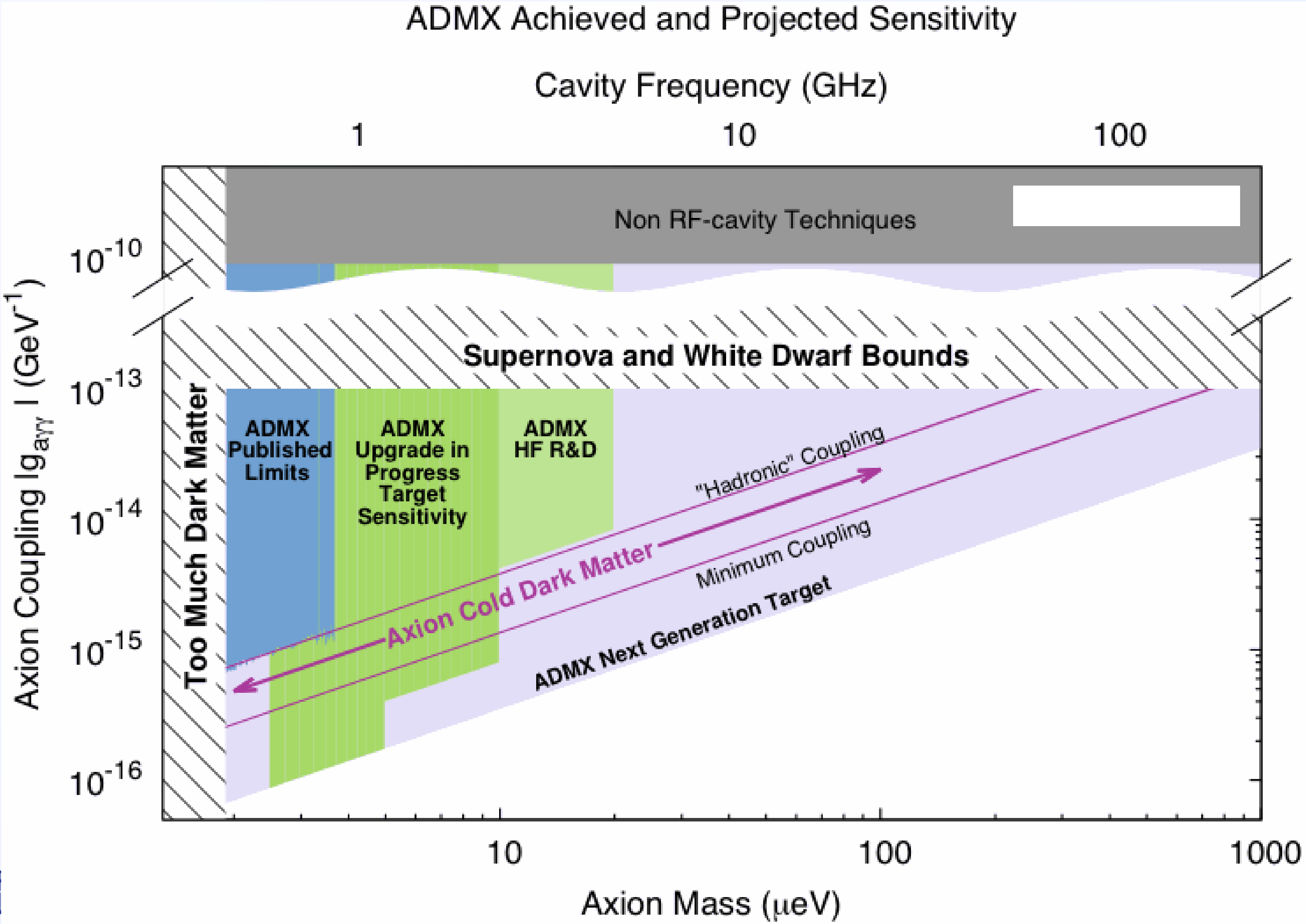
2011 – 2012 Construction of Phase II insert / infrastructure.

2012 – 2013 Commission Phase II detector
(pumped LHe^3 system ~ temp at 300 mK)
Order Dilution Refrigerator (1 year lead time)
Short Axion Search while awaiting Dil. Fridge

2013 – 2014 Install Dilution Refrigerator, Commissioning

2015+ Definitive Dark Matter Axion search commences!

ADMX Upgrade + ADMX-HF – year one

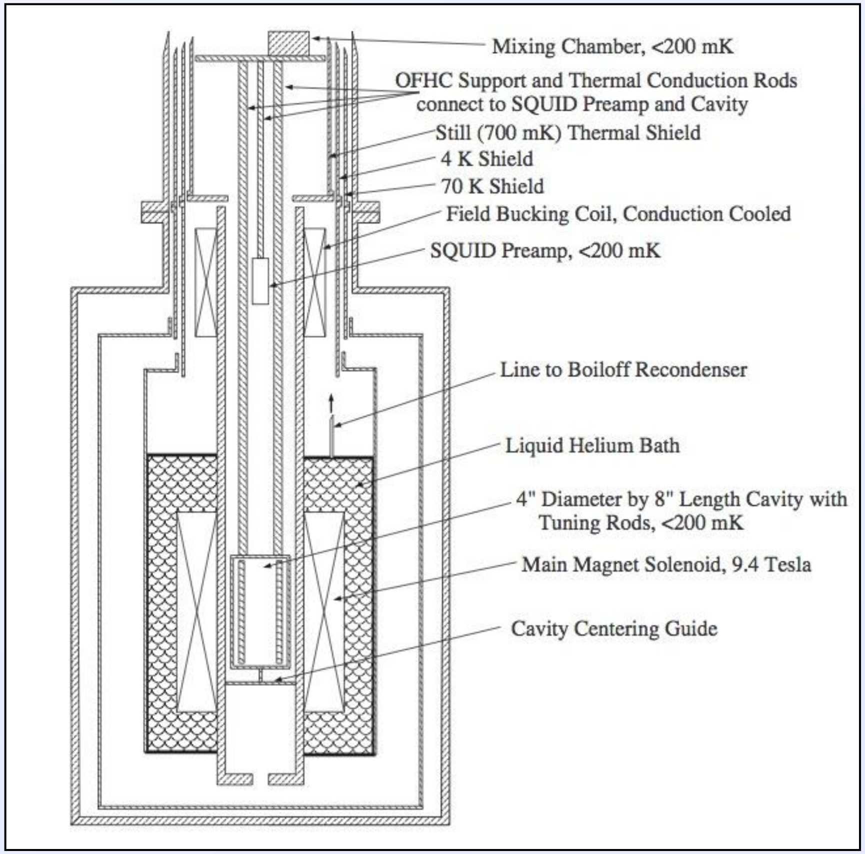


ADMX – HF: High Frequency (> 2 GHz)

Second ADMX site: Yale University

PI: Prof. Steve Lamoreaux

- **New Superconducting Magnet 5" diameter, 20" long, 9.4 T**
- **Dilution fridge already in place.**



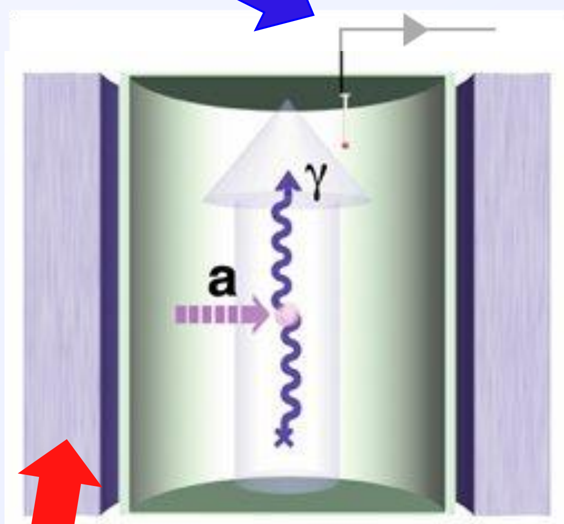
•Recently awarded NSF funding… magnet under construction

The radiometer eqn.* dictates the strategy

$$\frac{s}{n} = \frac{P_{sig}}{kT_S} \cdot \sqrt{\frac{t}{\Delta\nu}}$$

But integration time limited to ~ 100 sec

** Dicke, 1946*



System noise temp. now

$T_S = T + T_N$ ~ 1.5 + 1.5 K

But T_{Quant} ~ 30 mK

HAVE INVEST HERE!

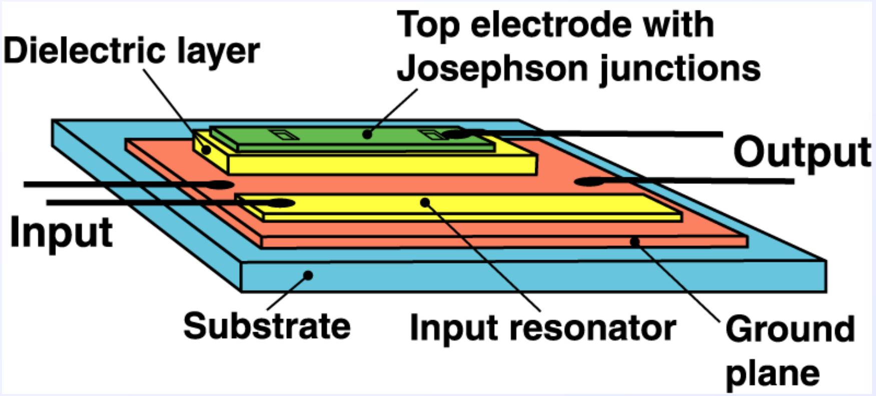
$P_{sig} \sim (B^2V\, Q_{cav})(g^2 m_a \rho_a)$

$\sim 10^{-23}$ watts

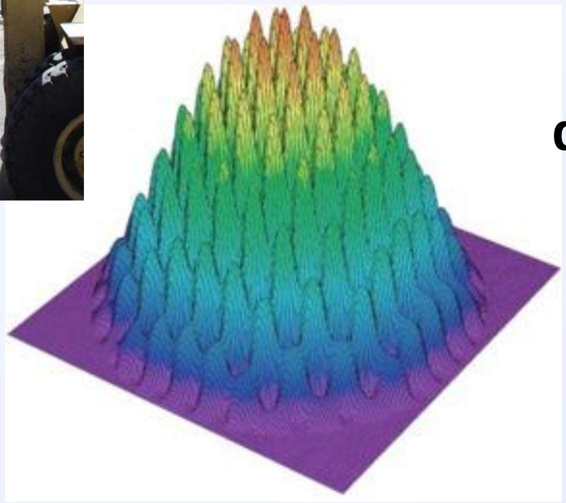
Magnet size, strength B^2V ~ $

To get > 10 μeV… Additional higher-frequency R&D required

More Powerful Magnets!

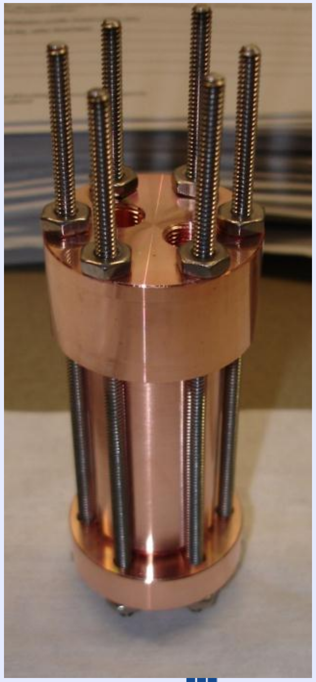


Higher-frequency near quantum-limited SQUIDs



higher-frequency, large volume resonant structures

“Hybrid” superconducting cavities

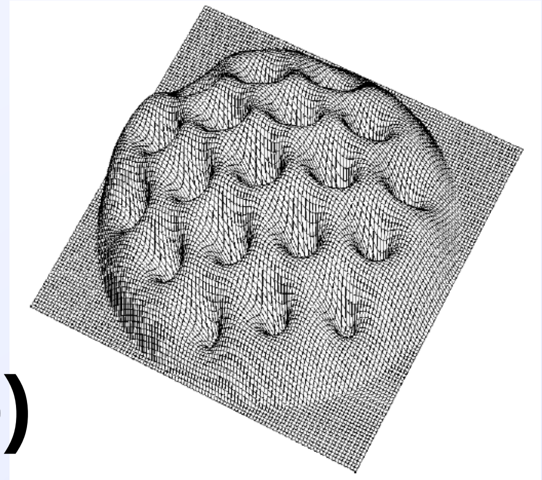


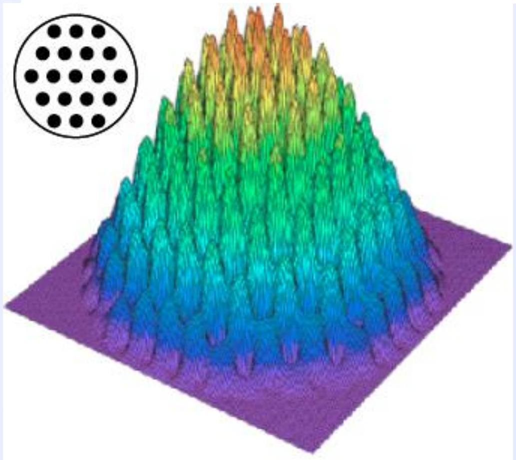
Goal: Higher frequencies without sacrificing volume

4 cavity array operated

D. Kinion Thesis

(b)

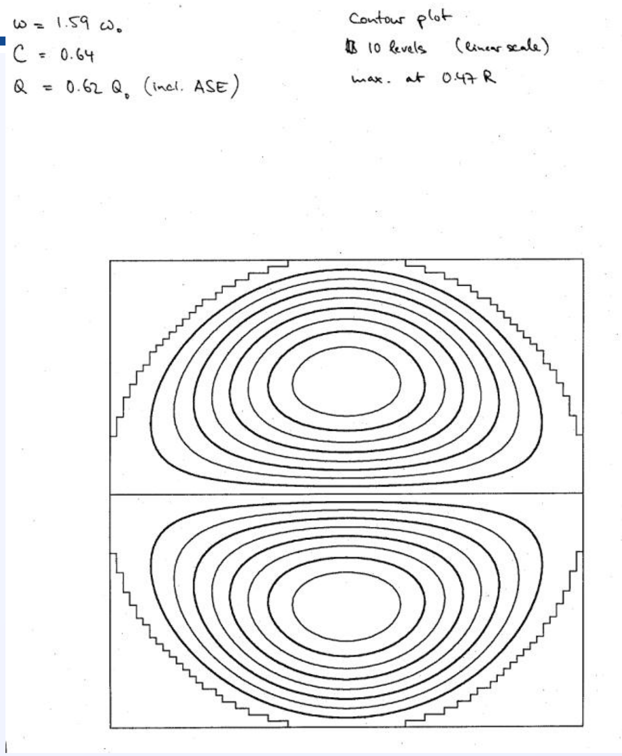


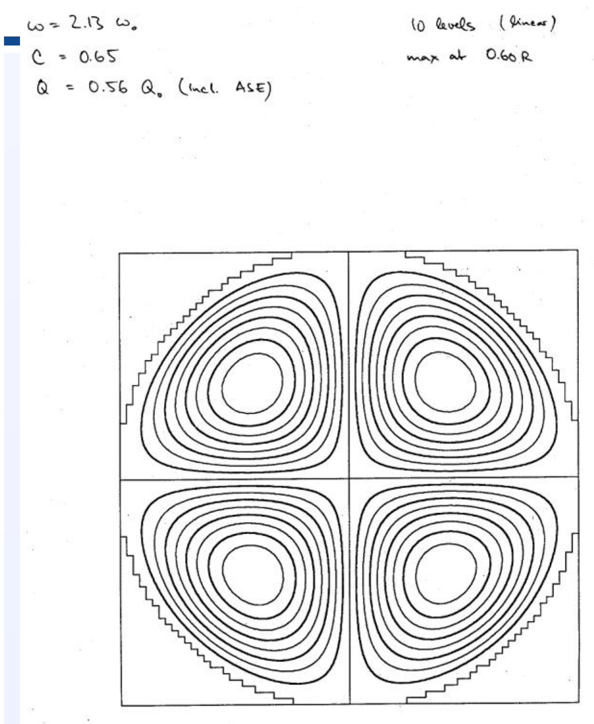


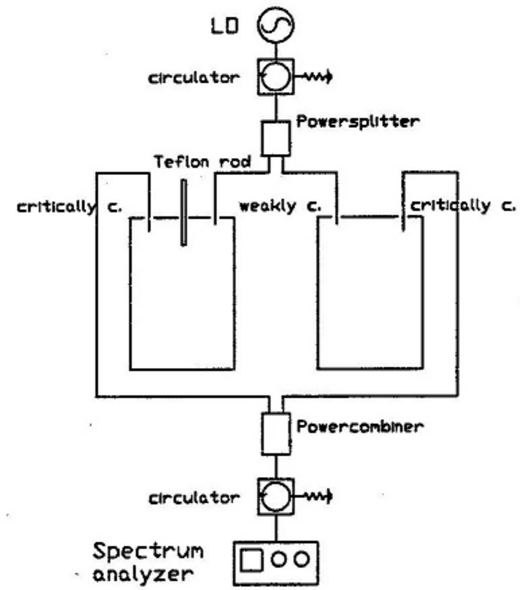
C. Hagmann simulation

Multipost systems possible

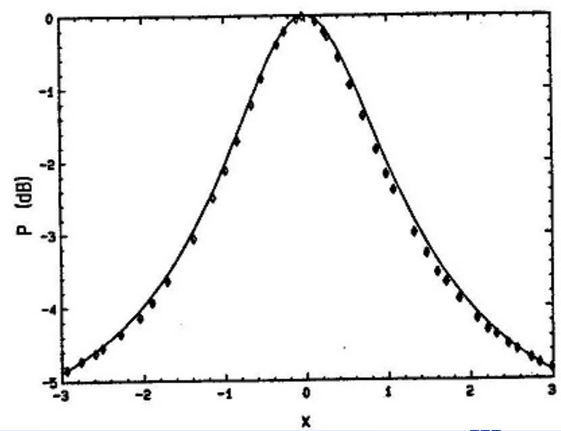
Multi-cavity array – work at U. of Florida







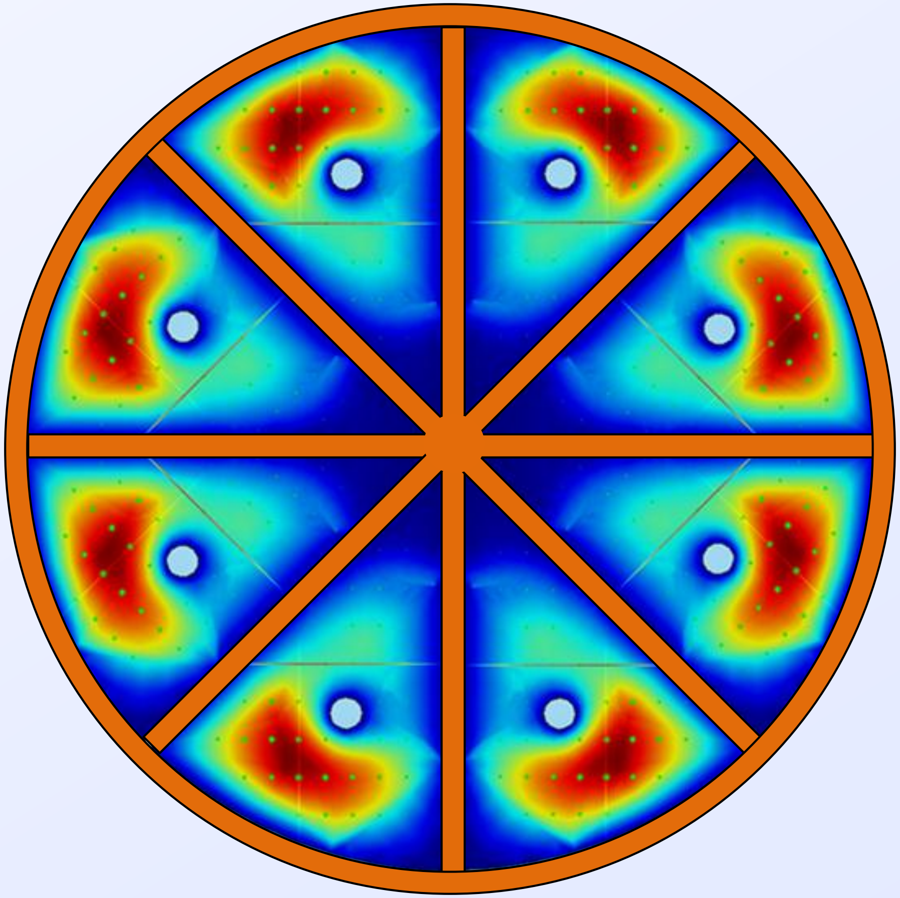
- Partitions reduce scale, increase frequency
- Efficient use of magnetic volume compared to, e.g., 4 parallel cylinders.
- Tune by moving rods from corner to center in each partition
- Issues with Q, coupling



Segmented Resonator

- **Method becomes highly complex above 8 segments**
  - Maximum TM_{010} Frequency for full scale cavity: ~2.2 GHz (9μeV)
- **Project going through cavity redesign and improvements…**

continued R&D effort



The "Hybrid" superconducting cavity concept

What's the point?

$$P \propto g^2 \cdot B^2 V \cdot \min(Q_L, Q_a)$$

$$\frac{1}{f} \cdot \frac{df}{dt} \propto g^4 \cdot B^4 V^2 \cdot \min(Q_L, Q_a)$$

For copper cavities, $Q_a \sim 10^6$, whereas $Q_L \sim 50{,}000$

If you could increase Q_L by a factor of *e.g.* x10 :

- P would increase by x10
- df/dt would increase by x10 *(for constant g)*
- g would improve by ÷1.8 *(for constant scan speed)*

Physi Life Sc

*slides from Karl van Bibber

The "Hybrid" superconducting cavity concept

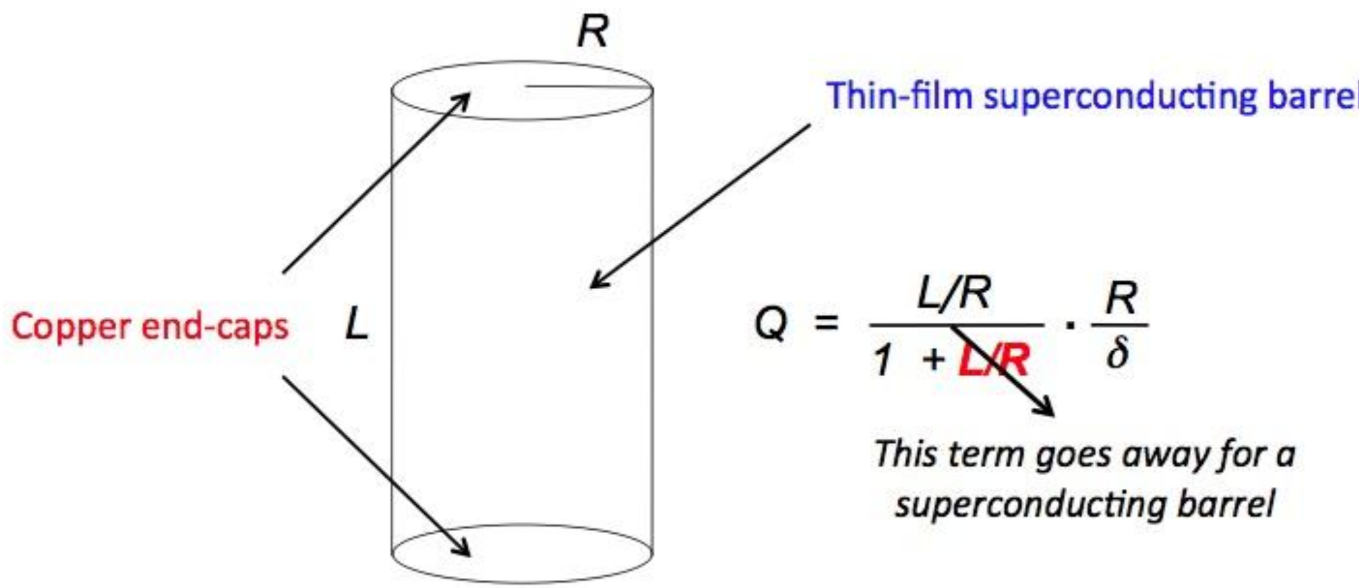
Q of the TM_{010} mode for a conventional Cu cavity:

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

Skin depth of Copper

The "Hybrid" superconducting cavity concept

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

The "Hybrid" superconducting cavity concept

The science of thin-film superconductors is mature

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

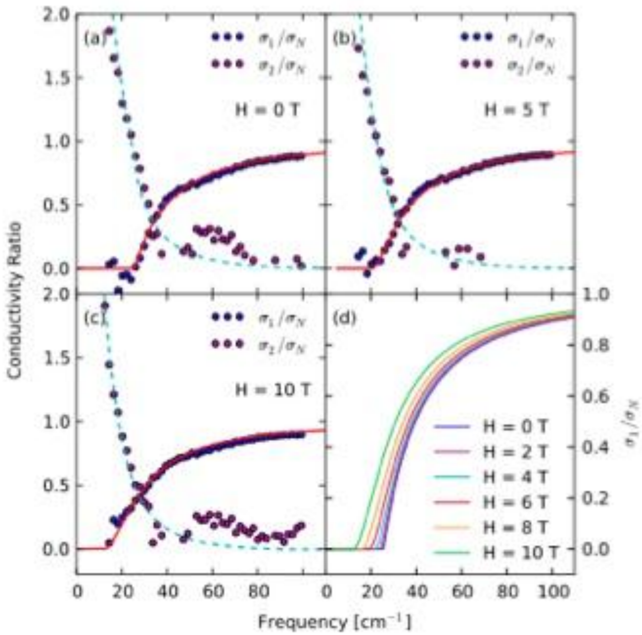
Far-Infrared Conductivity Measurements of Pair Breaking in Superconducting $Nb_{0.5}Ti_{0.5}N$ Thin Films Induced by an External Magnetic Field

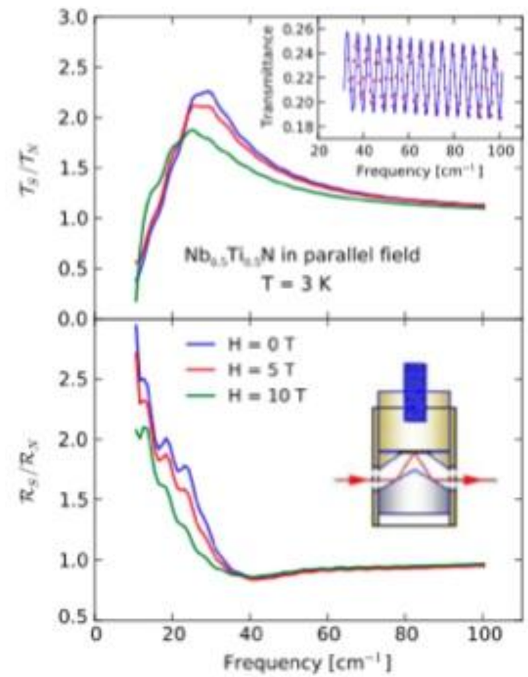
Xiaoxiang Xi,[1] J. Hwang,[1,2] C. Martin,[1] D. B. Tanner,[1] and G. L. Carr[3]
[1]*Department of Physics, University of Florida, Gainesville, Florida 32611, USA*
[2]*Department of Physics, Pusan National University, Busan 609-735, Republic of Korea*
[3]*National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York 11973, USA*

(Received 16 August 2010; published 16 December 2010)

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.

DOI: 10.1103/PhysRevLett.105.257006 PACS numbers: 74.78.−w, 74.25.Ha, 78.20.−e, 78.30.−j





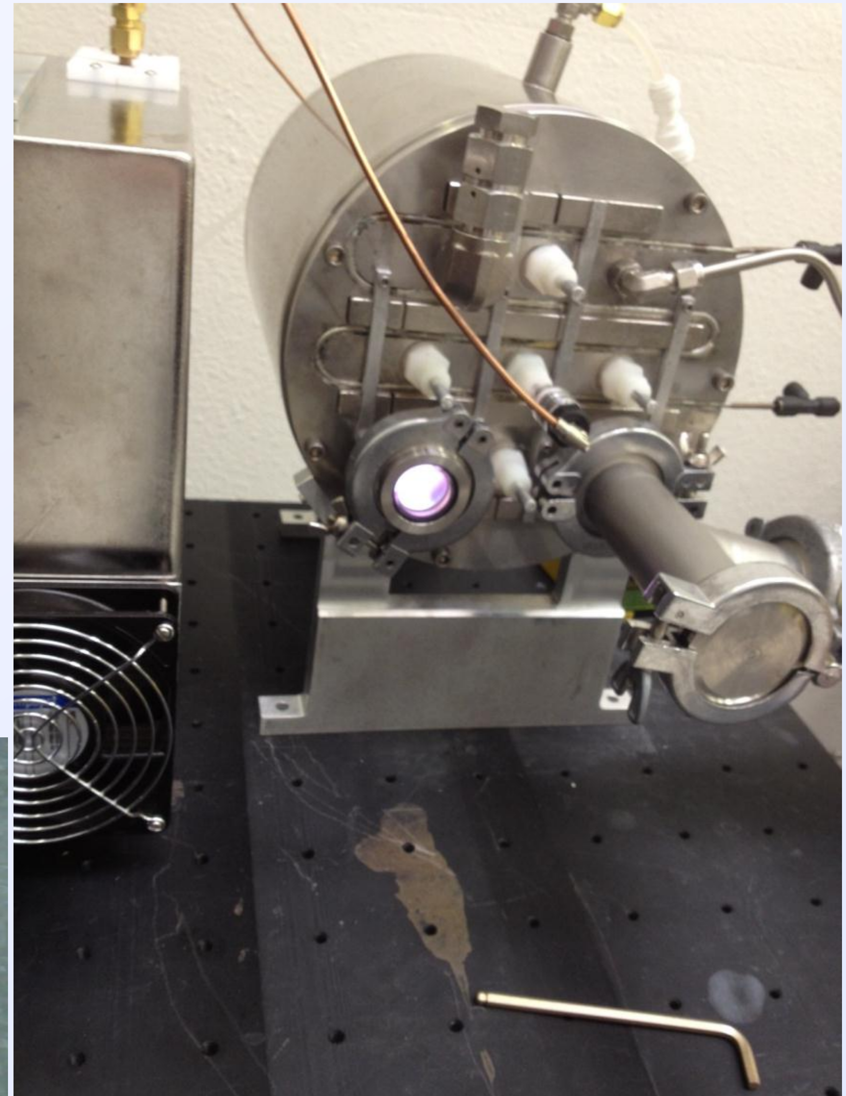
10 nm $Nb_{0.5}Ti_{0.5}N$ is perfect

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

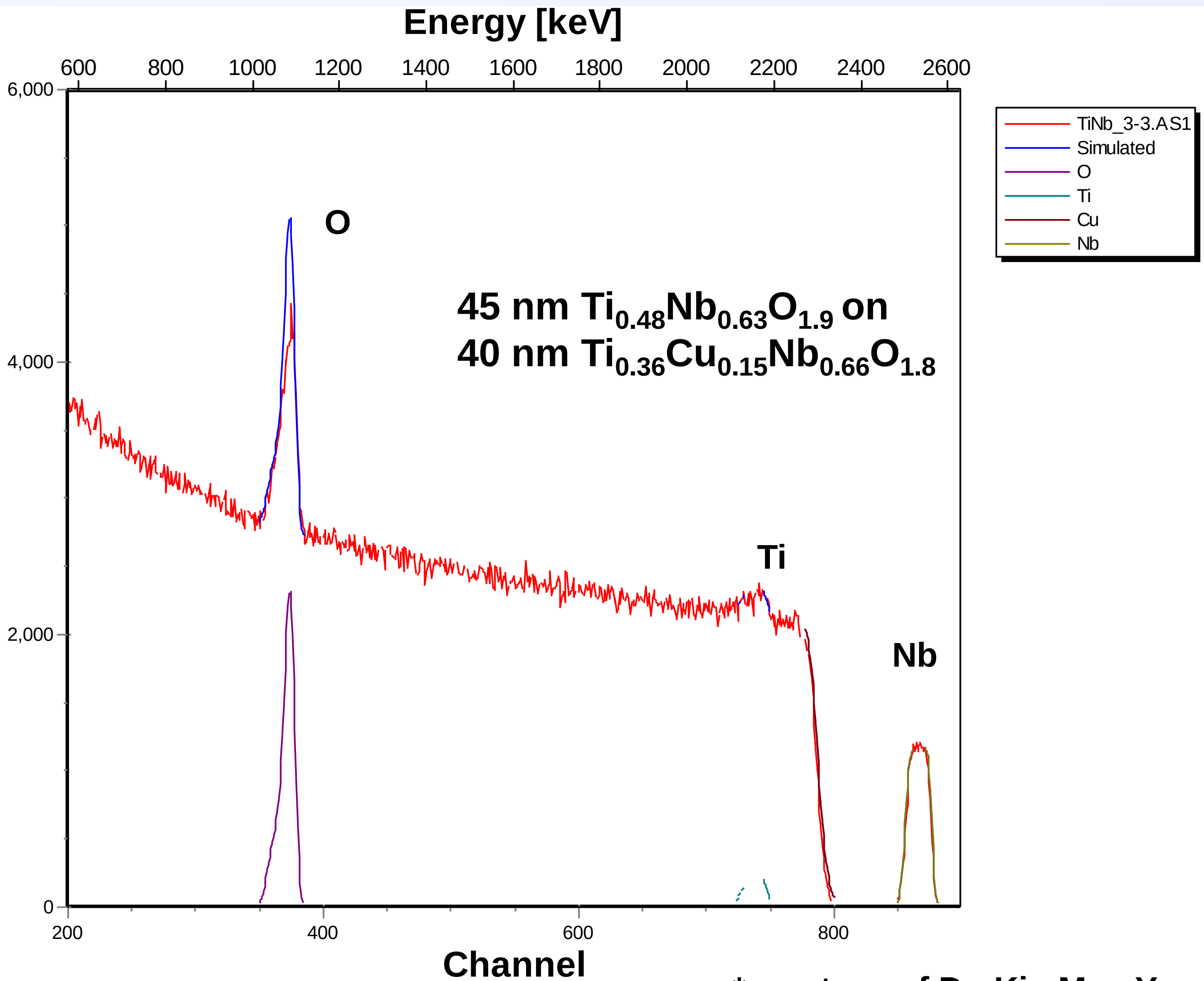
***slides from Karl van Bibber**

R&D has already begun on NbTiN superconducting coatings

Currently in the process of setting up RF vapor deposition on foils for

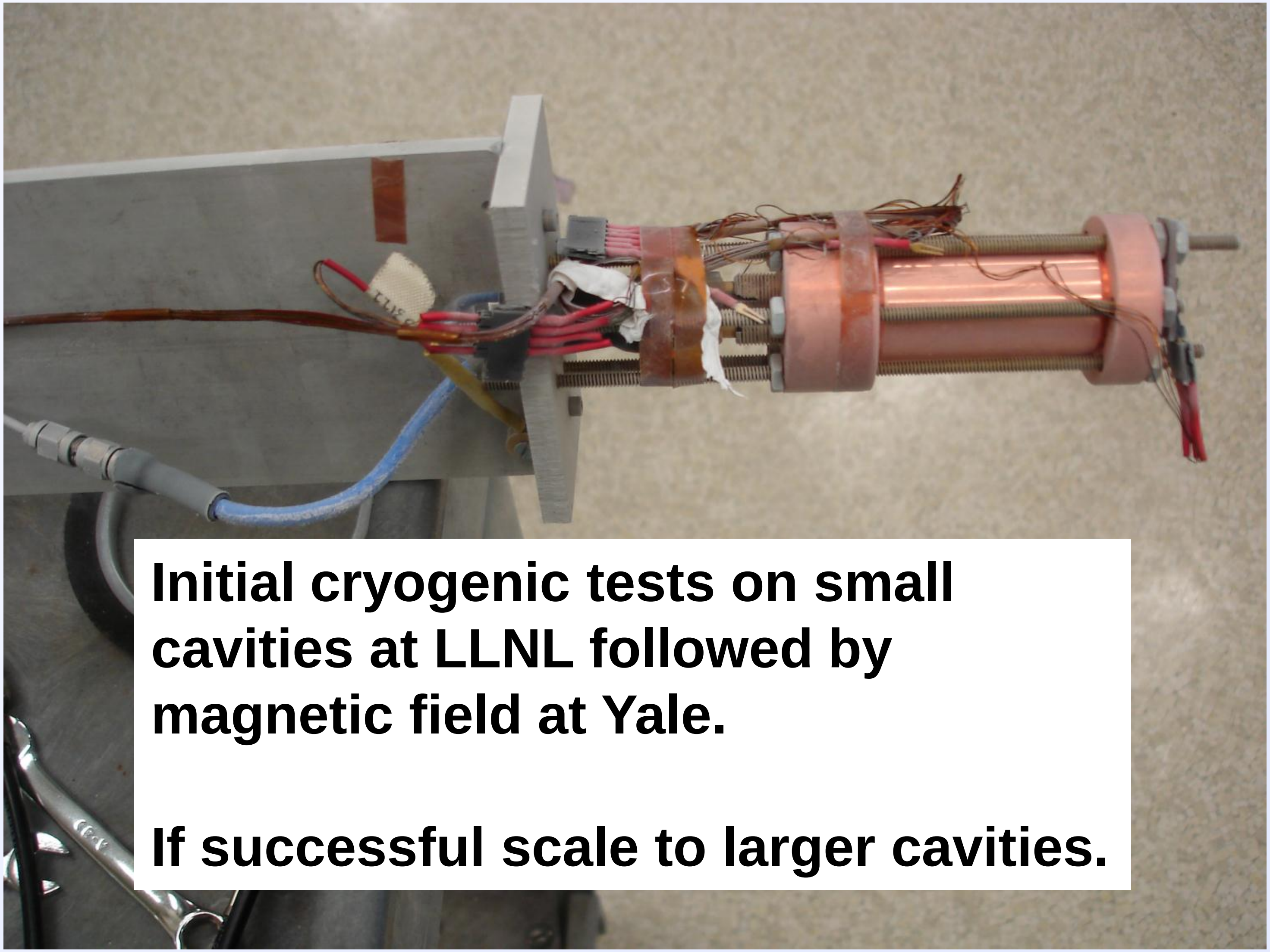


Rutherford backscattering of 20 min NbTi deposition on copper foil



*courtesy of Dr. Kin Man Yu of LBNL

Superconducting coatings will be placed on 1” cavity barrels

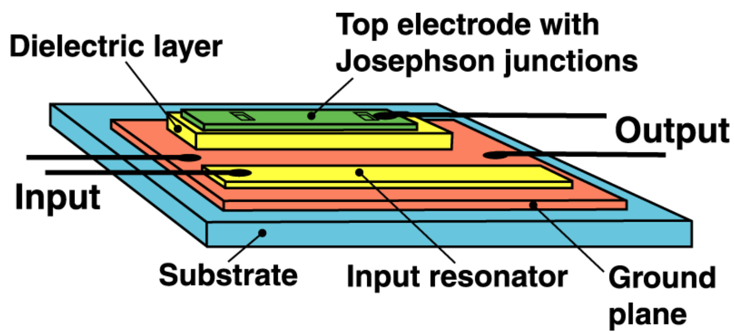


Initial cryogenic tests on small cavities at LLNL followed by magnetic field at Yale.

If successful scale to larger cavities.

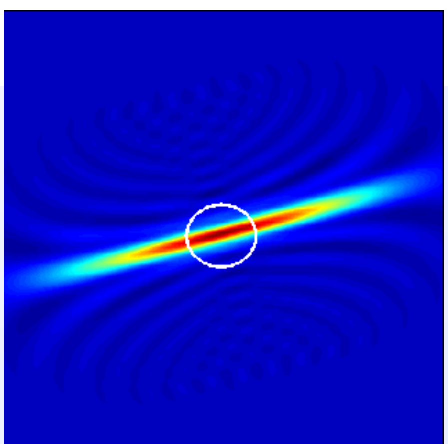
Higher Frequency Amplifiers

Current Microstrip SQUID Amplifiers have gain fall off at around a few GHz… need new ideas.

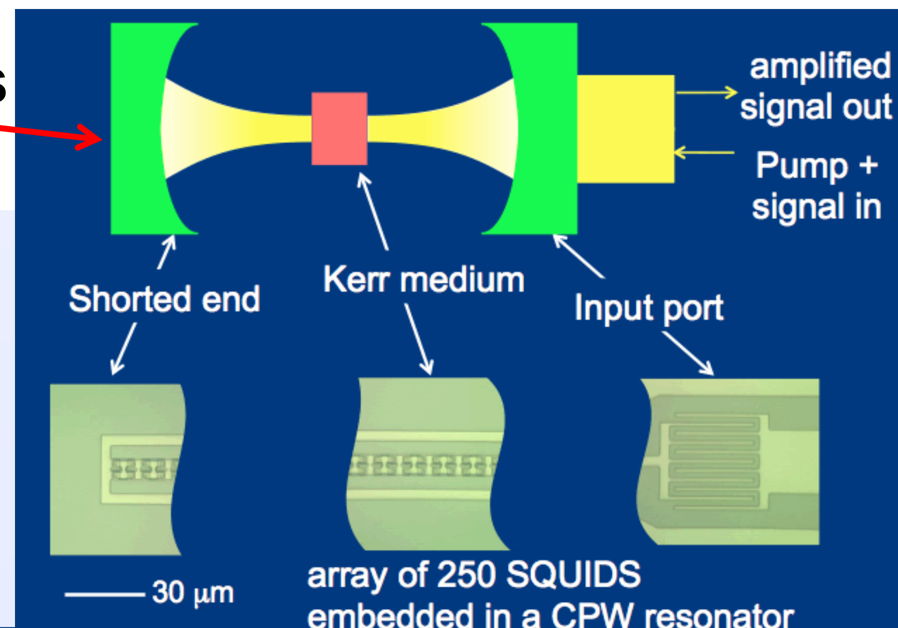


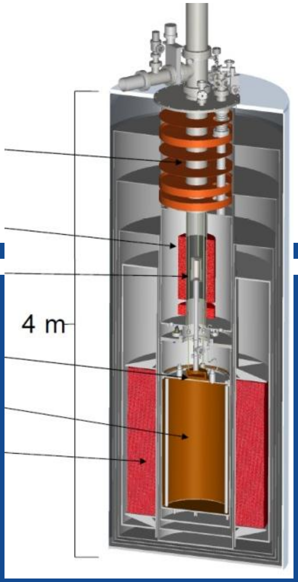
<u>Several possibilities</u>:

- **- in-line SQUIDs**
- **- "The Slug"**
- **- Josephson Parametric Amps**



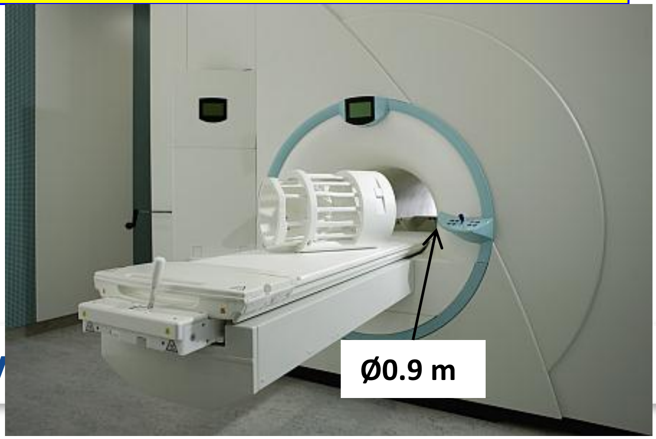
Konrad Lenhert
NIST

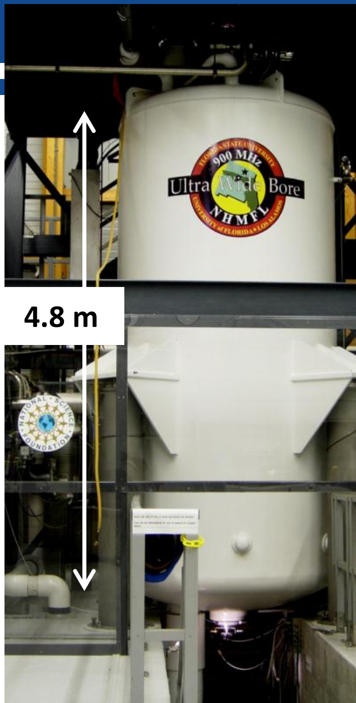




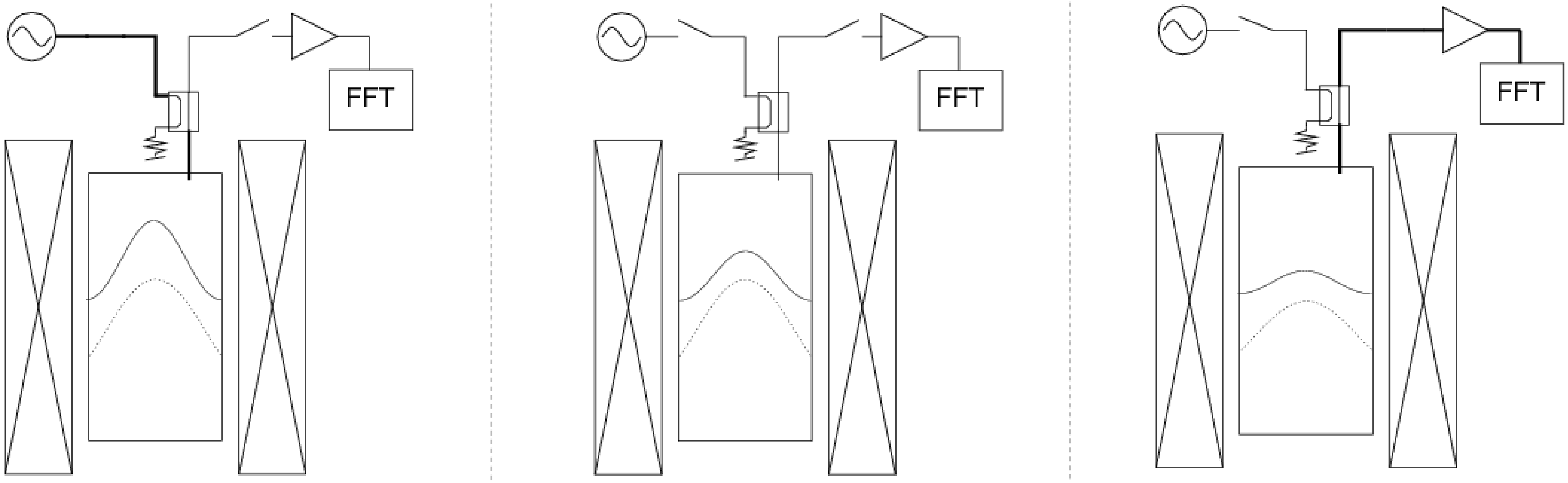
B_0^2V for Solenoids

Mark D. Bird
Director of Magnet Science & Technology at the National High Magnetic Field Lab, Tallahassee, FL





Utilizing ADMX for a Chameleon search



Step 1: Injected RF power excites E&M and chameleon modes

Step 2: Power is turned off, E&M modes decay

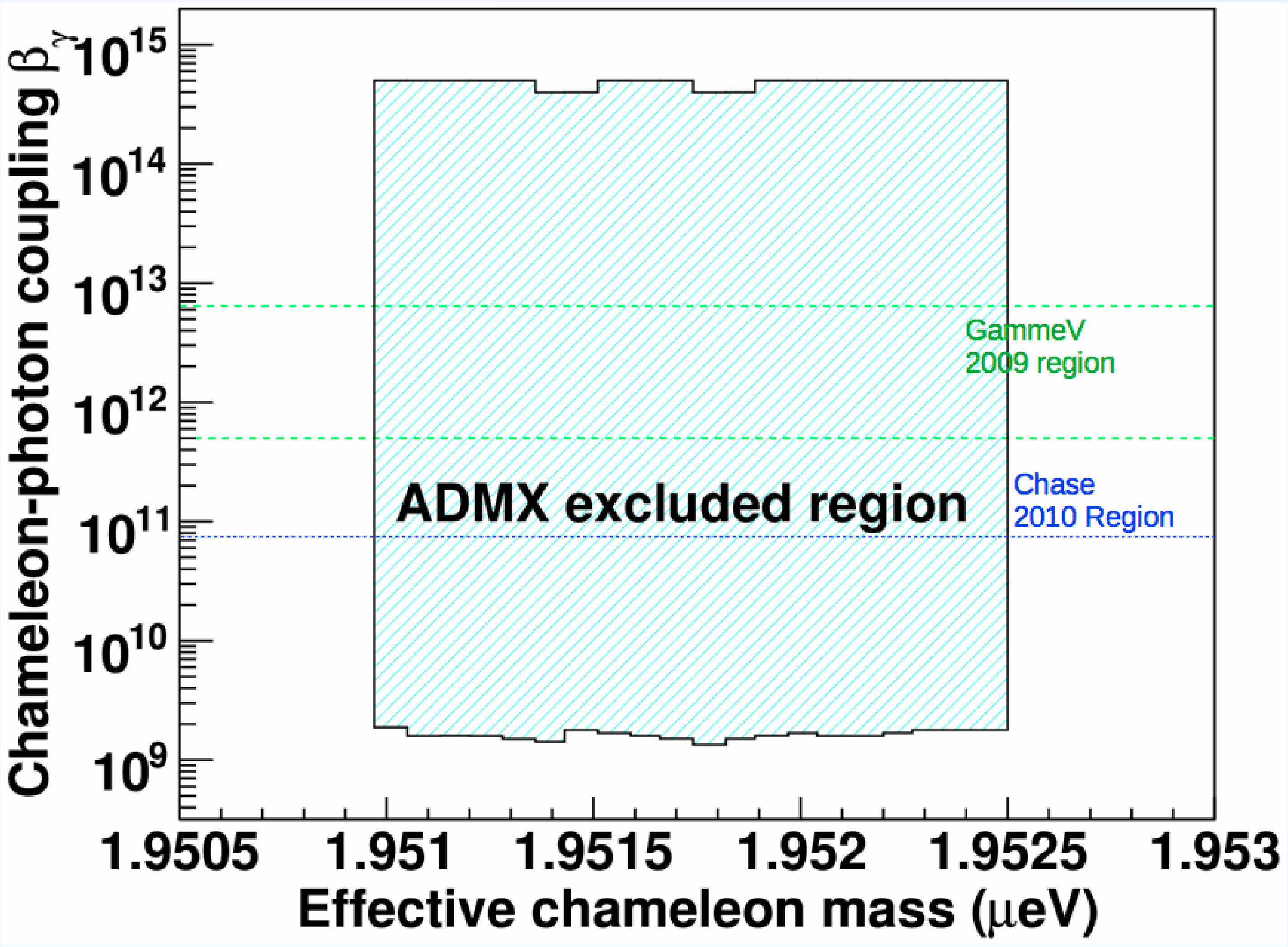
Step 3: Chameleon modes slowly decay into E&M modes which are detected through antenna

Timescale: 10 minutes
Power in ~ 25 dBm

Timescale: 100 milliseconds

Timescale: 10 minutes
Sensitivity ~ 10^{-22} W
Bandwidth ~ 20 kHz

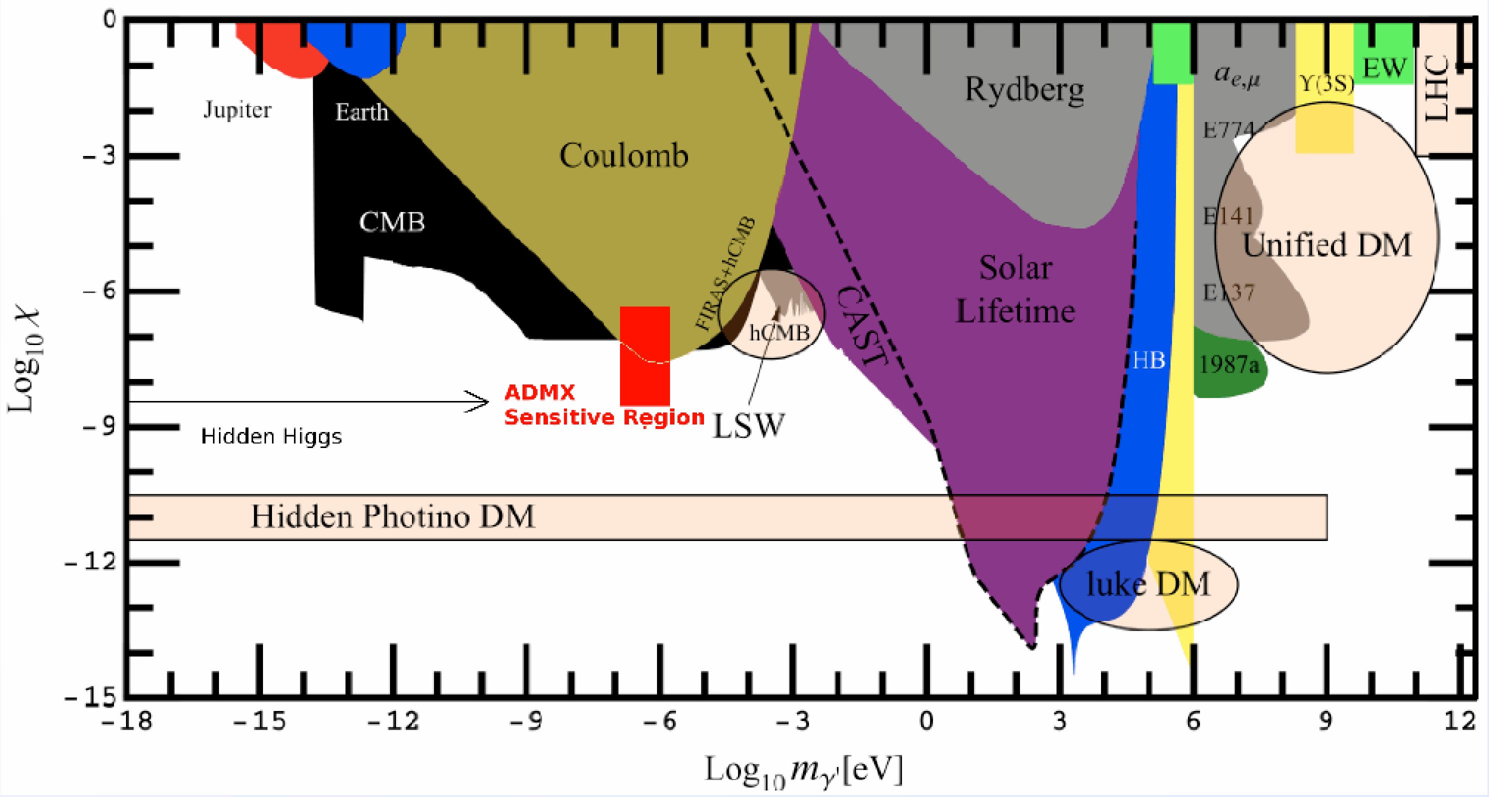
ADMX for a Chameleon search results (published in PRL)



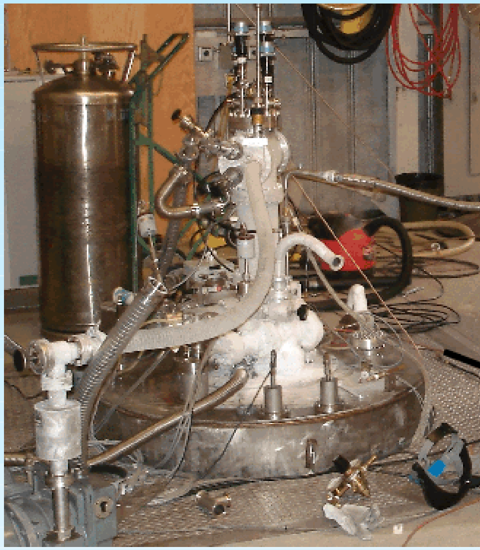
Laboratory Dark Energy Search

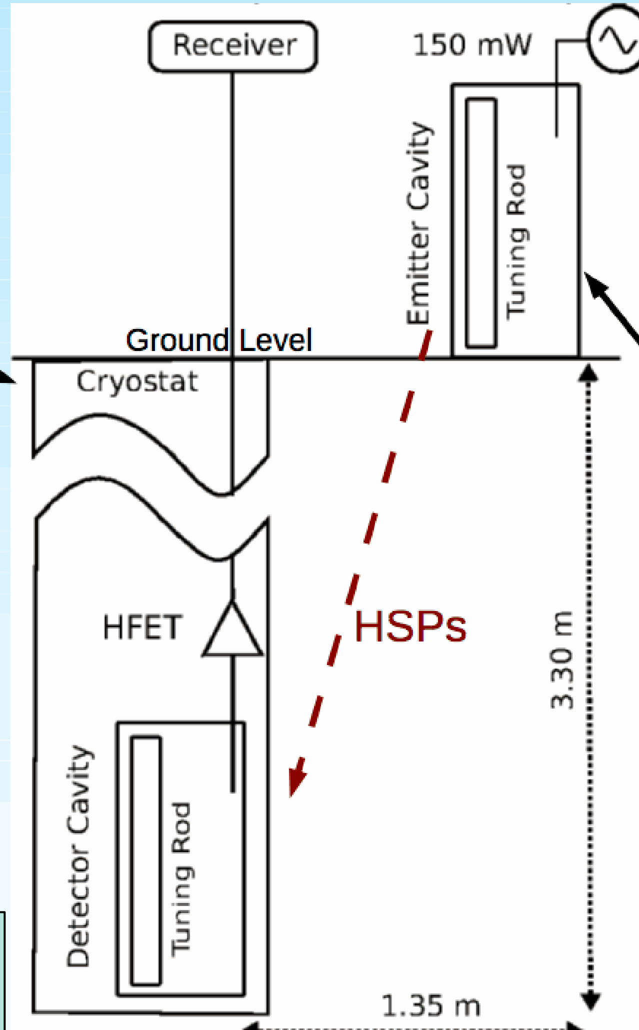
Other light bosons: Hidden Sector Photons

Additional U(1) symmetries that mix kinetically with the photon are ubiquitous in beyond-the-standard model physics
Other Names: U Boson, Paraphoton, Z', etc



Utilizing ADMX as a Hidden Sector Photon Receiver





1

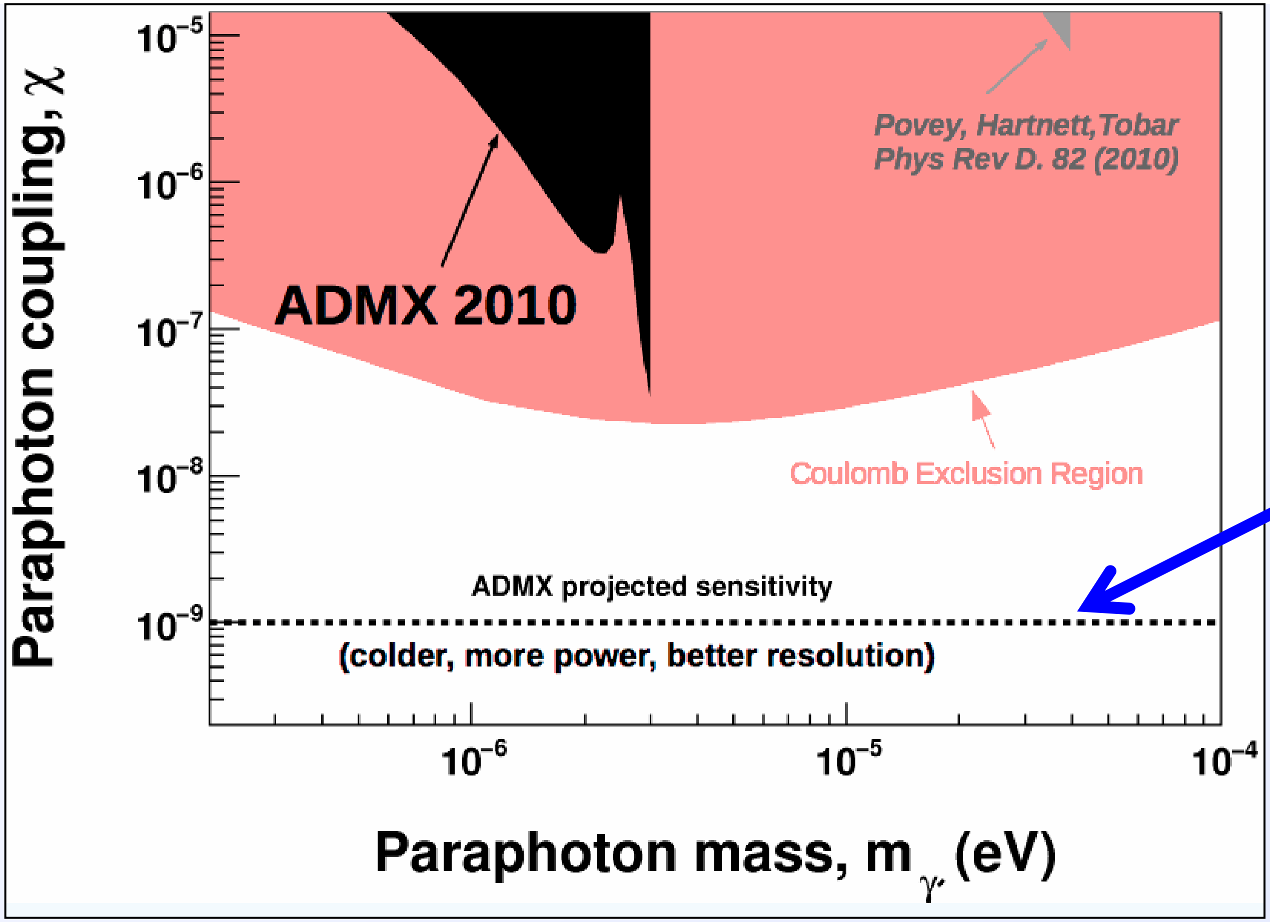
Photons in this driven cavity mix with HSPs and escape

2

HSPs mix with photons and are detected in the ADMX cavity

1 day of data taking as a proof of concept.

Results of ADMX search for hidden sector photons (published in PRL)

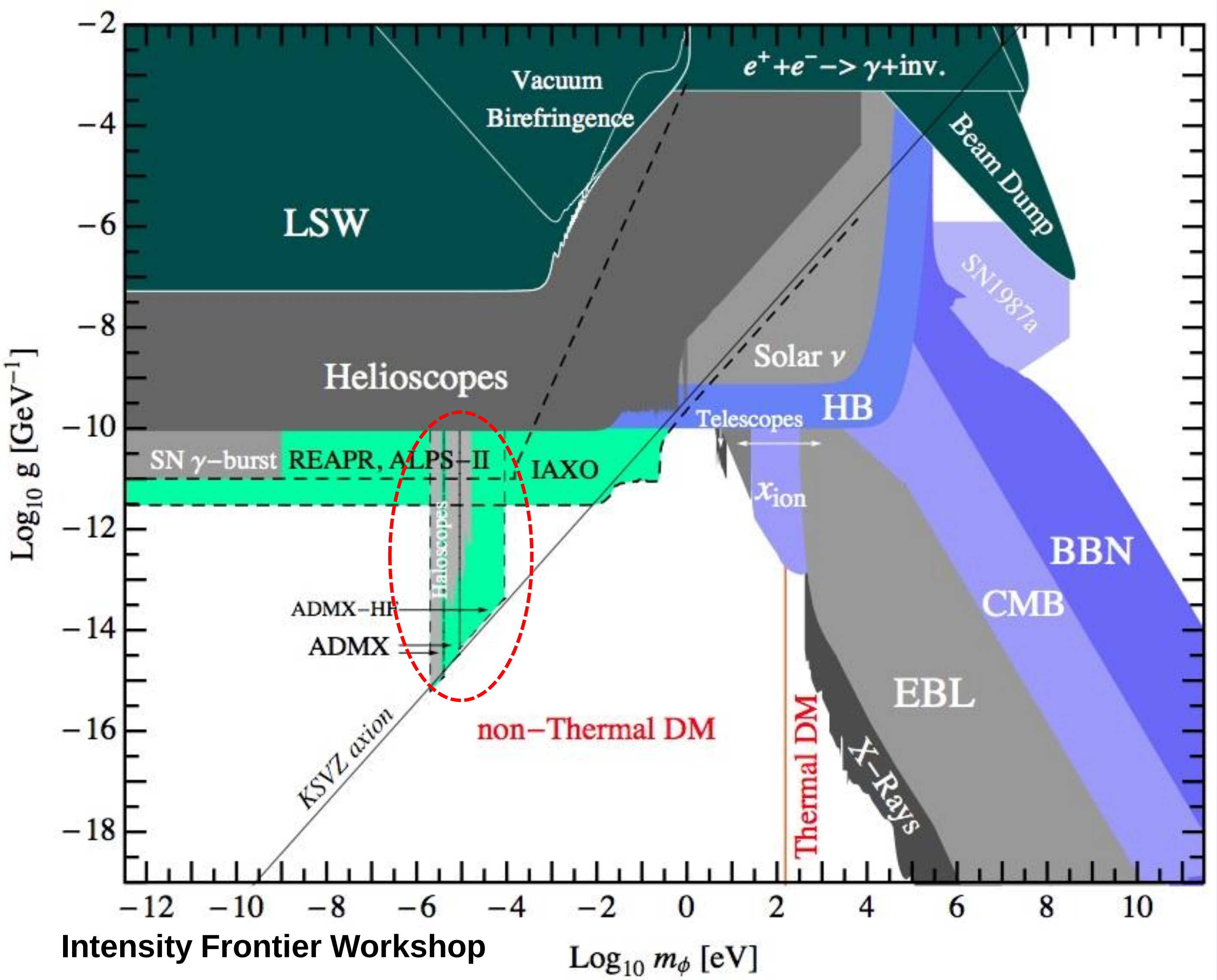


Run concurrently with Dark Matter Axion Search!

100x more sensitive than previous cavity search!
Competitive with indirect searches!

Questions?

View from 40,000 feet: Axion and Axion-Like-Particle Searches



Intensity Frontier Workshop