Results from phase 1: Axion Dark-Matter eXperiment

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The axion

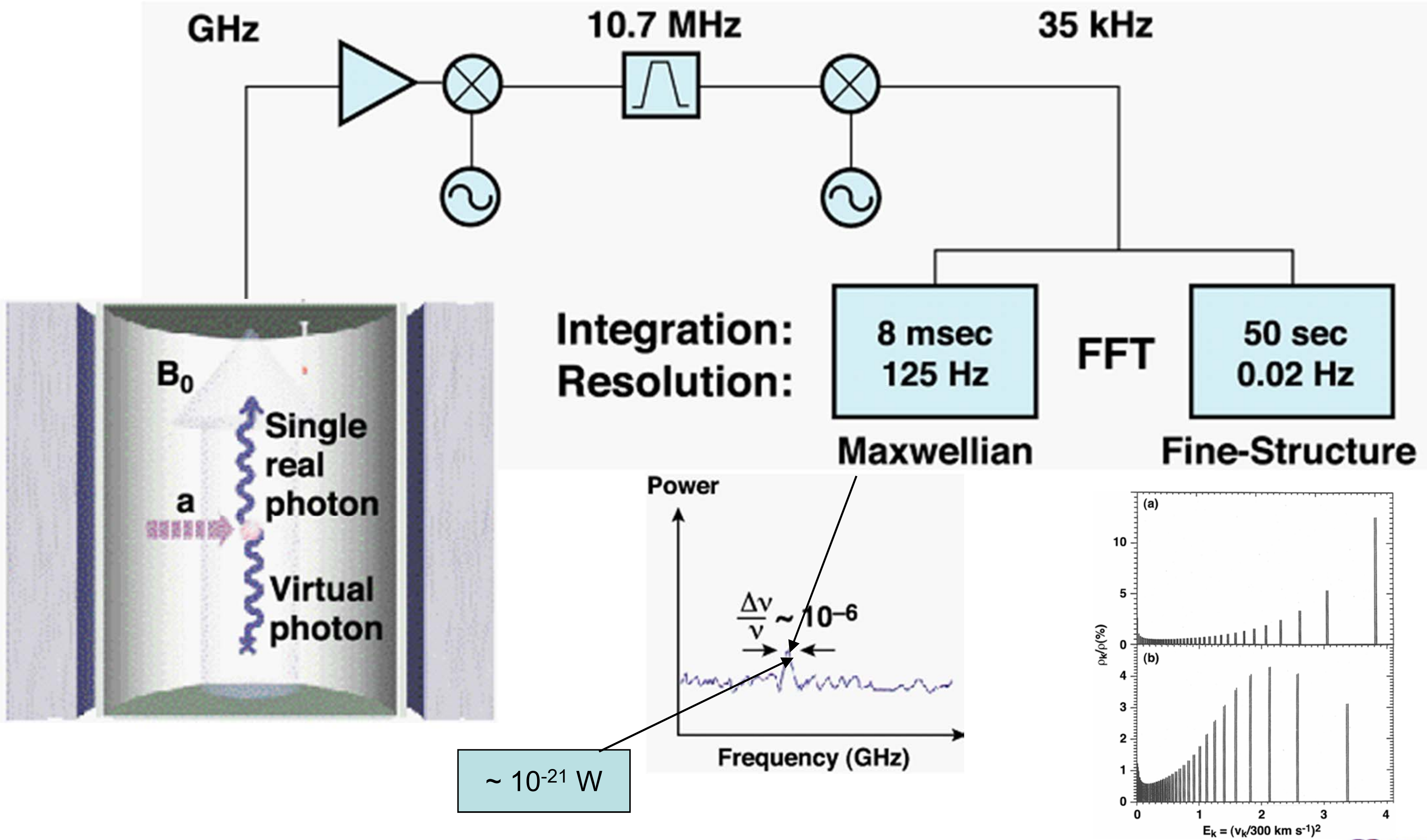
- Peccei-Quinn mechanism for strong CP problem -> *a*
- Decays by two-photon emission $a \rightarrow \gamma\gamma$ (but $\tau > \tau_{universe}$)
- Light axions very weakly coupled: $g_{aii} \sim m_a$
- Mass limits: $10^{-6} < m_a < 10^{-(2-3)}$ eV

  (*overclosure*) (*SN1987a*)

- Galactic halos may consist of axions
- At the Earth, ρ_{halo} = 0.45 GeV/cm^3 ~ 10^{14} /cm^3

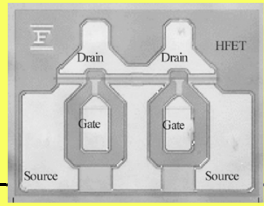
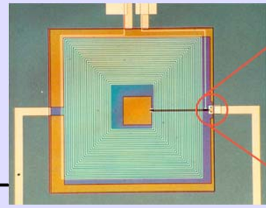
- Recent ideas (Bose condensation, caustics) make the case for axions even stronger

Cavity axion detector (Sikivie, 1983)

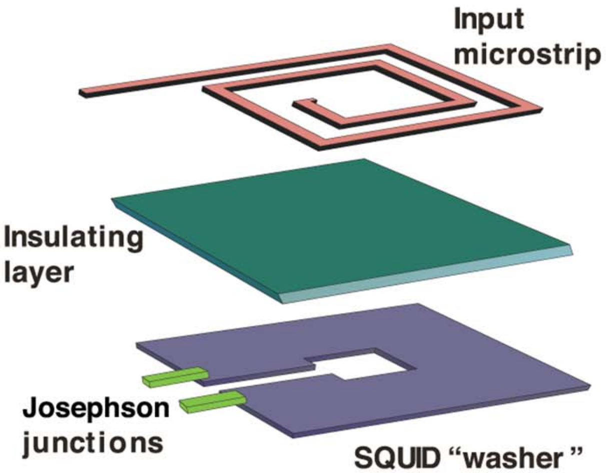


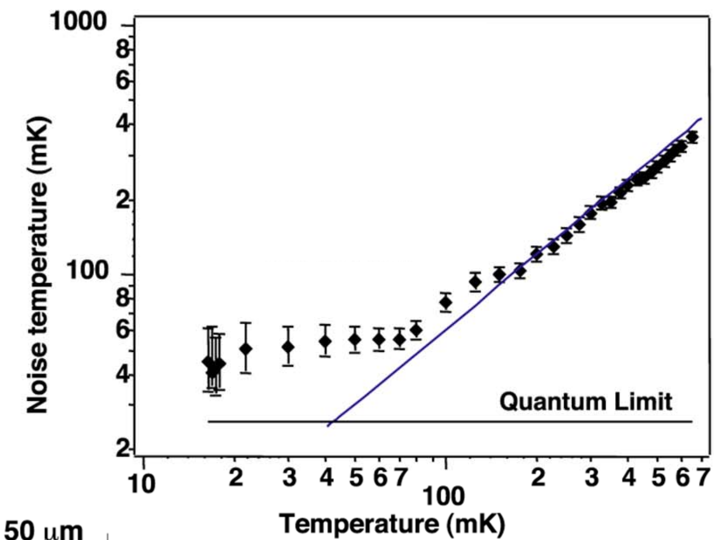
ADMX

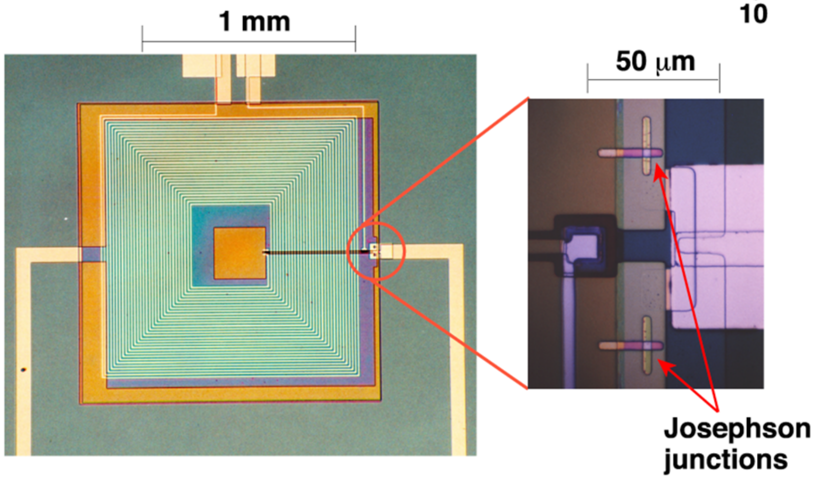
The Axion Dark Matter eXperiment

Stage	Orig. ADMX	Phase 1	Phase 2
Technology	HEMT; Pumped LHe 	Replace w. SQUID 	Add Dil Fridge 
T_{phys}	1.5 K	1.5 K	100 mK
T_{noise}	2 K	1 K	50 mK
$T_{sys} = T_{phys} + T_{noise}$	3.5 K	2.5 K	150 mK
Scan Rate $\propto (T_{sys})^{-2}$	1 @ KSVZ	2 @ KSVZ	300 @ KSVZ 17 @ DFSZ
		OR	OR
Sensitivity Reach $g^2 \propto T_{sys}$	KSVZ	0.7 KSVZ	0.25 DFSZ

ADMX Phase 1 exploits SQUID amplifiers





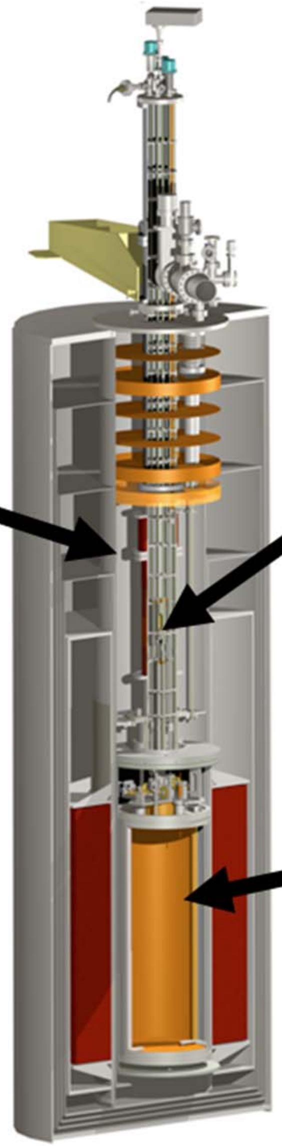


(J. Clarke *et al.*, U.C. Berkeley)

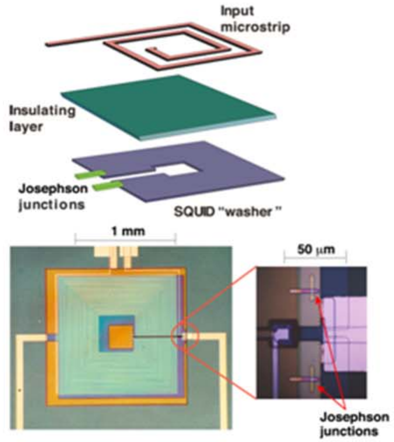
- SQUIDs have T_N~1 K, operated at T=1.5 K
- (~60 mK at ~100 mK)
- vs. 2.5-3 K for GaAs FETs
- Provides a significant increase in ADMX sensitivity

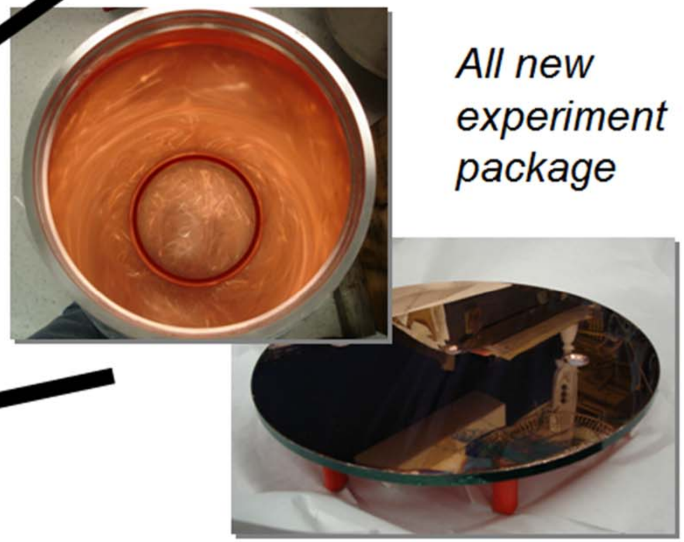
Phase 1 Upgrade

Field compensation magnet for SQUIDs



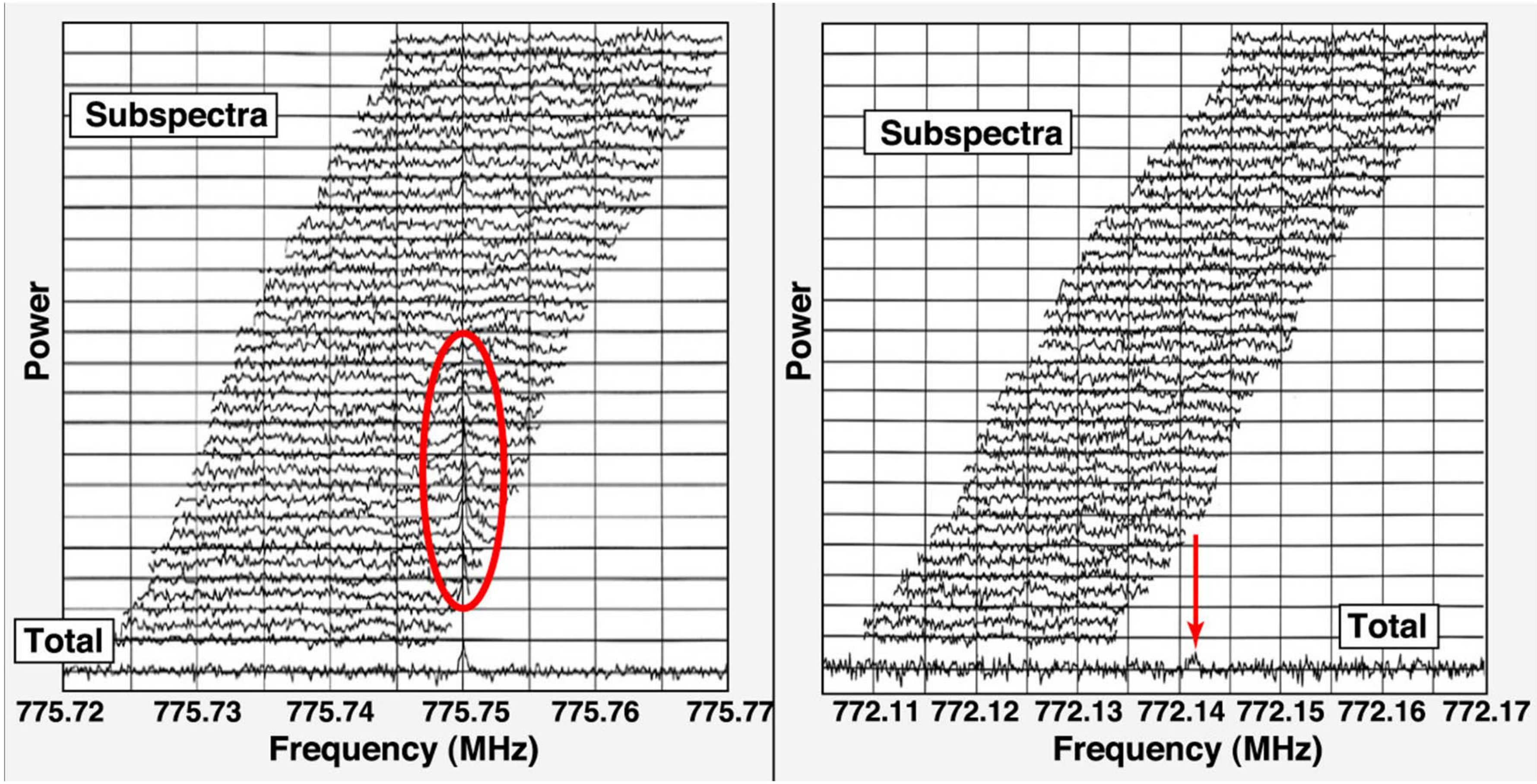
SQUID amplifier





All new experiment package

Cavity frequency stepped, measured ~80 sec, stepped…



- Maximizes off resonance:
  → external pickup

- In no single spectrum but appears in co-added spectra
  → statistical (or detection…)

Phase 1 operations: Science data

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SQUID-Based Microwave Cavity Search for Dark-Matter Axions

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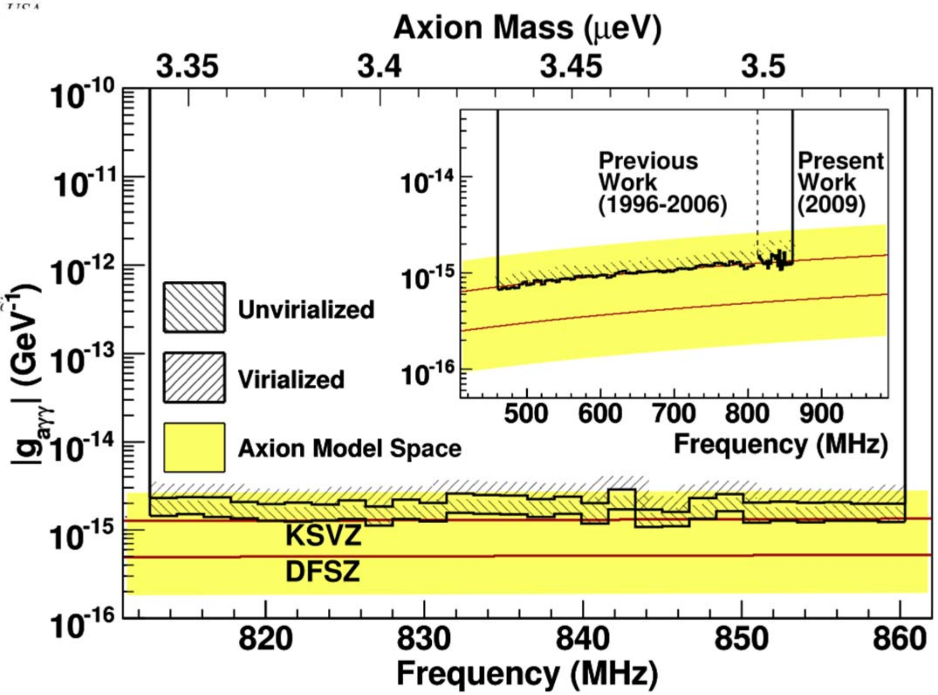
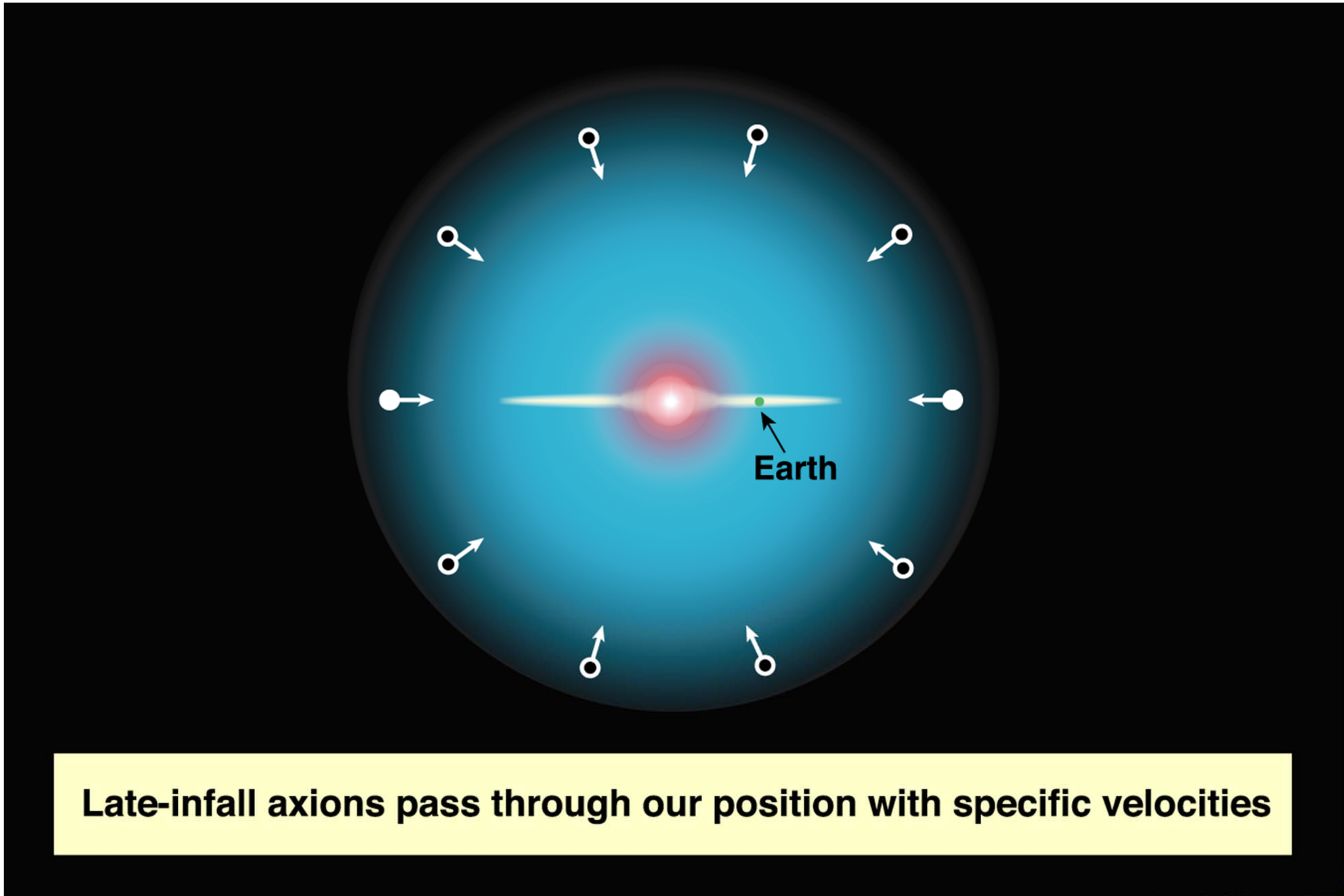


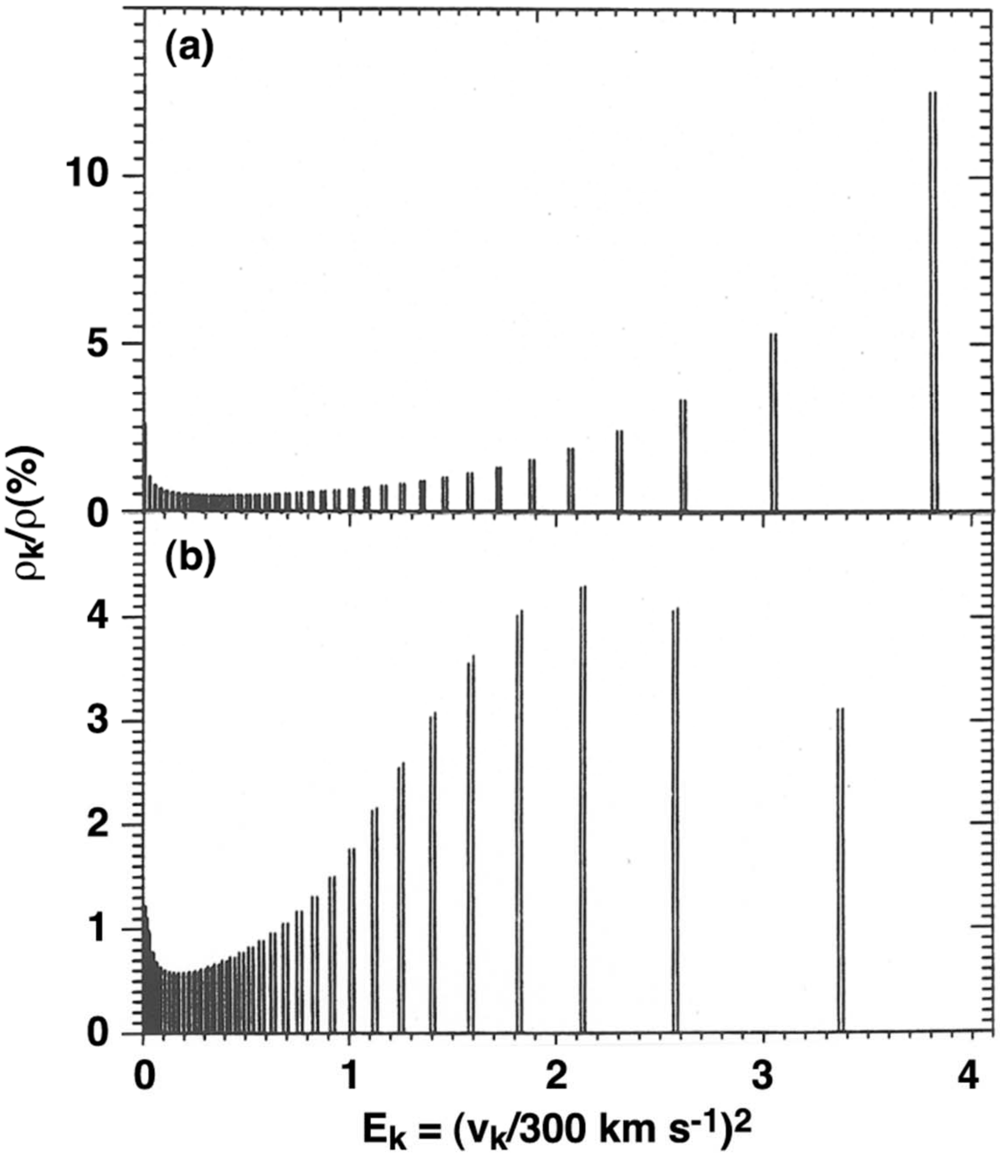
FIG. 5: Axion-photon coupling excluded at the 90% confidence level assuming a local dark matter density of 0.45 GeV/cm^3 for two dark matter distribution models. The shaded region corresponds to the range of the axion photon coupling models discussed in [23].

ADMX

Sharp features in the axion spectrum: the “HiRes” search



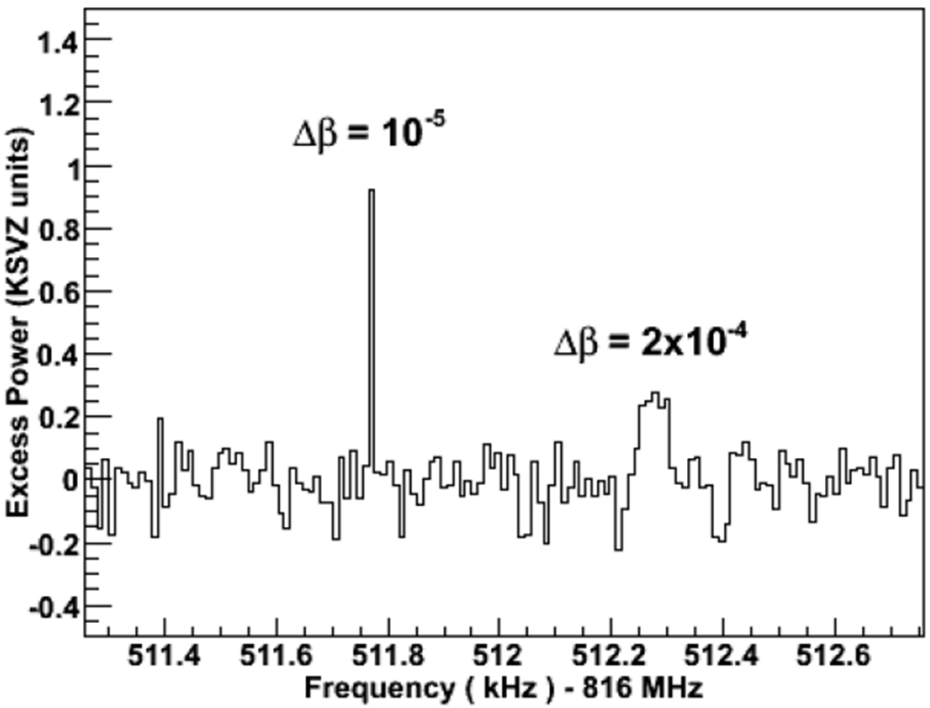
Velocity spectrum of axions at our solar system

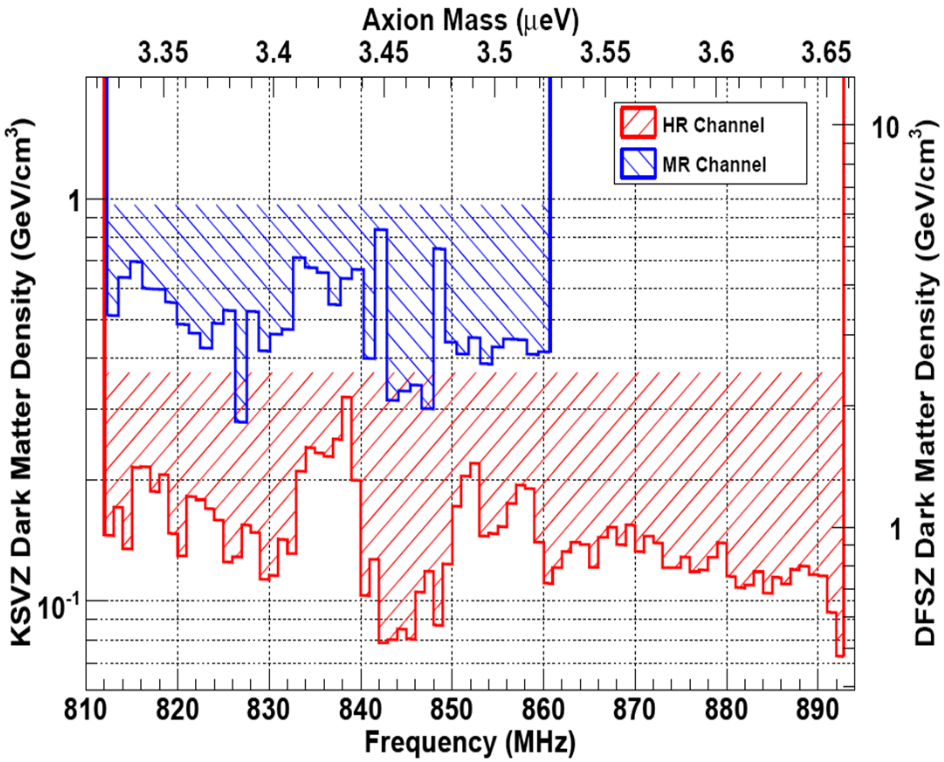


(a) No angular momentum

(b) Finite angular momentum

Phase 1 operations: High-Resolution Science data





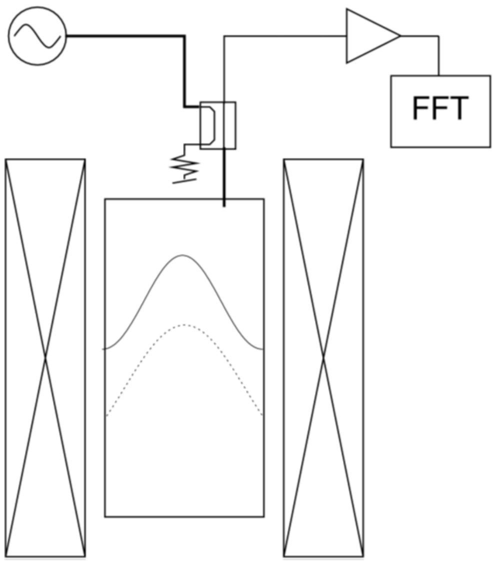
- •11 Hz bandwidth.
- Halo density ~ 0.45 Gev/cm3
- High resolution channel potentially gives greatly increased sensitivity
- Paper for PRD nearing final form.

ADMX

Phase 1 operations:
"Chameleons"& hidden-sector photons

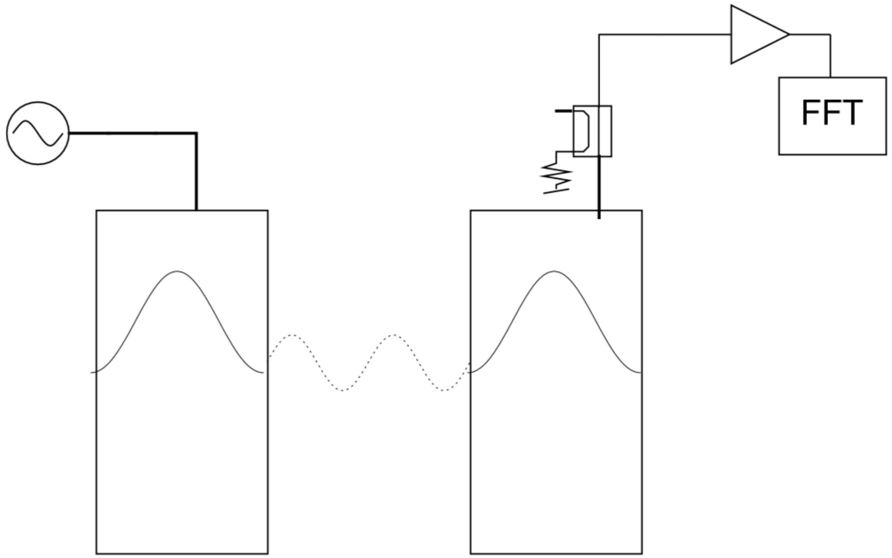
Chameleons

Scalars/pseudoscalars that mix with photons, and are trapped by cavity walls. Arise in some dark energy theories. Detectable by slow decay back into photons in cavity



Hidden-sector photons

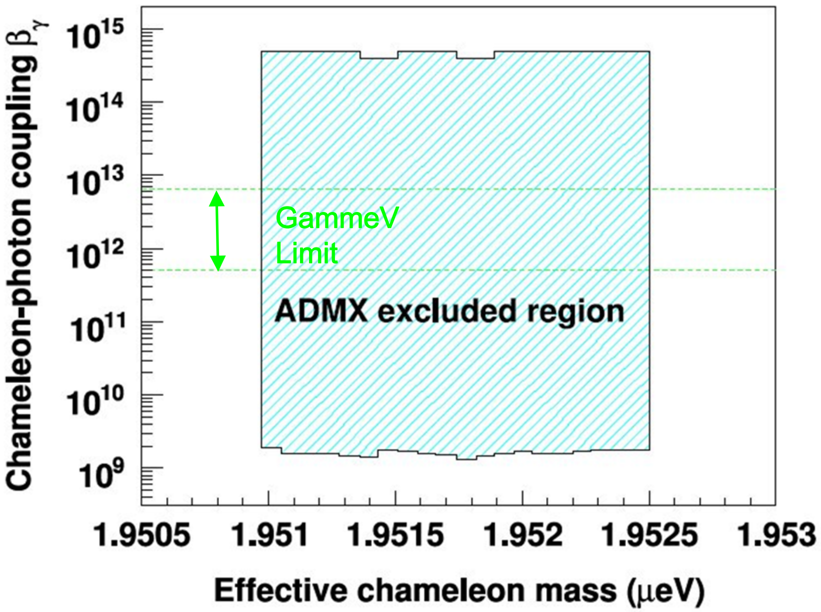
Vector bosons with photon quantum numbers and very weak interactions. Detectable by reconverting HSPs back into photons in ADMX cavity*



*Proposed by: *Jaeckel & Ringwald (2008)*

Phase 1 operations: "Chameleons"& hidden-sector photons (2)

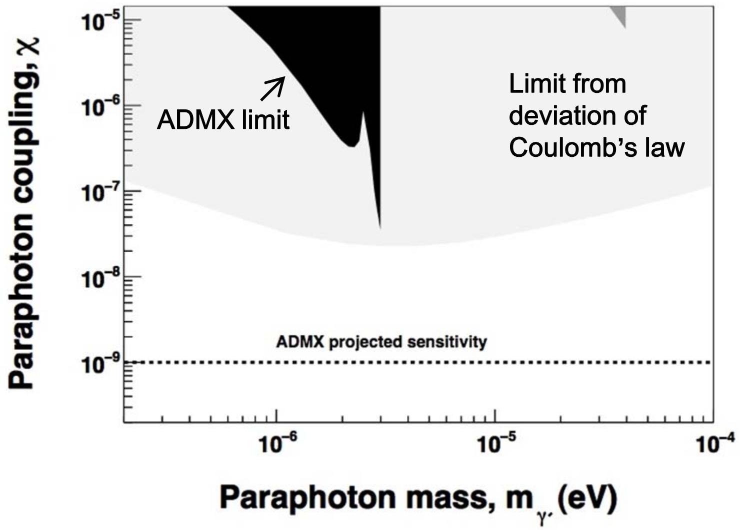
Chameleons



One day of running in June set limits 100 times more sensitive than GammeV experiment.

Published: □DOI:10.1103/PhysRevLett.105.051801

Hidden Sector Photons



ADMX direct limits on HSP coupling comparable to best indirect search. Next phase projected to extend limits by more than a factor of 10.

Paper submitted to PRL.
arXiv:1007.3766v1 [hep-ex]

ADMX

Prospects

The axion remains a very compelling dark-matter candidate.

The Phase 1 Upgrade to ADMX met its key milestones:

- Instrument: cryogenics, magnetic field cancellation, SQUID amplification
- Science papers: 3 PRL, 11 Hz HiRes for PRD, Receiver, Move,
  20 mHz HiRes

Phase 1 extended, FY2011-14:

Phase 2: FY2014-17

THE END

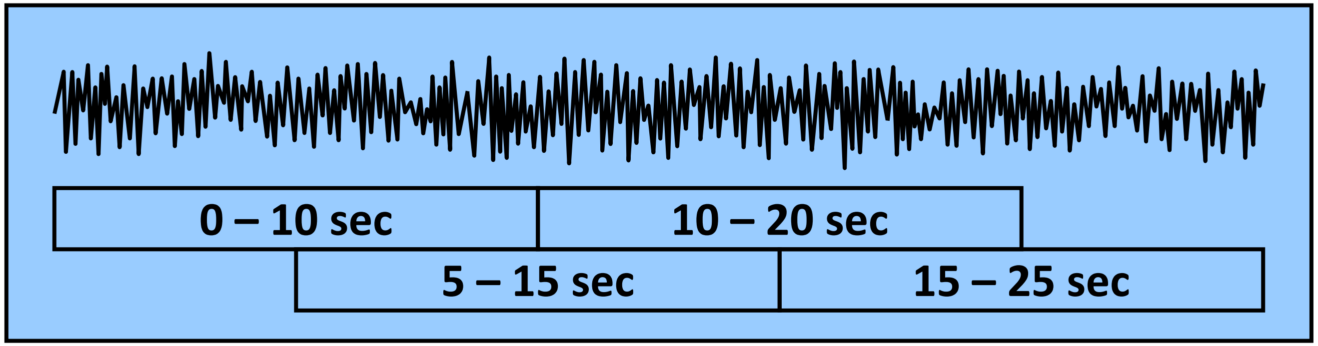
Signal Modulation

- Rotational motion:
  - v_r = 0.5 km/s
  - A_r = 3 Hz (over day)
- Orbital motion:
  - v_o = 30 km/s
  - A_o = 200 Hz (over year)

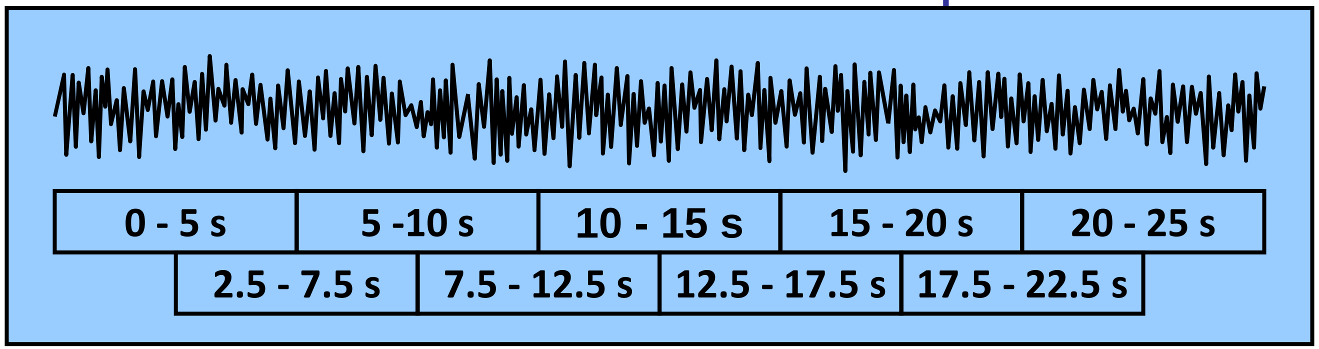
- Rotational modulation of 20 mHz/80 sec sets maximum resolution.
- We measure at each f_0 at 10-20 times in sequence and return to it again at 2-5 arbitrary times during a 3 month period.
- Candidates will Doppler between 0 and 195 Hz.
- Will need to search in vicinity of each candidate in a systematic way.

Multiple FT, then average

- Time series data can be broken up.



- Overlapping windows provides correlation.
- Smaller time intervals follow same pattern



Phase I operations: Science data

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Search for Chameleon Scalar Fields with the Axion Dark Matter Experiment

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Search for Hidden Sector Photons with the ADMX Detector

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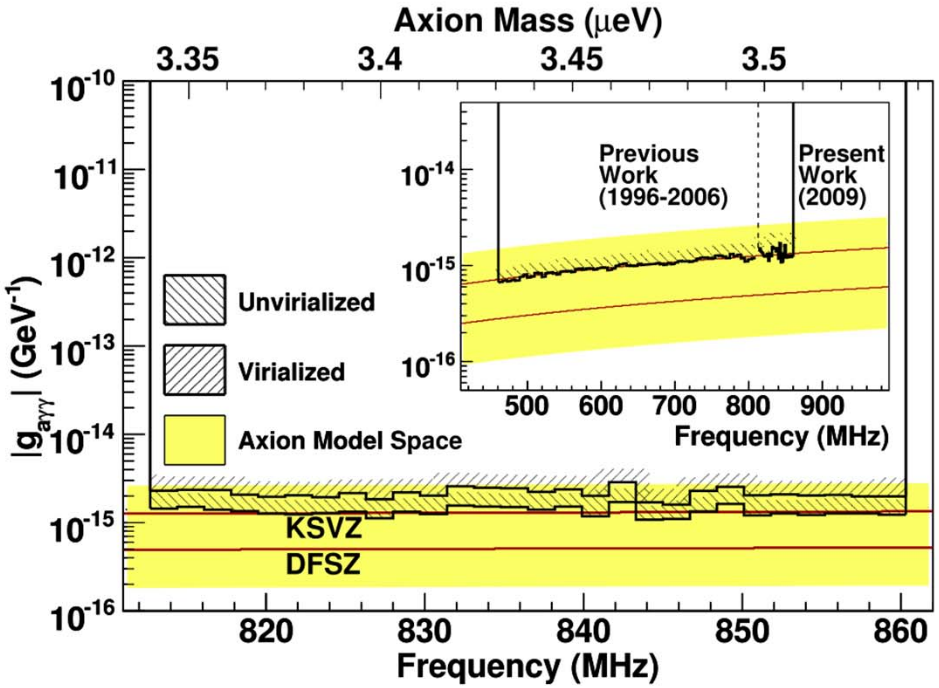

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ADMX

ADMX history through Phase 0

- Pilot experiments at Brookhaven (RBF) and Florida (1985 – 1992)
- R&D, preliminary design of “original ADMX” (1987 – 1992)
- “Phase 0” Construction (1992 – 1995)
- Commissioning (mid 1995 – March 1996)
- First PRL (March 1998)
- Data-taking (March 1996 – 2004); high duty-factor
- Original ADMX scanned 460–812 MHz (1.86 – 3.26 μeV) @ KSVZ

Signal strength

- Power from the cavity is

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

- $Q_L \sim 10^5$ and $Q_a \sim 10^6$

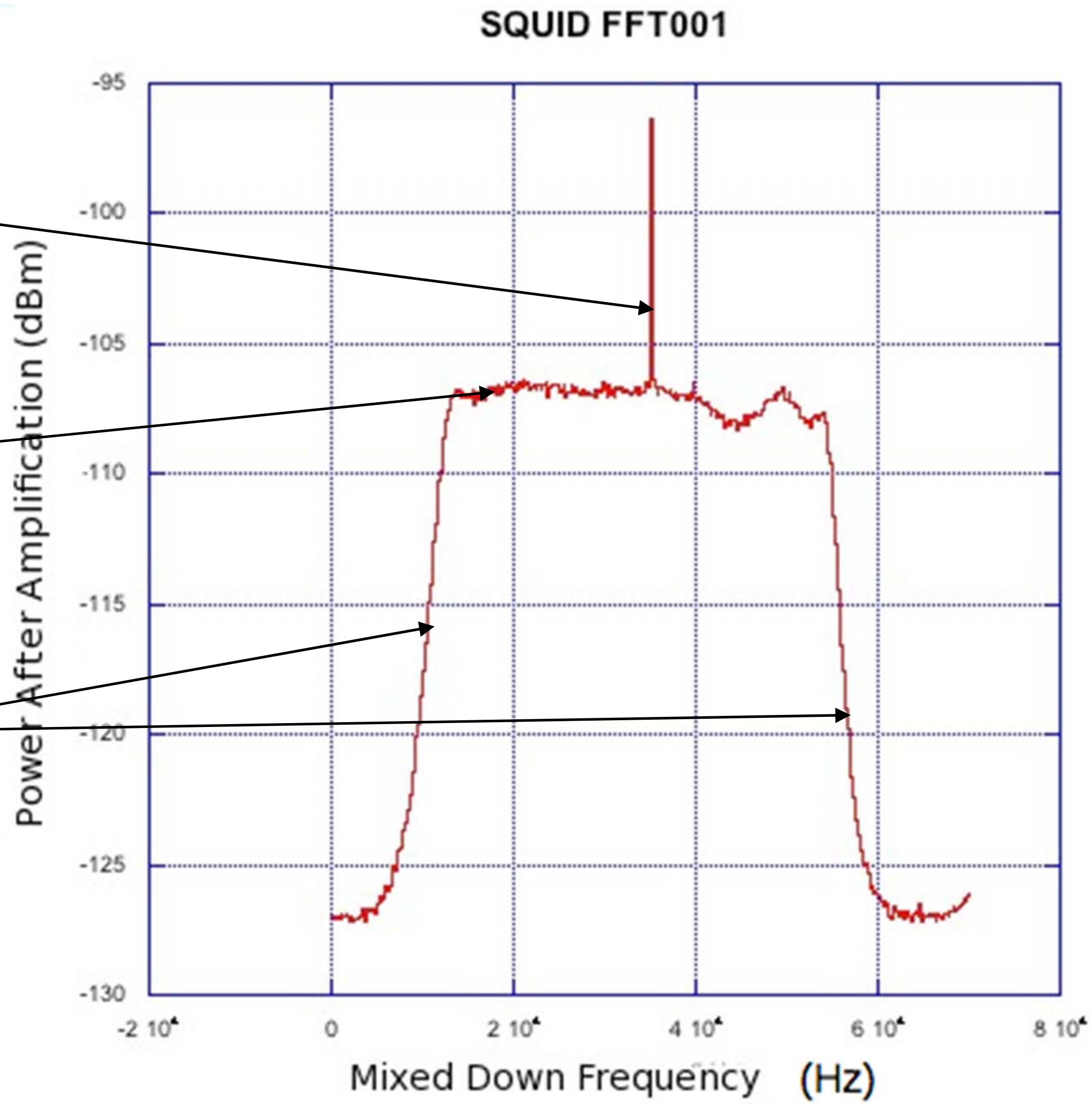
- For KSVZ axions, $g_\gamma \sim 0.97$,[1] whereas for DFSZ axions $g_\gamma \sim 0.36$.[2]

[1] The KSVZ model is one implementation of the 'hadronic axion,' J.E. Kim, Phys. Rev. Lett. **43**, 103 (1979); M.A. Shifman, A.I. Vainshtein and V.I. Zakharov, Nucl. Phys. **B166**, 493 (1980).

[2] The DFSZ model is based on a simple GUT scenario M. Dine, W. Fischler, and M. Srednicki, Phys. Lett. **B104**, 199 (1981); A.R. Zhitnitsky, Yad. Fiz. **31**, 497 (1980) [Sov. J. Nucl. Phys. **31**, 260 (1980)].

Phase I SQUID amplifier

- Injected Power
- Noise floor
- IF crystal filter



Timeline of ADMX Phase I

- Original ADMX: Phase 0, 7 years, scanned 460–812 MHz (1.86–3.26 meV) @ KSVZ
- Build insert for Phase I Upgrade (SQUIDS) (2004-2007)
- First cool-down of Phase I Upgrade (Fall 2007)
- Start of Phase I Upgrade operations at third cool-down (April 2008)
- Sept 2008–Dec 2008 Operations
- Jan 2009–Feb 2009 Access to fix thermal issues
- March 2009 – August 2010: Major milestones achieved:
  (1) Heat load at design value
  (2) Magnetic field bucking system operational
  (3) SQUID receiver chain operational
  (4) Production data-taking, axion search, chameleon search, hidden-sector photon search
  (5) Several papers from Phase 1, more to come.

Current issues

- Used a 10 Hz bin resolution.
  - Daily signal modulation of order 3 Hz
  - 256 co-added 40 mHz bins
  - Requires analysis change
- Oscillator stability is 10^{-10}.
  - For a signal at 800 MHz 0.08 Hz
  - Practical resolution limit of b ≈ 100 mHz
  - Max useful integration time of ~ 10 sec
  - Requires hardware improvements