ADMX:
Searching for Axions and Other Light Hidden Particles

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SLAC Dark Forces Workshop, Sept. 2009

ADMX

Axion **D**ark **M**atter e**X**periment

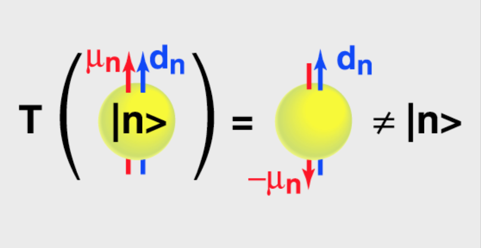
University of Washington
LLNL
University of Florida
UC Berkeley
NRAO
Sheffield University

1) Dark Matter Axion Search
2) Chameleon Search
3) Hidden Sector Photon Search

Axions

The Strong CP Problem

Lack of neutron electron dipole moment indicates strong force is CP invariant



edm<3·10^{-26} e-cm
Baker et al.
PRL 97 2006

How can the weak force be CP violating but the strong force remains CP invariant? O(10^{-10}) cancellation required

The Peccei-Quinn Solution

Add a dynamic field, spontaneously broken, which cancels the CP violation

This results in a new pseudo-goldstone boson, the Axion

-Weinberg, Wilczek

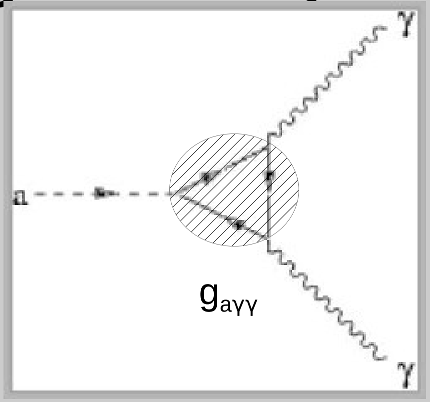
Axion Vocabulary

Axion – neutral pseudoscalar particle invented to explain why QCD is CP-invariant

Peccei, Quinn, Weinberg, Wilczek, etc.

Axion Mass (m_a) – single free parameter in standard axion ($\sim 1/f_a$)

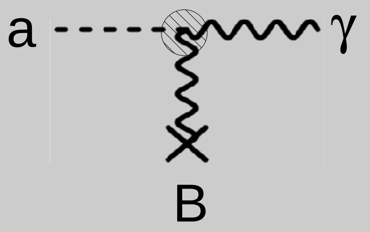
Axion-Photon Coupling ($g_{a\gamma\gamma}$) – experimentally accessible coupling. Mostly fixed by m_a.



Just like a light π^0

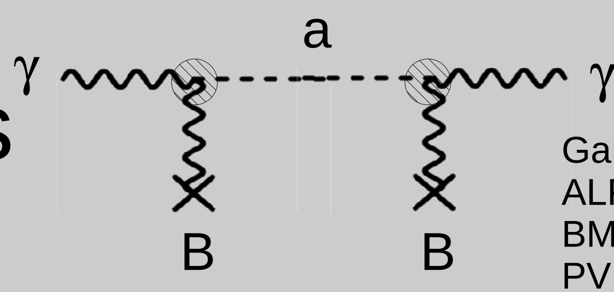
How to Look for Axions

- Look for Axion-Photon Conversion



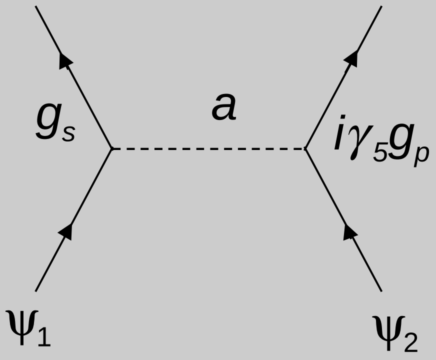
ADMX
CARRACK
CAST
Tokyo Axion Helioscope

- Make your own Axions



GammeV
ALPs
BMV
PVLAS
too many more to list...

- 5th Force Searches



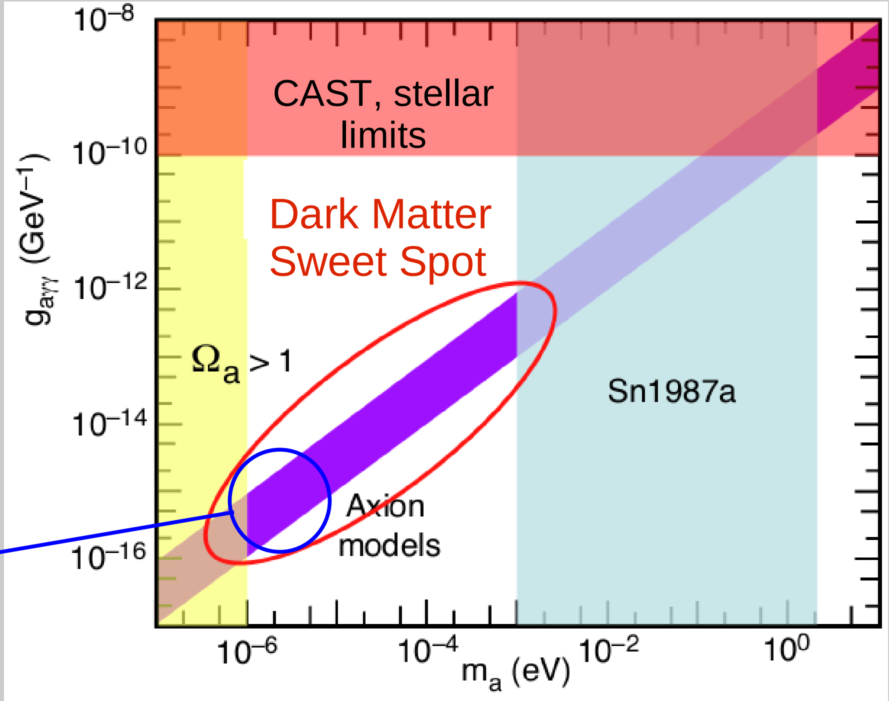
Eöt-Wash group
Equivalence principle tests

Axions as Dark Matter

When Peccei-Quinn symmetry is broken, a large number of axions are produced. (Vacuum misalignment mechanism)

With the right conditions, this makes enough Axions to account for dark matter

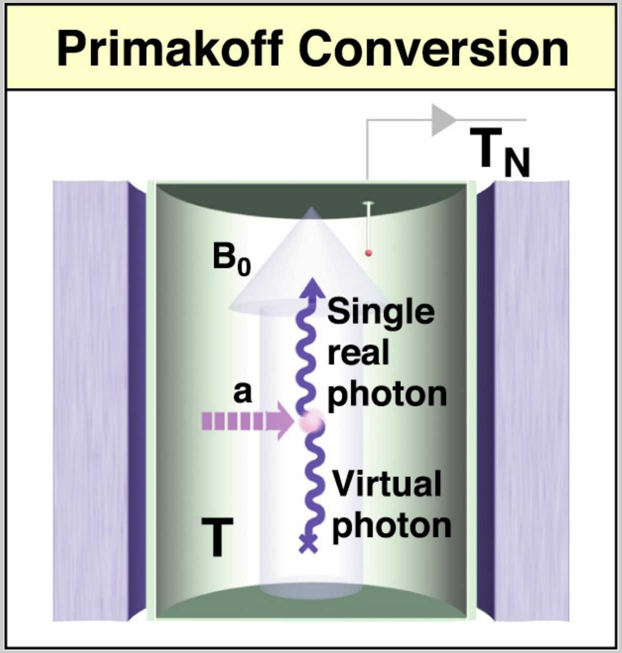
m_a<1 μeV
Makes too much Dark Matter



m_a>1 meV
Disfavored by SN1987a

ADMX
Target Region

Dark Matter Axion Cavity Experiments



Dark Matter Axions will convert to photons in a magnetic field.

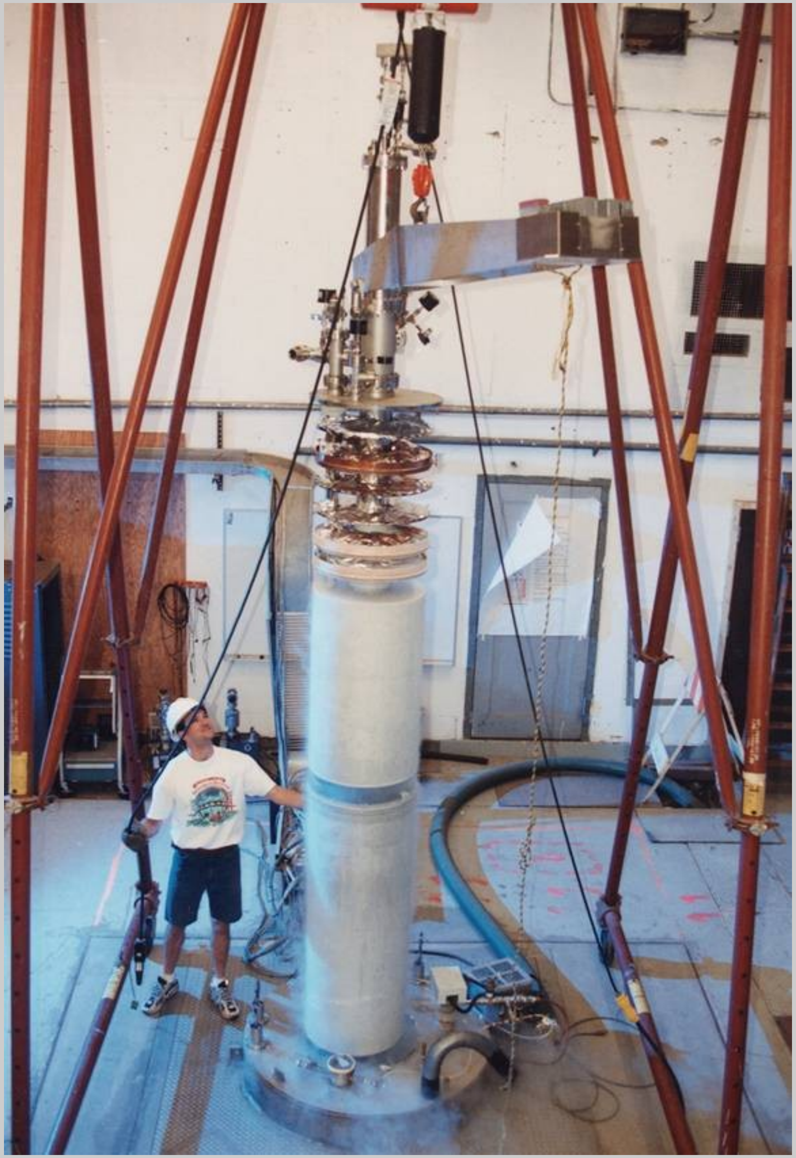
The measurement is enhanced if the photon's frequency corresponds to the cavity's resonant frequency.

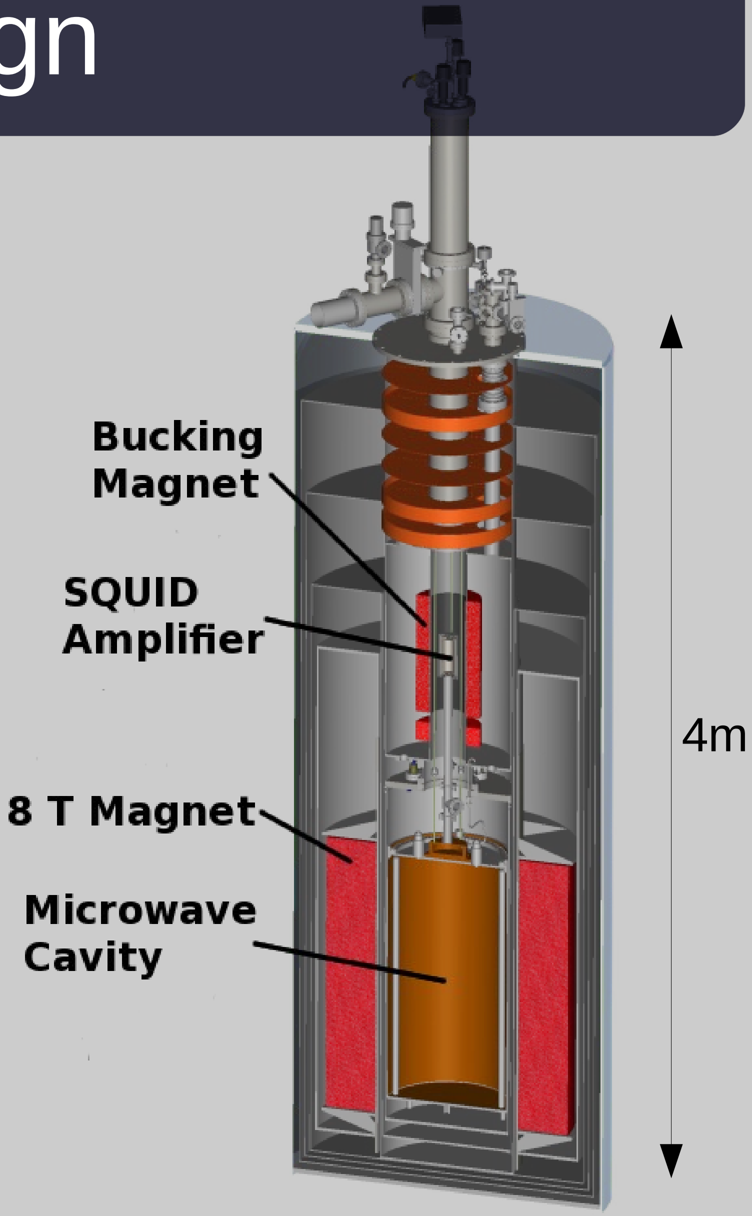
See: Sikivie, Phys. Rev. Lett. 1983

You Want:
-Large Cavity Volume
-High Magnetic Field
-High Cavity Q

You Don't Want:
-High Thermal Noise
-High Amplifier Noise

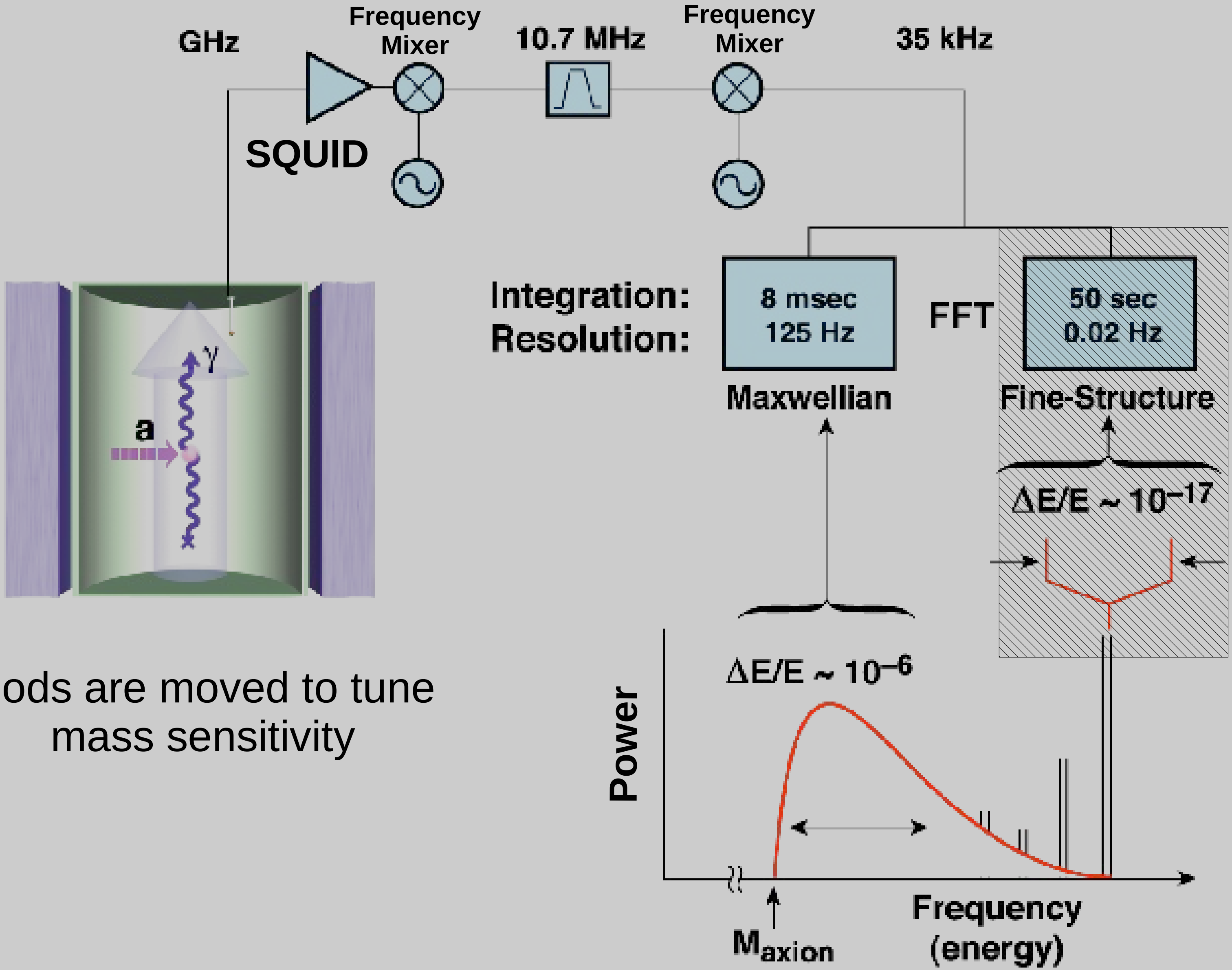
ADMX Design





Cavity Frequency changed by moving metal rods (not shown) inside cavity

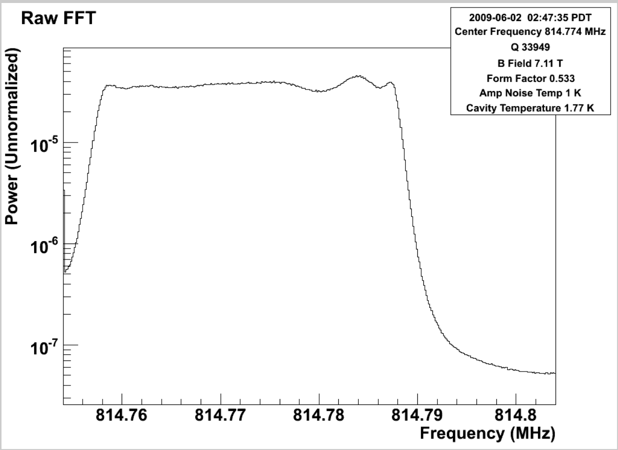
Axions to Power Spectra



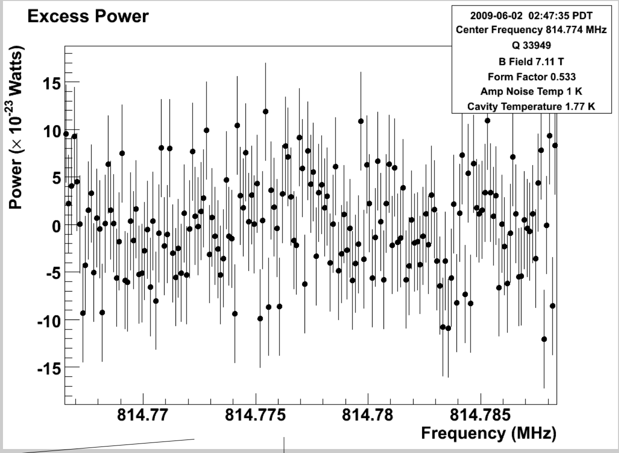
Rods are moved to tune mass sensitivity

Data Analysis

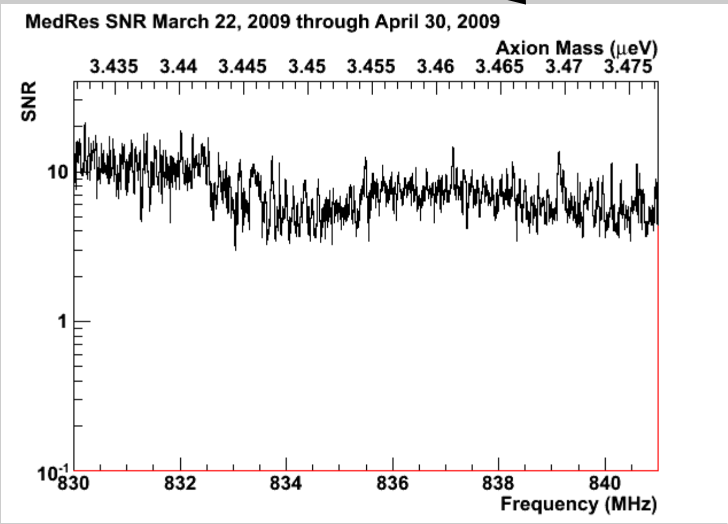
Raw Power Spectrum

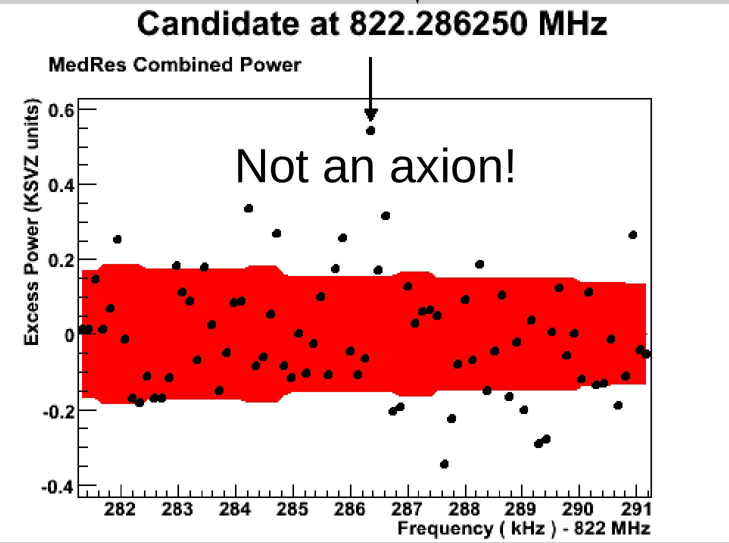


Receiver Effects Removed



Take a 20 KHz scan
Every 90 Seconds

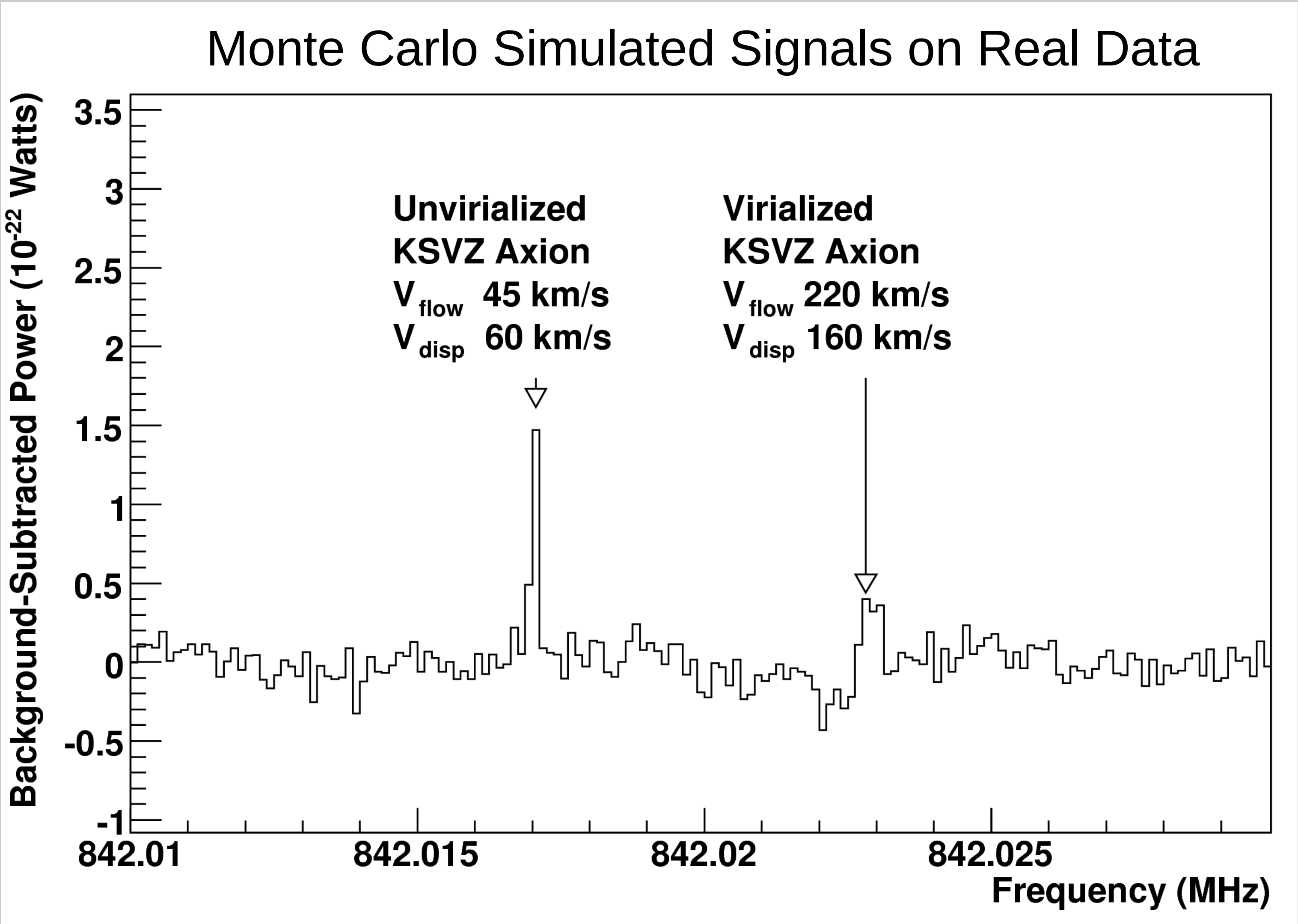




Combine scans into
10 MHz “nibble”

Rescan low SNR areas
and candidate axions
Every week

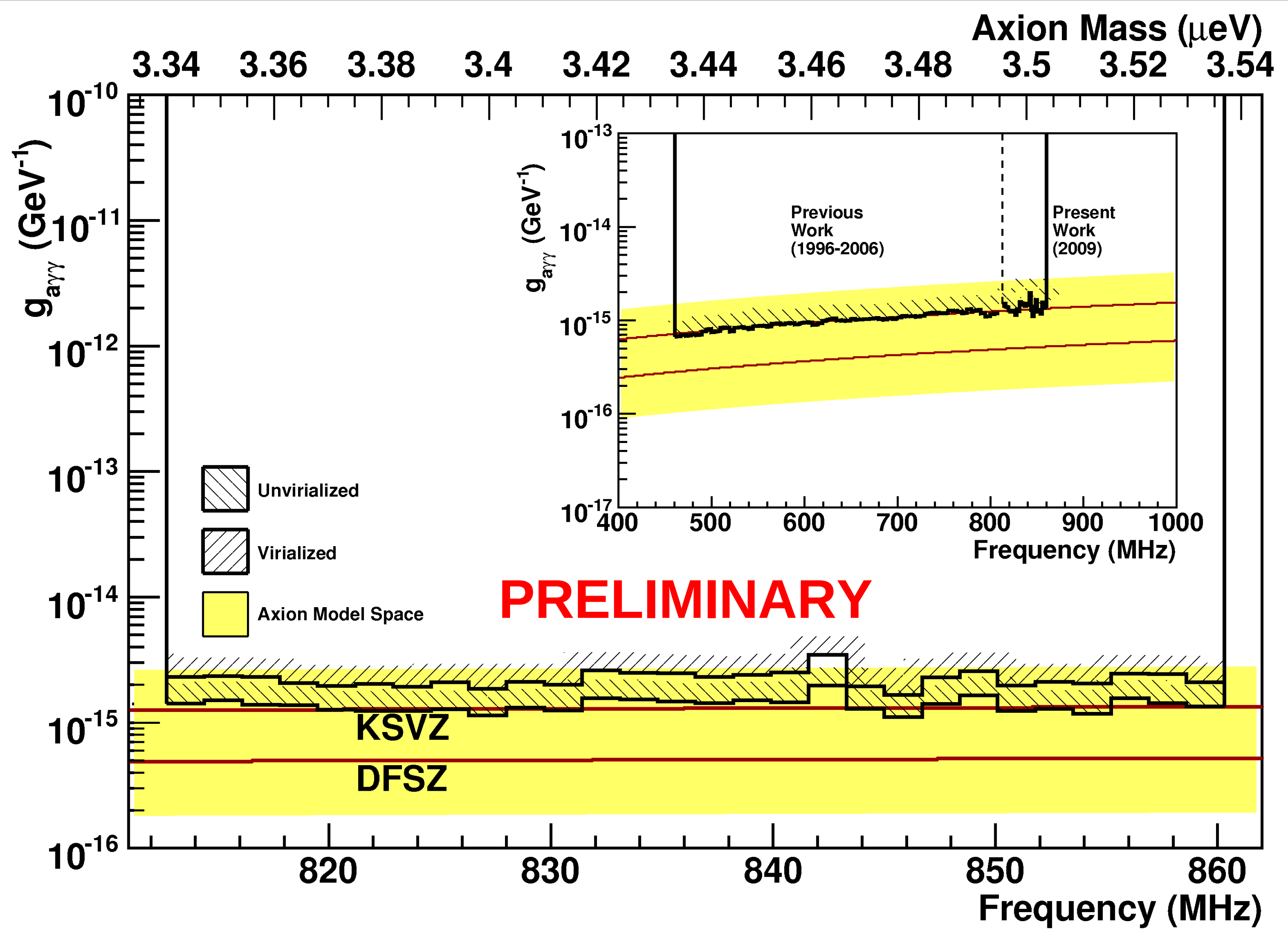
What Would Axions Look Like?



Power is proportional to axion-photon coupling

Sensitivity depends on dark matter distribution

Current Sensitivity



Assuming ρ_{DM}=0.45 GeV/cm^3

Sensitive to stronger models of axion-photon coupling

Especially sensitive to colder DM distribution models

What's Next for ADMX?

ADMX Phase 2 Goal

<u>Explore all reasonable dark matter axion models from 1μev to 10μeV</u>

How?

Dilution Refrigerator
allows us to reach temperatures
of 50 mK (We're at ~2 K now)

10 times lower temperature
= 100 times faster scan speed
-or-
10 times faster scan +
10 times more sensitive
to $g_{a\gamma\gamma}$

1-10 μeV covered
in half a year instead
of 50 years

Sensitive to Dark Matter Axions even at a fraction of halo density!

What else can we do?

While Axions are particularly well motivated, they aren't the only game in town

Chameleons

Light particles common to many New Physics theories

Couplings are severely limited by short-range gravity experiments, solar measurements

“Chameleon Interaction”: Mass dependent on local energy density

Makes experimental limits much weaker: thin-shell effect, no solar production, etc.

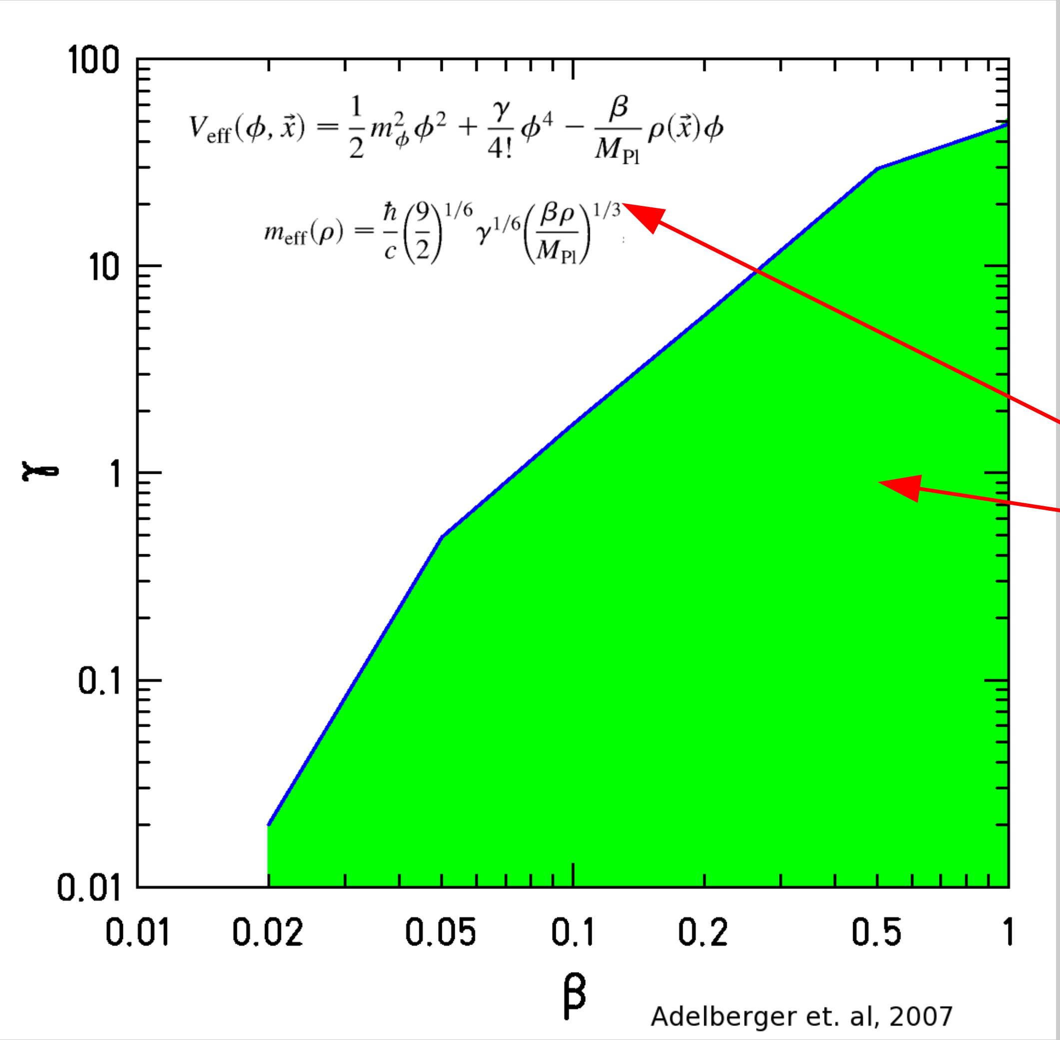
Chameleons: Motivation

OK, that sounds pretty ad-hoc, but...

- Energy density dependent mass ubiquitous to non-linear, self-interacting couplings
- Scalar fields are a useful way of making Dark Energy; the chameleon mechanism may have hidden them from short range gravitational experiments

Given that we don't have any better Dark Energy candidate, we might as well poke around for them.

Chameleons: Current Limits



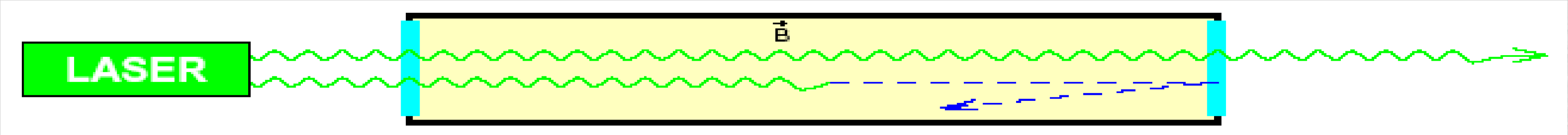
Fifth force and equivalence principle experiments still put the most stringent limits on chameleons

Pick a potential
Exclude Natural Parameters

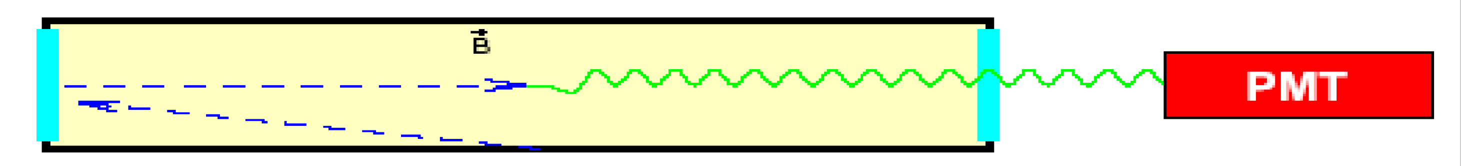
More exotic potentials still allowed.

Chameleons: Current Limits

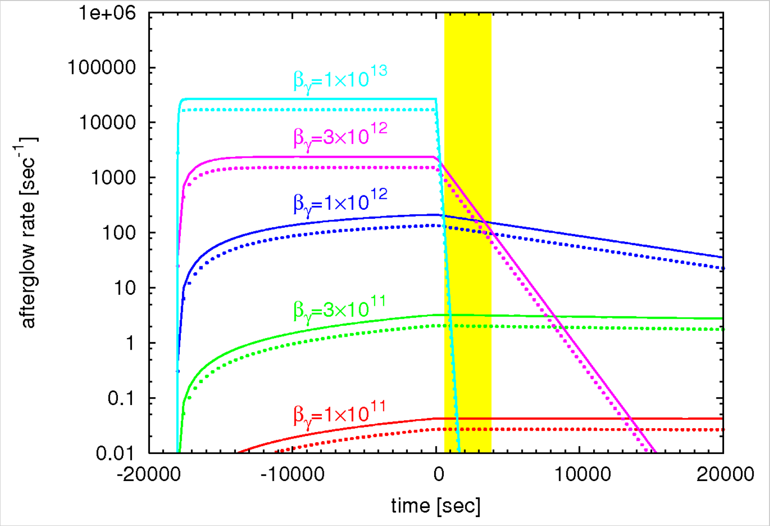
The GammeV Experiment looked for chameleon-photon coupling (Fermilab)



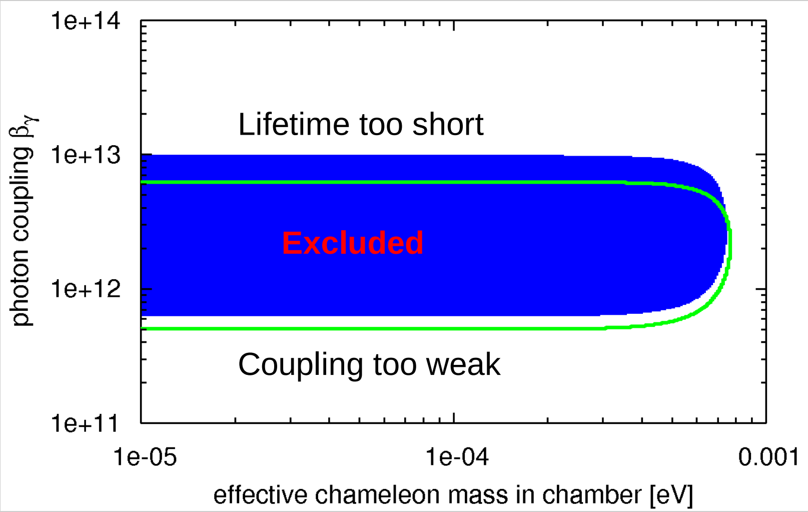
Step 1: Fill box with chameleons made from photons



Step 2: Look for photons from chameleon decay



Weakly coupled chameleons live longer

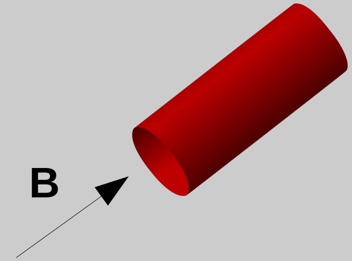


See: Chou et al. Phys. Rev. Lett., 2009

Chameleons in Microwave Cavities

Back to ADMX...

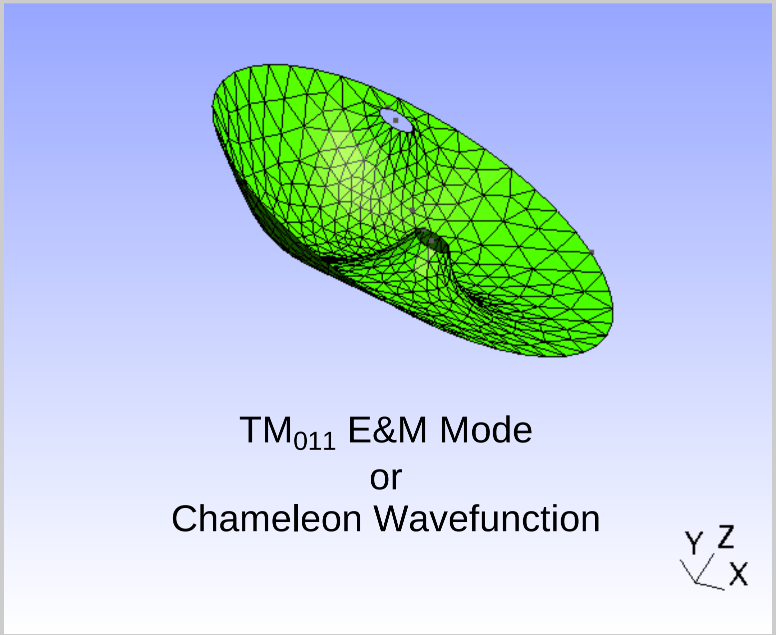
In a cylindrical cavity with a longitudinal B Field:



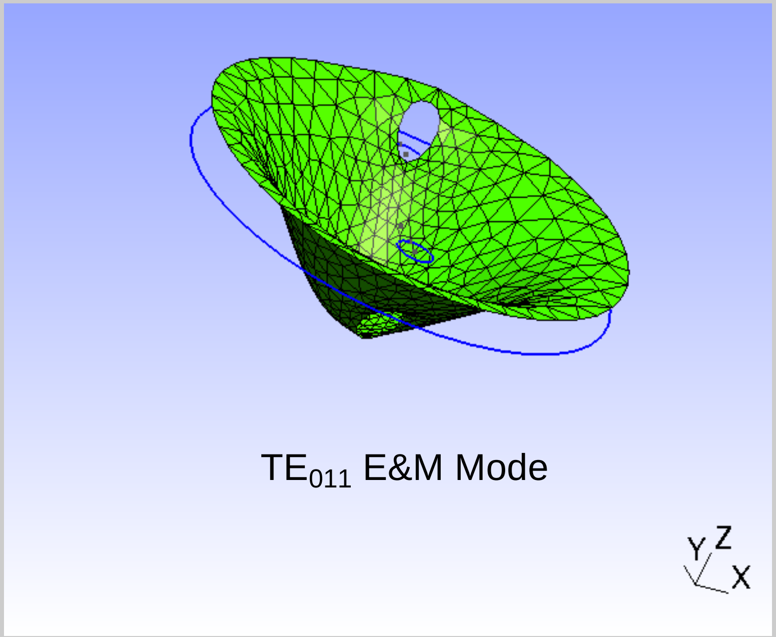
Pseudoscalar Coupling: E·**B** couple TM modes to chameleon modes

<u>Scalar Coupling</u>: B·**B** couple TE modes to chameleon modes

Vector Coupling: No **B** Field Necessary



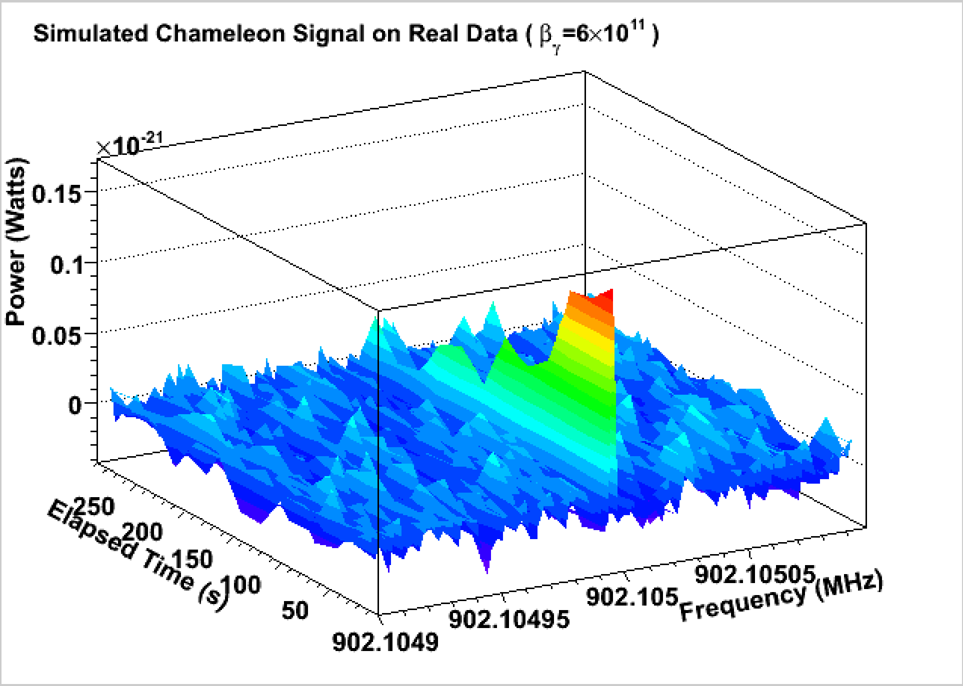
TM_{011} E&M Mode
or
Chameleon Wavefunction

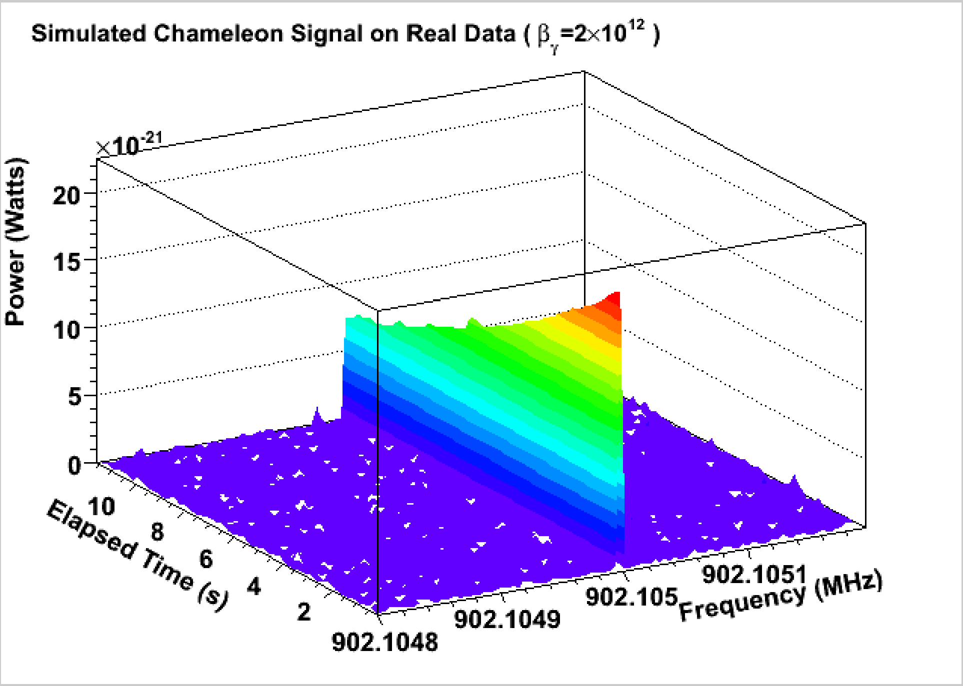


TE_{011} E&M Mode

Chameleon Search with ADMX

1) Tune E&M Mode so that $\omega^2_{E\&M}=\omega^2_{chameleon}+m^2_{chameleon}$
2) Excite E&M Mode with as much power as you can, for as long as you can afford (this in turn excites chameleon mode)
3) Turn off excitation, look for chameleon mode decaying into E&M mode

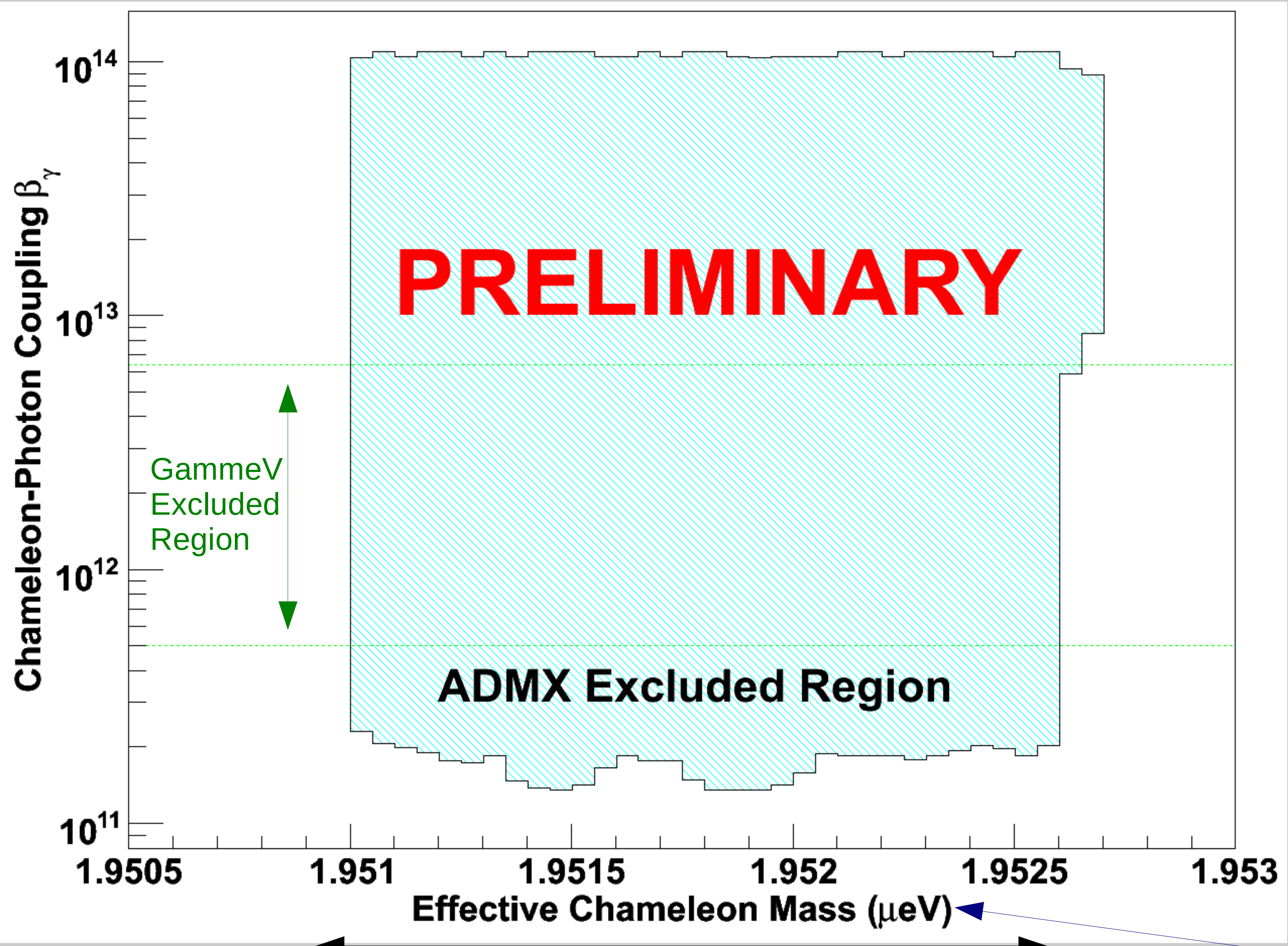




Weaker coupling leads to less signal, longer decay

Stronger coupling leads to more signal, but short decay time

ADMX Scalar Chameleon Sensitivity



One day of data-taking

Wide Coupling Sensitivity

Effective Mass in Cavity model-dependent

Very Narrow Mass Sensitivity

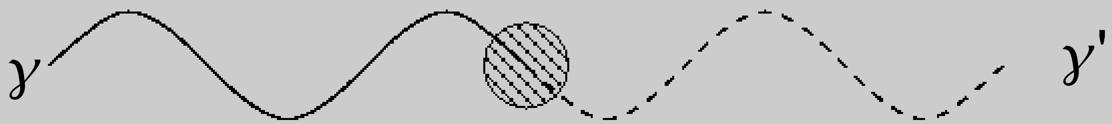
Conclusions from Chameleon Search

- A single day of data taking with ADMX probed new scalar chameleon model space
- Cavity searches have excellent sensitivity to chameleon-photon coupling, but only over a narrow effective mass range
- This is most useful if a model makes a precise mass prediction, or for confirmation of candidates found by other means

Hidden Sector Photons

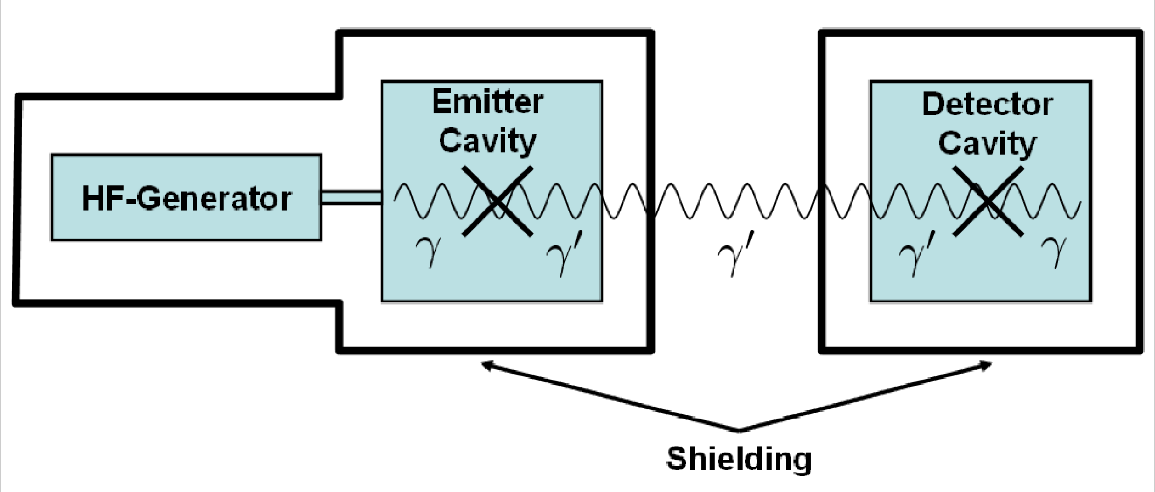
What if photons mix with a weakly coupled, ultralight vector particle?

“Hidden Sector Photon” or “paraphoton”



These paraphotons would couple nearby electromagnetic resonant cavities

See: Jaeckel and Ringwald, Phys. Lett. B 659 (2008) 509



Coming soon: An ADMX paraphoton search...

Conclusions

- ADMX is presently the most sensitive Dark Matter Axion experiment in the world
- ADMX Phase 2 will be sensitive to even pessimistic models over the preferred DM axion mass range
- ADMX is also setting limits on scalar chameleons and paraphotons

Sensitivity of Microwave Cavities

Chameleon Coupling

Form Factor

Cavity Quality

Magnetic Field Strength

Excitation Time

Elapsed Time

$$P_{measured} \approx P_{excited} \left(\frac{B\beta f Q}{\omega}\right)^4 (1-e^{-t_0/\tau}) e^{-t/\tau}$$

Resonance Frequency

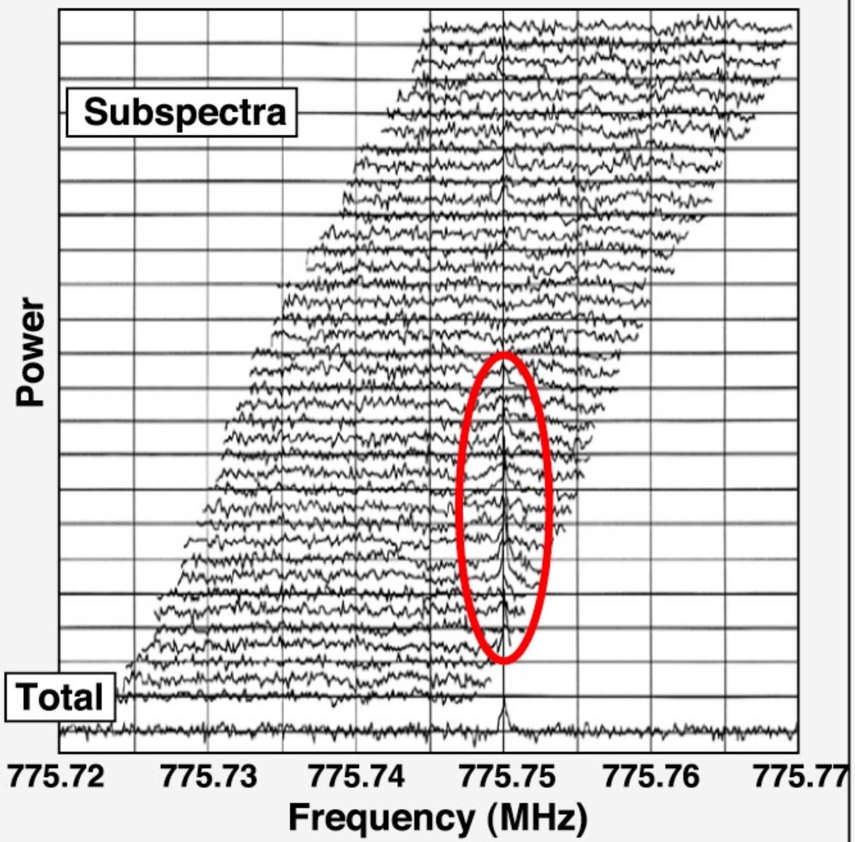
Chameleon Resonance Lifetime

$$\tau \approx \frac{\beta^2 B^2 f^2 Q}{\omega^3}$$

Summary: coupling sensitivity depends weakly on power sensitivity

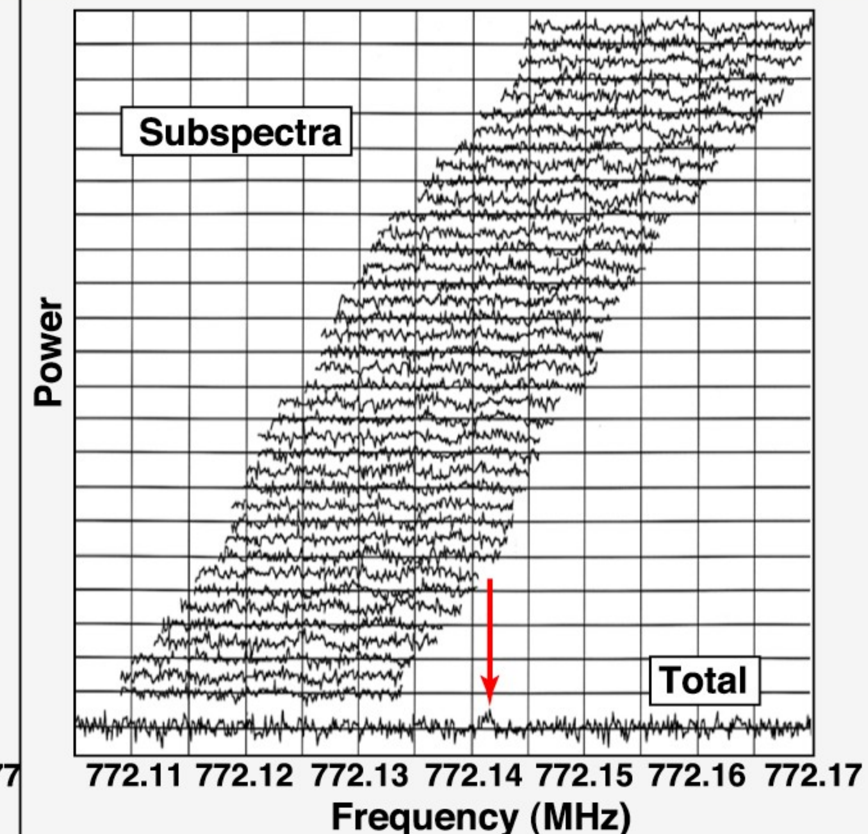
What Else Looks Like an Axion?

Environmental



Signal maximizes off-resonance: Radio peak

Statistical



Signal distributed over many sub-spectra: a good threshold candidate (but did not persist in rescan)