Subgroup Charge Presentation
CF3: Non-WIMP Dark-Matter

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“Snowmass”

Community Planning Meeting

FNAL, October 12, 2012

Interest in Axions and Axion-Like Particles is Strong and Growing

Recall the properties of dark matter:
1. Very weak interactions with normal matter and radiation.
2. Non-relativistic during structure formation.
3. Cosmological stability.

WIMPs are probably the favored DM candidate. (C.f. the title of C3 “non-WIMP …” .)
However, we should carefully listen to nature.

The jury is still out, but preliminary LHC searches as well as sensitive direct searches have not not found evidence of dark-matter WIMPS. This makes it especially timely to look closer at other ways to realize the essential features of dark matter.

Properties of axions and axion-like particles (ALPS):
1. Very weak interactions.
2. Non-thermal production. (Non-relativistic.)
3. Low mass. (Long life.)

Planning process started early this year at the “Roadmap Workshop”

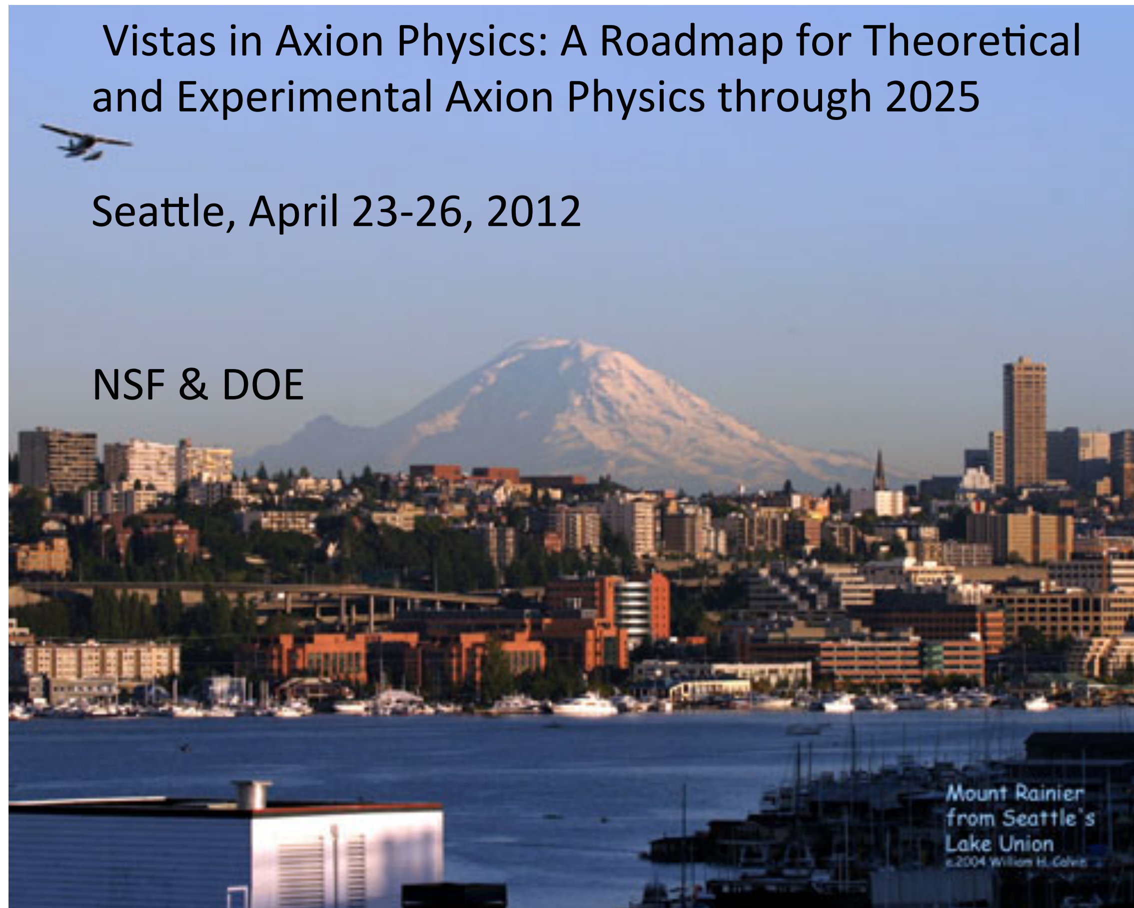
This gave CF3 a running start.

“This workshop will (1) organize much of the scientific foundation for the next generation of axion and axion-like-particle (ALP) experiments and searches, (2) and will be a roadmap for the researchers, research sponsors and the broader scientific community.”

Vistas in Axion Physics: A Roadmap for Theoretical and Experimental Axion Physics through 2025

Seattle, April 23-26, 2012

NSF & DOE



CF3 goals include:

Be aggressive in assembling input from the broad axion and ALP community.

Connect with other groups (Intensity, Cosmic, …).

Bring together the viewpoints and wisdom of very diverse researchers in axion and ALP science.

Agency guidance: Flesh out the roadmap, priorities.

Highlight key theory and instrumentation challenges.

Review the theory and instrumentation state of the art and attempt to divine where they are going.

Total success would include seeding future collaborations and directions.

Identified theory challenges going forward (1) include

Generic DM Issue: Structure formation

n-body simulation and NFW halo profiles?

n-body simulation and fine structure?

Axions and radiation from topological strings

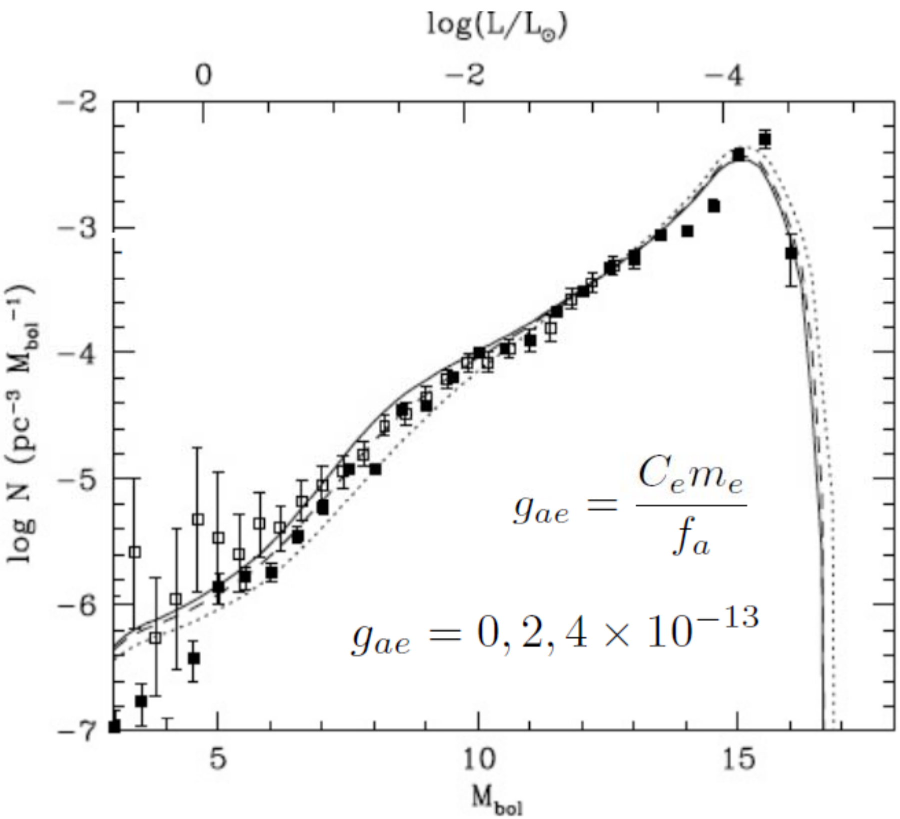
What axion mass gives sensible Ω_m?

Anticipate discoveries at the LHC

Axinos and f_{PQ}

Theory challenges going forward (2) include

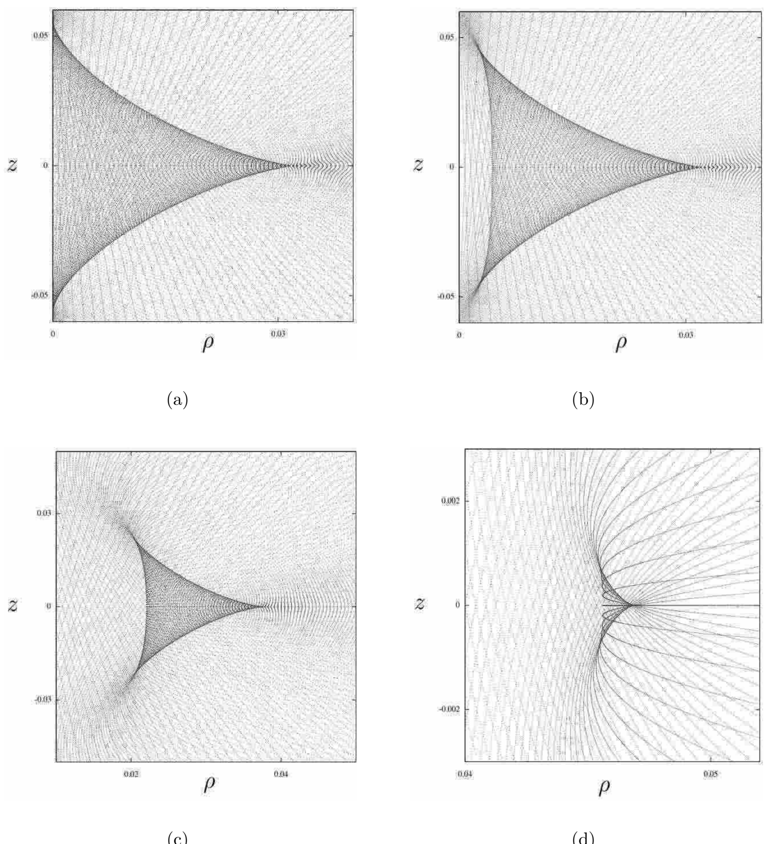
White dwarfs: Can we better understand cooling?



Isern et al., 2010

Theory challenges going forward (3) include

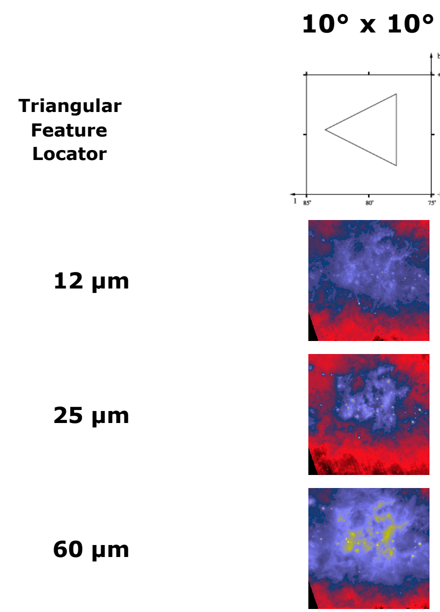
Bose-condensates & structure: Is the DM a Bose condensate?



Nararajan & Sikivie, 2005

FIG. 13: Cross sections of the inner caustics produced by the axially symmetric initial velocity field of Eq. (27) with $g_1 = -0.033$, and (a) $c_1 = 0$, (b) $c_2 = 0.01$, (c) $c_3 = 0.05$, (d) $c_3 = 0.1$. Increasing the rotational component of the initial velocity field causes the tent caustic (a) to transform into a tricusp ring (d).

For instance:
Look where n=5 ring would be in our galaxy
Skyview virtual observatory



Collect ideas to broaden the mass reach …

The meV mass frontier of axion physics

Georg G. Raffelt,[1] Javier Redondo,[1] and Nicolas Viaux Maira[2]

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Av. Vicuña Mackenna 4860, 782-0436 Macul, Santiago, Chile.

(Dated: 19 August 2011)

For $f_a \sim 10^{17}$ GeV: $\theta_i \simeq 10^{-3} \Longrightarrow$ $\delta v = 10^{-4}$ sensitive to $r = 10^7$!

We could detect an axion string 10,000,000 times horizon lengths away (6×10^{16} light-years)

David B. Kaplan ~ INT ~ April 25, 2012

It isn't crazy to think about searches for neV axions

Peter Graham & Surjeet Rajendran

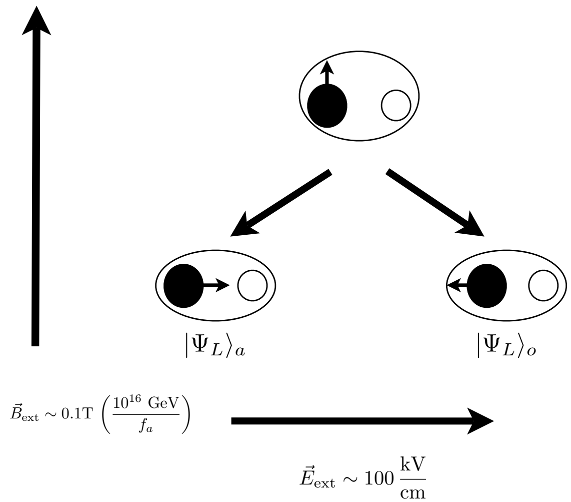


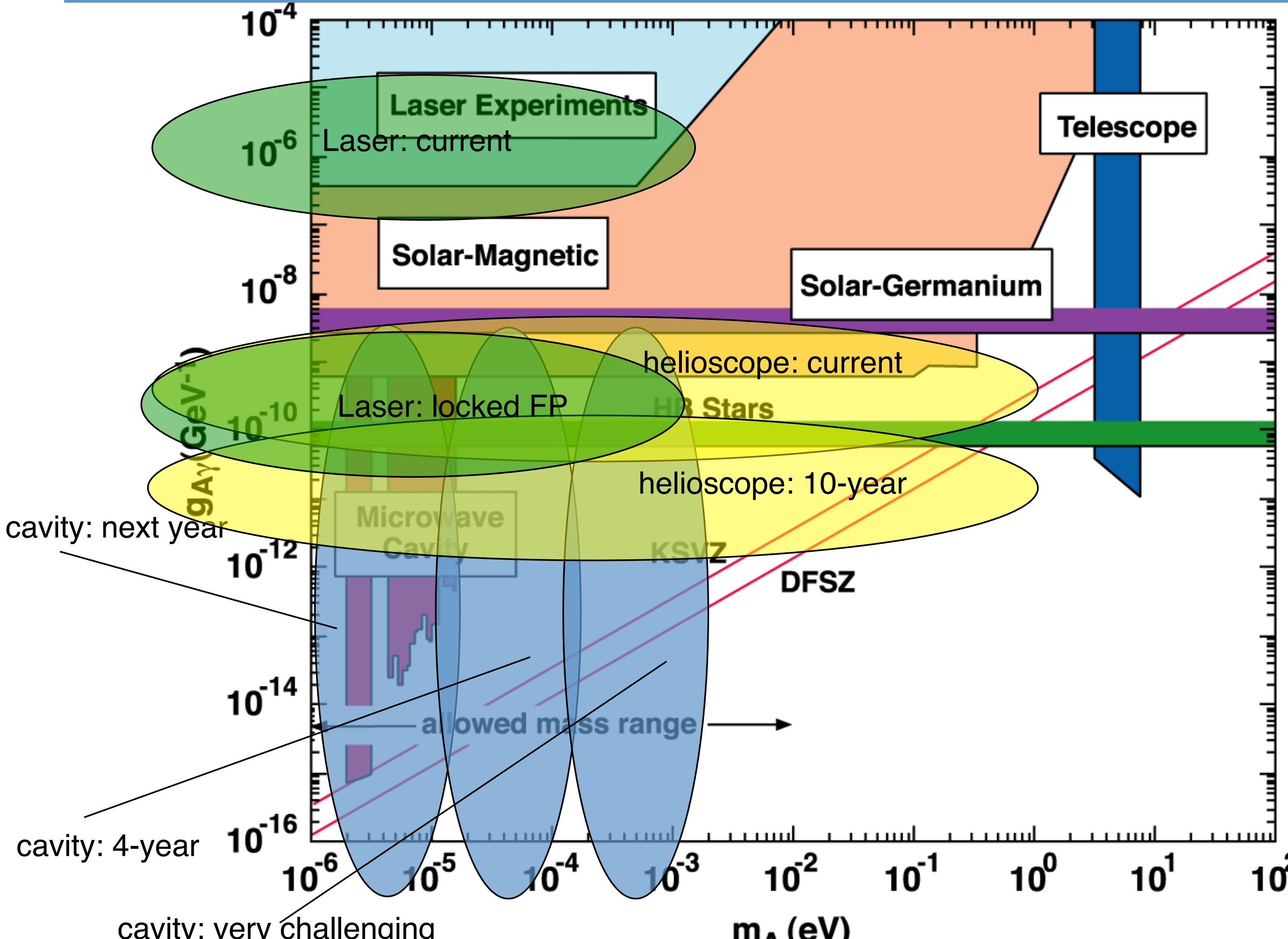
FIG. 2: The molecules are polarized by an external electric field $\vec{E}_{\rm ext} \sim 100\,\frac{\rm kV}{\rm cm}$. They are then placed in a linear superposition of the two states $|\Psi_L\rangle_a$ and $|\Psi_L\rangle_o$, where the nuclear spin is either aligned or anti-aligned with the molecular axis respectively, leading to a phase difference between them in the presence of the axion induced nuclear dipole moment d_n. The external magnetic field $\vec{B}_{\rm ext} \sim 0.1\ \mathrm{T}\left(\frac{f_a}{M_{\rm GUT}}\right)$ causes the spins to precess, so that the phase difference can be coherently accrued over several axion oscillations. The frequency can be scanned by dialing this magnetic field $\vec{B}_{\rm ext}$ until it is resonant with the axion frequency.

field. When the precession frequency matches the axion frequency, a phase shift will be continually accrued over several axion oscillations. After interrogation for a time T, the phase shift in the experiment (using the energy shift δE from (11)) is

$$\delta\phi = \delta E\, T \sim 10^{-10}\left(\frac{T}{1\ \mathrm{s}}\right)\left(\frac{\delta E}{10^{-25}\ \mathrm{eV}}\right) \qquad (13)$$

This relative phase between the two spin states $|\Psi_L\rangle_a$ and $|\Psi_L\rangle_o$ can then be measured.

Experimental situation: focus comes back to three key technologies



RF cavity futurism (1)

RF-Driven Josephson Bifurcation Amplifier for Quantum Measurement

I. Siddiqi, R. Vijay, F. Pierre, C. M. Wilson, M. Metcalfe, C. Rigetti, L. Frunzio, and M. H. Devoret
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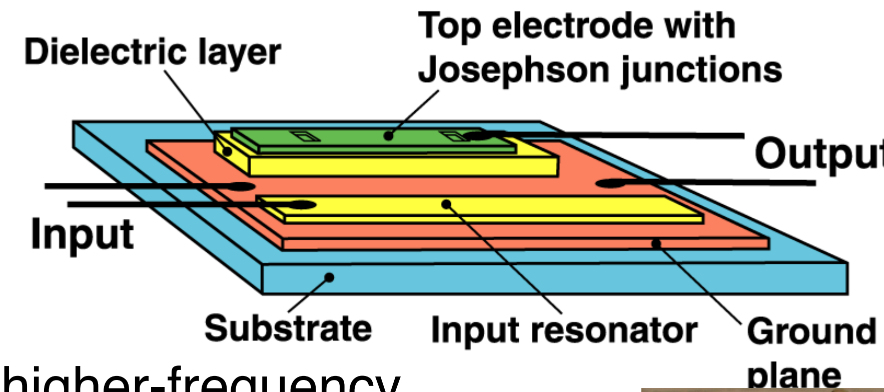
(Received 11 February 2004; published 10 November 2004)

We have constructed a new type of amplifier whose primary purpose is the readout of superconducting quantum bits. It is based on the transition of a rf-driven Josephson junction between two distinct oscillation states near a dynamical bifurcation point. The main advantages of this new amplifier are speed, high sensitivity, low backaction, and the absence of on-chip dissipation. Pulsed microwave reflection measurements on nanofabricated Al junctions show that actual devices attain the performance predicted by theory.

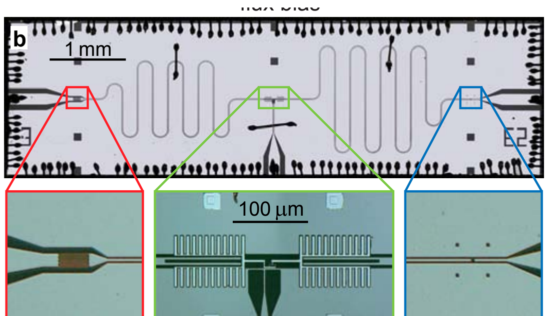
new amplifier technologies

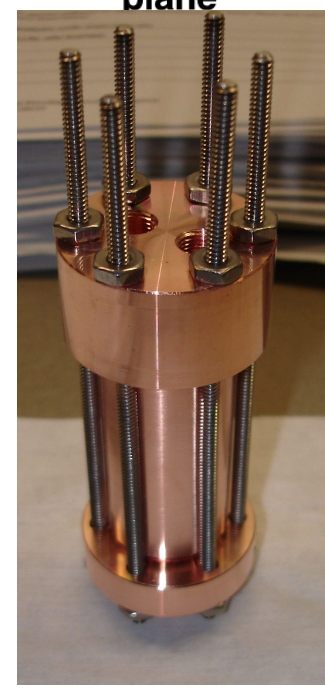


higher-frequency quantum-limited amplifiers

Quantum Non-demolition Detection of Single Microwave Photons in a Circuit

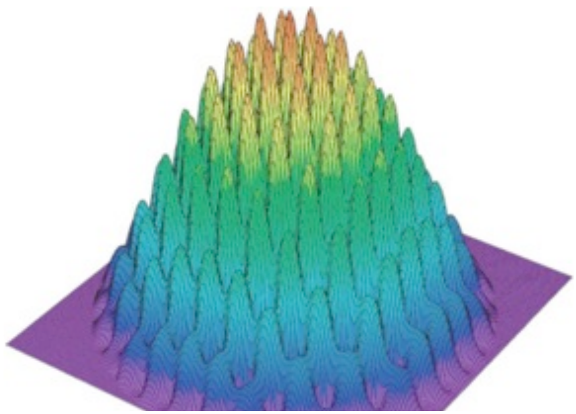
B. R. Johnson,[1] M. D. Reed,[1] A. A. Houck,[2] D. I. Schuster,[1] Lev S. Bishop,[1] E. Ginossar,[1] J. M. Gambetta,[3] L. DiCarlo,[1] L. Frunzio,[1] S. M. Girvin,[1] and R. J. Schoelkopf[1]
[1] *Departments of Physics and Applied Physics, Yale University, New Haven, CT 06511, USA*
[2] *Department of Electrical Engineering, Princeton University, Princeton, NJ 08544, USA*
[3] *Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Waterloo, ON, Canada, N2L 3G1*
(Dated: March 12, 2010)





“hybrid” superconducting cavities

RF cavity futurism (2)



higher-frequency, large volume
resonant structures

meV RF search maybe isn't crazy

Axion detection in the 10^{-4} eV mass range

Pierre Sikivie, D. B. Tanner, and Yun Wang*

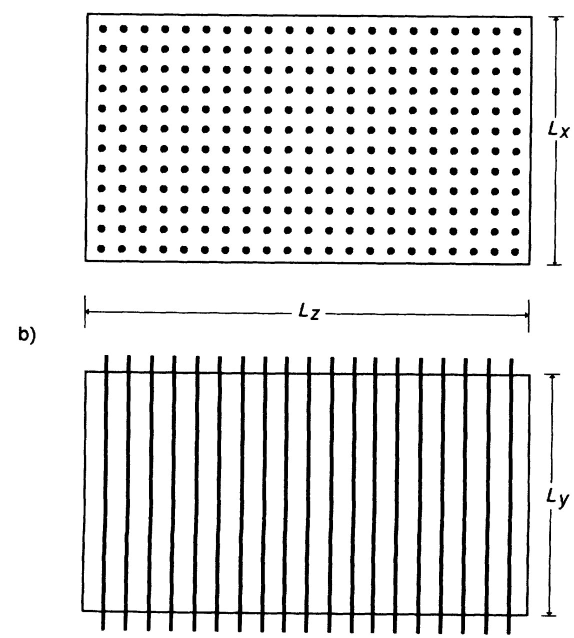
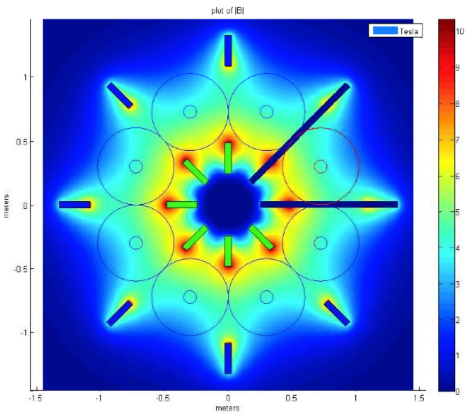
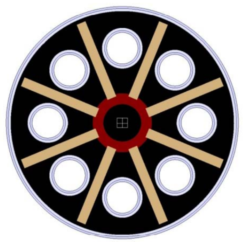


FIG. 1. Top and side views of the detector, showing the arrangement of wires.

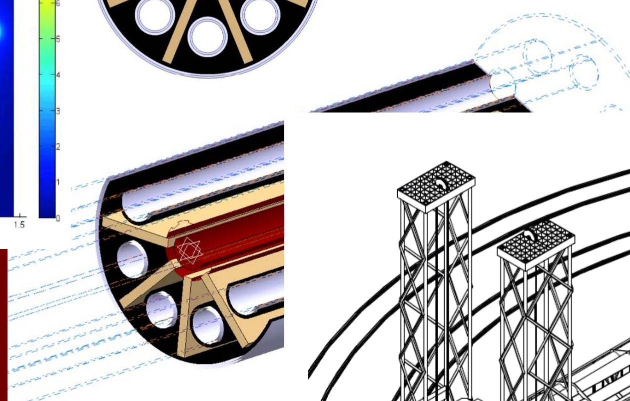
Helioscope futurism: Big Magnets

IAXO magnet: 1st concept



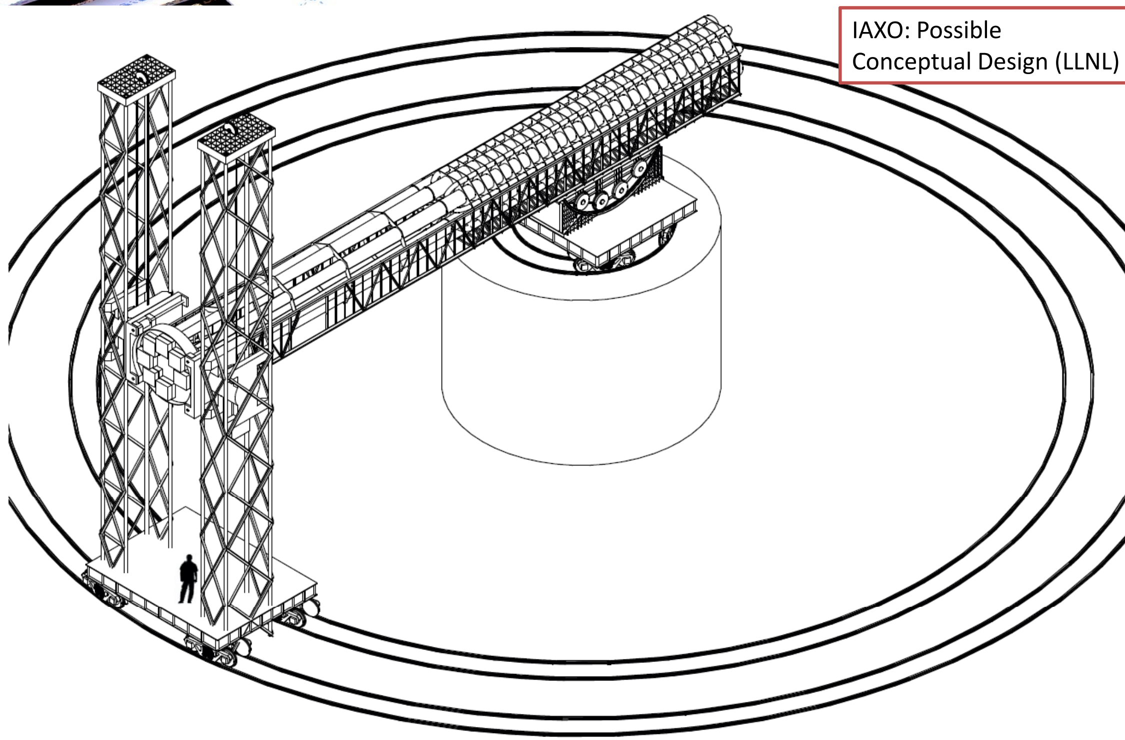


Total R = 2 m
Bore diameter = 600 mm
N bores = 8
Average B in bore = 4 T
(in critical surface)
MFOM = 770



IAXO scenario 2 conservative
Surpass IAXO scenario 3 is possible
Further optimization ongoing

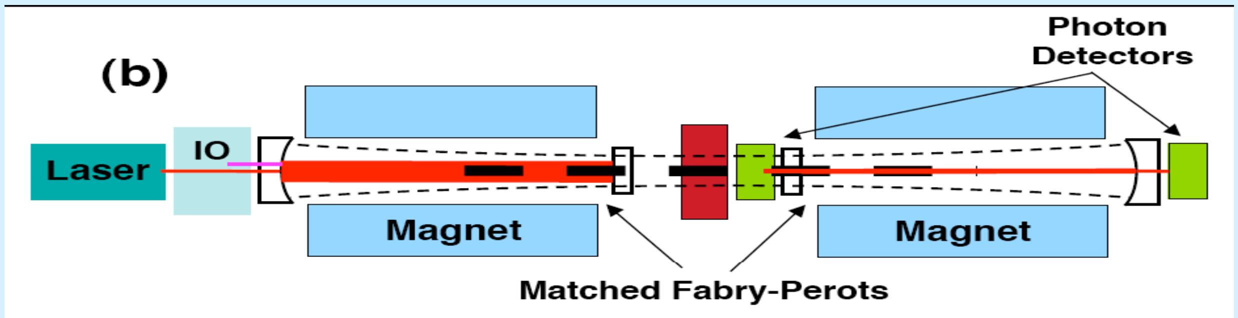
INT Washington, April 2012 Igor G. Irastorza / Universidad de Zaragoza



IAXO: Possible Conceptual Design (LLNL)

Laser futurism: High Finesse w/ Locked Fabry-Perot

REAPR Requirements



- Optimize magnetic field length — Talk by P. Mazur
- High finesse cavities — Talk by D. Tanner
- Cavities locked to each other with no leakage from the generation cavity
- Need sensitive photon detection

CF3 Feeding into the Snowmass Process

The CF3 instrumentation, involving intense lasers, strong magnetic fields and quantum-limited amplifier technology can explore couplings many orders of magnitude smaller than those explored in collider or WIMP experiments. This is very attractive to experimenters. (Neutrinos in this context are strongly interacting.)

This meeting kicks off the "Snowmass" phase of CF3 planning.

We're working hard to assemble community input.

We're looking at overlaps with other groups.

We are working with European counterparts: G. Raffelt and A. Ringwald.

We're ramping up activity: SnowDark late March, SC Workshop early March.

We hope to have a working document by Snowmass 2013:

The pacing issue is one of inclusion and agreement.