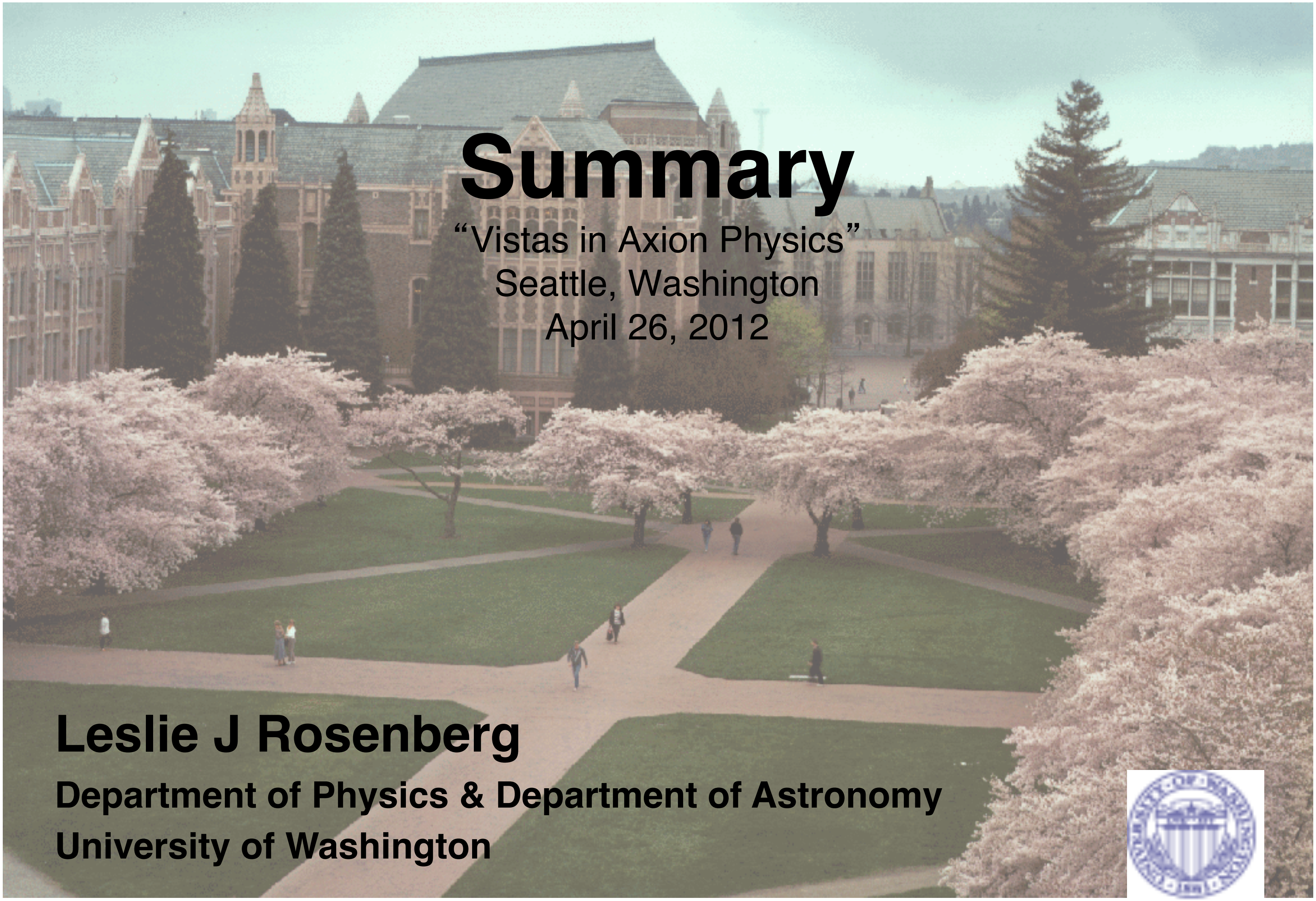


Summary

"Vistas in Axion Physics"
Seattle, Washington
April 26, 2012

Leslie J Rosenberg

Department of Physics & Department of Astronomy
University of Washington

Thank you for coming!

Workshop Goals

Agency guidance: Roadmap

Bring together the very diverse researchers in axion science

Highlight key technical challenges

Review the state of the art and predict the future

Seed future collaborations and directions

Theory challenges going forward (1) include

(My take on it)

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?

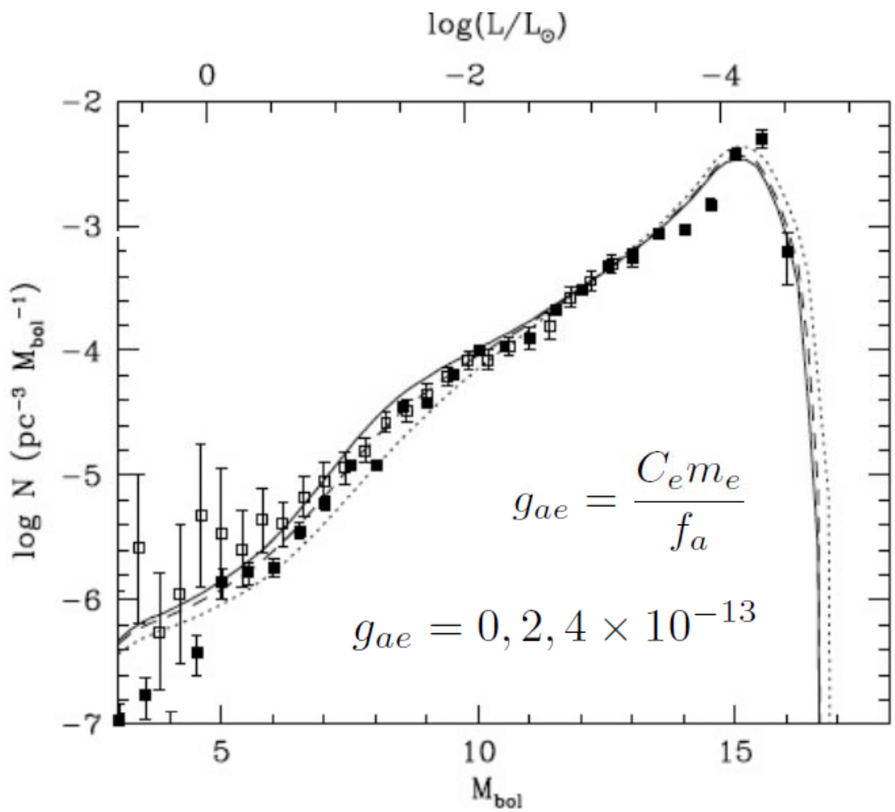
LHC

Axinos and f_{PQ}

Theory challenges going forward (2) include

White dwarfs:

Can we understand cooling?

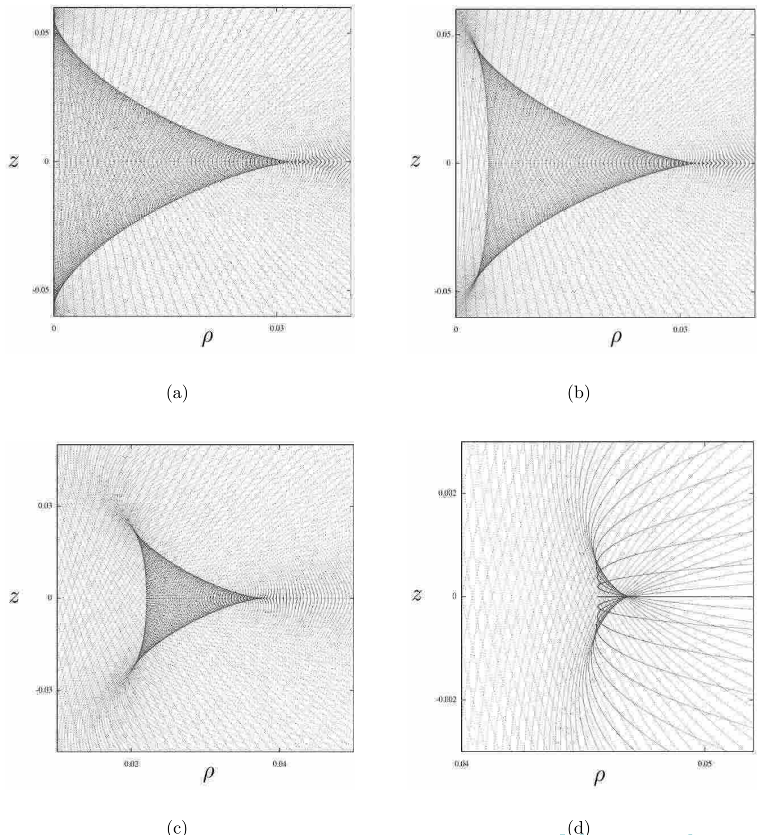


Isern et al., 2010

Theory challenges going forward (3) include

Axion Bose-condensates & structure

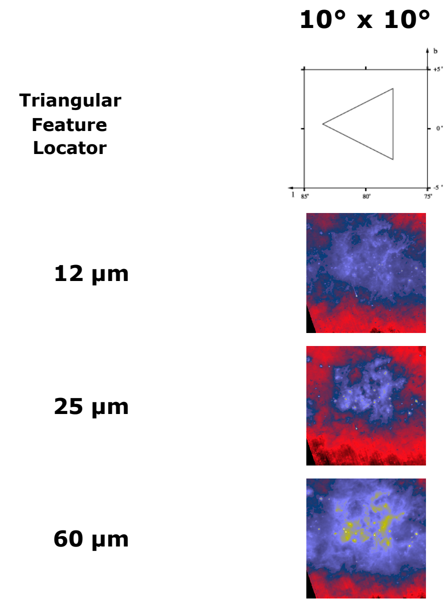
Is the dark matter a Bose condensate?



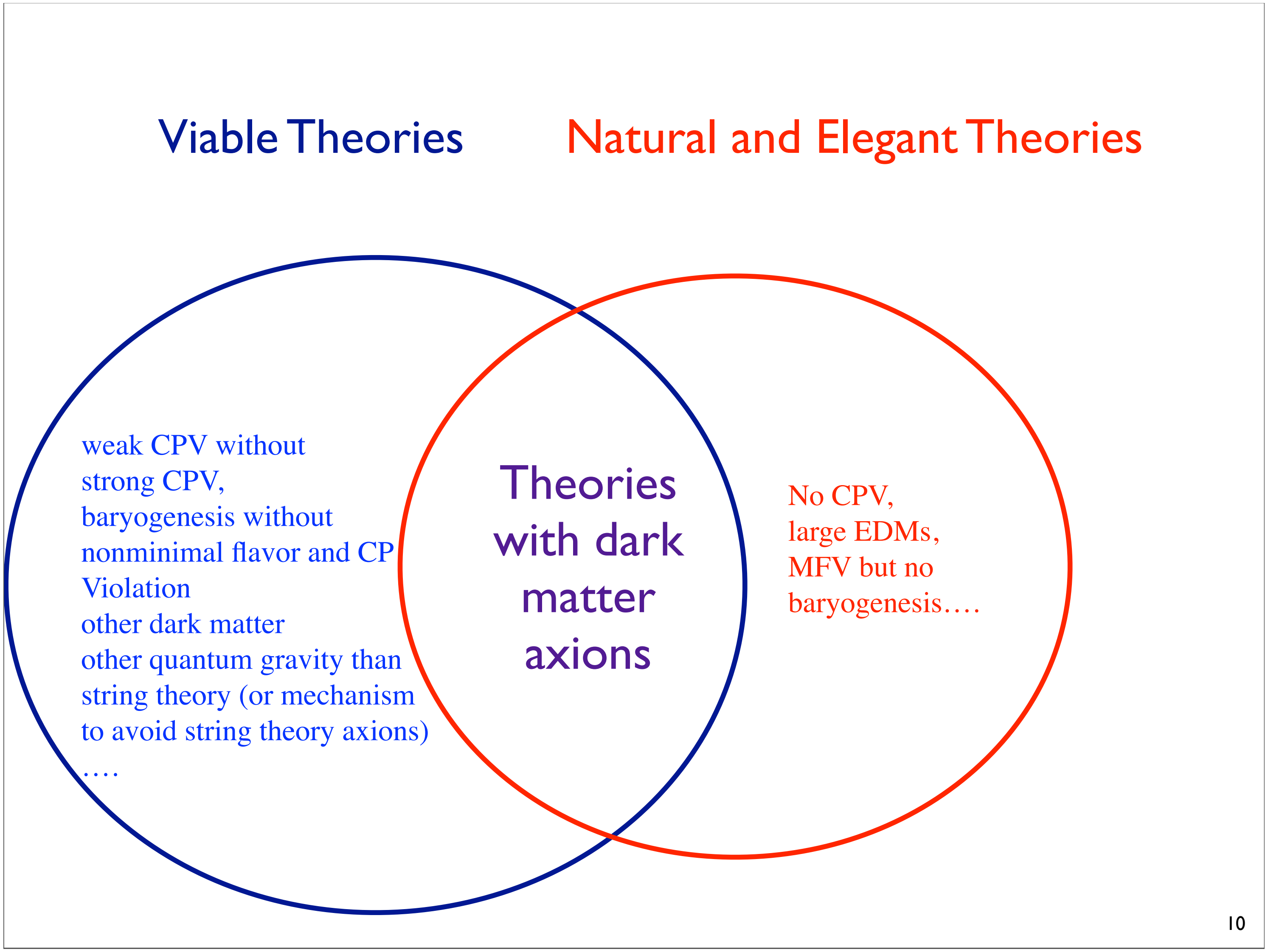
Nararajan & Sikivie, 2005

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



From A. Nelson



Wednesday, April 25, 2012 10

Ideas to broaden the mass reach include …

The meV mass frontier of axion physics

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

ıck-Institut für Physik (Werner-Heisenberg-Institut), Föhringer Ring 6, 80805 Münc
[2]Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica de Cl
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 detecting neV axion

Peter Graham &
Surjeet Rajendran

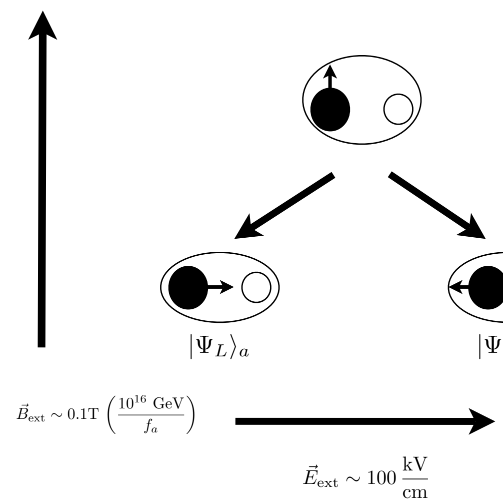


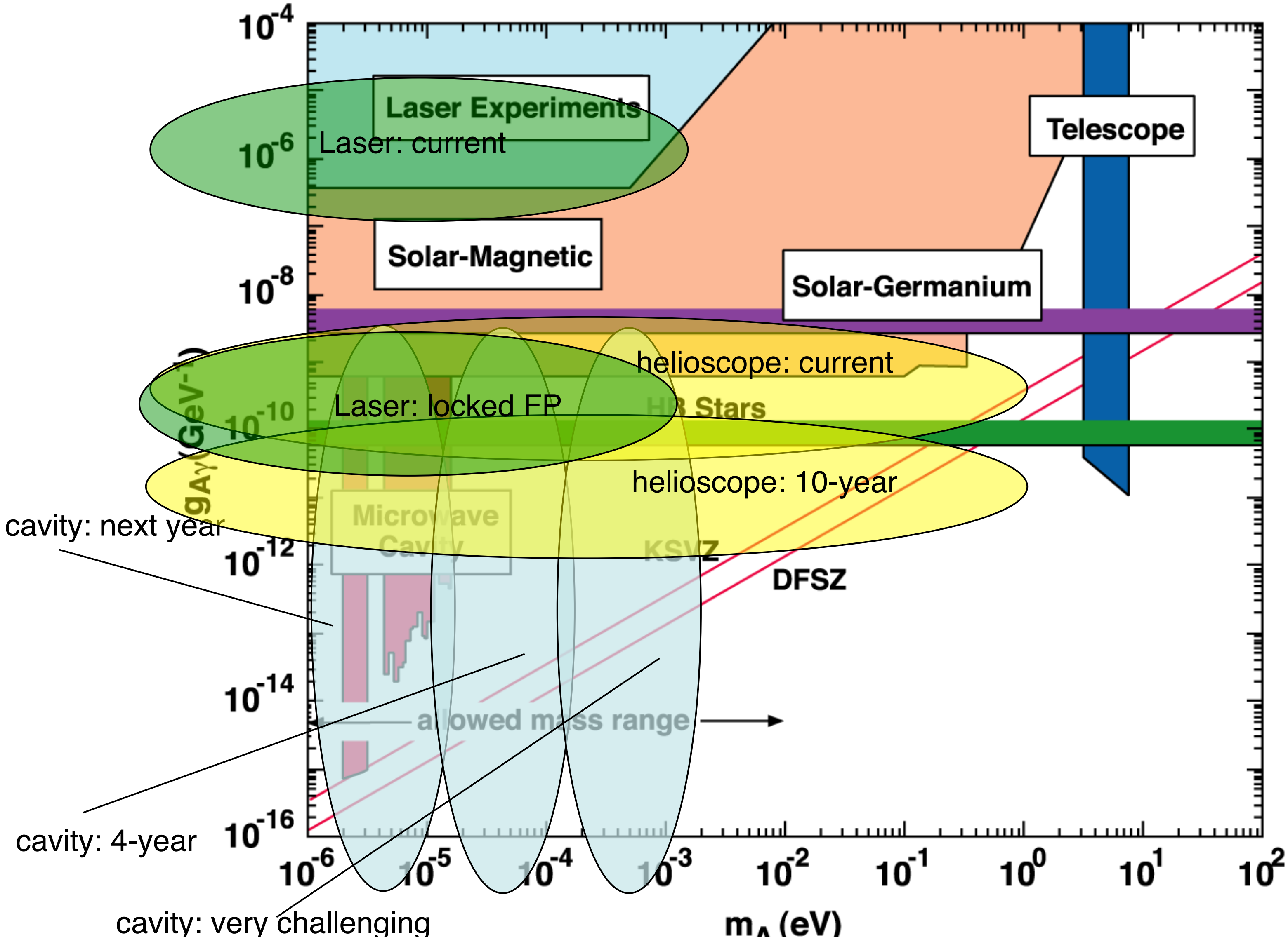
FIG. 2: The molecules are polarized by an external electric field $\vec{E}_{\rm ext} \sim 100\,\frac{\text{kV}}{\text{cm}}$. They are then placed in a linear superposition of the two states $|\Psi_L\rangle_a$ and $|\Psi_L\rangle_o$, where the nuclear spin is either aligned or anti-aligned with the molecular 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 $\vec{B}_{\rm ext} \sim 0.1$ 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

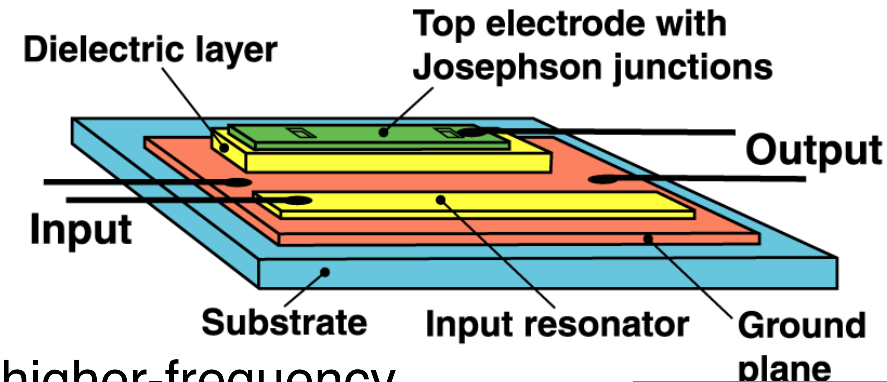
$$\delta\phi = \delta E\, T \sim 10^{-10}\left(\frac{T}{1\text{ s}}\right)\left(\frac{\delta E}{10^{-25}\text{ eV}}\right) \tag{13}$$

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

Experimental situation: focus on three key technologies



RF cavity futurism (1)



higher-frequency quantum-limited SQUIDs

RF-Driven Josephson Bifurcation Amplifier for Quantum Measurement

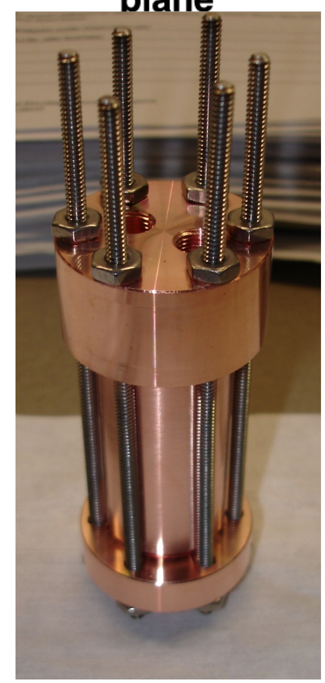
I. Siddiqi, R. Vijay, F. Pierre, C. M. Wilson, M. Metcalfe, C. Rigetti, L. Frunzio, and M. H. Devoret

Departments of Applied Physics and Physics, Yale University, New Haven, Connecticut 06520-8284, USA

(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

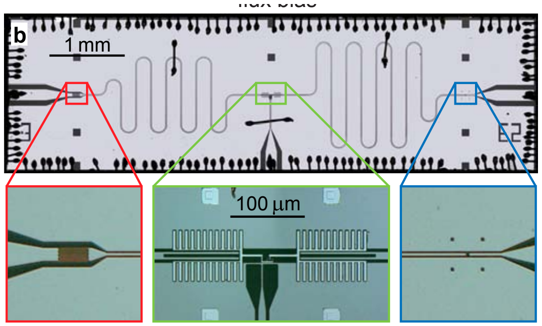


Quantum Non-demolition Detection of Single Microwave Photons in a Circuit

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]

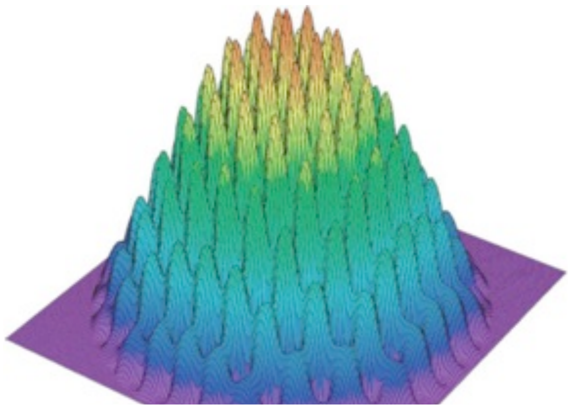
[1] *Departments of Physics and Applied Physics, Yale University, New Haven, CT 06511, USA*
[2] *Department of Electrical Engineering, Princeton University, Princeton, NJ 08544, USA*
[3] *Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Waterloo, ON, Canada, N2L 3G1*

(Dated: March 12, 2010)



“hybrid” superconducting cavities

RF cavity futurism (2)



higher-frequency, large volume resonant structures

meV RF search isn’t crazy

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

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

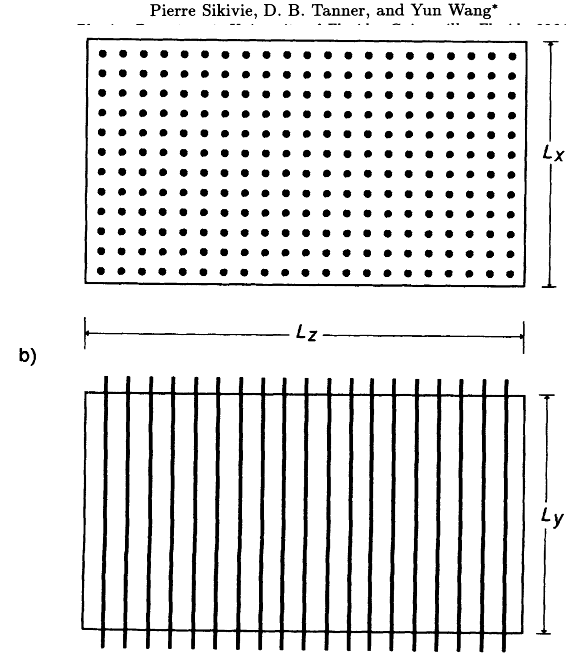
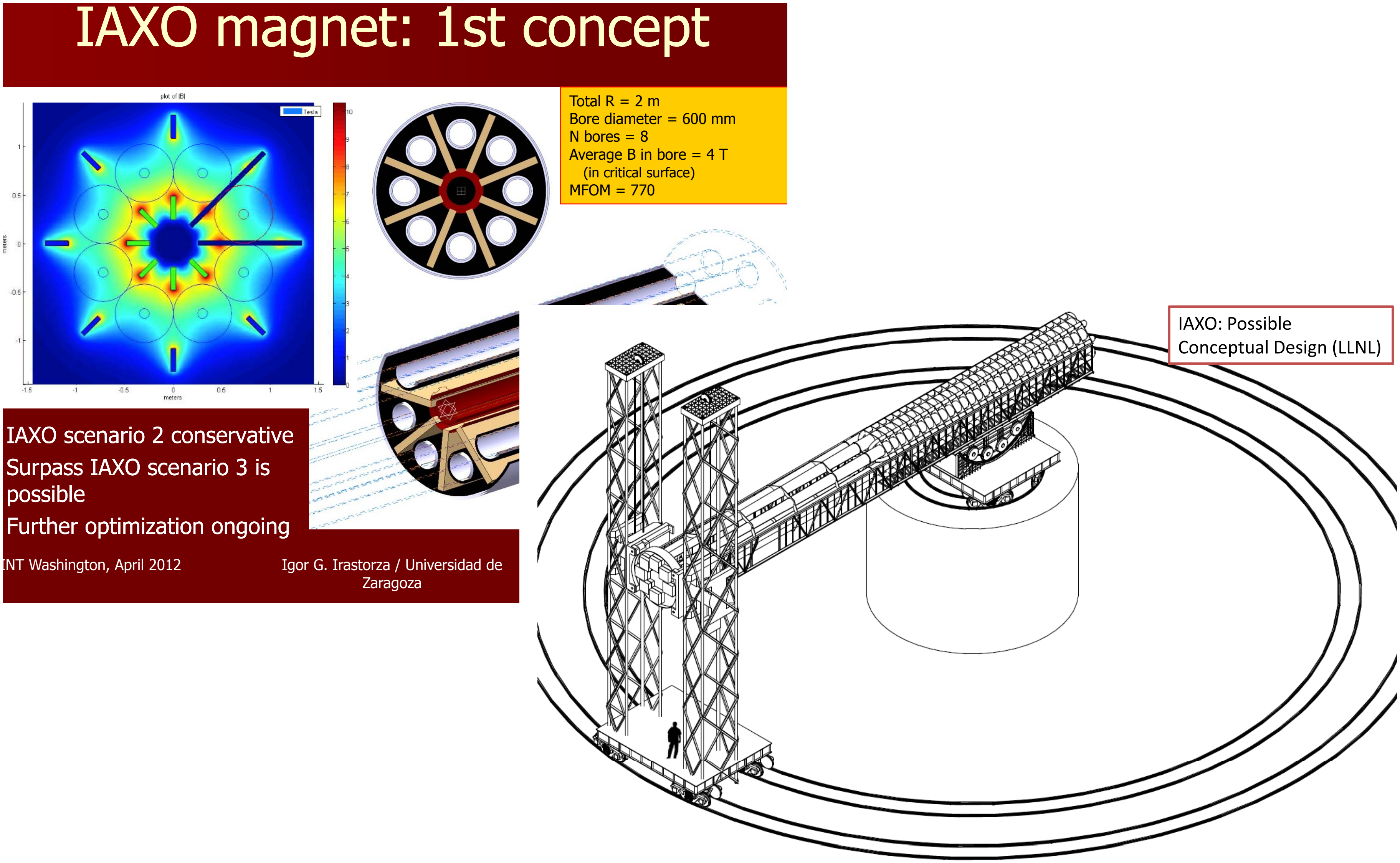


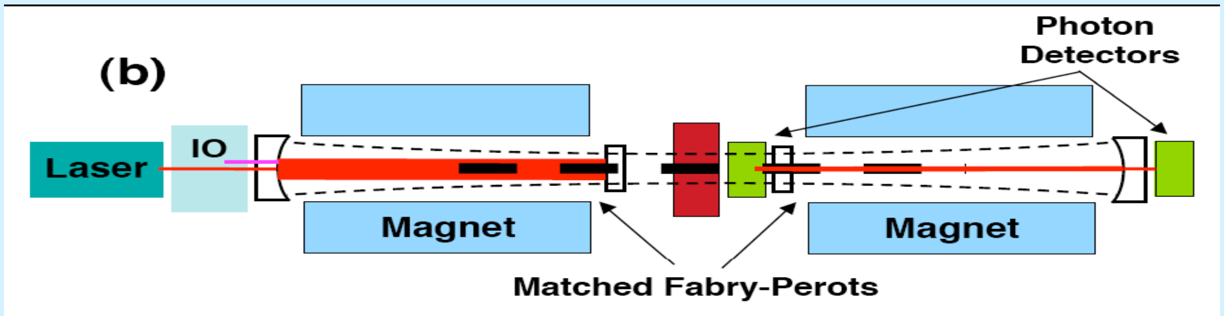
FIG. 1. Top and side views of the detector, showing the arrangement of wires.

Helioscope futurism



Laser futurism

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

Overall: Where are we?

Axion experiments have transitioned from R&D to production.

FUNDING OPPORTUNITY ANNOUNCEMENT

U.S. Department of Energy

Office of Science
Office of High Energy Physics

Second Generation Dark Matter Experiments

This situation has caught the attention of funding agencies.
NSF & DOE: “Joined at the hip”

“Gen 2” Dark-matter projects:
1 or 2 over MIE projects, not axions I’m guessing.
Room for several sub-MIE axion projects
($2M construction within $5M total project cost
+ “research”)

“Gen 3” FY17 axion detectors could, I envision, be within MIE ($100M class)

The “roadmap” of this workshop feeds into
the “Cosmic Frontier” planning: Report at Snowmass DM planning meeting.

Workshop Report

We were solicited by Rev. Mod. Phys. for an Axion Roadmap review.
Will be edited and reviewed. Model is "Intensity Frontier" roadmap.

Rapporteurs along with working groups supply science summary
to address the following questions at a high level:

– What is the scientific potential of such an experiment?
– What is the technological roadmap?

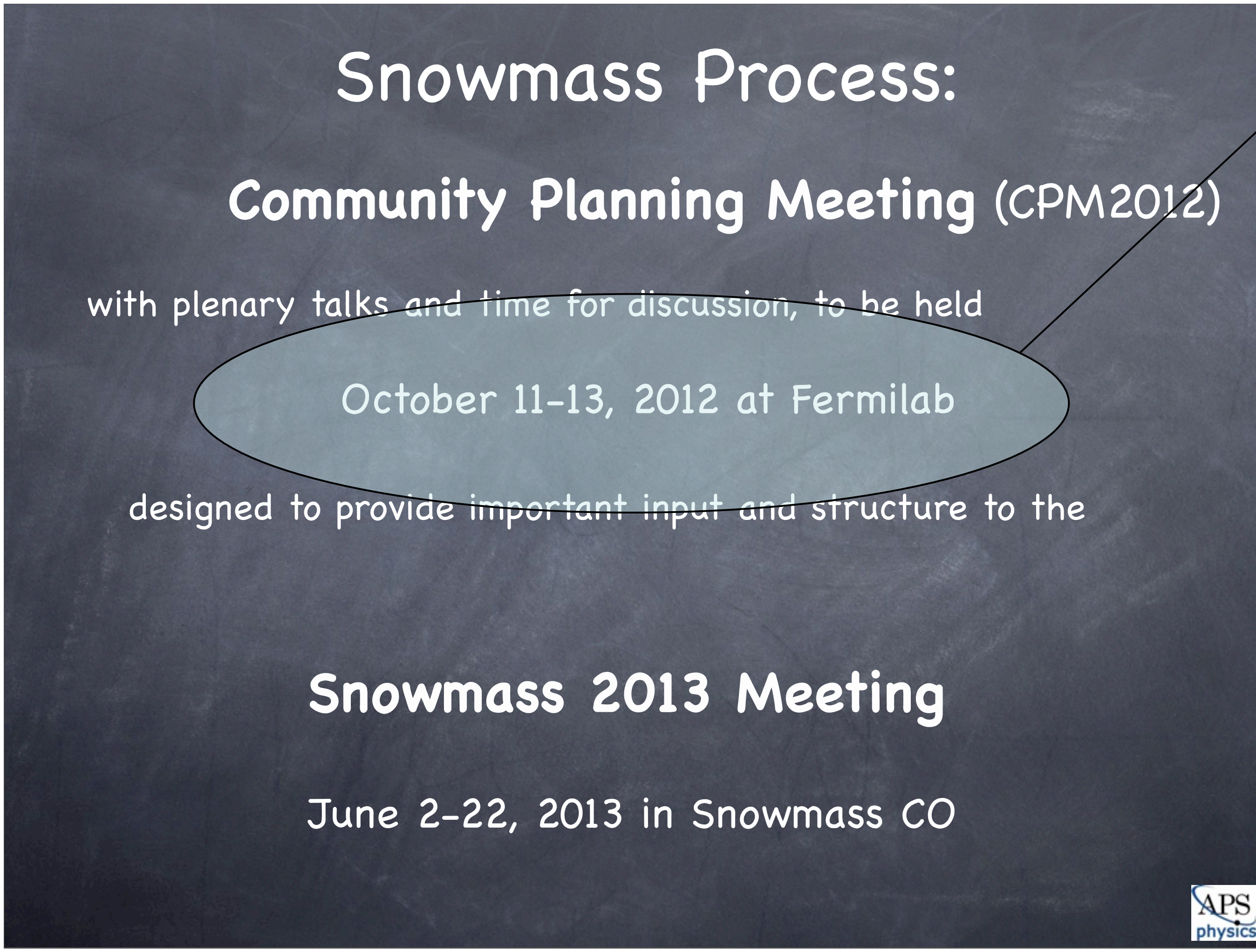
-What can be extrapolated with confidence
-What needs to be invented (don't be afraid of requiring a miracle)
-How long will it take and what will it cost

– Crude estimate of when can the experiment be built,
and how much will it cost

Editors tighten document & distribute to participants for comments.

Needs to be ready by fall Dark-Matter planning meeting at FNAL
(associated with Snowmass planning meeting).

Snowmass Planning



Monday, March 12, 2012

Likely be a another DM meeting (DOE and/or NSF) attached to this

Conclusions: Are we going to find the QCD Dark-Matter axion? Yup.

- The axion is in no ways less well motivated than the WIMP
- But somehow we've been stuck behind the door in agency priority
- Funding for SUSY DM is roughly 10x that of axion DM
- Our investment strategy should be informed by data
  - We must listen carefully to important messages Nature's telling us
  - So far, no sign of SUSY at LHC or WIMP in 100 kg DM detectors
- The agencies are listening
- We need to maintain a coherent, thoughtful push by the axion community

Thank you

Thank you for coming. We were overwhelmed by interest and applications to the workshop.

INT Organization for workshop administration.
All, but especially Laura Lee.

My ADMX Collaborators. I could not imagine a better group of experimenters and theorists.

My axion colleagues across the world. A very powerful group of scientists.

The DOE & NSF sponsors of dark-matter research.
(This workshop is supported by DOE/NP, HEP and NSF)

And I would like to thank David Schramm.