Summary

“Vistas in Axion Physics”
Seattle, Washington
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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 $\Omega_m$?

LHC
Axinos and $f_{PQ}$
Theory challenges going forward (2) include

White dwarfs:
Can we understand cooling?

\[ g_{ae} = \frac{C_e m_e}{f_a} \]

\[ g_{ae} = 0, 2, 4 \times 10^{-13} \]

Isern et al., 2010
Theory challenges going forward (3) include Axion Bose-condensates & structure

Is the dark matter a Bose condensate?

For instance:
Look where $n=5$ ring would be in our galaxy

Skyview virtual observatory

FIG. 13: Cross sections of the inner caustics produced by the axially symmetric initial velocity field of Eq. (27) with $q_1 = -0.033$, 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).

Nararajan & Sikivie, 2005
Viable Theories

- weak CPV without strong CPV,
- baryogenesis without nonminimal flavor and CP Violation
- other dark matter
- other quantum gravity than string theory (or mechanism to avoid string theory axions)

Natural and Elegant Theories

- No CPV,
- large EDMs,
- MFV but no baryogenesis….
Ideas to broaden the mass reach include ...
It isn’t crazy to think about detecting neV axion

FIG. 2: The molecules are polarized by an external electric field $\vec{E}_{\text{ext}} \sim 100 \text{ kV/cm}$. 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 $\vec{B}_{\text{ext}} \sim 0.1 \text{T}$ ($\frac{\text{muG}}{\text{cm}}$) 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 $\vec{B}_{\text{ext}}$ 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 $\delta E$ from (11)) is

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

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

- Laser Experiments
  - Laser: current
  - Laser: locked FP

- Helioscope
  - Helioscope: current
  - Helioscope: 10-year

- Solar-Magnetic

- Solar-Germanium

- Cavity
  - Cavity: next year
  - Cavity: 4-year
  - Cavity: very challenging

- DFSZ

- Microwave Cavity

- KSVZ

- Allowed mass range

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new amplifier technologies

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


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(Dated: March 12, 2010)

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RF cavity futurism (2)

higher-frequency, large volume resonant structures

meV RF search isn’t crazy

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

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
Laser futurism

REAPR Requirements

- Optimize magnetic field length
- High finesse cavities
- 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.

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

Snowmass Process:
Community Planning Meeting (CPM2012)

with plenary talks and time for discussion, to be held

October 11-13, 2012 at Fermilab

designed to provide important input and structure to the

Snowmass 2013 Meeting

June 2-22, 2013 in Snowmass CO

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.