L. ROSENBERG
SNOWMASS 2001

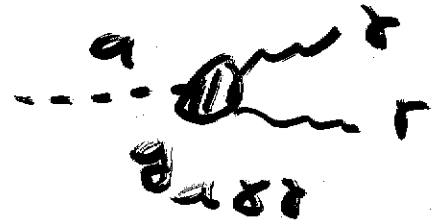
THE FUTURE OF AXION DETECTION

THE AXION IS A HYPOTHETICAL 0^- ELEMENTARY PARTICLE.

IT IS PART OF A SOLUTION TO THE STRONG CP PROBLEM IN QCD.

MASS? *a priori* UNKNOWN

COUPLINGS? e.g.,

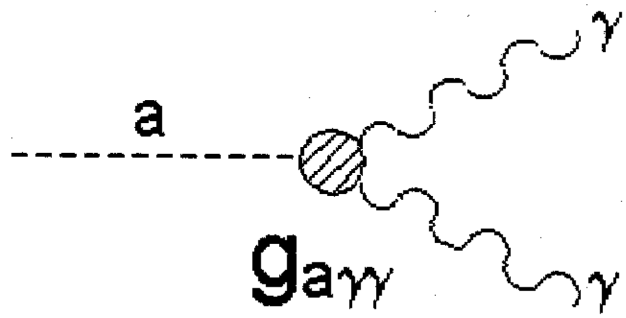


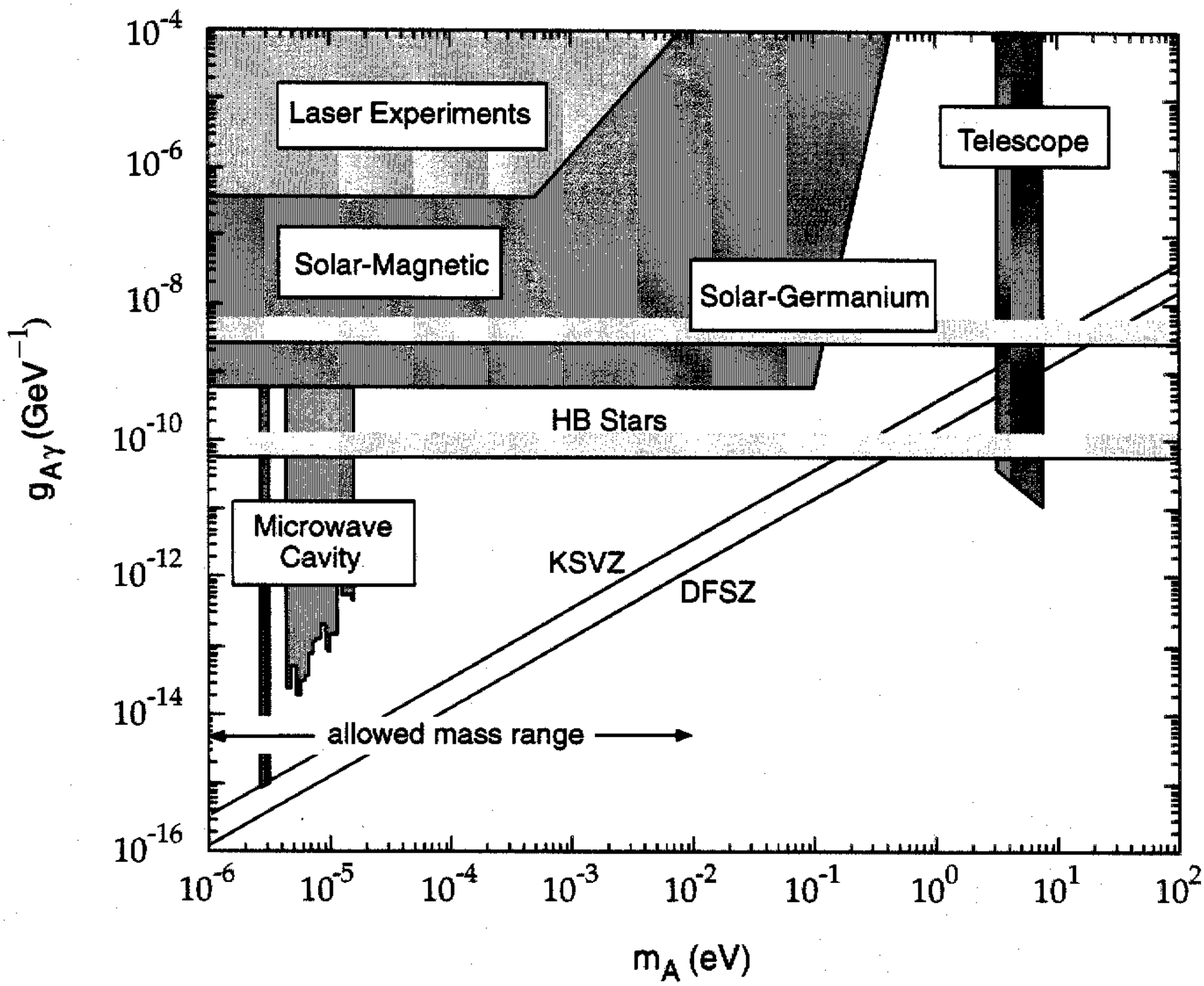
$$g_{a\gamma\gamma} \sim \frac{1}{f_a} \sim m_a$$

A LIGHT AXION IS A GOOD DARK MATTER CANDIDATE

Current State of CDM Axion Searches

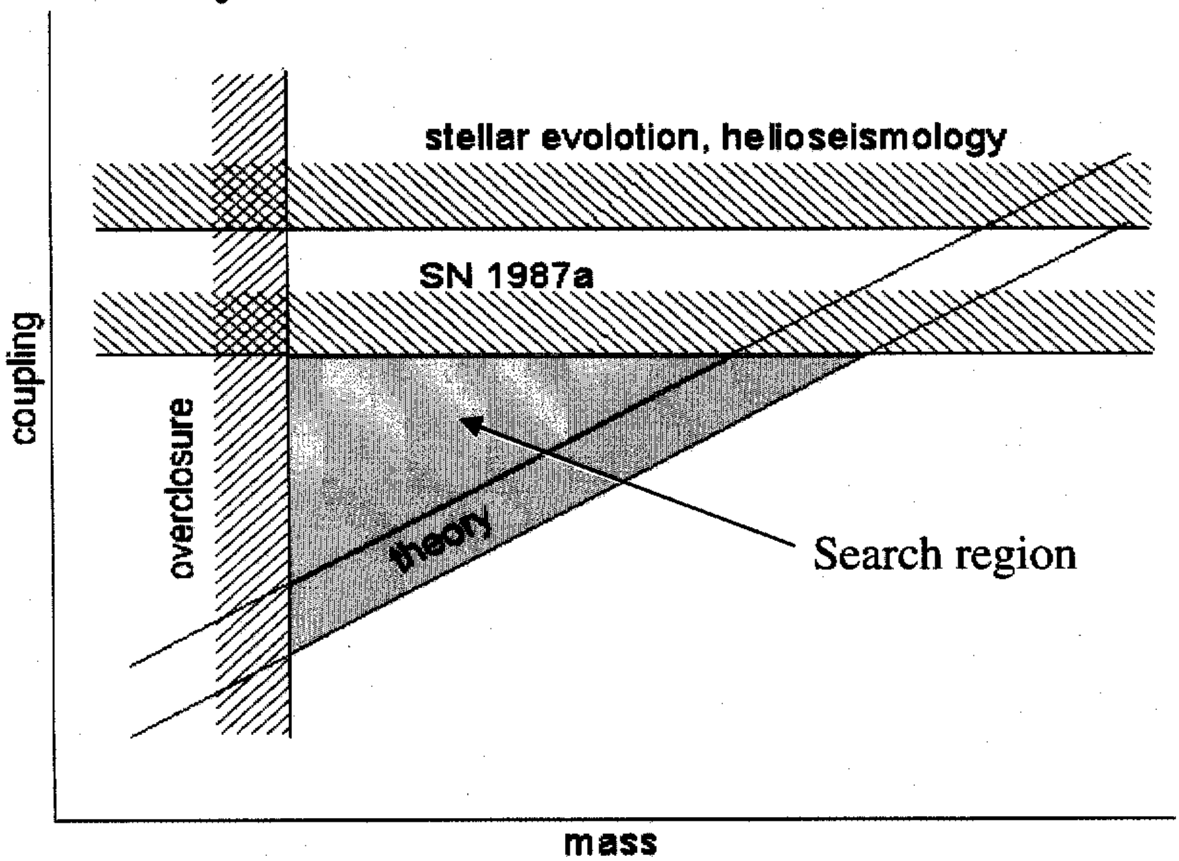
referenced to





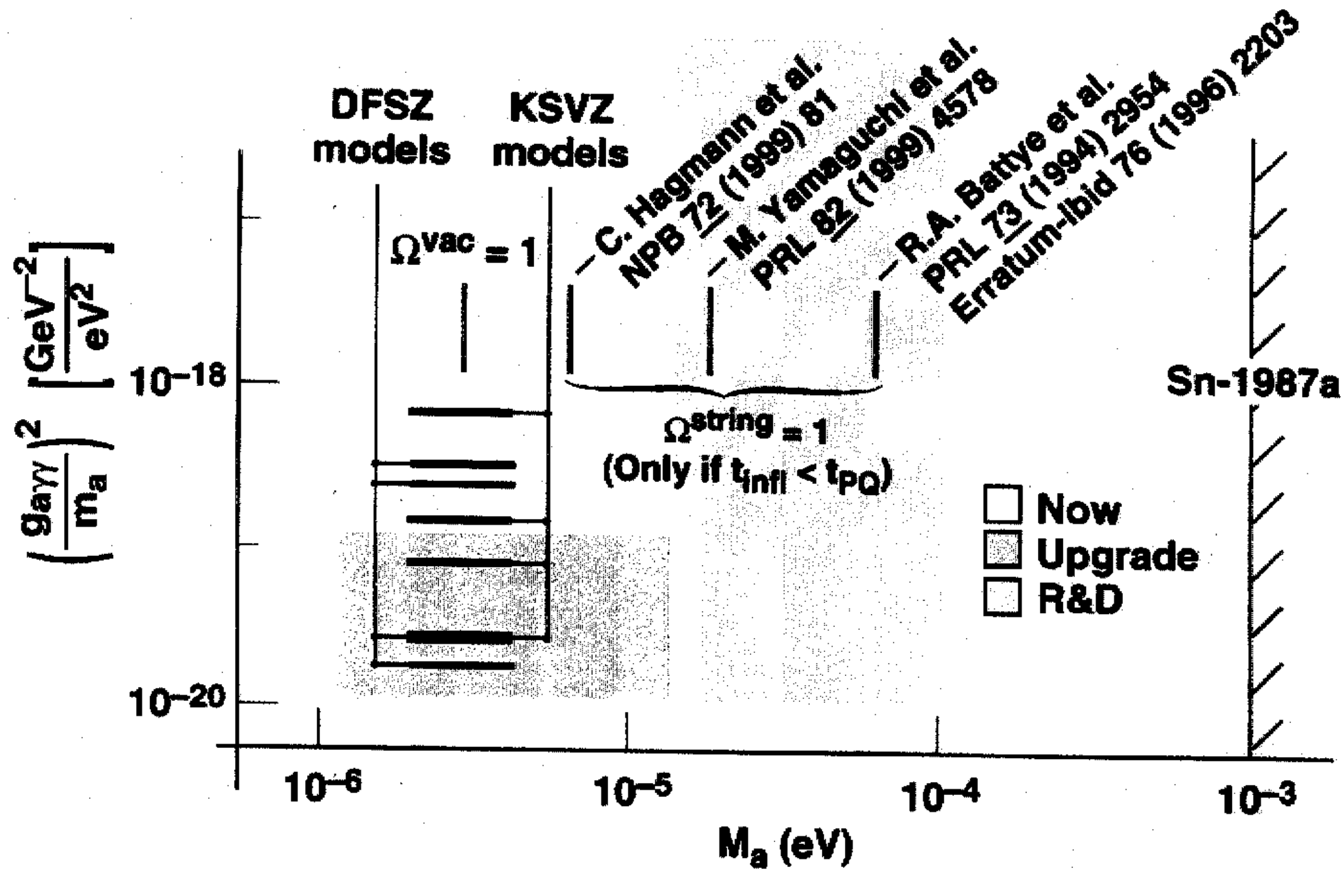
Axion Coupling-Mass Search Space: Main constraints

- $\Omega_a < 1$
- SN 1987a:
  not much of a new invisible channel
- Stellar evolution, helioseismology:
  likewise, little room for new channel
- Eventually, limits on $g_{a\gamma\gamma}$ run into theory:
  Interestingly, the coupling is constrained, to say, within a factor of 10



What's in the Search Space?

Various predictions:



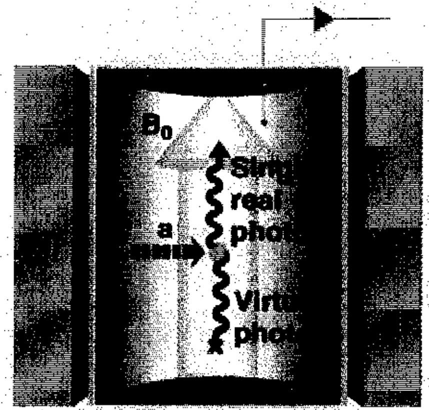
Lots of Axion Search Techniques

Microwave cavity
Solar Primakov
Solar germanium
Laser regeneration
Laser polarization
5th force
Halo axion decays
Astrophysics

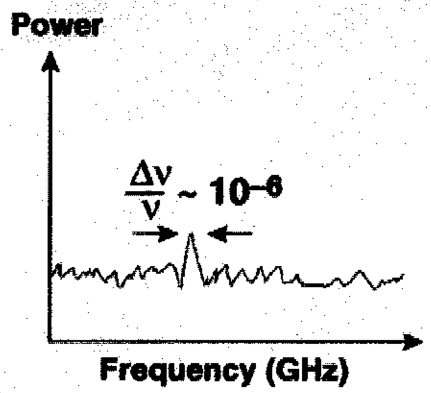
This talk will focus on searches that probe *terra incognita* in the dark matter window 10^{-6} eV $< m_a < 10^{-3}$ eV.

Microwave Cavity Searches

Primakoff Conversion



Signal



Resonant Conversion: $h\nu = m_a c^2[1 + O(\beta^2)]$

$$P_{sig} \sim (5\times10^{-22}\mathrm{W}) \cdot \left(\frac{B}{7.6\mathrm{T}}\right)^2 \cdot \left(\frac{V}{220\ell}\right) \cdot \left(\frac{g_\gamma}{0.97}\right)^2 \cdot \left(\frac{\rho_a}{0.45\ \mathrm{GeV/cm^3}}\right) \cdot \left(\frac{m_a}{3\ \mu\mathrm{eV}}\right)$$

Dicke's Radiometer Eqn. → Integration Time

$$\frac{s}{n} = \frac{P_{sig}}{kT_S} \cdot \sqrt{\frac{t}{\Delta\nu}} \quad ; \quad T_S = T + T_N$$

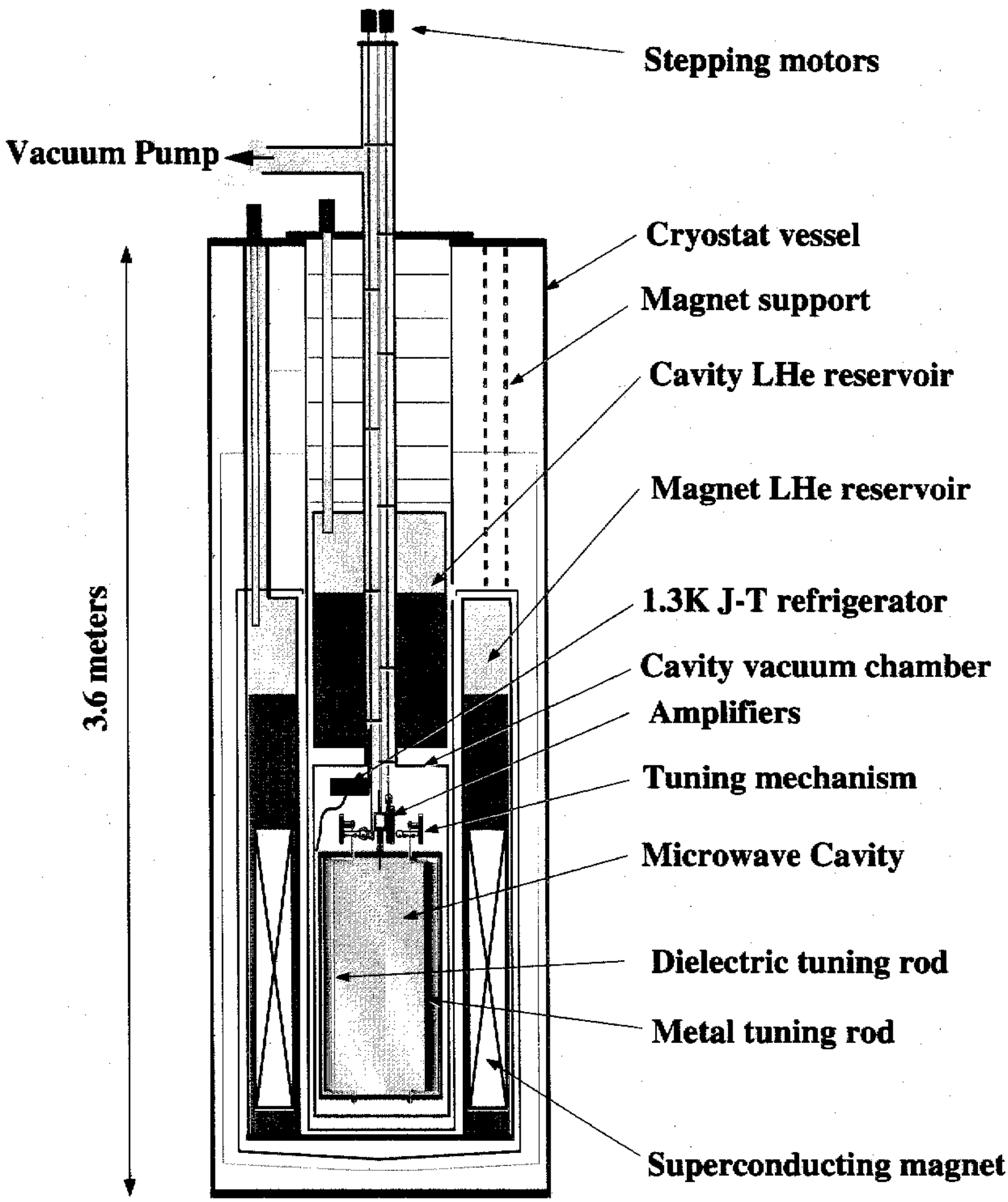
Present exp't: $T \sim T_N \sim 1.5$ K

Scaling Laws

$\frac{d\nu}{dt} \propto B^4 V^2 \cdot \frac{1}{T_S^2}$	$g_\gamma^2 \propto \left(B^2 V \cdot \frac{1}{T_S}\right)^{-1}$
For fixed model g^2	For fixed scan rate $\frac{d\nu}{dt}$

Most sensitive in search region, but narrow band.

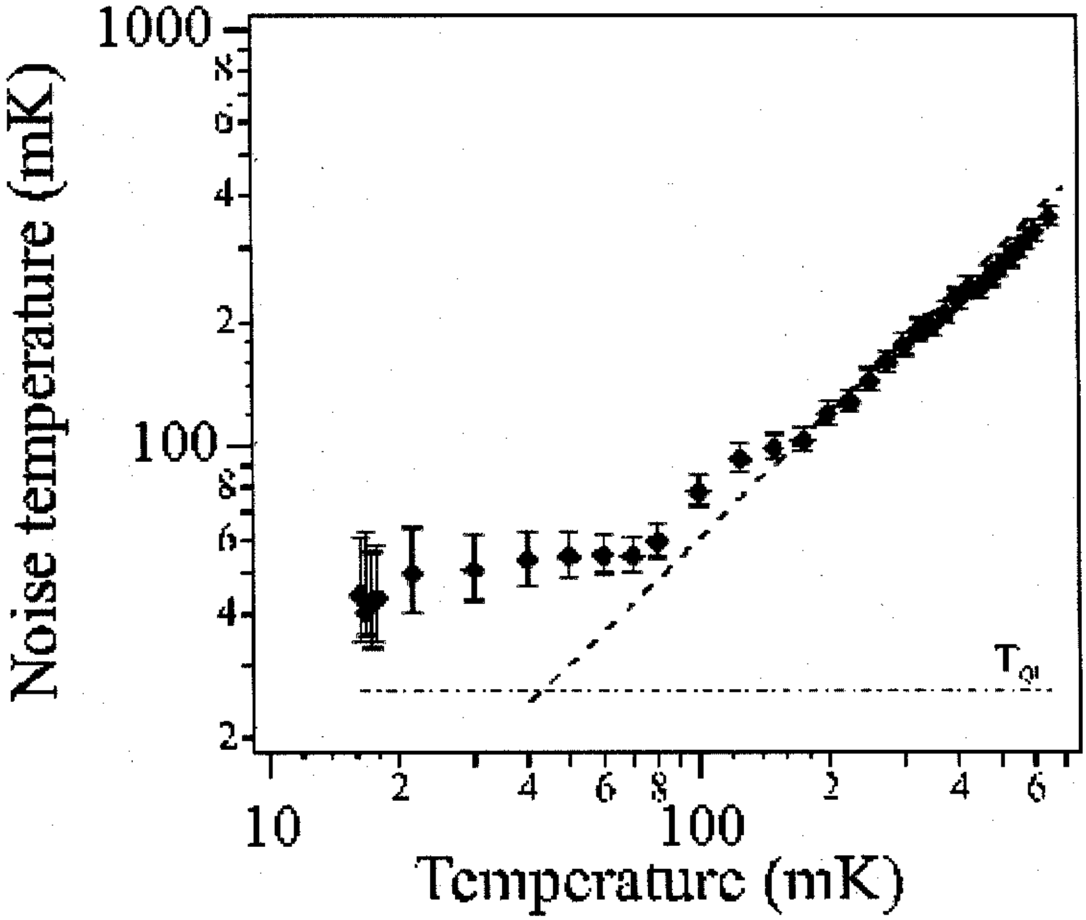
Sketch of US Axion Search



Futurism:
Microwave Cavity Searches I

1) US Search

Phase I ⇒ Lower noise with dc SQUID Upgrade



$$SNR = \frac{P_S}{k_B T_N B}\sqrt{Bt} \quad \Rightarrow \quad t \sim T_N^2$$

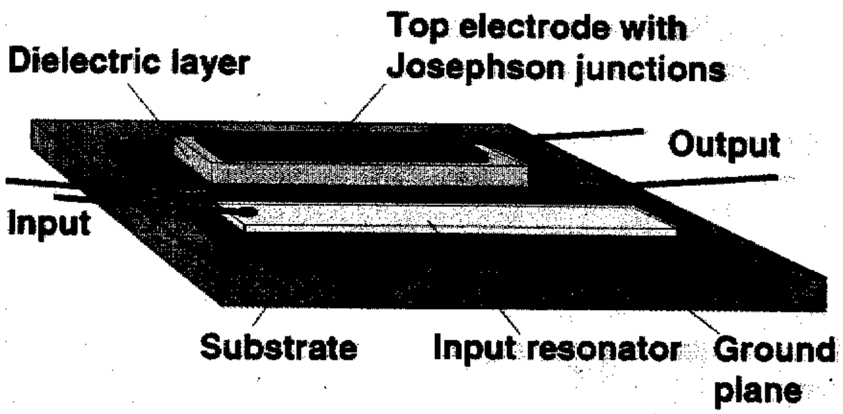
1st decade sensitivity to even pessimistic axion couplings at fractional dark matter halo density

Futurism:
Microwave Cavity Searches II

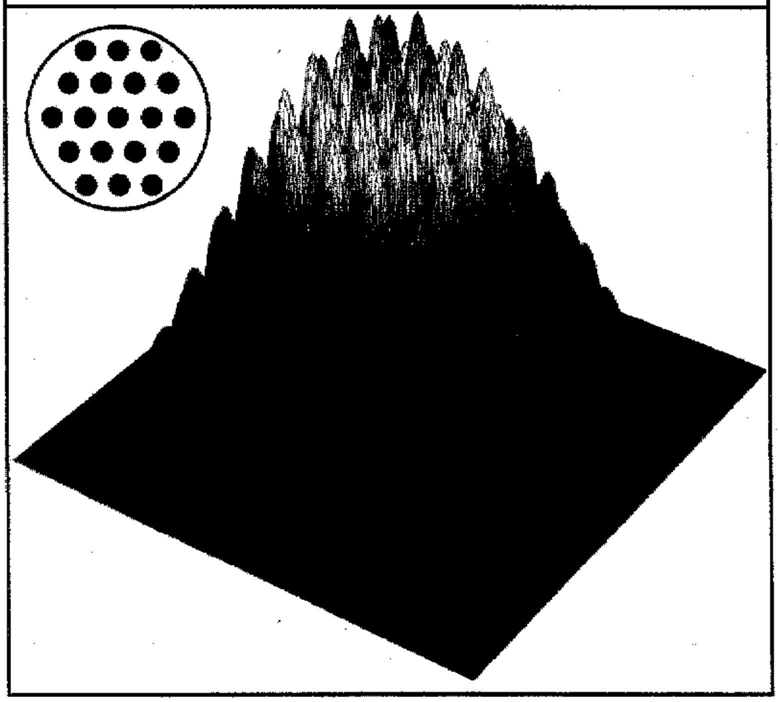
2) US Search

Phase II ⇒ Higher frequency SQUIDS
Higher frequency resonant structures

The 'In-Line' SQUID Amplifier



TM_{010} Electric Field for 96-post Array



2nd decade mass sensitivity

Both phases combined are a 10-year program

Futurism:
Microwave Cavity Searches III

3) Kyoto Search

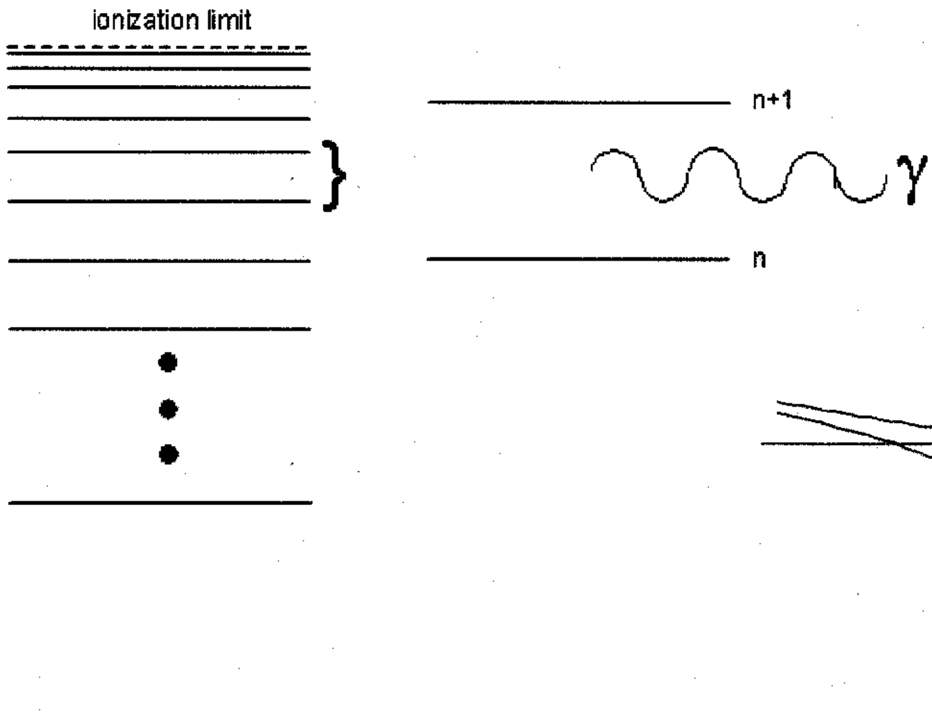
Lower noise: Microwave photon counting

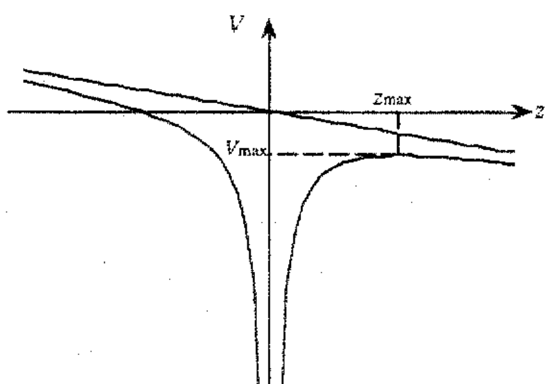
Photon number/phase uncertainty relation:

$$\delta n \, \delta\phi > 1/2$$

Can measure just photon number to arbitrarily high precision (a phototube is not far from this in the visible).

Rydberg atom atomic levels

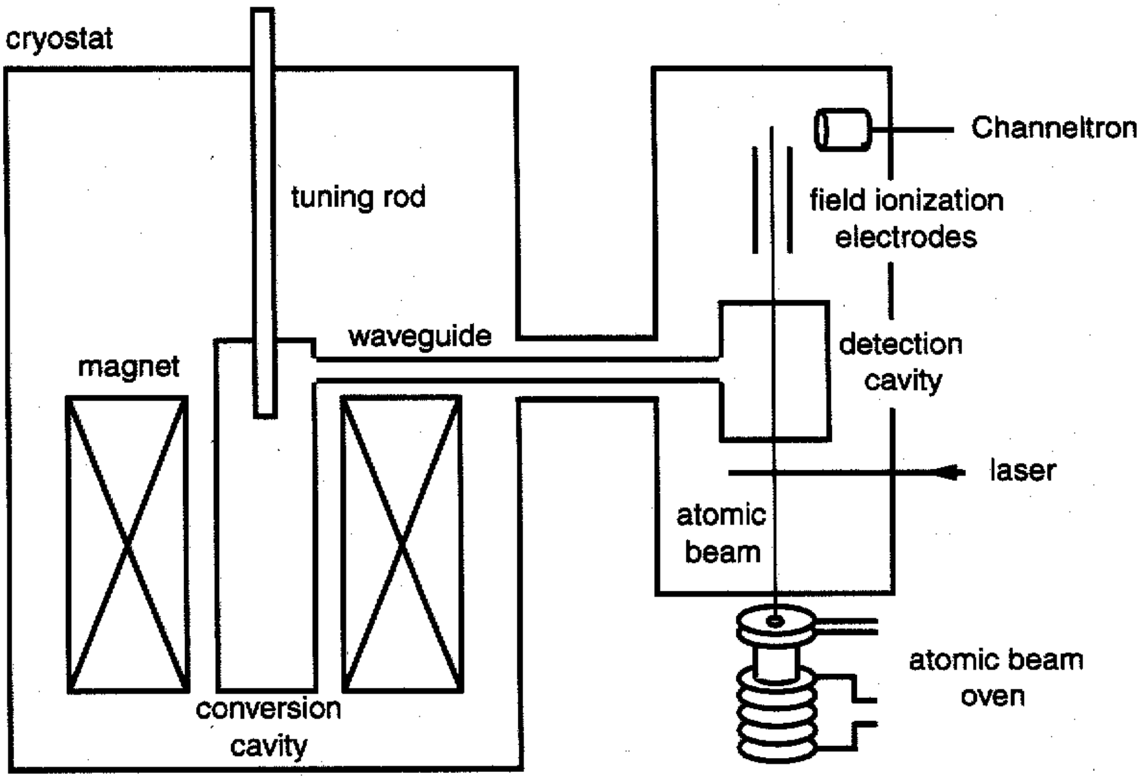




Selective field ionization

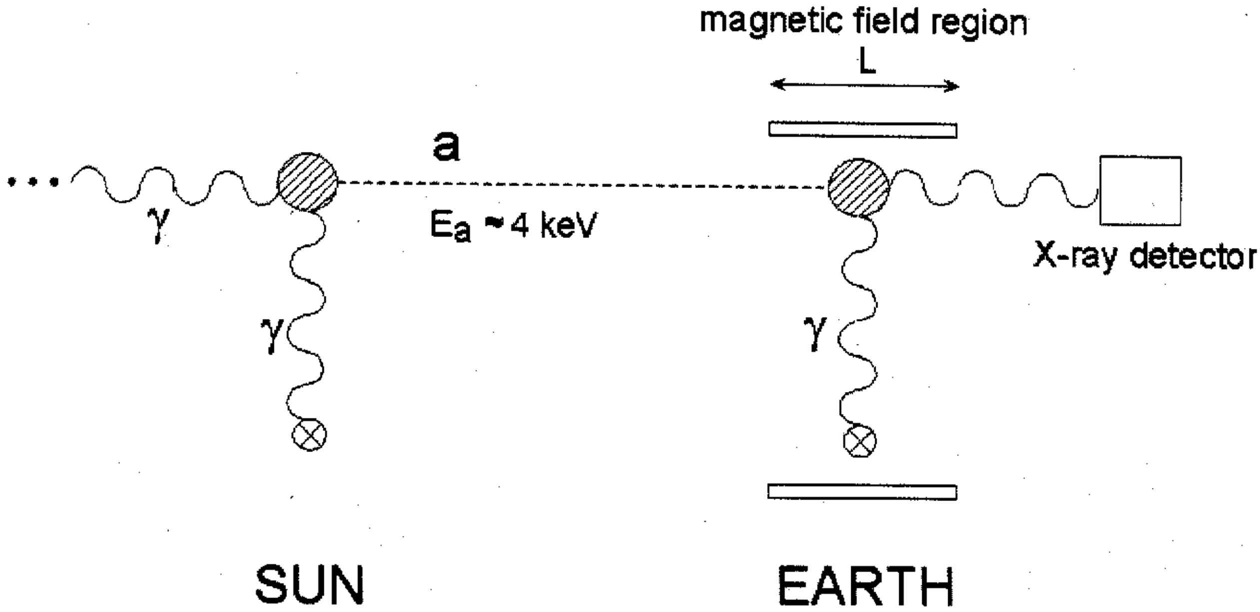
Futurism:
Microwave Cavity Searches IV

Conceptual drawing of microwave cavity / Rydberg atom axion detector



Practical details (e.g., collisional excitation, uniformity of ionizing field) limit sensitivity.

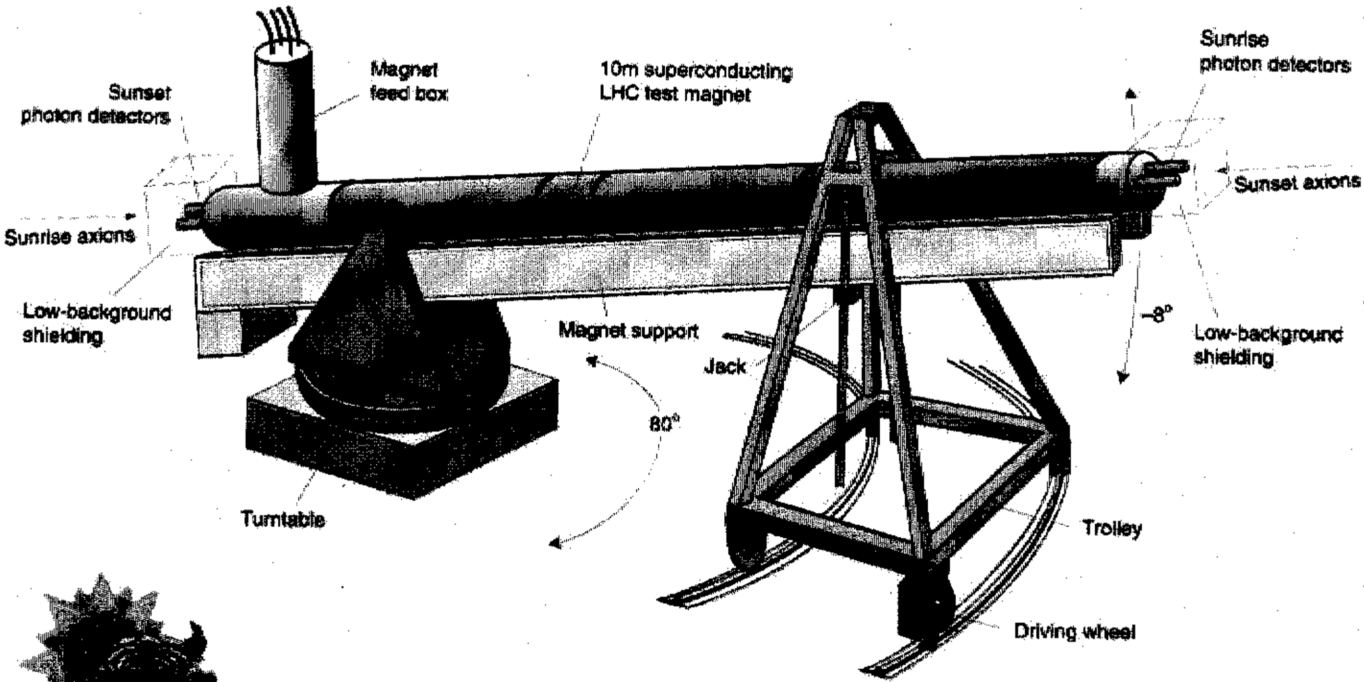
Futurism:
Sun as a Source of Axions I



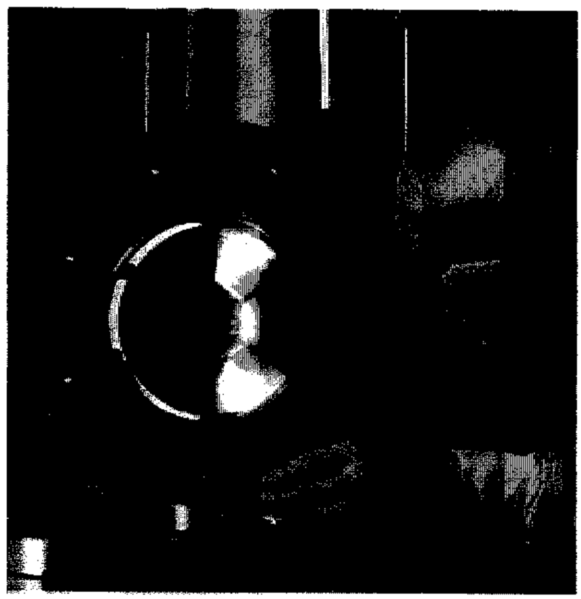
Issue of Coherence: Axion and photons mix.

Example: $L < 10$ m for $m_a \approx 10^{-2}$ eV

Futurism:
Sun as a Source of Axions II

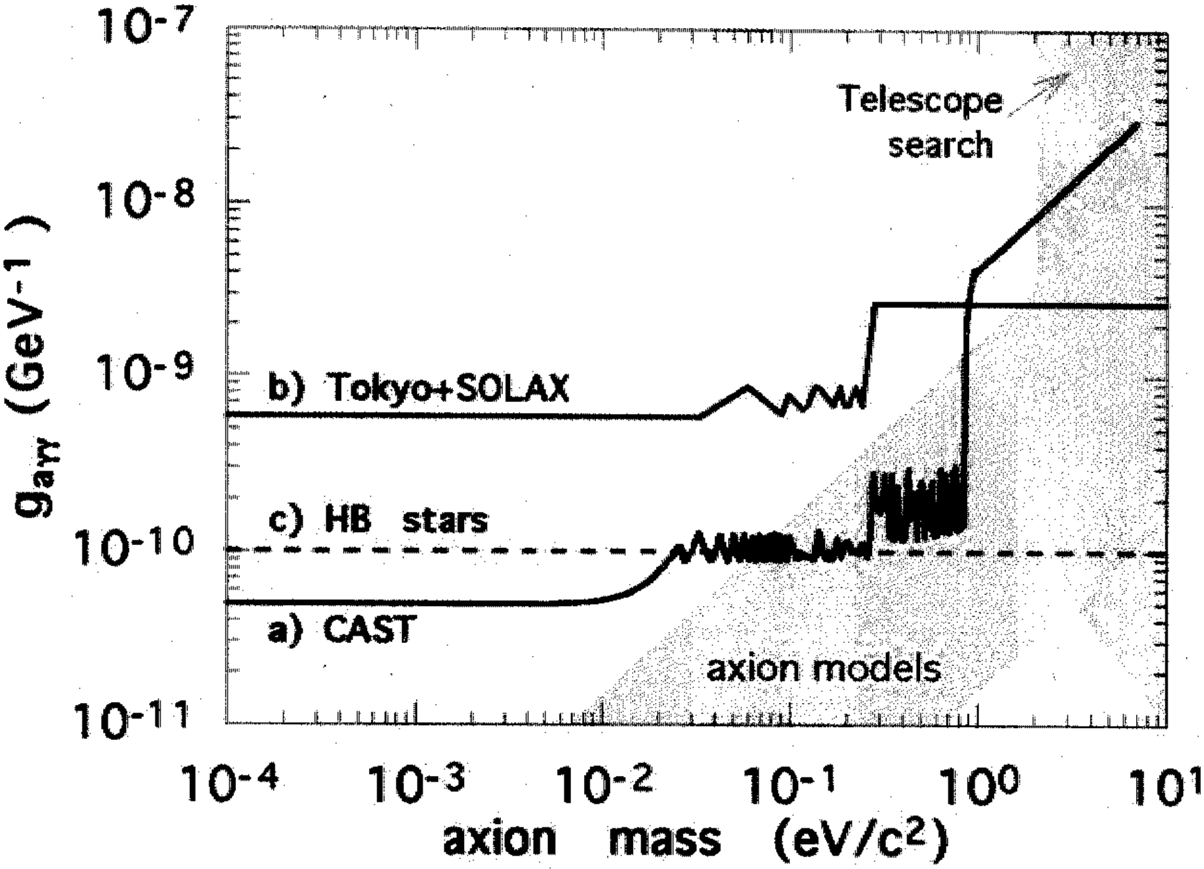


Cern Axion Solar Telescope



X-ray lens

Futurism:
Sun as a Source of Axions III

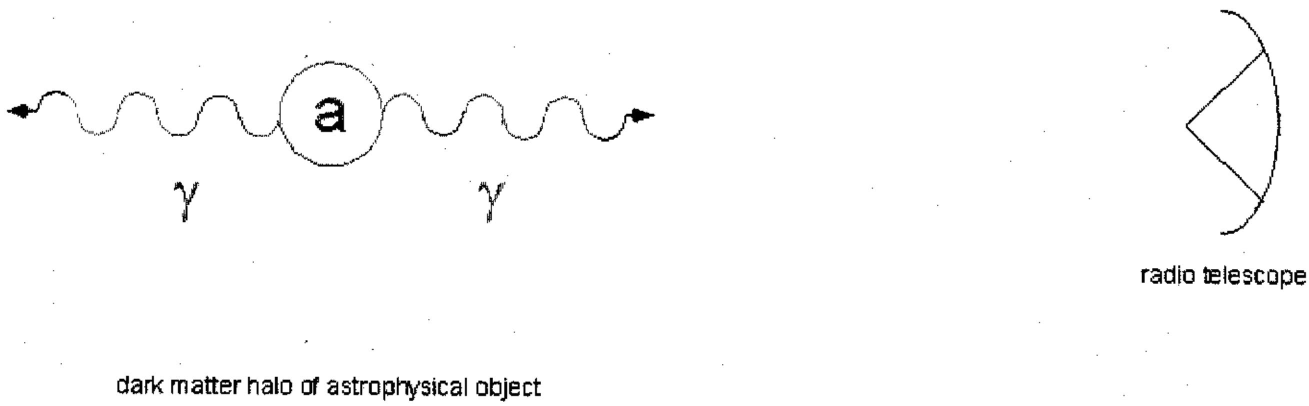


a) Attainable 99.7% c.l. limits on the coupling strength of axions to two photons as a function of axion rest mass in CAST (CERN Axion Solar Telescope).

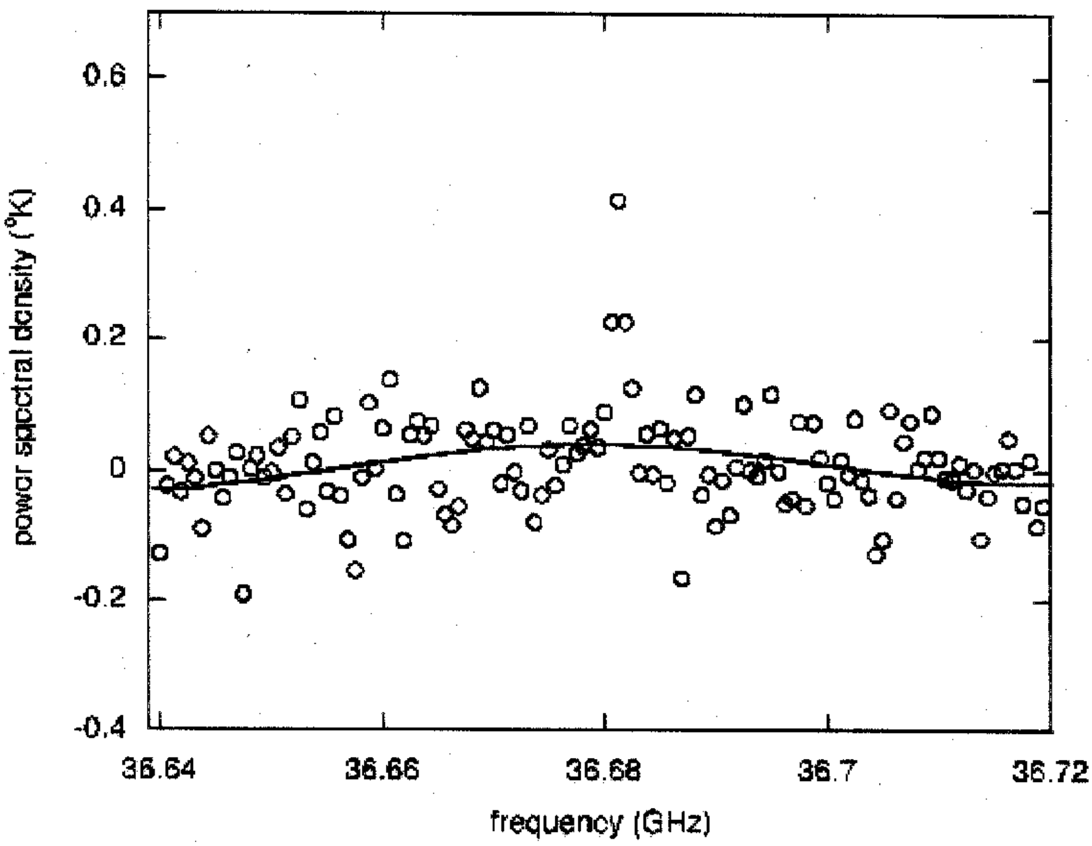
b) Present experimental limits (Tokyo axion helioscope + SOLAX).

c) Astrophysical constraints (HB stars, theoretical).

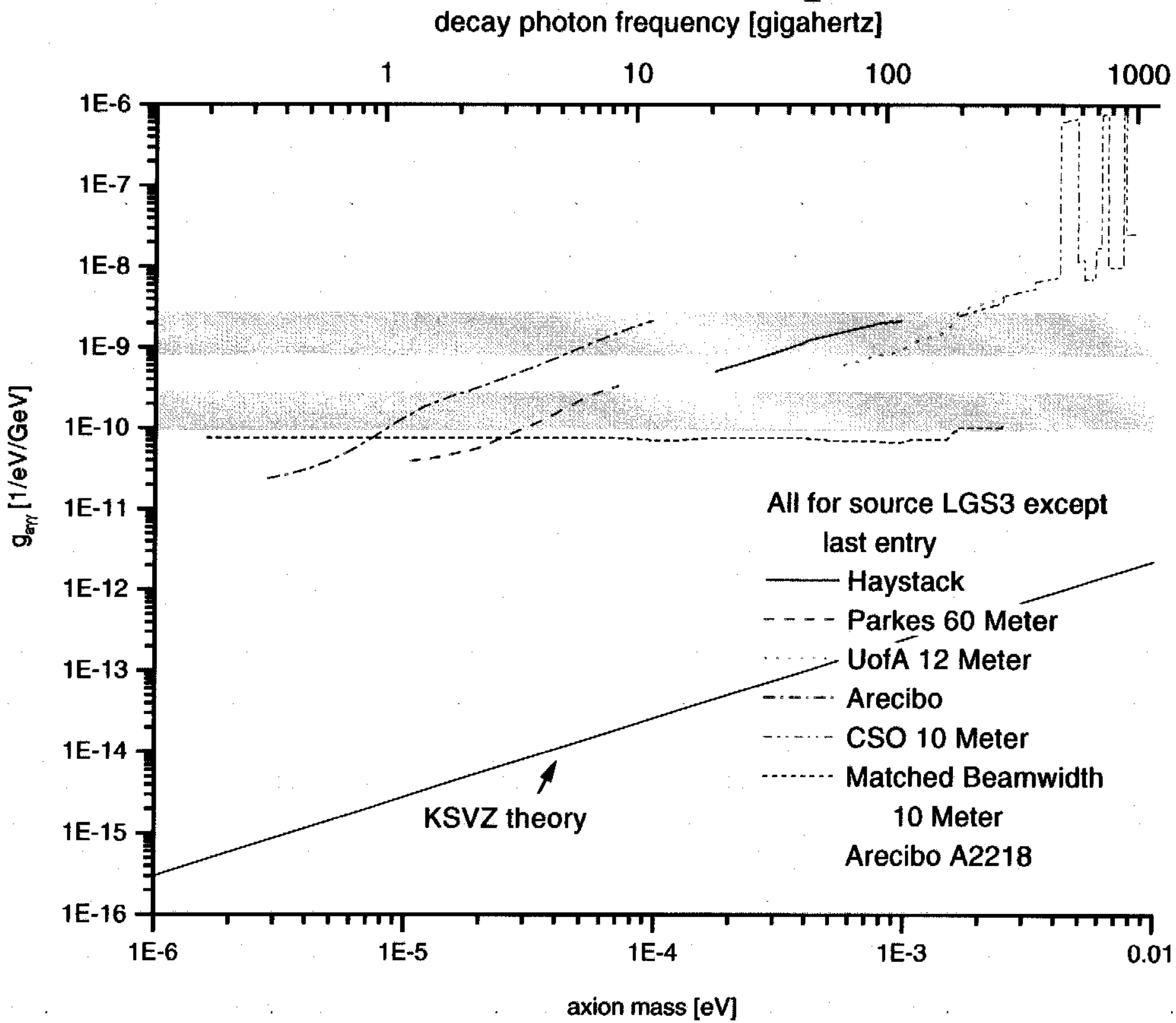
Futurism: Radio Telescope Search I



Simulated axion line from nearby dwarf galaxy

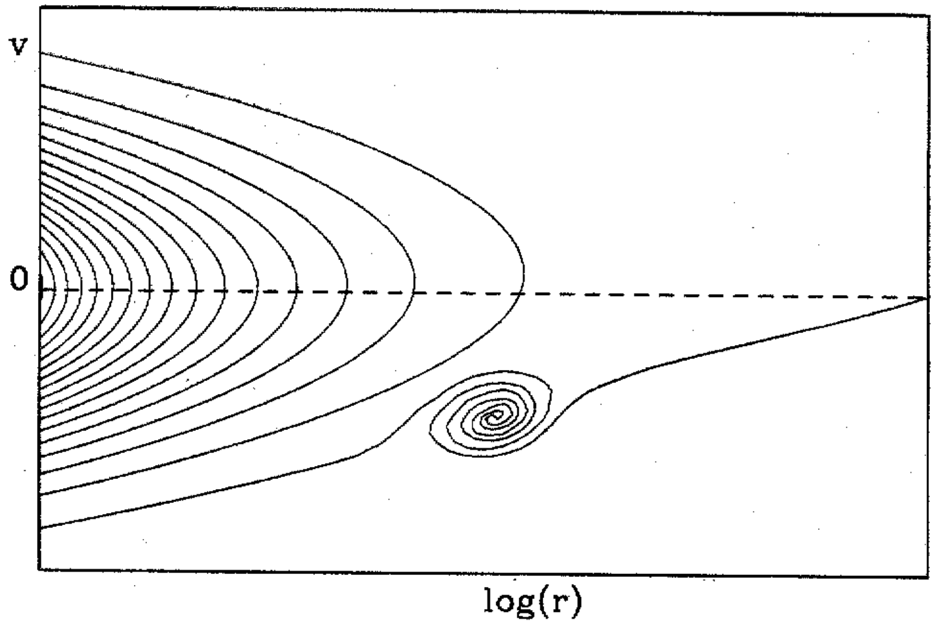


Futurism: Radio Telescope Search II

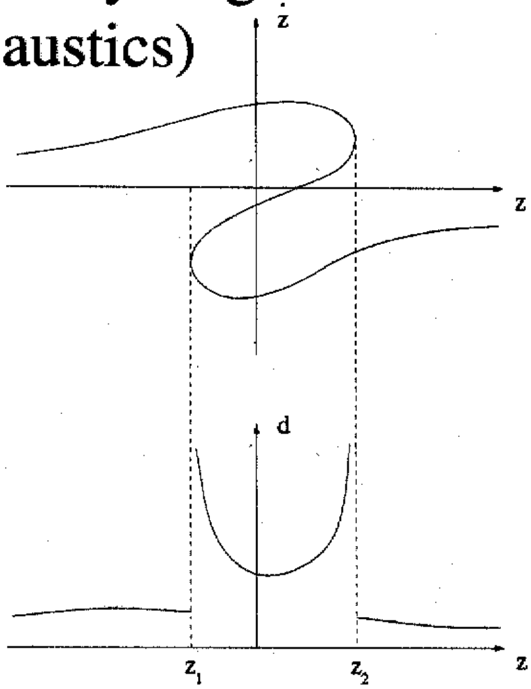


Futurism Example: Astrophysics I

2D slice of 6D galactic dark matter phase space



Folded phase space and density singularities (caustics)

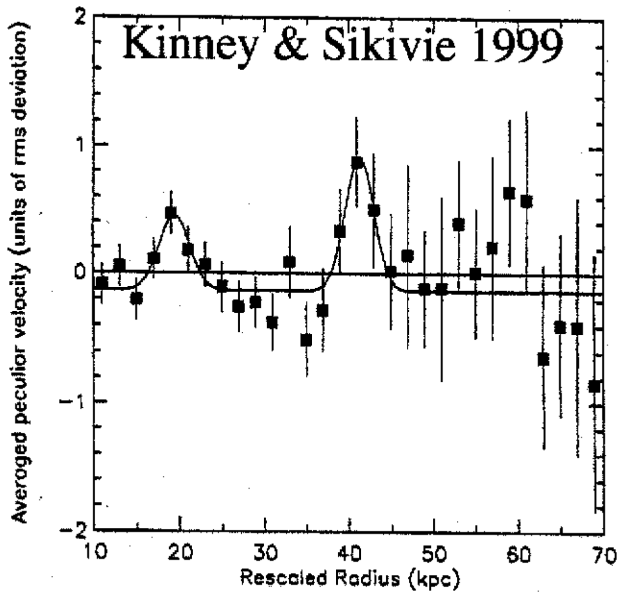


Questions:

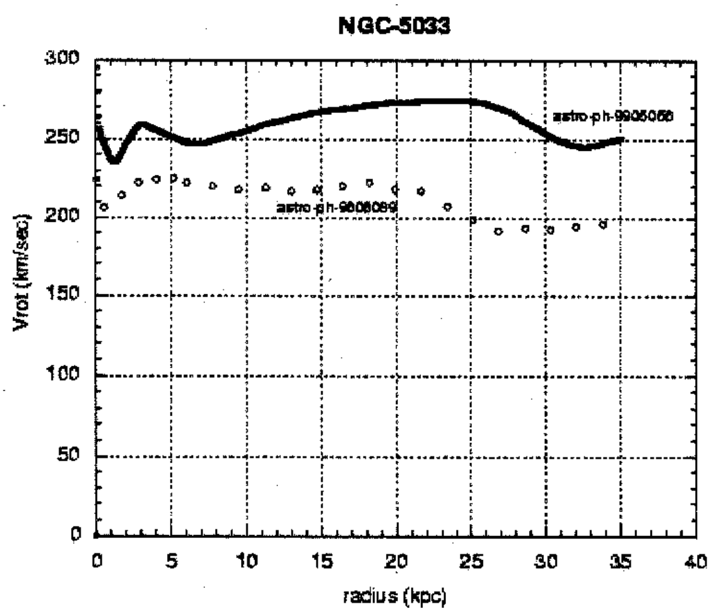
1) Is there such dark matter structure?
2) Is this dark matter structure impressed on baryons?
3) Is this a way to distinguish, e.g., WIMP and axion dark matter?

Futurism Example: Astrophysics II

Universal fine structure in outer spiral galaxy rotation curves?



… but, rotation curves vary between surveys



Can't tell yet if dark matter structure is impressed on baryons

Futurism Example : Astrophysics III

Lensing and imaging of dark matter structure

Hogan 1999

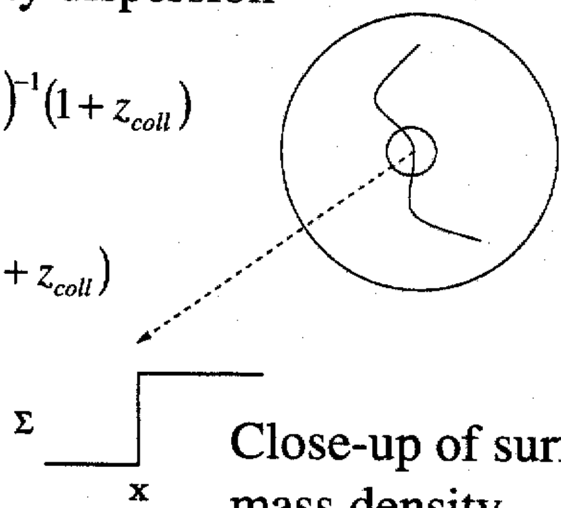
Primordial CDM velocity dispersion

axions

$\delta v_a / c = 3\times10^{-17}\left(m_a / 10^{-5} eV\right)^{-1}\left(1+z_{coll}\right)$

WIMPs

$\delta v_W / c = 10^{-11}\left(m_W / GeV\right)^{-1/2}\left(1+z_{coll}\right)$



Close-up of surface mass density

Lensing:
Look at stars crossing halo: very different than MACHOs
Timescales: axions ⇒ hours, WIMPs ⇒ years
Details are daunting.

Imaging (several different scenerios):
e.g., Bends in images of extended linear objects (jets, edge-on galaxies).
Again, details are daunting.

Conclusions

Light axions are a compelling Cold Dark Matter candidate.

The allowed space of axion coupling and mass is relatively tightly bounded.

The microwave cavity technique can discover or rule-out CDM axions within the decade.

The new generation of solar axion searches probe an unexplored mass-coupling range.

Other searches (e.g., 5^{th} force, halo decays) probe axions from certain special scenerios.

Considerable observational and theoretical astrophysics remains to be done on the implications of CDM cosmology.