
Axion
NEUTRO-CALCAIRE
+ ASSOUPLISSEUR
NEUTRALISE LE CALCAIRE
NETTOIE EN PROFONDEUR
AXION NEUTRO-CALCAIRE empêche le calcaire de se déposer sur votre linge et de le ternir.
Ainsi, ses AGENTS ACTIFS peuvent pénétrer au cœur des fibres et NETTOYER EN PROFONDEUR tout votre linge.
Votre linge est doux et frais

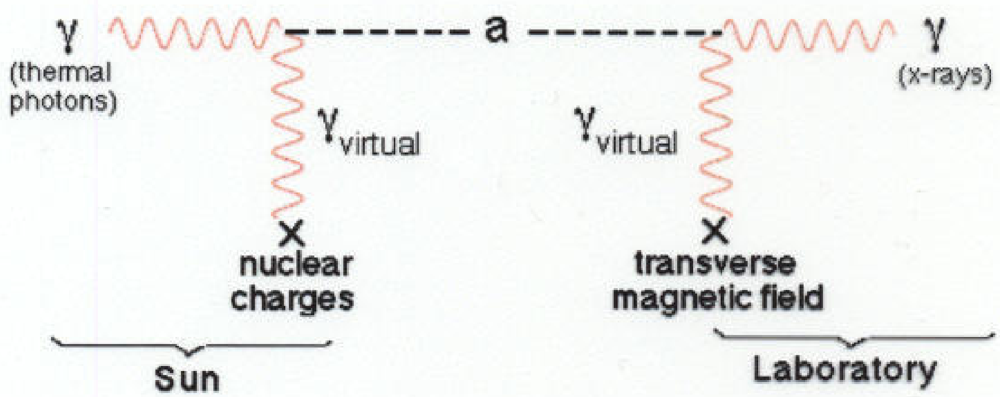
QCD is very successful BUT should violate CP invariance:

$\Rightarrow$ neutron electric dipole should be x10^{11} the experimental limit! = "STRONG CP-PROBLEM"

Several ways to kill CP-violating terms, favorite is Peccei-Quinn broken U(1) symmetry; Weinberg & Wilczek pointed out that this must generate a light pseudoscalar = AXION (named after a laundry detergent…).

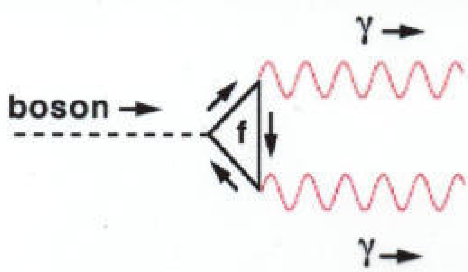
On top of this, an excellent Dark Matter candidate for some axion masses.

If Axions exist, they can be copiously produced in stellar interiors ($n+n \rightarrow n+n+a$, $\gamma+e \rightarrow a+e$, $e^{+}+e^{-} \rightarrow a+\gamma$, etc....) and play important role in stellar evolution:



"Primakoff effect" (x 2)

More generally: any boson which couples to charged particles can couple to two photons via fermion (quark & lepton) vacuum loops (Schwinger):



We are therefore looking for axions or **"axion-like"** particles!

Many axion couplings possible, some in close parallel to photon processes (e.g., "axioelectric effect")

Most experimental searches based on Primakoff effect (one of the photons being "man-made", i.e., a virtual photon provided by a strong magnetic field).

P.F. Smith and J.D. Lewin, Dark matter detection, Phys. Rept. 187 (1990) 203.

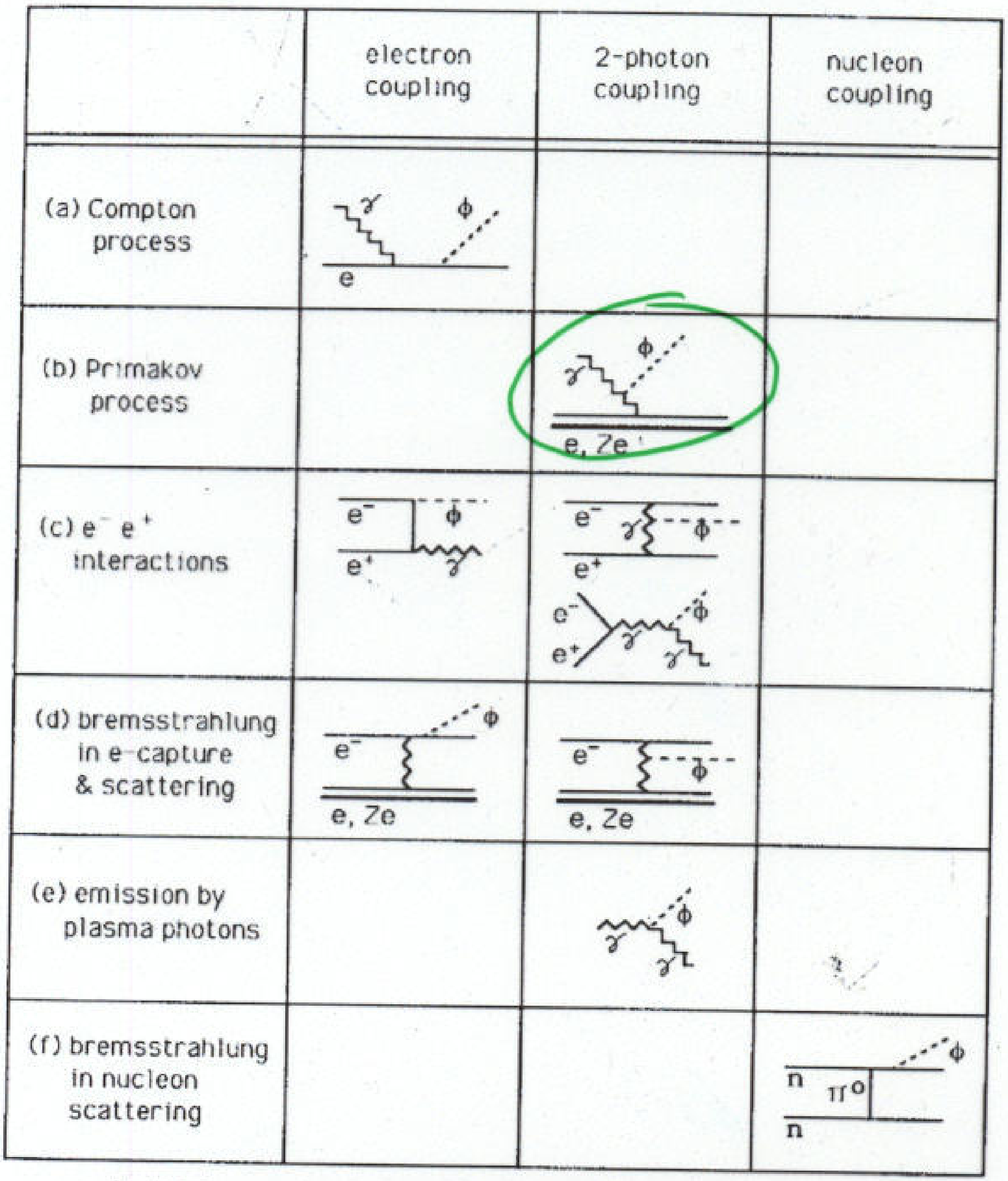
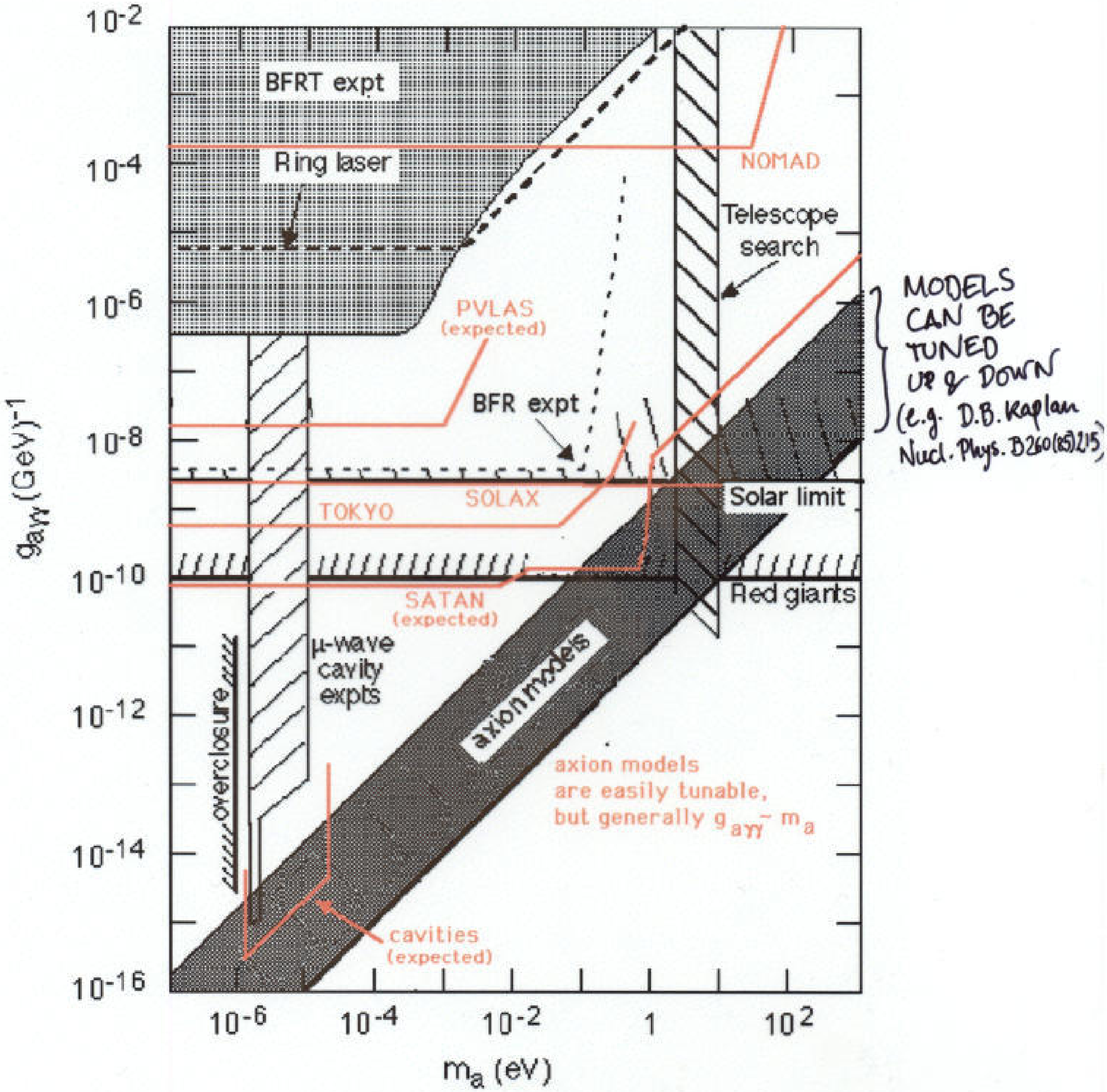


Fig. 5.3. Summary of possible stellar axion production processes (from ref. [5.13]).

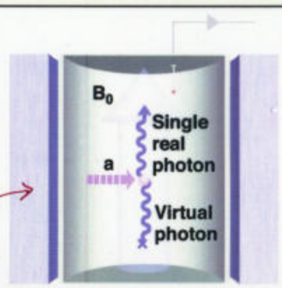
Old, ongoing & future searches + astrophysical constrains



How to detect dark-matter axions (Sikivie, 1983)

AXION

Primakoff Conversion



8T magnet

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

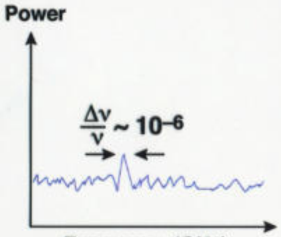
$$P_{sig} \sim (5\times10^{-22}\mathrm{W}) \cdot \left(\frac{B}{7.6\mathrm{T}}\right)^2 \cdot \left(\frac{V}{220\mathrm{l}}\right) \cdot \left(\frac{g_\gamma}{0.97}\right)^2 \cdot \left(\frac{\rho_a}{0.45\ \mathrm{GeV/cm^3}}\right) \cdot \left(\frac{m_a}{3\ \mu\mathrm{eV}}\right)$$

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

Signal



Scaling Laws

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

This is a narrow-band experiment. There is no other way to get the required sensitivity!

P01545-kvb-u-005

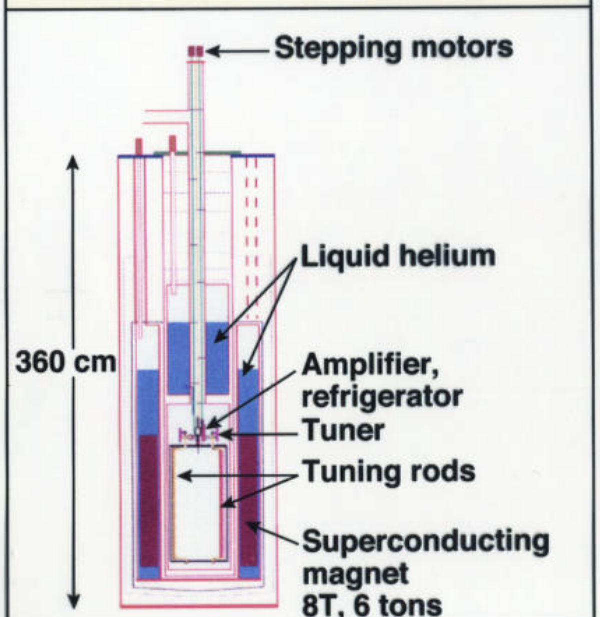
↑ A REFERENCE POINT: POWER RECEIVED FROM PIONEER 10 ($7\cdot10^9$ miles away) IS 10^5 LARGER!

LLNL (MIT + LLNL + U. of Florida + LBNL + FNAL + U. of Chicago + INR)

Axion hardware

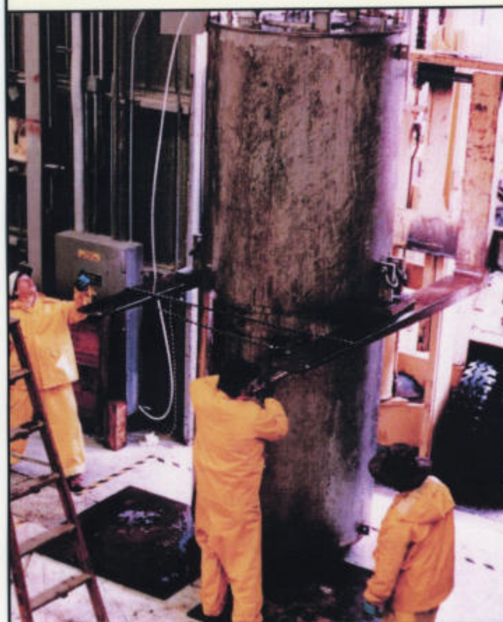
AXION

Magnet with Insert (side view)



Pumped LHe → T ~ 1.5 k

Magnet (Wang NMR Inc.)



8 T, 1 m × 60 cm ∅

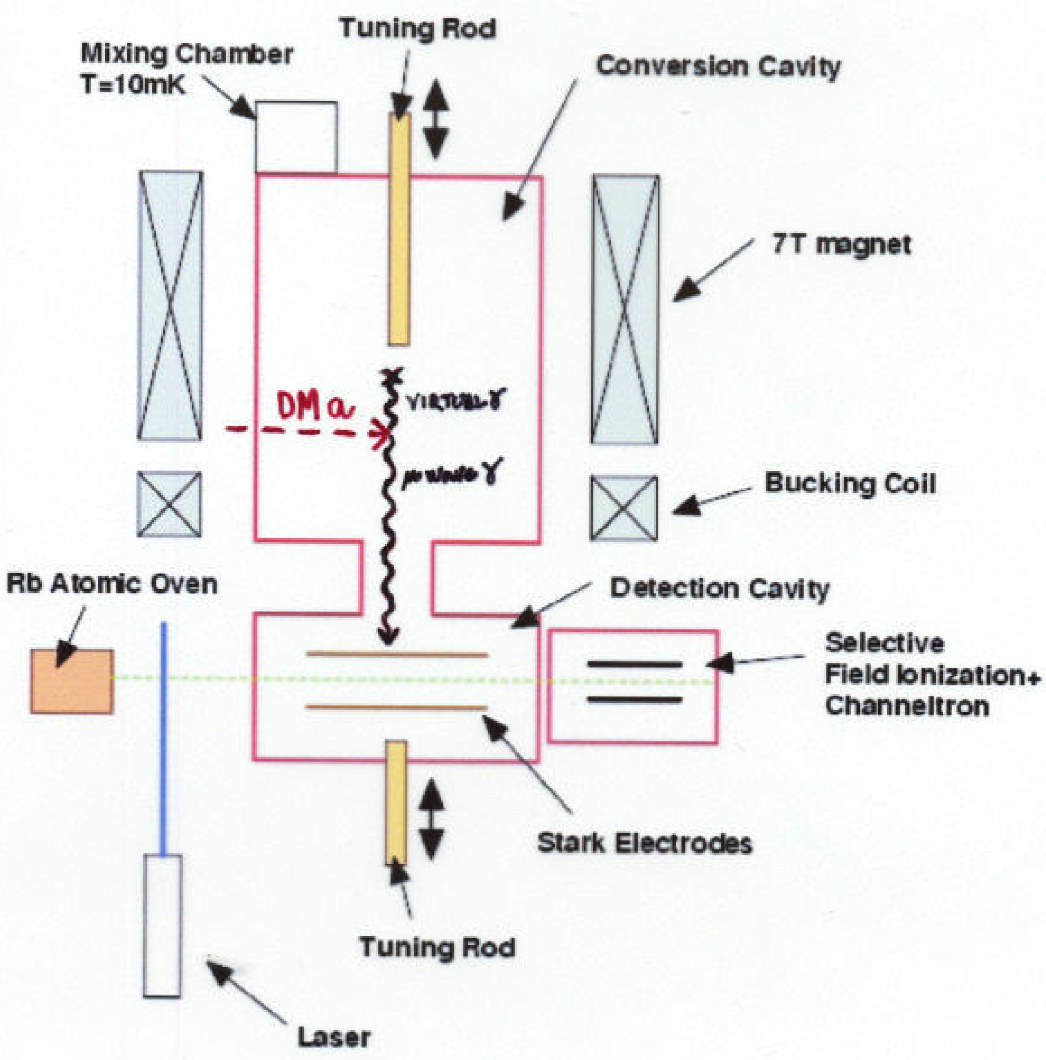
P01672-kvb-u-004

As if this wasn't hard enough : converted photon detection via Rydberg atom beam :

$$[\,\mathbf{axion}\,] \overset{B_0}{\Longleftrightarrow} [\,\mathbf{photon}\,] \;\Updownarrow\; \begin{matrix} -\,n' \\ \\ -\,n \end{matrix} \;[\,\mathbf{atom}\,].$$

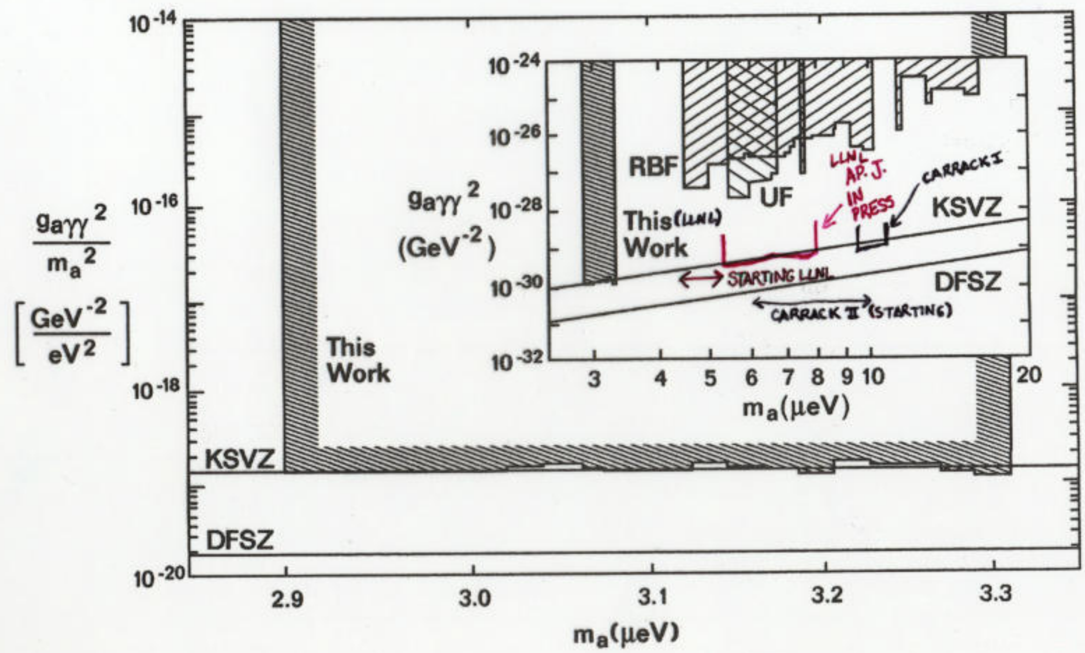
Kyoto Group Axion Detector Nucl. Phys. B 572, 164 (99)

- Photons are produced in tunable conversion cavity
- Passed into B-field free detection cavity
- Beam of Rydberg atoms absorb photons n->(n+1)
- Selective Detection of (n+1) states



First data at KSVZ sensitivity

AXION



(C. Hagmann *et al.*, Phys. Rev. Lett. 80 (1998) 2043)

P02031-kvb-u-017

IN A CLASS OF ITS OWN: "PRODUCES" ITS OWN AXIONS
(INDEPENDENT OF SOLAR OR ASTROPHYSICS CONSIDERATIONS)

PVLAS experiment

I.N.F.N. Legnaro, I.N.F.N. and University Trieste, Ferrara and Pisa - Italy

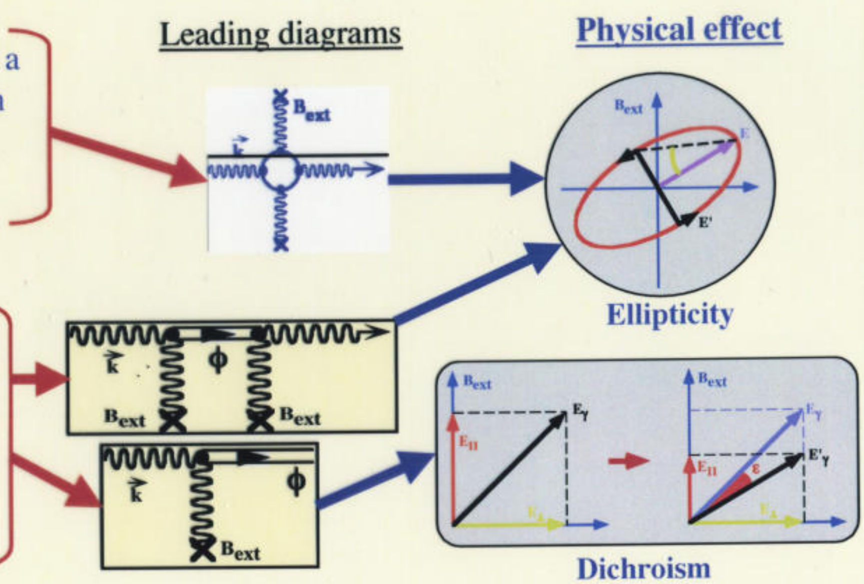
PVLAS principle

Perturb quantum vacuum with a magnetic field and **probe** it with a polarised light beam

PVLAS physics

Quantum Vacuum as a **birefringent** medium
QED and photon-photon scattering

Neutral, light (*axion-like*) particles interacting with two photons (dark matter candidates)



G. Cantatore - PVLAS Collaboration- March 2002

PVLAS status - March 2002

Milestones

Achieved in 2001

- installed Stress Optical Modulator (SOM) device (developed within the collaboration)
- several hours of data taking
- observed a "signal" at the expected frequency
- initiated series of tests to clarify the nature of the "signal"

Projected in 2002

- prove/disprove that "signal" is of physical origin
- upgrade apparatus to visible wavelength
- confirm year 2001 results

INFN Legnaro National Lab. PVLAS site (Padova, Italy)

- Main technologies
  - Superconducting, liquid He, 6 Tesla rotating magnet/cryostat (FAST!)
  - High finesse/high Q ($F = 100000, Q = 10^{12}$) **6.4 m long** Fabry-Perot optical resonator (~100 Km optical path length)

G. Cantatore - PVLAS Collaboration- March 2002

PVLAS - Main results as of February 2002

- Measurement runs have been conducted in the following conditions:
  - interaction region under vacuum ($P < 10^{-7}$ mbar)
    - $B = 0$
    - B from 3 T to 5.6 T
      - two different initial polarisation states
  - interaction region filled with N_2, Kr, Xe
    - several pressure values from $\sim 10^{-3}$ mbar to ~ 1 mbar
- Results as of February 2002
  - in vacuum
    - when $B = 0$ no signal is observed at the expected frequency
    - when $B \neq 0$ a peak appears in the signal spectrum at the expected frequency
      - preliminary evidence of "correct" dependence from B^2 and the initial polarisation state ← !!!
  - in gas
    - signal peaks at the expected frequency
      - preliminary evidence of "anomalous" peak amplitude in N_2 at low pressures
    - phase calibration of the apparatus
      - the vacuum peak phase appears to lie along the "physical" axis defined by the N_2 and Kr signal peak phases

ONE WAY FOR HELIOSCOPES AND BRAGG EXPERIMENTS TO HAVE MISSED THIS WOULD BE AN E_{thr} TOO HIGH.
(NEVER MIND ASTROPHYSICAL CONSTRAINTS...)

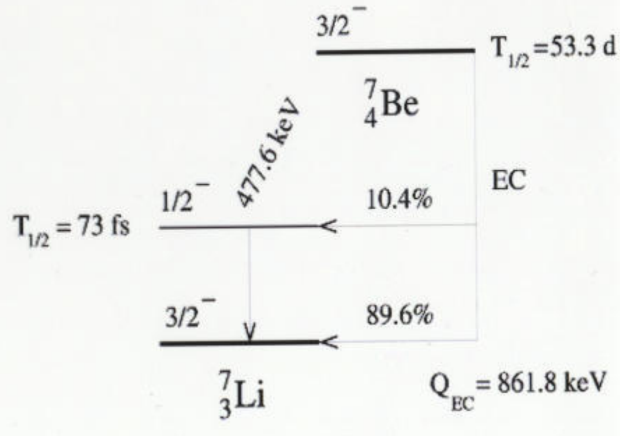
FINAL TEST TO EXCLUDE SYSTEMATICS THIS SUMMER!

M. Krcmar, Z. Krecak, A. Ljubicic, M. Stipcevic, and D. A. Bradley,
Phys. Rev. D 64 (2001) 115016

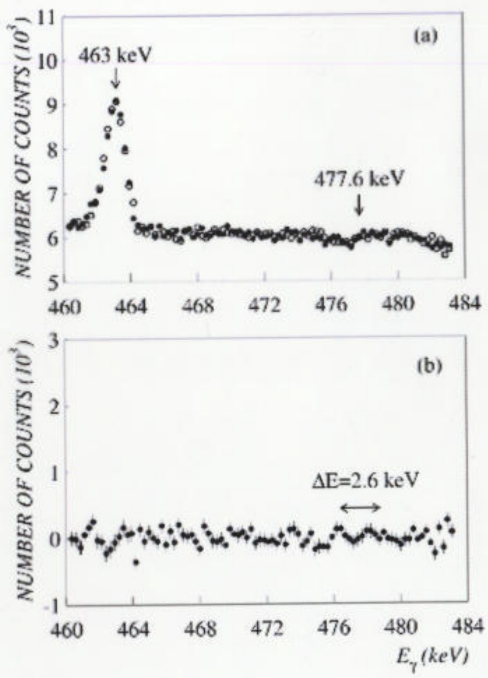
Search for solar axions using ^{7}Li

S. MORIYAMA
Phys. Rev. Lett. 75(95) 3222
(hep-ph/9805032)
^{57}Fe (14.4 keV)

- A novel approach to the search for solar axions has been proposed
- Hadronic axions of 478 keV might be emitted instead of γ rays in the deexcitation of ^{7}Li
- The axions are accompanied by emission of ^{7}Be solar neutrinos of energy 384 keV
- As a result of Doppler broadening, in principle these axions can be detected via resonant absorption by the same nuclide on the Earth

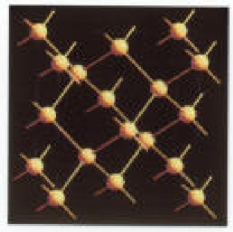


- The detection of subsequent emission of 478 keV γ rays would be a sign of axion existence



- An experiment was made (M = 56,72 g, $\varepsilon = 8.3\text{x}10^{-3}$, t = 111,11days, HPGe detector, background reduction ~10) which has yielded

$m_a < 32$ keV at 95% C.L.



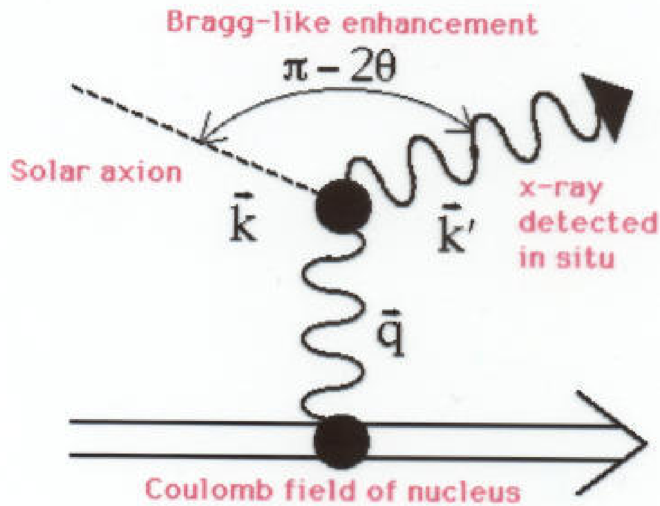
SOLAX

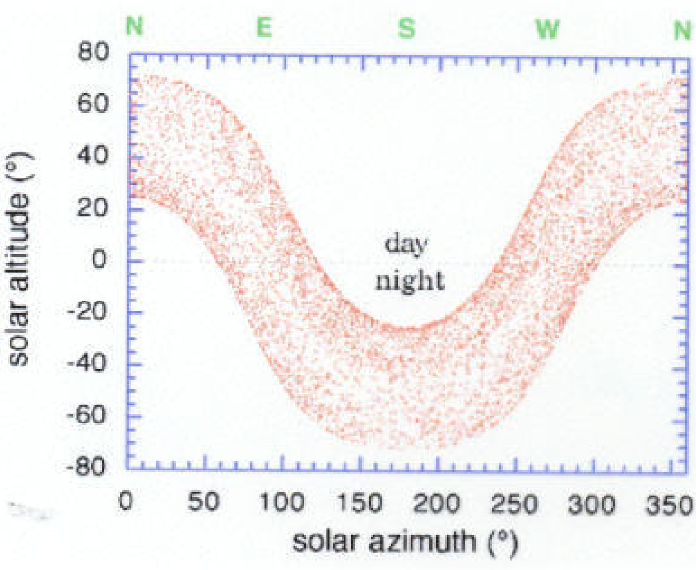
Coherent Primakoff conversion in crystalline low-bckg detectors

- **Proposed** : E.A. Paschos & K. Zioutas, Phys. Lett. B323 (1994) 367.
- **Developed** : R.J. Creswick *et al.*, Phys. Lett. B427 (1998) 235.
- **First search (HP Ge)** : F.T. Avignone *et al.*, Phys. Rev. Lett. 81 (1998) 5068.

IMPROVED BY ZARAGOZA & DAMA

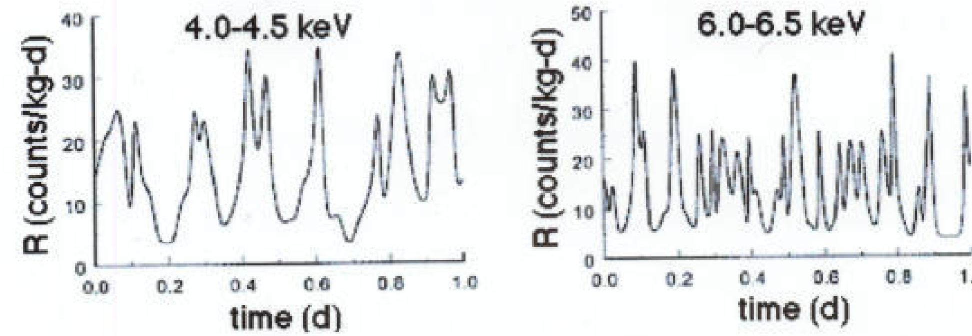
Piggybacks on searches for WIMPs, double-beta decay





First step : correlate each event in detector with solar position

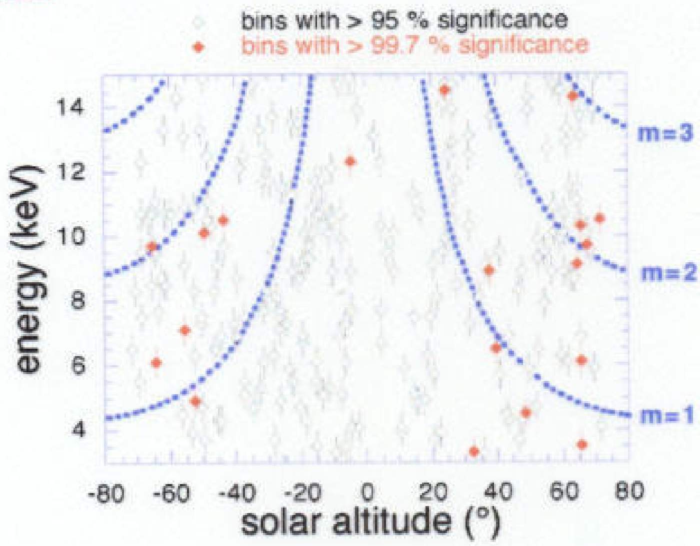
time-dependence of expected signal as Bragg angles are struck :



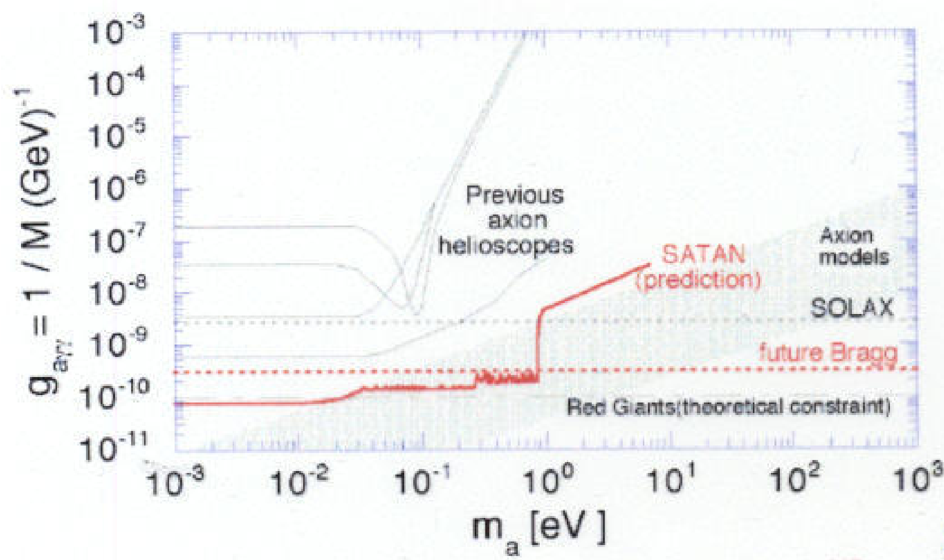
SIGNATURE IS WICKEDLY RICH !

Plenty of smoking-gun signatures. Example :

Axion-produced x-ray energy and Bragg angle are related as E (keV)= 12.396 / λ (Å) where $2\,d\,\sin\theta_B = m\ \lambda$ (m=1,2,3..., d= distance between atomic planes) ; as the Sun marches in the sky, the incidence angle on atomic planes varies ⇒ E for enhanced conversion varies accordingly... ⇒ **ghostly "threads" of events in E vs. Solar position parameter space expected...**



...none seen



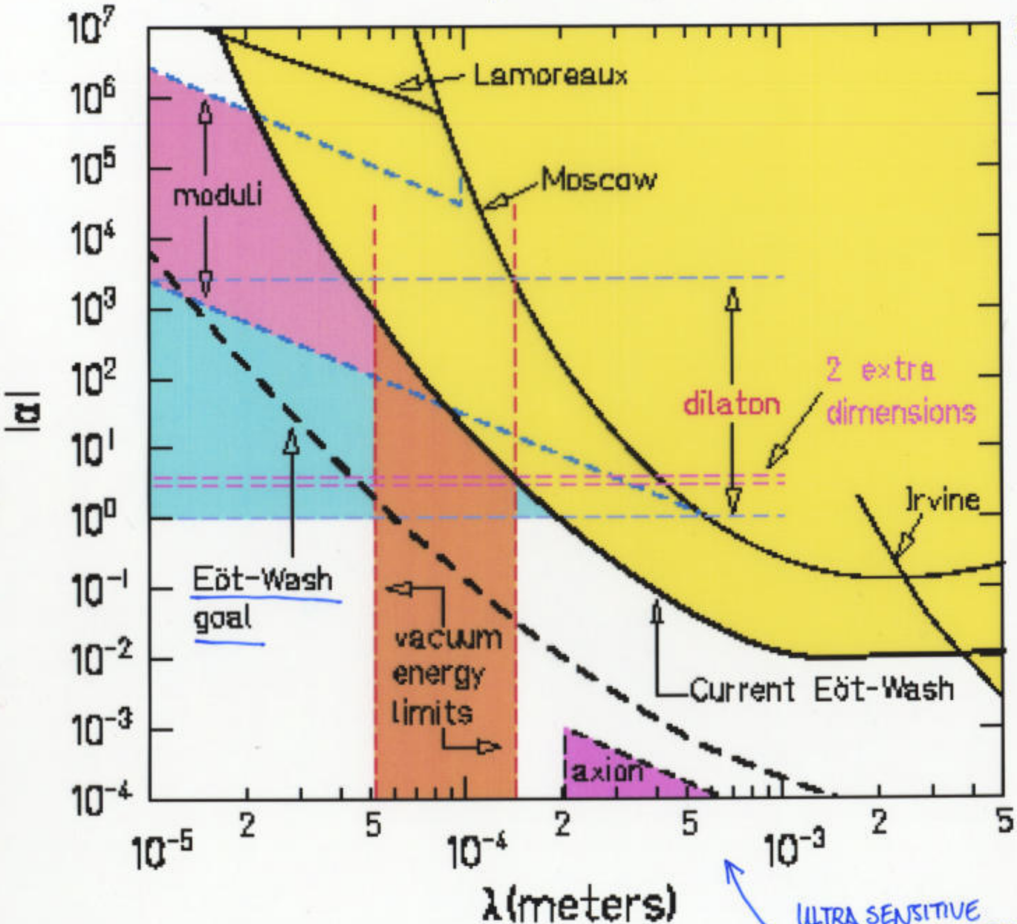
PARASITIC SEARCH IN ALL FUTURE LOW-BCKG SINGLE CRYSTAL EXPERIMENTS

Future limits (CUORE, GENIUS) increase only as exposure $^{1/8}$ (astro-ph / 9912491)

MUST BE MENTIONED:

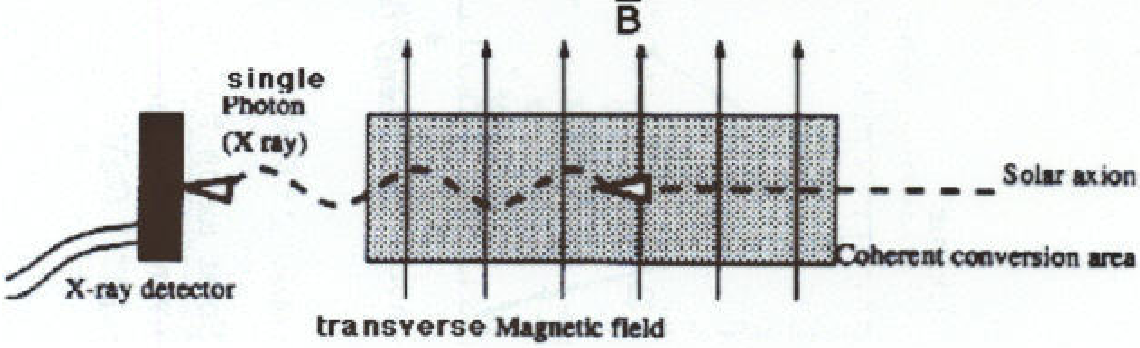
AXIONS OF MASS 1-1000 μeV CAN MEDIATE NEW MACROSCOPIC FORCES (R~0.2-200mm)

Moody & Wilczek
Phys Rev D 30(84)130



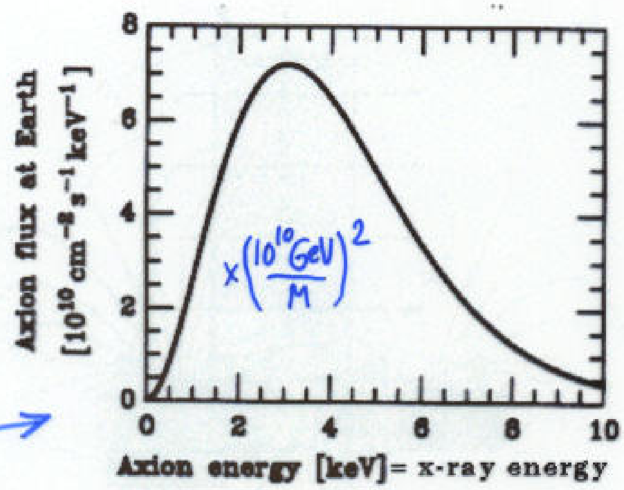
ULTRA SENSITIVE TORSION BALANCE EXPERIMENTS (e.g. C.D. Hoyle et al, hep-ph/0011014) MAY ONE DAY PROBE THIS POSSIBILITY

AXION HELIOSCOPES:



A low-background, low-energy detector required:

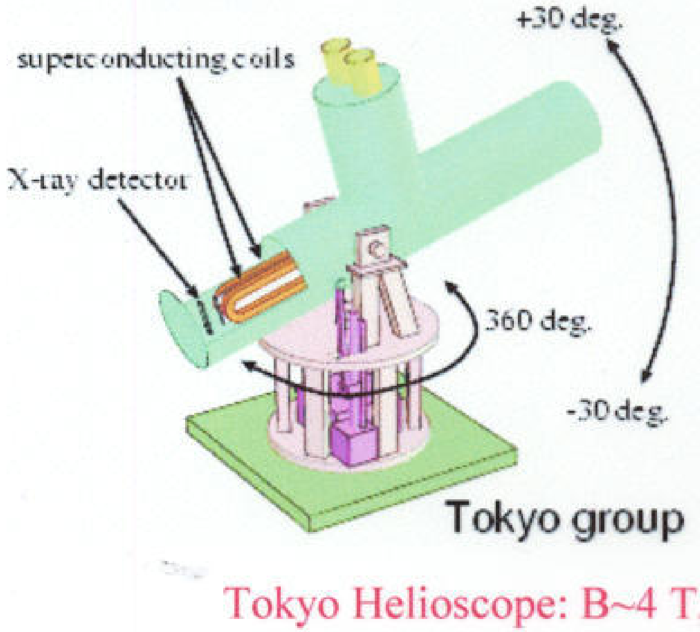
IN CORRESPONDENCE TO SOLAR CORE T: 10^7 K ~ 1 KeV

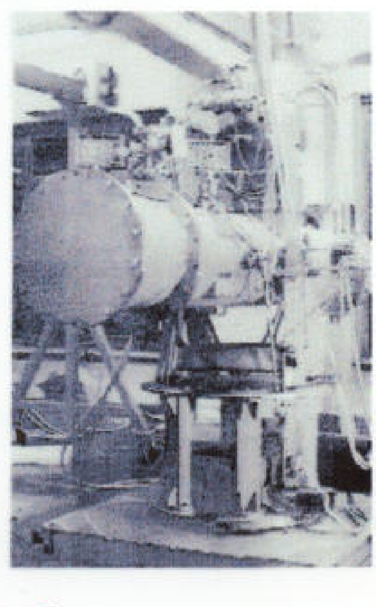


ROBUST PREDICTION (not sensitive to solar model details)

OTHER MODELS PREDICT E_{max} ~ 0.8 keV, ⇒ IMPORTANCE OF LOW E_{thr}

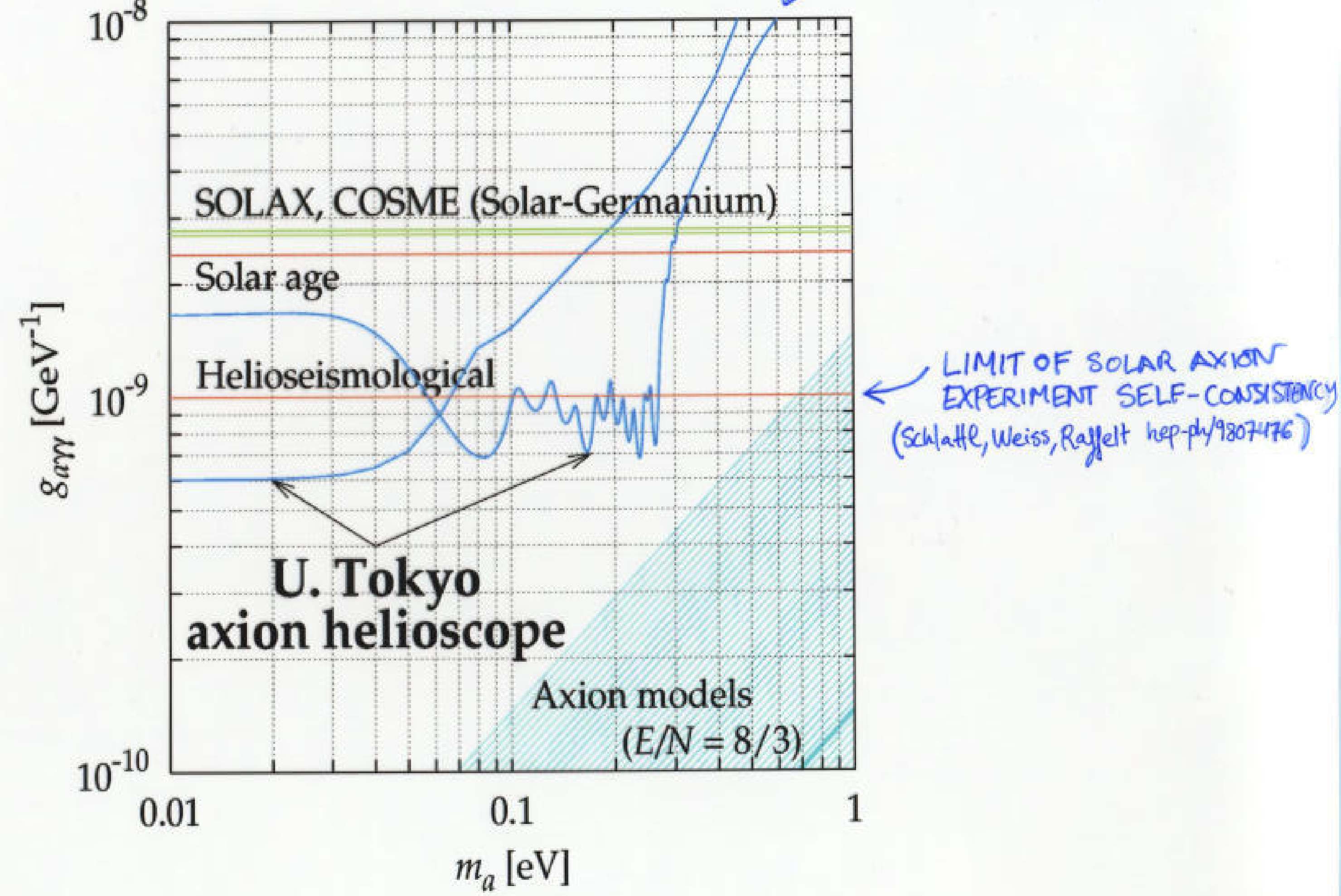
Several efforts already: D.M. Lazarus *et al*, Phys. Rev. Lett. 69 (92) 2333, S. Moriyama *et al*, Phys. Lett. B434 (98) 147.



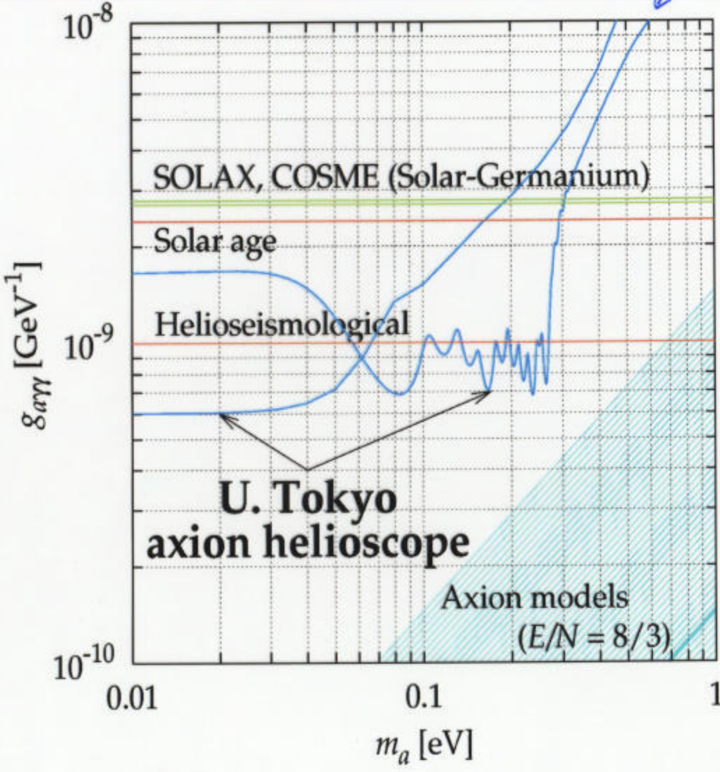


Tokyo Helioscope: B~4 T, L~2 m

Exclusion plot



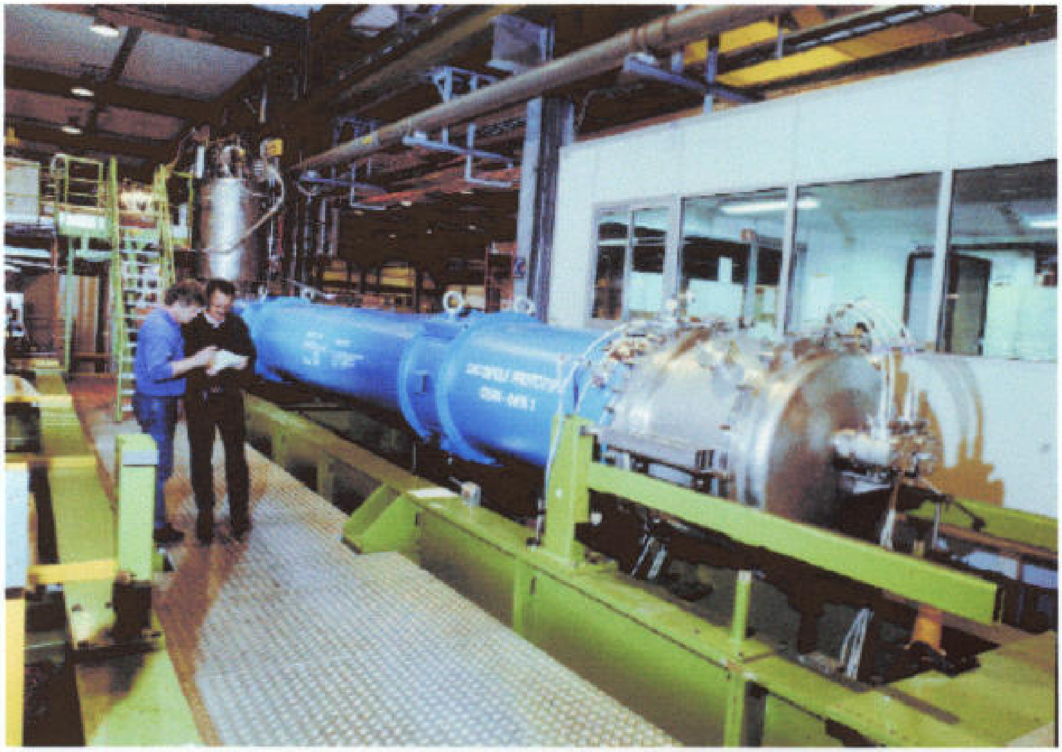
Exclusion plot



NEW LIMITS ADDING He GAS TO PRESERVE COHERENCE astro-ph/0204388

LIMIT OF SOLAR AXION EXPERIMENT SELF-CONSISTENCY (Schlattl, Weiss, Raffelt hep-ph/9807476)

LHC decommissioned test magnets:
a unique opportunity



B~9T, L~10 m ⇒ x 100 axion conversion power of Tokyo Helioscope.

<u>However</u>, attainable sensitivity roughly goes as:
($g^2_{a\gamma\gamma}$ appears in probability of detection <u>and</u> emission)

$$g_{a\gamma\gamma} \propto 1.42 \cdot 10^{-9}\ (\mathrm{GeV}^{-1}) \frac{b^{1/8}}{t^{1/8}\, B^{1/2}\, l^{1/2}\, A^{1/4}}$$

bckg = background in X-ray detector in counts / day in few keV region

t = time of solar alignment in days

B = magnetic field in Tesla

l = length of magnet in meters.

A = area of magnet opening in square cm.

Magnet length and intensity are the crucial factors.

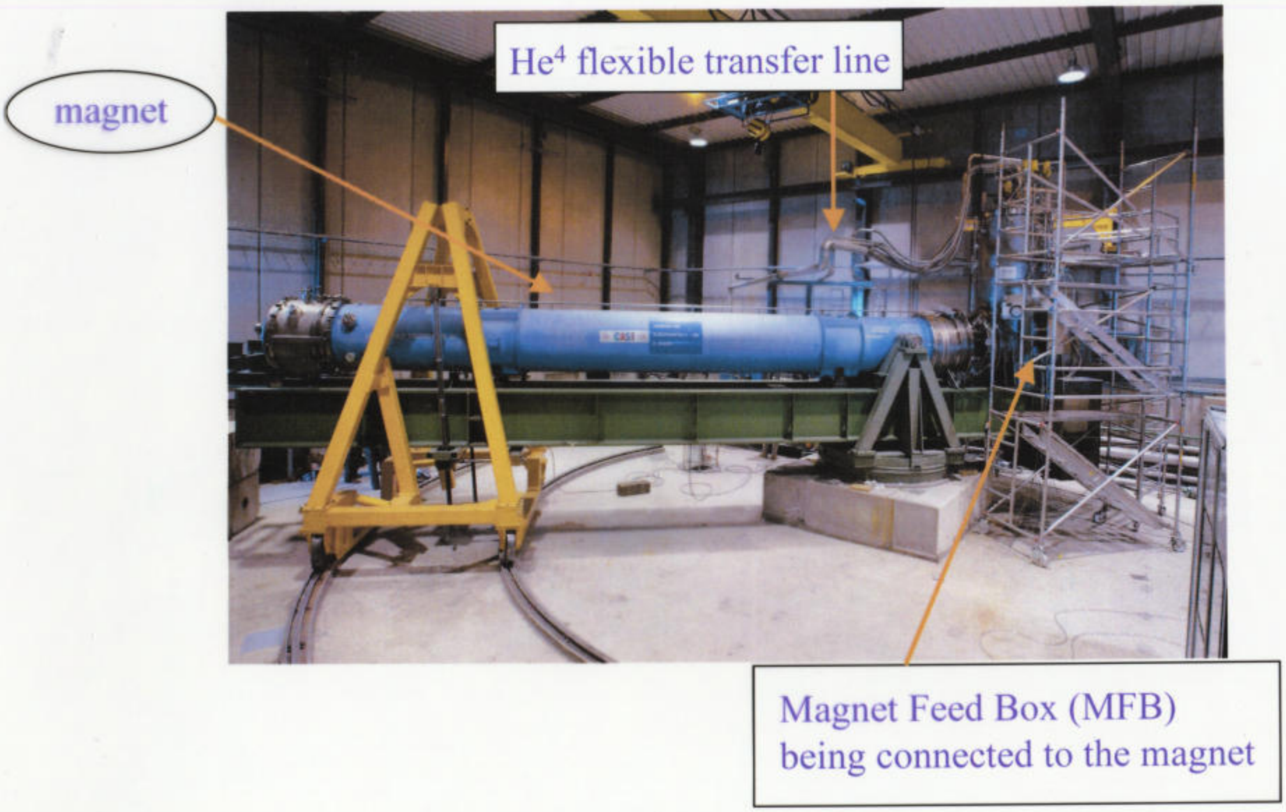
CAST
(CERN Axion Solar Telescope)
Search for Solar Axions Using a Decommissioned LHC Test Magnet

The Cast Collaboration

Athens, CERN, Chicago, Darmstadt, Istanbul, Lisbon, Milan, Moscow (INR), Munich (MPE-MPI), PNNL Washington, Saclay, South Carolina, Tel Aviv, Thessaloniki, Vancouver, Zagreb, Zaragoza

A BIG THANKS TO LHC DIVISION & DIRECTORATE !

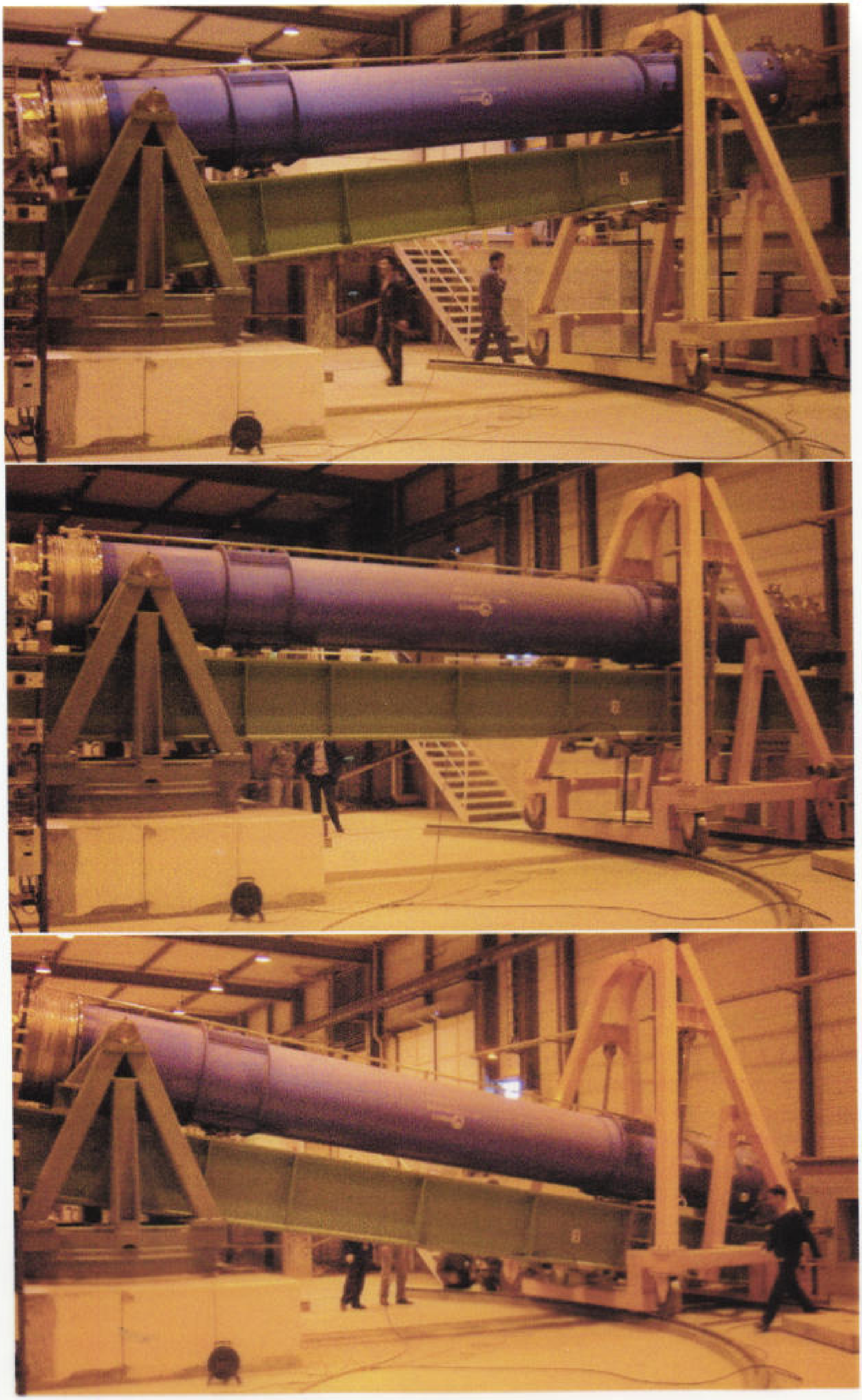
Magnet and platform status on May 14, 2002



East-side end (looking towards sunset)

TUD DARMSTADT
(CRYO/PUMPING, MMS)

SEEING IS BELIEVING... CAST FIRST VERTICAL MOTION (±8°) Feb. 2002

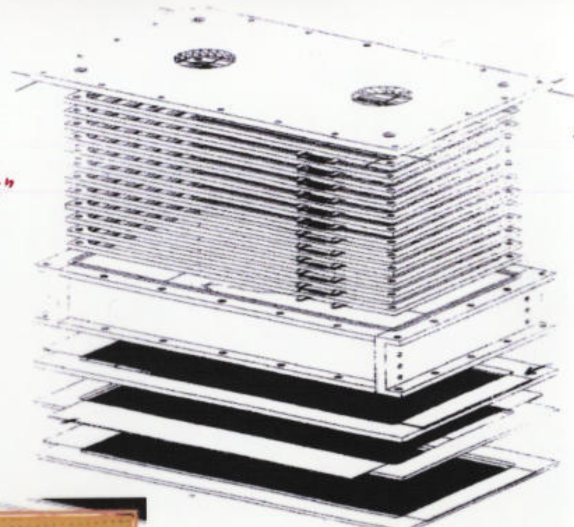


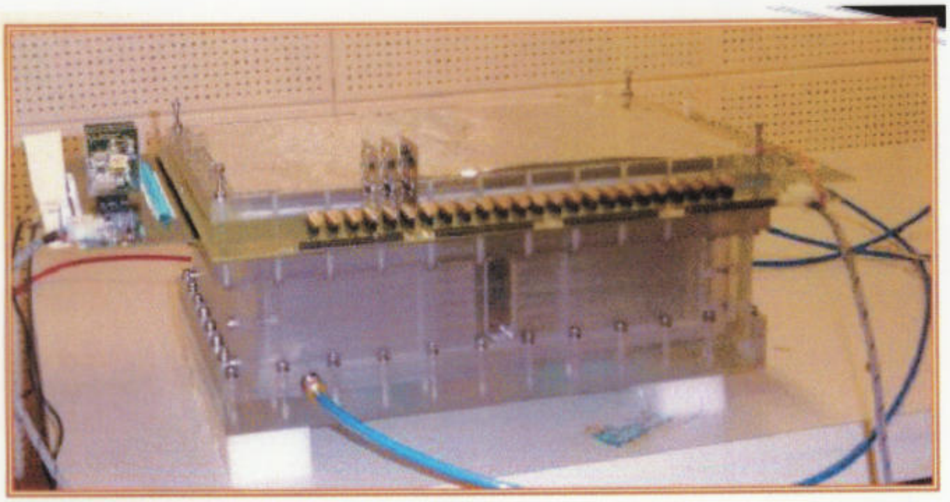
THE DETECTORS: SEVERAL TECHNOLOGIES PUT TO THE TEST

East side detector (looking at the setting Sun):

A conventional Time Projection Chamber (TPC) built with low radioactivity materials (mainly Plexiglas) "OLD RELIABLE"

Drift space 10 cm
Charge collected by a MWPC at the end of the drift space: 48 anode wires (y), 96 cathode wires (x)
wire spacing 3mm
Signal measurement by 10 MHz Flash-ADC s





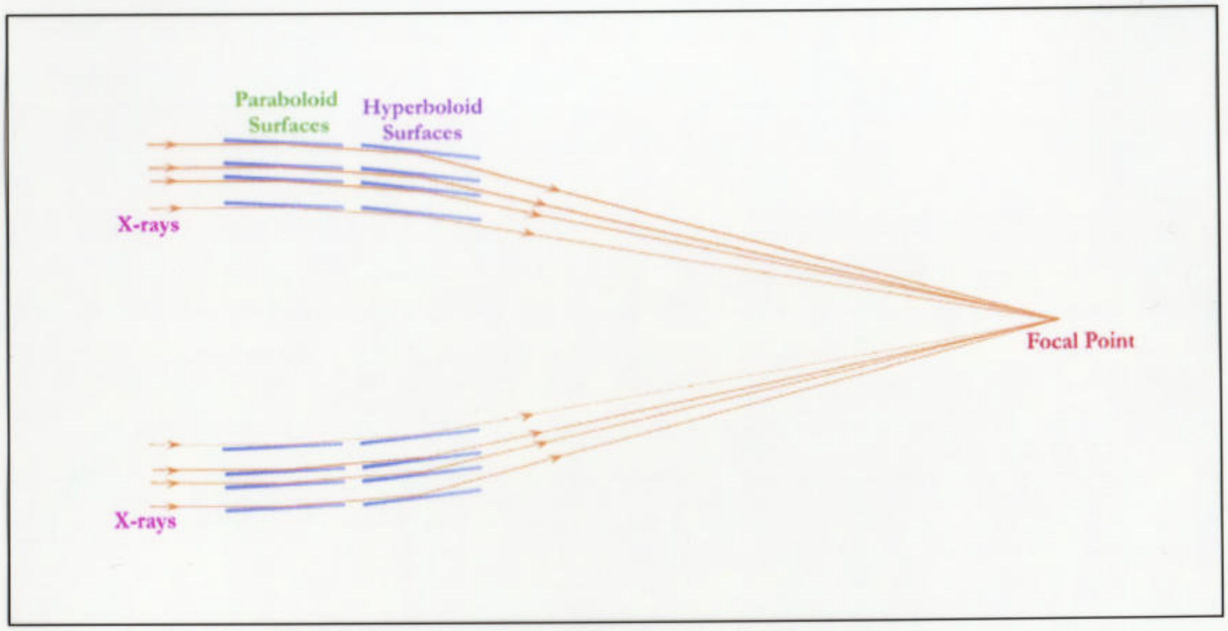
EXPLODED VIEW

Sensitive volume:
$29.1x14.7x10\ cm^3$

HOW TO REDUCE BACKGROUND EVEN FURTHER?
(TRICKY IN A SEA-LEVEL EXPERIMENT)

Grazing Incidence X-Ray Telescope

(see R. Giacconi, Sci. Amer. 242 (1980) 70)



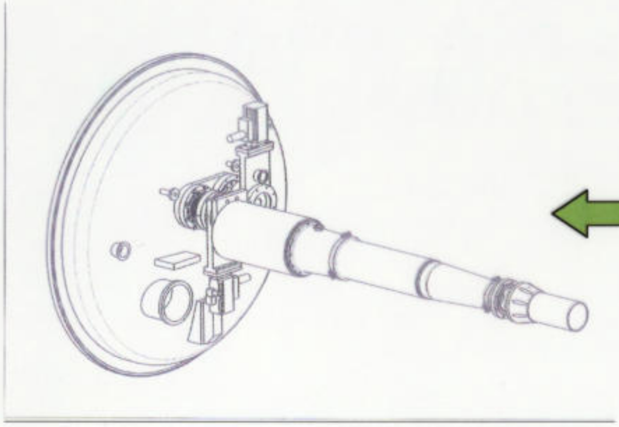
CAST X-Ray Telescope: X-rays from axion —photon conversion in the magnet are focused onto a ~1 mm diameter image at 1.7 m

→ very favourable signal/noise ratio because of the small region where signal is expected

The CAST X-Ray Telescope: a spare unit from the ABRIXAS Space Mission

(MPG, MPEP)

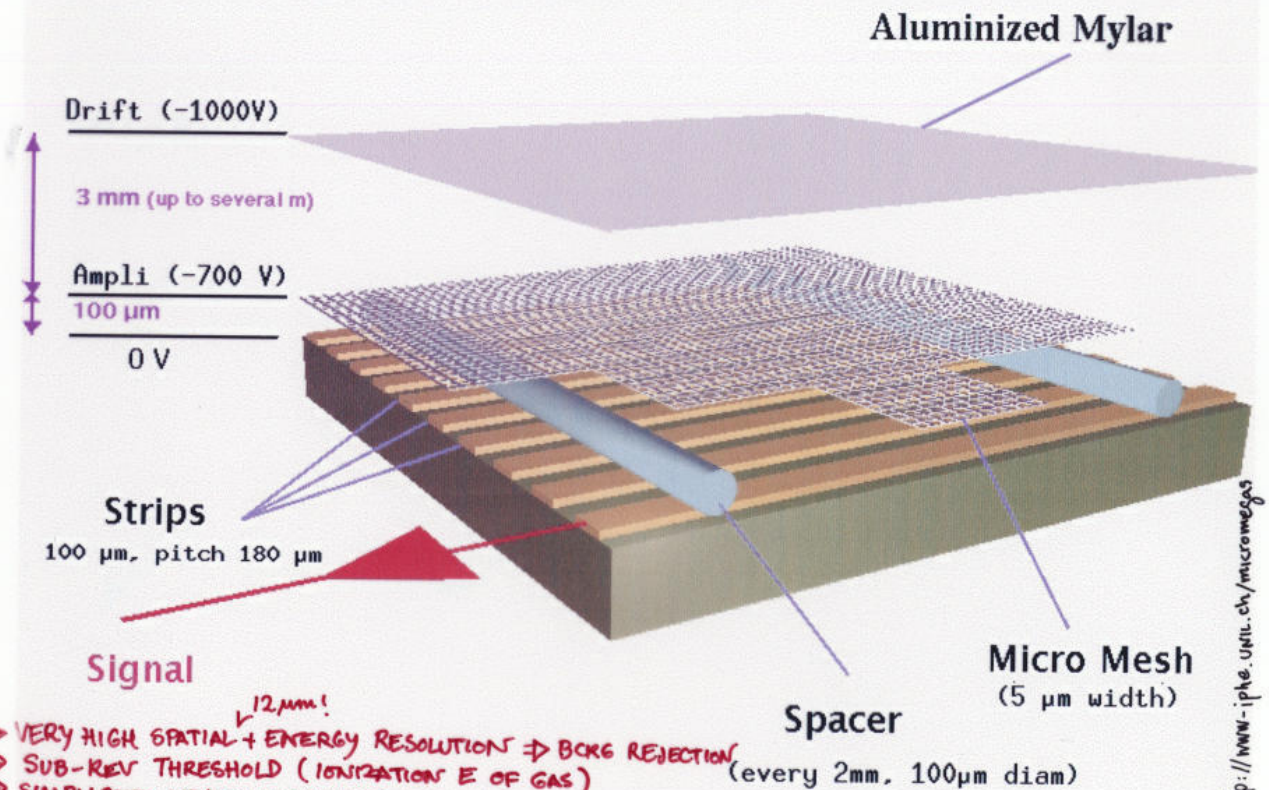
- 27 nested shells
- Focal length 1.7 m
- To be fitted asymmetrically to CAST magnet opening



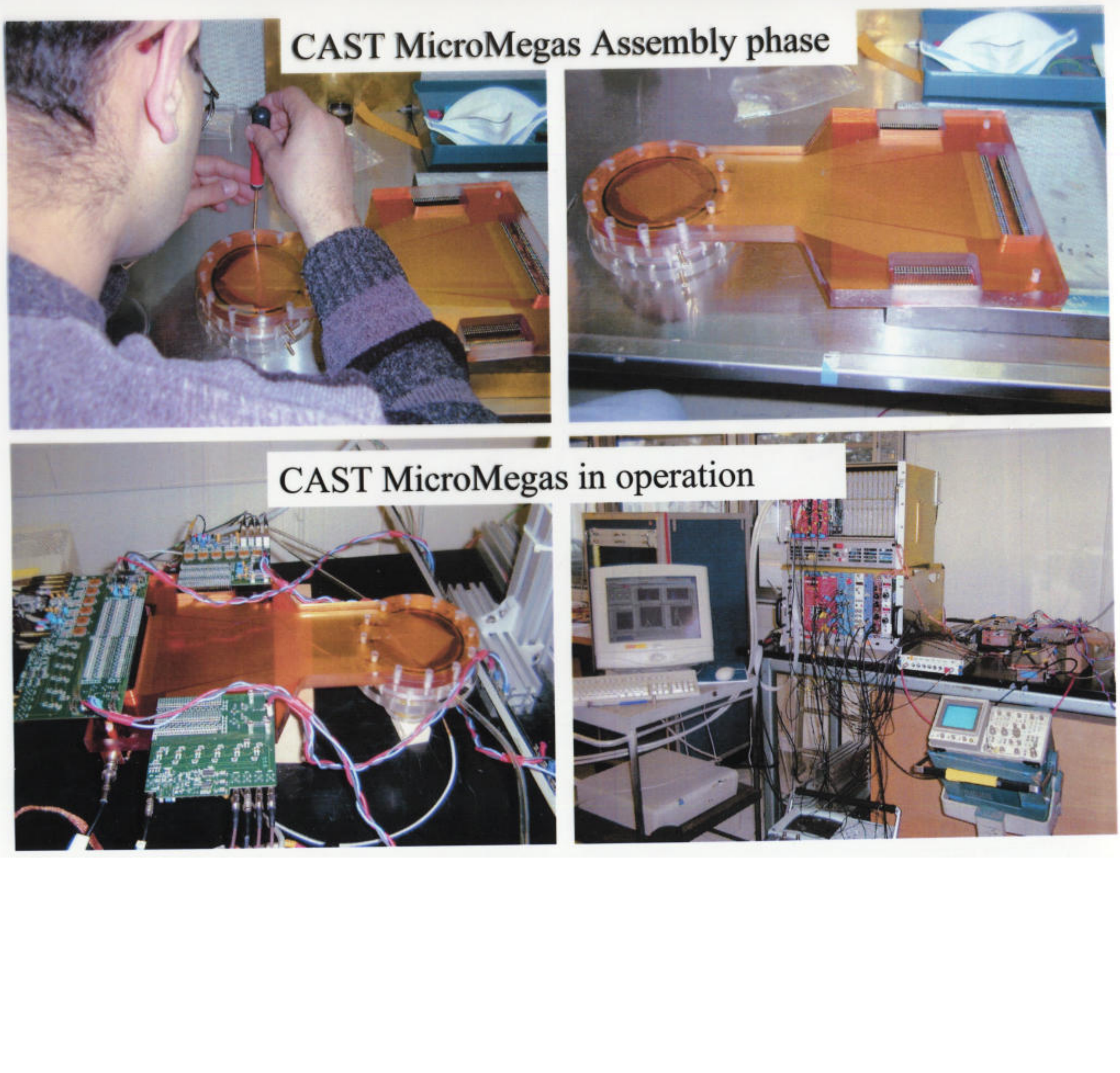
Telescope mounted on magnet (mechanical design)

A DETECTOR WITH FINE SPATIAL GRANULARITY
NEEDED TO PROFIT FROM FOCUSING

MICROMEGAS (MICRO-MESh GAseous Structure, Y. Giomataris, G. Charpak et al), A MPGD (LARGE FAMILY)



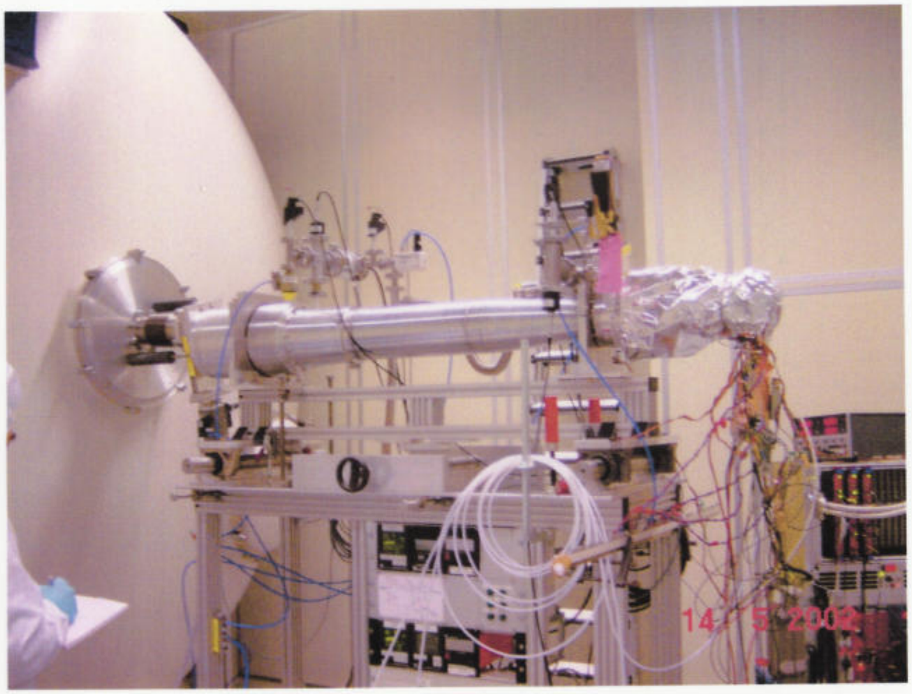
→ VERY HIGH SPATIAL (12 µm!) + ENERGY RESOLUTION ⇒ BCKG REJECTION
→ SUB-KEV THRESHOLD (IONIZATION E OF GAS)
→ SIMPLICITY OF DESIGN ALLOWS USE IN LOW-BCKG EXPERIMENTS
↳ COLLAR & GIOMATARIS, NUCL. INSTR. METH. A 471 (01) 254


CAST MicroMegas Assembly phase
CAST MicroMegas in operation

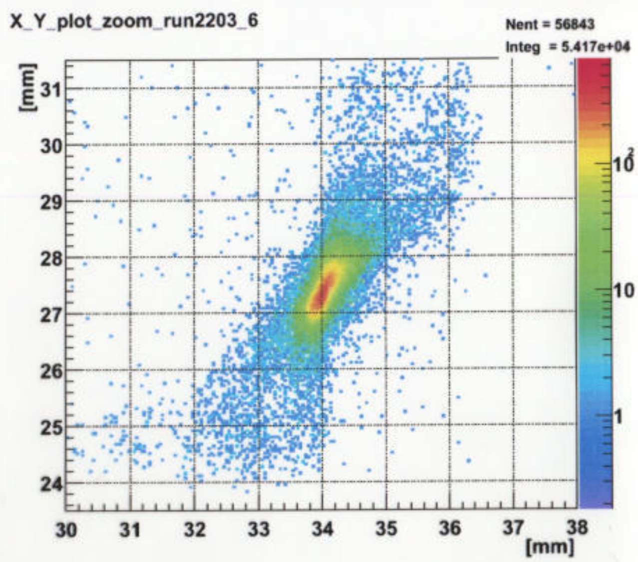
ALL DETECTORS TESTED IN MUNICH!

The CAST X-ray Telescope at PANTER

Test of the X-ray telescope with a MicroMegas detector

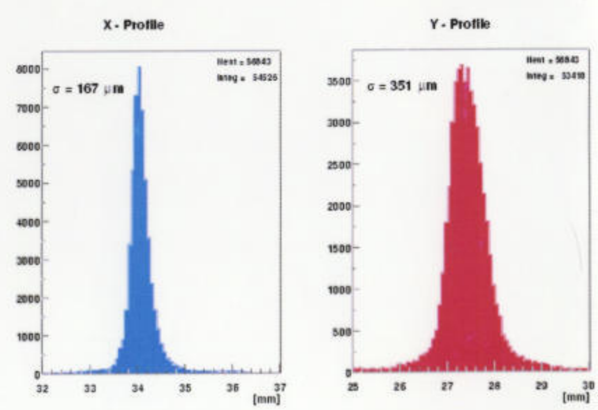


x-y image of 6.4 KeV X-ray beam in MicroMegas chamber (log scale for density)



COMBINATION OF FOCUSING + HIGH SPATIAL RESOLUTION ⇒ <40× INITIAL BACKGROUND EXPECTATIONS (w/o effect of shielding yet!)

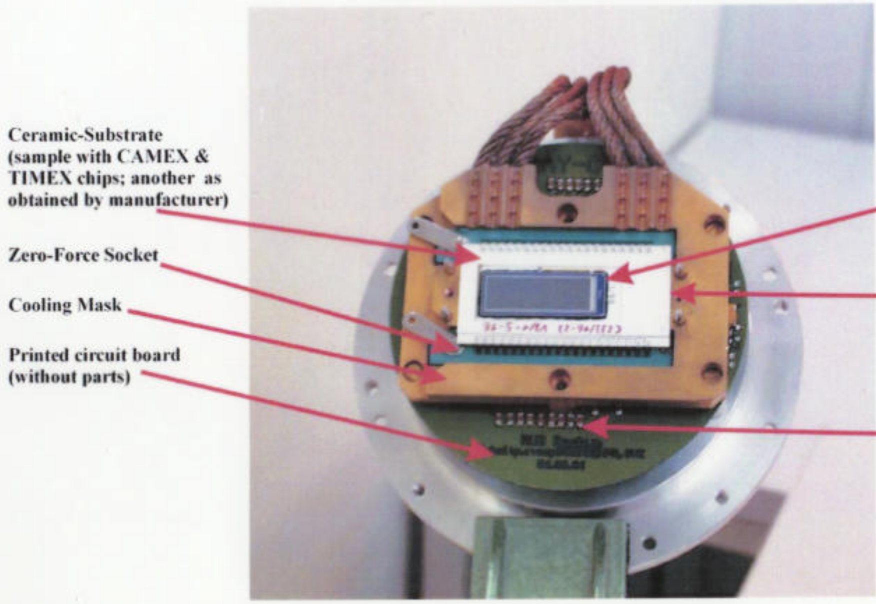
x, y projections



FREIBURG + MPI (Munich)

CCD detector for the X-ray Telescope:

A 1 x 3 cm² CCD presently in use in the XMM/Newton X-ray Observatory in combination with an X-ray Telescope similar to the one used by CAST



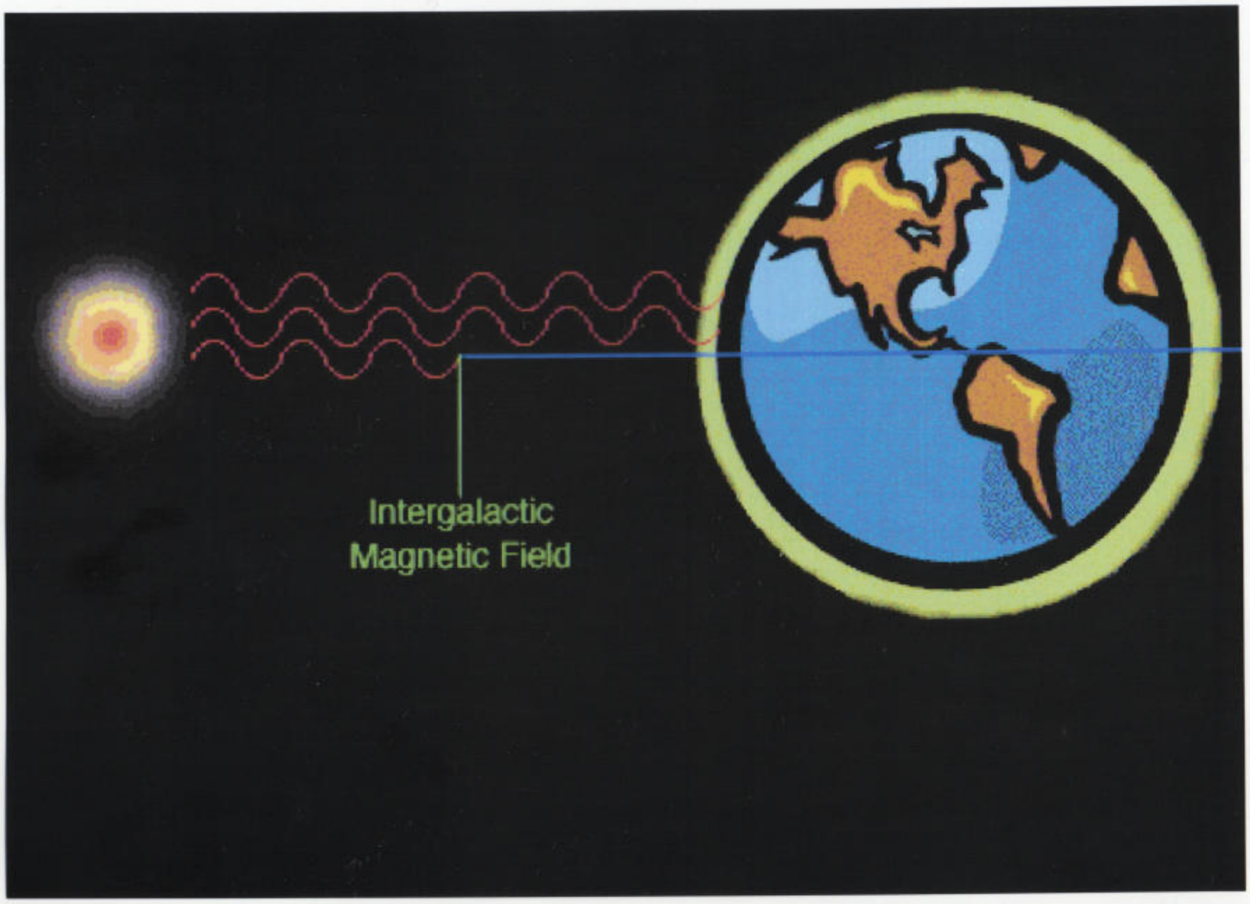
IF PVLAS "SIGNAL" STAYS... WILL THIS DETECTOR SEE IT?

CCD can work in vacuum ➡ no window is needed

Efficiency close to 100% over the full energy range

MPI Halbleiterlabor
Robert Hartmann
05.07.2001

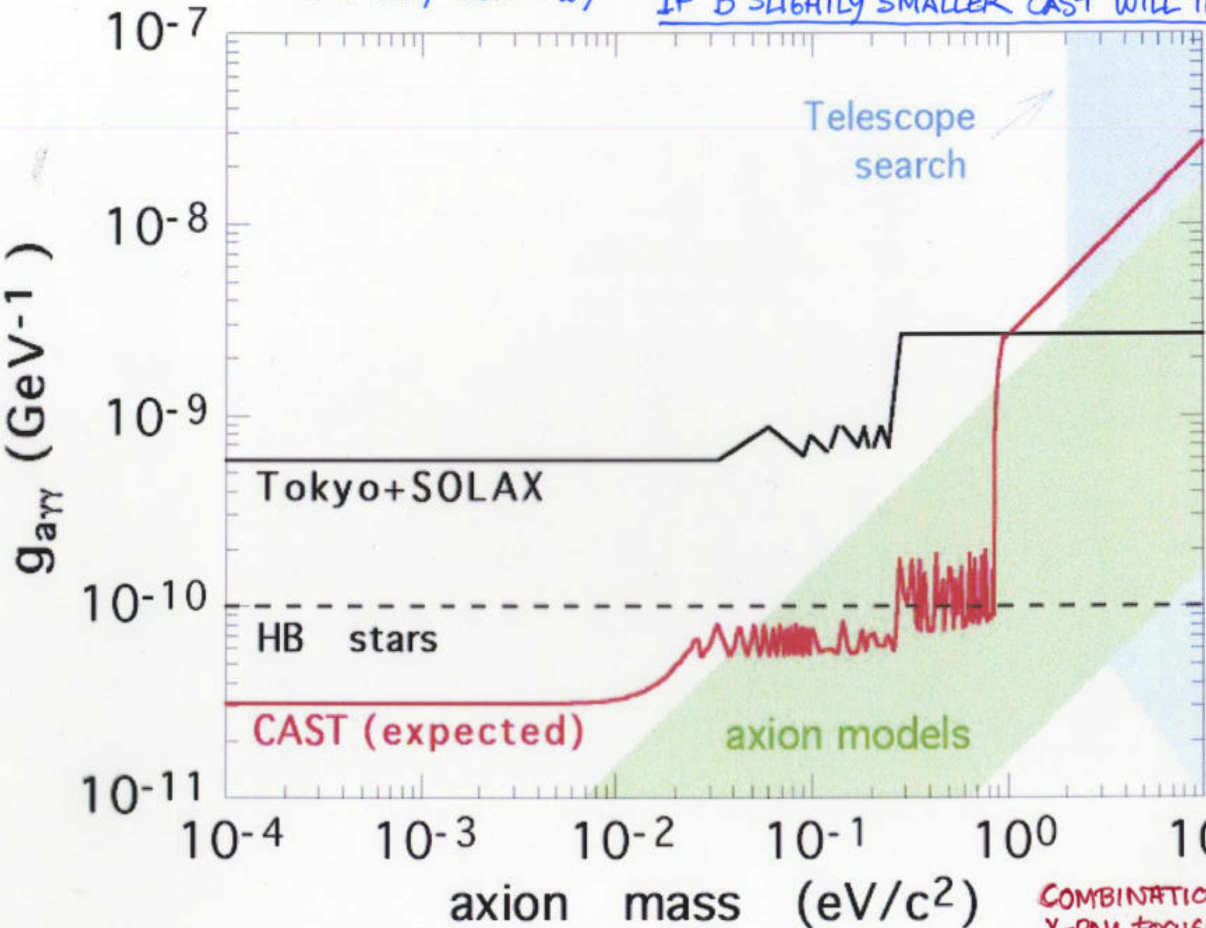
PHOTON - AXION OSCILLATIONS:
AN ALTERNATIVE TO DISTANT SN DIMMING W/O INVOKING "DARK ENERGY"



Csaki, Kaloper and Terning, Phys. Rev. Lett. 88 (2002) 161302 (hep-ph/0111311)
http://t8web.lanl.gov/people/terning/axion.html

INITIAL CONDITIONS SEEM TO HOLD..

FOR ONCE, INTERESTING COUPLINGS (ALMOST) WITHIN REACH
(BOUND ON INTERGALACTIC $B<10^{-8}$ G OVER 1Mpc GENERATES $g_{a\gamma\gamma}=5\cdot10^{-12}$ GeV^{-1}
and VERY LIGHT M_a) IF B SLIGHTLY SMALLER CAST WILL TEST THIS SCENARIO



COMBINATION OF
X-RAY FOCUSING AND
STATE-OF-THE-ART DETECTOR
TECHNOLOGY → < 1 event/d/10keV