Recent results from the CERN Axion Solar Telescope (CAST)

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DESY/Zeuthen Di./Mi. SEMINAR

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First Results from the CERN Axion Solar Telescope

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DNA sequencing

Different dyes for clear-cut colours

Proc. Natl Acad. Sci. USA 102, 5346–5351 (2005)

Since its introduction almost 20 years ago, four-colour DNA sequencing has largely relied on the same, somewhat error-prone, method. Now Ernest K. Lewis *et al.* have built a prototype sequencing machine that could improve accuracy.

In conventional colour sequencing, the chemical bases that make up DNA are tagged with fluorescent dyes — a different colour for each of the four bases. A machine shines a laser onto the DNA molecules, and detects the wavelength of light emitted from each base to determine their sequence. But mistakes happen, partly because the spectra produced by the dyes overlap, and hence the glow from one dye can be mistaken for that from another.

For the new method, called pulsed multi-line excitation, the researchers developed a different set of four fluorescent dyes, each of which is excited by a separate wavelength. Their machine fires a series of four laser beams at the dye, but only the appropriate laser triggers a signal. The method could greatly improve the ease with which one base can be distinguished from another. **Helen Pearson**

Cancer

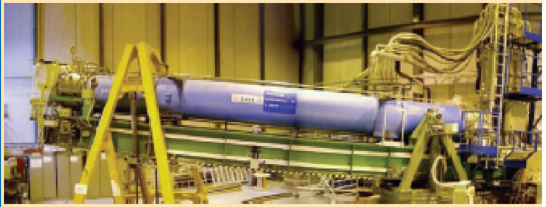
Remote control

Curr. Biol. 15, 561–565 (2005)

BRCA1 is notorious as the first gene to be linked with inherited susceptibility to breast and ovarian cancer. It has been thought of as a classic 'tumour suppressor', but Rajas Chodankar *et al.* suggest that it may have another, more subtle, effect.

Granulosa cells in the ovary produce the sex hormones that regulate the ovulatory cycle — and the growth of ovarian tumours. Given that repeated ovulations (that is, fewer pregnancies or reduced oral contraceptive use) are known to increase the risk of non-hereditary ovarian cancer, the researchers wondered whether decreased levels of BRCA1 protein in granulosa cells are involved. Using mice, they inactivated the gene specifically in these cells. The animals developed tumours in the ovaries and uterine horns. But the tumour cells looked like epithelial cells and had normal copies of the gene, implying that they had not developed from granulosa cells.

Inactivating *BRCA1* seems, therefore, to be controlling some intermediary produced by the granulosa cells. It is this unidentified factor that appears to promote tumours in the ovary epithelium, so providing a lead for further investigation. **Helen Dell**



Particle physics

The elusive axion

Phys. Rev. Lett. 94, 121301 (2005)

An effect known as charge–parity violation is linked to the fact that the Universe contains far more matter than antimatter, and it is well documented in processes involving the so-called weak nuclear force, one of the four fundamental forces of nature. But it seems to be suppressed by the strong force, and this can be explained by postulating a hitherto undiscovered particle, the axion. Axions interact hardly at all with radiation or other matter, making them hot candidates to be the 'cold dark matter' that is thought to pervade the Universe.

The CAST (CERN Axion Solar Telescope) collaboration has adopted an innovative approach to the search for axions. They are pointing a powerful test magnet (pictured), decommissioned from CERN's Large Hadro Collider, at the Sun. Axions might be produ the solar plasma when photons are scatter strong electromagnetic fields. CAST has pu scattering effect into reverse by producing photons from solar–axion interactions on E

The magnet can be tilted at either end an angle that allows the Sun to be observe sunrise and sunset, both ends being fitted X-ray detectors and an X-ray telescope rec from the German space programme. The re assuming a very small axion mass, show n above background, and constrain the axion coupling strength by a factor of five compa with results from previous lab experiments Future measurements should deliver still b sensitivity, and also test the axion hypothes higher masses. **Rich**

Neurobiology

Illuminating behaviour

Cell 121, 141–152 (2005)

Through genetic engineering, researchers have developed a new technique for exciting neurons and influencing fruitfly behaviour. Whereas scientists typically excite these cells with electricity, the effect here was achieved with laser light.

Susana Q. Lima and Gero Miesenböck designed fruitflies to express particular ion channels in neurons that control escape mechanisms — such as jumping and wing beating — or in the dopamine-producing cells that influence movement. The next step involved injecting the flies with ATP (energy-storing molecules) held in chemical cages.

A 200-millisecond pulse of laser light — directed at the flies — removed the cage from the ATP molecules, allowing them to stimulate the channels and depolarize the neurons. When the authors targeted the neurons linked to escape mechanisms, the light set off jumping and wing flapping in the fruitflies. Similarly, targeting dopamine-producing cells altered the insects' walking behaviour. The authors speculate that this ability to direct animal behaviour by remote control will enable them to study how specific behaviours are related to specific neurons. **Roxanne Khamsi**

Spintronics

How electrons relax

Phys. Rev. Lett. 94, 116601 (2005)

In the burgeoning field of spintronic binary bits of data are stored in the s of electrons, rather than in their char with a '1' equating to spin up and a '0 spin down. But one problem facing th development of spintronic devices is although electron spin can be manip it tends not to stay so — an induced s decays as the electron interacts with t magnetic field of nearby nuclei.

P.-F. Braun and colleagues have n directly observed this 'spin relaxatio in quantum dots — clusters of atoms just nanometres across — made of th semiconductor materials indium ars and gallium arsenide. The authors fo that the initial spin polarization of su decays with a half-life of just 0.5 nano — half a millionth of a millisecond – remaining stable at about a third of i value for at least a further 10 nanose

However, they also report that thi relaxation process can be suppressed an externally applied static magnetic of just 100 mT, which can be provide small permanent magnets. Such a fie increases the characteristic decay hal to around 4 nanoseconds, and could prove useful in future practical devic they suggest. **M**

said. "We are trying very hard to get support from NASA to reduce the cost and risk of the mission." Canada, Japan, and Russia might also take part in the mission, he added.

European researchers see the 2011 mission as preparation for a much more ambitious round trip to return samples of Mars rock, soil, and atmosphere. Space scientist John Zarnecki of The Open University in the United Kingdom, a participant in the workshop, said the group recommended working toward such a mission in 2016, which would think everyone hopes and expects that this is going to be a big international push with ESA, NASA, and possibly other agencies," Zarnecki says.

This work is designed to prepare for possible international crewed missions to Mars, which ESA hopes will begin around 2030. Gardini said the sample-return mission would be valuable practice in making the round trip. Aurora faces a big test in December, when ESA's governing council will vote on funding.

–MASON INMAN

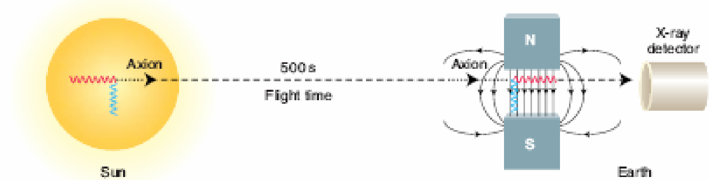
PARTICLE PHYSICS

Magnetic Scope Angles for Axions

After 2 years of staring at the sun, an unconventional "telescope" made from a leftover magnet has returned its first results. Although it hasn't yet found the quarry it was designed to spot—a particle that might or might not exist—physicists say the CERN Axion Solar Telescope (CAST) is beginning to glimpse uncharted territory. "This is a beautiful experiment," says Karl van Bibber, a physicist at Lawrence Livermore National Laboratory in California. "It is a very exciting result."

CAST is essentially a decommissioned, 10-meter-long magnet that had been used to design the Large Hadron Collider, the big atom smasher due to come on line in 2007 at the particles exist (*Science*, 11 April 1997, p. 200). If axions do exist, however, oodles of them must be born every second in the core of the sun and fly away in every direction.

That's where CAST comes in. "When an axion comes into your magnet, it couples with a virtual photon, which is then transformed into a real photon" if the axion has the correct mass and interaction properties, says Konstantin Zioutas, a spokesperson for the project. "The magnetic field works as a catalyst, and a real photon comes out in the same direction and with the same energy of the incoming axion." An x-ray detector at the bottom of the telescope is poised to count those photons.



X-files. CAST "telescope" hopes to detect hypothesized particles from the sun by counting the x-rays they should produce on passing through an intense magnetic field.

CERN, the European high-energy physics lab near Geneva. When CERN scientists turn on the magnet, it creates a whopping 9-tesla magnetic field—about five times higher than the field in a typical magnetic resonance imaging machine. From a particle physicist's point of view, magnetic fields are carried by undetectable "virtual" photons flitting from particle to particle. The flurry of virtual photons seething around CAST should act as a trap for particles known as axions.

Axions, which were hypothesized in the 1970s to plug a gap in the Standard Model of particle physics, are possible candidates for the exotic dark matter that makes up most of the mass in the cosmos. Decades of experiments have failed to detect axions from the depths of space, and many physicists doubt

The first half-year's worth of data, analyzed in the 1 April *Physical Review Letters*, showed no signs of axions. But CAST scientists say the experiment is narrowing the possible properties of the particle in a way that only astronomical observations could do before. "It's comparable to the best limits inferred from the stellar evolution of red giants," van Bibber says, and he notes that plans to improve the sensitivity of the telescope will push the limits further. Even an improved CAST would be lucky to spot axions, van Bibber acknowledges, because most of the theoretically possible combinations of the particle's properties would slip through the telescope's magnetic net. Still, he's hoping for the best. "Maybe Nature will deal a pleasant surprise," he says.

–CHARLES SEIFE

CREDIT: R. HUEY/SCIENCE

Lockheed Boosts Los Alar

U.S. aerospace giant Lockheed Ma strengthened its bid to run Los Ala National Laboratory in New Mexi week by recruiting a key senior sci Sandia National Laboratories Dire C. Paul Robinson, who spent 18 ye Alamos before moving to Sandia i has joined the proposal team for t Bethesda, Maryland–based compa

Lockheed officials want Robins head Los Alamos if they beat out t current contractor, the University nia. Final competition details are e soon, with bids in the summer. Me former weapons chief Thomas Hu been promoted to director of San has facilities in California and New

–E

Pig Flu Scare—Case Clo

The World Health Organization (W hopes that the results of a new stu put to rest suspicions that pigs in S Korea have become infected with a tially dangerous flu strain.

Last fall, Sang Heui Seo of Chung National University in Daejeon, Kor deposited flu sequences in GenBan gested that Korean pigs carried WS strain widely used in labs but not kn occur in nature. Several experts and missed the findings as the result of l tamination (*Science*, 4 March, p. 13 Yoshi Kawaoka of the University of Madison, and his colleagues have te 400 samples from two Korean pig f WHO says, and found no trace of W

Seo declined to comment. Hen a business owner in Philadelphia w Seo's claim, says Kawaoka's study w broad enough to refute the theory WHO flu expert Klaus Stöhr, "we'v too much time on these speculatio already."

–MART

Plant Center to Cut Jobs

The John Innes Centre in Norwich, of Europe's top plant science instit plans to cut up to 35 researchers f 800-person staff. Director Christop announced on the center's Web sit week that the center began losing 18 months ago when two funders- European Union and private indust became "less reliable sources." Inco center, which has a $40 million ann budget, has dropped by $5.7 millio

This is "a big blow," says plant g Michael Wilkinson of the Universit ing, U.K., adding that the institutio duces an "astonishing number" of cited basic science papers. –ELIOT

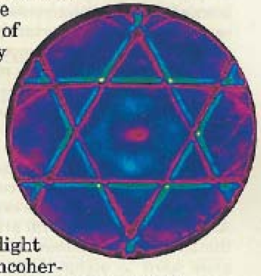
Physics Update

A new mode for desorption has been uncovered. The detachment of atoms and molecules from a surface is one of the fundamental processes of surface science. One of two mechanisms is generally invoked. Thermal desorption calls for the material to be heated, which can stretch and eventually break the bonds of adsorbed atoms and molecules through the action of phonons. In contrast, electronic desorption calls for an external stimulus—say, from an incident electron or photon—to induce an electronic transition of sufficient energy to promote the adsorbed atom or molecule from a bound to an unbound state. The two mechanisms operate on vastly different time scales, with electronic transitions being faster. Studying bromine adsorbed on silicon, John Weaver and his colleagues at the University of Illinois at Urbana-Champaign have found a third mode, one that has elements of both of the others. The researchers examined bromine's desorption kinetics as a function of silicon doping and of temperature. A detailed analysis revealed the rare but crucial event of 10–20 phonons simultaneously interacting with a single electron. Rather than directly breaking a bond as in the thermal case, the phonons induce an electronic transition that promotes the adsorbate to an unbound state. Thus, the Illinois group found the surprising result that electronic desorption prevails in this system without needing any external excitation. Multiphonon processes are common during a system's relaxation, but the Illinois work may show that they can also play an important role in surface chemistry. (B. R. Trenhaile et al., *Surface Science*, in press.) —SGB

A search for the hypothetical axion has produced a new limit on the axion–photon interaction strength. The putative axion, a leading candidate for cosmological dark matter, could be produced in a two-photon interaction with an electric or magnetic field. Now, the CERN Axial Solar Telescope (CAST) collaboration has investigated how axions produced at the Sun interact with a laboratory magnetic field to back-convert into x rays. In the CAST experiment, which ran for about six months in 2003, a 10-m-long, 9-T magnet refurbished from the Large Hadron Collider followed the Sun like a telescope. It was outfitted with x-ray detectors and an x-ray telescope recovered from the German space program. No axions were seen, but for lightweight axions of 0.02 eV or less, the data analysis improved the previous state-of-the-art laboratory limit on the axion–photon interaction strength by a factor of five. The CAST group expects further improvement after analyzing their 2004 data. (K. Zioutas et al., *Phys. Rev. Lett.* **94**, 121301, 2005.) —SKB

Direct detection of extrasolar planets has been achieved. Previously, the existence of planets around other suns has been inferred from subtle modulation of the starlight, either as a planet gravitationally tugged its star or as a star's light decreased when a planet eclipsed it. Now, two groups have used the *Spitzer Space Telescope* to directly record infrared light from eclipsing planets. The planets—with the prosaic names of HD 209458b (153 light years away) and TrES-1 (489 light years away)—have circular orbits a tenth the size of Mercury's, which makes the Jupiter-sized planets hot enough to be viewed by *Spitzer*. Unlike observations of other eclipsing systems, these detections relied on the planet being hidden *behind* the star. When the starlight was subtracted from the light of the complete system, only the planet's IR emission remained. (D. Deming et al., *Nature* 434, 740, 2005; D. Charbonneau et al., *Astrophys. J.*, in press.) —PFS

Seeing the Brillouin zones of photonic lattices. The properties of periodic photonic systems depend on fundamental features of periodic structures, as described in standard condensed-matter physics texts. Periodic photonic structures and their defects (for example, the hollow core of a photonic-crystal fiber) have been directly imaged routinely for some time, but their characterization is incomplete without knowledge of the momentum-space (reciprocal-lattice) structure of the system—its Brillouin-zone (BZ) structure. Researchers from the Technion–Israel Institute of Technology, the University of Zagreb in Croatia, and Princeton University in the US, have now directly imaged the extended BZs of two-dimensional square and trigonal photonic lattices. Their technique relies on Bragg diffraction of laser light that was made spatially incoherent with a rotating diffuser, and on an optical Fourier transform. The result is textbooklike pictures previously obtainable only by computer calculations. Shown here is a typical image of the first, second, and third BZs of a trigonal lattice with an embedded defect. According to the group's leader, Moti Segev, the BZ characterization technique is general and may be used to map the momentum space of any periodic photonic structure, as well as of periodic systems beyond optics. (G. Bartal et al., *Phys. Rev. Lett.*, in press.) —SGB



Tradition in Deutschland

1611 Erste teleskopische Beobachtung von Sonnenflecken durch Christoph Scheiner und Johannes Fabricius.

1814 Joseph Fraunhofer entdeckt die nach ihm benannten Linien im Sonnenspektrum.

1843 Samuel Heinrich Schwabe findet den 11-jährigen Zyklus der Sonnenflecken.

1896 Johannes Wilsing und Julius Scheiner postulieren Radiostrahlung von der Sonne.

1905 Das Kriterium für konvektive Instabilität wird von Karl Schwarzschild formuliert.

1930 Julius Bartels identifiziert die Sonne als Quelle regelmäßig wiederkehrender geomagnetischer Störungen.

1930 Albrecht Unsöld begründet die Physik der Sternatmosphären anhand der Untersuchung der Sonnenatmosphäre.

1939 Walter Grotrian entdeckt, dass die Korona der Sonne aus einem sehr dünnen und ca. 1 Million K heißen Gas besteht.

1949/1951 Georg Thiessen und Karl-Otto Kiepenheuer entwickeln den Magnetographen zur Messung solarer Magnetfelder.

1951 Ludwig Biermann sagt die Existenz des Sonnenwindes anhand von Studien an Kometenschweifen voraus.

1964 Fritz Krause, Karl-Heinz Rädler und Max Steenbeck formulieren das Prinzip des turbulenten selbsterregten Dynamos.

1974/76 Start der deutsch-amerikanischen Sonnensonden Helios 1/2, die erstmals die innere Heliosphäre erkunden.

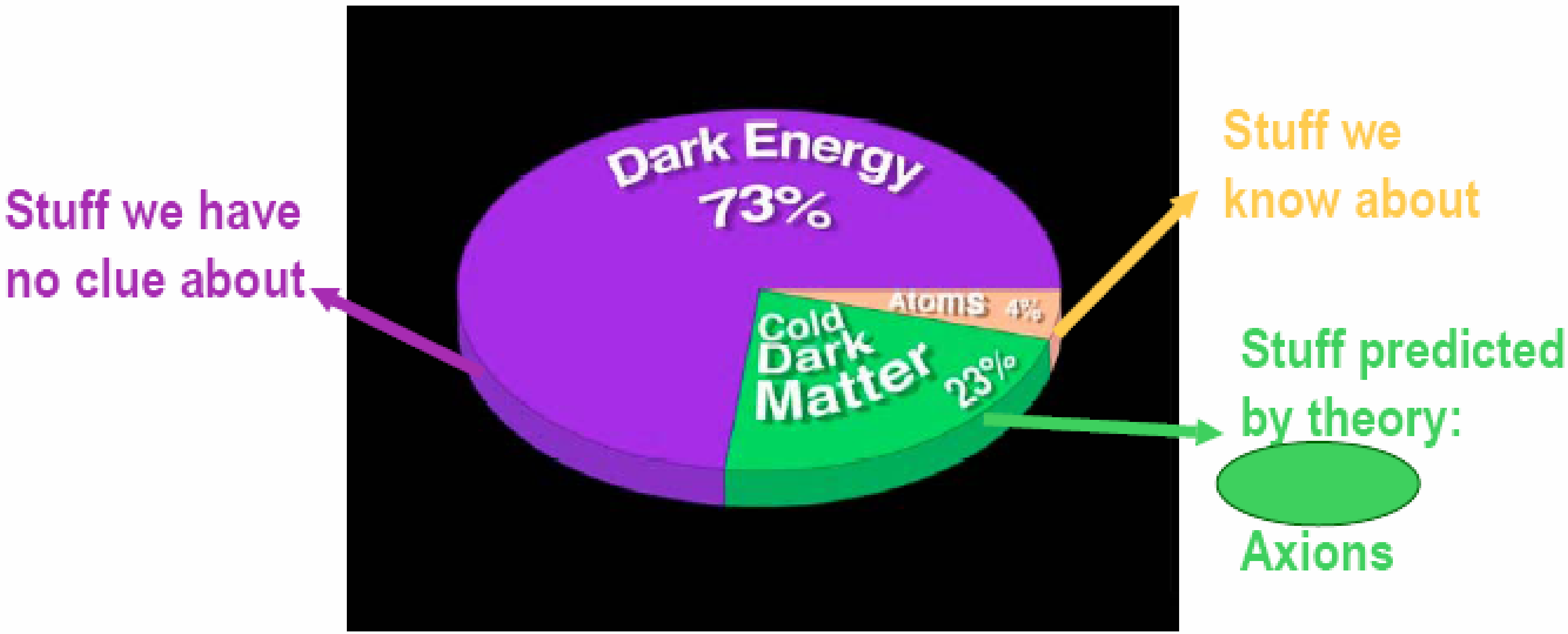
1975 Franz-Ludwig Deubner identifiziert die 5-Minuten-Oszillationen der Sonne und begründet damit die Helioseismologie.

→ **Die Sonne hat die Menschheit seit Anbeginn fasziniert.**

→ **In der Antike: Beobachtungen von Sonnenflecken mit blossem Auge durch griechische + chinesische Astronomen.**

http://www.linmpi.mpg.de/publikationen/perspektiven/Perspektiven.pdf

Motivation



The Universe, according to WMAP

Axion ➔ Dark Matter particle *candidate* ➔ new physics

http://www.fnal.gov/directorate/Longrange/PartAstro1003_Talks/Bauer.pdf

AXION PHYSICS

The QCD Lagrangian :

$$\mathcal{L}_{QCD} = \mathcal{L}_{\rm pert} + \theta \frac{g^2}{32\pi^2} G\widetilde{G}$$

$L_{\rm pert}$ ⇒ numerous phenomenological successes of QCD.

G is the gluon field-strength tensor

➔ **θ-term** → a consequence of non-perturbative effects

→ implies ***violation of CP symmetry***

→ would induce EDMs of strongly interacting particles

Experimentally ➔ CP is **not** violated in QCD → the neutron EDM $d_n < 10^{-25}$ *e cm* ⇒ $\theta < 10^{-10}$

⇒ *why is θ so small?* ➔ ***the strong-CP problem***

➔ ***the only outstanding flaw in QCD***

➔ To solve the strong-CP problem, **Peccei-Quinn** introduced a global $U(1)_{PQ}$ symmetry broken at a scale f_{PQ}, and non-perturbative quantum effects drive **θ → 0** ➔ **"CP-conserving value"** and also generate a mass for the axion :

$$m_{\rm PQ} = 6\ {\rm eV} \frac{10^6}{f_{\rm PQ}/1\ {\rm GeV}}$$

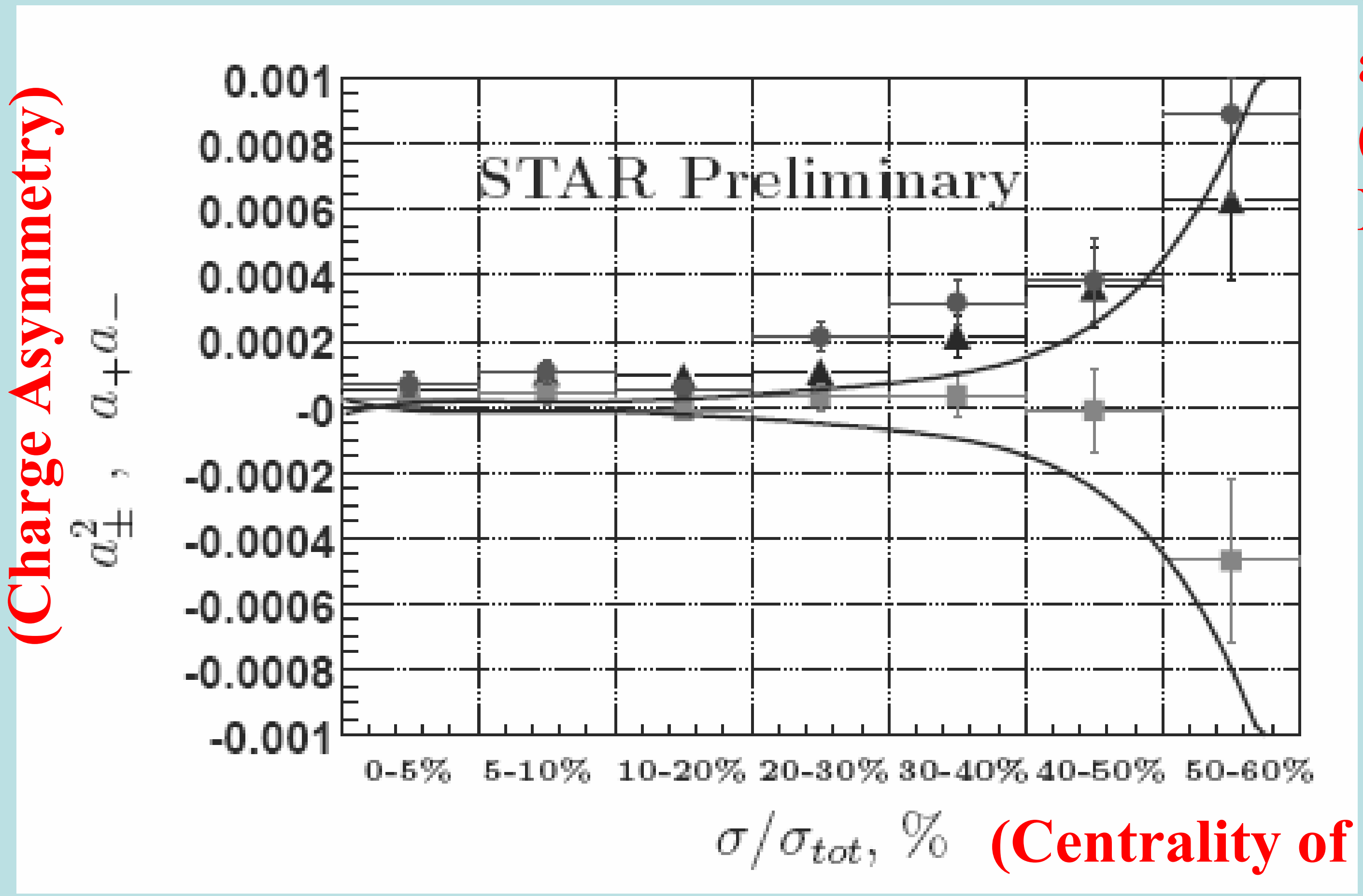
➔ All the axion couplings are inversely proportional to f_{PQ} .

…In the vicinity of the deconfinement phase transition θ_{QCD} might not be small: P & CP violating bubbles are possible at H.I. collisions. **D. Karzeev, R. Pisarski, M. Tytgat, PRL81, (1998) 512;**

D. K., R. P., PRD 61 (2000) 111901;

l D. K., hep-ph/0406125.

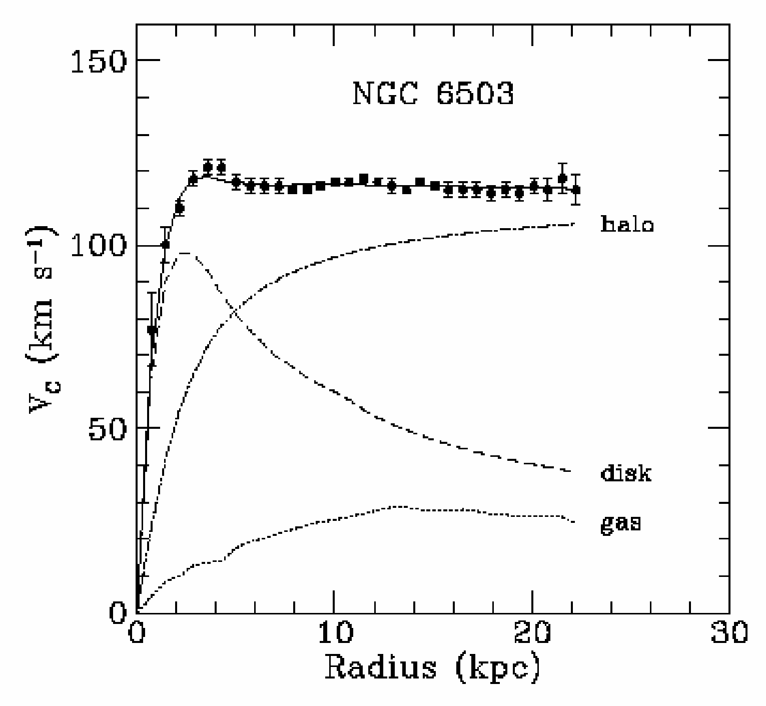
CP-violation at RHIC!! (preliminary) Nucl-ex/0510069



(Centrality of Collisions)

“ If the axion is discovered, it would be an extraordinary triumph for theoretical physics ”

Frank WILCZEK (1997)



Rotation curve of a spiral galaxy. The dashed and dotted curves are the contribution to the circular rotational velocity due to the observed disk and gas, respectively. The dot-dash curve is the contribution from **the dark halo**:

➔ ***Most of the mass of the Milky Way is contributed by its halo, presumably in the form of non-interacting cold dark matter.***

➔ **ρ_{DM} ~ 0.3 GeV/cm^3**

well-motivated dark matter candidates beyond the SM :

WIMPs (SS) & *Axions* (CP @ QCD)

$\Downarrow$

spin-parity $\Rightarrow$ **0^-** $\Rightarrow$ **~ π^o , γ (M1)**

Quintessenz – die fünfte Kraft

Welch **dunkle Energie** dominiert das Universum?

… die ***Griechen*** der Antike sahen in diesem Äther ein im Gegensatz zu Erde, Wasser, Luft und Feuer unfassbares fünftes Element. …

Ch. Wetterich, Physik Journal 3 (#12) (**2004**) 43

Primordial magnetic fields from dark energy

D.-S. Lee, W. Lee, K.-W- Ng , Phys. Lett. B542 (**2002**) 1

Evidences indicate that the dark energy constitutes about two thirds of the critical density of the universe. If the ***dark energy is an evolving pseudo scalar field*** that couples to electromagnetism, a cosmic magnetic seed field can be produced via spinoidal instability during the formation of large-scale structures.

Dimming Supernovae without Cosmic Acceleration

Csaba Csáki,[1,*] Nemanja Kaloper,[2] and John Terning[1]
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(Received 6 December 2001; published 9 April 2002)

We present a simple model where photons propagating in extragalactic magnetic fields can oscillate into very light axions. The oscillations may convert some of the photons, departing a distant supernova, into axions, making the supernova appear dimmer and hence more distant than it really is. Averaging over different configurations of the magnetic field we find that the dimming saturates at about one-third of the light from the supernovae at very large redshifts. This results in a luminosity distance versus redshift curve almost indistinguishable from that produced by the accelerating Universe, if the axion mass and coupling scale are $m \sim 10^{-16}$ eV, $M \sim 4 \times 10^{11}$ GeV. This phenomenon may be an alternative to the accelerating Universe for explaining supernova observations.

Anomalous Axion Interactions and Topological Currents in Dense Matter

M.A. Metlitski1, A.R. Zhitnitsky

hep-ph/**2005**05072

Abstract

Recently an effective Lagrangian for the interactions of photons, Nambu-Goldstone bosons and superfluid phonons in dense quark matter has been derived using anomaly matching arguments. In this paper we illuminate the nature of certain anomalous terms in this Lagrangian by an explicit microscopic calculation. We also generalize the corresponding construction to introduce the axion field. We derive an anomalous axion effective Lagrangian describing the interactions of axions with photons and superfluid phonons in the dense matter background. This effective Lagrangian, among other things, implies that an ***axion*** current will be induced in the presence of magnetic field. We speculate that this current may be ***responsible for the explanation of neutron star kicks***.

➔ Birth velocities 100 - 1600 km/s !

Sun's halo linked to dark matter particle

A MYSTERIOUS X-ray glow that surrounds the sun may be evidence for the existence of an exotic particle that physicists have been hunting for decades.

Astronomers have been puzzled by the sun's X-ray halo since it was first detected in the 1940s. Curiosity deepened when the Japanese satellite Yohkoh, launched in 1991, sent back X-ray pictures showing spectacular flares streaming from sunspots and a gentle glow emanating from the sun's outer atmosphere.

But the surface of the sun is not hot enough to produce such a bright X-ray glow. So where are the X-rays coming from? Konstantin Zioutas and his colleagues think that heavyweight particles called axions could be the source.

Zioutas, a theorist who works at the University of Thessaloniki in Greece and the CERN particle physics laboratory in Geneva, Switzerland, suggests that the X-rays are produced by the decay of axions. According to his team's model, axions are created in the hot core of the sun and expelled, only to become trapped by the sun's gravity. The physicists have calculated the rate at which axions might accumulate around the sun and combined it with an estimate of how quickly they might decay. This predicts how the brightness of the X-ray halo should change with increasing distance from the centre of the sun.

"Axions were dreamed up in the 1970s to explain anomalies in the way nuclear forces behave in experiments"

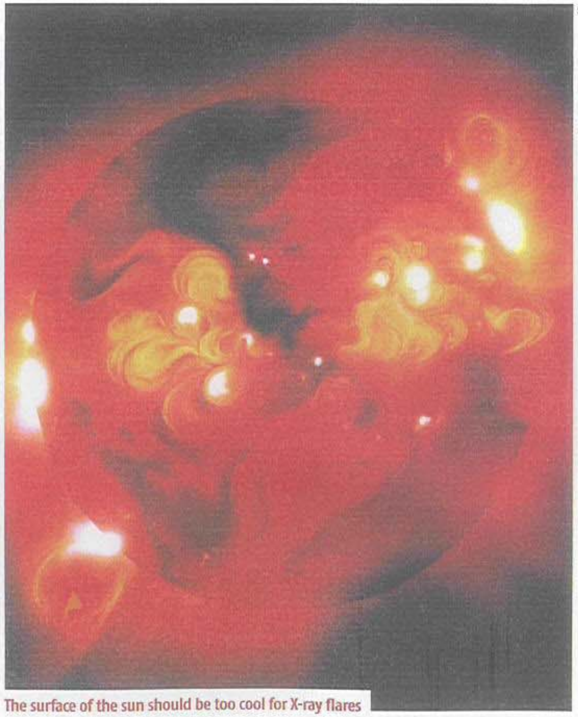
In a paper to be published in *The Astrophysical Journal* next month, Zioutas and his colleagues report that the predictions match brightness measurements made by the Yohkoh satellite.

The catch is that no one is sure axions even exist. Axions were dreamed up in the 1970s to explain differences between the way nuclear forces behave in experiments, and the way theories predict they should. The search for them intensified in the 1980s when cosmologists realised that axions could be the missing dark matter that holds the universe together. But they are predicted to interact with other matter only weakly and no axions have ever been detected.

Have Zioutas and his colleagues finally managed to pin them down? "It's exciting," says Pierre Sikivie, a theorist in the physics department at the University of Florida in Gainesville, "but I don't think the evidence presented can, at this point, be considered proof that axions exist." There may be a simpler explanation for the origin of the solar X-rays.

Until all the alternatives have been ruled out, says Leslie Rosenberg, head of an axion-hunting experiment at Lawrence Livermore National Laboratory in California, assuming that axions are responsible for the sun's X-ray glow is "like coming home, seeing the door to your house open and saying, 'Oh my God, Martians must have been here'". It's not wrong, but it is wildly speculative.

Rosenberg also cautions that Zioutas's model relies on a type of axion that can only exist in a universe with more than four dimensions – and so far we have no evidence for extra dimensions in ours. **Jenny Hogan**



The surface of the sun should be too cool for X-ray flares

"This case represents an extraordinary decision by a woman in labour."

A doctor at Dr Manuel Velasco Suarez Hospital in San Pablo, Mexico, on a patient's decision to perform a Caesarean on herself (BBC Online, 7 April)

"We all have a need to decorate Mother Nature because it belongs to us all."

Marco Evaristti, Danish artist, after painting an iceberg red in Greenland (Associated Press, 26 March)

"Animals are more tactile and supportive. The workplace is seeing less of that these days."

Psychologist Cary Cooper on a Zoological Society of London plan to ask volunteers to mimic chimp behaviour at work (BBC Online, 7 April)

"It is as likely to happen next week as in a randomly selected week a thousand years from now."

Lindley Johnson of NASA tells the US Senate why it is important to search for objects that could hit the Earth (7 April)

"Our science has been in such a poor condition that it is simply unable to produce anything that can represent state secrets."

Physicist Valentin Danilov, who was cleared of spying last December, on the jailing of Russian nuclear weapons expert Igor Sutyagin for espionage (*The Moscow Times*, 7 April)

"Peter has been very clever at keeping undercover. They thought they would never see him again."

Natalie Pritchard of the Earthwatch Institute, after a celebrated penguin was found alive and well in South Africa. Peter rose to fame after being rescued from an oil spill in June 2000 (*The Guardian*, London, 7 April)

New Scientist 17 April 2004

Strong CP: No Problem

P. Mitra

hep-ph/**2005**04053

Strong CP: No Problem

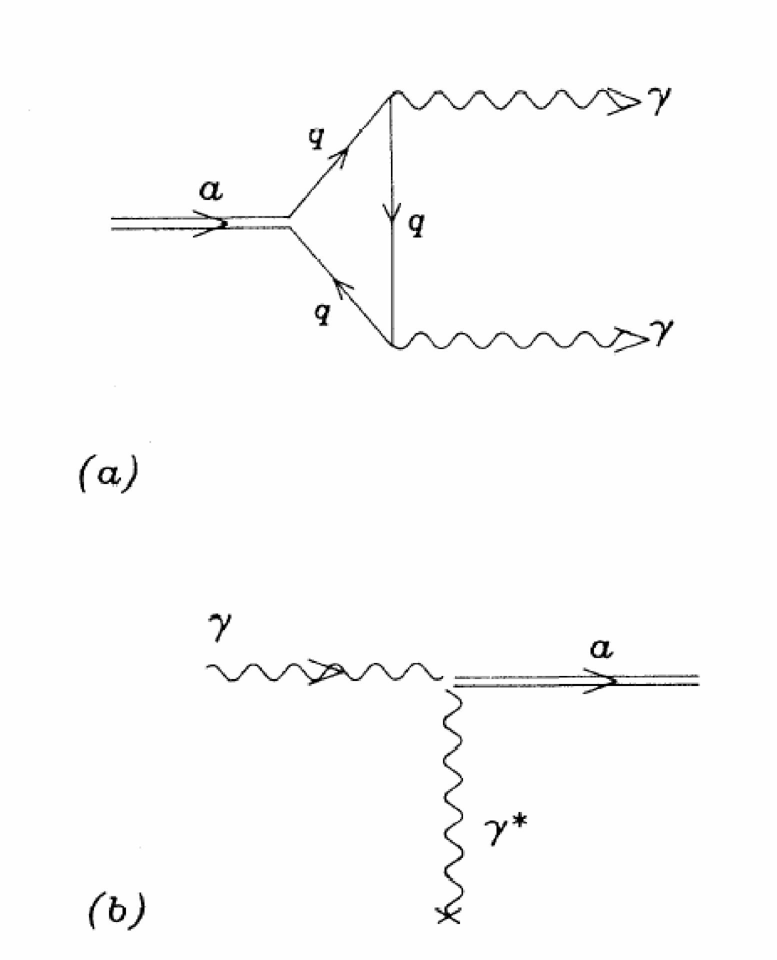
P. Mitra

hep-ph/**2005**04053

Abstract

Detailed analysis shows that the phase of a complex mass term of a quark does not violate CP, while the QCD vacuum angle can naturally be set equal to zero. There is no strong CP problem and ***no need for axions*** or similar speculative constructions ***to be experimentally looked for.***

Of particular interest ➔ ***axion coupling to two photons*** (in all models)



(a) Axion coupling to two photons through a loop diagram.

(b) Axion production by photon propagating in a static magnetic field (**Primakoff effect**). *R. Cameron et al.,PRD47(*1993*)3707*

before CAST ?

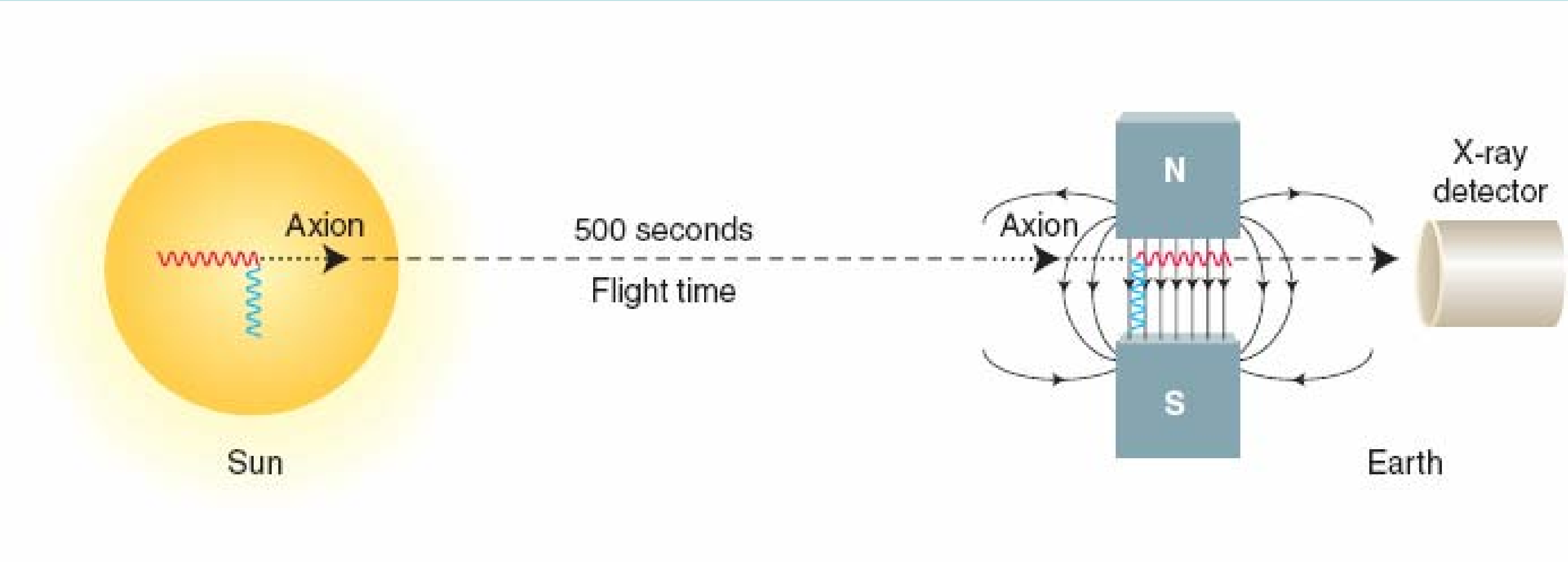
➔ BNL & Tokyo

➔ axion-Bragg @ Ge-detectors

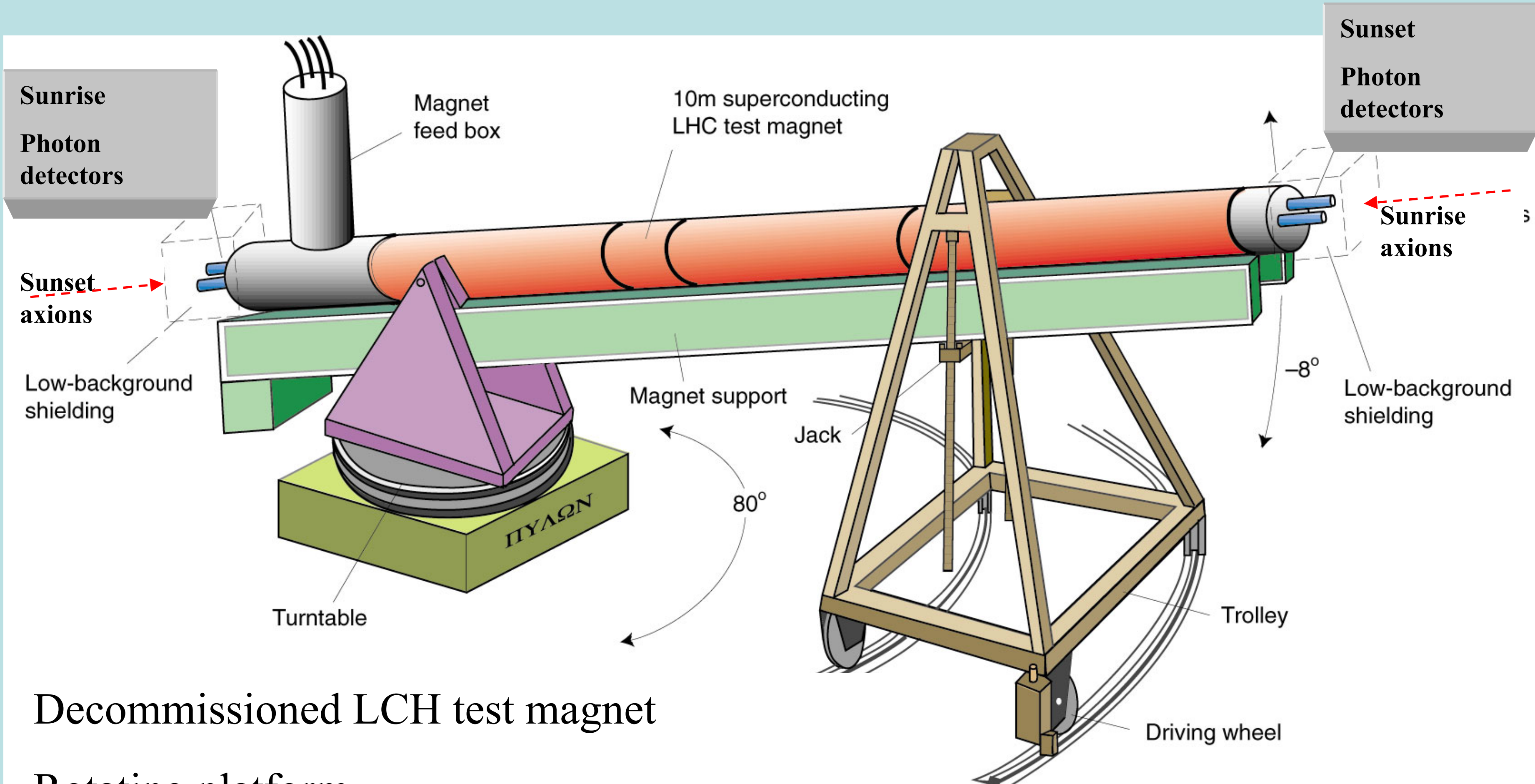
The CAST experiment

Axion - source ↓

Axion - detection ↓



Cern Axion Solar Telescope



Decommissioned LCH test magnet

Rotating platform

3 X-ray detectors

X-ray Focusing Device

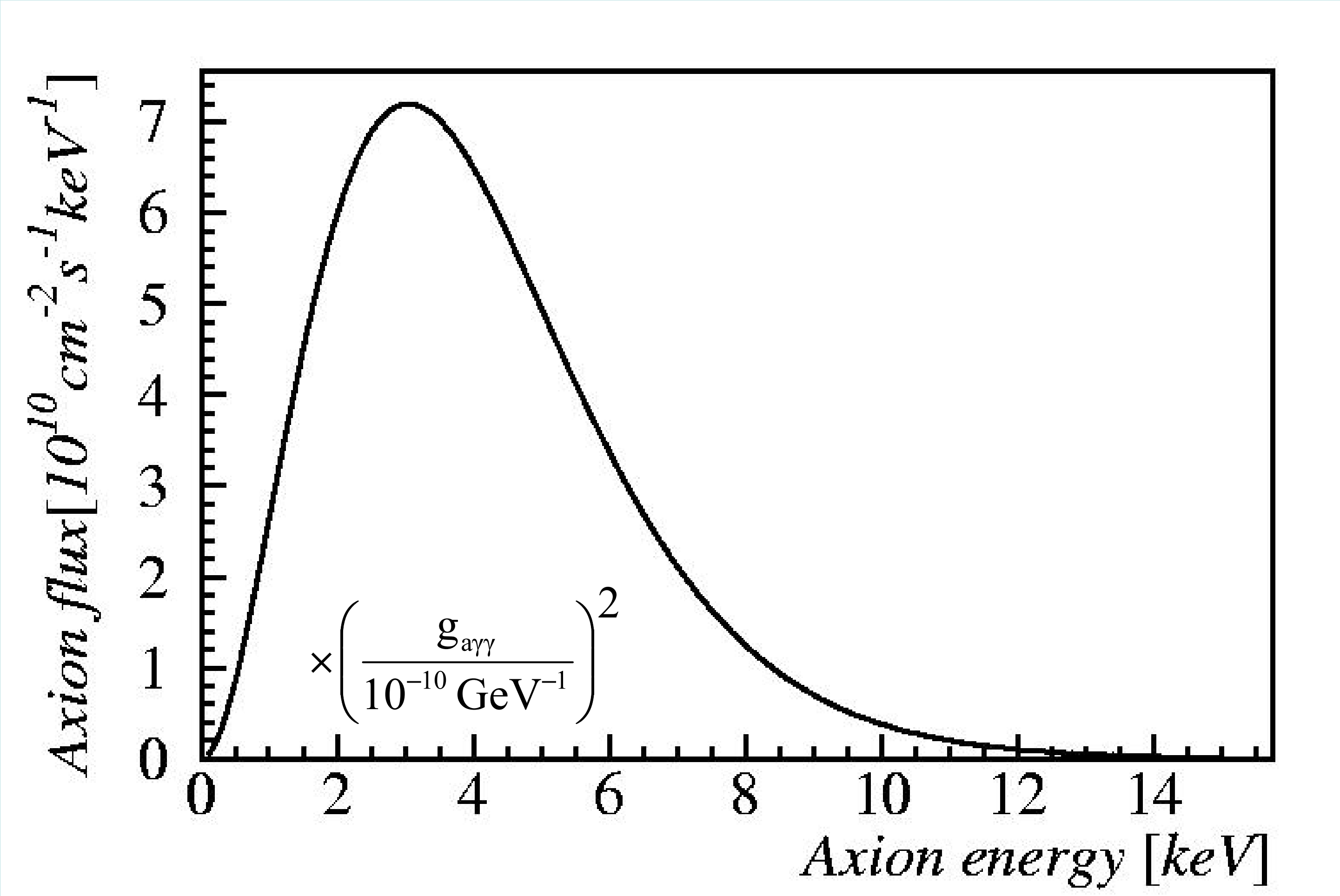
Shelly Stoody of Whittier, California and his ***mobile*** **Zeiss** *Refractor* (**1933**).

CAST

➔ *recycling* !


3sat

Solar axion spectrum



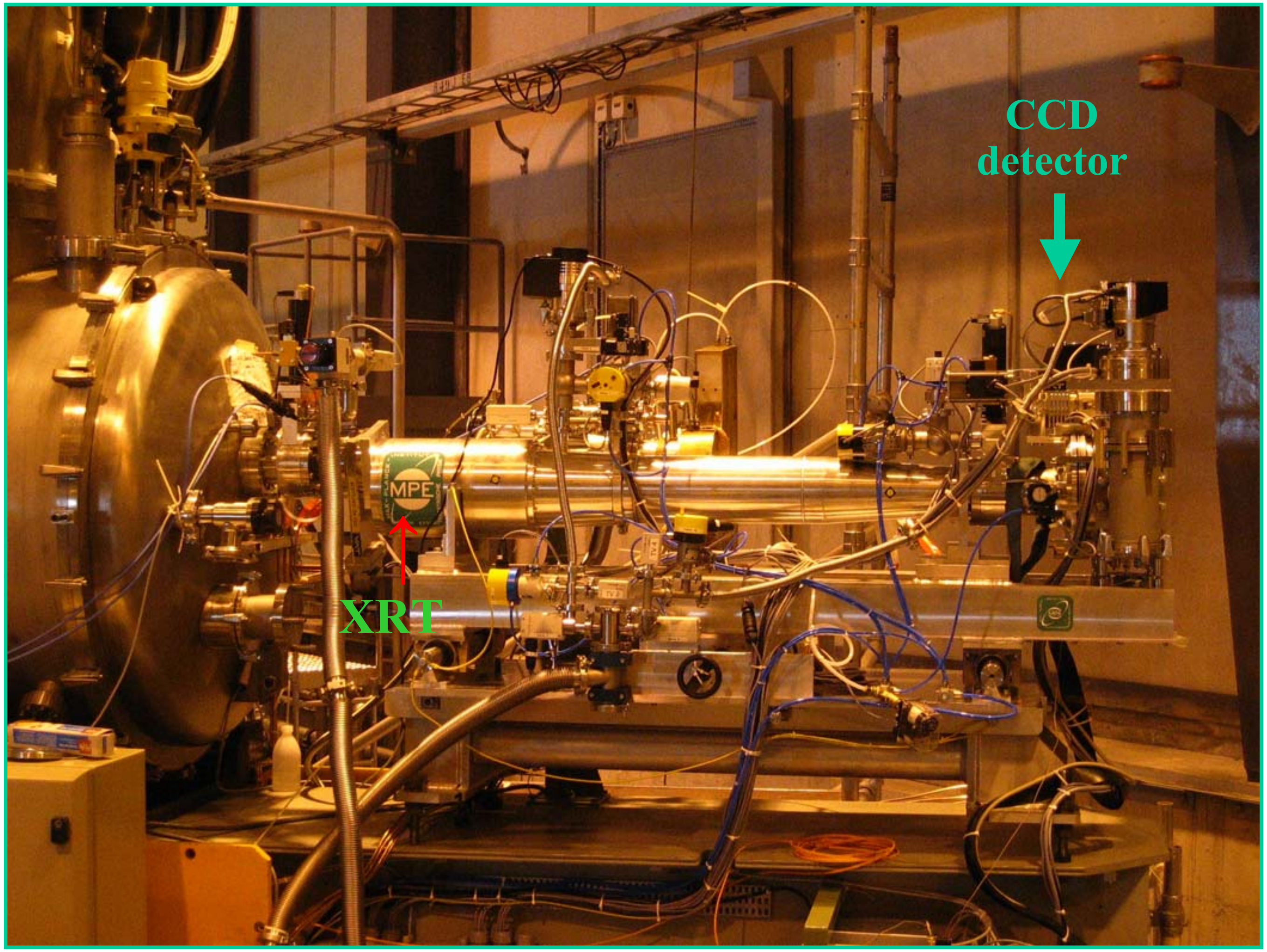
$P_{a \to \gamma} \approx 1.7 \times 10^{-17}$ ➔ $\Phi_\gamma = 0.51\ \mathrm{cm}^{-2}\ \mathrm{d}^{-1}\ g_{10}^4 \left(\frac{L}{9.26\ \mathrm{m}} \right)^2 \left(\frac{B}{9.0\ \mathrm{T}} \right)^2$


TPC
X rays
POLE PROTOT
2003/01/02 23:39:11

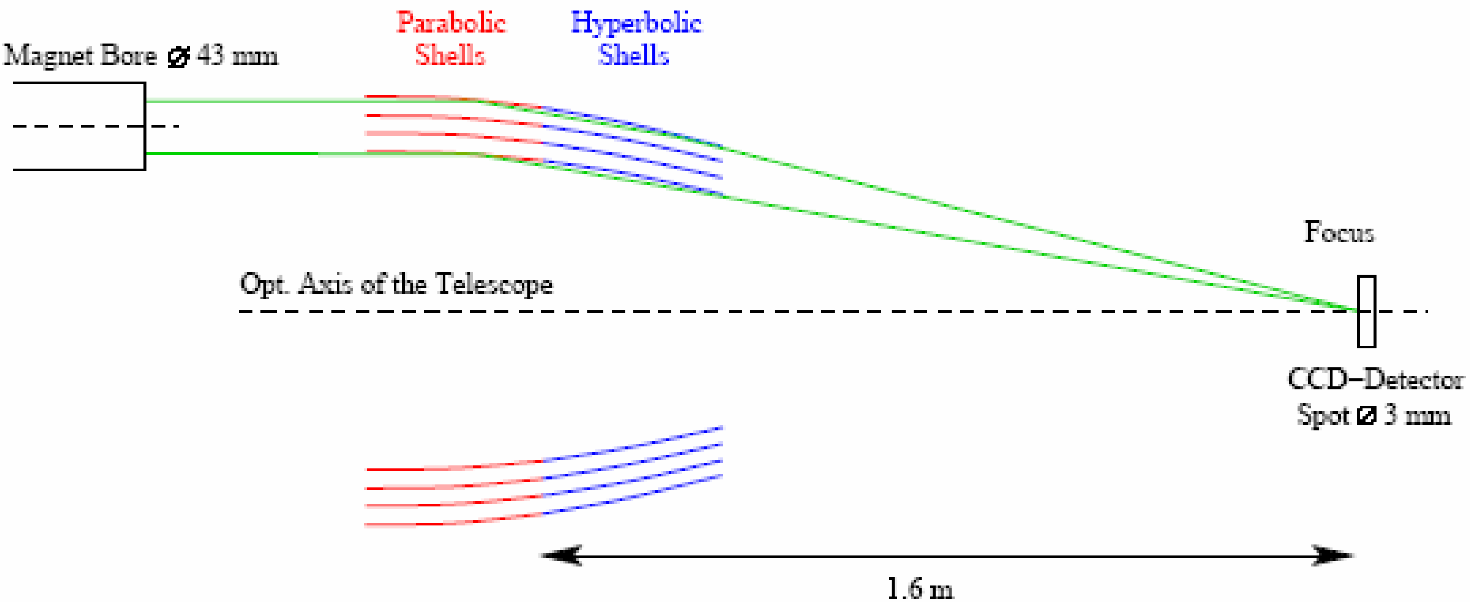
THE CAST X-ray telescope

A spare unit from the ABRIXAS Space Mission

- 27 nested shells
- Focal length 1.7 m
- Transmission 35%



The X-ray Telescope of CAST

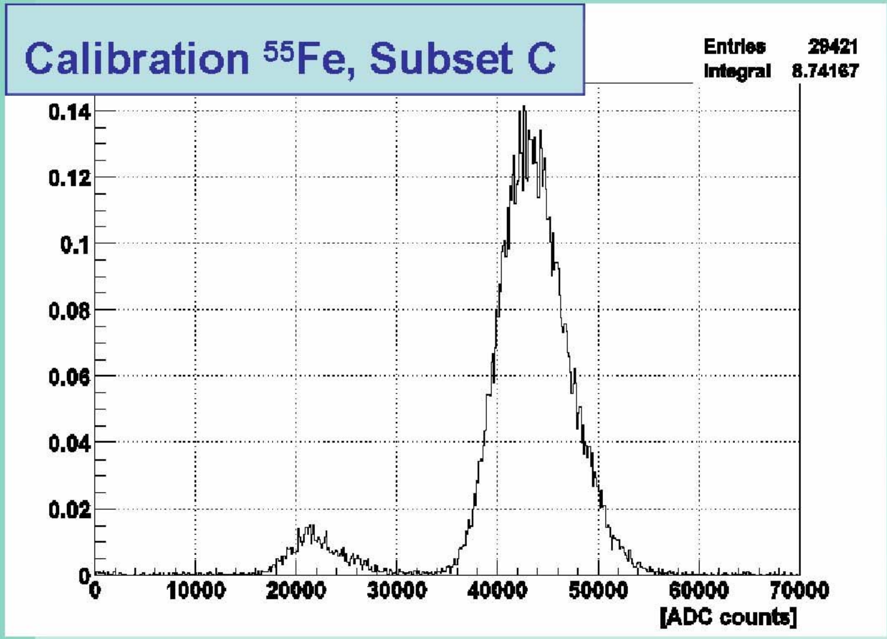


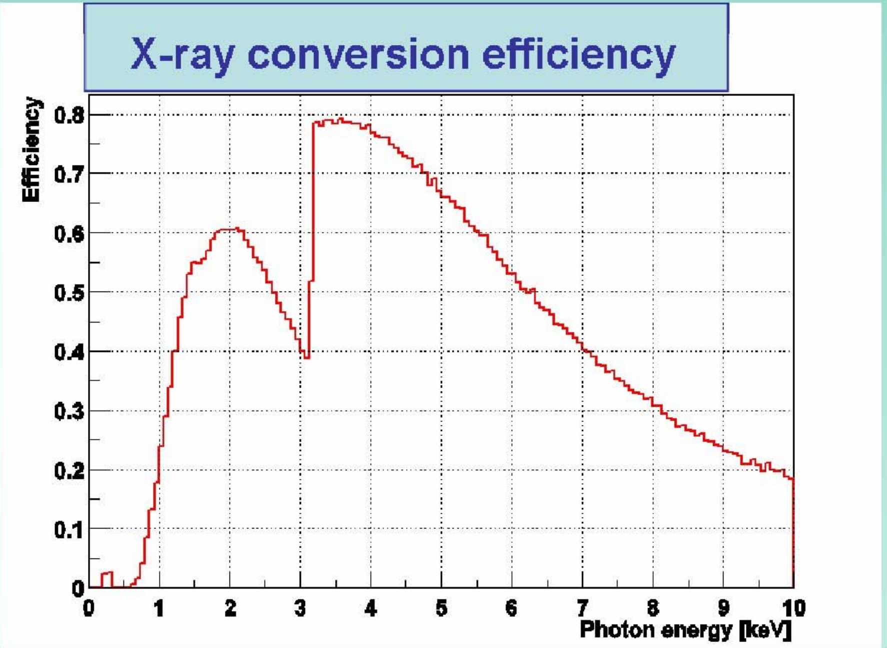
Wolter I type grazing incident optics (Prototype for *ABRIXAS* space mission):

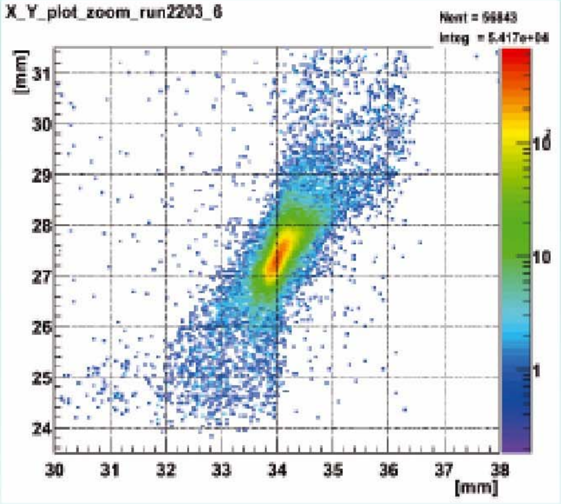
- 27 nested gold coated nickel shells, on-axis resolution ≈ 43 arcsec
- Telescope aperture 16 cm, used for CAST 43 mm
- Only one sector of the full aperture is used for CAST

⌀43 mm (LHC Magnet aperture) $\Longrightarrow$ ⌀3 mm (spot of the sun)
Significantly improves the signal to background ratio !

Micromegas–Performance





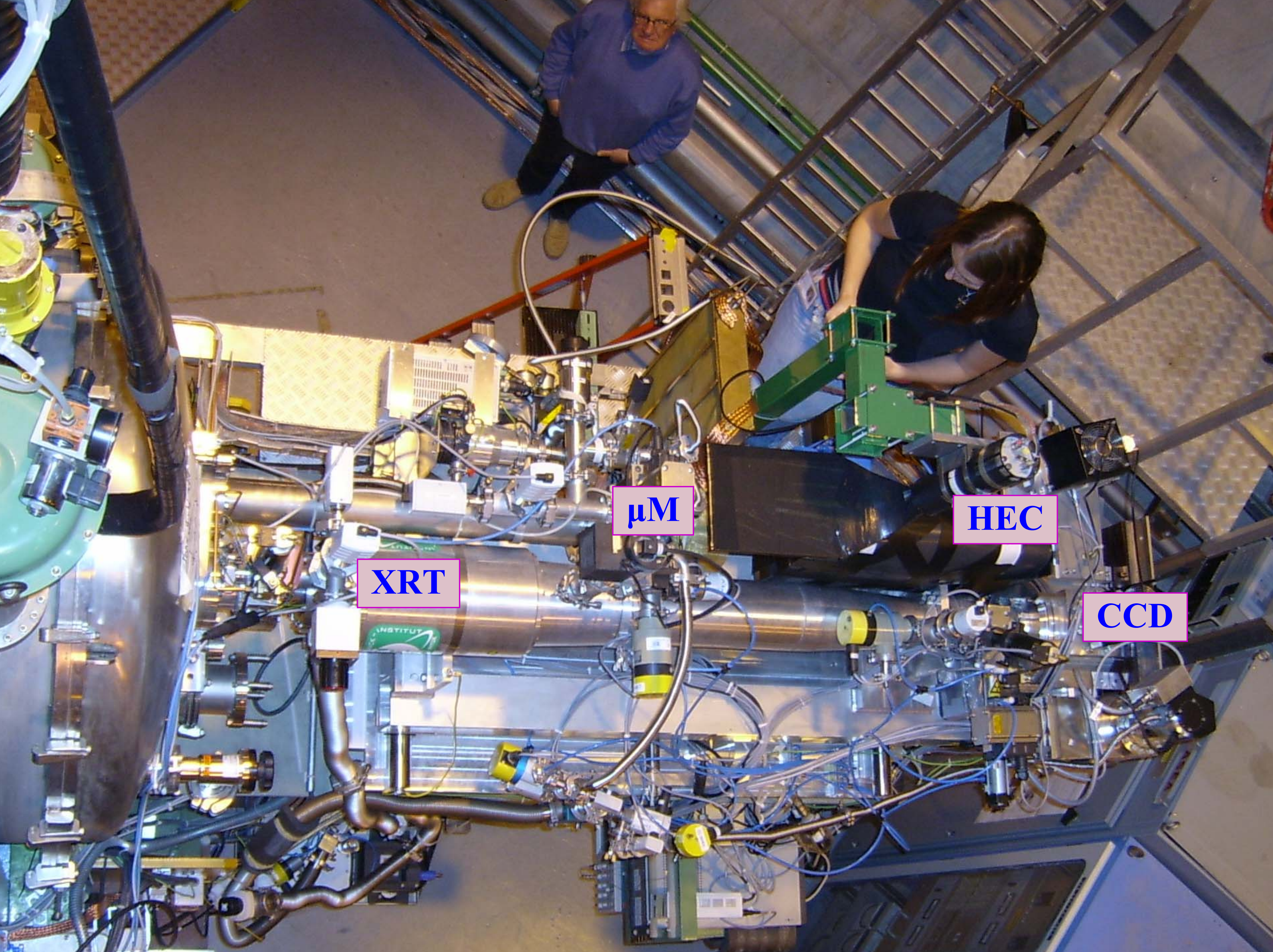


Detector Dead time: 5 %

Software efficiency

77%@3 keV 87%@6 keV

2003 detector is replaced by a new detector with better performance for 2004 !


μM
HEC
XRT
CCD

GRID measurements:

→ with the surveyors of CERN

→ define pointing of the magnet + XRTelescope

→ at ~ 100 positions

→ cold & warm

→ **Tracking System**:

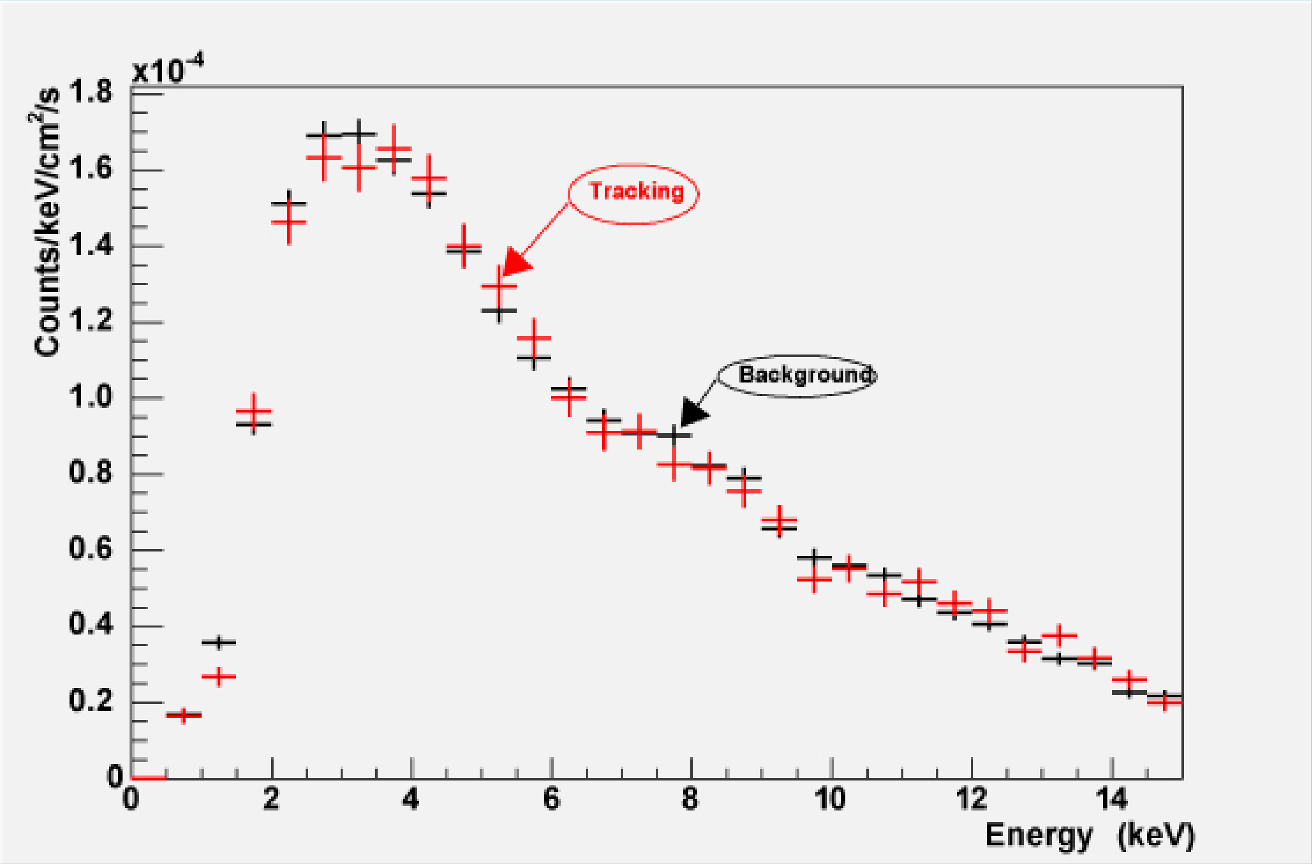
→ Calibrated and correlated with celestial coordinates

Filming of the Sun:

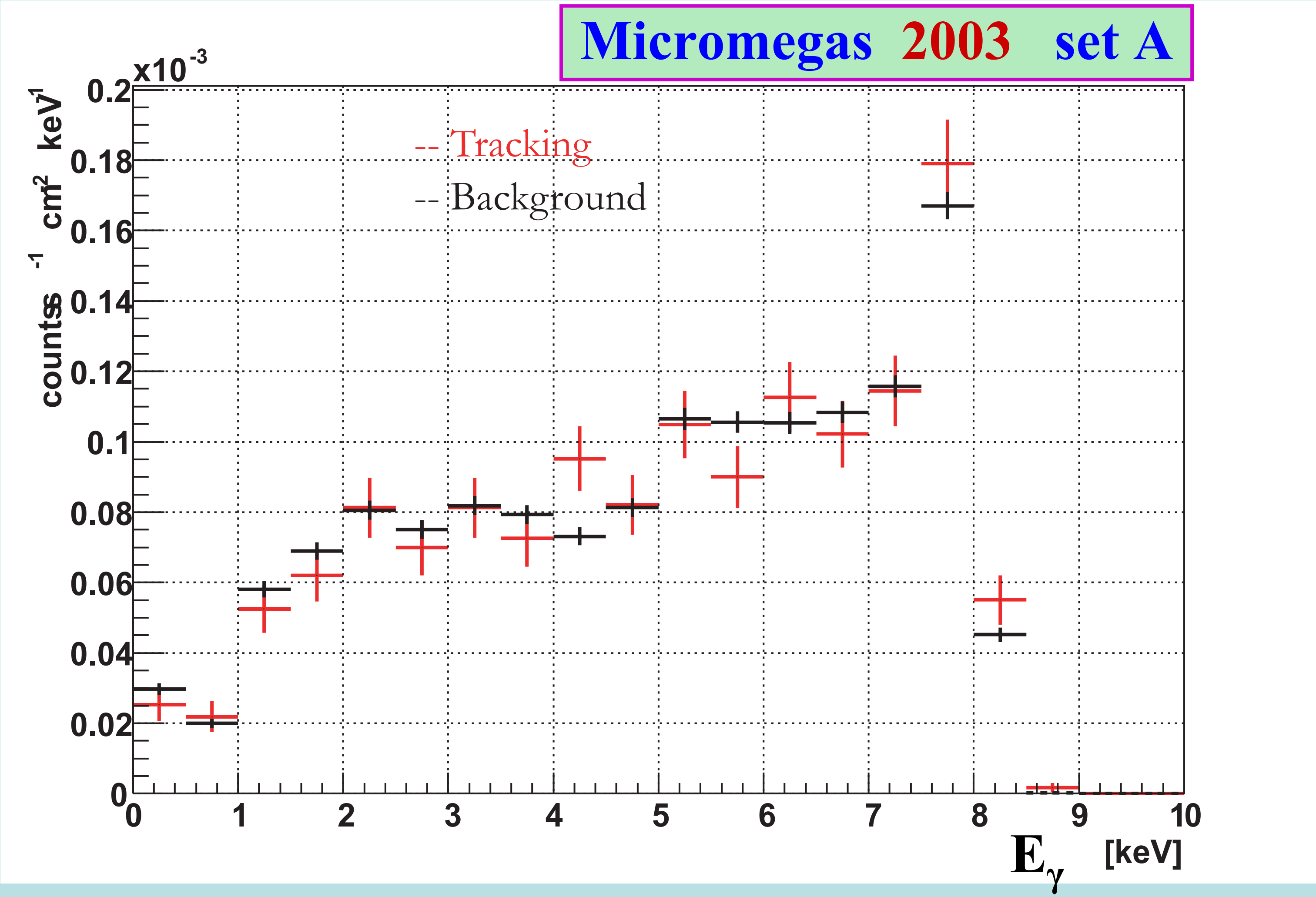
→ March & September

→ alignment cross check

TPC 2003



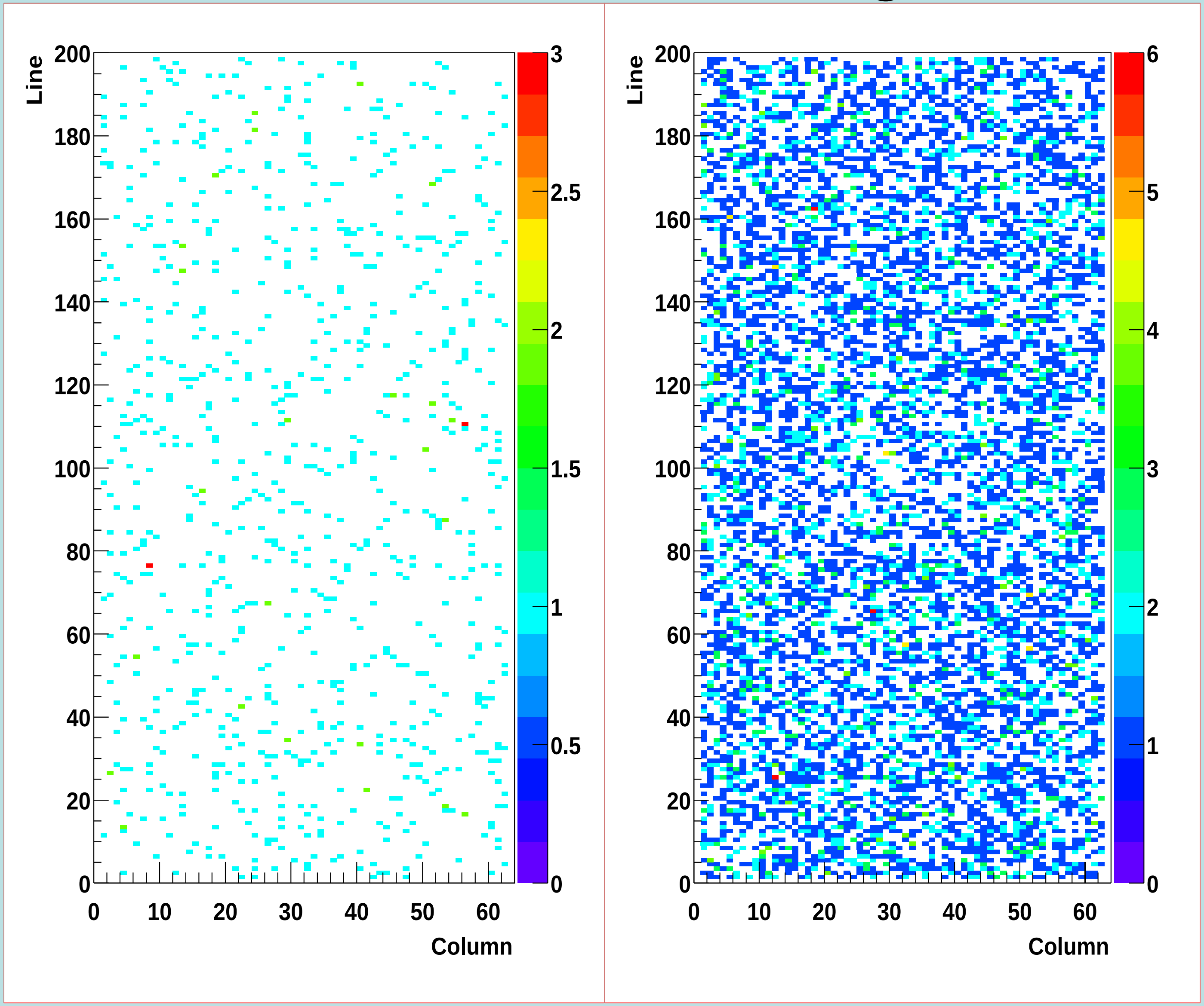
Energy spectra with **TPC**. Data corresponding to sun tracking (***red***) and background (***black***) obtained during part of the **2003** operation period.


Micromegas 2003 set A
x10^-3
counts s^-1 cm^2 keV^-1
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-- Tracking
-- Background
0
1
2
3
4
5
6
7
8
9
10
Eγ [keV]

Full image

CCD 2003

tracking *background*



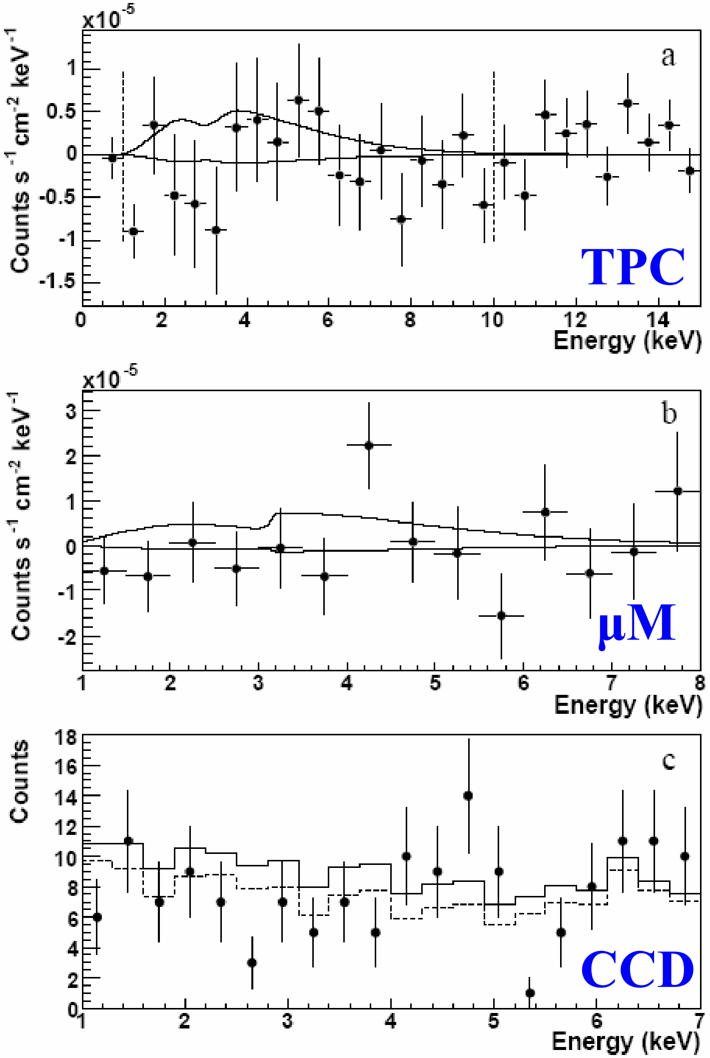


FIG. 1: Panels (a) and (b) show respectively the experimental subtracted spectrum of the TPC data set and MM data set A, together with the expectation for the best fit $g_{a\gamma}$ (lower curve) and for the 95% CL limit on $g_{a\gamma}$. For (a) the vertical dashed lines indicate the fitting window. Panel (c) shows both the tracking (dots) and background (dashed line) spectra of the CCD data set, together with the expectation (background plus signal) for $g_{a\gamma}$ at its 95% CL limit, in units of total counts in the restricted CCD area (54.3 mm^2) in the tracking exposure time (121.3 h).

2003

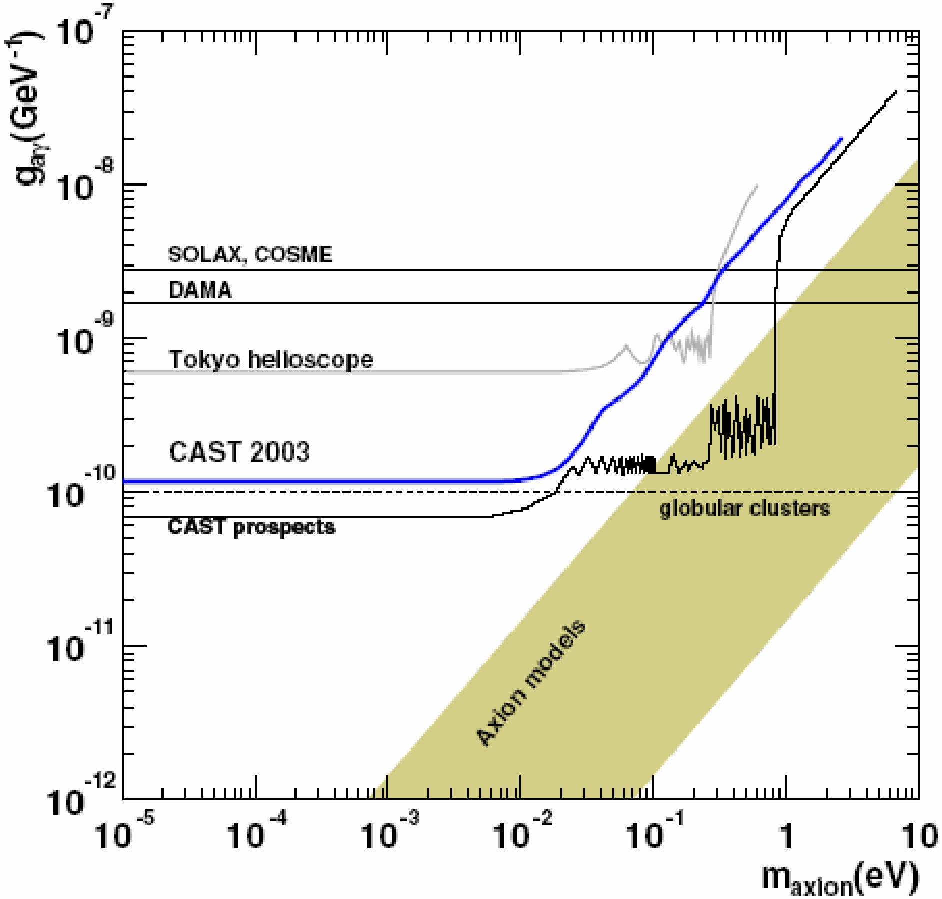


FIG. 2: Exclusion limit (95% CL) from the CAST 2003 data compared with other constraints discussed in the introduction. The shaded band represents typical theoretical models. Also shown is the future CAST sensitivity as foreseen in the experiment proposal. **K.Z. *et al.*, PRL 94 (2005) 121301**

$g_{a\gamma\gamma}$(95% CL)<1.16×10^{-10} GeV^{-1} (m_a< .02eV)

2004

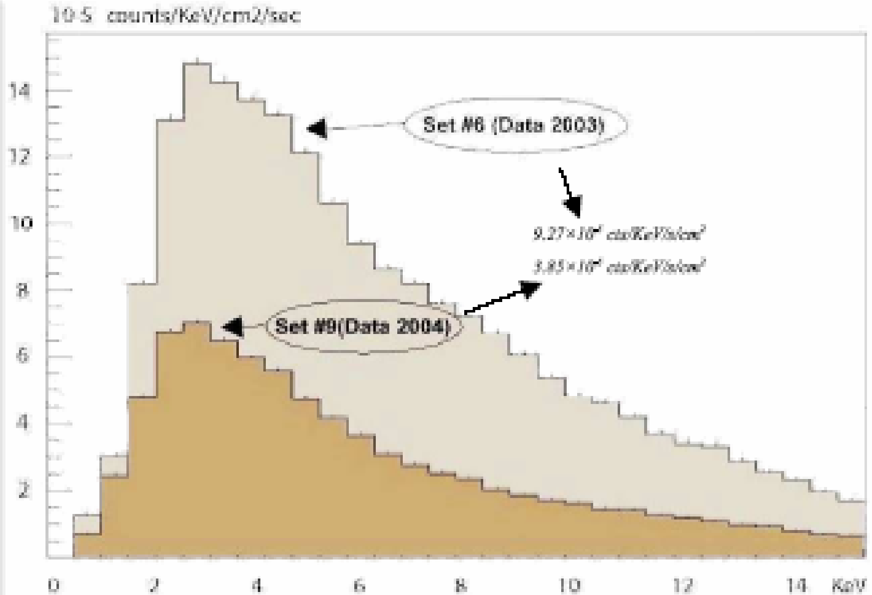
➔ ***improvements***

CAST Detector – Improvements in 2004

TPC

- Differential pumping system
- Improved passive shield
  PE, Cd, Pb, and Cu-box
- Permanently flushed with N_2
  $\Longrightarrow$ reduces Radon
- Active veto to reduce muon background

TPC Background



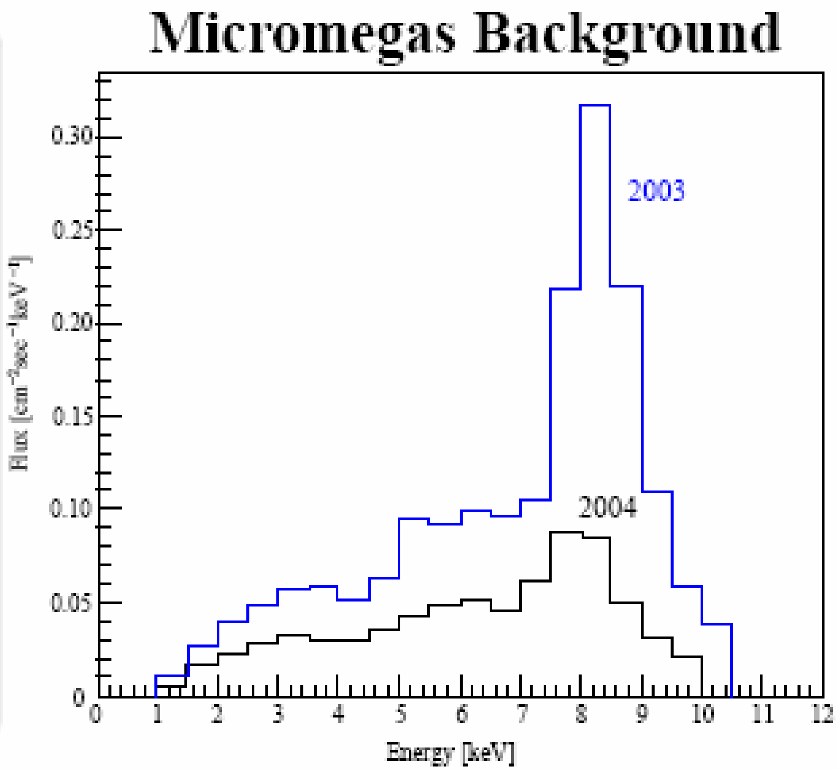
Background 1–7 keV

2003: 9.27×10^{-5} photons $cm^{-2}\ sec^{-1}\ keV^{-1}$
2004: 3.85×10^{-5} photons $cm^{-2}\ sec^{-1}\ keV^{-1}$
Background reduction by a factor of 2.4

CAST Detector – Improvements in 2004

Micromegas

- 2003 detector was replaced by a new model
  better quality of the strips
  less cross-talk
- Less Cu $\Longrightarrow$ less fluorescent emission
- New VME digitizing board
- Automated calibration source



Background 1–7 keV

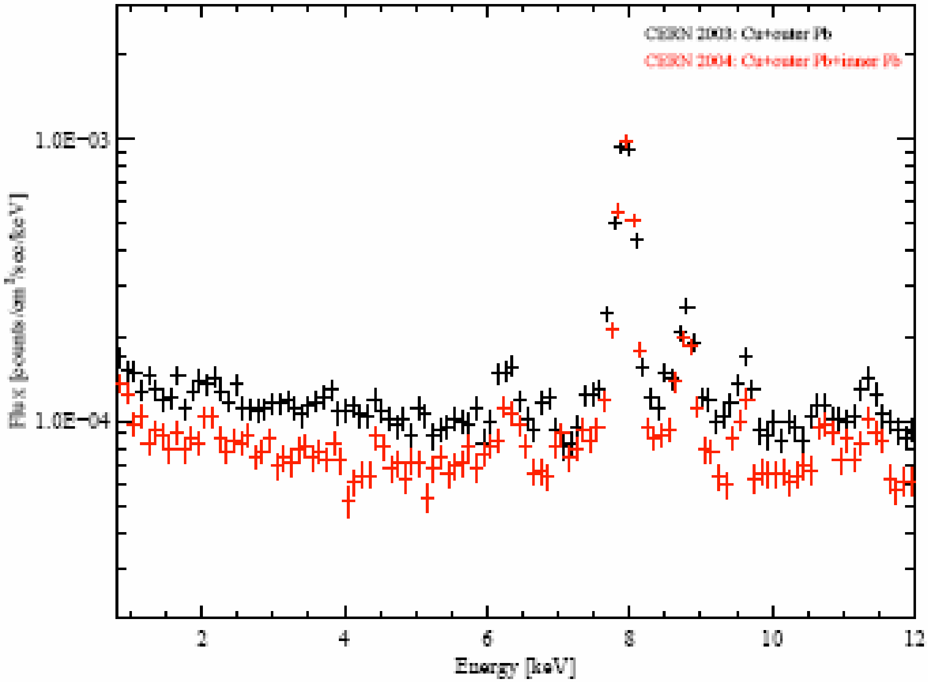
2004: 4.82×10^{-5} photons cm^{-2} sec^{-1} keV^{-1}
Background reduction by a factor of ≈ 2

CAST Detector – Improvements in 2004

X-ray Telescope/pn-CCD

- Installed additional shield inside the vessel at the end of 2003
- Installed X-ray finger source for continuous checking of the Telescope's alignment

CCD Background



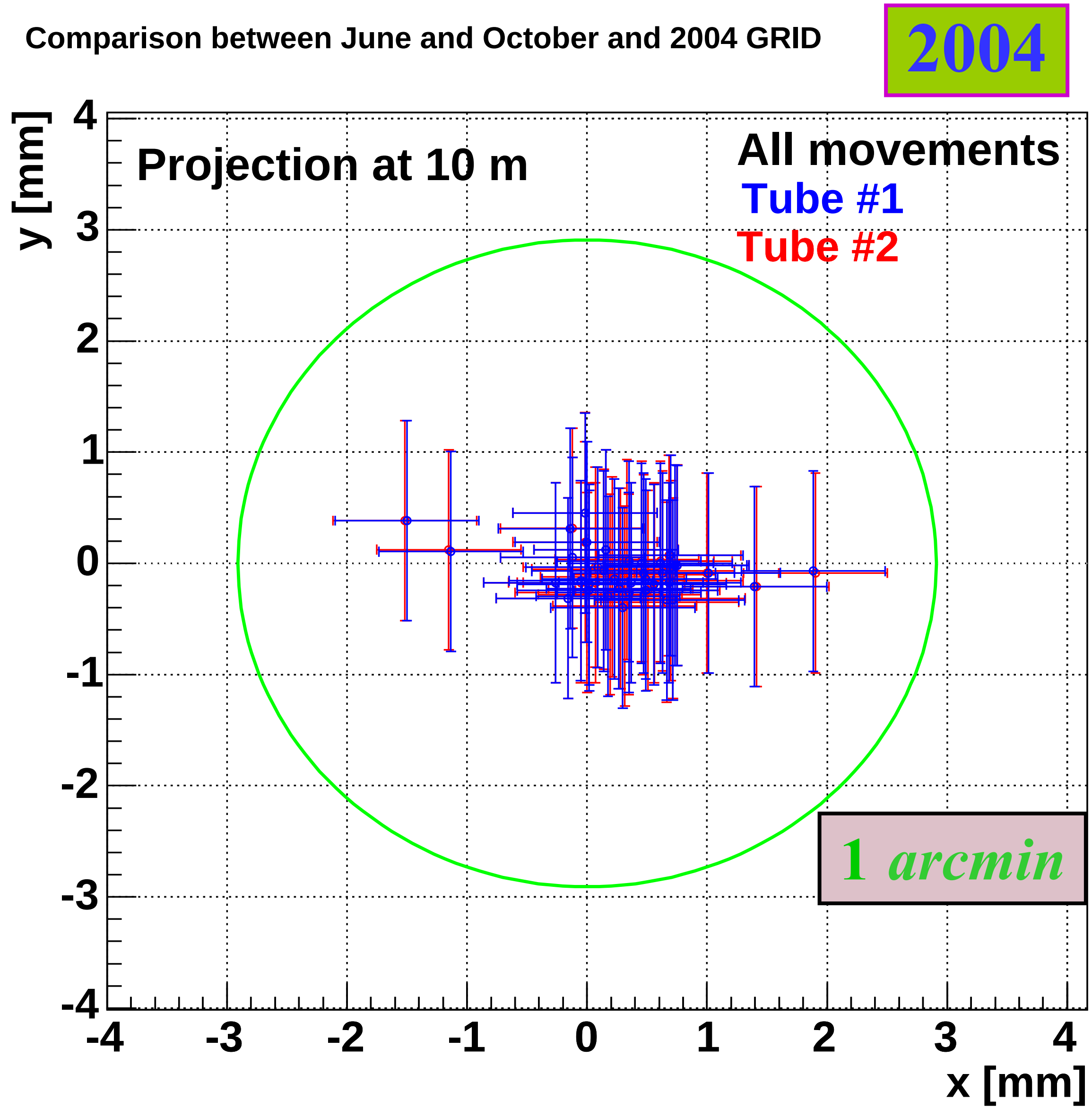
Background 1–7 keV

2003: $11.5 \pm 0.2 \times 10^{-5}$ photons cm^{-2} sec^{-1} keV^{-1}

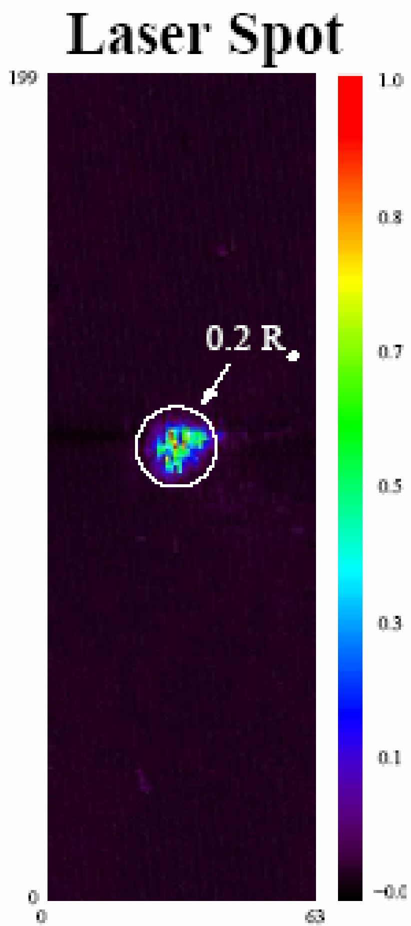
2004: $7.69 \pm 0.07 \times 10^{-5}$ photons cm^{-2} sec^{-1} keV^{-1}

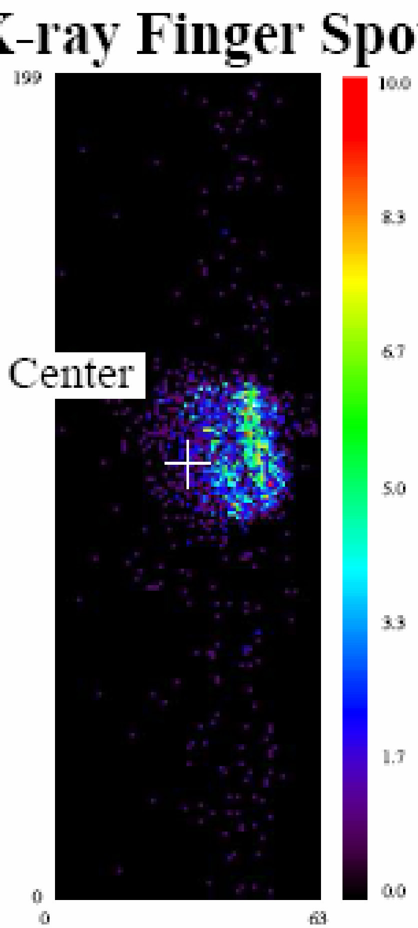
Background reduction by a factor of 1.5

Comparison between June and October and 2004 GRID



Telescope Alignment – Improvement





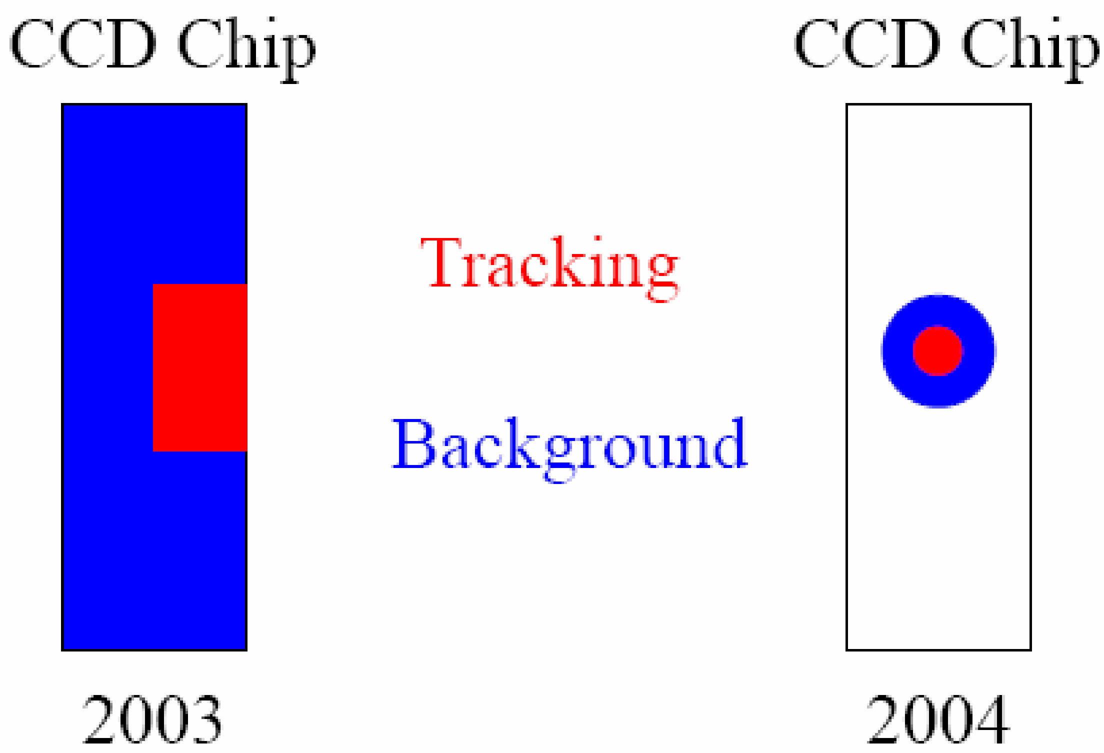
Defines the location of the Axion signal !

$$X = 30.8 \quad Y = 109.6$$

Defines the reference position to verify the alignment !

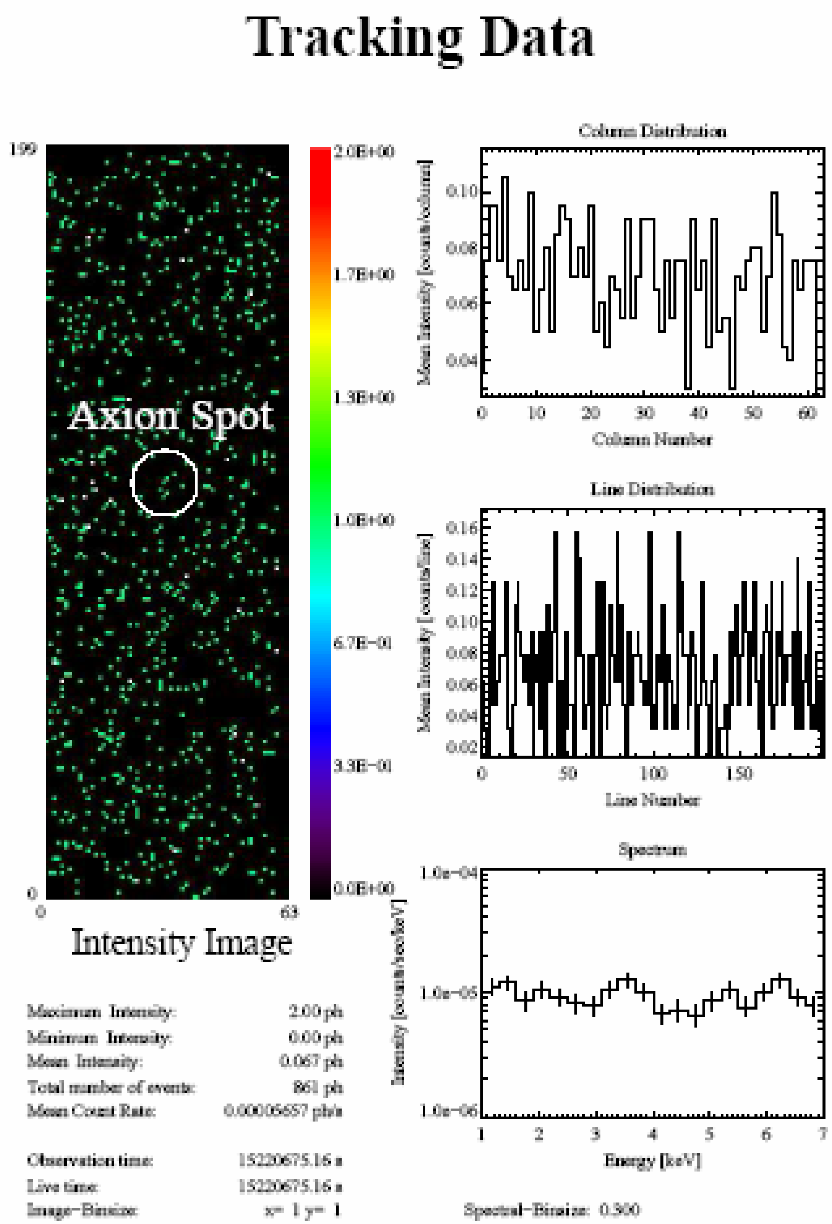
$$X = 43.5 \quad Y = 108.0$$

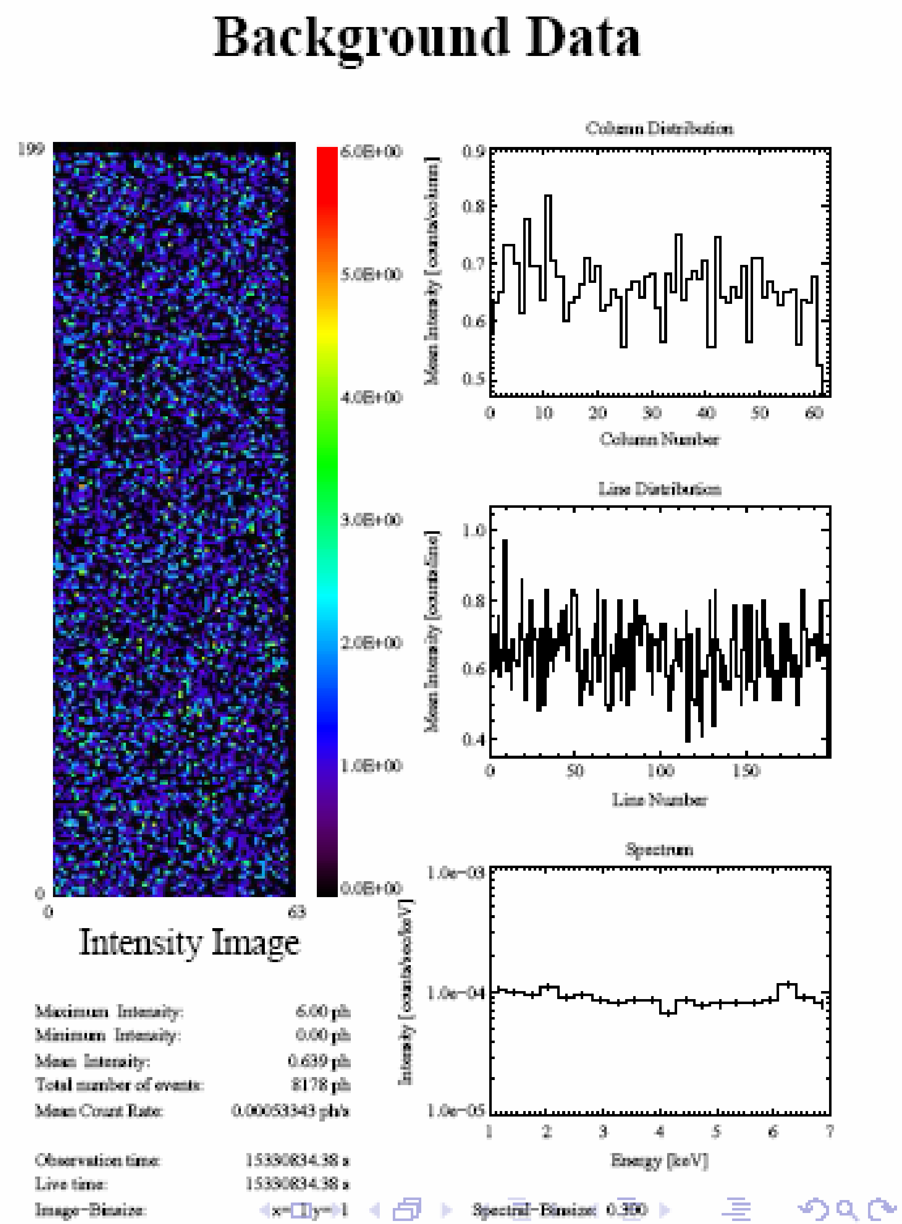
Telescope Spotsize 2003 $\longrightarrow$ 2004



For 2004 signal area = axion spot size ($51\,\mathrm{mm}^2 \Longrightarrow 6\,\mathrm{mm}^2$) !
Exploiting the full sensitivity of the X-ray telescope !

2004 CCD Images

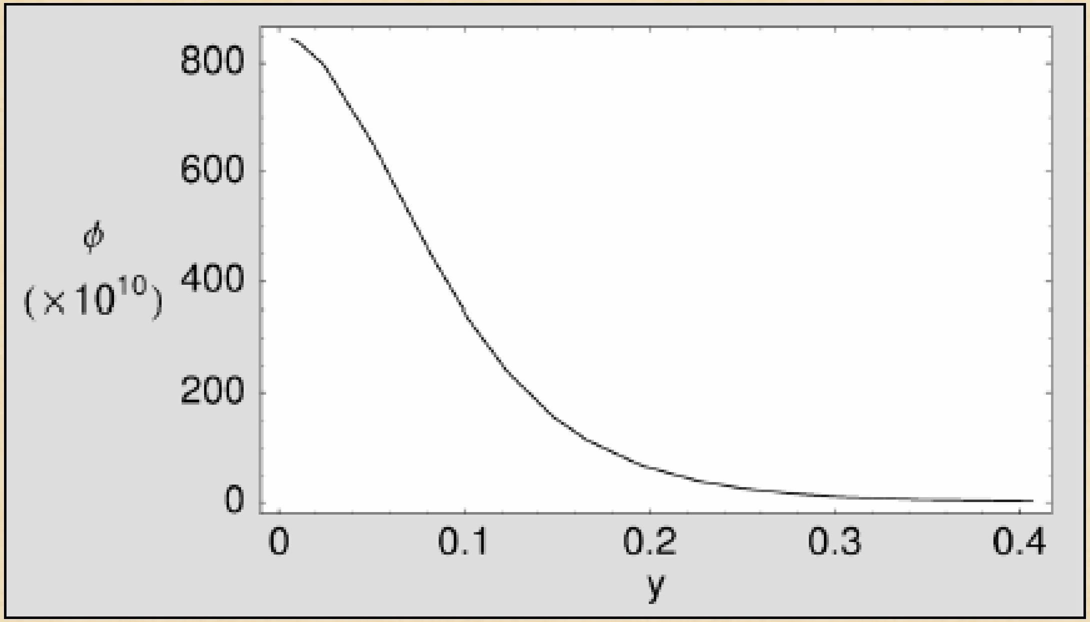


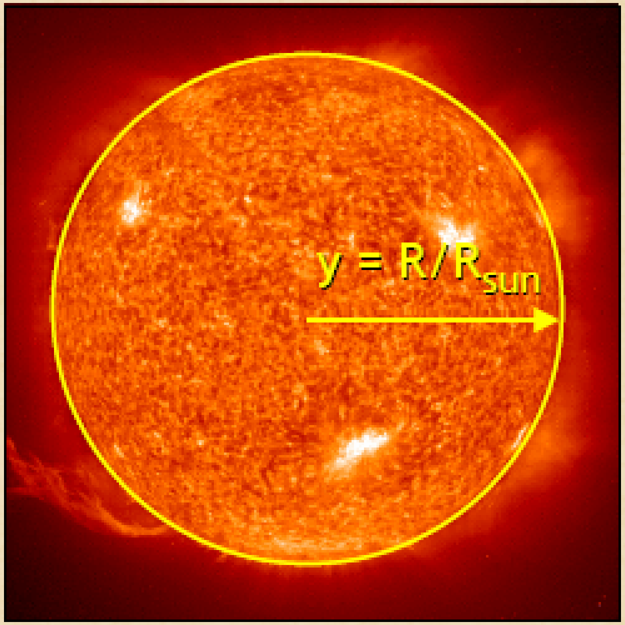


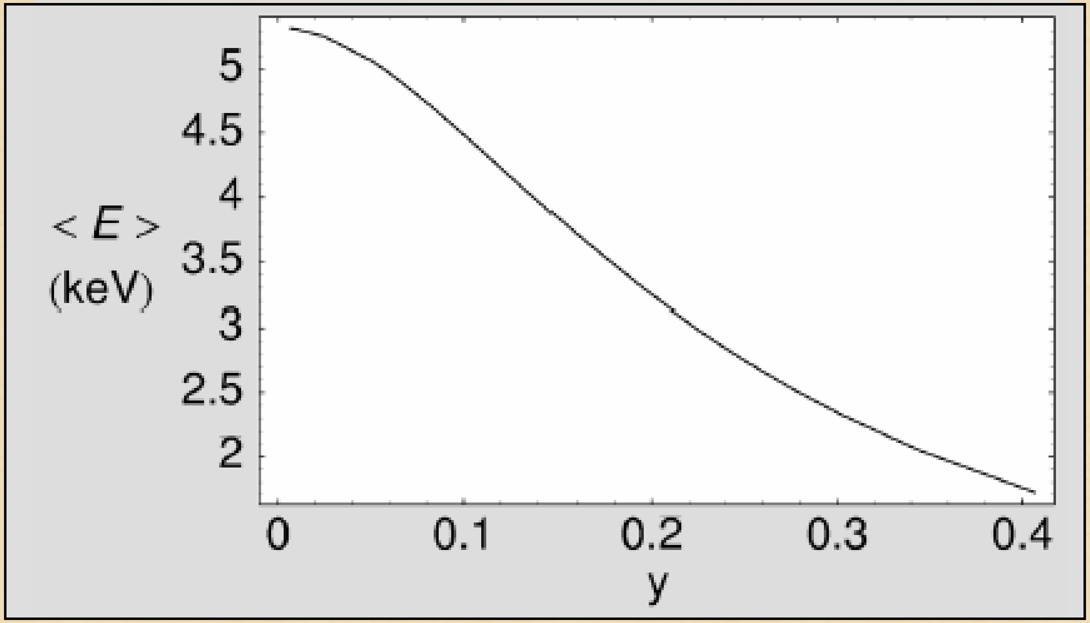
Systematics

→ ***variations with time*?**

Axion "Surface Luminosity" on Solar Disk







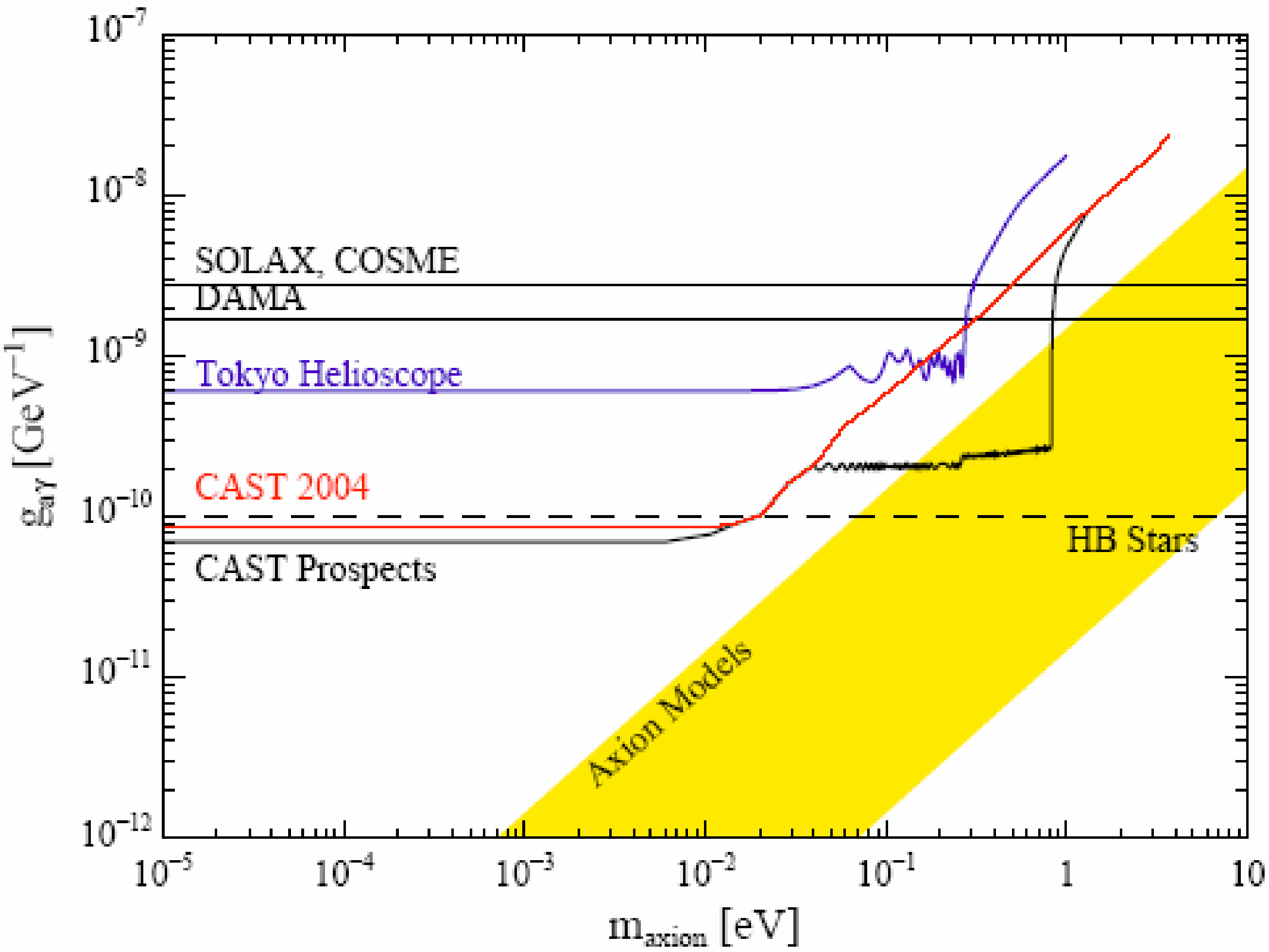
"Surface luminosity" is axion luminosity per unit square on solar disk (solar disk radius = 1 unit)

2004 data

→ ***analysis ongoing***

Exclusion Plot 2004 VERY PRELIMINARY !!

VERY PRELIMINARY



VERY PRELIMINARY

2004 CAST limit includes statistical errors only !

Search for energetic axions

➔ ***Axions*** from nuclear reactions @ Sun's core:

$d + p \rightarrow {}^3He + \gamma$ (5.5 MeV, $\sim 2 \cdot 10^{38}$/sec)

$n + p \rightarrow d + \gamma$ (2.2 MeV)

➔ ***High Energy Calorimeter***

Motivation:

- Broad band axion search with the high axion-to-photon conversion efficiency inside the CAST magnetic pipes
- Axion coupling to nuclear magnetic dipole transitions

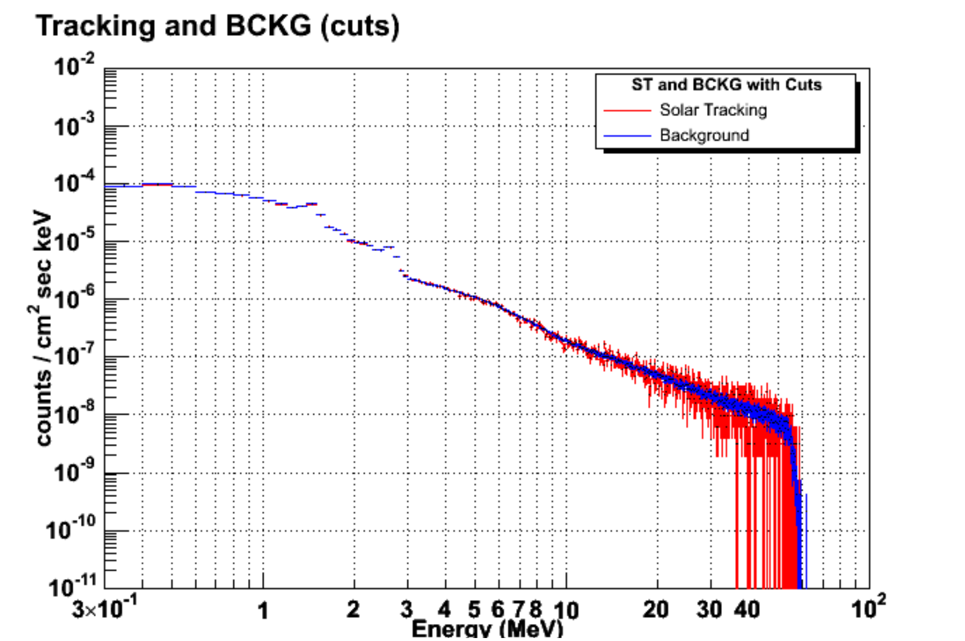
➔ The Sun is the strongest source of **M1** transitions!

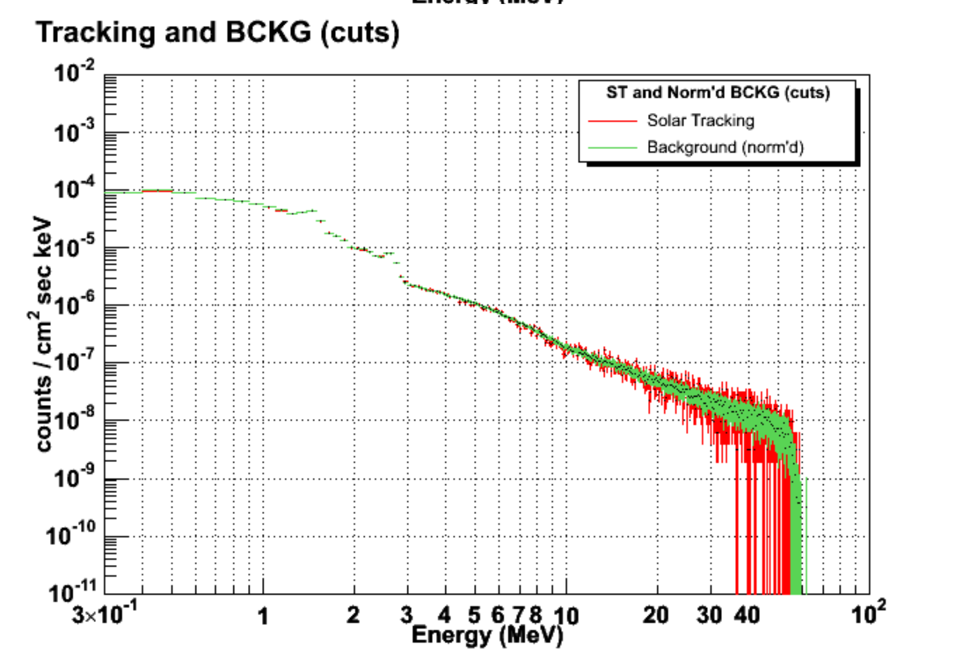
➔ **Non-solar *axions* ??**

➔ G.C., Sco X-1, Crab pulsar. ← TBE

H.E. Calorimeter → **CdWO4** crystal 0.6 kg (Ø45mm x 50 mm)

pectrum





- ***Without* position normalized background data**
  - Good agreement, *but* we know there is a systematic effect due to the pointing position of the magne
- ***With* position normalization**
  - Error bars increase by factor x2
  - Systematic effect of position reduced

CAST Phase II → **2005 - 2007**

→ ***why*** **?**

→ ***how*** **?**

AXIONS: RECENT SEARCHES AND NEW LIMITS

G.G. RAFFELT, hep-ph/**2005**04152

New cosmic structure-formation limits imply ➔

$$m_a < 1 - 2 \ \text{eV}$$

➔ a new **hot dark matter** component, in addition to ν's .

➔ New cosmological limit on relic axions:

$$m_a < 1.05 \ \text{eV}$$

S. Hannestad, A. Mirizzi, G. G. Raffelt, hep-ph/**2005**04059

CAST Phase II

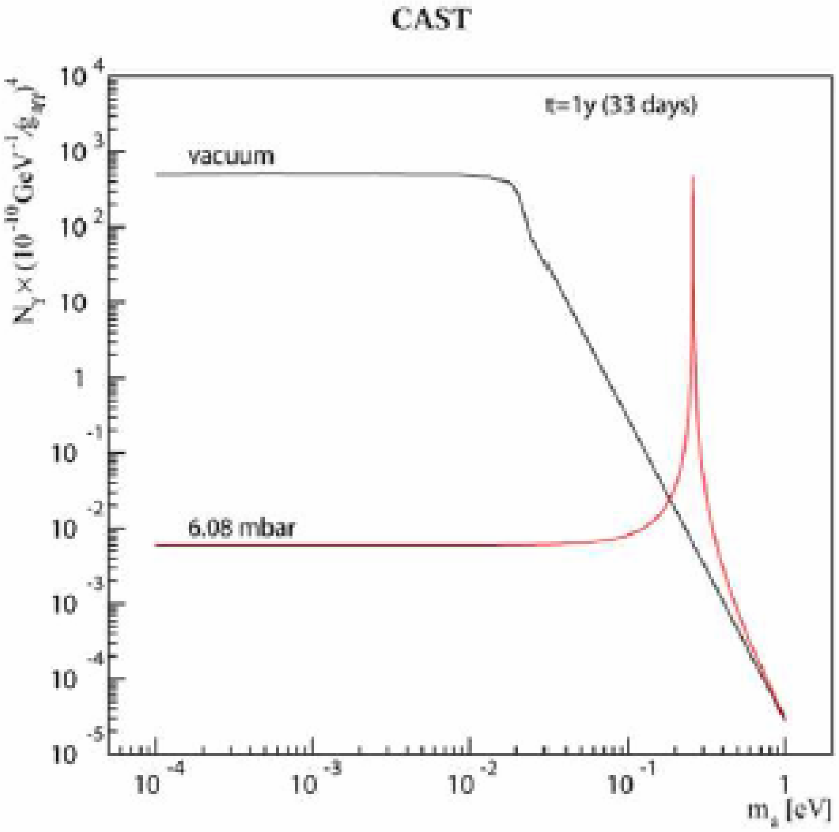
Fill magnet bore with buffer gas

^{4}He or ^{3}He

($p_{\text{vap}} = 16/140\,\text{mbar}@1.8\,\text{K}$)

$\Longrightarrow$ photon acquires an effective mass

$$m_{\gamma,\text{eff}} \approx \sqrt{0.02 \frac{P[\text{mbar}]}{T[K]}}[\text{eV}/c^2]$$



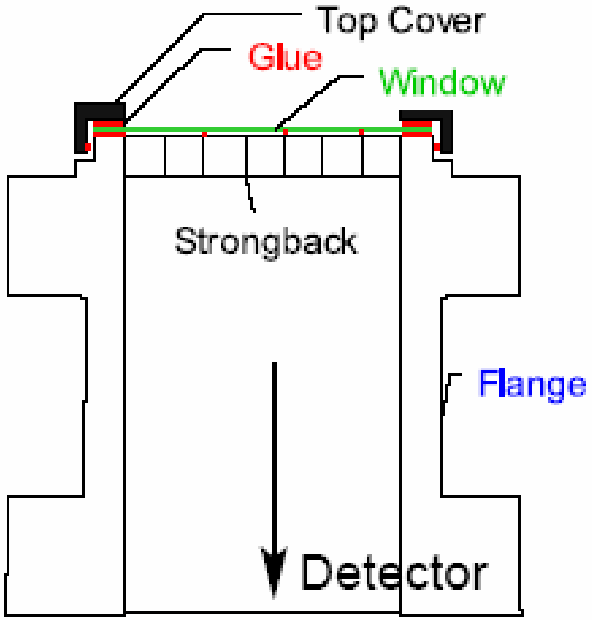
Systematically change pressure $\Longrightarrow$ scan mass range $m_a > 0.02\,\text{eV}/c^2$

- ^{4}He: $\approx$ 74 pressure steps $0 \leq p \leq 6\,\text{mbar}$, $m_a \leq 0.26\,\text{eV}/c^2$
- ^{3}He: $\approx$ 590 pressure steps $6 < p \leq 60\,\text{mbar}$, $m_a \leq 0.8\,\text{eV}/c^2$

$\Longrightarrow$ Allows to scan axion masses $0.02\,\text{eV}/c^2 \leq m_a \leq 0.8\,\text{eV}/c^2$

Cold Windows R&D – Saclay – CERN – Freiburg

Prototype Cold Window 2005

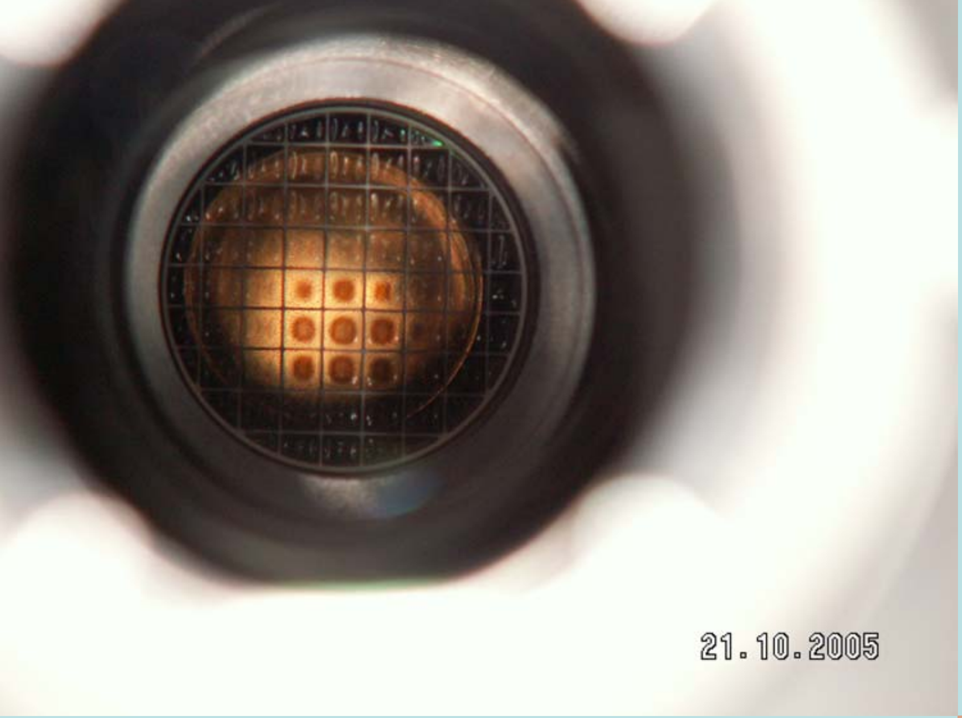


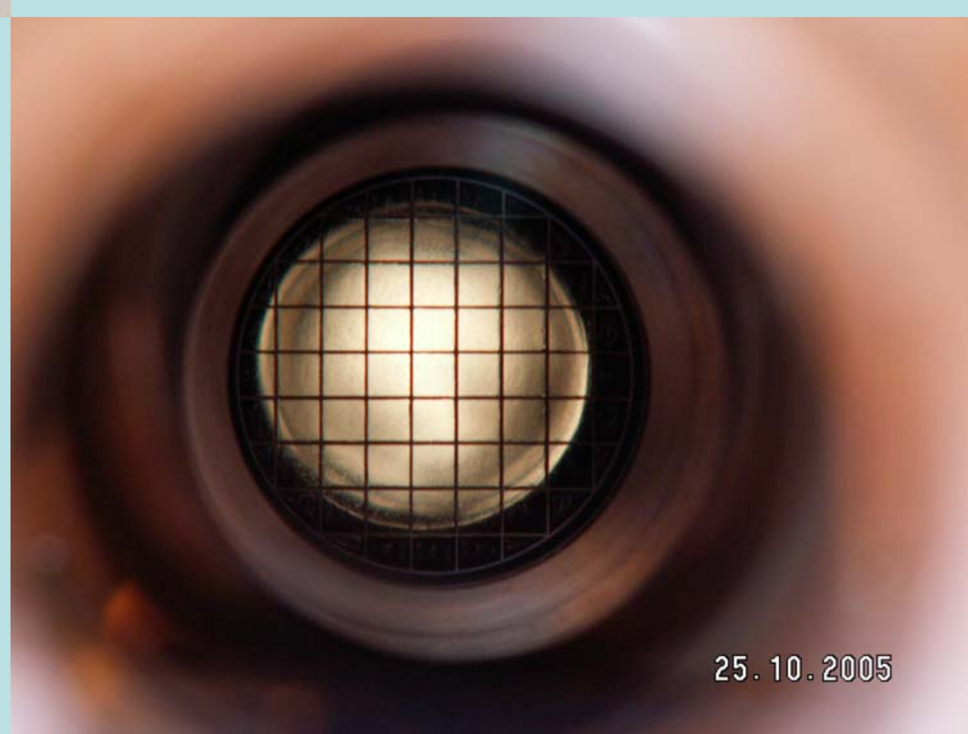
Technical Requirements

- High transmissivity at 1–7 keV
- Minimizing He leak rate $q_{^4\mathrm{He}} < 10^{-8}$ mbar l/s at 1.8 K
- Transparent in the optical $\Longrightarrow$ alignment of the telescope
- Withstand pressure differences during a "Quench" ($\approx$ 1 bar)
- Robust under normal operating conditions

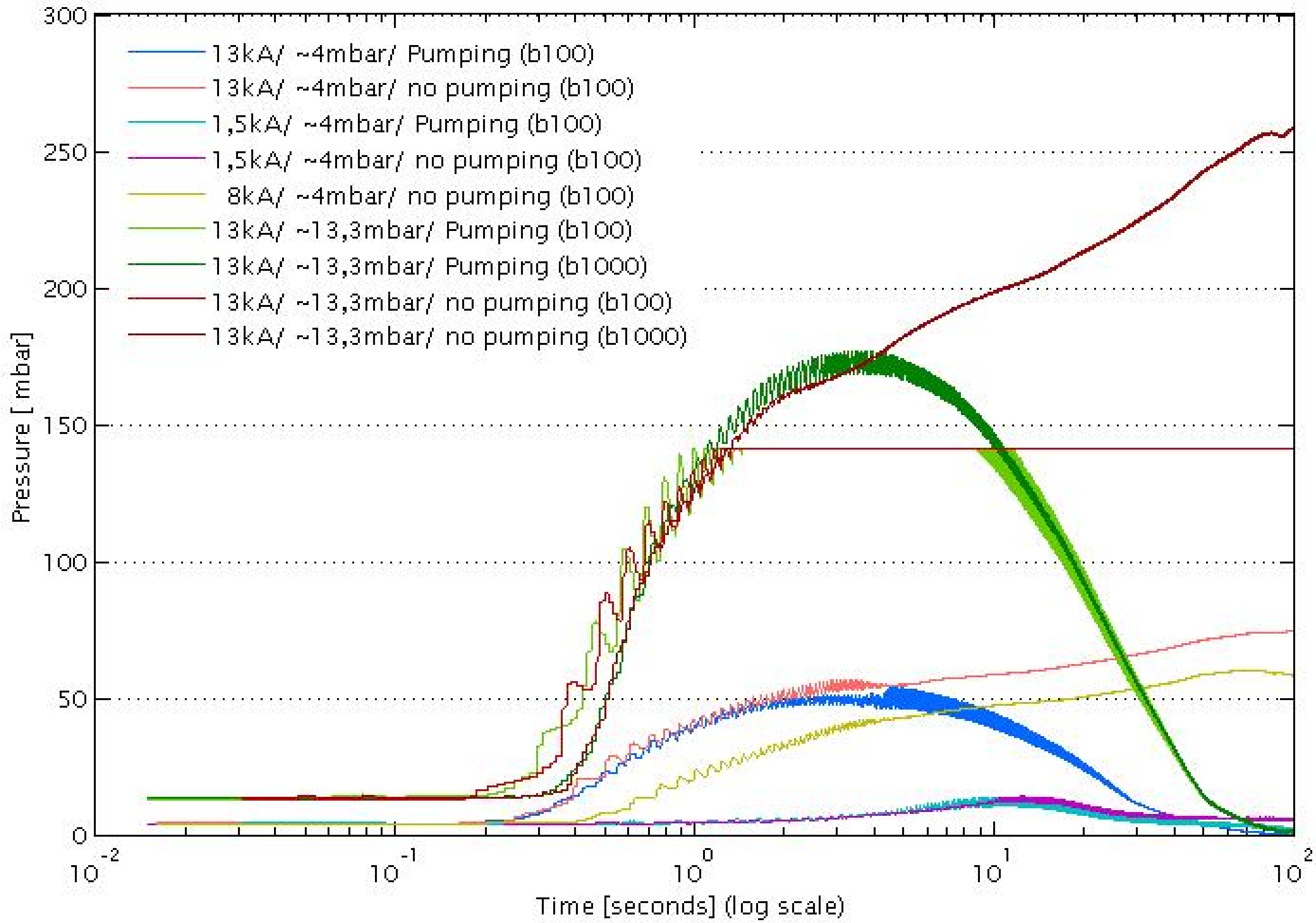
Technical requirements constrain the design of the window and the selection of the material.

Thin windows @ 1.8K

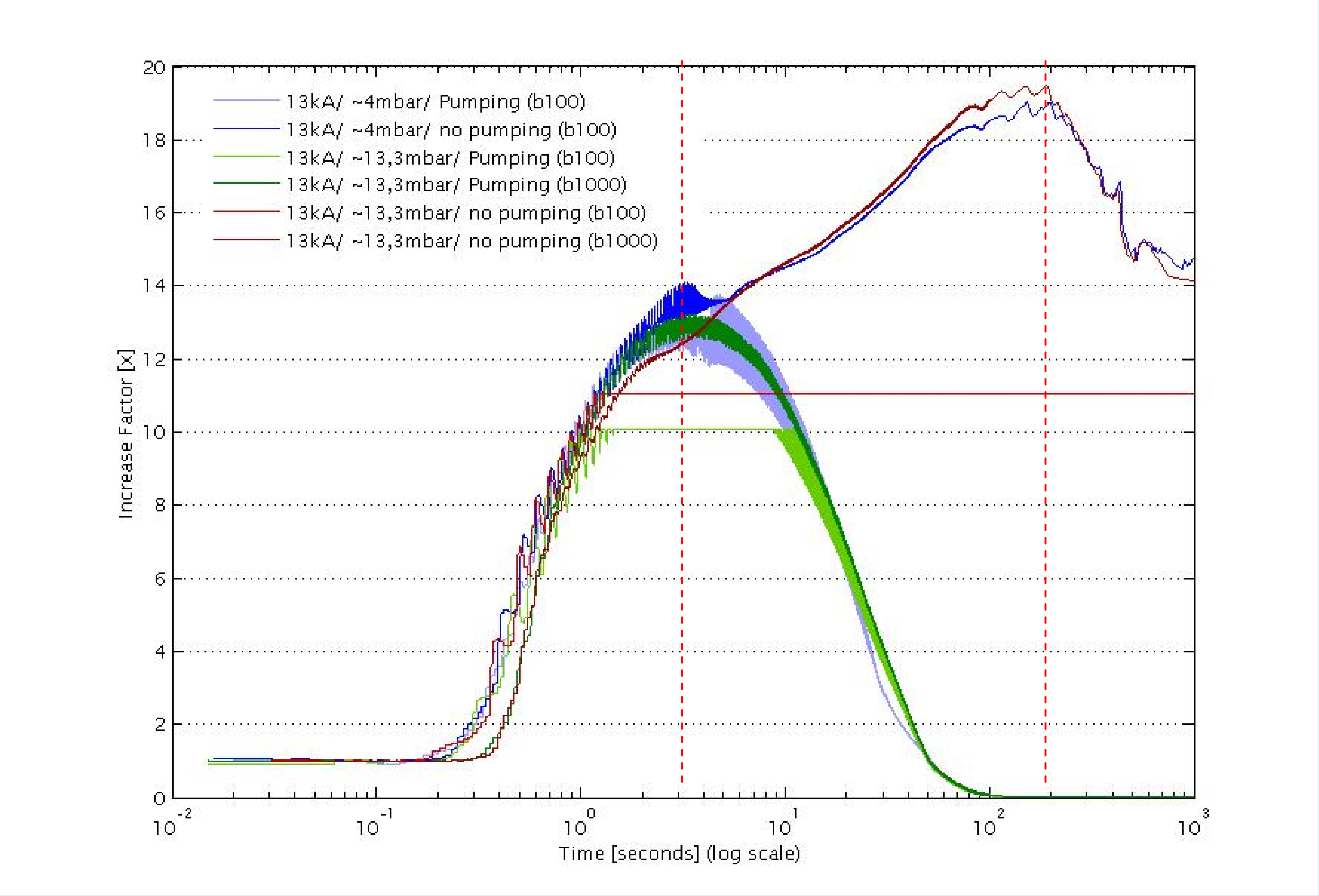




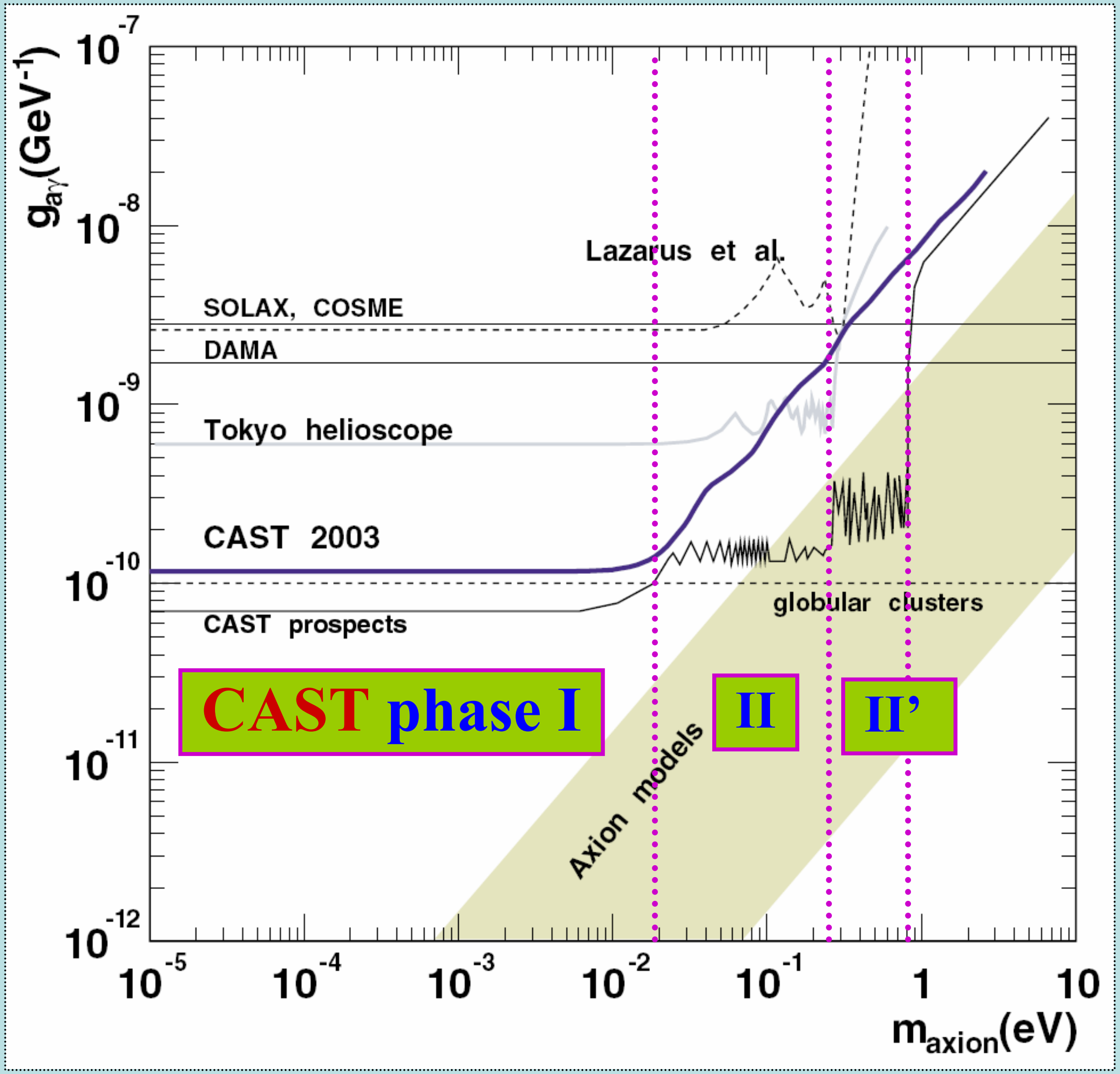
Quench – Pressure Evolution



Quench – Pressure/Temperature



- Fast Increase - ~13x, in about 3 seconds,
- Maximum increase < 20x, in about 200 seconds.

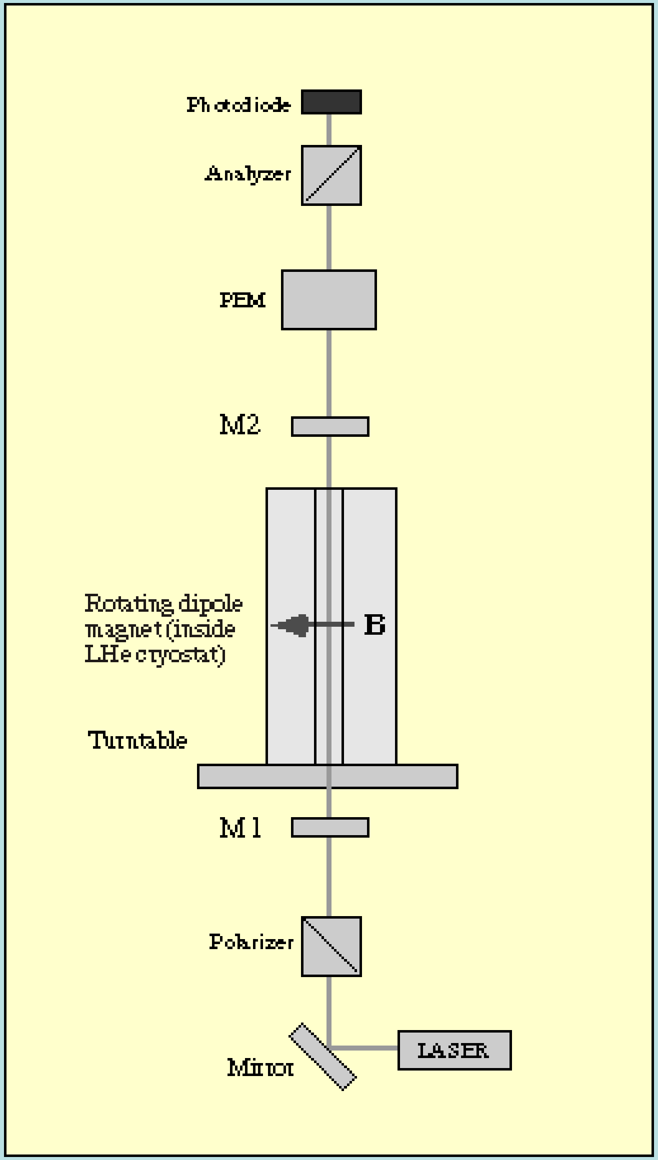


2005 ~ 100 pressure settings ^{4}He (0 – 6mbar)

2006/7 ~ 700 for ^{3}He (6-60 mbar)

Other experiments ?

PVLAS-experiment



M1 & M2

→ very high reflectivity dielectric mirrors

→ Fabry-Perot optical resonator

→ 1 msec

LASER

→ linearly polarized light

→ elliptical polarized

Magnet : http://www.ts.infn.it/experiments/pvlas/magnet/pict-magnet/cryogen.jpg

Optical production & detection of dark matter candidates

F.Brandi etal., *N.I.M.**A**461(**2001**) 329*

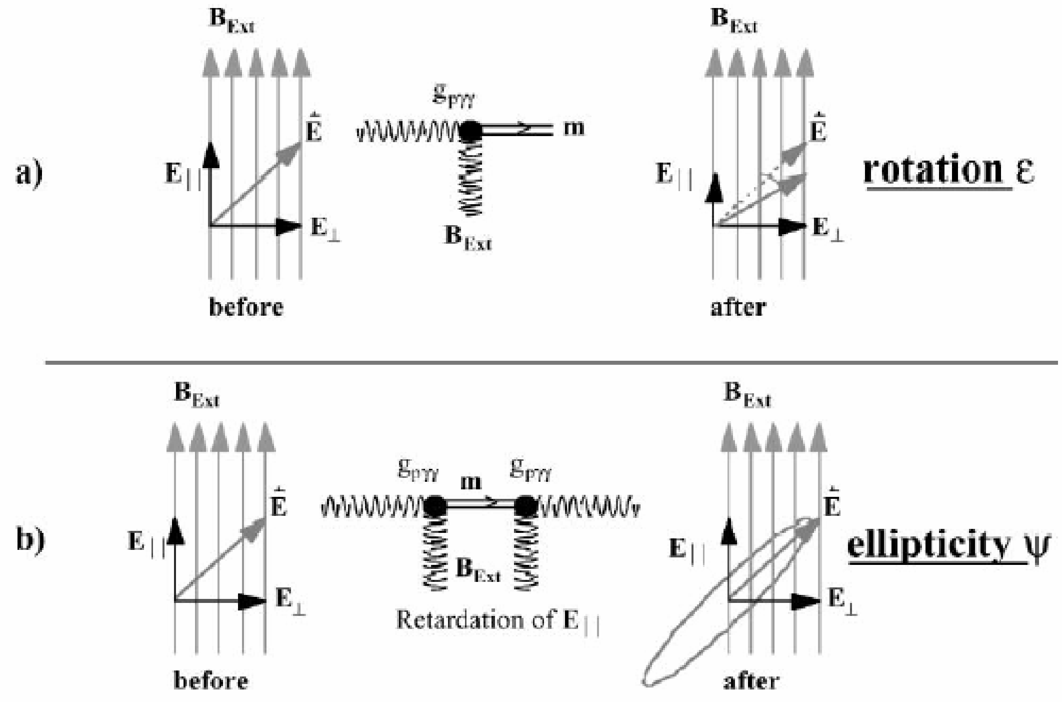
Previous works:

K.Van Bibber etal., PRL59(1987)759

Y.Semertzidis etal., PRL64(1990)2988

G.Ruoso etal., Z.Phys. C56(1992)505

R.Cameron etal., PRD47(1993)3707



a) *Dichroism* induced by the production of a massive particle coupling to two photons ➔ ***rotation of the polarization plane.***

b) *Ellipticity* induced by the ***retardation*** between the two components of the electric field of the laser beam by the virtual production of a massive particle coupling to two photons.

B rotates normal to the light propagation direction

➔ ***a time-modulation of the effect*****.**

X ← **PVLAS** → e.g. KK-axions

≠ PQ axions

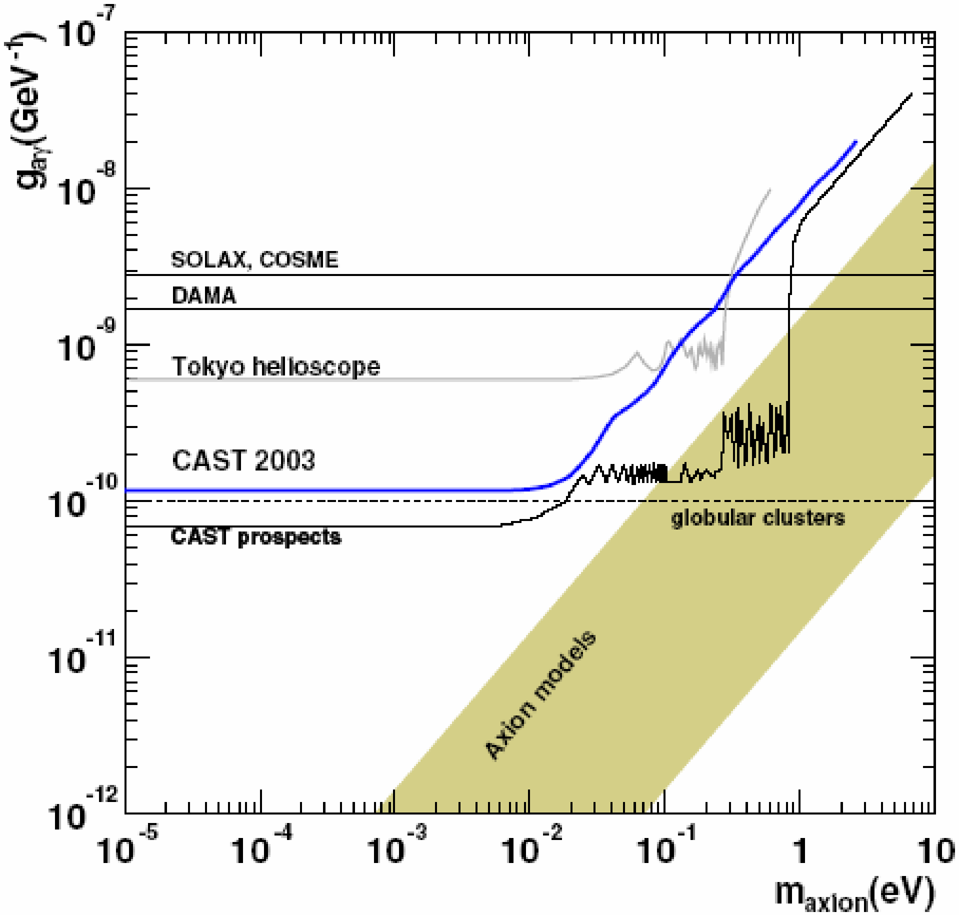
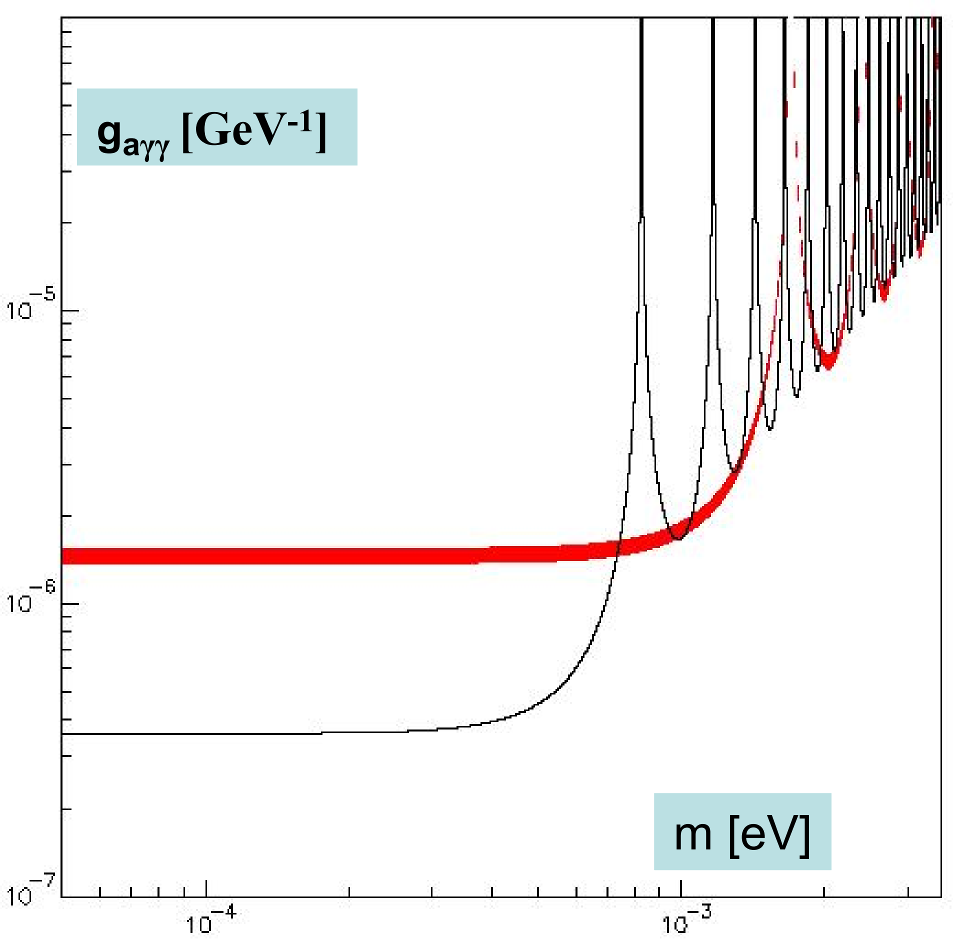


FIG. 2: Exclusion limit (95% CL) from the CAST 2003 data compared with other constraints discussed in the introduction. The shaded band represents typical theoretical models. Also shown is the future CAST sensitivity as foreseen in the experiment proposal.



PVLAS PRL (hep-ex/0507107)
Cameron et al., PLD47 (1993) 3707

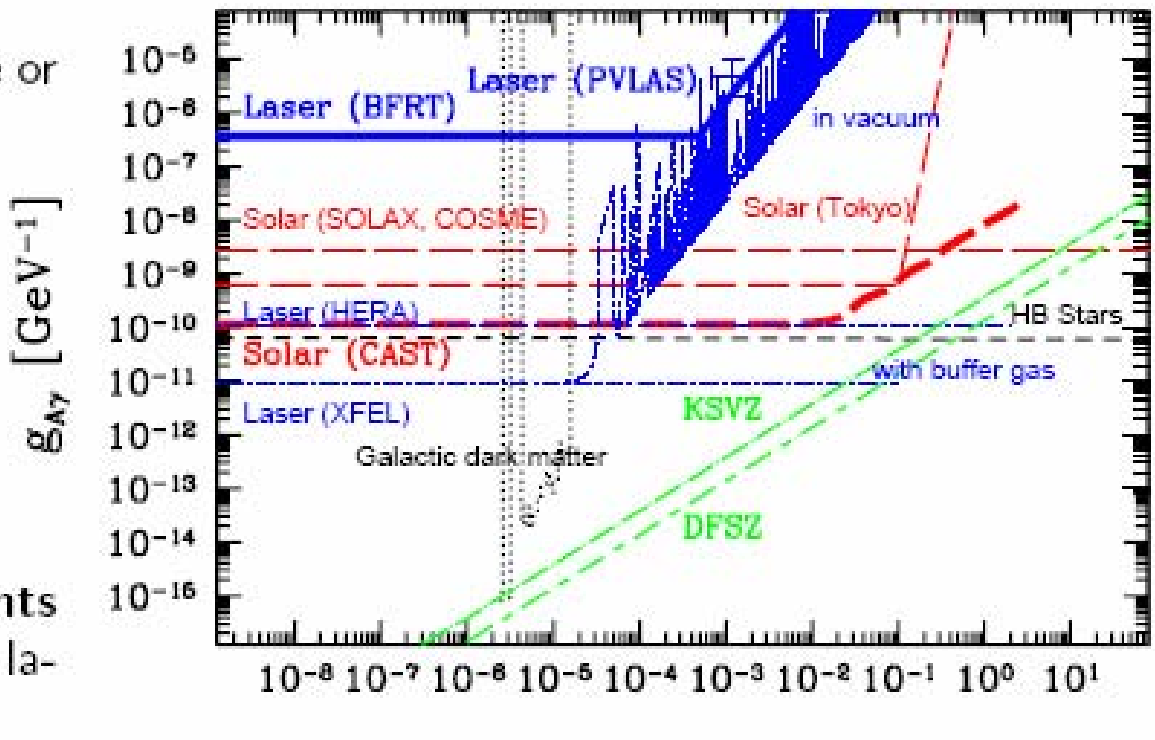
1.165 eV for PVLAS,
2.412 eV for Cameron et al.

Thanks Luigi Di Lella

- **Experimental results:**

Strongest bounds:
Production in **early universe** or in **astrophysical sources**; detection in laboratory:

- Search for **dark matter**
  - Microwave cavity experiments: RBF, UF, ADMX, CARRACK
- Search for **solar axions**
  - Germanium: SOLAX, COSME
  - Magnetic: Tokyo helioscope, CAST



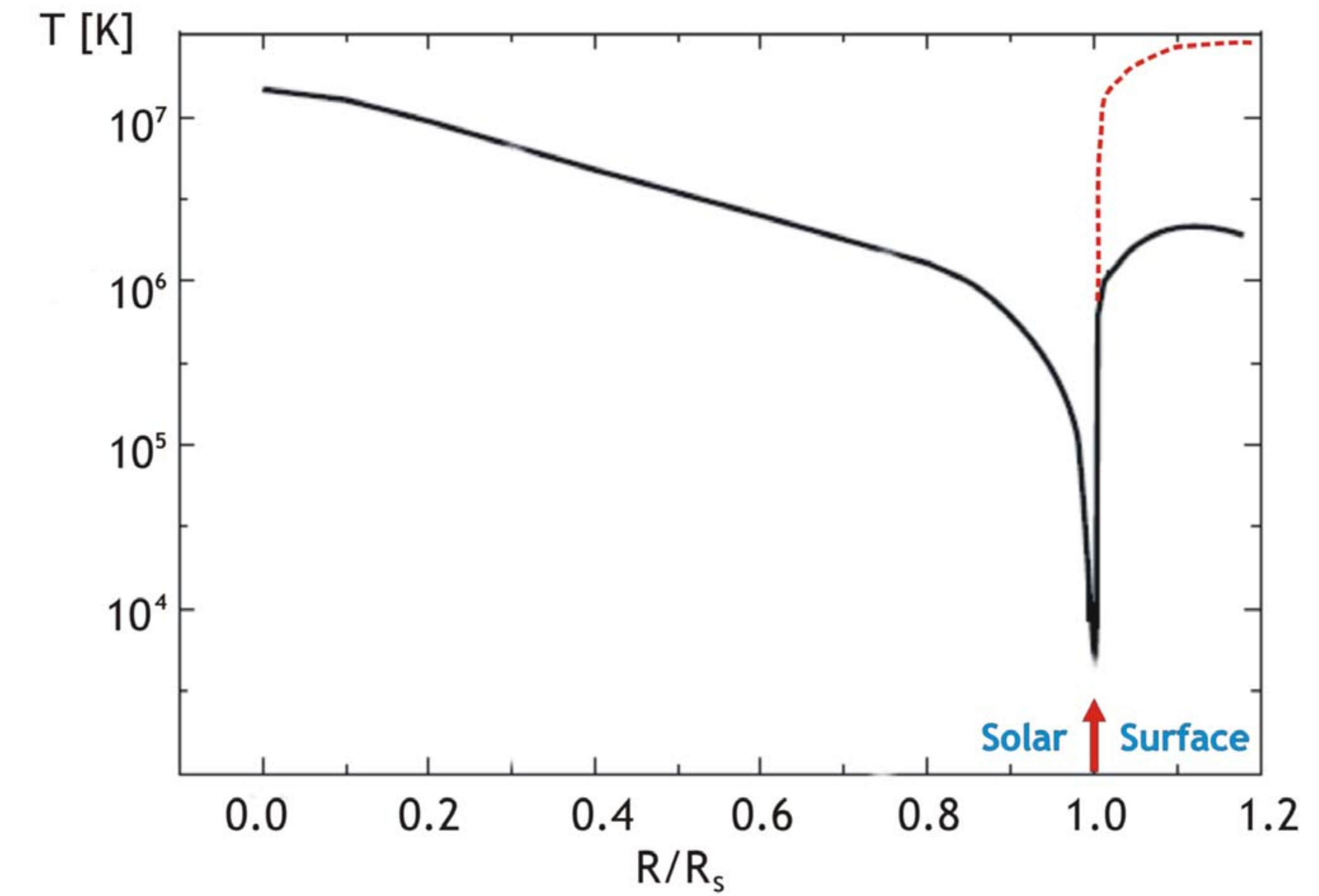
Much less sensitivity:
Pure laboratory experiments (detection **and** production in laboratory):

mimic CAST ?

$\Downarrow$

indirect axion-signal ?

Solar temperature distribution



↛ **2nd Law of Thermodynamics?** ➔ **solar corona problem**

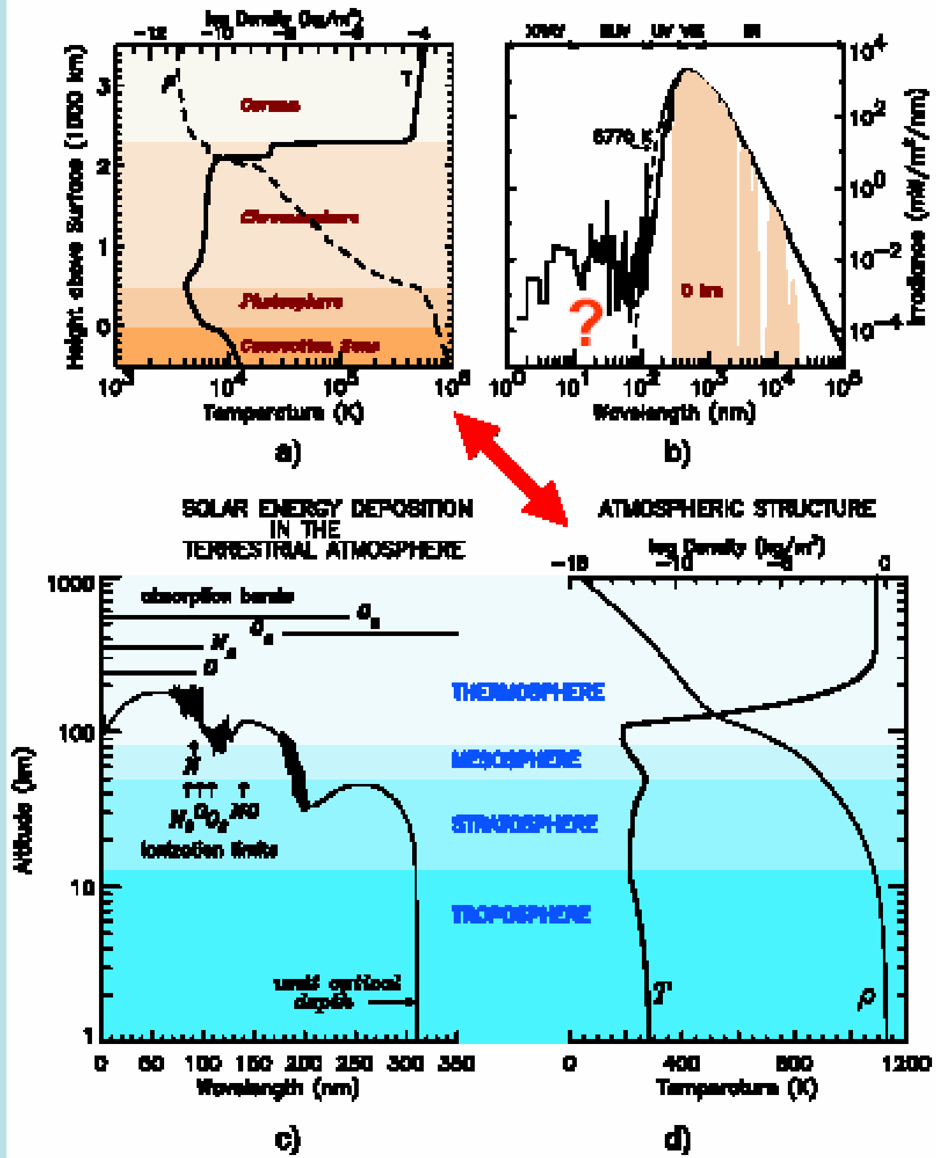
Grotrian (**1939**)

➔ ***The enigma of coronal heating represents one of the most challenging problems in astrophysics at the present time.***

E. R. Priest, D. W. Longcope, J. Heyvaerts, ApJ. 624 (**2005**) 1057

↷ 2nd Law of Thermodynamics ➔

Heat transfer → hotter-to-cooler

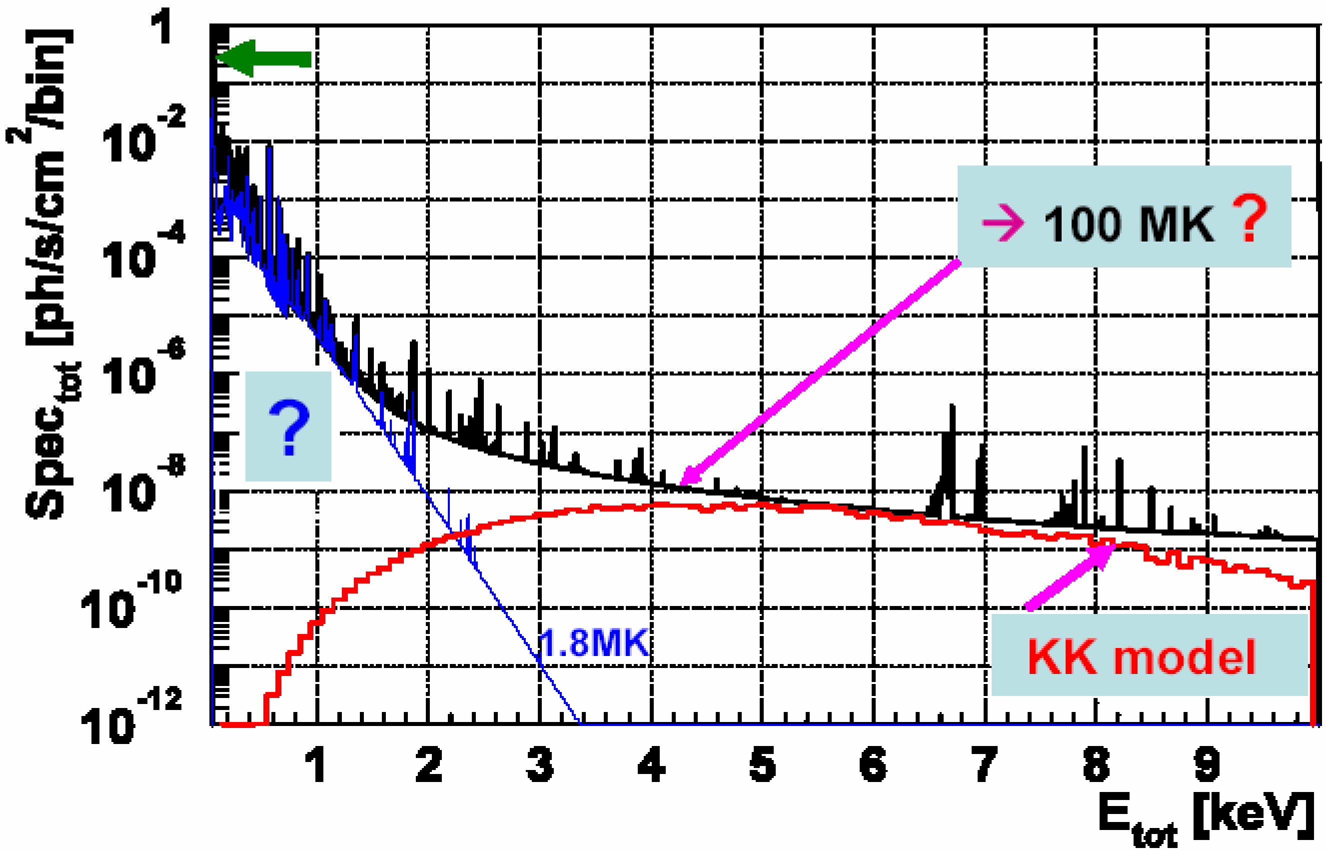


<u>**Suggestion:**</u>

➔ solar X-ray
self-irradiation

L. DiLella, K. Z. Astropart. Phys. 19 (2003) 145

Observational evidence for gravitationally trapped massive axion(-like) particles



KK-*axions*

↓

generic

↓

$g_{a\gamma\gamma} \sim 9 \cdot 10^{-14} GeV^{-1}$

$\overline{T}_{flare} < 20MK$

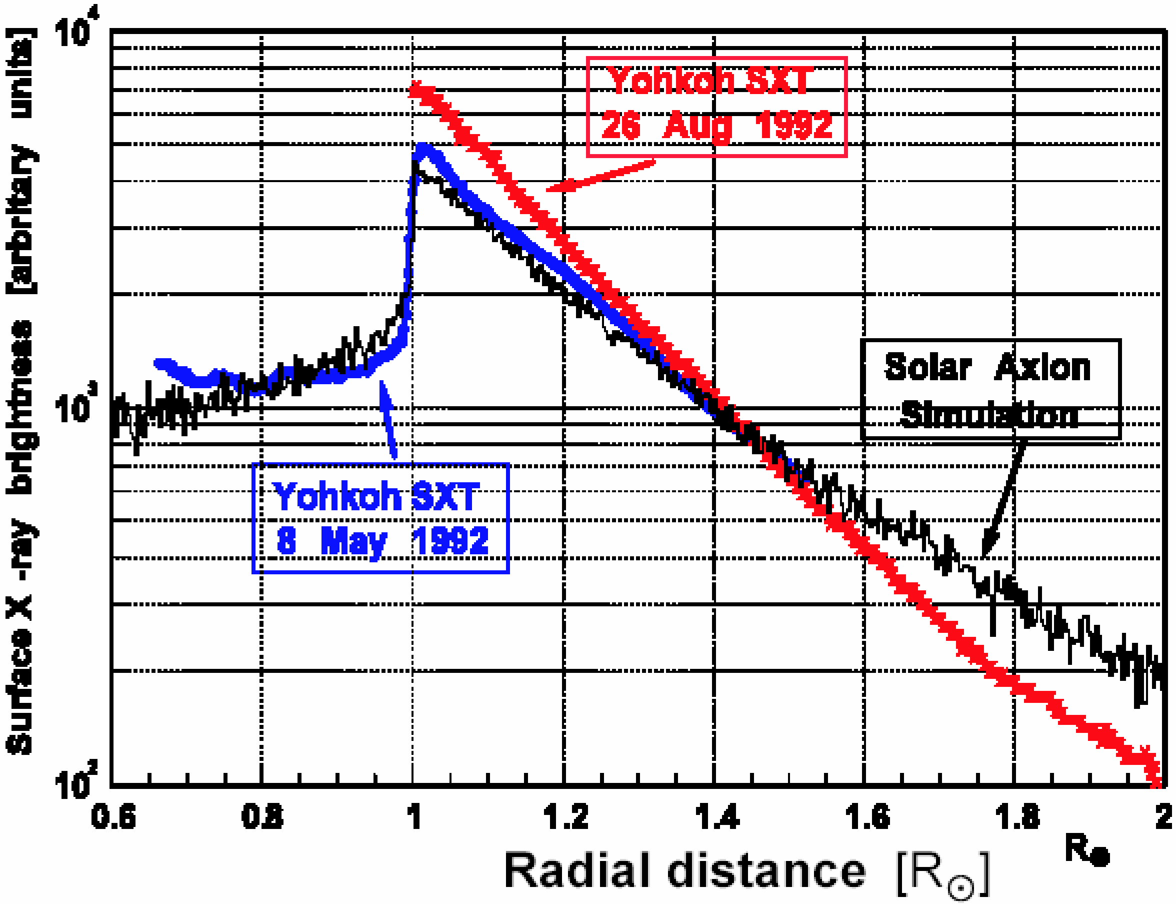
Reconstructed X-ray spectrum

→ ***non-flaring Sun @ solar minimum*** [X].

[X] G. Peres, S. Orlando, F. Reale, R. Rosner, H. Hudson, ApJ. 528 (2000) 537

L. DiLella, K. Z., Astropart. Phys. 19 (**2003**) 145

Quiet Sun X-rays as Signature for New Particles



Soft X-ray surface brightness from the quiet Sun.

Simulation with trapped solar KK-axions ⇒ $g_{a\gamma\gamma} < 40 \cdot 10^{-14} GeV^{-1}$.

26 August: off-pointing
(JL Culhane, Adv. Space Res. 19 (1997) 1839)

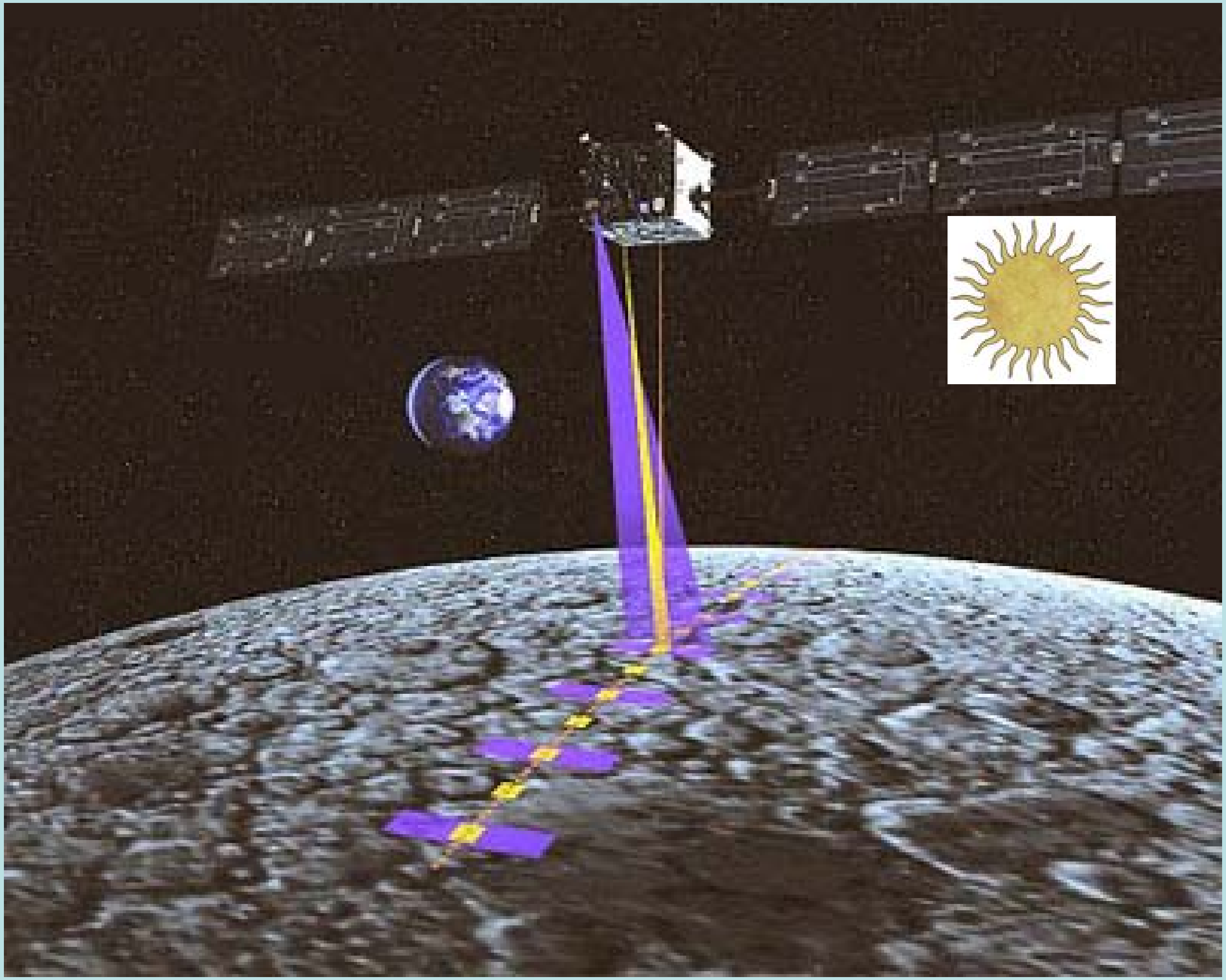
- **Diffuse emission.**
- **Hydrostatic equilibrium doesn't fit observations**
- **closed loops of increasing height … cannot reproduce the observed behaviour of T & ρ @ diffuse structure.**
- **AR emission … no strong correlation with T_{plasma} ➔** **This suggests that the natur of coronal heating mechanis does not change through the cycle.**

. . . .

- **Soft X-Ray Emission has been detected from a north polar coronal hole.**
  (see Foley, Culhane, Acton ApJ. 491 (1997) 933

Z., Dennerl, DiLella, Hoffmann, Jacoby, Papaevangelou, ApJ. 607 (**2004**) 575

SMART: ***orbiting X-ray detectors*** → ***dark*** **moon** → **large volume + backgr.**
→ **Sun**



collaboration with
Observatory UH-FI
RAL-UK

Search for ***massive ~axions*** → spontaneous radiative decays **a** $\rightarrow \gamma\gamma$

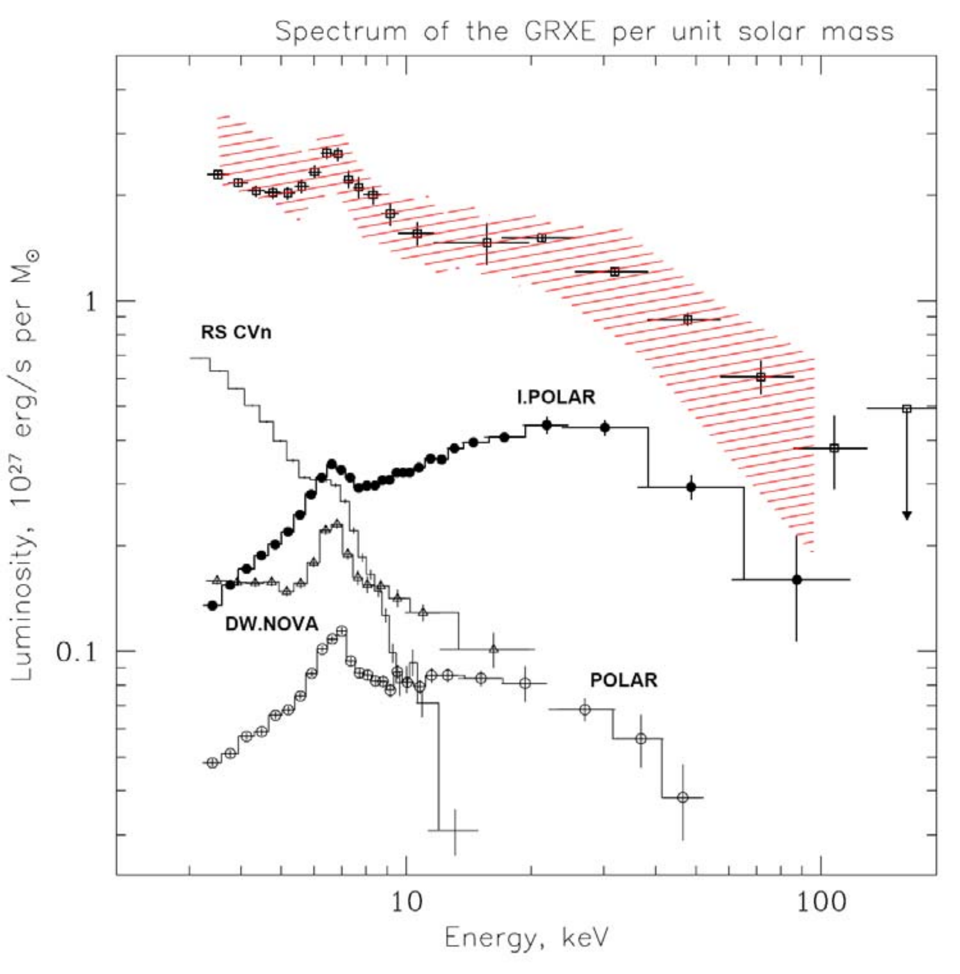
RHESSI Major Events

***************************2005***************************

October 18, 09:00 UT RHESSI was again put into drift mode to view the x-ray emission of the quiet Sun "out of the corner of its eye". This mode began at the time noted above. RHESSI was commanded back to the Sun at 06:10 UT on **October 28**, and arrived shortly after 08:00 UT on that day. The Sun was very quiet during this time, but anyone wishing to analyze data within that interval should contact the instrument team. ➔ **10 days**

July 19, 06:00 UT At this time, RHESSI was put in a new mode that let it drift up to 1 degree away from the Sun and slewed back, repeatedly. ***The purpose of this mode was to study the x-ray emission of the quiet Sun*** (the Sun was extremely quiet beginning at this time). RHESSI returned to normal operations at around 04:00 UT on **July 26**. If you wish to analyze any flares during this week, please contact the instrument team. ➔ **7 days**

Origin of the GRXE ➔ *(un)explained ?*



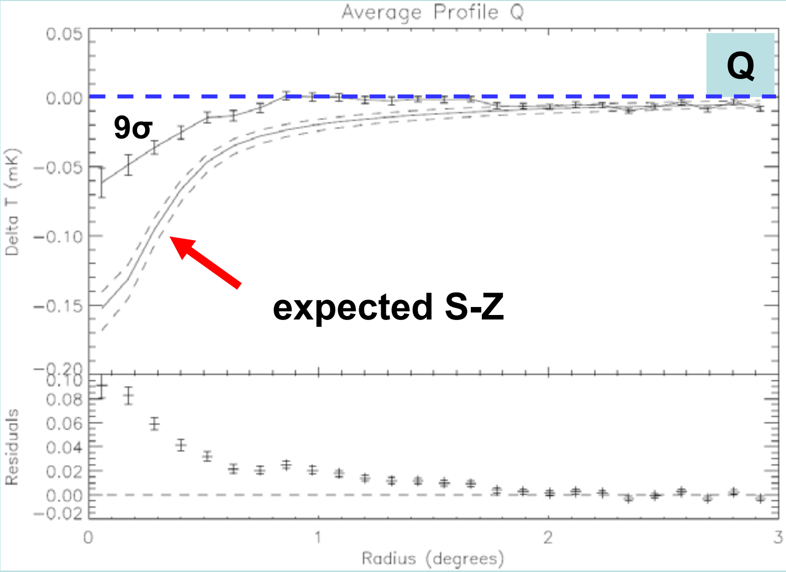
GRXE broad-band spectrum (squares) and spectra of its main contributors divided by 2 for clarity. The data points in the 3–20 keV band (RXTE/PCA) were converted to unit-stellar-mass emissivity. The data points in the 20–100 keV band show the spectrum of the Galactic Center source IGR J17456−2901 measured by INTEGRAL divided by the estimated total mass in stars (~$10^8 M_{solar}$) contained in the nuclear region (~30 pc around Sgr A∗). The INTEGRAL spectrum was additionally multipled by a factor 0.6 to match the RXTE/PCA spectrum near 20 keV. Also shown are typical spectra of X-ray source classes expected to significantly contribute to the GRXE: intermediate polars (filled circles), polars (open circles), dwarf novae (SU UMa, triangles), and coronally active binaries. These spectra are plotted with normalizations corresponding to their expected relative contributions to the GRXE divided by 2. The individual source spectra were obtained by the instruments PCA (3–20 keV) and HEXTE (20–100 keV) aboard RXTE.

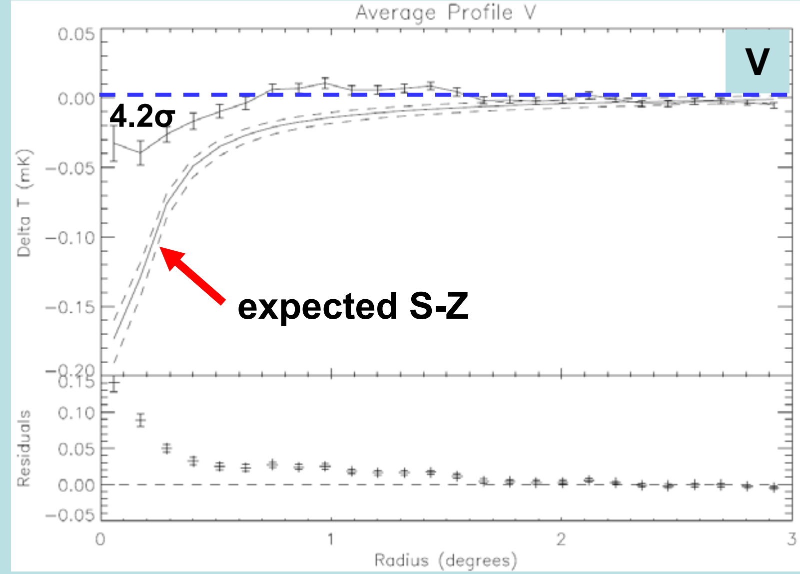
➔ **The *shaded region* shows a sum of these spectra reflecting uncertainties in the individual spectra and their relative weights.**

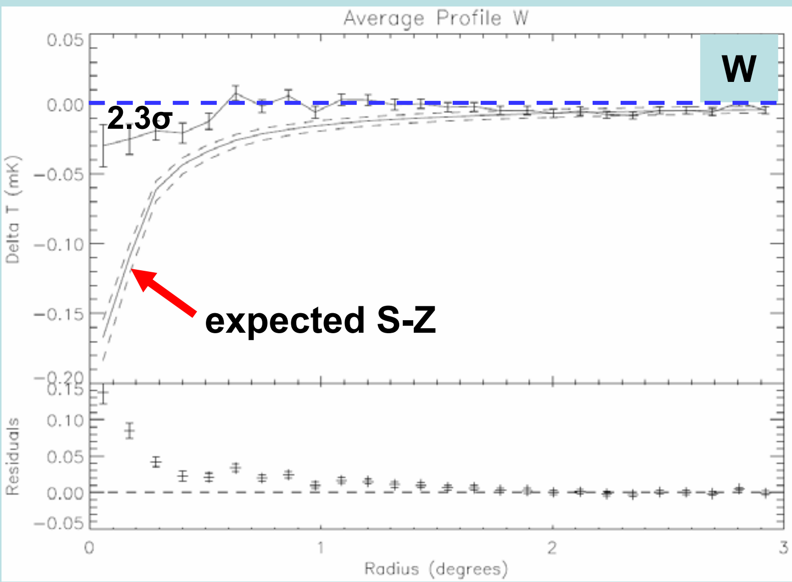
Mean 3-20 keV X-ray luminosity per M_{solar}

≈ (3.5±0.5) 10^{27}erg/s ≈ x$10^5 L_{x,solar}$

M. Revnivtsev, S. Sazonov, M. Gilfanov, E. Churazov, R. Sunyaev
astro-ph/200510050 ➔ A.&A.





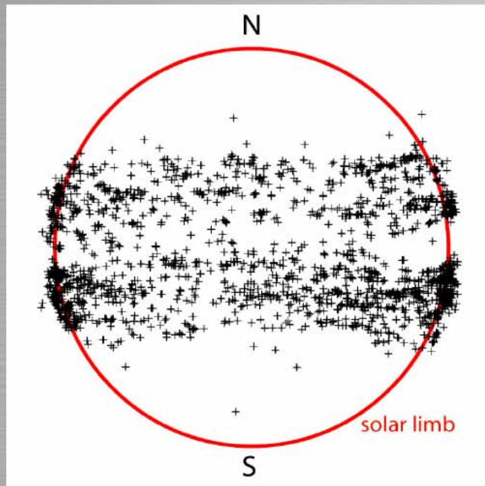


X-rays observ. → Hot gas properties
31 co-added **WMAP** cluster fields →
expected S-Z effect 4x bigger → **less e^-**
→ Radiative decay of massive particles,
→ e.g. axions of the KK-type
→ to reconcile contradiction

R. Lieu, J.P.D. Mittaz, M. Bonamente, S-N.Zhang,
astro-ph/**2005**10160

The average **WMAP** observed and predicted radial profile for the 31 clusters. The continuum of the prediction curve is fixed by alignment with the 2°-3° data, which is at a level higher than that of the central 1° data points by 9σ (Q), 4.2σ (V), and 2.3σ (W).

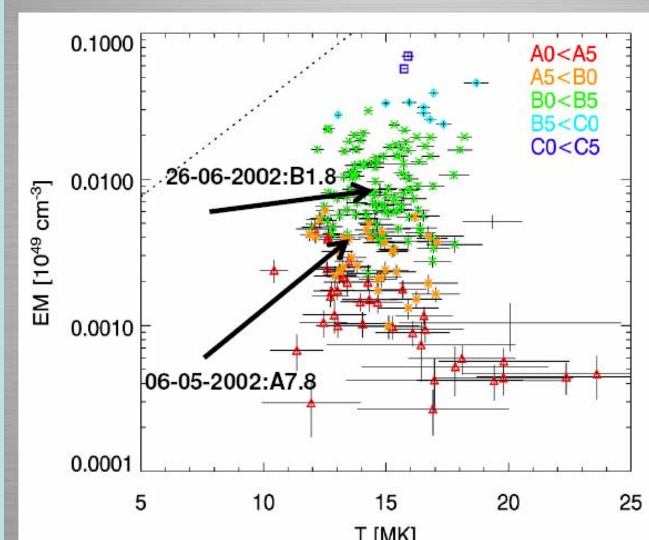
RHESSI Microflares



Rauscher et al.

- These are small flares (A-C Class), occurring in active regions
  - coronal acceleration (reconnection?)
  - heated & accelerated electrons
  - then bremsstrahlung out.
- RHESSI provides the x-ray spectrum and image of these events
  - times of shutter out and no decimation (quiet times) get about 2.5 flares per hour

T vs EM at Peak Time



Emission Measure vs Temperature at the time of peak i 3-6 keV for 199 flares.

Colour coded by background subtracted GOES class

Dotted line from Feldman et al [1996]: Average BCS T vs EM from BCS, GOES (1-8)Å and (0.5-4)Å

No clear correlation

All T >10 MK

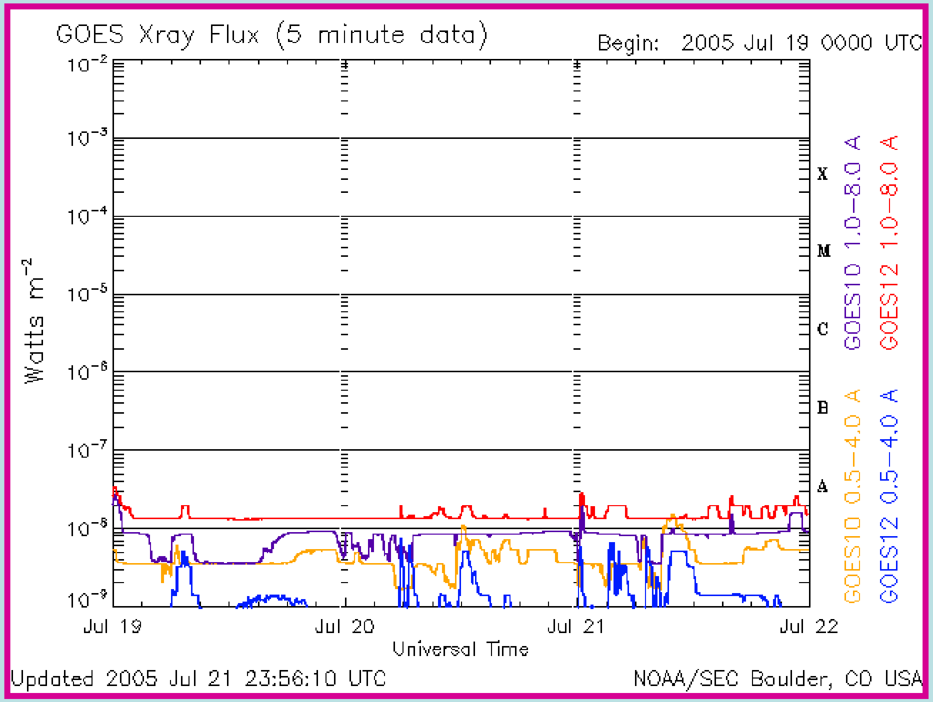
RHESSI sees higher T or lower EM

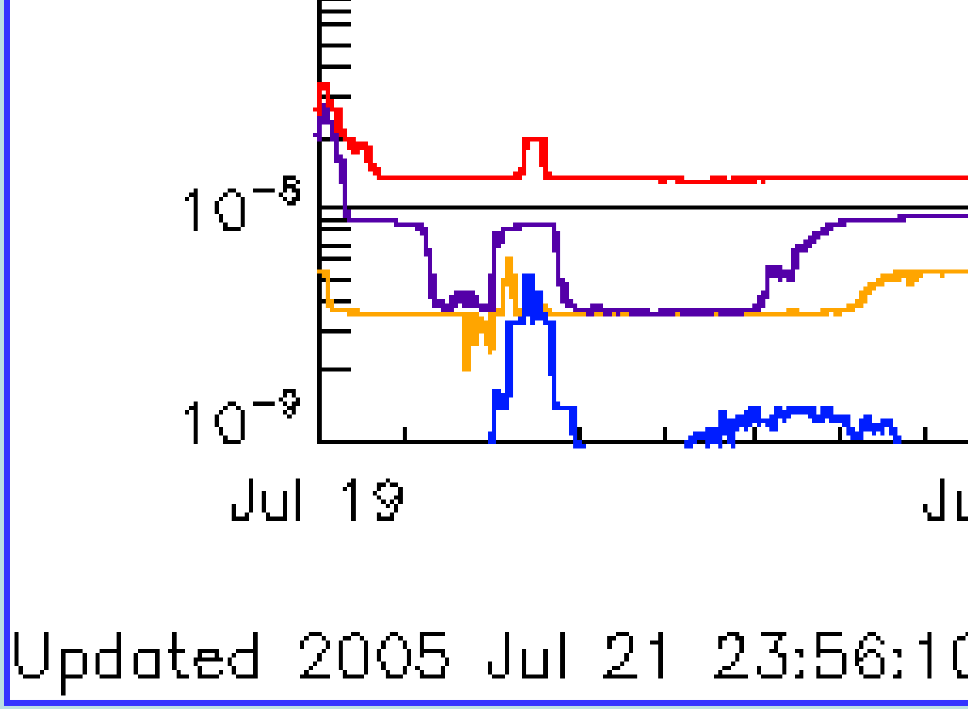
μflares are small flares that occur in active regions.

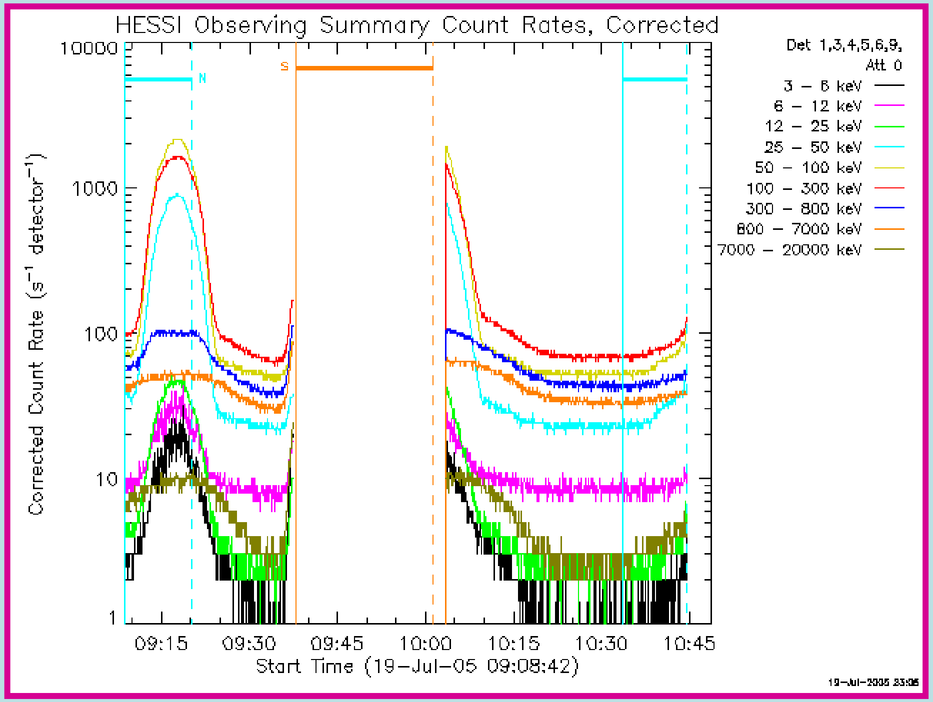
They are hot (>10 MK) with presence of Fe K Complex
Difficult to interpret thermal vs non-thermal spectrum or super-hot component.
Possibly a lot of energy in the non-thermal electrons.

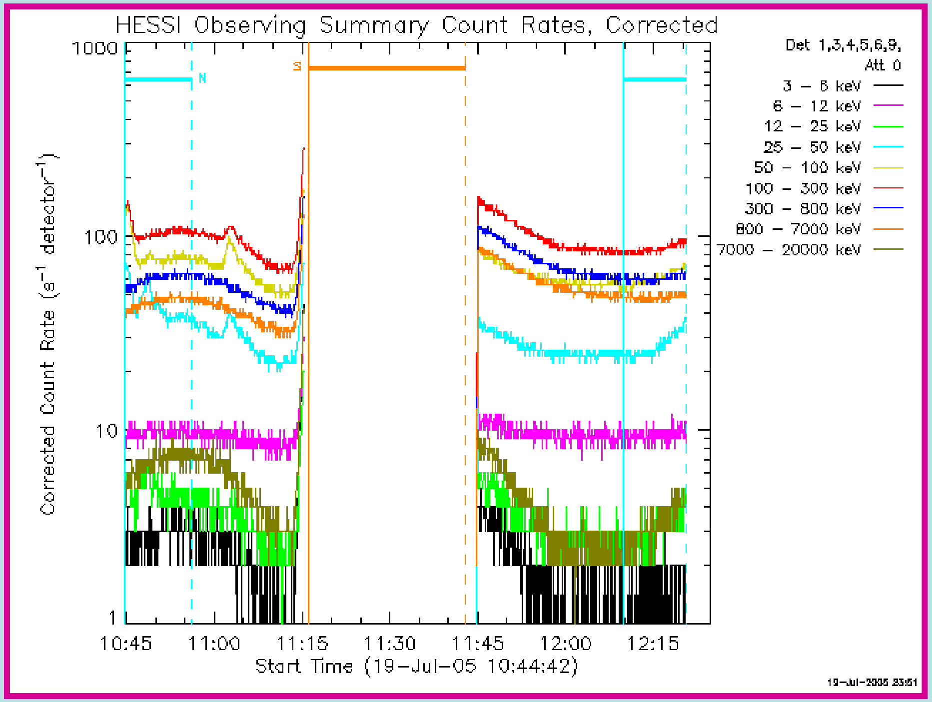
Sept. **2004**

http://www.soho15.org/PDF/hannah.pdf


GOES Xray Flux (5 minute data)
Begin: 2005 Jul 19 0000 UTC
Watts m⁻²
X
M
C
B
A
GOES10 1.0−8.0 A
GOES12 1.0−8.0 A
GOES10 0.5−4.0 A
GOES12 0.5−4.0 A
Jul 19
Jul 20
Jul 21
Jul 22
Universal Time
Updated 2005 Jul 21 23:56:10 UTC
NOAA/SEC Boulder, CO USA


Jul 19
Updated 2005 Jul 21 23:56:1


HESSI Observing Summary Count Rates, Corrected
Det 1,3,4,5,6,9, Att 0
3 − 6 keV
6 − 12 keV
12 − 25 keV
25 − 50 keV
50 − 100 keV
100 − 300 keV
300 − 800 keV
800 − 7000 keV
7000 − 20000 keV
Corrected Count Rate (s⁻¹ detector⁻¹)
09:15
09:30
09:45
10:00
10:15
10:30
10:45
Start Time (19−Jul−05 09:08:42)


HESSI Observing Summary Count Rates, Corrected
Det 1,3,4,5,6,9, Att 0
3 − 6 keV
6 − 12 keV
12 − 25 keV
25 − 50 keV
50 − 100 keV
100 − 300 keV
300 − 800 keV
800 − 7000 keV
7000 − 20000 keV
Corrected Count Rate (s⁻¹ detector⁻¹)
10:45
11:00
11:15
11:30
11:45
12:00
12:15
Start Time (19−Jul−05 10:44:42)

CAST @ Sun ?

P. Sikivie [1983]

→ 2nd component

$$a + \gamma_B \rightarrow \gamma$$

$$I_x \sim B^2$$

→ *low energy solar spectrum + transient phenomena*

➔ **magnetic fields** of ***several* kG *in sunspots***

➔ probably **~10 T** in the tachocline (-200000 km)

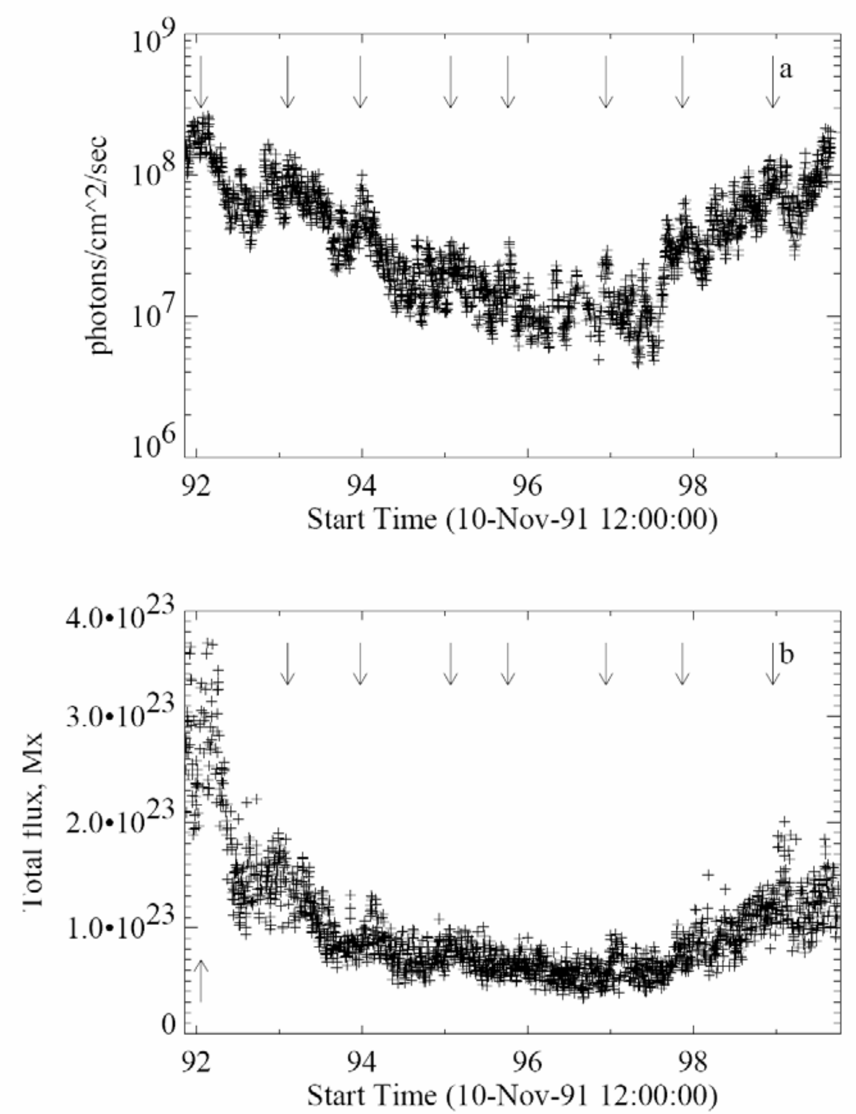
M. Aschwanden, *Physics of the Solar Corona* (**2004**) p.175

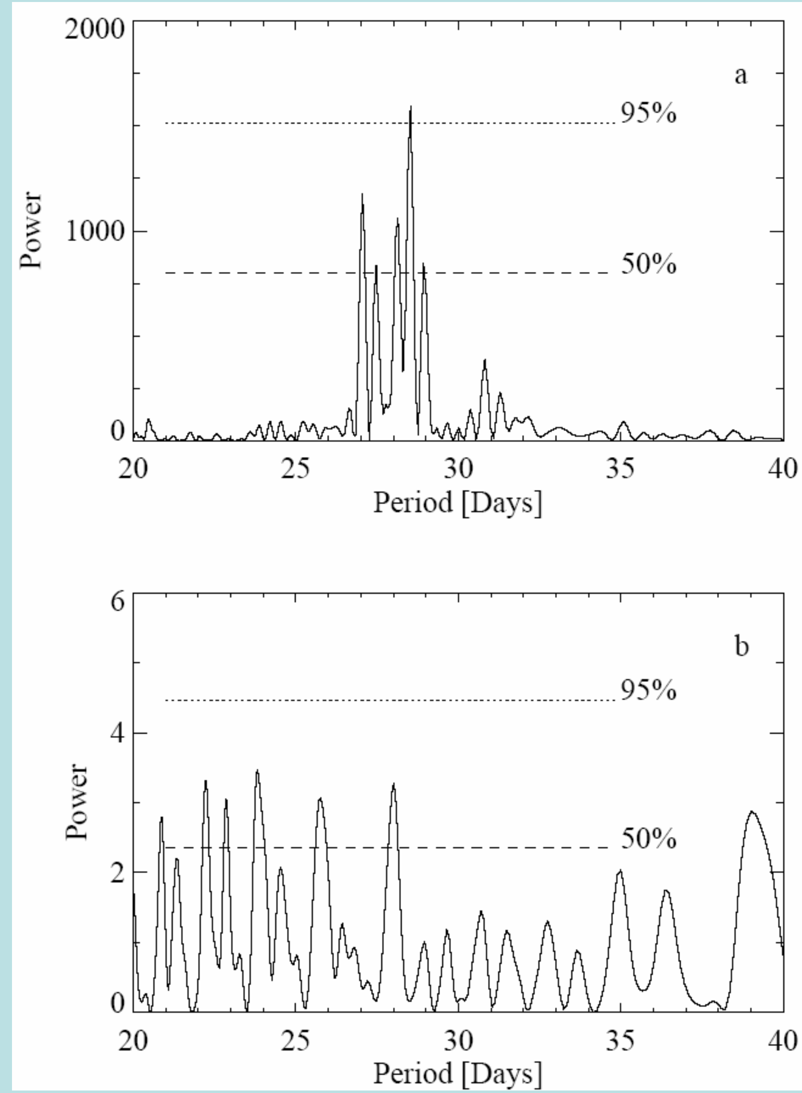
➔ X-rays: $\gamma \rightleftarrows$ **axion**

It is believed that much, if not all, of the magnetic flux penetrating the **photosphere** is aggregated in 200-300 km Ø, in which the field strength is of order **1.5 kGauss** (~2% of the surface).

P.A. Sturrock, ApJ. 521 (**1999**) 451
J. Sanchez Almeida A.& A. (**2005**) in press, astro-ph/0504339

➔ **Visible light:** $L_{vis} \rightleftarrows L_{axion}$





(a) Soft X-ray irradiance, (b) <magnetic Flux> over the *quiet Sun*. Arrows: activity episodes in X-rays.

➔ $L_x \otimes B$

Lomb-normalized periodograms of (a) X-ray irradiance and (b) magnetic Flux for *quiet-Sun* area at S50W00 ➔ *similar @ disk center*

QUIET SUN 1992-96 @ disk center ➔ $L_x \propto B^{2.4}$

At ±50°N exponent >4 **!** ➔ **axions ?**

A.A. Pevtsov, L.W. Acton, ApJ. 554 (**2001**) 416

FLARES

→ **The precise causes of solar flares & CMEs is one of the great solar mysteries** → **2003**

→ ⊗ **B**

→ what initiates the energy release?

→ what makes some magnetic configurations more likely to flare than others?

→ Fundamental question:

how and why ***reconnection*** starts as an explosive process in flares?

→ ***The trigger site of flares is still elusive.***

→ ***Understanding how energy is released in solar flares is a central question in astrophysics*** → **1999**

G. Barnes, D. W. Longcope, K. D. Leka, ApJ. 629 (**2005**) 561

K. Kusano, T. Maeshiro, T. Yokoyama, T. Sakurai, ApJ. 610 (**2004**) 537

G. Allen Gary, L.R. Moore, ApJ. 611 (**2004**) 545

DH Hathaway, http://science.msfc.nasa.gov/ssl/pad/solar/quests.html (**2003**)

Warren, Bookbinder, Forbes, Golub, Hudson, Reeves, Warshall ApJ. 527 (20.12.1999) L121

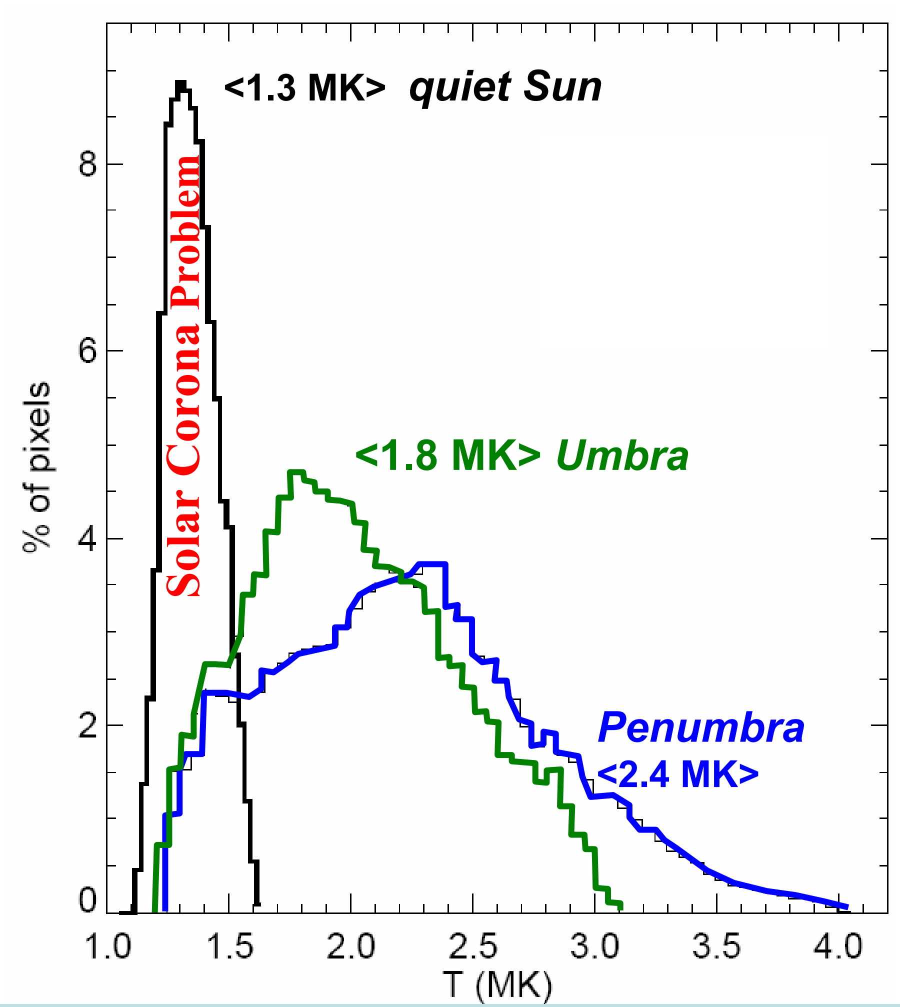
→ **Less magnetic activity = fewer solar X-rays.**

→ The magnetic activity is determined by a magnetic dynamo within the Sun.

http://star-www.st-andrews.ac.uk/~mrt2/XRU2a.pdf

SUNSPOTS

➔ **Yohkoh - XRTelescope**



Temperature distributions

Sunspots = "*dark spots*" → **T** ⇩

➔ **photosphere**
~ 4500K ➔ ***heat flux problem***
in ***umbra + penumbra***

Spruit, Scharmer, A.&A. (2005), astro-ph/0508504

➔ **Corona**

Soft X-ray fluxes **T** ⇧

Sunspots:	~ 50 - 190	DN/s
Quiet Sun:	~ 10 - 50	DN/s
(**AR**s:	~ 500 - 4000	DN/s)

→ ***sunspot plasma parameters are higher than @ quiet-Sun***

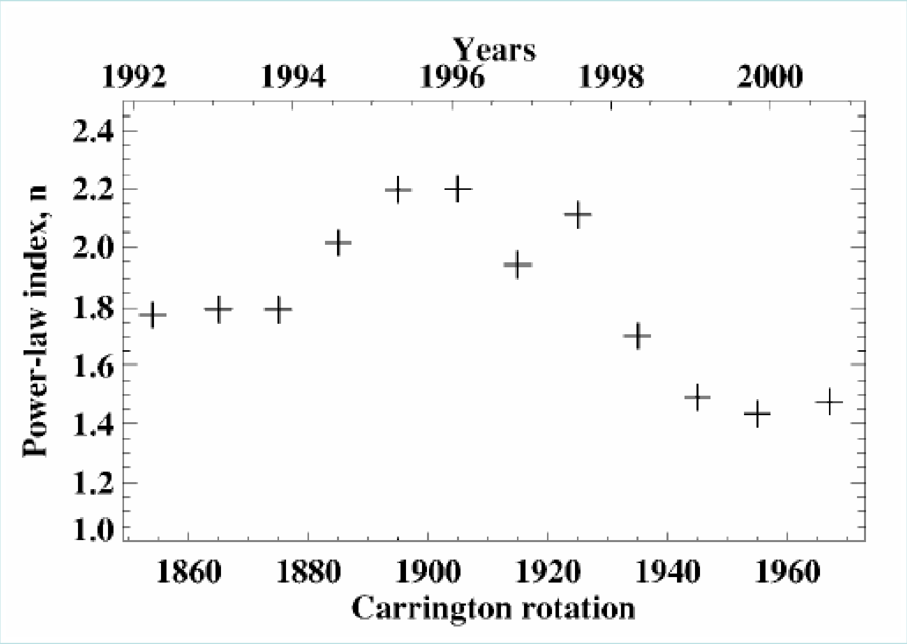
➔ **B ~ 2 kG above most sunspots !**

A.Nindos, M.R.Kundu, S.M.White, K.Shibasaki, N.Gopalswamy, ApJ. SUPPL. 130 (2000) 485

➔ **"… sunspots remain mysterious".**

➔ **The penumbral mystery … the very reason for its existence unknown.**

http://www.solarphysics.kva.se/NatureNov2002/background.html



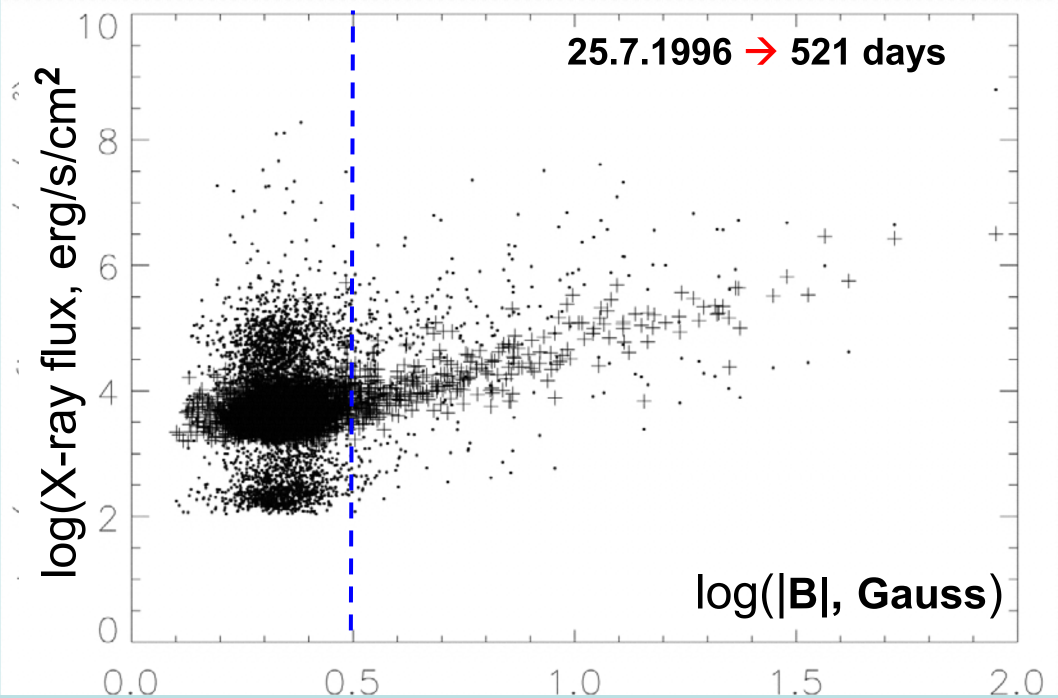
Power-law index **n** of $\mathbf{L_x \sim B^n} = f(\text{time})$ ➔ **YOHKOH** / XRT

The relation between the solar soft X-ray flux (below ~4.4keV) …and B can be approximated by a power law with an averaged index close to 2.

Benevolenskaya, Kosovichev, Lemen, Scherrer, Slater ApJ. 571 (**2002**) L181

Note: **axion-to-photon oscillation** $\propto$ **(LB)**^{2} ➔ e.g., in **CAST**

D.H.H. Hoffmann, K. Z., Nucl. Phys. B Suppl. (**2006**) *in press.*



… essentially NO correlation between the X-ray flux & the average line-of-sight magnetic field <B>.

+ P.A. Sturrock, *Private communication*

→ it resembles **Primakoff effect.**

X-ray flux vs. photospheric magnetic field → quiet + ARs → |**B**| = average field magnitude.

→ **Yohkoh** / XRT

Dots: flux calculation based on a temperature determined from filter ratios.
Crosses: flux calculation based on a fixed temperature of 2 MK.
The correlation between X-ray flux and **B** is higher with fixed-temperature, but the implied power-law index is higher with the filter-ratio temperatures.

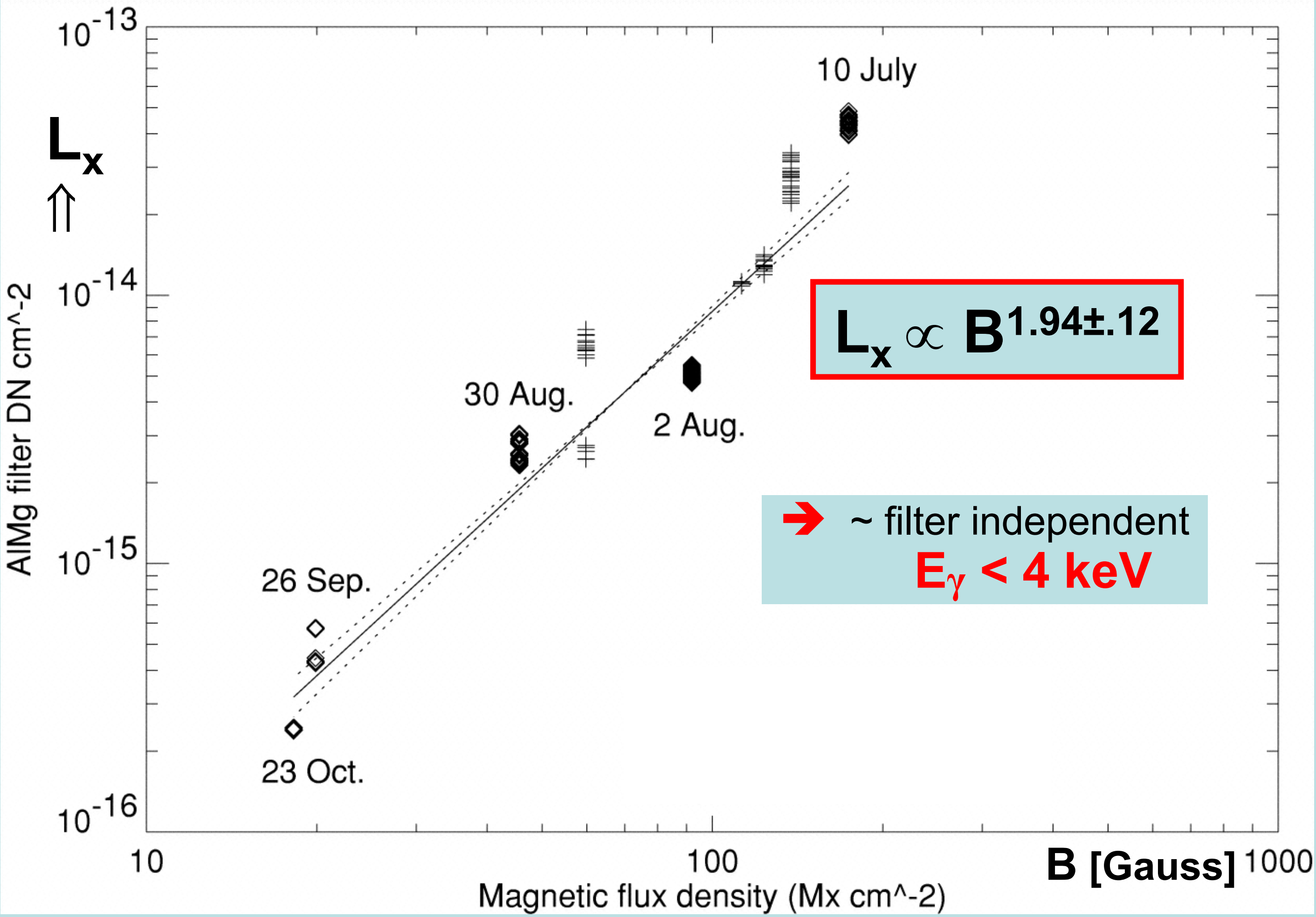
→ **For log(|B|) > 0.5, both methods give slopes = 1.86 - 1.88.**

→ **Most of the correlation is due to the high-field data … hint at a relation between $B_{photospheric}$ & heating processes ⇒ X-ray emission, but**

→ **no insight into the nature of such a relation!**

R. Wolfson, C.B. Roald, P.A. Sturrock, ApJ. 539 (**2000**) 995

The long-term evolution of AR 7978 (S10°) ➔ Yohkoh / SXT



X-ray flux outside flaring times in AR7978

- ***increased steeply @ flux emergence***

\- - - - - + - - - - -

🡐 ***decreased @ decay phase***

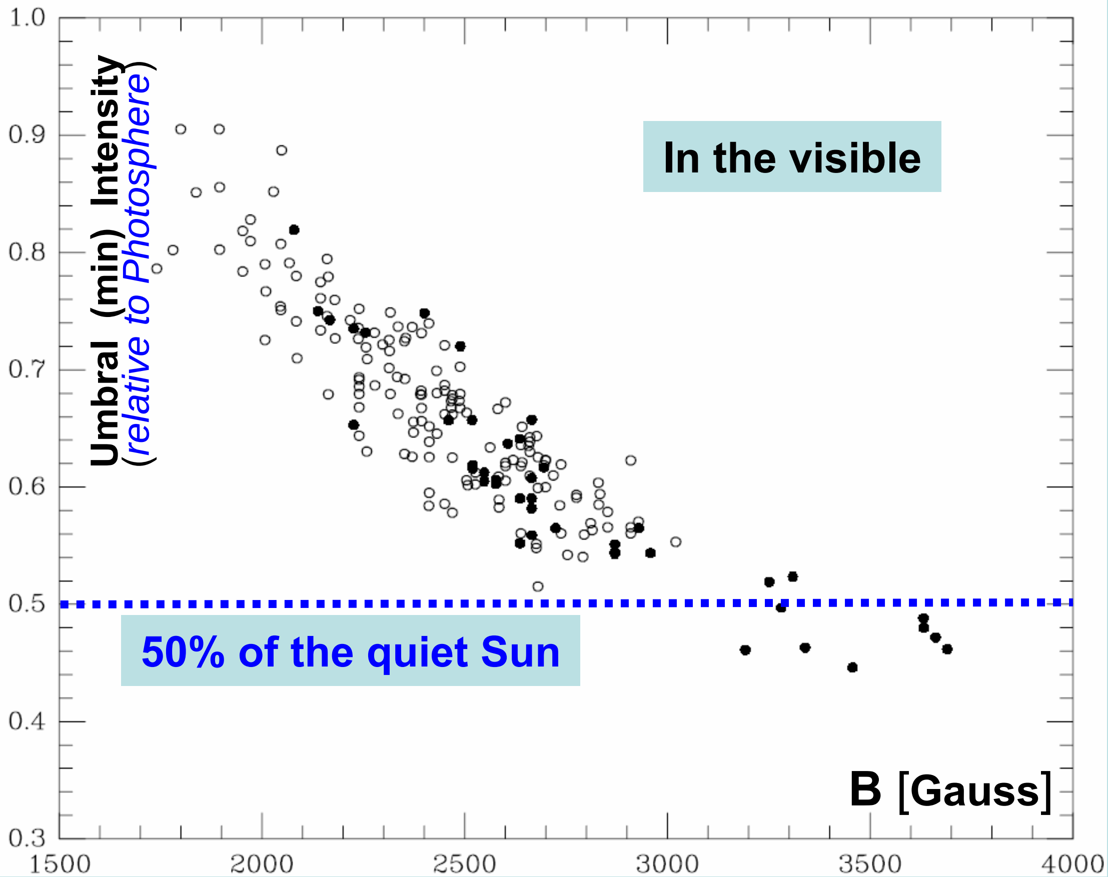
<X-ray flux> / (cm^2 -AR7978) vs. magnetic field <**B**>(=total magnetic flux / **AR**$_{\text{surface}}$).
Solid line: the linear fit; dotted lines: the 3σ error in the slope of the solid curve.
Only the decaying phase (diamonds) is included in the fit → **July-Nov. 1996**

➔The only sizable and long-lived AR on the solar disk @ 5 solar rotations

➔ it produced 3 slow CMEs + 3 major flares

L. van Driel-Gesztelyi, P. Démoulin, C.H. Mandrini, L. Harra, J.A. Klimchuk, ApJ. 586 (**2003**) 579

SUNSPOTS



Umbral normalized continuum intensity vs. umbral field strength **B**. Plotted is the minimum value and the maximum value of **B** of each sunspot.

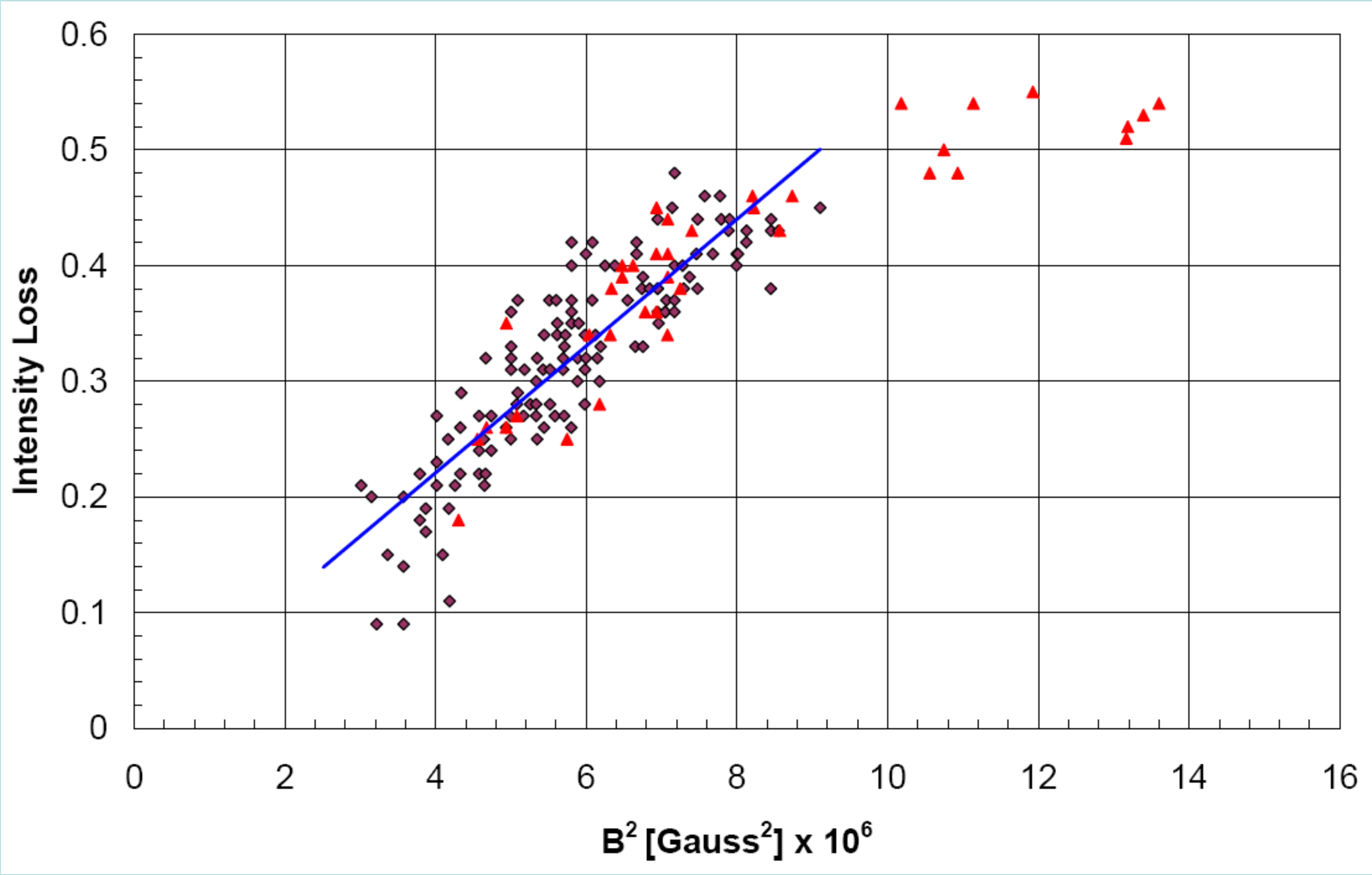
Filled circles (1990–1991)

Open circles (2000–2001)

A number of fundamental questions remain unanswered.

- ***What determines the intrinsic brightness of umbrae and penumbrae, in spite of the strong magnetic field which inhibits convection?***
- ***Is an additional mechanism needed?***
- ***How is the umbral chromosphere heated?***
- ***Why are penumbrae brighter? ….***

S.K. Solanki, A.&A. Rev. 11 (**2003**) 153



Thanks Thomas Papaevangelou

S.K. Solanki, A.&A. Rev. 11 (**2003**) 153

➔ **The magnetic field plays a crucial role in heating the solar corona** (this has been known for many years) ➔ ***the exact energy release mechanism(s) is(are) still unknown*.**

➔ **the process by which it is converted into heat and other forms remains *a nagging unsolved problem*.**

K. Galsgaard, C.E. Parnell, A.& A. 439 (August **2005**) 335
R.B. Dahlburg, J.A. Klimchuk, S.K. Antiochos, ApJ. 622 (**2005**) 1191

➔ the **reconnection** of **B** lines plays a key role in .. ***solar flares***, ***CME***s ….

➔ (μ)flares ⊗ **polarity inversion** lines with strong sheared **B** lines.

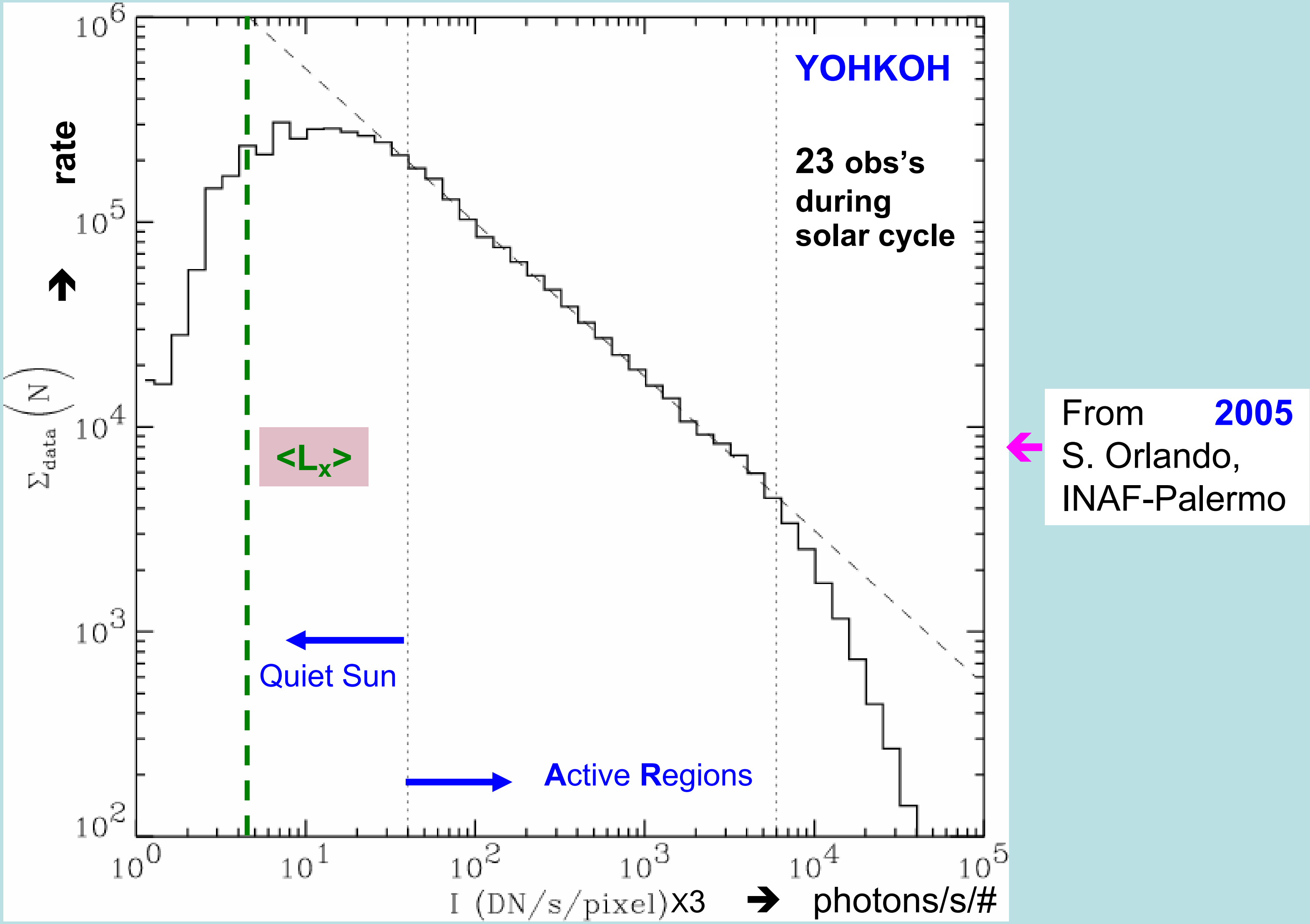
➔ In ARs, …places with field as strong or stronger than in brightest features, but the corona is dimmer.
➔ ***...a hidden process*** **controls coronal heating.**

➔ Emerging Φ ⊗ trigger ***transient brightenings*** (~10^{24} – 10^{28} ergs).

⇩

origin?

M. Hahn et al., ApJ 629 (**2005**) 1135; M. Barta, M. Karlicky, ApJ (**2005**) ***in press***
D.A. Falconer et al., ApJ 482 (**1997**) 519; 593 (**2003**) 549
T. Shimizu, IAU Symp. No. 223 (**2004**) 345



19th December 1995: 6583 quiet Sun pixels, **13.539 photons per #** with <0.128 keV> [512x512 #s] → L_x(0.5-4keV)≈4x10^{24} erg/s → **<$g_{a\gamma\gamma}$≈22x10^{-14}GeV^{-1}>** (between previous values)

Note:

Quiet Sun L_x → MINIMUM: ***spontaneous decay*** + Residual: ***Primakoff-effect***

In short:

1) Radiative decay of trapped massive ~axions

→ Constant component of L_x

→ Use XRTs:

Yohkoh, RHESSI,…, SMART → *background subtraction*

2) Oscillations between light ~axions & γ's inside $B_{solar\text{-}surface}$

→ Solar local effects in the eV-to-keV range

→ ⊗ 11-years solar cycle?

→ Suggestive for solar ~axion searches below 1keV → 1eV

3) Beyond the Sun → real plasma modified

→ Galactic Center, Galaxy Clusters + S-Z effect, ..., CXRB?

4) ~axion–condensate(s) ?

→ theoretical work???

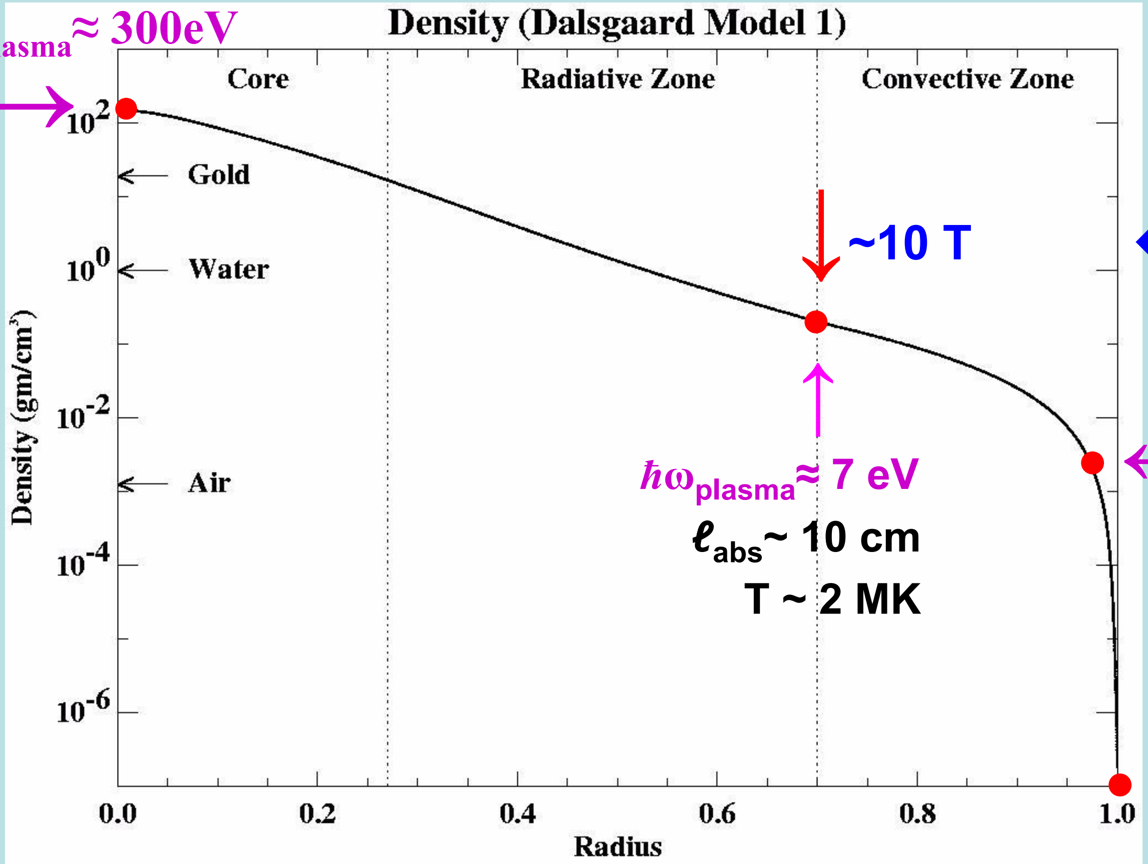
Thus, …

➔

… important evidence remained unnoticed?

The inner SUN

$\hbar\omega_{plasma} \approx 300$eV



M. Schüßler, M. Rempel A.&A. (**2005**), astro-ph/0506654 **#)**

$\hbar\omega_{plasma} \approx$ 1eV → **-20000 km**

ℓ_{abs}**~20 m**

$\hbar\omega_{plasma} \approx 10^{-2}$eV → **surface**

ℓ_{abs}**~100 km**

If $\hbar\omega_{plasma} \approx m_{axion}c^2$ → **~ resonance crossing**

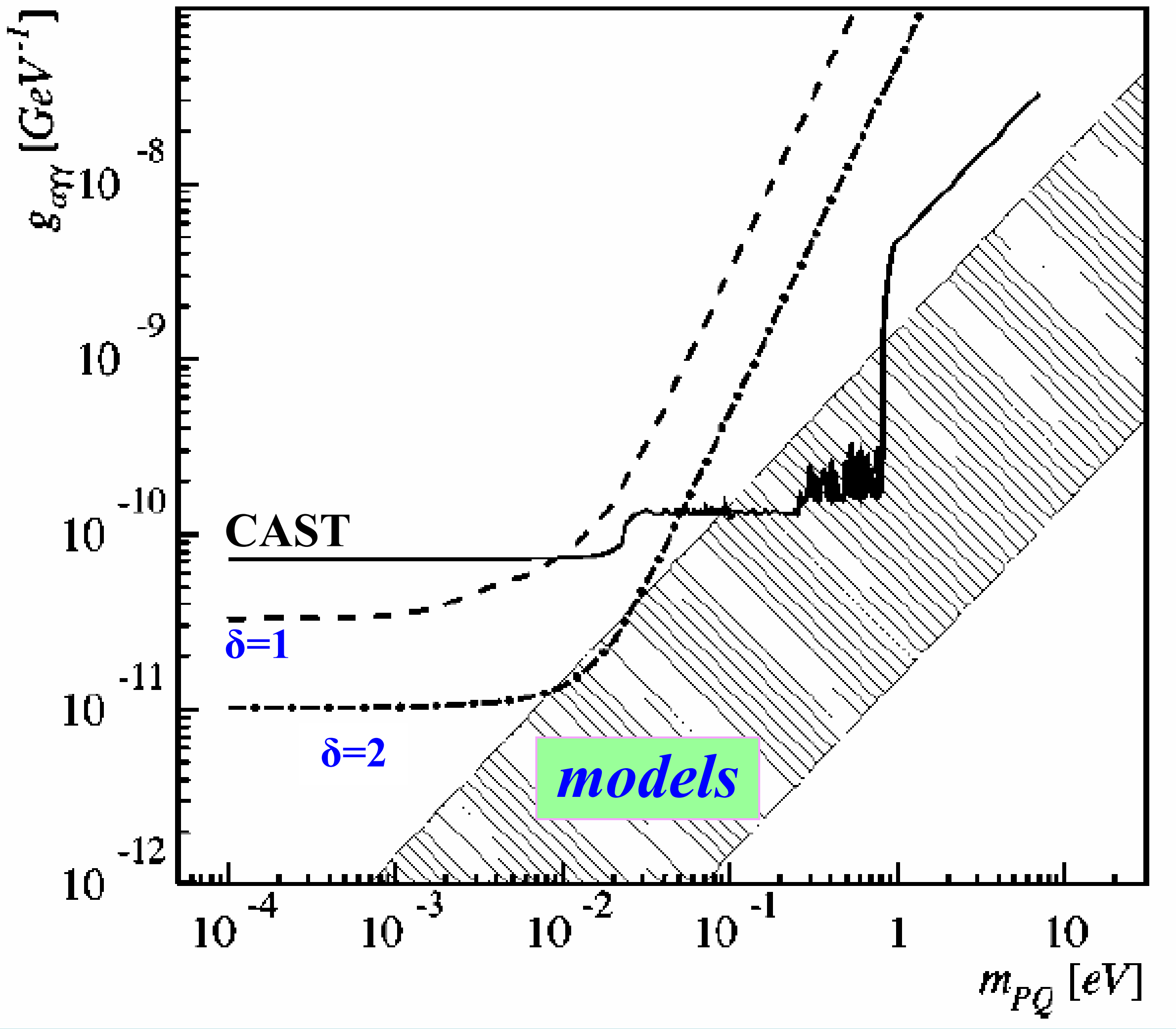
→ $(\text{Primakoff})_B$ >> $(\text{Primakoff})_{Coulomb}$

→ **New solar axion spectrum?**

http://science.msfc.nasa.gov/ssl/pad/solar/interior.htm

#) also: M. Aschwanden, *Physics of the Solar Corona* (**2004**)175

CAST as a probe of large extra dimensions



Limits on the axion-photon coupling $g_{a\gamma\gamma} = f$ (fundamental PQ mass m_{PQ}). The dashed region marks the theoretically favored relation between $g_{a\gamma\gamma}$ and m_{PQ} in axion models in 4D. The dashed and dot-dashed lines correspond to prospects of CAST for KK axions in the case of two extra dimensions (R =0.150 mm) for δ=1 and for δ=2, respectively.

R. Horvat, M. Krcmar, B. Lakic, Phys. Rev. D69 (**2004**) 125011

“ *the future is bright* → *the present is painful* ”

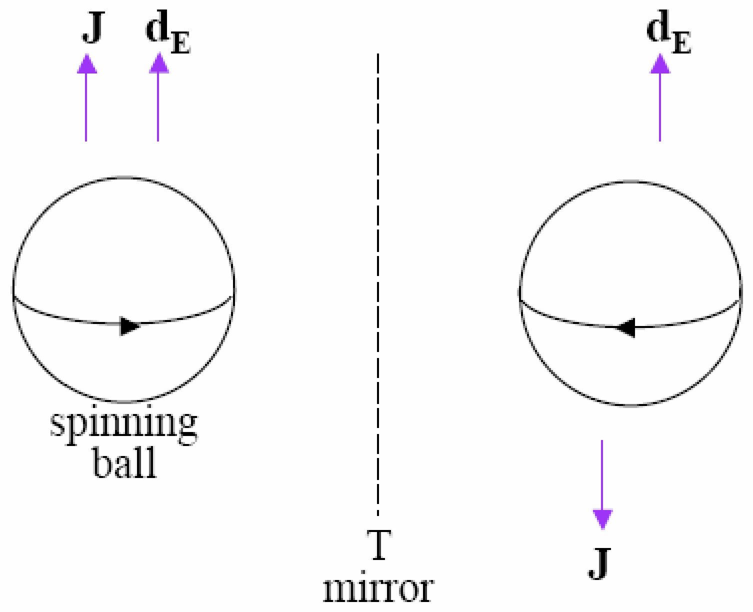
C.S. Kochanek, astro-ph/**2004**12089

The discrete symmetry "mirrors"

T ≡ time reversal

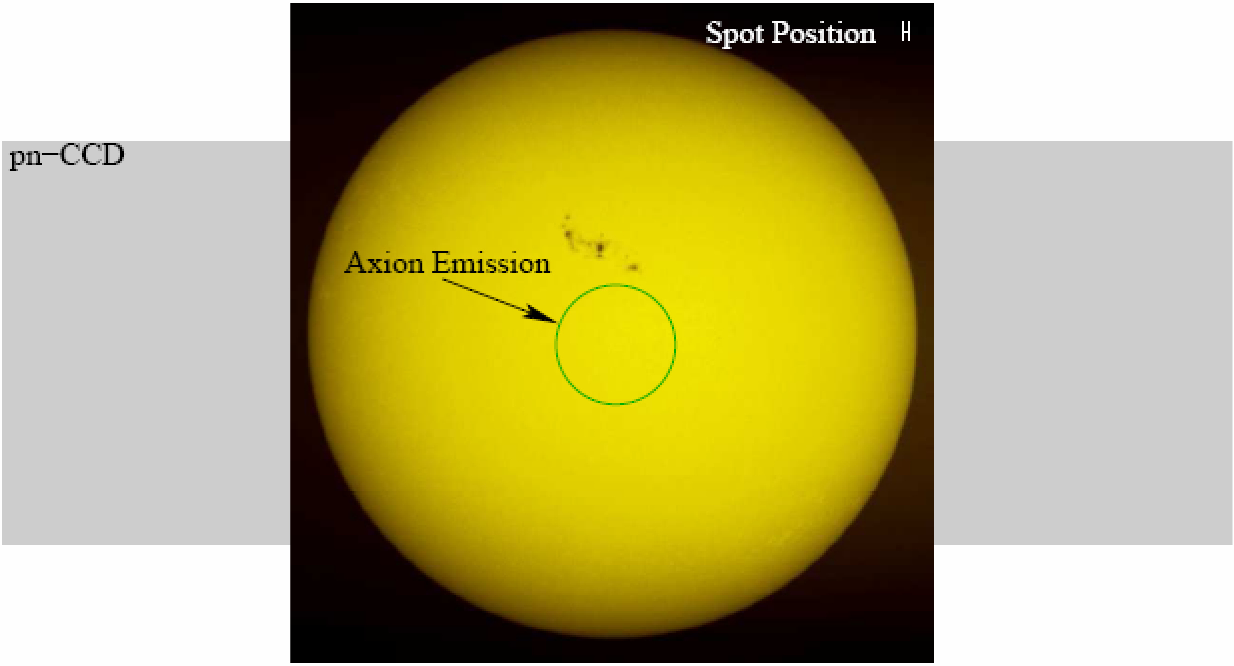
C ≡ changing particles to antiparticles

P ≡ space inversion

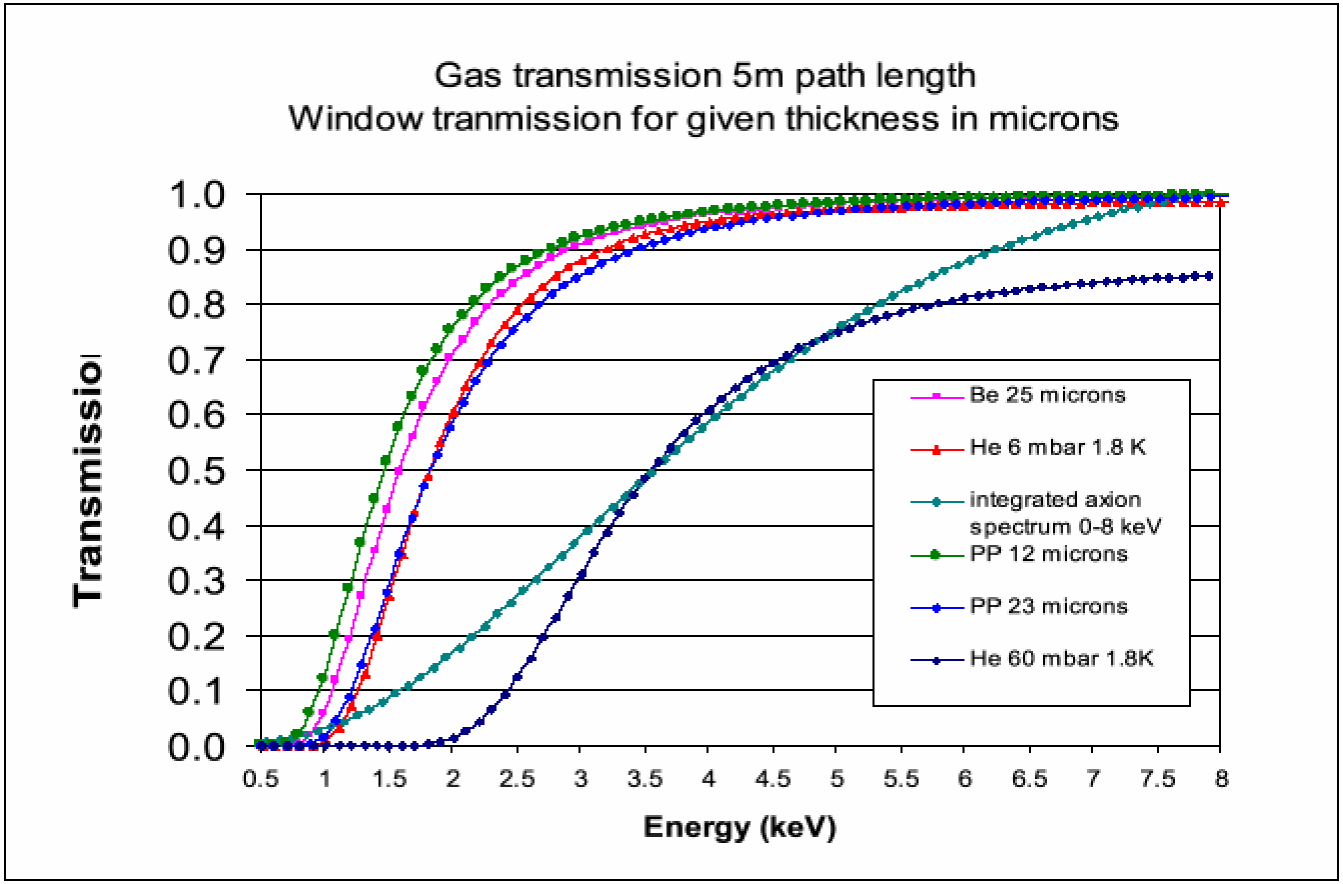


If you see an EDM: $\not{T}$ + CPT = $\not{C}$P

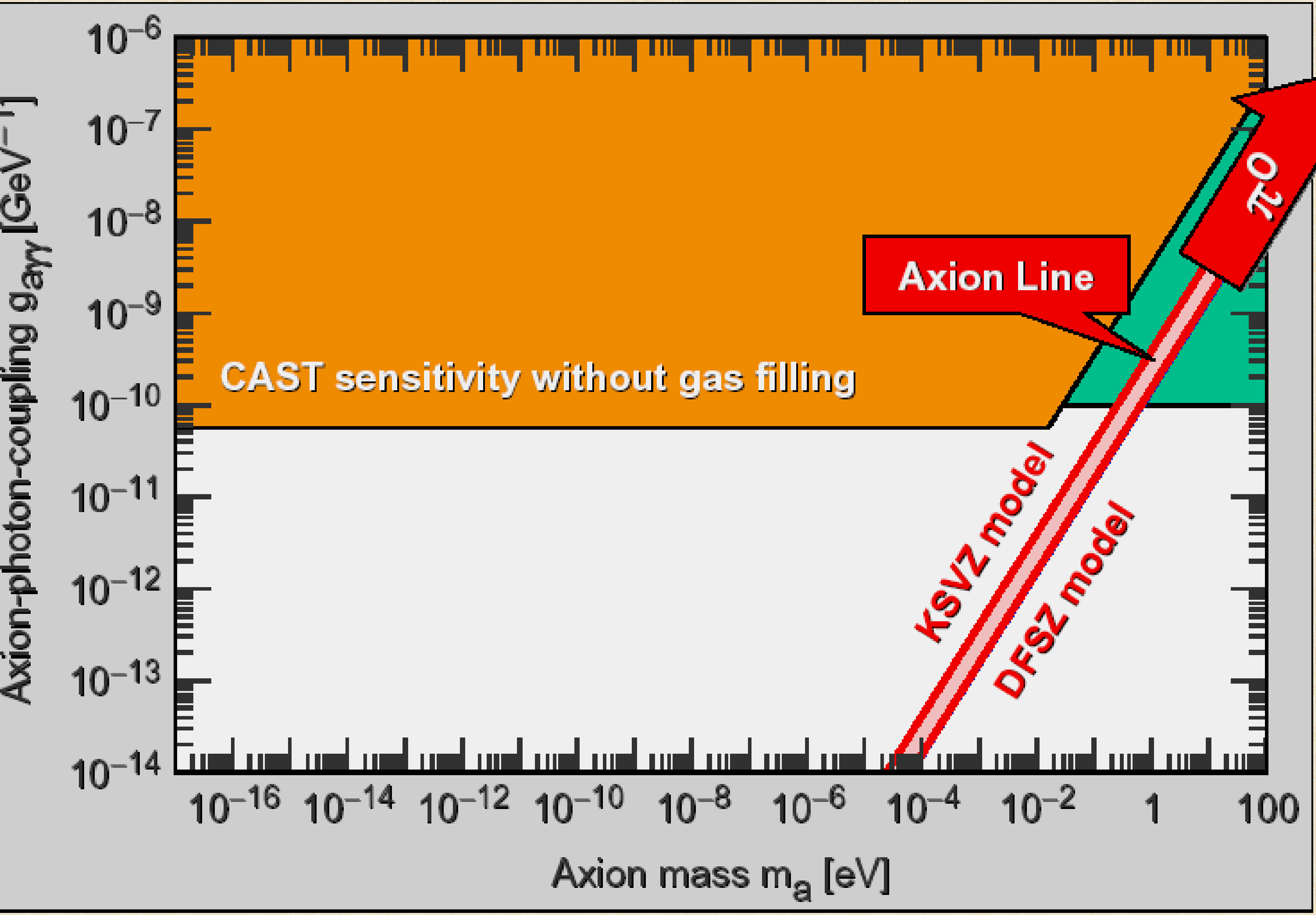
Dimensions



Cold Window Transmission



Axion-Like Particles that Couple to Photons



CAST Phase II

Fill magnet bore with buffer gas

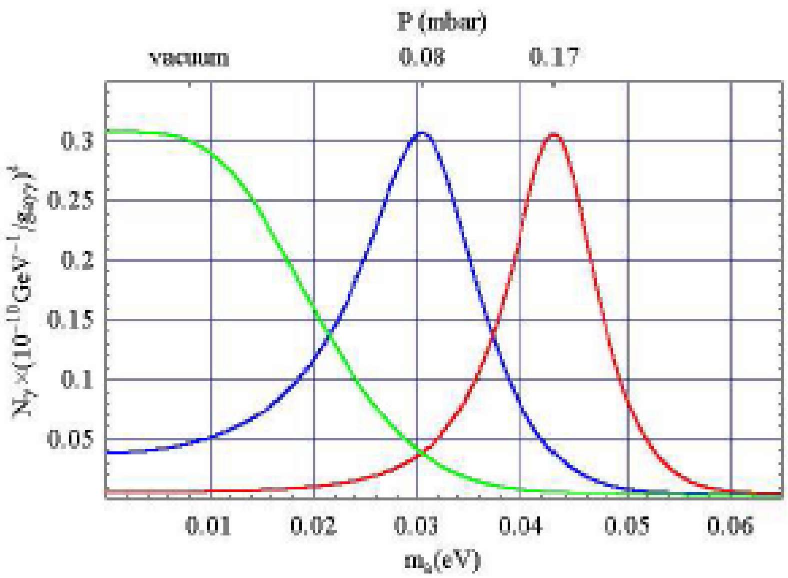
^{4}He or ^{3}He

$(p_{\rm vap} = 16/140\,{\rm mbar}@1.8\,{\rm K})$

$\Longrightarrow$ photon acquires an effective mass

$$m_{\gamma,\rm eff} \approx \sqrt{0.02\frac{P[\rm mbar]}{T[K]}}[{\rm eV}/c^2]$$

Different Pressure Settings



Systematically change pressure $\Longrightarrow$ scan mass range $m_{\rm a} > 0.02\,{\rm eV}/{\rm c}^2$

- ^{4}He: ≈ 74 pressure steps $0 \leq p \leq 6\,{\rm mbar}$, $m_{\rm a} \leq 0.26\,{\rm eV}/{\rm c}^2$
- ^{3}He: ≈ 590 pressure steps $6 < p \leq 60\,{\rm mbar}$, $m_{\rm a} \leq 0.8\,{\rm eV}/{\rm c}^2$

$\Longrightarrow$ Allows to scan axion masses $0.02\,{\rm eV}/{\rm c}^2 \leq m_{\rm a} \leq 0.8\,{\rm eV}/{\rm c}^2$