The CERN Axion Solar Telescope (CAST) and Axions from the Sun and beyond.

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&
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➔ ILIAS

NIC Summer School

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First Results from the CERN Axion Solar Telescope

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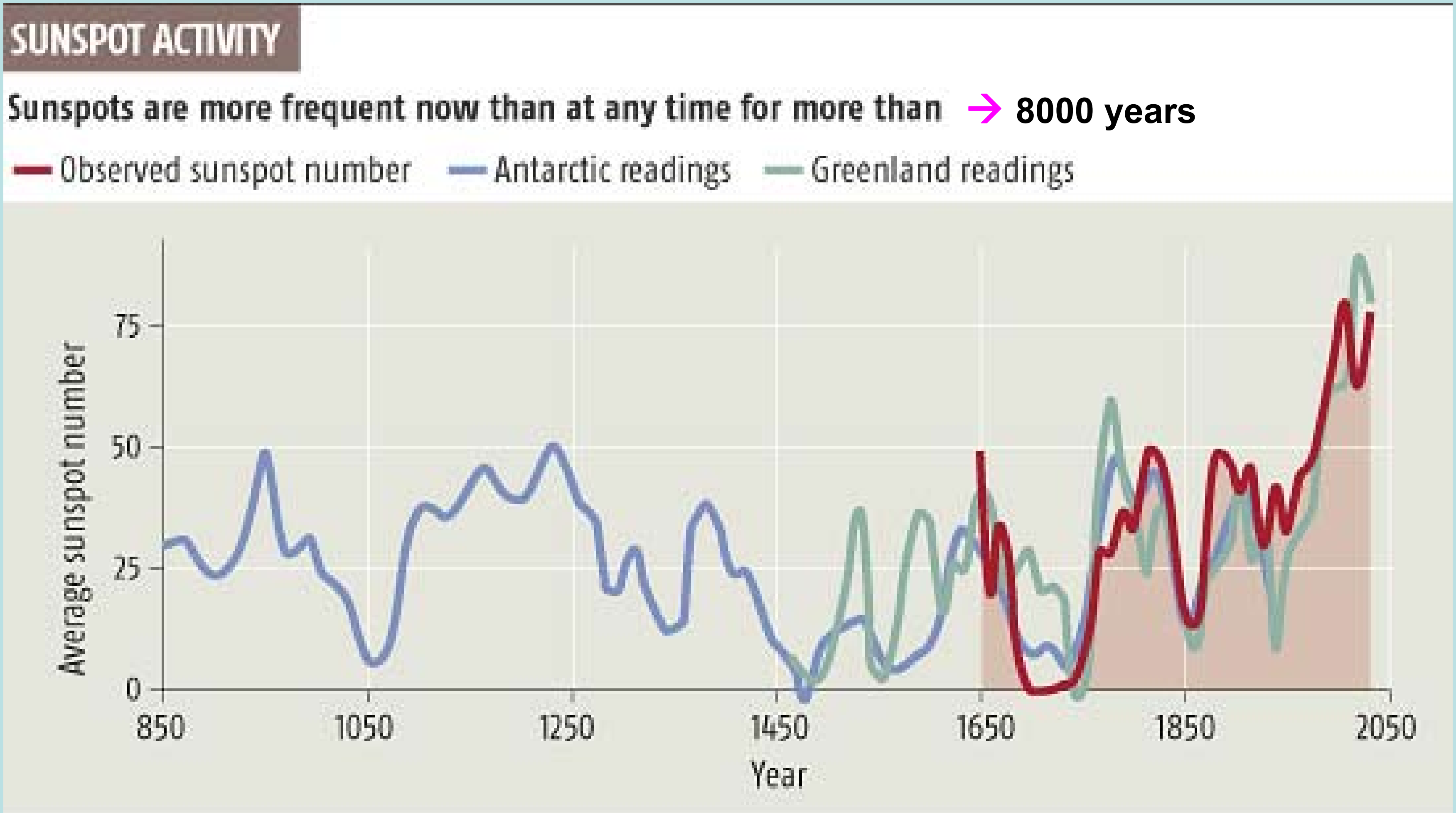
→ P. Sikivie

→ Istanbul **2x**

1944- Exceptional Solar Activity since 8kyears → <76 SN / year>



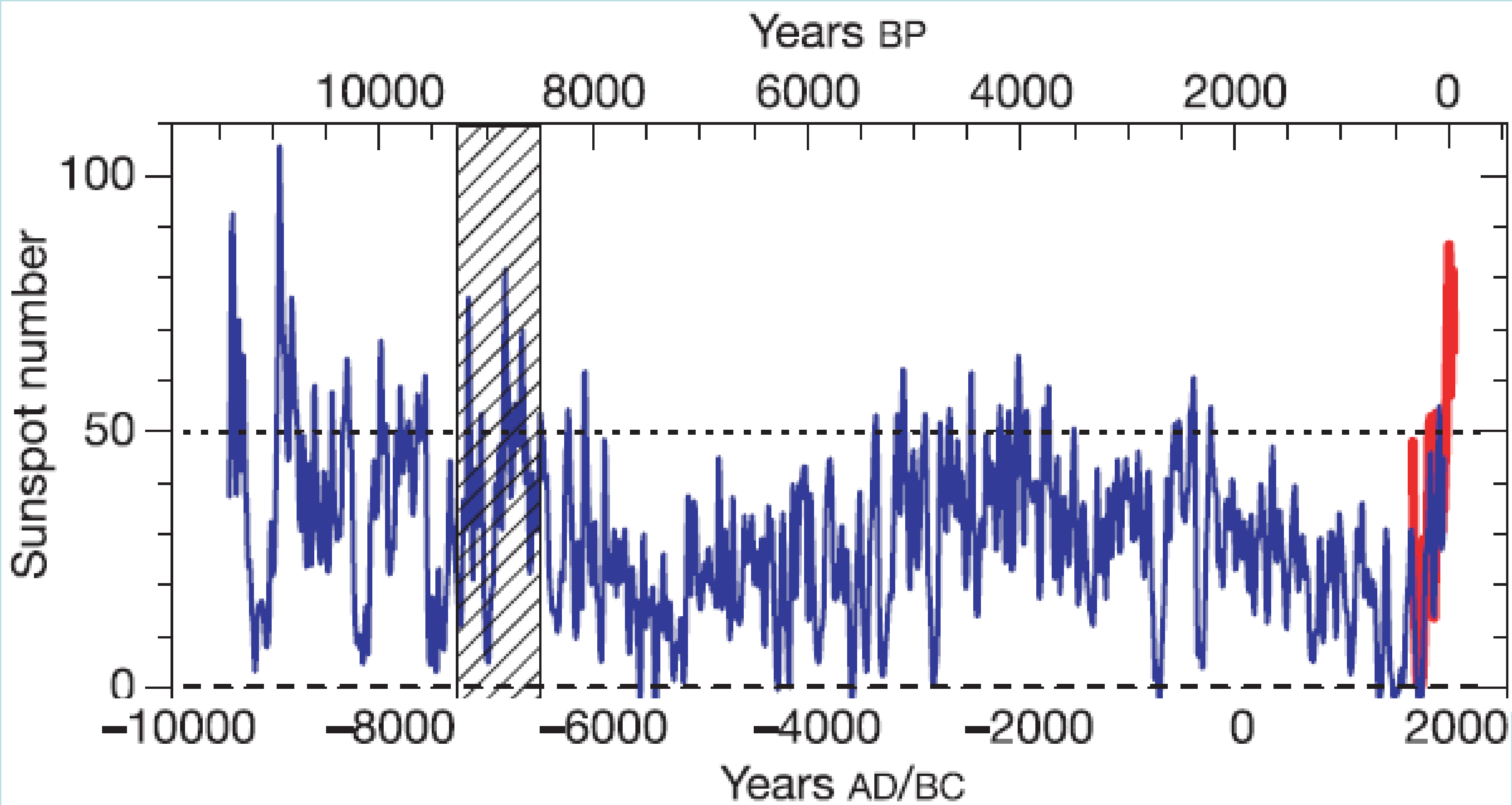
We are living with a very unusual sun at the moment ← Usoskin etal. **PRL91(2003)211101**

→ ***similar period occurred ~8000years ago*** → Solanki etal Nature 431(2004)1084

Sunspots are a symptom of fierce magnetic activity inside. → **New Scientist:**

http://www.newscientist.com/article.ns?id=dn4321 ← Jenny Hogan

Unusual activity of the Sun during recent decades compared to the previous 11 kyears



Reconstructed sunspot number,10-year averaged SN reconstructed from Δ[14]C data since 9500 BC (***blue***) and 10-year averaged group sunspot number (GSN) obtained from telescopic observations since 1610 (***red***). The horizontal dotted line marks the threshold above which we consider the Sun to be exceptionally active.

SK. Solanki, IG. Usoskin, B. Kromer, M. Schűssler, J. Beer, Nature 431(**2004**)1084

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 produc 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 cha with a '1' equating to spin up and a '0 spin down. But one problem facing t development of spintronic devices is although electron spin can be manip it tends not to stay so — an induced decays as the electron interacts with magnetic field of nearby nuclei.

P.-F. Braun and colleagues have n directly observed this 'spin relaxatio in quantum dots — clusters of atom just nanometres across — made of t semiconductor materials indium ars and gallium arsenide. The authors fo that the initial spin polarization of s decays with a half-life of just 0.5 nan — 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 magneti 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

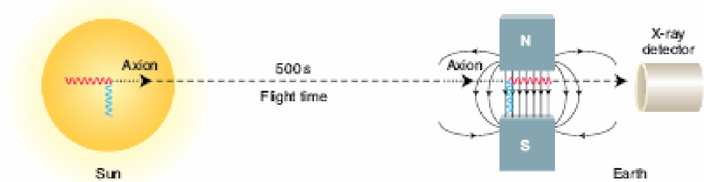
PARTICLE PHYSICS

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

Lockheed Boosts Los Alar

U.S. aerospace giant Lockheed Mar strengthened its bid to run Los Ala National Laboratory in New Mexic week by recruiting a key senior sci Sandia National Laboratories Direc 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 GenBank gested that Korean pigs carried WSN 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. 139 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. Henr a business owner in Philadelphia w Seo's claim, says Kawaoka's study broad enough to refute the theory. WHO flu expert Klaus Stöhr, "we'v too much time on these speculatio already."

—MARTI

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 fr 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 an budget, has dropped by $5.7 millio

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

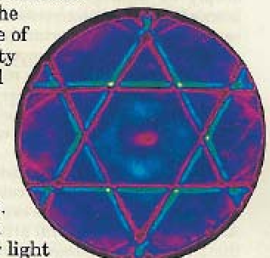
Physics Update

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 ■



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"

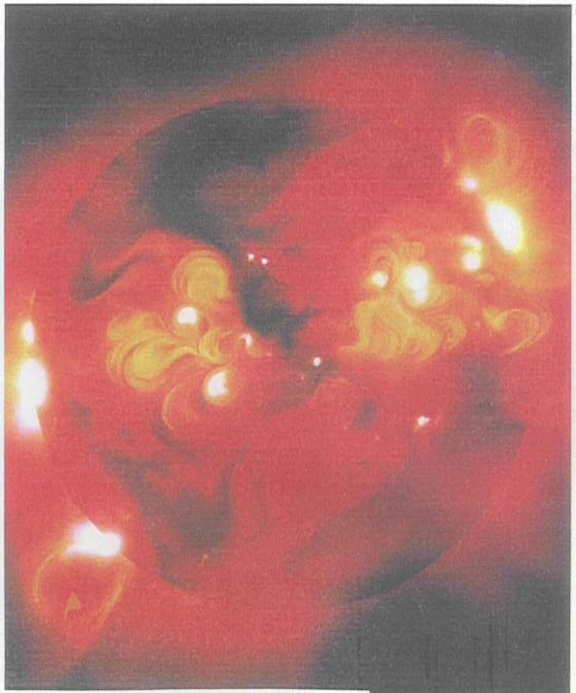
In a paper to be published in *The Astrophysical Journal* next month, Zioutas and his colleagues report that the predictions match brightness measurements made by the Yohkoh satellite.

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

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

PHYSICAL REVIEW LETTERS

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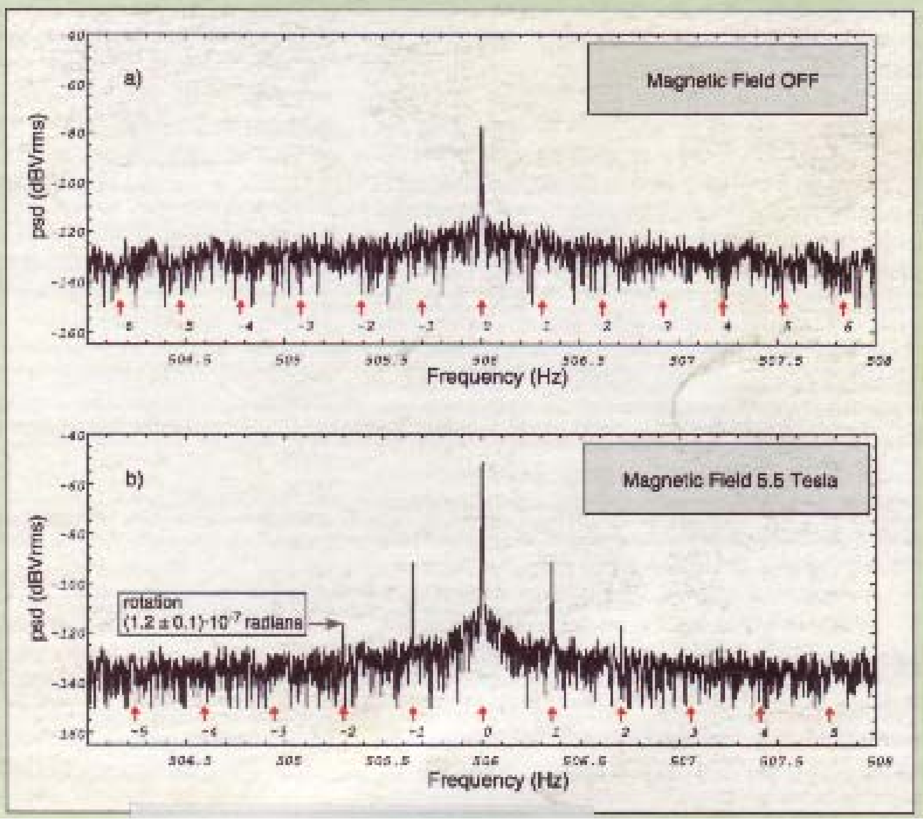
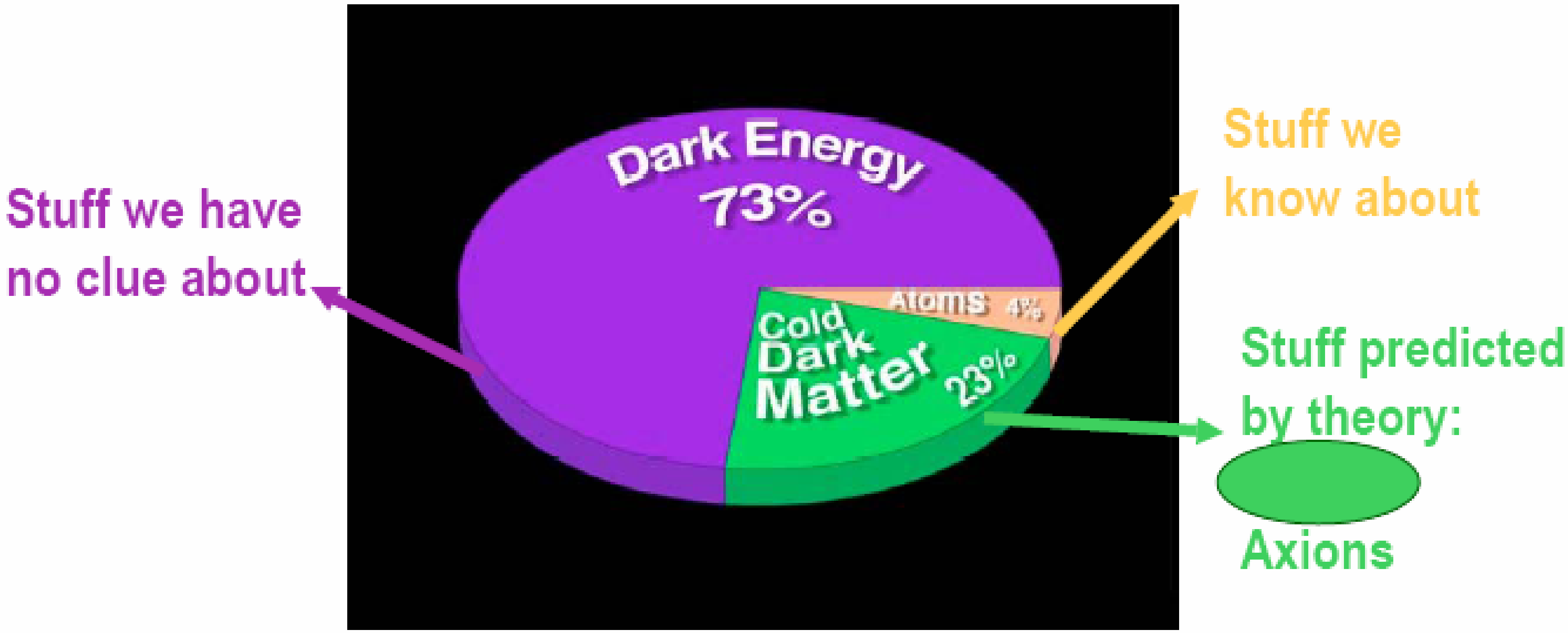


Motivation?



The Universe, according to WMAP

Axion ➔ Dark Matter particle *candidate* ➔ new physics

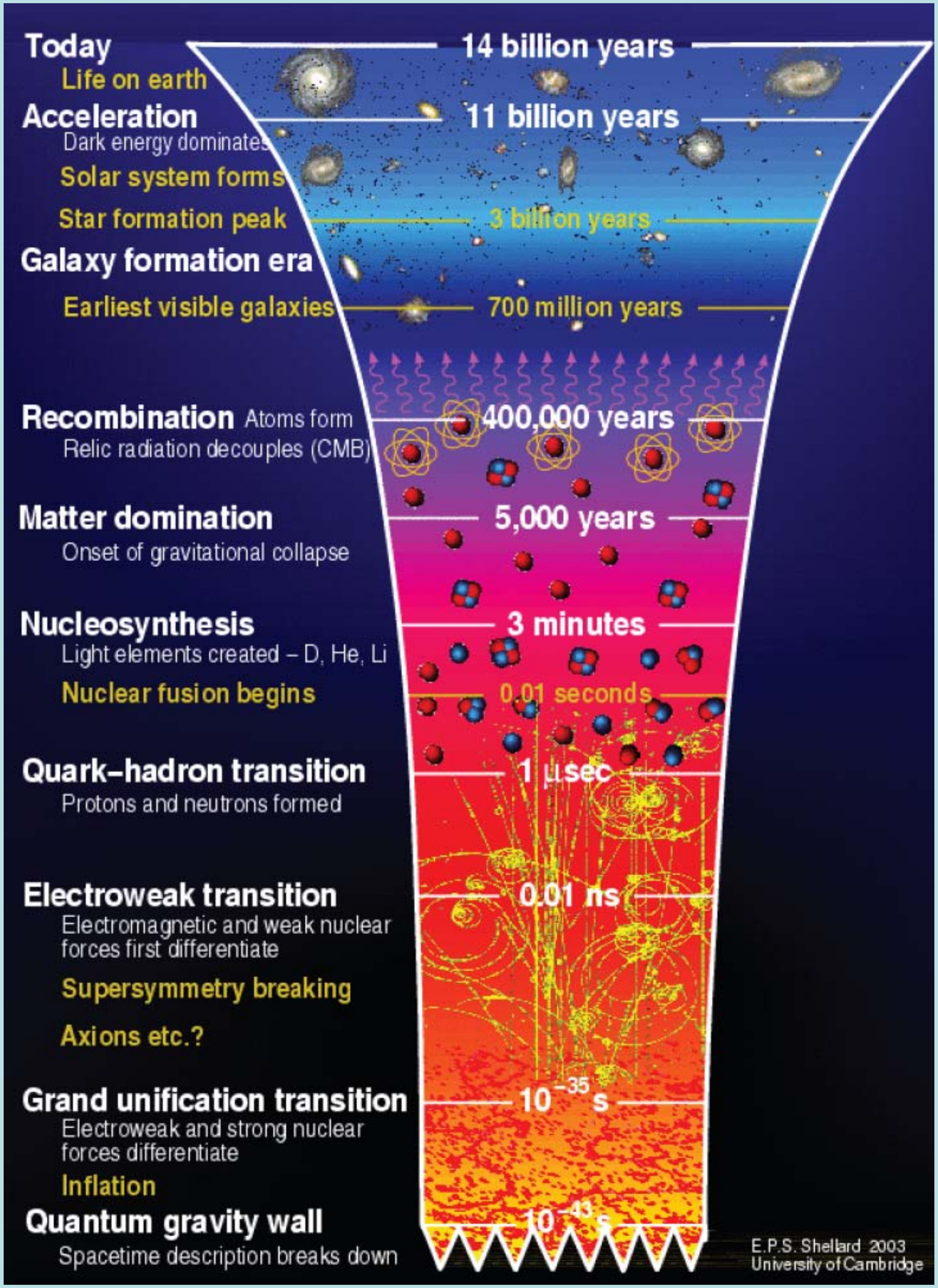
http://www.fnal.gov/directorate/Longrange/PartAstro1003_Talks/Bauer.pdf

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



The history of the Universe

Planck time ➔ present

Physics Letters B 282 (1992) 137–141
North-Holland

Planck-scale physics and the Peccei–Quinn mechanism

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Received 3 February 1992

Global-symmetry violating higher-dimension operators, expected to be induced by Planck-scale physics, in general drastically alter the properties of the axion field associated with the Peccei–Quinn solution to the strong-*CP* problem, and render this solution unnatural. The particle physics and cosmology associated with other global symmetries can also be significantly changed.

After almost twenty years of experimental verification, there is little room to doubt that quantum chromodynamics (QCD) is the true theory of the strong interactions [1]. Perhaps the only outstanding flaw in the theory arises from non-perturbative effects which, unless suppressed, lead to a neutron electric-dipole moment orders of magnitude larger than that observed. This is the infamous strong-*CP* problem. Essentially, the problem is that the QCD lagrangian contains a term

$$\bar{\theta}\frac{g^2}{32\pi^2}G^{a\mu\nu}\tilde{G}_{a\mu\nu}\,, \tag{1}$$

where $G^{a\mu\nu}$ is the gluon field and $\bar{\theta}$ is an undetermined parameter. This term leads to an electric-dipole moment of order $d_n \simeq 5\times10^{-16}\,\bar{\theta}\,e$ cm. The current experimental limit is $d_n \lesssim 10^{-25}$ e cm which constrains $\bar{\theta}$ to be less than 10^{-10}. Here we have performed an anomalous chiral rotation to move the phase of the determinant of the fermion mass-matrix into the theta-term, resulting in a net theta-angle $\bar{\theta}$.

To date, the most elegant and intriguing solution to the strong-*CP* problem has been that proposed by Peccei and Quinn [2] where $\bar{\theta}$ becomes a dynamical field with a potential minimized at $\bar{\theta}=0$. Their solution involves introducing a new global chiral symmetry $U(1)_{PQ}$ spontaneously broken at a scale f_{PQ} which leads to a Nambu–Goldstone boson, the axion [3]. Due to the anomalous nature of the $U(1)_{PQ}$ symmetry, QCD-instanton (and other, more general, non-perturbative) effects result in the axion acquiring a periodic potential

$$V_{QCD}(\bar{\theta}) = (m_a^i)^2 f_{PQ}^2(1-\cos\bar{\theta})\,, \tag{2}$$

minimized at $\bar{\theta}=0$ (where, for simplicity, we consider the case where no axion domain walls occur). Here

$$m_a^i \simeq 0.4\frac{f_\pi m_\pi}{f_{PQ}} \tag{3}$$

is the mass of the axion induced by QCD non-perturbative effects.

In this letter we make the simple observation that the existence of higher-dimension symmetry-violating operators expected to be induced at the Planck scale by quantum-gravity effects spoils the Peccei–Quinn solution to the strong-*CP* problem. Generally,

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AXION PHYSICS

The QCD Lagrangian :

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

$L_{\rm pert}$ ⇒ 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 :

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

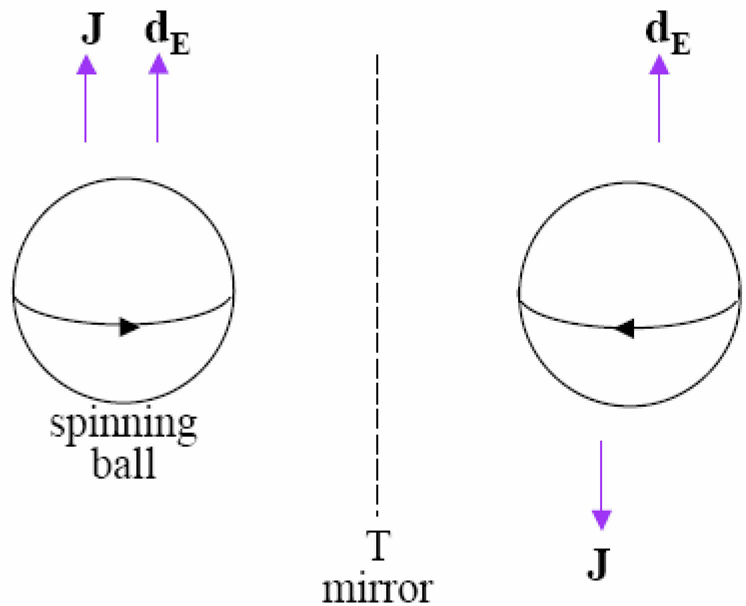
➔ All the axion couplings are inversely proportional to f_{PQ} .

The discrete symmetry "mirrors"

T ≡ time reversal

C ≡ changing particles to antiparticles

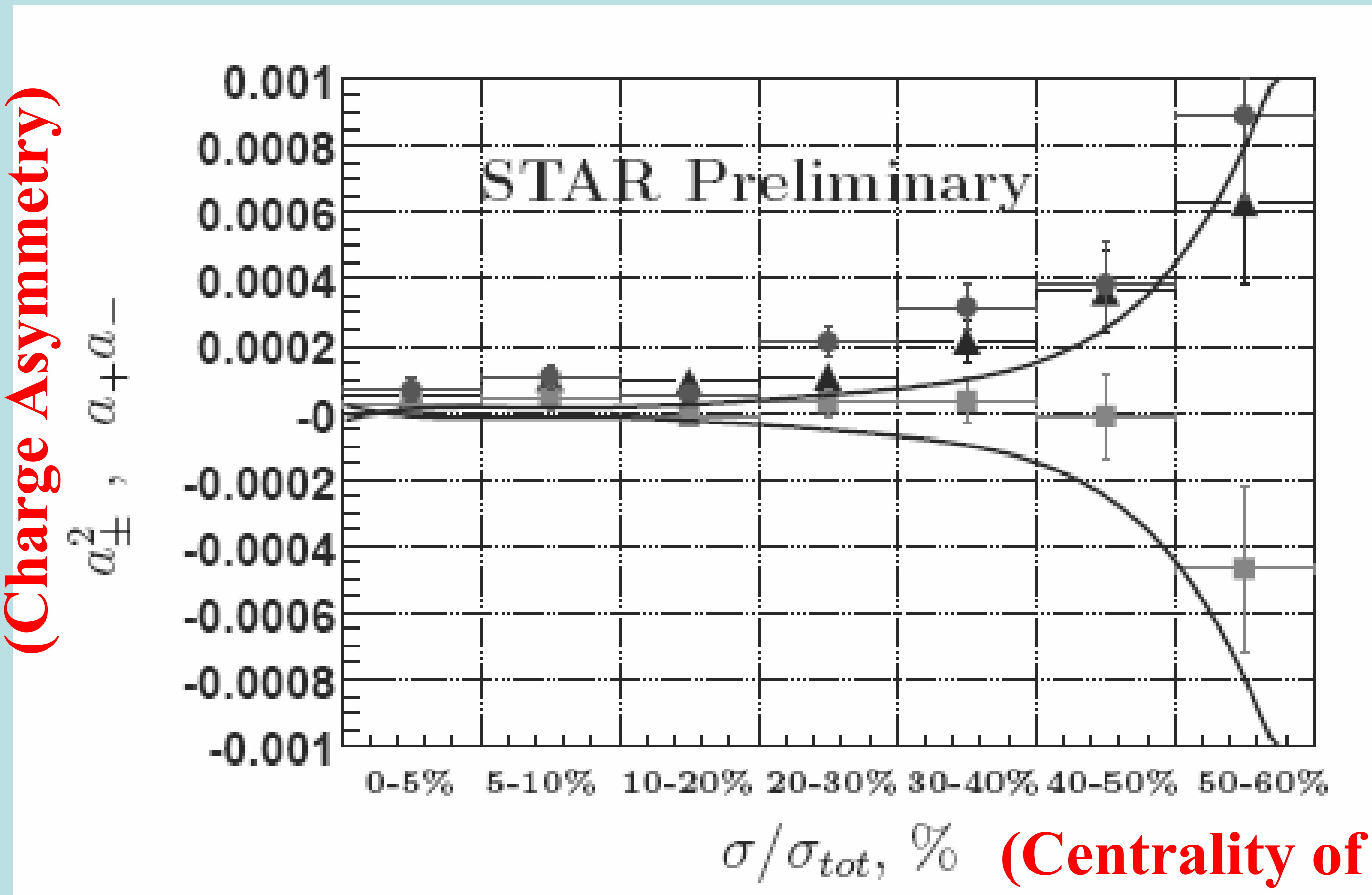
P ≡ space inversion



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

…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.

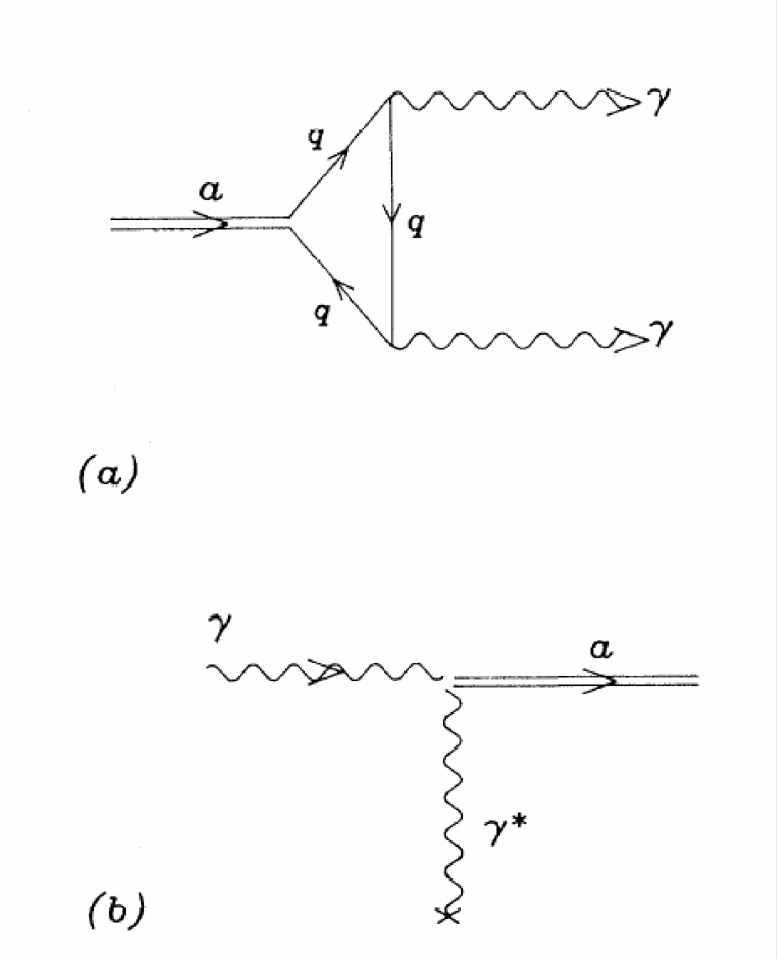
CP-violation at RHIC!! (preliminary)
Nucl-ex/0510069



(Charge Asymmetry)

(Centrality of Collisions)

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*

VOLUME 88, NUMBER 16 PHYSICAL REVIEW LETTERS 22 APRIL 2002

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.

➔ **cosmology**

355 quasars with significant optical polarization

… the observed behavior remarkably corresponds to the dichroism and birefringence predicted by ***photon-pseudoscalar oscillation*** within a magnetic field, suggesting that ***we might have found a signature of either dark matter or dark energy.***

D. Hutsemékers R. Cabanac H. Lamy D. Sluse Astron. & Astroph. 441(**2005**)915

Strong CP: No Problem

P. Mitra

hep-ph/**2005**04053

Abstract

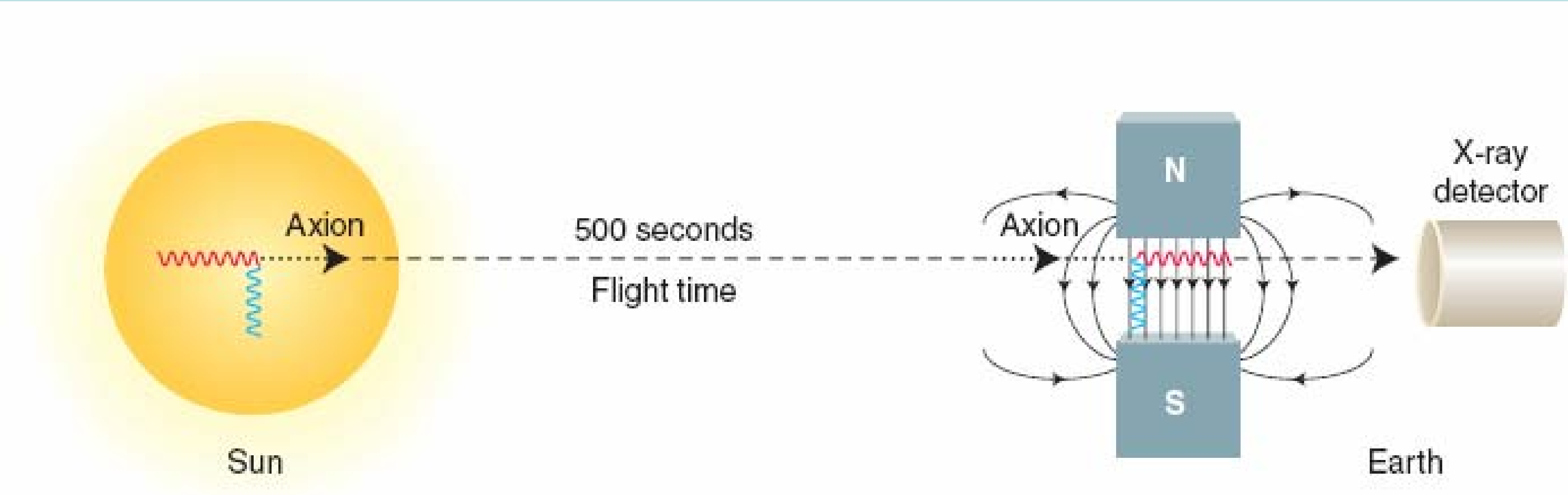
Detailed analysis shows that the phase of a complex mass term of a quark does not violate CP, while the QCD vacuum angle can naturally be set equal to zero. There is no strong CP problem and ***no need for axions*** or similar speculative constructions ***to be experimentally looked for.***

WRONG!

before CAST:

- ➔ BNL & Tokyo
- ➔ axion-Bragg @ Ge, NaI, …

CAST *working principle* ➔ Sikivie [1983]

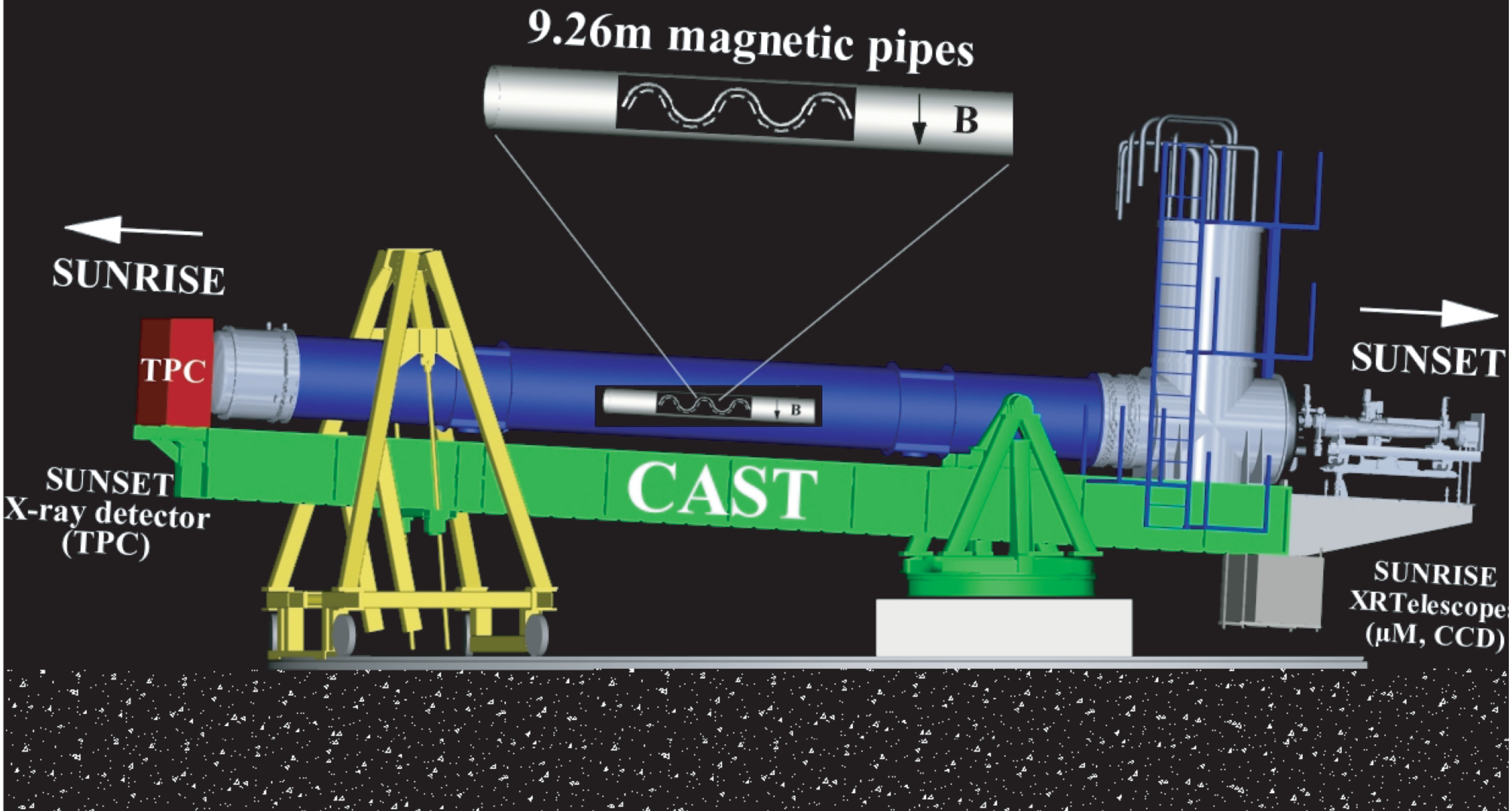


Axion source

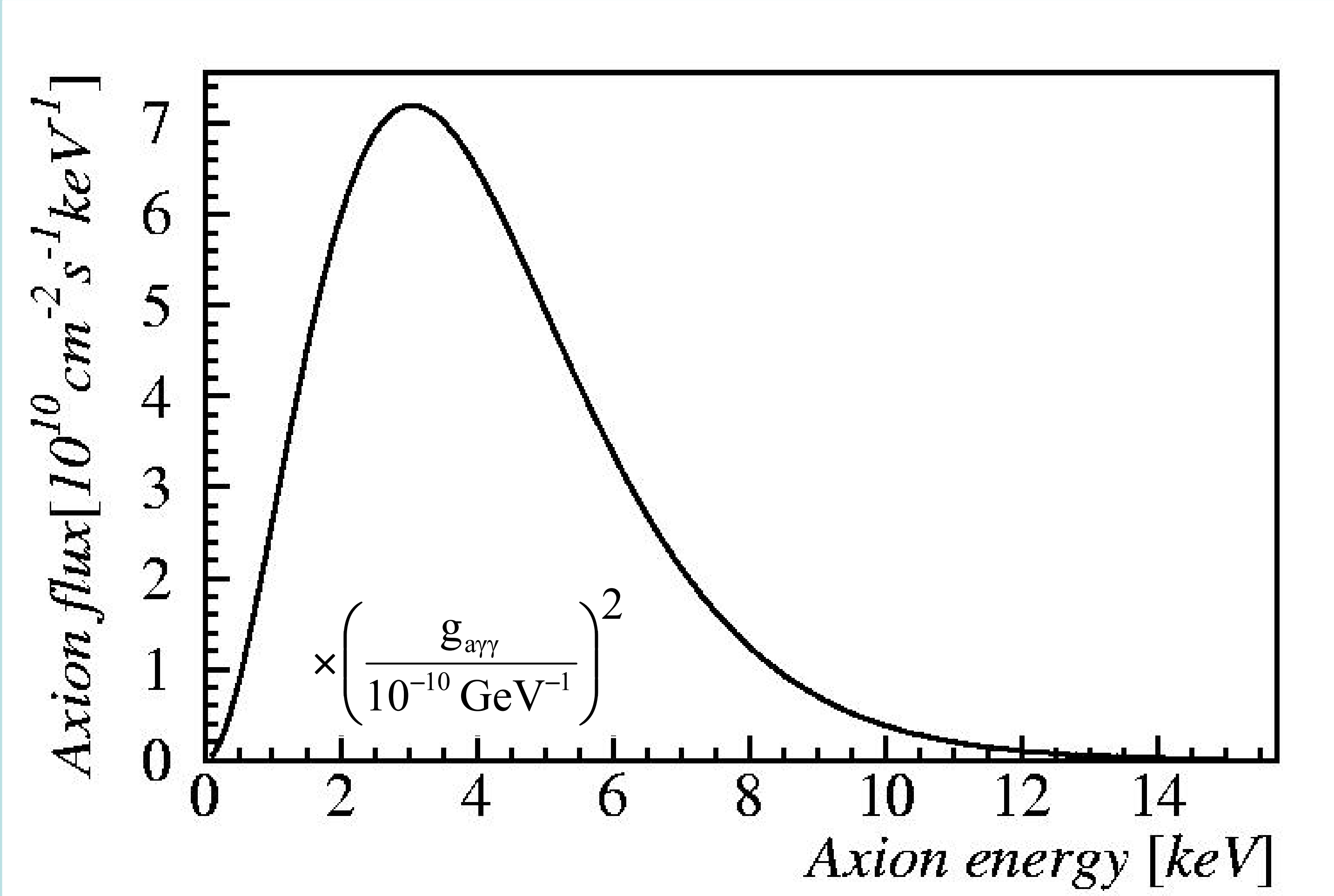
Axion detection

➔ CAST @ Sun ?

Cern Axion Solar Telescope

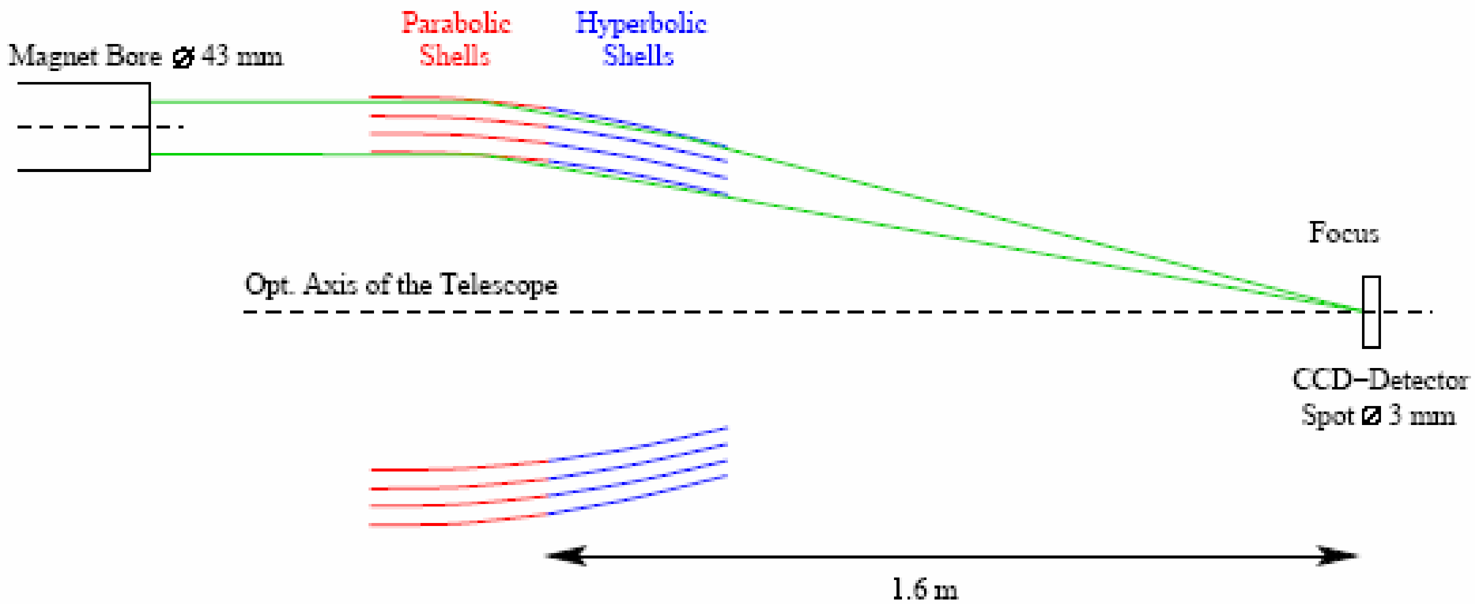


Solar axion spectrum



$P_{a\to\gamma} \approx 1.7\times10^{-17}$ ➔ $$\Phi_\gamma = 0.51\ \mathrm{cm}^{-2}\ \mathrm{d}^{-1}\ g_{10}^4 \left(\frac{L}{9.26\ \mathrm{m}}\right)^2 \left(\frac{B}{9.0\ \mathrm{T}}\right)^2$$

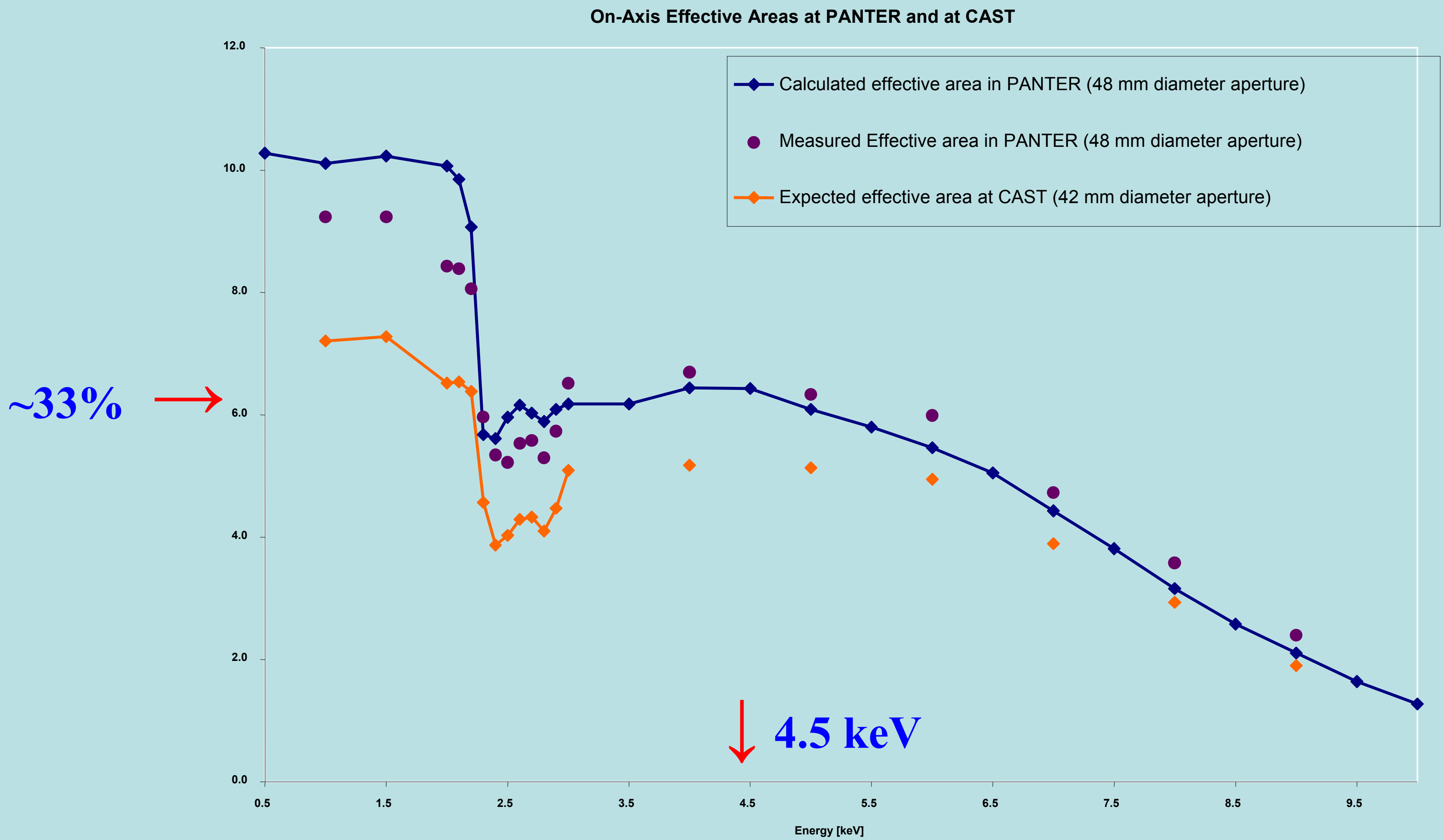
The X-ray Telescope of CAST



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

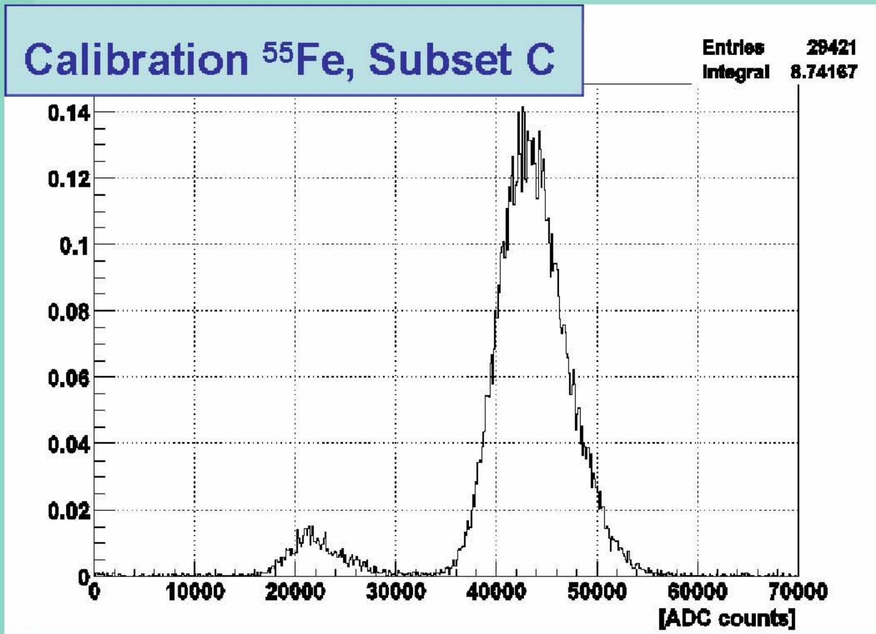
- 27 nested gold coated nickel shells, on-axis resolution ≈ 43 arcsec
- Telescope aperture 16 cm, used for CAST 43 mm
- Only one sector of the full aperture is used for CAST

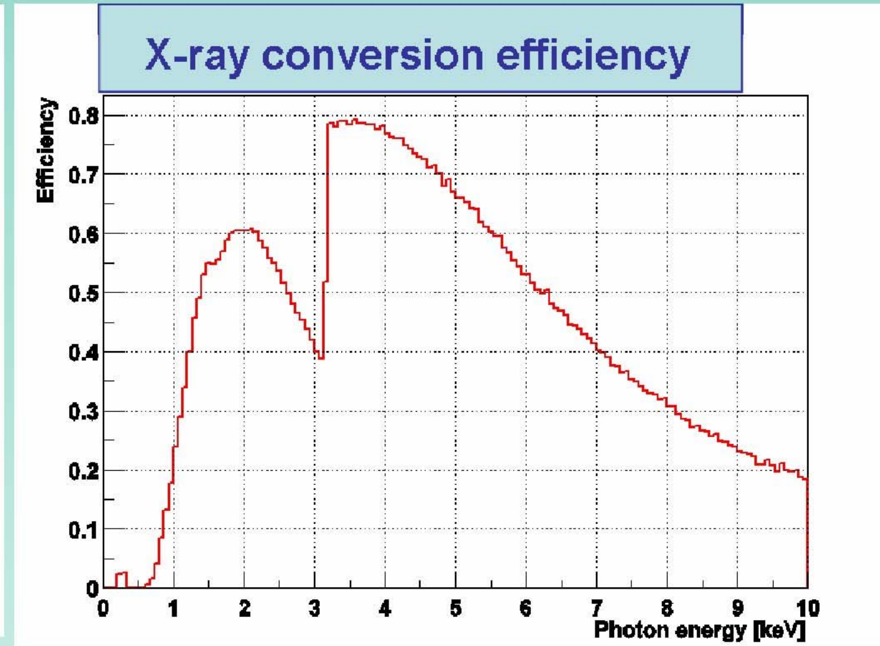
⌀43 mm (LHC Magnet aperture) $\Longrightarrow$ ⌀3 mm (spot of the sun)
Significantly improves the signal to background ratio !

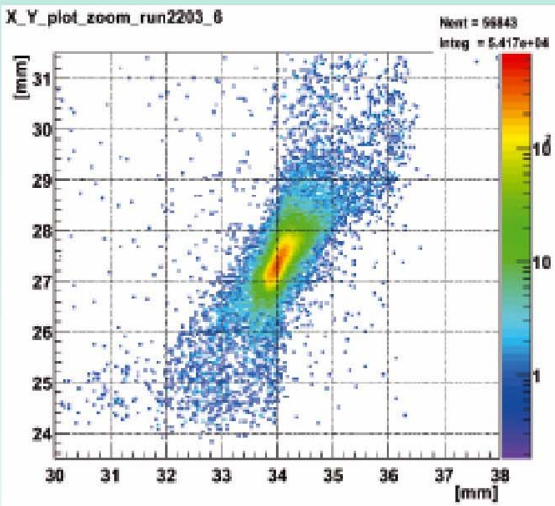


The effective area of the X-ray telescope $f(E_\gamma)$.

Micromegas–Performance







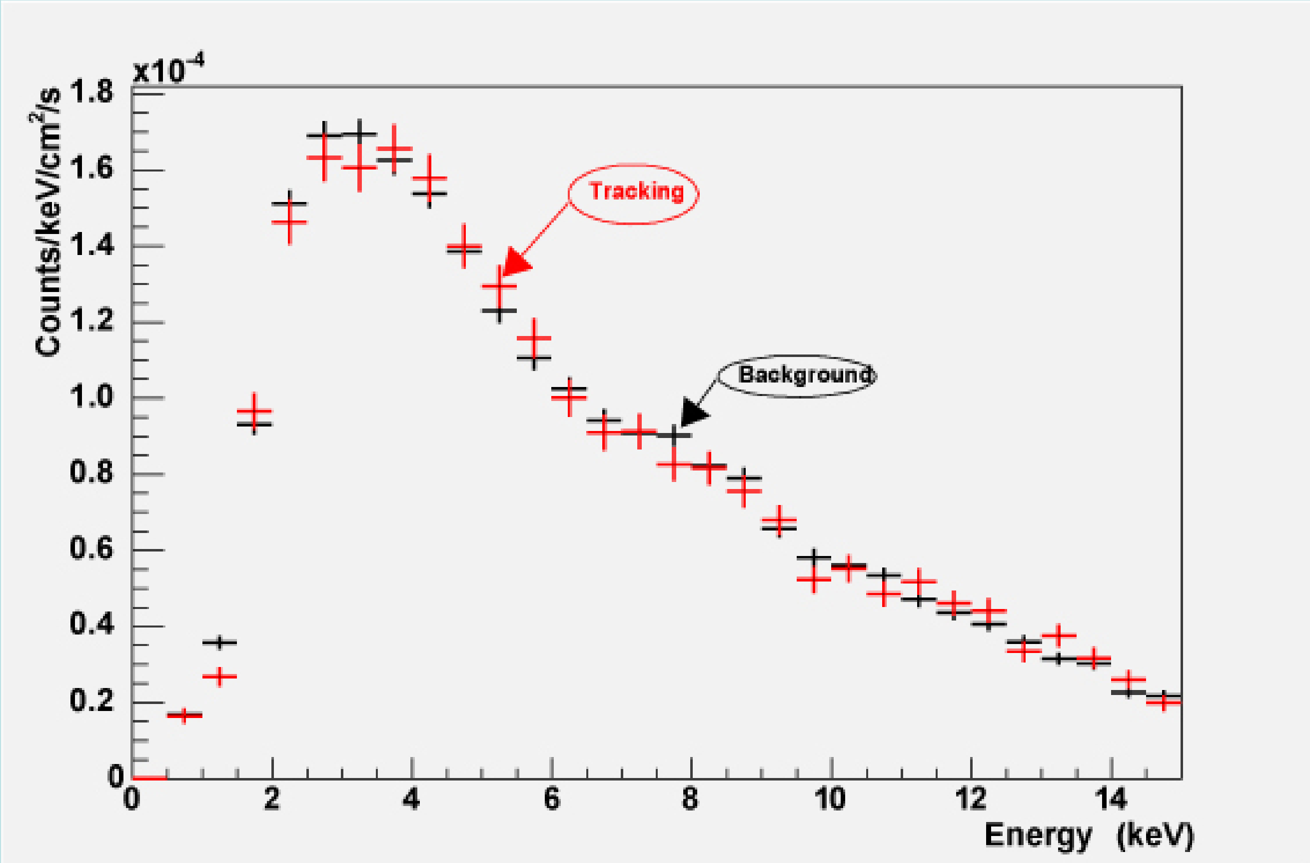
Detector Dead time: 5 %

Software efficiency

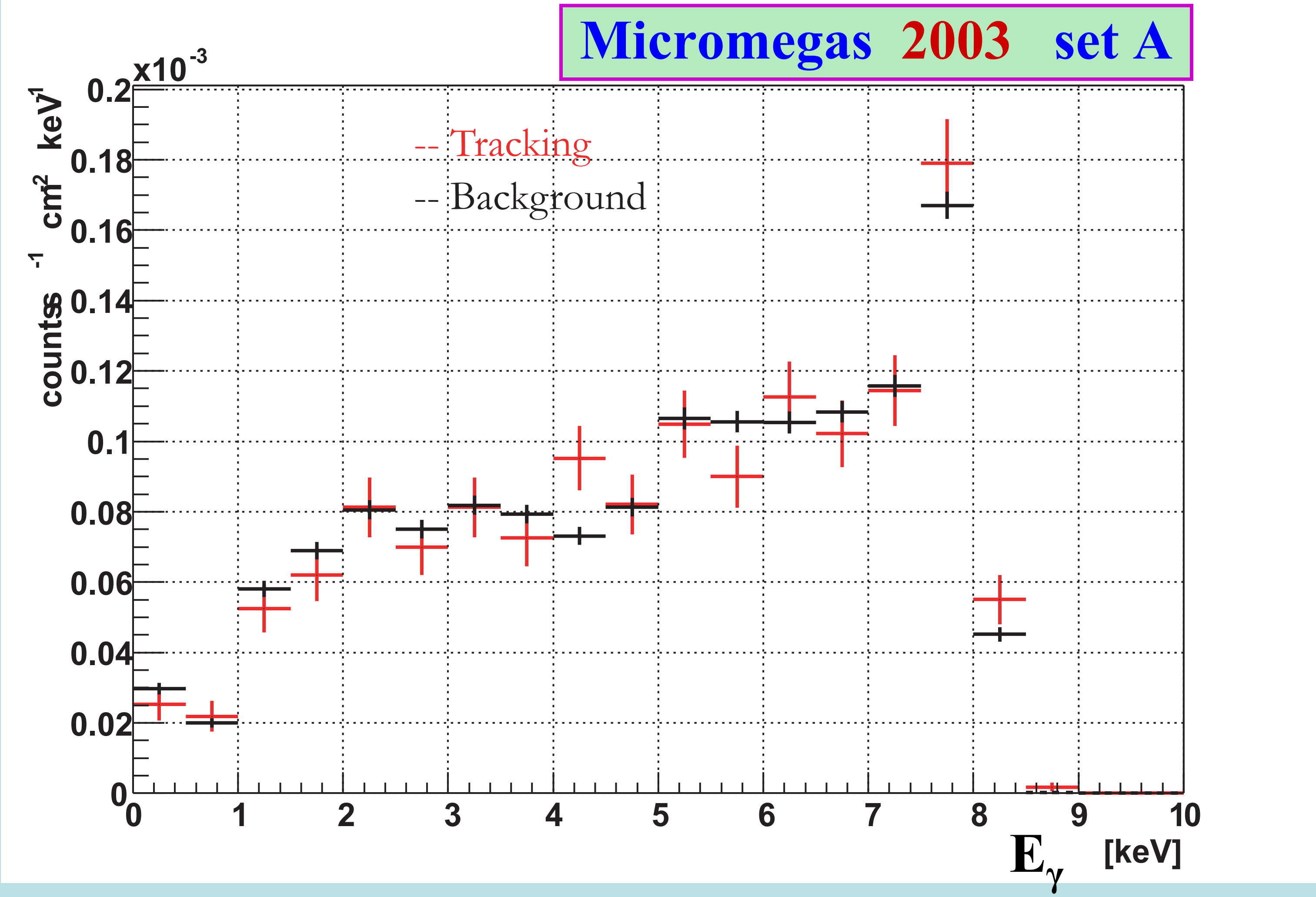
77%@3 keV 87%@6 keV

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

TPC 2003



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



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

2003

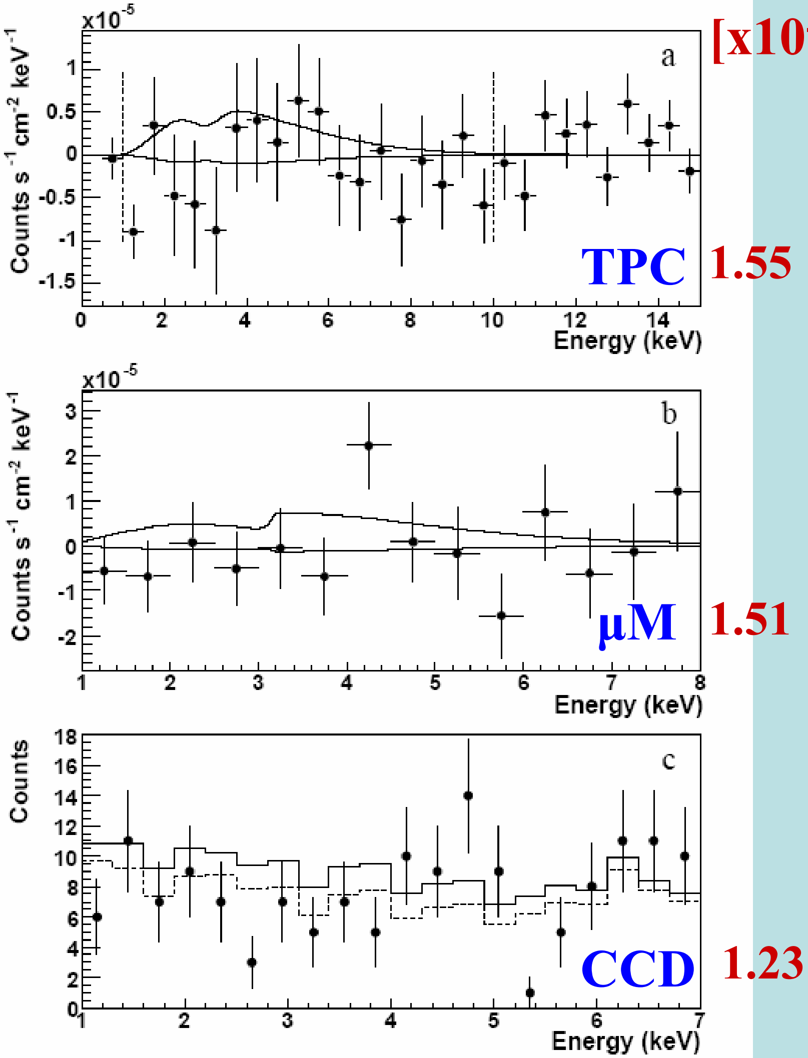


FIG. 1: Panels (a) and (b) show respectively the experimental subtracted spectrum of the TPC data set and MM data set A, together with the expectation for the best fit $g_{a\gamma}$ (lower curve) and for the 95% CL limit on $g_{a\gamma}$. For (a) the vertical dashed lines indicate the fitting window. 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).

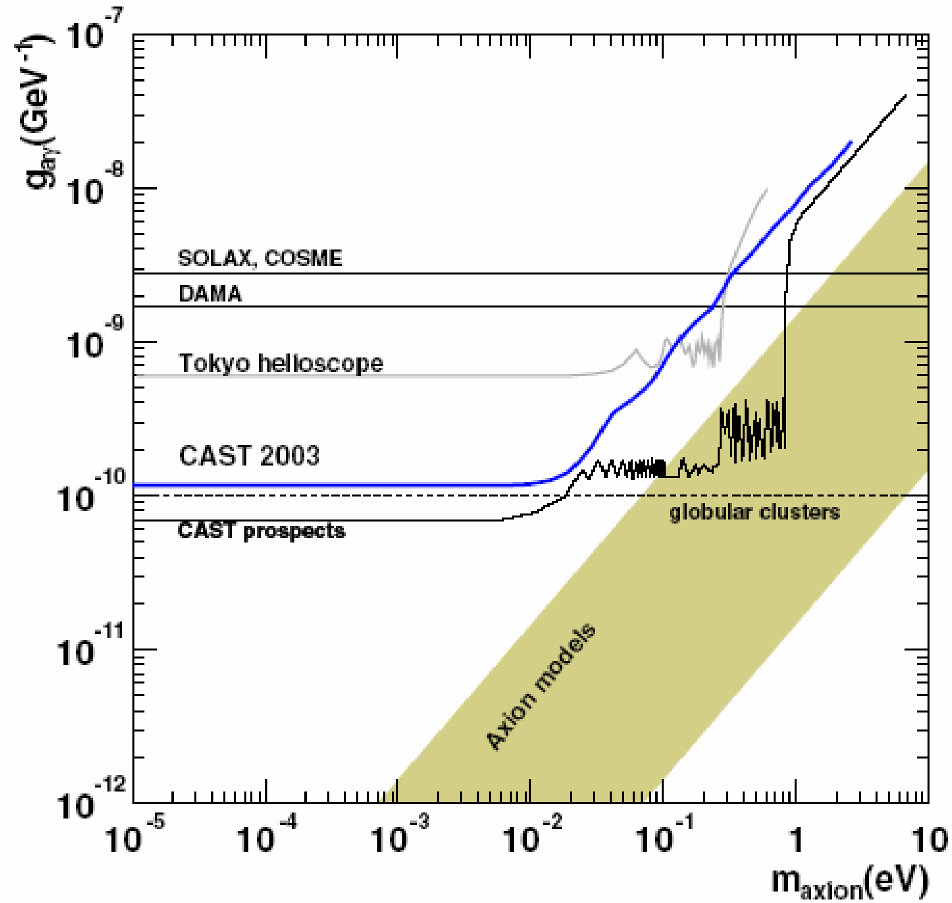


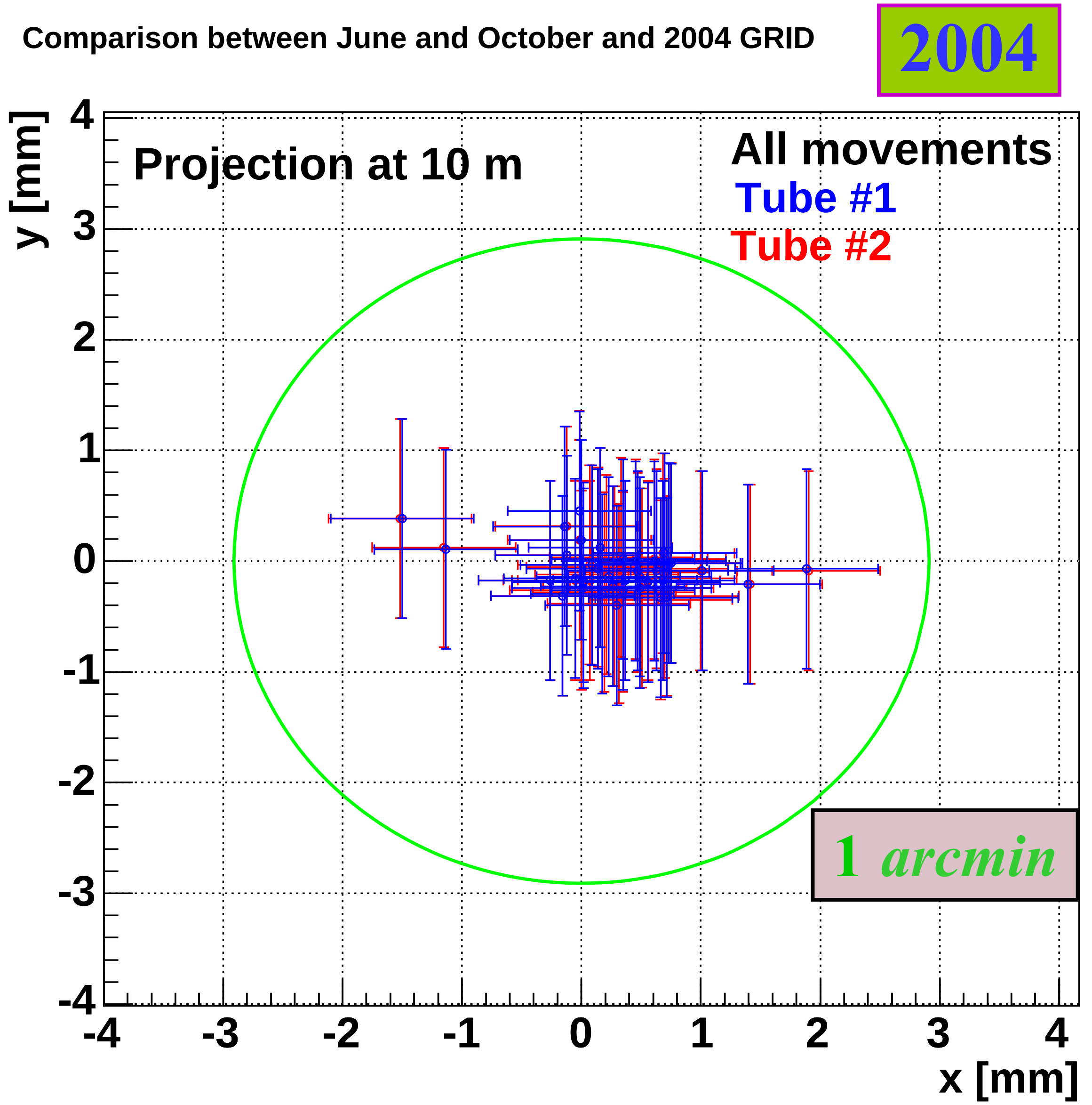
FIG. 2: Exclusion limit (95% CL) from the CAST 2003 data compared with other constraints discussed in the introduction. The shaded band represents typical theoretical models. Also shown is the future CAST sensitivity as foreseen in the experiment proposal. **K.Z. *et al.*, PRL 94 (2005) 121301**

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

2004

- ➔ ***improvements***
  - ➔ ***less detector background***

Comparison between June and October and 2004 GRID



GRID measurements:

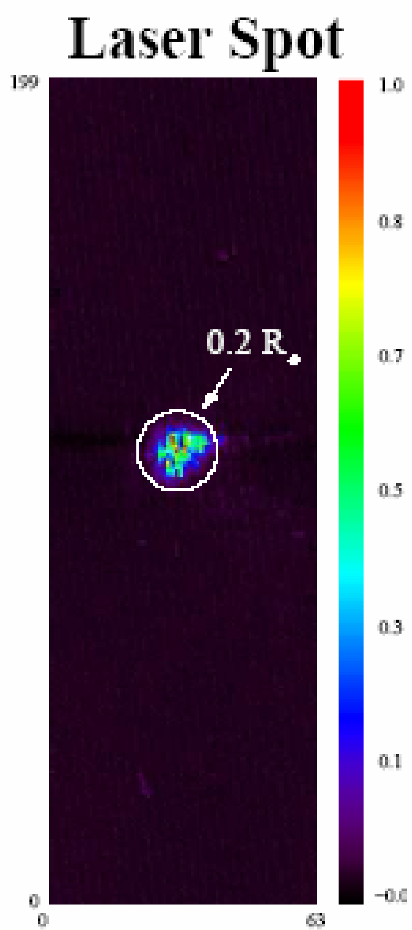
- with the surveyors of CERN
  - define pointing of the magnet + XRTelescope
    - at ~ 100 positions
      - cold & warm

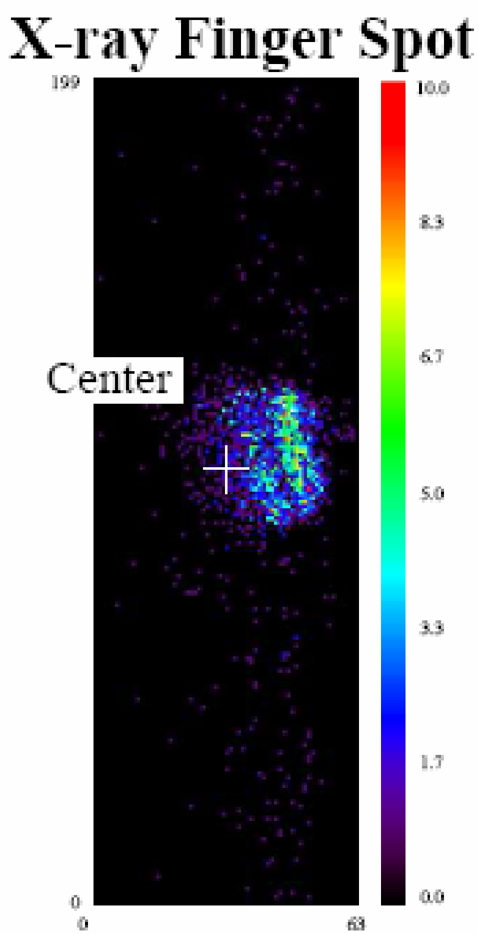
- **Tracking System**:
  - Calibrated and correlated with celestial coordinates

Filming of the Sun:

- March & September
  - alignment cross check

Telescope Alignment – Improvement





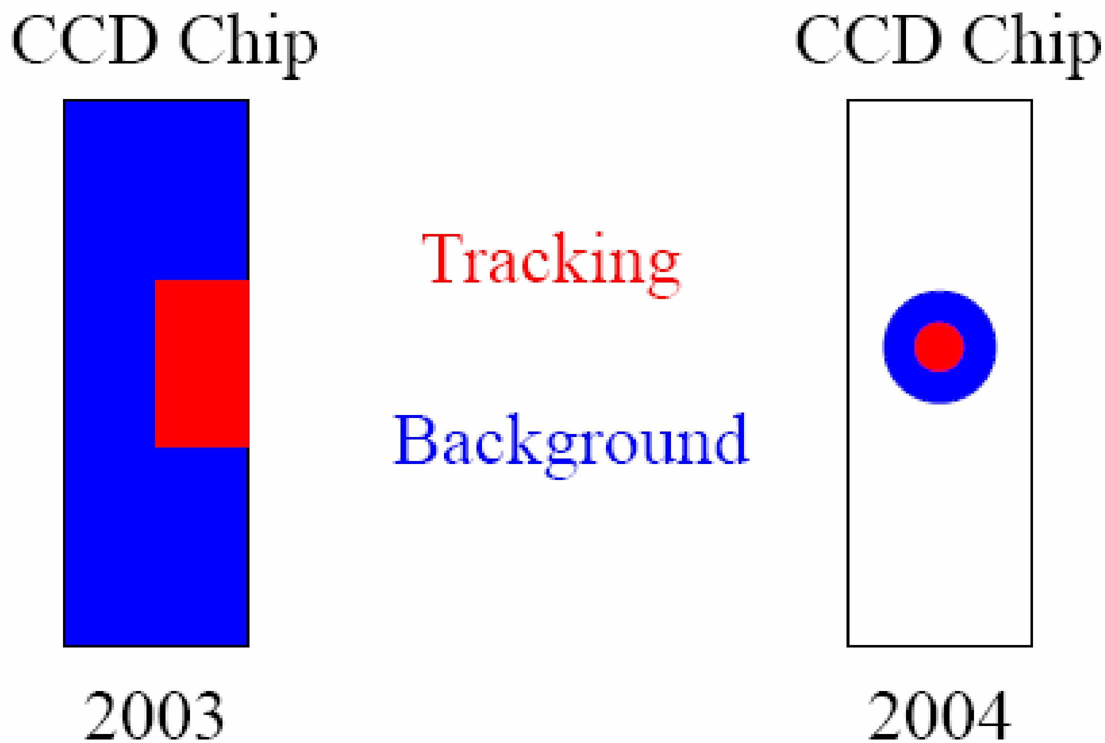
Defines the location of the Axion signal !

$X = 30.8 \quad Y = 109.6$

Defines the reference position to verify the alignment !

$X = 43.5 \quad Y = 108.0$

Telescope Spotsize 2003 → 2004

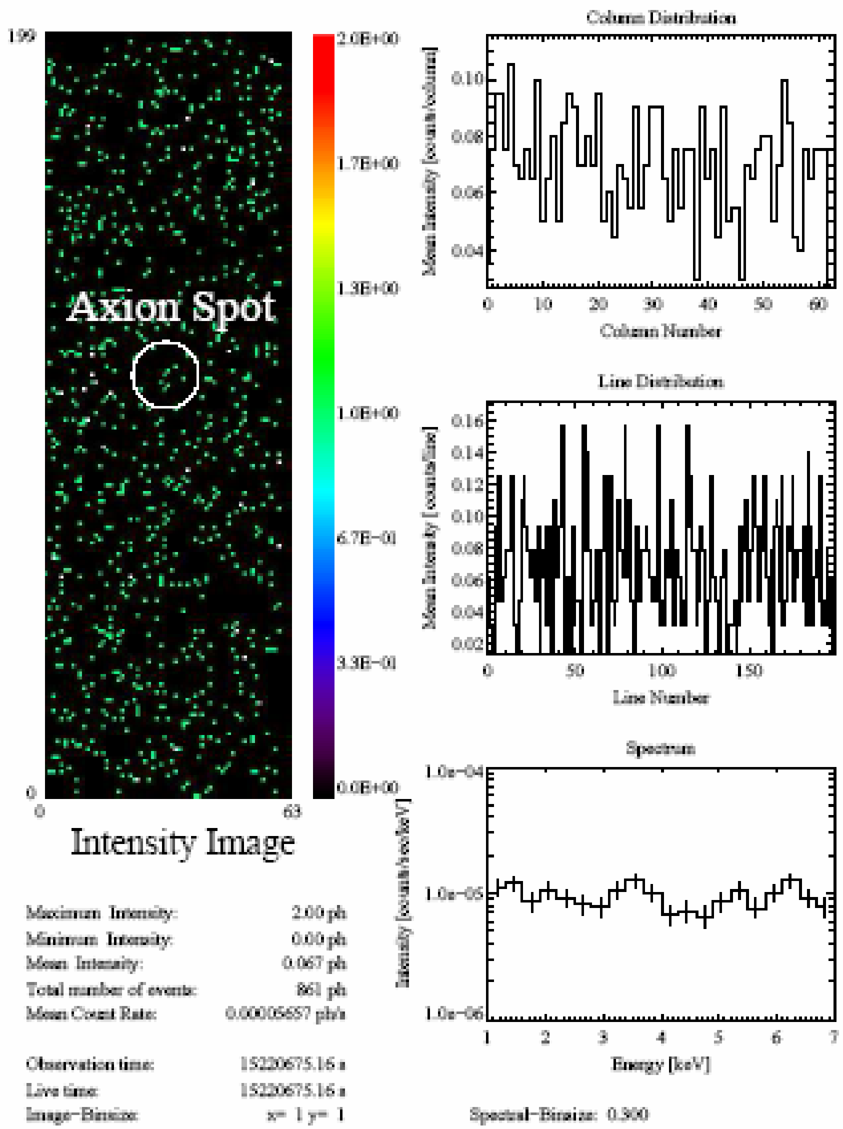


For 2004 signal area = axion spot size ($51\,\mathrm{mm}^2 \Longrightarrow 6\,\mathrm{mm}^2$) !

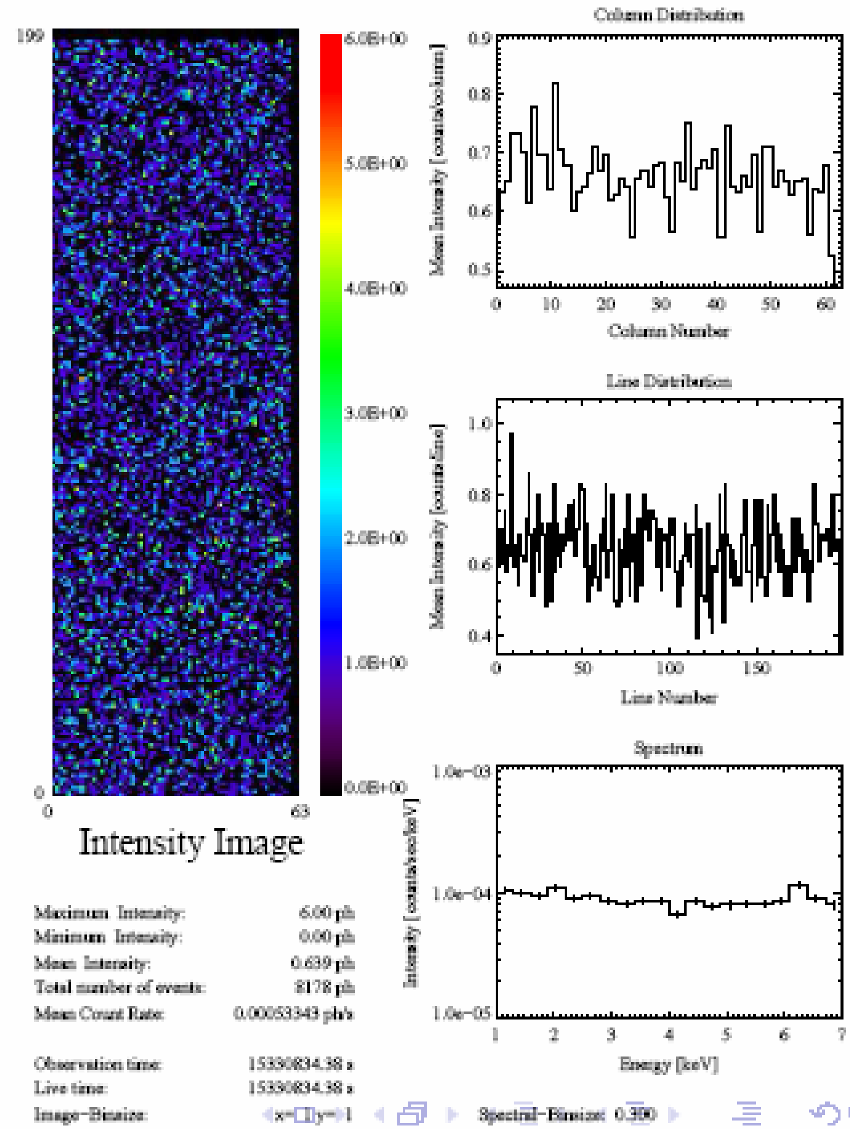
Exploiting the full sensitivity of the X-ray telescope !

2004 CCD Images

Tracking Data

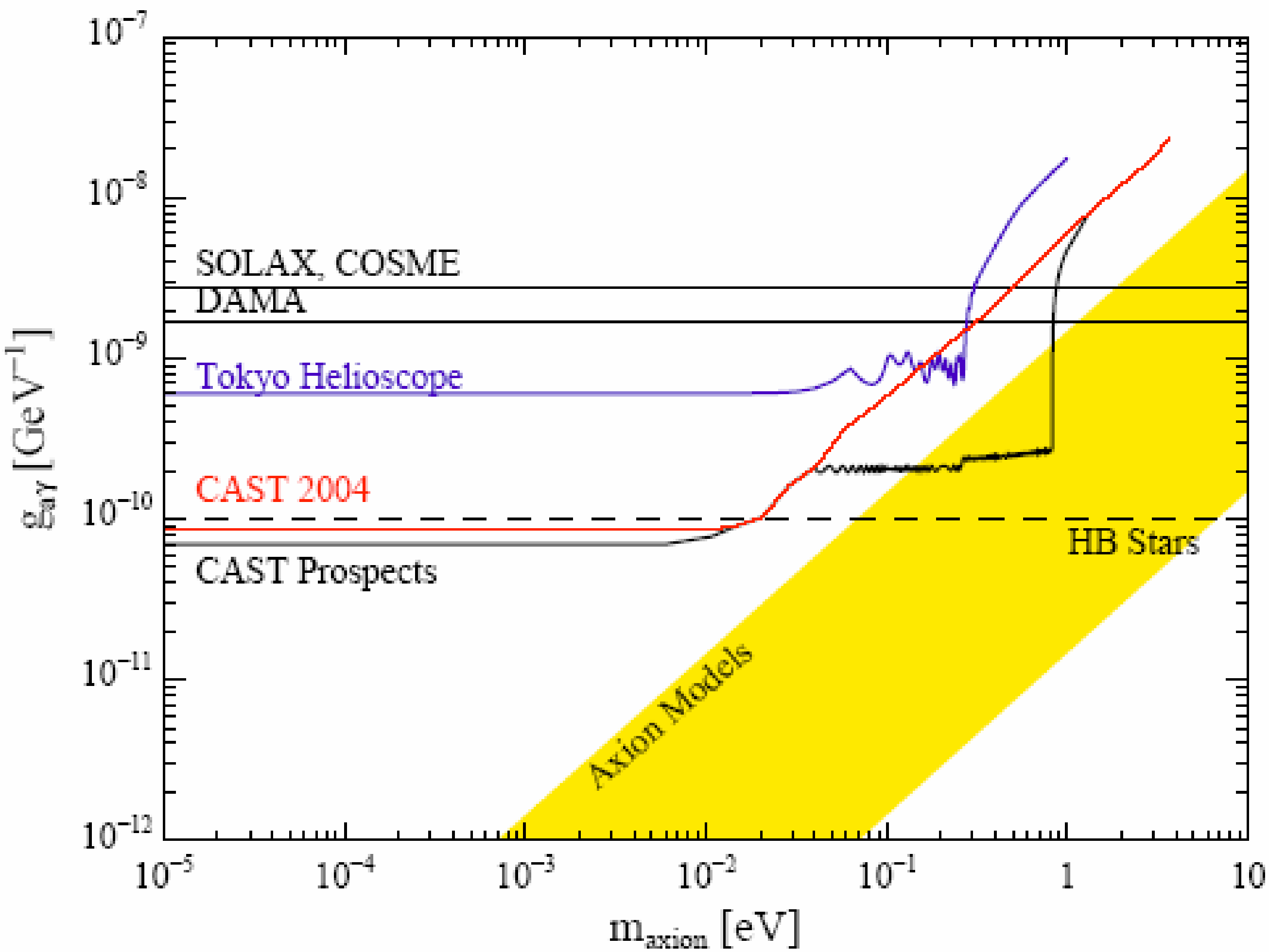


Background Data



Exclusion Plot 2004 VERY PRELIMINARY !!

VERY PRELIMINARY



VERY PRELIMINARY

2004 CAST limit includes statistical errors only !

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 ➔

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

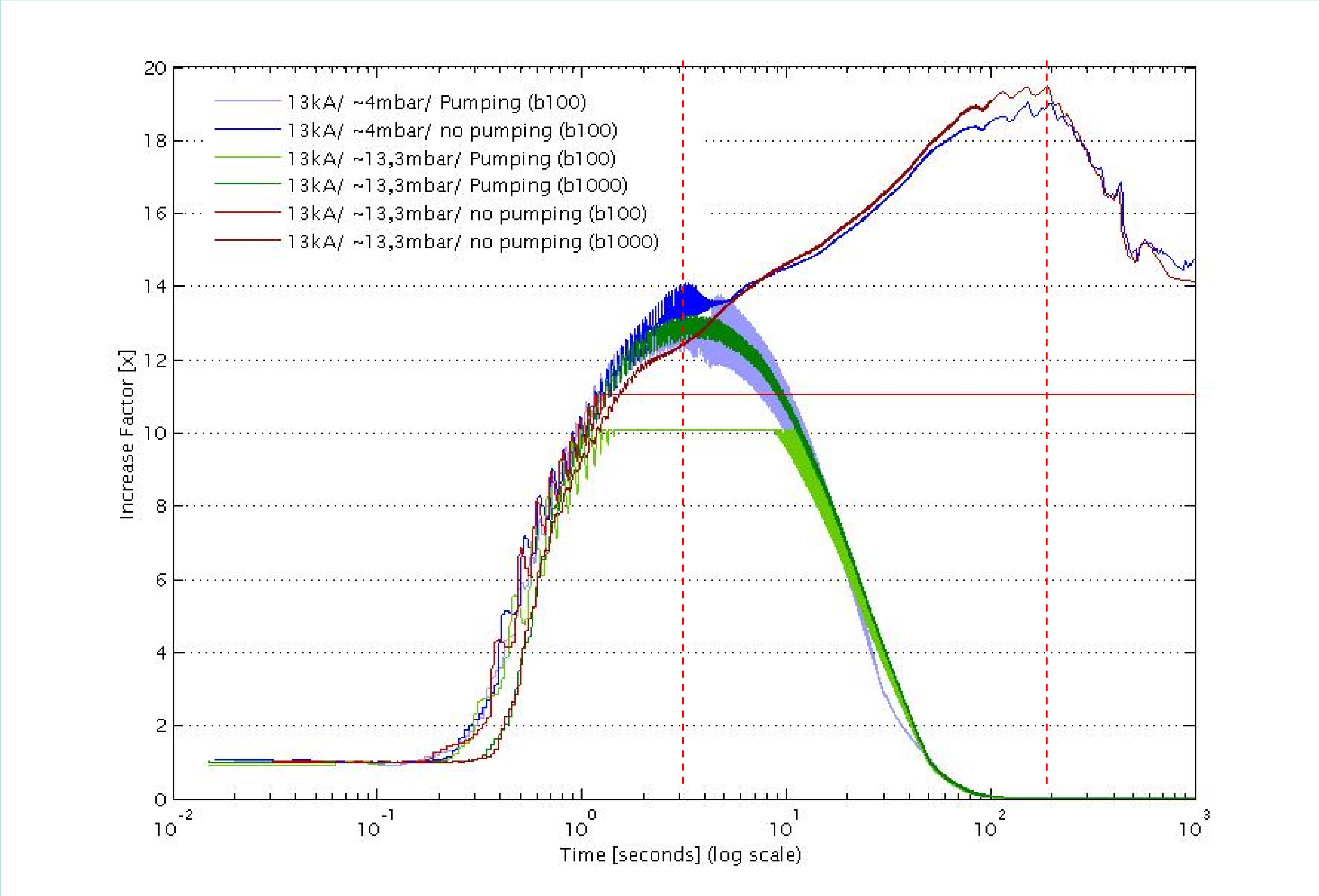
➔ a new **hot dark matter** component, in addition to ν's .

➔ New cosmological limit on relic axions:

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

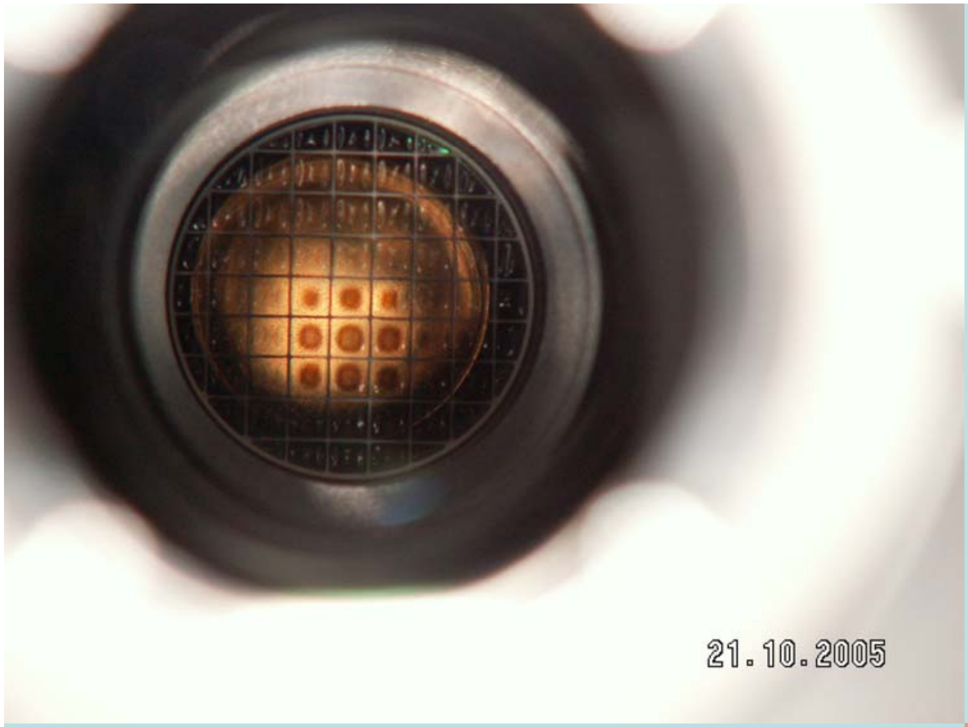
S. Hannestad, A. Mirizzi, G. G. Raffelt, hep-ph/**2005**04059

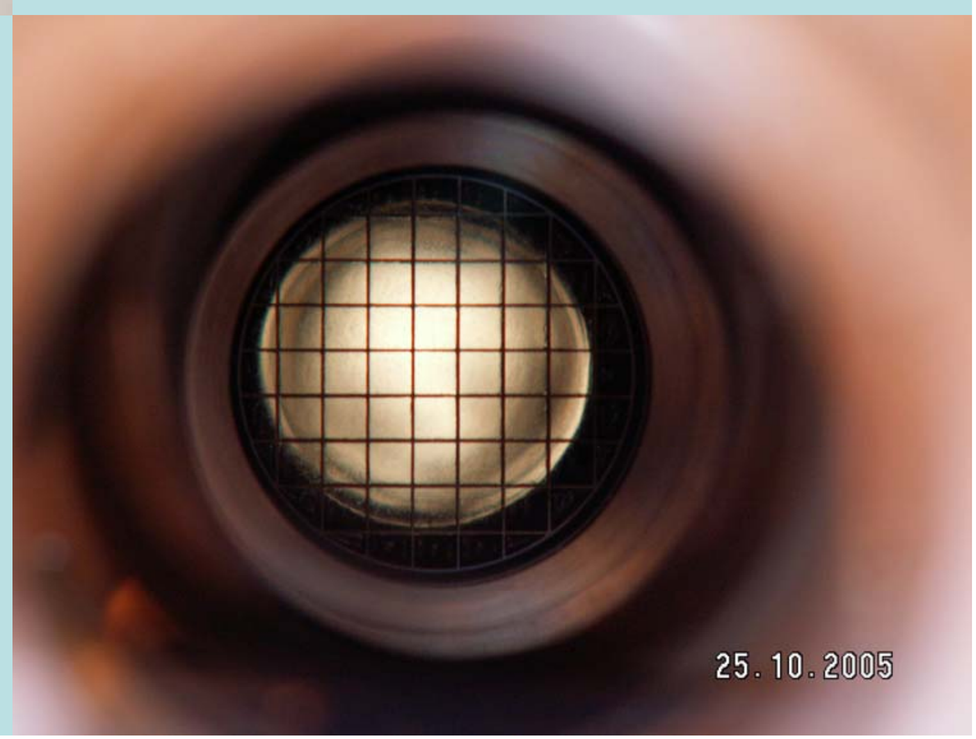
Quench – Pressure/Temperature Evolution



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

Thin windows @ 1.8K





CAST Phase II

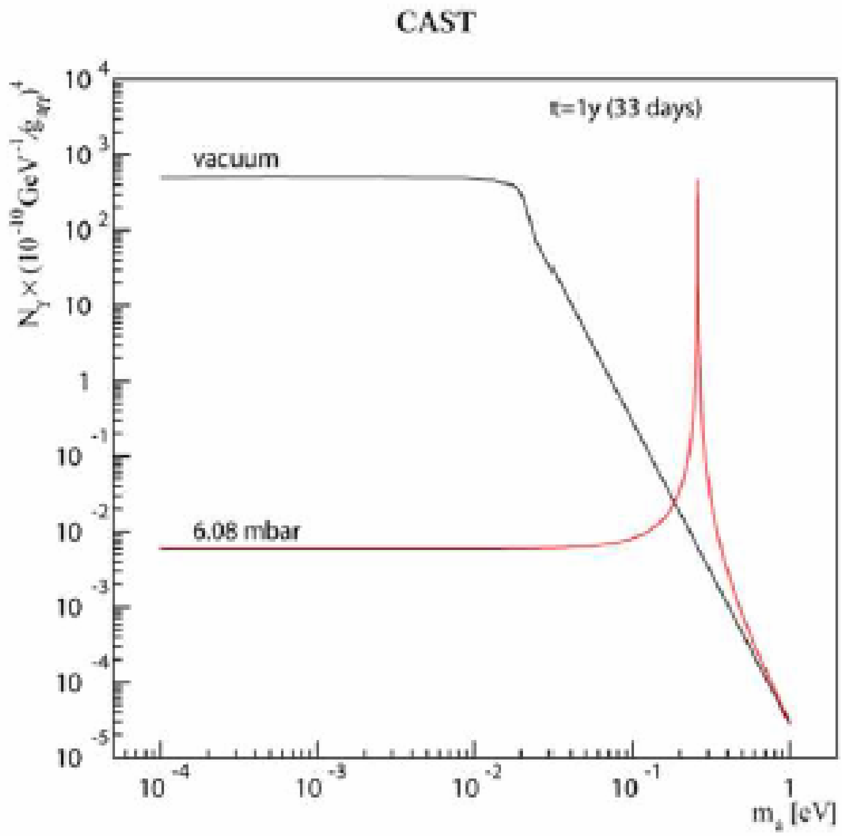
Fill magnet bore with buffer gas

^4He or ^3He

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

$\Longrightarrow$ 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 $m_{\text{a}} > 0.02\,\text{eV}/\text{c}^2$

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

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

CAST Phase II

Fill magnet bore with buffer gas

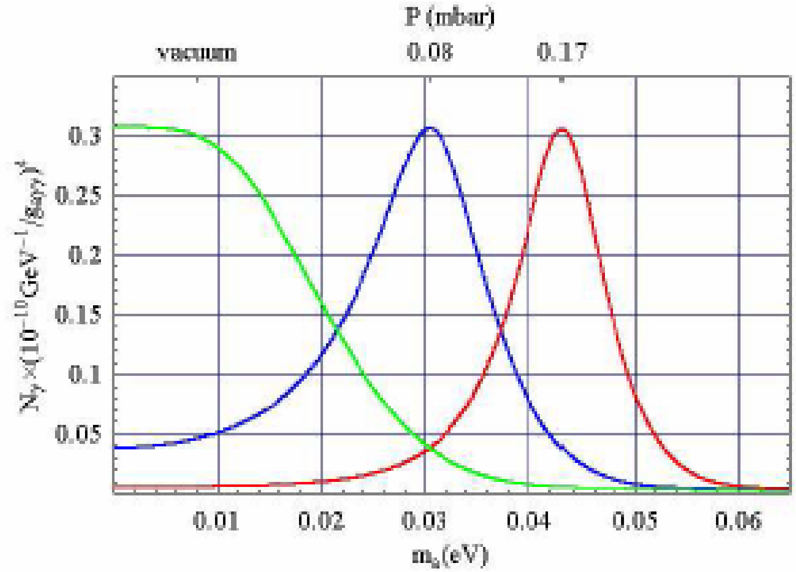
^{4}He or ^{3}He

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

$\Longrightarrow$ photon acquires an effective mass

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

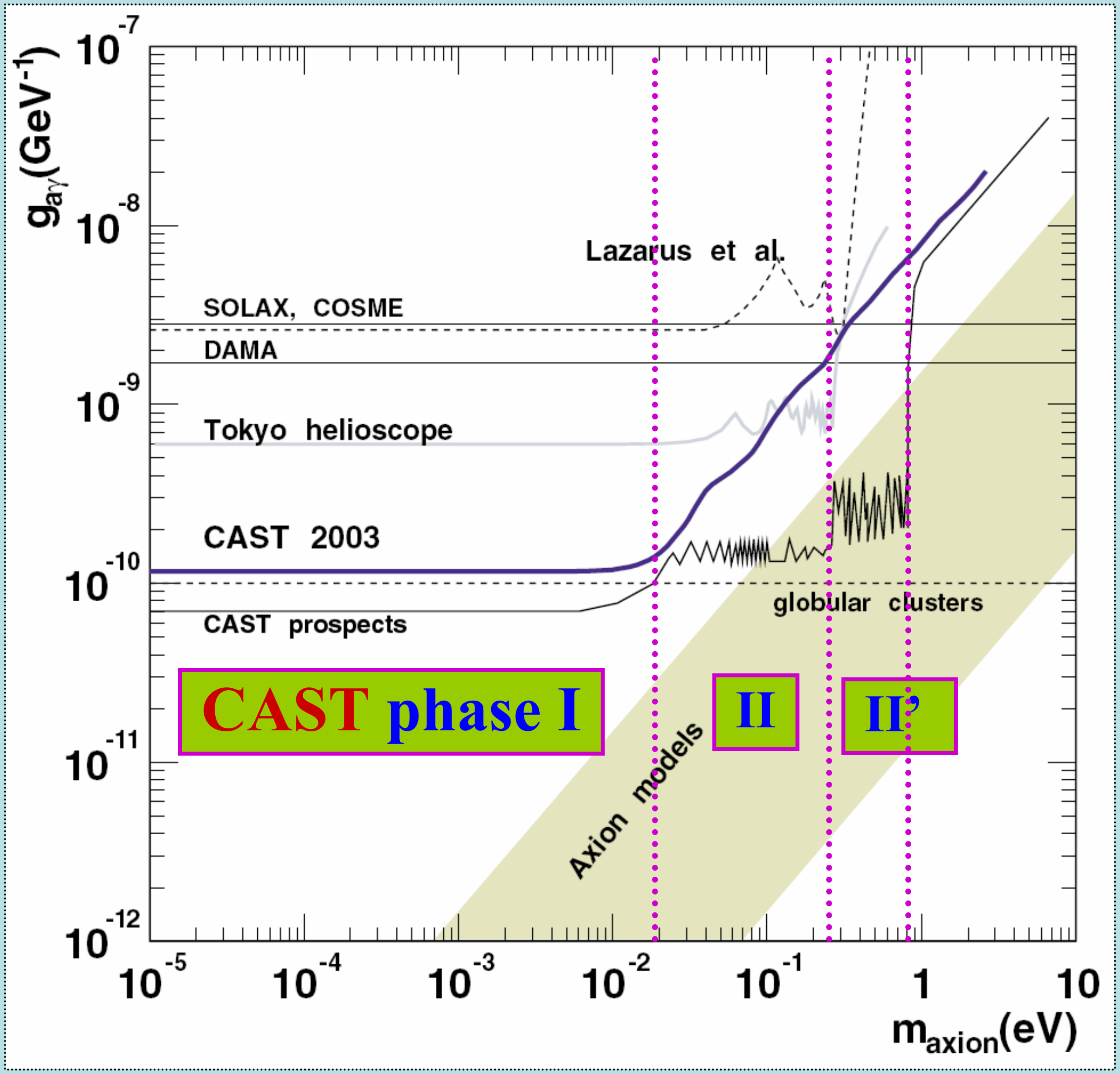
Different Pressure Settings



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

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

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



2005 ~ 100 pressure settings ^4He (<6 mbar)

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

Coherence as a function of axion energy and 0.2 eV axion mass

Yannis Semertzidis-BNL
June 2006

The axion/photon oscillation length in vacuum is given by [1,2]

$$qL = 2\pi \Rightarrow L = \frac{4\pi\omega}{m_a^2}$$

Where ω is the axion energy and the converted photon energy as well. In order to improve the axion mass coverage one can "slow down" the photons by effectively giving them mass [3]. Right at the resonance condition the oscillation length is infinite. The axion mass range covered at one pressure setting is limited and it depends on the axion mass, the length of the magnetic field and the energy of the axion. The plasma angular velocity frequency is given by [2]

$$\omega_p = \omega\left(\frac{m_a}{\hbar\omega}\right)\left[1 \pm \frac{\pi}{kL}\left(\frac{\hbar\omega}{m_a}\right)^2\right] = \left(\frac{m_a}{\hbar}\right)\left[1 \pm \frac{\pi}{L}\frac{\hbar^2\omega c}{m_a^2}\right]$$

It is clear that the plasma frequency that corresponds to one axion mass is independent of the axion energy. The axion energy influences linearly the width of the pressure setting that is valid to a specific axion mass. As an example for 3 KeV axion energy, L=10 m and 0.2 eV axion mass, the equation becomes:

$$\omega_p = 0.3\times10^{15}\,\mathrm{s}^{-1}\left[1 \pm 0.005\right]$$

For 6 KeV axion energy the equation becomes:

$$\omega_p = 0.3\times10^{15}\,\mathrm{s}^{-1}\left[1 \pm 0.01\right]$$

Another way to show the axion mass dependence on the axion energy is by solving the equation (see ref. [2], the slide on Axion-photon conversion in gas) for the axion mass:

$$m_a = \hbar\omega_p\left[1 \pm \frac{\pi\omega c}{L\omega_p^2}\right]$$

Here clearly, the axion energy does not influence the axion mass at the resonance condition, it only influences the range of the axion mass the pressure setting is sensitive

to. For 3 KeV axion energy, L=10 m and 0.2 eV axion mass, the specific pressure sett
is sensitive to an axion mass range:

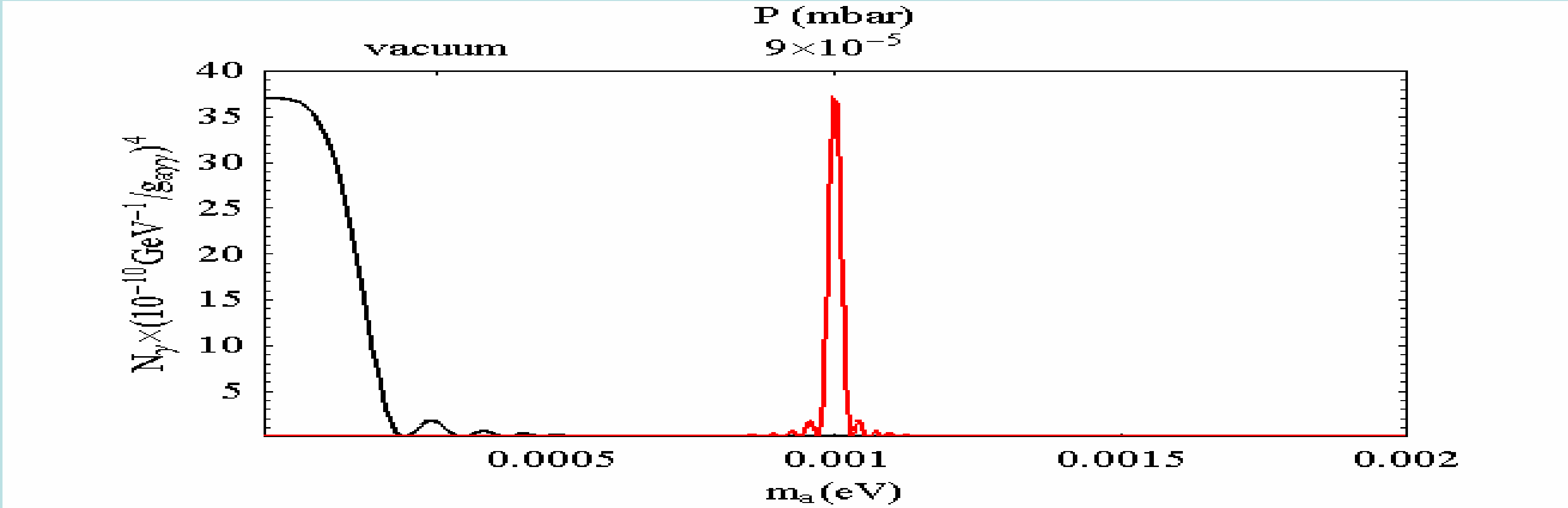
$$m_a = 0.2\ \text{eV}\ [1 \pm 0.005]$$

giving the same width as above!

Note: Strictly speaking, for every photon counted, we should take into account the energy of the photon and assign a limit to a specific axion mass range.

References:

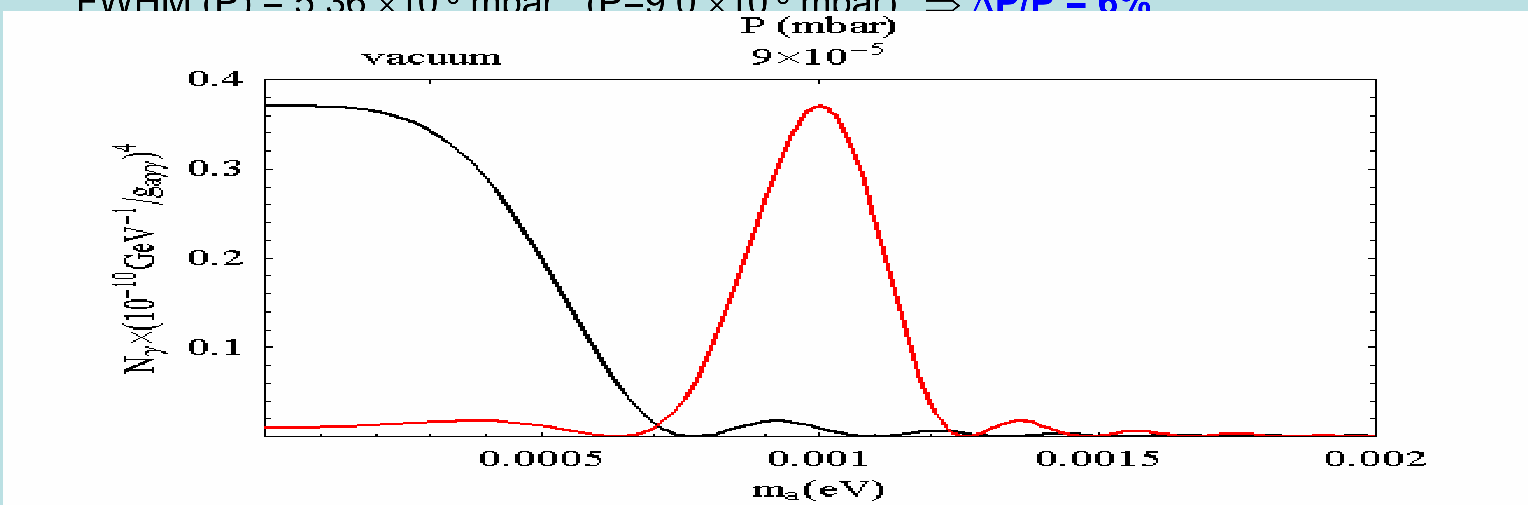
1. G. Raffelt and L. Stodolsky, Phys. Rev. **D37**, 1237 (1988).
2. Y. Semertzidis, presentation on axion/photon coherence in Patras, May 2006.
3. Karl van Bibber *et al.*, Phys. Rev. **D39**, 2089 (1989).



Coherence region for **E=2.4 eV, L=100 m**:

FWHM (m_a) = 2.98×10^{-5} eV (m$_a$=1.0×10^{-3} eV) ⇒ Δm/m = 3%

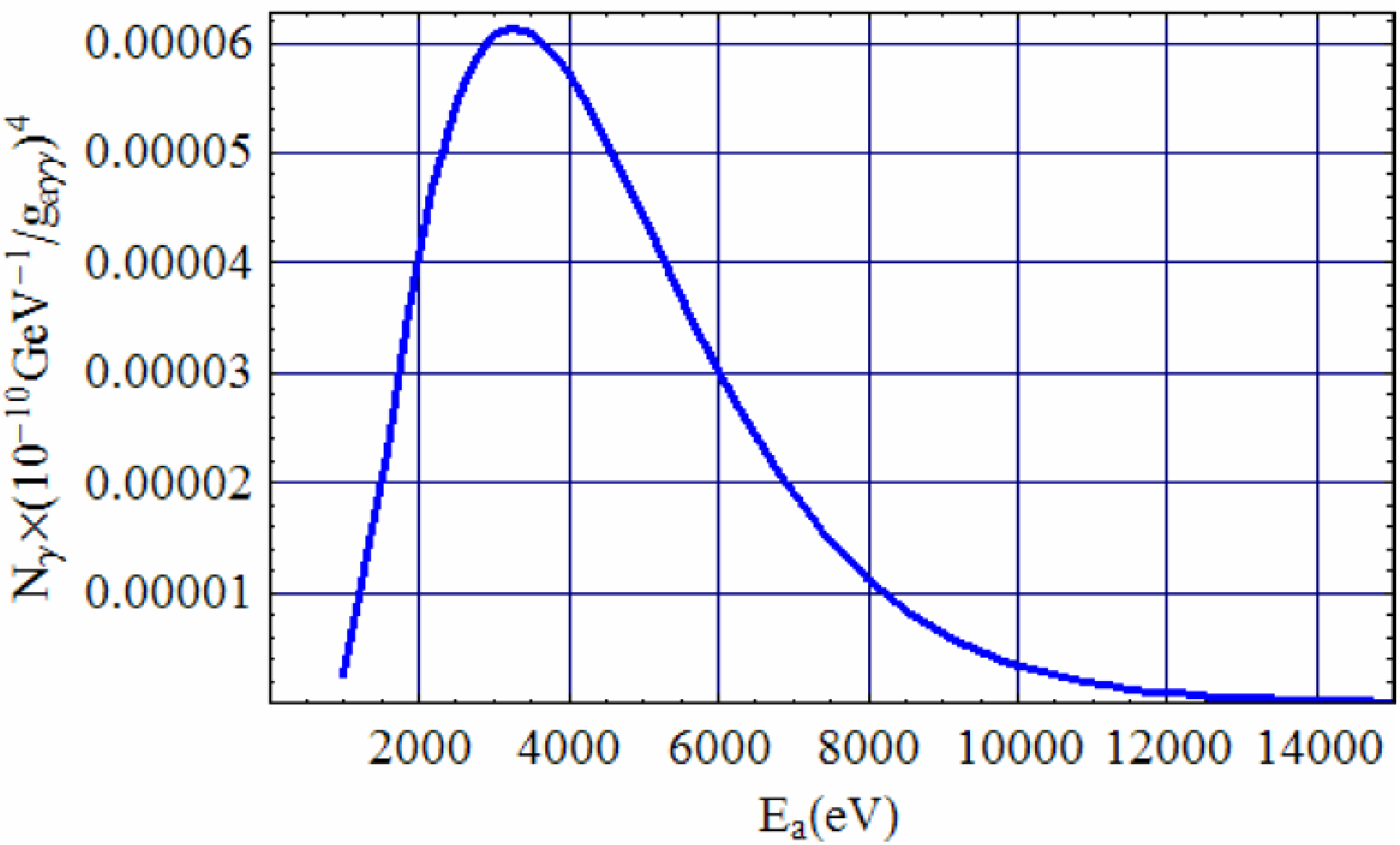
FWHM (P) = 5.36 ×10^{-6} mbar (P=9.0 ×10^{-5} mbar) ⇒ **ΔP/P = 6%**



Coherence region for **E=2.4 eV, L=10 m**:

FWHM (m_a) = 3.01×10^{-4} eV (m$_a$=1.0×10^{-3} eV) ⇒ Δm/m = 30%

FWHM (P) = 5.36 ×10^{-5} mbar (P=9.0 ×10^{-5} mbar) ⇒ **ΔP/P = 60%**



1) $\Delta m=0$, $\Delta P=0$ (resonance!); $\langle E \rangle = 4.48$ keV

RBI group / Zagreb

Other experiments ?

X ← **PVLAS** ➔ e.g. KK-axions

≠ PQ axions

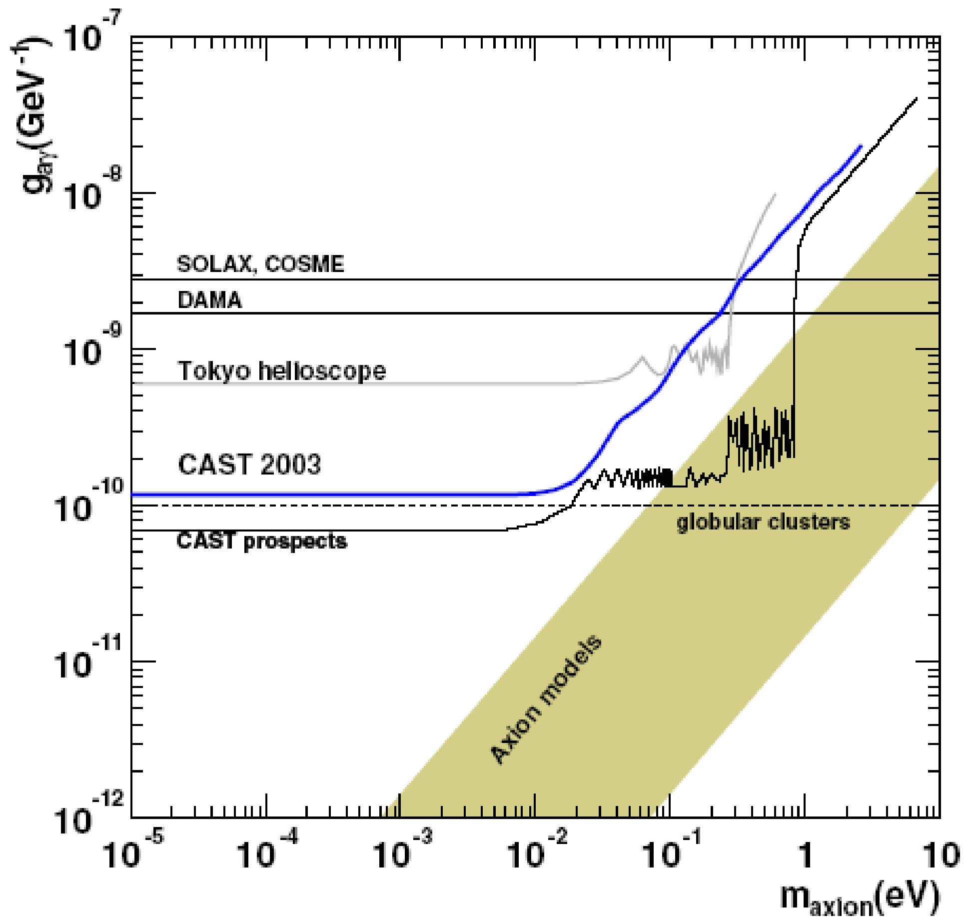


FIG. 2: Exclusion limit (95% CL) from the CAST 2003 data compared with other constraints discussed in the introduction. The shaded band represents typical theoretical models. Also shown is the future CAST sensitivity as foreseen in the experiment proposal.

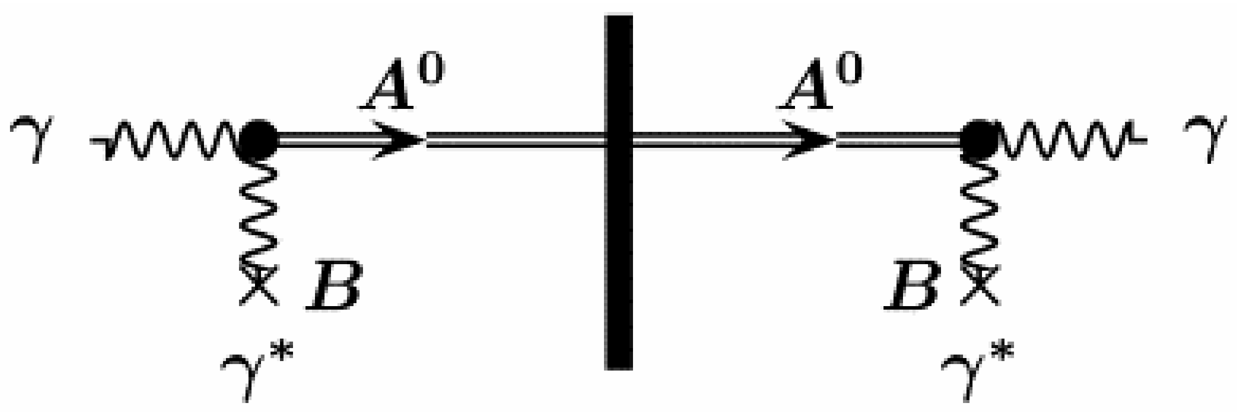
K.Z. et al. PRL 94 (2005) 121301

?

Test PVLAS @ CERN & DESY(2006) & JLAB?

"*Light shining through a wall experiment*" ➔ *direct detection*!

➔ *Andreas Ringwald* / **DESY**



➔ **Possible options:**

- CAST + 1 LHC magnet
- CAST/2
- 2 LHC magnets @ SM18
- **≥ eV solar axions ⊗ CAST**

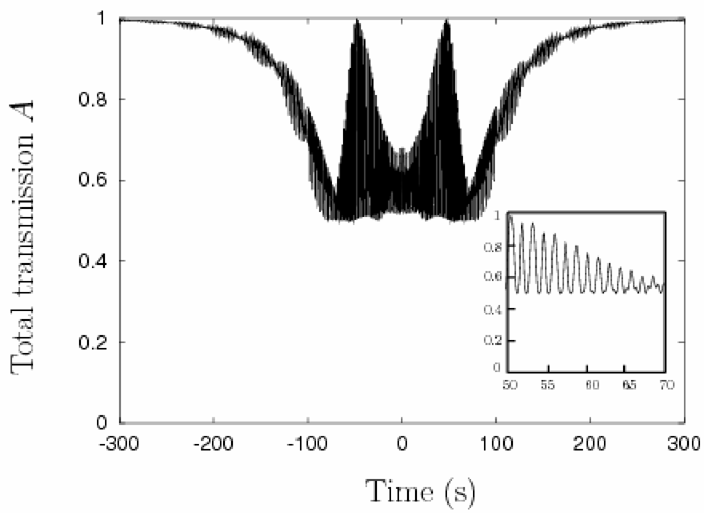
➔ ***see VILLARS meeting 2004***

mimic CAST

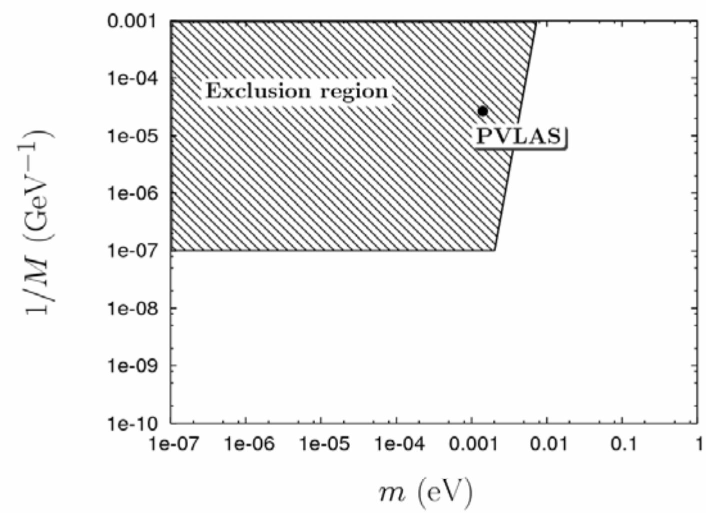
$\Downarrow$

(in)direct axion-signals ?

Système binaire d'étoiles à neutrons J0737-3039



Densité de flux du pulsar A vue de la terre à cause de la production de LPBs
(valeurs de masse et constante de couplage donnés par PVLAS).



A. Dupays et al., PRL 94 (**2005**) 161101 & PRL 95, 211302 (**2005**).

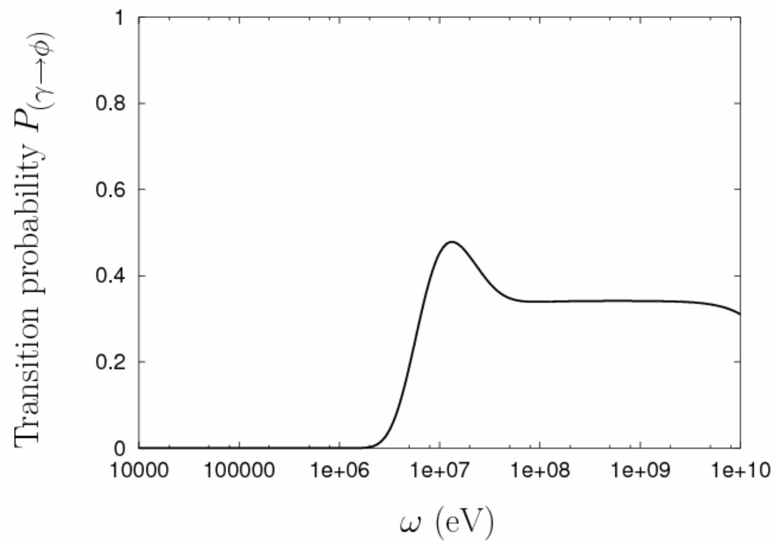
GLAST → 2006, 2007 **Carlo Rizzo**

Système binaire d'étoiles à neutrons J0737-3039

GLAST :
Opérationnel en 2007,
Contact pris, observation programmée

Grâce à GLAST on multipliera le nombre de pulsars connus dans la région gamma d'un facteur 10

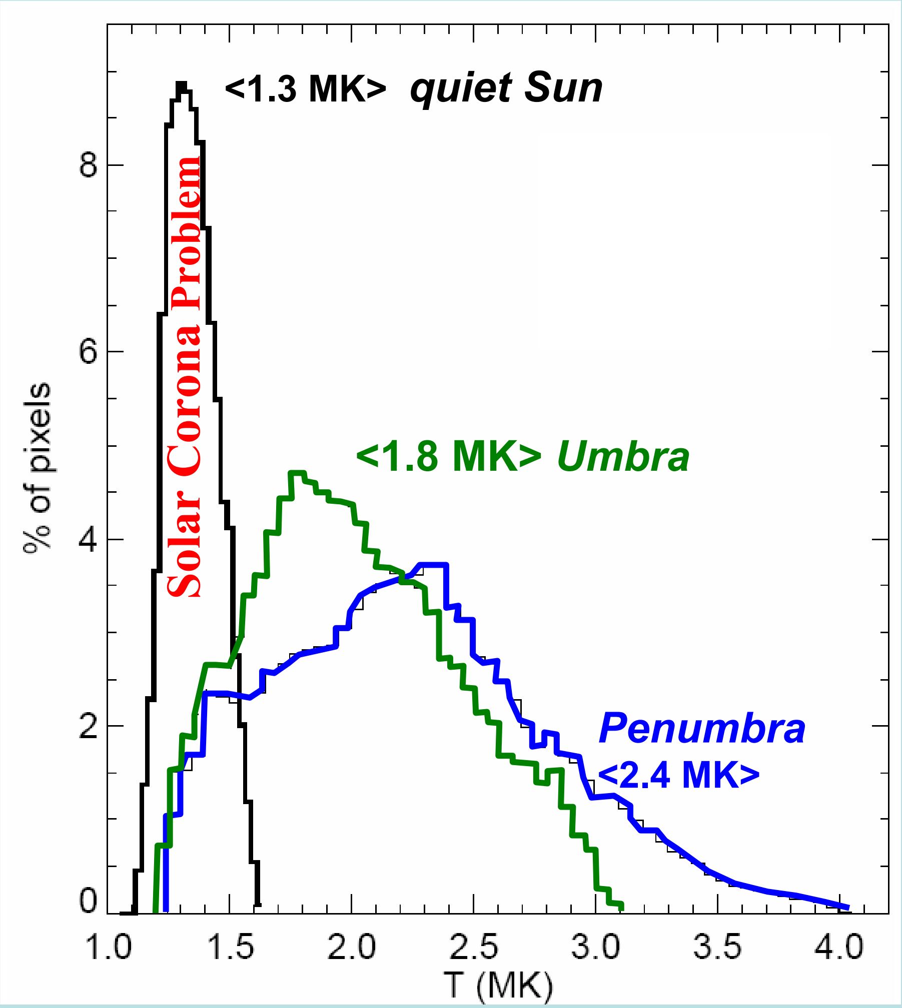
AGILE
« 1/16 de GLAST »
Opérationnel en 2006
Contacts pris



Dans ce système, la probabilité de transition Photon-LPB est maximal pour les rayons gamma.

A.Dupays etal. PRL 94 (2005)161101
& 95 (2005)211302

SUNSPOTS



Temperature distributions

➔ **Yohkoh - XRTelescope**

➔ **TAUP2005**

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
(ARs:	~ 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

Stellar observations + theory on stellar evolution

↛ stars might possess atmospheres … that produce X-rays.

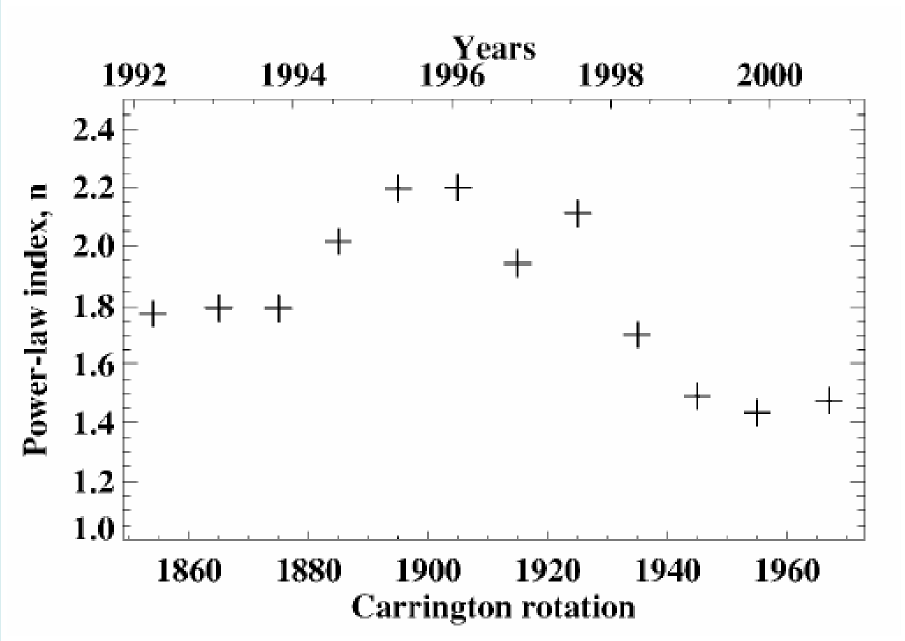
L.W. Acton, Magnetodynamic Phenomena in the Solar Atm. (**1996**) 3

- **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

➔ Signal for Axions?



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

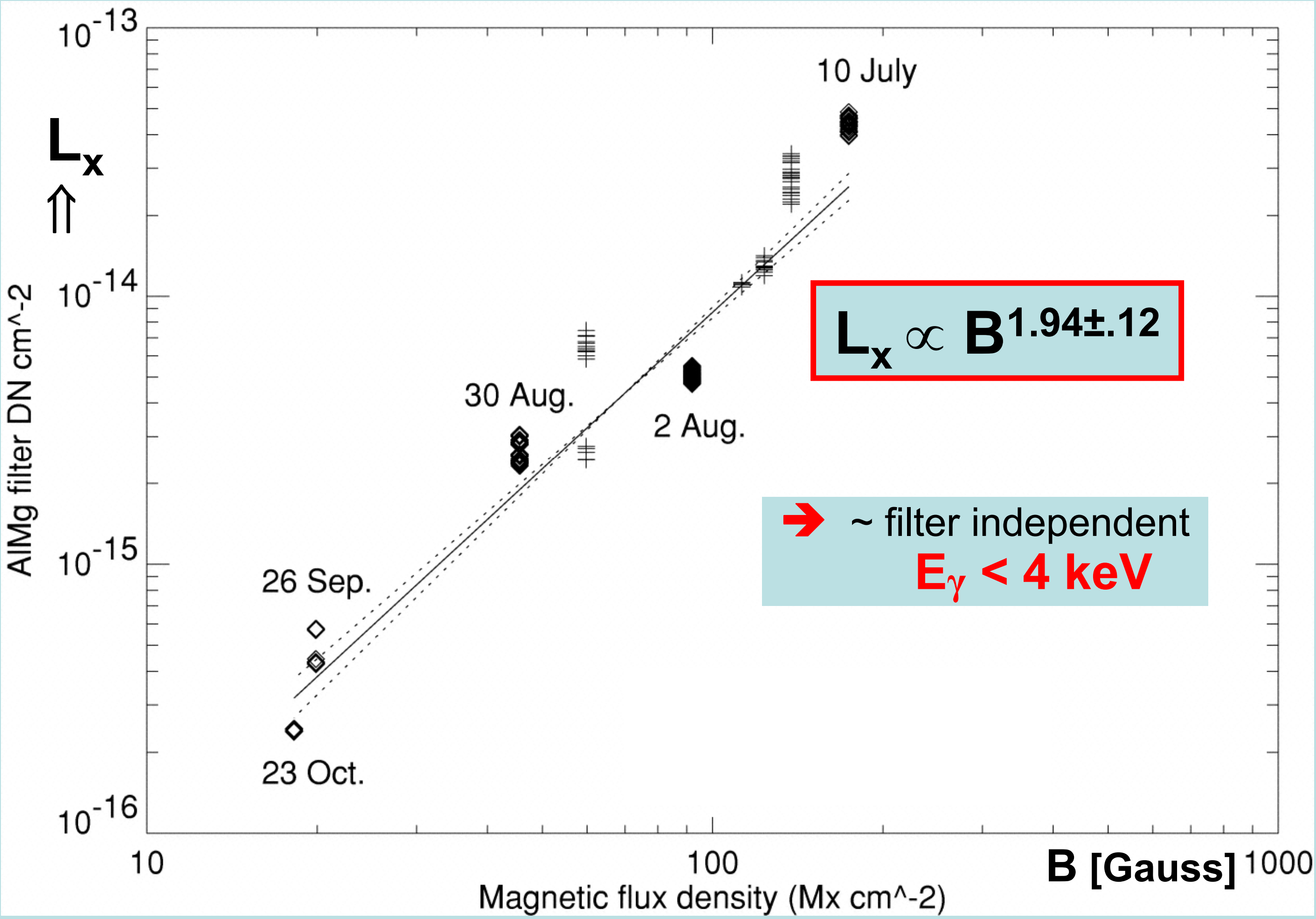
Benevolenskaya, Kosovichev, Lemen, Scherrer, Slater ApJ. 571 (**2002**) L181

Note: axion-to-photon oscillation $\propto$ B^2 ➔ e.g., in **CAST**

D.H.H. Hoffmann, K. Z., Nucl. Phys. B Suppl. 151 (**2006**) 359

➔ **11 years solar cycle?** ←

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



➔ TAUP2005

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 / **$AR_{surface}$**).
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

CAST @ Sun ?

P. Sikivie [1983]

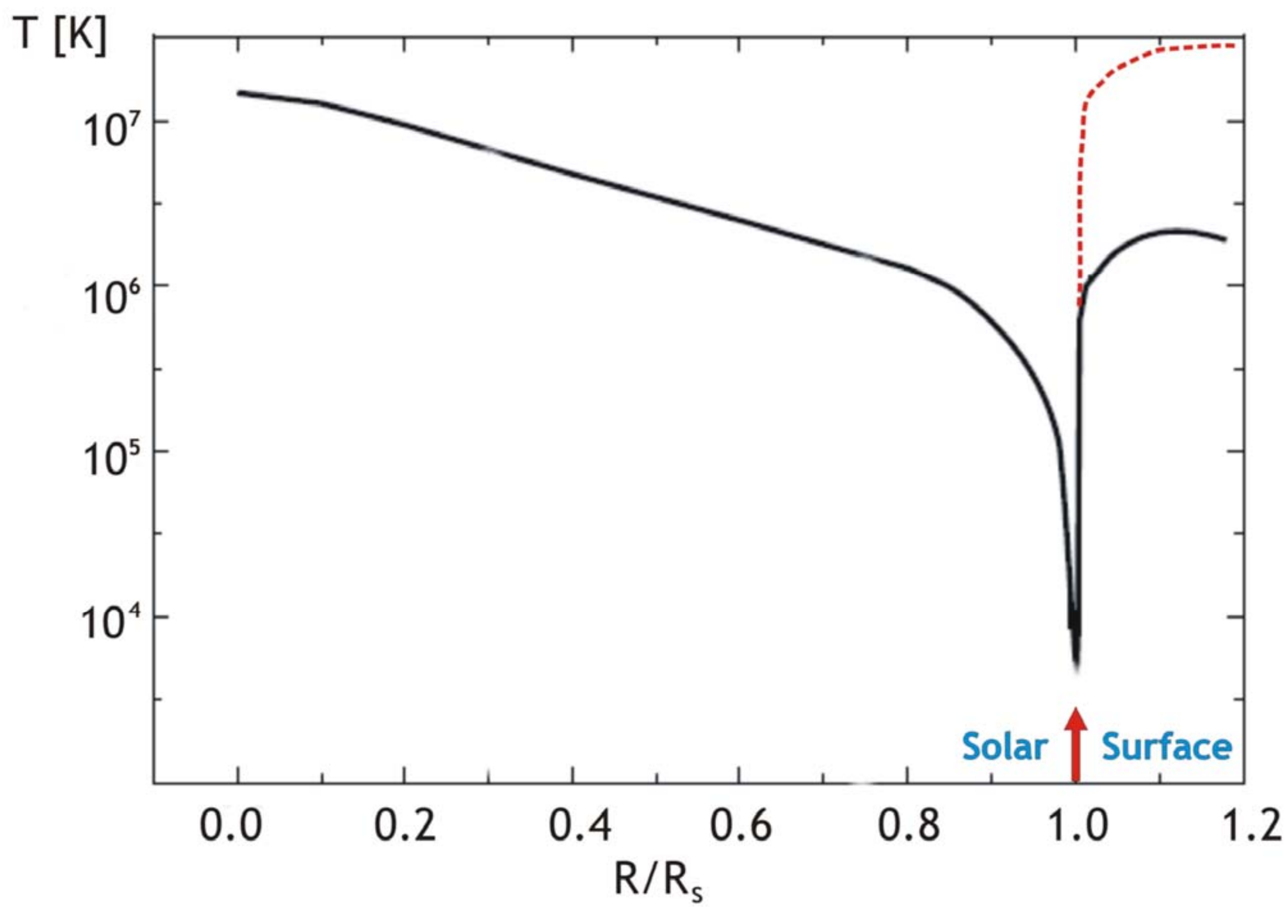
➔ 2nd component

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

$$I_x \sim B^2$$

➔ *low energy solar spectrum + transient phenomena*

Solar temperature distribution

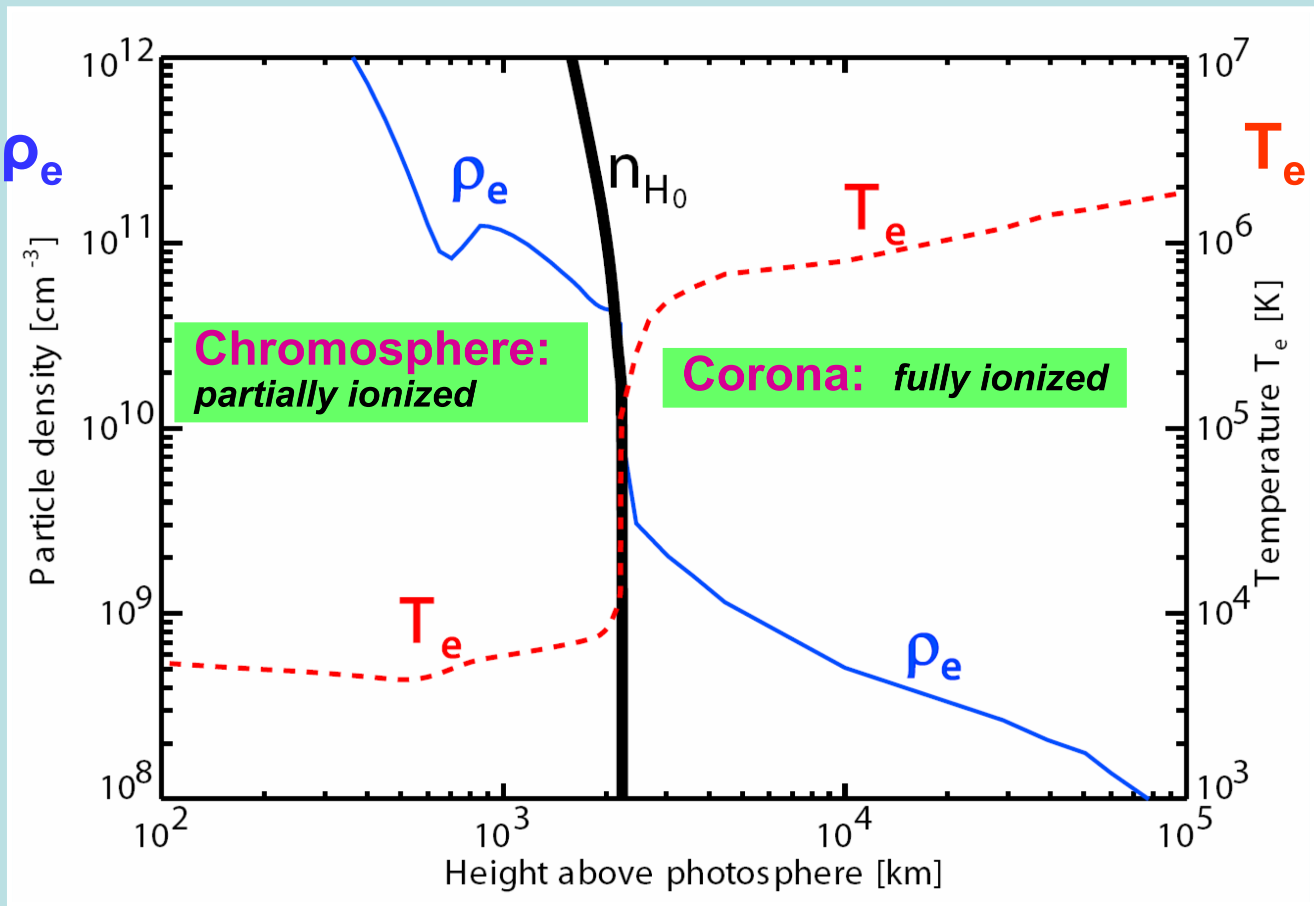


↛ **2nd Law of Thermodynamics?** ➔ **solar corona problem**

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



Electron density (ρ_e) and temperature (T_e) model of the chromo-sphere and the corona. The plasma becomes fully ionized at the ***sharp transition***: *)

Chromosphere → Corona

n_{H_0} = neutral hydrogen density.

***) ~100 km thick (vertical)** (S. Patsourakos et al., ApJ. 522 (1999) 540)

"At any given height, ρ_e varies by a factor of 10 - 100 over the entire corona." …

"The physical understanding of this high temperature in the solar corona is still a **fundamental problem in astrophysics**, because it seems to violate the **second thermodynamic law**, given the photospheric temperature T≈5785K (and drops to T~4500K in **sunspots**)."

M. Aschwanden, *Physics of the Solar Corona* (**2004**) p.24-26

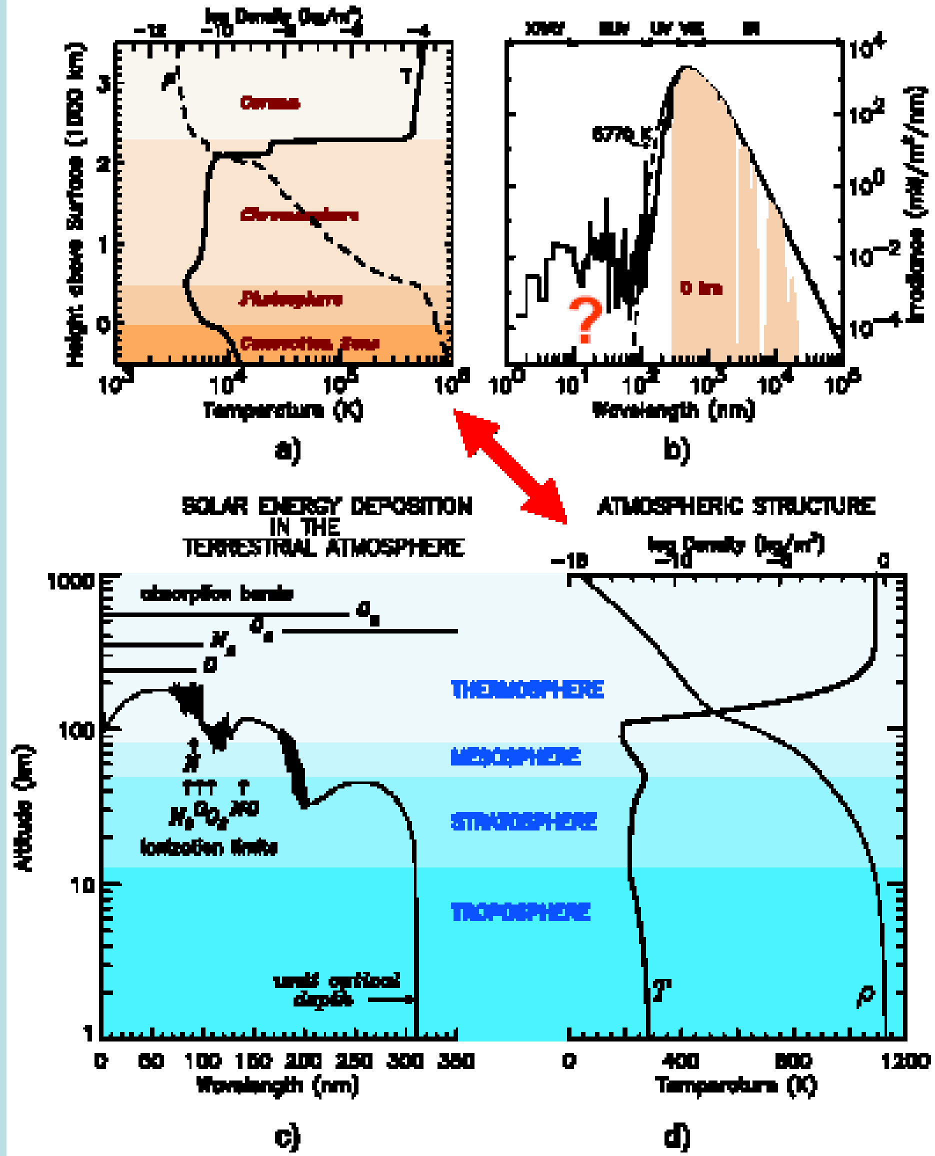
➔ **The mechanism that heats the solar corona remains elusive.**

➔ **Everything above the photosphere … would not be there at all.**

M.J. Aschwanden, A.I. Poland, D.M. Rabin, A.R.A.A. 39 (**2001**) 75
C.J. Schrijver, A.A. van Ballegooijen, ApJ. 630 (1st September **2005**) 552

2nd Law of Thermodynamics ➔

Heat transfer ➔ hotter-to-cooler

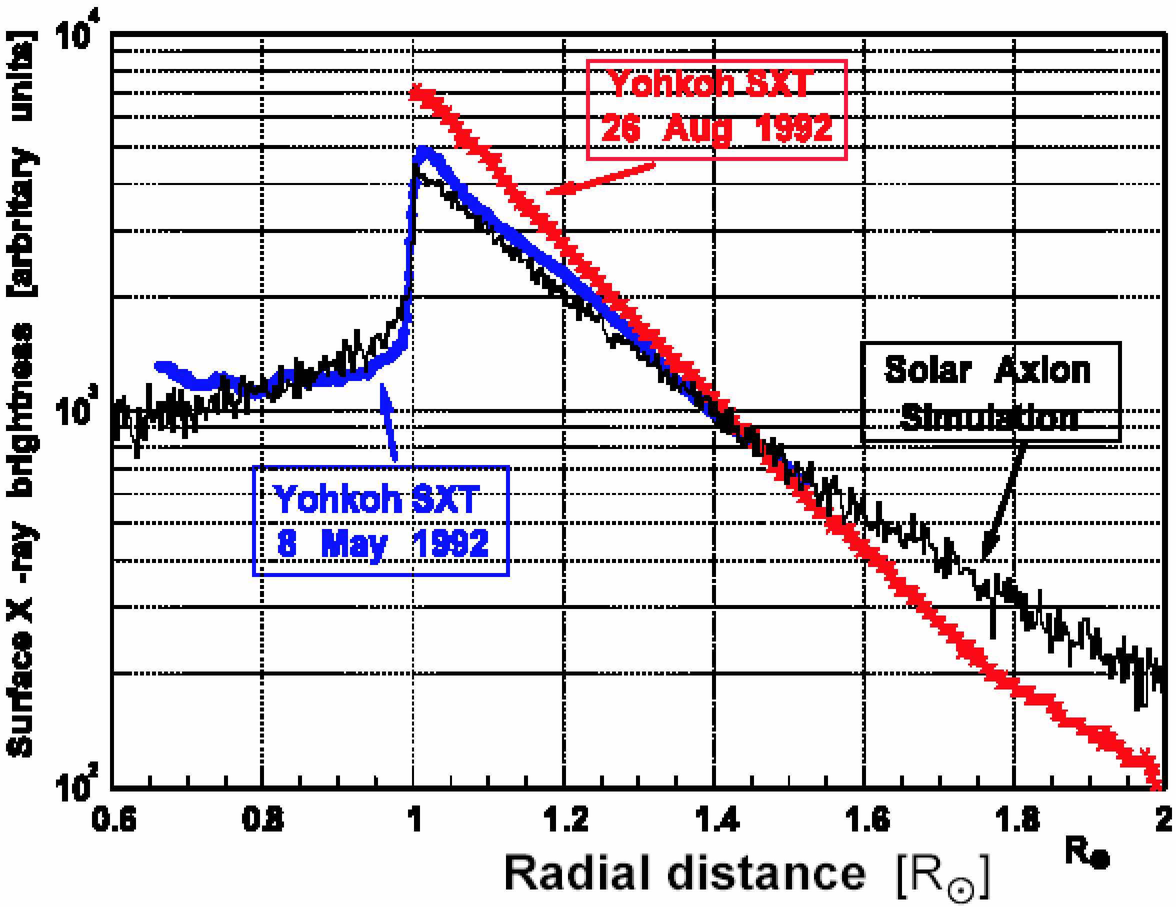


<u>**Suggestion:**</u>

➔ solar X-ray self-irradiation

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

Quiet Sun X-rays as Signature for New Particles



Soft X-ray surface brightness from the quiet Sun.

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

26 August: off-pointing

(JL Culhane, Adv. Space Res. 19 (1997) 1839)

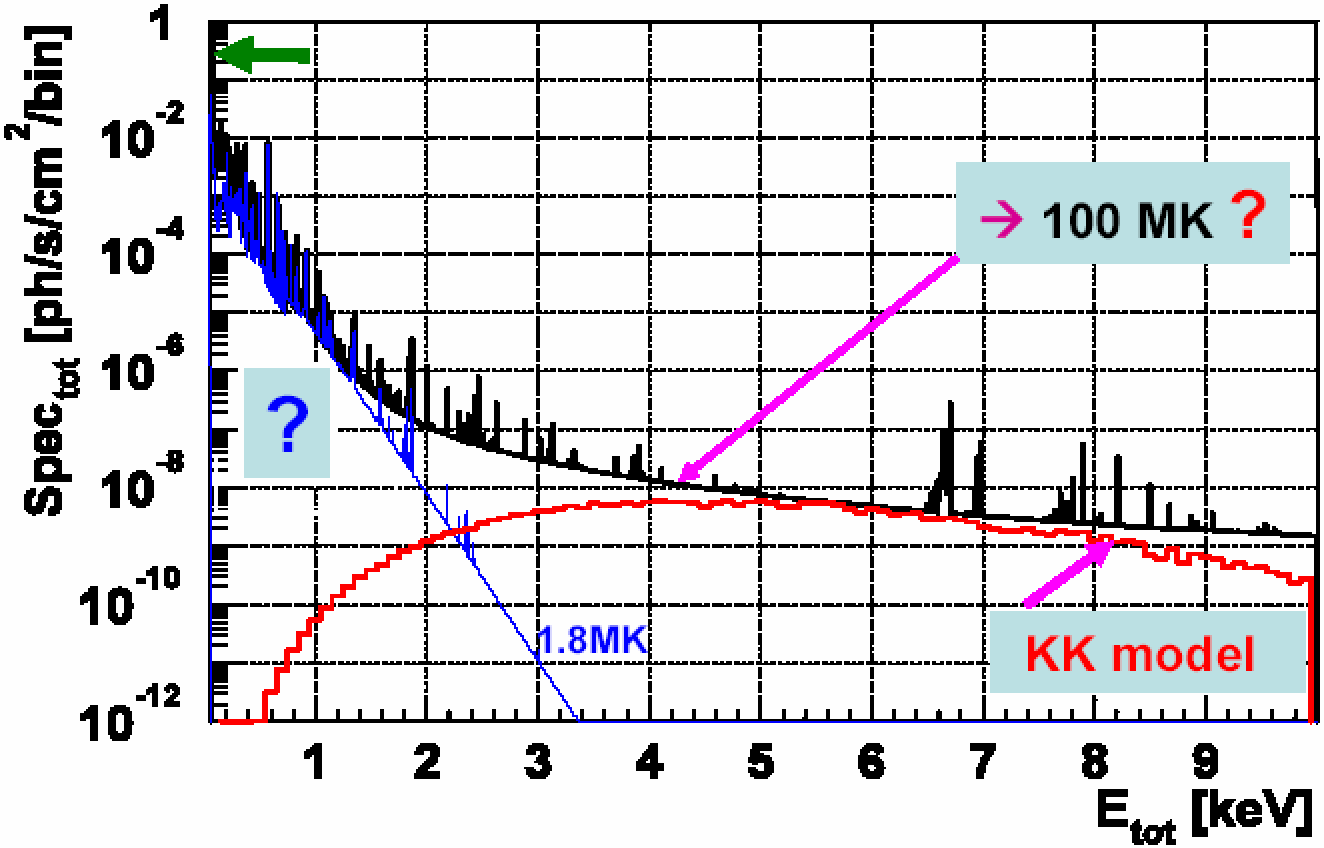
- **Diffuse emission.**
- **Hydrostatic equilibrium doesn't fit observations**
- **closed loops of increasing height … cannot reproduce the observed behaviour of T & ρ @ diffuse structure.**
- **AR emission … no strong correlation with T_{plasma} ➔**
  This suggests that the natur of coronal heating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

. . . .

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

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

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



KK-*axions*

↓

generic

↓

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

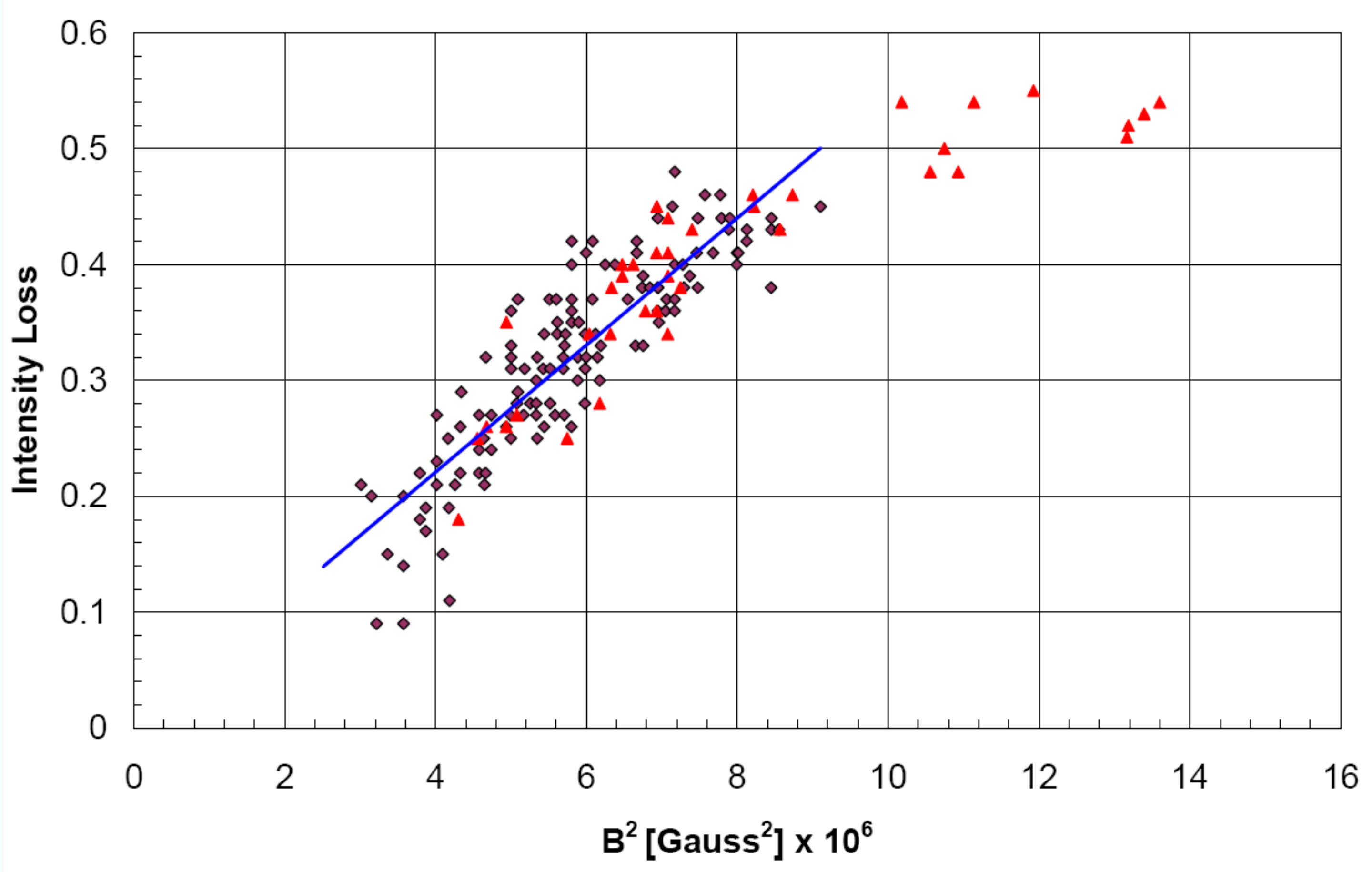
$\bar{T}_{flare} < 20MK$

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

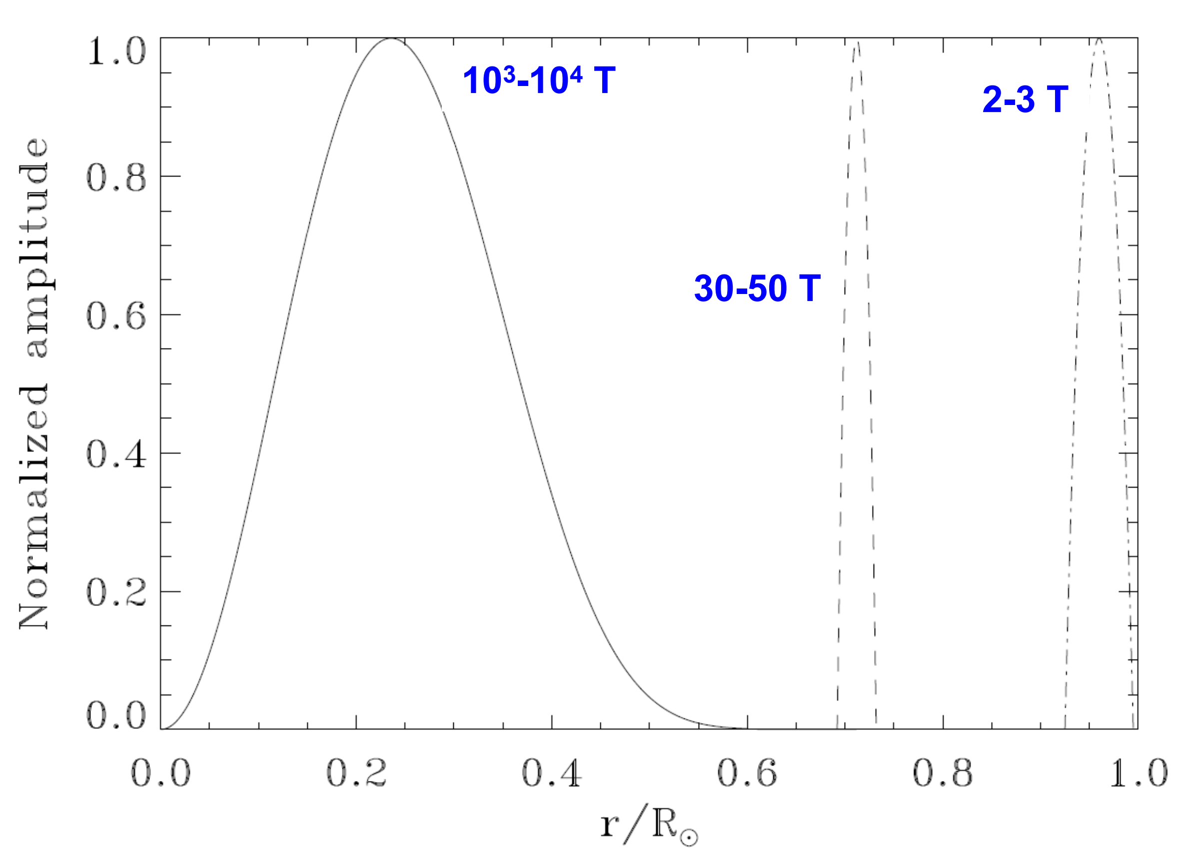
L. DiLella, K. Z., Astropart. Phys. 19 (**2003**) 145



Thanks Thomas Papaevangelou

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

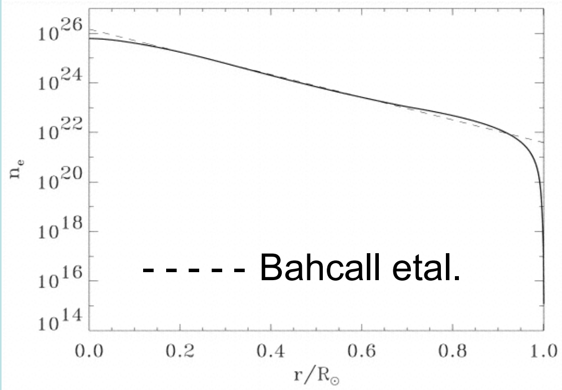
Solar seismic models + the ν-predictions



...seismic models are very close to the real Sun in the regions of concern.

But ➔

... as far as the internal rotation profile is not included in the study, new surprises may appear ...



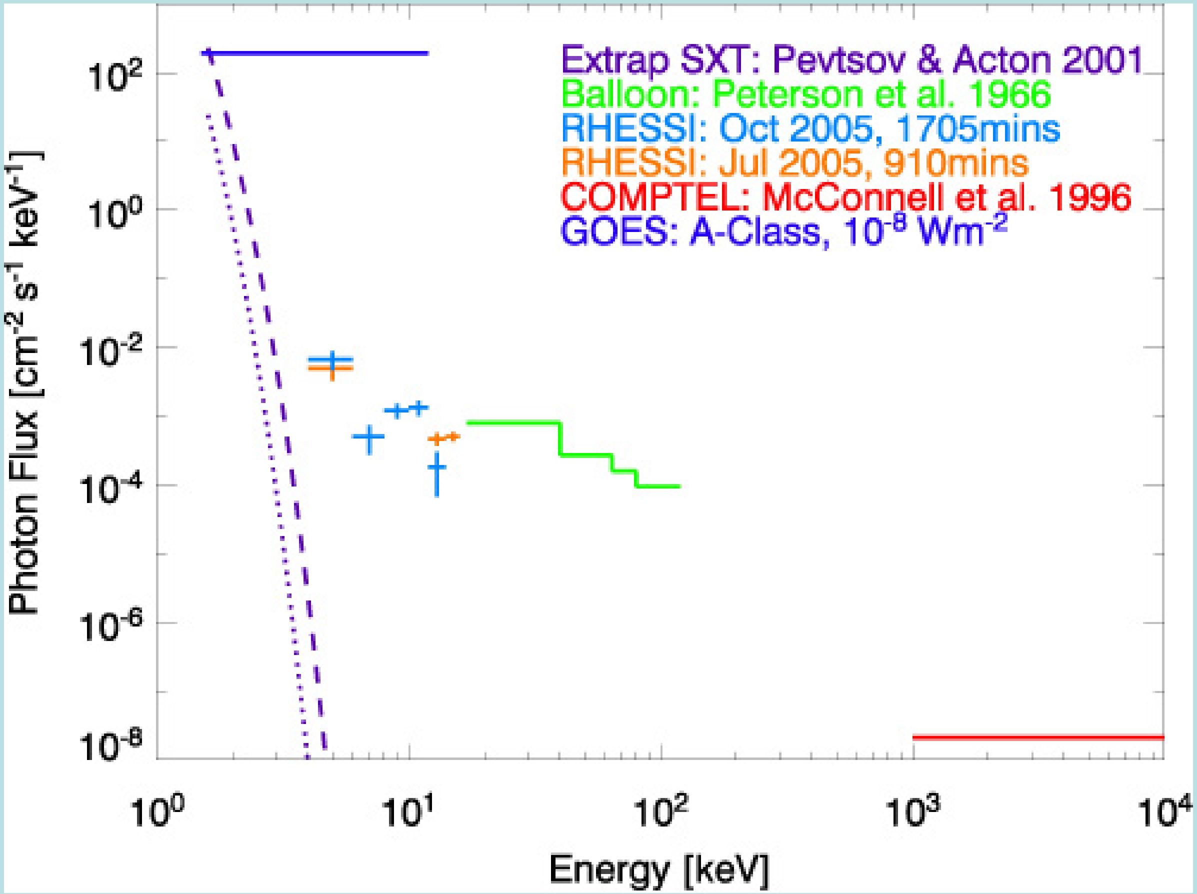
Magnetic fields simulated. The amplitudes of the fields have been normalized by their maximum intensity.

S. Couvidat, S. Turck-Chieze, A. G. Kosovichev. ApJ. 599 (**2003**) 1434

Exploring the Quiet Sun I.

2005-12-19 I. Hannah

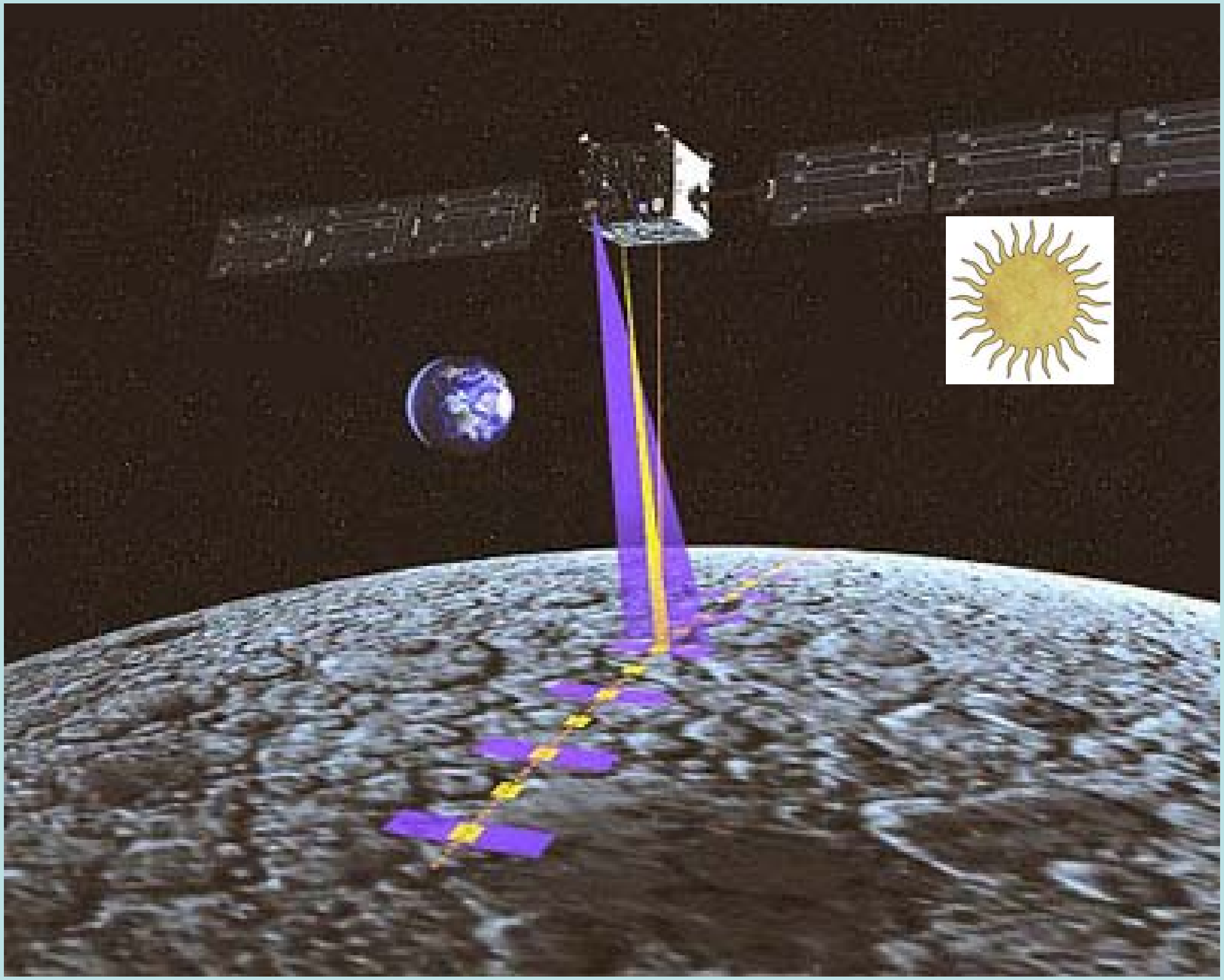
RHESSI
→ axions



The observational limits on the quiet-Sun X-ray spectrum from previous data and from our preliminary RHESSI estimate using the offpointing technique, as detailed in this Nugget. Only RHESSI can put useful limits in the 3-17 keV range, but we can compare the limits to the 1966 balloon data above 17 keV. The SXT values are extrapolated from observations at 1.6 keV assuming temperatures of either 1.1 MK (dotted) or 1.3 MK (dashed).

http://sprg.ssl.berkeley.edu/~tohban/nuggets/?page=article&article_id=16

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** $\rightarrow \gamma\gamma$

…. axion search spreads!

➔ RHESSI, SMART, …?...

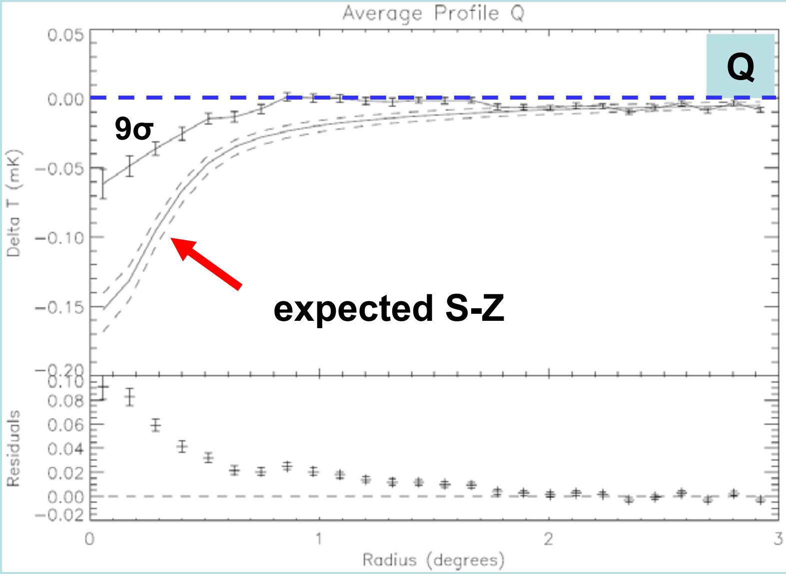
X-ray mysteries:

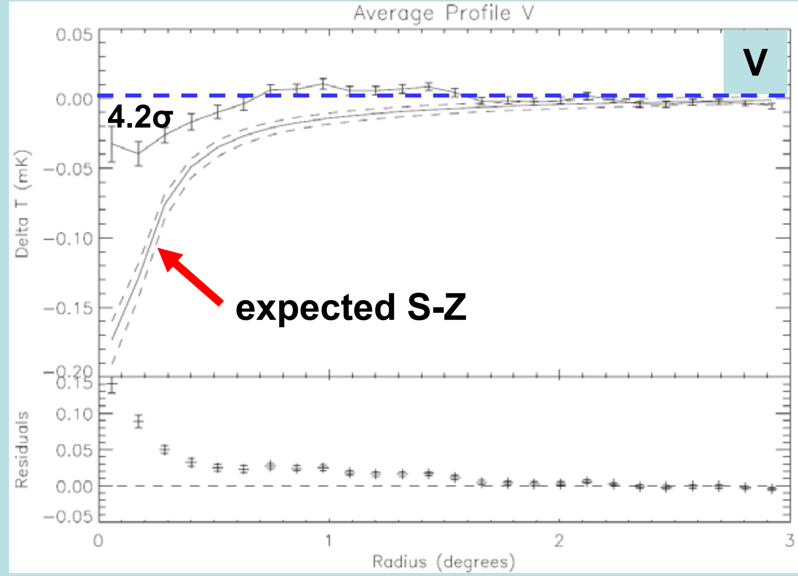
- **Class 0 protostar** (10-100 kyears) → **origin of X-rays (<10 keV): matter is falling 10x faster?**
  K. Hamaguchi *et al.*, ApJ. 623 (**2005**) 291
  → **Similar-to-Sun logic = wrong** ←

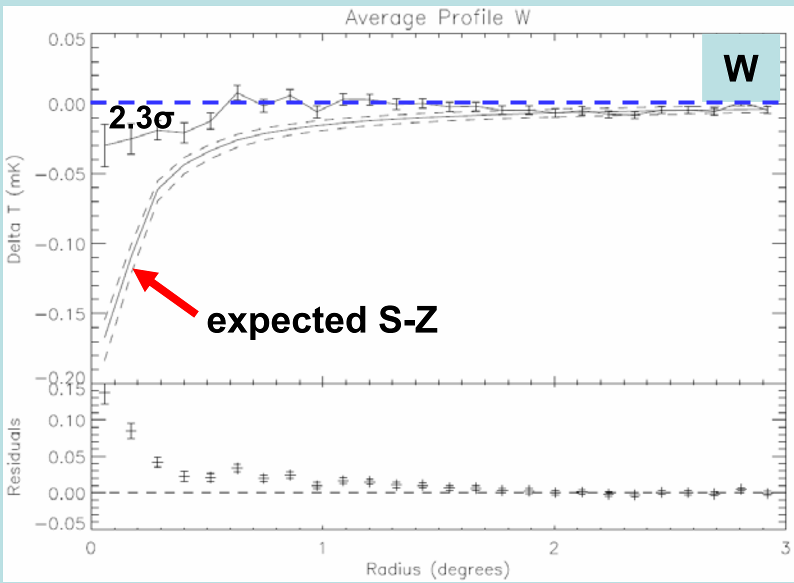
Galactic Center → **origin of diffuse X-rays?**
too hot (~ 90MK) to be a gravitationally bound plasma!
→ ***how to produce it?***

Clusters of Galaxies → **"strong evidence of some thing wrong"**
"physical mechanism for the energy (or the entropy) excess? "
"some homogeneous process heats the gas"
P. Tozzi, astro-ph/0602072

XRB*radiation* ← **origin?**







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).

Probing Light Pseudoscalars with Light: Propagation, Resonance and Spontaneous Polarization

S. Das, P. Jain, J.P. Ralston, R. Saha, JCAP (**2005**) in press (hep-ph/0408198)

Radiation propagating over cosmological distances can probe light weakly interacting pseudoscalar (or scalar) particles. **The existence of a spin-0 field changes** the dynamical symmetries of **electrodynamics.** It predicts **spontaneous generation of polarization** of electromagnetic waves due to mode mixing in the presence of background magnetic field. We illustrate this by calculations of propagation in a uniform medium, as well as in a slowly varying background medium, and finally with resonant mixing. Highly complicated correlations between different Stokes parameters are predicted depending on the parameter regimes. The polarization of propagating waves shows interesting and complex dependence on frequency, the distance of propagation, coupling constants, and parameters of the background medium such as the plasma density and the magnetic field strength. For the first time we study the resonant mixing of electromagnetic waves with the scalar field, which occurs when the background plasma frequency becomes equal to the mass of the scalar field at some point along the path. Dynamical effects are found to be considerably enhanced in this case. We also formulate the condition under which the adiabatic approximation can be used consistently, and find caveats about comparing different frequency regimes.

Gamma rays from the neutralino dark matter annihilations in the Milky Way substructures

The radiation fluxes from a dark matter halo is given by:

$$\Phi(E) = \phi(E)\frac{\langle\sigma v\rangle}{2m^2}\int dV \frac{\rho^2}{4\pi d^2} = \frac{\phi(E)}{4\pi}\frac{\langle\sigma v\rangle}{2m^2} \times \int_{\Delta\Omega} d\Omega \int_{\mathrm{l.o.s}} dl(r)\rho^2(r)$$

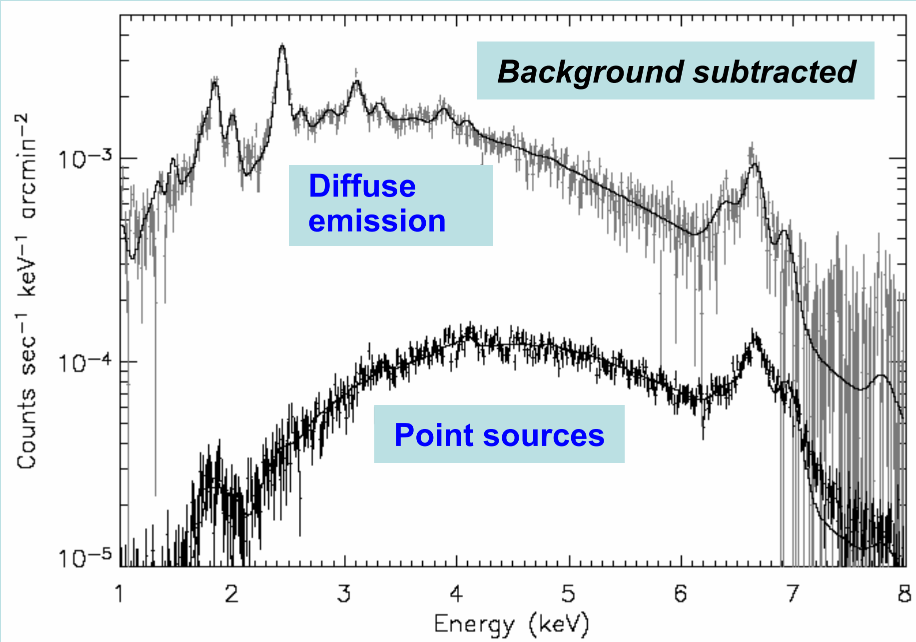
X.-J. Bi, astro-ph/0510714 10 Jan 2006

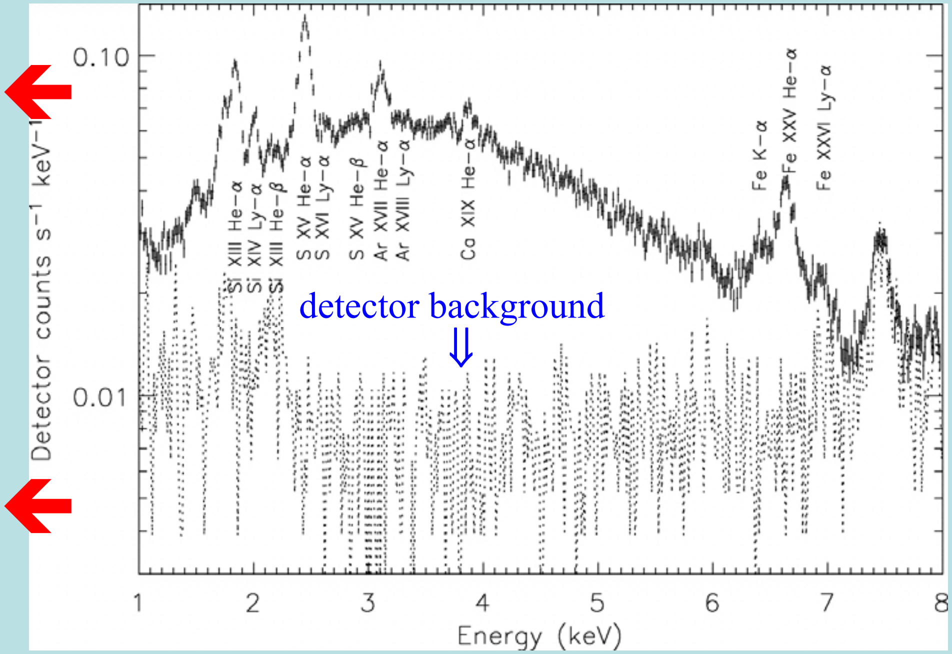
SZ-effect ~ $\rho_e x T_e$
$\Phi_{X\text{-rays}}$ ~ $(\rho_e)^2 x (T_e)^{1/2}$

S. J. LaBoque et al., astro-ph/**2006**04039

➔ Radiative decay rate ~ ρ

DIFFUSE X-RAY EMISSION OF THE GALACTIC CENTER ➔ Chandra





…this soft plasma is probably heated by supernovae, along with a small contribution from the winds of massive Wolf-Rayet and O stars. The kT~8 keV component is more spatially uniform… Neither supernova remnants nor WR/O stars are observed to produce thermal plasma hotter than ~3 keV. Moreover, ***a kT ~ 8 keV plasma would be too hot to be bound to the Galactic center***, and therefore would form a slow wind or fountain of plasma.

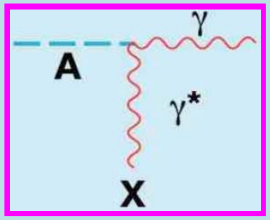
Alternative explanations for the hard diffuse emission that were intended to lessen the energy required are equally unsatisfying. The suggestion that the hard diffuse emission originates from undetected stellar X-ray sources is unlikely because ***there is no known class of source that is numerous enough, bright enough, and hot enough to produce the observed flux of kT≈ 8 keV diffuse emission.*** We are left to conclude that either there is a significant shortcoming in our understanding of the mechanisms that heat the interstellar medium, or that a population of faint ($< 10^{31}$ erg s^{-1}), hard X-ray sources that are a factor of 10 more numerous than CVs remains to be discovered. M. Muno et al., ApJ. 613 (**2004**) 326

➔**Chandra *confirmed the astonishing evidence of a diffuse, hot, plasma at* T~90 MK *to extend over* a few 100 pc *in GC* (➔ ~ 9MK).** R. Belmont et al., ApJL. (20.9.**2005**)

➔ it would escape in <40000years and its origin is therefore unexplained … continuum difficult to reconcile with

AXION: a light pseudoscalar resulting from the **Peccei-Quinn** mechanism to solve the **strong CP-problem:** why is the *n*EDM too small? → **Dark Matter candidate**

Primakoff - effect is the basis of **axion creation** (←) & **detection** (→) **P. Sikivie**



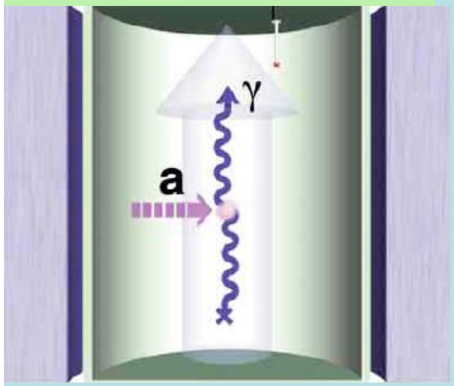
ongoing axion work

PVLAS → signal

LASER polarization ⊗ $B_{\perp}$

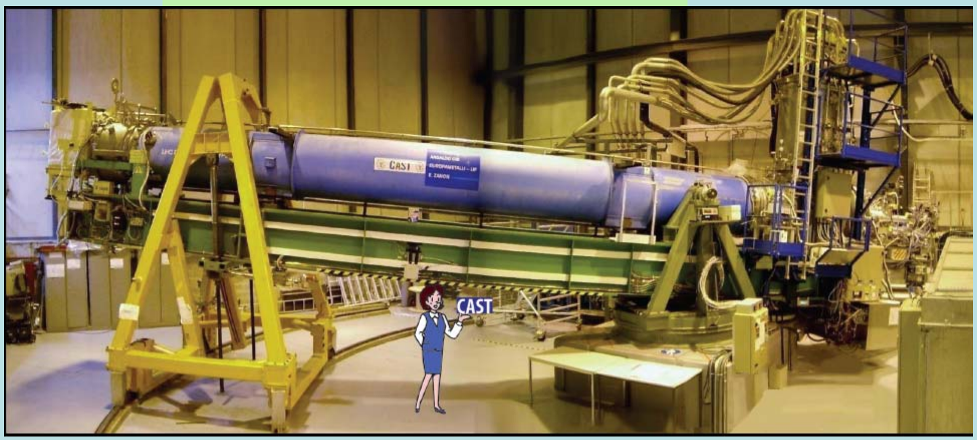
μwave Cavity ⊗ B

→ **ADMX**

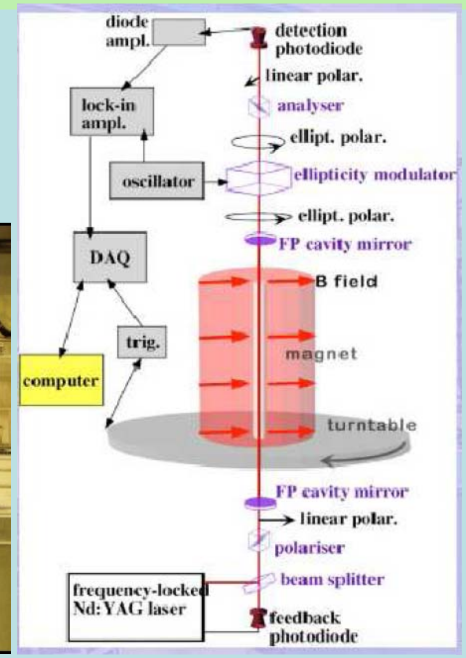


USA, JAPAN

CAST solar axions



CERN, JAPAN (Tokyo helioscope)



ITALY

RHIC → CP-violating events observed? → ALICE

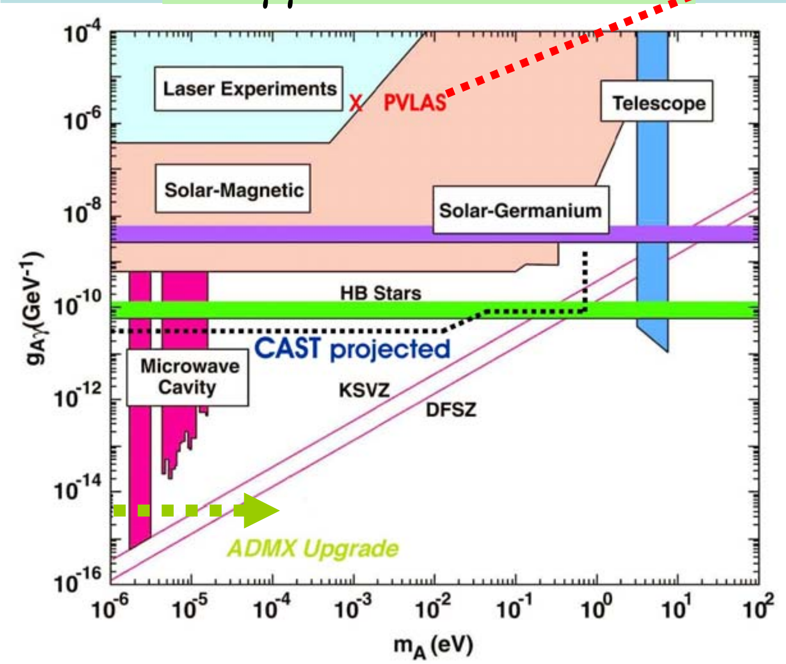
Astrophysical observations suggestive for **axion(-like)** particle involvement

→ **X-rays** from Sun, Galactic Center, …

→ **light polarization** from quasars, e.g. **a**↔γ mixing in cosmic magnetic fields

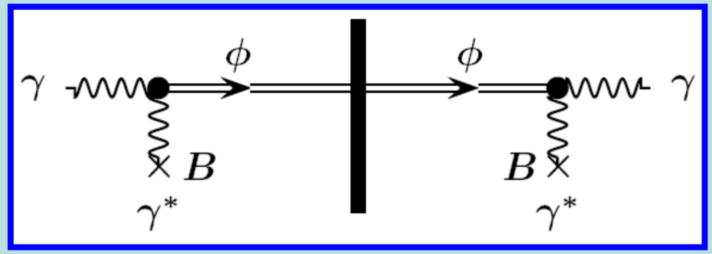
K. Zioutas, University of Patras

$g_{a\gamma\gamma} \leftrightarrow m_{axion}$



PVLAS signal at $m \approx 10^{-3}$eV & $g_{a\gamma\gamma} \approx 2.5\,10^{-6}$ GeV^{-1}

- **Interpretation of PVLAS result → axion-like →** ongoing work
- **"*Light shining through the wall*"** → ***direct*** *experimental detection*



Other approaches:
- **Decay of massive axions** in
  → **1m^3 DRIFT, LHC large chambers?**
- **Search for single γ's + missing transverse energy in e^-e^+ colliders.**
- **X-rays from quiet & spotless Sun**
  → **RHESSI preliminary results.**
- **SMART-X-ray detector ⊗ dark-Moon**
- **GLAST: γ-ray attenuation in binary pulsars.**
- **Photon-Photon scattering with 4-wave mixing → intense LASERs.**

Plans:
- **CERN γ-regeneration with LHC magnets + Magnetic Birefringence & Dichroïsm**
- **DESY VUV-FEL 5 x 2.3 Tm magnets**
  Start 2006: ***up to 30000 regenerated γ's assuming PVLAS parameters in 12x12 h***
- **"PVLAS type" experiment with pulsed magnet (14.2 T) / Toulouse → 2007-**
- **Search for low energy solar axions**

→ exciting axion work in progress ←

K. Zioutas, University of Patras

Future Plans for axions

CAST, TOKYO → m_{axion} < 1-1.2 eV (**solar**)

ADMX → m_{axion} < 10^{-4} eV (**DM**)

Motivated by **PVLAS** result:

→ **continues own tests**

Direct tests →

→ **CERN** light-regeneration + polarization

→ **DESY** VUV-FEL 5 x 2.3 Tm magnets

<u>2006</u>: **regenerated γ's → test PVLAS**

→ **JeffersonLab** FEL → below ~1 eV

→ "**PVLAS** type" experiment with pulsed magnet (14.2 T) / Toulouse → **2007-**

→ Low energy solar axions

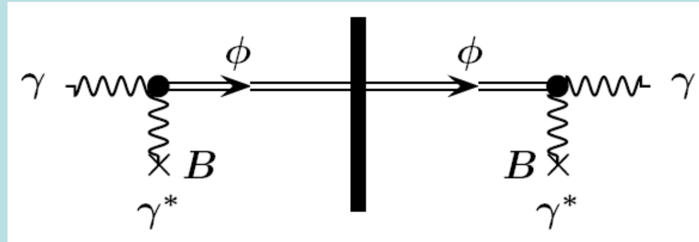
→ Astrophysical obs's → axion(-like) particles

→ solar X-rays, light polarization (quasars), …

→ **RHESSI, SMART, ….**

ILIAS-CAST-CERN Axion training / workshops

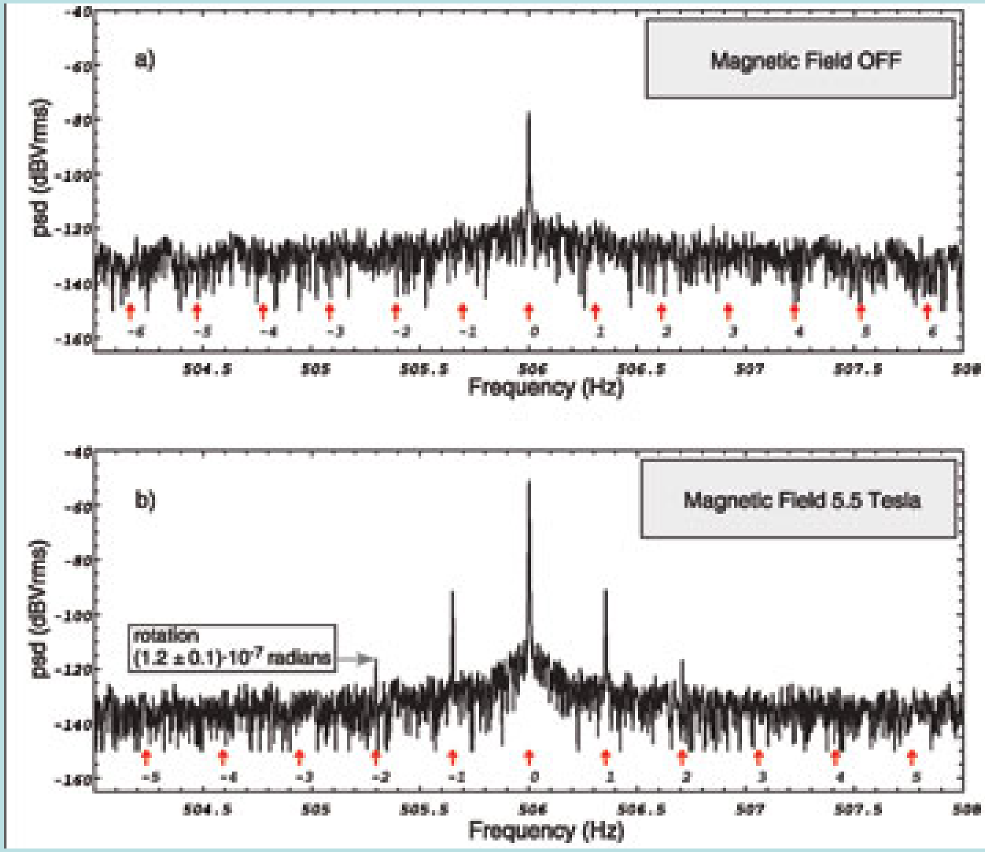
Light regeneration



also → underground detectors

RHIC → **ALICE**

CP-violating events?



PVLAS collaboration data providing evidence for light polarization rotation in vacuum with a transverse magnetic field. The signal (arrow) is at a frequency shift twice that of a rotating magnet. A light neutral spin-zero particle could cause such polarization rotation, though there are strong astrophysical constraints.

E. Zavattini et al., Phys. Rev. Lett. 96 (2006) 110406