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The CAST Collaboration

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7. Enrico Fermi Institute and KICP, University of Chicago, Chicago, IL, USA
8. Aristotle University of Thessaloniki, Thessaloniki, Greece

~axions
(In)direct & astrophysical signatures

$T_a \sim$ eV - TeV

$m_a \sim$ eV - neV

K. Zioutas

University of Patras / Greece

2000- Collaboration work with:

V. Anastassopoulos, L. Di Lella, A. Nordt,
Th. Papaevangelou, Y. Semertzidis, M.Tsagri.

Profit / encouraged from many others within
CAST, ILIAS(next), CERN & U. Patras libraries

ILIAS 5th Annual meeting, Jaca, Spain, 19th – 21st February 2008

The emerging solar axion(-like) picture:

- ~axion source(s):
  » extended & > few eV
  → various masses OR different particles?

- ~axion conversion @ Sun's surface
  → in/outwards radiation pressure

- Transition Region → most sensitive place?

. . . .

→ B_{sun}= transient trigger (not energy storage?)#

see section 4 in S Dalla, L Fletcher, NA Walton, A&A 468 (2007) 1103

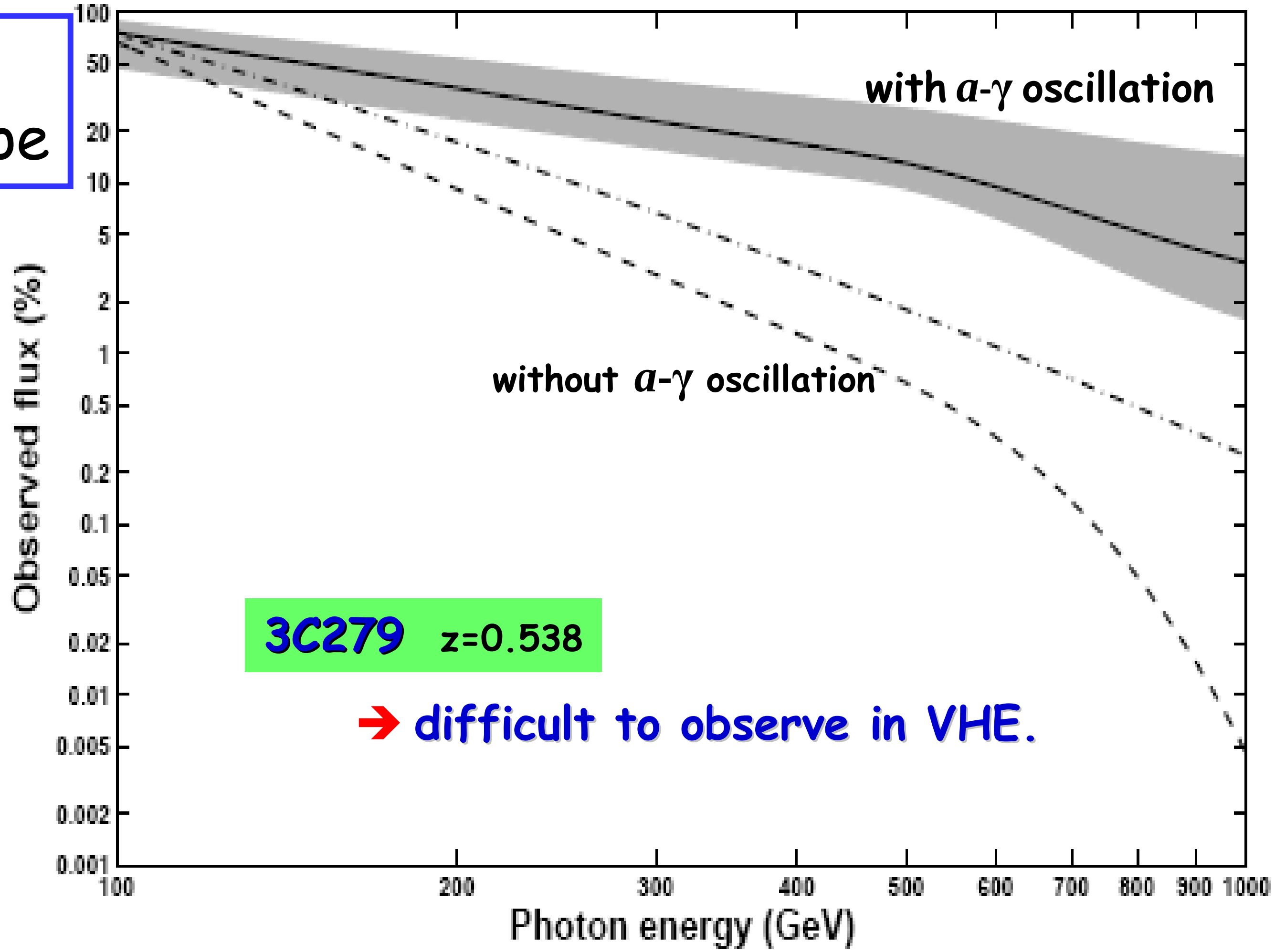
~axions in the spotlight!

➔ others ...

Large transparency to extragalactic light

→ New Physics

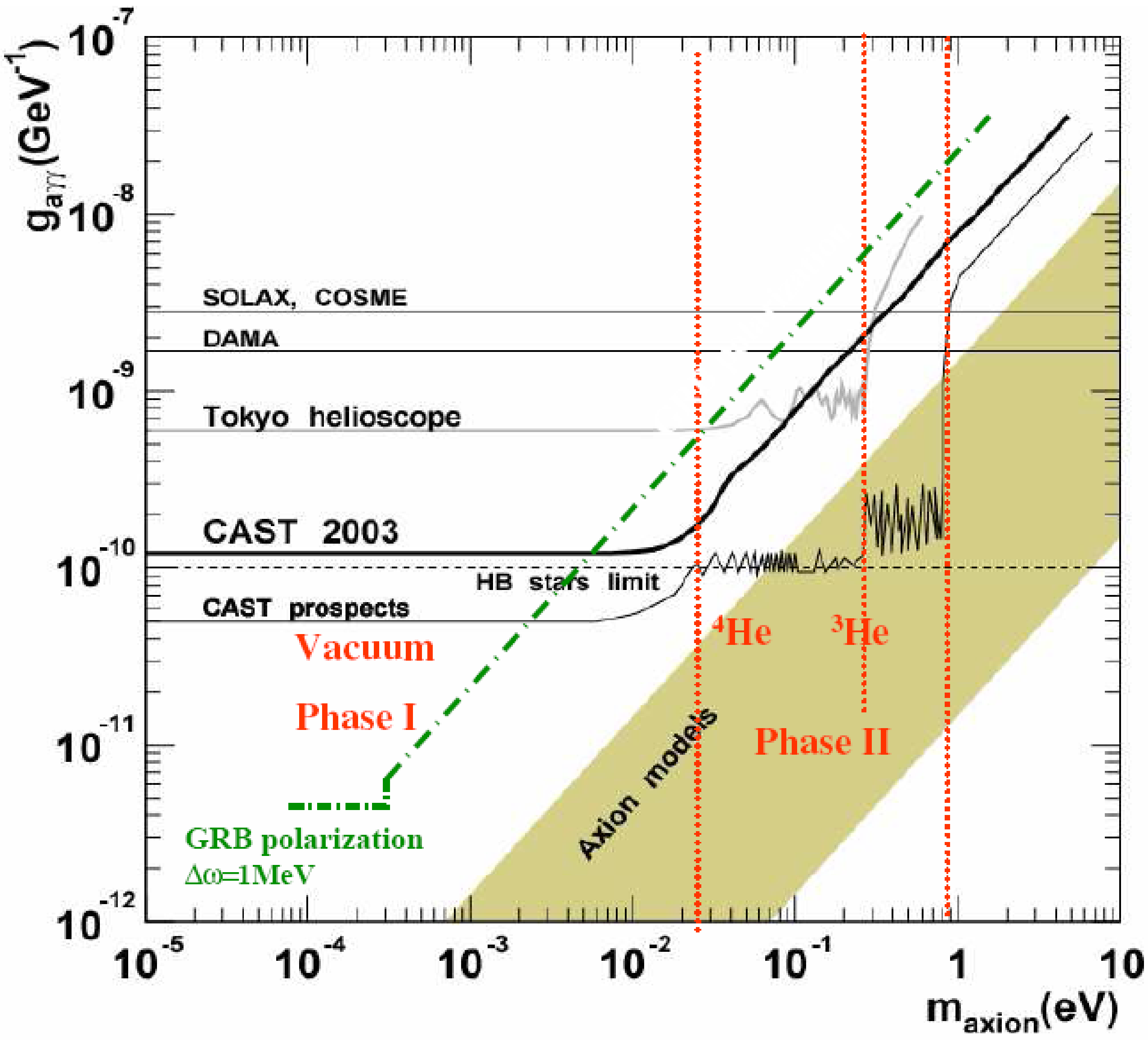
MAGIC telescope



Photons survive (dashed line) with an enhancement factor ~20 as expected in the absence of an a-γ oscillation: $m_a \ll 10^{-10}$eV, $g_{a\gamma\gamma} < 2.5 \cdot 10^{-12}$GeV^{-1} → **~axion**

A. De Angelis, O. Mansutti, M. Roncadelli, PRD 76 (**2007**) 121301

Constraining axion by polarized prompt emission from GRB

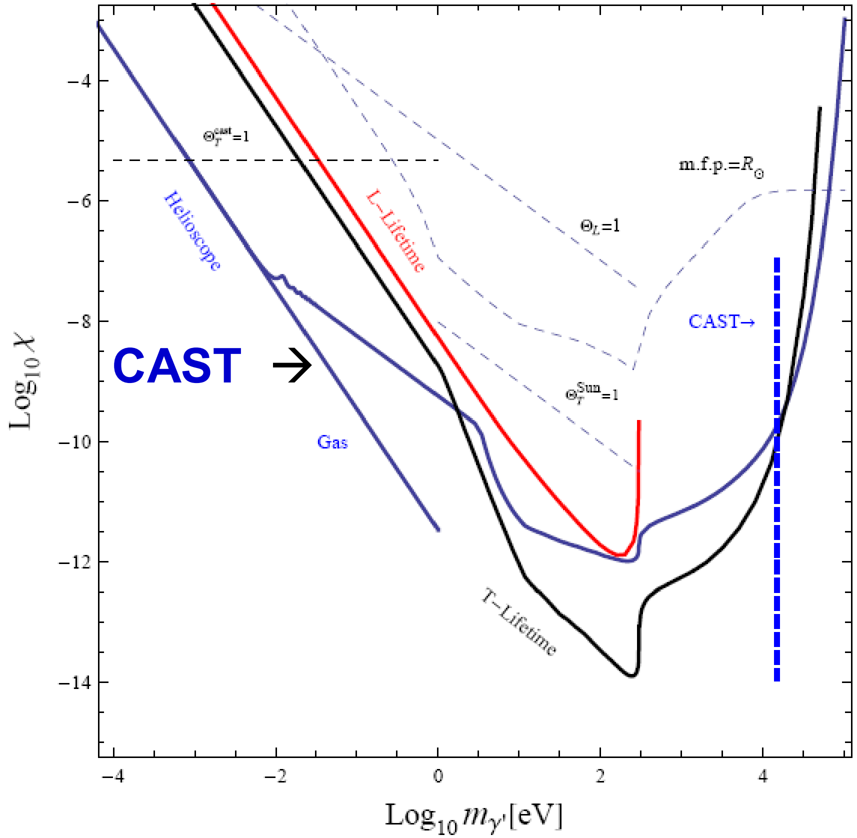


A. Rubbia, A.S. Sakharov, Astropart. Phys. 29 (2008) 20

Helioscope Bounds on Hidden Sector Photons

Javier Redondo → **paraphotons**

DESY



← **hep-ph/0801.1527**

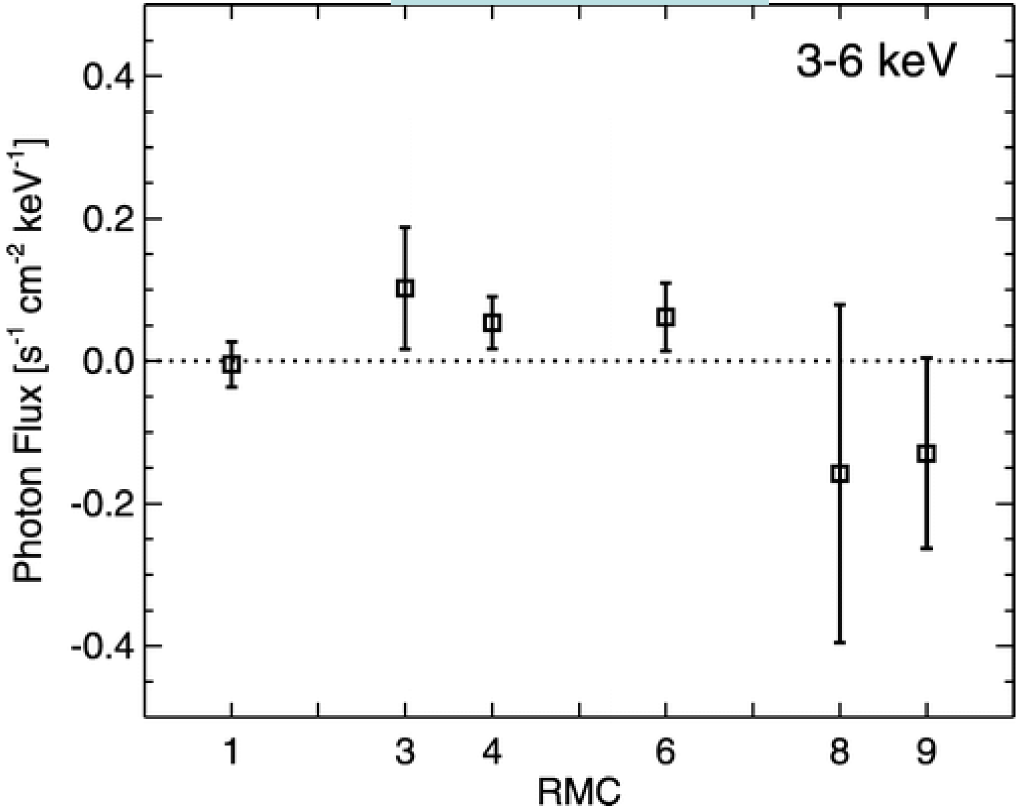
Result with the "first" CAST visible run in 2007.

Quiet sun

RHESSI

Energy (keV)	Weighted Mean (10^{-4} photons s^{-1} cm^{-2} keV^{-1})	σ (10^{-4} photons s^{-1} cm
3–6	330.99	±207.25
6–12	−5.24	±8.46
12–25	−0.73	±1.34
25–50	0.14	±0.63
50–100	0.74	±0.54
100–200	−0.79	±0.42

NOTE.—When the *GOES 12* 1–8 Å flux <10^{-8} W m^{-2}.



Zioutas etal. published limits… derived from *RHESSI* data taken during solar maximum and had not been corrected for instrumental response. … we obtain an X-ray luminosity about 100x smaller…we find a **somewhat smaller** limit … of $g_{a\gamma\gamma}$ « $6\times10^{-15}GeV^{-1}$.

?

The 3-6 keV flux observed in each of RHESSI's rotation modulation collimators averaged over the times when the GOES-12 1-8 Å flux was < 10nW/m².

➔ **still offpointing obs'.**

I.G. Hannah, G.J. Hurford, H.S. Hudson, R.P. Lin, K. van Bibber, ApJL.659(2007)77

Minutes of the 13th Hinode Monthly Meeting
November 28-29, 2007

The 12th Hinode Monthly Meeting was chaired by Prof. Watanabe and he… …er 25, 2007 at 7:00 AM (JST). The Agenda circulated by Prof. Wat… …d.

+ Tokio helioscope

+ RHESSI

+ HINODE

1. Instrument and Spacecraft Status

SOT: Berger referenced Tarbell's e-mai… …at the H-alpha filter is not being used, except where it is… …to meeting the science requirements, due to wavelength shifting … …to temperature variations. More testing for temperature dependence is unde… way.

XRT: DeLuca reported that operations were normal. When the Sun is very quiet, they have started taking images for the AXION program and many time a day they are switching to the medium Be filter. During this process they have made a large number of rotations of FW1 without seeing any evidence of sticking over the last week and a half. Shimizu asked about the progress on understanding the contamination problem. DeLuca stated that it is still being investigated by both sides. They are monitoring the situation and have limited the use of the aluminum mesh filter as they are concerned about the effect of the EUV flux passing through the filter may have on polymerization of the contamination. The case for another bakeout is under discussion within the XRT teams.

EIS: Culhane referred to Harrah's e-mail (Appendix B) and had nothing further to add.

Spacecraft: Shimizu referred to his e-mail (Appendix C) on spacecraft issues. He was concerned about the rate of rise in temperature of the sun sensor, which they found difficult to explain.

http://www.isas.jaxa.jp/home/solar/hinode_op/archives/MM_minutes/2007_11/MonthlyMeeting_13.pdf

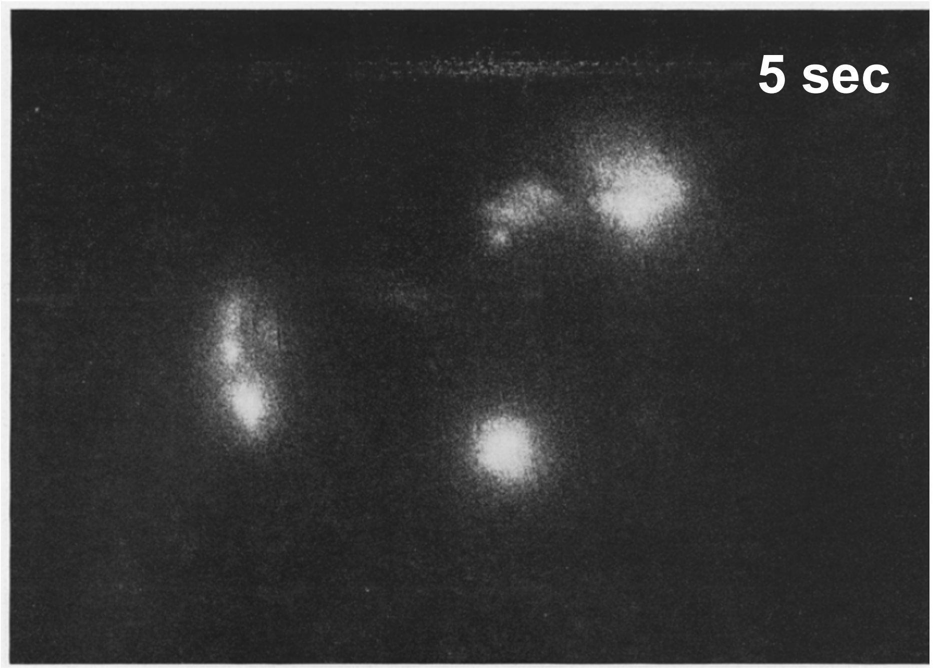


Fig. 7. Frame No. A6.

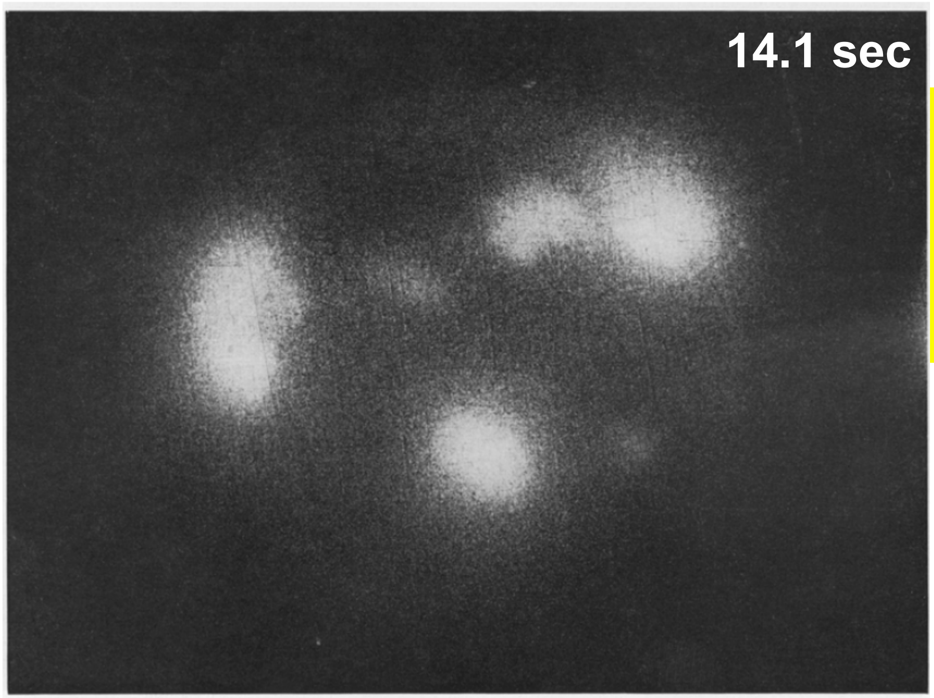


Fig. 8. Frame No. B4.

0.6 – 1.55 keV

→ XRT

…also a weak general emission from the disc …
8-20Å pictures have a more diffuse character

JH Underwood, WS Muney, Solar Phys. 1 (1967) 129

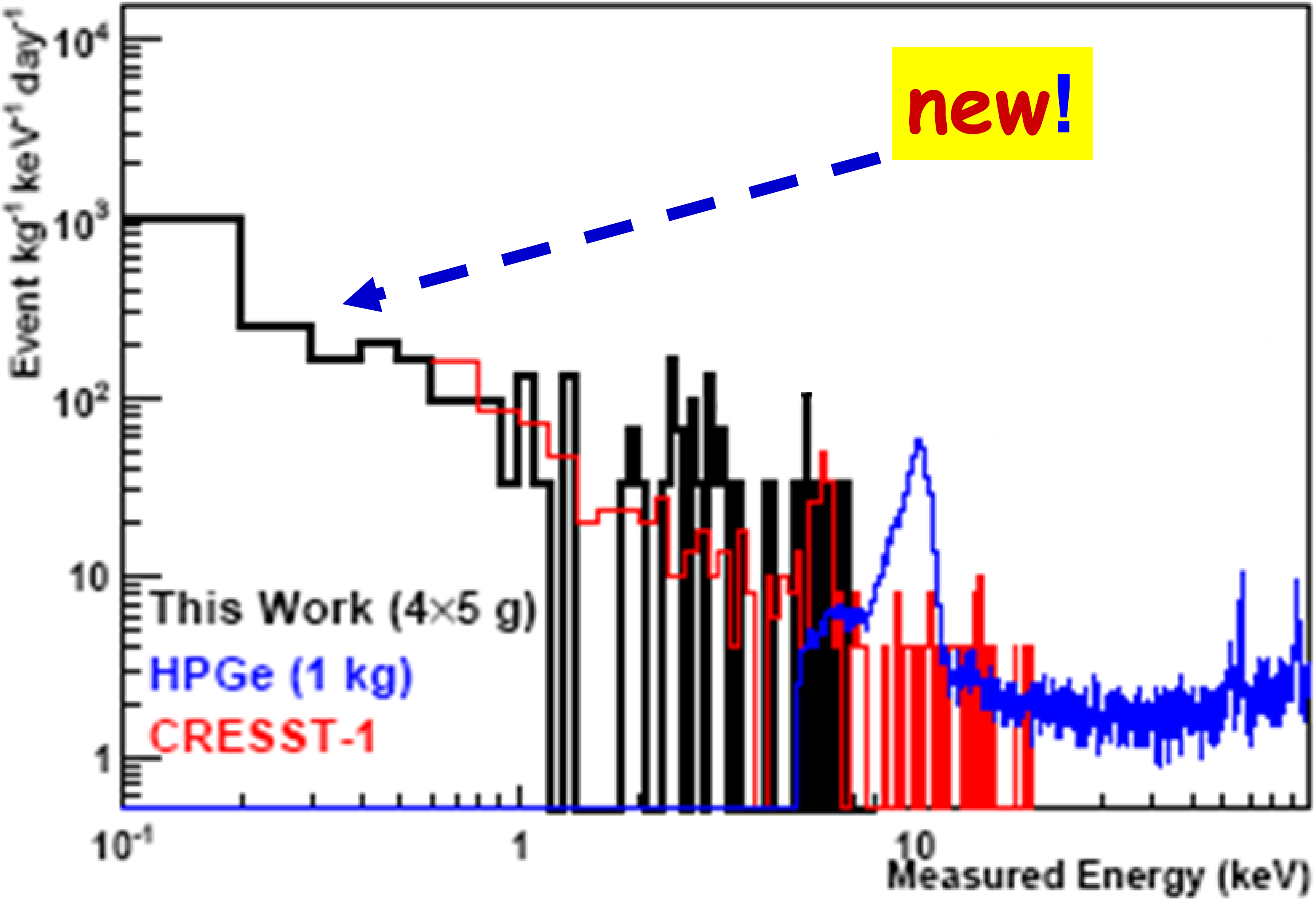
Axion search

Hot plasma on the quiet sun

→ HINODE 16th November 2007

While searching for the X-ray signature of Axions (see RHESSI Science Nugget), XRT has taken a set of 8x8 binned images with long exposures through our Medium Beryllium filter. This filter is mainly sensitive to thermal plasma around **10 MK**. The images seen in the movie show hot plasma in small x-ray bright points and in large scale unresolved structures above the quiet sun. Some of the large scale stucture connects distant regions of strong magnetic field, some appears to be connecting quiet sun near the pole with lower latitude. **The heating of this unresolved plasma is not understood.**

E. DeLuca, L. Golub, http://xrt.cfa.harvard.edu/xpow/20071116.html



Sofar: only WIMPs → LES~axions?

S.T. Lin et al., hep-ex/0712.1645

Searching for Decaying Axionlike Dark Matter from Clusters of Galaxies

➔ new τ ← KK-axions

Riemer-Sørensen, Z, Hansen, Pedersen, Dahle, Liolios
PRL99 (2007) 131301

3rd Joint ILIAS-CERN-DESY Axion-WIMPs Training Workshop

University of Patras* / Greece
19-25 June 2007

AXIONS

Let there be axions

Konstantin Zioutas reports on the first Joint ILIAS–CAST workshops, which covered a wide range of studies, from reactors to investigations of the roles of axions in solar ph

One of the biggest mysteries of science is the nature of dark matter, which first became apparent as astronomer Fritz Zwicky's "dunkle Materie" in 1933. The two leading particle candidates for this "missing matter" are weakly interacting massive particles (WIMPs) and axions – hypothesized uncharged particles that have a very small but unknown mass, which barely interact with other particles. To bring together the widespread axion community, the Integrated

Axions bridge the gap between theory and observation of the strong interaction, and have also inspired the artist Evdoxia Kyrmanidou.

of experiments started by Nobel laureates Norman Ramsey and Edward Purcell in the 1950s, which continues today with the ambitious goal of reaching 10^{-28} e cm by the end of the decade. Other proposed neutron EDM experiments include those at the Paul Scherrer Institut and at the Spallation Neutron Source in Oak Ridge with goals of 10^{-27} e cm and 10^{-28} e cm, respectively. A new technique with the deuteron

NEW PARTICL

Axions create excitement and doubt at Princeton

A workshop at the Institute for Advanced Study paid much attention to a small-scale experiment that might have found the first direct indication of a new particle.

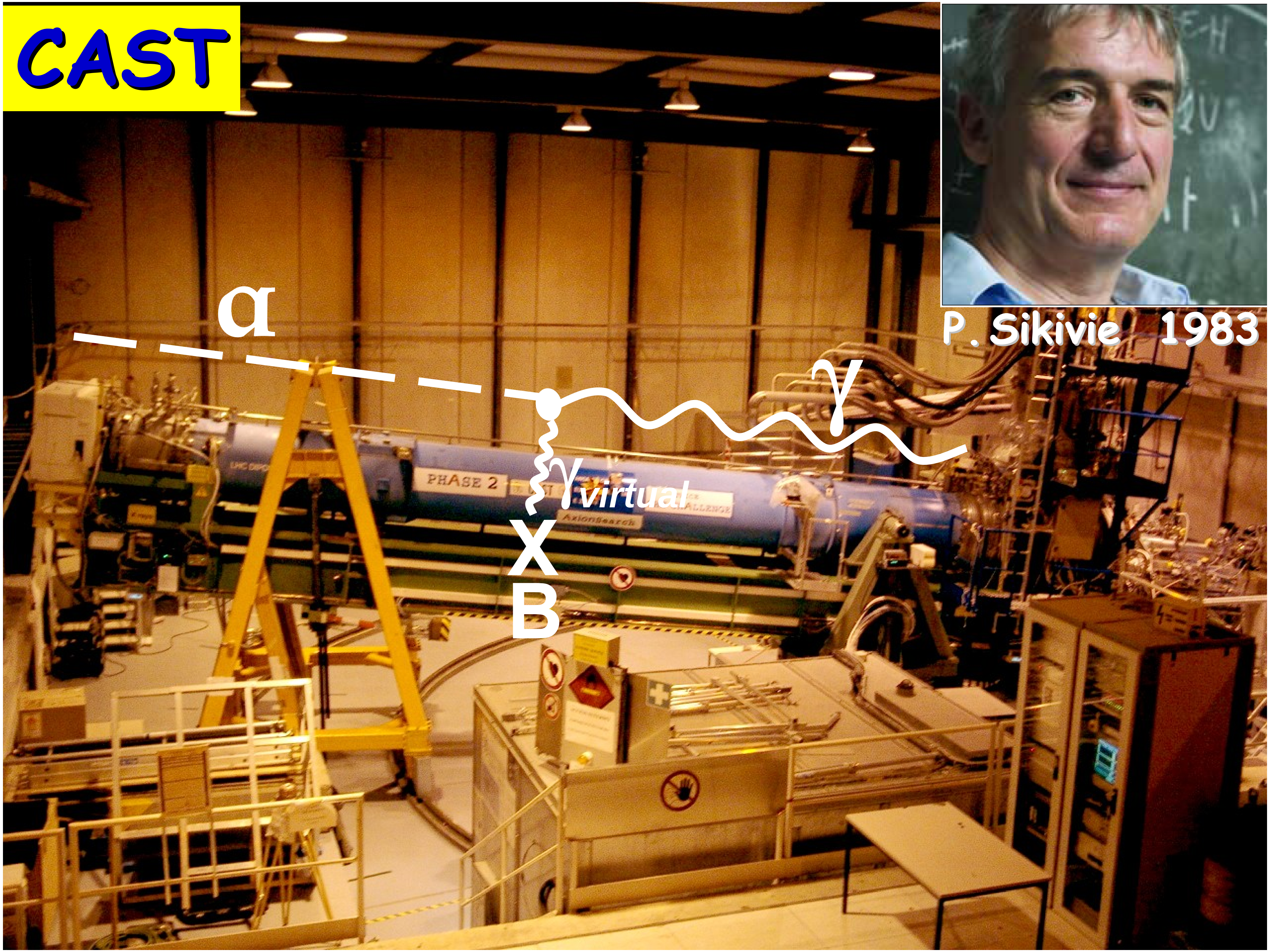
Workshop participants pose in the sunshine outside of the Institute for Advanced Study at Princeton in October 2006.

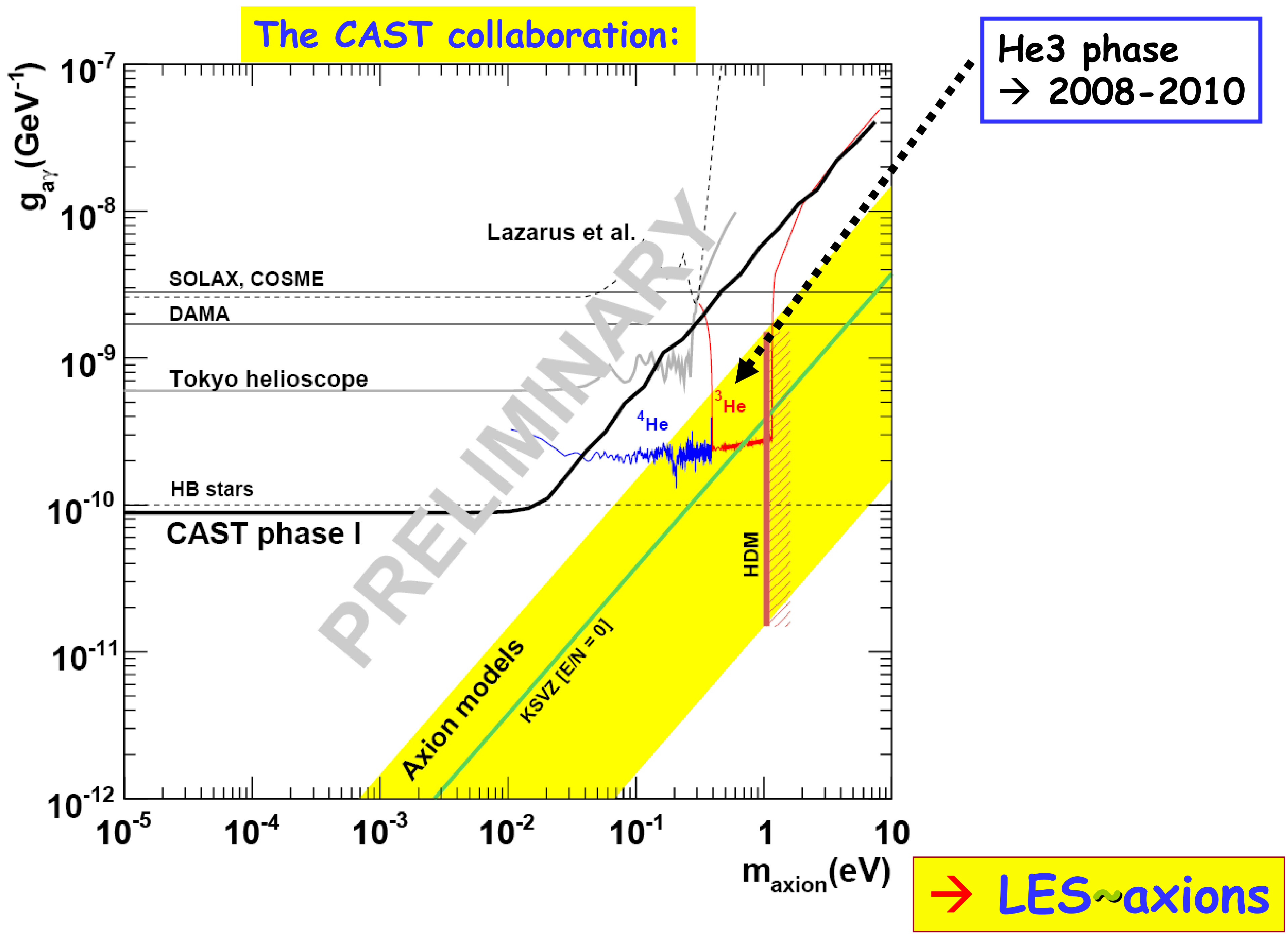
WORKSHOP

Fundamental physics re-explored in Patras

Participants gather at the 3rd Joint ILIAS–CERN–DESY Axion–WIMPs training workshop.

sruhe), N. Elias (CERN), E. Gazis (NTU & CERN), I. Giomataris (Saclay), m U), J. Jochum (U.Tübingen), M. Karuza (Trieste), S. Katsanevas (U.Paris ... Kuster (Darmstadt), B. Lakic (RBI, Zagreb), A. Lindner (DESY), G. Lutz (MPI), D. Nanopoulos (Texas A&M U., Houston HARC & Athens, Academy), P. Pugnat (CERN), J. Redondo (U. Barcelona), S. Riemer-Sorensen (DARK Copenhagen), A. Ringwald (DESY), C.Robilliard (Toulouse), Y. Semertzidis (BNL), A. Siemko (CERN), S. Solanki (MPS Lindau), J. Steffen (Fermi LAB), J. Vigen (CERN), K. Zioutas (U. Patras)


CAST
α
γ
γvirtual
X
B
P. Sikivie 1983
PHASE 2
AxionSearch


The CAST collaboration:
He3 phase
→ 2008-2010
$g_{a\gamma}$ (GeV^{-1})
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
Lazarus et al.
SOLAX, COSME
DAMA
Tokyo helioscope
HB stars
CAST phase I
PRELIMINARY
^{4}He
^{3}He
HDM
Axion models
KSVZ [E/N = 0]
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
m_{axion}(eV)
→ LES~axions

Sun + Sun-like obs' →

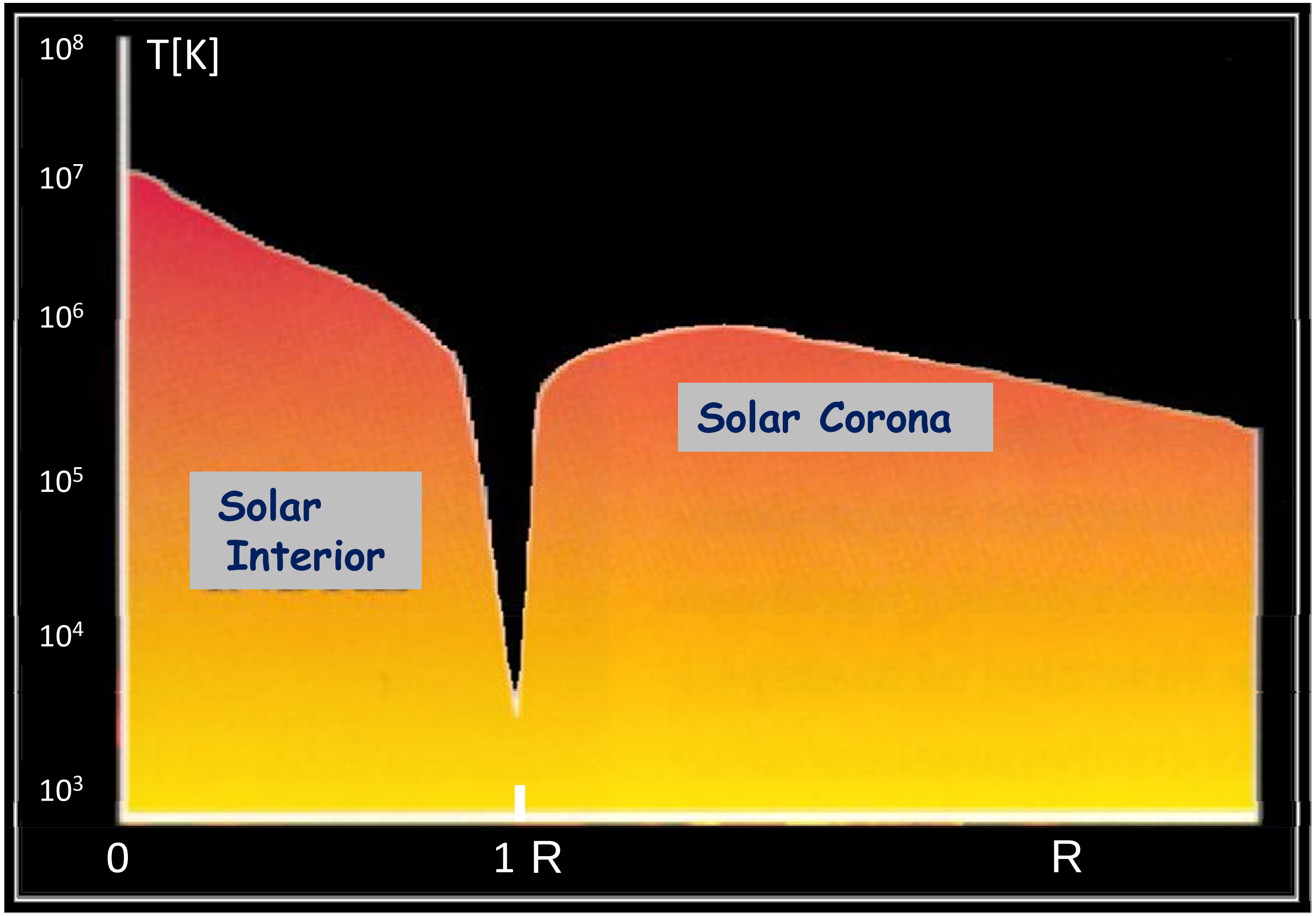
Solar mysteries

- 11 years cycle!?
- Solar corona heating problem
- Flares
- Dynamo(s) → B
- Sunspots heat flux problem[1]
- Ne composition ← "Solar Model problem"

➔ » smoking-gun signatures for new physics?

~axions and/or others fit!

[1] Spruit, Scharmer, A&A 447 (2006) 343



Inverted Temperature:

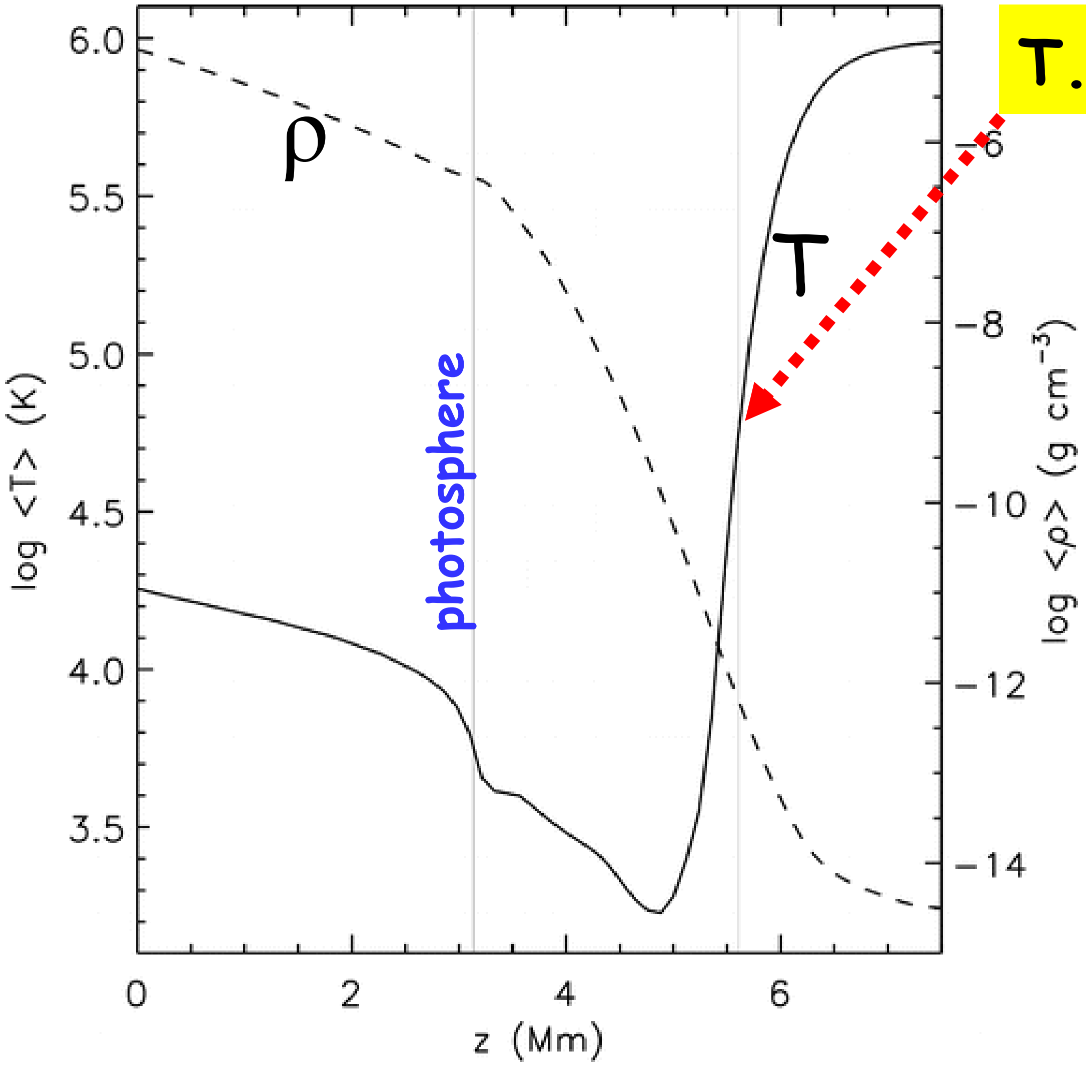
the coronal heating problem / paradox

→ Grotrian (**1939**)

The enigma of coronal heating

one of the outstanding puzzles of stellar astronomy +
one of the most challenging problems in astrophysics.

Aschwanden, Adv. Space Res. 39 (2007) 1867
Jefferies, McIntosh, Armstrong, Bogdan, Cacciani, Fleck, ApJL. 648 (2006) 151
Priest, Longcope, Heyvaerts, ApJ. 624 (2005) 1057



Horizontally <temperature> & <density> distributions.

T.R. height → variable!!

→ QS ≠ CH ≠ AR

→ Origin of CMEs, solar wind,...

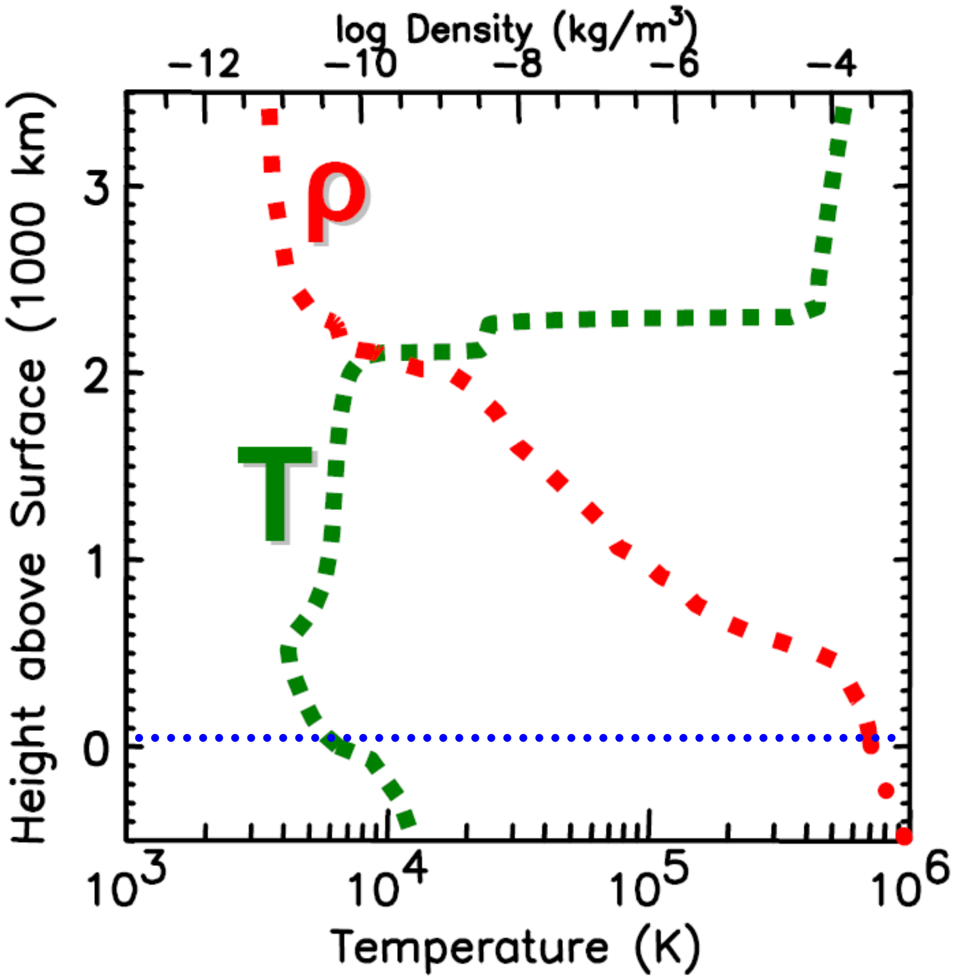
→ Sensitive 2-components equilibrium?!

→ ρ → $\omega_{plasma} \sim 10^{-5}$eV
→ $L_{coh} \sim 10^4$km
→ 10^6xCAST
→ B ~ 2kG

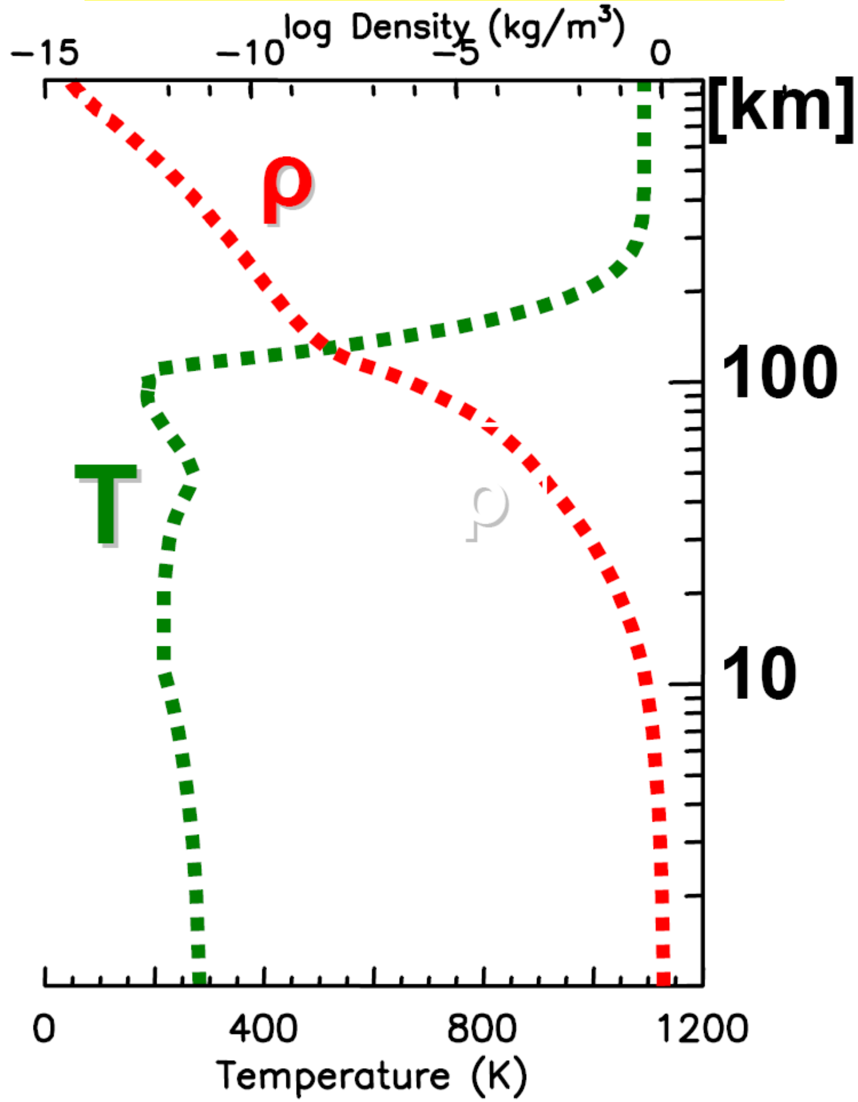
→ $I_x \sim B^2$

WP Abbett, ApJ. 665 (**2007**) 1469

Solar Atmosphere



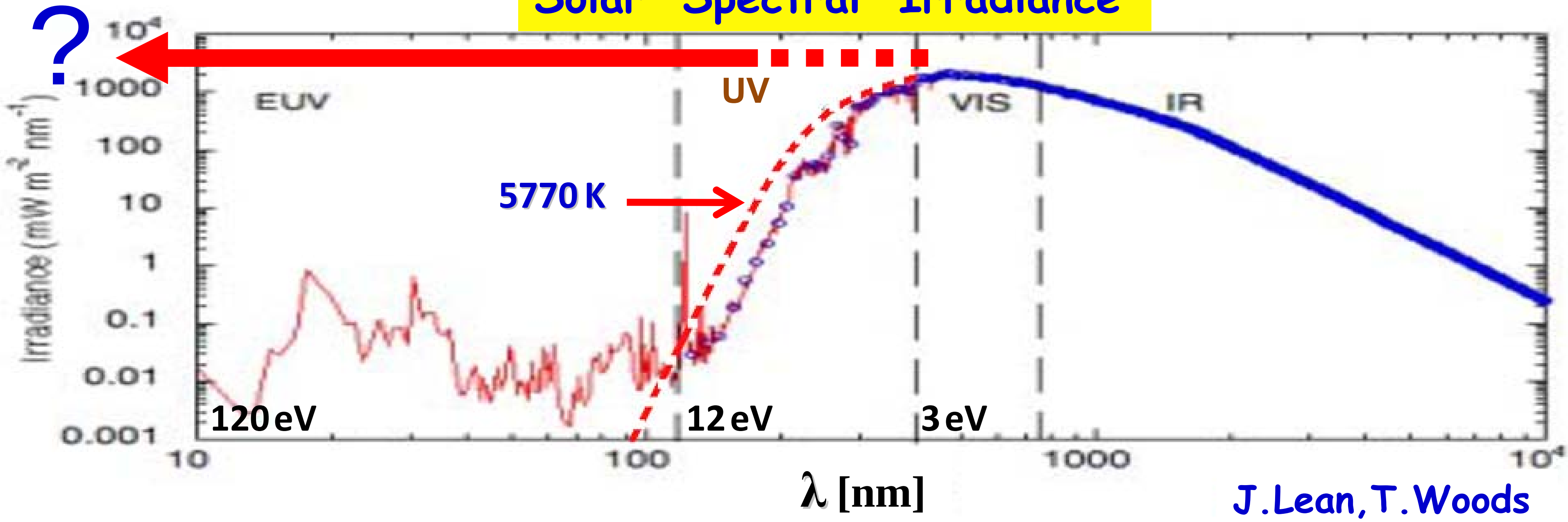
Earth Atmosphere



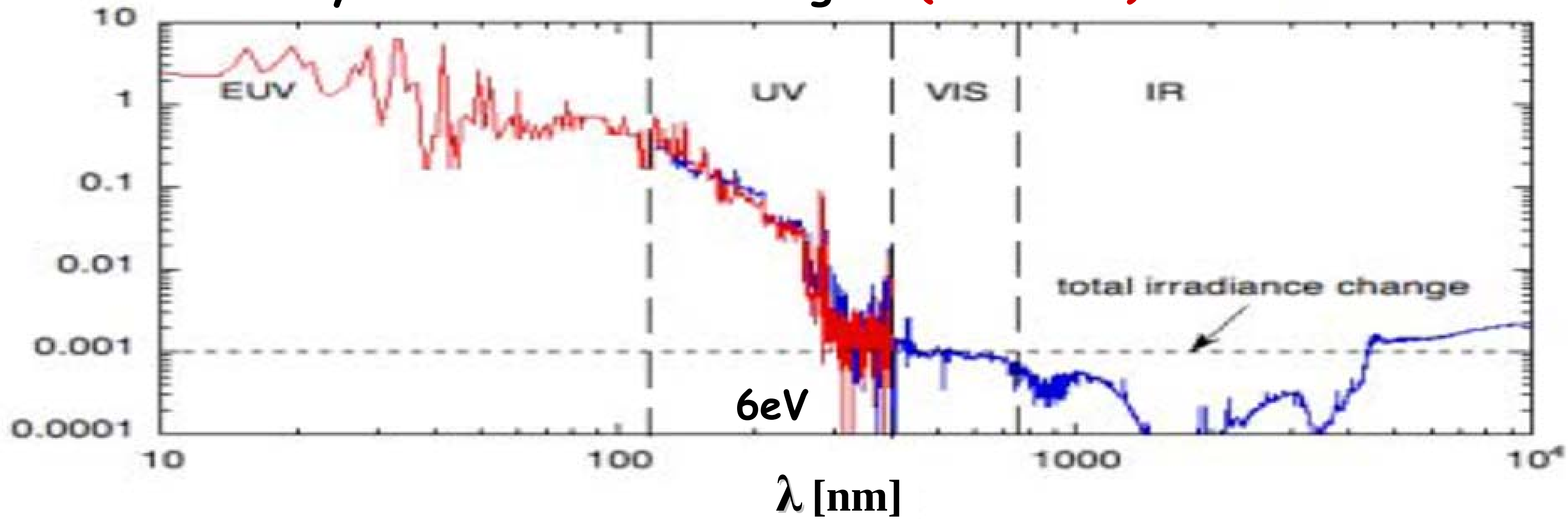
solar self-irradiation? ← solar irradiation

L. DiLella, K.Z.

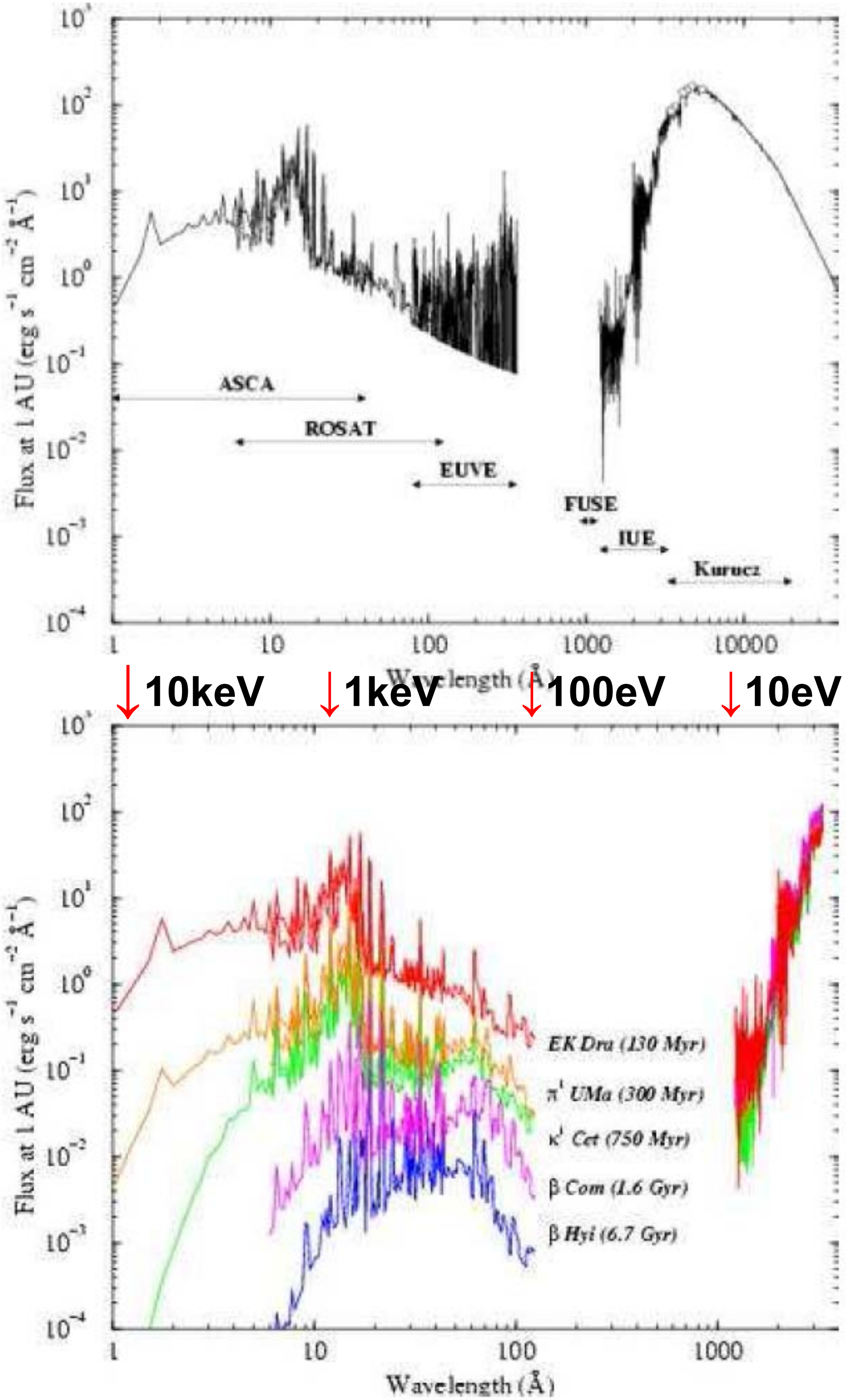
Solar Spectral Irradiance



11 years Irradiance Change: (Max-Min)/Min



http://www-sosst.larc.nasa.gov/meetings/2004/0615/presentations/08-kinnison.pdf



← Spectral irradiance of EK Dra for a distance of 1AU.

→ **L_x saturates < $L_{\sim axion}$!**

← Irradiances at 1AU from solar analogs with different ages.

Observations suggest:

magnetic energy =

main energy source for solar active phenomena.

open question:

how magnetic energy is rapidly released in the solar corona so as to create solar explosions such as flares + CMEs

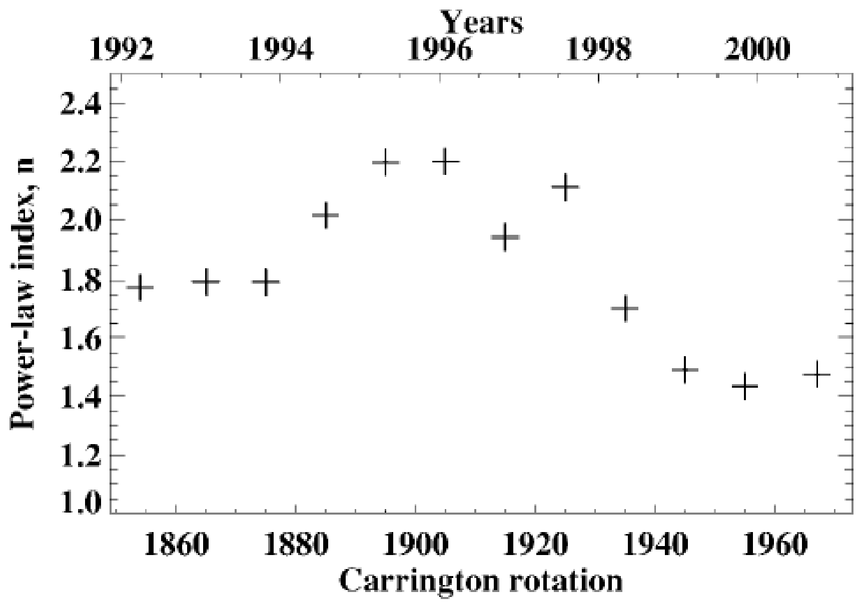
…. catastrophic events.

….

Y. Chen, Y. Q. Hu, L. D. Xia, astro-ph/0705.3886, Adv. Space Res. (2007) *in press*
Y. Chen, Y.Q. Hu, S.J. Sun, astro-ph/0705.3885, ApJ. 666 (Sept. 2007) *in press*

→ ~axions = a solution!

L_x vs. B



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

The relation between the solar soft X-ray flux <u>below ~4.4keV</u> …and B can be approximated by a power law with <index> ≈ 2.

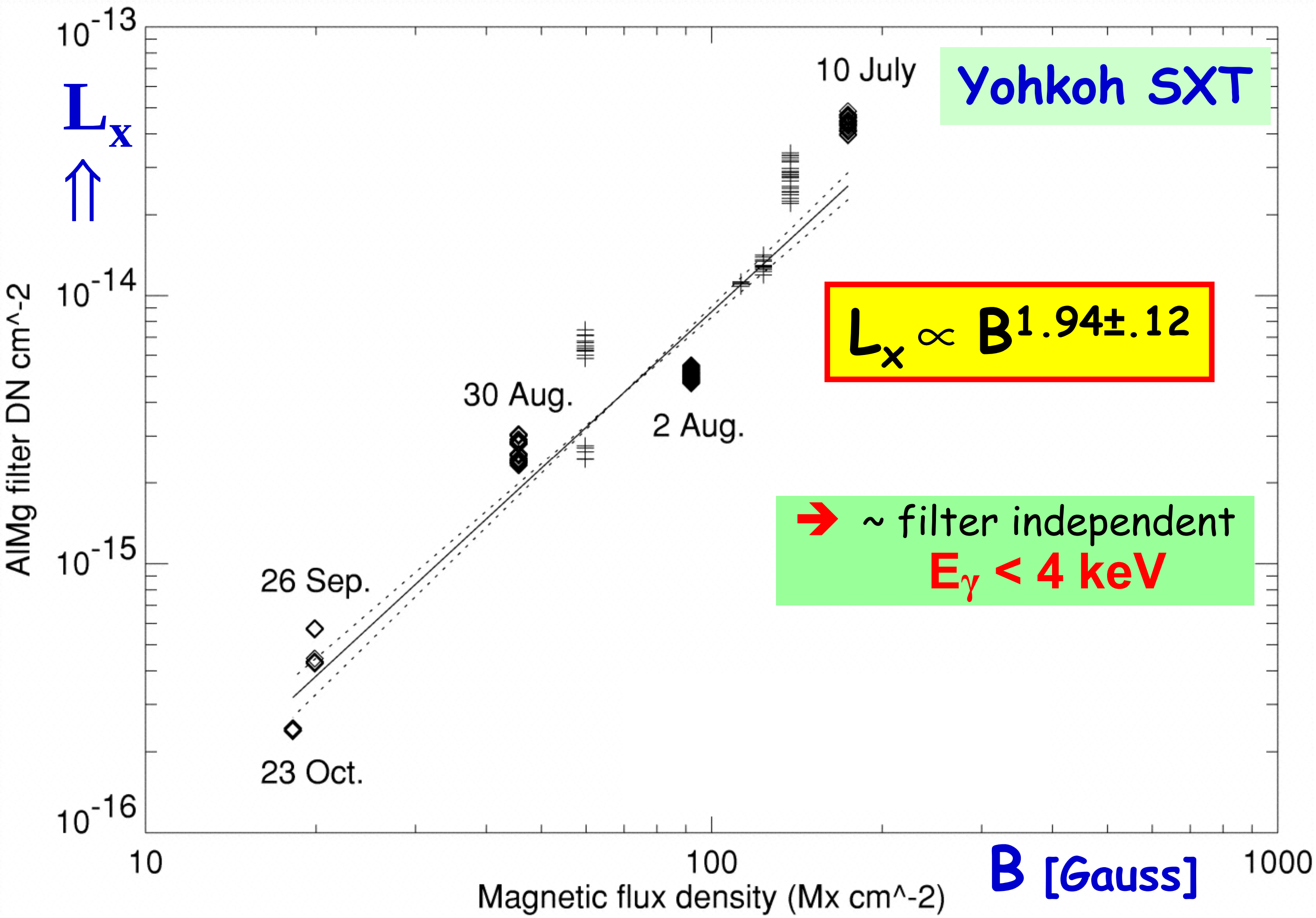
Benevolenskaya, Kosovichev, Lemen, Scherrer, Slater ApJ. 571 (2002) L181

<u>Note:</u> axion-to-photon oscillation □ B^2

Hoffmann, Z., Nucl. Phys. B S151 (2006) 359

⊗ **11 years solar cycle?**

The long-term evolution of AR7978



RHESSI :
often hard X-ray emission from non-flaring ARs.
→ $\gtrsim$ 5 keV

Hannah, Hurford, Hudson, Abstract: 2005AGUFMSH11A0242H AGU Fall meeting, 5-9/12/2005

<X-ray flux> / cm^2 vs. <B>

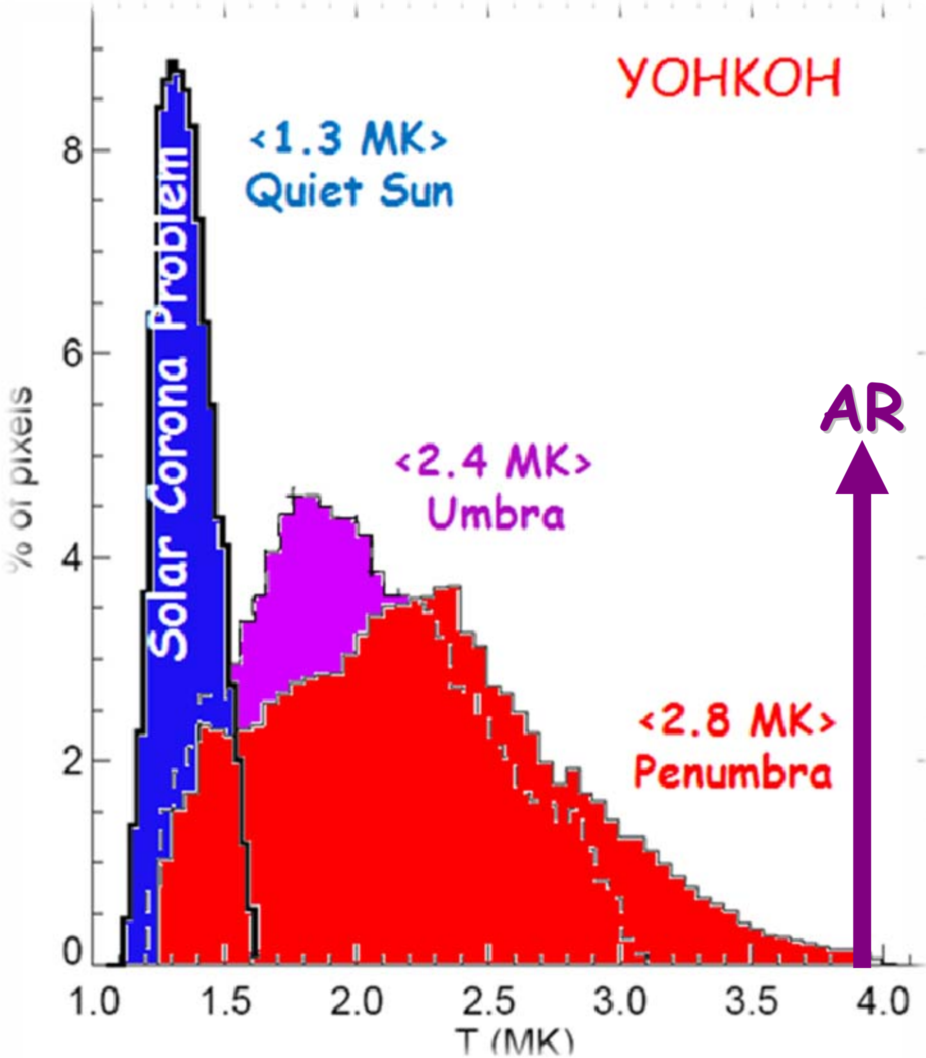
July-Nov. 1996

L van Driel-Gesztelyi, Démoulin, Mandrini, Harra, Klimchuk, ApJ.586 (2003) 579

K. Zioutas, K. Dennerl, M. Grande, D.H.H. Hoffmann, J. Huovelin, B. Lakic, S. Orlando, A.Ortiz, Th. Papaevangelou, Y. Semertzidis, Sp. Tzamarias, O. Vilhu J. Phys. Conf. Ser. 39 (2006) 103

Origin of **Sunspots** → one of the great puzzles of astrophysics

Zhao, et al., ApJ. 557 (**2001**) 384



Temperature distributions

Photosphere: T ⇩ ~4500K

Corona: T ⇧

Transition Region ⇧ (!?)

B ~2kGauss above most sunspots!

→heat flux problem @ umbra / penumbra

Spruit, Scharmer, A.&A. 447 (2006) 343

Some ARs are more productive

→ productivity $\otimes$ B-configuration, as in the case of large flares.

Qiu et al., ApJ. 612 (**2004**) 530

Nindos, et al., ApJ. SUPPL. 130 (**2000**) 485

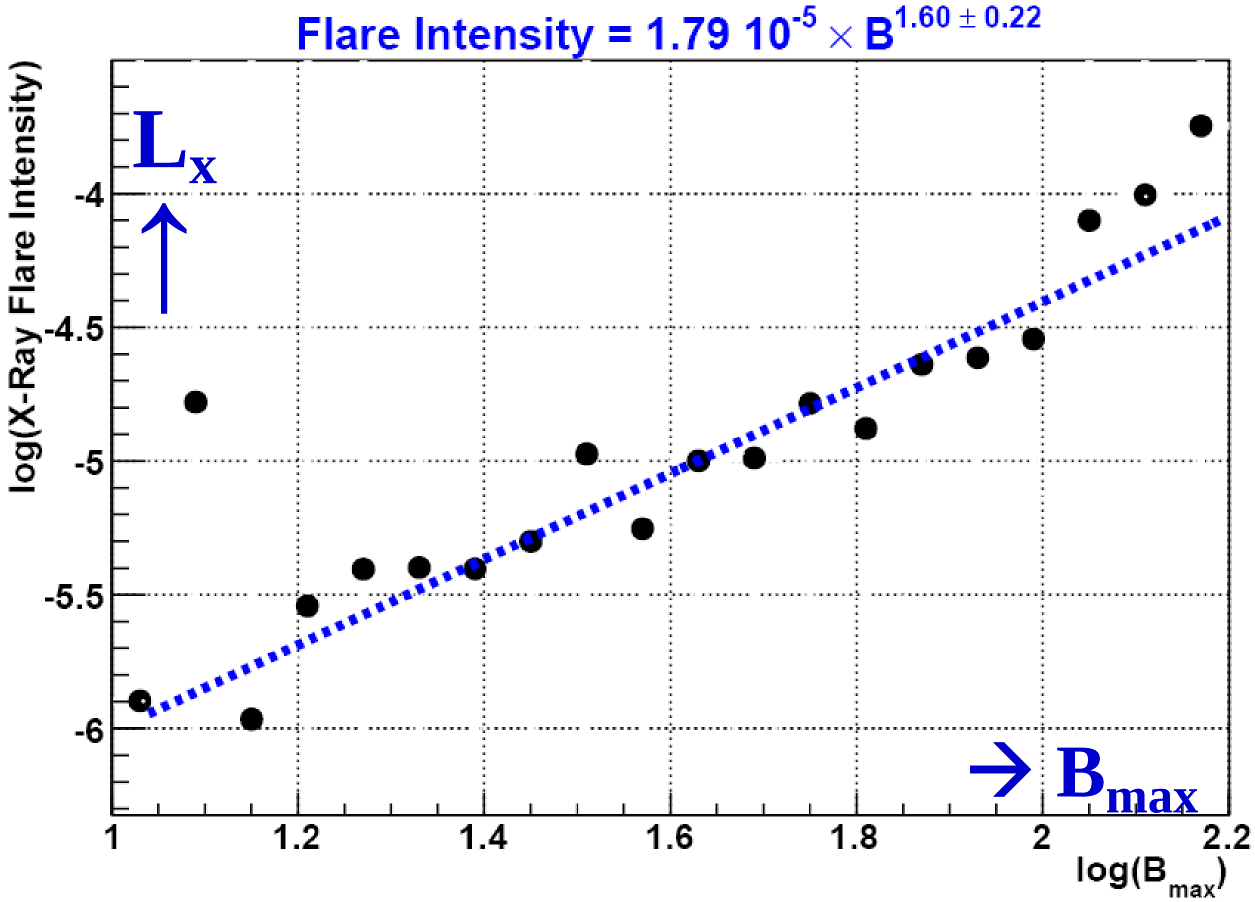
FLARES

1st surface brightness < max. L_{axion}

2nd <T> ~ 15-20MK

3rd $L_x \propto B^2$

4th ~axion

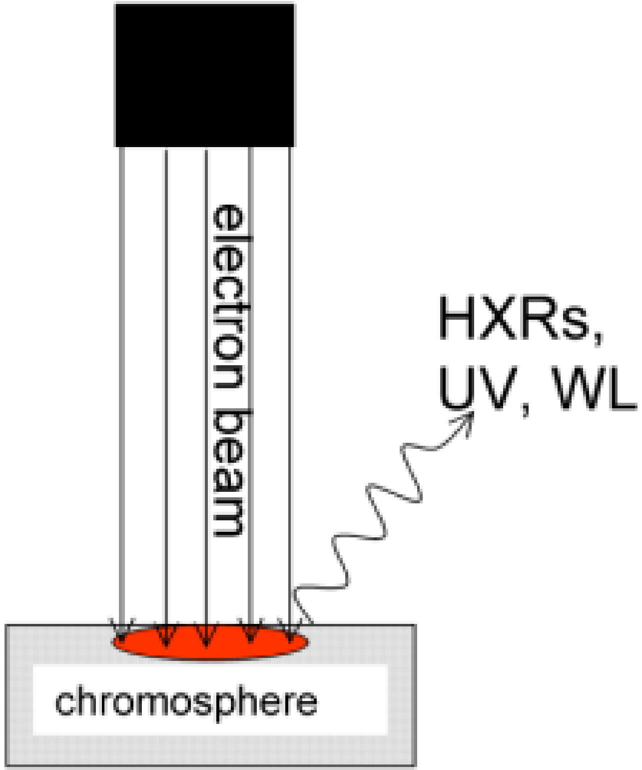


The Electron "Problem"
e^- ≈ 10^5× hard X-rays
from Bremsstrahlung!

Rebinned peak flare X-ray intensity → B_{max}

Mason et al., ApJ. 645 (2006) 1543 → B^2 correlation

G. Emslie (2005)
http://www.astro.auth.gr/%7Evlahos/ascona/memberstalks/energeticsEmslie.ppt#366,8



FLARES

Waving goodbye to…

The standard model = black-box

in the corona that accelerates nonthermal electrons, which stream down into the chromosphere and deposit energy there. …

conceptual simplicity
+
various pieces of (ambiguous) observational support

"this model has occupied our best theoretical minds for ~ 4 decades".

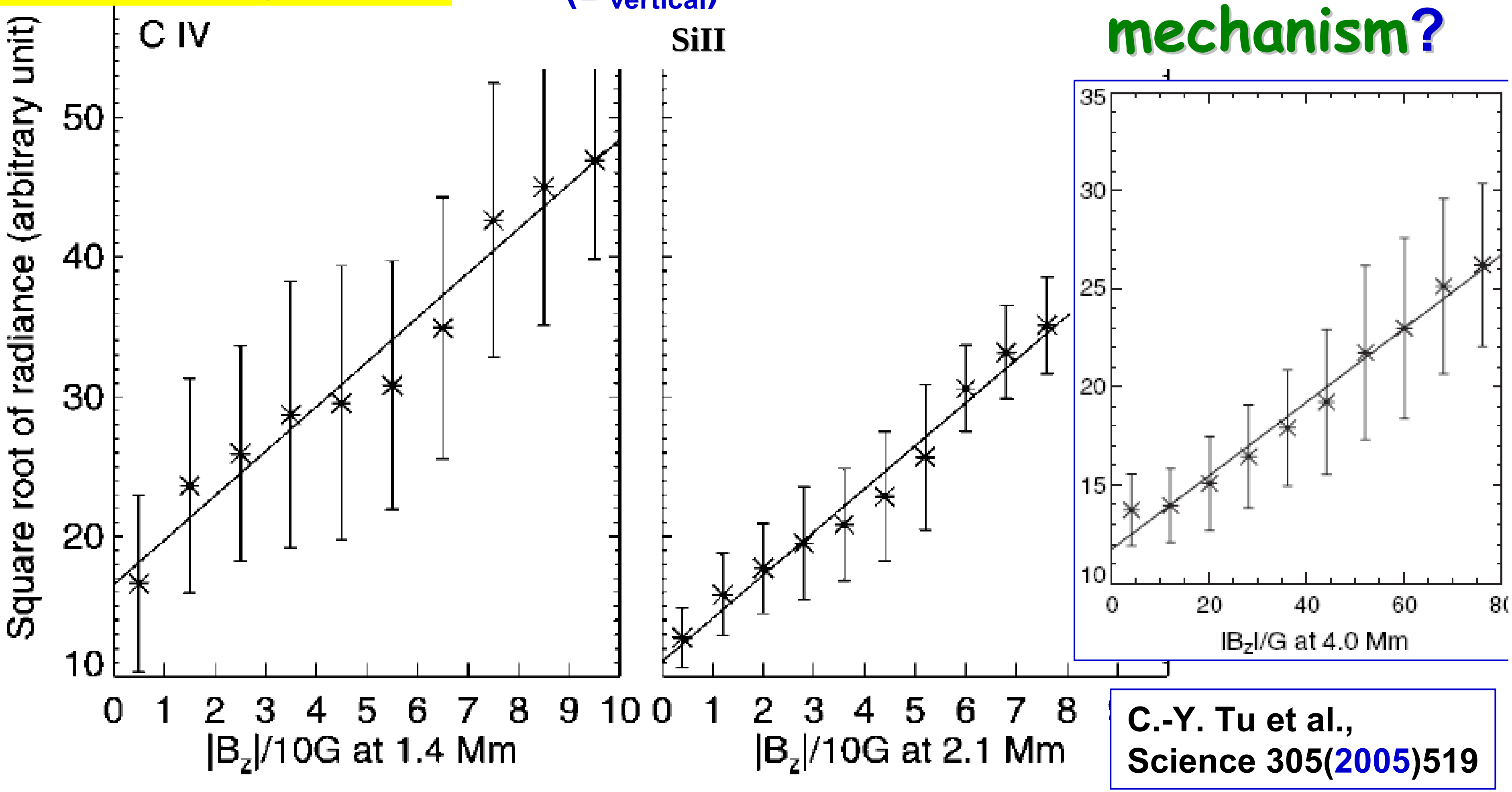
UV + optical continuum .. dominate the luminosity of a flare energy-wise.

•A new scenario …Alfven waves… poses theoretical problems

L. Fletcher, H. Hudson, RHESSI 68th Science Nugget (4th February **2008**)

Transition Region lines $\propto (B_{vertical})^2$ → TR in CHs 2000km → ~5000km!

mechanism?

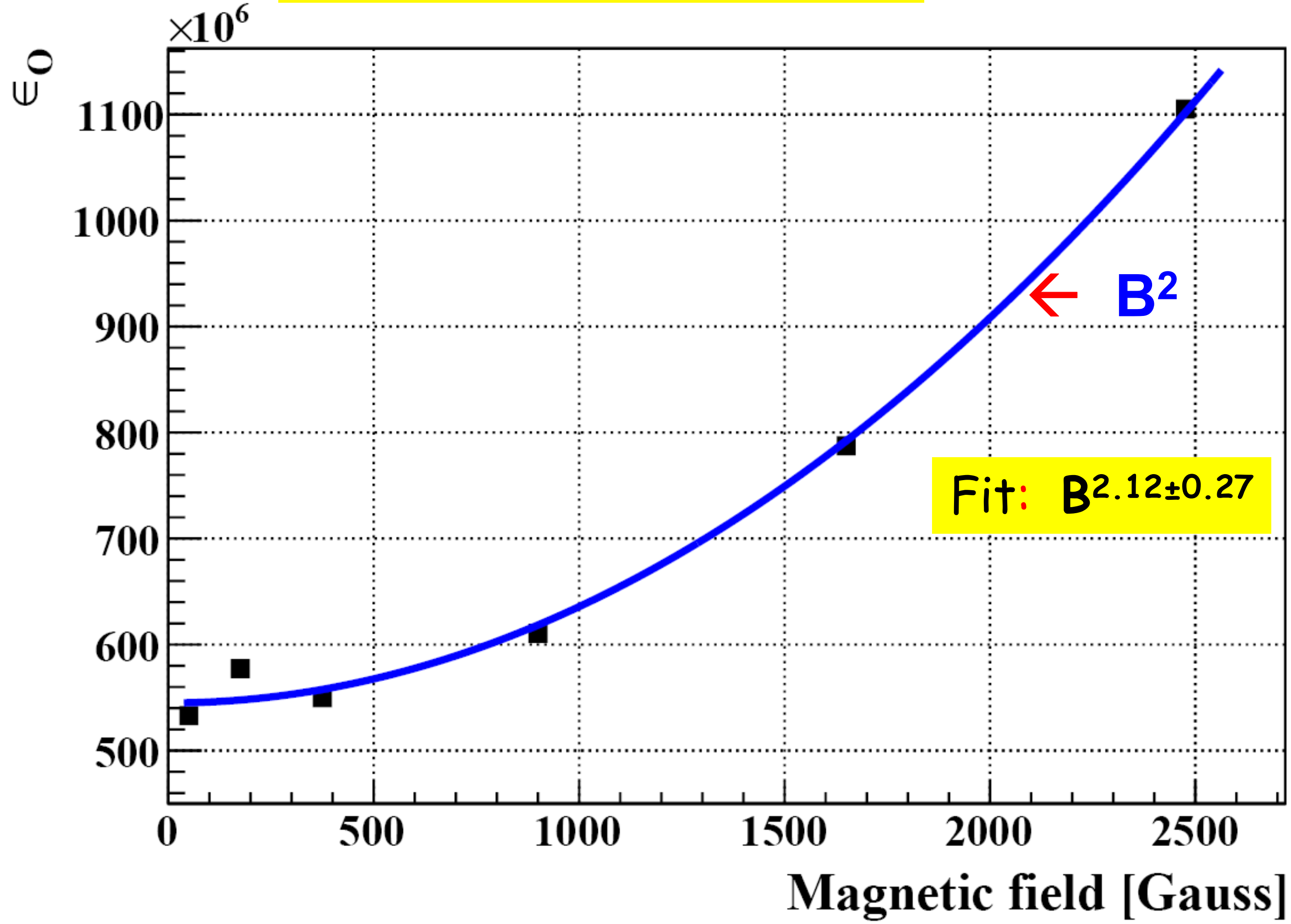


C.-Y. Tu et al., Science 305(2005)519

FIG. 2.—Dependence of the square root of the radiances of the C IV and Si II lines on $|B_z|$. The asterisks show the averages of the square root of the radiance in each bin as a function of $|B_z|$. The uncertainties show the corresponding standard deviations of the averages. The solid lines show linear fits to the averages. The correlation coefficient in both cases is 0.98.

C.Y. Tu et al., ApJ. 624 (2005) L133, G.Q. Zhou, J.S. He, C.Y. Tu, E. Marsch, Chin. A.& A. 31 (2007) 137

Oxygen abundance



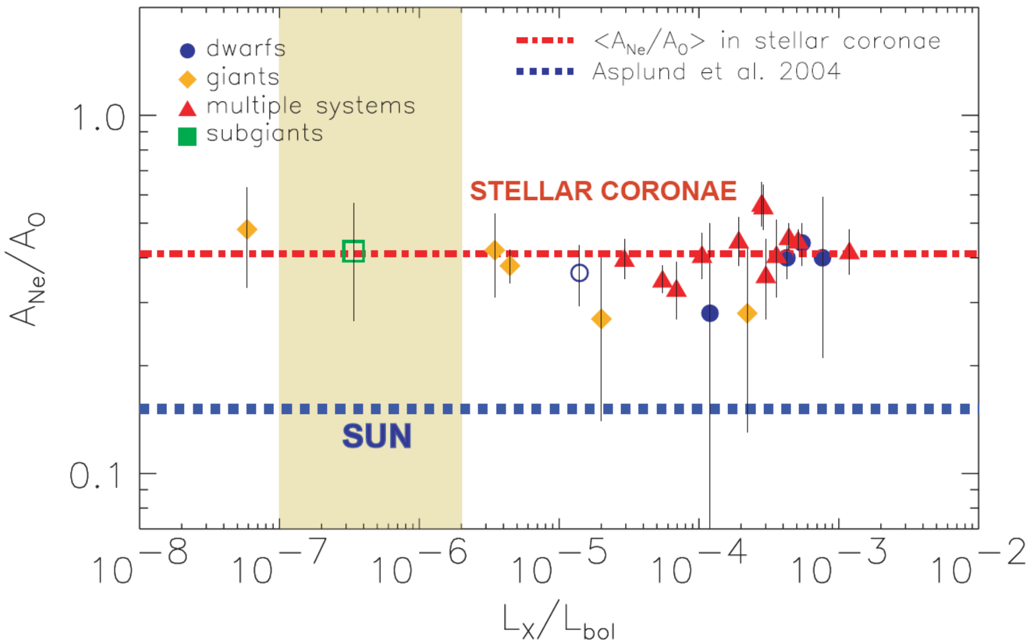
Solar oxygen abundance → **B** **at the base of the photosphere near a pore**. The blue line: B^2-dependence + constant component

→ Private communication, H. Socas-Navarro.

Z., Tsagri, Semertzidis, Papaevangelou, Nordt, Anastassopoulos, astro-ph/200701627

M. Asplund et al., astro-ph/200410214 :

measured photospheric abundances of C, N, O, Ne ~30% below prediction!



Ne/O abundance ratios vs. coronal activity.

Quiet ARs:
Ne / O ~ 0.15
Flares:
enhanced Ne detection (~2x)

+ solar TR dynamical behaviour:

2 ~axion components?!

- Outwards (B)
  ➔ >Ne
- Inwards(self-irradiation)
  ➔ <Ne

Note: $\sigma_{pe(Ne\text{-}to\text{-}O)}$ > 2× @ Eγ~1 keV

➔ models incorrectly predict

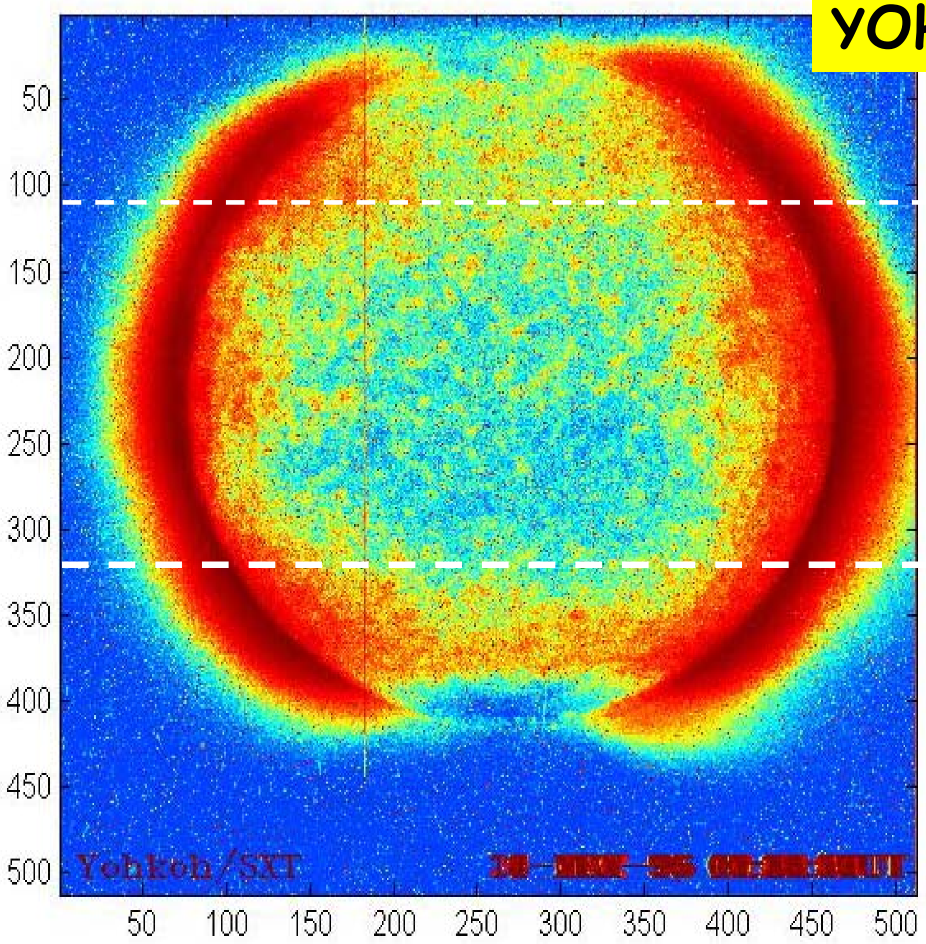
- the depth of the convection zone
- the depth profiles of sound speed and density
- the helium abundance

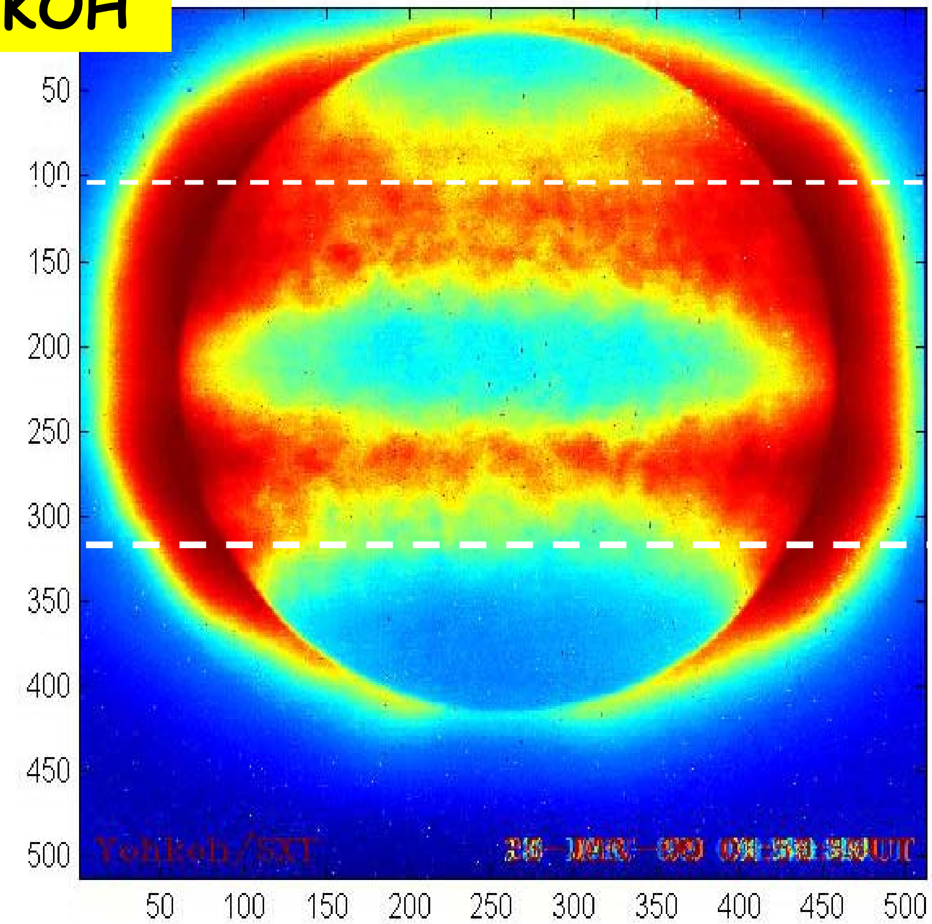
➔ why the Sun is so special?

C.Liefke, JHMM. Schmitt, A&A L. (2006)

Solar Minimum   Solar Maximum

YOHKOH





~250 eV - ~4 keV

New!

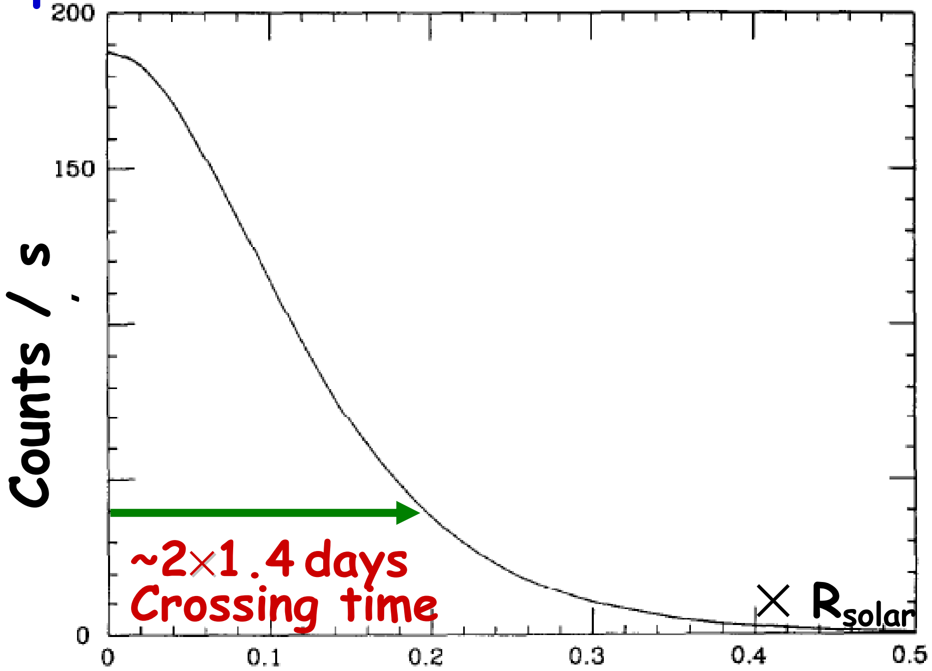
Yohkoh image processing @ lowest intensities!

CAST in Sunspots?

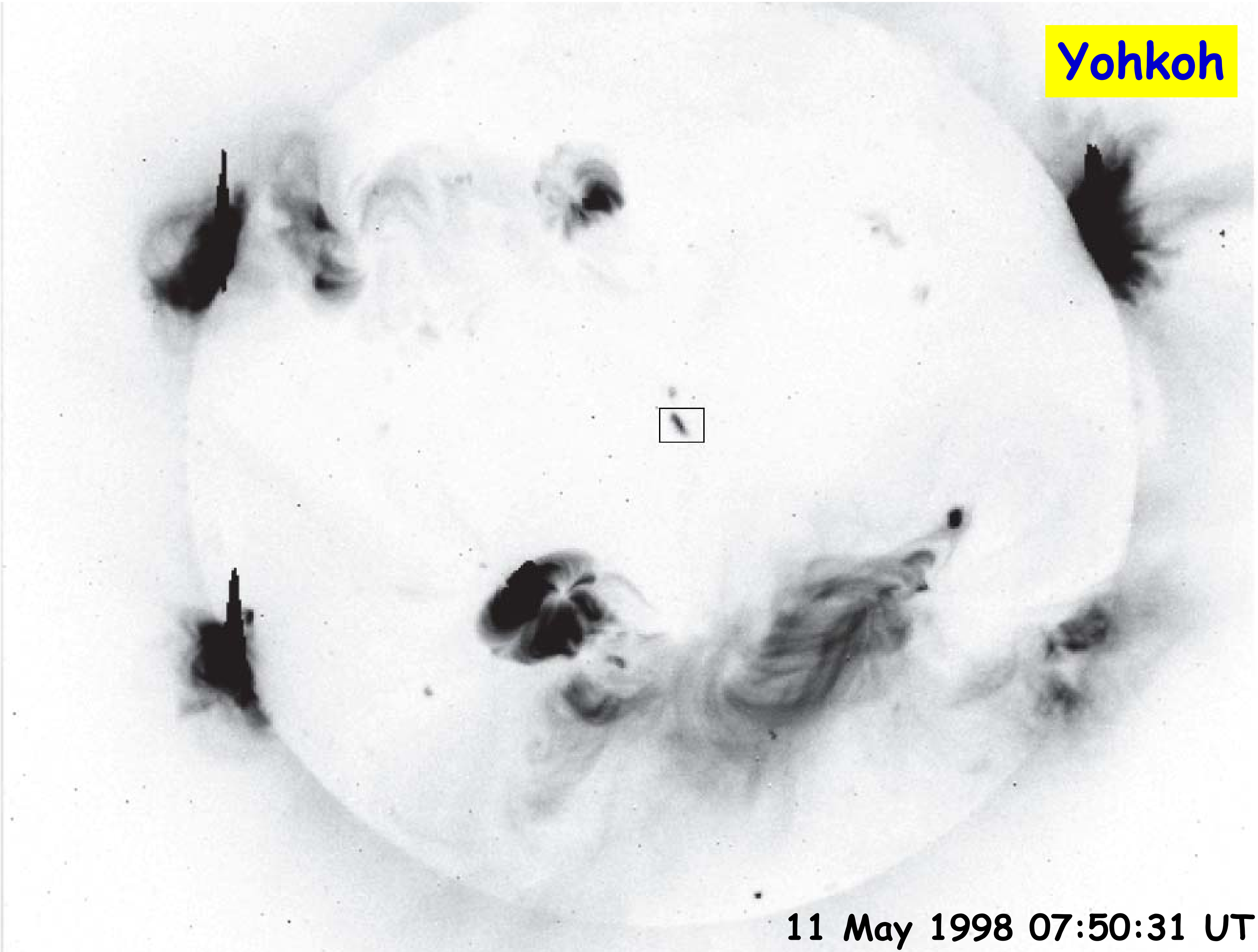
" Unfortunately, the signal is dominated by background → the time evolution of X-ray emission from sunspots as they cross the disk centre of the Sun

→ a brightening @ ±10% " → ~3 days!

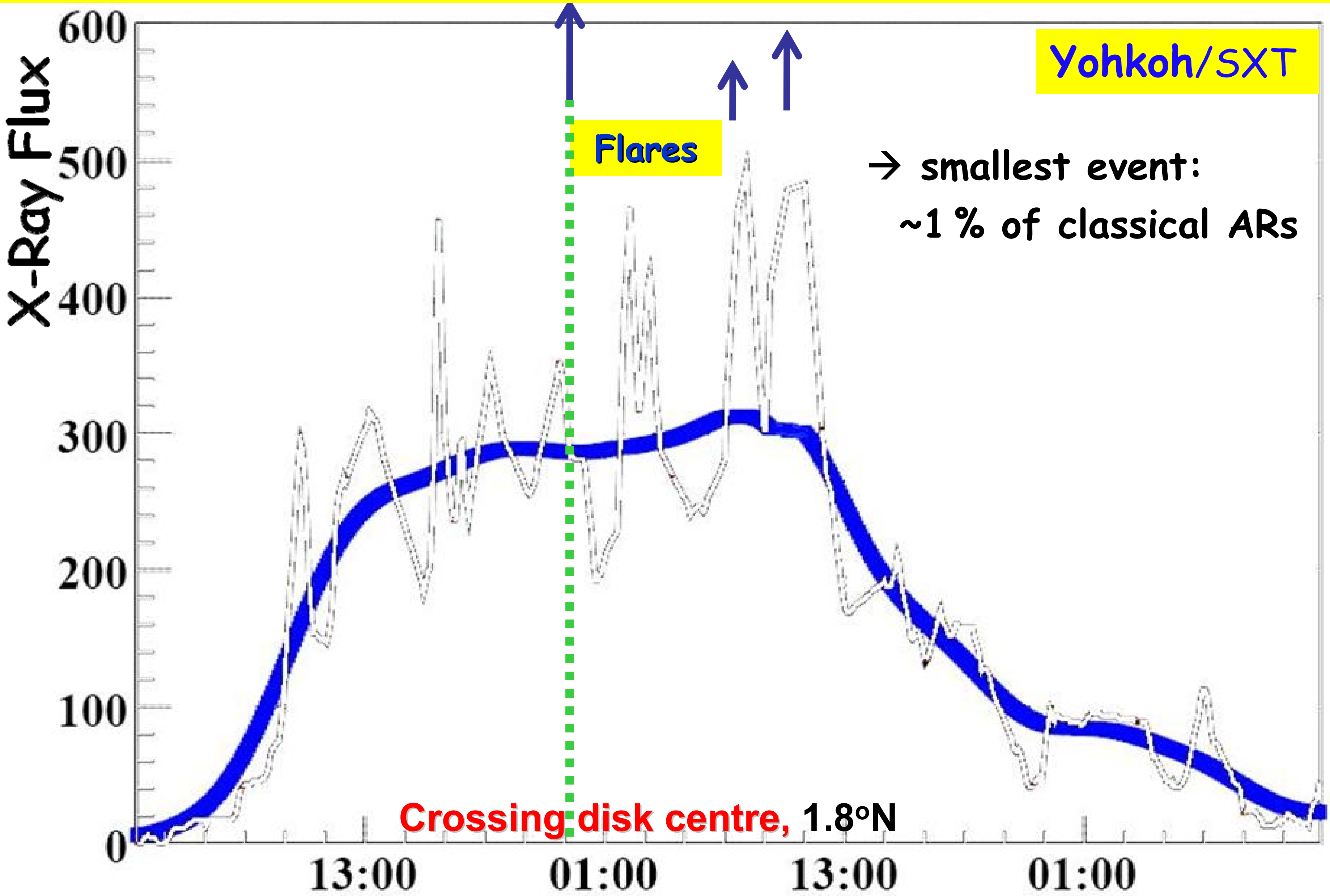
Carlson, Tseng , Phys. Lett. B365 (**1996**) 193



→ RHESSI, Hinode search for axions


Yohkoh
11 May 1998 07:50:31 UT

X-Ray Bright Point @ Solar Disk Centre → ~2.5 d



Mandrini et al., A&A 434(**2005**)725

L.vanDriel-Gesztelyi, private communication

The emerging solar axion(-like) picture:

- ~axion source(s):
  » extended & > few eV
  → various masses OR different particles?

- ~axion conversion @ Sun's surface
  → in/outwards radiation pressure

- Transition Region → most sensitive place?

. . . .

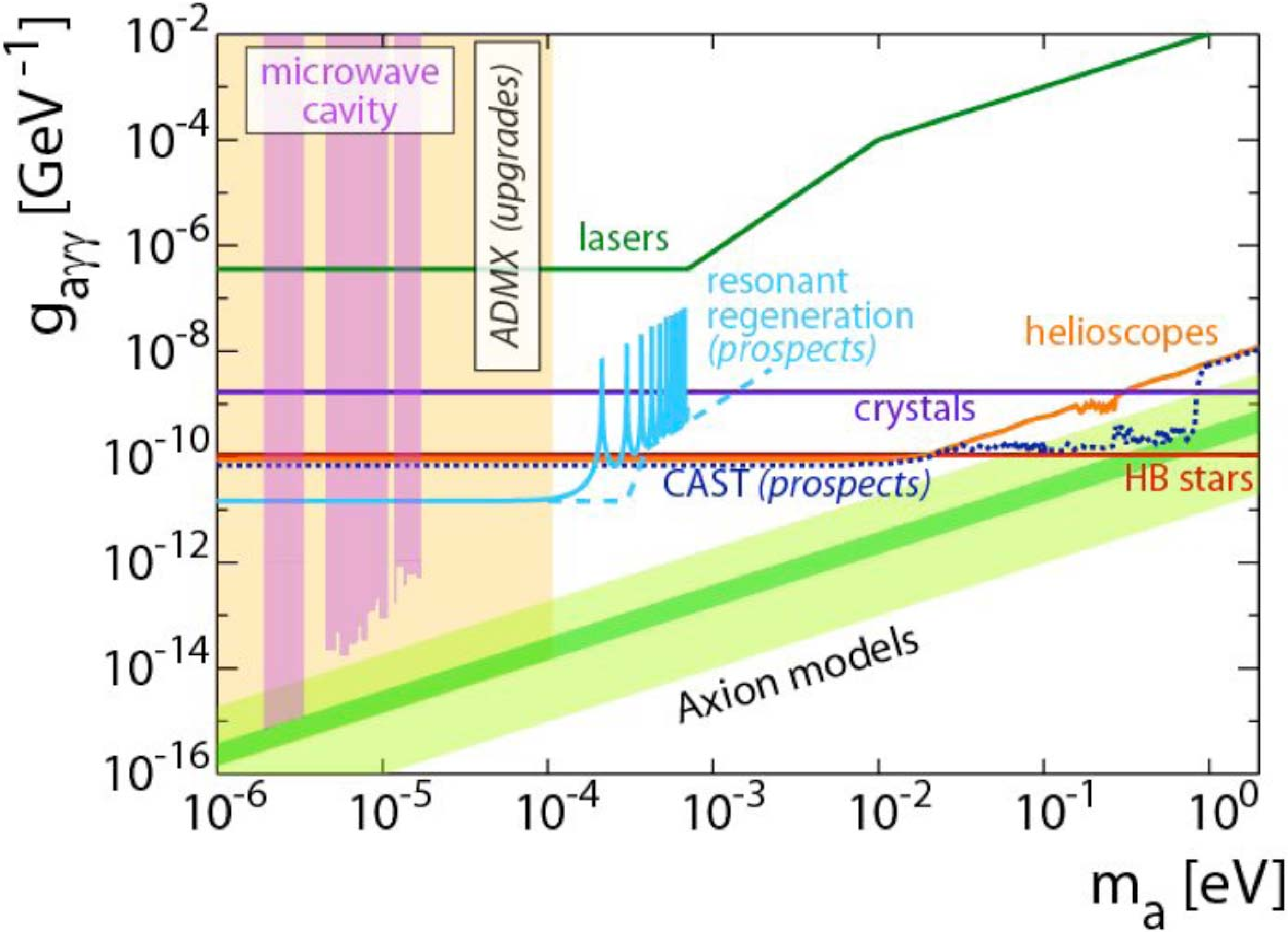
→ B_{sun}= transient trigger (not energy storage?)

... thanks ILIAS(next) !

see section 4 in S Dalla, L Fletcher, NA Walton, A&A 468 (2007) 1103

Additional slides

Excluded $g_{a\gamma\gamma}$ vs. m_a with all experimental and observational constraints

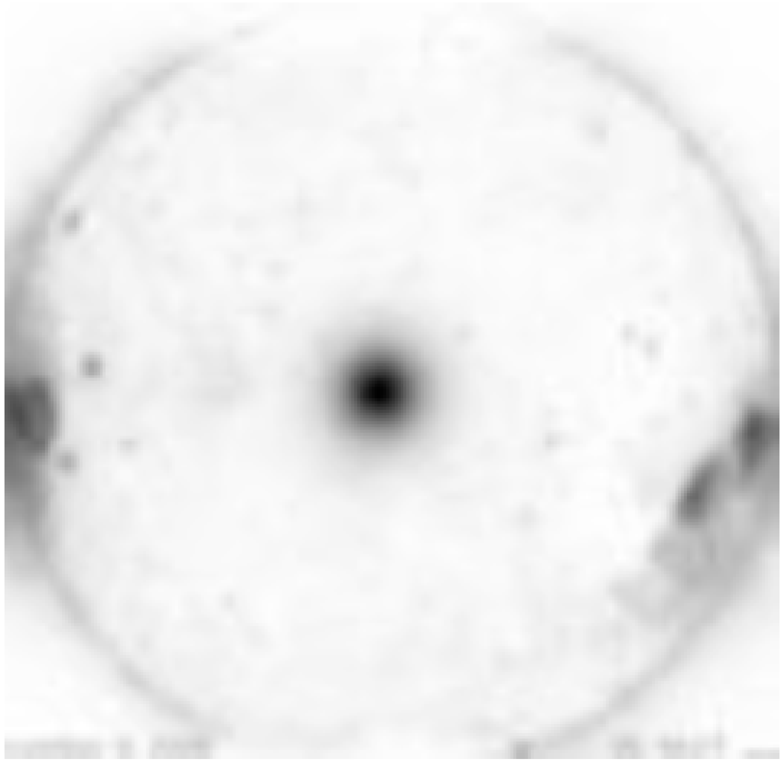


Summary & final remarks

The theoretical case is better than ever

"If the axion doesn't exist, please tell me how to solve the Strong-CP problem" (Wilczek)

"Axions may be intrinsic to the structure of string theory" (Witten)

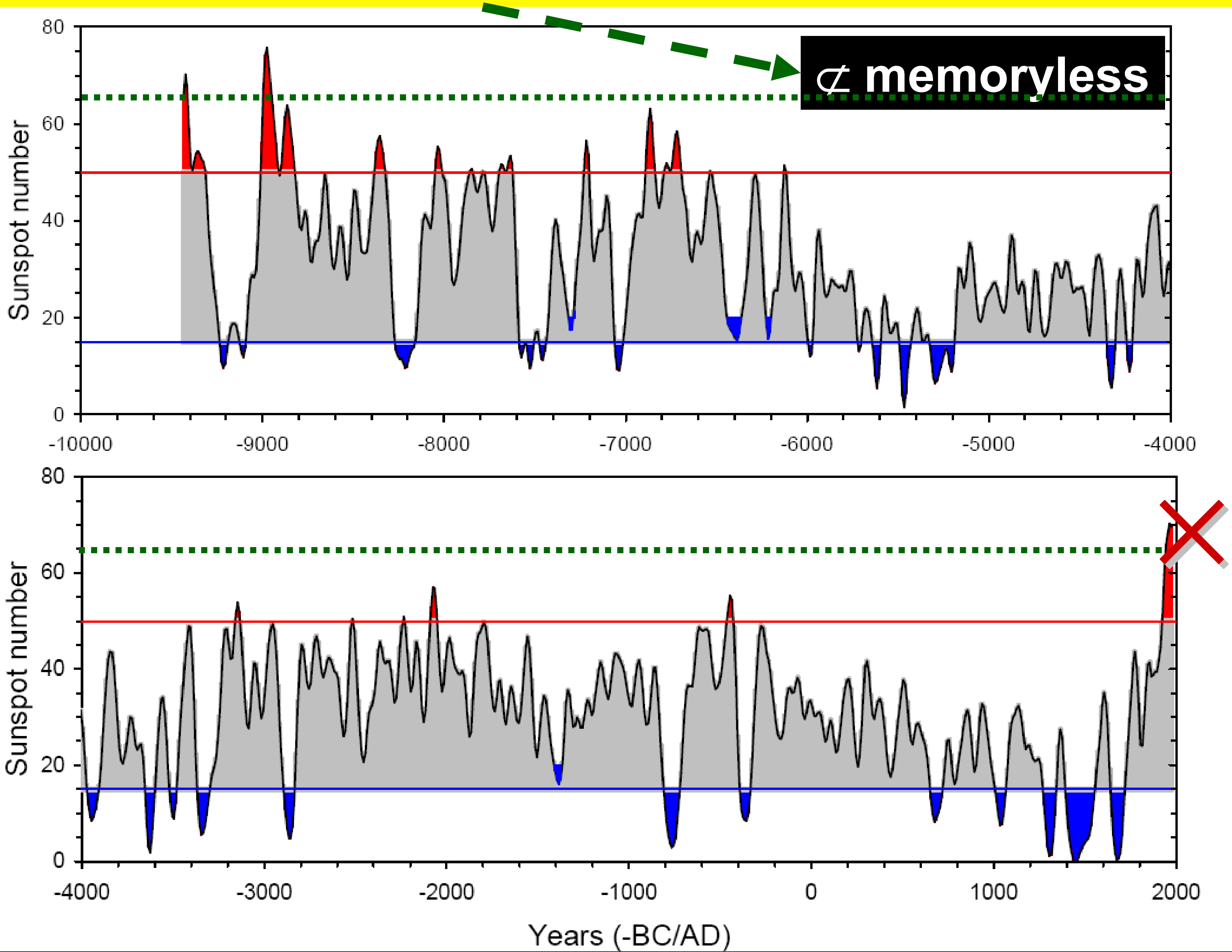


Experimental progress is excellent & discovery would teach us a lot

Be prepared for the unexpected

The really unexpected ...

Grand minima / maxima of solar activity



I.G. Usoskin, S.K. Solanki, G.A. Kovaltsov, Astron. & Astrophys. (2007) *in press.*

X-ray mysteries:

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

  → **Similar-to-Sun logic = wrong** ←

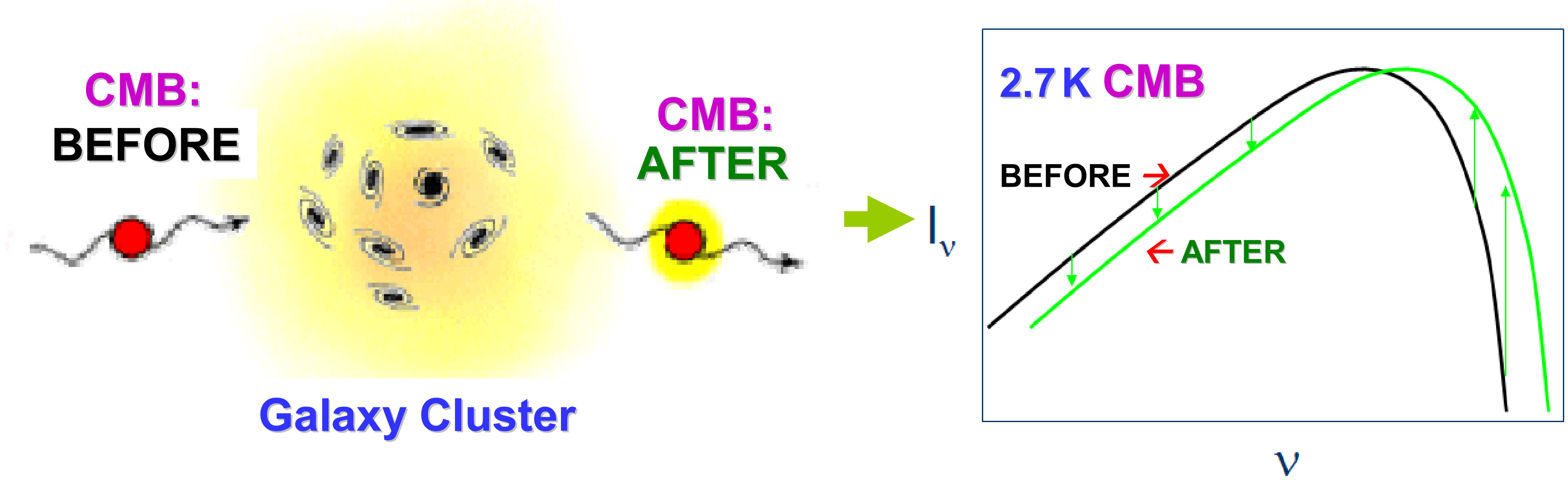
Galactic Center → **origin of diffuse X-rays?**
too hot (~ 90MK) to be a gravitationally bound plasma!
→ ***how to produce it?***

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/**06**02072
[see also B.A. Reid, D.N. Spergel, astro-ph/0601133 v2 (**23.7.2006**)]
pp. 4-6,27,30

XRB*radiation* ← **origin?**

Sunyaev - Zel'dovich (SZ) effect



- Scattering of CMB off hot electrons in the ICM: $\sigma_{compton} \sim \rho_e$
- Probes the thermal energy distribution of electrons in the ICM.
- SZ flux is redshift independent: $\sim \rho_e \times T_e$

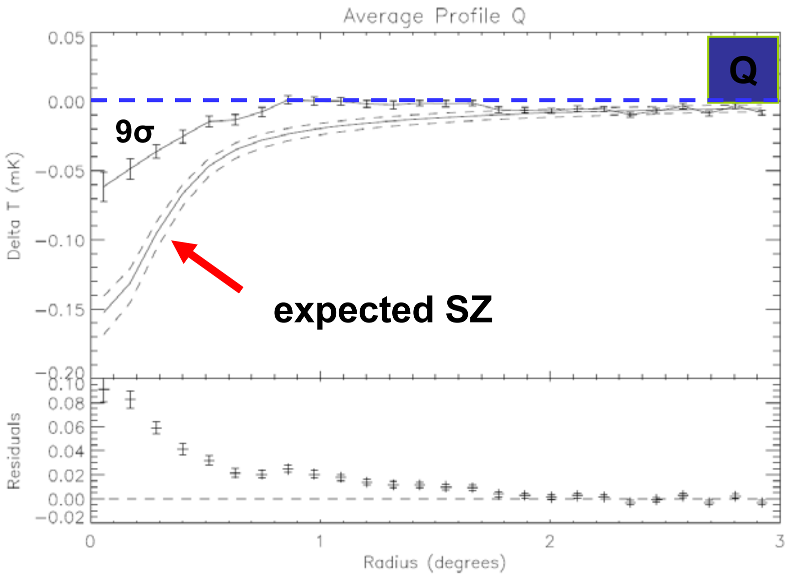
  a) NOT contamination of radio sources
  b) X-rays, only from Bremsstrahlung? ➔ $\Phi_{X\text{-rays}} \sim (\rho_e)^2 \times (T_e)^{1/2}$

+ radiatively decaying ~axions?

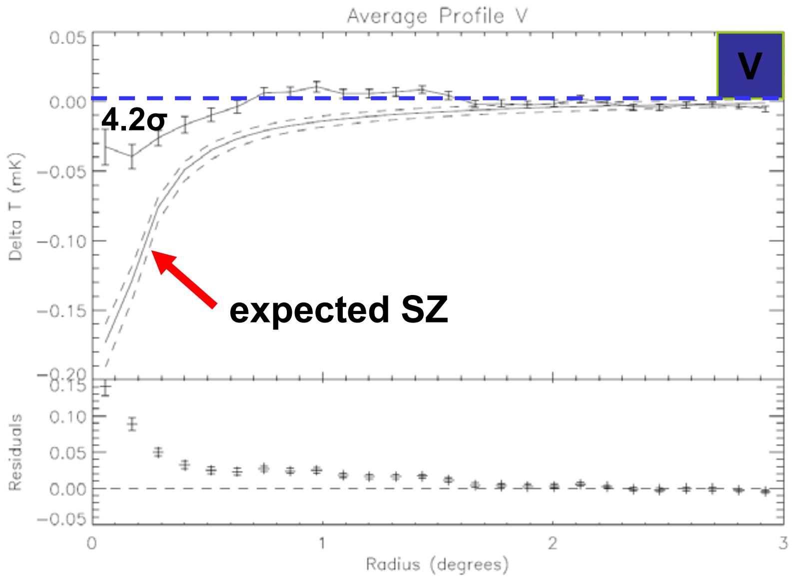
→ Decay rate $\sim \rho_{axion}$

ghost plasma

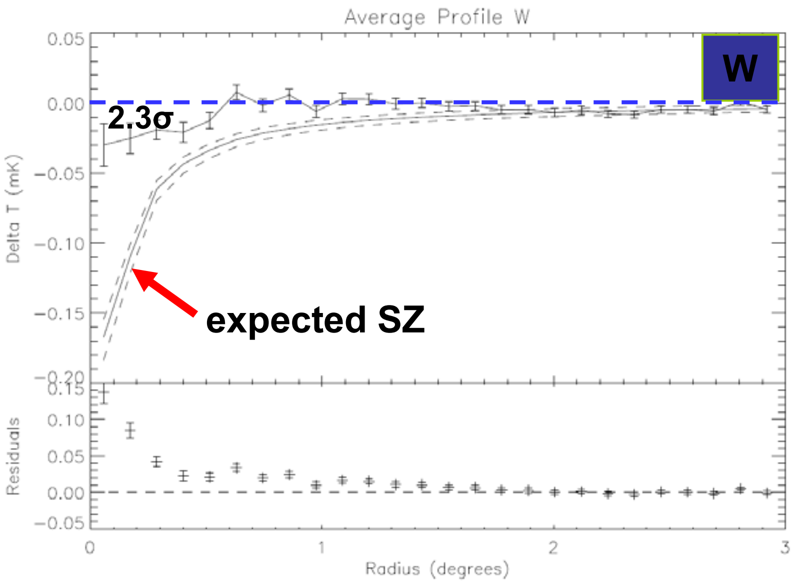
Z., Dennerl, Hoffmann, Papaevangelou SCIENCE 306 (2004) 1485
LaBoque et al., ApJ. 652 (2006) 917



Average Profile Q
Q
9σ
expected SZ
Delta T (mK)
Residuals
Radius (degrees)

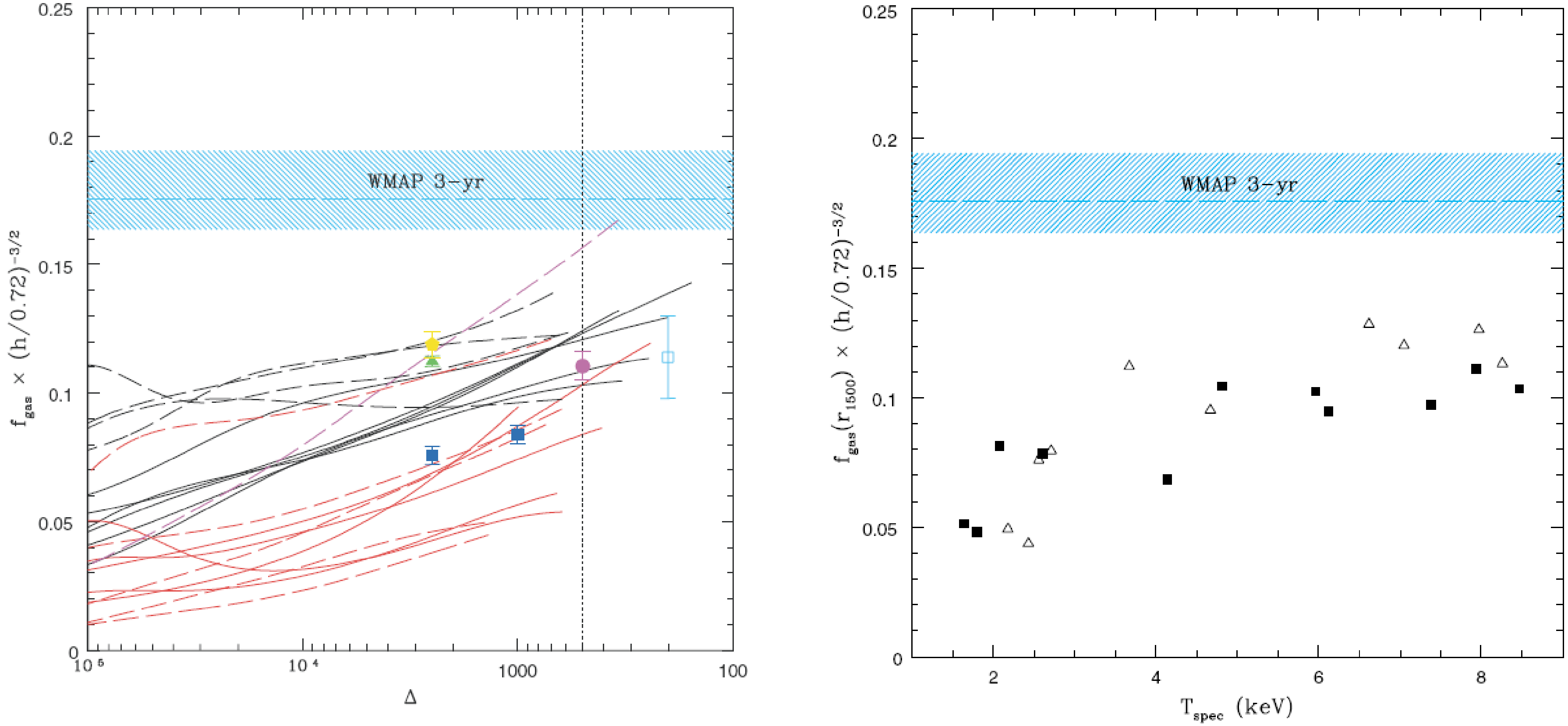


Average Profile V
V
4.2σ
expected SZ
Delta T (mK)
Residuals
Radius (degrees)



Average Profile W
W
2.3σ
expected SZ
Delta T (mK)
Residuals
Radius (degrees)

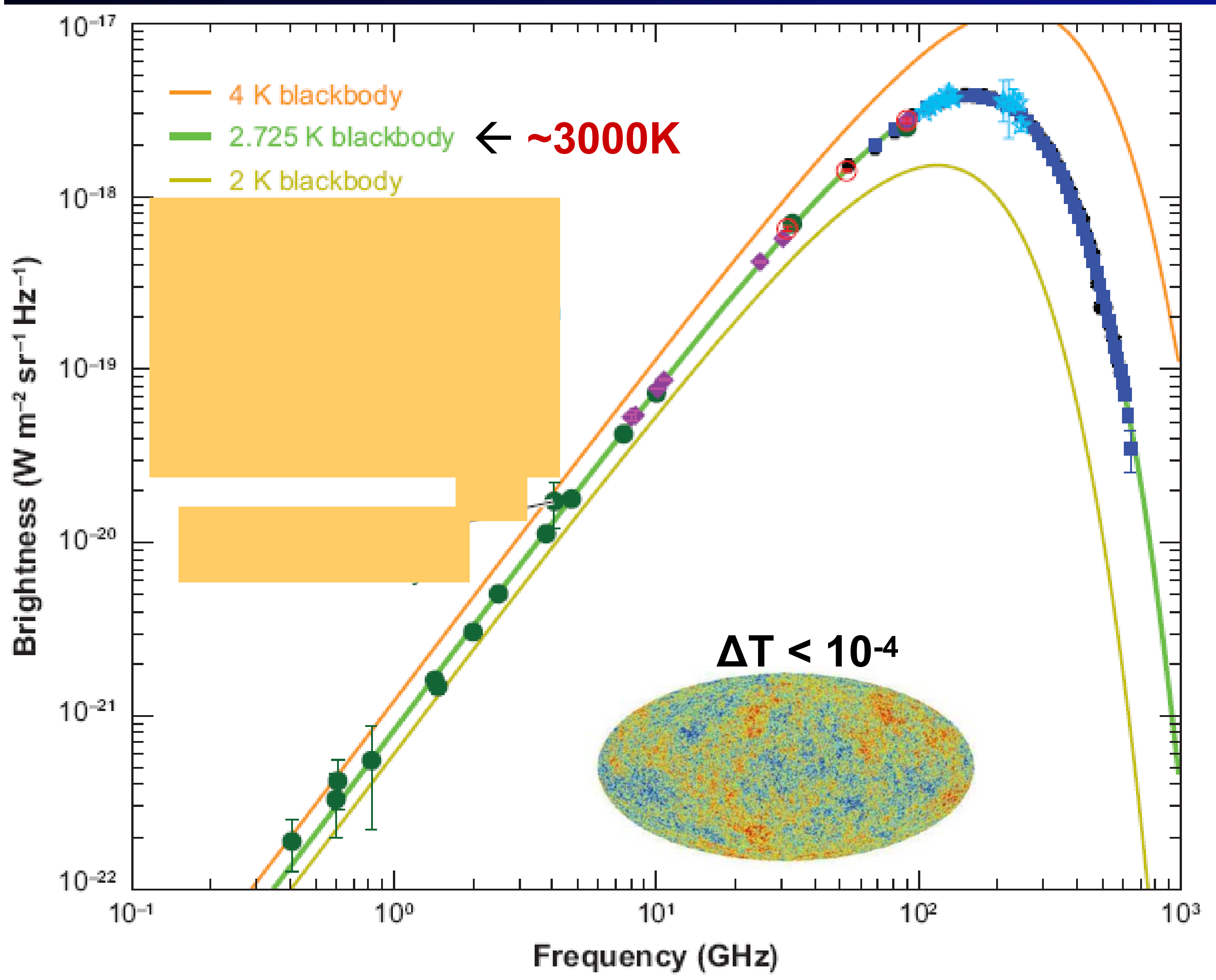
Galaxy Clusters → WMAP_3years



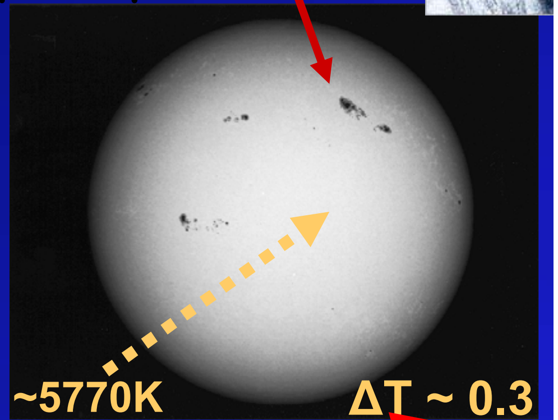
Observed integrated gas mass fractions = f(overdensity Δ) [left]
→ within Δ=1500 of the ICM [right]. ➔ Chandra & XMM-Newton

McCarthy, Bower, Balogh, MNRAS 377 (**2007**) 1457

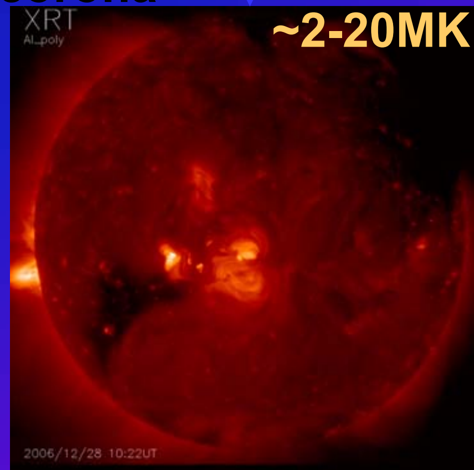
The Cosmic Microwave Background



photosphere



corona



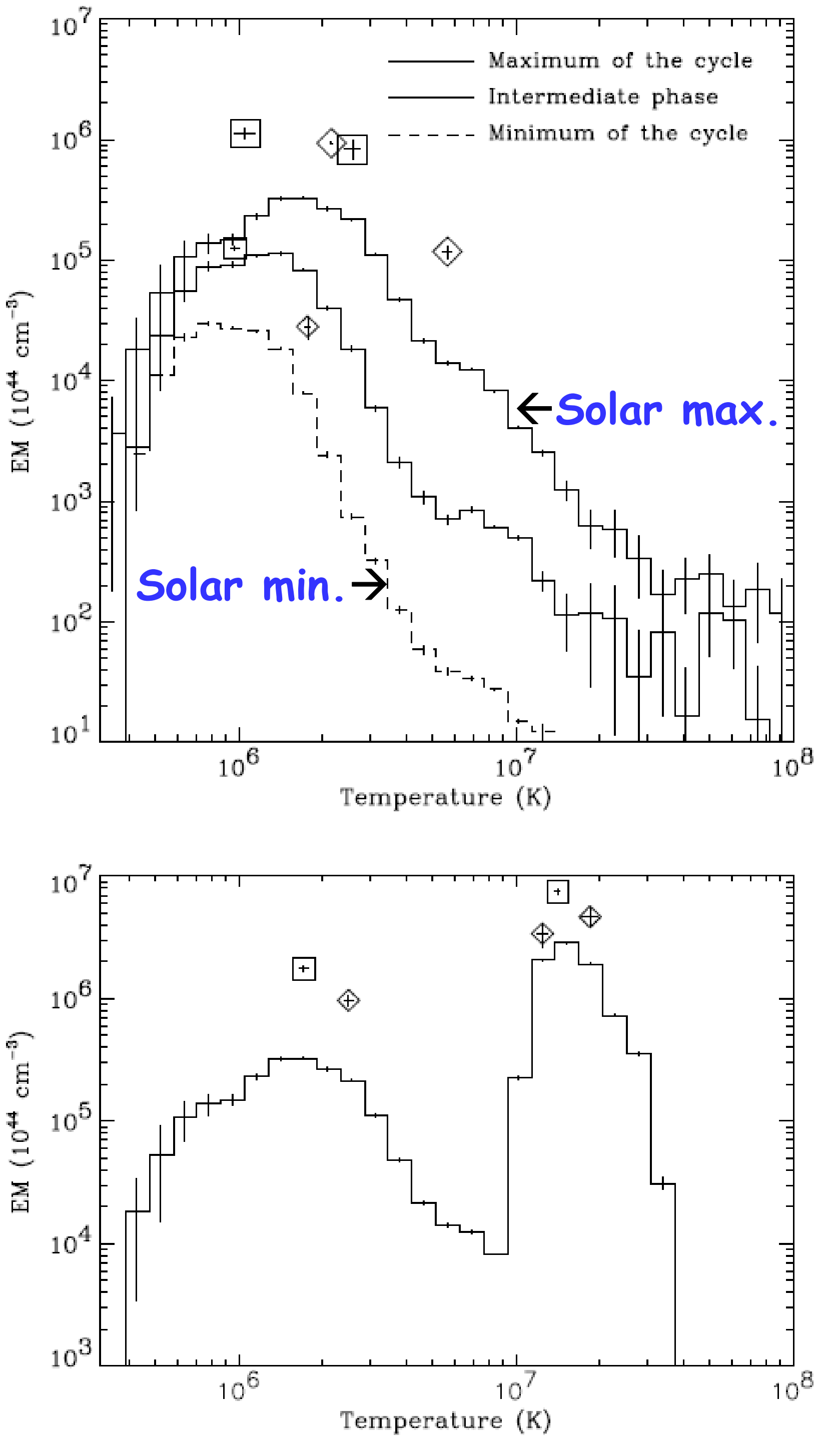
D. Samtleben, S. Staggs, B. Winstein, ARNPS 57 (2007) 245

We were extremely fortunate to have had a large sunspot at the solar limb during our observing campaign.

Magnetic fields are widely believed to play a major role in solar coronal physics, from global properties like heating and wind acceleration to energetic transient phenomena like flares and coronal mass ejections.

To summarize, we measure a coronal magnetic field strength of **1750 *G*** at a height of **8000 km** above a large sunspot in AR 10652 at the west solar limb on 2004 July 29 using coordinated observations with the VLA, *TRACE*, and three instruments (CDS, EIT, MDI) aboard *SOHO*. This observation is the first time that coronal radio brightness temperatures (6.9×10^5 K) have been analyzed in a 15 GHz solar radio source projected above the limb. Observations at 8 GHz yield coronal magnetic field strengths of 960 *G* at a height of 12,000 km. Both the 15 and 8 GHz sources are unpolarized at their respective peaks. The field strength measurements combine to yield a **magnetic scale height L_B ~ 6900 km**.

J.W. Brosius, S.M. White, ApJ. 641 (2006) L69

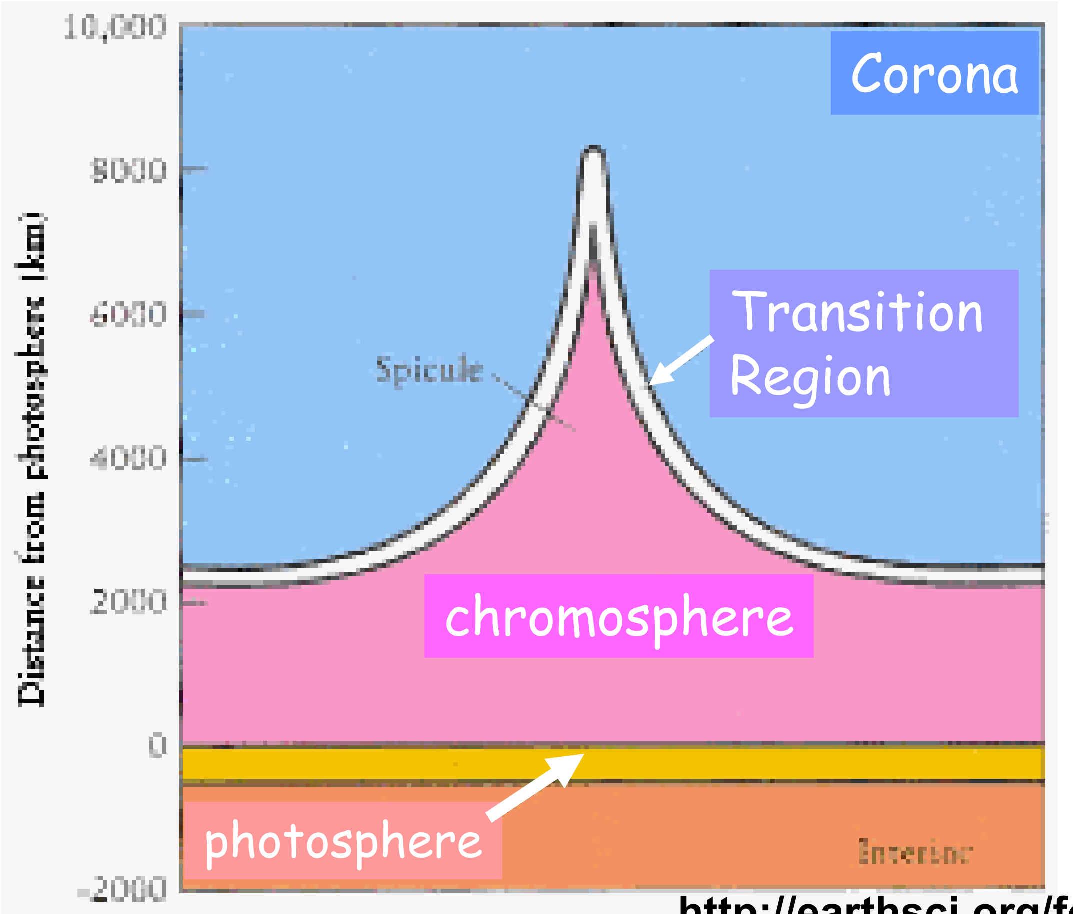


From **Yohkoh**/SXT images ➔ whole-Sun X-ray EM vs. T in the range $10^{5.5}$ -10^8 K, during the specific observation. The total amount and the distribution of EM change dramatically during the cycle, in particular at T>10^6K.

Distributions of the emission measure vs. temperature for the three very different phases of the solar cycles the 1992 January 6 observation (solar maximum; thick solid line), that of 1993 July 27 (thin solid line), and that of 1994 June 1 (solar minimum; dashed line). The line in the lower panel contains the contribution of the whole corona during the solar maximum (thick solid line in upper panel) and of the LongDurationEvent Flare of 1992 November 2.

→ **Yohkoh**

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



http://earthsci.org/fossils/space/sun/sun.html

All of the energy that heats the corona and drives the solar wind, must flow through this discontinuity →TR

J.T. Mariska ARAA 24 (1986) 23

Transient solar $B_{horizontal}$

 astro-ph/0802.1769

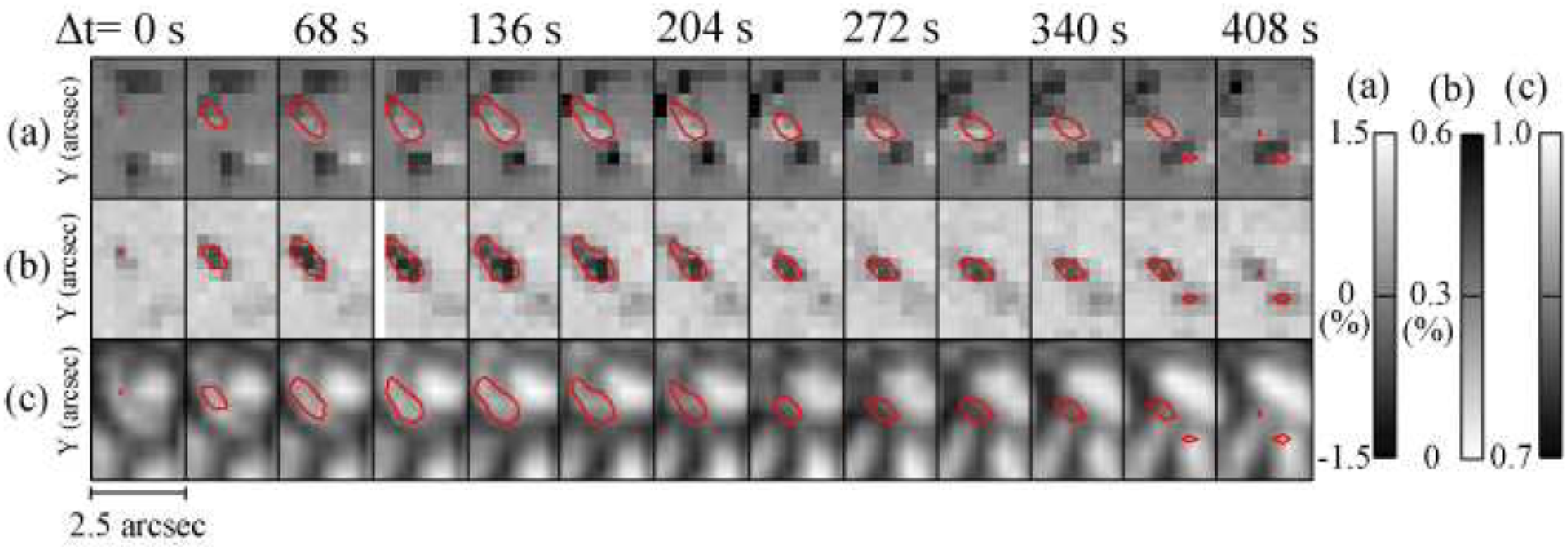
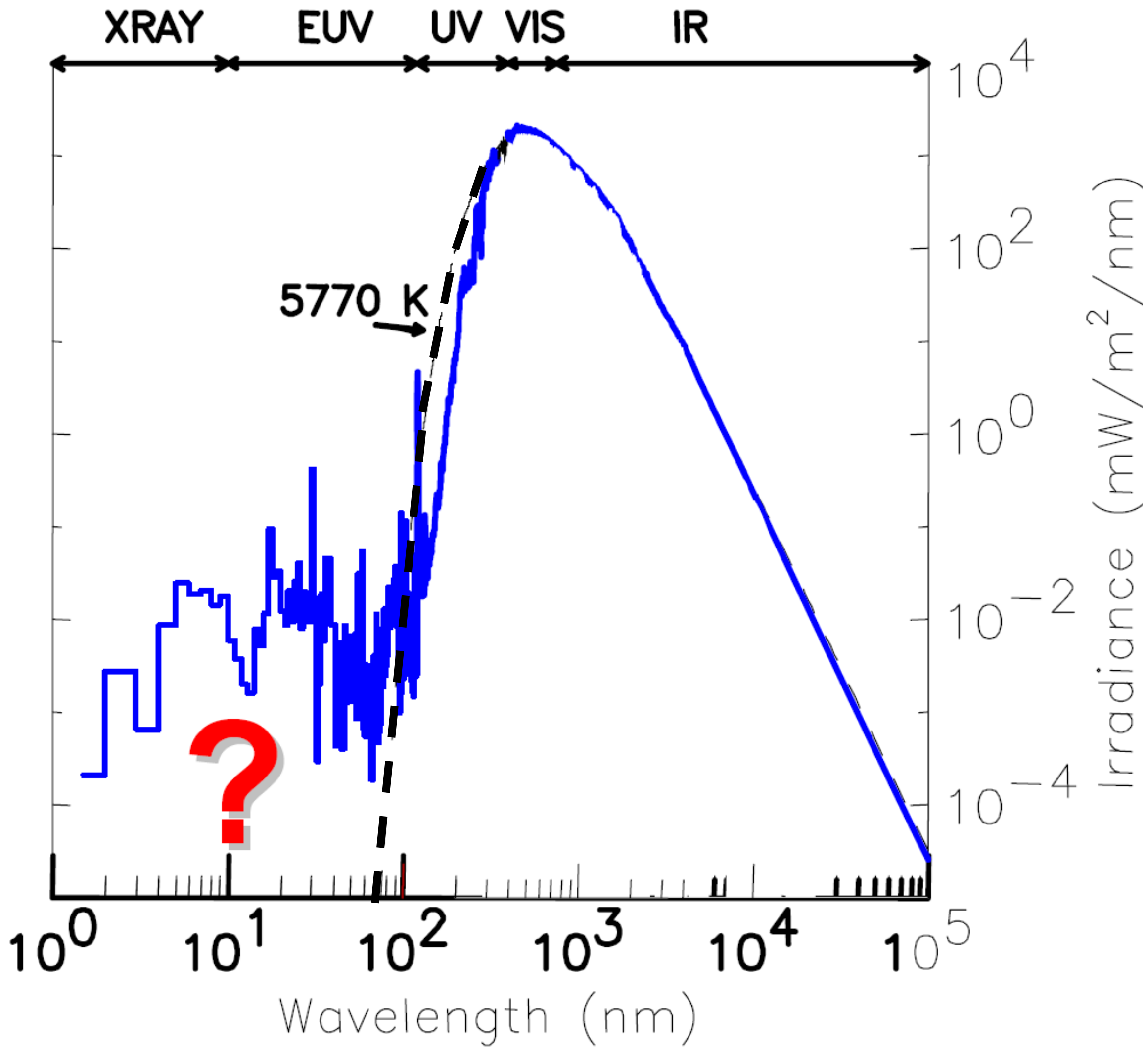
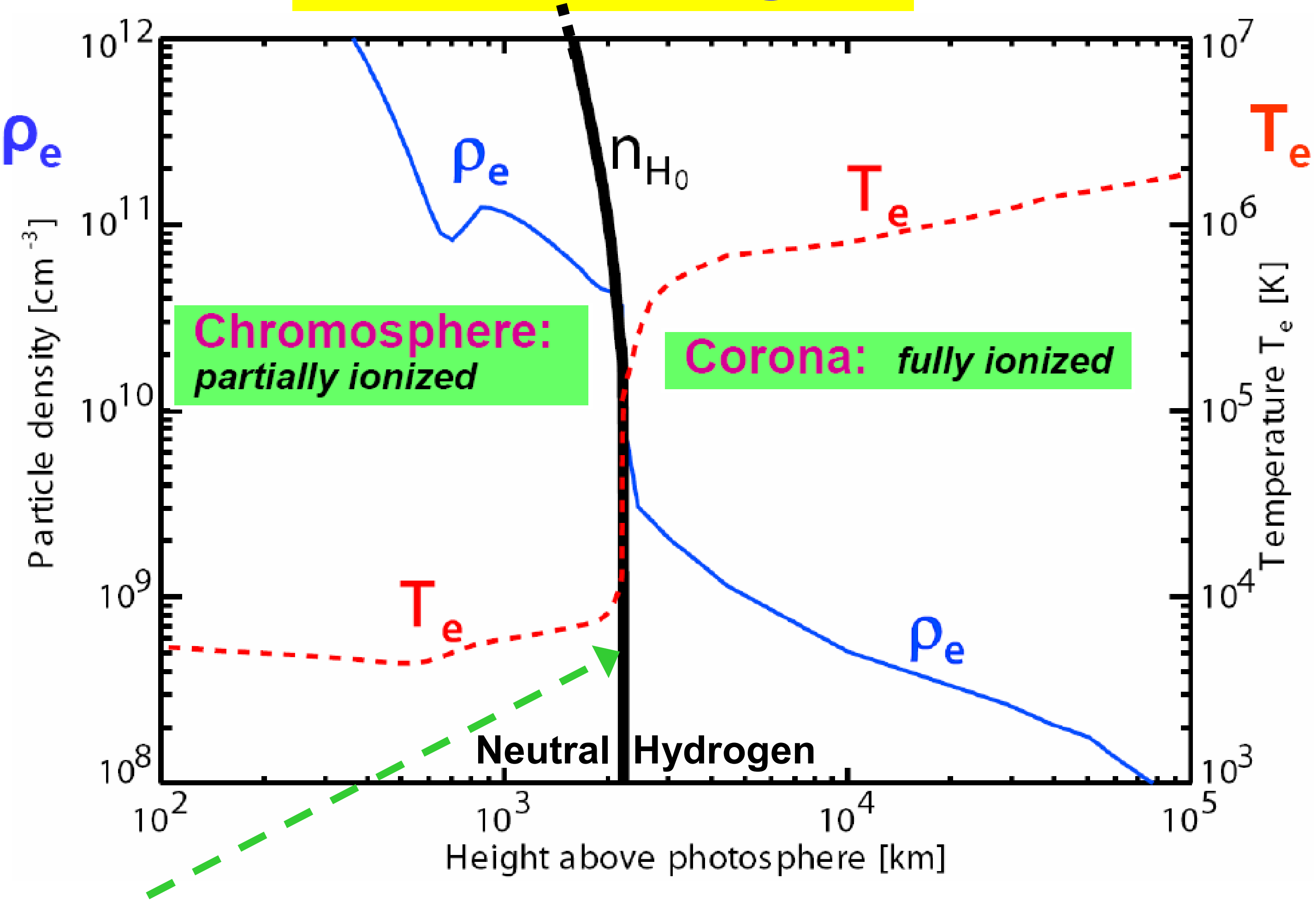


Fig. 1. The plage region located near disk center (72″W, 76″S) was observed from 16:00 to 16:40 UT on February 10, 2007. The Stokes profiles at two slit positions with integration time of 1.6 s each and scan step of 0.″16 each are summed, and 2 pixels along the slit with a pixel size of 0.″16 are also summed to obtain polarization accuracy better than 0.1%: The images consist of 8 slit positions (0.″32 width) with a total scan time of 34 s. The pixel size along the slit is 0.″32. The evolution of physical quantities for the plage region are shown: (**a**) *CP* (vertical magnetic field), (**b**) *LP* (horizontal magnetic field), (**c**) I_c. The region where *LP* is larger than 0.3% is enclosed by red lines. The emergence of the horizontal magnetic flux starts at $\Delta t = 0$ s. Solar north is up and east to the left in all images of this report.

Solar spectrum



Transition Region



TR: ~100 km thin!

→ **S. Patsourakos et al., ApJ. 522 (1999) 540**

Corona: ρ_e **varies ~10 – 100x**

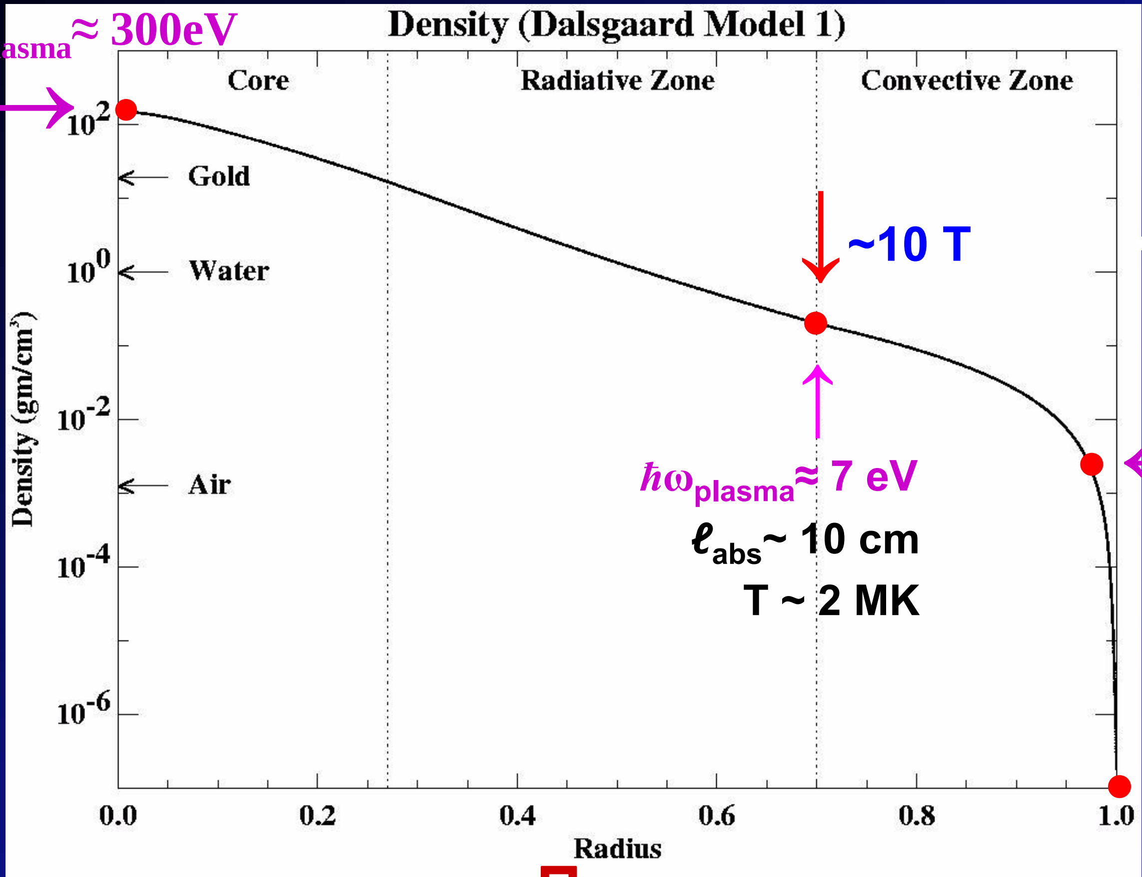
→ **M. Aschwanden, *Physics of the Solar Corona* (2004) 24-26**

Photosphere: **~1‰ of the gas is ionized** (= plasma).

→ **http://www.windows.ucar.edu/tour/link=/sun/atmosphere/photosphere.html**

The inner SUN

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



← M. Schüßler, M. Rempel A&A 441 (**2005**) 337 #)

← $\hbar\omega_{plasma} \approx$ 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**

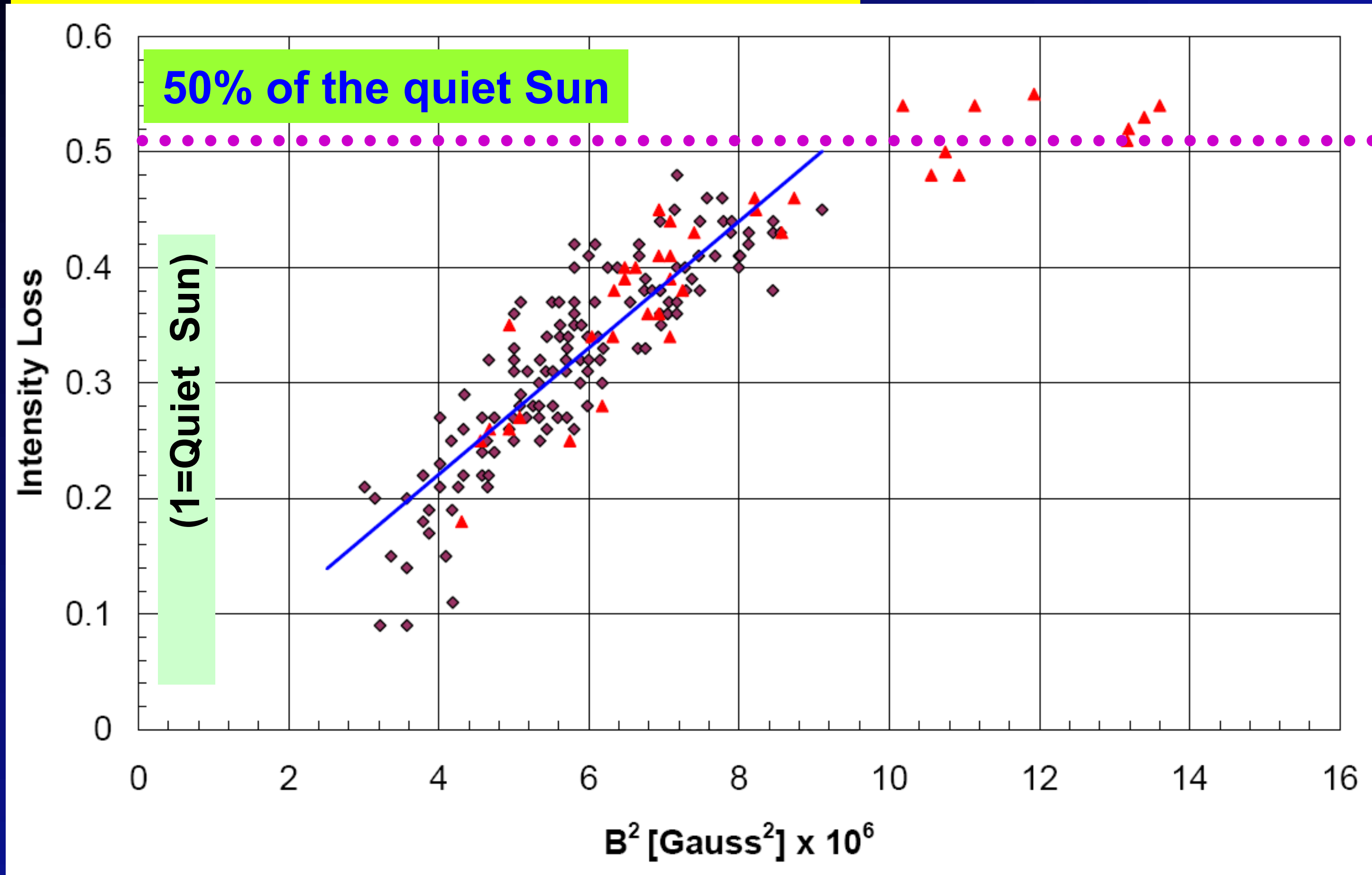
→ $(\text{Primakoff})_B$ >> $(\text{Primakoff})_{Coulomb}$

→ modify solar axion spectrum?

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

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

SUNSPOTS → origin?



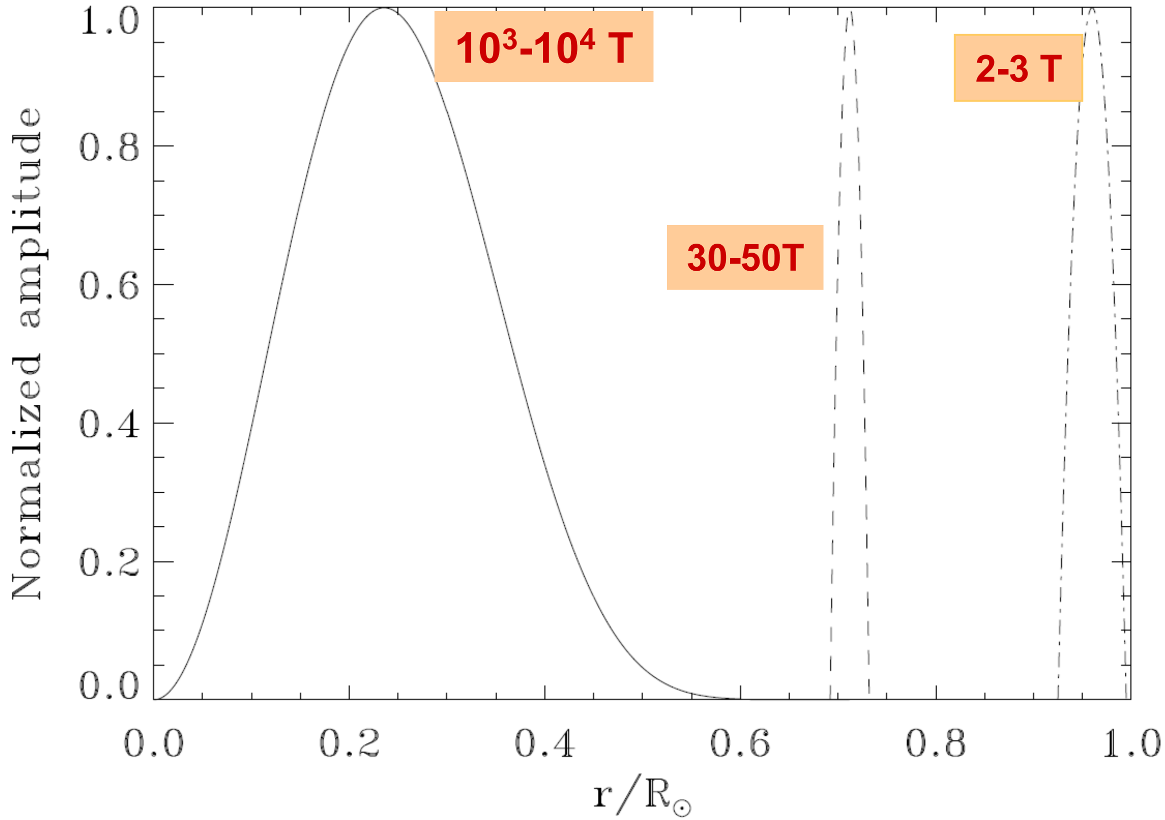
→ polarization?
C. Beck

Z., Dennerl, Grande, Hoffmann, Huovelin, Lakic, Orlando, Ortiz, Papaevangelou, Semertzidis, Tzamarias, Vilhu **TAUP2005**, J. Phys. Conf. Ser. 39 (**2006**) 103

Plot reconstructed from: Solanki A&A Rev. 11 (**2003**) 153 →

- **fundamental questions remain unanswered.**
- **is an additional mechanism needed?**

Solar seismic models + the ν-predictions



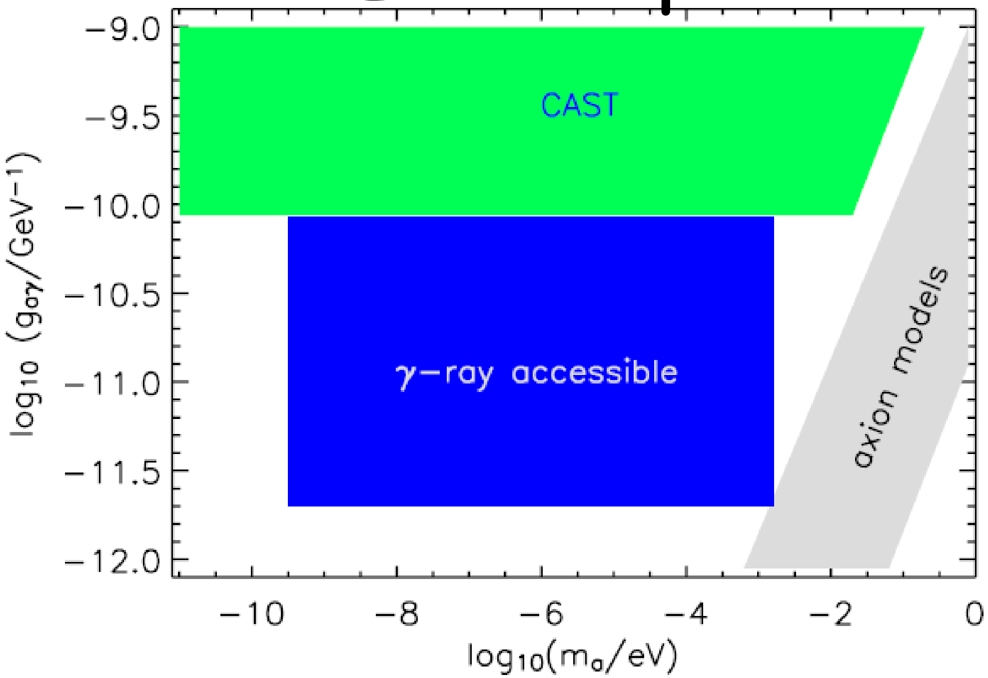
?(Primakoff)$_B$ » (Primakoff)$_E$?

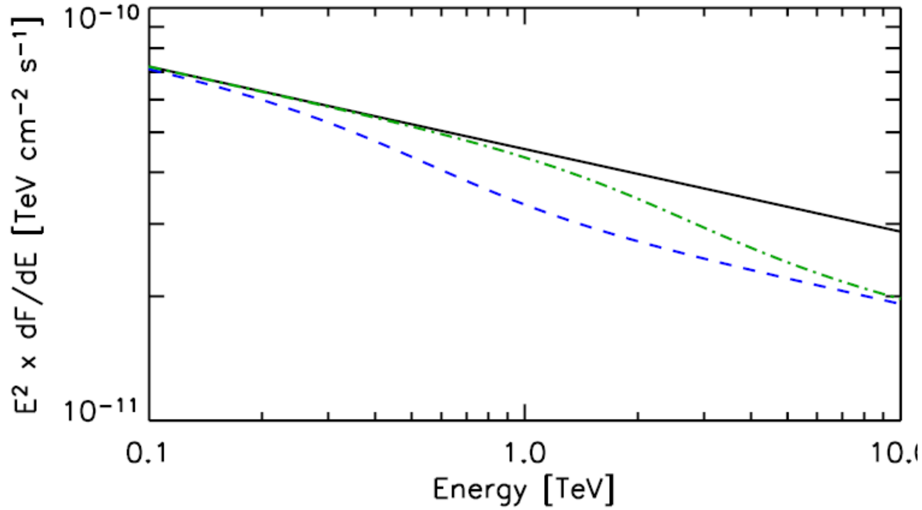
PRL 99, 231102 (2007) PHYSICAL REVIEW LETTERS week ending 7 DECEMBER 2007

Detecting Axionlike Particles with Gamma Ray Telescopes

Dan Hooper and Pasquale D. Serpico
Center for Particle Astrophysics, Fermi National Accelerator Laboratory, Batavia, Illinois 60510-0500, USA

Exclusion plot



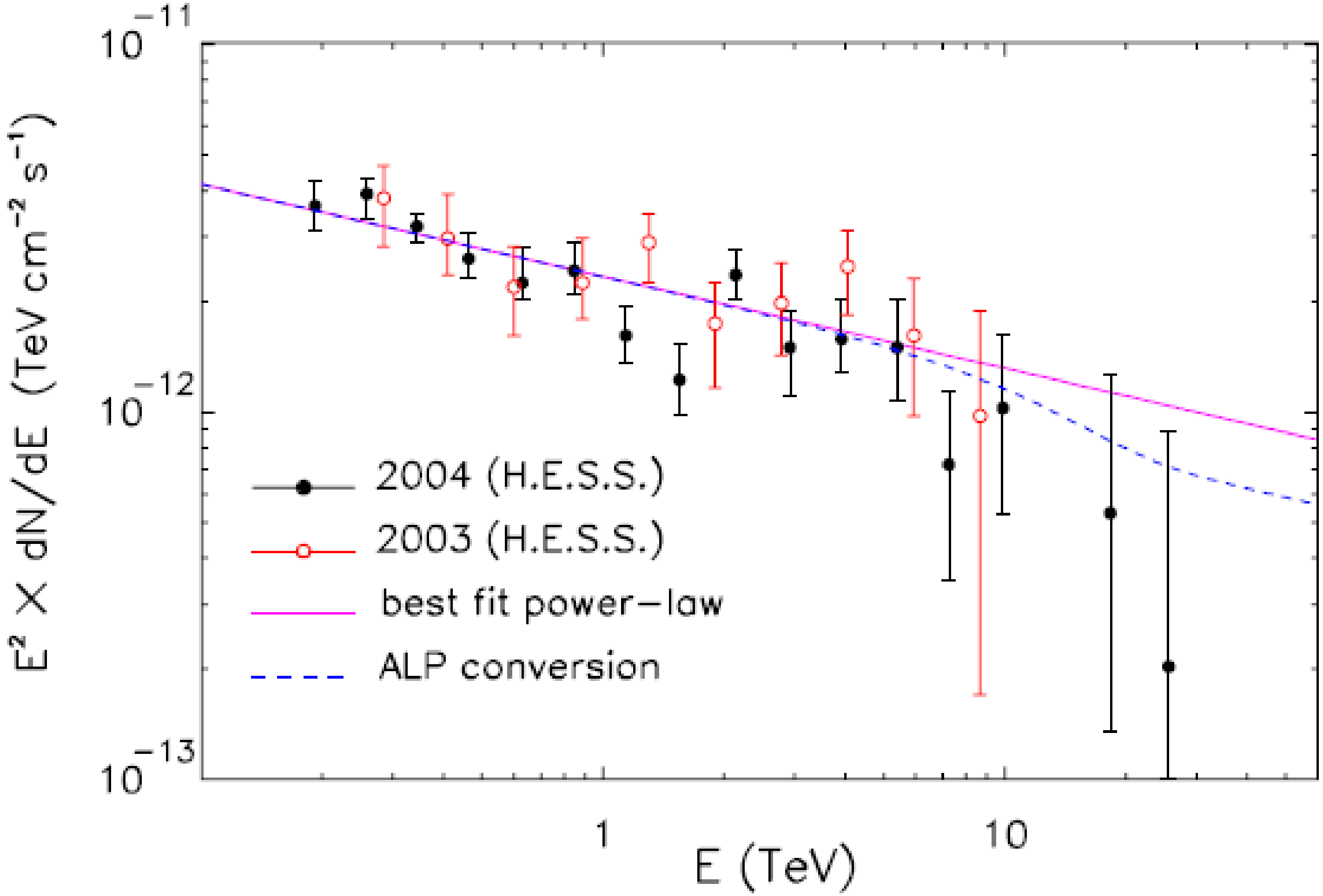


A typical power-law γ-ray spectrum (solid line) and its distortion for photon-ALP conversion with A=1/3 and critical energies E=500GeV (dashed) and E=2:5 TeV (dashed-dotted).

PHYSICAL REVIEW D **76**, 023001 (2007)

Signatures of axionlike particles in the spectra of TeV gamma-ray sources

Alessandro Mirizzi,[1,2] Georg G. Raffelt,[1] and Pasquale D. Serpico[3]



The energy source

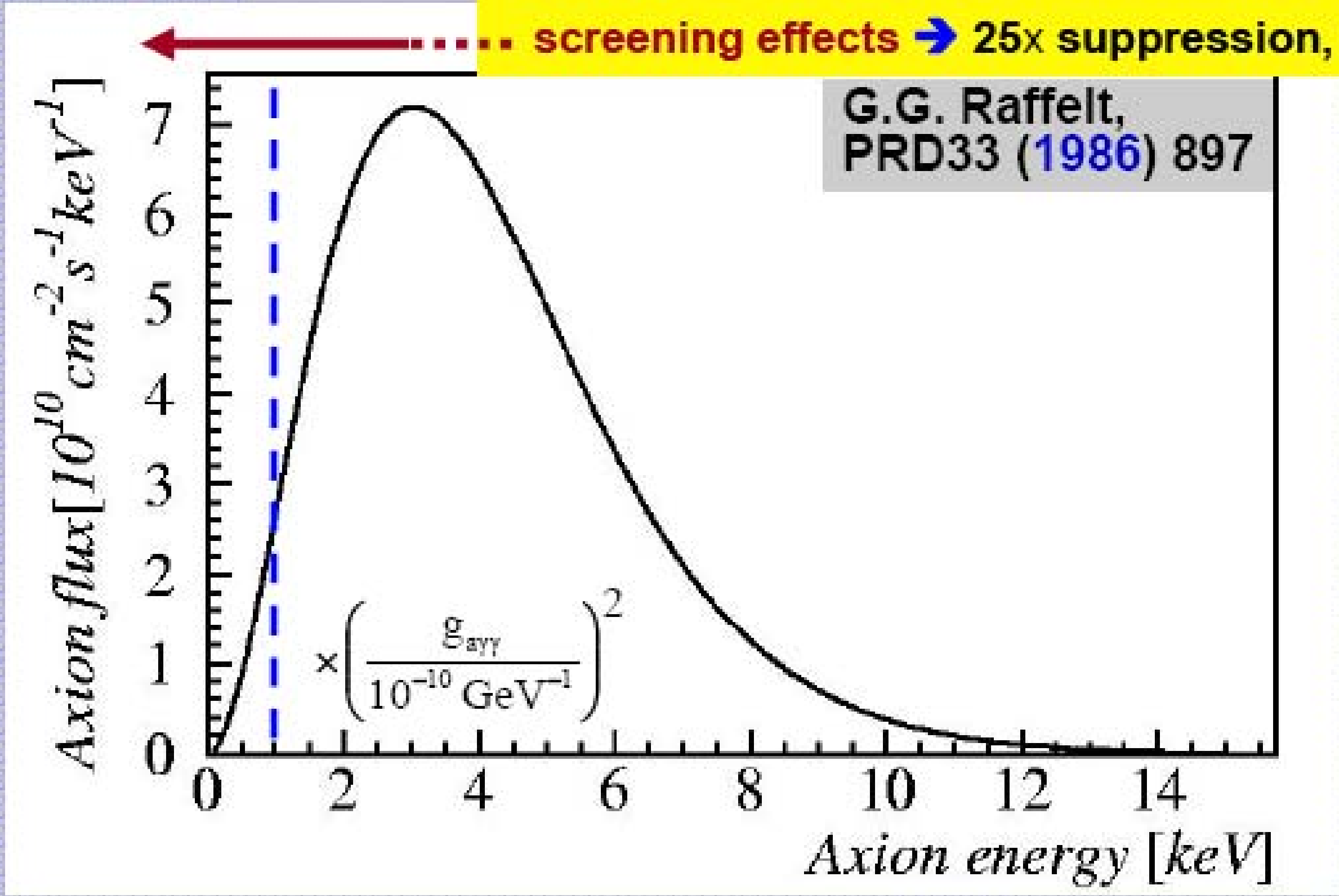
driving the acceleration of **the solar wind + heating of the quiet corona** remains unknown.

One promising candidate is **Alfvén waves** …

B. De Pontieu et al., Science 318 (7 December **2007**) 1574

Solar axion spectrum

screening effects → 25x suppression, or?

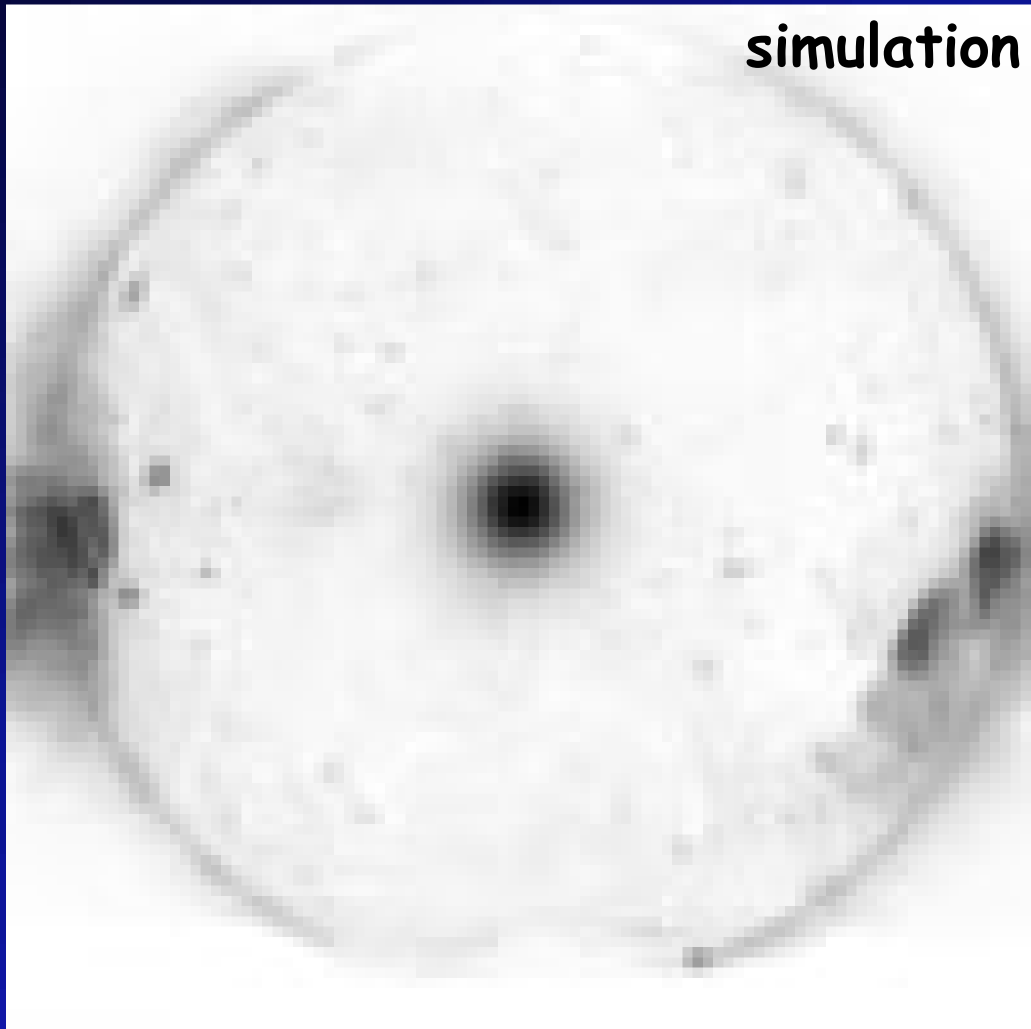


→ Theoretically + experimentally

.... ILIASnext!

→ direct LES~axion signal ←

Search for solar X-rays from axions



RHESSI
science nugget
H. Hudson,
30.4.2007

Soft X-rays from **Hinode/Yohkoh** showing an axion signal. The axions, for a uniform coronal magnetic field,would give an **image of the solar core**.

Annual Review of Nuclear and Particle Science
Vol. 58 (November 2008)

Strategies for Determining the Nature of Dark Matter

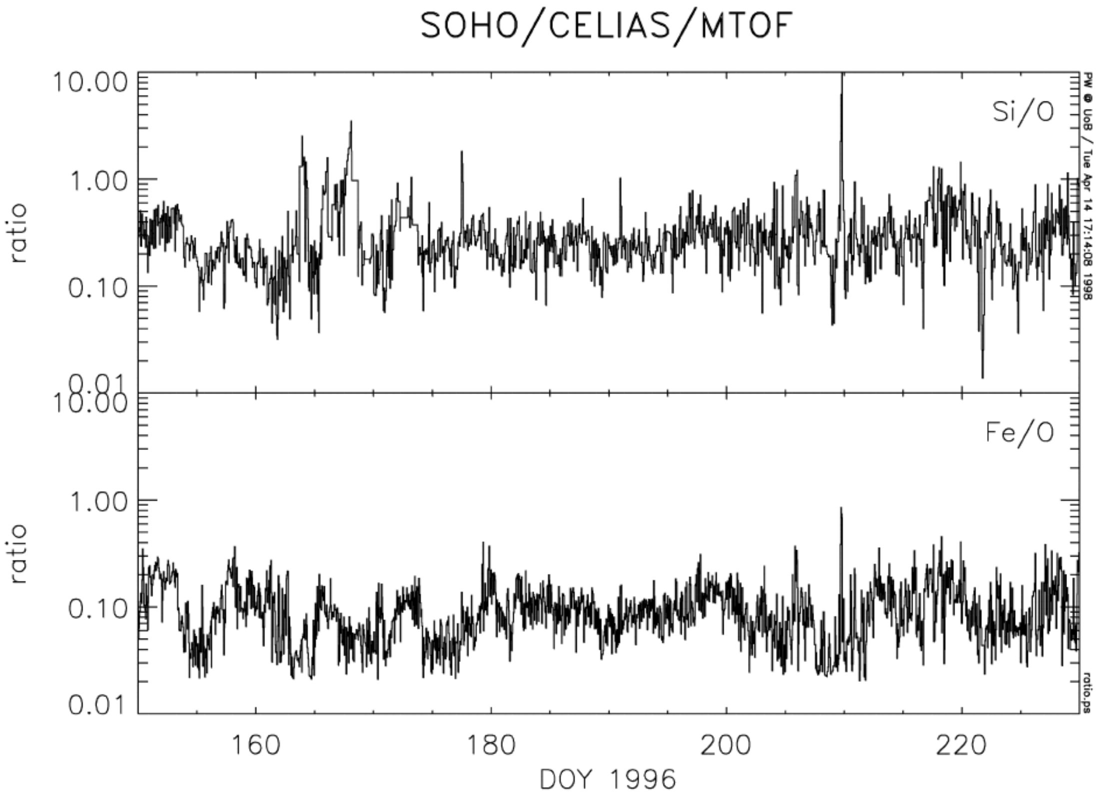
D. Hooper & E. A. Baltz

→ axions → zero x

→ global [ ] on more DM particle candidates:

➔ 10 lines on axions / 33 pages, noticing:
… relic ρ_{axions} = uncertain + [axions]✓

➔ ~axions = 3rd order effect!?



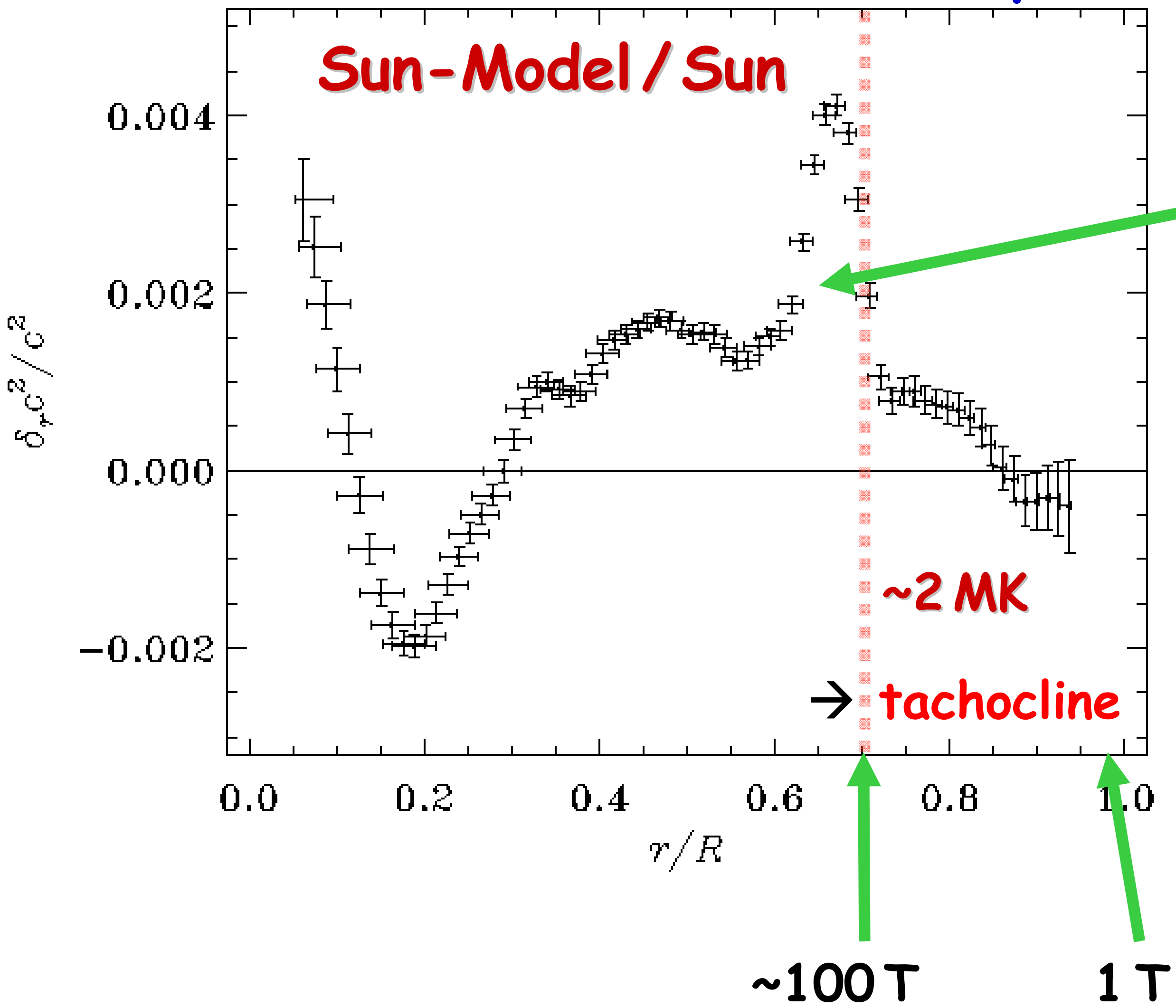
Elemental abundances in the solar corona are the basis of comparison for investigations of the coronae of other stars and for abundances measured in the solar wind. They **differ from solar photospheric abundances by as much as an order of magnitude, and they vary from place to place and time to time.**

Abundance ratios of Si and Fe to O. 30 min running averages of 5 min data from CELIAS/MTOF - SOHO.

J.C. Raymond et al.,
CP598, Solar and Galactic Composition, ed. R. F. Wimmer-Schweingruber A I P (2001) 49

Helioseismology

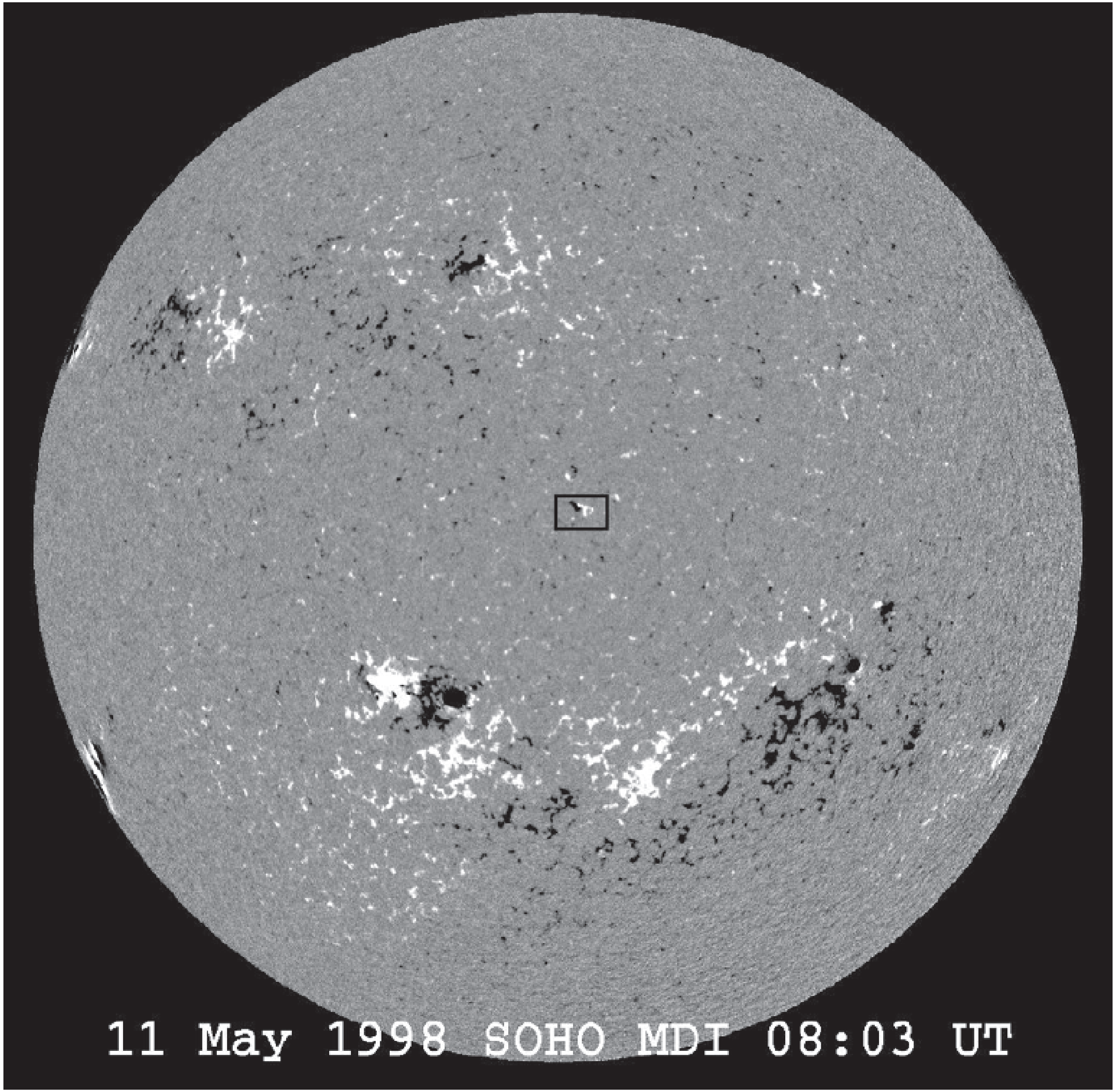
The solar internal sound speed



overshoot layer?
additional heating?

→ S Solanki,
private communication

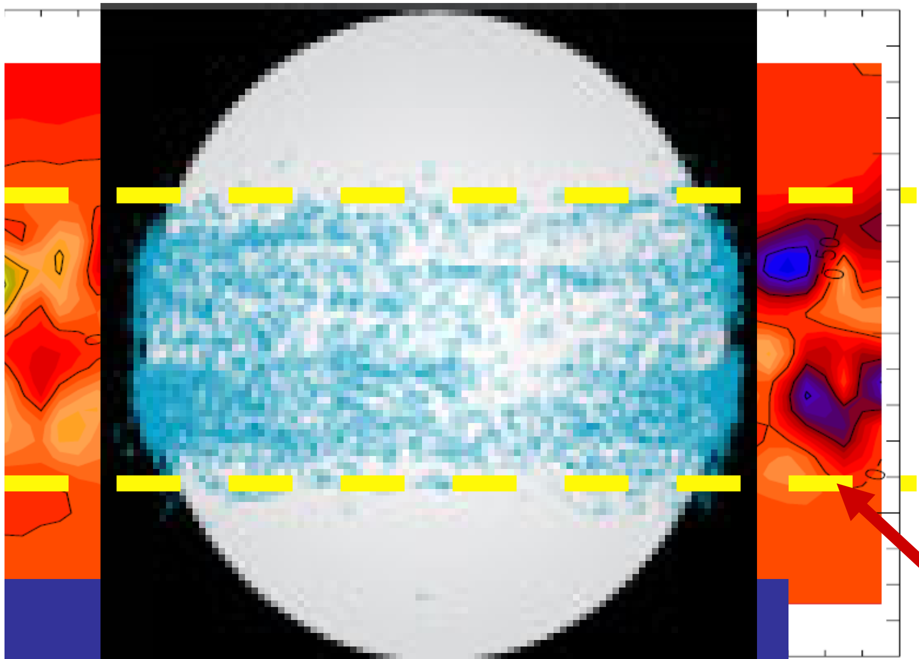
Hiremath, Lovely ApJ. 667 (**20.9.2007**) 585


11 May 1998 SOHO MDI 08:03 UT

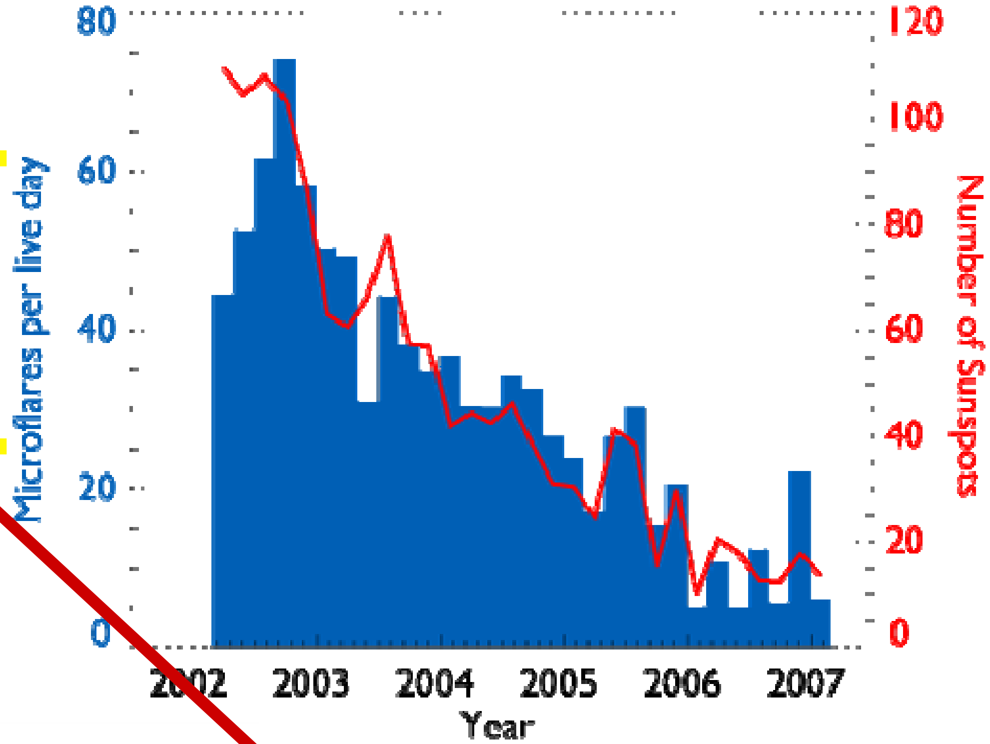
From our ongoing work

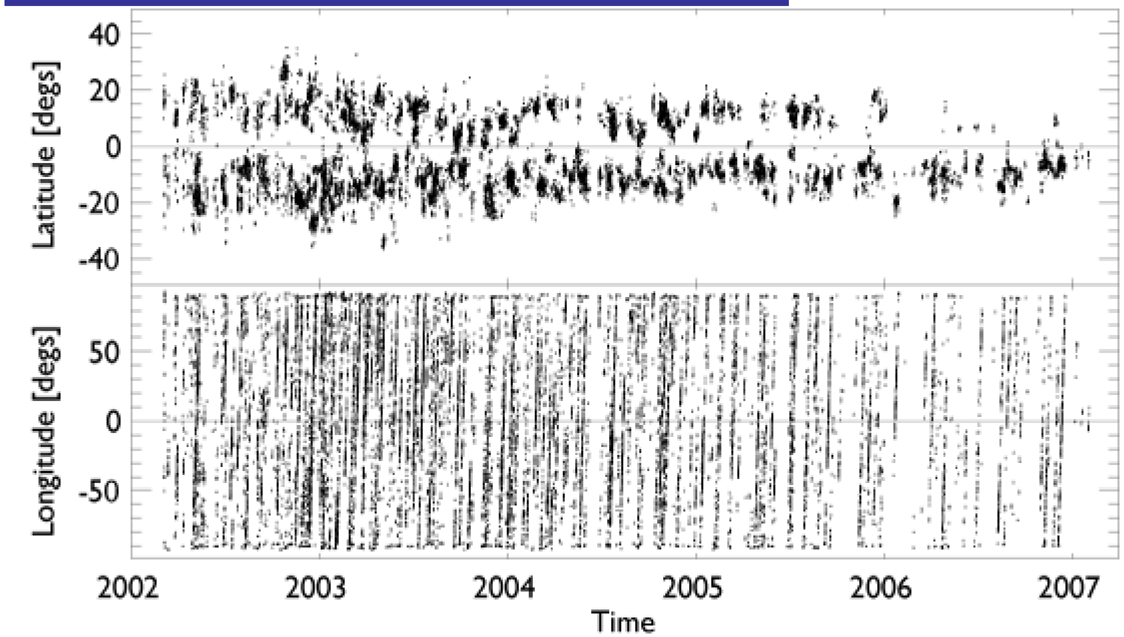
→ **2 "firsts"**

→ must motivate more



Longitude + latitude positions of ~24000 μflares





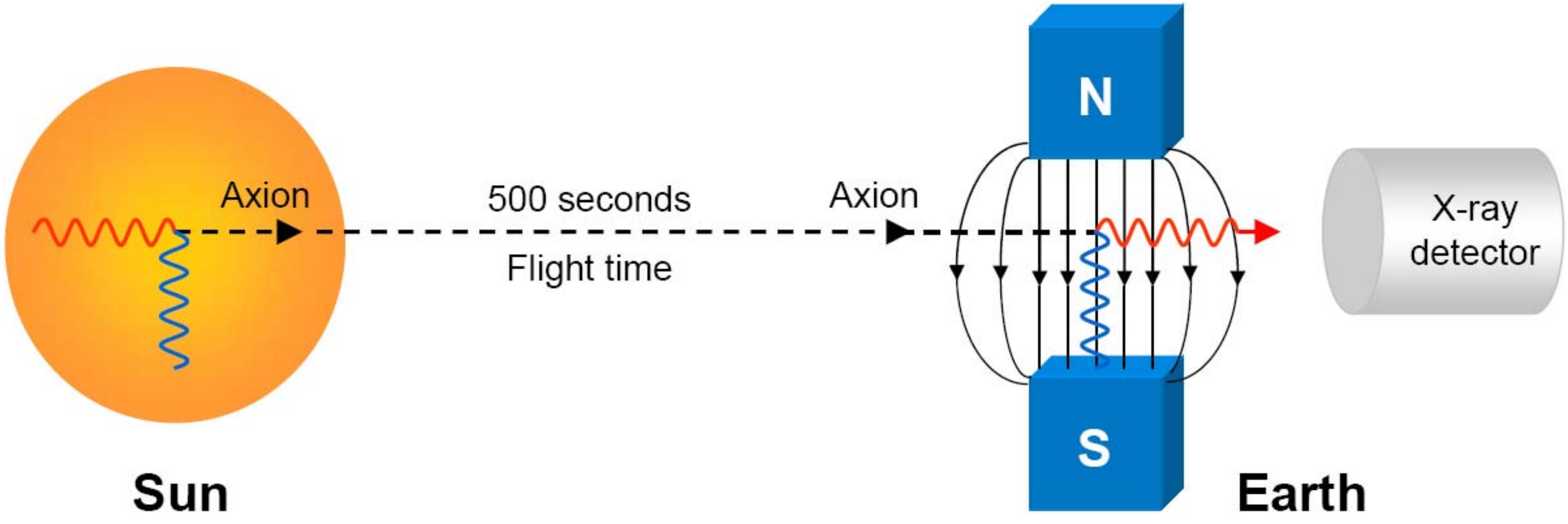
Magnetic flux ~95% in ±40°

R. Howard, Sol Phys 38(1974)59

New results from Hinode should help explain some long-standing mysteries of the Sun.

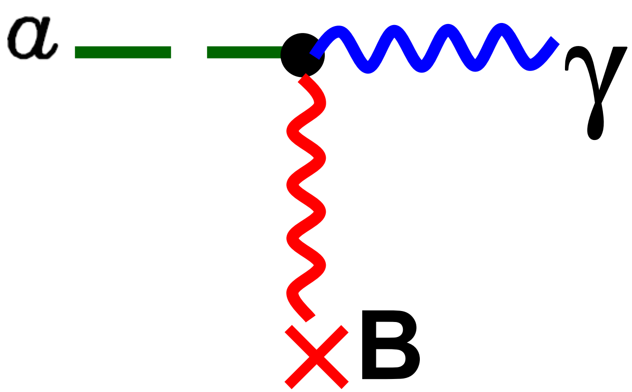
One of the big mysteries about the Sun is called the "**corona problem**." How does the corona get so hot? Several of the *Science* articles ***report the discovery*** of a type of magnetic wave, known as an Alfen wave, which ripples through the plasma of the Sun's corona. **These waves could potentially heat the corona** to extreme temperatures by releasing energy as they travel outward from the Sun.
In another study, researchers pinpointed one of **the sources of the solar wind**, …. Taro Sakao of JAXA, has now pinpointed a region of the Sun … could be a major source of the solar wind.
These are just a few of the new discoveries that have emerged from the Hinode mission. Researchers expect many more to come.

CAST

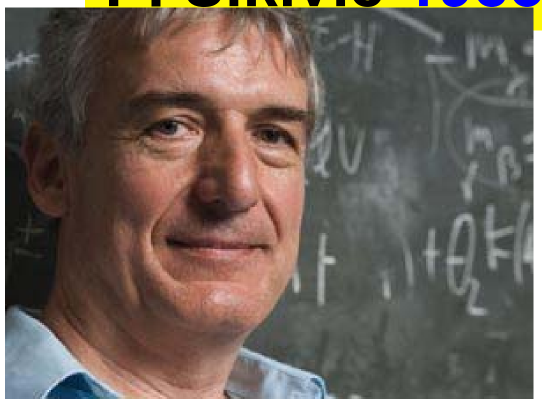


axion source

axion detection



P. Sikivie 1983



- … **scattering between DM and baryons would result in capture of DM particles over celestial bodies**, with the most remarkable effect for stars to host within their bosom an additional source of energy due to the captured DM annihilation.

➔ annihilation $\propto \rho^2$

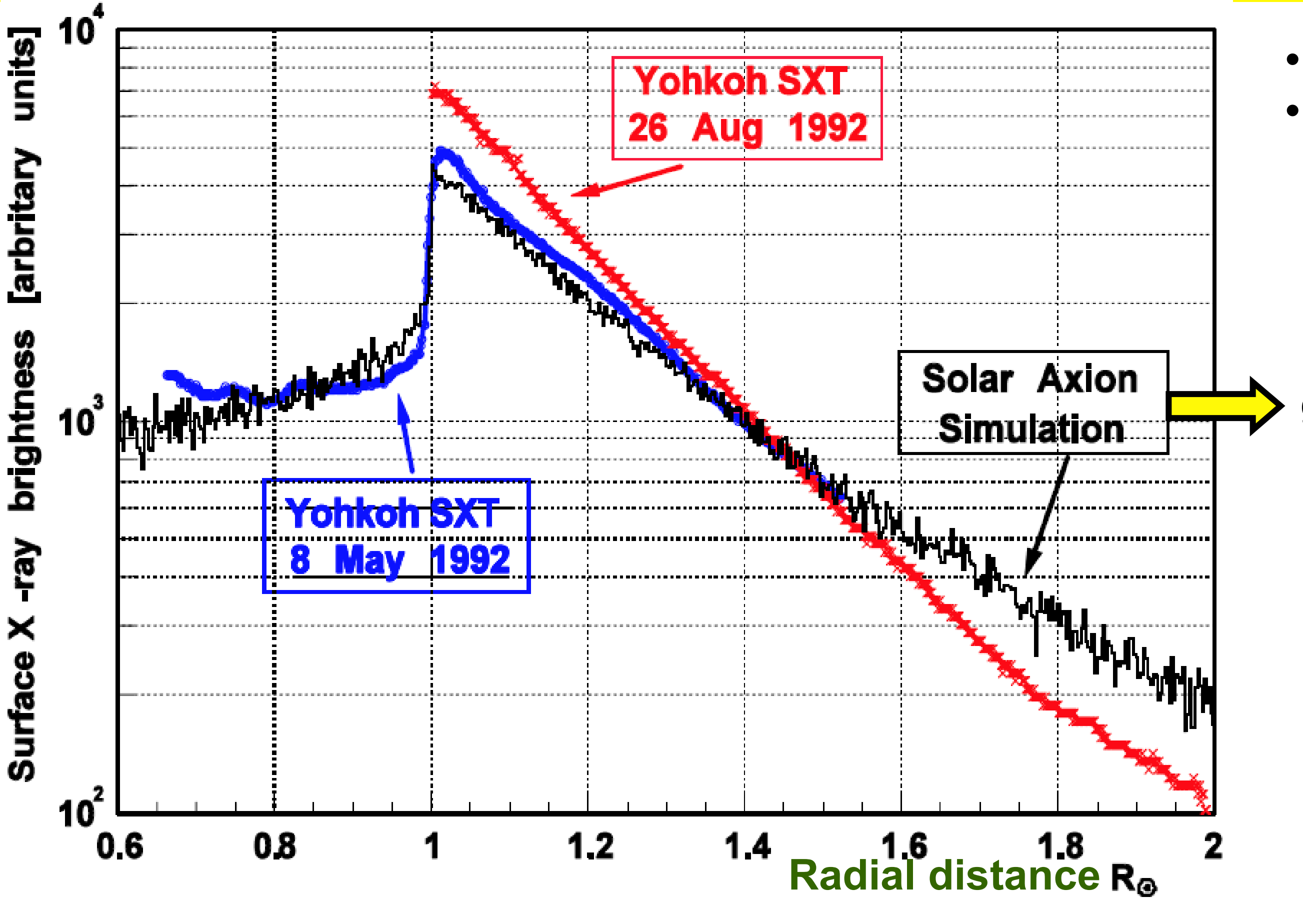
F. Iocco, astro-ph/200802.0941

- Massive ~axions ← gravitational self-trapping!

➔ radiative decay $\propto \rho$

L. DiLella, K.Z. (2000)

Quiet Sun surface soft X-ray brightness



- Diffuse emission
- Hydrostatic equilibrium

↛ observations

26th Aug.: JL Culhane, Adv Sp Res 19(1997)1839

$g_{a\gamma\gamma} < 4 \cdot 10^{-13} GeV^{-1}$

OFFPOINTINGS:

1992 → YOHKOH

2005- → RHESSI >43 days 14.2.2007 –

2006- → HINODE?

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

SUN:

➔ 5 Mtons / s of energy is released

~100 ktons ~axions / s …

… overlooked?

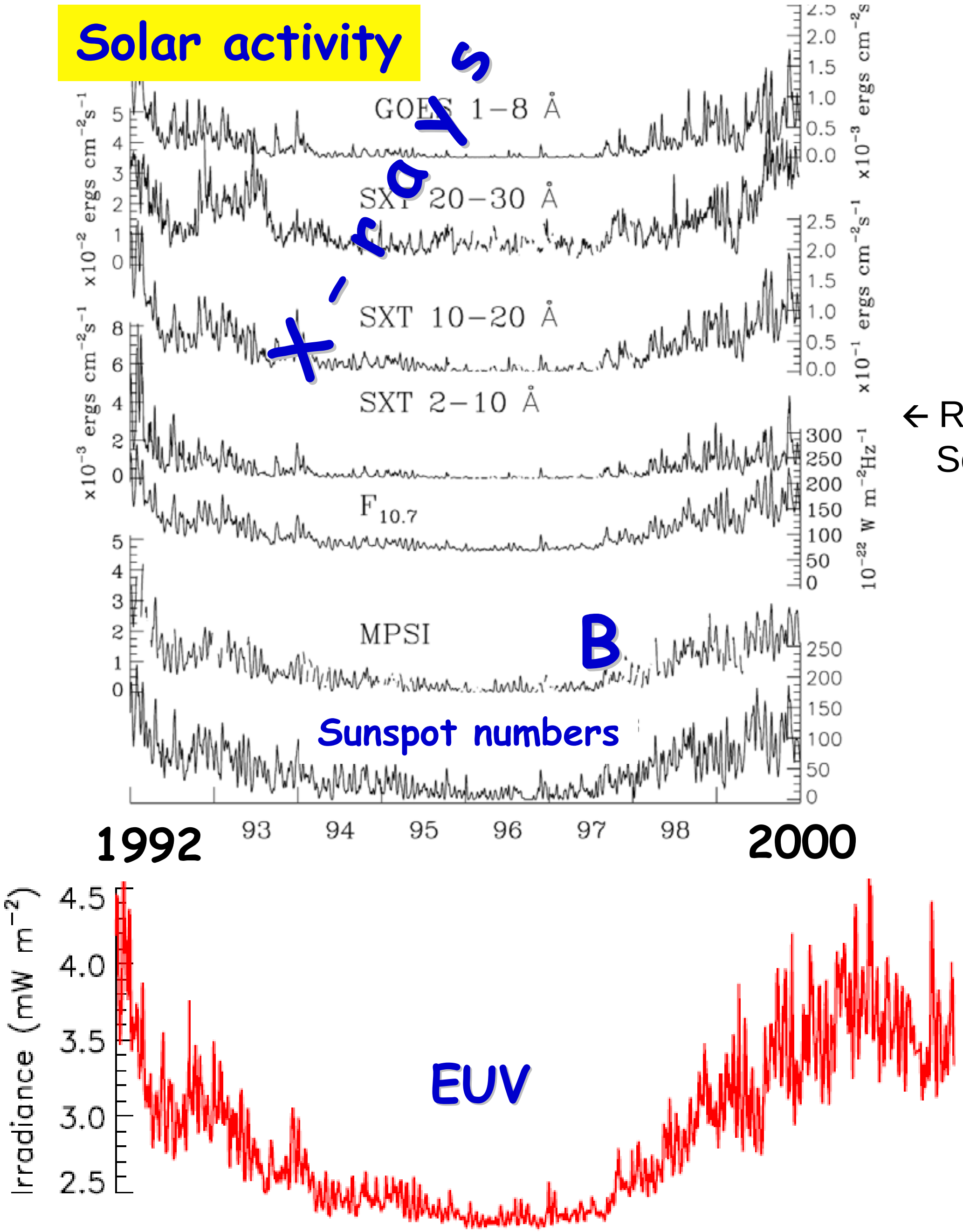
… the Coronal Heating Problem …

"one of the most important problems in astrophysics"

"There are many different heating mechanisms operating in the corona"

J.A. Klimchuk, Solar Physics 234 (2006) 41
→ invited review

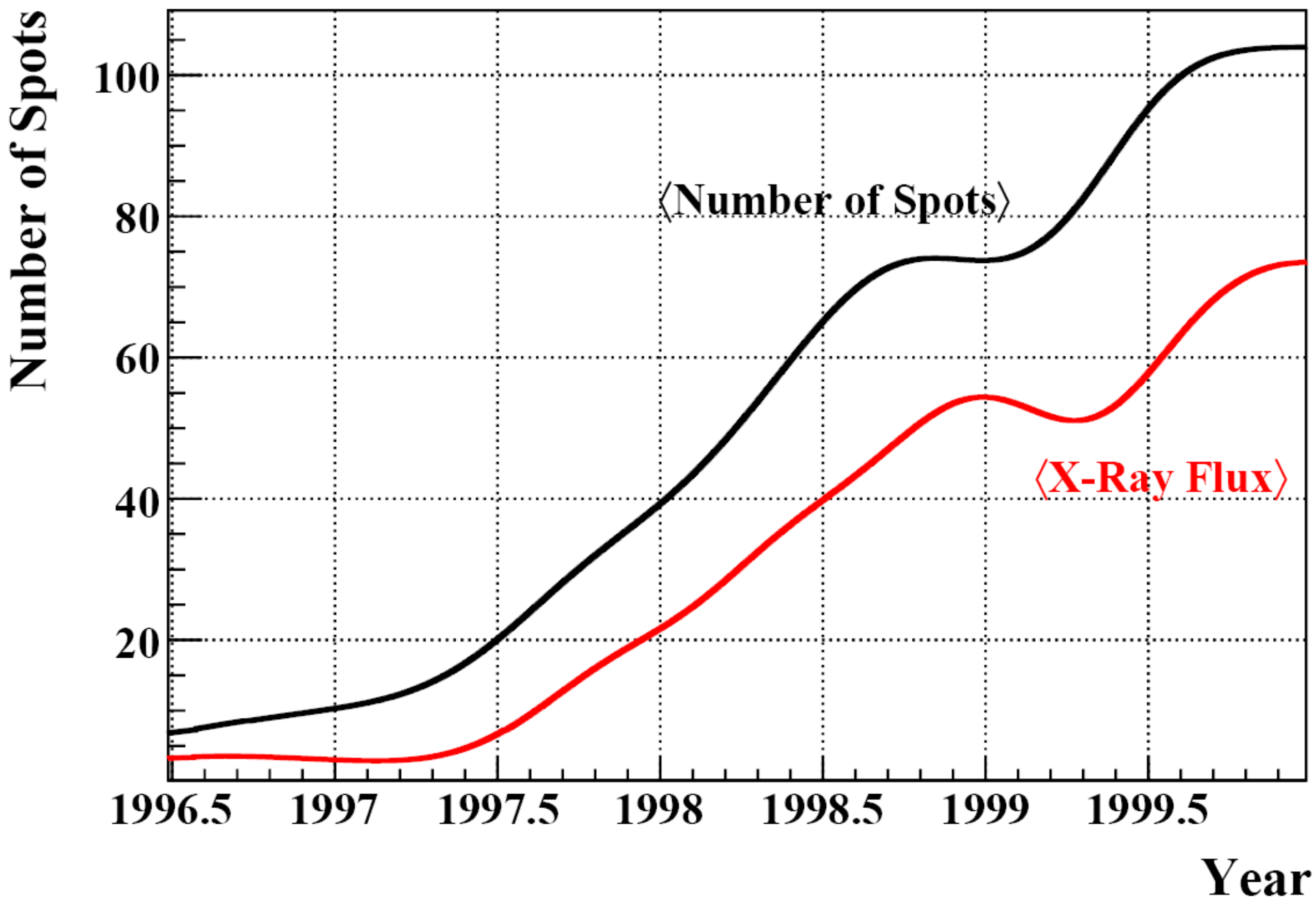
Solar activity



← Ramesh,Sundararaman Solar Phys. 234(**2006**)393

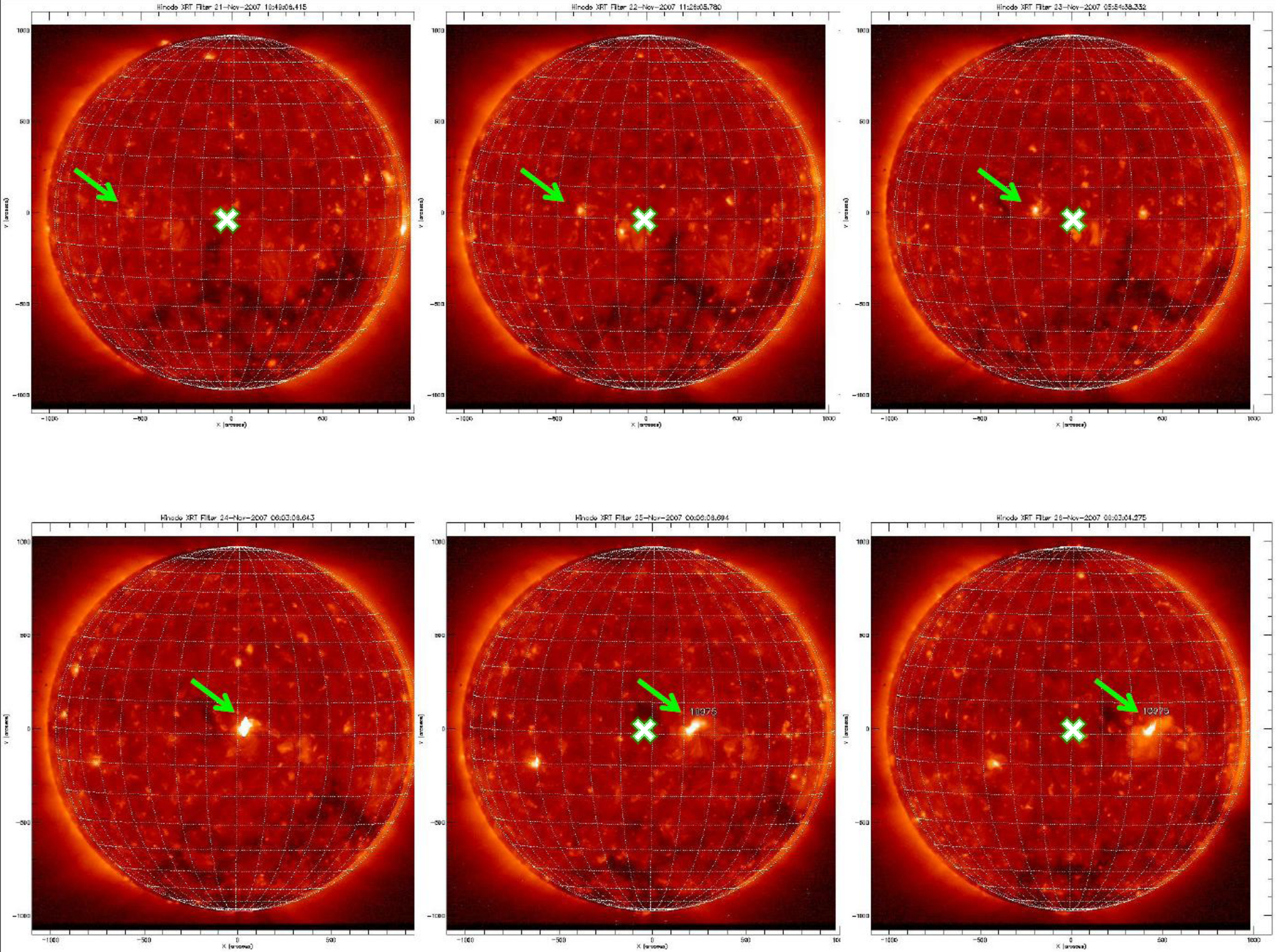
← **EUV = RoI!**

Yohkoh

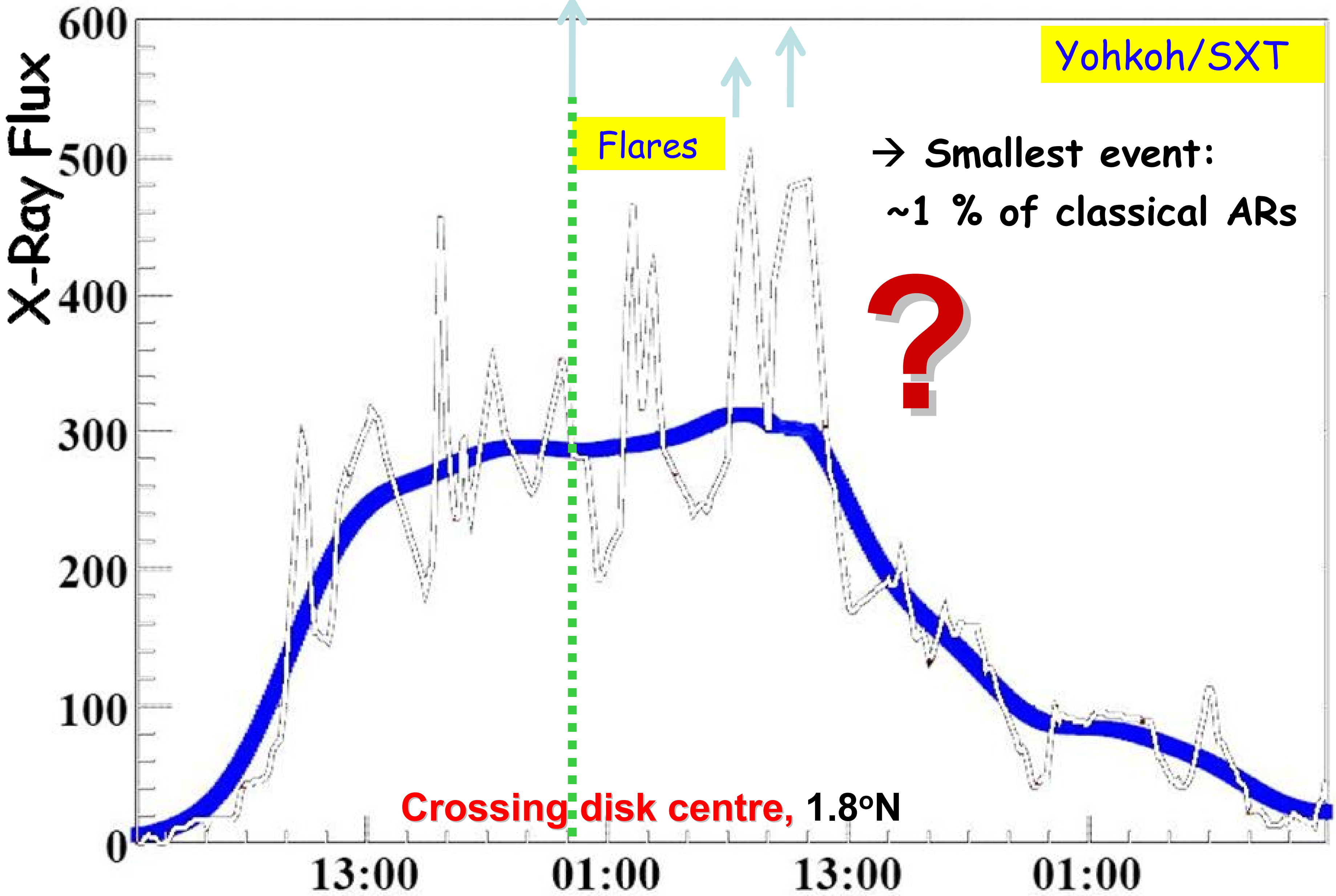


Number of Spots
100
80
60
40
20
⟨Number of Spots⟩
⟨X-Ray Flux⟩
1996.5
1997
1997.5
1998
1998.5
1999
1999.5
Year

HINODE XRT   21-26 November 2007



X-Ray Bright Point @ Solar Disk Centre → ~2.5 d



Mandrini et al., A&A 434(**2005**)725

L. vanDriel-Gesztelyi,private communication

→ …lower CAST threshold!

- 0.5 – 1keV
- 0.3 – 0.5keV
- 0.1 – 0.3keV
- EUV
- UV
- visible → "first"

→ Direct axion signal ←

…. ILIASnext!

~all present solar mysteries:

→ ~eV - ~keV

<< sub eV rest mass → HE cosmic photons

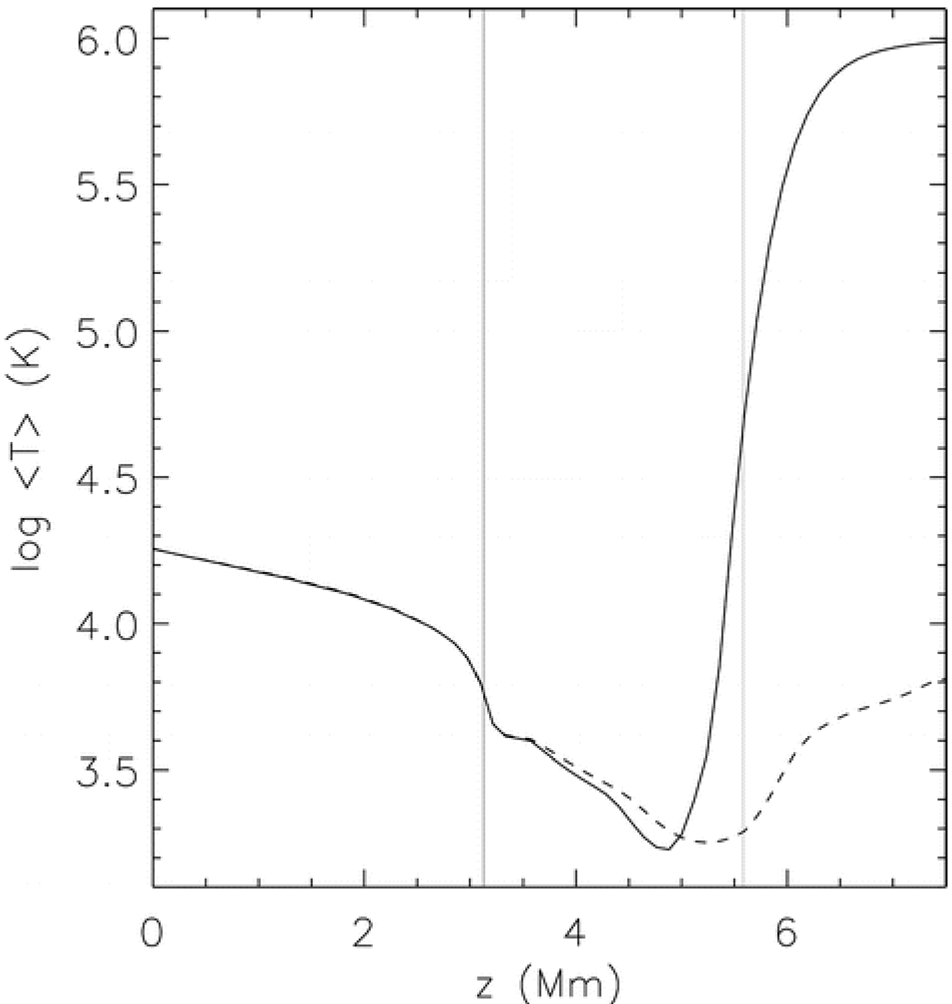


Fig. 12.— Horizontally averaged temperature stratification during a time when the empirically based magnetic heating is active (solid line) and 4.5 minutes after the empirically based coronal heating is shut down leaving resistive dissipation as the principal coronal heating mechanism (dashed line). The figure demonstrates that Joule heating alone over this time period in our model was not sufficient to maintain a corona at X□ray–emitting temperatures.

WP Abbett, ApJ. 665 (2007) 1469

Galaxy Cluster

One of the most surprising findings:

⇒ Anomalous SZ Contribution to 3 Year WMAP Data

⇒ ~30-40%

⇒ Missing Baryons or New Astrophysics?

e.g.: **Or, decaying massive ~axions?**

Z., Dennerl, Hoffmann, Papaevangelou SCIENCE 306 ( ) 1485

Differential inwards/outwards radiation pressure

Flares:

e.g.: Ne:O ≈ 0.42 in SEPs & variations of ~2× ← observed stars more active!

Quiet ARs,quiet Sun:
Ne / O at ~0.15. → The "Solar Model problem" !

Axion scenario:

Outwards pressure (→ B) → more Neon

Inwards pressure (→ self-irradiation) → less Neon

Note: σ_{pe}(Ne-to-O) > 2× at Eγ~1 keV

s. Schmelz et al., ApJ.634 (**2005**) L197,
+ Shemi, MNRAS 251 (**1991**) 221;
Young, astro-ph/**2005**10264

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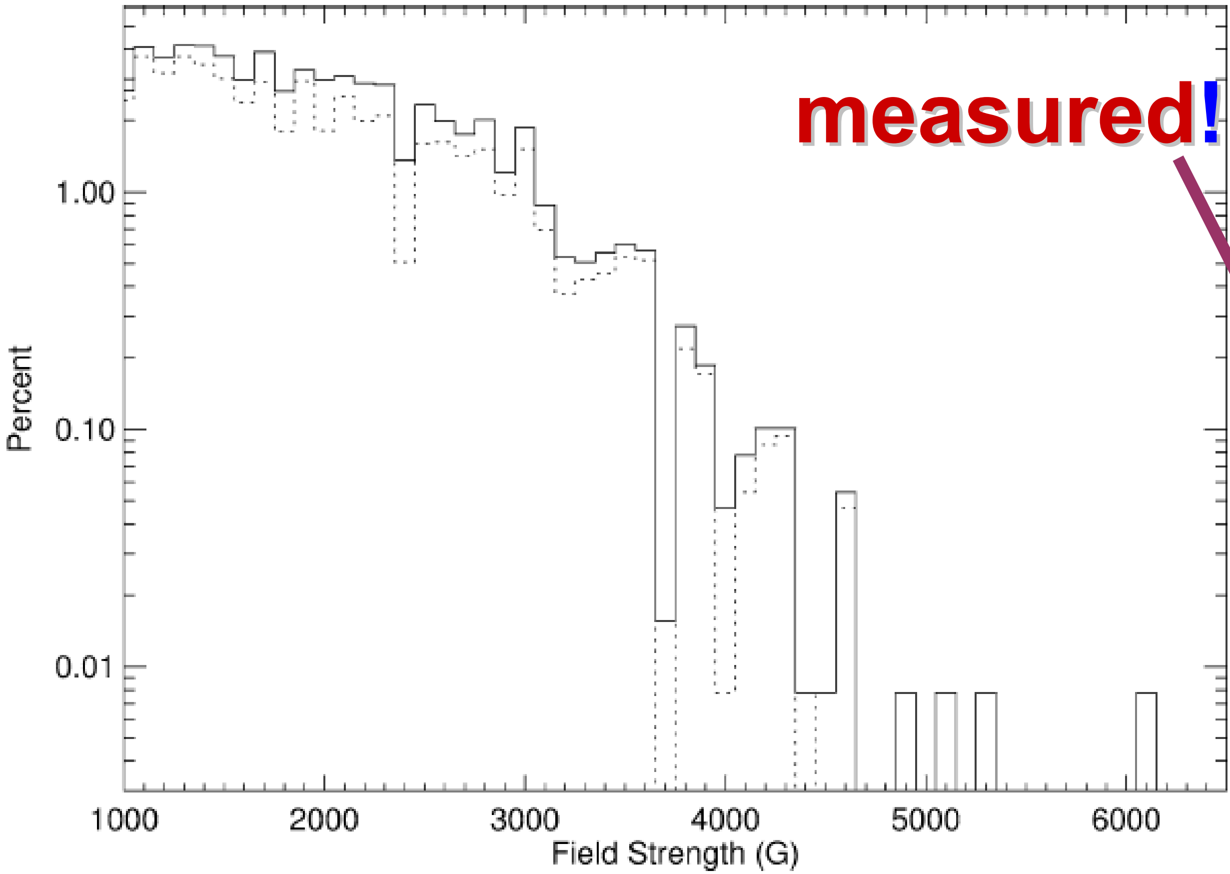
+ Shemi, MNRAS 251 (**1991**) 221;
Young, astro-ph/**2005**10264

Magnetic field in sunspots



measured!

locally?

Add more isolated cases!?

Compare XBPs:

Near disk centre with rest of the disk ✚ crossing times

… ➔

- **CAST @ CERN**

  → working principle Phase I & II → *first results*

- **Sun**

  ↛ only its core → insisting problems!

  → ⊗ axions!

  → ubiquitous B_{sun} → *ignored*

- **CAST @ Sun**

  ↛ B_{sun} in solar models

. . . .

- **Beyond the Sun**

work in progress

Cranmer, van Ballegooijen, Edgar, ApJS. 171 (**august 2007**) 520

One of the most persistent problems in solar physics has been the unambiguous identification of the mechanisms that heat the Sun's corona and accelerate the solar wind. **Many processes have been proposed for converting some fraction of the mechanical energy in subphotospheric convective motions to heat, but it has proved very difficult to make distinguishing comparisons between the predictions of these competing ideas and specific observations.**
We are entering an era, however, where both the models and the measurements are improving to the point of soon being able to eliminate many of the candidate theories.

… one of the main unanswered questions in solar physics:
Why is the outer solar atmosphere hotter than its surface?

Jess, Andic, Mathioudakis, Bloomfield, Keenan astro-ph/0707.2716,A&A (**2007**) *in press*

The heating of the solar corona is still a largely unknown phenomenon, **despite its being central to the physics of the solar corona and of the acceleration of the solar wind. Many models have been developed to explain the multimillion degree temperature of coronal plasmas and the properties of the solar wind.**

Feldman, Landi, Doschek, ApJ. 660 (**May 2007**) 1674

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

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 (2005) 552

The magnetic field plays a crucial role in heating the corona … the exact energy storage & 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, CE Parnell, A.& A. 439 (2005) 335
RB Dahlburg, JA Klimchuk, SK Antiochos, ApJ. 622 (2005)1191
S Regnier, RC Canfield, Proc. SOHO 15 Workshop - Coronal Heating, St. Andrews, Scotland, 6-9 September 2004, ESA SP-575 (2004) 255

~ axions …