The enigmatic Sun:
always ahead contemporary physics

K. Zioutas
University of Patras & CERN

+ M. Tsagri, Y. Semertzidis, Th. Papaevangelou,
A. Nordt, V. Anastassopoulos,

further reading

http://xxx.lanl.gov/ftp/astro-ph/papers/0701/0701627.pdf

behind a mystery
→ a hidden unknown physics!

many citations!

- (Un)solved central solar problems

  Light source → solar nuclear reactions

  ν - deficit → ~30 years → ν - mass

  Corona heating? → 1937-

  ⇩

  EUV / (soft) X-rays → (some) from solar ~axions?!

- Astrophysical (in)direct DM-signatures

  WIMPs ✓

  axions? (✓) …improving

  >>> these workshops!

- Constrains on ~axions from stellar evolution / cooling

  → ~NO PROBLEM with inner SUN (B, helioseismology),

  but with …

outerSUN:

- Overlooked physical proces(ses)?

  we may not know every underlying process @ sun ✓

- Note: axions, ALPS, WISPs, paraphotons, chameleons, ...?..
  → some only a few years old! They ☒ **B**! → @ Sun?!

  e.g.: Primakoff effect ☒ **B**✓

- Various UNexplained obs' related also to **B** → **B²**
  → Overlooked axion signatures?
  → does not fit our picture of QCD-axions
  → **ALPs?** → unpredicted new physics??
  → **the challenge** ←

- ☒ dB/dz?! Eduardo Guendelman's idea very suggestive

  ➔ *the* idea?!

Axions or ALPs or ….?

Take: $g_{a\gamma\gamma} \sim 10^{-10}GeV^{-1}$, m_{axion}=1eV, 1 kGauss & $L_{coherence}$ ~10m

➔ $L_{x\text{-}solar} \sim 10^{-21}L_{a\text{-}solar} \sim 10^{-24}L_{solar} = \mathbf{10^{10}}$ **erg/sec**

➔ **ALPs**

- **We may miss some enhancement process(es)?**

  Primakoff effect needs a fine tuning. <<< Not excluded!

  Other mechanism(s)?! <<< possible!

searching for ~axions with space missions

Axion search

Hot plasma on the quiet sun

→ HINODE Nov. 2007

"…help explain some long-standing mysteries of the Sun".

Science, 2007

… searching for the X-ray signature of axions …

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

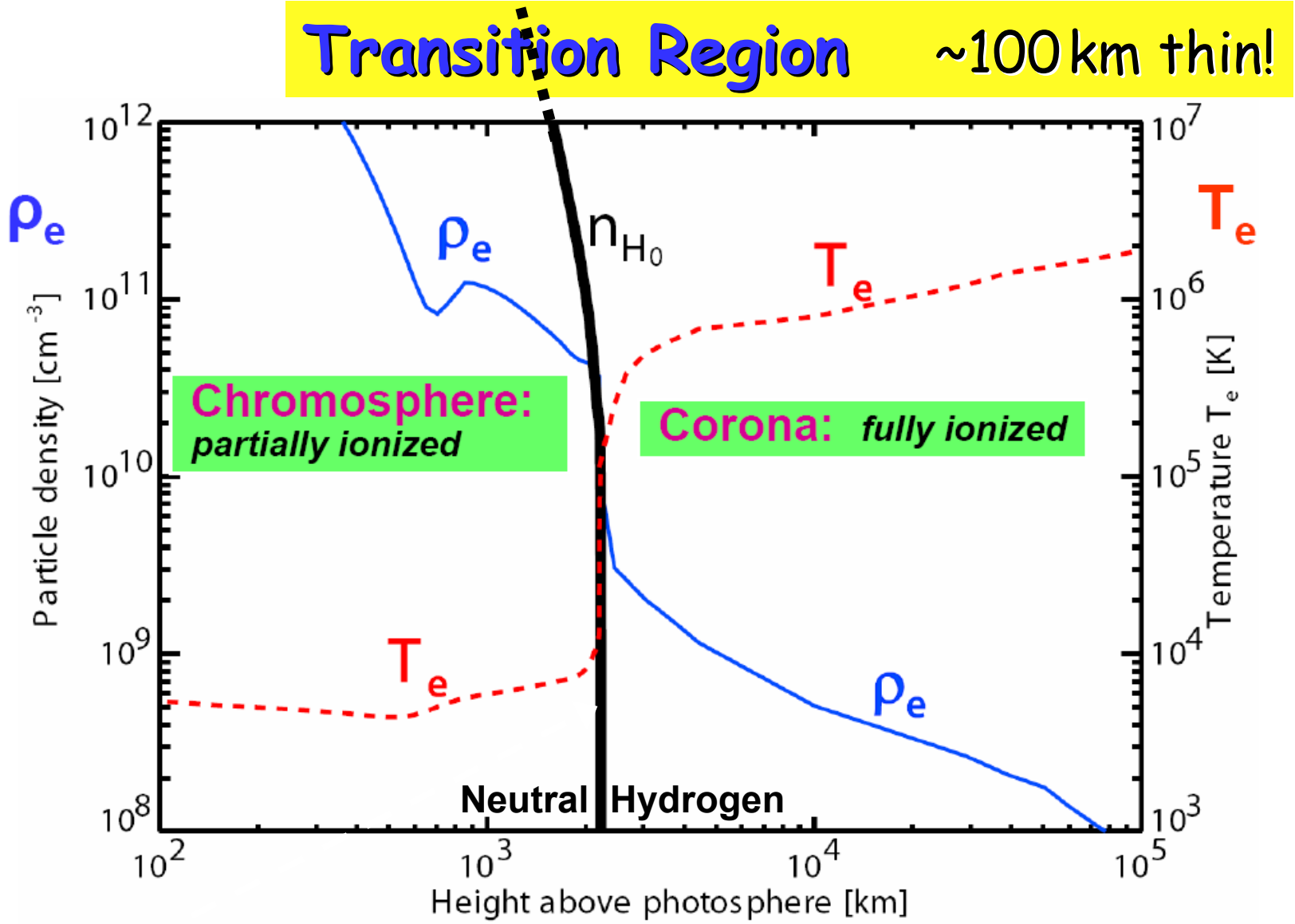
Searching the X-ray Sun for Solar Axions

H. S. Hudson (SSL Berkeley)
L. W. Acton (MSU)
E.E. DeLuca (CfA)
I.G. Hannah (U. Glasgow)
G.J. Hurford (SSL Berkeley)
R.P. Lin (SSL Berkeley)
K.P. Reardon (INAF/Arcetri)
K. Van Bibber (LBNL)

St. Louis, AAS, #212,#4.02 May 2008

The enigmatic sun …

Solar atmosphere → Corona



Corona: ρ_e **varies ~10x – 100x**

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

S Patsourakos *et al*, ApJ. 522 (1999) 540; M Aschwanden, Physics of the Solar Corona (2004) 24-26

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

The heating of the hot corona remains unknown →
a long-standing problem of broad astrophysical importance.
… a hidden process controls coronal heating!

DA Falconer, RL Moore, JG Porter, GA Gary, T Shimizu, ApJ. 482 (1997) 519

There have been numerous models explaining coronal heating; however, a solution remains elusive.

D Tripathi, HE Mason, PR Young, G Del Zanna, A&A Letters, astro-h/200802.3311

… quiet-Sun magnetic field
→ key to the coronal heating problem
➔ … the corona is hotter where the fields are stronger!

S Regnier, CE Parnell, AL Haynes, A.&A. (2008) *in press*
A Mohan, BN Dwivedi, Current Science 81 (2001) 349

… the basic physical processes … for heating the corona + accelerating the solar wind are still not known.

SR Cranmer, astro-ph/200804.3058

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 Chromosphere

Chromosphere's heating mechanism?

… acoustic waves: ~10% of the radiative energy losses

➔ An **alternative mechanism is required** for heating the non-magnetic low chromosphere (filling factor <1%)

SS Hasan, Adv. Space Res. 42 (2008) 86

Transition Region

→ **Chromosphere–Corona Temperature inversion**

An outstanding problem:

… predicted line intensities several orders of magnitude less than observed

Encyclopedia of Astronomy & Astophysics (2001) 3444

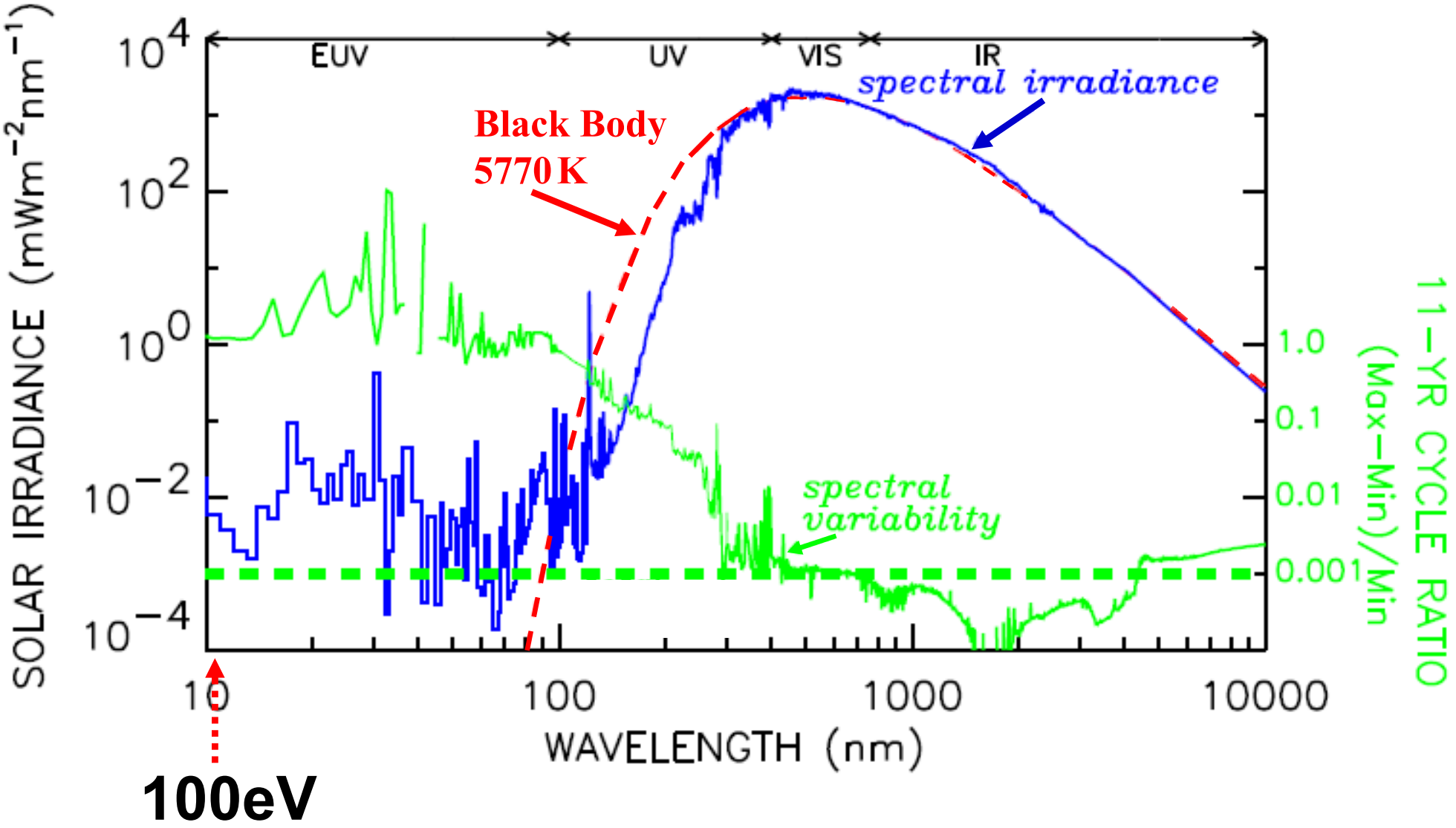
The nature of the transition region:

→ **a primary unanswered question in solar physics.** …

Q: what physical process is producing *most* of the 10^5K plasma?

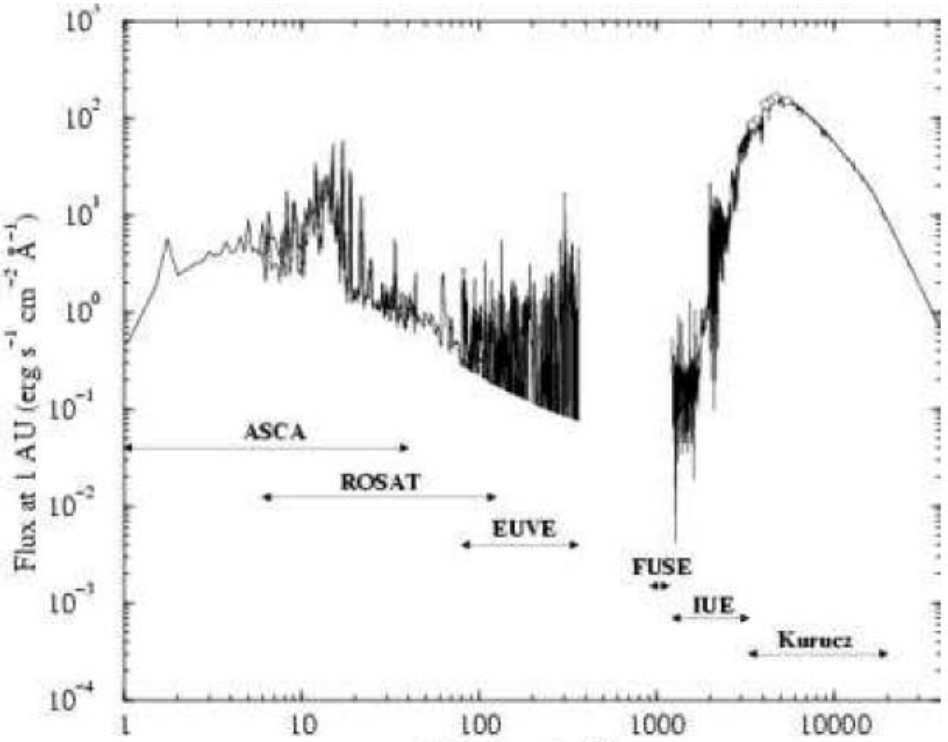
E. R. Priest, A. W. Hood, D. Bewsher, Sol. Physics 205 (2002) 249
D. Bewsher, C.E. Parnell, R.A. Harrison, Sol. Physics 206 (2002) 21, 249
D. Bewsher, C.E. Parnell, C.D. Pike, R.A. Harrison, Sol. Physics 215 (2003) 217

Solar e/m spectrum

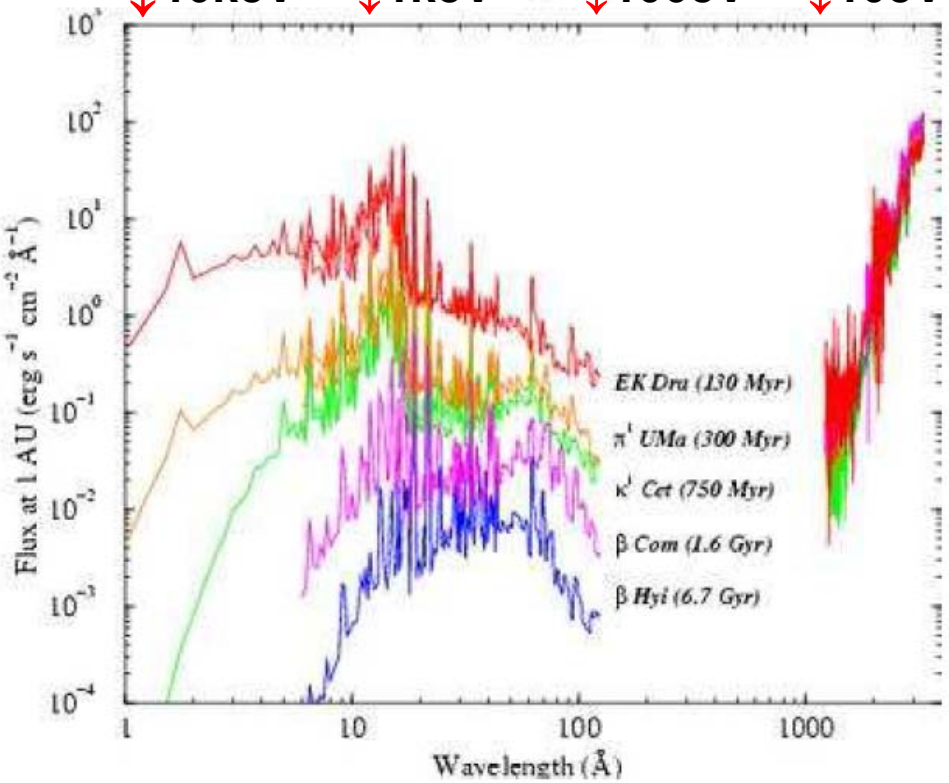


➔ suggestive for low energy (solar) ~axion search!

10eV - 1000eV the favorit for solar ALPS



↓10keV ↓1keV ↓100eV ↓10eV



← 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.

Solar activity

→ **Flares**

CMEs (Coronal Mass Ejections)

…

The Mysterious Origins of Solar Flares

GD Holman, SCIENTIFIC AMERICAN, April 2006

What produces solar flares?

➔ The precise causes of solar flares & CMEs
is one of the great solar **mysteries**. (2003)

➔ flare-quiet ≈ flare-imminent regions

… storage and release of the energy that powers solar flares
is generally **believed** to be in the coronal *magnetic field* …
+ magnetic reconnection necessary for solar flares to occur.

What ignites solar flares?

➔ How do they unleash so much energy so quickly?

Barnes, Leka, ApJ. 646 (**2006**) 1303,
ibid. 595 (**2003**) 1277
Hathaway, http://science.msfc.nasa.gov/ssl/pad/solar/quests.html (**2003**)
http://science.nasa.gov/headlines/y**2002**/06feb_hessi.htm

Understanding how energy is released in solar flares is a central question in astrophysics.

Warren, Bookbinder, Forbes, Golub, Hudson, Reeves, Warshall, ApJL. 527 (**1999**) L121

Solar flares + CMEs

➔ the most energetic phenomena in the solar atmosphere

➔ magnetic phenomena
thought to be powered by the magnetic free energy ….

. . . . . .

➔ **an open question how magnetic energy is released.**

- The magnetic structure for CME precursors +
  the triggering mechanisms → **fundamental unanswered questions**...

Su, Van Ballegooijen, McCaughey, Deluca, Reeves, Golub ApJ. 665 (**20 august 2007**) 1448
Chen, Hu, Sun ApJ. 665 (**20 august 2007**) 1421
Wang, Zhang ApJ. 665 (**20.august 2007**) 1428
Fan, Gibson preprint doi:10.1086/'521335, ApJ. (**2007**)

Flares must be E/M in origin.

JJ Sudol, JW Harvey, ApJ. 635 (10.12.2005) 647

FLARES: unpredictable **magnetic "explosions"**

B-reconnection (~annihilation)

→ is widely (but not universally) accepted to be essential

→ is reconnection the flare trigger?

OR,

is reconnection a consequence of the "explosion"?

RL Moore, AC Sterling, HS Hudson, JR Lemen, ApJ. 552 (2001) 833

The dynamical energy balance of ARs presents challenges.

… the source of the flare energy is not well understood.

MS Wheatland, ApJ. 679 (June 2008) 1621

The solar "reconnection flare" concept is deceptive …

… many unknowns.

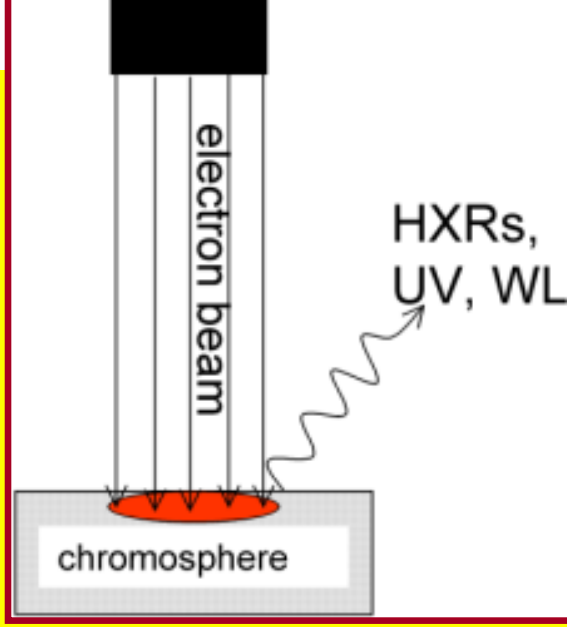
HS Hudson, SPD, May 27th 2008

The flare "number problem"

the high total number of (non-thermal) electrons required compared to that available in the corona

&

the more problematical supply + **re**supply problems.



40 years of theoretical work:

Different acceleration mechanisms … generated by **reconnection** …
BUT, acceleration site still presents some problems for theory … implied by hard X-rays, UV and WL continuum observations.

… **outstanding theoretical issues**

➔ ***A new scenario*** … **Alfen waves** … ***poses theoretical problems***

L Fletcher, HS Hudson, ApJ. 675 (2008) 1645 & RHESSI 68th Science Nugget (2008)

… **goodbye … standard flare model** (=black-box)

Summary on flares:

- Flare surface ≈ 10^{-3}(Solar Surface)

  GOES: $L_{x\text{-}rays} \sim 4 \cdot 10^{30}$ erg/s ~ $10^{-3} L_{solar}$

  → **whole sun flaring!**

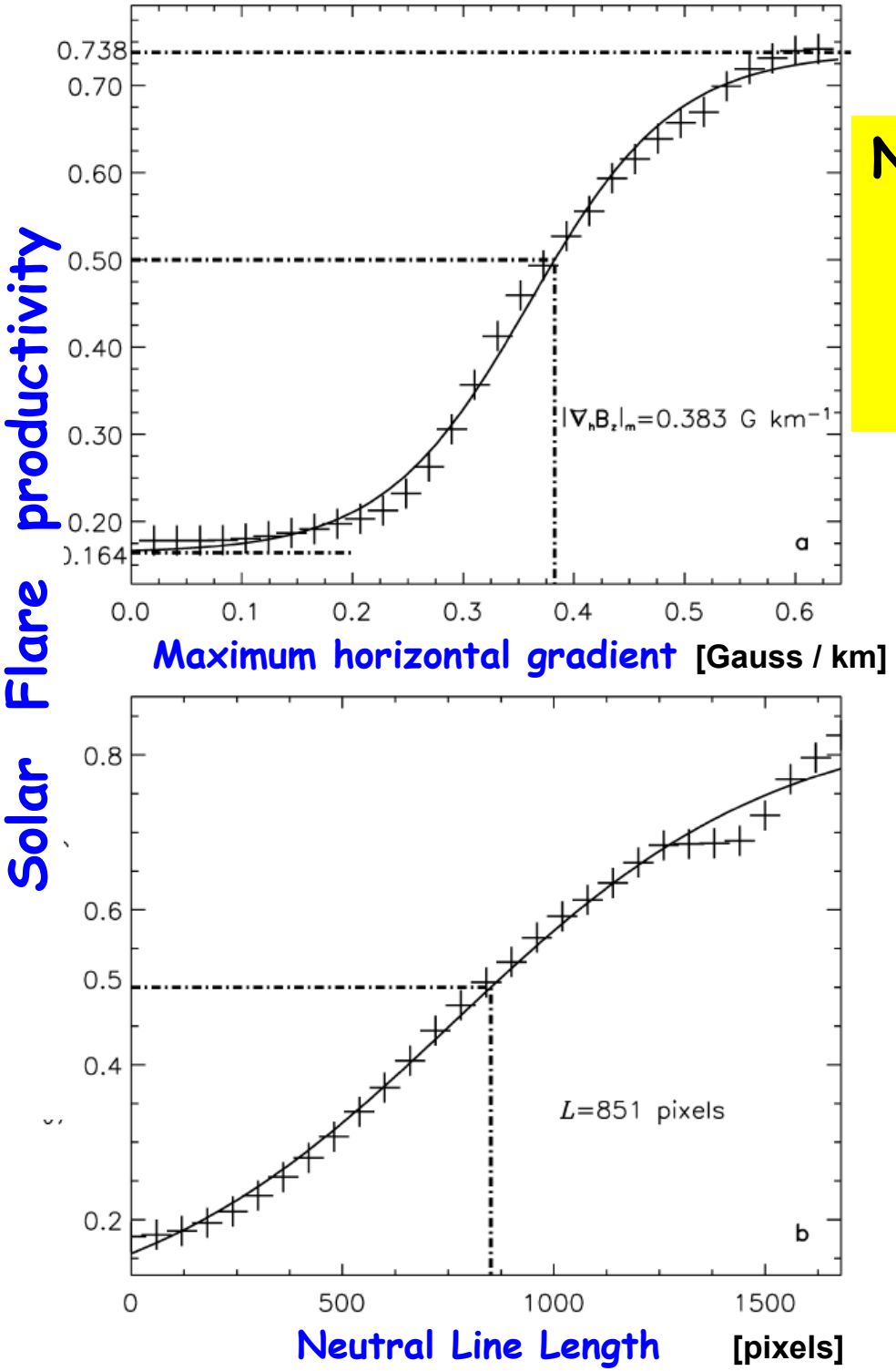
- **$\langle T \rangle \approx$ 10-30 MK $\approx T_{core}$ = 16 MK**

- **$L_{x\text{-}rays}$ = f(B, dB/dz)** $\propto$ B^2 (one case so far [Mason])

- **Flares $\not\rightarrow$ explosions**

- **$\not\rightarrow$ Standard flare model** → electron Nr. Problem, etc.

Mason et al., ApJ. 645 (2006) 1543



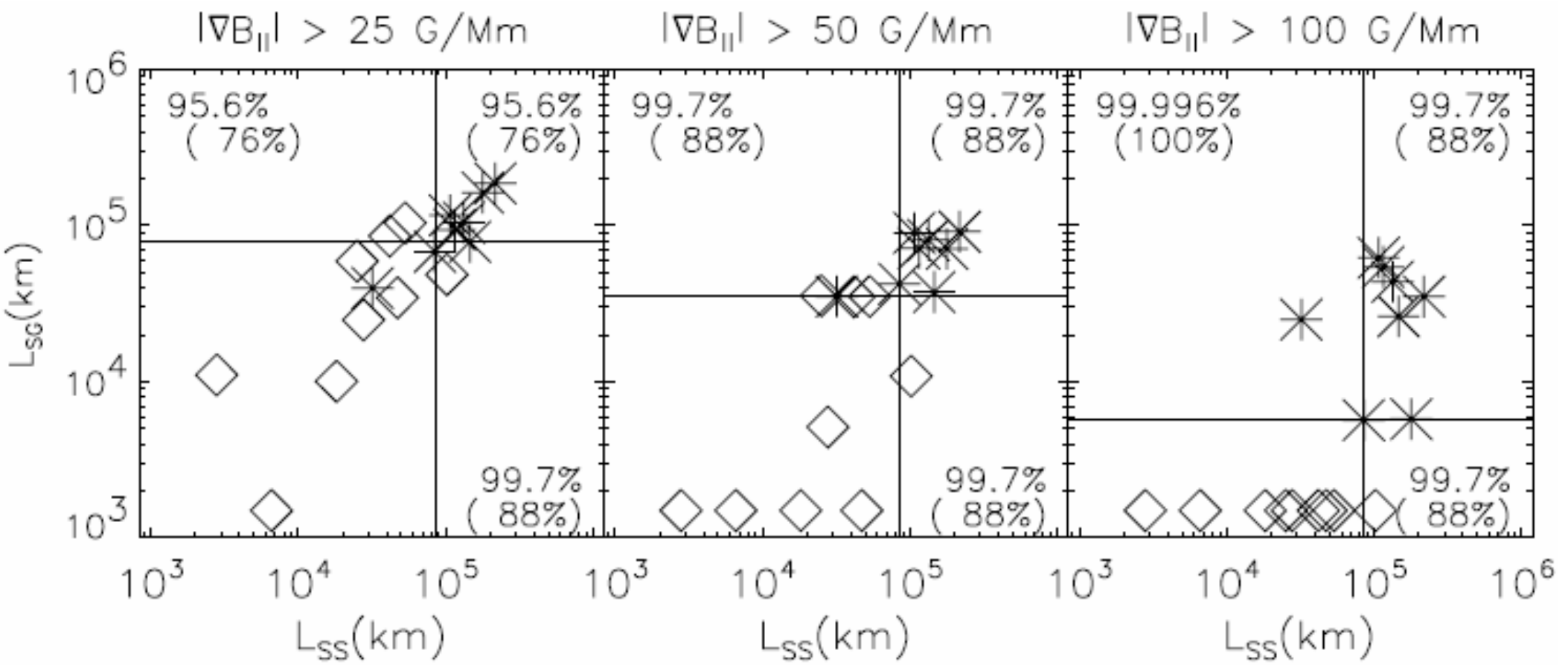
Neutral line in ARs: opposite B-polarities

➔ High magnetic field gradient

➔ solar activity & flares + CME

Y. Cui et al., Sol. Phys. 237 (2006) 45 & 242 (2007) 1

CMEs <=> magnetic field gradients

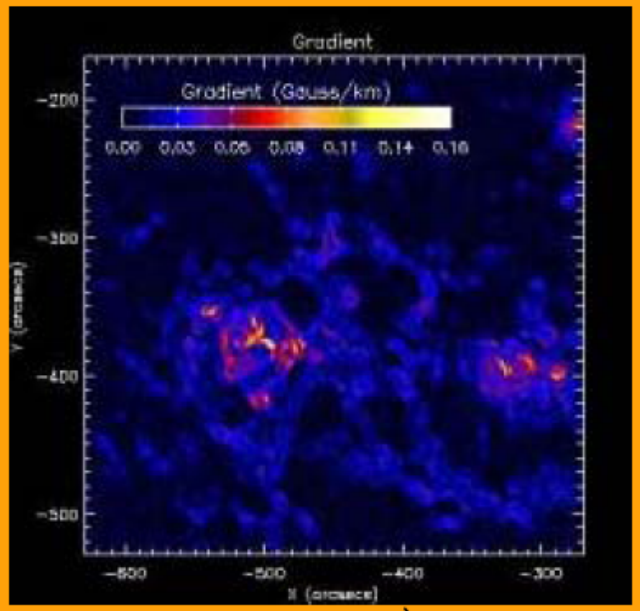


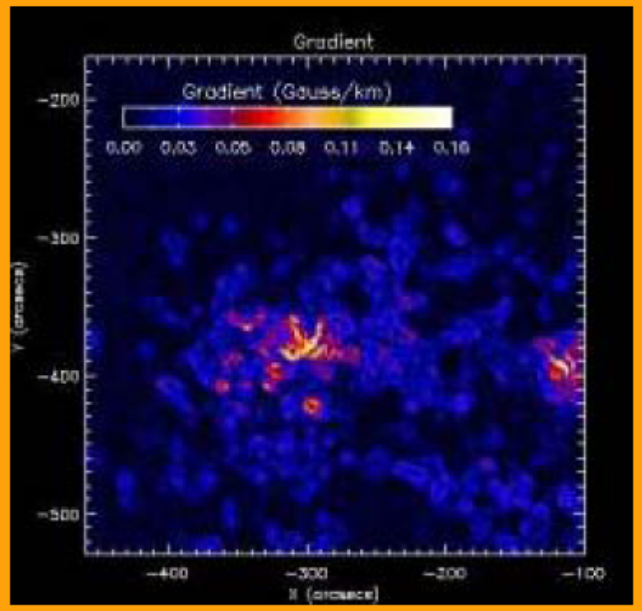
L_{SG} = Strong Gradient length (neutral line) L_{SS} = Strong Shear length

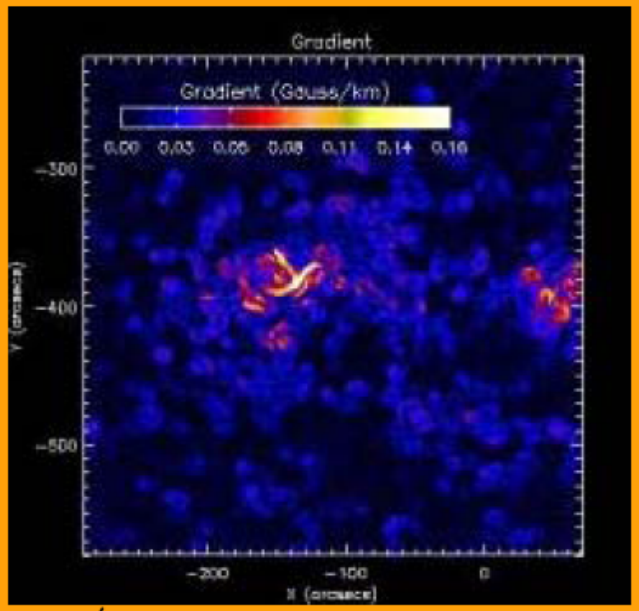
Asterisks: magnetograms of ARs that were **CME** productive within ±2-days;
Diamonds: no **CME**s.

D.A. Falconer, R.L. Moore, G.A. Gary, J. Geophys. Res. 108 (#A10) (**2003**) 1380

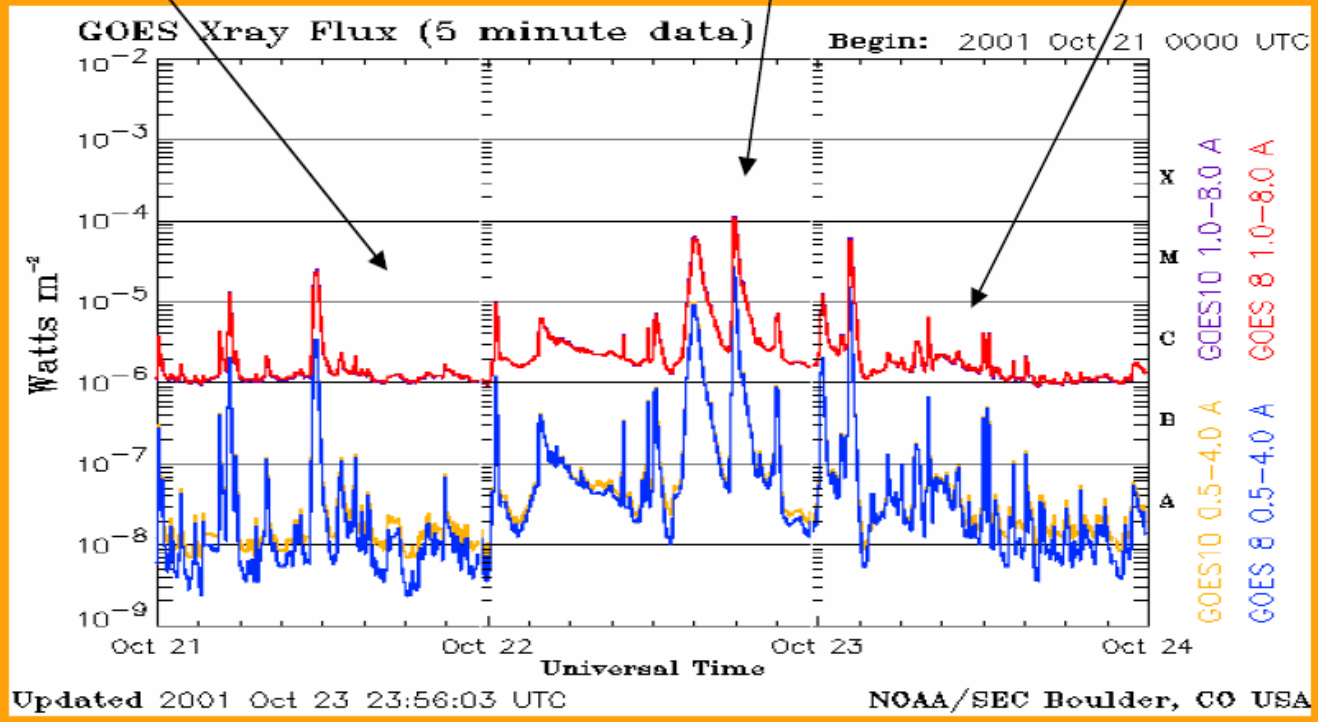
Evolution of AR 9672







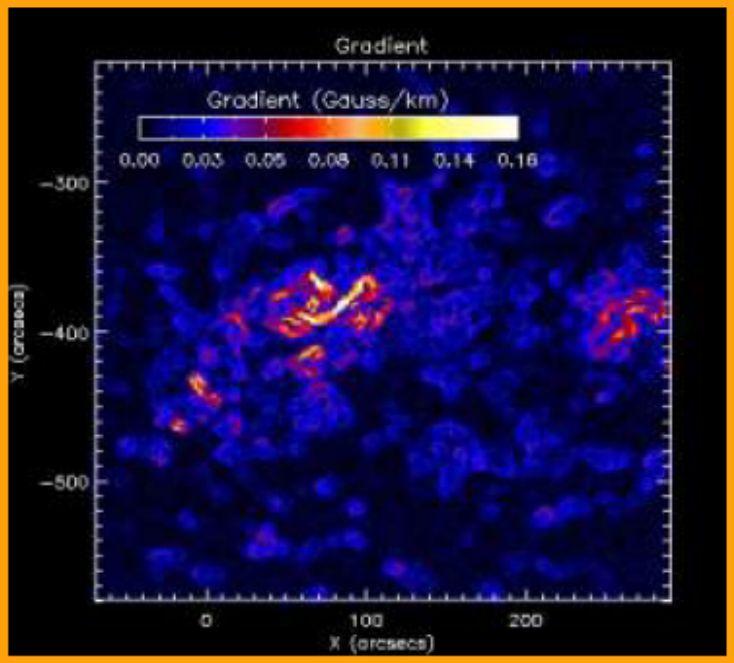
21-OCT-2001 **22-OCT-2001** **23-OCT-2001**



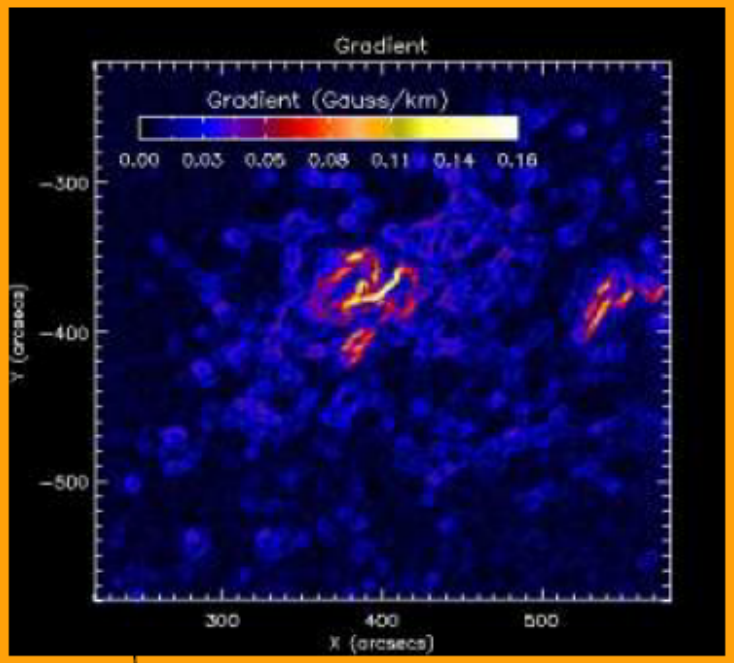
Gradient values (Gauss/km)
OCT/21 0.13
OCT/22 0.31
OCT/23 0.56

~10^{-5}G/cm

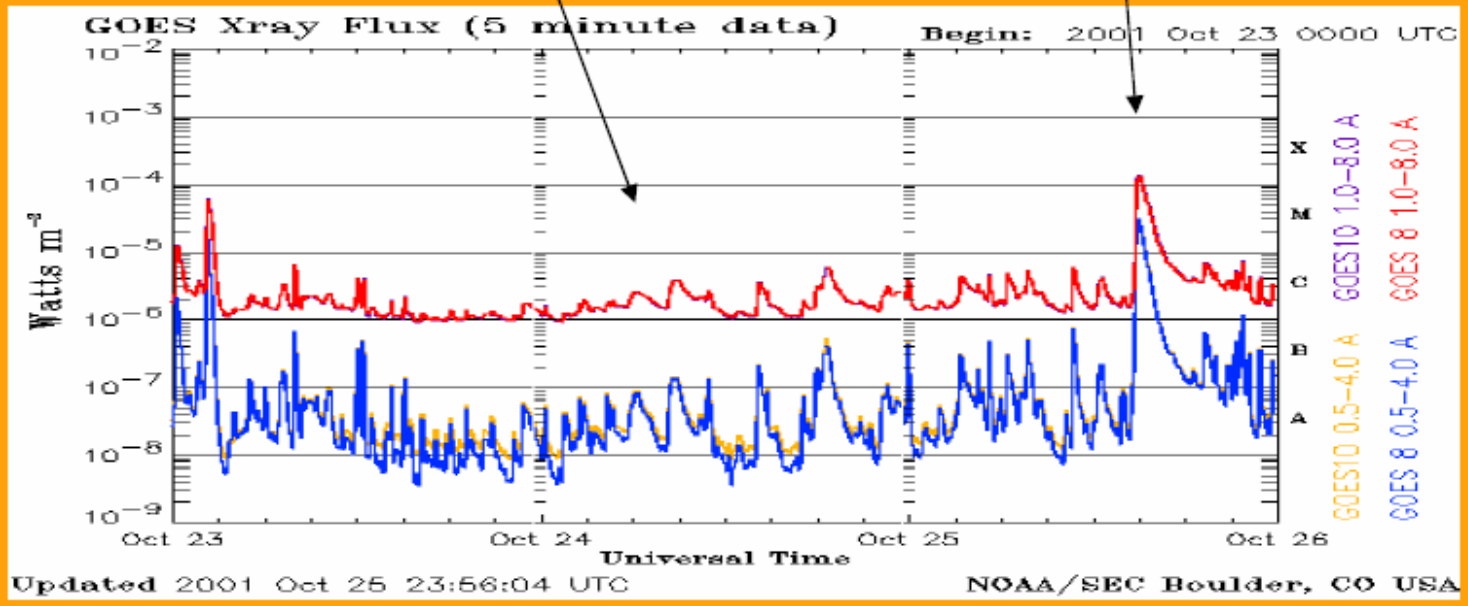
Evolution of AR 9672 cont…



24-OCT-2001



25-OCT-2001



Gradient values (Gauss/km)
OCT/24 0.18
OCT/25 0.29

8-AUG-2003 LASP Adrian E. Cortes

➔ relationship between B-gradients + Solar Flare Activity

…more candidates?

(short) brightenings

→ "Ellerman bombs (1917)
several triggering models proposed
→ magnetic reconnection

see H. Watanabe et al, astro-ph/200805.426

Available online at www.sciencedirect.com
ScienceDirect
Physics Letters B 662 (2008) 445–448
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

Photon and axion splitting in an inhomogeneous magnetic field

E.I. Guendelman

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Received 3 February 2008; received in revised form 20 March 2008; accepted 22 March 2008

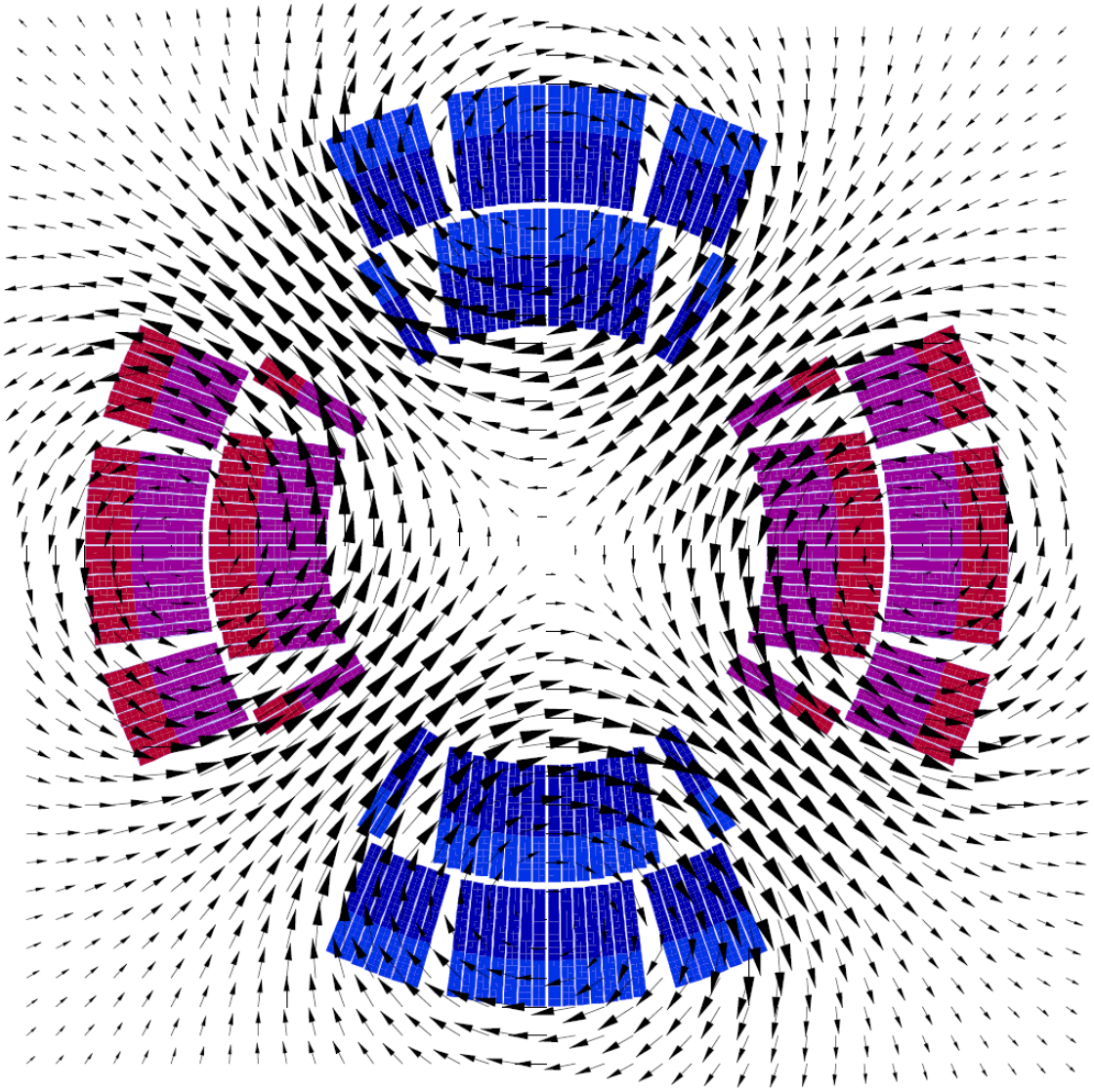
Available online 1 April 2008

Editor: T. Yanagida

New axion↔photon interaction?

➔ **Novel experimental approaches** ➔

Quadrupole magnet



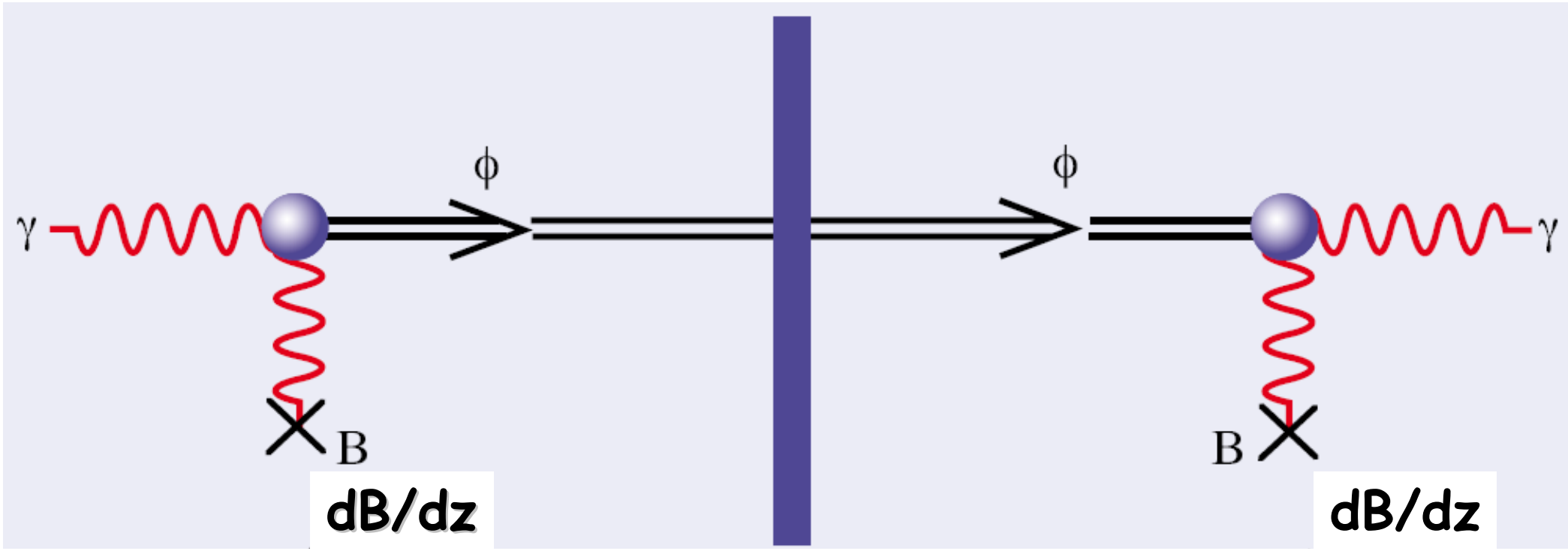
Stephan Russenschuck

SUN	aQuadrupoles
~10^{-8} Tesla / m	>100 Tesla / m
$10^{7\pm1}$ m	~10 m
Length x gradient	
< 1	>1000

Will check Eduardo's idea:

K. Baker, E. Guendelman, P. Sikivie, K.Z. ← **this workshop**

"light shining through a wall"



dipole → quadrupole magnet

Google News Alert for: **solar axions**

Sun Might Hold Secret of Dark Matter

- **Now, for the first time a team hopes to look inside the sun ...**

  ➔ neutrinos? helioseismology?

- **"... will be found in a pleasantly unsuspected way."** ✓

  ➔ unconventional, unorthodox

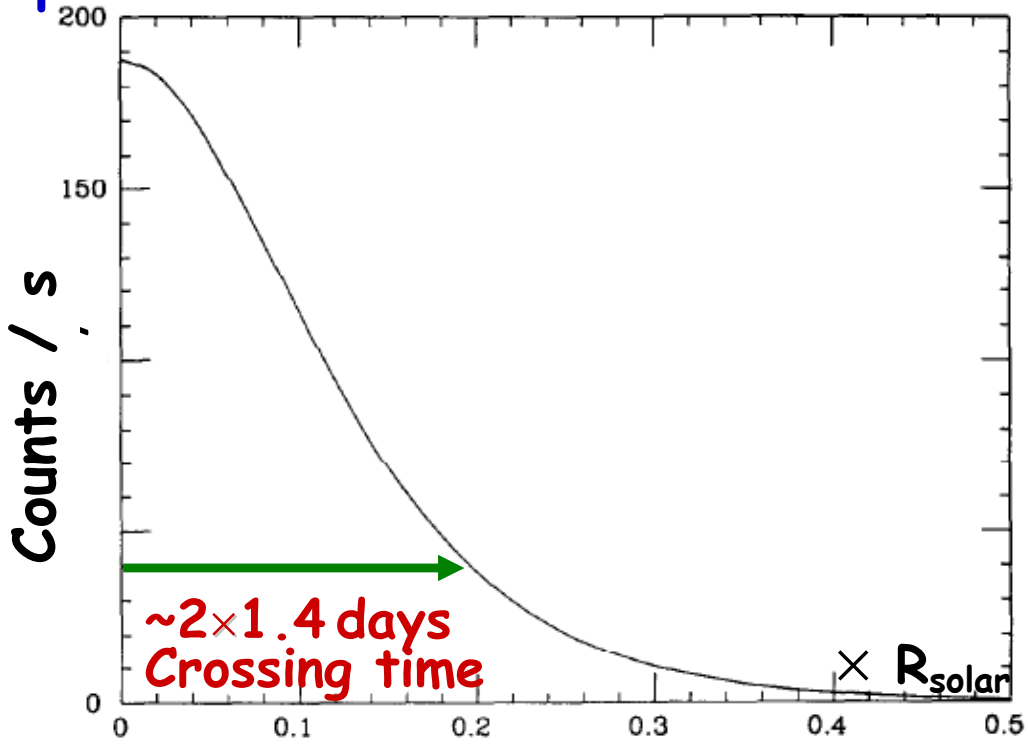
this work →

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!

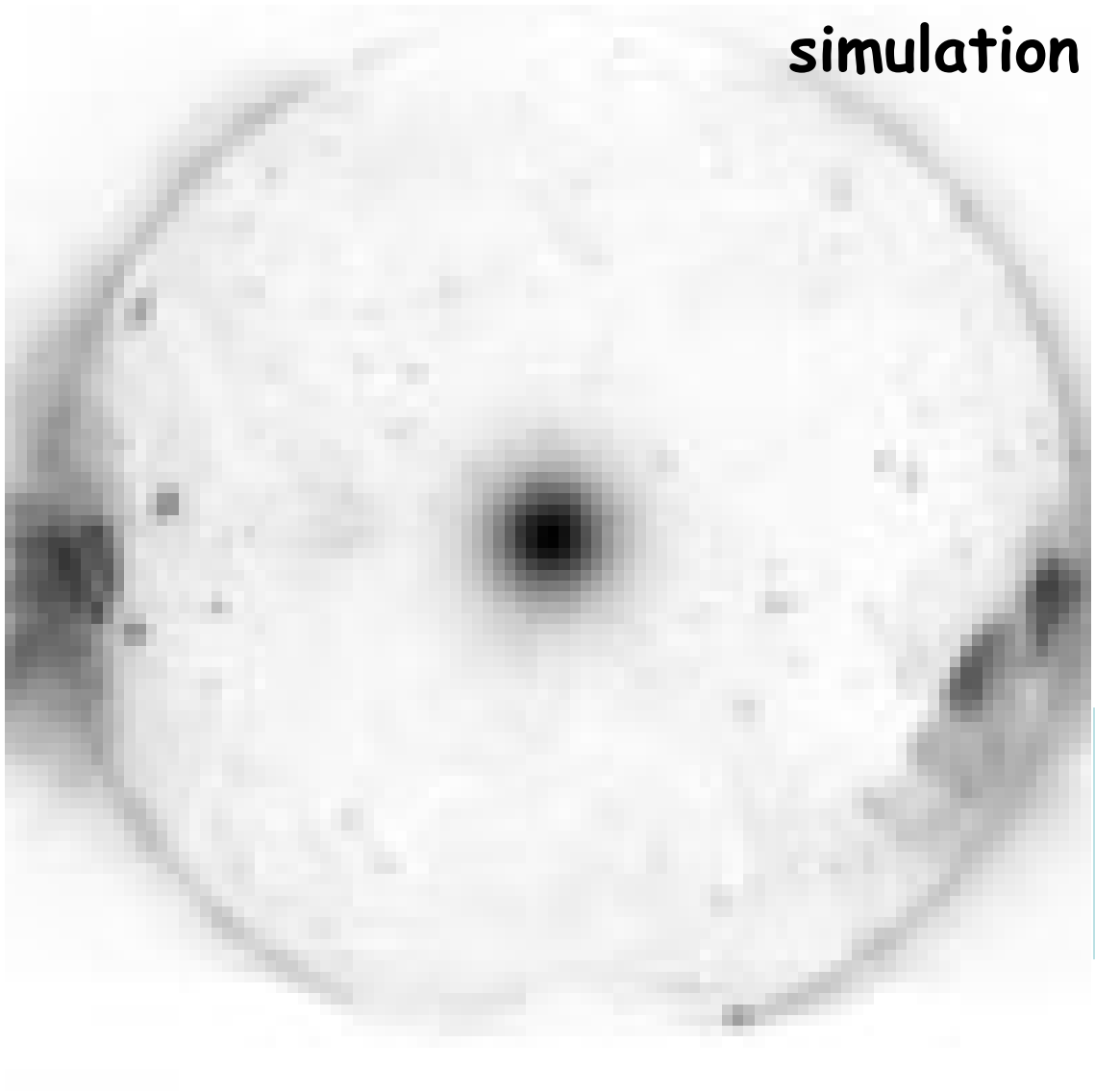
Carlson, Tseng , Phys. Lett. B365 (**1996**) 193

Sunspot counts



RHESSI, Hinode search for axions → ALPs

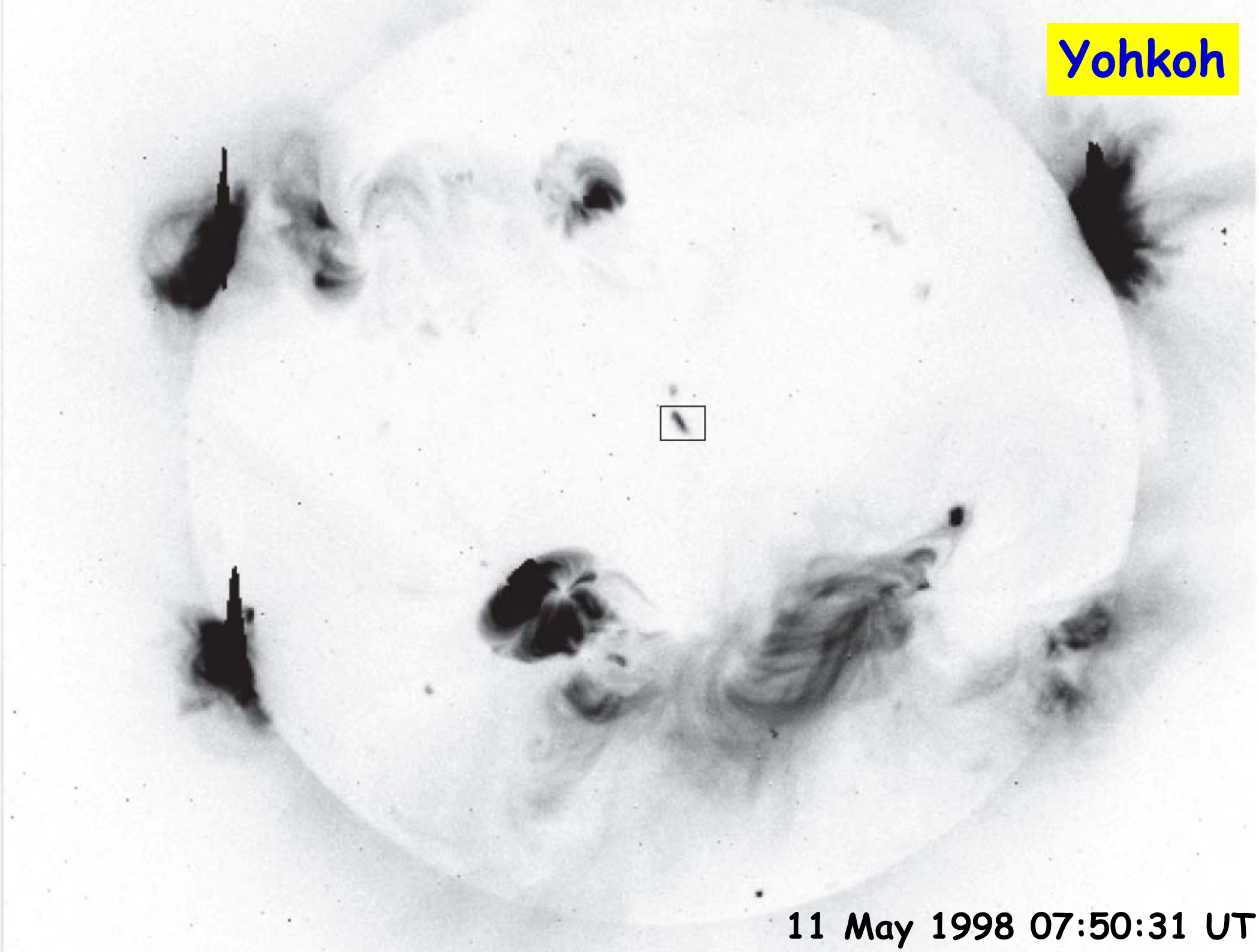
Search for solar X-rays from axions



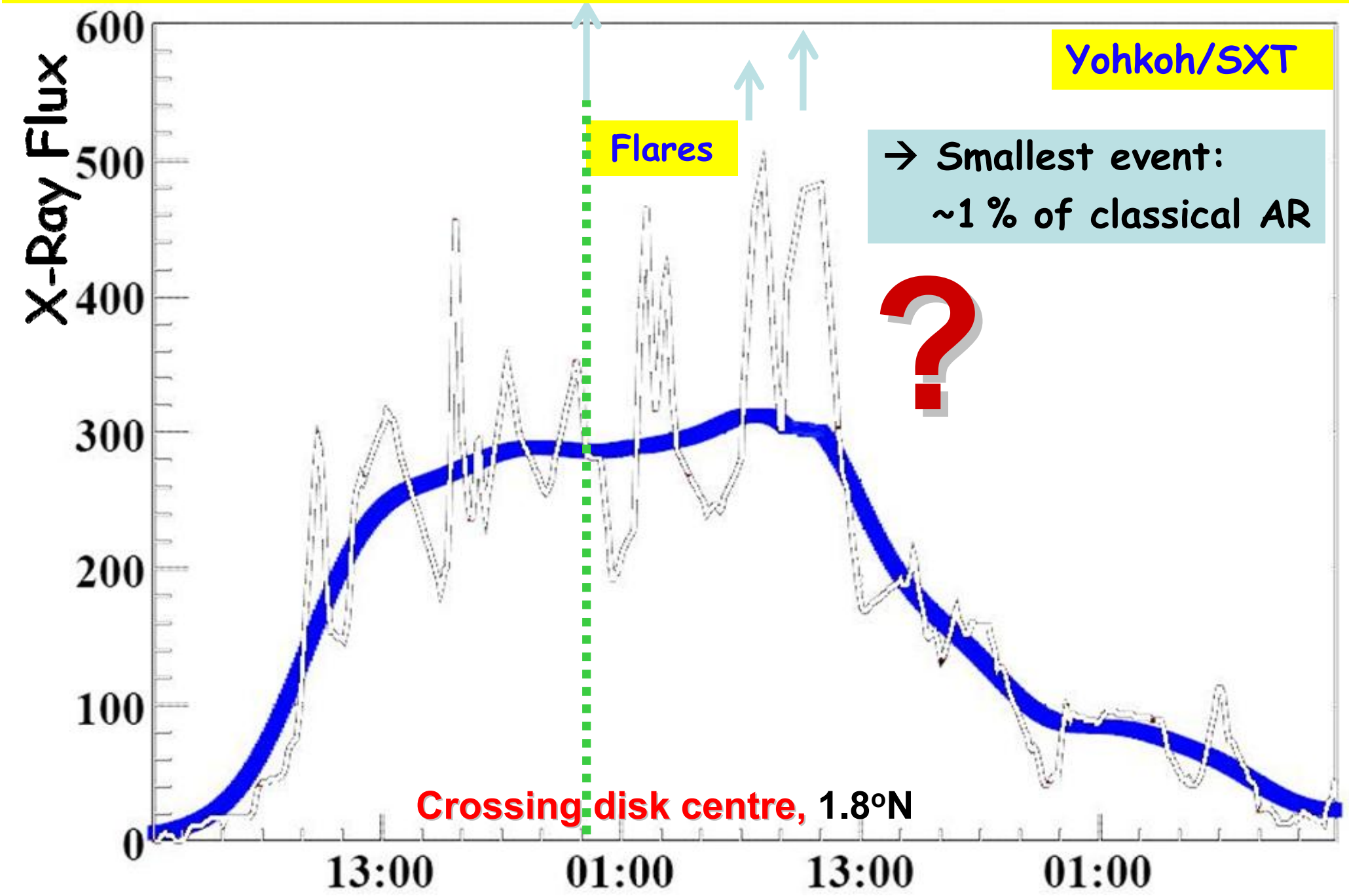
RHESSI
science nugget
H. Hudson,
30.4.**2007**

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**.

Hinode/Yohkoh → axion-like, RHESSI → QCD axion


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

Start Time 10 May 1998_00:00

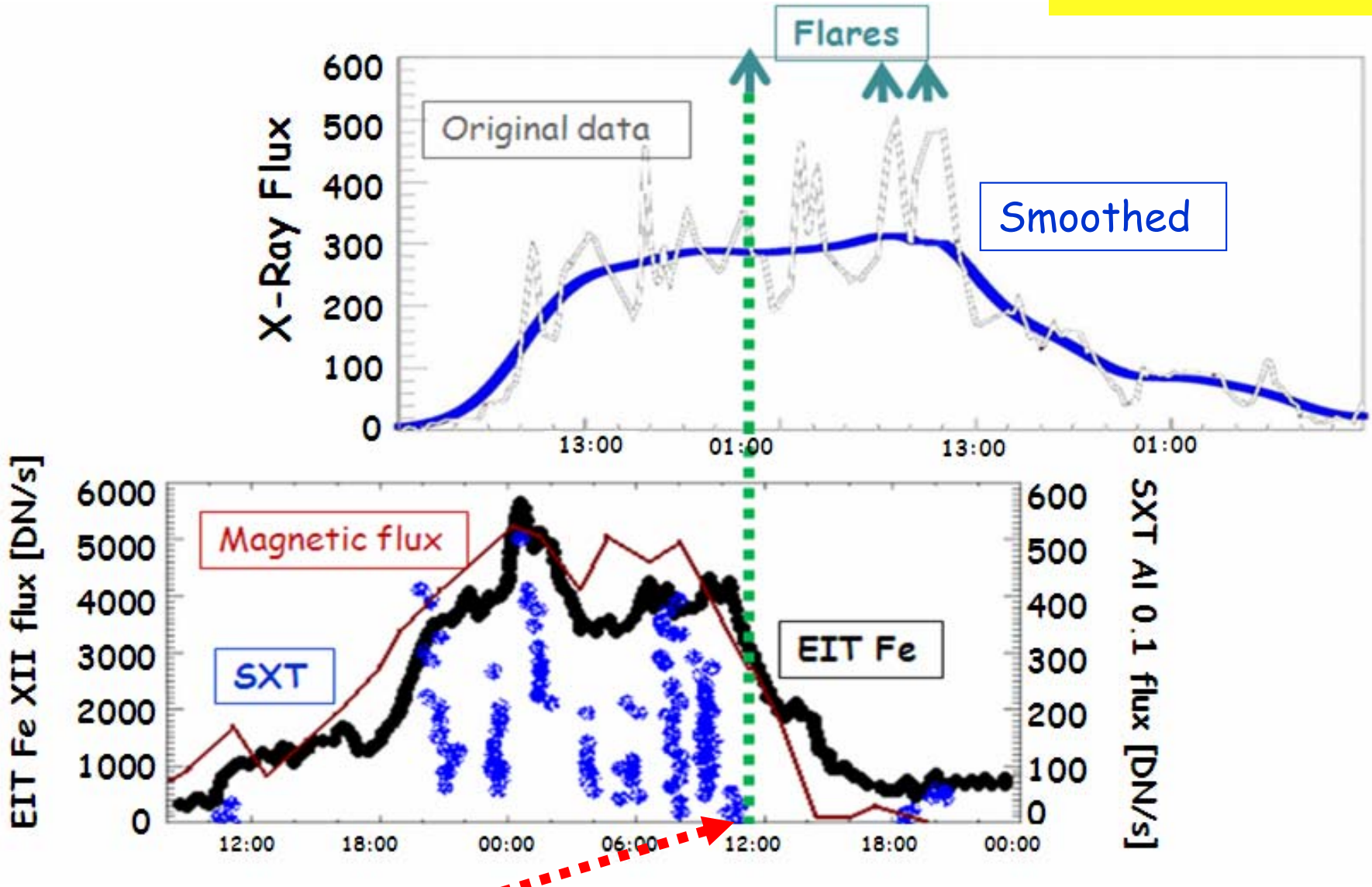
Add more isolated cases!?

Compare XBPs:

Near disk centre with rest of the disk + crossing times

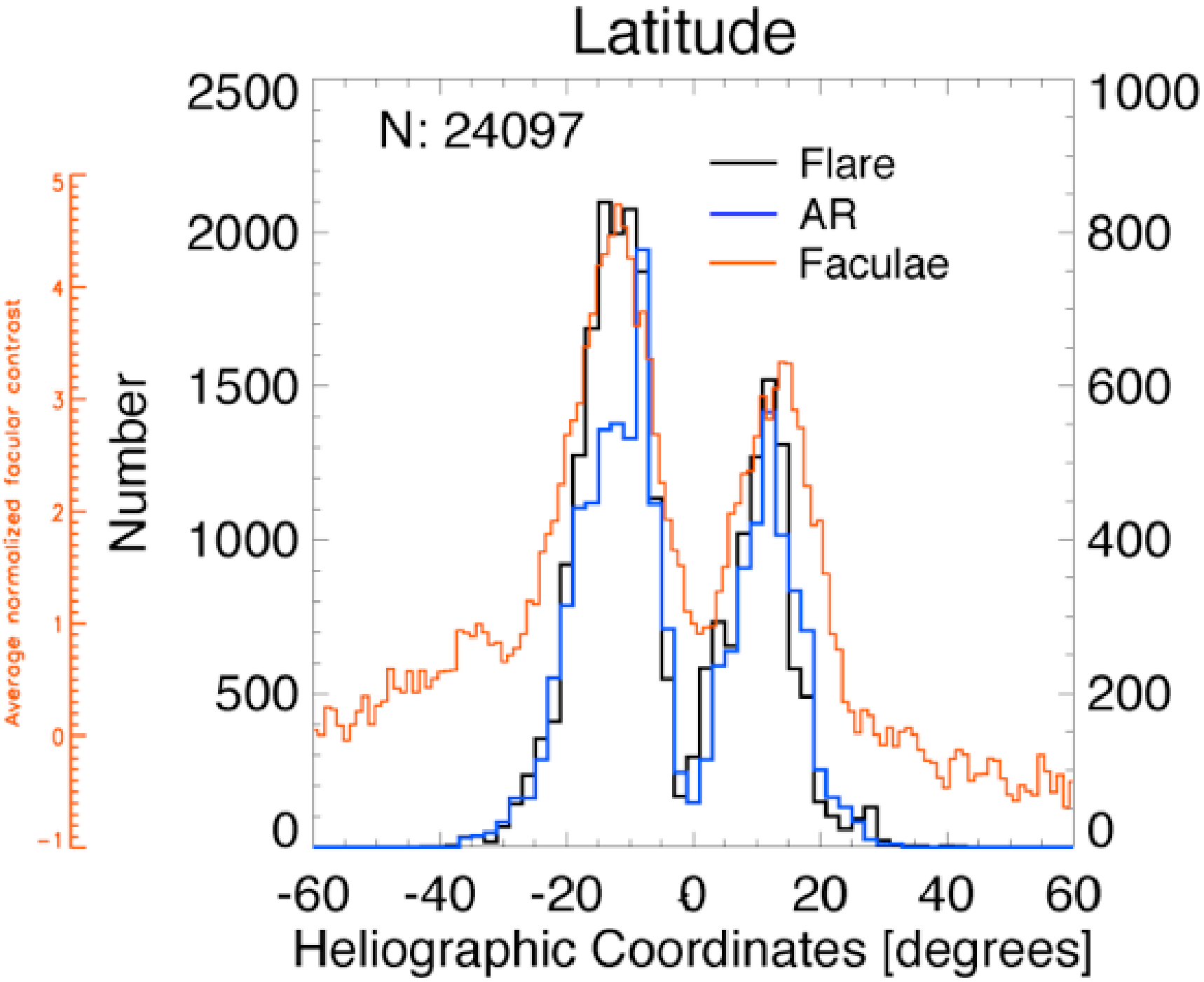
... ➔

1.5 events?



Crossing solar disk centre

A) CH Mandrini *et al.*, A&A 434 (**2005**) 725
B) P Preś, KJH Phillips, ApJL. 510 (**1999**) L73



J. Zahid, S.Christe, RHESSI Science Nugget (16.6.2008)

(solar) ~axions in the spotlight!