Solar axions / ALPs signatures

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CERN

Profited from: **CAST** + V. Anastassopoulos, P. Brax, G. Cantatore, T. Dafni, L. Di Lella, E. Guendelmann, Koutchmy, W. Livingston, T. Papaevangelou, R. Russell , Y. Semertzidis, I. Shilon, M. Tsagri, T. Vafeiadis, J. Vergados, ...

→ A. Knabbe, J. Redondo, ...

Axions /ALPs → solar evolution ✓

more?

→ this work

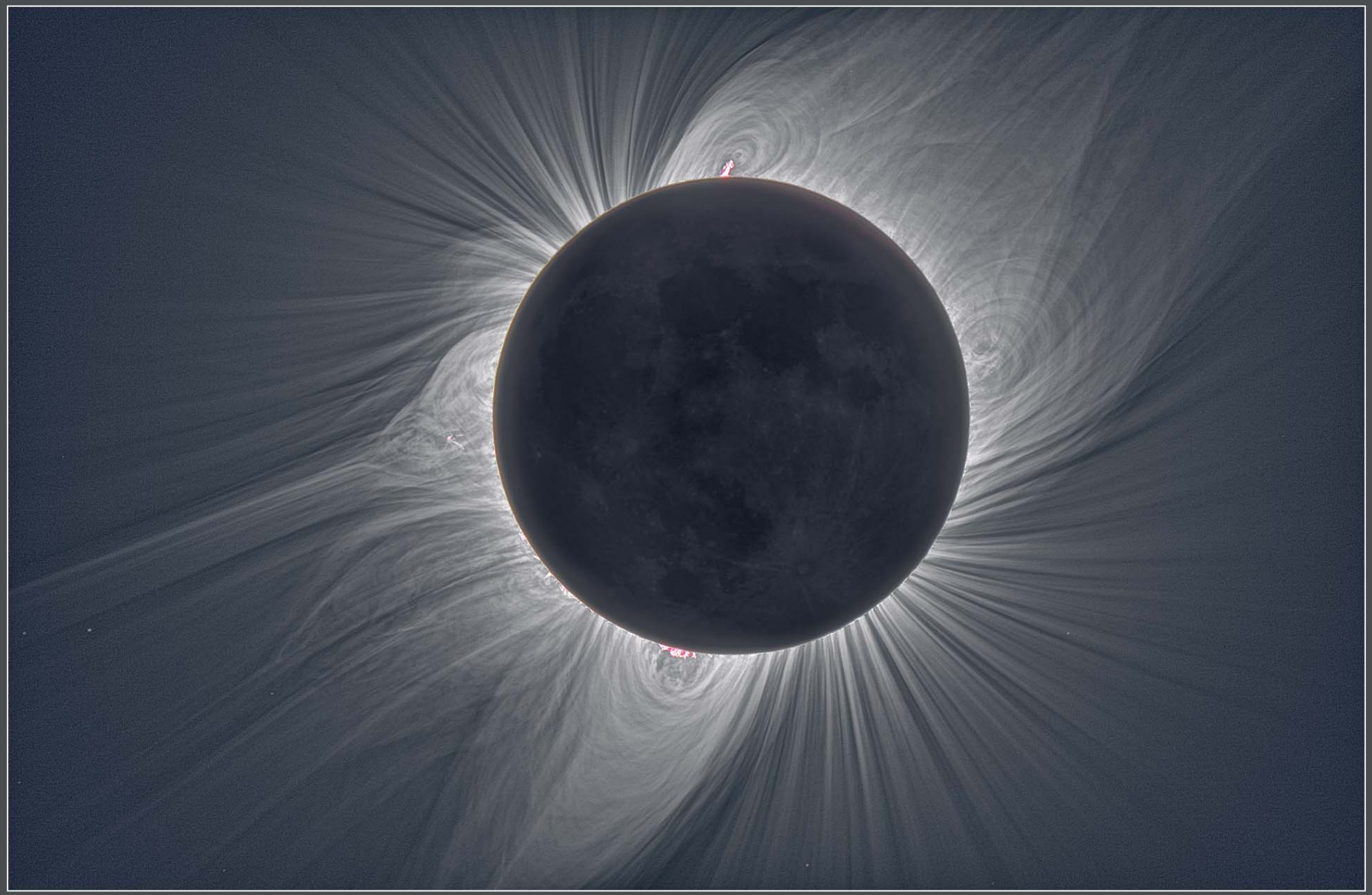
Solar X-ray missions search for ~axions:

- YOHKOH
- RHESSI
- HINODE

- NuSTAR
- FOXSI
- STIX/Solar Orbiter
- SPhinX

...

Why the sun?



Total Solar Eclipse 2008

So far:

Manifestation of hidden new solar physics:

- the solar energy output → nuclear fusion reactor ✓
- the solar neutrino deficit problem → solar ν-oscillations ✓

➔ Both appeared first in the sun → **sun the better laboratory!?**

The reverse reasoning:

- Still, sun's mysteries raise Qs on their origin.
  (11years clock, **corona heating,** flares, CMEs, sunspots, spicules, ...?)

➔ **Manifestation of hidden new solar physics** $\otimes$ ρ_e, $B_\odot$??

→ new ingradient(s) , like ~axions, chameleons, ALPS, ... **WISPs.**

2010

The **coronal heating problem**, i.e., the heating of the solar corona up to a few hundred times the average temperature of the underlying photosphere, **is one of the most perplexing and unresolved problems in astrophysics to date.**

.....

how magnetic energy is converted to thermal energy of the corona remains unknown.

So far: **> 100 models**

Antolin, P ; Shibata, K ; Kudoh, T ; Shiota, D ; Brooks, D, Proc. **2010**, http://www.springerlink.com/content/x2017120x66mj042/
HP Warren, AR Winebarger, DH Brooks, ApJ. 711 (1.3.**2010**) 228 , http://iopscience.iop.org/0004-637X/711/1/228

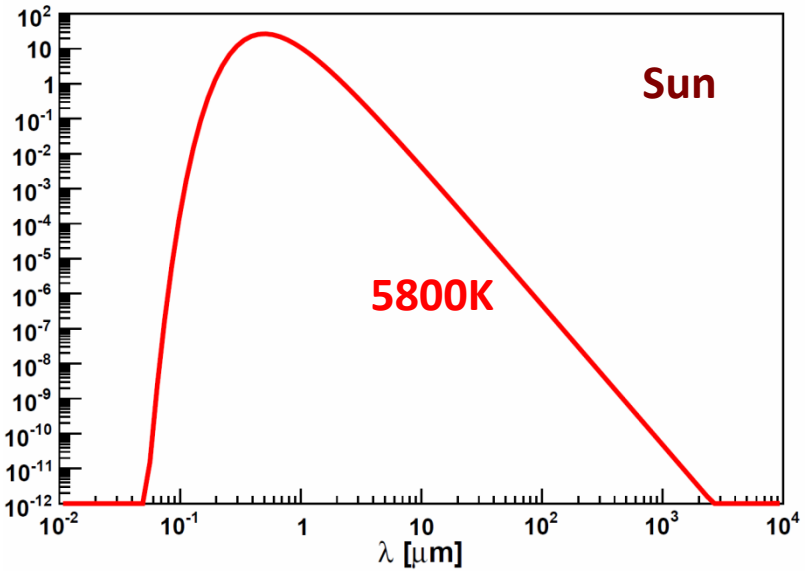
FLARES: unpredictable magnetic "explosions"

- Where does solar flare energy come from?
- ... at least the magnetic field serves as a conduit for the energy flux supplying the flare. 2010
- The solar "reconnection flare" concept is deceptive, ... many unknowns. (HS Hudson, SPD, May 2008)

http://xxx.lanl.gov/PS_cache/arxiv/pdf/1004/1004.5318v1.pdf

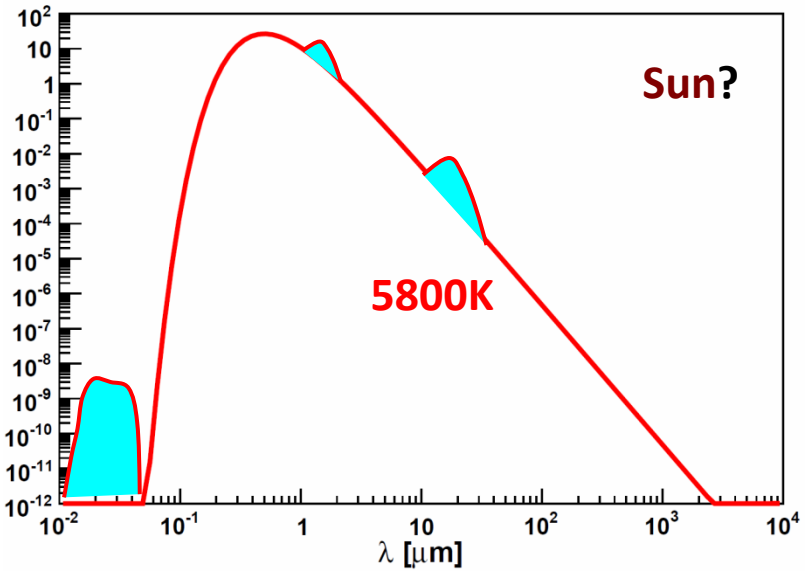
Black body radiation

... , e.g. early Universe,



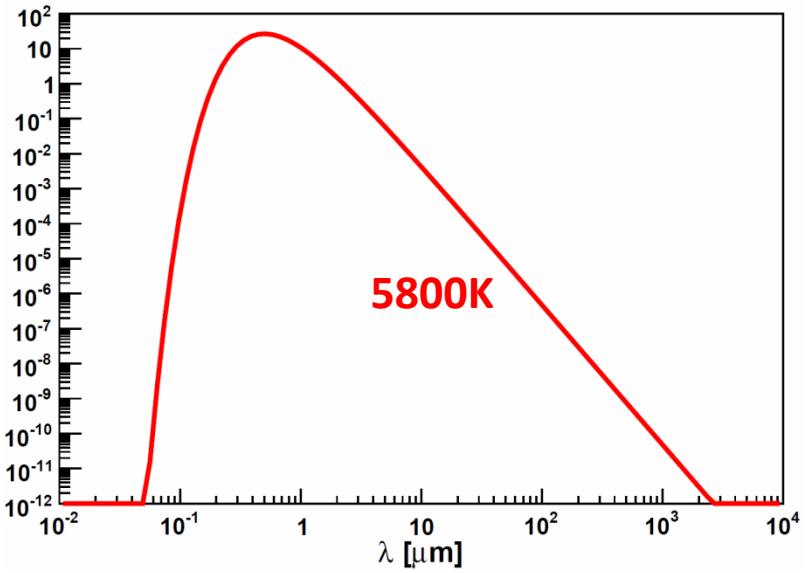
OR, ... + more??

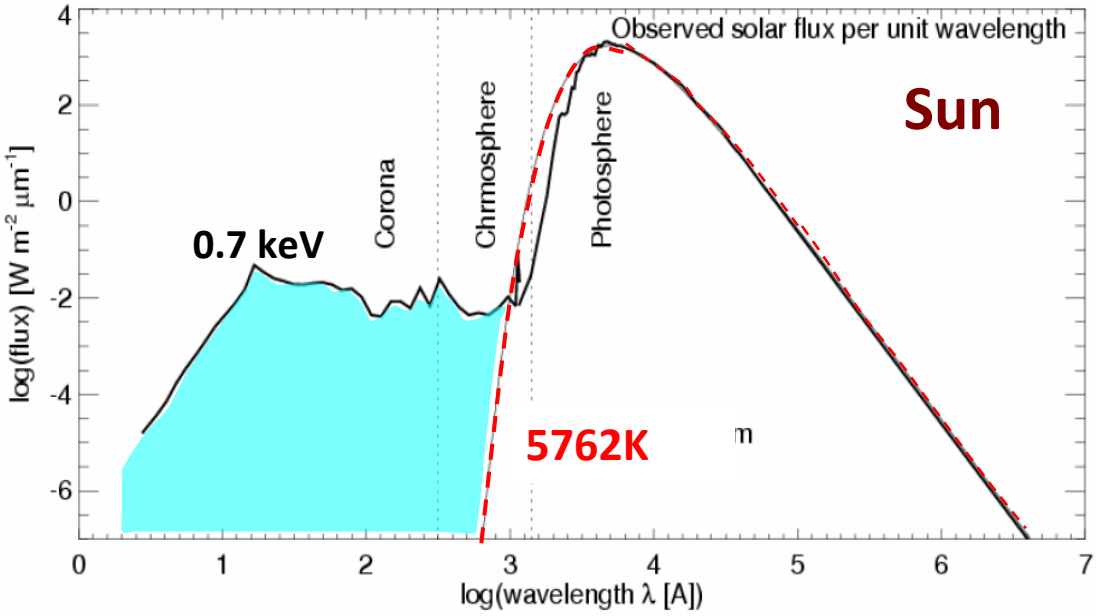
Black body radiation + ...



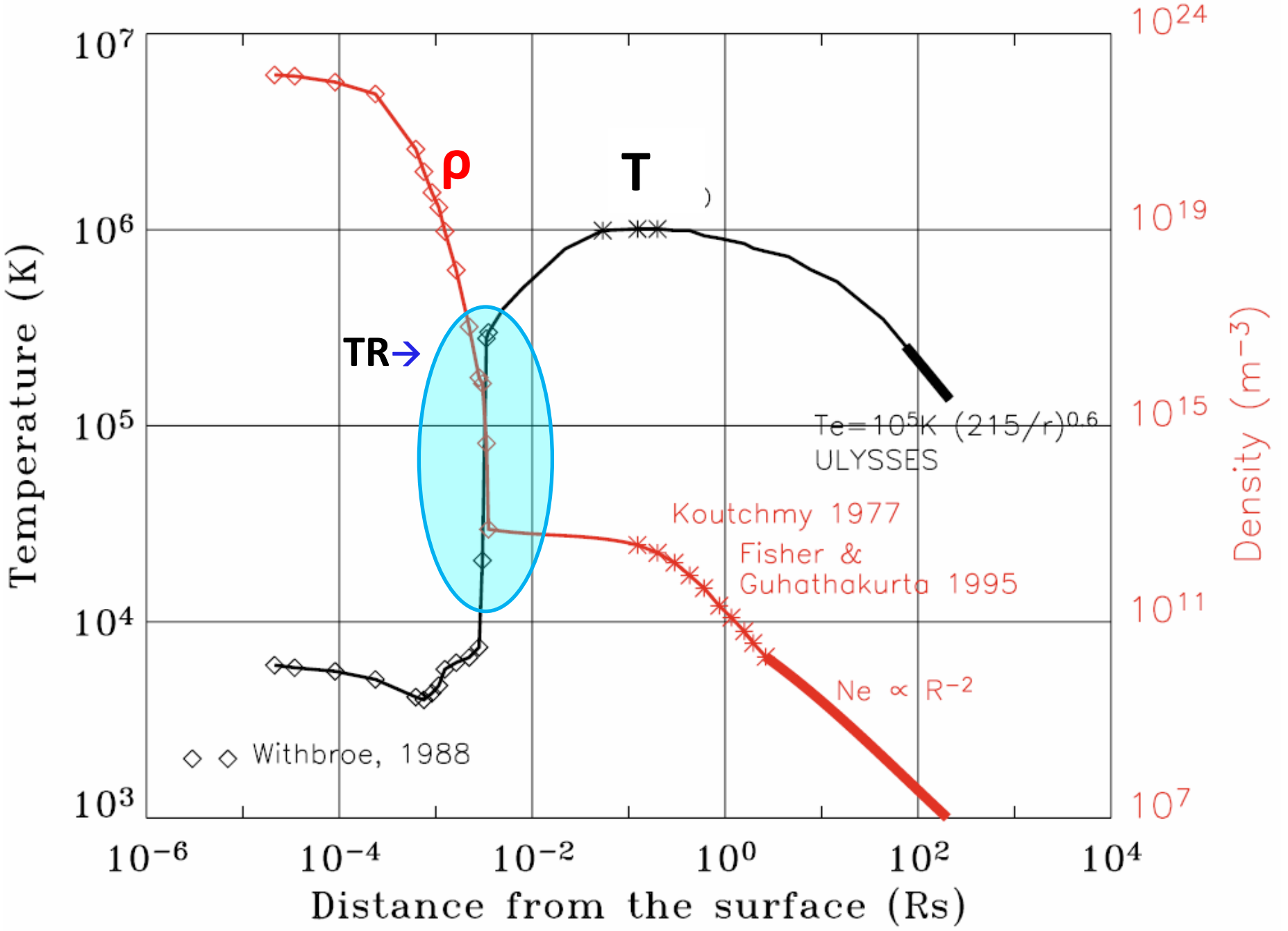
Black body radiation

+ hot chromosphere + corona



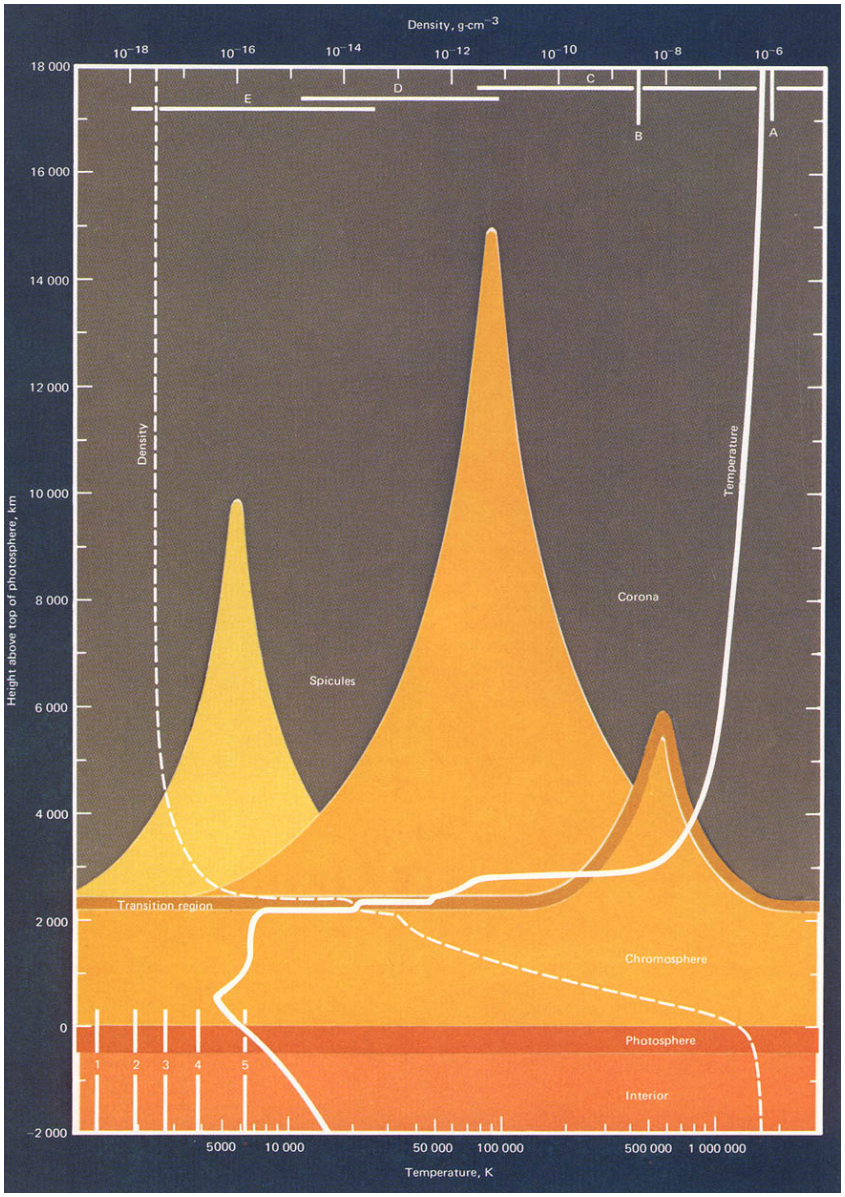


M. Aschwanden, private communication



M. Maksimovic, Lecture Notes Phys. 725 (**2007**) 191

Spicules

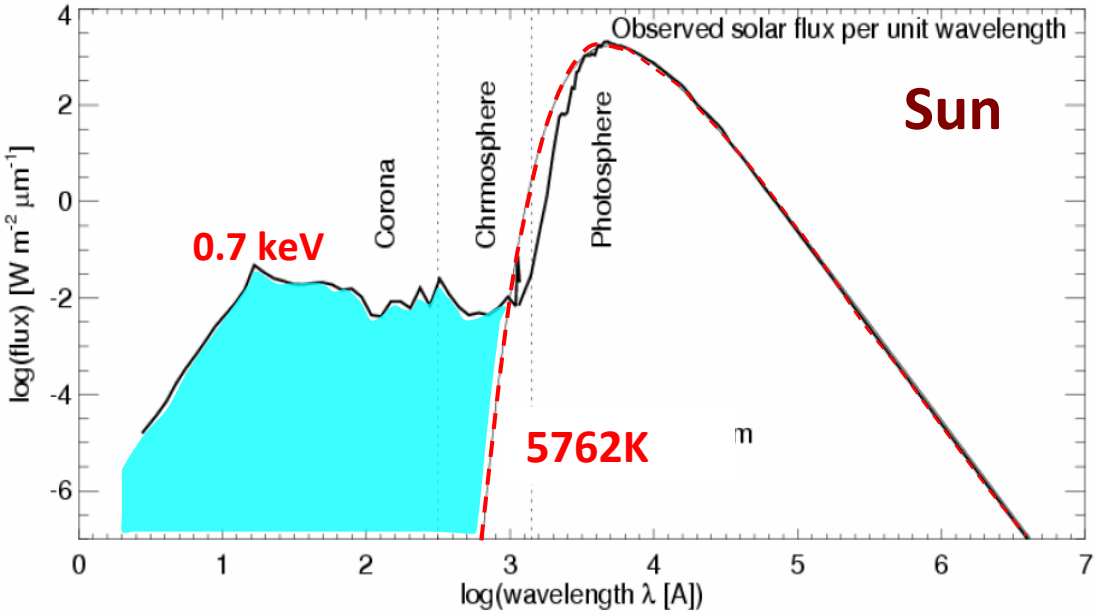


"Plasma, bubbling upward from the Sun's interior to the surface".

→ "a deep mystery"

Black body radiation

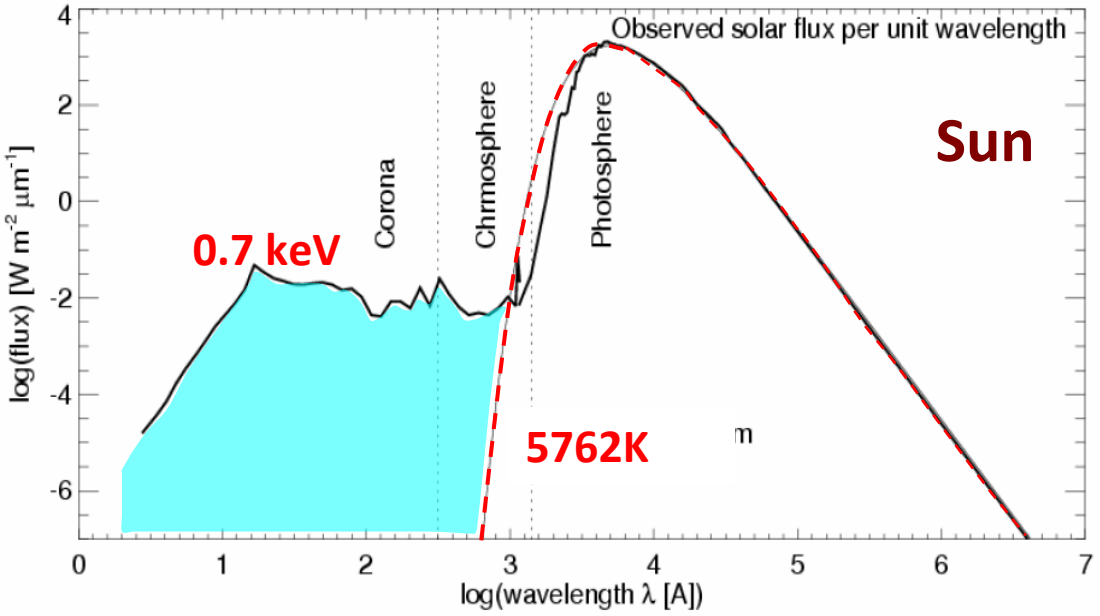
solar constant = 1366.1W/m²

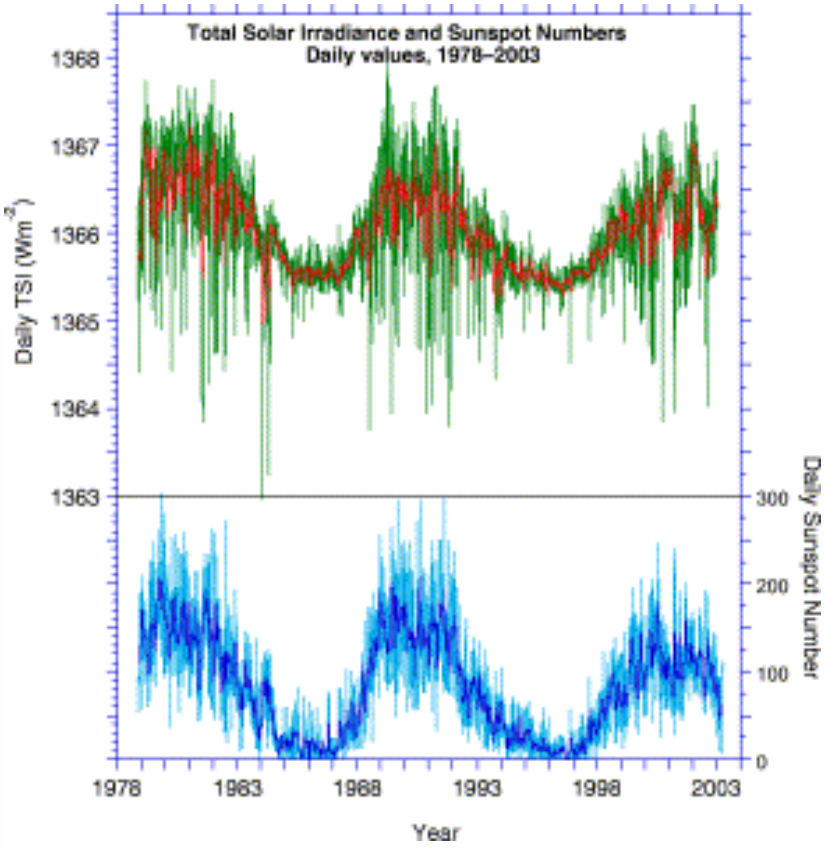


M. Aschwanden, private communication

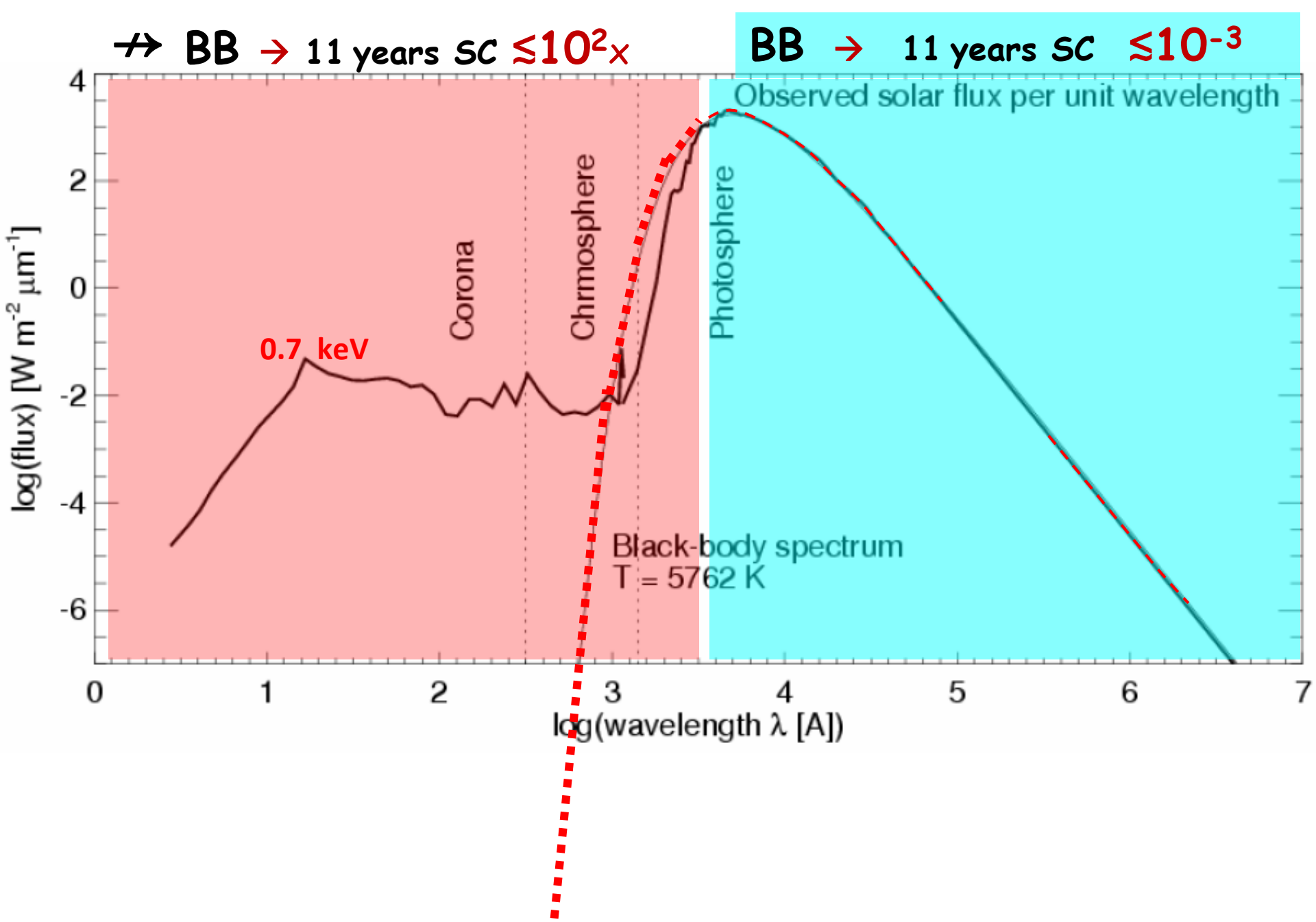
Black body radiation

solar constant = 1366.1W/m^2

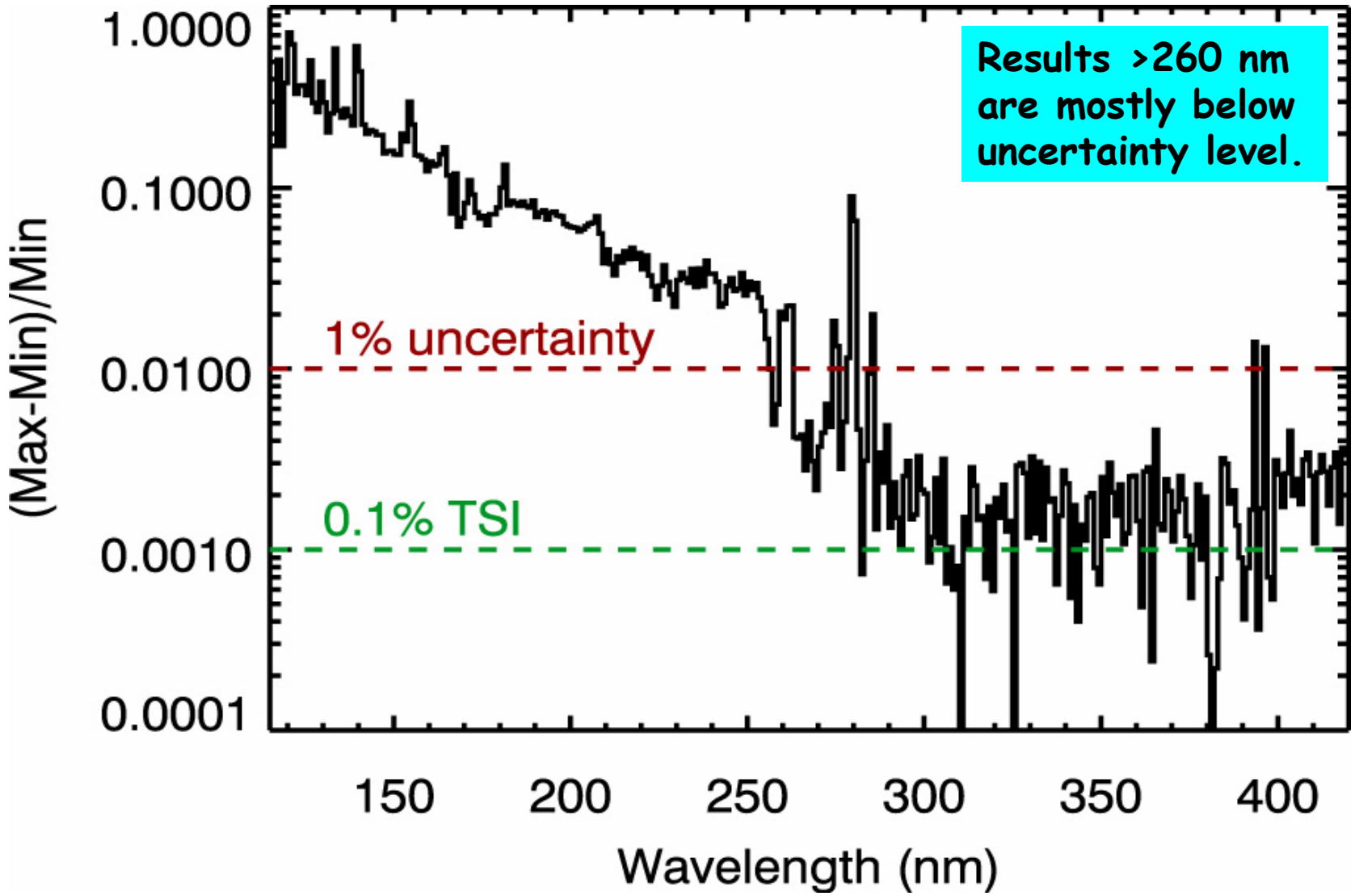




M. Aschwanden, private communication



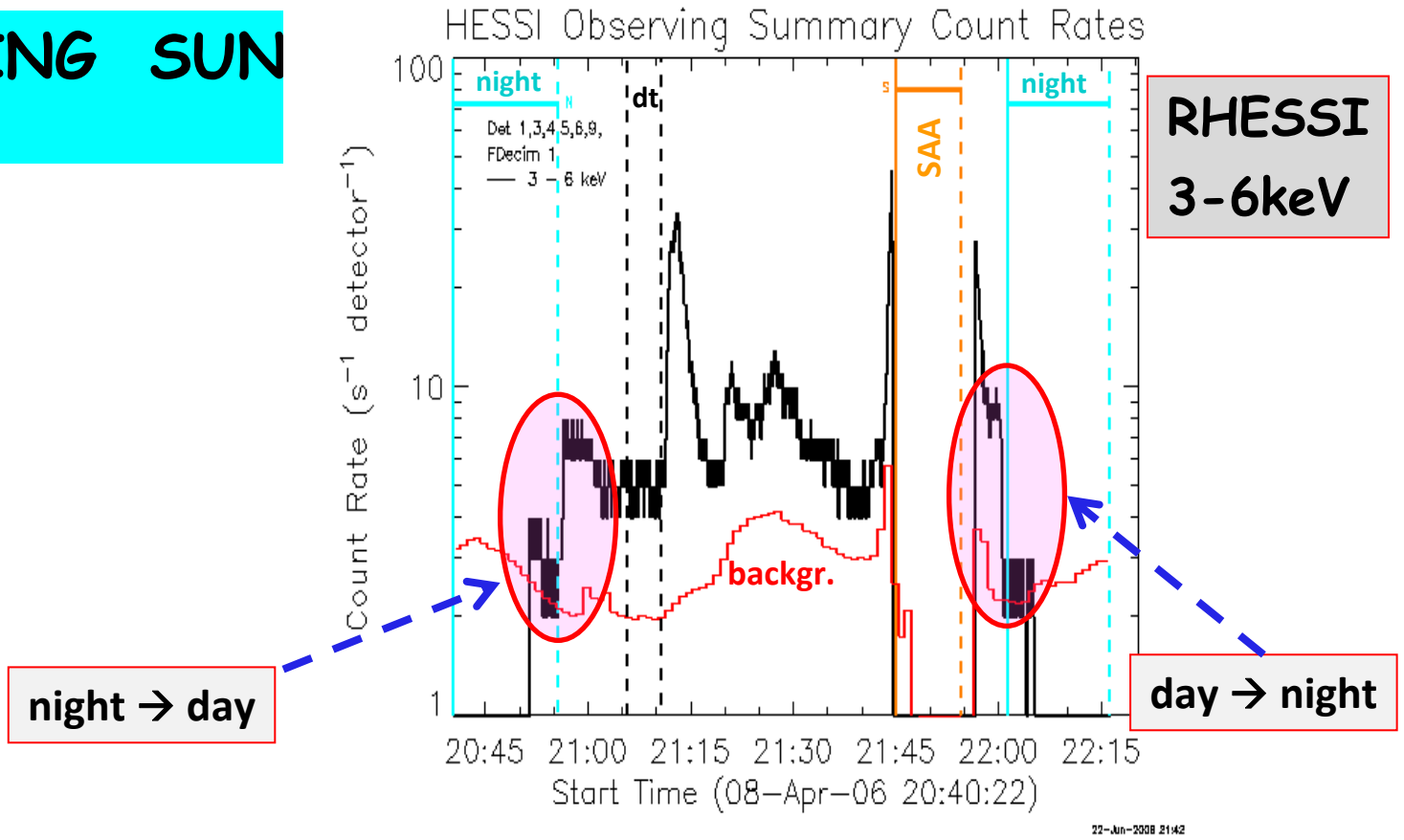
M. Aschwanden, private communication



- Enhanced variability ≤400nm ➔ ~3eV ?? threshold??

Tom Woods, LASP / University of Colorado

NON-FLARING SUN
2002-2006



The count rate during spacecraft daytime is always higher than that immediately before + after, independent of any flaring activity, this **excess** is clearly solar emission.

…

there **exists 5–10 MK emission from the Sun, in the absence of solar flares** …

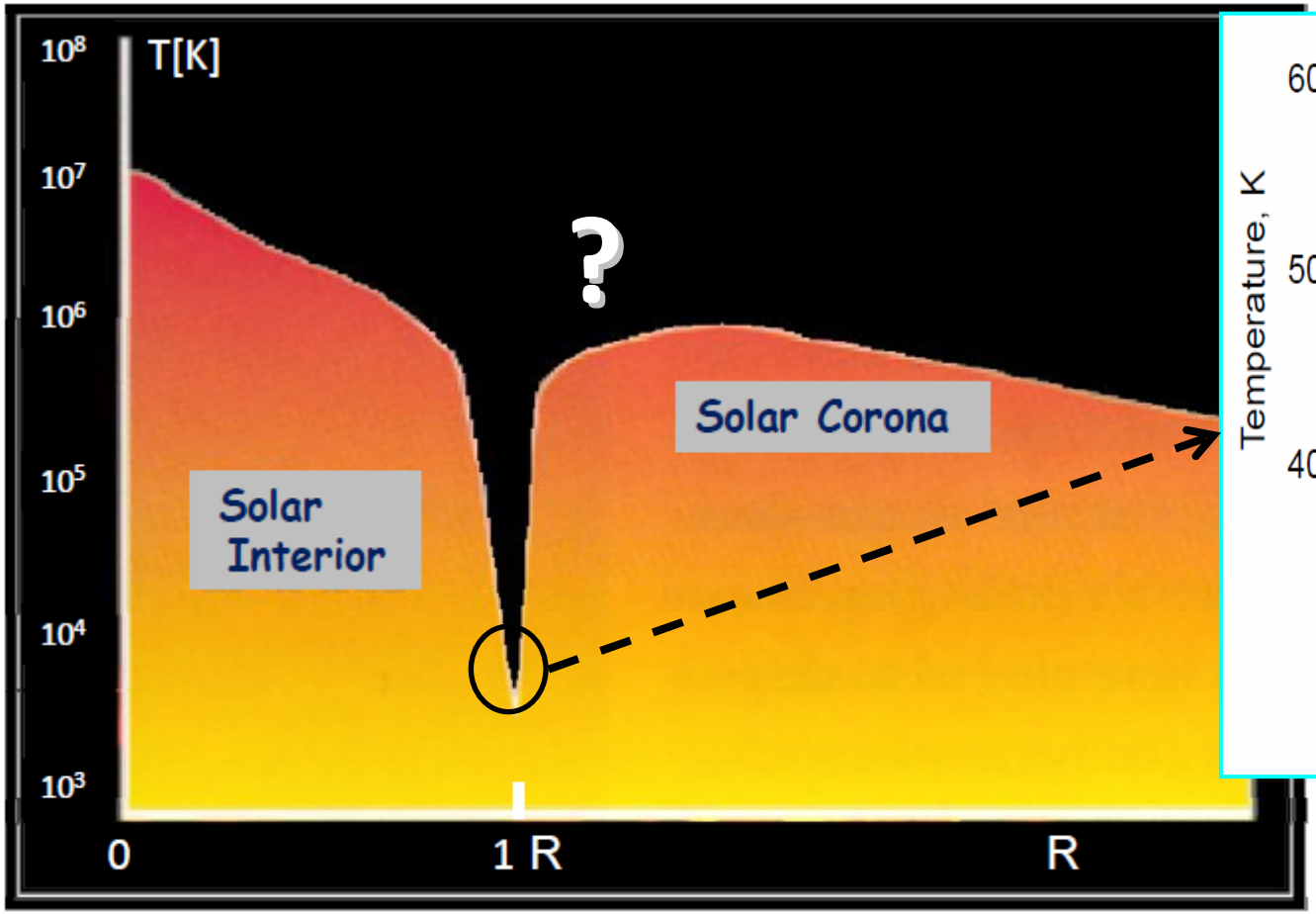
J.M. McTiernan, ApJ. 697 (**2009**) 94

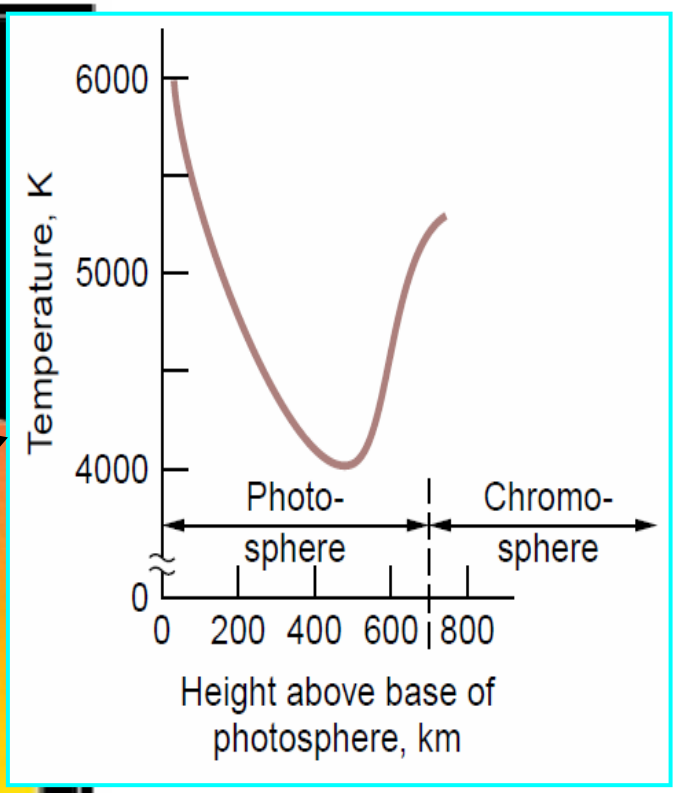
http://www.iop.org/EJ/article/0004-637X/697/1/94/apj_697_1_94.pdf?request-id=3d4e2922-b50e-44ea-a70f-8e8aa6d73f3d

It is remarkable + fascinating that the Sun emits intense X-rays ... it still remains a mystery .

S.Tsuneta, AAPPS Bulletin, 19(#3) (**June 2009**) 11
http://www.cospa.ntu.edu.tw/aappsbulletin/data/19-3/11Hinode.pdf

The solar atmosphere





The chromosphere remains the least understood layer of the solar atmosphere

MA Loukitcheva, SK Solanki, S White, Science with the **ALMA** (2008) 197
http://www.springerlink.com/content/p54r220375p6504w/

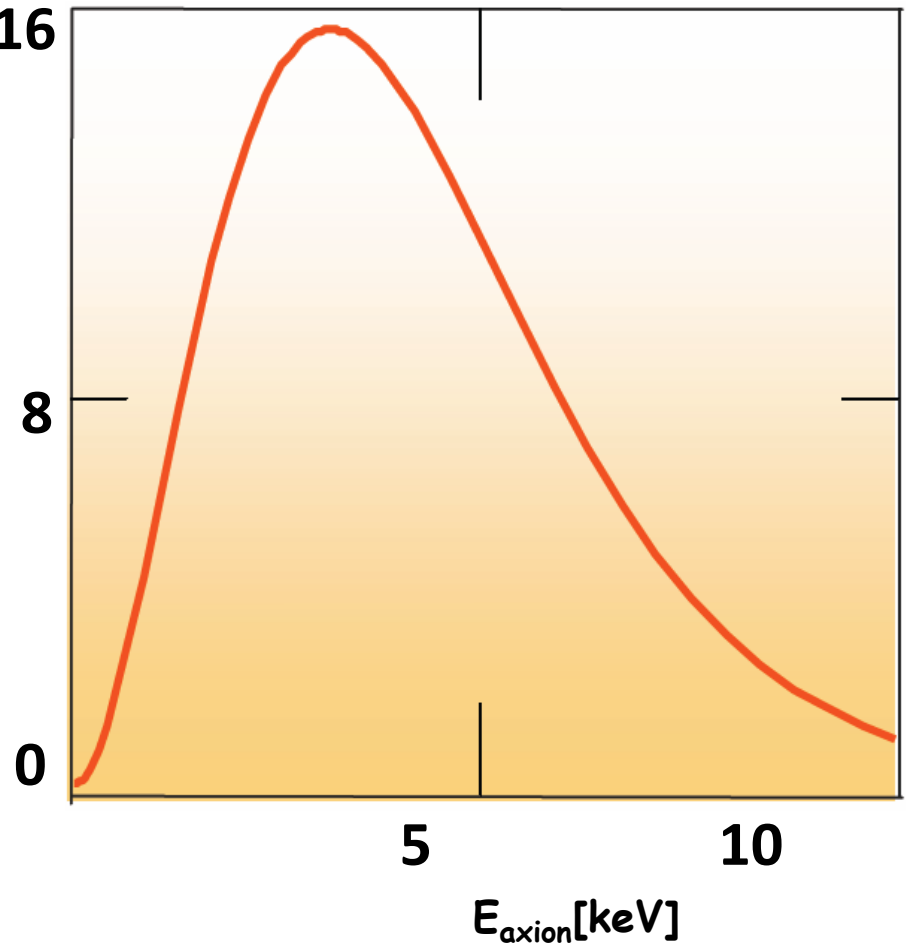
Mystery ⇔ unknown physics

~axions, if solar activity ...

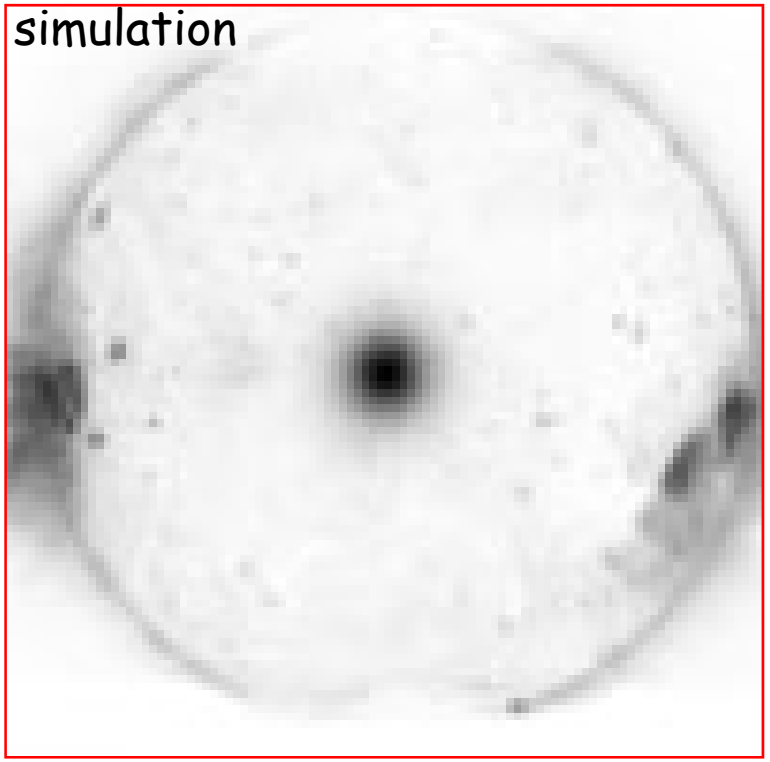
- ⊗ B
- ⊗ B^2 → excess / deficit
- ⊗ ρ_{plasma}
- Spectral shape
- spatial distribution

.... expected ➔

Solar Axion spectrum



Spatial distribution



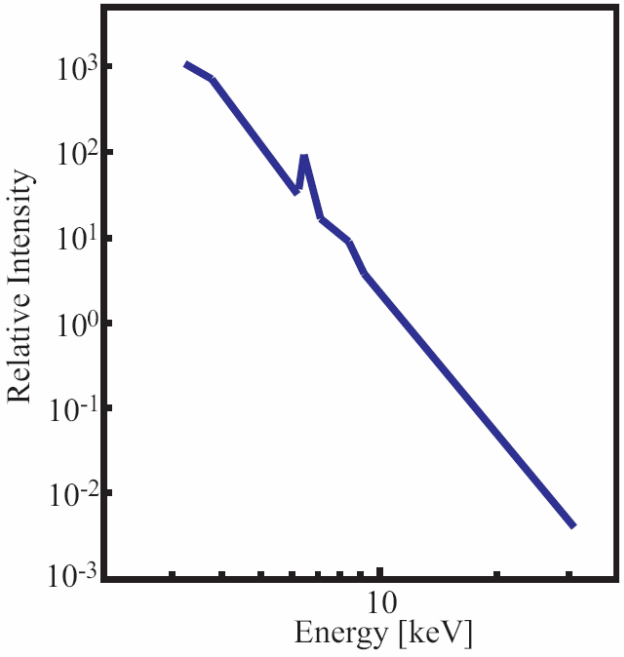
RHESSI science nugget, H. Hudson (2007)

➔ $m_a \ll 10^{-4}\,eV/c^2$

K. van Bibber, http://www-astro-theory.fnal.gov/events/080201presentation.pdf

.... observed ➔

Typical spectral shape

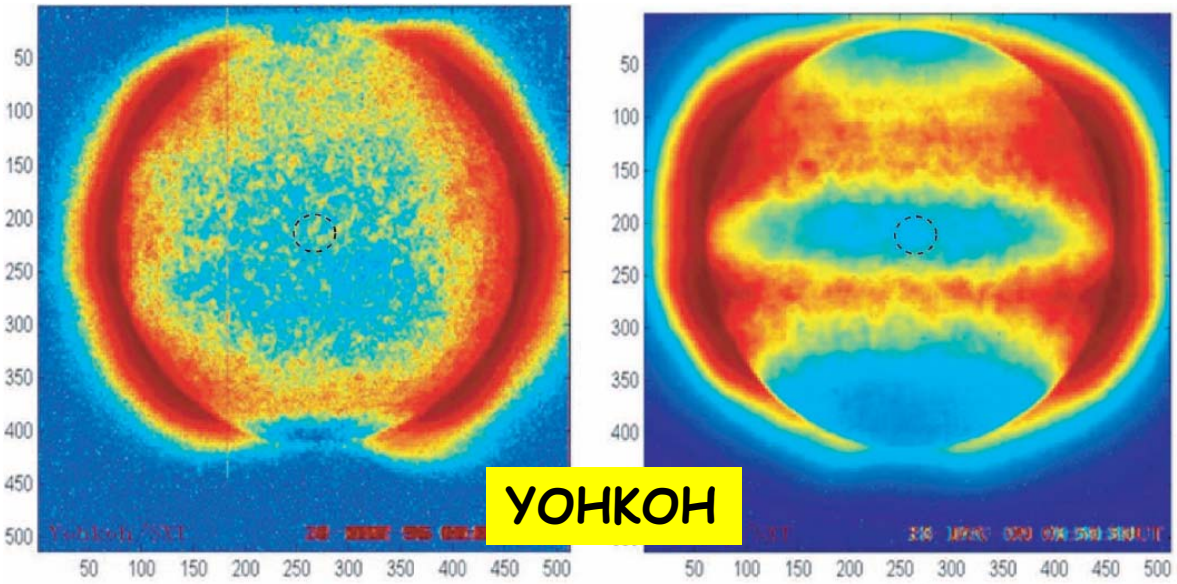


Spatial distribution

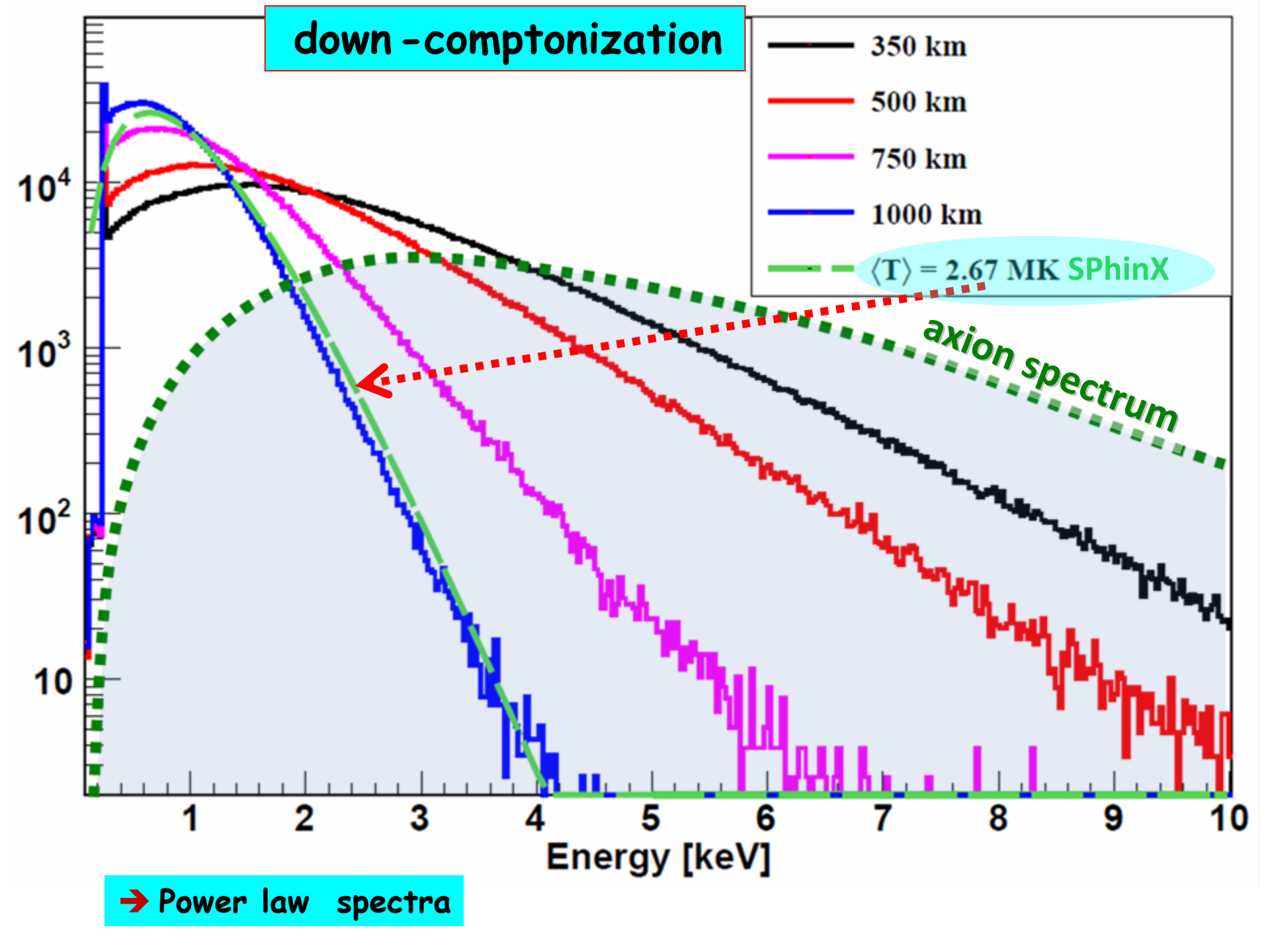
$E_\gamma \approx 0.3 - 4$ keV

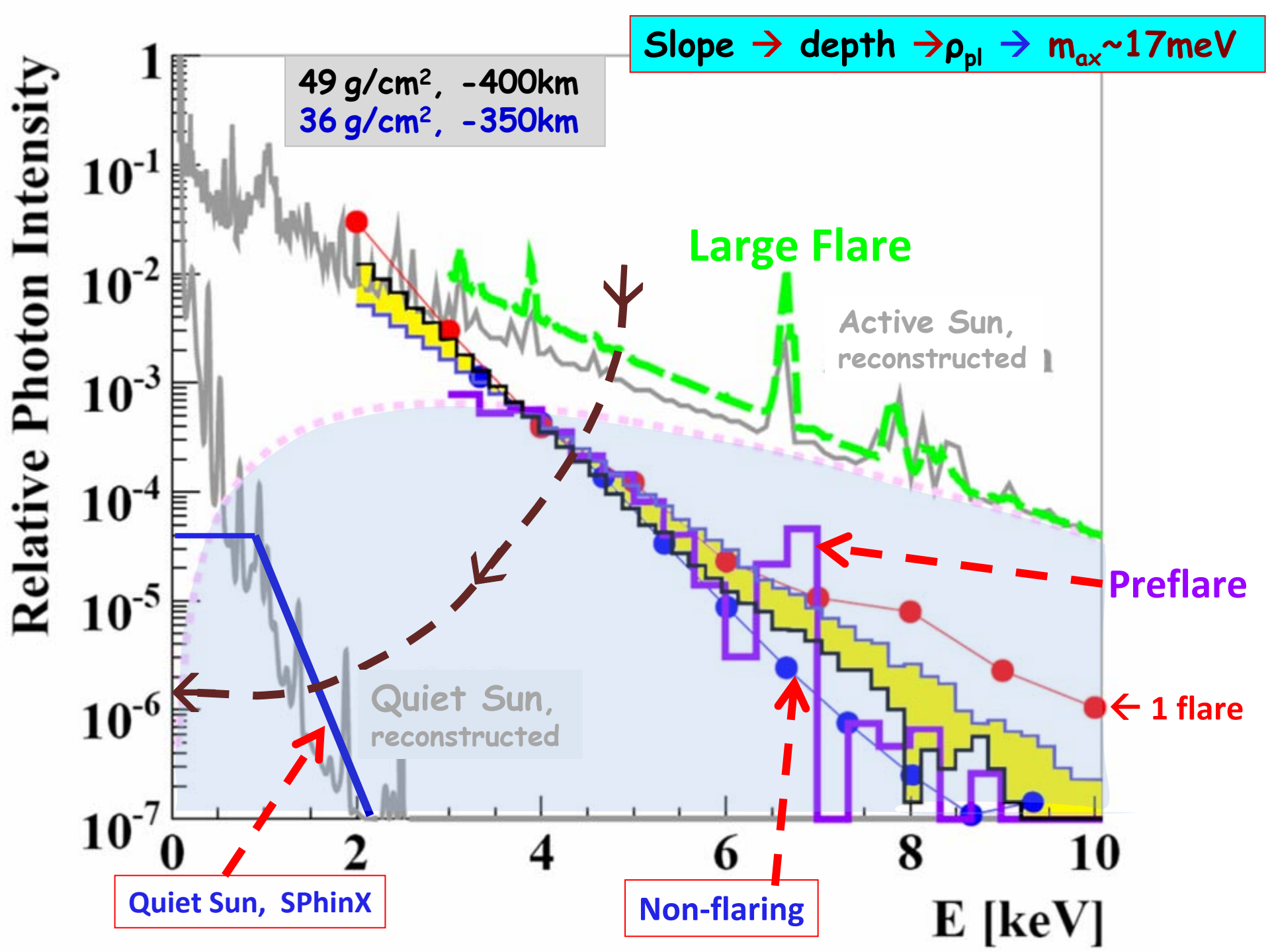
solar minimum

solar maximum

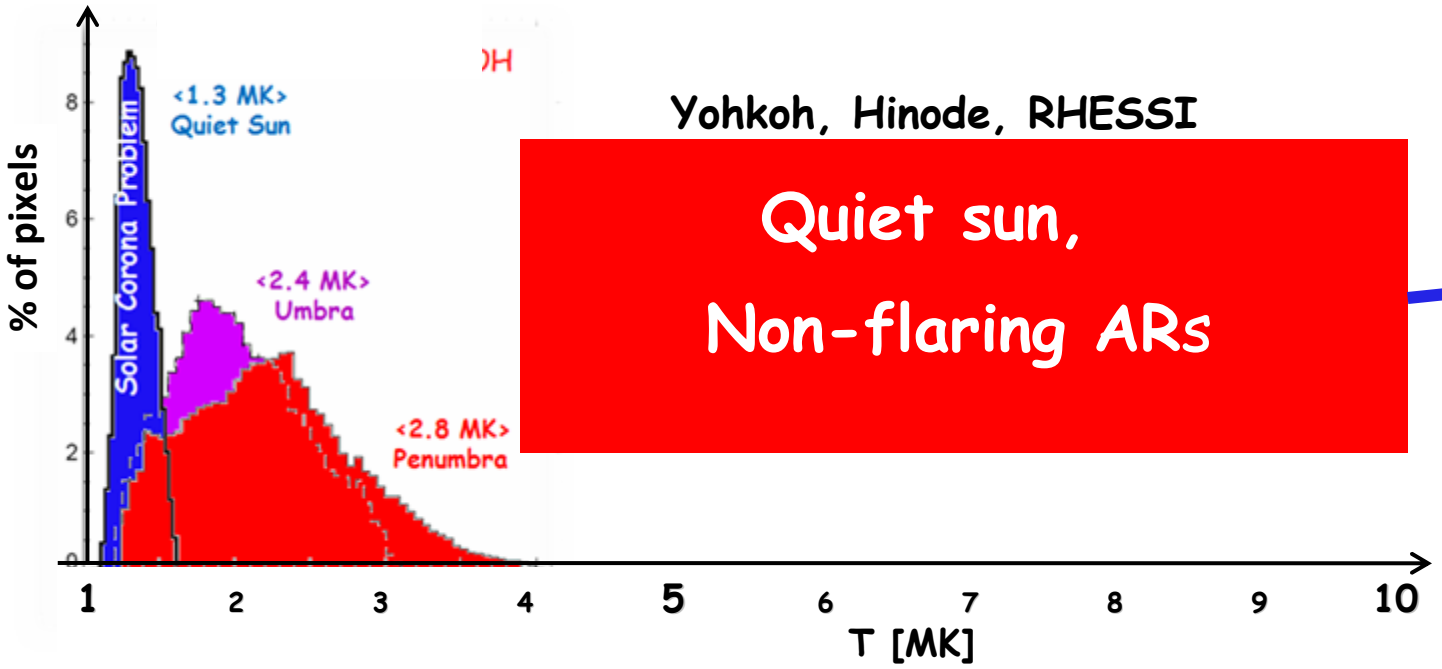


➔ Can be reconciled for $m_a \gtrsim$ few 10^{-3} eV/c^2


down -comptonization
350 km
500 km
750 km
1000 km
⟨T⟩ = 2.67 MK SPhinX
axion spectrum
10^4
10^3
10^2
10
1
2
3
4
5
6
7
8
9
10
Energy [keV]
Power law spectra


Slope → depth → ρ_{pl} → m_{ax}~17meV
49 g/cm², -400km
36 g/cm², -350km
Large Flare
Active Sun, reconstructed
Preflare
← 1 flare
Quiet Sun, reconstructed
Quiet Sun, SPhinX
Non-flaring
Relative Photon Intensity
E [keV]
1
10-1
10-2
10-3
10-4
10-5
10-6
10-7
0
2
4
6
8
10

Temperature distributions



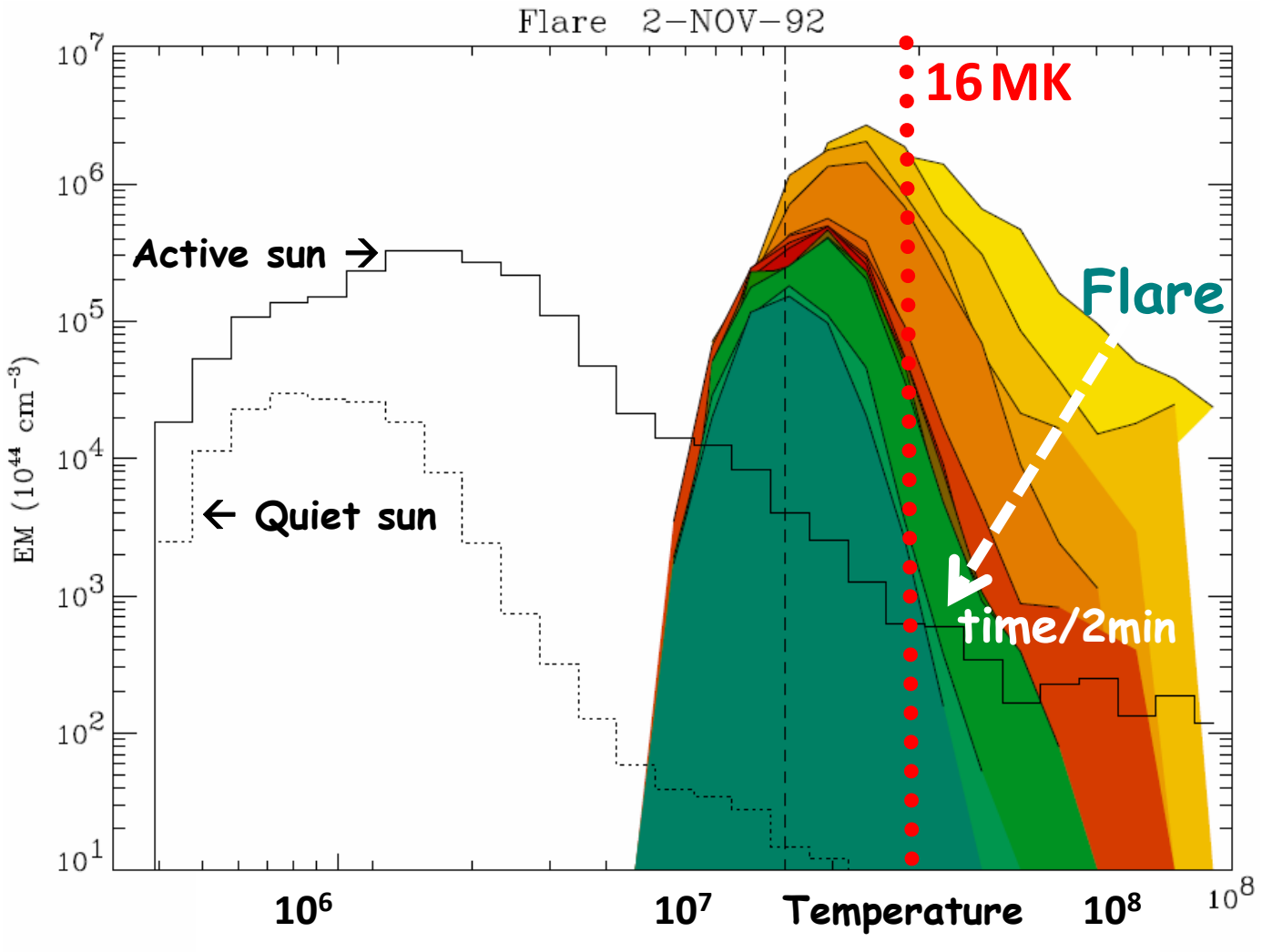
Yohkoh, Hinode, RHESSI

Quiet sun,

Non-flaring ARs

→ T_{flares}!?

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



S Orlando, G Peres, F Reale, Adv.SpaceRes. 32 (**2003**) 955

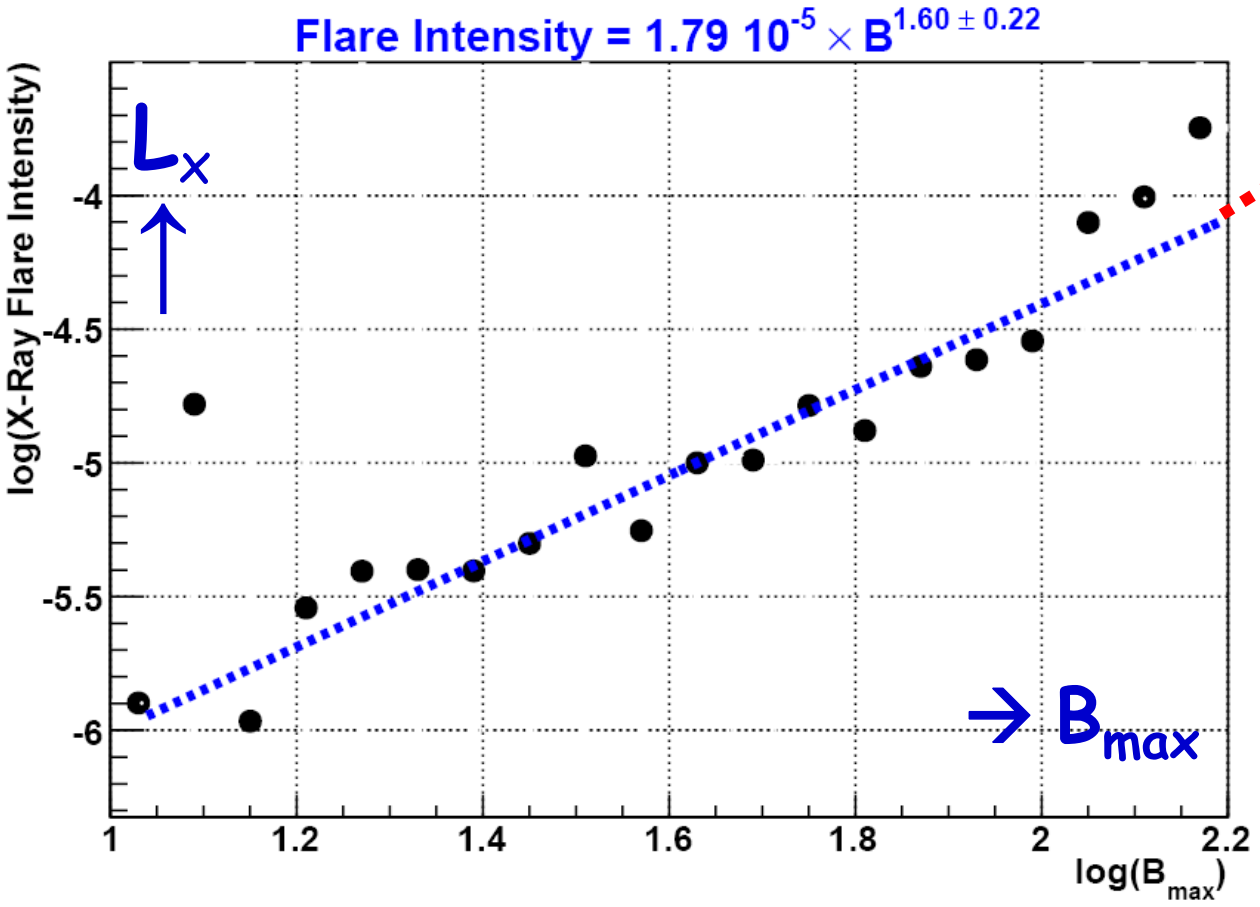
- **Biggest mystery: the flare 'trigger'**

P. Chamberlin – Solar Flares - REU June 12, **2007**

- **The luminosity of a flare originates predominantly in the chromosphere.**

H. Hudson, http://sprg.ssl.berkeley.edu/~hhudson/presentations/fairbanks.070320/

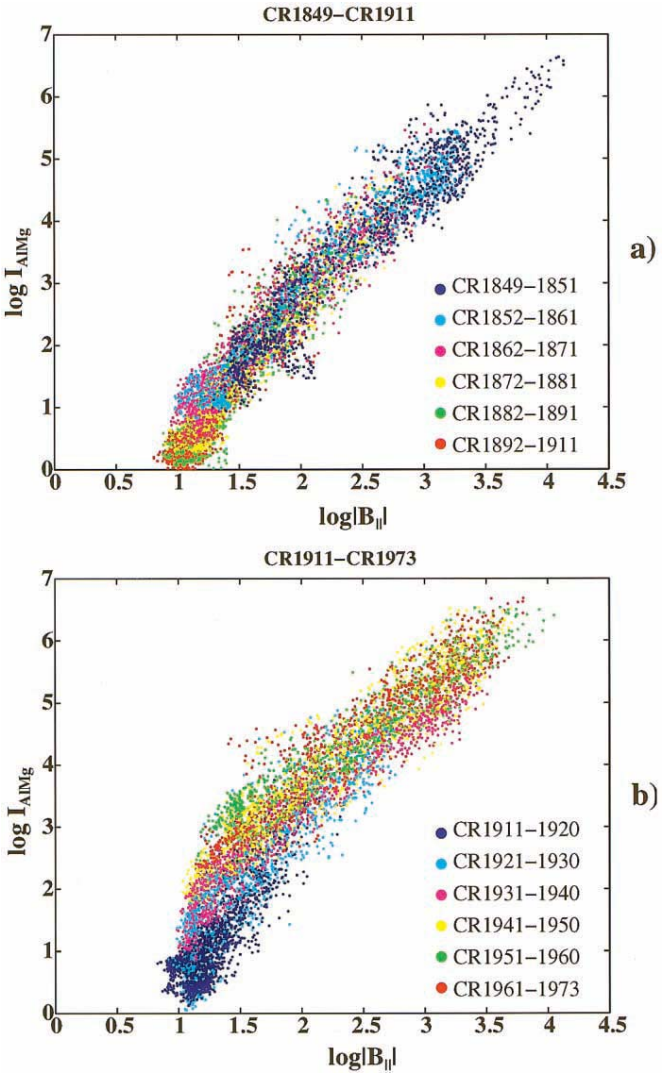
Many flares



B^2 correlation

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

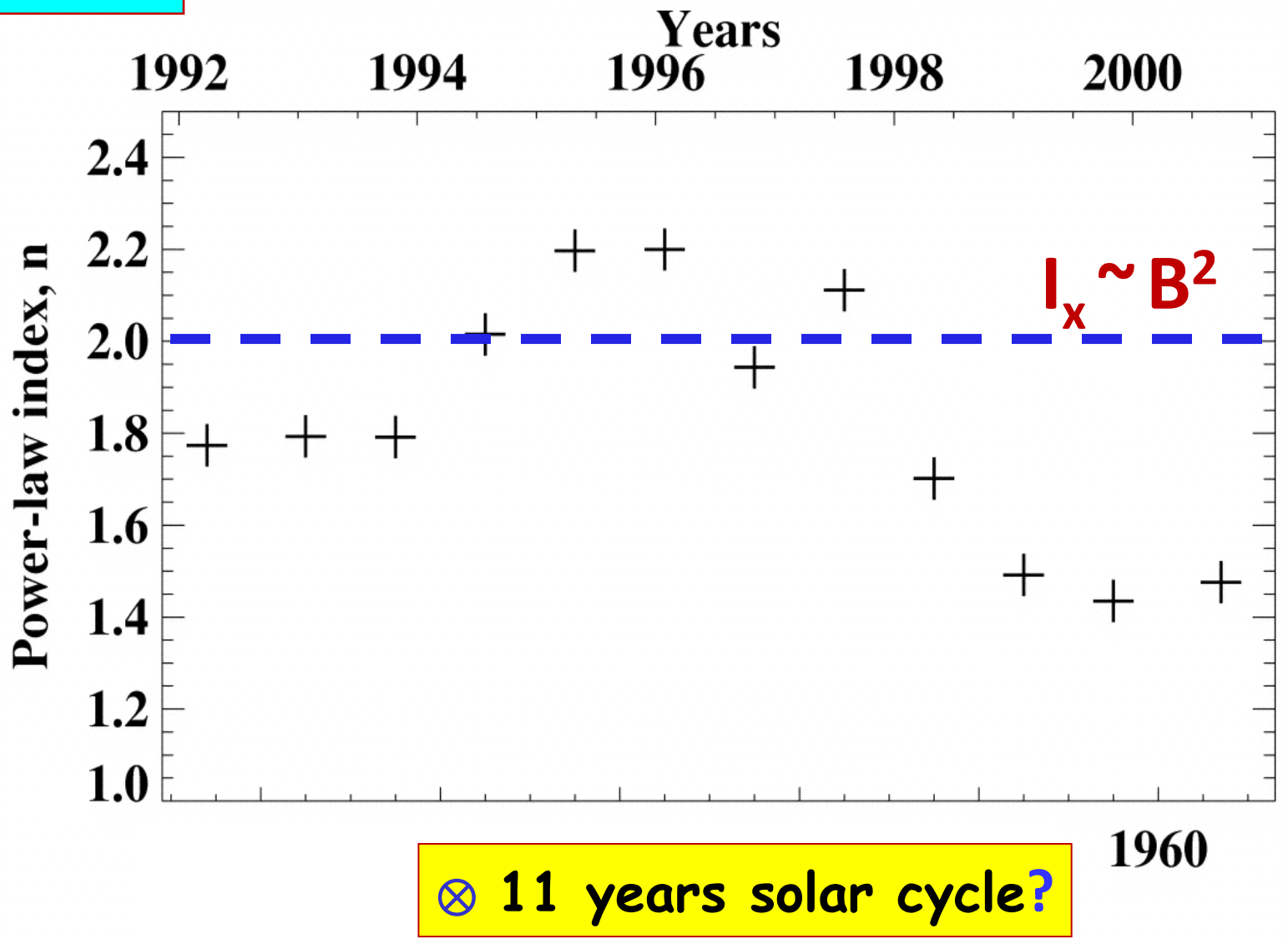
YOHKOH / soft x-rays *vs.* B →



Soft X-ray intensity as a function of B for the latitudinal zone from -55° to 55° : a) 11.11.1991 to 25.7.1996, and b) 28.6.1996 to 13.3.2001.

EE Benevolenskaya, AG Kosovichev, JR Lemen, PH Scherrer, GL Slater, ApJ. 571 (2002) L181
http://iopscience.iop.org/1538-4357/571/2/L181/pdf/1538-4357_571_2_L181.pdf
EE Benevolenskaya, Adv. Space Res. 39 (2007) 1491,

L_x vs. B



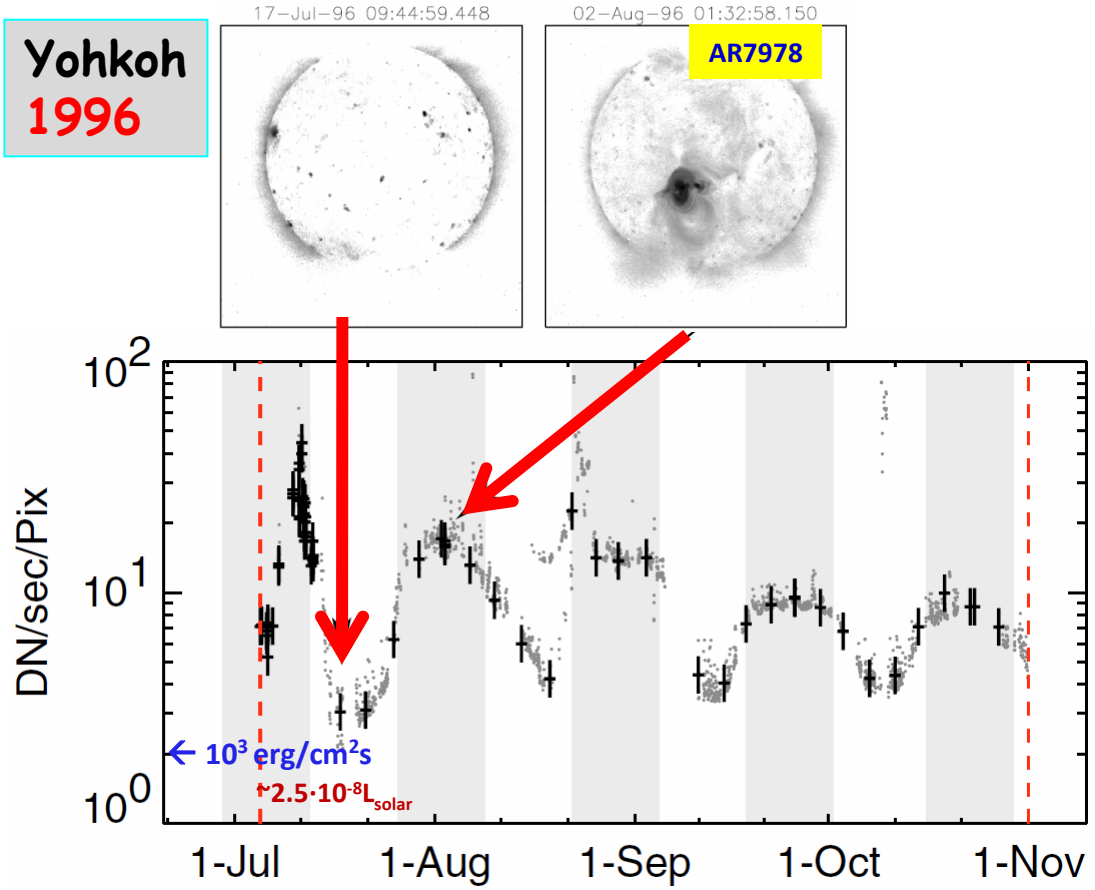
⊗ 11 years solar cycle?

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

EE Benevolenskaya, AG Kosovichev, JR Lemen, PH Scherrer, GL Slater, ApJ. 571 (2002) L181

Active Region evolution, rotational modulation & non-flaring X-ray emission

Yohkoh
1996



1DN ~$1.5 \cdot 10^{19}$erg @ sun
1Pix = $3 \cdot 10^{16}$cm^2

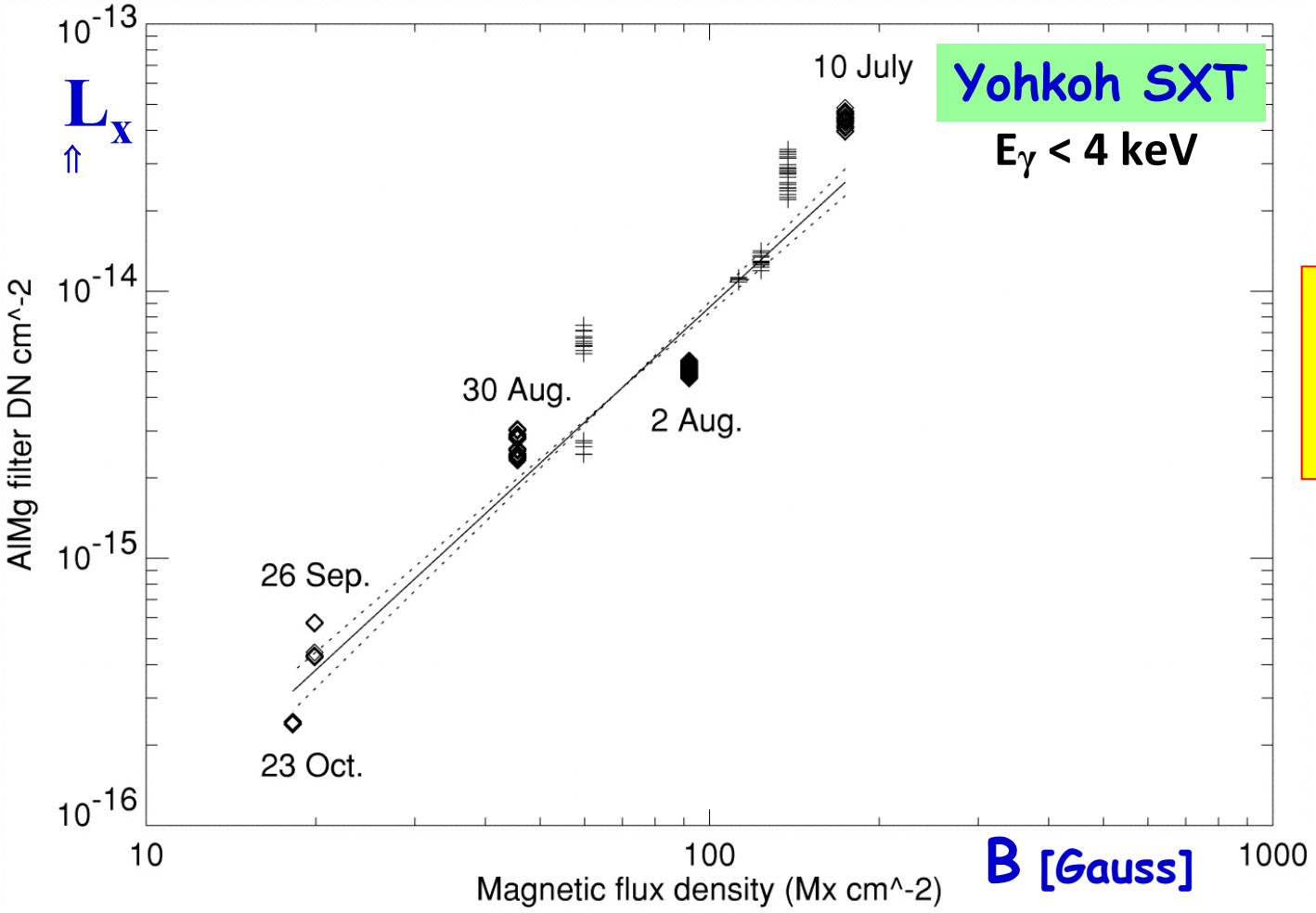
QS$_{min}$:

$L_x \sim 4 \cdot 10^{21}$erg/s~$10^{-12} L_\odot$

AA Pevtsov, *et al.*, ApJ. 598 (2003) 1387
http://www.iop.org/EJ/article/0004-637X/598/2/1387/16398.html

S. Orlando, G. Peres, F. Reale, A&A 424 (2004) 677

The long-term evolution of AR7978 → Non-flaring

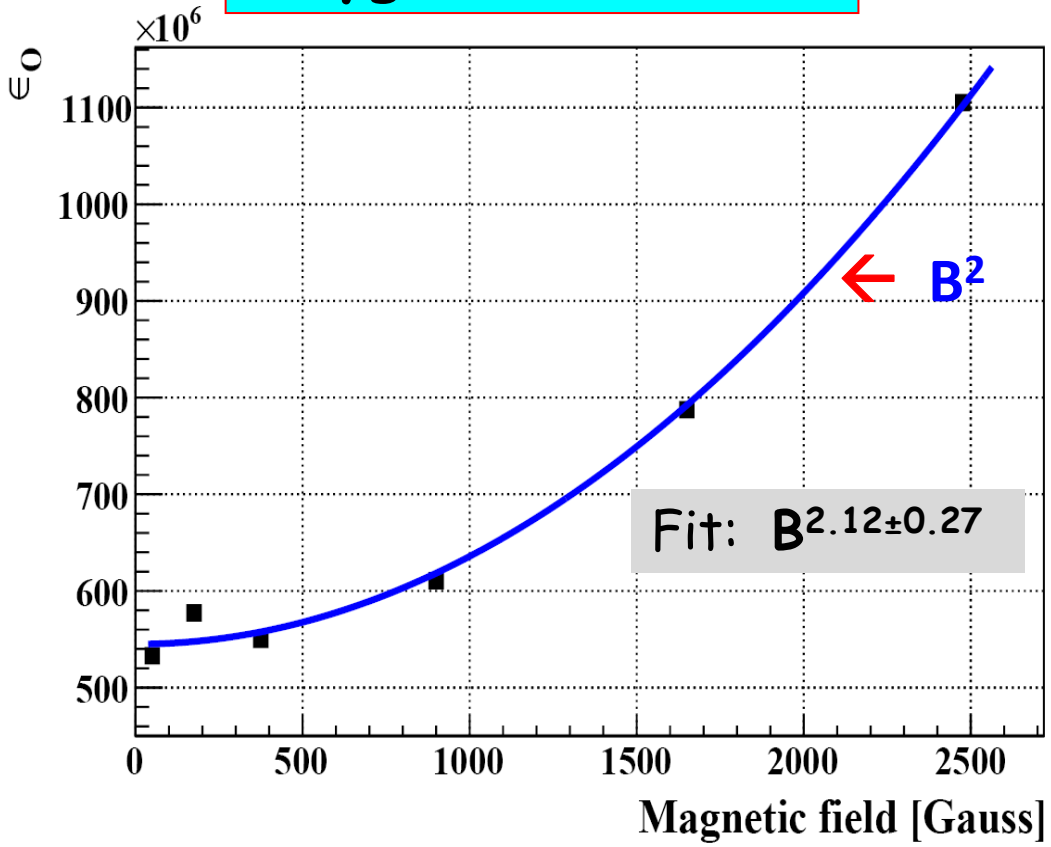


$L_x \propto B^{1.94\pm.12}$

@ ~10^4 erg/cm^{2}s

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

Oxygen abundance



Photoelectric effect @ work?

→ **more photons from?**

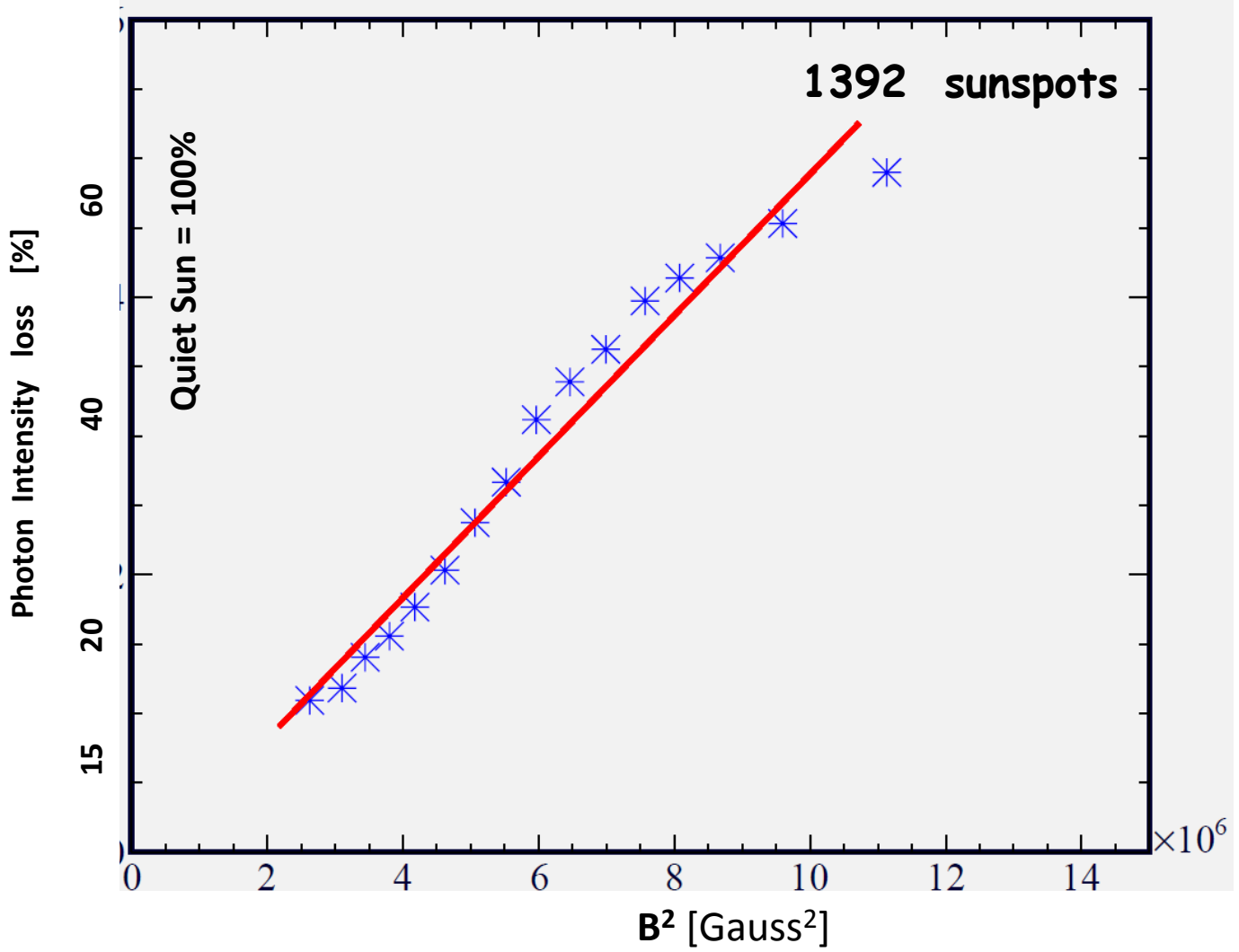
→ **axions, ..?..**

→ **Asymmetric DM**

B → at the base of the photosphere near a **pore**.

H. Socas-Navarro, Private communication.

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



The observed **IR** intensity loss in the darkest position of sunspot umbrae vs. B^2.
A quadratic fit to the data is also shown. Data set observed from **1992** to **2009**.

William Livingston, ***private communication***

W. Livingston , M. Penn, Eos, 90 #30 (**2009**) 257

Light Deficit in sunspots ✓

Photon	⇔	axion
⇩		⇩
many tries (multiple scatterings)		1 try

Disappearance of photons into ~axions :

- $I_{mising} \sim B^2$
- ⇝ 100% ⇢ ½ , 1/3 , ¼
- Dynamic Sun -> disk / limb

➔ source of LES ~axions!?

... more?

→ Sun as DM converter?

→ B + ρ_e

Sun 's external irradiation ($L_{\odot}=3.8\cdot10^{33}$ erg/s:=1)

- CMB ~10^{-14} (~$3\cdot10^{20}$ erg/s ≈ 1 SFU) ✓
- DM ~10^{-8} (~ $4\cdot10^{25}$ erg/s) ✓

  ↛ WIMPs

  → solar ~axions (self-trapping) (→ $B_{\odot}$)

- ↛ **neutrons (1970 → corona heating)**

  Nature 230, 518

- ↛ **gravity waves (1962 → corona heating)**

  ApJ.137(1963) 914

- ↛ **interplanetary matter (1940's)**

  Solar Phys. 7 (1969) 321

Magnetised plasmas @ Sun's atmosphere

→ (relic) ~axion-to-photon conversion?

Flare (kernels)

- $\rho_e \sim 10^{14}/cm^3$ → $\omega_{pl} \sim 3 \cdot 10^{-4} eV \sim 100 GHz$ -> 3mm

Spicules (~1% surface)

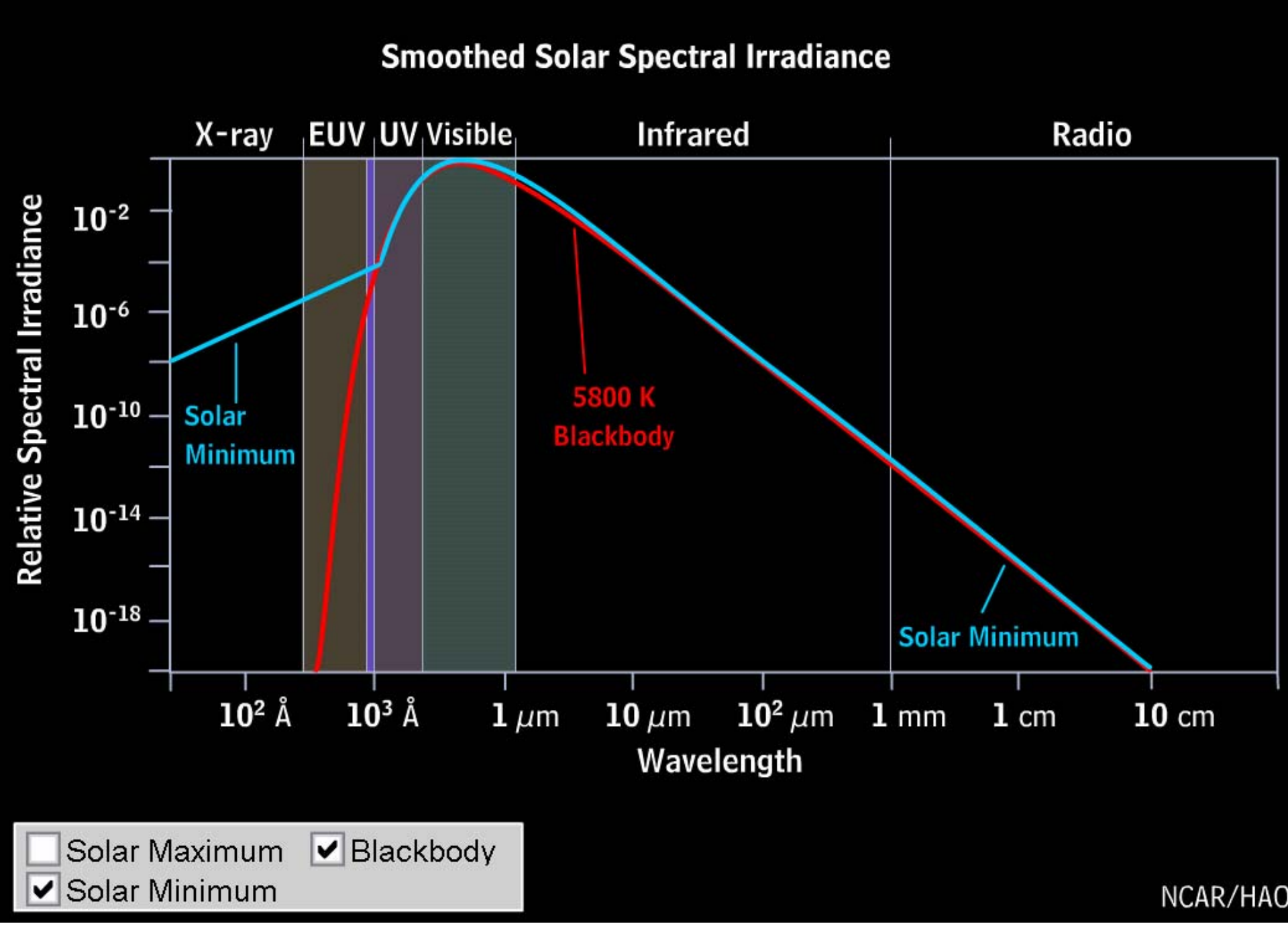
- $\rho_e \sim 10^{12}/cm^3$ → $\omega_{pl} \sim 3 \cdot 10^{-5} eV \sim 10 GHz$ -> 30mm

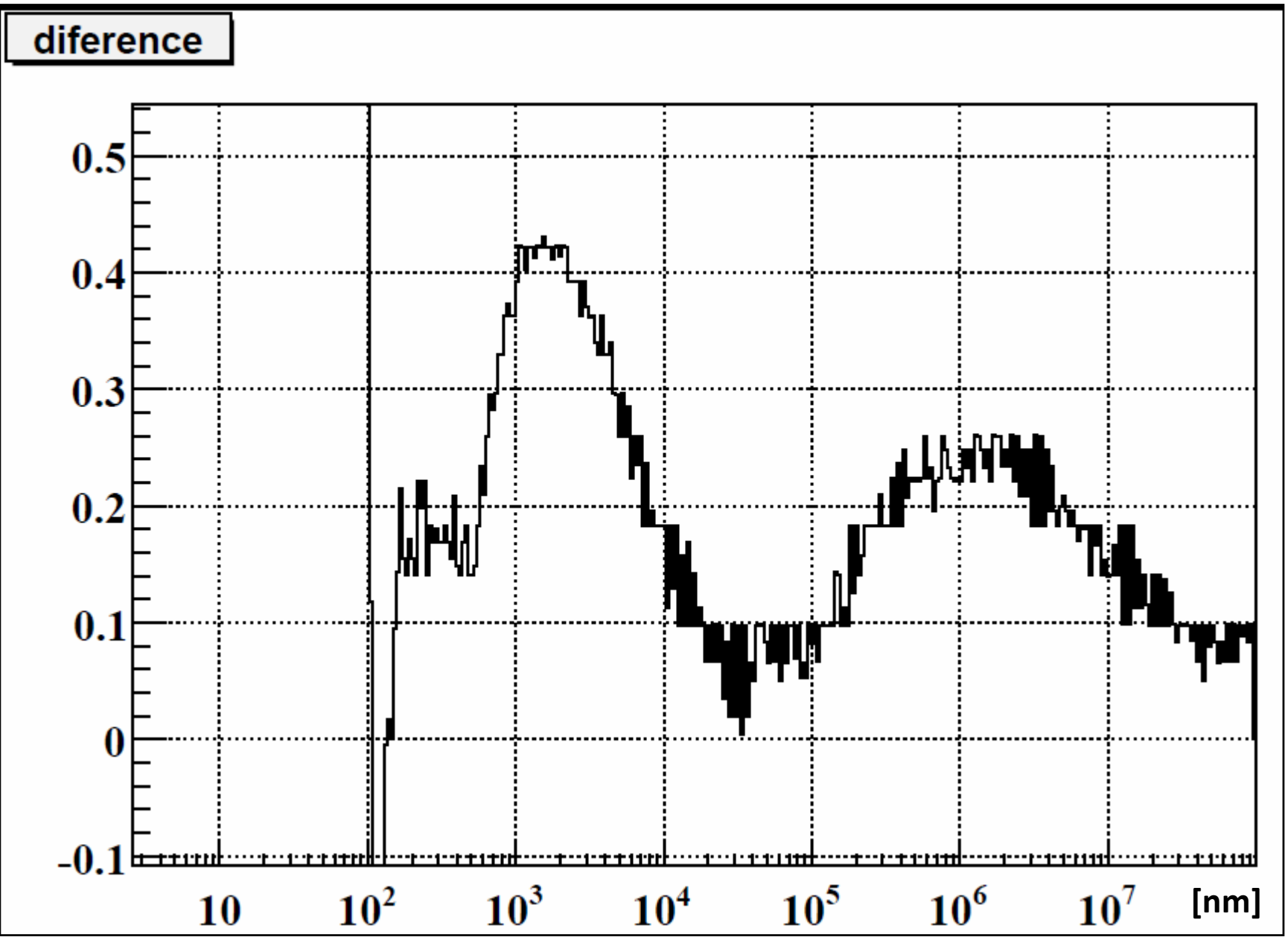
(>10x ρ_e-environment)

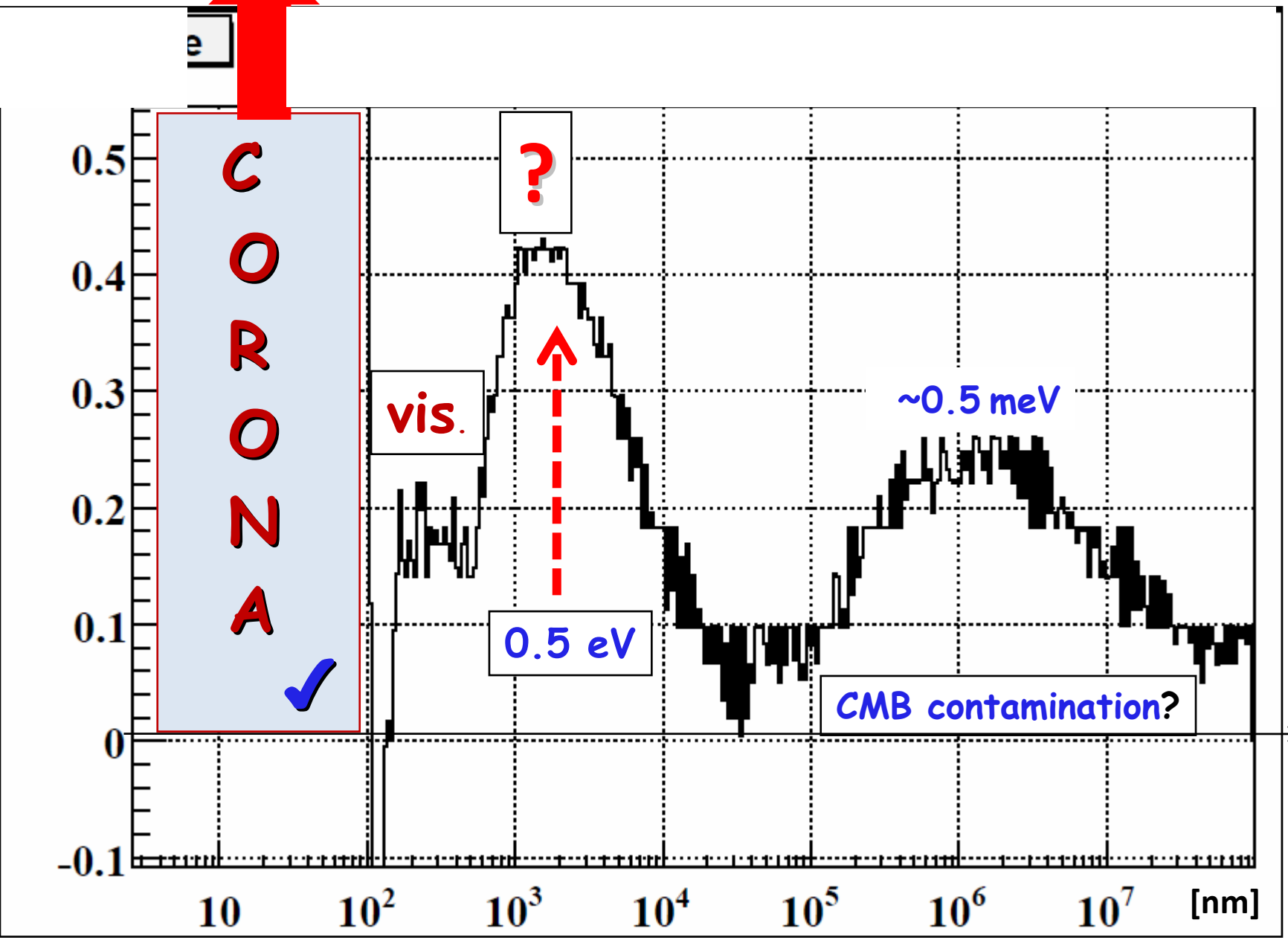
...?more places?...

→ a rest mass region not easily accessible yet!

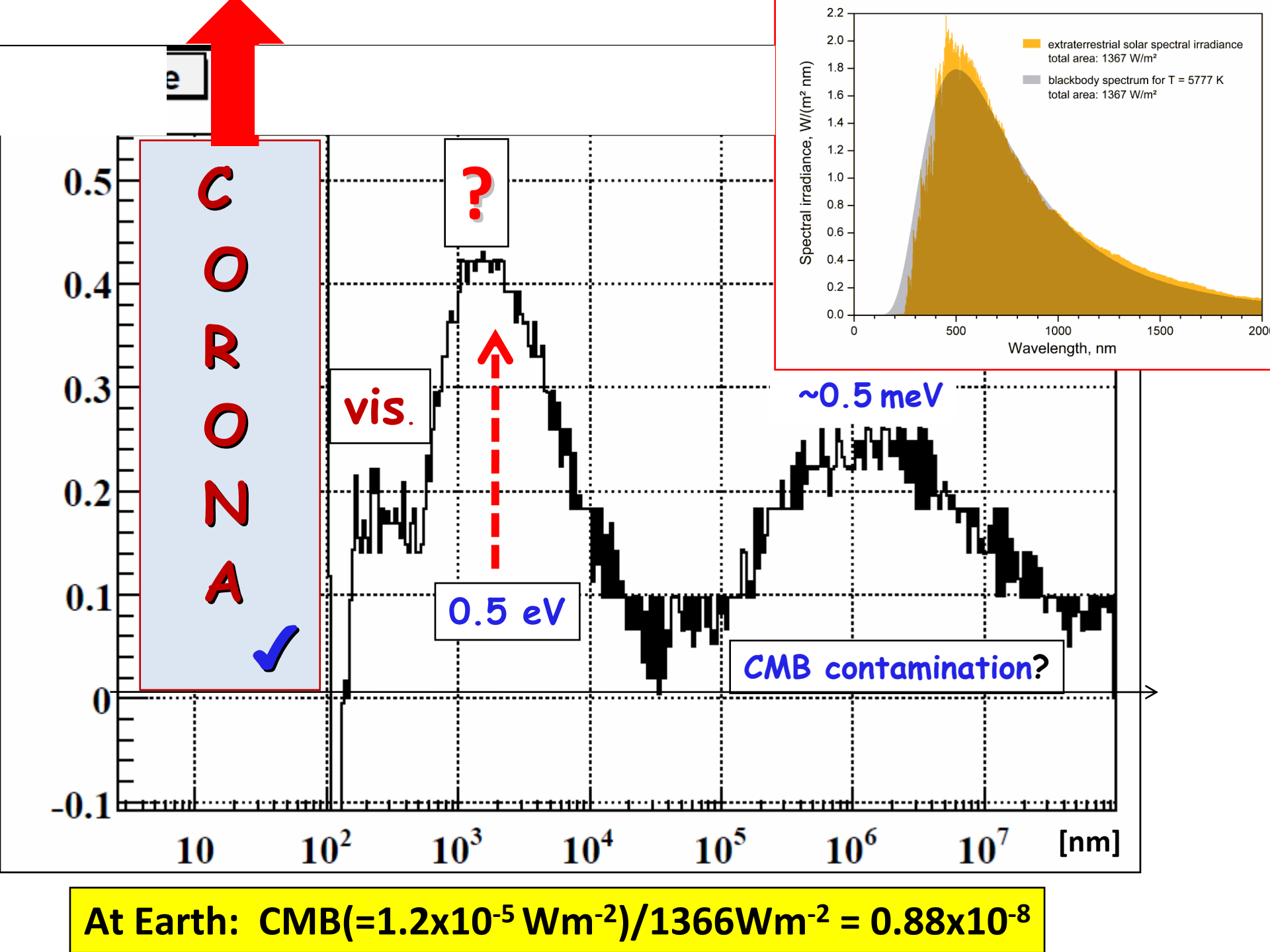
Spectrum?


Smoothed Solar Spectral Irradiance
X-ray
EUV
UV
Visible
Infrared
Radio
Relative Spectral Irradiance
10-2
10-6
10-10
10-14
10-18
Solar Minimum
5800 K Blackbody
Solar Minimum
10² Å
10³ Å
1 μm
10 μm
10² μm
1 mm
1 cm
10 cm
Wavelength
Solar Maximum
Blackbody
Solar Minimum
NCAR/HAO


diference
0.5
0.4
0.3
0.2
0.1
0
-0.1
10
10^2
10^3
10^4
10^5
10^6
10^7
[nm]



At Earth: CMB(=1.2×10^{-5} Wm^{-2})/1366Wm^{-2} = 0.88×10^{-8}



At Earth: CMB(=1.2×10^{-5} Wm^{-2})/$1366 Wm^{-2}$ = 0.88×10^{-8}

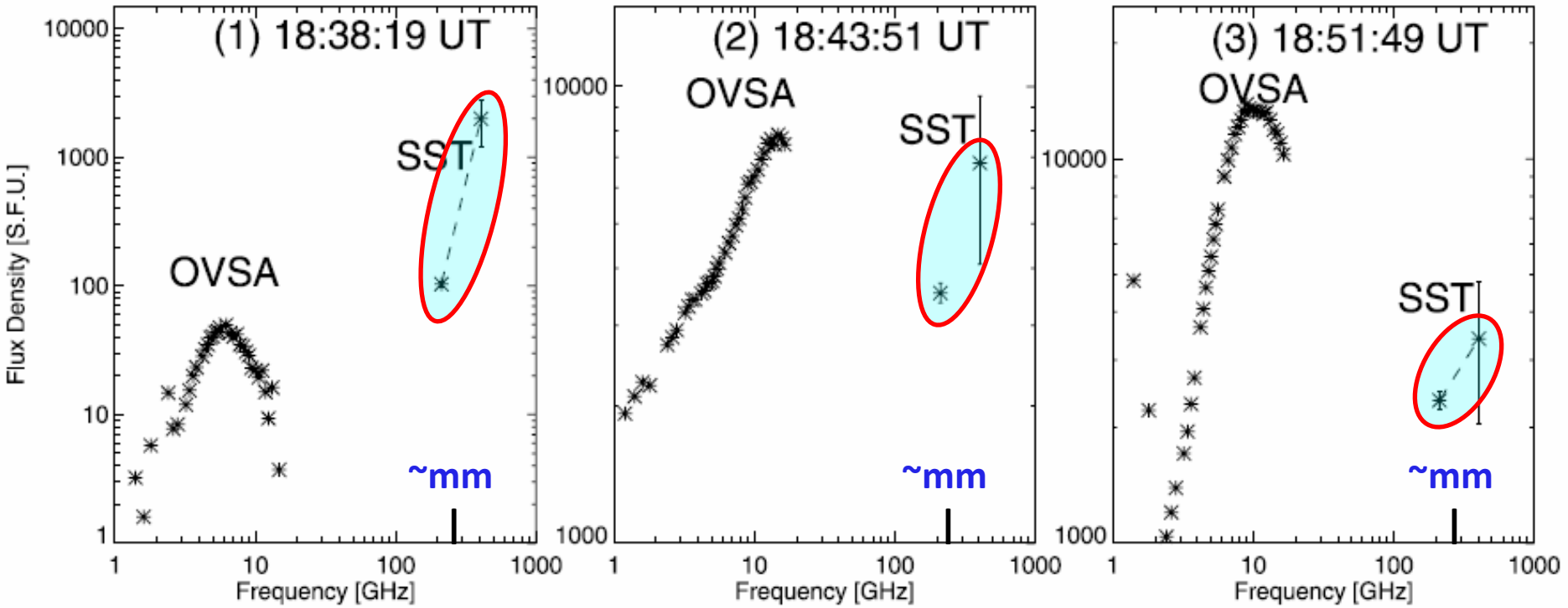


Figure 2 Complete burst spectra, from decimeter to submillimeter waves, for the burst times 1 – 3 labeled at the top of Figure 1. Bars refer to an arbitrary uncertainty assumption of 10% changes in the optical depths. The presence of the sub-THz component is particularly well defined for the precursor-like structure, the impulsive phase, and suggested for the following phase.
http://www.springerlink.com/content/d2108r07101815lx/fulltext.pdf

10^{-3}eV ... under investigation!

→ **BIMA**, **ALMA** (2011), ... solar ~*mm*-range missions

The nature of the flare THz-rays component is **mysterious**... difficult to reconcile using current models.

P. Kaufmann, et al., http://rp.iszf.irk.ru/hawk/URSI2005/pdf/J05.4(0308).pdf

GD Fleishman, EP Kontar, ApJ. 709 (2010) L127

Focus on paradoxes ...

Frank Wilczek

… focus on the Sun.