Solar flares (+ more) as harbinger of new physics

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Collaboration with:
V. Anastassopoulos, T. Dafni, A. Gardikiotis, E. Georgiopoulou, T. Papaevangelou , Y. Semertzidis, M. Tsagri,...

Profitted from: **CAST** , P. Brax, E. Georgoulis, K. Galsgaard, A. Lindner, A. Vourlidas, ...

1939- The mysterious solar corona **22/06/2011** update

- **Coronal heating … unsolved problem …**

+

… one of **the prominent challenge**s...

- **CAST II @ Sun?** → additional evidence … **this work**

http://xxx.lanl.gov/PS_cache/arxiv/pdf/1106/1106.4270v1.pdf
http://xxx.lanl.gov/ftp/arxiv/papers/1106/1106.4196.pdf

?

CAST II ⟺ **solar physics**

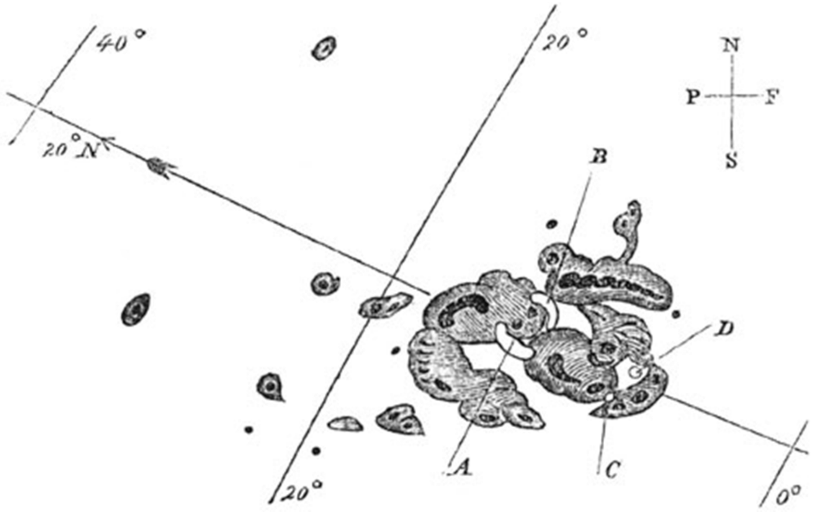
axion signal → $[B_\odot]^2$ + $\rho(m_{ax})$ + ℓ_{coh} $(\Delta\rho)$ → **excess of photons**

Dynamic Sun

spatiotemporal dependence!! -> **viable flare foreCASTing tools**

+ Chameleons! → **vacuum** (= outer Sun) ***vs.*** **plasma** (sub-surface)

1859 … the first flare!



Sunspots of 1 September 1859 as sketched by Richard Carrington:
"…an appearance … which I believe to be exceedingly rare…"

JC Martinez Oliveros, *et al*., Sol. Phys. 269 (**2011**) 269

→ **Several open Qs remain!**

→ **still unpredictable**

→ the Bremsstrahlung mechanism not applicable: too much energetic e^- s required to explain the visible!

+ non-thermal particles' origin?

L_{WL} ~ 100x L_x ?!

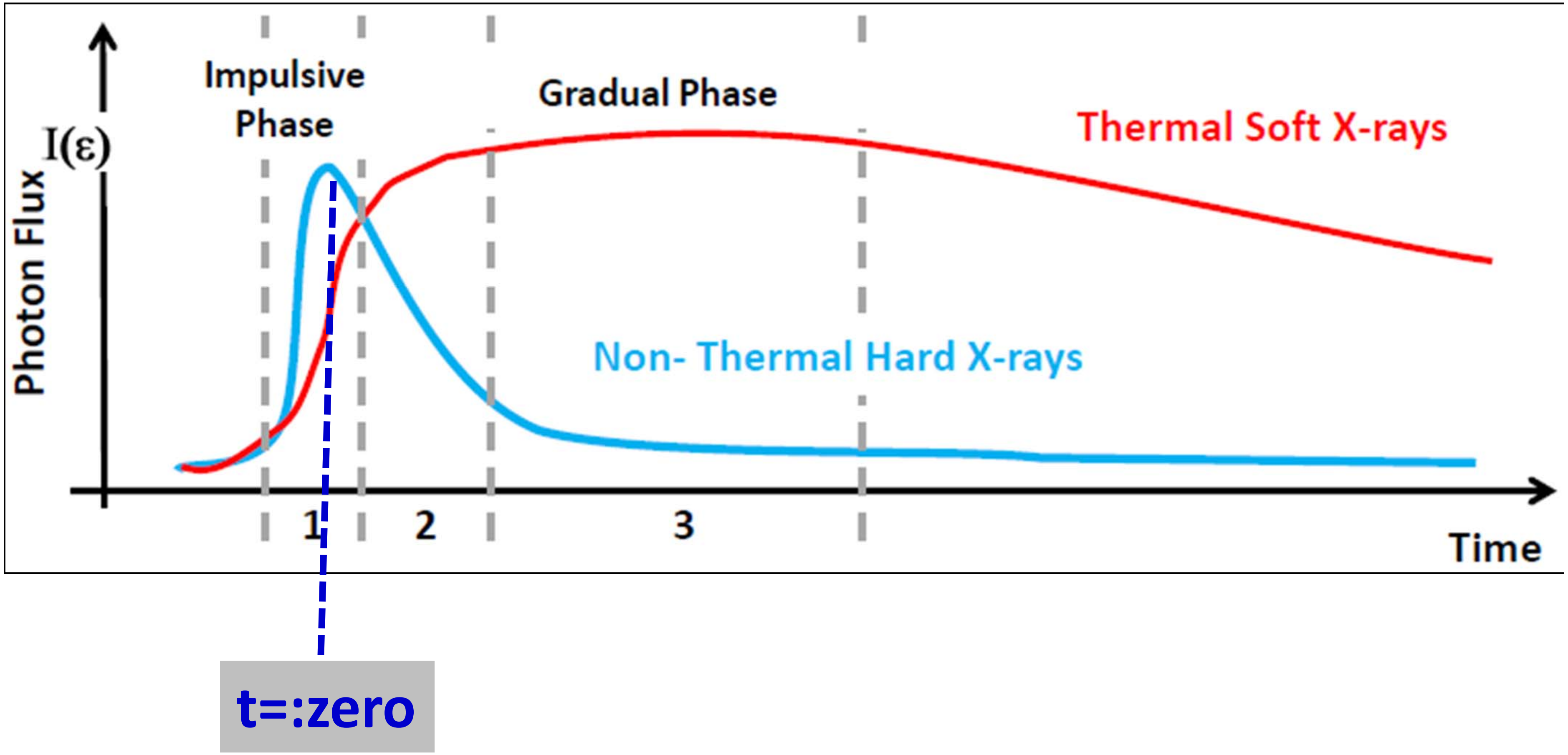
This work: - - - - > L_{WL}

Flare's energy: "must be stored in $B_\odot$"

In the axion/CHameleon approach: **$B_\odot$ → the catalyst**

N. Mittal, U. Narain, Initiation of CMEs: A Review, J. Atm. Sol.-Ter. Phys. 72 (**2010**) 643
http://www.sciencedirect.com/science/article/pii/S1364682610000921

A solar flare:



http://www.astro.gla.ac.uk/solaire/RHESSI_MATERIAL/rhessi_spectra_hannah.pdf

No viable *conventional* flare model yet

-/-> **SM**

1971 -

An outstanding Qs:

- **where**
- **when**
- **how**

electrons are accelerated.

GD Fleishman, EP Kontar, GM Nita, DE Gary, ApJ. 731 (**April 2011**) L19
http://iopscience.iop.org/2041-8205/731/1/L19/fulltext

"... has occupied our best theoretical minds for ~4 decades"
H. Hudson (**2008**)

..solar "reconnection flare" concept is deceptive, … many unknowns.
(HS Hudson, SPD, May **2008**)

what powers / triggers a solar eruption? → **B:** a viable flare foreCASTing tool
M. Kretzschmar, astro-ph/**2011**03.3125

Alfven waves scenario … poses theoretical problems
L. Fletcher, H. Hudson, RHESSI 68th Science Nugget (4th February **2008**)

→ Flares **X** nuclear physics**!?**

CAST @ Sun? Then …

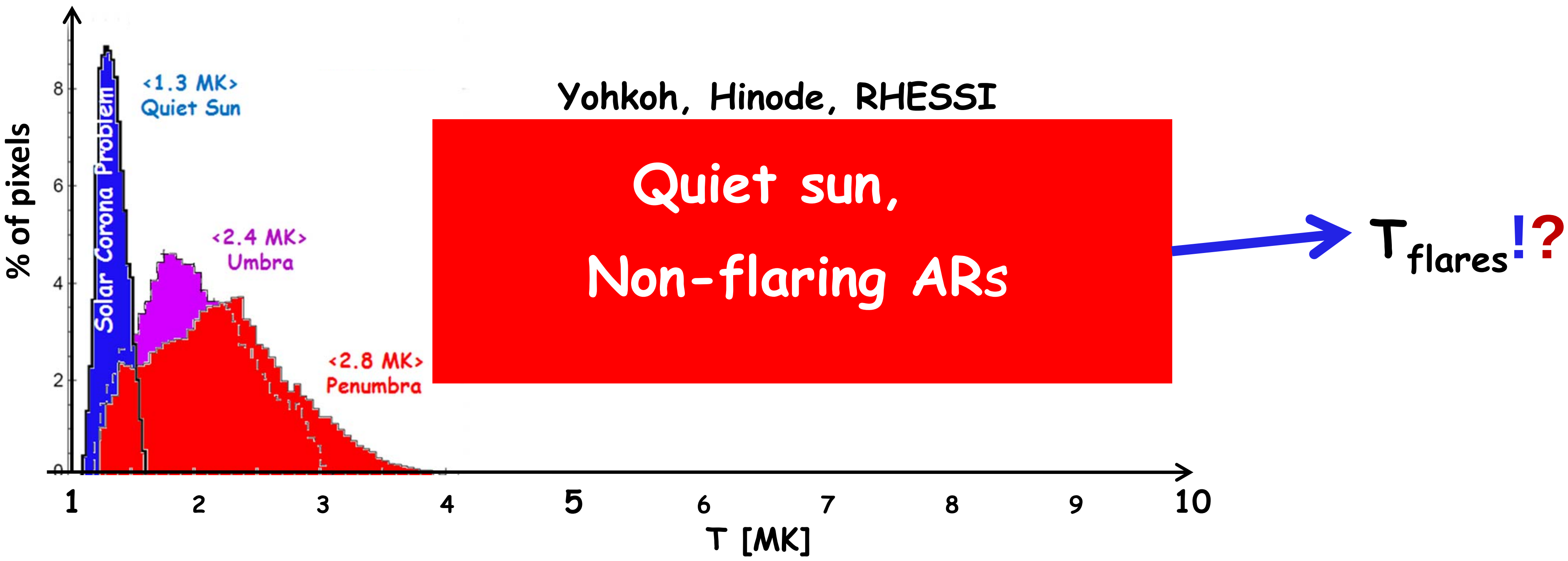
… look above **AR**s → flare's place of birth

- non-flaring / quiet AR corona is hotter:
    - 1 to **~10MK** + spectral shape (power law?)

"Sun's intense X-ray emission: remarkable + fascinating …mystery ".

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

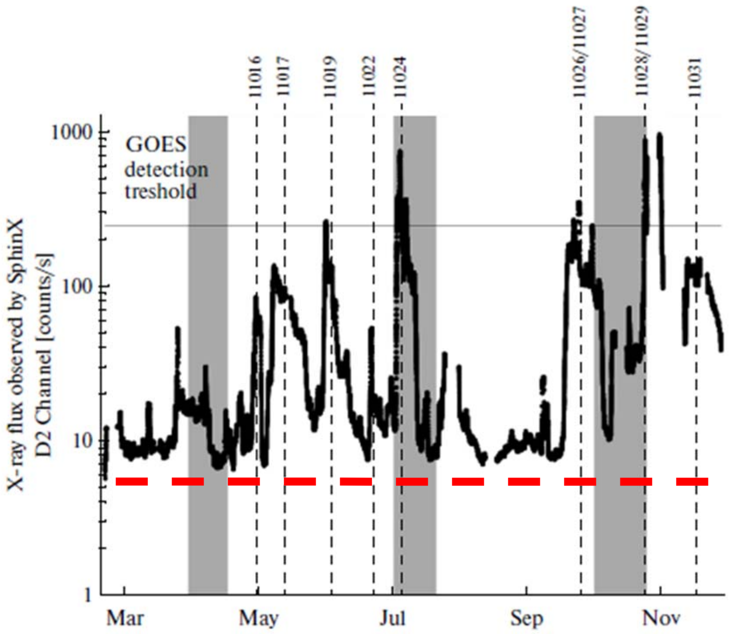
Temperature distributions: QS



Direct measurements →

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

SPHINX light curve with AR numbers



Minimum rate 5-6 cts/s =>

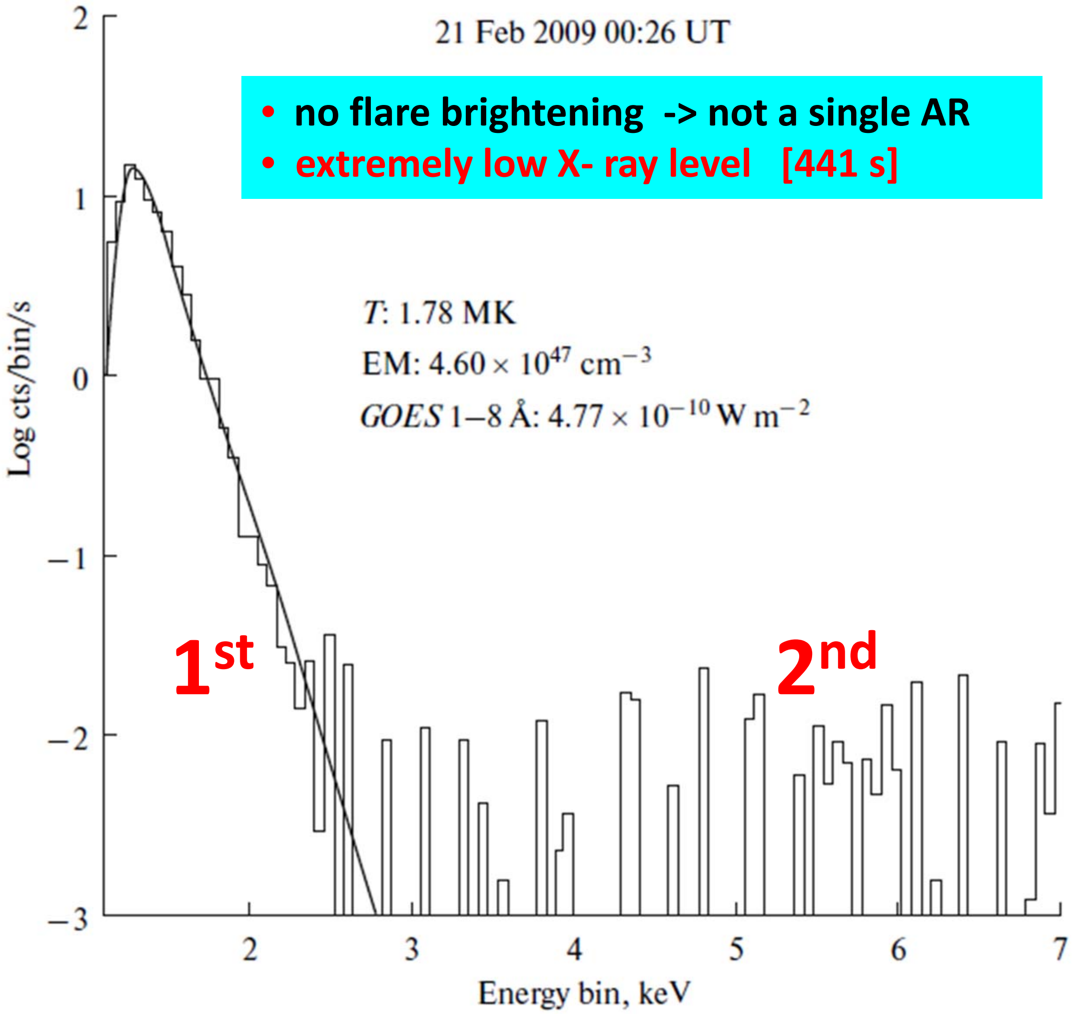
$L^{x}_{>1keV} \approx 6.7 \cdot 10^{20}$ erg/s $\approx 1.5 \cdot 10^{-13} L_{\odot}$

- **Stronger and more variable solar X-ray flux when ARs are present.**
- **there is some minimum -> basal level (~5–6 cts/s)**

  => Previous solar minimum: X-ray level was >100x.

  ➔ $2.5 \cdot 10^{-10}$ W/m² ➔ $L^{x}_{>1keV} \approx 0.67 \cdot 10^{21}$ erg/s $\approx 1.5 \cdot 10^{-13} L_{\odot}$

S. Gburek, et al., Solar System Research, 45 (**2011**)182,
http://www.springerlink.com/content/63471725640h1032/fulltext.pdf [see EOS 91 (2010)73].



Observed, nonactive coronal spectra variability points towards a transient nature over time scale of few minutes.

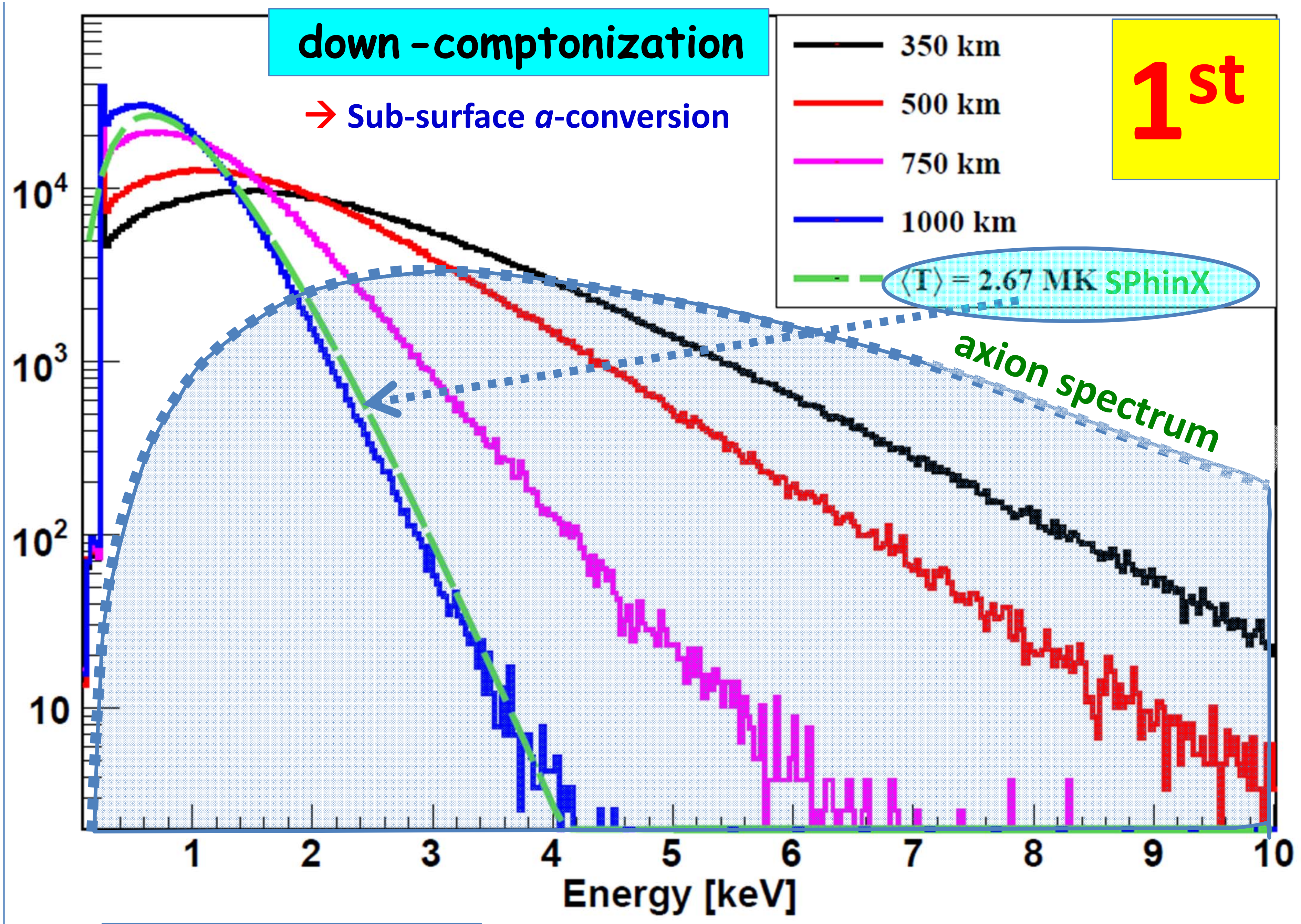
1st light *a*'s /WISPs

2nd massive-*a*'s / **CH**ameleons from solar core?

...**??**..

origin?

S. Gburek, et al., Solar System Research 45 (**2011**)189
http://www.springerlink.com/content/n011j4414n4220n6/fulltext.pdf



→ Power law spectra

2nd

Massive solar KK axions / massive WISPs → 2γ

- gravitationally trapped by the Sun **+** accumulated over ~4.5 Gyears

> " …Unfortunately, such decay x-rays from accumulated relatively short - lived trapped axions create a "ghost plasma" **heating the Sun's** (or other) **real plasma** complicating its interpretation…"

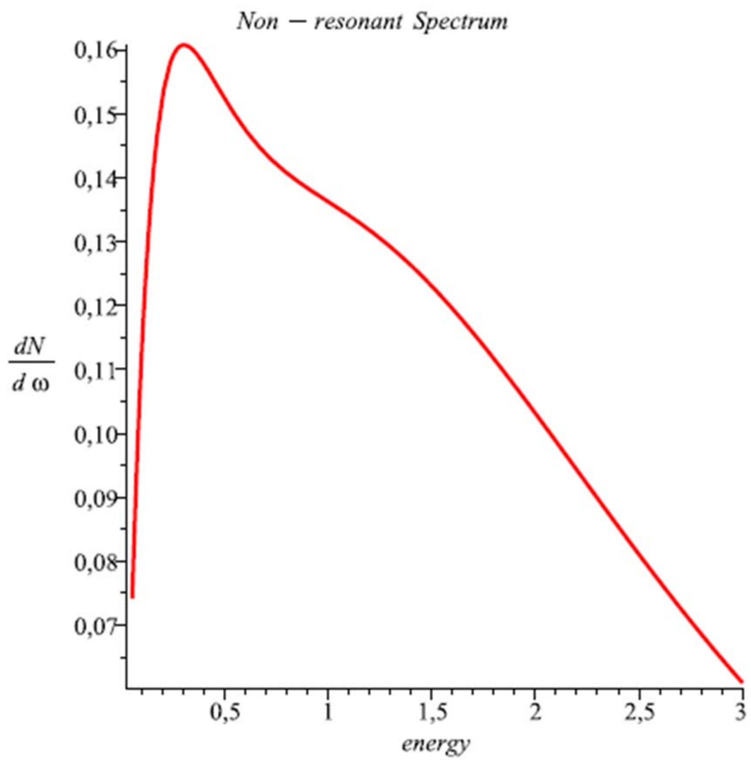
Zioutas, Hoffmann, Dennerl, Papaevangelou, Science 306 (**2004**) 1485

2nd'

CHameleons? … from solar core being converted at the outer $\mathbf{B}_{\odot}$

B configuration?

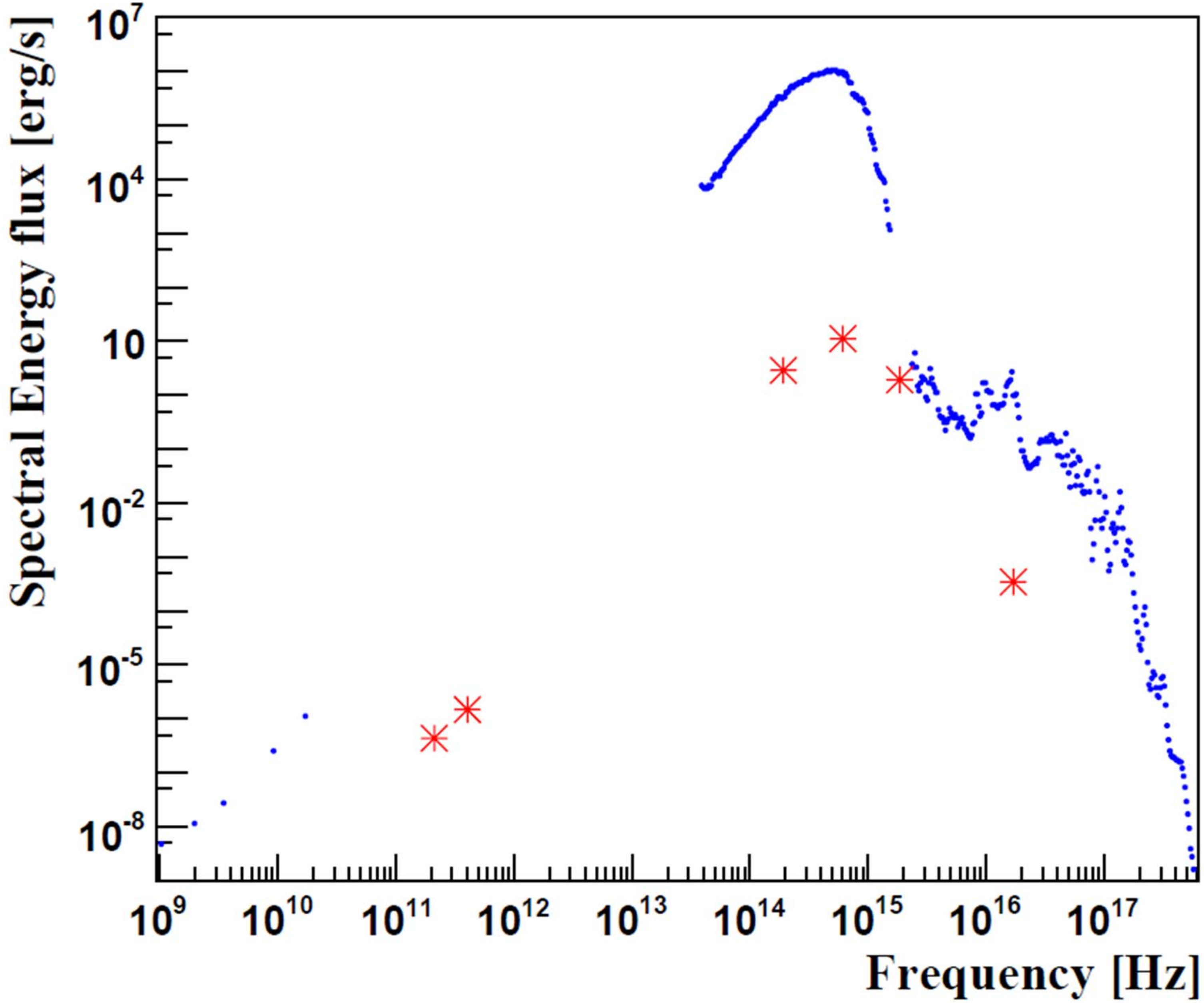
P. Brax, A. Lindner, K. Zioutas (2011)



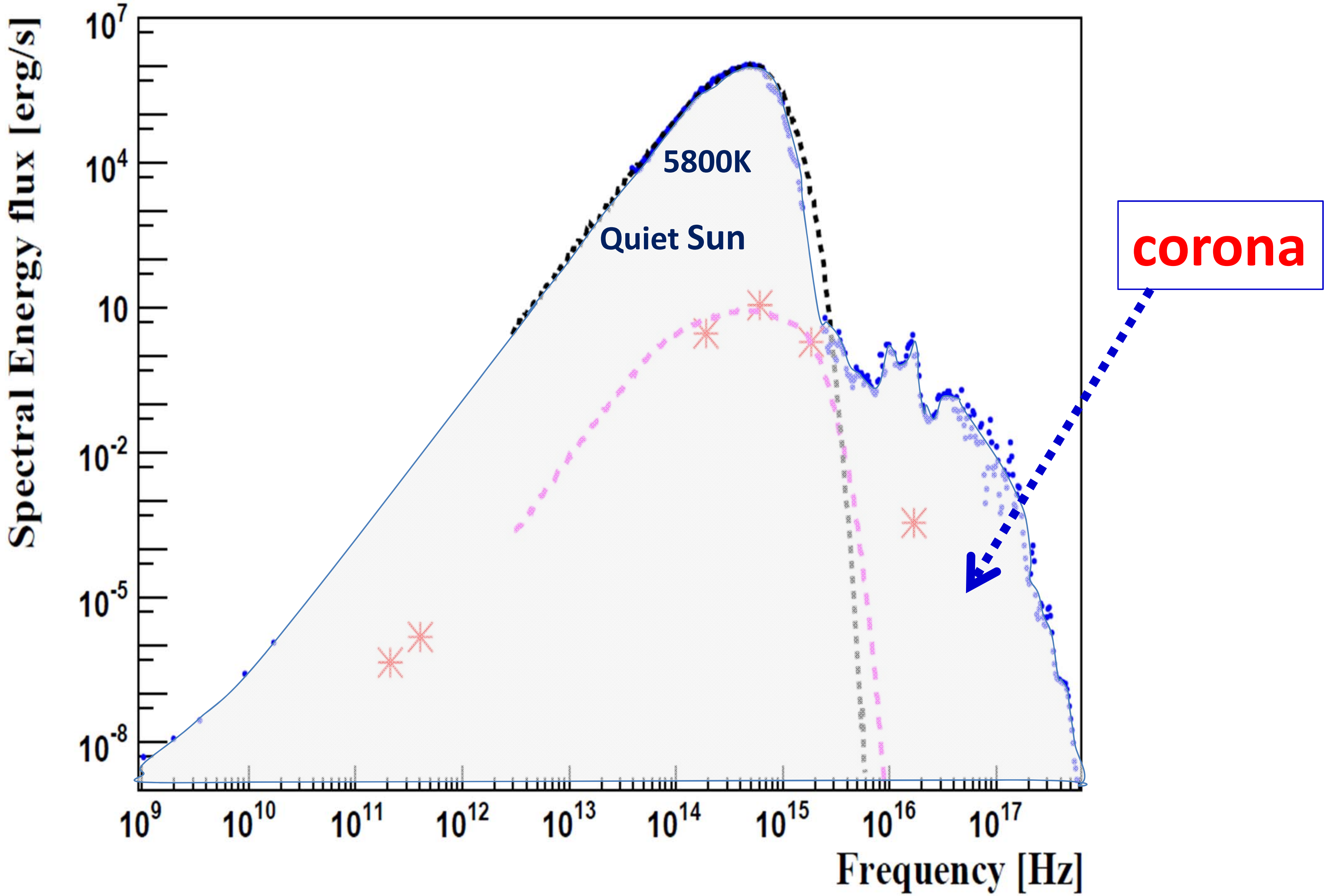
Regenerated chameleons.

$\mathbf{B}_{\mathbf{core}}$ = 100T

Flare radiation spectra →

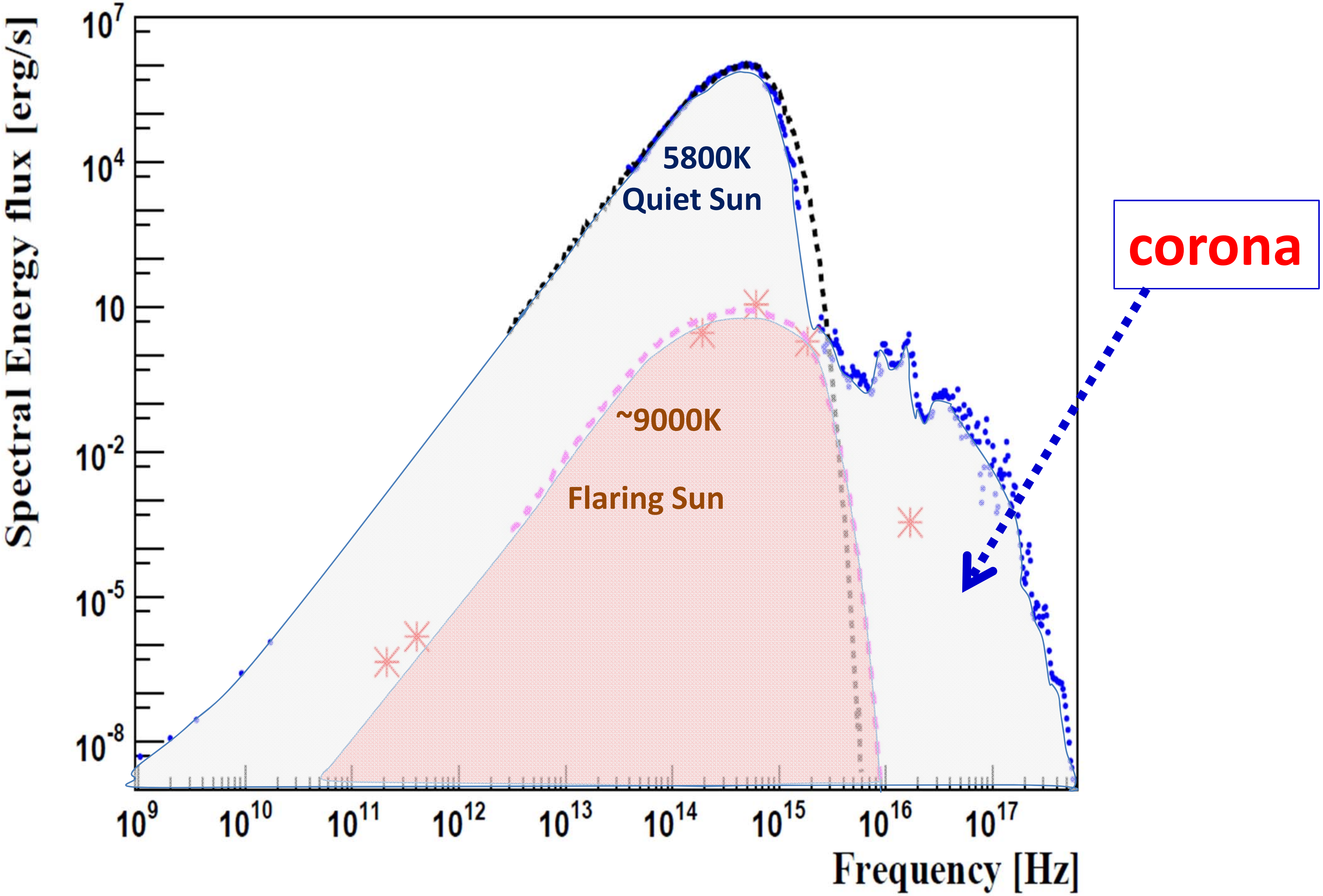


HS Hudson, Space Sci Rev 158 (**2011**) 5
http://www.springerlink.com/content/g3074x2810686465/fulltext.pdf



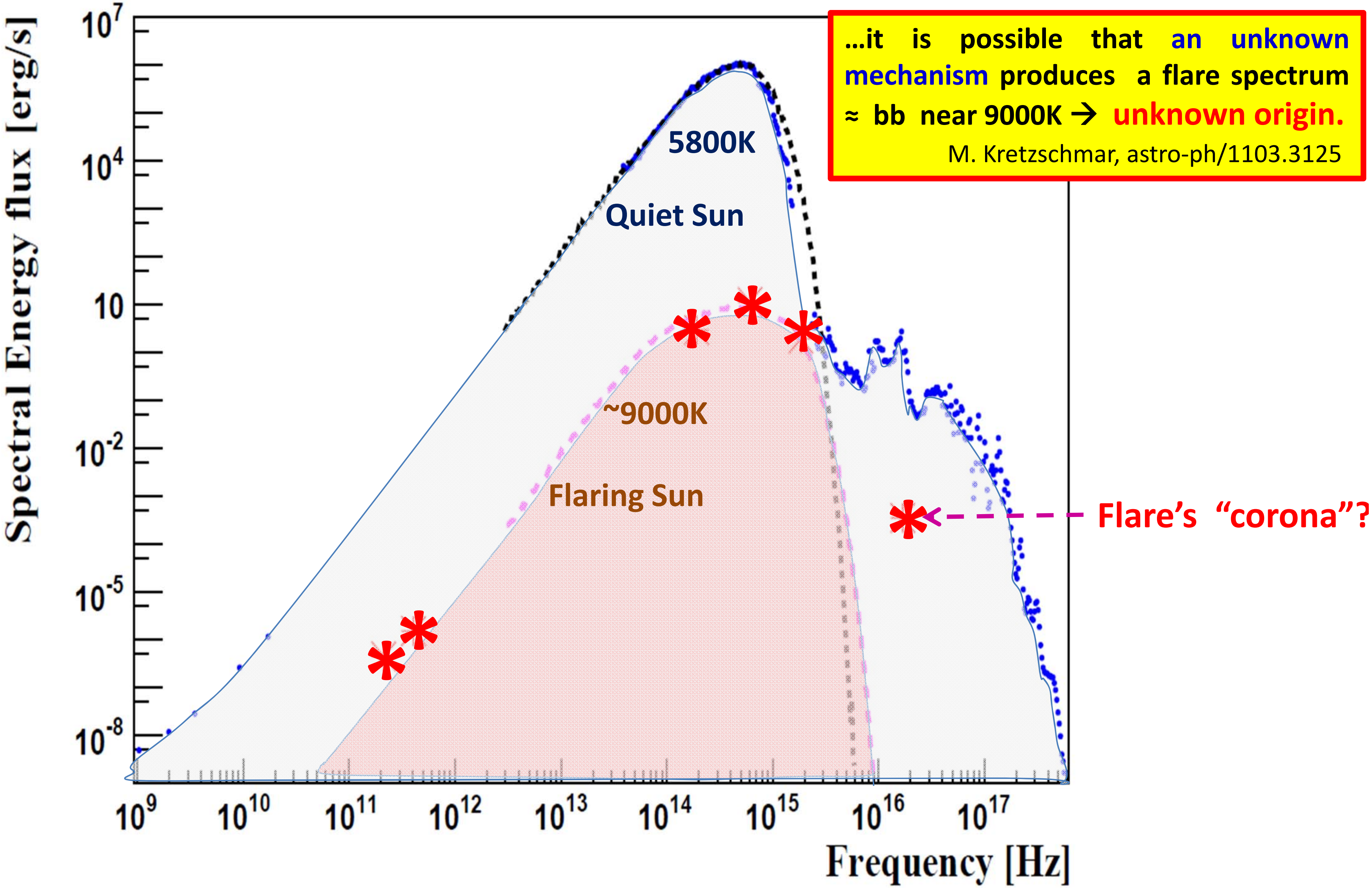
HS Hudson, Space Sci Rev 158 (**2011**) 5

http://www.springerlink.com/content/g3074x2810686465/fulltext.pdf



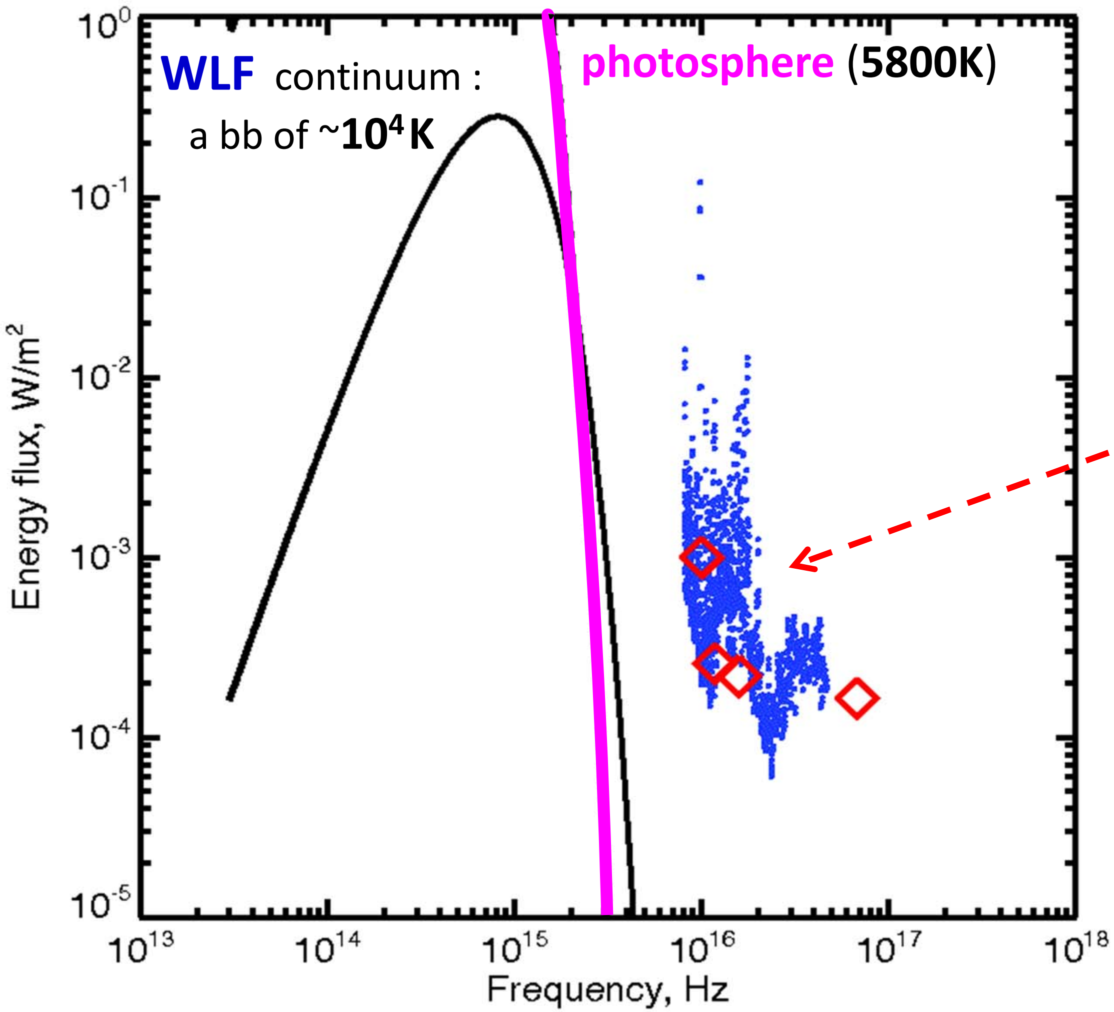
HS Hudson, Space Sci Rev 158 (**2011**) 5

http://www.springerlink.com/content/g3074x2810686465/fulltext.pdf



HS Hudson, Space Sci Rev 158 (2011) 5

http://www.springerlink.com/content/g3074x2810686465/fulltext.pdf



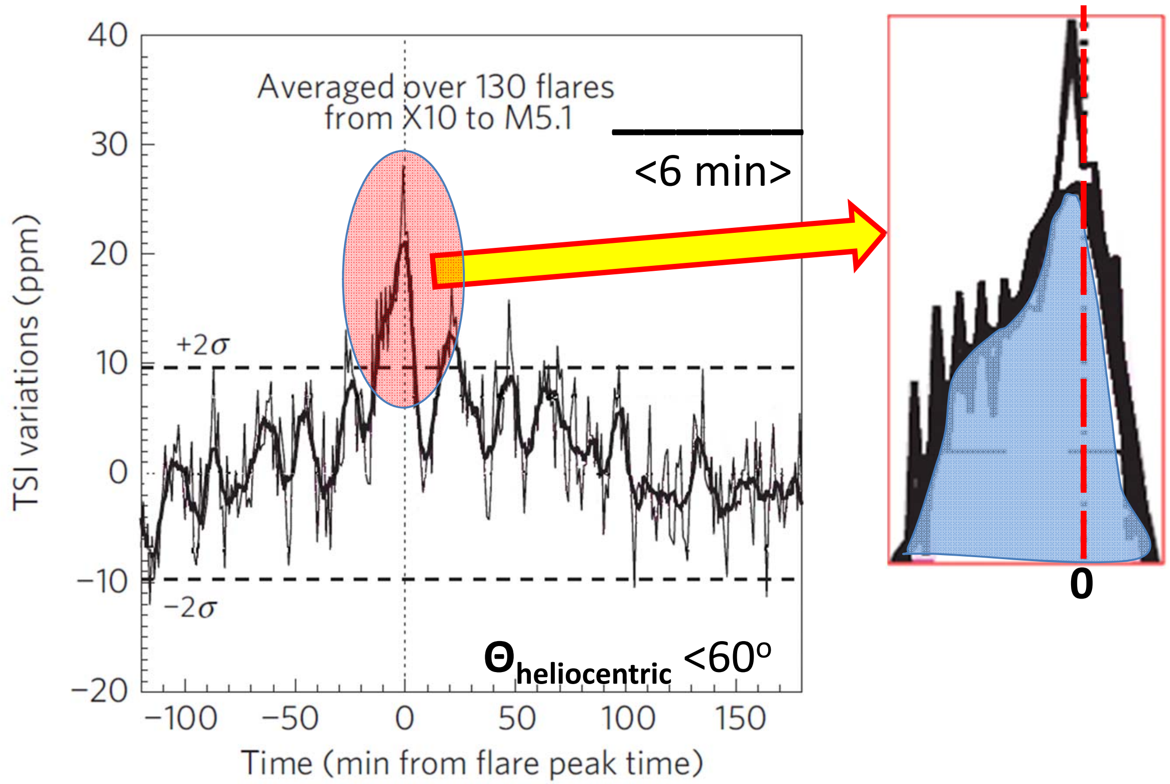
A broad-band spectrum of the impulsive phase. The smooth line roughly describes the WL-flare continuum, the points the EUV background from EVE, and the diamonds, the EVE broad-band points.

EUV intensity well below the WL-flare continuum:

FLARE'S intense "corona"?

http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/At_last,_the_EUV_Spectrum

Time correlation in flares?

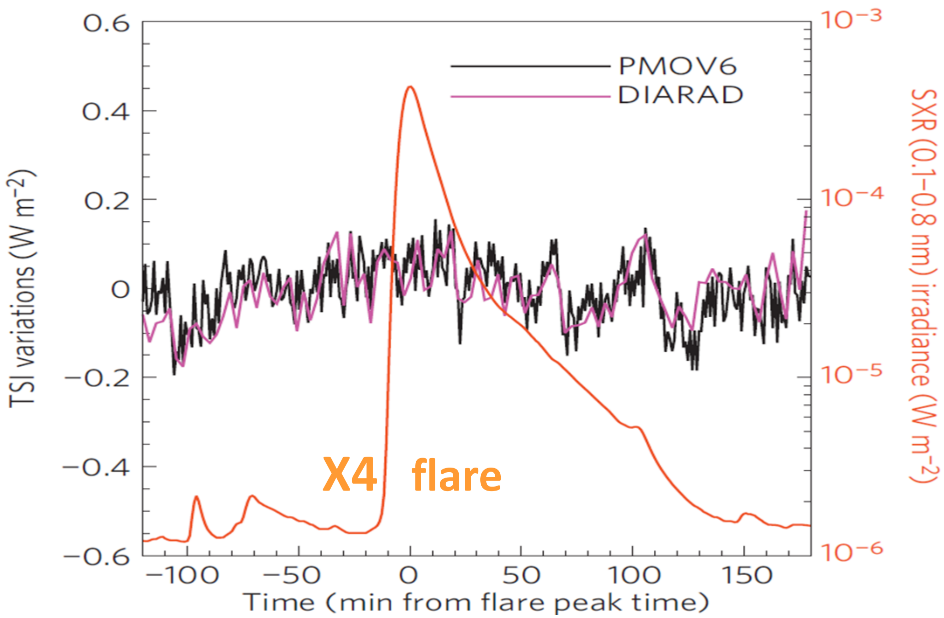


... the total energy radiated by flares exceeds by ~100x the flare soft X-ray energy emission.

➔ a major contribution in the visible + near-UV !

TSI increases before SXR ➔

X-rays after WL emission.



Flare light curves (28/10/2003)

➔

... the visible light and TSI peak about 5 minutes before SXR, confirming the importance of the impulsive phase.

(astro-ph/1103.3125)

M. Kretzschmar, et al., Nature Physics 6 (**2010**) 690

http://www.nature.com/nphys/journal/v6/n9/pdf/nphys1741.pdf

http://xxx.lanl.gov/PS_cache/arxiv/pdf/1103/1103.3125v1.pdf

Timing between WL (first) and soft X-rays (afterwards): m_{ax}>10meV

- **~axion scenario:** energy deposition @ sub-photosphere => ionization / ~thermalization

  at ρ -> m_{ax} x ℓ_{coh} → escape + in addition:

  … compression possible due to **B** #) moving the conversion place (ρ ≈ m_{ax}) upwards, from where down-comptonization occurs less + less => escaping as X-rays

  - propagation speed#) of energy deposition, e.g., by converted axions/CHs/WISPs:

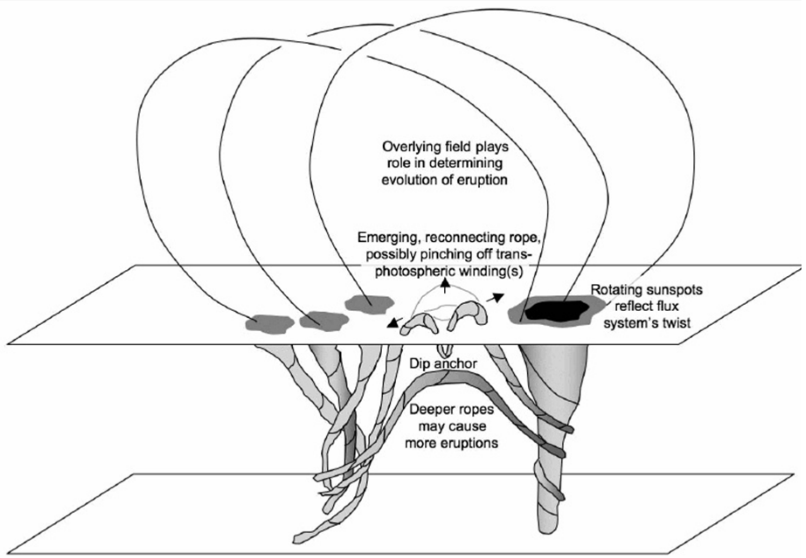
  ~0.1 – 1 km/s ~ accumulation time

  i.e., propagation time from -1000km to the surface ➔ 10min to 100min ≈ observation!

Spectral energy range:

1st : WL (~10^4K) => ~thermalized ~keV-photons at large depths before escaping!?

2nd : SXR => converted axions at smaller depths (relative to WL)



#) **Thanks to K. Galsgaard, E. Georgoulis, A. Lindner, A. Vourlidas**

CJ Schrijver, Adv.Space Res. 43(2009)739

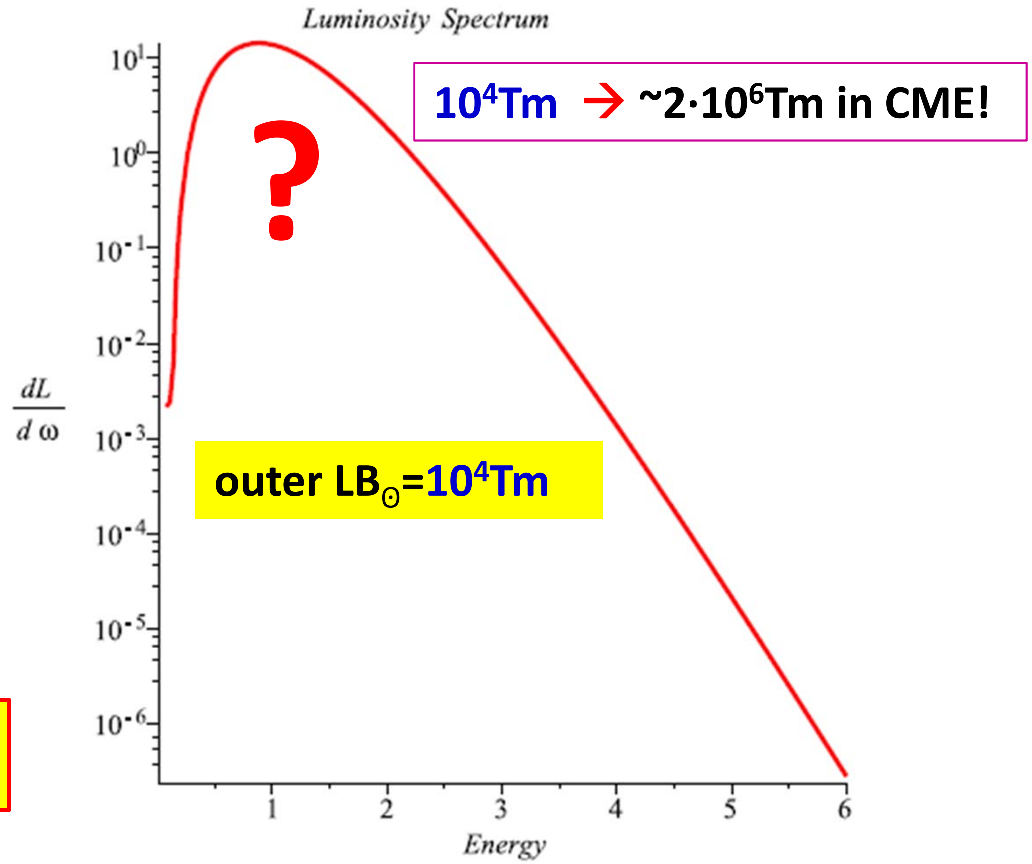
+ synergism: => with conventional physics **/** WISPs

- *a*'s + CHs -> generic examples

→ not one single global mechanism at work

- not only one exotic particle involved: see axions ≈ CHameleons
- behave very differently

Back-converted Chameleons (to photons) from the quiet sun [erg/keV/s/cm^2] at altitudes >5000 km and B=1G. →

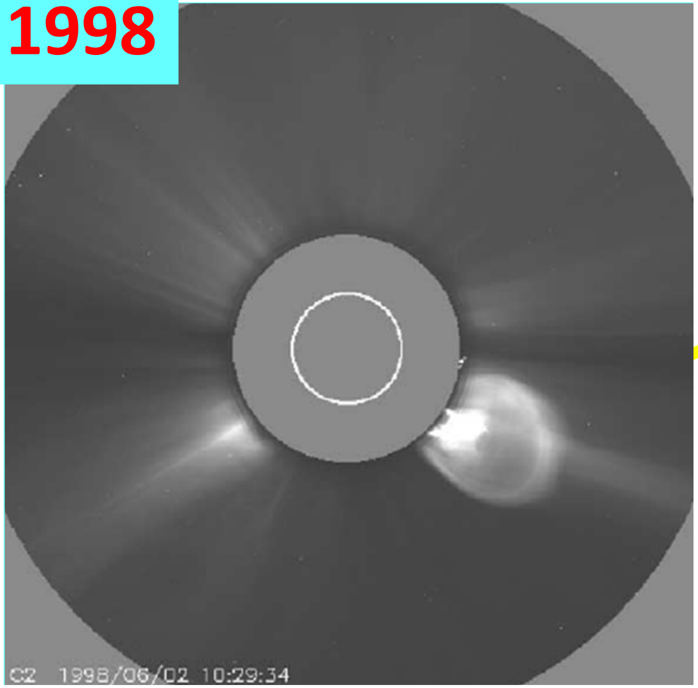


≈ **SPHINX spectrum** (SXR)

CHs: the missing ingredient?!

P. Brax, A. Lindner, K. Zioutas (**2011**)

1998

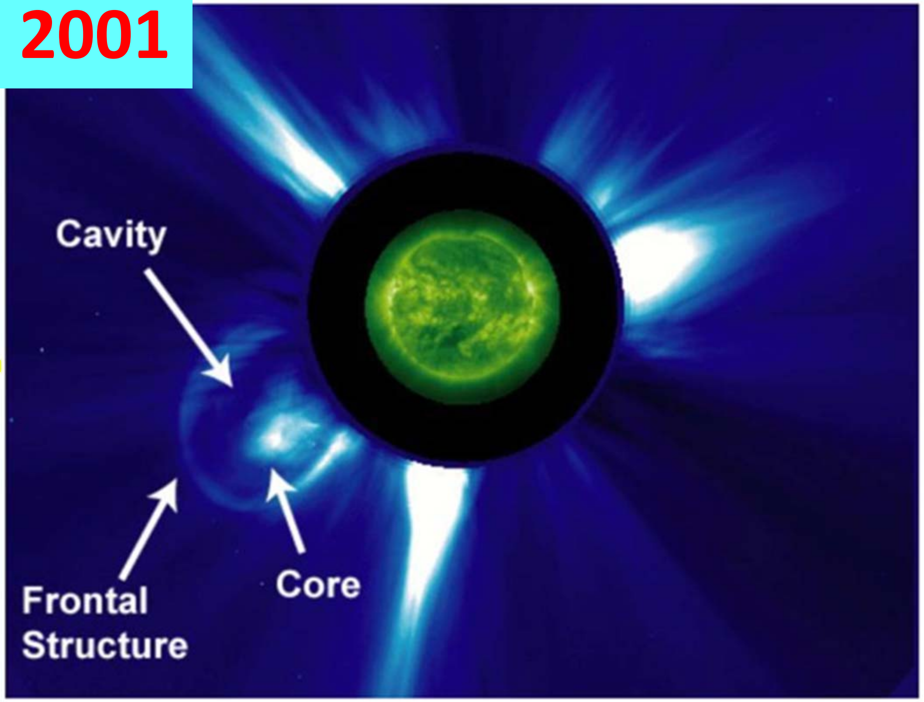


CME with LASCO C2 coronagraph (1030UT 2/6/1998). The classic three-part structure of the CME (front, cavity, and prominence) is apparent.

E.W. Cliver, H.S. Hudson, J. Atm.Sol.-Ter. Phys. 64 (2002) 231
http://www.sciencedirect.com/science/article/pii/S1364682601000864

CME

2001



SOHO/LASCO image (EIT 195 image superposed) **obtained 20/12/2001 ➔ the 3-part structure of a CME above the SW .**

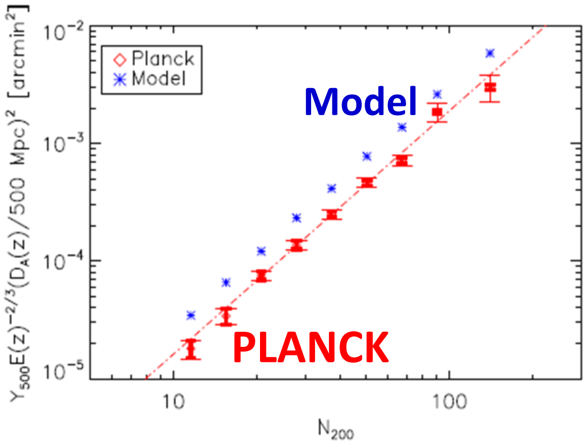
N. Mittal, U. Narain , J. Atm. Sol.-Ter. Phys. 72 (2010) 643
http://www.sciencedirect.com/science/article/pii/S1364682610000921

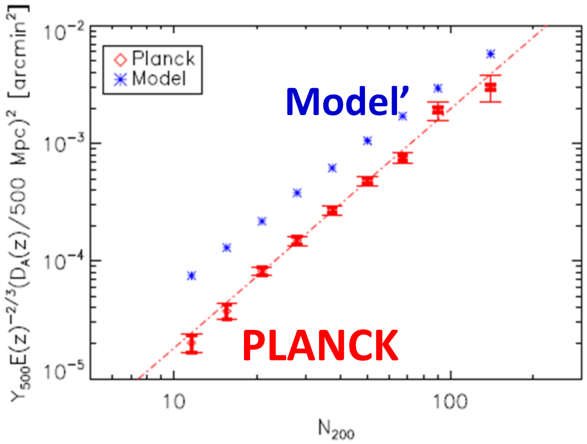
V ≈10^{30}cm^3 **&** **B≈200 [G] ➔ BL ≈ 2·10^6 [Tm]**

- **The CME trigger => origin?**
- **Rising soft X-rays ?**
- Bright Hα ribbons @ solar disk
- Hα loops @ corona
- EIT dimmings, ...

>> **CHameleons!?**

SPHINX + other XRTs





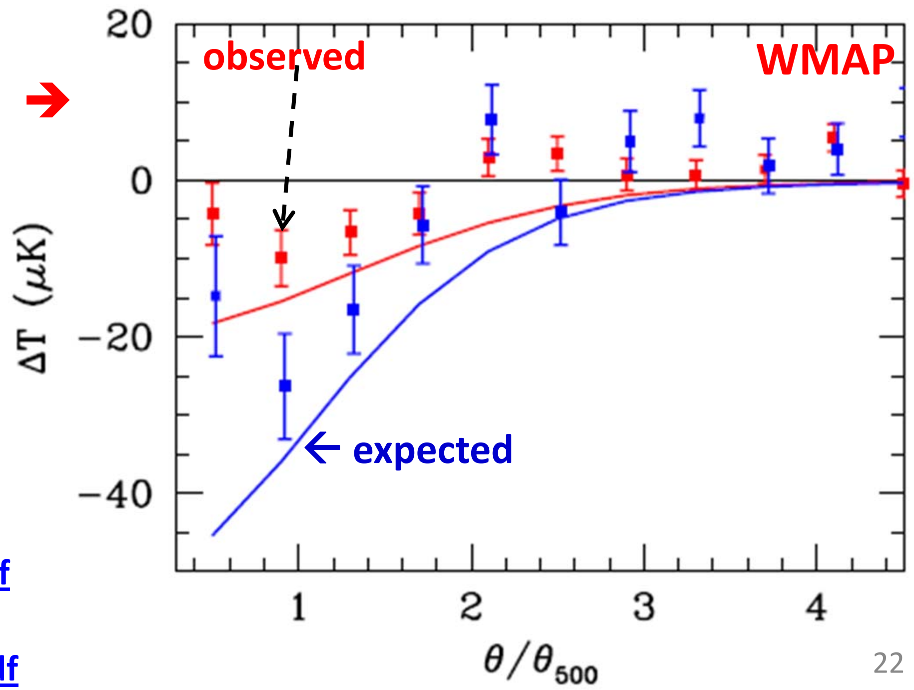
The SZ-decrement from these clusters fell significantly below their expectations
= less electrons

Scaled SZ signal measurements, Y500, binned by richness, N200.

→ A clear discrepancy between the model and the Planck SZ measurements for both mass calibrations.

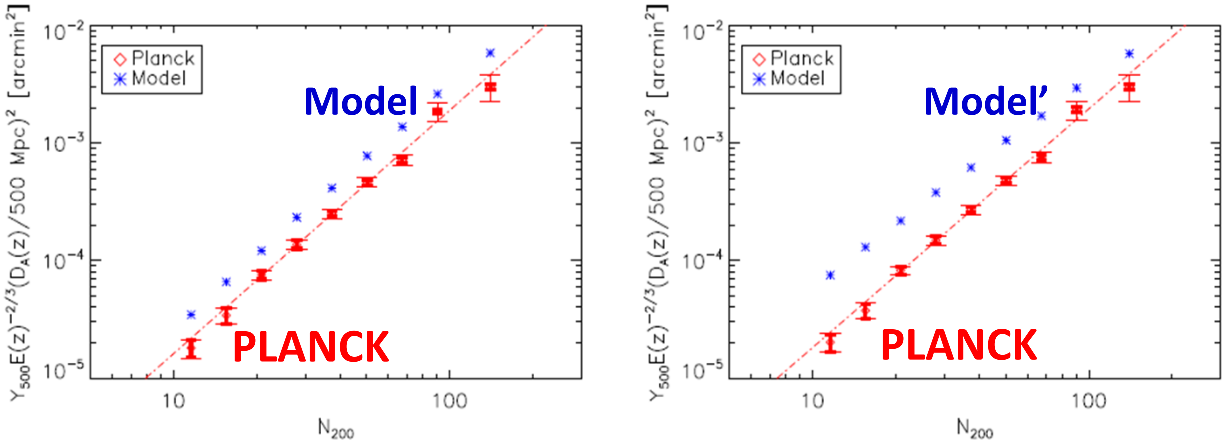
… lower … than predicted based on X-ray models …

SZ signal as a function of distance from the cluster center… in agreement with the PLANCK results. →



The discrepancy is likely to remain an active field of research in immediate future.

PLANCK 2011:
http://xxx.lanl.gov/PS_cache/arxiv/pdf/1101/1101.2027v1.pdf
WMAP 2011:
http://xxx.lanl.gov/PS_cache/arxiv/pdf/1106/1106.2185v1.pdf



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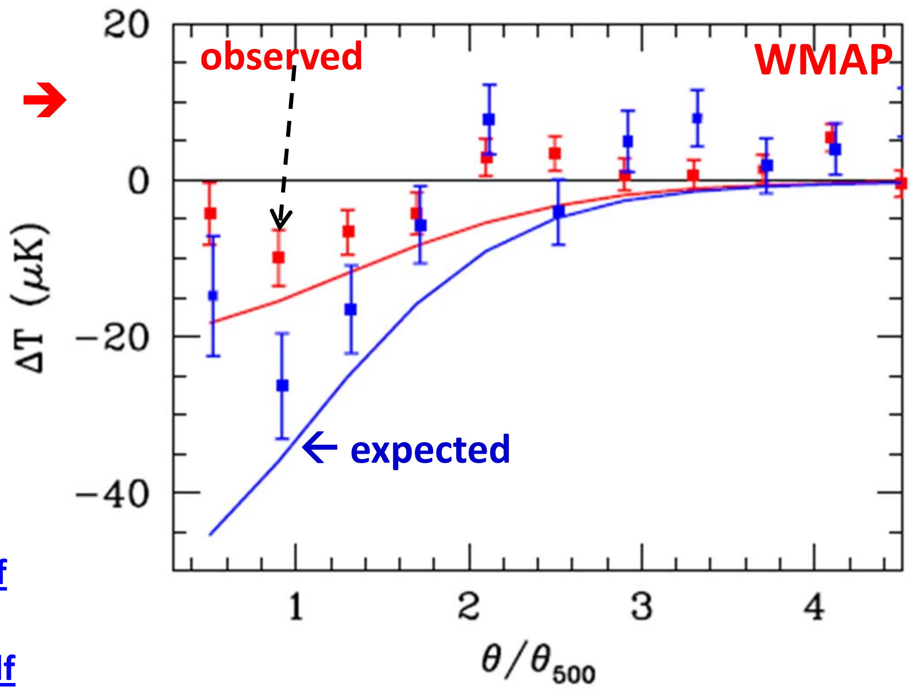

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PLANCK 2011:
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WMAP 2011:
http://xxx.lanl.gov/PS_cache/arxiv/pdf/1106/1106.2185v1.pdf

Unfortunately, such decay x-rays from accumulated relatively short-lived trapped **axions create a** "**ghost plasma**"heating the Sun's (or any other) real plasma and complicating its interpretation. However, other phenomena in the galactic center and in galaxy clusters may fit the axion scenario.

Zioutas, Hoffmann, Dennerl, Papaevangelou, Science 306 (**2004**) 1485

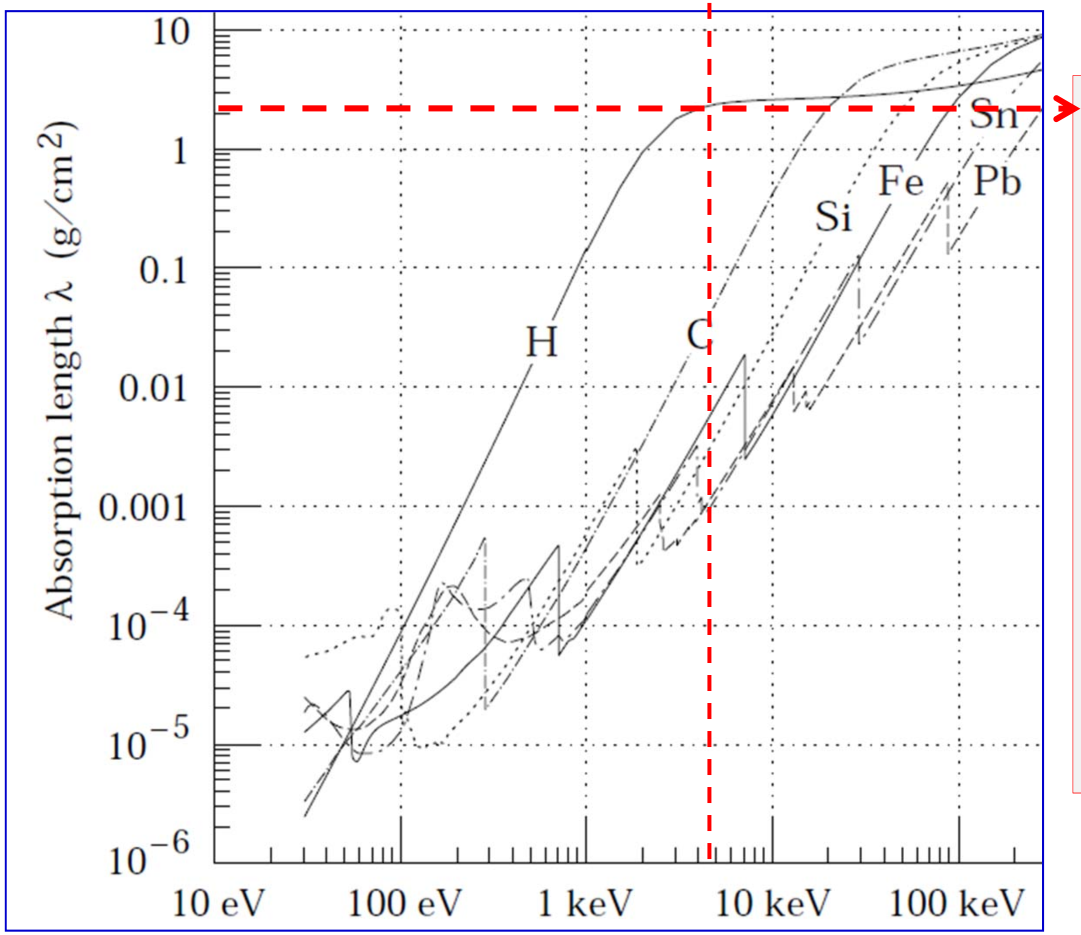
Thank you Sun!!

Back-up slides

Abstract:

The trigger mechanism of the energy release of solar flares is still unknown. In this work we will update an alternative mechanism based on the involvement of exotic particles like axions and/or chameleons or other as yet not predicted particles. The various findings on the behavior associated with (white-light) solar flares will be presented.

Possible earth-bound experiments and solar X-ray searches will be proposed.



mfp=2gr/cm^2

for ρ=2x10^{-7}gr/cm^3 @ −350 km

⇒ **10km → 0.2gr/cm^2 + Δρ/ρ √**

⇒ towards max. **ℓ$_{coh}$ ≈ 100 km**

due to compression**?**

➔ flattening of density decrease!?

Free-free (bremsstralung, Gaunt factor of 1):

σ(ν, **cm^2) ≈ 2·10^{-25}N$_e$(10^{21} cm^{-3})·Z^2·T$_e$(eV)$^{-1/2}$· [hν(keV)]$^{-3}$**

For ρ=2x10^{-7}gr/cm^3 **&** hν > 100eV➔ **σ << σ$_{compton}$**

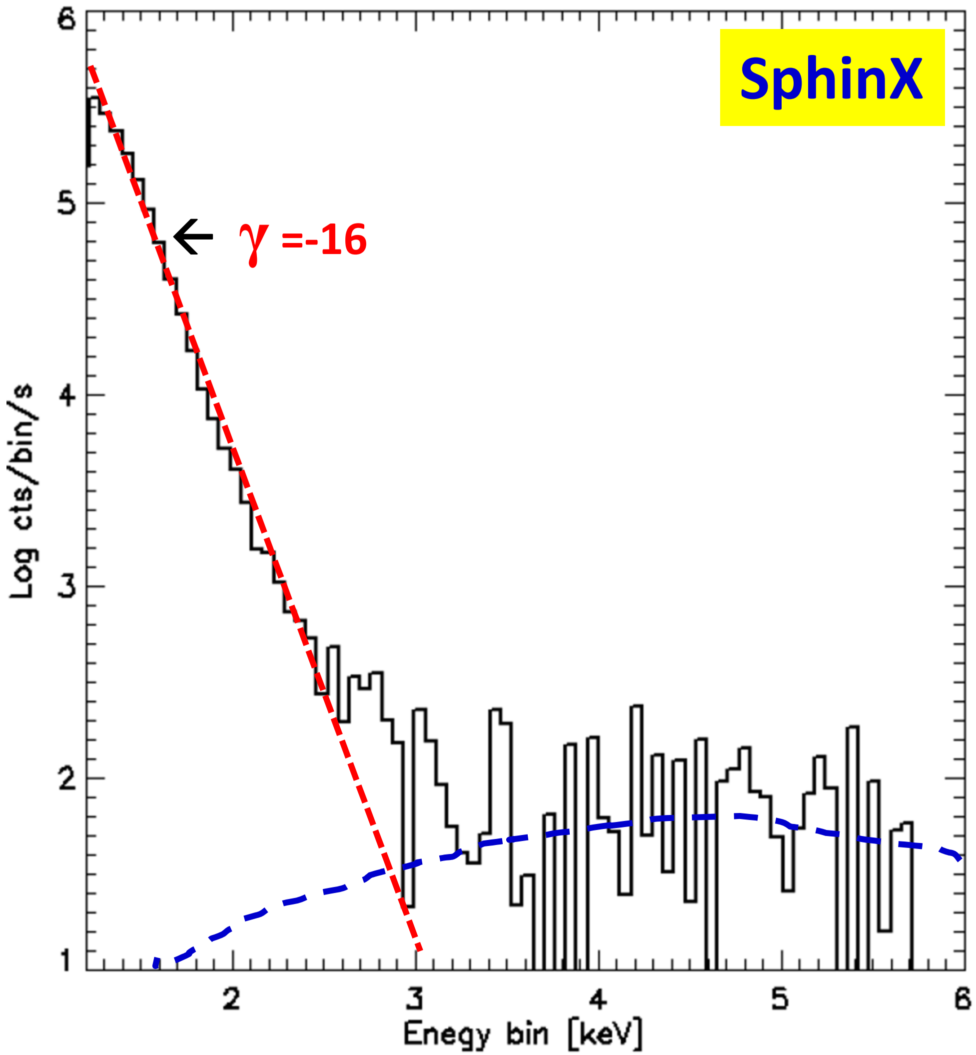
http://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html

From 3 independent results:

- **WDs (g_{ae})**
- **SN1987A (g_{aN})** ← limit
- **Sun ($g_{a\gamma\gamma}$)**

➔ $m_{ax} \approx 10 - 20\,[meV/c^2]$

➔ CAST!?



- **1-15keV :** $L_x \approx 4 \cdot 10^{22}$ erg/s
- **3-15keV :** $L_x \approx 0.003 \cdot 4 \cdot 10^{22} \approx (1\text{-}2) \cdot 10^{20}$ erg/s

Before

KK-axions:

- $L_x = 10^{23}$ erg/s => $g_{a\gamma\gamma}$ $=9.3 \cdot 10^{-14}$ GeV^{-1}
  $m_{KK} \approx 10^{-3}$ eV/c^2 (2003, L_x *overestimated*)
- $L_x \approx 6 \cdot 10^{21}$ erg/s => $g_{a\gamma\gamma} \approx 2.5 \cdot 10^{-14}$ GeV^{-1} (2004)
  $m_{KK} \approx 2.5 \cdot 10^{-4}$ eV/c^2

Now

SphinX, with $L_x \approx 10^{20}$ erg/s => $g_{a\gamma\gamma}$ ≈ **$3.4 \cdot 10^{-14}$ GeV^{-1}**

➔ **$m_{KK} \approx 3.4 \cdot 10^{-4}$ eV/c^2**

Yohkoh (0.3-4keV), with **$L_x \approx 4 \cdot 10^{21}$ erg/s => +SphinX**

$L_{x\ >3keV} \approx 0.003 \cdot 4 \cdot 10^{21} \approx 10^{19}$ erg/s =>

$g_{a\gamma\gamma} \approx 10^{-14}$ GeV^{-1} **& $m_{KK} \geq 10^{-4}$ eV/c^2**

~thermal?
axions x $B_{photosphere}$
m_{axion} ~17meV/c^2
NJP (2009)

massive KK axions
spontaneous decays
Astrop.Phys. (2003)

$m_{KK} \approx 10^{-3}\text{-}10^{-4}$ eV/c^2

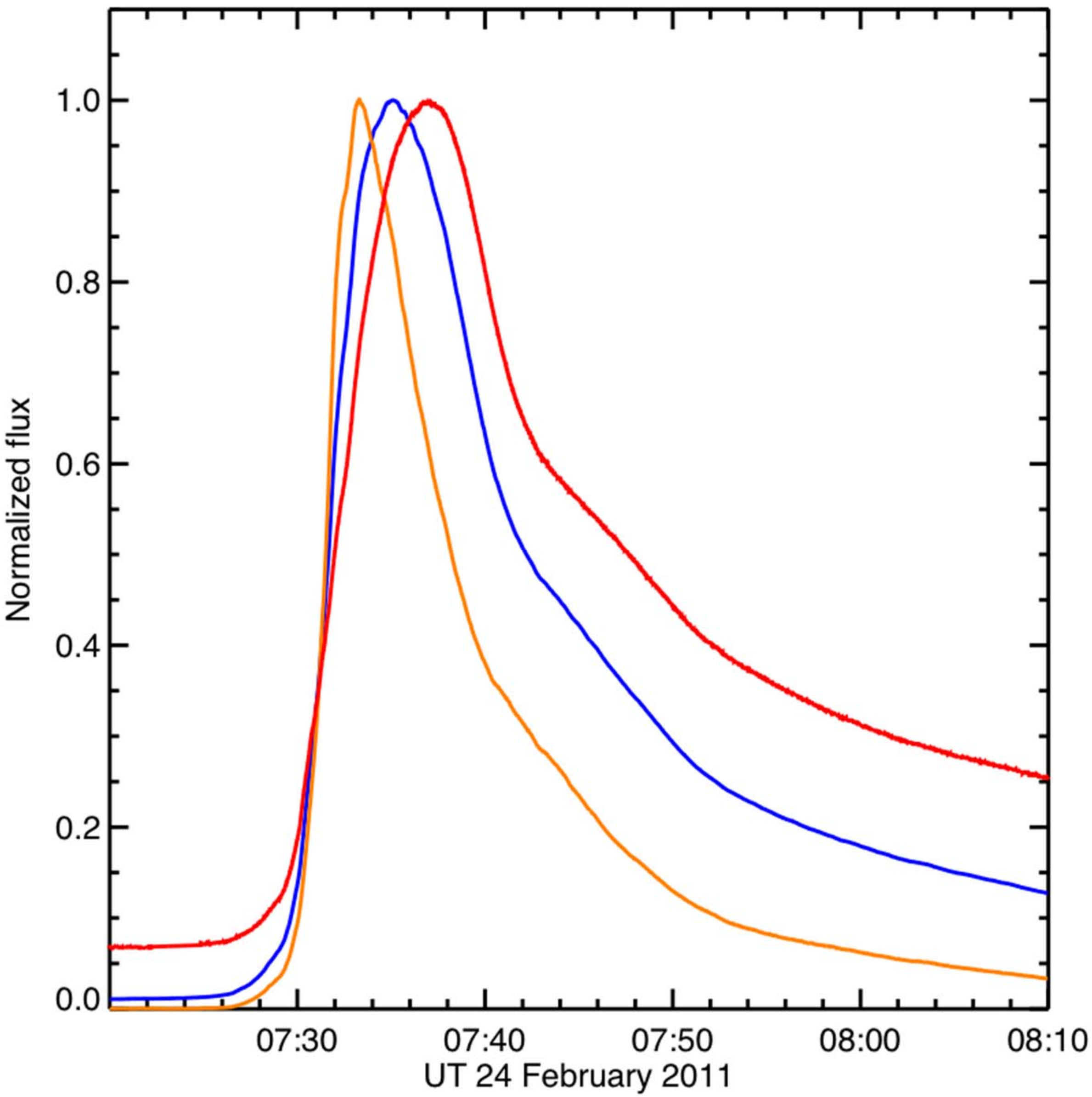
From: SOLAR CORONAL LOOPS WORKSHOP IV Wednesday, Florence, July 1, 2009, J. Sylwester

Suggestive to directly measure quiet Sunspot’s spectral shape > 100eV

-> beyond the reproduced ones!

E.g.:

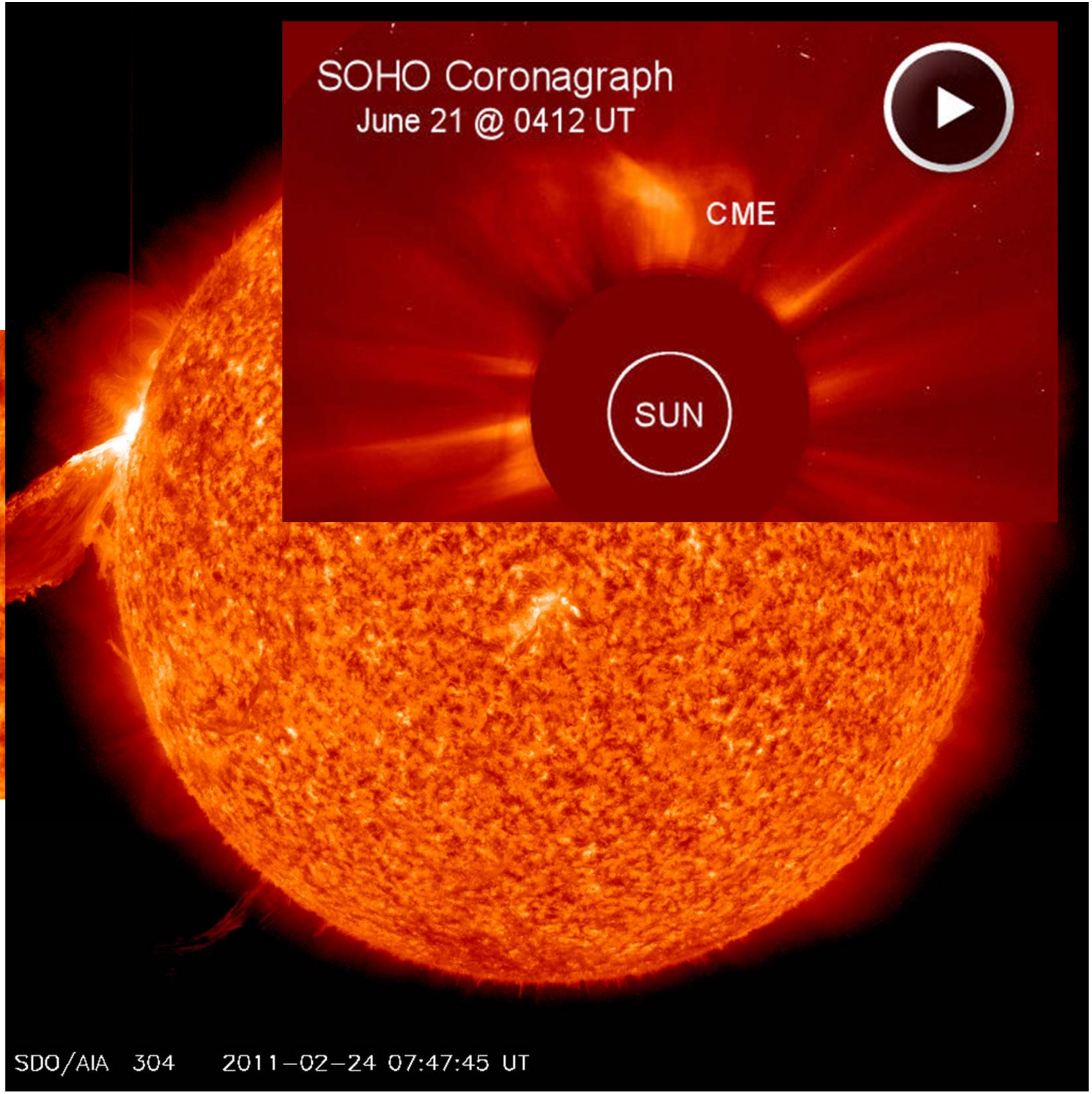
- RHESSI >4keV
- SPHINX > 0.8keV?
- .... more to come



Left: Comparison of the [ESP] zeroth-order signal ("QD"), in red, and the GOES low-energy channel (blue). Two features are striking: first, the EVE signal peaks later, and second, it has a substantial preflare excess. These both point to longer effective wavelengths. Right: A blow-up of the preflare variation, showing how much better the ESP photometry (1/4 sec binning, much lower noise) than GOES is (3 sec binning, much greater noise). **H Hudson**

http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/EVE/ESP_and_the_Neupert_Effect

2011


SOHO Coronagraph
June 21 @ 0412 UT
CME
SUN
SDO/AIA 304 2011-02-24 07:47:45 UT

CAST @ Sun?

➔ axion / CHameleon scenario => couple to **B**

- *a* *vs*. CH -> fixed *vs*. ~variable mass

  - Solar *a*'s => $\ell_{coh} \approx 10m$ ➔ CHs x large scale fields

    - preferentially in vacuum!