Axion - Chameleon signatures in solar observations

+ other exotica

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Wrocław, 20-22 XI 2012

Progress on EUV & X-ray spectroscopy and imaging

http://www.cbk.pan.wroc.pl/conferences/conference_nov_2012/index.php?page=0

Abstract:

Axions or other exotica from the dark sector like *paraphotons* and *chameleons* can be created inside the sun, and not only in the early universe. Such a "dark" solar luminosity can be **$\leq$10%** $\times$ **$L_{\odot}$**. Once axions / chameleons escape from the sun, they can convert to photons in the magnetized outer sun's layers / atmosphere via the Primakoff-effect. Paraphotons do not require even a magnetic field. Massive exotica like axions, with ~keV rest mass, can be gravitationally trapped giving rise to an *x-ray afterglow* due to enhanced spontaneous radiative decay ($\tau_{spont} \sim m^{-3}$). A single or more such as yet unexpected processes can explain the "mysterious sun". Novel signatures for physics beyond the Standard (Solar) Model may be uncovered in existing and/or future data from (soft) x-ray observatories. This exciting perspective is suggestive for a synergism between astronomers and astroparticle physicists.

Further reading:

Proceeding PATRAS workshops http://axion-wimp2012.desy.de/

>>> "Patras 2013" 24-28 June, 2013, in Mainz/Germany

Euclid → Ptolemy I **-2300**

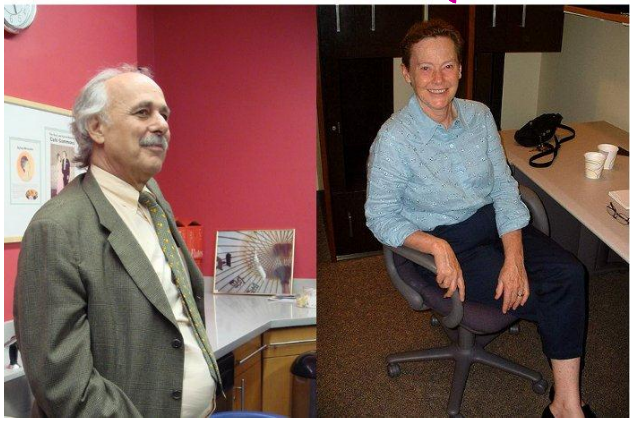
Ουκ εστι βασιλικη οδος

There is no Royal Way to …

axions, chameleons, … **+** solar physics**!**

Summary **>>**

Physics motivation for axions



Sakurai prize 2013

... P. Higgs (2010)

solve the strong CP problem:

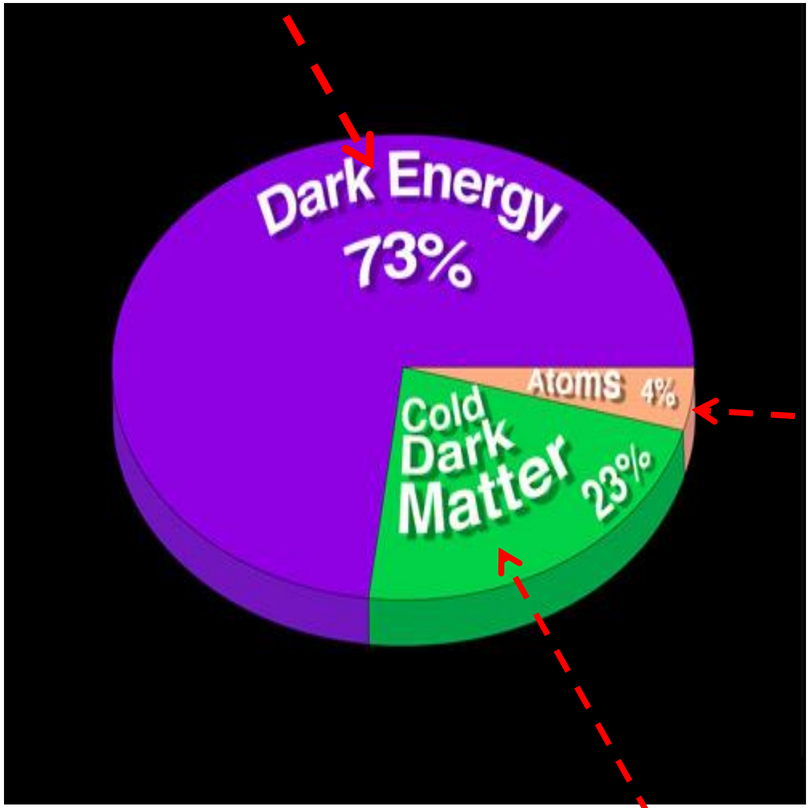
why nEDM $\rightarrow$ 0

spin-parity $\Rightarrow$ **0^-** $\Rightarrow$ $\approx \pi^o, \gamma$ (M1) ~ stable!

Axions → cosmology → dark matter

→ solve also solar problems?!

Chameleons … to explain **DE** → Khoury + Weltman **2004**



Higgs

CHs: inspiring particles!

↓

Rigorous theory missing

↓

Searches ongoing for:

solar-, lab-, cosmic - ***a***/**CH**s

→ Beyond Standard Model physics!

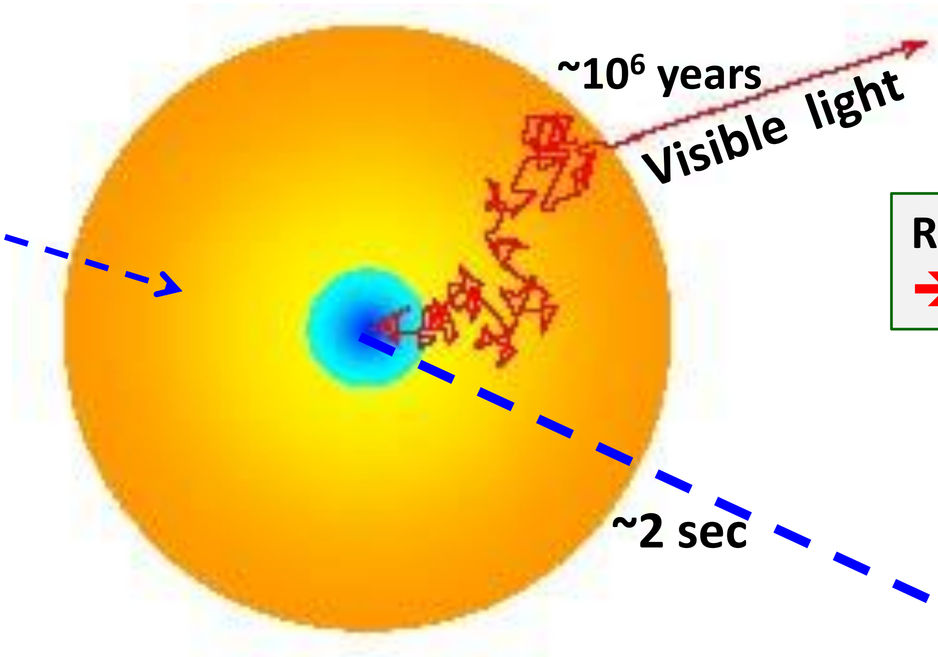
Axions … to explain **DM** **->** *…and more*!?

Sun: A perfectly shielded "radioactive" source of exotica

$B_\odot$ essential!

.. truely LSW!

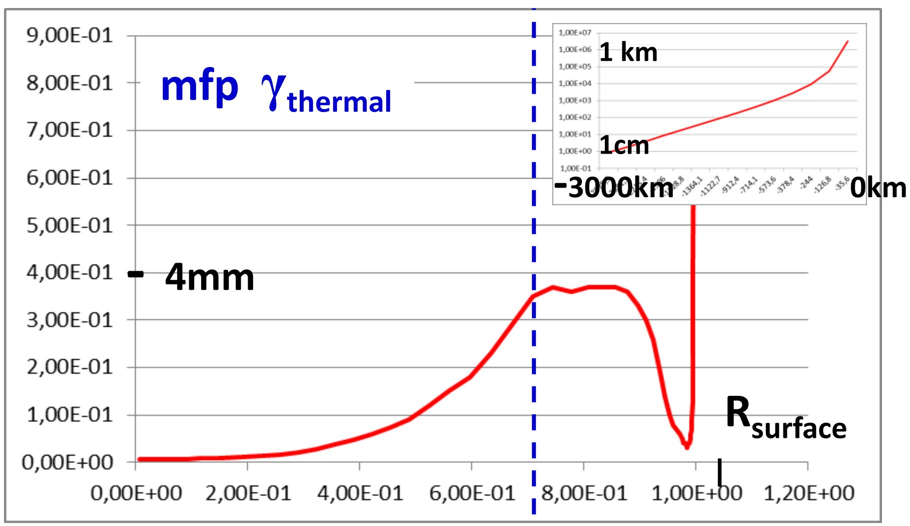
ALPS, OSQAR, …



Random walk over L:
→ Conversion ~$(B_{solar}L)^2$

<10% × $L_\odot$

ν's
Axions
Chameleons
Paraphotons
… WISPs



tachocline

$\phi_{tot} \approx 3.9 \cdot 10^{13} cm^{-2} s^{-1}$ at $g_{a\gamma\gamma} = 1 \cdot 10^{-10}\ \mathrm{GeV}^{-1}$

Corona … enigma…. 1939 –
the heating mechanism remains unknown!

…waiting = ??

One of the most enduring problems in modern astrophysics is to explain:
how the MK solar corona is created and sustained.

S.J. Bradshaw, J.A. Klimchuk, J.W. Reep, http://xxx.lanl.gov/pdf/1209.0737.pdf

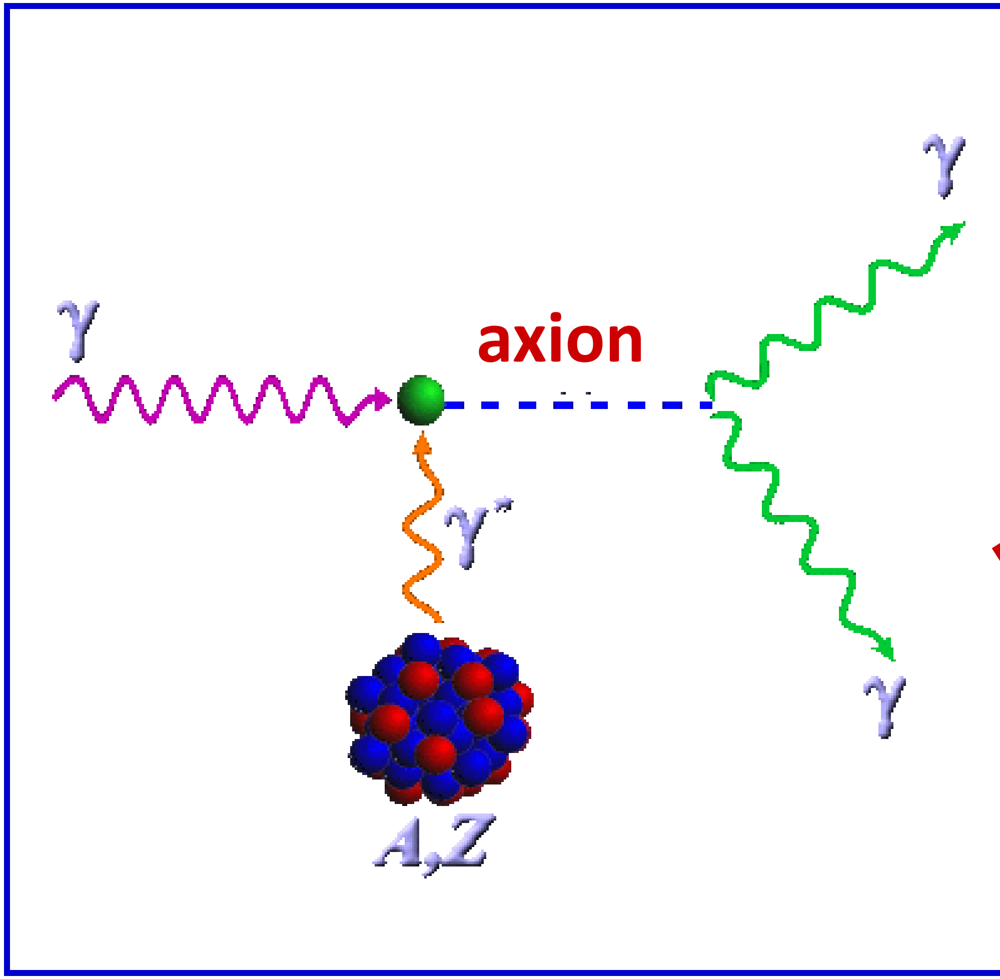
➔ **Recall the working principle of …**

B. De Pontieu, et al., Science 331 (**2011**) 55, ttp://www.sciencemag.org/content/331/6013/55.abstract
See also http://www.sciencemag.org/content/suppl/2011/01/05/331.6013.55.DC1/De-Pontieu.SOM.pdf

… a / CH - helioscopes

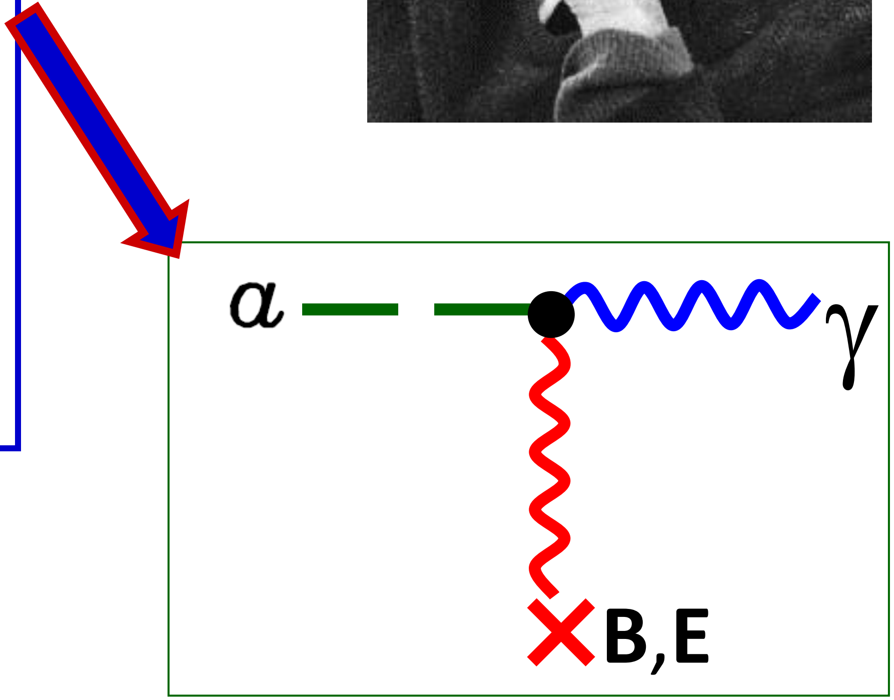
… terrestrial / celestial

The Primakoff - effect 1951

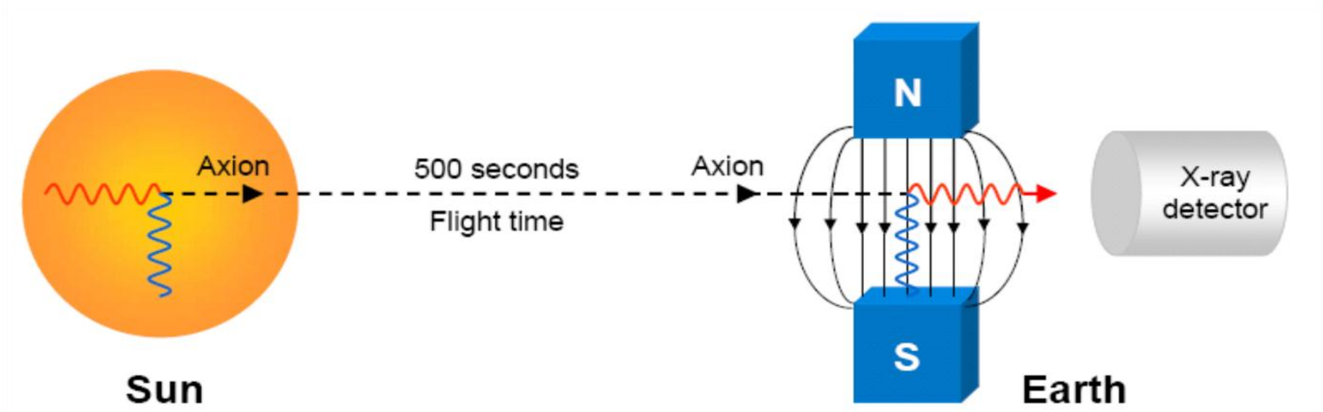


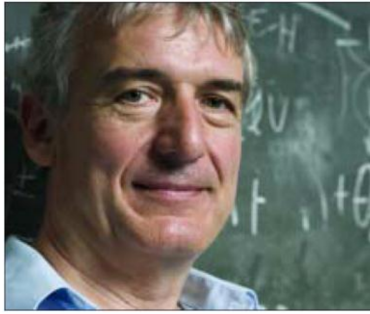
H. Primakoff

Behind all present axion work!



CERN Axion Solar Telescope
>> also Chameleon helioscope





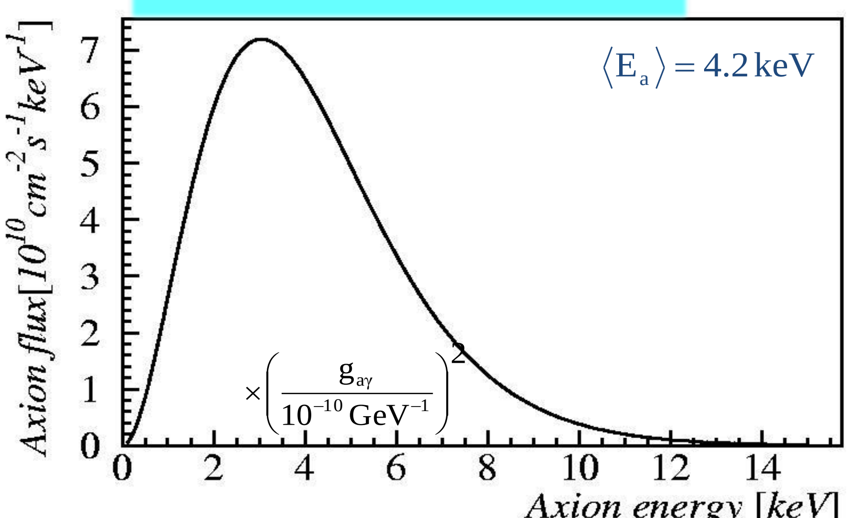
Pierre Sikivie 1983

Signal: **excess** of X-rays during alignment.

Production: Primakoff effect
Thermal photons interacting
with solar nuclei produce Axions.

Detection Inverse Primakoff:
axion interacting coherently with a strong magnetic field (~(**LB**)^2) converts to a photon

Differential axion flux on Earth



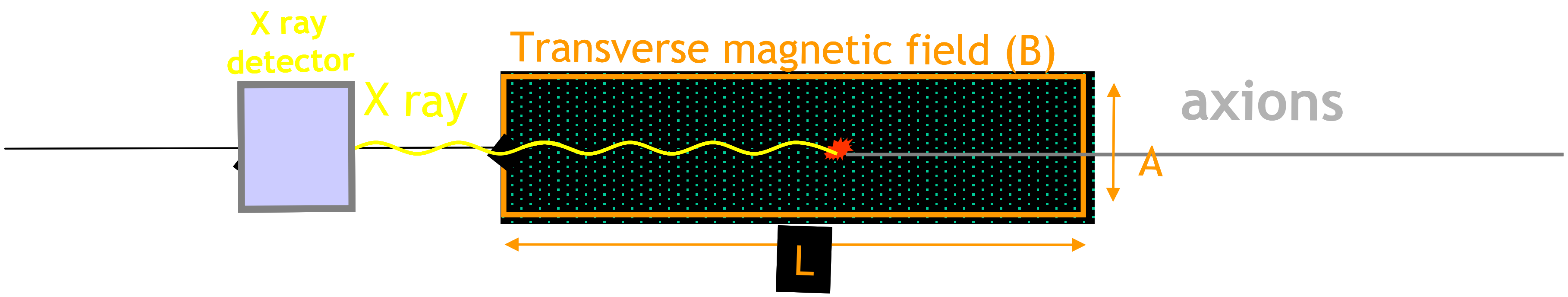
$$P_{a\to\gamma} \approx (g_{10} B_{9T} L_{9m})^2 \cdot 1.7 \cdot 10^{-17}$$

+

Photon-m.f.p. = max. $\mathbf{L}_{coherence}$

$$\Phi_\gamma = 0.51\ \mathrm{cm}^{-2}\ \mathrm{d}^{-1}\ g_{10}^4 \left(\frac{L}{9.26\ \mathrm{m}}\right)^2 \left(\frac{B}{9.0\ \mathrm{T}}\right)^2$$

CAST phase II – principle of detection m_a > 0.02 eV

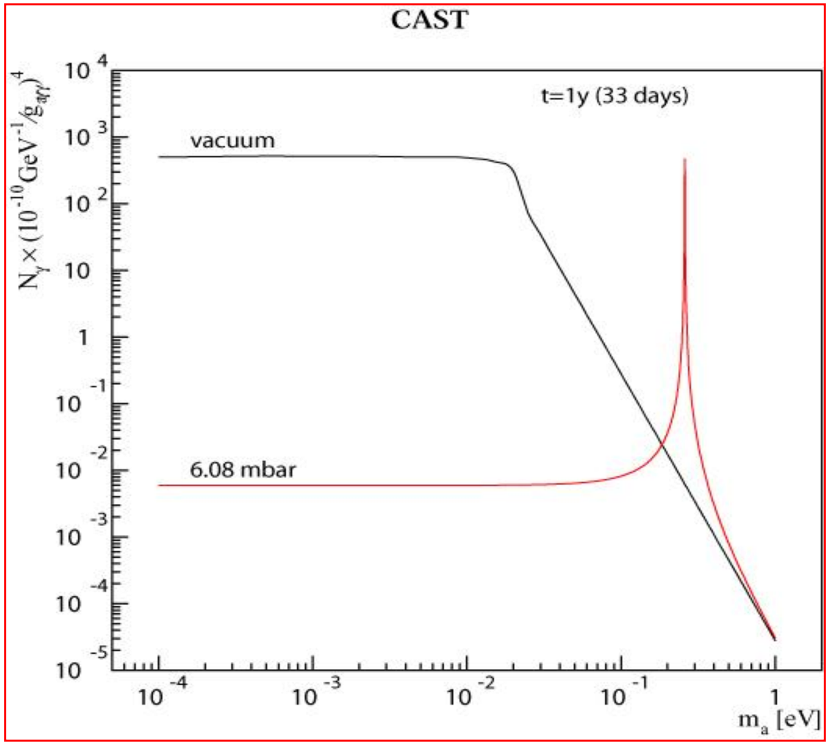


- Extending the coherence to higher axion masses...
- Coherence condition (qL << 1) is recovered for a narrow mass range around m_γ

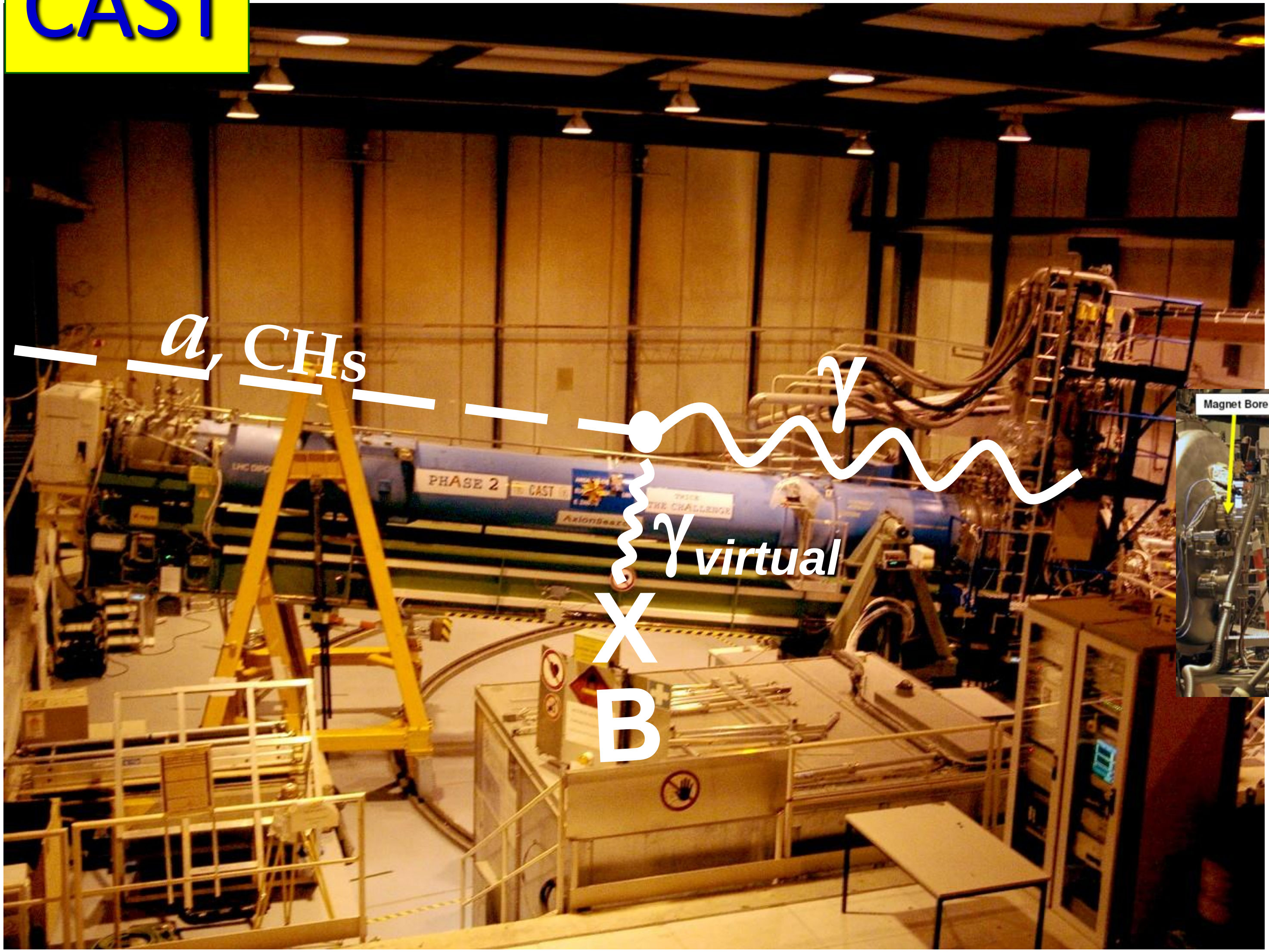
$$|q| = \frac{m_a^2 - m_\gamma^2}{2E}$$

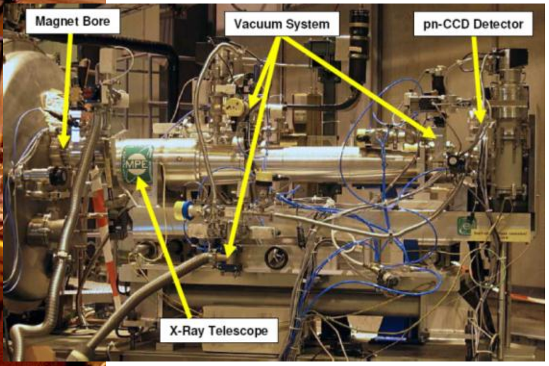
$$m_\gamma \approx \sqrt{\frac{4\pi\alpha N_e}{m_e}} = 28.9\sqrt{\frac{Z}{A}\rho} \quad \text{eV}$$

N_e: number of electrons/cm³
ρ: gas density (g/cm³)



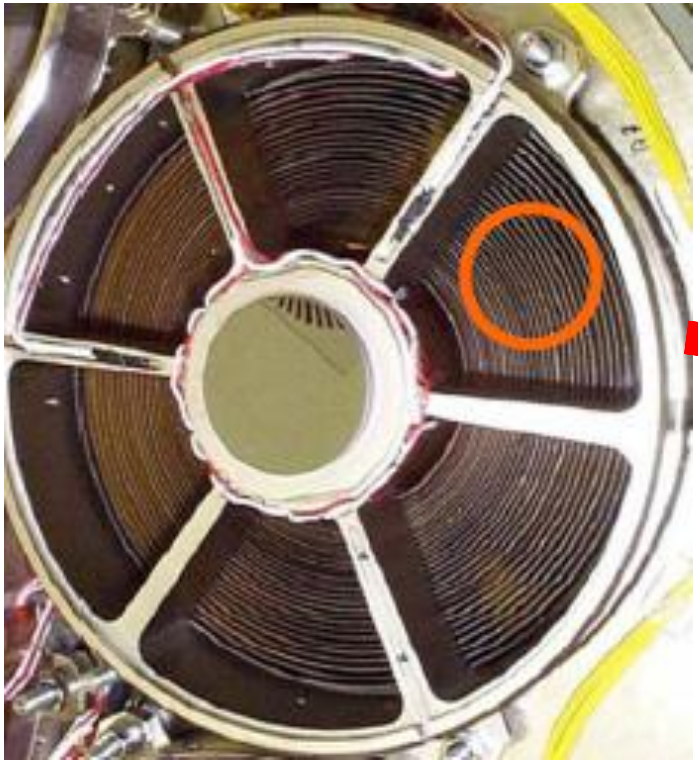
CAST


a, CHs
γ
γvirtual
X
B
PHASE 2
CAST
THE CHALLENGE

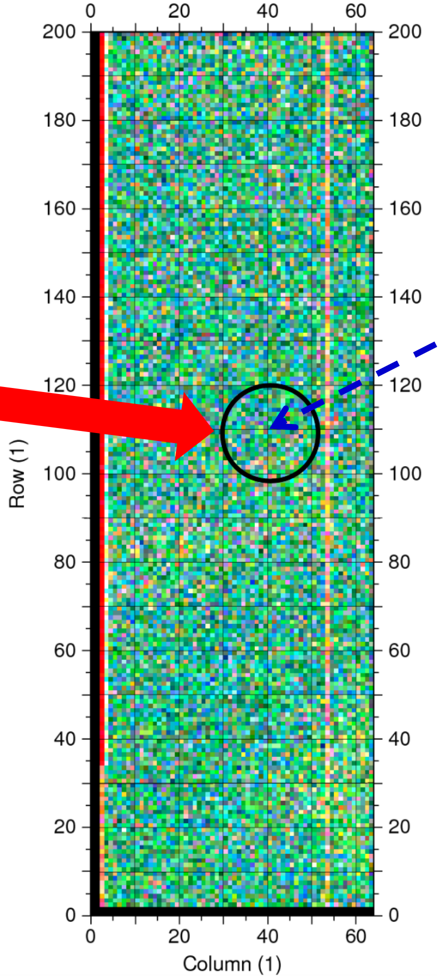

Magnet Bore
Vacuum System
pn-CCD Detector
X-Ray Telescope

CAST: Solar axion / chameleon ID

The **recycled** **CAST** XRTelescope
from the german space program

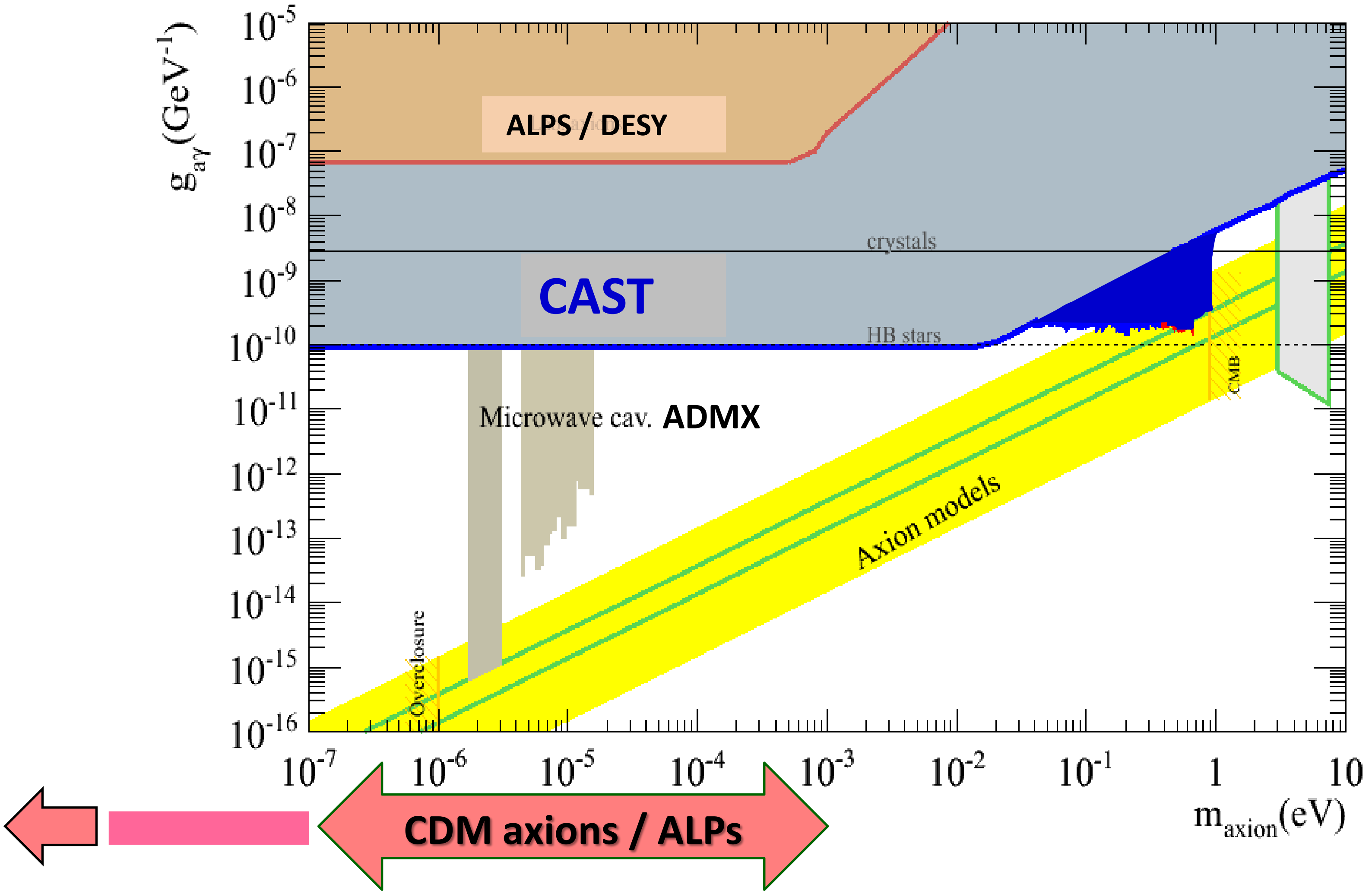


CCD at focal plane



expected
axion **signal**

Axions: exclusion plot… … defines remaining "phase space" .



From solar x-rays observations:

“remarkable + fascinating ..the sun emits intense x-rays...a mystery”

S. Tsuneta, AAPPS Bulletin, 19(#3) (2009) 11

- **SPHINX : basal x-ray emission** @ **2009** extreme solar minimum!!

- ***More solar x-rays from magnetized areas + corona is hotter there***

  → **mechanism(s)?**

… although it is well established that the ultimate energy source is the coronal magnetic field, the question of

how the magnetic energy is transformed to heat the coronal plasma is still to be solved …

one important issue is whether the heating is released **gradually + continuously** **or** in the form of **discrete**, rapid and intense pulses.

http://xxx.lanl.gov/pdf/1204.0041.pdf

>> fit solar ~axion scenario, but… ➔

Note: **Axions, Chameleons, …, ALPS ⊗ B^2**

Ubiquitous: $\mathbf{B}_\odot$ and $\mathbf{B}_{\odot\rightarrow\oplus}$ → ~ignored

~axion scenario:

B = the catalyst

…. "dark" → x-ray photon >> heat

$\leq$**10%** $\times$ $L_{\odot}$

Energy source

A hot plasma **+**
an invisible Energy-source

… ~different

More specifically …

CAST >> solar atmosphere?

a/CH signal → ($[L_{osc}B_{\odot}]^2$ + ρ) → (dis)appearance of photons

→ γ - deficit / **excess**

spatiotemporal dependence

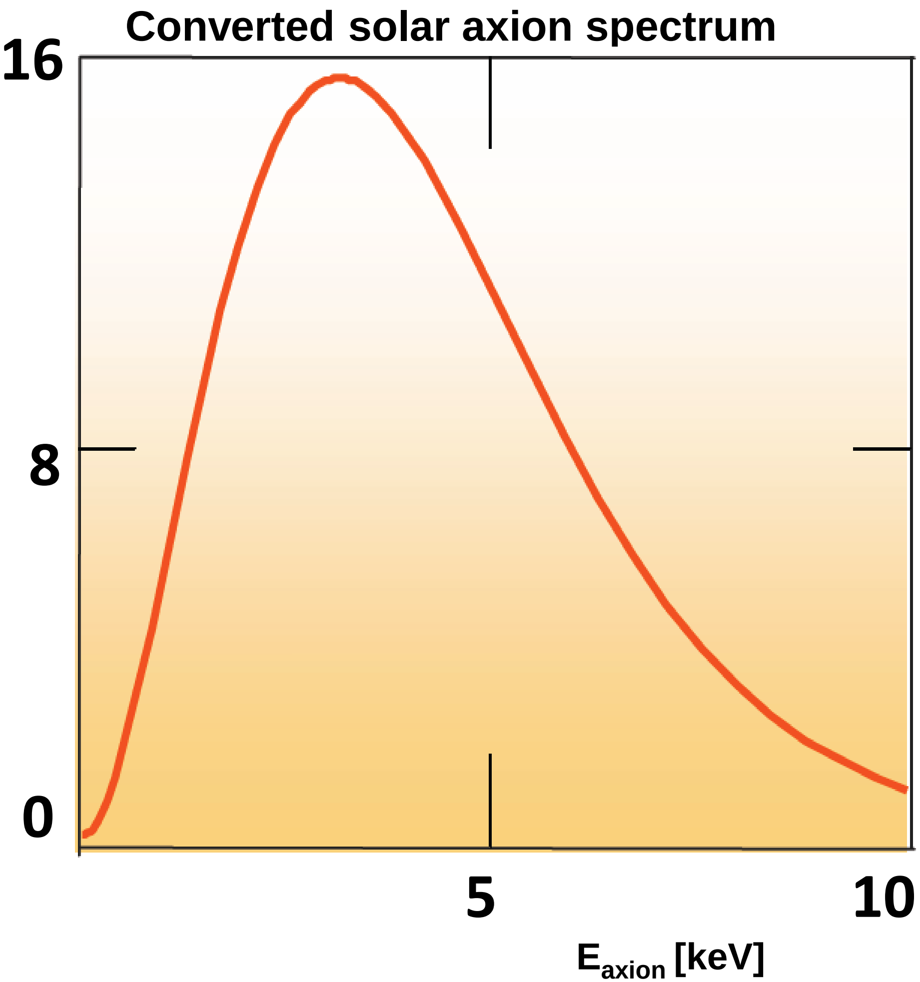
“unexpected”

transient events, e.g.: nanoflares

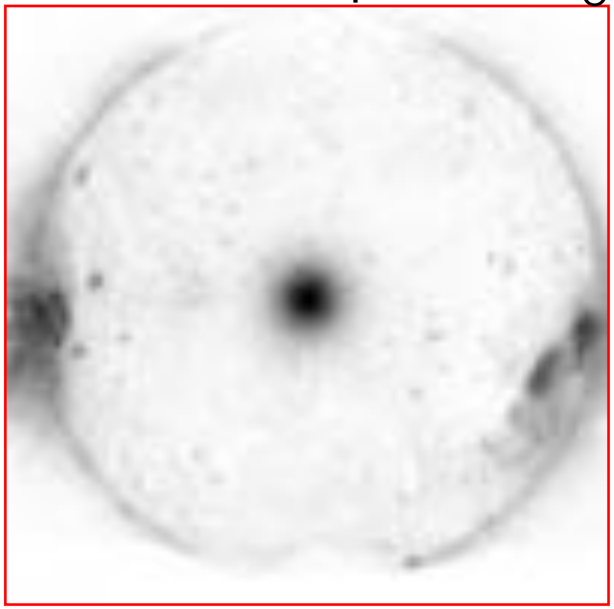
e.g. @ ARs?

Expected CAST-like signatures in space

$m_a \ll 10^{-4}\,eV/c^2$



Simulation >> spot ≈ $10^{-2} \cdot F_{\odot}$



RHESSI nugget, H. Hudson (2007)

x-ray spot @ DC -> $B_{\odot}$

No signal yet! But, what if…

Pseudoscalar conversion and X-rays from the sun,
D Carlson, L-S Tseng, PLB 365 (1996) 193

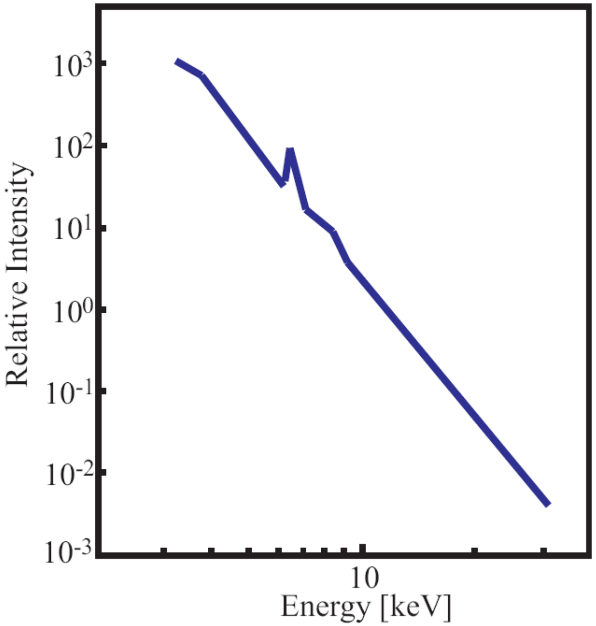
…m_{axion} ≈ 10 - 20 [meV/c²]

… **axion conversion @ inside photosphere:** $\hbar\omega_{plasma} \approx m_{axion}c^2$

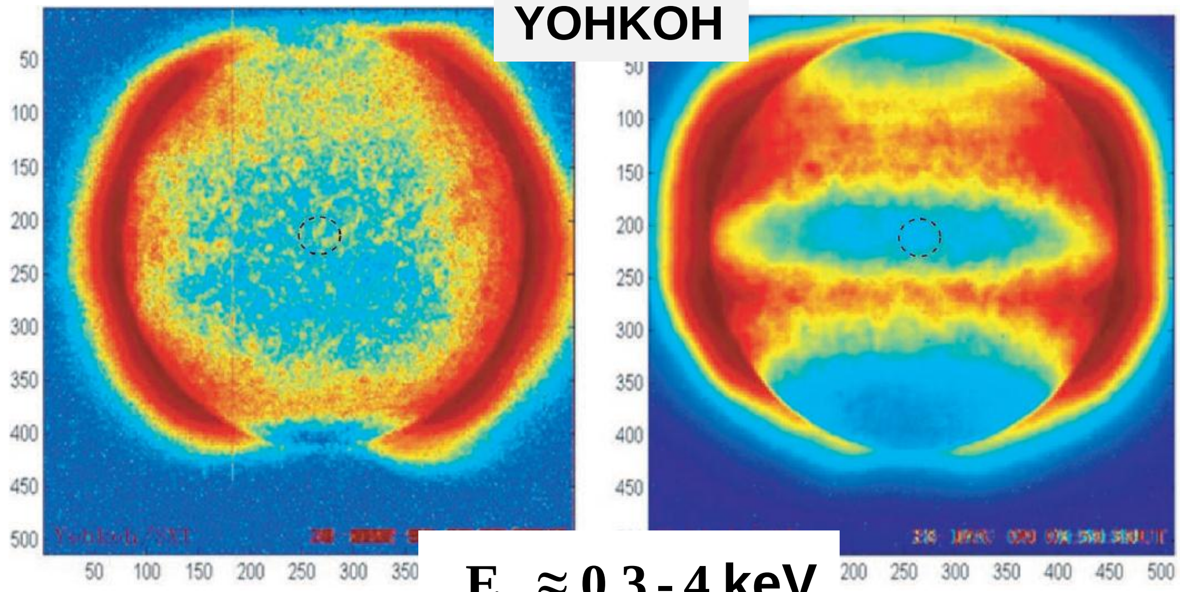
>> absorption, down-comptonization ➔ ***isotropic*** x-ray re-emission!!

>> observational implications!

Typical analog solar x-ray spectrum

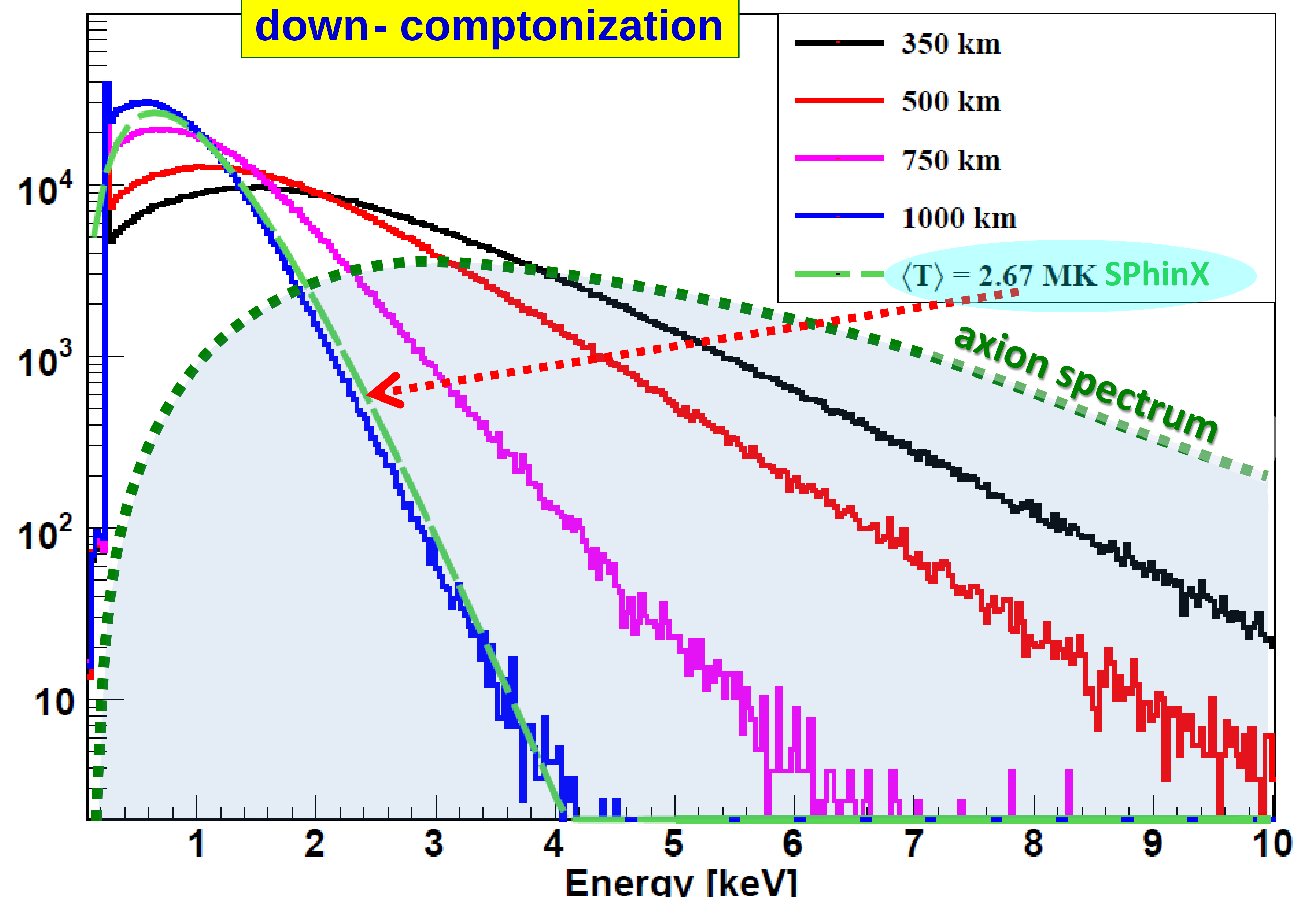


solar minimum **solar maximum**



$E_\gamma \approx 0.3 - 4$ keV

K. Z., M Tsagri, Y Semertzidis, T. Papaevangelou, T. Dafni, V. Anastassopoulos, New J. Phys. 11 (2009) 105020 http://iopscience.iop.org/1367-2630/11/10/105020



converted axions' reach thermal shape: bad for ID

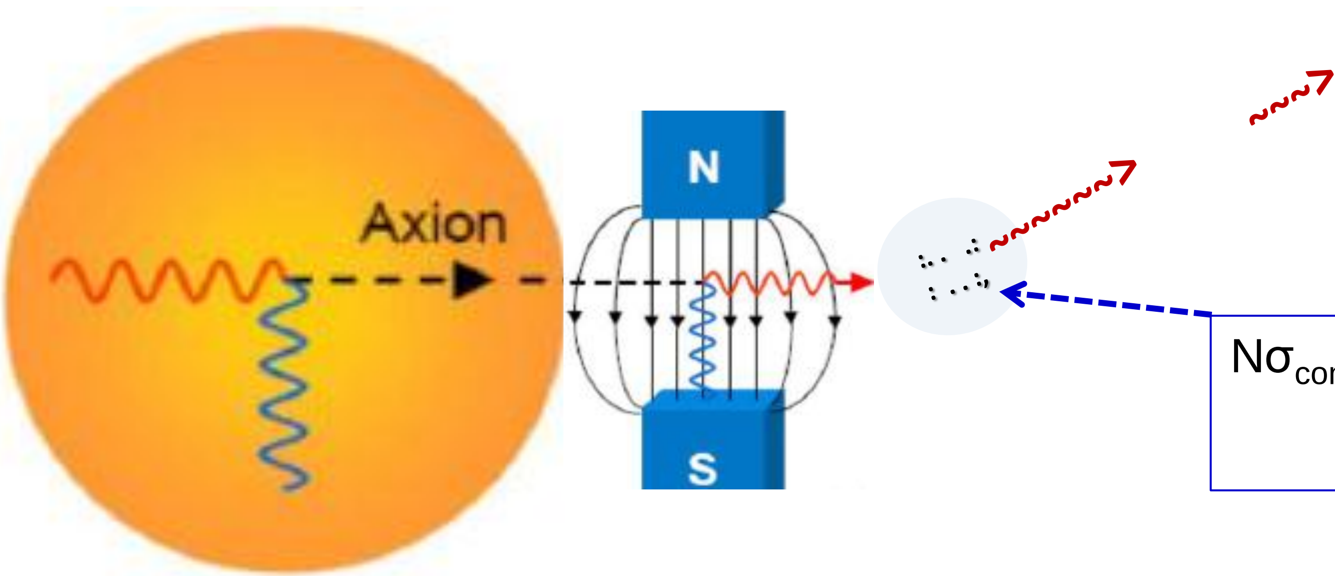
m_{ax}~17 meV

DC_Θ is not the only place to look at!

…where else? how? ➔

A new detection concept for solar a's / CHs

x-ray mission



$N\sigma_{compton} \approx 10^{-3}$ @ ~mgr/cm^2

>> *signal from whole Sun*

Isotropic Compton-scattering =
f(*column density*) → **[≈0 / ≈1]**

~axion scenario for "thin" solar atmosphere:

- **x-ray emission radially outwards!**
- **~% $F_{\odot}$ @ DC** **not distinguished**, or worse, if:
- **$B_{\odot}$** → small, or
- $m_{ax} > 10^{-2}$ eV/c^2 **>>** [$\mathbf{L_{coh}\, B_{\odot}}$]^2 → smaller

Therefore …

… look also at the outer solar atmosphere
for scattered bell-shaped hard x-rays!

Our suggestion … … past(?) / future:

IF the $DC_{\odot}$ fails to convert out-streaming ~axions,
but the magnetized higher latitude places do it
(in the outer sun) even more efficiently than CAST:

Solar x-ray satellite in / out of Earth's shadow:

- **off-pointing!?** *and/or*
- **large aperture x-ray detectors**

>>> hard x-rays spectral shape => direct axion signal ID!!

<u>Obs' periods of interest:</u> Quiet and active sun **>>** L_{osc} **=?**

>> targeting not the initial place of the $DC_{\odot}$ (see PLB, 1996),
but instead the entire solar magnetized bands at ~± (5°-40°)!!

F.O.M.: $DC_{\odot}$ only (directly) *vs.* ~whole sun (indirectly)

→ **0?** ≠0

Search for a QCD-inspired solar axion component (hard x-rays)
@ the upper end of the mainly soft solar power-law spectra.

- **axions:** conversion above / below solar surface**!?**
  → **ID >>** *different spectral shape*:
  → peaking at ~4keV *vs.* exponential **>>> p.t.o.**

- **Chameleons:** maximum emission at ~0.6 keV

Note:

SPHINX observed: **>> 1.71MK** (minimum T_{corona})

>> ~2.7MK

>> ~8MK

Within the ~axion scenario:

- **down-comptonization initiation at different depths**

Obs': B_{QS} → at larger depths

solar Chameleons

↓

>> A ~revised–relaxed axion scenario →

Further reading:

Solar chameleons

P. Brax, K. Zioutas,
Phys. Rev. D82 (**2010**) 043007

Detection prospects for solar and terrestrial chameleons

P. Brax, A. Lindner, K. Zioutas,
Phys. Rev. D85 (**2012**) 043014

arXiv:1201.0079v1 [astro-ph.SR]

A chameleon helioscope

O.K. Baker, A. Lindner, A. Upadhye, K. Zioutas

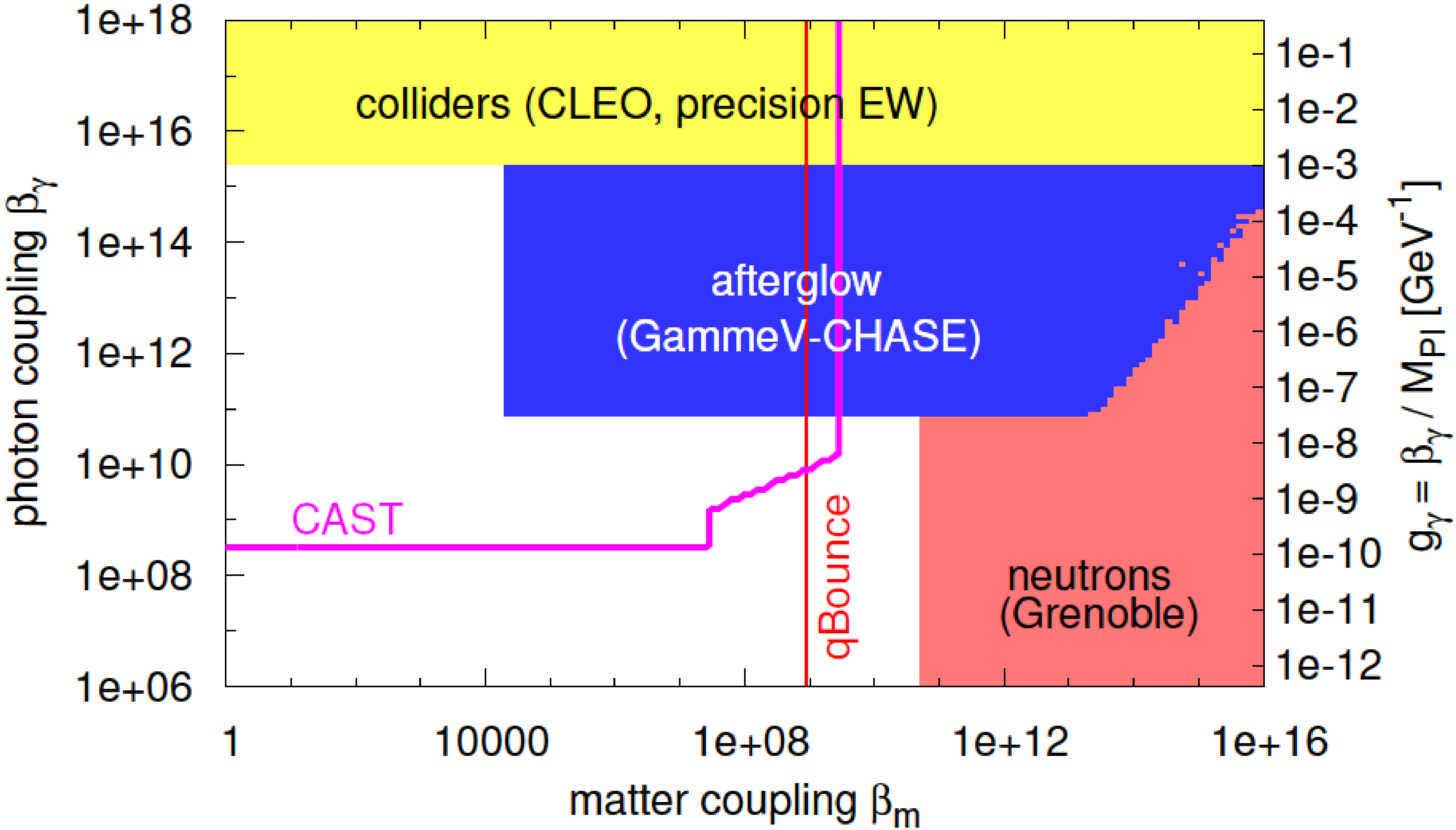
arXiv:1201.6508v1 [astro-ph.IM]

Detection of radiation pressure from solar chameleons

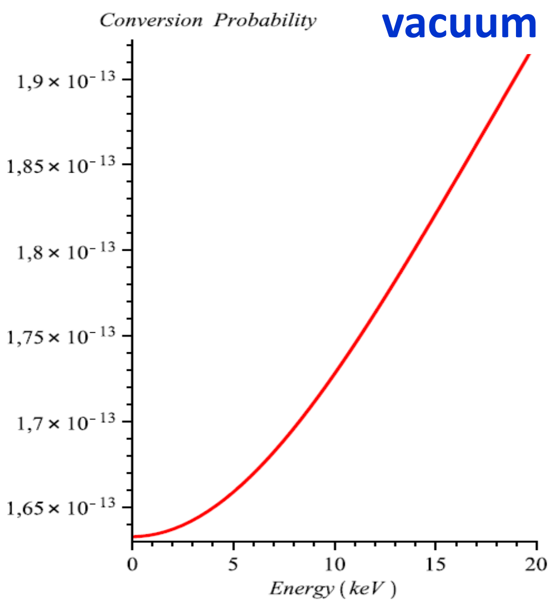
O.K. Baker, A. Lindner, Y.K. Semertzidis,
A. Upadhye, K. Zioutas

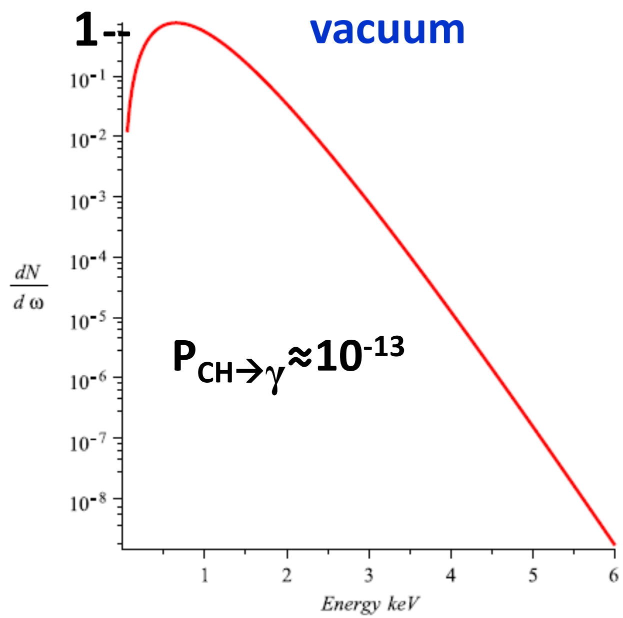
} **CH** - **matter** interaction

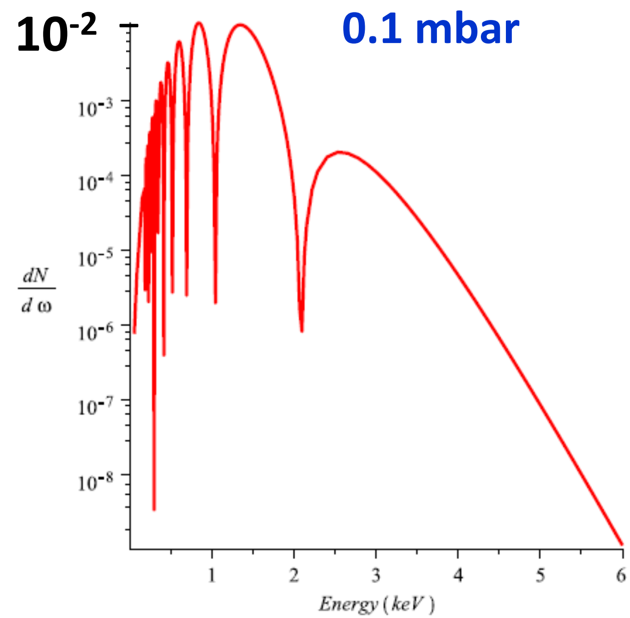
Chameleons: exclusion plot ……. defines remaining "phase space"



Converted Solar Chameleons in 82 [Tm] = CAST







CH conversion in vacuum:
$\beta_m=10^6$ / $\beta_\gamma=10^{10.32}$.

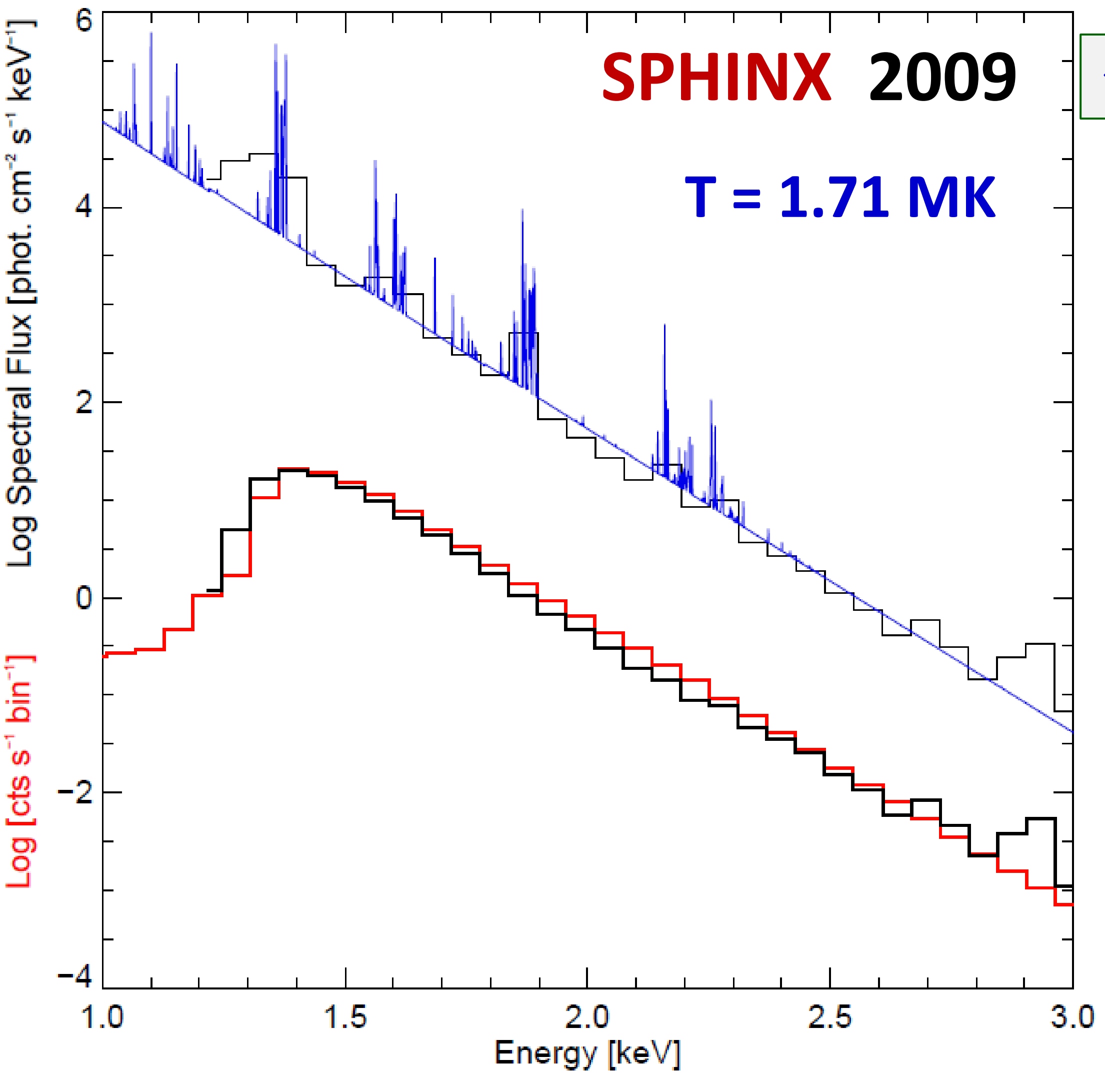
> LE saturation!

The analogue spectrum [/h / keV] of regenerated photons as predicted to be seen by CAST: $\beta_m=10^6$, $B_\odot$=30T in a shell of width 0.01$R_\odot$ around the tachocline (~0.7$R_\odot$).

Need:

sub-keV detector threshold + vacuum ⟹ **The same applies to x-ray missions!!**

The 2009 solar minimum x-ray emission



← **UNIQUE** direct measurement**!?**

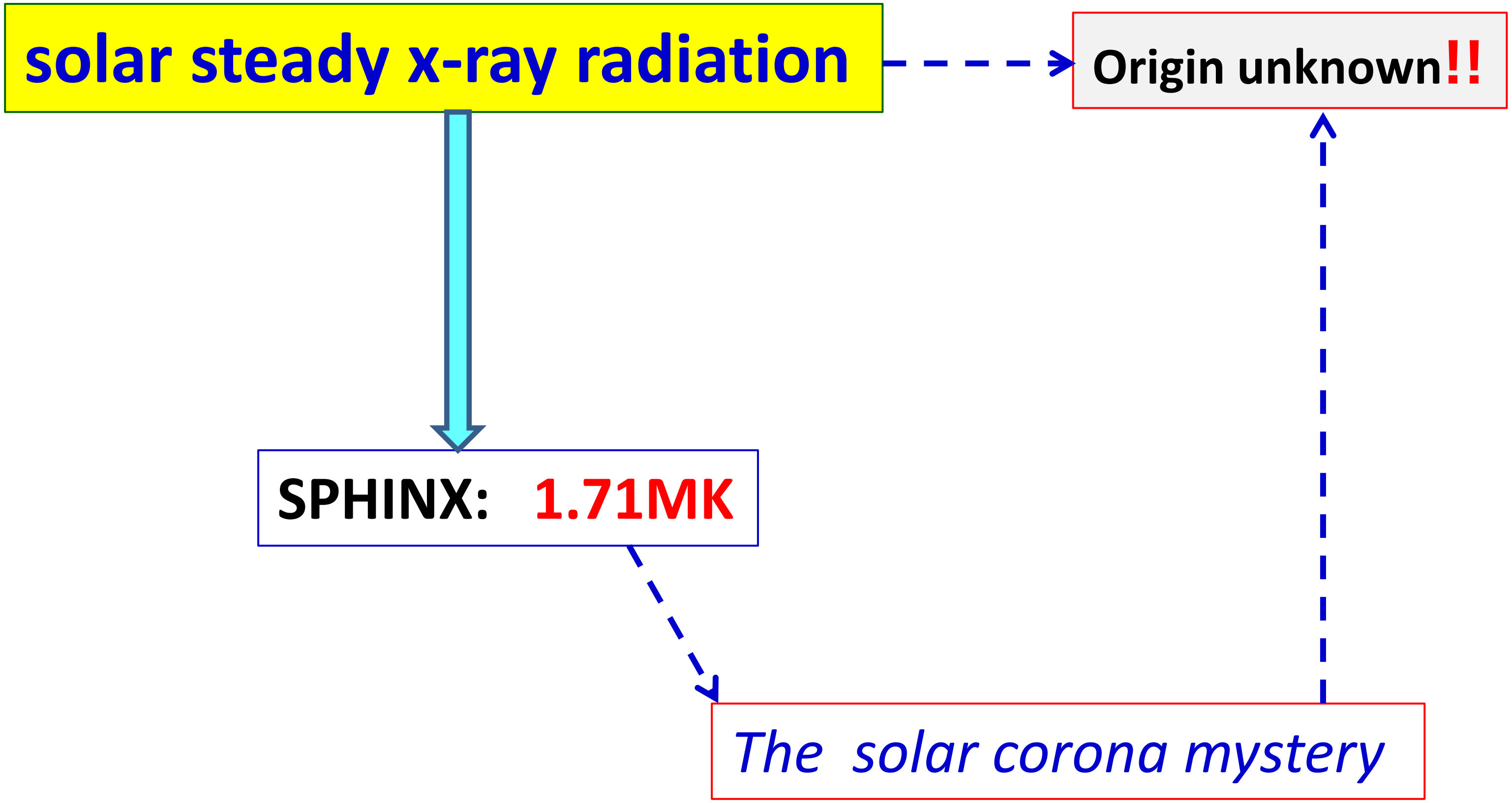
<Photon analog spectrum> (upper histogram) September 16th 2009, between 01:50 UT and 07:33 UT, … when the total **SphinX** D1 count rate was **<110 cts/s**.

The ***blue*** curve is the reconstructed.

Chameleon spectrum steeper**!?**

axions →

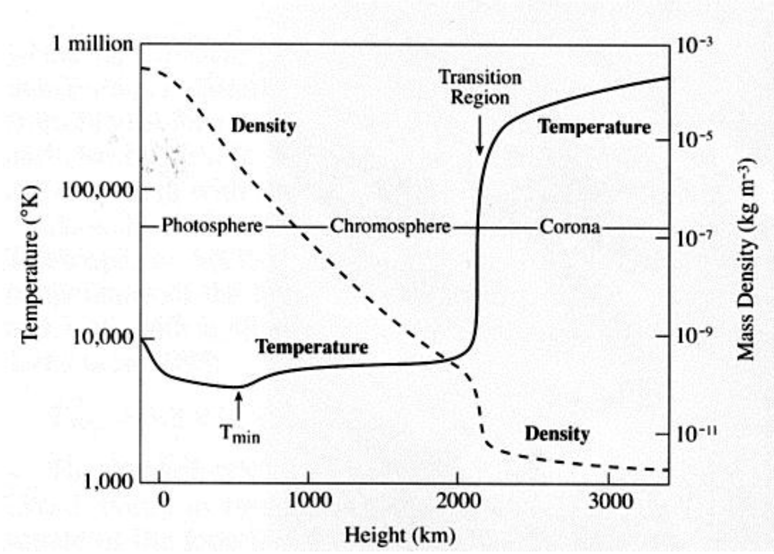
J. Sylwester *et al.*, ApJ. 751 (**2012**) 111 **DOI: 10.1088/0004-637X/751/2/111 ; arXiv:1203.6809v1 [astro-ph.SR]**


solar steady x-ray radiation
Origin unknown!!
SPHINX: 1.71MK
The solar corona mystery

SUN → the convenient lab for new physics!?

Note:

Allowed emission of exotica **< 10% L_{solar} !!**



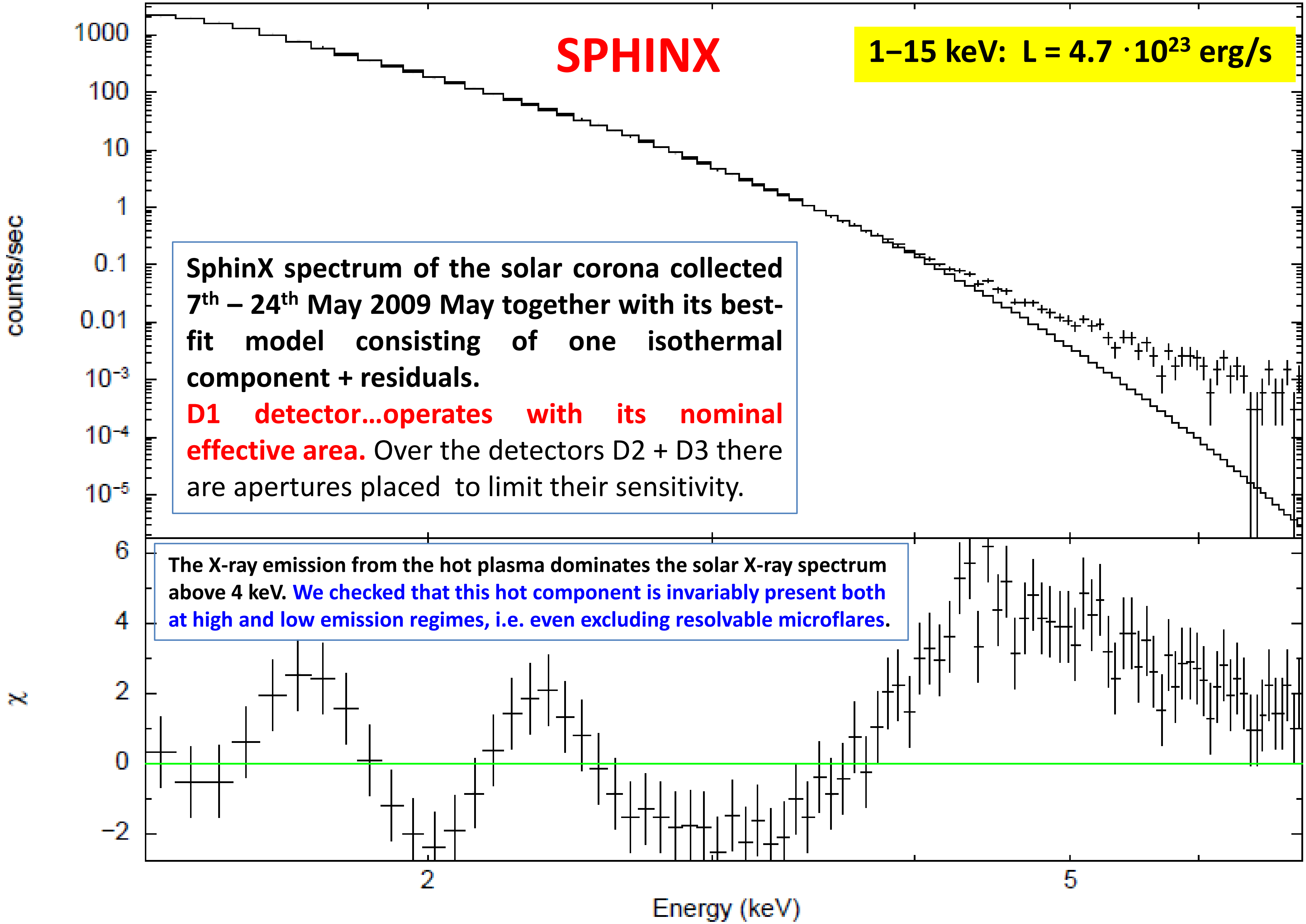
\+ gravitational self-trapping of massive ~axions
→ (yield $\sim 10^{-7}$)

→ accumulation over 4.5 Gyears
-> **afterglow / self-irradiation >> T.R.**

Massive solar exotica:

L.Di Lella, K.Zioutas, Astroparticle Physics 19 (2003) 145 — **KK-axions**
M. Cicoli, M. Goodsell, A. Ringwald, JHEP 1210 (2012) 146 — **ALPS**
K. Arisaka, …, R.D. Peccei, …, arXiv:1209.3810v2 (2012) — **axions / vector-bosons**

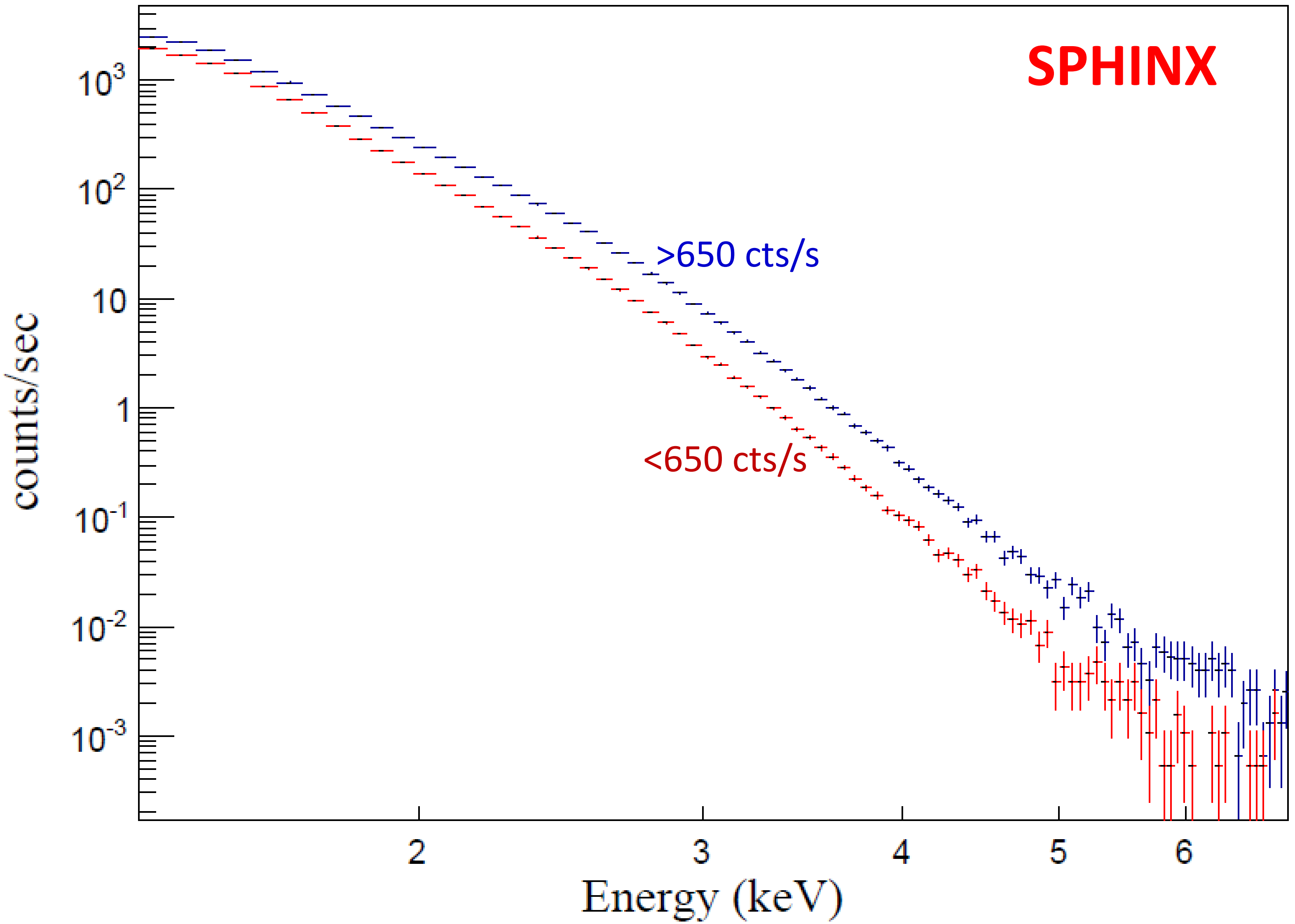
SPHINX



SphinX spectrum of the solar corona collected 7th – 24th May 2009 May together with its best-fit model consisting of one isothermal component + residuals.
D1 detector…operates with its nominal effective area. Over the detectors D2 + D3 there are apertures placed to limit their sensitivity.

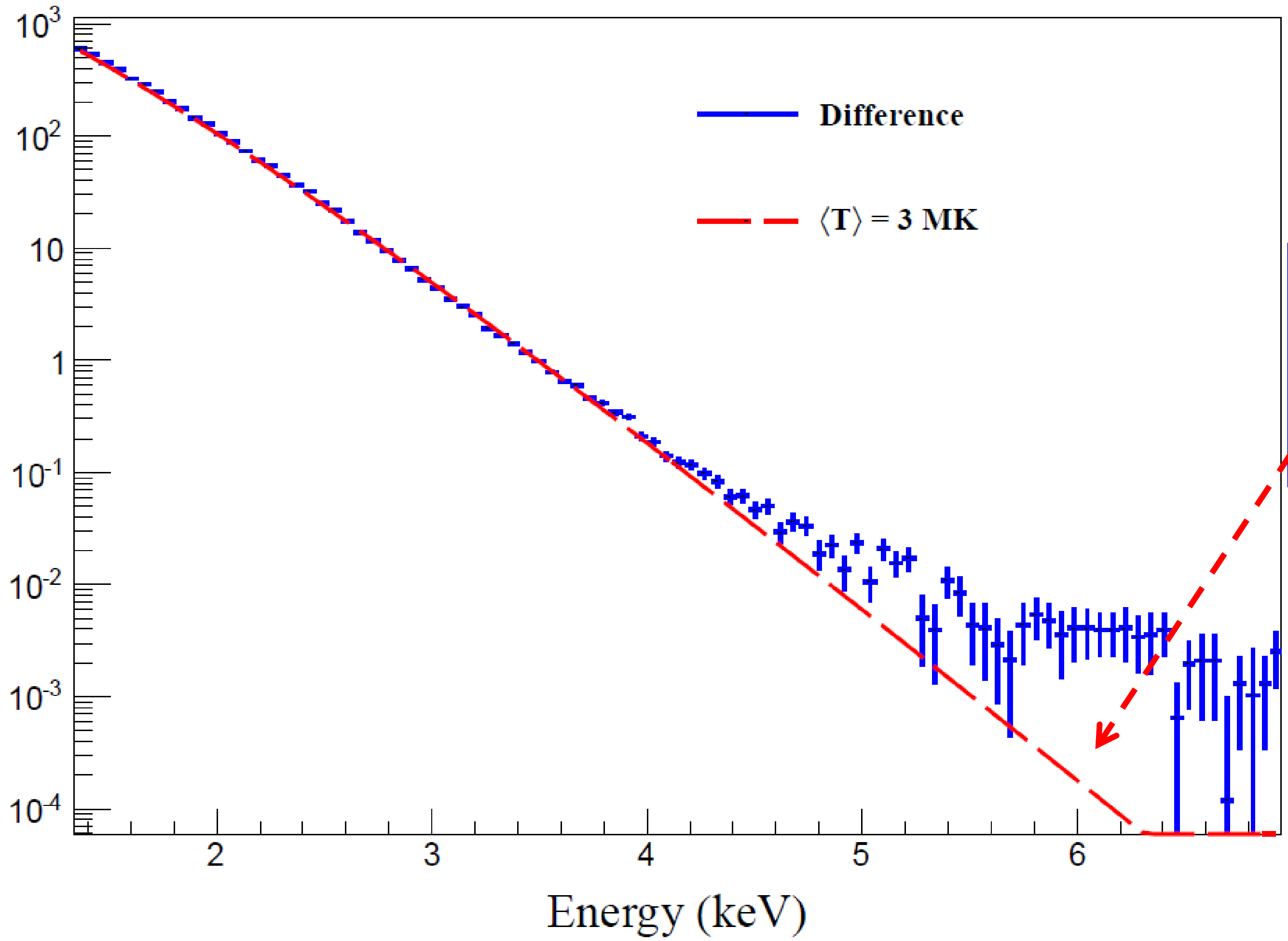
The X-ray emission from the hot plasma dominates the solar X-ray spectrum above 4 keV. We checked that this hot component is invariably present both at high and low emission regimes, i.e. even excluding resolvable microflares.

 http://xxx.lanl.gov/abs/1207.4665 see also http://xxx.lanl.gov/pdf/1203.6809.pdf



Note: <110 cts/s **>>** **1.71MK**

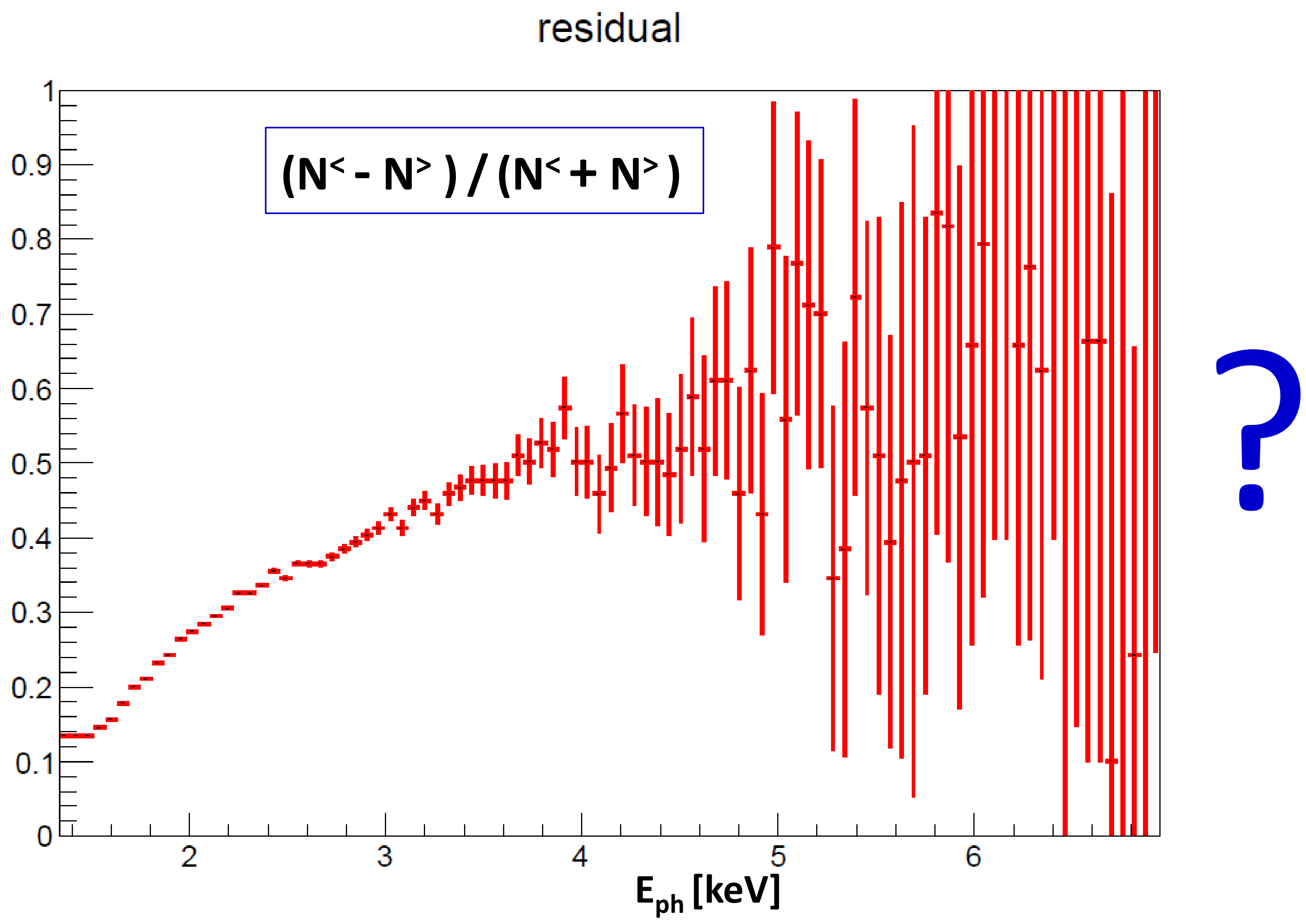
Derived from SPHINX data



~3MK = corona problem

~8MK = ?
physics reasoning??

"There is nothing in my work that requires the emission to be high_T plasma, but it is the simplest explanation. "
1st July 2009, Jimm McTiernan



Thermal OR solar axion spectral shape? >> TBD

Flares?!

Fe/Ni line intensity ratio **= Thermometer**

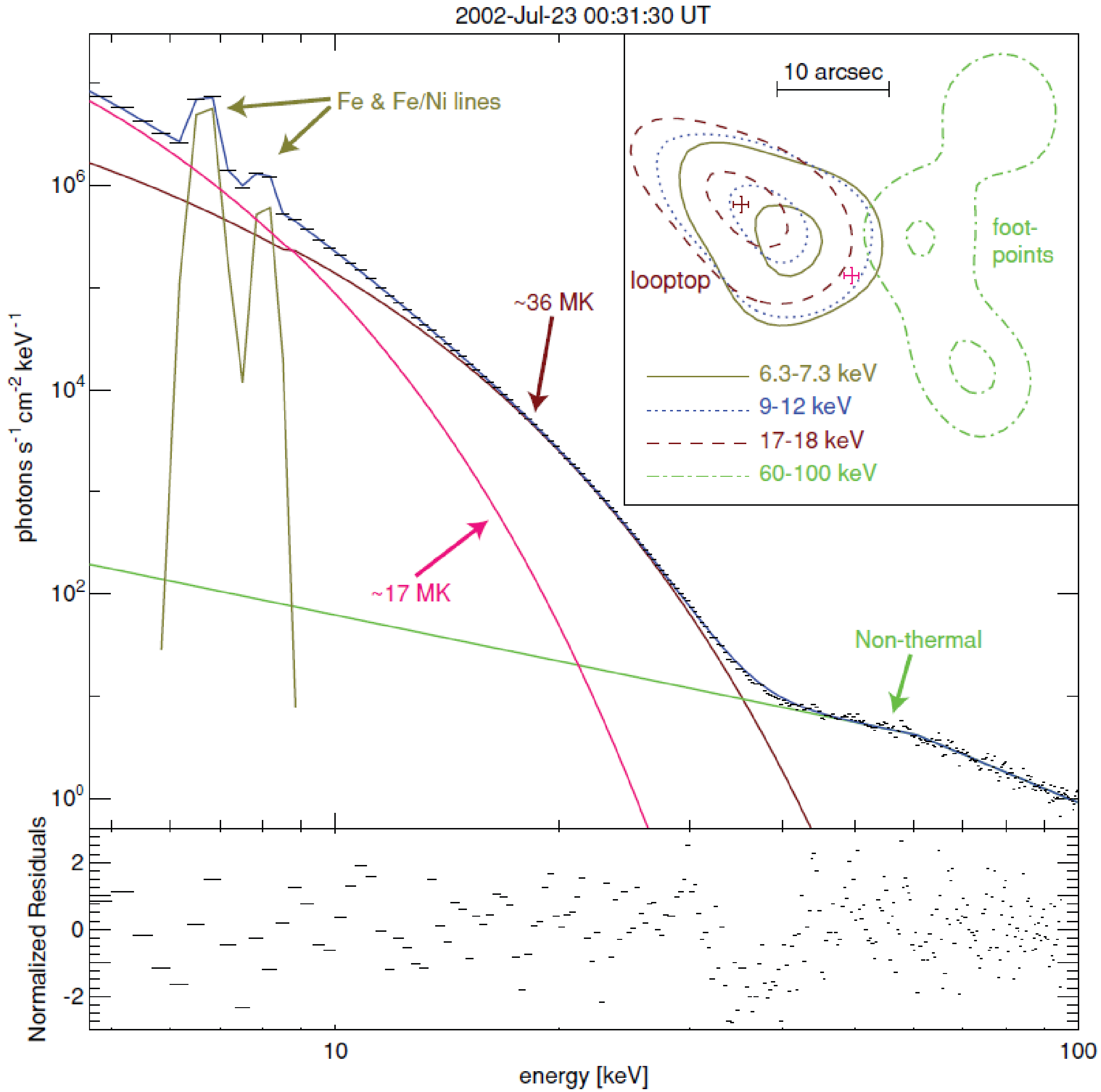


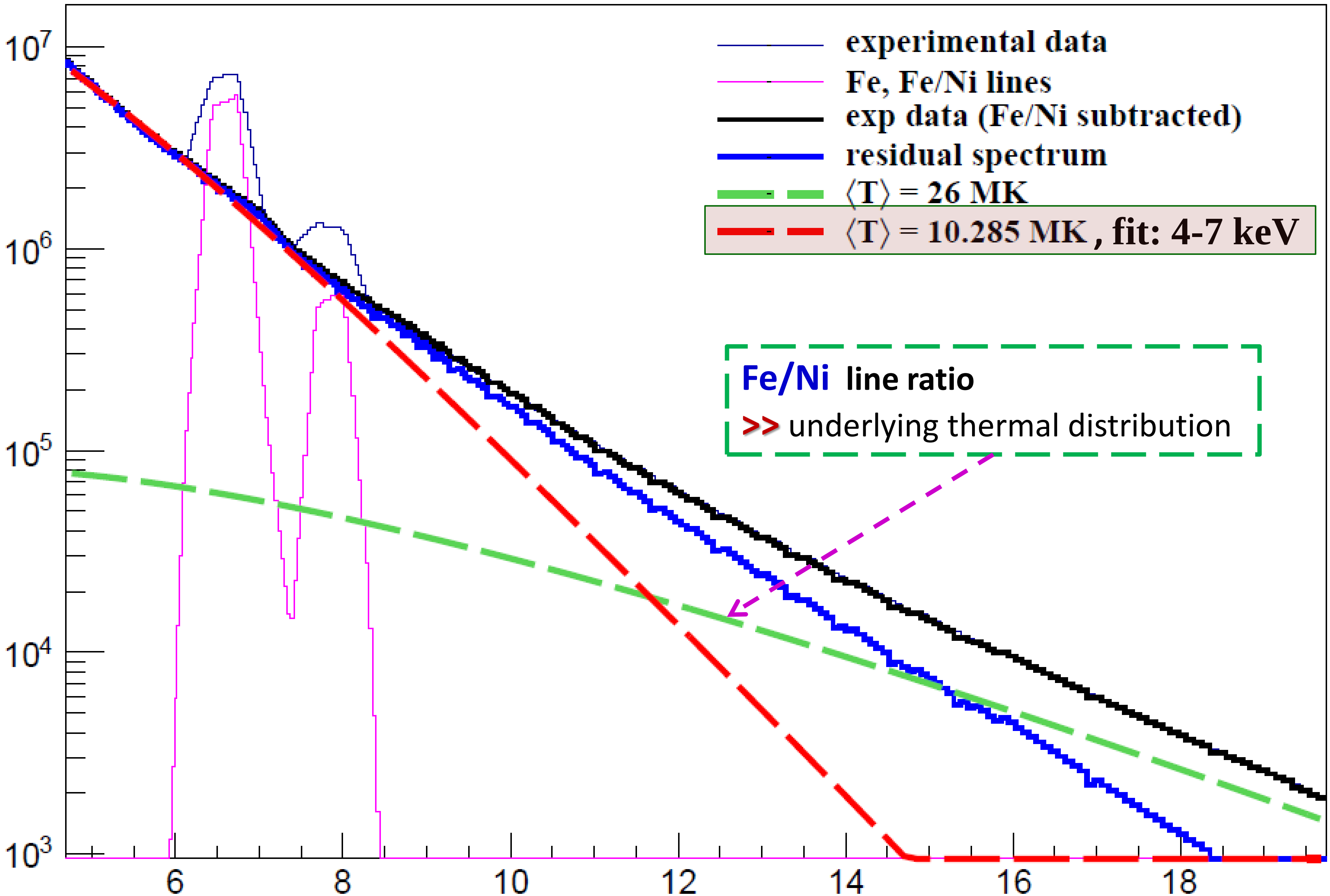
Figure 2. Photon flux spectra (black), model fit (Fe and Fe–Ni lines: olive; super-hot: brown; hot: magenta; non-thermal: green; total model: blue), and normalized residuals during the *RHESSI* SXR peak (~00:31:30 UT), when the super-hot component is strongest. Inset: 50% and 90% contours of 6.3–7.3 (olive solid), 9–12 (blue dotted), 17–18 (brown dashed), and 60–100 keV (green dot-dashed) images at the same time; the crosses denote the derived centroid locations (and uncertainties) of the super-hot (brown; left) and hot (magenta; right) components.

Caspi dissertation 2010

http://iopscience.iop.org/2041-8205/725/2/L161 **2010**

X-ray Flare

experimental data



Conclusion:

At the quiet and the flaring sun

>> **present** a **~10MK** thermal component**!?**

Summary

- Solar axions or other similar exotica (dark matter)
- Solar chameleons or other similar exotica (dark energy)
- Solar paraphotons (Hidden Sector)
- Primakoff- effect
  - Axions / CHs → (soft) X-ray photons @ $\mathbf{B_\odot}$
    $\mathbf{B_\odot}$ -> ***as the catalyst and not the energy source of solar activity***
- Massive solar exotica (m ≈ keV/c^2)
  - gravitationally self trapping + spontaneous radiative decay
    - X-ray afterglow + self-irradiation of the Sun >> TR's T / ρ steps?
- Unexpected solar X-rays since 1930s: *the* problem!
  - quiet / active sun → SPHINX 2009 => unique
  - conventional *vs.* axion scenario >> an alternative for both thermal components
- Compton thin/thick far/near corona: (in)direct $\mathbf{B_\odot}$ - ~*a*/CH conversion
- Signal for physics beyond the Standard (Solar) Model ➔ **New Physics!**
- **Of potential interest:** spicules, prominences, solar wind, CMEs, ...

Thanks Sun!!

Some additional slides

Axions *vs.* Chameleons … *vs.* WIMPs?

The **axion** is a hypothetical elementary particle postulated by the Peccei–Quinn theory in 1977 to resolve **the strong CP problem** in QCD. If axions exist and have low mass within a certain range, they are of interest as a possible component of **CDM**.

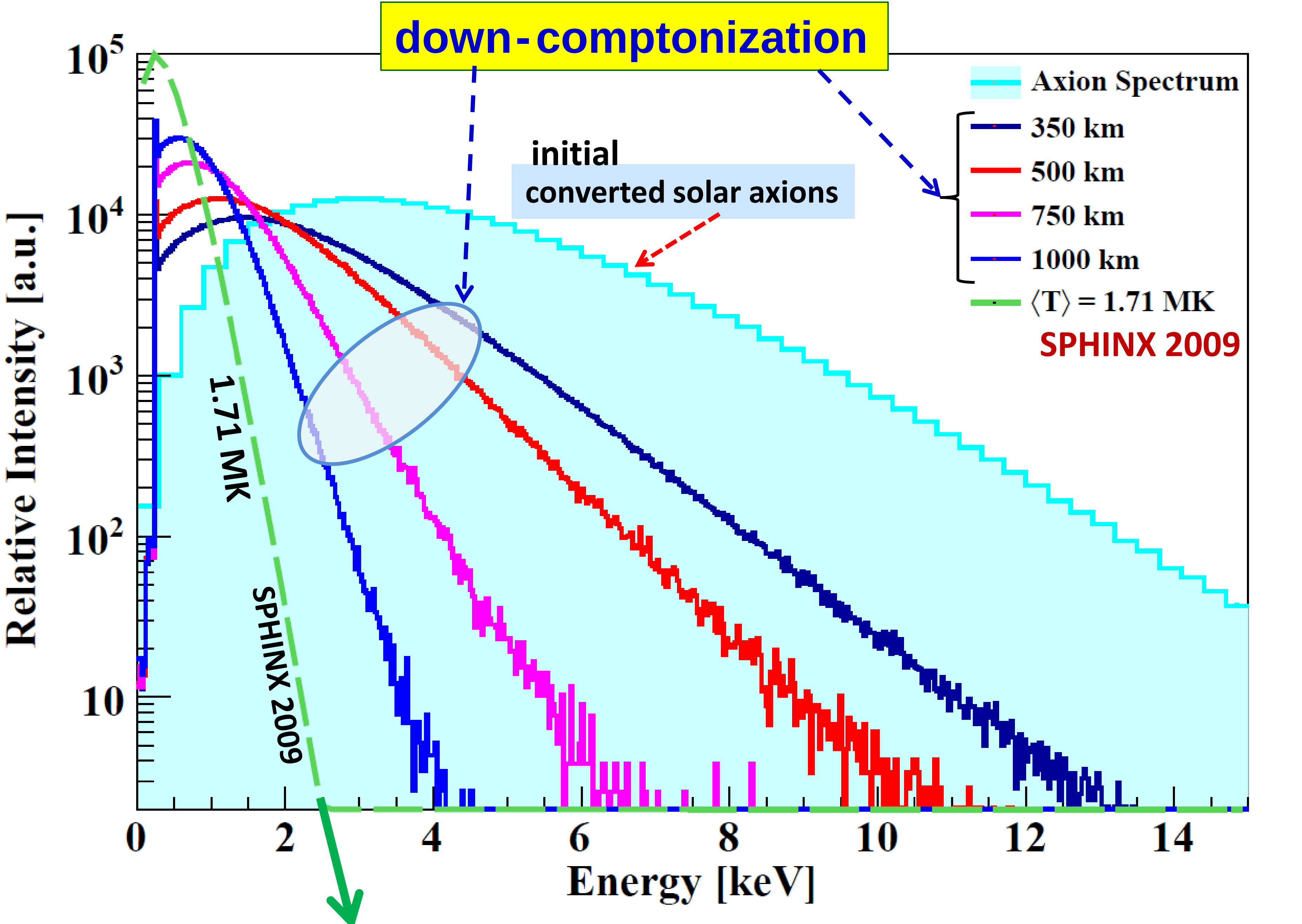
http://en.wikipedia.org/wiki/Axion

The **"chameleon"** is a postulated scalar particle with a non-linear self-interaction which gives the particle an **effective mass** that depends on its environment. It would have a small mass in much of intergalactic space, but a large mass in terrestrial experiments, making it difficult to detect. The chameleon is a possible candidate for **DE + DM** …

http://en.wikipedia.org/wiki/Chameleon_parti

Detection via Primakoff- effect (***a***, **CH**) ➔ radiation pressure (**CH**)

➔ Lab-experiments (LSW), Helioscopes, Haloscopes ➔ afterglow, radiation pressure



m_{ax}~17 meV

from WDs (also recently)

X-raying hot plasma in solar active regions with the SphinX spectrometer

M. Miceli[1,2], F. Reale[1,2], S. Gburek[3], S. Terzo[2], M. Barbera[1,2], A. Collura[2], J. Sylwester[3], M. Kowalinski[3], P. Podgorski[3], and M. Gryciuk[3]

http://xxx.lanl.gov/pdf/1207.4665.pdf

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Received September 15, 1996; accepted March 16, 1997

➔ 2009 data taking

thesoft, 1.34–3keV, to hard (3–7keV) flux ratio is ∼1000 in the LR spectrum and ~ 500 in the HR spectrum. This result supports a possible link between high count-rate + microflare activity.

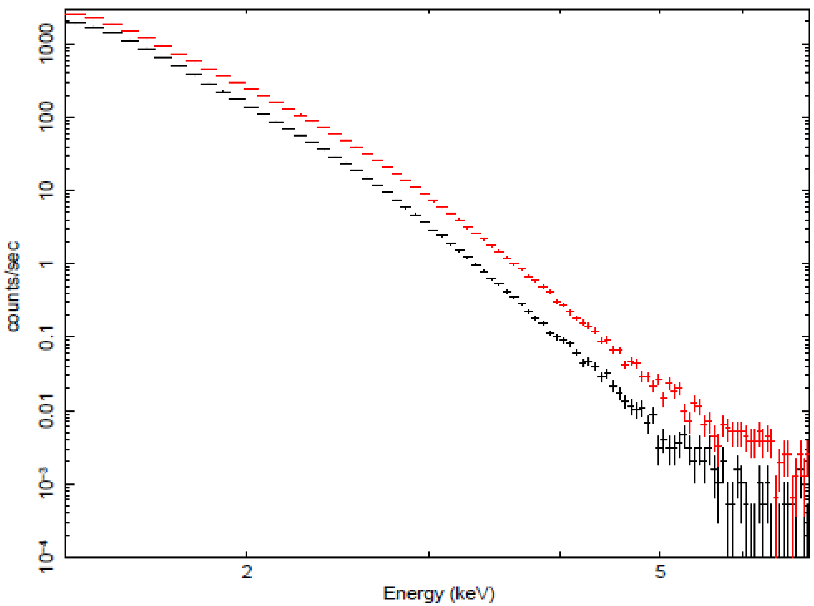


Figure 5. SphinX spectrum of all the events detected at low count-rate (< 650 s^{-1}, black crosses) and at high count-rate (> 650 s^{-1} red crosses) between 2009 May 7 and 2009 May 24.

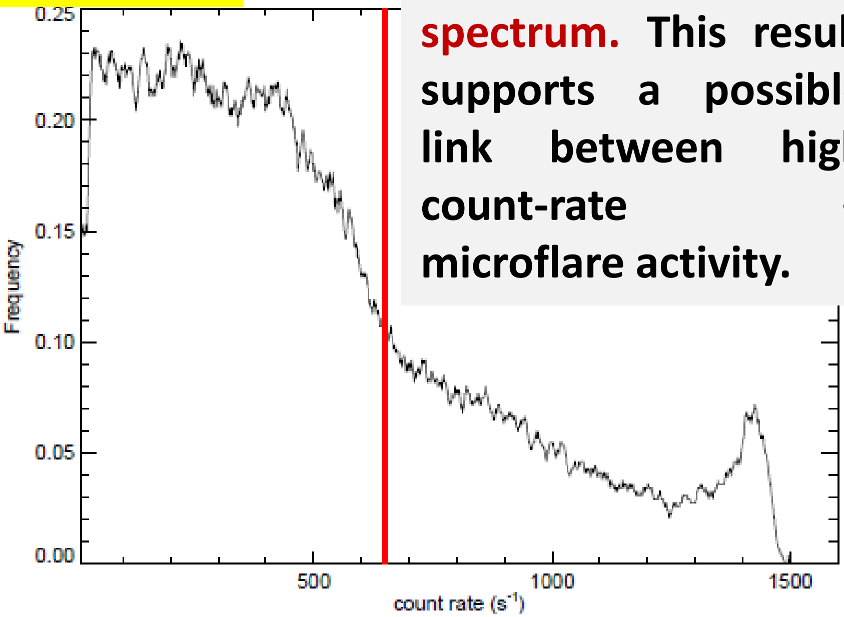
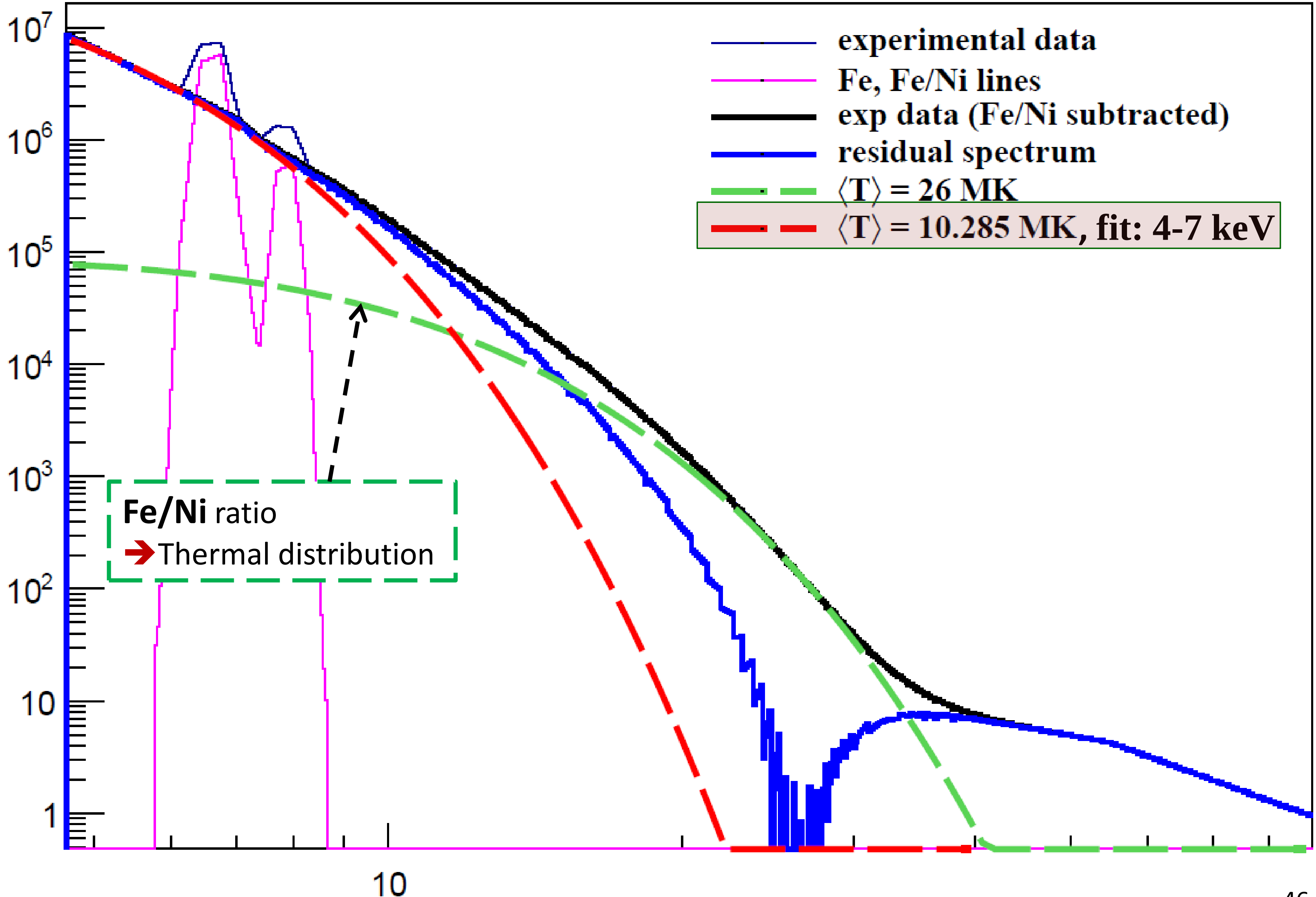


Figure 4. Distribution of the X-ray count-rate observed by SphinX between 2009 May 7 and 2009 May 24. The red vertical line indicates the threshold chosen to extract the low count-rate spectrum and the high count-rate spectrum (see text).

X-ray Flare



10⁷
10⁶
10⁵
10⁴
10³
10²
10
1
10
experimental data
Fe, Fe/Ni lines
exp data (Fe/Ni subtracted)
residual spectrum
⟨T⟩ = 26 MK
⟨T⟩ = 10.285 MK, fit: 4-7 keV
Fe/Ni ratio
➔ Thermal distribution