Signatures of ~axions in astrophysical observations

→ QSOs, PVLAS @ ~eV
→ linear polarization → ~axions
→ favour ~ eV?

→ ww indirect DM searches @ HE
For axions a few

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+ collaboration also with:

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...

CAST motivated

⇒ more are welcome!
good solar news:

⇒ sun exceptionally active
since 8000 years!
Reconstructed sunspot number, 10-year averaged SN reconstructed from $\Delta^{14}C$ data since 9500 BC (blue) and 10-year averaged group sunspot number (GSN) obtained from telescopic observations since 1610 (red). The horizontal dotted line marks the threshold above which we consider the Sun to be exceptionally active.

We are living with a very unusual sun at the moment. Similar period occurred ~8000 years ago. Sunspots are more frequent now than at any time for more than 8000 years.

Sunspots ➔ fierce magnetic activity inside

1944- Exceptional Solar Activity since 8k years ➔ <76 SN / year>

Usoskin... PRL91(2003)211101
New Scientist: http://www.newscientist.com/article.ns?id=dn4321

Jenny Hogan
solar X-rays

!unexpected!
RHESSI Observations of the Quiet Sun
Iain Hannah Submitted: 27-Apr-2006 13:47

Description: We are using RHESSI's excellent sensitivity in 3-100 keV to determine the X-ray spectrum of the non-flaring, spotless, active-region-free Sun, i.e. the quiet Sun. RHESSI's normal imaging method is not suited to measuring signals that are potentially widely distributed across the Sun, so instead we have had to adopt a novel offpointing technique. By making RHESSI point slightly away from the Sun the quiet Sun signal is modulated against the background allowing it to be measured directly. However the quiet Sun signal is still weak and we need to accumulate a lot of data to determine whether we have an actual signal or only noise upper limits. We have been able to put RHESSI into this offpointing mode 4 times so far (up to April-2006) during periods of low activity and have determined that the technique works and have preliminary quiet Sun spectra. These spectra are not of the quietest possible times however, and so this work is an ongoing investigation, with us planning further offpointing periods as we pass through Solar minimum. See http://sprg.ssl.berkeley.edu/~tohban/nuggets/?page=article&article_id=16 for more information.

Participants: Hannah, I.G., Hurford, G.J, Hudson H.S, Lin, R.P
The observational limits on the quiet-Sun X-ray spectrum from previous data and from our preliminary RHESSI estimate using the offpointing technique, as detailed in this Nugget. Only RHESSI can put useful limits in the 3-17 keV range, but we can compare the limits to the 1966 balloon data above 17 keV. The SXT values are extrapolated from observations at 1.6 keV assuming temperatures of either 1.1 MK (dotted) or 1.3 MK (dashed).

http://sprg.ssl.berkeley.edu/~tohban/nuggets/?page=article&article_id=16
Observational evidence for gravitationally trapped massive axion(-like) particles

Reconstructed X-ray spectrum

$\rightarrow$ non-flaring Sun @ solar minimum [X].


Solar KK-axions,
Observational evidence for gravitationally trapped massive axion(-like) particles

Reconstructed X-ray spectrum

→ non-flaring Sun @ solar minimum [X].


The relation between the solar soft X-ray flux (below ~4.4 keV) ...and B can be approximated by a power law with an averaged index close to 2.


Note: axion-to-photon oscillation $\propto B^2$ e.g., in CAST


$\Rightarrow$ 11 years solar cycle?
The long-term evolution of AR 7978 (S10°) → Yohkoh / SXT

X-ray flux outside flaring times in AR7978

- increased steeply @ flux emergence
- decreased @ decay phase


<X-ray flux> / (cm²-AR7978) vs. magnetic field <B>(=total magnetic flux / ARsurface).
Solid line: the linear fit; dotted lines: the 3σ error in the slope of the solid curve. Only the decaying phase (diamonds) is included in the fit → July-Nov. 1996

The only sizable and long-lived AR on the solar disk @ 5 solar rotations

→ it produced 3 slow CMEs + 3 major flares

if solar X-rays from axions …

1) enhance low energy axions?
2) axion-to-\(\gamma\) near solar surface

⇒ both, how?
Magnetic fields simulated. The amplitudes of the fields have been normalized by their maximum intensity.


solar axion spectrum: B ignored sofar!
The inner SUN

\[ \hbar \omega_{\text{plasma}} \approx 300 \text{eV} \]

\[ \hbar \omega_{\text{plasma}} \approx 7 \text{eV} \]
\[ \ell_{\text{abs}} \approx 10 \text{ cm} \]
\[ T \approx 2 \text{ MK} \]

\[ \hbar \omega_{\text{plasma}} \approx 1 \text{eV} \to \ell_{\text{abs}} \approx 20 \text{ m} \]

\[ \hbar \omega_{\text{plasma}} \approx 10^{-2} \text{eV} \to \text{surface} \]
\[ \ell_{\text{abs}} \approx 100 \text{ km} \]

If \( \hbar \omega_{\text{plasma}} \approx m_{\text{axion}} c^2 \) \( \rightarrow \) resonance crossing
\( (\text{Primakoff})_B \gg (\text{Primakoff})_{\text{Coulomb}} \)

New solar axion spectrum?

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

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

M. Schüßler, M. Rempel
Sunspots = “dark spots”

Photosphere

\[ T \approx 4500 \text{K} \]

heat flux problem

in umbra + penumbra


Corona

Soft X-ray fluxes

\[ \begin{align*}
\text{Sunspots:} & \quad \sim 50 - 190 \text{ DN/s} \\
\text{Quiet Sun:} & \quad \sim 10 - 50 \text{ DN/s} \\
\text{(ARs:} & \quad \sim 500 - 4000 \text{ DN/s})
\end{align*} \]

Sunspot plasma parameters are higher than @ quiet-Sun

\[ B \approx 2 \text{ kG} \]

above most sunspots!

“... sunspots remain mysterious”.

The penumbral mystery … the very reason for its existence unknown.

Most successful models assume: the variations of the total solar irradiance are essentially caused by the evolution of the solar surface magnetic field *). Figure illustrates a dip in total solar irradiance due to the passage of a sunspot group across the solar surface.


The physical cause of these variations remains a subject of debate & There is strong evidence that the magnetic elements with higher flux are LESS bright ➔ Conclusion: solar-surface magnetic field is the main driver of the solar irradiance variability.
mimic CAST @ $B_{\text{solar-surface}}$?

+ transient phenomena

Thus:

• steady component $\rightarrow$ decays
• variable component $\rightarrow$ $\alpha \leftrightarrow \gamma$ conversion

2nd solar X-ray component
X-ray mysteries:

- **Class 0 protostar**
  - (10-100 kyears)
  - origin of X-rays (<10 keV):
    - matter is falling 10x faster?
    - 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/0602072

- **XRB radiation**
  - origin?
In stellar physics:

→ Similar-to-Sun logic = wrong

e.g.: to explain energetic flare of a 10-100 kyears Sun.
High-energy spectrum of **IGR J17456–2901** → XMM-Newton (1–10 keV); Isgri (20 to 400 keV). The X-ray portion of the spectrum was build by integrating over a circular region of radius 8′. The model used is an absorbed two-temperature plasma plus a broken power-law where the **low** and **high** temperature components are drawn in **red** and **green** respectively, the power-law is in **dark blue** and the 6.4 keV line is in **light blue**.

G. Belanger et al., astro-ph/200508128
The average WMAP observed and predicted radial profile for the 31 clusters. The continuum of the prediction curve is fixed by alignment with the $2^\circ$-$3^\circ$ data, which is at a level higher than that of the central $1^\circ$ data points by $9\sigma$ (Q), $4.2\sigma$ (V), and $2.3\sigma$ (W).

X-rays observ. $\rightarrow$ Hot gas properties
31 co-added WMAP cluster fields $\rightarrow$
expected S-Z effect 4x bigger $\rightarrow$ less $e^-$
$\rightarrow$ Radiative decay of massive particles,
$\rightarrow$ e.g. axions of the KK-type
$\rightarrow$ to reconcile contradiction

Gamma rays from the neutralino dark matter annihilations in the Milky Way substructures

The radiation fluxes from a dark matter halo is given by:

\[ \Phi(E) = \phi(E) \frac{\langle \sigma v \rangle}{2m^2} \int dV \frac{\rho^2}{4\pi d^2} = \frac{\phi(E) \langle \sigma v \rangle}{4\pi} \frac{\rho^2}{2m^2} \times \int_{\Delta \Omega} d\Omega \int_{1.o.s} dl(r) \rho^2(r) \]

SZ-effect \( \sim \rho_e x T_e \)
\( \Phi_{X-rays} \sim (\rho_e)^2 x (T_e)^{1/2} \)

S. J. LaBoque et al., astro-ph/200604039

Radiative decay rate \( \sim \rho \)

X.-J. Bi, astro-ph/0510714 10 Jan 2006
Axion(-like) particles:

• $m_a \sim \text{eV}$
  - PVLAS & QSO's $\rightarrow$ linear polarization $\rightarrow$
    direct detection of $\sim\text{eV}$-solar axions (CAST)
  - *visible-photon-to-axion* inside $B_{\text{solar}}$ @ photosphere
  - axion $\otimes$ forbidden atomic M1 transitions,
    e.g. *green* + *red* Fe-lines
  - *outer Sun* = source of $\sim\text{eV}$ axions?
  - *solar spectrum* below $\sim0.5\text{ keV}$ unknown

• $m_a \sim \text{keV}$
  - Kaluza-Klein axions
    - direct detection $\rightarrow$ CAST, DRIFT, SMART, …
    - indirect signatures $\rightarrow$ solar X-rays, …
      $\rightarrow$ RHESSI, SMART, …