Solar X-ray Searches for Axions

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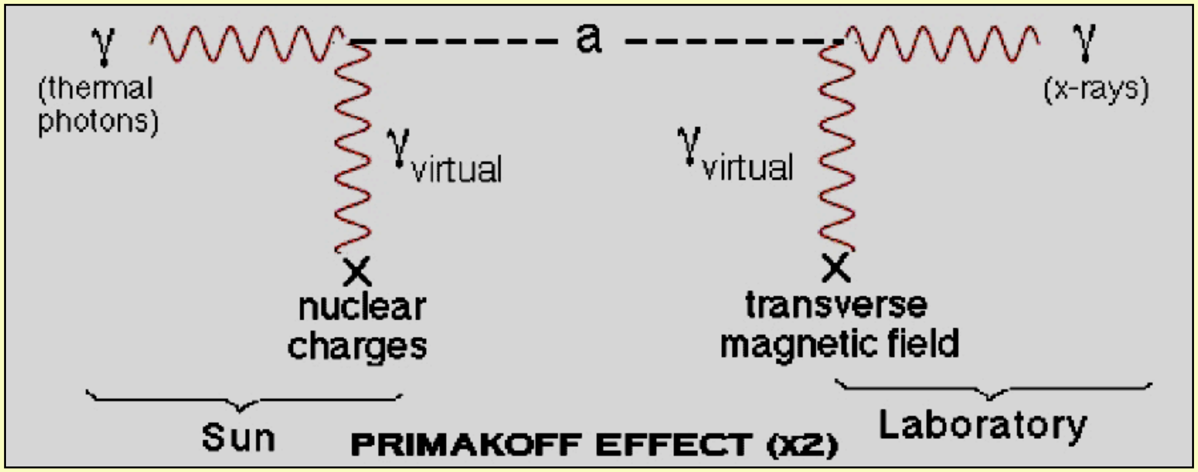
http://sprg.ssl.berkeley.edu/~hhudson/presentations/cern.090127/

Outline

- Basic ideas
- Solar tutorial
  - spectral, spatial, temporal properties
  - why the chromosphere is important
- Existing instrumentation
- Future instrumentation



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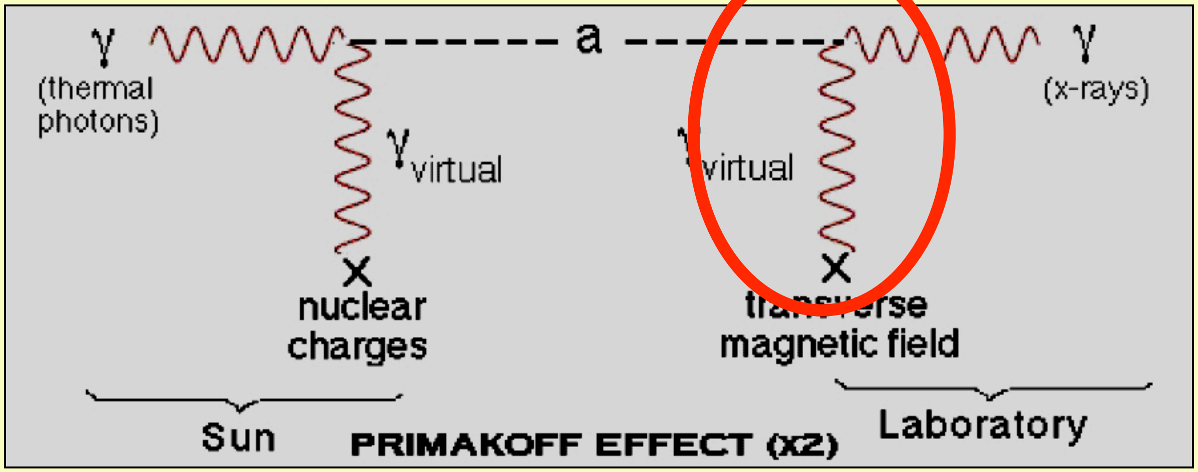
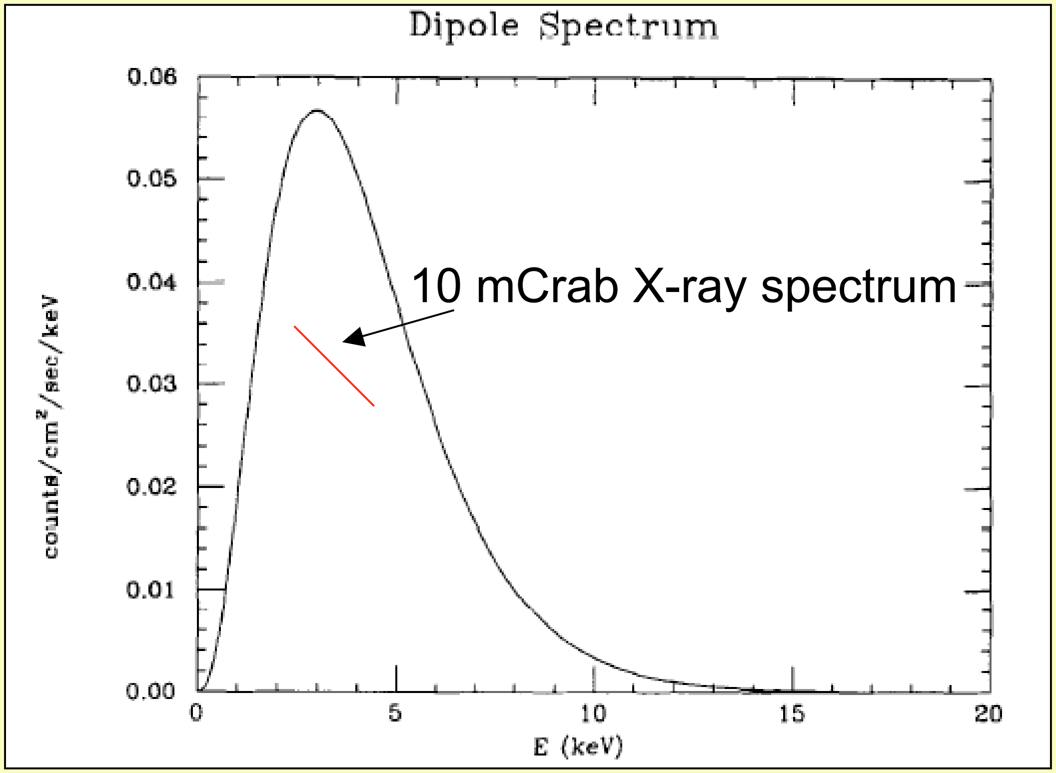
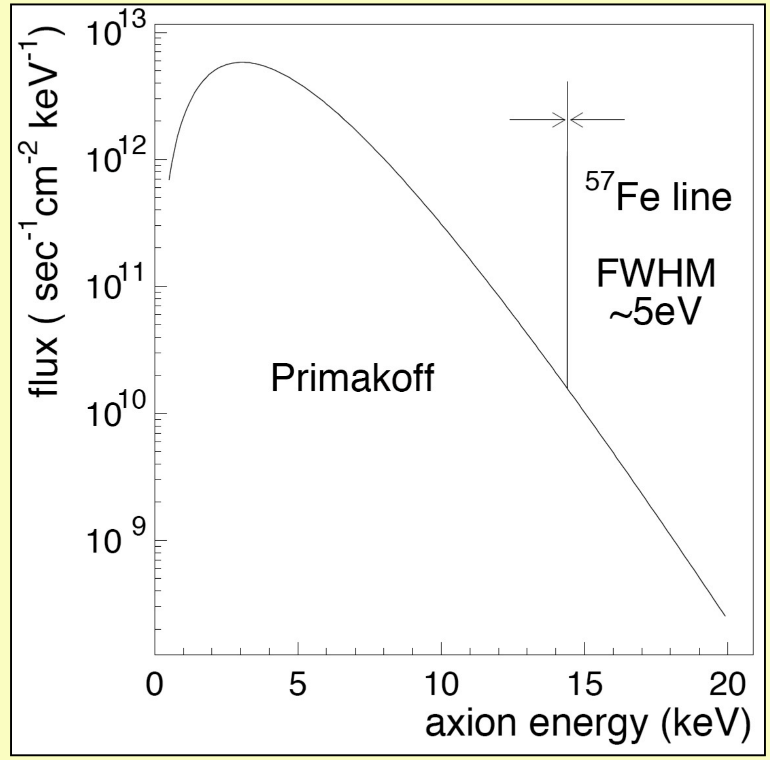
Solar atmosphere



Predicted solar fluxes



Carlson & Tseng (1996)

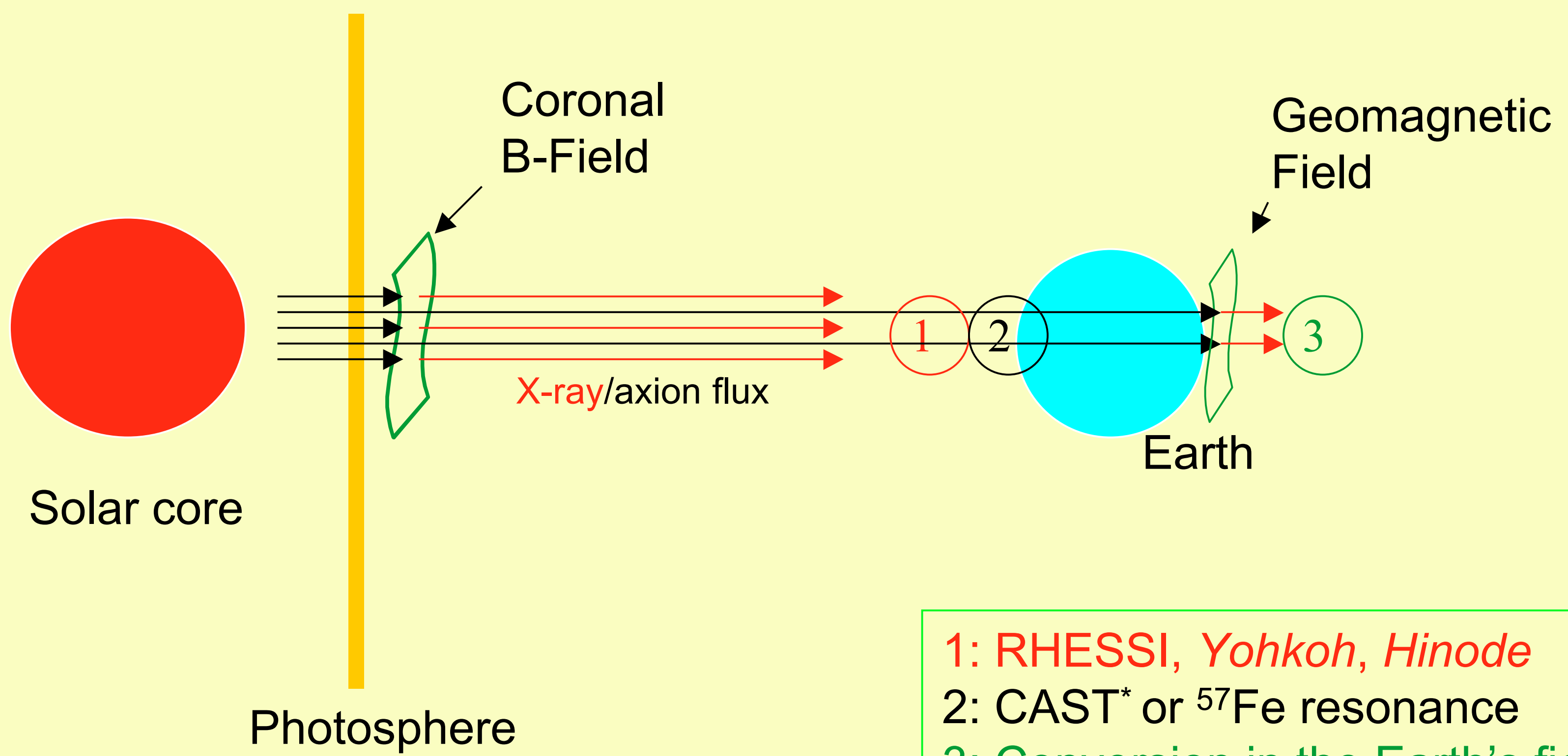


Moriyama (1996)

- The main ~5 keV emission, due to the Primakoff effect, is shown here for a specific value of the coupling constant g

- The 14.4 keV line is the γ-ray used in Mössbauer studies, here photonuclear

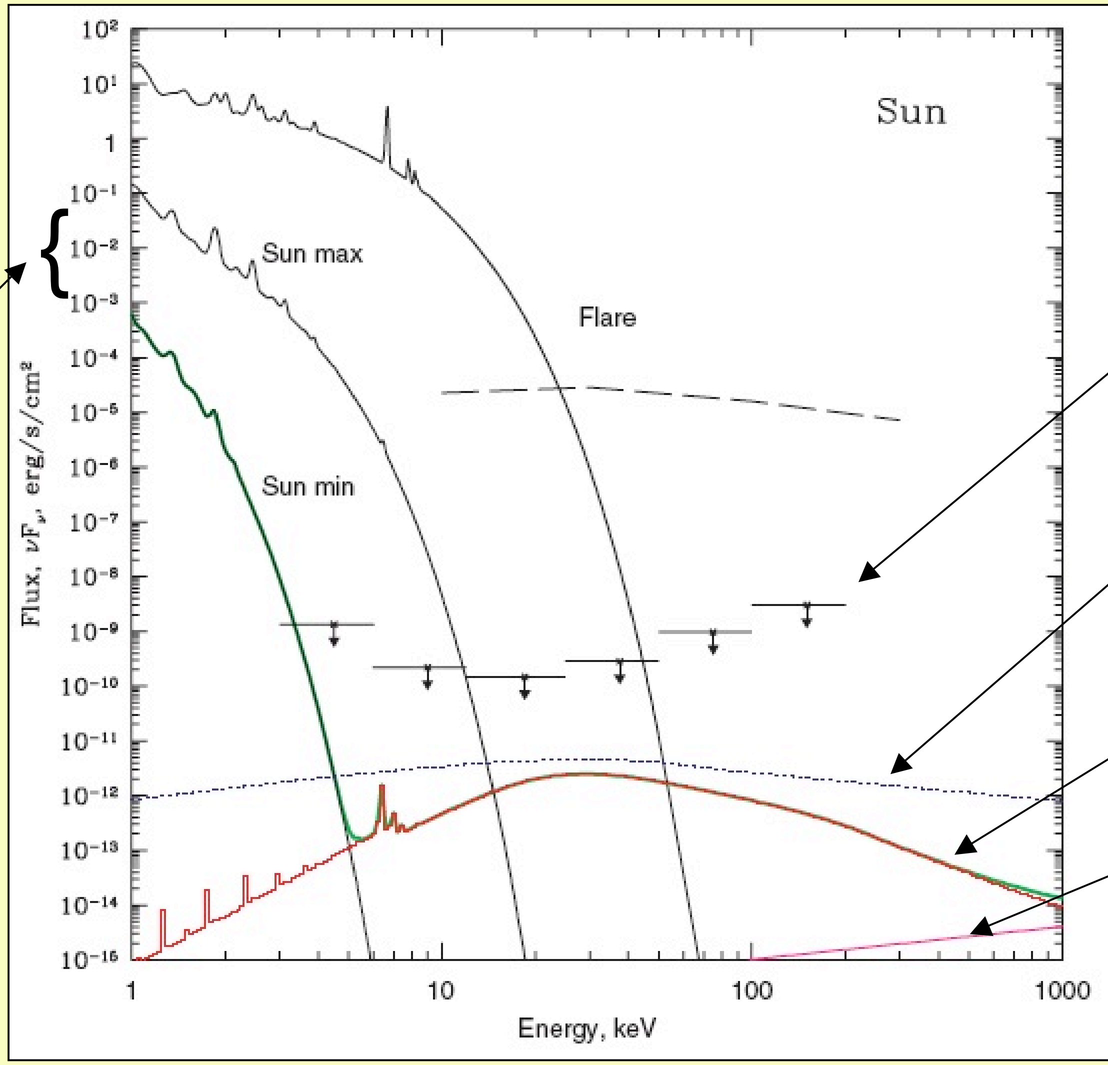
Geometries for solar axion detection



1: RHESSI, *Yohkoh*, *Hinode*
2: CAST* or ^{57}Fe resonance
3: Conversion in the Earth's field*

*Andriamonje et al. 2007
*Davoudiasl & Huber, 2005

Solar X-ray spectra



11-year cycle

RHESSI upper limits (Hannah et al. 2007)

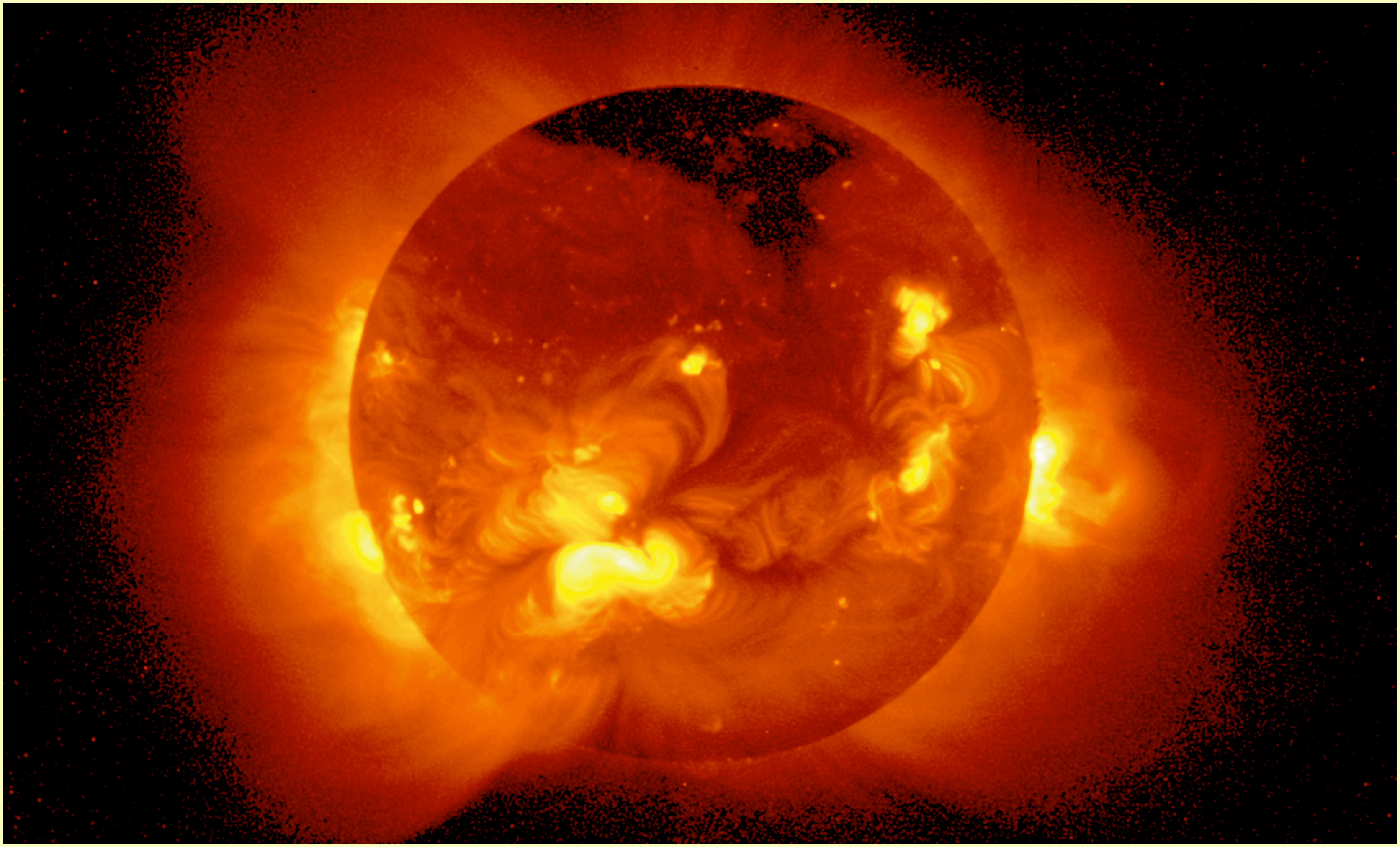
X-ray background (negative source!)

Albedo

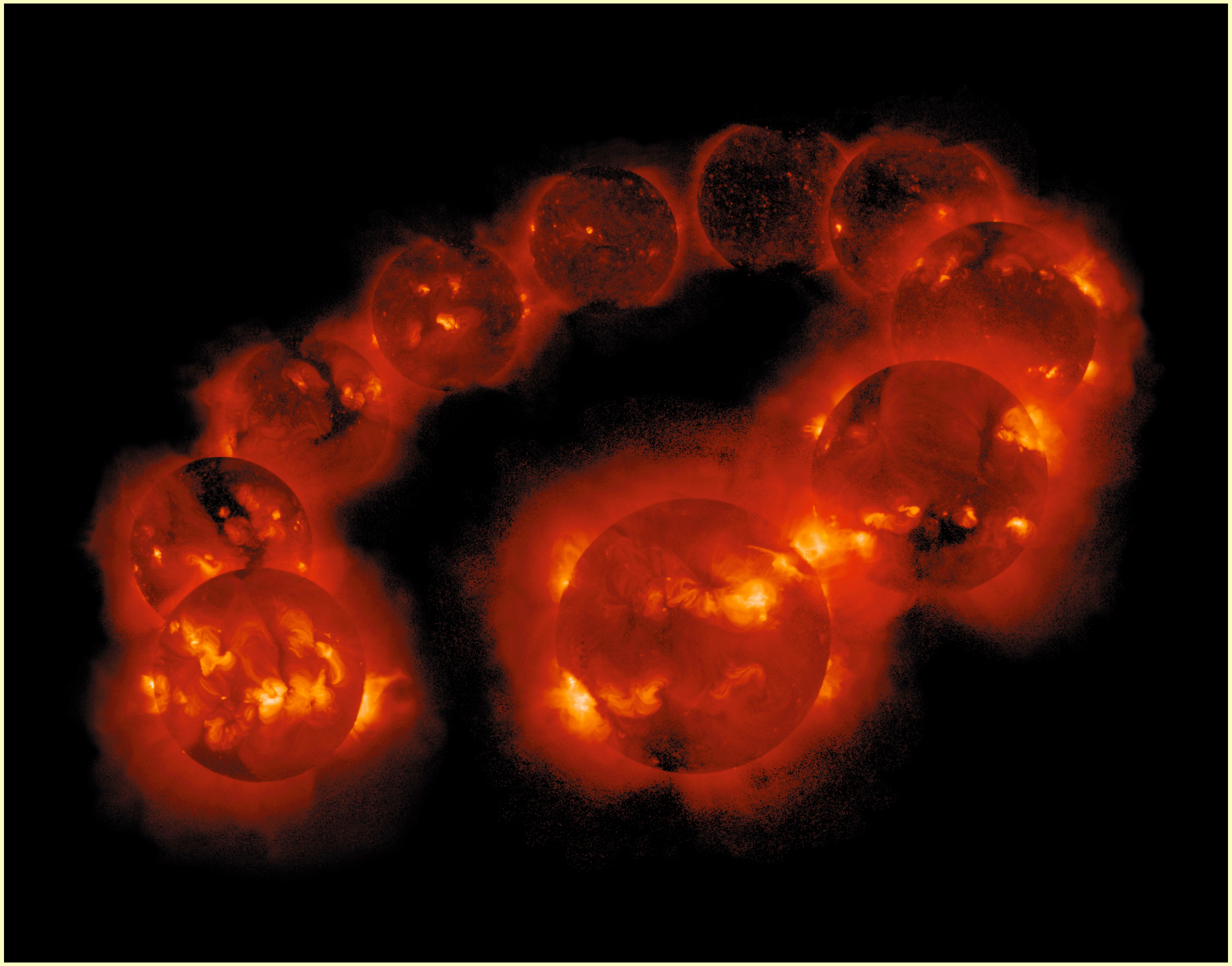
CR interactions

Churazov et al. (2008)

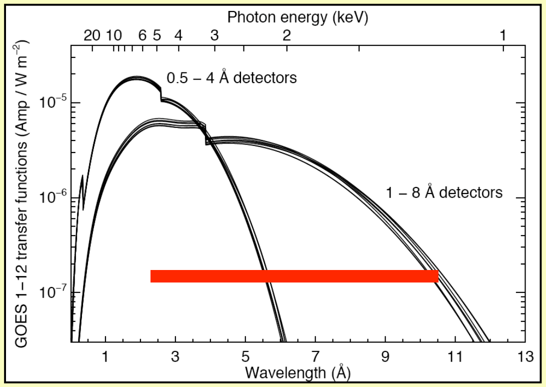
X-ray Images 1

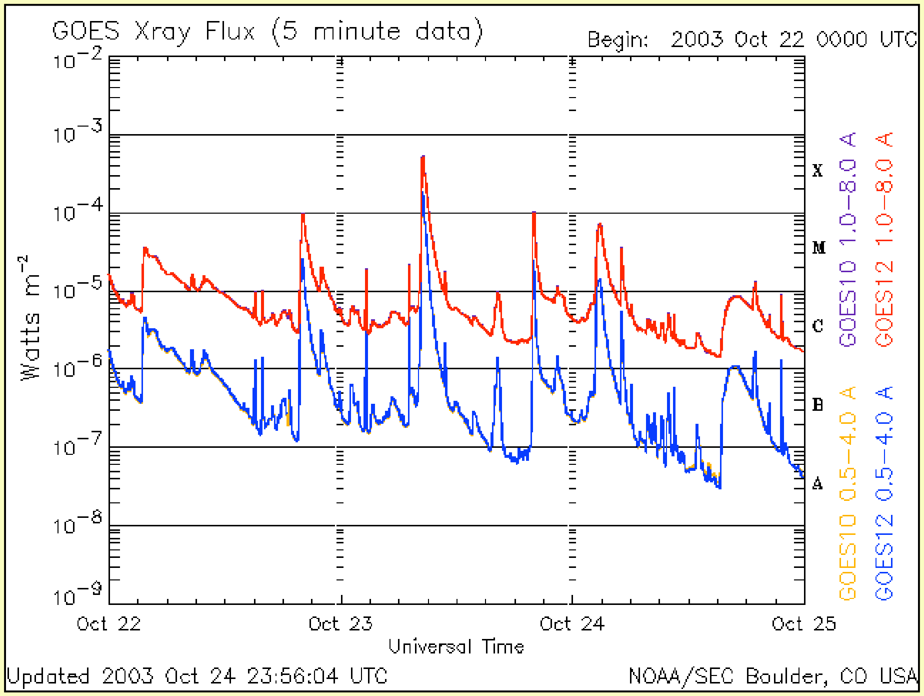


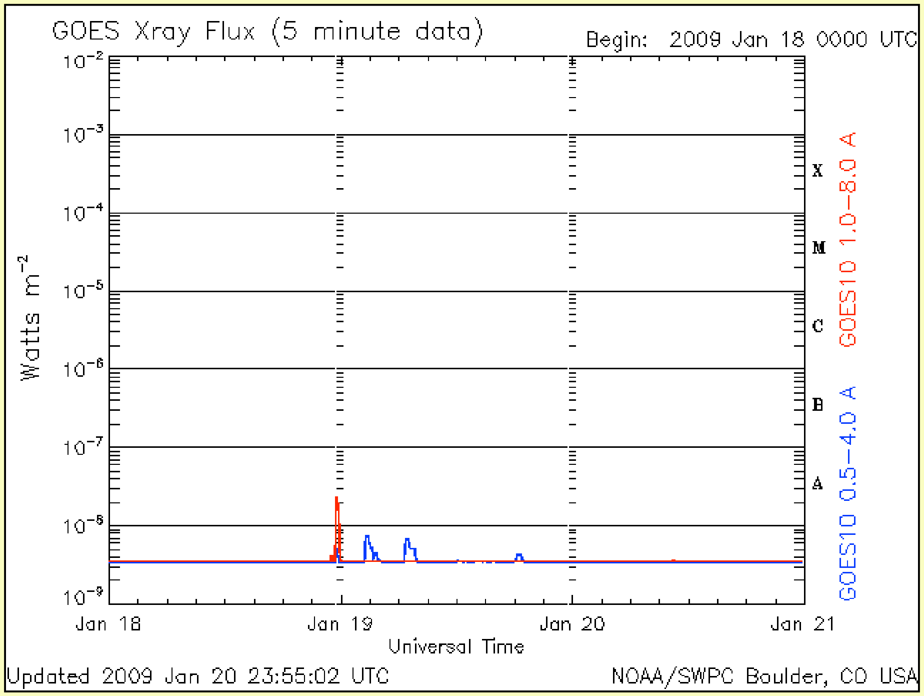
X-ray Images 2



X-ray Timeseries from GOES







High activity - October 2003

Low activity - January 2009

Conversion in the solar atmosphere

$$P = \frac{1}{4} g^2 \, |\boldsymbol{D}(x, y)|^2 \, .$$

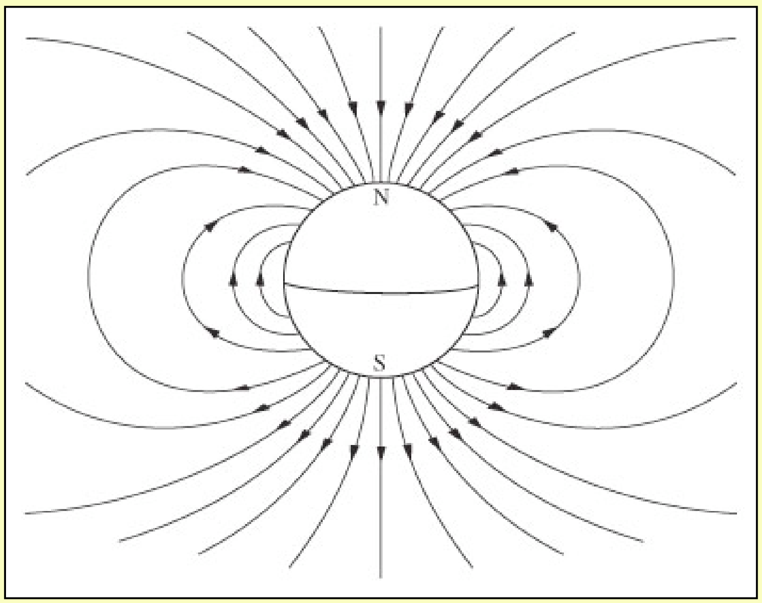
$$\boldsymbol{D}(x, y) = \int_0^L \boldsymbol{B}_\perp(x, y, z) \, e^{i\theta(z)} \, dz$$

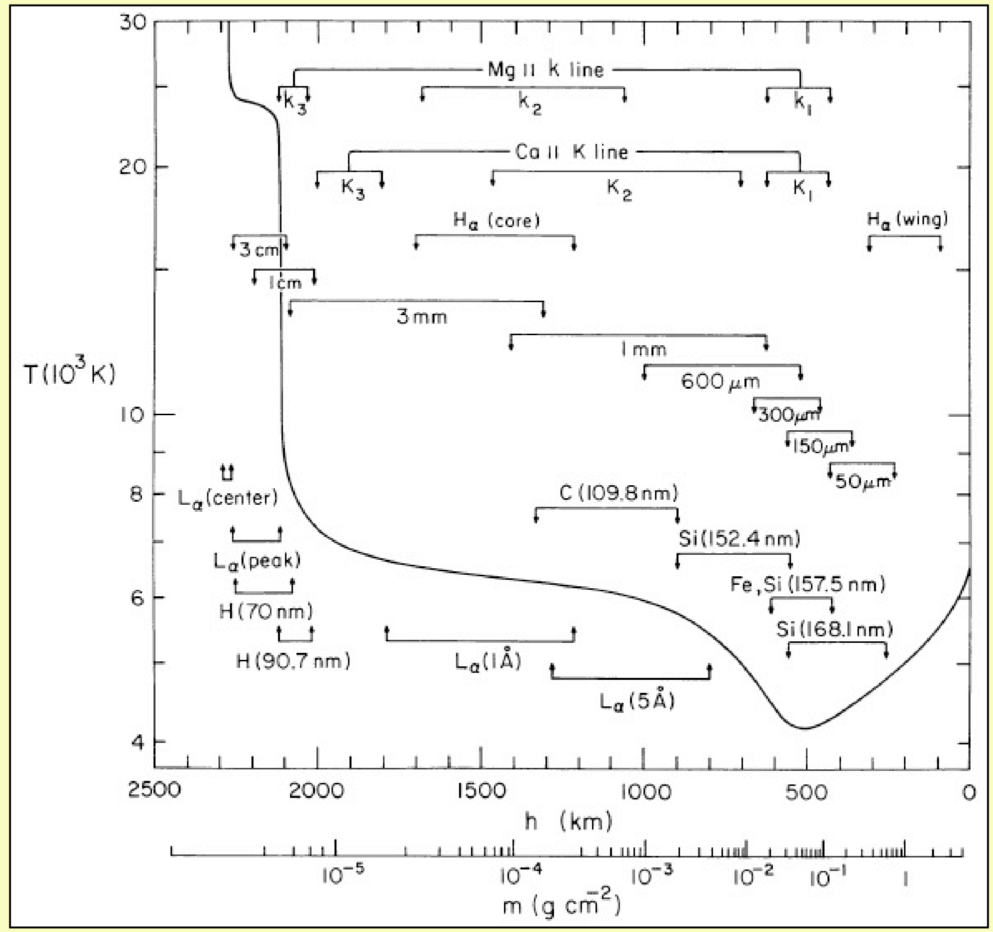
$$\theta(z) = \int_0^z \left(\frac{2\pi\alpha n_e(z')}{m_e E} - \frac{m^2}{2E} \right) dz'$$

Need $\langle B_{perp} L \rangle$
Need $n < n_0(m)$

What (n, B) do we have?

First approximation to solar (B, n): dipole field, spherical symmetry



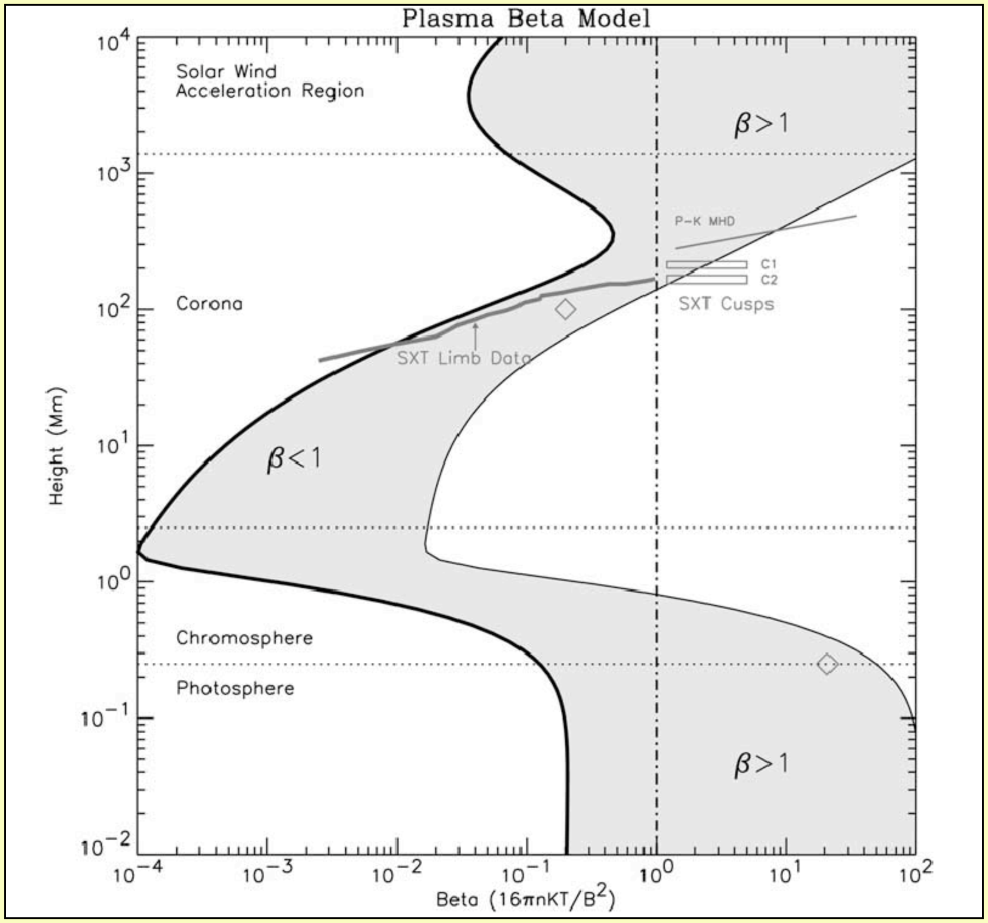


$B_{perp} \sim 10^{-3}$ T
at photosphere

"VAL-C" semi-empirical model

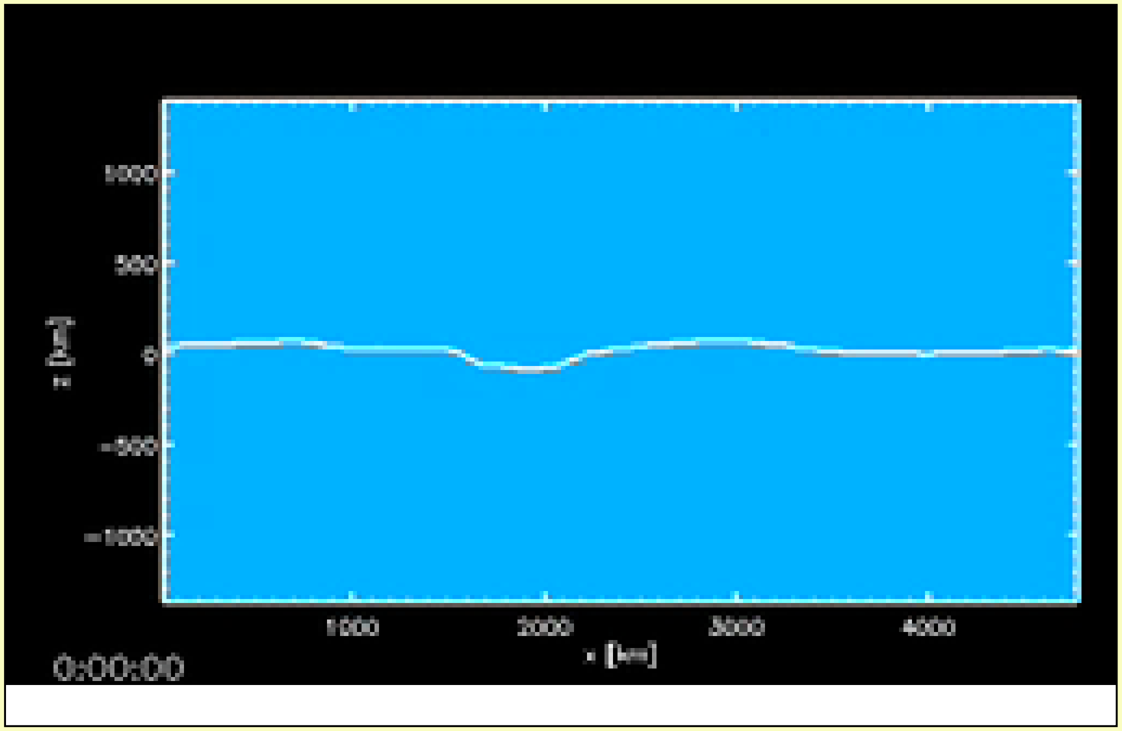
Second approximation: complex field and dynamic plasma

Druckmuller eclipse imagery



Gary (2001)

Simulations of the chromosphere



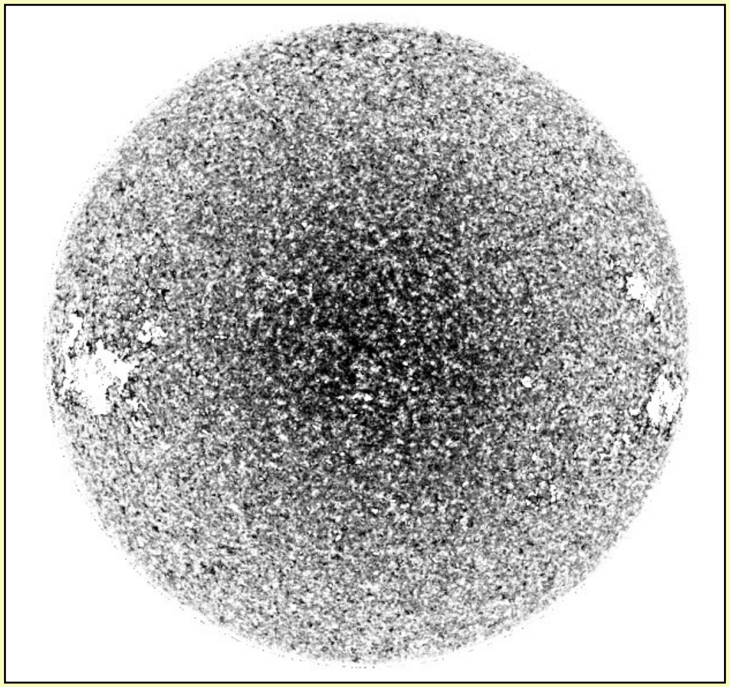
MHD simulations by O. Steiner
(Kiepenheuer Institut für Sonnenphysik,
Freiburg)

The solar magnetic field 1

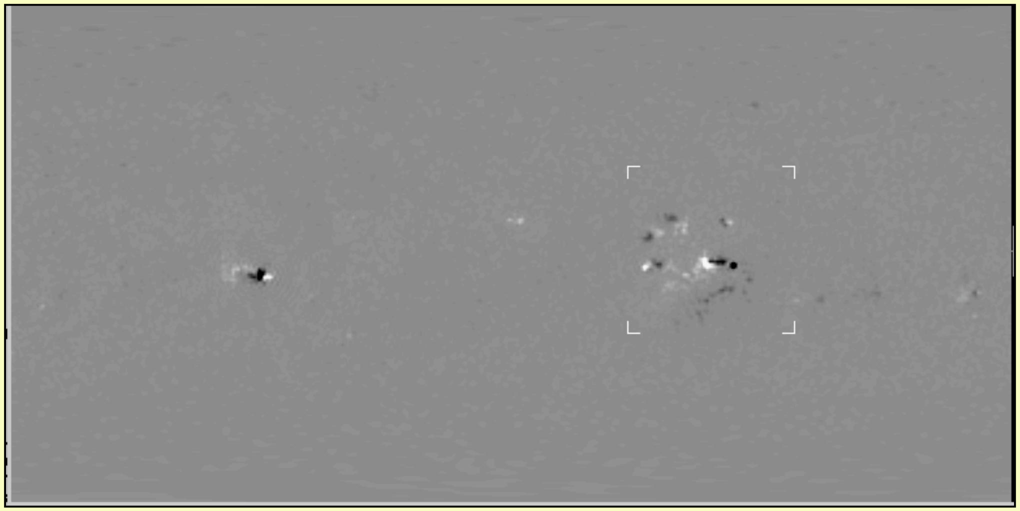
- We only really know the line-of-sight component of the photospheric field (Zeeman splitting, Hanle effect)
- The coronal field is *force-free* and currents circulate in it ($\nabla \times \mathbf{B} = \alpha \mathbf{B}$)
- Some of the field is “open,” ie linking to the solar wind
- We estimate the coronal field by extrapolation
- All knowledge is also limited by telescope resolution to scales of 100 km or so
- A potential representation (no coronal currents) is often used as a first approximation (“PFSS”)

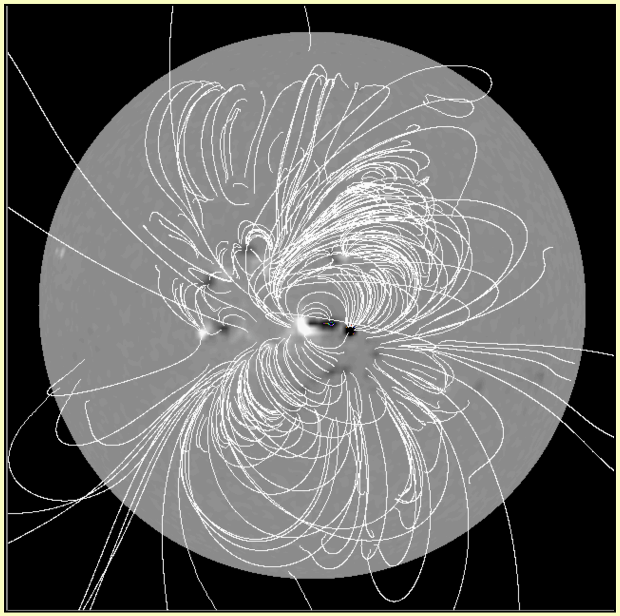
The solar magnetic field 2

- The "seething field" (Harvey et al., 2007)
- Hidden magnetism (Trujillo Bueno et al., 2004)
- The *Hinode* 40-gauss field (Lites et al., 2008)



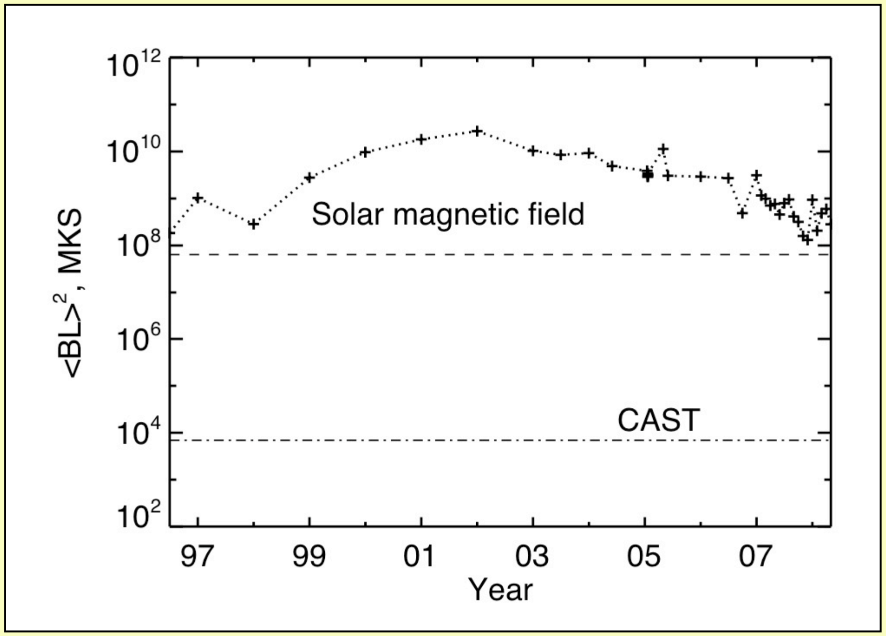
Using the Schrijver-DeRosa PFSS solar magnetic model





- Line-of-sight B component derived from photospheric Zeeman observations
- Potential-field extrapolation used to approximate the coronal field
- Integration across theoretical axion source distribution => <BL>^{2}

PFSS Prediction for solar $\langle BL \rangle^2$ Strengths and Weaknesses



- The solar $\langle BL \rangle^2$ product is much larger than that achievable in laboratories
- The field is strongly variable in both space and time, and not well known quantitatively
- Strong fields drive solar activity, potentially confused with the axion signal or a source of background

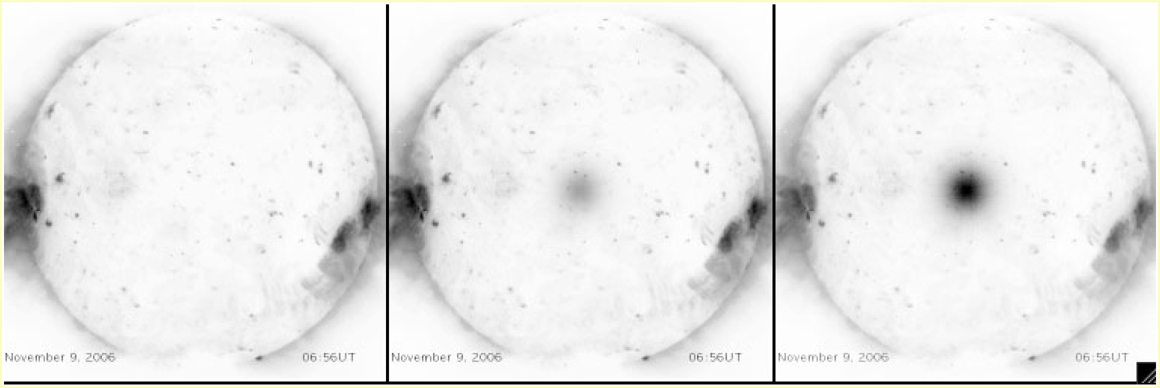
Solar X-ray telescopes

Yohkoh
(focusing)

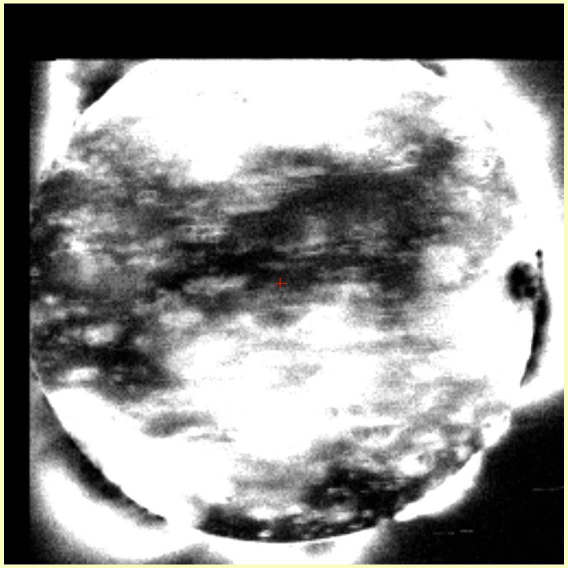
RHESSI *(image modulation)*

Hinode
(focusing)

Studying the *Yohkoh* and *Hinode* soft X-ray data

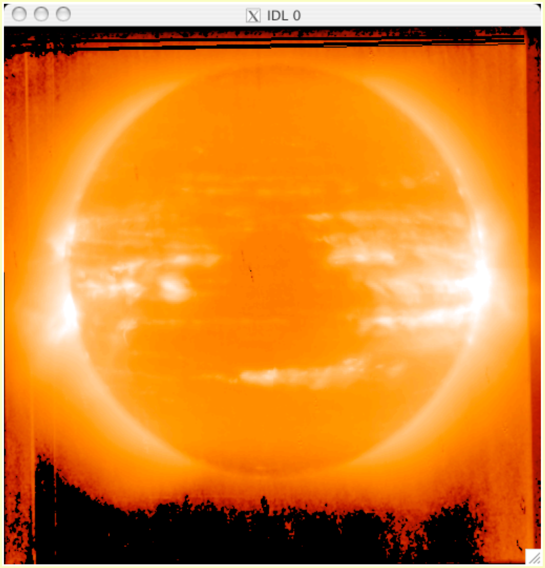


Prediction: increasing levels of theoretical source intensity

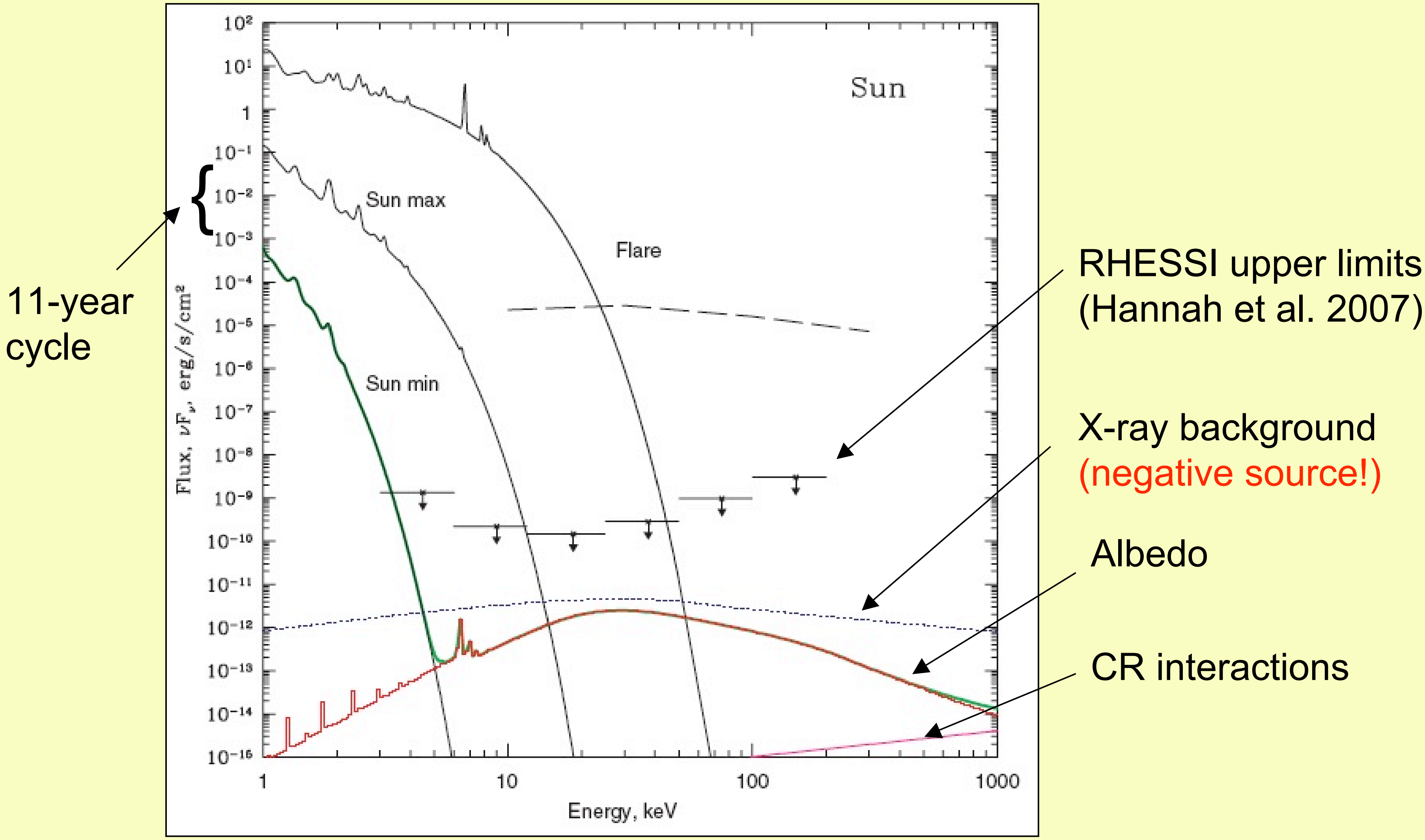


Hinode observation via histogram analysis of 400 images

Yohkoh observation: selection for no disk center active regions at solar minimum (1996)



Solar X-ray spectra



Churazov et al. (2008)

Figure of Merit for X-ray and γ-ray observations

$$FOM = \sqrt{\epsilon A \Delta t / B \Delta E}$$

ε	= efficiency
A	= detector area
Δt	= integration time
B	= background rate
ΔE	= energy range

Figure of Merit results

CAST	1.0
RHESSI	0.005
^{57}Fe*	2×10^3
X-ray**	7×10^4

*14.4 kev photonuclear γ-ray

**1000 cm^2, B = 2×10^{-4} $(cm^2.sec.keV)^{-1}$

n.b. X-ray and γ-ray estimates based on a SMEX-level satellite plan - one could do better! This model is better than a "cubesat"

Conclusions

- Conversion in the solar magnetic field should be the best way to see solar thermal axions of low mass
- The solar atmosphere is not well understood, so any interpretation of an axion signal will be fuzzy (we should be so lucky!)
- Calculations of resonance conditions in solar (B, n) distribution need to be done
- Future instrumentation could greatly improve on the sensitivity