Search for (solar) ~axions in the visible

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ILIAS-CAST-CERN Axion Training

CERN / Geneve

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➔ **magnetic fields** of ***several*** **kG** ***in sunspots***

➔ probably **~10 T** in the tachocline (-200000 km)

M. Aschwanden, *Physics of the Solar Corona* (**2004**) p.175

➔ X-rays: $\gamma \rightleftarrows$ **axion**

It is believed that much, if not all, of the magnetic flux penetrating the **photosphere** is aggregated in 200-300 km Ø, in which the field strength is of order **1.5 kGauss** (~2% of the surface).

P.A. Sturrock, ApJ. 521 (**1999**) 451
J. Sanchez Almeida A.& A. (**2005**) in press, astro-ph/0504339

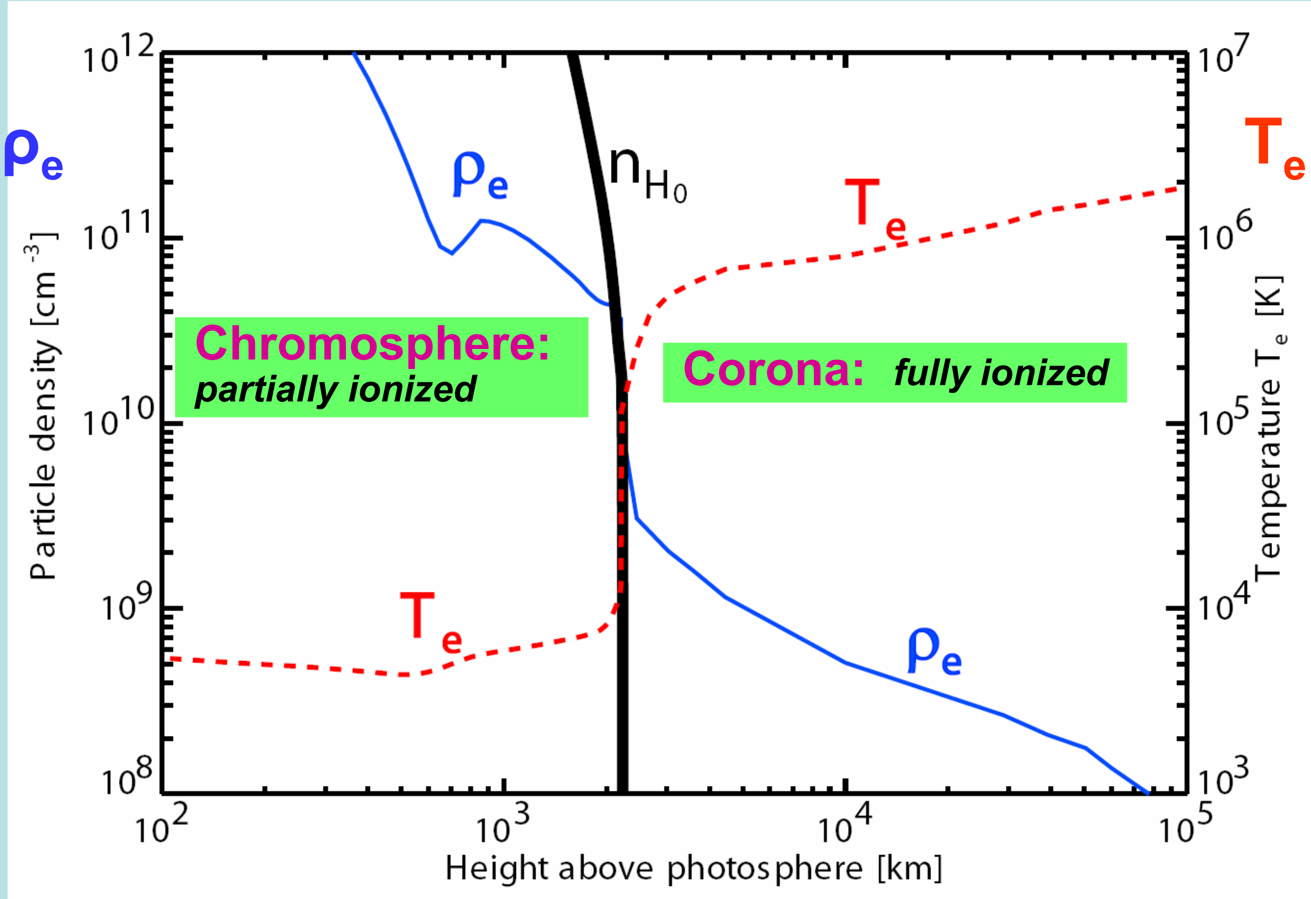
➔ **Visible light:** $L_\odot \rightleftarrows L_{axion}$

→ Primakoff effect ⊗ B at solar surface + below

$$a + \gamma_B \rightarrow \gamma \quad \text{or} \quad \gamma + \gamma_B \rightarrow a$$

$$I_x^{\pm} \sim B^2$$

→ ~ eV - solar axions → missing estimate <0.5keV



Electron density (ρ_e) and temperature (T_e) model of the chromosphere and the corona. The plasma becomes fully ionized at the ***sharp transition***: *)

Chromosphere → Corona

n_{H_0} = neutral hydrogen density.

*) **~100 km thick (vertical)**
(S. Patsourakos et al., ApJ. 522 (1999) 540)

"At any given height, ρ_e varies by a factor of 10 - 100 over the entire corona." …

"The physical understanding of this high temperature in the solar corona is still a **fundamental problem in astrophysics**, because it seems to violate the **second thermodynamic law**, given the photospheric temperature T≈5785K (and drops to T~4500K in **sunspots**)." M. Aschwanden, *Physics of the Solar Corona* (**2004**) p.24-26

Photosphere: **only ~0.1% of the gas is ionized** (= plasma).

http://www.windows.ucar.edu/tour/link=/sun/atmosphere/photosphere.html

TOTAL SOLAR IRRADIANCE

→ visible light

➔ *strong evidence that the magnetic elements with higher flux are less bright.*

N.A. Krivova, S.K. Solanki, M. Fligge, Y.C. Unruh, A.&A. 399 (2003) L1

Table 1.1: The plasma-β parameter in the solar atmosphere.

Parameter	Photosphere	Cool corona	Hot corona	Outer corona
Electron density n_e (cm^{-3})	2×10^{17}	1×10^{9}	1×10^{9}	1×10^{7}
Temperature T (K)	5×10^{3}	1×10^{6}	3×10^{6}	1×10^{6}
Pressure p (dyne cm^{-2})	1.4×10^{5}	0.3	0.9	0.02
Magnetic field B (G)	500	10	10	0.1
Plasma-β parameter	14	0.07	0.2	7

M.J. Aschwanden,
Physics of the Solar Corona (**2004**)

CAST *performance in the visible* with PVLAS *results & solar input*

➔ **PVLAS:** $g_{a\gamma\gamma} \approx 2.5 \cdot 10^{-6}$ **GeV^{-1} & $m_{axion} \approx 10^{-3}$ eV/c^2.**

Above the solar photosphere, **we take**:

- **$B_{solar} \approx$ 10 Gauss**
- solar oscillation length **L ≈ 1 km**.

  ➔ at the solar surface the density ($\rho \sim 10^{-4}$ bar) is decreasing exponentially outwards. In order to have $m_{axion} \approx m_\gamma$ inside the solar atmosphere (as for CAST 2nd phase), a $\rho \approx 10^{-5}$ bar is needed. Therefore, above the solar surface the photon-to-axion conversion can be enhanced in the axion rest mass range $\sim 10^{-2}$ to $\sim 10^{-5}$ eV/c^2. I.e., for a distance of ~1 km the local density is the required one to restore coherence.
- $L_{solar} \approx 4 \cdot 10^{33}$ erg/s.

➔ **$P_{\gamma \to a} \approx 6 \cdot 10^{-13}$** ➔ **$\Phi \approx 10^6$ axions / sec·CAST-exit**

In CAST:

➔ **$P_{a \to \gamma} \approx 10^{-9}$** (assuming ~5 m oscillation length)

➔ Rate = $P_{a\rightarrow\gamma} \cdot \Phi \approx 10^{-3}$ photons / sec·CAST-exit

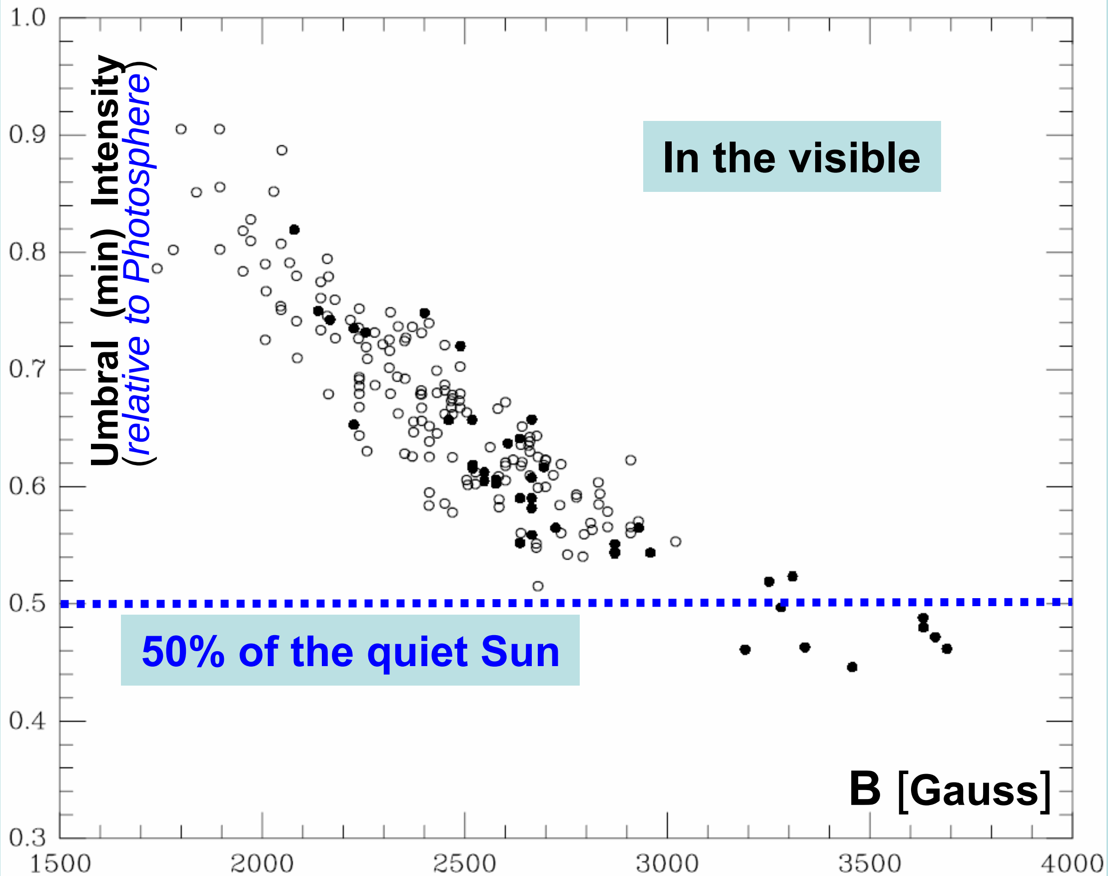
Note:
this is probably a conservative estimate. The solar oscillation length may be taken ~10 km, since the opacity in the visible seems to be reasonable for some 1000 km above the photosphere. Also, the local (quiet) $\mathbf{B}_{solar}$ might be even larger with peaks at ~1.5 kGauss.

[see F. Cataaneo, ApJ. 515 (**1999**) L39; S.R. Cranmer, astro-ph/**04**09260; R.M. Sainz et al., ApJL. 614 (10.10.**2004**)].

Thus, the photon rate during solar tracking with CAST can be

➔ **Rate ~ $10^{-3} \rightarrow 1$ visible phot. / sec·CAST-exit**

➔ **oscillation length?**



SUNSPOTS

Umbral normalized continuum intensity vs. umbral field strength **B**. Plotted is the minimum value and the maximum value of **B** of each sunspot.

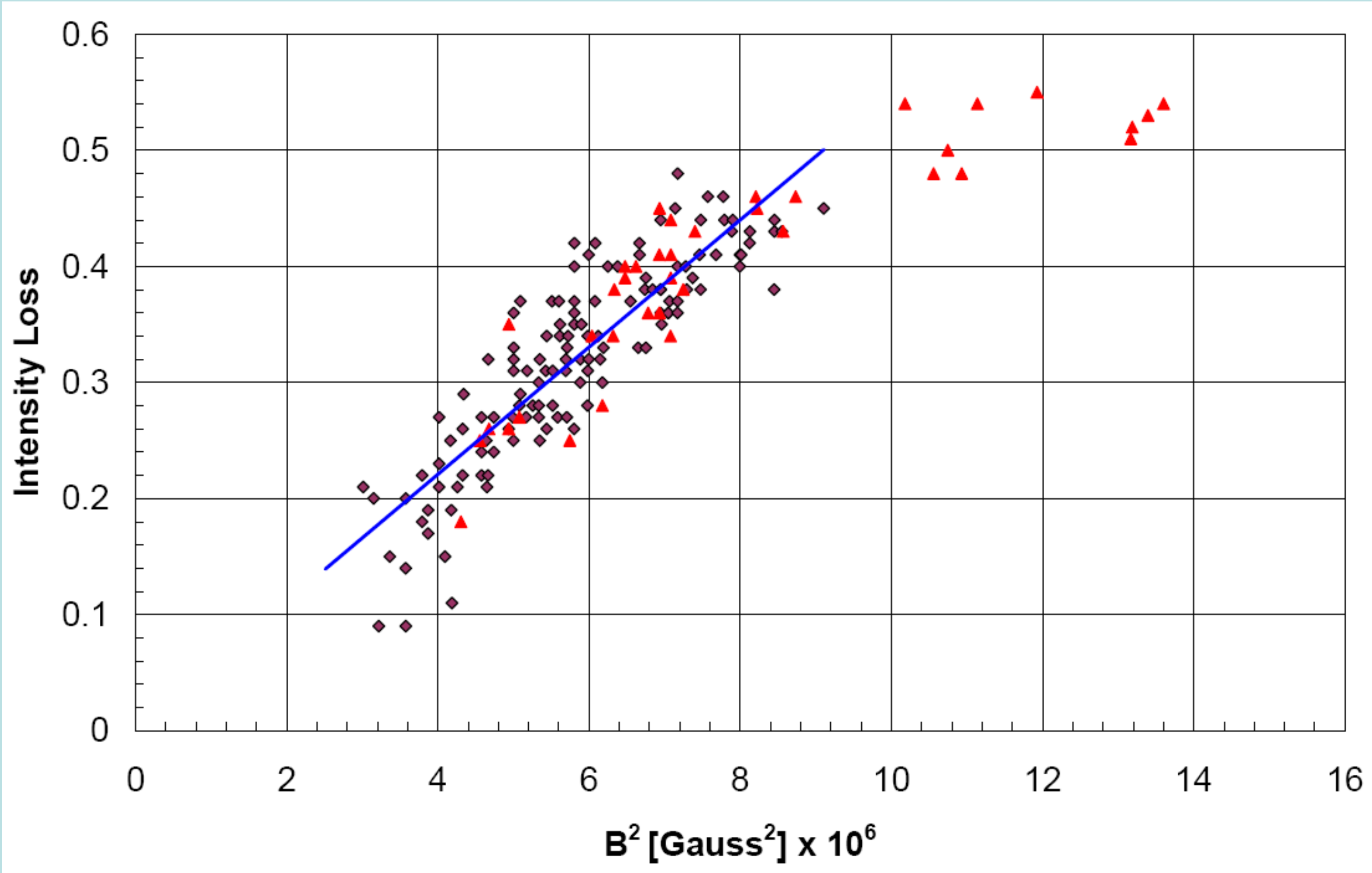
Filled circles (1990–1991)

Open circles (2000–2001)

A number of fundamental questions remain unanswered.

- ➔ ***What determines the intrinsic brightness of umbrae and penumbrae, in spite of the strong magnetic field which inhibits convection?***
- ➔ ***Is an additional mechanism needed?***
- ➔ ***How is the umbral chromosphere heated?***
- ➔ ***Why are penumbrae brighter? ….***

S.K. Solanki, A.&A. Rev. 11 (**2003**) 153



Thanks Thomas Papaevangelou

S.K. Solanki, A.&A. Rev. 11 (**2003**) 153

- **Oscillations between light ~axions & γ's inside $B_{solar-surface}$**

  ➔ **Solar local effects in the eV-to-keV range**

  ➔ **Suggestive for solar ~axion searches below ~1keV → 1eV**

  ➔ **NO estimate of the solar axion spectrum below ~0.5 keV**

- $L^{2-8keV} \approx 10^{22\pm1}$ erg/s $\Rightarrow$ $10^{-12} L_{\odot}$

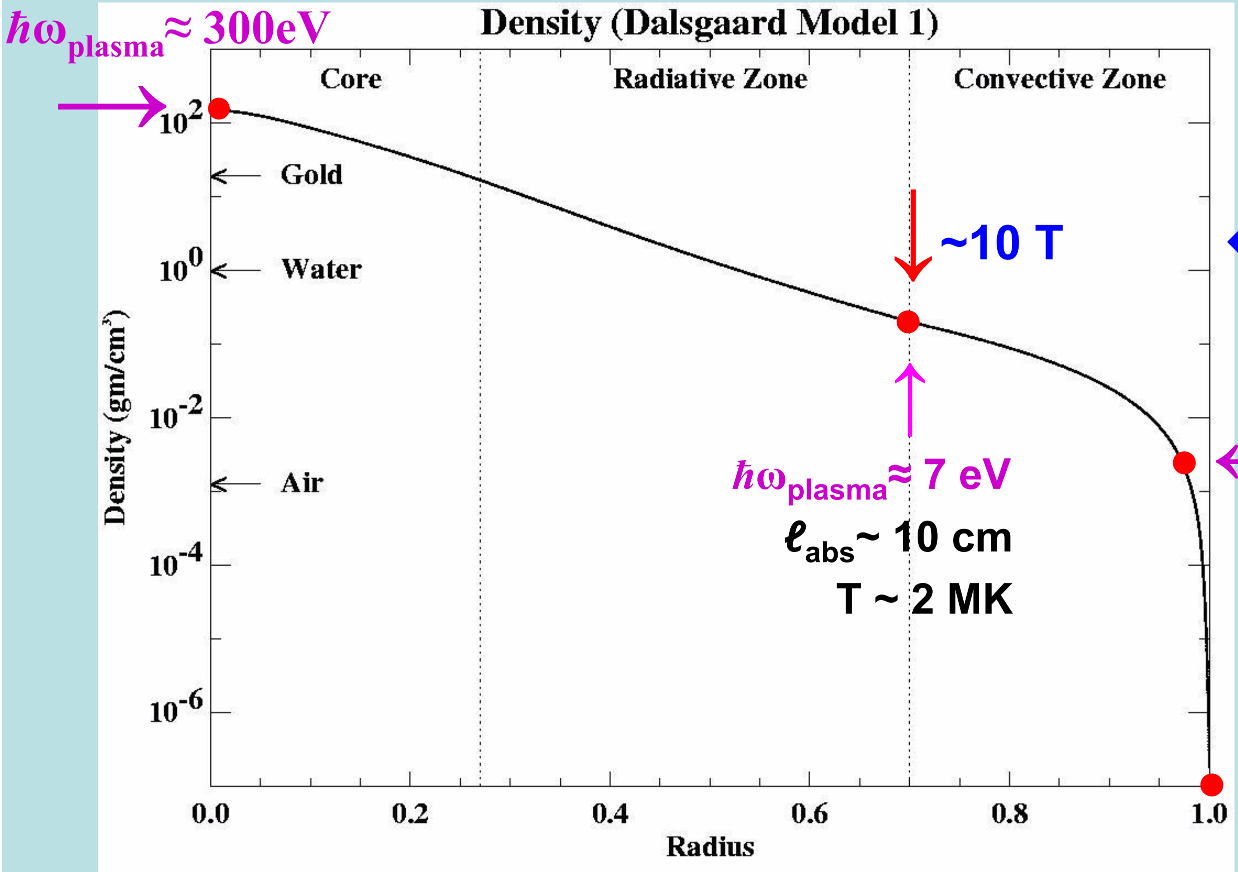
  ➔ $P_{a\to\gamma}$ (100km/2kG/10^{-10}GeV^{-1}) + $\omega_{pl} \approx m_a$ **or** **PVLAS**

  TSI → deficit @ sunspots

- Low energy solar axion Luminosity

- Intensity up to $\sim 1‰ L_{\odot}$ **?!** ⇐ **PVLAS**

The inner SUN



M. Schüßler, M. Rempel A.&A. (**2005**), astro-ph/0506654 **#)**

$\hbar\omega_{plasma} \approx 1eV$ → -20000 km
ℓ_{abs}~20 m

$\hbar\omega_{plasma} \approx 10^{-2}eV$ → surface
ℓ_{abs}~100 km

⇩

If $\hbar\omega_{plasma} \approx m_{axion}c^2$ → **~ resonance crossing**
→ $(\text{Primakoff})_B$ >> $(\text{Primakoff})_{Coulomb}$

→ **New solar axion spectrum?**

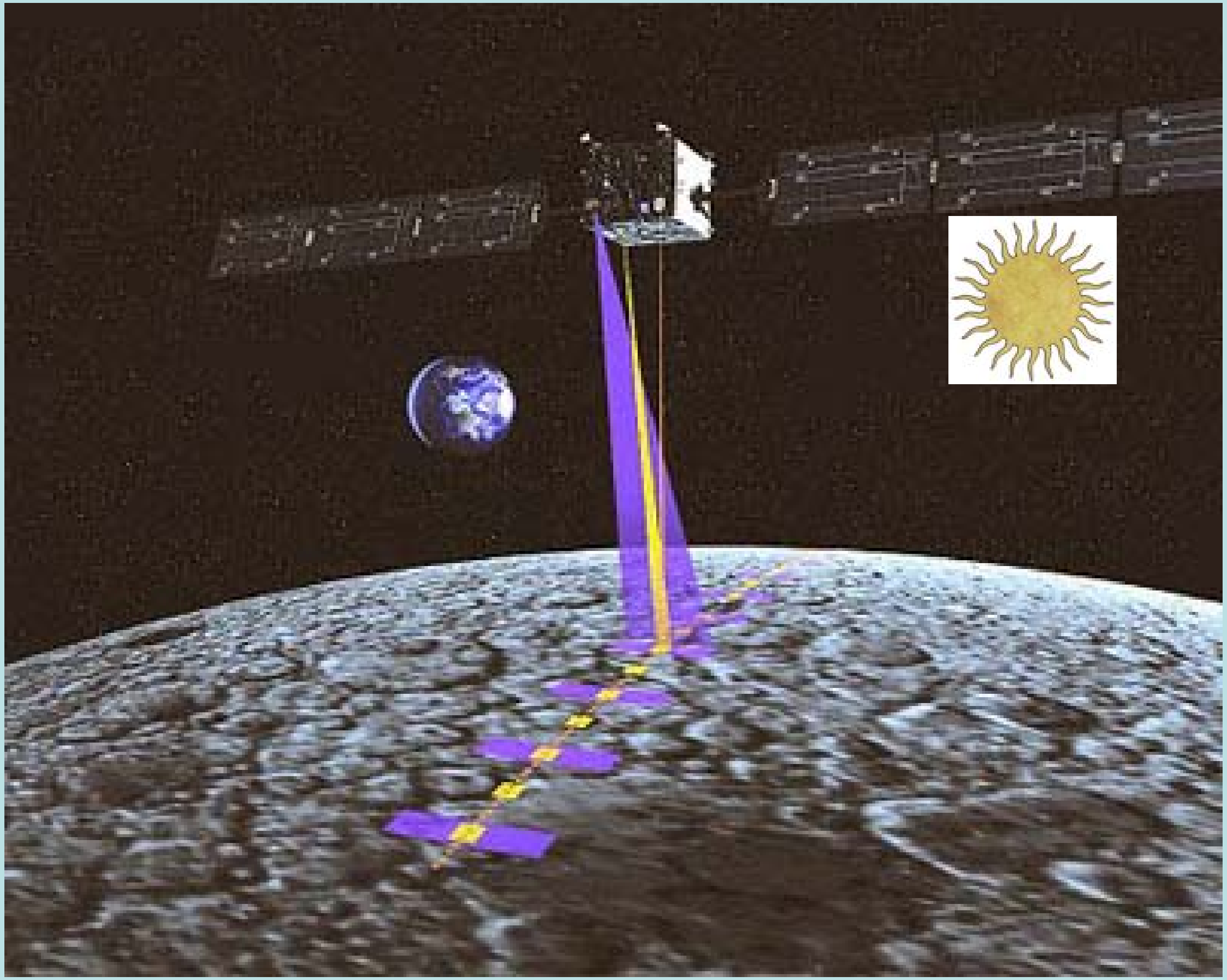
http://science.msfc.nasa.gov/ssl/pad/solar/interior.htm

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

This might be *the* option to think about.

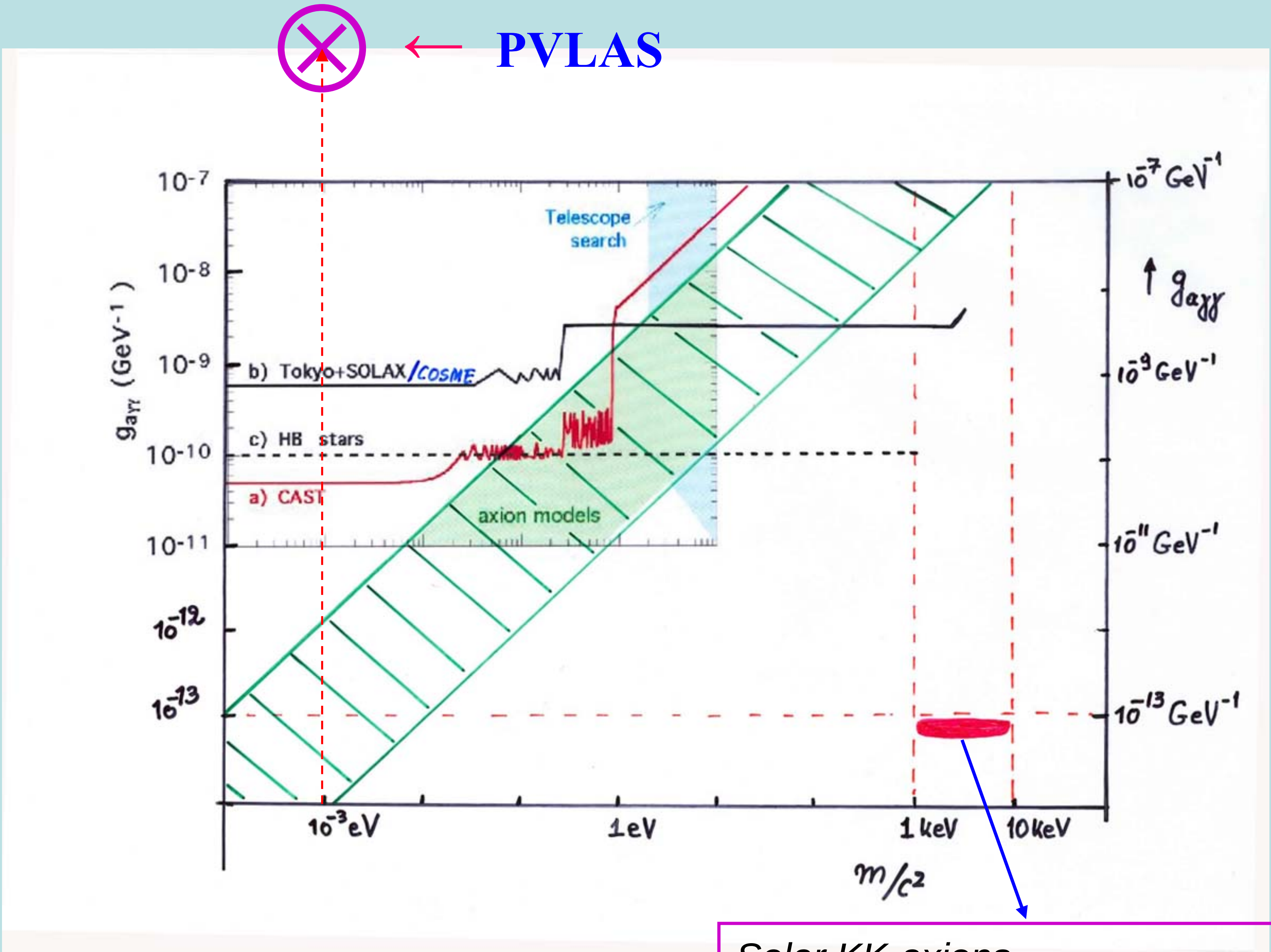
SMART: ***orbiting X-ray detectors*** → ***dark*** **moon** → **large volume + backgr.**

→ **Sun**



collaboration with
Observatory Helsinki

Search for ***massive ~axions*** → spontaneous radiative decays **a** $\rightarrow \gamma\gamma$

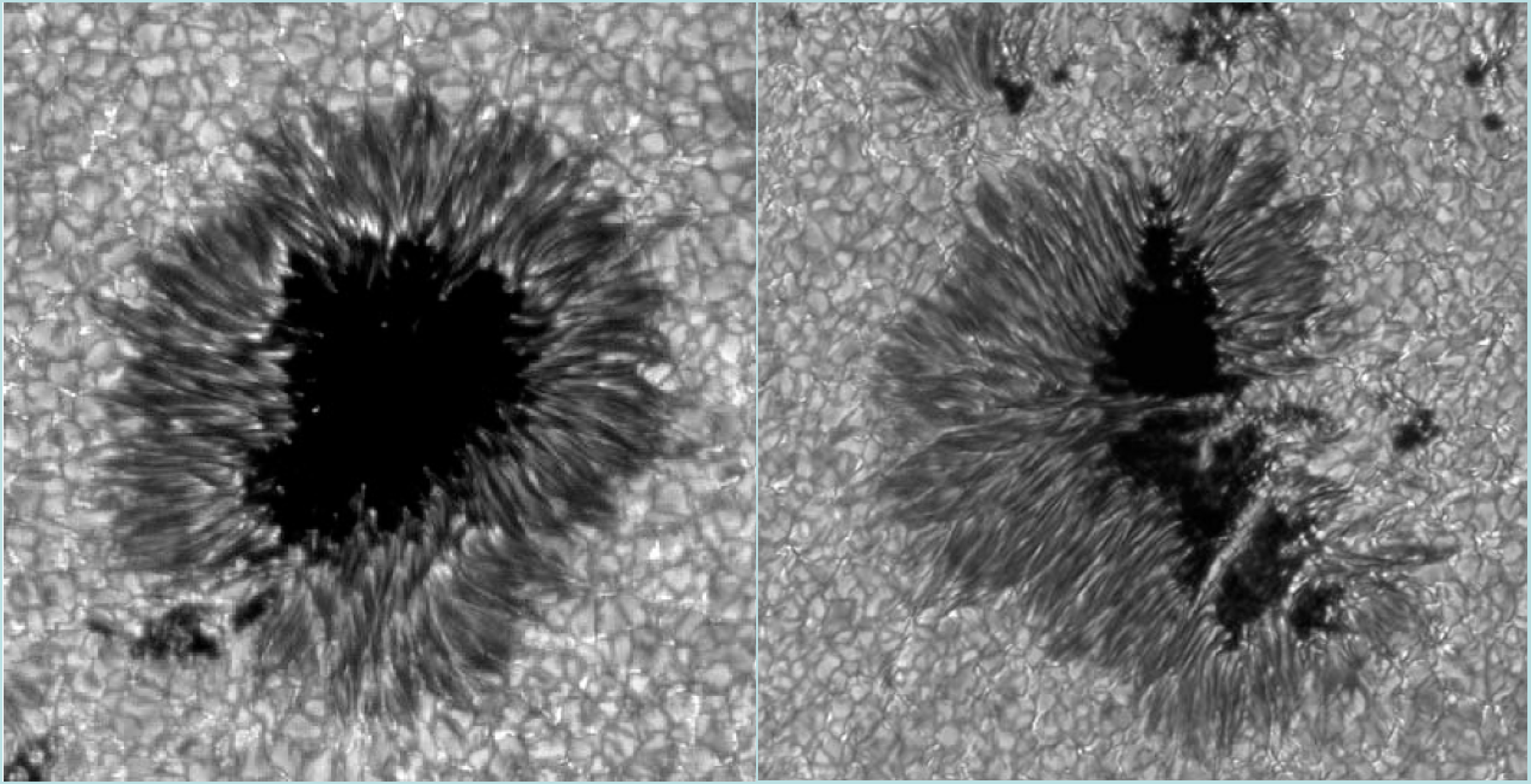


Solar KK-axions,

DiLella, Z., Astropart. Phys.19 (**2003**)145

http://www.unine.ch/phys/corpus/tpc2002/zioutas.ppt

Sunspots



Images recorded in a roughly 10 Å wide band centered on 4306 Å of a relatively regular sunspot (***left***) and a more complex sunspot (***right***). The central, dark part of the sunspots is the ***umbra***, the radially striated part is the ***penumbra***. The surrounding bright cells with dark boundaries are granular convection cells. Sunspot has a maximum diameter of ~30000 km (***left***), ~50000 km (***right***).

S.K. Solanki, A.&A.Rev. 11 (2003) 153