No axions from the Sun

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Preliminary evidence of solar axions in XMM-Newton observations has quite recently been published by Fraser et al. These authors also estimate the axion mass to be $m_a \simeq 2.3 \cdot 10^{-6} \text{eV}$. Since an axion with this mass behaves as a cold dark matter particle, the considered preliminary detection directly concerns cold dark matter as well. So, it would be a revolutionary discovery if confirmed. Unfortunately, we have identified three distinct flaws in the analysis by Fraser et al. which ultimately make it totally irrelevant both for axions and for cold dark matter.

In spite of the fact that cold dark matter is a compelling requirement of the standard cosmological model, no convincing evidence for its detection exists to date. Among so many candidates for cold dark matter particles, the neutralino and the axion are certainly the most popular ones [1]. We stress that an axionic cold dark matter would also naturally solve the long-standing strong CP problem [2].

Quite recently, a paper by Fraser et al. has been published [3]. The title is rather modest: “Potential solar axion signature in X-ray observations with the XMM-Newton observatory”. Also the abstract has a similar style, and in particular it is stated: “we conclude that this variable signal is consistent with the conversion of solar axions in the Earth’s magnetic field, assuming the resultant photons are not strictly forward-directed, and enter the field of view of XMM-Newton”. However, in the text Fraser et al. write the following sentence: “the positive detection of solar axions, if confirmed, must have implications not only for our understanding of the true CXB [cosmic X-ray background] but also for the identification of Galactic cold dark matter (CDM). According to Raffelt (2007) [4], an axion mass in the $10^{-5} \text{eV}$ range is sufficient, for a non-thermal dark matter axion population, to account for the entire Galactic CDM density”. Finally, in the conclusions the authors say: “On the basis of our results from XMM-Newton, it appears plausible that axions – dark matter particle candidates – are indeed produced in the core of the Sun and do indeed convert to soft X-rays in the magnetic field of the Earth, giving rise to a significant, seasonally-variable component of the $2–6 \text{keV CXB}$”.

As a consequence, the reader is left with the impression that a preliminary evidence of the axion is found as well as that cold dark matter in the form of axions has likely been discovered. Given the importance of these topics, a very careful analysis of the paper by Fraser et al. looks compelling.

Accomplishing this task is precisely the aim of the present Letter. We are ultimately
led to the conclusion that it is *impossible* that the signal detected by the XMM-*Newton* observatory has anything to do either with axions potentially emitted from the Sun or with cold dark matter.

In order to facilitate the reader’s understanding, we start by schematically summarizing the main argument of the paper.

Actually, the *observational result* is the evidence of a seasonally modulated background in excess of the instrumental background and the constant cosmic X-ray background (CXB). The authors make a big effort to show that this effect is not an artifact of the detectors but a physical result.

The proposed *interpretation* can be broadly sketched through the following chain of arguments.

- The Sun is supposed to isotropically emit axions owing to three different production channels (among others which are irrelevant for the present discussion): Primakoff effect, Compton effect and electron Bremsstrahlung effect [5]. Below roughly 4.8 keV electron Bremsstrahlung dominates, and it is with this part of the spectrum that Fraser *et al.* are mainly concerned. Because axion production in the Sun occurs in the core, it can be regarded for all practical purposes as a point-like axion source.

- According to a suggestion previously put forward by Davoudiasl and Huber [6], these axions are supposed to convert to X-rays in the geomagnetic field. Note that these authors suppose as usual that an X-ray is collinear with the parent axion.

- The XMM-*Newton* observatory obviously never points towards the Sun, in order to avoid immediate destruction of its X-ray detectors. Instead, during its orbit it points in a varying direction always quite different from the line of sight to the Sun. So, the obvious question arises: how is it possible that the X-rays originating from the conversion of solar axions in the geomagnetic field can enter the XMM detectors all the time?

- Fraser *et al.* answer such a question by invoking a result of Guendelman and collaborators [7]. Basically, the latter authors show that when an axion-to-photon conversion takes place in an inhomogeneous magnetic field then the produced photon can be non-collinear with the parent axion. To be sure, this result has been proved only for very special configurations of the magnetic field and what happens in the geomagnetic one is totally unknown. As these author themselves remark, this is just the analog of the Stern-Gerlach effect for photons or axions (depending on which particle is produced).

- For the sake of illustration, we find it convenient to deal with a much more familiar situation: we consider the *Gedanken* experiment in which solar axions are replaced by electrons and the XMM detectors by charged-particle detectors. That is to say, we imagine that the Sun emits electrons rather than axions isotropically from the core and with the same flux as that assumed for axions (of course, we neglect interactions among electrons). In such a situation, the geomagnetic field – being extremely complicated – certainly possesses a gradient, so that the usual Stern-Gerlach effect takes place. Therefore, the electrons from the Sun will be effectively isotropized, thereby giving rise to a background wherein electrons move along any direction. Note that the flux of such a background is *strongly reduced* with respect to the solar flux in the absence of the Stern-Gerlach effect [5]. Moreover, XMM has a very small field of view, which entails
that only a very small fraction of the electron background can be detected. Returning now to the real case of axions, Fraser et al. explicitly state: “It is thought here that isotropic scattering axion-to-photon conversion probabilities can attain values of the same order as for purely collinear scattering”. We denote by $\Pi$ the *isotropization parameter*, which quantifies the photon flux reduction arising from the “photonic” Stern-Gerlach effect [7] and by $\xi$ the *geometric factor* that accounts for the very small field of view of XMM. As usual, $\xi$ is defined as

$$\xi \equiv \frac{\Omega_{\text{XMM}}}{\Omega_{\text{SC}}} \quad \Omega_{\text{XMM}} < \Omega_{\text{SC}} ,$$

where $\Omega_{\text{XMM}}$ is the aperture of XMM and $\Omega_{\text{SC}}$ the scattering solid angle, namely the solid angle encompassing the total detectable flux (obviously we have $\xi \equiv 1$ for $\Omega_{\text{XMM}} \geq \Omega_{\text{SC}}$). Manifestly, the result of Fraser et al. should depend on both $\Pi$ and $\xi$.

- As we said, Fraser et al. focus their attention on the solar axion flux below 4.8 keV, where the electron Bremsstrahlung is the dominant process, which is obviously controlled by the axion-electron coupling constant $g_{ae}$. Nevertheless, they also take into account the sub-leading contributions from the Compton emission and the Primakoff processes, which depend on the axion-photon coupling constant $g_{a\gamma}$. In order to fit their observed spectrum they need to assume $g_{ae} \simeq 2.2 \cdot 10^{-12}$ and $g_{a\gamma} \simeq 10^{-10} \text{GeV}^{-1}$.

- Fraser et al. also attempt to make an estimate of the axion mass. Because the region where they are most sensitive is around $10^{-6} \text{eV}$, they conclude that the axion mass has to be $m_a \simeq 2.3 \cdot 10^{-6} \text{eV}$. This is a value for which the axion is a very good candidate for cold dark matter [1].

Let us now outline our criticism.

We start from what we regard as the main point. Fig. 20 of Fraser at al. represents their basic result, since it is from this Figure that they indeed draw their conclusions. Because we are unable to see where the parameters $\Pi$ and $\xi$ enter the calculations leading to Fig. 20, we have attempted to reproduce it, taking as a starting point $\Pi = \xi = 1$. Their observed spectrum of time-dependent excess background is taken from that Figure and reported in our Fig. 1 as black squares. Next, using their equations we have evaluated the flux contributions from Primakoff, electron Bremsstrahlung and Compton emission processes according to their choice of the relevant parameters, namely $g_{ae} \simeq 2.2 \cdot 10^{-12}$ and $g_{a\gamma} \simeq 10^{-10} \text{GeV}^{-1}$, and the axion-to-X-ray conversion probability in the geomagnetic field: they are shown in Fig. 1 by the long-dashed orange, the dashed cyan and the solid blue lines, respectively. Finally, we have summed them getting the solid black line in Fig. 1, which turns out to exactly match the data points and in fact coincides with the fitting line in Fig. 20 of Fraser at al. for the same values of the parameters. The crux of the argument is that we have exactly reproduced what of Fraser at al. actually find under the assumption $\Pi = \xi = 1$. This is the best proof that their results hold true only under the impossible assumption that XMM points directly towards the Sun and that the axion-to-photon conversions are fully collinear!

As a side remark, we show that if the solar axion flux were fully isotropized by the invoked “photonic” Stern-Gerlach effect [7] then XMM would detect no signal whatsoever. Indeed, in such a situation we would have $\Omega_{\text{SC}} = 4\pi$ and denoting by $\theta_{\text{XMM}}$ the field of view of XMM we get $\Omega_{\text{XMM}} = \pi \theta_{\text{XMM}}^2$. Because $\theta_{\text{XMM}} \simeq 30 \text{arcmin}$, Eq. (1) yields $\xi \simeq 10^{-5}$. So, we do not even need to estimate the isotropization parameter $\Pi$ to prove our conclusion.
FIG. 1: EPIC pn difference spectrum (black points, from Fig. 20 of Fraser et al.) with the expected X-ray converted spectrum from solar axion (solid black line) calculated as detailed in the text with $g_{ae} \simeq 2.2 \cdot 10^{-12}$ and $g_{a\gamma} \simeq 10^{-10} \text{GeV}^{-1}$. The long-dashed orange, the dashed cyan and the solid blue lines show the contributions from the Primakoff, electron Bremsstrahlung and Compton emission processes, respectively.

A second flaw of the considered paper is the specific choice of the axion-electron coupling constant $g_{ae} \simeq 2.2 \cdot 10^{-12}$, which exceeds by about a factor of 5 the most recent upper bound $g_{ae} < 4.3 \cdot 10^{-13}$ [9]. A similar flaw – even if less significant – concerns the axion-photon coupling constant $g_{a\gamma} \simeq 10^{-10}$, since the most recent upper bound is $g_{a\gamma} < 0.6 \cdot 10^{-10}$ [10].

A third flaw concerns the estimated value of the axion mass $m_a \simeq 2.3 \cdot 10^{-6} \text{eV}$. Actually, it is well known that in any axion model its mass $m_a$ is strictly related to the axion-photon coupling constant $g_{a\gamma}$ by the equation [2]

$$m_a = 0.7 \beta \left( \frac{g_{a\gamma}}{10^{-10} \text{GeV}^{-1}} \right) \text{eV} ,$$  

(2)

where $\beta$ is a model-dependent constant of order 1 [11]. As a consequence, with the choice of
Fraser et al. the axion mass would be $m_a = 0.7\beta eV \sim 1 eV$ and the axions would behave as hot dark matter \[12\]. So, if they were the dominant component of the dark matter, the structure formation in the Universe would be impossible \[13\].

In conclusion, we have demonstrated that neither solar axions nor cold dark matter have anything to do with the claims of Fraser et al. \[3\].

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\[8\] This circumstance is analogous to the fact that in the usual Stern-Gerlach setup concerning the splitting of a beam of spin $s$ atoms into $s$ beams, the intensity of each split beam is $s$ times smaller than the intensity of the original beam.
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\[10\] A. Ayala et al., \texttt{arXiv:1406.6053}.
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