Solar X-rays as Signature for New Particles

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Abstract

Massive axions of the Kaluza-Klein type, created inside the solar core, can be gravitationally trapped by the Sun itself in orbits inside/outside the Sun, where they accumulate over cosmic times. Their spontaneous or "induced" radiative decay can give rise to various solar phenomena, like the celebrated solar coronal heating, which lacks a conventional explanation since its first observation in 1939. Such and other recent observations favour the existence of a halo of exotic particles near the Sun. X-ray (solar) telescopes can provide novel and important informations for astroparticle physics and cosmology. The underlying solar axion scenario is presented in details in ref.’s [4, 15], which can be consulted for further reading.

1 Introduction

In order to solve the strong CP problem, a new neutral particle with spin-parity $0^-$, the axion, was invented (see recent ref.’s, e.g., [1]). Axions, along with Weakly Interacting Massive Particles (WIMPs), are the two leading
particle candidates for dark matter in the Universe. Axions should also be abundantly produced inside the solar core. The expected decay to two photons ($a \rightarrow 2\gamma$) results in a lifetime much longer than the age of the Universe. However, in theories of extra-dimensions, the ‘conventional’, almost massless axions become as massive as the reaction energies involved. In the case of the solar axions, the expected mass spectrum of the excited Kaluza-Klein (KK) states reaches $\sim 10\,\text{keV}/c^2$ [2], with a relatively short lifetime ($\tau \sim 10^{20}\text{s}$), because of the $\tau \sim m^{-3}$ dependence. The underlying axion-photon-photon coupling constant, $g_{a\gamma\gamma}$, remains the same for the ‘conventional’ (≈ massless) axion and for the massive KK-axions. In this approach, the KK-axions are taken as a generic example of particles which can be created inside the hot solar core, while a small fraction of them being highly non-relativistic ($\sim 10^{-7}$) can be gravitationally trapped by the Sun itself in orbits where they accumulate over cosmic times [3, 4]. Their derived density increases enormously near the solar surface.

The spontaneous (or "induced") radiative decay of gravitationally trapped massive axions or other particles (from the solar core) with similar properties can give rise to a self-irradiation of the solar atmosphere explaining the observed X-rays from the solar disk and limb; note, an alternative conventional explanation is missing since 1939, when Grotrian [5] made the puzzling discovery that the solar corona is $\sim 100\times$ hotter than the underlying photosphere. Remarkably, the physical origin of the coronal heating became "one of the most fundamental problems in stellar (and solar) astrophysics" [6].

2 What are the Signatures?

According to the considered level of significance, the relevant signals of X-rays, originating (in)directly from the decay of exotic particles around the Sun, are:

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A) **The radial temperature-density profile** of the solar atmosphere near the surface of the Sun is strikingly similar to the one of the Earth’s upper atmosphere [4], which we know is being exposed to solar illumination. This seems to be the strongest evidence in favour of a quasi continuous external irradiation of the Sun, providing also the energy source for heating the solar corona.

B) **The quiet Sun X-ray spectrum** as it has been reconstructed from the emission measure distribution at the solar minimum [7, 4] provides a high energy component up to $\sim 10$ keV. This is the only analog solar spectrum found so far, which extends far beyond $\sim 1$-2 keV, which is the range of interest for the axion scenario. In fact, its energy range coincides with the Monte Carlo generated spectrum following the example of the radiative decay of gravitationally trapped solar KK-axions, as it has been worked out in ref. [4]. In order to normalize the theoretical solar KK-axion decay X-ray spectrum to the intensity of the reconstructed hard X-ray spectrum, the derived value of the coupling constant axion-to-photon is: $g_{a\gamma\gamma} = 9.2 \cdot 10^{-14} \text{GeV}^{-1}$. Note, this value is by $\sim 4$ orders of magnitude far below the present detection sensitivity of any known massive axion search in underground solid state detectors [8]. This demonstrates at the same time the potential power behind solar X-ray investigations.

Orbiting X-ray telescopes (e.g. RHESSI, or upcoming solar X-ray missions) could measure directly the analog X-ray spectrum associated with extended quiet Sun periods during the next solar minimum ($\sim 2005 - 2008$). In fact, the importance of X-rays from the quiet and/or not so quiet Sun have been overlooked, inspite of the detection constraints.

C) **Hard X-rays from the non-flaring Sun** above 3.5 keV as it was first observed by the HXIS spectrometer on SMM [9]. Later, the NEAR mission [10] provided quiescent solar hard X-ray spectra, too. In addition, the INTERBALL mission [11] measured hard solar X-rays, noticing (unbiased
at that time) full in the sense of the solar axion scenario: "We have found it very unexpected that there is present quiet-Sun emission in the 10-15 keV band in the period of the lowest solar activity (1995)"). Recently, also the RHESSI observatory [12], has observed a continuous X-ray emission, from 3 to $\sim$15 keV, with frequent (every few minutes) microflaring [13], when there are no observable flares present [14].

The derived quiet Sun X-ray spectrum [7] below $\sim$15 keV corresponds rather to a $\sim$80-100 MK hot plasma component. These photons are much more energetic than the bulk of thermal photons from the celebrated $\sim$2 MK solar corona plasma (e.g. $E_\gamma \approx 3kT \approx 0.5$ keV). These findings make any conventional explanation much more difficult. Note, this part of the quiet Sun is even hotter than the $\sim$17 MK solar core. However, this is not in contradiction with the generic KK-axion scenario, which works then, so to say, as a built-in amplifier between the inner and the outer Sun. This also demonstrates the complexity of the underlying mechanism, which must be at work to explain the solar corona X-rays.

D) **The X-ray surface brightness** resulting from the decay of the trapped axions around the Sun is expected to be continuous and quasi stable with time and to decrease rapidly with increasing distance from the Sun [15]. Possible contributions from active regions on the solar disk into the limb region due to scattering in the X-ray telescope must be excluded. For example, in the considered Yohkoh observations of two quiet Sun regions [15], they constitute a small but not insignificant fraction [16, 17].

E) **The inward heat flux in the solar atmosphere.** The conventional explanation of the aforementioned two Yohkoh quiet Sun observations [16, 17] suggest a mechanism that deposits *somehow* nonthermal energy as heat beyond the observed range of heights above the limb ($R \geq 1.5$-2 $R_\odot$), consistent with an inward heat flux. In addition, within the adopted model, there is no evidence for nonthermal heating in either the observed regions
or in the inner corona \[18\]; the paradox conclusion from this observation is: 
"the solar wind may supply heat to the inner corona rather than the other way around. ... The standard view may need revision ..." \[18\] \[1\].

F) The solar $L_x \sim B^2$ dependence is striking, though it can not be considered yet as evidence, inspite of its potential importance for solar axion searches. Remarkably, the relation between the observed soft X-ray flux (photon energy below $\sim 4$ keV) and the solar magnetic flux $B$ can be approximated by a power law with an averaged index close to 2, i.e., $L_x \sim B^{1.8\pm0.4}$, changing smoothly over a solar cycle \[19\]. For comparison, in the ongoing CAST experiment at CERN \[20\] we expect an axion-to-photon conversion probability \[21\] inside the transverse magnetic field to depend also on $B^2$. Therefore, it is interesting to explain quantitatively whether the CAST working principle may well take place, for some reason(s), more efficiently near the Sun \[22\]. If this happens to be the case, it might be suggestive for a new experimental approach in axion research 1 AU from the Sun.

For the invented massive solar KK-axions \[4\], the coherent conversion probability inside a magnetic field must be suppressed, at least at first sight, due to the $(m_{\text{axion}})^{-2}$ dependence of the coherence length. But, if finally the observed $L_x \sim B^2$ relation reflects an electromagnetically induced axion materialization (whatever the physical mechanism is found to be behind it at the end), this might open a window to the 11-years solar cycle, because the solar X-ray variability during the solar cycle is strong and well established.

In addition, such magnetic field related effects could provide also the explanation for a plethora of local solar X-ray emission phenomena. If this is axion related, it is an important perspective.

\[1\] According to the standard view, the deposition of nonthermal energy occurs in the inner corona and this region in turn supplies heat to the upper corona and to the solar wind, a term used to represent the continuous expansion of the corona into planetary space \[18\].
3 Conclusions

A short summary of potential solar signals are given, which are consistently in favour of the generic KK-axion scenario, thus extending the lines of reasoning given in details in the ref.’s [4, 15]. The basic idea behind the axion scenario is the following: massive axion(-like) particles of the Kaluza-Klein type are created inside the solar core. Some of them are highly non-relativistic and they can be gravitationally trapped by the Sun itself, in orbits inside and outside of it, where they accumulate over cosmic time scales. Such highly dense exotic particles around the Sun can decay (spontaneously and/or "induced"), explaining thus various, yet as mysterious characterised, solar phenomena.

The solar axion scenario provides then the required continuous and steady power input into the solar atmosphere. The photon energies are rather high for (quiet) solar standards, for which, so far, any conventional explanation is missing. However, depending on the local physical conditions, e.g. magnetic field strength, plasma density, etc., an additional axion-to-photon conversion mechanism may enhance locally this energy input, providing an explanation also for the not so rare local solar X-ray effects.

Therefore, the ongoing as well as the upcoming solar X-ray spectroscopy missions, along with additional theoretical work about possible, yet unforeseen, dynamical behaviour of the highly dense solar axion(-like) cloud, could provide mutual feedback. This might prove to be essential for a deeper understanding of those relatively high energy solar phenomena. The same axion scenario should also apply to other places in the Universe, like the Galactic Center and the X-ray luminous Clusters of Galaxies [4], which, in this context, are also dominated by interesting "mysterious" observations [23].
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