The mysterious Sun: a source and a trap of exotica.

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Abstract. A few solar phenomena are given whose origin remains rather mysterious. The claimed observations of anomalous nuclear decays suggest new experiments, whose design should be observationally driven, i.e., going beyond conventional thinking. Also, the non-observation of delayed solar radioactivity after few large flares makes this issue more puzzling, while the solar flare trigger is considered anyhow as one of the biggest solar mysteries.

1. Introduction

In the past, first hints from the Sun for new physics were observationally driven. The solar energy output and the solar neutrino “deficit” problem were two typical examples. At present, similarly, persistent solar mysteries/anomalies might be the otherwise overlooked fingerprints of new solar ingredients like axions, chameleons, paraphotons, or more generally for the dubbed WISPs (Weakly Interacting Slim Particles). In fact, the Sun may emit some $\sim$100 ktons energy equivalent per second in exotica like axions, and this since 4.5 Gyears, without giving rise to visible ageing effects. The unexpected surface photon excess/deficit or some other anomalous solar behaviour could be due to some locally occurring “invisible” processes, resulting thus to the many faces of the paradoxical Sun.

Thus, in an inside-out approach moving from the solar core outwards to the solar surface, its atmosphere and further in outer space all along to Earth’s orbit and even beyond, unknown solar physics might still be at work at such relatively large scales. We mention below, for example, gravitational anomalies observed within the solar system. Though, it is an open question the actual dark matter distribution within the solar system and the formation/evolution of the solar system on a dark matter solar halo [1].

2. Sun’s anomalous behaviour: harbinger of new physics?

Helioseismology does not describe exactly the inner Sun, while the peak-like appearance of an overshooting near the tachocline could be due to some locally occurring additional heating. From the axion or chameleon point-of-view, this place (some 200000 km underneath the solar surface) is widely considered to be magnetized with a magnetic field strength of about 50 T. This is also the roots of the solar surface magnetism reaching few kGauss in sunspots [2]. Note that below $\sim$0.2R\textsubscript{sol} the rotation profile is unknown.

The Sun is a target/source for the indirect detection of dark matter particles being gravitationally trapped and accumulated over cosmic times by the Sun, e.g., the celebrated WIMPs. In addition, other massive exotic particles like Kaluza-Klein (KK) axions created inside the Sun can be gravitational
self-trapped. The self-trapping efficiency can be small (about $10^{-7}$ per created particle) [3]. But, their accumulation over the last 4.5 Gyears can result to a total mass orbiting the Sun of $M_{KK} \sim 10^{-11} M_{\text{Solar}}$. This is, however, not sufficient to explain the pioneer anomaly ($\alpha = 10^{-7} \text{cm/s}^2$), for which one needs a trapped total mass of $\sim 10^{-4} M_{\text{Solar}}$. At the atmosphere, there is the so called solar coronal mystery, since the known physics could not provide as yet a viable microscopic heating mechanism [4]. In fact, it was suggested that a whole Sun external self-irradiation by the spontaneous decay of the trapped exotica, e.g., KK-type axions or other WISPs, can occur. This, along with the outwards emitted X-rays from converted axions / WISPs streaming out of the inner Sun (occasionally), can be the main two components behind the unexpected solar spectral shape, which deviates enormously from a thermal distribution expected to be even below $\sim 5800 \text{K}$. In fact, it is remarkable and fascinating that the Sun emits intense X-rays, and this is a mystery [5].

In addition to the striking solar corona problem, which is considered as one of the biggest problems in the whole of astrophysics, we mention here some solar gravitational anomalies. We recall cosmic gravitational anomalies like the flat rotation curves of spiral galaxies and the accelerated expansion of the universe, point at the existence of dark matter and dark energy, which are still the biggest unsolved problems of all physics. Thus, the Sun gives rise somehow to the following observations of as yet unknown explanation:

- **The Pioneer anomalous acceleration** in outer solar system ($\sim 100 \text{ AU}$). Various distributions of DM in the solar system have been proposed already to explain the deceleration due to an additional gravitational pull towards the Sun, but the mystery remains.

- **The increase of the [AU]** of about +15 cm/year, which should be decreasing instead due to the escaping solar mass and radiation, though to a much lesser extent to the solar wind.

- **Earth Flyby anomalies** during gravity assist, giving rise to a strange, step-like acceleration change (max. 13 mm/s), and this is also a mystery [6, 7].

- **Anomalous nuclear decay rate signatures**? Data taken over long time intervals with radioactive sources in BNL/USA and at the PTB/Germany exhibited frequencies in the range 1-15 / yr. Except the annual modulation, other oscillation frequencies are compatible with inner solar rotation frequencies (e.g., $T \sim 33 \text{ days}$), where the nuclear reactions take place. The question arises then as to how the Sun could be affecting (terrestrial) nuclear decays? While neutrinos have been considered as the first potential candidates, there is no reaction mechanism with such a large cross section, which could be behind the claimed nuclear decay rate oscillations [8].

Such an effect, if definitely true, seems not to fit any conventional physics reasoning. Therefore, the solution should be searched beyond known physics. Exotic particles like axions, chameleons, and WISPs, can also not provide a quantitative explanation, i.e., they also cannot change an intrinsic nuclear property like the lifetime. Nevertheless, such particles can be inspiring for novel experimental approaches [9]. In addition, the claimed anomalous nuclear decay ($^{54}\text{Mn}$ decay), being correlated with solar flares, makes the whole issue more intriguing, but also stronger (see below) [10]. These results raise questions concerning solar physics and particle physics alike. Not only are such observations a mystery, but also their explanation [11]. Therefore, we face then a real challenging situation, if all this is true.

If it is a new particle or field of solar origin behind this claim, then it is reasonable to assume that its impact on nuclear intrinsic properties should be stronger near to the Sun. While keeping in mind that of potential importance in this context are the various solar mysteries, e.g., the solar corona problem, we also have searched for a similar nuclear behaviour that is taking place near the sun. Indeed, an interesting example is the search for long-lived radioactive nuclei expected from solar flares, due to the nuclear interaction of flare-accelerated ions with the ambient solar atmosphere.
Prompt gamma-ray line emission has been observed in many flares, with the most notable one being the isotope $^{56}$Co, which has a half-life of $T_{1/2}=78.8$ days and two lines at 847 keV and 1238 keV. The long half-life of $^{56}$Co allows the produced radioactive material to accumulate in case of multiple flares [12]. Surprisingly, the delayed 847 keV line should appear after very large flares, but it has not yet been observed with the best performing orbiting telescope (i.e., RHESSI) [13]. Moreover, “delayed X- and $\gamma$-ray line emission from solar flares has been recently searched for with the RHESSI spectrometer but unsuccessfully...” [14]. This non-observation should be seen along with the claimed anomalous nuclear decay ($^{54}$Mn) being correlated with solar flares (see above), which makes the whole issue even more interesting. In addition, we recall that the flare trigger is considered to be among the biggest solar mysteries, while its mean temperature resembles that of the Sun’s core some 700000 km underneath [15]. Is this just a chance coincidence or does this reflect an exotic coupling between the inner and the outer Sun?

3. Conclusion
The question arises as to what exotic particles like axions, chameleons, paraphotons, and more generally WISPs can do, provided the aforementioned anomalous nuclear observations are real? Given the fact that such phenomena do not obey the law of physics, new unconventional terrestrial / celestial experimental approaches must be invoked. The design of the novel experiments should be observationally driven, going thus beyond conventional thinking [16].

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