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Solar flares and the axion quark nugget dark matter model

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ABSTRACT

We advocate the idea that the nanoflares conjectured by Parker long ago to resolve the corona heating problem, may also trigger the larger solar flares. The arguments are based on the model where emission of extreme ultra violet (EUV) radiation and soft X-rays from the Sun are powered externally by incident dark matter particles within the Axion Quark Nugget (AQN) Dark Matter Model. The corresponding annihilation events of the AQNs with the solar material are identified with nanoflares. This model was originally invented as a natural explanation of the observed ratio $\Omega_{\rm dark} \sim \Omega_{\rm visible}$ when the DM and visible matter densities assume the same order of magnitude values. This model gives a very reasonable intensity of EUV radiation without adjustments of any parameters in the model. When the same nuggets enter the regions with high magnetic field they serve as the triggers igniting the magnetic reconnections which eventually may lead to much larger flares.

Technically, the magnetic reconnection is ignited due to the shock wave which inevitably develops when the dark matter nuggets enter the solar atmosphere with velocity $v_{\rm AQN} \sim 600$ km/s which is much higher than the speed of sound c_s, such that the Mach number $M = v_{\rm AQN}/c_s \gg 1$. These shock waves generate very strong and very short impulses expressed in terms of pressure $\Delta p/p \sim M^2$ and temperature $\Delta T/T \sim M^2$ in vicinity of (would be) magnetic reconnection area. We find that this mechanism is consistent with X-ray observations as well as with observed jet like morphology of the initial stage of the flares. The mechanism is also consistent with the observed scaling of the flare distribution $dN \sim W^{-\alpha} dW$ as a function of the flare's energy W. We also speculate that the same nuggets may trigger the sunquakes which are known to be correlated with large flares.

1. Introduction

A variety of anomalous solar phenomena still defy conventional theoretical understanding. For example, the detailed physical processes that heat the outer atmosphere of the Sun to 10^6 K remain a major open issue in astrophysics, see e.g. [1] for review and references on the original results. This persisting puzzle is characterized by the following observed anomalous behavior of the sun: the quiet Sun emits an extreme ultra violet (EUV) radiation with a photon energy of order of hundreds of eV which cannot be explained in terms of any conventional astrophysical phenomena; the total energy output of the corona is quite small, see (1) below. However, it never drops to zero as time evolves. To be more specific, the total intensity of the observed EUV and soft X-ray radiation (averaged over time) can be estimated as follows,

$$L_{\odot\,(\text{from Corona})} \sim 10^{30} \cdot \frac{\rm GeV}{\rm s} \sim 10^{27} \cdot \frac{\rm erg}{\rm s}. \qquad (1)$$

which represents about $(10^{-7} - 10^{-6})$ fraction of the solar luminosity.

At the transition region, the (quiet Sun) temperature continues to rise very steeply until it reaches a few 10^6 K, i.e., being a few 100 times hotter above the underlying photosphere, and this within an atmospheric layer thickness of only 100 km or even much less. Therefore, after several decades of research, it may be that the answer on these (and many others related) questions lies in a new physics.

It was precisely the main subject of Ref. [2] where it was advocated that a number of highly unusual phenomena (including, but not limited to the EUV radiation) observed in solar atmosphere might be related to the gravitational lensing of "invisible" streaming matter towards the Sun. The main argument of Ref. [2] is based on analysis of a number of different correlations between the relative orientations of the Sun and its planets on the one hand and the frequency of the observed flares on the other hand of the analysis. As an example of the observed correlations we reproduce on Fig. 1 some sample plots for the so-called "multiplication spectrum" from Ref. [2] where the frequency of occurring of the X-flares is shown as a function of the Mercury (on the top) and the Earth (on the bottom) heliocentric longitude. We refer to the original paper [2] for the specific discussions, definitions and the details on the data analysis. In this Introduction the only

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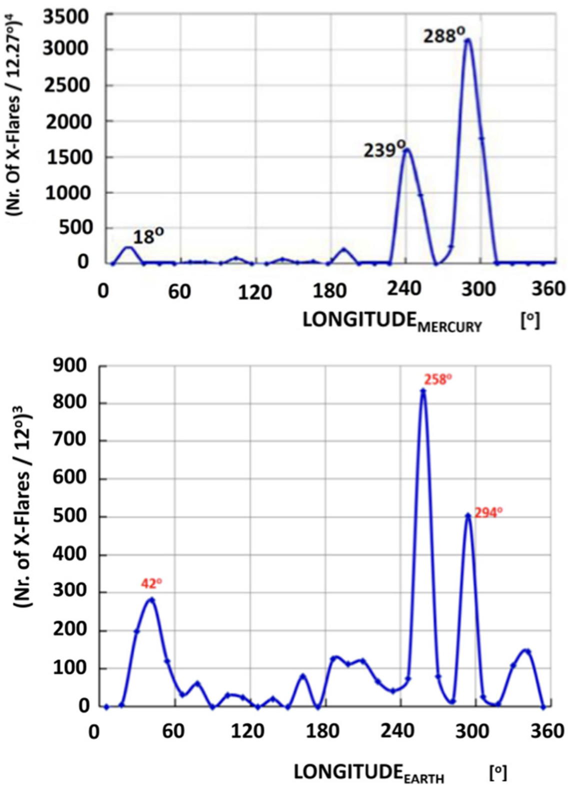

Fig. 1. The "multiplication spectrum" is defined as $Y(J) \equiv \Theta_1(J)\cdot\Theta_2(J)\cdot\Theta_3(J)\cdot\Theta_4(J)$, where Θ is the deflection angle related to the gravitational lensing analysis. The subscript (1–4) denotes the four solar cycles (1975–1986, 1986–1997, 1997–2009, 2009–2014) and J denotes the bin number with widths (6°, 12°, 16°). The plots are taken from [2].

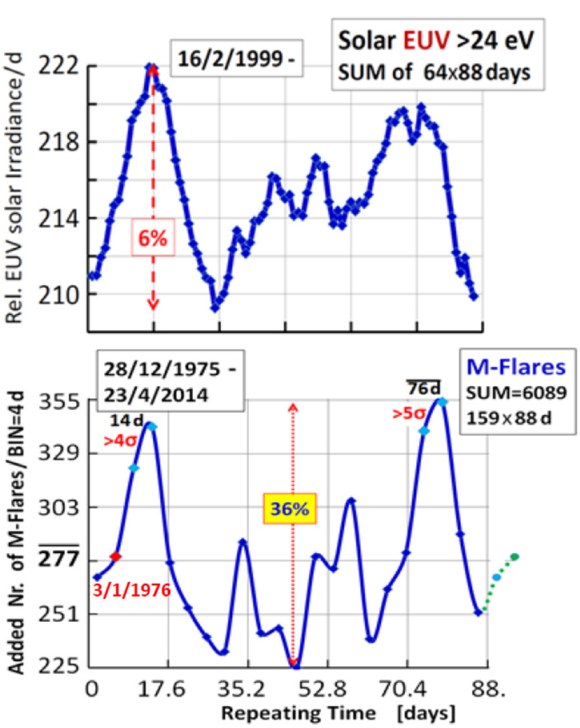

Fig. 2. This plot demonstrates the connection between the relative EUV radiation (top) and the number of M-flares during the same period of time (bottom). The BIN size is 1 day for the EUV data and 4 days for M-flares analysis. The plots are taken from [2].

comment we would like to make is that one should not expect any correlations between the X flare occurrences and the position of the planets. Nevertheless, Fig. 1 obviously demonstrates that this naive expectation is not quite correct, and that the enhancement is happening around the same heliocentric longitude for Mercury and Earth in spite of the fact that periods of the Earth and Mercury are very different ($T_{\rm Mercury} = 87.969$ days) and they appear at this specific heliocentric longitude when the enhancement occurs, in general, at different moments.

One should comment here that "the solar corona heating problem" includes a number of elements which are hard to explain using a conventional framework. In particular, the hot corona cannot be in equilibrium with the $\sim$ 300 times cooler solar surface (violating thus the second law of thermodynamics [3]). In order to maintain the quiet Sun high temperature corona, some non-thermally supplied energy must be dissipated in the upper atmosphere [4]. There are many other problems which are nicely stated in review article [5] as follows "everything above the photosphere...would not be there at all". In particular, the observed X-rays in 1–10 keV energy range in the non-flaring Sun are hard to explain using traditional solar physics [6].

It has been recently argued in [7] that the dark matter AQNs might be the source of the heating of outer atmosphere of the Sun and, therefore, might be directly responsible for the observed EUV radiation and heating the corona. Recently, this proposal has received a strong numerical support [8]. We review the basic arguments supporting this proposal in Section 3. The only comment we would like to make here is that this proposal simultaneously resolves the two problems mentioned above: "solar corona heating" problem and mysterious and unexpected correlation of the solar activity with position of its planets.

To recapitulate: this proposal links the EUV radiation and occurrences of the X, M flares as these two apparently distinct phenomena in fact intimately related as they obviously accompany each other according to Fig. 2, and they *both* are correlated with positions of the planets[1] as argued in [2].

It turns out that if one estimates the extra energy being produced within the AQN dark matter scenario one obtains the total extra energy $\sim 10^{27}$erg/s which precisely reproduces (1) for the observed EUV and soft X-ray intensities [7]. The numerical Monte Carlo simulations [8] fully support the estimate (1). Furthermore, the numerical analysis [8] also shows that the energy injection occurs precisely in the vicinity of the transition region at the altitude $\sim$ 2000 km. This confirms the order of magnitude estimate [7] that the emission will be mostly in form of the EUV and soft X-rays.

One should emphasize that the production of extra energy is expressed exclusively in terms of known dark matter density $\rho_{\rm DM} \sim 0.3$ GeV cm^{-3} and dark matter velocity $v_{\rm DM} \sim 10^{-3}c$ surrounding the Sun without adjusting any parameters of the AQN model, see Section 3 below with relevant comments. We interpreted this "numerical coincidence" as an additional argument supporting our proposal that the heating of the corona and the chromosphere is originated form the AQNs entering the solar atmosphere from outer space.

The main purpose of the present work is to present a very specific mechanism which may provide a hint on how these two naively distinct phenomena nevertheless might be closely related to each other. This deep relation between these two distinct effects may shed some light on the nature of the dark matter which

[1] We should comment here that a deep relation between these two distinct phenomena should not be confused with equal-time correlation between the two. The connection which is shown on Fig. 2 has pure statistical interpretation. Essentially it demonstrates that the higher intensity of the "invisible" streaming matter toward the Sun (averaged over many solar cycles) generates a higher intensity for the EUV radiation. The same increase of the "invisible" matter flux also leads (again, averaged over many solar cycles) to a higher frequency of the flare occurrences.