The mysterious diffuse UV radiation and Axion Quark Nugget dark matter model

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Abstract

It has been recently argued \cite{1, 2, 3} that there is a strong component of the diffuse far-ultraviolet (FUV) background which is hard to explain by conventional physics in terms of the dust-scattered starlight. We propose that this excess in FUV radiation might be result of the dark matter annihilation events within the so-called axion quark nugget (AQN) dark matter model, which was originally invented for completely different purpose to explain the observed similarity between the dark and the visible components in the Universe, i.e. $\Omega_{\text{DM}} \sim \Omega_{\text{visible}}$. We support this proposal by demonstrating that intensity and the spectral features of the AQN induced emissions are consistent with the corresponding characteristics of the observed excess of the FUV radiation. If the future studies confirm the puzzling characteristics observed in \cite{1, 2, 3} it might unlock a much more deeper and fundamental problem of modern cosmology– it may reveal the nature of the dark matter.

Keywords: dark matter, axion, diffuse UV radiation

1. Introduction and Motivation

The title of this work seemingly includes two contradicting terms: the first one is “the radiation”, while the second term of the title is “the dark matter” (DM) which, by definition, must decouple from the baryons and the radiation. However, the main goal of this work is to argue that the puzzling features observed in \cite{1, 2, 3} in fact can be explained within a specific dark matter model, the so-called axion quark nugget (AQN) dark matter model \cite{4}. Therefore, the contradiction in the title is only apparent, while the DM in form of the AQNs strongly couples to the baryons and can emit light. Furthermore, if the future and more precise analysis confirms the puzzling observations \cite{1, 2, 3} it could serve as an extraordinary evidence revealing the nature of the dark matter, see few additional comments at the very end of this Introduction.

Before we proceed with our arguments we should, first of all, highlight the mysterious properties of the observations \cite{1, 2, 3} which are very hard to understand if interpreted in terms of the conventional astrophysical phenomena.
Indeed, the widely accepted picture is that the dominant source of the diffused ultraviolet (UV) background radiation is the dust-scattered radiation of the UV emitting stars. However, the recent analysis carried out in [1] and in subsequent papers [2, 3] disproves this conventional picture. The corresponding refutal arguments are based on the following puzzling features of the observations:

1. “uniformity puzzle”: The diffuse radiation is very uniform in both hemispheres, see Figs 7-10 in [1]. This feature should be contrasted to the strong non-uniformity in distribution of the UV emitting stars;

2. “galactic longitude puzzle”: The diffuse radiation is almost entirely independent of Galactic longitude. This feature must be contrasted with localization of the brightest UV emitting stars which are overwhelmingly confined to the longitude range $180^0 - 360^0$, which strongly suggests that the diffuse background radiation can hardly originate in dust-scattered starlight;

3. “galactic latitude puzzle”: The diffuse radiation increases in brightness toward lower galactic latitude at all galactic longitudes. This should be contrasted with conventional modelling [1] which predicts very low brightness at low Galactic latitudes. This observation also suggests that the recorded diffused emission has galactic, not extragalactic origin. Indeed, the extragalactic light cannot strongly vary toward lower galactic latitude. Due to the same reasons, the observations also conclusively suggest that this emission has celestial, and not terrestrial nature;

4. “non-correlation puzzle”: Conventional picture for the UV diffuse radiation suggests that it must be correlated with the 100 $\mu$m thermal emission as both radiations are assumed to be related to the dust and its distribution in the galaxy. However, this conjecture dramatically fails as the 100 $\mu$m thermal emission is highly asymmetric and explicitly shows a strong correlation with localization of the emitting stars, while UV diffuse emission is highly uniform and it is not correlated with the dust distribution, see Fig. 14 in [1].

The authors of [1] conclude, I quote “the source of the diffuse FUV emission is unknown –that is the mystery that is referred to in the title”. I keep the same term “mysterious radiation” in the title of the present work. Furthermore, the authors of [1] argued that this “exotic” mysterious component of emission is unknown but must be galactic origin, and might be due to the interaction of the DM with the nuclei of the interstellar medium. In addition, the authors of [1] also suggested that if the DM particle is electrically neutral but represents a composite system, than such DM particles may contribute to the “exotic” diffuse UV component. In fact this proposal had been advocated even earlier in [2].

In the present work we offer a specific DM model, the so-called AQN dark matter model which is capable to produce the required “exotic” diffuse UV radiation as mentioned in previous paragraph. The AQN model was invented long ago [4] for drastically different purpose (unrelated to the present studies) to explain the observed similarity between the dark matter and the visible matter densities in the Universe. The original motivation [4] for the AQN model can be explained in two lines as follows. It is commonly assumed that the Universe began in a symmetric state with zero global baryonic charge and later (through
some baryon number violating process, non-equilibrium dynamics, and CP violation effects, realizing three famous Sakharov’s criteria [6] evolved into a state with a net positive baryon number, which represents the idea of baryogenesis. In the AQN framework the baryogenesis is actually a charge segregation (rather than charge generation) process in which the global baryon number of the universe remains zero at all times. This scenario should be considered as an alternative path which is qualitatively distinct from conventional baryogenesis.

The AQN construction in some respects is similar to the Witten’s quark nuggets, see [7, 8, 9]. This type of DM is “cosmologically dark” not because of the weakness of the interactions with the visible SM particles, but due to their small cross-section-to-mass ratio, which scales down many observable consequences of an otherwise strongly-interacting DM candidate.

The main distinct feature of the AQN model which plays absolutely crucial role for the present work is that nuggets can be made of matter as well as antimatter during the QCD transition as a result of this charge segregation (rather than charge generation) process. In this scenario the DM density, $\Omega_{DM}$ representing the matter and anti-matter nuggets, and the visible density, $\Omega_{\text{visible}}$, will automatically assume the same order of magnitude densities $\Omega_{DM} \sim \Omega_{\text{visible}}$ as they are both proportional to one and the same fundamental dimensional parameter of the theory, the $\Lambda_{\text{QCD}}$. Therefore, the AQN model, by construction, actually resolves two fundamental problems in cosmology without necessary to fit any parameters of the model. For the present studies we take the agnostic viewpoint regarding the questions on formation mechanism of the AQNs, and assume that such nuggets made of antimatter are present in our Universe, see [10] for a short overview on specific questions related to the nugget’s formation, generation of the baryon asymmetry, and survival pattern of the nuggets during the evolution in early Universe with its unfriendly environment. This assumption is consistent with all available constraints as long as the average baryon charge of the nuggets is sufficiently large $\langle B \rangle \geq 3 \cdot 10^{24}$.

The presence of the antimatter nuggets in the system implies that there will be annihilation events leading to large number of observable effects on different scales: from galactic scales to the terrestrial rare events. In fact, there are many hints suggesting that such annihilation events may indeed took place in early Universe as well as they are happening now in present epoch. In particular, the AQNs might be responsible for a resolution of the “Primordial Lithium Puzzle” [11] during Big Bang Nucleosynthesis (BBN) epoch. The AQNs may also alleviate the tension between standard model cosmology and the recent EDGES observation of a stronger than anticipated 21 cm absorption feature as argued in [12]. The AQNs might be also responsible for famous long standing problem of the “Solar Corona Mystery” [13, 14] when the so-called “nanoflares” conjectured by Parker long ago [15] are identified with the annihilation events in the AQN framework. The AQNs could be also responsible for mysterious and anomalous Cosmic Ray (CR) like events such as mysterious bursts [16] observed by the Telescope Array collaboration or Multi Modal Clustering anomalous events [17] observed by the HORIZON 10T collaboration. Sufficiently large (and vary rare) AQNs with $B > 10^{27}$ entering the Earth’s atmosphere could produce
infrasound and seismic acoustic waves as discussed in [18] when the infrasound and seismic acoustic waves indeed have been recorded by dedicated instruments while a synchronized all-sky camera network (visible frequency bands) ruled out a conventional meteor source.

The list with numerous deviations from the standard cosmology at different scales which could be explained in terms of the same antimatter nuggets within the same framework as mentioned above is already quite long, but definitely is far from being complete. Our comment here is that the presence of the antimatter nuggets directly impacts all these (seemingly unrelated) fields of physics, from baryogeneration (replaced by charge segregation) and the “Primordial Lithium Puzzle” in early Universe to excess in diffuse FUV background and rare CR-like anomalous events at present time. If the future observations and more precise data confirm these hints on deviations from the standard astrophysics and cosmology it will be an extraordinary evidence revealing the nature of the dark matter.

2. The AQN Dark Matter model

The typical baryon number density of such dense objects is the same order of magnitude as the conventional nuclear matter density \( n \sim 10^{40}\text{cm}^{-3} \), while typical baryon charge of the nugget is around \( B \sim 10^{25} \) which implies that the mass of a typical nugget is around \( M \sim 10^g \), while its size \( R \sim 10^{-5}\text{cm} \), see below with more specific and technical details.

If the AQNs enter the regions of the surrounding material (such as stars, planets or interstellar medium) the annihilation processes start and the internal temperature of the nuggets \( T \) starts to rise. A typical internal temperature of the AQNs for the galactic environment of density \( n \) can be estimated from the condition that the radiative output, the surface emissivity \( F_{\text{tot}}(T) \) must balance the flux of energy due to the annihilation processes \[19\], i.e.

\[
4\pi R^2 \cdot F_{\text{tot}}(T) \approx \kappa \cdot (\pi R^2) \cdot (2 \text{ GeV}) \cdot n \cdot v_{\text{AQN}},
\]

where the left hand side accounts for the total energy radiation from the AQN’s surface per unit time while the right hand side accounts for the rate of annihilation events when each successful annihilation event of a single baryon charge produces \( \sim 2m_p c^2 \approx 2 \text{ GeV} \) energy. In Eq. \(1\) we assume that the nugget is characterized by the geometrical cross section \( \pi R^2 \) when it propagates in environment with local density \( n \) with velocity \( v_{\text{AQN}} \sim 10^{-3}c \). The factor \( \kappa \) is introduced to account for the fact that not all matter striking the AQN will annihilate and not all of the energy released by an annihilation will be thermalized in the AQNs by changing the internal temperature \( T \). In particular, some portion of the energy will be released in form of the axions, neutrinos, and also in form of the x-rays from the so-called hot spots, see details below. The high probability of reflection at the sharp quark matter surface lowers the value of \( \kappa \). The ionization of the AQNs, on the other hand, may induce the negative charge of the AQNs, and as a consequence may increase the value of \( \kappa \).
by effectively increasing the cross section \(\sigma\). Furthermore, the density of the galactic environment \(n(r)\) changes dramatically from region to region, which implies that the temperature of the nuggets also varies correspondingly, which also introduces a large uncertainty.

One can dramatically reduce all these numerous uncertainties in the estimation for the effective temperature \(T_{\text{eff}}\) by normalizing the intensity of the emission to some specific observations which can be identified with the AQN annihilation events in interstellar medium. In fact, it has been argued in [20] that the diffuse x ray emission analyzed in [21] cannot be explained in terms of any conventional astrophysical sources but can be naturally explained in terms of the AQN annihilation events. The combination of the arguments from [19, 20] then suggest that the effective temperature of the AQNs in the central region of the galaxy could be very high \(T_{\text{eff}} \geq (2.5 - 5) \text{ eV}\), see estimate below. Such high temperature for \(T_{\text{eff}}\) implies that these nuggets could be very strong UV emitters, which is precisely the topic of the present work.

To proceed with our estimates we need the expression for the spectral surface emissivity due to the bremsstrahlung radiation from electrosphere at temperature \(T\). It has been computed in [19]:

\[
\frac{dF}{d\omega} (\omega) \approx \frac{4}{45} \frac{T_3 \alpha^{5/2}}{\pi} \sqrt{\frac{T}{m}} \cdot f(x), \quad x \equiv \frac{\omega}{T}
\]  

(2)

where dimensionless function \(f(x)\) with sufficient accuracy can be approximated as follows:

\[
f(x) \approx \begin{cases} 
(1 + x) e^{-x} (17 - 12 \ln(x/2)) & x < 1, \\
(1 + x) e^{-x} (17 + 12 \ln(2)) & x \geq 1.
\end{cases}
\]

The total surface emissivity entering \(\Gamma\) is given by:

\[
F_{\text{tot}}(T) = \int_0^{\infty} d\omega \frac{dF}{d\omega} (\omega) \approx \frac{16}{3} \frac{T^4 \alpha^{5/2}}{\pi} \sqrt{\frac{T}{m}}.
\]

(3)

The most important feature of this bremsstrahlung radiation is that, in contrast with black body radiation, it is very flat for \(\omega \leq T\), while it starts to diminish only for sufficiently high frequencies \(\omega \gg T\). Numerically, the intensity of radiation (3) is also much smaller than black body radiation by factor \(\sim 10^{-6}\) for relevant temperatures around \(T \sim \text{eV}\).

To compute the observable flux \(\Phi_\Gamma\) for a given frequency band from all nuggets one should multiply \(\Gamma\) by the number density of the nuggets \(n_{\text{DM}} \approx \rho_{\text{DM}}/(m_p B)\) and integrate along the line of sight \(\Gamma\), i.e.

\[
\Phi_\Gamma \propto \int_\Gamma dl n(l)n_{\text{DM}}(l),
\]

(4)

where we assume that all other parameters, except density \(n\), entering the right hand side of (1) are approximately the same. The key point here is that the comparison between observations for different frequency bands along the same
line-of-sight is possible because the local emission for any frequency band depends only on the local rate of annihilation $\propto n(r)n_{DM}(r)$ as the spectrum is fixed by (2). Therefore, the main uncertainties (mentioned above and related to the AQN dynamics as well as to the matter and DM distributions) will be cancelled out when comparing the emissions from the same position in the sky.

3. The FUV diffuse emission

From the arguments outlined above one can represent the spectral emissivity with frequency $2\pi \nu = xT$ produced by AQNs at arbitrary direction in sky determined by path $\Gamma$ as follows

$$\frac{d\Phi_T(x)}{dx} \approx \Phi \left[ \int_0^\infty f(x)dx \right] \left[ \int_{\Gamma} dl n(l)n_{DM}(l) \right] \left[ \frac{1 - g}{g} \right].$$

In expression (5) the parameter $g$ is unknown empirical factor of order of one to be discussed below while the main normalization factor $\Phi$ is chosen as the excess of the diffused X-ray emission from the galactic core as observed by Chandra and analyzed in [21]. This choice is based on the following arguments [20]. The X-ray emissions from the galactic core provide a puzzling picture: they seem to indicate that an 8 keV thermal plasma is being maintained, but the source of energy fuelling this plasma is a mystery. After subtracting known X-ray sources from the Chandra X-ray images of the galactic core, one finds a residual diffuse thermal X-ray emission with a thermal component well described by a hot 8 keV plasma with surface brightness $\Phi_{keV} = (1.8 - 3.1) \times 10^{-6} \text{erg/cm}^2/\text{s/sr}$ [21]. To sustain this plasma, some $10^{40} \text{erg/s}$ of energy must be supplied to the galactic core which is much more than the observed rate of supernovae, for example, can explain [21].

In has been argued in [20] that the spectrum and the intensity of the AQN induced X-ray emission fits the observations, which is the crucial argument for our normalization\(^1\) in terms of factor $\Phi$ entering (5):

$$\bar{\Phi} \approx (2.5 - 3.9) \cdot 10^{-5} \frac{\text{erg}}{\text{cm}^2 \cdot \text{s}}, \quad [\text{X-ray observations}]$$

where we multiply by factor $4\pi$ the observed intensity $\Phi_{keV}$ extracted in [21] as quoted above. As discussed in [20] the X-ray emission in the AQN framework

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\(^1\)Another way to normalize the intensity is to use the observed excess in 511 keV line as it was done in the original paper [20]. However, in this case an extra uncertainty appears due to unknown relation between 511 keV line emission which is due to $e^+e^-$ annihilation and the baryon charge annihilation processes within AQN core. In fact it has been recently claimed [22] that the mechanism for the $e^+e^-$ annihilation is different from the original proposal [23] as the annihilation of the visible electrons with AQN’s positrons may occur far away from the nugget’s location due to the strong ionization features of the AQNs. Alternatively, one could normalize [23] in terms of DM and visible matter distributions as it was done in [24]. However, it would bring an enormous uncertainty in normalization, which we try to avoid by normalizing to the observed flux.
is originated from the so-called “hot spots” which represent the very localized regions close to the nugget’s surface, where the annihilation events take place. The corresponding portion of the energy released from “hot spots” is parameterized by unknown factor \( g \ll 1 \) entering (5). The dominant portion of the energy \((1 - g)\) due to the annihilation will be thermalized, and will be emitted with the spectrum determined by (2). It explains the numerical factor \((1 - g)/g\) entering (5). The last factor \(\Gamma\) which requires the explanation represents a specific path \(\Gamma\) in the direction to the galactic core where uniform X-ray diffused flux (6) is recorded. We also use notations \(\ell\) for the integration variable for the path \(\Gamma\) to be distinguished from generic path \(\Gamma\).

Now we want to argue that a typical temperature \(T_{\text{eff}}\) which implicitly (through parameter \(x \equiv \omega/T_{\text{eff}}\)) enters (5) indeed typically assumes the values in the eV range such that the AQNs will be the source of the diffuse UV radiation, which represents the main claim of this work. Indeed, to avoid a large number of uncertainties mentioned above we can estimate \(T_{\text{eff}}\) by comparing the excess of radiation observed by WMAP collaboration and coined as the WMAP haze \[25, 26, 27, 28, 29\] and the X-ray diffused radiation we already mentioned. Assuming that the observed WMAP haze intensity is saturated\(^2\) by the AQN radiation as advocated in [19] with the flat spectrum (2) extending from UV to GHz emission, one arrives to the following estimate for \(T_{\text{eff}}\) (quoted above) in terms of the parameter \(g\):

\[
\frac{eV}{T_{\text{eff}}} \cdot \frac{1 - g}{g} \approx (2-4) \quad \Rightarrow \quad T_{\text{eff}} \geq (2.5 - 5) \text{ eV},
\]

where for numerical estimates we use \(g \simeq 0.1\). One should emphasize that the uncertainty of parameter \(g\) is not a deficiency of the AQN framework itself. Rather, this inevitable uncertainty results from very complex annihilation pattern of the baryons from visible material (confined hadronic phase) with antimatter from the AQNs (colour superconducting phase). Therefore, this parameter \(g\) fundamentally cannot be computed from the first principles and will be treated in what follows as empirical phenomenological parameter.

The key point here is that both emissions, the WMAP haze as well as diffuse X-ray emissions are originated from approximately the same region in the sky, and both are related to the same annihilation processes of the baryon charge within the AQN framework such that the only uncertainty in the estimate of the \(T_{\text{eff}}\) comes from parameter \(g\) defined above\(^3\).

It is very instructive to compare our estimates determined by (5) and (6) with intensities of the diffuse FUV emission as recorded by [1, 2, 3]. To proceed

\(^2\)It has been argued in [26] that the WMAP haze can be attributed to the spinning dust or the dark matter annihilation \[23, 25\]. As the physical source of this excess of GHz emission remains to be a matter of debate we assume in our estimates\(^4\) that a finite fraction of this excess is due to the AQN annihilation events as argued in [19].

\(^3\)Of course a number of uncertainties related to extracting WMAP haze intensity and the X ray intensity remain. Our claim refers to the theoretical uncertainties related to the AQN model itself and its interaction with environment.
with such comparison we have to use the same units. The simplest way to compare is to use the conversion worked out in \[1\] where, I quote “the intensity of excess FUV radiation detected by GALEX over its bandpass (1380-2500)˚A is $10^{-5}$erg cm$^{-2}$ s$^{-1}$, assuming a flat spectrum with 300 photons (cm$^{-2}$ s$^{-1}$sr$^{-1}$˚A$^{-1}$),”

This implies that the magnitude of 300 photons which typically emerges in analysis \[1, 2, 3\] corresponds to the intensity $10^{-5}$erg cm$^{-2}$ s$^{-1}$ which appears in our prediction \[5\] with normalization factor $\Phi$ defined by \[6\]. Several numerical factors modify this crude estimate. First, there is an intensity suppression due to decreasing of the interstellar medium density \(n(l)\) entering \[5\] for the path $\Gamma$ for FUV (where the excess with 300 photons is measured) in comparison with path $\bar{\Gamma}$. This suppression factor might be largely neutralized by the enhancement factor $1/g \sim 10$ entering \[5\]. The same factor $g^{-1}$ may also increase the effective temperature $T_{\text{eff}}$ comparison with oversimplified estimate \[7\]. Furthermore, the $T_{\text{eff}}$ might assume somewhat higher values in the galactic core regions, which also contribute to FUV measured at higher latitudes due to the re-scattering from the dust. Important point here is that the observed FUV intensity is consistent with the temperature range \[7\] as the spectrum given by $f(x)$ is very flat and effectively starts to diminish only for sufficiently high frequencies $2\pi\nu \geq T_{\text{eff}}$.

Precise portion of the emission in the FUV frequency band within the window $\Delta\nu$ is determined by the parameter $\chi$ defined as follows:

$$
\chi \equiv \frac{\int_{x_{\text{min}}}^{x_{\text{max}}} dx f(x)}{\int_0^\infty dx f(x)}, \quad \left(\frac{2\pi\nu}{T_{\text{eff}}}\right) \in (x_{\text{min}}, x_{\text{max}}).
$$

(8)

The suppression factor $\chi$ obviously dramatically depends on effective internal temperature $T_{\text{eff}}$ of the nuggets, which itself is determined by the local interstellar medium density $n$ according to \[1\]. As an illustration let us consider a typical temperature $T_{\text{eff}} \simeq 5$ eV as estimated in \[7\] and bandpass (1380-2500)˚A where the excess of FUV radiation was detected by GALEX. The factor $\chi$ in this case is about $\chi \simeq 0.2$, which implies that quite substantial portion of the energy will be emitted by the AQNs in this relatively narrow frequency band.

Our estimates presented above suggest that the AQN-induced FUV radiation may naturally assume $\sim 10^{-5}$erg cm$^{-2}$ s$^{-1}$ intensity range. However, those estimates were based on comparison with emission in a different frequency band (X-ray emission) which is assumed to be also the AQN-induced radiation. Now we want to support the basic normalization factor \[5\] by independent direct estimates without referring to any other observed diffuse radiation.

First, we estimate a total luminosity $L_{\text{AQN}}$ from a single AQN by multiplying \[3\] to the surface area:

$$
L_{\text{AQN}} \approx 4\pi R^2 \cdot F_{\text{tot}}(T) \approx 4.7 \left(\frac{T}{5 \text{ eV}}\right) \frac{\Phi}{s},
$$

(9)

where for numerical estimates we use $R \approx 2.2 \cdot 10^{-5}$cm and $B \approx 10^{25}$ as in our previous studies for other applications in this model, see \[10\] for review. To estimate the total FUV intensity $\Phi_{\text{FUV}}^{\text{AQNs}}$ produced by all AQNs one should
multiply the luminosity $L_{AQN}$ to the nugget’s density $n_{AQN} \sim \rho_{DM}/(m_p B)$ and the mean free path $\mathcal{R}$ in the local interstellar medium, i.e.

$$
\Phi_{FUV}^{AQN} \sim L_{AQN} n_{AQN} \mathcal{R} \chi \sim 5 \cdot 10^{-5} \left( \frac{T}{5 \text{ eV}} \right)^{12/5} \frac{\text{erg}}{\text{s} \cdot \text{cm}^2},
$$

(10)

where for numerical estimates we take the conventional value for the DM density $\rho_{DM} \simeq 0.3 \text{ GeV/cm}^3$. We also used parameter $\chi \simeq 0.2$ as estimated above. This relatively large value for $\chi$ is a result of the “flatness” of the bremsstrahlung radiation as mentioned after (3). We also adopted parameter $\mathcal{R} \simeq 0.6 \text{ kpc}$ used in [1]. It represents the result of conventional estimates for the mean free path of the FUV photons propagating in the galaxy.

It is instructive to compare the estimate (10) with analogous estimates for WIMP-like DM particles performed in [1]. The authors of [1] claim that the total FUV intensity produced by WIMPs cannot exceed $10^{-17} \text{erg/(s} \cdot \text{cm}^2)$ which according to the authors of [1] represents a model-independent upper limit for WIMP-like models. It should be contrasted with our AQN based estimates which show a perfect consistency with the observed intensity on the level $10^{-5} \text{erg/(s} \cdot \text{cm}^2)$ as well as with estimates (5), (6) based on normalization to the X ray diffuse emission.

We are now in position to explain how the puzzles 1-4 listed above are naturally resolved within AQN framework. First of all the “uniformity puzzle” is obviously resolved as the DM in form of the AQNs are uniformly distributed in the galaxy. Similarly, the “galactic longitude puzzle” is resolved as the DM particles are not sensitive to the galactic longitude, as the AQNs are not correlated with locations of the UV emitting stars. The “galactic latitude puzzle” is also naturally resolved as the increase in brightness toward lower galactic latitude is a direct consequence of the AQN framework when the number of annihilation events is proportional to interstellar matter density according to (4) which obviously leads to the increase of the temperature $T$ and as the consequence to the brightness toward lower galactic latitude. Finally, the “non-correlation puzzle” with the 100 $\mu$m thermal emission is resolved as the dominant fraction of the 100 $\mu$m radiation follows the locations of the emitting stars, in contrast with AQNs, which contribute very little to the thermal 100 $\mu$m radiation. One should emphasize that a conventional WIMP-type DM models are not capable to generate the required intensity of the signal as it was already pointed out in [1], as it was already mentioned. The AQNs, in contrast with WIMP-type particles, are the macroscopically large objects made of strongly interacting quarks and gluons of the Standard Model (SM). In this sense it is indeed a “composite system” in terminology of [1].

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4 Indeed, a typical observed value for the 100 $\mu$m emission line ranges in $(0.7 - 2.5) \text{MJy/sr}$ depending on location, see Figs. 12, 13 in [1]. This observed intensity is numerically much larger than the AQN induced contribution to this frequency band as determined by the spectrum (2) with normalization (5).
4. Concluding comments

There are several profound consequences of our proposal identifying the mysterious diffuse UV radiation [1, 2, 3] with the emissions by hot AQNs. First of all this proposal may also shed some light on a long standing problem related to the nature of the re-ionization of the Universe. Indeed, by studying the variety of spectra the authors of [30] argued that the same DM source which is responsible for FUV diffuse emission (which is the topic of this work) must also emit, I quote: “a continuum of photons in the range $\sim 850\,\text{Å}$ to about $2000\,\text{Å}$. This feature is obviously present in the AQN framework as the spectrum (2) is very broad and for $T_{\text{eff}} \geq 5\,$ eV extends to the shorter wavelengths well beyond the cut off at the $912\,\text{Å}$ when the hydrogen atom can be ionized as this wavelength exactly corresponds to the Rydberg constant 13.6 eV. In different words, the same AQNs could be the source of ionizing radiation which is known to be present well above the galactic plane 30).

Furthermore, the same DM source in form of the AQNs may also contribute to the resolution of another long standing problem related to the Extragalactic Background Light (EBL). Indeed, it has been known for some time that the conventional measurements cannot be explained by diffuse galaxy halos or intergalactic stars. The discrepancy could be as large as factor $\sim (2 - 3)$ or even more, see e.g. recent review [31]. Our comment here is that the AQNs may fulfill this shortage as the spectrum (2) is very broad and includes optical and IR light.

There is a number of direct tests which can be performed in future to substantiate or refute this proposal identifying the mysterious diffuse UV radiation [1, 2, 3] with the emission by AQNs. Some specific suggestions for future studies have been already discussed in [1, 2, 3, 30], and include such instruments as the Alice UV spectrometer aboard the New Horizon mission, and we have nothing new to add here. The only original comment we would like to make is that the intensity and spectral features of the radiation in the AQN framework are determined by the line of sight which includes both: the DM and visible matter distributions according to (4). It should be contrasted with conventional WIMP-like models when it is exclusively determined by the DM distribution. Therefore, some specific morphological correlations with DM and visible matter distributions can be explicitly studied in future.

It is quite amazing that the spectral features and intensities for “exotic” sources which were required (anticipated) by analysis [1, 2, 3, 30] in form of the “composite system” in terminology [1] to fit the observations are automatically present in the AQN framework which was originally invented for dramatically different purposes with very different motivation, see [10] for review. One should also emphasize that in the present work we use the same basic parameters which were previously used for very different applications in drastically different environment without any attempt to modify these parameters to better fit the observations. We consider this “miracle coincidence” as a strong argument supporting this proposal.

If our interpretation on source of the excess of the diffuse FUV emission
is confirmed by future studies it would represent an extraordinary evidence supporting the resolution of two long standing puzzles: it reveals the nature of the DM and the matter-antimatter asymmetry of our Universe as these two problems of the cosmology are intimately linked in the AQN framework.

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References

[1] R. C. Henry, J. Murthy, J. Overduin, J. Tyler, The Mystery of the cosmic diffuse ultraviolet background radiation, Astrophys. J. 798 (1) (2014) 14. doi:10.1088/0004-637x/798/1/14 URL https://doi.org/10.1088/0004-637x/798/1/14

[2] M. S. Akshaya, J. Murthy, S. Ravichandran, R. C. Henry, J. Overduin, The diffuse radiation field at high galactic latitudes, Astrophys. J. 858 (2) (2018) 101. doi:10.3847/1538-4357/aacbc9 URL https://doi.org/10.3847/1538-4357/aacbc9

[3] M. S. Akshaya, J. Murthy, S. Ravichandran, R. C. Henry, J. Overduin, Components of the diffuse ultraviolet radiation at high latitudes, Mon. Not. R. Astron. Soc. 489 (1) (2019) 1120–1126. arXiv:1908.02260 doi:10.1093/mnras/stz2186

[4] A. R. Zhitnitsky, ‘Nonbaryonic’ dark matter as baryonic colour superconductor, JCAP 10 (2003) 010. arXiv:hep-ph/0202161 doi:10.1088/1475-7516/2003/10/010

[5] R. C. Henry, Progress in understanding the diffuse UV cosmic background, Mem.S.A.It. 83 (2012) 409. arXiv:1205.0430

[6] A. Sakharov, Violation of CP Invariance, C asymmetry, and baryon asymmetry of the universe, JETP Lett. 5 (1967) 24–27. doi:10.1070/PU1991v034n05ABEH002497

[7] E. Witten, Cosmic separation of phases, Phys. Rev. D30 (1984) 272–285. doi:10.1103/PhysRevD.30.272

[8] E. Farhi, R. L. Jaffe, Strange matter, Phys. Rev. D30 (1984) 2379–2390. doi:10.1103/PhysRevD.30.2379

[9] A. De Rujula, S. L. Glashow, Nuclearites - A novel form of cosmic radiation, Nature 312 (1984) 734–737. doi:10.1038/312734a0
[10] A. Zhitnitsky, Axion quark nuggets. Dark matter and matter–antimatter asymmetry: Theory, observations and future experiments, Mod. Phys. Lett. A 36 (18) (2021) 2130017. arXiv:2105.08719
[11] V. V. Flambaum, A. R. Zhitnitsky, Primordial Lithium Puzzle and the Axion Quark Nugget Dark Matter Model, Phys. Rev. D 99 (2) (2019) 023517. arXiv:1811.01965
[12] K. Lawson, A. R. Zhitnitsky, The 21 cm absorption line and the axion quark nugget dark matter model, Phys. Dark Univ. 24 (2019) 100295. arXiv:1804.07340
[13] A. Zhitnitsky, Solar Extreme UV radiation and quark nugget dark matter model, JCAP10 (2017) 050. arXiv:1707.03400
[14] N. Raza, L. van Waerbeke, A. Zhitnitsky, Solar corona heating by axion quark nugget dark matter, Phys. Rev. D 98 (10) (2018) 103527. arXiv:1805.01897
[15] E. N. Parker, Nanoflares and the solar X-ray corona, Astrophys. J.330 (1988) 474–479. arXiv:2008.04325
[16] A. Zhitnitsky, The Mysterious Bursts observed by Telescope Array and Axion Quark Nuggets, J.Phys.G:Nucl.Part.Phys. arXiv:2008.04325
[17] A. Zhitnitsky, Multi-Modal Clustering Events observed by Horizon-10T and Axion Quark Nuggets, Universe 7 (2021) 384. arXiv:2108.04828
[18] D. Budker, V. V. Flambaum, A. Zhitnitsky, Infrasonic, acoustic and seismic waves produced by the Axion Quark Nuggets, Symmetry 14 (2022) 459. arXiv:2003.07383
[19] M. M. Forbes, A. R. Zhitnitsky, WMAP haze: Directly observing dark matter?, Phys. Rev. D78 (8) (2008) 083505. arXiv:0802.3830
[20] M. M. Forbes, A. R. Zhitnitsky, Diffuse x-rays: Directly observing dark matter?, JCAP 01 (2008) 023. arXiv:astro-ph/0611506
[21] M. P. Muno, F. K. Baganoff, M. W. Bautz, E. D. Feigelson, G. P. Garmire, M. R. Morris, S. Park, G. R. Ricker, L. K. Townsley, Diffuse x-ray emission in a deep Chandra image of the Galactic center, Astrophys. J. 613 (2004) 326–342. arXiv:astro-ph/0402087
[22] V. V. Flambaum, I. B. Samsonov, Radiation from matter-antimatter annihilation in the quark nugget model of dark matter, Phys. Rev. D 104 (6) (2021) 063042. arXiv:2108.00652 doi:10.1103/PhysRevD.104.063042

[23] D. H. Oaknin, A. R. Zhitnitsky, 511 keV Photons from Color Superconducting Dark Matter, Phys. Rev. Lett. 94 (10) (2005) 101301. arXiv:hep-ph/0406146 doi:10.1103/PhysRevLett.94.101301

[24] A. Zhitnitsky, Width of the 511 keV line from the bulge of the galaxy, Phys. Rev. D 76 (10) (2007) 103518. arXiv:astro-ph/0607361 doi:10.1103/PhysRevD.76.103518

[25] D. P. Finkbeiner, Microwave ism emission observed by wmap, Astrophys. J. 614 (2004) 186–193. arXiv:astro-ph/0311547 doi:10.1086/423482

[26] D. P. Finkbeiner, G. I. Langston, A. H. Minter, Microwave ISM emission in the Green Bank Galactic Plane Survey: Evidence for spinning dust, Astrophys. J. 617 (2004) 350–359. arXiv:astro-ph/0408292 doi:10.1086/425165

[27] D. Hooper, D. P. Finkbeiner, G. Dobler, Possible evidence for dark matter annihilations from the excess microwave emission around the center of the Galaxy, Phys. Rev. D 76 (2007) 083012. doi:10.1103/PhysRevD.76.083012 URL https://link.aps.org/doi/10.1103/PhysRevD.76.083012

[28] D. Hooper, G. Zaharijas, D. P. Finkbeiner, G. Dobler, Prospects For Detecting Dark Matter With GLAST In Light Of The WMAP Haze, Phys. Rev. D 77 (2008) 043511. arXiv:0709.3114 doi:10.1103/PhysRevD.77.043511

[29] G. Dobler, D. P. Finkbeiner, Extended Anomalous Foreground Emission in the WMAP 3-Year Data, Astrophys. J. 680 (2008) 1222–1234. arXiv:0712.1038 doi:10.1086/587862

[30] R. C. Henry, J. Murthy, J. Overduin, Discovery of an Ionizing Radiation Field in the Universe arXiv:1805.09658

[31] K. Mattila, P. Väisänen, Extragalactic Background Light: Inventory of light throughout the cosmic history, Contemp. Phys. 60 (1) (2019) 23–44. arXiv:1905.08825 doi:10.1080/00107514.2019.1586130