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Dark matter as a cancer hazard

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ABSTRACT

We comment on the paper "Dark matter collisions with the human body" by K. Freese and C. Savage (2012) [1] and describe a dark matter model for which the results of the previous paper do not quite apply. Within this mirror dark matter model, potentially hazardous objects, mirror micrometeorites, can exist and may lead to diseases triggered by multiple mutations, such as cancer, though with very low probability.

Are the dark matter collisions with the human body dangerous to human health? This question was investigated and answered negatively in the interesting article [1] by Freese and Savage (possible biological effects of dark matter were also previously discussed in [2]). This reassuring conclusion is based essentially on two premises. Namely, dark matter particles deposit much less energy in collisions (~ 10 keV) than the cosmic-ray muons (~ 10–100 MeV) and the expected rates of the dark matter collisions are rather low. As a result, dark matter related radiation exposure is negligible compared to other natural radiation sources and is harmless to the human body.

The quoted paper [1] assumed Weakly Interacting Massive Particles (WIMPs) as a leading candidate for the dark matter. For WIMPs the above mentioned two premises are well justified and the conclusions of [1] are indeed very convincing. However, WIMPs are just one possible candidate, although most popular, for dark matter particles. Can the main conclusion of [1] that dark matter is harmless to human health be extended to other dark matter models too? Not necessarily. There is a dark matter model in which the first premise that dark matter projectiles deposit negligible energy compared to cosmic-ray muons might be not valid.

Mirror dark matter with sufficient photon – mirror photon kinetic mixing provides the dark matter model we have in mind (for recent review and further references see [3]). In this model the matter and gauge fields content of the universe is doubled compared to the Standard model. Mirror partners of ordinary elementary particles can constitute a parallel mirror world as complex and rich in various structures as our own one. This fascinating possibility was first anticipated by Kobzarev, Okun and Pomeranchuk in [4]. They demonstrated that besides gravity only very weak interactions were allowed between the mirror and ordinary particles. Among these allowed interactions the most important for our purposes is the possible photon – mirror photon kinetic mixing [5,6]

$$\mathcal{L}_{mix} = \frac{\epsilon}{2} F^{\mu\nu} F'_{\mu\nu}. \tag{1}$$

As a result of this mixing, mirror charged particles acquire a small ordinary electric charge [6,7] and, in contrast to electromagnetically neutral WIMPs, such mirror dark matter particles scatter off ordinary nuclei via Rutherford-type interaction. Therefore, the reaction rates of [1] for dark matter interactions with human body should be recalculated in the case of mirror dark matter. However, this is not our main concern here. We suspect that recalculated radiation exposure will be still negligible compared to other natural radiation sources in the case of mirror matter too. What's the fuss then? The point is that the mirror matter provides a completely new type of radiation hazard not found in WIMP-type dark matter models. What are these new hazardous objects causing it?

Although the microphysics in the mirror world is the same as in our own one, its macro-evolution with such key stages as baryogenesis, nucleosynthesis, recombination, can proceed in somewhat different conditions than in ordinary world [8,9]. Nevertheless, the resulting mirror world very much resembles our ordinary one, as far as the existence of various familiar astrophysical objects is concerned [3,10,11]. Namely, asteroid or comet sized small mirror matter space bodies can exist and their collisions with the Earth can result in truly catastrophic events [12,13]. Fortunately, it seems that the near Earth space is not teeming with such objects.

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Though, the number of small mirror dust particles could potentially be quite large as they are generated in collisions of mirror space bodies with themselves and ordinary bodies [14]. The impact of mirror dust particles, mirror micrometeorites, on the Earth was explored in [14]. In our opinion, mirror micrometeorites constitute the above mentioned new type of health-hazardous objects absent in WIMP-type dark matter models. Let us take a closer look at how they lose their energy when penetrating the ordinary matter.

We begin by calculation of how much energy is transferred to initially motionless ordinary nucleus of mass m_A and charge Ze in Rutherford scattering of the mirror nucleus of mass $m_{A'}$ and effective charge $\epsilon Z'e$. We can do this as follows [15]. The mirror nucleus moving with the velocity V creates the radial electric field of the strength [16]

$$\mathcal{E}=\frac{\epsilon Z'e}{r^2}\,\frac{1-\beta^2}{(1-\beta^2\sin^2\theta)^{3/2}} \tag{2}$$

at the location of the ordinary nucleus. Here $\beta=V/c$ and θ is the angle between the relative mirror nucleus – ordinary nucleus radius-vector and the direction of motion of the mirror nucleus. In the Rutherford scattering, small scattering angles dominate and, therefore, at first approximation we can assume that the mirror nucleus moves at a straight line. Then, obviously,

$$\sin\theta=\frac{b}{r}, \tag{3}$$

b being the impact parameter, and the transverse momentum transferred to the ordinary nucleus during the collision is

$$p=\int\limits_{-\infty}^{\infty} Ze\mathcal{E}_y\,dt=\int\limits_{-\infty}^{\infty} Ze\mathcal{E}\,\sin\theta\,dt. \tag{4}$$

But

$$dt=\frac{dx}{V}=\frac{d(b\cot(\pi-\theta))}{V}=\frac{b}{V}\,\frac{d\theta}{\sin^2\theta}, \tag{5}$$

and (4) takes the form

$$\begin{aligned} p&=\frac{ZZ'e^2\epsilon}{bV}\int\limits_{0}^{\pi}\frac{(1-\beta^2)\sin\theta\,d\theta}{(1-\beta^2\sin^2\theta)^{3/2}}\\ &=\frac{ZZ'e^2\epsilon}{bV}\int\limits_{-1}^{1} d\frac{x}{\sqrt{1-\beta^2+\beta^2x^2}}=\frac{2ZZ'e^2\epsilon}{bV}. \end{aligned} \tag{6}$$

Therefore, the transferred energy equals to

$$T=\frac{p^2}{2M_A}=\frac{2}{M_A}\left(\frac{ZZ'\alpha\epsilon}{bV}\right)^2. \tag{7}$$

Note that we are using natural units $\hbar=c=1$ and Gaussian units for the electric charge, so that $e^2=\alpha$.

When a mirror micrometeorite, consisting of N mirror nuclei, traverses a distance dx in the ordinary matter, the total energy deposition equals:

$$dE=Nn_A\,dx\int 2\pi b\,T\,|db|, \tag{8}$$

where n_A is the number density of ordinary nuclei. But from (7)

$$\frac{|db|}{b}=\frac{dT}{2T}, \tag{9}$$

and we get

$$\frac{dE}{dx}=\pi Nn_A\int b^2T\frac{dT}{T}=\frac{2\pi NZ^2Z'\alpha^2\epsilon^2n_A}{M_AV^2}\ln\frac{T_{max}}{T_{min}}. \tag{10}$$

The maximal energy transfer, T_{max}, corresponds to the head-on collision and is equal to:

$$T_{max}=4T_0\frac{\mu^2_{AA'}}{M_AM_{A'}}=2\frac{\mu^2_{AA'}}{M_A}V^2, \tag{11}$$

where $T_0=M_{A'}V^2/2$ is the initial kinetic energy of the mirror nucleus and $\mu_{AA'}=M_AM_{A'}/(M_A+M_{A'})$ is the reduced mass.

The minimal energy transfer, T_{min}, can be estimated as follows. During the collision, transverse momentum of the ordinary nucleus is uncertain with $\Delta p_y\sim p/2$. According to the uncertainty principle, the corresponding uncertainty in the nucleus transverse position is $\Delta y\sim 1/\Delta p_y=2/p$. It is reasonable to require $\Delta y<r_0$, r_0 being the radius at which the screening effects due to the atomic electrons becomes effective. Therefore $p\ge 2/r_0$ and

$$T_{min}=\frac{1}{2M_A}\left(\frac{2}{r_0}\right)^2=\frac{2}{M_Ar_0^2}. \tag{12}$$

Finally,

$$\frac{T_{max}}{T_{min}}=(\mu_{AA'}Vr_0)^2 \tag{13}$$

and (10) takes the form

$$\frac{dE}{dx}=\frac{4\pi NZ^2Z'^2\alpha^2\epsilon^2n_A}{M_AV^2}\ln(\mu_{AA'}Vr_0). \tag{14}$$

As far as dE/dx is concerned, human body can approximately be substituted by water which corresponds to the following change in (14):

$$\begin{aligned} &\frac{Z^2}{M_A}n_A\,\ln(\mu_{AA'}Vr_0)\\ &\quad\to\frac{\rho_{H_2O}}{M_{H_2O}}\left(2\cdot\frac{1}{u}\cdot 1.9+\frac{8^2}{16u}\cdot 4.3\right)\approx 21\,\frac{\rho_{H_2O}}{M_{H_2O}}\,\frac{1}{u}, \end{aligned} \tag{15}$$

where $u\approx 931$ MeV is the atomic mass unit and where for $V=30$ km/s, $\ln(\mu_{HA'}Vr_{0H})\approx 1.9$ and $\ln(\mu_{OA'}Vr_{0O})\approx 4.3$, if we use the Lindhard–Thomas–Fermi formula (which takes into account the screening effects from both ordinary and mirror electrons) [17]:

$$r_0=\frac{0.8853\,r_B}{\sqrt{Z^{2/3}+Z'^{2/3}}},\quad r_B\approx 5.29\cdot 10^{-9}\ \text{cm}\approx 2.68\cdot 10^{-4}\ \text{eV}^{-1}, \tag{16}$$

for the effective screening radius r_0, and assume the mirror iron micrometeorite ($Z'=26$). Then we get from (14)

$$\frac{dE}{dx}=\left(\frac{N}{10^{15}}\right)\left(\frac{\epsilon}{10^{-9}}\right)^2\left(\frac{30\ \text{km/s}}{V}\right)^2\ 13\ \text{GeV/cm}. \tag{17}$$

Note that (14) differs by a factor of $M_{A'}/M_A$ from the corresponding expression in [14]. Let us explain the source of this difference.

In one collision the mirror nucleus changes its longitudinal momentum by the amount

$$\Delta p_x=-M_{A'}V_c(1-\cos\theta_c)\approx -M_{A'}V_c\frac{\theta_c^2}{2}, \tag{18}$$

where

$$V_c=V-u=\frac{M_AV}{M_{A'}+M_A} \tag{19}$$

is the mirror nucleus velocity in the center-of-mass frame ($u = M_{A'}V/(M_{A'}+M_A)$ is the velocity of the center-of-mass), and

$$\theta_c = \frac{2ZZ'e^2\epsilon}{\mu_{AA'}bV^2} = \frac{2ZZ'\alpha\epsilon}{M_{A'}bV^2}\,\frac{M_{A'}+M_A}{M_A} \tag{20}$$

is the center-of-mass scattering angle. Therefore,

$$\Delta p_x = -\frac{2Z^2Z'^2\alpha^2\epsilon^2}{b^2V^3}\,\frac{M_{A'}+M_A}{M_AM_{A'}}. \tag{21}$$

Note that the energy loss of the mirror nucleus after one collision equals:

$$\begin{aligned} T &= \frac{1}{2}M_{A'}[V^2-(u+V_c\cos\theta_c)^2-V_c^2\sin^2\theta_c] \\ &= 2M_{A'}uV_c\sin^2\frac{\theta_c}{2} \approx M_{A'}uV_c\frac{\theta_c^2}{2}, \end{aligned} \tag{22}$$

which is equivalent to (7).

The number of collisions during a time interval dt is equal to

$$dN_{coll} = 2\pi b|db|n_A V dt = \pi b^2 n_A V dt\,\frac{dT}{T}, \tag{23}$$

and, therefore, the mirror micrometeorite loses momentum at the rate

$$\begin{aligned} \frac{dP_x}{dt} &= \int N\Delta p_x \frac{dN_{coll}}{dt} \\ &= -\frac{M_{A'}+M_A}{M_AM_{A'}}\,\frac{2\pi NZ^2Z'^2\alpha^2\epsilon^2n_A}{V^2}\ln\frac{T_{max}}{T_{min}} \\ &= -\frac{M_{A'}+M_A}{M_AM_{A'}}\,\frac{4\pi NZ^2Z'^2\alpha^2\epsilon^2n_A}{V^2}\ln(\mu_{AA'}Vr_0). \end{aligned} \tag{24}$$

For the mirror micrometeorite's kinetic energy $E_K = P_x^2/(2NM_{A'})$, we get

$$\frac{dE_K}{dx} = \frac{P_x}{NM_{A'}}\,\frac{dP_x}{dx} = V\frac{dP_x}{d(Vt)} = \frac{dP_x}{dt}. \tag{25}$$

Therefore,

$$\frac{dE_K}{dx} = -\frac{M_{A'}+M_A}{M_A}\,\frac{4\pi NZ^2Z'^2\alpha^2\epsilon^2\rho}{M_AM_{A'}V^2}\ln(\mu_{AA'}Vr_0), \tag{26}$$

where we have substituted $n_A = \rho/M_A$, ρ being the density of the target medium. This quantity was calculated in [14] and the results coincide if the replacement $M_A \to \mu_{AA'}$ is made in the result of [14].

Transverse momentum acquired by mirror nuclei in the Rutherford scattering is dissipated as heat Q in the mirror micrometeorite whose temperature will rise. This circumstance explains the difference between (26) and (14). Namely,

$$\frac{dE}{dx} = \frac{M_{A'}}{M_A+M_{A'}}\left(-\frac{dE_K}{dx}\right),\quad \frac{dQ}{dx} = \frac{M_A}{M_A+M_{A'}}\left(-\frac{dE_K}{dx}\right). \tag{27}$$

For water and mirror iron micrometeorite, $M_{A'}$ is significantly larger than M_A and in the first approximation the difference between dE_K/dx and $-dE/dx$ can be neglected. Then we can take $E = NM_{A'}V^2/2$ in (17) and solve the resulting differential equation for $V(x)$. As a result we get that the stopping distance L in water for the iron mirror micrometeorite moving with the initial velocity V can be estimated as:

$$L = \left(\frac{10^{-9}}{\epsilon}\right)^2\left(\frac{V}{30\ \mathrm{km/s}}\right)^4 100\ \mathrm{km}. \tag{28}$$

It was argued [3] that the mirror dark matter can provide an adequate description of the known dark matter phenomena provided that $\epsilon \sim 10^{-9}$. Then two important conclusions can be drawn from (28) and (17). The first indicates that mirror micrometeorites reach the Earth's surface essentially without losing their velocity in the atmosphere for all range of expected initial velocities 11–70 km/s (for mirror micrometeorites which are bound to the solar system and which have not yet been trapped by the Earth). On the other hand, according to (17), when moving through a human body they deposit a lot of energy greatly exceeding energy deposition from cosmic-ray muons. It is true, however, that in the case of the mirror micrometeorite, the energy deposition doesn't have a point-like character thus involving many and many target molecules. The second difference from the cosmic-ray muons is that energy deposition from the mirror micrometeorite is not ionizing. The cosmic-ray muons move with velocities much greater than the velocities of atomic electrons. In this case Rutherford scattering on atomic electrons dominates and leads to ionization energy losses well described by the celebrated Bethe–Bloch formula [18]. Energy losses due to Rutherford scattering on target nuclei leading to the corresponding nuclear recoils are negligible. On the contrary, mirror micrometeorite's velocities are much smaller than the atomic electrons velocities, and in this case energy losses due to the Rutherford scattering on target nuclei dominates while the scattering effects on electrons give a negligible contribution [18].

Transferred energy (17) will be dissipated as vibrations and rearrangements of the target biological molecules. Each mirror nuclei will collide with σn_A ordinary nuclei per length unit. Therefore, the total number of collisions per unit length is

$$\frac{dN_{coll}}{dx} = N\sigma n_A. \tag{29}$$

Here σ is the screened Rutherford cross section which can be obtained by integrating the differential cross section [19]

$$\frac{d\sigma}{d\Omega} = \frac{Z^2Z'^2\epsilon^2\alpha^2}{\mu_{AA'}^2V^4(1-\cos\theta+\alpha_0)^2},\quad \alpha_0 = \frac{1}{2(\mu_{AA'}Vr_0)^2}. \tag{30}$$

The result is [19]

$$\sigma = \frac{4\pi Z^2Z'^2\epsilon^2\alpha^2}{\mu_{AA'}^2V^4\alpha_0(2+\alpha_0)} \approx \frac{4\pi Z^2Z'^2\epsilon^2\alpha^2}{V^2}r_0^2, \tag{31}$$

because $\alpha_0 \ll 1$.

For sufficiently large momentum transfer, nucleus structure becomes relevant and we should include nucleus form factor in the cross section calculation to take into account the corresponding decoherence effects. In our case, however, simple estimates show that the decoherence effects are irrelevant. Indeed, only for the Milky Way bound dark matter with $V \sim 300$ km/s, when the typical momentum transfer is [20] $q = M_{A'}|\Delta\vec{V}| \sim 10^{-3}M_{A'} \approx 50\ \mathrm{MeV} \approx (4\ \mathrm{fm})^{-1}$, $q^{-1} \sim 4$ fm gets comparable to the size of mirror iron nucleus $R_{A'} = 1.2A'^{1/3}\ \mathrm{fm} \approx 4.6$ fm, and we should consider (presumably still rather small) decoherence effects. For $V \sim 70$ km/s (maximal Earth impact velocity for solar bound dark matter at Earth's location), the typical momentum transfer will be four times smaller and thus, decoherence effects can be safely ignored.

Substituting (31) into (29), we get

$$\frac{dN_{coll}}{dx} = \frac{4\pi NZ^2Z'^2\epsilon^2\alpha^2n_A}{V^2}r_0^2. \tag{32}$$

Therefore, the average energy transfer per interaction equals to

$$\epsilon = \left(\frac{dE}{dx}\right)\Big/\left(\frac{dN_{coll}}{dx}\right) = \frac{\ln(\mu_{AA'}Vr_0)}{M_Ar_0^2}. \tag{33}$$

This quantity depends very weakly on the velocity V and for hydrogen, oxygen, nitrogen and carbon targets, assuming $V = 30$ km/s and mirror iron micrometeorite, we get $\epsilon_H \approx 0.4$ eV, $\epsilon_O \approx 0.07$ eV, $\epsilon_N \approx 0.07$ eV and $\epsilon_C \approx 0.08$ eV respectively. Hence, the average value for the water target is $\epsilon_{H_2O} = (2\epsilon_H + \epsilon_O)/3 \approx 0.3$ eV.

Let us estimate how much the atoms of human DNA could be affected by interactions with mirror iron micrometeorite. For a given atom in the DNA the number of collisions with mirror nuclei equals to $p \sim \sigma R n_{A'}$, where

$$R = \left(\frac{3N}{4\pi n_{A'}}\right)^{1/3} \approx 1.3 \cdot 10^{-3} \left(\frac{N}{10^{15}}\right)^{1/3} \text{cm} \tag{34}$$

is the size of the micrometeorite assuming it has spherical form and taking $n_{A'} \sim 10^{23}$ cm^{-3}. Using equations (17), (29), (33) and assuming $n_{A'} \sim n_A$, $\epsilon \sim 0.3$ eV, we can estimate p as follows:

$$p \sim \frac{n_{A'}}{n_A} \frac{1}{N} \frac{dN_{coll}}{dx} R \sim \frac{1}{N\epsilon} \frac{dE}{dx} R \approx 6 \cdot 10^{-8} \left(\frac{N}{10^{15}}\right)^{1/3} \left(\frac{\epsilon}{10^{-9}}\right)^2 \left(\frac{30 \text{ km/s}}{V}\right)^2. \tag{35}$$

As we see, p is a very small number. In fact, it gives the probability that a given ordinary atom will be involved in the interaction when a mirror micrometeorite passes through it. However, there are about $N_{DNA} \sim 10^{11}$ atoms in the human DNA (to quote Carl Sagan's apt comparison, "There are as many atoms in one molecule of DNA as there are stars in a typical galaxy"). Therefore, when a mirror micrometeorite passes through a human DNA, the expected number of perturbed atoms can be estimated as

$$pN_{DNA} \sim 6 \cdot 10^3 \left(\frac{N}{10^{15}}\right)^{1/3} \left(\frac{\epsilon}{10^{-9}}\right)^2 \left(\frac{30 \text{ km/s}}{V}\right)^2. \tag{36}$$

However, not all collisions can lead to mutations but only those in which energy transfer exceeds some threshold value E_{mut}. From eq. (22) we get that in this case the center-of-mass scattering angle θ_c satisfies

$$\theta_c > \theta_{c0} = \frac{\sqrt{2M_A E_{mut}}}{\mu_{AA'} V}. \tag{37}$$

Correspondingly, the angular integration range for the equation (30) is reduced, and we get

$$\sigma_{mut} = \frac{\alpha_0}{2} \frac{2 + \theta_{c0}^2/2}{\alpha_0 + \theta_{c0}^2/2} \sigma \approx \frac{2\alpha_0}{\theta_{c0}^2} \sigma, \tag{38}$$

as $\alpha_0 \ll \theta_{c0}^2/2 \ll 1$ for the relevant range of parameters. The suppression factor

$$\eta = \frac{2\alpha_0}{\theta_{c0}^2} = \frac{1}{2M_A E_{mut} r_0^2}, \tag{39}$$

assuming $E_{mut} = 1$ eV and mirror iron micrometeorite, equals to $\eta_H \approx 9 \cdot 10^{-2}$, $\eta_O \approx 7.6 \cdot 10^{-3}$, $\eta_C \approx 9.6 \cdot 10^{-3}$ and $\eta_N \approx 8.5 \cdot 10^{-3}$ respectively for hydrogen, oxygen, carbon and nitrogen. As atoms of these elements are present in DNA roughly in comparable amounts, for estimate we use the averaged suppression factor $\eta = (\eta_H + \eta_O + \eta_C + \eta_N)/4 \approx 3 \cdot 10^{-2}$. As a result, we get the following order of magnitude estimate of the number of mutations in DNA:

$$N_{mut} \sim 180 \left(\frac{1 \text{ eV}}{E_{mut}}\right) \left(\frac{N}{10^{15}}\right)^{1/3} \left(\frac{\epsilon}{10^{-9}}\right)^2 \left(\frac{30 \text{ km/s}}{V}\right)^2. \tag{40}$$

We can thus speculate that the mirror micrometeorite, when interacting with the DNA molecules, can lead to multiple simultaneous mutations and potentially cause disease (note that the energy of only 0.1–10 eV is required to displace an atom in organic molecules and cause a DNA strand break [2]). There is an evidence that individual malignant cancer cells in human tumors contain thousands of random mutations and that to account for these multiple mutations rates found in human cancers it is necessary to assume that the usual mechanisms to repair corrupted DNA somehow were also damaged. It was suggested, therefore, that mutation accumulation during tumor progression due to lesion of DNA repair mechanisms probably plays a major role in triggering the cancer growth [21]. Thus, it can turn out that mirror micrometeorites are much more dangerous carcinogens than other natural radiation sources because of their potential capability to produce simultaneous multiple mutations and at the same time damage genes that control DNA repair mechanisms. It is even not excluded that the passage of solar system through a dense mirror dust cloud can lead to mass extinctions [22]. However, we suspect that usually the probability that the DNA damage due to mirror micrometeorite eventually will lead to cancer is very low because even hundred mutations, as a rule, are insufficient to significantly deteriorate multiple pathways for DNA repair found in normal cells.

On the other hand, multiple simultaneous mutations may allow organisms to leap across fitness valleys and thus can potentially be beneficial for evolution [23]. It is possible, therefore, that mirror micrometeorites, if proven to exist, had played a role in rare evolutionary events requiring simultaneous multiple mutations (potential role of mutagenic effects of dark matter in observed diversification of life after mass extinctions was also suggested in [22]).

To conclude, we have indicated a dark matter model for which the conclusion of [1] that the dark matter is harmless for human health, doesn't directly apply. It will be premature to worry about though. Although some cosmological, astrophysical and experimental facts can be interpreted in favor of mirror dark matter existence [3,24,25], no definite conclusions can be drawn at present and mirror dark matter, not to speak of mirror micrometeorites, remains a highly speculative idea. Besides, even if we assume the reality of this threat, we have every reason to consider the health risks as normally very low (excluding, perhaps, such rare speculative events as passing of the solar system through a dense mirror dust cloud mentioned above) because all living organisms have been continuously exposed to this threat from the dawn of life and had plenty of time to mitigate this risk factor.

Moreover, normally the flux of mirror micrometeorites is not expected to be large. It is known [26,27] that the flux of ordinary micrometeorites before atmospheric entry is about $3 \cdot 10^4$ tons per year. It is difficult to reliably estimate the amount of mirror matter in the solar system but a very rough estimate indicates that about 10^{-5} fraction of all solar system matter could be mirror matter which might have accumulated in the vicinity of the solar system during its formation [3]. Therefore, we will assume that the flux of mirror micrometeorites doesn't exceed 300 kg per year. Assuming that mirror micrometeorites contain 10^{15} mirror iron nuclei, this number corresponds to about $3 \cdot 10^{12}$ mirror micrometeorites per year. Thus, the probability that one of these micrometeorites hits a human with about m^2 effective cross section doesn't exceed $3 \cdot 10^{12}/(4\pi R_{Earth}^2) \approx 6 \cdot 10^{-3}$ per year, which is quite a small number.

Mirror dust particles can potentially be observed in cryogenic detectors such as NAUTILUS gravitational wave detector [14]. Interestingly, NAUTILUS has found several anomalously large energy depositing events which if interpreted as caused by mirror dust particles imply the flux of about $2 \cdot 10^{-6}\ \mathrm{m}^{-2}\,\mathrm{s}^{-1}$ [14]. Such a flux corresponds to several tens of mirror micrometeorites impact events per year and per human and is several orders of magnitude larger than the flux estimated above. It seems unrealistic that these NAUTILUS events are due to mirror micrometeorites impacts but we hope that our observation that such impacts might be hazardous to human health will stimulate experimental searches of mirror micrometeorites and further dark matter research.

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