Detection and Study of Dark Electric Matter Objects – Presumably Planckian Black Holes

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Abstract. The ideology and results of detection of Dark Electric Matter Objects, daemons, which are supposedly Planckian objects captured from the Galaxy disc and accumulated in the Earth-crossing orbits, are described. Daemons carry a high negative electric charge, $Ze \approx 10e$, and, therefore, a great number of scintillation-active particles are emitted when daemons capture atomic nuclei. Our two-screen ZnS(Ag) detector registers daemons with $V < 30$ km s^{-1}. The measured flux of daemons with $V = 10$--15 km s^{-1} falling out from the near-Earth almost circular heliocentric orbits reaches a value of $\sim 10^{-7}$ cm^{-2} s^{-1} and varies with a period of 0.5 yr. The daemon paradigm makes it possible to interpret within a unified approach (occasionally, even quantitatively) the results of some experiments (DAMA/NaI, Troitsk anomaly) and certain phenomena (generation of positrons in the Galaxy nucleus, excessive Earth's heat flux, etc.). The advisability of development of this paradigm in a number of definite directions is noted.

1. General ideology

The gravitating clumping substance of unknown nature, the so-called Dark Matter (DM), constitutes about 25% of the whole mass of the Universe and 80-90% of the mass of galaxies. It is a common belief now that DM objects are weakly interacting massive particles (WIMPs) with a mass of $\sim 10^2$ GeV, which are predicted by various theories of elementary particles beyond the Standard Model (see review [1]). However, efforts of numerous high-level research teams failed to produce real results in the last 15 years. Only the DAMA/NaI experiment in Gran Sasso, with C.L. = 6.3σ revealed an annual modulation of the number of signals in a narrow range 2-6 keV, with a maximum in June [2]. The authors of this experiment attribute the effect to the Galaxy halo WIMP flux modulation owing to an inclination of the Earth's orbit relative to direction of the Sun's motion around the Galaxy center.

We concentrated our efforts on a search for elementary Planckian black holes (their gravitation radius cannot be smaller than the Compton wavelength) carrying a negative electric charge of up to $Ze \approx 10e$. Similar Dark Electric Matter Objects, daemons, have been considered by a number of authors [3-6], but the possibility of their detection was looked at rather skeptically [3]. First, their flux incident from the Galaxy halo onto the Earth reaches only a value of $\sim 3\times10^{-12}$ cm^{-2} s^{-1} (= 1 m^{-2} yr^{-1}) and, second, it was believed that they cannot cause scintillations at astronomical velocities ($\sim 10^6$ cm s^{-1}) [3].

We surmounted these doubts by pointing out that the capture of daemons from the Galaxy disc under the common action of the Sun and the Earth leads to their accumulation in Earth-crossing orbits and, as a result, their flux incident onto the Earth is as large as $f \approx 3\times10^{-7}$ cm^{-2} s^{-1}. Second, we noted that negative daemons are nuclear active particles. By analogy with the muon catalysis of the deuteron fusion, it can be believed that a daemon with $Ze \approx 10e$ can catalyze exothermal fusion both of several protons captured by the daemon, with positron emission [7], and of heavier nuclei: Li, Be, and even carbon. The reaction products are scintillation-active. At the same time, capture, say, of Fe or Zn nucleus by the daemon releases a binding energy of ~100 MeV, which leads to emission of atomic electrons (and refilling electrons in the metallic phase) and ejection of ~10 nucleons. These particles can also cause an intense scintillation. In addition, we put forward a hypothesis that, remaining within the nuclear residue and finding its way into a nucleon (it is noteworthy that, because of the large mass of the objects, the radius of the ground level of the system constitutes only a fraction of the nucleon size), a daemon catalyzes its decay (according to our estimates, this occurs in $\Delta\tau_{\mathrm{ex}} \approx 10^{-7}$-$10^{-6}$ s [8]; the decay mechanism is unknown, but it is appropriate to mention here the monopole catalysis of the proton decay [9]). Therefore, after a certain time the daemon frees itself from the nucleus residue (or, at least, it becomes that $|Z_{\mathrm{n}}| < |Z|$) and can capture a new nucleus with excitation of a new scintillation, etc. It is noteworthy that, at an effective charge $|Z_{\mathrm{n}}| - |Z| = -1$ and a daemon velocity $V \approx 10$ km s^{-1}, a nucleus is captured in a condensed substance along a path of only ~1 μm [10].

Below, we briefly describe the operation principle of the detector and the basic results obtained in daemon detection, which for the most part confirm and largely specify the starting working hypothesis (for more details, see our previous publications [10,11]). It is noted also that results of the DAMA/NaI experiment can be quantitatively(!) interpreted in terms of the daemon paradigm. We also name the apparent consequences to which this paradigm leads (positron generation in the Galaxy nucleus, source of the excess energy at the center of the Earth and in the Sun, etc.). Experiments reveal a number of yet non-understood phenomena whose interpretation requires a theoretical development in the definite areas of atomic, nuclear, and Planckian physics.

2. Description of the detector

After three years of tests with a number of variants of detectors based on the ideology described above [12], we set our choice on the simplest design [10,11]. The detector comprises two transparent 4-mm-thick 0.5×0.5 m^2 polystyrene screens coated from below with a ~3.5 mg cm^{-2} layer of the ZnS(Ag) powder scintillator. Such a thin layer is weakly sensitive to γ-radiation and fast cosmic ray particles. The screens, spaced by 7 cm and separated with black paper, are horizontally placed in the middle of the tin-plate (0.3 mm Fe + 2 μm Sn on each side) cubic case with a side of 51 cm. The upper cover of the case is made of black paper. We intentionally created an asymmetry with respect to the upwards/downwards direction in order to enhance the difference in recording of fluxes from above and below, if the fluxes exist. Each screen is observed from its side by a FEU-167 photomultiplier tube (PMT) whose photocathode (100 mm dia.) is flush with the case cover. In all, four identical modules were fabricated. Pulses from two PMTs of each module are fed into a double-trace digital oscilloscope (with the oscilloscope triggered by the upper PMT signal). If there is a signal in the second trace, too, the event is stored in a computer. After year and a half of the detector operation in St-Petersburg (from February 2000 till June 2001), during which reasons for the monthly non-reproducibility of the results remained unclear, we realized that there is a seasonal variation of the flux, with maxima in March and September [12,13].

It was assumed that, having captured a Zn (or S) nucleus in the ZnS(Ag) layer, a daemon excites scintillation within this layer. If $\Delta\tau_{\mathrm{ex}} \approx 10^{-7}$ s, then, at a velocity of 50-30 km s^{-1}, it has enough time to "digest" protons in the residue of the captured nucleus, so that, at $|Z_{\mathrm{n}}| < |Z|$, the daemon can capture a new nucleus, with scintillation excited in the second ZnS(Ag) screen.

The time shift Δt between the signals can be used, with the detector size taken into account, to judge about the direction (downward or upward) and the vertical component of the velocity of an object, with the number of events determining (with regard to the detector size and efficiency) the flux of daemons.

3. Some experimentally revealed properties of daemons and their flux

A typical distributions $N(\Delta t)$ of the number of paired events (for Marches 2000-2005) are shown in the range $-100 < \Delta t < 100$ μs in Fig. 1a (see, e.g., [10-12]). Here, only those events are taken into account for which the shape of the signal from the upper PMT is similar to scintillations caused by heavy non-relativistic particles, such as α-particles: the rise time of the signal from the beginning to the maximum value is 2-3 μs. These are heavy-particle scintillations (HPSs). (Signals of another type, with the leading-edge time ≤ 1.7 μs, are characteristic of scintillations caused by light relativistic particles and intrinsic noise of the PMT, including the noises induced by cosmic rays; these are named noise-like signals, NLSs.)

A peak at $\Delta t \approx 30$ μs (or, more precisely, at $20 < \Delta t < 40$ μs) is prominent in Fig. 1a. The number of events in this peak corresponds to a downward flux $f > 10^{-9}$ cm^{-2} s^{-1} (it will be recalled that the detector efficiency is << 1).

The velocity of the objects belonging to the peak, calculated from the distance between the scintillators (7 cm), was found to be incomprehensibly low, V = 2-3 km s^{-1} only. If however, we take as the base distance that between the upper scintillator and the lower tin cover of the case (29 cm), the velocity becomes V = 8-14 km s^{-1}, which is characteristic (~11.2-14 km s^{-1}) of the fall-out of objects from the near-Earth almost circular heliocentric orbits (NEACHOs). This choice is confirmed by the results of our Baksan experiment (see below, Sec. 4).

It is believed that, in this case, the NLS in the bottom PMT is excited by the scintillation created in the lower ZnS(Ag) layer by hundreds of electrons ejected from the metal of the bottom cover of the module in (re)capture of an Sn or Fe nucleus by a daemon here (it is difficult to simulate this process, and, therefore, it is not improbable that the bottom PMT itself responds to a daemon passing through it by generation of NLS, see below and Sec. 4).

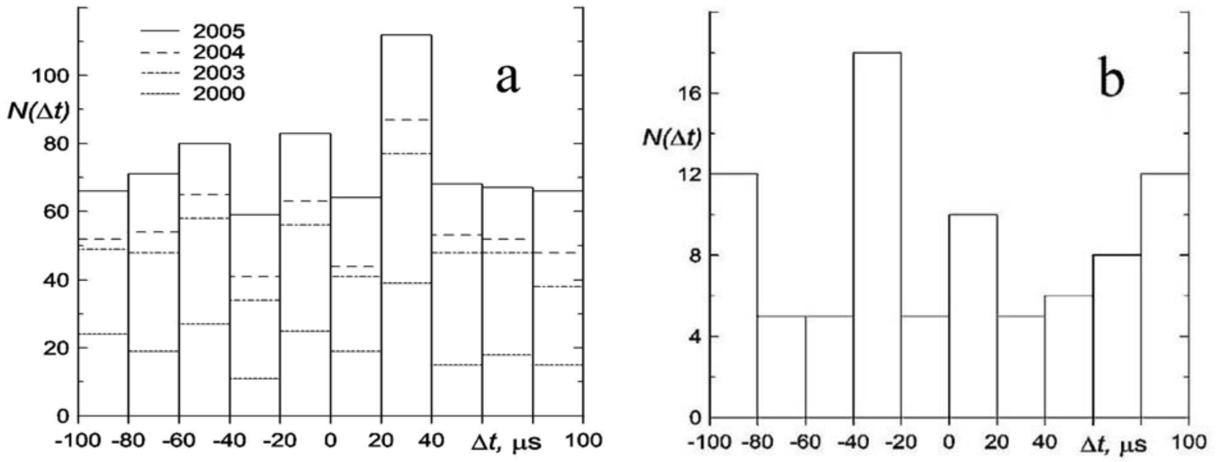

Fig. 1. Distributions $N(\Delta t)$ of pair events on their time shift relative to the upper screen HPSs. (a) The sum of Marches 2000, 2003, 2004, and 2005. The +30μs maximum exceeds the mean level by 33 events; its significance is 3.63σ (C.L. > 99.97 %) [14]. (b) The underground Baksan experiment [15]. The photo-cathode of the bottom PMT, which is sensitive to daemon passages due to its thick 1 μm inner Al coating, is screened with Al foil. Observations during September 3-11, 2005; 86 events altogether. Significance of the −30 μs maximum is 2.2σ.

We were deeply concerned about the monthly non-reproducibility of the results. Only by the middle of 2001 we understood that the reason is the seasonal modulation of the NEACHO flux of daemons with P = 0.5 yr and maximum values in March and September, 10-15 days ahead of the equinoctial points. We also observed a gradual drift of the 30 μs peak in $N(\Delta t)$ to greater Δt, i.e., the appearance of a flux of objects with $V < 10$ km s^{-1}, captured into geocentric Earth-surface-crossing orbits (GESCOs), which gradually (in 2-3 months [10]) shrink below the Earth's surface because of the deceleration of daemons by the Earth's matter.

These experiments enabled a number of important observations and conclusions about the interaction of daemons with matter.

For example, the very existence of the ~30-μs maximum may indicate that the time of ~30 μs determines the process of "digestion" of nucleons (protons?) by a daemon in a Zn nucleus ($Z_n = 30$) captured in the scintillator, i.e., $\Delta\tau_{ex} \sim 10^{-6}$ s is expended per nucleon (rather than ~10^{-7} s assumed when designing the detector). This is an important result, which can form a basis for the future theory of interaction between daemons and nucleons. Hence it follows also that our detector (with a base of ~30 cm) cannot detect objects with $V > 30$ km s^{-1}.

Another interesting observation, which would be expected in terms of the daemon paradigm, was that the shape of the HPS depends on the motion direction of a daemon. If the daemon moves across the ZnS(Ag) layer downwards, i.e., exits into free space after capturing a Zn (or S) nucleus, the HPS is, on average, longer (has larger area normalized to the amplitude) than that in the case when a daemon moves upwards. In the latter case, the daemon enters, after passing the ZnS(Ag) layer, the bulk of the polystyrene plate and, therefore, a certain fraction of particles emitted after the daemon captures a nucleus in ZnS(Ag) are decelerated in polystyrene and fail to reach the ZnS(Ag) layer, with the result that the scintillation becomes shorter [10].

A rather important conclusion was that at least some PMTs can by themselves, without a scintillator, feel a daemon transit with a rather high efficiency (~10%) [14]. These are FEU-167 with an accidentally increased (because of departures from their fabrication technology) thickness (~1 μm) of the aluminum coating deposited onto the inner surface of the photocathode section (125 mm dia., length ~45 mm) of their glass bulb. The standard thickness of the Al coating is ~0.1 μm and a daemon (with $|Z_n| - |Z| \leq -1$) crossing this coating at a velocity $V = 10$-15 km s^{-1} has not enough time to capture a nucleus. A nucleus can only be captured in the glass, which is an insulator, with emission of a small number (~10-20) of atomic electrons. However, the probability of capturing a nucleus in an Al layer of thickness ~1 μm is high, and the capture is accompanied by emission of not only the electrons surrounding the given nucleus, but also a considerably larger number of refilling electrons from the conduction band of the metallic coating. As a result, a PMT of this kind gives a strong NLS when a daemon passes through. An also important circumstance in this case is that, when a daemon with a nucleus residue passes through the vacuum of the PMT photocathode section (45 mm long), the daemon/nucleus complex can increase its negative charge by several units, so that the probability of capture by this complex of an Al nucleus in the PMT coating accordingly increases.

4. Underground experiment in Baksan

The property of a PMT with a thick inner Al coating to register daemons’ passage was used in our underground experiment with a cosmic ray background weakened by a factor of $\sim 10^3$, performed in a rather low-latitude (42^o N) Baksan Neutrino Observatory in September, 2005, and March, 2006 [15]. A single detector module with only the upper ZnS(Ag) screen was used. FEU-167 with a thick Al inner coating served as the bottom sensitive element. Its photocathode was shielded with a thin aluminum-coated Lavsan film, so that it was "blind" and insensitive to light. To eliminate the radon background, the module was continuously washed with a liquid nitrogen vapors.

This system proved to be sensitive to daemons coming from below, from underground. As a result, a maximum at $-40\ \mu s < \Delta t < -20\ \mu s$ (henceforth the -30-μs maximum) was clearly pronounced the September, 2005, experiment (Fig. 1b). Its existence in the absence of the maximum at $20\ \mu s < \Delta t < 40\ \mu s$ in the first half of September and, by contrast, the absence of the -30-μs maximum and the presence of that at +30 μs in the first half of March, 2006, mean that, during the first two weeks of these months, we recorded, in low-latitude Baksan, mostly the primary flux of daemons that overtake the Earth in its motion along the orbit, and only after that, beginning in the middle of March or September, the flux of daemons recently captured into GESCOs starts to manifest itself. This means that daemons are particularly efficiently accumulated on NEACHOs lying outside the Earth's orbit [15].

It should be noted that the recorded flux reached a value $f \approx 10^{-7}$ cm^{-2} s^{-1}, in agreement with the expected improvement of the efficiency of a detector with a daemon-sensitive PMT. At the same time, it is not improbable that PMTs themselves recorded a certain fraction of the daemon flux in our first St-Petersburg experiments. This version requires a special analysis (it is noteworthy that, because of the seasonal variation of the flux, any study of this kind takes approximately a year, which requires that appropriate priorities should be established in this case).

5. Celestial-mechanics aspects of the behavior of daemons and the daemon interpretation of the DAMA/NaI experiment

Daemons from the Galaxy disc, with a velocity dispersion $\Delta V \approx 4$-30 km s^{-1} [16] may find themselves on Earth-crossing orbits if, after passing through the Sun, they are decelerated to such an extent that they do not go away into infinity, but fall back onto the Sun by moving along permanently contracting rosette-like trajectories with perihelia lying within the Sun. If a particle moving along a trajectory of this kind crosses the Earth's sphere of action, the perihelion leaves the Sun’s body with a high probability and the daemon transfers in a stable strongly elongated Earth-crossing heliocentric orbit (SEECHO). The inevitable subsequent passages through the Earth's sphere of action make the orbit increasingly close to the Earth's orbit, and the object starts to move along a NEACHO. When passing through the Earth's body, some of these particles are decelerated to such an extent that they are captured into GESCOs. At the same time, gravitational perturbations by the Earth attempt to throw the NEACHO objects into the region of external planets, but they are insufficient for making this in a small number of encounters with the Earth. As a result, daemons accumulate, as observations do demonstrate (see the preceding Sec. 4), in NEACHOs external relative to the Earth's orbit and overtake the Earth in their perihelia.

Already the first celestial-mechanics calculations (for more details, see [17]) demonstrated that transition from rosette-like trajectories in SEECHOs (and, as a consequence, in NEACHOs) is the most favorable near the equinoctial zones and, what is interesting, there are virtually no SEECHOs that cross the Earth's orbit in a zone oriented toward the Sun's apex with respect to the nearest objects (stars or interstellar gas clouds).

The last circumstance makes understandable not only the annual periodicity of the signals recorded by DAMA/NaI, but also the very fact of their being recorded in a narrow window of scintillations with an electron equivalent energy range 2-6 keV and the non-reproducibility of these results in the cases when detectors of other types are used. The point is that objects from SEECHOs fall onto the Earth with $V = 30$-50 km s^{-1}. If these objects elastically knock-out iodine ions in the NaI(Tl) crystal, then the recoil energy of these ions lies just in the range $E_r \approx 2$-6 keV (taking into account the channeling of the ions in a crystal makes the efficiency of the channeled ion recording at $E_r < 10$ keV as high as that of electrons) [18]. The sensitivity of other detectors is poorer than 10 keV, so that they cannot record daemons of this kind. As already noted, our detector is sensitive, owing to its geometrical parameters, to daemons with $V < 30$ km s^{-1}, i.e., to the

NEACHO objects. Results of our experiments and of the celestial-mechanics calculations can be brought in agreement with the DAMA/NaI data if the cross-section σ determined by the deceleration force φ acting on daemons in their transit through the Sun $\varphi = \sigma\rho V^2$ (ρ is the substance density in the Sun) is $\sigma \approx 10^{-19}$ cm^2 (at a daemon mass of 3×10^{-5} g) [17]. The flux of daemons, found from the results of the DAMA/NaI measurements, is $f \approx 6\times10^{-7}$ cm^{-2} s^{-1} [18], which is close both to the value we measured in our experiments and to the value needed for the "Troitsk anomaly" observation [19] (this anomaly is a half-year drift of the end-point of the tritium-decay β-spectrum discovered in some experiments devoted to the direct neutrino mass measurements).

6. Some conclusions and prospects

To all appearance, we successfully detected daemons with the use of simplest concepts of their nature and interaction with matter. In the course of the study, we even could to some extent ascertain these concepts and revealed additional aspects of the interaction of daemons with matter, which improved the detection efficiency. Based on these results, we could suggest an interpretation of the experiments that led to discovery of the Troitsk anomaly and of the results of the DAMA/NaI experiment and made a number of predictions concerning some of their consequences (for example, it would be expected [19] that the Troitsk anomaly should be even more strongly manifested in the KATRIN experiment with a gas source, and making larger the number of NaI(Tl) crystals in LIBRA may fail to lead to a corresponding increase in the number of recorded events in proportion to the NaI(Tl) mass if the single-hit criterion is used, - the last criterion is useful if the cross-section of a DM particle interaction with a nucleon is very small, that is not the case for the daemons). The daemon paradigm makes understandable also the generation of an excess energy and ^{3}He in the center of the Earth [20] and positrons in the Galaxy nucleus.

At the same time, a hard work is to be done to reveal details of numerous processes both at the level of interaction of daemons with the electronic and atomic structures of substance and at the nuclear level, and, further, at the level of interaction with internal structures of the elementary particles themselves, of the type of protons and neutrons. In this regard, daemons can be used as ultramicroscopic probes.

Even deeper, on the Planckian scale, there occur fundamental processes that are somehow reflected on the results of our experiments and require that novel theoretical approaches should be developed for their description. At present, it is unclear why, for example, nuclear nucleons (presumably neutrons) are completely "digested" without leaving a trace, as follows from our CsI(Tl) experiment [12], and their substance is possibly accumulated near the gravitation radius of a daemon. It is unclear how there occurs (occasional?) discharge/evaporation of this excess of mass so that the daemon could regain its initial state (for the time being, we believe that daemon is the final product of evaporation of a black hole). It is needed to explain the very existence of such (Planckian?) objects with a stable negative charge $Ze = (9\text{-}10)e$.

It is necessary to develop the celestial-mechanics aspects of how, on the one hand, the daemon population of the Solar system is captured and evolves (of interest is, e.g., the accumulation of daemons on NEACHOs external relative to the Earth's orbit [15]) and, on the other hand, how the DM population component by itself has appeared in the Galaxy disc.

Further, it is obviously important to continue and modify both the experiments we commenced and those of the DAMA/NaI type and to redirect the latter from the WIMP area to studies of daemons. In the nearest future, we are going to perform experiments with evacuated detectors, including those with specially fabricated PMTs with calibrated thickness of their inner metallic coating. Variation of parameters of the elements of our measuring systems will make it possible not only to record the transit of daemons, but also to understand the nature of their interaction with matter at strongly different – atomic, nuclear, and Planckian - levels, which is important for a purposeful development of the related theories, including the cosmological ones.

References

1. Primack J.R., Seckel D. and Sadoulet B. // Ann. Rev. Nucl. Part. Sci. 38, 751-807 (1988).
2. Bernabei R., Belli P., Capella F. et al. // Riv. Nuovo Cim. 20(1), 1-73 (2003); astro-ph/0307403.
3. Markov M.A. // Sov. Phys. JETP 24, 584-592 (1967).
4. Hawking S. // Mon. Not. Royal Astron. Soc. 152, 75-78 (1971).

5. M.Turner M., in “Dark Matter in the Universe” (IAU Symp. No117), J.Kormendy & G.R.Knapp (eds.) // Dordrecht: Reidel, pp.445-488 (1987).
6. J.D.Barrow J.D, E.J.Copeland T.J. and A.R.Liddle A.R. // Phys. Rev. D46, 645-657 (1992).
7. Drobyshevski E.M. // Mon. Not. Royal Astron. Soc. 282, 211-218 (1996).
8. Drobyshevski E.M. // Mon. Not. Royal Astron. Soc. 311, L1-L3 (2000).
9. Rubakov V.A. // Pis’ma v ZhETF 33, 658-660 (1981).
10. Drobyshevski E.M., Beloborodyy M.V., Kurakin R.O. et al // A&A Trans. 22, 19-32 (2003); astro-ph/0108231.
11. Drobyshevski E.M. // A&A Trans. 21, 65-73 (2002); see also astro-ph/0007370.
12. Drobyshevski E.M. and Drobyshevski M.E. // arXiv:0711.4779.
13. Drobyshevski E.M., Drobyshevski M.E., Izmodenova T.Y. et al // A&A Trans. 22, 263-271 (2003); astro-ph/0305597.
14. Drobyshevski E.M. // A&A Trans. 25, 43-55 (2006); astro-ph/0605314.
15. Drobyshevski E.M. and Drobyshevski M.E. // A&A Trans. 25, 57-73 (2006); astro-ph/0607046.
16. Bahcall J.H., Flynn C. and Gould A. // ApJ. 389, 234-250 (1992).
17. Drobyshevski E.M. and Drobyshevski M.E. // A&A Trans. 26, 289-299 (2007); arXiv:0704.0982.
18. Drobyshevski E.M. // arXiv:0706.3095.
19. Drobyshevski E.M. // hep-ph/0502056.
20. Drobyshevski E.M. // A&A Trans. 22, 19-32 (2003); astro-ph/0108231.