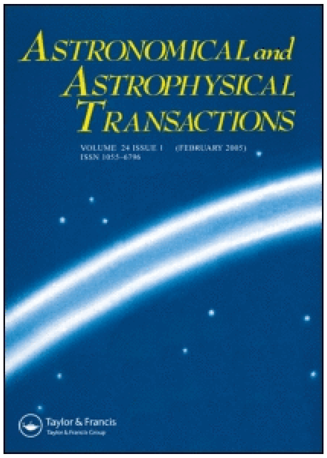

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Observation of the March maximum in the daemon flux from near-Earth orbits in the year 2005: new efforts and new effects

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The experiments in 2005 aimed at detection of low-velocity (about 10–15 km s^{-1}) daemons falling on to the Earth's surface from near-Earth, almost circular heliocentric orbits have corroborated once more the existence of the March maximum in their flux by raising the confidence level to 99.99%. In addition, these experiments permitted us to identify several FEU-167-1-type photomultiplier tubes, with an inner aluminium coating a few times thicker, which appear to be capable of detecting, without any scintillator, the crossing of negatively charged daemons. As a result, the detection efficiency increases tens of times, thus raising the measured level of the March daemon flux to $f_{\oplus} \geq 0.5 \times 10^{-7}$ cm^{-2} s^{-1}.

Keywords: Black-hole physics; Detection of dark matter; Elementary particles; Detectors

1. Daemons and detection of their near-Earth population: uncontrollable parameters in their detection

Dark-electric-matter objects, i.e. daemons, presumed to be relic Planckian elementary black holes with $M \approx 3 \times 10^{-5}$ g and $r_{\mathrm{g}} \approx 2 \times 10^{-33}$ cm, carry an electric charge of up to $Ze \approx G^{1/2}M \approx 10e$ whose repulsion is compensated by self-gravitation (see, for example, [1–4]). When moving with velocities on the astronomic scale (about 10–100 km s^{-1}), they do not trigger a scintillator [1].

Nonetheless, in our *scintillation-based* (sic!) experiments we drew upon [5] the following.

(i) *Negative* daemons are capable of capturing atomic nuclei in matter with an ensuing release of binding energy $W \approx 1.8ZZ_{\mathrm{n}}A^{-1/3}$ MeV ($\approx$100 MeV) and the resultant emission of atomic electrons and ejection of nucleons from the nuclei.
(ii) Successive daemon-stimulated *proton decays*, with an approximately 1 μs mean interval, occur inside the remainder of the captured nucleus [6]. The latter process lowers the charge of the daemon and nuclear remainder complex to $Z_{\mathrm{eff}} = |Z_{\mathrm{n}}| - |Z| < 0$, thus making capture by the daemon of a new nucleus possible. If the daemon propagates in matter,

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the process is repeated. Thus, in contrast with conventional nuclear physics particles, daemons do not produce a continuous track in a scintillator. Their path is recorded by events which are spaced fairly far apart in both time and space.

(iii) The flux of daemons as a part of the Galactic disc or halo population is fairly weak, about $3 \times 10^{-12}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. This is why we focused our attention in the experiments on the detection of slow ($V \approx 10$–$30\,\mathrm{km\,s}^{-1}$) objects captured from the Galactic disc low-velocity population [7] by the combined action of the Sun and the Earth and building up in heliocentric orbits crossing the Earth's orbit. In their motion with such a low velocity through condensed matter, daemons capture at $Z_{\mathrm{eff}} = -1$ a nucleus in a distance of about 1–10 μm. Rough estimates suggest that their flux intercepted by the Earth may reach as high as $f_{\oplus} \approx 3 \times 10^{-7}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ [8].

We started experiments in autumn 1996 and, after exploring several avenues, we chose the simplest possible detection system [5].

The detector consisted of two transparent polystyrene plates, 4 mm thick and 0.5 m × 0.5 m in size, which were coated on the underside with a $3.5\,\mathrm{mg\,cm}^{-2}$ layer of ZnS(Ag) powder about 8 μm thick. Heavy non-relativistic particles, such as α particles or protons, release in crossing such a layer approximately 1 MeV of energy, whereas β- and γ-rays and cosmic-ray muons release less than 10 keV. The plates separated by a $7\,\mathrm{mg\,cm}^{-2}$ sheet of black paper were arranged horizontally at a distance of 7 cm from one another at the centre of a tin–iron (0.3 mm iron + 2 μm tin on both sides) cubic box of side 51 cm. They were each viewed by a FEU-167 photomultiplier (PM) tube with photocathodes mounted flush with the horizontal sides of the box. The top side of the box was made of two sheets of black paper. The PM tubes were powered, according to the specifications, by a voltage corresponding to their sensitivity of $10\,\mathrm{A\,lm}^{-1}$ (in fact, they were adjusted with a photodiode to operate at the same sensitivity close to this value).

The outputs of both PM tubes were connected to an S9-8 double-trace digital storage oscillograph. The operation was triggered by a signal from the top PM tube (the first oscillograph trace). If a signal was detected on the second trace within ±100 μs from the beginning of the first, the event representing two digitized oscillograms was stored in computer memory. Two types of event were observed: one of these, with a flat maximum at about 2.5 μs, is characteristic of α-particle scintillations (referred to in what follows as heavy-particle scintillations (HPSs)), and the other, with a sharp maximum at 1–1.5 μs, is typically assigned to the passage of cosmic rays or the PM tube background, including signals produced in the PM tube by cosmic rays (or noise-like signals (NLSs)).

We started by building four detection modules of the above type. The experiments performed on these in March 2000 revealed a clearly pronounced maximum at $20\,\mu\mathrm{s} < \Delta t < 40\,\mu\mathrm{s}$ in the $N(\Delta t)$ distribution of events in the time displacement Δt of the beginning of the signal on the second trace relative to the beginning of the HPS signal on the first trace (figure 1) (see also figure 2 in [5]). We assigned this event to the crossing of near-Earth, almost circular heliocentric orbit (NEACHO) daemons with $V \approx 10$–$15\,\mathrm{km\,s}^{-1}$ [9]. This is argued for, if by nothing else, by the small width of this 30 μs peak. Indeed, the velocity excess of NEACHO objects compared with the Earth's orbital velocity of $29.8\,\mathrm{km\,s}^{-1}$ may lie within $0\,\mathrm{km\,s}^{-1} < |\Delta V| < 12.3\,\mathrm{km\,s}^{-1}$ (objects with $|\Delta V| \to 12.3\,\mathrm{km\,s}^{-1}$ should move in other than NEACHOs). A NEACHO object enters the detector with a velocity $V_{\mathrm{fall}} = (11.2^2 + \Delta V^2)^{1/2}$, i.e. $11.2\,\mathrm{km\,s}^{-1} \leq V_{\mathrm{fall}} < 16.6\,\mathrm{km\,s}^{-1}$. The daemon path length in the detector, depending on the actual inclination of its trajectory, varies from 29 to 42 cm (see below). Therefore, the 20 μs width of this peak should be identified with objects moving with velocities $7.5\,\mathrm{km\,s}^{-1} < V_{\mathrm{fall}} < 22\,\mathrm{km\,s}^{-1}$. We readily see that this interval encompasses the possible values of V_{fall} from NEACHOs with a large margin.

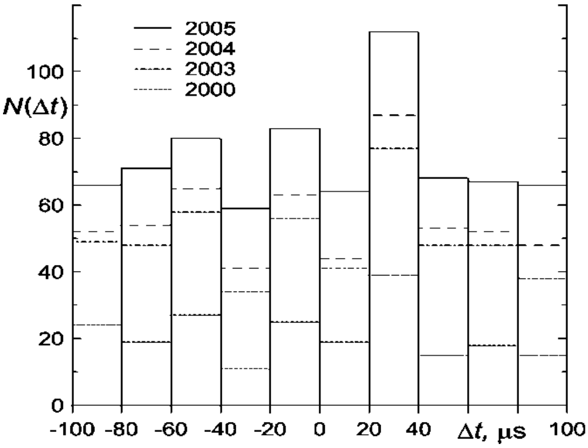

Figure 1. The sum of $N(\Delta t)$ distributions for the system of four modules 1, 2, 3 and 4 collected during March 2000 (24 February–27 March; $N(\Delta t)$ for the interval $-100\,\mu\text{s} < \Delta t < 100\,\mu\text{s}$, 24, 19, 27, 11, 25, 19, 39, 15, 18, 15), March 2003 (24 February–27 March; $N(\Delta t)$ for the interval $-100\,\mu\text{s} < \Delta t < 100\,\mu\text{s}$, 25, 29, 31, 23, 31, 22, 38, 33, 30, 23), March 2004 (8–20 March; $N(\Delta t)$ for the interval $-100\,\mu\text{s} < \Delta t < +100\,\mu\text{s}$, 3, 6, 7, 7, 7, 3, 10, 5, 4, 10) and March 2005 (three modules 1, 2 and 24; 5–25 March; $N(\Delta t)$ for the interval $-100\,\mu\text{s} < \Delta t < 100\,\mu\text{s}$, 14, 17, 15, 18, 20, 20, 25, 15, 15, 18). The 30 µs maximum in the total distribution exceeds the mean level by 33 events and has a significance of 3.63σ (confidence level, greater than 99.97%) (see also text).

The above discussion emphasizes the importance of the detection and study of the 30 µs peak. Observations carried out during the subsequent months, which involved also variation in the parameters of the system (for instance, the introduction of tinned iron sheets between the scintillators, or turning the modules upside down) did not, however, yield reproducible results while at the same time did not reveal any errors in the operation of the system. Starting in October 2000, another four-module system (modules 21–24), which could be operated in

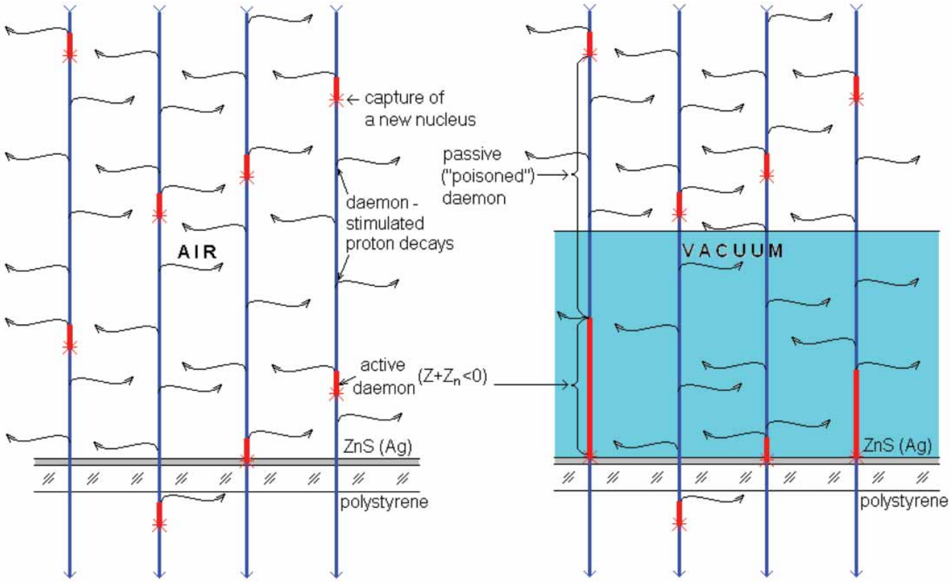

Figure 2. Positive effect of vacuum on the detection efficiency of the passage of negative daemons. The vacuum preserves the daemon in an active state up to its entering the scintillator, because it prevents poisoning of the daemon by the excess positive charge of the nuclei captured by it from the air.

somewhat different regimes, was assembled. Its top polystyrene plates coated on the underside by ZnS(Ag) were 1 mm thick. The experiment revealed that the new system had a slightly lower sensitivity than that of the old system. In June 2002, both systems were transferred to an air-conditioned room.

The lack of month-by-month reproducibility of the data amassed from March 2000 to March 2001 suggested the existence of a seasonal variation in the daemon flux [9], a conjecture borne out by a continuous exposure of the second four-module system (without variation in its parameters), first from April 2001 to April 2002 [10], then to April 2003 [11], and (with a break) to December 2004 [12]. This permitted us to detect at a confidence level of 99.9% a variation in parameters of the near-Earth daemon flux with a period $P = 0.5$ year and with maxima in February–March and again in August–September. We believe that, at about this time, the Earth crosses the areas with denser NEACHOs for objects captured in these orbits by the combined action of the Earth and the Sun as a result of motion of the Solar System relative to the daemon population of the Galactic disc. This is where the probability that the daemons transfer into the Earth-crossing orbits (and further to the NEACHOs) following their crossing and slowing down in the Sun reaches a maximum, because the projection of the Earth's orbital velocity on the Sun's apex direction achieves in these areas its largest value [11].

On the other hand, we have not succeeded in observing a maximum in the March HPS $N(\Delta t)$ distributions for $\Delta t \approx 30\,\mu\text{s}$ in subsequent years which would be as significant as the maximum in the year 2000. Figure 1 presents also the March data summed over the years 2000, 2003 and 2004. While the significance of the $30\,\mu\text{s}$ peak increases from one year to another to reach 3.33σ in 2004 (confidence level, 99.9%), these results cannot be accepted as satisfactory. Indeed, it is easy to verify that a simple repetition of the results of March 2000 would have yielded a significance of about 4σ for the $30\,\mu\text{s}$ maximum. (We calculate the statistical significance of the maximum in the simplest way possible, i.e. we divide its excess over the arithmetic mean of the number of events per bin in the distribution by the root square of the number of events in the bin with the maximum. This is a fairly moderate estimate. Indeed, one can find the excess of the maximum over a weighted mean for all ten bins (which is less than the arithmetic mean) and divide it by the square root of the sum of squared errors, i.e. by the square root of the sum of the number of events in the maximum and the squared error of the weighted mean (see, for example, [13]). One could also calculate the weighted mean for nine bins (i.e. except for the bin with the maximum), find the excess of the maximum over this weighted mean and again express it in terms of the squared sum of errors. One can readily verify that for the $30\,\mu\text{s}$ March peak in the $N(\Delta t)$ total distribution for the years 2000, 2003, 2004 and 2005 (figure 1), which has been calculated in this way, these values for statistical significance become 3.63σ (confidence level, 99.97%), 3.72σ (confidence level, 99.98%) and 3.96σ (confidence level, 99.99%). One could, of course, continue refinement of the estimate further, but this would hardly add anything of value to the experiment as such).

We are going to describe in section 3 below one more attempt to reproduce our first (and, thus far, the best) results of the year 2000. This attempt was crowned only by a partial but very essential success. We have understood that among such uncontrollable factors as the use of PM tubes, which produce inevitable noise because of radioactive potassium present in their glass envelopes, may be the response of a PM tube to a daemon crossing it. This response is caused by deviation of the thin internal structural components of a PM tube from specified values, which may originate from unavoidable variations in the technology of their fabrication. Such deviations in no way affect the photometric characteristics of the device specified in its certificate. As will be shown in section 5, however, it is because of such deviations that some PM tubes of the FEU-167-1 series can themselves serve as sensitive detectors of daemons crossing them.

2. Factors influencing detection sensitivity; advantages of an evacuated detector

The reasons responsible for the drop in detector efficiency after March 2000 have been a constant source of concern for the subsequent 5 years. The only natural way to reveal these reasons seemed to be to vary on purpose the parameters of the system that, from the standpoint of our hypothesis of the existence and probable properties of negative daemons, could exert any influence. Obviously, the situation is complicated by the fact that we are not yet able to identify unambiguously the events initiated by the passage of daemons and, thus, have to use, as a basis, statistical data, where daemons falling from NEACHOs with $V \approx 10$–$15\,\mathrm{km\,s^{-1}}$ and crossing the detector produce a $30\,\mu\mathrm{s}$ maximum in the March $N(\Delta t)$ distribution. If we had not had this maximum, it would have been much more difficult to insist on the existence of daemons.

Unfortunately, the data obtained with detectors with modified parameters can be compared only once a year. Nevertheless, we have been making these attempts during recent years. It was found, for instance, that the scintillator layer degrades with time because the finest fraction in the ZnS(Ag) powder falls out. We checked the conjectures that daemons become ‘poisoned’ by aluminium or silicon nuclei in passing through paper containing kaolin $Al_2Si_2O_5(OH)_4$ (in addition to black paper, we sometimes used white paper to wrap up the black paper in order to increase the reflection of light), that absolute air humidity in the room may also contribute, etc.

The latter consideration resulted from a basically simple idea that the detector efficiency is proportional to the time during which a daemon resides in active state with $Z_{\mathrm{eff}} \leq -1$ with respect to the time that it spends poisoned with $Z_{\mathrm{eff}} \geq 0$, when a daemon is not capable of capturing a new nucleus and exciting a scintillation. It would thus appear that (figure 2) an evacuated detector should possess the highest efficiency, because here the daemon, on having disintegrated the nucleus that it had captured earlier, is not poisoned by nuclei in the air and, in approaching in the active state (with $-1 \geq Z_{\mathrm{eff}} \geq Z$) the ZnS(Ag) layer, should with almost 100% probability capture a nucleus here and excite a scintillation.

Considered from this standpoint, detectors filled with hydrogen or helium instead of air should possess a higher efficiency. Detectors filled with water vapour, the molecule of which has two protons, could occupy an intermediate place. Because of the potential explosion hazard involved, we did not risk starting experiments with hydrogen; experiments with helium cost us, however, the loss of two FEU-167 PM tubes (I.N. Kolyshkin warned us in time that helium diffusion through glass causes deterioration of the vacuum and PM tube degradation). Experiments performed in air with a humidity raised to 30–50% at $T = 28$–$30\,^{\circ}\mathrm{C}$ did not produce conclusive results. Nevertheless, the studies performed within the framework of the above considerations on the possible effect of various factors on the detection efficiency eventually shed light on some of the reasons for the poor reproducibility of our results and indicated certain ways to improve the detector.

3. The March 2005 experiment and its main results

A new attempt at reproducing the results of March 2000 was undertaken by us in March 2005. The thickness of the ZnS(Ag) layer was increased by spraying to about $6\,\mathrm{mg\,cm^{-2}}$, and the sensitivity of all PM tubes was again matched by properly adjusting their voltages. Also, all the PM tubes that we had at our disposal were classified by their intrinsic noise (at an output signal level of not less than 2.5 mV). The lowest-noise tubes were mounted to view the bottom scintillators in the modules (the intrinsic NLSs of the upper PM tubes affect solely the trigger frequency of the system and not the final result, because we are processing only events with an HPS signal on the upper trace occurring at the trigger level of not less than 2.4–2.6 mV, and the signals on the second trace are taken into account starting from a level not less than 0.6 mV; recall that the PM tube anode load contains, besides an active 9.2 kΩ resistor, an inductance of 4.69 mH, through which the signal is supplied by a cable with a 490 pF capacitance directly to the 30 pF oscillograph input; this L–C filter, while leaving the HPS amplitude unchanged, suppresses NLSs approximately threefold). The thin (1 mm thick) top scintillator plates in modules 21–24 were turned with the ZnS(Ag) layer up. Starting from the end of January 2005, the humidity in the air-conditioned room was maintained at a level of 30% at $T = 28\,^{\circ}\mathrm{C}$.

The eight-module detector was exposed from the evening of 5 March to 25 March 2005 inclusive (483 h altogether). During this period, some parameters were varied as follows.

(i) 15–20 March (116 h total time): the bottom PM tube of module 23 was screened with black paper.
(ii) 16–19 March: the bottom PM tubes in modules 1 and 3 were interchanged (70 h; this time was not included in subsequent data treatment, but the experiment showed that the rate of the double-event recording depends on the properties of the bottom PM tube).

The observations yielded very interesting results. All the eight modules could be clearly divided into three groups according to the number of recorded double events with HPSs triggering the top PM tube (events with $|\Delta t| \leq 0.4\,\mu\mathrm{s}$ were rejected).

Three modules (1, 2 and 24) recorded 62, 60 and 55 events each during this time, which is broadly in agreement with the count rate of double events in 2000 (when four modules (1–4) recorded, from 24 February to 27 March, 212 double events altogether with HPSs on the upper traces). The $20\,\mu\mathrm{s} < \Delta t < 40\,\mu\mathrm{s}$ bin of the $N(\Delta t)$ distribution contains 25 out of the total of 177 events (1.46σ significance). However, if the results are normalized to four modules and to the corresponding exposure time, we have to admit that we still have not reached the efficiency of the year 2000, i.e. some parameters remain uncontrollable. Nevertheless, adding these new data to those obtained in March 2000, March 2003 and March 2004 (see figure 1) raises the significance of the $30\,\mu\mathrm{s}$ peak to 3.63σ (confidence level, 99.97%).

Two of the modules (21 and 22) recorded, accordingly, 103 and 119 events with a noticeable excess of events with $\Delta t < 0$ (57 and 69 respectively, compared with 46 and 50 for $\Delta t > 0$), which may be assigned to recording an excess flux of objects propagating upwards.

Finally, modules 3, 4 and 23 recorded a still larger number of double events. Module 3 recorded 959 events ($N(\Delta t)$ for the interval $-100\,\mu\mathrm{s} < \Delta t < 100\,\mu\mathrm{s}$, 73, 96, 105, 85, 73, 101, 124, 102, 106, 94), module 4 recorded 923 events ($N(\Delta t)$ for the interval $-100\,\mu\mathrm{s} < \Delta t < 100\,\mu\mathrm{s}$, 95, 98, 100, 97, 94, 87, 96, 90, 80, 86) and module 23 recorded 436 events ($N(\Delta t)$ for the interval $-100\,\mu\mathrm{s} < \Delta t < 100\,\mu\mathrm{s}$, 42, 38, 42, 48, 52, 36, 44, 33, 61, 40) or, after subtraction of 116.5 h of exposure with black paper, 321 events ($N(\Delta t)$ for the interval $-100\,\mu\mathrm{s} < \Delta t < 100\,\mu\mathrm{s}$, 34, 25, 33, 35, 41, 22, 31, 20, 46, 34). If we restrict the signal amplitude in the upper channels to $3.5\,\mathrm{mV} \leq U_1 \leq 10.0\,\mathrm{mV}$ and in the lower channels to $0.6\,\mathrm{mV} \leq U_2 \leq 0.9\,\mathrm{mV}$, then the number of such events in module 3 drops to 497 ($N(\Delta t)$ for the interval $-100\,\mu\mathrm{s} < \Delta t < 100\,\mu\mathrm{s}$, 40, 52, 55, 40, 32, 51, 68, 54, 64, 41), in module 4 to 613 ($N(\Delta t)$ for the interval $-100\,\mu\mathrm{s} < \Delta t < 100\,\mu\mathrm{s}$, 67, 63, 62, 68, 64, 53, 70, 56, 56, 54) and in module 23 to 230 ($N(\Delta t)$ for the interval $-100\,\mu\mathrm{s} < \Delta t < 100\,\mu\mathrm{s}$, 19, 14, 21, 25, 26, 20, 29, 18, 36, 22) (or to 168 ($N(\Delta t)$ for the interval $-100\,\mu\mathrm{s} < \Delta t < 100\,\mu\mathrm{s}$, 15, 9, 15, 18, 20, 12, 20, 13, 28, 18) if the events obtained with black paper are disregarded), i.e. 1340 events altogether. The total $N(\Delta t)$ distribution of these 1340 events is presented in figure 3. We readily see a $30\,\mu\mathrm{s}$ maximum with 167 events, which exceeds the average level by 33 events, standing out with a significance of 2.55σ. (It appears worth noting that the $N(\Delta t)$

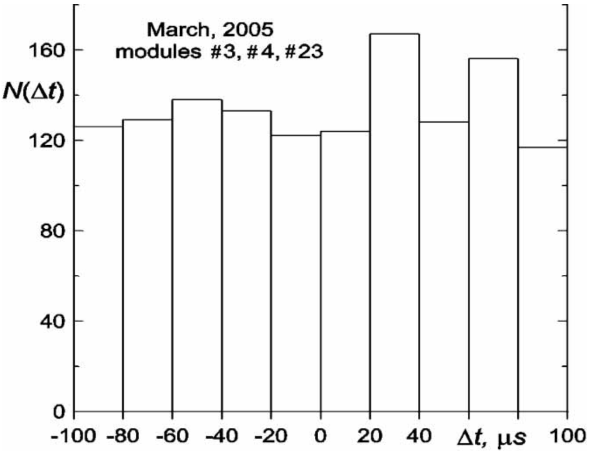

Figure 3. Total $N(\Delta t)$ distribution for 5–25 March 2005 of double events with HPS on the top scintillator obtained for modules 3, 4 and 23, where the bottom PM tubes have a thicker internal aluminium coating. The distribution was plotted for 1340 events with amplitude 3.5 mV$\leq U_1 \leq$ 10.0 mV in the upper channel and 0.6 mV$\leq U_2 \leq$ 0.9 mV in the bottom channel.

distribution for double events with NLSs in the first channel of module 3 (with the total number of events about 2120) exhibits a maximum in the $-40\,\mu\text{s} < \Delta t < -20\,\mu\text{s}$ bin with a significance of about 2.56σ (with no 30 μs maximum observed). Such features for NLSs were not seen earlier. We may consider it now to be of a purely stochastic nature. Obviously, the case deserves a more detailed study.)

Calculations yield for the daemon flux corresponding to this excess (total area of the three modules, 0.75 m^2; exposure time, 1.75×10^6 s) $f_\oplus \approx 2.5 \times 10^{-9}\,\text{cm}^{-2}\,\text{s}^{-1}$, a value exceeding by a factor of 3–4 the flux recorded in March 2000 (18 excess events; total area of four modules, 1 m^2; exposure time, 2.5×10^6 s). It would seem that everything is all right, because the goal of the experiment has been reached, and we have demonstrated compatibility with the earlier results, so that the only problem still remaining to deal with was to eliminate some minor inadequacies.

4. Analysis of experimental results: possible role of the inner photomultiplier tube structure

A question that immediately comes to mind is: what could be the reason for such strong differences in the behaviours of different groups of modules having presumably identical parameters, including the PM sensitivity to light? Strange though this might seem, an intrinsically non-contradictory answer can be put forward, drawing again on the concept of the existence of daemons.

We assumed that different PM tubes (or their different groups) exhibit, depending on the time and method of fabrication and the related inevitable deviations from the ideal standard technology, some features which, while not affecting markedly their spectral and photometric properties, give rise to different responses when crossed by daemons, as well as by components of other penetrating radiations.

In fact, we bought 12 FEU-167 PM tubes, some of which were selected for the first four modules, from Svetlana Co. (St Petersburg) (located close to the Ioffe Institute) in 1998. It is at Svetlana Co. that the FEU-167 PM tubes with excellent characteristics had been developed in the early 1980s under G.S. Wildgrube. In the late 1980s, the production of the FEU-167 PM tubes was transferred to Ekran Co. in Novosibirsk, where in June 2000 we bought four FEU-167 and 12 FEU-167-1 PM tubes. The best of these (as we believed) were used to replace the PM tubes in the already-operated four-module detector which demonstrated poorer performance. Our PM tubes bought from Svetlana and Ekran had hardly the best performance, because they were chosen from those left over from what had been produced a few years before (for well-known reasons, industrial production in Russia had nearly stopped by the late 1990s).

To identify these unapparent parameters by which PM tubes could differ from one another, we had to study their design and technological details of their manufacture. The glass envelope of FEU-167 (figure 4) consists of three parts:

(i) a cylindrical photocathode section, 125–130 mm in diameter and about 40–45 mm long whose front part is protected by a glass disc $5_{-0.3}$ mm thick;
(ii) a cylindrical stem, 50 mm in diameter and about 70 mm long, accommodating the dynodes and the anode;
(iii) a conical photocathode junction section 25–30 mm high.

The envelope wall thickness is 2.3–2.5 mm. The photocathode and the junction sections are coated on the inside with a specular aluminium layer deposited by evaporation in vacuum. According to the original specifications of Svetlana, the thickness of the aluminium layer, although not strictly regulated because it is not able to influence critically the PM tube's photometry properties, is about 0.1 μm. The surface of the aluminium layer and of the transparent front glass disc are coated by a transparent current-conducting Sb−Na−K−Cs photosensitive layer. The disc and the envelope of the photocathode section are made of S49-1 low-background boro-silicate (potassium-free) glass (in the Svetlana version, 67.5 wt% SiO_2–20.3 wt% B_2O_3–3.5 wt% Al_2O_3–8.7 wt% Na_2O) or S52-1 boron–potassium glass (in the Ekran version used

Figure 4. FEU-167 and FEU-167-1 PM tubes. The photocathode section diameter is 125–130 mm.

in FEU-167-1, a PM tube similar in all other respects to FEU-167, except for a K_2O content of 4.4 wt%).

Based on the general idea of the capture, disintegration and transport by a daemon of the remainder of the captured nuclei, we assumed that the incomplete reproducibility of the first results, as well as the above strong difference in the number of recorded double events in the three groups of modules, may be caused to a certain extent by differences in construction of the different PM tubes too and, in particular, by the differences in thickness of the aluminium and photosensitive layer (referred to below as the aluminium coating for brevity) in their photocathode sections.

We carried out comparative measurements of the thicknesses of the electrically conductive aluminium coatings in different PM tubes. We used for this purpose two inductance coils (2 turns of 100 mm diameter). On one of these the PM tube was placed with its front screen down, and the other was put on its conical section at a distance of 60 mm from the first. A pulsed electric signal was supplied to the first coil, and the inductively induced pulse was obtained from the other. The system was calibrated by a set of aluminium foil discs, 140 mm in diameter and 0.05 μm thick, placed between the coils. The larger the total foil thickness, the weaker is the inductive coupling between the coils, and the weaker is the induced pulse, the sensitivity of the method decreasing naturally with increasing foil thickness. Because of the configurations of the foils (discs) and of the aluminium coatings in the PM tube are different (gently sloping cone connecting with the cylinder), measurements of this type are not capable of yielding an absolute value of the thickness of the conductive coating in a PM tube (because of specific features of deposition it may turn out to have an inhomogeneous thickness). Nevertheless, these measurements provide a judgement of the relative thicknesses of the current-conducting layer in different PM tubes.

The Svetlana-produced PM tubes were found to be, on the average, more noisy for output signals not less than 2.5 mV than their Novosibirsk counterparts and, therefore, in our new arrangement all the lower PM tubes in all the modules turned out to be Novosibirsk produced (FEU-167 in module 1, and FEU-167-1 in others). The thickness of the aluminium coating in the Novosibirsk PM tubes was, however, about three to ten times that of the Svetlana devices. Moreover, it was found that the bottom PM tubes in modules 3, 4 and 23 belong to a group with the largest coating thickness.

5. Photmultiplier tube as a vacuum detector of daemons

The above adds up to the following, inevitably strongly simplified scenario of daemon passage through the modules containing PM tubes with internal aluminium coatings of different thicknesses and with envelopes made of different types of glass (low background, i.e. potassium free, or boron–potassium).

In our standard scenario (see figure 2), if a daemon propagates through air, it becomes poisoned, as it were, by the nitrogen or oxygen nuclei that it captures, for a long time, because, on having acquired an excess positive charge, it is no longer capable of capturing and exciting a new nucleus. Having 'digested' in 5–10 μs the excess protons and assumed $Z_{\text{eff}} = |Z_{\text{n}}| - |Z| < 0$, the daemon becomes active for a certain time and, with $V \approx 10$–$15\,\text{km}\,\text{s}^{-1}$, propagates through air about 1–4 mm until the capture of another nucleus [9]. If during this interval it crosses the ZnS(Ag) layer approximately 10 μm thick, it will capture with a high probability a nucleus here and excite it to produce an HPS. (Recall that the passage of a daemon or of cosmic-ray particles through the upper PM tube generates only NLSs, so that these events are not considered here). Continuing its downward flight, the daemon, still poisoned by the remainder of the nucleus, at $V > 5\,\mathrm{km\,s^{-1}}$ crosses the bottom scintillator without producing a scintillation. The bottom scintillator will be excited if by the time that it approaches the bottom tinned-iron lid of the casing the daemon becomes active again and captures a nucleus here. The numerous electrons emitted in the capture cross the 22 cm layer of air separating them from the bottom ZnS(Ag) scintillator and excite here an NLS; it is this that causes the double event. This is the scenario of ideal detector operation, which apparently was primarily realized in March 2000, when the Svetlana PM tubes were used.

However, if, on crossing the upper ZnS(Ag) layer and exciting there an HPS, the daemon reaches the level of the lower lid of the casing and enters the PM tube, it may, while passing the 4–5 cm path in vacuum, lower its Z_{eff} to about $-(4–6)$ as protons in the remainder of the captured nucleus continue to disintegrate.

Obviously, the response of a PM tube to the passage of such a daemon should depend critically on the structural details of its photocathode section.

If the thickness of the aluminium coating inside it is not greater than $0.1\,\mu\mathrm{m}$, the daemon with $Z_{\mathrm{eff}} \approx$–(4–6) will cross the electrically conductive coating without interaction with its nuclei, enter the glass and, only on capturing here a boron, sodium, silicon or aluminium nucleus (S49-1 glass) with ejection of a small number of electrons (10–15) contained in the nearest (dielectric) environment of the excited nucleus, will generate in the PM tube a weak NLS. Note that the number of secondary electrons is small, because the work function of an electron from an inorganic dielectric is comparable with the ionization energy of its constituent molecules (about 10 eV). If, however, the thickness of the aluminium coating inside the PM tube is not less than $0.5\,\mu\mathrm{m}$ thick, the daemon with $Z_{\mathrm{eff}} \approx$ –(4–6) propagating with $V = 10$–$15\,\mathrm{km\,s^{-1}}$ will capture here a nucleus with almost 100% efficiency (recall that calculations similar to those performed by Drobyshevski *et al.* [9] yield, for aluminium, $\lambda|Z_{\mathrm{eff}}| \approx 2.5\,\mu\mathrm{m}$ for $V = 10$–$15\,\mathrm{km\,s^{-1}}$, where λ is the mean free path to nucleus capture). In addition to 13 atomic electrons, the nucleus excited in the capture will eject from the aluminium layer a large number of refilling electrons (in the metallic phase), as well as secondary electrons, because the energy needed to release an electron here (the work function), in contrast with that in the glass, is low. For pure aluminium, it is about 4 eV and, for aluminium coated by thin layers of sodium, potassium, caesium, antimony and their compounds, about 1 eV.

This is why a PM tube with a sufficiently thick internal aluminium mirror is capable of operating by itself, without a scintillator, as an efficient vacuum detector of daemons (with an efficiency as high as tens of per cent). (The idea is in no way new. Application of a PM tube (more exactly, of its dynode assembly) as an electron multiplier for direct high-efficiency particle detection is nearly seven decades old (see, for example, [14, 15])). It is clear also that, because of avalanche multiplication of electrons in a thick aluminium film, such a PM tube will respond to and detect cosmic rays and intrinsic radioactive radiations crossing it with a higher efficiency than a tube with a thin aluminium layer. This is why the number of recorded stochastic double events (background) in modules 3, 4 and 23 is very large. We may recall also that the envelopes of the bottom FEU-167-1 PM tubes are made of potassium-containing glass, so that a sizeable fraction of small-amplitude NLSs triggered by them may in actual fact be initiated by the β radioactivity of ^{40}K. It appears appropriate to point out here that cosmic rays, which produce double NLSs with $\Delta t = 0$, on the average, once every few minutes, and sometimes simultaneously in several modules, generate these signals in the PM tubes themselves (including those screened by black paper); judging from the rate of their appearance, such double NLSs with $\Delta t = 0$ ensue from cosmic rays in the dynode part of a PM tube.

The response of PM tubes with an intermediate aluminium mirror thickness to daemons (and background radiations) should naturally be more complex than that with a thin or thick aluminium layer. It will depend in large measure on the parameters of the electron optics governing the motion of electrons with different energies and emitted from different parts of internal surface of the photocathode section, as well as on the compositions of the envelope and disc glass.

It is along these lines that one may look for explanation of the fact that the bottom PM tubes in modules 21 and 22 detect preferentially daemons arriving from below (the excess of events with $\Delta t < 0$). It may be conjectured that it is primarily the low-energy electrons emitted in the capture of nuclei by daemons in potassium-containing S52-1 glass of the disc that are intercepted by the dynode section with their subsequent multiplication rather than the electrons ejected from the aluminium-coated walls of the conic section or side cylindrical walls. The role of secondary-electron emission produced as electrons strike the glass walls and the comparatively thin aluminium coating is unclear (one should not forget that all these surfaces are coated by a thin (approximately 10 nm) Sb$-$Na$-$K$-$Cs active layer).

While the efficiency of detection of daemon passage with $V \approx 10\,\mathrm{km\,s^{-1}}$ through a ZnS(Ag) layer can be estimated as a ratio of a few millimetres of air path in the active state to about 10 cm of flight in the poisoned state (see figure 2), i.e. as a few per cent (about 3%) (so that our detector made up of two such layers has an efficiency of approximately 10^{-3}), the efficiency with which a daemon crossing a PM tube with a thick aluminium mirror could be detected may amount to tens of per cent. (The low efficiency is suggested also by the fact that, in a year-long exposure in 2004 of modules 1–4 mounted under modules 21–24 (and in the opposite arrangement), no reliable triple event involving shifted HPSs on the top scintillators in the modules arranged one over another was recorded.) Assuming the area of the PM tube's front disc to be $115\,\mathrm{cm}^2$, accepting that the $30\,\mu\mathrm{s}$ maximum in the $N(\Delta t)$ distribution in figure 3 exceeds the background during 20 days by 33 events and assuming also that the bottom PM tubes in modules 3, 4 and 23 are identical, we obtain that the flux of daemons with $V \approx 10$–$15\,\mathrm{km\,s^{-1}}$ measured in March 2005 is $f_\oplus \approx 0.5 \times 10^{-7}\,\mathrm{cm^{-2}\,s^{-1}}$. This value exceeds by approximately 50 times the flux measured by our detector earlier [5]. (On the other hand, taking into account the sensitivity of the PM tube itself to the passage of a daemon, we have discovered that one should not overlook the possibility that some of the NLSs on the bottom PM tubes detected in previous experiments were also generated by the passage of daemons through them rather than by scintillations in the bottom ZnS(Ag) layer induced by electrons from the lower lid of the casing which were emitted by the nucleus captured here by the daemon, as we had been inclined to believe before. Further studies are obviously needed to clarify this point). Allowing for the low efficiency of the top scintillator–PM tube assembly (about 3%), we arrive at $f_\oplus \approx 10^{-6}\,\mathrm{cm^{-2}\,s^{-1}}$ for the real flux. This value is consistent with our earlier estimates of the daemon flux of about $3 \times 10^{-7}\,\mathrm{cm^{-2}\,s^{-1}}$ from heliocentric orbits [8] and with a value of $10^{-7} - 10^{-6}\,\mathrm{cm^{-2}\,s^{-1}}$ derived from an analysis of the origin and behaviour of the 'Troitsk anomaly' observed near the end point of the tritium β spectrum obtained in neutrino mass measurements [12].

An additional argument in favour of the working hypothesis that it is the PM tube itself that responds to daemons is offered by the experiment with module 23, in which the bottom PM tube scintillator was screened during 116.5 h by black paper (from 18 h 20 min, 15 March 2005, to 20 h 00 min, 20 March 2005). Strange as this might seem, it is significant that the $30\,\mu\mathrm{s}$ maximum in the experiment with the PM tube screened for nearly 5 days, rather than dropping, even increased somewhat. The statistics involved here are naturally poor, so that further experiments with PM tubes screened from the scintillators are under way in the Baksan Neutrino Observatory, yielding support for this view [16].

6. Main conclusions and prospects

The March 2005 experiments have yielded interesting results in two main directions: astrophysical and methodological.

Starting with the *astrophysics*, the following features have been shown.

(i) The March maximum of the low-velocity ($V \approx 10 - 15\,\mathrm{km\,s^{-1}}$) ground-level daemon flux incident from NEACHOs is apparently far in excess of the lower limit $f_\oplus \approx 10^{-9}\,\mathrm{cm^{-2}\,s^{-1}}$ set by previous experiments and reaches $f_\oplus \approx 0.5 \times 10^{-7}\,\mathrm{cm^{-2}\,s^{-1}}$, a value approaching our old estimates obtained on theoretical grounds [8].

(ii) Summing up the data obtained in 2000, 2003, 2004 and 2005 raises the significance of the 30 μs March maximum in the $N(\Delta t)$ distribution to 3.63σ (to 99.97%; see figure 1). (Taking into account data from modules 3, 4 and 23 would naturally increase still more the significance of the 30 μs peak, but these results were obtained, in a sense, with another, much more efficient detector, whose parameters have yet to be appraised and quantified. Therefore it would hardly be possible to carry out at present an indisputably correct summation of the confidence levels of these two data sets).

Now with respect to *methodology* we have the following.

(i) We have developed an understanding that our two-scintillator detector with thin ZnS(Ag) layers has a fairly low sensitivity (about 10^{-3}) because of the small ratio of the times that the daemon moving through air spends in the active state, in which it can capture a new nucleus, to that in passive state, where it is poisoned by nuclei with $|Z_\mathrm{n}| \geq |Z|$.

(ii) This understanding has helped us to realize the merits of evacuated detectors, where the daemon which has reached an active state by disintegrating protons in the captured nucleus would reside in it until it enters the sensitive (e.g. scintillator) layer.

(iii) The experiment has revealed that some FEU-167-1 PM tubes, which by their spectral and photometric characteristics do not stand out among other FEU-167 PM tubes, possess the properties of a high-efficiency evacuated daemon detector. Inductive measurements of the thickness of the electrically conducting coating inside the cylindrical cathode section (diameter, 125 mm; length, approximately 45 mm) showed it to exceed the specified value (about 0.1 μm) by a few times to reach about 1 μm. It is conceivable that the daemons that have become active after entering the evacuated cathode section of the PM tube retain and even increase it (the value of $|Z| - |Z_\mathrm{n}| > 0$ increases) in crossing the section 45 mm long and, on striking the fairly thick layer of electrically conducting material (Sb−Na−K−Cs photosensitive layer and aluminium coating), capture with a high probability a nucleus here, which gives rise to the emission of hundreds of electrons (internal conversion, Auger, refilling and secondary) generating a noticeable PM tube signal. Capture of a nucleus in the thin layer of deposited aluminium or in the Sb−Na−K−Cs coating should occur with a very low probability and, if taking place in glass, would bring about the emission of only a few tens of electrons (there would be very few secondary and refilling electrons).

Thus, in addition to the urgently needed experiments on PM tubes with screened photocathodes (front glass discs), one could conceive of at least two areas where the detection of daemons could be improved methodologically so as to raise its efficiency.

(a) Thin-layer scintillator detectors could be placed in vacuum.

(b) Purposefully modified PM tubes could be used or, more specifically, firstly, PM tubes with a larger thickness and/or variable composition of the electrically conducting cathode coating, secondly, PM tubes with a longer cathode section to increase the fraction of daemons that become active here and the degree of their activity, i.e. the difference $|Z| - |Z_\mathrm{n}| > 0$, and, thirdly, blind PM tubes (if such devices can still be called PM tubes; they are actually electron multipliers [14]) with front discs also coated on the inside by electrically conducting layers with optimally chosen thickness and atomic composition and which are, possibly, opaque to light. One cannot rule out the possibility that the composition of the envelope and disc glass could also be of importance here.

Although the confidence level of the main results obtained in this study is in itself not very high (about 90–95%), nevertheless, the results do suggest new prospects and directions for further investigations and use of the interesting information that we have gained. Moreover, adding the new data to what had been amassed in previous experiments raises the confidence level of the existence of the March maximum in the daemon flux from NEACHOs to 99.99%, let alone the weight that it renders to the argument that the totality of observations collected by us thus far defies any other interpretation except the scenario proposed within the daemon concept, the basis underlying our experiments.

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