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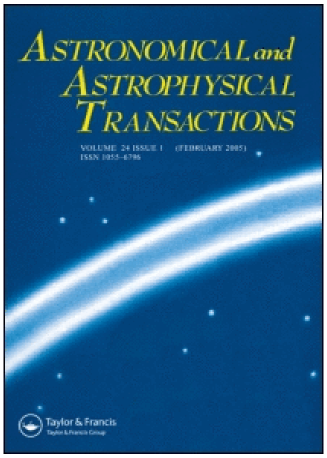

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Study of the spring and autumn daemon-flux maxima at the Baksan Neutrino Observatory

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Detection of daemons in low-background conditions in September 2005 and March 2006 has provided supportive evidence for the maxima in the flux of daemons with $V \approx 10$–$15\,\mathrm{km\,s^{-1}}$, which hit the Earth from near-Earth almost-circular heliocentric orbits (NEACHOs) and which were expected to occur at those times. The ability of some FEU-167-1 photomultiplier tubes (PMTs) with a thicker inner aluminium coating to detect directly (without a scintillator) daemon passage through them has also been demonstrated, an effect giving a hundredfold increase in the detector efficiency. As a result, the daemon flux recorded at the maxima was increased from about 10^{-9} to about $10^{-7}\,\mathrm{cm^{-2}\,s^{-1}}$. At the maxima, two phases in the observed flux can be discriminated. The first of these is associated with objects which catch up with the Earth when moving in outer NEACHOs and cross it. The intensity and direction of the flux during this phase which lasts about 2 weeks depend on the time of day and latitude of observations (therefore, synchronous measurements in the northern and southern hemispheres of the Earth are desirable). In the second phase, where the flux consists primarily of a few objects captured into geocentric Earth-surface-crossing orbits during the first phase, the daytime and latitude dependences become less pronounced. The experiments suggest an explanation for the fairly poor reproducibility of our earlier ground-level measurements (subtle differences in PMT design, varying radon background, etc.). All the experimental results thus obtained either support the conclusions following from the daemon paradigm or find a simple interpretation within it.

Keywords: Black-hole physics; Dark matter; Elementary particles; Detectors

1. Introduction

The properties of dark-electric-matter objects, daemons, which made possible their detection by the scintillation technique are in line with the expected characteristics of elementary black holes with $m \approx 3 \times 10^{-5}$ g, Planckian particles, if they carry a negative electric charge $Ze \approx -10e$ corresponding to their mass (see, for example, [1]). Among these is the capture of nuclei in matter, with their excitation and ejection of electrons and nucleons [2], and subsequent daemon-stimulated disintegration in the remainder of the nucleus of one proton after another [3] with an interval of about 1 μs, which makes possible the capture of another

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nucleus [4]. (At a velocity $V \approx 10\,\mathrm{km\,s^{-1}}$, disintegration of a nucleus comes to an end within a path of about 10 cm, and the capture of another nucleus in air, in approximately 1–3 mm). Of considerable significance is also the high penetrability of the daemon, permitting it to cross the Sun and the Earth with very weak deceleration, a property that enables daemons populating the Galactic disc to become captured and to accumulate in heliocentric orbits including near-Earth almost-circular heliocentric orbits (NEACHOs) and, subsequently, in geocentric Earth-surface-crossing orbits (GESCOs), which contract in a relatively short time to disappear finally inside the Earth.

Daemon transfer to NEACHOs is most probable in the zones where the projection of the Earth's orbital velocity on to the solar apex direction is maximal. This is why the daemon flow undergoes a semiannual periodicity. These zones lie close (by pure chance) to the equinoxes [5].

Detection of daemons at the Ioffe Physico-Technical Institute (PTI), Russian Academy of Sciences, St Petersburg, was carried out by Drobyshevski [6] and Drobyshevski *et al.* [4] with a thin (about $10\,\mu\mathrm{m}$) ZnS(Ag) layer deposited on the underside of two horizontal polystyrene plates, $0.5\,\mathrm{m} \times 0.5\,\mathrm{m}$ in area and 4 (or 1) mm thick, with a distance of 7 cm between them and arranged at the centre of a tinned-iron sheet cube, of side 51 cm. Eight such modules were employed altogether. Each plate is viewed by its FEU-167 photomultiplier tube (PMT), whose output is fed into a dual-trace digital storage oscillograph. The time shift Δt between the start times of the scintillator signals enables the velocity of the object to be judged. There are two types of signal. Signals of the first type, with a long (about $2\,\mu\mathrm{s}$) flat maximum 2–2.5 μs from the start time, are scintillations caused by heavy non-relativistic particles, e.g. α particles (heavy-particle scintillations (HPSs)); the other type, initiated, in particular, by cosmic rays (these are signals with $\Delta t = 0$, occurring sometimes simultaneously in several modules) and characteristic of intrinsic PMT noise, have a steep (approximately $1.5\,\mu\mathrm{s}$) leading edge ending in a sharp maximum (noise-like signals (NLSs)). We focused our attention on double events with HPSs in the top channel, whose output triggered the oscillograph sweep.

Because most of the double events originate from the background produced by cosmic rays and natural radioactivity, the events of interest to us are isolated by a statistical analysis of the distribution of the number $N(\Delta t)$ of events in the time shift Δt separating them. Significant results were obtained with the first four modules almost immediately, in March 2000, when a maximum in $N(\Delta t)$ was observed within the $+20\,\mu\mathrm{s} < \Delta t < +40\,\mu\mathrm{s}$ bin. The statistical significance of this $+30\,\mu\mathrm{s}$ peak was 2.85σ. Its small width corresponds to the small spread in the velocity of the objects striking the Earth from NEACHOs. One more March observation, we thought, and the significance would rise to 4σ. However, because of the continuous changes in system parameters the hope of revealing novel effects in the detector efficiency decreased. Only summation of data amassed in the months March 2000, March 2003, March 2004 and March 2005 raised the significance of this peak to 99.99% [7]. Although in these years we detected a seasonal variation with a period $P = 0.5$ years [8] and some indications of a September maximum similar to the March maximum, it became clear that some important parameters are still eluding us.

The ground-level observations performed in March 2005 suggested (for more details, see [7]) that some FEU-167 PMTs are capable of generating themselves, without scintillator, a signal when crossed by a daemon. These seemed to be PMTs with a larger (up to about $1\,\mu\mathrm{m}$) thickness of the inner aluminium coating of their photocathode section. This thickness is usually not specified because it does not affect the photometric characteristics of a PMT but, according to the original specification, it should be about $0.1\,\mu\mathrm{m}$.

Indeed, in passing a distance of 4–6 cm in the vacuum cathode section of a PMT, about 50% of daemons should reduce the charge Z_n of the nuclei captured outside in air to the level where

$|Z_\mathrm{n}| - |Z| < 1$ or, colliding in vacuum with no new nuclei, even to $|Z_\mathrm{n}| - |Z| \approx -(4-6)$. As the daemon enters now the internal, electrically conducting photomultiplier coating and captures there with a high probability a nucleus with the concomitant ejection of nucleons and hundreds of (refilling) electrons, it generates in the PMT a measurable signal. This behaviour was observed in the lower PMTs of three of the eight modules (these are the FEU-167-1 PMTs with envelopes made of potassium-containing glass). Attributing the origin of the $+30\,\mu$s peak in these modules to the above effect, the effective detector area decreases markedly, so that the calculated daemon flux rises to $f_\oplus \approx 0.5 \times 10^{-7}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ ([7]).

Hence it immediately follows that a detector should operate even without the lower scintillator, if the PMT itself acts as a sensitive element. It is this consideration, as well as a desire to carry out the September and March maxima in well-controlled low-background conditions, that have motivated the present experiments at the Baksan Neutrino Observatory (BNO). The specific features of the detector used are described in section 2. Sections 3 and 4 list and discuss the data obtained in September 2005, while the March 2006 data will be discussed in sections 5 and 6. The measurements to be analysed provide compelling evidence not only for the existence of both the latitude and (possibly) the diurnal variations within the September and March maxima in the flux of low-velocity daemons from the outer NEACHOs but also for the possibility of using PMTs as primary daemon detectors; the need to monitor the content of radon in air in ground-level observations is also emphasized.

2. Description of the detector and its set-up

We brought from the Ioffe PTI to the BNO only detector module 3 [7]. The lower PMT in the module was screened by two layers of Lavsan film $6\,\mu$m thick and coated on one side with an aluminium layer $0.05\,\mu$m thick. We left only one polystyrene plate, 4 mm thick, with its approximately $6\,\mathrm{mg\,cm}^{-2}$ ZnS(Ag) scintillator layer *face up*, and it was viewed by the top PMT from a distance of 22 cm. Previously, the plates in our modules were always turned with the ZnS(Ag) layer down (the only exclusion having been made for the upper plates 1 mm thick in modules 21–24 in the measurements of March 2005 [7]). Now the plate had to be turned in order to put two transparent Lavsan films $50\,\mu$m thick on the ZnS(Ag) layer. In addition, the scintillator corners were screened with black paper, so that the scintillator area viewed by the PMT amounted to $2100\,\mathrm{cm}^2$. The films protected the scintillator from direct incidence of α particles of radon and of radiative products of its decay contained in air. In addition, the module was continuously blown from below by nitrogen evaporated from a Dewar flask ($12\,\mathrm{cm}^3\,\mathrm{s}^{-1}$ flow rate).

These measures permitted us, starting from 3 September 2005, to reduce the average HPS triggering rate from the top PMT from the initial level of about $0.75\,\mathrm{s}^{-1}$ down to one trigger in about 60 s, at our standard oscillograph trigger level of approximately 2.6 mV (events with $U_1 \geq 2.8$ mV were processed). NLS-initiated trigger signals occur 10–12 times less frequently than the HPS-produced signals. In the period from 3 to 23 September 2005, during live time operation for 436 h, we recorded 27 600 trigger signals, with 290 of these having been double events (one event per about 95 triggers); of these 290, in turn, 25 events were triggered by NLSs on the top trace, including seven events with $\Delta t \leq 0.4\,\mu$s (which adds up to 0.35 events per day). This was not surprising, because the module was installed at a depth of 400 meters of water equivalent (MWE), and NLSs with $\Delta t \approx 0$ are produced, as we now know, primarily by cosmic ray muons crossing the PMT dynode blocks [7].

In the ground-level experiments performed in St Petersburg (its latitude is 60°) in March 2005 [7], during the total time of 413 h $\approx 1.5 \times 10^6$ s, trigger signals from module 3 (3×10^5 signals altogether) followed by an average interval of about 5 s. One event was recorded per 28 trigger signals. The total number of double events recorded was about 10^4. They included 69% NLSs with $\Delta t \approx 0$, 21.4% NLSs with $\Delta t \neq 0$, and 9.6% with HPSs on the first trace. Thus, the number of NLS events with $\Delta t \approx 0$ caused by cosmic rays at the PTI is about 10^3 times that obtained at the BNO. Also, the rate of detection of double events with HPS recorded on the upper trace with the same module 3 at the BNO (13 per day) is only one quarter of that at the PTI (55 events per day), which suggests a substantial effect of the radon background on ground-level measurements. All this makes the advantages of carrying out experiments at the BNO only too obvious.

3. Results of the September 2005 experiment; some surprises

After the final adjustments had been completed, the module was put into operation and exposed from 3 to 23 September 2005. The complete list of main results, including the $N(\Delta t)$ distributions accumulated by the time of arrival of a possible event of daemons falling from the NEACHO, is presented in tables 1 and 2.

The most essential finding is that the lower FEU-167-1 PMT with a screened photocathode does indeed respond to its traversal by daemons, as could be expected from the ground-level experiments at the PTI. Indeed, the conclusion that the $N(\Delta t)$ distributions, treated by the χ^2 criterion, cannot be represented by a constant has a significance of about 90–99%.

One more striking observation is that figure 1 displays, in our opinion, the most significant $N(\Delta t)$ distribution. The expected peak is seen to be confined not in the $+20\,\mu\text{s} > \Delta t > +40\,\mu\text{s}$ bin, but rather in the exactly opposite bin $-20\,\mu\text{s} > \Delta t > -40\,\mu\text{s}$! In other words, the events recorded were generated by objects that had crossed the Earth while almost retaining their velocity characteristic of falling from the NEACHOs on to the opposite side of the Earth. The statistical significance of the peak is as high as 2.2σ, which is substantially more than we expected and should be attributed, we believe, to the reduced (radon) background. If such data had been obtained at the BNO in a standard four-module set-up as was done at St Petersburg, the significance would have certainly been about 4σ.

4. Discussion of the September 2005 results

Figure 2 presents graphically the variations in some measured parameters with time and was drawn using tables 1 and 2.

The variations both in the number $N_{-30}(t)$ of events in the $-30\,\mu\text{s}$ bin and in the average number of 'background' events $\{N(t)\}_9$ per one of the remaining nine $20\,\mu\text{s}$ bins are plotted here. The latter is approximated with a confidence level 99.5% by a straight line $1.27t - 5.77$, which corresponds, on the average, to 12.7 events per day in the $-100\,\mu\text{s} < \Delta t < +100\,\mu\text{s}$ range.

We readily see that the rate of rise in the number of events in the $-30\,\mu\text{s}$ bin is initially quite high, noticeably higher than that of background events, but 10 days after the beginning of observations the rise stops (figure 3). It appears that we have indeed, as expected, arrived exactly at the September maximum of the NEACHO daemon flow, when the Earth passes through the crowding zone of these orbits, where they cross one another and the Earth's orbit. It would hardly be possible to state that we have observed the very beginning of this flow, and,

Table 1. $N(\Delta t)$ distributions ($-100\,\mu\mathrm{s} < \Delta t < +100\,\mu\mathrm{s}$) accumulated from 3 September 2005 (11 h) to 18 September 2005 (17 h) (here and subsequently, the times are reckoned from local astronomical midnight). Ten bins, each $20\,\mu\mathrm{s}$ wide, are centred at the Δt specified in the table. The $N(\Delta t)$ distributions are given for the time of recording of an event in the $-30\,\mu\mathrm{s}$ bin. Σ is the total number of events in $N(\Delta t)$; N_{-30} is the number of events in the $-30\,\mu\mathrm{s}$ bin; $\{\sigma\} = (N_{-30} - 0.1\Sigma)N_{-30}^{-1/2}$ refers to statistical significance of the $-30\,\mu\mathrm{s}$ maximum; $\{N\}_9 = (\Sigma - N_{-30})/9$ is the average number of 'background' events per one bin (except for the $-30\,\mu\mathrm{s}$ bin).

Event number	September (days)	$N(\Delta t)$										Σ	$\{\sigma\}$	$\{N\}_9$
		$-90\,\mu\mathrm{s}$	$-70\,\mu\mathrm{s}$	$-50\,\mu\mathrm{s}$	$-30\,\mu\mathrm{s}$	$-10\,\mu\mathrm{s}$	$+10\,\mu\mathrm{s}$	$+30\,\mu\mathrm{s}$	$+50\,\mu\mathrm{s}$	$+70\,\mu\mathrm{s}$	$+90\,\mu\mathrm{s}$			
249 471	3.825	1	0	1	1	0	1	0	1	0	0	5	0.50	0.44
250 237	4.487	2	1	1	2	0	2	1	1	1	2	13	0.49	1.22
251 259	5.417	4	1	1	3	1	4	1	1	1	3	20	0.58	1.89
251 656	5.707	4	1	1	4	1	4	2	1	1	3	22	0.90	2.00
252 241	6.044	6	2	1	5	1	4	2	2	2	3	28	0.98	2.56
253 473	6.897	6	2	1	6	1	5	3	2	3	6	35	1.02	3.22
253 524	6.931	6	2	1	7	1	5	3	2	3	6	36	1.28	3.22
253 549	6.956	6	2	1	8	1	5	3	2	3	6	37	1.52	3.22
254 583	7.801	7	3	1	9	2	6	3	4	4	7	46	1.47	4.11
255 192	8.246	7	3	2	10	2	8	3	4	4	8	51	1.52	4.56
256 517	9.237	9	3	3	11	3	8	4	4	4	9	58	1.57	5.22
256 729	9.397	9	3	3	12	3	9	5	4	4	10	62	1.67	5.56
257 069	9.612	10	4	3	13	4	9	5	4	5	10	67	1.75	6.00
257 695	10.073	11	4	5	14	4	9	5	4	6	10	72	1.82	6.44
257 951	10.243	11	4	5	15	4	9	5	4	6	10	73	1.99	6.44
259 242	11.102	12	5	5	16	5	10	5	6	8	11	83	1.92	7.44
259 362	11.182	12	5	5	17	5	10	5	6	8	11	84	2.09	7.44
259 530	11.312	12	5	5	18	5	10	5	6	8	12	86	2.22	7.56
260 149	11.725	13	6	7	19	6	10	8	6	9	12	96	2.16	8.56
261 715	12.851	17	7	9	20	7	15	8	8	11	12	114	1.92	10.44
262 937	13.733	18	7	9	21	10	18	8	10	13	12	126	1.83	11.67
265 114	15.335	20	9	10	22	12	18	12	12	15	15	145	1.60	13.67
266 215	16.052	21	10	11	23	14	18	12	15	15	15	154	1.58	14.56
266 349	16.151	22	10	11	24	14	18	13	15	15	16	158	1.67	14.89
266 396	16.191	23	10	11	25	14	18	13	15	15	16	160	1.80	15.00
270 012	18.647	28	13	17	25	15	23	16	18	24	19	198	1.04	19.22

Table 2. $N(\Delta t)$ distributions accumulated from 18 September 2005 (18 h 15 min) to 23 September 2005 (12 h 45 min) after the interchange of the PMTs in the detector module (the top PMT had a screened photocathode, and the lower PMT viewed the 2500 cm^2 ZnS(Ag) layer and triggered the oscillograph upper trace). The $N(\Delta t)$ distributions correspond to recording a new event in the +30 µs bin; $\{\sigma\}$ is calculated for the bin centred at $\Delta t = 10\,\mu\text{s}$ (i.e. for the $0\,\mu\text{s} \leq \Delta t \leq +20\,\mu\text{s}$ bin); the values of $\{N\}_9$ were derived by the subtraction of the number of events in the +30 µs bin and normalized against the 2100 cm^2 area of the ZnS(Ag) layer.

Event number	September (days)	$N(\Delta t)$										Σ	$\{\sigma\}$	$\{N\}_9$
		−90 µs	−70 µs	−50 µs	−30 µs	−10 µs	+10 µs	+30 µs	+50 µs	+70 µs	+90 µs			
271 683	19.727	2	1	1	1	1	2	1	2	2	1	14	1.33	1.21
273 471	20.929	4	2	2	2	1	8	2	5	2	2	30	1.77	2.61
274 775	21.953	7	2	3	2	2	8	3	5	4	4	40	1.41	3.45
274 862	22.018	7	2	3	2	2	8	4	5	4	4	41	1.38	3.45
276 666	23.478	7	3	4	5	5	11	5	8	5	5	58	1.57	4.95

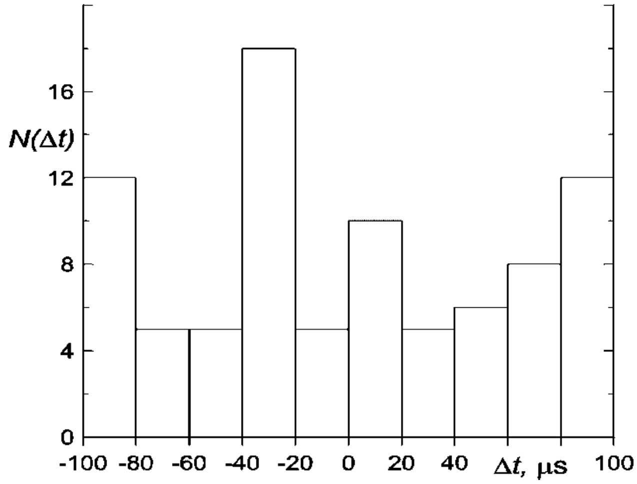

Figure 1. The $N(\Delta t)$ distribution of double events, with HPSs on the top PMT viewing the ZnS(Ag) scintillator, in the time shift Δt between the beginnings of the signals. The photocathode of the lower PMT is screened with aluminium foil. The observations were run from 3 September 2005 (11 h) to 11 September 2005 (7 h 30 min); there were 86 events altogether. The statistical significance of the maximum in the $-30\,\mu$s bin is $\{\sigma\} = (N_{-30} - 0.1\Sigma)N_{-30}^{-1/2} = 2.2\sigma$.

therefore, we did not approximate the data in figure 3 with a probability integral. Nevertheless, if we assume the dependence of flux intensity on time to be a Gaussian, its half-width should be not less than 3 days, and the maximum flux becomes $f_\oplus \approx 1.0 \times 10^{-7}\,\text{cm}^{-2}\,\text{s}^{-1}$, which almost coincides with the March flux $f_\oplus \approx 0.5 \times 10^{-7}\,\text{cm}^{-2}\,\text{s}^{-1}$ derived from ground-level observations in 2005 but is at least an order of magnitude lower than the real flux, if we allow for the low efficiency of the scintillator part of the detector [7]. The duration of the flow, only about 10 days, which corresponds to approximately 10° displacement of the Earth along its orbit, is unexpectedly short. Further experimental and theoretical studies would be needed to find an explanation for this.

Figure 2 also plots $\{\sigma(t)\}$, the behaviour with time of the statistical significance of the $-30\,\mu$s peak in the $N(\Delta t)$ distributions obtained on different days in September 2005. On 11

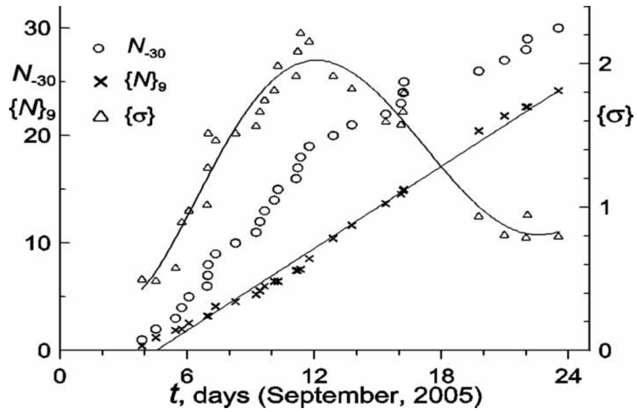

Figure 2. The behaviour of some parameters with time t of the observation run in September 2005. $N_{-30}(t)$ is the number of events in the $-30\,\mu$s bin of the $N(\Delta t)$ distribution; $\{N(t)\}_9$ is the number of background events occurring, on the average, in each of the nine bins, excluding the $-30\,\mu$s bin; the $\{N(t)\}_9 = 1.27t - 5.77$ approximation has a confidence level of 99.5%; $\{\sigma\}$ is the statistical significance of the $-30\,\mu$s bin maximum in the $N(\Delta t)$ distribution.

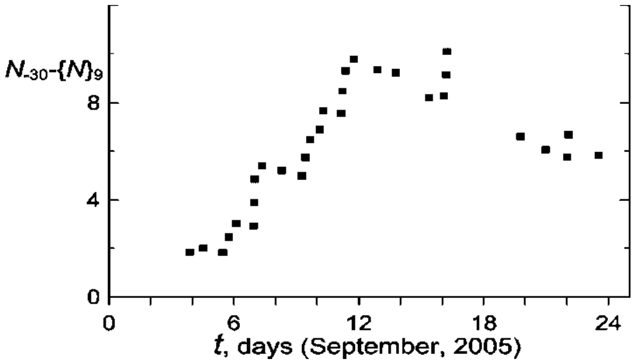

Figure 3. The excess in the number N_{-30} of events in the $-30\,\mu$s bin above the $\{N\}_9$ background plotted versus time. $N_{-30} - \{N\}_9$ for t after 18.75 September 2005 was calculated as $N_{+30} - \{N\}_9$ and by summing the data in tables 1 and 2. After 17 September 2005, no daemons with velocities 10 (11.2) – 15 km s^{-1} have been observed manifestly.

September 2005 (for $N_{-30} = 18$), the statistical significance reaches $\{\sigma\} = 2.2\sigma$ (confidence level of 97%). We calculate the statistical significance of a peak in the simplest way possible, namely we divide the excess of the number of events in the peak over the arithmetic mean of the ten bins by the square root of the number of events in the peak. This is enough to see how improbable is a purely stochastic appearance of such an overshoot. More sophisticated approaches to calculation of the statistical significance [9], for instance by division of the peak excess over the weighted mean by the square root of the sum of the squared weighted mean error and of the number of events confined in the peak, while yielding a somewhat higher statistical significance (2.5σ in place of 2.2σ in the above example), carry a slight flavour of scholastics. Application of these methods could hardly be justified here, because the numbers of events in neighbouring bins of the $N(\Delta t)$ distribution are not statistically independent, which follows from the daemon hypothesis. The $N(\Delta t)$ distribution varies continuously with time, as we believe, e.g. because some daemons transfer from NEACHOs to GESCOs, i.e. through their diffusion in the velocity–time (and Earth's latitude (see below)) space. This brings about a broadening of the $-30\,\mu$s peak and appearance in the $N(\Delta t)$ distribution of statistically significant side lobes corresponding to GESCOs with velocities of up to 3–5 km s^{-1} (see figure 1, as well as [4]). This is why, after 17–18 September 2005, one even observes a decrease in the $N_{-30}(t) - \{N(t)\}_9$ difference (see figure 3 and tables 1 and 2).

Consider now the maximum in the $0\,\mu\text{s} < \Delta t < +20\,\mu$s bin. In the first and last days of the experiment it even competes with the $-30\,\mu$s peak. Treated from the standpoint of the daemon hypothesis, it corresponds to a velocity greater than 15 km s^{-1}, but its intensity and position (downward flux with no excess events in the neighbouring $+30\,\mu$s bin) are not clear. We are inclined to assign its appearance to excitation of scintillations in the ZnS(Ag) layer by some short-lived (approximately 10^{-5} s) radioactive or isomer nuclei, which decay with the emission of a particle (e.g. a neutron) entering the oppositely arranged screened PMT with a corresponding delay.

To check this assumption, we waited until the $-30\,\mu$s peak almost stopped growing and, starting from 18 September 2005 (17 h 50 min) (and to the end of the experiment, 23 September 2005 (12 h 45 min)) interchanged the PMTs; the PMT viewing the scintillator (the scintillator area seen from below is 2500 cm^2) and triggering the oscillograph was placed below, and the PMT with the photocathode screened by aluminium foil was placed at the module top. The $N(\Delta t)$ distribution obtained in such an arrangement was expected to become exactly opposite to the previously obtained $N(\Delta t)$ relative to $\Delta t = 0$; indeed, particles propagating downwards

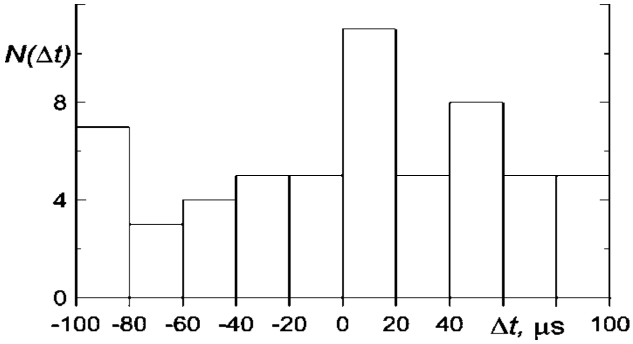

Figure 4. The $N(\Delta t)$ distribution after a 4.7 day exposure of the detector with PMTs interchanged on 18.75 September 2005 (see text and table 2). There were 58 events altogether. The maximum in the $+10\,\mu\mathrm{s}$ bin has $\{\sigma\} = 1.57\sigma$. PMT interchange did not change the position of this invariably present maximum (see figure 1, table 1 and section 5) adjoining $\Delta t = 0$ from the right, which evidences its non-daemon origin.

should now have yielded signals with $\Delta t < 0$, and vice versa. This PMT rearrangement did not change the position of the maximum under study (table 2 and figure 4); it remained in the $0\,\mu\mathrm{s} < \Delta t < +20\,\mu\mathrm{s}$ bin and, therefore, is not of daemon origin. (Also, the position of the $-30\,\mu\mathrm{s}$ peak observed during the previous 2 weeks can hardly be interpreted from a similar standpoint, i.e. generation of thermal neutrons with their subsequent capture by a nucleus in the PMT, etc.).

5. Results of the March 2006 observations

Much of what had not found ready explanation at the time was clarified in the underground experiments carried out half a year later from 3 March 2006 (16 h) to 26 March 2006 (8.1 h).

These experiments were conducted with the same module 3, in which the upper PMT triggering the oscillograph viewed the $10\,\mu\mathrm{m}$ ZnS(Ag) layer on the top surface of the polystyrene plate 4 mm thick. To protect this layer against background α radiation, it was, as before, covered by two layers of $50\,\mu\mathrm{m}$ Lavsan film. Because the film reduced the α background strongly, we believed that this meant that it was justified to abandon blowing liquid-nitrogen vapours through the system. This increased, however, by about 20% the fraction of NLS triggers from the upper PMT, which is apparently due to the ZnS(Ag) scintillator responding to numerous δ electrons knocked out by the β and γ radiation of radon and its derivatives from the polystyrene underlying the ZnS(Ag) coating. Because we are interested only in HPS events from the upper PMT, this factor, while increasing the background, can hardly affect noticeably the final conclusions (and at any rate is not capable of embellishing them). The triggering level in this experiment was lowered to about 2.4 mV, thus increasing the trigger rate to one in approximately 40 s. The number of double events with NLS and $U_1 \geq 2.8$ mV on the first trace was 80 (with 14 of these, with $|\Delta t| \leq 0.4\,\mu\mathrm{s}$, being caused by cosmic rays).

The results of the measurements are listed in table 3.

Viewed in parallel to the September 2005 data discussed above, these results appear puzzling; indeed, in contrast with the September experiment, there is no maximum in the $-40\,\mu\mathrm{s} < \Delta t < -20\,\mu\mathrm{s}$ bin. As in the ground-level March experiments in previous years [4–7], the maximum lies in the $+20\,\mu\mathrm{s} < \Delta t < -20\,\mu\mathrm{s}$ bin (figure 5), i.e. in the interval corresponding to the downward fall of NEACHO daemons.

Unfortunately, the maximum associated with the fall of NEACHO objects is paralleled, even to a greater relative extent than was the case in September 2005, by a maximum in the

Table 3. $N(\Delta t)$ distributions ($-100\,\mu\mathrm{s} < \Delta t < +100\,\mu\mathrm{s}$) accumulated from 3 March 2006 (16 h 00 min) to 26 March 2006 (6 h 42 min). Ten bins, each 20 µs wide, are centred at the Δt specified in the table. The $N(\Delta t)$ distributions are given for the time of recording of an event in the +30 µs bin. Σ is the total number of events in $N(\Delta t)$; N_{+30} is the number of events in the +30 µs bin; $\{\sigma\} = (N_{+30} - 0.1\Sigma)N_{+30}^{-1/2}$ refers to the statistical significance of the +30 µs maximum; $\{N\}_9 = (\Sigma - N_{+30})/9$ is the average number of 'background' events per one bin (except for the +30 µs bin); $\{N\}_8 = (\Sigma - N_{+10} - N_{+30})/8$ is the average number of 'background' events per one bin (except for the +10 µs and +30 µs bins).

Event number	March (days)	$N(\Delta t)$													
		−90 µs	−70 µs	−50 µs	−30 µs	−10 µs	+10 µs	+30 µs	+50 µs	+70 µs	+90 µs	Σ	$\{\sigma\}$	$\{N\}_9$	$\{N\}_8$
1 161 500	3.667														
1 162 569	4.402	2	0	0	0	3	0	1	1	2	0	9	0.10	0.89	1.00
1 163 748	4.748	2	0	0	0	3	0	2	1	2	0	10	0.71	0.89	1.00
1 163 997	4.944	3	0	0	0	3	1	3	1	2	0	13	0.98	1.11	1.12
1 165 561	6.065	3	4	3	0	3	2	4	4	4	2	29	0.55	2.78	2.88
1 165 729	6.190	3	5	3	0	3	3	5	4	4	3	33	0.76	3.11	3.12
1 165 829	6.271	3	5	3	0	3	3	6	5	4	3	35	1.02	3.22	3.25
1 166 113	6.494	3	5	4	0	3	4	7	6	4	3	39	1.17	3.56	3.50
1 166 981	7.141	3	5	5	2	4	4	8	7	4	4	46	1.20	4.22	4.25
1 168 207	8.026	4	5	6	3	6	5	9	8	4	7	57	1.10	5.33	5.38
1 170 307	8.916	4	6	9	4	7	7	10	10	5	7	69	0.98	6.56	6.50
1 170 352	8.941	4	6	9	4	7	7	11	10	5	7	70	1.21	6.56	6.50
1 170 489	9.026	4	6	9	4	7	7	12	10	5	7	71	1.41	6.56	6.50
1 172 827	10.621	4	10	10	5	8	10	13	12	6	8	86	1.22	8.11	7.88
1 176 863	12.635	7	12	11	6	9	14	14	13	9	9	104	0.96	10.00	9.50
1 176 976	12.699	7	12	11	6	9	14	15	14	9	9	106	1.14	10.11	9.62
1 177 778	13.216	9	12	12	7	10	16	16	14	9	9	114	1.15	10.89	10.25
1 179 308	14.297	10	14	13	8	10	19	17	16	9	10	126	1.07	12.11	11.25

1 179 352	14.318	10	14	13	8	10	19	18	16	9	10	127	1.25	12.11	11.25
1 181 214	15.457	11	14	14	8	10	19	19	16	13	11	135	1.26	12.89	12.12
1 182 018	15.960	12	14	15	8	10	21	20	16	13	11	140	1.34	13.33	12.38
1 183 482	16.884	13	15	16	9	10	21	21	16	14	11	146	1.40	13.89	13.00
1 185 456	17.883	15	17	17	11	10	24	22	18	15	11	160	1.28	15.33	14.25
1 185 549	17.913	15	17	17	11	10	24	23	18	15	11	161	1.44	15.33	14.25
1 189 016	19.391	15	21	20	14	11	27	24	20	19	11	182	1.18	17.56	16.38
1 189 068	19.412	15	21	20	15	11	27	25	20	19	11	184	1.32	17.67	16.50
1 189 147	19.448	15	21	20	15	11	27	26	20	19	11	185	1.47	17.57	16.50
1 189 510	19.617	15	21	21	16	11	27	27	20	19	11	188	1.58	17.81	16.75
1 189 942	19.796	15	21	21	17	13	28	28	20	19	11	193	1.64	18.33	17.12
1 191 974	20.600	17	22	24	19	14	31	29	22	20	12	210	1.48	20.11	18.75
1 192 918	20.998	17	22	24	19	15	31	30	22	20	13	213	1.59	20.33	19.00
1 199 835	23.234	18	26	28	22	17	33	31	25	23	17	240	1.26	23.22	22.00
1 200 213	23.410	18	27	28	22	17	34	32	25	23	18	244	1.34	23.56	22.25
1 201 168	23.868	18	27	28	23	17	34	33	25	24	19	248	1.43	23.89	22.62
1 201 630	24.063	18	27	28	23	17	34	34	25	24	19	249	1.56	23.89	22.62
1 202 457	24.406	18	28	28	24	17	34	35	25	24	19	252	1.66	24.11	22.88
1 202 603	24.467	19	28	28	24	17	34	36	25	24	19	254	1.77	24.22	23.00
1 206 942	26.279	21	31	31	26	19	36	36	26	25	19	270	1.50	26.00	24.75

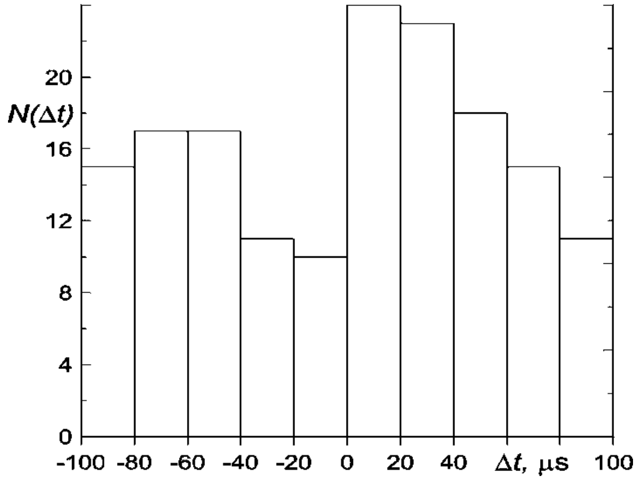

Figure 5. The same as figure 1 but for the time span from 3 March 2006 (16 h) to 18 March 2006 (4 h). $N(\Delta t)$ equals 15, 17, 17, 11, 10, 24, 23, 18, 15 and 11, i.e. 161 events altogether (see table 3). The statistical significance of the maximum in the +30 μs bin is $\{\sigma\} = (N_{+30} - 0.1\Sigma)N_{+30}^{-1/2} = 1.44\sigma$.

0 μs < Δt < +20 μs bin. It grows at almost the same rate as the September peak. A fraction of the events which it consists of may certainly be caused by the fall of objects moving in the extreme outer NEACHOs, but the statistics are still too poor to allow anywhere near definite conclusions. This is even more so because the September experiments (see end of section 4 and figure 4) do not bear out this assumption.

Because of competition with this near-zero maximum, the confidence level of the +30 μs peak accumulated during the whole observation period does not exceed (1.4–1.6)σ, which corresponds to only five to seven events above background (see figure 5), i.e., $f_\oplus \approx 0.4 \times 10^{-7}$ cm^{-2} s^{-1}. As seen also from figure 6, the behaviour of $N_{+30}(t)$ undergoes a break after 18 March 2006, with the rate of event arrival increasing approximately 1.5 times. We note also

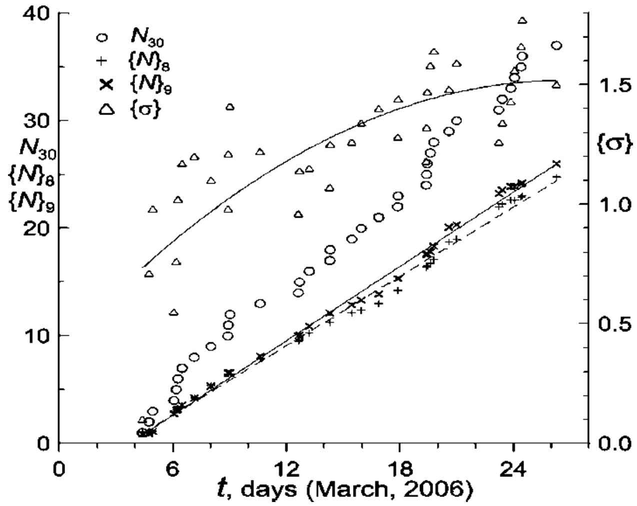

Figure 6. The same as figure 2 but for March 2006. $N_{+30}(t)$ is the number of events in the +30 μs bin of the $N(\Delta t)$ distribution. The $\{N(t)\}_9 = 1.15t - 4.29$ approximation has a confidence level of 99.7%; the $\{N(t)\}_8 = 1.07t - 3.81$ approximation has a confidence level of 99.6%; $\{\sigma\}$ is the statistical significance of the +30 μs bin maximum in the $N(\Delta t)$ distribution.

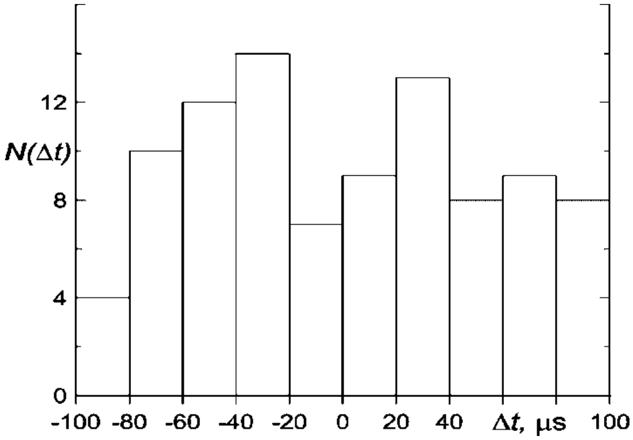

Figure 7. The same as figures 1, 4 and 5 but for the time span from 18 March 2006 (4 h) to 24 March 2006 (24 h). $N(\Delta t)$ equals 4, 10, 12, 14, 7, 9, 13, 8, 9 and 8, i.e. 94 events altogether.

that the behaviour of $N_{-30}(t)$, which corresponds to the bin recording the upward flux of the objects, reveals after 18 March 2006 likewise an increase in the rate of arrival of the events.

As a result, the $N(\Delta t)$ distribution accumulated in the period from 18 March to 24 April 2006 (figure 7) has two symmetric maxima, N_{+30} and N_{-30}; in other words, starting from 18 March, the upward flux rises to catch up with the downward daemon flux.

6. Discussion of the March 2006 data

The latter observation can be interpreted as the recording of two different daemon populations, more specifically that before 18 March 2006 we record primarily objects falling from NEACHOs, which, having crossed our detector and, subsequently, the Earth, escape to re-enter the NEACHOs. The slowest part of these is, however, decelerated by the Earth's matter to the extent that they become capable of transferring to GESCOs and accumulating there. It is these daemons that apparently produce the second population symmetric with respect to the up–down direction, whose flux $f_{\oplus} \approx 0.6 \times 10^{-7}\,\mathrm{cm^{-2}\,s^{-1}}$ is initially recorded in the $+30$ and $-30\,\mu$s bins but, after accumulation of the objects in GESCOs, increases to exceed slightly the flux of the primary 'through' population ($f_{\oplus} \approx 0.4 \times 10^{-7}\,\mathrm{cm^{-2}\,s^{-1}}$).

As already mentioned, we found the appearance of the maximum in the $-30\,\mu$s bin of the September $N(\Delta t)$ distribution surprising. We first supposed that it resulted from the fact that the scintillator plates had been turned with the ZnS(Ag) layer up (this was caused by the need to place two Lavsan films on ZnS(Ag); see above). Indeed, we used earlier [4] the dependence of the HPS shape on the direction in which the daemon that has captured an atomic nucleus in the ZnS(Ag) layer was moving, into the air or into the bulk of the polystyrene. In the latter case, some of the nucleons emitted in the capture by a nucleus being dragged by a daemon stop in the polystyrene and do not reach the phosphor, thus distorting the scintillation pulse shape. In our case, we made an attempt to assign the appearance of the $-30\,\mu$s maximum to the quasivacuum properties of polystyrene. We assumed that an active daemon (i.e. the complex of the remainder of the nucleus captured earlier plus the daemon carrying a negative charge $|Z_{\mathrm{n}}| - |Z| < 0$) does not capture a carbon nucleus or protons because of the difficulties that it would face in getting rid of excess energy (indeed, the excitation energy of the first nuclear level of carbon is 4.4 MeV) and, therefore, only on entering the ZnS(Ag) layer would it be able to capture a new nucleus by expending the excess capture energy in its excitation (for the zinc nucleus, the excitation energy is about 1 MeV).

Therefore, when starting our observations at the BNO in March 2006, we were expecting to find the maximum in the $-30\,\mu$s bin. The maximum appeared, however, in the $+30\,\mu$s bin, which was quite unexpected, although in ground-level experiments with ZnS(Ag) deposited on the lower side of the polystyrene plate the March maximum always appeared in the $+30\,\mu$s bin.

One has thus to find an explanation to the observation that, in March, daemons fall from above and produce a peak in the $+30\,\mu$s bin whereas, in September, they arrive in an upward-moving stream to be recorded in the $-30\,\mu$s bin.

The situation becomes clearer if we recall the celestial mechanics aspects of the problem. The Earth's axis of rotation is inclined by 23.5° to the ecliptic plane, which accounts, as is well known, for the alternation of seasons. Our detector responds to objects with a vertical velocity component. It is located in the northern hemisphere. In March, the northern hemisphere of the Earth is inclined backwards relative to the direction of its orbital motion. In September, it is oriented forwards. Therefore, the observed effect should appear if daemons catch up with the Earth, in particular, in moving in NEACHOs lying predominantly outside the Earth's orbits, especially those with perihelia close to the Earth's orbit.

The objects catching up with the Earth with velocities of up to approximately $12.3\,\mathrm{km\,s^{-1}}$ appear in these orbits as a result of their gravitational interaction with the Earth. It is known that a small body at rest colliding elastically with a moving body of a large mass can acquire a velocity twice that of the large body. Coulomb (gravitational) interaction is elastic, so that gravitational interaction of daemons with the Earth should initially first transfer and accumulate them in outer NEACHOs with respect to the Earth. As the escape velocity for the Earth is $11.19\,\mathrm{km\,s^{-1}}$, it cannot change the velocity of oncoming particles by more than this value. For a body to escape from the Earth's orbit to infinity, its velocity should exceed the orbital velocity of the Earth of $29.8\,\mathrm{km\,s^{-1}}$ by $12.3\,\mathrm{km\,s^{-1}}$. It thus becomes clear that particles can escape from NEACHOs to infinity only through gradual summation of the gravitational perturbations imparted to them by the Earth and other planets. This process by which daemons increase their energy in NEACHOs is counteracted by the fact that they are slowed down by matter in their rare transits through the Earth, as a result of which their orbits approach that of the Earth. The net outcome of these processes would require a comprehensive analysis. Nevertheless, there are grounds to believe that daemons should accumulate in outer orbits with respect to the Earth, which have a noticeable eccentricity and approach closely at perihelion the Earth's orbit on the outside. Such orbits could be called NEACHOs only with some reservations. Objects leaving them would fall primarily on the night side of the Earth, or rather late in the evening, because they catch up with the Earth. This relates also to the March flux of the 'through' population moving downwards. Because in September we record daemons that have crossed the Earth, their upward flow should reach a maximum in the morning. Only the few daemons that were slowed down by the Earth's matter, transferred into GESCOs and accumulated in them will enter the detector both from above and from below (see figure 7). Although the relevant statistics are poor, our observations (figure 8) do not disagree with expectations of the presence of such diurnal variations in the flux of the 'through' population.

There should exist also a latitude dependence of these daemon fluxes, which may manifest itself, if in nothing else, in the absence of a clearly pronounced $-30\,\mu$s maximum in the September measurements conducted at St Petersburg (60° latitude). By contrast, in the southern hemisphere we should have the opposite situation. The March maximum, in particular, should be seen there in the $-30\,\mu$s bin and originate from upward-moving 'through' objects in the first half of the day. This stresses the importance of performing simultaneous measurements in different latitudes (the latitude of the BNO is 43.2°) and, of course, in the southern hemisphere.

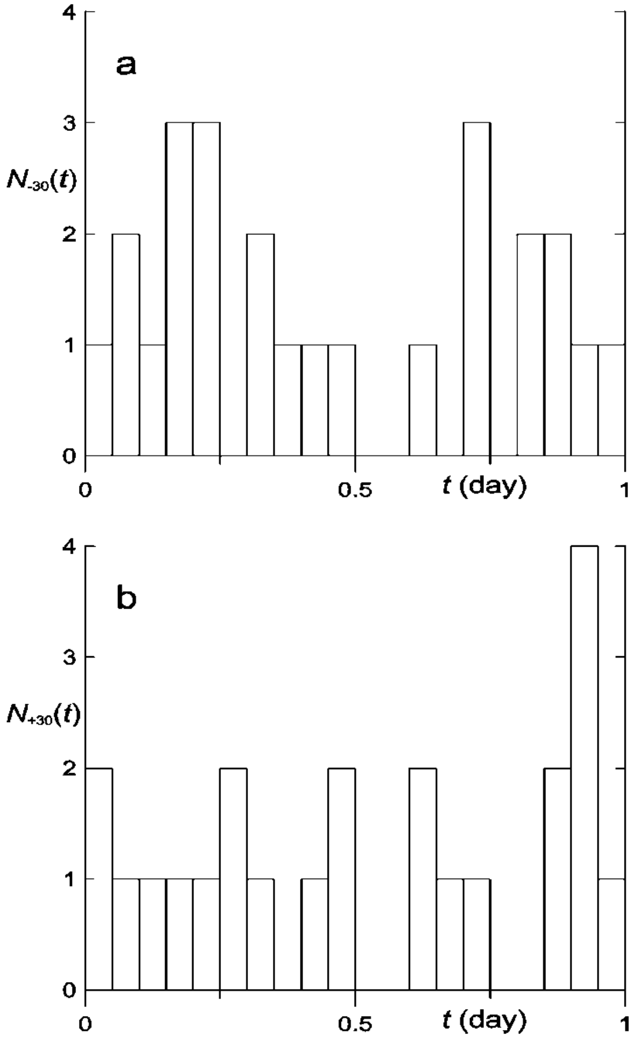

Figure 8. Distribution of double events versus the time of day (reckoned from midnight; the day is divided into 20 intervals): (a) events in the −30 μs bin, 3–16 September 2005 (25 events altogether: 1, 2, 1, 3, 3, 0, 2, 1, 1, 1, 0, 0, 1, 0, 3, 0, 2, 2, 1 and 1); (b) events in the +30 μs bin, 3–18 March 2006 (23 events altogether: 2, 1, 1, 1, 1, 2, 1, 0, 1, 2, 0, 0, 2, 1, 1, 0, 0, 2, 4 and 1).

It is appropriate to note here one more point. We have in mind the specific features of gravitational focusing of the daemon flux by the Earth. The total flux of daemons catching up with the Earth and striking it in March in the northern hemisphere from above is amplified by the Earth's gravitational pull nearly twofold, but it maintains monotonicity of its latitude (and daytime) distribution because, outside the Earth (until it enters the detector), the flow feels gravitational attraction, as it were, of a point mass. The September flow of 'primary' daemons, which have crossed the Earth, was subjected there to gravitation of a quasispherical but radially non-uniform mass. Focusing of this kind may give rise to the formation of surfaces (caustics) with an enhanced (or lower) flux. Therefore, one may envisage considerable temporal and qualitative differences in the variation in the parameters of the March and, in particular, the September primary 'through' fluxes. Because of the rosette-like motion in the field of a non-point mass, the secondary population trapped into GESCOs forgets its original orientation, a factor that should cause the disappearance of the diurnal (and latitude) dependences of its flow through the Earth's surface.

7. Conclusions

The low-background experiments intentionally performed at the BNO in September 2005 and in March 2006 and aimed at observation of the expected maxima in the low-velocity daemon flux have confirmed the existence of the maxima at the predicted time, thus providing support for the daemon paradigm. These experiments revealed also the influence of a number of previously uncontrolled parameters on the efficiency of the scintillation-based daemon detection method.

We have, for instance, confirmed the possibility of using some FEU-167-1 PMTs as sensitive elements. Indeed, daemons crossing the photomultiplier evacuated envelope and carrying the remainder of a previously captured nucleus retain and even increase their net negative charge, so that such a PMT detects the passage of daemons with an efficiency of tens of per cent.

The working hypothesis, by which the base distance needed for the velocity estimates in the St Petersburg experiments with double scintillators was chosen to have not a 7 cm but rather a 29 cm separation between the top scintillator plate and the lower tinned-iron sheet of the module case [6], has found support. Initially, this hypothesis was based on celestial mechanics considerations that the daemons striking the Earth should accumulate in NEACHOs and have a velocity of not less than 11.2 km s^{-1}, which accounts for the small dispersion of their velocities (about 11.2–15 km s^{-1}) making the $+30\,\mu$s peak in the March $N(\Delta t)$ distribution so narrow and revealing.

It has been shown that the uncontrollable (and varying) radon background (as well as differences not in the photometric but rather in the design parameters of PMTs) could be a major cause of poor reproducibility of the ground-level experiments performed at the PTI in 2002–2005. Indeed, in March 2000 the observations were run in a well-ventilated room of 85 m^3 volume and, starting in June 2002, in a 43 m^3 closed room with a split-type air conditioner. The measurements of the HPS–α background carried out already in December 2005 with module 1 [7] reassembled in each room and run for several hours, thus excluding the decrease in radon concentration due to its decay inside the module, showed the HPS background in the second room to be four to five times higher than that in the first room (this difference depends on the direction and strength of the wind, which appears only natural in the conditions where radon enters the air from the walls or the soil (see, for example, [10])).

By using the FEU-167-1 PMTs as a high-efficiency vacuum sensor responding to daemon passage through them, we have succeeded in raising a hundredfold the detector efficiency per unit area. Indeed, in March 2000 the 1 m^2 detector recorded 18 excess events in the $+30\,\mu$s bin in 2.5×10^6 s, which corresponds to a flux of about $0.7 \times 10^{-9}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. In the BNO experiment performed in September 2005, the PMT (diameter, 12 cm; area, 115 cm^2) recorded eight or nine excess events in 0.7×10^6 s, thus yielding $f_\oplus \approx 1.0 \times 10^{-7}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. Allowing for the low efficiency of the scintillator section of the detector (about 3%), the true value of the maximum daemon flux from the NEACHOs may be 10–30 times higher, a value which fits fairly well our old estimates [2].

Because the dimensions of the lower sensor in these experiments were reduced compared with the original ground-level experiments from 50 to 10 cm, the solid angle viewed by the detector decreased approximately to one half. It is the increase in angular resolution that apparently has resulted in our having revealed finer details in the daemon flux variation and, in particular, some evidence for the existence of diurnal variations, as well as of a primary population (in NEACHOs) and a secondary population (in GESCOs). It becomes understandable now why in the measurements in 2000 the March maximum extended from 27 February to 27 March [6], whereas this year it was shorter and lasted approximately from 3 to 24 March.

One has naturally to carry out a comprehensive theoretical analysis of the capture of daemons from the Galactic disc into NEACHOs and their evolution in these orbits, with subsequent transfer of some of them into GESCOs, etc. Investigation of the latitude and diurnal variations would require accumulation of reliable statistics, including parallel experiments in the northern and southern hemispheres.

To sum up, our BNO experiments aimed at detection of the September and March daemon fluxes have revealed a number of factors that had not been controlled properly in previous ground-level and high-latitude experiments in St Petersburg. The underground experiments permitted measurements with a detector of a new type developed with a deeper understanding of daemon behaviour in matter and in vacuum. The results of these observations provide compelling evidence for the many consequences and conclusions of the daemon paradigm. We believe that the most fundamental and intriguing implication of the DM in the Universe being made of Planckian rather than other (e.g., of the type of WIMPs) objects is possibly that each of them, in principle, can be an independent quasi-closed universe very weakly opened by a small electric charge (coined ‘friedmon’ by Markov and Frolov [11]). We approach here realization of a concept of Multi-Universe Cosmos (see, e.g., [12]), where each universe contains countless similar universes (and so, possibly, *ad infinitum*).

Acknowledgements

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