Is the source Cygnus X-3 being observed in underground experiments?

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Data obtained at the Baksan underground scintillation telescope of the Institute of Nuclear Physics from March 1982 to February 1986 are reported. These results do not confirm the presence of a signal from the source Cygnus X-3 in the muon energy ranges $E_\mu > 200$ GeV and $E_\mu > 500$ GeV.

The first reports of the observation of γ rays in the energy range 10^{14}–10^{16} eV from the well-known x-ray source Cygnus X-3 appeared[1–3] in 1983. Reports of the observation of a signal from this source at several underground installations were particularly sensational.[4–7] If the results of Refs. 4–7 are correct it not only becomes necessary to assume that the power of this source is fantastically high but also to assume a completely new physics in order to explain the ratio of the signals at the surface and underground.

No increase in the average count rate in the direction of this source was observed in the SOUDAN[4,5] and NUSEX[6,7] experiments. The presence of a signal was inferred exclusively from the inhomogeneous distribution of events in the phases of the period, which is known from observations in the x-ray range to be 4.8 h. In the NUSEX experiment, an excess over the background level was observed in the phase interval 0.7–0.8, and in the SOUDAN experiment an excess was observed in the interval 0.65–0.9 (the period is assigned a value of one, and the zero phase corresponds to the minimum intensity in the x-ray range).

We have studied the signal from the source Cygnus X-3 at the Baksan underground telescope. The telescope is at a depth of 850 meters water equivalent and has dimensions of[8] $16.7 \times 16.7 \times 11.1$ m. It consists of six outer and two inner planes, each containing about 400 detectors. The angular distribution of individual muons has been under study with this telescope for several years.[9] An event in which the detectors which operate lie on one straight line is regarded as an event in which a single muon has passed through the apparatus. Another necessary condition is that detectors in the two outer planes operate, and yet another is that the path length in the telescope must exceed 7 m. In this case the angular resolution is about 2°. The count rate of these events is 7.1 s^{-1}. The data are accumulated in the form of a two-dimensional histogram, representing the upper hemisphere, partitioned into 2329 angular cells. The data are stored on magnetic tape every 15 min. Cells spanning a band of constant width, with a center corresponding to the declination of the source, 40.9°, are formed from these results. The width of the band in declination is chosen to be 5° in one case and 10° in another. The width of the observation window in right ascension is chosen to be 5° (this is a minimum value, set by the drive time and the angular resolution) or 10°, for comparison with results of other experiments. The profile of a mountain made it possible to select two regions of identical (within 10°) depth, one corresponding to a muon energy $E_\mu > 200$ GeV (the hour angle of the source is 20°–101°), and the other to $E_\mu > 500$ GeV (234°–298°). Data from 1 March 1982 to 28 February 1986 were analyzed. The effective observation time was 3.28 yr (82%).

For the middle of each 15-min interval of t, we calculate the phase from the formula

$$\Phi = (t - T_0)/P_0 - ((t - T_0)/P_0)^2 \dot{P}/2,$$

where the values $T_0 = \text{JD}2440949.8986$, $P_0 = 0.1996830$ day, and $\dot{P} = 1.18 \times 10^{-9}$ were taken from Ref. 10. The phase distributions for the case $\Delta\delta — 10°$, $\Delta\alpha = 10°$ and for two values of the energy are shown in Figs. 1a and 1b.

The *a priori* assumption that the background phase distribution is uniform may not be correct. This distribution is determined by the variation of the area of the apparatus and of the thickness of the mountains in the direction toward the source over the course of the sidereal day and also by the time intervals in which the apparatus is not operating, since the period of the source is approximately 1/5 of a sidereal day, and the time required for the averaging of a given phase over all thicknesses is

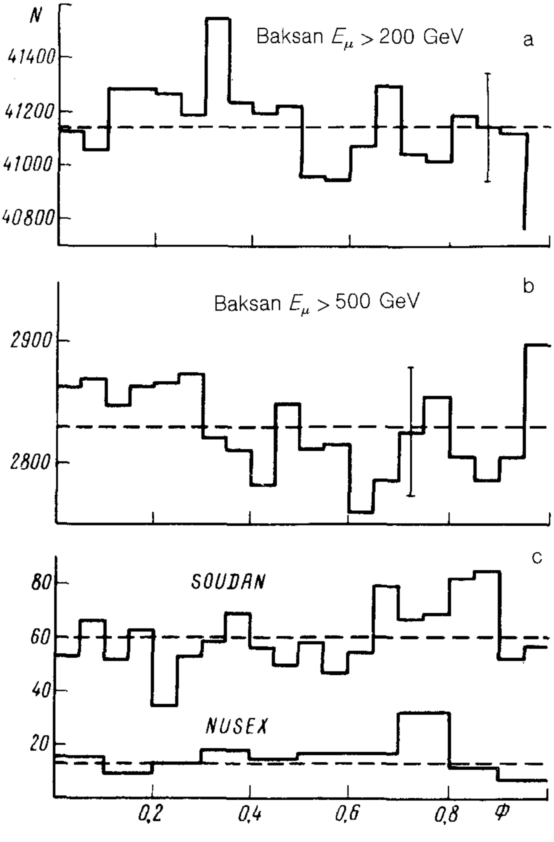

FIG. 1. Phase diagrams from three experiments.

about 170 days. We accordingly corrected for the nonuniformity of the actual background distribution.

Comparison of the phase diagrams obtained at the Baksan telescope (Figs. 1a and 1b) with data from the NUSEX and SOUDAN experiments (Fig. 1c) reveals a substantial difference in the phase interval 0.6–0.9. The Baksan data, with a significantly better statistical base, show no indication of the presence of an effect at any phase, including the interval 0.7–0.8. In comparing the data of the three experiments we should consider the following factors:

	NUSEX	SOUDAN	Baksan
Observation time	6.82–2.85	9.81–11.83	3.82–2.86
Depth, Gg/cm^2	5500	1800	850 and 1700
Threshold muon energy, GeV	3000	600	200 and 500
Angular aperture	10°×10°	radius of 3°	10°×10°

We would regard an explanation of this discrepancy on the basis of different depths or different data acquisition periods extremely unlikely. The periods essentially overlap, and the depths of the Baksan telescope and the SOUDAN apparatus are also essentially the same. There are several circumstances which cast doubt on the positive effect found in Refs. 4–7. In Ref. 6, for example, the size of the angular window was chosen by a method of *a posteriori* optimization of the signal. This approach could not fail to increase the probability for the appearance of a false effect. The background phase distribution was found through the use of events in the declination band 35.9°–45.9° and the right-ascension band 337.9°–277.9°. Without a phase shift for each 10°×10° window, depending on the right ascension, this procedure leads to an artificially uniform distribution. That there was a misunderstanding of the effect of the modulation of the signal by the mountain with a period equal to the sidereal day is also implied by the comment that "a given phase precesses through our detector 2.9 times per year." In other words, the cycle in mind was the 128-day cycle in solar time, which has no bearing on this effect.

In the first study by the SOUDAN group,[4] an excess above the background in the phase interval 0.65–0.90, amounting to 84 ± 20 events, was chosen as a signal. The angular window was shifted 2.7° from the source in order to maximize the nonuniformity of the phase diagram. It follows from Fig. 2 of Ref. 4 that in the direction of the source the probability for a uniform phase distribution is 10%. In the following study,[5] based on the same data and a window centered on the source, a probability of 2×10^{-4} for this situation was reported. That result is difficult to reconcile with the earlier result. The method described in Ref. 4 for obtaining the background distribution, involving a simulation based on the acutal data, will clearly lead to a uniform distribution. In other words, the modulation effect is completely ignored, although in that experiment it was particularly important because of the short observation period and the low efficiency ($\approx 40\%$).

The results found by us lead to a limitation on the flux of muons from the source Cygnus X-3 for our energies (Fig. 2). Our results contradict the data of the NUSEX and SOUDAN groups if we assume the standard mechanisms for muon production.

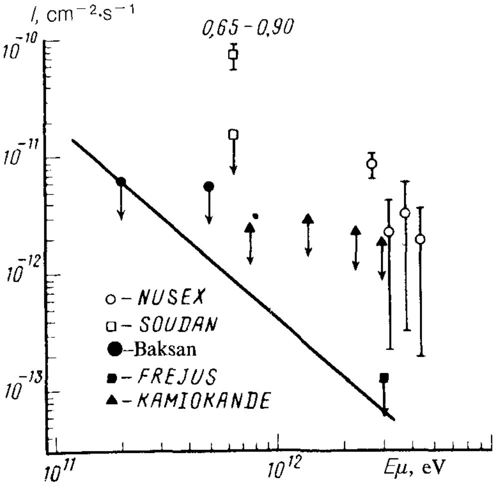

FIG. 2. Experimental data on the particle flux. The phase interval for all points where this interval is not specified is 0.7–0.8. A line $E_\mu^{-1.7}$, corresponding to the spectrum of muons from a hadron cascade with $E_0 \gg E_\mu$, is drawn through the Baksan point.

The results of the KAMIOKANDE[11] and FREJUS[12] experiments, recently published, also fail to confirm the presence of a signal from Cygnus X-3.

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