EVIDENCE FOR LONG-TERM VARIABILITY IN THE ULTRA HIGH ENERGY PHOTON FLUX FROM CYGNUS X-3

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1. Introduction. A time-correlation analysis of atmospheric Cerenkov pulses recorded at Gulmarg (altitude: 2743 m) by a wide-angle photomultiplier system was previously shown (Bhat et al. 1980) to have present in it a nonrandom component which seemed associated with the Right Ascension (R.A.) range $\sim 20 \pm 04$h (Fig. 1). A recent examination by Bartelt et al. (1985) of the multi-muon events recorded by SOUDAN-1 proton-decay detector shows a similar time-dependent effect which matches closely the Gulmarg event rate peak both in position and amplitude and in that sense supports our suggestion that the effect is of a genuine cosmic origin However, even though Cyg. X-3 lies well inside the region of our peak intensity, it does not seem possible to ascribe the whole effect to this source, for the implied photon flux turns out to be too large to be reconciled to various γ-ray measurements of Cyg. X-3 (Bhat 1982, Eichler and Vestrand 1984). We have now subjected the Gulmarg data to a phase-histogram analysis and find that only 2.5% of our overall recorded events are compatible with a phase-dependent emission from Cyg. X-3. Assuming these events to be γ-rays yields a detected flux of $(2.6 \pm 0.3) \times 10^{-12} \gamma \mathrm{cm}^{-2} \mathrm{s}^{-1}$ above 5×10^{14}eV. We compare this value with more recent UHE photon data from this source, including that taken in Gulmarg during Sept.-October 1984. We suggest that the available data generally favour a long-term reduction in the Cyg. X-3 inferred luminosity ($> 10^{13}$eV) by a factor of (1.8 ± 0.3) per year, provided that the measurements in question are free from large systematic errors.

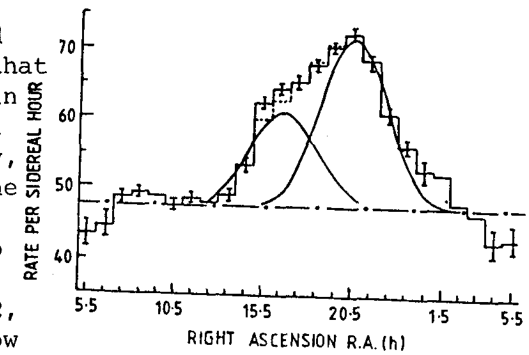

Fig. 1. Gulmarg ACP rates averaged for the period 1976-77 and plotted as a function of R.A. A broad-peak is evident in R.A. = 15-02 h. Point-spread functions of the form $\sim \cos^4\psi$ are fitted to the data.

2. Experimental Arrangement. Essentially, it comprises 2 large-area (490 cm^2) photomultiplier tubes (PMT) exposed to the sky on clear, moonless nights in a cone of semiangle 70° relative to the vertical. The PMT, fed sufficiently low EHT to stabilize their gains against variations in the night-sky background light, are operated in a prompt-coincidence mode (resolution time $\sim 10\ \mu$s). Atmospheric Cerenkov pulses (ACP), with amplitudes $> 4\sigma_V$ (σ_V being shot noise voltage), are recorded along with their occurrence time, generally maintained accurate to ~ 1 ms. The average ACP detection rate is $\sim 1\ \mathrm{m}^{-1}$ which, when considered together with the system threshold optical flux of $\sim (12 \pm 3)$ quanta cm^{-2} event^{-1} and the effective solid angle of 0.5 sr (for ACP),

corresponds to a minimum energy of $\sim 1.4 \times 10^{15}$eV for a proton primary and $\sim 5 \times 10^{14}$eV for a γ-ray primary (Bhat et al. 1985).

3. Data Analysis. The present study is based on 12,665 ACP recorded between 1976 Jan.-1977 Dec. in 212h of observations. The events are divided into 3 groups: (i) ON-source events, recorded when Cyg. X-3 (R.A. $\sim$ 20h) is at an hour angle $\psi \leq 40°$, (ii) INTERMEDIATE events, when the source is at $\psi = 40° - 70°$ so that its 'signal' cannot be recorded as efficiently as in case (i) because of the zenith-angle dependence of Cerenkov radiation, and (iii) OFF-source, when Cyg. X-3 is outside the detector geometrical field of view ($\psi > 70°$). While cases (i) and (ii) together consist of 6569 events, belonging to 63h and 37.5h of observations in 1976 and 1977 respectively, the OFF-source data comprise a total of 6096 events recorded in 70h of observations in 1976 and 41.5h in 1977. The daily observation runs belonging to all the three cases are broken up into a series of 15m intervals and the number of ACP recorded in each of these bins is noted. Next, each bin is assigned a phase value ϕ using Cyg. X-3 ephemeris due to Parsignault et al. (1976), which is preferred as it is more contemporary to our observation period. The resulting periodograms, comprising ACP rate per 15m bin averaged over the number of times (n) the bin was observed, is shown in Fig. 2 separately for the cases (i) -(iii) along with the distribution of n as a function of ϕ.

The OFF-source phasogram (Fig. 2c) displays no rate variations at >2σ and is compatible with a flat distribution (reduced $\chi^2 = 1.53$). The ON-source (Fig. 2a) and the INTERMEDIATE case (Fig. 2b) phasograms, on

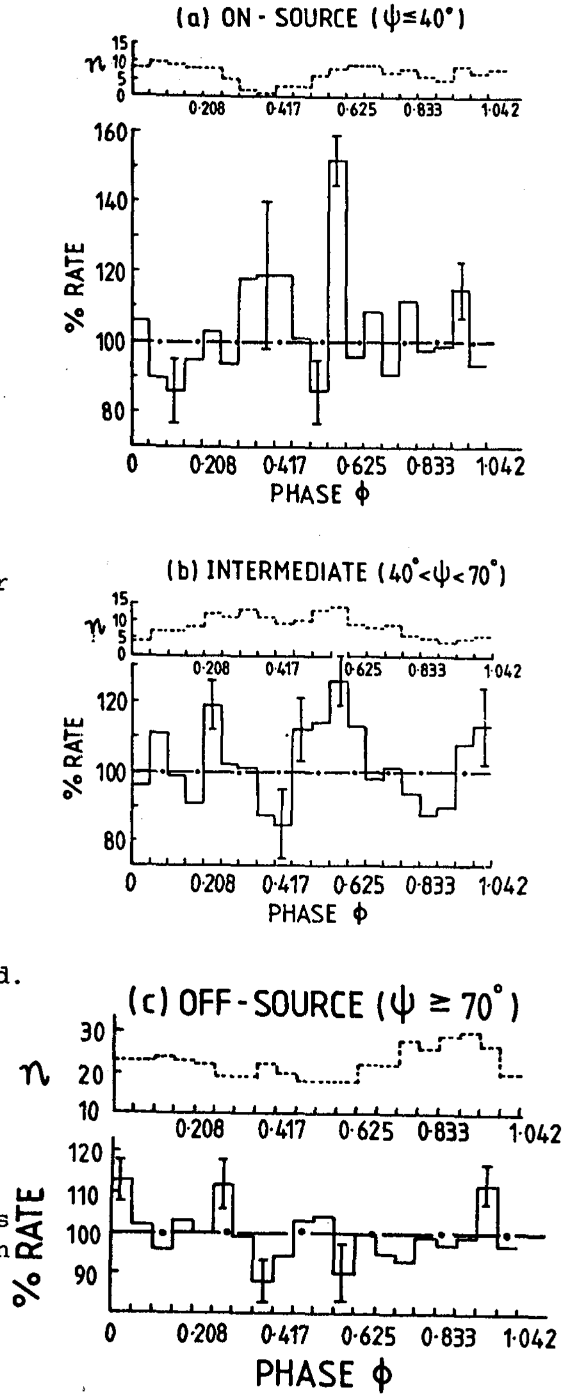

Fig. 2. Dot-dash lines represent phase-average ACP rates, which are 18.5, 12 and 13.7 per 15m for a, b and c respectively.

the other hand, exhibit peaks at ϕ = 0.572-0.625 for which the respective probabilities for consistency with a phase-independent uniform distribution (with equal weight for all bins) are 1.6 x 10^{-8} ($\psi \le 40°$) and 2.6 x 10^{-3} (ψ = 40°-70°) and the reduced χ^2 = 3.84 and 1.05 respectively. The reduced peak amplitude in Fig. 2b relative to that in Fig. 2a is expected in view of the zenith angle dependence of ACP and consolidates the association of the peak-feature in Fig. 2a with Cyg. X-3.

4. Results & Discussion. The above result can best be interpreted as a reflection of a phase-dependent component of γ-rays from Cyg. X-3 with a period of 4.8h, duty-cycle ∿ 5% and a phase-averaged flux of (2.6 ± 0.3) x 10^{-12} γ $cm^{-2}s^{-1}$ at > 5 x 10^{14}eV (Bhat et al. 1985). This flux is plotted in Fig. 3a along with the results of other measurements at energies > 10^{13}eV, including an upper limit (95% C.L.) obtained from 40h of new Cerenkov observations at Gulmarg during September-October 1984. It is evident that the quoted flux values are mutually incompatible by factors of up to ∿ 9 (for the plausible spectral form $\sim E_\gamma^{-1.1}$).

There can be several reasons for this apparent inconsistency. We examine here one: since the measurements refer to different observation epochs, whether they can be reconciled with one another by invoking the possibility of a secular variation in Cyg. X-3 emission characteristics (Rana et al. 1984)? To consider this, we first correct the measured fluxes for absorption by the microwave background radiation (MWB), taking Cyg. X-3 distance as 11.6 kpc (Cawley & Weekes 1984). The resulting flux values are shown in Fig. 3b. Note the consistency of the 1984 Gulmarg upper limit with other recent observations. The Fly's Eye data (Baltrusaitis et al. 1985) are not shown in Fig. 3b since they are not likely to represent long-term flux averages.

A series of lines, each with slope -1.1 and representing different observation epochs, seem to fit the corrected spectral data rather well,

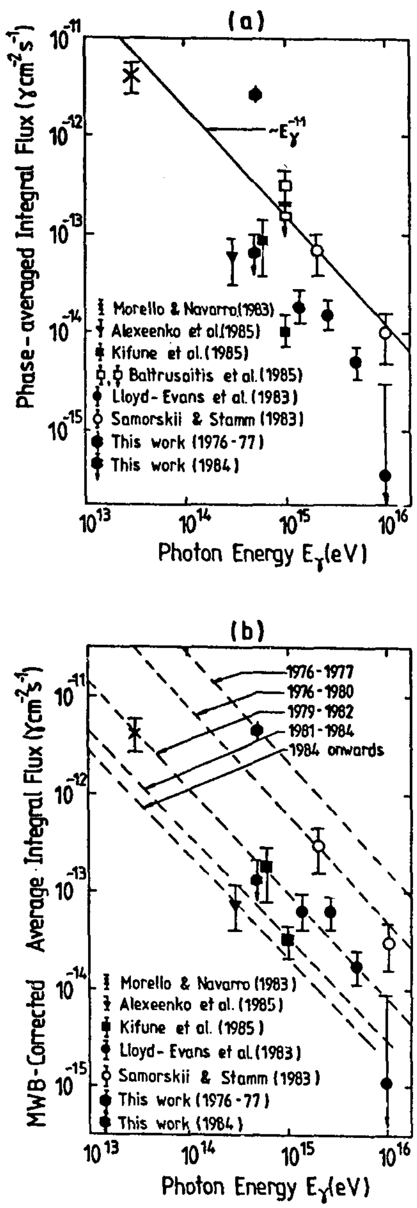

Fig. 3. Cyg X-3 spectrum at >10^{13}eV before (a) and after (b) correcting for γ-γ interactions with the microwave background (MWB). Cygnus X-3 distance is taken as 11.6 kpc.

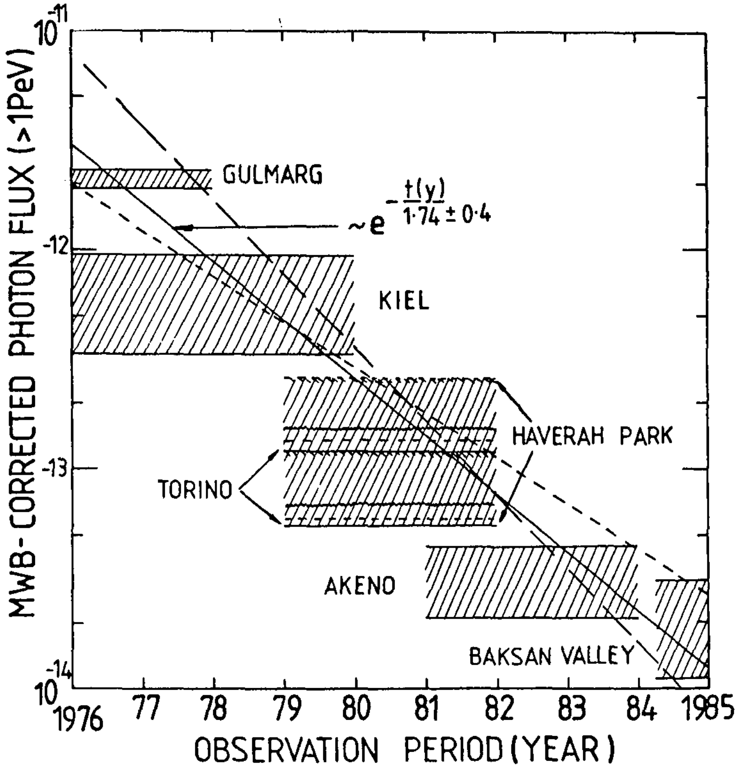

Fig. 4. Cyg. X-3 flux above 1 Pev deduced from measurements belonging to different observation epochs. There is a suggestion of this flux decreasing with time on a long term basis.

suggesting that a single power law spectrum can fit the UHE data well, provided we allow for a long-term reduction in Cyg. X-3 flux at > 10^{13}eV. An estimate of the rate of this suggested variation follows from Fig. 4 where we have plotted the MWB-corrected flux above 1 PeV as deduced from various measurements (for spectral form $\sim E_\gamma^{-1.1}$) against the corresponding observation period. A time-constant of (1.7 ± 0.4) years is inferred, corresponding to a flux reduction by a factor (1.8 ± 0.3) per year. In view of several uncertainties afflicting the present-day experimental data (viz. anomalous muon content of Kiel events, threshold ambiguities, rather enigmatic phase-characteristics of the UHE signal etc.), it will be more prudent to treat this as an upper limit on the rate of decrease of Cyg. X-3 UHE flux. The 'evidence' presented here needs to be examined by dedicated experiments that are currently in progress as it has crucial implications on Cygnus X-3 UHE photon emission process as also on the nature of the source (pulsar?) responsible for this flux.

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