OBSERVATIONS OF CYGNUS X-3 ABOVE 10^{15} eV FROM 1979 - 1984

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ABSTRACT

The ultra high energy γ-ray source, Cygnus X-3, has been observed more or less continuously with an array sensitive to $>10^{15}$eV primaries between 1 Jan 1979 and 31 Dec 1984. We find there is evidence for time variability in the phase of γ-ray emission over this period.

1. Introduction. Cygnus X-3, enigmatic in its behaviour at X-ray and radio wavelengths, is proving to be equally puzzling in ultra high energy γ-rays. Following our confirmation and extension of the initial measurements of Samorski and Stamm (1983) (Lloyd-Evans et al 1983) we have continued observation of the source. Here we report on a nearly continuous sequence of measurements from 1 Jan 1979 - 31 Dec 1984 using an array sensitive to events above 10^{15} eV and on a further three months of data obtained in 1984 with an independent array sensitive to showers from primaries above 5×10^{14} eV. We find evidence for time variability: between 1979 and 1983 the amplitude near $\phi \approx 0.25$ has reduced slightly and shifted by a small amount in phase, while in 1984 there are significant peaks at $\phi \sim 0.27$ and ~ 0.63 in the data from both arrays.

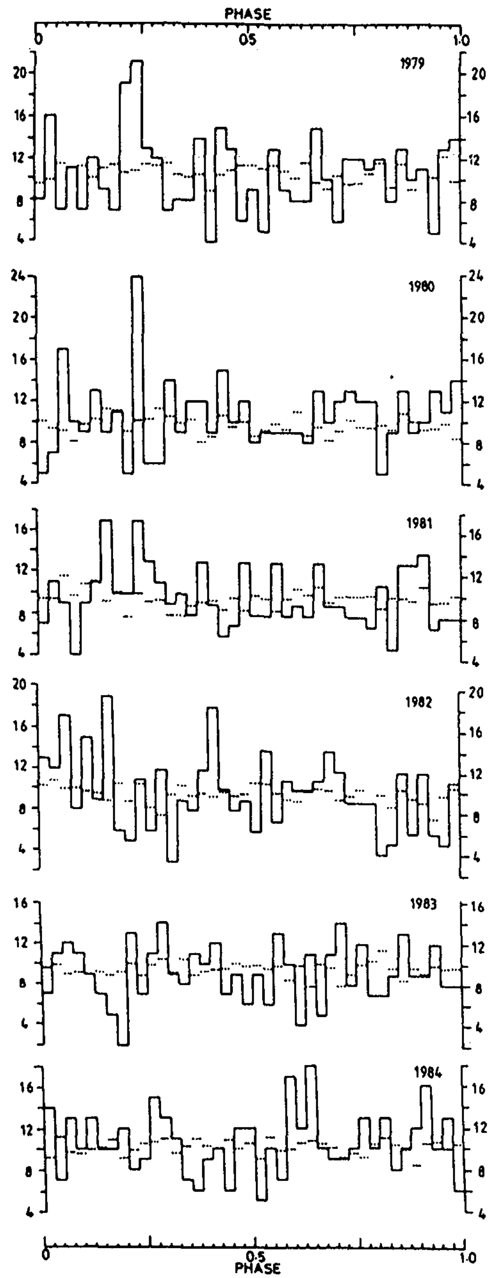
2. Experimental Data. Of the two arrays, array B is the complex of $4 \times 13.5\,m^2$ water-Cerenkov detectors (threshold 10^{15} eV) used in our earlier work, while array P was purpose built around our central detector (~ 2 km from B), at which there is a $10\,m^2$ (500 MeV threshold) muon detector operated by the Nottingham group, (Blake et al 1977). Array P comprises $4 \times 7.7\,m^2$ water-Cerenkov detectors on a 50 m grid and was operated at a lower threshold. The angular resolution of the two arrays is similar and from the array B results in 1979 - 81 is deduced to be approximately Gaussian with a standard deviation of about 2.5°. Note that the long rattle time of light in the large volume water-Cerenkov detectors leads to an angular resolution much inferior to that attainable with plastic scintillators. The primary energy is estimated by measuring the water-Cerenkov density at 50 m, ρ(50), in each event and using a standard spectrum to equate rate to energy.

The 'on-source' data shown in Figure 1 refers to a $9^{\circ} \times 6^{\circ}$ (RA,δ) area centred on Cyg X-3 when it was within 30° of the zenith. The events detected within this area were flagged as source events and, after correction of the time arrival to the heliocentre, binned in one of 40 phase bins using the ephemeris of van der Klis and Bonnett-Bidaud (1981).

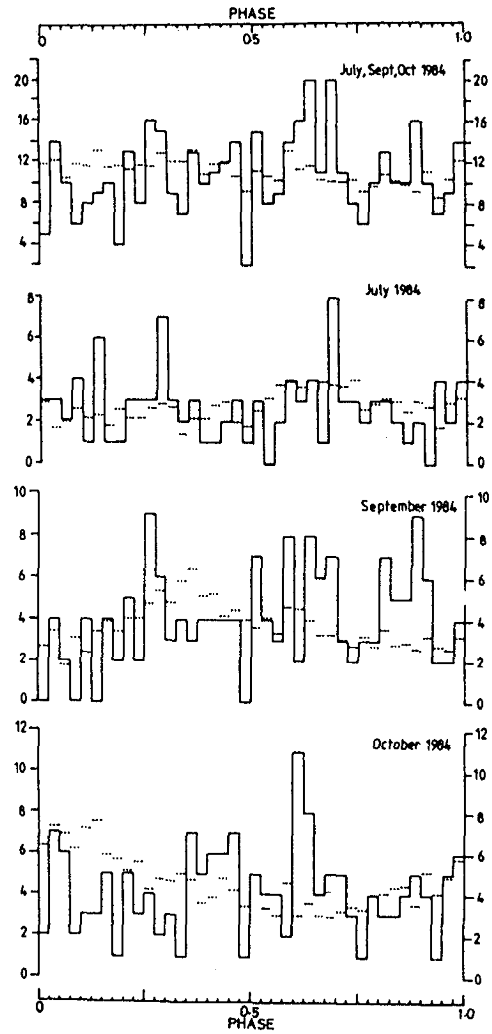
3. Discussion. It is clear from Figure 1 that the signal is not constant in phase and amplitude from year to year. We refute the possibility that the absence of a signal in phase bin 10 during the years 1982-84 is due to use of an erroneous ephemeris. Firstly, an updated ephemeris has been

Array B $E > 10^{15}$ eV

Figure 1



Array P $E > 5 \times 10^{14}$ eV

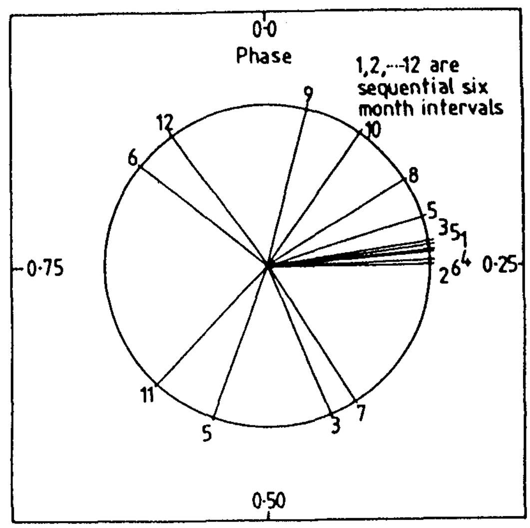


All data analysed using the ephemeris of van der Klis and Bonnett-Bidaud (1981).

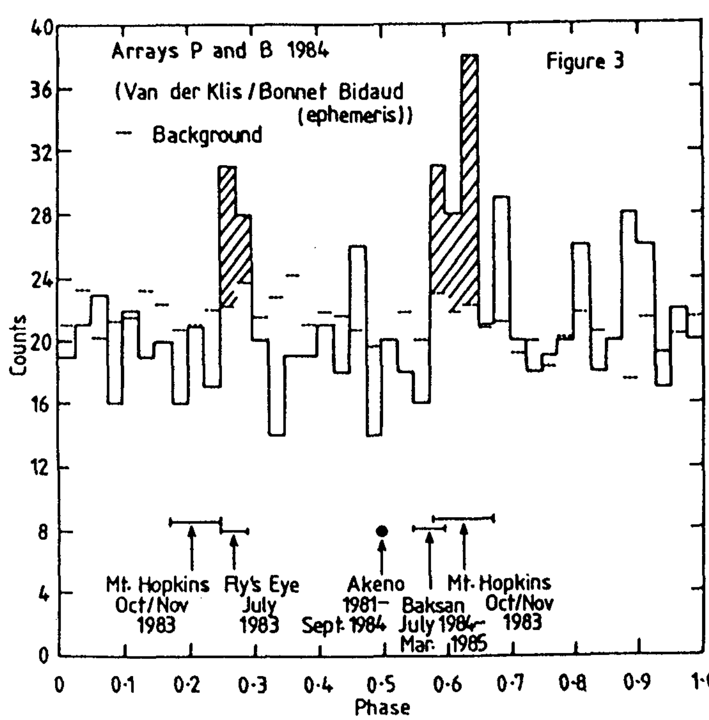
obtained by van der Klis (private communication), incorporating measurements from COS B and EXOSAT, which differs insignificantly from that used to derive Figure 1. Secondly, we note the consistency of the TeV signal at phase ~ 0.6 through to 1983 which has been achieved with this ephemeris (Cawley et al 1985).

In the context of a source model in which γ-rays are formed from π^0's generated in a gaseous target (e.g. Hillas 1984) and in view of the variability of emission at X-ray energies (Willingale et al 1985) it seems unreasonable to expect stability of the target material to within 0.025 of the binary period over many years. Consequently the data of Figure 1 have been searched using the 'sliding-bin' technique suggested by Hillas (1975) to locate the phase position of the largest excesses found in the twelve six-month intervals between 1979 - 1984. The positions of these peaks are shown in a phase diagram (Figure 2); where two or more equal 'excesses' exist they have been plotted separately. These data have been examined for directionality using the Rayleigh test (e.g. Mardia 1972); the probability that such a distribution could arise by chance is 0.05 and the mean phase is (0.20 ± 0.05).

Figure 2: Largest excesses in six month intervals



Examination of the combined data from arrays B and P for 1984 suggests that there is a double peak structure in the UHE γ-ray light curve. The search technique used above reveals a peak of 38 counts at $\phi = 0.27$ and 40 counts at $\phi = 0.63$ against an average background of 21.2 events. The chance probability of obtaining two such peaks is 2.3% so that evidence for a clear signal is not compelling. However the phases of emission are similar to the UHE phase found at earlier epochs ($\phi \sim 0.25$) and to the preferred TeV phase ($\phi \sim 0.6$). The data are shown in Figure 3 binned in the phase intervals of Figure 1. Also indicated are the phases of emission found by Cawley et al (1985) (1 TeV), Baltrusaitis et al (1985) (5×10^{14} eV), Alexeenko et al (1985, OG 2.1-12) (3×10^{14} eV) and Kiffune et al (1985) ($> 10^{15}$ eV) in the most recent observations known to us.



4. Time Variability.

If indeed the emission phase does vary in the manner suggested by our analysis it is difficult, with the present levels of significance, to address accurately the question of time variability of the amplitude. However, we have evaluated the γ-ray flux, at energies $> 10^{15}$ eV, as follows: (a) assuming that the signal is distributed over the five shaded phase bins of Figure 3 we obtain a value $\sim 4.5 \times 10^{-14}$ cm^{-2} s^{-1} which is comparable to that observed in 1979-82 for the emission at $\phi \sim 0.25$ (Lloyd-Evans et al 1983), (b) taking the largest excess in a single phase bin ($\phi = 0.64$) the flux is $\sim 7 \times 10^{-14}$ cm^{-2} s^{-1}. Either flux rules out the large decrease of $\sim$ x 0.5 per year deduced by Bhat et al (1985), through their interpretation of the Kashmiri Cerenkov light enhancement as a signal from Cyg X-3.

There is, however, clear evidence for time variability of the TeV emission and in particular we note that Vladimirsky et al (1973), Fomin et al (1981) and Cawley et al (1985) have reported enhanced emission following the 1972, 1980 and 1982 radio flares respectively. Furthermore, the Fly's Eye group (Baltrasaitis et al 1985) saw a 3.5σ signal from Cyg X-3 at $\phi = 0.25$ on a few nights in July 1983 but observed nothing significant during two similarly short observing periods in late September and October 1984.

We believe that the appearance of a signal at $\phi \sim 0.6$ during 1984 to be the most significant evidence of time variability available within our data. We speculate that the change in emission pattern follows the radio flare in 1983 (Johnston et al 1985) noting that Geldzahler et al (1983) suggest that sequences of radio outbursts are linked to starquakes in the crust of the neutron star. Such 'quakes' may also disturb the magnetic field configuration and the emission pattern through the plasma which they eject which may modify the accelerating potential in the region of the neutron star and the distribution of target material. For example, TeV emission at $\phi \sim 0.2$ is observed relatively infrequently and may be associated with occasions when the proton beam in that direction hits a thicker than usual stellar atmosphere. Conversely a 10^{15} eV signal at $\phi \sim 0.6$, as seen in 1984, might reflect a thinner than normal atmosphere in that direction at that time.

5. Conclusions.

We have reported evidence for the time variability of the amplitude and phase of the 10^{15} eV signal seen from Cyg X-3. In particular, the UHE γ-ray light curve for 1984 shows a double peaked structure with emission seen at $\phi \sim 0.27$ and 0.63.

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