PERIODIC GAMMA-RAY EMISSION FROM 'GEMINGA' AT $\geqslant 10^{12}$ eV

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ABSTRACT

Analysis of data from an atmospheric Cerenkov telescope at Gulmarg (India), has indicated the periodic emission of gamma-rays of energy $\geqslant 10^{12}$ eV, at 60.25 second period, from 2CG 195+4. The gamma-ray flux at 99% confidence level is estimated to be 9.5×10^{-12} photons cm^{-2} s^{-1}.

1. Introduction. The high energy gamma-ray source 2CG 195+4 (Geminga), detected by SAS II and COS B satellites at $\geqslant$ 50 MeV [1,2], has been tentatively identified with an unusual soft x-ray and optical source, for which the gamma-ray to x-ray to optical luminosity ratio is 10^{6} : 10^{3} : 1 [3]. This identification has been strengethened by the observation of nearly 60 second periodic variation in the x-ray source, similar to that reported in gamma-rays. A recent analysis of Einstein Observatory and Exosat x-ray data [4], alongwith the ground-based observations of Zyskin and Mukanov [5], has further revealed a very high positive period derivative for this source, which seems to increase still further between 1979 and 1983. Here we report the results of the analysis of our atmospheric Cerenkov telescope data from Gulmarg India, which reveals periodic gamma-ray emission from this source at a flux level of 9.5×10^{-12} photons cm^{-2} s^{-1}, at photon energies $\geqslant 6.1\times10^{12}$ eV.

2. Experimental Method. The experiment was carried out at Gulmarg, India (altitude $\sim$ 2743 meters), during Dec. 1984 to February 1985. The experimental set up, shown in Figure 1, consists mainly of three 90 cm. diameter (f/2) parabolic searchlight mirrors, each of which has an RCA 8055 photomultiplier tube mounted at its focus. The tubes are provided with 3.8 cm. diameter aperture masks to limit the effective field of view to 2.5°. All three mirrors are mounted on individual equatorial mounts, with a tracking capability of better than 0.5° in 4 hours. An LED lamp compensator is also fixed on all three mirrors to ensure a constant anode current, by compensating for background light fluctuations due to changes in night sky intensity and atmospheric transparency. Triple coincidence rates, integrated over 2 seconds (coincidence resolving time $\leqslant$ 50 ns) alongwith the corresponding time are recorded on a printer. The time information is provided by a temperature controlled crystal clock which is maintained accurate to $\sim$ 1 ms by periodic synchronization with standard time-code signals. Alongwith the prompt coincidence rate, the chance coincidence rate, obtained by introducing suitable time delays in the outputs from the three channels, is also recorded continuously to monitor the behaviour of system electronics and the background variations.

The effective area of the telescope is 5812 cm^{2} and the energy threshold for shower detection has been estimated to be 6.1×10^{12} eV. Observations have been taken in the tracking mode, by pointing the mirrors alternately at the 'source' and an 'off-source' region (6°to the east of source), for 24 minute durations. The results reported below refer to the zenith distance range $|z| \lesssim 30°$. Since on-source and off-source data refer to the same zenith angle, no zenith angle dependence is considered in the comparison of on-source and off-source rates.

3. Results. Observations were taken from Dec. 20, 1984 to Feb. 20, 1985, for a total period of 19.75 hours, comprising 11.3 hours of on-source data and 8.45 hours of off-source data. The three-fold prompt coincidence rate was adjusted to be ~ 0.4 per second, for single channel rates of $\lesssim$ 20kHz. The delayed coincidence rate was less than 10% of the prompt coincidence rate throughout the course of these observations. A total of 22,730 events were recorded and the ratio of on-source to off-source counting rate was found to be 1.17.

The search for periodicity was realized by generating 30-bin phasograms for 41 periods, in the range of 59-61 seconds, at 0.05 second interval, both for the on-source and the off-source data sets. In the absence of an ephemeris for this source, t_0 was chosen to be the start of our observations (J.D=2446055.27083333), so that the calculated phases are not absolute and cannot be compared directly with those derived by earlier workers [4,5]. As shown in Figure 2, the highest signal-to-noise ratio was found at a period of 60.25 seconds, where we see a statistically significant (3.3σ) peak at a phase value of 0.46. No such structure is seen in the case of off-source data. The probability that the peak at 0.46 phase is due to chance is estimated to be 1.01×10^{-5} for a single trial, while the probability increases to 4.15×10^{-3} when the total number of independent trials is considered.

Figure 3 shows the distribution of χ^2 values for various periods in the range of 59-61 seconds. As is obvious, χ^2 attains a maximum value of 52.3 (for 29 degrees of freedom) at the period of 60.25 seconds, showing that the phasogram for this period exhibits non-randomness at a confidence level of 99%. Assuming that the peak at 0.46 phase is due to gamma-rays of $\geq 6.1\times10^{12}$ eV, we can compute the gamma-ray flux from the source as 9.5×10^{-12} photons $cm^{-2}\ s^{-1}$ at the 99% confidence level.

4. Discussion. The Einstein Observatory and Exosat x-ray observations of 'Geminga' reported by Bignami et al. [4] reveal a period $p_0 = 60.06$ seconds and $\dot{p} = 4.68\times10^{-9}\ s\ s^{-1}$ for the Sep. 1983 epoch. If these results are correct and also valid for our observation period, we should expect $p_0 = 60.26$ seconds during the period of our observations. This is very close to the period of 60.25 seconds derived by us from our preliminary analysis of the Gulmarg data and confirms both the periodic nature of gamma-ray emission from this source as well as its high period derivative. It may be mentioned here that because of the limitations of our analysis, the period derived above could be in error by ± 0.05 seconds. A direct comparison of the light curve derived by us with that derived by earlier workers [4,5] is not possible due to the different t_0 used in getting the various results. However, a 10-bin phasogram constructed from our 30-bin phasogram

(Figure 2) exhibits a striking similarity with the x-ray light curve [4], with a main peak at o.4 phase and an intermediate peak at 0.8 phase.

The gamma-ray flux of 9.5×10^{-12} photons cm^{-2} s^{-1} at 6.1×10^{12} eV, estimated from the present study, compares favourably with the value of $(5 \pm 3) \times 10^{-11}$ photons cm^{-2} s^{-1} at $E \geq 10^{12}$ eV, obtained from the ground-based observations at Tian-Shan [5] and is compatible with a power law energy spectrum with exponent = -2.3.

References

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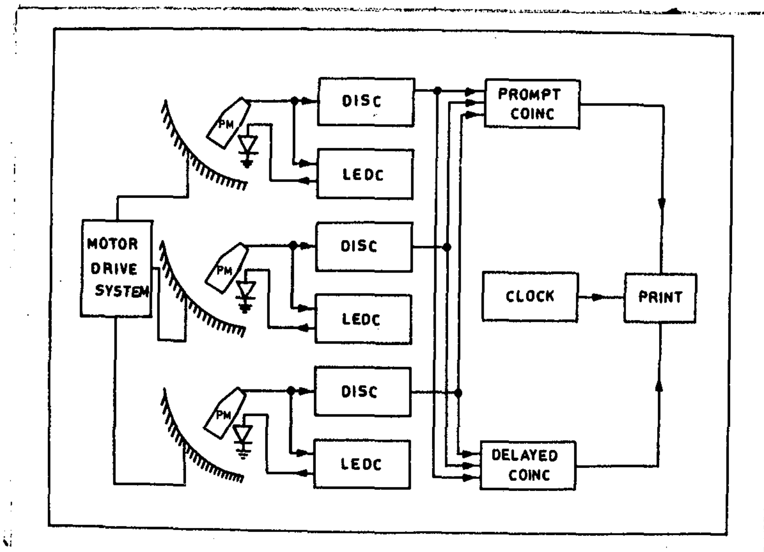

Figure 1

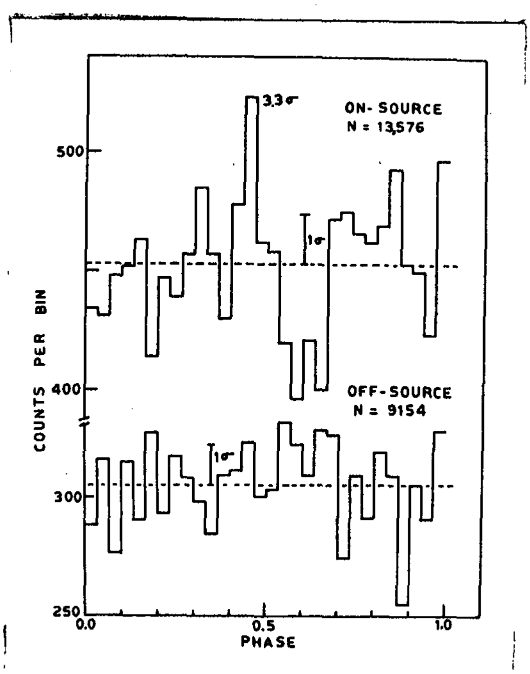

Figure 2

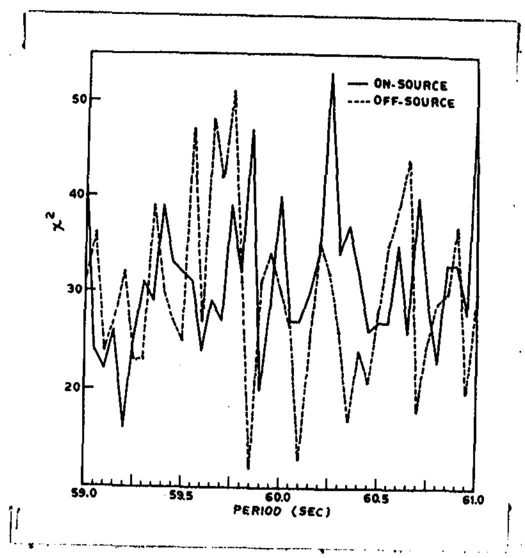

Figure 3