Bull. Astr. Soc. India (1998) **26**, 603-608

Coordinated optical and gamma-ray observations of cataclysmic variables

C. L. Bhat, R. K. Kaul and C. L. Kaul
Bhabha Atomic Research Centre, Nuclear Research Laboratory, Mumbai 400 085, India

Abstract. Several Cataclysmic Variables (CVs) have recently been claimed to be emitters of high energy (≥ 100 MeV) gamma-rays from the analysis of COS-B satellite experiment data. Two CVs, namely, AM-Her and AE-Aqr, have also been claimed to be emitters of TeV (≥ 10^{12} eV) gamma-ray signals on the basis of observations conducted with generation-I (non-imaging) atmospheric Cerenkov telescopes. In both the cases, the statistical significance of the inherently weak gamma-ray signals is significantly enhanced by virtue of a strong correlation between the gamma-ray and the optical emission features. However, more recent experiments, both satellite-based (EGRET) and ground-based (Whipple Imaging Cerenkov Telescope) have failed to confirm the earlier results. It has, therefore, become important to carry out time- and space-coordinated, multispectral-band (IR / optical / gamma-ray) observations of CVs to verify the earlier claims and to constrain the proposed gamma-ray emission mechanisms.

1. Introduction

Cataclysmic Variables are binary systems comprising a white dwarf (WD) and a late-type, low-mass companion that overflows its Roche lobe and transfers matter to the white dwarf. AM-Her is the prototype of a class of CVs, called Polars, in which the strong magnetic field of ~ 10^7 G of the WD channels the accreting matter to one or both polar caps, leading to the emission of polarized radiation via cyclotron emission. Around 10 such systems are known (Patterson, 1984) which have been studied extensively in the optical-X-ray region. Synchronous rotation of the system and the absence of an accretion disk are the main distinguishing features of polars.

AE-Aquari (AE-Aqr), a prototype of the Intermediate Polar class of CVs, is a disk-accreting type CV at a distance of 100pc. This system is highly variable in the optical band, with visual magnitude varying from ~ 12.5 during quiescence to ~ 10 during flares, making it accessible to observations with even small telescopes. It consists of a K5 red dwarf which, while overflowing its Roche lobe, transfers matter via an accretion disk onto a magnetic WD with surface magnetic field ~ 6×10^4 G. AE-Aqr shows unusually strong flares (δm_υ~ 2) in optical emission, accompanied by flickering and quasi-periodic signals whose frequencies are always red-shifted with respect to the rotation frequency of the WD. Not much attention has been paid to γ-ray observations of magnetic CVs, possibly because the radially infalling accreting matter onto the WD surface leads to the hot-spot temperature of only 30 keV, characteristic of X-ray energies. However, γ-ray emission in the MeV-GeV range from CVs is likely to arise from non-thermal processes where the acceleration of the progenitor particles is through the diffusive shock acceleration process. A rough estimate shows that for an accretion luminosity of ~ 10^{33} erg s^{-1}, a spectral index of -2, and a typical distance of ~ 100pc, the inferred γ-ray fluxes are of the order of ~ 10^{-6} photons cm^{-2} s^{-1} (for a 10% conversion efficiency of accretion luminosity to γ-ray luminosity), making CVs detectable with the COS-B and EGRET experiments. Kaul et al (1993) have shown that diffusive shock acceleration can lead to proton acceleration upto several TeV's and the accelerated protons can generate detectable TeV gamma-ray fluxes through the beam dumping process in the accretion column, in case of AM-Her type CVs.

2. Gamma-ray observations of CVs

2.1 TeV Energy Range :

Bhat et al (1991) presented the first evidence for a possible phase modulated TeV gamma-ray signal from AM-Her. The results were based on a detailed analysis of ~ 50h of data, recorded from the direction of AM-Her on clear moonless nights by the Gulmarg Atmospheric Cerenkov Telescope (Koul et al. 1989). Fig.1 shows the derived on-source γ-ray light curve (phasogram) alongwith the distribution of exposure time per phase bin and the phasogram for the chance events. The γ-ray light curve shows two broad peaks centred at magnetic phases ϕ_m= 0.1 and 0.6, with statistical significance of 6σ and 2.9σ respectively. From the inferred phase-averaged flux of $(5.6 \pm 2.1) \times 10^{-11}$ photons cm^{-2} s^{-1}, a source luminosity of 2×10^{32} erg s^{-1} for $E\gamma > 2$ TeV easily follows assuming isotropic emission and source distance of 100pc. A remarkable feature of the TeV light curve is its striking morphological similarity with the circular polarization light curve of AM-Her (Piirola et al. 1987), shown by the broken line in Fig.1.

Several claims of transient pulsed TeV γ-rays from AE-Aqr have been reported on the basis of observations with non-imaging atmospheric Cerenkov telescopes, (Brink et al. 1990; Meintjes et al. 1991), with a time-averaged VHE luminosity of $(1.5 \pm 0.3) \times 10^{32}$ ergs $^{-1}$ above 2.4 TeV (corresponding to a conversion efficiency of ~ 15%). Most of the observed TeV emission features closely resemble the optical flaring emission features, as seen in Fig.2, which shows the TeV γ-ray and optical pulse profiles derived from a simultaneous optical and TeV γ-ray observation campaign carried out by the South African group (Meintjes et al. 1994). The Durham group (Bowden et al. 1992) have also reported short (~ 1 minute duration) TeV γ-ray flares from AE-Aqr with pulsations at the 16.54s period (half the WD rotation period of 33.08s), identical to optical flares of similar time structure reported by De Jager and Meintjes (1993).

More recent attempts to detect TeV γ-ray emission from CVs, using the high sensitivity Whipple Imaging atmospheric Cerenkov telescope, have been unsuccessful till date, creating some doubts about the earlier positive claims. However, Bhat et al. (1994) have pointed out that the energy dependence of the image selection criteria, used by the Whipple group in their data analysis procedure, may lead to a significant loss of γ-ray events in case of sources with spectra harder than that of Crab Nebula. Further observations with imaging Cerenkov telescopes using more realistic

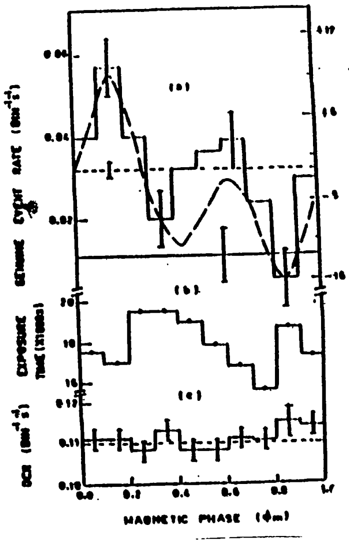

Figure 1. a) TeV gamma-ray light curve of AM Her and V-band circularly polarized light curve. b) exposure time distribution and c) phasogram of chance event rates.

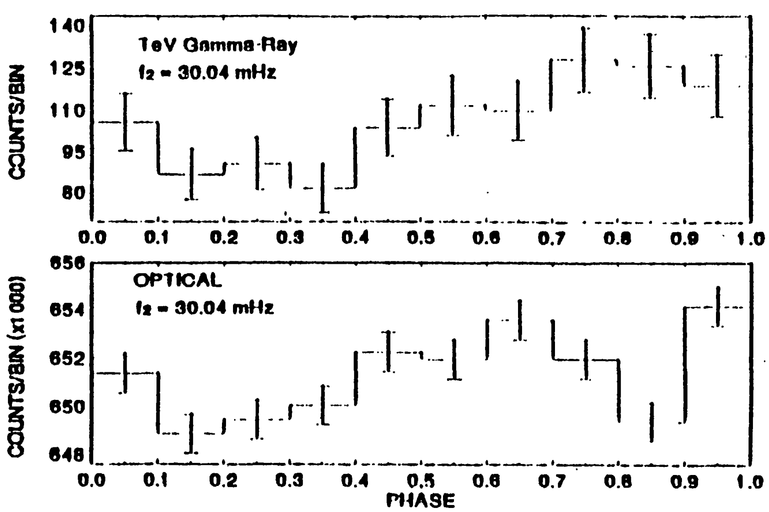

Fig.2: The TeV and optical pulse profiles of AE Aqr. Both profiles have been folded at the 33.08 s rotation period of the WD.

Figure 2. The TeV and optical pulse profiles of AE Aqr. Both profiles have been folded at the 33.08 s rotation period of the WD.

energy-independent background-rejection criteria, are, therefore, needed to verify the earlier claims of TeV gamma-ray emission from CVs.

2.2 MeV-GeV Range

Based on a detailed analysis of the COS-B data set Bhat et al. (1989) have earlier presented evidence which suggests that at least two polars, namely, E1405-451 and VV-Pup, emit ≥ 100 MeV γ-rays modulated at the WD rotation period. Fig.3 shows the derived light curves for these two sources, alongwith the corresponding phase distribution of the circularly polarized light in the V-band. The on-source phasograms of these sources closely follow the phase behaviour

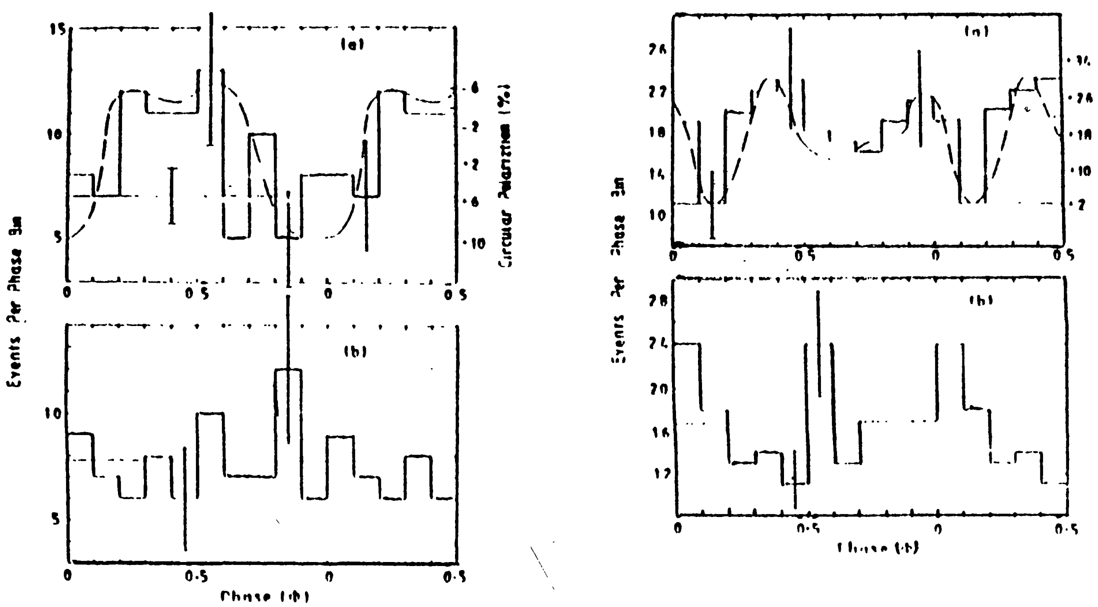

Figure 3. Gamma-ray (>50 MeV) light curves of VVPup (left) and E1405-451 (right). Panels marked 'a' refer to on-source events while (b) corresponds to off-source events. The broken curves show the phase distribution of circularly polarized light in the V-band.

of the V-band circularly polarized light, analogous to the trend exhibited by TeV γ-rays from the prototype source AM-Her. It is significant that, although the light curves of the circularly polarized light in all these cases are quite different and complicated in structure, the same structure is consistently seen in the corresponding γ-ray light curve. The inferred γ-ray luminosities are of the order of ~ 10^{32} erg s^{-1} for a typical disance of 100pc, assuming the emission to be isotropic and lead to a reasonable value of ~ 10% for the accretion luminosity to γ-ray conversion efficiency. The low inferred flux levels probably explain why the two polars (COS-B had no exposure in the direction of AM-Her) were missed in earlier surveys for point sources (Hermsen, 1980). Barrett et al. (1995) have recently analysed a part of the EGRET data to search for ≥ 100 MeV γ-ray emission from the three polars referred to above and report no evidence of either a dc or a periodic signal. Barrett et al. (1994) have also failed to detect a MeV-GeV γ-ray signal from AE-Aqr (averaged over a few years). While these negative results can be understood if the emission is transient (or the spectrum is hard), the need for further observations of these sources is clear.

3. Coordinated optical / IR and gamma ray observations

In view of the conflicting reports about possible MeV / GeV and TeV γ-ray emission from CVs, as discussed above, there is a general realization that three types of basic inputs are essential to verify the earlier positive claims of γ-ray emission from CVs : higher sensitivity experiments, reliable theoretical estimates and data from other spectral bands obtained in a space / time coordinated manner. As regards the first input, a high-sensitivity imaging Cerenkov telescope is already operational at Mt. Abu, India (Bhat et al 1996), close to the Gurushikhar Optical / IR telescope. The two systems, alongwith the Uttar Pradesh State Observatory (UPSO) telescope at Naini Tal can be used for mounting coordinated observation campaigns on the above sources to obtain more reliable information on correlated optical / γ-ray emission in the various spectral bands. The optical / infra-red observations would help in providing the following important information : (i) provide a measure of confirmation for the reported γ-ray detection claims, especially in case of transient emission episodes, (ii) help to derive up-to-date ephemerides for retrieving weak γ-ray signals (as in the case of AE-Aqr) and, more importantly, (iii) provide reference light curves in the optical and IR bands, useful in searching for weak γ-ray emission from sources like E1405-451 and VV-Pup through a correlation between the gamma-ray and the optical light curves.

It is, therefore, important that a coordinated observational campaign be launched on potential CV candidate sources using the TACTIC array for observations of γ-rays of energies $\geq$ 0.5 TeV, the Gurushikhar telescope for IR observations and polarimetry and the UPSO telescope for optical observations (especially for flares from sources like AE-Aqr). One main advantage of using these systems is that, being located in nearly the same longitude band and subject to almost similar weather conditions, a candidate source can be followed on a night-to-night basis, thereby increasing the probability of recording possible correlated emission features in the three spectral bands.

References

Barrett P. et al., 1995, ApJ, 450, 334.
Barrett P. et al., 1994, Proc. 2nd CGRO Symp., New York.
Bhat C.L. et al., 1996, Proc. Int. Symp. on Very High Energy Gamma Ray Astronomy, TIFR, August 1996.
Bhat C. L. et al., 1994, Proc. "Toward a Major Atmospheric Cerenkov Detector-II, Tokyo.
Bhat C. L. et al., 1991, ApJ, 369, 475.
Bhat C. L. et al., 1989, Proc. GRO Sci. Workshop, NASA / GSPC, 4, 57.
Bowden C. C. G. et al., 1992, Astropart, Phys., 1, 47.
Brink C. et al., 1990, Proc. 21st ICRC, 2, 283.
Hermsen W., 1980, Ph.D Thesis, Univ. of Leiden.
Kaul C. L. et al., 1993, A&A, 272, 501.

Koul R., et al., 1989, J. Phys. E. Instr., 22, 47.

Meintjes, P. J. et al., 1994, ApJ, 434, 292.

Meintjes, P. J. et al., 1991, Proc. 22nd ICRC, 1, 360.

Patterson, J. 1984, ApJ Suppl, 54, 443.

Piirola, V. et al., 1987, Proc. Workshop on Polarized Radiation of Circumstellar origin, Vatican Observatory.