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Flares on AM Canum Venaticorum

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Summary. AM CVn, an interacting binary system consisting of two helium white dwarfs, has been classified as a nova-like object. Normally it exhibits only small amplitude modulations of 0.05 mag with a 1051s periodicity. In this paper, we report what is believed to be for the first time, two unusually intense optical flares in AM CVn during 1985–87. The characteristics of the two flares in white light observed on 1985 February 24 and 1986 February 7 with $\Delta m = 0.34$ and $\Delta m = 1.07$ respectively are described. We estimate the maximum amount of energy released from these flares as $2.7\,10^{36}$ erg and suggest in the light of current models possible sites of origin of the flaring activity.

Key words: cataclysmic variables – white dwarfs – flares – AM CVn

1. Introduction

AM Canum Venaticorum (AM CVn), the shortest period twin white dwarf system with a periodicity of 1051s has been studied extensively for more than two decades. The system has continued to attract the attention of observational astronomers in view of the strong possibility of detecting the effects of gravitational radiation through changes in the orbital periodicity. Available observations however have not been able to conclusively establish the nature of the 1051s predominant periodicity, its long term variations as well as the possible existence of rotational modulation (Patterson et al., 1979; Solheim et al., 1984 and references therein). In view of above, we conducted optical observations of AM CVn during 1985–87. During the course of our observations, we surprisingly detected, what is probably for the first time, intense flaring activity from this degenerate system. We present in Sect 2 the observational data and describe the characteristics of two flares observed on 1985 February 24 and 1986 February 7 (Narayanan Kutty et al., 1986; Rao, 1986). A discussion on the energetics related to the flare and the possible locations for the origin of flares are presented in Sect 3.

2. Observations and results

Our observations were carried out with a photometer employing a thermoelectrically cooled RCA C31034 flat response photomultiplier tube attached to the 1 m/2.34 m telescopes of the Vainu Bappu Observatory at Kavalur. The program star, a comparison star and the sky near them were observed in U,B and V filters. The long runs were however conducted in white light i.e., without any filter. Observation time amounted to 9 hours in 1985, 7 hours in 1986 and 14 hours in 1987. Integration times of 1 s or 2 s and a diaphragm size of 24″ were used in all observations.

Photometric data collected by us during 1985–87 amounting to a total of 30 hours exhibit in general the typical 1051s period with a 0.05 magnitude variation. On 1985 Feb 24, at $20^{h}17^{m}$ UT we observed an intense flare in white light lasting nearly 200 s. The flare light curve is shown in Fig. 1. We note that the peak emission in white light amounts to an excess of 37% over the quiescent level value. The rise and decay times of the flare are about 108 s and 96 s, respectively. The equivalent duration T of the flare, computed as

$$T = \int \frac{I_{0+f}(t) - I_0}{I_0} \mathrm{d}t$$

is 15 s. Here $I_{0+f}(t)$ is the intensity of the star at time t during the flare, I_0 is the quiescent level intensity before the flare and the integration is carried out over the entire duration of the flare.

Following the flare, our observations reveal the typical double-humped structure of the AM CVn light curve. The amplitude of this 'M' structure (= 0.15 mag) is three times larger than the typical values reported by other observers (e.g. Smak, 1967). We ruled out possible artifacts in our observation by subsequent U,B and V filter measurements on the program star, the comparison star and the sky, and confirmed that the program star had indeed returned to its quiescent V magnitude of 14.1 around 21^{h} UT.

We emphasize that:

—the 'M' structure lasts precisely a full period of 1051s;
—the phase of the secondary minimum at $20^{h}45^{m}$ UT with respect to the primary minimum at $20^{h}34^{m}$ UT is 0.57 which is in accordance with previous observations of other authors (Smak, 1967; Ostriker and Hesser, 1968), and
—the second hump of the 'M' structure is flatter at its top and is less symmetric when compared to the first hump.

The present observation characterized by long duration and enhanced 'M' structure is therefore qualitatively different from the only other reported observation of a brief activity by Elsworth et al. (1982).

During our observations on 1986 February 7 we noticed that the quiescent level variations were of the order of 0.15 mag. This in itself is comparable to the amplitude of the enhanced 'M' structure observed by us in 1985, which in turn is three times the normal

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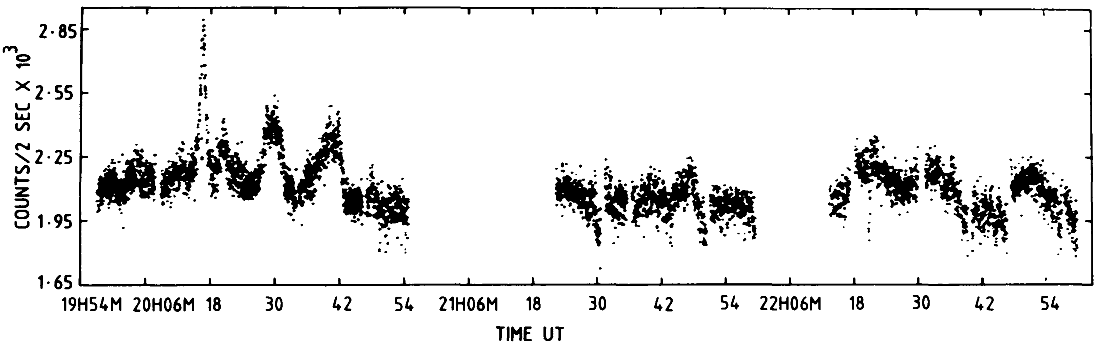

Fig. 1a. Light curve of AM CVn on 1985 Feb. 24 in white light

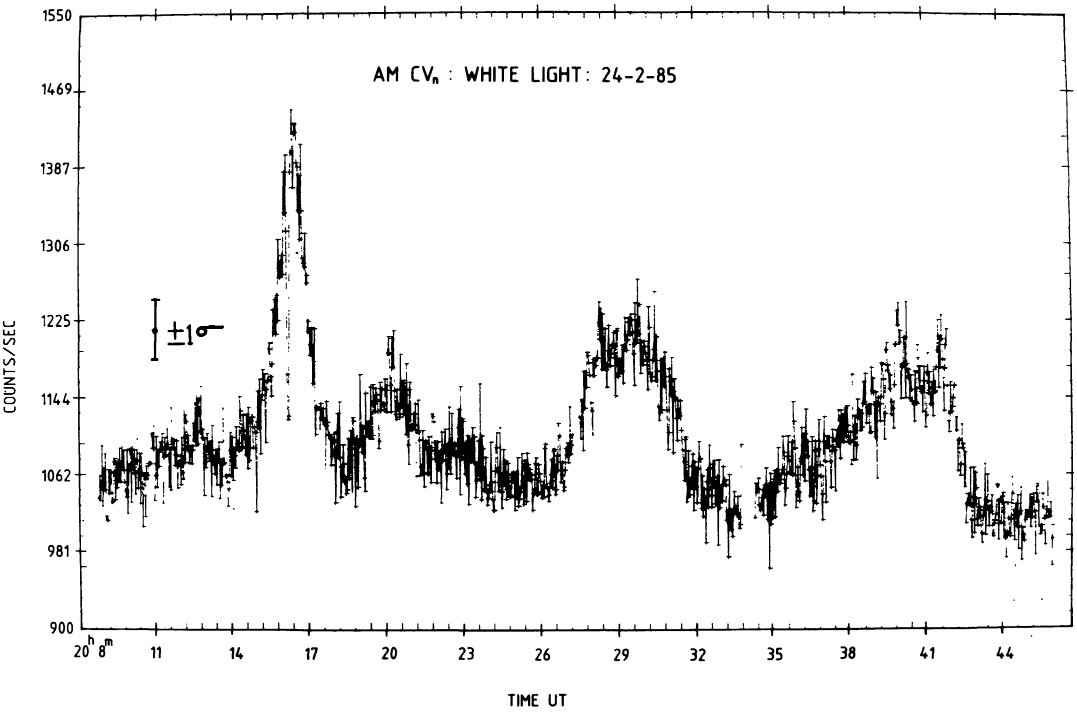

Fig. 1b. Flare portion of Fig. 1a expanded

modulation. Once again we detected a major flare starting at 21^h15^m UT and an enhanced emission beginning at 21^h24^m UT. The light curves corresponding to these observations are shown in Fig. 2.

The peak emission in white light during the flare is about 2.7 times the quiescent value which corresponds to a $\Delta m = 1.07 \pm 0.03$. The flaring activity ceased around 21^h23^m UT. This was followed by an enhanced emission again varying by 1.06 ± 0.03 magnitude and lasting for about 10 minutes. We may also note that the minimum at about 21^h23^m UT is deeper than the average quiescent level emission before the flares. With respect to this (which we refer to as primary minimum) the secondary minimum at 21^h33^m UT has a phase of 0.56. This is also consistent with earlier observations on the object.

This intense activity is by far the largest ever observed on AM CVn. The major flare that lasts nearly 212 s is reminiscent of the one observed by us in 1985. It has a rise time of about 80 s and a decay time of nearly 75 s. It has a unique flat top lasting nearly 28 s. The equivalent duration of the flare is 109 s. The second and more violent activity lasts about 10 minutes. This corresponds to the typical duration of the second half of the normal 'M' structure. The rise to the maximum and its decay are characterized in this case by violent flickers.

We also note that the first flare of both the 1985 and 1986 data are very similar except for their amplitudes. The portion of the light curve following the first flare shows an enhanced 'M' structure lasting 1051 s in the 1985 data and a peak lasting 590 s in the 1986 data. Noting violent changes in the enhanced peak of the 1986 data, we made a measurement on the comparison star at 21^h44^m UT, to check the system performance and confirmed that the V magnitude of the program star was 14.0 at 21^h49^m. During this process however, we probably might have missed 'seeing' the

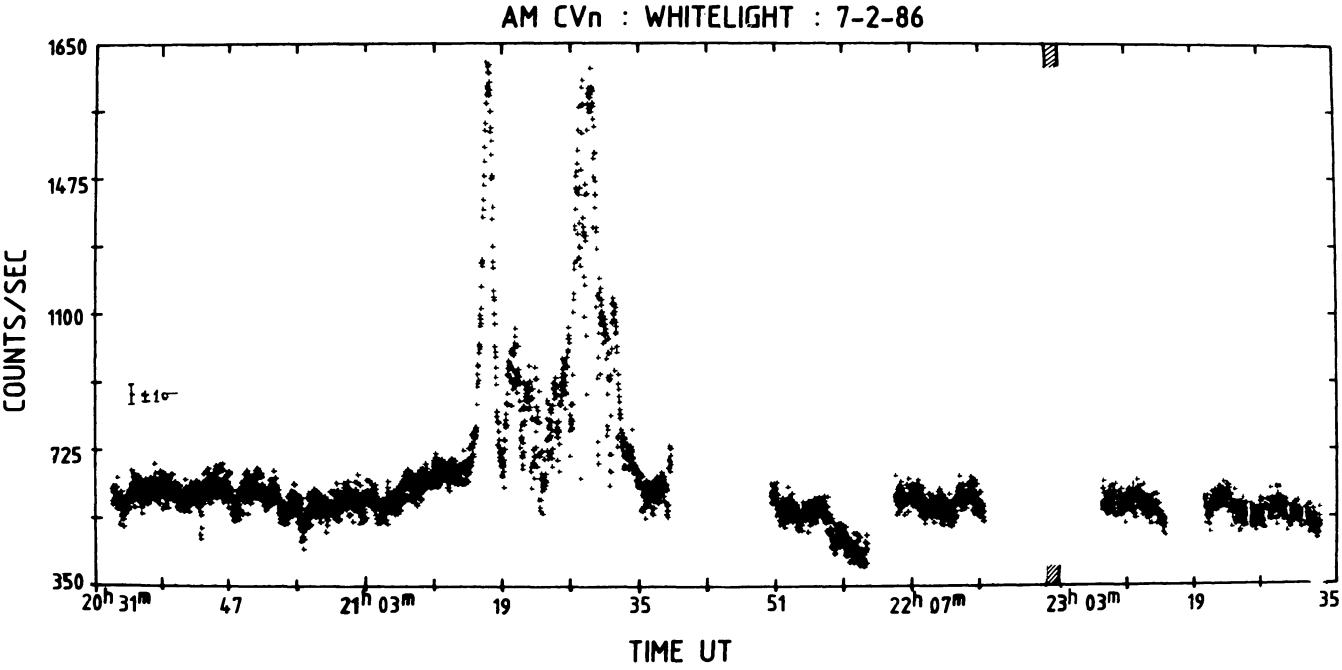

Fig. 2a. Flare of AM CVn on 1986 Feb. 7

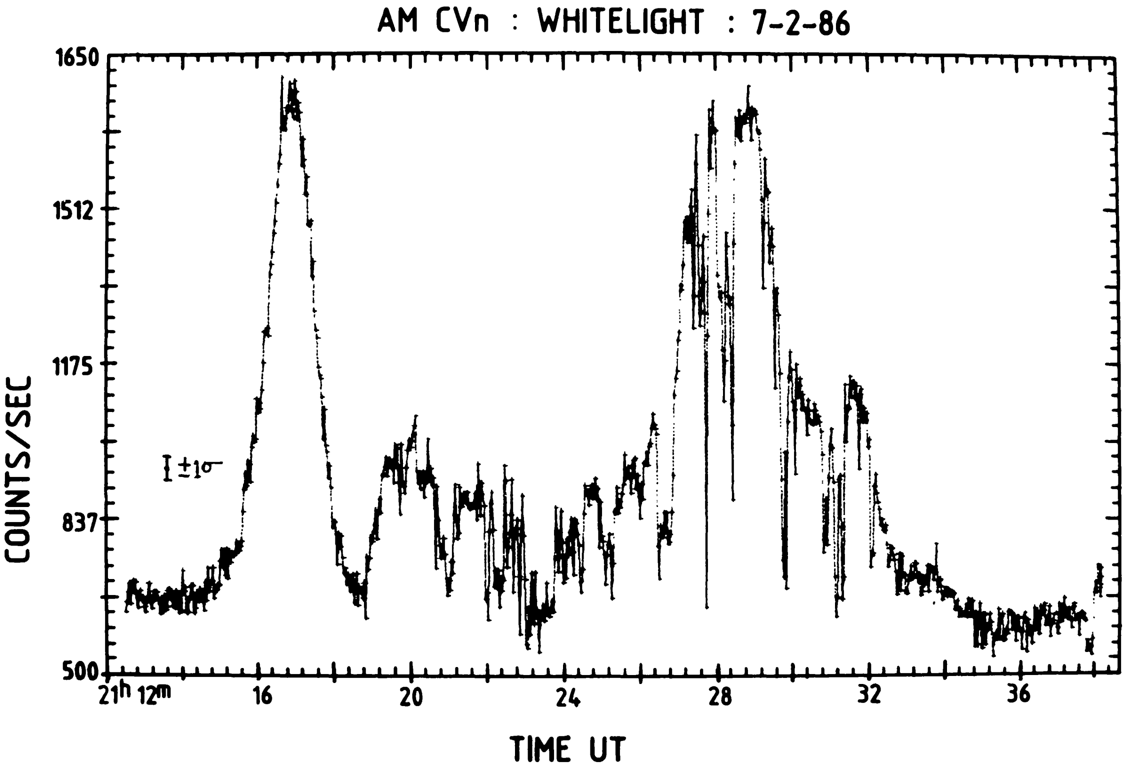

Fig. 2b. Flare portion of Fig. 2a expanded

second hump of the 'M' structure if it had occurred. We emphasize that the evidence of a 1051 s/525.5 s modulation consequent to the flaring activity, in both the data sets is unmistakable. The entire flaring activity can also be seen to be characterized by flickerings over time scales of minutes. This is a typical characteristic of many cataclysmic variables.

3. Discussion

Our observations of intense optical flares reveal yet another behaviour of the interacting binary source AM CVn. Although our observations add up to a total duration of 30 hours only, we detected two intense flares on AM CVn whereas the earlier observers with much longer data lengths have not so far reported any. During the 1987 observational campaign on this object (where our data length measured upto 14 hours) neither we nor other observers (Solheim, private communication) noticed any unusual activity from this system. This would indicate that the object was perhaps going though a high activity phase during 1985–86. With possible detection of winds from this system (Solheim and Moe, 1987) intense activity cycles on this object cannot be ruled out.

We estimate the energy liberated in the flare of 1986 as follows. The effective temperature of the accretion disc which is responsible for most of the optical emission from AM CVn has been estimated to be about 20,000 K (Wampler, 1967). This would imply a bolometric correction of about -2.0. Since the quiescent apparent V magnitude of the system is 14.1, the apparent bolometric magnitude (quiescent) is 12.1. Maximum variation of the flare in white light in the passband 3000–8500 Å was found to be 1.1 magnitude. AM CVn, not being a very strong X-ray source, it is reasonable to assume a bolometric variation also of the same magnitude. At the peak of the 1986 flare the apparent bolometric magnitude is therefore 11.0. This gives a quiescent flux of $3.0\ 10^{-10}$ erg cm^{-2} s^{-1} and a peak flux of $8.2\ 10^{-10}$ erg cm^{-2} s^{-1}.

In order to calculate the energy content in this flare it is necessary to know the distance to the object. However in the case of AM CVn only very poor estimates of the distance were available. Solheim et al. (1984) derive an absolute visual magnitude of either $+9.5$ $(+1.0, -2.0)$ or $+5.8$ which would in turn imply a distance of 83 pc or 450 pc respectively. On the other hand, Patterson et al. (1979) give a rather large distance estimate of 2.5 kpc. We wish to draw attention to the fact that AM CVn is classified as a nova-like object and therefore using a statistical average of absolute V magnitude of novae equal to $+4.5$ (Warner, 1976), we derive a distance of 832 pc. Using this latter value which is a fair average of the above mentioned extreme values, we obtain a quiescesnt luminosity of $2.5\ 10^{34}$ erg s^{-1} and a peak flare luminosity of $6.8\ 10^{34}$ erg s^{-1}. Noting that the equivalent duration of the flare is 109 s, the total energy liberated in it is $2.7\ 10^{36}$ erg. We therefore conclude that both in terms of energetics and time scales, being symmetric and the decay time being substantially less than 9 times the orbital period (Bailey, 1975; Bath and Pringle, 1985), these flares are not like typical outbursts on cataclysmic variables and appear to be unique.

It would be interesting to speculate on the possible sites of the flaring activity. As already mentioned since the decay times ($\sim 10^2$ s) of the flares are significantly less than the viscous time scales ($\sim 10^4$ s) of a typical accretion disk in AM CVn, it is unlikely that the flare could have originated as a large disturbance on the disk or on the bright spot where the accretion stream from the companion star strikes the disk. Also we have emphasized that the enhancement in the 1051 s modulation results from the flaring activity and that it occurs about 525 s later in both the data sets. We therefore examine the location of the flare in the light of the two models proposed to explain the 1051 s periodicity. The first model assumes that the 1051 s period 'P' represents the orbital modulation (Warner and Robinson, 1972). The photometric light variation having an amplitude of 0.05 magnitude is then thought to arise from the eclipsing of the bright spot. Both the unsymmetric nature of the phase of the minima and the occasional occurrence of a single hump lasting 1051 s are explained in terms of movement of the bright spot. With reference to this model the flare of the 1985 data occurs approximately 18 minutes before the central minimum of the following enhanced 'M' structure (which we call as the primary minimum i.e., that which is deeper and precedes the broader hump). The geometry of the system is such that the secondary star is away from the observer during the primary minimum. Thus the flare has occurred where a minimum is expected. We propose that the flaring occurred on the secondary star and the mass stream sent out by the star took $P/2$ seconds to cause a variation in the bright spot and/or disc luminosity which remained bright for the duration of one full orbit. In the case of the 1986 flare it started at the secondary minimum i.e., when the secondary star is nearer the observer. Once again the enhanced emission evident as an orbital modulation is seen only after $P/2$ seconds. We therefore propose that the flaring occurred on the secondary star. If this were true this is the first time the 'feather-light' secondary white dwarf has ever been 'seen' prominently.

In the second model the 1051 s period is attributed to the rotational period of the magnetised primary white dwarf (Solheim et al., 1984). The optical light modulation results from the varying visibility of the polar caps. As per this model, the flare could have occurred on the primary white dwarf followed by an ejection of plasma. This could be reaccreted through the accretion columns causing the 1051 s enhanced structure. It is quite obvious that further continuous monitoring and theoretical modelling of the nature of this exotic blue variable.

4. Conclusion

The flares detected by us on AM CVn in white light during 1985 February 24 (with Δ m = 0.34) and 1986 February 7 (with Δ m = 1.07) are unique both in their structure and time duration. We estimate an energy release of $2.7\ 10^{36}$ erg during the flare of 1986 alone. The flares could have originated either on the secondary star or the primary white dwarf depending on the orbital/rotational models proposed for the origin of the 1051 s period. The rapid variations in intensity during and between the flares might be caused by variabilities in accretion rates and are possibly controlled by the magnetic field of the accreting white dwarf. Further observations to confirm many of the reported temporal features of the emission from AM CVn together with further theoretical studies are called for to understand the nature of the system.

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