

AM CVn – FINALLY SOLVED? RESULTS OF XCOV4, MARCH 1990

Jan-Erik Solheim

*Institute of Mathematical and Physical Sciences, University of Tromsø,
Auroral Observatory, N-9037 Tromsø, Norway.*

Received August 1, 1993.

Abstract. Preliminary results of the analysis of the XCOV4 campaign data in March and April 1990 for AM CVn are presented. The pulse spectrum has five harmonics of the undetected fundamental period 1051 s. In addition, sidebands are observed with a 21 μ Hz spacing, always on the high-frequency side. It is not possible to explain these observations as g-mode pulsations. Most likely, AM CVn is a system of two interacting dwarf stars transferring mass through an elliptical disk slightly tilted with respect to the orbital plane. The disk has a retrograde precession with a period of 13.4 h, resulting in the 21 μ Hz side bands observed. We interpret the 1051 s fundamental period as the superhump period and 1028 s as the orbital period, while 1011 s is a beat period of a prograde precession of the disk with a period of 17 h. The 13.4 h period is also detected in variations of the absorption line profiles, proving that this period represents a disk phenomenon (Patterson et al. 1993).

Key words: stars: cataclysmic variables – stars: individual: AM CVn

1. Introduction

The previous contribution concerning AM CVn, prepared for the 1st WET Workshop, November 1991 (in the following called AMW1), gives a general presentation of XCOV4 observations of AM CVn, some problems in the analysis and some preliminary conclusions. In particular, the stability of various peaks in the FT was discussed, and we concluded that the particular window function observed has

created an amplitude and phase modulation which almost disappeared when sidebands were removed with the prewhitening procedures. Another conclusion was that the triplet splitting could be interpreted as an indication of g-mode pulsations. With a central object with temperature of 150 000 K, the pulsations could be located on the surface of the central DO white dwarf in the system.

In this contribution, we will present further analysis and some new conclusions, hopefully approaching the interpretation of this system. The idea that the pulsations originate in the disk is supported by time-resolved spectroscopy, which detected one of our observed periods. We will also discuss a $\dot{P}$ determination which is of the same order as predicted by the General Relativity as a result of loss of the angular momentum by gravitational radiation. The full analysis will be published in the near future (Solheim et al. 1994).

2. Further analysis

The analysis of the spectrum of AM CVn shows that it qualifies as a novalike object, or a helium cataclysmic variable (CV) stuck in a high state (Solheim 1993; Patterson et al. 1992), and that it has circumbinary hot matter and a line profile of He II (1640 Å) also observed in a cool DO white dwarf (Solheim and Sion 1994). The basic property to be kept in mind in the interpretation of the optical pulses is that the disk contributes more than 100 times the light from the central hot object in the optical part of the spectrum (AMW1).

The analysis of XCOV4 light curves (AMW1) resulted in the series of pulses displayed in Fig. 1. We have a sequence of 5 higher harmonics of a fundamental frequency $\Omega_0 = 951.3 \mu\text{Hz}$ ($P_0 = 1051 \text{ s}$). The first and second harmonics have a triplet structure, while the third and the fourth have a doublet structure, all with $\partial f = 21 \mu\text{Hz}$ spacings on the high frequency side of the harmonically related frequencies. No power is found at the fundamental frequency (Ω_0), but we observe a sideband at $\Omega_0 + \partial f$ ($P = 1028 \text{ s}$) and another one at $\Omega_0 + \partial f + 16 \mu\text{Hz}$ ($P = 1011 \text{ s}$). The 16 μHz spacing indicates a different origin for this period.

If we compare the observed light curves with the synthetic light curves constructed from the frequencies and amplitudes shown in Fig. 1, we obtain the light curves shown in Fig. 2, upper and central panels, for observations on two successive nights obtained with the 3.6 m and 0.6 m telescopes at the Mauna Kea Observatory, Hawaii.

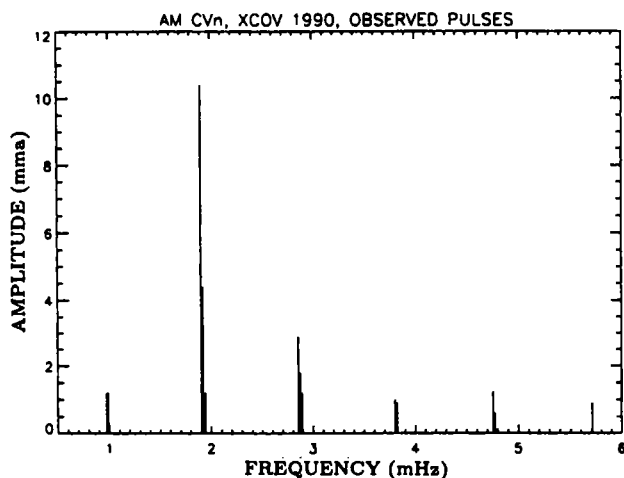


Fig. 1. Observed pulses for AM CVn in the XCOV4 campaign.

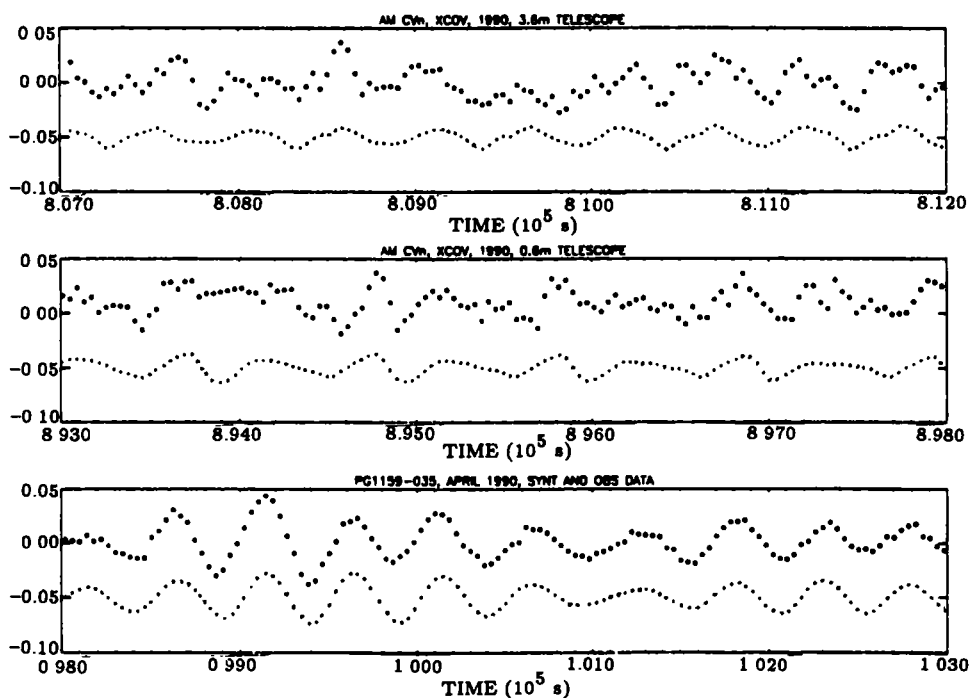


Fig. 2. The observed (large dots) and synthetic (small dots) light curves for AM CVn and PG 1159–035. See explanations on the top of the panels and in the text. The time between tick marks is 1000 s.

Even in the noise-free light curve obtained with the big telescope, we observe "erratic pulses" in addition to the average modulation seen in the synthetic spectrum. We also notice that many of the maxima and minima are slightly out of phase compared with the synthetic curve.

For comparison, the bottom panel shows the observed and synthetic light curves for a certified DO pulsator, PG 1159-035. We can only admire how close the synthetic and observed light curves follow each other. The conclusion based on this comparison is that the light curve of AM CVn does not originate from a pure pulsator: something produces additional modulation of the light curve and introduces a phase jitter also noticed in the earlier analysis (Solheim et al. 1984). This is most likely a product of modulations in a disk, not on the stellar surface as we shall describe later.

Investigation of the pulse shapes of the various pulsations shows that the $P = 1028$ s pulse has an almost triangular shape (Fig. 3a). The $P = 514$ s pulse, which shows an unstable phase and amplitude (AMW1), is, therefore, most likely a high frequency harmonics for

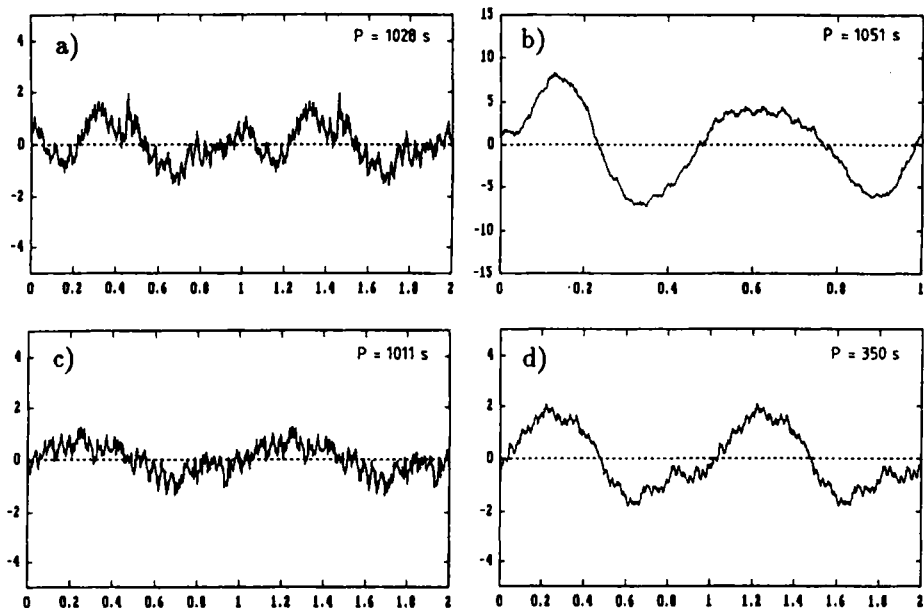


Fig. 3. Average pulse profiles for some of the pulses observed in AM CVn.

this period. We also observe that the average profile for the fundamental period $P_0 = 1051$ s (Fig. 3b) contains two peaks, one narrow and one wide. This must be a result of the sum of higher harmonics observed for this period. The higher harmonics all have a stable phase and a relatively constant amplitude (AMW1) and it may be tempting to assign them to real physical modulations and not to pulse shape harmonics.

The periods 1011 s (Fig. 3c) and 350 s (Fig. 3d) and the sideband pulsations observed are all close to pure sinusoids and may be a result of geometric modulations.

After the XCOV4 in 1990, AM CVn has been observed several times in order to determine period variations. On one occasion (La Palma, January 1992), we observed it in the U, B, V system, and the colour temperature of each pulse has been determined (Fig. 4).

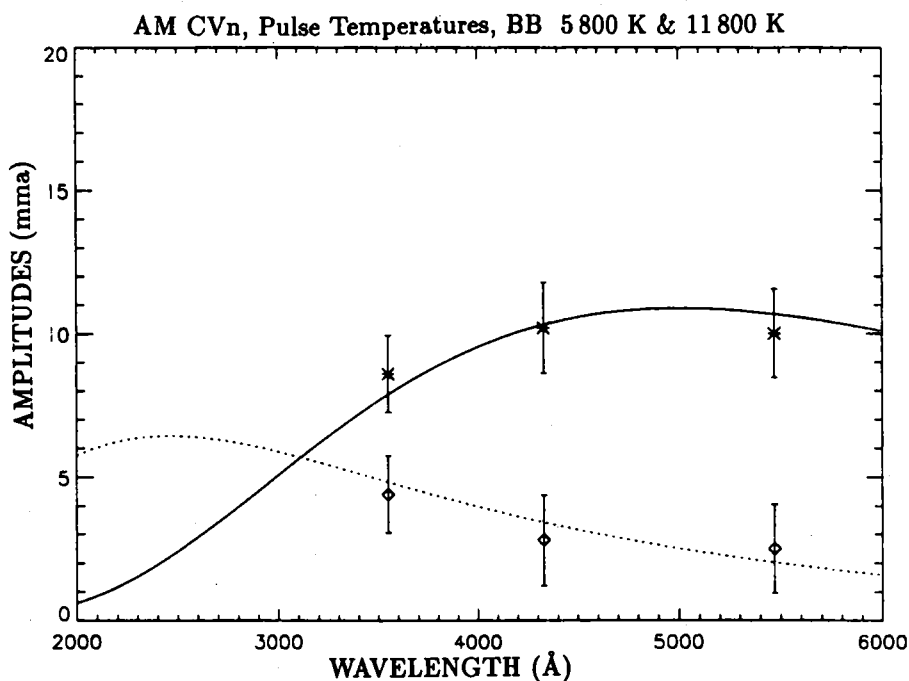


Fig. 4. The UBV amplitudes for two of the pulses observed in AM CVn, compared with the black body curves. The solid curve is a 5800 K black body curve fitted to the $P = 525$ s pulse amplitudes, while the broken curve is a 11800 K black body curve fitted to the $P = 350$ s pulse amplitudes.

The surprising result was that the 525 s set of pulses can be explained with a temperature of about 6000 K, while the 350 s pulse requires a temperature of nearly 12000 K if we assume a blackbody flux distribution. We may then conclude that the 350 s pulse originates at a hotter location than the other pulses. Since the errors in this determination do not preclude an equal pulse amplitude, this conclusion should be tested with new observations.

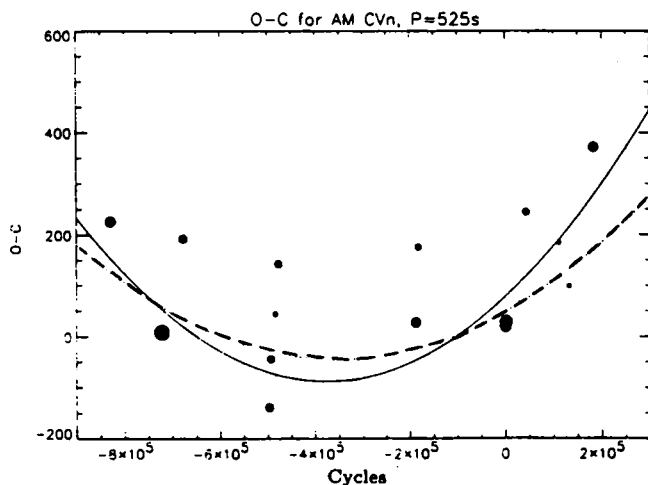


Fig. 5. The $O-C$ diagram for AM CVn for the years 1976–1993, based on a period of $P = 625.62011$ s. Sizes of the dots are proportional to the weight assigned to each observation.

For all the periods shown in Fig. 1 we get $\dot{P} \geq 0$. Only for the strongest pulse with the period 525 s we find a value definitely greater than 0. The $O - C$ diagram for this period for observations 1976–1993 is shown in Fig. 5. We find that the separate determinations of $O - C$ define a band which is almost $0.7 P$ wide. The phase variations can be interpreted as a slightly different period each observing season, as if the clock in the system we observe sometimes runs a little slower or faster than on the average. If the clock resets gradually or jumps back, is yet unknown. AM CVn should be observed each month for a couple of years to determine the short term period changes. The weight of each determination of $O - C$ is proportional to the area of the black dots in Fig. 5. The best value for $\dot{P}$ is $(4.4 \pm 1.8) \times 10^{-12} \text{ s s}^{-1}$.

If we exclude the last observation (1993), then we get $\dot{P} = (2.9 \pm 1.8) \times 10^{-12} \text{ s s}^{-1}$.

3. Discussion

From the spectrum of AM CVn we conclude that this is a system with a disk, most likely in permanently high state. The periods observed are in the same range as observed for some pulsating DO white dwarfs. However, if the triplets are interpreted as $l = 1$ g-mode pulsations with rotational splitting, we find $P_{\text{rot}} \approx 6 \text{ h}$, which is very unlikely in a system with a disk. Such a slow rotator in a disk would create a hot boundary layer in order to accrete on the central object. This would give rise to strong X-ray radiation, which is not observed.

In order to observe the pulsations against the bright disk, we would expect them to be strongly nonlinear, and we should observe fundamental frequencies with high order coherent harmonics. For AM CVn, we observe only higher harmonics of a *missing* fundamental. Finally, we observe phase variations which are unlikely for stable pulsations.

The final blow to the g-mode pulsation interpretation comes from the recent observations by Patterson et al. (1993) of the absorption line profile variations with a period of $P = 1/\partial f = 13.4 \text{ hrs}$, which they propose as a period of precession for an elliptical disk, created by the low mass ratio. It is then simple to propose that this period reveals itself as the high-frequency sidebands to all other physical periods present in the system.

Following Patterson et al. (1993), we can then identify $P = 1028 \text{ s}$ as the orbital period (P_{orb}) of the system and $P = 1051 \text{ s}$ as the superhump period (P_{su}). The superhump period is only 2 per cent longer than the orbital period, which indicates from simulations (Osaki 1985; Lubow 1991) that we have a binary system with an extremely low mass ratio of $q \approx 0.09$. With this small mass ratio the strong 3 : 1 parametric resonance is present inside the tidal radius of the disk which explains the eccentricity and most of the 13 periods detected (Whitehurst and King 1991).

An explanation why we observe only the first harmonic (525 s) period and not the fundamental period in the FT has to be looked for in the changing aspects of a feature in the disk twice per superhump period.

The other triplet with a period of about 350 s can be also explained because $P = 350$ s is $P_{\text{su}}/3$ and $P = 347$ s corresponds in this case to the orbital period of particles in the disk at the resonance radius (Whitehurst and King 1991). The higher temperature of the variation with this period, if real, can come from a standing shock in this part of the disk, if accreting particles moving inwards are suddenly exposed to a ring of lower density as we observe in the planetary rings.

And finally, $P = 1011$ s can be explained as a beat with a prograde precession of the nodal line of the disk, $P_{\text{prec}} \approx 60 P_{\text{orb}}$, if the disk is tilted, as proposed by Patterson et al. (1993).

The $\dot{P}$ determinations are still too uncertain to draw firm conclusions (Fig. 5), but the values obtained for orbital changes are of the order predicted by the General Theory of Relativity (Faulkner et al. 1972) which we calculate to be

$$\dot{P} \approx 3 \times 10^{-12} \text{ s s}^{-1}$$

for $P_{\text{orb}} = 1028$ s, $q = 0.09$ and $M = 1.0M_{\odot}$.

The slightly higher observed value may be due to loss of angular momentum by wind (10 per cent for CVs) or other mechanisms.

4. Conclusions

We are now able to make a preliminary identification of the observed periods of the AM CVn system in the following way:

- (a) $P = 1051$ s is the superhump period, which is not observed directly, but by its first and higher harmonics which are related to aspect changes of the disk.
- (b) $P = 1028$ s is the orbital period, which modulates the light curve with a small and variable amplitude.
- (c) $P = 13.4$ h = $1/\partial f$ is the period of eccentric precession of the disk, which beats with all other frequencies observed and creates the high frequency sidebands observed for most of the harmonically related periods. This period of precession represents a periodic change of the viewing angle of the disk.
- (d) $P = 1011$ s is a beat period between the nodal line precession and the orbital period.
- (e) $P = 350$ s, the second harmonics, is created by particles just inside the 3:1 resonant orbit heated up by shocks from inward moving particles passing into an empty ring.

- (f) And finally, the $\dot{P}$ determination is too uncertain to claim that we have its value different from zero.

Acknowledgments. I am grateful to R. E. Nather, D. E. Winget, J. L. Provencal and P. A. Bradley for their help, encouragement and many discussions. I also thank the many members of the WET teams who made observations under difficult conditions. This research has in part been supported by grants from the Norwegian Research Council.

References

- Faulkner J., Flannery B. P., Warner B. 1972, *ApJ*, 175, L79.
Lubow S. 1991, *ApJ*, 381, 268.
Osaki Y. 1985, *A&A*, 144, 369.
Patterson J., Sterner E., Halpern J. P., Raymond, J. C. 1992, *ApJ*, 384, 234.
Patterson J., Halpern J., Shambrook A. 1993, *ApJ*, 419, 803.
Solheim J.-E. 1993, in *White Dwarfs: Advances in Observation and Theory*, ed. M. Barstow, Kluwer, Dordrecht, p. 387.
Solheim J.-E., Sion E. 1994, *A&A*, in press.
Solheim J.-E., Provencal J. L., Bradley P. A., Vauclair G., Barstow M., Kepler S. O., Fontaine G., Grauer A. D., Winget D. E., Nather R. E., Marar T. M. K., Leibowitz E. M., Emanuelsen P.-I., Chevreton M., Dolez N., Kanaan S. O., Henry G. A., Bergeron P., Wood M. A., Claver C., Clemens J. C., Kleinman S. J., Hine B. P., Seetha S., Ashoka B. N., Matzehl T., Meistas E., Bruvold A. 1994, in progress.
Whitehurst R., King A. 1991, *MNRAS*, 249, 25.