THE AM CVn TRIAL: THE CASE FOR SUPERHUMPS

D. O'Donoghue

Department of Astronomy, University of Cape Town, Rondebosch 7700, Cape Town, South Africa.

Received August 11, 1995.

Abstract. The AM CVn stars are hydrogen deficient stars which are explained by an interacting binary white dwarf model. In this model, a low mass white dwarf fills its Roche lobe and transfers He-rich material to another white dwarf via an accretion disk. This paper advances a superhump mechanism to explain the photometric oscillations seen in the light curves of these stars.

Key words: stars: cataclysmic variables - stars: individual: AM CVn.

1. Introduction

The AM CVn stars are a small class of hydrogen deficient ultraviolet strong stars (see Warner 1994, O'Donoghue et al. 1994 and O'Donoghue 1995 for reviews and discussion of their class properties). Only one model has so far been devised which explains all the properties of these stars: a low mass ($\sim 0.02 M_\odot$) white dwarf fills its Roche lobe and transfers He-rich material to another white dwarf via an accretion disk (Faulkner, Flannery & Warner 1971). Although the gross properties of the stars are explained by this model, understanding of many of the details is lacking: in particular, with the exception of GP Com, all members of the class show low amplitude optical oscillations with a period between 500 and 2000 s. The oscillations have a complex and variable harmonic structure (e.g. O'Donoghue & Kilkenny 1989). It is the purpose of this paper to propose a superhump model for these oscillations. Clemens (these Proceedings) will advance a model invoking nonradial pulsations of the mass accepting white dwarf to explain the oscillations.
2. A synopsis of superhumps

Full reviews of the properties of superhumps include Warner (1985), O'Donoghue (1992) and Molnar & Kobulnicky (1992). We include only a brief summary here.

Superhumps are found mainly during the long or superoutbursts of SU UMa-type dwarf novae (although permanent superhumps are now being found in other hydrogen-rich cataclysmic variable systems: e.g. Skillman & Patterson 1993). The most enigmatic property of superhumps is their period: they are optical variations with a period a few per cent longer than the binary orbital period. In the early stages of superoutbursts, the superhumps are of large amplitude with a pulse shape resembling a cepheid: a rapid rise and more gradual decline. Later, the superhumps decrease in size and often assume a more complex pulse shape. Spectrophotometric observations (Hassall 1985) and constraints from eclipse light curves (Horne 1984, O'Donoghue 1990) have shown that the superhump light source is located in the outer regions of the accretion disk, is cool \( (T_{\text{eff}} \sim 6000 \text{ K}) \) and occupies a large area \( (\sim 10^{20} \text{ cm}^2) \).

Although many of the details remain to be worked out and a strong test by observations has yet to be done, the currently favored model for superhumps involves tidal stressing in the outer regions of the accretion disk (Whitehurst 1988, Whitehurst & King 1991, Lubow 1991a,b).

3. Photometry of the AM CVn stars

50% of the AM CVn stars undergo large luminosity changes of up to 4 mag. During these changes, which can take place on a time scale of one day or less, the colors of the stars vary little and are still rich in ultraviolet emission. The only known mechanism for such rapid, large amplitude changes is mass transfer and, as mentioned, the model for the AM CVn stars involves a semi-detached binary. A semi-detached configuration is, of course, the structure of cataclysmic binaries of which the SU UMa dwarf novae, those which show superoutbursts and superhumps, are members. If this underlying model for the AM CVn stars is correct, their orbital periods must be approximately half an hour (to within a factor of two). This is the same range of periods shown by the oscillations of the AM CVn stars. Superhumps in the SU UMa stars have periods a few per cent longer than the binary orbital period. This therefore demonstrates
that the periods of the oscillations in the AM CVn stars are of the right size to be identified with superhumps.

Fig. 1. Pulse shapes of V 803 Cen from O'Donoghue & Kilkenny (1989). Numbers of observing runs are indicated.

The pulse shapes of the oscillations in the AM CVn stars vary from relatively simple, looking like the light curve of a cepheid or an RR Lyrae star, to remarkably complex with numerous harmonics. Fig. 1 illustrates the pulse shapes of V 803 Cen (O'Donoghue & Kilkenny 1989). No pulsating white dwarf star has a pulse shape or light curve showing the intricacy seen in Fig. 1, especially the rise to maximum in the pulse shapes of the run S4042.
Fig. 2. Light curve of AM CVn (top) and light curve (middle) and power spectrum of V 1159 Ori (bottom) in late superoutburst (taken from Patterson et al. 1995).
With a small number of exceptions, which nevertheless remain a puzzle and which should be accounted for in any successful model, all the periods seen in the power spectra of the AM CVn stars are harmonically related (i.e. are a part of the sequence \( nf \), where \( n \) is an integer and \( f \) is the fundamental frequency). AM CVn would fit this scheme if the period of the fundamental were 1051 s. A potential problem to this interpretation, which has been remarked upon repeatedly, is the fact that this period has never been seen in any of the numerous published power spectra of AM CVn (a nearby period at 1028 s is sometimes present but this should not be confused with 1051 s). Although this is certainly a fact to be worried about, it is not fatal:

(a) No fundamental law is violated by its absence. Indeed in media electromagnetic broadcasting on earth, the fundamental of the carrier signal may be undetectable.

(b) The discovery of and subsequent study of EC 15330-1403 (O'Donoghue et al. 1994) has provided a star which is virtually identical to AM CVn in its overall behavior: it has no large luminosity changes and a relatively simple pulse profile with a fundamental period of 1119 s and two additional harmonics. This makes the behavior of AM CVn, if not more understandable, at least atypical of the other AM CVn stars.

(c) Fig. 2 shows a section of the light curve of AM CVn (top) along with that of the SU UMa star V 1159 Ori (middle) (Patterson et al. 1995). The power spectrum of the V 1159 Ori light curve is shown underneath. In the early stages of its superoutbursts, V 1159 Ori superhumps are single-humped as is typical for the class. The variations seen in V 1159 Ori light curve in Fig. 2 are superhumps in the late stages of a superoutburst and are obviously double humped. In fact, so much power is concentrated in the first harmonic of the V 1159 Ori light curve of Fig. 2, that the fundamental, which dominated the power spectrum a week earlier, is not seen in the power spectrum (the alias pattern near the fundamental is, in fact, not at the correct frequency to be identified with the fundamental of the superhump signal).

4. Spectroscopy of the AM CVn stars

Spectra of the AM CVn type stars bear little resemblance to those of DB white dwarfs: the lines in AM CVn stars are narrower, much shallower, with emission at HeII \( \lambda 4686 \) Å and the HeI \( \lambda 4713 \) Å
Fig. 3. Spectra of AM CVn (top) from Patterson et al. (1993) obtained at two phases of its 13.4 h period. The middle spectrum is that of GD 358, a prototype DBV white dwarf. The bottom spectra are of TY PsA (from Warner, O'Donoghue & Wargau 1989) obtained at two phases of its 2nd beat period, differing by 0.5.
line missing. This is illustrated in Fig. 3 which shows the spectrum of AM CVn at two phases of its 13.4 h period, differing by 0.5, along with the spectrum of GD 358, the prototype DBV white dwarf.

At the bottom of Fig. 3, there are two spectra of the SU UMa dwarf nova TY PsA (Warner, O'Donoghue & Wargau 1989) during superoutburst. These spectra were taken at two phases of its 2nd "beat" cycle, 0.5 cycle apart. There is a striking resemblance between these spectra: although the features are He lines in AM CVn and H lines in TY PsA, the shape and depth of the lines are similar, both being much shallower than the lines of either DA or DB white dwarfs. These line profiles are typical of those of an optically thick accretion disk, implying that most of the light is being emitted by the disk and not the white dwarf primary in each case.

Even more dramatic, however, is the similarity in the profile changes. Both stars undergo line profile changes with a period of 13.4 h in the case of AM CVn (Patterson et al. 1993) and 2 d in the case of TY PsA (Warner, O'Donoghue & Wargau 1989). Fig. 3 shows two spectra of each star, obtained half of their respective cycles apart. In both stars the line profiles are asymmetric and the sense of the asymmetry changes with the 13.4 h and 2 d periods, respectively. This kind of line profile behavior is commonly seen in SU UMa stars during their superoutbursts (see Warner et al. 1989 for a discussion). The resemblance between V 1159 Ori and AM CVn is compelling. In the case of TY PsA, the 2 d period is clearly established as the "beat" period between the orbital and superhumps periods (see the cited reviews for discussion of the significance of this period). We conclude this section by noting that no such profile changes have ever been observed in the DBV stars.

5. Conclusion

If the oscillations of the AM CVn stars are white dwarf pulsations, they would have to have unique properties amongst the pulsating degenerates: located in a mass-accreting binary (else how are the large luminosity changes to be explained?), remarkably complex pulse shapes (as in V 803 Cen) and spectra whose overall appearance and variations in shape are not seen in other pulsating degenerates.

On the other hand, if the oscillations of the AM CVn stars are superhumps, they fit naturally into a well-observed (although incompletely understood) phenomenology seen in SU UMa dwarf novae: similar light curves, similar spectra and the presence of a "beat" pe-
period in both groups of stars. We feel the weight of evidence clearly favors the second explanation in preference to the first.

Although this paper has sought to prove the superhump interpretation of the oscillations in the AM CVn stars on the basis of the similarity of the observed properties (i.e. without reference to any theory), the tidal explanation for superhumps requires them to be visible in the AM CVn stars. This is because the theory predicts an asymmetric and precessing disk for all semi-detached binaries with a mass ratio smaller than $\sim 0.25$. The double degenerate model for the AM CVn stars implies a mass ratio very much smaller than 0.25 and thus the presence of an asymmetric and precessing disk. The very much smaller mass ratio in the AM CVn stars this could be the reason that their pulse shapes can be so much more complex than in the typical superhumps of the SU UMa stars.

6. Postscript

A crucial test of the two competing models is the stability of the oscillations in AM CVn. Opposing views on this question include those of Patterson et al. (1992), who believe that no stable ephemeris for the oscillations can be found, and Provencal et al. (1995), who claim to have established such an ephemeris. Given the fact that the dispute is clearly over the method of analysis of already existing data, we urge a further and independent study to attempt to resolve this question.

Acknowledgments. I am grateful to Judge R.E. Nather and opposing counsel J.C. Clemens for an entertaining debate, to Joe Patterson for inspiring the debate and to D.E. Winget and J.L. Provencal for useful discussions.

References

The AM CVn trial: the case for superhumps
