THE INTERMEDIATE POLARS

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INTRODUCTION

Until 1976, cataclysmic variable star research proceeded with few requirements for the inclusion of magnetic fields in theoretical models. Although models for low-mass X-ray binaries stressed the importance of magnetic fields (Lamb *et al.* 1973) and there was an increasing number of known magnetic single white dwarfs (Angel 1977), and a magnetised white dwarf had been one of the models proposed to explain the rapid oscillations in DQ Her (Herbst *et al.* 1974, Katz 1975), there was no anticipation of the more general role that magnetic fields now seem destined to play. The two major reviews of the time (Robinson 1976, Warner 1976) scarcely considered the presence of magnetic fields.

The discovery that AM Her combines the characteristics of cataclysmic variable, low-mass X-ray binary and magnetic white dwarf (Cowley and Crampton 1977, Priedhorsky 1977, Szkody and Brownlee 1977, Tapia 1977), and the subsequent discovery of several similar objects (reviewed by Tapia in this volume), revolutionised the subject. It rapidly became evident that, as large magnetic fields demonstrably dominate the flow pattern of accreted material onto synchronously rotating primaries in the polars (AM Her-type objects: Kruszewski 1978), lesser magnetic fields may play important roles in other cataclysmic variables, with detectable effects in many (perhaps all) of them. In other words, we may suspect that in the polars we see only the extremum of a range of magnetic field strengths and that, as with an iceberg, the visible tip implies a large body of a similar nature but less immediate detectability.

There are many cataclysmic variables for which there is as yet no clear need to invoke magnetic fields, but there is also an increasing number of objects in which magnetic fields do appear to play a role which, although less spectacular than that seen in the polars, is sufficient to introduce the classification "intermediate polar".

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IMPOTENT POLARS

In a polar the magnetic field strength of the degenerate star is sufficiently large that synchronous rotation results through magnetic interaction with its companion (Joss *et al.* 1979). Furthermore, the accretion flow is completely controlled by the geometry of the field, so that material funnels from the companion into an accretion column at one or both magnetic poles. No accretion disc would be expected in such a system. Most of the radiation in the system arises in the accretion columns which, with synchronous rotation, leads to the observed orbitally phase-locked large circular and linear polarization. Field strengths of 1-3 x 10^7 gauss have been detected in the polars VV Pup (Wickramasinghe and Visvanathan 1980) and AM Her (Schmidt *et al.* 1981, Latham *et al.*, 1981).

Senescent polars, in which the field is decaying, will break synchronism as the degenerate star is spun up by the accretion torque. The degree of asynchronism will depend on the rate of mass transfer, the strength of the field and the time lapsed since rotation ceased to be synchronous. Adolescent polars in which the field is strong but the system is relatively young, will not yet have reached synchronism. Systems born with smaller fields will be more or less braked by magnetic interaction and may show any degree of asynchronism.

All of these systems must appear under the classification of intermediate polar; it remains to discover whether we can distinguish between these different types and whether representatives of all classes can be found. For systems in which the field is large enough to establish an extensive magnetosphere, with its attendant accretion columns, some similarities with the polars themselves may be anticipated: e.g. weak polarization or X-ray emission. As is evident from this qualitative discussion, demonstrable asynchronism is the primary classification criterion for intermediate polars.

INTERMEDIATE POLARS DISCOVERED

The precise position of the X-ray source 2A0526-328, determined by Schwartz *et al.* (1979), enabled Charles *et al.* (1979) to identify it with a previously unknown star of the cataclysmic variable type - the first to have been discovered by means of its X-ray emission. It was noted that the spectrum of 2A0526-328 (now designated TV Col) is almost identical to that of the polars AM Her and EF Eri (2A0311-227). High speed photometry (Warner 1980a) showed that the system has the colours and rapid flickering of a cataclysmic variable.

Extensive photometry (Motch 1981) and spectroscopy (Hutchings *et al.* 1981) established the singular property that whereas the orbital period (from radial velocity modulation) is $5^h29^m.2$, the principal photometric period is $5^h11^m.5$. The beat period between these ($4^d.024$) shows as a modulation of the light curve, i.e. both periods are present as luminosity variations.

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The model proposed for TV Col by Hutchings *et al.*, in analogy with an older model developed for DQ Her (discussed below), is that the binary contains a magnetic degenerate star, rotating progradely once in $4^{d}.024$ relative to the binary revolution. A beam of light from the accretion column rotates with the degenerate star, producing more or less illumination according to the distribution of material in the system.

Simultaneous with these studies of TV Col, the identification and elucidation of another source was in progress. H2252-035 was identified with a previously unrecognised 13th magnitude variable by Griffiths *et al.* (1980). Its spectrum resembles that of a dwarf nova at minimum light.

High speed photometry showed the system to have prominent luminosity variations with a 14.3 min period and a mean brightness orbitally modulated with period 3.6 hrs (Warner 1980b, Patterson and Price 1980). White and Marshall (1980, 1981) found that the X-ray flux is modulated at a period of 13.4 min; this period was also found at low amplitude in optical photometry (Warner and O'Donoghue 1980, Warner *et al.* 1981).

The combination of photometric and spectroscopic observations led to a model (Patterson and Price 1981, Warner *et al.* 1981, Hassall *et al.*, 1981) in which an X-ray beam emitted from the rotating degenerate star (period P_D = 13.4 min) illuminates either the companion (Patterson and Price 1981) or the gas in the extended hot spot region (Hassall *et al.* 1981) and is converted to optical emission. The period P_{opt} (=14.3 min) of the latter would then be associated with P_D and the orbital period P_{orb} by $P_{opt}^{-1} = P_D^{-1} - P_{orb}^{-1}$: - a relationship borne out by observations (Warner *et al.* 1981).

The similarity of the models for TV Col (for which, however, X-ray modulation with the $5^{h}11^{m}.5$ period still has to be observed) and H2252-035, in both of which slowly rotating (but asynchronous) degenerate stars are postulated, established that intermediate polars had been observed. Neither of the stars shows optical polarization, indicating magnetic fields at least an order of magnitude lower than in the polars.

With the steady production of precise X-ray positions, the past year has seen the identification of several more polars and intermediate polars:-

TABLE 1

The Intermediate Polars

Variable Star	X-Ray	Orbital Period	Other Period(s)
TV Col	2A0526-328	$5^{h}29^{m}.2$	$5^{h}11^{m}.5$
	H2215-086	4 01.5	20.9 (22.9)
AO Psc	H2252-035	3 35.5	14.3 (13.4)
V1223 Sgr	4U1849-31	3 22.8	13.2
	3A0729+103	3 14.2	15.2

SPECTRA AND ENERGY DISTRIBUTIONS

The emission line spectra of the five established intermediate polars (Table 1), typical examples of which are shown in Figures 1 and 2, closely resemble those of polars (Raymond *et al.* 1979) or nova remnants (Warner 1976). The great strength of HeII 4686Å and the presence of the 4640Å CIII/NIII blend distinguishes them from dwarf novae. Observations in the range 1000-2000Å with IUE (Hassall *et al.* 1981, Bonnet-Bidaud *et al.* 1982) show strong CIV emission and the presence of CII, SiIV and NV.

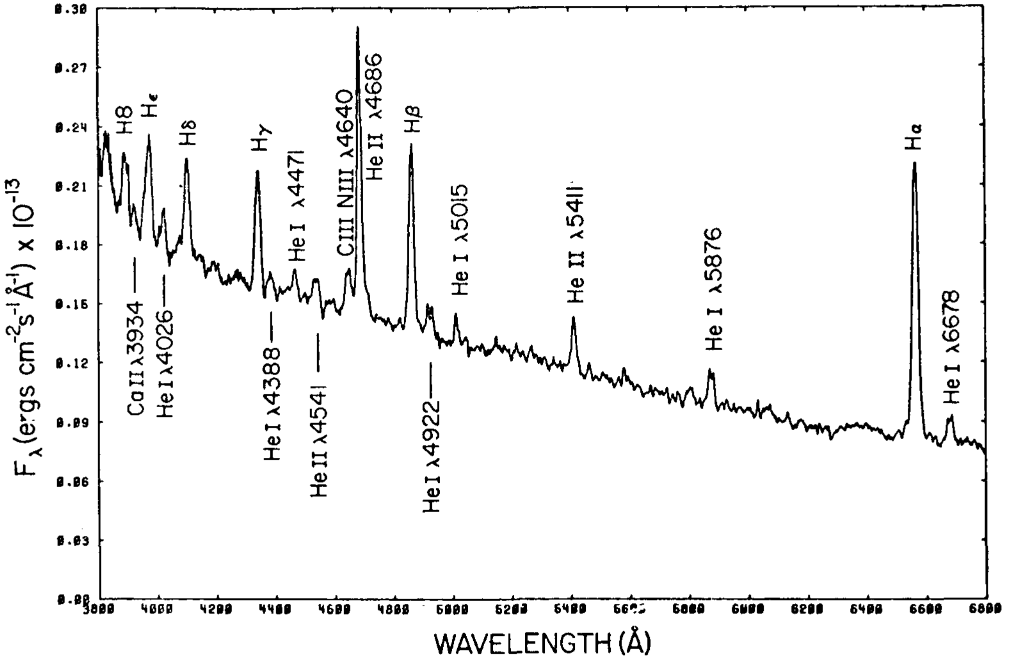

Figure 1. Spectrum of H2215-086. (Reproduced by permission from Shafter and Targan, *Astron. J. 87*, 655, 1982)

All five objects have broad lines, with FWZI ~1000-1200 km s^{-1} (Shafter and Targan 1982, Hassall *et al.* 1981, Watts *et al.* 1980, Warner *et al.* 1982, Steiner *et al.* 1981). Variability of line width and line splitting is seen in 2A0526-328 (Watts *et al.* 1980); Hutchings *et al.* (1981) find line widths up to 3000 km s^{-1} on occasion in this star and large variations in intensity uncorrelated with either of the periodicities.

In contrast to the situation in the polars, where the flux distribution shows the presence of two components with temperatures $\gtrsim$10 keV

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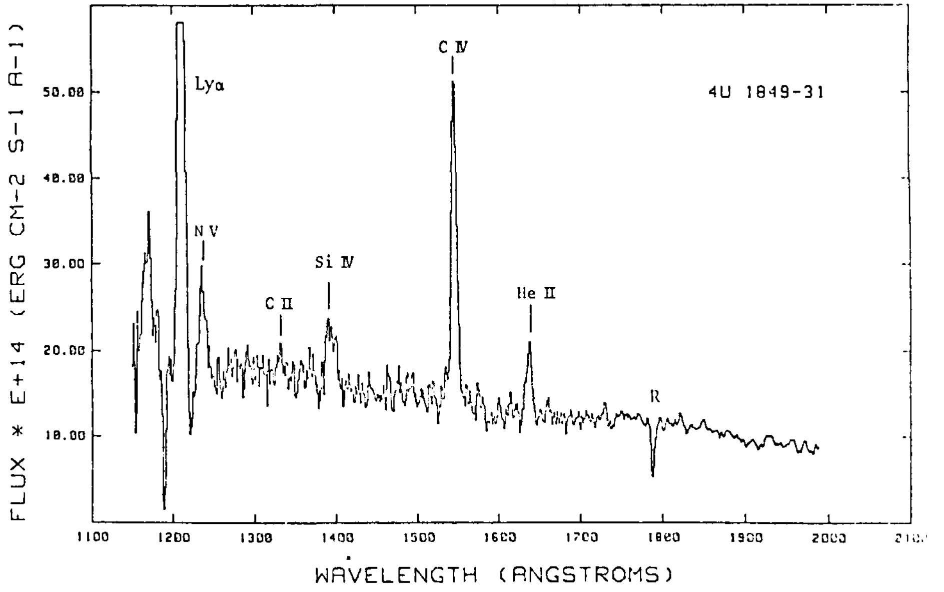

Figure 2. Spectrum of V1223 Sgr. (Reproduced by permission from preprint of Bonnet-Bidaud, Mouchet and Motch)

and $\lesssim$0.1 keV respectively (e.g. Kylafis and Lamb 1982) the fluxes in H2215-086 (Shafter and Targon 1982), H2252-035 (Griffiths *et al.* 1980) and V1223 Sgr (Bonnet-Bidaud *et al.* 1982) are in general quite well described by $F_\lambda \propto \lambda^{2.2 \pm 0.2}$ which is characteristic of an accretion disc. However, in H2252-035, Hassall *et al.* (1981) and Cordova (1981) obtain a better fit with a composite of disc and 12 000 K blackbody. The latter is attributable to a hot spot. Wickramasinghe *et al.* (1982) find an S-wave distortion in the spectra of this star, characteristic of that seen from the hot spots in dwarf novae. This, together with the broad emission lines, is a strong indicator that at least a partial disc with a hot spot is present in the intermediate polars.

X-RAY EMISSION

The polars typically possess both hard (kT$\sim$40 keV) and soft (kT$\lesssim$0.1 keV) X-ray emission components (Kylafis and Lamb, 1982, and references therein). The recognition of the five identified intermediate polars has resulted from their appearance in surveys for hard X-rays. The emissions from V1223 Sgr and H2252-035 are characterised by either thermal emission with kT > 10 keV or a power-law model of photon index $\sim$1.4 (Steiner *et al.* 1981, White and Marshall 1981). None of the five stars has been detected in the soft X-ray region.

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In H2252-035 the X-ray flux is highly modulated with a period of 805 secs (Patterson and Garcia 1980, White and Marshall 1981). This period is also seen in the optical (Warner *et al.* 1981) and has been shown (Motch and Pakull 1981) to have a steeper spectrum in the ultraviolet than the 859 sec reprocessed component. These authors show that the source of the 805s optical pulsation is beamed in the same direction as the X-ray emission and can be attributed to the Rayleigh-Jeans tail of a hot blackbody. This could be a result of X-ray heating of the degenerate star below the accretion column, or from X-ray reprocessing as the beam sweeps round the uniform parts of the accretion disc. The existence of an X-ray and optical beam argues strongly for an accretion column close to the surface of the degenerate star.

3A0729+103 is the only other of these stars for which an X-ray modulation has been detected: McHardy and Pye (1982) find evidence for a period in the range 900-1000 secs, similar to the 913 sec optical period.

POLARISATION

No positive detection of circular polarisation has yet been made in the intermediate polars. Quoted limits are 0.07% in 2A0526-328 and H2252-035 (Stockman *et al.* 1982). Williams and Johns (1980) give an upper limit of 0.2 percent for modulated linear polarisation in H2252-035.

In the polars, circular polarisation is attributed to cyclotron emission from the accretion column (e.g. Wickramasinghe and Visvanathan 1980). The wavelength dependence of the polarisation shows the correct behaviour - increasing in the red region of the spectrum. In the polars we are fortunate that the field strengths ($\sim 10^7$ gauss) are just sufficient to produce significant polarisation in the optical region. In order to confirm the lower fields postulated for the intermediate polars, polarimetric observations in the infrared will be required.

LONG-TERM OPTICAL BEHAVIOUR

The polars are well-known for possessing both high and low states of luminosity, differing by 2-3 magnitudes and with gradual transitions between them. Historical light curves, derived from the Harvard plate collection, have been determined for two intermediate polars by Belsepene (1981) which show that V1223 Sgr spends most of its time in a high state but suffered 5 transitions to low states (2-3 magnitudes fainter) and a twelve year interval of irregular brightness at intermediate magnitudes. H2252-035 has shown only one drop of a magnitude below its normal high state.

RAPID OPTICAL BEHAVIOUR

All five intermediate polars show the rapid flickering activity characteristic of cataclysmic variables (Warner 1976). Short lived quasi-periodic oscillations have been seen in H2252-035 with periods ∿100 secs (Warner *et al.* 1981). The striking feature of this group, however, is the large amplitude of modulations associated with rotation of the degenerate component, as illustrated in Figures 3 and 4.

In H2252-035, as discussed earlier, the principal optical period (859 secs) differs from the X-ray period and demonstrates that the modulated optical flux originates from X-ray heating of a feature that is fixed in the rotating frame of the binary system. Patterson and Price (1981) suggested that this object is the secondary star, but Hassall *et al.* (1981) rejected this in favour of reprocessing in the region of the hot spot. More recent work (Motch and Pakull, 1981) shows that the flux distribution of both the 859 sec and the orbitally modulated components are similar and consistent with calculated X-ray illumination of the atmosphere of the secondary (Milgrom 1976). The relative phasing of the 805 and 859 sec modulations supports this conclusion (Motch and Pakull 1981, Patterson 1981a). The amplitude of the optical 805 sec modulation varies and is at times too small to be detected (Wickramasinghe *et al.* 1982). These same authors show that the quantitative arguments against the heated secondary hypothesis in H2252-035, made by Hassall *et al.*, are negated when allowance is made for the contribution made by disc luminosity and shadowing effects.

In H2215-086 the situation is the reverse of that in H2252-035. The large amplitude 20.9 min oscillations in brightness (Shafter and Targan 1982, Patterson and Steiner 1981) are accompanied by a low amplitude oscillation at 22.9 mins which is the side band produced by the orbital period of $4^{h}.03$ (Patterson 1982). In this case, therefore, either we see mostly the direct effects of heating of the axially symmetric parts of the accretion disc and the secondary intercepts only a small fraction of the beam, or, most unlikely, the degenerate star is rotating retrogradely. An X-ray period is required to distinguish between the possibilities.

3A0729 + 103 appears to have one or more periodicities longer than the 15.2 min principal oscillation, but these are not clearly connected with an orbital sideband (Warner *et al.*: in preparation). In TV Col both "synodic" and "sidereal" periods show themselves in the photometry (Motch 1981); their amplitudes are about equal.

WHITE DWARF OR NEUTRON STAR?

The X-ray luminosity of H2252-035 is estimated to be $4 \times 10^{32} \times (d/220\ pc)^2$ ergs sec^{-1} (White and Marshall 1981). This, together with the fact that $L_X/L_{opt} \sim 1$, typical for cataclysmic variables known to contain a white dwarf, led Patterson and Price (1981) to argue that

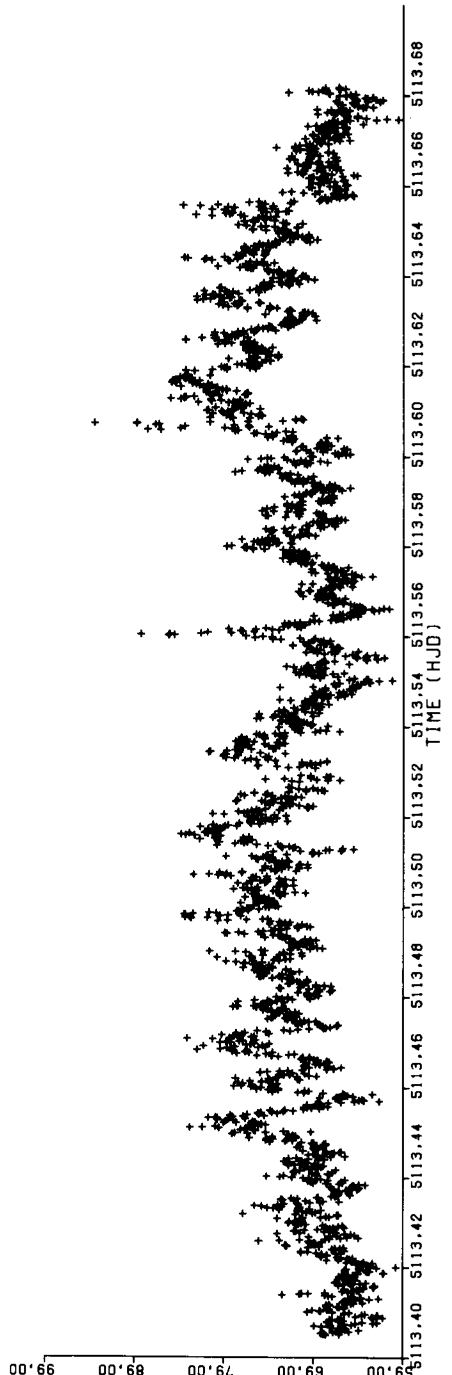

Figure 3. Light curve of V1223 Sgr. 23 May 1982.

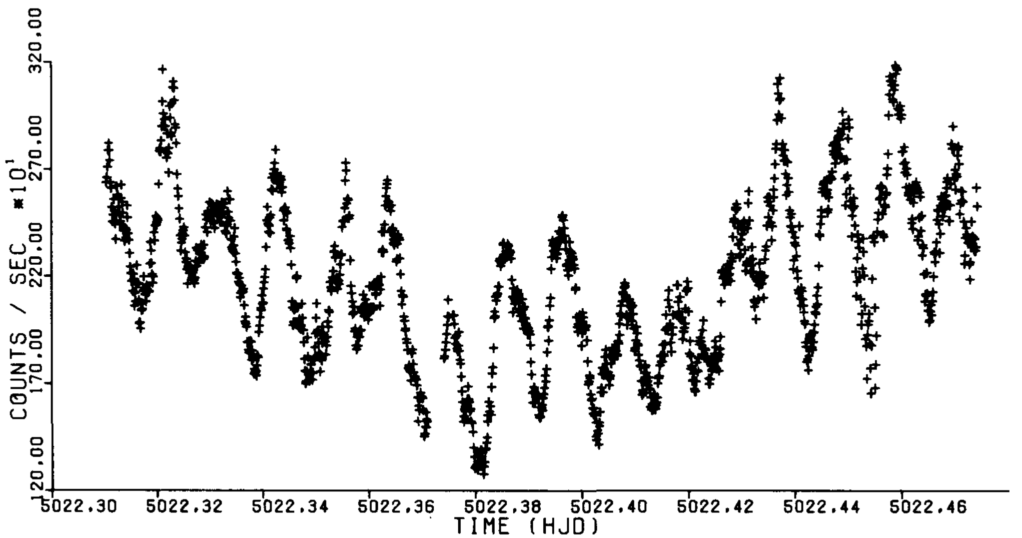

Figure 4. Light curve of 3A0729+103 21 February 1982

H2252-035, and by analogy the other intermediate polars, contain a white dwarf. The more comprehensive discussion by White and Marshall, however, leaves the situation open: they show that most of the light in the system probably comes from reprocessing off the disc; the luminosity required implies a large (unobservable) soft X-ray or far-UV flux, which is independent of the nature of the compact object and can readily bring Lx/Lopt down to $\sim$1 instead of the $\sim$300 normally expected for a neutron star. In addition, although $L_X \sim 10^{32}$ ergs sec^{-1} is five orders of magnitude lower than typical values for neutron stars, the X-ray neutron pulsar X Per has $L_X \sim 10^{32}$ ergs sec^{-1} and similar rotation period to H2252-035.

A possible method of distinguishing between white dwarf and neutron star primaries is to look at the rate of spin-up produced by the accretion torque. White and Marshall (1981) show that the expected Alfven radius in either case (for magnetic fields $\lesssim 10^{5 \text{ or } 6}$ gauss for the white dwarf) implies slow rotation in the definition of Ghosh and Lamb (1979); the latters' equations (15)-(18) and their Figure 8 may therefore be used. Then

$$-\frac{\dot{P}}{P} \simeq 8 \times 10^{-5} \ \mu_{30}^{2/7} \ R_6^{6/7} \left(\frac{M}{M_\odot}\right)^{-3/7} I_{45}^{-1} \ P \ L_{37}^{6/7} \quad yr^{-1} \qquad (1)$$

where μ,R,I and L are respectively the magnetic moment, radius, moment of inertia and luminosity (in cgs) of the degenerate star. For a neutron star $R_6 \sim 1$, $I_{45} \sim 2$ and for a $1M_\odot$ white dwarf $R_6 \sim 10^3$ and $I_{45} \sim 10^5$. The weak dependence on μ is convenient, as is the fact that a neutron star with a field $\sim 10^{12}$ gauss and a white dwarf with field $\sim 10^5$ gauss have similar magnetic moments.

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For X Per, P = 836s, L = 1 x 10^{34} ergs sec^{-1} (Mason 1977) and equation (1) predicts $\dot{P}/P \sim -9 \times 10^{-5}$ yr^{-1} for a neutron primary, which compares moderately well with the observed value of -1.7×10^{-4} yr^{-1}.

In the case of the intermediate polars, where P $\sim 10^3$s, equation (1) gives ($M = 1M_\odot$)

$$\begin{aligned} \frac{-\dot{P}}{P} &\sim 1.5 \times 10^{-5} \left(\frac{P}{10^3}\right) L_{34}^{6/7} \quad yr^{-1} \text{ for neutron star} \\ &\sim 1.1 \times 10^{-7} \frac{P}{10^3} L_{34}^{6/7} \quad yr^{-1} \text{ for white dwarf} \end{aligned} \quad (2)$$

For a given luminosity and period, therefore, we have a factor of approximately 100 difference in timescale for the two processes. Furthermore, the neutron star case is large enough to be detectable in observations made over a baseline ∿1 year, whereas the white dwarf case requires ∿10 years.

None of the intermediate polars in Table 1 has been observed long enough yet to distinguish definitely between the two possibilities. Observations of V1223 Sgr (Warner *et al.*: in preparation) show the same period in 1981 and 1982 to within ∿0.007 sec, but a full analysis of the data is still in progress.

POSSIBLE INTERMEDIATE POLARS

(i) TT Arietis

TT Arietis possesses many of the properties of an intermediate polar. Its spectroscopic orbital period is well-established by Cowley *et al.* (1975) to be 3^h18^m, but the photometric period appears to be 3^h11^m (Smak and Stepien 1975). The effect of the slippage between the two periods is clearly seen in Figures 2 and 3 of the paper by Mardirossian *et al.* (1980).

The long-term optical behaviour (Fuhrmann 1981) shows that the star is normally at $m_V \sim 10^{m}.8$ but there have been occasional drops to $\sim 12^{m}.3$ (in 1956, 1958 and 1967) and most recently to $14^{m}.5$ in November 1980.

Stockman *et al.* (1982) gives an upper limit of 0.02 percent circular polarisation in TT Ari.

Cordova *et al.* (1981) found hard X-ray emission from TT Ari with L_X(0.1-4.5 keV) $\sim 1.4 \times 10^{32}$ erg sec^{-1}. Later observations (Mason and Cordova 1982) found good correlation between optical and X-ray brightness variations, both for the orbital modulation and for faster flickering and quasi-periodic variations.

Although TT Ari shows the broad emission lines of HeII and NIII/CIII in the optical (Cowley *et al.* 1975) and CIV, NIV, NV in the far-UV

(Krautter *et al.* 1981) the optical region also shows broad absorption lines characteristic of an optically thick accretion disc (Cowley *et al.* 1975). In this manner, TT Ari differs substantially from the established intermediate polars and may represent a system undergoing a higher rate of mass transfer than the latter objects.

(ii) EX Hya

EX Hya, classified from its light curve as a dwarf nova, although an unusual one (Warner 1976), is uncharacteristic in showing weak NIII emissions in its optical spectrum (Cowley *et al.* 1981). The total line width of ∿7000 km sec^{-1} (Cowley *et al.*) indicates an accretion disc reaching close to the surface of the degenerate star (if it is a white dwarf).

The most remarkable aspect of EX Hya, however, is the presence of a brightness modulation with period 67.0 min (Vogt *et al.* 1980), quite distinct from the orbital period of 98.3 min which is established both spectroscopically and from the presence of eclipses.

Warner and McGraw (1981) found from the morphology of the eclipses that the 67-min optical modulation may arise either from periodically variable rate of mass transfer or from the rotation of an illuminating beam in the manner of an intermediate polar. They pointed out that if the optical modulation arises in the same manner as in H2252-035 (i.e. as X-ray heating of the hot spot) then a rotation period of 40 mins would be required for the degenerate component.

EX Hya is one of the brightest of the cataclysmic variables in hard X-rays (Watson *et al.* 1978). Kruszewski *et al.* (1982) find that the X-ray spectrum contains two components, the lower energy (kT $\lesssim$ 1.8 keV) is modulated with the 67 min period but the higher one is not. It is clear, therefore, that the optical modulation is derived from X-ray heating of axially symmetric parts of the accretion disc, and not from the hot spot or secondary.

The interpretation given by Warner and McGraw assumed that the EX Hya eclipses are of a hot spot on the outer edge of the accretion disc. The observed variations in eclipse depth would then be explicable as grazing eclipses of a spot whose radius vector varies and whose luminosity is dominated and modulated by X-ray heating from the rotating beam. In view of the 67 min, rather than 40 min, X-ray period this model is no longer tenable. However, the discovery (Warner and Cropper 1982) that in the dwarf nova V2051 Oph, whose orbital period of 90 mins puts it in the same class as EX Hya, the flickering and most of the optical flux from the system arises in the *inner disc* and not from the hot spot, provides the solution to the otherwise incompatible EX Hya observations.

In EX Hya, as in V2051 Oph, the disc region close to the degenerate component is now proposed as the source of most of the optical flux. Much of this luminosity derives from heating from an X-ray beam emitted by the 67-min rotation of the primary. The broad emission lines, arising from this same region, are excited by the beam thus causing the 67 min modulation in line intensities found by Gilliland (1982). The latter also found a line intensity modulation with period 33.5 min, attributable to beams emitted from accretion columns at both magnetic poles of the primary.

The optical eclipses must now be attributed to grazing eclipses of the bright central region of the accretion disc. In the absence of significant luminosity from the outer disc regions or a bright spot this is as compatible with the photometry as was the former model. As is the case in V2051 Oph (Warner and Cropper 1982), the central disc region varies both in size and brightness, causing variations in eclipse profile. The absence of X-ray eclipses (Kruszewski *et al.*) implies that the primary itself is not eclipsed - only the nearside of the inner parts of the accretion disc.

Gilliland (1982) finds that the 67 min period is changing at a rate $P/\dot{P} \sim -2.8 \times 10^6$ yrs. The bolometric luminosity of EX Hya is $\sim 6 \times 10^{33}$ ergs sec^{-1} (Bath *et al.* 1980) which in equations (2) give $P/\dot{P} \sim -2.6 \times 10^4$ yrs for a neutron star and $P/\dot{P} \sim -3.5 \times 10^6$ yrs for a white dwarf. The agreement with prediction for the white dwarf case is very satisfactory.

THE DQ HERCULIS STARS

The nova remnants DQ Her (Herbst *et al.* 1974 and references therein) and V533 Her (Patterson 1979a) and the nova-like variable AE Aqr (Patterson 1979b) have optical brightness oscillations of 71.1, 63.6 and 33.1 secs respectively. DQ Her is not detected in the X-ray region (Cordova *et al.* 1981), probably because of its high inclination. V533 Her similarly has yet to be detected in X-rays (but the upper limit, $L_X \lesssim 3 \times 10^{31}$ ergs sec^{-1} is a factor of ten higher than in DQ Her: Mason and Cordova 1982). However, AE Aqr not only has measurable flux in the 0.1 - 4 keV range but shows large modulation of this flux in phase with the optical oscillations (Patterson *et al.* 1980). All three objects show high stability: DQ Her $P/\dot{P} = -2.7 \times 10^6$ yr (Patterson *et al.* 1978), V553 Her $|P/\dot{P}| > 8 \times 10^6$ yr (Patterson, quoted by Cordova and Mason 1982) and AE Aqr $|P/\dot{P}| > 4 \times 10^7$ yr (*Ibid.*). The high stability suggests a phenomenon associated with the degenerate component, rather than with structures in the accretion disc. With luminosities $10^{34} - 10^{35}$ ergs sec^{-1} for nova remnants (Warner 1976) and AE Aqr (Patterson 1979b), equations (2) require that the primaries be white dwarfs.

In the case of DQ Her, eclipses of the white dwarf and disc provide a probe of the oscillations. The phase shift of the 71 sec oscillations during the eclipse (Warner *et al.* 1972; Patterson *et al.* 1978) have been successfully interpreted in terms of a beam reflected (or reprocessed off of the accretion disc (Petterson 1980 and references therein).

The similarity with the longer period intermediate polars is increased by the presence of circular polarisation at ∿0.6%, synchronised with the 71 secs oscillations (but with a fundamental period of 142 secs: Swedlund *et al.* (1974), Kemp *et al.* (1974).

AE Aqr is circularly polarised in the optical region by ∿0.6 percent (Szkody *et al.* 1982).

The model of DQ Her deduced by Chanon *et al.* (1978) (see their Figure 4) and the model of AE Aqr given by Patterson (1979b) (see his Figure 12) are closely analogous to the model we have described for the longer period systems.

The properties of these systems are more familiar than the newly discovered longer period intermediate polars, so we will not discuss them fully. It is clear, however, that they have the appearances of rapidly rotating magnetised white dwarf primaries. The decreasing period of DQ Her suggests a late stage of evolution of a once slowly rotating intermediate polar.

RELATED SYSTEMS

(i) The Short Period Systems

Passing from the high stability of the DQ Her stars we find a range of similar systems of lower stability. UX UMa has an oscillation period near 29 secs, which can change by up to 0.4 percent in a night but which shows a phase shift through eclipse similar (but in the opposite sense) to that in DQ Her (Nather and Robinson 1974). This has been interpreted in terms of a beam model by Petterson (1980).

The dwarf nova HT Cas has ∿20 sec oscillations during outburst which show similar phase variations through eclipse (Patterson 1981b) and which therefore establish the beamed nature of all the oscillations seen in dwarf novae during outburst. The lack of long term stability ($P/\dot{P}$ ∿ days in many cases), however, excludes the pure rotation model that we have discussed so far.

The basic model, however, may not be so very different. Suppose, for example, the primaries in dwarf novae are slow magnetic rotators and that outbursts result from an instability in the outer accretion disc (or ring) in accordance with recent conclusions (e.g. Cannizzo *et al.* 1982). The increased mass flow during an outburst reduces the size of the Alfvén radius but later, as the flow diminishes, allows it to expand again. Inhomogeneities around the Alfvén circumference would modulate the accretion flow down the magnetic poles and produce luminosity variations modulated at a frequency given by the difference in frequencies of the accretion disc at the Alfvén radius and the rotation of the primary. Such modulation would show the phase jitter seen in soft X-rays oscillations of outbursting dwarf novae (Cordova *et al.*

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1980), although maintaining a basic underlying period. This period would vary in the manner seen in dwarf nova outbursts (i.e. $P < 0$ on the rising branch and $\dot{P} > 0$ on the descending branch: Warner and Brickhill 1978).

In this manner, or in any other in which magnetic fields may be deduced to be present and determining the accretion geometry, all of the dwarf novae may eventually be considered as intermediate polars.

(ii) The Longer Period Objects

MV Lyr (Robinson *et al.* 1981, Schneider *et al.* 1981) is a nova-like variable with an orbital period of 3^h12^m derived from radial velocity observations. Its claim to be considered as a possible intermediate polar derives from the long-term light curve behaviour: it is normally at magnitude 12.0 - 14.0 but occasionally fades to 18.0 or fainter, where it can stay for as long as $1\frac{1}{2}$ yrs (Robinson *et al.* 1981 and references therein). No periodicity in the light curve, which could provide the rotation period of the primary, has yet been found. Robinson *et al.* (1981) dismiss the suggestion by Voikhanskaya *et al.* (1978) that MV Lyr is a polar, but their arguments still allow the possibility that it is an intermediate polar.

The hard X-ray emission from MV Lyr (Becker 1981) is not exceptional for a cataclysmic variable.

Stepanian's star is another possible candidate, having shown a low state (Liller 1980). Radial velocities provide the orbital period of 3^h48^m (Margon *et al.* 1980), confirmed by the eclipse period determined by Horne (1980) but the latter found no other orbitally modulated light variations. If the system is like TV Col or EX Hya then longer photometric runs would be required to detect an asynchronous periodicity. Szkody (1981) has drawn attention to the fact that Stepanian's star does not have the energy distribution of a typical cataclysmic variable.

VY Scl, which shows occasional low states, but for which no orbital or rotation period is yet known (Warner and Van Citters 1974), is another possible candidate.

A whole range of possibilities have been uncovered by Schoembs' (1982) discovery that the otherwise normal dwarf nova CN Ori possesses a doubly-periodic light curve with humps recurring at periods of $3^h54^m.9$ (the supposed orbital period) and $3^h49.7$. The connections between this behaviour, the similar phenomenon seen in TV Col (Table 1) and the appearance of superhumps (with periods a few percent *longer* than the orbital periods) during outbursts of the SU UMa class of dwarf novae (Warner 1976) are not yet clear.

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DISCUSSION FOLLOWING B. WARNER'S TALK

TAPIA: The orbital period of all intermediate polars seems to be larger than the orbital period of the polars, do you have anything to say about that?

WARNER: I don't have any evolutionary model to suggest. As an observer all I can say is that this is what we are given. You will notice there is a strong concentration of these periods around 3.5 hours.

CHANMUGAM: If they have long orbital periods that does not rule out the fact that they could have strong fields, because the Alfven radius may not extend to the companion and the white dwarf could be spinning rapidly. Have you done optical polarimetry on these objects?

WARNER: The upper limits on the circular polarimetry are all around about 0.06% or so.

TAPIA: The time resolution that we can achieve is of the order of a minute and I think that we would notice anything for those that have 20-13 min polarimetric period, but we haven't. If the polarimetric modulation is faster than that, we may have do do fast polarimetry.

ROBINSON: Can I ask how you explain the simultaneous presence of two periods in WZ Sge?

WARNER: At the moment I don't have a full explanation of any of the very short period non coherent ones.

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ROBINSON: But WZ Sagittae is coherent.

WARNER: Yes. What I was trying to draw attention to there, is that there is a sequence, as you look at the DQ Her stars which are coherent through UX UMa which is not coherent (but is not bad over a night) and through the very poorly coherent ones in the dwarf novae and if you believe the model of DQ Her then I think you almost have to accept the same model for UX UMa and by extrapolation to all the dwarf novae and I would have to include WZ Sagittae, but I don't have a clear picture.

LAMB: I would like to comment on the previous exchange. From analysis of the spin-up behaviour of these sources we can definitely say that the long period DQ Her stars as a group have field strengths that are about of factor of 10 less than the AM Her stars. There is no reason I know why that necessarily has to be so, unless the strength of the magnetic field has an effect on the evolution of the binary. So I expect that we should eventually find some long period DQ Her stars with fields comparable to the AM Her stars, just as we do have one short period system, EX Hydrae, with a period which is significantly less than that of AM Her and which is not synchronously rotating. That is because it also has a magnetic field which is about 10 times less than the other AM Her stars.

COWLEY: In the case of the systems like V2051 it is not straight forward to tell from spectroscopy whether the eclipse is of the star or a region very close to the star and the hot spot, the phasing in spectroscopy would be remarkably different.

WARNER: Yes, we have no spectra. The history of this is that Angel discovered it as an eclipsing binary about 1977, but nothing was published and then Howard Bond at the Rochester meeting said that Angel's period of 96 min was wrong and that it was really 90 min and again nothing was published, finally last year I started observing it and as far as I know this is the first detailed photometric study, but I have no spectra of it.

TAPIA: We see striking spectral similarities between the intermediate polars and the polars, isn't that evidence that the emission lines are coming from a region where the magnetic field is not important or that it is weak?

LAMB: I am not sure that that is the case. The magnetic field probably does not produce measurable Zeeman splitting of the emission lines, but it almost certainly does channel the accretion flow.

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