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Long-Term Walraven Photometry of Cataclysmic Variables

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During the last seven years we have been observing cataclysmic variables (CV's) with the Walraven photometer behind the 90-cm Dutch telescope at La Silla. An advantage of this photometric system for strongly variable blue sources is that it allows simultaneous detection in five passbands, extending from the optical (5400 Å) to the ultraviolet (3200 Å). We have observed these CV's by monitoring them for several hours, and reduced the measurements differentially with respect to nearby comparison stars.

Results obtained so far include measurements of changes in the rotation periods of accreting white dwarfs in CV's, quite strong upper limits to secular changes in optical brightness of dwarf novae (DN) between outbursts, and the recognition that accretion instabilities similar to DN outbursts also occur in systems not classified as such.

Introduction

Cataclysmic variables are close binary stars consisting of a white dwarf and a low-mass ($< 1\ M_\odot$) near-main-sequence companion. This "secondary" star fills its so-called Roche lobe, i.e. the critical equipotential surface, outside which matter is no longer bound to the star (see Fig. 1). At the point on the line through the two stellar centres, where the Roche lobes of the secondary and the white dwarf touch each other, matter from the secondary can easily fall into the gravitational potential well of the white dwarf.

Such matter, flowing from the secondary star, has angular momentum with respect to the white dwarf, due to the orbital revolution of the binary. It will therefore settle into a more or less Keplerian orbit around the white dwarf. It is generally believed that viscous processes give rise to exchange of angular momentum, by which an initially formed ring spreads and forms a flat disk-like configuration, the accretion disk, around the white dwarf. Matter transferred from the secundary gradually spirals inward along quasi-Keplerian orbits. During this diffusion of the particles, the other half is radiated away.

This radiation from the accretion disk generally dominates the optical and UV luminosity of cataclysmic variables. The kinetic energy of the inflowing material is eventually dissipated close to the white dwarf surface, e.g. in a transition region from the accretion disk to the white dwarf surface.

Based on observational characteristics, cataclysmic variables have been divided into several groups. During our observing project, we have paid most of our attention to the following types of cataclysmic variables:

Dwarf Novae

In the dwarf-nova systems the accretion rate onto the white dwarf changes in a spasmodic way. Long time intervalls of the order of months of a low accretion rate (and therefore luminosity) are interrupted by outbursts, lasting for a few days to about two weeks, during which the accretion rate increases by a large factor (see Fig. 2).

Intermediate Polars

In these cataclysmic variables the white dwarf has a magnetic field that is strong enough to dominate the motion of the inflowing matter within a certain distance from its centre. Within this "magnetospheric radius" the matter is channeled onto regions near the magnetic poles of the white dwarf. Inside this magnetosphere an accuration disk cannot exist; what fraction of the accretion disk remains depends on the size of the magnetosphere, relative to that of the Roche lobe around the white dwarf.

Brightness Variations

Most cataclysmic variables with an accretion disk show brightness variations with the orbital period, which are

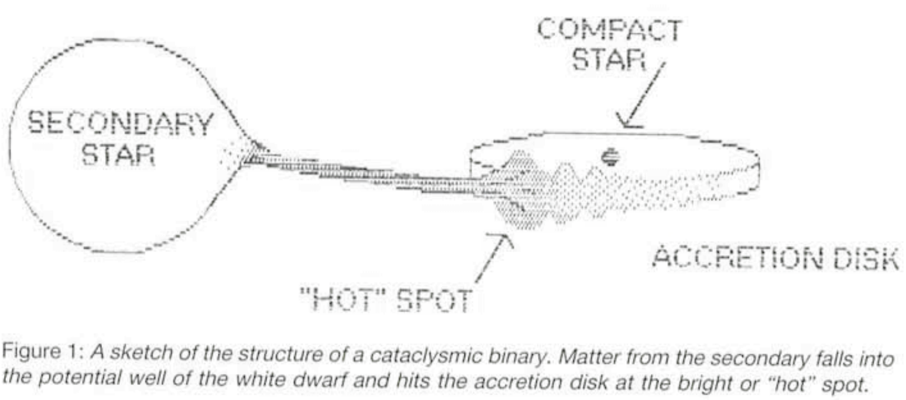

Figure 1: *A sketch of the structure of a cataclysmic binary. Matter from the secondary falls into the potential well of the white dwarf and hits the accretion disk at the bright or "hot" spot.*

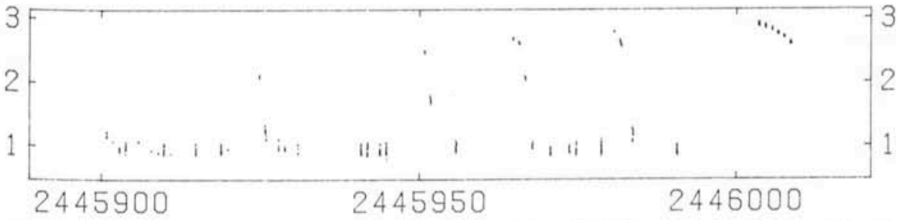

Figure 2: *An overview of the optical observations of the SU UMa-type dwarf nova VW Hyi during July–November 1984, when the source went into a normal outburst 4 times and finally went into a superoutburst. Drawn is the Walraven-B-flux in log F_ν, with F_ν in units of milli-Jansky's, against Heliocentric Julian Day.*

due to a so-called "bright spot" at the outer edge of the disk, where it is hit by the stream of matter flowing in from the secondary (see Fig. 1). In systems with a magnetized white dwarf the light can also be modulated with the white dwarf rotation period, due to the higher emissivity from the magnetic pole regions and their general non-alignment with the rotation axis of the star. In these systems the light can also be modulated with a third period, the beat period between the white dwarf rotation period and the binary revolution period, which is the rotation period of the white dwarf in the reference frame of the binary. Modulations with the beat period are due to processing of electromagnetic radiation from the rotating white dwarf by parts of the binary system that are not distributed axially-symmetric around the white dwarf, e.g. the secondary and the bright spot on the accretion disk's outer rim (see Fig. 3 for an example of these modulations).

Dwarf Novae

Two types of models have been proposed to explain the outbursts of dwarf novae. In the disk-instability model [1] the accretion disk can exist in two different modes, corresponding to a high and a low value of the mass accretion rate through it. In the quiescent state the accretion rate through the disk is smaller than the the mass transfer rate from the secondary, so that the density in the disk builds up steadily. Coupled to this secular increase of the density one expects an increase of its brightness (mainly in the optical and UV). When the density has reached a particular value, the disk cannot remain in this state of low accretion, but suddenly switches to a state with a high accretion rate. During this outburst the mass accretion rate onto the white dwarf is higher than the mass transfer rate from the secondary. When the density has declined sufficiently, the disk returns to its quiescent state. In the mass-transfer-instability model [2], the outbursts are explained by mass-transfer bursts from the secondary, which are directly transported through the disk to the white dwarf. During quiescence, when the accretion rate onto the white dwarf equals the mass transfer rate from the secondary, no secular changes are expected in the accretion disk's state.

One of the aims of our long-term photometric project of cataclysmic variables was an attempt to distinguish between these two types of model, by studying the possible secular brightness variations of dwarf novae in quiescence. For this purpose we have observed the system VW Hyi during 42 nights over a time interval of 4 months, during which 5 outbursts occured. These observations were coordinated with observations with EXOSAT, Voyager, IUE, and Walraven [3] (see Fig. 2). The main outcome of this study is that there is no evidence for a significant trend in the optical brightness from the system between outbursts (see Fig. 4). The same was found in the X-ray and UV observations (if any change is discernable it is a secular decrease, not an increase). This result is not easy to reconcile with simple versions of the disk-instability model.

At the end of our campaign VW Hyi went into a so-called superoutburst. VW Hyi belongs to a subgroup of dwarf novae, the SU UMa systems, that show two rather different types of outbursts (superoutbursts and "normal" outbursts). Superoutbursts are different from normal outbursts – in their rate of occurrence (less often), their duration (longer), and their maximum luminosity (higher). Apart from this, it is found that during superoutburst, the optical brightness is strongly modulated; these so-called superhumps recur with a period that is slightly longer than the orbital period; also this superhump period is not exactly constant, but increases through the superoutburst. The superhumps have always been a big problem, which resisted theoreticians' attempts to model them. However, recently Whitehurst has proposed that the superhump phenomenon might be the result of a mass-transfer burst from the secondary, leading to a slowly precessing, more or less eccentric disk, as the result of tidal distortion by the secondary of the orbits of particles in the outer disk regions [4]. His model successfully accounts for many of the strange properties of the superhumps.

Our Walraven observations of the superoutburst of VW Hyi, which were done in five channels simultaneously, have led to the discovery of another strange property of superhumps: the whole superhump-modulation light curve arrives later when seen at longer wavelengths. The total shift from 3200 Å to 5400 Å is + 0.06 in phase of the superhump period [5]. We cannot offer an explanation for this finding.

Intermediate Polars

In intermediate polars the influence of the white-dwarf magnetic field does not

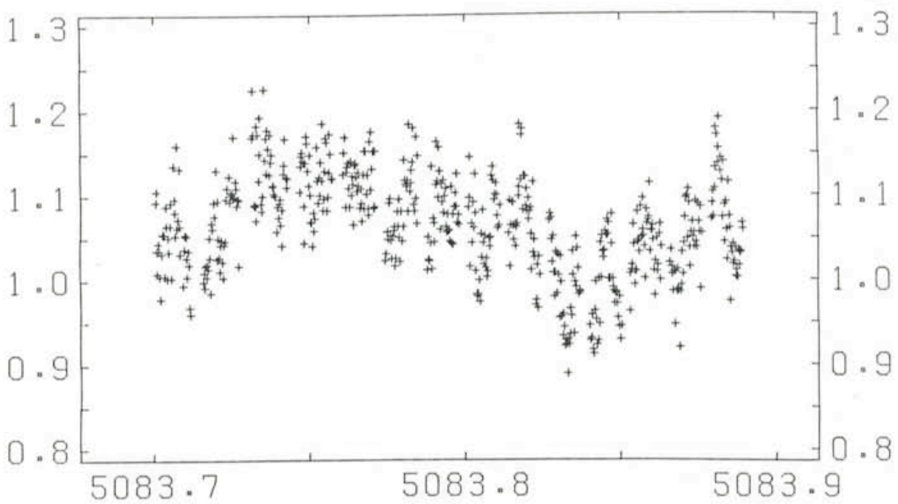

Figure 3: *Modulations of the Walraven-B-band brightness of the intermediate polar V1223 Sgr on 1982 April 24. A long-term modulation with the binary revolution period of 3.4 hours (0.14 day) and a modulation with the beat period between the white rotation period and the orbital period, of 13.2 minutes (0.0092 day), can be seen. The flux is given in flux units of a local comparison star; time is given in HJD-2440000).*

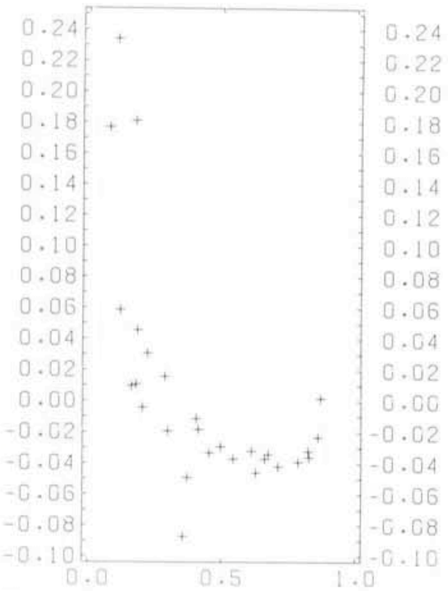

Figure 4: *VW Hyi. The residual flux in the Walraven-B band, averaged over one orbital cycle, relative to the overall average orbital light curve, is given against the relative phase in time between two successive normal outbursts. Apart from the decline of the flux after an outburst, no rising or falling trend is seen in the brightness of VW Hyi during the quiescent state of the dwarf nova.*

extend to the secondary. Consequently, matter spiralling inward in the outer accretion disk region becomes connected to the magnetic field (and will corotate with the white dwarf) only within the magnetosphere of the white dwarf. When it is connected, it either looses angular momentum to the white dwarf or gains angular momentum from it. This accretion torque accelerates or decelerates the white dwarf's rotation, until the white dwarf has reached an equilibrium period at which the net torque vanishes (this equilibrium period depends on the magnetic field strength and the mass accretion rate).

From our long-term observations of intermediate polars we found that the white dwarf in V1223 Sgr spins down, while in H2252-035 it spins up (see Fig. 5); Pakull & Beuermann also found a down-spinning white dwarf in H2215-086. Previous to our observations, only spin-ups of accreting magnetized white dwarfs had been found. From models which link the accretion torque to the rate of change of the spin period of the white dwarf, we found that the white dwarfs do not spin close to their equilibrium spin rate. One way in which these white dwarfs could be unable to reach their equilibrium spin period, is by large changes in the mass accretion rate. We estimate that such equal changes in the mass transfer rate take place on time scales less than 10^{5-6} years, which is very short compared with the evolution time scale of the binary; therefore these changes in the mass transfer rate should occur very often in the lifetime of the binary [6]. As there is no reason why this should only happen in intermediate polars, it is likely to occur in all cataclysmic variables.

A possible explanation for long-term variations in the mass transfer rate from the secondary, might be the occurrence of thermonuclear flashes on the surface of the white dwarf (classical nova outbursts), in which about 10^{-5} $M_{\odot}$ is lost. These classical novae possibly lead to an increasing separation of the two stars and a temporary disconnection of the secondary from its Roche lobe, so that the mass transfer process stops (or at least becomes much smaller) [7]. In the following stage of "hybernation" of the cataclysmic variable, the two stars will gradually come closer to one another as the result of loss of orbital angular momentum, due to emission of gravitational radiation and to magnetic braking, and mass transfer will restart when the secondary again touches its Roche lobe.

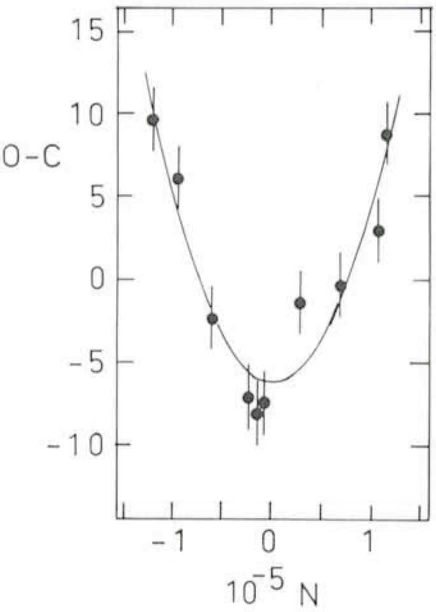

Figure 5: *The deviations (O–C, in units of 0.0001 day) of the optical beat pulse arrival times in the intermediate polar V1223 Sgr from a linear fit against their cycle-number (N). The parabolic curve drawn gives an estimate of the rate of increase of the white dwarf rotation period (spin-down). The spin period is 0.0092 day.*

Do All Cataclysmic Variables Burst?

During recent observations of the intermediate polar TV Col we encountered a surprising feature, only seen once before in this system. Within one week this source showed two outbursts, that looked remarkably similar [8]. Both bursts lasted less than about half a day, and reached an amplitude of 2 magnitudes; they last therefore much shorter and are less luminous than dwarf nova outbursts. We have in 1984 also detected a similar short burst in V1223 Sgr, with the same characteristics as the bursts in TV Col (see Fig. 6). In addition to the photometry, the observers (H. Schwarz of ESO and M. Heemskerk of Uv Amsterdam) collected spectra of the second outburst. From the spectral line information obtained, it became clear that this outburst developed in a different way than normal dwarf nova outbursts do.

It is attractive to relate the differences in the outburst characteristics of the intermediate polars and dwarf novae, with the difference in their accretion disk structure. It looks as if the absence of an inner disk in the intermediate polars precludes the full development of the burst as a real dwarf-nova outburst.

It appears valuable to follow the cataclysmic (physically) variable

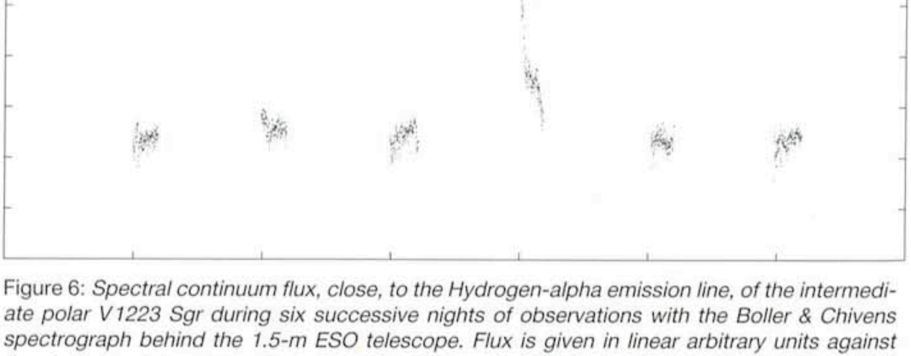

Figure 6: *Spectral continuum flux, close to the Hydrogen-alpha emission line, of the intermediate polar V1223 Sgr during six successive nights of observations with the Boller & Chivens spectrograph behind the 1.5-m ESO telescope. Flux is given in linear arbitrary units against time in units of days. The decline of a burst is visible in the 4th night of observations (on 1984 Aug 31). During the declination of the flux, the more or less sinusoidal orbital modulation of the light is visible.*

binaries, to see how they behave on a long time scale. The spasmodic emission of radiation due to the unstable mass transfer/accretion process, makes it necessary to open the observing window a bit more in order to detect crucial phenomena at the right moment. From the long-term behaviour of these systems we have probably been able to derive information on their evolutionary scenario.

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IRAS Molecular Clouds in the Hot Local Interstellar Medium

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1. Introduction

The picture of the nearby (d ≤ 100 pc) interstellar medium, as resulting from the observations in the wavelength range from X-ray to radio, consists of a very hot, low-density gas, forming a hot bubble, filled with many cloudlets of ionized and neutral material and located near to an interstellar condensation (see the "Local Interstellar Medium", NASA CP-2345, 1984; and Cox and Reynolds, 1987).

Only recently the existence of a colder counterpart in the nearby gas was argued by Magnani, Blitz and Mundi (1985), who reported the detection of a large number of "local" molecular clouds at high galactic latitude and inferred from statistical arguments an average distance of about 100 pc.

A comparison with the IRAS maps showed that all the high latitude molecular clouds can be identified with the cores of the new discovered infrared (60 and 10 μm) features: "the IRAS cirrus" (Weiland et al., 1986).

Nearby molecular clouds are then associated to the cold interstellar material with temperatures ranging from 14 to 40 K.

In order to understand the physical properties of the local medium and their effect on other observations, it is interesting to tackle the problem of the coexistence of a cold and neutral gas with a hot medium and the mixing between these two gaseous phases.

The distance, the morphology and other properties of the clouds, belonging to the local interstellar medium, can be determined by mapping the interstellar absorption lines toward stars at different distances and projected along the line of sight to these clouds.

The feasibility of this procedure has already been demonstrated by Hobbs et al. (1986) who estimate the distance of the cloud Lynds 1457/8 at about 65 pc.

We selected several high latitude clouds detected by IRAS and/or at CO wavelength (2.6 mm) by Magnani, Blitz and Mundi (1985) and gathered echelle spectra of a few stars with the ESO CAT telescope at La Silla, Chile.

2. The Observations

From the IRAS HCON 1 survey (see IRAS Explanatory Supplement, 1984), we selected those clouds at 100 μm, which were already detected at the CO band (Magnani et al., 1985) and located at high galactic latitude (| b | ≥ 25°).

The MIDAS software package (ESO Operating Manual No. 1, 1984) has been used to analyse the IRAS maps. The whole procedure of IRAS images analysis will be published elsewhere (Andreani et al., 1988).

Table 1 lists the known properties of the clouds from infrared and CO measurements. The position, photometry, spectral type and distance are taken from the Bright Star Catalogue for the brightest programme stars, and from the HD Catalogue for the others. Stars were chosen to be bright, hot, and of early spectral type.

High-dispersion Ca II K and Na I D spectra were gathered during 1986–1987 with the Coudé Echelle Spectrometer fed by the 1.4-m CAT telescope and equipped with either a

TABLE 1. *Infrared and CO Properties of the Clouds*

	Cloud	Coordinates				IRAS					CO
#	Name	α (h)	δ (°)	l (°)	b (°)	12 μ	25 μ	60 μ (MJy/sr)	100 μ	T_d (K)	T_a (K)
20	L 1642	4 33	−14 20	210.9	−36.5	–	–	.3 ± .2	11.2 ± 2.8	20	6.8
126	ϱ-Oph	16 16.3	−19 48	355.5	−21.1	–	–	10 ± 3	12 ± 3	29	9.2
113	–	15 17.1	−29 25	337.8	−23.04	–	–	13 ± 4	12 ± 4	32	6.1