COMMUNICATIONS
FROM THE
KONKOLY OBSERVATORY
OF THE
HUNGARIAN ACADEMY OF SCIENCES

MITTEILUNGEN
DER
STERNWARTE
DER UNGARISCHEN AKADEMIE
DER WISSENSCHAFTEN

BUDAPEST — SZABADSÁGHEGY

No. 86.

ERUPTIVE PHENOMENA IN STARS

EDITED
BY
L. SZABADOS

BUDAPEST, 1986

ISBN 963 8361 22 0
HU ISSN 0324 — 2234

Felelős kiadó: Szeidl Béla

Hozott anyagról sokszorosítva

8616412 MTA Sokszorosító, Budapest. F. v.: dr. Héczey Lászlóné

CONTENTS

LIST OF PARTICIPANTS

BULGARIA

Popova, M.D.
Tsvetkov, M.K.
Tsvetkova, A.G.

CZECHOSLOVAKIA

Chochol, D.
Harmanec, P.
Urban, Z.

GDR

Luthardt, R.
Richter, G.

HUNGARY

Jankovics, I.
Kelemen, J.
Oláh, K.
Szabados, L.
Szécsényi-Nagy, G.

POLAND

Schwarzenberg-Czerny, A.
Ziolkowski, J.

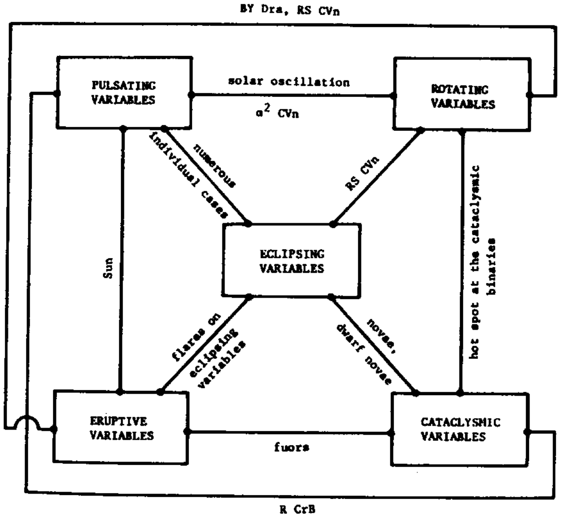
USSR

Chavushian, H.S.
Denisov, A.A.
Dmitrienko, E.
Gasparian, K.G.
Gavrilov, V.V.
Gershberg, R.E.
Golovaty , V.V.
Goncharova, R.I.
Katsova, M.M.
Kimeridze, G.N.
Lozinskaya, T.A.
Merkulov, V.N.
Mirzoyan, L.V.
Natsvlishvili, R.S.
Pylskaya, O.P.
Romanov, Yu.S.
Sat, L.
Zalinjan, V.P.

INTRODUCTORY REMARKS

The Symposium "Eruptive Phenomena in Stars" was held at Konkoly Observatory, Budapest, from 10-12 September 1985. This biennial symposium of the multilateral co-operation "Stellar Physics and Evolution" was organized by Subcommission No. 3 ("Nonstationary stars") and the host institution.

Because one of the primary goals of these symposia is to gather as many astronomers taking part in the co-operative work as possible, the title of the conference was chosen so as to cover a very wide field. The eruptive variables themselves form a very diverse and inhomogeneous bunch of the variable stars. Recently, the fourth edition of the General Catalogue of the Variable Stars (Moscow, 1985) separated the cataclysmic variables from the eruptive (mostly young) ones. The realm of the variable stars, however, is not so simple that any sharp division of the main classes could successfully be applied. Eruptive phenomena do occur in other types of variables as well. The accompanying scheme clearly shows how the eruptive, cataclysmic, pulsating, rotating and eclipsing types of variability co-exist in real variable stars. This figure is the simplest example illustrating that the term "eruptive phenomena" embraces all types of variables in addition to the classical eruptive variables.



The 33 participants from six countries enjoyed five review lectures and 27 contributed papers. This volume contains a detailed version of the reviews and two-page abstracts of the contributions. The order is not strictly that in which they were presented.

I should like to thank all authors who submitted their manuscripts in camera-ready form at the beginning of the conference as requested thereby facilitating the editorial tasks. In particular, I express my gratitude to Mrs. É. Végvári and Mr. H. Shenker for their help in editing the proceedings. Our thanks go to the Hungarian Academy of Sciences for the financial support.

Budapest - Szabadsághegy, 6 February 1986

The Editor

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

THE NATURE OF DWARF NOVAE

Alex Schwarzenberg-Czerny

Warsaw University Observatory,
Warsaw, Poland.

0. Introduction.

In this paper only brief description of Dwarf Novae (DN) is given and interested reader is encouraged to look into reviews by Meyer (1985) and Smak (1984a) for more detailed account of theory and observations, respectively.

Reviews by Cordova and Mason (1982), King (1985), Pringle, (1981), Robinson (1976), Szkody, (1985) and Warner (1983) are on topics related to DN.

1. The Position of DN among Cataclysmic Binaries.

DN belong to Cataclysmic Variables. They all in fact are Cataclysmic Binaries (CBs) with short period consisting of a cool star (a red dwarf) filling its Roche Lobe and loosing mass, and a white dwarf. The stream of the gas from the cool star has excess angular momentum and it forms an accretion disk around a white dwarf, unless its magnetic field prevents it. Observations, discussed in detail by Robinson (1976), may be summed up as follows.

i/ The cool stars cause eclipses and their spectra are seen in the near infrared in some cases. Since their Roche Lobe is usually small, only red dwarfs may fit in. They have to fill it completely to transfer mass to their companions.

ii/ The disks are sources of blue and UV continuum and of emission lines with radial velocities varying in phase with the unseen star (the white dwarf). The lines are frequently doubled due to the Keplerian rotation of the disks and they show peculiar rotation shifts during eclipses, namely the low velocity cores are eclipsed first and the high velocity wings later. The collision region of the stream with the disk, called the hot spot, is a source of continuum and line emission variable in intensity and wavelength due to aspect and Doppler effects, respectively.

iii/ White Dwarfs are rarely seen directly, however their presence is inferred from the presence of high Keplerian velocities in the double lines from the orbits near the star's surface. In principle high velocities are permitted on orbits around neutron stars but gas crushing against their surface would emit too much soft X-rays to accommodate with observations.

The classification of CBs is based on their light curves with exception of systems with strong polarisation of light and, presumably, strong magnetic field called AM Her or Polar type stars (King, 1985).

DN have outbursts with amplitudes ranging from 2 to 6 magnitudes and which last several days and repeat on a time scale from weeks up to years (c.f. Fig. 1). Those outbursts are called normal outbursts. There are three subclasses of DN:

U Gem - type stars which suffer from normal outbursts alone.

Z Cam - type stars which after some outbursts fail to decline to the pre-outburst luminosity and remain in an intermediate state of brightness for prolonged time intervals, called standstills. Eventually they complete the decline to quiescence and resume their normal outburst activity.

SU UMa stars apart from normal outbursts have superoutbursts lasting several times longer and with larger amplitude. The peak of superoutbursts is followed by a plateau.

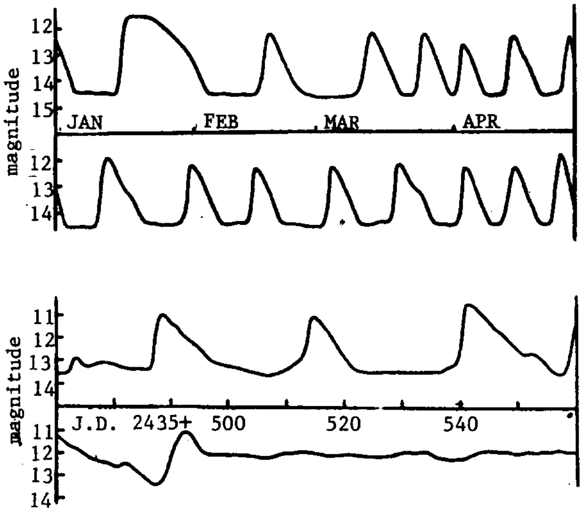


Fig. 1. The visual light curves of SU UMa (top) and Z Cam (bottom) (Glasby, 1968). Units are 30 and 10 days, respectively, and one magnitude.

Other CBs are Novae (N), which undergo violent outbursts, with amplitudes significantly exceeding 10 magnitudes, Recurrent Novae (RN) which multiple outbursts were observed and Nova-like stars (NL) which resemble old novae but were not seen in outburst. It is believed that outbursts of N and RN are thermonuclear explosions of white dwarf envelopes and we shall not concern with them any more in this paper.

2. $\dot{M}$ B P classification.

We shall demonstrate that three well defined theoretical parameters of the systems suffice to recover the same classification. The parameters, namely the accretion rate $\dot{M}$, the strength of magnetic field B and orbital period P, can be estimated from observations independently of the light curve.

The main source of energy in CV is gas falling down to the white dwarf, so time-averaged luminosity of CV is proportional to the accretion rate $\dot{M}$ and the visual rather than bolometric luminosity may be used since it is less sensitive to unknown mass of the white dwarf. Magnetic fields B are not measured directly but their presence is inferred in Polar stars unambigously from their light polarization.In the three dimensional space defined by the parameters $\dot{M}$ B P CB stars tend to group according to their variability class (see Fig. 2).

RN, N and NL stars are unresolved by the MBP classification, however, they all could have unobserved outbursts in the past and thus it is likely they are all the same but differ by the frequency of their outbursts. The Intermediate Polar (IP) and DQ Her (DQ) stars may be just one subclass (King, 1985). CB's form a highly inhomogeneous class and it has to be kept in mind the segregation is not strict. Among one hundred of systems in Ritter's (1984) catalogue HT Cas, UU Aql, VW Vul, V2051 Oph, T Leo, TU Men, CP Lac and AM Her, 1E2003+225, EX Hya lay on the wrong side of period border while GK Per and VY Aqr are simultaneously members of N and U classes.

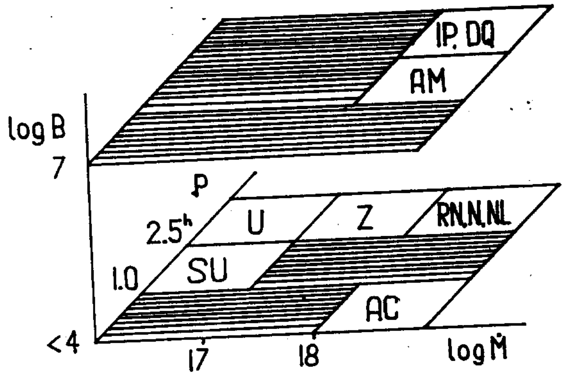


Fig. 2. The ṀBP classification of Cataclysmic Binaries. See text for details.

3. Stationary Accretion Disks.

In thin stationary disks radial gradients are smaller than those vertical by a ratio of thickness to radius $H/R \sim 1/30$ and may be neglected in the vertical structure equations. As in the stellar case there are four equations with the independent variable being fractional surface density rather than fractional mass. For our purpose suffice to use dimension relations:

$$\Sigma \sim H\rho \qquad \text{continuity}$$

$$kT/\mu \equiv v_s^2 \sim v_k^2 (H/R)^2 \qquad \text{hydrostatic equilibrium}$$

$$\sigma T^4 \sim \Sigma \nu \omega^2 + NTE \qquad \text{energy balance} \tag{1}$$

$$T/T_e \sim (\Sigma\kappa)^{\beta/4} \qquad \begin{array}{ll} \beta = 1 & \text{rad. transport} \\ \beta = 4\frac{\gamma-1}{\gamma} & \text{conv.} \end{array}$$

where v_s and v_k are sound and Keplerian velocities and T and T_e are central plane and effective temperatures.

For lack of better theory we are forced to use α- prescription for viscosity: $\nu \sim \alpha v_s H$ where $\alpha \approx 0.2$ agrees with observations. Time scales and velocities of propagation of perturbations to the stationary disk are listed in Table 1.

Solution of the structure equations gives $T - \Sigma$ relation (Hoshi, 1979), an analogue of the stellar mass - luminosity relation:

$$(\mu\sigma/k\omega)^{1/(\beta+1)}\,(T^3/\kappa^\beta\alpha)^{1/(\beta+1)} \sim \Sigma \tag{2}$$

In sufficiently high temperatures opacity κ, dominated by the electron scattering, is constant and Σ decreases with T. However, as temperature drops below 10000 K, hydrogen recombines and opacity decreases so drastically that it overcompensates the decrease of the temperature and rises. At still lower temperatures opacity varies slower and decreases with T again: A complication caused by switching on the convective transport does change the exponent but does not change the general character of the T - Σ relation (Fig. 3). Since energy losses due to radiation are balanced by the gain due to viscosity, temperature increases as the local accretion rate increases and reverses.

Table 1.

time	velocity	type
$1/\omega$	$\omega R \equiv v_k \sim (GM/R)^{1/2}$	orbital
$1/\omega$	$v_k(H/R)$	vertical dynamic
$1/\omega\alpha$	$v_k(H/R)\,\alpha$	vertical thermal
$1/\omega\alpha\ (H/R)^{-1}$	$v_k(H/R)\,\alpha$	front propagation
$1/\omega\alpha\ (H/R)^{-2}$	$v_k(H/R)^2\,\alpha$	accretion.

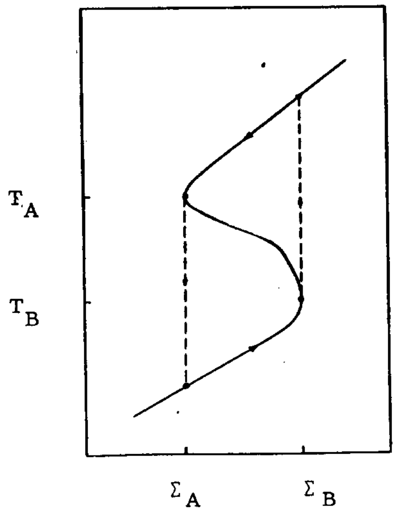


Fig. 3. Log Temperature - Log Surface Density plot for a given location in the disk.

4. Non-stationary Disks.

The stability of the disk depends on the fate of the perturbations with the thermal time scale. On one hand, the dynamical time scale is shorter than the thermal one so the hydrostatic equilibrium holds. On the other hand, the surface density remains practically constant during the thermal time scale. Out of the thermal equilibrium cooling is not compensated by heating and the NTE term in Eqtn. 1 does not vanish. Since they both enter in the same place in Eqtn. 1, the NTE term out of the equilibrium has the same effect as the departure of the α-viscosity term in the equilibrium from its original value for α_o. Thus, the disk with the α_o-viscosity during cooling resembles the stationary disk with the α-viscosity, where $\alpha > \alpha_o$ (Smak, 1984). Such disk's place in Fig. 3 is to the left of the equilibrium line and it cools on the thermal time scale, at nearly constant surface density, moving vertically down in Fig. 3. By virtue of similar arguments disks to the right of the line heat up and move vertically up.

Stationary disks on the middle branch of $T - \Sigma$ relation are locally thermally unstable: if cooled a little bit, they would continue cooling till they reach the bottom stable branch or heated they would reach the top stable branch. Thus, for a range of accretion rates no stationary disk may exist. What happens, if mass is supplied at such rate? Let the disk be originally cool and it allows mass through at slower rate than it is supplied. The density in the disk rises and it evolves slowly, on the accretion time scale, up the equilibrium line. After some time the density reaches the maximum value on the stable branch, Σ_B, and the disk falls out of the thermal equilibrium, heating up on the thermal scale till the top stable branch is reached. However, now the local accretion rate in it is faster than the supply rate, surface density decreases down to Σ_A and and again the disk falls out of the thermal equilibrium and it lands back on the bottom cool branch. In such a way locally the disk follows a limit cycle. Its global behaviour depends on synchronisation of the local cycles.

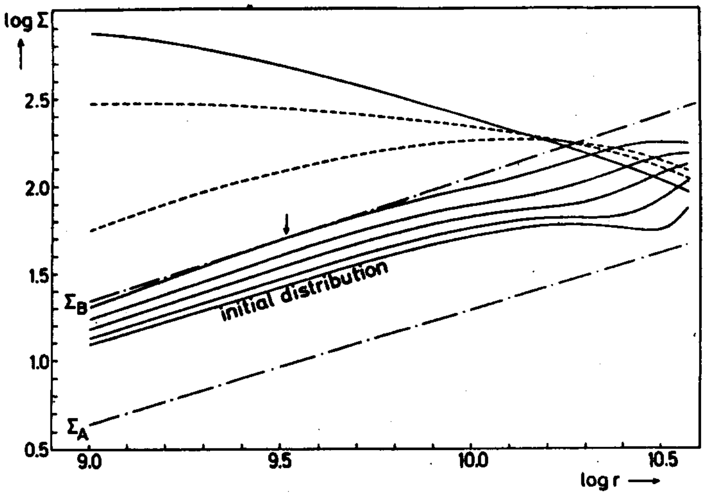


Fig. 4. Log Surface Density - Log Radius plot for the whole disk. It evolves from the bottom to top distribution of density. Start of outburst is marked with an arrow. Dot-dashed lines mark the instability region (Meyer and Meyer-Hoffmeister, 1984)

Generally, disks evolve on the accretion time scale R^2/ν, subjected to the mass and angular momentum conservation conditions. One consequence of the conservation of momentum is that the accretion rate for a ring in the disk is proportional to the rate at which a net couple, resulting from non-equality of the viscous torques at inner and outer boundary, removes its angular momentum. The rate of the accumulation of mass in the ring is proportional to the gradient of the accretion rate (c.f. Lightman, 1974, for the rigorous diffusion equation):

$$(3)\qquad \dot{M} \sim \partial(\Sigma\nu)/\partial r \qquad\qquad \partial\Sigma/\partial t \sim \partial^2(\Sigma\nu)/\partial r^2$$

On the surface density - radius plot (Fig. 4) two lines delimit the instability region. Let us consider again a cool disk to which mass is supplied at the rate high enough to cause its accumulation. Surface density increases and the disk falls out of the equilibrium in the ring where first violation of the Σ_B limit occured. During the thermal time scale the ring reaches again equilibrium in the hot, high viscosity state. Small viscous torques from outside and inside the ring are not capable to balance its internal torques, so the ring expands in and out. Some mass gets into the adjacent rings, thus helping to start transition there. In effect transition fronts propagate from the initial ring inwards and outwards.

The fronts move faster than the accretion velocity since they are accelerated by steep gradients. On one hand the velocity of the front is the ratio of its thickness to the time of regaining equilibrium, the thermal time scale in our case, $v_f \sim l/\tau_t$. On the other hand, the accretion rate and so the velocity, are proportional to the rate of viscosity increase to the front thickness: $v_f \sim \nu/l$. Combining the two equations we get the answer given in Table 1. In a similar fashion the reverse transitions propagate. In effect, all limit cycles in the unstable part of the disk are synchronised within time shorter than the accretion time scale and longer than the thermal time scale (Meyer, 1984).

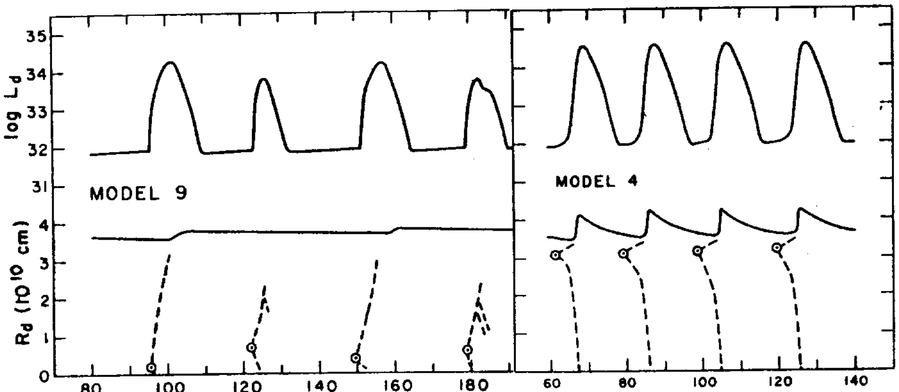


Fig. 5. Calculated bolometric light curves and location of transition fronts in type A (right) and type B (left) outbursts of DN (Smak, 1984b).

The detailed calculations of the evolution of accretion disks were conducted by Meyer and Meyer-Hoffmeister, (1984), Smak, (1984b) and also by Papaloizou et al. (1983) and Mineshige and Osaki (1983). In their models disks in DN in quiescence remain cool and accumulate mass on the accretion time scale. Eventually, after accumulation of sufficient mass the transition starts and during the front propagation time scale the whole disk becomes hot at the beginning of an outburst. The outburst lasts for the accretion time, and eventually density decreases so that the reverse transition stops it.

The authors of calculations found two types of outbursts possible:

- type A which starts near the rim of the disk and propagates inwards, they tend to repeat periodically,
- type B which starts inside the disk and propagates outwards. The latter does not leave the disk in the original state, so alternate or irregular strength and frequency outbursts occur (see Fig. 5).

They were able to reproduce the observed ratio of the length of the outburst to the length of the whole cycle only with an arbitrary decrease of viscosity during quiescence. Meyer and Meyer-Hoffmeister (1984) gave some justification of this modification.

5. Evidence from Observations.

In a stationary flow both the spot and disk are powered by the accreted gas and in quiescence the ratio of their luminosities should be equal the ratio of the corresponding gravity potentials: $L_s/L_d \sim (R_d/R_{wd})^{-1}$. In fact the spot is too bright by a factor of 10 so that mass accreted by the spot during quiescence is accumulated in the disk and it is released during an outburst (Osaki, 1974). Indeed, the ratio of luminosities averaged over the outburst cycle is correct.

Paczynski and Schwarzenberg-Czerny (1980) strengthened the argument using more realistic models of the disk and spot to estimate the accretion rate. The estimates of the spot's luminosity from UV observations (Wu and Panek, 1982) and 2D hydrodynamic models of the flow in the spot (Rozyczka and Schwarzenberg-Czerny, 1986) lend further support to Osaki's hypothesis.

Osaki also noted that the cycle length - amplitude relation in DN is typical for a limit cycle proposed.

Smak (1984a) presented evidence that dwarf novae indeed occupy an instability strip of accretion rates as expected from the theory. We stress that GK Per is a true bilingual Rosetta stone in that its disk is cool enough to allow DN instability in its outer parts and at the same time it has accretion rate sufficient for a nova. It is worth of notice that no outbursts are observed in Polar stars where no disks exist but envelopes of the red stars should not be affected by companions magnetic field and where the accretion rate on occasions fall to the same level as in DN in quiescence.

Data for detailed comparison of outbursts are scarce. On one hand, theoretical models need further elaboration in order to give colours and spectra for outbursts of real DN. On the other hand, few outbursts were observed from the beginning to the end and with wide spectral coverage.

A complete outburst of VW Hyi was observed in the UV and visual bands simultaneously (Schwarzenberg-Czerny et al., 1985). Similarity of the observed light curves presented in Fig. 6b with those calculated for the type A outburst (Fig. 6a) suggests that outburst started near the disk's rim. At the very beginning , the UV flux and spectrum of the disk remained the same as in quiescence while the visual flux raised substantially (Fig. 7).

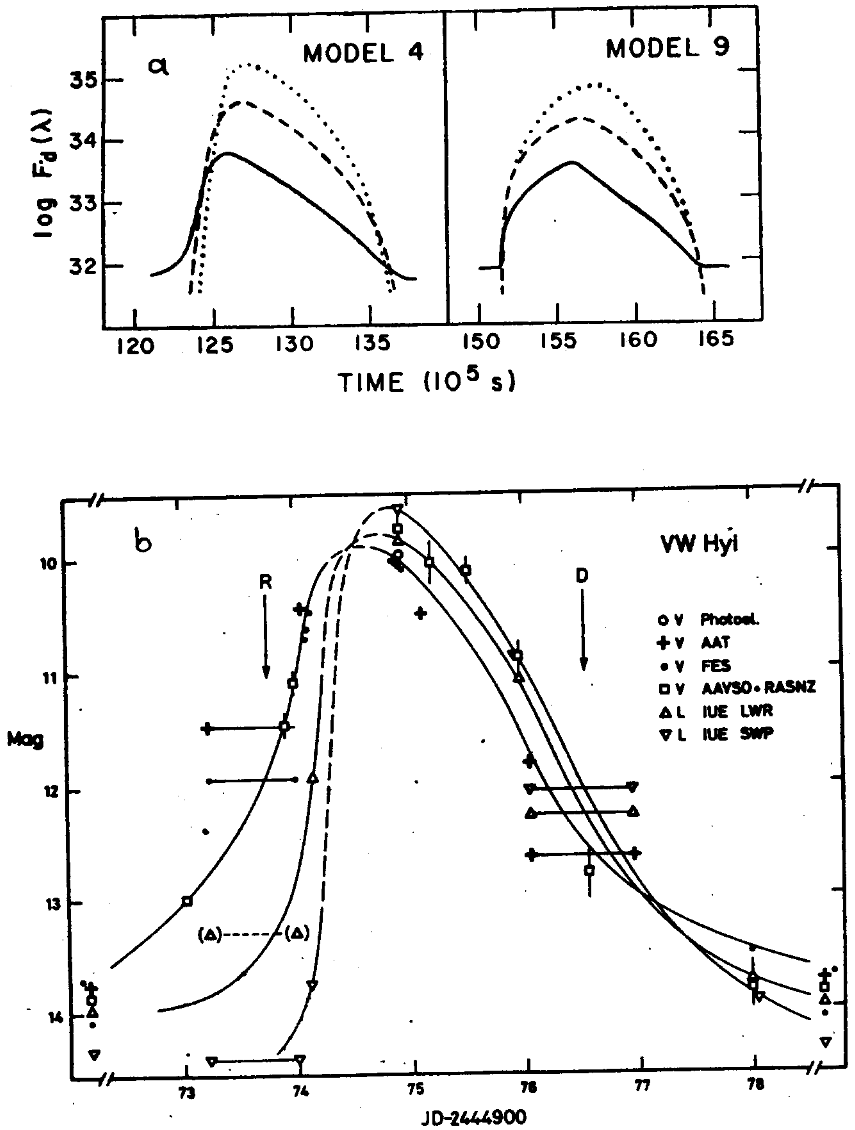


Fig. 6. Monochromatic light curves for 5500 Å (solid), 2500 Å (broken) and 1200 Å (dotted lines): a) calculated (Smak, 1984b), b) observed for VW Hyi (Schwarzenberg-Czerny et al., 1985). Note the delay of 1200 Å curve with respect to 5500 Å one.

The rise of the UV flux was delayed by a day and it took only several hours. Presumably in that time the transition front reached to the centre of the disk. Similar delay was observed in outbursts of RX And, SS Cyg and U Gem compiled by Szkody (1985). Widening of optical eclipses at the beginning of outbursts (Vogt, 1981a) is understandable for A type outbursts.

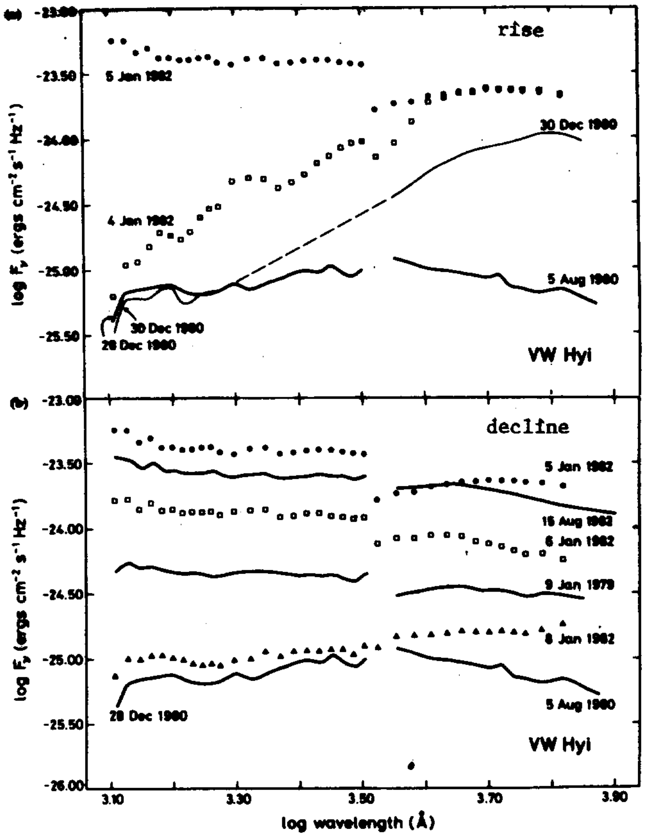


Fig. 7. Evolution of the continuous spectrum during the rise of the same outburst as on Fig. 7b (Schwarzenberg-Czerny et al., 1985).

No outburst observed in detail was of type B, but alternate type outbursts, known for long in SS Cyg and other DN, may be of that type.

6. Unresolved Problems and Future Prospects.

6.1 The SU UMa Syndrome.

Apart from superoutbursts SU UMa stars possess other distinct properties. Their periods (except for TU Men) are shorter than 2-3 hours period gap. The superoutburst light curves display modulation, called superhump, and with period by several percent longer than the orbital period (Warner, 1983).

Observations of eclipsing systems indicate that it is the disk that becomes bright during the superoutbursts. They appear to be triggered by normal outbursts, but, since the accretion time scale may not be longer than the duration of normal outbursts, they are aided by the increased mass transfer. At least in one star, VW Hyi, there is a slight increase of mass transfer during the normal cycles preceding a superoutburst (Vogt, 1985) and correlations exist between the length of normal cycles and occurrence of superoutbursts (Smak 1985).

The amplitudes of superhumps do not depend on inclination and their peaks are too narrow for an aspect effect being responsible for them. Thus, they are the intrinsic variations of brightness.

The mechanism of superoutbursts is not clear. The red star instability model may enjoy here some success (Charles et al., 1985) although alternative explanations for superhumps and/or superoutbursts were proposed (Papaloizou and Pringle, 1979, Vogt, 1981b, Warner, 1983, Hensler, 1985).

6.2 Mass Supply.

The nature of CB's depends so much on the mass transfer that their ultimate explanation has to await clarification of the mechanism which supports the transfer. The latter requires angular momentum loss from the binary and/or expansion of the cool star.

One way of angular momentum loss, by the gravity radiation, is known to be efficient for short period systems only (Paczynski, 1967, Faulkner, 1971). However, there are plenty of long period systems with high accretion rate. Verbunt and Zwaan, (1981), Spruit and Ritter, (1983) reworked the magnetic braking model, involving a wind from the cool star, to explain both mass transfer and the period gap in CBs.

If the companion happens to be a giant, the nuclear time scale for expansion is short enough to ensure sufficient mass loss, as in case of GK Per. In the general case, however, the observed mass loss of cool stars is faster than expected by theorists. To decide whether evolution off the main sequence and/or departures from thermal equilibrium play role in the red stars more measurements of their radii are required (Wade, 1981).

Instability of the mass transfer on the time scale short in comparison to the stellar thermal time scale (not the envelope time scale) is observed in SU UMa stars (see Section 6.1) and in Polar and NL stars (so called antioutbursts).

References

Charles, P.A., Bath, G.T, Clarke, C.J., Whitehurst, R., and Bailey, J., 1985, in "Recent Results on Cataclysmic Variables", ESA workshop in Bamberg, ESA, Paris,

Cordova, F.A., and Mason, K.O., 1982, Cataclysmic variable stars from X-ray to IR wavelength: Recent results on continuum distribution, IAU Trans. Vol. XVIIIA,

Faulkner J., 1971, Astrophys. J., 170,99,

Glasby, J.S., 1968, Variable stars, Constable,London,

Hensler, G., 1985, Astron. Astrophys., 148,423,

Hoshi, R., 1979, Progr. Theor. Phys., 61,1307,

King, A., 1985, in "Recent Results on Cataclysmic Variables", ESA workshop in Bamberg, ESA, Paris,

Lightman, A.P., 1974, Astrophys. J., 194,429,

Meyer, F., 1984, Astron. Astrophys., 131,303,

Meyer, F., 1985, in "Recent Results on Cataclysmic Variables", ESA workshop in Bamberg, ESA, Paris,

Meyer, F., and Meyer-Hoffmeister, E., 1984, Astron. Astrophys., 132,143,

Mineshige, S. and Osaki, Y., 1983, P.A.S.J., 35,377,

Osaki, Y., 1974, P.A.S.J., 26,429,

Osaki, Y., 1985, Astron. Astrophys., 144,369,

Paczynski, B., 1967, Acta Astron., 17,287,

Paczynski, B. and Schwarzenberg-Czerny, A., 1980, Acta Astron., 30,127,

Papaloizou, J., Faulkner, J., and Lin, D.N.C., 1983, M.N.R.A.S., 208,721,

Papaloizou, J., and Pringle, J.E., 1979, M.N.R.A.S., 189,293,

Pringle, J.E., 1981, Ann. Rev. Astr. Astrophys., 19, 137,

Ritter, H., 1984, Astron. Astrophys. Suppl., 57,385,

Robinson, E.L., 1976, Ann. Rev. Astr. Astrophys., 14, 119,

Rozyczka, M., and Schwarzenberg-Czerny, A., 1986, in preparation,

Schwarzenberg-Czerny, A., Ward, M., Hanes, D.A., Jones, D.H.P., Pringle, J.E., Verbunt, F. and Wade, R.A., 1985, M.N.R.A.S., 212,645,

Smak, J., 1984a, P.A.S.P., 96,5,

Smak, J., 1984b, Acta Astron., 34,161,

Smak, J., 1985, submitted to Acta Astron.,

Spruit, H.C., and Ritter, H., 1983, Astron. Astrophys., 124,267,

Szkody, P., 1985, in "Recent Results on Cataclysmic Variables", ESA workshop in Bamberg, ESA, Paris,

Verbunt, F., and Zwaan, C., 1981, Astron. Astrophys., 100,L7,

Vogt, N., 1981a, habilitation thesis (in German), Bochum University,

Vogt, N., 1981b, Astrophys. J., 252,653,

Vogt, N., 1983, Astron. Astrophys., 118,95,

Wade, R.A., 1981, Astrophys. J., 246,215,

Warner, B., 1983, Interacting Binaries, NATO Advanced Studies Institute, Cambridge,

Wu, C.-C., and Panek, R.J., 1982, Astrophys. J., 262, 244.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

KUWANO-HONDA'S PECULIAR OBJECT (PU Vul) AND SOME PROBLEMS OF EXTREMELY SLOW NOVAE

R.E. Gershberg

Crimean Astrophysical Observatory
Crimea, Nauchny 334413, USSR

The results of many years' photometric, spectral, spectrometric and polarimetric observations of Kuwano-Honda's peculiar object (PU Vul) are briefly given. They permit this object to be attributed to anomalous slow novae of the RT Ser type and its observable properties to be connected with results of theoretical calculations of surface thermonuclear flares in binary systems containing accreting white dwarfs and with ideas on dust formation during nova explosions.

For six years a team of investigators of non-stationary stars from the Crimean Astrophysical Observatory (T.S. Belyakina, N.I. Bondar', K.K. Chuvaev, Yu.S. Efimov, R.E. Gershberg, V.I. Krasnobabtsev, E.P. Pavlenko, P.P. Petrov, I.S. Savanov, N.I. Shakhovskaya and N.M. Shakhovskoj) in cooperation with Dr. V. Piirola from the University of Helsinki and Dr. V.I. Shenavrin from the Sternberg Astronomical Institute, Moscow, carried out a study of Kuwano-Honda's peculiar object (PU Vul). This study covers the period of the brightness maximum in 1979, the episode of a deep minimum in 1980-81, the ascending stage from this minimum, and the last 4 years' duration of the brightness maximum. The PU Vul spectrograms obtained in 1979 at the Ondřejov observatory by Drs. D. Chochol, J. Grygar and L. Hric have been used as well.

In 1978 PU Vul flared from 14^m to 9^m, and in the maximum of 1979 it showed quasi-periodic brightness variations with an amplitude of about $0^m.2$ and 78^d quasi-period. In the maximum of 1982-85 quasi-periodic brightness variations disappeared but short-lived brightness decreases with unusual colour characteristics have taken place and then brightness increases with significant bluishing occurred. The deep optical range minimum in 1980-81 was accompanied by IR brightness variations of small amplitude only.

Spectrometric observations have shown a close similarity in energy distributions within the optical range of spectra of the normal supergiant Alpha Per and of PU Vul in brightness maximum. Spectral features over a wide range of wavelengths were identified for spectrograms obtained during the phase of brightness increase in March-April 1981 and during the brightness maxima in 1979 and 1981. In spring 1981 the spectrum of PU Vul contained numerous emission lines of different elements and TiO absorption bands, and amongst the emission features we found many lines of La II, Sc II, Y II and Nd II but only a few Fe lines. In the brightness maximum periods the PU Vul absorption spectrum corresponded to the spectrum of a normal supergiant with no chemical anomalies.

Polarimetric observations have shown essential variations of intrinsic polarization parameters which were found to be closely correlated with variations of the photometric characteristics of PU Vul: during brightness decreases in 1979 and 1982, polarization with a "concave" dependence of a polarisation degree on wavelengths appeared, while after the deep minimum in 1980-81, p(λ) increased monotonically towards the short wavelengths. A particular feature that was observed was a correlation between the angle of polarization and brightness variations in the second half of 1982.

Analysis of the observations leads to the following conclusions. PU Vul is a binary system consisting of a normal M giant and an exploded component with a maximum luminosity M_V of about $-6\overset{m}{.}3$. The system is located about 800 pc above the galactic plane and at a distance of about 5.3 kpc from the Sun. In 1979 and 1982 the exploded component was not different from a normal F supergiant in its absolute luminosity, the physical conditions in its atmosphere, or in its chemical abundances. Brightness variations of small amplitudes that had been observed in 1979 may be due to quasi-periodic pulsations of the extended atmosphere of the component. An effective temperature of the cool component of the PU Vul system is about 2400 K, such a temperature corresponds to an M 6.5 giant. The deep minimum in 1980-81 cannot be due to a usual eclipse in a binary system but is caused by the formation and consequent dissipation of a heavy dust structure within the PU Vul system. In the framework of the model of a non-stationary dust envelope that was formed around the exploded hot component

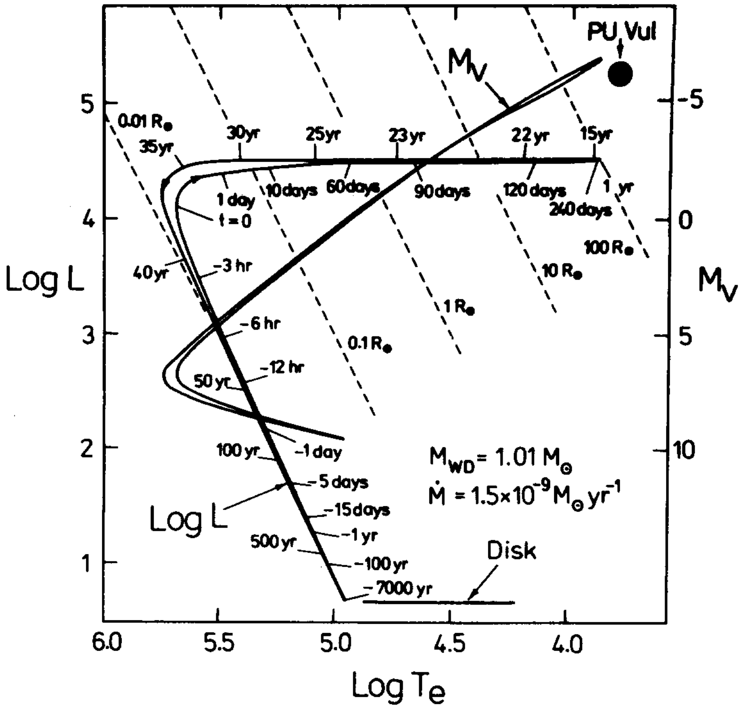


Fig. 1. The theoretical track of an accreting white dwarf computed by Iben (1982) and the position of PU Vul in the M_V, log T_e - plane

of the system, we found a reasonable explanation for the evolution of the polarization characteristics of Kuwano-Honda's object, for small indices B-V and U-B in the brightness minimum, for measured magnitudes of intensity jumps near molecular band heads and for the brightness of the system in the near infrared region during the deep minimum.

The study carried out permits us to attribute Kuwano-Honda's object to anomalous slow novae of the RT Ser type. Comparing the observed properties of the PU Vul system with the features of accreting white dwarfs in a "giant stage" calculated by I. Iben (Astrophys. J. v. 259, p. 244, 1982), one finds close similarities in effective temperatures and absolute luminosities in maximum, in the rate of brightness increase during a flare, and in the maximum phase duration. Further studies of Kuwano-Honda's object may throw light on problems relating to the non-linear pulsations of extended atmospheres of supergiants, dust formation during nova explosions, chemical abundances of novae, the evolutionary status of high galactic latitude F supergiants, as well as on other problems.

Details of our investigations on PU Vul have been published in the following papers:

Belyakina et al., Astron. J. USSR v. 59, pp. 1-5, 1982;
Gershberg et al., Astron. J. USSR v. 59, pp. 6-14, 1982;
Belyakina et al., Astron. J. USSR v. 59, pp. 302-306, 1982;
Belyakina et al., Astron. Astrophys. v. 132, L12-14, 1984;
Belyakina et al., Izvestiya Crim. Astrophys. Obs. v. 72, 1985.

We are continuing to observe PU Vul, using Crimean telescopes, the 6 m reflector of the Special Astrophysical Observatory, and the Astrophysical Space Station "Astron".

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

PECULIAR SLOW NOVA-LIKE OBJECT PU Vul - FACTS AND INTERPRETATION

D. Chochol[1], J. Grygar[2]

[1]Astronomical Institute, Slovak Academy of Sciences,
CS - 059 60 Tatranská Lomnica, Czechoslovakia

[2]Institute of Physics, Czechoslovak Academy of Sciences,
CS - 250 68 Řež, Czechoslovakia

1. Light curve

PU Vul (Kuwano-Honda's object 1979) varied erratically between 16^m and $14\overset{m}{.}5$ in the years 1898-1977. Then a major flare-up occurred and within 1.5 years it brightened to 9^m. After reaching the maximum it displayed periodic variations with amplitude $0\overset{m}{.}25$ and period 78.1 days. The flat maximum lasted till January 1980 when a rather steep decline started ending in August 1980. After a short minimum at $13\overset{m}{.}65$ the object recovered until a new maximum ($8\overset{m}{.}6$) in August 1981. The whole episode lasted about 540 days. Since then its brightness has been increasing very slowly with occasional non-periodic fluctuations, particularly in 1982. In 1984 it reached $8\overset{m}{.}4$. Colour indices (B-V), (U-B), (V-R) and (V-I) exhibited strong variations during the decline and recovery in 1980-81, in the sense that the decline was steepest at the shortest wavelengths (see Kolotilov, 1983, 1984b; Chochol et al., 1984).

2. Spectrum

Continuum seems to be superimposed from two black-body curves of T_{eff} = 6300 K and T_{eff} = 2400 K. This corresponds well to the determined spectral classes of the components, F 8 Iab and M 6.5 III. The spectrum is normally in absorption, except for the 1980-81 episode when various emissions and during the minimum when nebular (forbidden) lines were also observed. P Cygni profiles of H_{alpha} are seen around the light maxima indicating the expansion velocity of the envelope of about 50 km/s (Iijima and Ortolani, 1984). Radial velocities determined from absorption as well as emission (em) lines are compiled in Fig. 1.

3. Interpretation

The light curve resembles that of very slow nova (RT Ser). The deep decline and more than complete recovery is more consistently interpreted as the formation and subsequent dilution of a dust envelope (see nova FH Ser). The absolute magnitude of the bursting component is $-6\overset{m}{.}3$. This corresponds to the F supergiant and to the Eddington luminosity for a stellar mass close to 1 $M_\odot$ (Belyakina et al. 1984). Thus we are strongly convinced that

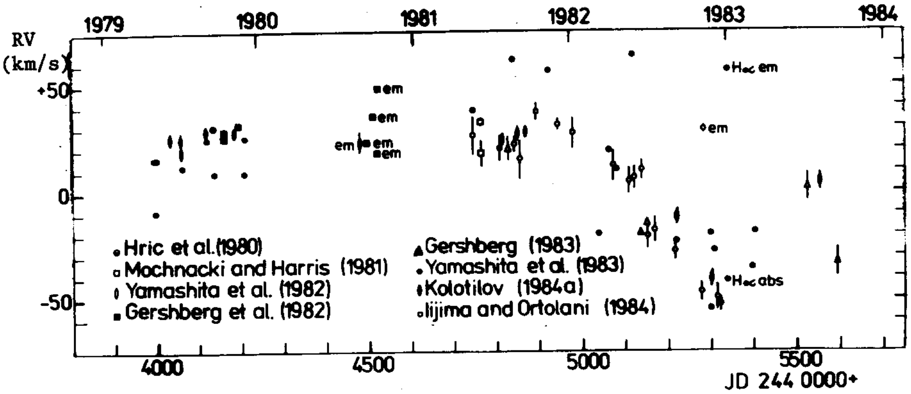


Fig. 1. Radial velocities of PU Vul

PU Vul is a close binary, consisting of an M giant and a hotter component that in the course of accretion expanded and flared-up to become a supergiant. According to Fadeyev (1984) the 78 day period of light variations is the consequence of nonlinear pulsations of the yellow supergiant (radius 154 $R_\odot$) that evolved from the original white dwarf (mass 1 $M_\odot$) via supercritical accretion of hydrogen-rich matter from the red giant. Assuming that the absorption lines originate in the atmosphere of the F supergiant we may infer from Fig. 1 that the changes of radial velocities reflect an orbital motion with a period of more than 5 years. If confirmed this would support the idea that the system resembles wide symbiotic binaries.

References:

Belyakina, T.S., Bondar, N.I., Chochol, D., Chuvaev, K.K., Efimov, Y.S., Gershberg, R.E., Grygar, J., Hric, L., Krasnobabtsev, V.I., Petrov, P.P., Piirola, V., Savanov, I.S., Shakhovskaya, N.I., Shakhovskoy, N.M., Shenavrin, V.I., 1984, Astron. Astrophys. 132, L 12.

Chochol, D., Hric, L., Skopal, A., Papoušek, J., 1984, Contr. Astron. Obs. Skalnaté Pleso 12, 261.

Fadeyev, Yu.A., 1984, Astrophys. Space Sci. 100, 329.

Gershberg, R.E., Krasnobabtsev, V.I., Petrov, P.P., Chuvaev, K.K., 1982, Astron. Zh. 59, 6.

Gershberg, R.E., 1983, personal commun.

Hric, L., Chochol, D., Grygar, J., 1980, Inform. Bull. Var. Stars No. 1835.

Iijima, T., Ortolani, S., 1984, Astron. Astrophys. 136, 1.

Kolotilov, E.A., 1983, Astron. Zh. 60, 746.

Kolotilov, E.A., 1984a, Pisma Astron. Zh. 10, 284.

Kolotilov, E.A., 1984b, Pisma Astron. Zh. 10, 609.

Mochnacki, S.W., Harris, H.C., 1981, IAU Circ. No. 3614.

Yamashita, Y., Maehara, H., Norimoto, Y., 1982, Publ. Astron. Soc. Japan, 34, 269.

Yamashita, Y., Norimoto, Y., Yoo, K.H., 1983, Publ. Astron. Soc. Japan, 35, 521.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

ANALYSIS OF LIGHT CURVES OF DQ HERCULIS BASED ON FIVE-COLOUR PHOTOMETRY IN 1982-1985

E.S. Dmitrienko

Crimean Astrophysical Observatory, Crimea, 334413, USSR

The light curves of DQ Her with a time resolution of 12-45 s in five broad band filters close to the standard UBVRI system using 1.25 m and 2.6 m reflectors were observed at the Crimean Astrophysical Observatory by Dmitrienko, Efimov, Shakhovskoy in 1982-1985. The photometer-polarimeter of Helsinki Observatory was used. The instrumentation and observations of 1982-1983 are available in the literature (Dmitrienko et al., 1985). The observations of 1984-1985 and an analysis of all available photometric data are due to be published elsewhere (Dmitrienko, 1986). Here we give some results of this analysis: (1) There is day-, month-, and year-scale variability. The out-of-eclipse light of DQ Her itself in 1982-83 became brighter compared with that in 1978 and was near the light level of 1954. In 1984-85 it decreased to the level of 1978. The mid-eclipse light level of DQ Her changed insignificantly. Hence, it is an eclipsed source which is variable: the primary, the side of the secondary which is turned to the primary and the gaseous stream. (2) The shape of the primary minima suggests the possibility of a total eclipse for several minutes. However, the mid-eclipse colours U-B, B-V indicate that a blue source is strong still. This may be due to the presence of a common gaseous envelope around the components. (3) Compared with 1954 (Walker, 1956) and 1975 (Nelson, Olson, 1976), in 1982-85 the greater shoulder is observed only at the ingress into eclipse. This implies the relative stabilization of the hot spot on the disk in 1982-85. (4) All light curves observed in 1982-85 can be classified into three types (see Fig. 1). Types 1-3 have the lowest, intermediate and greatest values of out-of-eclipse light level (L) at phases near 0.45 and it is different from the level at phases near 0.2. The relative height of the shoulder (ΔH) at phases near 0.89 is intermediate, greatest and lowest for types 1-3. Values of L, ΔH of 1978 (observations by Schneider and Greenstein, 1979) allow one to suppose type 1. The progressive change of DQ

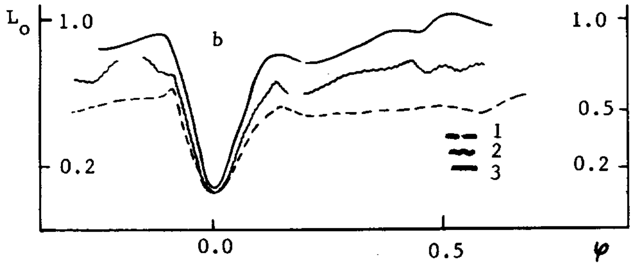


Fig. 1. Three types of schematic light curves in b-filter. The value of the light at phases near 0.45 of 20 July 1982 has been taken as unity

Her status corresponds to the evolution of light curves practically at the same time for all five colours from type 1 (1978) through type 2 (25-27 May to 18-19 July 1982) to type 3 (19-20 July 1982) and back through type 2 (13-15 Sep 1982, to 13-14 Aug 1983) to type 1 (28-29 Apr 1984 and 18-19 May, 18-22 May 1985). It is necessary to emphasize that observations can give us only the upper limit for the time-scale variability and the lowest limit for the light-scale one. The full transition "type 1 - type 3" indicates an increase of the brightness of the eclipsed source of about 70%. (5) The resemblance of the photometric behaviour of the old Nova DQ Her to that of the dwarf novae, e.g., Z Cha during its transition from normal - to superoutburst, as well as the correlation of mass exchange rates in both systems leads to the possibility of the following conclusion: After 50 years of nova-outburst DQ Her shows an activity in which

(a) the state with type 1 light curves corresponds to the state of dwarf nova in normal outburst;

(b) the transition "type 1 - type 3" corresponds to one of dwarf nova from normal - to superoutburst;

(c) the intermediate state with type 2 light curves, when the maximum value of ΔH was observed, indicates the possibility of the reduction of the disk size and/or the increase of the mass loss rate from the secondary before the rise of the brightness of the eclipsed source to its observed maximum value.

References:

Dmitrienko, E.S., Efimov, Y.S., Shakhovskoy, N.M., 1985, Astrofizika, 22, 31.
Dmitrienko, E.S., 1986, in preparation.
Nelson, M.R., Olson, E.C., 1976, Astrophys. J. 207, 195.
Schneider, D.R., Greenstein, J.L., 1979, Astrophys. J. 233, 935.
Walker, M.F., 1956, Astrophys. J. 123, 68.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

ON THE NATURE OF THE RECURRENT NOVA T PYXIDIS

Zdeněk Urban

Astronomical Institute of the Slovak Academy of Sciences,
CS-059 60 Tatranská Lomnica, Czechoslovakia

The observed recurrent novae (hereafter RNs) form a small but very heterogeneous group (Webbink, 1982). Presumably all are white dwarf (WD), or blue star - cool star interacting binaries. However, some RNs contain red giants as the mass-losing components and are thus rather wide binaries, while the giant components are almost certainly excluded in the other members of the group. There are also further serious differences among the group members. Thus, RNs as a single group must be considered very cautiously. In general, all but one of the observed RNs differ to a relatively large extent from the ordinary classical novae when all the system and outburst properties (in addition to the multiple character of a RN outburst) are taken into account. The only exception is T Pyx (Urban, 1985a).

T Pyx has undergone five recorded outbursts to date: in 1890, 1902, 1920, 1944 and in 1966-1967. Concerning the outburst light curves, spectral development during the outbursts, photometry at minimum as well as the spectral energy distribution at minimum in the optical and in the UV - in all these aspects T Pyx strongly resembles ordinary slow novae. Moreover, there exists a well-developed ejected shell around T Pyx. The shell is ionized by UV radiation coming from the stellar nova remnant and has approximately solar heavy element abundances although there is probably some deficiency of He in relation to H. The absolute magnitude of T Pyx at minimum is probably about +1.5. This value is higher than the average value observed in old novae, although it is not unique (exact references to the observations of T Pyx are due to be given in a more detailed paper - Urban (1985b)). All this evidence brings T Pyx closer to the ordinary slow novae than to its co-RNs.

In order to understand the observed behaviour of T Pyx, we are carrying out a re-analysis of all the published observations of this nova in comparison with the ordinary slow novae (e.g. HR Del, RR Pic). The preliminary conclusion is that T Pyx is a quite normal nova but with an extraordinarily shortened outburst recurrence time, T (rec). This makes T Pyx of extreme interest for our understanding of the nova phenomenon (Duerbeck, 1984; Urban, 1985c). By analogy with the ordinary slow novae, we suggest a white dwarf (WD) - red dwarf (RD) interacting binary working model for T Pyx with an orbital period of a few hours. In fact, an orbital period as short as 2.2 hr has been suggested for T Pyx (Vogt, 1982), based on indirect evidence. Current thermonuclear runaway (TNR) nova theory allows for a relatively short T (rec) observed in RNs (tens of years) but at the price of rather limiting choices in the values of the main theory parameters - WD mass and luminosity, mass accretion rate, etc. (Truran, 1982). In a recent important study (Starrfield et al., 1985) RN-like behaviour was achieved using an accretion of material of solar abundance on a very massive WD. Besides the high WD mass, the mass accretion rate was taken as higher than the average observed in nova binaries. Inasmuch as nothing is known about the WD mass in T Pyx, we adopt a value of about 1 $M_{\odot}$ suggested as a typical mean value in nova binaries (Truran, 1979 and MacDonald, 1983). In order to obtain a higher accretion rate (there is no giant donor which would ensure a high mass transfer rate like the situation in T CrB and related RNs - see Bath and Shaviv (1978)), we suggest the heating of the mass-losing component atmosphere by high energy radiation from the WD and an accretion disk. The WD component is in a thermally perturbed state of longer duration with the observed outbursts being only the peaks on the generally increased level of activity. This excited WD/accretion disk radiation together with the small system dimensions (Vogt, 1982) ensure the self-induced high mass transfer rate needed to replenish the hydrogen-rich envelope of the WD (necessary prerequisite for a TNR leading to the nova outburst) in a relatively short time. Moreover, there is a possibility that during a RN outburst only a fraction of the accreted envelope is really ejected. What is the possible cause of this thermally perturbed state in the WD component? It was pointed out (Webbink et al., (1978), Taam, (1980) see also Iben (1982) for a general analysis of quasi-static WD accretion) that *helium* TNR may play a significant role in the long-term evolution of nova activity (see also Urban, 1986). We suggest that perhaps some form of a mild He-TNR (Taam, 1980) may help T Pyx to have several *hydrogen* TNR during a relatively short time interval. A detailed discussion of the theoretical aspects as well as of the available observations of T Pyx is currently in preparation (Urban, 1985b).

In conclusion, necessary constraints on any theoretical picture of T Pyx must come from the observations. Unfortunately, our present knowledge of this exciting star is less than satisfactory. Detailed photometric and spectroscopic observations are highly desirable. In particular, radial velocity measurements allowing reliable estimates of the system dimensions and component masses are badly needed. Such observations would be of extreme importance for T Pyx may be well on its way to the next, in this case the sixth, observed outburst (Duerbeck, 1984).

References:

Bath, G.T., Shaviv, G., 1978, Mon. Not. R. astr. Soc. 183, 515.

Duerbeck, H.W., 1984, Ap. Space Sci. 99, 363.

Iben, I. Jr., 1982, Astrophys. J. 259, 244.

MacDonald, J., 1983, Astrophys. J. 267, 732.

Starrfield, S., Sparks, W.M., Truran, J.W., 1985, Astrophys. J. 291, 136.

Taam, R.E., 1980, Astrophys. J. 237, 142.

Truran, J.W., 1979, In: "White Dwarfs and Variable Degenerate Stars", IAU Coll. No.49, J.M. Van Horn and V. Weidemann (eds.), Rochester, p. 469.

Truran, J.W., 1982, In: "Essays in Nuclear Astrophysics", C.A. Barnes et al. (eds.), Cambridge Univ. Press, p. 467.

Urban, Z., 1985a, To be submitted to Ap. Space Sci.

Urban, Z., 1985b, In preparation.

Urban, Z., 1985c, In: "Recent Results on Cataclysmic Variables", Proc. ESA Workshop, ESA SP-236, p. 33.

Urban, Z., 1986, These proceedings, p.367.

Vogt, N., 1982, Mitt. Astr. Ges. 57, 79.

Webbink, R.F., 1982, In: "Pulsations in Classical and Cataclysmic Variables", J.P. Cox and C.J. Hansen (eds.), JILA, Boulder, CO, p. 1.

Webbink, R.F., Truran, J.W., Gallagher, J.S., 1978, Bull. AAS 10, 438.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

THE AMPLITUDE - CYCLE LENGTH RELATION OF LONG-CYCLIC CATACLYSMIC BINARIES

G.A. Richter

Zentralinstitut für Astrophysik der Akademie der
Wissenschaften der DDR, Sternwarte Sonneberg

In 1934 Kukarkin and Parenago showed that there is a relationship between the amplitude A and the cycle length C of U Geminorum stars, that seemingly continues smoothly to the recurrent novae.

As the long cycles ($C \gtrsim 1^a$) given in the literature are affected by systematic errors, I have carried out a revision.

Two kinds of systematic errors can be found in the published material:

1. The mean interval between two eruptions is often equated with the cycle length C without an estimate of whether undiscovered eruptions exist or not.

2. Some objects occasionally show, after apparently long, quiet intervals, series of eruptions in relatively rapid succession. In such cases the common practice is to take the shortest interval as the cycle length.

Dr. W. Wenzel and I have taken the opportunity to use the numerous Sonneberg Sky Patrol plates for re-examining, in connection with the results of amateur organizations, the published cycle lengths and to make statistical statements concerning the most probable values of C. We have used three methods:

1. N photographic exposures may be distributed by chance over a certain period t. Because of the daylight gap we must replace the interval t by $T = t \cdot f$, where f is the fraction of the year during which observations are carried out. a_k stands for the observed number of eruptions recorded on a total of k plates. Taking the mean, each of the eruptions is present on $g = \sum_1^\infty k a_k / \sum_1^\infty a_k$ plates. On the other hand, one can show that $g = \lambda/(1-e^{-\lambda})$, where λ is the mean of the Poisson distribution. From this follows the cycle length ($\sum_1^\infty k a_k = n$):

$$C_1 = \lambda T/n \ . \qquad (1)$$

The advantage of this method is the fact that the duration L of the eruptions need not be known. Its disadvantage is the great demand on the homogeneity of the material.

2. It can be shown that $T/L = N/\lambda$. Substituting in (1) and by changing index 1 to 2 we obtain the formula

$$C_2 = L\,N/n \qquad (2)$$

which has already been used several times by W. Wenzel. It has the advantage that the daylight gap is eliminated; the disadvantage is that errors in L are transferred to C_2.

3. By subdivision of the year into ν equal parts and plotting the number of observed eruptions over the season (e.g. monthly, $\nu = 12$), one can adjust the plots to a sinusoidal curve which has its maximum value ρ at about the season in which the upper culmination of the object is about midnight. We have then

$$C_3 = \frac{t}{\nu \cdot \rho} \,. \qquad (3)$$

Strictly speaking, this value is an upper limit.

For 12 U Geminorum stars with $C > 240^d$ we obtained the relation

$$A = -3.4 + 3.35 \log C;$$

and for 5 recurrent novae,

$$A = -2.7 + 2.73 \log C.$$

The 3 recurrent X-ray novae are within the error limits in the neighbourhood of the recurrent novae, which may be pure chance.

U Sco is an outsider, also spectroscopically. It should have $C \approx 200$ years and not 39 years as is observed.

A more detailed discussion is being prepared for publication in Astron. Nachr.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

MASS TRANSFER BURSTS IN THE SYMBIOTIC BINARY SYSTEM CH Cyg DURING THE MAXIMUM OF ITS ACTIVITY IN THE YEAR 1982

D. Chochol[1], A. Skopal[1], T.S. Galkina[2]

[1]Astronomical Institute, Slovak Academy of Sciences,
CS - 059 60 Tatranskå Lomnica, Czechoslovakia

[2]Crimean Astrophysical Observatory, P/O Nauchny
334413 Crimea, USSR

The spectrum of CH Cygni usually looks like the spectrum of an M6 III star but during outbursts it resembles the spectra of symbiotic stars. Outbursts were observed in the periods: Sept. 63 - Aug. 65; June 67 - Sept. 70; May 77 - Dec. 84.

Mikolajewski and Biernikowicz (1985) investigated the radial velocities and intensities of the H_β profile as well as a drop of U,B,V brightness in August - December 1984 and came to the conclusion that the end of activity was caused by the eclipse of the hot component by the cool M giant in the binary system. This is in agreement with the epoch of eclipse predicted from a long period orbit of 5750 days, found by Yamashita and Maehara (1979).

CH Cygni reached the maximum brightness ($V = 5^{m}.5$) in 1982 (Chochol et al., 1984). The increase of brightness in 1981 was accompanied by spectroscopic changes: increase of intensity in blue continuum, in emission lines and in the velocity gradient of Balmer series (Skopal, 1985). The most interesting feature, well visible at high dispersion spectra (dispersion 6.5 Å/mm), was the splitting of shell lines of ionized metals Ti II, Cr II and Sc II into two components. Skopal explained the emergence of the red component of these lines by the sudden increase of mass flow from the M giant into the accretion disk of the hot component. The orientation of the binary system with respect to the observer was suitable to observe the projection of the receding gaseous stream onto the hot component.

Our spectroscopic material was obtained with the 1.22 m telescope of the Crimean Astrophysical Observatory and consists of 14 spectrograms with dispersion 36 Å/mm taken during the maximum of activity of CH Cygni in the period Sept. 13 - Nov. 29, 1982. While at high dispersion spectra the main and additional absorption components of ionized metals are well separated ($\Delta\lambda \sim 0.7$ Å), at low dispersion spectra the emergence of red absorption causes only red shift of the centre of the main absorption line. Due to the long period orbit of CH Cygni the orientation of the binary system in the years 1981 and 1982 did not differ too much, so the sudden changes of radial velocities of absorption shell lines of ionized metals can be interpreted as an increase of mass transfer between the components. As is seen from Fig. 1, where the radial velocities of Ti II shell lines are plotted, the time scale of mass transfer bursts is about 20 days.

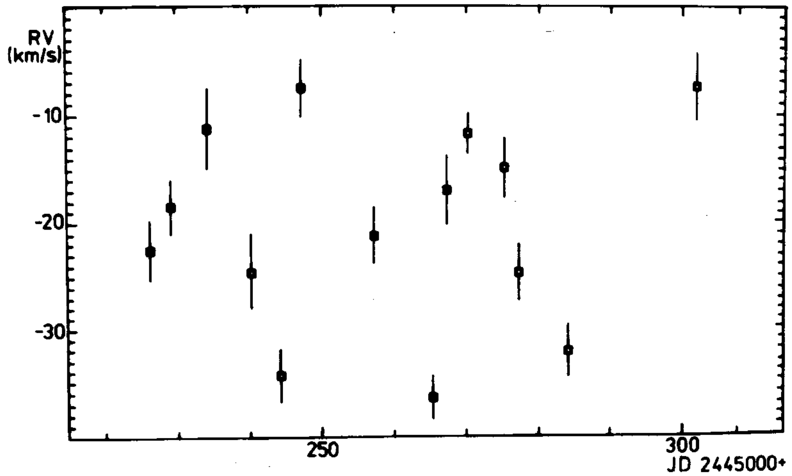


Fig. 1. Radial velocities of Ti II lines in CH Cyg

Our observations are in agreement with the theory of bursting mass transfer by the cool component in cataclysmic variable stars (Bath, 1984).

References:

Bath, G.T., 1984, Astrophys. Space Sci. 99, 127.
Chochol, D., Hric, L., Skopal, A., Papoušek, J., 1984, Contr. Astron. Obs. Skalnaté Pleso 12, 261.
Mikolajewski, M., Biernikowicz, R., 1985, Astron. Astrophys. (in press).
Skopal, A., 1985, Bull. Astron. Inst. Czechosl. (in press).
Yamashita, Y., Maehara, H., 1979, Publ. Astron. Soc. Japan 31, 307.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

ON THE PERIOD OF THE SYMBIOTIC STAR AG PEGASI

R. Luthardt

Zentralinstitut für Astrophysik der Akademie
der Wissenschaften der DDR, Sternwarte Sonneberg

Two different periods of this symbiotic star have been published recently. This induced me to carry out a new photometric analysis.

AG Peg has shown a novalike light curve over the last 150 years. After a rapid brightening reaching 5th magnitude in 1855 the brightness has been decreasing. Now the star is near 9th magnitude again as before its outburst.

The spectrum of AG Peg has also shown significant variations. It is comparable to a typical nova spectrum - an emission spectrum with higher excitation features with decreasing magnitude (Merrill, 1958). An absorption spectrum of an M-giant also became increasingly more visible.

Measurements of radial velocities were carried out on highly resolved spectra taken between 1930 and 1970. The data could be best fitted by periods of about 790 to 840 days (Cowley et al., 1973; Hutchings et al., 1975). The material did not yield a better estimate.

Photoelectric measurements in U, B and V by Belyakina (1965) also showed magnitude variations with a period of about 800 days. Meinunger (1983) observed the light variations on plates of the Sonneberg Sky Patrol taken between 1930 and 1982. He found a period of 827 days. This period fits well into the radial velocity curve of the M-absorption lines which is a confirmation of its accuracy. Slovak (1982) published a period which differs considerably from that of Meinunger. He found 733 days. In order to find an explanation for this discrepancy I examined further observations: Visual estimations of the A.F.O.E.V. from 1970 to 1983, and photoelectric measurements with the Sonneberg 60 cm mirror II (Luthardt, 1984). I found two minima in addition to those detected by Meinunger. The differences $(O-C)_1$ derived from the elements of Meinunger are very large. The new elements calculated with the last 5 minima are: Min. = J.D. 244 $2370+760^{d}\cdot E_2$.

Table I

Min. J.D.	Author	E_1	$(O-C)_1$	E_2	$(O-C)_2$
244 2360	Meinunger	17	$+51^d$	0	-10^d
3150	Meinunger	18	+ 14	1	+20
3920	Meinunger	19	− 43	2	+30
4650	Luthardt	20	−140	3	0
5400	Luthardt	21	−217	4	−10

Table I shows these minima and differences $(O-C)_1$ (elements of Meinunger) and $(O-C)_2$ (elements of the author).

There is a systematic decrease of $(O-C)_1$, and the minima are well represented by the new elements.

The previous minima from $E_1 = 0$ to $E_1 = 16$ are well determined by the elements of Meinunger.

We may therefore suspect a change of period at about J.D. = 244 2000... ...3000.

Further observations, photoelectric measurements as well as radial velocities are necessary.

The point is whether the recently obtained radial velocity curve correlates with the old or with the new period.

Only in this way is a confirmation of the suspected period change possible. If this period change really exists,its cause would be of immense interest.

References:

Belyakina, T.S., 1965, Krim Isw., Tom. XXXIII, 226.
Bull. A.F.O.E.V., No. 8 to No. 26.
Cowley, A., Stencel, R., 1973, ApJ., 184, 687.
Hutchings, J.B., Cowley, A.P., and Redman, R.O., 1975, ApJ., 201, 404.
Luthardt, R., 1984, IBVS, No. 2495.
Meinunger, L., 1983, Mitt. Veränderl. Sterne, 9, 22.
Merrill, P.W., 1958, ApJ., 129, 44.
Slovak, M.H., 1982, Journal AAVSO, 11, No. 2, 67.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

OUTBURST ACTIVITY IN CATACLYSMIC BINARIES: PARALLEL EVOLUTION OR ACTIVITY CYCLES?

Zdeněk Urban

Astronomical Institute of the Slovak Academy of Sciences,
CS-059 60 Tatranskå Lomnica, Czechoslovakia

The possibility of finding very different modes of the outburst activity (classical and dwarf nova states, nova-like states) in otherwise structurally similar cataclysmic binaries (hereafter CBs) is one of the greatest puzzles related to these systems (Whyte and Eggleton, 1980). Nevertheless, all the observed differences between the various classes of CBs can be reduced to the differences in their accretion discs (Smak, 1984). The widely held opinion is that these differences reflect differences in the amount of mass coming into the disc, i.e. in the mass transfer rate (MTR) between the red dwarf (RD) and the white dwarf (WD) components of CBs (Patterson, 1984), although the heating of the accretion disc by the star inside it might confuse the story (Friedjung, 1985). It was suggested that MTR is correlated with the orbital period, P(orb), in CBs (Patterson, 1984). However, the spread in MTR at a given P(orb) may be up to three orders of magnitude (Szkody, 1985). It might be argued that different MTRs further reflect some deep-rooted systematic differences between the classes of CBs not sufficiently well recognized to date, say, in mass ratios (Smak, 1983). The simultaneous existence of a classical nova, a dwarf nova and a nova-like variable at approximately the same P(orb) would thus be explained by the parallel evolution of these systems on the secular evolution time-scale (see Ritter (1983) for a review), with different outburst behaviour conditioned by different MTR representing the natural spread in basic system parameters.

Another possibility is that MTR is not fixed but there can exist a modulation of it superimposed on the general decrease in MTR with P(orb) decreasing during the secular evolution. The classes of CBs may thus represent different phases of the more general outburst activity cycle which repeats many times during the secular evolution of these systems (see Urban (1985) for a general picture). We identify the main components of such a cycle with the consecutive nova outbursts, for nova activity must recur many times during the secular evolution of a given CB characterized by more or less persistent WD accretion. Evolution towards and after the nova outburst leads to alternating phases of heating and cooling of the WD primaries and thus to variable RD atmosphere irradiation mediated variations in MTR with MTR being higher during the hotter states and lower during the cooler ones. We identify, following earlier suggestions by several authors, the hotter states with the observed old novae and nova-like stars and cooler ones with the dwarf novae.

In order to test the possibility of such a cycle, we are carrying out a comparative analysis of the published data on various classes of CBs to find possible sequences of objects representing different phases of our activity cycle in different short intervals of P(orb). Our efforts extend to those of Vogt (1982) who, in fact, first proposed a more detailed picture of such a cycle. We are also investigating possible changes in the character of the nova outburst during the secular evolution of a CB. The primary goal of all these efforts is to understand the observed behaviour of CBs within a unified evolutionary picture of the main modes of the outburst activity. Only preliminary conclusions can be made at present but it can be stated with a relatively high level of certainty that an extended form of Vogt's cycle is at least compatible with the present database of CBs.

However, the role (if any) of the magnetic CBs (polars and intermediate polars) in our scenario is unclear. Are these systems dormant perpetually with respect to the outburst activity? The question of the possible fate of the accreted matter on the surfaces of WD primaries in these systems is highly intriguing.

A detailed discussion of the results of comparative analysis of the observational data on CBs as well as of the theoretical aspects is currently in preparation.

I thank Dr. Paula Szkody for communicating me her results prior to publication.

References:

Friedjung, M., 1985, Astron. Astrophys. 146, 366.
Patterson, J., 1984, Astrophys. J. Suppl. Ser. 54, 443.
Ritter, H., 1983, Mitt. Astr. Ges. 60, 159.
Smak, J., 1983, Astrophys. J. 272, 234.
Smak, J., 1984, Publ. Astr. Soc. Pacif. 96, 5.
Szkody, P., 1985, Astron. J., in press.
Urban, Z., 1985, In: "Recent Results on Cataclysmic Variables", Proc. ESA Workshop, Bamberg, W. Germany, 17-19 April 1985, ESA SP-236, p. 33.
Vogt, N., 1982, Mitt. Astr. Ges. 57, 79.
Whyte, C.A., Eggleton, P.P., 1980, Mon. Not. R. astr. Soc. 190, 801.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

INFLUENCE OF THE ACCRETION COLUMN'S ASYMMETRY ON THE ORBITAL VARIABILITY OF POLARS

I.L. Andronov

Odessa State University, T.G. Shevchenko Park 270014 Odessa, USSR

According to a standard model of AM Her-type stars, the plasma ejected from the atmosphere of the secondary through the inner Lagrangian point moves along the field lines to the magnetic pole of the white dwarf (Kruszewski, 1978). This cannot explain the observed asymmetry of orbital light curves in a wide spectral region from X-ray to IR, nor the phase curves of polarization and radial velocities. Thus the emitting region must be asymmetric (Stockman, 1977) for the following reasons:

1. the plasma does not fall vertically onto the magnetic pole, and the accretion column is inclined (Andronov, 1983);
2. the centres of the magnetic dipole and the white dwarf do not coincide (Kruszewski, 1978);
3. the plasma begins its motion along field lines not from the inner Lagrangian point but later, when it is sufficiently ionized by the hard emission;
4. in the vicinity of the compact star the field configuration essentially deviates from the dipole one (Mitrofanov et al., 1977);
5. the column is not axi-symmetrical.

If the accretion column is axi-symmetrical but inclined, the asymmetry may be observed only if the magnetized star saturates the column's base during orbital motion and the axis of the column, does not cross the rotational axis of the white dwarf (Andronov, 1983). The asymmetry increases with increasing contribution to the whole emission by the saturated regions of the column. If the column becomes higher, the light curves become more symmetrical and have one maximum if the column's axis during its rotation does not pass the plane of view otherwise two maxima are seen.

If the column's cross-section is not circular, then during the orbital period one may observe variability up to ten percent even if the angle Θ between the column's axis and the line of sight is constant - which may also cause the asymmetry.

In a real accretion column the density does not decrease abruptly with increasing distance from the column's axis but continuously (although rather rapidly). Thus the observed brightness and the value of the effective radius are not constant. They also depend on the wavelength we use for observation so the spectrum and polarization of the observed emission are essentially affected by this phenomenon (Andronov, 1983).

In the column self-oscillations may be excited (Langer et al., 1982) which may essentially change the emission characteristics usually investigated using stationary models. In the three-dimensional column, five additional types of instability may exist as well. The transfer of energy, generated due to accretion, becomes inefficient near the column's base, then the regions with low density and optical thickness appear, through which the energy is transferred from the inner parts of the column. The instability of the accretion flow causes the excitation of non-radial motions in the column. The column's asymmetry complicates the scenario much more.

The aim of this paper is not to interpret quantitatively the observations; it is planned to do this elsewhere. We have only briefly discussed the problems of magnetic close binary systems.

References:

Andronov, I.L., 1983, Dissertation, Univ. of Odessa.

Kruszewski, A., 1983, In: "Nonstationary Evolution of Close Binaries"; ed. A. Zytkow, Warszawa, p. 55.

Langer, S.H., Chanmugam, G., and Shaviv, G., 1982, Astrophys. J., 258, 285.

Mitrofanov, I.G., Pavlov, G.G., Gnedin, Yu.N., 1977, Pis'ma v Astron. Zhu., 3, 341.

Stockman, H.S., 1977, Astrophys. J., 218, L 57.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

INFLUENCE OF THE MAGNETIC FIELD ON ACCRETION IN CLOSE BINARY SYSTEMS

I.L. Andronov

Odessa State University, T.G. Shevchenko Park 270014 Odessa, USSR

Magnetic close binary systems (MCBS) are objects with a secondary which fills its Roche lobe, and a white dwarf with a magnetic field which is sufficient to make the dimensions of the magnetosphere greater than the orbital separation (see Chiapetti et al. (1980) for a review). Accreting plasma in MCBS moves along the magnetic field lines. We now know 13 similar objects ("polars") in which a white dwarf rotates synchronously with the orbital motion.

Asynchronism of rotational and orbital motions leads to a change of the accretion scenario. Additional centrifugal force, in a direction from the white dwarf, appears and acts as an additional potential barrier. The dependence of the limit velocity, which is necessary to penetrate through this barrier, on the initial conditions (Andronov, 1982b) shows that plasma is ejected from asynchronous MCBS, moving outside the magnetosphere. This "propeller stage" is analogous to that of neutron stars investigated by Illarionov and Sunyaev (1975). During this period the white dwarf will be synchronized with the time $t_s \leq 10^3$ yr (Andronov, 1982b).

Systems at the "propeller stage" are unsuitable for observation because the plasma is ejected but not accreted. However, for the period of a white dwarf's rotation $P_{wd} \approx 1$ min. due to the excitation of MHD-waves, about 10^{33} erg/s (Lamb et al., 1983) is lost. The observed flux may change with a period P_{wd} (or $P_{wd}/2$). The deceleration of rotation leads to a reduction in the systemic luminosity and thus makes the discovery of such a system much more difficult. During this stage, the X-ray emission due to accretion is absent, but the plasma is still being ejected, the MHD-waves are being excited, the radioemission is appearing (Chanmugam and Dulk, 1983; Lamb et al., 1983). With the diminishing value of the parameter of asynchronism, the shape of the magnetosphere changes. The quantity of plasma falling onto the white dwarf increases thereby causing a redistribution of the moments of forces.

If the angle Θ between the magnetic axis and the line of the centres is near 90°, the moment of forces - affecting the white dwarf - is zero. Near this equilibrium state the non-linear oscillations of orientation of the magnetic axis may be excited (Joss et al., 1979; Andronov, 1982c), causing cyclic variations of the orbital curves of polarization, radial velocities, and flux in different spectral regions from X-ray to IR. Similar variability of the photometric period with a 3-year cycle was discovered in AM Herculis (Andronov, 1982c). This value corresponds to the characteristic time of the changes, in the orientation of the dipole which is necessary to explain the observed radioemission (Lamb et al., 1983; Chanmugam and Dulk, 1983).

In MCBS one may observe a unique phenomenon for close binaries - the modulation of the accretion rate by the magnetic field of the white dwarf. The accretion rate is at maximum when $\Theta = 0^{\circ}$ and sharply decreases with increasing value of Θ. If $\Theta = 90^{\circ}$, the "magnetic valve" is fully closed, the magnetic field prevents the flow from the secondary. This mechanism explains the observed slow variations of the polar's luminosity (Andronov, 1982a, 1984).

Asynchronous MCBS (classified as III P (Lipunov, 1984)) are progenitors of polars (III M), but the "intermediate polars" (III A), in their evolutionary scenario, possibly do not have the "classical polar" stage because of the lack of a sufficiently high magnetic field.

The discovery of asynchronous MCBS, which discovery is difficult due to the above cited complexities, may allow us to fill another gap in the evolutionary scenario of the cataclysmic variables.

References:

Andronov, I.L., 1982a, Preprint VINITI, No. 5900-82 Dep., 20 pp.
Andronov, I.L., 1982b, Preprint VINITI, No. 5901-82 Dep., 29 pp.
Andronov, I.L., 1982c, Preprint VINITI, No. 5981-82 Dep., 23 pp.
Andronov, I.L., 1984, Astrofizika, 20, 165.
Chanmugam, G., and Dulk, G.A., 1983, In: "Cataclysmic Variables and Related Objects"; eds. M. Livio, G. Shaviv; Reidel, Dordrecht, p. 223.
Chiapetti, L., Tanzi, E.G., and Treves, A., 1980, Space Sci Rev., 27, 3.
Illarionov, A.F., and Sunyaev, R.A., 1975, Astron. Astrophys., 39, 185.
Joss, P.C., Katz, J.I., and Rappaport, S.A., 1979, Ap. J., 230, 176.
Lamb, F.K., Aly, J.J., Cook, M.C., and Lamb, D.Q., 1983, Ap. J., 274, L 71.
Lipunov, V.M., 1984, Adv. Space Res., 3, 323.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

ADDITIONAL PHOTOMETRIC DATA FOR THE X-RAY SOURCE KR AURIGAE DURING 1971-1980

V.N. Popov, Z.T. Kraicheva, M.D. Popova

Department of Astronomy with National Astronomical Observatory
Bulgarian Academy of Sciences, Sofia, Bulgaria

In this communication some photometric data for the X-ray source KR Aur for the time interval 1971-1980 are presented. Popova's (1965) sequence was used for the magnitude estimation.

For the mentioned period only 31 values were known (Liller, 1980). We obtained 73 additional estimates: 47 from Sonneberg Sky Patrol plates (S), 15 based upon plates taken with the 40 cm astrograph in Sonneberg (A) and 11 made in Bulgaria (B). Fortunately, the 40 cm astrograph plates cover the fading of the brightness from Oct. 1971 till Apr. 1972 and fill the lack of observations during the minimum. In Table I the numerical values of the estimates are presented and the same data are presented with filled circles in Fig. 1. In the same figure Liller's data are also given with open circles.

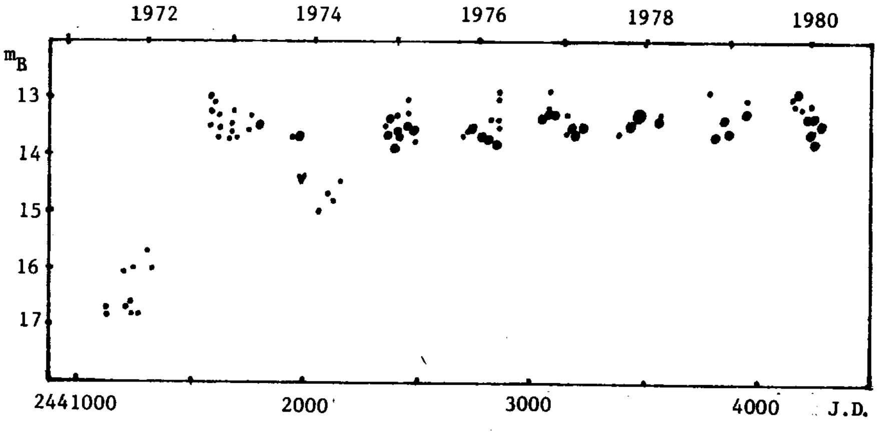


Fig. 1

Table I

J.D.	m_B	Obs.	J.D.	m_B	Obs.
244...			2359.453	13.5	S
1236.412	16.7	A	2395.409	13.4	S
1248.523	16.8	A	2449.282	13.3	S
1249.493	16.7	A	2449.347	13.0:	S
1300.543	16.1	A	2449.351	13.3	S
1322.396	16.7	A	2472.285	13.6	S
1333.506	16.6	A	2472.341	13.8	S
1334.460	16.8	A	2697.572	13.7	S
1350.294	16.0	A	2714.451	13.6	S
1356.260	(16	A	2717.519	13.7	S
1361.269	16.8	A	2831.425	13.5	B
1366.275	(16	A	2834.389	13.4	B
1390.300	15.7	A	2835.420	13.5	B
1394.297	16.5	A	2837.424	13.4	B
1421.402	16.0	A	2838.376	13.5	B
1592.494	14.0:	S	2839.325	13.1	S
1595.545	13.0	A	2839.444	13.5	S
1595.566	13.2	S	2841.344	13.0	S
1596.540	13.1	S	2858.306	13.2	S
1599.584	13.3	S	2866.369	12.9	S
1600.594	13.6	S	2867.392	13.3	B
1602.547	13.7	S	2868.403	13.5	B
1679.400	13.6:	S	2870.324	13.0	S
1680.445	13.7	S	3078.471	13.2	S
1681.382	13.7:	S	3078.519	12.9	S
1685.401	13.5	S	3157.340	13.3	S
1689.374	13.2	S	3162.417	13.3	S
1708.345	13.6	S	3400.576	13.6	S
1738.365	13.3	S	3482.543	13.3	S
1765.315	13.3	S	3483.449	13.3	S
1773.386	13.3	S	3575.395	13.3	S
1957.555	13.7	S	3789.511	12.9	S
1982.533	(14.4	S	3963.350	13.0	S
2068.367	15.0	B	4169.507	13.0	S
2091.369	14.7	B	4171.588	13.1	S
2118.335	14.8	B	4200.447	13.2	S
2151.320	14.5	B	4234.528	13.1	S

References:

Liller, M.H., 1980, Astron. J., 85, 1092.
Popova, M.D., 1965, Peremennye Zvezdy, 15, 534.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

RECENT PHOTOMETRIC DATA FOR THE X-RAY SOURCE KR AURIGAE

A.P. Antov, V.N. Popov, M.D. Popova

Department of Astronomy with National Astronomical Observatory
of Bulgarian Academy of Sciences, Sofia

The interest in KR Aurigae is determined by its peculiar features. Photometric investigations after its discovery in 1960 (Popova, 1960) showed variability in all observed time intervals. The star spends more time in maximum varying between the 12th and 14th magnitudes but sometimes its brightness drops to between the 17th and 18th magnitude. This photometric behaviour has led to the suggestion that KR Aur belongs to a new type of variability - anti nova (Popova, 1974). On the basis of the spectral characteristics of the star a new class of nova-like variables known "anti-dwarf novae" was proposed by Bond (after Shafter, 1983). The spectra of these normally resemble dwarf nova at maximum. KR Aur was found to be a binary system (Shafter, 1983, Kraicheva et al., 1982) and a weak X-ray source (Mufson et al., 1980).

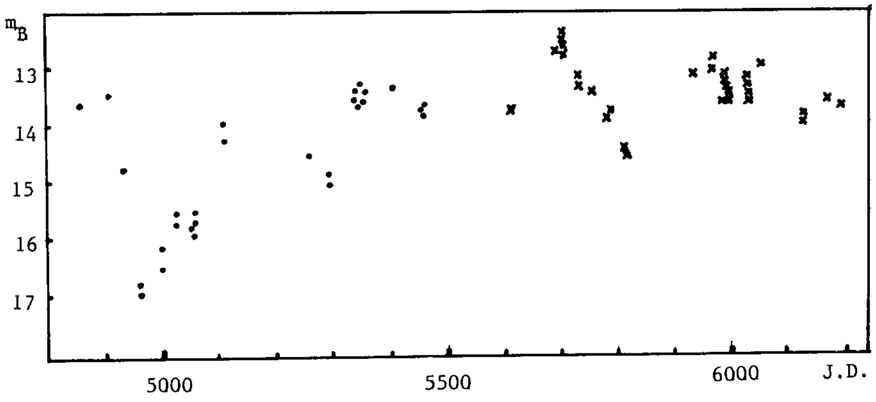


Figure 1

Further data on the light curve of KR Aur are of importance to clarify the nature of this remarkable variable. Systematic photometric observations are carried out with the 50/70 cm Schmidt, 60 cm Cassegrain and 2 m RC telescopes of the National Astronomical Observatory of the Bulgarian Academy of Sciences.

In this communication the éstimates of the photographic magnitude of KR Aur are reported for the period J.D. 2445600-2446200. They are based on Popova's (1965) standard stars. The new data are shown by crosses in Fig. 1. In the same figure dots denote the known photometric data preceding the new observations.

References:

Kraicheva, Z.T., Popov, V.N., Popova, M.D., Antov, A.P., 1982, Publ. Symp. Relativistic Objects in Close Binary Systems of the Multilateral Co-operation on Stellar Physics and Evolution, Cluĵ-Napoca, Romania.
Mufson, S.L., Wisniewski, W.Z., and McMillan, R.S., 1980, IAU Circ. No. 3471.
Popova, M.D., 1960, Mitt. Ver. Sterne (Sonneberg), No. 463.
Popova, M.D., 1965, Peremennye Zvezdy, 15, 534.
Popova, M.D., 1974, In: "Late Stages of Stellar Evolution, ed. R.J. Tayler, p. 192.
Shafter, W.A., 1983, Astrophys. J., 267, 222.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

ON THE LAST CYCLE OF OPTICAL VARIABILITY OF X-RAY SOURCE KR AURIGAE

Z.T. Kraicheva, V.N. Popov, M.D. Popova, A.P. Antov

Department of Astronomy with National Astronomical Observatory
of Bulgarian Academy of Sciences, Sofia

The photometric variations of the X-ray source KR Aurigae have been followed for a considerably long time interval - about 100 years. The observational material comes mainly from the plate collections of the Sonneberg and Harvard Observatories (Popova, 1975; Liller, 1980; Popov et al., 1986). In recent years the star was observed systematically by the National Astronomical Observatory of the Bulgarian Academy of Sciences and by Sonneberg and Harvard Observatories (Popov, 1982; Popova et al. 1984; Liller and Popova, 1984; Götz, 1982, 1984). All the magnitudes in these investigations are based on Popova's (1965) sequence and well complement each other.

We have used all this observational data to analyse the peculiarity of the long term photometric behaviour of KR Aurigae obtaining the mean semiannual photographic magnitudes. The results for the years 1970-1985 are given in Fig. 1. The range of the magnitude variations is also presented.

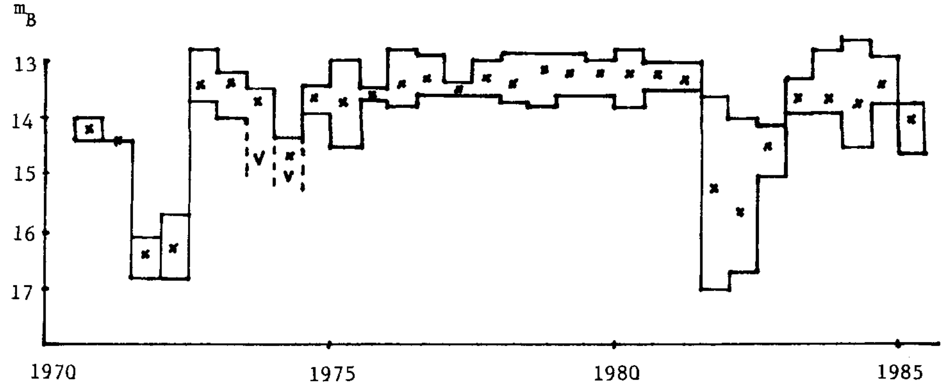


Figure 1

This latter cycle is unique in the sense of the number of observations taken with telescopes large enough to follow the lower part of the light curve. It is worth while to note the secondary minima in 1974 and 1984. If the character of the next cycle is similar to the last one, a deep minimum to 17-18 magnitude can be expected around 1990. It should be noted, however, that sometimes periods of irregular variations or some-years-long low stages occur between the cycles. It is interesting to study the possible relationship between the drop of the brightness of the variable and the decrease of the mass transfer from the secondary component (Shafter, 1983). Further photometric observations and spectrophotometry in different stages are needed.

References:

Götz, W., 1982, IAU Comm. 27 IBVS No. 2364.
Götz, W., 1984, IAU Comm. 27 IBVS No. 2540.
Liller, M.H., 1980, Astron. J., 85, 1092.
Liller, M.H., Popova, M.D., 1984, IAU Comm. 27 IBVS No. 2464.
Popov, V.N. 1982, IAU Comm. 27 IBVS No. 2095.
Popov, V.N., Kraicheva. Z.T., Popova, M.D., 1986, these Proceedings, p.373.
Popova, M.D., 1965, Peremennye Zvezdy, 15, 534.
Popova, M.D., 1975, Astrophys. Issled. (Sofia), 1, 68.
Popova, M., Popov, V., Antov, A., and Kraicheva, Z. 1984, Adv. Space Res., Vol. 3, No. 10-12, 55.
Shafter, W.A., 1983, Astrophys. J., 267, 222.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

EJECTION OF MATTER BY MASSIVE STARS

Tatjana A. Lozinskaya

Sternberg State Astron. Inst., Moscow, USSR

Massive start ($M_{in} \gtrsim 10M_\odot$) lose matter in the following ways: 1. Stellar wind, 2. Ejection of a "slow" shell, 3. Supernova (SN) explosion. Previous investigations all concentrated on a single type of these ejecta. It is now clear that the problem should be investigated only when these separate threads combine into a unified picture. Real SN ejecta interact with pre-supernova wind and with a slow shell (if it exists), a slow shell may be accelerated by the wind, etc. Some items of the picture can be confronted with the following observations:

I. Recent UV, radio and IR observations indicate that early-type stars with $M_{init} > 10M_\odot$ always show evidence of a "fast wind" ($\dot{M} \simeq 10^{-7}$ - $10^{-6}M_\odot$/yr, $V_\infty \simeq$ 1000-2000 km/s). A stronger fast wind ($\dot{M} \simeq 10^{-5}$ $M_\odot$/yr, $V_\infty \simeq 2\cdot10^3$ km/s) is attributed to Of stars and to post-main-sequence WR stars; a "slow" wind ($\dot{M} \simeq 10^{-5}$ $M_\odot$/yr, $V_\infty \simeq$ 10 km/s) - to red supergiants being progenitor stars of type II SNe. Probably there is a very short "superwind" stage just before the SN explosion ($\dot{M} \simeq 10^{-3}$ $M_\odot$/yr). The stellar winds disturb ambient ISM producing bubbles and shells with radii of the order of 1 to 20 pc and velocities 10-100 km/s (e.g. wind-blown bubbles around WR and Of: NGC 6888, NGC 2359, thin filamentary shell in NGC 6164-5).

II. Some WR- and Of- ring nebulae are generally ejected material rather than ISM swept up by stellar wind. The nebulae M1-67, RCW58, and the innermost shell of NGC 6164-5 are certainly slow shell ejecta with radii $\simeq$ 1 pc, $M \simeq$ 1-5 $M_\odot$, velocities $\simeq$ 20- 100 km/s.

Both processes, slow ejecta and stellar wind, work in common. Expansion of an ejected shell takes place inside a bubble blown by the wind at the early "pre-ejecta" stage of the star evolution. A "post-ejecta" wing accelerates the ejected shell. Such a scenario is probably demonstrated by the system of four concentric shells NGC 6164-5.

III. When a massive star explodes as a supernova, the SN ejecta will interact mainly with stellar material (stellar wind and slow ejected shell). This is confirmed by:

a) Optical, radio-, UV-, IR- and X-ray light curves of the type II SN 1979c and 1980k (Chevalier, 1984).

b) Spectral line profiles with two absorption features P Cyg in SN 1984g (NGC 3169) are probably evidence of a "superwind" before the SN-explosion (Dopita et al., 1984).

c) Optical or X-ray halos around the Crab Nebula, Cas A, G292.0+1.8 and other young SNRs.

d) Ambient density ($n_o \simeq 0.5$ cm^{-3} as required by X-ray observations of the SNRs Tycho and Kepler) is too large for ISM at $z \simeq$ 300-400 pc. The most reasonable explanation seems to be the interaction of SN ejecta with the circumstellar material.

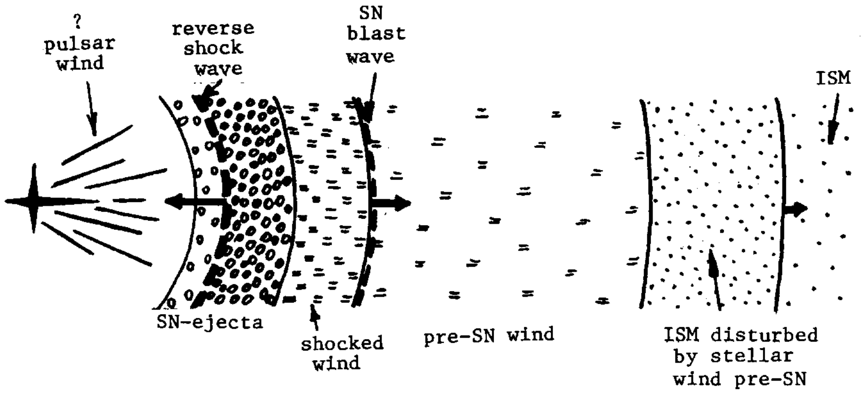


Fig. 1

e) A very thin radio "rim" surrounding the main radio shell of the Tycho SNR cannot be explained without a shell of matter - presumably a pre-SN planetary nebula - around the exploding white dwarf (Dickel, Jones, 1985).

f) In Cas A and Tycho SNRs X-ray emission of SN ejecta and of shocked progenitor's wind is resolved in space and corresponds to different T_e, n_e.

g) Optical and X-ray observations of Cas A show a two-component composition of the progenitor stellar wind (dense stationary optical condensations and diffuse X-ray shell) and two-component SN ejecta (fast optical filaments and diffuse X-ray shell). The X-ray image of Tycho's SNR (Seward et al., 1983) also shows diffuse and clumping SN ejecta.

h) A class of "O-rich" SNRs (Cas A, G292.0+1.8, N132D, 1E0102-7219) demonstrates non-spherical SN ejecta: an expanding torus plus a diffuse spherical shell, surrounded by a faint halo. Such a peculiar structure provides a model of a massive rotating (or with a compact companion) precursor with strong stellar wind, the most probable candidate being a WR star.

References:

Chevalier, R.A., 1984, 11. Texas Symp., Ann. N.Y.Acad.Sci., p. 215.
Dickel, J.R., Jones, E.M., 1985, Ap. J. Lett. v. 287, L69; Ap. J. v. 288, p. 707.
Dopita, M.A., Evans, R., Cohen, M., Schwartz, R.D., 1984, Ap. J. Lett. v. 287, L69.
Seward, F., Gorenstein, P., Tucker, W., 1983, Ap. J., v. 266, p. 287.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

DISPERSION OF THE CHEMICAL ABUNDANCES IN CRAB NEBULA GAS FILAMENTS

V.V. Golovaty and V.I. Pronik

Lvov University Observatory and
Crimean Astrophysical Observatory, USSR

In a previous paper (Golovaty and Pronik, 1973) we presented qualitative arguments relating to the dispersion in the chemical abundances of Crab nebula filaments. However, this conclusion was based only on Woltjer's (1958) spectral observations of the filaments. There is now much more extensive information upon many individual condensations (Davidson, 1978 and 1979; Davidson et al., 1982; Fesen and Kirshner, 1982; Miller, 1978) and the present quantitative analysis was based on this information.

The complete set of spectral line intensities I(λ) suitable for determining the chemical abundance of individual filaments has been observed, unfortunately, only for several bright condensations. To obtain the intensities I(λ) which are missing from the observational data we studied the correlations between different I(λ) using data on filaments for which these lines were observed.

As a result we were able to reveal all available relations between the intensities of different spectral lines: $[OIII]/H_\beta \leftrightarrow [OII]/H_\beta$; $[OIII]/H_\beta \leftrightarrow I(\lambda)/H_\beta$; and $[OIII]/H_\beta \leftrightarrow [OII]/I(\lambda)$. These relations were used to obtain a combined spectra of the filaments. We consider three types of filament spectra (A,B,C) corresponding to the ratios of the intensities λ4959+5007 $[OIII]/H_\beta$ equal to 5, 16 and 40. These values correspond to minimum, average and maximum values of $[OIII]/H_\beta$ observed. In order to determine the abundances of the chemical elements we used the method based on the photoionization models of filaments (Golovaty and Novosiadly, 1985). The best agreement between calculated and observed spectra is achieved for the following chemical compositions:

	A	B	C
He/H	0.15	0.48	1.2
N/H(10^{-4})	0.92	0.33	0.28
O/H(10^{-4})	1.4	2.3	2.2
Ne/H(10^{-4})	0.78	0.86	0.80
S/H(10^{-4})	0.64	0.35	0.10

It is seen that the dispersion of abundances is real for He/H, N/H, S/H and possible for O/H. The chemical composition of the filaments of group A is near the normal one.

References:

Davidson, K., 1978, Astrophys. J., 220, 177.
Davidson, K., 1979, Astrophys. J., 228, 179.
Davidson, K., Gull, T.R., Maran, S.P., Stecher, T.P., Fesen, R.A., Parise, R.A., Harvel, C.A., Kafatos, M., and Trimble, V.L., 1982, Astrophys. J., 253, 696.
Fesen, R., and Kirshner, R., 1982, Astrophys. J., 258, 1.
Golovaty, V., and Novosiadly, B., 1985, Astrofizika, 22, (in press).
Golovaty, V., and Pronik, V., 1973, Astr. Zhu., 50, 1147.
Miller, J., 1978, Astrophys. J., 220, 490.
Woltjer, L., 1958, BAN, 14, No. 483, 39.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

RUNAWAY INSTABILITY IN THE INNER COOLING REGION OF OPTICALLY THIN, BREMSSTRAHLUNG DISKS AROUND KERR BLACK HOLES

H.G. Paul

Zentralinstitut für Astrophysik der AdW der DDR,
Sternwarte Babelsberg. DDR-1502 Potsdam, Rosa-Luxemburg-Str. 17a

There is an inner rapidly cooling region in thin α-accretion disks (Fang, 1980; Zhang and Jiang, 1982) that is induced by gravity (Paul, 1985a) and shows non-singular inner boundary behaviour between the radii of marginally stable, r_{ms}, and marginally bound, r_{mb}, test particle orbits (Paul, 1985b). In the very short dynamic timescale t_{φ} of this region "catastrophic" mass overflow is found by taking into consideration the hole's change in the total mass-energy M and total angular momentum $a_{*} = a/M$. The hole evolution appearing during the change of its gravitational field is described by the differential equations $\delta M = E^{+}(r_{in})\delta M_{o}$ and $\delta a = [L^{+}(r_{in}) - aE^{+}(r_{in})] \frac{\delta M_{o}}{M}$ (Bardeen, 1970; Thorne, 1974). E^{+} and L^{+} are the specific energy and angular momentum, respectively, of the disk matter on the inner disk edge and these are carried into the hole by the accretion flow $\dot{M}_{o}$ through the free fall region ($\delta L^{+} = 0$). Consequently, the cusp-like wall of the effective disk potential braking and supporting the disk matter in its innermost region, varies ($\delta r_{o}/r_{o} = K\delta M_{o}/M$) with the corresponding variation of the inner disk boundary ($\delta r_{in}/r_{in} = N\delta M_{o}/M$). For sufficiently high angular momenta of the Kerr hole ($1 > a_{*} \gtrsim 0.8$), runaway instability appears ($K > 0$, $K > N$) and operates on the dynamic timescale $t_{\varphi} = \frac{2\pi}{\Omega} = 2\pi \frac{r^{3/2}}{M^{1/2}} \left(1 + \frac{aM^{1/2}}{r^{3/2}}\right)$ of the inner cooling region. The instability condition $K > N$ is fulfilled while $\partial_{r} \ln T(r) > f(r)$ and $K > 0$. (T is the temperature profile and f(r) is an algebraic function determined by the Kerr space time.) This instability condition breaks down near the radius of the marginally stable test particle orbit, r_{ms}, being the inner boundary of the standard models. That means that the runaway instability acts in the inner cooling region only, $r_{mb} < r < r_{ms}$.

The runaway instability found in thick accretion disks in the slender torus approximation for the Schwarzschild hole (Abramowicz et al., 1983) does not exist for the thin α-disk models.

Very short aperiodic luminosity bursts could be connected with the instability, found here, because these act in the extremely short dynamic timescale t_φ of the disk matter moving in the immediate vicinity of the Kerr hole. For example, using the system parameter of Cyg X-1 and assuming an angular momentum $1 > a_* \gtrsim 0.8$ for the black hole candidate we get burst durations of 0.64 ms $> t_\varphi > 1.7$ ms. ($a_* \simeq 0.8$ appears to be the best value with respect to the observation.) In the case of type II bursts of galactic bulge and cluster sources (Shapiro and Teukolsky, 1983) (t_φ is in the order of seconds to minutes) $M \simeq 10^6 M_\odot$ and $1 > a_* \gtrsim 0.8$ must be imposed as the most convenient hole parameter. The typical history of the unstable inner cooling region repeating many times, could possibly be described by the filling up of the cooling region with the following emptying of the innermost disk region as a function of the time required for filling up.

References:

Abramowicz, M.A., Calvani, M., Nobili, L., 1983, Nature 302, 597.
Bardeen, J.M., 1970, Nature, 226, 64.
Fang, L., 1980, Scienta Sinica, 9, 867.
Paul, H.G., 1985a, Astron. Nachr. 306, 3.
Paul, H.G., 1985b, Astron. Nachr. in press.
Shapiro, S.L., Teukolsky, S.A., 1983, In: Black Holes, White Dwarfs, and Neutron Stars. John Wiley & Sons, New York.
Thorne, K.S., 1974, Ap. J. 191, 507.
Zhang, J., Jiang, S., 1982, Acta Astrophys. Sin., 2, 277.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

SHELL PHENOMENON IN Be STARS

P. Harmanec

Astronomical Institute, Czechoslovak Academy of Sciences,
251 65 Ondřejov, Czechoslovakia

By definition, a Be star is a star of spectral type B which exhibited emission in at least one H I Balmer line on at least one occasion. Surprisingly enough, most of the objects meeting this purely descriptive definition show notable mutual similarities in their behaviour. Their basic properties are quite similar to those of normal main-sequence B stars.

Most bright Be stars cluster around the B2 spectral subclass with a secondary maximum near B8. One notable property of Be stars is the lack of very low $v \cdot \sin\ i$ values. The projected rotational velocities of most of these stars lie between 200 and 300 km/s.

Be stars are not rare. They represent at least 10 to 20 per cent of all B stars, perhaps even more because the time scales involved are long in many cases, and new (even bright) Be stars are being discovered almost every year.

A fascinating property of Be stars is their spectacular time variability. They are apparently the most variable objects in the upper main sequence. Spectral variations include line-profile variations, including a complete disappearance and re-appearance of the Balmer emission in some cases (most often on a time scale of years to decades), as well as radial-velocity and V/R variations of the double emission lines. Accompanying - or independent - light, colour and polarization variations have also been found for a number of Be stars. The time scales of these variations range from at least 0.5 days to decades, even for a particular star. (For a more detailed description of time variations of Be stars see, e.g., the reviews by McLaughlin 1961, Slettebak 1979 or Harmanec 1983b.) Although systematic work has led to discoveries of some periodic components in these variations, the future time behaviour of any real Be star appears unpredictable at the moment. This fact may be either an essential property of Be stars or may reflect the fact that much longer series of observations (over several hundreds of years) are necessary to discover some regularity in the Be-star time behaviour.

In some Be stars, narrow absorption lines of hydrogen, metals, and (for early B stars) of He I are observed, superimposed on the photospheric and/or emission lines. These lines are usually called *shell lines*. Stars exhibiting shell lines have been called *shell stars*. Once, they were considered to form a distinct group of objects. Nowadays, the occurrence of a shell spectrum is understood as a certain phase in the time variability of Be stars which may or may not occur in particular objects (see Underhill and Doazan 1982, and references therein). It is preferable, then, to speak about the *shell phenomenon* rather than about shell stars.

In the classical picture, the hydrogen emission is assumed to originate in an extended envelope (shell, disk) around the star, and the shell lines in the parts of the envelope projected against the stellar disk. However, neither the nature of the Be and shell phenomenon nor the mere geometry of the envelopes is well understood. This is best illustrated by the fact that the number of hypotheses trying to explain the Be phenomenon is still increasing - obviously all of them have active proponents. In their historical order, they are as follows:

1. Rotational hypothesis by Struve (1931). This hypothesis assumes the formation of Be envelopes by the rotational instability of underlying stars, arguing with the observed correlation between the emission-line widths and v · sin i. This hypothesis, however, offers no clear explanation of the time variations observed. Extensive modelling of observable parameters has been carried out on the basis of the rotational hypothesis (see, e.g., Poeckert and Marlborough 1978, Kříž 1979, and references therein). A recent defence of the rotational model can be found in Dachs et al. (1984).

2. The hypothesis of a radial outflow of matter due to radiative pressure by Gerasimovič (1934, 1935) postulates cycles in which the increasing density of envelopes stops further outflow, thus explaining qualitatively the long-term variations of the envelopes.

3. Binary hypothesis by Kříž and Harmanec (1975) (see also Harmanec and Kříž, 1976 and Harmanec, 1982). This understands Be envelopes as accretion disks produced by mass transfer from a secondary (which is often unseen) in a binary system. Be stars are interpreted as close relatives of

Algol-type binaries, symbiotic binaries and similar objects. The binary model is potentially able to explain many of the time variations observed. Indeed, the number of known Be binaries (including the optical counterparts of the massive X-ray binaries) is still increasing, and the causal connection between binarity and the time variations observed in such objects appears well established. However, due to the negative results of the attempts to prove the binary nature of a number of well-known Be stars, most astronomers are reluctant to accept the binary hypothesis as a universal interpretation of Be stars.

4. *Variable spheroidal mass flux hypothesis* by Doazan and Thomas (see Chapter 13 in Underhill and Doazan, 1982, and references therein). In some respects this is reminiscent of Gerasimovič's model. It does not make any specific conclusions about the cause of the postulated mass flux. Mass flux, radiative energy flux, and non-radiative energy flux are considered as three independent parameters controlling the formation and the time variations of Be envelopes. The following - essentially radial - sequence of regions is postulated: photosphere, a hot region (chromosphere-corona) with large expansion velocities, and a cool Be envelope, with only small expansion velocities. A potential problem of this hypothesis in its present form is that the evidence of large mass outflows based on the observations of the UV resonance lines appears much less safe than believed so far (see Hubený et al., 1985). In some sense, however, the variable mass flux hypothesis represents an interesting attempt at unifying all other hypotheses as special cases of a more general one. The disadvantage of the present "empirical" approach is, however, that it does not offer any verifiable predictions other than "omnia mutant".

5. *The hypothesis of local magnetic fields* is being developed by Underhill and her collaborators (Underhill, 1982; Underhill and Fahey, 1984). It assumes the existence of local bipolar magnetic fields on the surface of Be stars, and connects the observed variations with them. Unfortunately, there is little hope of detecting such fields directly by means of available observational techniques. However, the mere existence of Be stars with strong global magnetic fields (Landstreet and Borra, 1978) makes this hypothesis worth developing further.

6. *Hypothesis of non-radial pulsations*. This hypothesis - originally proposed by Baade (1979, 1982), and further developed by Vogt and Penrod (1984) and Willson (1985) - assumes that Be stars are non-radial pulsators

and that their envelopes are formed when the amplitude of non-radial pulsations increases beyond a certain limit. Different investigators have different opinions, however, as to the relative role of pulsation, rotation, and stellar winds in the whole process. The main argument of the proponents of this hypothesis is that the line-profile variations, detected by signal-generating detectors, can usually be modelled successfully by (often high-order) non-radial pulsational modes.

Let us turn back to the observational evidence of the shell phenomenon. Recent studies have indicated that one has in fact to recognize the following distinct phenomena:

1. A particular phase of the long-term variations. Spectacular long-term spectral variations have been known for years for a number of Be stars. In extreme cases, transitions from the B to the Be phase and from the Be shell phase and back to the B phase have been observed. Until recently, there tended to be a lack of simultaneous photometric observations although as early as in 1928 Gerasimovič (1928) suspected a correlation between the light and the H I emission during the long-term variations of Mu Cen. After the pioneering systematic photoelectric observations of BU Tau by Sharov and Lyuty (1976 and references therein), Harmanec, Horn and Koubský (1980) organized an observing campaign on long-term photoelectric monitoring of all bright Be stars. At present, this campaign is supplemented by systematic H alpha profile monitoring of the same stars, initiated by Barker (1981). The first results obtained by this campaign as well as those obtained by other observers allowed Harmanec (1983a,b) to define two basic extreme cases of the long-term variations observed:

A) The positive correlation between the long-term light variations and the strength of the H I emission has been observed for most of the Be stars studied. The brightness of such objects increases during the transition from the B to the Be phase. In the U-B versus B-V diagram, such objects move from the main sequence to supergiants, essentially unchanging their photometric spectral type at the same time.

B) The inverse correlation between the long-term light and H I emission variations has been observed for several Be stars during the transition from the B to the Be phase. Such objects usually move along the main sequence towards later spectral subtypes in the U-B/B-V diagram, without changing their luminosity class.

A transition from Be to the Be shell phase is usually connected with a light decrease. Also, an increase in the degree of polarization usually accompanies the development of the envelope.

Harmanec (1983b) proposed that the above-mentioned types of behaviour can qualitatively be well understood as a geometrical effect of flattened Be envelopes that change their density and/or extent with time.

In a broader context, it is of interest that the light and spectral behaviour of long-term variations with the positive correlation is reminiscent of a very mild nova outburst (the full amplitude of the light changes of Be stars is usually less than 1^{m}, however) while the inverse correlation bears some resemblance to the variations of R CrB stars.

2. Recurrent shell episodes. The periodic or nearly periodic reappearance of a well-developed shell spectrum has been reported for several Be stars, for instance AX Mon (P = $232\overset{d}{.}5$, Cowley, 1964), KX And (P = $38\overset{d}{.}91$, Struve, 1944), and HR 2142 (P = $80\overset{d}{.}86$, Peters, 1983). All such changes are now understood as phase-locked variations connected with the orbital motion of corresponding Be stars in binary orbits. The shell spectrum is observed when the gas stream between the components is projected against the disk of the Be component. A light minimum, observable in the U colour only, often accompanies such "shell" episodes.

3. Occasional occurrence of the blue-shifted shell lines. Doubling of the hydrogen shell lines, occurring at apparently irregular intervals, has been reported for several Be stars - particularly for known binaries with cool secondaries such as AX Mon, 17 Lep or KX And. The second system of shell lines is always blue-shifted, with velocities of about -100 to -300 km/s, and often of comparable intensity with respect to the basic system of the H I shell lines. The nature of this phenomenon is completely unclear at present.

4. Narrow blue-shifted components of the UV resonance lines. Such lines, with velocities ranging from -100 to -1500 km/s, have so far been observed in the resonance doublets of the C IV, N V, Si III, Si IV, etc., of about ten Be stars. The lines appear and disappear at apparently irregular intervals. Multiple components with several distinct velocities have been reported for a few stars. The same feature is quite common among the OB supergiants. Harmanec (1983b) called attention to the fact that these lines are observed only for Be stars of spectral type B2 and earlier. He also pointed out that the blue-shifted H I lines, seen in the optical spectra, and these narrow components may in fact represent the same phenomenon.

Henrichs et al. (1983) developed a model of a radial outburst of a more dense material within a steady stellar wind to account for the existence of the narrow components, while Underhill and Fahey (1984) argue that the character of these lines indicates that the material is flowing from localized areas onto the stellar surface and they postulate the existence of local bipolar magnetic fields.

One may ask which of the observed phenomena are indicative of "eruptions" from Be stars. The answer to this question is not quite clear at present. Tentatively, one may consider the following phenomena:

i) Long-term variations, taking into account their similarity to novae eruptions.

ii) The narrow blue-shifted shell lines, keeping in mind, however, that they often persist for months or years.

iii) Photometric evidence: There is rather unconvincing work by Bakos (1969, 1970, 1984). He detected a 3^m flare of the B8e star HD 160202 occurring within several minutes. The trouble is that the flare was recorded with an experimental TV system. The image on the TV screen was regularly recorded on photographic plates. Subsequent photoelectric observations of the star over two observing seasons failed to detect any variations in excess of $0\overset{m}{.}01$. Page and Page (1970) found a flare-like brightening of 66 Oph for more than 1^m from their patrol photographs. Subsequent photoelectric photometry of the star by several groups of observers revealed only variations smaller than $0\overset{m}{.}1$, however.

iv) The following sequence of observations of Lambda Eri is worth mentioning: Lambda Eri is a Be star which was found to vary regularly in light and radial velocity, with a stable period of 0.7 days (Bolton, 1982; Percy, 1981). The amplitude of these variations changes with time, down to practically zero on some epochs. Penrod (1985) observed line-profile variations of this star and modelled them as non-radial pulsations. He recorded the following sequence of events:

1983 Aug 25, Sept 20	no Balmer emission	large "pulsational" amplitude (10–15 km/s)
Oct 10	emission present	amplitude still large
Nov 22	emission present	pulsations unseen
Dec 19	still emission	only small-amplitude variations
1984 Apr 12, Aug 17	no emission	pulsational variation returned.

One possible interpretation of this sequence of events, advocated by Penrod, is that the pulsational energy was temporarily spent on the release of a Be envelope. Harmanec (1984) advocates another interpretation, however. He pointed out that the rapid Be variables have usually double-wave light curves, and suggested that such Be stars may be spotted stars, similar to magnetic CP stars or RS CVn stars (see Olåh, page 393 in this volume). He mentioned three such cases but since then, other rapidly variable Be stars have been discovered and the number of Be stars with confirmed double-wave light curves now amounts to almost fifteen, including Lambda Eri itself. Practically all of them have periods between 0.5 and 2 days, i.e. in the range of expected rotational periods.

Concluding, I would like to stress the following two points:

i) The general importance of Be stars in a broader context lies, perhaps, in the fact that they may represent, after all, more simple examples of non-stationary phenomena such as are observed in violent form in novae, symbiotic or eruptive stars.

ii) Only new, systematically obtained observational data, and a careful critical analysis of existing observations along with continuing progress in theoretical modelling, could help in deciding between the various existing hypotheses of the Be phenomenon. It is of primary importance to find the ways how to decide whether non-radial pulsations or some geometrical (obscuration) effects are responsible for the rapid variations observed.

Acknowledgements

I am deeply obliged to Dr. John R. Percy for several discussions on the problem, and to Dr. Ivan Hubený for critically reading this manuscript.

References:

Baade, D., 1979 Thesis, Astron. Inst., Univ. Münster.
Baade, D., 1982, Astron. Astrophys., 105, 65, and 110, L15.
Bakos, G.A., 1969 in "Non-Periodic Phenomena in Variable Stars", ed. by L. Detre, Akadémiai Kiadó, Budapest, p. 159.
Bakos, G.A., 1970 Sky and Telescope 40, 214.
Bakos, G.A., 1984 in "The Origin of Nonradiative Heating / Momentum in hot Stars", ed. by A.B. Underhill and A.G. Michalitsianos, NASA CP 2358, p.62.

Barker, P.K., 1981 Be Newsletter 3, 14.

Bolton, C.T., 1982 IAU Symp. 98, 181.

Cowley, A.P., 1964 Astrophys. J. 139, 817.

Dachs, J., Hanuschik, R., Kaiser, D., 1984 Mitt. Astr. Gesell. No. 62.

Gerasimovič, B.P., 1928 Harvard Bull. 854, 3.

Gerasimovic, B.P., 1934 Mon. Not. R. astr. Soc. 94, 737.

Gerasimovic, B.P., 1935 Observatory 58, 115.

Harmanec, P., 1982, In: Proc. IAU Symp. No. 98; Eds. M. Jaschek and H.G. Groth, Reidel, Dordrecht, p. 279.

Harmanec, P., 1983a in "Advances in Photoelectric Photometry I", ed. by R.C. Wolpert and R.M. Genet, Fairborn, p. 42.

Harmanec, P., 1983b in "Workshop on Rapid Variability of Early-Type Stars", ed. by P. Harmanec and K. Pavlovski, Hvar Obs. Bull. 7, 55.

Harmanec, P., 1984 Bull. Astron. Inst. Czechosl. 35, 193.

Harmanec, P., Horn, J., Koubský, P., 1980 Be Newsletter 2, 3.

Harmanec, P., and Křiž, S., 1976, in "Be and Shell Stars", Proc. IAU Symp. No. 70, ed. A. Slettebak; Reidel, Dordrecht, p. 385.

Henrichs, H.F., Hammerschlag-Hensberge, G., Howarth, I.D., Barr, P., 1983 Astrophys. J. 268, 807.

Hubený, I., Štefl, S., Harmanec, P., 1985 Bull. Astron. Inst. Czechosl. 36, 214.

Křiž, S., 1979 Bull. Astron. Inst. Czechosl. 30, 83 and 95.

Křiž, S., Harmanec, P., 1975 Bull. Astron. Inst. Czechosl. 26, 65.

Landstreet, J.D., Borra, E.F., 1978 Astrophys. J. 224, L5.

McLaughlin, D.B., 1961 J. Roy. Astron. Soc. Canada 55, 13 and 73.

Page, A.A., Page, B., 1970 Proc. Astron. Soc. Australia 1, 324.

Penrod, G.D., 1985 Paper presented at a workshop on "Pulsation and Mass Loss in OB Stars", Univ. Colorado, Boulder, April 1985.

Percy, J.R., 1981 in "Workshop on Pulsating B Stars", ed. by G.E.V.O.N. and C. Sterken, Nice Obs., p. 227.

Peters, G.J., 1983 Publ. Astron. Soc. Pacific 95, 311.

Poeckert, R., Marlborough, J.M., 1978 Astrophys. J. Suppl. 38, 229.

Sharov, A.S., Lyuty, B.M., 1976 IAU Symp. 70, 105.

Slettebak, A., 1979 Space Sci. Rev. 23, 541.

Struve, O., 1931 Astrophys. J. 73, 94.

Struve, O., 1944 Astrophys. J., 99, 75.

Underhill, A.B. 1982 Be Newsletter 6, 21.

Underhill, A.B., Doazan, V., 1982 "B Stars with and without emission lines", NASA SP-456 Monograph.

Underhill, A.B., Fahey, R.P., 1984 Astrophys. J. 280, 712.

Vogt, S.S., Penrod, G.D., 1983 Astrophys. J. 275, 661.

Willson, A.L., 1985 Paper presented at a workshop on "Pulsation and Mass Loss in OB Stars", Univ. Colorado, Boulder, April 1985.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

STARSPOT PROBLEMS

K. Olåh

Konkoly Observatory, Budapest, Hungary

"To the extent that there is an active relationship between spots and flares, spots should be viewed therefore not simply as cool areas which are dull, compared to the more interesting behaviour exhibited by flares: rather, spots should be viewed as engines which do the work of converting the energy of convective flows into flare-compatible form." Mullan, 1983.

It is, of course, common knowledge that starspots are general features on some kinds of late type stars. The class of spotted stars is large and contains the BY Dra stars, the RS CVn stars with short, medium and long periods, and some of the W UMa stars. It is a well known fact that the BY Dra variables are the most eruptive family of spotted stars but some of the others also exhibit flare activity, e.g. the short period RS CVn star SV Cam, as was shown by Patkós (1981).

The spots and flares are closely linked but whereas flares are transient phenomena, spots have a long lifetime and can be traced.

My intention, in this report, is to review our knowledge about starspots but since even this question is too large I should like to concentrate on two main tasks: problems related to the temperature of spots, and the differential rotation in stars.

I. Starspot temperatures

I should first like to summarize the history of starspot temperature determinations. The first estimate of a spot temperature was made by Hall (1972) for RS CVn itself. It has a sunspot-like activity on the cooler star's surface. Hall assumed a dark region extending ± 30° from the equator in latitude and 180° wide in longitude. A spot of this size would occupy ~60% of the fainter hemisphere. From the typical amplitude of the light curve he found that the cooler hemisphere should be 2/3 as bright as the other which implies ~1000 K difference between the cooler and the warmer side. In the case of assuming a completely dark spot, the latitude extent would be $\pm 15^{\circ}$ occupying 1/3 of the cooler disk.

Another method for calculating the spot sizes and temperatures of the spots was developed by Mullan (1974). He pointed out (Mullan, 1973) that the diameter of starspots should increase when the depth of the convective zone increases. The starspots would have the size of the "super" convective cells which are ~2-3 times the depth of the convective zone. He carried out numerical calculations for stars having masses > 0.4-0.5 $M_{\odot}$. In the case of YY Gem he found the convective zone to be 0.33 R_* and the upper limit for the spot extent of 50°. In the presence of a magnetic field as large as B = 20 kGauss, T_e (spot umbra) was found to be ~1600-1900 K.

The increasing number of multicolour observations of RS CVn and related stars called attention to the colour variations. This feature can be explained by different temperatures. However, Vogt (1975) tried to explain the (B-V) amplitudes (which should not exceed 0.015) for BY Dra in another way: colour variations of this order may be due to variable Balmer and CaII H and K emission.

Barnes et al. (1978) continued angular diameter measurements together with UBVRI and BVRI photometry and developed relationships between F_V (surface brightness parameter) and $(U-B)_0$, $(B-V)_0$, $(V-R)_0$ and $(R-I)_0$ colour indices. Their very important results gave a good possibility for the direct determination of the spot temperatures. A very good and tight relationship was found between F_V and $(V-R)_0$ over the whole sample including all luminosity classes and spectral types. Moreover, the form of the relation very much resembles the blackbody case. The colour amplitude actually indicates a difference in temperature between the disk at maximum and minimum light. It approximates the spot temperature fairly well if not too many spots are seen in maximum light.

A similar method was used by Eaton and Hall (1979). They obtained a reasonably good result for the spot temperature of SZ Psc which was found to be 1200 ± 400 K cooler than the surrounding surface. For RS CVn they got $\Delta T \geq 500$ K.

Bopp and Noah (1980) also used the blackbody approximation to calculate spot temperatures. They derived $\Delta T = 800$ K for λ And from two colour data. A very important conclusion of their paper was that no single ΔT can be appropriate for all stars. Moreover, a given star may exhibit variations in ΔT from season to season. (In their model the effect of the limb darkening was neglected.) The same conclusion was found for HK Lac by Olåh (1983).

Dorren et al. (1981) obtained intermediate and narrow band observations of V711 Tau: from the data they determined the spot temperature of 3800 K. For the star's surface temperature they gave 5660 K, which was obtained from spectral classification. The temperature difference here, viz. $\Delta T = 1660$ K, is again close to the solar value.

Vogt (1981a) obtained low dispersion Reticon spectrophotometry of II Peg when the spots were least and most in view. The flux ratio of the spectrum with the spot in view was divided by the flux ratio of the spectrum with the spot out of view. From the resulting flux ratio the spectral type of the spot could be derived which gave some information about the spot temperature (T_{spot} ~3400 K).

Vogt (1981b) gave a unique, well determined solution for deriving spot temperatures using the Barnes-Evans relation. The crucial but, at the same time, weak point of this model is that it gives a good solution only in those cases when the spots pass completely out of view at some phase, and therefore the unspotted light level is precisely obtained.

His resulting temperature differences were: for II Peg, $\Delta T = 1200 \pm 100$; for BY Dra, $\Delta T = 600 \pm 450$; and for HK Lac, $T \gtrsim 950 \pm 200$. (In the case of HK Lac a lower limit only of ΔT can be calculated because the unspotted light level was not well determined.)

Vogt (1983) in his review paper briefly discussed the temperature modelling for different stars. He gathered the results for several cases and arrived at the conclusion that the starspot temperature is 3600 ± 200 K regardless of spectral type.

Stauffer (1984) gave a statistical minimum for the ΔT values. He concluded that spotted stars are $\sim 0^{m}.04$ bluer in (B-V) relative to (V-I) than are normal stars. If the emitted light from the spotted stars is given as a sum of the emission from two normal stellar photospheres with different temperatures, this colour difference manifests itself at $\Delta T > 700$ K.

Jahn and Stepien (1984) carried out detailed modelling of magnetic starspots. They calculated the relation between the masses of the stars and ΔT for given mixing length parameters (which reflects the efficiency of the convection). They found that the difference between the temperature outside and inside the spots practically does not depend on the magnetic flux. To derive the $M_* - \Delta T$ relation they supposed (using observed ΔT values) that practically one and the same ΔT exists for each star.

Ramsey and Nations (1981) determined $\Delta T = 1100 \pm 450$ K for II Peg with the help of the Barnes-Evans relation using V and R data.

Eaton and Poe (1984) redetermined the Barnes-Evans relation which is still very useful for deriving spot temperatures. The same authors (Poe and Eaton, 1985) used their modified Barnes-Evans relation for computing ΔT for some RS CVn systems. Their results for II Peg for different years strengthened the conclusion of Bopp and Noah (1980) about the existence of different ΔT's in stars at different times. They found $\Delta T = 910^o$, 1020^o and 730^o for 1977.6, 1979.7 and 1980.7, respectively. They noted that the variation of the limb darkening value can produce great variations in the colour curves. We shall discuss this point later.

And finally I should like to draw attention to an important result of Maltby et al. (1983) for the Sun: "The umbral temperature appears to increase by ~300 K from the beginning to the end of each solar half-cycle" - which is evidence again for different ΔT values in the same star at different times.

Regular observations of the spotted stars date back only about 10-15 years (in some cases 20 years). This is a relatively short time interval in which to draw some sort of picture about the spot-cycles, the development of individual spots, etc. The situation is even worse when we collect only those observations which were made in the more powerful red regions for temperature calculations. At present, it is very fashionable to collect suitable colour data for spotted stars during 1-2 observing seasons and then derive the most correct values possible for the spot parameters for that short time. If we wish to obtain information from the old UBV data so that we can follow the long term variations we must carefully examine the reliability and accuracy of the results which can be derived from them. Unfortunately, single-colour observations cannot be used for this investigation.

The spot model used here for the calculations was developed by Budding (1977). The basic task of this model is to decrease the degree of freedom of the process. In view of this we should derive as many parameters as we can, independently of the spot model process. Let us examine these parameters.

First, we need the inclination (i) of the star. Since most spotted stars are members of binary systems, in those cases - at least when we have double-lined binaries - i is more or less well determined. If the binary is single lined and only the mass function is known, we can give limits for i and choose an appropriate value (see Olåh et al., 1985). Regardless, i must be kept constant during the modelling (it very strongly affects the latitude (β) value).

Other very important parameters are the limb-darkening coefficients. Unfortunately there exist no well established model atmospheres for late-type dwarfs. For late-type giants the situation is better in that the tables of Manduca, Bell and Gustaffson (1977) are very useful. Nevertheless, it seems to me to be better to use some previously determined values for these coefficients rather than to consider them as variables since this increases the degree of freedom of the process. Poe and Eaton (1985) stated that when they used different limb darkening values in their model calculations they found great changes in the colour curves. They used a completely dark spot (T_{spot} = 0 K) with a radius of $33\overset{\circ}{.}6$ and the u_λ values were varied between 0.5 and 1.0 when u_V was fixed to 0.8.

We made model calculations to see how the (B-V) amplitude (A(B-V)) depends on the different limb darkening values. A realistic spot size ($\gamma = 30^o$), latitudes ($\beta = 10^o$, 40^o, 70^o) and temperature differences ($\Delta T = 1000^o$, 1500^o) were assumed. Limb darkening coefficients were altered from 0.5 to 1.0 with a 0.1 difference between u_V and u_B. The resulting colour amplitudes versus different limb darkening values are displayed in Figs. 1 and 2. In the first case (Fig. 1) a surface temperature of an MOV star (T_{eff} = 4100 K), in the second case a surface temperature of a KOIII star (T_{eff} = 4800 K) was used to calculate the flux ratio with the help of Planck's function.

It is well illustrated in Figs. 1 and 2 that the different limb darkening values do not very much affect A(B-V). In the worst case (between the 0.5-0.6 and 0.9-1.0 pairs), the difference in A(B-V) is about 0.01 mag. which is similar to the usual observation error. The 0.1 difference between u_V and u_B is great with respect to the directly obtained values for dwarf stars so the real effect should be even less than displayed here.

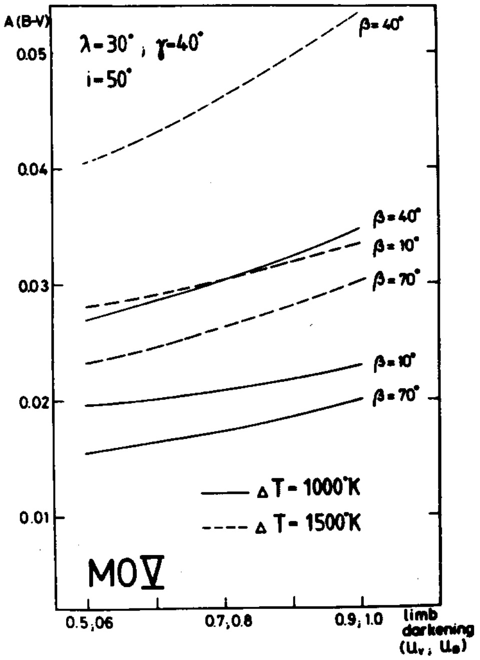


Figure 1. Amplitudes of B-V colour index vs. different limb darkening coefficients at different latitudes for an MOV star

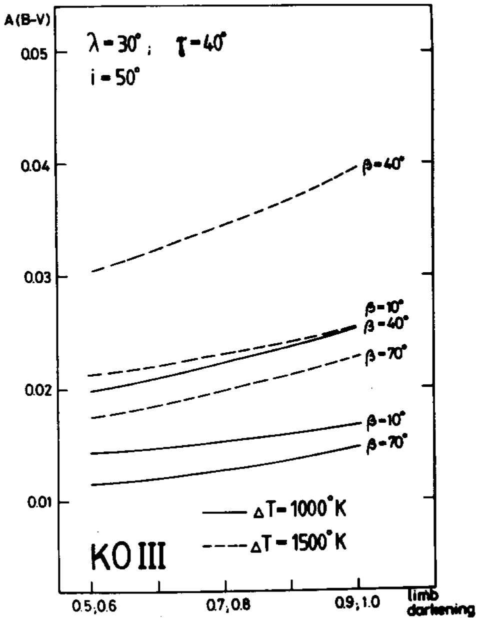


Figure 2. Amplitudes of B-V colour index vs. different limb darkening coefficients at different latitudes for a KOIII star

The question of the unspotted light level remains open; with the help of the literature some assumptions should be made.

A series of models was examined to study the dependence of the colour amplitude A(B-V) on ΔT. All the other parameters were fixed. In Table I the parameters used for the calculations are listed. Again, to obtain the flux ratio, Planck's function was used. The resulting curves are displayed in Figs. 3-11.

Table I

Spectral type	u_V	u_B	$\beta(^o)$	$\gamma(^o)$
MOV	0.78	0.82	10, 40, 70	30, 40
KOIII	0.75	0.85	10, 40, 70	30

It is not surprising that the greatest change in the colour amplitude is caused by the change in the spot area. Within the most probable ΔT interval (500-1500 K) the dependence of A(B-V) on orbital inclination i is not very strong in most cases. This means that the dependence of A(B-V) on the latitude of the spots is similar since i and β are closely related. (From this it follows that if the orbital inclination is well established with the use of a method other than spot modelling, the β value would be much better determined.)

We can now see that the most problematic point in spot modelling is to find suitable ΔT and γ values. One possibility exists to solve this problem, viz.: we must keep the parameters i, u_V, u_B and ΔT fixed during the process. Light curve models must be elaborated for the V and B light curves separately for a given ΔT value. Then, with different ΔT values, the procedure is repeated (with unchanged i, u_V and u_B values). The best solution that can be found is when the resulting spot parameters for the V and the B light curves are most similar to each other. An example of this method is given in Fig. 12, where the parameters for light curve modelling are given. The star which showed the light variation modelled here is BY Dra and the observations were carried out at Catania Observatory (Rodono, 1984). To solve the light curve, it was sufficient to assume one spot. In the modelling the unspotted light level was fixed very high, therefore no solu-

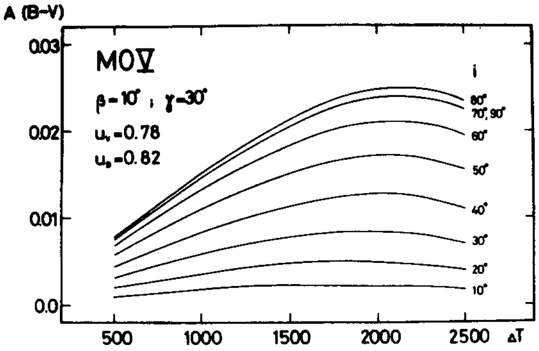


Figure 3

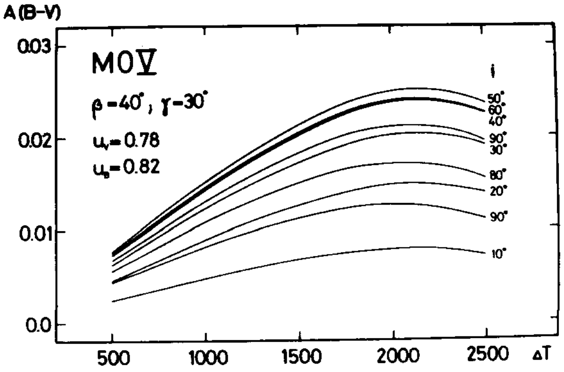


Figure 4

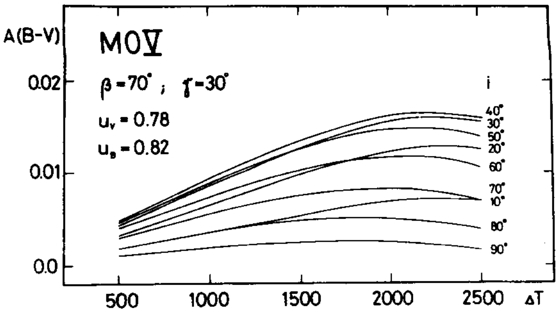


Figure 5

Figures 3-11. Amplitudes of B-V colour index vs. ΔT (T_{star} - T_{spot}) in case of different inclinations. β = spot latitude, γ = spot radius, u_V and u_B = limb darkening coefficients in V and B, respectively

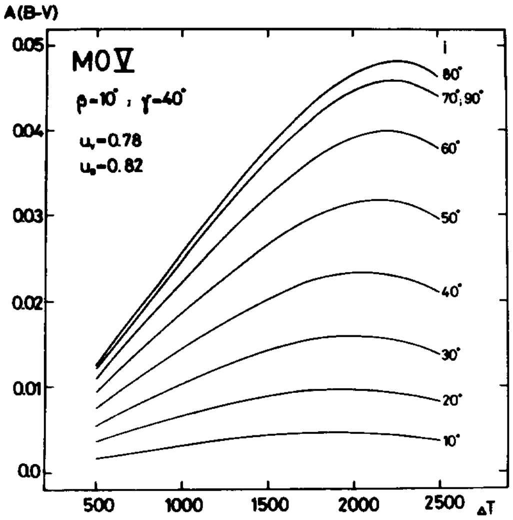


Figure 6

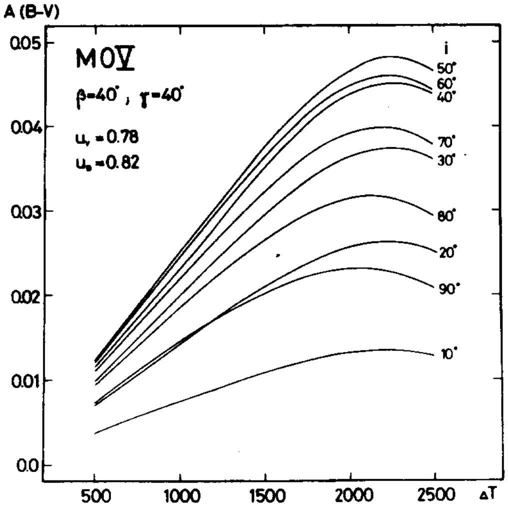


Figure 7

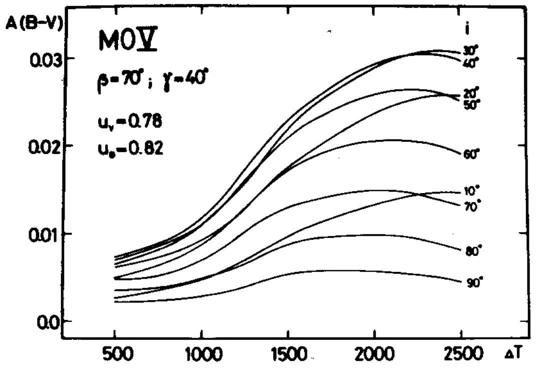


Figure 8

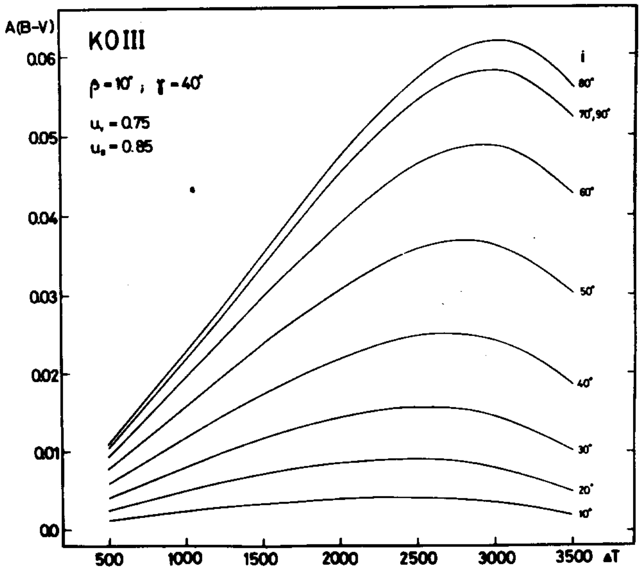


Figure 9

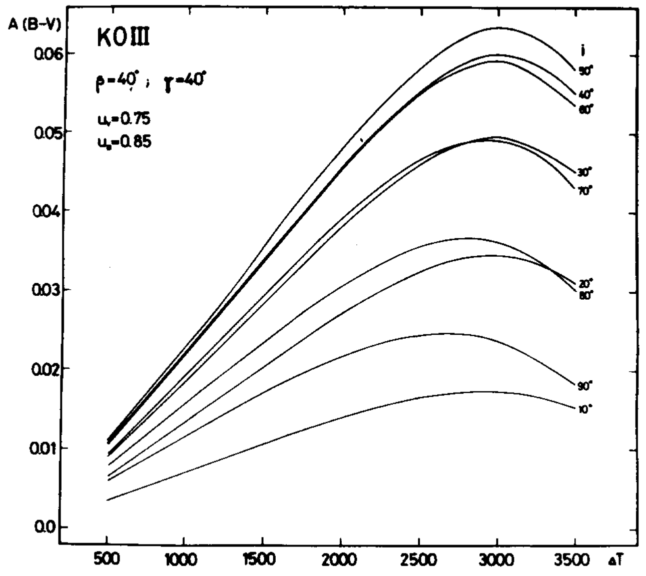


Figure 10

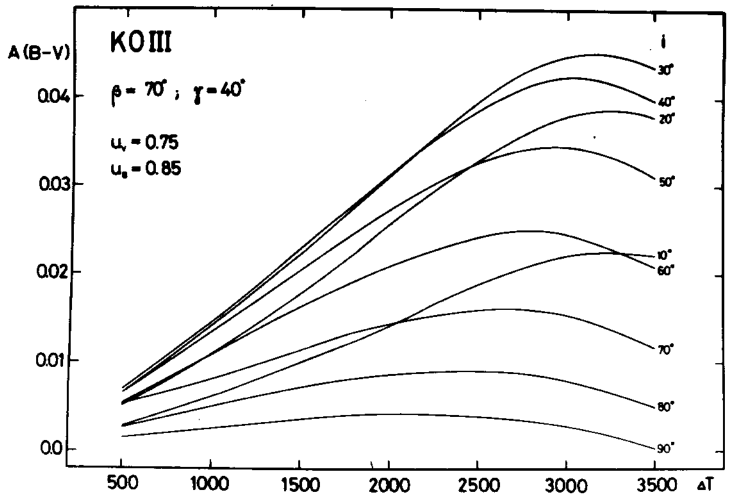


Figure 11

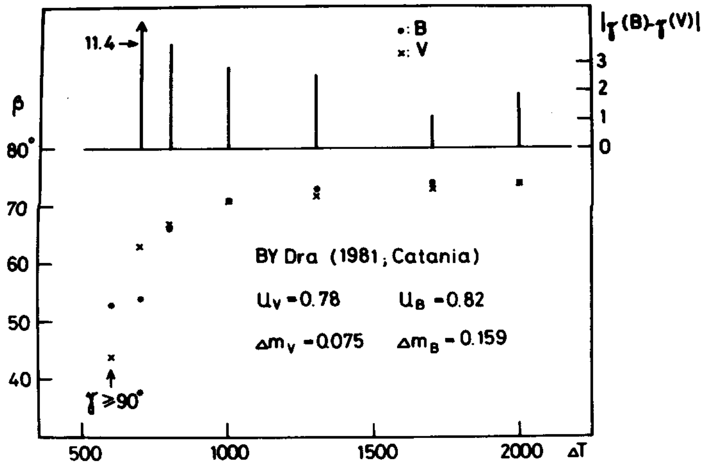


Figure 12. Latitudes and spot sizes' differences vs. ΔT ($T_{star} - T_{spot}$) using V and B light curves for modelling BY Dra.

tion exists for low temperatures. (The used value of the unspotted light level was chosen because at a given time the star was the brightest ever measured, and when it was observed, no light variation was found.)

In the upper part of the figure the differences between the resulting γ values (radius) for V and B colours are displayed. It is seen from the lower panel that the β coordinate of the spot soon became stable, and remained constant for a wide range of ΔT values. The λ (longitude) values were very stable during the whole modelling. The differences between the sizes of the spots have a minimum value around ΔT ~1500 K. Using the previously assumed and derived parameters with different methods this will provide the best solution for ΔT. The other parameters which were calculated by the model program enable the final solution of the spot coordinates to be obtained.

A similar method was used by Dorren et al. (1981) for V711 Tau. They determined the spot temperature from multicolour data and then that value was used in the course of the modelling.

II. Differential rotation

Since the very early period of starspot modelling researchers have been interested in the possibility of proving the existence of the differential rotation of the surface of spotted stars. The long-term behaviour of the spots on a star represents an excellent means of following the motions on the surface. However, this task needs more or less continuous observations of a given star for years. Here, I should like to stress the importance of the use of old UBV or even single colour observations. (Single colour observations can be used to determine the differential rotation since the great displacements - the coordinate changes - of the spots are not too much affected by the temperature differences between the spot and the surface.) The rotational and orbital periods, which we need to know for investigating the problem, are independent of the ΔT values. Determination of the differential rotation from the starspot motions needs no special procedure. Here we summarize some of the results obtained by different authors about different stars.

In one of the very first papers about RS CVn stars Hall (1972) discussed the light variation of RS CVn. By analysing the existing data he found that it was necessary to suppose the differential rotation which would produce the *migration of the distortion wave. A co-rotating latitude* at about 30° was estimated for the star. At that time no well defined starspot model existed so only indirect estimation of the spot coordinates was possible.

Chugainov (1973) found different periods for different epochs of BY Dra between 1965 and 1971 - doubtless these were caused by the differential rotation. This was theoretically discussed by Mullan (1974). Finally, using observations of BY Dra made between 1966 and 1977, Vogt (1981) determined a latitudinal shear for latitudes 40-80°; this was similar to the value given for the Sun in the same latitudes. In order to calculate this value, Vogt used well determined rotation periods and numerically derived spot coordinates using Budding's (1977) method.

Eaton and Hall (1979) found a link between the nonuniform rotation and the magnetic structure of the stars following the solar analogy.

Dorren et al. (1981) mentioned the possible existence of the differential rotation in V711 Tau.

Hall (1981) summarized our knowledge about the migration waves in different RS CVn systems and found them to be variable in most cases, as a possible consequence of the latitude drifts of the spots in the 19 stars studied.

In spite of the fact that there was no possibility to derive accurate spot latitudes in λ And, Dorren and Guinan (1983) found direct evidence of the differential rotation. They found a spot cycle ~6 years long with corresponding period changes, which were thought to be caused by the relative displacements of the spots in differentially rotating latitudes (see Fig. 2 of their paper).

From the different migration rates of the maxima and minima of II Peg Rodono et al. (1983) found evidence of the differental rotation and gave a lower limit of the latitudinal shear in the star.

Based on solar analogy a method was developed by Busso et al. (1984) to determine the places of the co-rotating latitude, the spot forming region and the measure of the differential rotation. They used time series analysis for nonequally spaced data and they interpolated and reconstructed the light curves. With the help of the known value of the phase displacements of the migrating waves, Busso et al. (1984, 1985) calculated the parameters of the differential rotation for 5 systems (SV Cam, VV Mon, SS Boo, RU Cnc, CQ Aur).

Direct evidence (using a long series of V observations and the spot model) of the existence of the differential rotation was found by Olåh et al. (1985) for HK Lac. One of the spots rotated slightly faster and the other slightly slower than the orbital motion. Knowing the average latitudes of these spots we were able to estimate the co-rotating latitude of $25^{\circ} \pm 12^{\circ}$. The mean spot latitudes and the corresponding periods gave the other value of $31^{\circ} \pm 2^{\circ}$ for the co-rotating latitude.

Baliunas et al. (1985) carried out a survey on red dwarfs measuring the relative strength of the chromospheric CaII H and K emission cores during several seasons. From power spectra analysis of the data they found varying periodicities in 12 stars. For 10 stars significant peaks in the power spectrum at two different frequencies were found. These authors gave two possible explanations for this feature: either the two periods originate from two active areas at different latitudes (which are rotating differentially with respect to each other), or the active areas are born and subsequently decay at different longitudes. For 4 stars the differential rotation seemed to be the more likely explanation for the varying periodicities. For these stars the fractional differential rotation was found between 5% and 21%.

Both tasks mentioned here, viz. the ΔT problem and differential rotation, suffer from the lack of long series of observations. Nevertheless, some promising results are already available and it is to be hoped that within the next few years and with the help of better observational techniques, these questions can be answered in detail.

References:

Baliunas, S.L., Horne, J.H., Porter, A., Duncan, D.K., Frazier, J., Lanning, H., Misch, A., Mueller, J., Noyes, R.W., Soyumer, D., Vaughan, A.H., Woodard, L., 1985, Astrophys. J. 294, 310.

Barnes, T., Evans, D.S., Moffett, T.J., 1978, Mon. Not. Royal Astr. Soc. 183, 285.

Bopp, B.W., Noah, P.V., 1980, Publ. Astr. Soc. Pacific 92, 717.

Budding, E., 1977, Ap. Sp. Sci. 48, 207.

Busso, M., Scaltriti, F., Cellino, A., 1985, Astron. Astrophys. 148, 29.

Busso, M., Scaltriti, F., Blanco, C., Catalano, S., Marilli, E., Pazzani, V., Rodono, M., 1984, Astron. Astrophys. 135, 255.

Chugainov, P.F., 1973, Izv. Krymsk. Ap. Obs. 48, 3.

Dorren, J.D., Guinan, E.F., 1983, In: Cool Stars, Stellar Systems and the Sun, ed. by S. L. Baliunas and L. Hartmann, p. 259.

Dorren, J.D., Siah, M.J., Guinan, E.F., McCook, G.P., 1981, Astron. J. 86, 572.

Eaton, J.A., Hall, D.S., 1979, Astrophys. J. 227, 907.

Eaton, J.A., Poe, C.H., 1984, Acta Astronomica 34, 97.

Hall, D.S., 1972, Publ. Astr. Soc. Pacific 84, 323.

Hall, D.S., 1981, In: Solar Phenomena in Stars and Stellar Systems, ed. by R.M. Bonnet and A. Dupree, p. 431.

Jahn, K., Stepien, K., 1984, Acta Astronomica 34, 1.

Maltby, P., Albregtsen, F., Kjeldseth Moe, O., Kurucz, R., Avrett, E., 1983, In: Cool Stars, Stellar Systems and the Sun, ed. by S.L. Baliunas and L. Hartmann, p. 176.

Manduca, A., Bell, R.A., Gustaffson, B., 1977, Astron. Astrophys. 61, 809.

Mullan, D.J., 1973, Astrophys. J. 186, 1059.

Mullan, D.J., 1974, ibid. 192, 149.

Mullan, D.J., 1983, In: Activity in Red Dwarf Stars, IAU Coll. No. 71, ed. by P.B. Byrne and M. Rodono, p. 527.

Nations, H.A., Ramsey, L.W., 1981, Astron. J. 86, 433.

Olåh, K., 1983, In: Activity in Red Dwarf Stars, IAU Coll. No. 71, ed. by P.B. Byrne and M. Rodono, p. 403.

Olåh, K., Eaton, J.A., Hall, D.S., Henry, G.W., Burke, E.W., Chambliss, C.R., Fried, R.E., Landis, H.J., Louth, H., Renner, T.R., Stelzer, H.J., Wasatonic, R.P., 1985, Ap. Sp. Sci. 108, 137.

Patkós, L., 1981, Astrophys. Letters 22, 1.

Poe, C.H., Eaton, J.A., 1985, Astrophys. J. 289, 644.

Rodono, M., 1984, personal comm.

Rodono, M., Pazzani, V., Cutispoto, G., 1983, In: Activity in Red Dwarf Stars, IAU Coll. No. 71, ed. by P.B. Byrne and M. Rodono, p. 179.

Stauffer, J.R., 1984, Astrophys. J. 280, 189.

Vogt, S.S., 1975, Astrophys. J. 199, 418.

Vogt, S.S., 1981a, ibid. 247, 975.

Vogt, S.S., 1981b, ibid. 250, 327.

Vogt, S.S., 1983, In: Activity in Red Dwarf Stars, IAU Coll. No. 71, ed. by P.B. Byrne and M. Rodono, p. 137.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

FLARE STARS - PHYSICS AND EVOLUTION

L.V. Mirzoyan

Byurakan Astrophysical Observatory, Armenia, USSR

Introduction

The most significant investigations on the study of flare stars and the phenomenon of stellar flares have been fulfilled during the last two decades. This work has resulted in a great deal of development and has helped to place the problem in one of the foremost positions in modern astrophysics.

Possibly the most important consequence of these investigations is the establishment of the flare activity stage in stellar evolution.

In the establishment of this important feature the following three results have played the decisive role:

1. Photographic observations of the Orion association region with wide-angle telescopes, leading to the discovery of some flare stars in this young system (Haro and Chavira, 1966).
2. The discovery of the first flare star HII 1306 in the Pleiades cluster (Johnson and Mitchell, 1958) thereby stimulating analogous photographic observations in this comparatively young system, owing to which some dozen flare stars were found in it.
3. The statistical estimation of the total number of flare stars in Pleiades (Ambartsumian, 1969) showing that almost all stars of low luminosity in this system are flare stars.

Highly significant results were obtained on the physical properties of stellar flares.

In this paper an attempt is made to present a state of the art report of the flare stars problem on the basis of flare star observations.*

---

*The fundamental tenets of the physical and evolutionary consideration of flare stars, on the basis of the observational data, were earlier given by Ambartsumian and the present author (1971, 1975) and in more detail by the present author (1981, 1984).

General Remarks

At the present time there is no doubt that the flare stars in star clusters and associations and the UV Ceti stars in the solar vicinity represent the same class of non-stable stars and the differences observed between them (luminosities, relation to nebula, etc.) are explained by the differences of their ages (see, for example, Mirzoyan, 1981).

Some apparent difference between them arises from the fact that the UV Ceti stars are studied, each individually, by methods possessing comparatively high time resolution (photoelectric photometry, slit spectroscopy, etc.) while the flare stars in systems are studied mostly by mass methods (photographic photometry, spectroscopy with objective prisms, etc.) having much lower time resolution.

Each of these approaches has its advantages and is suitable for the solution of different problems - the former of them related to physics and the latter to the evolution of flare stars.

At the same time, as expected, the most important results on stellar flares have been obtained by synchronous observations in different passbands.

The number of known UV Ceti stars in the solar vicinity has now reached 100 (a list of these stars is given in Gershberg's (1978) monograph). Apparently the majority of these stars are comparatively old stars which have already left the parent systems and have kept this activity until now owing to the longer duration for stars of very low luminosities (Mirzoyan, 1981) (see later).

Younger flare stars, possessing - on average - higher luminosities, are observed in star clusters and associations. By photographic observations with wide-angle cameras, carried out during about 7500 hours, approximately 1300 flare stars were found in the nearest systems.

Table I gives the distribution of flare stars in the comparatively better studied systems, according to Mirzoyan and Ohanian (1985). In it the total time of monitoring - τ, the number of known flare stars - n, the number of flare stars which showed only one flare-up during the whole time of photographic monitoring - n_1, and an estimation of the total number (low limit) - N of flare stars in the system, obtained by Ambartsumian's formula (Ambartsumian, 1969; Ambartsumian et al. 1970) are presented.

Table I. Flare Stars in Some Nearest Star Clusters and Associations

	τ (hours)	n	n_1	N
Pleiades	3175	546	287	994
Orion I	1406	482	380	1471
Taurus Dark Clouds	937	102	88	532
Cygnus (NGC 7000)	938	67	58	403
Praesepe	698	54	44	215
Monoceros I (NGC 2264)	105	42	40	442
around γ Cygni	324	16	15	129
Total	7583	1309	912	4186

In Table I the striking fact is that the majority of known flare stars (about 70%) during the observations showed only one single flare-up. This can be explained by the too low mean frequency of flares in the majority. Really, as the distribution function of mean flare frequency for the stars of Pleiades cluster shows, the mean flare frequency for the majority of stars is very low in spite of the fact that there are great differences in these frequencies for different stars. This function was derived by Ambartsumian (1978) on the basis of the chronology of discoveries and the chronology of confirmations of flare stars. On the other hand, as a result of this, less than one third of all flare stars have been discovered up to now in the systems studied. If we take into account that the estimates of total number of flare stars in systems N, presented in Table I correspond to the lower limit of this magnitude (Ambartsumian et al., 1970), then it must be admitted that at present we know only a small part of all flare stars even in comparatively better studied systems like Pleiades and Orion.

Therefore, further photographic observations of regions of star clusters and associations with wide-angle telescopes are essential.

Evolutionary Stage of Flare Activity

Even before the determination of the evolutionary stage of flare activity the physical similarity between the emission of T Tauri type stars and the emission appearing during stellar flares, revealed by Ambartsumian (1954), suggested that the non-stable stars of these two classes are related.

Later, Haro and Chavira (1966), on the basis of the results of flare star photographic observations in associations and clusters, postulated that the stage of flare stars follows the stage of T Tau stars. A telling argument in favour of the evolutionary connection between these two stages was the discovery by Haro and Chavira (1966) and by Rosino (1969) of some T Tau type stars showing classical flare-ups in the Orion and the Monoceros associations.* This discovery has shown that the evolutionary stages of T Tau and UV Cet partly overlap in time. During the period of coverage the star is of the T Tau type and flare star, simultaneously.

Using the statistical data concerning the Orion association Ambartsumian (1970) has shown that the time of coexistence of these stages is equal to approximately one fourth of the duration of the T Tau stage. At the same time the observational data show that the duration of the flare star stage varies over wide limits.

Thus, the existence of flare stars in the Orion association (age of the order of 10^6 years (Allen, 1973)) gives us grounds to assume that the flare activity stage can begin very early. On the other hand, in this association there are stars of high enough luminosities which do not show flare activity or, at least, activity which is available for photographic observations. In the older systems, such as Pleiades (age of the order of 10^8 years (Allen, 1973)), and Hyades and Praesepe (age of the order higher than 10^8 years (Allen, 1973)), there are still some flare stars as well as the stars of high luminosities which have already ceased their flare activity. Finally, among stars of the solar vicinity there are flare stars whose age exceeds 10^9 years (Gershberg, 1978). Therefore, on the basis of the observational data, it can be concluded that the flare activity stage already begins when the age of stars is of the order of 10^6 years and even smaller and sometimes continues to more than 10^9 years.

It can be assumed that for an individual star the initial and ending phases of flare activity depend on the luminosity (mass) of the star: the higher the luminosity the earlier the flare activity begins and, correspondingly, ends.

In the case of the ending of flare activity phase this regularity is confirmed by the data related to the mean luminosities of flare stars in the system of different ages (Mirzoyan and Brutian, 1980). They show that

---

*Of about 90 flare stars, discovered by Hojaev (1985) recently in the Taurus Dark Clouds, 13 were found to be the known T Tau type stars.

the older the system (flare stars) the lower the mean luminosity of flare stars in it. This regularity can explain the fact that there are practically no flare stars of comparatively high luminosities in the general galactic field.

The inverse correlation between the mean luminosity of flare stars and the age of the system to which they belong, can be considered as direct observational evidence in favour of the idea that the evolution rates of stars depend directly on their luminosities (masses): stars possessing higher luminosity evolve more quickly than stars of lower luminosity (Mirzoyan, 1982).

Thus, the observational data allow one to outline the following evolutionary sequence of dwarf stars - T Tau stars - T Tau stars possessing flare activity - flare stars - stars of practically constant brightness.

Certainly, some questions connected with the presented evolutionary sequence have not yet been finally answered. For example, the transition from the T Tau stage to the flare star stage is apparently connected with the difficulty of solving the problem of masses.

The important question as to whether all stars, at least the dwarfs, pass through a flare activity stage, has not yet been solved. For example, the observations of flare stars in Pleiades testify that the positive answer to this question needs to assume that flare activity of stars has a cyclic nature: the periods of high flare activity alternate with the periods of comparatively low activity (Mirzoyan and Ohanian, 1977).

However, it is unlikely that new studies can lead to any essential change in the foregoing main evolutionary sequence.

Some Appearances of Flare Activity

The stellar flare is a rapid increase of the stellar brightness (usually during less than one minute) with its comparatively slower decrease to the former value. The course of the brightness variations during a flare can be given by its light-curve.

Investigations of light-curves of stellar flares have shown their large diversity (see, for example, the investigations of Oskanian (1969) and Moffett (1974)). It has turned out that to obtain an exact picture of the course of the brightness variations during a flare its observation with a sufficiently high time resolution is required.

Photoelectric observations of flares of the UV Cet type stars carried out with a time resolution of the order of 1 sec by Moffett (1974), Cristaldi and Rodono (1970), and by others has enabled flares to be recorded that have very complicated shapes of light-curves and that include the cases of superposition of a number of flares on each other. This fact led to the idea that the stellar flare is a complex phenomenon and, in general, it represents a multiple appearance of the additional energy released during the flare (Moffett, 1972; Mirzoyan, 1980).

It is necessary to note that the fine structure of light-curves of stellar flares can be studied only on the basis of observations possessing a sufficiently high time resolution. When time resolution is low, the shapes of light-curves are distorted. For example, very fast flares are usually lost and the complex shapes of flare light-curves obtained by the photographic multiexposure method are greatly distorted (see, for example, Mirzoyan, 1981).

For the study of fine details of flare light-curves, recorded by the photographic method in associations and clusters, the method of stellar tracks can be used successfully, as Chavushian (1985) has shown. In this method instead of a chain of images for each star its trace is recorded on the photographic plate.

With regard to the fine structure of flare light-curves the optical observations of flares of the UV Cet type stars carried out recently by Beskin et al. (1985) are valuable. The detailed analysis of some dozen light-curves of flares registered during these observations allowed them to affirm, in the author's opinion, that no major variation of their fine structure during the time of the order of 0.5 sec has been observed.

It should be noted that though the shape of the light-curve does not depend on the power of the flare (very powerful flares with spike-like light-curves and small flares with complex shape of light-curves have been observed (Moffett and Bopp, 1976)), however, there is some evidence that the more powerful a flare, on average, the higher the probability of observing a complex light-curve (Mirzoyan and Melikian, 1985).

A very essential property of stellar flares was discovered by Haro (1964). He divided all flares into two groups: "fast" and "slow", according to the flare rise time, using his multi-exposure photographic observations. Haro showed that for the majority of flares the rise time was short, that is 10-15 minutes ("fast"), whereas there are rare flares for which the flare rise time reaches 20-30 minutes and more ("slow"). Haro also found that "fast" and "slow" flares differ from each other apparently by colours too ("slow" flares tend to be redder than the "fast" ones).

The difference between "fast" and "slow" flares can successfully be explained, if one assumes following Ambartsumian (1954), that the flare rise time is determined by the depth of the stellar atmospheric layers in which the flare takes place: the greater this depth the longer the flare rise time. Naturally, the flare rise time cannot be very long because if the depth is large enough then the flare will not be observable.

At present it can be said that Haro's classification, which was very fruitful, is actually a conditional one and is determined by the method of his observations. In reality the distribution of flare rise time durations is continuous: there is no sharp transition between "fast" and "slow" flares (Mirzoyan and Melikian, 1985). It is very probable that the flare rise time is indeed determined by the characteristics of those layers of stellar atmosphere in which the flare occurs. As evidence in favour of this idea the important fact can be considered that the majority of stars which have shown "slow" flares were also observed in "fast" flares (see, for example, Mirzoyan, 1981).

The fuor-like variations of star brightness (FU Ori phenomenon) can be considered as a remarkable manifestation of flare activity. After the brightening of V 1057 Cyg, before T Tau type spectrum, it has been revealed that such wonderful variations take place with some T Tau type stars (see, for example, Herbig, 1977). Ambartsumian (1971) - proceeding from the idea on the liberation of surplus flare energy in the surface layers of stars having different depths - has shown that a definite parallel exists between the differences in the emission of a prefuor and a postfuor, on the one hand, and the differences between the emission of "fast" and "slow" flares, on the other.

The results of Natsvlishvili's (1985) observations of the star Ab 24, on which Parsamian earlier found a flare, can be considered as some confirmation of this point of view. They show that fuor-like variations of star brightness in a smaller scale can occur in the flare activity stage. These observations give some reason to assume that the phenomena which occur during fuor-like variations of the stellar brightness and during "slow" flares have the same physical nature.

It can be added that fuor-like variations of star brightness are apparently connected with the throwing out of some noticeable quantity of matter by a star leading to the formation of an envelope. Ambartsumian's (1971) interpretation of the fuor phenomenon is based on this assumption. There are indications of the appearance of a gas envelope around the star V 1057 Cyg after its brightening, see Chalonge et al. (1982), and of a dust envelope, see Kopatskaya (1984).

Optical Observations of Flare Emission

In order to reveal the nature of the emission originating during stellar flares it is important to obtain the spectral composition and its variations during the flare with high enough time resolution.

The optical spectrum of flare emission is unusual. According to the photoelectric observations of the flares of UV Cet type stars carried out with a time resolution of the order of 1 s the colour indices U-B and B-V of the flare radiations correspond to the different temperatures.

In the flare maximum they are, on average, equal to (see, for example, Moffett, 1974):

$$U - B \simeq - 1.0 , \qquad B - V \simeq + 0.3 .$$

These colour indices, however, differ for different flares and vary somewhat irregularly during a given flare (see, for example, Mirzoyan, 1981).

The colour indices U-B and B-V of flares in the star clusters and associations, determined from photographic observations with low resolution (~5 minutes) confirm this result (see, for example, Mirzoyan et al., 1981).

When considering the possible influence of emission lines on the colour indices U-B and B-V it is necessary to take into account that the maximum strengthening of emission lines follows after the maximum brightness and their extinction ends after the extinction of a flare (Moffett and Bopp, 1976; Kunkel, 1967).

The spectral observations of the UV Cet flare stars, which are very few, have also revealed the dominant role of the continuum emission, mainly at short wavelengths, and the sharp increase of brightness at the beginning of the flare, noted already in the pioneering paper by Joy and Humason (1949).

This significant result has been confirmed with special clarity by parallel spectral and photoelectric flare observations of the stars UV Cet, EV Lac, YY Gem, and EQ Peg, carried out by Bopp and Moffett (1973), and Moffett and Bopp (1976), with a high time resolution. These observations allowed them to establish that the whole flare emission in the beginning - in "spike" phase - is conditioned by the continuous emission and only after - in the "slow" phase - does the line emission play an essential role. This result of Moffett and Bopp shows that the continuous emission is primary one at least when compared with the line emission.

These synchronous spectral and photometric observations (Bopp and Moffett, 1973; Moffett and Bopp, 1976) of flare emission also allowed a study to be carried out on its spectral variations in the later phases of flares.

A more detailed study of the flare emission spectrum should be based on the narrow-band photoelectric observations of stellar flares possessing higher time resolution. Unfortunately, such kind of observations have been carried out up to now only for a very limited number of flares by Chugainov (1972) and Kodaira et al. (1976).

For the problem of the nature of the flare phenomenon the following fact, found by Greenstein and Arp (1968) in the flare spectrum of Wolf 359, is of importance: all spectral lines were broadened and shifted to the ultraviolet.

Radio and X-Ray Observations of Flare Emission

The first observations of stellar flares in the radio-frequencies (see, for example, Lovell, 1964) already showed that in some cases the optical flares are accompanied by radioflares.

The problem of correlation between optical and radioflares has been considered in detail by Spangler and Moffett (1976) using the synchronous observations in both regions. They have shown that any strong correlation between the manifestations of stellar flare activity in optical and radiofrequencies is in fact absent. Some optical flares were accompanied by radioflares, but a number of optical flares do not have a radio counterpart. In some cases the radio counterparts of optical flares began earlier or later than the optical flares themselves. Finally this study gives a reason to assume that some radio flares occur which do not have their optical counterparts.

The recent synchronous optical and radio observations carried out with radio interferometers by Gibson et al. (see, for example, Gibson, 1983) testify to this significant conclusion. In addition, the radiointerferometric observations of flare stars has led to two unexpected results:

1. the discovery of the radioemission out of the flare - the *quiescent* radioemission of some UV Cet type stars; 2. the detection of circular polarization of flare radioemission, which can reach 100%, whereas linear polarization is completely absent.

It should also be noted that the data on the spectra of polarization and brightness temperature of radioflares have confirmed (Fisher and Gibson, 1981) the earlier result (Ambartsumian, 1954) concerning the non-thermal nature of flare emission.

The X-ray observations of stellar flares were begun later. X-ray flares were registered from some UV Cet stars. The synchronous optical and X-ray observations of flares showed the absence of any correlation between manifestations of flare phenomenon in the considered two spectral regions, too.

The quiescent X-ray emission from many flare stars was detected by the X-ray satellite "Einstein". Later on it was revealed that *all dwarf stars* of spectral classes F-M are *X-ray quiescent emission sources,* the intensity of this emission being determined by the stellar rotation velocity (Golub, 1983).

From this point of view note should be taken of the results of van Leeuwen's (1985) study, showing the rapid rotation of the brightest flare stars in the Pleiades.

Conclusion

The results of flare star investigations obtained during the last decades have turned out to be completely unexpected in terms of the existing theoretical stellar models.

This concerns, first of all, the conclusion that flare stars represent an evolutionary stage, this conclusion being obtained on the basis of their observations in star clusters and associations. No stellar evolution theory suspects this.

This concerns also the results obtained by studying the physical peculiarities of flare emission and, in general, the stellar flare phenomenon. The observational data in some cases contradict the theoretical calculations (for details, see Mirzoyan, 1981). The difficulties in this field increased essentially after the space observations of flare stars. This fact was taken into account by Rosner (1983) when, in his introductory paper presented at the IAU Colloquium "The Activity of Red Dwarf Stars", he noted "...the recent new CaII, UV and X-ray observations have shown that *the behaviour of "activity" on stars is substantially more complex than hitherto suspected"*.

Therefore, we have some grounds to hope that further studies in this branch of astrophysics can lead to essentially new consequences in the physics and evolution of stars.

In actuality, the hope of obtaining new significant results from the study of flare stars is based on two well founded regularities, viz. that flare activity is a feature of stars being in one of the early stages of evolution immediately following the earliest stage, represented by the T Tau type stars; that flare emission has a non-thermal nature and seems to be closely connected with the more general problem of stellar energy sources (Ambartsumian, 1954). In almost all suggested interpretations of flare emission solely the probable mechanism of the origin of flares is considered without paying special attention to the problem of the energy source. Obviously the presence or the appearance of the sources of energy in the star atmosphere which are necessary for flares must be considered.

The features mentioned above give some grounds to assume that the revealing of the sources of flare energies can contribute to the solution of the problems of stellar energy at least in the early stages of evolution.

It can be supposed that some of the problems connected with the study of flare activity and flare stars will be solved thanks to new investigations, including those which are planned at present using the coordinated synchronous ground-based and space observations of stellar flares and the quiescent emission of flare stars (Rodono, 1985). From this point of view essential results can be expected, in particular, from the realization of space observations of stars according to the program "Stellar Activity" suggested as "A Key Project" for the space telescope (Vaiana et al. 1985).

Thus, it seems to us that the flare star problem, being part of a more general problem of stellar activity in the initial stages of evolution, will remain for years as one of the most real astrophysical problems. Its final solution, of paramount significance for the ascertaining of the nature of stellar activity, will be obtained only when, on the basis of the observational data, we understand all the complex phenomena connected with the physics and evolution of this activity.

References:

Allen, C.W., 1973, Astrophysical Quantities, The Athlone Press, London.

Ambartsumian, V.A., 1954, Comm. Byurakan Obs., 13.

Ambartsumian, V.A., 1969, Stars, Nebulae, Galaxies; Ac. Sci. Armenian SSR, Yerevan, p. 283.

Ambartsumian, V.A., 1970, Astrofizika, 6, 31.

Ambartsumian, V.A., 1971, Astrofizika, 7, 557.

Ambartsumian, V.A., 1978, Astrofizika, 14, 367.

Ambartsumian, V.A., and Mirzoyan, L.V., 1971, In: Proc. IAU Coll. No.15, Bamberg Veröff., 9, No. 100, 98.

Ambartsumian, V.A., and Mirzoyan, L.V., 1975, In: Proc. IAU Symp. No. 67, eds. V. Sherwood, L. Plaut, Reidel, Dordrecht, p. 3.

Ambartsumian, V.A., Mirzoyan, L.V., Parsamian, E.S., Chavushian, H.S., and Erastova, L.K., 1970, Astrofizika, 6, 3.

Beskin, G.M., Neizvestnyi, S.I., Plachotnichenko, V.L., Pustilnik, L.A., Chekh, S.A., Shvartsman, V.F., and Gershberg, R.E., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).

Bopp, B.W., and Moffett, T.J., 1973, Astrophys. J., 285, 139.

Chalonge, D., Divan, L., and Mirzoyan, L.V., 1982, Astrofizika, 18, 263.

Chavushian, H.S., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).

Chugainov, P.F., 1972, Izv. Krim Obs., 44, 3.

Cristaldi, S., and Rodono, M., 1970, Astron. Astrophys. Suppl. Ser., 2, 223.

Fisher, P.L., and Gibson, D.M., 1981, In: "Cool Stars, Stellar Systems and the Sun", eds. M.S. Giampapa, L. Golub, Smithsonian Astrophys. Obs., Special Report 392, vol. 2, 109.

Gershberg, R.E., 1978, Flare Stars of Small Masses; Nauka, Moscow.

Gibson, D.N., 1983, In: Proc. IAU Coll. No. 71, eds. P.B. Byrne, M. Rodono, Reidel, Dordrecht, p. 273.

Golub, L., 1983, In: Proc. IAU Coll. No. 71, eds. P.B. Byrne, M. Rodono, Reidel, Dordrecht, p. 83.

Greenstein, J.L., and Arp, H.C., 1968, Astrophys. Letters, 3, 49.

Haro, G., 1964, In: "The Galaxy and the Magellanic Clouds", Proc. IAU-URSI Symp. No. 20, eds. F.J. Kerr, A.W. Rodgers, Australian Ac. Sci., Canberra, P. 30.

Haro, G., and Chavira, E., 1966, Vistas in Astronomy, 8, 89.

Herbig, G.H., 1977, Astrophys. J., 217, 693.

Hojaev, A.S., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).

Johnson, H.L., and Mitchell, R.I., 1958, Astrophys. J., 128, 31.

Joy, A.H., and Humason, M.L., 1949, Publ. Astron. Soc. Pacific, 61, 133.

Kodaira, K., Ichimura, K., and Nishimura, S., 1976, Publ. Astron. Soc. Japan, 28, 665.

Kopatskaya, E.N. 1984, Astrofizika, 20, 263.

Kunkel, W., 1967, An Optical Study of Stellar Flares; Texas University, Austin.

Lovell, B., 1964, Observatory, 84, 191.

Mirzoyan, L.V., 1980, "Flare Stars, Fuors and Herbig-Haro Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan, p. 45.

Mirzoyan, L.V., 1981, "Stellar Instability and Evolution", Ac. Sci. Armenian SSR, Yerevan.

Mirzoyan, L.V., 1982, Publ. Astrophys. Obs. Potsdam, Nr. 110, 71.

Mirzoyan, L.V., 1984, Vistas in Astronomy, 27, 77.

Mirzoyan, L.V., and Brutian, G.A., 1980, Astrofizika, 16, 97.
Mirzoyan, L.V., Chavushian, H.S., Melikian, N.D., Natsvlishvili, R.Sh., Ohanian, G.B., Hambarian, V.V., and Garibjanian, A.T., 1981, Astrofizika, 17, 197.
Mirzoyan, L.V., and Melikian, N.D., 1985, In: "Flare Stars and Related Objects", ed. L.V.Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).
Mirzoyan, L.V., and Ohanian, G.B., 1977, Astrofizika, 13, 561.
Mirzoyan, L.V., and Ohanian, G.B., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).
Moffett, T.J., 1972, Nature, Phys. Sci., 240, 41.
Moffett, T.J., 1974, Astrophys. J., Suppl., 29, 1.
Moffett, T.J., and Bopp, B.W., 1976, Astrophys. J., Suppl., 31, 61.
Natsvlishvili, R.Sh., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).
Oskanian, V.S., 1969, In: "Non-Periodic Phenomena in Variable Stars", Proc. IAU Coll. No. 4, ed. L. Detre, Akadèmiai Kiadò, Budapest, p. 131.
Rodono, M., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan, (in press).
Rosino, L., 1969, In: "Low Luminosity Stars", ed. S.S. Kumar, Gordon and Breach Science Publishers, New York - London - Paris, p. 18.
Rosner, R., 1983, In: "Activity in Red Dwarf Stars", IAU Coll. No. 71, eds. P.B. Byrne, M. Rodono, Reidel, Dordrecht- Boston- Lancaster, p. 5.
Spangler, S.R., and Moffett, T.J., 1976, Astrophys. J., 203, 497.
Vaiana, G.S., Praderie, F., and Rodono, M., 1985, Stellar Activity: a Key Project for the Space Telescope, preprint.
van Leeuwen, F., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

PHOTOELECTRIC OBSERVATIONS OF EV Lac IN 1984: FAST FLARE ACTIVITY?

M.K. Tsvetkov, A.P. Antov, A.G. Tsvetkova

Department of Astronomy and National Astronomical Observatory,
Bulgarian Academy of Sciences, Bulgaria

Investigations of flare stars in the solar neighbourhood were carried out in the autumn of 1984 for a $15^h42^m.7$ monitoring of the flare star EV Lac. The observations were carried out using the 60 cm Cassegrain reflector of the Rozhen National Astronomical Observatory with an EF-1 single-channel photoelectric photometer in the U-colour. The accuracy of the observations carried out is within the limits of $\sigma_u \sim (0^m.04-0^m.09)$, the integration time being 1 second. During the period from 18 October to 10 November 1984 17 flares were observed and the mean magnitude of EV Lac in the instrumental UBV system was $v = 10^m.04 \pm 0^m.04$, $b = 11^m.42 \pm 0^m.05$, $u = 12^m.24 \pm 0^m.05$ (Tsvetkov et al., 1985). Along with the "classical" flares observed in EV Lac (Figs. 1, 2) we also observed 5 fast flares (Figs. 3, 4) of a duration of 1-2 seconds and an amplitude reaching $m_u = 1^m.77$. The nature of these peak-flares is still disputable which is due, above all, to their short duration, commensurable with the integration time of the instruments used. On the other

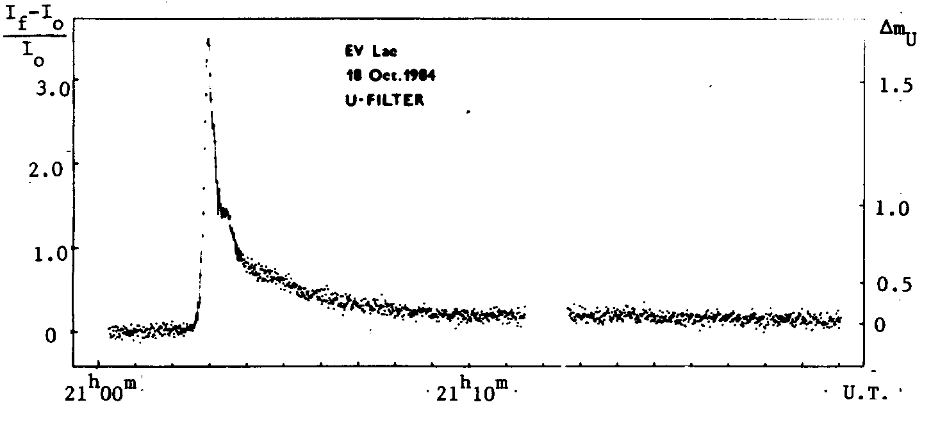


Figure 1

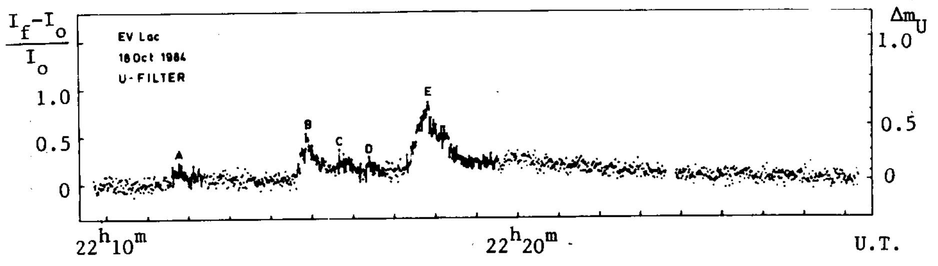


Figure 2

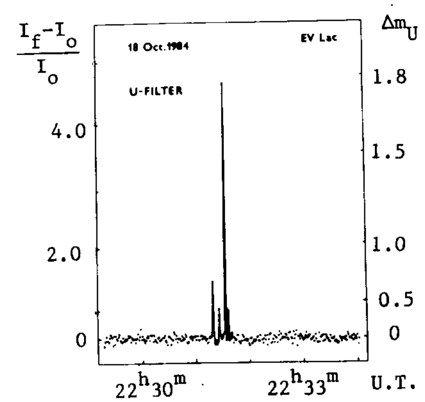


Figure 3

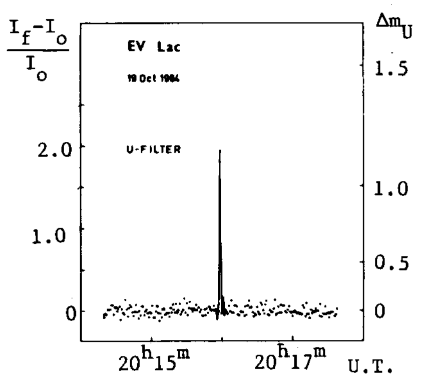


Figure 4

hand, fast flares were observed on only one telescope and in order to explain their nature it would be interesting to carry out parallel observations in the U-colour on different telescopes. In this sense, the case with a similar flare (Gershberg and Petrov, 1985) noticed during observations with the three-channel photometer of the Astron satellite is a significant example.

References:

Gershberg, R.F., Petrov, P.P., 1985, Proc. Symp. "Flare Stars and Related Objects", Byurakan, Ed. L.V. Mirzoyan.
Tsvetkov, M.K., Antov, A.P., Tsvetkova, A.G., 1985, (in preparation).

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

ON THE FLARE ACTIVITY VARIATIONS OF HII 2411

G. Szécsényi-Nagy

Department of Astronomy, L. Eötvös University, Budapest

Object number 2411 ($\alpha_{1900} = 3^h43^m44^s\!.8$, $\delta_{1900} = +24^\circ0'48''$, $m_{pg} = 15.52$) on Hertzsprung's second star-list of the Pleiades field (1947) is a Hyades member (Binnendijk, 1946). Its variability was discovered in 1963 and it was classified as a flare star (Hyades 1) by Haro and Chavira (1966). During 117^h50^m it showed 4 remarkable flare-ups ($\Delta m_U \geq 0.5$) and also small variations ($\Delta m_U \leq 0.3$).

Its spectral type was found to be M4e by Herbig (1962) and M2-M3 by McCarthy and Treanor (1964). High-speed photoelectric photometry of the star was initiated in 1972 by Rodono (1974). Measurements were only carried out in one colour near the B band. During 15 hours of observations 3 flare events were detected and the flare frequency of II Tau (= HII 2411) could be assumed to be almost the same or even higher than that of many UV Cet-type stars. The mean flare frequency for HII 2411 - determined by photoelectric methods - seemed to change from year to year. In the fall of 1972 it was found to be 0.25 h^{-1} but the next year Rodono (1975) observed a mean frequency of 1.56 h^{-1}.

Unfortunately systematic patrol observations of the object with high-speed photometers failed to materialize and we have only sporadic data about short-lived and low-energy flare-ups of II Tau. On the other hand a very long series of patrol observations of the Pleiades field has been carried out with fast (D:F ~ 1:3) photographic cameras. The effective duration of these observations totalled about 3200 hours in the period 1963--1983 (Szécsényi-Nagy, 1983, 1985). Albeit the average time-resolution reached by photographic methods is 5 minutes in the pg and 10 minutes in the U-band and consequently the majority of flare-ups (the very short ones and the low-amplitude flares) is indiscernible on the plates, 131 flare events of the object were discovered during that time. Regrettably 5 of them are only mentioned, without any particulars being given. This is the reason for limiting our statistical investigations to 126 occurrences.

In 108 cases the ultraviolet light of the flares was detected; in the remaining 18 measurements were performed in the B-band or in the pg-region only. In order to obtain a homogeneous sample the results of the latter were transformed into the U-band. The weakest 6 flares ($\Delta m_U = 0.4$) were discarded because most of the authors set a limit of detectability at $\Delta m_U = 0.5$. In such a way a mean flare frequency of 0.04 h^{-1} could be computed whereas Haro and Parsamian (1969) got a 2.25 times higher frequency for the same kind of flare-ups from the results of 551 hours of photographic patrol of the Pleiades field. It is strange that including further discoveries Rodono (1974) obtained a somewhat smaller frequency (0.07 h^{-1} as against 0.09 h^{-1}). All these pointed to a new possibility, namely the determination of flare activity variations in the range of most energetic flares by photographic patrol of a star field.

With a view to having statistically meaningful samples, results of some consecutive observational periods had to be combined. Six "sections" were shaped as follows: A(1963/68), B(1968/70), C(1970/72), D(1972/73), E(1973/77) and F(1977/81). The calendar length of these ranges from 1 to 5 years, but they are almost equal if we compare the total effective time of observations carried out in different observatories during the given periods. Inequalities were removed by comparing the numbers of observed flare-ups of the star (n_f) in the different sections and the quantity (N_f) of all other flare events discovered on the same plates in the corresponding sections. A rarity index defined by the formula $R = N_f/n_f$ was used to classify the sections A, B, ... according to the actual average flare frequency of II Tau. The above procedure was performed at different Δm_U levels and the ranks (or placing numbers) of the sections were summarized. Subtotals of this sum were computed at each level and the sections were arranged as is done in figure skating championships.

In this way we could determine (irrespective of the actual Δm_U level) that the flare activity of the object peaked during section F and that the sequence continues in this manner: B, A, C, E, D. From this succession it is clear that HII 2411 was very active in the late seventies and also in the late sixties.

The significance of the result was checked by computing Kendall's coefficient of concordance and its amount ($w = 0.9263$) mathematically proves that the ranks alloted to the different sections are independent of the amplitude of flare-ups.

The conclusions of the study presented here are:

1. The activity variation is not a result of observational selection effects, it surely originates in physical processes taking place on or in the star.

2. The variation is relatively fast and if cyclic, its *cycle-length* (perhaps period?) *is in the range of 10-15 years!* (From the statistics of $\Delta m_U \geq 1$ flares a cycle-length of 10-12 years can be derived, while from that of all events with $\Delta m_U \geq 0.6$ 13 years and from the statistics of all published flare-ups of II Tau 13-15 years.)

3. When the star is very active it produces 2-4 times more high amplitude flare-ups than when it is quiet or least active.

References:

Binnendijk, L., 1946, Ann. Sterrew. Leiden 19, part 2.

Haro, G., Chavira E., 1966, in Vistas in Astronomy, Eds. A. Beer and K. Aa. Strand, Vol. 8, p. 89.

Haro, G., Parsamian, E., 1969, Bull. Obs. Tonantzintla Tacubaya 5, 41.

Herbig, G.H., 1962, Ap. J., 135, 736.

Hertzsprung, E., 1947, Ann. Sterrew. Leiden 19, part 1A.

McCarthy, M.F., Treanor, P.J., 1964, Richerche Astr. 6, 535.

Rodono, M., 1974, Astron. and Astrophys. 32, 337.

Rodono, M., 1975, in Variable Stars and Stellar Evolution, IAU Symposium No. 67, Eds. V.E. Sherwood and L. Plaut, Reidel, Dordrecht, p. 69.

Szécsényi-Nagy, G., 1983, Publ. Astr. Inst. Czech. Acad. Sci. No. 56, 219.

Szécsényi-Nagy, G., 1985, in Flare Stars and Related Objects, Ed. L.V. Mirzoyan, Yerevan (in press).

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

FLARE STARS' COUNT IN ORION

R.Sh. Natsvlishvili

Abastumani Observatory, Georgia, USSR

The total number of flare stars in Pleiades was estimated statistically by Ambartsumian (1969). We have applied another method to estimate the total number of flare stars for the Orion Nebula region in the field covered by a 70/100/210 cm Maksutov-type telescope with the centre in the Orion Trapezium comprising 306 hours' effective observational time; during that period 127 new flare stars were discovered. In all, 182 flare phenomena were recorded. To escape data inhomogeneities we took Abastumani observations (Kiladze, 1972; Kiladze and Natsvlishvili, 1980; Natsvlishvili, 1981, 1982a, 1982b, 1984; Natsvlishvili and Melikian, 1980) as a basis and used flare stars from other observations (Haro, 1968; Melikian, 1984; Parsamian et al., 1978; Rosino and Pigatto, 1969; Roslund, 1969; Tsvetkov and Tsvetkova, 1982, and references therein).

Flare stars may be divided into two groups: A and B according to the chronology of their discovery. Group A contains stars discovered in the initial observational time interval t_0t_1, the number of which is Q; all other unknown flare stars make group B. Let us assume that in the period t_1 to t, new flare stars from group B, denoted as Z, were revealed. At the same time during interval t_1t repeated flares occurred both in Q and Z, their total numbers designated as X and P correspondingly. Therefore, during the interval t_1t the number of flares that occurred in B will be Z+P. Assuming that flare phenomena are accidental in time, the mean flare frequency measure in A is X/Q, and in B it is P/Z.

Because flare stars in group A are known during the observational time t_1t, and B group stars are gradually revealed and are then being traced, to compare the mean frequencies of groups A and B one should know the number of repeated flares in A in the observational time t_0t_1, during which stars were discovered, their number designated as Z. If the total number of such repeated flares is K, then the mean frequency measure for group A will be K/Z.

If Z+P greatly exceeds X, then either the mean frequency of flares is more than B, or the number of stars is more, or else both conditions are fulfilled. But flare frequency of individual stars in B must be less as stars with less flare frequency are, on average, chronologically revealed later and eventually the least active stars remain undiscovered. So the frequency ratio $(K/Z)/(P/Z) = K/P$ is characterized by the degree to which the mean frequency in A is larger than in B. If $K/P > 1$, then $Z+P \gg X$ means that the number of flare stars in group B greatly exceeds that in A. At the same mean frequency the number of flare stars in B must be $Q\cdot(Z+P)/X$. Taking into account the frequency difference factor, their quantity will be $Q\cdot K\cdot(Z+P)/(X\cdot P)$, and the total number of flare stars N in the aggregate is:

$$N = Q + Q \cdot K \cdot \frac{Z+P}{P \cdot X} \qquad (1)$$

Using the correlation for the Orion aggregate and inserting corresponding values: Q = 358, Z+P = 138, X = 43, K/P = 1.3, we obtain that the total number of flare stars in Orion equals N = 1852. This represents the number of stars that are potentially capable of undergoing flares with amplitudes exceeding $0\overset{m}{.}5$.

The dependence (1) in individual cases gives a lower limit of true quantity in the sense that stars dimmer than a certain brightness are unobservable and it is possible that systems may contain objects of very low flare frequency.

Another factor might influence the result by increasing the number of flare stars in the systems: we originally thought that the flare activity of individual stars did not change, i.e. the mean frequency in groups remained unchanged, but if we assume that during the time of observations not all potentially flare stars with a cyclic activity showed flare activity (Mirzoyan and Ohanian, 1977), the number of flare stars will increase. However, if we do not know the duration of activity of individual groups and the interval between such cycles, it is impossible to determine statistically the number of undiscovered flare stars. Although flare activity in individual stars may be cyclic and there is also a group appearance of flare fluctuations of a star's brightness, for the numerous groups of such objects the sequence of flare phenomena is accidental in time.

References:

Ambartsumian, V.A., 1969, Stars, Nebulae, Galaxies, Yerevan.

Haro, G., 1968, In: "Stars and Stellar Systems", vol. 7, Chicago University Press, Chicago.

Kiladze, R.I., 1972, IBVS, No. 670.

Kiladze, R.I., Natsvlishvili, R.Sh., 1980, IBVS, No. 1725.

Melikian, N.D., 1984, IBVS, No. 2621.

Mirzoyan, L.V., and Ohanian, G.B., 1977, Astrofizika, 13, 561.

Natsvlishvili, R.Sh., 1981, IBVS, No. 1926.

Natsvlishvili, R.Sh., 1982a, IBVS, No. 2062.

Natsvlishvili, R.Sh., 1982b, IBVS, No. 2231.

Natsvlishvili, R.Sh., 1984, IBVS, No. 2565.

Natsvlishvili, R.Sh., and Melikian, N.D., 1980, IBVS, No. 1726.

Parsamian, E., Chavira, E., and Gonzalez, G., 1978, Bol. Obs. Tonantzintla, 2, No. 4.

Rosino, L., and Pigatto, L., 1969, Contr. Asiago Obs., No. 231.

Roslund, C., 1969, Uppsala Astr. Obs., Medd. No. 169.

Tsvetkov, M.K., and Tsvetkova, A.G., 1982, IBVS, No. 2132.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

SEARCH FOR FLARE STARS WITH THE ESO GPO ASTROGRAPH IN LA SILLA

M.K. Tsvetkov[1], W.C. Seitter[2] and H. Duerbeck[2]

[1]Department of Astronomy and National Astronomical Observatory,
Bulgarian Academy of Sciences, Bulgaria

[2]Astronomical Institute of the University of Münster, FRG

An important role in the investigations of flare stars is given to programs that search for and study their properties with wide-angle telescopes. In this respect, surveys carried out with Schmidt-type telescopes are essential, the investigations being focused mainly on regions of stellar clusters and associations in the northern hemisphere.

Schmidt telescopes, which have recently been put into operation in the southern hemisphere, are engaged basically in programs to develop atlases, in fundamental surveys, etc.

In this respect, for the further development of surveys that study flare stars in southern regions, it is also necessary to make use of the possibilities offered by astrographs, thus widening the scope of the investigations carried out.

The aim of our program was to test the possibilities for flare star search by using the 40 cm GPO-astrograph of the European Southern Observatory in La Silla (Chile). For this purpose, observations for the search for and investigations of flare stars in relatively young aggregates (IC 2391, IC 2602 and Chamaeleontis T1) were carried out in January 1985. Control observations were done in the Orion aggregate M 42/43. During the processing of the material obtained in Orion with the GPO (Tsvetkov et al., 1985) nine flares have been discovered, seven of which were new flare stars, the effective time of monitoring being 26^h50^m. The comparison of these results with some of the first observations for the search for flare stars in Orion carried out with various Schmidt telescopes (Table I) shows that the effective use of the GPO astrograph is justified for the solving of such problems. If in the calculations of the relative frequency of

Table I. Data of surveys with different telescopes in the search for flare stars in the Orion Nebulae region (M42/43)

Observatory Type of telescope	Aperture (m)	Focal length (m)	Field (sq.deg.)	T_{eff} (h)	Number of observed flares	ν (flares/hour)	Light	References
Tonantzintla Schmidt	0.66/0.76	2.17	25	112.2	62	0.55	U,pg	1
Abastumani Meniscus	0.70/0.92	2.10	23	64.3	49	0.76	pg	2,3
Asiago Schmidt	0.67/0.92	2.15	25	114.4	48	0.42	pg	4
Mt. Stromlo Schmidt	0.50/0.65	1.73	13	39.6	15	0.38	B,U	5
Rozhen Schmidt	0.50/0.70	1.72	16	44.8	13	0.29	U	6,7
Byurakan Schmidt	1.00/1.30	2.13	16	32	9	0.28	U	8
La Silla Astrograph	0.40	4.00	4	26.8	9	0.34	pg	9

References: 1) Haro (1965); 2) Kiladze (1972); 3) Kiladze and Natsvlishvili (1980); 4) Rosino and Pigatto (1969); 5) Roslund (1969); 6) Tsvetkov et al. (1980); 7) Tsvetkov and Tsvetkova (1982); 8) Melikian (1981); 9) Tsvetkov et al. (1985)

flares the recording of the total number of flare stars in the area of $2^{o} \times 2^{o}$ investigated with the GPO astrograph was also taken into account, then the real frequency would be 0.56 flares/hour.

The authors thank the relevant authorities of the European Southern Observatory and the Department of Astronomy of the Bulgarian Academy of Sciences for the observing time provided by the ESO and the programs for completing this work.

References:

Haro, G., 1965, Stars and Stellar Systems VII, 141, Univ. Chicago Press.
Kiladze, R., 1972, IBVS, No. 670.
Kiladze, R., Natsvlishvili, R., 1980, IBVS, No. 1725.
Melikian, N.D., 1981, IBVS, No. 2018.
Rosino, L., Pigatto, L., 1969, Contrib. of Asiago Obs., No. 231.
Roslund, C., 1969, Arkiv för Astronomi, B 5, No. 22.
Tsvetkov, M.K., Tsvetkov, S.A., Tsvetkova, A.G., 1980, IBVS, No. 1889.
Tsvetkov, M.K., Tsvetkova, A.G., 1982, IBVS, No. 2132.
Tsvetkov, M.K., Duerbeck H., Seitter W., 1985 (in preparation).

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

PHOTOGRAPHIC PHOTOMETRY OF NEW FLARE STARS IN THE ORION NEBULA

A. Tsvetkova, S. Tsvetkov

Department of Astronomy and National Astronomical Observatory
Bulgarian Academy of Sciences
Sofia, Bulgaria

Monitoring photographic observations of flare stars in the Orion region (M 42-43) were carried out in 1980-1981. The plate-filter combination (ZU21-UG2) yielded U-magnitudes. A known multiexposure method was applied and each plate contained 6 exposures of a 10-minute duration. For a total effective observing time of 44^h50^m, 13 new flare stars were discovered (Tsvetkov et al., 1980, 1982, Tsvetkov, 1982). Photographic photometry was carried out by applying the method of Argue (Argue, 1960) using the Carl Zeiss Jena ASCORIS photometer of the NAO.

Table I contains the results of photographic photometry of all the flares and the mean moments of observations.

Figure 1 shows the light curves of some of the observed flares.

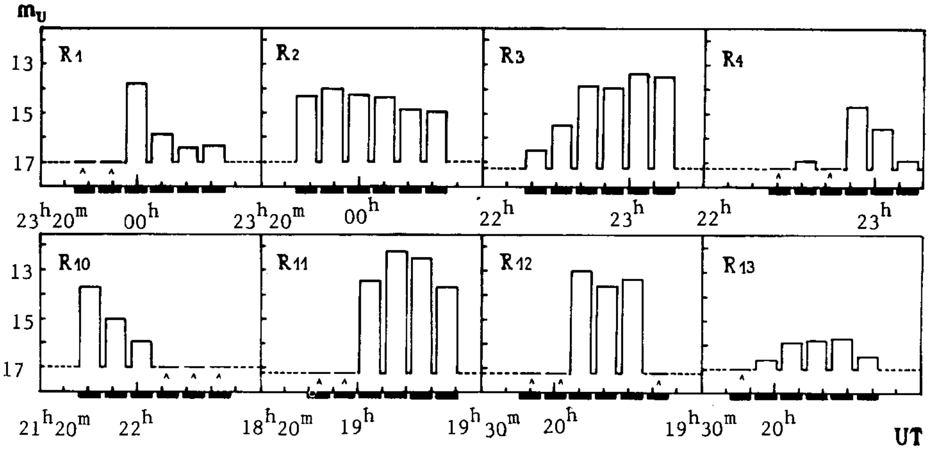


Fig. 1. Light curves of some of the observed flares in Orion

Table I. Photometric data for the observed flares in Orion

No.1 Umin = $18\overset{m}{.}5$

UT	mu
1. $23^{h}33^{m}$	(17^{m}
2. 23 43.5	(17
3. 23 54	13.75
4. 00 04.5	15.84
5. 00 15	16.40
6. 00 25.5	16.32

No.2 Umin = $18\overset{m}{.}3$

UT	mu
1. $23^{h}33^{m}$	$14\overset{m}{.}25$
2. 23 43.5	13.95
3. 23 54	14.20
4. 00 04.5	14.30
5. 00 15	14.82
6. 00 25.5	14.88

No.3 Umin = $16\overset{m}{.}1$

UT	mu
1. $22^{h}16^{m}$	$16\overset{m}{.}50$
2. 22 26.5	15.47
3. 22 37	13.85
4. 22 47.5	13.90
5. 22 58	13.37
6. 23 08.5	13.47

No.4 Umin = $17\overset{m}{.}1$

UT	mu
1. $22^{h}16^{m}$	($17\overset{m}{.}2$
2. 22 26.5	16.9:
3. 22 37	(17.2
4. 22 47.5	14.7
5. 22 58	15.6
6. 23 08.5	16.9

No.5 Umin = $15\overset{m}{.}8$

UT	mu
1. $21^{h}53^{m}$	$14\overset{m}{.}45$
2. 22 03.5	15.15
3. 22 14	14.75
4. 22 24.5	14.15
5. 22 35	14.07
6. 22 45.5	14.15

No.6 Umin = $18\overset{m}{.}1$

UT	mu
1. $18^{h}14^{m}$	$15\overset{m}{.}3$
2. 18 24.5	15
3. 18 35	14.93
4. 18 45.5	(17
5. 18 56	(17
6. 19 06.5	(17

No.7 Umin = $17\overset{m}{.}4$

UT	mu
1. $00^{h}30^{m}$	($17\overset{m}{.}2$
2. 00 40.5	(17.2
3. 00 51	(17.2
4. 01 01.5	(17.2
5. 01 11	15.37
6. 01 21.5	15.17

No.8 Umin = $16\overset{m}{.}2$

UT	mu
1. $18^{h}04^{m}$	(17^{m}
2. 18 14.5	(17
3. 18 25	(17
4. 18 35.5	(17
5. 18 46	15.97
6. 18 56.5	15.60

No.9 Umin = $18\overset{m}{.}5$

UT	mu
1. $19^{h}40^{m}$	(17^{m}
2. 19 50.5	16.95
3. 20 01	16.50
4. 20 11.5	16.47
5. 20 22	(17
6. 20 32.5	(17

No.10 Umin = $18\overset{m}{.}0$

UT	mu
1. $21^{h}35^{m}$	$13\overset{m}{.}7$
2. 21 45.5	15.0
3. 21 56	15.9
4. 22 06.5	(17
5. 22 17	(17
6. 22 27.5	(17

No.11 Umin = $20\overset{m}{.}2$

UT	mu
1. $18^{h}38^{m}$	($17\overset{m}{.}2$
2. 18 48.5	(17.2
3. 18 59	13.39
4. 19 09.5	12.17
5. 19 20	12.45
6. 19 30.5	13.65

No.12 Umin = $21\overset{m}{:}$

UT	mu
1. $19^{h}44^{m}$	($17\overset{m}{.}2$
2. 19 54.5	(17.2
3. 20 05	12.95
4. 20 15.5	13.55
5. 20 26	13.27
6. 20 36.5	(17.2

No.13 Umin = $19\overset{m}{.}2$

UT	mu
1. $19^{h}40^{m}$	(17^{m}
2. 19 50.5	16.6
3. 20 01	15.9
4. 20 11.5	15.77
5. 20 22	15.72
6. 20 32.5	16.5

References:

Argue, A., 1960, Vistas in Astronomy, v. 3, ed. A. Beer, Pergamon Press, p. 184.

Tsvetkov, M., Tsvetkov, S., Tsvetkova, A., 1980, IBVS No. 1889.

Tsvetkov, M., Tsvetkova, A., Tsvetkov, S., 1982, IBVS No. 2132.

Tsvetkov, M., 1982, Communications from the Konkoly Observatory, No. 83, Budapest, p. 206.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

PHOTOGRAPHIC PHOTOMETRY OF FLARE STARS IN PLEIADES

J. Kelemen

Konkoly Observatory
H-1525 Budapest, P.O.B. 67, Hungary

Some preliminary results are given of the photographic photometry of Pleiades flare stars. The measurements - on the multiexposure plate material between 1975 and 1983 - began in 1984.

The plates were obtained with the 60/90 cm Schmidt telescope of Konkoly Observatory. The observed material is homogeneous because all the exposures were made on KODAK 103aO plates +2 mm UG2 colour filter.

Flare searching was carried out by means of a blink-comparator. The flare-ups were measured by a Cuffey iris-type astrophotometer. The comparison stars were chosen from Johnson's photoelectric standards (Johnson, 1952).

Because there were six successive images of each star on the plates six individual photometric reductions were made. The results of the reductions show that the plate limit was, on average, between 17 and 18 mag. The mean error of the magnitude determinations for those stars brighter than 16 mag. was found to be less than 1 mag., but below 16 mag. the error increases very rapidly. The high error level is due to the following circumstances: the U band is very sensitive to atmospheric conditions; the long effective exposure time (1 hour) increases the veil level; the sky background in the Pleiades region is not uniform due to the bright circumstellar nebulosities.

The amplitude distribution of the 49 measured new flares is in good agreement with the amplitude distribution of the 519 known flares from the newest Haro catalog (Haro et al., 1982). However there is a strong selection effect on small amplitudes because the poor time resolution of the multiple exposure method smoothed out the flares and the high error level overwhelms the events.

The well-known Oskanyan exponential flare model (Oskanian, 1975) was used to compute theoretical light curves of the flare events. The numerical integration of the test curves shows that the measurable photographic amplitudes are only 1/2-2/3 of the true amplitudes. This means that these observational effects greatly influenced the usefulness of the common photographic, photoelectric flare amplitude statistics.

The relation between the number of the flare and the total observing time shows a flare frequency of about 1 flare-up/hour inside a 5 degree diameter circle around Alcyone.

References:

Haro, G., Chavira, E., and Gonzales, G., 1982, Bul. Inst. Tonantzintla, 3, No. 1.

Johnson, H.L., 1952, Ap. J., 116, 640.

Oskanian, V.S., 1975, In: "Nestatsionarnye Zvezdy", ed. M.A. Arakelyan, Yerevan.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

A SYSTEM FOR RECORDING FAST VARIATIONS OF STELLAR BRIGHTNESS

V.P. Zalinian, H.M. Tovmassian

Byurakan Astrophysical Observatory, Armenia, USSR

In order to understand the nature of flare stars the study of the light curves of fast flares, especially of their very short-lasting rising parts, is very important. For detecting and recording such flares, observations with a time constant of 0.1 sec or less are needed. The event of a flare is a casual one and for its detection long patrolling is inevitable. For observations with small time constants a large amount of registration paper, paper tapes or magnetic tapes are needed.

We propose a method for registering light curves of flares with time constants of the order of 0.1-0.001 sec using microcomputers. The essence of the method is that the recording equipment operates only in the case of variations of the brightness of the observed star. During observations the output of the photoelectric photometer, operating in the photon counting mode, is connected with a computer which determines the mean value of the signal at a given time interval and the square root deflections from it. Then each subsequent count is compared with the value determined in the adjacent time interval. If the measured signal does not differ from the mean value by, say, 3 σ, nothing is being recorded in the computer memory. If the measured signal differs from the mean value by 3 σ all subsequent counts are automatically recorded in the computer's memory. This procedure stops when the output signal returns to its previous mean value.

The photoelectric photometer was tested in the laboratory and then in observations. During about 20 hours of operation with a dark photomultiplier nothing was recorded. Recording started immediately each time after flashing a lamp in front of the photomultiplier.

Observations were made with a 40 cm Cassegrain telescope. No flare was recorded during 50 hours of observations of standard stars. Similarly, no flare was recorded during 55 hours of observations of the flare stars AD Leo, Wolf 630, V 1258 Aql and BY Dra.

However, in the case of EV Lac, 3 flares were recorded during 22 hours of observation. Two of them happened within 40 minutes on 19 July 1985. The duration of both flares was about 3 seconds, the amplitudes of the flares were about $1^m.3$. These flares were recorded with a 1 sec time constant.

The duration of the third, larger flare of $\sim 2^m.2$ was about 18 sec. It was recorded with a 0.1 sec time constant. The increase of brightness occurred during ~ 1 sec.

Thus, the proposed method permits short flares with very high time resolution to be recorded without wasting a large amount of recording paper and time for its analysis.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

THE COMMON NATURE OF FLARING PROCESSES ON THE SUN AND RED DWARFS

Maria M. Katsova* and M.A. Livshits**

*Sternberg State Astron. Inst., Univ. of Moscow, USSR
**IZMIRAN, Troizk, Moscow Region, USSR

A continuous transition is revealed from solar flares to other types of events, characteristic of late-type stars, i.e. to phenomena accompanied by the appearance of optical continuum radiation. It is shown that the value of the rate of increase of the flaring optical continuum intensity, following from the gas-dynamic model for the flare secondary processes, agrees well with the observations of impulse stellar flares, recently conducted using a 6 m telescope with extremely high time resolution.

We have compared the events in the hard (impulsive) phase of solar flares, which are only rarely accompanied by optical continuum emission, with the events on red dwarfs, when flare optical continuum is generated. The physics of both phenomena consists of sudden impulsive energy release in the upper chromosphere or low corona in the form of electron beams or heat fluxes and the subsequent development of the ensemble of secondary processes (Syrovatskii, 1972). The main secondary effects for the events considered are the peculiar "burn" of the lower dense atmospheric layers and the subsequent evaporation of the hot plasma into the upper part of magnetic tubes. Such a process for solar flares was first considered by Kostyuk and Pikel'ner (1974), but for conditions in the red dwarf atmosphere the numerical modelling of this process was given by Livshits et al. (1981), and Katsova et al. (1981). The low-temperature radiation in this model arises, in the main, behind the downward-moving shock wave front. The strong compression of the gas in the relaxation zone behind the front is connected with the radiative losses. Two possible regimes of the energy balance in the low-temperature source are revealed theoretically (Livshits, 1983): either the heating is compensated by the Balmer line emission or by recombination radiation of hydrogen for the most intense events. We show that the two above-mentioned possibilities are realized in solar and in stellar flares respectively.

1. The theory predicts that the distinctive peculiarity in these two possibilities of energy balance in the low-temperature source is the noticeable decrease of the X-ray-to-optical luminosity ratio L_X/L_{opt} by transition of one type of flares to the other. The consideration of the now available observational data on the solar and stellar flares indeed shows that the ratios L_X/L_{opt} decrease by approximately an order of magnitude by the transition from ordinary solar flares to the stellar ones with optical continuum. The characteristics of the emission source density $n \geq 10^{15}$ cm^{-3}, temperature $T \approx 8500$-12000 K and height extent 1-10 km satisfy the observations. This relates to both the colours of the flares and to their effective temperature: $T \approx 8500$ K according to Mochnacki and Zirin (1980); from

appearing now multichannel photometric data on the flares $T \approx 10000$ K (Rodono, 1985).

2. The observational light curves of stellar flares agree with our gas-dynamic model better than with nonthermal models, where millisecond fluctuations are possible. Let us discuss in more detail the question about the steepness of the rising part of optical continuum bursts. At the arrival of the downward-moving perturbation - the source of the low-temperature radiation - to the rather dense layers, the conditions in the relaxation zone behind the shock front approach LTE. The kinetic energy of the wave is thereby spent on intense emission. The radiation at the optical-continuum frequencies lasts while the wave runs 1-2 scale heights in the chromosphere. From the numerical modelling, carried out for a weak stellar flare (Katsova et al. 1981), as well as from a previous estimate (Katsova and Livshits, 1985), it follows that the minimum rise time of the optical continuum intensity $\tau_1 = v_s/M'g$ (v_s-the sound velocity in undisturbed chromosphere, $M' = v/v_s$-the Mach number for the motion of the gas behind the shock wave front, g-acceleration due to gravity on the star). From the energy of the flaring continuum it follows that $M' \approx 10-30$ and $\tau_1 \gtrsim 0.7$ s.

The observations in the U-band for several tens of flares on FL Vir and V577 Mon were carried out recently using a 6 m telescope (Beskin et al. 1985). The value τ_1 for some of these flares is 1s, for other ones 2-10s, typical for impulsive events. From these extremely high time resolution data, it follows that the millisecond features on the rising part of the light curve are undoubtedly absent. This can be considered as additional independent confirmation of the gas-dynamic model.

Thus, the general idea about the analogy of the solar and stellar flares (Gershberg, 1978) is supported here: the further development of the solar physics ideas allows us to explain naturally the origin of the optical continuum radiation by stellar flares.

References:

Beskin, G.M., Neizvestnyi, S.I., Plachotnichenko, V.L., Pustilnik, L.A., Chekh, S.A., Shvartsman, V.F., and Gershberg, R.E., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).

Gershberg, R.E., 1978, "Flare Stars of Low Masses", Nauka, Moscow.

Katsova, M.M., Kosovichev, A.G., and Livshits, M.A., 1981, Astrofizika, 17, 285.

Katsova, M.M., and Livshits, M.A., 1985, In: "Flare Stars and Related Objects", ed. L.V. Mirzoyan, Ac. Sci. Armenian SSR, Yerevan (in press).

Kostyuk, N.D., and Pikel'ner, S.B., 1974, Astron. Zhu., 51, 1002.

Livshits, M.A., 1983, Astron. Zhu., 60, 964.

Livshits, M.A., Badalyan, O.G., Kosovichev, A.G., and Katsova, M.M., 1981, Solar Physics, 73, 269.

Mochnacki, S.W., and Zirin, H., 1980, Astrophys. J., 239, L27.

Rodono, M., 1985, Osserv. Astrofis. Catania, Prepr. No. 1.

Syrovatskii, S.I., 1972, Solar-Terrestr. Phys., 3, 106.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

SPACE DISTRIBUTION OF THE H_α AND FLARE STARS IN THE ORION OB1d ASSOCIATION

K.G. Gasparian

Byurakan Astrophysical Observatory, Armenia, USSR

The association Orion OB1d is concentrated around a multiple star - the Orion Trapezium. At present, the total number of known emission H_α stars in the association is 534 (Parsamian and Chavira, 1982) the number of flare stars is about 500. Until now the space distribution of these stars had been studied only by dividing the studied region into concentric rings with the Trapezium in the centre. Since this method is not sufficiently accurate, Mnatsakanian (1969) suggested, in the case of spherical symmetry, a more exact method for determining the space distribution of stars in poor globular clusters. Subsequently this method was utilized to determine the distribution of flare stars in Pleiades (Mirzoyan et al., 1971, 1980).

The aim of the present paper is to apply this method to determine the space distribution of flare and H_α-emission stars in the Orion OB1d association. For this purpose the apparent distribution of 420 flare and 495 H_α-stars was studied. As a first approach, spherically symmetric distribution of these stars in the association was supposed.

According to Mirzoyan et al. (1980) the function F(x), that is, the number of stars in the (-x, x) zone with the centre x = 0, is equal to

$$F(x) = N_o - \frac{2}{\pi} \sum_{\rho_i > x} \mathrm{arc\ cos}\, \frac{x}{\rho_i} ,$$

where ρ_i is the plane projection of the distance of the i-th star from the centre of the association, N_o is the total number of stars in it.

N(x) was determined graphically as the crossover point of the tangent of function F(x) at the point x with the vertical axis. In fact N(x) gives the number of stars inside a sphere of radius x. In order to find the density of stars at a distance x from the centre, i.e. the space distribution of the stars, it is sufficient to find the number of stars in the spheres with radii x-Δx and x+Δx. By dividing the difference of star numbers by the difference of the volumes of the spheres, we find the density of stars in the ring within the interval x-Δx and x+Δx. In this case it is necessary to choose Δx so that the number of stars in the neighbourhood of point x be the optimum for calculating the star density.

By applying this method we obtained the dependence of the densities of flare and H_α-stars of the Orion OB1d association on the distance r from the centre (Fig. 1). The distance of the Orion OB1d association was assumed to be 500 pc. In Fig. 1 the distribution of stars with r < 3 pc is not given because the apparent distribution of stars in this region is strongly distorted by the light of the Great Orion Nebula.

It is interesting to note that the ratio n_f/n_α of the number of flare stars to that of H_α-stars (Fig. 2) shows that the number of flare stars in comparison with the number of H_α-stars increases continuously with the increase of the distance from the centre of the association. This is in agreement with results of Gurzadyan (1970) and Gasparian (1975) achieved by the method of "breaked up" rings using comparatively poorer observational material.

It is pleasure for the author to express his gratefulness to M.A. Mnatsakanian for valuable discussion.

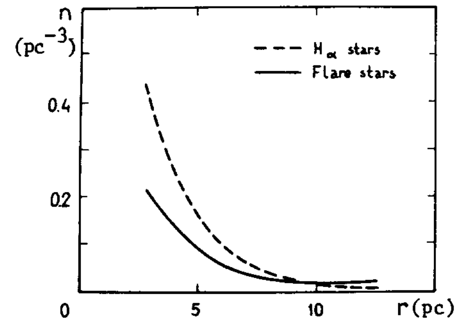


Figure 1

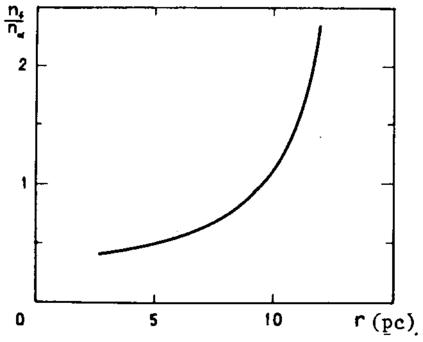


Figure 2

References:

Gasparian, K.G., 1975, Dissertation, 1975.

Gurzadyan, 1970, Bol. Obs. Tonantzintla, 35, 263.

Mirzoyan, L.V., and Mnatsakanian, M.A., 1971, IBVS, No. 528.

Mirzoyan, L.V., Mnatsakanian, M.A., and Oganian, G.B., 1980, In: "Flare Stars, Fuors and Herbig-Haro Objects", Ac. Sci. Armenian SSR, Erevan, p. 113.

Mnatsakanian, M.A., 1969, Dokl. A.N. Arm. SSR, 49, 33.

Parsamian, E.S., Chavira, E., 1982, Bol. Inst. Tonantzintla, 3, No. 1, 69.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

INTERPRETATION OF THE PHOTOMETRIC AND POLARIMETRIC OBSERVATIONS OF T TAURI STARS

N.P. Red'kina, K.V. Tarasov, N.N. Kiselev, G.P. Chernova

Institute of Astrophysics, Dushanbe, 734670, USSR

Simultaneous photometric (UBV and H_α) and polarimetric (V) observations of T Tau and RY Tau were obtained with the 0.7 m telescope at Gissar Astronomical Observatory during the 1979-1982 observing seasons. UBVR and i(7660 Å) photometry and UBVR polarimetry of T Tau and RY Tau were obtained during the 1984-1985 observing season with the 1 m telescope at Mount Sanglok Observatory.

T Tau has the greatest range of variability in U and smaller ranges at longer wavelengths. There is a flare (J.D. 2444142) in U ($\Delta U_{max} = 0\overset{m}{.}6$) and H_α(Δ $m_{max} = 0\overset{m}{.}3$). Variations at F($H_\alpha$) are correlated with U-B and polarization in V (Red'kina and Chernova, 1982). The wavelength dependence of polarization for T Tau is obtained.

RY Tau gets bluer in U-B and B-V when it is fainter during the local minima of 1979 (J.D. 2444165-196). It does the same in U-B and reddening in the other colours B-V, V-R and R-i during the local minima in 1984 (J.D. 2445959-6060). RY Tau shows a direct correlation of polarization in the V bandpass with brightness in V during the minima 1979.

Our interpretation is based on the hydromagnetic activity of T Tau stars. We have supposed that the variability of T Tau stars occurs due to the appearance and disappearance of spots. If the surface of the star has a global patchy structure (Gershberg, 1982) then a decrease in the strength of the magnetic field of a spot below the critical level will remove the magnetic inhibition of optical radiation and a normal bright photosphere (i.e. a hot spot) will appear. The other kind of variability is connected with the appearance of the new cool spots on the surface of the star if a normal photosphere prevails. Strong photospheric activity leads to the formation of external active areas like the solar one in the envelope and chromosphere; a large variation of the flux in U and H_α will take place. The spot model (Torres and Ferraz-Mello, 1973) is used for the calculation and an envelope radiation according to Sobolev (1950) is added. T Tau has the following parameters: T_{eff}=4900 K; $T_{hot\ spot}$=6600 K; N_e=10^{10}-10^{11} cm^{-3}; T_e=10000-20000°. RY Tau: T_{eff}=4900 K; $T_{cool\ spot}$=3000 K; N_e=10^{10}-10^{11} cm^{-3}; T_e=7000-20000°.

The hypothesis of hydromagnetic activity can be proved by observational evidence showing the existence of both the global patchy structures and the strong magnetic fields on these stars. The direct demonstration of magnetic fields of the T Tau stars is a very hard task. The magnetic field of T Tau is determined from the wavelength dependence of linear polarization with the help of the method suggested by Gnedin and Silant'ev (1980). The magnitude of the field is estimated to be 100-400 gauss for a spherical envelope and 300-1200 gauss for an ellipsoidal envelope (Gnedin and Red'kina, 1984). The complicated motion of the polarization vector of RY Tau in the U-Q plane during a few days appears to be due to the interaction of the magnetic fields of starspots with the electron component of the star shell.

References:

Gershberg, R.E., 1982, Astron. Nachr., 303, No.4, 251.

Gnedin, Yu.N. and Silant'ev, N.A., 1980, Soviet Astron. J. Letters 6, 344.

Gnedin, Yu.N. and Red'kina, N.P., 1984, Soviet Astron. J. Letters 10, 613.

Red'kina, N.P. and Chernova, G.P., 1982, in Binary and Multiple Stars as Tracers of Stellar Evolution; D. Reidel Publ. Co., Dordrecht, Holland, p. 231.

Torres, G.A. and Ferraz-Mello, S., 1973, Astron. Astrophys., 27, 231.

Sobolev, V.V., 1950, Soviet Astron. J. 27, 81.

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

FLARE ACTIVITY OF ANTIFLARE STARS

G.U. Kovalchuck

Main Astronomical Observatory, Ukrainian
Academy of Sciences, Kiev, USSR

The results are presented of a study of the flare activity of antiflare stars (AFS). The objects investigated belong to the "Irregular variables, connected with diffuse nebulae, and rapid irregular" (GCVS).

Figures 1-6 show the light curves of the observed flares. The symbol "↓" indicates the moments of the maximum brightness during a flare in the U-band.

All the flares are connected with an active state of variable stars. (The active state of AFS is not only the minimum brightness state, but also the pre- and post-minimum -1^d -2^d -state.) "AS" (Figs 1-6) indicates the extent of activity of each variable star on the night of observation: "0" is the minimum brightness state; "+1" or "-1": 1^d after the minimum and 1^d before the minimum respectively. Δm is the deviation of the brightness from the normal brightness state (in V-band) in magnitude.

The variability of AFS is interpreted in the framework of an eruptive model (Pugach, 1983) according to which the global weakening of AFS brightness is due to the appearance of the absorbing matter near the variable star. The appearance of flares of the AFS in the minimum of brightness is caused, in our opinion, by the active processes in the chromosphere-like envelopes of AFS (Pugach, 1983; Kovalchuck, 1985).

References:

Kovalchuck, G.U., 1985, Kinematika i Fizika Nebesnich Tjel, 1, No. 3, p. 25-32.

Pugach, A.F., 1983, Astrometr. Astrofiz., Vyp. 49, p. 55-60.

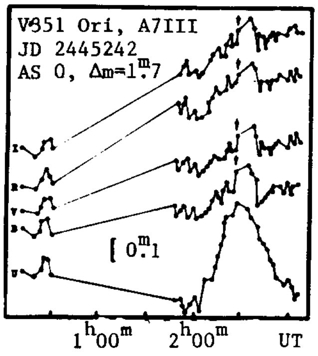


Figure 1

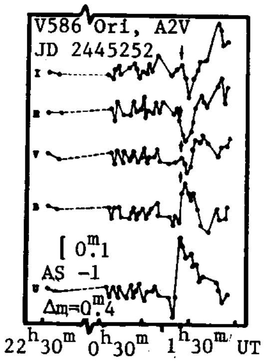


Figure 2

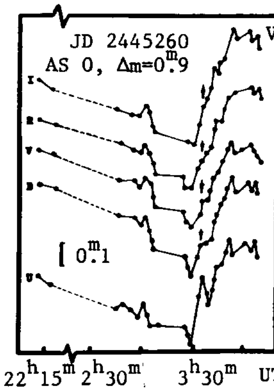


Figure 3

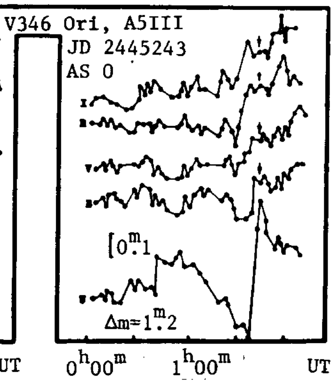


Figure 4

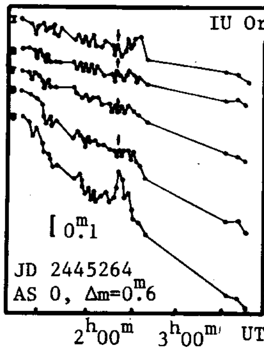


Figure 5

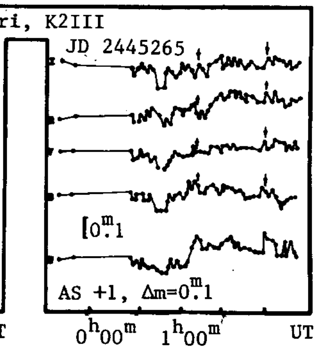


Figure 6

"Eruptive Phenomena in Stars"
Commun. Konkoly Obs. Hung.
Acad. Sci., No.86, Budapest

ANALYSIS OF R CORONAE BOREALIS VARIABILITY FROM PHOTOELECTRIC OBSERVATIONS

R.I. Goncharova

Main Astronomical Observatory, Ukrainian Academy of Sciences, USSR

RY Sgr, a star of R CrB type, clearly shows periodic pulsations. In this case it was found that the fading of stellar brightness takes place just at the moment of the pulsation peak (Pugach, 1977). An attempt has been made to find out the connection between pulsations and deep light fadings for R CrB by analogy with RY Sgr.

The oscillations of the maximum light of R CrB with a mean amplitude of about $\Delta m_V = 0^{\mathrm{m}}.15$ were revealed by photoelectric magnitude estimates. In the paper by Goncharova et al. (1983) it was shown that R CrB had three pulsation periods: $P_1 = 27^{\mathrm{d}}.36$, $P_2 = 39^{\mathrm{d}}.96$, $P_3 = 53^{\mathrm{d}}.64$. A comparison was made between the observed and computed moments of the maximum light pulsations before the beginning of deep light fadings. It was concluded that the brightness of the variable faded after the maximum of pulsational light variability with periods P_1 and P_2, in some cases the pulsation maxima (P_1 and P_2) and (P_1 and P_3) practically coincide before the light decline of the variable into the minimum from the normal state.

Figure 1 shows three starting moments of R CrB fading observed photoelectrically. The vertical line indicates the calculated moments of maximum with $P_1 = 27^{\mathrm{d}}.36$.

Thus, R CrB seems to decrease its brightness after the maximum of pulsational light variability with any of three periods but after the maximum of $P_3 = 53^{\mathrm{d}}.64$ the fading is less probable.

There is a suggestion that the R CrB phenomenon is triggered by the ejection of matter during a particularly large pulsation. From photometric observations during the maximum light we know that the star shows light fluctuations of about $0^{\mathrm{m}}.1$ or $0^{\mathrm{m}}.2$ with mean V-magnitudes of about $5^{\mathrm{m}}.8$-$5^{\mathrm{m}}.9$ (Fernie, 1982). Observations of R CrB near maximum light before the beginning of the light decline are shown in Fig. 1. It is clear that the 1983 minimum started after the light pulsation with the amplitude $\Delta m_V \approx 0^{\mathrm{m}}.1$. The star reached $5^{\mathrm{m}}.8$ in the V-filter at the maximum moment of this pulsation and for a month before the starting of the light fading the star showed mean light fluctuations of about $\Delta m_V \approx 0^{\mathrm{m}}.15$. That is to say that when falling into the minimum the pulsation amplitude and the maximum value of the star's visible light had the mean values typical of the maximum light of this star.

On the other hand, near the maximum light the amplitude of R CrB light variations exceeds its mean values to a great extent from time to time. The pulsation with the maximum registered amplitude near maximum light - $\Delta m_V = 0^{\mathrm{m}}.36$ was observed by Goncharova et al. (1983).

From the above it follows that pulsation amplitudes (neither accidental fluctuations nor superposition of several periods) do not affect the beginning of deep light fadings.

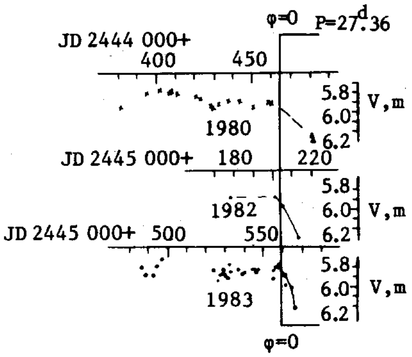


Fig. 1.

Starting moments of R CrB fading observed photoelectrically. Filled circles represent observations by the author, the other estimates were obtained from the literature

Table I. Comparison between the observed and computed moments of maximum light pulsation before the beginning of deep light fadings

Observed moments		Computed moments		
	J.D.	$P_1 = 27^d.36$	$P_2 = 39^d.96$	$P_3 = 53^d.64$
1938	2 429155	-	2 429152	-
1942	30632	-	30631	-
1962	37820:	2 437817	37823	-
1972	2 441(360:-380:)	41346	41380	-
1974	2 442029:	42030	42019	-
1975	42685:	42687	-	2 442689
1977	43180:	43179	43179	-
1983	45557	45559	-	-

References:

Fernie, J.D., 1982, Publ. Astron. Soc. Pacific., 94, No. 557, 172.
Goncharova, R.I., Kovalchuck, G.U., Pugach, A.F., 1983, Astrofizika, 19, 279.
Pugach, A.F., 1977, Inform. Bull. Variable Stars, No. 1277, 1.