NARROW BAND PHOTOMETRY AND OBSERVABLE EFFECTS IN ALGOL TYPE SYSTEMS

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The application of narrow band photometry to Algol type systems is considered and advantageous circumstances pointed out. Observable effects can be divided into two kinds: classical (associated essentially with differential centre to limb variation) and interactive (where an emission component may be present in the line). Observations of U Sge and β Per are discussed from this basis and deductions made about the size and shape of an emitting region. Conclusions are compared with theoretical ideas about such regions and their expected stability, both for these and other similar systems.

1. Motivation

The circumstance of eclipsing binarity can make highly significant addition to the effectiveness of narrow band photometry as an astrophysical tool. This can be particularly effective in Algol type systems, where one star, though of comparable size to the other, may be of very different luminosity. The eclipsing star then acts as a screen, allowing differences between the centre to limb variation of a line and the surrounding continuum to be monitored. Differential effects originating in the atmosphere of the brighter star or some other surrounding material, may, in this way, be capable of detailed investigation. The technique has already been exploited by various authors, notably by Guinan et al. (1976). Special points relevant to the present work are given in more detail by Budding and Marngus (1980).

2. Technicalities

A convenient approach to narrow band photometry is made with the aid of interference filters. The basic principle is one of comparison between flux in the vicinity of some spectral feature and the surrounding continuum. The Hβ line appears to have received most attention in this way, probably because of its strength and position in relation to the spectral sensitivity of photocathodes. Some preliminary observations of U Sge, to be discussed later, were made with Hβ filters and the notation

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in what follows will correspond to this, though the formulae are, in principle, quite general. Ideally, the narrow filter should be tuned to the line centre and just wide enough to comfortably accommodate broad wings. The wide filter could also be an interference filter, though of lower finesse, and a transmission minimum at the line centre would be advantageous.

3. Formulary

A formula which relates a quantity of theoretical specification (equivalent width) to something observable, and which can be shown to be fair for suitably selected filter pairs is of the form

$$w_{\beta} = a + b\beta \quad , \tag{1}$$

(cf. Crawford, 1958); i.e., a linear transformation. Such a transformation applies to standardize actual β index values observed with different apparatus, i.e.

$$\beta_{\mathrm{standard}} = c + d\beta_{\mathrm{local}} \quad , \text{ (a,b,c,d are constants)}. \tag{2}$$

A general formula relevant to the situation obtaining in eclipsing binaries where circumstellar gaseous material may be present is:

$$\bar{w}_{\beta} = \frac{L_{c_1} w_{\beta_1}\big(1 - (p\alpha_c - (p-1)\alpha_{\beta})\big) + L_{c_2} w_{\beta_2} - i_{\beta}(1-\alpha_{em})}{L_{c_1}(1-\alpha_c) + L_{c_2} + L_{c_3}} \tag{3}$$

where L_{c_1}, L_{c_2} and L_{c_3} represent fractional continuum luminosities (their sum = 1) of primary, secondary and circumstellar continuum sources respectively; w_{β_1}, w_{β_2} and $\bar{w}_{\beta}$ are fairly self evident, and α_c,α_{β} and α_{em} represent light loss functions. The first two have well known forms, though α_{β} requires us to consider a quantity $\bar{u}_{\beta}$ which represents a linear limb darkening coefficient for a line region of effective width p. A suitable definition of p is $L_{c_1}/(L_{c_1}-L_{\beta_1})$ where L_{β_1}/L_{c_1} is the fractional depth of the line centre. The third component of the numerator in (3) represents an emission contribution of equivalent width i in terms of the composite spectrum, associated with circumstellar plasma. Attention is then directed to the form of the light loss function α_{em} for this source. Explicit expressions for this have been evaluated for some simplified, optically thin shell and disk models, though if asymmetry, stratification or self-absorption effects require consideration, numerical integration may be called for. In any case, some parameter h, indicatint the relative extent of the emission region above the primary photosphere in terms of its radius, in addition to the quantities i_{β} and $\bar{u}_{\beta}$ mentioned already, will be of some significance in representing the observed effects. For various reasons disk models seem to offer the most appropriate approach to observations of the Algol type systems mentioned in the first section. For such a case we have (for central "occultation" eclipses)

$$k \geq 1 + h \quad \begin{cases} d \geq 1+h+k \; ; & \alpha_{em} = 0 \\ 1+h+k > d \geq 1+k \; ; & \alpha_{em} = \alpha(s)/c \\ 1+k > d \geq k-1 \; ; & \alpha_{em} = \left(\alpha(s)+\alpha(s_1)-\alpha(s')/(1+h)^2\right)/2c \\ k-1 > d \geq k-1-h \; ; & \alpha_{em} = 1 - (1-\alpha(s))/c \\ k-1-h \geq d \; ; & \alpha_{em} = 1 \end{cases} \qquad (4)$$

where the "straight edge" α-function $\alpha(s)$ is given by $\alpha(s) = (\cos^{-1}(s) - s\sqrt{1-s^2})/\pi$ and the various other quantities are as follows: $d = (\sin^2\theta \sin^2 i + \cos^2 i)^{\frac{1}{2}}/r_1$, $k = r_2/r_1$, $s' = d-k$, $s_1 = 1/(1+h)$, $s = s's_1$, $c = \alpha(s_1) + \frac{1}{2}(h^2+2h)s_1{}^2$; the basic quantities being, in the usual notation, primary and secondary relative radii r_1, r_2, and orbital inclination and phase i and θ. If i differs from 90° the foregoing formula still approximately holds good, but k is replaced by $k' = (r_2{}^2 - \cos^2 i)^{\frac{1}{2}}/r_1$. The same formula also describes the "transit" eclipse, but to account for the reappearing part of the disk we introduce $d' = d-2k'$ and then

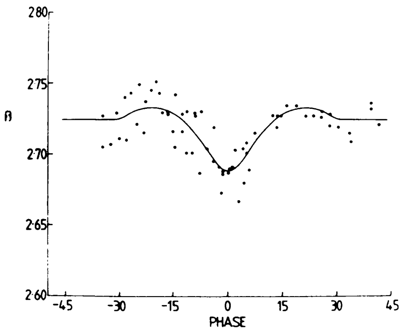
$$\alpha_{em,tr} = \alpha_{em,oc}(d) - \alpha_{em,oc}(d') \qquad (5)$$

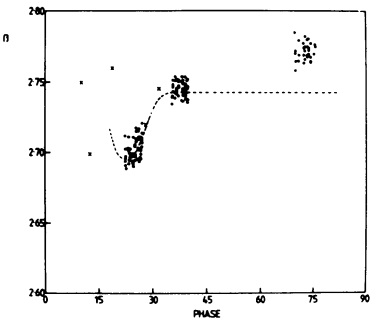
4. Observations

Observations have been made on a few nights in July 1978 and 1979 at Kottamia in Egypt. The region of primary minimum of U Sge was concentrated upon. Targets were to assess the extent of limb darkening (cf. Redman, 1936) and the possible role of any circumstellar emitting material (McNamara, 1951). Simultaneous comparison of the two fluxes was effected by means of a two beam system equipped with an achromatic beamsplitter. DC recordings were measured and processed with the aid of a large screen digitizer at the University of Manchester's Regional Computer Centre.

5. Results

An encouraging result appears from the fitting of the simple disk model of section 3 to the Hα observations of Guinan et al (1976)(Fig.1). In





x = Redman's observations

• = Author's observations

the model zero limb darkening in the line with a representative value of $u_c = 0.45$ for the continuum have been assumed. The relative height of the disk in terms of the primary radius is 0.3, suggesting a relatively large structure but not extending so far as the Roche lobe itself. The apparent scatter at ingress may reflect a real photometric variation at different observation periods.

In the case of the preliminary observations of U Sge (Fig.2) the position is less clear. The drop in equivalent width around fourth contact is in the opposite sense to the expected. It could be matched by some choice of parameters but an unacceptable level of emission is required, or some asymmetric distribution is implied.

6. Ideas

The idea of an overflow of gaseous material from the contact component of a "semi-detached" close binary system has become widely discussed in the literature (for a review see Sahade and Wood's book, 1978). Some appreciation of the situation may be afforded by reference to Fig.3.

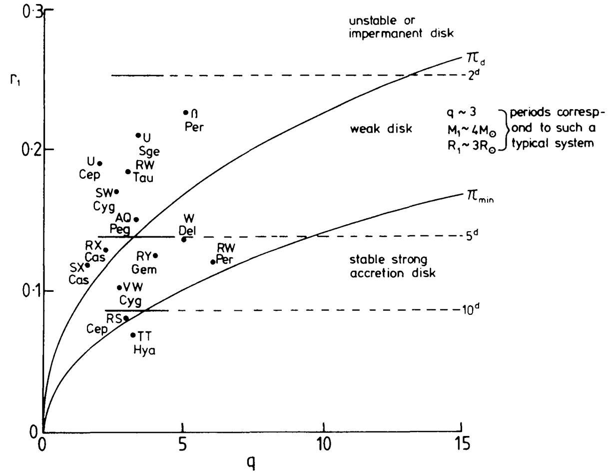


Fig.3. THE DIFFERENT ZONES OF DISK FORMATION SHOWN IN THE DIAGRAM RELECT THE STRINGENT FIXING OF THE π_d, π_{min} CURVES, WHICH DO NOT TAKE INTO ACCOUNT THE ROLE OF DISK VISCOSITY OR RADIATION PRESSURE. OBSERVED POINTS (●) ARE RATHER UNCERTAIN IN SOME CASES.

The curves of closest approach $_{\min}$ and stable quasi-circular particle orbit distance π_d have been taken from the work of Lubow and Shu (1975). Those systems for which the primary radius is less than $\pi_{\min}$ may be expected to form accretion disks in the manner proposed by Lubow and Shu, however for systems like β Per and U Sge the outer boundary of the star would be interposed before the particles could take up steady circular orbits. It may be expected, therefore, that while there could still be mass transfer and a circulation effect around the primary in such "semi-detached" systems, such a transfer would not lead to a thick accretion disk, but should be characterized by low densities and unsteadiness. Perhaps the asymmetric distribution suggested by the U Sge results could be understood in terms of such unsteadiness as well as the fluctuations observed in Guinan's data for Algol.

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DISCUSSION FOLLOWING BUDDING

Andersen: In your last diagram, I see SX Cas at a mass ratio q = 1 - 2. Was this based on any new data, or how was it derived? If we assume that the secondary fills its Roche lobe, we get q = 8 - 10.

Budding: I will check this point. I think I have taken these stars from an onld paper by Struve or maybe some other old catalogue.

Plavec: I have studied SX Cas very thoroughly in recent months. Andersen is quite right. Struve's original radial velocity curves published in 1944 are completely unreliable since they reflect the complex motions in the envelope of the hotter component, and nothing more. If there exists any reliable radial velocity determination at all for this system, it is Andersen's estimate for the cool component. In order to get the mass ratio, we must make additional assumptions; an indeed, if we postulate that the cool star fills its critical Roche lobe, the mass ratio must be at least 8. There is growing suspicion, though, that considerable mass loss may occur even for late-type giants not filling their respective Roche lobes. Even if we relax this condition, the mass ratio can hardly be smaller than 3, otherwise we get quite unrealistic masses of both stars.