HERCZEG: Let me add to Dr. DETRE's remark that we at Hamburg recently investigated 15 well studied cases of possible light-time effect among eclipsing binaries. None of them turned out definitely as a member of a triple system, although a few of them are still to be kept on the list of possible candidates. In many cases, indeed, we have a nice „periodicity" of the O—C values for several years or decades, which later turns out to be spurious.

Concerning membership of eclipsing binaries in globular clusters I should like to emphasize that the three possible members have as a counterpart some 1500 RR Lyrae stars discovered in clusters. There are virtually tens of thousands of stars investigated and the small number of eclipsing binaries found indicates clearly how extremely infrequent these stars are in the magnitude range considered. I think the membership of V 78 in ω Centauri is still a question not yet settled.

WALTER: Are there cases where the variations of periods repeated several times as one should expect that they arise by the binary character?

COUTTS: In Variable 13 in M 3, the cycle is repeated.

PERCY: It seemed that the amplitude of the phase variation was consistent with the approximate periods. Is this so?

COUTTS: In many cases.

BAKOS: Have you looked at the variations of O—C among non-cluster RR Lyrae variables?

COUTTS: No, this investigation has been limited to one cluster only.

Simultaneous Photometric and Image-Tube Spectroscopic Observations of Short Period Binary Systems and Rapid Intrinsic Variables *

M. F. WALKER (Santa Cruz)

An extremely important new frontier in variable star research lies in the application of image tube techniques to the study of the spectroscopic phenomena in extremely rapid intrinsic variables and in short-period binary systems. Within limits, the use of image tubes for the spectroscopic observation of constant or slowly varying stars can be regarded as a convenience — as a means of increasing the efficiency of use of time at the telescope; the same results could, in principle, be obtained by observing for a longer time by conventional means. However, when one wishes to observe rapid changes, there is no substitute for the higher information collection rate provided by the image tube. Electronographic image tubes are especially well suited to this type of investigation owing to their high quantum efficiency, high resolution, large storage capacity, and linearity of response. Typically, image tubes of this type may have quantum efficiencies of 10% to 20%, an information-rate gain of 10 to 20 over the fastest photographic plate (baked Kodak IIaO at 4000 A), and resolutions between 80 and 100 lp/mm. With proper choice of photographic emulsion to record the electronic images, a linear relationship exists between photographic density and intensity of the incident light up to densities of about six, making electronographic image tubes especially valuable for spectrophotometric observations. Despite the great potential of this technique,

* Contributions from the Lick Observatory, No. 345.

very little work of this type has so far been done. In this paper I shall outline some of the results that have been obtained at Mount Hamilton to illustrate the possibilities of this type of observational research.

Since 1959, I have been engaged in a number of different observational programs using electronographic image tubes mounted at the focus of the 20-inch focal length camera of the coudé spectrograph of the 120-inch reflector. The first observations were obtained using the electronic camera developed by Prof. LALLEMAND at the Paris Observatory; since 1967, these programs have been continued using the Spectracon produced by Prof. McGEE at the Imperial College, London. Among the spectroscopic programs undertaken was a series of observations of the rapid spectroscopic changes that occur in old novae, SS Cyg stars, and related variables showing rapid irregular variations in light. In most cases, simultaneous photoelectric observations were secured with the 24-inch photometric reflector in order that the spectroscopic and photometric variations might be correlated. The spectroscopic observations were made using the „single trail" technique in which the star is trailed once along the slit of the spectrograph during the exposure at a carefully controlled, uniform rate. That control was obtained by guiding the star on the wire of a micrometer eyepiece, and advancing the position of the wire by equal increments at intervals that depended upon the brightness of the star, but which were usually of the order of one minute or less. Single-trail observations of this type have several advantages:

1) Continuous monitoring of the star for an extended period of time is possible. Such coverage is extremely important when randomly occurring, transient phenomena are being investigated.
2) Much better time-resolution is obtained than if a series of discrete exposures are made, since each of the spectra must be widened somewhat in order to make the lines more reliably visible and measurable.
3) The visibility of faint features in the spectrum is enhanced, since the time-resolved spectra are usually very wide.

In all of these observations, a grating was used that gave a dispersion of 48 A/mm on the photocathode of the electronographic image tube, and the electronic images were recorded on Ilford G 5 nuclear research emulsion, which was developed 5 min. in D 19 developer at 65 °F.

One of the first stars to be investigated in this way was the short-period explosive variable AE Aqr (WALKER 1962, 1965, 1966). Some of the time-resolved spectra obtained are reproduced in Figure 1. The photographic magnitude of the system during all of these observations was about B ≅ 12.5. The time-resolution obtained by the single-trail method depends strongly on the optical turbulence or seeing during the observations. With the seeing conditions that prevailed during the exposures on AE Aqr, the time resolution of the spectra is about 5 minutes. These spectra show very clearly the velocity variation of the late-type component of the system whose spectrum consists of the absorption features plus narrow emissions of Ca II. Broad emission of hydrogen and Ca II associated with the hot star are also visible. „White-light" flare activity occurs, as is shown by the changes in the brightness of the continuum; spectrophotometric measurements of the spectra show that during these maxima the absorption lines of the late-type component are filled in by just the amount required if the brightness of that component remains constant and the additional radiation is supplied from some other source in the system. In addition, smaller explosions occur involving only the emission lines. These explosions are apparently associated with either of the stars and are detectable photometrically only in blue and ultraviolet light since none of the emission features are contained within the visual-filter pass-band. Occasionally, emission features traverse the region between the emissions associated with the two stars in the system, and may represent the actual ejection of material from one star to the other.

Single-trail spectra of SS Cyg are shown in Figure 2. The time resolution of these observations, made when the system was at minimum light (B ≅ 11.8), is about 5 minutes for the observations on July 21, 1965, and about 10 minutes for the observations on October 16,

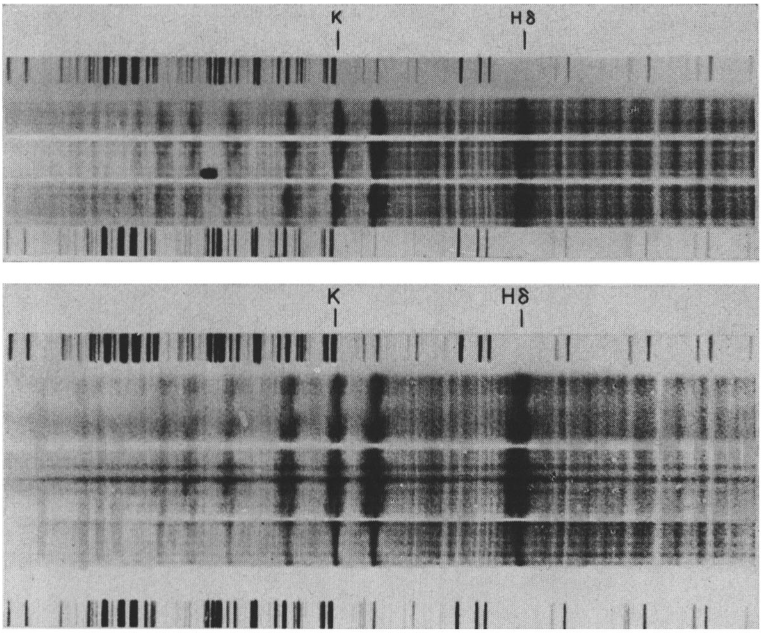

Fig. 1: Single-trail of AE Aqr observed on July 1, 1964 (top) and July 2, 1964 (UT) (bottom). Time increases uniformly from top to bottom in each set. The separations between the spectra taken on the same night represent the time interval between them. The observations on July 1 extend from 7^h20^m to 11^h16^m UT; those on July 2 from 7^h15^m to 11^h16^m UT.

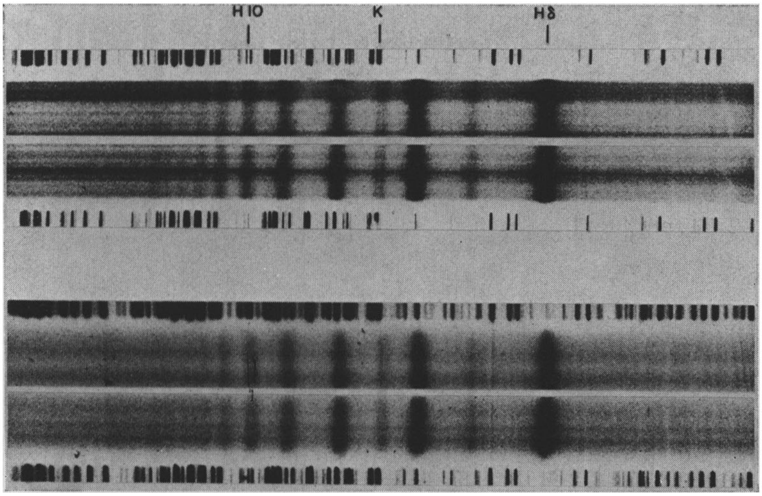

Fig. 2: Single-trail spectra of SS Cyg observed on July 21, 1965 (top) and October 16, 1965 (bottom). Time scale as in Figure 1. The observations on July 21 extend from 8^h23^m to 9^h25^m UT; those on October 16 from 3^h49^m to 6^h42^m UT.

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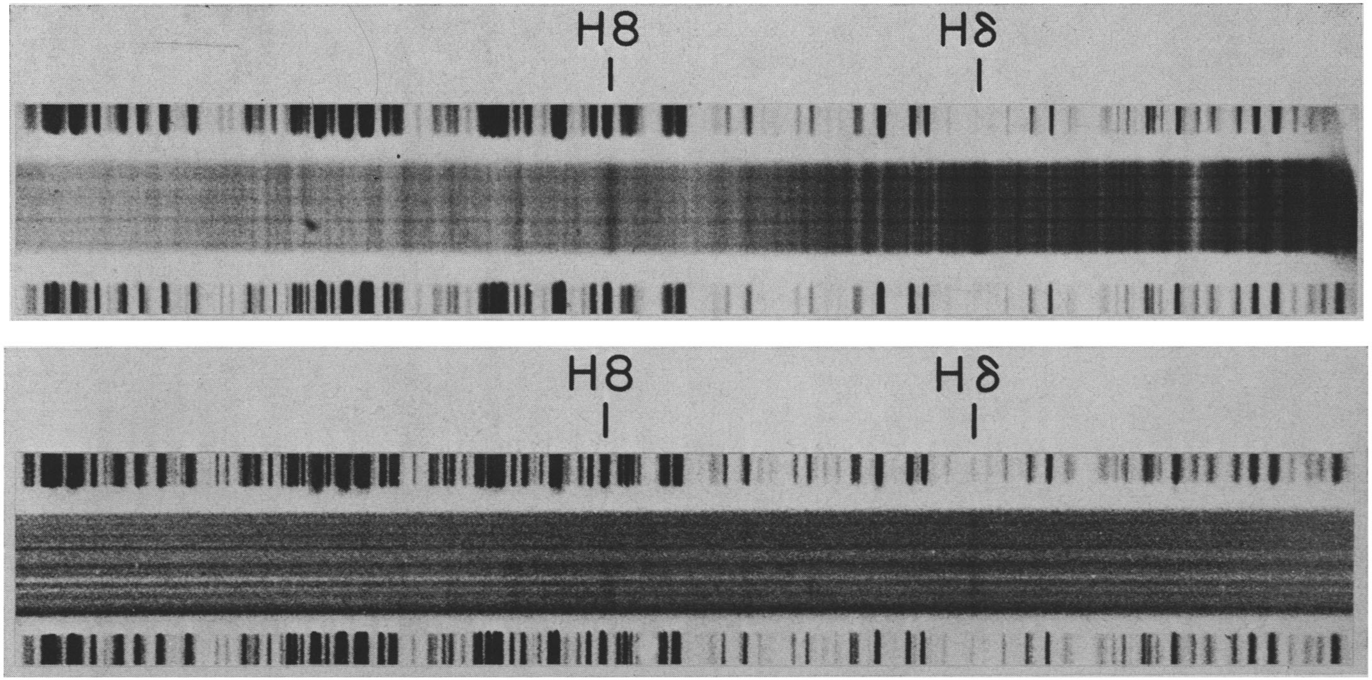

Fig. 3: Single-trail spectra of T CrB (top) and MV Lyr (bottom). Time scale as in Figure 1. The observations of T CrB were made on June 7, 1965 and extend from 7^h32^m to 8^h40^m UT, while those of MV Lyr were made on July 7, 1965 and cover the interval from 6^h34^m to 7^h32^m UT.

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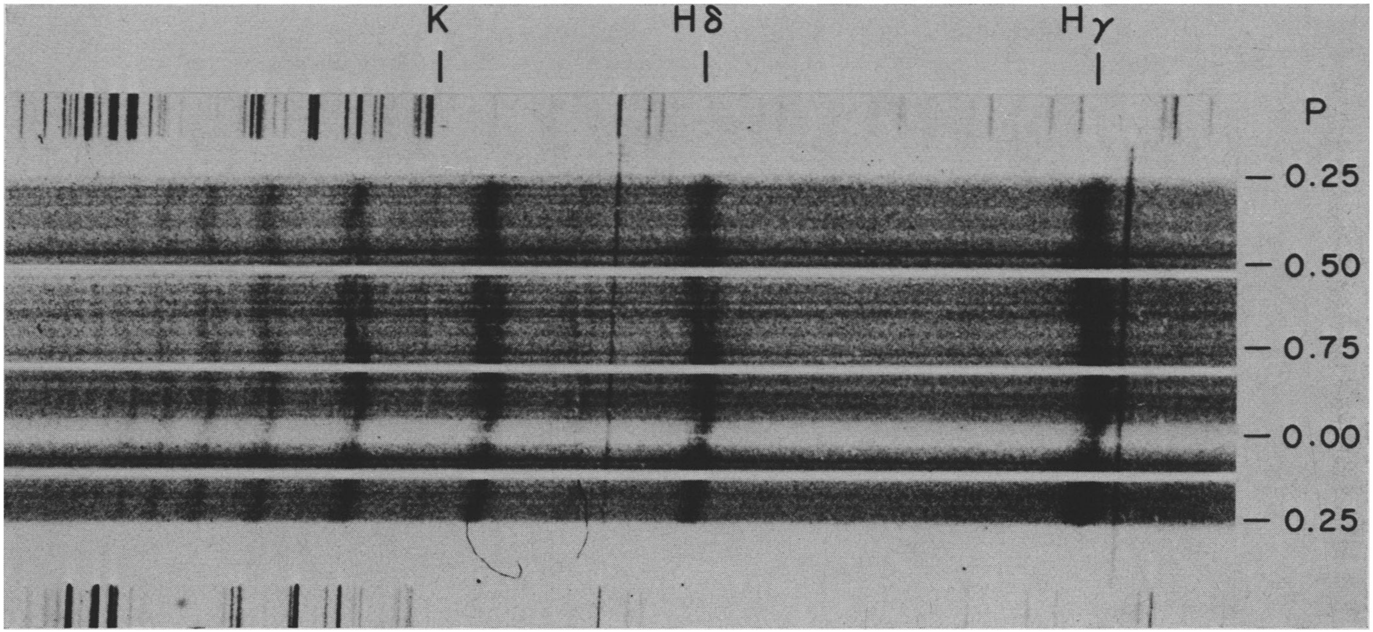

Fig. 5: Single-trail spectra of RW Tri, observed on September 10, 1970. Time scale as in Figure 1. The observations extend from 7^h05^m to 12^h42^m UT.

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1965. A detailed discussion of these observations has appeared elsewhere (WALKER and CHINCARINI 1968). As in AE Aqr, the absorption spectrum of the late-type component is visible, but in this system is veiled by continuous emission. The emission lines of hydrogen and Ca II are usually doubled and appear to originate in a ring or disk around the hot star. The rapid variations in light characteristic of SS Cyg at minimum light (WALKER 1954; GRANT 1955) are seen from the spectra and from the simultaneous photometric observations to originate from the occurence of „white-light" flares, the intensity of the emission lines remaining essentially constant. As in AE Aqr, the brightness of the late-type star remains constant during these flares. Other observations, made during one rise to maximum of one of the characteristic SS Cyg-type maxima, indicate the source of these explosions is the hot component of the system. This result has been questioned by SMAK (1969) since the time-distribution of the older radial velocity observations is such that they can be fitted by more than one value of the period. However, additional image-tube spectra obtained in 1970 confirm this conclusion (WALKER and REAGAN 1971).

Time-resolved spectra of the old nova T CrB and the rapid, irregular variable MV Lyr (McRae $+ 43^\circ$ 1) (WALKER 1954) are shown in Figure 3. Both of these objects display the rapid light-variations characteristic of old novae, SS Cyg stars, and related systems at minimum light (WALKER 1957). During these observations, the brightness of T CrB was $U \cong 12.5$ while MV Lyr was $B \cong 12.5$. The time-resolution on the spectra is: T CrB, 4 minutes; MV Lyr, 2 minutes. Comparing these spectra with the simultaneous photometric observations, we find that the variations in the density of the spectra can be correlated with the light variations and thus result from changes in the brightness of the stars, rather than changes in seeing. Here again, as in SS Cyg, we see that the rapid variations in light result entirely from changes in the brightness of the continuous emission.

Single trail spectra of the short-period Algol-type eclipsing binary RW Tri (WALKER 1963) obtained using the Spectracon image tube are shown in Figure 5, and the simultaneously observed light curve in yellow light is shown in Figure 4. These observations were made on September 10, 1970 (UT) when the brightness of the system at maximum light was $V \cong 13.6$ and $B \cong 13.8$. The time-resolution on these spectra is about 7 minutes. The phases of the observations calculated using the photometric elements (zero phase at primary minimum) are shown at the right-hand edge of the figure. An extensive series of photometric observations of this system made in 1957 (WALKER 1963) show that the form of the light-curve is very similar to those of UX UMa and DQ Her. In addition, variations in the general level of brightness of the system outside eclipse occur. The depth of primary eclipse is correlated with these changes, the eclipse being deepest when the system is faintest at maximum light. The 1957 observations suggested that the bright star in this system is surrounded by a partly luminous stream of material, similar to those that have been postulated to account for the light-curves of UX UMa (WALKER and HERBIG 1954) and DQ Her (WALKER 1956) and, in addition, an extended atmosphere, cloud or halo whose size and brightness are subject to irregular variations. The observations in 1970 were obtained at a time when the system was as faint, and the eclipse curve as deep, as was ever observed in 1957.

Figure 4 shows that the spectrum consists of a continuum with strong hydrogen and weak He I and Ca II emission features which are double during portions of the 5^h34^m orbital period. Microphotometer measures show that the apparent absorption features associated with the emission are not actual absorptions, but only the minima between the doubled emission features. It will be noted that the comparison lines and the lines of Hg at λ 4046 A and λ 4358 A caused by the lights of San Jose are slightly inclined to the direction of dispersion. This inclination results from distortion in the particular Spectracon image tube used for these observations.

The analysis of these observations is still in progress, and a definitive model of the system has not yet been derived. Basically, the spectra indicate that the hot star is surrounded by a rotating ring or disk, giving rise to the double emission. The center of gravity of the system is located outside the ring, so that the double emission varies in velocity with the

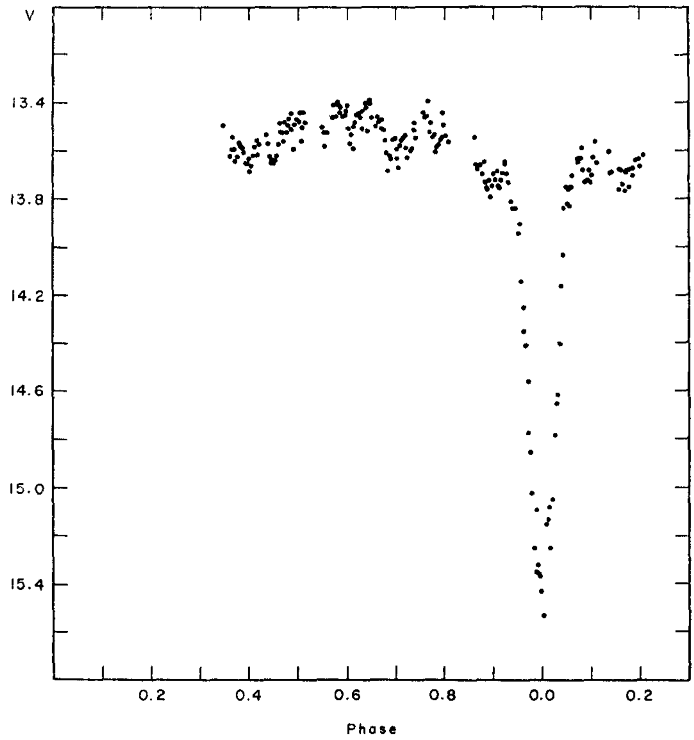

Fig. 4: Photoelectric light-curve of RW Tri in yellow light, observed on September 10, 1970, simultaneously with the spectroscopic observations shown in Figure 5.

orbital motion of the system. In addition, there is either (1) an „S-wave" emission component similar to that found by KRAFT in WZ Sge (1961) having a phase lag of about 90° with respect to the photometric elements, or (2) a region of much greater emission intensity on the ring or disk located about 90° to the line of centers of the two stars, on the side of the ring following the hot star in its orbital motion. In either case, the phenomenon is probably due to material ejected from the dark component of the system. In case (1), we observe the actual stream of material between the stars, as is the case in WZ Sge (KRZEMINSKI and KRAFT 1964), while in case (2), we observe the region of the ring brightened by collisional excitation of the impinging stream. Additional observations may be required to distinguish between these two interpretations. In any case, further observations of RW Tri are planned, in order to study the spectroscopic behavior of the system at times when the system is bright and the eclipse-curve is filled in.

As the foregoing observations demonstrate, the application of electronographic-type image-tubes to the high time-resolution spectroscopic study of rapid variables, together with simultaneous photoelectric observations, can be expected in the future to make an enormous contribution to our understanding of short-period or rapid variables of all types. I therefore strongly recommend that observers give serious consideration to this type of observational program.

References:

GRANT, G., **1955**, Ap. J., **122**, **566**.
KRAFT, R. P., **1961**, Science, **134**, **1433**.
KRZEMIŃSKI, W., and KRAFT, R. P., **1964**, Ap. J., **140**, **921**.
SMAK, J., **1969**, Acta Astronomica, **19**, **287**.
WALKER, M. F., **1954**, Carnegie Yearbook, **53**, **10**.
WALKER, M. F., **1954**, P.A.S.P., **66**, **71**.
WALKER, M. F., **1956**, Ap. J., **123**, **68**.
WALKER, M. F., **1957**, in I.A.U. Symp. No. **3** (Cambridge: Cambridge University Press), pg. **46**.
WALKER, M. F., **1962**, Adv. in Electronics, **16**, **341**.
WALKER, M. F., **1963**, Ap. J., **137**, **485**.
WALKER, M. F., **1965**, Sky and Telescope, **29**, **23**.
WALKER, M. F., **1966**, Adv. in Electronics, **228**, **761**.
WALKER, M. F., and CHINCARINI, G., **1968**, Ap. J., **154**, **157**.
WALKER, M. F., and HERBIG, G. H., **1954**, Ap. J., **120**, **337**.
WALKER, M. F., and REAGAN, G. H., **1971**, Information Bull. on Var. Stars, Commission **27** of the I.A.U., No. **544**.

Discussion to the paper of WALKER

O'CONNELL: Have you worked out the absolute dimensions of RW Tri from the data obtained with this very effective technique? Secondly, have you got other eclipsing binaries on your programme, e. g. DQ Her?

WALKER: The absolute dimensions are just being calculated and definitive values are not yet available. I certainly plan to observe VX UMa, and to obtain further observations of RW Tri at times when the light curve is different. DQ Her may be possible but is more difficult owing to its faintness; the time-resolution will be poorer.

RW Arietis; an RR Lyrae Variable Star in an Eclipsing System

W. Z. WISNIEWSKI (Cracow)

Abstract:

RW Arietis was observed photoelectrically in the UBV-system during fall and winter 1966 with the 70 cm telescope at the Lunar and Planetary Laboratory Catalina station, University of Arizona, Tucson, on 19 nights. Peculiar variations of the usually stable RRc light curve observed on three nights can be interpreted as a superposition of the RR Lyrae type variation and an eclipsing type variation.

From the additional variations it is concluded that the RR Lyrae star is part of the eclipsing system with the elements

Primary Minimum = JD 243984.97 + 3.1754 · E.

The elements of the RR Lyrae variation are

Maximum = JD 2428183.324 + .3543184 · E.

Since the RR Lyrae variation does not disappear during primary minimum, and since the depth of primary minimum is about $0^{m}_{.}8$ in V the pulsating component is eclipsing the brighter secondary star during primary eclipse. If it is assumed that the RR Lyrae star is (at minimum light) a F0 giant then the color indices found lead to the conclusion that the secondary component should be a blue giant or a young B-type star.

(The paper has been published in full length in Acta Astronomica, Vol. 21 (1971), No. 3, page 307 ff.).

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