THE CHROMOSPHERIC SPECTRUM OF THE ζ AUR BINARY HR 6902

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ABSTRACT. Observations of the composite-spectrum binary HR 6902 around the time of total eclipse reveal absorption features that are due to the chromosphere of the G9 II primary star. By the application of our method of digital subtraction we have succeeded in isolating the spectrum of the stellar chromosphere.

Binary stars exhibiting composite spectra form a particular class of double-lined binary systems. In the present application a composite spectrum is one which arises from a binary or multiple stellar system whose components have a very small angular separation and dissimilar spectral types; composite-spectrum binaries of interest here consist of a late-type giant and a main-sequence star of type A or B. Spectra of composite systems are rather confusing; spectral classification presents considerable difficulties, and so does the measurement of the features of the spectrum of one component in the presence of those of the other. If, however, the two spectra can somehow be separated then we can learn much more about the system. In particular, if the relative radial velocities of the two components can be measured, the mass ratio of the two stars follows immediately as the inverse of the velocity ratio; and since the masses of main-sequence stars are known tolerably well we can determine the mass of the cool giant with reasonable confidence. Our method avoids any reliance on spectroscopic gravities, which have been responsible for the notorious uncertainty associated with giant star masses, and in applying it to composite-spectrum binaries we are exploiting a hitherto neglected class of object.

We have developed a technique of digital subtraction which enables the components of composite spectra to be separated. As the details of our technique have been described fully elsewhere (Griffin, 1986) we will only summarize here the main features of the procedure.

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First, a digital record of the composite spectrum has to be prepared and linearized in wavelength in the rest-frame of the primary star. From a library of standard single-star spectra, similarly linearized in wavelength in their respective rest-frames, we then select by trial and error one that matches the primary, and subtract it point-by-point from the composite spectrum. When a good match is achieved and the right proportion of it is subtracted, the spectrum of the secondary is uncovered. The procedure is optimized iteratively until there is no trace of the spectrum of the primary left to contaminate that of the secondary; to achieve that requires careful control, since both spectra will contain some of the same spectral features unless the secondary is appreciably earlier than type A0. The secondary spectrum thus revealed can then be used for any purpose that a spectrum would normally serve, including spectral classification and the measurement of radial velocities and equivalent widths.

Studies of this nature require very high S/N, because in the process of subtraction the signal is subtracted but the noise is added. In addition, attempts at spectral classification are aided by the availability of long regions of spectra, as also are the assessments of the subtraction procedure itself. Furthermore, spectra of normal late-type giants have very narrow lines, and in order to subtract away the primary spectrum cleanly without leaving traces of apparent P-Cygni profiles, such as occur if the two spectra are not aligned accurately enough, it is imperative to achieve adequate resolution per pixel element of the detector, and to sample the data sufficiently frequently. The photographic plate is a detector which satisfies all of these stringent requirements: it can cover a large wavelength region in one exposure and it gives a virtually continuous record; S/N ratios can be increased at will by co-adding digitized spectra, and as a matter of routine we also widen the spectra as far as conditions will permit by trailing the star image along the slit of the spectrograph. Suitable photographic facilities were made available to us for this project at the coudé focus of the 100-inch telescope on Mt. Wilson. We have chosen to work at a dispersion of 10 Å/mm throughout, in order to handle spectra of composite stars down to 7^m in the same way as those in the library of standards; the spectra are digitized every 5μ on the plate, and the intensities are computed at intervals of 50 mÅ.

The first system which we analyzed, HR 6902, was found to have components of types G9 II ad B8 V; part of the results of the subtraction procedure are shown in Fig. 1. As the B8 V star has very narrow lines we were able to measure accurately (by cross-correlation with a B8 V standard) the difference in radial velocity between the two components, and to derive for the system a double-lined orbit. The orbit solution gave a mass ratio of 1.31 ± 0.021, the individual masses being

$$m_1 \sin^3 i = 3.86 \pm 0.13\ M_\odot \text{(G9 II) and}$$

$$m_2 \sin^3 i = 2.95 \pm 0.09\ M_\odot \text{ (B8 V).}$$

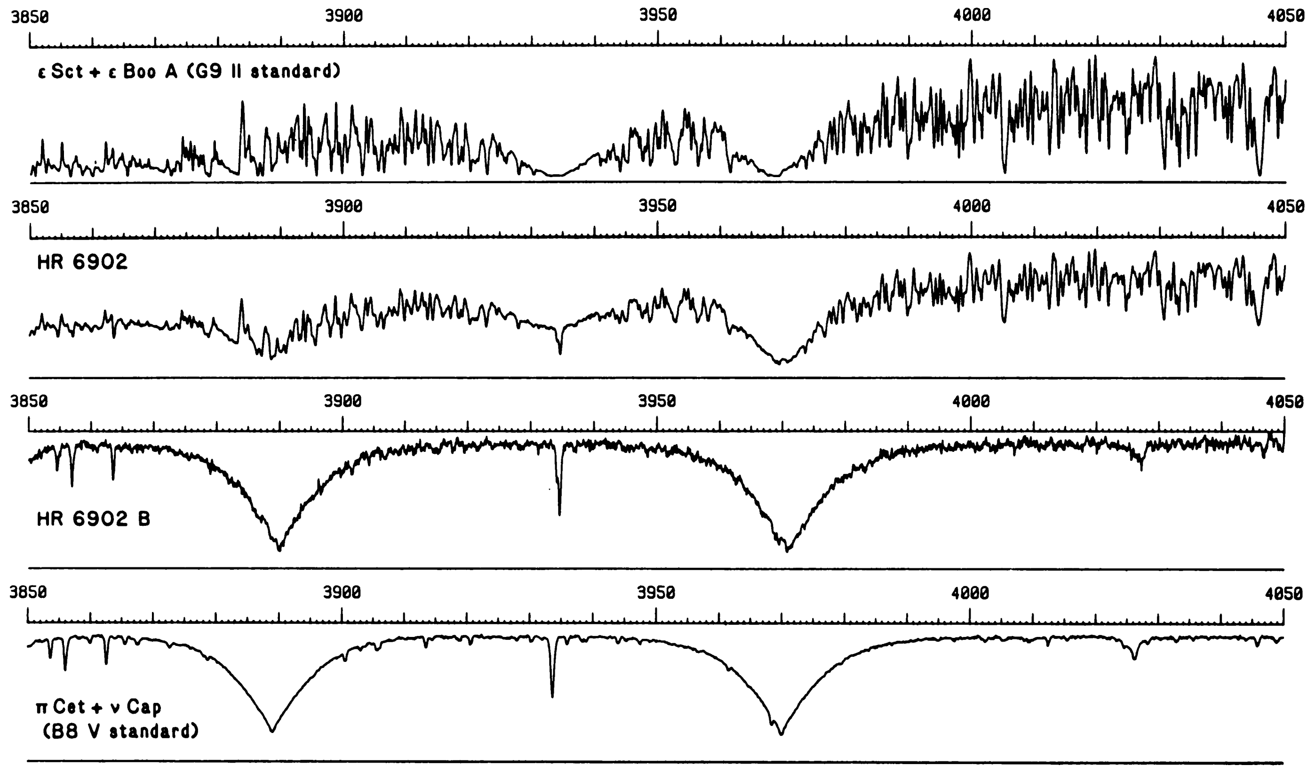

Figure 1. Subtraction of spectra. The top spectrum is adopted as the analogue of the late-type component of HR 6902. Subtraction of an optimal proportion of it from the spectrum of HR 6902 (second tracing down) isolates the early-type component (third tracing), which may be compared with the standard spectrum at the bottom. The horizontal line below each tracing is the zero-intensity level.

However, according to Popper (1980) the mass of a B8 or B9 dwarf is near 3 $M_\odot$, and since our value of m_2 has a minimum of 2.95 $M_\odot$ then the angle i must be very close to 90°, i.e. the system is likely to undergo eclipses.

In order to verify the occurrence of eclipses, photographic spectra of the system were obtained with the D.A.O. 48-inch telescope and coude spectrograph during the week following the predicted date of mid-totality. An eclipse did take place, and moreover the spectra showed clear evidence of an atmospheric eclipse which is characteristic of ζ Aur binaries: immediately before and after totality the hot dwarf shines through the eclipsing giant's extended atmosphere, which causes additional absorption lines to appear in the composite spectrum (see, for example, the sequence of events shown by Wright (1952) during the atmospheric eclipse of 32 Cyg). Since the giant component in HR 6902 is less luminous than the primary stars of the classical ζ Aur binaries and therefore has a less extended atmosphere, the atmospheric eclipse phase lasted only two or three days and little height-resolution in the chromosphere could be obtained.

The atmospheric-eclipse spectra were first processed like normal composite spectra, by subtracting the spectrum of the system in totality to reveal the B8 V spectrum with additional chromospheric lines superimposed. We removed the B8 V spectrum by dividing it by our standard B8 V spectrum, and thereby isolated the G9 II's chromospheric lines. They include strong, narrow Ca II H and K lines that are black in the line cores, narrow Balmer lines, and a few resonance or low-E.P. metallic lines such as Mg I, Al I, Ca I, Ti II, Cr I, Mn I, Fe I and Sr II.

We hope to be able to improve upon our result during a future eclipse of HR 6902, and also to apply the method to some of the classical ζ Aur binaries in due course; in the latter events we expect to be able to obtain spectra of the chromospheric material at different heights above the photosphere of the giant star. An observational analysis of this kind has apparently been attempted once before (Morbey et al., 1975; Wright, 1975) for 31 Cyg, but was unfortunately left in a preliminary stage and not fully discussed in the literature.

References

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DISCUSSION

COTTRELL You want to be able to monitor effects which have time scales of less than a day and yet you only obtain one photographic spectrum per day. Surely you need to go to a solid-state system to do this?

GRIFFIN The geometry of the system is such that we cannot get height- resolution; we still need large wavelength coverage for classification purposes.

SODERBLOM What S/N ratio were you able to achieve with your photographic plates? To what extent was this limited by horizontal streaks (guiding errors?) on the original spectra?

GRIFFIN In our spectra at very high resolution (1 Å/mm or better) we can reduce the noise level to a fraction of 1 %. The work on composite spectra employs 10 Å/mm, though the S/N achieved will depend upon the opportunity to co-add spectra. Horizontal streaks are caused by imperfections in the entrance slit as well as by guiding errors during short exposures and are to be avoided where possible. If the continuum density lies on the linear region of the characteristic curve the relative error will be small, but the effect in absolute terms may cause some anxiety.

MOROSSI How did you make the actual subtraction of the standard spectrum from the composite one? I refer to consistency of the two wavelength scales.

GRIFFIN There is no problem. A wavelength scale is established for each spectrum in the rest-frame of the star, by identifying stellar lines. We do not use a reference spectrum.