EXTRACTION OF THE SHELL SPECTRUM OF EPSILON AURIGAE (*)

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ABSTRACT. A sample of high-dispersion optical spectrograms of ε Aur,taken on different epochs before and during eclipse, has been processed by computer in order to extract the shell spectrum,produced by the eclipsing body. Using an uneclipsed spectrum as reference, the primary's dominant contribution was removed, and this makes it possible for the first time to study the secondary body spectrum separately at all eclipse phases. As the first striking result, one finds that the internal regions of the extended eclipsing body are hotter than the outer zones.

1. INTRODUCTION

During the two-year-long eclipse of ε Aur, an obscure object passes in front of the FOIa primary star, reducing its optical luminosity to about one half. The eclipsing body was extensively studied during the last 1982 -84 by different authors showing the presence of multiple components within an ellipsoidal rotating structure. A cool (500-1000K) and optically thick dusty disk, seen almost edge-on, is contained along the equatorial plane (Backman et al.,1984). A dwarf B star (Boehm,Ferluga and Hack,1984) or a close binary (Lissauer and Backman,1985) is probably embedded in the center. A rotating gaseous shell, having a temperature slightly lower than the primary star,surrounds the disk (Ferluga, Hack,1985: paper I).

This gaseous shell,during the eclipse,produces the well-known shell spectrum. It consists of a set of sharp additional absorption components, superimposed over the primary's spectral lines and drifting from the red side of the profile (at ingress) to the violet side (at egress), because of the shell rotation. These features were already studied during the egress phase of the previous 1955-57 eclipse, showing evidence of low density and diluted radiation (Hack,1959). During the last 1982-84 eclipse, we observed the shell features at all phases of the eclipse, analyzing a set of high-dispersion spectrograms (GC type, 7.2 Å/mm, or at least GB type, 12.4 Å/mm) taken at the Haute Provence Obs. (France) and listed in paper I.

At ingress and during totality the shell components of the metallic

(*) Based on observations at the Observatoire de Haute Provence (OHP), processed at the ASTRONET pole of Trieste with the ELSPEC/11 software.

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lines are much fainter than at egress, and in the case of weak lines they can be revealed only as small perturbations of the stellar line profile. Around mid-eclipse, a considerable deepening of the Balmer series is observed, but the shell components are superimposed with no relative shift over the corresponding broad stellar lines, and cannot be analyzed separately. For these reasons, a complete study of the shell spectrum at all phases of the eclipse is not feasable simply by direct analysis of the observed spectrograms. The underlying contribution of the primary's spectral lines should be removed in advance. The removal procedure is described in section 2; finally the spectrum of the gaseous envelope, extracted in such a way, is discussed in section 3.

2. DATA PROCESSING

Reduction of the spectrograms was performed at the ASTRONET pole in Trieste, starting with the digitation at the PDS microdensitometer, and then following the standard ELSPEC/11 procedure (Pasian et al.,1982)which provides calibrated, heliocentric and normalized intensity tracings, and also allows mathematical treatment of the spectra. In order to minimize the noise,groups of spectra taken at the same phase,with only a few days' interval,were averaged together. Average spectra for a dozen different phases of the eclipse were then obtained, together with an almost noise-free reference spectrum, which is an average of 6 normalized spectra taken out of eclipse on January 1981. Doppler-shift correction was finally applied,reducing to zero the orbital velocity of the F star at all phases.

The shell spectrum is formed in the eclipsing body, by absorbing the radiation of the primary F star. Hence the local continuum,for a general shell line, is given by the profile of the corresponding line of the F star, on which the shell component is superimposed. So, if one divides an eclipsed spectrum containing the shell components,by a pure uneclipsed spectrum of the F star, one obtains a normalized spectrum of the eclipsing body. Such a method,taking the spectrum of the F star as the continuum for the shell lines, was already used in a single case for the extraction of the Hδ shell line during the previous 1955-57 eclipse (Hack,1959).

Taking the Jan.'81 uneclipsed spectrum as reference, we applied the extraction procedure to our sample of phase-averaged eclipsed spectra (after careful equalization of their zero-intensity levels). As a result, we could obtain the first individual spectra of the gaseous component of the eclipsing body, at all phases of the eclipse.

3. THE EXTRACTED SHELL SPECTRUM

A portion of the shell spectrum, extracted at different eclipse phases, is shown in Figure 1. All the properties of the shell lines, already detected by previous investigations, clearly appear at the first inspection of the shell spectra. One observes for example the sharpness of metallic lines, the prevalence of low-excitation features, the redward and blueward shift (depending on phase), and the deepening on egress. The dilution is evident, since the Fe I multiplet 152 is extremely weak, in particular at ingress. Undesired spurious effects,appearing in the extracted shell spectrum because of stellar variability, are generally

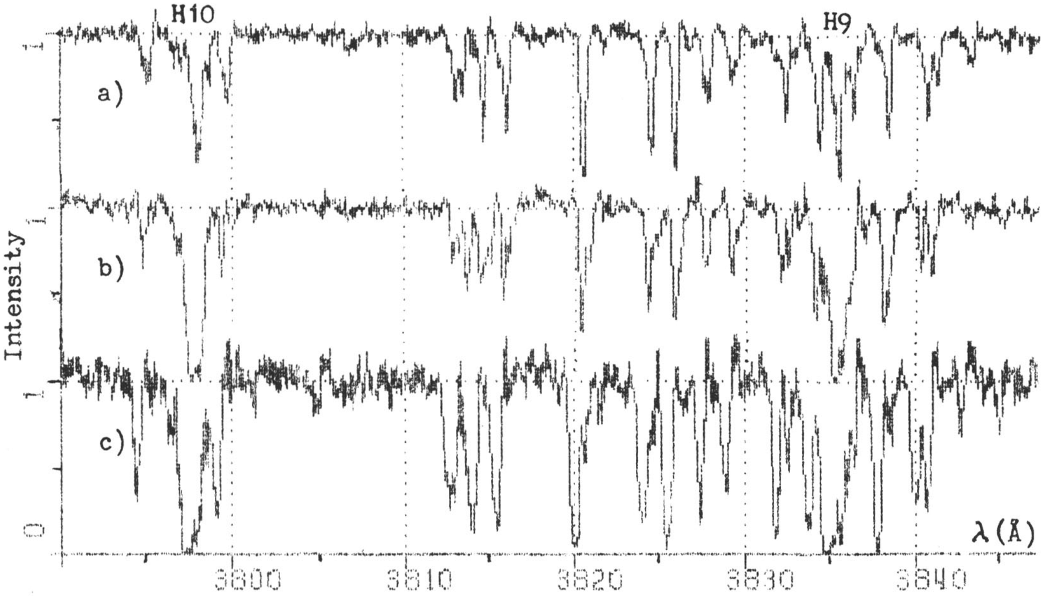

Fig.1. Extracted spectrum of the eclipsing companion of ε Aur. a) mid-ingress, Sep. 82; b) mid-totality, Aug. 83; c) early-egress, Mar. 84.

negligible: residual absorptions or over-compensations of stellar lines (pseudo-emissions) can appear during partial eclipse phases (because of shrinking line-profiles), or can affect the H and K lines of calcium which are intrinsically variable in the F star (Castelli, 1978).

Particularly interesting is the fact that a lot of new physical phenomena can be identified for the first time in the eclipsing body, by analyzing the extracted shell spectra. There is one striking difference between the shell spectra at mid-eclipse, and those in the partial phases: the Balmer series. It clearly dominates during the whole totality, showing broad lines with very steep profiles and no wings (width at half-depth corresponds to a velocity dispersion of ~90km/s); on the contrary at mid-ingress the Balmer series, for $n \geq 4$, is much sharper (corresponding to a velocity of ~30 km/s). Also the metallic lines are slightly broader in totality, than in the partial phases.

During the various phases of the eclipse, different parts of the eclipsing body pass in front of the F star; this means that the phase-dependence of the shell spectrum provides a natural "scanning" of the inner parts of the eclipsing body. The interpretation of the observed behaviour of the shell spectra during totality is then clear: the internal regions of the eclipsing body show evidence of low density, high rotational velocity, and a remarkably higher temperature, that is of the order of an A-type star (precision measurements are in progress). The hot source, causing the far-UV excess of ε Aur, should then be at the center of the shell.

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