In this connexion it is interesting to consider the doubling of the absorption lines H and K and H_α in the spectrum of RR Lyrae* and the doubling of many absorption lines on a spectrogram of AC Herculis obtained 10 July 1949.

A spectrogram of T Mon at phase $0{\cdot}00P$ was obtained on 25 March 1951 with a dispersion of 2·3 A./mm. and one of SV Vul at phase $0{\cdot}94P$ on 30 May 1952 with a dispersion of 4·4 A./mm. The lines of Sr II, Sc II and Ti II were not resolved into two components on these spectrograms but both showed wide lines not only of these elements but of other elements as well. However, optimum resolution was not realized on either of these spectrograms.

7. SHOCK WAVES IN THE ATMOSPHERES OF PULSATING STARS

By MARTIN SCHWARZSCHILD

The profiles of the absorption lines in cepheids (their width, asymmetry, and doubling) have to be interpreted in terms of the motions throughout the reversing layer. To cover the entire volume of the reversing layer one has to integrate both over the surface of the visible hemisphere and throughout the depth of the reversing layer. The effect of the surface integration has already been discussed in this symposium by Dr Savedoff. Here will be discussed the effects of the depth integration.

In the case when the pulsations in the atmosphere are synchronous, i.e. have the character of a standing wave, the depth integration will not add sensibly to the line profile since at any one moment the pulsational velocity will differ little from point to point in the reversing layer. If, however, the atmospheric pulsation has the character of a progressive wave, the phase delay from the bottom to the top of the reversing layer will introduce velocity differences which may appreciably affect the appearance of the lines. Let us consider a shock wave as an extreme case of a progressive wave.

Fig. 1 shows schematically the motions of the top, the middle, and the bottom of the reversing layer as a periodic function of time.

To start with, at phases 0·1 to 0·3 all strata move outwards, more or less with the same velocities. Next, the strata reach successively their largest distances from the centre and their motions turn inwards until the entire reversing layer is in a more or less uniform downwards motion during the phases 0·7 to 0·9. At phase 0·9 suddenly the shock front enters from below the bottom of the reversing layer and reverses the velocity of the lowest strata from a fast downwards motion into a fast upwards motion. Subsequently the shock front moves upwards through the whole reversing layer, reversing successively the direction of the velocity of all strata and finally leaving the top of the reversing layer at phase 0·1. Now, again, the reversing layer is in an essentially uniform upwards motion and the cycle can begin again.

The density variations in this type of atmospheric pulsation can be read directly from Fig. 1 by considering the vertical distances between the three curves. For the low reversing layer which presumably is responsible for the light variations, one finds that highest compression occurs about at phase 0·0, at which time therefore one should expect light-maximum.

Let us now consider the effect of this type of motion on the appearance of the absorption lines. At any time between phases 0·1 and 0·9 the velocity difference between top and bottom of the reversing layer is not very large and hence no radical effects on the line profiles could be expected. However, at any time between phases 0·9 to 0·1 the reversing layer is sharply divided into a lower portion with a fast upwards motion and an upper portion with a fast downwards motion, thus, for example, at phase 0·95 about one-quarter of the reversing layer has already been passed by the shock front while the upper three-quarters of the reversing layer are still falling down undisturbed, similarly at phase 0·05 the lower three-quarters of the reversing layer have been hit by the shock front and

* R. F. Sanford: *Mt Wilson Contr.* No. 757; *Ap. J.* **109**, 208, 1949.

are in upwards motion while only the top quarter is still continuing in the downwards motion. Hence one should expect for the phases between 0·9 to 0·1 (roughly centred on light-maximum) a doubling of the lines. Further, one should expect that the ultra-violet components which represent the lower portion of the reversing layer should increase in intensity during this phase interval from zero to the full line intensity, while at the same time the red components which represent the upper portion of the reversing layer should decrease from the full value to zero. This appears to be in complete agreement with Dr Sanford's observations on W Virginis which were presented earlier in this symposium.

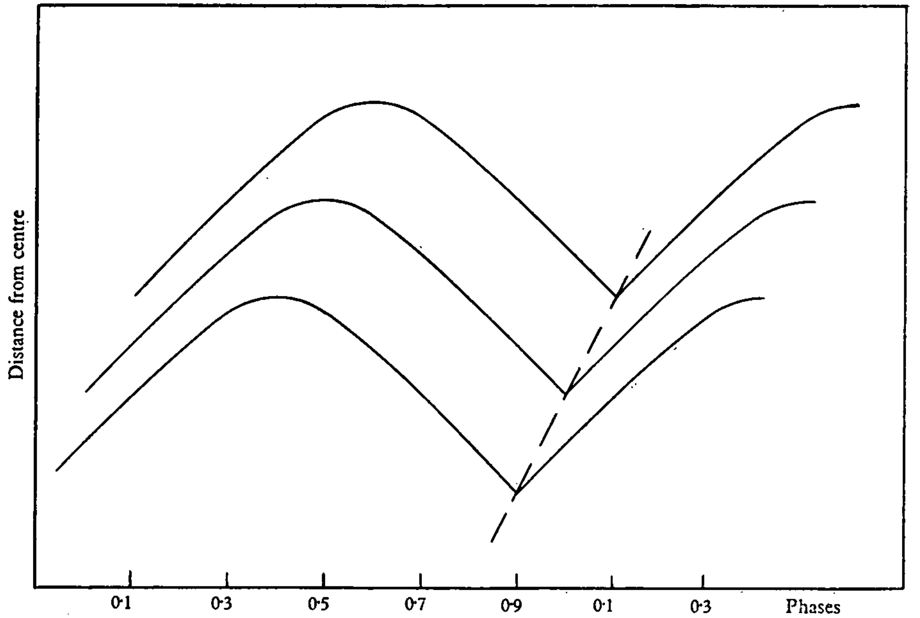

Fig. 1. The motion of the reversing layer of a cepheid for the extreme case that once each period a shock wave passes through the atmosphere. The three curves represent the motions of the top, middle, and bottom of the reversing layer, respectively. The motion of each layer abruptly changes direction when it is hit by the shock front (represented by the dashed line).

It is tempting to speculate that the same shock wave which appears to cause the doubling of the absorption lines also causes the observed occurrence of emission lines. Since presumably the emission lines arise in layers somewhat below the reversing layer and since the shock wave should pass these lower layers somewhat before it enters the reversing layer, one should expect the emission lines to appear before the absorption lines show doubling. This again seems in agreement with Dr Sanford's observations on W Virginis.

If this shock wave picture as an explanation of the observed line doubling in W Virginis is substantiated by future quantitative measurements of line intensities, then new weight would be given to the earlier suggestion that the pulsations in the atmospheres of cepheids take the form of progressive waves, of which shock waves may represent just an extreme case.