between light and radial-velocity curves for both the main and the beat period is highly significant, although it cannot be commented upon here.

The remarkable beat period of $0^d{\cdot}38$ shows that the star is pulsating with two periods of about $0^d{\cdot}112$ and $0^d{\cdot}086$, the corresponding amplitudes being of the same order. It is well known that many RR Lyrae variables show two periods which combine to give a beat period, which is, however, rather large (from 60 to 1000 times the main period); this is in satisfactory agreement with the simplified theory of the coupling of two modes (8). According to this theory, if a star possesses two modes whose frequencies are in the ratio 1:2, approximately, and if the first of them is excited, a second frequency equal to the difference of the two will be excited by resonance. According to this kind of coupling the star will ultimately pulsate with two almost equal frequencies; one obtains thus rather long beat periods in agreement with observations.

This kind of coupling, however, cannot hold in the case of AI Velorum, due to the large difference between the excited frequency and, consequently, to the shortness of the beat period. It is therefore possible that the observations of AI Velorum might oblige us to revise the theory of excitation and coupling of modes in a pulsating star, which is of course, admittedly, in a quite provisional state.

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13. EMISSION LINES IN THE SPECTRA OF LONG-PERIOD VARIABLE STARS

By PAUL W. MERRILL. (*Presented by* I. S. Bowen)

It is remarkable that bright hydrogen lines, requiring 13 volts for their production, should appear in the spectra of objects as cool as long-period variables. The reversing layer and the photosphere, with temperatures of about 2000°, have nothing like the necessary amount of energy to offer. The curious irregularities in the Balmer series do not yield the interpretation; it is now clear that they are due to absorption by overlying gases. This fact indicates one important item, namely, that the origin of the bright lines is not in an extended outer atmosphere, but in a level lying near, and even partly below, the photosphere.

The bright lines of neutral metallic atoms that have been identified include those of Mg, Al, Si, Sc, Ca, Mn, Fe, Co, Ni, Ga, Zr, and In. Among the ionized lines are those of Ca, Ti, Mn, Fe, and Sr, and probably the Mg II lines near 2800 A. The Mg II lines cannot be observed directly because the Earth's atmosphere shuts them out, but their presence is inferred by fluorescent effects. Forbidden lines of Fe II also are present, but the occurrence of those of other elements is doubtful.

One point about the behaviour of the numerous bright lines should be emphasized.

Their relative intensities are not symmetrical with respect to the maximum of the light curve, or in fact with respect to any other phase. (Some text-books are in error on this point.)

It is important to realize that the cyclical behaviour of the bright lines is a *one-way sequence*. Think of a succession of similar rockets shot upward at equal intervals in an exhibition of fireworks. Each rises through the air, displays a definite sequence of minor explosions and coloured sparks, fades, and vanishes from view. The return of the dead stick is not observed. A few moments before a rocket disappears, another is released and runs through a similar sequence. A theory founded on the hypothesis that on its downward trip the rocket displays in reverse order the phenomena of the upward flight would not correspond to observation.

The fundamental cause of variability remains obscure; but as far as the phenomena of emission lines are concerned, the general hypothesis called for seems rather clearly to be that of the outward propagation of a disturbance originating below the photosphere. This disturbance recurs periodically; it may or may not be connected with a volume pulsation of the whole star; it probably has approximate spherical symmetry. It might possibly come from the centre, like the bubble imagined by Rosseland to explain novae. There may, however, be a release of energy nearer the surface.

In my opinion the source and nature of this outbound disturbance is one of the key problems of long-period variables. We might think of a shock wave, or of acoustical noise as discussed by Schwarzschild in his paper on the solar corona; or the disturbance might be in the nature of geysers or prominences passing outward, or it might be magnetic or electrical. It is probably accompanied by electrical and magnetic effects, whether or not they are fundamental to the phenomena.

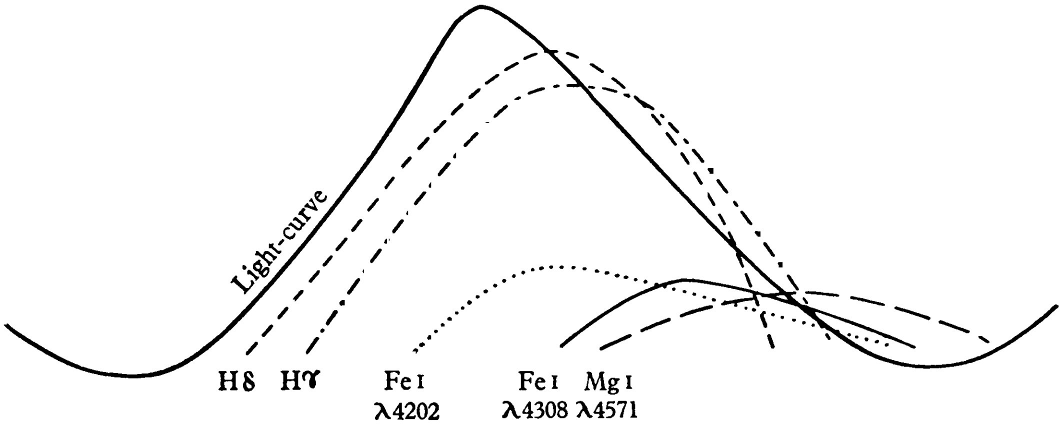

Fig. 1. Schematic representation of the intensities of emission lines in the spectra of long-period variable stars.

Let us assume that beneath the photosphere the disturbance has the general nature of a shock wave advancing outward. The front surface of the wave will be incandescent, and in fact more brilliant than its surroundings because of higher temperature and higher density. Thus by means of light waves it can telegraph ahead (like an atom bomb, but unlike an ordinary supersonic wave in air). It cannot communicate very far ahead, however, because of the high opacity of stellar material below the photosphere. As the shock wave travels outward with a moderate velocity it will be preceded by a halo of light. The width of the halo will depend upon the opacity of the star and will be greater for longer wave-lengths than for short ones. This means that as the shock wave proceeds, the first thing to strike the photosphere will be infra-red light. The arrival of this infra-red light at the photosphere is marked by thermal warming and general brightening. The arrival of the ultra-violet light with quanta of higher energy is marked by bizarre spectroscopic effects. The wave proceeds out through the atmosphere with diminishing energy and a whole series of phenomena follows. This corresponds to the right sequence of events, although it does not prove the physical interpretation.

In the outward motion of emitting gases above the photosphere, the acceleration is *inward* for *neutral* atoms such as Fe I, Si I, Mg I. The corresponding force could be gravity or viscosity. The acceleration is *outward* for *charged* particles such as hydrogen (recombination from H^+), Fe II, Ca II, this hints of electric or magnetic forces.

It is a remarkable fact that at no time does the absorption spectrum give evidence of a radical shock. The absorption lines and bands indicate rising temperature during increasing light, falling temperature during declining light. The absence of observable shock may possibly be due to the very great extent of the normal reversing layer. Except for the development of emission on the shortward edges of certain lines, effects other than those of moderate changes of temperature are slight. These facts suggest that the disturbances may proceed in columns (geysers or prominences) that cover only a fraction of the superficial area of the star. Tremendous changes in apparent photospheric brightness with only small changes in the absorption spectrum still afford a certain standing to the veil theory.

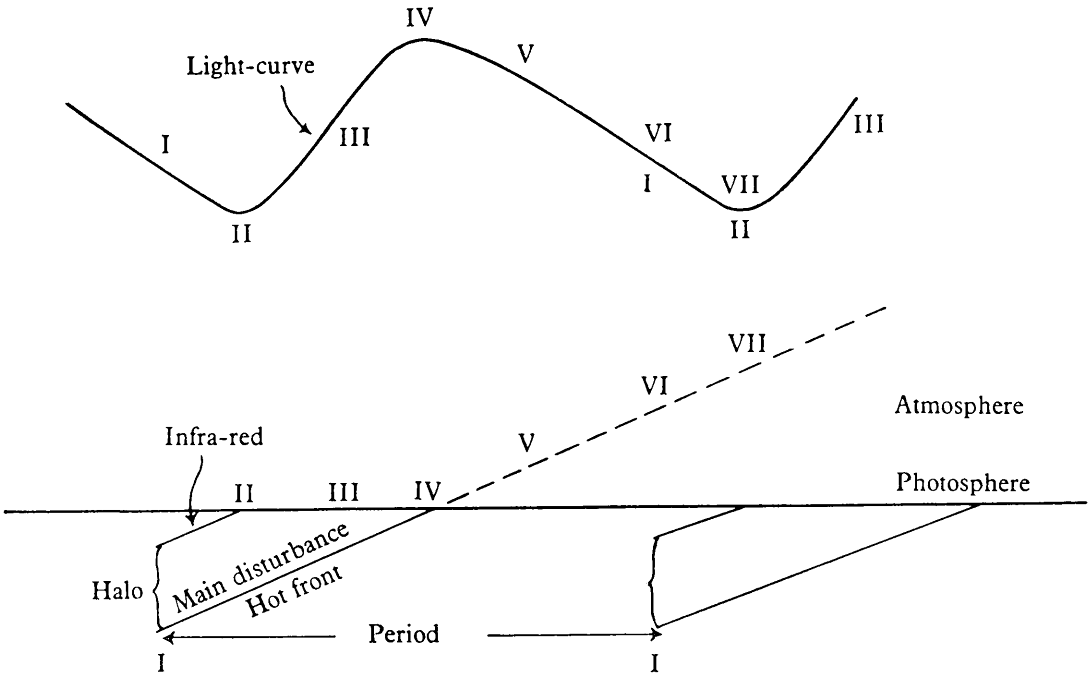

Fig. 2. Schematic representation of the outward-moving disturbance in long-period variable stars:

I	Internal disturbance begins; nothing visible.
II	Minimum light: first disturbance (infra-red?) reaches photosphere which begins to brighten.
III	Bright hydrogen lines appear: higher quantum energies reach the photosphere.
IV	Maximum light: disturbance has now passed through the photosphere which begins to fade. Disturbance in mild form goes on through reversing layer and outer atmosphere.
V	Bright hydrogen lines are intense and metallic lines are increasing.
VI-I	Hydrogen lines are weaker and metallic lines are stronger. [Fe II] and unidentified lines appear.
VII-II	Minimum. Holdover of metallic lines [Fe II], and unidentified lines. All disappear before III.

Any successful theory of long-period variables must explain not only the characteristic pattern of spectroscopic behaviour exhibited by numerous objects; it must be sufficiently flexible to account for variation from star to star and from cycle to cycle. The fundamental cause of periodic variation evidently is accompanied by circumstances, possibly relatively minor or fortuitous, which may decidedly modify the observable phenomena.