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

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Introduction

The presence and behaviour of the emission lines in the spectra of the long-period variable stars pose one of the most interesting problems yet unsolved in astronomical spectroscopy.

There is no time in a ten-minute paper to go into detail. Let me say, though, that the primary question is 'Where and how, in the atmospheres of the cool late-type giants of spectral types M, N and S which make up the long-period variables, can there exist the source of energy for production of the observed emission lines?'

An hypothesis for explaining the spectroscopic behaviour of the long-period variables, in particular the emission lines, should meet the following requirements:

(1) *Source of energy*. Must have u.v. quanta or ions much in excess of amounts in thermal equilibrium at $T=2000$ to 3000° K. Hence must involve a wide departure from thermal equilibrium. However, energy needed for emission lines is only very small fraction of the total energy radiated.

(2) *Emission deep in atmosphere*. Emission must take place well below outer reaches of atmosphere to explain 'mutilated' hydrogen emission lines and irregularities in Balmer decrement.

(3) *Cyclical behaviour*. The behaviour of the emission lines with the light cycle should be explained.

(4) *Negative displacement*. It would be desirable to explain the displacement toward the violet of the emission lines with respect to the absorption lines.

(5) *Pulsation*. Radial-velocity measurements indicate pulsation of the outer layers of the long-period variables. If the suggested hypothesis could also explain the pulsations, the likelihood of it being the correct one would be enhanced.

(6) *Basic phenomena*. The underlying cause is more fundamental than the division between the spectral types M, N, S; all these (spectral) classes show similar phenomena.

In considering possible sources of energy, one is led by inductive reasoning to consideration of the hydrogen convective zone as the most probable source. We believe that we can show that the hydrogen convective region has the properties required as a source of the emission lines in the spectra of the long-period variables; that the properties go far toward fulfilling the requirements (1) to (6).

The hydrogen convection zone

A. *General properties*

The hydrogen convection zone occurs in the region of the star where the hydrogen is partly ionized and partly neutral. Its occurrence was discussed first by Unsöld and later by Eddington and others. As visualized by Eddington it consists of rising and falling columns of gas, the rising columns being almost completely ionized and the falling columns almost completely neutral. At the top of the layer there is an excess of hydrogen ions and of ultra-violet radiation. The layer also has the property of being able to store for periods of time part of the outflow of energy from the stellar interior.

The main question is, 'Has the hydrogen convective layer a suitable depth—physically and optically—to produce the observed effects in the spectra of the long-period variables?'

B. *Convection layer in the Sun*

In the sun, the convective zone (temperature range 9000° K. to 27000° K.) is wholly sub-photospheric. *Probably* the granular nature of the solar surface is associated with a sort of 'froth' above the top of the layer and *possibly* some of the super thermic phenomena observed in the solar atmosphere have their source in the layer.

C. *Convective layer in the cepheids*

Eddington studied the question of the convective zone in the cepheids and explained, on the basis of the properties of the zone and the pulsatory instability of this group of stars: (1) the occurrence of the atmospheric pulsations as due to the energy-storing properties of this layer, (2) the existence of a period-luminosity relation, and (3) the occurrence of the well-known phase shift. Here the zone is much extended geometrically but only goes down to about 14000° K. because of the lower temperature gradient.

D. *Convective layer in the long-period variables*

Eddington and others have considered the long-period variables as a natural extension of the cepheids to later types. In particular, they are considered to be the group, among the coolest stars, having the same pulsatory instability as the cepheids. Hence, their pulsations, too, could be attributed to energy storage in the hydrogen convective zone. For these stars the zone is still more extensive and heat-storage capacity correspondingly greater. Using the figures given by Eddington for cepheids and applying dimensional (or homologous) arguments, it can be shown that the layer would give phase shifts greater than $5/4\pi$, and that the convective layer would be much more extensive and reach closer to the surface. The latter conclusion is supported by the recent calculations of Ueno and Matsushima who have found that for M-type giants, the top of the hydrogen convective zone is effectively at the surface of the star (log T a negative value). Thus, we believe that as a long-period variable pulsates, the top of the convective zone is visible to greater and lesser extents, the emission lines arising from recombination in the excess of ions brought up by the rising currents.

Referring to items (1) to (6) in the introduction, each one is readily explainable.

Furthermore, the general observation by Merrill that the strength of emission lines in the spectrum increases with light range, follows from our hypothesis.

Have we any other possible spectroscopic evidence or proof of our contention? We can refer to the case of the cepheids. Joy at Mount Wilson and Jacobsen here, have found a brief transitory, violet-shifted emission in the H and K lines at the phase corresponding to smallest extent of the star, for η Aquilae. Could this arise as we just, for a short while, glimpse the very top of the convective zone in the cepheids?

If our suggestion is found to be correct by further investigation, not only would there be an explanation for the occurrence and behaviour of the emission lines in the spectra of the long-period variables, but, perhaps of greater importance, we would have a means of investigating observationally the hydrogen convective zones of stars.

Discussion

Other possible cases in which the hydrogen convective layer may have spectroscopic significance.

(1) Emission lines in M-type dwarf stars, possibly related to flares of flare stars.

(2) Can *symbiotic* spectra such as those of Z And, BF Cygni, arise from single stars of very late type (TiO bands) and unusually low density in which the convective zone is seen all the time (to a somewhat varying extent, hence spectral and light variations).

15. THE MOTIONS OF THE ATMOSPHERE OF MIRA CETI

By Alfred H. Joy (*Presented by* I. S. Bowen)

The measurement of recent high-dispersion spectrograms of Mira Ceti makes it possible to review and revise some of the conclusions published in 1926 in regard to the atmospheric motions of this well-known long-period Me variable star.

Ninety-two coudé spectrograms, many of which were taken by Merrill, with the 100-inch telescope on Mount Wilson and by Bowen and O. C. Wilson with the 200-inch