SYMPOSIUM: ATOMIC AND MOLECULAR SPECTRA IN ASTROPHYSICS *

RECENT PROGRESS IN STELLAR SPECTROSCOPY

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This paper is concerned with the physical properties of the atmospheres of several giant and supergiant stars. Some years ago I noticed that the absorption lines of δ Canis Majoris gave a most peculiar curve of growth: the weaker lines define a turbulent velocity of about 5 km/sec, while the stronger metallic lines were consistent only with a much larger velocity, of the order of about 30 km/sec or even more. Even more remarkable was the conclusion by K. O. Wright at Victoria that different sets of lines in ϵ Aurigae give entirely different turbulent velocities. Finally, M. Schwarzschild, in a study of η Aquilae, suggested that large-scale motions (described as convection in the 1934 paper on turbulent motions by Struve and Elvey) may be superposed upon small-scale turbulent motions. Some earlier results on Capella and 17 Leporis are being published elsewhere.

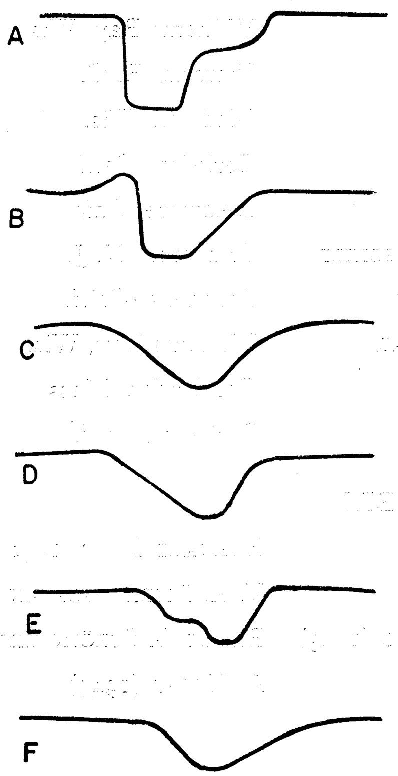

Figure 1. Contours of absorption lines.

The spectrum of ϵ Aurigae has been photographed with high dispersion at Mount Wilson. The following is a summary of some of the results.

1. On March 23 and 24, 1951, the absorption lines (exclusive of *H*) could be classified in five groups, according to their contours:

2. Class A is represented only by the lines D_1 and D_2 of *Na* I.

3. Class B is represented by the strongest observed transitions of *Ti* II:

λ 3685.2	Intensity 250	$a^2F-z^2D^\circ$	e.p. 0.6v
λ 3759.3	Intensity 200	$a^2F-z^2F^\circ$	e.p. 0.6v
λ 3761.3	Intensity 200	$a^2F-z^2F^\circ$	e.p. 0.6v

4. The great majority of the other lines of *Ti* II belong in classes C, D, E, and there is no distinct correlation between line-class and excitation potential, or wave length. Thus, the low-level lines

λ 4012.4	Intensity 4	$a^2F-z^4G^\circ$	e.p. 0.6v
λ 3814.6	Intensity 4	$a^2F-z^4F^\circ$	e.p. 0.6v

belong to classes D or C.

5. It is probable that *Ti* II lines of intermediate strength exhibit the asymmetry described by contours D and E, while in the weakest transitions this asymmetry cannot be detected, and they are classified C.

6. The observable lines of *Fe* I, including the very strong transitions from the ground level, $a^5D-z^5D^\circ$, e.p. 0.0v., λλ 3859.9, 3886.3 belong to classes C or D, and differ strikingly from the strong, low-level *Ti* II lines, which are steep on their shortward edges.

7. The lines of *Fe* II nearly all belong to class E, although the strong multiplet $b^4P-z^4D^\circ$, e.p. 2.6v. may be more nearly of class D. The asymmetry of class E is especially pronounced in multiplet $b^4F-z^4F^\circ$, e.p. 2.8v. λλ 4583.8, 4549.5, 4522.6, 4508.3.

8. The lines *Mg* II 4481, *Sr* II 4078, *Mg* I 3838, *Y* II 4178, *V* II 3903, etc. all belong to class C. *Sc* II 4247 is class E, but *Sc* II 4321 and 4374 are C.

9. The *Ca* II lines H and K have strong, sharp,

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and deep shortward absorption cores, described as circumstellar in a recent note in the *Ap. J.* These cores are probably identical with the violet components of the *Na* I lines and the very strong *Ti* II lines.

10. *Hα* has broad emission borders previously described by D. B. McLaughlin.

11. A few strong metallic absorption lines suggest broad emission borders: on the shortward sides of *Ti* II 3759, 3761 and on the longward sides of *Sr* II 4078 and the more conspicuous metallic lines of class E.

12. On September 23 and 24, 1950, the *Na* lines were not observed. The strongest *Ti* II lines were less conspicuously of class B and may be regarded as approaching class C. The rest of the metallic lines were quite definitely of class C (symmetrical) or F, although these same lines were classified D or E in March, 1951.

13. The Paschen lines are broad and diffuse. The Balmer lines consist of sharp, central cores which can be seen to *H* 29 or *H* 30, and of diffuse, underlying wings which are easily seen at *H* 11, 12, 13, etc. Undoubtedly, the absence of sharp cores in the Paschen lines is somehow related to the metastability of the 2*s* level in *H* which produces an over-population in that level. Ordinarily, geometrical dilution of radiation is required to produce such a departure from a Boltzmann distribution in the various levels. But R. M. Thomas has recently suggested to me a possible explanation in terms of a "kinetic" temperature $T_e \gg T_r$, where T_r is the "reference" temperature inferred, for example, from the continuous spectrum. In ε Aurigae there is all reason to suppose that violent motions in the outermost layers gradually dissipate and produce the required T_e.

14. The preceding results indicate:

(a) the absorbing layer of ε Aurigae is far from uniform. It probably resembles much more closely a large field of prominences than a normal atmosphere in hydrostatic equilibrium. D. H. Menzel and I have repeatedly urged that this picture be given serious consideration. It is entirely consistent with most observational results, such as A. Pannekoek's discussion of Cepheids.

(b) This, in turn, throws grave doubt upon the validity of recent applications of the more refined, modern theory of turbulence to the spectra of supergiant stars. It may have been an unfortunate coincidence that Elvey and I used the term "turbulence" to denote certain statistical effects of Doppler broadening in stellar spectra, while at the same time theoretical thought developed under the impetus of studies of random motions in our atmosphere. It may be desirable to analyze carefully the basic assumptions of the theory in order to ascertain which conclusions are likely to retain their value in the case of a field of prominences which move under the influence of magnetic, or other, forces centered in different regions of the star's photosphere.

(c) The peculiar results of K. O. Wright undoubtedly find their explanation in the stratification that is responsible for the diversity of line contours. For example, at e.p. 0.6 volt, the weak lines of *Ti* II are nearly symmetrical and probably originate in the deepest strata of the atmosphere, while the strongest lines with their pronounced B character are produced at several different levels, and are perhaps built up from contributions of different prominences. The corresponding curve of growth would simulate a large turbulent velocity. At higher values of the excitation potential all lines originate at the bottom of the atmosphere, and the resulting turbulent velocity is that of this layer alone.

(d) Previous observations had indicated that the radial velocity and the light vary in a somewhat irregular manner, with waves of 100–150 days in duration. It is probable that the changes in contour are connected with these fluctuations.

(e) It is possible that these phenomena are related to the binary nature of ε Aurigae. It should be remembered that the bright, F-type component is again approaching eclipse by the invisible I star. Hence, even now circumstellar gases in the form of streams or prominences may form an appreciable optical thickness in front of the F star.

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