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MOTIONS IN THE ATMOSPHERE OF ETA AQUILAE.

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INTRODUCTION.

Light Variation. The discovery of the light variation of Eta Aquilae ($19^{\text{h}} 47^{\text{m}}.4, + 0^{\circ} 45'$) is usually credited to Pigott² in 1784; although according to Wurm³ Justus Byrgius in 1612 noted a variable star in Antinous, which was probably the one designated η by Bayer and assigned different magnitudes by various observers. Bayer and Flamsteed recorded its magnitude as 3 and Piazzi marked it 5. (The visual range is from 3.7 to 4.5.) The period determined by Pigott was $7^{\text{d}} 4^{\text{h}} 38^{\text{m}}$ ($7^{\text{d}}.193$). Wurm⁴ in 1814 obtained a more accurate value of the period, $7^{\text{d}}.17604$. The light period was divided by Pigott into four parts: the time of increase 36^{h} , duration of maximum 44^{h} , the decrease 62^{h} and duration of minimum 30^{h} . Goodricke's eclipse theory appeared to be a sufficient explanation. It was soon found, however, by Argelander and others that the law of its light variation was too complicated to be accounted for by this simple explanation and Goodricke's alternate theory was favored, i. e., the rotation of a star having fixed spots that vary in size. The increase of light required about 2.7 days and the decrease 4.5 days. On the descending branch of the light curve was found a secondary maximum or pause at a phase $1\frac{1}{2}$ to 2 days after light maximum. The period was also suspected of variability by some observers, while others rejected the idea. Luizet⁵ adopted a mean period of $7^{\text{d}}.176382$ and a periodic term $+0^{\text{d}}.14 \sin (0.044E + 304^{\circ})$. Hellerich⁶ found that this mean period is satisfactory, but rejected the harmonic term. Wylie⁷ using the photographic observations of Kohnlchütter⁸ and his own photo-electric data finds that the value of the period between 1906 and 1920 was $7^{\text{d}}.17670$.

Changes in the form of the light curve of Eta Aquilae have also been suspected, especially with reference to the time and duration of the pause on the descending

¹ Note: This paper was submitted in 1926 as a dissertation in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the University of Michigan. A few changes have been made in preparing for publication in 1932.

² PT 75, 129 (1785).

³ AJB 144 (1814).

⁴ AJB 121 (1817).

⁵ AN 163, 362 (1903).

⁶ AphJ 44, 287 (1916).

⁷ AphJ 50, 217 (1922).

⁸ AN 183, 265 (1909).

branch. Wylie concludes that the light curve did not change between July and November 1920. In addition to confirming the "secondary maximum" or pause in the decrease of light from phase 1.8 to 2.4 days he found another fluctuation with maximum about phase four days. Becker⁹ using Plassmann's data from 1895 to 1925 and combining in four year periods obtains seven curves which indicate wide variations in the form of the descending branch. Schwarzschild¹⁰ found in 1898 that the photographic range of variation, 1^m.29, is about twice the visual. Kohlschütter's¹¹ value of the photographic range is 1^m.09. Wylie's photo-electric range is 1^m.12. Changes in the value of the maxima and minima have been suspected.

Radial Velocity. The variable radial velocity of Eta Aquilae was discovered by Bépolsky¹² in 1895, who derived an orbit. Wright,¹³ using 27 spectrograms and assuming an orbital period of 7.176 days, found the following elements:

$$V = -14.16 \text{ km} \pm 0.17 \text{ km.}$$

$$e = 0.489 \pm 0.014.$$

$$\omega = 68^{\circ}.91 \pm 1^{\circ}.95.$$

$$T = 6^{\text{d}}.210 \pm 0^{\text{d}}.028 \text{ after light maximum.}$$

$$K = 20.59 \text{ km.} \pm 0.36 \text{ km.}$$

$$a \sin i = 1,545,000 \text{ km.}$$

Atmospheric Motion. From a study of 42 spectrograms of Eta Aquilae, Rufus found many interesting results bearing on atmospheric motion and pulsation phenomena.¹⁴ His results on variations in line displacements at different levels, with indications of a lag of phase in the higher elements, particularly hydrogen, are summarized in the paper which precedes this one, to which reference should be made. Henroteau¹⁵ also obtained different displacements for lines of different levels in Eta Aquilae.

The Spectral Variation. The classification of the spectrum of Eta Aquilae has been a subject of much difference of opinion. Bépolsky placed it intermediate between Secchi's types II and III and noted its close resemblance to the spectrum of Delta Cephei. Wright placed it between types I and II. In the Draper Catalogue it is designated as class G (?). Wright found that the lines of Delta Cephei are better defined than those of Eta Aquilae. Shapley¹⁶ in his study of the spectral variations of Cepheids found that the spectrum of Eta Aquilae varies from A8 just before light maximum to G5 at light minimum. Using Shapley's data, the

⁹ AN 225, 1 (1925).

¹⁰ Müller-Hartwig, Lichtwechsel der Sterne, 2, 229 (1920).

¹¹ Müller-Hartwig, Lichtwechsel der Sterne, 2, 229 (1920).

¹² AphJ 6, 393 (1897).

¹³ AphJ 9, 59 (1899).

¹⁴ Pop Astr 32, 228 (1924); Proc NAS Wash. 20, 264 (1924).

¹⁵ JRAS Can 19, 82 (1925).

¹⁶ AphJ 44, 273 (1916).

spectral variation curve resembles the light curve, but the pause on the descending branch is of longer duration.

Adams and Joy¹⁷ found that there is a greater range in the spectral class of the Cepheids given by the intensity of the hydrogen lines than by the general spectral features. The enhanced lines also show a greater change of intensity than the normal lines.

In the case of Eta Aquilae Henroteau¹⁸, using the change in the relative intensity of a pair of lines, 4534.139 Ti_{II}, and 4534.953 Ti_I, determined a curve of the variation of ionization, which in its main features agrees quite closely with the spectral variation curve based upon Shapley's data, including a long pause on the descending branch.

The change in color index determined by Schwarzschild¹⁹ also corresponds quite closely with the spectral change indicated by the hydrogen lines. His values are 0^m.46 at light maximum (about F₁) and 1^m.08 at light minimum (about G₆). This range is much greater than would be expected from the spectral change indicated by neutral metallic lines.

OUTLINE OF METHOD.

The Purpose of the Investigation. This investigation has had for its aim the systematic study of the displacements of lines of different elements originating at different assumed levels in the atmosphere of Eta Aquilae. In particular the effect of the systematic differences in velocities at different levels has been applied as a test of atmospheric pulsation. A search for a possible compressional wave traveling outward from the photosphere was also made. It was further proposed to isolate the lines due to ionized atoms and to study their difference in behaviour at different levels and to compare their displacements with the displacements of lines due to neutral atoms. The relationship between these atmospheric velocity differences, the changes in light, and the mean radial velocity of the star have been studied.

*The Method of Attack.*²⁰ About seventy selected lines of the spectrum of Eta Aquilae were divided into seven groups according to their height in the chromosphere of the sun as determined by Mitchell.²¹ Although the atmosphere of Eta Aquilae may be many times as extensive as the sun's, it is assumed that in general the distribution of the elements follow the same order of height in the star as in the sun, while the absolute height may be many times as great. It is well known that in general the elements in the atmosphere of the sun are distributed at heights according to their atomic weights, the heavier atoms occupying the lower levels. An

¹⁷ Proc NAS Wash 4, 129 (1918).

¹⁸ JRAS Can 19, 82 (1925).

¹⁹ Müller-Hartwig, Lichtwechsel der Sterne, 2, 229 (1920).

²⁰ Pop Astr 32, 22 (1924).

²¹ AphJ 38, 407 (1913).

exception to this general rule applies to the ionized atoms, which occupy higher levels than the neutral atoms of the same element. The first group of lines correspond to a mean solar chromospheric height of 660 km., the second 860, the third 1390, the fourth 2070, the fifth 2400, the sixth 5500, and the seventh 8200. The lack of suitable lines originating between heights 1600 to 5000 km. should be noted.²²

The mean velocity curve, using lines from all levels, was formed; also individual curves for each of the seven groups. To study the difference in velocities at different levels two methods were followed. In the first method seven velocity-difference curves were formed by subtracting the mean velocities obtained from all lines from those of each group. In the second method the velocities obtained from the lines of the first group (the lowest) was used as the basis from which the velocity-differences were formed.

An attempt to trace the progress of a compressional wave through the successive layers was made by deriving the velocity-differences of adjacent groups, always subtracting the velocities of one group from the next higher, i. e., the second from the first, the third from the second, etc.

The next step was the separation of the lines due to the ionized atoms from those due to the neutral atoms. The above method of grouping by level was followed in both divisions as far as possible and the same types of velocity-difference curves were formed. Differences were then formed between the velocities of these two classes of lines for each level, and between the mean of all lines due to the ionized atoms and the mean of all lines due to the neutral atoms.

THE SPECTROSCOPIC OBSERVATIONS.

Table of Observations. Table I contains a list of the 71 observations. Column one gives the plate numbers; column two the time of mid-exposure expressed in Greenwich mean time; column three the duration of exposure; and column four the phase after light maximum.

The Spectrograms. The spectrograms used in this investigation were made with the I-prism spectrograph attached to the 37½ inch Cassegrain reflecting telescope of the Observatory of the University of Michigan. Seed 23 photographic plates were used. The quality of the spectrograms is uniformly good, as all poor plates, and those with unequal comparison or weak stellar spectrum were rejected. This was done in an attempt to measure every line used in the investigation on each one of the plates and to retain every measurement and resulting velocity.

The Quality of the Lines. As pointed out by Wright, "The lines which are fairly numerous, have the general characteristics of breadth and haziness, which

²² Mitchell's corrected photospheric heights (AphJ 71, 11-42 (1930)), have made necessary a revision of the values originally employed by Lee. The mean heights of his seven levels, however, have not been changed in relative order by the revision and are, respectively, 660 km., 860 km., 1390 km., 2070 km., 2400 km., 5500 km., and 8170 km. These values have accordingly been substituted throughout for the level ranges originally used by Lee. W. C. R.

tend to make them objectionable for purposes of accurate measurement.” These characteristics also complicate the difficulties introduced by the blending of close lines which would be resolved if they were sharper and more clearly defined. Another obstacle is the unequal change of intensity of the components of blended

TABLE 1. OBSERVATIONS.

Plate Number	Date: G.M.T.	Duration of Exposure	Phase	Plate Number	Date: G.M.T.	Duration of Exposure	Phase
1923				1924			
6199	May 24.786	0 ^h 50 ^m	3.682	6804	Apr. 26.817	0 ^h 40 ^m	4.416
6215	May 29.775	0 40	1.495	6805	Apr. 26.480	0 48	4.439
6216	May 29.809	0 38	1.523	6811	Apr. 30.892	0 48	1.315
6228	June 4.872	0 30	0.408	6837	May 15.809	0 40	1.879
6240	June 15.816	0 40	5.175	6847	May 20.793	0 36	6.863
6254	June 26.699	1 0	0.707	6848	May 20.816	0 30	6.886
6260	June 28.668	0 50	2.675	6858	May 22.721	0 40	1.615
6265	June 29.797	0 24	3.805	6859	May 22.757	0 40	1.651
6272	June 30.819	0 36	4.827	6873	June 4.824	0 40	0.365
6275	July 2.736	0 32	6.745	6886	June 9.860	0 48	5.401
6280	July 3.683	0 25	0.514	6913	June 30.681	0 50	4.692
6281	July 3.706	0 20	0.536	6914	June 30.715	0 50	4.727
6282	July 3.720	0 20	0.557	6921	July 1.835	0 40	5.847
6283	July 3.740	0 22	0.571	6933	July 3.631	0 40	0.466
6284	July 3.764	0 26	0.595	6937	July 3.766	0 30	0.601
6287	July 7.705	0 44	4.536	6941	July 4.808	0 40	1.643
6296	July 12.775	0 24	2.423	6945	July 5.694	0 40	2.530
6306	July 16.649	0 25	6.304	6953	July 10.682	0 34	0.341
6307	July 16.668	0 30	6.323	6963	July 12.686	0 40	2.345
6312	July 17.672	0 22	0.150	6987	July 20.684	0 55	3.167
6313	July 17.694	0 11	0.172	6989	July 22.658	1 0	5.140
6316	July 18.802	0 11	1.280	7007	July 26.808	0 56	2.114
6330	July 25.764	0 30	1.066	7014	July 31.810	0 45	7.117
6337	July 29.727	0 33	5.029	7021	Aug. 2.627	1 0	1.757
6348	Aug. 13.796	0 27	5.745	7047	Aug. 14.615	0 30	6.568
6351	Aug. 14.700	0 22	6.649	7074	Aug. 17.665	0 30	2.442
6352	Aug. 14.728	0 24	6.677	7093	Aug. 21.699	0 32	6.476
6384	Aug. 22.815	0 20	0.418	7132	Aug. 24.703	0 35	2.304
6392	Aug. 23.684	0 30	1.280	7171	Aug. 28.648	0 36	6.249
6393	Aug. 23.715	0 28	1.312	7208	Sept. 2.657	1 0	4.081
6406	Aug. 25.693	0 36	3.290	7241	Sept. 18.627	1 0	5.699
6421	Aug. 28.595	0 34	6.190	7247	Sept. 22.696	0 30	2.591
6422	Aug. 28.623	0 36	6.220	7253	Sept. 23.540	0 40	3.435
6565	Oct. 25.609	0 20	6.794	7254	Sept. 23.567	0 38	3.463
6578	Nov. 1.612	0 45	6.621	7270	Sept. 25.624	1 0	5.519
				7382	Oct. 22.582	0 48	3.772

lines due to the periodic change of spectrum, which produces a greater effect on the enhanced lines than on the neutral lines. It was found that this difficulty was greater on plates that were weak, and consequently several spectrograms were rejected that would otherwise have been considered suitable for radial velocity determination.

MEASUREMENT AND REDUCTION.

Measurement. The spectrograms were measured on measuring engine number five of this observatory, which is provided with a photographic reticle having an interrupted line to take the place of the ordinary cross-hair. Three settings were made on each line measured; then the plate was reversed and the process was repeated to reduce the personal equation as much as possible. About twenty titanium spark lines were measured on each plate for the comparison spectrum.

Preliminary Wave-lengths. Sufficient consideration was then given to wave-lengths for the purpose of verifying the identification of lines. Using the values of R as previously determined the wave-lengths were computed by means of the Hartmann formula.²³

$$\lambda = 2197.682 + \frac{227282.66}{186.184 - R}$$

The computed values were corrected by applying the ordinates of the correction curve corresponding to the micrometer readings. Comparison with the Rowland wave-lengths as given by Mitchell showed fair agreement at this stage of the work; although further consideration was deemed advisable after all the measurements should be made.

Radial Velocity Determination. The method of velocity determination proposed by Curtiss was followed. It was necessary, however, from the nature of the problem, to keep the velocities for the individual lines separate. 71 plates were measured and reduced. Phases were determined from the formula adopted by Wylie:

$$\text{Maximum} = \text{J. D. } 2,422,606.652 + 7^d.176382 E.$$

The results were tabulated for each selected line on the 71 plates. In order to reduce the lines to approximate homogeneity, the mean velocity for each line from the total number of plates was found. The mean of these means was taken and corrections for each individual line were applied to reduce the velocities to the same zero.

The Data Sheet. The results from the 71 plates were then combined into 24 places for each line by grouping three places into one arbitrarily according to phase, the last place having only two. These reduced data, upon which all the further work is based, are given in Table 2.

WAVE-LENGTHS OF SELECTED LINES AND BLENDS.

The Corrections. The velocity corrections, which were determined and applied to render the lines homogeneous, provided data sufficient to correct the provisional wave-lengths computed for the purpose of identification. Multiplying the velocity

²³ *These Publications* 2, 112 (1916).

TABLE 2. VELOCITY DATA.*
MEAN CHROMOSPHERIC HEIGHT 660 KM.

λ	4067.0	4127.7	4132.1	4154.2	4156.3	4191.4	4205.1	4258.3	4367.8	4374.7	4415.1	4454.8	4461.7	4855.4
Phase														
0.221	-23.1	-16.4	-22.7	-24.6	-20.0	-24.2	-25.2	-25.8	-27.4	-22.8	-23.6	-26.3	-25.0	-19.4
0.397	-22.4	-19.3	-22.1	-20.4	-19.9	-23.8	-22.4	-23.6	-26.4	-19.2	-19.8	-22.7	-20.1	-19.0
0.505	-9.0	-17.3	-16.5	-20.9	-16.9	-22.3	-21.7	-23.4	-21.7	-24.5	-19.5	-24.0	-26.0	-22.4
0.574	-13.5	-15.5	-20.3	-17.7	-16.0	-14.0	-21.3	-22.7	-17.1	-18.9	-19.1	-25.0	-22.3	-16.7
0.791	-20.5	-14.1	-18.8	-23.4	-24.1	-21.9	-22.9	-25.9	-27.2	-19.0	-24.0	-25.2	-25.2	-16.6
1.291	-10.8	-11.2	-11.9	-17.4	-17.3	-12.4	-12.6	-20.8	-16.1	-17.0	-17.6	-17.6	-20.7	-22.7
1.444	-10.7	-10.1	-16.2	-18.3	-16.1	-17.8	-19.5	-11.0	-11.2	-11.7	-13.5	-15.6	-17.0	-17.7
1.636	-14.8	-11.4	-14.7	-12.3	-15.9	-11.3	-12.1	-14.6	-8.9	-15.5	-15.8	-15.4	-14.2	-19.9
1.917	-13.8	-12.5	-13.2	-13.7	-15.9	-11.5	-13.2	-11.8	-14.3	-7.6	-9.5	-0.9	-9.1	-4.9
2.209	-16.1	-14.6	-17.7	-19.0	-15.2	-16.2	-16.2	-10.6	-8.7	-10.1	-12.6	-2.6	-5.2	-1.2
2.403	-10.3	-13.1	-13.0	-8.9	-14.1	-19.7	-17.7	-7.8	-9.4	-9.8	-12.7	-10.4	-14.6	-0.4
2.588	-14.8	-12.0	-5.9	-0.0	-9.3	-6.8	-6.7	-4.8	-10.3	-7.9	-3.8	-0.9	-8.5	-14.9
3.297	-9.5	-3.3	-8.2	-1.8	-4.5	-3.4	-4.7	-5.9	-2.4	-4.6	-10.2	-4.5	-2.5	-11.3
3.639	-8.4	-1.2	-6.2	-6.3	-6.6	-6.4	-6.5	0.8	-2.2	-5.2	-9.7	-4.3	-0.2	-12.6
4.101	-5.9	-1.8	-2.1	-2.0	-4.7	-0.2	2.1	3.5	-2.3	-5.1	-2.3	-2.3	1.0	-7.2
4.556	1.7	4.9	9.5	7.0	6.3	16.8	4.3	11.7	12.4	2.3	4.7	4.7	8.5	-2.9
4.861	3.1	2.4	10.9	7.6	7.7	2.8	11.5	16.2	12.1	10.3	3.7	4.8	21.8	6.3
5.278	8.8	10.9	11.6	9.1	8.5	6.8	14.0	10.0	7.9	12.3	10.4	15.8	16.9	18.3
5.764	13.6	9.8	14.1	15.1	10.8	9.6	15.1	9.2	7.6	6.9	12.1	10.2	13.3	8.1
6.220	10.6	8.4	4.0	9.0	8.3	16.9	12.2	1.1	6.6	10.4	3.5	1.0	5.5	6.8
6.368	-4.5	6.6	-0.4	1.5	2.1	0.6	-0.8	-4.1	-7.9	-7.8	3.0	-5.3	6.8	-9.4
6.631	-9.3	-6.8	-16.2	-10.4	-5.4	-5.2	-10.3	-14.9	-10.9	-10.4	-14.8	-8.6	-17.2	-14.0
6.801	-19.0	-17.5	-18.4	-16.9	-17.7	-17.2	-15.5	-22.4	-24.4	-14.4	-8.8	-16.4	-19.6	-22.3
7.007	-21.8	-20.1	-19.3	-18.6	-18.2	-16.8	-20.6	-26.1	-25.4	-24.4	-22.3	-22.6	-27.5	-23.2

* While it is realized that the tenths of kilometers have little meaning when the character of the spectrum of this star and the dispersion employed are taken into account, these have been retained for convenience in the means tabulated above.

TABLE 2. VELOCITY DATA—Continued.
MEAN CHROMOSPHERIC HEIGHT 860 KM.

λ	4024.7	4118.6	4161.4	4163.7	4187.0	4198.4	4236.0	4242.6	4250.5	4254.4	4260.5	4282.8	4305.7	4330.7	4344.3	4351.6	4435.3	4483.7
Phase																		
0.221	-24.2	-19.7	-24.5	-23.5	-26.5	-24.4	-23.2	-24.1	-20.2	-27.6	-24.9	-18.7	-21.1	-26.6	-14.6	-21.3	-23.3	-24.4
0.397	-19.8	-22.3	-20.7	-22.2	-20.1	-21.1	-21.2	-24.5	-19.9	-20.5	-22.4	-21.2	-20.6	-22.4	-19.5	-20.0	-20.3	-16.7
0.505	-15.2	-21.7	-16.8	-22.7	-25.2	-25.0	-20.5	-26.8	-16.6	-14.7	-24.8	-24.6	-22.2	-26.8	-15.8	-19.7	-22.0	-20.9
0.574	-15.3	-18.5	-15.9	-15.3	-17.0	-21.6	-20.2	-25.9	-20.6	-20.8	-21.5	-24.6	-20.4	-19.9	-18.2	-18.4	-20.2	-21.5
0.791	-21.3	-20.7	-20.5	-24.8	-25.0	-22.5	-21.8	-25.7	-22.8	-21.8	-24.7	-22.2	-26.4	-24.7	-24.2	-21.9	-18.5	-21.5
1.291	-16.2	-16.5	-17.5	-13.6	-17.4	-16.3	-17.5	-18.8	-14.9	-10.8	-19.1	-18.8	-17.1	-17.1	-18.1	-20.9	-19.3	-15.8
1.444	-14.9	-9.2	-14.6	-12.3	-17.0	-16.0	-17.1	-15.0	-11.3	-10.8	-10.4	-11.9	-16.7	-11.5	-14.5	-19.9	-12.0	-15.5
1.636	-11.4	-12.9	-15.0	-19.3	-12.0	-11.6	-11.3	-16.8	-14.4	-10.0	-12.2	-15.4	-16.7	-22.3	-14.2	-13.0	-21.7	-13.2
1.917	-12.0	-16.3	-16.7	-15.0	-17.3	-14.1	-15.6	-11.6	-10.4	-10.9	-11.5	-13.5	-8.4	-9.2	-9.9	-4.7	-5.7	-15.0
2.209	-12.6	-9.0	-13.0	-17.7	-12.5	-17.5	-17.1	-13.9	-14.0	-13.3	-12.0	-18.0	-18.9	-14.1	-5.2	-10.8	-9.5	-2.6
2.403	-8.4	-12.2	-11.5	-11.3	-7.2	-11.0	-10.5	-13.8	-11.3	-16.4	-14.5	-9.5	-10.8	-7.6	-15.1	-10.4	-16.1	-3.7
2.588	-8.5	-3.1	-9.9	-11.8	-1.4	-9.8	-11.1	-6.5	-8.6	-15.5	-4.2	-5.4	-4.0	-3.9	-9.0	-14.2	-6.7	-13.8
3.297	-9.3	-6.9	-5.9	-5.7	-9.7	-11.2	-10.8	-0.7	-9.3	-10.9	-4.1	-7.7	-9.2	-9.4	-17.3	-11.6	-7.4	-6.2
3.639	-11.3	-9.0	-5.1	-4.5	-6.5	-2.5	-5.0	-4.2	-5.2	-8.5	-11.5	-3.1	-5.5	-6.2	-8.5	-8.0	-2.7	-3.3
4.101	-3.0	-15.4	-0.4	-1.0	-4.8	-5.3	-2.2	-3.6	-6.0	-11.5	-5.3	-2.9	-5.3	-1.4	-4.8	-1.0	-5.1	-0.2
4.556	-1.8	-3.5	-9.9	-11.3	-6.7	-8.0	-15.1	-10.5	-0.4	-3.7	-7.8	-10.6	-7.1	-2.9	-8.9	-1.4	-0.5	-4.1
4.861	-3.5	-1.5	-8.1	-11.8	-7.8	-2.3	-7.5	-9.4	-9.9	-2.7	-9.8	-12.4	-5.0	-11.6	-7.1	-5.2	-15.6	-3.6
5.278	-15.0	-9.9	-5.6	-9.9	-9.2	-10.4	-11.6	-16.9	-4.8	-6.8	-10.2	-9.3	-10.5	-12.4	-4.2	-12.3	-14.2	-3.3
5.764	-17.0	-12.3	-2.9	-11.7	-10.8	-13.2	-12.1	-19.6	-7.2	-7.9	-11.6	-11.7	-12.7	-13.3	-5.6	-9.5	-6.1	-13.9
6.220	-12.6	-10.6	-7.5	-7.7	-10.2	-9.7	-6.5	-3.7	-8.7	-5.0	-3.9	-5.7	-5.9	-5.6	-0.2	-6.0	-2.9	-10.0
6.368	-4.7	-6.6	-1.5	-4.9	-7.7	-1.5	-1.7	-11.3	-2.6	-4.3	-1.8	-3.7	-7.6	-7.1	-0.4	-2.3	-5.1	-3.1
6.631	-8.5	-7.9	-10.9	-9.0	-9.1	-4.6	-10.6	-12.2	-6.0	-2.7	-3.5	-6.6	-10.0	-9.5	-0.8	-3.1	-8.0	-4.1
6.801	-13.1	-10.9	-9.3	-15.7	-16.7	-10.5	-19.5	-19.5	-18.3	-9.3	-12.8	-19.9	-15.0	-14.7	-10.7	-17.7	-9.2	-15.9
7.007	-22.1	-11.6	-23.4	-19.5	-17.1	-23.1	-21.8	-25.0	-20.8	-19.2	-20.6	-21.9	-21.2	-16.2	-21.3	-21.2	-25.0	-19.1

TABLE 2. VELOCITY DATA—Continued.
MEAN CHROMOSPHERIC HEIGHT 1390 KM.

λ	4005.3	4012.4	4063.6	4071.8	4271.6	4274.8	4314.5	4320.9	4325.5	4337.6	4400.4	4404.8
Phase												
0.221	-23.1	-24.8	-23.6	-17.3	-29.8	-25.4	-26.0	-26.2	-26.3	-23.6	-20.9	-17.5
0.397	-18.4	-21.1	-18.8	-17.6	-20.3	-22.1	-25.0	-21.7	-20.4	-22.4	-20.6	-20.6
0.505	-19.9	-18.8	-19.6	-16.2	-24.0	-22.0	-23.4	-23.2	-23.3	-19.7	-20.0	-21.4
0.574	-14.3	-18.8	-19.5	-15.8	-18.3	-20.0	-25.3	-17.3	-19.6	-21.6	-24.3	-19.8
0.761	-21.7	-20.9	-21.1	-21.1	-26.1	-22.1	-24.6	-26.4	-25.7	-20.3	-24.5	-21.8
1.291	-15.9	-19.8	-16.5	-17.6	-16.8	-15.9	-20.9	-19.9	-15.1	-15.3	-16.2	-19.9
1.444	-12.2	-13.6	-19.4	-17.6	-13.5	-17.8	-13.1	-13.8	-13.9	-11.8	-17.3	-18.0
1.636	-11.4	-11.0	-13.8	-16.5	-18.4	-10.8	-13.8	-15.9	-18.4	-11.9	-14.3	-17.6
1.917	-15.0	-10.2	-18.4	-13.8	-11.0	-6.7	-5.7	-4.5	-12.4	-8.2	-7.8	-3.8
2.209	-10.3	-9.8	-24.6	-16.3	-16.0	-11.0	-11.5	-10.1	-14.8	-12.7	-8.8	-8.2
2.403	-9.4	-12.1	-8.6	-13.3	-13.1	-12.5	-9.6	-6.5	-18.5	-5.8	-6.3	-4.5
2.588	-5.0	-4.5	-14.4	-2.3	-6.5	-4.5	-2.8	-6.5	-6.6	-8.9	-6.3	-8.8
3.297	-13.0	-9.0	0.1	-2.2	-3.8	-3.3	-6.4	-7.5	-5.7	-9.4	-3.7	-9.7
3.639	-7.7	-2.2	0.5	-2.7	-0.3	-5.1	-2.4	-4.1	-1.1	-3.8	-4.7	-9.4
4.101	-9.3	-3.4	-0.4	-0.9	-1.7	2.0	1.5	-3.1	4.1	-3.9	8.2	-2.8
4.556	5.6	4.6	-1.4	1.7	4.9	7.4	5.5	2.7	11.8	0.0	16.3	0.4
4.861	9.6	5.3	-1.0	3.8	12.2	6.9	10.4	6.2	13.5	4.5	15.7	7.1
5.278	10.8	4.4	7.9	10.8	5.9	14.6	12.4	7.2	10.9	13.9	8.2	8.4
5.764	13.7	7.6	21.4	14.5	9.7	14.2	10.4	17.0	10.5	7.8	10.8	10.9
6.220	7.9	5.6	16.1	10.6	6.9	4.7	4.6	4.2	8.8	3.9	-1.7	-1.1
6.368	-3.2	-3.4	-11.5	-9.2	-3.8	-2.5	-2.3	-3.7	-1.0	-4.8	-11.8	-6.3
6.631	-8.1	-7.7	-12.3	-8.3	-8.5	-10.3	-14.7	-5.6	-10.7	-7.5	-14.8	-14.6
6.801	-19.0	-15.6	-17.5	-8.6	-17.3	-23.9	-17.1	-14.0	-16.4	-16.3	-16.2	-18.5
7.007	-21.8	-15.7	-21.5	-24.2	-12.0	-15.5	-22.3	-24.9	-26.0	-19.8	-25.8	-22.1

TABLE 2. VELOCITY DATA—Continued.
MEAN CHROMOSPHERIC HEIGHT 2070 KM.

λ	4045.7	4233.2	4294.2	4300.0	4534.0	4572.0	4583.8
Phase							
0.221	—23.9	—24.1	—26.7	—26.9	—19.1	—17.2	—20.1
0.397	—19.9	—14.3	—24.2	—20.6	—21.9	—19.3	—21.7
0.505	—17.1	—17.5	—23.8	—23.5	—17.7	—22.3	—22.0
0.574	—19.0	—15.9	—23.5	—18.5	—14.9	—17.2	—18.1
0.791	—24.0	—24.7	—23.7	—18.7	—14.5	—16.0	—17.8
1.291	—16.7	—16.5	—17.6	—16.4	—19.1	—13.7	—18.2
1.444	—17.4	—19.9	—9.6	—16.7	—13.5	—16.6	—13.7
1.636	—12.1	—13.9	—9.8	—16.5	—10.9	—18.5	—17.3
1.917	—13.0	—16.9	—8.0	—17.8	—13.9	—11.0	—12.1
2.209	—14.9	—12.4	—8.2	—10.3	—13.4	—6.3	—9.9
2.403	—9.6	—8.3	—22.6	—7.1	—0.2	—5.4	—13.1
2.588	—12.0	—8.9	—9.9	—7.6	—13.2	—9.7	—8.6
3.297	—10.1	—8.5	—9.3	—8.7	—13.6	—8.8	—3.3
3.639	—6.1	—9.3	—4.4	—4.3	—11.8	—14.4	—3.0
4.101	4.0	—7.8	—0.2	0.4	3.8	—9.2	1.7
4.556	2.7	5.1	12.0	5.8		—4.6	0.2
4.861	7.1	5.0	10.6	14.0	4.3	4.9	6.4
5.278	6.4	1.6	10.1	13.2	3.8	5.1	9.9
5.764	6.3	14.2	14.2	11.4	7.5	12.8	7.7
6.220	13.2	14.3	—5.2	1.9	12.7	4.0	14.9
6.368	9.1	2.9	—5.4	0.6	—7.4	—2.4	—3.4
6.631	—8.1	—5.1	—8.8	—10.0	—9.4	—10.3	—7.9
6.801	—21.8	—10.5	—18.2	—13.6	—11.5	—13.7	—15.1
7.007	—21.9	—18.5	—16.9	—21.9	—16.7	—21.6	—22.7

TABLE 2. VELOCITY DATA—Continued.

MEAN CHROMOSPHERIC HEIGHT 2400 KM.					MEAN CHROMOSPHERIC HEIGHT 5500 KM.					MEAN CHROMOSPHERIC HEIGHT 8170 KM.				
λ	4289.7	4443.6	4468.6	4501.3	4549.6	λ	4077.7	4215.5	4226.7	4246.8	λ	4101.8	4340.5	4861.3
Phase						Phase					Phase			
0.221	-20.7	-20.2	18.0	-23.8	-15.3	0.221	-24.0	-24.5	-24.5	-24.0	0.221	-24.2	-14.8	-17.6
0.397	-21.0	-20.2	-22.6	-22.8	-18.6	0.397	-22.2	-21.6	-22.6	-21.3	0.397	-20.0	-23.1	-20.5
0.505	-20.3	-25.7	-25.9	-22.7	-24.2	0.505	-22.2	-24.8	-22.4	-21.3	0.505	-24.0	-16.3	-21.9
0.574	-18.1	-18.9	-21.8	-22.2	-17.3	0.574	-20.0	-23.6	-19.3	-22.1	0.574	-21.3	-17.3	-21.3
0.791	-24.2	-20.0	-21.3	-26.7	-21.3	0.791	-16.8	-28.9	-20.8	-23.4	0.791	-22.7	-19.1	-21.2
1.291	-17.7	18.2	16.6	-18.0	-19.8	1.291	15.3	18.5	-19.7	-21.4	1.291	-14.9	-18.1	-18.9
1.444	-18.0	-18.3	-20.2	-17.7	-17.3	1.444	-15.1	-14.5	-14.3	-12.0	1.444	-13.0	-16.1	-12.2
1.636	-13.0	-19.2	-14.7	-19.8	-8.7	1.636	-15.8	-13.0	-15.7	-8.6	1.636	-14.1	-13.7	-14.7
1.917	-6.6	-10.7	-7.3	-6.6	-4.6	1.917	-16.4	-17.0	-13.5	-8.8	1.917	-16.4	-8.1	-14.6
2.209	-12.3	-9.3	-6.1	-11.9	-6.2	2.209	-14.3	-16.9	-13.9	-7.7	2.209	-14.1	-10.3	-8.6
2.403	-8.2	-15.0	-15.1	-9.9	-9.5	2.403	-10.5	-11.8	-12.4	-8.4	2.403	-12.2	-11.6	-8.1
2.588	-7.9	-9.2	-6.2	-9.1	-9.9	2.588	-10.8	-12.1	-8.4	-10.2	2.588	-17.3	-8.7	-7.9
3.297	-7.7	-7.1	-6.8	-9.8	-12.4	3.297	-7.2	-5.3	-8.1	-5.2	3.297	-10.6	-6.6	-8.2
3.639	-10.2	-11.9	-0.6	-1.4	-8.1	3.639	-5.0	-2.4	-2.7	-2.4	3.639	-3.8	-9.4	-4.9
4.101	-11.1	-2.5	1.1	-4.4	-5.6	4.101	-6.5	-0.4	-4.9	-2.3	4.101	-6.6	-1.0	-9.2
4.556	1.7	0.6	3.1	9.0	-2.5	4.556	7.6	5.3	5.8	2.4	4.556	3.1	-2.6	-2.9
4.861	1.7	3.1	13.0	11.4	6.5	4.861	11.7	5.1	15.4	3.9	4.861	1.2	1.9	5.8
5.278	6.7	6.6	13.3	13.0	12.9	5.278	13.2	12.4	12.5	11.6	5.278	16.2	6.0	9.5
5.764	8.8	10.5	7.2	17.7	8.8	5.764	12.6	15.6	12.9	17.0	5.764	12.6	10.4	10.5
6.220	7.0	17.2	16.0	9.5	1.7	6.220	14.1	11.4	3.9	8.4	6.220	11.9	10.0	12.1
6.368	1.4	-4.7	-6.3	-1.2	-2.8	6.368	-1.1	0.6	-6.0	1.6	6.368	-1.3	-6.6	15.6
6.631	-7.0	-9.7	-14.6	-10.0	-6.3	6.631	-7.5	-8.4	-10.4	-11.1	6.631	-5.7	-6.1	-7.9
6.801	-10.6	-10.9	-18.9	-17.1	-11.8	6.801	-14.3	-12.1	-9.7	-16.8	6.801	-15.5	-11.6	-11.6
7.007	-13.1	-20.5	-24.0	-24.4	-26.4	7.007	-23.5	-20.2	-20.5	-21.0	7.007	-16.5	-22.8	-19.1

correction Δv by the factor $\Delta \lambda / \Delta v$ for the corresponding wave-lengths gave the corrections to be applied to the computed wave-lengths.

The Identifications. The width of each line was measured in terms of R and the corresponding value in terms of λ was used to indicate the range of spectrum included in the measured line or blend. All the chief lines given in Rowland's Pre-

TABLE 3. WAVE-LENGTHS OF SELECTED LINES AND BLENDS.*

λ in Star I.A.	λ in Sun I.A.	Element	Height in Sun, km.	λ in Star I.A.	λ in Sun I.A.	Element	Height in Sun, km.
4005.12	4005.26	FeI.	1000 ✓	*4299.77	4300.05	TiII, TiI.	2000
4012.35	4012.39	TiII, CeII.	1500 ✓	4305.68	4305.71	ScII, TiI, FeI.	600
4024.77	4024.73	FeI, TiI, TiII.	750 ✓	*4314.64	4314.54	ScII, TiII.	1200
4045.73	4045.83	FeI.	1800	*4320.92	4320.93	ScII, TiII.	1500
4063.50	4063.61	FeI.	1500	4325.49	4325.52	FeI, ScII.	1500
4066.93	4066.99	FeI.	700 ✓	4330.60	4330.71	TiII, NiI, FeI.	700
4071.60	4071.75	FeI.	1500	*4337.61	4337.77	TiII, CrI.	2000
*4077.73	4077.73	SrII.	6000	4340.50	4340.48	H γ	8000
4101.61	4101.75	H δ	8000	4344.28	4344.29	TiII, CrI.	700
4118.50	4118.56	FeI, CoI.	600	4351.59	4351.56	FeI, CrI, MgI, FeII.	1200
4127.68	4127.71	FeI, Bl.	600	*4367.83	4367.68	TiII, FeI.	600 ✓
4132.27	4132.07	FeI.	900	*4374.69	4374.66	ScII, TiII, YII	1000
4154.26	4154.19	FeI, Bl.	500 ✓	4383.41	4383.56	FeI.	1600
4156.37	4156.31	ZrII, FeI.	500 ✓	4395.19	4395.25	TiII, VI.	2500
4161.31	4161.42	TiII, ZrII.	900	*4400.48	4400.40	ScII, VI.	800
*4163.60	4163.66	TiII, (CrI), FeI.	1000	4404.77	4404.76	FeI.	1200
*4187.20	4187.05	FeI, CeII.	900	4408.44	4408.43	FeI, VI.	450
4191.47	4191.44	FeI.	800	4415.11	4415.14	FeI.	800
4198.50	4198.40	FeI, Bl.	800	4435.26	4435.26	CaI, FeI, Bl.	800
4205.10	4205.06	EuII?, VII, Bl.	600	4443.47	4443.58	TiII, FeI, Bl.	2500
*4215.67	4215.54	SrII.	6000	4454.88	4454.79	ZrII, CaI.	800
4227.03	4226.74	CaI, FeI.	5000	4461.61	4461.66	FeI.	700
4233.27	4233.17	FeII, CrII.	2200	*4468.74	4468.62	TiII, Bl.	2500
*4235.92	4235.95	FeI, (YII?).	900	*4501.24	4501.28	TiII.	2500
*4242.62	4242.61	FeI, MnII.	800 ✓	4533.74	4533.97	TiII, CoI.	500
*4247.02	4246.84	ScII.	5000	*4549.46	4549.60	TiII, FeII, Bl.	2500
4250.54	4250.47	FeI, Bl.	900 ✓	4554.05	4554.04	BaII, FeI.	2000
4254.37	4254.35	CrI.	1500	4563.63	4563.77	TiII.	2500
*4258.33	4258.33	FeII, FeI, ZrII.	500	4571.74	4571.98	TiII, CrI.	2500
4260.44	4260.49	FeI.	1000	*4583.40	4583.84	FeII, TiII.	1500
4271.58	4271.60	FeI, Bl.	1500	4823.84	4823.74	CrII, Mn, Bl.	750
4275.14	4274.81	CrI, TiI.	1500	4855.42	4855.42	NiI, FeI.	300
4282.67	4282.75	FeI, CaI, Bl.	700	4861.16	4861.34	H β	8500
4289.91	4289.73	CrI, CeII, TiII.	2000				
*4294.35	4294.15	TiII, FeI.	2000				

* Table 3 has been revised by transforming the wave-lengths as given by Rowland to international angstroms, and by substituting St. John's values and identifications from his "Revision of Rowland's Preliminary Table of Solar Spectrum Wave-Lengths" (1928).

The wave-length of the chief component is given except in cases marked Bl, in which the wave-length has been computed by weighting in accordance with the intensities of the lines involved. Lines preceded by an asterisk were segregated later in the search for a correlation with ionization potential. W. C. R.

liminary Table of Solar Spectrum Wave-lengths²⁴ within the limits thus found for each blend were then combined by weighting them according to their intensities;

²⁴ AphJ Table in Volumes 1 and 2 (1895).

and the resulting wave-lengths together with the values determined in the star are given in Table 3. Rowland's identifications as corrected and supplemented by Mitchell with some additional information regarding lines due to ionized elements as given by Russell²⁵ formed the basis for the list included in the table.

RADIAL VELOCITIES.

The Displacements. On the assumption that the line displacements are due to the Doppler effect radial velocities were determined for all the measured lines. Systematic differences in displacements for different elements at different levels found by Rufus and by Henroteau have been confirmed and a more detailed analysis has been carried out.

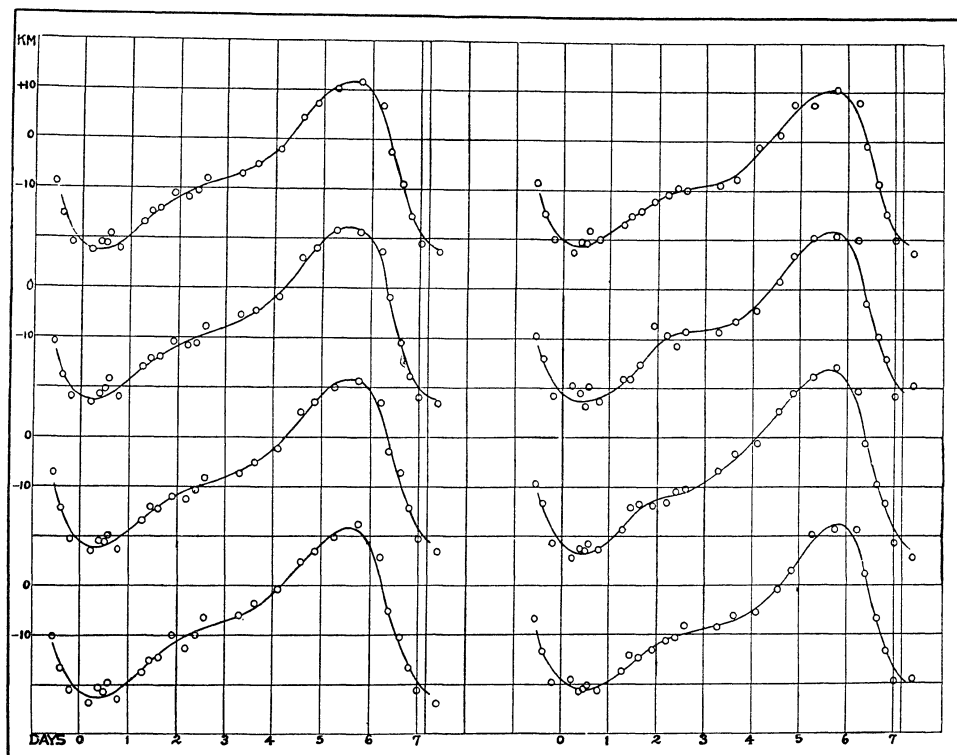


FIGURE 1. Radial Velocity Curves of Eta Aquilae. Upper left curve,—Mean of All Levels. Following curves,—Seven levels in order of increasing height, downward on left side then downward on right.

The Mean Radial Velocity Curve. Combining the radial velocities from the lines of all levels a mean radial velocity curve was formed. The chief feature is a pause on the ascending branch between phases about 2.5 days and 3.5 days after

²⁵ AphJ 61, 47 (1925).

light maximum. This occurs near the "center-of-mass" velocity, or, on the assumption of radial pulsation of the star as a whole, it coincides with the time of the greatest volume. Orbital elements were not determined, so the following data are entirely empirical. The minimum velocity -22.2 km. occurs at phase about 0.4 days; the maximum 11.3 km. at 5.6 days; giving an amplitude of 33.5 km., which is nearly 8 km. smaller than found by Wright. Minimum and maximum velocities follow maximum and minimum light by an interval of about one-half day. The ascending branch of the curve occupies 4.8 days and the descent 2.4 days. The center-of-mass velocity is about -7 km., which differs from the one found by Wright, -14 km. The difference may indicate a variation in the centre-of-mass velocity, as in the case of S Sagittae;²⁶ although the difference in the method used renders this conclusion uncertain.

Velocities at Seven Arbitrary Levels. In general the maxima are quite broad and flat with an indication of becoming sharper at higher levels. No systematic difference in amplitude is indicated. A progressive lag of phase of the higher levels appears to be well established. At maximum velocity and minimum velocity its value is about 0.3 day. The pause is also later at higher levels, although the regular progression is not clearly indicated. At the highest level, hydrogen, the phenomenon occurs about one day later than at the lowest level. In particular the sixth level appears to be discrepant, as the pause begins as early as in the first level. This may be due, at least in part, to its poor determination, as this group contains only four lines; or it may be attributed to an ionization effect which will be discussed later. The beginning of the pause for the lowest level is about phase 1.9 days and the end 2.9 days. In general the duration is the same for all levels.

VELOCITY DIFFERENCES.

Deviations of Different Levels from the Mean of All Levels. The mean radial velocities using the lines of all levels was used as a standard from which the deviations of the different levels were measured. The physical significance of the mean velocities is evidently the average rate of rise and fall of the atmosphere as a whole; so the velocity-differences found by taking the mean velocity from the velocities of the different levels should reveal the behavior peculiar to each level. These results are evidently dependent on the effective height of the mean of all levels.

The velocity-differences obtained from the second level minus the mean form approximately a straight line suggesting that the second level closely corresponds in its motion to the mean of all levels. This level corresponds to a mean height of 860 km. in the atmosphere of the sun. There appears to be evidence of an increase of amplitude of the velocity-difference curves with height, part of which may be a

²⁶ Pop Astr 32, 218 (1924).

phase effect. Some of the levels, however, give deviations which are opposite in sense to the general order. These apparent inconsistencies are partly explained by the separation of the level groups into two sets of lines, one due to neutral atoms and the other to ionized atoms.

Deviations from the Lowest Level. The velocity differences obtained by using the first level as a standard were also formed and in general confirmed the results of the preceding method. The curves, however, are more irregular as the errors in

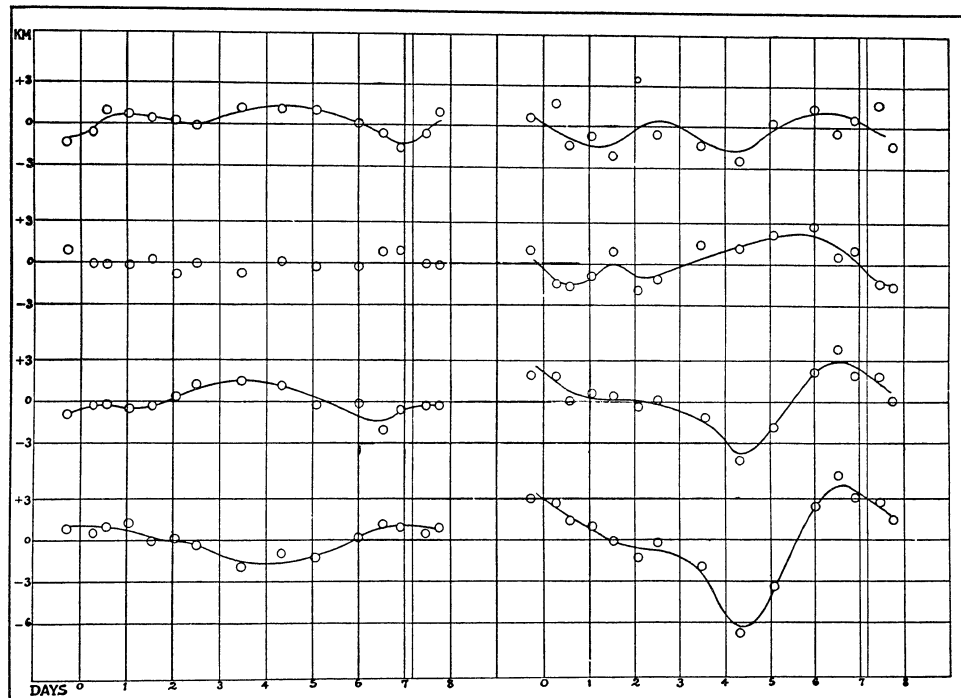


FIGURE 2. Velocity-Differences. Deviation of seven levels from the mean of all levels. Lower right, hydrogen minus lowest level.

the velocities of the first group enter into all the results. An attempt was made to obtain a smoother curve for the first level by weighting the observations using their residuals from the arithmetic mean and the quality of the lines on the spectrograms. The result was not entirely satisfactory and it seems quite probable that the grouping of lines due to neutral atoms with those due to ionized atoms caused part of the difficulty. The same trouble was encountered in the attempt to form the velocity differences of one level from the next in order of height. The close resemblance of the velocity-difference curves formed from the second level minus the first and from hydrogen minus the first is evidently due to the fact that the results

are based chiefly on lines of the same nature. The added phase effect at the higher level probably accounts for the larger amplitude of the second curve.

Velocity-Differences from Neutral Atoms. 28 lines due to neutral atoms are distributed in the level groups as follows: 9 in the first, 8 in the second, 6 in the third, 1 in the fourth, 1 in the sixth, and 3 in the seventh. It is clearly evident that reliable results can not be obtained for the intermediate and higher levels by this method.

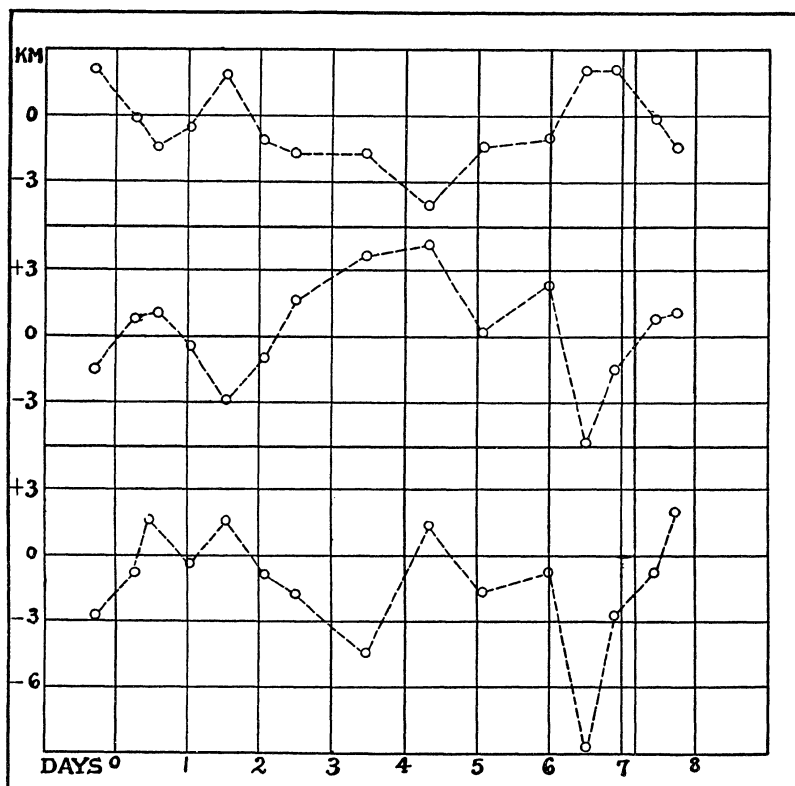


FIGURE 3. Velocity-Differences Obtained from Neutral Atoms. Second level minus first, third minus second, and fourth minus third.

The mean of the velocities from the 28 normal lines was taken as the standard for comparing the motions of the lower levels. The second level minus the mean shows very small amplitude. The first minus the mean and the third minus the mean give similar results with long flat maxima at phase 4 to 5 days and sharper minima just before 7 days.

The three velocity-difference curves from neutral atoms for the second level minus the first, the third minus the second, and the fourth minus the third are

interesting. They are plotted in Figure 3 with broken lines to connect the observations in order that the resemblance of some of the secondary features may be compared. Although the range is not large (5 to 10 km.) the systematic distribution

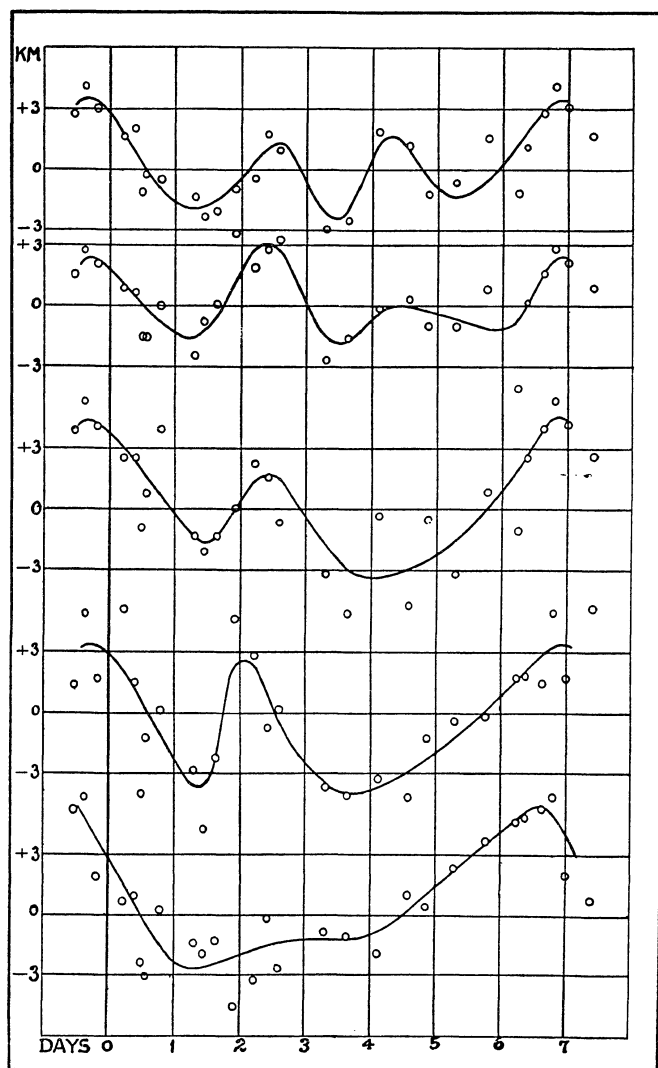


FIGURE 4. Velocity-Differences Obtained from Ionized Atoms. Deviations of Five Levels from the Lowest Level.

and the greater accuracy of the differential method lend support to the reality of the results.

Special attention is called to the regular progression of several similar features. A maximum and minimum occur in the first curve at phases -0.5 and $+1.5$ days

respectively. The same features are evident about one day later in the second curve and about two days later in the third with an irregular maximum and a somewhat greater lag of the minimum. A lag of about one day between the first and second curves is also indicated by a secondary minimum which occurs in the first at phase 4 days. This feature and a very pronounced minimum at 6.5 days are practically synchronous in curves two and three. The first maximum occurring about 0.5 day before light maximum in the lowest curve appears like a compressional wave followed by the minimum which indicates expansion. This compression in the lower atmosphere may be due to an upward acceleration at the time the star begins to expand. If the phenomenon is real the progress of the compressional wave may be traced as far as the fourth level. The synchronous features in curves two and three occur after the star has reached the greatest radial expansion, the prominent maxima at 6.5 days indicating that the lower levels (two and three) are falling more rapidly respectively than the next higher levels (three and four). This takes place after the original upward impulse has spent its force and the gases are freely falling.

Velocity-Differences from Ionized Atoms. The selection of lines to represent the systematic motion of the ionized atoms gave some difficulty on account of the numerous blends composed of both neutral and ionized components. Selections were made of lines due to ionized atoms alone or in which the very weak neutral components are negligible. To these were added several good blends in which the ionized component is much stronger than the neutral. Twenty of the best representative lines were selected in this manner. These are indicated by asterisks in Table 3. The mean velocities from the twenty lines were found, also the velocities for the different levels. The differences from the mean were formed for each level. The chief features seemed to be approximately synchronous. The differences from the first level, plotted in Figure 4, confirmed the above result and brought out an interesting comparison with the velocity-differences of the neutral lines, viz., the continuance of the special features during ascent and the gradual dying out during fall when gravitation becomes predominant. The result of the strong impetus just preceding light maximum is also clearly demonstrated.

Velocity-Differences, Ionized Minus Neutral. Three curves were formed at levels one, two, and three, where data were available for comparing the motion of the ionized and the neutral atoms. The three curves plotted in Figure 5 are quite similar in form with prominent maxima about 0.5 day before light minimum and minima about the same length of time before light maximum. A fourth curve was formed by taking the differences between the velocities obtained from all the ionized lines and the velocities from all the neutral lines in the same sense ionized minus neutral. The principal maximum and minimum agree with the corresponding features in the separate curves. The pause or secondary feature on the ascending

branch is also well established. The range of the ionization curve is 6 km. The striking resemblance of this curve to the radial velocity curves can not fail to attract attention. The chief features, however, of this velocity-difference curve ionized-minus-neutral precede the corresponding ones of the mean velocity curve

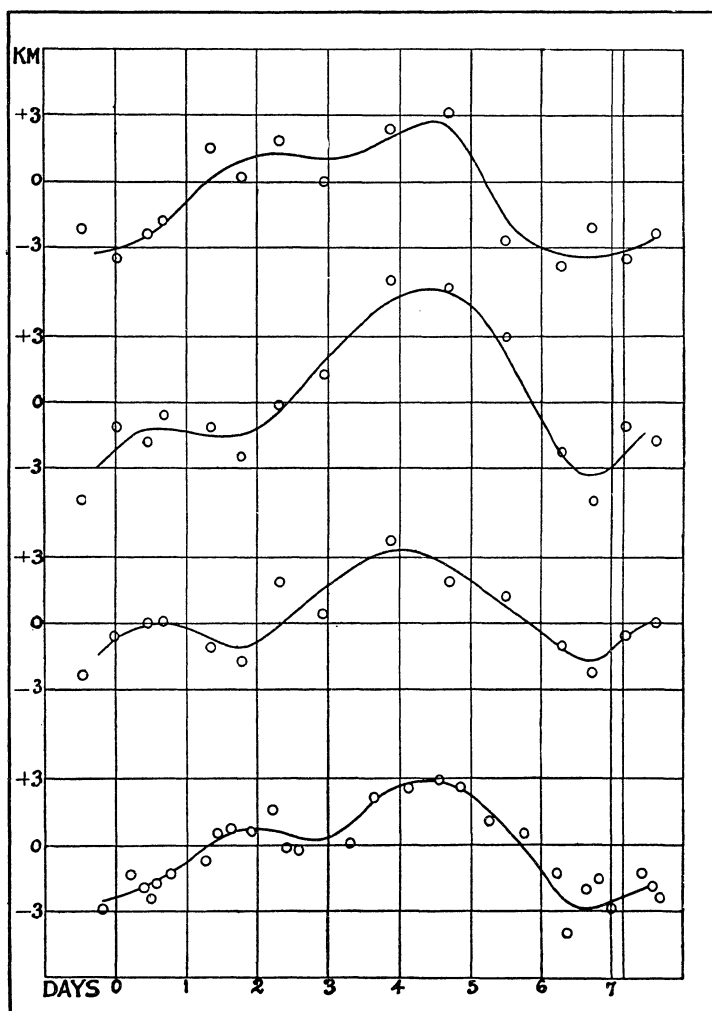


FIGURE 5. Velocity-Differences, Ionized Minus Neutral. For first, second, and third levels. Fourth curve, mean of all ionized minus mean of all neutral.

by about one day. The positive differences, ionized minus neutral, indicate an excess of fall of the ionized atoms with reference to the neutral with a maximum at 4.5 days and the negative differences indicate an excess of rise with a maximum at 6.5 days. These phases agree fairly well with the minimum and maximum of ioniza-

tion as found by Henroteau, although the maximum of his curve is drawn a little later. Similar results were found in Zeta Geminorum by Rufus.²⁷

SUMMARY.

1. The secondary variation on the ascending branch of the mean radial velocity curve of Eta Aquilae has been confirmed.

2. While a change in the velocity of the center of mass is indicated by a comparison of the values here secured and those found by other investigators, this difference may well be fictitious and caused, at least in part, by the methods of reduction and treatment followed in this paper. It would be unwise to assert that this change is definitely established, and its confirmation must depend upon results secured in the future.

3. Systematic differences in line displacements at seven different levels in the atmosphere of this star have been measured.

4. A gradual increase in the general lag of phase of the radial velocities at higher levels seems to be established.

5. Special features of the velocity-differences of the neutral atoms suggest a compressional wave which was traced through four of the lower layers of the atmosphere.

6. The effect of an upward impulse seems evident during the period of ascent.

7. An ionization effect on line displacements has been isolated and correlated with the light and velocity phases and with Henroteau's variation of ionization.

8. Assuming that these displacements are Doppler effects a circulation of the ionized atoms with reference to the neutral has been observed with a maximum fall preceding light minimum by about one half day and maximum rise preceding light maximum by the same length of time.

9. Support is evidently found for the radial pulsation theory of Cepheid variation supplemented by atmospheric pulsation.

The writer desires to express his grateful appreciation of the privileges extended by Director Hussey for the use of instruments and materials and for his continued interest during the progress of this work. Special acknowledgement is made of the assistance given by Dr. Rufus, whose preliminary work on Eta Aquilae was made available, and under whose direct supervision the results of this investigation were rendered possible. Thanks are also extended to Dr. R. H. Curtiss and other members of the Observatory staff for coöperation in securing the spectrograms upon which this study was based.

²⁷ Pop Astr 34, 242 (1926).