NOTE ON THE SPECTRUM OF ε AURIGAE

By W. S. Adams and R. F. Sanford

Extensive photometric and spectroscopic studies of the variable star ε *Aurigae* have been made by numerous observers because of its remarkable characteristics. Its light variation is of the *Algol* type, but its period is extraordinarily long, about 27.14 years. At maximum, the star has a visual magnitude of 3.3; it diminishes in brightness 0.7 magnitude in about 180 days, according to Ludendorff's values, remains at constant minimum brightness for 340 days, and rises to normal brightness again in 180 days. The duration of the eclipse, therefore, is more than eleven months.

The radial velocity of the star was found by Vogel and Eberhard to be variable, and several observers, especially Ludendorff, have attempted to derive orbital elements. In addition to the long period of 27 years, one of about 150 days is indicated by many of Ludendorff's observations, but very different elements are found at different epochs. As in the case of several other stars of variable velocity, among which are some Cepheid variables and other stars of great intrinsic brightness, secular variations in velocity and other disturbing factors seem to be involved.

The spectrum of ε *Aurigae* is classed in the *Draper Catalogue* as cF5. The *c*-characteristic, however, cannot be interpreted as indicating narrow lines, but rather lines with comparatively sharp edges and inconspicuous wings. Normally, under moderate dispersion the lines are unusually broad, but well defined, with a flat intensity curve. The lines of the ionized atom, especially of iron and titanium, are extraordinarily strong; those due to the neutral atom are relatively weak.

A very interesting result was found by Ludendorff in his study of spectrograms taken at Potsdam during the increase in brightness in 1902. Several lines, including Hγ and some enhanced lines of iron and titanium, became broader at this time, with a diffuse appearance toward the red but a sharp boundary on the violet side. To obtain homogeneous results he made all of his measures upon the stronger violet portion of the lines. He called attention to the large positive difference in velocity given by Hγ due to its peculiar character. Ludendorff concluded, however, that the differences in velocity given by other lines are not systematic in character when measured in the manner described. Recent observations by McLaughlin at Ann Arbor have confirmed Ludendorff's observations in showing a component to the Hγ line, and microphotometer tracings by Elvey at the Yerkes Observatory in 1928 showed asymmetry in the case of the four enhanced lines investigated. The results of further investigations by Struve and Elvey have appeared since this note was first prepared. In addition to confirming Ludendorff's long- and short-period fluctuations in radial velocity, their observations lead them to conclude that the absorption lines strengthen during eclipse. Many of them are unsymmetrical, being sharp on the red side at the beginning, nearly symmetrical at the middle, and sharp on the violet side at the end of eclipse. They state that Hβ and many other strong lines gave discordant velocities: during the first part of the eclipse these lines were displaced toward the red with respect to fainter lines, but during the latter part of eclipse, toward the violet.

The middle of the predicted light minimum of ε *Aurigae* should have occurred about May, 1929, but modern observations have shown such irregularities in its light that its behavior is still uncertain. It seems probable from Stebbins' observations, however, that in December, 1928, the date of our first spectrogram, the star was near its minimum brightness.

Our results are based upon three spectrograms taken with the 9-foot coudé auto-collimating spectrograph with a total dispersion of two 52-degree prisms. The linear scale of the spectra is 4.8 A per millimeter at Hγ. The dates of the spectrograms are as follows:

Coudé 126	......	1928, December 28
Coudé 229	......	1929, November 15
Coudé 269	......	1930, February 5

The first spectrogram taken in December, 1928, with the star at or near minimum of light showed Hγ and Hβ extremely broad and perhaps double, the enhanced lines broad, and the neutral lines of about normal appearance. The radial velocities (reduced to the Sun) given by a list of lines selected as most suitable for measurement are as follows:

Neutral Lines	km	Enhanced Lines	km	H Lines (whole width)	
4226 *Ca* ...	+3.0	4233 *Fe+* ...	+11.1	Hγ	+21.5
4236 *Fe* ...	+5.4	4246 *Sc+* ...	+10.7	Hβ	+19.2
4254 *Cr* ...	+7.5	4290 *Ti+* ...	+10.2		——
4271 *Fe* ...	+8.5	4337 *Ti+* ...	+ 9.6		+20.4
4274 *Cr* ...	+1.8	4374 *Sc+*, *Y+*	+14.3		
4282 *Fe* ...	+7.9	4395 *Ti+* ...	+13.1		
4325 *Fe* ...	+4.0	4416 *Fe+* ...	+12.4		
4383 *Fe* ...	+3.6	4417 *Ti+* ...	+14.0		
4404 *Fe* ...	+4.1	4443 *Ti+* ...	+11.3		
4415 *Fe* ...	+6.3	4468 *Ti+* ...	+10.3		
4494 *Fe* ...	+6.4	4491 *Fe+* ...	+10.8		
4528 *Fe* ...	+5.4	4501 *Ti+* ...	+11.1		
	——	4508 *Fe+* ...	+12.9		
	+5.3	4515 *Fe+* ...	+14.7		
		4520 *Fe+* ...	+ 9.8		
		4522 *Fe+* ...	+12.2		
		4533 *Ti+* ...	+12.1		
		4558 *Cr+* ...	+ 9.2		
		4563 *Ti+* ...	+11.4		
		4571 *Ti+* ...	+10.5		
		4583 *Fe+* ...	+15.4		
		4588 *Cr+* ...	+12.2		
		4590 *Ti+* ...	+ 7.4		
		4924 *Fe+* ...	+10.1		
			——		
			+11.5		

The lines of the neutral elements are all much weaker than the enhanced lines or those of hydrogen, and it seems clear from these results that a component was probably present on the red side of the lines which affected the measures of the strong enhanced lines but was too weak in the neutral lines to influence the measures seriously.

The next spectrogram taken on November 15, 1929, showed this actually to be the case. The enhanced and the hydrogen lines are clearly double, and the separate components can be

Neutral Lines				Enhanced Lines				
	Coudé 229	Coudé 269			Coudé 229		Coudé 269	
	Component I	Component I	Component II		Component I	Component II	Component I	Component II
4226 *Ca*	−39.9	−35.4	...	4233 *Fe*+	−43.7	+ 9.9	−32.7	+ 2.3
4254 *Cr*	37.5	35.9	...	4246 *Sc*+	35.0	+10.2	35.5	− 0.6
4271.8 *Fe*	36.1	36.7	+6.4	4290 *Ti*+	33.5	− 0.6	34.9	+ 2.0
4274 *Cr*	37.6	36.6	...	4337 *Ti*+	32.8	+11.4	36.2	+ 4.6
4325 *Fe*	....	35.4	...	4374 *Sc*+, *Y*+	....	...	38.8	...
4383 *Fe*	34.7	36.2	6.0	4395 *Ti*+	32.4	+ 7.4	33.7	+12.0
4404 *Fe*	−33.0	34.9	+9.7	4417 *Ti*+	....	...	34.9	+ 8.7
4415 *Fe*	....	37.8	...	4443 *Ti*+	35.3	+ 7.6	35.4	+ 8.1
4528 *Fe*	....	−38.0	...	4468 *Ti*+	32.2	+ 6.1	35.3	+ 1.5
				4491 *Fe*+	32.9	+ 1.8	....	...
	−36.5	−36.3	+7.7	4501 *Ti*+	34.5	+ 0.7	34.1	− 0.2
				4508 *Fe*+	....	...	32.2	+ 1.5
				4515 *Fe*+	....	...	32.4	+ 1.8
				4520 *Fe*+	....	...	34.9	+ 1.5
				4522 *Fe*+	34.6	+ 1.0	34.3	+ 2.8
				4533 *Ti*+	35.4	+ 1.3	34.0	+ 5.9
				4563 *Ti*+	34.1	+ 2.9	34.1	+ 7.2
				4571 *Ti*+	33.7	+ 0.1	35.1	+ 1.9
				4583 *Fe*+	36.6	+ 1.8	35.6	+ 0.8
				4590 *Ti*+	....	...	−36.3	+ 1.0
				4924 *Fe*+	−39.0	0.0	....	...
					−35.0	+ 4.1	−34.8	+ 3.5

measured for most of the enhanced lines. A few lines are greatly widened but cannot be resolved. Faint fringes can be seen on some of the neutral lines, but no measures of the red component were made.

The third spectrogram, taken on February 5, 1930, showed a spectrum similar to that of the preceding plate. The red component could be measured in the case of a few of the neutral lines, but in most cases it was too faint. The radial velocities for both components given by this spectrogram are almost identical with those of the November spectrogram. The values reduced to the Sun are given above.

Three conclusions may be drawn from these results.

1. The differences in velocity between neutral and enhanced lines found on the spectrogram of December, 1928, are to be ascribed to the presence of the faint red component which affects the enhanced lines and the hydrogen lines much more than the neutral lines.

2. When the components are separated sufficiently to permit of individual measurement, these differences disappear within the errors of setting on these rather diffuse lines. The red component in particular is difficult of measurement.

3. The presence of the component is certain to affect seriously radial-velocity determinations made with low or moderate dispersion. This is shown clearly in a comparison with Ludendorff's results. In a series of observations extending over many years the largest negative velocity found by him was —23.7 kilometers per second. Our recent spectrograms, which may by no means give the maximum values, show velocities of —35 kilometers per second for the stronger component. As already stated, Ludendorff attempted to measure only the maximum on the violet side of the line, but the lack of symmetry can hardly fail to affect the measures. Struve and Elvey confirm Ludendorff's radial-velocity results but find asymmetry in the structure of the strong lines. Evidently they have been able, with the dispersion at their disposal, to go a step farther than Ludendorff, but had not enough dispersion to enable them to measure the strong and weak components separately.

It is evident that observations extending over other portions of the period of light variation will be needed to show the origin of the fainter component. Ludendorff concluded that the spectrum of a third star could not be present since he found no evidence of asymmetry in the lines at any time during maximum of light. Struve and Elvey state that "no trace of the spectrum of the second component of the long-period binary system could be found at the time of maximum relative velocity (1922–1923)." Whether such would be the case on spectrograms of higher dispersion than they used is not certain. Ludendorff ascribed the red component to the absorption of light from the brighter star traversing the atmosphere of the fainter star as the eclipse was passing off. The existence of differences in velocity between neutral and enhanced lines on our spectrogram of December, 1928, when the star was apparently at minimum light, would seem to be opposed to this hypothesis. The appearance of the lines, even at maximum separation, suggests that physical causes are involved similar, perhaps, to those which produce changes of width and intensity in the spectra of Cepheid variables.

The D lines of neutral sodium are of extraordinary intensity in the spectrum of ε *Aurigae,* and microphotometer tracings show that the residual radiation at the centers of these lines is extremely small. The Hα line on all three of our spectrograms consists of an absorption line with a bright component on the red side displaced about 1 angstrom unit toward longer wavelengths. Struve and Elvey's results for the Hβ line show nearly complete absorption near its center similar to the great absorption in the D lines. The faint narrow emission, Hβ, to which they refer as being in the exact center and therefore not analogous to the Hα emission, may perhaps be interpreted as a portion of the continuous spectrum between the two components of Hβ in absorption. This seems to be the case on our spectrograms.

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