SPECTROGRAPHIC NOTES

By EDWIN B. FROST

I. REANNEALED PRISMS

Those who have had to use large prisms in their spectroscopes are aware of the difficulty often experienced in obtaining glass of adequate homogeneity for refined work. This obstacle was encountered in the construction of the Bruce spectrograph, as recorded in this *Journal* (**15**, 14–15, 1902). The prisms were 57 mm high, of 66° angle, with faces of 117, 127, and 135 mm; for λ 4405, $n = 1.6374$. Having heard of the occasional success of reannealing, I took up the question with Mr. Brashear, who learned that the maker of the glass, M. Parra-Mantois, would be glad to undertake to reanneal the prisms which had proved so disappointing.

The process was completed and the prisms were returned from Paris to Pittsburg last spring. An examination of one prism which was at once figured by the Brashear Company indicated that the improvement was enough to justify putting new faces on all of the prisms, which was done. The prisms were now cut down somewhat, so that all three are of nearly the same dimensions: 54 mm high and 115 mm long in face.

A number of trial spectrograms of spark spectra and of sunlight were obtained with these prisms in the Bruce spectrograph, chiefly by Dr. D. V. Guthrie, who was spending the summer quarter here. The outcome of the trials was that although greatly improved, the three prisms together did not equal in definition the performance of the train of prisms of Jena flint O 102 regularly used with the instrument. The prism which was most cut down before it was figured, however, gave as fine definition as any one of the Jena prisms, and it was accordingly used for one-prism work with the spectrograph during a part of the summer, over 100 stellar spectrograms being obtained with it. The inconvenience of having the scale of the plates slightly different from that of the 1600 other spectrograms taken with one prism led to the subsequent restoration of the Jena prism to its position. The inference may be drawn by spectroscopists, however, that prisms lacking in homogeneity may in some cases be successfully reannealed, with great improvement in their optical

performance. I am glad to put on record our appreciation of the interest and assistance of the Brashear Company in this experiment and of the generosity of M. Parra-Mantois in doing the work of reannealing without expense to the observatory.

II. PECULIAR SPECTROSCOPIC BINARIES

A peculiar interest attaches to those stars of the *Orion* type in which the characteristic lines are broad and diffuse but the H and K lines of calcium are narrow and sharp. Examples of such stars for which data have been published are δ *Orionis* and *9 Camelopardalis*. In his investigation of the spectroscopic orbit of the former, Hartmann reached the conclusion "that the calcium line at λ 3934 does not share in the periodic displacements of the lines caused by the orbital motion of the star."[1] In measuring the Bruce spectrograms of *9 Camelopardalis*, it was found[2] by Mr. Adams and myself that the H and K lines were very sharp and well suited for measurement and that they yielded a variable radial velocity differing from that given by the broad lines usually measured and from which the binary character of the star was first inferred. The detection of some peculiarities in other stars having such spectra led me about two years ago to examine all our spectrograms which included H and K. I was not prepared to find that such spectra were so common, for I was able to list about twenty-five stars having this spectrum. I was struck by the fact that about half of them had already been detected here as binaries from the variable displacements of the broad lines. For nearly all of the others, the data at hand were far too meager for definite inferences on this point.

This would accordingly seem to indicate that we are dealing in such cases with composite spectra. The general principle of such a discrimination was laid down long ago by Professor E. C. Pickering,[3] and it has been applied in the *Harvard Annals*, **28** and **56**, by Miss Maury and by Miss Cannon. This particular variety of composite spectrum has, however, not been described by the Harvard observers.

As the discovery of spectroscopic binaries here is incidental to our regular programmes, we have not yet been able to follow up the stars

[1] *Astrophysical Journal*, **19**, 273, 1904. [2] *Ibid.*, **19**, 350, 1904.

[3] "The Discovery of Double Stars by Means of Their Spectra," *Astronomische Nachrichten*, **127**, 155, 1891.

of this sort on our lists and find what precentage of those having sharp H and K, with the other lines broad, are *not* spectroscopic binaries.

When I noted recently the presence of sharp K in ϵ *Orionis*, I arranged to have a few spectrograms taken, in the confident expectation that variable velocity would be indicated, although the earlier observations by myself and Mr. Adams (with three prisms, spectrum measurable between λ 4340 and λ 4713) did not show variation. Mr. Lee has measured all of our one-prism plates with the following results:

RADIAL VELOCITY OF ϵ *Orionis*

Plate	Date	G. M. T.	Taken by*	Broad Lines		H and K		Quality of Plate†
				No.	Velocity	No.	Velocity	
					km		km	
IB 227	1903 Dec. 26	17^h 20^m	F.	6	+30	..	....	..
484	1905 Jan. 21	15 49	F.	6	22	..	....	g.
1327	1908 Jan. 14	15 55	B.	5	27	2	+31	g.
1337	Jan. 17	18 10	L.	5	30	2	41	g.
1353	Jan. 20	15 1	B.	6	28	2	23	w.
1463	Feb. 17	13 39	P.	6	17	2	20	g. w.
1496	Feb. 21	13 19	F.	8	30	1	39	g.
1770	Oct. 2	23 1	L.	7	35	2	23	v. g.
1788	Oct. 9	23 3	L.	6	30	..	....	g } too weak for *Ca* lines
1805	Oct. 16	23 15	L.	8	27	..	....	v.g } too weak for *Ca* lines
1813	Oct. 30	23 53	L.	8	30	2	28	p.
1905	Dec. 14	21 0	B.	6	37	2	28	g.
1926	Dec. 26	15 30	F.	8	30	2	30	v.g.
1946	1909 Jan. 1	18 0	B.	8	16	2	20	v.g.

* B.=Barrett; F.=Frost; L.=Lee; P.=Parkhurst. Mr. Sullivan assisted as usual in guiding.
† g=good; p=poor; w=weak.

The earlier measures[1] of three-prism plates are added for completeness:

Plate	Date	G. M. T.	No.	Adams	No.	Frost
A 208	1901 Sept. 4	22^h 10^m	3	+28 km	..	.....
B 228	Nov. 13	19 50	6	29	5	+24 km
B 298	1902 Mar. 13	15 11	5	26	4	26
B 316	April 9	14 21	3	26	3	28

1 "Radial Velocities of Twenty Stars Having Spectra of the *Orion* Type," *Publications of Yerkes Observatory*, **2**, 210, 1903.

The inference is that in this case the H and K lines share in the oscillations of the broad lines, so that this would not be an instance of a composite spectrum.

I reserve for a later discussion the remarkable feature of the binary character of some of these stars, already alluded to, that the component responsible for the sharp H and K lines appears to have a different velocity (γ) of its orbital center of gravity from that of the component having broad lines. The first inference in such a case would be that we are dealing with a quaternary system—two pairs of spectroscopic binaries; if so, however, a change in the relative velocity of the center of gravity would be expected within a few months or years, and in at least one instance our observations cover a longer period of time.

I have in mind particularly the star ξ *Persei*, the first observations of which were made by Mr. Adams[1] in 1903. The five plates then measured yielded a velocity of +85 km, which would be entirely exceptional for a star of the *Orion* type not a spectroscopic binary. We therefore expressed the opinion that later observations might be expected to show the star to be a binary. A range of 30 km was given by a plate taken later in that year, establishing the variation in velocity, and we have been observing the star occasionally each year since, so that we now have over 30 spectrograms, of which about one-half are measured. We do not appear to have caught the star with a negative velocity on any plate, the total range shown on our measured plates being about 60 km. Mr. Plaskett reports his measures of 7 plates taken in the autumn of 1908 in the *Journal of the R. A. S. of Canada* (**2**, 325, 1908), giving a range of velocity from −2 to +143 km.

The lines are exceptionally broad and diffuse, even for spectra of that type, but H and K are quite sharp, although H cannot always be separated from $H\epsilon$. In 1906 at my request Mr. Ichinohe measured the ultra-violet portion of a number of the earlier plates, and obtained for the calcium lines only moderately positive velocities, having a range of about 25 km, but differing greatly from the values derived from the broad lines (generally by not less than 50 km). I have also measured some later plates with similar results. The star evidently is of the sort of ρ *Camelopardalis* and δ *Orionis*, but

[1] *Astrophysical Journal*, **18**, 388, 1903.

its thorough investigation will be a difficult task on account of the evil character of the broad lines.

I am well aware that Professor Julius finds an explanation of such stars in anomalous dispersion, regarding the broad lines as dispersion bands.[1] Perhaps some physical effects will have to be invoked to explain the peculiarities of such stars; but I am not yet convinced that anomalous dispersion is here a sufficient cause.

III. SPECTROSCOPIC BINARIES AMONG STARS IN PROFESSOR BOSS'S STREAM IN *TAURUS*

In a brief paper read at the Baltimore meeting of the American Association I reported on the beginning made here in observing the radial velocities of the stars in the "moving cluster in *Taurus*" described by Professor Lewis Boss in No. 604 (**26**, 31, 1908) of the *Astronomical Journal*. As my remarks were printed in *Science* (**29**, 156, 1899), practically in full, I will not repeat myself further than to state that observations of those 40 stars have now been in progress, as circumstances permitted, for about six months with the Bruce spectrograph, a dispersion of one prism, which is as high as many of the spectra will stand, being employed.

About seventy spectrograms have been so far obtained, chiefly by Mr. Barrett and Mr. Lee, of 21 of the stars. The six stars of that list which we had found to be spectroscopic binaries at the time that paper was prepared, were: *90 Tauri* and *B. D.* 15° 637 found by Mr. Barrett; *64* and *97 Tauri*, found by Mr. Lee; and θ^2 and υ *69 Tauri*, found by myself. Two that I then regarded as suspicious, *71 Tauri* and *92 Tauri*, have since proved by measurement to be also variable in velocity. The particulars of the measures thus far made of six of these stars will be given here and in the following note by Mr. Lee. Mr. Barrett will report later on his measures of *90 Tauri* and *B. D.* 15° 637. It must be acknowledged that the proportion of binaries is surprisingly large, 8 out of the 14 stars for which we have two or more spectrograms.

The observations with the Bruce spectrograph indicate a proportion of spectroscopic binaries of not less than 1:3 among stars

[1] "Dispersion Bands in the Spectra of δ *Orionis* and *Nova Persei*," *Astrophysical Journal*, **21**, 286, 1905.

of the *Orion* type, but the proportion here would seem to be still greater. The 14 stars, with one exception, have spectra of the first type or of one intermediate between the first type and the early solar type: in the current Harvard designation they are of types A, A2, A3, or A5, with the exception of θ' *Tauri*, of type K.

The spectrum of θ^2 *Tauri* is of type A5. With a dispersion of two prisms (scale at λ 4500 : 1 mm = 15 t.-m.) the lines are very diffuse for measurement; with one prism the lines are better, but some seem to be complicated by the presence of companions due to a second component. The radial velocity is therefore liable to considerable uncertainty. On being informed by Professor Boss regarding his cluster, I asked Mr. Lee to measure the two plates of this star then on hand, both taken with two prisms. The other measures are by myself. The variable radial velocity was at once apparent after we began to get spectrograms with one prism.

θ^2 *Tauri* ($\alpha = 4^h\ 23^m$; $\delta = +15°\ 39'$; Mag. = 3.7)

Plate	Date	G. M. T.	Taken by	No. Lines	Velocity	Remarks
IIB 86	1906 Aug. 31	$21^h\ 11^m$	F.	4	+42 km	
180	1907 Nov. 4	18 32	L.	4	(+29)	Very weak
IB 1707	1908 Aug. 25	22 32	B.	5	+64	
1734	Sept. 8	22 45	B.	6 2	+88 +40	Second Component
1741	Sept. 18	20 32	L.	7	+10	
1794	Oct. 12	20 25	B.	4 3	+39 + 8	Second Component
1836	Nov. 8	18 46	L.	5	+36	
1895	Dec. 7	15 1	L.	5	+38	
1900	Dec. 11	15 2	F.	4	+31	

The spectrum of *69 Tauri* is a very difficult one to deal with. To classify it as of type A5 fails to express the diffuse character of the lines. My re-examination of our first plate, taken three years ago, led me to believe that the spectrum is composite and this was confirmed by the measures of the subsequent plates. It is difficult and often incorrect to combine into means the velocities from lines which in some cases belong to different components; where the components are not separated, the setting on the center of the apparently single line has no definite meaning. My measures are as follows:

69 (Upsilon) *Tauri* ($\alpha = 4^h\ 20^m$; $\delta = +22°\ 35'$; Mag. = 4.5)

Plate	Date	G. M. T.	Taken by	No. Lines	Velocity
IIB 24	1905 Nov. 24	$17^h\ 26^m$	B.	2 2	− 81 km + 16
IB 1747	1908 Sept. 21	19 40	B.	2	+102
1896	Dec. 7	16 21	L.	1 2	+ 82 +130
1901	Dec. 11	16 1	F.	6	+ 38
1954	1909 Jan. 3	18 28	B.	2	+ 34

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