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ADAPTING A UNIVERSAL SPECTROSCOPE FOR RADIAL VELOCITY DETERMINATIONS.

BY

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TORONTO.
1907.

ADAPTING A UNIVERSAL SPECTROSCOPE FOR RADIAL VELOCITY DETERMINATIONS.

By J. S. Plaskett.

ONE of the chief lines of work planned by the Director in obtaining the instrumental equipment of the Dominion Observatory was stellar spectroscopy. It was hoped that satisfactory work in that line could be done with a fifteen inch telescope and a suitable spectroscopic outfit. Recent investigations by the writer have shown that such a telescope, with an efficient correcting lens, can successfully attack almost all the stars reached by some of the larger equipments, and that the field open to it for one particular branch of spectroscopic work, the determination of the radial velocities of stars, is a very wide one. Consequently the greater part of my time has been devoted to putting the instrument into satisfactory shape for the accurate determination of such velocities, and other spectroscopic work has only been partially touched upon. It is hoped however in the near future, when more assistance has been obtained, to broaden the line of research to include investigations into the spectra of stars of different types, into peculiar spectra, and into some parts of stellar spectra,—the region of longer wave length, now almost entirely unknown and untouched upon.

The principal radial velocity work so far undertaken has been the determination of the velocities of certain of the brighter stars, the so-called standard velocity stars inaugurated by Frost, and the determination of the velocity curves and orbits of some half dozen spectroscopic binaries. The chief value of the velocity determination of the standard stars in this case lies undoubtedly, as will be evident below, in the test they furnish of the accuracy of the spectrograph. That such tests were necessary will appear when I come to describe the process of putting the instrument into shape for accurate work.

Owing to preparations for and absence on the Eclipse expedition, and other work of a pressing nature, it was not until late in November, 1905, that any work in stellar spectroscopy was undertaken. It did not take long to discover that the instrument, as originally constructed, was unsuited for obtaining accurate velocity values. While it admirably fulfilled the purpose for which it had been designed, general spectroscopic work, radial velocity determinations require an altogether different type of construction, and it was inevitable that difficulties in the way of flexure should occur in the long exposures required in stellar spectra.

DESCRIPTION OF THE INSTRUMENT.

The spectroscope is of the universal type similar to those furnished by the same maker, Brashear, to the Lick, Naval,

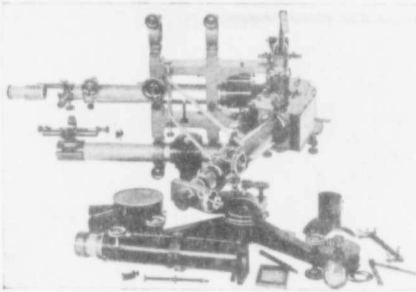


FIG. 1.

and Yerkes Observatories. It is arranged to be used both visually and photographically with the following dispersing media: (1.) A light flint prism. (2.) A dense flint prism. (3.) A train of three dense flint prisms. (4.) A plane grating. The instrument, which, with its various attachments, is shown in Fig. 1, with the prism train in place, is supplied with a swinging arm and rotating table, whose angular movement can be read to half-minutes by verniers on a graduated circle. This adapts it for use as a laboratory spectroscope and spectrometer. The whole instrument is thoroughly well made and serviceable for a great variety of general work, but, as previously stated, the universal construction is one which is least adapted for use where the great stability and rigidity required in stellar velocity determinations is necessary. For that purpose the universal form has been entirely abandoned elsewhere, and spectrographs of the most rigid possible construction have been obtained in which all universal features have been sacrificed to stability, and which make photographs of star spectra only in one region of the spectrum. Until such a spectrograph could be obtained here, I undertook the task of so modifying the present instrument as to render it serviceable for accurate radial velocity work, with what success will hereafter appear.

The dimensions of the optical parts are as follows :—The collimator objective is of 15 inches focus and 1¼-inch aperture, but diaphragmed to slightly over an inch, to have the same angular aperture as the system of objective and correcting lens. The camera is of 15 inches focus and 1¼-inch aperture. The train of three prisms has been the sole dispersing medium used in radial velocity work, the prisms of which are of such dimensions as to transmit the full beam from the collimator, and are made of dense flint glass whose index of refraction for H_γ is about 1·64. The refracting angle of each prism is about 62° 30′, which gives a total deviation for H_γ of about 160°. The resolving power at H_γ is about 40,000, the purity with a slit 0·025 mm., the normal width used here, is slightly over 8,000, and the linear dispersion 18·6 tenth-metres per millimetre.

ADJUSTMENT OF THE SPECTROSCOPE.

In placing a spectroscope in adjustment, three points require careful attention :—(1.) The collimator focus. (2.) The camera focus. (3.) The adjustment of the prisms to minimum deviation. Of these, in my opinion, the exact focussing of the camera is, for reasons that will appear later on, by far the most important in radial velocity work.

Collimator Focus.—Three methods of determining the collimator focus were employed, Schuster's*, Lippmann's†, and Newall's‡, with fairly accordant results.

Schuster's method consists in placing the observing telescope at a greater deviation than the minimum, and so changing the focus of the collimator and observing telescope that the line at minimum will be in sharp focus in the two positions of the prism that bring it into the field. This gave good values, the mean collimator setting being 15·6 mm., successive determinations differing by 0·2 mm. only. Lippmann's method, depending on the displacement of the two halves of the pencil by two plane parallel plates placed obliquely, and the consequent doubling of the spectral lines when the emergent beam is not parallel, seems by no means so sensitive and accurate as Schuster's. Newall's method, as my experiments have shown, is more applicable to the exact determination of camera focus. Any deviations of the collimator focus to the extent of nearly 2 mm. on either side could be so compensated by changing the camera focus as not to be evident by the displacement of the lines he speaks about.

The only observable change in eight series of test plates at eight collimator settings between 14·0 and 17·5, with six plates in each series at six camera settings near the focus, was in the length of field in good focus, which was the greatest at setting 15·0 and 15·5 with a slight advantage to 15·0. This was taken as showing, not that 15·2 was the focus of the collimator, but that at that focus the curvature of field of the camera lens was reduced to a minimum. I believe that 15·6, the setting determined by Schuster's method, is nearly exact, but that, by moving the slit away from the lens, a greater length of spectrum can be brought into focus. Hence the final setting was fixed at 15·2.

* *Phil. Mag.*, (5), vol. 7, p. 95-99, (1879).

† *C. R.*, vol. 129, p. 569-570, (1899).

‡ *M. N.*, vol. 57, p. 572; also vol. 65, p. 642.

and, as the changes in focus due to temperature are very slight, it remains at that setting.

Focus of Camera.—The accurate focussing of the camera is in my opinion much more important than that of the collimator. Here one cannot depend upon the test of definition, as the focus may be changed through a half-millimetre, an amount fatal to accuracy in line of sight work, without appreciably affecting the sharpness of the lines. The method employed here of obtaining the camera focus was evolved from Newall's method of focussing the collimator, a somewhat similar method being described by Hartmann*, and the focus is tested on every night the spectroscope is used. The method depends upon the displacement of the spectral lines on a plate not in focus when the pencil which forms them has its centre of intensity separated by a sensible distance from the centre of the objective.

Practically, the procedure is as follows. By a pair of diaphragms or windows situated close in front of the slit, which will be presently described, two spectra can be made side by side on the same plate, or rather one spectrum about 0·3 mm. wide along the centre of the plate has on each side a spectrum about 1 mm. wide. These spectra touch each other so that when there is no displacement of the lines they appear continuous, but the slightest displacement is at once apparent. Below the collimator lens is an opening in which a brass plate slides. This plate has a rectangular opening about 12 mm. wide and 30 mm. long, and the position of this opening is regulated by stops, so that in one position it allows a pencil of light of half the aperture to pass through the prisms near the refracting edge, and in the other position near the base. The middle spectrum is made through the refracting edges, and the outside spectra through the bases of the prisms. Hence the centres of intensity of the two pencils through the camera objective are separated by about 12 mm., and if the camera is not in exact focus the lines of the spectrum will not be con-

* *Astrophysical Journal*, vol. XII., p. 45.

tinuous. The method is so sensitive that, if a plate is 0·05 mm. distant from the true focal plane, a displacement of the lines is noticed. The camera was originally furnished with a plain index and scale reading to millimetres only, but it was found necessary to rule and apply a vernier to read to tenths, and to estimate to twentieths of a millimetre. The importance of accurate focus in line of sight work cannot be too highly emphasized, for, as the method outlined above shows, any inaccuracy of focus will result in a relative displacement of the star and comparison lines whenever, as often happens, the centres of intensity of the illumination pattern of star and comparison light do not exactly coincide.

Adjustment of Prisms.—Instead of using the minimum deviation device attached to the prism train and allowing any part of the spectrum to be brought into the centre of the field, the prisms were placed so that the ray H_γ was central and then rigidly fastened*.

MODIFICATIONS AND ADDITIONS.

The greatest difficulty encountered was that of flexure of the parts, but, in order to guard against every possible chance of systematic displacement, the whole instrument was thoroughly overhauled and changes made wherever it was thought any error could occur. The principal alterations were in the slit diaphragms, the slit, the comparison apparatus and in the addition of various trusses to overcome flexure. These will be described briefly in turn.

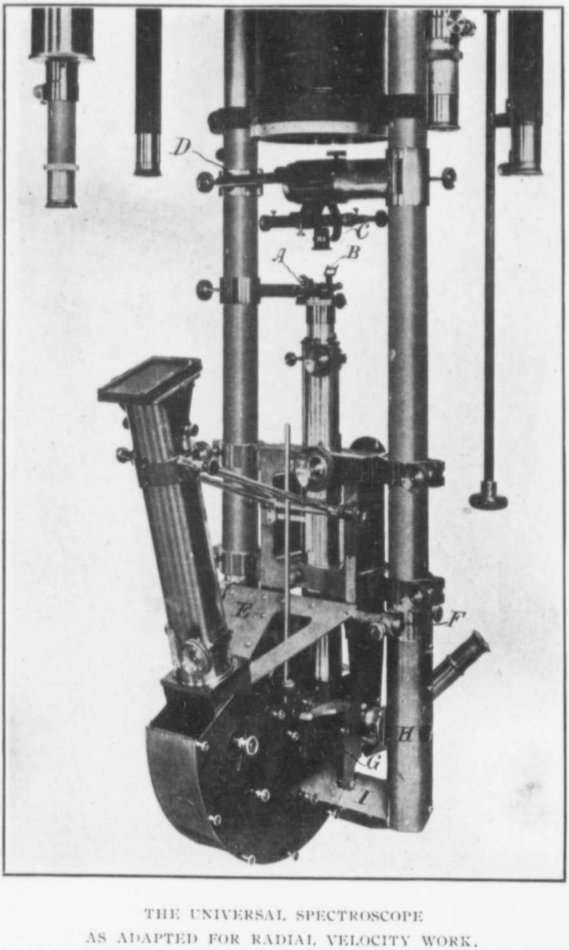
* Screws passing through the top of the box and pressing on the top of the prism cells are provided for clamping the prisms in position, but sufficient pressure for this purpose will induce unequal strains in the glass and affect the definition. As the collimator and camera lenses are corrected for H_γ, the camera and train were placed to make this ray central, and screws were inserted through the base of the box and the arms of the minimum deviation link-work, clamping the cells firmly to the base without fear of inducing strains in the glass. The strips on the bases of the cells, defining the positions of the prisms were loosened, and the prisms re-adjusted for minimum deviation. After the strips had been tightened, the top plates supplied with cork washers bearing on the prisms, were so adjusted as to introduce only sufficient pressure to hold the prisms in an invariable position without affecting the definition.

The Slit Diaphragms.—The diaphragms provided in front of the slit for making star and comparison spectra of the right width and in the right position were a modification of Hartmann's device*, and were attached to the slit head. To change from the opening through which the star was exposed to the opening for the spark, the brass plate containing these openings was moved between adjustable stops. As displacements of the lines were sometimes noticed in two spark spectra taken side by side through these windows, it was feared that the sliding of this brass plate might induce strains in the slit. This arrangement was dismounted and that shown at *A*, Pl. IV., was made to replace it. There are two separate diaphragms, one for the star light, *B*, having an opening about 0·3 mm. wide in the centre, all the rest of the plate over the slit being cut away except two narrow bars about 0·2 mm. wide to limit the star light. This was done for convenience in setting on the slit and guiding. The diaphragm for the spark light, has two openings each about 1 mm. wide, separated by an opaque bar, about 0·35 mm. wide, which is central and occupies the same position on the slit as the opening for the star-light. These are mounted on adjustable pins so that either can be readily turned down in position, while the whole arrangement is mounted on an arm clamped to one of the supporting tubes, as shown in the figure. It can be placed at any desired distance in front of the slit, or at once moved away to leave the slit entirely free if desired. It does not touch the slit or slit head at all, and hence all chance of displacement of the lines from this cause is avoided. It is also much more convenient in use than the old arrangement. The window for the star light is only turned down at first to get the star image central, and occasionally throughout the exposure to ensure that the required width of spectrum is being uniformly exposed.

The Slit Jaws.—In the tests for flexure to be presently described, I noticed that, even when there was no movement of

* *Astrophysical Journal*, XII., p. 46.

PLATE IV.



THE UNIVERSAL SPECTROSCOPE
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Journal of the Royal Astronomical Society of Canada, 1907.

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the telescope and spectroscope between the exposures of the adjacent spark spectra, one made through the star, and the other through the spark windows, there was sometimes a displacement of the lines of one spectrum with respect to the other. After the diaphragms had been changed as above described this could only be due either to the slit or the comparison apparatus. An examination of the slit jaws showed that they were not brought to a sharp edge but consisted of two flat vertical surfaces about 0·7 mm. wide. One could not say what part of such jaws acted as the source of light, the focus would be uncertain, and trouble might arise from reflections between these flat and nearly parallel surfaces. The slit was taken apart, the jaws bevelled off to a sharp edge and ground perfectly straight. Great care was taken to ensure that the edges of these two jaws lay in one plane perpendicular to the axis. Even when this had been finished a photographic test by adjacent spectra showed occasional displacement of the spectral lines, and there only remained the comparison apparatus to be examined as the cause of the trouble. I may say that this work was done previous to the evolution of the focussing method above referred to, so that the camera focus may have been inexact to the extent of three or four tenths of a millimetre. This amount of displacement of the sensitive surface from the focal surface is quite sufficient to cause a marked displacement of the spectral lines, provided there is any faulty centering of the star or spark light.

The Comparison Apparatus.—The iron spark has up to the present time been used for the comparison light, the energy being supplied by a Queen 15-inch spark coil with a capacity, in parallel, of six half gallon jars. The spark gap was originally mounted to one side of the collimator tube, the spark light being reflected into the slit to one side of the light from the star or source to be examined, by a small diagonal prism. This was changed to a direct mounting of the terminals and condensing lens in the optical axis of the collimator about 80 mm. above the slit, as shown in *C*, Plate IV. When the star spectrum was being photographed the apparatus was swung to one side and to ensure it being brought back to the same position, a stop, *D*, was clamped to the other supporting tube.

The angular aperture of the condensing lens is much greater than that of the collimator and this should, theoretically speaking, ensure the uniform illumination of the collimator objective even if not in exact adjustment. However it was feared that the spark gap might not always return to exactly the same place, and besides, the spark terminals were parallel to the slit, which is open to objection. The whole apparatus was therefore remodelled, the terminals and holders being shortened, made more compact and placed transversal to the slit. Then, with the condensing lens, they were mounted on a brass plate swinging between centres rigidly attached to one of the supporting tubes. When not in use it was simply tilted up out of the way, and when brought down again was absolutely certain to come back to the original position, so that when once in adjustment it would stay in adjustment To render the illumination more uniform a small piece of finely ground glass was placed about midway between the spark and the condensing lens, a position which extended trial showed to be best.

After these changes in slit, slit diaphragms and comparison apparatus, there was no further displacements of the spectral lines in adjacent spectra made one after the other, even with considerable mal-adjustment of camera focus, so long as the telescope and spectroscope were stationary. Any movement of telescope and spectroscope however, was at once followed by a displacement of the lines, undoubtedly due to flexure of the spectroscope.

Flexure of the Spectroscope.—Flexure of the parts was the greatest difficulty encountered. Owing to the design of the instrument the prism box has no adequate support. It is fastened by a single screw to the rotating table, which carries the grating or the single prisms, and which from its nature cannot be rigid. It is further secured by two rods reaching down from the box and clamping to the edge of the divided circle, which is a thin ribbed plate of brass not sufficiently stiff to furnish much support to the prism box. The outer end of the prism box, which carries the camera, is entirely unsupported and could be moved by a pressure of the hand three or four millimetres to one side or the other. I had always suspected that flexure might cause trouble, but had no idea, until I made a test, of the extent of the displacement of the spectral lines that would be caused by a movement of the telescope with spectroscope attached through two hours in right ascension, the duration of an exposure on a faint star. The test was made in a similar manner to those above described, by making a spectrum of the iron spark through the star diaphragm, and, after moving the telescope, a second adjacent spectrum through the comparison diaphragm. Any shift of the lines due to flexure will at once be shown, and the shifts at first were very marked. A movement of the telescope through two hours showed in some declinations a displacement of the lines eqivalent to a velocity of 20 kms. per second. A rotation of the spectroscope of 90 degrees around the optical axis, when the telescope was at hour angle 0^h, declination 0°, showed a shift equivalent to about 50 kms. per second. These figures at once showed that it was necessary to stiffen the parts wherever possible. The frame work of the instrument consists of a hollow built-up structure of rectangular section, seen in the illustrations, which is fastened by four hinged clamps to the two supporting tubes of the adapter. The collar into which these tubes fasten can turn on an inner collar, which screws into the eye end of the telescope. The two tubes are of 1⅞ inches diameter, of steel thick enough not to bend appreciably under the weight of the spectroscope. It was thought preferable to attach any stiffening trusses direct to these tubes rather than to the spectroscope frame which is not rigid enough for that purpose. The first truss made, shown at *E*, Plate IV., was built of thick sheet brass screwed to a brass rod which entered into clamps on each tube directly below the spectroscope frame, one of the clamps being shown at *F*. This triangular shaped brass plate, which had a second plate screwed at right angles underneath, extended diagonally across the back or base of the prism box almost under the third prism. It was firmly screwed to the base of the box and served to prevent flexure at the outer edge of the prism box and the lower end of the camera. The upper end of the camera was provided with a brace, but this was further stiffened by a diagonal connecting rod. The prism cells, as before mentioned, had already been firmly clamped to the base of the box so that no displacement could arise there.

So far as stiffness of the outer end of the prism box is concerned, the spectroscope was immeasurably improved by this truss. A test of the displacement showed that the flexure had been much reduced, as a movement of two hours caused a displacement equivalent to about 5 kms. per second.

This was still too great, and a careful examination showed that it was probably due to a movement of the collimator end of the prism box, which was only supported by one projecting arm of the frame work. A built-up brass T-piece of suitable thickness was inserted between the other projecting arm, to which it was firmly screwed, and the top of the prism box. The arms of the T were made sufficiently long to extend to the outer walls of the box to which they were also screwed, the upper plate not being thick enough to form much support. The introduction of this piece further stiffened the instrument and resulted in a reduction of the displacement to an amount equivalent to between 2 and 3 kms. per second.

As this displacement was still rather great, I removed the swinging arm, which carried the telescope or camera when used with the single prisms or grating, the verniers on the circle and other small attachments. Two pieces of two inch brass tubing were bored out to fit the projecting ends of the 1⅞ inch supporting tubes, and these, one of which is shown at *H*, were firmly joined at their lower ends by a rigid U-shaped truss *I*, built up of brass plate to which the outer edge of the prism box was screwed. The projecting arms of the frame work were also firmly attached to the tubes *H*, while the prism table and divided circle were rigidly connected together by a screw and block. The whole instrument with these additions seemed now very rigid, and a test showed that the displacement of the lines due to flexure was now reduced, at the most, to an amount equivalent to from 1 to 2 kms. per second for two hours movement while in some declinations of the telescope the flexure was hardly appreciable. This amount of flexure would not affect the final result by half the velocity mentioned, owing to the displacement being compensated to a considerable extent by a similar displacement of the comparison lines which are exposed for half the time before, and half after the exposure on the star. As I could contrive no further means of stiffening the instrument without rebuilding, it seemed preferable to keep it intact for work on other parts of the spectrum and to make all velocity determinations with an instrument of more modern type, designed expressly for line-of-sight work, and now nearing completion in our workshop.

The Temperature Case.—It was realized from the first that it would be necessary to provide some means of keeping the instrument at constant temperature during an exposure, for not only does the deviation and dispersion of the prisms change with change of temperature but the expansion of the metal parts would also be liable to introduce differential displacements of the star and comparison lines. The errors thereby introduced in velocity determinations might be comparatively large owing to the small displacements measured, one millimetre being equivalent to about 1300 kms. per sec.

A light wooden case enclosing the whole spectrograph was constructed and supplied with coils of German Silver wire for heating. The heat was at the beginning automatically regulated by a makeshift thermostat arrangement but this was finally abandoned for simple hand control by turning current on and off the coils. In the new spectrograph an automatic arrangement modelled after that by Hartmann will be employed.

The Correcting Lens.—After the thorough tests and the modifications and additions just described, I expected to get results free from systematic error, but star spectra made with the instrument still gave velocities up to and sometimes greater than 2 kms. per second different from the mean of the values obtained by other observers of the same star.

Knowing that such differences could not be due to accidental errors of measurement a close search was made for the seat of the trouble, and it was found to be due to the fact that the star light was distributed irregularly and unsymmetrically over the collimator and camera lenses. The slit was placed in all positions, both at and near the apparent star focus and at a considerable distance within and without, but in no position could the illumination be made even approximately uniform. The position of the correcting lens was altered in each direction without any improvement, and the lens itself was inverted in its cell, which made matters worse. Acting on a suggestion of Dr. R. H. Curtiss, of the Allegheny Observatory, to whom I am indebted also for other help, I made a double slide carrier for the correcting lens, adjustable from the eye-end, which allowed the lens to be collimated exactly by means of a bright star, but this gave no useful result.

It was noticed, when the slit was very narrow, that the illumination became more uniform, which was likely due to the diffractional spreading of the light. Furthermore, when the slit was made 0·2 mm. wide the illumination was uniform, the inference being that with a slit of this width the entire star image was transmitted while with a narrower one part of the image was cut off by the jaws. Indeed the star image seemed to have a core about 7″ in diameter which was much too large, and pointed to some defect in objective or correcting lens, or both. This was also indicated by the very long exposures required to obtain measurable spectra.

The difficulty was narrowed down and shown to be in great part due to the correcting lens. At H_γ more than twice as much exposure was required when the correcting lens was in place as without it, showing that it apparently increased the diameter of the image. This was shown also by measurements of the width of spectra made with the slit in different positions in the neighborhood of the star focus. The spectra were made linear by using a bright star, Vega, by opening the slit to half a millimetre wide, and by turning the spectroscope until the slit was parallel to an hour circle so that irregularities in driving would not widen the spectrum. The widths with the correcting lens were never less than 6″, and moreover did not change much as the slit was moved within and without the focus to the extent of 6 mm. on each side. Some of the out-of-focus spectra had a condensation in the centre, with diffuseness at each side of the strip, the whole appearance being decidedly characteristic of spherical aberration. In the spectra made without the correcting lens the width was about 3″, and with no evidence of condensation at the centre in the out-of-focus parts.

The trouble, as stated above, was diagnosed as possibly due to spherical aberration, and the correcting lens was taken out of the cell and examined carefully. There were apparently no defects in the surfaces, for, so far as could be seen without specially testing, they were all spherical. One cause of the trouble might be the wrong placing of the elements in the cell, for if one of the elements were inverted it would probably introduce sufficient spherical aberration to cause the observed effects. The lens consisted of a double equi-convex, presumably of flint glass, and a double concave of crown. The curvature of the outside surface of the concave was the same as that of the convex, while the inside surface, against the convex lens, was of greater curvature. As it seemed possible when one of the surfaces of the concave was of the same curvature as the convex, that it had been intended to place them together, the paper separators were moved to the other side and the concave inverted so that the contact surfaces faced each other.

This seemed to remove the difficulty, for the illumination pattern on the collimator and camera lenses was now found to be practically uniform for all slit widths, and had the same appearance as that given when the correcting lens was removed. While the necessary exposure required to get measurable star spectra was diminished by more than one-half.

So far as regards the removal of systematic error due to the eccentric position of the centre of intensity of the star light, the negatives made since, so far as measured, show no signs of such error, but give accordant results.

However, the results of a later extended quantitative investigation into the character of the star image in spectrographic work, which will appear in this JOURNAL*, shows that there is still considerable residual spherical aberration. The investigation shows, moreover, that this is due to the chromatic differences of spherical aberration of a visual objective used photographically, not being compensated for by the correcting lens, and indicates the possibility of a considerable advance, so far as regards the efficiency and range of the spectrograph, by the introduction of a suitable correcting lens. A comparison of the performance of existing spectrographic equipments shows that others are probably affected in the same way, and an improvement here suggests the possibility of a similar improvement elsewhere.

Although the various difficulties encountered in making the spectroscope suitable for accurate velocity determinations have prevented as much work being accomplished as could otherwise have been done, they have not been without advantage, for they have certainly formed an education on spectrographic peculiarities and causes of error, which could not otherwise have been obtained. The new spectrograph, which I have designed especially for radial velocity work, and which is now being constructed in our workshop, is so arranged that it is hoped all the difficulties above detailed will be more completely overcome or avoided than has been possible with the present instrument, and that it will prove to be very efficient for determinations of velocity in the line of sight.

* Also in the *Astrophysical Journal.*

Feb. 2
G.M.T

Feb. 22, 1906.
G.M.T., 16^h 15^m.

Observed by J. S. Plaskett.
Measured by J. S. Plaskett.

Measured Wave Length	Normal Wave Length	Displacement	Velocity kms. per sec.
4582·970	2·634	·336	+ 21·41
4554·617	4·211	·406	26·72
4550·064	9·766	·298	19·64
4536·292	5·965	·327	21·61
4529·174	8·807	·367	24·30
4523·174	2·854	·320	21·22
4480·254	5·888	·366	24·45
4476·549	6·214	·335	22·41
4473·338	2·957	·381	25·53
4467·143	6.771	·372	24·96
4459·683	9·304	·379	25·47
4448·253	7·892	·361	24·30
4442·947	2·510	·437	29·45
4427·807	7·420	·387	26·20
4415·681	5·293	·388	26·34
4405·250	4·951	·299	20·33
4395·623	5·286	·337	22·95
4379·712	9·331	·381	26·06
4376·405	6·107	·298	20·38
4371·630	1·312	·318	21·81
4370·272	9·856	·416	28·53
4353·326	2·923	·403	27·72
4352·365	2·006	·359	24·74
4341·012	0·634	·378	26·08
4328·463	8·080	·383	26·50
4319·190	8·817	·373	25·86
4315·495	5·178	·318	22·07
4294·668	4·273	·395	27·57
4292·644	2·319	·325	22·69
4288·540	8·134	·416	29·04
4254·822	4·505	·317	22·34
4251·284	0·954	·330	23·27
4247·955	7·566	·389	27·42
4247·340	6·996	·344	24·25
4245·803	5·455	·348	24·56
4236·477	6·112	·365	25·80
4235·671	5·389	·282	19·94
4222·718	2·382	·336	23·82
4219·836	9·520	·316	22·44
4210·846	0·523	·323	22·97
4204·007	3·730	·277	19·75
4200·464	0·114	·350	25·03
4191·257	0·874	·383	27·38
4189·989	9·723	·266	19·01
4185·390	5·058	·332	23·77
4179·889	9·542	·347	24·87
4171·472	1·140	·332	+ 23·84

	Mean		+ 24·61
r = + 2·67	V_a	−19·59	
r_n = + 0·33	V_d	− 0·14	
	Curvature	− 0·50	− 20·23
	Radial Velocity		+ 4·4

i.e. a recession of 4·4 kilometres per second.

COMPARISON OF RESULTS.

Star	Dominion Observatory			Other Observers			
	Plate No.	Date	Velocity	Observer	Velocity	No. of Plates	Range
β Geminorum	196	Feb. 22	+4·2	Frost	+3·2	3	0·6
	197	Feb. 22	4·4	Adams	3·7		0·2
	212	Mar. 5	3·8	Lord and Maag	5·3	5	5·4
		Mean +4·1		Belopolsky	3·4	9	1·4
		Range	0·6	Newall	2·0	6	3·0
				Slipher	3·3	3	0·2
α Boötis	199	Feb 22	−4·2	Frost	−4·7	5	1·3
	216	Mar. 5	5·6	Adams	4·9		0·9
	220	Mar. 23	4·6	Belopolsky	6·1	9	3·3
	230	Mar. 28	4·7	Lord and Maag	3·2	7	3·2
	238	Apr. 2	5·2	Frost, Adams	4·3	8	1·8
	252	Apr. 24	5·5	Newall	5·8	5	2·7
	253	Apr. 24	3·4	Newall	6·6	19	4·5
	300	June 18	5·1	Slipher	4·7	5	1·4
	312	June 27	4·7				
	319	July 2	4·9				
	325	July 4P.	3·3				
	325	H.	3·3				
		Mean −4·6					
		Range	2·3				
β Ophiuchi	327	July 4	−10·3	Frost	−11·3	3	0·8
	334	July 6	12·2	Adams	10·9		0·7
	353	July 18	11·7	Newall	15·8	2	1·9
		Mean −11.4		Slipher	11·3	3	1·1
		Range	1·9				
γ Aquilae	323	July 2	−2·0	Frost	−1·4	3	0·7
	323	July 2	1·6	Adams	2·2		1·0
	329	July 4	1·3	Belopolsky	2·0	10	3·8
	335	July 6	1·8	Newall	1·9	4	4·2
	354	July 18	2·1	Slipher	2·1	3	1·4
	361	Aug. 1	1·3				
		Mean −1·7					
		Range	0·8				
ε Pegasi	378	Aug. 15	+5·0	Frost	+6·2	3	0·5
	400	Sep. 27	6·5	Adams	6·2		0·4
	409	Oct. 16	5·5	Belopolsky	6·0	7	1·4
				Newall	3·3	3	2·6
		Mean +5·9		Lord and Maag	6·1	5	5·8
		Range	1·0	Campbell	5·7	4	1·2
				Slipher	6·1	4	1·8
α Arietis	331	July 4	−13·5	Frost	−13·5	3	0·8
	337	July 6	16·0	Adams	13·9		0·7
	364	Aug. 1	16·5	Campbell	14·1	4	0·6
	393	Sep. 10	13·7	Newall	14·3	3	2·8
				Lord and Maag	12·4	5	1·8
		Mean −14·9		Lord	14·0	2	2·7
		Range	3·0	Newall	16·4	8	6·3
				Slipher	14·3	3	0·5

COMPARISON OF RESULTS, (*Continued*).

Star	Dominion Observatory			Other Observers			
	Plate No.	Date	Velocity	Observer	Velocity	No. of Plates	Range
α Persei	330	July 4	− 3·4	Frost	− 2·3	} 3	1·6
	336	July 6	0·6	Adams	2·0	}	1·3
	411	Oct. 16	2·3	Campbell	2·2	10	2·0
				Belopolsky	2·9	8	3·7
		Mean − 2·1		Lord and Maag	+ 0·6	5	3·7
		Range	2·8	Newall	− 2·6	14	5·7
				Vogel	3·2	13	3·3
				Newall	4·6	5	5·5
				Slipher	2·5	5	1·3

CONCLUSION.

As evidence of the success attending the improvement of the spectrograph there is inserted above, an abridgment of the reduction sheet of a spectrum of β Geminorum, showing the agreement between the velocities obtained for the different star lines. I also include a summary of the results obtained for seven of the "standard velocity stars," and, for convenience of reference and comparison, the values obtained by other observers so far as known to the writer, with the range or difference between the greatest and least velocity.

It must be remembered in comparing the Ottawa results with those of other observers that the dispersion of the instrument used here is about 40 per cent. less, thus increasing the relative error of setting on the lines; that our results were obtained from an adapted universal spectroscope which has never before been successfully used in radial velocity work, and finally that practically all the spectra here given were made within eight months of starting work on the spectrograph, the instrument during that period having been investigated and corrected in the manner detailed above.

It gives me pleasure to acknowledge here the able part taken by Mr. W. E. Harper in the observation of some and the measurement and reduction of many of the spectra and I am glad also of this opportunity of signifying my appreciation of the help and encouragement so readily given by Dr. W. F. King, Director of the Observatory, in the prosecution of the work.