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THE THREE-PRISM STELLAR SPECTROGRAPH OF THE MOUNT WILSON SOLAR OBSERVATORY[1]

By WALTER S. ADAMS

The original design of the 60-inch reflector provided for the use of three stellar spectrographs in connection with the three principal mirror combinations. The first of these to be completed was the powerful spectrograph of 5.5 m focal length used with the coudé combination of telescope mirrors at the equivalent focus of 45.7 m. This instrument was employed for the investigation of the spectra of some of the brighter stars under high dispersion.[2] In the following year a small low-dispersion spectrograph was constructed for use at the primary focus of the large mirror. On account of the presence of the Newtonian plane mirror it was necessary to mount this spectrograph on the side of the tube of the telescope and to introduce an auxiliary reflection between the slit and the collimating lens. The instrument proved extremely efficient for qualitative work upon the spectra of faint stars, and the radial velocity results obtained with it were so promising as to warrant the construction of an instrument of similar type mounted directly in the axis of the telescope. In this way the loss of light at two reflecting surfaces is avoided and much greater mechanical stability is insured. This spectrograph is now nearing completion in the Observatory instrument shops.

Intermediate between these two spectrographs, one of very high and the other of low dispersion, is the three-prism spectrograph mounted at the lower end of the telescope tube and employed with the Cassegrain combination of mirrors. At this point the equivalent focal length of the telescope is 24.4 m, or the ratio of aperture to focal length is 1 to 16. This is much the same ratio as that of most of the large refracting telescopes used for spectrographic work, and accordingly the dimensions of the optical system in the

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 59.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 50; *Astrophysical Journal*, **33**, 64–71, 1911.

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spectrograph are similar to those of some of the larger stellar spectrographs employed in radial velocity determinations. The instrument was built by William Gaertner & Co. of Chicago in accordance with designs provided by the observatory, and has been in regular use on Mount Wilson during the past year.

The very massive character of the telescope mounting and the proximity of the spectrograph to the center of rotation of the telescope made the consideration of its weight of less importance than is usually the case. Accordingly the main frame of the instrument consists of a single heavily ribbed iron casting. The base of the casting is rectangular in shape and about 84×61 cm in size. It is accurately surfaced and is attached directly to a planed flange upon the frame of the telescope by means of a number of strong studs. The slit of the spectrograph is behind the face of the casting and so is well protected from possible injury during the process of changing of instruments. The opening in the telescope frame through which the light passes from the diagonal plane mirror is about 33 cm in diameter, being made sufficiently large to provide for direct photography at this point. The corresponding aperture in the spectrograph casting opposite the slit is about 15 cm square.

At right angles to this base and forming a part of the same casting is the large plate which constitutes the frame of the spectrograph. It is about three-quarters of an inch in thickness and is planed over a large portion of its surface. Fastened directly to this plate are the prisms and the tubes carrying the collimating and camera lenses. The plate is about 140 cm long and tapers slightly from its base toward the prism box.

The focal length of the collimating lens was determined by two considerations: first, the size of the prisms available for use; and second, in a less degree, by the fact that a very long instrument would prevent observations of the region of the sky near the pole on account of striking the floor of the dome. The difficulty of securing optical glass of a quality suitable for prisms of considerable size is very great at the present time, as is fully recognized by most spectroscopists. Fortunately, in the case of this spectrograph, prisms of good quality were known to be available. At the time

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at which the five-foot spectroheliograph was designed four prisms 210 mm high and with faces 125 mm wide were ordered from Jena. Three of these proved to be of excellent quality. They are of glass No. O. 102, with an angle of 63° 29′, which provides for a deviation of 180° at $H\gamma$ when three prisms are employed. Since only two prisms are required for the work of the spectroheliograph the third prism became available for the stellar spectrograph. Accordingly it was cut in our optical shop into three prisms, each 67 mm high and with faces the same, of course, as those of the original prism; that is, 125 mm in width. A prism with faces of this size would utilize a beam 59 mm in width at minimum deviation for $H\gamma$. In view of these considerations a diameter of 64 mm (2.5 inches) was fixed upon for the aperture of the collimating lens, which with a ratio of 1 to 16 gives a focal length of 102 cm (40 inches). When more than one prism is employed there is an appreciable loss of light for wave-lengths other than that at minimum deviation on account of the spread of the beam, but as the spectrograph was designed largely for work with one prism it seemed desirable to retain the large aperture. The collimating lens is a cemented triplet corrected for the $H\gamma$ region, made by the J. A. Brashear Co., and has proved very satisfactory in use.

Two camera lenses have been employed with the spectrograph. The longer one of these is an uncemented triplet by Brashear of 88 mm aperture and 102 cm focal length. The other is a Cooke lens of the "Astro-photographic" type with an aperture of 102 mm and a focal length of 46 cm. Both lenses give excellent definition, and the latter, on account of the transparency and the thinness of its components, has proved exceptionally efficient photographically. For all work with a single prism the longer camera has been used, while with two prisms the shorter camera has usually been found sufficient.

An important advantage possessed by the form of construction adopted in the spectrograph is that of adaptability for different regions of the spectrum. The prisms are mounted in cast-iron cells which rest upon three legs. These pass through slotted openings in the main plate of the spectrograph and are clamped rigidly with nuts upon the other side of the plate. The slotted

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openings are provided with scales and the prism mounting has upon it an index by which they may be read. The scale-readings for each prism were determined when the three prisms were originally adjusted for minimum deviation at a definite wave-length, and in case it is desired to set the prisms for any other wave-length, changes are made in the scale-readings corresponding to the difference of deviation. Similarly the camera is mounted on a heavy iron plate which swings through an angle corresponding to that of the third prism, and is clamped in position by powerful bolts. This simple arrangement has proved most satisfactory in use.

The great length of the camera regularly employed with the single-prism arrangement and the difficulty of supporting it with sufficient rigidity led to the interposition of a mirror between the prism and the camera lens. In this way the camera may be left in the same position as that used when three prisms are employed. The objections to this proceeding are: first, the loss of light by reflection at the mirror; and, second, the difficulty of supporting the mirror with sufficient stability. The first objection is not very serious, since the mirror is entirely inclosed, and the silver coat deteriorates very slowly and may be kept in excellent condition. Under these conditions the reflecting power for the region of the spectrum usually photographed is not far from 90 per cent. The second objection is met by making the mirror exceptionally thick and holding it in a strong cell in much the same way as a diffraction grating is supported. The photographs obtained with the spectrograph have shown no impairment as regards definition or accuracy of results since the mirror was employed. When two prisms are used the mirror cell is moved toward the camera lens along a slide provided with a graduated scale and is clamped in position.

For comparison spectrum purposes the iron arc is used. The arc lamp is fastened to the outside of the spectrograph case. The light passes through a mica window and falls upon a lens which renders it roughly parallel. This throws it upon a piece of opal glass which thoroughly diffuses it, and an image of this glass is thrown upon the slit by a second lens. The glass, accordingly, serves as the effective source of illumination for the spectrograph. A totally reflecting prism, which is moved in front of the slit by a

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handle on the outside of the spectrograph, serves to reflect the light into the instrument. An occulting screen with small openings through which the light from the star or from the arc may fall upon the slit also is controlled by a rod projecting from the side of the spectrograph.

The entire spectrograph is inclosed in a wooden case, the walls around the prism-box being of double construction. For purposes of automatic temperature control the convenient device first employed by Professor Campbell has been adopted, a pair of Draper thermostat strips with platinum contacts acting through a relay to throw the heating current on and off. The heating coils are placed outside of the first wall of the prism-box and are distributed as symmetrically as possible about it. A small fan placed inside of the outer cover serves to distribute the air around the outside of the prism-box and prevents stratification. When the instrument is under temperature control, readings of a thermometer placed inside the prism-box indicate ranges of temperature rarely greater than $0^\circ.1$ to $0^\circ.2$ C. throughout an entire night.

For guiding purposes we have used the customary device of a reflecting slit, the jaws being inclined at an angle of about $2^\circ.5$ to the normal. The reflected light is first collimated by a small lens and then reflected by diagonal prisms through a long tube to a point beneath the spectrograph where it is observed through a telescope. The arrangement is very similar to that employed by Professor Frost on the Bruce spectrograph. A finder of 4 m focal length attached to the tube of the large reflector is used to bring the star within the field of view. The observer keeps the star upon the slit by means of slow-motion motors controlled by switch buttons arranged upon a fiber bar held in his hand. Similar buttons control a motor at the upper end of the telescope tube which moves the convex mirror inward or outward and thus enables the observer to correct for changes of focus during the night. If the large mirror has been protected throughout the day by the canopy, as is regularly the case, these changes are rarely of large amount unless there is a marked change of temperature during the night.

This brief description of the general features of the spectrograph

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is perhaps sufficient to give a satisfactory conception of the instrument as a whole. Plate X shows the spectrograph attached to the 60-inch reflector. A part of the outer cover has been removed as well as both covers to the prism-box, so that the arrangement of the prisms and of the camera and collimating tubes is well shown. The tube through which the light reflected from the slit is observed is seen beneath the spectrograph in the lower right-hand corner of the photograph.

PROGRAM OF WORK AND EXPOSURE TIMES

A large part of the time of the spectrograph during the year it has been in operation has been devoted to a determination of the radial velocities of some selected lists of stars, mainly of types A and B, whose proper motions have been measured by Boss and whose velocities are of especial importance in studies of star streams. The lists have been prepared by Professor Kapteyn and consist of stars which for the most part lie between magnitudes 5.5 and 6.5,[1] although a few are brighter. The experience of numerous observers of stellar spectra has shown that by far the greater number of stars with spectra of types A or B can be studied to better advantage with moderate dispersion and linear scale than with high dispersion, on account of the diffuse and broad character of their lines. Some experiments with our spectrograph showed that an optical system consisting of two prisms and the 46 cm camera, or a single prism and the 102 cm camera, gave the most satisfactory results for the majority of the stars. Both combinations have been used and as between the two it is largely a question of the type of spectrum and conditions of seeing. For stars with numerous lines in their spectra the greater resolving power of the two-prism arrangement is preferable. For stars with few lines, however, the single prism is adequate, and the greater width of spectrum obtained with the long camera is an important advantage. In fact, under good conditions of seeing the time occupied in running the star's image along the slit sufficiently to obtain a measurable width of spectrum

[1] The magnitudes used in this article are those given in the "Preliminary General Catalogue of 6188 Stars for the Epoch 1900," by Lewis Boss, *Carnegie Institution of Washington Publication* No. 115. A comparison of these magnitudes with those of the Potsdam and the Harvard Photometry is given in the "Catalogue."

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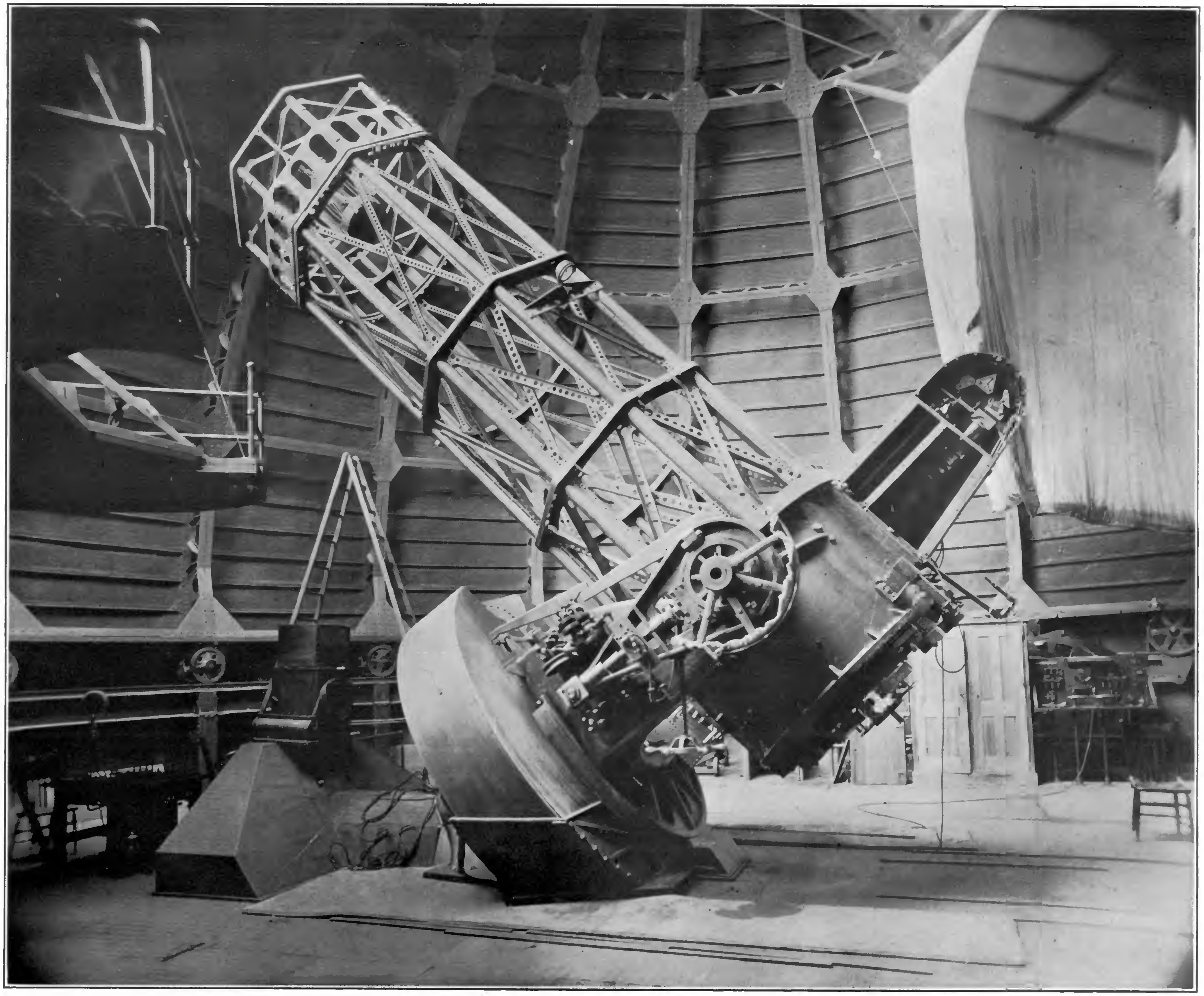
PLATE X



Sixty-Inch Reflecting Telescope of the Mount Wilson Solar Observatory with the Three-Prism Stellar Spectrograph Attached

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is a considerable drawback to the use of the short camera. The linear scale at $H\gamma$ of the photographs obtained with the two arrangements is as follows:

Two prisms and short camera, 1 mm = 18.0 Ångströms
One prism and long camera, 1 mm = 15.7 Ångströms

The three prisms and long camera as used for the spectra of the brighter stars give a linear scale at $H\gamma$ of 1 mm = 5.2 Ångströms.

The exposure times with the spectrograph vary widely, of course, with the conditions of seeing. Under good conditions, when the silver surfaces of the telescope are bright, a fully timed negative of a star of type A or B of magnitude 6.0 on Boss's system may be obtained in one hour, when one prism and the long camera are employed. The exposure times with two prisms and the shorter camera are slightly less. Under average conditions the exposure times are somewhat longer, and under the poorest conditions of the winter season may be several times as long. Usually an exposure about one-fourth longer is given to stars of types F, G, K, and M than to stars of types A and B. The difference would be greater but for the fact that the density of negative required for satisfactory measurement is less in the case of spectra containing numerous lines than for those of types A and B. Under very good conditions of seeing, a fully timed negative of *Groombridge 1830* (Mag. 6.5, Spectrum G) has been obtained in 75 minutes with a slit-width of 0.050 mm. A narrower slit has been employed upon some nights of exceptionally fine seeing, but this width has been used for a majority of the photographs.

METHOD OF REDUCTION

The range of spectrum in good focus upon the negatives and upon which measures may be made extends from about λ 4250 to λ 4900. As a rule in the case of stars of types A and B the measures are limited to the portion between $H\gamma$ and $H\beta$. Within this region fall several of the most important helium lines, the magnesium line λ 4481, and a large number of enhanced metallic lines whose appearance is so characteristic of a portion of the A-type stars. The fact that $H\gamma$ and $H\beta$ are almost without exception measurable lines in the spectra of A- and B-type stars has led us to the use of auxiliary

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tables which have enabled us to save much time in the reduction of the photographs.

The method employed is that used by Professor Frost and several other observers, in accordance with which each negative is reduced independently from measures of three standard lines in the comparison spectrum. It has the marked advantage of requiring no adjustment of the measures on account of changes of focus of the camera or collimator or variation in the scale of the spectrum due to the different temperatures of the prism-train. The chief objection to it is the amount of time required to compute the constants of the Cornu-Hartmann formula for each plate. For the reduction of our spectrograms we have constructed tables giving the values of these constants for the entire range of variation of scale which may occur. This is accomplished in the following way. Two suitable comparison lines are selected at the extremities of the region measured and another line intermediate between them, and these lines are measured upon all of the photographs. The lines selected for our purposes are λ 4337.216 near $H\gamma$, λ 4859.928 near $H\beta$, and the intermediate line λ 4531.327. Let us indicate these lines by λ'', λ, and λ', and the corresponding readings of the comparator by S'', $S+\delta$, and S', as follows:

4859.928	λ	$S+\delta$
4531.327	λ'	S'
4337.216	λ''	S''

The solution of the Hartmann formula gives for the values of the constants:

$$\lambda_0=\lambda-\frac{a(\lambda-\lambda'')-b(\lambda-\lambda')}{a-b+\delta(\lambda'-\lambda'')},$$

$$S_0=\frac{aS'-bS''-\delta S'(\lambda-\lambda')+\delta S''(\lambda-\lambda'')}{a-b+\delta(\lambda'-\lambda'')},$$

$$C=(\lambda''-\lambda_0)(S''-S_0),$$

where $a=(\lambda-\lambda')\ (S''-S)$ and $b=(\lambda-\lambda'')\ (S'-S)$.

If we develop the values λ_0 and S_0 into series we obtain:

$$\lambda_0=\lambda-\alpha(1-\beta\delta+\beta^2\delta^2-\ \ldots\ .)$$

$$S_0=c-d\delta+d^2\delta^2-\ \ldots\ .$$

in which α, β, c, and d are constants. Both series are rapidly convergent for small values of δ. It is, of course, a simple matter to

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adjust all of the spectrograms under the comparator in such a way that the reading upon λ 4337 shall always be the same, or S'' constant. Then for any value of $S'-S''$ we may obtain the values of λ_0 and S_0 corresponding to a set of readings $S+\delta$ from the series given above. Since δ never exceeds 0.025 mm for our photographs the term δ^3 is negligible, and if extreme values of λ_0 and S_0 are known, all intermediate values may be obtained by simple interpolation in which the second differences are constant. To illustrate the construction of a page of the tables we may consider a specific case. Let the readings be:

4859.928..........56.500+δ
4531.327..........41.317
4337.216..........30.000

A range in δ of 0.025 will readily take care of all the differences which may arise in the reading upon λ 4859 for a given reading upon λ 4531. Accordingly three Hartmann formulae are solved for readings of 56.500, 56.512, and 56.525. With these values of λ_0, S_0, and C we derive the values of the first and second differences for purposes of interpolation, and are enabled to compute rapidly the values of λ_0, S_0, and C corresponding to 56.501, 56.502, etc. This page of the table corresponds to the argument $S'-S''=$ 11.317. For the value $S'-S''=11.318$ a second page is computed, and the process is repeated throughout the range of scale which may occur. The measurement of a few photographs taken at different temperatures gives sufficient knowledge of the mean values about which the table should be constructed. In the case of our own photographs a table consisting of forty pages has been found sufficient to care for the entire range of variation of scale observed, and a table of this size was completed by a single computer with the aid of a calculating machine in about six days.

The constants of reduction for a given spectrogram being obtained by inspection from this table, the wave-lengths of the stellar and comparison lines are computed in the usual way from the constants, and the stellar wave-lengths are corrected according to the deviations of the comparison lines. The complete reduction of a spectrogram containing fifteen stellar and comparison lines occupies about twenty minutes.

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TABLE I

STARS OF VARIABLE RADIAL VELOCITY

Boss Number Designation R.A. (1910) Dec. (1910)	Mag. and Type	No. of Plate	Observer	Date	G. M. T.	Radial Velocity	Measured by	Quality	Remarks
					h m	km			
Boss 67	5.6	29	A.	1910, Dec. 20	16 17	+5	L.	Fair	
Groom. 58	B 5	36	P.	1910, Dec. 21	15 32	−35	L.A.		
$0^h19^m.4$		161	A.P.	1911, Jan. 21	16 18	0	L.A.		
$+51°31'$		944	K.	1911, Dec. 11	15 19	+2	L.E.		
		988	A.	1912, Jan. 7	15 34	−4	L.		
Boss 68	5.6	25	A.	1910, Dec. 18	16 14	−18	L.	Poor	
12 Cassiop.	B 9	37	P.	1910, Dec. 21	16 42	−49	L.A.		
$0^h19^m.8$		160	A.	1911, Jan. 21	15 34	−12	L.A.		
$+61°20'$		934	K.	1911, Dec. 9	17 10	+5	L.E.		
		1009	A.	1912, Jan. 11	15 24	−19	L.		
Boss 91	5.4	624	P.	1911, Aug. 13	22 15	−3	L.E.	Fair	
49 G Ceti	A 2	859	K.	1911, Oct. 13	19 42	+15	L.E.A.		
$0^h25^m.9$		915	K.	1911, Nov. 5	16 48	+32	L.E.A.		
$-24°17'$									
Boss 159	5.5	30	A.	1910, Dec. 20	17 08	+18	L.	Fair	
23 Cassiop.	B 9	38	P.	1910, Dec. 21	17 40	−30	L.A.		
$0^h41^m.7$		135	A.	1911, Jan. 18	15 22	−16	L.A.		
$+74°21'$		874	A.	1911, Oct. 30	20 05	+3	L.E.K.		
		935	K.	1911, Dec. 9	18 16	+5	L.E.		
		981	K.	1912, Jan. 5	15 55	+11	L.E.		
Boss 412	5.7	138	B.	1911, Jan. 18	17 37	+77	L.A.	Poor	
1 Persei	B 3	876	A.	1911, Oct. 30	22 05	−12	L.A.		
$1^h46^m.1$		945	K.	1911, Dec. 11	16 20	−6	L.E.		
$+54°42'$		989	A.	1912, Jan. 7	17 40	−23	L.E.		

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Boss 425	5.2	20	A.	1910, Dec. 17	15 30	+ 12	L.A.	Good	
ω Cassiop.	B 9	139	B.	1911, Jan. 18	18 42	− 46	L.A.		
$1^h49^m.0$		148	A.	1911, Jan. 19	18 25	− 44	L.A.		
$+68°15'$		995	A.	1912, Jan. 8	17 00	− 41	L.E.		
Boss 522	5.4	710	K.	1911, Sep. 9	21 37	− 40	L.E.	Fair	Probably composite spectrum
62 Andromedae	A	766	K.	1911, Sep. 17	21 18	− 21	L.E.		
$2^h13^m.5$		801	A.	1911, Oct. 6	21 45	− 22	L.E.A.K.		
$+46°58'$									
Boss 641	5.5	70	P.	1910, Dec. 24	16 38	− 9	L.A.	Good	
π Arietis	B 5	146	A.	1911, Jan. 19	16 48	− 12	L.A.		
$2^h44^m.2$		209	A.	1911, Feb. 10	15 51	+ 32	L.E.		
$+17°5'$		951	K.	1911, Dec. 12	15 50	+ 7	L.E.		
Boss 731	5.7	711	K.	1911, Sep. 9	22 39	− 4	L.E.	Good	Probably composite spectrum
Piazzi 9	A	767	K.	1911, Sep. 17	22 19	− 8	L.E.		
$3^h9^m.8$		820	A.	1911, Oct. 8	21 46	− 17	L.E.A.		
$+30°13'$		860	K.	1911, Oct. 13	21 30	− 4	L.E.A.		
		959	K.	1911, Dec. 14	18 00	+ 2	L.E.		
Boss 740	5.5	12	A.	1910, Dec. 16	17 02	+ 23	L.A.	Poor	
30 Persei	B 5	32	A.	1910, Dec. 20	18 42	+ 12	L.A.		
$3^h11^m.7$		40	P.	1910, Dec. 21	19 28	− 6	L.A.		
$+43°42'$		77	P.	1911, Jan. 7	15 15	− 14	L.A.		
		87	P.	1911, Jan. 8	14 36	+ 11	L.A.		
Boss 796	6.1	33	A.	1910, Dec. 20	19 40	+ 24	L.A.	Poor	
Brad. 480	B 8	41	P.	1910, Dec. 21	20 30	+ 2	L.A.		
$3^h24^m.2$		97	P.	1911, Jan. 11	17 43	− 1	L.A.		
$+47°48'$		107	P.	1911, Jan. 12	18 01	+ 13	L.A.		
Boss 841	5.7	51	P.	1910, Dec. 22	18 12	− 59	L.A.	Poor	
13 Tauri	B 8	177	A.	1911, Feb. 7	16 12	+ 9	L.W.		
$3^h37^m.1$		997	A.	1912, Jan. 8	19 05	+ 8	L.E.		
$+19°25'$									

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TABLE I—*Continued*

Boss Number Designation R.A. (1910) Dec. (1910)	Mag. and Type	No. of Plate	Observer	Date	G. M. T.	Radial Velocity	Measured by	Quality	Remarks
					h m	km			
Boss 857	5.4	62	P.	1910, Dec. 23	17 28	+ 61	L.A.	Poor	
24 Eridani	B 8	110	P.	1911, Jan. 12	18 44	+ 75	L.A.		
3^h39^m9		127	B.	1911, Jan. 17	16 24	+ 41	L.A.		
$-1°29'$									
Boss 878	5.3	724	A.	1911, Sep. 11	22 40	− 19	L.E.	Good	
42 Persei	A 2	790	A.	1911, Oct. 5	23 14	+ 13	L.E.A.		
3^h43^m8		891	A.	1911, Nov. 1	21 25	− 7	L.		
$+32°49'$		967	K.	1911, Dec. 30	18 42	− 40	L.E.K.		
Boss 992	5.6	35	A.	1910, Dec. 20	21 59	− 35	L.A.	Poor	
Groom. 809	B 3	42	P.	1910, Dec. 21	21 46	+ 3	L.A.		
4^h13^m4		180	A.	1911, Feb. 7	18 41	− 42	L.W.A.		
$+50°42'$		271	A.	1911, Mar. 15	15 29	− 7	L.A.		
		1007	A.	1912, Jan. 9	19 35	− 40	L.E.		
Boss 1076	4.4	826	K.	1911, Oct. 9	21 48	− 43	L.E.A.	Good	
88 Tauri	A 2	904	K.	1911, Nov. 3	22 31	− 40	L.E.A.		
4^h30^m7		984	K.	1912, Jan. 5	19 54	+ 71	L.E.		
$+9°59'$									
Boss 1249	6.0	211	A.	1911, Feb. 11	18 06	+ 61	L.	Good	Two spectra present, B 5 and probably A 3. Measures on stronger spectrum B 5
Pulk. 801	B 5 p	272	A.	1911, Mar. 15	16 30	+ 64	L.A.W.		
5^h10^m4		281	A.	1911, Mar. 16	16 26	+ 53	L.A.		
$+34°13'$		309	P.	1911, Mar. 24	16 20	+ 63	L.W.		
		936	K.	1911, Dec. 9	20 38	+ 53	L.E.		
		998	A.	1912, Jan. 8	20 13	+ 64	L.E.		
Boss 1349	5.6	64	P.	1910, Dec. 23	19 18	+134	L.A.	Fair	
Green. 412 (1860)	B 2	112	P.	1911, Jan. 12	21 28	−138	L.A.		
5^h28^m9									
$-1°13'$									

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Boss 1607 Groom. 1149 $6^h18^m.8$ $+56°20'$	5.7 A 5	877 910 949	A. K. K.	1911, Oct. 30 1911, Nov. 4 1911, Dec. 11	23 02 22 08 23 28	− 55.8 + 21.2 − 75.8	L.E.A. L.E.A. L.E.	Good	
Boss 1906 Brad. 1056 $7^h15^m.5$ $+55°29'$	5.9 B 8	68 103 132	P. P. B.	1910, Dec. 23 1911, Jan. 11 1911, Jan. 17	23 10 23 40 21 58	− 80 + 90 − 6	L.A. L.A. L.A.	Fair	Two spectra present
Boss 2400 *62 Cancri* $8^h52^m.2$ $+15°40'$	5.3 A 3	930 969 1025	K. K. K.	1911, Dec. 8 1911, Dec. 30 1912, Jan. 24	23 11 23 08 21 58	− 46 − 35 − 13	L.E. L.E.K. L.E.A.	Good	
Boss 2407 *a Cancri* $8^h53^m.6$ $+12°12'$	4.4 A 3	923 931 1026	K. K. K.	1911, Dec. 7 1911, Dec. 8 1912, Jan. 24	1 08 23 56 22 50	− 54 − 59 − 21	L.E. L.E. L.E.A.	Good	
Boss 2451 *19 Hydrae* $9^h4^m.3$ $-8°14'$	5.6 B 8	191 202 256 392	A. A. A. A.	1911, Feb. 8 1911, Feb. 9 1911, Mar. 11 1911, May 9	19 24 19 38 18 16 16 10	+ 14 + 18 + 46 + 4	L.E.A. L.W.A. L.A. L.A.	Poor	
Boss 2866 *42 Leo. Min.* $10^h40^m.9$ $+31°9'$	5.4 B 9	75 104 157	P. P. A.	1910, Dec. 25 1911, Jan. 12 1911, Jan. 20	0 03 1 20 0 40	− 2 + 40 − 9	L.A. L.A. L.A.	Poor	
Boss 3123 *95 Leonis* $11^h51^m.0$ $+16°9'$	5.7 A 2	950 1027	K. K.	1911, Dec. 21 1912, Jan. 25	0 32 0 01	− 90 + 7	L.E. L.E.A.	Fair	

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TABLE I—*Continued*

Boss Number Designation R.A. (1910) Dec. (1910)	Mag. and Type	No. of Plate	Observer	Date	G. M. T.	Radial Velocity	Measured by	Quality	Remarks
					h m	km			
Boss 3138	5.4	183	A.	1911, Feb. 7	22 34	+16	L.W.	Good	
31 Crateris	B 3	258	A.	1911, Mar. 11	20 26	−116	L.A.		
$11^h56^m.2$		311	P.	1911, Mar. 24	20 15	+85	L.A.		
$-19°9'$		348	A.	1911, Apr. 12	18 56	−21	L.E.		
Boss 3546	6.4	302	B.	1911, Mar. 19	22 22	+11	L.A.	Poor	
85 Virginis	B 9	312	P.	1911, Mar. 24	22 00	−93	L.A.		
$13^h40^m.7$									
$-15°19'$									
Boss 3915	5.6	363	A.	1911, Apr. 14	21 30	+16	L.E.A.	Poor	
50 Boötis	B 9	509	A.	1911, July 6	18 38	−3	L.E.A.		
$15^h18^m.2$		539	B.	1911, July 11	16 41	−41	L.E.A.		
$+33°15'$									
Boss 3944	5.7	303	P.	1911, Mar. 19	23 55	−23	L.E.A.	Poor	Possibly composite spectrum
35 Librae	B 3	314	P.	1911, Mar. 24	23 39	−19	L.A.		
$15^h27^m.8$		489	A.	1911, June 17	15 57	+30	L.A.E.		
$-16°33'$									
Boss 3993	5.3	232	B.	1911, Feb. 17	0 30	+3	L.W.	Good	
χ Serpentis	A 3 p	333	P.	1911, Apr. 9	20 47	−4	L.		
$15^h37^m.6$		478	A.	1911, June 15	16 10	+36	L.A.		
$+13°8'$									
Boss 4097	5.8	359	A.	1911, Apr. 13	22 22	−13	L.	Poor	
11 Scorpii	B 9	496	A.	1911, July 4	17 45	−30	L.E.A.		
$16^h2^m.6$		527	A.	1911, July 9	16 40	−6	L.E.		
$-12°30'$		533	A.	1911, July 10	17 19	−50	L.E.A.		

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Boss 4353	6.2	442	B.	1911, June 10	21 26	− 14	L.A.	Fair	
Piazzi 303	A	464	P.	1911, June 11	19 48	− 21	L.E.A.		
$17^h3^m.6$		497	A.	1911, July 4	19 07	− 39	L.A.		
$-0°58'$		540	B.	1911, July 11	17 56	− 8	L.E.A.		
Boss 4402	5.5	674	B.	1911, Sep. 6	60 00	− 18	L.E.	Fair	
70 Herculis	A	726	K.	1911, Sep. 12	15 22	− 26	L.E.A.		
$17^h17^m.2$		812	A.	1911, Oct. 8	15 10	− 3	L.E.A.		
$+24°35'$									
Boss 4643	5.7	660	B.	1911, Sep. 4	16 07	− 94	L.E.A.	Good	
108 Herculis	A 3	714	K.	1911, Sep. 10	15 35	− 62	L.E.		
$18^h17^m.5$		813	A.	1911, Oct. 8	16 09	− 28	L.E.A.		
$+29°49'$		822	K.	1911, Oct. 9	15 25	+ 38	L.E.A.		
Boss 4867	5.7	667	B.	1911, Sep. 5	16 59	− 42	L.E.A.	Poor	Probably composite spectrum
Piazzi 318	A 3	728	K.	1911, Sep. 12	16 36	− 6	L.E.A.		
$19^h3^m.0$		906	K.	1911, Nov. 4	15 00	− 24	L.E.K.		
$+28°29'$									
Boss 4947	6.2	591	B.	1911, Aug. 9	18 21	+ 61	L.E.	Good	
2 Sagittae	A 3	879	A.	1911, Oct. 31	15 46	+ 18	L.E.A.		
$19^h20^m.3$									
$+16°46'$									
Boss 5042	6.4	629	P.	1911, Aug. 14	19 18	− 27	L.E.A.	Good	
ψ Aquilae	A p	720	K.	1911, Sep. 11	17 29	− 2	L.E.A.		
$19^h40^m.4$		763	K.	1911, Sep. 17	17 20	+ 16	L.E.		
$+13°5'$									
Boss 5113	5.6	518	A.	1911, July 7	21 44	− 65	L.E.A.	Poor	
Groom. 2984	B 3	886	A.	1911, Nov. 1	15 32	+ 23	L.E.A.		
$19^h54^m.1$									
$+40°8'$									

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TABLE I—*Continued*

Boss Number Designation R.A. (1910) Dec. (1910)	Mag. and Type	No. of Plate	Observer	Date	G. M. T.	Radial Velocity	Measured by	Quality	Remarks
					h m	km			
Boss 5178	6.0	519	A.	1911, July 7	22 44	−16	L.E.A.	Poor	$H\beta$ doubly reversed
20 Vulpeculae	B 8 p	536	A.	1911, July 10	20 48	−32	L.E.A.		
$20^h8^m.2$		552	B.	1911, July 13	20 36	−37	L.E.A.		
$+26°13'$		796	A.	1911, Oct. 6	17 50	−15	L.A.K.		
Boss 5211	5.8	691	B.	1911, Sep. 7	18 58	+2	L.E.A.	Fair	
36 Cygni	A	738	K.	1911, Sep. 14	18 13	−27	L.E.A.		
$20^h15^m.1$		823	K.	1911, Oct. 9	17 03	−10	L.E.A.		
$+36°43'$									
Boss 5292	5.5	706	K.	1911, Sep. 9	17 51	+45	L.E.A.	Good	
ι Delphini	A 2	770	K.	1911, Sep. 18	18 06	+18	L.E.		
$20^h33^m.5$		894	A.	1911, Nov. 2	15 08	+24	L.E.A.		
$+11°4'$									
Boss 5322	5.8	692	B.	1911, Sep. 7	20 12	−40	L.E.	Good	
Groom. 3258	B 9	755	K.	1911, Sep. 16	17 59	−25	L.E.		
$20^h38^m.7$		914	K.	1911, Nov. 5	15 34	−16	L.E.A.		
$+41°24'$									
Boss 5573	6.2	593	B.	1911, Aug. 9	21 25	+33	L.E.	Fair	
76 Cygni	B 9	640	P.	1911, Aug. 15	21 48	−7	L.E.		
$21^h38^m.0$									
$+40°18'$									
Boss 5581	6.2	588	B.	1911, Aug. 8	20 40	+23	L.E.	Poor	
45 Capricorni	A 2	621	P.	1911, Aug. 13	19 40	+45	L.E.		
$21^h39^m.1$		654	P.	1911, Aug. 17	19 34	−3	L.E.A.		
$-15°10'$									

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Boss 5692 *25 Pegasi* $22^h3^m.6$ $+21°16'$	5.9 B 5 p	852 887 954	K. A. K.	1911, Oct. 12 1911, Nov. 1 1911, Dec. 13	18 23 16 48 15 32	− 55 − 59 − 36	L.E.A. L.E.A. L.E.	Fair	*Hβ* bright
Boss 5738 Br. 2938 $22^h11^m.0$ $+62°43'$	6.4 B 8	601 858	B. K.	1911, Aug. 10 1911, Oct. 13	22 08 17 36	− 15 + 28	L.E.A. L.E.A.	Poor	
Boss 5833 *8 Lacertae* $22^h31^m.9$ $+39°10'$	5.9 Oe p	608 632 807	B. P. A.	1911, Aug. 11 1911, Aug. 14 1911, Oct. 7	22 16 22 22 19 44	− 39 + 7 + 4	L.E.A. L.E. L.A.K.	Poor	*Hβ* unsymmetrically reversed
Boss 5848 *30 Cephei* $22^h35^m.5$ $+63°7'$	5.3 B 9	732 784 866	K. A. K.	1911, Sep. 12 1911, Oct. 5 1911, Oct. 14	21 42 18 24 17 30	+ 40 − 5 + 16	L.E.A. L.E.A.K. L.E.A.	Poor	
Boss 5856 *12 Lacertae* $22^h37^m.5$ $+39°45'$	5.4 B 2	648 702 756 786	P. K. K. A.	1911, Aug. 16 1911, Sep. 8 1911, Sep. 16 1911, Oct. 11	23 00 21 49 19 03 19 34	+ 3 + 6 − 8 − 43	L.E. L.E.A. L.E. L.E.	Good	
Boss 6075 *18 Andromedae* $23^h34^m.8$ $+49°58'$	5.4 B 8	602 633 659 799	B. P. P. A.	1911, Aug. 10 1911, Aug. 14 1911, Aug. 18 1911, Oct. 6	23 28 23 30 0 07 19 56	+ 37 − 3 − 1 + 1	L.E.A. L.E. L.E.A. L.E.A.	Poor	
Boss 6142 Br. 3184 $23^h51^m.0$ $+56°55'$	6.2 Oe p	888 987 1003	A. A. A.	1911, Nov. 1 1912, Jan. 6 1912, Jan. 9	18 12 15 54 15 12	− 53 − 11 −133	L.E.A. L.E. L.	Fair	Spectrum probably composite

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SOME RESULTS

A list of fifty spectroscopic binaries.—We have found the above 50 stars mainly of types A and B to have variable velocities in the line of sight. The initial given in the column headed "Observer" refers to Messrs. Adams, Babcock, Kohlschütter, and Pease, and in the column "Measured by" to Miss Lasby, Miss Ensign, Miss Waterman, and Messrs. Kohlschütter and Adams. The type of spectrum given is in most cases from our own observations. The column in the table preceding "Remarks" indicates roughly the general character of the spectrum for purposes of measurement. There is evidence of complexity of the hydrogen lines in the spectra of many of these stars, and no doubt more would be found were the density of the negatives made somewhat less. As a rule, however, considerable density of the continuous spectrum aids in the measurement of the broad hazy lines characteristic of the spectra of most of these stars.

In addition to the stars given in Table I we have secured observations which agree in confirming the variability of velocity of the following stars announced from other observatories:

Name	R. A. 1910	Dec. 1910	Mag.	Observatory
25 Serpentis	$15^h41^m.4$	$-1°31'$	5.6	Yerkes
χ Ophiuchi	16 21.8	$-18°14'$	4.8	Lick
ζ' Lyrae	18 41.7	$+37°31'$	4.4	Lick
δ¹ Lyrae	18 50.6	$+36°52'$	5.7	Yerkes
θ Aquilae	20 6.7	$-1° 5'$	3.2	Meudon
6 Lacertae	22 26.6	$+42°40'$	4.5	Yerkes

Stars with bright hydrogen lines.—The stars *20 Vulpeculae*, *25 Pegasi*, and *8 Lacertae* in Table I have one or more hydrogen lines bright. In *χ Ophiuchi*, as has been announced by Professor Campbell, both $H\gamma$ and $H\beta$ are bright. The following stars also have bright hydrogen lines:

Name	R. A. 1910	Dec. 1910	Mag.	Bright Lines
11 Camelopardalis	$4^h58^m.3$	$+58°51'$	5.3	$H\gamma$ and $H\beta$
165 G Canis Majoris	7 20.6	$-16° 1'$	5.3	$H\gamma$ and $H\beta$
25 Vulpeculae	20 18.2	$+24°10'$	5.7	$H\beta$

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TABLE II

STARS WITH GREAT RADIAL VELOCITIES

Designation R.A. (1910) Dec. (1910)	Mag. Spectrum	No. of Plate	Observer	Date	Radial Velocity	Mean Radial Velocity	Velocity in Space	Angle to Line of Sight
					km	km	km	
Lal. 4855	7.2	β 74	A.	1910, Jan. 18	−120	−120	186	130°
2^h33^m3	G							
$+30°28'$								
Lal. 5761	8.0	β 75	A.	1910, Jan. 18	−156			
3^h3^m1	F	β 91	A.	1910, Feb. 18	−153			
$+26°\ 0'$		β 104	A.	1910, Feb. 21	−150	−153	188	144°
Groom. 864	7.3	β 81	A.	1910, Jan. 21	+103			
4^h35^m2	G	β 86	A.	1910, Feb. 17	+102			
$+41°58'$		β 97	A.	1910, Feb. 20	+101			
		β 105	A.	1910, Feb. 21	+ 97			
		γ 237	P.	1911, Feb. 18	+100.8			
		γ 245	P.	1911, Feb. 21	+103.7	+101	163	52°
Groom. 1830	6.5	γ 194	A.	1911, Feb. 8	− 99.7			
11^h47^m7	G	γ 247	P.	1911, Feb. 21	− 99.2			
$+38°23'$		γ 362	A.	1911, Apr. 14	− 96.2			
		γ 399	A.	1911, May 11	− 95.8	− 97.7	343	107°
Lal. 28607	7.3	γ 323	P.	1911, Apr. 7	−166			
15^h38^m2	A	γ 368	A.	1911, Apr. 15	−168			
$-10°39'$		γ 446	B.	1911, June 7	−172			
		γ 516	A.	1911, July 7	−175	−170	173	128°
31 b Aquilae	5.2	γ 335	P.	1911, Apr. 9	− 95.9			
19^h20^m7	G	γ 377	A.	1911, Apr. 16	− 97.0	− 96.4	119	144°
$+11°45'$								
Lal. 37120–1	6.6	β 227	A.	1910, May 20	−162			
19^h30^m1	G	β 235	A.	1910, May 21	−163			
$33°\ 0'$		γ 364	A.	1911, Apr. 14	−161.9			
		γ 409	P.	1911, May 15	−161.8	−162	167	166°

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Some stars with great radial velocities.—In the course of our observations of some stars of large proper motions with known parallaxes we have found a few stars with very great radial velocities. Most of these had previously been observed with the small focal plane spectrograph and approximate velocities determined. Accordingly in Table II the spectrograms obtained with the focal plane instrument are indicated by the series letter β and those with the large spectrograph by γ. The values obtained with the small spectrograph are of course subject to considerable uncertainty.

With the exception of *Groombridge 1830*, for which Professor Campbell has published a value of -95 km, no other observations are available for these stars. The star *Lalande 28607* is of especial interest because of its type of spectrum. No star of type A with a constant velocity approaching this in magnitude has been observed heretofore.

Since the parallaxes and the proper motions of these stars are known, a computation of their velocities and directions of motion in space becomes of interest. These are given in the last two columns of Table II, the requisite data being taken from the list of parallax determinations compiled by Kapteyn and Weersma.[1]

I am indebted for much assistance in connection with the results referred to in this communication. In particular I wish to express my appreciation to Mr. Pease for his great aid in the design of the spectrograph, many important features of which are due to his suggestions; to Mr. Babcock and Dr. Kohlschütter for observations with the instrument; and to Miss Lasby, Miss Ensign, and Miss Waterman for the difficult work involved in the measurement of the spectra.

MOUNT WILSON SOLAR OBSERVATORY
February 1912

[1] *Publications of the Astronomical Laboratory of Groningen*, No. 24.

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