VARIABLE STARS OF VERY SMALL RANGE

By Robert H. Baker

The application of the photoelectric cell to stellar photometry has brought about the detection and study of variations in starlight too minute for the more frequent types of photometers. These investigations are confined chiefly to the past twelve years and to the Berlin-Babelsberg, Illinois, Lick and Wisconsin Observatories. It may be well to assemble in a preliminary way what has been learned about small periodic light variations not produced by eclipses.

We do not know how numerous this class of stars will turn out to be. Their number is now small, too small in fact to justify anything more than tentative generalization. The following statements will describe, as well as any at this time, their outstanding features:

(1) The period is constant, frequently very short—only a few hours.

(2) The range of the light variation is of the order of 0.1 magnitude. It is variable, at times falling to almost nothing.

(3) The shape of the light curve changes; but the interval from minimum to maximum light does not depart markedly from one-half the period.

(4) These stars are spectroscopic variables. The lines oscillate in the period of the light variation with accompanying changes in their intensities.

(5) The amplitude and shape of the velocity curve do not remain the same. The mean velocity varies periodically.

Some spectroscopic variables exhibit the characteristics (1), (4) and (5), but they are not variable in light.

Seven stars, in Table I, comprise the known membership of this class. It should be noted that the light variations of three have been studied thus far only at one observatory and that the identity of one of these stars is still in question. There is little doubt that all seven are variable stars. In this table and those that follow I have omitted the spectroscopic references in case they already appear in the *Third Catalogue of Spectroscopic Binaries.*[1]

It is natural to search for further additions to this list among the stars which are known or suspected to have the characteristics (1), (4) and (5)—the *β Canis Majoris* type according to Henroteau's designation. Having in mind the

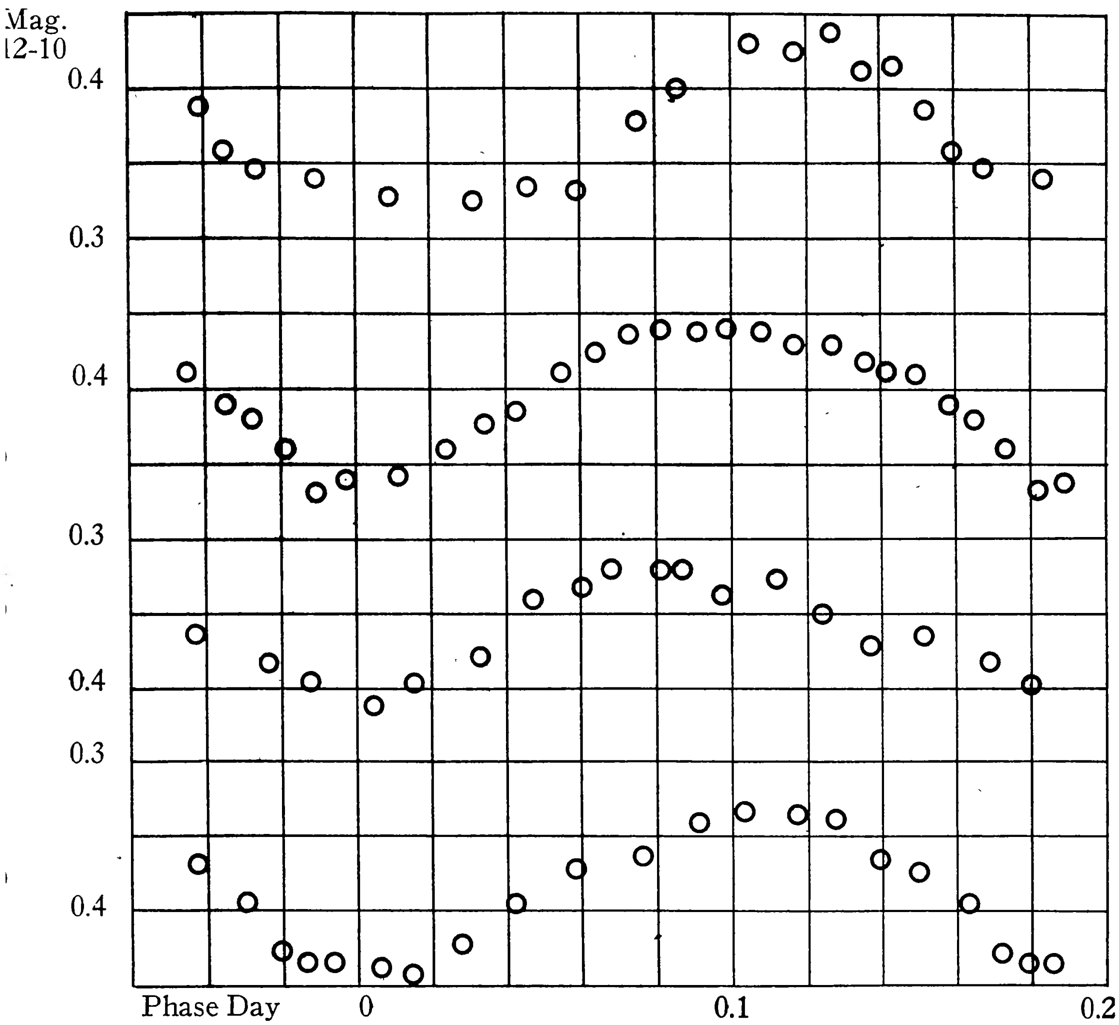

Figure 1. Mean Light Curves of 12 *Lacertæ*.
(a) 1918 Berlin; (b) 1920 Berlin; (c) 1922 Lick; (d) 1925 Illinois.
Phases are based on the spectroscopic elements:
Perihelian=2420761.149+0.1930890 days.

necessarily accompanied by changes in brightness. The case of *τ Cygni* is fairly conclusive from both points of view and a

[1]*Lick Obs. Bull.*, **11**, 141, 1924.

like situation is strongly suggested for other stars for which unfailing correlation which is found in Cepheids between spectroscopic and photometric variations, we are surprised to find what appears to be the lack of such correlation in the stars of the type under discussion. Spectroscopic variations are not the available data are assembled in Tables II and III.

As Stebbins has already remarked concerning eclipsing

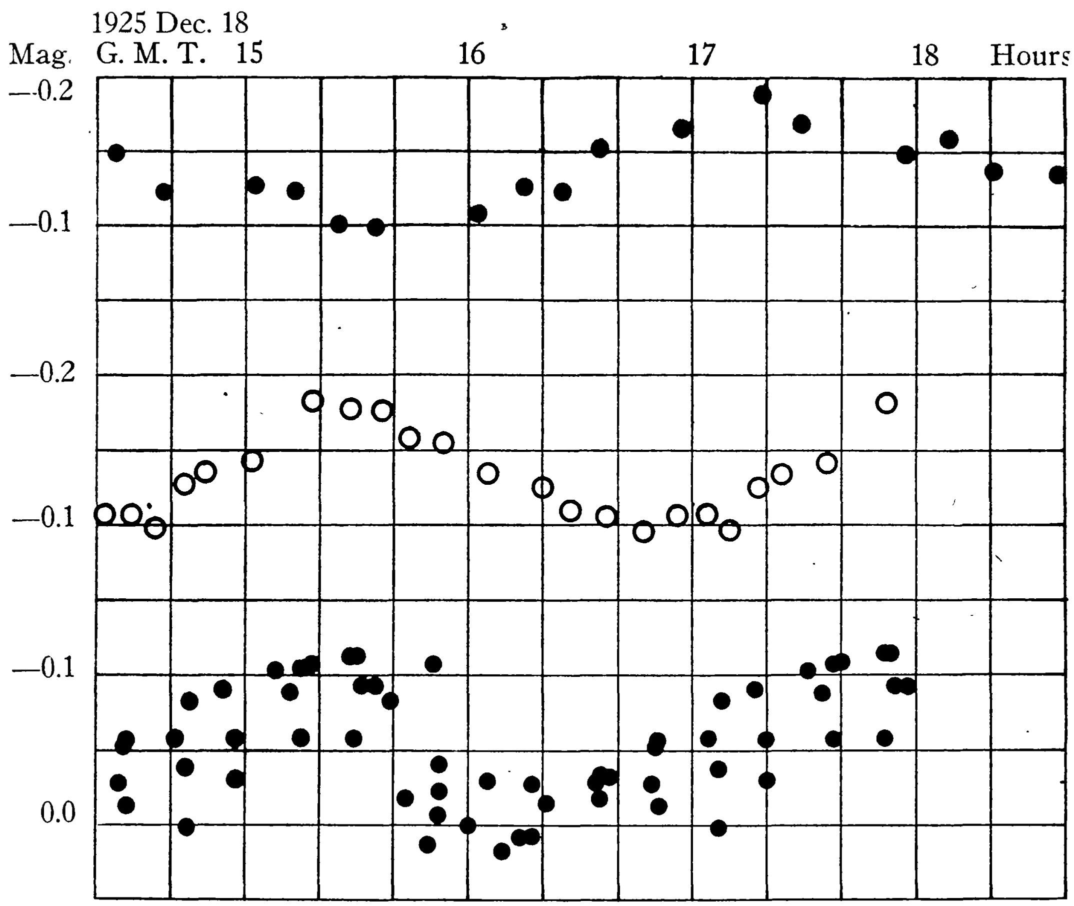

Figure 2. Light Curves of *ν Eridani* and *γ-ζ Ursæ Min.* (a) Single Series of *ν Eridani* (*ν-μ*); (b) Mean Curve of *ν Eridani;* (c) Five Series of *γ-ζ Ursæ Minoris.*

binaries, it is a simpler matter to say that a star varies in light than that it does not vary. A single series of photoelectric observations of *ν Eridani* is shown in Figure 2 to indicate the precision of these measurements. The variation of .08 magnitude is unquestionable. If the form of the light curve does not change, as with many eclipsing binaries, a range of .02 magnitude could be detected. But for the more complex fluctuations of the stars under consideration, it is a serious matter to disentangle actual slight variations in brightness from apparent variations produced by instrumental and atmospheric irregularities, if the range is much less than .04 magnitude.

Viewing the characteristics above in the light of the material in the tables, we find frequent verifications and occasional inconsistencies. The constancy of the period is well illustrated by 12 *Lacertæ*. After a succession of nearly 20,000 cycles there is no indication of any change in its value. The mean curves for four different epochs, in Figure 1, exhibit very well the variations in form which appear to characterise these stars. It is interesting to notice that the year of the sharpest and most delayed maximum, 1918, is also the time of greatest negative mean velocity according to Young,[2] who estimates the value of the long period spectroscopic variation as fifteen or twenty years.

We may well suppose, although there is no observational evidence to support this view, that variations in spectroscopic and photometric ranges are simultaneous. From both points of view 12 *Lacertæ* is a good illustration of variations in amplitude. On the spectroscopic side Young has observed amplitudes from 70 km to nothing at all. Henroteau has advanced the suggestion that the minimum amplitude may go beyond zero and assume a negative value. On these grounds he justifies the period assigned to *β Canis Majoris* which predicts either a maximum or a minimum of the velocity curve. At the other extreme we find *σ Scorpii* whose short period variation shows little evidence of amplitude change.

Especially interesting is the case of α^2 *Canum Venaticorum* in which only a few spectrum lines vary in position and intensity. Guthnick's persistent photoelectric observations since 1914 establish beyond doubt the periodic character of the light variation; furthermore, they inform us of the suspension of the

[2] *Pop. Astron.*, **30**, 20, 1922.

activity of this star for at least two months in 1920 and the resumption of the fluctuation with unchanged period in the following year. Apparently June, 1925, was a time of unusual activity, for the Illinois observations during this month show a variation two or three times greater than that found in former years at Berlin. The question is raised whether α^2 *Canum Venaticorum* whose light variations are interrupted by periods of inactivity and such stars as η *Aurigæ* and γ *Ursæ Minoris* which are said to vary only occasionally are not intermediate between 12 *Lacertæ* and τ *Cygni.*

A possible characteristic of stars of this type may be worth mentioning, namely, that maxima and minima of the light variations of β *Cephei* and 12 *Lacertæ* are coincident, respectively, with maximum and minimum compressions of the stars within less than one-tenth of the period. For the latter star this agreement is well shown in Figure 1 where the phases are taken from minimum compression (or perihelion). But we at once find an exception in α *Ursæ Minoris;* here maximum light occurs nearer the time of maximum *velocity* of expansion as with the normal Cepheid.

The relation of the stars under discussion to other variable stars requires attention. In the sense that all periodic variable stars, excluding of course eclipsing binaries, appear to be closely related and to require the same physical interpretation, there is no reason for separating these stars from the others. If, for example, we include them in a graph (Figure 3) in which the logarithm of the period is plotted against spectral class, we find that they fall into a linear sequence with the others. However, the frequencies of variable stars are greater for certain periods, as the figure shows and as is of course well known, and their characteristics vary from one maximum frequency to the next. On this basis it is customary to classify periodic variable stars as long-period, Cepheid and cluster variables.

A new maximum frequency is appearing for periods of the order of 0.15 day, comprising the stars we are now consider-

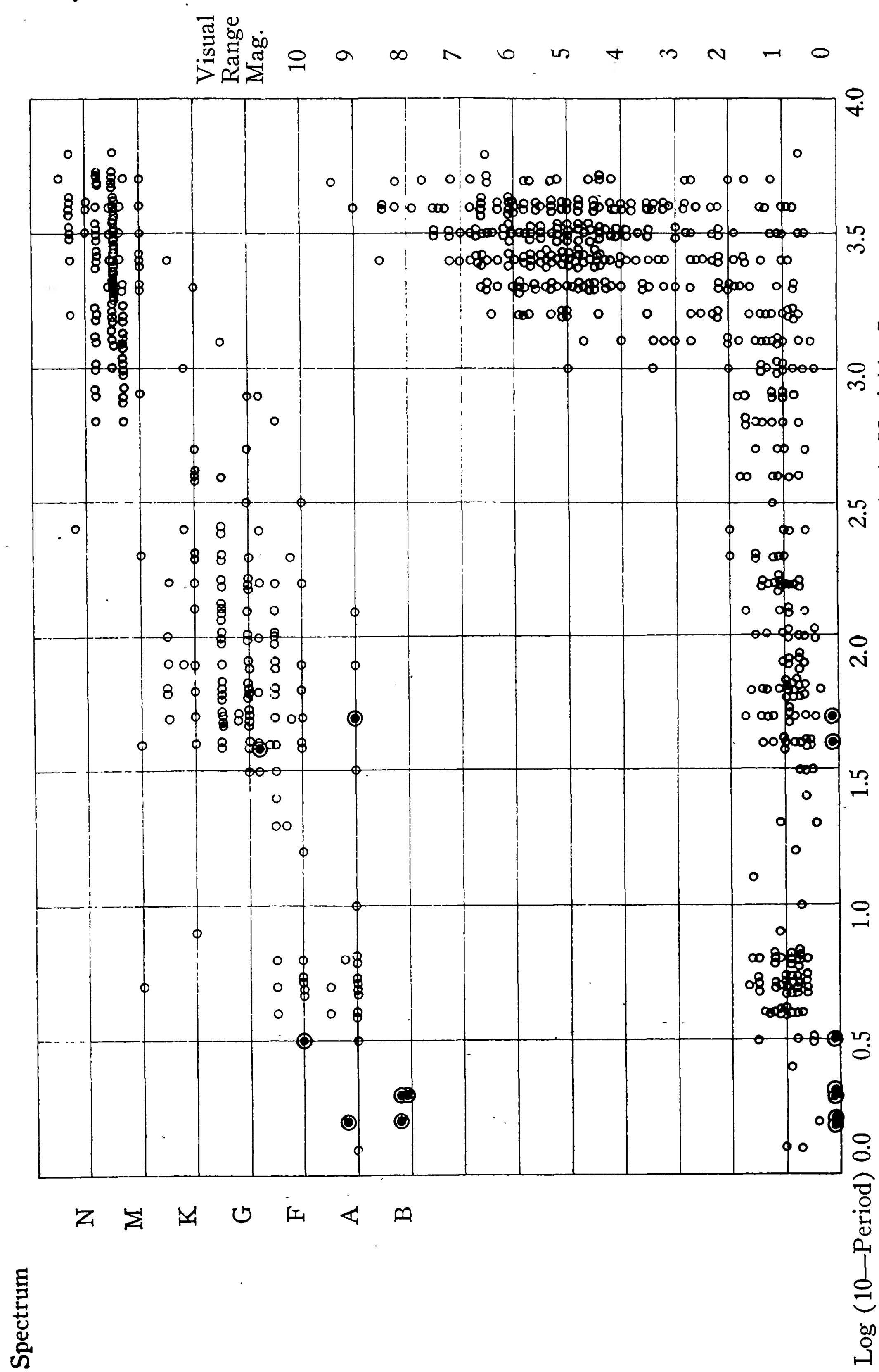

Figure 3. Spectral and Visual Ranges of Periodic Variable Stars.

ing. This group of stars differs from the adjacent cluster variables in the form and range of the light curve and in the greater instability of these features. Henroteau's designation of the group as *β Canis Majoris* type[3] has gained some following. From the photometric viewpoint it would be more fortunate if the typical star were known to be a light variable.

Until the physical causes which underlie stellar variability are more clearly understood, a classification of variable stars may proceed on any basis so long as it serves a useful purpose. If we plot range of magnitude against the logarithm of the period, as in Figure 3, and slice the diagram horizontally rather than vertically, as is usual, we have the apparently logical classes: of large range, of moderate range, and of very small range. I have no disposition to defend this arrangement except for the present purpose. It justifies at least the title of this paper. It serves to separate the stars here considered from variables of very short period such as XX *Cygni,* RV *Canum Venaticorum* and RZ *Tauri* which appear to fit in better with cluster variables. It permits the inclusion of α^2 *Canum Venaticorum* and *α Ursæ Minoris,* and suggests a search for other stars of this class with periods of the order of a day. Finally it provides a logical connection with stars such as *τ Cygni* which have the characteristics of this class except light variability.

Although the present paper is concerned with periodic variability, mention may be made of another type of light variation of very small amount which is frequently encountered with the photoelectric photometer and whose reality is beyond doubt. Stebbins[4] has found irregular variations of two or three percent in as many weeks in the light of several white stars, slightly larger changes in yellow stars and still greater ones in red stars. Such variations probably appear also in

[3]The use of this designation is not intended to indicate the writer's approval of it as a permanent choice.
[4]*Science,* **62,** 519, 1925.
[5]*Ap. J.,* **56,** 220, 1922.
*In Figure 3 the 7 known variables of very small range are indicated by larger symbols. The remainder of the material is taken from *V. J. S.,* **59,** 1924. When many points occur together, especially for the spectrum of long period variables, no attempt is made to show all the points.

Guthnick's published results. Wylie[5] found a progressive change in the red star β *Aquilæ* which amounted to .05 magnitude in 100 days. Recent series of δ—γ *Ceti*, both white stars, at Illinois, show a progressive change in the difference amounting to .02 magnitude in two months.

The present paper is preliminary. Its object is not to insist on anything presented, but rather to assemble some of the material in the hope that it will be serviceable to those who are interested in this problem.

University of Illinois Observatory,
February 2, 1926.

TABLE I

PERIODIC VARIABLE STARS OF SMALL RANGE, THE MAJORITY HAVING VERY SHORT PERIODS

Star	R.A.	Decl.	Mag.	Class
νEridani	$4^h31^m.3$	—3° 33′	4.12	B2

Photoelectric observations at Illinois in 1925 establish a periodic light variation with a range of 0.1 magnitude. The elements are: Max. =2424465.764+0^d.15430. A single series and the mean curve from several series are shown in Figure 2. In *LOB* II, 147, 1924, the spectroscopic period is given as 0.1899 day.

Star	R.A.	Decl.	Mag.	Class
γBootis	$14^h28^m.1$	+38° 45′	3.00	F

Elements of the light variation are: Max.=2420252.501+$0.^d$290313 (*Veröff, Berlin-Babelsberg* II, 3, 128, 1918). The range is .05 magnitude. Guthnick (*Festschrift für Seeliger,* page 394) finds the period constant during the interval 1914-23. The spectroscopic variability is undecided.

Star	R.A.	Decl.	Mag.	Class
γUrs. Min.	$15^h20^m.9$	+72° 11′	3.14	A2, or
ζUrs. Min.	15 47 .6	+78 06	4.34	A2

Five series of differences γ minus ζ at Illinois in 1925 show a range of 0.1 magnitude and are represented (see Figure 2) by preliminary elements: Max.=2424301.78+0^d.14335. For the present it would be unwise to assign the variation to γ. This period does not agree with Struve's spectroscopic period (Table II). Moreover a light variation of this range and periodicity would not have escaped the Berlin observers; they compared γ *Ursæ Min.* with α *Draconis.* Finally, inversion of the light curve gives it a more familiar appearance. Part of the asymmetry, however, may be fortuitous.

Star	R.A.	Decl.	Mag.	Class
βCephei	$21^h27^m.4$	+70° 07′	3.32	B1

The first discovered, by Guthnick, of this class and representative of the others. The light variation is somewhat less than 0.1 magnitude. The period, 0.1904795 day satisfies both photometric and spectroscopic results. The photometric evidence is reviewed by Miss Cummings (*LOB* **11**, 99, 1921).

12 Lacertæ . . . . . . $22^h37^m.0+39° 43'$ 5.18 B2

The spectroscopic variation has been studied persistently by Young. Since the discovery of the light variation, independently by Stebbins and Guthnick, the photometric history is known from photoelectric observations by Guthnick (*AN* **208**, 219, 1918; Jubilee Number, page 12, 1921) and by the writer. Mean light curves for four epochs appear in Figure 1. Young's spectroscopic period thus far requires no alteration. His elements are: Perihelion=2420761.1488+$0^d.193089$. The range of the light variation is 0.1 magnitude.

αUrs. Min. . . . . . . $1^h22^m.6+88° 46'$ 2.12 F8

The spectroscopic period is 3.96809 days. The character of the spectroscopic variation changes and the mean velocity varies in a period as yet unknown. The light varies in this period (Hertzsprung, *AN* **189**, 89, 1911) with a range of about 0.1 magnitude.

α^2Can. Ven. . . . . . $12^h51^m.4+38° 52'$ 2.90 A0p

The spectroscopic period is 5.5 days. Guthnick found a light variation of .05 magnitude and the elements: Max.=2420242.04+$0^d.553$ (*Veröff Berlin-Babelsberg,* **11**, 3, 128, 1918). In *Festschrift für Seeliger,* page 398, he gives the improved period 5.470 days and the history of the light fluctuations during the interval 1914-23; both the form and the range of light curve vary. Photoelectric observations at Illinois in June, 1925, show a variation greater than 0.1 magnitude in a period of 5.5∓ days.

TABLE II

SPECTROSCOPIC VARIABLE STARS OF VERY SHORT PERIOD, NOT KNOWN TO VARY PERIODICALLY IN LIGHT

Star	R.A.	Decl.	Mag.	Class

δCeti . . . . $2^h34^m.4—0° 06'$ 4.04 B2

A normal example of the *β Canis Majoris* type, according to Henroteau (*DO* **9**, 26, 1925). The period is 0.16122 day; mean velocity varies. The light was constant on two nights in 1924. (Guthnick, *VJS* **60**, 65, 1925). Six series at Illinois in 1925 showed no short period light variation greater than .04 magnitude.

γUrs. Min. . . . . . . $15^h20^m.9+72° 11'$ 3.14 A2

Struve's spectroscopic period is 0.108449 day. Minute light fluctuations of the order of .04 magnitude were detected by Guthnick in 1914 and again by Bottlinger on three nights in 1922 (*Festschrift für Seeliger,* page 395) but no period could be assigned. Further remarks appear in Table I.

σScorpii . . . . $16^h15^m.1—25° 21'$ 3.08 B1

The spectroscopic period is 0.24683 day. The mean velocity varies with a period about one month. The amplitude of the short period variation does not change noticeably. Stebbins remarks (*LOB* **8**, 193, 1915) that the light is perhaps variable with a range of .03 magnitude.

θOphiuchi . . . . . . $17^h15^m.9—24° 54'$ 3.37 B3

The spectroscopic period is 0.28620 day.

γLyræ . . . . 18h55m.2+32° 33′ 3.30 A

Curtiss suspected a spectroscopic period of 3 or 4 hours. In Struve's list (*ApJ* **60**, 172, 1924) it appears as 0.15 day. Guthnick (*Festschrift für Seeliger,* page 394) found slight variations in the light in no assignable period. The light was constant at Illinois on two nights in 1925.

δAquilæ . . . . 19h20m.5+2° 55′ 3.44 F0

Henroteau assigns this star to the β *Canis Majoris* type, with a period about 0.1571 day. Light variation of 0.1 magnitude was suspected by Stebbins (*ApJ* **49**, 354, 1919). Guthnick (*VJS* **59**, 80, 1924) finds no variation. Two series at Illinois in 1925 leave the question undecided.

τCygni . . . . 21h10m.8+37° 37′ 3.82 F0

The spectroscopic period is 0.143 day. Henroteau (*DO* **9**, 32, 1925) finds a variation of the mean velocity in a period about 22 days. The light is constant (Stebbins, *PA* **29**, 276, 1921; Guthnick, *AN* **215**, 397, 1921; *VJS* **60**, 65, 1925). Two series at Illinois in 1925 show no variation.

Table III

Stars Known or Suspected to Be Spectroscopic Variables of Very Short Period, But With Periods Unknown, of Which Photoelectric Observations Are Available

Star	R.A.	Decl.	Mag.	Class
μTauri	4h10m.1	+8° 39′	4.32	B5

Suspected β *Canis Majoris* type (*DO* **5**, 55, 1921). Stebbins, in 1922, considered light constant.

ηAurigæ . . . . 4h59m.5+41° 06′ 3.28 B3

Suspected β *Canis Majoris* type (*DO* **5**, 62, 1920). Light varies occasionally .03 to .04 magnitude. (Berlin, *AN* **215**, 396, 1921).

βCan. Maj. . . . . . . 6h18m.3—17° 54′ 1.99 B1

Spectroscopic variable. According to Henroteau a period of 0.25 days predicts either a maximum or minimum of the velocity curve. Stebbins, in 1922, found the light constant. It was constant on three nights in 1923 at the Lick Observatory.

42 Camelop. . . . . . . 6h40m.5+67° 41′ 5.04 B3

Suspected β *Canis Majoris* type (*DO* **5**, 340, 1921). Light constant on one night in 1923 at the Lick Observatory.

β Urs. Maj. . . . . . 10h55m.8+56° 55′ 2.44 A

A suspected spectroscopic variation with a period of 0.31 days was not confirmed (*LOB* **9**, 22, 1916). Struve, in *ApJ* **60**, 172, 1924, lists it as a spectroscopic variable. According to Guthnick (*Festschrift für Seeliger,* page 394) the light varies occasionally with this period and a range of .02 magnitude.

ι Aquilæ . . . . $19^h31^m.5$—1° 31′ 4.28 B5

Spectroscopic variable of *β Canis Majoris* type. Six series of photometric measurements at Illinois in 1925 leave the question of its light variability still undecided.

55 Cygni . . . . $20^h45^m.5$+45° 45′ 4.89 B2

Spectroscopic variable of very short period. Five series at Illinois in 1925 suggest that the light varies, but the period is undetermined.

9 Cephei . . . . $21^h35^m.2$+61° 38′ 4.87 B2

Suspected *β Canis Majoris* type (*DO* **5**, 358, 1921). Light constant on two nights in 1925 at Illinois.

THE SPECTROHELIOSCOPE

By George E. Hale

The simple instrument for observing the Sun in monochromatic light, which I developed two years ago and tested then in a preliminary way,[1] has recently given me extraordinarily interesting views of the entire hydrogen atmosphere of the Sun. The optical parts of the spectroscope used in the earlier work are now rigidly mounted in a well beneath the low tower of my new Solar Laboratory in Pasadena. A beam of sunlight, reflected vertically downward from the second mirror of a coelostat mounted at the summit of the tower, falls on a 30 cm objective loaned me by the Yerkes Observatory. This forms a solar image 5 cm in diameter on the slit of the spectroscope in the laboratory at the base of the tower. A 15 cm concave mirror 3.96 m below the slit (in the spectrograph well which descends to a depth of about 24 m) sends a parallel beam nearly vertically upward to a large plane grating, ruled by Jacomini with 600 lines to the millimeter on the ruling machine of the Mount Wilson Observatory. From the grating the dispersed rays descend to a second 15 cm concave mirror, (also of 3.96 m focal length) mounted on the same support with the collimating mirror. The center of the image of the spectrum formed by this mirror is 26.7 cm from the center of the first slit, and in the same plane. I thus work out of the

[1]*Proceedings of the National Academy of Sciences*, **10**, 361, 1924. The principle of the spectroheliosope dates from the earliest days of solar prominence observation without an eclipse, when it was suggested by Janssen, Lockyer, Zöllner, and others. A spectroscope embodying it, built for Young, is illustrated in Lockyer's *Solar Physics*, p. 167. Unfortunately it did not survive the introduction by Huggins of the wide slit method of observing prominences at the limb, and I find no record that it was ever used for observations of the disk.