LUMINOSITIES OF THE M-TYPE VARIABLES OF SMALL RANGE*

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ABSTRACT

Spectroscopic luminosity classes and absolute magnitudes have been determined for 67 semiregular or irregular variable stars of types K and M. These are stars for which the amplitude of the light-variation is less than 2 mag.

The visual absolute magnitudes range from zero (normal giants) to −5 or −6, but the stars are not uniformly distributed over this interval. Thirteen are brilliant supergiants of types K5–M3, while the remainder are of markedly lower luminosity and chiefly of types M3–M6. Irregular variability appears to be uncommon among early M-type giants.

The supergiant variables not only are concentrated near the galactic plane but also show a pronounced grouping in longitude. Five of them are members of the double cluster, h and χ Persei.

Several of the supergiants recognized in this survey are among the most luminous stars known. One of them, RW Cep, is probably brighter than μ Cep.

The red variable stars can be divided into two groups on the basis of the amplitude of their visual light-variation. The stars with a range greater than 2 mag. include nearly all the long-period variables, while those of smaller range are essentially the semiregular and irregular variables. These latter stars, in which the light fluctuates by a comparatively small amount, have always been difficult to classify with respect to the nature of their light-curves, and many of them have been shuttled back and forth between such rather indefinite groups as μ Cephei stars, UU Herculis stars, RV Tauri stars, etc.[1] Consequently, it is now evident that further direct data on the physical properties of such variables must be collected before much progress can be made toward a definitive classification.

We consider, first, the spectral types of the stars with $\Delta m \leq 2^{m}$. They are distributed roughly as follows:[2]

M...........	59 per cent	R..............	2 per cent
K...........	15	S..............	1
N...........	22	Peculiar.........	1

The stars of types K and M, constituting more than two-thirds of the whole group, are especially well suited to the determination of spectroscopic luminosities, since their spectra are relatively free from the emission lines characteristic of the long-period variables and the spectral changes shown by a given star are usually not great. The special value of spectroscopic parallaxes lies in the fact that they can be found for individual stars, thus making it possible to estimate the degree of homogeneity of the group with respect to the two important physical parameters—luminosity and temperature.

In order to investigate the range of luminosities present in a fair sample of the variables of small range, spectra of 67 stars were obtained during the months of November and December, 1941, with the Cassegrain spectrograph of the McDonald reflector. The combination of glass prisms and f/2 Schmidt camera gave a scale of 66 A/mm at λ 4200. The observed stars are listed in Table 1, followed by the Julian dates of observation, the visual range (except for those values printed in italics, which are photographic magni-

* *Contributions from the McDonald Observatory, University of Texas*, No. 48.

[1] Cf. the discussion by Payne-Gaposchkin and Gaposchkin, *Variable Stars*, chaps. v and vi, 1938.

[2] Taken for the most part from Schneller, *Katalog und Ephemeriden veränderlicher Sterne*, 1941.

TABLE 1

TYPES AND LUMINOSITIES OF K AND M VARIABLES

($\Delta m \leqslant 2.0$)

Star	JD 2430000+	m_v	l	b	Period	Type	Luminosity
SS And	345	8.9– 9.9	76°	− 7°	160ᵈ:	M6	II
UX And	343,346	8.4– 9.9	103	−13	393:	M6	III
TU Aur	346	7.7– 9.1	136	+16	75	M4:	III
TW Aur	345,356	8.0– 8.9	135	+11	....	M4:	III
UX Aur	342	8.4– 9.2	128	+ 7	90	M4	II
UZ Aur	356	7.7– 9.3	136	+ 2	66	M3	III
RS Cam	357	8.1– 9.5	102	+34	166	M4	III
RV Cam	346	7.9– 9.0	115	+ 7	107	M4	II–III
RY Cam	331	7.6– 9.3	112	+12	135	M3	III
Z Cnc	345	8.5– 9.8	177	+29	80	M6	III
RS Cnc	352,357	5.3– 6.8	163	+43	239	M6	I*b*–II
RT Cnc	341	7.3– 8.6	185	+33	100	M4	III
TZ Cas	352,356	9.1– 9.7	84	− 1	....	M2	I*a*–I*b*
μ Cep	330	4.0– 4.8	68	+ 4	750	M2	I*a*
RU Cep	342	8.3– 9.3	93	+23	117	M0	III
RW Cep	331,350	6.8– 7.5	71	− 1	....	M0:	I*a*–0
SS Cep	330,342	6.7– 7.8	104	+10	100	M5	III
ST Cep	346	7.7– 8.9	72	− 1	....	M0	I*b*
VV Cep	329,330	4.9– 5.6	72	+ 7	7430:	M1p	0
AR Cep	342	7.1– 7.8	87	+23	116:	M4	III
T Cet	359	5.2– 6.0	45	−78	159	M5	II
RW Cyg	338,344	7.6– 9.4	46	0	631:	M3	I*a*
AB Cyg	356	8.3– 9.3	50	−15	529	M4:	III
AZ Cyg	345	8.1– 9.4	55	0	....	M2:	I*a*
U Del	342	5.6– 7.5	30	−16	....	M5	II–III
V Eri	345	8.3– 9.4	177	−42	....	M6	II
Z Eri	345	6.4– 7.8	160	−57	74,1200	M4	III
RR Eri	353	7.2– 8.5	154	−53	....	M5	III
SU Eri	356	*9.5–10.1*	158	−37	....	M4:	III
η Gem	350	3.2– 4.2	157	+ 4	236	M2	III
SW Gem	359	9.2–10.6	158	+15	680	M5	III
TV Gem	355	7.0– 7.8	157	+ 3	....	M1:	I*a*
TW Gem	329,346	7.7– 9.3	161	+15	....	M0	III
BK Gem	342	8.0– 8.3	166	+ 3	....	K5	III
RV Hya	346,351	7.6– 8.3	203	+20	....	M5	II
SU Hya	352	*9.4–10.4*	226	+27	....	M4	III:
AK Hya	348,351	*7.1– 8.0*	209	+16	....	M4	III
Z Leo	351	8.6–10.0	170	+50	57	M3	III–IV
V Lyn	345	8.6– 9.8	120	+23	87	M5	III–IV
Y Lyn	338,345	6.9– 7.4	140	+26	....	M5	I*b*–II
RT Mon	330,331	8.1– 9.3	199	+13	115	M3	III
SW Mon	356	9.1–10.6	173	− 3	110	M4	III
α Ori	344,355	0.1– 1.2	168	− 8	2070	M2	I*b*
BQ Ori	355	6.9– 8.9	155	+ 1	130	M5	III
CI Ori	340	*5.1– 6.8*	171	−17	....	K5:	III
CK Ori	352	*6.7– 7.3*	167	+14	....	K2	III
AF Peg	350	8.9– 9.9	55	−36	52	M5	II–III
ρ Per	355	3.2– 4.1	117	−16	910:	M3	III
T Per	331,346	8.0– 9.0	102	− 1	....	M0	I*a*–I*b*
RS Per	329,330	8.0– 9.4	103	− 3	....	M3	I*a*–I*b*
SU Per	338	7.0– 8.5	103	− 4	477	M3	I*a*–I*b*
SW Per	350,346	8.2– 9.8	125	− 7	84	M5	III
TT Per	359	8.0– 9.2	100	− 7	92	M5	III
UZ Per	350	7.8– 9.5	124	−20	90	M5	II–III
YZ Per	355,359	7.6– 8.3	105	− 2	....	M1	I*a*–I*b*

TABLE 1—*Continued*

Star	JD 2430000+	m_v	l	b	Period	Type	Luminosity
AD Per	329,339	7.7– 8.4	103°	− 3°	....	M1	I*a*–I*b*
TV Psc	346,352	*6.9– 7.3*	84	−44	....	M3	III
W Tri	350,352	8.2– 9.0	115	−22	148	M4	II
U UMa	351,357	6.1– 6.8	117	+49	....	M0	III
Y UMa	357	7.7– 9.3	91	+61	....	M7	II–III:
Z UMa	357	*8.4–10.2*	104	+57	198	M5	III
RY UMa	351	7.2– 8.3	95	+56	311	M3:	III
ST UMa	357	6.5– 7.3	128	+66	81	M4	III
SV UMa	357	8.8–10.0	120	+55	76	K3p:	I*a*:*
TT UMa	357	8.9– 9.5	122	+41	....	M6	III
TV UMa	351,357	*8.2– 9.0*	142	+75	....	M4	III
RW Vir	375	7.0– 8.2	250	+58	....	M5	III

* SV UMa; the line ratios suggest high luminosity, but all lines in the spectrum are so weak that the application of luminosity criteria is uncertain. There is some similarity to the spectra of V Vul and R Sct. If the luminosity criteria are accepted at face value, SV UMa must be situated several thousand parsecs above the galactic plane.

tudes), galactic co-ordinates, and periods.[3] The spectral types given in the seventh column were estimated on the Mount Wilson system[4] on the basis of the strength of the *TiO* bands on the blue side of λ 5500, the limiting wave length in the yellow reached by the Agfa Super Plenachrome Press films on which the spectra were taken.

In relying entirely upon the bands of a single molecule for the assignment of spectral classes, the assumption is made that the relative abundance of the elements composing the molecule is constant in the group of stars considered and that the fraction of the material which will be in the molecular form does not pass through a maximum in the range of temperatures considered. If these conditions are fulfilled, the classification defines a temperature sequence. In the case of the variables photographed at McDonald Observatory it was possible to test the consistency of the classification through the fact that for many of them rather heavily exposed spectra were available, showing the region around λ 4000, where the atomic lines are not seriously weakened by overlying band absorption. Several ratios of resonance lines of elements of low ionization potential to excited lines of iron were selected as independent indicators of temperature. Those most useful were *Ti* 3982, 3989, 3999, 4009/*Fe* 4005, *Ca* 4226/*Fe* 4143, and *Cr* 4254/*Fe* 4250, 4260. Their behavior in the spectral sequence of giants is shown in Plate XIV, in which both variable and nonvariable stars are included. The progression in the ratios for all the stars examined is in agreement with the descriptions given by Merrill[5] and leaves little doubt that the subdivisions of type M giants represent a smoothly decreasing sequence of temperatures. For the supergiants also the scale is probably consistent, but it must be kept in mind that the temperature corresponding to a given spectral type will presumably be a function of luminosity.

The investigation of the luminosities can be carried out most conveniently in two steps: first, the setting-up of a series of standard stars in which known luminosity criteria change progressively and, afterward, the calibration of this scale in terms of absolute magnitudes. The stars used as standards defining the luminosity classes for types M0–M3 are given in Table 2.

The notation is designed to be consistent with that in use for the earlier spectral types.[6] The most sensitive line ratios are 4077/4045, 4172–5/4143, 4216/4226, and 4376,

[3] Taken mostly from Table V, I, of Payne-Gaposchkin and Gaposchkin, *op. cit.*

[4] *Trans. I.A.U.*, **2**, 119, 1925.

[5] *Ap. J.*, **63**, 13, 1926; *Mt. W. Contr.*, No. 306.

[6] Morgan, *Ap. J.*, **87**, 460, 1938; Keenan, *Ap. J.*, **91**, 506, 1940.

4389/4383. In each case the ratio increases as the luminosity becomes greater, and the changes are sufficiently pronounced to be followed easily in Plate XV, *a*, from which VV Cep has been omitted because of the peculiar weakness of all the lines in its composite spectrum, which is not closely matched by any of the other variables observed. The stars of high luminosity are so red that the region to the violet of λ 4200 is usually too far underexposed to be used, but the remaining lines are sensitive enough to make it easy to interpolate between the main classes. The lines at λ 4376 and λ 4389 belong to one of the two multiplets of iron, originating at the normal level of the atom, which Adams and Joy[7] were the first to use as criteria of absolute magnitude.

TABLE 2

Luminosity Class	Stars	Luminosity Class	Stars
0	VV Cep	II	5 Lac, π Aur
I*a*	μ Cep	II–III	β Peg
I*b*	α Ori, α Sco, 119 Tau	III	β And, χ Peg, η Gem

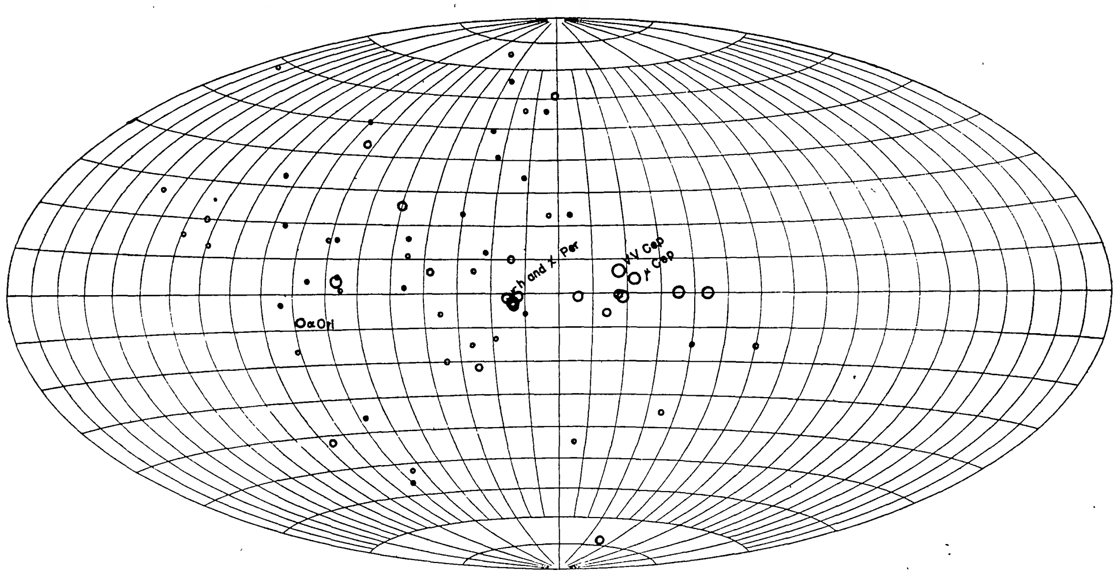


FIG. 1.—Galactic co-ordinates of the variable stars observed. Center of the diagram is at $b = 0°$, $1 = 90°$. Size of circle indicates luminosity of each star, the supergiants being largest.

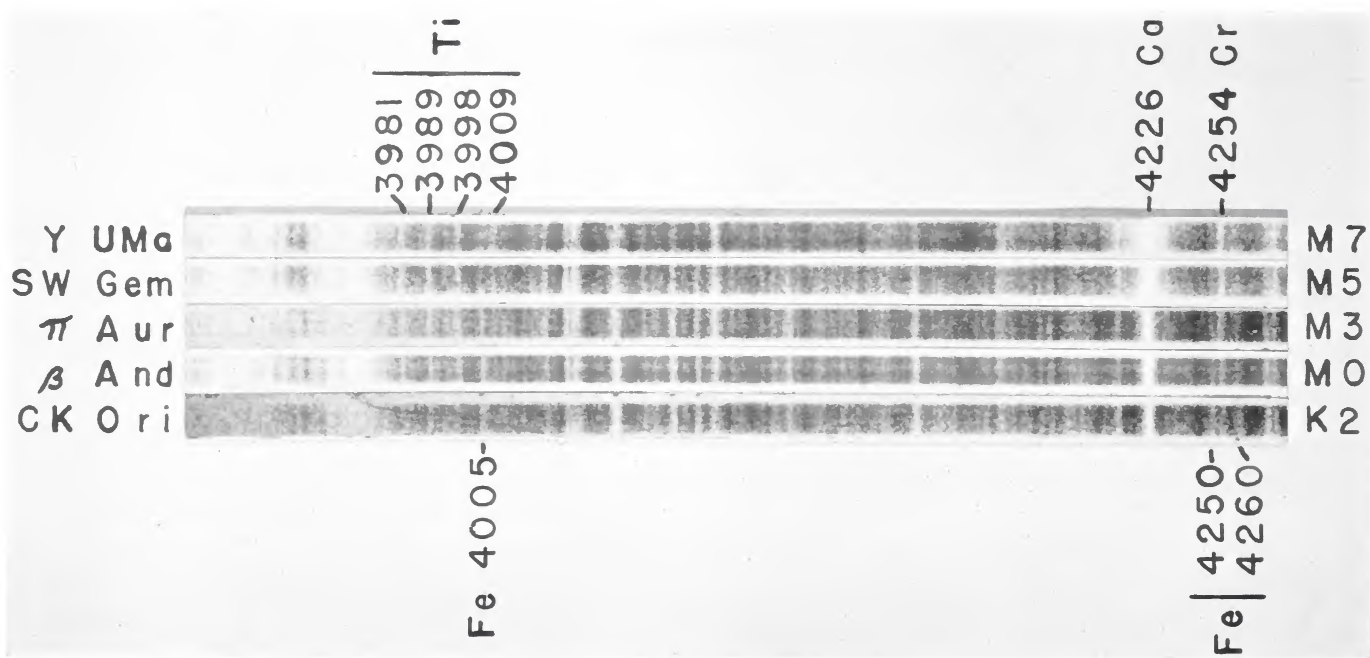
The application of these criteria to the variable stars is illustrated in Plate XV, *b*, *c*, for types M0 and M3. In the spectrum of RW Cep all lines are stronger than normal, and the enhancement of the lines sensitive to luminosity is so great as to make it appear probable that this star has the greatest absolute brightness of any of those studied here, with the exception of VV Cep. It is of interest that these two stars and μ Cep are situated in the same part of the Milky Way, within a few degrees of one another.

SU Per is one of 5 stars in the list which appear to be members of the double cluster, h and χ Persei. Three of them—AD, SU, and RS Per—were assigned to the cluster by Adams, Joy, and Humason[8] on the basis of their radial velocities and proper motions. For

[7] *Pub. A.S.P.*, **35**, 328, 1923.

[8] *Ap. J.*, **64**, 225, 1926; *Mt. W. Contr.*, No. 319.

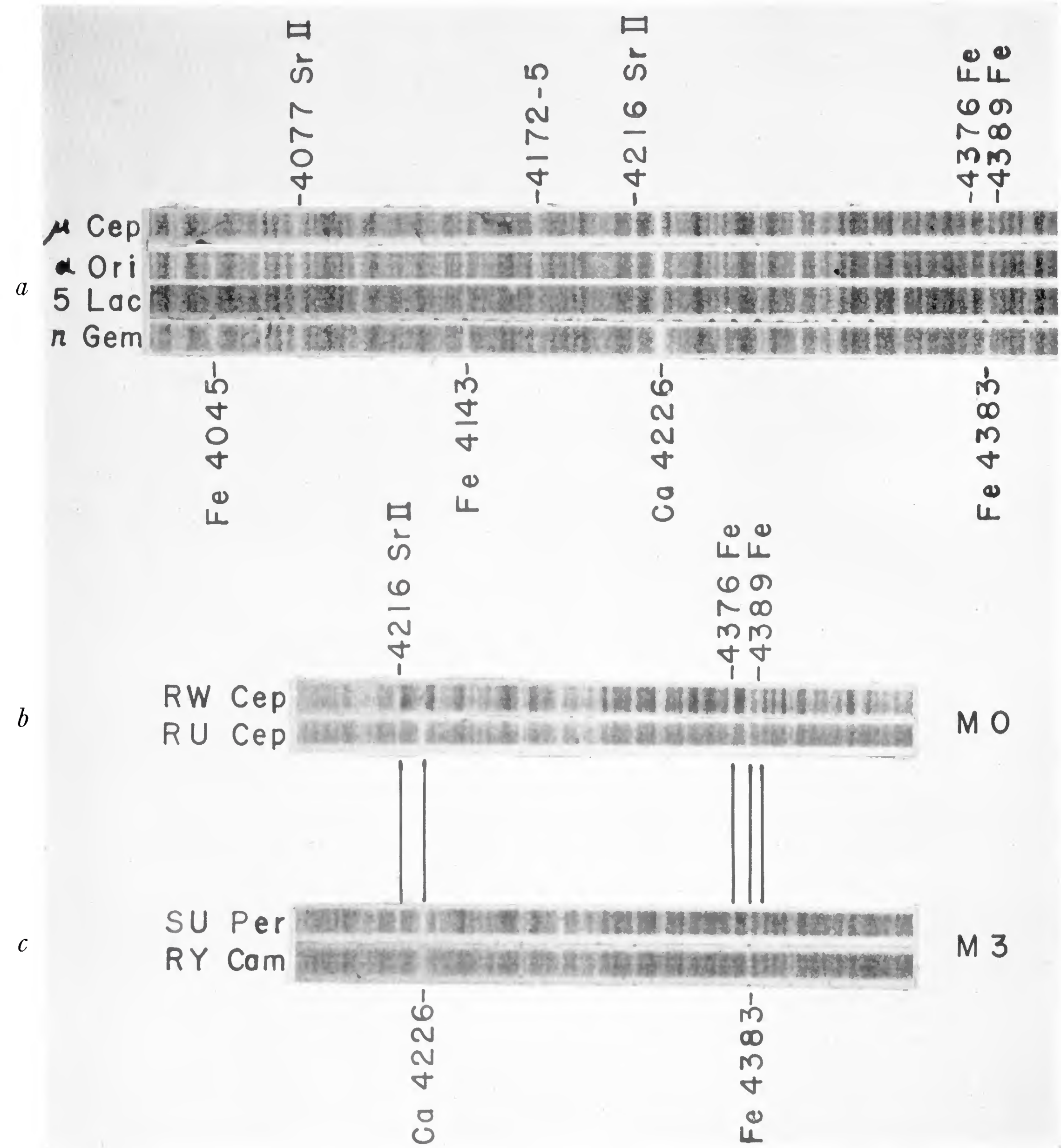
PLATE XIV



SPECTRAL SEQUENCE

Types assigned from bands in the green region are given at the right. Lines which become stronger with later type are marked at the top.

PLATE XV



a) Luminosity Sequence for Types M0–M3

As the luminosity increases the lines marked at the top become relatively stronger in comparison to those indicated below the spectra.

b, *c*) Luminosity Effects in Variable Stars

Supergiants (RW Cep and SU Per) are shown above giants (RU Cep and RY Cam) of similar spectral type.

the other 2 the proper motions only are available, but they are consistent with membership in the cluster. These stars are all supergiants intermediate in luminosity between α Ori and μ Cep. Further confirmation of their membership in the cluster is found in the distribution over the sky of the observed variables (Fig. 1). Since the material is reasonably complete down to the ninth apparent magnitude within the range of galactic coordinates accessible in winter, the absence of other supergiants within a radius of more than 10° from the cluster emphasizes the physical association of the 5 stars.

The distance of h and χ Persei can now be used to find the mean absolute magnitude of these stars. From a discussion of Oosterhoff's magnitudes and the magnitudes and spectral types given by Trumpler, W. P. Bidelman has derived an apparent modulus of $12^{m}.5$, taking the photographic absolute magnitude of the main sequence at B9 as $-0^{m}.3$.[9] The distance obtained in this way is to be preferred to that determined from the radial velocities, since the latter method involves the uncertain assumption that the whole motion of the cluster is to be ascribed to galactic rotation. The modulus of $12^{m}.5$ leads to the following median visual absolute magnitudes for the variables in the cluster:

T Per	$-4^{m}.0$	RS Per	$-3^{m}.8$
AD Per	-4.5	YZ Per	-4.5
SU Per	-4.7		

The mean is $M_v = -4^{m}.4$ at luminosity class I*a*–I*b*.

Another calibration point, of rather low weight, is furnished by α Sco (type I*b*). If it is assumed to be a member of the Scorpius cluster, its absolute magnitude is in the neighborhood of -4.0.

TABLE 3

CALIBRATION OF LUMINOSITY SCALE

Luminosity Class	M_v	Luminosity Class	M_v
I*a*	-5.2	II	-2.0
I*b*	-3.8	III	-0.2

For the ordinary giants of class III trigonometric parallaxes can be used. The numerous published means for M-type giants might be expected to differ systematically from the proper value for class III, since they generally include some admixture of stars of higher luminosity but none less bright, as no subgiants of type M are known. For this reason a mean was computed from 10 of the brightest class III stars of types M0–M3; the value fround was $\bar{M}_v = -0^{m}.2$.

Finally, the star VV Cep is of some value in estimating the upper end of the scale, where it was placed because λ 4383 is definitely weaker than λ 4376 and is roughly equal to λ 4389 in its spectrum. By combining the spectroscopic and photometric observations of the eclipsing pair, Goedicke,[10] following Gaposchkin, obtained two solutions for the parallax. These correspond, for the M2 component, to $M_v = -6.8$ if there is a sharp photosphere, and to $M_v = -5.0$ if there is a diffuse photosphere extending to 3 per cent of the radius. Probably a simple mean of the two values is the most reasonable estimate to adopt.

From a plot of these calibration points, Table 3 was constructed to allow the reduction of luminosity classes to absolute magnitudes.

[9] This is a provisional value, which Mr. Bidelman has kindly furnished in advance of the publication of his study of the cluster.

[10] *Pub. Univ. Michigan Obs.*, **8**, 1, 1939.

With the help of Table 3 the absolute magnitudes of the observed variable stars can be easily found. However, only the luminosity classes have been entered in the eighth column of Table 1, because the calibration can be improved when a sufficient number of stars of each luminosity class are known to provide reliable mean absolute magnitudes computed from the motions. Then, too, the reduction table applies strictly only to types M3 and earlier. For the later types the luminosity classes themselves are less definite because the atomic line intensities are disturbed by the increasing band absorption, and no good standards of absolute magnitude are known. Thus λ 4045 is badly blended with λ 4044 and λ 4047 of potassium, and *Ca* 4226 is too strong to serve as a good reference line. Consequently, *Fe* 4063 and *Cr* 4254 are used in their stead. With this modification the extension of the criteria to the late M-type stars is reasonable, and real differences in absolute

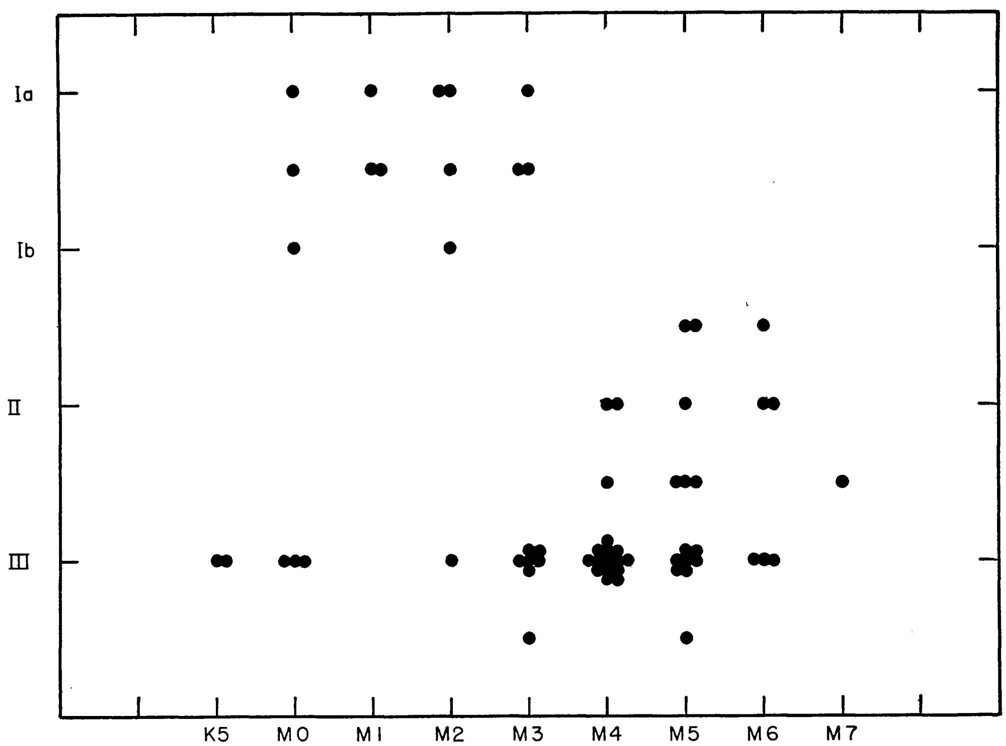


FIG. 2.—Luminosity-spectrum diagram for the variable stars observed

brightness appear to exist, as between Y Lyn and BQ Ori, which are reproduced in Plate XVI.

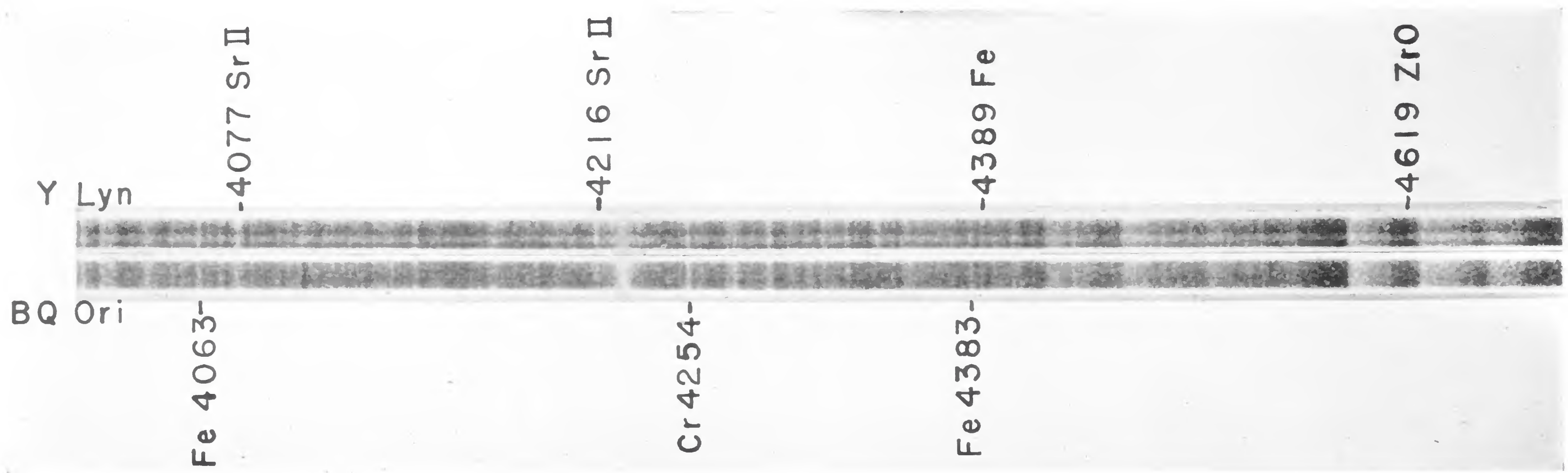
The distribution of the observed variables in luminosity and spectral type is shown in Figure 2. Most striking is the concentration of supergiants between types M0 and M3 in contrast to the excess of normal giants in the more advanced types. This feature has been suspected before, from the fact that the known red supergiants have only moderately strong bands.[11]

Our knowledge of the nonvariable early M-type stars is sufficient to indicate that their distribution in luminosity is just the reverse of that of the variables, for relatively few supergiants are known among them. Thus the known comparative freedom from variability of the K-giants continues as far as type M3.[12]

[11] Cf. McLeod, *Pop. Astr.*, **45**, 155, 1937; Joy, *Pub. A.A.S.*, **10**, 115, 1941.

[12] This is in agreement with the conclusions reached by Stebbins (*Pub. Washburn Obs.*, **15**, 139, 1934).

PLATE XVI



Luminosity Effects in Giants at Type M5
The lower spectrum is that of an ordinary giant

The apparent preference of the supergiant variables for the early subdivisions of type M may be influenced by the uncertainties in the spectral classification for the stars of high luminosity and in the luminosity sequence for the stars of late type, as well as by the increasing bolometric corrections at low temperatures.[13] However, it is doubtful that these factors are sufficient to produce the discontinuity in the upper right-hand part of Figure 2. Rather, it appears likely that *this region is the domain of stars of type S*, which are known to combine low temperature and high luminosity. In other words, if a star has the absolute magnitude and temperature corresponding to this region, it will presumably develop the bands of *ZrO* and no longer be classed as of type M.

This view is supported by the fact that the *ZrO* band at λ 4619 can be seen faintly in the low-dispersion spectra of several of the late-type variables classed as moderately luminous (Y Lyn; see Pl. XVI) but is not perceptible in the ordinary giants. However, further spectroscopic observations must be made on the few S-type variables of small range before it will be possible to fit them into the diagram, and this will offer some difficulty because of their extreme redness.

It is a pleasure to acknowledge the value of discussions of this problem with Dr. Morgan and the co-operation of the McDonald staff in the observational work.

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[13] This last point was suggested by Dr. Kuiper.