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RADIAL VELOCITIES AND SPECTRAL TYPES OF SOME BRIGHT BLUE STARS IN THE OLD OPEN CLUSTER M67

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ABSTRACT

Slit spectra at a dispersion of 128 Å/mm were obtained of eight stars in M67 which, in the color-magnitude diagram, lie either in the Hertzsprung gap or near the main sequence but above the turn-off point of the majority of the cluster members Radial-velocity measures based on these spectrograms show that the brightest star in the Hertzsprung gap is most probably not a cluster member and, in addition, give no evidence that any of the stars are short-period, large-amplitude spectroscopic binaries, although duplicity is not disproved. Spectral types of seven of the stars are compatible with cluster membership; two of them are Am stars, the others appear normal.

The color-magnitude diagrams of several globular and old open clusters exhibit a handful of stars near the zero-age main sequence but above the point where the cluster main sequence turns off into the subgiant and giant regions. These "blue stragglers," as they are sometimes referred to, are anomalous in that we cannot account for their existence within the framework of our current evolutionary interpretations of the color-magnitude diagrams of old clusters. Because of the well defined main-sequence turn-off point and fairly narrow subgiant and giant branches, a spread in the time of formation of the cluster stars is not an attractive explanation. Therefore, most attempts to explain these stars have invoked mixing or accretion. McCrea (1964) suggested that the "blue stragglers" are members of close binary systems to which mass has been transferred from the original primaries.

In order to learn more about these stars and, in particular, to search for radial velocity variations in the hope of finding out if "blue stragglers" are members of close binary systems, a series of spectrograms were obtained of some bright blue stars in the old open cluster M67. This cluster was selected for two reasons: (1) the B-magnitude range of the bright blue stars is 10–12, which makes them fairly accessible for spectrographic observations; and (2) a recent investigation of proper motions in the field of M67 (Murray, Corben, and Allchorn 1965) has confirmed earlier studies (Ebbinghausen 1940; Van Maanen 1942) indicating that the bright blue stars are cluster members. The stars observed and the schematic color-magnitude diagram of M67 are shown in Figure 1, which is based on the photometry of Eggen and Sandage (1964). There is some question as to whether these bright blue stars in M67 are really "blue stragglers" or are more appropriately described as horizontal-branch stars as was done by Eggen and Sandage. Since the number of stars in question is so small and because we have no other observational evidence[1] for the existence of a horizontal branch in an old open cluster or on the position of such a horizontal branch in the color-magnitude diagram, it is difficult to make a decision about this matter. However, the point is not crucial for the present paper since no conclusions are drawn which depend upon these stars being either "blue stragglers" or horizontal-branch stars.

The spectrograms were obtained during seven nights in January, 1965, with the Meinel Cassegrain-focus spectrograph (Schulte 1963) of the Kitt Peak 36-inch reflector mounted on the Kitt Peak 84-inch telescope with a negative lens before the slit to change the Cassegrain f/7.5 beam to match the f/13.6 spectrograph collimator. The spectra, which were widened ~0.3 mm, have a dispersion of 128 Å/mm and a resolution

[1] See, e.g., the color-magnitude diagrams of NGC 188 (Sandage 1962) and NGC 6791 (Kinman 1965).

of ~10 μ. Eastman Kodak IIaO plates were used and were developed in D76. Exposure times for the stars in M67 ranged from about ten minutes at $B = 10$ mag to about 45 min at $B = 11.5$ mag.

Several radial-velocity standards were observed each night in order to determine if a systematic correction was required and also to serve as controls—that is, to determine the scatter in repeated observations of stars presumed to have constant radial velocity. These observations are summarized in Table 1. The average internal probable errors (based on the line-to-line variations of velocity in one spectrum), shown in the eighth column, and the probable errors of the average velocities (based on the plate-to-plate variation about the average), shown in the tenth column, agree well with the corresponding values obtained by Rubin (1965) using the same spectrograph and dispersion. The scatter in the velocity determinations, as indicated by the probable errors per plate in the ninth column, is in general larger than one would expect on the basis of the

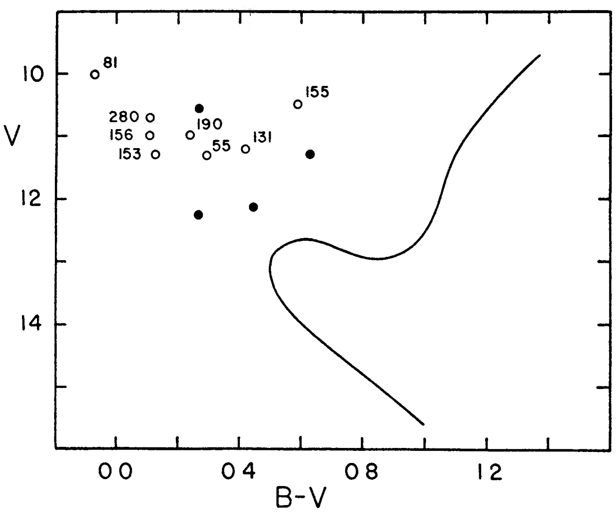

FIG. 1.—The schematic color-magnitude diagram of M67 and its bright blue stars. *Open circles:* stars for which observations are reported on in this paper; *filled circles:* stars which are also cluster members according to proper-motion studies (except one star for which no data are available) but which were not observed by the author.

internal probable errors. Indeed, in several cases, the probable errors per plate are larger than the internal probable errors by factors between 2 and 3. However, all the stars in Table 1 have been observed repeatedly at higher dispersion and not found to be variable in radial velocity. The *Catalogue of Bright Stars* (Hoffleit 1964) notes that HD 20365 has a variable radial velocity; this is apparently based on early observations by Plaskett and Pearce (1931). On the other hand, Petrie (1953), with twenty-one plates at his disposal, has included HD 20365 as one of the primary standards to establish wavelengths for radial velocity determinations from B-type spectra. In the absence of further information, the author prefers to conclude that the scatter in velocity determinations is instrumental rather than that several of the standard stars have variable radial velocity. Inspection of the eleventh column of Table 1, which gives the differences between the catalogue and the average observed velocities, shows no clear systematic difference. Hence, no correction has been applied to any of the velocities. The general agreement between the probable errors of the average velocities (tenth column) and the differences between the catalogue and average observed velocities (eleventh column) is good, and suggests that five plates taken with the Meinel spectrograph at 128 Å/mm yield a velocity which is good to ±5 km/sec. This also agrees with the results of Rubin (1965) using the same spectrograph and dispersion.

The observations of the bright blue stars in M67 are given in Table 2. The spectral

TABLE 1

OBSERVATIONS OF RADIAL VELOCITY STANDARDS

Star		Spectral Type*	Catalogue Velocity (km/sec)	Source†	Average Observed Radial Velocity (km/sec)	No. of Plates	Average Internal Probable Error (km/sec)‡	Probable Error per Plate§ (km/sec)	Probable Error of Average Obs. Vel.‖ (km/sec)	Catalogue Minus Average Observed Velocity (km/sec)
HD	Other									
HD 37209	ADS 4212A	B1 V	+27.1	a	+18	3	4.3	5.1	3 0	+9
HD 20365.	29 Per	B3 V	− 3 6	a	− 1	6	3.3	8.3	3 4	−3
HD 27778.	ADS 3179A	B3 V	+16.5	a	+10	5	4.5	4.3	1.9	+6
HD 21071.		B6 V	− 0.4	a	+ 1	4	3.2	4.8	2.4	−1
HD 23408.	20 Tau	B7 III	+ 7 6	a	+10	6	2.2	7 4	3 0	−2
HD 137391.	μ^1 Boo	F0 V	− 9.3	b	− 6	2	4.6	6.7	4.8	−3
HD 113129	78 U Ma	F2 V	− 9.5	c	− 2	4	4.1	12.3	6.2	−8
HD 89449	40 Leo	F6 IV	+ 6.5	d	0	4	5.2	9 1	4.6	+6

* Spectral classification from the *Catalogue of Bright Stars*.

† a, Petrie (1953). These stars are among the "primary standards" of Petrie. The values given are weighted means of the velocity determinations listed by Petrie in Table 5; b, Petrie, Andrews, and McDonald (1957); c, Petrie (1948); d, Pearce (1955).

‡ Average of the probable errors based on the line-to-line variations within each plate.

§ Probable error per spectrum based on plate-to-plate variation about the average velocity.

‖ Probable error of the average radial velocity.

TABLE 2

OBSERVATIONS OF STARS IN M67

Fagerholm No.*	Eggen & Sandage No.†	Spectral Type, Present Study	Other Spectral Types (Source)§	Average Observed Radial Velocity (km/sec)	No. Plates	Average Internal Probable Error (km/sec)	Probable Error per Plate (km/sec)	Probable Error of Mean (km/sec)	Other Radial-Velocity Determinations (Source, No. of Plates)‖ (km/sec)
55	I-27	Am‡	A4(Tr)	18	3	2.7	4.0	2.3	27 (D, 1)
81	......	B8 V	B9(Tr), B8-9V(P)	41	8	4.3	7 4	2.6	42 (W, 5)
131	......	F0 IV:	F1(Tr), F4IV(B)	14	2	3.2	11.6	8.2	....
153	......	Am‡	A3(Tr), A2V(P)	32	4	3 4	7.9	4.0	31 (D, 1)
155	I-1	G2 V	gG0(Tr)	− 7	7	4.5	10 1	3.8	....
156	......	A2 V	A1(Tr), A2V(P)	38	2	2.4	7.2	5.1	26 (D, 1)
190	......	A8 IV–V:	A8(Tr), A7III: (P)	34	5	3.2	11.1	5.0	18 (D, 1)
280	......	A3 V	A2(Tr)	36	5	3.8	5.6	2.5	....

* Fagerholm (1906).

† Eggen and Sandage (1964).

‡ No. 55: K-line type A5, metal-line type F2. Similar to 60 Tau (Roman, Morgan, and Eggen 1948). No. 153: K-line type A2, metal-line type A7. Similar to ζ UMa (ft) (*ibid.*).

§ Spectral types by Trumpler ("Tr") as reported by Ebbighausen (1940); Popper ("P") (1954), Burbidge and Burbidge ("B") (1959).

‖ D, radial velocity by Deutsch (1966), who estimates a probable error of ±3 km/sec except for No. 153, for which the estimated probable error is ±1 km/sec.

W, radial velocity by Wallerstein (1959).

types in the third column were assigned by the author, using spectra of MK standards taken during the same observing run as the spectra of stars in M67, plus some additional standards from the collection taken with the closely similar spectrograph of the Warner and Swasey Observatory.

The new radial velocities and spectral types given in Table 2 permit a reconsideration of the cluster membership of these stars. The radial velocity of Fagerholm No. 155 is sufficiently discordant with the other velocities in Table 2 and with the average velocity of $+33 \pm 3$ km/sec obtained by Popper (1954) for thirteen stars in M67 that it appears this star cannot be a physical member. The spectral classification of G2 V confirms this conclusion; if it were a cluster member, its absolute visual magnitude would be 0.95 mag, a value incompatible with its assigned luminosity class. When one considers the small number of plates available and compares the results of this study with those of Deutsch (1966), the radial velocities do not exclude any of the other bright blue stars from membership in the cluster. The weighted average velocity of the cluster from this author's data only (excluding Fagerholm No. 155) is $+31$ km/sec with an estimated uncertainty of about ± 5 km/sec. Fagerholm No. 81 has the best determined radial velocity of any star in M67, and its value differs from that of the cluster by about 10 km/sec. This difference seems a bit large, but not large enough to reject this star as a cluster member. The spectral types of all the stars in Table 2 (with the exception of Fagerholm No. 155) are compatible with these stars being cluster members insofar as absolute magnitude is concerned.

A comparison of the average internal probable errors of the radial velocities of the standard stars with those of the stars in M67 shows that they are essentially equal. The same is true for the probable errors of a single radial velocity determination. This means that the scatter in radial-velocity measures of the bright blue stars in M67 is no larger than the scatter encountered in repeated determinations of the radial velocities of the standard stars. In keeping with the discussion of the standard star data, this is interpreted as meaning that there is no evidence that any of the bright blue stars in M67 has a variable radial velocity. Using five plates taken over a period of eight years, Wallerstein (1959) similarly found no evidence of variable radial velocity for the star Fagerholm No. 81. Thus there is no indication that the stars observed are members of close binary systems. However, because of the limited number of observations, and the possibility of large mass ratios (resulting in negligible orbital motion of the primary component), membership in close binary systems cannot be excluded. Hence the observations neither confirm nor disprove McCrea's (1964) theory.

The evidence of the spectral types is similarly inconclusive. The spectra of many close binary systems display peculiarities arising from the interaction between the two components, such as emission lines from gaseous rings (Sahade 1960; Wood 1962). However, the visibility of the emission lines seems to depend on the orbital inclination, and, furthermore, systems are known (Huang and Struve 1956) in which one component touches the inner contact surface but which have shown no emission or sporadic emission. The presence of any peculiarities in the spectra of the bright blue stars in M67 would thus have been suggestive, but the absence of such peculiarities does not prove that these stars are not members of close binary systems.

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