# THE ASSOCIATION I GEMINORUM

D. Crawford, D. Nelson Limber, E. Mendoza V.,* D. Schulte,
H. Steinman, and T. Swihart
Yerkes Observatory
*Received July 14, 1954; revised July 30, 1954*

## ABSTRACT

A study of the O association I Geminorum is made. This association has an apparent diameter of about 5°. A distance of 1400 parsecs is obtained, giving a true diameter of 120 parsecs. Thirty-two stars are found to be members of the association; these stars range in spectral type from C6 to B9 and in apparent magnitude from 4.7 to 10.2. Several special features of the association are discussed, and a comparison with I Orionis and I Persei is made.

## I. INTRODUCTION

In the field of galactic structure the study of stellar associations as outlined by Morgan, Whitford, and Code (1953) has proved to be of great importance. As these associations are composed of population I objects, accurate distances provide definitive information on the spiral structure of the Milky Way system. These observations are independent of any assumed model of the Galaxy and thus provide a check on the results of radio astronomy.

A detailed study of individual associations is also important. Considerations of the internal motion of associations and of energy generation indicate that associations are very young objects. The applications to stellar evolution are apparent; furthermore, the clustering tendency exhibited by early-type stars makes possible an accurate calibration of the luminosity of supergiants. The present paper is an investigation of the association in Gemini, near the nebulosity NGC 2175. The association I Geminorum is No. 25 in the list of Morgan, Whitford, and Code.

A plot of HD and HDE O–B5 stars in the region bounded by $5^h30^m \leq \alpha \leq 6^h40^m$ and $+15° \leq \delta \leq +30°$ (Fig. 1) reveals a marked clustering. This clustering has a diameter of around 5° and is centered near $\alpha(1900) = 6^h8^m$, $\delta(1900) = +23°31'$; the galactic co-ordinates are $l = 156\overset{\circ}{.}0$ and $b = +4\overset{\circ}{.}0$ on the Lund system.

An observing program was carried out for the determination of spectroscopic parallaxes. Over one-half of the stars plotted in Figure 1 were observed.

## II. OBSERVATIONS

Spectra of seventy-five stars were taken with the one-prism spectrograph attached to the Yerkes 40-inch telescope. The dispersion is about 125 A/mm at $H\gamma$. Many of the plates were taken for the general Yerkes spectroscopic parallax program and were classified by W. W. Morgan. The remainder were taken by Limber and were classified by Limber and Morgan. The spectra were classified on the MK system (see Johnson and Morgan 1953). The provisional calibration of spectral-luminosity types into absolute visual magnitudes was furnished by Morgan and Keenan and differs only slightly from that published by Keenan and Morgan (1951).

The apparent magnitudes used were those given in the *Henry Draper Catalogue* and *Henry Draper Extension*. The magnitudes in the latter catalogue are photographic, but, since the color indices of these objects are very nearly zero, no corrections were made. The colors of thirty-two of the stars were taken from the list of Stebbins, Huffer, and

* Fellow of the University of Mexico.

Whitford (1940). The apparent magnitudes of these stars were then corrected for absorption by using the intrinsic colors and the ratio of reddening to total visual absorption given by Morgan, Harris, and Johnson (1953). True distance moduli were then computed.

An inspection of the distance moduli of these thirty-two stars showed that ten of them are definitely foreground objects. These ten stars were eliminated from further consideration. The data concerning the remaining twenty-two stars are given in Table 1. The first two columns give the HD number and the apparent visual magnitude. The third column gives the revised color excess on the $C_1$ system of Stebbins, Huffer, and Whitford (1940).

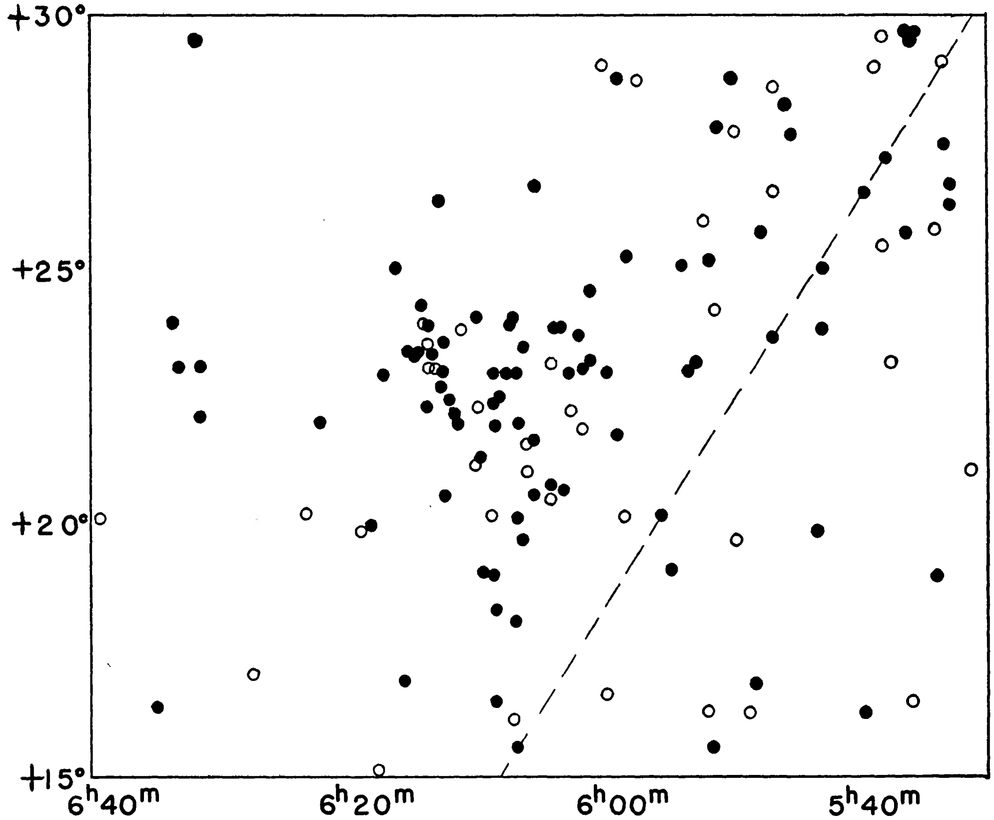


FIG. 1.—Plot of HD and HDE stars of classes O–B5, in the region bounded by $5^h30^m \leqq \alpha \leqq 6^h40^m$ and $+15° \leqq \delta \leqq +30°$. Open circles represent HD stars; filled circles represent HDE stars. The dashed line indicates the galactic equator.

The next three columns list the apparent visual magnitude corrected for absorption, the spectral type on the MK system, and the true distance modulus. The final column gives the radial velocity, taken from the catalogue of Wilson (1953).

Of the stars listed in Table 1, fourteen are grouped very close together in the sky, while nine are scattered over a much larger area. These nine stars were not considered in determining the characteristics of the association, although they are possibly outlying members. The color excesses of the fourteen remaining stars, indicated by an asterisk (*) in Table 1, were plotted as a function of position on the sky. From this plot (see Fig. 2, which also includes the nine outlying members) the approximate color excesses of the stars not in the Stebbins, Huffer, and Whitford list could be obtained. The area of the sky was divided into two regions: in one region the color excesses were all approximately 0.25 mag., while in the other region they were about 0.20 mag. The dividing line between

TABLE 1

OBSERVED STARS WITH COLORS

| HD | $m$ | $E_1$ | $m_0$ | Sp. | $m_0-M$ | $V$ (Km/Sec) |
|---|---|---|---|---|---|---|
| 38010..... | 6.86 | 0.15 | 5.9 | B1 Vep | 9.1 | +19 |
| 38191..... | 9.5 | .19 | 8.3 | B1 V | 10.6 | ........... |
| 39340..... | 8.1 | .10 | 7.5 | B3 V | 9.5 | ........... |
| 39746..... | 7.7 | .18 | 6.6 | B1 II | 11.7 | ........... |
| 39970..... | 6.02 | .18 | 4.9 | A0 I*a* | 11.9 | + 0.5 |
| 40111..... | 4.90 | .08 | 4.4 | B1 I*b* | 10.4 | + 8 |
| 41117*.... | 4.71 | .21 | 3.4 | B2 I*a* | 10.4 | +16.8 |
| 41398..... | 7.45 | .21 | 6.2 | B2 I*b* | 11.9 | +17.9 |
| 41690*.... | 8.0 | .20 | 6.8 | B1 V | 10.0 | +15.5 |
| 42087*.... | 5.76 | .18 | 4.7 | B2.5 I*b* | 10.4 | +16 |
| 42088*.... | 7.40 | .17 | 6.4 | O6 | .......... | +23.4 |
| 42379*.... | 7.8 | .24 | 6.3 | B1 II | 11.4 | ........... |
| 42400*.... | 6.9 | .16 | 5.9 | B5 II | 10.4 | ........... |
| 43078*.... | 8.6 | .27 | 7.0 | B0.5 III | 11.4 | ........... |
| 43384*.... | 6.26 | .23 | 4.9 | B3 I*ab* | 11.3 | +13.2 |
| 43703*.... | 8.7 | .28 | 7.0 | B1 IVp(e) | 10.8 | ........... |
| 43753*.... | 8.1 | .22 | 6.8 | B0.5 III | 11.2 | ........... |
| 43818*.... | 7.03 | .26 | 5.4 | B0 II | 10.6 | +18.2 |
| 43836*.... | 7.03 | .25 | 5.5 | B9 II | 9.5 | ........... |
| 48532..... | 8.60 | .08 | 8.1 | B2 V? | 10.7: | ........... |
| 248753..... | 8.5 | .18 | 7.4 | B1 Venn | 10.6 | ........... |
| 253214*.... | 9.5 | 0.25 | 8.0 | B2 Vnn | 10.6 | ........... |

* See text.

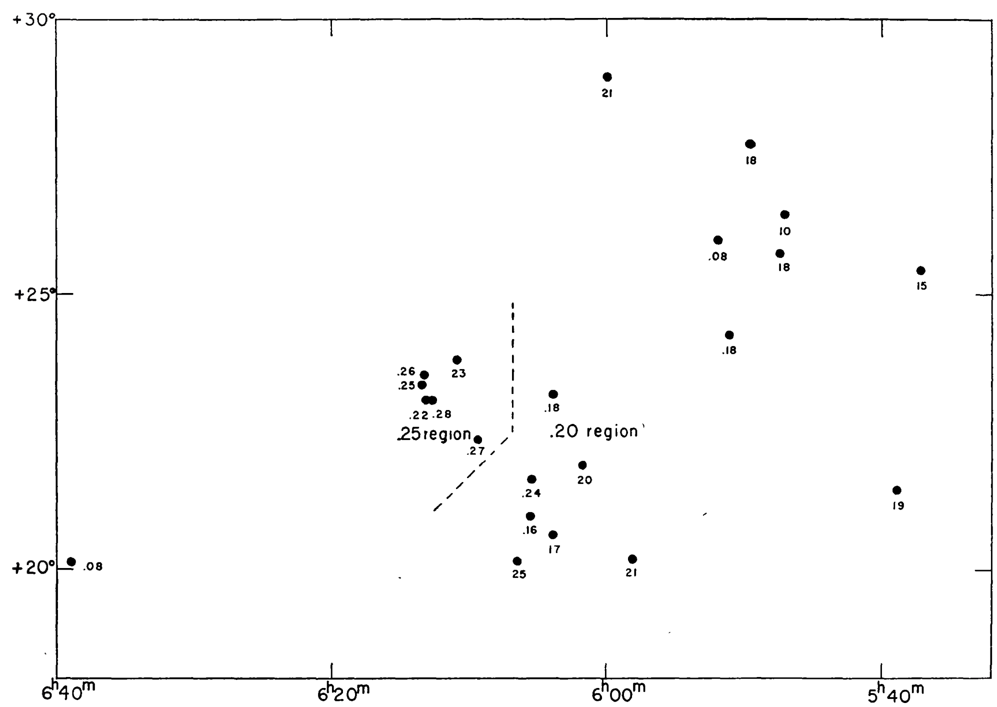


FIG. 2.—Positions and color excesses of stars with colors in the Stebbins, Huffer, and Whitford table. The dashed line represents the division into 0.20 and 0.25 mag. regions for color excesses of stars without measured colors.

the two regions is shown in the figure. These color excesses were applied to the stars for which colors were not available and which were within about three degrees of the center of the main concentration.

The data for these stars are shown in Table 2, the arrangement of which, with the addition of a "Remarks" column, is the same as that of Table 1. The estimated $E_1$'s in the fourth column are, of course, less accurate than the measured ones. Three of the four stars without distance moduli were omitted because their spectra were blended with moonlight, making the spectral type uncertain; the fourth is a peculiar emission-line star.

TABLE 2

PROBABLE ASSOCIATION MEMBERS WITHOUT COLORS

| HD | $m$ | $E_1$ | $m_0$ | Sp. | $m_0-M$ | $V$ (Km/Sec) | Remarks |
|---|---|---|---|---|---|---|---|
| 41831 | 9.0 | 0.20 | 7.8 | B3 V | 9.8 | ........ | |
| 249788 | 9.4 | .20 | 8.2 | B1 V | 11.4 | ........ | |
| 250163 | 10.2 | .20 | 9.0 | B2 Vpe | 11.6 | ........ | |
| 250310 | 9.0 | .20 | 7.8 | B3 V | 9.8 | ........ | |
| 251670 | 9.0 | .20 | 7.8 | B1–2 V? | ........ | ........ | Moonlight |
| 251726 | 10.0 | .20 | 8.8 | B2 III–Vpe | ........ | ........ | Peculiar |
| 251847 | 8.7 | .20 | 7.5 | B1 IV | 11.3 | ........ | |
| 252321 | 8.9 | .20 | 7.7 | B1 V | 10.9 | ........ | |
| 253180 | 9.6 | .20 | 8.4 | B0.5 V | 12.0 | ........ | |
| 253236 | 9.6 | .20 | 8.4 | B1 V: | 11.6: | ........ | |
| 253591 | 9.8 | .25 | 8.3 | B1 V | 11.5 | ........ | |
| 253683 | 9.5 | .20 | 8.3 | B3 III: | 12.0: | ........ | |
| 253981 | 9.4 | .20 | 8.2 | ........ | ........ | ........ | Moonlight |
| 254042 | 8.8 | .25 | 7.3 | B1 III | 11.6 | ........ | |
| 254346 | 9.6 | .25 | 8.1 | B2–3 III? | ........ | ........ | Moonlight |
| 254577 | 9.5 | .25 | 8.0 | B0.5 II–III | 12.8 | +18 | Strong K |
| 254699 | 9.3 | .25 | 7.8 | B1 V | 11.0 | ........ | |
| 254755 | 9.0 | .25 | 7.5 | O9 Vp | 11.7 | + 9 | |
| 255055 | 9.1 | .25 | 7.6 | O9 Vp(e?) | 11.8 | ........ | |
| 255091 | 9.4 | .25 | 7.9 | B2 V | 10.5 | ........ | |
| 255093 | 9.4 | .25 | 7.9 | B1.5 V | 10.8 | ........ | |
| 255134 | 9.2 | .25 | 7.7 | B1 IVp | 11.5 | ........ | |
| 255168 | 9.6 | .25 | 8.1 | B1 V | 11.3 | ........ | |
| 256035 | 9.6 | 0.25 | 8.1 | O9 V:p | 12.3: | ........ | |

## III. DISCUSSION

The distance moduli of the probable association members in Table 1 range between 9.5 and 11.4 mag.; the mean distance modulus is 10.7 mag., with an estimated probable error of $\pm 0.2$ mag. As would be expected, the distance moduli from the stars without colors, given in Table 2, are not so consistent as those of Table 1. The mean value for the former is 11.2 mag.; however, either the spectra of seven of these stars are peculiar, or the types are somewhat uncertain. If these seven are excluded, the mean distance modulus becomes 11.0 mag. In view of the fact that the stars in Table 1 carry a much greater weight than those in Table 2, the distance modulus of the association is taken as 10.7 mag. This corresponds to a distance of about 1400 parsecs. The apparent diameter of I Gem, around 5°, corresponds to a linear diameter of about 120 parsecs.

The radial velocities offer further evidence that we are dealing with a physically connected group of stars; the radial velocities of these stars are all approximately +17 km/sec.

Figure 3 gives an H-R diagram for the stars in the central condensation. The agreement between luminosity class and position on the diagram is satisfactory.

## IV. OBJECTS OF SPECIAL INTEREST

In the study of the I Persei association by Bidelman (1943), the Double Cluster was found to be physically connected with the group of supergiants in the neighborhood. In the region of I Gem, Trumpler (1930) lists several galactic clusters. However, using the criteria of position and distance as listed by Trumpler, it seems that none of these clusters is related to the Gemini association.

One of the most interesting objects in this region is the O6 star, HD 42088, and the

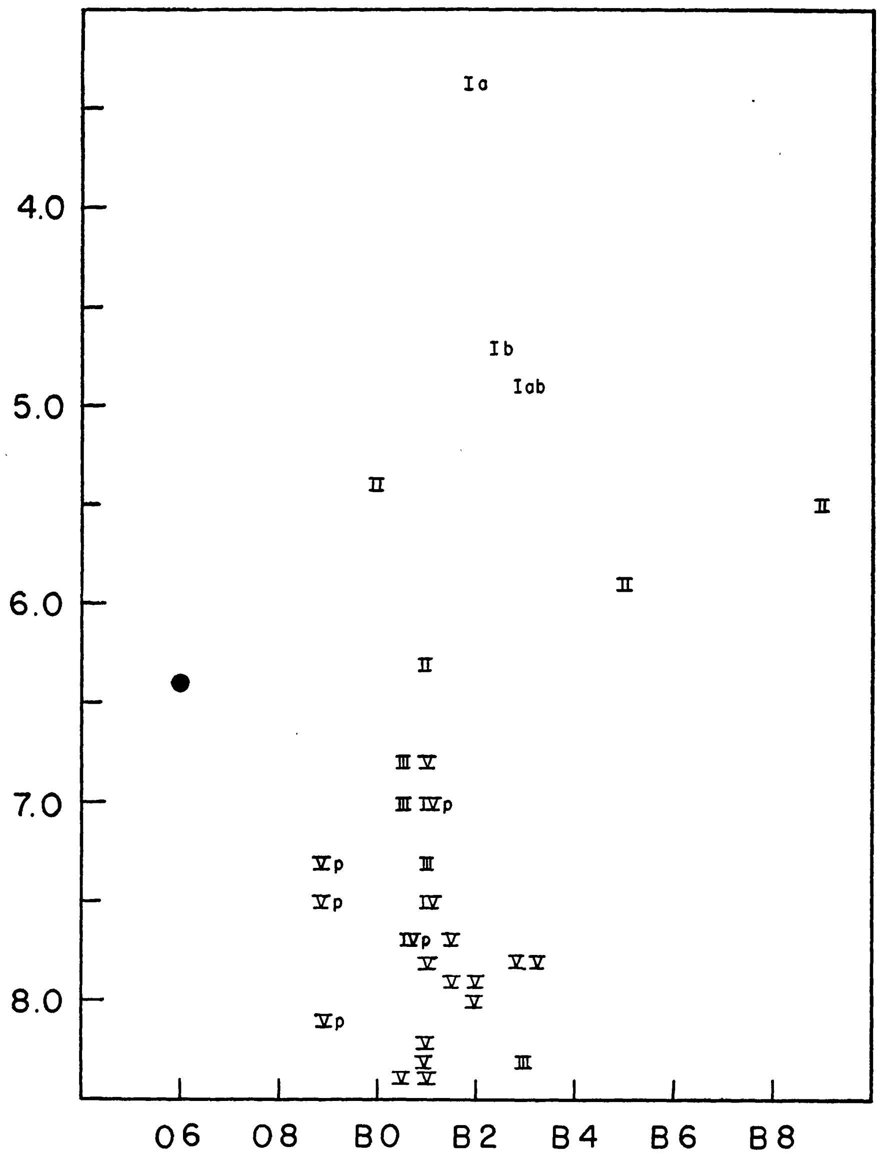


FIG. 3.—H-R diagram with corrected apparent magnitudes and spectral types for members of I Gem. Roman numerals indicate the luminosity classes of the stars in the association. The filled circle represents the O6 star HD 42088.

surrounding nebulosity NGC 2175. According to Collinder (1931), the nebulosity NGC 2175 is a nebulous cluster containing about sixteen members. This cluster has $\alpha(1900) = 6^h04^m.8$ and $\delta(1900) = +20°31'$ and is 15 minutes in diameter. Collinder gives its distance as 2700 parsecs, but this measure is based on a mean of parallaxes derived from integrated magnitudes and apparent dimension. Since the nebulosity and hence the cluster are connected with the O6 star discussed in this section, the question of whether the cluster is physically related to I Gem depends on whether the O star is.

The color of HD 42088 is given in the Stebbins, Huffer, and Whitford list and, with the HD magnitude, gives a corrected apparent magnitude of 6.4. Now, if we assume that $M = -5.0$ for a main-sequence O6 star,[1] we find a distance modulus of 11.4 mag., which is within the range of distances for the association members. The intensity of the interstellar K line in the spectrum of HD 42088 also suggests a distance of the same order as that of the association. This is in agreement with the relatively small absorption, of about one magnitude, found for the star.

The apparent radius of the nebulosity NGC 2175 is 13 minutes. Thus the linear radius, $s$, of the nebula is related to the distance, $r$, by the formula $s = 0.0038r$, where $s$ and $r$ are measured in the same units. If one applies the analysis of Strömgren (1939) on $H$ II regions to the nebula, using Kuiper's (1938) values for the temperature and bolometric correction, one obtains the values shown in Table 3 for the radius in terms of the number

TABLE 3

| | $M$ | | | |
|---|---|---|---|---|
| | −6.0 | −5.5 | −5.0 | −4.5 |
| $sN^{2/3}$ . . . . . . . | 160 | 136 | 117 | 100 |

of hydrogen atoms and ions per cubic centimeter, $N$. In this table $s$ is given in parsecs. One finds that the absolute magnitude is very sensitive to the value of $N$; thus, if $M = -6.0$, the hydrogen density is about 50 $cm^{-3}$, while for $M = -4.5$ one finds that $N$ is about 80 $cm^{-3}$. Thus an independent measure of $N$ is needed to determine the distance accurately, for example, an observation of the emission measure of the nebula (see Strömgren 1951).

Another star in this region which deserves special attention is HD 254577. Figure 4 shows the spectrum of this star and that of HD 255091 for comparison. These two stars have nearly the same line of sight and were taken during the same night on the same plate. The distance modulus for HD 254577, computed by the method described in section II of this paper, with $E_1 = 0.25$, is 12.8 mag. (3630 parsecs). The assumption of this color excess seems valid, since the blend at λ 4430, which is closely related to the interstellar reddening, is similar to that for the stars of the association. However, the interstellar H and K lines are much stronger than for the association members, indicating a larger distance for HD 254577. This would lead us to believe that the distance is as large as computed. Because of the great strength of the interstellar calcium lines, HD 254577 deserves further observation.

We can almost definitely relate several M supergiant irregular variable stars with I Gem. The two stars BU Gem and TV Gem have the magnitudes listed below, according to Kukarkin and Parenago (1949). The radial velocities ($V$) are from Wilson's catalogue

[1] This is in approximate agreement with Roman's estimate (1951).

(1953). BU Gem is a standard on the MK system, whereas TV Gem was classified by the authors.

| Star | $\alpha(1900)$ | $\delta(1900)$ | $m$ | Sp. | $V$ (Km/Sec) |
|---|---|---|---|---|---|
| BU Gem........ | $6^h06^m.2$ | 22° 56′ | 6.1–7.5 | M1 I*a* | +21.5 |
| TV Gem........ | 6 05.8 | 21 53 | 6.6–8.0 | M1 I*ab* | +17 |

If we accept the luminosities of Keenan and Morgan and correct for absorption according to Figure 2, using $m_{\max}$, we obtain the following:

| Star | $E_1$ | $A_1$ | $m_0$ | $M$ | $m_0 - M$ |
|---|---|---|---|---|---|
| BU Gem....... | 0.25 | 1.5 | 4.6 | −7.0 | 11.6 |
| TV Gem....... | 0.20 | 1.2 | 5.4 | −5.7 | 11.1 |

The resulting distance moduli place the stars within the range of the association. If the distance for the association is correctly taken as 10.7 mag., and we assume that these stars are in the association, we obtain a luminosity of −6.1 for BU Gem, a class I*a* star, and −5.3 for TV Gem, a class I*ab* star.

Bidelman (1954) suggests that WY Gem may also be connected with the association. The spectral class given below is from Kukarkin and Parenago:

| Star | $\alpha(1900)$ | $\delta(1900)$ | $m$ | Sp. | $V$ (Km/Sec) |
|---|---|---|---|---|---|
| WY Gem....... | $6^h05^m.9$ | 23° 14′ | 7.4 | M3 ep | +16 |

The radial velocity is similar to those of the association stars. On following the procedure outlined above, we find the spectroscopic absolute magnitude would have to be about −4.5 for WY Gem to be in I Gem.

## V. COMPARISON WITH OTHER ASSOCIATIONS

From the data derived in this investigation, a comparison can be made between I Gem and two other OB associations. Table 4 gives this comparison. On the basis of this table,

TABLE 4

COMPARISON OF THREE ASSOCIATIONS

| | ASSOCIATION | | |
|---|---|---|---|
| | I Gem | I Ori* | I Per |
| Diameter (parsecs)............. | 120 | 125 | 160 |
| Distance (parsecs)............. | 1400 | 500 | 2300 |
| Spectral type of class I supergiants. | B2–B3 | O9.5–B8 | B0.5–A2 |
| Number of stars earlier than B0... | 4 | 6 | 3 |
| Number of late-type supergiants.. | 2–3 | 1? | 13 |
| Earliest spectral type............ | O6 | O6 | O7 |

* Data from Sharpless (1952, 1954).

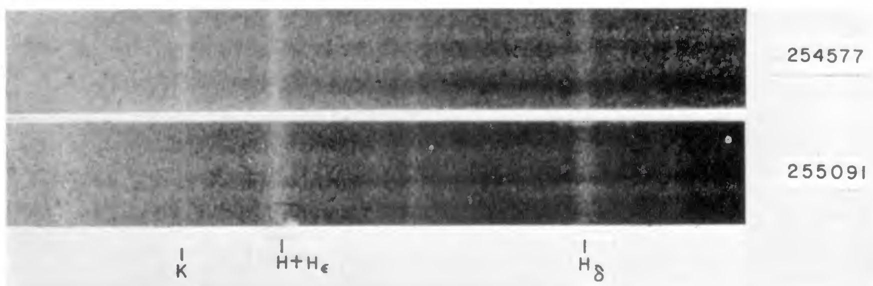


FIG. 4.—Spectra of B0.5 II–III star HD 254577 with strong K line, and B2 V star HD 255091.

I Gem can be placed somewhere between I Ori and I Per in a possible evolutionary sequence. All three are large associations. The associations I Ori and I Gem contain an O6 star imbedded in a gaseous nebula. The association I Per is somewhat peculiar, in that it contains the Double Cluster. There seems to be a transition in spectral type of the supergiants, earliest-type stars, the number of late-type supergiants, and the number of O stars. Also, the number of dark clouds in each association decreases in the same way, but this could be an observational effect due to increasing distance. In general, therefore, I Gem appears to be older than I Ori and younger than I Per.

The authors are deeply indebted to Dr. W. W. Morgan both for suggesting this investigation and for his valuable advice and helpful discussions.

## REFERENCES

Barnard, E. E. 1927, *Atlas of Selected Regions of the Milky Way* (Washington, D.C.: Carnegie Institution of Washington), Pls. 9 and 10.
Bidelman, W. P. 1943, *Ap. J.*, **98**, 61.
———. 1947, *ibid.*, **105**, 492.
———. 1954, "The Space Distribution of Supergiant Stars of Types Later than B" (paper presented at the June meeting of the American Astronomical Society in Ann Arbor, Michigan).
Collinder, P. 1931, *Ann. Lund Obs.*, **2**, B6.
Johnson, H. L., and Morgan, W. W. 1953, *Ap. J.*, **117**, 313.
Keenan, P. C., and Morgan, W. W. 1951, in J. A. Hynek (ed.), *Astrophysics* (New York: McGraw-Hill Book Co., Inc.), p. 23.
Kuiper, G. P. 1938, *Ap. J.*, **88**, 429.
Kukarkin, B. V., and Parenago, P. P. 1948, *General Catalogue of Variable Stars* (Moscow).
Morgan, W. W., Harris, D. L., and Johnson, H. L. 1953, *Ap. J.*, **118**, 92.
Morgan, W. W., Whitford, A. E., and Code, A. D. 1953, *Ap. J.*, **118**, 318.
Roman, N. 1951, *Ap. J.*, **114**, 492.
Sharpless, S. 1952, *Ap. J.*, **116**, 251.
———. 1954, *ibid.*, **119**, 200.
Stebbins, J., Huffer, C. M., and Whitford, A. E. 1940, *Ap. J.*, **92**, 193.
Strömgren, B. 1939, *Ap. J.*, **89**, 526.
———. 1951, *Problems of Cosmical Aerodynamics* (Dayton: Central Air Documents Office,), chap. ii.
Trumpler, R. L. 1930, *Lick Obs. Bull.*, **14**, 154.
Wilson, R. E. 1953, *General Catalogue of Stellar Radial Velocities* (Washington, D.C.: Carnegie Institution of Washington).