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EXPANDING MOTIONS IN THE LACERTA AGGREGATE

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ABSTRACT

The aggregate of O–B5 stars in Lacerta, centered at $l = 67°$, $b = -14°$ and containing, among others, the stars 6, 8, 10, 12, 14, and 16 Lacertae, is found to show an expansion similar to that of the ζ Persei aggregate. Figure 3 shows the proper motions. The coefficient of expansion is 0".00086 per year per degree and hence the age of the aggregate probably is 4.2×10^6 years. Its distance is about 460 parsecs, and the projected dimensions are 120×70 parsecs. Table 1 lists the stars in the aggregate. Table 2 summarizes its principal properties.

INTRODUCTION

The two-dimensional spectral classifications of O–B5 stars in the system of the Yerkes *Atlas of Stellar Spectra*, accumulated during recent years at the Yerkes Observatory, provide a new basis for the study of the motions and the distribution in space of these stars. The present paper deals with a group of stars in Lacerta and is part of a general study of the nature of the peculiar motions of the early-type stars. The recent discovery of the expanding motions in the ζ Persei aggregate[1] suggested that this phenomenon might be detectable also in other near-by aggregates. It is indeed found to be present in the one in Lacerta.

The luminosity classifications in the Yerkes system are in terms of the luminosity classes I–V. The final calibration of these luminosity classes will have to be based, at least partly, on proper motions as a criterion of distance. Their interpretation requires knowledge of the kinematical properties of the stars concerned. Therefore, the study of the peculiar motions precedes the final calibrations.

THE DISTRIBUTION IN THE SKY

The aggregate in Lacerta can be recognized rather easily on a plot of the O–B5 stars in the *Henry Draper Catalogue*. Figure 1 shows the distribution in the region $l = 45°–90°$, $b = 0°$ to $-30°$. Those stars which, according to the new spectral classifications and provisionally adopted absolute magnitudes,[2] have distance moduli between 7.0 and 9.5 (250–800 parsecs) are represented by dots. Newly classified stars outside these limits of distance modulus are not represented. All stars for which no reliable determination of the distance modulus was available are represented by plus signs. These include stars not yet observed for new classification, as well as the newly classified stars to which no luminosity class could be assigned and those not occurring in Stebbins, Huffer, and Whitford's list of colors.[3] There is a conspicuous clustering in the central region of the chart. It includes, among others, the stars 8 and 10 Lacertae and the β Canis Majoris type stars, 12 and 16 Lacertae.

Table 1 lists the 29 stars, represented on the chart in the area between the limits $l =$ 60° and 75°, $b = -5°$ and $-20°$. The visual magnitude m is taken from the *Henry Draper Catalogue*. The color excess E_1 is from the catalogue of Stebbins, Huffer, and Whitford,[3] with a slightly corrected zero point. The visual magnitudes corrected for interstellar absorption $m_0 = m - 7E_1$ are in the next column. The visual absolute magnitudes M_v are derived from these corrected apparent magnitudes and the mean distance modulus of the

[1] A. Blaauw, *B.A.N.*, No. 433, 1952.

[2] P. C. Keenan and W. W. Morgan, *Astrophysics*, ed. J. A. Hynek (1952), chap. i, Table 1.5.

[3] *Ap. J.*, **91**, 20, 1940; *Mt. W. Contr.*, No. 621, 1940.

group $m_0 - M = 8.3$ (distance 460 parsecs). The latter is based mainly on the B2 V and B3 V stars for which the provisional calibration of the mean absolute magnitudes has the largest weight. The H-R diagram, based on the absolute magnitudes of Table 1 and on the Yerkes spectra, is shown in Figure 2. It should be borne in mind that the stars studied were selected from the *Henry Draper Catalogue*, which is incomplete beyond $m = 8.3$. It is quite possible that there are other, undetected, members of the aggregate not listed in Table 1, with m_0 between 7 and 8 or even brighter, but more heavily obscured by interstellar absorption than the stars listed. Very little can yet be said about the membership of stars of later types than B3. A survey of the spectral classes of faint stars in the region

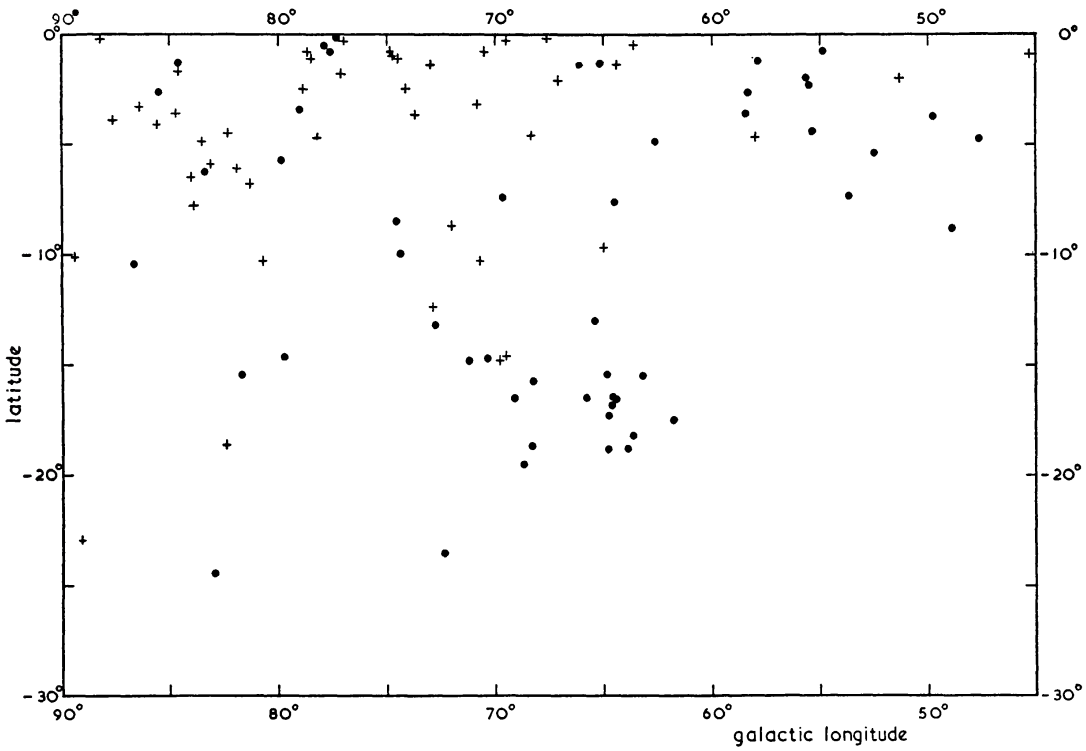

FIG. 1.—Distribution of the O–B5 stars in the *Henry Draper Catalogue*. Dots represent stars with well-determined distance modulus between 7.0 and 9.5; plus signs, stars with uncertain distance modulus. Stars with reliable distance modulus outside the interval 7.0–9.5 are not represented.

of the aggregate and adjacent ones, supplemented with luminosity classifications and color measures, would be necessary to settle this question. The average color excess of the stars in Table 1 is +0.083 mag. and, hence, the average amount of absorption in visual light is 0.6 mag.

THE PROPER MOTIONS

Annual proper motions for most of the stars are given in the tenth and eleventh columns of Table 1. They are in the average of the systems of FK3 and N30 with precessional corrections applied. Twenty-one stars are in B. Boss's *General Catalogue*. Many of the faint ones are in the *Second Greenwich Catalogue* ($Gr_2 25$). For four stars no proper motions are available. In many cases the GC proper motion was improved by combining it with the $Gr_2 25$ value and with an independent value derived from modern meridian observations, computed by Dr. H. R. Morgan at the Naval Observatory and kindly put at our disposal.

STARS IN THE LACERTA AGGREGATE

	HD	1900 R.A.	1900 Decl.	l	b	m	E_1	m_0	Sp.	M_v	Unit 0″.001 $\mu_\alpha \cos\delta$ p.e.	Unit 0″.001 μ_δ p.e.	Radial Vel. p.e. (Km/Sec)	Remarks
	209961	22h 2m.0	47° 45′	64°.5	− 7°.6	6.16	+0.08	5.6	B2 V	−2.7	− 1± 3.5	+ 4± 3.3	−17.8 Orb.	1
	211835	14.9	45 18	65.0	− 9.7	8.47	......	.....	B3:Ve	......	......	......	......	......
	212883	22.4	36 57	61.8	−17.5	6.39	+ .08	5.8	B2 V	−2.5	+ 6± 4.2	− 4± 2.6	− 6.5±0.7	Field star?
	212978	23.1	39 19	63.2	−15.5	6.07	+ .06	5.7	B2 V	−2.6	+14± 3.7	− 2± 3.6	−16.8±0.8	Field star?
6 Lac	213420	26.1	42 36	65.4	−13.0	4.54	+ .09	3.9	B2 IV	−4.4	− 7± 2.0	− 2± 1.4	− 9.8±0.9	
	213976	30.1	40 16	64.9	−15.4	7.00	+ .10	6.3	B1.5 V	−2.0	−17± 4.0	− 3± 3.0	−17.2±1.9	
8 Lac ft	214167	31.4	39 7	64.5	−16.5	6.55	+ .00	6.5	B2 V	−1.8	− 7± 4.2	− 6± 3.3	−13.4±1.5	
8 Lac br	214168	31.4	39 7	64.5	−16.5	5.83	+ .11	5.1	B1 Vne	−3.2	− 2± 2.0	−10± 1.5	−12.5±4	
	214240	31.8	49 33	69.7	− 7.4	6.20	+ .12	5.4	B3 V	−2.9	0± 2.0	+ 7± 1.8	−15.3 Orb.	2
	214263	31.9	37 19	63.7	−18.1	6.75	+ .04	6.5	B2 V	−1.8	− 4± 8.3	0± 5.9	−19.5±0.4	
	214432	33.0	38 55	64.7	−16.8	7.4	+ .08	6.8	B3 V	−1.5	−10± 7.0	−11± 7.0	......	
	214652	34.6	36 51	63.9	−18.8	6.67	+ .09	6.0	B2:V	−2.3	0± 4.4	− 6± 3.4	−12.6 Orb.	3
10 Lac	214680	34.8	38 32	64.8	−17.3	4.91	+ .06	4.5	O9 V	−3.8	+ 4± 1.1	− 4± 0.8	− 9.5±0.4	
12 Lac	214993	37.0	39 43	65.8	−16.5	5.18	+ .04	4.9	B2 III	−3.4	− 2± 2.6	− 3± 1.8	−15	4
	215191	38.4	37 17	64.8	−18.8	6.22	+ .11	5.5	B1 V	−2.8	+11± 7.0	−11± 5.0	−17.8±1.5	
	216092	44.9	47 24	70.7	−10.3	8.1	......	.....	B1:V	......	......	......	......	
14 Lac	216200	45.8	41 26	68.2	−15.7	5.84	+ .16	4.7	B3 IV:	−3.6	+ 9± 1.8	0± 1.7	−20.2±0.7	
	216534	48.6	49 20	72.0	− 8.7	8.0	......	.....	B3 V	......	......	......	......	
	216684	49.8	43 0	69.5	−14.6	7.8	......	.....	B3 V	......	+ 1±10.0	+10±10.0	......	
	216851	51.3	43 2	69.8	−14.7	7.68	......	.....	B3 V:n	......	+ 1± 9.0	− 6± 9.0	......	
16 Lac	216916	51.9	41 4	69.1	−16.5	5.54	+ .07	5.1	B2 IV	−3.2	+ 1± 2.1	− 4± 1.5	−13.6	5
	217101	53.1	38 48	68.3	−18.7	6.07	+ .07	5.6	B2 IV–V	−2.7	0± 2.5	− 9± 1.9	−15.5±0.7	
	217227	54.2	43 18	70.4	−14.7	7.02	+ .07	6.5	B2: V	−1.8	+14± 8.0	+13± 7.0	−14.4±0.7	
	217543	56.3	38 10	68.6	−19.5	6.39	+ .07	5.9	B3	−2.4	+ 8± 6.0	− 5± 6.5	−13.7±3.4	
	217811	58.2	43 31	71.2	−14.8	6.32	+ .12	5.5	B2 V	−2.8	− 1± 3.5	− 1± 2.4	− 8.3±0.4	
	218325	23 2.0	46 23	72.9	−12.4	8.0	......	.....	B3 V	......	......	......	......	
	218344	2.1	50 33	74.6	− 8.5	7.17	+ .06	6.8	B2 V	−1.5	− 6±11.0	+12±11.0	−12.7±1.2	
	218407	2.7	45 33	72.8	−13.2	6.56	+ .09	5.9	B2 V	−2.4	− 1± 3.0	0± 2.5	−15.1 Orb.	6
	218674	4.8	49 7	74.4	−10.0	6.53	+0.13	5.6	B3 IV	−2.7	+ 6± 4.0	0± 3.0	− 3.9±3.9	

NOTES TO TABLE 1

1. Orbit by R. K. Young, *Pub. Dom. Ap. Obs. Victoria*, **1**, 193, 1920, based on 32 observations in 1918 and 1919.
2. Orbit by S. N. Hill, *Pub. Dom. Ap. Obs. Victoria*, **3**, 358, 1926, based on 32 observations in 1925 and 1926.
3. Orbit by A. McKellar, *Pub. Dom. Ap. Obs. Victoria*, **6**, 369, 1937, based on 55 observations in the years 1925–1937.
4. 12 Lacerta, β Canis Majoris type, see O. Struve, *Ap. J.*, **113**, 589, 1951, and papers referred to by this author.
5. 16 Lacerta, β Canis Majoris type, see O. Struve *et al.*, *Ap. J.* **116**, 81, 1952, and papers referred to by this author.
6. Orbit by R. K. Young, *Pub. Dom. Ap. Obs. Victoria*, **1**, 239, 1920, based on 27 observations in the years 1918–1920.

In comparing the GC and the Greenwich catalogues it was found that a systematic difference exists between the proper motions in right ascension for stars fainter than $m = 6$. It amounts to $0^s.0012$ per year and does not seem to vary much with the apparent brightness for magnitudes fainter than 6, but does not occur for the brighter stars. We have assumed that it represents a magnitude error in the $Gr_2 25$ motions and accordingly have applied a correction of $-0^s.0012$ to the μ_α's for $m > 6$ in that catalogue. However, it is not certain that the error is wholly in the Greenwich catalogue and therefore there is considerable uncertainty in the proper motions in right ascension as used in the present investigation. The amount of $0^s.0012$ is large compared to the observed internal motions. The components μ_α are not used in the evaluation of the coefficient of expansion.

Total proper motions are represented as arrows in Figure 3. The scale and the directions of α and δ are indicated in the lower left-hand corner. Dotted arrows represent proper motions with probable errors larger than $\pm 0''.005$. The size of the dots indicates the apparent brightness of the stars. Faint stars for which no proper motions are available are represented by circles.

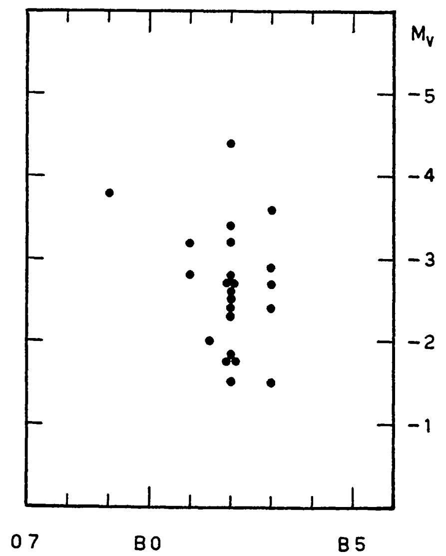

FIG. 2.—H-R diagram of the Lacerta aggregate

The heavy arrows at the lower left-hand corner represent the directions and amounts of the proper motions which correspond to the reflex of the standard solar motion for stars at the center of the aggregate (the υ component), the effect of differential galactic rotation, and the combined proper motion. As will be seen from Figure 3, the stars generally do not show this latter proper motion, but rather have the tendency to move outward from the center of the aggregate. There is considerable uncertainty in some of the proper motions, and there are a few cases, as, for instance, the star HD 212978 at $l = 63^\circ.2$, $b = -15^\circ.5$, which definitely move in the opposite direction. However, such exceptions are to be expected in the case of an expanding aggregate mixed with some field stars. On the whole, there appears to be fairly strong evidence that the Lacerta aggregate does show an expansion, similar to the ζ Persei aggregate.

EVALUATION OF THE EXPANSION

The expansion has been derived quantitatively only from the proper motions in declination, the components in right ascension being excluded for the reasons mentioned above. All stars with known proper motion in Table 1 were used, including some doubtful members. Apart from the uncertainty with regard to the magnitude error in the μ_α's, the proper motions in right ascension are a less reliable basis than those in declination, because the reflected solar motion of possible field stars affects the motions in right ascension much more than those in declination. The influence of a possible field star like HD 212978 mentioned before is thus reduced. Another favorable circumstance is that the aggregate is elongated in the direction of declination, indicating faster expansion in this direction.

Figure 4 shows the μ_δ's plotted against the declinations. The size of the dots indicates the weight of the μ_δ's. The expansion of the aggregate is revealed by the increase of μ_δ

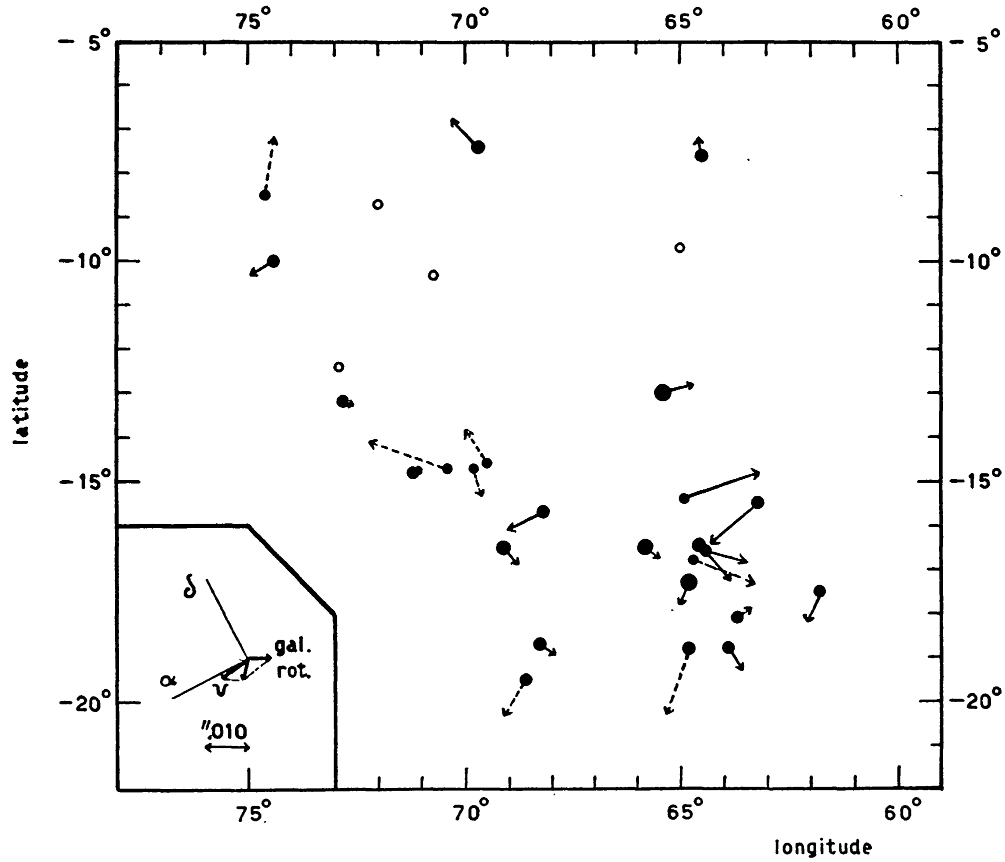

FIG. 3.—Proper motions of stars in the region of the Lacerta aggregate. Dashed arrows represent proper motions with probable errors exceeding $\pm 0\overset{''}{.}005$. Circles represent stars with unknown proper motion. The scale of the proper motions and the directions of increasing α and δ are indicated in the lower left-hand corner.

with increasing declination. A linear relation has been adopted, and the coefficient of expansion as found from a least-squares solution is

$$\frac{d\mu_\delta}{d\delta} = +\,0\overset{''}{.}00096 \text{ per year per degree} \pm 0\overset{''}{.}00013 \text{ (p.e.)}.$$

The correction for spurious expansion due to the motion of the aggregate with respect to the sun along the line of sight is $-0\overset{''}{.}00010$ per year per degree, based on the mean radial velocity -13.6 km/sec. Hence the real expansion is

$$\frac{d\mu_\delta}{d\delta} = +\,0\overset{''}{.}00086 \text{ per year per degree} \pm 0\overset{''}{.}00013 \text{ (p.e.)}.$$

Interpreting this result on the assumption that the stars originated in a volume of space much smaller than the present size of the aggregate and that they started their motions simultaneously, we find the age of the aggregate to be

$$T_x = 4.2 \times 10^6 \text{ years} .$$

The assumptions made here—the same as those on which the determination of the age of the ζ Persei aggregate were based—are, of course, rather simplifying. Especially with regard to the second assumption, it may be noticed that the time elapsed between the

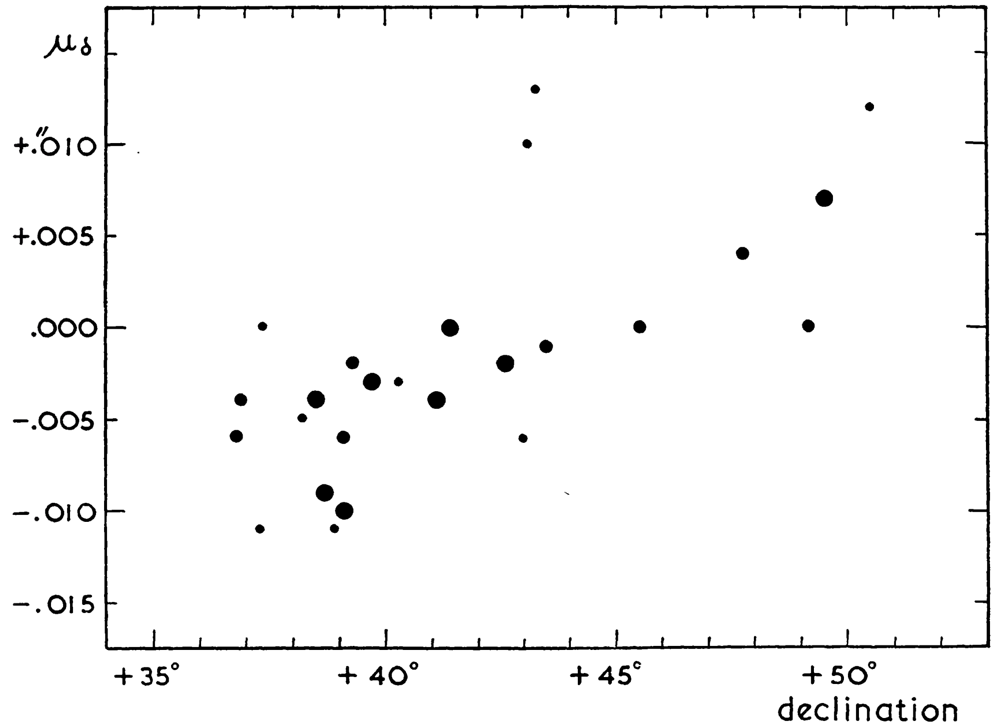

FIG. 4.—Components of proper motion in declination, μ_δ plotted against the declination. The sizes of the dots indicate the relative weights of the proper motions.

formation of different stars in the aggregate may well be an appreciable fraction of the ages found (1.3×10^6 years for the ζ Persei aggregate). The derived ages refer mainly to the stars which have moved farthest from the center of formation, as these contribute most of the weight in the solution for the coefficient of expansion. These may be the oldest stars.

THE MEAN VELOCITY OF EXPANSION

The radial velocities of the stars in the aggregate are in the next to the last column of Table 1. Most of them are taken from the Victoria lists[4] or from Moore's catalogue;[5] a few are from a recent Mount Wilson list.[6] Systemic velocities of spectroscopic binaries and mean velocities of 12 and 16 Lacertae are taken from the sources referred to in the notes to the table.

After elimination of the standard solar motion from the individual velocities by means

[4] J. S. Plaskett and J. A. Pearce, *Pub. Dom. Ap. Obs. Victoria*, Vol. **5**, 1931; J. A. Pearce and R. M. Petrie, *Pub. Dom. Ap. Obs. Victoria*, Vol. **8**, 1951.

[5] *Pub. Lick Obs.*, Vol. **18**, 1932.

[6] R. E. Wilson and A. H. Joy, *Ap. J.*, **111**, 221, 1950.

of the Prague tables,[7] we find the mean of the velocities left to be −2.4 km/sec. The average residual without regard to sign with respect to this mean, derived from 16 stars with the most reliable velocities and corrected for the influence of accidental errors, is

$$\eta_{\mathrm{rad}} = \pm 3.1 \text{ km/sec.}$$

The relatively large accidental errors of the proper motions exclude a reliable determination of the mean velocity of expansion directly from the proper motions as given in Table 1. We can, however, derive it from the coefficient of expansion already determined and from the positions of the stars with respect to the center of the aggregate. In this way we find from the components in δ and α, respectively,

$$\eta_{\delta} = \pm 6 \text{ km/sec} \quad \text{and} \quad \eta_{\alpha} = \pm 4 \text{ km/sec},$$

and for the average velocity of the stars with respect to the center,

$$\eta = 8 \text{ km/sec}.$$

POSSIBLE MEMBERS OUTSIDE THE REGION OF FIGURE 3

The region of the aggregate to which the data in Table 1 and Figure 3 refer may seem to be chosen somewhat arbitrarily; the concentration of stars noticed in the center of Figure 1 merges gradually into the star field in the upper and left-hand parts of the diagram. Whether there are members of the aggregate outside the region of Figure 3 can be decided only on the basis of the directions and amounts of the proper motions. These must be expected to point radially outward from the center of the aggregate (if the center is at rest and corrections for solar motion have been applied) and to be proportional to the angular distance from this center (assuming the expanding motions to have started simultaneously).

There are some stars in the left-hand part of Figure 1 for which the proper motions seem to meet these requirements, but the evidence is not conclusive. The uncertainty arises mainly from the fact that the directions of expanding motions for these stars do not deviate much from the direction of the reflected solar motion. Accidental errors in the elimination of the latter, due to errors in the estimated distances of the stars, can easily have caused spurious residual proper motions resembling the expected expanding proper motions.

The situation is somewhat different in the region west of the aggregate. Near the upper right corner of Figure 1 the proper motions of possible members of the aggregate must be directed approximately opposite to the solar reflex. Three stars for which this is the case are:

HD 197419: GC 28861, at $l = 44\overset{\circ}{.}4$, $b = -5\overset{\circ}{.}0$, B2 V, $m_0 - M = 8.7$;
HD 199356: $\mathrm{Gr}_2 25$ 8841, at $l = 49\overset{\circ}{.}8$, $b = -3\overset{\circ}{.}8$, B2e, $m_0 - M = 8.8$;
HD 201910: GC 29627, at $l = 52\overset{\circ}{.}5$, $b = -5\overset{\circ}{.}4$, B5 V, $m_0 - M = 8.3$.

Their total proper motions with respect to the center of the aggregate are: $0\overset{''}{.}018 \pm 0\overset{''}{.}004$; $0\overset{''}{.}014 \pm 0\overset{''}{.}012$ and $0\overset{''}{.}012 \pm 0\overset{''}{.}005$ (p.e.), respectively. At the average angular distance of these stars from the center of the aggregate (about 20°) the predicted proper motion is $0\overset{''}{.}018$. These stars may thus have originated in the aggregate. However, the observational data are still very weak and certainly are no proof of an association of these stars with the aggregate. There is a fair chance that they are field stars with peculiar motions which happen to fit the picture of the expansion. The only way to obtain conclusive evidence is the determination of new positions from meridian observations in order to improve the accuracy of the proper motions.

At the present stage of the investigations of expanding aggregates we prefer to take a conservative attitude when considering the possible membership of stars at large angu-

[7] *Tables d'apex solaire*, ed. F. Link. ("Mem. and Obs. Czechoslovak Astr. Soc.," No. 9 [1948]).

lar distances from the centers. The somewhat arbitrary way in which investigators in the past have sometimes selected lists of (spurious) members of moving clusters indicates the need for care in this matter.

THE β CANIS MAJORIS TYPE MEMBERS

An interesting feature of the aggregate is the presence of the two β Canis Majoris type stars, 12 and 16 Lacertae. Both are B2 stars of intermediate luminosity; the values found here, $M_v = -3.4$ and -3.2, respectively, are very close. It is of some interest to compare these stars with others of the same category. σ Scorpii[8] is classified as B1 III, and its visual absolute magnitude, taken from *Groningen Publications*, No. 52, Table 33*a*, and corrected for interstellar absorption, is $M_v = -4.5$. For β Cephei, type B2 III, and β Canis Majoris, type B1 II–III, we derive, from the v component of the proper motions, $M_v = -2.8$ and -4.9, respectively.

These results suggest that the β Canis Majoris type of variation is closely related to the small region of the Hertzsprung-Russell diagram defined by the intermediate luminosities at spectral types B1 and B2. Other examples are ν Eridani,[9] type B2 III, and HD 199140,[10] type B2 III.

TABLE 2

	Lacerta Aggregate	ζ Persei Aggregate
Mean co-ordinates	$l=67°$; $b=-14°$	$l=128°$; $b=-15°$
Number of stars	29	17
Dimensions	120×70 psc	40×25 psc
Distance	460 psc	300 psc
Space velocity	<6 km/sec	15 km/sec
Mean velocity of expansion	8 km/sec	12 km/sec
Coefficient of expansion	0″00086 per year per degree	0″00268 per year per degree
Age derived from expansion	4.2×10^6 years	1.3×10^6 years

PROPERTIES OF THE AGGREGATE AS A WHOLE

The mean co-ordinates for 1900 are $\alpha = 22^h40^m$, $\delta = +42°$, $l = 67°$, $b = -14°$; and the projected dimensions are about $15° \times 9°$, corresponding to linear dimensions of 120×70 parsecs.

The mean components of proper motion in galactic longitude and latitude corrected for solar motion and differential galactic rotation are $-0\overset{''}{.}0014$ and $+0\overset{''}{.}0020$, respectively, corresponding to linear velocities of -3 and $+4$ km/sec. The mean radial velocity corrected for solar motion, for differential galactic rotation, and for an estimated gravitational red shift of $+1.5$ km/sec, is -1.0 km/sec. The motion of the aggregate as a whole with respect to the field stars thus appears to be less than 6 km/sec.

It would be interesting to know whether there exists a close association between the aggregate and the interstellar matter within which it was formed, as in the case of the ζ Persei aggregate. Only a few photographs covering the region of the aggregate or parts of it have been published. On the whole, the distribution of the faint stars seems to be rather smooth, but a dark cloud in the densest part of the aggregate is weakly indicated. Further observations are required to investigate this matter.

Table 2 summarizes the principal data concerning the Lacerta aggregate. Those for the ζ Persei aggregate are added for comparison.

[8] See R. D. Levée, *Ap. J.*, **115**, 402, 1952, and references given there.

[9] See D. H. McNamara, *Pub. A.S.P.*, No. 377, p. 76, 1952, and references given by this author.

[10] R. M. Petrie, *J.R.A.S. Canada*, **40**, 149, 1946.