THE SPACE MOTIONS OF AE AURIGAE AND μ COLUMBAE WITH RESPECT TO THE ORION NEBULA

A. BLAAUW AND W. W. MORGAN
Yerkes Observatory
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ABSTRACT

The B0 V star, μ Columbae, appears to move in the direction away from the Orion association, with the same speed, 127 km/sec, as the O9.5 V star, AE Aurigae, discussed by the authors in a previous paper. The motions of the two stars are, moreover, almost exactly opposite. The observational data suggest that the stars were formed in the same physical process 2.6 million years ago and that this took place in the neighborhood of the Orion Nebula.

I. INTRODUCTION

In a previous paper[1] we have shown that the O9.5 V star AE Aurigae possesses a high space velocity, 128 km/sec, in the direction away from the Orion association, and we suggested that it probably originated there 2.7 million years ago. The evidence for its high velocity is supported by the peculiar structure of the emission nebula IC 405, surrounding AE Aurigae.

TABLE 1

OBSERVATIONAL DATA ON AE AURIGAE AND μ COLUMBAE

	AE Aur	μ Col
α, δ (1900)	$5^h9^m.7$, $+34°12'$	$5^h42^m.3$, $-32°21'$
l, b	$139°.8$, $-0°.9$	$204°.5$, $-25°.9$
m, visual magnitude	5.8	5.2
m_0, magnitude corrected for interstellar absorption	4.4	....
Spectral type in revised system of Yerkes spectral atlas	O9.5 V	B0 V
Radial velocity (km/sec) and p.e.	$+59.3 \pm 0.7$	$+109.9 \pm 2.1$
$\mu_\alpha \cos \delta$ (unit $0''.0001$)	-2 ± 22	$+81 \pm 21$
μ_δ (unit $0''.0001$)	$+401 \pm 24$	-266 ± 20

Since that paper was written, we have found that the star μ Columbae, spectral type B0 V, possesses similar properties, in that it also moves away from the Orion region, with approximately the same space velocity, and must have originated there at about the same time as AE Aurigae. Moreover, the motion of μ Columbae is directed just opposite to that of AE Aurigae. The two stars present a phenomenon which has not been encountered before and which throws new light on the process which causes the expanding motions in the associations of O and B stars. In the present case there is strong reason to think that the point of origin of the two stars is located in the neighborhood of the Orion Nebula.

II. THE OBSERVATIONAL DATA

Table 1 summarizes the observational data on the two stars. The proper motions are in the average of the systems of FK3 and N30, with precessional corrections applied.

[1] *B.A.N.*, No. 448, p. 76, 1953.

For AE Aurigae, as was described,[1] a solution was based on all available meridian observations, including some very recent ones. μ Columbae (HD 38666) appears both in the *General Catalogue* and in the recently published N30 catalogue (GC 7230, N30-1235); and for this star we made no new solution but combined the data given in the two catalogues. The catalogue values reduced to the fundamental system mentioned above, including the precessional corrections, are given in the accompanying tabulation.

	$\mu_{\alpha} \cos \delta$	μ_{δ}
From *GC*........	$+0''.0102 \pm 0''.0024$ (p.e.)	$-0''.0252 \pm 0''.0022$ (p.e.)
From N30.......	$+0.0018 \pm 0.0041$	-0.0315 ± 0.0041

The star deserves further observation; for the present we adopt the weighted mean given in Table 1. The radial velocities of both stars are those given in Moore's catalogue (*Pub. Lick Obs.*, Vol. **18**, 1932). For μ Columbae no measure of the color excess is available as yet.

Figure 1 shows the position of the two stars in the sky with respect to the Orion group. Large dots and open circles are the stars brighter than apparent visual magnitude 3.5; solid dots represent the OB supergiants. It is interesting to note the isolated position at relatively high latitude of μ Columbae, which also belongs to this class.

Arrows indicate the directions of the proper motions of AE Aurigae and μ Columbae; their sizes correspond to the displacements in 4×10^5 years. These proper motions are the observed ones after elimination of the standard solar motion (20 km/sec toward R.A. 270°, Dec. +30°). The great circles defined by these proper motions have been traced backward in Figure 1; the shaded areas indicate the uncertainty in their directions corresponding to the probable errors of the proper motions. If the medium in which the two stars originated is at rest with respect to the standard of rest obtained by elimination of the standard solar motion, then this medium must now be located somewhere on the great circles traced backward from the proper motions. Or, rather, in view of the uncertainty in the directions of the proper motions, it will probably be located somewhere in the shaded areas. If the medium is not at rest in the reference system defined by elimination of the standard solar motion, it need not be on the backward-traced circles. For instance, in view of what will be said below, it may be that both stars originated in the cloud surrounding θ^2 Orionis (the Trapezium stars). The position of this cloud east of the two shaded areas would then indicate a positive proper motion in right ascension for this cloud in the adopted reference system.

III. THE SPACE MOTION OF μ COLUMBAE

It is of interest to estimate the amount and the direction of the space motion of μ Columbae. In the following computations in this section it will be assumed that the standard solar motion is eliminated. The "observed" radial velocity then is +90.0 km/sec and the total proper motion $0''.0282$. Assuming the visual absolute magnitude −3.9, in accordance with the provisional calibrations as given in *Astrophysics* (ed. J. A. Hynek), page 23, and neglecting interstellar absorption (which probably is quite low in this direction), we find a distance of 600 parsecs and a space velocity of 126 km/sec. That this motion is away from the Orion association not only in its projection on the sky but also in space can be shown as follows. Assuming for the Orion association a distance of 500 parsecs, as found by Sharpless,[2] we find that a velocity of 126 km/sec along the line connecting it with μ Columbae corresponds to a radial velocity of + 86 km/sec and a proper motion of $0''.0293$. Both are very close to the "observed" values. The distance

[2] *Ap. J.*, **116**, 25, 1952.

of μ Columbae from the center of the Orion association is about 320 parsecs; this would have been traveled with the speed of 126 km/sec in 2.5×10^6 years. This is almost equal to the age of AE Aurigae found in the previous paper: 2.7×10^6 years.

These results, together with the observation of the opposite directions of the space motions, suggest strongly that we are not dealing here with a chance phenomenon but that the two stars must have originated in the same physical process. The probable relation of the medium in which the process took place with the Orion Nebula makes the

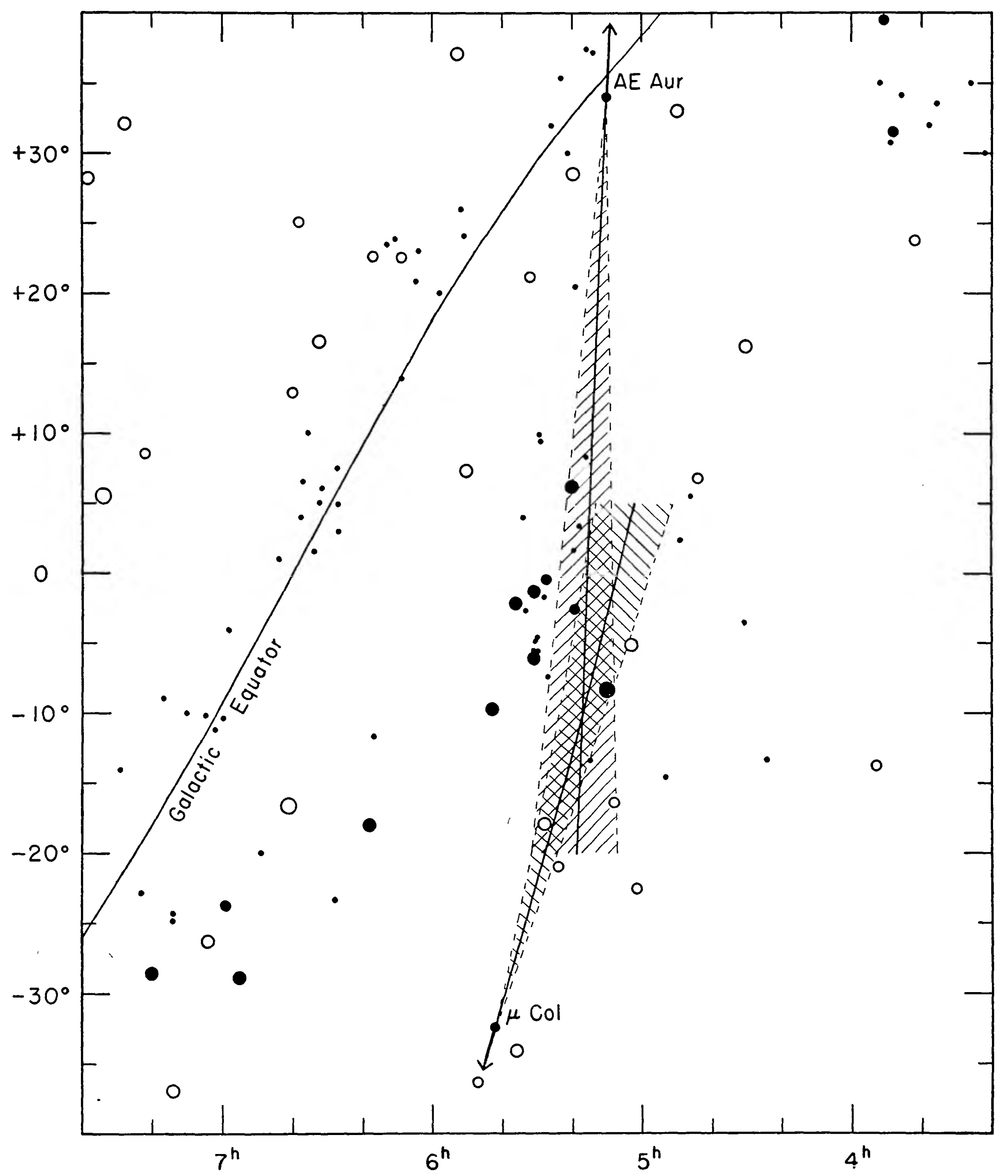

FIG. 1.—The positions of AE Aurigae and μ Columbae with respect to the Orion association. Arrows show the directions of their proper motions when corrected for the standard solar motion. The paths of the two stars with respect to the standard of rest thus defined are shown by the great circles traced backward from the proper motions. The shaded areas indicate the uncertainty in their directions. The sizes of the arrows correspond to the displacements in 4×10^5 years. Stars brighter than apparent magnitude 3.5 are represented by large dots (OB supergiants) and open circles. Small dots represent the fainter OB supergiants.

phenomenon particularly interesting. The relative importance of the process of the formation of the two stars may be illustrated by the following consideration. The average speed of the O and B stars in the Orion Nebula and its immediate neighborhood, as inferred from the radial velocities and proper motions, is about 8 km/sec. The stars μ Columbae and AE Aurigae therefore represent the same amount of kinetic energy as do about 500 stars in the Orion group, on the assumption that the masses are the same. Actually, the total number of stars with spectral types B9 and earlier in the subsystem around θ^1 and θ^2 Orionis is only about 100, and the average mass will be lower than that of AE Aurigae and μ Columbae.

IV. THE HYPOTHESIS OF EQUAL AND OPPOSITE VELOCITIES

No explanation of the remarkable phenomenon of this pair of stars will be attempted in this paper. We shall, however, show how well the observations can be represented by the hypothesis that the stars were formed with exactly equal and opposite velocities with respect to the generating medium and shall discuss the probable present location of this medium.

On this hypothesis the medium must be located on the line connecting the two stars in space and at equal distances from the two. This means, in the first place, that it must be located on the great circle through the two stars. Part of this great circle is shown by the white dotted line in Figure 2, which represents a section of the Ross *Atlas* photograph of the Orion constellation. It shows that the great circle runs through the Orion Nebula, and computations show that it actually passes the Trapezium stars at an angular distance of only 23 minutes of arc. This corresponds to a projected distance of 3.3 parsecs at the distance of the Orion group. It strongly suggests that the origin of the stars is indeed in the Orion Nebula.

In order to see where exactly it would be located on the above hypothesis, we have proceeded as follows. For AE Aurigae we have adopted, as before, the distance of 525 parsecs given in our first paper. For μ Columbae the distance has been taken as an unknown. The present hypothesis, combined with the observed proper motions and radial velocities of the two stars, then allows a determination of the distance of μ Columbae, the direction and the distance of the origin of the two stars, the motion of the two stars with respect to it, and the space motion of this origin. The results of the solution are summarized in Table 2. In this table all observed and computed quantities are referred to the sun and not to the system of reference adopted in the previous section.

The distance of μ Columbae is found to be 675 parsecs, corresponding to $m_0 - M = 9.14$. With the adopted absolute magnitude $M_v = -3.9$ (see the preceding section), we find $m - M = 9.1$. There may be some interstellar absorption; and one might expect, therefore, a somewhat higher value for $m - M$ than 9.1. On the other hand, the adopted value of M_v is also uncertain by at least a few tenths of a magnitude.

The velocity of the two stars with respect to their origin, 127 km/sec, and their distance from the origin, 337 parsecs, leads to an age of 2.6×10^6 years for the pair. The agreement between the observed and computed values of the μ_δ's and the radial velocities is not surprising, as it is mainly these quantities which determine the relative speed of the stars, the distance of μ Columbae, and the motion and location of the point of origin. The agreement of the observed and computed values of $\mu_\alpha \cos \delta$ for both stars, on the other hand, is significant, in that it means that the two stars move with respect to each other along the connecting line.

The distance of the generating medium is found to be 502 parsecs; this is equal to the distance of the Orion association. The position of the generating medium (R.A. $5^h27^m.8$, Dec. $-3°47'$ for 1900) is indicated by the cross in Figure 2. The motion of the generating medium is small, as shown in the lower part of Table 2. If we convert these data into the radial velocity and the components of proper motion, we get the values at the bottom of Table 2. For comparison, the mean proper motions and radial velocity of the stars in the

FIG. 2.—Section of the Ross atlas photograph of the Orion region. The white dotted line is part of the great circle connecting AE Aurigae and μ Columbae. The white cross indicates the position of the point of origin as found on the hypothesis of equal and opposite velocities of the two stars.

subsystem around θ^1 and θ^2 Orionis (12 stars in the region R.A. 5^h20^m to 5^h40^m, Dec. $-4°$ to $-6°45'$) are also given, together with the quantities which would be observed for an object at the location of the Orion Nebula but showing only standard solar motion and galactic rotation. As could be foreseen, the space motion of the generating medium with respect to this assumed object is quite small. Of more interest is the question: Can it be identified with the Orion Nebula? The fact that its position is found to be a little

TABLE 2

SOLUTION BASED ON HYPOTHESIS OF EQUAL AND OPPOSITE VELOCITIES

QUANTITIES RELATING TO THE TWO STARS AE AURIGAE AND μ COLUMBAE

Distance of μ Col	675 parsecs
Distance from point of origin	337 parsecs
Speed with respect to point of origin	127 km/sec
Time elapsed since stars left point of origin	2.6×10^6 years

	AE Aur		μ Col	
	Obs.	Comp.	Obs.	Comp.
$\mu_\alpha \cos\delta$ and p.e.	$-0''.0002\pm0''.0022$	$+0''.0003$	$+0''.0081\pm0''.0021$	$+0''.0077$
μ_δ	$+0.0401\pm.0024$	$+0.0401$	-0.0266 ± 0.0020	-0.0271
Radial velocity	$+59.3\pm0.7$	$+59.7$	$+109.9\pm2.1$	$+109.8$

QUANTITIES RELATING TO THE POINT OF ORIGIN

Position (1900)	$\alpha=5^h27^m.8$, $\delta=-3°47'$; $l=174°.8$, $b=-17°.7$
Distance	502 parsecs
Motion with respect to the sun:	
Component X ($\alpha=0°$, $\delta=0°$)	-11.6 km/sec
Y ($\alpha=90°$, $\delta=0°$)	$+20.9$ km/sec
Z ($\delta=90°$)	-8.0 km/sec

DATA EXPRESSED IN "OBSERVED" QUANTITIES

	$\mu_\alpha \cos\delta$	μ_δ	Radial Velocity (Km/Sec)
Motion of point of origin	$+0''.0061$	$-0''.0028$	$+19.5$
Motion of subsystem around θ^1, θ^2 Ori	$+.0011\pm.0015$	$+.0015\pm.0015$	$+25.0\pm1.2$
Standard solar motion plus galactic rotation	$+0.0020$	-0.0039	$+25.6$

north of the nebula is of little importance; a slightly different assumption with somewhat different velocities of the stars with respect to their origin, not violating the observed quantities, could easily bring this origin somewhat farther south. Somewhat more significant may be the difference in the motion in right ascension. The position of the nebula somewhat east of the line connecting the two stars would indicate a relative motion eastward with respect to the point of origin. The observed relative motion of the subsystem of stars around θ^1 and θ^2 Orionis, which may also be the motion of the nebula, is in the opposite direction. The difference amounts to 0".0050 ± 0".0015 (p.e.). But the possibility of a systematic error in the relative motions in right ascension of a few thousandths of a second of arc is not entirely ruled out, and therefore it does not seem justified to discard the hypothesis that the origin of the stars was in the Orion Nebula.

In a more refined discussion we would also have to take into account the curvature of the paths of the two stars as a consequence of the gravitational field of force of the galaxy, i.e., principally the force $K(z)$ perpendicular to the plane. A rough estimate of its influence has been made on the assumption that $K(z)$ around the Orion association is the same as it is around the sun, according to Oort's paper in *B.A.N.*, No. 238, an assumption that will be only approximately true in view of the very presence of the cloud complex in and around Orion. It is found that this field of force has only slightly changed the path of the two stars. This is due to the short time the force has acted. For μ Columbae, for which the influence must have been greatest, the total deceleration is about 2.2 km/sec; the lag in distance z, 2 parsecs; and the deviation of the direction of its path less than 1°.

In conclusion, it can be said that the hypothesis described in the beginning of this section seems to describe the phenomenon remarkably well. The ages of 2.6 million years are quite reasonable, in view of what has been found for the expansion ages of similar stars in other near-by associations. The question of whether or not the formation of these two stars took place at the same time as the stars of the Orion association should be left open for the present.

The occurrence of early-type stars with these exceptionally high velocities leads us to expect the presence of a few such stars in high galactic latitudes. AE Aurigae and μ Columbae will reach distances of 1500 parsecs from the galactic plane, but it takes them about 50 million years to travel this distance, and by that time they may not be O or B0 stars any longer. The statistical study of such objects would present interesting possibilities for the study of their evolution, if they are numerous enough. The further discussion of this topic, however, is beyond the scope of the present paper.

Note added in proof.—After this paper was submitted for publication, the color of μ Columbae was measured with the 20-inch reflector of the Lowell Observatory by Dr. D. L. Harris, to whom we are indebted for permission to quote his results here. He also measured AE Aurigae and found the values given in the accompanying tabulation.

	V	$B-V$	$U-B$	Measured on
AE Aurigae.......	5.94	+0.23	−0.72	2 nights
μ Columbae.......	5.20	−0.31	−1.05	3 nights

These measures show μ Columbae to be one of the bluest bright stars we know. In their table of intrinsic colors for main-sequence stars (*Ap. J.*, **117**, 346, 1953), Johnson and Morgan give for type B0 V, to which μ Columbae belongs, $B - V = -0.32$ and $U - B = -1.13$; and they indicate that both values are extrapolated and hence somewhat uncertain. These values are so close to the observed colors for μ Columbae that the total visual absorption almost certainly is less than 0.1 mag. This is a remarkable result for a star at the distance of 675 parsecs. It justifies the assumption of negligible absorption made in the above computations. For AE Aurigae, the new observation confirms the color excess adopted in our earlier discussion.