АСТРОФИЗИКА

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THE OB RUN-AWAY STARS FROM SCO-CEN AND ORION REVIEWED*

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We study the past paths of the run-away star Zeta Oph from the OB association Sco-Cen, and of the run-away stars AE Aur, Mu Col and 53 Ari from the OB association Ori OB1, in connection with the question of the origin of these high velocities. Should the binary-hypothesis be adhered to (supernova explosion of one of the components) or, perhaps, dynamical evolution in young, dense clusters offer a clue to this phenomenon? It is shown that the latter hypothesis is very unlikely to apply to Zeta Oph. For the run-away stars from Orion conclusive evidence may well be obtained in the course of the next decade, from improved accuracy of the proper motions.

Introduction. In recent years, the question of the origin of the OB run-away stars has received renewed attention. In my first paper on the subject [1], I proposed that these stars originate from close, massive binaries of which the most massive component undergoes rapid and complete (or nearly complete) mass loss, resulting in the release of the secondary component with a velocity approximately equal to its original orbital velocity. In subsequent years, this simple model was found to require reconsideration in view of the important role of mass transfer in close massive binaries. As a consequence of this mass transfer, at the time of the explosion of the primary (i. e. of the originally most massive component) so much mass may have been transferred to the secondary component that explosion of the former does not lead to loss of more than half of the total mass of the binary system. In that case the system remains bound and its systemic velocity with respect to the original centre of gravity may well become considerably less than the velocity of the "single" run-away in the original scenario. The problem of the run-away OB stars in the light of the mass transfer in massive binaries has recently been reviewed by Van den Heuvel [2]. For a recent discussion of the binary-hypothesis and of the kinematics of the run-away stars see Stone [3], and for a rediscussion of

* An article dedicated to Victor Ambartsumian at the occasion of his 80-th birthday.

observational data (particularly of newly determined radial velocities) and arguments in favour of broadening the range of possible mechanisms for the origin of this class of stars, see Gies and Bolton [4]. The latter authors suggest that especially an alternative model based on ejection of stars as a consequence of dynamical evolution of young, dense clusters merits further study.

Thus, it appears useful to have a close look at the question, how well the volume of space within an OB association in which the run-away stars have been ejected can be identified, and whether this supports, or perhaps eliminates, the possibility of such a cluster-dynamical origin. In the present paper we do this for a few objects for which the observational data are the most favourable. They are: the run-away star Zeta Ophiuchi with respect to the Sco-Cen association, and the run-away stars AE Aur, Mu Col and 53 Ari with respect to the Ori OB1 association. A number of relevant data are collected in Table 1.

Table 1

ADOPTED OBSERVATIONAL DATA

Parent association	Subgroup Upper Sco of Sco-Cen association	Orion OB1, subgroups c and d		
Range for distance	150 pc—200 pc	400 pc — 500 pc		
Mean proper motion in R. A. and in Decl.	−0″.0105, −0″.0220	−0″.0060, +0″.0020		
Mean radial velocity	−4 km/s	+29 km/s		
Run-away star HD number	Zeta Ophiuchi 149757	AE Aur 34078	Mu Col 38666	53 Ari 19374
Spectral type	O9.5 V	O9,5V	O9.5 V	B2V
Range for distance (pc)	150, 200	500, 600	700, 800	400, 500
Proper motion in R. A., p. e.	+0″.0120, 9	−0″.0072, 20	+0″.0006, 20	−0″.0210, 20
in Decl., p. e.	+0″.0232, 10	+0″.0451, 30	−0″.0274, 30	+0″.0050, 30
Radial velocity, p. e. (km/s)	−19, 8	+57, 2	+110, 4	+24, 3
"Reconstructed" total proper motion	0″.0480	0″.0513	0″.0325	0″.0258
Position angle (equatorial)	26°	357°	172°	289°

Our approach will be the following. Ideally, we should draw a three-dimensional picture of the spatial configuration of the parent association and its run-away star, and trace back the path of the latter by means of the relative space velocities; this should lead to the identification of the cylindrical volume within the association in which the run-away must have started its journey. Such a presentation is not suitable, however, because it mixes in a somewhat confusing way the possible sources of error affecting our conclusion. These sources are: the errors in the distances to be adopted for the parent association and for its run-away; the errors in the proper motions; and the errors in the radial velocities. It turns out that the first and the last mentioned of these are the least important. The errors in the proper motions dominate the conclusions notwithstanding the fact that in recent years important new astrometric data have become available. At the same time, it is in just this field, that there is a promise ot continued ameliorations in view of the rapid increase in the accuracy of meridian circle observations and of related types of transit instruments, whereas moreover the astrometric satellite Hipparcos will provide a wealth of data in the coming decade. For these reasons, we proceed in such a way, that the evidence derived from the proper motions remains clearly visible. In order to judge the influence of errors in the distances of the run-away stars and of the parent associations we work out solutions for different assumed values which reasonably cover the range imposed by their various sources of error, the principal ones of which are those in the adopted luminosities and in the correction for interstellar absorption.

The principal preparatory step, updating the proper motions, took into aocount recently published meridian circle observations contained in the following catalogues:

Catalogue P70 with mean epoch of observation about 1970 [5]; Catalogue W5—50; with mean epoch of observation about 1969 [6]; and Catalogue W4—50, with mean epoch of observation about 1959 [7]. The Catalogue FK4, which represents the best available fundamental system of proper motions and positions, contains only the run-away star Zeta Oph; we checked and slightly improved its FK4 proper motion by means of the three modern catalogues just mentioned, which led to the extremely accurate proper motion of this star mentioned in Table 1. Of the three run-aways from Ori OB1, AE Aur and Mu Col are in both P70 and W5—50; 53 Ari only in W5—50. These modern positions were combined with the position at mean epoch of observation (around the year 1900) in B. Boss' General Catalogue, taking into account the reduction to the system of FK4 as prescribed in the tables of Brosche, Nowacki and Strobel [8]. These newly derived proper motions were combined with those given in the catalogue of Rhynsburger and Gauss [9] for 53 Ari and AE Aur, and with the one in the N30 Catalogue [10] for Mu Col, also reduced to the system of FK4. The final proper motions, given in Table 1, include the adjustment of the precessional corrections as recommended by Fricke [11].

With these proper motions and with the radial velocities given in Table 1 we compute space velocities tor the sets of distances given in

Table 1; the true distances probably lie between these extremes. These space velocities are with respect to the sun and are used to compute the space velocities of the run-away stars with respect to the parent association. We then convert these relative space velocities again to proper motion components as seen from the position of the Sun. The procedure is, of course, equivalent to removing from the observed proper motion of the run-away star the part due to the motion of the Sun with respect to the parent association. For each pair (run-away, parent), the four combinations of association distance and stellar distance produce four different directions of this "reconstructed" proper motion. For the presentation of the results we select those with the two extreme position angles as a measure of the uncertainty due to possible errors in the adopted distances.

Zeta Oph and the association Sco-Cen. Figures 1 and 2 present the results for Zeta Oph wiih respect to the potential candidate-parents which are three subgroups of the association Scorpio-Centaurus. The nearest and most likely candidate is the subgroup Upper Sco. In Figure 1, which pertains to this subgroup, the width of the filled-in cone corresponds to the extreme position angles of the "reconstructed" proper motion of Zeta Oph as defined above for different distances in a reference frame at rest with respect to this subgroup. The dashed lines mark the width of the cone corresponding to the probable errors of the "reconstructed" proper motion. A time scale may be obtained by assuming Zeta Oph to have originated from the centre of Upper Sco and using mean distances of 175 pc for both star and subgroup. This leads to a kinematic age of 1.0 million years for Zeta Oph and an ejection velocity of 42 km/s. For our present purpose it is important to note that one can almost certainly eliminate the hypothesis of a cluster-dynamical origin of this run-away star in this subgroup, in view of the following considerations. In my paper at the occasion of Ambartsumians 70-th birthday (see Mirzoyan [12]), discussing internal motions in this subgroup, I provided evidence that the subgroup was formed about 4 million years ago from a volume smaller than the present one. Thus, the subgroup was more compact at the time of ejection of Zeta Oph than it is now, but the difference is not large enough that the subgroup would have had the high density required for dynamical ejection of one of its members. One other possibility to consider would be, a possible origin in the dense, star-forming domain of the Ophiuchus molecular clouds associated with the subgroup Upper Sco. The obvious candidate in that case would be the infrared cluster inbedded in this cloud; its position is marked in Figure 1. It appears to be located so far outside the possible volume of formation of Zeta Oph that we must exclude its progenitor nature.

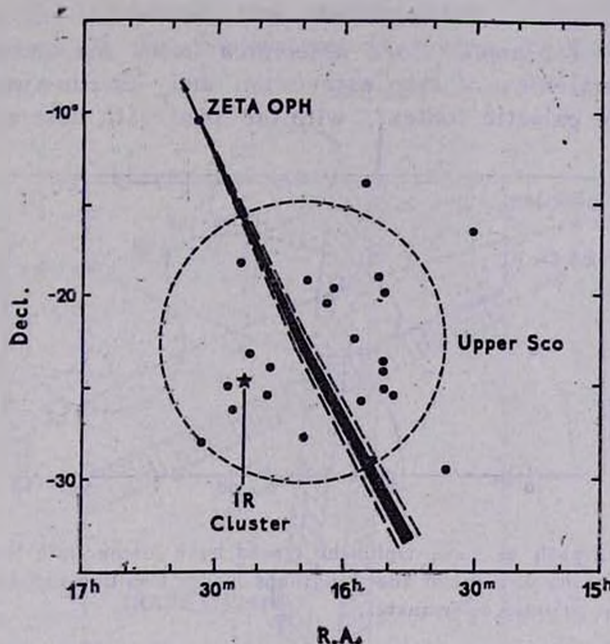

Fig. 1. The path of the run-away star Zeta Oph through the subgroup Upper Sco of the association Sco-Cen, projected on the sky, as derived from updated proper motion data. The filled-in cone represents the uncertainty in the distances of star and subgroup; the dashed lines mark deviations corresponding to the probable error of the proper motion. Also marked is the position of the compact infrared cluster embedded in the Ophiuchus molecular clouds which are associated with the subgroup. Co-ordinates are for 1950.

In view of the short time scale of one million years implied in a possible origin of Zeta Oph in Upper Sco, we further extend in the past the path of this star; see Figure 2 which is a presentation in galactic context. Three-dimensional reconstruction does not exclude that this path may also have traversed, and thus the star may have originated in, the subgroups Upper Cen-Lup or Lower Cen-Cru. The corresponding time scales are then about 2.5 and 4.5 million years, respectively. These kinematic ages would not be incompatible with the main-sequence spectral type, O9.5V of Zeta Oph. On the other hand, these subgroups have estimated nuclear ages around 12 and 10 million years, respectively [13] which makes such an origin rather unlikely. We note, moreover, that no dense young clusters are known to occur within the domains of these subgroups.

We therefore conclude, that it is most unlikely that the run-away star Zeta Oph has originated from dynamical evolution in a dense young cluter.

The three run-away stars associated with the association Ori OB1. The overall-view of this association and its run-aways is shown in Figure 3, in galactic context, with the past path determined by the

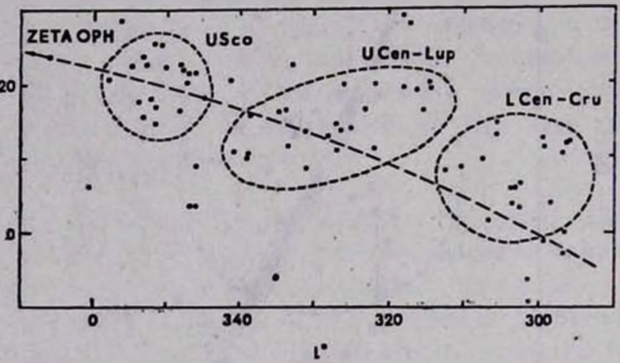

Fig. 2. The path of Zeta Ophiuchi traced back further into the past than in Figure 1, through the domains of the subgroups Upper Cen-Lup and Lower Cen-Cru; representation in galactic co-ordinates.

"reconstructed" proper motions which were computed with respect to the youngest part of the association, that is the subgroups c and d. An enlargement of the region of the association itself is shown in Figure 4,.

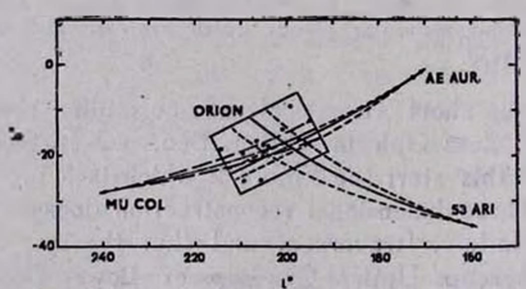

Fig. 3. The paths of the run-away stars Mu Col, AE Aur and 53 Ari through the region of the association Ori OB1, projected on the sky, as derived from updated proper motions. Dashed lines mark the deviations of the paths corresponding to the probable errors of the proper motions; see also Figure 4.

in which the hatched sections represent the uncertainty in the past paths due to the uncertainty in the adopted distances; their widths correspond to the extreme position angles of the proper motions. More-important, however, for our considerations are the possible errors in the proper motions. Their accuracy is somewhat lower than that of Zeta Oph, as indicated in Table 1. Figure 3 shows by means of the dashed lines the ranges of the possible paths corresponding to the probable errors of the "reconstructed" proper motions. In order to

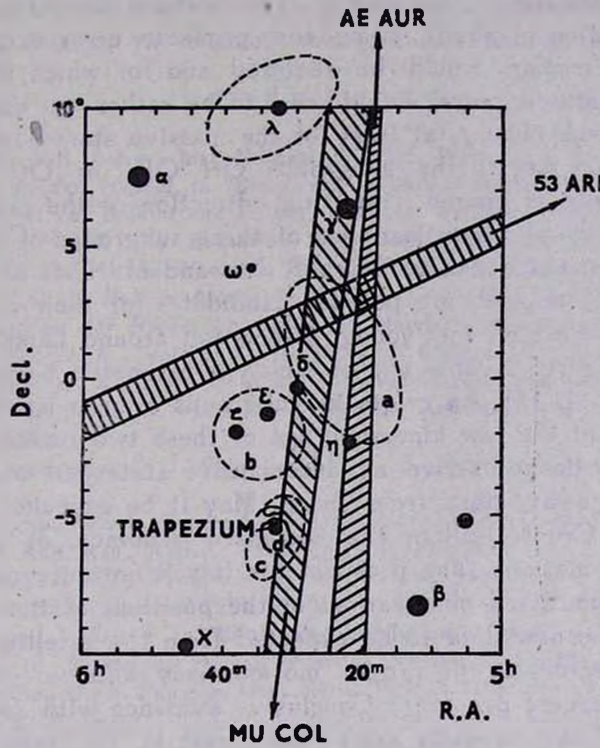

Fig. 4. Enlargement of the region of the Orion association marked in Figure 3, but this time in equatorial co-ordinates (for 1950), with indication of the outlines of the subgroups Ori OB1a, 1b, 1c and 1d, the latter being the Trapezium cluster. Also marked is the Lambda Ori association. Hatched areas represent the uncertainty in the projection of the past paths due to the uncertainty in the adopted distances of the run-away stars and the Orion association.

avoid confusion these are not repeated in Figure 4. From these presentations we see that for the estimate of the kinematic ages of the run-away stars it is of little importance to know in which of the subgroups located in the domain of Figure 4 a star originated. Rough estimates are:

about 2.6 million years for AE Aur,
„ 2.8 „ „ „ Mu Col,
„ 6.0 „ „ „ 53 Ari.

These ages for Mu Col and 53 Ari are somewhat higher than those given in my earlier paper [1], due mainly to somewhat larger adopted distances. From these ages, and the configurations shown in Figure 4, we now conclude as follows.

For none of the three stars it can be excluded that they have originated in the Trapezium cluster. This is least likely for 53 Ari, for which a deviation of about twice the probable error in the direction of the proper motion would be required and for which the kinematic age, about 6 million years, would seem to be rather in excess of that of the Trapezium cluster, at least of the massive stars contained in it. An origin of 53 Ari in the subgroups Ori OBa or Ori OBb would seem more likely as judged from the direction of the proper motion, and also in view of the nuclear ages of these subgroups of about 11 and 8 million years, respectively. For AE Aur and Mu Col, all four of the subgroups a through d; are possible candidates for their origin, and to these should be added the young association around Lambda Ori, also marked in Figure 4, the age of which is estimated between 2 and 6 million years [14, 15]. An origin in subgroups a or b is, however, less likely in view of the low kinematic age of these two run-away stars.

Thus, we do not arrive at a conclusive statement with regard to the three run-away stars from Orion. May it be expected trom future observations? Crucial will be the increased accuracy of the direction of the proper motions. The prospect for this is not unfavourable. With continued groundbased observations of the positions of these stars and, in addition, the new data to be expected from the satellite Hipparcos, the probable errors in the proper motions may well be reduced to below one milli-arcsec per year. Conclusive evidence with regard to possible origin of the run-away stars from Orion in the Trapezium cluster, or elimination of such an origin, may then well be obtained for these objects or at least for some of them.

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ЕЩЕ РАЗ О ОВ-БЫСТРОЛЕТЯЩИХ ЗВЕЗДАХ ИЗ СКОРПИОН—ЦЕНТАВРА И ОРИОНА

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Исследованы прошлые траектории быстролетящей звезды ζ **Oph из ОВ-ассоциации Sco-Cen и быстролетящих звезд AE Aur,** μ **Col и 53 Ari из ОВ-ассоциации Ori OB 1, в связи с вопросом о происхождении этих**

высоких скоростей. Следует ли привлечь к этому вопросу гипотезу двойственности (взрыв одного из компонентов как сверхновой) или, может быть, динамическая эволюция молодых плотных скоплений представляет ключ этого явления? Показано, что последняя гипотеза весьма невероятна в применении к ζ Oph. Для быстролетящих звезд из Ориона решающее свидетельство вполне возможно будет получено в течение следующего десятилетия благодаря улучшенной точности собственных движений.

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