on the scans can be assessed. Thus by combining photographic and photoelectric data a fairly accurate set of nebular line intensities can be obtained (see Fig. 2). Unfortunately we have not found it possible to secure the necessary supplementary spectrograms.

The southern hemisphere contains many fainter planetaries, but their effective observation would entail a much more extended program.

Among the objects we have observed, IC 4642 clearly deserves much more detailed study. Also NGC 3211, 2867, 2792, and 3918 would merit closer examination with adequate spectrographic equipment.

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12. THE SCORPIO–CENTAURUS ASSOCIATION

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I. Introduction

The Scorpio–Centaurus association extends from about $l^{\text{II}}=356°$, $b^{\text{II}}=+20°$ towards lower longitudes over about 90° of the southern sky. Between $l^{\text{II}}=312$ and 356° it is located between latitudes +10 and +25°, and appears well detached from the more distant B-star population at lower latitudes. At longitudes below 312° it approaches and crosses the galactic plane and is seen projected against the general low latitude B-star population from which it is more difficult to separate. These features are clearly brought out by Figures 5 and 6 of the author's thesis (1946) and had been recognized earlier by others (e.g. Kapteyn 1914).

The association is part of the general population of early-type stars in the region within 500 pc which forms the subsystem usually referred to as the Local

System. This System is characterized by a tilted space distribution, shared by the local interstellar matter, and usually called the Gould Belt. For a recent discussion of the projected and the space distribution of the brightest stars in the Local System we refer to Eggen (1961), particularly to his Figures 1, 2, and 3. Because the Scorpio–Centaurus association forms a subsystem in this Local System it may be questioned whether there is justification in considering it as a separate group when studying kinematic properties. The part between $l^{\mathrm{II}}=312$ and $356°$ stands out so conspicuously that a separate treatment seems justified; this is, however, somewhat less the case with the part between longitudes $l^{\mathrm{II}}=292$ and $312°$, and still less for the lower longitudes. For these reasons the study by Bertiau (1958), which was aimed primarily at obtaining accurate absolute magnitudes for a sample of B stars, was confined to the region $l^{\mathrm{II}}>292°$ ($l^{\mathrm{I}}>260°$); it did not deal with the structural properties.

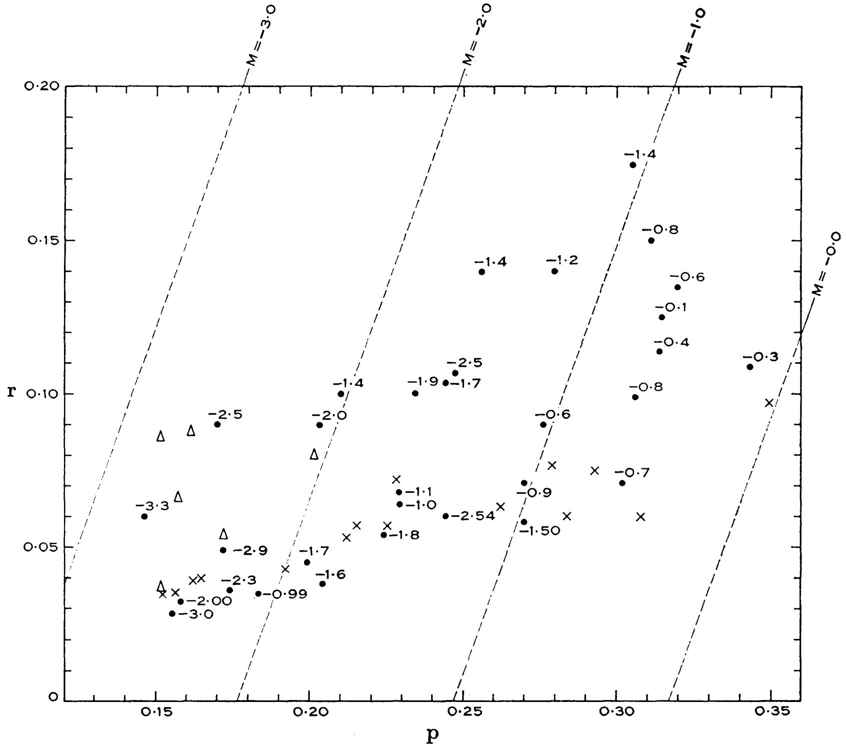

Fig. 1.—The p, r diagram for Scorpio–Centaurus stars (dots) and for some stars in h and χ Persei (triangles) and in the Orion association (crosses), based on multicolour photometry of Borgman and of Walraven and Walraven. Figures near the dots are the observed visual absolute magnitudes, M_V. Dashed lines represent loci of constant M_V according to formula (1).

II. Distances based on Multicolour Photometry of the Sco–Cen Association

An important aspect of current work on the Scorpio–Centaurus association is its role in the establishment of the distance scale in the Galaxy. Once the distances of the Sco–Cen stars have been determined, those of more distant objects of the same

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spectral types can be inferred by accurate photometric comparisons. Procedures involving the narrow-band photometries of Borgman (1960) and of Walraven and Walraven (1960) are summarized by the author (Blaauw 1963) and will be described in detail by Borgman and the author in a forthcoming issue of the *Bulletin of the Astronomical Institutes of the Netherlands.*

The author's summary refers to a provisional application of Borgman's multicolour photometry for the definition of quantities p and r, which are a function of visual absolute magnitude and of spectral class. For the most southern stars, which were not accessible to Borgman's observations, those by Walraven and Walraven were incorporated after suitable quantities derived from them were reduced to p and r. Figure 1 shows the part of the p, r diagram which allows the empirical deter-

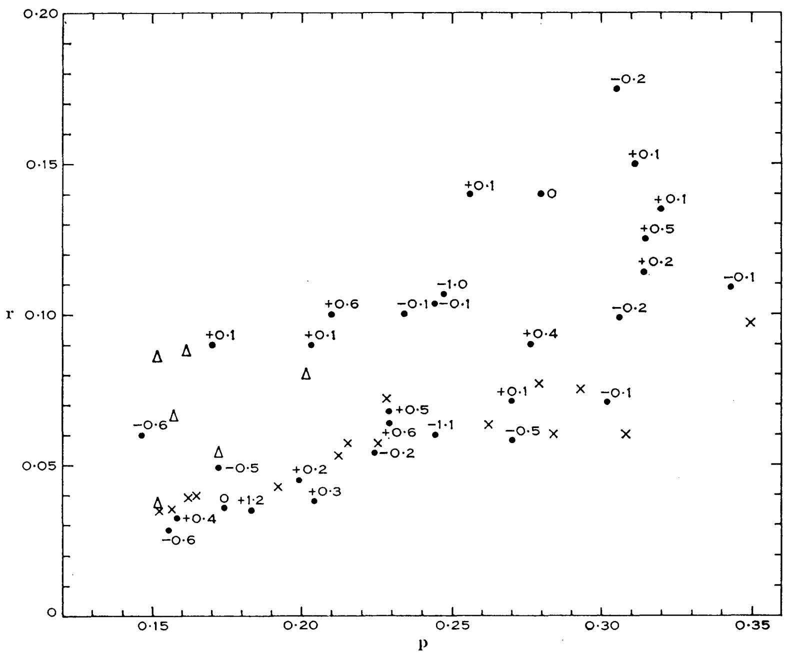

Fig. 2.—Same as Figure 1, except that figures near the dots now represent difference between the observed M_V and the values predicted by formula (1).

mination of the visual absolute magnitude as a function of p and r. Numbers written next to the dots are the visual absolute magnitudes of Sco–Cen stars based on the work of Bertiau (1958) and of Hardie and Crawford (1961). These values of M_V can be represented with satisfactory accuracy by the interpolation formula,

$$M_V = -4{\cdot}55 + 14{\cdot}4p - 5{\cdot}1r, \tag{1}$$

which implies straight lines of constant luminosity. Such lines for $M_V=0$, -1, -2, -3 are shown in Figure 1. Figure 2 shows the residuals between the individual values of M_V and those predicted by formula (1).

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As an example of the application to the distance determination of other groups, we quote the preliminary result for the distance modulus of the association h and χ Persei. Stars belonging to the double cluster are represented by the triangles in Figures 1 and 2, in so far as they occur in Borgman's (1960) paper. Using the relation (1) and allowing a slight extrapolation, we compute values of M_V for these six stars and hence derive the mean distance modulus corrected for interstellar absorption:

$$m_0 - M = 11{\cdot}7 \pm 0{\cdot}18 \text{ (internal p.e.)}$$
$$\pm 0{\cdot}29 \text{ (external p.e.).}$$

This may be compared to the result based on the curve-fitting procedure starting from the known distance of the Hyades:

$$m_0 - M = 11{\cdot}8 \pm 0{\cdot}23 \text{ (external p.e.).}$$

A similar procedure may be used for the I Orion association, some stars of which are marked by crosses in Figures 1 and 2. See also Blaauw (1963).

III. Distance of Sco–Cen Association

The reliability of the former procedure depends largely on the precision with which the distances of the Sco–Cen stars are known. These are based on an analysis of proper motions and radial velocities. The interpretation of these data has been the subject of various discussions in the literature, most recently by Bertiau (1958) and by Petrie (1962). A brief discussion of the principles involved appears to be useful.

Proper motions and radial velocities show immediately that the random internal motions are very small. (See, for instance, Figure 1 of the paper by Bertiau (1958) and Figure 2 of Petrie's (1962) paper.) The proper motions are rather similar to those of the Hyades in that they converge to one convergent point for the whole group, and that their sizes are approximately equal, indicating nearly equal distances from the Sun. This has led to the early analyses of the Sco–Cen association based on the assumption of equal and parallel space motions of all stars with respect to the Sun — similar to the analysis of the Hyades. The expected relations for the proper motions, μ, and radial velocities, V_r, in the case of that assumption are given in the top part of Figure 3, where S is the common velocity with respect to the Sun, and λ the angular distance of the star from the solar anti-apex, p being the parallax. The K term in the expression for the radial velocity represents such effects as (a) systematic error in the measurements, (b) gravitational red shift, and (c) possible atmospheric effects; but it contains *no* kinematical term, for this is exclusively accounted for by the first term.

If this sort of analysis is carried out, a K term is found of about $+10$ km/sec (Bertiau 1958; Petrie 1962). This is incompatible with the possible values of the components (a), (b), (c) just mentioned. Therefore the assumption of equal and parallel space motions is not valid.

A more satisfactory representation of the observational data is obtained if one assumes linear expansion of the association. The then expected relations for the proper motions and the radial velocities are given in the lower part of Figure 3, including the diagram which shows the two-dimensional analogous case. The motion of a star relative to the Sun is now the vector sum of the motion, s, of the star with respect to an adopted centre, C, of the group, and the reflex, V', of the solar motion, V, with respect to C. The proper motion and the radial velocity are, however, more easily evaluated if the motions are referred to an imaginary star I, located at the position of the Sun and participating in the linear expansion of the association. The motion of any member of the association with respect to the Sun can now be described as the sum of (i) the motion of that member with respect to I, and (ii) the motion of star I with respect to the Sun. This latter part is the vector sum of the motion, S_{I}, of I with respect to C, plus the vector V'; this combined vector is S'. It is clear that this part S' is the same whichever member of the association is considered, whereas the first part is equivalent to the expansional motion of the chosen star with respect to I.

	PROPER MOTIONS		RADIAL VELOCITIES
EQUAL AND PARALLEL VELOCITIES	EXACT CONVERGENCE	$\mu = pS \sin \lambda$	$V_r = S \cos \lambda + K$
LINEAR EXPANSION	EXACT CONVERGENCE	$\mu = pS' \sin \lambda'$	$V_r = S' \cos \lambda + rk + K$

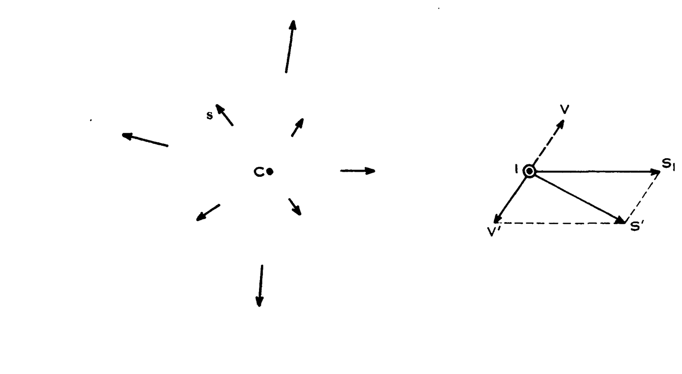

Fig. 3.—Behaviour of proper motions and radial velocities for the two hypothetical states of motion.

The proper motions are determined only by the vector S′. Since this is the same for all stars, there is, as in the case of equal and parallel velocities, *strict* convergence, the direction of the convergent now being that of the vector S′. Angular distances λ' are to be counted from this convergent. The resulting expression for the proper motions is given in the lower division of Figure 3; it has the same form as the expression in the top part. Velocities are expressed in astronomical units per year.

The radial velocities contain terms due to *both* the elements (i) and (ii) referred to above. The vector S' leads to the term with cos λ'; this is similar to the first term in the top division. The expansion leads to the term rk, where r is the distance of the star from the Sun (because this is its distance from the imaginary star I), and k is

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the expansion coefficient. The additional term K accounts for the same non-kinematical effects as were accounted for in the case of equal and parallel motions. If we neglect this term, which does not exceed a few kilometres per second, we find that the term rk according to the solutions already mentioned must be about $+10$ km/sec. Strictly, this term is different for each star, since it contains the individual distance, r. In the case of the Sco–Cen stars, however, there is a rather small range of distances and the mean distances $<r>$ for different longitude divisions are nearly the same (see, for instance, Bertiau 1958). We may therefore, as a first approximation, write $<r>k$ for the second term and solve this as an unknown common to all stars. For $<r>$ about 200 pc, and $<r>k=+10$ km/sec, the expansion rate is $k=0\cdot05$ km/sec.pc, which corresponds to an expansion age of the association of 20×10^6 years.

This second approach, based on the hypothesis of linear expansion, thus appears to give a more satisfactory interpretation of the observations. With the increasing accuracy of the proper motions and radial velocities which is to be expected in the future, a still more refined approach will be possible. This does not yet seem necessary at the present moment, except that, instead of assuming the same mean distance $<r>$ for different longitudes, we now might incorporate the available photometric evidence on the ratio of the distances of stars in different parts of the association.

TABLE 1

MEAN VALUES OF τ COMPONENTS IN THREE SUBDIVISIONS

Subdivision	l^{II}	$<\tau>$	No. of Stars
Upper Scorpio	$>341°$	$-0''0010$	29
Upper Centaurus+Lupus	$313–341°$	$+0\cdot0006$	26
Lower Centaurus	$292–313°$	$+0\cdot0005$	22

In the more refined future analyses we will have to consider possible deviations from the rather simple picture of linear expansion. There may be small deviations, common to the stars belonging to the various subsystems into which the association may be subdivided. One way to check such deviations is to consider the mean of the τ components for stars in different parts of the association. Table 1 gives such mean values derived from Bertiau's Table 1 for the three subdivisions indicated in the first column (see also Bertiau's Table 5). Their amounts are well within the present uncertainty of the fundamental system of proper motions.

The proper motions used by Bertiau are in the N30 system. Recent work in the improvement of the fundamental systems has lent support to the N30 system. Yet, the possibility of fairly large revisions remains open, particularly for the most southern declinations to which the association extends. Thus, systematic corrections amounting to as much as $0''004$ per yr in the lower Centaurus division, at mean declination $-54°$, cannot be excluded. These may lead to a revision of the position of the convergent of as much as $5°$, and corresponding revisions of the absolute magnitudes of the order of a tenth of a magnitude.

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Discussion

de Vaucouleurs: What is the depth of the cluster on the line of sight?

Blaauw: For the majority of members, the range was about 20% of their mean distance from the Sun. (Indicated on slide.)

Lindblad: I should like to ask how the formula between M_V and the spectrophotometric quantities p and r was calibrated.

Blaauw: The M_V values were taken from Bertiau's work (with some improvements by Hardie). The p, r values are mainly from Borgman's photometry but for the most southern stars, which could not be reached from McDonald, we used Walraven's photometry which could be converted into p, r for the main sequence stars.

Bok: Which southern clusters are most needed for Borgman–Walraven studies comparable to those by Borgman for h and χ Persei? I presume you are thinking of NGC 4755, IC 2944, and NGC 6231?

Blaauw: I have not thought much about that aspect of the studies, knowing that Walraven had covered many objects already. Borgman was mainly concerned about developing the principles of the method.

Eggen: Is it not true that the known systematic differences between proper motion systems can lead to apparent expansions in the association?

Blaauw: With regard to the possible systematic errors in the N30 proper motions which were used by Bertiau, an idea of the possible size of the errors may be obtained from a comparison between the FK4 system and N30. Data on the differences between these two have been mentioned in the literature. For the term $(\Delta\, 15\mu_\alpha \cos\delta)_\delta$ and $\Delta(\mu_\delta)_\delta$ (Scott, *A.J.* **67**: 690–5 (1962)), they indicate possible systematic errors up to $0''.004$ and $0''.002$, respectively. The differences are largest for the most southern part of the association and I estimated that they correspond to a maximum shift in the position of the convergent of about 4° and would not affect the mean absolute magnitudes of the stars of a given spectral type by more than 0·1 magnitude. Data on terms $(\Delta\, 15\mu_\alpha \cos\delta)_\alpha$ and $\Delta(\mu_\delta)_\alpha$ have not yet been published. (For a remark about proper motion affecting the expansion see the text of the paper which has been somewhat enlarged on this point. The text implies that errors in the proper motions are important in so far as they affect the position of the convergent point.)

Buscombe: If there is no secure evidence for systematic differences in the radial velocities for B stars at different observatories, why has the IAU not recognized any stars of early type as secondary standards of velocity?

Blaauw: It is desirable to put all radial velocities on the same system. A common systematic error of all radial velocities would affect the term K, not S'. A systematic error of 2 km/sec would correspond to roughly 20% of K.

Buscombe: Can the sources of difference between Petrie's and Morgan and Johnson's calibration of luminosities of early-type stars be resolved?

Blaauw: I have doubts about the methods of Petrie as they pertain to the distances of the clusters used and the values of the secular parallaxes.

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