HYDROGEN CONTENT OF YOUNG STELLAR CLUSTERS

III.* CLUSTERS NGC 3293, 6167, 6193, 6200, AND 6204

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[Manuscript received 6 April 1972, revised 5 February 1973]

Abstract

The total amount of hydrogen associated with the O-type clusters NGC 3293, 6193, and 6204 and the suspected clusters NGC 6167 and 6200 has been measured. Neither neutral nor ionized hydrogen was found to be associated with NGC 3293 and the visible nebula in this region is most likely associated with a single O7-type star, which does not appear to belong to the cluster, while an irregular expanding shell of neutral hydrogen probably surrounds the ionized nebula. The mass of hydrogen associated with NGC 6193 does not exceed $500\,M_\odot$. Neither neutral nor ionized hydrogen was detected at the position of NGC 6204. The features detected by hydrogen-line observations at the positions of suspected clusters NGC 6167 and 6200 provide evidence that both visual groupings may be real clusters. The amount of neutral hydrogen probably connected with NGC 6167 is $\sim 1000\,M_\odot$.

Introduction

The results of 21 cm line and continuum observations of the O-type stellar clusters NGC 3293, 6193, and 6204 and of the doubtful clusters NGC 6167 and 6200 are presented. The methods of observation and reduction are described in Part I (Tovmassian 1973, present issue pp. 829–35).

Measurements and Results

NGC 3293

NGC 3293 is a compact cluster, situated not far from the Carina complex, in a region that is very rich in large HII nebulae. The cluster itself is believed to be embedded in a small nebula of ionized hydrogen. Our continuum observations (see isophotes in Figure 1(*a*)) show a complex structure in this region and reveal a weak source near the cluster position, with two strong sources separated by $\sim 1^\circ$ on either side. We have obtained a brightness distribution (Fig. 1(*b*)) for the weak source by assuming Gaussian brightness distributions for the two strong sources and subtracting these from the drift curves, as shown in Figure 2. The resulting isophotes of the weak source can be seen to be fairly symmetrical and almost circular. Their centre is displaced from that of the cluster by $\sim 10'$ arc and coincides fairly well with the O7-type star HD 91824, which is the brightest in the region and is almost certainly responsible for the ionization of the nebula. This star is located outside the main

* Part II, *Aust. J. Phys.*, 1973, **26**, 837–42.

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condensation of the cluster stars and does not appear to belong to the cluster. Feast (1958) has expressed doubt as to whether this star actually belongs to NGC 3293 while, more decisively, Markarian (1957) and Buscombe (1963) have considered the B0 star HD 91969 to be the brightest member of the cluster. Thus if the O7-type star does not belong to NGC 3293 then neither does the nebula, as was suggested by Tovmassian (1970).

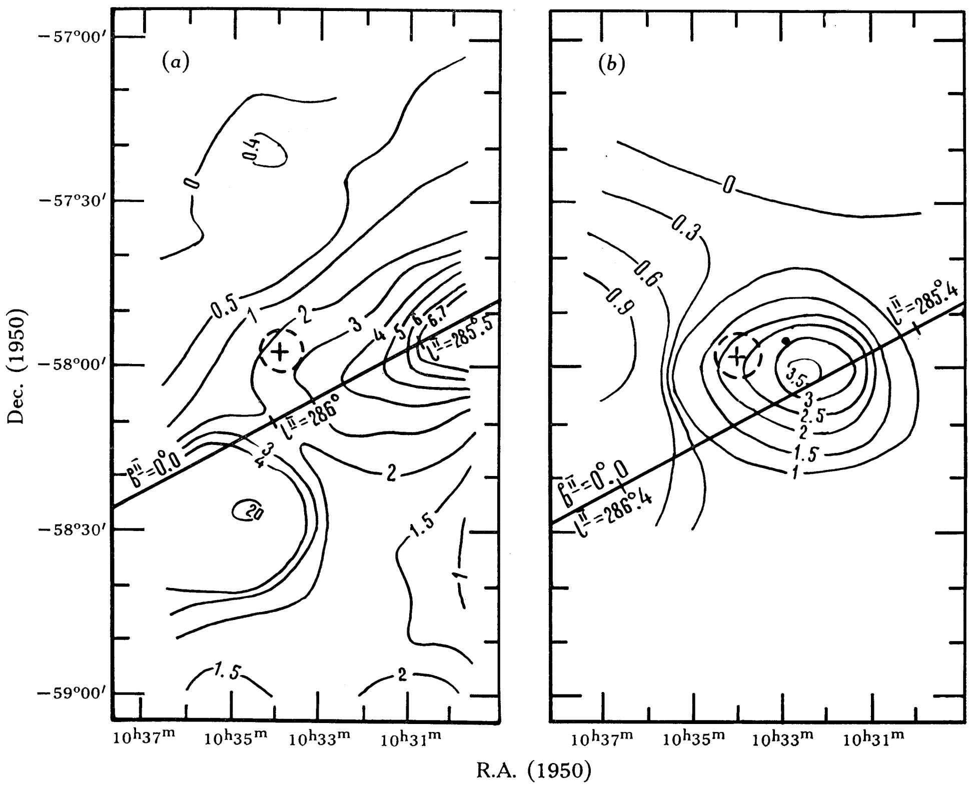

Fig. 1.—NGC 3293. Isophotes of brightness temperature in kelvins at 1410 MHz above the galactic background emission, with the position of the cluster indicated by a dashed circle. Part (*a*) shows the raw data and part (*b*) shows contours of weak emission in the vicinity of the cluster that were obtained by subtraction of emission from the background and two nearby strong sources. The position of the O7-type star HD 91824 is indicated by a small solid circle.

The total flux density from the nebula is slightly less than 20 f.u. and its half-power width is $\sim 20'$ arc. The distance moduli of the O7 star and the cluster are very close (Feast 1958) and the star could be only several hundred parsecs more distant. For a distance to NGC 3293 of $2 \cdot 6$ kpc, equations (5) and (6) of Part I (Tovmassian 1973) yield an electron density of $\sim 13\ \mathrm{cm}^{-3}$ and a mass of ionized cloud around the O7 star of $2000\ M_{\odot}$. In a medium of this density, an O7-type star would ionize a region of radius of $18 \cdot 5$ pc, which is in excellent agreement with our measured value of 19 pc for the radius of the full extent of the nebula detected (that is, $\sim 25'$ arc at a distance of $2 \cdot 6$ kpc). This implies that the nebula is ionization bounded rather than density bounded and provides evidence for the O7 star being far from the cluster, where the rest of the nebula cannot be ionized by the other B0 stars of the cluster.

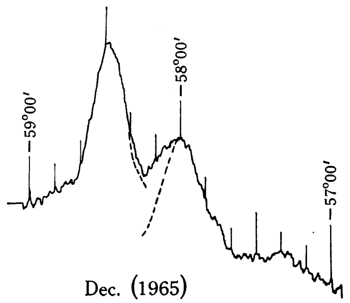

Fig. 2.—NGC 3293. Drift curve of continuum emission taken through the centre of the cluster, with the assumed Gaussian brightness distributions of the two strong sources in the vicinity of the cluster indicated by dashed lines. The declination marks are for the epoch of the observations (1965).

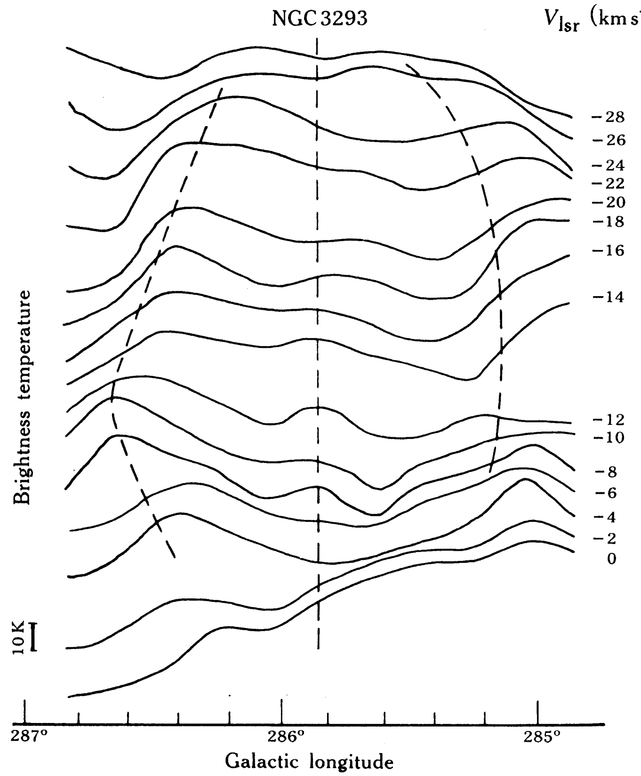

Fig. 3.—NGC 3293. Drift curves of hydrogen-line emission taken with the narrow-band receiver through the centre of the cluster.

The neutral hydrogen emission in the vicinity of NGC 3293 also has a complex structure. Line profiles obtained with both the wide- and narrow-band (Fig. 3) receivers show a feature which could be considered to be an expanding shell of neutral hydrogen with a nonuniform brightness distribution and an expansion velocity of ~ 12 km s^{-1}. The centre of the shell is displaced from that of the cluster by $\sim 10'$

arc to smaller galactic longitudes, and thus the shell seems to be associated with the O7-type star responsible for the excitation of the ionized nebula rather than with the cluster NGC 3293. Furthermore, the inner diameter of the shell at half-intensity points is $\sim 1°$, just about the diameter of the full extent of the ionized nebula. This provides evidence in favour of the presence of the shell and of its connection with the O7-type star, although the radial velocity of the shell's centre, about $-10\ \mathrm{km\,s^{-1}}$, substantially differs from that of the stai, $-27\ \mathrm{km\,s^{-1}}$ (Feast 1958). If the shell is at the distance of the star, its outer and inner radii are 38 and 23 pc respectively. With a mean brightness temperature for the nonuniform shell of ~ 15 K and a full linewidth at half-power of $\sim 10\ \mathrm{km\,s^{-1}}$, the mean density of neutral hydrogen atoms is $\sim 2\ \mathrm{cm^{-3}}$ and the total mass of the shell is $\sim 8000\ M_{\odot}$. However, the existence of such a massive shell of neutral hydrogen and its connection with a single O-type star are uncertain. If such is the case it is unique and more detailed study is required.

Line profiles taken through the cluster position show the existence of a neutral hydrogen cloud which was considered to be associated with the cluster by Tovmassian (1970) in a preliminary report of this work. The half-width of the cloud is nearly 20′ arc, its full linewidth at half-power is $\sim 10\ \mathrm{km\,s^{-1}}$, and its brightness temperature is slightly less than 20 K. The coincidence of the radial velocities, about $-26\ \mathrm{km\,s^{-1}}$, of the cloud and cluster (Feast 1958) provided the basis of Tovmassian's earlier identification. However, at the distance of NGC 3293, the neutral hydrogen atom density of the cloud would be less than $5\ \mathrm{cm^{-3}}$ and the presence of five B0-type stars in the cluster (Feast 1958) would make it impossible for the cloud to persist in a neutral state. A detailed analysis of the drift curves shows that this cloud is actually displaced from the cluster by $\sim 10'$ arc to the south and to higher galactic coordinates. Furthermore the coincidence of radial velocities is not necessarily significant owing to the very small gradient of negative radial velocity with distance in the direction ($l^{\mathrm{II}} = 260°$) of NGC 3293 (for contours of radial velocity in the galactic plane, see Kerr 1962). We therefore conclude that the neutral hydrogen cloud detected in the vicinity of NGC 3293 is not related to the cluster. Thus neither neutral nor ionized hydrogen is associated with NGC 3293. The ionized nebula surrounding the O7-type star HD 91824 is probably connected solely with this star, which does not seem to be a member of the cluster.

NGC 6167, 6193, 6200, and 6204

The four clusters NGC 6167, 6193, 6200, and 6204 belong to the rich association I Ara, which was studied in detail by Whiteoak (1963). According to Whiteoak there are two groupings of OB stars in this direction. The clustei NGC 6193 belongs to the nearer group at a distance of ~ 1300 pc and is embedded in a large region of ionized hydrogen, while the cluster NGC 6204 is more distant at ~ 2500 pc and is probably not connected with the OB grouping around NGC 6193. Whiteoak also concluded that NGC 6167 and 6200 were probably just apparent stellar groupings rather than real clusters. Since all of these objects are contained within $\sim 3°$, the whole region containing them was observed. Our drift curves of hydrogen-line emission taken along the galactic plane through the centres of NGC 6167, 6193, and 6204 are shown in Figures 4(*a*), 4(*b*), and 4(*c*) respectively.

NGC 6167

According to Whiteoak (1963) NGC 6167 is not a real cluster and the apparent visual grouping of OB stars at its position is probably due to irregularities in the distribution of interstellar absorbing matter. NGC 6167 is located near the adopted boundary of the visual grouping of OB stars of the stellar association I Ara and, if it were a real cluster, it would be at a distance of ~2 kpc. Since the mean radial

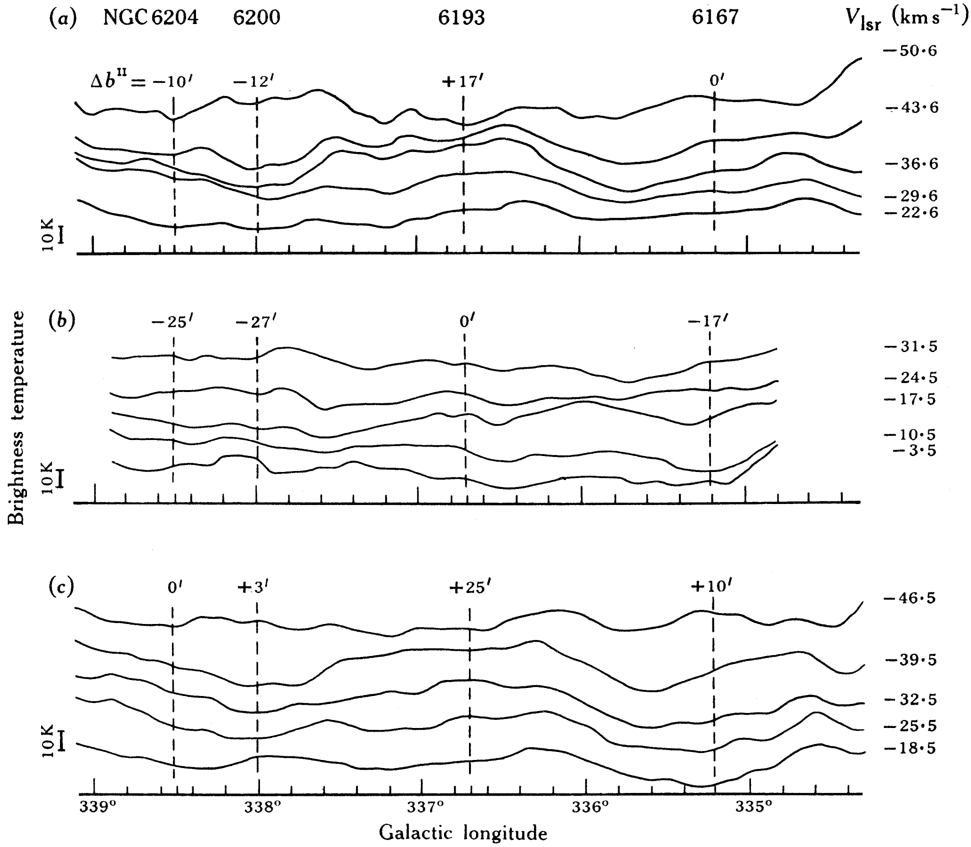

Fig. 4.—NGC 6167, 6193, 6200, and 6204. Drift curves of hydrogen-line emission at constant galactic latitude taken with the wide-band receiver through the centre of (*a*) NGC 6167, (*b*) NGC 6193, and (*c*) NGC 6204 respectively. The displacements in galactic latitude of the neighbouring clusters are indicated at the cluster longitudes.

velocity of three stars in NGC 6193, the nearest cluster in this region, is about -11 km s^{-1} (Rubin *et al.* 1962) and that of four stars in the remote cluster NGC 6204 is about -40 km s^{-1} (Whiteoak 1963), we may expect the radial velocity of NGC 6167 to be in the range -20 to -25 km s^{-1}.

Our continuum observations reveal no emission feature which could be associated with the suspected cluster NGC 6167. Drift curves taken across the galactic plane through the cluster position show a neutral hydrogen feature that is displaced from the cluster centre by $\sim 5'$ arc away from the galactic plane and possesses a radial velocity of about $-25\ \mathrm{km\,s^{-1}}$ (Fig. 5) while, on the other side of the cluster position at $\sim 15'$ arc toward the galactic plane, there is a definite deficiency of neutral hydrogen. If these features are at the same distance as the stellar grouping, they provide evidence for the reality of the cluster NGC 6167. However, our drift curves taken along the galactic plane (Fig. 4(*a*)) show no definite HI cloud structure at around this velocity.

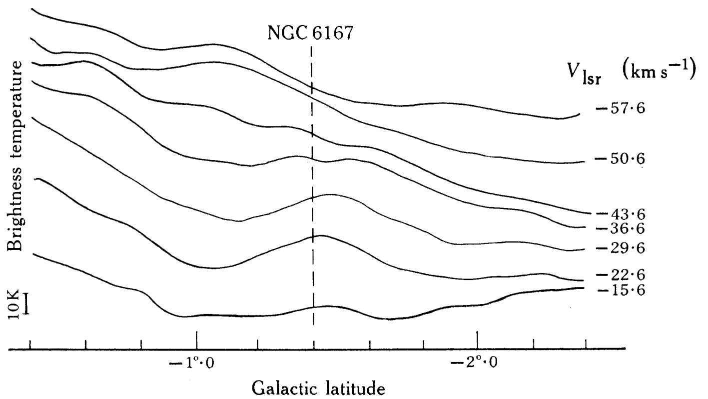

Fig. 5.—NGC 6167. Drift curves of hydrogen-line emission taken with the wide-band receiver through the centre of the cluster across the galactic plane.

Other drift curves taken in the region show that the feature seen in Figure 5 is due to a large cloud elongated along the galactic plane by $\sim 1°$ and with a width of $\sim 25'$ arc. As NGC 6167 is not situated near the centre of this feature it is unlikely to be associated with the cloud. However, if it were associated, the cloud would have an atom density of $\sim 13\ \mathrm{cm^{-3}}$ and a mass of $\sim 1000\ M_{\odot}$. These results were obtained on the assumption of a distance to the cloud of ~ 2 kpc while values of 20 K and $15\ \mathrm{km\,s^{-1}}$ were used for the brightness temperature and the linewidth at half-power respectively.

NGC 6193

Our continuum observations show two sources in the direction of NGC 6193, one of which is very large while the other is almost unresolved on our records (hereinafter in this subsection, these sources are referred to as the large and small sources respectively). Both sources may be seen on the drift curves taken through the cluster position (Fig. 6). The positions, angular sizes, and integrated flux densities of the sources were determined by means of a separation procedure similar to that used in the case of NGC 3293 above. The resulting contours of equal brightness temperature for both sources are shown in Figure 7.

The small source is at R.A. $16^{\mathrm{h}}36^{\mathrm{m}}\!\cdot 3$, Dec. $-48°46'$ (1950) and is displaced by only $\sim 10'$ arc to the west of the centre of the cluster, which has a diameter of $\sim 15'$ arc. The source was recently observed at 5000 MHz (Goss and Shaver 1970) and with better resolution at 408 MHz (Shaver and Goss 1970*a*), and a half-width

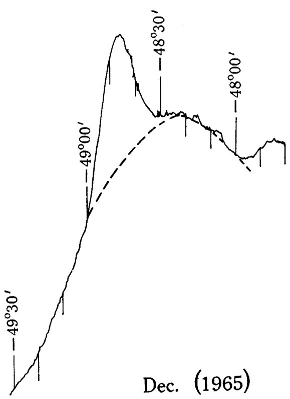

Fig. 6.—NGC 6193. Drift curve of continuum emission taken through the centre of the cluster, with the assumed Gaussian brightness distribution of the large source indicated by a dashed line. The presence of the small source is quite evident. The declination marks are for the epoch of the observations (1965).

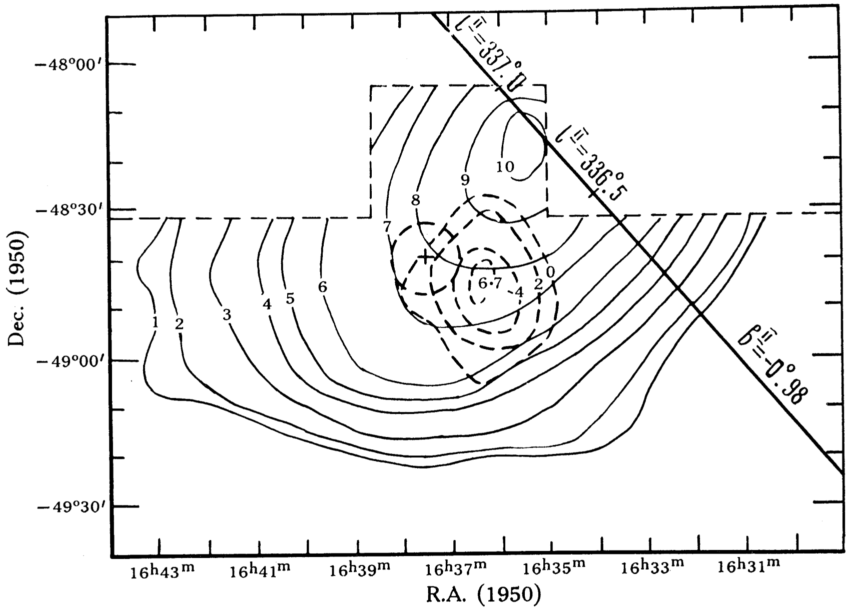

Fig. 7.—NGC 6193. Isophotes of brightness temperature in kelvins at 1410 MHz above the galactic background emission, with the position of the cluster indicated by a dashed circle. The large and small sources are indicated by solid and dashed lines respectively.

for the cloud of $\sim 1'$ arc was obtained. The emission is thermal (Shaver and Goss 1970*b*) and the total flux density at 1410 MHz is nearly 7 f.u. The radial velocities, -18, -39, and $+23\ \mathrm{km\,s^{-1}}$ (Rubin *et al.* 1962) of three apparent members of NGC 6193 (HD 150041, 150135, and 150136 respectively) have very large dispersion for stars belonging to a cluster. The radial velocity of the small source from optical (Courtès *et al.* 1970) and H 109α recombination-line measurements (Wilson *et al.* 1970) is about $-23\ \mathrm{km\,s^{-1}}$, which is in the range of the stellar velocities. If it were at the distance of the cluster, this HII condensation would have a very high mean electron density of $\sim 1200\ \mathrm{cm^{-3}}$ and a mass of less than $3\,M_{\odot}$.

Our hydrogen-line observations show a small dip at the position of the HII condensation on the drift curve for radial velocity $-17\cdot5\ \mathrm{km\,s^{-1}}$ (Fig. 4(*b*)). It would appear that part of the hydrogen is ionized and that the remaining neutral hydrogen forms a shell-like structure around the cluster. Rough estimates of the density and mass of this neutral hydrogen shell, obtained on the assumption that it is associated with NGC 6193, are $\sim 3\cdot 5\ \mathrm{cm^{-3}}$ and $\sim 400\,M_\odot$ respectively, while the mass of the ionized interior of the shell is roughly $\sim 100\,M_\odot$.

On the other hand, it seems certain that the large source is not associated with NGC 6193. This source has a flux density of ~ 150 f.u. but its centre is displaced from that of NGC 6193 by $\sim 30'$ arc toward the galactic plane and its half-width is nearly 70′ arc, both of which coincide rather well with those of region No. 108 in the Mount Stromlo catalogue of HII regions (Rogers *et al.* 1960). It was formerly assumed that this large cloud was ionized by the many OB stars in the association but there is no indication on our line profiles of the presence of this large ionized cloud at the distance of NGC 6193. Furthermore, the line observations show that the bulk of neutral hydrogen is at radial velocities of about $-40\ \mathrm{km\,s^{-1}}$ (Figs. 4(*a*) and 4(*c*)) at the location of the maximum of the ionized nebula (about 15–25′ arc toward the galactic plane from the cluster centre). We suggest that the neutral hydrogen cloud is not an ionized part of the hydrogen complex in this region. The radial velocity of the neutral hydrogen cloud is just that of the remote stars HD 151300, 328857, and 329033 (Rubin *et al.* 1962; Feast and Thackeray 1963), which are at a distance of ~ 2500 pc. Thus the large ionized nebula does not seem to be connected with NGC 6193, and the total amount of gas associated with the cluster can be no more than $500\,M_\odot$.

NGC 6200 and 6204

The cluster NGC 6204, which contains many OB stars, is at the eastern edge of the association I Ara and is at a distance of ~ 2500 pc (Whiteoak 1963). The mean value of the radial velocities of HD 150958, a member of NGC 6204, and three other stars (HD 151300, 328857, and 329033) in the immediate vicinity of the cluster is $-37\ \mathrm{km\,s^{-1}}$. The suspected cluster NGC 6200, considered by Whiteoak as a visual grouping of OB stars due to the effects of irregular interstellar absorption, is at $\sim 45'$ arc to the south–west of NGC 6204. If NGC 6200 is a real physical grouping then it is roughly at the same distance as NGC 6204 (the near equality of the distance moduli has been shown by Whiteoak 1963). Consequently, we may expect that their radial velocities are also similar.

Our continuum observations, which covered only the region of NGC 6204, show no emission feature that could be related to the cluster and neither do the hydrogen-line observations at the expected radial velocities (Fig. 4(*c*)). Thus neither neutral nor ionized hydrogen is associated with NGC 6204. The position of NGC 6200 coincides very well, at the expected radial velocity of about $-40\ \mathrm{km\,s^{-1}}$, with a possible deficiency of neutral hydrogen. Our impression is that the hydrogen in this vicinity is ionized by an OB star. If this interpretation is correct then the visual grouping may be a genuine physical grouping and NGC 6200 may constitute a genuine stellar cluster.

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