HYDROGEN CONTENT OF YOUNG STELLAR CLUSTERS

II.* CLUSTERS NGC 2175, 2264, 2353, AND 2362

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Abstract

Measurements of the total amount of gaseous hydrogen associated with the O-type stellar clusters NGC 2175, 2264, 2353, and 2362 are reported. For the nebula in which NGC 2175 is embedded, a mean electron density of $20\,cm^{-3}$ and a mass of ionized hydrogen of $1400\,M_{\odot}$ were obtained. For the nebula in which NGC 2264 is embedded, a mean electron density of $10\,cm^{-3}$ and a mass of ionized hydrogen of $60\,M_{\odot}$ (with a possible, though unlikely, additional $40\,M_{\odot}$ of neutral hydrogen) were obtained. No hydrogen in association with NGC 2353 or 2362 was detected.

Introduction

The results of 21 cm line and continuum observations of the four young stellar clusters NGC 2175, 2264, 2353, and 2362 are presented. The methods of observation and reduction are described in Part I (Tovmassian 1973, present issue pp. 829–35).

Measurements and Results

NGC 2175

The cluster NGC 2175 is embedded in a small bright nebulosity that is ionized by radiation from an O6-type star HD 420088, the brightest member of the cluster. Our drift scans of 1410 MHz continuum emission in this region show the emission from the nebula associated with the cluster standing out distinctly above a comparatively flat background. In addition, the radio isophotes of the nebula are almost circular, which facilitated accurate calculation of the integrated flux density and dimensions of the nebula. A flux density of ~ 30 f.u. and a half-power width of $\sim 20'$ arc were obtained.

Figure 1 reproduces the region of the Palomar Sky Survey red print that contains the nebula, with contours of 1410 MHz continuum emission superimposed. Similarities between the distribution of optical and radio brightness (also noted by Terzian 1965) indicate that the sharp boundary on the eastern side of the nebula is not due to absorption.

By assuming a distance to the nebula of 2 kpc, the distance of the exciting star (Rubin *et al.* 1962), equations (5) and (6) of Part I (Tovmassian 1973) yield a mean electron density and an ionized hydrogen mass of $\sim 20\,cm^{-3}$ and $\sim 1400\,M_{\odot}$

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respectively. From measurements of the distribution of density within the nebula, Terzian (1965) obtained a larger value of 4000 $M_{\odot}$ for the mass. The radial velocity of the ionized nebula according to Hα (Courtès *et al.* 1966) and hydrogen recombination-line measurements (Dieter 1967; Miller 1968) is about $+10\ \mathrm{km\,s^{-1}}$, the same as that of the exciting star (Rubin *et al.* 1962).

Our hydrogen-line observations show a rise in emission on the eastern side of the cluster at radial velocities near that of the cluster. The Maryland–Green Bank hydrogen-line survey maps reveal this feature as part of a large neutral hydrogen cloud in the galactic plane that is situated at the edge of the association Gem. I. It is most unlikely that such a large neutral hydrogen cloud would be connected with the

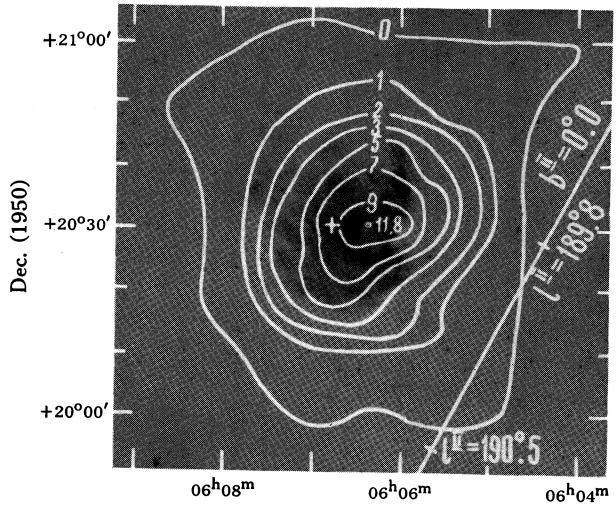

Fig. 1.—NGC 2175. Isophotes of brightness temperature in kelvins at 1410 MHz above the galactic background emission superimposed on the red plate of the Palomar Sky Survey. The position of the cluster is indicated by a cross.

emission nebula surrounding NGC 2175. Indeed, in a medium with a mean density of hydrogen atoms of $20\ \mathrm{cm^{-3}}$, the Strömgren radius of an HII region around an O6-type star would be more than 16 pc.* However, if a distance of 2 kpc is accepted, the linear radius of the full extent of the continuum source is less than 10 pc. Thus the ionized nebula is density bounded rather than ionization bounded, its small size implying that it is not part of a large neutral hydrogen cloud which would be ionized by radiation from the O6-type star. The previously mentioned agreement between the radial velocities of the large neutral hydrogen cloud and the cluster is of minor consequence as both objects lie at $l^{\mathrm{II}} \approx 190°$ near the galactic anticentre, where the radial velocity gradient due to galactic rotation is very small. For these reasons we conclude that only the ionized hydrogen nebula with a total mass of $\sim 1400\ M_{\odot}$ is associated with NGC 2175.

* In this paper and in Parts III (Tovmassian *et al.* 1973*a*, present issue pp. 843–51), IV (Tovmassian *et al.* 1973*b*, present issue pp. 853–60), and V (Tovmassian and Nersessian 1973, present issue pp. 861–6) the dimensions of Strömgren spheres have been obtained from Table 2 of Murdin and Sharpless (1968).

NGC 2264

The cluster NGC 2264 is associated with an ionized hydrogen nebula that is most probably excited by the earliest member of the cluster, the O7-type star S Mon. situated at the centre of the nebula. The other stars of the cluster are of types later than B2. The connection of S Mon. with the nebula is fairly convincing despite an appreciable difference in radial velocity: $+17\ \mathrm{km\,s^{-1}}$ (Rubin *et al.* 1962) for the star and about zero for the nebula according to Hα (Courtès *et al.* 1966) and hydrogen recombination-line measurements (Miller 1968). However, it should be noted that the velocity field of the cluster stars has a very large dispersion and Raimond (1966) has even suggested that the cluster is composed of two groups of stars with different velocities.

Our brightness contours in the region of NGC 2264 are shown in Figure 2(*a*). The region is evidently rich in faint clouds of ionized hydrogen, one of which coincides quite well with the position of the cluster and is taken here to be associated with NGC 2264. The apparent north–south elongation of this cloud results from the presence on either side of the cluster of two small faint clouds that are probably background features like many others in the region. The total flux density of the suggested association is ~ 4 f.u. and its half-power width is nearly 25′ arc. For a distance to the cloud of 760 pc, the distance of NGC 2264 (for references, see Raimond 1966), the electron density is $\sim 10\ \mathrm{cm^{-3}}$ and the ionized hydrogen mass is $\sim 60\ M_{\odot}$, a value that does not change appreciably if the small northern and southern clouds are included.

The neutral hydrogen in the vicinity of the stellar association Mon. OB1, which contains the cluster NGC 2264, has been investigated by Menon (1958) and, with better frequency and angular resolutions, by Raimond (1966). In the vicinity of NGC 2264, Raimond detected three large HI clouds, two of which he suggested were associated with the cluster. However, the positions and sizes of these clouds raise doubts as to their direct connection with NGC 2264 and a general association with Mon. OB1 seems more probable.

Our narrow-band observations, made with better angulaı resolution than those of Raimond (1966), reveal a small neutral hydrogen cloud in the direction of the cluster at radial velocities from $+6$ to $+10\ \mathrm{km\,s^{-1}}$ (Fig. 2(*b*)). At $+12\ \mathrm{km\,s^{-1}}$ this cloud has almost disappeared while a new feature has emerged. Unfortunately no scans at radial velocities exceeding $+12\ \mathrm{km\,s^{-1}}$ were taken so that we have not been able to follow this new feature. The mean radial velocity of the small cloud ($+8\ \mathrm{km\,s^{-1}}$) coincides with the mean radial velocity for 17 stars of the cluster (Walker 1956). The half-power width of the cloud is $\sim 27'$ arc, its brightness temperature almost 20 K, and the linewidth at half-power $\sim 8\ \mathrm{km\,s^{-1}}$. On the assumption that the cloud is at the distance of the cluster (760 pc), equations (8) and (9) of Part I (Tovmassian 1973) yield for the HI cloud an atom density of $12\ \mathrm{cm^{-3}}$ and a mass of $35\ M_{\odot}$ respectively.

The presence of an HI cloud within the cluster is highly doubtful as the cluster contains ionizing OB stars. Even if the density of the HII cloud were twice our estimate, the Strömgren radius around S Mon. would be ~ 14 pc, while the radius of the full extent of the nebula is less than 5 pc. Nevertheless, in the unlikely event that the neutral hydrogen cloud is also associated with the cluster, the total hydrogen content of the nebula would be $\sim 100\ M_{\odot}$.

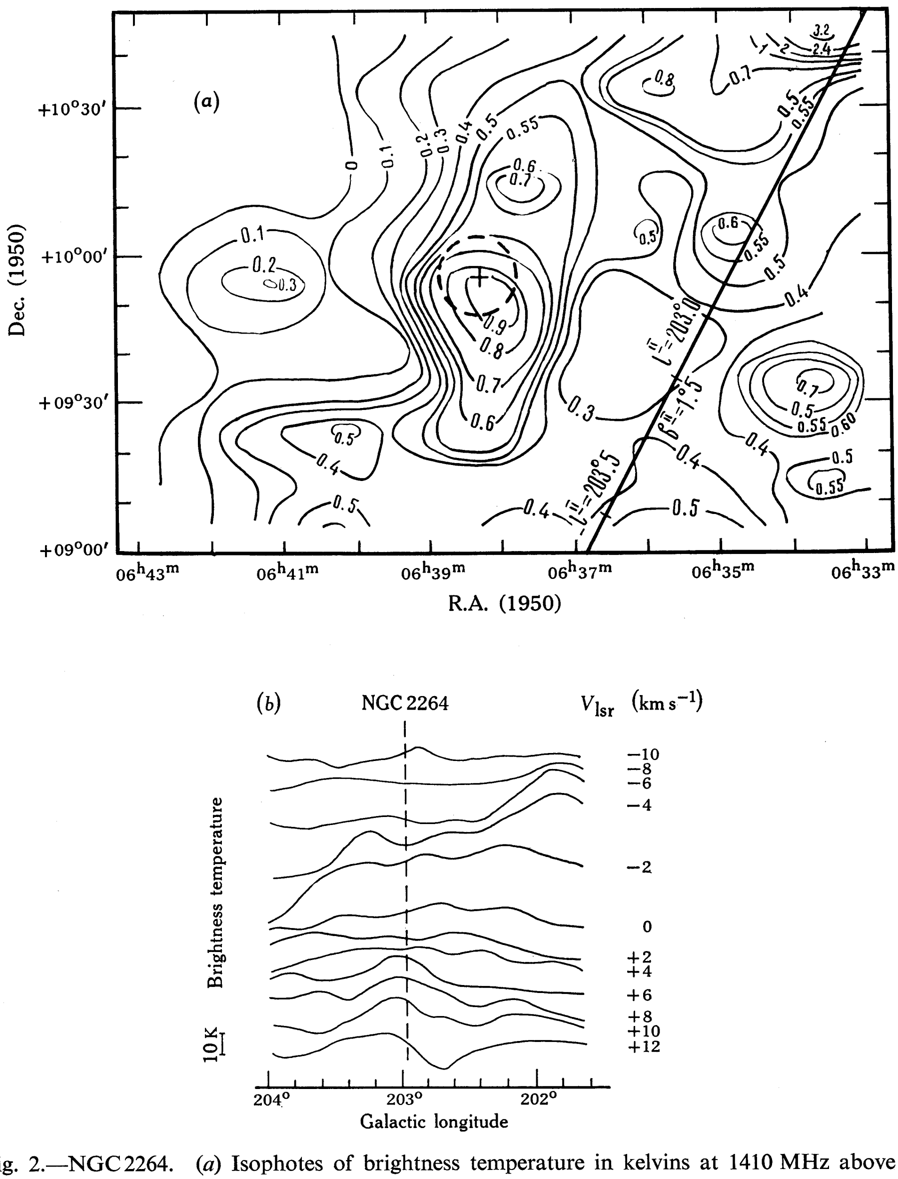

Fig. 2.—NGC 2264. (*a*) Isophotes of brightness temperature in kelvins at 1410 MHz above the galactic background emission, with the location of the cluster indicated by a dashed circle. (*b*) Drift curves of hydrogen-line emission taken with the narrow-band receiver through the centre of the cluster and along the galactic plane, with the position of the cluster indicated by the dashed line.

NGC 2353

Our continuum observations failed to reveal any emission at the position of the cluster (Fig. 3(*a*)) although the brightest member of the cluster, a B0 III-type star, would be able to ionize hydrogen if it were present. Similarly our hydrogen-line profiles taken through the position of the cluster failed to reveal any neutral hydrogen

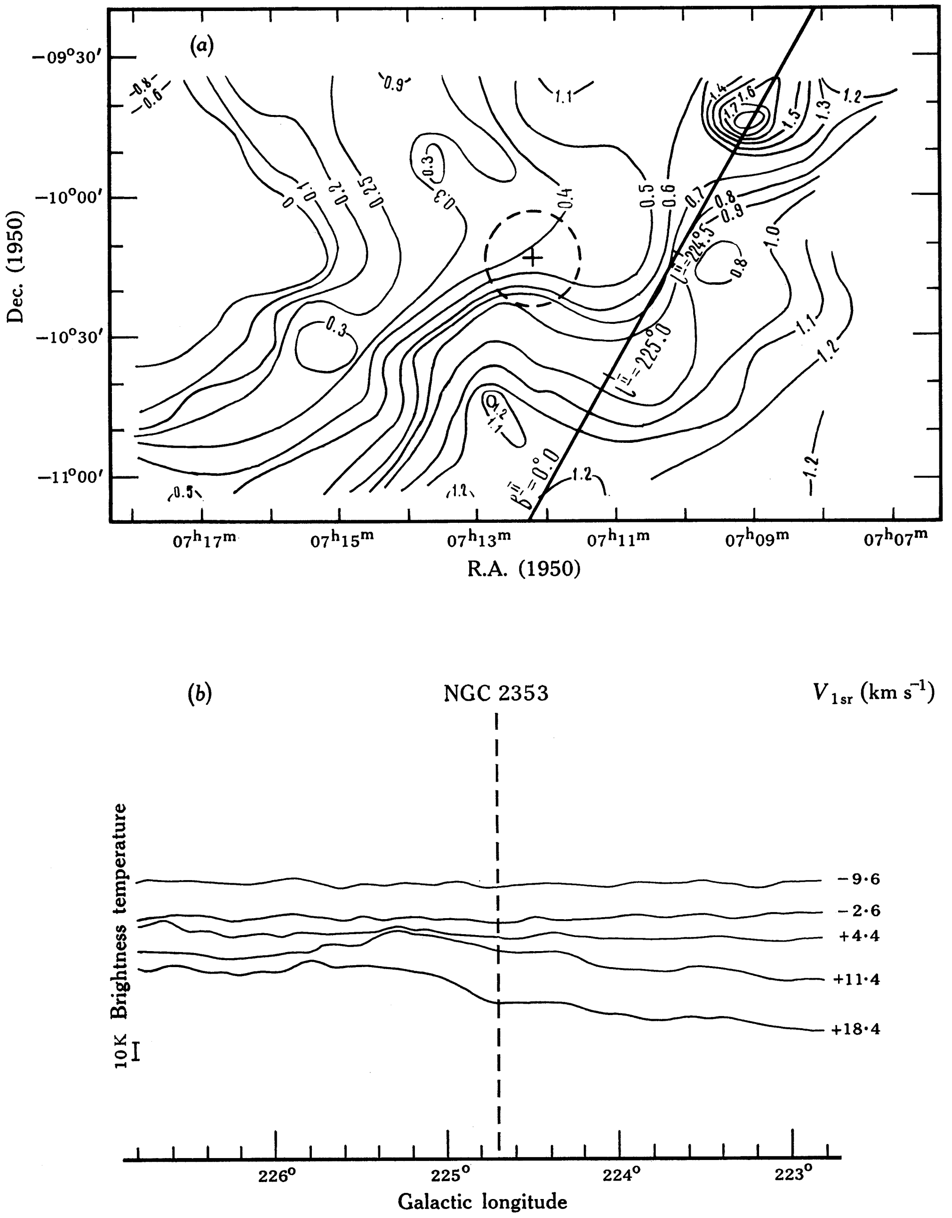

Fig. 3.—NGC 2353. (*a*) Isophotes of brightness temperature in kelvins at 1410 MHz above the galactic background emission, with the location of the cluster indicated by a dashed circle. (*b*) Drift curves of hydrogen-line emission taken with the wide-band receiver through the centre of the cluster, with the position of the cluster indicated by the dashed line.

cloud structure. All profiles spanning a wide velocity range about that of the cluster ($+7\ \mathrm{km\,s^{-1}}$; Rubin *et al.* 1962) are quite smooth (Fig. 3(*b*)). It therefore appears that no appreciable amounts of neutral or ionized hydrogen are associated with NGC 2353.

NGC 2362

The small O-type cluster NGC 2362 has angular dimensions of ~7′ arc and is situated at $b^{II} = -5°\cdot 5$, an appreciable angular distance from the galactic plane. For this reason our drift curves of HI emission taken parallel to the galactic equator are quite smooth. These observations reveal a neutral hydrogen cloud of rather symmetric form, about half a degree in diameter, and at a distance of ~30′ arc from the centre of the cluster (to the south and at higher galactic longitude). The mean radial velocity of the cloud is about $+30\ \mathrm{km\,s^{-1}}$ while the mean radial velocity of five of the cluster stars is $+15\ \mathrm{km\,s^{-1}}$ (Rubin *et al.* 1962). However, in the direction of NGC 2362 ($l^{II} = 238°$) the gradient of radial velocity due to galactic rotation is very great (Kerr 1962). Consequently the discrepancy in radial velocity coupled with the discrepancy in position suggests that the cloud is not connected with the cluster for, at a distance of 1·5 kpc for NGC 2362 (Buscombe 1963), the diameter of the cluster is ~3 pc while its separation from the cloud would be at least 13 pc.

The continuum observations reveal a small unresolved compact source of flux density ~4·5 f.u. at R.A. $07^{h}15^{m}\cdot 2$, Dec. $-24°56'\cdot 8$ (1950). The source is ~20′ arc south–west of the cluster and can hardly be associated with it. There are no other continuum features in the region. Thus there is no hydrogen associated with this cluster either.

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