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Commentary on Interstellar Matter Associated With 18 Open Clusters

David Leisawitz
Goddard Space Flight Center
Greenbelt, Maryland

NASA
National Aeronautics and
Space Administration
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Scientific and Technical
Information Division

Preface

This report summarizes information supplementary to that contained in Section IV of an article entitled "A CO Survey of Regions Around 34 Open Clusters" (Leisawitz, Bash, and Thaddeus 1989). The information presented here, which describes the interstellar environments of young clusters and some cluster physical characteristics, comes from observations published in the astronomical literature and the author's carbon monoxide (CO) emission line survey, and may help clarify our understanding of the interaction of massive stars with the interstellar medium.

Identification and Galactic coordinate data for the open clusters discussed in this report are given in Table 1. Additional information about the clusters can be found in Leisawitz, Bash, and Thaddeus (1989; hereafter referred to as Paper I) and in the Catalog of Open Clusters and Associated Interstellar Matter (Leisawitz 1988). Following the table, the clusters and their associated interstellar matter are described. The molecular cloud nomenclature is that of Paper I.

TABLE 1

Identifications and Galactic coordinates of clusters

Cluster Identification			Member of Association	Associated H II Region		Galactic Coordinates	
OCL[a]	Common Name	Alias		S[b]	W[c]	l_{II} (deg)	b_{II} (deg)
100	NGC 6709			···	···	42.16	4.70
124	NGC 6823		Vul OB1	86	55	59.41	-0.15
138	Roslund 4	IC 4954/5		···	···	66.96	-1.26
205	NGC 7062			···	···	89.93	-2.72
222	IC 1396	Tr 37	Cep OB2	131	···	99.29	3.73
244	NGC 7380		Cep OB1	142	···	107.08	-0.90
286	Berkeley 59		Cep OB4	171	1	118.25	4.95
313	NGC 281			184	···	123.13	-6.24
321	NGC 457			···	···	126.56	-4.35
339	Stock 5			···	···	130.74	2.65
345	NGC 744			···	···	132.39	-6.16
364	IC 1848		Cas OB6	199	5	137.19	0.92
394	NGC 1444		Cam OB1	···	···	148.16	-1.29
403	NGC 1624			212	···	155.35	2.58
406	NGC 1605			···	···	158.61	-1.58
439	NGC 1893	IC 410	Aur OB2	236	···	173.59	-1.70
441	NGC 1931		Aur OB1	237	···	173.90	0.28
476	NGC 2175		Gem OB1	252	···	190.20	0.42

[a] Open cluster number from the catalog of Alter, Ruprecht, and Vanysek (1970).
[b] Emission nebula number from the catalog of Sharpless (1959).
[c] Radio source number from the catalog of Westerhout (1958).

1. NGC 6709

Gordon, Howard, and Westerhout (1968; hereafter referred to as GHW) detected H I 21-cm emission in the direction of NGC 6709 at a velocity nearly coincident with that of the cluster. They estimated a mass for the atomic gas of only about 24 $M_\odot$ for an assumed distance equal to that of the cluster, but were not confident that the H I emission was produced by gas associated with the cluster. The excess H I column density toward the cluster (relative to the local background) that we infer from the measurements of GHW is 1.0×10^{20} cm^{-2} and our non-detection of CO emission along that line of sight (see Paper I) implies a comparable upper limit to the H_2 column density (see, e.g., Dame and Thaddeus 1985). The total (H I plus H_2) gas column density corresponds to a (B - V) reddening upper limit about 0.08 mag for a normal dust-to-gas ratio (Bohlin, Savage, and Drake 1978), a small fraction of the reddening measured toward cluster stars by Hagen (1970) and Polishchuk (1970). Therefore most, if not all, of the 1 magnitude of visual extinction of NGC 6709 (Becker and Fenkart 1971; Neckel 1967; also see Wallenquist 1975) is probably due to dust well removed from the cluster (for comparison, see D'Odorico and Felli 1970).

2. NGC 6823

The combined observations of Altenhoff et al. (1978), Schwartz (1971), and Tovmassian and Nersessian (1973) cover the thermal radio spectrum of the ionized gas around NGC 6823 from 1.420 to 4.875 GHz. From the radio data, we estimate a peak emission measure of 7800 cm^{-6}pc. If the distance to the cluster is 2.70 kpc (Lyngå 1987), and if the ionized gas is distributed uniformly, then the ion density in the H II region is about 20 cm^{-3} and the ionized gas mass is about 1500 $M_\odot$. The Stromgren sphere radius for the Lyman continuum flux of NGC 6823 in a 20 cm^{-3} medium is $\lesssim$10 pc, in good agreement with the size of the radio H II region for the distance assumed. Courtès, Cruvellier, and Georgelin (1966; hereafter referred to as CCG) used a Fabry-Perot interferometer to observe Hα and determined a mean radial velocity for the ionized gas of about 36 km s^{-1}, 4 km s^{-1} more positive than that of the molecular cloud NGC 6823B.

GHW noted that H I is seen in absorption along the entire dust lane that corresponds to the molecular cloud NGC 6823A. The absorption line velocity, 23 km s^{-1}, agrees fairly well with the velocity of the molecular cloud (see Paper I). Tovmassian and Nersessian (1973) suggested that the atomic hydrogen is in a shell surrounding the H II region and that the mass of H I in the shell is about 2000 $M_{\odot}$. The shell model surely is an oversimplification, but a more detailed description of the H I distribution is not warranted because the 21-cm line background is complicated.

3. Roslund 4

The dereddened color-magnitude diagram of Racine (1969) shows that the most massive cluster stars have begun to evolve away from the ZAMS; no star is bluer than $(B-V)_o$ = -0.28 mag. No Hα emission is visible (see Parker, Gull, and Kirschner 1979), but the region is heavily obscured (Racine 1969) so this does not peclude the possibility that ionizing stars are present. In fact, a 180 Jy continuum peak in the 1400 MHz survey of Condon and Broderick (1985) is consistent with membership in the cluster of a star of late O or early B spectral type. These observations suggest an age for Roslund 4 of less than or about 10 Myr (Janes and Adler 1982; Lyngå 1982; also see Racine 1969).

4. NGC 7062

GHW detected two 21-cm line features near NGC 7062, one at -5 km s^{-1} and another at 0 km s^{-1}. They estimated a mass of atomic hydrogen approximately 1200 $M_{\odot}$ if the H I is at the distance of the cluster. If, instead, the H I is at the distance of Cyg OB7, as suggested by the fact that its velocity coincides with that of the CO emission (see Paper I), then the H I mass would be lower by a factor of about 4.5. At 0 km s^{-1}, GHW observed a depression in the H I background near the cluster. Such a feature could be produced by a "hole" in the atomic gas centered on the cluster, but too little information was provided for this to be considered here in more detail.

5. IC 1396

As is generally true of the clusters with H II regions, only a minor fraction of the interstellar gas near IC 1396 is ionized. Matthews et al. (1980) mapped the region for 2695 MHz continuum emission and concluded that the H II region is ionization bounded, about 15 pc in radius, and has a mean electron density approximately 7 cm^{-3}. Therefore, the total mass of ionized gas around the cluster is about 3000 $M_{\odot}$, only 20% of the mass estimated to be present near IC 1396 in the form of molecular clouds (see Paper I). Simonson and van Someren Greve (1976) calculated that 2 x 10^4 $M_\odot$ of atomic gas is associated with IC 1396, an amount comparable to the mass present in the form of associated molecular clouds, but, since clouds IC 1396C and D appear to extend beyond our surveyed region, we can only place lower limits on their masses.

Strong radio emission is found in the directions of the molecular clouds, probably from relatively high density ionized gas on the cloud surfaces (Matthews et al. 1980). For example, we estimate from the observations of Matthews et al. an emission measure about 1800 $cm^{-6}pc$ in the direction of cloud A and we calculate that Lyman continuum photons that reach a 10^3 cm^{-3} cloud located 5 pc from an O6.5V star will penetrate to a depth of 10^{16} cm, implying that the mean electron density on the cloud surface is about 750 cm^{-3}. An interesting feature of this calculation is that the depth of the ionized layer on the cloud surface is expected to decrease rapidly with increasing distance from the ionizing star and with increasing cloud density; thus the cloud could not be very much farther than 5 pc from the star or very much denser than 10^3 cm^{-3} or the ratio of the emission measure to the path length of ionized gas would imply a mean electron density greater than the H_2 density of the cloud. This example demonstrates how radio continuum observations of molecular clouds associated with young clusters can be used to estimate the distances between the cloud surfaces and the ionizing stars.

Measurements of the Hα line velocity along six lines of sight toward IC 1396 (see CCG) yield a mean velocity for the ionized gas about 0 km s^{-1}, but there is a large dispersion in the measurements that can be explained by the presence of the molecular clouds (see Miller 1968). Molecular clouds can affect the measured Hα line velocities in two ways. First, only ionized gas in front of a molecular cloud contributes to the optical emission line for a line of sight that intersects a cloud. Second, the kinematics of the ionized gas are mediated by the clouds if, for example, dense ionized gas flows away from cloud surfaces or if an outflow of ionized material from the central star cluster is impeded by the presence of a molecular cloud. Since obscuration does not affect radio recombination line emission, the measurement by Rieu and Pankonin (1977) of the H110α line velocity -3.5 km s^{-1} in the direction of IC 1396A suggests that ionized gas may be streaming away from the surface of that cloud at about 3 km s^{-1} in the direction of the cluster.

6. NGC 7380

Radio continuum observations of S142 (Israel 1977; Schwartz 1971) indicate the presence of ~1200 $M_\odot$ of ionized gas. Optical emission line spectroscopy (CCG; Miller 1968; Reynolds 1985; Williamson 1970) has shown that the radial velocity of this gas is about -41 km s^{-1}, 14 km s^{-1} more negative than the cluster velocity (Palous et al. 1977; Wramdemark 1982).

7. Berkeley 59

Since the Lyman continuum photons from visible O and B stars are able to support the ionization estimated from radio continuum observations (Angerhofer et al. 1977; Rossano, Angerhofer, and Grayzeck 1980), we conclude that no star of spectral type earlier than O7 is concealed by the dense dust in front of S171 (see Appendix B of Paper I). A main sequence O7 star is the most massive star in the region. An upper limit for the cluster's age, based on the main sequence lifetime of such a star, is about 6 Myr (MacConnell 1968); a more stringent limit on the age, about 2 Myr, may be implied by the anomalously large reddening of the luminous cluster members (Blanco and Williams 1959; MacConnell 1968; Reddish 1967).

Lozinskaya and Sitnik (1977; also see Sitnik 1979) and Grayzeck (1980) have argued that the interstellar matter around Berkeley 59 is concentrated in an irregular, expanding shell. If the measured hydrogen recombination linewidths correspond to shell expansion (Sitnik 1979), then the shell's $\gtrsim 2°$ diameter ($\gtrsim 35$ pc at the distance of the cluster) can be used to calculate a dynamical age $\gtrsim 1$ Myr, consistent with the age of the cluster.

The disrupted appearance of the Berkeley 59 region may be the result of a violent event. Thus it is of interest that, although the radio spectrum of W1 is thermal when measured in the direction of brightest optical nebulosity (a direction in which the CO intensity is relatively low), a non-thermal source is present at G118.1+5.0 (Churchwell and Felli 1970), a heavily obscured region. The thermal spectrum is not surprising since ionizing stars are present, but the non-thermal source could be an obscured supernova remnant.

8. NGC 281

Using 21-cm continuum and line observations, and assuming a distance of 2200 pc (Hogg 1959), Roger and Pedlar (1981) estimated the mass of ionized gas as about 2000 $M_\odot$ and the mass of atomic hydrogen in the region about 10^4 $M_\odot$, of which one-third is in a shell that surrounds the star cluster. The Lyman continuum flux needed to ionize S184 can be supplied by the visible O stars.

9. NGC 457

Perhaps some support can be offered for the cautious suggestion of GHW that a -35 km s^{-1} feature in their 21-cm line map may be due to a cloud of atomic hydrogen associated with the cluster. From the Weaver and Williams (1973) 21-cm line survey, we estimate an H I column density about 1.6×10^{21} cm^{-2} from emission in the velocity range -25 to +10 km s^{-1} (i.e., "local" emission). The (B-V) reddening expected on the basis of this column density is approximately 0.28 mag (Bohlin, Savage, and Drake 1978), but this is only about half of the measured cluster reddening (Becker 1963; Hagen 1970; Moffat 1972), a significant discrepancy considering the small scatter in the Bohlin _et al_. column density-reddening relation. D'Odorico and Felli (1970) also concluded that the cluster is reddened excessively (albeit with the use of a simple model for the foreground reddening that can only be expected to apply statistically to clusters along many lines of sight), and they attributed the additional reddening to dust associated with the cluster. Assuming it is real, the reddening discrepancy can be explained in one of two ways: either the dust-to-gas ratio is anomalously high in the direction of the cluster, or some 21-cm emission at velocities less than -25 km s^{-1} originates in foreground atomic hydrogen. If one accepts the latter explanation and attributes the extra reddening to the -35 km s^{-1} cloud of GHW, then one finds that this cloud is receding from the cluster at about 7 km s^{-1}. If the H I cloud is at the distance of NGC 457, its mass is only about 750 $M_\odot$ (see GHW); for comparison, the mass of the cluster is about 4000 $M_\odot$ (Lohmann 1971; Popova 1969; Reddish and Sloan 1971; Schmidt 1963; also see Bruch and Sanders 1983).

10. Stock 5

The plerionic supernova remnant (SNR) 3C 58 is separated from Stock 5 by 24′, only 1.6 times the cluster angular diameter (see Table 1 in Paper I) and may be in the neighborhood of the cluster. From the extinction-corrected distance moduli of the giant stars in Stock 5 (Schmidt-Kaler 1961), we estimate the cluster's distance to be 1.6 ± 0.6 kpc. The radio source 3C 58 has been estimated discrepantly to lie at a distance of 2.6 kpc (Green and Gull 1983) or 8 kpc (Wilson and Weiler 1976 and references therein) based on H I absorption line radial velocities and on the Σ-d relation for supernovae. Note that the Σ-d relation is largely calibrated using absorption line kinematic distances and that such distances may be in error not only because of uncertainties in the rotation curve of the Galaxy, but also because of systematic (Bash and Leisawitz 1985) and random (Shaver et al. 1982) departures from circular motion about the Galactic center. In particular, the distance to a supernova remnant in the second quadrant of galactic longitude can be overestimated if a cold H I cloud accelerated by the supernova is seen in absorption. Fesen (1983) argued on the basis of the expansion rate of the SNR that its distance can be constrained to lie between 1 and 3 kpc. Thus, 3C 58 could lie at the distance of Stock 5 and could have arisen from the explosion of a star that had been a cluster member.

Additional support for this idea is contained in the morphological and kinematical structure found in our CO map of the Stock 5 region (Paper I). We find some evidence, albeit not compelling, that the SNR is in the middle of a "molecular shell." Enhanced infrared emission was detected by the IRAS on the side of cloud A that faces 3C 58 and no star that is sufficiently luminous to explain the heating of this cloud is in a position that could account for the IR brightness distribution. Furthermore, compression of the radio continuum contours and warping of the magnetic field orientation (Wilson and Weiler 1976; also see Er and Strom 1983) on the side of the SNR that faces cloud A may signify the presence of a density gradient in the interstellar medium, as one would expect to be present near the surface of a molecular cloud. Clouds Stock 5D and E, which have similar radial velocities (about -3 km s^{-1}), connect to form a partial ring that surrounds the SNR on three sides. Since clouds Stock 5A and B have a velocity about -7 km s^{-1}, we postulate that they lie on the near side of the radio source (this hypothesis could be tested with, e.g., sensitive H_2CO line observations) and that the expansion velocity of the molecular shell is approximately 4 km s^{-1}. If the distance to this region is 1.6 kpc, then the inner radius of the ring is about 12 pc and the dynamical age of the shell is 3 Myr.

These observations, if not merely coincidental, have a number of important implications, the first and most obvious of which is that the supernova or its precursor apparently had a major impact on the distribution of interstellar material in the region near Stock 5.

Second, the molecular shell dynamical timescale indicates that the precursor, rather than the supernova explosion, accelerated the molecular clouds. If the supernova itself exploded 3 Myr ago then the mean expansion velocity inferred from the size of the radio source would be only about 1 km s^{-1}. For comparison, Mayall and Oort (1942) estimate that the Crab Nebula expansion velocity is 1500 km s^{-1}, and Fesen (1983) measured a similar expansion velocity for several optical filaments associated with 3C 58. Whether or not 3C 58 is the remnant of the supernova of A.D. 1181 is a subject that has been debated in the literature (Becker, Helfand, and Szymkowiak 1982; Er and Strom 1983 and references therein; Fesen 1983; Stephenson 1971), but the Crab-like nature of 3C 58 argues for an age closer to 10^3 than to 10^6 yr.

Third, since the shell expansion is centered at -3 km s^{-1}, it is highly unlikely that the distance to the supernova is as great as 8 kpc; a very near kinematic distance is implied. Cloud Stock 5D, which extends to the border of our CO map (Paper I), probably is the edge of the cloud that is responsible for a more than 2° region of obscuration on the POSS prints (see Becvar 1962). The large angular size of this region and the fact that the cloud produces a marked diminution of the star density are further indications that cloud D is not very distant. If the distance of 3C 58 is the same as that of Stock 5 then the SNR is Crab-like in size and its expansion age is consistent with an association with SN1181 (for related arguments, see Fesen 1983; Green and Gull 1983; and Table 4 of Wilson and Weiler 1976). Furthermore, the foreground hydrogen column density toward 3C 58 (Becker, Helfand, and Szymkowiak 1982; Green and Gull 1983), about 2.5×10^{21} cm^{-2}, implies a mean space density $n_H \sim 0.5$ cm^{-3} if the radio source distance is 1.6 kpc; this value is consistent with measurements of the mean reddening per kpc in the outer Galaxy (Leisawitz and Hauser 1988 and references therein; also see §IV of Paper I).

An important consequence for supernova research of a 2 kpc distance for 3C 58 is that its radio and X-ray luminosities will be revised downward relative to the values calculated by Becker, Helfand, and

Szymkowiak (1982) and by Davelaar, Smith, and Becker (1986) and will be much lower than the corresponding luminosities of the Crab Nebula (a factor 2800 lower than the Crab in 2-10 keV X-rays, a factor 6300 lower in 0.1-4 keV X-rays, and a factor 27 lower in 10 MHz - 100 GHz radio emission). Since the two remnants are of a similar age, these differences may be attributable to mass differences in the precursor stars and may provide an explanation for the presence of a pulsar in the Crab Nebula and the absence of one in 3C 58 (Becker, Helfand, and Szymkowiak 1982). Although the combined visual extinction expected from the foreground H I and the molecular cloud Stock 5B is less than 2 magnitudes (for comparison, see Fesen 1983; Green and Gull 1983), 3C 58 has no bright optical counterpart (van den Bergh 1978).

11. NGC 744

GHW found in their 21-cm observations two features that they suggest may be associated with NGC 744. They found H I in emission at -21 km s^{-1} and in absorption at -16 km s^{-1}. For comparison, the radial velocity adopted for the cluster from its distance and the Galactic rotation curve is -18 ± 3 km s^{-1}. The total atomic hydrogen mass, if the 21-cm features do indeed arise in clouds at the distance of the cluster, is only a few tens of solar masses.

12. IC 1848

Radio continuum observations of W5 (Schwartz 1971; Vallée, Hughes, and Viner 1979 and references therein) suggest that the massive stars are surrounded by 10^4 $M_\odot$ of ionized gas concentrated in a non-uniform shell of thickness ~5 pc and inner radius ~15 pc. The visible O stars supply enough Lyman continuum radiation to explain the radio observations. An adjacent 8000 $M_\odot$ Stromgren sphere (S201), centered on the O7V star HD 18326, also lies within the CO map of the IC 1848 region shown in Paper I.

Two observations suggest that the surfaces of molecular clouds illuminated by IC 1848 are the source of much of the ionized gas in the region: (a) radio (Dieter 1967; Hart and Pedlar 1976) and optical (CCG; Miller 1968) hydrogen recombination line observations indicate that the mean radial velocity of the ionized gas is the same as the mean CO velocity of the molecular clouds; and (b) the most intense radio continuum emission is found in the directions of the molecular clouds, especially where the cloud surfaces are exposed to strong UV radiation from the massive stars. For example, extended, strong radio continuum emission found by Vallée, Hughes, and Viner (1979) near l = 136°.9, b = +1°.1 coincides with the molecular cloud IC 1848A. Scatter in the Hα velocities from position to position (CCG; Miller 1968) may be due to differences in the motion of the ionized gas (Georgelin 1970; Miller 1968) as affected by the presence of molecular clouds IC 1848A and B.

13. NGC 1444

There is no evidence for the ongoing formation of massive stars near this cluster. Such stars produce compact H II regions in molecular clouds that are radio and infrared sources of small angular extent. The IRAS Point Source Catalog contains no source stronger than a few tens of Jy in the region surveyed, whereas a B0 star in a cloud at the distance of the cluster should be at least a 10^3 Jy source. The radio sources discussed in §IVb(xxi) of Paper I tend to lie along lines of sight toward which little or no CO emission is found.

14. NGC 1624

The nearly invisible H II region S211 is located at the periphery of the region surveyed for CO emission (Paper I), at (l, b) = 154°.65, +2°.46. Radio observations of S211 (McCutcheon et al. 1986) are consistent with ionization by a main sequence star of spectral type O7.5 or O8 based on the excitation parameters of Panagia (1973). Even if the distance of S211 is the same as that of S212 (6.0 kpc; Moffat, Fitzgerald, and Jackson 1979), the two H II regions are separated by at least 74 pc, so their apparent close relationship (i.e., similar physical properties and small angular separation) may be superficial.

15. NGC 1605

Neither cloud NGC 1605A nor cloud B intervenes along the line of sight to NGC 1605, yet the cluster is obscured by about 3.65 mag of visual extinction (Becker and Fenkart 1971). Most, if not all, of this extinction must be produced by dust associated with atomic hydrogen clouds. Indeed, the H I column density corresponding to the strong 21-cm emission found by Weaver and Williams (1973) near the position of the cluster is consistent with the extinction.

16. NGC 1893

Differential reddening is responsible for the large scatter in uncorrected color-magnitude diagrams; when the stars are individually dereddened using the data from Table IV of Cuffey (1973) and a selective extinction of 3.1, a well-defined main sequence with no turnoff is found (Moffat 1972; Note: not even the stars that Cuffey classified as overluminous appear to be evolved). The obscuring cloud that produces the differential reddening was found in the star count map of Wallenquist (1975).

Radio continuum (Cunningham 1968; Terzian 1965) and Hα (Vidal 1980) observations of the associated H II region IC 410 are consistent with the spectrophotometric determination that ionization is dominated by a star with the excitation parameter of an O4V star (Panagia 1973). The H II region can be described approximately as a Stromgren sphere of radius 20 pc and electron density about 15 cm^{-3} (Cunningham 1968; Vidal 1980). In this picture the mass of ionized material exceeds 10^4 $M_\odot$, making IC 410 an exceptionally massive H II region.

By analyzing <u>IRAS</u> observations of the region around NGC 1893, Leisawitz and Hauser (1988) determined that the infrared luminosity of a 74 pc radius region surrounding the cluster is a small fraction of the cluster luminosity and concluded from this, assuming the canonical ratio of dust to gas, that most of the volume surrounding the cluster contains low-density gas (<1 cm^{-3}). Their conclusion can be reconciled with direct observations of the ionized gas if the gas is clumpy. In this case, the Stromgren sphere model overestimates the mean electron density and hence the mass (probably by a factor of about 5).

GHW looked for atomic hydrogen in the vicinity of NGC 1893 and found 21-cm features at -16 and -3 km s^{-1}. The -16 km s^{-1} gas covers the entire IC 410 emission nebula and produces an absorption (or self-absorption; see GHW) feature. This gas may be cold, foreground H I, in which case it is receding from the star cluster at about 20 km s^{-1}. The -3 km s^{-1} gas, which coincides kinematically and positionally with the molecular cloud NGC 1893C (see Paper I), emits more intensely and has a greater angular extent than the absorbing material. If both of the 21-cm line features are due to H I associated with NGC 1893, then the total atomic hydrogen content of the region exceeds 10^4 $M_\odot$, only about 2000 $M_\odot$ of which is contained in the absorbing gas (for comparison, see D'Odorico and Felli 1970).

Observations of optical emission lines have been used to study the motion of the gas ionized by NGC 1893. Fabry-Perot Hα interferograms were obtained by CCG who measured line velocities -3.4 and 8.4 km s^{-1}, and by Georgelin and Georgelin (1970) who obtained 0.2 km s^{-1}. Johnson and White (1980) employed a similar technique to map the velocity field of IC 410 in the [N II] and [O III] lines and estimated that most of the ionized gas is concentrated at 11 km s^{-1} (split lines were found in the northwestern quadrant of the nebula). Miller (1968) used a slit spectrograph and found Hα emission at -5.1 km s^{-1}. The dispersion among the various Hα measurements is consistent with internal measurement errors (especially in the interferogram data) and thus cannot be attributed to the fact that different positions within IC 410 were observed. It is interesting that the [N II] and [O III] lines are centered at a velocity that differs significantly from that of the Hα-emitting gas, but it should be verified that the discrepancy was not caused by a systematic error in calibration. We conclude from the Hα measurements that the ionized gas motion is similar to that of the cluster and therefore that the ionized gas is receding from the molecular cloud NGC 1893A. Radio recombination line observations of IC 410 could contribute significantly to our understanding of the kinematic structure of the NGC 1893 star formation region but, to the best of our knowledge, no such observations have been published.

17. NGC 1931

Moffat, FitzGerald, and Jackson (1979) obtained UBV photometry of four stars and derived what is presently the only published estimate of the distance to the cluster. Although their distance modulus appears to agree with their color-magnitude diagram, the diagram is inconsistent with the tabulated photometry. Specifically, the distance modulus implied by the tabulated data is about 12.6 mag but the quoted distance modulus is 11.3 ± 0.3 mag, corresponding to a distance of 1800 pc. We adopted in Paper I the published distance, but note that, at 1800 pc, a B0.5 main sequence star would be 1.5 magnitudes brighter than the brightest star measured by Moffat et al. An interpretation consistent with the Glushkov, Denisyuk, and Karyagina (1975) optical emission line spectrum, the radio continuum observations of Condon and Broderick (1985; see Paper I), and the photometry tabulated by Moffat et al. is that the distance of NGC 1931 really is about 3.3 kpc. Based on the U, B, and V magnitudes of the brightest star and the age calibration of Doom, de Greve, and de Loore (1985), we estimate that the age of the cluster is about 10 Myr.

18. NGC 2175

The region surveyed for CO emission around NGC 2175 (Paper I) also contains S247, an H II region excited by a B0 III star (Georgelin 1975; Georgelin, Georgelin, and Roux 1973). The distance to S247 implied by the spectroscopic parallax of the ionizing star is about 3.5 kpc (Moffat, FitzGerald, and Jackson 1979). This estimate is inaccurate, however, and radio observations of S247 (Felli and Harten 1981 and references therein) can be understood more readily if the H II region is closer, in which case it may be a neighbor of S252. Both of these H II regions evidently are more distant than most of the members of the Gem OB1 association (Humphreys 1978), although it is possible that they are association members (Markarian 1952).

Radio observations have been made of the non-molecular interstellar gas associated with NGC 2175. Single-dish radio continuum measurements show that S252 contains a few times 10^3 $M_{\odot}$ of ionized gas (Felli, Habing, and Israel 1977 and references therein; Tovmassian and Shahbazian 1973). Tovmassian and Shahbazian (1973) detected 21-cm line emission near the nebula at approximately the radial velocity of NGC 2175 (Georgelin 1975; Rubin et al. 1962) but they concluded that the atomic hydrogen was not associated with the cluster and did not discuss the result in detail.

Pismis (1970) pointed out a ring-like spatial distribution of stars in part of NGC 2175. Her suggestion that this could be an artifact of differential obscuration is not substantiated by our CO observations (Paper I) or those of Lada and Wooden (1979). Also, the close correspondence of extended thermal radio emission to optical emission line nebulosity from S252 indicates that none of the molecular material is on the near side of the star cluster. The peculiar star distribution would be interesting if it correlated with the dynamics of the cluster, a hypothesis that could be tested with a radial and proper motion study, but the possibility remains, as noted by Pismis, that the central star density void is merely a statistical fluctuation.

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16. Abstract

This report summarizes information supplementary to that contained in Section IV of an article entitled "A CO Survey of Regions Around 34 Open Clusters" (Leisawitz, Bash, and Thaddeus)published in the Astrophysical Journal Supplement Series, Volume 70, Number 4, August 1989. The information presented here, which describes the interstellar environments of young clusters and some cluster physical characteristics, comes from observations published in the astronomical literature and the author's carbon monoxide (CO) emission line survey, and may help clarify our understanding of the interaction of massive stars with the interstellar medium.

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