INFRARED OBSERVATIONS OF STAR FORMATION REGIONS

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1. INTRODUCTION

This review is divided into three parts. The first section gives a brief introduction to the different infrared wavelength ranges and to the various kinds of infrared objects seen in regions of star formation. The second section reviews the recent progress in infrared observations, concentrating on the three years since the review by Wynn-Williams and Becklin (1974) was written. The third section describes in more detail four varied examples of star formation regions.

1.1 Infrared wavelength ranges

For astronomical purposes it is convenient to divide the infrared spectrum into four wavelength ranges. This differentiation is necessitated by the wide variations in technique which are imposed by detector and, in particular, by atmospheric limitations.

The "near" or "photographic" infrared is effectively an extension of the visible wavelength range as far as it is possible to use photographic emulsions and image tubes. Currently this limit is about 1μm; at all wavelengths longer than this, single element detectors, such as photoconductors or bolometer elements, must be used. Between 1μm and about 40μm there are a number of atmospheric windows through which observations may be made from ground-based observatories using large optical or infrared telescopes. The windows at 2.0–2.4μm and 8–13μm, for example, are relatively transparent and much used, while the 20μm and 34μm windows are sensitive to water vapour fluctuations and require the use of high altitude observatories.

Between about 40μm and 350μm infrared observations are impossible from the ground, and telescopes must be mounted in aircraft or under balloons. The chief disadvantage of these techniques, apart from their expense, is that spatial resolving power is limited by diffraction effects in the small telescopes which must be used. Longward of 350μm
Figure 1. Schematic representation of the relative dispositions of the various types of infrared sources described in this paper.

Figure 2. Schematic energy distributions of the various types of infrared sources described in this paper.
the atmosphere gradually becomes transparent enough for ground-based observations. The two commonly used bands are the "submillimetre" band at 350 \( \mu \)m and the "millimetre" band between 0.7 mm and 1.4 mm.

The spatial resolution possible in the infrared depends very much on wavelength. Shortward of about 20\( \mu \)m the limit is set by atmospheric seeing to a few arc seconds, between 40\( \mu \)m and 2 cm it is set by diffraction to somewhat less than 1 arc min, while longward of 2-cm aperture synthesis telescopes allow one second resolution again.

1.2 Types of Infrared Source

The infrared objects observed in regions of star formation fall into four main classes: obscured stars, compact HII regions, protostars and molecular clouds. These are illustrated schematically in Figure 1, while their typical energy distributions are shown in Figure 2. The infrared properties of pre-main sequence objects such as T-Tauri and Herbig-Haro objects are discussed in S.E. Strom's article elsewhere in this volume.

**Obscured Stars.** Since, at infrared wavelengths, the extinction due to interstellar dust is much smaller than at visual wavelengths, infrared searches will often disclose stars hidden behind dust clouds. Two sorts of star are of particular interest: the exciting stars of HII regions (e.g. Beetz et al. 1976) and young stars embedded in dark clouds. A good example of the latter situation, namely the 2.2\( \mu \)m infrared sources associated with the \( \rho \) Ophiuchi dark cloud, is described in P. Thaddeus' article in this volume, and by Vrba et al. (1975). The flux densities from the hot photospheres of these stars decreases with increasing wavelength longward of 1\( \mu \)m; for this reason there are few observations of dust-embedded stars at wavelengths longer than 3\( \mu \)m.

**Compact HII Regions.** As a result of various selection effects, the best studied HII regions are those having diameters in the range 0.05 to 0.5 pc and electron densities 10\(^3\) to 10\(^4\) cm\(^{-3}\). As described by Wynn-Williams and Becklin (1974) the dust grains which emit over the wavelength range 2 to 20\( \mu \)m appear to be coextensive with the ionized gas and produce an approximately power-law energy distribution over this wavelength range. At longer wavelengths it is unclear, except in a few cases such as the Orion Nebula (section 3.1), how much of the infrared emission comes from dust within the ionized gas and how much comes from the molecular clouds surrounding or very close to the HII region. Inadequate spatial resolution at 100\( \mu \)m is the main cause of this uncertainty. The question of the ways in which the dust grains are heated in and around HII regions has led to much theoretical calculation. An extensive series of models for dusty HII regions is described by Natta and Panagia (1976).

"Protostars". There is now a rapidly increasing number of 2 to 20\( \mu \)m infrared sources which have properties which suggest that they may
be of protostellar origin. The earliest known examples are the BN source in Orion (Becklin, Neugebauer and Wynn-Williams 1973) and W3-IRS5 (Wynn-Williams, Becklin and Neugebauer 1972), but Werner, Becklin and Neugebauer (1976a) list 13 objects which are probably of this type. Their typical characteristics are small angular size (<2 arcsec), an energy distribution resembling a black body at a few hundred degrees Kelvin with a strong silicate absorption, H2O and/or OH maser emission, but no visual counterpart. Usually the objects have no radio emission themselves, but are in the vicinity of compact HII regions. The objects range in luminosity from about 100 L⊙ for OMC2-IRS3 (Gatley et al. 1974) to 4 x 10⁴ L⊙ for RCW57-IRS1 (Frogel and Persson 1974).

The infrared energy distributions of these objects indicates that they consist of a thick layer of hot dust surrounding some energy source. Some authors (e.g. Penston, Allen and Hyland 1971) have suggested that the central objects are highly evolved stars, but the frequency with which these infrared sources are found near to the centres of molecular clouds makes this alternative statistically implausible. If the central objects are main sequence stars they would in most cases be of type O; to account for the absence of radio emission it is therefore necessary to conjecture that the star is surrounded by such a thick layer of dust that the formation of an HII region is inhibited. It is difficult to explain the existence of such a thick "cocoon" surrounding the star unless the material was connected with the recent formation of the star; it would therefore seem reasonable to allow the term protostar to include such a configuration.

The use of the term "protostar" to describe these infrared sources is perhaps contentious in view of how little is known about their structure and dynamics. From an observational point of view, however, it is convenient to use the term to refer to a compact infrared source whose major observable characteristics are believed to be a consequence of its current or its very recent accretion of matter. The value of this definition is that it relates to the external, observable properties of the object rather than to its internal constitution; the word used in this sense would not necessarily exclude ultra-compact HII regions such as NGC7538-IRS1 (Wynn-Williams, Becklin and Neugebauer 1974), and would certainly include Kahn's (1974) cocoon stars. The question of whether the objects have started nuclear burning is left open (see e.g. Appenzeller and Tscharnuter 1974). If the word "protostar" is not to be used to describe this class of infrared source, another word must be coined. Whether a term such as "Dustar" would appeal to the astronomical community must be considered doubtful.

Molecular Clouds. At wavelengths longward of about 50µm, emission is seen mainly from extended, comparatively cool molecular clouds. These are the same objects as are studied by molecular line astronomers (see P. Thaddeus' article in this volume), and a close correlation has been found in some cases between molecular line and 1-mm continuum emission (Harvey et al. 1974). Radial density and temperature gradients suggestive of collapse have been found in some clouds.
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(Westbrook et al. 1976), and in almost all cases the density peak coincides with one or more protostars or compact HII regions.

2. PROGRESS IN INFRARED OBSERVATIONS

2.1 "Near" infrared ($\lambda \leq 1\mu m$)

The Heidelberg infrared group has been studying several HII regions at photographic infrared wavelengths (Beetz et al. 1976). Using a cooled image tube working at 0.70$\mu$m and 0.92$\mu$m they were able to find obscured probable ionizing stars in several HII components in W3. They also discovered an obscured star cluster nearly coincident with the peak of the extended infrared and radio emission in M17, as well as a near-infrared counterpart to the Kleinmann-Wright infrared object. Near-infrared photography has the advantage of permitting large areas to be surveyed fairly quickly; it is an excellent method of finding stars obscured by 5-15 magnitudes of visual extinction, and of investigating dust clouds with extinctions in this range.

2.2 Mapping and photometry at $1\mu m < \lambda \leq 20\mu m$

Many infrared groups are now involved in mapping and photometry of HII regions and other infrared sources in this wavelength range. The main improvements in the last three years have been in the limiting sensitivity of ground-based observations as a result of the introduction of new types of detector. Table 1 gives very approximate values for the current minimum detectable flux densities in one second of integration at 2.2$\mu$m and 10$\mu$m using a large instrument such as the Palomar 5m telescope. For comparison, limits are also given at 100$\mu$m for the C-141 aircraft and at 1 mm for the 5m telescope. Longer integrations can reduce these limits by factors of about 100 at 2.2$\mu$m, and 20 at the longer wavelengths before systematic effects dominate; in at least some areas of the galactic plane, however, confusion by faint field stars appears to set the practical sensitivity limit at 2.2$\mu$m, even with diaphragms as small as 5 arcsec in diameter.

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Limit in 1sec</th>
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<tr>
<td>2.2$\mu$m</td>
<td>1mJy (14.5 mag)</td>
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<tr>
<td>10$\mu$m</td>
<td>150mJy (6 mag)</td>
</tr>
<tr>
<td>100$\mu$m</td>
<td>200Jy</td>
</tr>
<tr>
<td>1 mm</td>
<td>30Jy</td>
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Table 1. Minimum detectable fluxes at infrared wavelengths in 1 second integration. (Becklin, private communication). 1Jy = $10^{-26}$ W m$^{-2}$ Hz$^{-1}$. © International Astronomical Union • Provided by the NASA Astrophysics Data System
2.3 The window at 34μm

At a few high altitude observatories it is sometimes possible, on very cold dry nights, to make observations in the rather murky 30-40μm atmospheric window. Measurements of HII regions in this wavelength range have been reported by Low, Rieke and Armstrong (1973), using Mount Lemmon, by Sutton, Becklin and Neugebauer (1974), using Las Campanas and by Dyck and Simon (1976) using Mauna Kea. Because of atmospheric problems, observations in the 34μm window are difficult and photometric accuracy is low. The ground-based observations at these wavelengths are, however, extremely important, since they provide a link between the short-wavelength/high-spatial-resolution observations made from the ground and the long wavelength/low-spatial-resolution observations made from the air; with a 2.5 m ground-based telescope the diffraction limit at 34μm is about 4 arcsec, several times less than that of the C-141 airborne observatory. In the study of compact HII regions the high spatial resolution at this wavelength can help solve the question of how much of the λ > 30μm radiation from the vicinity of compact HII regions comes from dust coextensive with the ionized gas and how much comes from the surrounding molecular clouds. In this context Dyck and Simon (1976) showed that much of the 34μm radiation attributed to W3(A) must come from regions exterior to the ionized gas.

2.4 Ground-based spectroscopy

Infrared spectroscopy of objects related to star formation now embraces molecular, atomic, ionic and solid-state phenomena. Almost all the observations have been made from the ground, most frequently at Kitt Peak, and in most cases involve variable-thickness interference filters or grating spectrometers with typical spectral resolutions of λ/Δλ ≈ 100. Much higher resolving powers are now becoming available, however, as a result of the development of Fourier Transform Spectrometers.

Molecular Hydrogen. Gautier et al. (1976) used a Fourier Transform Spectrometer to detect seven lines of the 1-0 vibration-rotation quadrupole spectrum of H₂ in emission from the vicinity of the BNKL sources in Orion. Their resolution was about 3 cm⁻¹ at 2μm. The remarkable feature of this discovery is the high strength of the lines, which require a temperature of about 2000K for their excitation. The authors estimate that the lines are produced in a region with a column density of 10¹⁹ to 10²⁰ molecules cm⁻². The OMC1 molecular cloud has a temperature of about 70K and a column density of about 10²³ cm⁻², so the region where the 2μm lines are formed must be rather special, and is perhaps associated with a shock front.

Atomic and Ionic Lines. The most commonly observed lines are some of the higher recombination lines of hydrogen such as the Brackett-α line at 4.05μm and the Brackett-γ line at 2.17μm. Measurement of the
strengths of these lines in HII regions can help to disentangle the contributions of the gas and the dust to the infrared continuum and, in the case of visually obscured HII regions, can allow the extinction to be estimated by comparison with the radio flux density. The 2.06μm line of neutral helium is strong in HII regions, but is very sensitive to optical depth and density variations. Fine structure lines of several ions have now been detected in HII regions including \([\text{NeII}]\) at 12.8μm (Aitken and Jones 1974), \([\text{ArIII}]\) at 8.99μm (Soifer and Pipher 1975) and \([\text{SIV}]\) at 10.52μm (Willner 1976). The wide range in ionization potential of these species may make them useful tools in obtaining a better understanding of the ionization structure of dust-embedded HII regions.

Silicates and Ices. A feature at 9.7μm attributed to silicate grains is seen in emission in the Trapezium region of the Orion Nebula (Forrest, Gillett and Stein 1975) and in absorption in front of a large number of compact HII regions and protostars (e.g. Gillett et al. 1975a; Aitken and Jones 1973; Willner 1976a; Persson, Frogel and Aaronson 1976). Most authors have interpreted their 10μm spectra in terms of a warm emitting region behind a layer of cool dust that produces the silicate extinction. Kwan and Scoville (1976), on the other hand, show that a depression at 10μm may arise naturally as a result of radiative transport effects in an object with a radially decreasing temperature, and that the strength of the 10μm feature is not easily related to the visual extinction in front of the object. Their model correctly predicts a correlation between the colour temperature of a protostar and the depth of its 10μm feature, and can account for the weakness of the 20μm silicate absorption in the Orion BNKL sources (Forrest and Soifer 1976).

Comparison of celestial infrared spectra with those of laboratory materials favours identification of the 9.7μm feature with amorphous, hydrated types of silicates (Day 1974; Penman 1976), but the interpretation of this feature is made more complicated by the fact that the infrared absorption properties of silicates are found to vary significantly with temperature (Day 1976).

After the 9.7μm silicate feature the strongest absorption band usually seen at infrared wavelengths is the "ice" band at 3.1μm, which is believed to be a blend of H₂O and NH₃ features (Merrill, Russell and Soifer 1976). Gillett et al. (1975b) found large variations in the ratio of the strengths of the ice and silicate features in different directions, from which they inferred that ice grains are found only in molecular clouds, not in interstellar space. Kwan and Scoville (1976), however, show that the apparent variation in the ice/silicate ratio may be partly attributable to radiative transport effects.

Unidentified features. Two unidentified emission features, also seen in the planetary nebula NGC7027, have been found in the Orion Nebula and M17 by Grasdalen and Joyce (1976). Their wavelengths are 3.28μm and 3.4μm. The lines are also seen as a blend by Soifer, Russell
and Merrill (1976). A possible identification of one of the features with the CH⁺ molecule was suggested by Grasdalen and Joyce.

2.5 Polarimetry

Strong linear polarization has been detected from the Orion BN object at wavelengths between 1.6µm and 10µm (Breger and Hardorp 1973; Loer, Allen and Dyck 1973; Dyck et al. 1973). The polarisation is strongest at the wavelengths where the extinction is strongest, namely shortward of 2µm and in the 3.1µm and 9.7µm ice and silicate absorption bands. Circular polarization of 0.9 per cent at 3.4µm from the same object has been found by Serkowski and Rieke (1973). Dyck and Beichmann (1974) show that the observations can be satisfactorily explained by invoking the Davis-Greenstein mechanism in a cold uniform medium in front of the BN object. Linear polarization at 2.2µm has also been reported in CRL2591, another infrared protostar, by Oishi et al. (1976).

2.6 "Airborne" infrared mapping (30µm ≤ λ < 350µm)

The number of HII regions surveyed by comparatively small balloon-borne telescopes has been greatly increased by the surveys of Furniss, Jennings and Moorwood (1974) and Oltorf (1974). The reflection nebula NGC2023 was studied at 40–350µm by Emerson, Furniss and Jennings (1975). The most significant recent advance at these wavelengths, however, has been the introduction of much larger diameter telescopes, in particular the 1.02 m diameter Harvard-Smithsonian-Arizona balloon-borne telescope (Fazio et al. 1974) and the NASA 0.92 m telescope mounted in a C-141 aircraft. These telescopes have permitted greatly improved spatial resolution at these wavelengths; Harvey, Campbell and Hoffmann (1976), for example, have mapped several HII regions with a spatial resolution of 17 arcsec at 53µm using the C-141 instrument.

2.7 "Airborne" spectroscopy

Until now, only one spectral feature has been detected in the wavelength range 30µm ≤ λ < 350µm, namely the 88.16µm line of [OIII] in M17 (Ward et al. 1975). Several groups have made observations delineating the continuum spectra of strong far infrared sources; Erickson et al. (1976a, 1976b), for example, have used a Michelson interferometer aboard the C-141 aircraft to measure the spectra of the central 1.4 arcmin regions of SgrB2 and OMC1 in Orion between 30 and 250µm. The spectra are smooth, indicating dust temperatures of about 30K and 80K respectively for the two sources.

2.8 Submillimetre and millimetre observations (λ > 350µm)

The 350µm window suffers greatly from variable atmospheric
attenuation, but successful observations have been made at Mauna Kea (Rieke et al. 1973; Righini, Simon and Joyce 1976) and Mount Lemmon (Soifer and Hudson 1974). All the objects so far observed have their spectral energy peaks considerably shortward of 350μm, so that measurements in the submillimetre range can be used to estimate the gradient of the "Rayleigh-Jeans" part of the spectrum (see Figure 2). The measured spectral indices generally lie in the range 3–4, significantly steeper than the black-body slope of +2, indicating that the objects are optically thin and that the emissivity of the warm grains decreases with increasing wavelength, as expected for small particles.

Atmospheric problems are much less severe at a wavelength of 1 mm, but since the spatial resolution at this wavelength is usually set by diffraction, large dishes must be used. The Kitt Peak 11 m radio telescope has been used by Clegg, Rowan-Robinson and Ade (1976) for a brief look at many sources, while the Palomar 5 m telescope has been used for more extensive studies of a number of objects (e.g. Werner et al. 1975). The importance of 1 mm observations is that the emission, being optically thin, is uncomplicated by radiation transfer effects and is not very temperature dependent (only linearly, not exponentially). As discussed by Westbrook et al. (1976) continuum maps at 1 mm provide a much better guide to the distribution of matter in molecular clouds than do maps of the molecular line emission or shorter wavelength infrared emission. The clouds studied by Westbrook et al. (1976) have typical masses of 1000 M☉ and column densities corresponding to a visual extinction of about 100 magnitudes. Several have density profiles similar to those expected in a collapsing cloud, and each contains at least one compact HII region or protostar at its centre.

3. RECENT STUDIES OF SOME PARTICULAR REGIONS

3.1 The Orion Nebula and molecular cloud

The Orion region is the nearest and best studied HII region/molecular cloud complex. Both the HII region, centred close to the Trapezium stars, and the molecular cloud OMCl, about 1 arc minute away, are strong infrared sources (see, e.g. Wynn-Williams and Becklin 1974; Zuckerman and Palmer 1974). The Trapezium stars and the cluster of protostars near the centre of OMCl both contribute to the heating of the dust. Figure 3 shows a 1 arc minute map of the Orion Nebula made by Werner et al. (1976b) at 100μm, using the C-141 aircraft. The main peak coincides with the centre of the molecular cloud, but there is an extended subsidiary maximum near the ionization front to the lower left of Figure 3. The infrared emission from this ionization front has been studied in detail by Becklin et al. (1976), who show that this warm dust is associated with neutral gas just outside the HII region itself. They also show that there must be a factor of ten increase in the dust density between the HII region and the neutral matter into which the ionization front is moving. Emission from warm dust just outside of the HII region appears to comprise a significant fraction of
Figure 3. Map of the 100\,µm emission from the Orion Nebula (Werner et al. 1976b). The shaded circle shows the half-power beamwidths. The optical photograph, by T.R. Gull, is in the $\lambda 6300$ line of OI and emphasises ionization fronts. The Trapezium cluster is at 05$^h$ 32$^m$ 49$^s$, $-5^o$ 25.2$'$.
the total flux at 100\,\mu m; in contrast the 20\,\mu m emission is concentrated within the HII region.

The strongest region of emission seen in Figure 3 coincides with the molecular cloud OMCI and includes at its centre the compact BN and KL sources. Grasdalen (1976) has reported detection of the Brackett-\alpha hydrogen emission line in the BN object, and Gautier et al. (1976) have found molecular hydrogen emission at 2\,\mu m from this region (see Section 2.4). From the variation of infrared colour temperature Werner et al. (1976b) show that the Orion molecular cloud must be heated from within by an energy source of at least $1.2 \times 10^5 \, L_\odot$. The cluster of infrared protostars seen at the centre of the cloud is almost certainly responsible for this heating.

3.2. **Sharpless 106.** The HII region Sharpless 106 is another optically visible nebula, but in this case most of the radio flux comes from a group of visually obscured HII regions (Pipher et al. 1976). The most interesting feature of Sharpless 106, however, is a compact infrared source (Sibille et al. 1975), particularly prominent at 3.5\,\mu m, which is coincident with a faint patch of nebulosity seen at 0.8\,\mu m. Pipher et al. (1976) show that the object may be a Trapezium-like exciting cluster, in which case it would be one of the youngest star clusters known.

3.3. **K3-50 and ON-3.** New infrared observations of the K3-50 region have been made by Wynn-Williams et al. (1976). They show that the visible nebula K3-50 is significantly displaced from its infrared and radio counterpart and probably lies at the edge of a molecular cloud some 2,500 M_\odot. The OH source ON-3 lies within or behind a second molecular cloud, and suffers several hundred magnitudes of visual extinction. The K3-50 region is a good example of the clustering of compact HII regions; five such regions are seen associated with two molecular clouds.

3.4. **NGC7538.** Observations of NGC7538 from the C-141 aircraft (Thronson et al. 1975) together with unpublished ground-based and millimetre observations by the Caltech group have shown that the compact group of sources NGC7538-IRS1/2/3 discovered by Wynn-Williams et al. (1974) are, in fact, part of a larger region of star formation which extends southwards and eastwards from NGC7538. In particular there is a new protostar whose properties closely resemble those of NGC7538-IRSI, except in the absence of radio or maser emission. NGC7538 contains an extremely rich variety of young objects, including at least two O stars, two maser sources, three compact HII regions, one extended HII region and two protostars. Together they comprise at least seven distinct and different manifestations of new stars within a radius of a few arc minutes. Whether this activity extends over a larger area than this is the subject of a further study.

4. **CONCLUSIONS**

The infrared study of star formation is, in some sense, still in
its infancy. The objects that have been found and studied are more or less what had been predicted to exist, although this is partly because the predictions have been vague. The phenomena seen are: molecular clouds, as luminous and as massive as star clusters with density and temperature gradients suggestive of collapse: fragmentation, both in the grouping of molecular clouds and in the existence of groupings of protostars and compact HII regions at their centres: protostars, or, at least, cocoon stars, and young star clusters still embedded in dust clouds.

The main trends in the next few years are likely to be a great increase in the resolution, sensitivity and quantity of spectroscopic observations, better spatial resolution, especially at 1 mm wavelength, and the reduction of selection effects by the use of CO and infrared surveys rather than optical or radio signposts to look for infrared signs of star formation.

REFERENCES


DISCUSSION FOLLOWING REVIEW BY C.G. WYNN-WILLIAMS

GILRA: You showed 100 μ maps of the Orion Nebula in the neighbourhood of the Trapezium. I want to point out that the dust emission in the immediate vicinity of θ²A Orionis is probably due to the same dust seen around θ²A Orionis in scattering in the direct photographs at "continuum" wavelengths discussed by Wurm and Rosino about two decades ago. Now I want to ask a question. You suggested that the 100 μ emission around θ²A Orionis was due to UV photons from the Trapezium. Has θ²A Orionis been completely ruled out as the source of this radiation?

WERNER: The following points suggest that the infrared radiation from the ionization front in the Orion Nebula is not due to heating by θ²A Orionis: (1) θ²A is believed to lie well in front of the ionized region, and (2) the 10 μ spectrum of the emission from within a few arcseconds of θ²A differs from that from the other points along the ridge. This suggests that the heating due to θ²A is confined to its immediate vicinity (see also Becklin et al. Ap.J. 207, 770, 1976). Now I have a question for Dr. Spitzer. I believe Copernicus has looked at θ¹C Orionis and θ²A Orionis. In connection with the discovery of H₂ emission from the Orion Nebula, I want to ask whether the H₂ electronic rotational lines were seen in absorption in the far-UV spectra of these two 0 stars? What kind of excitation do the observations show?

SPITZER: The Trapezium stars are rather close together for the Copernicus telescope to guide on individually. We have made attempts to observe these stars, but I believe that the results are not yet in a form suitable to be reported.

I.P. WILLIAMS: Interstellar grains can be observed at many wavelengths other than the infrared. There is now general agreement that the optical extinction shows a bimodal size distribution, one corresponding to a silicate core of radius several hundred Ångstroms and the other to an "ice"-coated larger grain of a few thousand Ångstroms. However, these days, there is a feeling that the ice need not be water-ice or ammonia but could be a more complex general "mush" based on C, N and O. It may even be that some of the complex molecules found in space have their origin in this ice.

Hot molecular hydrogen in Orion

FIELD: The Gautier et al. (Ap.J. 207, L129, 1976) observations of vibrationally excited H₂ may be due to a shock-wave propagating from the Orion Nebula into the background molecular cloud. This is interesting in connection with the Elmegreen-Lada prediction that subgroups within associations are formed as the result of such shock-waves. Gautier et al. concluded from line ratios that the H₂ is vibrationally excited by
collisions. Field et al. (Ap.J. 151, 953, 1968) showed that HII region-driven shock-waves would excite \( \text{H}_2 \) rotational lines as well, and this theory was applied by Aannestad and Field (Ap.J. 186, L29, 1973) to explain the \( \text{H}_2 \) rotational excitation observed by Copernicus in \( \lambda \text{Orionis} \) and other early-type stars. I would like to ask Dr. Copernicus whether it is possible to choose unambiguously between shock excitation and fluorescent excitation of these lines?

SPITZER: Our studies of high-velocity clouds do not seem to be consistent with collisional excitation of the rotational levels at a high kinetic temperature produced by a shock. The radial velocities of \( \text{H}_2 \) lines absorbed from levels of different J are nearly constant with J, when the contributions from the different components observed in Na I and Ca II by Hobbs are separated out; in contrast one would expect a substantial change of radial velocity with J if high temperatures behind a shock were responsible for rotational excitation, with different levels excited at different locations as the kinetic temperature falls behind the shocks. However, the evidence is less clear for low-velocity clouds, especially for those showing a relatively low rotational excitation temperature for the levels of lowest J.

ZUCKERMAN: The authors of the recent paper reporting \( \text{H}_2 \) vibration-rotation lines from Orion stated that their observations were incompatible with the ultraviolet excitation model of Black and Dalgarno (Ap.J. 203, 1976). Dr. Dalgarno commented on this in Grenoble that at the high \( \text{H}_2 \) densities required by Gautier et al. to explain their observations the ultraviolet pumping model is not inconsistent with the observations. Indeed ultraviolet excitation might be required to explain the high population of the \( v = 1 \) levels. It remains to be seen if the hypothetical source of UV actually exists.

LADA: Joyce and Grasdalen have recently made a map of the IR emission due to the vibrationally excited \( \text{H}_2 \) lines. This map shows that the \( \text{H}_2 \) infrared emission is extended in a ridge which is roughly parallel to the ionization front observed by Gull and Martin. This ridge is also found to be displaced from the Kleinmann-Low and BN objects. In reference to Professor Field's question, both the orientation and position of the observed ridge of IR emission are consistent with, but not required by, the ionization driven shock proposed by Elmegreen and Lada for the formation mechanism of OB stars in associations. In addition, the separation of the ionization front and the \( \text{H}_2 \) ridge is also consistent with our model. It is interesting that the \( \text{H}_2 \) and OH masers and the Kleinmann-Low and BN infrared sources are located between the ionization front and the \( \text{H}_2 \) ridge, just as would be expected from the Elmegreen-Lada model. However, it is possible that the IR emission is not related to the shock of an ionization front but instead associated with some independent phenomena in the star-forming layer. Clearly more work on this interesting result would be highly desirable.
Far-infrared observations of Orion

WERNER: I will report briefly on recent far-infrared observations of the Orion region done from the C-141 airplane with 25" resolution at 30\(\mu\), 50\(\mu\) and 100\(\mu\).

The principal features of the spatial distribution of the far-infrared radiation are a sharp peak at the position of the infrared cluster to the northwest of the Trapezium, a smooth extension along the molecular ridge to the north and south of this peak, and an apparent ring of emission around the HII region, which includes the ionization front source described earlier by Wynn-Williams.

Because the objects in the infrared cluster in Orion are the closest and most accessible of the candidate protostars, it is very important to study them and their environment in as much detail as possible.

Two relevant points emerging from the present data are: (1) the peak in the far-infrared emission coincides within a few arc seconds with the position of the cluster, (2) the 50 to 100\(\mu\) colour temperature of the emission decreases smoothly along the molecular ridge from \(\approx 130\) K at the peak to \(\approx 60\) K 90" from the peak. The positional coincidence and the temperature gradients show that the infrared cluster is heating the dense central regions of the molecular cloud and therefore strongly support the assertion that the cluster is buried within the cloud, as would be expected if it had formed there in a recent collapse process.

The data show that the far-infrared luminosity from the central 30" around the infrared cluster is \(\approx 4 \times 10^4\) L\(_\odot\), and that the total far-infrared luminosity from the 4' x 4' region mapped is \(\approx 2 \times 10^5\) L\(_\odot\).

About one half of this luminosity comes from the molecular cloud region and is attributable to heating by the infrared cluster, which must therefore have a luminosity of \(10^5\) L\(_\odot\). The remaining far-infrared luminosity comes from the edge of the HII region and, to a lesser extent, from within the HII region, and is attributable to heating by the Trapezium cluster.

SCHATZMAN: How are your results related to the problem of star formation?

WERNER: They provide information about the nature and properties of the objects in the Orion infrared cluster, which are the closest and most accessible candidate protostars.

SOLOMON: The 100\(\mu\) map you presented has very smooth contours and does not appear to show any fragmentation on the scale of your resolution (about 20" corresponding to 2 \(\times 10^{17}\) cm). There are clearly several objects which have already formed and these are the 20\(\mu\) sources, but there does not appear to be any protostellar fragmentation. There is however, obviously fragmentation on a larger scale resolved even by the one arcminute radio beams. This is shown on any large scale map of giant molecular clouds, showing more than one hot spot in CO emission.
ERICKSON: What is the 100\(\mu\) optical depth at the center of your map of the Kleinmann-Low Nebula? This bears on the question of fragmentation, in that it may be possible that the radiation could be coming from the individual components of the infrared cluster rather than from the central 30 arcsecond region as a whole.

WERNER: The 100\(\mu\) optical depth is \(\approx 0.3\).

THADDEUS: A general comment on determining masses from the far-IR measurements: the far-IR emission properties of interstellar grains are of course poorly known, so the mass or density determinations are purely relative ones. An empirical calibration against masses determined by other means would be useful.

GILRA: The observations of the spatial distribution of H\(_2\) 2\(\mu\) emission were mentioned earlier. It was suggested that the maximum emission occurs northwest of the BN object. I do not think that such an inference can be made in a straightforward fashion. We just heard from Dr. Werner that the dust optical depth in emission at 100\(\mu\) at the center of the K-L nebula is a few tenths. That means that the optical depth in extinction at 2\(\mu\) (where the H\(_2\) lines are observed) will be substantial. The spatial distribution of extinction at 2\(\mu\) in the neighbourhood of the K-L nebula has to be disposed of for a proper understanding of the actual spatial distribution (as opposed to the observed distribution) of H\(_2\) emission in and around the K-L nebula.

STROM: Without wishing to begin a semantic discussion concerning the definition of "protostar", I would like to ask whether you feel that you can exclude the possibility that the luminous embedded objects (covered by the rubric "protostars") are actually pre-main sequence objects of high mass approaching the main sequence along equilibrium radiative tracks? Should we not wait for spectroscopic or other more indirect evidence of infall before accepting these fascinating objects as "protostellar"?

WYNN-WILLIAMS: Theoretical models of the evolution of massive proto-stars by Larson, Appenzeller and Kahn indicate that the Kelvin-Helmholtz timescales are shorter than the accretion timescales. The core of one of these objects therefore approximates to a ZAMS star of continually increasing mass. In other words, massive stars do not have a recognisable equilibrium radiative track as far as we know.

Ionization fronts in Orion

ZUCKERMAN: Dr. Wynn-Williams has emphasized the ionization front in the Orion Nebula that lies between \(\theta^1\) and \(\theta^2\). I would like to call attention to another probable ionization front in Orion that has recently been investigated by Kutner, Evans and Tucker (Ap.J.209, 952, 1976).
Since Orion is now moving into the night sky, I hope that those astronomers to whom such considerations matter will investigate this ionization front this winter. The front in question lies just to the south of NGC 1977 where Kutner et al. show that the extended Orion CO cloud ends abruptly. It is probable that NGC 1977 is ionization-bounded by the molecular cloud; therefore a variety of observations are suggested. Optical astronomers might measure the ionization state and radial velocity of various elements as a function of distance from the presumed ionization front. Infrared astronomers might detect a "bar" of radiation parallel to the front as they have done in the Orion Nebula. Radio astronomers could attempt to detect C\(^+\) and H\(^+\) recombination radiation from in front of and behind the front respectively and, in addition, make a continuum aperture synthesis map of the HII region. Because of its relative proximity to the Earth, this HII region is worthy of special study.

FIELD: While Dr. Zuckerman is on the stage, would he be willing to describe the morphology of the Orion Nebula and NGC 1977 with respect to the CO cloud? In particular, how would he describe the arrangement of material in depth?

ZUCKERMAN: It was pointed out by Kleinmann and Low and by Kutner and Thaddeus that the K-L nebula and the molecular cloud, respectively, must be located behind the main emitting mass of the Orion HII region (or else they would absorb its light). I have suggested that the HII region is ionization-bounded on its rear side by the molecular cloud (Ap.J. 183, 863, 1973; Ann. Rev. Astr. Ap. 12, 279, 1974) and that the K-L nebula is located in the front portion of the molecular cloud right behind this ionization front (HII Regions and Related Topics, Wilson and Downes ed., Springer-Verlag, 1975, p.360). The infrared cluster OMC-2 is apparently also near the front edge of the molecular cloud or else the CalTech astronomers could not have detected it. It therefore probably lies at about the same distance from the Earth as either the K-L nebula or the Trapezium but \(\lesssim 1\) pc to the north. (The K-L nebula and the Trapezium are probably separated by no more than \(\lesssim 0.5\) pc along the line of sight). Finally according to the recent observations of Kutner, Evans, and Tucker the molecular cloud appears to end abruptly at NGC 1977. This suggests that NGC 1977 is ionization-bounded to the south by the molecular cloud, similar to the Orion Nebula case, but rotated by \(\sim 90^\circ\) with respect to our line of sight. Again, since we see NGC 1977 it must be towards the front and/or to the north of the molecular cloud.

PEIMBERT: We have made optical observations at many points of the Orion Nebula located to the east and west of the optical ionization front between \(\theta^1\) and \(\theta^2\) Ori. We find that the ionization and energy input in the western regions are dominated by \(\theta^1\) Ori C while the eastern regions are dominated by \(\theta^2\) Ori. About 80% of the ionizing flux corresponds to \(\theta^1\) Ori C and about 20% to \(\theta^2\) Ori. The heating of the dust in the
eastern part of the ionization front and in particular the 10 µ emission might very well be due to θ² Ori. A determination of the dust temperature might help to decide which is the energy source.

STEIN: I am still confused by the location of the I-front interaction between the Orion HII region and the molecular cloud. From Zuckerman's description it seems the I-front lies behind the visible HII region perpendicular to the line of sight. Is that correct?

ZUCKERMAN: Yes, that is correct for one of the two fronts we have been speaking about. The other front is optically visible and lies between θ¹ and θ².

McCrea: Would you please draw a section in a plane at right angles to the plane of the sky as inferred from the observations?

Zuckerman:
ISOBE: I would like to report on evidence for globules in the Orion Nebula from optical observations. The continuum light scattered by dust grains is strong evidence for dust inside the nebula. From a statistical treatment of intensity fluctuations of several lines, Tamura (Contribution from Tohoku University 1977) obtained that the number and the size of globules in the central region (<3') are ~400 and 0.001 pc, respectively. These results are consistent with the globules proposed by Dyson (Ap. Space Sci. 1, 388, 1968) in order to explain the line splitting of [O III] lines. Therefore, we conclude that there are many globules even in the region within 0.3 pc from the Trapezium.

KUIPER: Several years ago, Dr. Neal Evans and I, in collaboration with Dr. Zuckerman, started a project to map the C75α line at 15 GHz with the NASA 64 m antenna at Goldstone, California, which has a resolution of 1'3 at that frequency. The data are very incomplete but indicate a few interesting things pertinent to the present discussion. The carbon line vanishes abruptly across the ionization front to the northwest, and was not seen at all at the Kleinmann-Low position where we had expected it to be strong. Towards the southeast, at the position of that ionization front, the line becomes quite narrow, about half of its width at the Trapezium position, and at one point just across the front, it was not seen. The line was also quite strong to the north, at a position in the dark lane. Unfortunately, because of the heavy spacecraft-tracking commitments of the Goldstone facility, we were unable to complete this project.

The ρ Ophiuchi cloud

ELSÄSSER: Presently at our new observatory in Southern Spain, observations of dark clouds are carried out with a cooled S1 image-tube camera and other IR equipment for longer wavelengths. I would like to present a few preliminary results of the ρ Oph dark cloud which were obtained by Mr. Chini, Dr. Weinberger and myself. These results are based on photographs in R (0.7μ) and I (0.9 - 1.0μ).

Strom, Grasdalen and Vrba (SGV) in two papers (Ap.J. 184, L53, 1973; Ap.J. 197, 77, 1975) published 67 sources which were mainly discovered by 2μ observations. On our I photographs of the same field we could identify 27 of those sources, that means about 40%. 15 of those are also recorded on our R plates. The identified sources are not the brighter ones of the SGV-sample. Their H magnitudes are between 7 and 11.8, whereas the unidentified ones have H between 7.8 and 12.3 (according to Table 1 of Vrba et al., Ap.J. 197, 77, 1975).

For several of the sources we have in common with SGV, we determined spectral types and extinction taking into account our R and I brightnesses in addition to the IR magnitudes of SGV. This determination is not a unique one since different combinations of spectral type and extinction can reproduce the observed energy distribution. If we assume main
sequence stars we find spectral types between B and F, but G and K giants with less extinction also reproduce the observations. The latter most probably would be background objects. The $A_V$ values we find are $\lesssim 15$ with very few exceptions and tend to be lower than those of SGV.

On the other hand we find on the R and I photographs numerous, very red stars which were not recorded by SGV, within their field and in neighbouring areas. We cannot exclude at this moment that these are mainly stars in the background of the cloud.

We do not find any object at the position of Oph 6, the most intense compact HII region within the cloud according to Brown and Zuckerman (Ap.J. 202, L 125, 1975). It lies in a surprisingly empty area where the visual extinction could well be above 20 magnitudes.

WERNER: What were your sensitivity limits at R and I?

ELSÄSSER: The limiting magnitudes are 16th magnitude in the I filter and 18th magnitude in the R filter.

BAART: We have mapped the $\rho$ Ophiuchi region at 2.3 GHz and we find an extensive HII region which is ionisation-bounded, to the south of the dark cloud. Do infrared objects show any clustering towards the south side of the dark cloud where the ionisation front is?

ELSÄSSER: Not according to the now available observational material which does not yet cover the whole cloud.

ENCRENAY: We have made a synthesis map of the $\rho$ Ophiuchi dark cloud with the Westerbork array. We have detected more than 10 sources, only 3 of them coincide with the sources published by Brown and Zuckerman. Within our noise limit, there is no source at the position of the B3 star HD 147 889.

GILRA: I want to make a comment about an infrared source in the $\rho$ Oph dark cloud discussed briefly by Dr. Thaddeus yesterday. The source was found by Fazio et al. (Ap.J. 206, L 165, 1976) and is somewhat to the east of the B2 V star HD 147889. I want to point out that there is a CRL source at about this position at 10$\mu$ and 20$\mu$. In the CRL Catalogue this source has been identified with a variable star which is the star SR 22 in the Struve and Rudkjøbing paper on T Tauri and related stars in the $\rho$ Oph dark cloud (Ap.J. 109, 92, 1949). Struve and Rudkjøbing classified it as A?. However, L. Kuhi and M. Cohen (private communication) have classified it as M3e. I do not think that SR 22 is the identification for this CRL object. I think that the CRL source and the Fazio et al. source are the same. The question whether HD 147889 is responsible for the infrared radiation can be resolved by mapping this source at 10$\mu$ and 20$\mu$. This mapping has not been done presumably because the object is listed as identified in the CRL Catalogue!
ENCRENAZ: We have carried out observations of the Carbon recombination lines C 164α and C 210β of the ρ Ophiuchi cloud with the Nançay radio-telescope (Astr. Astroph. 48, 167, 1976; Astr. Astroph. 52, 299, 1976). A broadening of the lines is explained by collisions of Carbon atoms with ions rather than with electrons which are much more efficient at the prevailing conditions in dark clouds (n(e) ≈ 1.5 cm⁻³, T ≈ 10-20 K).

SCHATZMAN: Would you think that the CII lines are formed in a different region than the molecular lines?

ENCRENAZ: The peak of the carbon-emitting region does not coincide with the peak of the molecular emission (¹³CO, H₂CO, CS, C₂H). There is 5 or 6 arc minutes difference in right ascension clearly resolved with the Nançay telescope (Carbon line) and with the Millimeter Wave Observatory (molecules). However, the situation is not as clear for the molecular ions (HCO⁺, N₂H⁺,...).

VANDEN BOUT: In response both to Dr. Strom's plea for infrared mapping of "less prominent" regions and Dr. Solomon's question as to whether the 2μ sources detected in dark clouds are actually associated with the clouds, let me say that we have searched numerous CO clouds for 2μ sources and almost always find one or more at the position of peak CO emission intensity. Additional infrared sources are also found, but the high rate of coincidence with CO "hotspots" certainly means that some are embedded in the clouds. We believe this technique of CO mapping followed by 2μ mapping and longer wavelength infrared photometry is a very efficient method for locating BN-like objects. The infrared source we found in the S140 cloud is a prime example.

ELSÄSSER: If you find an IR source coincident with an HII region, the energy distribution of which can be represented by a highly obscured early-type star, one can be rather sure that the object belongs to the cloud. If there is no coincidence of this type, one cannot exclude that it is a background object. Another kind of evidence would be an increase of the number of highly obscured objects with increasing extinction in the cloud. This we do not observe in the Oph cloud.

BOK: Is there any hope that fairly soon infrared observers will be able to detect objects like Barnard's with temperatures of the order of 10 K?

WERNER: Dust clouds of this temperature can be detected at 1 mm if their 1 mm opacity is ≥0.01; this 1 mm opacity corresponds roughly to ≥100 magnitudes of visual extinction.

Miscellaneous contributions

THOMPSON: I would like to present some results based on 1-2.5μ spectra of MWC 297 and MWC 349 at a resolution of Δλ/λ = 3x10⁻⁶. These sources
are newly formed stars still embedded in their natal material. Emission lines of the Brackett and Paschen series of Hydrogen and 0 I \( \lambda 11287 \) are seen in both objects. MWC 349 displays He I recombination lines, one of which \( \lambda 20581 \) is very density-sensitive. A high excitation line of the 0 I quintet series is seen at 5925 cm\(^{-1} \) in MWC 349. The continuum flux is due to dust emission.

HABING: In his review paper, Dr. Wynn-Williams mentioned a characteristic group of infrared point sources that he described as "similar to the BN object in Orion". He mentioned two possible interpretations for these objects given in the literature: that they could be late-type supergiants, reddened by large amounts of foreground extinction or that they could be protostars. Although the latter interpretation has attracted the largest interest, it lacks theoretical support. As far as I am aware, the only attempt to give a self-consistent model for the BN object has been made by Larson (1969, M.N.R.A.S. 145, 297). Although this model fitted reasonably well the observations available at that time, it no longer fits the new observations, notably those at 10 and 20 \( \mu m \). I would like to report on calculations of an improved model, that does fit all observations. The calculations have been made by P.J. Bedijn at Leiden Observatory.

The model is as follows. A star of mass \( M \) and luminosity \( L \) is at the centre of a spherical cloud (cocoon) that collapses in free-fall onto the star. Since the mass inflow rate \( \dot{M} \) is assumed to be constant throughout the cloud, the density distribution is proportional to \( r^{-3/2} \). Through absorption of the stellar flux, the dust in the infalling gas is heated and re-radiates its energy in the infrared. The radiative flux is conserved, but its spectrum becomes cooler, the farther out one goes. Bedijn calculates in a self-consistent way the emerging spectrum and the temperature distributions of dust particles in the cocoon. It turns out that beyond about \( 10^{16} \) cm the infalling matter is so cool that it no longer emits radiation in the wavelength range of interest (1\( \mu m \) to 30\( \mu m \)). However, it does absorb heavily in this wavelength range. Hence, the density structure outside \( 10^{16} \) cm is irrelevant and the only thing that counts is the total optical depth outside \( 10^{16} \) cm, which one can express in terms of \( A_V \). For this absorption Bedijn uses Van de Hulst's curve No.15 (called by some people the "dutch opacity"), to which a silicate absorption band is added, of the form given by Gillet and Forrest (1973, Ap.J. 179, 483) and with \( A_V/\tau_{10\mu m} = 24 \).

The model calculations show that the most critical assumptions concern the dust opacity. To explain the observations the following two assumptions proved to be necessary:

1. Taking dust particles with realistic absorption characteristics, at least two kinds of particles are required: silicate and graphite. Without the first, there is never enough radiation at 20\( \mu m \) compared to that at 10\( \mu m \); without the second, the peak is never at wavelengths as short as is observed, nor is there sufficient optical depth at \( \lambda <5\mu m \).

2. The silicate grains must have a considerable opacity at \( \lambda \approx 5\mu m \), in spite of what is found for terrestrial silicates. Although this
assumption may appear rather ad hoc, it is supported by the fact that an analysis of the infrared spectra of late type oxygen-rich giants requires the same kind of silicate absorption properties. This latter conclusion has also been independently reached by Jones and Merrill, 1976, Ap.J.209, 509.

Model parameters for a best fit to the spectrum of the BN object are: L=11000 L_\odot, M=11 M_\odot (corresponding to a BOV star) and \dot{M}=3.7\times10^{-6}M_\odot yr^{-1}. Silicate particles constitute 0.6 percent of the gas mass density, graphite particles 0.2 percent. The spectrum of the collapsing cloud is modified by A_V=50^M foreground extinction. The agreement between model and observations is quite good. The 3.1 \mu m absorption band of ice could have been included in the model calculations, without changing any fundamental results. There is a slight systematic deviation between the predicted and the observed shape of the 9.7 \mu m silicate band that occurs also in the control calculations of late-type giants. This is probably due to the simplifications that Gillett and Forrest made in deriving the intrinsic shape of the silicate band.

The model fit is not unique; other combinations of L, M and A_V can reproduce the observed spectrum. However, the conclusion that at least two dust particles are required to explain the observations, appears quite firm. Finally, models like this are probably good starting points for further calculations, e.g. for the study of maser theories.

FIELD: Your model is very nice, and I can understand why you see silicate in absorption; it is simply that the outer layers are cooler. I don't understand, however, Dr. Wynn-Williams' statement that Scoville's model explains the apparent absorption simply as a "radiative transfer effect".

WYNN-WILLIAMS: The paper by Kwan and Scoville showed that the material responsible for the 10\mu feature can be associated with the emitting object and need not necessarily be truly interstellar. Of course it is cooler than the dust toward the centre of the source or else no line would be formed.

FIELD: You mentioned calculating the evaporative surface for silicates and graphite. Presumably you could do the same for ice. If you were to do that, do you think that there would be enough ice outside the evaporative surface to explain the observed ice band?

HABING: Yes. Assuming that ice evaporates around T \approx 100 K, we find that the whole cloud outside 10^{16} cm will be cool enough to contain ice. Assuming \dot{A_V}/\dot{\tau}_{\text{ice}} \approx 30 (Gillett et al., Ap.J. 207, 763 (1976) find this for NGC 2024 \# 2) one obtains \dot{\tau}_{\text{ice}} \approx 1.7, comparable to the observed value 1.46.

LENA: The Meudon Observatory and the Space Science Group in Groningen have jointly observed from aircraft the source L1204 near the S140 region. Scans made across the ionization front show strong emission in two
spectral bands (70-95\(\mu\) and 115-195\(\mu\)), of a source smaller than 5 arc min located on the dark cloud side. Fluxes are respectively 6.4 and 3.2 \(x\) \(10^{-14}\) W cm\(^{-2}\) in these bands. Assuming a \(\lambda^{-2}\) emissivity of the dust, one gets \(T_{dust} = 35 \pm 2.5K\) comparable to \(T(12^{12}CO) = 27K\). These values are close to Goldreich and Kwan's values of 35K and 26K respectively, for a rather high density of \(2 \times 10^6\) cm\(^{-3}\). We derive the opacity in three different ways: using the ratio \(^{12}CO/^{13}CO = 89\) and the observed lines, one gets \(\Delta V = 22\); using a standard dust model (Ryter and Puget, Ap.J. in press) and the derived total IR luminosity, one gets \(N_H = 4.2 \times 10^{22}\) cm\(^{-2}\) and \(\Delta V = 18\); finally, using the near-IR observations of a bright source located at the same position, we get a value of \(M_V = -6.5\) which fits the total IR luminosity and needs \(\Delta V = 30\) to explain the near-IR observations. This region seems to be a typical dense molecular cloud, probably at a distance of 900 pc, where the geometry is rather simple and deserves further study.

I would also like to report on some other work by D. Rouan, J.L. Puget, K.de Boer and myself. We have observed the diffuse emission from the galactic plane in a wavelength band 70-95\(\mu\) from the Caravelle aircraft. We scanned at \(l = 28^\circ\) over a latitude interval \(-1^\circ < l < 0^\circ\), in an area selected to avoid known HII regions or dark clouds. The scans consistently show diffuse emission with an intensity of \(1.4 \times 10^{-4}\) W m\(^{-2}\) ster\(^{-1}\) in the band. A wide component is detected within \(|b| < 0.5^\circ\), and a narrow component within \(|b| < 0.1^\circ\). The correspondence between the infrared brightness distribution of the narrow component and the \(^{12}CO\) brightness distribution perpendicular to the plane at the same longitude is striking. A not previously observed source has also been detected at a distance of about 40' below the plane. Although we cannot rule out a chance coincidence of this diffuse emission with a nearby source in the 6.3' beam, we believe to have detected the integrated dust emission from the plane. Computing the total hydrogen column density to be \(N_H(l(l) = 30^\circ) = 1.5 \times 10^{23}\) cm\(^{-2}\), one gets \(\tau(100\mu) = 0.2\) with a reasonable dust model (1% ratio to gas in mass, amorphous silicates, \(\lambda^{-2}\) wavelength emissivity dependence). The dust should be a good tracer of the total amount of material along the line-of-sight. Since only one wavelength band could be observed in this run, it is impossible to derive a unique value for the mean dust temperature. According to a recent model by Ryter and Puget (Ap.J. in press) the dust temperature and the total IR luminosity are related as follows: \(L_{IR} = 3.2 \times 10^{-38} T_5.8\) watt(H atom\(^{-1}\)). An average temperature of 22K for the dust along the line-of-sight fits the measured IR luminosity in the band. It is true that a smaller amount of dust at a higher temperature would also agree with the measured value, but then the total IR luminosity would be much higher, in contradiction with earlier measurements made by J. Pipher (IAU 53, p.559, 1973).

Although multi-band measurements are required to confirm this result, we point out several implications: (a) the fact that \(T_{dust} > T_{CO}\), the latter having been quoted to be 10K, indicates that the dust is located on the average in clouds where the density does not allow complete thermalization of gas and dust; (b) the total IR luminosity is a measure of the total stellar radiation field which is ultimately transferred to long
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Model parameters for a best fit to the spectrum of the BN object are:
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RYTER: It is true that the IR and optical luminosities are very similar, but the spatial distribution is quite different. Most of the IR radiation comes from the 5 kpc ring of clouds, whereas a large fraction of visible light comes from the galactic bulge. The radiation field exciting the IR emission has a density \( \geq 10 \) times the average starlight density.