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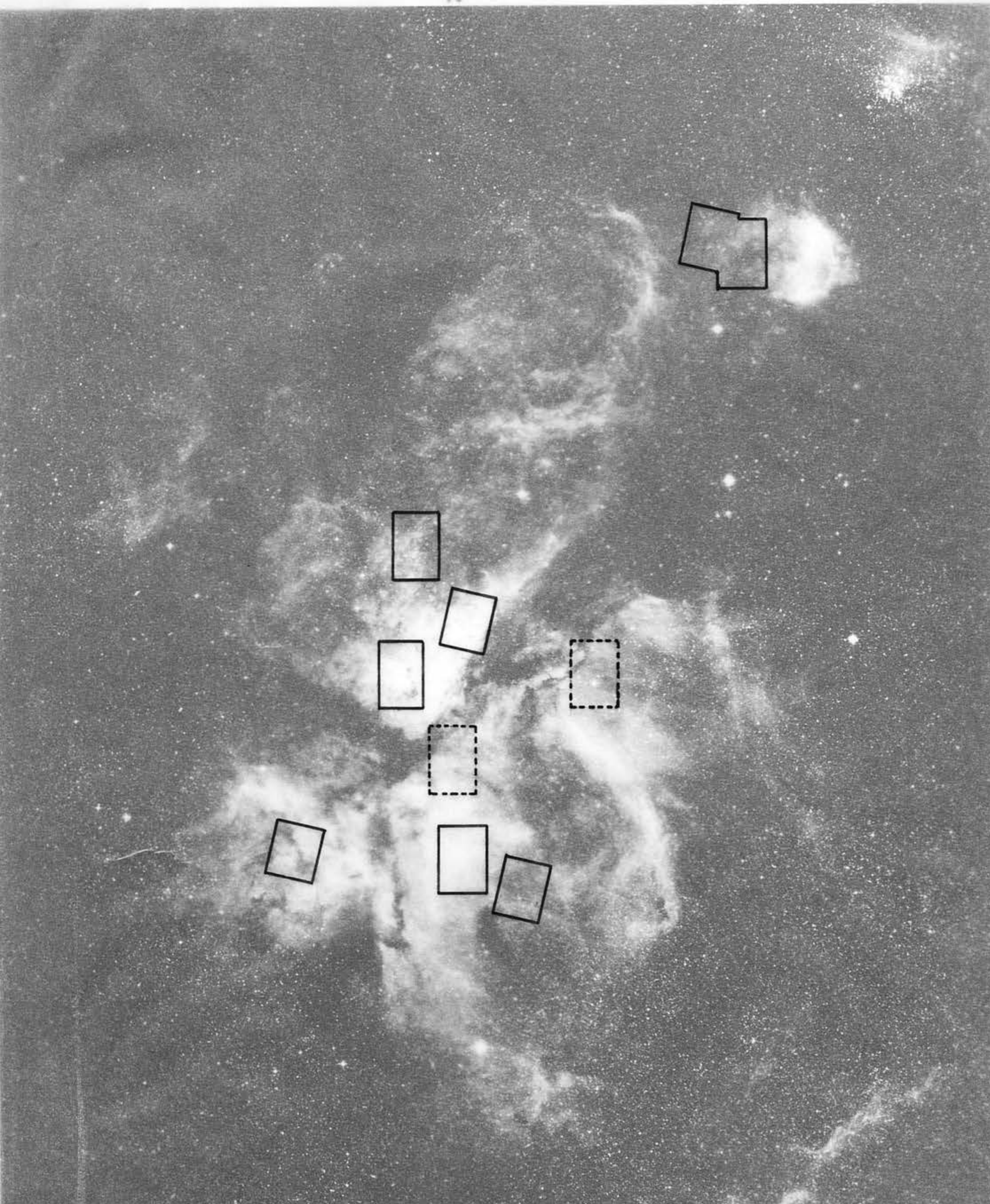

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INFRARED STUDIES OF SELECTED REGIONS OF

THE MILKY WAY

Mauricio Manuel Tapia-Ibarguengoitia

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University of Edinburgh

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This thesis has been composed by me and consists entirely of my own work, except where specifically indicated in the text.

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ABSTRACT

The results of a large scale near-infrared survey of small sky areas of the Milky Way containing trapezium-type star multiple systems immersed in bright and dark nebulosities or southern Herbig-Haro objects are presented. Photometric maps at wavelength 2.2 microns complemented with broad-band JHKL photometry of the majority of the sources detected and of the star members of the clusters were obtained. A number of randomly chosen comparison regions along the galactic plane were also mapped and the results were also used, with recent semi-empirical models, to determine the number of field stars expected for the program surveys. In a number of regions, mainly located in the centres of young open clusters, excesses of infrared-bright stars were found and, in many cases, these were interpreted as probable embedded stars. The infrared two-colour diagrams were studied in detail in order to: (1) obtain the values of the colour excess-ratios E(J-H)/E(H-K), E(H-K)/E(K-L) and E(J-K)/E(K-L) which represent the general reddening law at these wavelengths; and (2) differentiate between the numerous reddened "normal" late-type stars from those stars with intrinsic infrared excess. Low resolution two-micron spectra were also obtained for a limited number of sources. A short description and analysis of the results are given for each of the regions observed as well as for the most interesting individual objects detected. Most infrared sources found in the surroundings of Herbig-Haro objects appear not to be associated with these emission/reflection nebulae.

INTRODUCTION

The development of infrared techniques and the establishment of photometers and spectrometers sensitive in the wavelength range 1 - 20 microns for general use in most major observatories in the world during the last decade has given great impetus to the observational study of stellar evolution at these wavelengths, from the very begining of the life of stellar objects (the "protostellar stage") to their ultimate death, in particular before and after their stay in the main sequence. The reason for this is simple, it is during these relatively short stages in the life of the stars when they strongly interact with the surrounding matter. Galactic infrared observations have proved to be most useful with regard to the interstellar (including circumstellar) medium, mainly for the study of ionised gas Brehmsstrahlung and warm dust thermal emission which occur primarly in the infrared region of the electromagnetic spectrum. It also takes advantage of the larger optical depths obtained at longer wavelengths. These properties make infrared observations especially useful in the detection of highly obscured pre-main sequence objects embedded in dense molecular clouds as well as stars surrounded by thick circumstellar dust shells.

The present work consists of an observational infrared study (in the wavelength range 1 to 5 microns) of small areas in the Milky Way within dark and bright nebulosities which contain early-type trapezium-type star multiple systems or Herbig-Haro objects. Chapter I gives a short review of the subjects which were found to be relevant to the understanding of the results; Chapter II describes the observations; Chapter III presents and describes the observational results and includes a general discusion of the results of the program. Chapter IV presents individual discusions for most of the regions under study and Chapter V gives a summary of the results and a final discusion. Appendix I presents the results of a small number of visual broad-band photometric observations and Appendix II contains a reprint of a published paper which forms part of the present work.

Along the present dissertation, the wavelength range .8 to 600 microns have been divided, for practical reasons, into four intervals, each involving a different observational technique. These (arbitrary) definitions are:

"Photographic infrared" or "far-red": λ = .80 to .99 microns,
"Near-infrared": λ = 1.0 to 5.5 microns,
"Mid-infrared": λ = 5.6 to 21 microns and
"Far-infrared": λ = 22 to 600 microns.

CHAPTER I

REVIEW OF RELEVANT ASPECTS

1) Pioneering work in infrared astronomy

The first reports on the existence and properties of infrared radiation were made by William Herschel (1800) describing 230 experiments carried out using simple thermometers as detectors and the Sun and a chimney as sources of radiation. He concluded that infrared (IR) radiation, which he called "heat rays" obeyed, like (visual) light, the laws of reflection, refraction, dispersion and scattering and suggested that both types of radiation were indeed related. Herschel's investigations began when, whilst observing the Sun with a series of colour filters, he found that by using some of them he could "feel the sensation of heat" though he saw little light, while other filters gave him much light with scarcely any sensation of heat.

Infrared detectors developed very slowly and it was not until the second half of the 19th Century that the first conclusive measurements of IR radiation from a celestial object other than the Sun were made. The Astronomer Royal for Scotland Piazzi Smyth (1858) in an expedition to the Peak of Tenerife used thermocouples as detectors and just succeeded in recording infrared radiation from the Moon. Among the first stellar measurements with these devices were those by Pettit and Nicholson (1928) whose radiometric measurements of 124 bright stars provided for a long time the only basis for the knowledge of the properties of the IR energy distribution of stars as seen from the Earth. With this and a few other exceptions, work on IR astronomy was devoted to the Solar System and only a few new interesting results came out in the literature. One example was the deduction by Wesselink (1948) of the value of the thermal conductivity of the material covering the Moon's surface, making use of the IR observations by Pettit (1940). This value suggested for the first time that that the lunar surface was covered with fine dust powder.

Probably the next big step in observational IR astronomy was the development of highly sensitive PbS photoconductive detectors, working at $\lambda < 4$ microns (Cashman, 1946 and Oxley, 1946) and their subsequent applications to astronomy: Kuiper (1947) for planetary spectroscopy and Whitford (1948) and Fellgett (1951b) for stellar photometry. Johnson (1962a, 1964) defined his IR photometric system JKLMNQ using a faster, but at the time, less sensitive photovoltaic InSb detector for wavelengths up to 5 microns and a gallium-doped germanium bolometer (Low, 1961; Low and Johnson, 1964) for longer wavelengths.

2) Infrared photometric Systems

The choice of central wavelengths of the near and mid-IR photometric wide-bands for ground-based observations is determined by the emission/transmission properties of the terrestrial atmosphere. These bands must coincide with the so-called atmospheric windows which are spectral regions where the absorption and emission of the atmosphere is less efficient, i.e. where there is a gap in the density of the relevant transitions of the most important molecules, mainly H_2O, CO_2, O_3, CO, N_2O and CH_4. Detailed analysis of the atmospheric transmission and emissivity at various altitudes have been carried out by Traub and Stier (1976) based on a single-layer model atmosphere and including 109,000 known transitions in the range 2 - 5,000 microns.

Multilayer interference filters are used at wavelengths < 30 microns to define accurately the photometric passbands (Low and Rieke, 1974). The Arizona-Tonantzintla group headed by H.L. Johnson completed the definition of the UBVRIJKLM system with a list of observations of standard stars in the sky accessible to Northern Hemisphere observatories (Johnson et al, 1966). For the Southern Hemisphere, two sets of standard stars are available in the literature: Glass' (1974), which was tied-up to Johnson's via observations of common equatorial stars and the one by Thomas et al (1973) which also revised the absolute calibration using a single-star model atmosphere, though these observations were made with a bolometer and therefore, the short wavelength data are far from reliable to be used as standards. The last two sets include observations in the H band which was omitted in the original Johnson's system. The absolute flux calibration problem has been tackled by a number of researchers and the results seem to be converging quite rapidly (Hayes, 1979 and references therein). Over the years, some additions and modifications to the system have been adopted by various groups, notably the addition of the important H band and the use of the L′ (3.8 microns) band at slightly longer wavelength than L, where the atmosphere is cleaner from molecular absorption and to avoid the inclusion of the 3.1 micron "ice" and 3.4 micron (CH) bands seen in the spectra of various IR sources as well as the 3.07 micron band in carbon stars. The 10 micron band N has been split into narrower bands, i.e. centred at 8.6, 9.6, 11.6, 12.6 microns for measuring the strengths of broad spectral features without obtaining the full spectrum. For the detection of the absorption CO and H_2O bands in late-type stars, it has proved convenient to use intermediate-band photometric systems. For example, sets of narrow-band filters centred at 2.09, 2.19 and 2.30 microns (Baldwin et al, 1973) or at 2.17 and 2.41 microns (Pilachowsky, 1978), all within the two-micron window. Clearly, observations from outside the Earth's atmosphere are free of wavelength restrictions but, since these projects are only starting, no established photometric system has emerged.

3) Infrared spectrometry

Immediately after the de-classification of the PbS detector, Kuiper et al (1947) built a spectrometer using a couple of quartz prisms for observations in the range 0.75 to 3.0 microns. The instrument system was based on the scanning of the spectrum across the detector by means of a synchronous motor. Kuiper (1947) obtained with this instrument planetary spectra with a resolving power $R = \lambda/\Delta\lambda \simeq 100$. Similar resolutions were obtained using wedge filters, also called continously (or circular) variable filters (CVF). These are interference filters in which the thickness of the deposited layers varies continously across the filter; for practical reasons, this is of annular shape. Gillett et al (1968) employed such a filter (at room temperature) to measure spectra of various bright late-type stars in the regions, 2 - 5 and 7.5 - 10 microns but the sensitivity much improved by cooling the CVF to liquid Nitrogen temperatures (Gillett and Forrest, 1973). The resolving power of these filters is limited to $R \lesssim 200$. Since then, this type of "low-resolution spectrometry" has been widely used at $\lambda < 14$ microns, though, from the instrumental point of view, it would be better classified as "very narrow-band photometry".

Cryogenically cooled grating spectrometers have being built with higher resolving powers. Aitken and Jones (1972) developed one such spectrometer with R = 140 which worked by tilting the reflection grating to scan the spectrum across the detector. To gain speed, arrays of detectors have been used and resolutions up to R = 500 - 1000 have been obtained with these systems (see Soifer and Pipher, 1978 and references therein).

The doors to real high-resolution spectroscopy were opened by the development of Fourier Transform spectroscopy (FTS). Michelson (1891, 1892) used this interferometer to study the properties of light and formulated the principles of FTS but astronomical spectroscopy with such instruments did not begin until 70 years later. Fellgett (1951a) showed that signal to noise levels were greatly improved by the use of the Michelson interferometer instead of scanning spectrometers. Nevertheless, fifteen years passed before reliable astronomical spectra were obtained by the FT method and in the mean time there was a controversy on the feasibility of the astronomical use of the system. Bowers (1964) gave a relatively simple mathematical proof that atmospheric turbulence introduces an error in the result of interferometric spectroscopy, making it impossible for ground-based observations. Mertz (1965) and Connes and Connes (1966) were able to demonstrate, by obtaining stellar and planetary spectra, that the FTS does work for astronomical purposes; the scintillation problems were overcome by rapidly scanning or phase modulating the spectrometer moving mirror, so that the fringe frequencies exceeded scintillation frequencies (Mertz, 1967). Spectral resolutions as high as $R = 3 \times 10^5$ have been obtained for bright planets and stars (Connes and Michel, 1974, 1975). A review of the astronomical information obtained from stellar IR spectroscopy to date has been recently written by Merrill and Ridgway (1979).

4) Infrared Surveys

By the 1960's, the knowledge of the IR properties of stars was based on Whitford's, Fellgett's and partly Johnson's observations of bright stars. With a few exceptions, these measurements showed that stellar energy distributions at $\lambda > 1$ micron behave as expected from black bodies corresponding to the temperatures determined from the spectral types, hence the astronomical community could not foresee the major importance of making systematic observations of stellar objects at IR wavelengths. In the absence of two-dimensional infrared astronomical detectors (including photographic plates) large-scale surveys have been necessary to acquire the picture of the infrared sky. For practical reasons, these have limited spatial resolution. The results of the pioneering Two-micron Sky Survey (Neugebauer and Leighton, 1969) showed that for a great variety of celestial bodies, studies in the IR were crucial for their understanding, since they emit a large fraction of their energy at wavelengths between 1 and 1000 microns. Unlike most of the ambitious astronomical projects in recent times, the California Institute of Technology (CIT) two-micron survey was carried out with very limited amount of resources and support (see Neugebauer and Leighton, 1968) but at the end, it opened for good a new branch in observational astronomy. The catalogue is complete to K= 3 for declinations $\delta > -33$ (5612 entries). Beforé the publication of the catalogue, some of the most conspicous sources were reported in separate papers (Neugebauer et al, 1965 and Ulrich et al, 1966).

In a limited-effort attempt to extend this survey to the Southern Sky, Price (1968) covered approximatly 50% of the sky between declinations δ = -30 to -52 , detecting 414 sources with a similar sensitivity limit as the CIT survey. His observations were based on Mt. John, New Zealand.

The surveys mentioned above revealed a great number of unexpected singular objects. Aware of this, the AFCRL/AFGL undertook a sky survey in the bands centerd at 4.2, 11.0, 19.8 and 27.4 microns using small cryogenics-cooled rocket-borne telescopes. Although the results of the original survey were kept classified for a couple of years, the final AFGL (which includes the AFCRL) catalogue released (Price and Walker, 1976) contained 2363 entries and covered approximately 85% of the sky at 4, 11 and 20 microns. The authors claimed it to be statistically complete to m(4.2)=1.3, m(11.0)=-1.1 and m(19.8)=-3.1.

For a long time a number of groups dedicated their efforts to identify and classify, by means of ground-based accurate visual and IR observations, most of the originally "anonymous" sources detected in the CIT and AFGL surveys. Of the former, the great majority of detections turned out to be late-type M stars, some early M stars and a small number of carbon stars, though a few unusual objects were also found in the sample (Bidelman, 1980 and references therein). Since the AFCRL/AFGL survey was carried out at longer wavelengths, cooler objects were discovered. Nearly 80% of the sources in the final version have been confirmed and classified from a variety of ground-based observations (Cohen, 1975; Ney et al, 1975, Westerbrook et al, 1975, Gehrz and Hackwell, 1976; Lebofsky and Kleinmann, 1976, Lebofsky et al, 1976, 1978, Cohen and Kuhi, 1976,1977; Kleinmann et al, 1979; Joyce et al, 1977; D. Allen et al, 1977). Although many of the originally unidentified sources were also found to be cool M and carbon stars, this sample also contains a large fraction of HII regions and reflection nebulosities, as well as some of the most exciting IR sources known.

The CIT and AFGL are the only large-scale surveys so far performed at wavelengths longer than 2 microns and it seems clear that in the future these studies will be made from spacecraft and artificial satellites with no atmospheric limitations and with cooled telescopes, able to achieve acceptable limits of detectability with small size telescopes. The "IR Astronomical Satellite" (IRAS) will be the next space mission to observe in the infrared for astronomical purposes. During its one year life-time it is expected to carry out a deep all-sky survey in the wavebands 8-15, 15-30, 30-60 and 60-120 microns (e.g. Moorwood, 1978).

Nevertheless, ground-based observations are still needed for deeph surveys with high spatial resolution, though for practical considerations, only small areas can be studied at a time. The most efficient frequencies at which these surveys may be carried out are 2 and 10 microns; at the shorter wavelengths, observations involve less instrumental and sky emission problems, but the choice depends primarly on the astronomical goals. Essentially, searching for hot dust emission in the interstellar medium requires long wavelength observations, while cool and highly reddened stellar objects are detected more effectively at 2 - 3 microns.

In fact, in some cases like HII regions, the two kinds of observations are complementary and necessary; the possibly obscured exciting stars are generally detected in the short wavelength surveys while the distribution of emitting dust is determined by 10 and 20 micron maps of the regions. These, combined with radio continuum observations, have provided important information on the physical and evolutionary conditions of these objects. Survey work in the near and mid IR have been concentrated towards a large number of HII regions (see Wynn-Williams and Becklin, 1974; Lahulla, 1977; Habing and Israël, 1979; Fernández and Lortet, 1979 and references therein) and the Galactic Centre (see Becklin and Neugebauer, 1978; Becklin et al, 1978a,b and references therein) while searches at 2 microns have been made towards the folowing dark clouds: Ophiuchus (Grasdalen et al, 1973; Vrba et al, 1975; Elias, 1978c), Lynds 1630, 1517, 1551 (K.M. Strom et al, 1976a,b), NGC 1333, 7129 and Serpens (S.E. Strom et al, 1976a,b), R CrA (Vrba et al, 1976), Monoceros (Iijima and Ishida, 1978), IC 5146 (Elias, 1978a), Taurus (Elias, 1978b), Coalsack (Smyth and Sim, 1980; Jones et al, 1980), Chamaeleon (Jones and Hyland, 1980b); as well as around Herbig-Haro objects (S.E. Strom et al, 1974; Cohen and Schwartz, 1979, 1980). Searches at 3.6 microns have been performed in molecular clouds (Beichman, 1979; Bally and Scoville, 1980) and around water vapour maser sources (Moorwood and Salinary, 1980).

The knowledge of the distribution of field stars which will be present in two-micron surveys is of vital importance for studies of specific regions for the statistical differenciation between background (and foreground) sources and those probably associated with the sites under examination. Elias(1978a,d) has made considerable contributions towards the understanding of this problem which, in fact, is present in all these surveys.

The early two-micron surveys of several dark clouds by the Stroms and collaborators showed the technique to be very useful in detecting obscured clusters of stars associated with the clouds although it seems clear now that many more of the sources then discovered than the authors believed are background stars. It is a fact that in all unbiased samples of near-infrared sources over a large area of sky, a large proportion of field stars are present. In another case, the Coalsack, where there is no independent evidence of recent star formation, Jones et al (1980) found no cluster associated with globule number 2; in contrast, studies of Ophiuchus and Taurus dark clouds by Elias (1978b,c) showed the complexes to have a large population of young objects, though of different characteristics and distribution along the clouds, suggesting that the dominant star formation mechanisms in each region are different.

In summary, the knowledge of the IR sky gained during the last ten years or so, although far from complete, provides evidence of a series of problems which were overlooked before the "infrared revolution". Among them is the presence of considerable mass-loss from luminous early and late-type stars and from hot and cool pre-main sequence objects. Circumstellar dust shells have been found to be quite common in late type giants and supergiants. Their study should provide important information towards the understanding of these critical evolutionary stages.

Infrared techniques are useful to study not only thermal emission from cool material but also other plasma processes as well as making it possible to "look through" absorbing material more effectively and still of being able to detect stellar emission, extending in a sense, visual techniques towards highly obscured objects. A brief description of the state of the knowledge of various kinds of infrared emitters relevant to the present work follows.

5) Late-Type Stars

Late-type stars constitute the great majority of the near-infrared galactic emitters so far found and have been widely studied at these wavelengths since they first emerged from the CIT survey. The infrared properties of these stars have been summarized by Merrill (1977) and only the main characteristics will be mentioned here.

The study of late-type stars (with photospheric temperature T < 3000 K) is largely complicated by the presence of molecules in their atmospheres and whose abundances depend on the stellar luminosity, temperature and element abundance; in particular, on the value of the ratio of oxygen to carbon in the upper layers. Merrill and Stein (1976a) showed that normal oxygen-rich stars are quite distinct from carbon-rich stars when observed in the region 2 - 13 microns. M stars show the 9.7 micron silicate feature and, increasingly strong towards later types, the 1.9 and 2.7 micron H_2O bands; all these are lacking in C-star spectra. Both classes are characterized by the CO band at 2.3 microns but, although the 3.07 micron band due primarily to HCN and C_2H_2 (Ridgway et al, 1978) and the 11.5 micron band, attributed to SiC (Gilra, 1972), are always present in C-rich stars, they are not observed in M stars.

Independently of the value of O/C, the stellar photosphereric continuum emission resembles a black body (Rayleigh-Jeans tail) at a temperature equivalent to the spectral type ($T > 2400$ K). Nevertheless, it is well known that IR excesses are common in late-type stars. These are normally interpreted as due to thermal emission by warm dust located around the star (Woolf, 1973 and references therein), though contributions by other mechanisms have been shown also to reproduce the observations: free-free and free-bound emission (Gilman, 1974) and photospheric activity (Lambert and Snell, 1975).

The observed shapes of the spectral energy distributions with IR excesses are different for carbon-rich stars than for oxygen-rich stars. This is expected if the circumstellar dust giving rise to the IR emission is a product of condensation of material ejected from the star. Theoretical studies by Gilman (1969) indicate that the value of the ratio O/C is important to the onset of the condensation of various compounds at a given temperature. For instance, for low values of O/C, the production of graphite and SiC particles is expected. In fact, infrared observations of some carbon stars with large excesses have been successfully fitted by optically thick graphite shells (Jones and Jones, 1976) and there is spectroscopic evidence (from 10 micron spectra) of the presence of SiC in these shells (Treffers and Cohen, 1974).

IRC+10 216 is so far the best-studied C-rich Mira variable (Becklin et al, 1969) with the most extreme IR excess. Toombs et al (1972) observed two lunar occultations of this star at 2.2, 3.5, 4.8 and 10 microns and could fit their data with a simple double-component dust model consisting of an optically thick 600 K shell sorrounded by an optically thinner one at 375 K.

On the other hand, dust emission from oxygen-rich stars is characterized by the 9.7 micron feature in emission or absorption, depending on the optical depth of the shell. The IR spectroscopic properties of these stars have been explained with a shell emission consisting of "dirty" particles of mixed silicates, carbon and metallic composition (Jones and Merrill, 1976). A well known example of an extreme late M-type Mira variable is IK Tau (NML Tau; Wing and Lockwood, 1973).

The properties of the dust shells may also depend on luminosity. Late-type supergiants form, hence, a distinctive group, showing almost always (for types later than M4) excesses at $\lambda > 5$ microns which generally account for less than 5% of the total radiation. This is thought to be emission from optically thin shells. There are some exceptions like VY CMa and NML Cyg; both appear to have optically thick circumstellar shells, emitting a considerable fraction of their total radiation at $\lambda > 5$ microns.

A systematic infrared spectral study of IRC and AFGL sources by Merrill and Stein (1976b,c) provides a clear framework in which the different classes of late-type stars with excess IR emission can be studied. In approximatly 6% of the so-called IR stars, i.e. those late-type stars radiating most of their energy in the IR, class IIb OH maser emission (Turner, 1970) is found having two symmetric velocity components ($\Delta v \simeq 5 - 80$ Km/s) sometimes associated with another H_2O or SiO maser sources at velocities in between OH components. The maser emission is believed to originate in the expanding envelopes of the stars and to be pumped by IR photons, as suggested by the observed synchronization of the IR and maser variations (Harvey et al, 1974).

6) Evolved Early-Type Stars

A large number of early-type emission-line stars (Be) have been found to exhibit excess emission in the near and mid IR. In most of these, the long-wavelength emission is explained by free-free radiation in a hot ionized gas shell (Gehrz et al, 1973 and references therein). Nevertheless, some peculiar Be stars (like HD 45677) also show IR excesses stronger than those predicted by Bremsstrahlung mechanisms alone and hence, optically thick circumstellar shells were successfully invoked to explain the excess (Swings and Allen, 1971).

Circumstellar plasma emission is also the main process producing the IR output from Wolf-Rayet (WR) stars. These very hot stars are characterized by enormously wide emission lines evidencing huge mass-loss. They group naturally into nitrogen-dominated (WN) and carbon-dominated (WC) spectra. Observed near-IR energy distributions can be reproduced by free-free emission (e.g. Cohen et al, 1975) but there is clear indication that dust shells are present in at least some stages in the (short) life of late WC stars (e.g. Cohen et al, 1975; Williams et al, 1978). The analyses of H and K broad band photometry is further complicated by the presence of at least strong He I and C IV emission lines (Williams et al, 1980).

With a very few exceptions, luminous (non-hydrogen deficient) intermediate-type stars do not show IR emission above the Rayleigh-Jeans tail, their "normal" photospheric emission. Because of the small number known, these exceptions require special attention. It is likely that they are in a particular stage in their evolution which lasts only a very short time. The only examples so far discovered are HD 101584 (Humphreys and Ney, 1974), 89 Her (Gillett et al, 1970), AFCRL/AFGL 2688 (the central star of the "Egg nebula"; Ney, 1975), IRC +10420 (Humphreys et al, 1973), Roberts 22 (D. Allen et al, 1980), CP-61 2935 (this work, Ch. IV) and, with some licence, Eta Carina as observed in 1892. The spectral types of these stars are F2eIap, cAp, F2Ia, F5Ia, F8Ia, A2Ie, F0Ia and F5I respectively. It is well known that the spectrum of Eta Carina has changed dramatically into a nebular one and the "central star" has become completely hidden by a thick shell. Although considerable effort has been dedicated to study these examples, their nature and evolutionary state is not understood and there is no evidence of these objects comprising a separate class (see Chapter IV for a discussion).

7) Molecular Clouds and Models of Star Formation

The idea that stars form from material in the interstellar medium which condensed into clouds has been in astronomers' minds for many decades. A cloud whose mass, temperature and density satisfy Jeans' criterion is bound to collapse under its gravitation, unless another agent prevents it.

A large number of interstellar clouds are known to exist in the Galaxy, the most massive ($M \sim 10^4 M_\odot$) by far satisfy Jeans' criterion while other much less massive clouds ($M \sim 10 - 10^2 M_\odot$) do not. The latter are more commonly detected visually as dark clouds while the former have denser cores and higher kinetic temperatures whose molecular emission is more easily detected. In both of these large groups internal and external agents (such as total angular momentum, grain formation, magnetic fields, galactic density waves, supernova shocks and others) play basic roles in their subsequent evolution, probably leading to the formation of stars. It seems that only low-mass stars form in low-mass clouds (e.g. Elmegreen, 1980) while in giant clouds both high and low-mass stars do form (see reviews by Evans, Silk, Chaisson and Vrba, Field and by Herbst and Assousa in Gehrels, 1978).

Consider a massive contracting cloud, probably the product of an early fragmentation of a giant cloud (e.g. Silk, 1978). Its central part will almost immediatly become denser than the rest. While the non-homologous contraction continues, the core density becomes higher. At the begining, due to IR and molecular line emission, the dust and gas kinetic temperatures remain low until the core becomes opaque to IR radiation and collisions become important. This leads to a rise in kinetic temperature and, hence, in pressure, which subsequently stops the collapse and some sort of equilibrium is reached ($\rho \sim 2 \times 10^{-10}$ gr/cm^3 and $T \sim 200$ K). At this stage a CO "hot spot" is observed. The core continues to accrete material adiabatically and the temperature rises to $T \sim 2000$ K and the H_2 molecules begin to dissociate causing a further collapse and the core reaches a temperature $T \sim 2 \times 10^4$ K and density $\rho \sim 2 \times 10^{-2}$ gr/cm^3. The hydrostatic core grows in mass as the rest of the cloud is accreted and eventually becomes optically thin allowing the core to be visible as a pre-main sequence star (Larson, 1977; and references therein).

For small mass stars ($M < 2\ M_{\odot}$), the kinetic energy of the material entering the core is converted into thermal energy reaching temperatures of the order of 10^3 to 10^4 K, and therefore radiating ultraviolet photons which are absorbed by the dust grains in the infalling envelope and re-radiated in the infrared. The kinetic energy of the material will have a maximun when approximately half of the mass has accreted and the density of the envelope is very low. This is represented as a peak in the luminosity which is $L \simeq 30\ L_{\odot}$ for a protostar of 1 $M_{\odot}$. At this stage, the star would be seen located at the end of the corresponding Hayashi track in the H-R diagram (Larson, 1977). The final properties of the core depend on the collapse time of the envelope, and this in turn, depends slightly on the initial density (see also Larson, 1974).

The case for the more massive clouds ($M > 5\ M_{\odot}$) is somewhat different because the time scales for the accretion of the envelope material are larger than the time-scales for the radiative cooling and contraction of the core. Consequently, the luminosity increases continously as the core grows in mass and now the whole radiation originates in the core which is already burning hydrogen although it is still surrounded by the protostellar envelope. Put in a different way, the core contracts all the way to the main sequence and begins nuclear burning while it continues to acreete matter. The approach to radiative equilibrium is characterised by a rapid increase in the luminosity of the core until the radiative pressure becomes large enough to halt the accretion. For relatively low-mass stars ($5\ M_{\odot} < M < 19\ M_{\odot}$) a minor fraction of the original mass is expelled through this mechanism (Larson, 1972; Larson and Starrfield, 1971; Westerbrook and Tarter, 1975).

If the original mass of the protostar is larger than 20 $M_{\odot}$, the radiation pressure is such that the entire infall envelope, which may contain a considerable fraction of the total mass, is blown off, setting an upper limit to the mass of a main sequence star. Larson and Starrfield considered that the strongest limitations to the mass of a main sequence star is provided by the formation of an HII region in the envelope, but more detailed analysis by Kahn (1974) showed that the limit is provided by the heating of the mixture of gas and dust, which cannot cross the boundary when grains start melting. Under solar vicinity conditions, his upper mass for a main sequence star was 40 $M_{\odot}$. Computations by Yorke and Krügel (1977) considered dust and gas as separate hydrodynamic components coupled by friction and their results were in general agreement to to the models discussed above. For a cloud of initial mass 150 $M_{\odot}$, they formed a main sequence star of mass 35 $M_{\odot}$. The envelopes obtained had a "double cocoon" structure with the inner shell at $T \sim 1000$ K and the outer shell at $T \lesssim 200$ K.

Recent two and three-dimensional hydrodynamic calculations indicate that a collapsing cloud will form rings which eventually break into two or more orbiting subcondensations with the possible development of stellar multiple or planetary systems (for details, see Larson, 1977; Boddenheimer and Black, 1978 and references therein).

With this picture of the formation of stars in mind, a short analysis of the relevant available observational material concerning low and high mass stars follows.

8) Massive young stars

As mentioned before, ultraviolet radiation from a massive star heats the dust particles present in its surroundings even at an early stage in the evolution when mass accretion has not stopped. The warm dust, in turn, re-radiates at far-infrared wavelengths. When the cloud begins to be dispersed by radiation pressure, near and mid-infrared emission coming from the "protostar" itself will be observed as the optical depth falls. At this stage an ultracompact HII region is developed and will also continue to expand, the plasma will mix with the dust until the well developed star or cluster of stars becomes visible as a "normal" main sequence object.

Compact (unresolved) objects whose properties fit into the different stages of this evolutionary picture have been observed at near and mid-infrared wavelengths, these include W3/IRS5 (Wynn-Williams et al, 1972), S140/IRS (Harvey et al, 1978), the BN/KL complex in Orion (Becklin el al, 1973), NGC 7538/IRS1 (Wynn-Williams et al, 1974), W3/IRS1 (Wynn-Williams et al, 1972) and the Orion Trapezium (Wynn-Williams and Becklin, 1974). These examples probably form a continous evolutionary sequence for massive early-type stars. From analysis of the energetics of these objects, the stars forming in these regions are of O or early B spectral type (see Werner et al, 1977 and references therein).

Independent evidence of the youth of these objects is given by the presence of H_2O and Type I OH ("main line") maser sources. The observed characteristics of H_2O masers and the conditions where they are found suggest that they exist in groups in the expanding envelopes of extremely young massive stars and represent one of the earliest observable stages in their evolution towards the main sequence (Genzel and Downes, 1977; Downes and Genzel, 1980). The OH masers are very often found when ultracompact HII regions have already developed (e.g. Habing and Israël, 1979).

A distinction should be made between the compact IR sources discussed above and the extended far infrared sources associated with HII regions. The extended emission, sometimes coexists with, but is not necessarily coincident with compact sources. In many well developed HII regions (like W3 A), the energy distribution clearly shows two superposed emission components, one corresponding to the well studied Bremsstrahlung spectrum and the other to a (slightly broader) cool black body ($\sim$100 K). The latter being the product of thermal emission by dust particles (at various temperatures) in the cloud. There is a general coincidence between radio continuum and far-infrared maps of HII regions (e.g. Rodríguez and Chaisson, 1978) suggesting that the dust and gas are well mixed, though dust depletion occurs only within the ionized region.

Approximately two-thirds of the emission from an O-type star is in Lyman-continuum photons ($\lambda < 912$ A), a large fraction of which will be converted into Ly_{α} and other lower energy photons by ionization and recombinations in the gas. These Ly_{α} photons are resonantly trapped in the region until they are absorbed by the dust grains increasing the temperature and re-emitt IR photons when equilibrium is reached (see Fazio, 1978 and references therein).

The detailed IR properties of HII regions have been explained by a multicomponent dust model consisting of: 1) small (0.1 micron) grains of unknown composition responsible for most ultraviolet absorption and infrared and submillimetre emission; 2)graphite grains of sizes 0.01 microns resposible for the observed increased visual opacity; 3) silicate particles responsible for the 9.7 micron feature emission and 4) water ice located outside the ionized region causing the 3.1 absorption band. The total dust to gas ratio (by mass) implied by this model is 10^{-2} (Panagia, 1977 and references therein).

Most, if not all HII regions are associated with molecular clouds and, from the results of general detailed CO surveys, HII regions seem to be always located in the edges and never deep into the molecular clouds (e.g. Myers, 1977). As a consequence, the expansion and further evolution of the ionized regions is non-spherical and , following the suggestion by Zuckerman (1973), this has been successfully modelled by Israël (1978) (see also Tenorio-Tagle, 1980). The ionizing star creates a half-open cavity in the clouds and the ionized gas flows out of the cavity, forming a low-density envelope (as compared to the ionized gas near the ionization front) "like a 'blister' on the skin of a molecular cloud". In the oposite direction, i.e. towards the interior of the molecular cloud, ionization fronts propagate generating shock waves into the cloud. The ionization fronts driven by the recently formed star or cluster of stars cause neutral material to accumulate between the fronts (Kahn, 1954). Elmegreen and Lada (1977) proved that after a few million years (depending on the density), the layer becomes unstable to gravitational collapse, triggering the formation of a new generation of massive stars deeper into the cloud. This mechanism explains the effect first discovered by Blaauw (1964), that OB associations consisted of separate subgroups differing in age but having approximatly the same number of stars. Other triggering mechanisms are required for the onset of the formation of the first stellar generation in any molecular cloud. Models that have been proposed include spiral desity waves (Woodward, 1976), supernova shock waves (Herbst and Assousa, 1977) and cloud-cloud collisions (Loren, 1976).

9) Trapezium-type Multiple Systems

The small cluster of early spectral type stars embedded in the infrared Kleinmann-Low nebula in Orion is commonly referred to as the 'Trapezium', due to the projected geometrical configuration formed by its four brightest members. The fact that similar systems are observed in other OB associations led Ambartsumian and Markarian (1949) to point out the importance of the study of these "Trapezium-type systems" (TTS). Ambartsumian (1954) defined a TTS as a multiple star system where there are at least three components whose separations are very similar, i.e. within a factor of three. He also compiled a catalogue of 108 systems satisfying this definition and whose primaries were of early spectral types; his source was Aitken's Visual Double Star Catalogue. In an atempt to avoid as many "optical" systems as possible, Ambartsumian rejected those which very probably were pairs seen as binaries due to projection effects using an empirical statistical criterion. Most of the systems in his list were members of OB associations, strengthening the idea that they were young. Furthermore, Ambartsumian applied the formula for the mean life-time of clusters in the limiting case of having very few members and deduced a value of two million years. Simultaneously and independently, Sharpless (1954) remarked that TTSs were particularly frequent among O-type stars connected with emission nebulosity and reported six additional systems not included in Ambartsumian's list.

Based on assumptions (which later have proved to be incorrect) and on micrometric observations by Parenago (1953) suggesting that the Orion Trapezium was expanding (also later refuted on stronger observational basis by C. Allen et al, 1974), Ambartsumian (1954) stated that the total energy of the trapezia was positive. This view was not shared by Sharpless (1966) who claimed that the so called expansion of trapezia was due to a dynamical process in which a system with negative total energy disolves to form massive binary systems. Recently, Allen and Poveda (1974,1975) ran a series of computer simulations of the dynamical evolution of a number of small clusters consisting of six massive stars and, in some cases, of ten low-mass stars with initial conditions similar to those now observed in the Orion Trapezium. After a million years, only 30% of the systems continued to be of the Trapezium type, the rest dissolving leaving behind massive binary stars in order to satisfy the conservation of energy. Allen and Poveda concluded that the life-time of a TTS was around one million years.

In order to update the catalogue of visual TTSs, C. Allen et al (1977,1980) obtained a list of around one thousand trapezia compiled from the 1975 version of the Index Double Star Catalogue (IDS; Jeffers et al, 1963). These authors also rejected the most probable optical systems, though using a more flexible criterion: For each entry, they computed the probability that in the direction (l,b), a pair of stars separated a distance d will be seen as a binary due to projection,

$$P = \pi d^2 N(m)_{l,b}$$

where m is the magnitude of the fainter star of the pair, $N(m)_{l,b}$ is the number of field stars per unit area in the direction (l,b); these taken from the tables by Seares and Joyner (1928). In the final catalogue, they included only systems with $P < 0.01$ for all its components and which still remained being trapezia.

Contrary to Ambartsumian's (1954) results, Allen et al found many more trapezia of late and intermediate spectral types than expected statistically (see Ambartsumian, 1954 for this analysis) which may be interpreted as evidence that low-mass stars are also formed in clusters (see below). Salukvadze (1978a,b, 1979) performed a similar study but using more stringent criteria (similar to Ambartsumian's) for the rejection of optical pairs; this led to their retaining less than half of the objects as compared to the list by Allen and collaborators. Salukvadze reached basically the same conclusion as Allen et al about the spectral type distribution of TTSs.

Due to the nature of the detection methods, all catalogues of visual binary and multiple systems are bound to be heavily contaminated by selection effects. Although the new catalogue of TTSs was carefully compiled (C. Allen et al, 1980), there appears to be far more contamination by selection and projection effects than simple statistics predict. For instance, the recent systematic photometry (UBVRI) of 68 out of the 108 sysytems in Ambartsumian's list by Echevarría et al (1979) showed that the number of optical systems in the sample is at least 13% while Ambartsumian's theoretical predictions gave 0.2%. Furthermore, Echevarria and collaborators concluded that only for those objects located in bright nebulae, there were enough evidence of their youth.

Some examples of early-type trapezium-type systems discovered visually are those located near the centres of the Orion Nebula, Trifid Nebula, NGC 3603, NGC 281. On the other hand, some TTSs have been discovered through IR surveys; these include those in S106 (Pipher, et al, 1976), S140, S255, Cep A (Beichman et al, 1979). All these are seen at the edges of molecular clouds, leaving little doubt that at least a large proportion of massive stars form in small clusters, probably also in the same regions as low-mass stars.

The fact that low-mass pre-main-sequence objects, such as T Tauri stars are not observed as members of Trapezium-type clusters (although Cohen and Kuhi, 1979, found a few binary T Tauri systems) provides further evidence that massive star formation differs essentially from low-mass star formation. Since the latter seems not to produce small-mass trapezia, there is no reason to believe that the observed low-luminosity late-type systems are physical (i.e. gravitationally bound) and hence, the suggestion by Echevarría et al (1979) that low-mass trapezium configurations may be stable is probably not correct. On the other hand, it is unlikely that most intermediate-type (A to G) systems present in the catalogues are all of high luminosity.

10) Low mass Young Stars

At present, there is enough evidence to suggest that T Tauri-type stars are low mass objects in the latest stages of their evolution towards the main sequence. T Tau stars (Joy, 1945) are characterised by 1) Rapid irregular light variations of about three magnitudes (in the visual); 2) Spectral types F5 - G5 with emission lines resembling those of the solar chromosphere and which may also be highly variable. Particularly strong are the H and K lines of Ca and sometimes no underlying continuum is visible; 3) Low luminosity; 4) Association with dark or bright nebulosity (Herbig, 1958, 1962) and 5) Infrared excesses.

The excess IR emission from T tauri stars was predicted on theoretical grounds by Poveda (1965) and this was first observed by Mendoza (1966, 1968). There is some controversy over the interpretation of the IR excesses. Rydgren et al (1976) analysed the IR energy distributions of a number of T Tau stars and assuming "abnormal" interstellar extinction in certain regions, were able to explain the near-IR excesses as due only to high temperature gas emission (Bremsstrahlung) processes (at T $\sim$ 20,000 K) originating in the same envelope as the emission lines and "veiling" effects. Cohen (1973) and Cohen and Kuhi (1979) gave evidence to support the view that at least a considerable fraction of the T Tauris have dusty circumstellar shells responsible for most IR emission, though not ruling out contributions by free-free, free-bound and bound-bound emisssion. The presence of the silicate feature in the 10 micron spectra of T Tauri stars is a further evidence of dust particles in their environments.

Cohen and Kuhi (1979) recently reported the results of a very efficient semi-automated IR and spectroscopic analysis of around 500 Hα emission-line stars, including all catalogued T Tauris. Most of the objects they observed were located above the main sequence in positions corresponding to convective-radiative evolutionary tracks (Iben, 1965). The masses and radii indirectly derived for the stars were in the range 1 to 5 $R_\odot$ and 0.2 to 3 $M_\odot$ respectively

In spite of the large number of observations available, T Tauri stars are largely a mystery. Most models lie in one of two contradictory groups. Models in the first group require systematic mass loss in the form of huge stellar winds while the other models explain the observed spectra with mass accretion, presumably from the remnant circumstellar clouds (see e.g. Ulrich, 1978). Spectroscopic observations often contribute by confusing matters instead of clarifying them. For instance, it is not uncommon to find in a star P Cygni line-profiles (normally interpreted as a result of mass-loss) in coexistence with lines showing "inverse" P Cygni profiles (interpreted as evidence for mass inflow; see Rydgren, 1977 and references therein).

To complicate things more, a few "normal" T Tauri stars have suffered sudden increases of their luminosity by a few magnitudes accompained by a complete spectral change in what is known as the FU Ori mechanism. Since the sample of this type of objects is very small, the processes responsible for the phenomenon are far from understood although from a statistical analysis, Herbig (1977) deduced that it is a periodic process (for a recent review, see Welin, 1978).

With the idea of finding the intermediate-mass analogues to T Tauri stars, Herbig (1960) obtained a list of 26 Ae and Be-type stars whose characteristics resemble T Tau : Emission line spectra, association with dust and bright nebulae. With the poor quality observational material available at the time, Herbig failed to find conclusive evidence confirming the extreme youth of these stars. Later Strom et al (1972b) succeded, by obtaining qualitative spectrophotometry and making use of published photometry, in locating the Herbig Be/Ae stars in the L-Teff diagram and found them also to be on the equilibrium radiative tracks (Iben, 1965) towards the main sequence for masses corresponding to those expected for B and A stars. Again, IR excesses were found from the stars and explained by free-free and dust emission (see Strom, 1977 and references therein). Mass loss estimates in the range $10^{-7} - 10^{-6}$ $M_{\odot}$/yr were computed by various spectrometric methods (Garrison, 1978 and references therein).

11) Burnham Nebula and Herbig-Haro Objects

-When the variable T Tauri had a deep minimum in luminosity, Burnham (1890) discovered a faint nebulosity surrounding the star. When T Tauri recovered its brightness this became dificult to observe visually until refined observational techniques became available. Herbig (1950) studied spectroscopically the nebula (not to be confused with NGC 1555, Hind's reflection nebula 45 arc sec West of T Tauri) and found low ionization [OII], [SII] and hydrogen emission lines in its spectrum. He proposed that it was a gaseous nebulosity produced by the "interaction with the dark nebula upon which it is seen projected". Osterbrock (1958) first suggested stellar winds as the source of its ionization and Schwartz (1974,1975a) performed a complete photometric and spectrometric study of the system. Combining the results with the mass-loss model for T Tauri by Kuhi (1964), Schwartz constructed a picture consisting of a star of mass 1.7 $M_{\odot}$ and radius 0.03 AU with a gaseous circumstellar envelope extending to 0.1 AU, both surrounded by the emission nebula about 1500 AU across. Schwartz concluded that about 0.9% of the total visual luminosity originated in the envelope and 0.1% in the nebula. By assuming considerable mass-loss from T Tau (4×10^{-8} $M_{\odot}$/yr; v = 100 Km/s; Kuhi, 1964), Schwartz (1975a) was also able to explain the spectrum of Burnham nebula as emission from the cooling regions after the passage of a shock front, as predicted by Cox (1972) for supernova remnants.

-Herbig-Haro objects (Herbig, 1951; Haro, 1952) are groups of small nebular knots or condensation seen only on the surface of dense dark clouds where other young objects are present (e.g. T Tauri stars). The Herbig-Haro Objects (HHOs) are characterized by the following observed properties:

1) Low excitation emission lines, very much like the Burnham's nebula (Herbig, 1951).

2)Their luminosity and spectra are highly variable with time-scales of the order of years (Herbig, 1969; Böhm and Schwartz, 1973) and each condensation (250 - 500 AU across) seems to behave independently (Herbig, 1969; Böhm and Schwartz, 1973).

3) A very faint underlying continuum, probably similar to that of a late-type star, is present in the spectra of some HHOs (e.g. Böhm et al, 1974).

4) The reddening determined from the visual spectral line ratio 4068/10317 of [SII] (Miller's method) suggests low obscuration: $E(B-V) \simeq 0.2 - 0.6$ (Böhm et al, 1974), far lower than expected, in particular when one considers that HHOs are always seen in regions of high obscuration.

5) Linear polarization as high as 24 % has been observed in some HHOs, while in many others it is negligible (K.M. Strom et al, 1974a; Schmidt and Vrba, 1975).

6) A very wide range of radial velocities determined spectoscopically, ranging from +300 Km/s in HH-32 (Dopita, 1978) to about -240 Km/s in M42HH-1 (Münch, 1977). In many cases the widths of the lines are comparable or even greater than the shifts of the lines themselves (Dopita, 1978; Schwartz, 1978).

7) Although in most cases there is no star visible in the vicinity of HHOs, infrared surveys (S.E. Strom et al, 1974; K.M.

Strom et al, 1974b; Elias, 1978c; Cohen and Schwartz, 1979, 1980) sometimes have revealed highly obscured stars displaced up to a few arc min away from the nebulosities, but in others, the search has been fruitless. The IR observations suggested that, when the star is detected, it may be of the T Tauri type.

8) Water vapour masers and compact HII regions have also been found in the vicinity of a number of HHOs; with the exception of one object, hydroxyl and SiO masers have not been detected (Paschchenko et al, 1979; Rodríguez et al, 1980; Haschick et al, 1980).

The number of known Herbig-Haro objects is around sixty but is increasing rapidly. Positions and short descriptions are given in the lists by Herbig (1974), S.E. Strom et al (1974), Schwartz (1977), Gyulbudaghian et al (1978), Elias (1978c) and Cantó et al (1980). Details of the visual spectral and infrared characteristics of HHOs can be found in Bohm (1975, 1978a,b) and Strom (1977). Some dark clouds containing Herbig-Haro objects have been mapped for H_2CO, CO, NH_3 by Lada et al (1974), Loren et al (1979) and Ho and Barrett (1980).

Since their discovery, HHOs have been associated with star formation, but the source of their excitation is not fully understood. Magnan and Schatzman (1965) considered the possibility of these objects being excited by streaming photons with energies around 100 KeV. In view of discoveries of the presence of probable pre-main-sequence stars slightly displaced from the positions of some

HHOs together with examples of objects showing considerable polarization whose vectors are perpendicular to the line HHO - IR stars, Strom et al (1974) suggested that H-H nebulae are the product of reflection of the (highly obscured in the line of sight) stellar emission which "leaked through holes or tunnels in the cloud". This simple model has been severely critizised for failing to explain many observations (see e.g. Haro, 1976; Herbig, remarks during discussion after Strom, 1977).

The most successful model so far proposed has been built up by a number of investigators and can be collectively called the "shock model". It was first considered when calculations of plane parallel shock waves by Raymond (1976, 1979) and Dopita (1978) proved quantitatively that the observed spectra of HHOs are explained if the emission originates from the cooling regions heated by a shock wave, probably as a product of mass-loss from a nearby star. Among many problems with this initial model was that the observed densities of the emitting regions (HHOs) were far lower than those of a dense cloud where they are located. Schwartz (1978) proposed a model in which a strong stellar wind from an embedded pre-main sequence star produces shock waves which interact with small ambient cloudlets and the shocked stellar wind formed around these clouds is responsible for the emission of the individual condensations within a HHO.

Cantó (1978, 1980) proved that the observed HHO spectra can be explained if they originate not in shocked ambient gas, but in shocked wind material and that it would be brightest when the region is at unit optical depth. His models imply that in a non-uniform cloud, the shock in the stellar wind does not have spherical symmetry about the star but would be ovoid, and that the shocked gas wind flows away with a considerable (supersonic) velocity component parallel to the shock towards less dense (outer) regions. Furthermore, the small angles subtended subtended by some HHO with respect to their exciting star (in the cases where it has been detected) were explained by Cantó and Rodríguez (1980): Based on Cantó's (1980) flow patterns, they suggested a focusing mechanism resulting from a density gradient in the cloud, with the exciting star embedded in the denser (inner) parts near the edge. In this picture, HHOs are the product of a second shock at the point where the two streams of refracted gas moving along the walls of the ovoid meet, i.e. roughly where the density reaches a minimum. In this scheme, the energetics of the mass flow are greatly alleviated by the focusing mechanism. One other important implication of Cantó's model is the ability of a strong stellar wind to create "tunnels" through which light from the exciting star can reach scattering parts of the outer edges of the cloud, explaining the important observational evidence recently produced by Schmidt and Miller (1979) showing that the HHO No. 24 knots are emission nebulae which also scatter emission from a T Tauri-like star suffering considerable mass loss.

Other models have been proposed to explain the observational properties of the Herbig-Haro objects. These involve FU Ori-type stars (Gyulbudaghian, 1975; Dopita, 1978) and early-type stars ejecting massive "bullets" to the interstellar medium (Norman and

Silk, 1979; Rodriguez et al, 1980) but have been less successful in explaining the overall properties of HHOs. As pointed out by Haschick et al (1980), it is preferable to think of clusters of stars of different type being formed in the same vicinity than to explain the observed radio maser and continuum emission detected in certain regions also containing Herbig-Haro objects as being originated by the same phenomenon.

CHAPTER II

OBSERVATIONS

The main body of the present work consists of a systematic search in the K photometric band (centred at 2.2 microns) for infrared sources in the immediate vicinity (up to 3′ - 4′) of a number of multiple systems of the Trapezium type, supported by JHKL photometry of the majority of their star members and of the sources found in the course of this survey. Some of these are expected to be very young stars which have not yet reached the main sequence and which are strongly interacting with the remainder of the material from which they were formed. This is the case for the Trapezium in the centre of the Great Orion Nebula, whose most massive members provide most of the energy to the surrounding HII region and, according to the recent and very attractive theory by Elmegreen and Lada (1977, 1978b), also triggered the formation of a subsequent generation of massive stars deeper into the molecular cloud located behind the optical nebulosity. Other examples, like W 4, indicate that, at least under certain circumstances, this mechanism acts effectively. Although the understanding of the formation of less massive stars is much poorer, low-mass pre-main sequence objects, such as T Tauri stars, are found in associations, almost always in dark clouds and often where massive early-type stars are also being formed (see e.g. Kholopov, 1958).

It is therefore of interest to investigate at infrared wavelengths regions where massive (Orion) Trapezium-like multiple star systems exist in order to search for other (obscured) young stars or protostars which may be associated. Their existence, location and properties should contribute towards the understanding of the overall processes governing multiple star formation in molecular clouds and the consequences and implications for the evolution of the intersttlar medium.

The Trapezium-type systems (TTS) considered for this survey were selected from the catalogue of 967 systems compiled by C. Allen et al (1980) on the basis of their location in the sky and the characteristics of their apparent environment. Only systems lying in regions where star formation is likely to have taken place recently, as indicated by the presence of molecular clouds (Turner et al, 1973; Morris et al, 1974; Wilson et al, 1974; Evans II et al, 1975; Wannier et al, 1976), dark clouds (Lynds, 1962; Fischer, 1963; Sim, 1968) emission and reflection nebulae (Maršálková, 1974; van den Bergh, 1966; Racine, 1968; van den Bergh and Herbst, 1975; Herbst, 1975), galactic clusters and OB and T associations (Alter et al, 1970; Kholopov, 1958; Gieseking, 1973) were condsidered. Cross correlation comparisons between the catalogue of trapezia and the lists mentioned above, together with catalogues of O stars (Cruz-González et al, 1974), T Tauri and other emission-line stars (Herbig and Rao, 1972; Wackerling, 1970; Henize, 1976) were made to obtain a short list of the TTSs most likely to have low ages. But it was a close examination of their appearance on the Schmidt plates from the National Geographic/Palomar Observatory (PSS) , the Science Research Council (SRC) and European Southern Observatory (ESO) that provided the last criterion for their inclusion in the final observing list. Special emphasis was made in the Southern Hemisphere where all kinds of observational data are largely incomplete.

The catalogue of TTSs includes only systems which have less than 1% probability of being chance optical associations (C. Allen et al, 1977). Nevertheless, as pointed out in Chapter I, considerable care should prevail in its use and hence, to minimize the chances of dealing with non-physical systems. Therefore, with a few outstanding exceptions, only those systems whose separations between components were of the order of 10 arc sec or less were retained in our list. As expected, all regions chosen lie close to the galactic plane and their longitude distribution is shown in Figure 2.1.

An altogether different study also reported in this dissertation refers to the long standing problem of localizing the source of energy to the small emission/reflection nebulosities observed in some dark clouds, known as Herbig-Haro objects. Current models of these objects (e.g. Cantó, 1980) predict the existence of highly obscured stars, probably of the T Tauri type, suffering considerable mass loss. Strom et al (1974) and Cohen and Schwartz (1979) succeeded in detecting at infrared wavelengths the probable exciting stars in some of the regions they studied. Considering that most of the IR

Figure 2.1. Distribution in galactic longitude of the observed regions. Continuous line refers to those containing trapezium-type systems and broken line refers to "reference" regions. In all but one case, $|b| \lesssim 7^{o}$.

Figure 2.2. Shape and approximate dimensions (to the nearest arc min) of the areas mapped at 2.2μm during run (a). The point o represents the position of the "central" object which is the zero point in the Figure.

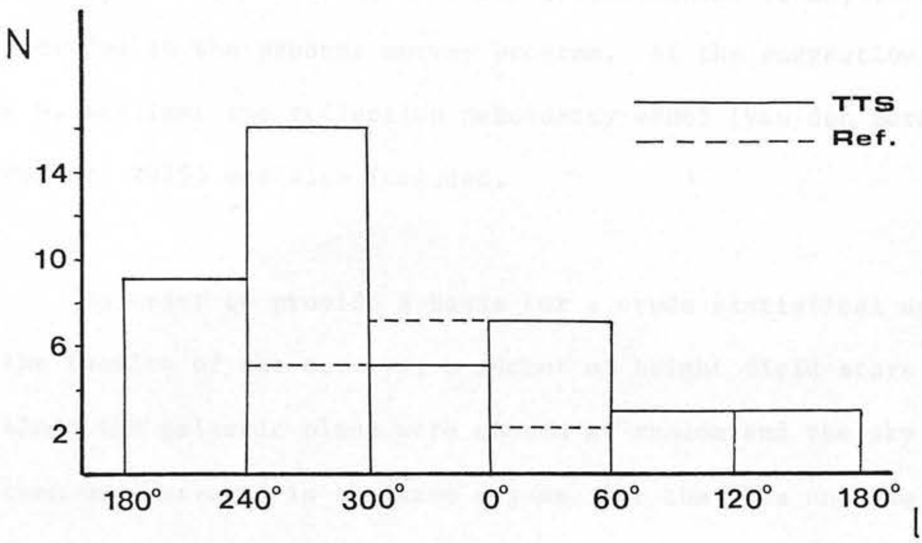


Figure 2.1

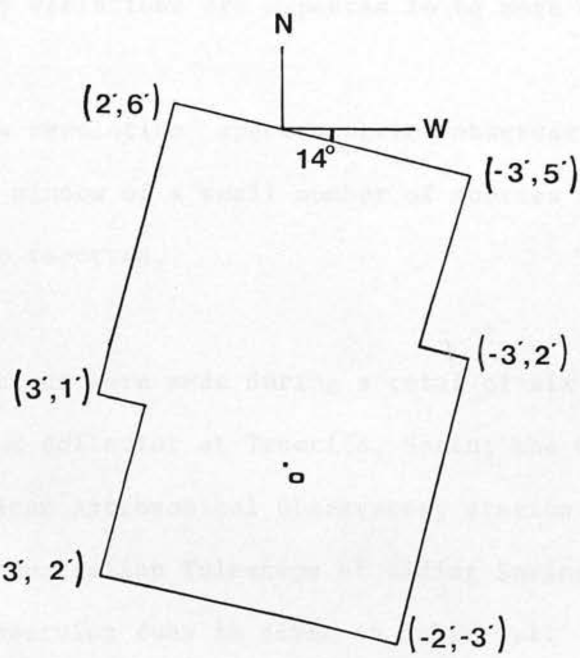


Figure 2.2

observations of HHOs are being made in the Northern Hemisphere, all catalogued Herbig-Haro objects south of declination -7 degrees (Herbig, 1974; Schwartz, 1977 and Gyulbudaghian et al, 1978) were included in the present survey program. At the suggestion of Dr. P.M. Williams the reflection nebulosity vBH65 (van den Bergh and Herbst, 1975) was also included.

In order to provide a basis for a crude statistical analysis of the results of the surveys, a number of bright field stars located along the galactic plane were chosen at random and the sky around them was surveyed in the same way as for the TTSs and the Herbig-Haro objects (HHO). The distribution in longitude of these regions is also shown in Figure 2.1. A larger number of "reference" regions were chosen close to the galactic centre where local projected density variations are expected to be more common.

Finally, low resolution spectrometric observations in the 2.0 - 2.5 micron window of a small number of sources related to some trapezia are also reported.

All observations were made during a total of six runs using the British 1.5 m flux collector at Tenerife, Spain; the 0.75 m reflector at the South African Astronomical Observatory station at Sutherland and on the Anglo-Australian Telescope at Siding Spring, Australia. A summary of the observing runs is given in Table 2.1.

TABLE 2.1

SUMMARY OF OBSERVING RUNS

Run	Dates	Site	Telescope	Instrumentation	Typ.Obs.[1]	Area scanned[2]
(a)	23 April to 8 May 1978	S.A.A.O.	0.75 m reflector	Mark I IR photometer[3]	M,P	55 sq arc min (See Fig. 2.2)
(b)	13 August to 17 August 1978	Tenerife	1.5 m Flux Collector	ROE IR photometer[6]	P	---
(c)	7 November to 9 November 1978	Tenerife	1.5 m Flux Collector	ROE IR photometer[6]	M,P	121 sq arc min (+-5.5,+-5.5)
(d)	25 January to 11 February 1979	S.A.A.O.	0.75 m reflector	Mark II IR photometer[4]	M,P	81 sq arc min (+-3.1,+7.1) (+-3.1,-3.1)
(e)	12 June to 2 July 1979	S.A.A.O.	0.75 m reflector	Mark II IR photometer[4]	M,P	86 sq arc min (+-3.1,+7.8) (+-3.1,-3.1)
(f)	31 January to 1 February 1980	A.A.T.	3.9 m reflector	AAO IR photometer/ spectrometer[5]	S	---

NOTES:

1.- M= 2.2 micron scans
P= JHKL photomety
S= 2.0 - 2.5 Spectrometry

2.- Pairs of numbers in brackets indicate the corners of the areas scanned in arc min with the "central" object as origin

3.- This instrument is described by Glass (1973)

4.- Similar to Mk I but with improved mechanics

5.- This instrument is described by Barton and Allen (1980)

6.- This instrument is described by Williams et al (1976)

1) **2.2 micron surveys:** Most of the 2.2 micron scans were made with the 0.75 m telescope at Sutherland with the infrared photometers built by Glass (1973), both having InSb detectors and working at liquid nitrogen temperature ($\sim$77K). Ten by ten (run (a)) and twelve by twelve (runs (d) and (e)) grids were mapped centred on each TTS or HHO. A single ten second integration was taken at each point with a 52" diameter aperture and the spacing between grids was 34" in both right ascension and declination. The rotating mirror chopper throw was 188", 235" and 272" for runs (a), (d) and (e) respectively, in the South-North direction.

It should be noted that the total area mapped with the method described above also includes a "bonus" area north of the original grids which is covered by the "negative" beam and hence, all sources in that region were recorded as negative signals at the output of the phase sensitive amplifier. This "bonus" area was considered in the computations of the numbers given in the last column of Table 2.1. Therefore, during the runs (d) and (e) the areas scanned were rectangles centred 117" and 136" north of the original "central" objects respectively. Early during run (a), a minor engineering problem developed: The offset guider graticule accidentally rotated some 14 degrees and then jammed. As the only way to twist it back seemed to require the dismantelling of the photometer (involving the risk of wasting considerable observing time), these scans were finally performed in rotated coordinates since the graticule was to be used as reference. As a consequence, the total area surveyed during this run was of the form and dimensions shown in Figure 2.2.

For the SAAO scans, the detector noise was almost always much lower than the sky background and hence, the limiting magnitude K(lim) for each area surveyed was determined primarly by variations, from point to point of the grid, in the number of faint unresolved sources present within the aperture. Clearly, K(lim) was different for each region. All sources brighter than the corresponding three sigma level above the sky (taken as the value for K(lim)) are believed to have been detected; furthermore, a good number of sources fainter than K(lim) were also recorded in many areas. All integrations were recorded on tape and later reduced to construct photometric maps for all the observed regions. The zero points were obtained by observing standard stars and air mass correctiones were applied. For point sources, the spatial resolution acquired was better than 15" and the photometry direct from the maps was estimated to be accurate to .2 - .3 magnitudes. For three different regions, the scans were repeated twice on different nights (in one case in two different runs) with essentially identical results.

During the Tenerife run (c), a different scanning method was used because the ROE photometers were equiped with vibrating mirror choppers which at long wavelengths introduce lower noise but have the disadvantage that only small throws (10" - 20" on the 1.5 m F/C) can be used; the chopping was always in the North-South direction. The procedure followed during these surveys was the following: The telescope was moved in declination scans at a rate approximately 2 arc sec per sec with a 30" aperture while monitoring the chart recorder. The separation in right ascension between scans was 28", covering total areas of dimensions 11′ x 11′. Once a source was localised, broad band photometry of it was performed. Since the IR photometer had a low-quality InSb detector with very high noise, the limiting K magnitude of these detector-noise limited surveys is estimated to be about 6.2.

2) **Broad band photometry:** JHKL (L′ for the Tenerife observations) photometry was performed for the majority of the star components of the TTSs and of the IR sources found in their vicinity as well as some sources near Herbig-Haro objects, although not all four colours were always measured. A summary of the properties of this photometric system is given in Table 2.2.

In all cases, the standard method for photometry was followed (see e.g. Allen, 1975, Ch.2). The separations between beams were the same as for the scans and the reference stars used were from the lists by Glass (1974) for the Southern Hemisphere and by Johnson et al (1966) for the North. The values of H and L′ for the latter were interpolated and extrapolated using the algorithms given by Glass (1974) and P.M. Williams (private communication) respectively.

For the Tenerife run, each IR source detected during the scans was centred in the aperture and measured in K and in some cases in other colours, followed by the resumption of the scan. For the SAAO

TABLE 2.2

PHOTOMETRIC SYSTEM

Band	Wavelength	log Fl (0 mag.)[1]
J	1.25 μm	3.18
H	1.65 μm	2.99
K	2.2 μm	2.79
L	3.5 μm	2.45
L′	3.8 μm	2.40

NOTE:

1.- Flux in Janskys

runs, the position of the sources was computed from the photometric maps and their colours were obtained on different nights. This served as a check to the reliability of the surveys. In no case was a source brighter than the limiting magnitude, as recorded in the maps, found to be spurious. Unless otherwise indicated in Tables 3.1, the measurements were made with an aperture of 26 arc sec on the 0.75m telescope and of approximately 5 and 20 arc sec during the two runs on the 1.5m flux collector.

3) Spectrometry: A small number of low resolution spectrometric observations ($\lambda / \Delta\lambda = 50$) in the 2.0 - 2.5 micron region were performed with the AAO infrared photometer/spectrometer attached to the AAT.

The aperture used was 7" and the atmospheric and instrumental responses were removed and the spectra reduced to flux (in arbitrary units) by dividing by standard stars of spectral type F0 (with an assumed $T_{b.b.} = 7500$ K) observed roughly at the same air mass. Due to poor weather conditions, no absolute flux calibration was attempted.

The objects observed were selected from those found to have very red or peculiar infrared colours but, as bad weather was the primary characteristic of this run, the sources finally observed were only those located in clear patches of the sky.

CHAPTER III

RESULTS

1) Catalogues of Observations

The results of the surveys and photometric observations are presented in Table 3.1 for the trapezium-type systems and in Table 3.2 for the Herbig-Haro objects. Each region is represented in the catalogues by, at least, one "main line" which is always preceded by a blank line to differentiate it from the previous region. The main line contains the equatorial and galactic coordinates of the centre of the scan, i.e. the TTS or the the approximate position of the Herbig-Haro object, and the K limiting magnitude of the respective survey. The following lines for each region refer to the stars or infrared (IR) sources related, in projection, to the central object and give the observational results as described below:

Column 1: Identification. In the "main line" it refers to the central object of each region, the primary star in the case of a TTS. In the other lines, it identifies the star components of the multiple system contained in the aperture, as given by the Index Double Star Catalogue (Jeffers et al, 1963) or an infrared source (IRS) found in the 2.2 micron survey. An asterisk (*) and/or a cross (+) indicate the presence of a note at the end of the table.

Columns 2 and 3: Right ascension and declination of the object. In the main lines in Table 3.1, the position of the primary star, as given by the SAO or GC catalogues, is quoted. If the system was not listed in those, its position was measured on the PSS/ESO/SRC Schmidt plates (on the SAO system) but in some cases this proved impracticable and the position quoted instead is from the Durchmusterung catalogues. For the HH objects, the centre of the scan, determined using offsets from nearby bright stars chosen close to the catalogued position, is always given. The positions of the IR sources were measured on the PSS/ESO/SRC plates when a likely identification of the source was posible by comparing (when available at ROE) a far-red plate (I-N or IV-N emulsion with a G715 filter giving $\lambda_0 \simeq$ 8000 Å) and a blue one (IIIaJ emulsion with a GG395 filter giving $\lambda_0 \simeq$ 4600 Å), both taken with the UK Schmidt telescope. For the northern regions, pairs of blue/red Palomar plates were used. These measurements were carried out on a digitalised TV-equipped Zeiss comparator at ROE and the errors are typically less than 4". When no identification was possible, the positions obtained from the scans are quoted and are accurate to 0.2 arc min. It should be noted that in some cases the short wavelength identification may be incorrect and the real 2.2 micron source would be within the observational error box mentioned above. When the objects were observed on the AAT and not contained in the

SAO catalogue, the console read-out coordinates are given (error < 4 arc sec).

Column 4: K magnitude from the scans. Accurate to 0.3 magnitudes (IRS lines only).

Columns 5, 8, 11, 14: J, H, K and L (L′ for the Tenerife observations) magnitudes. The apertures used, unless otherwise indicated in column 18, were 26" for runs (a), (d) and (e); 5" for run (b) and 20" for run (c). If blank, no measurement was made, or the object was fainter that the sensitivity limit in that colour. (All but main lines).

Columns 6, 9, 12 and 15: Errors in the J, H, K and L mesurements respectively. If blank, the errors are 0.05 magnitudes or less. (All but main lines).

Columns 7, 10, 13 and 16: Logarithm of the corresponding flux expresed in Janskys in the J, H, K and L bands respectively. (All but main lines).

Column 17: Code of the observing run (Table 2.1) during which: 1) The 2.2 micron survey (in main lines) or 2) The photometric observations (other lines) were performed.

Column 18: Other identifications or aperture information. Underlined identifications refer to the open cluster or nebulosity in which the whole area surveyed lies.

TABLE 3.1

Observations of regions centred in Trapezium-Type Systems

(1)	R.A. (2000.) (2)	Dec. (3)	Scan (4)	J (5)	Er. (6)	Log Fl. (7)	H (8)	Er. (9)	Log Fl. (10)	K (11)	Er. (12)	Log Fl. (13)	L (14)	Er. (15)	Log Fl. (16)	(17)	Notes (18)
ADS 719	0 52 50	56 37.6		l= 123.12 b= -6.25													NGC 281
AB							7.77	.07	(-0.12)	7.75	.12	(-0.31)				b	HD 5005
BD 59 555	2 51 36.4	60 33 12		l= 137.2 b= 1.05						Lim. K mag.= 6.2						c	IC 1848
IRS 1+	2 51 24	60 38.3	6.9				7.70	.14	(-0.09)	6.88		(0.04)	6.53	.18	(-0.17)	c	
ADS 2426	3 16 17.0	60 2 8		l= 140.1 b= 2.08						Lim. K mag.= 6.2						c	BD 59 618
IRS 1	3 16 10.8	60 6 57	5.2							5.16		(0.73)				c	HD 20040
IRS 2+	3 16 48	59 55.9	4.2	5.71		(0.90)	4.67		(1.13)	4.23		(1.10)	4.05		(0.84)	c	
ADS 4209	5 36 24.9	-6 42 59		l= 210.4 b= -19.73						Lim. K mag.= 8.2						d	NGC 1999
ABC+				7.69	.10	(0.11)	6.98	.09	(0.20)	5.91		(0.43)	4.36		(0.71)	c	V380 Ori
IRS 1	5 36 24.9	-6 44 41	7.7														
IRS 2	5 36 21.2	-6 45 38	8.2	11.08	.13	(-1.26)	9.30		(-0.73)	8.21		(-0.49)				c	
12 Gem	6 19 22.4	23 16 29		l= 188.7 b= 3.79						Lim. K mag.= 8.5						d	HD 43836
A				5.70		(0.90) -	5.48		(0.80)	5.36		(0.65)	5.32	.06	(0.33)	d	Cr 89
B				7.14		(0.33)	6.17		(0.53)	5.90		(0.44)	5.83	.07	(0.12)	d	
IRS 1	6 19 29.4	23 20 5	8.6	9.47		(-0.61)	8.74		(-0.51)	8.64		(-0.67)				d	
IRS 2	6 19 26.0	23 16 59	6.0	7.16		(0.32)	6.21	.06	(0.51)	5.95		(0.42)	5.83	.09	(0.12)	d	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
ADS 5165	6 31 55.5	4 56 35		l= 206.3 b= -2.07						Lim. K mag.= 8.1						d	NGC 2244
A				6.48		(0.59)	6.45		(0.42)	6.42		(0.23)				d	HD 46150
IRS 1	6 32 7.3	4 58 23	8.1														HD 46180
IRS 2	6 32 1.6	5 1 35	8.0	8.51		(-0.23)	7.87		(-0.16)	7.78		(-0.33)				d	Johnson 13
IRS 3	6 31 52.5	4 57 7	7.0	8.29		(-0.14)	7.22		(0.11)	6.90		(0.04)				d	Johnson 36
IRS 4	6 31 52.4	5 1 59	7.3														HD 46149
ADS 5316	6 40 38.3	9 47 18		l= 203.0 b= 2.08						Lim. K mag.= 8.1						d	NGC 2264
A				8.67		(-0.29)	8.66		(-0.48)	8.69		(-0.69)				d	HD 47755
B				8.33		(-0.16)	7.72		(-0.10)	7.31		(-0.14)				d	Walker 67
IRS 1	6 40 48.9	9 51 49	8.1														BD 9 1336
IRS 2	6 40 28.4	9 49 8	8.4														HD 47732
IRS 3	6 40 24.6	9 46 14	7.7	8.61		(-0.27)	8.26		(-0.32)	7.66		(-0.28)				d	BD 9 1330
S Mon	6 40 58.7	9 53 45		l= 202.9 b= 2.20						Lim. K mag.= 8.7						d	HD 47839
IRS 1	6 41 9.4	9 59 42	7.1	9.46	.07	(-0.61)	7.77		(-0.12)	7.09		(-0.05)	6.55	.16	(-0.17)	d	NGC 2264
IRS 2	6 40 48.8	9 51 48	8.5														BD 9 1336
D0637.2+09	6 42 37.1	9 1 9		l= 203.9 b= 2.16						Lim. K mag.= 8.4						d	
ABC				9.11	.07	(-0.47)	8.83	.06	(-0.55)	8.66	.06	(-0.68)				d	
IRS 1	6 42 40	9 4.1	7.7	8.93	.07	(-0.40)	7.89		(-0.17)	7.57		(-0.24)				d	
Tau CMa	7 18 42.4	-24 57 17		l= 238.2 b= -5.54						Lim. K mag.= 8.5						d	HD 57061
A										5.1	.2	(0.75)				d	NGC 2362
IRS 1	7 18 42	-25 0.2	8.5														Johnson 20
HD 57281	7 19 37.3	-24 1 32		l= 237.5 b= -4.93						Lim. K mag.= 9.2						d	vR 96
IRS 1	7 19 49.4	-23 56 42	7.5	8.94	.07	(-0.40)	7.92		(-0.18)	7.57		(-0.24)				d	
IRS 2	7 19 29.7	-24 3 9	9.4														

(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
VY CMa		7 22 58.1	-25 46 3		1= 239.4 b= -5.07						Lim. K mag.= 8.0						d	ADS 6033
	A										-0.6	.2	(3.03)				d	
IRS	1	7 23 12.8	-25 44 43	8.8	9.69	.07	(-0.70)	8.78		(-0.53)	8.46	.06	(-0.60)				d	
IRS	2	7 23 7.4	-25 45 27	8.3	9.14		(-0.48)	8.53		(-0.43)	8.31		(-0.54)				d	
IRS	3	7 22 48.8	-25 39 58	8.4														
ADS 6255		7 38 49.3	-26 48 8		1= 242.0 b= -2.44						Lim. K mag.= 8.3						d	HD 61555
	A										4.6	.2	(0.95)				d	
IRS	1	7 39 4	-26 49.6	6.6	7.68		(0.11)	6.76		(0.29)	6.50		(0.20)	6.29	.14	(-0.07)	d	
HD 71304		8 24 55.7	-44 18 4		1= 261.8 b= -3.77						Lim. K mag.= 7.7						a	
	ABC										7.1	.2	(-0.05)				a	
HD 76838		8 57 7.6	-43 15 23		1= 264.5 b= 1.46						Lim. K mag.= 8.4						d	vBH 25cde
	AB				7.31		(0.26)	7.31		(0.07)	7.29		(-0.13)				d	vBH 25c
T Anon		10 38 31.6	-58 38 58		1= 286.4 b= -0.12						Lim. K mag.= 8.2						d	
	ABC										8.2	.3	(-0.49)				d	
IRS	1	10 38 45.9	-58 36 22	6.7	8.56		(-0.25)	7.21		(0.11)	6.72		(0.11)	6.35	.11	(-0.09)	d	
IRS	2*	10 38 39.5	-58 36 25	8.0	10.17	.09	(-0.89)	8.88	.07	(-0.57)	8.41	.07	(-0.58)				d	
IRS	3	10 38 39.6	-58 37 47	6.2	8.35		(-0.16)	6.84		(0.26)	6.25		(0.30)	5.90	.07	(0.10)	d	
IRS	4	10 38 37.3	-58 38 34	8.2														
IRS	5	10 38 30.8	-58 40 44	8.5	11.05	.32	(-1.24)	9.18		(-0.69)	8.42		(-0.58)				e	
IRS	6	10 38 24.6	-58 36 7	8.3														
CP-57 3635		10 39 9.5	-58 37 2		1= 286.4 b= -0.05						Lim. K mag.= 8.3						a	HDE 303176
	ABC							9.68	.08	(-0.89)	9.74	.10	(-1.11)				a	LSS 1719
IRS	1	10 39 28.6	-58 38 52	6.4	8.78		(-0.34)	7.06		(0.17)	6.37		(0.25)	6.03	.13	(0.04)	d	
IRS	2	10 38 45.9	-58 36 22	6.7														
IRS	3	10 38 39.6	-58 37 47	6.2														

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
CP-59 2505	10 42 45.5	-60 12 3		l= 287.6 b= -1.22						Lim. K mag.= 7.4						a	
ALL							8.68	.06	(-0.49)	8.66	.06	(-0.68)				a	LSS 1794
ALL				8.77		(-0.33)	8.77		(-0.52)	8.65		(-0.67)				d	
IRS 1	10 42 52.7	-60 9 2	7.4														BG Car
IRS 2*	10 42 46.4	-60 10 25	6.7	8.46		(-0.21)	7.56		(-0.04)	7.29		(-0.13)				d	
IRS 3	10 42 53.8	-60 12 53	5.7	7.19		(0.31)	6.14		(0.54)	5.76		(0.49)	5.62		(0.20)	d	
IRS 4	10 42 26.1	-60 9 20	7.1	8.96		(-0.41)	7.84		(-0.15)	7.45		(-0.19)				d	A
IRS 4	10 42 22.9	-60 9 8	7.1														B
HD 93129	10 43 56	-59 32.9		l= 287.41 b= -0.58						Lim. K mag.= 7.6						a	Tr14
ALL				6.23		(0.69)	6.11		(0.55)	5.96		(0.41)	5.79		(0.14)	e	ap=17"
ALL				6.15		(0.72)	6.00		(0.60)	5.86		(0.45)	5.59		(0.22)	e	ap=25"
ALL				6.08		(0.75)	5.88		(0.64)	5.70		(0.51)	5.45		(0.27)	e	ap=34"
ALL				5.85		(0.85)	5.66		(0.73)	5.45		(0.62)				e	ap=51"
IRS 1	10 44 7.2	-59 34 32	6.4	7.21		(0.30)	7.12		(0.15)	7.03		(-0.03)				e	HD 93160
IRS 1	10 44 8.9	-59 34 36	6.4	7.41		(0.22)	7.28		(0.08)	7.20		(-0.09)				e	HD 93161
IRS 2	10 44 15.0	-59 34 31	6.1	8.77		(-0.33)	6.97		(0.21)	6.14		(0.34)	5.61	.06	(0.21)	d	
IRS 3	10 43 39.0	-59 29 19	8.0														
CP-59 2554	10 44 0.5	-60 6 5		l= 287.7 b= -1.06						Lim. K mag.= 7.7						d	Cr 228
ABC							8.53		(-0.43)	8.54		(-0.63)				a	
ABC				8.44		(-0.20)	8.40		(-0.37)	8.41		(-0.58)				e	Cr228-67,68
IRS 1	10 44 22.9	-59 59 36	5.4														HD 93206
IRS 2	10 44 5.5	-59 59 43	7.5														HD 305520
IRS 3	10 44 3.8	-60 0 19	7.6														CR228-45
IRS 4	10 44 0.0	-60 5 10	7.6							7.88		(-0.37)				e	HD 93146
IRS 4	10 43 59.2	-60 5 13	9.1														
IRS 5	10 43 52.2	-60 7 4	6.0														HD 93131
IRS 6	10 43 45.0	-60 3 11	7.7	8.81		(-0.35)	7.76		(-0.12)	7.36		(-0.16)				d	
IRS 7	10 43 36.8	-60 5 1	6.6	8.23		(-0.12)	7.02		(0.19)	6.53		(0.18)	6.32	.10	(-0.08)	d	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
HD 93249	10 44 43.9	-59 21 26		l= 287.4 b= -0.36						Lim. K mag.= 7.8						d	Tr 15
ABC				7.62		(0.14)	7.67		(-0.08)	7.73		(-0.31)				d	
IRS 1	10 45 8.2	-59 22 55	7.8	9.33		(-0.56)	8.19		(-0.29)	7.61		(-0.26)				d	
IRS 2	10 44 47.0	-59 24 44	2.4														RT CAR
IRS 3	10 44 45.0	-59 15 52	7.6	8.74		(-0.32)	7.90		(-0.17)	7.61		(-0.26)				d	
IRS 4	10 44 36.0	-59 24 16	7.3	8.05		(-0.04)	7.50		(-0.01)	7.16		(-0.08)				d	Tr15-18
IRS 5	10 44 20	-59 14.7	7.3	10.01	.07	(-0.83)	8.38		(-0.37)	7.53		(-0.23)				d	
IRS 6	10 44 19.8	-59 16 59	6.9														HD 93190
IRS 7	10 44 54.7	-59 16 44	8.1														
IRS 7	10 44 49.5	-59 16 47	8.1														
Eta Car	10 45 3.7	-59 41 0		l= 287.6 b= -0.63						Lim. K mag.= 7.3						d	HD 93308
IRS 1	10 45 18.6	-59 43 48	6.9														Tr 16
IRS 2	10 45 15.3	-59 37 53	7.9														
IRS 3	10 45 11.0	-59 40 6	5.8	7.80		(0.07)	6.54		(0.38)	6.00		(0.40)	5.54		(0.24)	d	
IRS 4	10 44 55.3	-59 38 1	7.9	9.31	.07	(-0.55)	8.63	.07	(-0.47)	8.04		(-0.43)				d	
IRS 5	10 44 48.8	-59 36 53	5.7	7.98		(-0.02)	6.37		(0.45)	5.72		(0.51)	5.31		(0.33)	d	
IRS 6	10 44 45.0	-59 33 55	6.8														HD 93250
IRS 7	10 44 43.8	-59 38 16	8.2	10.30		(-0.94)	9.11		(-0.66)	8.38		(-0.57)				e	
IRS 7	10 44 40.8	-59 38 18	8.2														
HD 93632	10 47 12.7	-60 5 51		l= 288.0 b= -0.87						Lim. K mag.= 7.2						a	Bo 11
ABC							8.49	.06	(-0.41)	8.42	.06	(-0.58)				a	LSS 1911
ABC				8.31		(-0.15)	8.06		(-0.24)	7.92		(-0.38)				e	
F				7.33		(0.25)	7.11		(0.15)	6.82		(0.07)				e	LSS 1907
F							7.04		(0.18)	6.90	.16	(0.04)				a	
IRS 1	10 47 29.5	-60 4 15	7.0	7.89		(0.03)	7.19		(0.12)	7.00		(-0.01)				d	
IRS 2	10 47 24.9	-60 6 47	7.4														
CP-62 1837	10 58 16.2	-62 52 2		l= 290.4 b= -2.77						Lim. K mag.= 7.5						a	HDE 308122
ABC				2.17		(2.32)	0.93		(2.62)	0.40		(2.63)	0.01		(2.45)	a	ap=17"
ABC				1.95		(2.40)	0.95		(2.61)	0.36		(2.65)	- 0.02		(2.46)	a	ap=34"
ABC				1.76		(2.48)	0.70		(2.71)	0.24		(2.70)	- 0.11		(2.50)	d	ap=17"
ABC				1.72		(2.50)	0.66		(2.73)	0.21		(2.71)				d	ap=68"
IRS 1	10 57 57.2	-62 47 52	7.1														

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
CP-59 2944	11 1 17.7	-59 50 32		l= 289.5 b= 0.13						Lim. K mag.= 7.6						d	Pismis 17
AP							9.27	.06	(-0.72)	8.99	.18	(-0.81)				d	vBH 46a
CDE							9.28	.07	(-0.73)	8.85	.18	(-0.75)				d	vBH 46bcd
IRS 1	11 1 19.1	-59 48 42	7.6	9.20		(-0.50)	8.04		(-0.23)	7.64		(-0.27)				e	
IRS 2	11 1 9.1	-59 47 48	5.9	7.01		(0.38)	6.28		(0.48)	6.03		(0.38)				d	Lod 3640 M0
IRS 3	11 1 34.3	-59 46 9	8.0														
HD 97950	11 15 9	-61 15.7		l= 291.62 b= -0.52						Lim. K mag.= 6.9						a	NGC 3603
ALL							5.82		(0.67)	5.48		(0.60)	4.98	.07	(0.46)	a	
ALL							5.82		(0.67)	5.47		(0.61)	5.08	.06	(0.42)	a	
IRS 4	11 15 3.8	-61 14 20	4.4	6.87		(0.44)	5.18		(0.92)	4.40		(1.04)	3.69		(0.98)	d	
IRS 5	11 14 51.3	-61 13 51	5.5														
IRS 6	11 15 26.2	-61 13 41	4.7	6.18		(0.71)	5.14		(0.94)	4.75		(0.90)	4.52		(0.65)	d	
IRS 8a	11 15 11.4	-61 16 10								8.3	.2	(-0.53)				e	ap=17"
IRS 8b	11 15 9.6	-61 16 20								8.6	.2	(-0.65)				e	ap=17"
IRS 8+9	11 15 15	-61 16.7	6.6	8.12		(-0.07)	7.45		(-0.02)	6.35		(0.26)				e	ap=51"
IRS 8+9	11 15 15	-61 16.7	6.6	8.11		(-0.07)	7.48		(-0.01)	6.34		(0.26)				d	ap=51"
IRS 9*	11 15 12.4	-61 16 43								8.0	.2	(-0.41)				e	ap=17"
IRS 9*	11 15 12.4	-61 16 43	6.6	9.60	.07	(-0.66)	8.84	.06	(-0.55)	7.53		(-0.23)	5.64	.07	(0.20)	d	ap=25"
IRS 9*	11 15 12.4	-61 16 43	6.6	9.09		(-0.46)	8.26		(-0.32)	7.01		(-0.02)				e	ap=34"
OFF	11 15 09	-61 16.7								9.75		(-1.11)				e	ap=17"
OFF	11 15 09	-61 16.7								9.14		(-0.87)				e	ap=34"
IRS 15	11 15 25.5	-61 12 3	6.6	8.33		(-0.16)	7.14		(0.14)	6.78		(0.08)				d	
IRS 16*	11 15 17.8	-61 14 50	6.4	9.75	.07	(-0.73)	7.40		(0.04)	5.92		(0.43)	4.38		(0.70)	d	
HD 101190	11 38 10.0	-63 11 49		l= 294.8 b= -1.49						Lim. K mag.= 7.3						a	IC 2944
A							7.25		(0.10)	7.19		(-0.09)				a	ap=17"
B							10.30	.25	(-1.13)	9.43	.08	(-0.99)				a	ap=17"
ABC							7.18		(0.12)	7.10		(-0.05)				a	
IRS 1	11 38 7.4	-63 10 30	7.1	9.44	.07	(-0.60)	7.85		(-0.15)	7.13		(-0.07)				d	
IRS 2	11 38 8.7	-63 13 12	4.1	5.80	.07	(0.87)	4.63		(1.14)	4.20		(1.12)	3.81		(0.93)	d	Ar&Mau-42

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
HD 104901	12 4 46.9	-61 59 48		l= 297.5 b= 0.38						Lim. K mag.= 7.5						a	
A							6.66		(0.33)	6.62		(0.15)				a	
B							5.89		(0.64)	5.21		(0.71)	3.90		(0.90)	a	Henize 747
B				6.42		(0.62)	6.04		(0.58)	5.38		(0.64)	4.10		(0.82)	e	CP-61 2935
C							10.02	.11	(-1.02)	10.44	.51	(-1.39)				a	
IRS 1	12 4 58.0	-61 56 40	6.4	8.94		(-0.40)	7.19		(0.12)	6.42		(0.23)	5.86	.06	(0.11)	d	
IRS 2	12 4 42.8	-62 1 26	7.2														
IRS 3	12 4 32.1	-61 56 57	6.6	9.46	.08	(-0.61)	7.49		(-0.01)	6.60		(0.16)	6.08	.07	(0.02)	d	
IRS 4	12 4 24.0	-61 59 19	7.7														
IRS 5	12 4 30.2	-62 2 17	7.8														
HD 146479	16 18 55.1	-50 23 31		l= 333.0 b= -0.06						Lim. K mag.= 7.3						a	Lynga 8
AB							9.15	.09	(-0.67)	9.25	.17	(-0.91)				a	ap=17"
IRS 1	16 19 1.4	-50 20 21	7.1	9.00		(-0.42)	7.83		(-0.15)	7.18		(-0.09)				e	
IRS 2	16 19 2.5	-50 22 57	6.0	7.19		(0.31)	6.05		(0.58)	5.68		(0.52)	5.44		(0.28)	e	
IRS 3	16 19 14.6	-50 24 25	3.3	7.09		(0.35)	4.58		(1.16)	3.29		(1.47)	1.94		(1.67)	a	
IRS 3	16 19 14.6	-50 24 25	3.3	7.00		(0.38)	4.35		(1.25)	3.04		(1.57)	1.80		(1.73)	e	
IRS 4	16 19 4.0	-50 19 8	7.4														
IRS 5	16 18 48.0	-50 23 8	7.3														
IRS 5	16 18 47.9	-50 23 41	7.3														
HD 150136	16 41 20.2	-48 45 47		l= 336.7 b= -1.57						Lim. K mag.= 7.3						a	NGC6193
AB							5.04	.06	(0.98)	4.98	.06	(0.80)	4.93	.08	(0.48)	a	ap=17"
C							6.32	.06	(0.47)	6.17	.16	(0.33)				a	ap=17"
IRS 1	16 41 8	-48 44.9	7.0	9.23		(-0.52)	7.60		(-0.05)	7.04		(-0.03)				e	
IRS 2	16 41 30	-48 47.9	6.7														H & H 147
IRS 3	16 41 11	-48 42.6	6.4	8.74		(-0.32)	6.99		(0.20)	6.34		(0.26)	5.71	.06	(0.17)	e	
IRS 4	16 41 38	-48 43.3	5.4	7.43		(0.21)	5.80		(0.68)	5.22		(0.71)	4.64		(0.60)	e	H & H 73

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
HD 152723	16 56 54.5	-40 30 43		l= 344.8 b= 1.61						Lim. K mag.= 7.9						e	Tr 24
ABC				6.64		(0.53)	6.59		(0.36)	6.60		(0.16)				e	
IRS 1	16 56 54.2	-40 23 14	6.9														
IRS 2	16 57 4.8	-40 23 17	7.7														
IRS 3	16 57 1.4	-40 23 35	7.0	7.87		(0.04)	7.23		(0.10)	7.11		(-0.06)				e	HDE 322426
IRS 4*	16 57 2.0	-40 29 4	7.1	10.14		(-0.88)	8.58		(-0.45)	7.94		(-0.39)				e	
IRS 5	16 57 4.9	-40 25 48	6.1	8.89		(-0.38)	6.88		(0.24)	5.98		(0.40)	5.36	.09	(0.31)	e	
IRS 6	16 56 55.2	-40 28 6	7.0														
IRS 7	16 56 51.3	-40 24 36	5.3	7.28		(0.27)	5.89		(0.64)	5.37		(0.65)	5.06	.06	(0.43)	e	
IRS 7	16 56 50.2	-40 25 7	5.3														
IRS 8	16 56 43.3	-40 30 51	7.9														
IRS 9*	16 56 39.4	-40 31 10	7.4	10.18	.06	(-0.90)	8.44		(-0.39)	7.82		(-0.34)				e	
IRS 10	16 56 51.8	-40 21 54	3.9	6.94		(0.41)	4.98		(1.00)	3.94		(1.22)	3.20		(1.17)	e	
HD 159176	17 34 42.3	-32 34 55		l= 355.67 b= 0.05													NGC 6383
ABC							5.52		(0.79)	5.50		(0.60)	5.39	.07	(0.30)	a	
ADS 10820	17 50 41.1	-29 16 43		l= 0.3 b= -1.12						Lim. K mag.= 7.0						e	HD 162120
A							7.84	.06	(-0.15)	7.78	.06	(-0.33)				a	ap=17"
BCD							7.90	.06	(-0.17)	7.84	.06	(-0.35)				a	ap=17"
IRS 1	17 50 45.9	-29 9 29	6.7														
IRS 2	17 50 49	-29 19.3	7.2														
IRS 3	17 50 41.7	-29 19 37	6.9														
IRS 4	17 50 42.9	-29 11 57	6.8														
IRS 5	17 50 37.1	-29 19 27	6.5														
IRS 6	17 50 35.0	-29 15 25	7.0														
IRS 7	17 50 33	-29 14.1	7.4														
IRS 8	17 50 27.8	-29 19 1	4.5														
IRS 9	17 50 50	-29 13.9	7.5														
IRS 10	17 50 49.6	-29 14 25	7.6														
IRS 11	17 50 48	-29 13.0	7.2														
IRS 12	17 50 28	-29 15.3	7.8														
IRS 13	17 50 33	-29 17.6	7.2														
IRS 14	17 50 27.8	-29 17 42	7.3														

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
ADS 10991	18 2 23.4	-23 1 51		1=	7.0 b=	-0.25				Lim. K mag.= 7.2						a	HD 164492
AB							7.32		(0.07)	7.17		(-0.08)	7.24	.34	(-0.45)	a	ap=17"
CD							7.65	.06	(-0.07)	7.10		(-0.05)	5.22	.06	(0.37)	a	ap=17"
CD				7.34		(0.25)	7.34		(0.06)	6.82		(0.07)	5.42		(0.29)	e	LkH$_{\alpha}$ 123
IRS 1	18 2 28.3	-22 55 54	3.5	5.33		(1.05)	4.01		(1.39)	3.50		(1.40)	3.08		(1.22)	a	Og&Ish 130
IRS 2	18 2 29	-22 57.2	5.9	10.57		(-1.05)	7.35		(0.06)	5.97		(0.41)	4.97		(0.47)	e	M 20
IRS 3	18 2 32.4	-22 57 53	6.4														CD-22 12456
IRS 4	18 2 35.9	-22 58 23	6.0	8.84		(-0.36)	6.82		(0.27)	6.08		(0.36)				e	
IRS 5	18 2 34.9	-22 59 41	6.7	10.92	.20	(-1.19)	8.19	.07	(-0.29)	6.98		(-0.01)				e	
HD 164536	18 2 38.5	-24 15 21		1=	6.0 b=	-0.91				Lim. K mag.= 7.4						a	M 8
AB							7.18		(0.12)	7.11	.16	(-0.06)				a	
C							8.59		(-0.45)	8.57	.17	(-0.64)				a	CD-24 13785
IRS 1*	18 2 33.6	-24 15 11	7.4	8.65		(-0.28)	7.50		(-0.01)	6.89		(0.04)				e	Blan&Grnt-1
IRS 2	18 2 51.0	-24 16 56	4.5														HD 164584
IRS 3	18 2 36.9	-24 10 19	6.8	8.85		(-0.36)	7.26		(0.09)	6.64		(0.14)				e	

(1)	(6)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
HDE 313706	18 3 1.9	-22 33 18		1= 7.5 b= -0.15						Lim. K mag.= 7.4						e	
IRS 1	18 3 16.7	-22 32 44	7.3	10.41		(-0.99)	8.36		(-0.36)	7.45		(-0.19)				e	
IRS 2	18 3 15.8	-22 35 27	5.9	8.80		(-0.34)	6.71		(0.31)	5.76		(0.49)	5.08		(0.42)	e	
IRS 3	18 3 15.9	-22 36 44	6.3														
IRS 3	18 3 17.3	-22 36 41	6.3	8.80		(-0.34)	7.01		(0.19)	6.23		(0.30)	5.59		(0.22)	e	
IRS 3	18 3 14.8	-22 36 19	6.3														
IRS 4	18 3 12.5	-22 31 58	5.7	7.92		(0.02)	6.36		(0.45)	5.77		(0.49)	5.37		(0.31)	e	
IRS 5	18 3 14.0	-22 28 2	4.5	6.62		(0.54)	5.11		(0.95)	4.43		(1.02)	3.91		(0.89)	e	
IRS 6	18 3 4.8	-22 25 54	7.5														
IRS 7	18 3 12.2	-22 26 38	6.9														
IRS 8	18 2 51	-22 27.5	7.5														
IRS 9	18 3 7.9	-22 31 54	6.9	10.70	.08	(-1.10)	8.07		(-0.24)	7.14		(-0.07)				e	
IRS 10	18 3 7.7	-22 34 10	7.3	9.75		(-0.73)	7.86		(-0.16)	7.10		(-0.05)				e	
IRS 11*	18 3 7	-22 31.9	6.3				8.30		(-0.33)	6.90		(0.04)	5.95		(0.08)	e	
IRS 12	18 2 58.9	-22 25 15	6.3	9.87		(-0.77)	7.34		(0.06)	6.29		(0.28)	5.52		(0.25)	e	
IRS 13	18 3 4	-22 32.0	{6.8}							8.12		(-0.46)				e	A
IRS 13	18 3 4	-22 32.0	{6.8}							7.71		(-0.30)				e	B
IRS 14	18 3 0.6	-22 28 22	7.3														
IRS 15	18 3 0.9	-22 36 25	7.6	10.52	.09	(-1.03)	8.45		(-0.39)	7.30		(-0.13)	6.28		(-0.07)	e	
IRS 16	18 2 56.9	-22 30 24	6.1	8.70		(-0.31)	6.94		(0.22)	6.20		(0.32)	5.63		(0.20)	e	
IRS 17	18 2 57.6	-22 26 49	7.7														
IRS 18*	18 2 53	-22 35.4	7.6				9.32		(-0.74)	8.19		(-0.49)				e	
IRS 19	18 2 50	-22 35.2	5.7	10.29	.11	(-0.94)	7.41		(0.03)	5.61		(0.55)	3.66		(0.99)	e	
IRS 19	18 2 50	-22 35.2	5.7	10.47	.09	(-1.01)	7.47		(0.01)	5.70		(0.52)	3.79		(0.94)	e	
IRS 20	18 2 53.7	-22 32 39	7.4	10.48		(-1.02)	8.43		(-0.39)	7.68		(-0.29)				e	
IRS 20	18 2 54.7	-22 33 16	7.4														
ADS 11169	18 13 45.7	-21 3 32		1= 10.00 b= -1.60													
A							3.07		(1.77)	2.96		(1.61)	2.78		(1.34)	a	NGC 6526 HD 166937

(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
ADS	11168	18 13 46.2	-18 48 35		l= 12.0 b= -0.53						Lim. K mag.= 7.2						a	HD 166934
	ABC				7.20		(0.31)	7.08		(0.16)	7.04		(-0.03)				e	
IRS	1	18 13 49.0	-18 46 31	5.0	8.65		(-0.28)	6.15		(0.54)	5.10		(0.76)	4.39	.12	(0.70)	e	
IRS	2	18 13 48.1	-18 46 31	6.2	9.80		(-0.74)	7.45		(0.02)	6.36		(0.25)				e	
IRS	3*	18 13 50.6	-18 46 17	7.1	9.91	.06	(-0.79)	7.51		(-0.02)	6.39		(0.24)				e	
IRS	4	18 13 56.3	-18 41 9	5.3														
IRS	5	18 13 50.0	-18 49 20	7.1														
IRS	6	18 13 46.4	-18 47 1	7.1														
IRS	7	18 13 53.1	-18 45 49	6.2														HD 166982
IRS	7	18 13 55.2	-18 45 8	6.4														
IRS	8	18 13 56.1	-18 42 55	6.4	8.55		(-0.24)	6.90		(0.24)	6.20		(0.32)	5.72		(0.17)	e	
IRS	9	18 13 33.9	-18 44 58	7.2	9.81	.07	(-0.75)	7.93		(-0.19)	7.15		(-0.07)				e	
IRS	9	18 13 33.9	-18 44 58	7.2	9.77		(-0.73)	7.81		(-0.14)	7.02		(-0.02)	6.60	.18	(-0.19)	e	
IRS	10	18 13 48	-18 43.9	6.8	11.12	.09	(-1.27)	8.28		(-0.33)	7.00		(-0.01)	6.41		(-0.12)	e	
IRS	11	18 13 39.7	-18 44 48	6.7	7.83		(0.05)	6.92		(0.23)	6.62		(0.15)				e	
IRS	12	18 13 52.3	-18 44 1	7.2	10.08		(-0.86)	8.37		(-0.36)	7.55		(-0.23)				e	
ADS	11193	18 15 16.6	-18 59 34		l= 11.99 b= -0.93													Markrn_38
	AP							6.82		(0.27)	6.82		(0.07)	7.11		(-0.40)	a	HD 167287
	BR							10.38	.13	(-1.17)	10.35	.25	(-1.35)				a	
ADS	11227	18 17 31.4	-16 31 29		l= 14.4 b= -0.22						Lim. K mag.= 7.2						a	HD 167792
IRS	1	18 17 39.1	-16 35 29	6.5														IC_4701
IRS	2	18 17 27.7	-16 37 49	5.1	8.83		(-0.36)	6.25		(0.50)	5.21		(0.71)	4.54		(0.64)	e	
IRS	3	18 17 25.3	-16 39 7	5.9	8.10		(-0.06)	6.59		(0.36)	6.00		(0.40)				e	
IRS	4	18 17 39.3	-16 39 27	5.7	7.11		(0.34)	6.15		(0.54)	5.84		(0.46)				e	
IRS	5	18 17 36.3	-16 32 7	6.8														
IRS	6	18 17 33.2	-16 33 29	7.2				9.38	.06	(-0.77)	7.53		(-0.23)					
IRS	6	18 17 33.2	-16 33 29	7.2				9.05		(-0.63)	7.51		(-0.22)	6.56	.13	(-0.18)		
IRS	7	18 17 32	-16 34.9	6.0	10.96	.23	(-1.21)	7.52		(-0.02)	6.08		(0.36)	5.14		(0.40)	e	

(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
D1827.6-08		18 33 3.7	-8 44 55		l= 23.1	b=	0.06				Lim. K mag.= 7.5						e	
ABC					8.28		(-0.14)	7.51		(-0.02)	7.41		(-0.18)				e	
IRS	1	18 33 18.2	-8 43 47	4.0	6.99		(0.39)	4.75		(1.10)	3.79		(1.28)	3.04		(1.24)	e	
IRS	2	18 33 12.9	-8 47 12	7.6														
IRS	3	18 33 12.7	-8 46 14	7.3	9.34		(-0.56)	7.93		(-0.19)	7.38		(-0.17)				e	
IRS	4	18 33 11.8	-8 38 49	7.8														
IRS	5*	18 33 6.6	-8 41 58	7.5	11.28	.10	(-1.34)	8.72		(-0.50)	6.92		(0.03)	5.65	.13	(0.20)	e	
IRS	6	18 33 8.2	-8 47 2	7.3	9.47		(-0.61)	7.72		(-0.10)	7.04		(-0.03)				e	
IRS	7	18 32 58.4	-8 46 19	5.4	7.19		(0.31)	5.97		(0.61)	5.40		(0.64)	5.07		(0.43)	e	
IRS	8	18 32 55.6	-8 48 18	3.9	7.20		(0.31)	4.89		(1.04)	3.81		(1.27)	3.04		(1.24)	e	
IRS	9	18 32 51	-8 40.7	6.6														
IRS	10	18 33 11	-8 44.1	7.7														
ADS 11667		18 46 28.4	0 57 41		l= 31.51	b=	0.67											HD 173654
A								5.64		(0.74)	5.60	.06	(0.56)	5.47		(0.27)	a	ap=17"
B								6.84		(0.26)	6.70	.06	(0.12)				a	ap=17"
C								6.75		(0.29)	6.47		(0.21)				a	ap=17"
ADS 12696		19 37 9.3	29 20 2		l= 64.00	b=	3.99											HD 185268
A+								6.76	.06	(0.29)	6.79		(0.08)	6.64	.13	(-0.21)	b	
HD 189864		20 0 44.6	36 35 24		l= 72.77	b=	3.38											
A+								7.29	.06	(0.08)	7.00	.06	(-0.01)	7.14	.10	(-0.41)	b	
B+								4.12		(1.35)	3.62		(1.35)	3.37		(1.11)	b	
C											9.15	.13	(-0.87)				b	
D											8.73	.13	(-0.71)				b	
ADS 13312		20 3 29.3	36 1 30		l= 72.6	b=	2.61				Lim. K mag.= 6.2						c	NGC 6871
AB+								6.18		(0.52)	6.18		(0.32)	6.21		(-0.04)	b	HD 190429
C											9.01	.20	(-0.82)				b	
IRS	1	20 3 6.9	36 0 12	7.2							7.16		(-0.08)				c	
IRS	2	20 3 16.4	36 5 37	5.5							5.51		(0.59)					
IRS	2	20 3 15.4	36 5 37	5.5													c	
IRS	2	20 3 15.2	36 5 25	5.5														
IRS	3+	20 3 32.7	35 56 54	2.9				3.43		(1.62)	2.86		(1.65)	2.39		(1.50)	c	IRC 40 376
IRS	4	20 3 8	35 56.5	6.1							6.07		(0.37)				c	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
ADS 13374	20 5 58.6	35 47 18		1=	72.65 b=	2.06											NGC 6871
A+							6.45		(0.42)	6.34		(0.26)	6.23	.07	(-0.05)	b	HD 190918
F+							6.87	.06	(0.25)	6.91		(0.03)	6.96	.07	(-0.34)	b	BD 35 3955
ADS 13376	20 6 1.2	35 45 57		1=	72.64 b=	2.04											BD 35 3957
A										7.41	.09	(-0.18)				b	
ADS 13789	20 23 3	40 47.7		1=	78.68 b=	2.05											
A										8.05	.14	(-0.43)				b	
ADS 14000	20 33 14.9	41 18 52		1=	80.2 b=	0.79				Lim. K mag.= 6.2						c	Cyg OB 2
A+							5.74		(0.70)	5.51		(0.59)	5.40		(0.30)	b	BD 40 4227
B+							6.98	.06	(0.20)	6.70		(0.12)	6.57	.06	(-0.18)	b	
D+							6.98		(0.20)	6.64		(0.14)	6.42		(-0.12)	b	
IRS 1+	20 33 10.6	41 15 6	5.6				5.98		(0.60)	5.61		(0.55)	5.41		(0.29)	c	Redd 35=S9
IRS 2	20 33 14.0	41 20 22	6.6							6.63		(0.14)				c	Redd 33=S7
IRS 3+	20 33 25.4	41 20 48	6.6	9.10	.21	(-0.46)	7.35	.08	(0.06)	6.56		(0.17)	5.88		(0.10)	c	
IRS 4+	20 33 31.7	41 18 54	5.9				6.52		(0.39)	5.88		(0.44)	5.32	.08	(0.32)	c	
IRS 5+	20 33 30.7	41 15 21	5.6				5.97		(0.61)	5.60		(0.56)	5.28		(0.34)	c	Redd 36=S18
IRS 6+	20 33 39.0	41 19 27	6.5				6.87		(0.25)	6.50		(0.20)	6.03		(0.04)	c	Redd 37=S19
IRS 7+	20 33 39.5	41 22 34	4.6	7.05		(0.37)	5.43		(0.82)	4.55		(0.98)	4.12		(0.81)	c	Ack 78-0-97
HD 206183	21 38 26.2	56 58 26		1=	98.9 b=	3.40				Lim. K mag.= 6.2						c	IC 1396
ABC+							7.29	.13	(0.08)	7.17	.10	(-0.08)	7.40	.22	(-0.51)	b	
IRS 1	21 39 5	56 55.1	7.3							7.25	.09	(-0.11)				c	
ADS 16677	23 19 12.4	61 31 5		1=	112.17 b=	0.59											BD 60 2519
A							7.61	.07	(-0.06)	7.45	.07	(-0.19)				b	

Standard Star

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
HD 118716	15 0 27.4	-62 37 57		l= 317.16	b=	-3.38											HR 5132
	15 0 27.4	-62 37 57		2.84		(2.05)	3.00		(1.79)	3.01		(1.59)	2.97		(1.27)		ap=17"
	15 0 27.4	-62 37 57		2.79		(2.07)	2.93		(1.82)	2.96		(1.61)	2.94		(1.28)		ap=25"
	15 0 27.4	-62 37 57		2.78		(2.07)	2.91		(1.83)	2.91		(1.63)	2.98		(1.26)		ap=34"
	15 0 27.4	-62 37 57		2.81		(2.06)	2.92		(1.83)	2.91		(1.63)	2.98		(1.26)		ap=51"

TABLE 3.2

Observations_of_regions_centred_in_Southern_Herbig-Haro_Objects

(1)	R.A. (2000.) (2)	DEC. (3)	Scan (4)	J (5)	Er. (6)	Log Fl. (7)	H (8)	Er. (9)	Log Fl. (10)	K (11)	Er. (12)	Log Fl. (13)	L (14)	Er. (15)	Log Fl. (16)	(17)	Notes (18)
Haro 249	5 38 43	-7 12.8		l= 211.14 b= -19.44						Lim. K mag.= 8.3						d	
IRS 1	5 38 53.1	-7 12 44	4.5														HD 37507
IRS 2	5 38 42.8	-7 12 44	8.2	11.11	.10	(-1.27)	9.63	.10	(-0.87)	8.49	.06	(-0.61)	7.04	.14	(-0.37)	d	Haro 249
IRS 2	5 38 42.5	-7 12 59	8.2														Haro 249c
IRS 3	5 38 30	-7 10.8	8.3				9.90	.09	(-0.97)	9.17	.08	(-0.88)				d	
HH12-15	6 11 27	-6 8.8		l= 213.90 b= -11.68						Lim. K mag.= 8.8						d	
HHGGD20-23	7 24 54	-24 31.0		l= 238.45 b= -4.10						Lim. K mag.= 8.5						d	
IRS 1	7 25 6	-24 34.1	8.4	10.32	.08	(-0.95)	9.09	.06	(-0.65)	8.66	.07	(-0.68)				d	
HH46,47	8 25 51.2	-51 2 14		l= 267.4 b= -7.50						Lim. K mag.= 8.8							
IRS 1	8 25 43.0	-50 59 19	8.4	9.05		(-0.44)	8.51		(-0.42)	8.39	.06	(-0.57)				d	
IRS 2	8 25 41.4	-50 58 21	8.5													d	
HH49-50	11 6 3	-77 33.3		l= 297.23 b= -15.87						Lim. K mag.= 9.0						d	
IRS 1	11 6 54	-77 30.4	9.0														
IRS 2	11 6 51	-77 27.5	9.0														
HH51	11 9 51	-76 25.3		l= 296.93 b= -14.73						Lim. K mag.= 8.9							
IRS 1	11 10 24	-76 26.3	7.3	8.55		(-0.24)	7.60		(-0.05)	7.34		(-0.15)				d	
IRS 2	11 9 17	-76 23.3	8.9													d	
IRS 3	11 9 17	-76 28.0	8.6														
IRS 4	11 9 03	-76 18.3	6.2	7.60		(0.15)	6.55		(0.38)	6.27		(0.29)	6.30	.12	(-0.07)	d	
HH52,54	12 55 28	-76 57.8		l= 303.15 b= -14.07						Lim. K mag.= 9.0						d	
IRS 1	12 56 12	-76 52.5	8.9														
IRS 2	12 54 53	-76 58.7	9.0														
IRS 3	12 54 43	-76 59.2	9.0														
IRS 4	12 54 34	-76 58.1	7.3														

(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
HH 55		15 56 42	-37 52.2		l= 338.62 b= 11.85						Lim. K mag.= 8.8						e	
IRS	1	15 56 42.3	-37 49 14	6.9														
IRS	2	15 56 31.7	-37 45 41	8.8														
IRS	3	15 56 27.0	-37 49 26	8.5														
HH56-57		16 32 32	-44 55.4		l= 338.55 b= 2.12						Lim. K mag.= 7.8						e	
IRS	1	16 32 50.9	-44 51 19	6.7	9.16		(-0.49)	7.83		(-0.15)	7.00		(-0.01)	6.39		(-0.11)	e	
IRS	2	16 32 40.8	-44 50 44	7.5														
IRS	3	16 32 23.4	-44 50 39	7.5														
IRS	4	16 32 33.0	-44 57 34	7.4														
IRS	4	16 32 33.4	-44 57 20	7.4														
IRS	5	16 32 23.6	-44 52 11	7.2														
IRS	6	16 32 37.8	-44 51 40	7.7														
IRS	7	16 32 28.8	-44 52 2	8.0														
IRS	8	16 32 15.6	-44 52 5	7.6														
HHGGD25		17 20 22	-35 54.0		l= 351.26 b= 0.67						Lim. K mag.= 7.7						e	NGC 6334
IRS	2*	17 20 32	-35 51.5	6.5	8.34		(-0.16)	7.67		(-0.08)	7.03		(-0.03)				e	
IRS	3	17 20 7	-35 53.7	7.4				8.82		(-0.54)	7.74		(-0.31)				e	
IRS	4	17 20 33	-35 54.2	8.1													e	
IRS	5*	17 20 30.3	-35 52 46	7.6	10.34	.06	(-0.96)	9.09	.06	(-0.65)	8.17		(-0.48)				e	
IRS	6	17 20 9.6	-35 52 31	8.1														
IRS	7	17 20 26	-35 49.7	7.6														HD 156673 ?
IRS	8	17 20 18	-35 48.6	7.5														
vBH 65a		15 0 58.4	-63 16 55		l= 316.9 b= -3.98						Lim. K mag.= 8.3						e	
	A				10.58	.07	(-1.06)	9.00		(-0.61)	7.83		(-0.35)				e	
	A				10.51	.06	(-1.03)	8.88		(-0.57)	7.78		(-0.33)				e	
IRS	1	15 1 24.5	-63 16 10	6.5	8.39		(-0.18)	6.93		(0.22)	6.49		(0.20)	6.08	.08	(0.02)	e	
IRS	2	15 1 10.5	-63 14 19	8.3														
IRS	3	15 0 46.1	-63 17 59	6.2														
IRS	4	15 0 27.4	-62 37 57	6.1	9.14		(-0.48)	7.12		(0.15)	6.14		(0.34)	5.48		(0.26)	e	

NOTES TO TABLES 3.1 and 3.2:

* K magnitude from maps differs significantly from photometric measurement

\+ L value corresponds to L′ (3.8 microns)

TABLE 3.3

Observations of "reference" areas

	R.A. (2000) (2)	Dec. (3)	Scan (4)		Run (17)
HD 83058	9 34 8.8	-51 15 20		l= 274.60 b= 0.43 Lim. K mag.= 8.5	d
IRS 1	9 34 15	-51 14.5	6.6		
HD 86440	9 56 51.7	-54 34 04		l= 279.35 b= 0.11 Lim. K mag.= 8.1	d
IRS 1	9 57 10	-54 34.9	8.0		
IRS 2	9 57 1	-54 32.2	7.3		
IRS 3	9 56 38	-54 30.9	7.7		
HD 92740	10 41 17.6	-59 40 37		l= 287.2 b= -0.85 Lim. K mag.= 8.4	e
IRS 1	10 41 37.3	-59 38 34	9.0		
IRS 2	10 41 27.5	-59 40 34	8.6		
IRS 3	10 41 22.0	-59 34 13	8.0		
IRS 4	10 41 13.9	-59 39 33	6.2		
IRS 5	10 41 16	-59 41.8	8.3		
IRS 6	10 41 11.9	-59 43 45	7.3		
IRS 7	10 40 59.0	-59 34 45	8.3		
Y Car	10 33 12	-58 29.9		l= 285.69 b= -0.33 Lim. K mag.= 8.0	d
IRS 1	10 33 29	-58 29.1	7.0		
IRS 2	10 33 26	-58 26.8	7.7		
IRS 3	10 33 24	-58 27.9	7.2		
IRS 4	10 33 4	-58 29.6	7.7		
IRS 5	10 33 0	-58 33.0	7.8		
HD 93130	10 44 0	-59 52.5		l= 287.57 b= -0.86 Lim. K mag.= 8.1	e
IRS 1	10 44 28.0	-59 45 21	7.7		
IRS 2	10 44 12.0	-59 45 1	7.5		
IRS 3	10 44 12.6	-59 47 58	7.8		
IRS 4	10 44 2.1	-59 52 43	7.3		
IRS 5	10 43 49.5	-59 49 42	7.9		
IRS 6	10 43 47.3	-59 47 12	6.3		
IRS 7	10 43 37.9	-59 47 32	8.0		
HD108248/9	12 26 37	-63 6.0		l= 300.13 b= -0.36 Lim. K mag.= 7.9	d
IRS 1	12 27 2	-63 1.2	6.7		
IRS 2	12 26 51	-63 7.9	7.9		
IRS 3	12 26 44	-63 1.2	8.1		
IRS 4	12 26 36	-63 8.5	7.3		
IRS 5	12 26 32	-63 7.4	5.2		
IRS 6	12 26 21	-62 58.9	7.6		
IRS 7	12 26 19	-62 59.6	8.2		
IRS 8	12 26 9	-63 4.5	5.4		
IRS 9	12 26 14	-62 58.9	8.0		
HD 108610	12 28 55.0	-61 52 15		l= 300.23 b= 0.87 Lim. K mag.= 7.9	d
IRS 1	12 29 39	-61 52.1	7.3		
IRS 2	12 29 09	-61 48.2	7.2		
IRS 3	12 29 04	-61 52.3	7.9		
IRS 4	12 28 55	-61 47.4	1.3		
HD 113904	13 8 0.5	-65 18 21		l= 304.68 b= -2.49 Lim. K mag.= 8.0	d
IRS 1	13 8 26	-65 19.8	7.3		
IRS 2	13 8 22	-65 20.9	7.6		
IRS 3	13 7 48	-65 14.4	5.6		
IRS 4	13 7 31	-65 14.1	6.6		

	(2)	(3)	(4)		(17)
HD 122451	14 2 49.5	-60 22 21		l= 311.65 b= 1.28 Lim. K mag.= 8.0	d
IRS 1	14 3 6	-60 15.9	7.2		
IRS 2	14 3 1	-60 15.9	8.0		
IRS 3	14 2 39	-60 15.9	6.9		
IRS 4	14 2 36	-60 21.5	7.7		
IRS 5	14 2 29	-60 18.3	6.7		
HD 135379	15 17 31.4	-58 47 57		l= 320.89 b= -1.12 Lim. K mag.= 7.8	d
IRS 1	15 17 56	-58 51.1	7.8		
IRS 2	15 17 43	-58 40.9	8.0		
IRS 3	15 17 40	-58 43.2	7.5		
IRS 4	15 17 37	-58 48.7	7.5		
IRS 5	15 17 35	-58 42.6	8.1		
IRS 6	15 17 30	-58 44.8	7.9		
IRS 7	15 17 25	-58 43.1	8.0		
IRS 8	15 17 19	-58 40.9	6.7		
IRS 9	15 17 8	-58 41.6	6.8		
HD 145397	16 13 17.4	-54 37 49		l= 329.49 b= -2.53 Lim. K mag.= 7.9	e
IRS 1	16 13 11	-54 37.5	7.5		
IRS 2	16 13 03	-54 34.7	7.9		
IRS 3	16 12 58	-54 30.8	7.2		
IRS 4	16 13 00	-54 40.5	7.4		
IRS 5	16 12 55	-54 36.1	7.6		
HD 146686	16 19 51.1	-50 9 18		l= 333.30 b= 0.01 Lim. K mag.= 7.8	e
IRS 1	16 20 10	-50 1.6	6.6		
IRS 2	16 20 10	-50 2.9	6.8		
IRS 3	16 20 1	-50 3.3	6.8		
IRS 4	16 19 56	-50 3.9	5.1		
IRS 5	16 19 46	-50 8.6	7.6		
IRS 6	16 19 42	-50 9.2	6.2		
IRS 7	16 19 32	-50 10.2	5.6		
HD 161592	17 47 33.6	-27 49 50		l= 1.17 b= 0.21 Lim. K mag.= 7.3	e
IRS 1	17 47 47	-27 48.3	7.7		
IRS 2	17 47 43	-27 46.7	7.9		
IRS 3	17 47 40	-27 48.4	7.5		
IRS 4	17 47 42	-27 50.1	7.5		
IRS 5	17 47 40	-27 51.2	7.2		
IRS 6	17 47 39	-27 45.5	7.2		
IRS 7	17 47 37	-27 43.3	5.7		
IRS 8	17 47 34	-27 46.7	7.1		
IRS 9	17 47 32	-27 42.7	7.8		
IRS 10	17 47 32	-27 42.2	7.3		
IRS 11	17 47 32	-27 43.9	7.0		
IRS 12	17 47 29	-27 51.3	7.0		
IRS 13	17 47 24	-27 43.3	5.9		
IRS 14	17 47 24	-27 52.4	7.6		
IRS 15	17 47 22	-27 46.8	7.1		
IRS 16	17 47 20	-27 47.4	7.7		
IRS 17	17 47 19	-27 45.1	7.3		

		(2)	(3)	(4)		(17)
HDE 313845		18 5 23.3	-23 0 11		l= 7.4 b= -0.84 Lim. K mag.= 7.1	e
IRS	1	18 5 29.6	-22 52 50	5.3		
IRS	2	18 5 13.8	-22 52 50	6.3		
IRS	3	18 5 37	-22 58.2	7.1		
IRS	4	18 5 37.1	-23 1 51	5.9		
IRS	5	18 5 33.7	-23 0 50	6.6		
IRS	6	18 5 33.7	-23 1 22	7.0		
IRS	7	18 5 32.7	-23 0 20	6.6		
IRS	8	18 5 17	-22 58.0	7.2		
IRS	9	18 5 14.1	-22 53 59	7.2		
IRS	10	18 5 11.2	-22 53 19	6.9		
IRS	11	18 5 12.1	-23 2 6	6.9		
IRS	12	18 5 22	-22 57.6	7.7		
IRS	13	18 5 9	-22 55.9	7.7		
HD 171443		18 35 12.3	-8 14 23		l= 23.8 b= -0.17 Lim. K mag.= 7.8	e
IRS	1	18 35 26	-8 10.0	6.5		
IRS	2	18 35 22	-8 12.9	7.1		
IRS	3	18 35 21	-8 10.0	7.4		
IRS	4	18 35 21	-8 10.6	6.8		
IRS	5	18 35 14	-8 15.3	7.8		
IRS	6	18 35 13	-8 7.9	6.7		
IRS	7	18 35 12	-8 6.8	7.3		
IRS	8	18 35 10	-8 9.2	6.1		
IRS	9	18 35 10	-8 10.0	6.0		
IRS	10	18 35 7	-8 17.0	7.3		
IRS	11	18 35 0	-8 14.9	7.2		

Table 3.3 gives the results from the scans of the "reference" random areas, centred on bright stars for convinieence. The format is similar to that of Tables 3.1 and 3.2, except that no multifilter photometry is reported for any source.

2) Two - colour diagrams

The photometric results are presented summarised in the form of J-H vs H-K (Fig. 3.1), H-K vs K-L (Fig. 3.2) and J-K vs K-L (Fig 3.3) diagrams. The star components of the TTSs are plotted as open circles, the IR sources found in the surveys around TTSs are crosses (x) and the sources near HH objects are presented by asterisks (*). The broken straight lines represent the sequence of black bodies with temperatures indicated in thousands of Kelvins; the curved lines represent the position of unreddened stars as given by Johnson (1966), Lee (1970), Frogel et al (1978) and Whittet and van Breda (1980); the hatched line gives the locus of a late-type photosphere with increasingly superposed thin free-free, free-bound and bound-bound continuum emission by gas at 10000 K as computed by Cohen and Kuhi (1979) and the straight lines represent the reddening vectors determined from the presents observations as described later.

<u>Figures 3.1, 3.2 and 3.3</u>. Two-colour diagrams from the present observations. Open circles are star-components of trapezium systems, crosses are near-IR sources found in their surroundings and asterisks are near-IR sources found in the vicinities of Herbig-Haro objects. Curved solid, broken and dotted lines give the location of main sequence, supergiant and giant stars respectively. Straight broken lines represent the black body sequences with the temperature indicated in Kelvins. The straight solid lines represent the reddening lines derived as explained in Chapter III.

<u>Figures 3.4, 3.5 and 3.6</u>. Two-colour diagrams from most of the stellar photometric data reported in the literature. Underlying lines are as in Figures 3.1-3.3.

<u>Figures 3.7, 3.8 and 3.9</u>. Superposition of present photometric results (*) and those taken from the literature (x).

<u>Figure 3.10</u>. Observed flux distribution curves for a selection of objects. The cross-identification is given in Table 3.5.

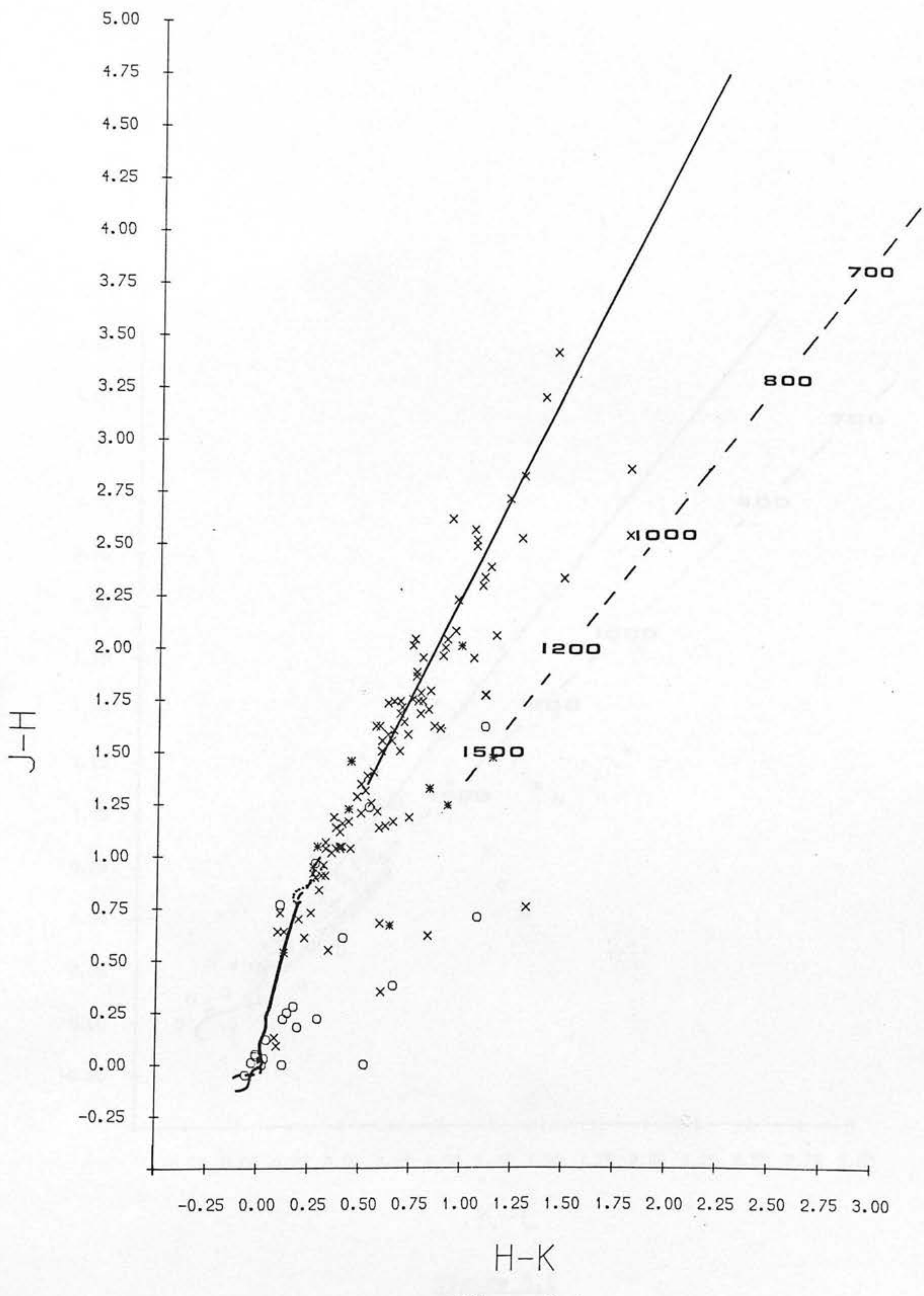

5.00
4.75
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
J-H
700
800
1000
1200
1500
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00
H-K

Figure 3.1

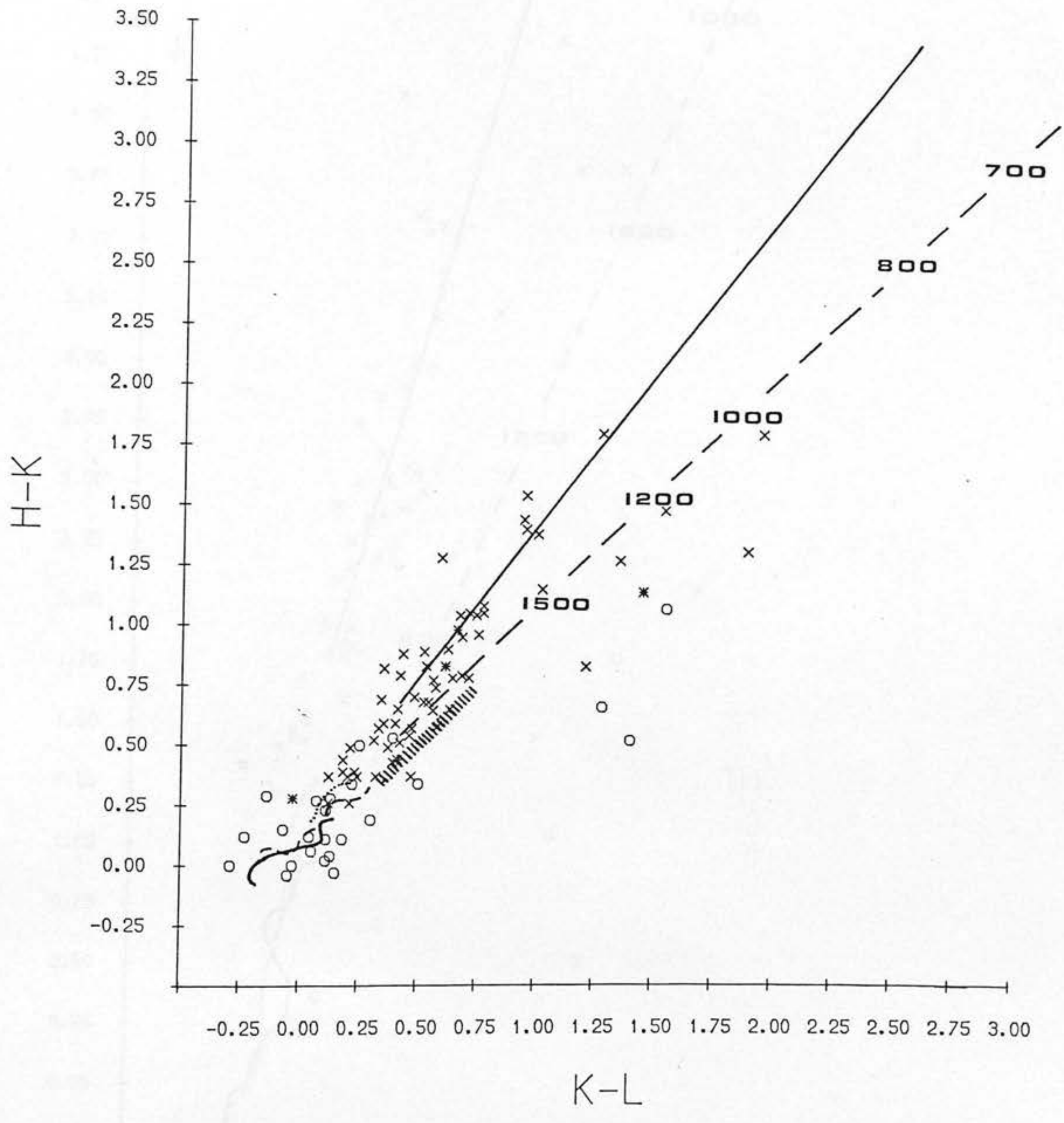

3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
H-K
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00
K-L
700
800
1000
1200
1500

Figure 3.2

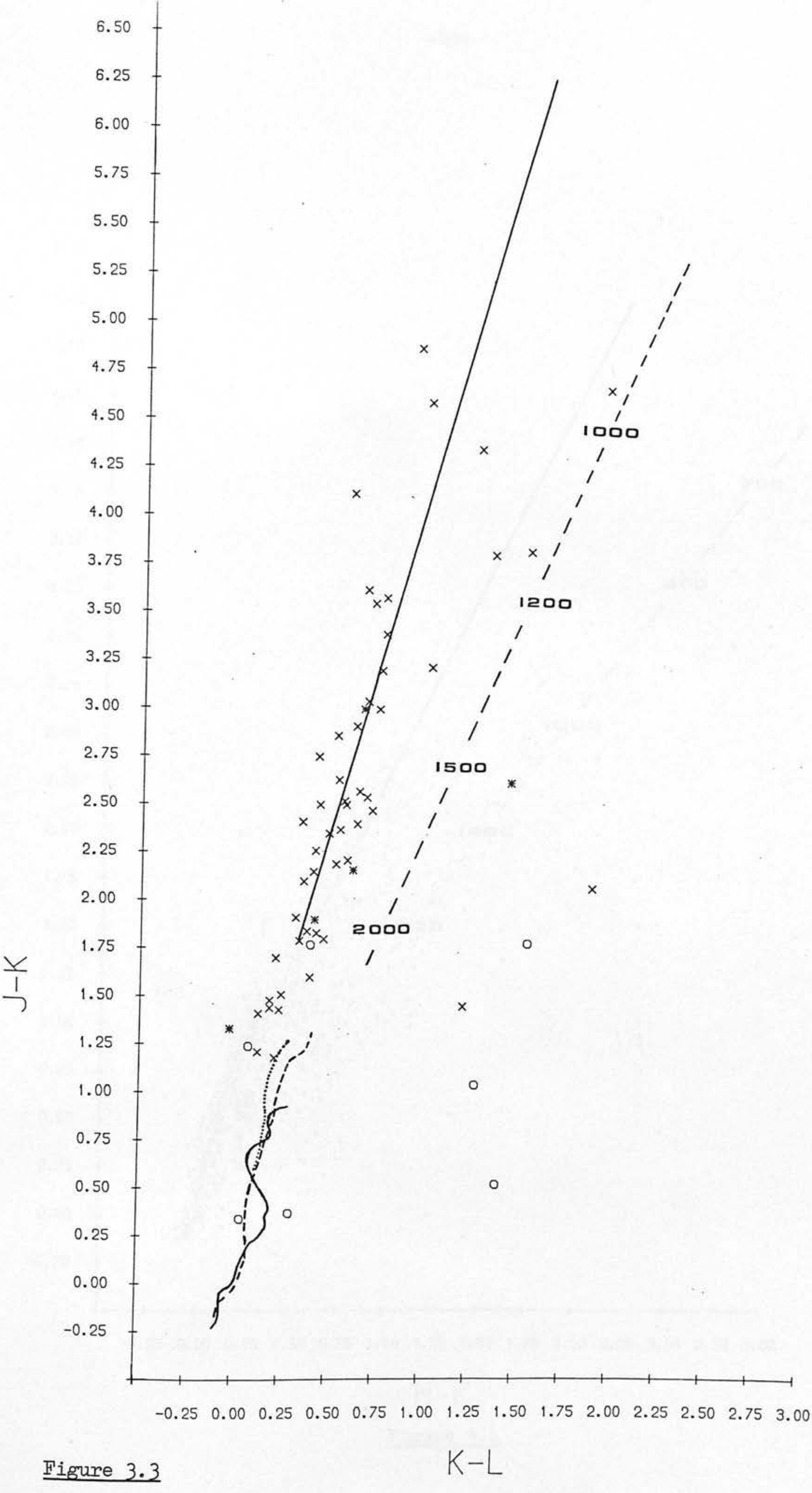
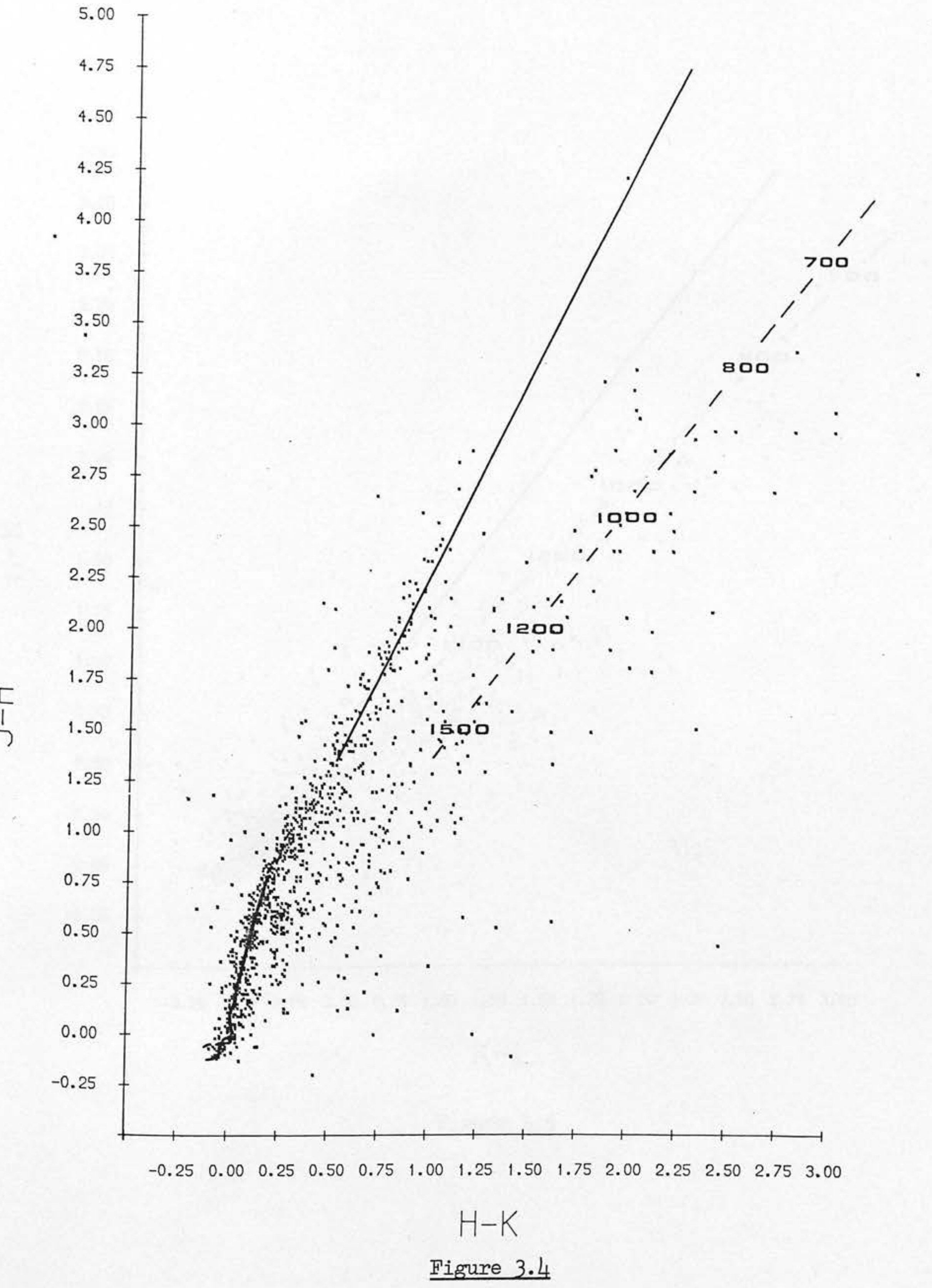

J-K
K-L
6.50
6.25
6.00
5.75
5.50
5.25
5.00
4.75
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00
1000
1200
1500
2000

Figure 3.3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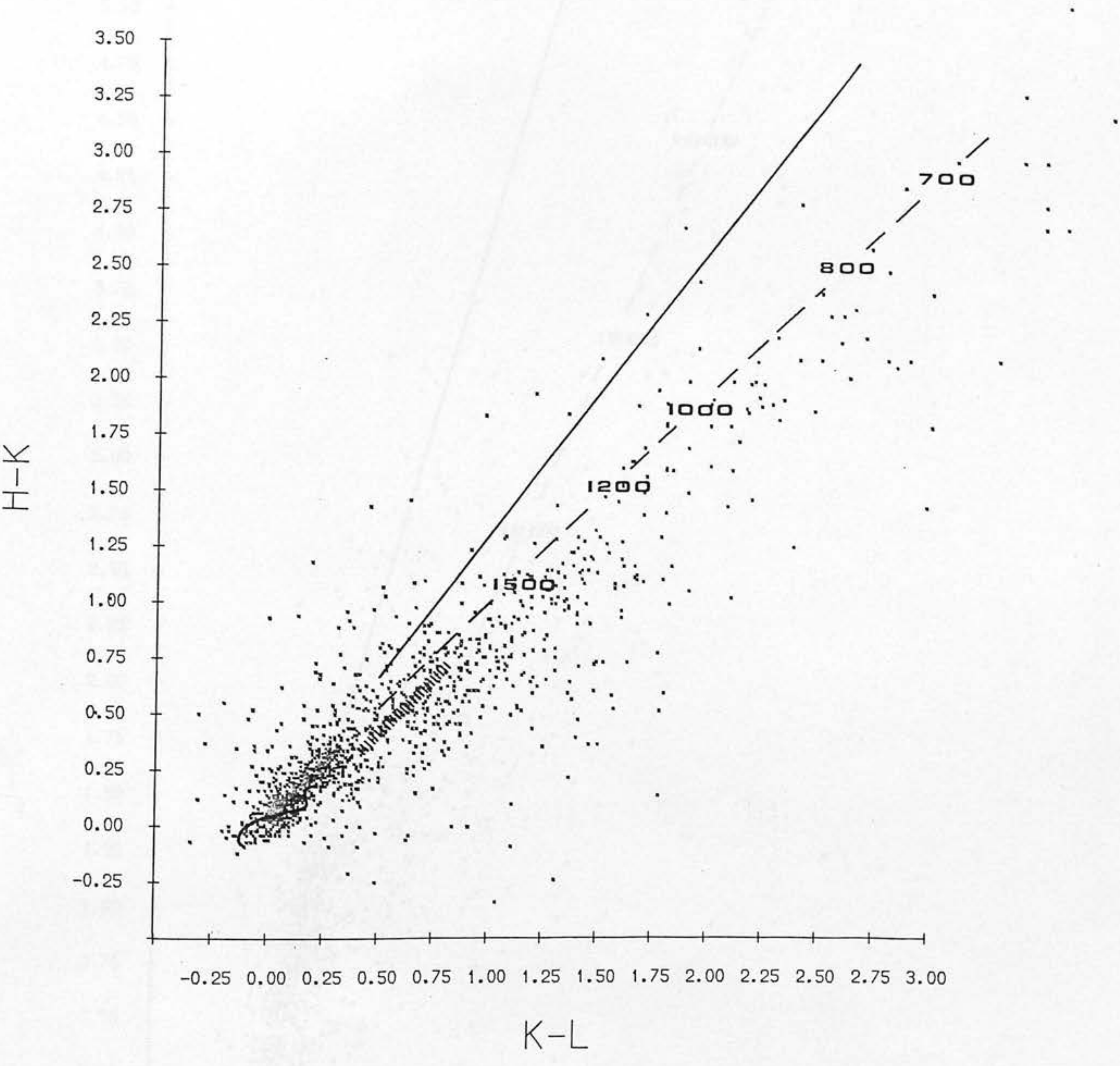
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
J-H
700
800
1000
1200
1500
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00
H-K

Figure 3.4



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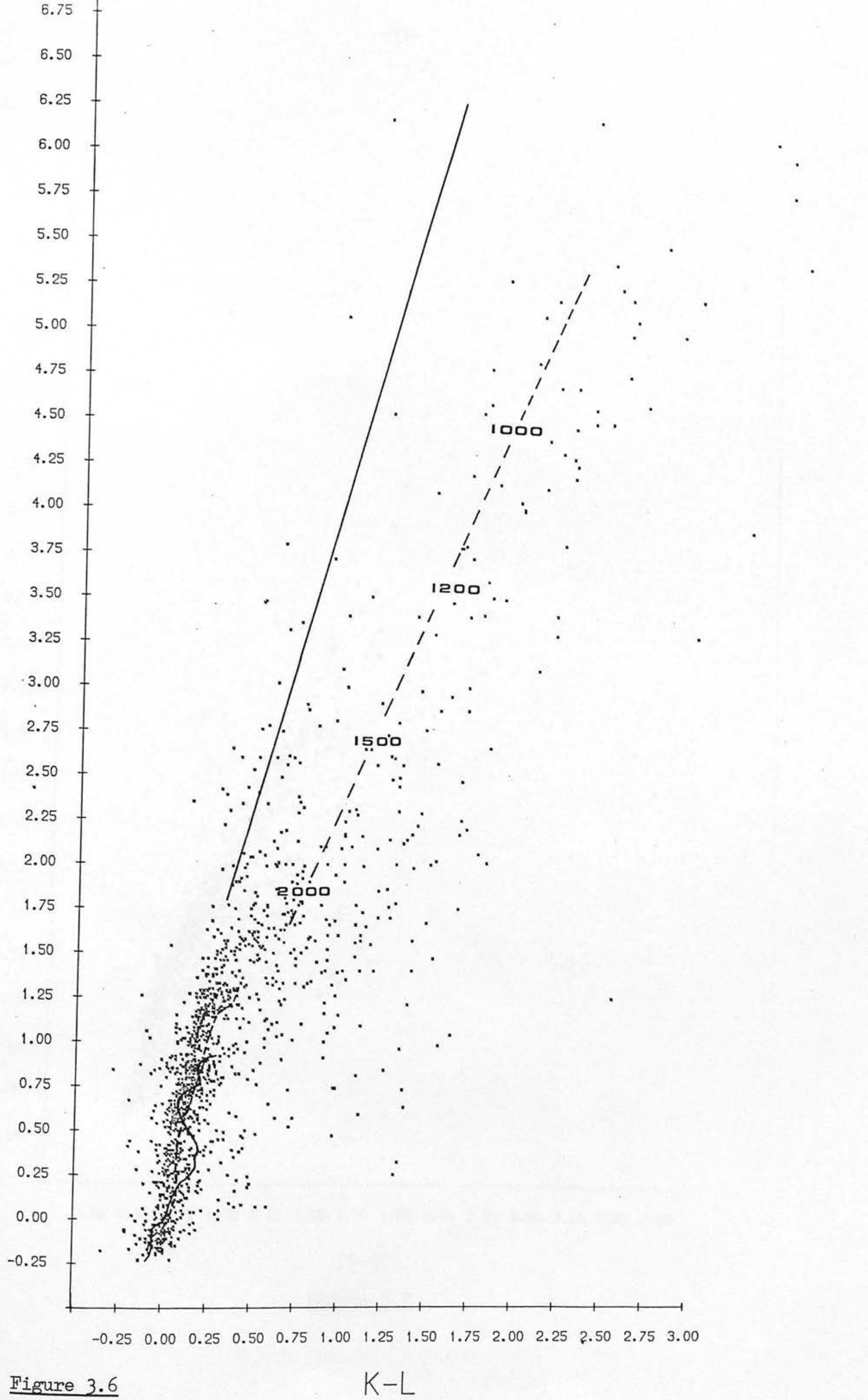
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
H-K
700
800
1000
1200
1500
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00
K-L

Figure 3.5



6.75
6.50
6.25
6.00
5.75
5.50
5.25
5.00
4.75
4.50
4.25
4.00
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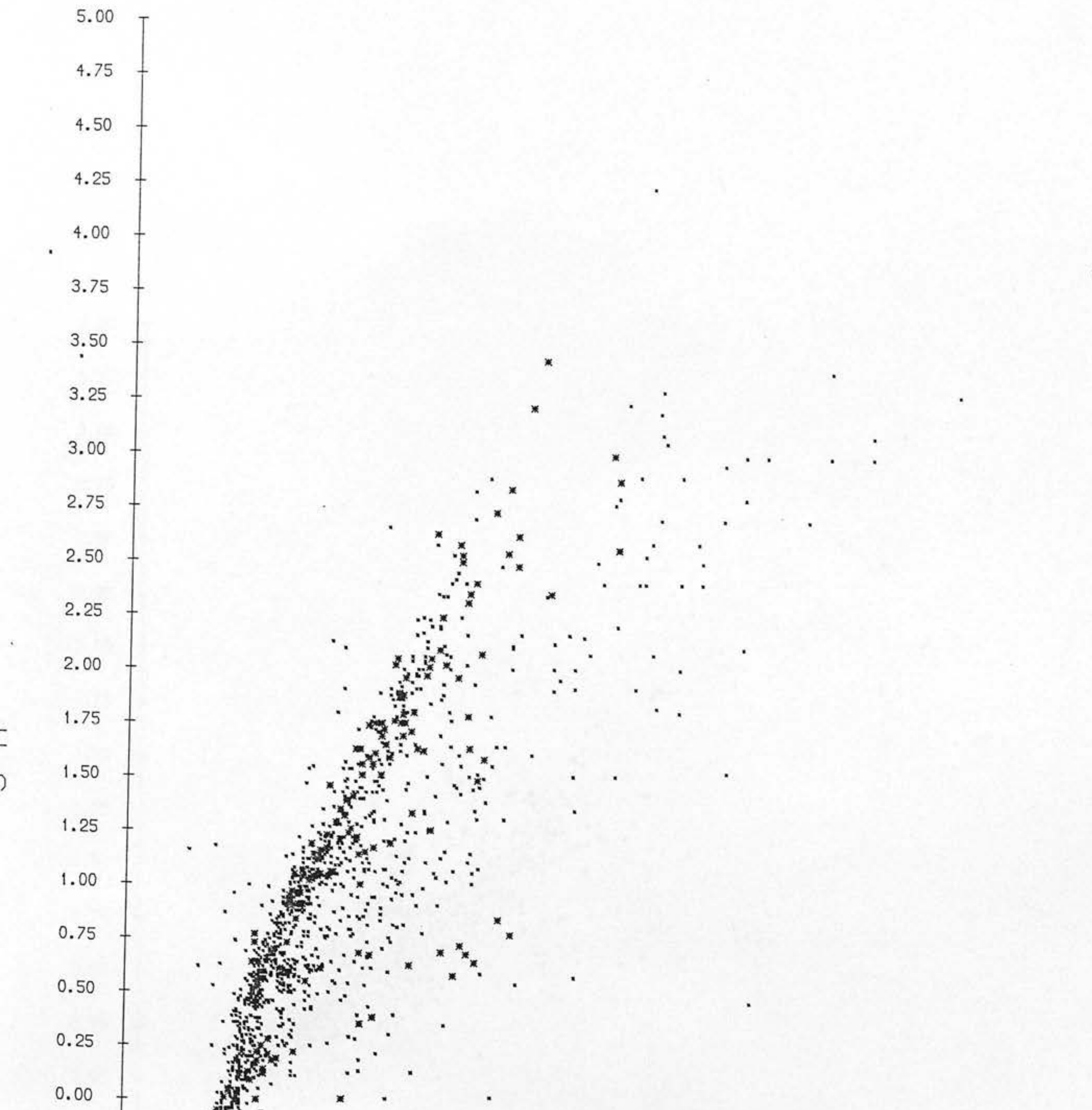
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
J-K
1000
1200
1500
2000
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00
K-L

Figure 3.6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4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
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1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00
H-K

<u>Figure 3.7</u>

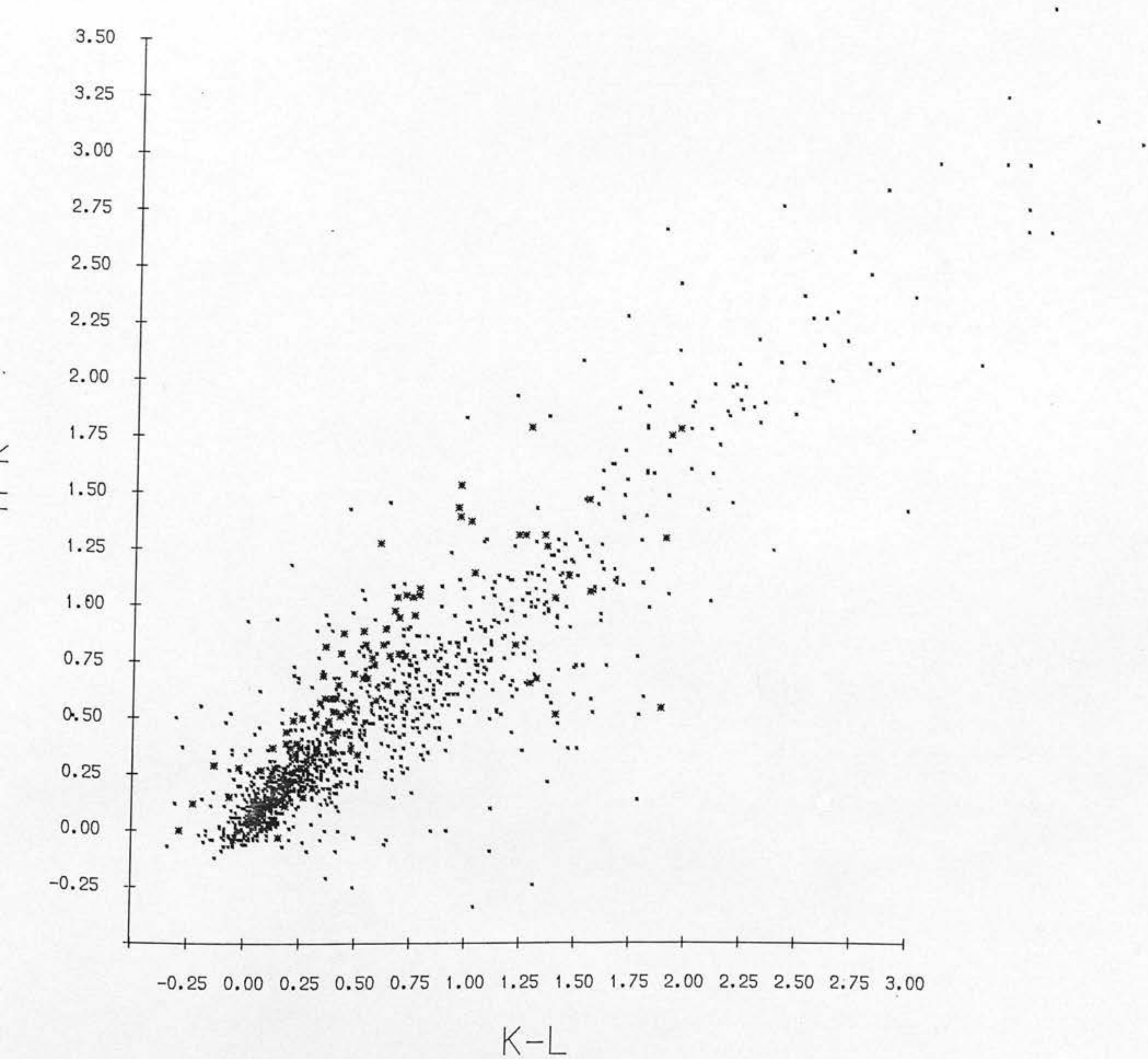

3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00
K-L

Figure 3.8

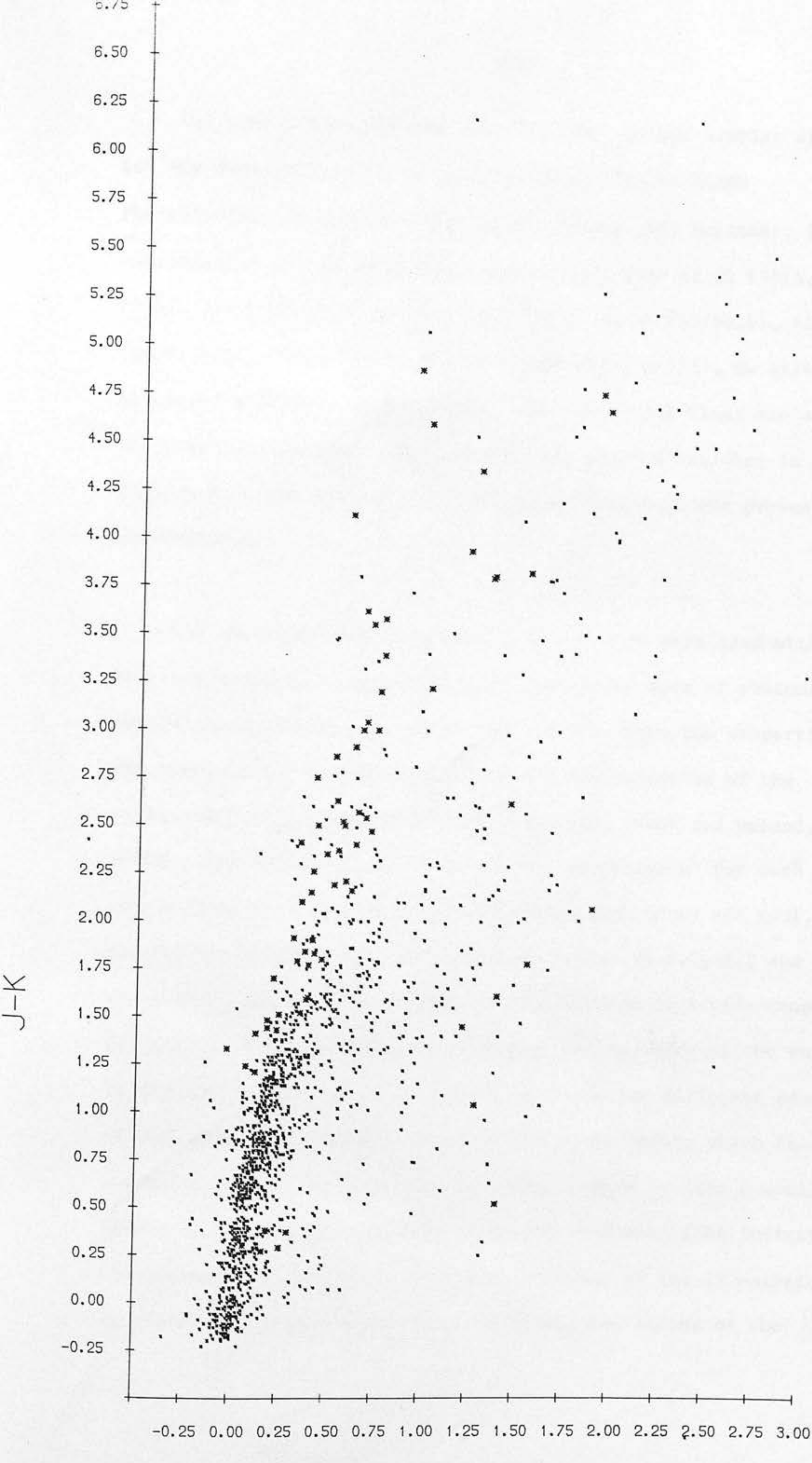

J–K
K–L
6.75
6.50
6.25
6.00
5.75
5.50
5.25
5.00
4.75
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00

Figure 3.9

For comparison, Figures 3.4, 3.5 and 3.6 show similar diagrams (on the same scale) for all entries in the "UBVRIJKLMNH Photoelectric Photometric Catalogue" (Morel and Magnenat, 1978) supplemented by the measuremnts reported by Vrba et al (1975, 1976), Strom K. et al (1976a,b), Strom S. et al (1976a,b), Elias (1978a,b,c), Glass (1978, 1979), Hyland et al (1972), D. Allen et al (1977) and Jones et al (1980). All underlying lines are as in the previous diagrams. The two sets are plotted together in Figures 3.7, 3.8 and 3.9, here asterisks represent the present observations.

The near-infrared two-colour diagrams have been used with relative success in the analysis of consistent sets of photometric observations directed to one of both of (1) study the properties of the interstellar matter by means of the determination of the reddening law at these wavelengths (see e.g. Jones and Hyland, 1980a), (2) determine the origin of the IR emission for each object from its location in such diagrams (see Cohen and Kuhi, 1979 and references therein). Examination of Figures 3.1, 3.2 and 3.3 shows that, although the surveys were performed in a wide range of directions close to the galactic plane, the majority of the sources in the sample are (mainly cool) stars suffering different amounts of interstellar (and maybe circumstellar) absorption which follows essentially the same reddening law; while there is also a small number of sources located well below the reddening line indicating the presence of, at least, a second component of the IR emission. By means of a least-square linear fitting, the slopes of the reddening lines clearly defined in the two colour diagrams were obtained without assuming specifically an "average" spectral type for the stars, but leaving out all sources whose positions in the diagrams indicate an intrinsic (i.e. circumstellar) IR excess and those points which are clearly away from the well defined reddening vector.

3) Reddening Law

There has been a great deal of discussion on the characteristics of the interstellar grains as studied from the interstellar extinction law, both from the observational point of view (see, e.g. Smyth and Nandy, 1978; Whittet and van Breda, 1980) and the theoretical (see e.g. Wickramasinghe and Nandy, 1972). In the last ten years or so, IR and UV observations have contributed considerably to the understanding of the main components of the solid interstellar matter. Nevertheless, the question concerning the homogeneity of the physical conditions governing the interstellar (IS) reddening law (towards different directions in the sky) is only recently being answered. Johnson (1968), using the colour-difference method, found that the values of $R = Av/E(B-V)$, the ratio of total to selective absorption, differ in certain regions (Cepheus, NGC 2244 and Orion) from the generally accepted value of ~ 3; while independent studies have given similar results for certain other regions, such as Carina (Herbst, 1976 and references therein) and the Ophiuchus dark cloud (Carrasco et al, 1973). On the other hand, an immense number of studies resulting in values of R = 3.0 - 3.5 from observations in most directions, including re-determinations of some "peculiar" regions (e.g. Orion), indicate that R is in fact reasonably constant in the general interstellar medium (for a discussion, see e.g. Lyngå, 1979), although some indications of slight variations with galactic longitude have been suggested (Whittet, 1977; Turner, 1976).

Most of the observational studies of the IS extinction in the past have been done mainly by combining visual, infrared and, lately, ultraviolet observations of moderately reddened field stars and stars in clusters, but only very recently has the behaviour of the extinction law at near-infrared wavelengths been investigated, mainly from observations of highly reddened stars in the galactic centre (Becklin et al, 1978), in dense dark clouds (Elias, 1978a,b,c; Jones et al, 1980) and in the general field (Jones and Hyland, 1980). Table 3.4 compares the values of E(J-H)/E(H-K), E(H-K)/E(K-L) and E(J-K)/E(K-L) determined theoretically by van de Hulst's model No. 15 as interpolated from the curves given in van de Hulst (1949) and Johnson (1968) and the values independently obtained by IR photometric observations. The last but one line gives the slope of the reddening line delineated on the J-H,H-K diagram of (almost) all IR observations reported in the literature as shown in Figure 3.5. This value of the slope was determined by eye-fitting a straight line along the points marking the upper left boundary of the filled area. Different and independent attempts to repeat the eye-fit gave values for the slope always within 0.2.

TABLE 3.4

Values of colour-excess ratios at wavelengths 1 - 4 microns

	$\frac{E(J-H)}{E(H-K)}$	$\frac{E(H-K)}{E(K-L)}$	$\frac{E(J-K)}{E(K-L)}$
van de Hulst (1949) Model No. 15 (Theory. From Fig. 7 and Table 14)	1.6	1.3	3.3
Johnson (1968) from Model No. 15 (Theory. Fig. 23 and Table 12)	1.8	1.3	3.6
Savage and Mathis (1979) (Ave. from early-type stars)			2.23
Becklin *et al* (1978) (Galactic Centre sources)	1.50 ± .10	1.54 ± .14	(3.85 ± .26)
Elias (1978b) (Field stars in Oph dark cloud)	1.60 ± .04	1.79 ± .13	(4.65 ± .22)
Elias (1978c) (Field stars in Tau dark cloud)	1.56 ± .05	2.08 ± .13	(5.32 ± .23)
Jones *et al* (1980) (Coalsack)	2.12 ± .04	0.9 ± .4	(2.7 ± .8)
Jones and Hyland (1980) (Selected compilation)	2.09 ± .10	1.47 ± .10	(4.54 ± .26)
All published IR photometry (See text)	1.9 (±.2)		
This work (observations)	2.00 ± .06	1.29 ± .06	3.56 ± .08

E(J-K)/E(J-H) = 1.45 ± .03

E(J-L)/E(J-H) = 1.70 ± .02

It is interesting to note that the diagrams involving K-L (Figures 3.4 and 3.6) do not show traces of the reddening vectors as compared with the equivalent diagrams from the present observations (Figures 3.1 and 3.3) which clearly do, though with somewhat large scatter. This is due to several factors: 1) While the majority of sources in our sample are "normal" stars reddened by large amounts and detected only through their brightness at 2.2 microns, the (much larger) sample taken from the literature consists mainly of unreddened and slightly reddened stars and, for the very red sources, there is a marked selection bias towards stars with intrinsic IR excess, such as emission-line stars and supergiants with circumstellar shells as well as objects discovered at wavelengths longer than 5 microns, many of them with very unusual IR properties. 2) Of the sample of highly reddened stars from the literature, almost all are in the directions of large, dense dark clouds (like the one in Oph) where the presence of features in absorption, like the "ice" band at 3.1 microns, or in emission, like the unidentified 3.5 micron band (Blades and Whittet, 1980), in the spectra of some stars might alter significantly the L band photometry and hence, increase the scatter in the K-L colours. Figures 3.4 - 3.9 were plotted using the values stated in the original papers, although in some cases, observers used slightly different filter sets.

The values of the colour excess ratios corresponding to the infrared reddening law obtained from the present observations are not in agreement, but are slightly higher than the theoretical predictions of van de Hulst's (1949) model No. 15, even considering the inevitable errors in interpolating from the curves and tables involved. The comparison between the reddening ratios from different observations is of particular interest. It is encouraging to see that the value of the ratio E(J-H)/E(H-K) obtained by Jones and Hyland (1980) from a selection of published observations, as well as some of their own, of some of the most heavily reddened late-type stars is in agreement with the present determination. The discrepancy arises for the value of E(H-K)/(K-L): Since Jones and Hyland reported very few observations at L, their determinations depend very heavily on a few published measurements of stars in the ρ Oph, R CrA dark clouds and of the galactic centre which are not representative of the general interstellar medium.

In fact, the values quoted in Table 3.4 for the excess ratios for the Oph and Taurus dark clouds and the galactic centre are distinctly different from ours. Although the ratios of the colour excesses in the clouds were obtained by a different method, i.e. by classifying the (2 micron) spectra of each star and assigning intrinsic colours to obtain the excesses; the corresponding two-colour diagrams confirm that in these clouds the reddening differs considerably from the "general" law. In the case of the Ophiuchus cloud, this only corroborates the results of previous studies (e.g. Carrasco et al, 1973). A similar argument would apply for the sources in the direction of the galactic centre (Becklin et al, 1978), but until data on a larger number of individual sources is available, no further conclusion can be reached. In particular, the recent discovery of the presence of the 3.4 micron absorption feature, presumably due to CH (Wickramasinghe and Allen, 1980), in some of these sources indicates that the broad-band L measurements may deviate strongly from representing the continuum level. If, as Wickramasinghe et al (1980) tend to believe, the 3.4 CH feature proves to be inherent to interstellar matter, the L band photometry should always be corrected in these studies. In any case, L′ (3.8 microns) filters should be incorporated in future IR photometric work.

Finally, it should not be surprising that the value of E(J-H)/(H-K) for the Coalsack (Jones et al, 1980) is very similar to the one obtained by Jones and Hyland (1980) since the former observations were used and contributed quite heavily to the latter study. No real importance should be given to the E(H-K)/E(K-L) value reported for the Coalsack since only four stars were used in this determination.

In summary, the self-consistent and independently determined set of colour-excess ratios obtained from the broad-band photometry of the IR sources discovered in the present study and found to be highly obscured stars indicate that the reddening law at $\lambda = 1$ to 4 microns along the galactic plane, even in the presence of moderately dense IS clouds, differs slightly from the model No. 15 by van de Hulst and is considerably different from the reddening in the direction of some large dense dark clouds. These differences have been attribuited to the presence of larger grains in these clouds (e.g. Carrasco et al, 1973).

4) Energy distribution and two - micron spectra

From all the IR sources observed during the present work, those which lie to the right of the reddening line in the two-colour diagrams are of special interest, since their energy distributions differ from those of normal stars, even those under the effects of high (normal) obscuration. In our sample, with the possible exception of one or two objects, to be discussed in Chapter IV, all the sources seem to be point-like and therefore of stellar nature in which the observed energy distribution is a combination of at least two of the following parameters: Normal photospheric emission, in accordance to its spectral type; thermal emission by dust particles in a shell around the star and free-free, free-bound and bound-bound emission by hot chromospheric gas. On top of all these, the effects of circumstellar and interstellar reddening are present.

The observed flux distributions, in the wavelength range 1.25 to 3.45 microns of the reddest sources for which multicolour broad-band photometry was available, are shown in Figure 3.10. For comparison, curves representing the emission of a normal A0 V atmosphere, black bodies at 2500 K and 1200 K are also shown. Table 3.5 provides the necessary cross-identification.

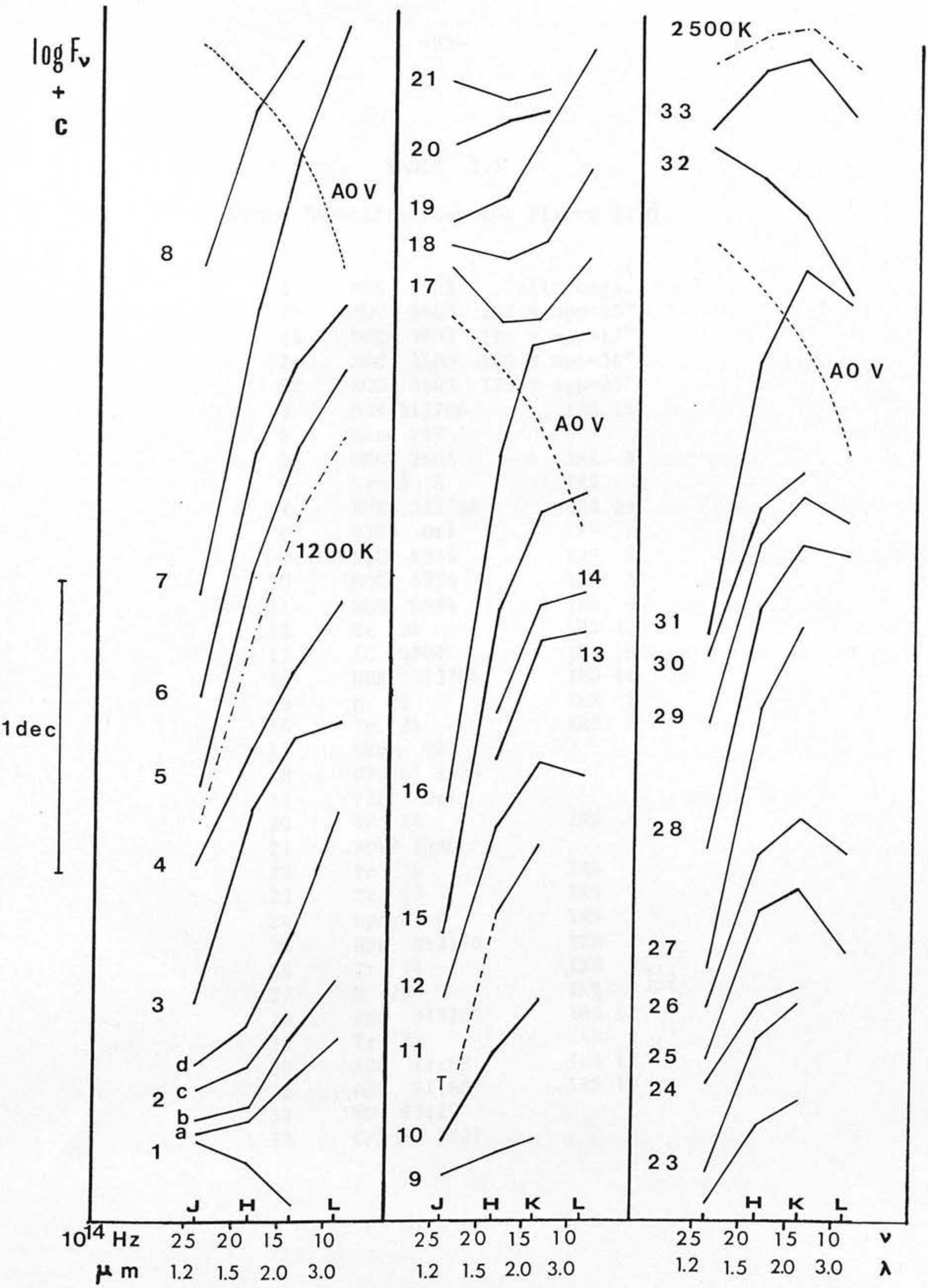

log Fν + C
1dec
AO V
1200 K
2500 K
1
2
3
4
5
6
7
8
a
b
c
d
9
10
11
12
13
14
15
16
17
18
19
20
21
T
23
24
25
26
27
28
29
30
31
32
33
J
H
K
L
10^14 Hz
25 20 15 10
μm
1.2 1.5 2.0 3.0
ν
λ

Figure 3.10

TABLE 3.5

Cross identification for Figure 3.10

1	NGC 3603	All Comps.
2a	NGC 3603 IRS 9	app=25"
2b	NGC 3603 IRS 9	app=17"
2c	NGC 3603 IRS 9	app=34"
2d	NGC 3603 IRS 9	app=25"
3	HDE 313706	IRS 15
4	Haro 249	
5	NGC 3603	IRS 5
6	Lyngå 8	IRS 3
7	HDE 313706	IRS 19
8	V380 Ori	IRS 2
9	NGC 6334	IRS 2
10	NGC 6334	IRS 5
11	NGC 6334	IRS 3
12	Tr 24	IRS 10
13	IC 4701	IRS 6
14	HDE 313706	IRS 11
15	M 20	IRS 2
16	Tr 24	IRS 7
17	LkHα 123	
18	CPD-61 2935	
19	V380 Ori	
20	Tr 16	IRS 4
21	BD+9 1330	
22	Tr 16	IRS 7
23	Tr 15	IRS 5
24	Lyngå 8	IRS 2
25	HDE 313176	IRS 1
26	Tr 14	IRS 2
27	M 20	IRS 5
28	HDE 313706	IRS 12
29	Tr 24	IRS 5
30	ADS 11168	IRS 12
31	ADS 11168	IRS 10
32	HD 93129	
33	CPD-62 1837	

The qualitative effects of the various emission processes on the two-colour diagrams and energy distributions in the near-infrared have been discussed at some length in the literature (e.g. Allen, 1973; Cohen and Kuhi, 1979; Hyland et al, 1972), but in fact, there is no straight forward method of determining accurately the origin of the IR excesses and only rough estimates are possible from near-IR broad-band observations alone. Indeed, other kinds of observations are required to provide a comprehensive picture leading to a realistic classification of most of our sources. One of the most effective methods of classifying infrared-bright objects with very faint optical counterparts is by means of low-resolution IR spectra, particularly in the 2.0 - 2.5 micron region where late-type stars are characterised by CO and, for the latest types, by H_2O absorption bands. These provide a convenient classification system, consisting in the measurement of the strengths of the bands (see Elias, 1978a and references therein). On the other hand, apart from WR stars, early-type stars are featureless in this region with the possible exception of the Brγ line at 2.17 microns.

In spite of adverse weather, the six two-micron spectra obtained and shown in Figure 3.11 cover a wide range of the different kinds of objects included in the present sample, as judged from the near-infrared energy distribution and position in the colour-colour diagrams. The spectra in panel (a) are of very

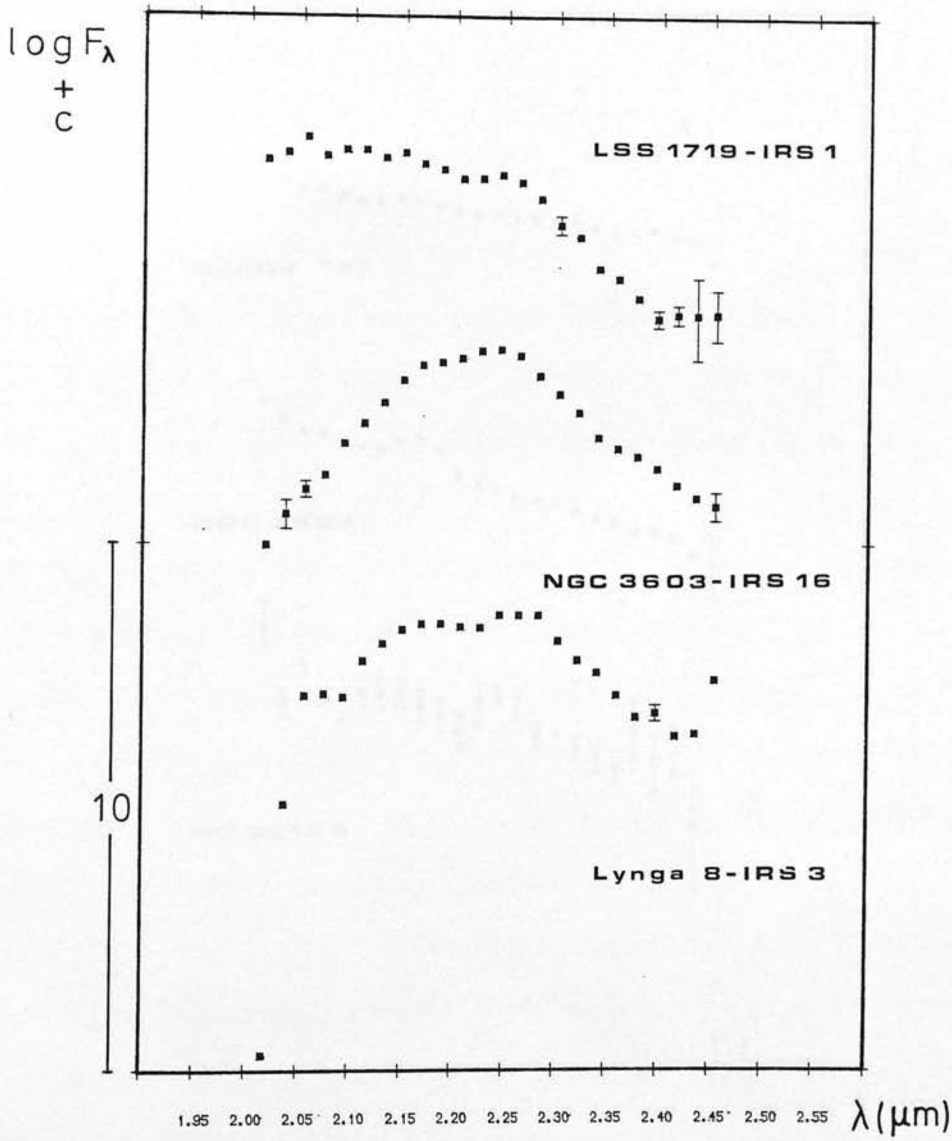
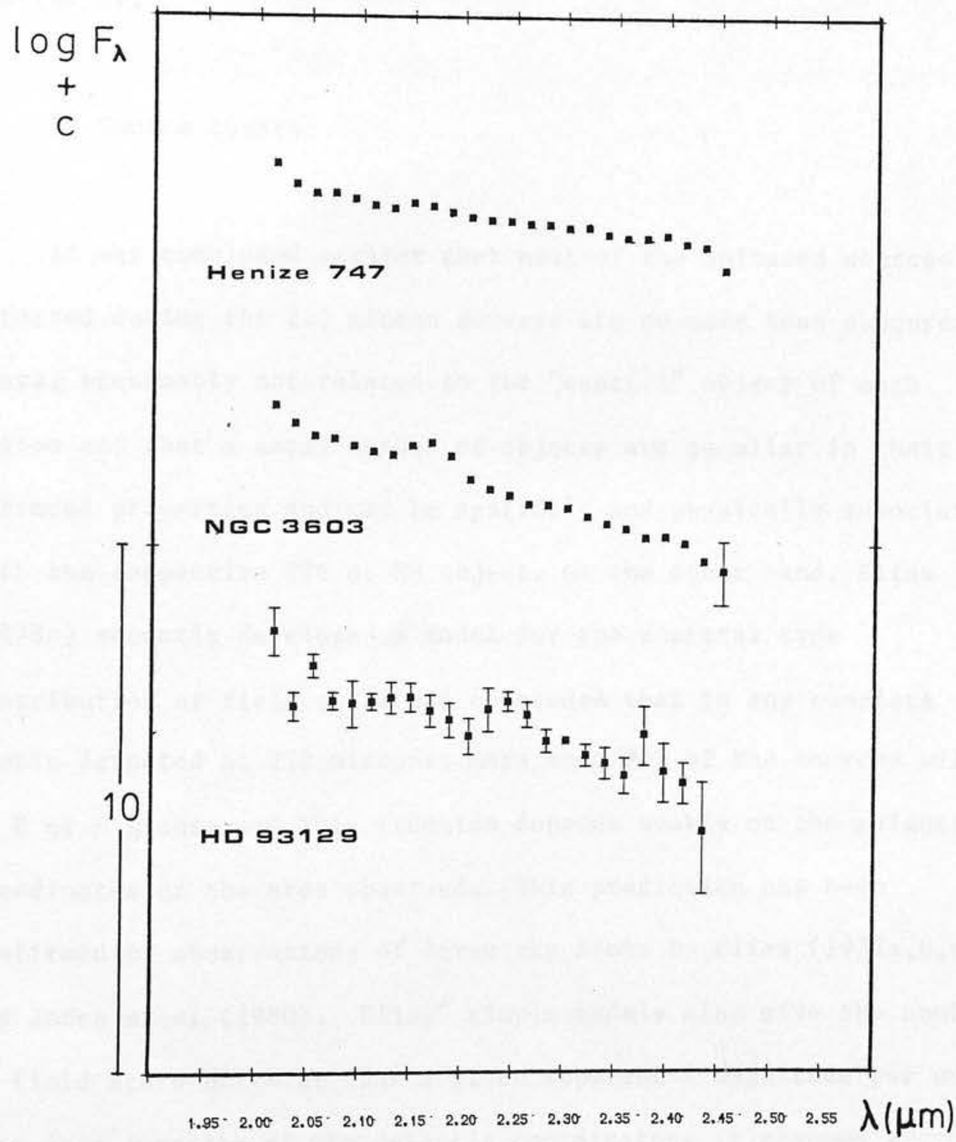


Figure 3.11a. CVF spectra of three reddened late-type stars.



<u>Figure 3.11b.</u> CVF spectra of stars in trapezium-type systems.

late-type stars while those in panel (b) belong to hotter, earlier-type stars. Each of the regions and the properties of a number of individual objects will be discussed in detail in Chapter IV.

5) Source counts

It was concluded earlier that most of the infrared sources detected during the 2.2 micron surveys are no more than obscured stars, presumably not related to the "central" object of each region and that a small number of objects are peculiar in their infrared properties and may be spatially and physically associated with the respective TTS or HH object. On the other hand, Elias (1978a) recently developed a model for the spectral type distribution of field stars and concluded that in any complete sample detected at 2.2 microns, more than 90% of the sources will be K or M giants and this fraction depends weakly on the galactic coordinates of the area observed. This prediction has been confirmed by observations of large sky areas by Elias (1978a,b,c) and Jones et al (1980). Elias' simple models also give the number of field stars brighter than a given apparent K magnitude per unit area as a function of the galactic coordinates. It assumes a standard form for the luminosity function and an exponential distribution of absorbing material relative to the galactic centre. Its predictions for the cumulative counts agree reasonably well with observations in directions not very close to the galactic plane but certainly fails at low galactic latitudes. T.J. Jones and collaborators (private communication) have worked on improving Elias' model and emerged with a "best fit" model which fits all available (at the time) observations "except the Coalsack". The results of this model have been kindly made available for the use in the present discussion.

The statistical study of the results from surveys of such small areas as the ones reported here is particularly dangerous and should be treated with considerable care especially when the observations are to be compared with simple-approximation, semi-empirical models of star and interstellar material distributions. Considering the enormous statistical errors in the cumulative counts introduced by the small number of sources detected, and this due to the small size of the areas surveyed, particularly in the anticentre directions, it was rewarding to find that the observed counts in the random "reference" regions, which are presumably typical of the general field, agreed in all but one case, after correction for coincidence, within 20 - 30 % with what the models by Jones et al predict in each corresponding direction, as did the slopes of the cumulative luminosity functions (at 2.2 microns). Even in the extreme case of the Galactic Centre, comparisons of the observations of the $1^0 \times 1^0$ area around the Centre by Becklin and Neugebauer (1978) with the extrapolated value from the theoretical predictions indicate that in this, probably the most complex and conspicuous direction in the sky, the number of 2.2-micron sources was underestimated by the model by some 40%

only. It is felt, therefore, that the observed excesses or deficiencies of more than, say, 70% in the counts relative to the predictions in the corresponding direction, are very likely real.

The regions which showed significant excesses in the number of sources were those centred in the TTSs located at or containing: Cyg OB2 (7.0), NGC 3603 (7.0), HD 104901, Haro 249 (3.0), ADS 11168, HHO-51 (2.5), HDE 313706 (2.2), IC 4701 (2.1), M 20 (2.0), Tr 14, 15, 16, Cr228 (1.9-2.1) and Lyngå 8 (1.9); most of these regions are known, optically studied young clusters. The only region observed to have a deficiency was in NGC 6334 (0.4). The values given in parentheses above indicate the number of sources detected divided by the number predicted by the models at the corresponding limiting magnitude and direction.

There are two possible ways of explaining the 2.2-micron source overabundance in any region. The first involves a cluster not much closer to the Sun than the distance modulus to the faintest stars detected in the sample, i.e. those with apparent magnitude equal to the limiting magnitude for completeness of the survey. The second involves a lower column density of the obscuring material in the relevant direction, as compared to that assumed by the model; in other words, the presence of a "hole" or "window". Clearly, the presence of a dense cloud in the foreground would cause the opposite effect. Establishing which of the interpretations applies to each of the observed "peculiar" regions requires a detailed individual analysis and that is the subject of Chapter IV.

It is possible that the source count fluctuations are caused by large scale anomalies in the near-IR integrated emission of the galaxy, but the low-resolution (1 degree) 2.4-micron maps of the of the central bulge of the Galaxy by Maihara et al (1978) shows no such discontinuities in or near the positions of the present studied regions in the range $l = 255^0$ to 20^0.

6) Comparison with other photometric studies

A number of objects observed as part of this program had previously been measured photometricaly in the near-IR by other authors, These measurements are quoted in Table 3.6 and compared with the present observations. Within the uncertainties of having some of the older measurements in slightly different systems, as in the case of some pioneering work, there appears to be no significant inconsistencies except when the sources are known or suspected to be variable (V380 Ori, LkH_α 123) or extended (HD 97950, NGC 3603-IRS 4, see Chapter IV).

TABLE 3.6

Comparison with other photometric measurements

Name	Coordinates (1950)	J	H	K	L	Reference
V380 Ori		7.9		5.9	4.4	Mendoza (1966)
		8.20		6.08	4.74	Mendoza (1967)
		8.20	7.20	6.08	4.74	Mendoza (1971)
			6.80	5.81		Allen (1973)
		8.02	6.96	5.93	4.74	Glass & Penston (1974)
		7.69	6.98	5.91	4.36	This Work
V380 Ori IRS 2	5 33 55.4	10.97	9.38	8.20	6.96	Cohen & Schwartz (1979)
	-6 47 24					
	5 33 55.4	11.08	9.30	8.21		This work
	-6 47 26					
Haro 249	5 36 23		9.54	8.31	6.94	Cohen and Kuhi (1979)
	-7 12 47		9.55	8.27	6.84	"
	5 36 17.5	11.1	9.6	8.49	7.0	This work
	-7 14 22					
Haro 249c	5 36 22		11.57	11.05	10.2	Cohen and Kuhi (1979)
	-7 12 50					
	5 36 17.2					This work
	-7 14 37					
12 Gem			5.49	5.52		Allen (1973)
		5.70	5.48	5.36	5.32	This work
HD 46150 A		6.50		6.41	6.03	Johnson (1965)
		6.48	6.45	6.42		This work
BD +9 1336			9.39	8.46	7.47	Strom, S. et al (1972a)
		9.47	9.10	8.63	7.4	Warner et al (1977)
				8.3		This work
HD 47732			8.59	8.61	8.78	Strom, S. et al (1972a)
		8.23	8.37	8.56	8.78	Warner et al (1977)
				8.4		This work
BD +9 1330			8.18	7.40	6.46	Strom, S. et al (1972a)
		8.43	8.13	7.55	6.66	Warner et al (1977)
		8.61	8.26	7.66		This work
S Mon A			5.16	5.21		Allen (1973)
		5.29		5.32		Johnson et al (1966)
			5.28	5.34	5.39	Strom, S. et al (1972a)
VY Canis Majoris		2.04	0.47	-0.72	-2.52	Low et al (1970)
		2.01		-0.62	-2.43	Hyland et al (1968)
				-0.6		This work
vBH 25c		7.30	7.31	7.35	6.90	Williams et al (1977)
		7.31	7.31	7.29		This work
HD 93129 AB (Ap=12")		6.21	6.06	6.04	6.08	Thé et al (1980)
(Ap=51")		5.85	5.66	5.45		This work
(Ap=34")		6.08	5.88	5.70	5.45	"
(Ap=25")		6.15	6.00	5.86	5.59	"
(Ap=17")		6.23	6.11	5.96	5.79	"
HD 93160		7.22	7.18	7.11	7.24	Thé et al (1980)
		7.21	7.12	7.03		This work
HD 93146		7.93	7.84	7.83	7.88	Thé et al (1980)
				7.88		This work
RT Car CD-58 3538				1.90	1.43	Humphreys et al (1972)
				2.4		This work
HD 93250		6.73	6.68	6.63	6.63	Thé et al (1980)
				6.8		This work

Name	Coordinates	J	H	K	L	Reference
HDE 303308		7.68	7.70	7.80		Whittet and van Breda (1980)
		7.65	7.63	7.56	7.68	The et_al (1980)
HD 97950 (Ap=22")	11 12 55.7	6.22	5.79	5.50	5.08	Frogel et_al (1977)
NGC 3603 (Ap=14")	-60 59 21		6.00	5.73	5.35	"
(Ap=25")	11 12 58.9		5.82	5.47	5.03	This work
	-60 59 17					
NGC 3603 IRS 5	11 12 40.4	8.11	6.78	5.54	4.37	Frogel et_al (1977)
	-60 57 38					
	11 12 41.9			5.5		This work
	-60 57 29					
" IRS 4	11 12 52.3	6.73	5.10	4.39	3.63	Frogel et_al (1977)
	-60 58 08					
	11 12 54.3	6.87	5.18	4.40	3.69	This work
	-60 57 58					
" IRS 6	11 13 14.3	6.09	5.09	4.76	4.46	Frogel et_al (1977)
	-60 57 26					
	11 13 16.5	6.18	5.14	4.75	4.52	This work
	-60 57 18					
" IRS 8	11 12 57.9	8.54	8.04	7.74	7.38	Frogel et_al (1977)
	-60 59 43					
IRS 8a+b				7.7		This work
IRS 8a	11 13 01.8			8.3		" "
	-60 59 48					
IRS 8b	11 13 00.0			8.6		" "
	-60 59 40					
IRS 9	11 13 02.8			8.0		" "
	-61 00 21					
" IRS 9	11 12 59.4		10.5	8.40	6.1	Frogel et_al (1977)
	-61 00 25					(Point source)
(Ap=51")	11 13 5	8.11	7.48	6.34		This work (d)
(Ap=25")	-61 00.3	9.60	8.84	7.53	5.64	" (d)
(Ap=34")		9.09	8.26	7.01		" (e)
(Ap=51")		8.12	7.45	6.35		" (e)
" IRS 15	11 13 13.7	8.20	7.09	6.74	6.47	Frogel et_al (1977)
	-60 55 45					
	11 13 15.7	8.33	7.14	6.78		This work
	-60 55 40					
LkHα 123			7.37	6.93	5.7	Allen (1973)
			7.65	7.10	5.22	This work (a)
		7.34	7.34	6.82	5.42	" (e)
HD 166937				3.19	3.08	Barlow and Cohen (1977)
			3.07	2.96	2.78	This work
HD 190918			6.36	6.30		Allen et_al (1972)
			6.38	6.24	5.97	Hackwell et_al (1974)
				6.3	6.1	Cohen et_al (1975)
			6.45	6.34	6.23	This work
Cyg OB 2 ADS 14000 D		7.26	6.97	6.76	6.30	Voelcker (1975)
			6.98	6.64	6.42	This work
" ADS 14000 C				8.50		Voelcker (1975)
" Red 35		6.75	6.11	5.81	5.36	Voelcker (1975)
		6.52		5.44	4.48	Johnson (1965)
		6.60		5.51		Johnson & Borgman (1963)
			5.98	5.61	5.41	This work
Cyg OB2 Red 33		7.25	6.62	6.68	6.05	Voelcker (1975)
				6.63		This work
" Red 36		6.92	6.39	5.77	5.71	Voelcker (1975)
			5.97	5.60	5.28	This work
" Red 37		7.30	7.01	6.46	5.96	Voelcker (1975)
			6.87	6.50	6.03	This work

CHAPTER IV

DISCUSION OF INDIVIDUAL REGIONS

1) Regions containing Trapezium-Type Systems

NGC 281.- The multiple star ADS 719 is responsible for the excitation of the HII region NGC 281 and is in the centre of the open cluster of the same name. The two brightest stars (components A and C) are separated by approximately four arc seconds and their brightness difference is 0.8 magnitudes (Sharpless, 1954). The available visual photometry, quoted in Table 4.1 most probably refers to the combined light of the close members A and C, though this is not explicitly stated by the observers (Hiltner and Johnson, 1956). The system is located in the Perseus arm at a distance of 2.1 kpc (Markarian, 1951). From a comparison between the excitation parameters determined from radio observations of the nebula and that derived from the properties of the exciting stars HD 5005A and C, Israel (1977) concluded that the nebula is density limited. Elmegreen and Lada (1978a) mapped the region for CO and found two clouds to the South and South-East of the trapezium. The former is the most massive ($\sim 1700\ M_{\odot}$) and coincides with an obscuring cloud which visually destroys the symmetry of the HII region. This molecular cloud contains a water vapour maser source near its peak emission. Elmegreen and Lada also derived a mass of 260 $M_\odot$ for the SE cloud; they concluded that NGC 281 is likely to be another example of star formation taking place at the edge of the molecular cloud near its interface with an expanding HII region in a region where star formation was probably triggered by the onset of the stars in the multiple system ADS 719.

Assuming that components ABC and D of the multiple system are all on the main sequence and the values for their absolute magnitudes as given by Panagia (1973), the deduced spectral types of stars B and D are B1 and B0 respectively. The value of the amount of reddening in front of the cluster obtained from the present infrared photometry agrees well with that from visual photometry alone, both suggesting a value $A_V \simeq 1.2$. Unfortunately no infrared mapping of the region could be performed.

IC 1848.- The HII region IC 1848 extends over one square degree in the sky. It has two contiguous components but each one excited by different stars. BD +59 555 and HD 17520 are immersed in the westernmost component. The complex, including the open cluster Cr 32 is at a distance 2.29 kpc and the stars show a mean colour excess of E(B-V) = 0.72 (Moffat, 1972). The two main components of BD+59 555 (A and B), situated in the northern part of the nebula, have almost equal brightness and both spectra are classified as B-type. The third component is rather faint. It seems probable that the trapezium system is in one of the latest stages of its dynamical evolution where the less massive members have been ejected and a massive binary (A + B) is left at its centre, in accordance with theoretical computations (Allen and Poveda, 1974). The two-micron map showed the presence of only one source located some five minutes north of BD+59 555. The infrared colours of the source are not peculiar. Its most likely identification is a faint star on the PSS plates and which is probably a foreground late-type star. It is worth mentioning that in the Estern edge of IC 1848 Loren and Wooten (1978) have found an infrared source near the CO excitation peak in a dense molecular cloud which was resolved by Beichman (1979) as a double source in the mid-infrared while, Thronson et al (1980) found it to contain a dust-embedded B0 star with a very compact HII region. The complex seems to be consistent with sequential star formation in the cloud, where the dissolving trapezium system BD+59 555 and the nearby main sequence early type stars on the Western edge represent the older generation of stars in the region while the star formation "wave" propagated towards the Eastern edge into the molecular clous where stars appear now to be forming.

ADS 2426.- The small "loose" cluster of bright stars Stock 23 contains, near its centre, a Trapezium-type system of five stars whose primary is BD+59 618. Apart from those by double star astronomers, no observations of the multiple system are available. The IDS catalogue quotes m = 7.9 for the primary component and the HD catalogue assigns a spectrum A0.

The present IR scans revealed two sources, one of them positively identifedied with HD 20040, the brightest member of the cluster Stock 23. Taking the V magnitude from the HD catalogue, the spectral classification gG0 (Morguleff and Véron, 1970) and the present K magnitude for HD 20040, a distance of approximately 160 pc is obtained. The other source (IRS 2) in the region was identified with a faint stellar image on the PSS red plate. The IR colours suggest that it is a reddened late type star, most likely not associated with the cluster.

NGC 1999.- The multiple nature of V380 Ori, at the centre of NGC 1999, is in doubt. Jonckheere (1917) reported the presence of a 13th magnitude companion (B) to V380 Ori and also noted the possible presence of a third star (C) about 15th magnitude. Couteau (1961) confirmed the existence of the fainter star but was unable to observe component B. The whole system is situated in the centre of a small bright reflection nebulosity, NGC 1999, which has a very similar spectrum to V380 Ori (Herbig, 1960). It is characterized by the presence of an extremely dark triangular cloud delineated towards the western part of the nebula and the stars (separation between components ~ 3 - 5 arc sec) lie within the brightest part of the nebula. Herbig (1960) suggested the possibility that the companions B and C were not stellar but part of the nebulosity. Herbig also gave evidence indicating that V380 Ori is in the same cloud as the Great Orion nebula, but on the basis of its relatively low obscuration, not very deep into it. As part of his comprehensive study of Be/Ae nebulous stars, Herbig (1960) concluded that the spectral properties of V380 Ori indicated that, most probably, it is a pre-main-sequence star with T Tau characteristics.

V380 Ori has been widely studied at wavelengths from UV to IR (Table 4.1; Gillett and Stein, 1971; Cohen, 1973; de Boer, 1977) and the computed total luminosity, assuming a distance of 400 pc, is $L \simeq 300\ L_{\odot}$ (de Boer, 1977; Imhoff and Mendoza, 1974). Apart from the work by Herbig, Allen (1973), Cohen (1973), Gillett and Stein (1971) and Cohen and Kuhi (1979) all agree that the presence of a dusty cicumstellar shell is necessary to explain the large infrared excess from this star, though free-free emission seems also to contribute considerably at $\lambda < 3$ microns.

The surrounding region is also of considerable interest because, within the area under study, also lie the Herbig-Haro objects No 1 and 3. The infrared source IRS-2 is very close to HH 1 and it was discovered independently by Cohen and Schwartz (1979) who also obtained a visual spectrum which classified the star as G8 with B = 20.1, V = 17.7 and A_V = 5.7 but showing an infrared excess large enough to require thermal emission by dust particles. Cohen and Schwartz discussed the star as the probable excitation source for the nearby Herbig-Haro object and, on the basis of its position on the H-R diagram above the main sequence, determined a mass $M \simeq 2\ M_{\odot}$ and an age of around 1.5 million years for the star.

A second source, IRS-1 was found to the North-East of HH 1. At 2.2 microns it is brighter than IRS-2 (K = 7.7 ± .2) but unfortunately no multifilter photometry is available at the moment. Nevertheless, from its appearance in direct photographs, it seems to have B-R and B-I colours very similar to IRS-2. In fact, the brightness difference between the two stars is roughly constant on the blue and red PSS plates, the red prints shown by Herbig (1974) and Cohen and Schwartz (1979) as well as the I (~ .8 microns) SRC Schmidt plate taken on IV-N emulsion, IRS-2 being about 1 magnitude brighter in all of them. This would imply that IRS-1 has larger near-infrared colours.

Collinder 89.- This system of which 12 Gem is the primary star is embedded in a nebulosity which mainly reflects the light from HD 43836. Results from visual photometry and spectroscopy (Table 4.1) indicate a distance modulus m - M = 8.7 suffering interstellar absorption amounting to about A_V = 1.67 (Racine, 1968) and hence probably is not a member of the Gem OB1 association. The present infrared photometry agrees with the expected continuum for its spectral type, visual magnitude and deduced extinction. The two infrared sources found in the vicinity of 12 Gem have relatively bright optical counterparts on the blue PSS plate and their infrared colours suggest that they are late-type stars in the field.

NGC 2244.- The system ADS 5165 is located in the central cavity of the Rosette nebula. This complex is composed of the shell-type HII region NGC 2237/2246 which surrounds the young open cluster NGC 2244 embedded in the "central hole" of very little optical nebular emission. In fact, radio observations (e.g. Menon, 1962) indicate that the cavity is real. After the formation of massive stars in a massive HI cloud, the gas material in the centre of the complex was radially driven out of the region by radiation pressure on dust particles (Mathews, 1967) and/or strong stellar winds (Mathews, 1966) which are still present in the most luminous stars in the cluster (Hutchings, 1976). Mathews (1967) suggested an age of the nebula of 5 million years, compatible with the observed nebular expansion motions (Smith, 1973) while HD 46150, the primary star of ADS 5165 seems to be just over a million years old and has a mass of 50 $M_\odot$ (Viner et al, 1979). The distance to the cluster and the nebula is 1.6 kpc (Heiser, 1977; Becker and Fenkart, 1971), assuming a "normal" value for R = Av/E(B-V). Johnson (1965), based on infrared observations of early types in the cluster (including HD 46150), found an exceptionally high value of R (=6), but, as in the case of other "anomalous" early-type clusters studied by Johnson, the infrared observations reflected the presence of circumstellar emission instead of the properties of the interstellar medium. This is undoubtedly the case for HD 46223 and 46150. Both are Of stars suffering extensive mass loss ($\dot{M} = 1.5 \times 10^{-6} - 10^{-7}$ $M_\odot$/yr; Hutchings, 1976). The free-free emission from the expelled ionized material gives rise to infrared excesses at $\lambda > 2$ microns (see Barlow and Cohen, 1977). It seems safe, therefore, to adopt a standard value of R for this region.

The trapezium system ADS 5165 has five components of which the primary is an O5.5f star and, based on the available visual photometry (Table 4.1), the components D and E are of approximately B9 and B6 spectral types respectively. Four infrared sources were found in the surroundings: IRS-4 is star HD 46149 (O8.5V), another exciting star of the Rosette nebula. IRS-1, an A3V star called HD 46180 and IRS-2, star classified as gG2 were found not to belong to the cluster from photometric and proper motion studies (van Schewick, 1958). Furthermore, the infrared data suggest IRS-2 to be to of a later spectral type than reported. Finally, IRS-3, for which no spectrum is available, seems to be an M-type star slightly reddened and therefore not a member of NGC 2244.

In summary, the present observations of the star members of the cluster NGC 2244 support a value for the interstellar extinction of E(B-V) = 0.47 and A_V = 1.45 and distance of 1.5 - 1.6 kpc. No unknown infrared-bright stars belonging to the cluster were found in the area mapped.

NGC 2264.- This is one of the best studied young open clusters. Its brightest star is S Mon. An extensive photometric and spectrometric study was made by Walker (1956) showing that the colour-magnitude diagram consisted of a normal main sequence extending from O7 to A0 but most of the cooler stars fell above their corresponding position on the main sequence, suggesting that these stars have not yet arrived at the main sequence. Walker deduced an age for the cluster of about 3 million years. Furthermore, he noted that stars later than about F8 showed abnormally high rotational velocities. These results were generally confirmed by Vasilevskis et al (1965) and Strom et al (1971). The cluster lies in projection towards a very dark cloud but most of its members seem to be relatively free from interstellar obscuration (E(B-V)=0.8), at a distance of 700 - 800 pc (Walker, 1956). Herbig (1954) found a large number of Hα -line emission stars, most of them of late spectral types, including a good number of T Tauri-type stars. Near-IR observations of stars in NGC 2264 have confirmed the presence of circumstellar envelopes in some, but not all the probable pre-main sequence stars in the cluster (Strom et al, 1972a, Warner et al, 1977, Cohen and Kuhi, 1979) and Warner et al concluded that the shape of the specrtral distribution of most of the stars showing the excesses could be explained by a combination of photospheric emission and a F_ν-constant component, probably due to hot optically thin free-free emission in the envelope.

Two trapezium-type clusters are members of the cluster: 1) S Mon is the primary star of ADS 5322 whose close companions (B,C and K) have not been classified due to their proximity to the very bright S Mon. 2) Located some 10 arc min to the SW is ADS 5316, a system with only three components, all likely members of the cluster (Vasilevskis et al, 1965). These two (overlapping) areas were mapped at 2 microns resulting in the detection of four sources (note that ADS5316-IRS-1=ADS5322-IRS-2). Table 4.1 gives the identification and visual data of the relevant stars. Walker Nos. 46, 50 and 100 had also been observed in the near infrared by Strom et al (1972a) and by

Warner et al (1977) and, since their results fully agree with the present ones, the reader is referred to those papers for a discussion. Only the source ADS 5322-IRS-1 had not been classified or observed before. At that position there is a faint image on the red PSS plate but none on the blue one. Its location on the IR two-colour diagrams suggests that it is a reddened star under at least seven magnitudes of visual absorption and no excess at $\lambda < 4$ microns. This star is probably located behind or embedded in the background dark cloud.

The present IR photometry of the spectroscopic binary HD 47755 (ADS 5316A) is consistent with a main sequence star with no circumstellar emission (see Table 4.1). Component B of this system (Walker No 67) is the only probable early-type member of the cluster reddened by as much as $A_V = 2.7$. If de-reddened, it lies "somewhat below the main sequence" (Walker, 1956) and in that case, its energy distribution shows an F_ν-constant near-infrared excess very similar to other stars in the cluster as shown by Warner et al (1977). If, as suggested by the proper motion study by Vasilevskis et al (1965), the star is a member of NGC 2264, it would be the hottest star (B2) in the cluster known to have infrared excess. If this is the case, an emission line spectrum would be expected from Walker-67 but in fact, it was not listed by Herbig (1954) in his catalogue of H_α-line emission stars of the region. Nevertheless, the star lies only 21 arc sec away from Walker No. 74 (p.a.=310^0) which is 2.4 magnitudes brighter and it is possible that the spectra of both stars overlapped in Herbig's slitless survey and hence, the brighter star masked the properties of the spectrum of Walker-67. Confirmation of the membership of the star to the cluster and slit visual spectra are desirable.

NGC 2362.- Tau Canis Majoris is the primary star of this well studied compact young blue cluster (see e.g. Becker, 1960). It is located at a distance 1.54 kpc and reddened by E(B-V) ≃ 0.12 (Becker and Fenkart, 1971) The spectral type and visual colours are given in Table 4.1 and the present IR measurement agree with the expected photospheric flux. The only infrared source found in its vicinity seems to be NGC 2362-20 (Johnson, 1950) and the aperture of the phtometric measurement also included a few fainter stars very close to it. The 2.2 micron magnitude obtained for NGC 2362-20 is a few tenths of a magnitude brighter than that expected for the B2V star alone but most probably, this is due to contamination from the nearby stars.

vB 96.- Although the Index Double Star catalogue (1975 edition) does not give a Durchmusterung identification to the entry IDS0715.4-2350, in fact it corresponds to BD-23 5277 = HD 57281. A reflection nebulosity surrounds the system, listed No. 96 in van den Bergh's (1966) catalogue. Racine (1968) classified the primary star as B9 and obtained a photometric distance of around 1.0 kpc. The present photometric map of the region indicates that the combined light of the triple star is fainter than K = 9.2, in agreement with the expected photospheric flux deduced from the visual data (Table 4.1). Two infrared sources were found in the vicinity of vB 96 of which only for the brightest (IRS 1), were multicolour measurements obtained. These locate the star on the reddening line ($A_V \gtrsim 1.5$) and the fact that the most likely identification is just above the PSS red plate limit, and invisible on the blue plate suggest that the star is of a very late spectral type. IRS-2 was identified in both plates with a faint star.

VY CMa.- Although VY CMa has been repeatedly reported as a close multiple system, Feast (1970a) and Herbig (1972) have provided strong evidence supporting the idea, first suggested by Herbig (1970a) that the "stellar companions" reported by double star observers were not so, but (variable) condensations of a reflection nebula only a few arc seconds in size. Itself, VY CMa is a much studied but most enigmatic object; the (primary) star has been classified M3-5 Ia/Iab and the main optical characteristics have been described by Herbig (1970a), while IR and visual photometry have been reported by Hyland et al (1979) and Low et al (1970). The IR spectral distribution (very much like that from NML Cyg) clearly reveals the presence of circumstellar dust emission; in fact VY CMa is one of the brightest objects in the sky at 20 microns. Strong H_2O, OH and SiO maser sources have been detected coincident with the star and a large molecular cloud complex associated with the bright rim located very close to VY CMa has also been found (Lada and Reid, 1978; see also references therein).

The most complete model yet proposed to explained the observed properties of VY CMa, is that by Herbig (1970a,b), later refined by

Schwartz (1975b). It consists of a central pre-main-sequence star with effective temperature 2700 K surrounded by an optically thick expanding disk of cool gas and dust seen almost edge on. Herbig assumed the object to be at the same distance as NGC 2362 on the basis of the (projected) association with a bright section of the large HII region S 310 which surrounds τ CMa. Similarities in the radial velocity determinations for NGC 2363, τ CMa, the nearby CO clouds and the various spectral lines in VY CMa as well as the SiO maser, strongly support a common distance of $\sim$ 1.5 kpc, strengthening the hypothesis that VY CMa is a pre-main-sequence object (Lada and Reid, 1978 and references therein), though the presence of a type IIb OH maser, typical of those associated with evolved late-type stars makes the evolutionary status of the remarkable VY CMa still uncertain.

The 2 micron map revealed the presence of three sources in the vicinity of VY CMa, two of them in the direction of the molecular cloud complex, but the JHK colours suggest that both are late-type field stars. In fact, the three sources coincide with faint stars on the PSS blue and red plates.

HD 71304 and vBH 25cde.- No infrared sources brighter than K=7.7 and K=8.4 were found in the areas around the trapezium systems HD 71304 and HD 78838 respectively. HD 71304 is a reddened O supergiant at an approximate distance of 2.3 kpc. Within the errors of the present 2.2 measurements (from the photometric map), the star does not show any significant excess in the V-K colour.

HD 76838 = vBH 25cde (van den Bergh and Herbst, 1975) has been observed at visual (Herbst, 1975) and infrared (Williams, et al, 1977) wavelengths. The present photometry fully agrees with the measurements by Williams and collaborators, who found a small excess at $\lambda > 3.4$ from HD 76838 but not at shorter wavelengths.

CPD -62 1837.- This system was first discovered to be triple by Tapia (1921) and was also measured micrometrically by Dawson (1922) and van den Bos (1951) but it has been completely neglected since. The results of the present observations of this system have been reported by Tapia and Catchpole (1980, Appendix II) and only a few speculative remarks on the nature of these stars are presented below.

From the fitted values for star components A and B of the system as given in Table II of Appendix II together with their spectral types, it is deduced that A must be of luminosity class III for, if it were a supergiant (I), it would lie at a distance of more than 6 kpc, which is inconsistent with its colour excess of only $E(B-V) = 0.26$. A similar argument was used to rule out a nearby dwarf. Hence, the reddening in front of CPD -62 1837 A is $A_V = 0.82$ and it is at a distance of $\sim$500 pc. From the observed energy distribution and assuming the same distance, star B would have an absolute bolometric magnitude of $M_{bol} \simeq -5.0$, in agreement with that expected for long-period variables (e.g. Smak, 1966); this supports the idea that the system CPD-62 1837 is physical (i.e. not optical). At this distance, the true separation between components A and B is $d \gtrsim 2,200$ AU and its orbital period $P \gtrsim 50,000$ years.

Figure 4.5 shows the spectral distribution of star B at the times of observation corrected for $A_V = 0.82$ together with a black body at T = 2700 K for comparison. The fact that the difference δV between the observed magnitude and the black body is large and exceedes δB confirms that star B is of a late M spectral type with strong TiO absorption. These bands produce a striking effect in its image on objective prism UK Schmidt plates, which at first sight look very much like quasars at redshifts of around $z \simeq 2$! (Savage, 1978, Clowes, 1980).

Great Carina Nebula.- This enormous nebulosity is one of the highlights of the southern Milky Way. As its "heart" it contains the enigmatic nova-like object η Car. The frontpage of the present dissertation is a print of the complex from a deep blue UK Schmidt plate revealing the complex morphology of this enormous association of luminous star clusters, bright ionized gas and dark dust clouds. As described by Walborn (1973d), it is one of the "most powerful laboratories available for investigating the early evolution of massive stars". No less than eight young stellar clusters (NGC3293, NGC3324, Tr14, Tr15, Tr16, Cr228, Bo10 and Bo11) exist within or close to the nebulosity. However, it has only recently become clear that they are at approximately the same distance from the Sun, at 2.7 ± .2 kpc (Turner and Moffat, 1980 and references therein) and possibly they all are physically associated. There seems to be a

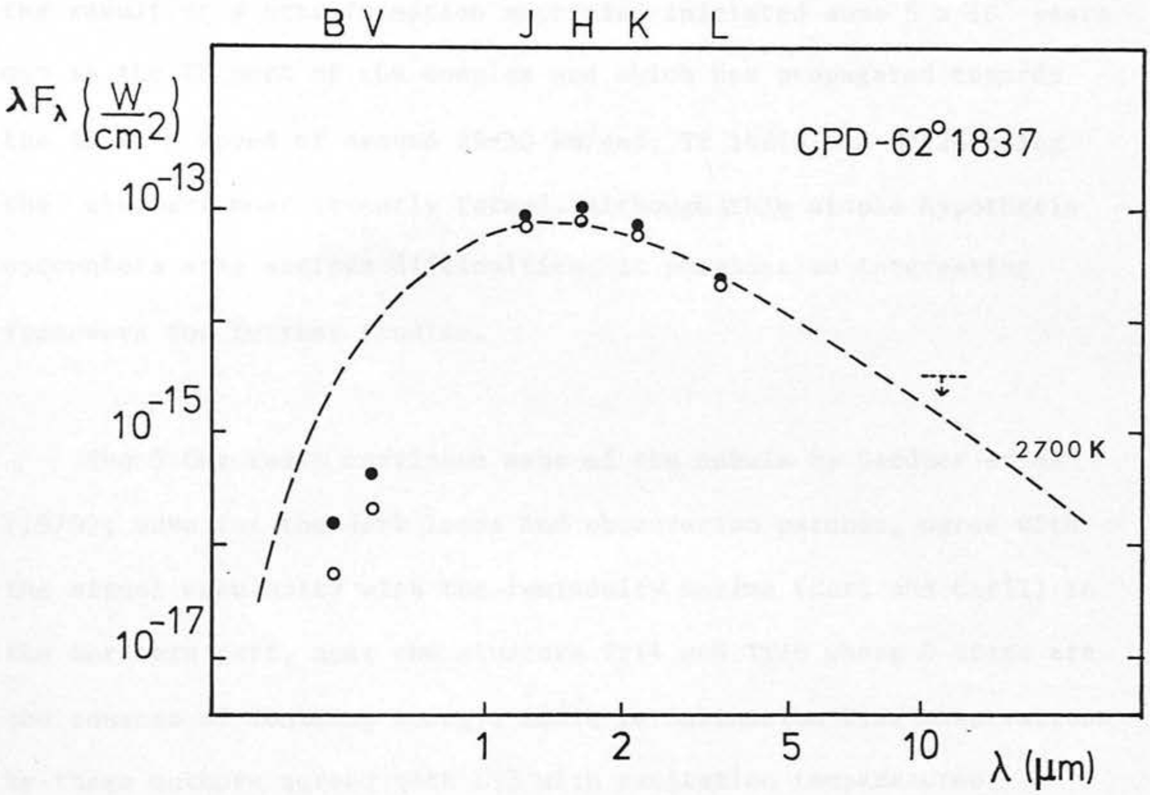


Figure 4.5. Spectral distribution for CPD-62 1837B corresponding to the May 1980 (open circles) and January-February 1979 (filled circles) observations. All corrected for Av = 0.85.

distinctive correlation between the ages of the star clusters (1 - 5 million years) and their position in the nebula. This result led Turner et al (1980) to suggest that the observed "age gradient" was the result of a star formation mechanism initiated some 5 x 10^6 years ago in the NW part of the complex and which has propagated towards the SE at a speed of around 25-30 km/sec; Tr 14/16 and Cr228 being the clusters most recently formed. Although this simple hypothesis encounters some serious difficulties, it provides an interesting framework for further studies.

The 5 GHz radio continuum maps of the nebula by Gardner et al (1970), save for the dark lanes and obscuration patches, agree with the visual nebulosity with the luminosity maxima (CarI and CarII) in the northern part, near the clusters Tr14 and Tr16 whose O stars are the sources of ionizing energy. Radio recombination line observations by these authors agreed with LTE with excitation temperatures averaging 7000K. Coincident with the two V-shaped dark lanes, H_2CO and OH absorption peaks were found by Gardner et al (1973) and Dickell and Wall (1974) respectively. They concluded that both the hydroxyl and formaldehyde molecules are physically associated with the dust cluds producing the optical absorption and that very little molecular absorption originates near the (radio) brightest parts of the HII region. From far-infrared maps of CarI and CarII Harvey et al (1979) proposed that the radio peaks represent ionization fronts at the boundaries of nearby dense cluds whose heated dust particles give origin to the observed far-infrared emission with the hot stars in Tr14/16 providing enough ionizing and heating energy. In particular, Harvey et al (1979) concluded that the dust grains in CarII must be optically thin ($\tau = 0.1$) and that the high gas/dust ratio deduced was probably due to destruction and evaporation of the dust; a fact which may be associated with the violent history of η Car.

The stellar content of the Carina Nebula remained neglected for a long time and it is only during the last decade that it has been extensively studied photometric and spectrometrically. At present, very few of the (optically) bright members of the young open clusters remain anonymous and reliable colour-magnitude diagrams exist for all the known clusters of the complex; all references are given in Table 4.1 where the available visual data relevant to the present study are quoted.

Arguments have been given in favour of the interstellar extinction being anomalous in this region, represented by a large value of $R = Av/E(B-V) \simeq 5.0$ (Herbst, 1976) but this data has recently been re-analysed by Turner and Moffat (1980) by using stricter criteria for the determination of cluster membership (including star counts) and rejection of stars of peculiar characteristics such as Be and Of stars. These author concluded that there is no real evidence for an anomalous value of R in this region. Furthermore, Turner and Moffat computed a value of $R = 3.20 \pm 0.28$ for the Tr14/16, Cr228 region.

Each of the massive clusters contains at least one Trapezium-type system near its centre. A total of seven of these systems were studied photometrically between 1 and 4 microns and their surroundings mapped at 2.2 microns. The results are shown in Table 3.1 where all entries in the right ascension range ($10^h38^m < \alpha_{2000} < 10^h48^m$) belong to the Carina Nebula complex. The system denoted T Anon had not been catalogued before but was chosen for it is a faint triple trapezium system in the centre of a dark cloud, though there is no evidence for its association with the other star clusters. The regions observed are indicated by solid lines in the first page of this dissertation. The primary stars of most of the trapezia under study are luminous O and B stars, many of them showing Of characteristics (Walborn, 1973d) and a number of similar stars in their vicinity were also detected in the IR surveys.

The results of the present near-infrared photometry combined with published visual observations for all early type (O and B) stars with known spectral classification were used to plot a colour-excess E(B-V) vs E(V-K) diagram, shown in Figure 4.1a, where emission-line stars and supergiants are plotted with different symbols (HD 303308 was also plotted with IR data from Whittet and van Breda, 1980). Although the sample is very small and the errors in the K measurements of some stars (from the 2.2-micron maps) are large, a marked difference in the IR properties of emission-line and supergiant stars and of "normal" giants and dwarfs is clear. Barlow and Cohen (1977) have shown that the ionized gas, produced by mass-loss from Of and OB supergiants, gives rise to infrared excesses of the same order of magnitude as those seen in Fig 4.1a. Furthermore, in the cases where BVRIJHKL photometry is available the

<u>Figure 4.1</u>. Colour excess diagrams for early type stars within the Great Carina Nebula for which spectral types and photometry are available. (a) Contains stars presently measured in the K photometric band (Table 3.1) and (b) was plotted using data by Thé et al (1980). In both, open circles are supergiants, crosses are stars with Of spectra and filled circles are non emission-line stars of luminosity classes II, III and V. The straight lines are the reddening vectors for three values of R, ratio of total to selective interstellar absorption, assuming $R = 1.1\ E_{V-K}/E_{B-V}$.

<u>Figure 4.2</u>. Two-colour diagrams for stars observed in three colours within the Great Carina Nebula (Table 3.1). Symbols are as in Figures 3.1 and 3.2.

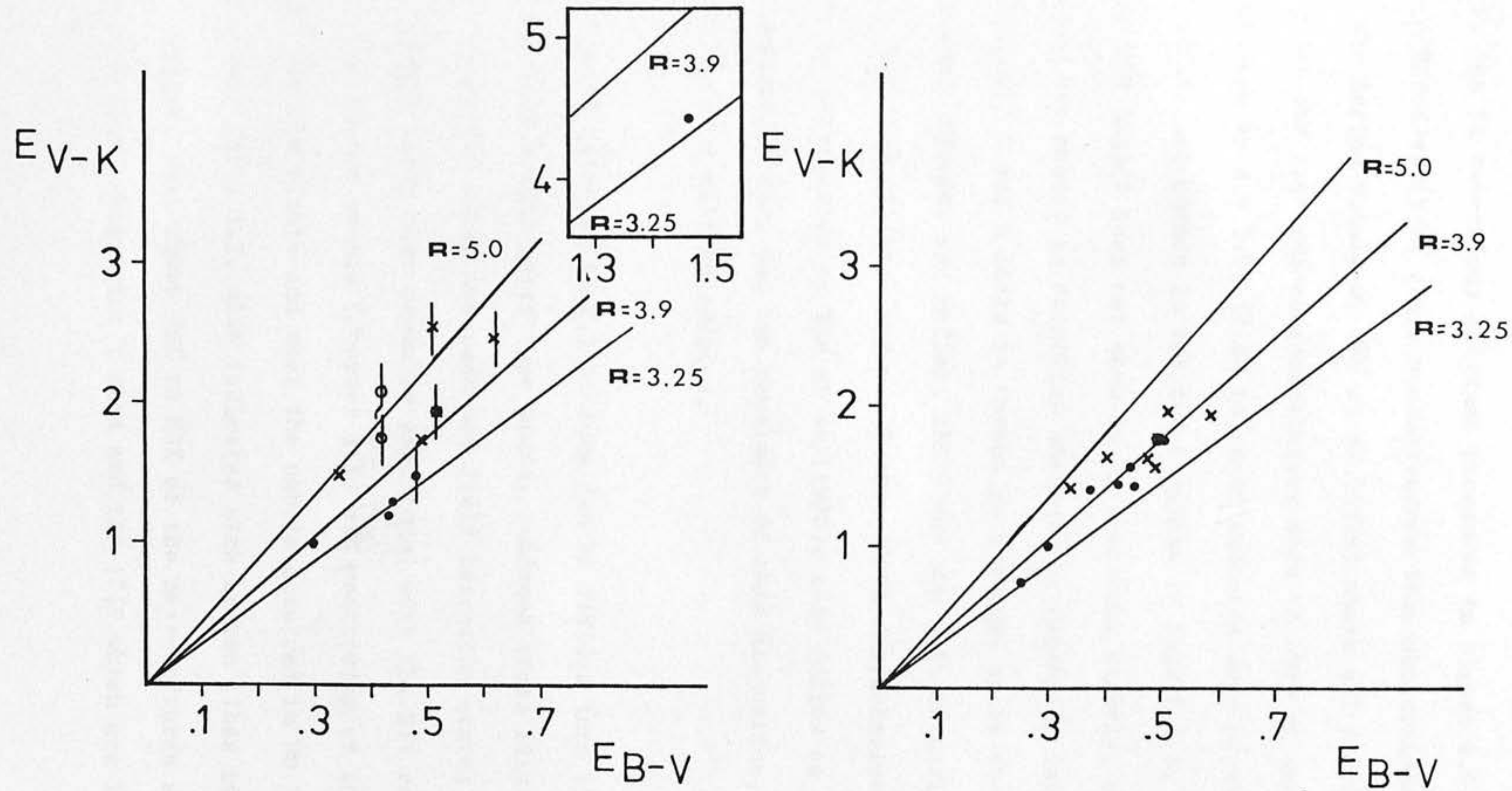


Figure 4.1

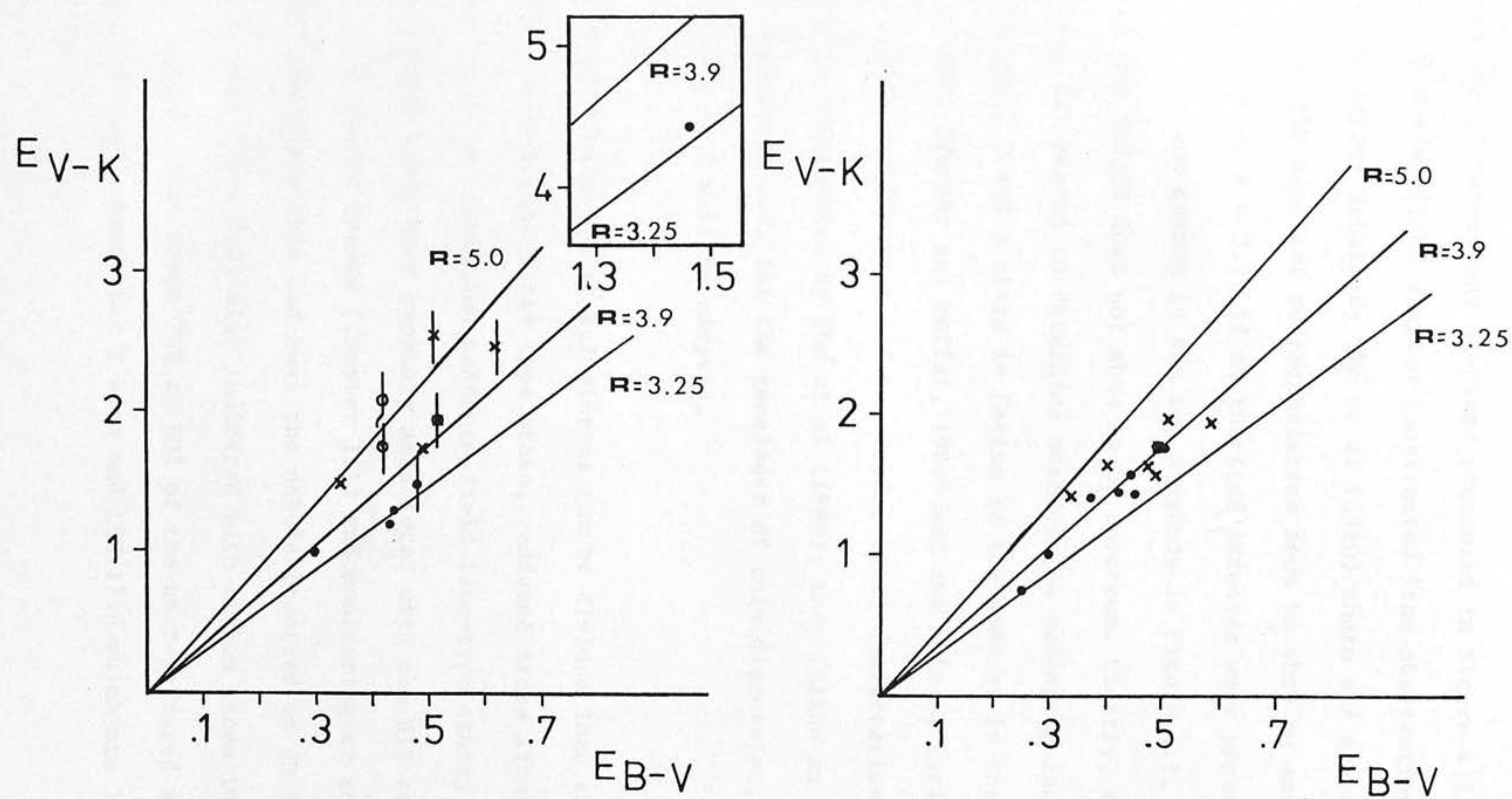

5
4
R=3.9
R=3.25
1.3
1.5
E V-K
3
2
1
R=5.0
R=3.9
R=3.25
.1
.3
.5
.7
E B-V
E V-K
3
2
1
R=5.0
R=3.9
R=3.25
.1
.3
.5
.7
E B-V

Figure 4.1

observed shape of the energy distributions is fully compatible with the free-free radiation studied by Barlow and Cohen. This is also evident in the IR two-colour diagrams presented in Figure 4.2. Figure 4.1b is an E(B-V)vsE(V-K) diagram constructed from observations of O stars in the Carina Nebula by Thé et al (1980) where **all** stars, regardless of the spectral characteristics seem to obey an extinction law represented by R = 3.9, if no infrared excesses were present. Only five stars are common in the two diagrams in Figure 4.1, of which only HDE 303308 does not show an Of spectrum. Clearly, more observations are needed to determine whether the reddening law towards "normal" O and B stars in Carina is the same as in the other cluster members (Turner and Moffat, 1980) and the bulk of early type stars in the Galaxy (Whittet and van Breda, 1980) characterised by R≃ 3.2 or, as interpreted by Thé et al (1980), they follow an abnormal extinction law. For the remainder of this discussion, a "normal" value of R will be adopted.

The objects detected at 2.2 microns can be divided into three groups: Optically bright early type stars, reddened stars likely to be of early spectral types and reddened field late-type stars; the first two groups being most probably associated with the HII region. The two-micron source counts (Chapter III) and monitoring of three "reference" regions within and near the nebula (centred in HD 92740, HD 93130, Y Car; Table 3.3, also indicated with broken lines in the frontpage) suggest that about 70% to 80% of the near-infrared sources are background stars except for T Anon and LSS 1719 which are located

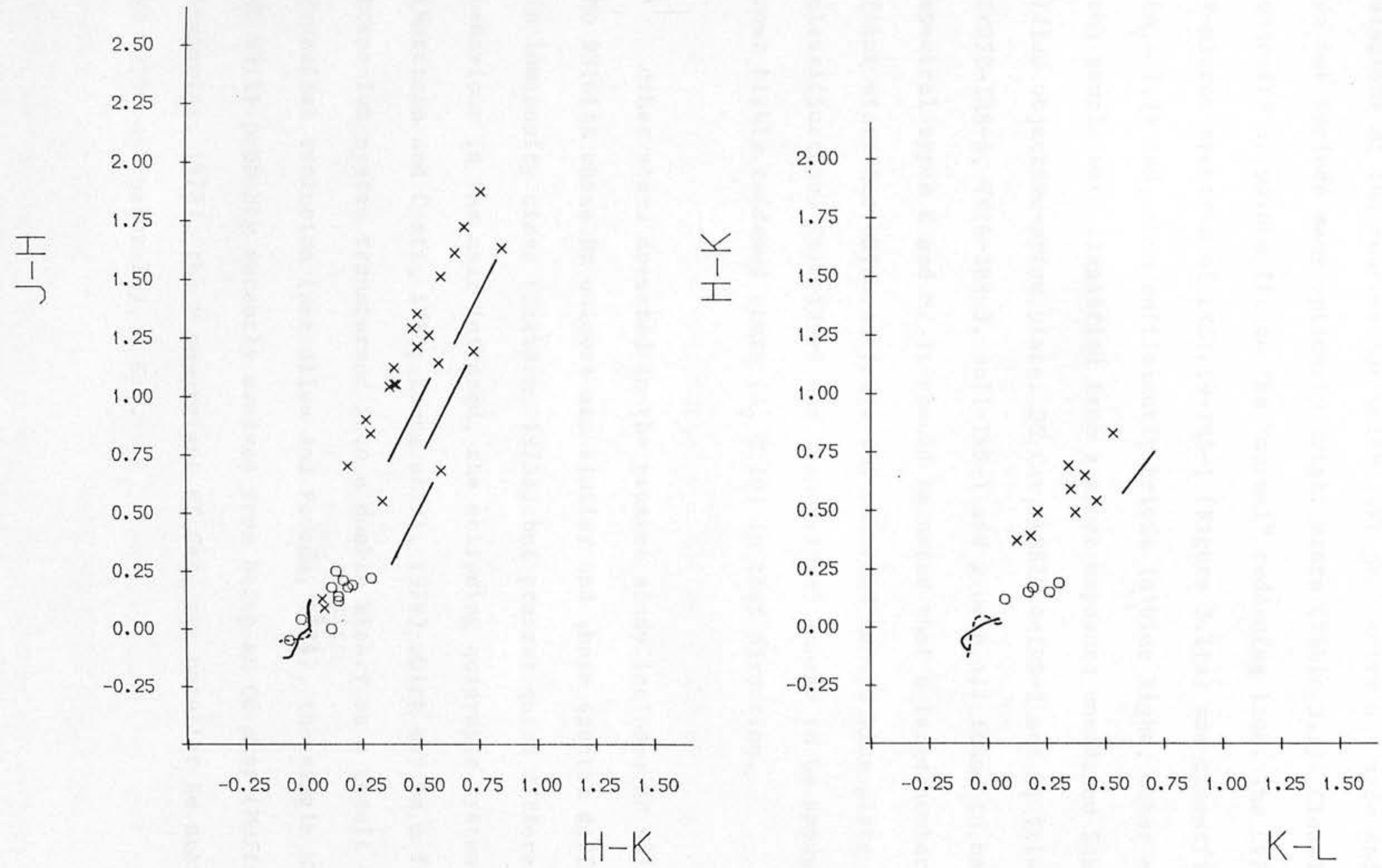

J-H
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50
H-K
H-K
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.25 0.00 0.25 0.50 0.75 1.00 1.25 1.50
K-L

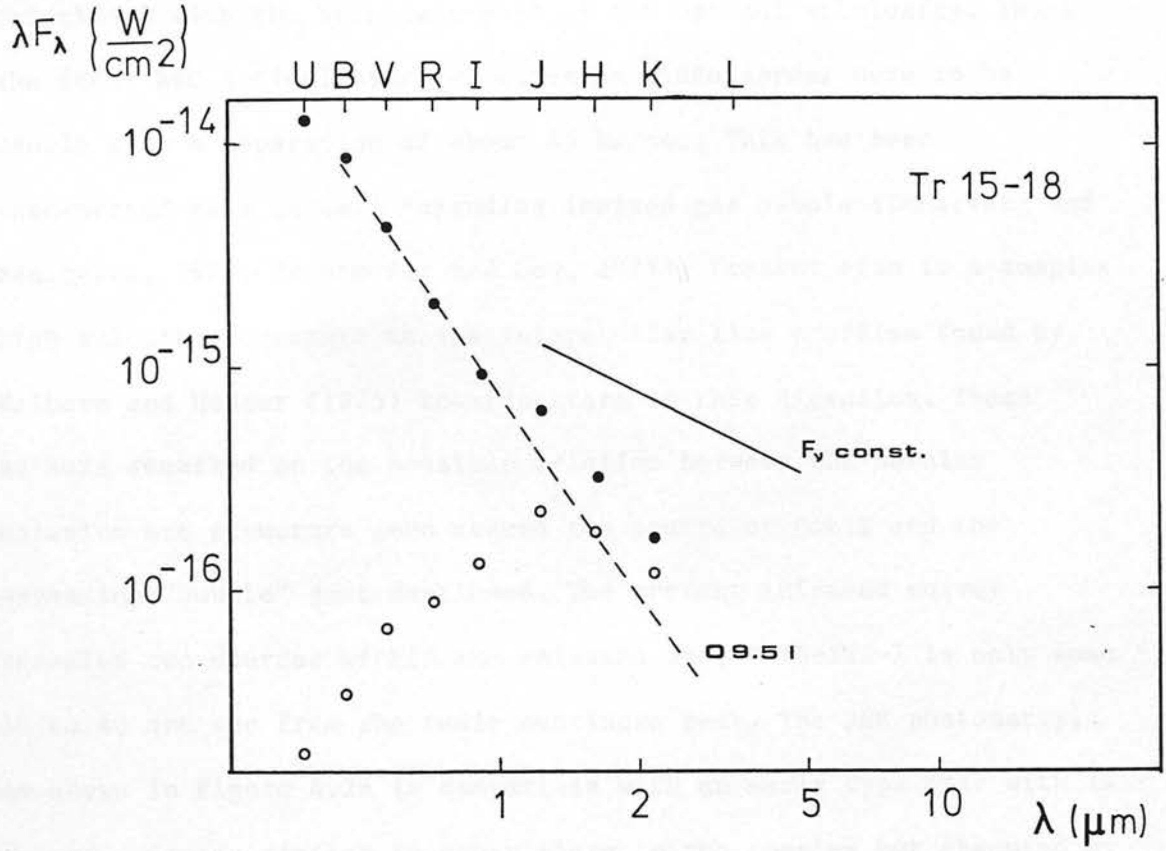
Figure 4.2

outside the large clusters and seem to contain no highly reddened early-type stars. Figure 4.2 shows the near-infrared two-colour diagrams of the sources for which JHKL photometry was made and which do not include many optically bright stars (Table 3.1). Clearly the majority of points lie on the "normal" reddening line. The CVF 2-micron spectrum of LSS1719-IRS-1 (Figure 3.11a) was classified M3 ($A_V \simeq 7.7$) and, when sufficiently bright in blue light, other stars in the sample were classified from a short exposure unwidened Schmidt IIIaJ objective-prism plate. BG Car, LSS1794-IRS-2 and 3, Tr14-IRS-3, Cr228-IRS-6, Tr16-IRS-3, Bo11-IRS-1 and 2 were all found to have spectral types K and M. It should be noted that a large number of faint stars for which no image was recorded on the blue plate escaped classification. Tr14-IRS-2 and T Anon-IRS-5 appear to be among the most highly reddened stars ($A_V \gtrsim 10$) in that direction.

Other stars detected in the present study include: HD 93160 and HD 93161AB whose BV colours are similar and whose spectra differ only in luminosity class (Walborn, 1973d) but present quite different behaviour in the near-infrared, the eclipsing quadruple system QZ Car (Morrison and Conti, 1980; Leung et al, 1979) which may be a former trapezium system transformed into a double binary as a result of its dynamical evolution (see Allen and Poveda, 1974), the single WN7 star HD 93131 probably recently evolved from being an Of star (Moffat and Seggewiss, 1978), the M supergiant RT Car, the peculiar Be star HD 93190 and naturally, η Car.

The only near-infrared sources found whose colours depart significantly from those of reddened cool stars are located within the cluster Tr15 and Tr16. Consider first Tr15. The central trapezium also contains a number of faint stars which surround it. RT Carina is only a few arc min to the South and is not certain to be a real cluster member but the presence of Forte's peculiar infrared nebulosity (reported by Feinstein et al, 1980), also seen in our IV-N plate, argues in favour of its membership to Tr15. Adjacent lies one of the most highly reddened OB stars observed in the Carina complex, Tr15-18, with a B-V excess of 1.42, corresponding to an obscuration of more than 2.8 magnitudes in excess of that observed in the rest of the cluster (Feinstein et al, 1980). The present JHKL photometry confirms this result as illustrated by the energy distribution from .4 to 3.5 microns (Figure 4.3). The de-reddened points show, not surprisingly, a small excess at $\lambda > 1$ micron. Tr15-IRS-1 and 5 are located almost along the same reddening vector as Tr15-18 in the (J-H) vs (H-K) diagram (Figure 4.2a) but corresponding to 5 and 10 magnitudes of extra visual absorption respectively.

The cluster Tr16 is centred in one of the most enigmatic and spectacular galactic objects known, η Car. Its present and past optical and infrared properties are described respectively by Walborn and Liller (1977) and Hyland et al (1979) and references therein. Sufficient will be here to say that the association of this object with the nebula, and hence to Tr16, has (only recently) been proven (Walborn and Liller, 1977; Allen, 1979) and, therefore, its presence should be considered in the study of the dynamics and evolution of the complex.



<u>Figure 4.3</u>. Spectral distribution for Tr 15-18. Open circles are observed points and filled circles corrected for Av = 4.53.

Only a few arc min to the NW is the radio continuum peak CarII, coincident with the brightest part of the optical nebulosity. There the radio and optical hydrogen emission lines appear here to be double with a separation of about 45 km/sec. This has been interpreted as a (local) expanding ionized gas nebula (Deharveng and Maucherat, 1975; Huchtmeier and Day, 1975). Present also is a complex high velocity structure in the interstellar line profiles found by Walborn and Hesser (1975) towards stars in this direction. These authors remarked on the possible relation between the nebular emission arc structure seen around the centre of CarII and the expanding "bubble" just mentioned. The present infrared survey revealed two sources within the emission arc. Tr16-IRS-7 is only some 30 to 40 arc sec from the radio continuum peak. The JHK photometry, as shown in Figure 4.2a is compatible with an early type star with IR excess emission similar to other stars in the complex but obscured by $A_V \simeq 10-12$. A similar argument applies to the nearby IRS-4, whose infrared colours suggest a lower value of A_V (3 - 5) but more extreme H-K excess. A finding chart for these two objects is given in Figure 4.4, a magnification from the far red IV-N Schmidt plate. As no unique identification was possible for IRS-7, the two stars with very large B-I colour within the positional error box are indicated in the chart and the coordinates of both are given in Table 3.1; also marked are some reference stars following the identification by Feinstein et al (1973). It is very important to determine the spectral characteristics of these stars in order to determine their role in

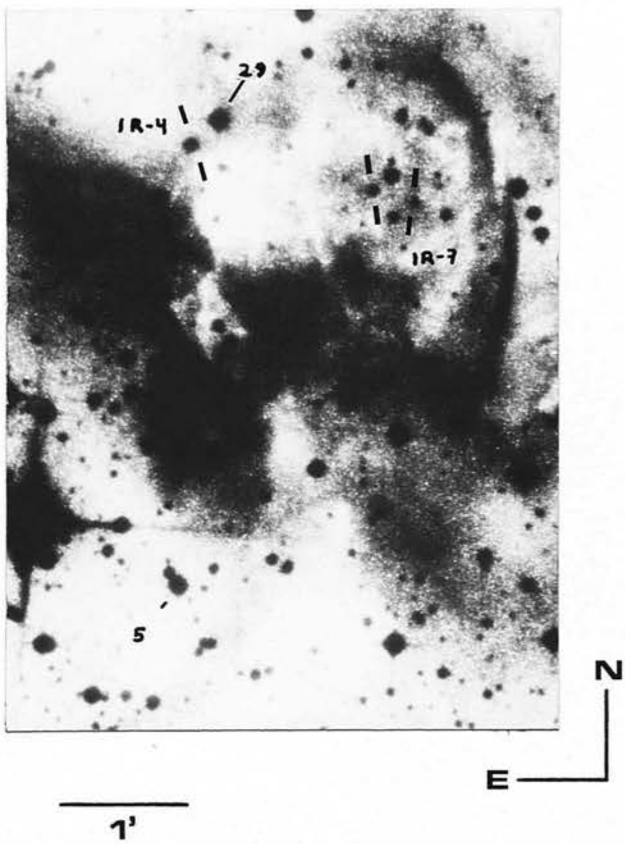
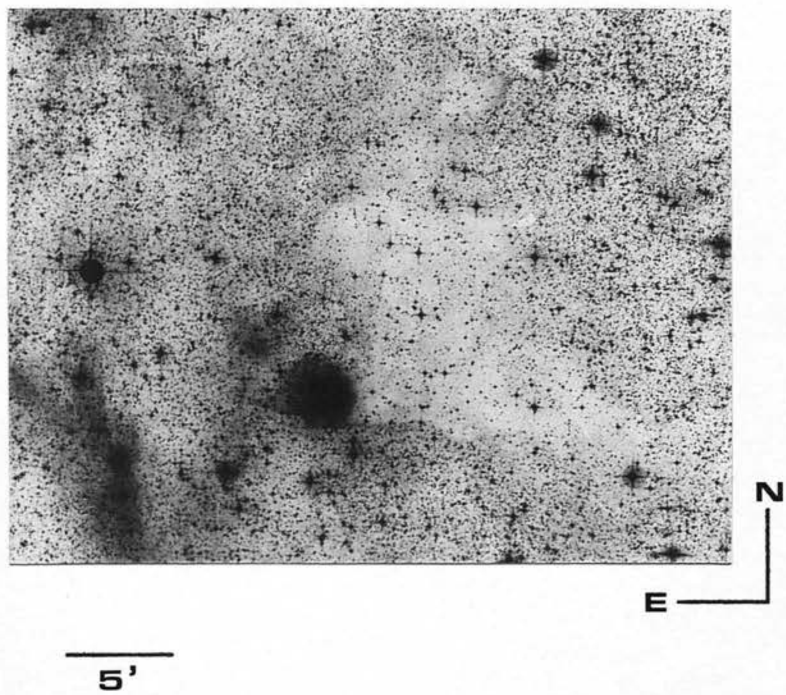


Figure 4.4. Finding chart, from a far-red plate, for Tr16 - IRS-4 and IRS-7. For the latter, two possible identifications are given. For reference, two stars from Feinstein et al (1973) are indicated.

this complex region. An optical spectroscopic study is difficult due to the brightness of the nebulosity and the faintness of the stars and further IR observations should prove to be of great value.

Among the challenges presented by Tr15-IRS-1 and 5 and Tr16-IRS-4 and 7 are, if they are indeed cluster members, the explanation for their anomalous reddening which must be of local origin as well as the determination of their role in the dynamics of the complex and, naturally, their evolutionary status. High resolution near- and mid-infrared mapping would also contribute towards the knowledge of the distribution of obscuring material in the northern part of the Carina nebula.

Pismis 17.- CPD-59 2944 is the primary star of a small Trapezium-type cluster (Pismis 17) embedded in the emission/reflection nebulosity Hoffleit 44 (Hoffleit, 1953), also designated vBH 46 (van den Bergh and Herbst, 1975) and a member of the association Carina R1 which is at the same distance as the Great Carina Nebula complex. From isolated UBV photometry of the cluster, Moffat and Vogt (1975) assigned a distance of 4.2 Kpc but this was based on data of only a few stars and the determination is less accurate. Table 4.1 shows the available visual data of the brightest members of Pismis 17, all of which are of early B spectral types. Herbst (1975) reported the presence of emission lines in their spectra but these may only be due to contamination from the nebulosity emission. Nevertheless, the present infrared observation



<u>Figure 4.6</u>. Deep blue print of the complex Pismis 17/Hoffleit 44.

microns overlapped with but did not include all the given 11-micron error box, this object was not detected. It is, therefore, of interest to study the region at longer wavelengths as well as to search for molecular line emission to investigate the process of past and possibly recent star formation in this region.

NGC 3603.- This name refers to both the radio/optical HII region (also catalogued as RCW 57B) and to the small cluster of young stars which are the source of its excitation. The central part of the cluster is a Trapezium-type system containing at least some ten stars of which the brightest six have been identified and their separations measured by double star observers (see IDS Catalogue, Jeffers et al, 1963); all lie within a radius of ~6 arc sec. A much larger emission nebulosity is asymmetrically distributed around the cluster. Photographs of the region at various wavelengths and exposures have been presented by Sher (1964), Walborn (1973c) and Frogel et al (1977). The distance to the complex has been a matter of controversy; Sher (1965) made photoelectrically calibrated photographic photometry of the stars in the inner region of the cluster and excluding the trapezium system and by making use of Johnson's published intrinsic colours of early type stars and assumed ones for the hottest, Sher derived a distance of 3.5 Kpc. A revision of Sher's photometry by Moffat (1974) who fitted the intrinsic colours for the bluest stars, resulted in a derivation of the photometric distance of d = 8.1± 0.8 kpc and colour excess E(B-V) = 1.32 - 1.37 (Moffat, 1974; van den Bergh, 1978; Somerville and Blades, 1980). Dynamical determinations of the distance to NGC 3603 using radio and optical radial velocities of the HII region yielded values between d = 7.2 - 8.4 Kpc (Goss and Radhakrishnan, 1969; Feast, 1970b), placing the complex at the furthest side of the Sagitarius-Carina arm (note that NGC 3576=RCW57A, only 22 arc min away in the sky, is at the nearer side of the arm, at a distance of 3.6 kpc; Goss and Radhakrishnan, 1969). NGC 3603 is, therefore, one of the most distant optically visible HII regions in the Galaxy and radio observations (Shaver and Goss, 1970) indicate that it is also one of the most luminous and massive ($M \simeq 1.4 \times 10^4\ M_\odot$).

Radio recombination line emission were detected from two clearly distinguished components within NGC 3603 (McGee et al, 1975) for which Frogel et al (1977; hereafter referred to as FPA) found associated 10 and 20 micron extended sources. An OH and H_2O maser sources were found some 7 arc min north of the optical and radio emission maxima (Robinson et al, 1974; Batchelor et al, 1980). All these are marked in Figure 4.7.

The trapezium cluster HD 97950, it should be noted, is well displaced from the optical and mid-infrared peaks and, as pointed out by FPA, it seems to be that radiation pressure and/or stellar winds from the cluster are actually interacting with the gas and dust in the complex. Although HD 97950 had been been listed as a Wolf-Rayet star, the detailed stellar content of the cluster was investigated by Walborn (1973c, 1977) who classified the integrated optical spectrum as WN6+05-6(n)-A(B) (Table 4.1). With the available data it is

Figure 4.7. Schematic diagram of NGC 3603. Large filled circle gives the position of the trapezium-system HD 97950, the solid lines are 10μm emission contours, the small crosses (x) mark the position of the 2.2μm sources, the small plus-signs (+) represent the H_2O (N) and OH (S) maser sources. Large crosses are the peaks of the radio continuum and recombination line emission. The straight broken lines show the limits of the present 2.2μm survey. All references are given in the text.

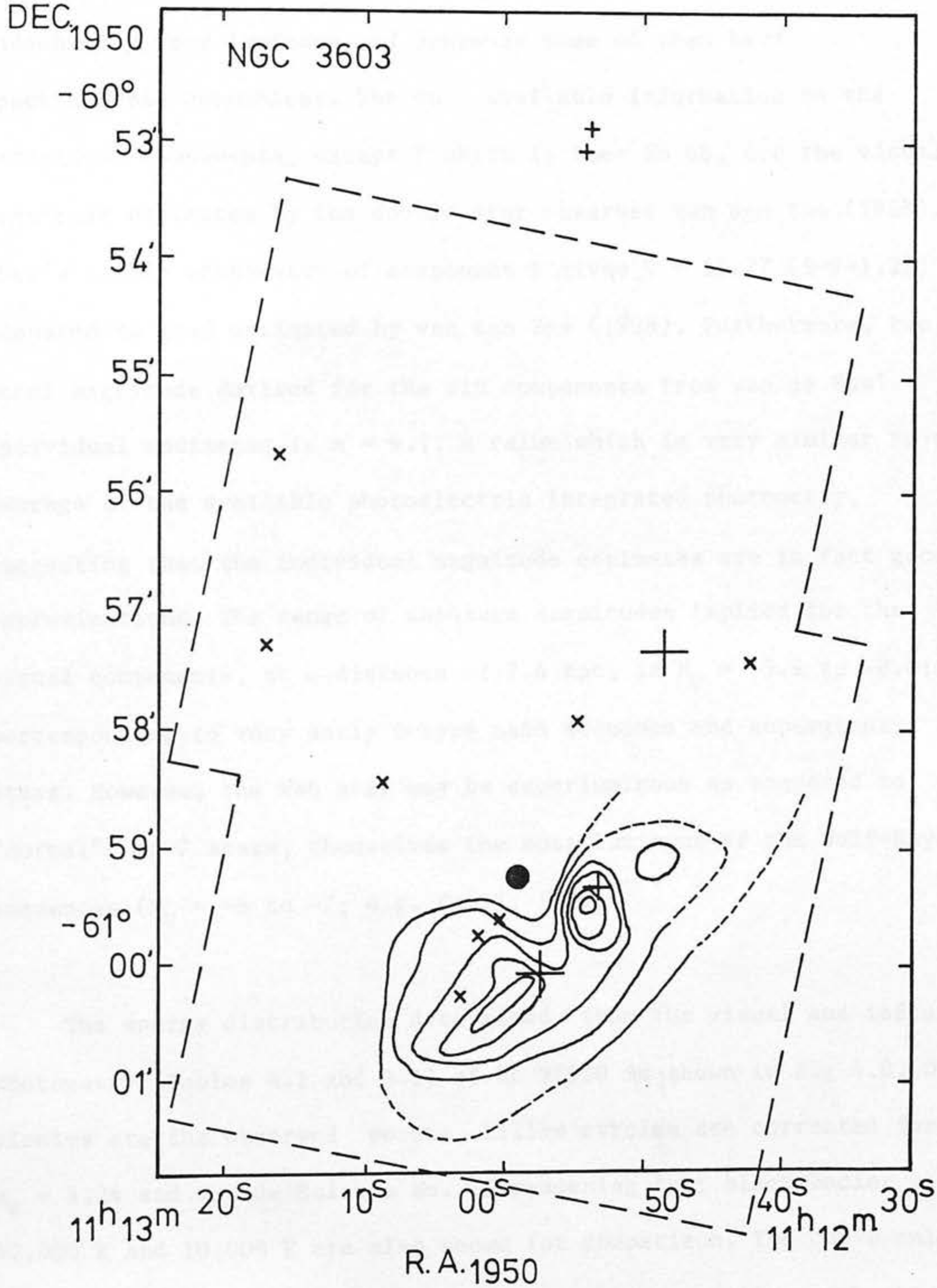

DEC 1950
NGC 3603
-60°
53'
54'
55'
56'
57'
58'
59'
-61°
00'
01'
11h 13m
20s
10s
00s
50s
40s
30s
11h 12m
R.A. 1950

Figure 4.7

impossible to know which of the stars in the cluster are the WR and O stars but, at the quoted distance, the brightest components are undoubtedly very luminous and probably some of them have spectroscopic companions. The only available information on the individual components, except F which is Sher No 66, are the visual magnitude estimates by the double star observer van den Bos (1928). Sher's (1965) photometry of component F gives V = 11.77 (B-V=1.27) as compared to 11.8 estimated by van den Bos (1928). Furthermore, the total magnitude derived for the six components from van de Bos' individual estimates is m = 9.1, a value which is very similar to the average of the available photoelectric integrated photometry, suggesting that the individual magnitude estimates are in fact good approximations. The range of absolute magnitudes implied for the visual components, at a distance of 7.4 kpc, is M_V = -5.9 to -8.0; corresponding to very early O-type main sequence and supergiant stars. However, the WN6 star may be superluminous as compared to "normal" WN6-7 stars, themselves the most luminous of the Wolf-Rayet sequences (M_V = -6 to -7; e.g. Conti, 1979).

The energy distribution determined from the visual and infrared photometry (Tables 4.1 and 3.1) of HD 97950 is shown in Fig 4.8. Open circles are the observed points, filled circles are corrected for A_V = 4.24 and van de Hulst's No. 15 reddening law; black bodies at 40,000 K and 10,000 K are also shown for comparison. The curve only confirms that the emission comes from O and B type stars with the contribution of the WN6 star dominating at the longer wavelengths due to its hot circumstellar plasma emission. The low-resolution 2-micron

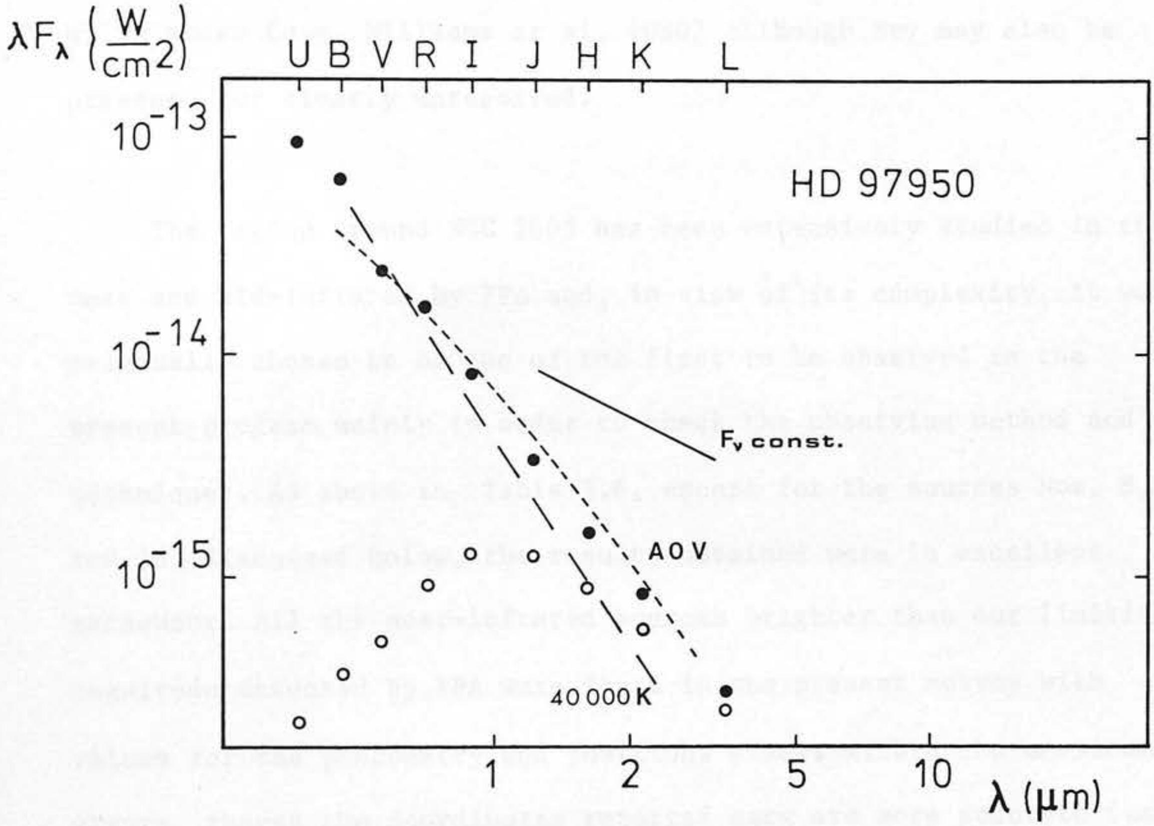


Figure 4.8. Spectral distribution of HD 97950 as observed (o) and dereddened for Av = 4.22 (•).

spectrum of the cluster (Figure 3.11b) shows only the strong emission line at 2.17 microns due to He II and an underlying continuum with higher slope than the photospheric emission, typical of WN stars (e.g. Williams et al, 1980) although Brγ may also be present, but clearly unresolved.

The region around NGC 3603 has been extensively studied in the near and mid-infrared by FPA and, in view of its complexity, it was originally chosen to be one of the first to be observed in the present program mainly in order to check the observing method and techniques. As shown in Table 3.6, except for the sources Nos. 8, 9 and 16, discussed below, the results obtained were in excellent agreement. All the near-infrared sources brighter than our limiting magnitude detected by FPA were found in the present survey with values for the photometry and positions always within the measurement errors, though the coordinates reported here are more accurate (see Chapter II). The identification system given by FPA for this region was consistently adopted throughout this dissertation.

The objects IRS 4, 5, 6 and 15, were found by FPA to show CO absorption bands in their infrared spectra and the observations were best fitted for their being K and M supergiants respectively. There was, nevertheless, one bright 2.2-micron source found during the SAAO scans (and re-observed on further occasions) which was not reported by FPA, although (presumably) it is located within the area FPA studied since it lies approximately midway between the centre of their scans (the Trapezium-type cluster) and IRS-6. This new object has been identified IRS-16 in Tables 3.1 and 3.4. The 1.2 to 3.4 micron colours of IRS-16 correspond to a black body at 1300 K, after correction for $A_V \simeq 4$. The CVF 2-micron spectrum (Figure 3.11a) of this star shows strong CO and H_2O bands which indicate a very late M spectral type (> M7), of luminosity class I if it is to be at a distance of 7 kpc. The shape of its energy distribution at 1 - 4 microns resembles that of VY CMa and NML Cyg , furthermore, no unambiguous optical identification of the source was possible by comparing a blue and far-red plates, i.e. no star with large B-I colour was found within or near the corresponding error box. Brightness variability of IRS-16 at two microns is suggested by the fact that the photometric map of the region indicated a magnitude K = 6.4 (±.2) while, nine months later, the photometry gave K = 5.92 (±.05). Intrinsic variations of more than 2.5 magnitudes at two microns seem too large to invoke for explaining its non detection by FPA but that possibility cannot be ruled out. This object requires continous monitoring.

Much closer to the 10-micron source IRS-2 lie three objects detected at 2.2 microns and resolved on the 0.75m telescope by means of higher-resolution scans of an area of approximately one square arc minute containing IRS 8 and 9 with an aperture of 17 arc sec. The results show that IRS-8, detected originally by FPA, consists of two sources IRS 8a and 8b separated some 16 arc sec, both of similar 2-micron brightness (Table 3.1) and, from the peculiar IR colours measured by FPA, of uncertain nature.

The coordinates of the enigmatic source IRS-9 were obtained from the console read-out of the A.A.T. but unfortunately the prevailing bad weather prevented any measurement of this fainter object. Table 3.1 reports JHKL photometry of this source with the 0.75m telescope where centreing problems could not be overcome due to contamination by the nearby IRS 8a and b and the background emission from the extended 10-micron source IRS-2. The latter was estimated from multiaperture measurements with the K filter at symmetric positions with reference to FPA's contour maps and subtracted accordingly. The resulting magnitudes for IRS-9 were:

K(ap=17")= 8.1; K(ap=25")= 7.7; K(ap=34")= 7.2; K(ap=51")= 7.0

with considerable uncertainty. The extension of the (centrally peaked) 2.2 micron emission was further suggested by the higher resolution maps. Assuming similar near-IR colours for IRS-1 and IRS-2, the deduced colour indices for IRS-9 are:

$$J - H \simeq 2.6; \quad H - K \simeq 2.5; \quad K - L \simeq 2.0.$$

With so limited observational data, the nature of this object remains unknown and further near-IR observations are planned.

The IR studies of NGC 3603 have revealed the presence of five sources with 2.2-micron magnitudes between 4.5 and 6.0, a factor of 10 more than what the recent galactic distribution models predict (see Chapter III) which do, however, basically agree with the number observed in nearby "reference" regions (Table 3.1). With the exception of HD 97950 and possibly of IRS-9, the IR brightest stars are of late spectral types but highly obscured. Whether their association to NGC 3603 is real or not has important implications for the evolutionary analysis of the region.

IC 2944.- This is a prominent HII region ionized by a cluster of O stars, one of which is HD 101190, itself the brightest star of a small Trapezium-type system composed, in addition to the components listed in the IDS (Jeffers et al, 1963), of stars Nos. 44 and 45 from the IC 2944 catalogue by Ardeberg and Maurice (1977b). A study of the visible (Table 4.1) and infrared (Table 3.1) stellar data revealed no anomalies in the energy distribution of HD 101190 A, B and C and the present results agree with the values for the reddening and distance to the cluster IC 2944 derived by Thackeray and Wesselink (1965) and Ardeberg and Maurice (1977a).

The photometric maps of the region showed the presence of two sources which is the number expected statistically for this part of the sky (Chapter III). In fact, both IRS-1 and IRS-2 lie on the reddening lines in the IR two-colour diagrams, corresponding to $A_V \simeq 8$ and 3 respectively, assuming late spectral types. Furthermore, IRS-2 was identified with IC2944-42 whose UBV colours and reported variability (Ardeberg and Maurice, 1977b) suggest to be an M supergiant or a Mira-type variable. None of the sources, therefore, appears to be a member of the cluster.

HD 104901.- This star is the primary component of a bright and wide triple system immersed in the very tenuous and extended HII region 297.7-0.4 (Georgelin and Georgelin, 1970). Both stars A and B are supergiants listed (Nos 2580 and 2581) in the "Luminous Stars in the Southern Milky Way" (Stephenson and Sanduleak, 1971) and presumably are at the same distance. Table 4.1 shows the available visual data. Although no spectrum has been obtained of star C, broad-band photometry suggests it to be of an early B spectral type and if on the main sequence, its absolute magnitude would be consistent with the system being physically associated. The present infrared photometry indicates no anomalies in the spectral distribution and reddening of HD 104901A and C, though the observational errors for the latter are quite large. The photometric distance was found to be 3.1 kpc for $A_V = 0.8$.

CPD-61 2933, also CoD-61 3326 is star B in the triple system under study. It is listed No. 747 in Henize's (1976) catalogue of southern H_α-emission line stars where the spectral type is mistakenly quoted (from the misleading note in the Henry Draper Catalogue) to be B8 and, hence, failing to attract the attention it deserves. Apart from the JHKL photometry, we also present a low resolution 2 - 2.5 micron spectrum shown in Figure 3.11b, UBV photometry kindly provided by Dr. R.J. Dodd (ROE) from observations on the 1.0m telescope at SAAO and an intermediate-resolution spectrum covering the region 4800 to 7000 A kindly obtained by Dr. D.A. Allen (AAO) with the Image Photon Counting System on the AAT. The photometric measurements are shown in Tables 3.1 and 4.1. The star shows a large infrared excess at $\lambda > 2$ microns as shown in its energy distribution curve (Figure 4.9), where the open circles represent the observations, the filled circles represent the dereddened points and the broken lines are the photospheric emission and a hypothetical cool, optically thin circumstellar cloud of graphite particles to match the observed colours (see Smyth et al, 1979).

The 2-micron spectrum is dominated by dust emission with only one possible emission feature corresponding to Brγ but a higher resolution spectrogram should be obtained to test the reality of the feature. The underlying continuum is the combination of the Rayleigh-Jeans tail of the photospheric emission and the rising dust emission.

The red spectrogram shows absorption lines (FeI, FeII, MgI, etc) characteristic of the star's spectral type with the strong Na D line clearly broader than the other lines. At the resolution ($\sim$3 A per channel), two (absorption) components, separated some 400 km/sec are seen. The only emission line in the spectrum is H_α, very strong.

A colour excess of E(B-V) = 0.30 is found from the visual photometry and the intrinsic colours listed by Johnson (1966) corresponding to A_V = 0.9, not in disagreement with the value found for the companion star HD 104901. If these stars are at the same distance, the origin of the absorption is clearly interstellar and no additional absorption (in the visual) could be attributed to the

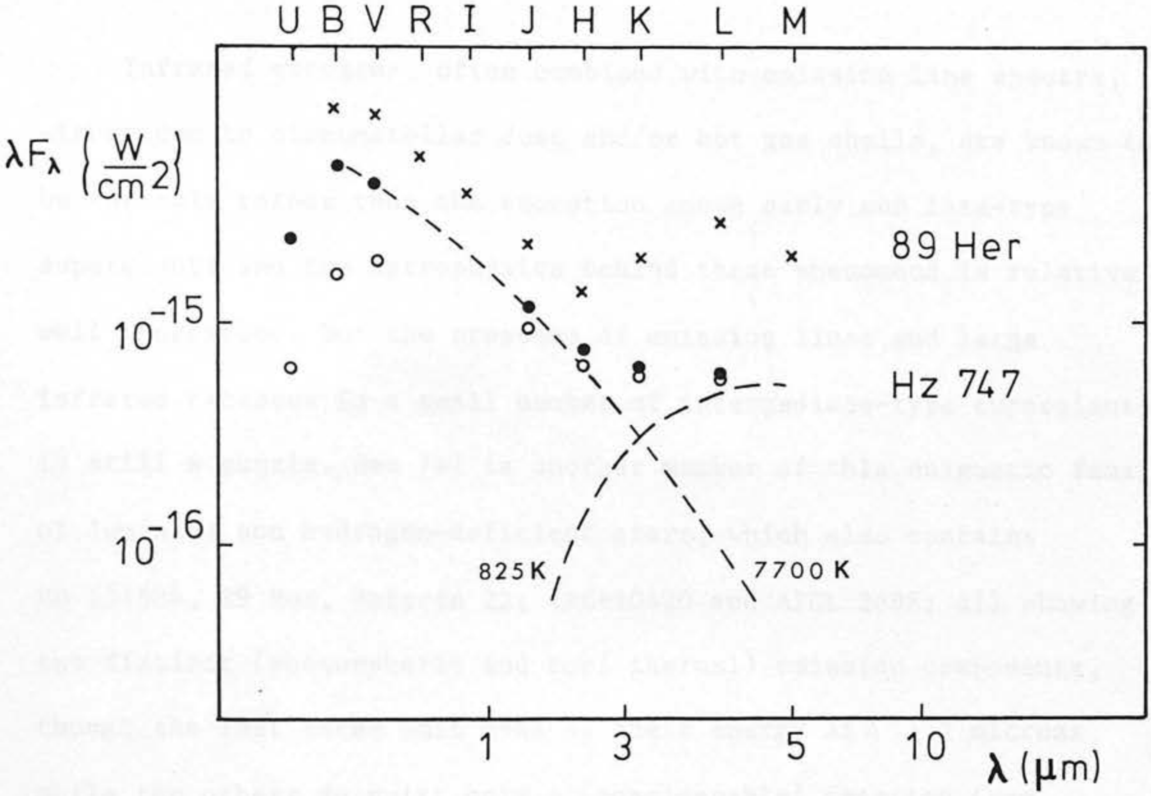


Figure 4.9. Spectral distribution of Hz 747 as observed (o) and dereddened for Av = 0.9 (•). The observed spectral distribution shifted vertically of 89 Her is shown for comparison.

circumstellar cloud, introducing some constraints to the size of the grains to account for the grey absorption.

Infrared excesses, often combined with emission line spectra, either due to circumstellar dust and/or hot gas shells, are known to be the rule rather than the exception among early and late-type supergiants and the astrophysics behind these phenomena is relatively well understood. But the presence of emission lines and large infrared excesses in a small number of intermediate-type supergiants is still a puzzle. Hen 747 is another member of this enigmatic family of luminous non hydrogen-deficient stars, which also contains HD 101584, 89 Her, Roberts 22, IRC+10420 and AFGL 2688; all showing two distinct (photospheric and cool thermal) emission components, though the last three emit most of their energy at λ > 2 microns while the others do emitt only a (considerable) fraction (see Humphreys and Ney, 1974; D. Allen et al, 1980; Craine et al, 1976 and Forrest et al, 1975). The infrared colours and spectra of all these stars cannot be explained by Bremsstrahlung emission alone and the presence of dust shells around the F stars or close companions is necessary.

Hen 747 presents characteristics remarkably similar to the well studied F2 Ia star 89 Her=HD193506 whose energy distribution is also shown, for comparison, in Figure 4.9 indicated by crosses (x) (the zero point on the ordinate is arbitrary for this star) from the photometry by Gillett et al (1970) and Humphreys and Ney (1974). A similar fit resulted in a hypothetical circumstellar graphite cloud at a temperature of 775 K. This infrared excess, in turn, resembles that observed in the carbon-rich A-F supergiant υ Sgr (Humphreys and Ney, 1974; Treffers et al, 1976), both showing faint silicate emission features in their ten-micron spectra. This is in spite of the fact that 89 Her has a normal atmospheric abundance and υ Sgr is carbon-rich, in which silicate particles are not expected to form at all (see Treffers et al, 1976 and references therein). This dilemma induced Humphreys and Ney (1974) to postulate the presence of very late type close companion stars which would be wholly responsible for the infrared emission in HD 101584, 89 Her, υ Sgr (and R CrB), leaving the A and F stars with normal photospheric emission. As pointed out by Treffers et al (1976), the binary model cannot be maintained in view of the fact that none of their 2-micron spectra show any trace of the CO bands which are present in all very cool stars (independent of the value of O/C) with the exception of the extreme object IRC+10216 where the absorption feature is completely washed out by the rising continuum. This latter effect almost certainly does not apply to all these hypothetical companions. The only remaining possibility seems to be that the dust shells are around the F supergiants, although their composition is not known.

Further evidence favouring the presence of a circumstellar shells in 89 Her came from the study of its visible spectrum by Sargent and Osmer (1969) who found variable Balmer and Na D absorption lines with blueshifted components with separations up to 150 km/sec. Of the hydrogen lines, only Hα was found to be in emission (with a variable P Cygni profile) while a few other faint stationary emission lines (Ni, Fe, Co, Ca) were also present in the red part of the spectrum. Sargent and Osmer interpreted these properties as evidence of circumstellar activity and variable mass loss from 89 Her. The spectrum of Hen 747 shows many peculiarities in common with that of 89 Her, the differences being the lack of the blueshifted Balmer absorption components and the faint heavy elements emission lines but H_{α} also is very prominent in emission and the complex structure of the Na D line has already been mentioned; in fact, if the separation betweeen components of this line in Henize 747 is interpreted as due to an expanding shell, the velocity of expansion would exceed the escape velocity of a normal supergiant.

In view of their many common characteristics, it is natural to believe that Hen 747 and 89 Her are the same type of object, probably in a similar evolutionary status. Guigere et al (1976) failed to detect OH 1612 MHz maser emission, often associated with expanding circumstellar clouds, from 89 Her and it would be interesting to observe Hen 747 searching for this emission.

More extreme infrared emission has been observed in three other intermediate type supergiants: IRC+10 420 (Humphreys et al, 1973) has a stellar appearance (though indirect evidence suggests that it is extended), no emision lines in its optical spectrum and a prominent 10-micron silicate feature, it is also a very strong OH maser source (but no H_2O or SiO masers detected). AFGL 2688, also known as the "Egg nebula" (see Humphreys et al, 1976) has a symmetric double-lobed reflection nebulosity, shows but only very faint Na D emission line, has a featureless IR spectrum and radio molecular observations suggest it to be a carbon-rich star. Roberts 22 (D. Allen et al, 1980) has a bipolar reflection nebula with a central dark lane, strong OH (1612 and 1665 MHz) maser emission and variable Balmer emission lines with P Cygni-type profiles.

The picture emerging from the present discussion is still far from clear as is the relation between these objects. Although there are some fundamental differences between these stars, they can also be seen as a group sharing a few peculiar characteristics (Allen et al, 1980). D.A. Allen (private communication) suggested the possibility of Hen 747 being similar to IRC+10 420, AFGL 2688 and Roberts 22 but seen end-on, and it may be that the supergiants considered here are massive stars in various stages in their rapid late evolution moving horizontally in the upper part of the H-R diagram. However, D. Allen et al (1980) gave arguments in favour of the pre-main sequence nature of these objects which naturally explains some properties of the implied configurations (like dusty equatorial rings), but the pre-main sequence hypothesis also falls short of explaining all the observed properties of these stars.

The scans around HD 104901 revealed five sources but only for the brightest two was JHKL photometry performed. The observed colours of IRS-1 and IRS-3 indicate that they are highly reddened ($A_V \gtrsim 8$ and $A_V \gtrsim 10$ respectively) stars, most likely luminous late type stars. The total number of objects detected in this survey is marginally higher than the number of field stars expected.

Lyngå 8.- Although this region is not very prominent in optical photographs, it has a rather complex structure at radiofrequencies. Within an area of less than one square degree, nine HII regions were detected in the H109α radio recombination line (5009 MHz) and the 5GHz continuum surveys by Wilson et al (1970) and Haynes et al (1979) respectively; half of these do not have optical Hα counterparts (Georgelin, 1970). From a detailed radial velocity study, Georgelin and Georgelin (1976) found that all but one of the HII regions in this group (333.8>l>332.7, -0.1>b>-0.7), of which RCW 106 is a prominent member, are at the same distance ($\sim$4.2 kpc) from the Sun in the Carina-Sagittarius arm and only the radio HII region G333.2-0.1 is located in the Norma arm at a distance 7.8 or 9.8 kpc (the ambiguity comes from the derivation of the kinematical distances in the inner 10 pc of the Galaxy), however Georgelin and Georgelin found additional evidence favouring the "near" distance (7.8 kpc) for this region.

HD 146479, a B9 V star (Houk and Cowley, 1978), is the primary of a close triple system located some 7 arc min from the centre of the HII region G333.2-0.1. Certainly this is only a projection since the distance to HD 146479 estimated from the visual magnitude and spectral type is more than one order of magnitude less than that to G333.2-0.1 and even to the much closer complex RCW 106. The present infrared photometry does not show an anomalous emission from these stars.

Five sources were discovered during the 2-micron survey of the region. With the possible exception of IRS-3, all objects appear to be red field stars with no unusual characteristics. IRS-3 presents extreme colours both in the optical and the near-infrared (Table 4.1). The source was identified on a UK Schmidt plate IV-N plate with a star of an I magnitude ~14 - 16 which is invisible on two SRC IIIaJ survey plates whose limiting magnitudes are B 23. The two micron spectrum of this star (Figure 3.11a) was classified as M4 and the two colour diagrams indicate that it suffers about 17 magnitudes of visual absorption and presents a small excess at the longer wavelengths. At present it is impossible to determine accurately the distance to IRS-3, but if the luminossity class is Ia, the corresponding photometric distance (from the absolute K magnitude given by Lee, 1970) coincides with that of the HII region G333.2-0.1 whose centre is some 6 arc min from the M star (Haynes et al, 1979). It is interesting to note that this object is remarkably similar to NGC 3603-IRS-4, previously discussed. They have in common the spectral types, the near infrared energy distributions, the amount of interstellar absorption (per kpc) and both are possibly related to massive HII regions.

NGC 6193.- This star cluster is in the central part of the association Ara OB1 (Whiteoak, 1963) and is embedded in the extended low surface brightness emission nebula RCW 108 of which the stars HD 150135 and HD 150136 are the main source of excitation. These are also the main star components of a Trapezium-type system which constitutes the centre of NGC 6193. At approximately 15 arc min to the West there is a dark cloud and a bright rim/elephant trunk structure at its interface. Near the most obscured part of the cloud, a small bright knot of nebulosity is seen which corresponds to the radio (continuum and H109α) HII region. Frogel and Persson (1974) detected a small 10 micron emission region almost coincident with the radio peak.

The photometric distance to the cluster (and hence, to the HII region) is 1.32 kpc (Herbst and Havlen, 1977) and it has a mean colour excess <E(B-V)> = 0.48. The infrared photometry of HD 159135 and HD 150136 support the results by Herbst and Havlen (1977) in the sense that there are small infrared excesses in the emission of these hot stars (Tables 3.1 and 4.1). The shapes of the excesses (at $\lambda < 4$) resemble a F_ν-constant function suggesting that these originate in thin circumstellar plasma shells and this explanation is preferred to the abnormal interstellar extinction proposed by Herbst and Havlen.

In the region searched at 2 microns, which does not include any part of the prominent dark cloud, four sources were located. Unfortunately no far-red I-N Schmidt plates of this region were available at ROE and, therefore, no optical identifications could be made but comparisons with published finding charts and photometry by Herbst and Havlen (1977) resulted in two stellar identifications. IRS-2 corresponds to the star No. 147 and IRS-4 to star No. 73. Analysis of their colours (Tables 3.1 and 4.1) indicate that both are foreground stars. The former was classified G5 by Herbst and Havlen and the latter seems to be a reddened early M-type star. No optical identifications were made for IRS-3 and IRS-1, however, they too are likely to be field red stars with $A_V \gtrsim 7$.

Trumpler 24.- The brightest star of this neglected cluster is HD 152723 and is the only known source for the excitation of the HII region IC 4628 (Courtès et al, 1968). It has three fainter components which form a Trapezium-type system. Star B of this multiple star is LSS 3858 (Stephenson and Sanduleak, 1971), listed as having spectral type OB. The cluster and nebulosity are at a common distance, d = 2.0 kpc, with NGC 6231 and RCW 113 (Georgelin and Georgelin, 1976) and all form most of the Sco OB 1 association which, from a detailed kinematical study, was found by Laval (1972) to be a young complex (about one million years old). Emerson et al (1973) found the HII region to have an infrared luminosity (40 - 350 microns) of 2.6 $L_\odot$.

The present infrared photometry of HD 152723 combined with the available visual data (Table 4.1) is interpreted as a normal stellar continuum at wavelengths up to 4 microns. Of the ten infrared sources detected in the region, all but one seem to be obscured red field stars unrelated to the association. Only IRS-10 lies off the reddening line for red stars in the IR two-colour diagrams and its energy distribution, as observed in the IR or estimated in the visual from its images (or absence of) in the blue, red and far-red Schmidt plates, can be explained as a very luminous early type (O,B) star at the distance of the Sco OB 1 association reddened by $A_V \simeq 18$ or, alternatively, by a Mira variable with extreme colours obscured by

$A_V \simeq 8$. This object is in a region of apparent high obscuration near the northern interface of the brightest part of the HII region and a neutral cloud but, with the present data alone, it is not possible to distinguish between the two alternatives.

M 20.- The Trifid is one of the best known emission nebulae partly because it is so magnificent that its photograph appears in countless astronomy books and even decorates the walls of many astronomers' offices. Also known as NGC 6514 and RCW 147, this HII region is almost spherically symmetric around its only known exciting star HD 164492 as seen on radio (e.g. Chaisson and Willson, 1975) and far-infrared (Wright et al, 1976) maps. Even at visual wavelengths, M20 is relatively unobscured except for the very dark dust lanes for which it is famous. In fact, the observed properties of this nebula are in closer agreement with what it is expected theoretically than are most other galactic HII regions and their physical parameters were summarized by Chaisson and Willson (1975; hereafter referred to as CW) in an extensive radio study. However, its distance from the Sun is still not known accurately although almost any value between 1.3 and 2.9 kpc has been freely adopted in the literature, sometimes without real basis.

There is little doubt that the gaseous nebula M20 is ionized mainly by the O7.5 star HD 164492. This is the primary member of a Trapezium-type system called ADS 10991, composed at least of another six stars, all within a radius of some 15 arc sec. In the same region lies a young galactic cluster which will be called NGC 6514 to differentiate it from the nebulosity M20. Some 6 arc min to the SW of the trapezium, the density peak of a molecular cloud was discovered through a 6cm H_2CO line survey of the region by CW and a 1720 MHz Type IIa OH maser emission source was found by Turner (1979) some 1.6 arc min W of HD 164492 as shown in Figure 4.10

Only very few photometric visual observations of HD 164492 are reported in the literature, and each of them made on different systems. Hiltner (1956) obtained V = 7.63 and the values given in Table 4.1 while Borgman (1960) made two individual observations on his (visual) KLMNPQR colour system giving v = 8.26 and 8.16 where the v magnitudes correspond to Johnson's V within 0.025 mag for all colours. No information was given, however, as to whether the star component B, only 6 arc sec away, was included in the diaphragm. Additional BVRI photometry of ADS 10991AB and CDE was kindly obtained for us by I.N. Reid and G.E. Gilmore (Edinburgh U. and ROE) in August 1980 with the 1.0m telescope at the SAAO; these results (Table 4.1) are in agreement with those of Hiltner (1956). Several spectroscopic observations of HD 164492 are available and the most reliable classifications are those by Walborn (1972) and Conti (1973): O7.5 III and O7.5 I respectively and the spectroscopic binary nature of this star is suggested by its variable radial velocity (Cruz-González et al, 1974). The B-V colour excess, assuming Johnson's (1966) intrinsic colours is, hence, 0.32 and this value is not affected after subtraction of the light from the nearby star B for which photographic photometry was made by Ogura and Ishida (1975), though the spectral classification assigned by these authors (to star B) is certainly not compatible with the visual photometry.

The infrared photometric observations given in Table 3.1, after correction for the presence of star B by assuming a spectral type inferred from its visual photometry, has a small infrared excess at $\lambda > 1.5$ microns, consistent with that observed in other luminous O stars. In this case, the excess could also be caused by emission from a cooler spectroscopic companion. An abnormal energy distribution was found from narrow-band photometry up to 1 micron by Anderson (1970). This effect is similar to that discussed above and does not necessarily imply a different from "normal" extinction law. Peytremann and Davis (1974) found HD 164492 to be more than three magnitudes brighter at 1596 and 2196 A than expected from its spectral type and B-V colour excess. We repeated this analysis using the ultraviolet fluxes reported by Thompson et al (1978) at 1565, 1965, 2350 and 2750 Å and arrived at similar results.

Star component C, some 10 arc sec SW of HD 164492, is a spectroscopic binary which also has a close visual companion (D) found to have an emission-line spectrum tentatively classified Be by Herbig (1957) and catalogued with the name LkHα 123. The present infrared photometry confirms the existence of a circumstellar dust shell around this star required to explain its extreme infrared colours, first observed by Allen (1973).

Even in this direction of the sky, such a Trapezium-like configuration is unlikely to be the result of projection, particularly considering that the primary star of the system is the only O star in or near M20 and, therefore, is its main source of ionizing energy, as well as the membership of the probable pre-main sequence star LkHα 123. The age of the nebula was indirectly found to be less than 10^5 years (Bohuski, 1973b) in agreement with dynamical ages of massive TTSs. Furthermore, the mean radial velocity of HD 164492 and that of LkHα 123 (the only ones available in the cluster) are almost identical and similar to those determined by optical and radio line observations of M20 (Georgelin, 1970; Bohuski, 1973a; CW) and of the OH maser (Turner, 1979). Of course, this does not prove that all these objects are mutually associated, as the general region is very complex. For example, it is interesting to note that the Type IIa OH maser is coincident with a dark lane and, although these masers are generally uncommon, the recent survey by Turner (1979) revealed twelve similar sources (with roughly the same radial velocity) in an area of 1.7 sq degrees, which is a much higher (projected) density of 1720 MHz emitters with main lines absorption than probably any other region in the catalogue. Although half of them seem to be concentrated near the supernova remnant W28, the rest are at some distance and apparently not correlated with any radio or optical feature, except the M20 source. This type of maser is normally found associated with non-thermal sources and only rarely with HII regions. It is, therefore, possible that the M20 OH maser is a chance projection.

Lying on the line of sight towards M20, the stellar cluster NGC 6514 was studied photometrically by Ogura and Ishida (1975) and, although little effort was made to distinguish the members from the field stars, they determined a mean colour excess $\langle E(B-V) \rangle = 0.23$ and a distance to the cluster of 1.4 kpc. by the main-sequence fitting methods and an age of 7×10^6 years. The association between such a young cluster and M20 seems almost natural except for the fact that their heliocentric distance appears to differ by one kiloparsec. Is this discrepancy real? The answer, of course, depends on the distance determination to M20, or rather, to its exciting star HD 164492. Neither the absolute nor the real apparent magnitudes of this star are known accurately, and for simplicity, we will neglect the BV contributions from the star ADS 10991B and from the possible spectroscopic companion; therefore, a value V=7.63 will be adopted in this discussion. The absolute magnitude M_V of HD 164492 is a function of its luminosity class and here there is a discrepancy between Conti (1973) and Walborn (1972) who assigned classes I and III respectively; this is not surprising since their classification criteria are different. The corresponding apparent distance moduli are 14.0 and 13.2 which, corrected for 1 magnitude of interstellar absorption (R=3.1), gives d = 4.0 and 2.7 kpc respectively, neither of which is even close to the NGC 6514 distance. In fact, 4 kpc is in disagreement with the optical and radio properties of M20 (e.g. Tovmassian et al, 1973). It is interesting to note that originally Conti and Alschuler (1971) had classified HD 164492 class III.

Only if, as suggested on totally different grounds by Wright et al (1976), the value of the ratio of total to selective absorption R in that region takes a much higher value ($\sim$5-6) can M20 be brought to the distance of NGC 6514 and, incidentaly, of M8, the Lagoon nebula. On the basis of the present infrared photometry, we find that this is unjustified leading to disagreement with the observed (V-H), (V-K) colours of HD 164492. Another possibility is that its B-V colour is erroneous but Hiltner's (1956) value has independently been confirmed (I.N. Reid and G.E. Gilmore, private communication). Furthermore, Ishida and Kawajiri (1968) and CW found, by comparing the radio continuum and Balmer lines brightness distributions that, avoiding the dark lanes, A_V varies outwards from one magnitude in the centre (where HD 164492 is) to 2-3 magnitudes at the edges. We, therefore support Buscombe (1963) and Tovmassian et al (1973) in locating M20 and its central Trapezium-type system at 2.7 kpc, unrelated to the galactic cluster NGC 6514 and find "compromise" distances, as that proposed by CW under an assumed A_V = 1.5 towards HD 164492, rather artificial.

Four infrared sources were found in the course of the 2-micron survey of the M20 region. The area covered is shown in Figure 4.10 where the dark lanes, outer radio continuum (CW) contours and far-infrared (Wright et al, 1976) and the OH maser source (Turner, 1979) are indicated in addition to the reddest near-infrared sources discovered. IRS-3 and IRS-4 (Table 3.1) are omitted in the diagram because, when the IR and visual (Table 4.1) data are combined, they were found to be foreground stars; the latter probably an M giant. The rest of the sources are, according to the infrared two-colour diagrams, highly reddened stars, none of them visible on the blue ESO Schmidt plate, where the nebulous emission does not veil the area.

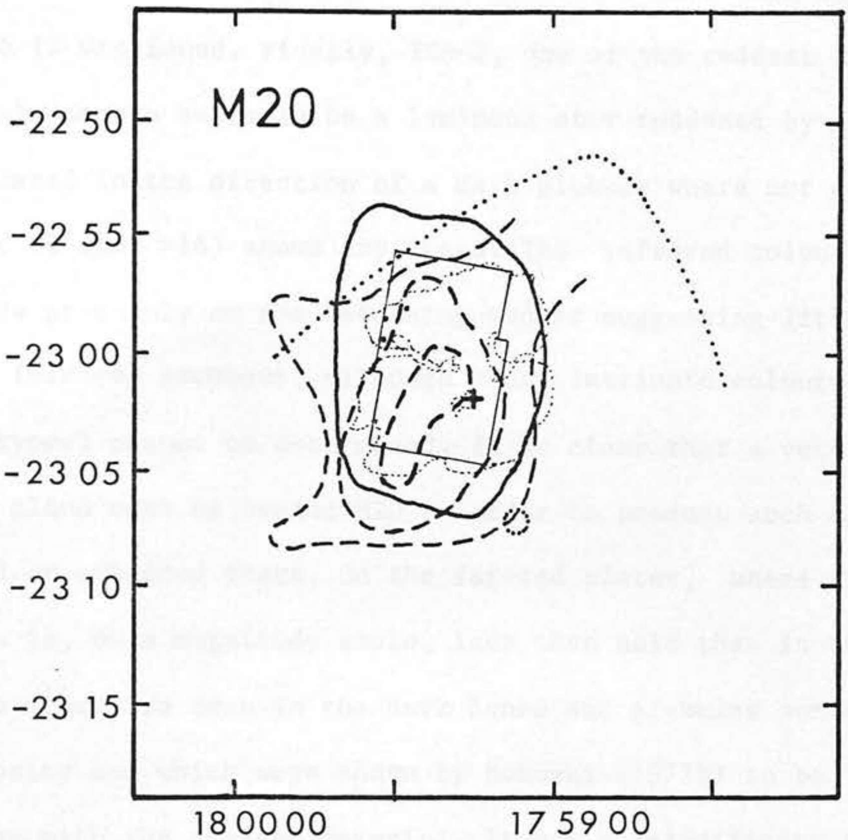


Figure 4.10. Schematic diagram of M20. The small dotted line outlines the visible nebulosity, curved solid line the lower 86Hz contour, curved broken lines the 69μm map, the large dotted circle and line indicate the peak and lower contour of the H_2CO cloud respectively, the cross indicates the position of the OH Type IIa maser source, the filled circles 2.2μm sources and the straight filled lines show the limits of the present survey. All references are given in the text.

IRS-4 was identified with an image of magnitude I ≃ 11 on a far-red IV-N Schmidt plate and an $A_V \gtrsim 10$ was derived. Similarly, IRS-5 corresponds to an I ≃ 14 star at the end of one of the dark lanes for which $A_V \gtrsim 17$ was found. Finally, IRS-2, one of the reddest objects in the whole sample seems to be a luminous star reddened by $A_V \gtrsim 20$ and is located in the direction of a dark globule where not even the IV-N plate (I(lim) ≃16) shows any image. The infrared colours locate these stars precisely on the reddening vector suggesting little or no intrinsic infrared excesses, although their intrinsic colours (i.e. spectral types) cannot be determined. It is clear that a very dense absorbing cloud must be behind M20 in order to produce such effect on background or embedded stars. On the far-red plates, where the extinction is, on a magnitude scale, less than half than in the visual, no stars are seen in the dark lanes and globules surrounding the nebulosity and which were shown by Bohuski (1973b) to be interacting with the ionized material. It may be significant that all the near-infrared sources detected in the region are in the NE part of M20 and this may be interpreted qualitatively as evidence for a steep density gradient of the absorbing material towards the SW, where CW found the H_2CO density peak (see Figure 4.10).

M 8.- This, the Lagoon nebula, has been extensively studied in almost all wavelength regions and appears superimposed on the open cluster NGC 6530. This was studied photometricaly by Walker (1957) who found some evidence for peculiar interstellar absorption and the presence of a large number of stars above the main sequence. However, the sample was found to contain too many field stars which tended to mask the cluster's overall properties (Thé, 1960). The data was subsequently extended and re-analysed, after a complete proper motion study, by van Altena and Jones (1972) who considered only likely members of the cluster, they derived the following parameters: E(B-V)=0.35, d = 1.78 kpc and age = 2 x 10^6 years.

The radio and optical properties of M8 were summarised by Lada et al (1976) and indicate that stars members of the cluster NGC 6530, mainly Herschel 36, are responsible for its ionizing energy. M8 seems to be very similar in excitation parameters to the Orion nebula and the complex also resembles some other galactic regions where star formation was triggered originally in the edges of a molecular cloud and is propagating inwards. Moreover, Lada et al (1976) found M8 to be expanding towards the Earth at some 7 km/sec relative to the molecular cloud behind the visible nebulosity.

One of the present "centres of activity" in the HII region is marked by the "hourglass" nebula and the star Herschell 36 coincident with CO and far-infrared emission peaks (Wright et al, 1977) while on the eastern side of the nebula, another strong CO, far and near-infrared source, called M8E, was found consistent with a ZAMS early O star reddened by some 40 magnitudes surrounded by a compact HII region (Wright et al, 1977).

The wide multiple system whose primary is HD 164536 is at the western edge of the optical nebulosity and was found probably to be a chance projection by van Altena and Jones (1972) where only the component C = CoD-24 13785 is a likely member of NGC 6530. Although no precise spectral classification is available, its optical and near-infrared colours fully agree with a B star, as listed by Stephenson and Sanduleak (1971). The 2.2 micron scans revealed three sources which represent a deficiency when compared with the expected number of field stars in that direction. Strong absorption by the continuation of the molecular cloud in the background (Thé, 1960; Wright et al, 1977) seems to be the cause of that effect. IRS-3 was the only of these sources not identified with previously known stars and appears to be of a late spectral type after 7 magnitudes of visual extinction. IRS-1 was identified with the M2 star No. 1 of the list by Blanco and Grant (1959).

HDE 313706.- This is a close triple system located to the NE of the Trifid nebula, in a region of high obscuration compared with the general background. Although it is not associated with any visible feature, the 2.2 micron map presented one of the highest near-IR-source surface densities of all the regions studied in the present work and which exceeds by a factor of two the number predicted by the field star model (Chapter III). Furthermore, the area contains some of the reddest objects of the present sample (Table 3.1).

In an attempt to determine whether this excess of 2-micron sources is real, a nearby (apparently) more crowded area centred in HDE 313845 (hereafter called "reference") was similarly scanned and found to contain some 40% fewer sources to approximately the same limiting magnitude, although the background noise was slightly higher than the scan around HDE 313706 (Table 3.3). In fact, the faintest sources detected in both regions had K ≃ 7.7. The central stars for both scans are indicated in Figure 4.11.

Star counts to the plate limiting magnitudes were performed on the SRC Schmidt survey blue, deep red and far-red IV-N plates in areas of size 11.2 sq arc min centred near the centre of gravity of the detected IR sources in each region, these were subsequently compared. The ratios of the number of stars in the reference area to the number in the trapezium area were found to be

N(ref)/N(trap) = 3.68 in the blue, N(ref)/N(trap) = 2.18 in the red and N(ref)/N(trap) = 1.77 in the far red plates,

which in a simple model can be explained by differences in the amount of obscuring material in the line of sight towards HDE 131706 and HDE 313845 and possibly small variations in the average space density of stars, but the observed value of N(ref)/N(trap) at 2.2 microns is 0.65, certainly not compatible with the ones observed in the visual and far-red for a normal λ-dependence (λ^{-1} to λ^{-3}) of the interstellar extinction. The effect can be understood by the presence of a clustering of stars embedded or behind a dense molecular cloud. Moreover, Turner (1979) detected OH line absorption from a position close to IRS-18 and IRS-19.

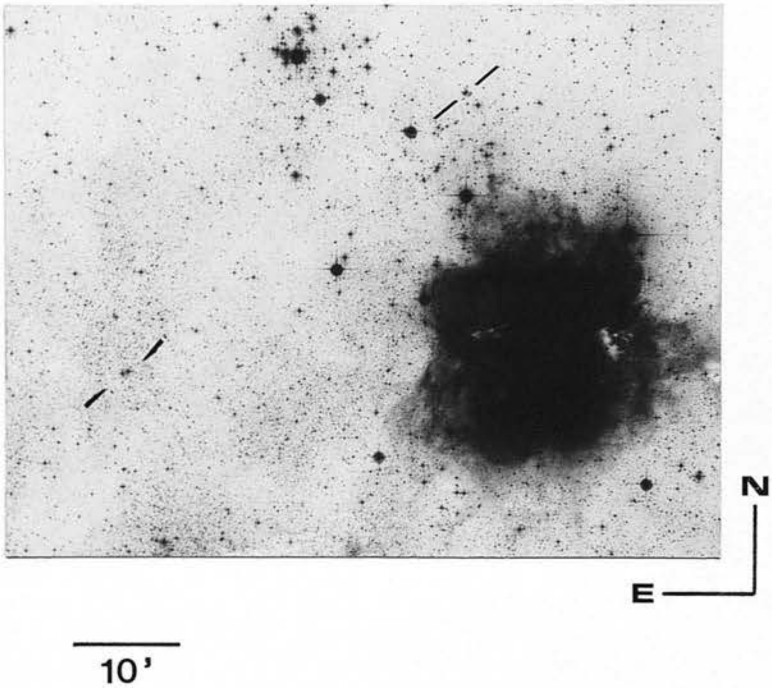


Figure 4.11. Finding chart, from a blue plate, for HDE 313706 (to the NW) and HDE 313845 (to the SE). The large nebulosity is M20.

More than half of the objects discovered in the program region were measured photometrically and with the exception of two, all objects were located on the infrared two-colour reddening lines. The highest absorption values were found for IRS-9 and 12 ($A_V \gtrsim 14$) and IRS-11 ($A_V \gtrsim 20$) for which, together with IRS-8, 18 and 19, no image could be associated on the IV-N plate suggesting that they are fainter than I = 17. IRS-19 is the reddest object and its 1 to 4 micron energy distribution resembles a black body at 1000 K approximately. The flux distribution of IRS-15 also deviates considerably from that of a purely reddened star.

ADS 11169.- μ Sgr (HD 166937) is the primary star of the system ADS 11169 for which only HKL photometry was performed. Extensive photometric and spectroscopic studies (Table 4.1) have been performed on this supergiant and it is known to suffer extensive mass-loss amounting to about 2-5 x 10^{-6} $M_{\odot}$/year (Hutchings, 1976; Barlow and Cohen, 1977). The present photometry reflects the free-free emision from the ejected gas studied in detail by Barlow and Cohen (1977), though a comparison with these authors' data suggestests some variability in the mass-loss rates from the star.

ADS 11168.- This close triple system is part of the association Sgr OB4 (distance ~ 2.1 kpc) of which the primary star HD 166934 (sp. B3) is a member, although no other observations of the system were found reported in the literature. When seen on blue Schmidt plates, the region around this star is characterised by its very low obscuration as compared to the general surroundings and this was also evident in the 2-micron mappings where the number of sources detected to K $\gtrsim$ 7.2 was a factor of two larger than than in nearby regions. All the objects for which broad band photometry was performed show late-type obscured star characteristics. For IRS-10, the reddest star in the field, a visual absorption value $A_V \gtrsim 17$ was computed. The only pecularity found in the region is the presence of a 1612 MHz maser emitter (Type IIb) with main line absorption (Turner, 1979) close (a few arc sec) to the measured positions of IRS-2 and 6.

ADS 11227.- This region, which contains an outer part of IC 4701, is very similar to ADS 11168 discussed above in the sense that the interstellar absorption is lower than the surrounding areas, which again explains the fact that the number of probable field stars detected is larger than expected. Of the objects for which broad-band photometry was obtained, IRS-7 was found to be reddened by more than 22 magnitudes and none is likely to be physicalkly associated with the HII region.

ADS 11667.- This system of Am stars shows infrared colours corresponding to those expected from their Balmer spectral types (A2 and A7 for components A and B respectively) according to published visual data (Table 4.1) and the present observations.

ADS 13374 and 13376.- These two Trapezium-type systems may well be considered as a single one in the centre of the galactic cluster NGC 6871 whose derived distance is ~1.60 kpc (Becker and Fenkart, 1971). The brightest member of the system is HD 190918, a Wolf-Rayet binary, and the cluster also contains a number of emission line stars. The present infrared photometry of the brightest stars agrees with the normal stellar flux extrapolated from visual data except for HD 190918 which shares the infrared charateristics of WN5 stars (e.g. Cohen et al, 1975).

ADS 13312.- In this trapezium system the two main components (stars A and B) are the highly luminous O stars HD 190429AB and they seem to be associated with a very dark globule Lynds 860 near the edge of the large HII region S109 (the Cygnus Nebula). Within the observational errors, the energy distribution of HD 109429 (both components were measured together) from the visual to the near infrared seem to be normal for their spectral types and $A_V = 1.27$. Judging from the photometry, the components C and D are of slightly later spectral type (B or A) if the reddening is similar to that of the primary star. The infrared map shows four sources of which IRS-3 is IRC+40 376, a field M9 star (Vogt, 1973), while IRS-4 could not be identified on the Palomar blue and red Schmidt plates. None of the objects detected is within the dark globule.

Cyg OB2.- This association was first noted for its great number of heavily reddened early type stars in a very small area of the sky. Johnson and Morgan (1954) studied the association photometricaly and determined a distance of 1.50 kpc. This work was extended by Schulte (1958) and Reddish et al (1966). The latter obtained a distance of 2.09 kpc and a stellar population of more than 3000 stars of which some 10% are of O and B spectral types. These authors also determined a mass for the complex of 1.1 - 6.3 x 10^4 $M_\odot$ of which 58% to 75% is stellar and the rest in the form of gas and dust. The age of the star complex is less than one million years. Throughout the present discussion, the stellar identification system by Schulte is adopted, unless specifically indicated.

As many young clusters, it has, near the centre, a Trapezium-type system having at least three O-type stars. Within the association, there are a number of Wolf-Rayet stars (e.g. Reddish, 1968), Of stars (Walborn, 1973a), a binary system (no. 5) which may be evolving towards the Wolf-Rayet phenomenon (Bohannan and Conti, 1976) and whose primary is one of the most massive stars known (60 $M_\odot$; Leung and Schneider, 1978). It also contains one of the earliest-type stars known (no. 7, O3 If; Walborn, 1973a) as well as (apparently) one of the most luminous OB stars in the Galaxy (no. 12; Sharpless, 1957). In fact, the whole association is one of the most highly obscured region so far observed.

In view of the presence of an enormous density of O-type stars in Cyg OB2, it is rather surprising that no compact HII regions are found, even at high radiofrequency and sensitivity. Huchtmeier and Wendker (1977) argue that all the hydrogen present within the boundaries of the association must be ionized to account for the huge amount of Lyman continuum photons and they identified a large diameter and low surface brightness HII region observed as a background component as the sink for the ionizing radiation. Extensive near-infrared photometric studies of a large number of stars in the association was performed by Voelcker (1975) and analysed by Voelcker and Elsässer (1973) and Elsässer and Voelcker (1974). These authors found that the dust inside Cyg OB2 amounts to about 100 $M_{\odot}$ and obtained a value for the gas to dust ratio of 10, which is far too low as compared to the "normal" interstellar medium, and that no evidence of warm circumstellar dust existed in the stars observed. Furthermore, they attributed most of the star to star differences in colour excess to variations in density within the cloud from which the young stars were formed, though they could not rule out completely local circumstellar extinction. Voelcker and Elsasser also found that the reddening law in the region can be represented by a "normal" value of the ratio of total to selective absorption R = 3.25.

The present near-infrared photometric observations of the previously known infrared-bright stars in the scanned region indicate the absence of infrared excesses apart from the ones arising due to free-free processes as the result of mass-losses from luminous O and B stars. Stars Schulte nos. 18 and 19, for which no spectral types are available, show energy distributions similar to other reddened early type stars in the area and star 19 shows the largest excess in the present sample at 3.4 microns but which is compatible with an F-constant emission component. The colour indices of star no. 8D, a member of the trapezium, could not be fitted with any single value of extinction and the presence of a redder unresolved companion is clearly needed to understand the BVRIHKL photometry.

The two-micron scans resulted in the detection of two new obscured stars IRS-3 and 4. Both are faintly visible on the blue Palomar survey plates, being about 1 and 3 magnitudes brighter than the plate limiting magnitude ($B \simeq 21$) respectively and are considerably brighter on the red plate. The red image identified with IRS-4 as seen through a microscope is of a very close (1-2 arc sec) double star, very unlikely a chance superposition. The near-infrared colours of this star are remarkably similar to those of the B8 Ia+ star No. 12, thought to be reddened by ~10 magnitudes (see Souza and Lutz, 1980 and references therein). The observed HKL colours of IRS-4 could be best fitted by an A0 photosphere obscured by 11.2 - 11.6 visual magnitudes if an extinction law identical to that observed in No. 12 is assumed. This is only a crude estimate and should be confirmed by a far-red or near-infrared spectrometry. IRS-7 was identified with star 78-0-97 from the survey of very red stars in Cygnus by Ackermann (1970)

IC 1396.- The cluster Trumpler 37, associated with the conspicuous HII region IC 1396 and a member of the Cep OB2 association has been studied extensively by Alksnis (1961), Simonson (1968) and Garrison and Kormendy (1976). The latter obtained a distance to the cluster of 1.0 kpc. One of the exciting atars of the nebula is HD 206183, the main component of the Trapezium-type system ADS 15174. The low sensitivity infrared scans performed in this region revealed only one faint source which could not be identified on the Palomar Schmidt plates.

2) Regions containing Herbig-Haro objects

Table 3.2 presents the list of all IR sources found in the vicinity of southern Herbig-Haro objects not previously studied at these wavelengths and of two nebulous stars immersed in dense dark clouds.

With the exception of HH12-15, at least one infrared source was found in each of the areas observed. A close analysis of the photometric data and of the likely stellar identifications (on the Schmidt plates), suggest that none of the infrared-bright objects reported here is the energy source of the corresponding Herbig-Haro object (HHO). Only in the case of HH-52 in the Chamaelion T2 association, was a faint infrared source (IRS-2) found in its highly obscured immidiate vicinity. At a distance of 115 pc (assumed to be the same as the Chamaelion T1 association; Grasdalen et al, 1975), the separation between the IR source and the Herbig-Haro object is approximately 0.04 pc. This source was on the detectivity limit of the survey (K ≃ 9.0) and should be confirmed with a more sensitive system.

In most cases, the IR sources were detected near or outside the boundaries of the dark clouds in which the Herbig-Haro objects are immersed. Of the stars outside Orion and NGC 6334 for which multicolour photometry was obtained, only HH56-57-IRS-1, having colours reminiscent of T Tauri stars, deviates from the reddening line for late type stars in the colour-colour diagram. The very high obscuration in the directions of the hypothetical exciting stars of HH objects requires surveys at longer wavelengths for their detection and this should be a key observational test for present and future models of HH objects.

Haro 249.- This emission-line star shows a small peculiar ring-shaped nebulosity visible in the red and far-red plates with the star conspicuously situated on its perimeter. The region is to the south of the Orion nebula and is characterised by very high obscuration with the presence of two HH objects (Herbig, 1974) less than 6 arc min from Haro 249. Photographic and photoelectric photometry of Haro 249 was kindly provided by Drs. D. Andrews (Armagh Observatory) and R.J. Dodd (ROE) respectively, the latter with the 1m telescope at SAAO with an aperture of 27 arc sec; the results are shown in Table 4.1. Visual spectroscopic and infrared photometric observations of this star were reported by Cohen and Kuhi (1979) who found no absorption spectrum and, hence, no classification was possible. Comparisons between the available observations indicate variations in brightness of more than one V magnitude while the IR data differs by only a few tenths of a magnitude at three different epochs. The infrared colours imply the presence of a circumstellar dust shell similar to other Orion population variable stars.

A nearby companion, some 15 arc sec away was denoted Haro 149/c and classified M0.5e by Cohen and Kuhi (1979). These authors considered, on the basis of a simple statistical analysis, that pairs of this type are likely to be physical.

It should be noted that the coordinates (epoch 1977) of Haro 249 and 249c reported by Cohen and Kuhi (1979) are incorrect (see Table 4.6) but their finding chart is accurate. IRS-3 was identified with a faint visible star showing a faint extended nebulosity seen in red prints (e.g. S. Strom et al, 1974) and probably is another low-mass pre-main-sequence star.

NGC 6334.- This large region is exemplary in the sense that it contains objects emitting at almost every wavelength which has been observed, and these cover a wide range of the electromagnetic spectrum! In the 30 arc min that the complex extends along the galactic plane, a wide collection of objects, all normally associated with star formation processes, is found. These include several HII radio continuum peaks, molecular line detections, including OH and H_2O masers, far infared and 1mm sources, OB stars, an ultracompact HII region and a possible Herbig-Haro object. These are generally not coincident as schematically illustrated in Figure 4.12. Detailed descriptions and references can be found in Moran and Rodríguez (1980) and McBreen et al (1979). At a distance of 1.74 kpc (Neckel, 1978), NGC 6334 is an extremely complex star-forming region where the obsuration is very high and variable (Neckel, 1978).

Moran and Rodríguez identified four separate evolutionary stages of the formation of massive stars, symmetrically distributed about the projected centre of the cloud, where the most evolved phase is observed. These are indicated in order of evolutionary status by Roman numerals in Figure 4.12. In view of the very short ages of the various objects spread over a large volume, Moran and Rodríguez (1980) suggested a ("hot dog") model where star formation is induced by a shock front perpendicular to the line of sight propagating in a bent molecular cloud from the centre to the edges.

Seven near-infrared sources were found during the scans centred near the possible Herbig-Haro object listed No. 25 by Gyulbudaghian et al (1978). The limits of the survey are also shown in Figure 4.12. None of these sources was in or close to the position of the H_2O maser source D (Moran and Rodríguez, 1980) which would be expected to contain at least one highly obscured star or protostar, probably similar to or slightly more evolved than NGC6334-IRS-1 found by Becklin and Neugebauer (1974) in the NE part of the complex. It is likely that the obscuration in that direction is too high, even at 2 microns and searches at longer wavelengths should prove more fruitful.

Of the detected sources only three, not identified with visually bright stars, lie on or close to the major axis of the complex (Figure 4.12) and these were measured photometrically in the JHK bands. IRS-3 appears to be a highly reddened ($A_V \gtrsim 13$) star, probably of a late spectral type. IRS-5 was identified with a faint (in blue light) star and its near-infrared colours are similar to those of Be and T Tauri stars with circumstellar dust shells but with considerable obscuration. A similar position in the colour-colour

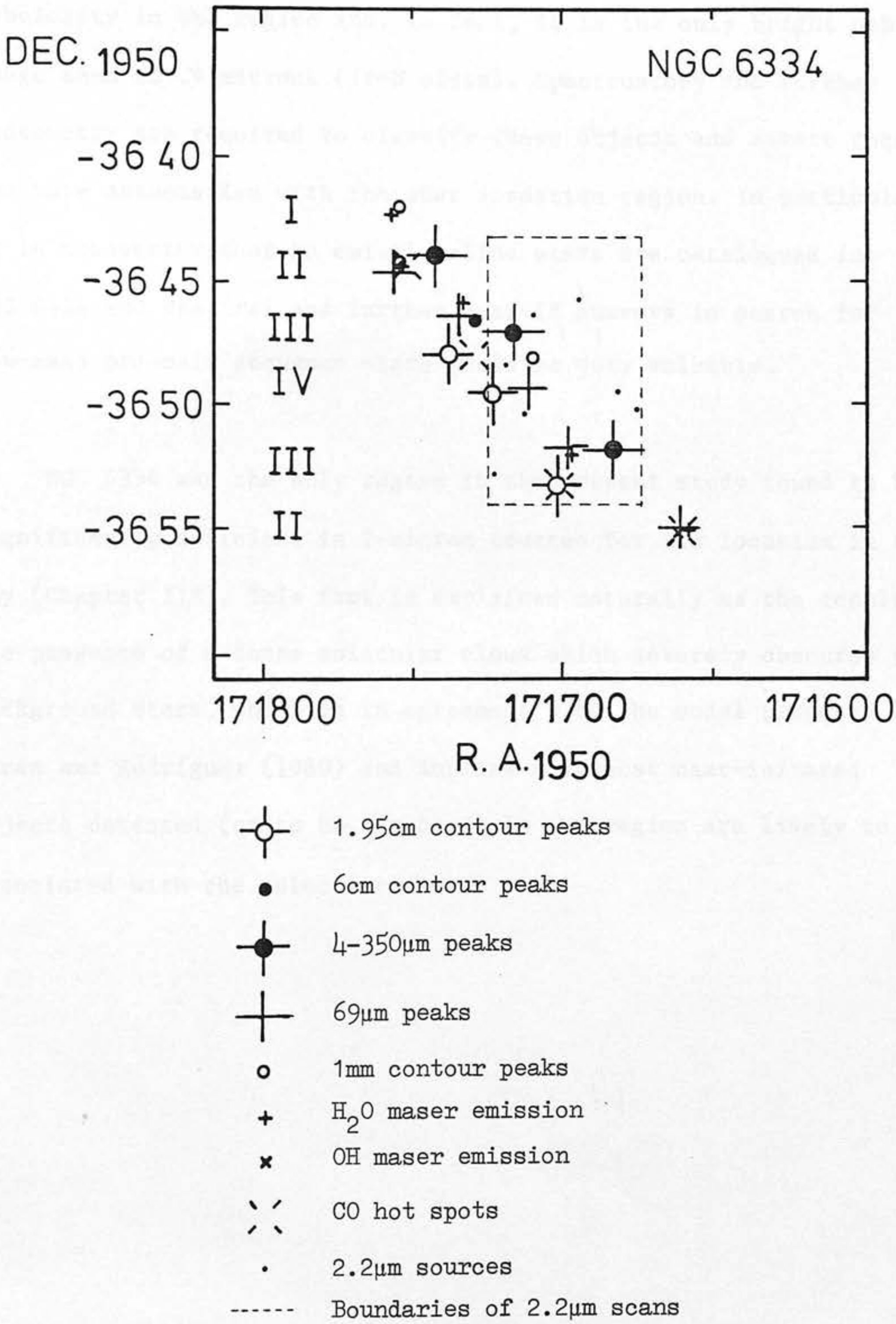


Figure 4.12. Schematic diagram of NGC 6334. See text.

diagram is IRS-2, though considerably less reddened. Its position in the sky corresponds to one of the brightest patches of optical nebulosity in the region and, in fact, it is the only bright nebulous image seen at .9 microns (IV-N plate). Spectroscopy and further photometry are required to classify these objects and assert their possible association with the star formation region. In particular, it is noteworthy that no emission-line stars are catalogued in NGC 6334 and spectral and further near-IR surveys in search for low-mass pre-main sequence stars would be very valuable.

NGC 6334 was the only region in the present study found to be significantly deficient in 2-micron sources for its location in the sky (Chapter III). This fact is explained naturally as the result of the presence of a dense molecular cloud which severely obscures the background stars, which is in agreement with the model proposed by Moran and Rodríguez (1980) and implies that most near-infrared objects detected (or to be detected) in the region are likely to be associated with the molecular cloud.

TABLE 4.1

Visual data available

Name	Other Ident.	V	B-V	U-B	V-R	V-I	Ref.	Sp.Type	Ref.
HD 5005	ADS 719 A	7.76	0.09	-0.86			2	O5.5f	1
	ADS 719 C							O9.0 V	1
V380 Ori	ADS 4209 A	10.70	0.44	-0.20	1.13	1.86	3	A1:e	4
		10.83	0.51	-0.23	1.25	1.93	3	B9e	5
		10.60	0.25	-0.35		0.95	6	---	
		10.37	0.53	-0.15			7	---	
Haro 249		15.55	0.15				91	---	
		16.6					5	---	
Haro 249/c		16.8					5	M0.5e	5
Haro 249 + c		16.19	1.27				36	---	
ADS 4209-IRS 1		17.7	2.4				8	G8	8
12 Gem	HD 43836	6.96	0.48	0.20			10	B9 II	9
HD 46150	ADS 5165 A	6.80	0.12	-0.84	0.24	0.34	11	O5.5f	1
NGC 2244-38	ADS 5165 D	12.40	0.44				12	---	
NGC 2244-29	ADS 5165 E	11.67	0.32	-0.30			12	---	
HD 46149	(IRS 4)	7.56	0.17	-0.78			12	O8.5 V	1
HD 46180	(IRS 1)	9.3					13	A3 V	14
NGC 2244-13	(IRS 2)	10.24	1.07				12	gG2	15
NGC 2244-36	(IRS 3)	12.32	1.95				12	---	
HD 47755	ADS 5316 A (Wk74)	8.44	-0.13	-0.60			17	B3 Vn	16
		8.75	-0.12	-0.74	0.07	-0.05	26	---	
NGC 2264-Wk67	ADS 5316 B	10.80	0.62	-0.43			17	B2 V	17
NGC 2264-Wk66	ADS 5316 C	12.28	0.70	-0.21			17	---	
NGC 2264-W100	BD -9 1336	9.98	0.14	0.07			17	A2 IV	17
		10.06	0.12	0.19	0.21	0.34	26	---	
NGC 2264-Wk50	HD 47732	8.11	-0.12	-0.73			17	B3 V	17
		8.16	-0.14	-0.83	0.00	-0.15	26	---	
NGC 2264-Wk46	BD -9 1330	9.19	0.21	0.13			17	A5 III	17
		9.24	0.21	0.39	0.27	0.47	26	---	
S Mon	HD 47839	4.66	-0.24	-1.11	-0.11	-0.33	18	O8.0 IIIf	1
Tau CMa	HR 2782	4.40	-0.15	-1.14	-0.04	-0.22	18	O9.0 III	19
NGC 2362-Johns 20		8.77	-0.16	-0.87			20	B2 V	9
HD 57281	vB 96	8.97	-0.06	-0.59			10	B9	10
VY CMa	HD 58061	7.39	2.20	2.21	2.30	4.06	21	M3-5Ia-ab	22
HD 71304		8.27	0.53	-0.51			23	O9.5 Ib	1
HD 76838	vBH 25c	7.31	0.00	-0.71			24	B3 V e	24
T Anon. (ABC)		10.24	0.01		0.15	0.31	0	OB-	38
HDE 303176	LSS 1719	10.07	0.12	-0.56			82	OB	38
CP-59 2505 A	LSS 1794	9.73	-0.04				78	---	
Cp-59 2505 B	Cr228-101	11.08	0.00	-0.60			78	---	
CP-59 2505 C	Cr228-102	11.33	0.09	-0.51			78	---	
CP-59 2505 D	Cr228-103	10.96	0.51	0.02			78	---	
CP-59 2505 ABCD		9.12	0.06	-0.63			82	---	
HD 93129 A		7.3	0.22				80	O3 If*	80
HD 93129 B		8.9	0.22				80	O3 V((f))	80
HD 93129 AB		6.97	0.16	-0.78			79	---	
		6.90			0.36	0.62	81	---	
		6.97			0.32	0.56	83	---	
HD 93160		7.81	0.17	-0.77			79	O6 III(f)	80
		7.74			0.32	0.49	81	---	
		7.82			0.33	0.50	83	---	
HD 93161 AB		7.84	0.22				80	O6.5 V((f))	80
		7.82	0.21	-0.70			79	---	
		7.82			0.36	0.58	83	---	
CP-59 2554 AB	Cr228-67	8.77	0.00	-0.82			84	O9 V	85
		8.80	-0.02	-0.88			78	---	
CP-59 2554 C	Cr228-68	10.16	0.05	-0.73			84	---	
		10.41	0.00	-0.80			78	---	
HD 93206	QZ Car	6.28	0.14	-0.80			84	O9.7Ib:(n)	80
		6.32	0.14	-0.83			78	O9.7Iab+B0Ib+ O9V+(B2V)	86

Name	Other Ident.	V	B-V	U-B	V-R	V-I	Ref.	Sp.Type	Ref.
HDE 305520	Cr228-4	8.68	0.17	-0.69			84	B0.5 Iab	85
		8.70	0.19	-0.73			78	---	
		8.71	0.18	-0.71	0.28	0.51	85	---	
		8.68			0.32	0.60	83	---	
Cr228-45		10.18	0.99	0.70			84	---	
		10.22	0.99	0.70			85	---	
		10.18	1.01	0.72			78	---	
HD 93146	Cr228-65	8.41	0.00	-0.90			78	06.5V((f))	80
		8.44	0.02				84	---	
		8.32			0.13	0.19	81	---	
Cr228-66		9.79	0.07	-0.79			84	---	
		9.91	0.01	-0.85			78	---	
HD 93131	Cr228-3	6.48	-0.02	-0.88			84	WN 7	71
		6.47	-0.04	-0.91			78	---	
HD 93249 A	Tr15-1	8.36	0.14	-0.75	0.15	0.30	87	08 II	87
		8.42	0.08				88	---	
HD 93249 B	Tr15-2	9.47	0.20	-0.73	0.11	0.28	87	09 III	87
HD 93249 C	Tr15-3	10.57	0.18	-0.54	0.18	0.33	87	B2 V	87
RT Car	CoD-58 3538	8.67	2.42		2.38	4.21	89	M2 Ia	89
		8.82	2.39	2.49	1.70	3.36	87	M2 Ia	87
Tr15-18		11.28	1.11	-0.09	0.85	1.75	87	09.5 I-II	87
								Bpe?	90
HD 93190		8.58	0.33	-0.82	0.29	0.63	87	B0:IV:pe	63
HDE 303308		8.16	0.14	-0.82			78	03 V	80
HD 93250		7.37	0.16	-0.85			79	03 V((f))	80
		7.36	0.17	-0.83			78	---	
		7.37			0.30	0.47	83	---	
		7.37			0.30	0.46	81	---	
HD 93632		8.39	0.29	-0.73			84	05 III(f)	34
		8.31	0.24	-0.73			82	---	
		8.40	0.27	-0.78			27	---	
		8.39			0.46	0.86	83	---	
		8.38	0.34		0.43	0.87	0	---	
CP-59 2702 A	LSS 1911	10.25	0.26	-0.69			27	---	
CP-59 2702 B		11.85	0.42	-0.57			27	---	
CP-59 2707 C		10.80	0.40	-0.60			27	---	
CP-59 2707 G		10.48	0.16	-0.68			27	---	
CP-59 2702 ABC	LSS 1911	9.67	0.43		0.50	0.99	0	OB	38
CPD-62 1837		9.57	1.43		1.38	3.90	25	K0+Me	25
		9.28	1.46		2.00	3.95	25	---	
CPD-59 2944	vBH 46a	10.40	0.21	-0.68			24	B0 V	24
		10.40	0.27		0.14	0.65	0	---	
	vBH 46b	11.33	0.21	-0.61			24	B2 V	24
		11.28	0.18	-0.62			27	---	
	vBH 46c	11.34	0.21	-0.58			24	B2 V	24
		11.27	0.20	-0.59			27	---	
	vBH 46d	11.38	0.18	-0.61			24	B2 V	24
		11.32	0.18	-0.60			27	---	
	vBH 46bcd	10.25	0.26		0.29	0.52	0	---	
HD 97950	NGC 3603	9.19	0.86	-0.16			28	WN5+0	29
		9.03	0.80	-0.19			30	WN6+05-6(n)	32
		9.66	0.97	-0.16			31	---	
		8.95	0.99	-0.07			33	---	
		9.30	1.07		1.1	1.96	0	---	
HD 101190	IC2944-43	7.32	0.06	-0.83			40	06 V((f))	34
		7.32	0.03	-0.87			35	0 5	35
		7.41	0.08		0.13	0.27	0	---	
IC 2944-42	(IRS-2)	11.18	2.23	2.88			35	---	
HD 104901A	CP-61 3325	7.38	0.22	-0.18			36	B89 Iab/b	37
		7.42	0.18	-0.17			39	B8 Ib-II	37
HD 104901B	CP-61 3326	7.63	0.52	0.33			36	F0 Ib/III	37
								F0 Ib-II	38
HD 104901C		10.15	0.11	-0.56			36	---	
		10.20	0.06	-0.56			39	---	
HD 150136	HR 6187	5.66	0.12	-0.81			41	05 III:n(f)	42
		5.62	0.16	-0.79			43	---	
HD 150135	CPD-48 11069(C)	6.88	0.10	-0.83			41	06.5 V((f)	43
		6.89	0.17	-0.79			43	---	
NGC6193-73	(IRS-4)	15.49				5.71	43	---	
HD 152723	CoD-40 10986	7.31	0.10	-0.81			23	06.5 III(f	)1

Name	Other Ident.	V	B-V	U-B	V-R	V-I	Ref.	Sp.Type	Ref.
HD 164492	ADS 10991A	7.63	0.00	-0.86			44	O7.5III((f))	42
								O7.5 III	47
								O7.5 I	48
ADS 10991 AB		7.54	-0.02		0.05	0.12	92	---	
ADS 10991 CDE		8.64	0.08		0.13	0.29	92	---	
ADS 10991 B	M20-144	10.37	0.03	-0.58			45	A2 Ia	45
ADS 10991 C	M20-146							B0 II	45
ADS 10991 D	LkHα 123							Be	46
ADS 10991 E	M20-147	12.68	0.31	0.19			45	---	
ADS 10991 F	M20-148	14.23	0.81	0.06			45	---	
ADS 10991 G	M20-149	13.37	0.53	0.20			45	---	
M20-130	(IRS-1)	11.69	2.50	2.27			45	M5	45
CD-22 12456	(IRS-3)	9.79	1.25	1.15			45	K0	45
HD 164536	CoD-24 13783	7.11	-0.03	-0.92			49	B4	50
CoD-24 13785	LSS 4575	8.64	0.01	-0.82			49	B	38
7 Sgr	HD 164584	5.35	0.52	0.26			49	F5 II	49
Blanco&Grant No. 1 (IRS-1)		13.6				2.5	51	M2	51
HD 166937	μ Sgr	3.85	0.22	-0.47	0.27	0.20	18	B8e Ia	53
		3.88	0.22	-0.52	0.32	0.15	52	B8 Iap	54
HD 167287		7.09	0.07	-0.78			55	B1 Ib	38
5 Aql	HD 173654	5.64	0.14	0.08	0.13	0.20	18	Am	58
		5.90	0.13	0.11	0.16	0.22	56	---	
		5.90	0.14	0.09			57	---	
ADS 11667 B		7.51	0.31	0.08			57	Am	58
HD 185268	HR 7466	6.45	-0.09	-0.51			60	B5n	59
HD 189864		6.70	-0.08	-0.44			61	---	
HD 190918	ADS 13374 A	6.75	0.13	-0.77			23	WN5+O9.5III	62
		6.67	0.17	-0.72	0.15	0.24	52	WN4.5+O9.5Ia	71
BD 35 3955	ADS 13374 F	7.37	0.25	-0.67			64	B0.5 II	62
								B0.7 Iab	67
ADS 13374 D		9.71	0.21	-0.63			65	---	
ADS 13374 G		12.70	0.00	-0.76			66	---	
ADS 13374 E		11.38	0.15				66	---	
ADS 13374 FG		7.30	0.23	-0.64	0.18	0.14	52	---	
HD 227634	ADS 13376 A	7.92	0.24	-0.66			64	B0 II	67
								B0 Ib	44
BD+35 3956	ADS 13376 C	8.85	0.20	-0.62			64	B0.5 V	44
HD 190429A	ADS 13312 A	6.56	0.19	-0.80			70	O4 If	34
HD 190429AB	ADS 13312 AB	6.63	0.15				61	O4f+O9.5III	48
		6.63	0.10	-0.71	0.12	0.23	52	O5f+O9.5Ibp	63
ADS 13312 C		9.71	0.17	-0.53	0.27	0.44	52	---	
ADS 13312 D		12.90	0.19	-0.57	0.57	0.64	52	---	
IRC +40 376	(IRS-3)							M9	72
ADS 14000 A	Cyg OB2-8A	9.03	1.24	0.15	1.12	2.07	73	O6 Ib(n)(f)	74
		8.98	1.29	0.14			75	---	
ADS 14000 B	Cyg OB2-8B	10.31	1.35				75	---	
ADS 14000AB	Cyg OB2-8AB	8.69	1.25	0.27	0.70	1.13	52	---	
ADS 14000 C	Cyg OB2-8D	11.93	1.43	0.30			75	O5 IIIf	74
		11.94	1.36	0.32			76	---	
		12.13	1.37	0.38	0.95	1.20	52	---	
ADS 14000 D	Cyg OB2-8C	10.08	1.35	0.10			75	O6	75
		10.14	1.31	0.11			76	---	
Cyg OB2-9	Redd 35	10.77	1.90	0.74	1.82	3.08	11	O5 If+	74
		10.87	1.89	0.66			76	---	
		10.80	1.93	0.65			75	---	
Cyg OB2-7	Redd 33	10.50	1.44	0.30			75	O3 If	74
		10.53	1.37	0.21			76	---	
Cyg OB2-18	Redd 36	11.09	1.91	0.65			77	---	
		10.93	1.93	0.69			76	---	
Cyg OB2-19	Redd 37	11.06	1.44	0.30			77	---	
		10.86	1.54	0.52			76	---	
HD 206183	ADS 15174 A	7.43	0.13	-0.78			68	B0 V	68
		7.42	0.11	-0.79			69	O9.5 V	69

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CHAPTER V

SUMMARY AND CONCLUSIONS

In the present dissertation the results of a large scale program consisting of the study, at wavelengths 1 to 4 microns, of 62 regions containing small trapezium-type star clusters and Herbig-Haro objects in dense clouds are presented.

51 trapezium-type visual multiple systems, lying in bright and dark nebulosities often in the centre of young open clusters and in the presence of other signposts of recent star formation, were selected from a recently completed catalogue. As expected, all these regions are very close to the galactic plane. The observations included JHKL photometry of most star members of the systems (71 stars measured) and photometric maps at the wavelength 2.2 microns, covering areas of approximately 85 sq arc min, centred in the trapezia. A total of 185 sources brighter than the appropiate survey limiting magnitude (averaging K = 6.2 in the Northern Hemisphere and K = 7.7 in the Southern Hemisphere) were found; of these, some 75% were not previously observed or catalogued. The majority of the sources detected were also observed photometrically in the wavelength range 1 to 4 microns. It was found that roughly 80% of the 2.2 micron sources in the sample most

probably consist of reddened late-type field stars. This is in agreement with predictions by available simple semi-empirical models, which were also independently tested by similar monitoring surveys of 15 randomly chosen "reference" regions along the galactic plane; for simplicity these were centred on bright stars. Most regions for which the number of infrared sources detected differred significantly from that expected, are naturally explained by the presence of star clusters and high or low obscuration.

The majority of the regions studied are discussed in detail and the significance of the presence of young early-type trapezium clusters associated with the other stellar and interstellar contents of the region is emphasised together with their possible connection with some of the new near-infrared sources with the aim of envisaging a picture of how star formation processes developed in these molecular clouds. However, in very few cases was there enough observational data available to draw definitive conclusions. As in most survey works, the most important findings are those for which little or no previous observational data existed.

Among the regions included in this program are some well-known and studied clusters and nebulosities as well as others presently observed at infrared wavelengths for the first time. Some interesting examples are:

-The cluster NGC 2264 where one of the members of the trapezium system was found to be the earliest-type star in the cluster known to have infrared excess emission.

-The neglected young cluster Pismis 17 which was found to be physically associated with the bright/dark cloud complex Hoffleit 44.

-The massive HII region NGC 3603 which contains OH and H_2O maser sources as well as a small trapezium system containing a Wolf-Rayet and several O stars. Its vicinity was found to be overabundant in late-type supergiants (classified by the depdth of the CO absorption band in the 2-micron region) within a radius of a few arc minutes from the central cluster. These stars were detected during the 2.2 micron surveys and include one star discovered in 1978 which was not reported in a previous similar survey described in the literature. However, not all the infrared sources located within the nebulosity have been classified. The importance of the study of the stellar population of the complex is emphasised.

-The F supergiant Henize 747 was discovered to exhibit strong infrared excess at wavelengths longer than 3 microns. This can only be understood as thermal emission by a circumstellar dust shell. Its evolutionary status is discussed in comparison with similar supergiants, particularly 89 Her.

-The discovery of the probable long-period variable CPD-62 1837, a likely member of a binary or triple system.

-The Trifid nebula where some of the most highly obscured stars in the sample were found, these were located near the edges of the dust lanes.

-Several young clusters in the Great Carina Nebula. From the study of the near infrared photometry of visually bright early-type stars and of faint background stars, it is found that the infrared reddening law in that direction follows a "normal" law and that infrared excesses are evident in a large number of emission-line and supergiant stars. This emission seems to be due to free-free processes in hot gas envelopes. Two possible luminous but highly obscured early-type stars were found in Carina II. The existence of these is possibly of importance in the dynamic study of the region which is characterised by an expanding gas sphere coincident with the brightest part of the optical and radio nebula.

-The obscured association Cyg OB2. Two new highly reddened probable members were dicovered. Their infrared colours resemble closely those of known obscured early-type stars in the association.

As a parallel effort, all catalogued Herbig-Haro objects south of -7 degrees and two nebulous stars in dense dark clouds (eleven in total) were included in the program and the sky in their vicinity was mapped at 2.2 microns in a search for highly reddened stars which are expected to be the source of excitation for the Herbig-Haro objects as well as for other pre-main sequence stars embedded in the clouds. Only one of the 38 near-infrared sources found in these regions appears to be directly associated with the respective Herbig-Haro object, suggesting that the obscuration in front of the hypothetical exciting stars is extremely high, as predicted by various models.

A product of such an extensive series of surveys in many directions of the Milky Way was the detection of a large number of highly reddened field stars. Their positions in the infrared colour-colour diagrams are analysed in order to determine the properties of the general interstellar reddening law from 1 to 4 microns. This is achieved by means of the computation of the colour excess ratios E(J-H)/H-K), E(H-K)/E(K-L) and E(J-K)/E(K-L). These are found to differ slightly from van de Hulst's model No. 15 and seem to be considerably different in certain peculiar regions in the Galaxy, such as the Taurus and Ophiuchus dark clouds and the Galactic Centre. As a check, a schematic comparison between the near-infrared two-colour diagrams from the present observations and from most stellar near-infrared photometry reported in the literature is presented.

The present infrared work includes a large sample of galactic objects in a wide range of evolutionary stages. Although the working hypothesis aimed primarily at the study of young stars and possibly other objects related to recent star formation, a large number of infrared sources in the present sample seem to have no relation to the gas, molecules, dust and stellar young complexes in the program, but some of them deserve especial atention and therefore, are also analysed and discussed in detail.

The extent to which the group of trapezium-type clusters here selected represents an interesting sample of young stars is indicated by a comparison of the visual and infrared photometric properties of the star members. This is shown in the Figure 5.1 in the form of the E(B-V) vs E(V-K) plot of all members of observed trapezia and nearby early-type stars for which spectral types are available in the literature. Emission-line stars and OB supergiants are indicated and different symbols are used for stars in well known young clusters.

The presence of infrared excesses is often indicative of youth and in this case supports the idea that massive trapezium-type systems associated with nebulosities are of short ages ($\lesssim 10^6$ years), in agreement with dynamical estimates, and in many cases, these have an important role in the formation of stars in the molecular clouds. We remark, however, on the necessity of individual analyses for each region and caution on the dangers of generalised studies of regions of star formation.

To conclude, it is stressed that the present results should be regarded as indicative of certain regions and objects which were found to be of particular astrophysical interest and which should be observed further in several wavelength ranges in order fully to understand their nature. In other words, the work reported here

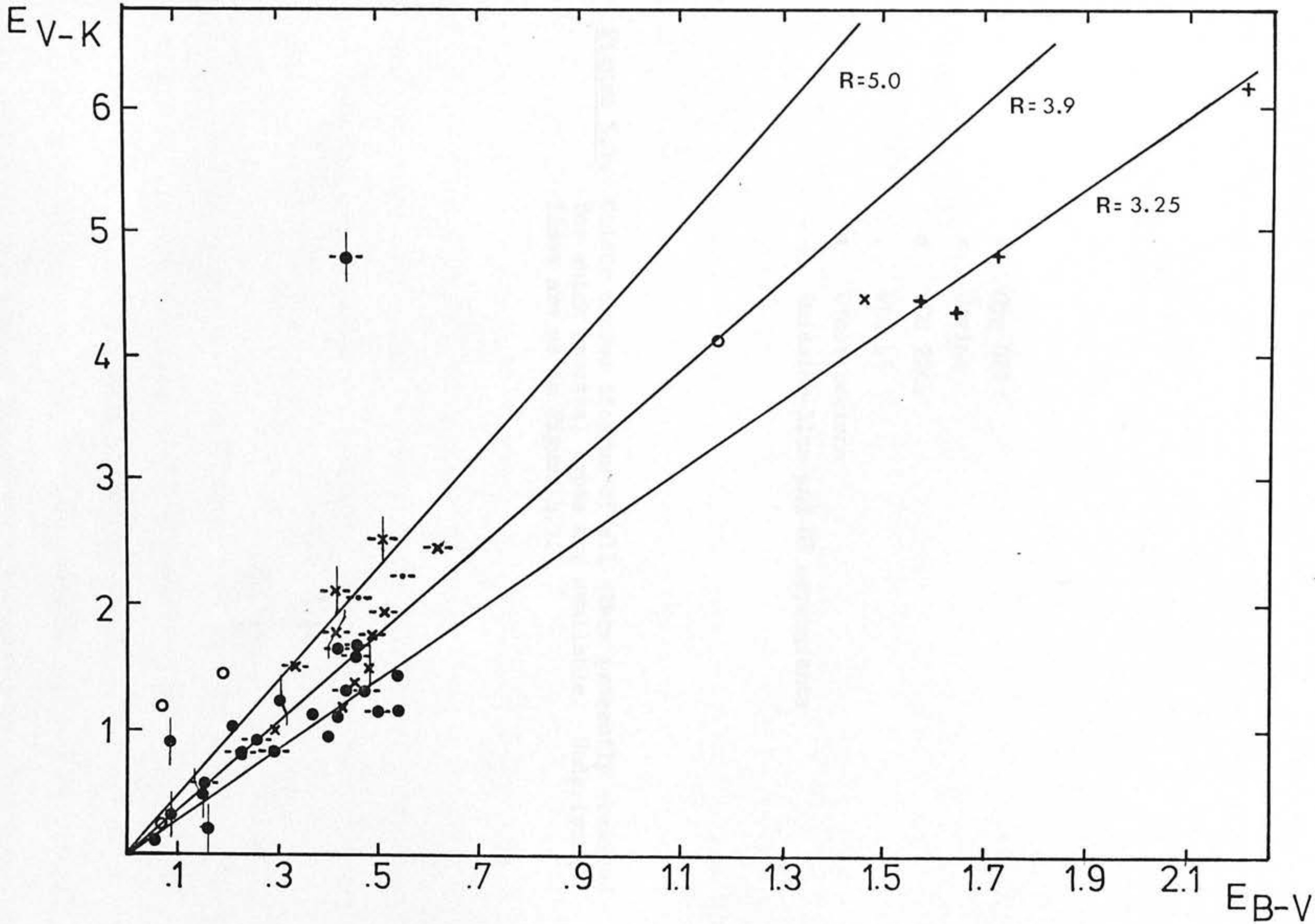

Figure 5.1

+ Cyg OB2
× Carina
o NGC 2264
. vBH 46
● Other regions
- · - Emission-line and OB supergiants

Figure 5.1. Colour excess diagram of all stars presently observed for which spectral types are available. Underlying lines are as in Figure 4.1.

asks many questions regarding a collection of galactic objects which, in many cases, had not been observed or known to exist before.

The continuation of this program will include optical, near and mid-infrared observations of a short list of objects here described in order to gather sufficient and unambiguous data which could make their full physical interpretation possible.

The observational results presented here do not provide a definitive answer to the initial question concerning the evolutionary role of the young trapezium-type systems. In particular no new active star formation sites were found within the regions studied.

The restrictions imposed by these results on star formation studies are not very severe. With an increase in the sensitivity of 2.2 μm surveys towards galactic plane regions, the number of field stars would increase enormously and confusion problems would be hard to overcome. Since the obscuration towards protostellar objects can be very high and their emission arises primarily in dust envelopes with mean temperatures of a few hundred degrees Kelvin, surveys at wavelengths longer than 3 μm but shorter than 20 μm will be more effective for their detection. It is in this wavelength range that the spectral distribution of protostars peaks. Furthermore, these surveys will not be contaminated so heavily by red field stars.

It is also concluded that, although each star formation region should be considered individually, deep infrared surveys of more extended areas are desirable. Where possible, their boundaries should be defined after analyses of the geometry of the complexes, as inferred from observations at other wavelengths. Particularly, molecular radio emission maps, alarmingly scarce in the Southern skies, will be of great value.

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APPENDIX I

ADDITIONAL VISUAL PHTOMETRY

Broad-band $BVR_{KC}I_{KC}$ photometry on the Cape-Kron system was carried out for certain Trapezium-type systems in 1978 May 5 and 8 with the People's photometer attached to the 0.5m telescope at the South African Astronomical Observatory station at Sutherland; always using a 14 arc sec apperture. The standard stars were from the E regions observed by Cousins (1973, 1976). The results are given in Table A.1 and the errors for all colours are within 0.03 magnitudes. For comparison purposes, the (V-R) and (V-I) indexes given in Table 4.1 referred to this Appendix were transformed into Johnson's photometric system using the colour equations reported by Cousins (1976).

TABLE A.1

ADDITIONAL VISUAL PHOTOMETRY

Name	V	V-B	$(V-R)_{KC}$	$(V-I)_{KC}$
T anon.	10.24	0.01	0.09	0.25
CP-59 2702	9.67	0.43	0.34	0.77
HD 93632	8.38	0.34	0.29	0.68
CPD-62 1837ABC	9.57	1.43	1.38	3.90
CP-59 2944A	10.40	0.27	0.08	0.51
CP-59 2944BCD	10.25	0.26	0.19	0.41
HD 97950	9.30	1.07	0.78	1.52
HD 101190 A	7.41	0.08	0.07	0.22

APPENDIX II

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A PROBABLE LONG-PERIOD VARIABLE IN THE SYSTEM CPD −62° 1837

By
M. Tapia
Department of Astronomy, University of Edinburgh
and
R. Catchpole
South African Astronomical Observatory

Visual and near-infrared observations of the triple star system CPD −62° 1837 are presented. The data are consistent with the system being physical and containing a new long-period variable.

Introduction. The system CPD −62° 1837 (HDE[1] 308122) contains three stars in an almost straight line with separations AB and BC both about 4″. The near equality of the separations places the system in the class of 'Trapezium-like' objects[2] and it was listed[3] as having less than 1 per cent probability of being a chance optical association. The *Henry Draper Catalogue* extension[1] classifies the star as K0 but makes no mention of its multiple nature. An M6 star with a blue magnitude of 10·9 was reported at that position in the *Spectral Survey of O, B, and M Stars in the Southern Milky Way*[4]. Otherwise the system has been almost completely neglected.

Observations and Results. Three different kinds of observations—simultaneous visual and near-infrared photometry and moderate-resolution visual spectroscopy—are reported, each performed with a different telescope at the South African Astronomical Observatory station at Sutherland.

(*a*) *Broad-band photometry:* $BVR_{KC}I_{KC}$ photometry on the Cape–Kron system[5,6] was carried out in 1978 May and 1979 January–February with the People's photometer attached to the 0·5-m telescope. The errors for all colours are within $0^m.02$ and $0^m.01$ for the 1978 and 1979 observations respectively. *JHKL* photometry was obtained at approximately the same time as the visual photometry on the 0·75-m telescope with the photometer described by Glass[7] in 1978 and a similar one in 1979, both having *InSb* detectors. The comparison stars were chosen from those having higher weights from the list by Glass[8], and the accuracy of the infrared photometry is believed to be 0·05 magnitudes. The results are given in Table I where each measurement is the average of at least two observations. In all cases the aperture was centred on star B and included all three components.

TABLE I

Photometric results for the combined system CPD −62° 1837

Dates	*Magnitudes*		*Colour Indices*		*Aperture*
1978 May 5–8	$V=9.57$	$B-V=1.43$	$V-R_{KC}=1.38$	$R_{KC}-I_{KC}=1.92$	14″
	$K=0.36$	$J-K=1.59$	$H-K=0.59$	$K-L=0.38$	26″
1979 Jan. 31–Feb. 2	$V=9.28$	$B-V=1.46$	$V-R_{KC}=2.00$	$R_{KC}-I_{KC}=1.95$	14″
	$K=0.24$	$J-K=1.52$	$H-K=0.46$	$K-L=0.35$	26″

(*b*) *Spectroscopy:* Spectra of stars A and B were obtained, through cloud and very poor seeing, during the night of 1979 February 4/5, with the image-tube spectrograph at the Cassegrain focus of the 1·88-m reflector. The spectra, recorded on baked Kodak IIa–O emulsion, cover the region 3840 Å to 4700 Å and have a dispersion 32 Å/mm at $H\gamma$. The spectrum of star A, although weak, is consistent with the HDE classification, K0. The spectrum of star B is probably heavily contaminated with that of A but shows weak bands of *TiO* at 4584 Å and 4422 Å as well as a number of emission lines which are certainly not present in the spectrum of star A. The most conspicuous emission lines are hydrogen $H\gamma$, $H\delta$, and $H\epsilon$, and *Fe* I lines at 4202 Å and 3852 Å, $H\gamma$ and $H\delta$ being of nearly equal intensity. According to Merrill[9], this is typical of post-maximum long-period-variable spectra. The absence of *Fe* I 4308 Å in emission suggests that the star was observed within 0·1–0·2 phase after maximum light[9].

A short-exposure unwidened objective-prism IIIa–J plate taken with the UK Schmidt on 1977 April 12 shows in the spectrum of star B a deep depression centred at 4500 Å following a region of enhanced emission centred at 4200 Å, both regions being very broad. This shape of the continuum is observed in very late M stars and at minimum light of some 'extreme' Miras, *e.g.* R Leo[10].

Discussion. The photometric analysis of close multiple systems is complicated by the fact that the measurements are the sum of the emission of all components. In CPD −62° 1837, star C is much fainter than the other components and is neglected in the present discussion.

The colours and spectral types listed in Table II are deduced from the composite *B* and *V* magnitudes listed in Table I by assuming that star A

TABLE II

Fitted individual colours for stars A and B in CPD −62° 1837

Star	*V*	*B−V*	*Sp. Type*
A (assumed constant)	9·94	1·30	K0
B (1978)	10·93	2·02	M8
B (1979)	10·14	1·76	M6*e*

remains constant and all the variation can be attributed to star B. This solution is clearly not unique but is in best agreement with the spectroscopic results.

In an attempt to construct a crude light curve, we examined four direct blue Schmidt plates (two from SRC and two from ESO surveys) taken in 1974–1976; no large-amplitude variations ($\gtrsim 1 \cdot 5$ magnitudes) of star B relative to A are apparent. Nevertheless, our photometry shows that at least one star is variable.

Our purpose in publishing this note is to present the available observational material in order to encourage further work on CPD $-62°$ 1837. Accurate binary-star photometric observations, *e.g.* like those described by Franz[11], together with additional spectroscopic data are needed. It is also important to investigate the possible physical connection between the members of the system by means of astrometric observations.

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