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INFRARED ASTRONOMY AND STAR FORMATION

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RESUMEN. La astronomía infrarroja es una herramienta natural para estudiar la formación de estrellas porque la luz infrarroja penetra el polvo circundante y porque se espera que las protoestrellas emitan luz infrarroja. Los mapas y la fotometría infrarrojos han permitido descubrir muchas fuentes compactas, a menudo ubicadas dentro de una masa de polvo caliente que está asociada con el núcleo de una nube molecular. Se han comenzado a realizar estudios más detallados de estos objetos y se están cuestionando las interpretaciones tradicionales. Ahora se piensa que algunas fuentes compactas son picos de densidades que no son autoluminosos. Los excesos infrarrojos vinculados a estrellas jóvenes quizás no siempre sean producidos por polvo circumestelar; mediciones por el procedimiento de interferometría de manchas (speckle) han mostrado que por lo menos parte del exceso en la dirección de T Tauri resulta de la existencia de una compañera infrarroja. Estudios espectroscópicos de núcleos densos en los cuales se forman estrellas, y de objetos compactos han puesto al descubierto numerosos fenómenos nuevos, entre los cuales se incluye la existencia frecuente de flujos energetizados. Nuevos descubrimientos con el IRAS y con otros telescopios infrarrojos que se han planeado continuarán aportando progresos en el campo.

ABSTRACT. Infrared astronomy is a natural tool to use in studying star formation because infrared light penetrates the surrounding dust and because protostars are expected to emit infrared light. Infrared mapping and photometry have revealed many compact sources, often embedded in more extensive warm dust associated with a molecular cloud core. More detailed study of these objects is now beginning, and traditional interpretations are being questioned. Some compact sources are now thought to be density enhancements which are not self-luminous. Infrared excesses around young stars may not always be caused by circumstellar dust; speckle measurements have shown that at least some of the excess toward T Tauri is caused by an infrared companion. Spectroscopic studies of the dense, star-forming cores and of the compact objects themselves have uncovered a wealth of new phenomena, including the widespread occurrence of energetic outflows. New discoveries with IRAS and with other planned infrared telescopes will continue to advance this field.

I. THE ROLE OF INFRARED ASTRONOMY

The primary role of infrared astronomy in the study of star formation stems from two facts: the ability of infrared light to escape from dusty regions and the tendency of dust around young stellar objects to reach temperatures in the range of 20 to 1500 kelvins. Because of these facts, infrared observations have been the primary means used to search for stars in the process of formation. At first these infrared searches were concentrated in the vicinity of

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compact H II regions, based on the premise that still younger objects might be associated with the young hot stars which ionize the gas in the H II regions (e.g. Wynn-Williams and Becklin 1974). Later the explosion of information resulting from the advent of millimeter wavelength astronomy provided a larger frame for the picture. It is now clear that nearly all reasonably compact HII regions are associated with molecular clouds which are invariably much larger and more massive than either the H II region or the aggregate of the stars which excite it. It is also clear that the "dark clouds" that have long been known to be associated with T Tauri stars are merely molecular clouds which are near enough to us to produce a substantial dark area on the sky. Maps of these molecular clouds in the spectral lines of carbon monoxide (CO) revealed regions of elevated temperature which turned out to be excellent hunting grounds for higher mass young stars. The result of a decade of this work is that we now have a large list of regions of star formation (cf. Wynn-Williams 1982) and detailed study of many of them. The searches have however been biassed by application of search techniques which had already proven successful. This situation will soon be rectified; in regions where it is not limited by confusion, the IRAS survey will include essentially all stellar and protoestellar objects which are surrounded by significant amounts of dust out to a distance of $\sim$ 1 kpc for a luminosity of 1 $L_\odot$ (Werner 1982). If we can separate these sources from other kinds of infrared sources, a much less biassed and a more complete picture of star formation will result.

II. THE ENVIRONMENT FOR STAR FORMATION

With the prospect of such a picture soon to emerge, it may be foolish to attempt a review of star formation now. If, however, we attempt to summarize the *current* picture, something like the following emerges. Star formation appears to occur invariably in molecular clouds, at least in our galaxy. The considerable range in CO luminosities among otherwise similar galaxies (Morris and Rickard 1982) raises questions as to the universality of the picture we derive from studies in our own galaxy. These *caveats* aside, the idea that stars form in molecular clouds has considerable appeal. After a period of controversy over whether molecular clouds are (Bash and Peters 1976; Cohen *et al.* 1980) or are not (Scoville, Solomon and Sanders 1979) confined to spiral arms, a consensus has emerged that molecular clouds are at least enhanced in spiral arms, while not being totally confined to them. This distribution is reasonably consistent with the traditional view, based largely on the blue colors of spiral arms in other galaxies, that massive stars are born in spiral arms.

Furthermore, molecular clouds are cold and massive objects, conditions which should favor star formation if simple Jeans mass arguments have any validity.

If we try to press on beyond this broad consistency to a more detailed scenario for star formation, we quickly encounter inconsistencies and puzzles. Unlike diffuse atomic clouds, which are confined by pressure, molecular clouds are gravitationally bound. A simple analysis leads to the conclusion that essentially all molecular clouds should be collapsing at the free-fall rate. Even at the lowest densities thought to exist in molecular clouds ($n \sim 100$ cm^{-3}), the time for free-fall collapse is $t_{ff} = 4\text{x}10^{7}\ n^{-1/2} = 4\text{x}10^{6}$ yrs. Since estimates for the total mass of molecular clouds in the galactic disk range upward form 10^{9} $M_\odot$ a naive interpretation would suggest a star formation rate of ≥ 250 $M_\odot$ yr^{-1}, which is much larger than conventional estimates.

Furthermore most of the molecular gas is concentrated into very large clouds or complexes with $M = 10^{5}$-10^{6} $M_\odot$, much bigger than open clusters or associations, which have typically 10^{3} $M_\odot$ of stars. Evidently, the process of star formation on large scales is inefficient in some sense; only a small fraction (0.1 to 1%) of a molecular cloud forms stars. This formal solution, low efficiency of star formation, is not satisfactory since it also requires explanation: what prevents the overall collapse of massive molecular clouds? Fragmentation can channel the collapse into multiple star formation, avoiding the formation of a supermassive object, but how is the gravitational binding energy overcome? How does a gravitationally bound object of 10^{6} $M_\odot$ become a 10^{3} $M_\odot$ cluster or association of stars and 10^{6} $M_\odot$ of unbound gas? While stellar winds, H II regions, and supernova explosions have all been proposed as means to disperse the unused gas, they have also been suggested as "triggers" to further star formation! The complexity of the hydrodynamical processes may preclude a clear theoretical analysis of cloud dispersal through these processes. Observational results do present a clear challenge to theory; CO observations of clusters indicate that the molecular cloud is dispersed by the time the last O9 star leaves the main sequence, corresponding to a duration of 20-40 x 10^{6} yr for the cloud once massive stars have formed (Bash, Green, and Peters 1977).

Other fundamental questions remain unanswered. How does the star formation process vary from cloud to cloud? Do massive stars form only in relatively massive clouds? Do small mo-

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lecular clouds ($M \sim 1\text{-}100\ M_\odot$) form isolated field stars? If clusters and field stars form in different places, what explains the *general* similarity of the initial mass function (IMF) for field stars and open clusters (Scalo 1978), at least for the mass range of 1-10 $M_\odot$. Perhaps the strangest puzzle involves the time sequence of star formation in a particular molecular cloud. H-R diagrams for open clusters, together with ages based on Hayashi tracks, indicate a considerable dispersion in stellar ages (Iben and Talbot 1966), supporting Herbig's (1962) idea that low mass stars form first in a cluster. Furthermore, the general scarcity of low mass stars above the main sequence indicates that the formation rate of low mass stars had to reach its peak and decline before formation of higher mass stars got underway (cf. Adams, Strom, Strom 1983). Perhaps the most dramatic example is the Pleiades where the age of the high mass stars is $\sim 7 \times 10^7$ years, while the apparent age of the lower main sequence is $\sim 2.5 \times 10^8$ years, indicative of an extremely long time span for star formation (Stauffer 1980). How does the cloud know to suspend formation of low mass stars long before it forms high mass stars? These results are so paradoxical that one is driven to question the accepted time scales for pre-main-sequence evolution. Since there appears to be a significant deficit of massive stars in the ρ Ophiuchi cloud (Lada and Wilking 1984), we may have caught a cloud in the act. Further infrared studies of this cloud may help us to resolve this puzzle.

Since these questions about large scale star formation are so puzzling, let's change the subject. What have we learned about the process of formation of individual stars? This general subject has been reviewed recently by Wynn-Williams (1982). Since recent advances in resolution, both spatial and spectral, have had a great impact on this subject, I will concentrate on those two aspects in what follows.

III. HIGH SPATIAL RESOLUTION

High spatial resolution studies of infrared emission at 10-20 μm have revealed that many emission regions break up into several sources (Beichman *et al.* 1979). Thus it appeared that the formation of very compact clusters was a common phenomenon. In a recent review, Wynn-Williams (1982) found that more than half of the "protostars" he catalogued were members of double or multiple groups with sizes less than 0.25 pc. This view has been challenged recently by observations in the first-discovered and prototypical "infrared cluster", the Kleinmann-Low nebula in the Orion molecular cloud. Polarization studies at 3.8 μm have shown that the polarization vectors form halos around two of the compact sources, IRc2 and the BN object (Werner, Dinerstein, Capps 1983). The high degree of polarization (> 30%) identifies scattered light as the primary source of polarization, rather than dichroic absorption. The polarization is high at the location of IRc3 and IRc4, two prominent sources at 20 μm, but low toward IRc2 and BN. These results suggest that IRc3 and IRc4 are not self-luminous. This possibility has recently been confirmed by high spatial resolution observations at 2-30 μm (Wynn-Williams *et al.* 1984). These maps reveal that the color temperatures determined from 8 to 12.5 μm and from 12.5-20 μm peak only on BN and IRc2 and are constant over the rest of the Kleinmann-Low nebula, including IRc3 and IRc4. The 20 and 30 μm *emission* peaks, in contrast, coincide with the regions of strong scattering at 3.8 μm emission. Wynn-Williams *et al.* interpret these peaks as resulting from heating by the self-luminous objects, principally IRc2. If this situation obtains in other regions where multiple sources have been found, we may have to revise our notion that massive stars commonly form in very tight clusters.

Meanwhile, observations with still higher spatial resolution have shown that a number of compact infrared sources are in fact double sources (Dyck and Howell 1982; Howell *et al.* 1981; Neugebauer *et al.* 1982) with spatial separations of 700-3000 A.U. In the case of Mon R2 IRS3, McCarthy (1982) finds evidence for a third, more extended (2"), component, whose colors indicate that it is scattered light from an envelope of dust centered on the double. The most dramatic example of this type is the speckle observation showing T Tauri to be a double star, with the cool (600-800 K) companion perhaps accounting for T Tauri's infrared excess between 2 and 20 μm (Dyck, Simon, Zuckerman 1982). The separation is only 80-150 A.U. The nature of the infrared companion is as yet unclear, but Hanson *et al.* (1983) have suggested that it may be a giant gaseous protoplanet which is accreting matter from a disk around T Tauri. Regardless of the exact nature of the T Tauri infrared companion, its discovery calls into question the traditional interpretations of infrared excesses around young, optically visible stars. Interferometric infrared techniques with substantial baselines will be essential for studying the nature of infrared emission regions around young stars; these techniques promise to be among the most important avenues for further exploration of star formation over the next decade.

The suggestion that the T Tauri infrared companion may be a protoplanet leads us to the very exciting notion that we might begin to study the process of formation of planetary systems. The potential coupling of star formation studies to solar system studies through observations of other planetary systems in formation is one of the most exciting prospects for the next several decades. The IRAS detection of an infrared excess apparently caused by relatively large solid particles around Vega further suggests that planetary system formation may be amenable to study. While the interpretation of these results is not yet clear, one possibility is that planetary system formation takes a fairly long time to complete, making it more susceptible to observational attack.

IV. HIGH SPECTRAL RESOLUTION

Just as high spatial resolution in the infrared has challenged traditional pictures of star formation, so high *spectral* resolution has opened new avenues of exploration and, by indirect means, allowed study of the environment of young stars at spatial resolutions still higher than those obtainable by direct means. To understand this situation let us first review the picture of protostars which was developed in the last decade. Based largely on the pioneering work of Larson (1969), several theorists developed models for hydrodynamical collapse. These spherically symmetric models inevitably found that a core forms when the density reaches a point where infrared photons are trapped. The core then contracts more slowly toward the main sequence. Spherical accretion and, eventually, nuclear reactions provide a luminosity source which is embedded in the accreting envelope for a considerable length of time. Such an object would appear only as an infrared source until the envelope cleared, revealing a visible object. Calculations (e.g. Yorke and Shustov 1981) of the predicted energy distribution of these protostars agree roughly with those of many objects found in molecular clouds -generally, a peak in flux density around 5-20 μm, with broad spectral depressions at wavelengths corresponding to dust grain resonances (*e.g.* the 9.7 μm silicate feature). Consequently many protostar candidates exist (*cf.* Wynn-Williams 1982). The problem is that other objects could look quite similar to protostars. Main sequence stars which are still surrounded by a dust shell, or even post-main-sequence stars which have ejected a dust shell, can have energy distributions very similar to those of the protostar models. Indeed sensitive searches for radio continuum emission or infrared recombination lines have revealed that many of the protostar candidates have ionized regions inside the dust shells. Such cocoon stars (Davidson and Harwit 1967) are presumably more evolved objects than true protostars. As the star ionizes an extremely compact H II region the accretion is reversed, as the pressure of the ionized gas reverses the flow and disperses the shell.

Given this picture of protostar evolution, the game plan seemed clear: find a protostar candidate with no radio continuum emission or infrared recombination lines; and find evidence for infall. The latter problem could be attacked by high-resolution infrared spectroscopy; using the infrared source as a background lamp, one should be able to identify infalling gas by virtue of its redshift relative to the rest of the molecular cloud, the velocity of which can be accurately determined from radio spectroscopy.

When this plan was followed in the case of the BN object (Scoville *et al.* 1983 and references therein), the results were dramatic -and totally contrary to expectations based on the picture discussed above. While a CO rovibrational system at 9 km/s (the ambient cloud velocity) is present, there are also distinct systems at -18 and -3 km/s, indicative of gas which is *blueshifted*, rather than *redshifted* relative to the ambient cloud. Also present in the spectrum are broad ($\Delta v \sim 200$ km/s) hydrogen recombination lines and CO overtone bandheads in *emission* at $\lambda \sim 2.3$ μm. These data are interpreted in terms of an ionized stellar wind with $n_e \sim 10^7$ cm^{-3} and total mass $\sim 3 \times 10^{-6}$ $M_\odot$, and a highly confined molecular region with $n \sim 10^{12}$ cm^{-3} and $T \sim 3500$ K. Furthermore, the molecular region appears to be inside the ionized region, which itself is confined to 20 A.U. Finally the systematic velocity of BN itself is v = 21 km/s, implying a motion of 12 km/s relative to the molecular cloud. If this motion is not orbital motion in a binary system, BN has only been in the dense cloud core in a few thousand years. Clearly, while BN has failed the protostar test, it is an extremely interesting object.

No other protostar candidate has been studied in as much detail as BN, which is the brightest of these objects, but a similar study has recently been made for NGC 2024 IRS 2 (Black and Willner 1983). In this case, only the ambient molecular cloud was seen in the CO rovibrational absorption lines; the velocity and width of these lines agree with measurements of emission lines at radio and millimeter wavelengths. As in BN, a wide ($\Delta v = 137$ km/s) Br γ line was seen.

The failure to see infall toward BN is less surprising when placed in the context of other developments. Indeed, Grasdalen (1976) has already detected a hydrogen recombination line from BN, and radio continuum emission has now also been detected (Moran *et al.* 1983). Consequently, one would have suspected that BN might have passed beyond the protostellar phase. Furthermore, millimeter CO lines revealed broad ($\Delta v \sim 200$ km/s) wings superposed on the narrow

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spike caused by the ambient cloud (Zuckerman, Kuiper, Rodriguez-Kuiper 1976; Kwan and Scoville 1976). Finally molecular H_2 quadrupole rovibrational emission was also seen in this region (Gautier *et al.* 1976). Further studies of this emission have shown that it arises in hot $T \sim 1000$-3000 K gas which has been shocked (cf. Beckwith *et al.* 1983 and references therein). Also arising from this gas are high J (up to 34) rotational lines of CO which appear throughout the far infrared (Watson 1982). All these data point toward a powerful outflow in the core of the Orion molecular cloud. The dominant outflow appears to be driven, not by BN, but by the more deeply embedded and highly luminous ($L \sim 10^5$ $L_\odot$) IRc2 (Downes *et al.* 1981). This picture of outflow has been combined with the polarization and color temperature results described above to synthesize a new model of the Orion core as a clumpy cavity centered on IRc2; most of the other infrared sources are interpreted as irregularities in the material defining the edge of the cavity (Wynn-Williams *et al.* 1984). An alternative view (Werner 1982; Werner, Dinerstein, Capps 1983) is that the other infrared sources may be colder cloud fragments, perhaps even the long-sought protostars. Persuasive evidence of infall, probably based on a narrow, long-wavelength, spectral line will be necessary to substantiate this conjecture. IRc4 is especially interesting in this regard because of its association with a warm, dense region revealed by highly excited radio NH_3 emission (Zuckerman, Morris, Palmer 1981) and recently detected far-infrared NH_3 emission (Townes *et al.* 1983).

V. THE OUTFLOW PHENOMENON

While the Orion region has received the most detailed scrutiny, the phenomenon of outflow around young stars has been increasingly recognized as extremely common. Bally and Lada (1983) have found evidence for such outflows in ∿ 35 regions of star formation. While most of the flows studied by Bally and Lada are driven by quite luminous stars, some are not. Beckwith, Natta and Salpeter (1983) argue that low mass stars are likely to produce the bulk of the flows. Indeed, a CO $J = 2 \rightarrow 1$ survey of relatively lower mass pre-main-sequence stars (T Tauri and related objects) in molecular clouds has found that ∿ 30-50% show evidence of outflow (Levreault 1983). Thus, outflow seems to be a nearly ubiquitous phase of early stellar evolution (*cf.* Genzel and Downes 1983). The majority of the flows show evidence for bipolarity, as a redshifted lobe in one direction is matched by a blueshifted lobe in the opposite direction. The classic example of a bipolar outflow is found in the dark cloud L1551 (Snell, Loren, Plambeck 1980). Apparently driven by an embedded infrared source of modest (30 $L_\odot$) luminosity (Beichman and Harris 1981), the redshifted and blueshifted lobes are very distinct and well-collimated. Several blueshifted Herbig-Haro objects are associated with the blueshifted CO lobe and proper motion studies indicate a transverse motion away from the central infrared source at velocities of about ∿ 150 km/s (Cudworth and Herbig 1979). Finally, Cohen, Bieging and Schwartz (1982) have detected a compact (∿ 2") radio continuum structure which is also elongated and aligned with the much larger CO flow structure.

While the velocity and other properties of the outflow vary considerably from source to source, systematic patterns suggest a common phenomenon as the ultimate source of the flows. For example, the mechanical luminosity in the flows ($L_{HVF} = 1/2\ MV^2/\tau$, where M is the swept-up mass, V is the velocity, and τ is the lifetime of the phenomenon), is an increasing function of L_*, the total stellar luminosity. While it is reassuring that $L_{HVF} < L_*$ in all cases, the mechanism for accelerating the flow is probably not radiation pressure. The required driving force ($F = \dot{M}V$) invariably exceeds that available from radiation pressure (L_*/c) by 10^2-10^3. Unless photons can be scattered 10^2-10^3 times before escaping, an alternative driving force must be found. While optical depths in some molecular clouds are high enough (*cf.* Phillips and Beckman 1980), the albedo is not sufficiently high to prevent degradation of optical and ultraviolet photons to longer wavelengths where they will quickly escape. The same arguments apply to those sources of outflow which have been identified by virtue of their 2 μm H_2 emission (*cf.* Beckwith 1981). Consequently, most outflows are attributed to stellar winds which are not driven by radiation pressure. The bipolarity may be explained as an intrinsic property of the wind or as an initially isotropic wind which is channeled by circumstellar (Snell, Loren, Plambeck 1980) or interstellar (Canto *et al.* 1981, Konigl 1982) disks. Even models for intrinsically bipolar flows make use of non-spherical geometry in the form of an accretion disk (Torbett 1983).

Leaving aside the details, it is quite clear that the bipolarity of the flows challenges the relevance of any spherically symmetric models of star formation. Rotation and magnetic fields are obvious choices for producing a favored axis, and the increases in magnetic field strength and rotational velocity that might accompany collapse make them likely candidates for the energy reservoir which drives the outflow. A model of rotationally driven winds has been proposed by Hartmann and McGregor (1982), while a model using magnetic bubbles produced by rota

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tion to drive the flow has been suggested by Draine (1983).Further theoretical effort can be expected; detailed predictions will be necessary for comparison with the increasing sophistication of the observational probes. More generally, the current situation indicates that rotation and magnetic fields will have to be included in any realistic hydrodynamical calculation of protostar formation, a daunting prospect given current limitations on computational power.

The apparent ubiquity of outflow from young objects may also have implications for some of the questions about large scale star formation. Norman and Silk (1980) proposed that stellar winds from stars in the T Tauri phase may provide sufficient energy to support a molecular cloud against overall collapse. They argue that the stellar winds stimulate the formation of other low mass stars and a feedback process produces a slow and steady rate of low mass star formation which avoids the extremes of cloud disruption of overall collapse. A criticism of this model is that it requires a very high density of T Tauri stars ($\gtrsim$ 10 pc^{-3}), but the much higher mass loss rates and forces ($\dot{M}V \sim 10^{-5}$ to 10^{-1} $M_\odot$ yr^{-1} km/s as opposed to 3 x 10^{-6}, as assumed by Norman and Silk) associated with the outflows revealed by CO and H_2 studies will decrease the required density. Taking a particular model for rotationally driven winds, Franco and Cox (1983) find that consistency with total galactic star formation rates of 5-10 $M_\odot$ yr^{-1} (*e.g.* Smith, Biermann and Mezger 1978) can be achieved if only 2 x 10^8 $M_\odot$ of the galactic molecular material ($\sim$ 10%) is contained in structures with a density $\sim 10^3$ cm^{-3}.

VI. IRAS RESULTS AND FUTURE PROSPECTS

The IRAS results are not yet available in any detailed form, but preliminary reports indicate several discoveries that will have a major impact on our understanding of star formation. In addition to providing a major catalogue of candidates for massive protostars, IRAS should locate many lower mass protostar candidates in nearby molecular clouds. For example, several very cold infrared sources have been located in B5 and the Chamaeleon I region. These are perhaps the best candidates for protostars in a very early infall phase. The discovery of remnant, cold dust around Vega addresses the other extreme of the evolutionary sequence -a main sequence star still intimately associated with substantial amounts of solid material. A follow-up study by Harvey, Wilking, and Joy (1984) confirms that the infrared source has a small angular size (46" ± 10"), which, at the distance of Vega, implies a radius of about 180 A.U. The low temperature of the grains then places a lower limit on their size of 20 μm. The Poynting-Robertson effect places and additional size limit; grains with radius a(μm) less than t_6 (the time since grain formation in 10^6 years) should have spiraled in to the central star. Thus, if Vega's age exceeds 10^7 years, the grain's diameter must exceed 20 μm (Harvey, Wilking, Joy 1984). Finally, the IRAS catalogue can serve as a major source of information for answering questions about the large-scale pattern of star formation in our galaxy.

Looking to the future, two major avenues for further investigation are evident. Essentially, they represent further application of the techniques of high spatial and spectral resolution discussed above. To advance both these efforts, large telescopes are important. Infrared speckle interferometry on a new generation of large ground-based telescopes (diameters from 7 to 15 m), which are planned for the next decade, will allow us to probe still smaller scales and assess the importance of binary systems in star formation. An alternative approach involves the use of several separated, preferably mobile, telescopes used as an interferometer. Large ground-based telescopes will also allow high spectral resolution studies of more protostar candidates to assess the generality of the phenomena associated with BN. The combination of high spectral resolution with speckle techniques (Dyck, Beckwith, Zuckerman 1983), when applied to the star formation problem, can provide a probe of protostellar structure in temperature, density, and velocity.

While much useful work can be done from the ground, infrared telescopes in space will be essential in developing a full understanding. The Shuttle Infrared Telescope Facility (SIRTF), being planned for the early 1990's, will provide still more sensitive photometric studies of star forming regions and, with appropriate instrumentation, detailed spectroscopic study of many more star forming regions like Orion. Still more exciting is the prospect of a Large Deployable Reflector (LDR), a large ($\sim$ 20 m) space telescope being planned for late in the next decade. LDR would achieve 1" resolution at 100 μm, bringing a wholly new clarity to the picture of star formation in our own and in other galaxies. Together with European efforts like ISO and FIRST, these space telescopes will revolutionize our understanding of star formation.

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DISCUSSION

Dottori: Does infrared astronomy say something about the upper masses limit and his relation with parameters of the clouds?

Evans: The ultimate upper limit to masses is not well studied by infrared astronomy but the shape of the high end of the mass function in a given cloud at the present time may be available with IRAS and follow-up data.

McCrea: Instead of the collapse of a single body of interstellar material, an alternative model of star formation is the accumulation of fragments of material. Some fragments would miss the condensation and so appear as in-falling and out-flowing material. Do you think that such a picture might fit the observations?

Evans: I know of no observations which would rule out such a picture.

Peimbert: Is it possible with IRAS to find out if star formation of low mass stars with respect to high mass stars is relatively larger in the interarm regions than in the spiral arm regions? Is there any evidence in this direction?

Evans: The IRAS catalogue may provide a good information on the mass function out to about 1 kpc, but future, more sensitive surveys may be necessary to really include spiral arm regions.

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