DISCUSSION FOLLOWING REVIEW BY P. THADDEUS

BOK: The globules that have been discussed today should always be referred to as "Barnard objects", so named after their discoverer, who photographed them one year before I was born.
It is cheerful to note that the masses from CO observations found by Robert Dickman agree rather well (to within 30%) with the minimum masses found from starcounts. It is most important to have near-infrared starcounts from IN photographic plates to faint limits to confirm the available minimum masses from starcounts. Photometrically calibrated starcounts from blue to near infra-red of the Southern Coalsack must be obtained with the 4-meter optical telescopes now in operation. Spectral counts - to supplement those of Westerlund (1960) - are also very much needed. Once these observations have been obtained, we shall optically be in a good position to list globule-like objects that deserve careful study by radio-molecular techniques.
There is every indication from starcounts that there is a dust concentration inside each large globule. The density varies at least as r^{-1} - possibly as r^{-2}. Infra-red counts and high-resolution CO observations are urgently required. Again the Southern Coalsack and its globule-like concentrations need to be studied with greatest urgency.

WERNER: With regard to the statement that all molecular clouds are CO clouds, this may be misleading because at least the ^{12}CO is optically thick and therefore one does not see into the cloud centers in this molecule. Perhaps the high optical depth effects may also account for the apparent absence of fragmentation seen in clouds mapped only in ^{12}CO. It would be interesting to know whether more evidence for fragmentation is seen in less optically thick molecular clouds.

DE JONG: I agree with Dr. Thaddeus that a lot of the molecules observed to date are not very useful to map molecular clouds. However, I would like to point out that as far as these molecules affect the thermal balance of the clouds they are of importance for the problem of star formation. When one goes deeper into a molecular cloud, cooling by CO lines becomes quenched because the cooling photons cannot get out. It may well be, in fact it is probable, that other molecules take over the cooling when one goes to greater densities and greater depths in these clouds. For instance OH and H_2O should be mentioned in this respect.

MICHEL: Could you tell me which proportion of the available C is condensed on grains (in the form of tars, oils, etc.) and which proportion is in CO?

THADDEUS: It is entirely possible that only a small fraction ($\lesssim$10%) of the available C exists in the form of CO and that the rest is incorporated in the grains (or in other molecules).

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HII regions, molecular clouds and young stellar groups.

PENZIAS: It seems to me that a consequence of shock-induced star formation is the location of all sites of such star formation on the same face of the molecular cloud. My impression is that this is generally true, but your map of the Cygnus X region may provide a counter-example. The complex contains both DR (obscured) and Sharpless (unobscured) regions. Can you recall an example of a molecular cloud with HII regions on opposite surfaces?

THADDEUS: The molecular cloud apparently connecting DR21 and DR23 is an obvious possible example, but the region is so complex that it is hard to be sure.

ELMEGREEN: Charles Lada and myself have noticed that OB stars tend to appear on one side of a molecular cloud for certain directions or longitude ranges in the Galaxy and that the stars and clouds appear superposed in other, orthogonal directions. This directivity agrees with our expectations from the spiral structure of the galaxy.

FIELD: You said that the Orion A cloud is rotating "end-over-end", implying a prolate shape. Can you rule out an oblate shape?

ELMEGREEN: With regard to the interpretation of the lower molecular cloud in Orion as a tumbling speroid, I would like to point out an alternative interpretation and that is of a cloud which is contracting along its length with a velocity in proportion to length. This is dynamically quite reasonable.

HABING: Concerning the association of HII regions and molecular clouds I should like to draw attention to a simple statistical test, originally proposed by Zuckerman, of the hypothesis that HII regions are usually on the outside of molecular clouds and consist of ionized gas that is flowing away from the molecular cloud. If the hypothesis is correct then one expects a velocity difference between that of the ionized gas, as derived, e.g. from the H 109α line, and that of the molecular cloud, e.g. that of the CO line. From the literature F.P. Israel in Leiden has collected a large number of radial velocity measurements and, indeed, the measured radial velocity differences $\Delta = V(H\ 109\alpha) - V(CO)$ range from -8 to +12 kms^{-1}. This point can be carried further by selecting only HII regions that are optically quite well visible and, apparently, are on our side of the molecular cloud. If one considers a histogram of Δ values for these HII regions one gets a very clear suggestion that on the average Δ is negative, i.e. the ionized gas is flowing off the dark cloud. While the data are not yet absolutely convincing, they are, in my opinion, sufficiently suggestive to draw your attention to them (F.P. Israel, Thesis, Leiden University, 1976).

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LADA: I would like to mention two interesting characteristics of OB associations and their related molecular clouds, which are illustrated by observations of M17, but may be important for many other associations as well. The first concerns the location of most recent star formation in the M17 complex and its orientation and relation to earlier epochs of star birth. Comparison of optical, infrared and millimeter-wave observations suggest that the "old", expanded cluster (NGC6618, Ser OB I) to the northeast of the M17 HII region, the newly discovered compact infrared cluster within the HII region, the ionization front at the interface between the HII region and the dense molecular cloud at the southwest edge of the HII region, and a string of maser and IR sources within the molecular cloud, are all related in a geometrical evolutionary sequence. In M17, star formation seems to have proceeded with time from the position of the "old" cluster through a previously more extensive molecular cloud, to the position of the masers and IR sources in the presently existing molecular cloud. This evolutionary sequence indicates that the formation of massive stars in M17 first started at the edge of a large cloud and has proceeded inward towards the center of the cloud or the other edge with time. This phenomenon is very similar to evolutionary sequences documented by Blaauw in 1964 for nearby associations (e.g. Orion, Sco-Cen, Cep OB III). The area of most recent star formation in M17 is delineated by a string of two H_2O maser groups and a near infrared source which are very close and aligned parallel to a strong ionization front located at the interface between the HII region and the molecular cloud. The intimate association of recently formed stellar objects and ionization fronts is also found in Orion, and in W3 where it is quite clear that a group of "massive" stars has recently formed directly ahead of an ionization front. In summary the site of star formation in M17 seems to have moved with time from the outer edge of a previously larger cloud inward to the position of an IR source and two masers located at the edge of the present molecular cloud. Most recent star formation has occurred very close to and directly ahead of an ionization front.

The second characteristic of the M17 complex that I would like to point out concerns the size of the molecular cloud. The existence of large OB associations such as Ori OB I and Sco-Cen which are nearly 100 pc in extent, implies that protostellar molecular cloud complexes of similar size should exist in the galaxy. In order to see if such a giant cloud was associated with M17, Bruce Elmegreen and I have attempted to find the true extent of the M17 molecular cloud. The results of this work were shown by Dr. Thaddeus earlier. We found that the molecular cloud extends southwest of the HII region for more than 85 pc and is aligned parallel to the galactic plane. The cloud contains roughly $10^6 M_\odot$ of molecular hydrogen with an average density of 10^3 H_2 cm^{-3}. We also find the cloud to contain a chain of 4 fragments of enhanced temperature and density, each of which may contain $10^5 M_\odot$ of material. The physical parameters of these fragments appear to represent the continuation of the evolutionary sequence described by the stars at the northeast end of the cloud. Since the separation of the fragments is similar to that of

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OB subgroups we suggest that each fragment can eventually be the site of a new OB subgroup. We also find that the fragments appear to be evolving on a time scale which is at least 6 to 10 times longer than the free-fall time for our derived densities. This may be due to the presence of internal magnetic fields of 4 to 10 x 10^{-4} Gauss.

In addition to M17, equally large molecular cloud complexes have been found to exist near Ori OB I and Cep OB III as reported at this conference by Dr. Thaddeus and Dr. Sargent. Thus the presence of extended molecular clouds near OB associations may not be a rare phenomena in our galaxy.

Finally, I would like to mention that the existence of such very large and massive molecular clouds suggests that the lifetime of molecular clouds is considerably longer than many now believe. This is well illustrated in the case of Orion. If the Ori OB I Association was formed from a single cloud complex, then the age of the presently existing molecular cloud at the southern edge of the association would be at least as old as the oldest members of the stellar association: the oldest OB stars in Orion are 10^7 years old. This age is about an order of magnitude higher than the estimated age of the molecular cloud of a few times 10^6 years suggested from arguments concerning both the expected free-fall time of the cloud and the time scale for turbulent dissipation obtained from analysis of observed line profiles. Thus the existence of large molecular cloud complexes implies lifetimes of at least 10^7 years for these objects.

In summary, observations suggest that OB associations may form from molecular clouds with extents of nearly 100 pc or more and masses near $10^6 M_\odot$

HABING: You imply that star formation progresses along strings of molecular clouds, which are parallel to the galactic plane. Is this progression always in the direction of galactic longitude or is there any other systematic behaviour of some kind?

LADA: The progression of old stars to young stars to molecular cloud seems to be parallel to the galactic plane in all the associations we have examined. In addition, in all these 7 associations, the directionality of the old to young sequence appears to be correlated with the expected direction of propagation of the spiral density wave at the location in the galaxy of the association in question.

DE JONG: Is there any evidence that the M17 molecular cloud is rotating, like in the case of the Orion molecular cloud discussed by Thaddeus?

LADA: There is a velocity gradient of about 1 km s^{-1} across the entire cloud (~85 pc). The sense of this gradient is opposite to that of galactic rotation. Whether or not this is due to rotation is of course difficult to determine.

SOLOMON: The large size of the extended M17 cloud which you observe is

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an important result. In our CO survey covering lattitudes $-1.4^{o}<b<1^{o}$, We have seen this same feature extending from $\ell = 12^{o}$ to $\ell = 16^{o}$ at $b = -0.5^{o}$; this cloud may even be larger than your map indicates. These extremely large features (Giant Molecular Clouds) are probably the major contribution to the overall galactic CO emission.

PISMIS: I should like to report on a region which is neither an association nor a large, extended region, but one where we encountered indication that the formation of HII condensations has occurred in successive epochs. The region I refer to consists of three small HII regions, S254, S257 and S255, aligned, at similar declination. Each of these regions has a centrally located star which is the source of its excitation. This "triple" nebula was included in our program of Fabry-Pérot interferometry. The interferometric Hα velocities from three interferograms yielded quite similar velocities. The common kinematic distance, based on the Schmidt curve was obtained as 2.5 kpc. Photoelectric photometry in UBV of the exciting stars was also performed. The photometric distances of the stars agreed surprisingly well with the kinematic distances of the HII regions, indicating thus that the three objects belonged to the same cloud complex. The photometry of the stars showed further that the extinction suffered by the exciting star in S254 ($A_V = 1.92$) was plausibly interstellar but that the excess extinction in S257 and S254 (0.72 and 1.56 magnitudes respectively) originated in the HII regions themselves; while S254 is optically thin, S257 and S255 contain a large amount of dust. The density of the dust thus increases along the line joining the three nebulae. Incidentally, the density of dust in S255 is estimated to be twice that in S257. If we add to this variation of dust content the fact that molecules, such as OH, H_2O and CS, are observed in S255, which also has an associated IR source, we may conclude that S255 is the youngest of the three HII regions. Next comes S257, while S254 at the other extremity is the oldest. Thus the three nebulae which presumably were formed out of the same gas cloud, are at different evolutionary stages. (A full report of this work will appear shortly in Astrophysics and Space Science).

LOREN: In a recent paper (Snell and Loren, 1976, Ap.J. in press) the few observed cases of self-reversed CO line profiles have been used as a test of the line formation models that have been suggested. Large-scale motions either collapse (Goldreich and Kwan, 1974, Ap.J. 189, 441) or expansion could dominate the line formation or turbulence might be the dominant effect (Zuckerman and Evans, 1974, Ap.J. (Letters) 192, L149).

The model presented here is meant to apply only to those molecular clouds in which a clear self-reversed CO feature is present. These clouds have several observed properties in common: (1) In all cases the lowest velocity CO feature is more intense than the highest velocity CO feature, (2) the velocity of the relative minima of the CO profile is at a higher velocity than the centre of rest velocity of the cloud as meas-

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measured by the ^{13}CO line or the lines of CS, HCN or the 2mm lines of H_2CO, V_{DIP} (CO) > V_{PK}(^{13}CO), (3) the self-reversal occurs at the position of greatest CO line broadening (with the possible exception of ρ Oph where no noticeable line broadening is seen), (4) while a self-reversed CO line could be produced by the presence of a foreground cloud this seems unlikely in these clouds since the angular extent of the self-reversal is very small, being largest for the closest cloud (ρ Oph) and smallest for the most distant (W3), (5) the limited angular extent of the self-reversal is coincident with the position of greatest excitation of CS, HCN and the 2mm H_2CO lines, (6) for a self-reversal feature to occur, the layer of gas producing the reversal must be colder than the core of the molecular cloud. Thus no stellar heating source can exist on the near side of the molecular cloud and an examination of the Palomar sky survey shows no extensive emission from an HII region within the antenna beam width in which the self-reversal is seen, (7) comparing the profiles from object to object shows that the weakest ^{13}CO line corresponds to the broadest CO line (W3) and the strongest ^{13}CO line is found associated with the narrowest CO line (ρ Oph).
The observed positive difference of V_{DIP}(CO) - V_{PK}(^{13}CO) indicates that the layer producing the self-reversed feature is moving towards the dense core and suggests collapse rather than expansion. As a result of these observations a line formation programme written by R. Snell was used to produce CO and ^{13}CO line profiles in a collapsing molecular cloud model in which the velocity law chosen was not the $V \alpha r$ used by Goldriech and Kwan, a model which cannot produce self-reversal features since the curves of constant line-of-sight velocity do not have multiple crossings of the line-of-sight. Instead a velocity law with $V \alpha r^{-\frac{1}{2}}$ was used. This velocity law is that which Larson (1972, MNRAS 157, 121) finds for non-homologous collapsing protostars and one which matches the observed variation of velocity extent of the CO profiles. This velocity law does have multiple positions along the line-of-sight which have the same radial velocity and thus a self-reversal can arise in the front half of the cloud, provided there is a decrease of the excitation temperature away from the cloud center.
It was found that in a model in which only collapse was present (no turbulence) self-reversed CO features were produced at a velocity greater than that of the centre of rest velocity. The calculated ^{13}CO profiles will not match the observations unless a turbulent component is present, in addition to the collapse in the centre of the cloud to produce a singly-peaked profile rather than a double-peaked profile. With this composite model of collapse and turbulence, but with collapse still dominant, all of the above observations are readily explained. As one observes away from the line of sight to the centre of the cloud, the self-reversal disappears, largely because of the geometry of the spherical collapse. The extent of the CO line broadening depends on the mass of the cloud. While the presence of self-reversed CO profiles in the five clouds presented here indicates a non-homologous collapse with $V \alpha r^{-\frac{1}{2}}$, this should not be considered a general model of line formation for all molecular clouds.

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ZUCKERMAN: Dr. Loren has suggested that observed asymmetries in self-reversed ^{12}CO profiles in 4 molecular clouds, (NGC 1333, Mon R2, ω3 and ρ Oph), suggest that these clouds are collapsing. I would suggest that alternative scenarios are still possible, based on existing data. In ρ Oph there is no increase in line-width at the position of self-reversal, which seems unlikely for most collapse models (e.g. $v \alpha r^{-\frac{1}{2}}$ or $v \alpha r$). In ω3 and Mon R2 6 cm H_2CO absorption profiles exist, which suggests that at least two separate clouds having different radial velocities exist along the line-of-sight to the HII regions. In each case one of these clouds could add ^{12}CO emission to an otherwise symmetrical, self-reversed ^{12}CO profile from the other cloud to produce a profile which mimics that expected from a collapsing cloud. Dr. M. Werner points out that the closer of the two ^{12}CO clouds should not be very optically thick or it will block the radiation from the background cloud. NGC 1333 is apparently a complicated situation and Dr. Loren has written a paper about it called "Colliding Molecular Clouds". Thus the observational situation regarding self-reversed profiles is unclear at present. Mrs. Sargent has observed an OB association (Cepheus OB3) which shows a similar asymmetry (suggesting collapse) but NGC 2024, according to Dr.A. Penzias, and NGC 2071, according to Dr.C. Lada, show the opposite asymmetry.

LOREN: In the ρ Oph cloud, the lack of observed CO line-broadening (Encrenaz, private communication) is, as indicated by Snell and Loren, the result of the lower mass of the ρ Oph complex and thus the greater relative importance of turbulence.
The Mon R2 cloud shows a 6cm-H_2CO line profile with two velocity features (Downes et al., 1975, Astronomy and Astrophysics 44, 293). One velocity coincides with the centre-of-rest velocity (10.5 km s^{-1}) while the other velocity at 8.0 km s^{-1} lies distinctly below the peak CO velocity feature at 9.5 km s^{-1}. The H_2CO results are consistent with the $v \alpha r^{-\frac{1}{2}}$ collapse model presented above.

A. SARGENT: Zuckerman has suggested alternative interpretations of the data presented by Loren. It still seems likely that in Cepheus OB3 the broadened profiles of both ^{12}CO and ^{13}CO, which show the self-reversal minimum of ^{12}CO shifted to a more positive velocity than the maximum of ^{13}CO, are indicative of collapse. Unfortunately 6cm H_2CO observations do not exist for this region.

LADA: Our CO observations also show a similar self-reversed CO profile toward the source NGC 2071. However, the absorption line is on the blue side of the line of symmetry of the CO profile.

A. SARGENT: To elucidate the relationship between star formation and molecular clouds, CO has been searched for and found in regions of recent star formation. The clouds observed are extremely large; in the case of the associations Cepheus OB3 the cloud is $\sim 1\frac{1}{2}^{\circ}$ x $2\frac{1}{2}^{\circ}$, corresponding to ~ 20 x 30 parsecs in size.
Extensive mapping in the 115 GHz line of ^{12}CO and partial mapping in the

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110 GHz line of ^{13}CO has been carried out. Additional observations at selected positions were made in the 140 GHz line of H_2CO. At three positions (A, B and C) the usual signposts of star formation (enhanced temperature, broadened lines, etc.) are seen. Like others that we have seen this afternoon, this cloud is considerably extended parallel to the galactic plane.

While slightly higher velocity components contribute to the cloud over extended areas, the "hotspots" occur around either -12.0 km/sec or -10.7 km/sec. The mean radial velocity of the Cepheus OB3 stars is -11 km/sec (Garmany, 1973), confirming an association between the stars and the cloud.

^{13}CO measurements indicate strong local density enhancement in the regions A, B and C. Further evidence of this is the observation of the 140 GHz line of H_2CO at these locations. At one position (Cep-A) high resolution profiles demonstrate that the ^{12}CO lines are self-absorbed, the velocity of the self-absorption minimum being more positive than the velocity of the ^{13}CO peak temperature. Following the arguments of Snell and Loren (1976), this is taken to be evidence for the presence of a centre of collapse. A comparison of the $T_A*(^{12}CO)$ and $T_A*(^{13}CO)$ contour maps for Cep-A defines the region of self-reversal, the $T_A*(^{13}CO)$ peaking over an area where $T_A*(^{12}CO)$ falls off dramatically. There is slight evidence for similar self-reversal at Cep-C, but absolutely none at Cep-B, the hottest spot in the cloud with $T_A*(^{12}CO) = 26$ K. The typical mass of a subgroup within an OB association is $\sim 10^3 M_\odot$. Thaddeus has already discussed the uncertainties in density and hence mass estimates made from ^{12}CO and ^{13}CO observations. Taking these into account, the masses of Cep -A, -B and -C are still such that each may be a potential subgroup. It is interesting to note that the separations of Cep -A, cep -B and Cep -C, being of the order of 10pc, are not incompatible with this suggestion, since the centres of the optically visible subgroups are separated by 12pc (Garmany, 1973).

When the $T_A*(^{12}CO)$ contours are superimposed on the PSS in the region of the Cepheus OB3 association, there is excellent agreement between the dusty regions and the areas covered by the contours. The HII region immediately adjacent to Cep-B is S155, whose $v_{LSR} \simeq -15$ km/sec (Georgelin and Georgelin, 1970) places it at the same location as the cloud. An N plate centred on 8300 Å shows a very faint ridge of nebulosity lying between the HII region and the 10 K contour line west of Cep-B. Nebulosity is also present to the north-west of the 15 K contour of Cep-A. It is unfortunately impossible to determine from inspection of the PSS blue and red plates and the available N plate whether or not the nebulosity contains stars.

It is anticipated that further investigation of these regions at infrared wavelengths will be carried out in the immediate future and their nature may become clearer. However, even at this stage it is evident that the association and its related cloud are still active regions and may be an excellent site for comparison of observations with the recent theoretical descriptions of the evolution of star forming regions.

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ELMEGREEN: I would like to discuss a theoretical proposal for the formation of extended OB associations. Consider a situation similar to that near M17, where a cluster of OB stars lies at the edge of a large (25pc x 85pc) molecular cloud which has an average hydrogen density of around 10^3 cm^{-3}. We are concerned with the future evolution of the molecular cloud.

At first, an ionization (I) front - isothermal shock (S) front system will advance into the cloud due to the Lyman continuum radiation of the OB cluster. The material that accumulates between the I and S fronts will eventually become unstable to gravitational collapse when it reaches a threshold column density. A new generation of stars is assumed to form at that time. The time and distance over which the shock travels before this instability occurs, depends almost entirely on the pre-shock (molecular cloud) density, although there is a slight dependence on the Lyman continuum output of the shock-driving OB cluster. For a moderate density of 10^3 cm^{-3} and for a typical photon output of OB subgroups, the age separation of stellar generations will be between 2 and 3 million years and their spatial separation will be between 10 and 20 parsecs.

It is important now to determine the nature of the new star cluster, which is assumed to form from the unstable shocked layer. Two factors lead us to suspect that this will be another OB cluster. In the first place, the total mass of the shocked material at the onset of the gravitational instability will be several thousand solar masses in a 3pc by 3pc area (for the typical parameters used above). This is sufficient for the formation of a cluster of stars rather than a single star. Secondly, the mass of each star is likely to be high. This follows from a qualitative argument which compares the physical conditions in the shocked gas to those far ahead of the shock, in the molecular cloud: the temperature of the gas nearest the HII region will be largest due to the more intense photon heating of grains (and the subsequent grain heating of the gas) in the vicinity of the I front. A slight turbulence in the decelerating shocked layer will also increase the root mean squared velocity there, simulating a higher temperature. Since the mass of a protostar which is optically thick to cooling radiation (and is therefore subject to further collapse without severe fragmentation) depends sensitively on the gas and grain temperatures, protostars near the I-front are likely to be more massive (by factors of perhaps 10 to 100) than those which form deep in the cool molecular cloud. Thus we suspect that the gravitational collapse of the shocked layer will lead to a new cluster of OB stars.

Once the shocked layer becomes unstable, stars will form rapidly (10^5 years) due to the high density of the shocked gas (10^5cm^{-3} to 10^6cm^{-3}). Their compact size allows them to become detached from the influence of gaseous pressure forces and they will drift out of the front of the shock as the shock recedes from the original OB cluster and therefore decelerates. Since the O stars will generally reach the main sequence before they emerge, they will first form compact HII regions and/or IR sources in the dense shocked layer. This may be the current stage of evolution in the main component of W3. When they emerge into the

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molecular cloud, their HII regions will become less dense and larger. After a relatively short time, the new HII regions will drive a shock back into the dense layer out of which stars formed, and this layer will disrupt due to non-uniform pressures or to a Rayleigh-Taylor instability. This disruption may have already occurred near the compact IR cluster in M17. A second I-S front will now advance further into the cloud, possibly causing the formation of another OB cluster.

Several observed characteristics of star formation result as a by-product of this simple model. (1) The mass of the OB cluster which forms in the shocked gas is very insensitive to the Lyman continuum luminosity of the OB cluster, which drives the shock (the total mass varies as the 1/5 power of this luminosity for a plane-parallel shock propagating into a homogeneous cloud). Thus cluster masses will rapidly converge in successive generations to a (theoretically) constant value which weakly depends on the molecular cloud density. OB subgroups in large associations (e.g. Orion) indeed appear to have similar masses for similar separations (i.e., indicating a relatively constant preshock density). (2) The part of the shock which most readily forms stars is that which moves parallel to the magnetic field (B) in the cloud. This is due to the relatively smaller magnetic inhibition to gravitational collapse in the part of the compression parallel to B. The alignment of subgroups in large associations is always roughly parallel to the galactic plane, which is also the expected orientation of B in the large (50pc - 100pc) primordial molecular clouds. (3) Observed OB cluster expansion is best explained by shock-induced star formation rather than by the gradual collapse and fragmentation of a cloud. Cluster expansion in the present theory can be caused by shock divergence or by variable shock velocity. Inhomogeneities in the preshock density, turbulence in the primordial cloud and other sources of inhomogeneous shock velocities may be combined to give the observed expansion velocities. (4) Several observational arguments support the idea that O stars and those of much lower mass may be formed by independent processes. Our theory of shock-induced O star formation is consistent with the formation of small mass stars ($9M_{\odot}$) by the gradual fragmentation and collapse of the molecular cloud far ahead of the shock. Then, ionization-shock fronts which assist the independent formation of O stars, can clear away the material which would otherwise obscure these lower mass stars from view.

MICHEL: What is - in your theory - the physical mechanism that determines the protostellar masses behind the shock?

ELMEGREEN: The present theory only incorporates a qualitative difference between the masses of protostars that may be formed far ahead of the ionization-shock front, in the molecular cloud, and those formed in the shocked gas. We rely on the fact that the temperature of the gas nearest the HII region is likely to be higher than that deep in the molecular cloud due to the infrared heating of grains near the HII region. Since the mass of a protostellar object depends sensitively on its temperature, we infer that the most massive protostars will occur nearest the ioniza-

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tion front. Another means of increasing the root mean squared velocity of gas in the compressed layer compared to the unshocked part of the molecular cloud (in addition to a thermal increase) is by the mild (subsonic) turbulence which will occur as the layer continuously decelerates. This will also tend to increase the protostellar masses in the shocked layer compared to those far ahead of the shock.

CUDABACK: What do the molecules have to do with your process, other than indicating high density?

ELMEGREEN: Nothing.

ZUCKERMAN: You suggested that the relatively more massive stars would tend to form near ionization fronts. In Orion at least this seems to be true, if the Kleinmann-Low infrared cluster is compared with the infrared cluster in OMC-2. The former cluster is apparently located within a few tenths of a parsec of the Trapezium, whereas OMC-2 is a parsec or more away. The K-L cluster contains more massive young and/or proto-stars than does OMC-2. It would be valuable if infrared and radio astronomers could search for other examples of this sort near nearby HII regions (say within 1 kpc). NGC 6334 might be a good candidate.

DE JONG: This morning we have heard about the distribution of molecular clouds in the Galaxy and we have heard typical sizes and separations of these clouds quoted of about 5pc and about 800pc, respectively. This afternoon several people have reported detailed observations of some molecular complexes and the sizes of these objects are observed to be about one order of magnitude larger, about 50pc. Could anybody tell me what the relation of these two kinds of molecular clouds is and, if they are the same objects, how should I understand the apparent difference?

SOLOMON: Most molecular clouds in the Galaxy do not have HII regions. The clouds which are being discussed this afternoon such as M17 and Orion have been mapped and studied specifically because they have HII regions. This is an observational bias that exists for much of the early work on molecular lines and is due to the availability of radio continuum positions. Our survey of CO emission in the Galaxy (Scoville and Solomon Ap.J. 199, L 105 (1975), Solomon et al. Ap.J., in press) shows that only a small fraction of Giant Molecular Clouds have known HII regions. The exact size distribution of the clouds has not yet been determined, but many of the clouds have r>>10pc. I agree with Thaddeus that the size of r = 5pc used by Burton for modelling is too small.

BLAIR: We have made a search for new sites of ongoing star formation using Hα emission nebulosity as a guide. The J = 1→0 transition of $^{12}C^{16}O$ (115 GHz) is used as a temperature probe of the structure of these regions and thus as an indicator of the position of heating sources

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embedded in these molecular clouds. Of the 60 Hα regions surveyed, 30 distinct areas of CO emission enhanced in one or more localized areas have been detected. Several are very strong molecular emission sources and some appear to be quite simple in structure compared to the giant molecular cloud /HII region complexes most commonly discussed in the literature. Hence giant molecular clouds need not be associated with giant HII regions. A search for high-density cores of these new regions was made using three transitions of the abundant isotope of H_2CO. The column density of $^{13}C^{16}O$ (110 G Hz) was used as a rough guide for the formaldehyde survey. Compact high density cores were found in six candidate regions with H_2 densities estimated to be greater than 10^4-10^5 cm^{-3}. At least five of the six high density regions found in the formaldehyde survey contain embedded infrared sources and exhibit H_2O maser emission. The infrared sources were found by mapping at 2.2μ. For two of the new molecular clouds, S140 and S255, sufficient data are available to assess the relative importance of various heat inputs to the clouds. Each cloud contains only one embedded source, while there are two nearby external stars. The gas kinetic temperature contour maps, obtained from detailed $^{12}C^{16}O$ observations are then used to predict the dust cooling through far-infrared radiation and gas cooling through $^{12}C^{16}O$ radiations. The predicted far-infrared emission greatly exceeds the cooling by molecular lines in both cases. In the case of S140 the far-infrared emission is expected to be of the order 10^4 $L_\odot$ from the central 50 (arc min)^2 region and should be observable in the far-infrared. Finally, we note that, in the case of the S140 molecular cloud, the embedded infrared source is almost certainly responsible for the heating of the cloud although to account for the predicted far-infrared radiation, a bolometric luminosity exceeding ten times that observed from 1-20μ is required.

MESTEL: Is it so unreasonable that there should sometimes be giant molecular clouds without associated giant HII regions? Would one expect an HII zone before the first OB stars have formed in the molecular cloud, induced e.g. by the passage of the galactic shock? Perhaps the different observers are looking at clouds at different stages in their history.

BLAIR: I don't believe anyone really knows yet what the mass of a molecular cloud has to do with the number and/or types of stars which form out of it. In the early molecular line surveys of giant HII region complexes it was often inferred in the literature that these giant clouds were the primary centers of active star formation in the Galaxy. Now we know that these observers were biased toward the most obvious signposts of "protostellar" activity. We cannot yet estimate the evolutionary state of these various molecular clouds. However, if the giant molecular clouds without giant HII regions are younger than those with, that would indeed lend support to the idea that the most massive stars are formed late in the evolution of a molecular cloud.

KERR: With regard to de Jong's remarks on the differences between the

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CO clouds discussed this morning and objects such as M17 and also Blair's lack of giant HII regions, we should remind ourselves that the solar neighbourhood may well be different from the inner region of the Galaxy. The shock will be weaker, and so the sizes of the clouds may be different. Also giant HII regions are not likely to be produced in the solar neighbourhood.

BURTON: The galactic plane CO surveys have not produced a measure of the characteristic clump size, because the survey is under-sampled. The modelling which we have done used clumps of 5pc diameter; such model clumps fill the beam over most of the Galaxy. Because of under-sampling and because the clumps are opaque, the synthetic profiles are not very sensitive to clump size if the beam is filled. (The specific value of 5pc was found, by indirect arguments, to be a characteristic scale of HI absorbing clouds by Baker and Burton, Ap.J. 198, 281, 1975). Quantities relating to the individual clumps which do follow from the galactic plane surveys are: the average line-of-sight separation of clumps, d>800 pc, a characteristic velocity dispersion of a clump, $\sigma_c = 2.5 \mathrm{kms}^{-1}$, and a measure of the line-of-sight peculiar motion of the clumps, given by the velocity dispersion of 4 kms^{-1}.

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