CONTINUUM OBSERVATIONS OF THE INFRARED SOURCES IN THE ORION MOLECULAR CLOUD

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The details of the processes which result in the formation of new stars are still virtually entirely obscure. Surprisingly little can be said with any assurance beyond the general view that the interstellar medium collects in large clouds, involving at least tens of solar masses, which then fragment into smaller pieces which proceed to collapse into individual stars. Numerous highly detailed theoretical predictions have been generated for the sequence of events expected in the fragmentation and collapse processes. However, the meager observational evidence we have on suspected young objects is fascinatingly at variance with these predictions.

The goal is obviously to understand the formation of stars of all masses. The formation of massive stars is particularly attractive for observational analysis. The large expected luminosity of young massive stars makes them accessible to detailed observation even at relatively large distances.

Further, massive stars appear to form in relatively large complexes which have stars in a wide range of evolutionary stages. One of the brightest of the objects thought to be in the early phases of massive star formation is the Becklin-Neugebauer-Kleinmann-Low complex near the Orion nebula.

The first observations of what we now know as the infrared manifestation of the Orion molecular complex were made by Becklin and Neugebauer (1967). They discovered an infrared point source apparently embedded in the Orion Nebula. This point source is commonly referred to as the BN object. Shortly after their discovery observations at longer wavelengths by Kleinmann and Low (1967) revealed a complex extended 20 micron nebula associated with the BN object. The common designation for this region is the KL nebula. To simplify matters we will refer to the region as the BNKL complex, since it seems clear that the entire region is an active region of star formation.

C. G. Wynn-Williams and D. P. Cruikshank (eds.), Infrared Astronomy, 179–186.

The infrared complex is now understood to be intimately involved with a dense molecular cloud. Although it is commonly referred to as the center of the cloud the exact relationship of the infrared sources to the molecular cloud is not yet clear. It is prudent not to allow overly symmetric models of the region to dominate our analysis of the object.

Our new observations of the BNKL complex were obtained with the Wyoming Infrared Observatory (WIRO) 2.3 meter telescope. The method of observation differed substantially from previous infrared maps of this region. The secondary of the WIRO telescope is controlled in position via the central computer system; this allows scans in the direction of chopping to be accomplished without driving the telescope. For the BNKL observations the chopping was in the direction of declination. The throw of the secondary was either 64" or 80" for the observations reported here. Thus there were no corrections applied to the data for signal in the reference beam. The signals from the detectors, germanium bolometers, were amplified and sampled every 5 ms by the computer, which then generated estimates of the signal for each chop of the secondary mirror. This allows single declination scans to be completed quickly. At a chopping frequency of 10 Hz a segment 60" long can be sampled every 1.0" in 6.0 seconds. After a declination scan, the telescope is moved the sampling spacing in Right Ascension and another scan of the secondary initiated. From this process, which is entirely automatic and digital, an "image" of the region is recorded. This technique has been described by Grasdalen et al. (1979).

The advantages of this proceedure are 1) the data do not require complex corrections for the negative beam; they are taken in a total power mode, 2) the image is obtained rapidly; a typical time for the accumulation of a frame is less than ten minutes; thus drifts in telescope position, detector sensitivity and sky conditions are minimized, and 3) since the data are entirely digital the reduction of the material can be handled in impersonal ways.

In Figure 1 we present a contour map of the 20 micron flux from the BNKL region derived from observations with a 3".5 beam. There are a number of condensations visible in the region. The positioning of the map has been derived from offsets from θ^1C in the Trapezium region; it depends only on the position of that star given in the SAO catalog. By comparing individual frames of the BNKL region we can estimate the positions of these condensations and the expected errors in their positions. The repeatability of the positions within the BNKL region is extraordinary; relative positions within the complex are stable to a fraction of an arc second. The results of these determinations are given in Table 1. The source IRc 6 in Table 1 refers to the extended patch of 20 micron emission nearly detached from the main nebulosity.

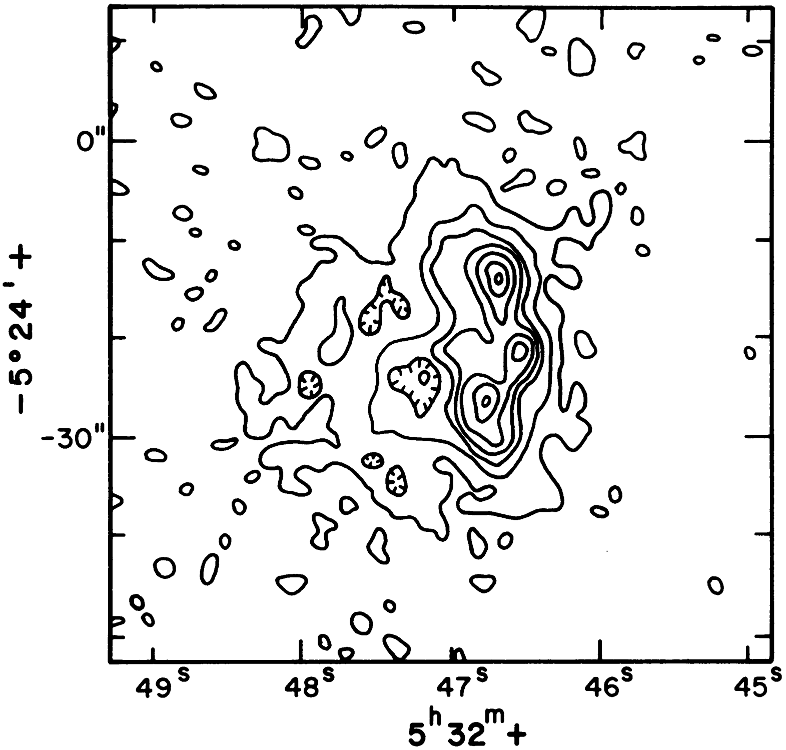

Figure 1. Contours of 20 μm emission from the BNKL complex. The beam was 3".5 in diameter.

In general the positions of the condensations agree quite well with those derived by Rieke, Low and Kleinmann (1973). In Figure 2 we have superposed their 20 micron contours on the WIRO map. However, we do not see a condensation in the position of IRc 5, the southernmost of their condensations. The reason for this descrepancy is not yet clear. The most tantalizing possibility is that this difference represents a real temporal change in the BNKL region. The region is undoubtedly related to the early phases of stellar evolution. Rapid and extreme variability is a common feature of well-studied optical pre-main-sequence objects. Thus it is reasonable to watch carefully for variability in this extreme region. During the past year we have been monitoring this region; as yet we have not seen any indications of variability. It is possible that the discrepancy with the older material is an artifact of the complex data analysis procedure required in the early days of infrared astronomy. In our maps of the BNKL region, there is a tongue of emission extending from IRc 4; this may have been displaced by Rieke, Low and Kleinmann into the separate source IRc 5. Until this region has been monitored for several more years this situation is unlikely to be completely resolved.

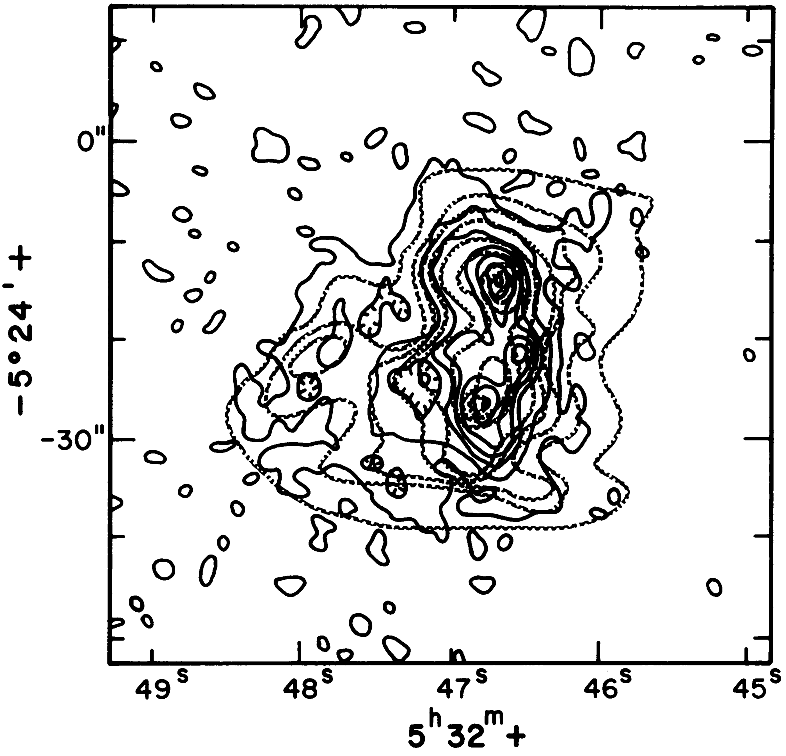

Figure 2. The WIRO 20μm observations with the 20μm contours derived by Rieke, Low and Kleinmann (1973) superposed.

Table 1
SOURCE POSITIONS IN THE BN-KL COMPLEX

	$05^h\ 32^m$ +	-5°24'
BN (IRc1)	46.68	15.9"
IRc2	46.98 ± 0.02	23″.4 ± 0.3
IRc3	46.58 ± 0.02	23.2 ± 0.3
IRc4	46.79 ± 0.02	27.8 ± 0.3
IRc6	47.7 ± 0.07	23 ± 1

Position errors are relative uncertainties with respect to BN. The absolute uncertainty in the position of BN is 0″.5 in each coordinate.

The BN object is known to exhibit a strong absorption feature near 10 microns, presumably due to silicate absorption (eg. Gillett and Forest 1973). Recently Aitken et al. (1980) have reported spectral scans of the two sources IRc 2 and 4, both of which show very strong absorption features Rieke et al. (1973) diagnosed the presence of these features from the photometric behavior of the sources between twenty and five microns. Using an array spectrometer system we have mapped the region in six wavelength bands which cover the silicate absorption feature. The optical and detector system has been described by Gehrz, Hackwell and Smith (1976). When used on the WIRO 2.3 meter telescope the system has beam sizes of 3″.5. The important feature of the instrument is that the spectral observations are made simultaneously through the same focal plane aperture. The contour maps derived from these observations are presented in Figure 3. From these maps we have derived photometry for the individual condensations. The energy distributions of the condensations are plotted in Figure 4. From this plot it is immediately obvious that the depth of the silicate feature in the BN object is relatively weak for the regions. Aitken et al. (1980) have in fact suggested that the apparently fainter sources in the KL nebula are the primary energy sources for the region. Examination of the contour maps reveals that the silicate extinction overlies the entire nebulous region. There is no evidence for an emission component with the characteristics of the Trapezium region: silicate emission peaking near 10.5 microns. Conservatively estimating the extinction to the diffuse component of emission as 30 magnitudes in the

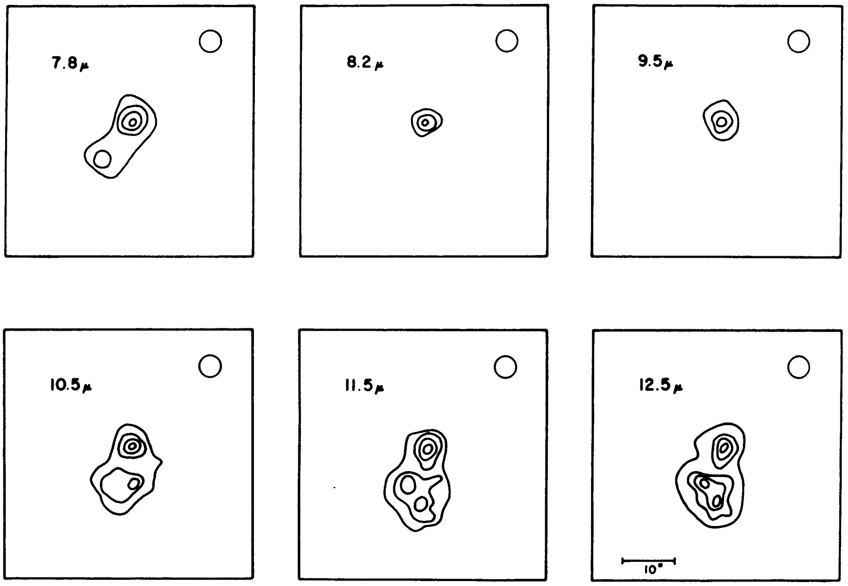

Figure 3. The array spectrometer data obtained for the BNKL region. The beam size is shown by the circle in the upper right of each panel.

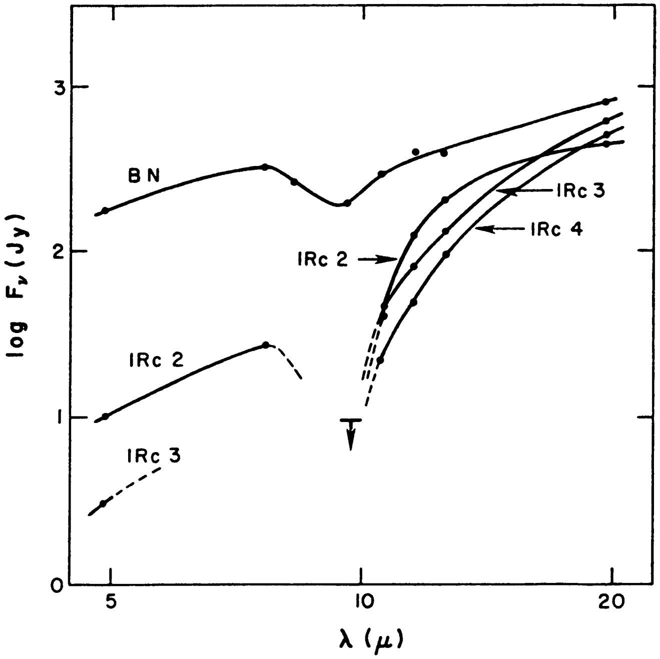

Figure 4. The mid infrared energy distribution for the four most prominent condensations in the BNKL complex.

visual we obtain a lower limit comparable to the extent of the nebula. The condensations are embedded in very dense material.

The similarity between the spectral behavior of the condensation and the surrounding nebula raises the question of the nature of the condensations. From photometric observations we cannot rule out the possibility that the condensations are not small stellar objects but dense knots in the nebula. For the BN object the angular diameter measurements of Sibille, Chelli and Lena (1979) demonstrate the object is less than 0.10" in diameter.

The region contains a number of radio molecular sources. One of the most interesting of these is the SiO maser source. The position of this source and IRc 2 agrees within the reported errors. There are also a large number of H_2O maser sources in this region (Genzel and Downes 1977, Genzel et al. 1980). A number of these appear to cluster near the condensation IRc 4 and run nearly along the tongue of 20 micron emission extending south and west from that source. As the positional uncertainty of the two wavelength regions improves we can expect further improvement in the relationship between the infrared sources and the radio sources. Currently the relationship is suggestive that the two types of observation may refer to the same physical object, but the case is not yet closed. There may only be a close relationship between the regions, not complete coincidence.

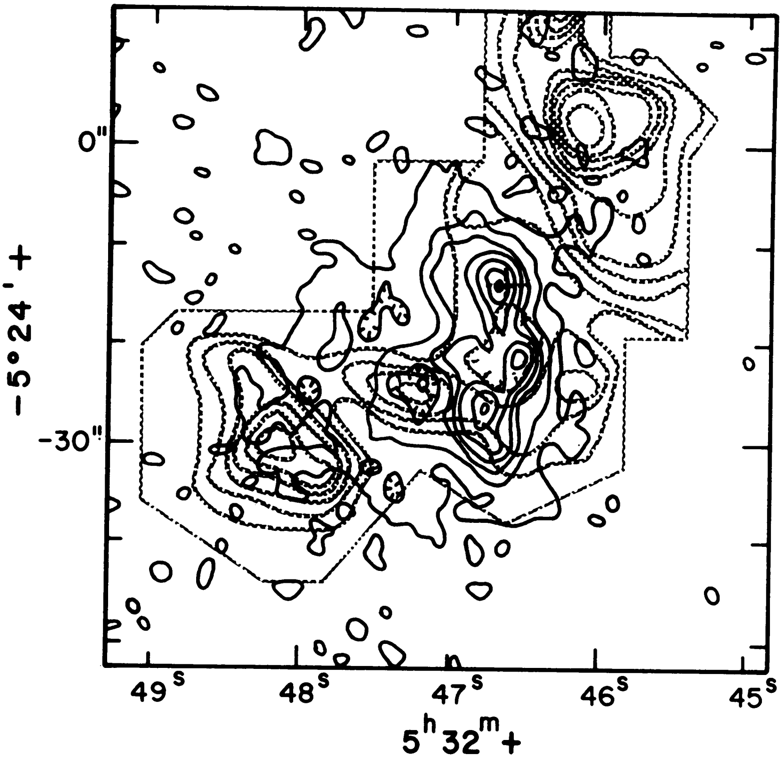

Figure 5. The WIRO 20μm observations with the contours of H_2 quadrapole emission line given by Beckwith et al. (1978) superposed. Note the strong anti-correlation of thermal dust emission and H_2 line emission.

The molecular hydrogen emission in the BNKL region has also presented a difficult case of interpretation. There have been no clear associations between the molecular hydrogen emission and other types of observation. (Gautier et al. 1976, Beckwith et al. 1978). From our 20 micron map we find a remarkable anti-correlation between the H_2 emission and the 20 micron flux. This is illustrated in Figure 5 where the contours of H_2 emission from Beckwith et al. have been superposed on the 20 micron map. The simplest interpretation would be to ascribe the reduction of intensity of the H_2 emission in regions of high 20 micron flux to the obscuration of overlying material. This would imply that the H_2 emission must lie behind the BNKL complex. Since the H_2 emission is due to shocked gas this geometry is attractive. It is difficult to see how substantial flows of energy could propagate through the dense material lying between us and the BNKL complex. If however the condensations lie on the far side of the obscuring material a relatively clear space might well exist on the far side of the complex. The situation would be almost exactly turned around from the currently accepted picture of the Trapezium region, in which the clear zone is believed to face us.

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Editors' Note: The record of the discussions which followed the several papers on the Orion Molecular Cloud have been combined and follow Scoville's review in this volume.