Mon. Not. R. astr. Soc. (1981) **197**, *Short Communication*, 17P–21P

Discovery of a protostar in the Large Magellanic Cloud

Ian Gatley *United Kingdom Infrared Telescope, Hilo, Hawaii*
E. E. Becklin *Institute for Astronomy, University of Hawaii, Honolulu, Hawaii*
A. R. Hyland and T. J. Jones *Mount Stromlo and Siding Spring Observatories, Australian National University, ACT, Australia*

Received 1981 September 9; in original form 1981 June 4

Summary. A near infrared search of the H II region/molecular cloud complex N159 in the Large Magellanic Cloud has revealed a very red (H–K = 2.1, K–L' = 2.7) compact object. The location, brightness, colour and 2.1–2.4 μm spectrum of this source suggest that it is very young, and similar to the galactic infrared 'protostars'.

This is the first identification of an infrared protostar in an external galaxy. Its discovery provides direct evidence of current star formation in the Large Magellanic Cloud, and suggests that regions of star formation in external galaxies will appear similar to those in the Milky Way.

1 Introduction

Over the last decade a picture of typical galactic sites of OB star formation has emerged from radio continuum, molecular line, and infrared observations (e.g. Habing & Israel 1979) as follows. Star formation occurs in massive molecular clouds. Large, well-formed, optically visible H II regions reside near the cloud edge; their exciting stars have largely emerged from the cloud in which they formed. Deeper in the cloud are found the compact H II regions, often accompanied by OH maser emission. Dynamical arguments show that these objects represent a very early stage in the life of an OB star. Finally there is an apparently younger population of objects deep within the molecular cloud, the so-called infrared 'protostars', typified in the literature by the BN source in Orion and by NGC 7538, IRS 1 and IRS9 (Werner *et al.* 1979).

The three generations described here, diffuse visible H II region, compact H II region, and protostar, are often found together in a complex whose characteristic size is a few parsecs. The galactic region NGC 7538 is a typical example where the diffuse optical H II region 2 pc in diameter lies at a projected distance of 3 pc from a cluster of compact H II regions and 4 pc from a protostar.

The molecular emission is most intense near the location of the young objects. The presence of all or most of the indicators of star formation usually implies that a near infrared search of an area a few parsecs in size will reveal infrared protostars (Werner, Becklin & Neugebauer 1977; Beichmann, Becklin & Wynn-Williams 1979).

The Large Magellanic Cloud is the nearest galaxy to the Milky Way in which the processes of star formation may be studied in some detail. It is also known to have undergone a radically different evolutionary history from that of the Galaxy (see, e.g. van den Bergh 1975; Hardy 1978). In an overall sense, the present rate of star formation in the LMC appears to be similar to its average rate over the last 10^{10} yr, but the picture differs markedly from region to region. In the bar of the LMC, it is thought that major star formation ceased some 4×10^7 yr ago (van den Bergh 1975) while in other regions (such as 30 Doradus) star formation has clearly been occurring until very recently ($\sim 10^6$ yr ago) (Hyland, Thomas & Robinson 1978; McGregor & Hyland 1981), in conditions of low density compared with galactic star formation regions (Werner *et al.* 1978).

Thus, although dark clouds are present in the LMC, it is not clear that the processes of star formation there will follow the same pattern as in the Milky Way. Freeman (1977) has pointed out that the young blue globular clusters in the LMC are not only to be found in the outer regions of the Cloud, but must also have been formed in low density regions by a mode unlike that found in the Galaxy.

The aim of this experiment is to determine if there are sites of star formation in the LMC which can be adequately described by the observational picture built up in the Galaxy. Specifically, scaling the observed appearance of NGC 7538 to the distance of the LMC (46 kpc, de Vaucouleurs 1980) leads us to expect protostars in the brightness range $K = 11-14$ mag to be found within about 30 arcsec of the optical H II region. In this paper we present the results of a very limited search for such protostars in the Large Magellanic Cloud (LMC).

The search was centred on N159, an H II region (McGee, Brooks & Batchelor 1972) with bright far-infrared emission (Werner *et al.* 1978), the only identified source of molecular emission at present (Huggins *et al.* 1975), OH maser emission (Caswell & Hayes 1981) and H_2O maser emission (Scalise & Braz 1981) in the LMC; no accurate positions yet exist for the maser sources. This search revealed two objects brighter than $K = 13.5$, one of which is identified as a protostar.

2 Observations

All the observations presented in this paper were made using the 3.9-m Anglo-Australian Telescope and the Infrared Photometer-Spectrometer. A region 1 arcmin square centred at α (1950) = $5^h 40^m 23^s.6$, δ (1950) = $-69° 46' 29''$ was searched at a wavelength of 2.2 μm (K) to a limiting magnitude of $K = 14$. For the two sources brighter than $K = 13.5$ revealed by this search, multi-aperture photometry at wavelengths of 1.2 μm (J), 1.65 μm (H), 2.2 μm (K) and 3.8 μm (L') and 2.1–2.4 μm CVF spectroscopic data were subsequently obtained. Finally a region 20×25 arcsec ($\alpha \times \delta$) containing the protostellar candidate was mapped at 1.2 μm (J) and 2.2 μm (K) with 3.5 arcsec resolution in DC mode, that is, without spatial chopping, in order to investigate the contributions from diffuse nebular radiation associated with N159. Positions were measured from the details of the AAT, and should be accurate to 2 arcsec (Straede & Wallace 1976).

3 Results

The positions and photometric magnitudes of the two sources found in the search are given in Table 1. The errors are ± 0.05 mag at all wavelengths except L', where the error is

Table 1. Infrared sources in N159.

Source	Beam size (arcsec)	1950 Coordinates h	m	s	°	′	″	*J*	*H*	*K*	*L′*
Field star	5	5	40	21 .4	– 69	46	52	15.70	13.90	13.19	–
Protostar	3.5	5	40	26.4	– 69	46	54	16.69	14.21	12.11	9.4
Protostar	10							15.88	13.81	11.90	–

± 0.10 mag. The infrared colours of both these objects are much redder than typical LMC stars (e.g. McGregor & Hyland 1981; Glass 1979). Comparison of the *J, H, K* colours with, for example, highly reddened galactic field giants (Hyland & Jones 1980) shows that one of the two objects, which we refer to as 'the field star', is in all probability an LMC field giant suffering an extinction $A_v \sim 10$ mag. This extinction is much larger than the galactic foreground reddening of $A_v = 0.33$ (de Vaucouleurs, de Vaucouleurs & Corwin 1976) and is presumably caused by dust within N159.

The second object, which we refer to as 'the protostar', has an intrinsically red colour corresponding to a blackbody temperature of 850 K.

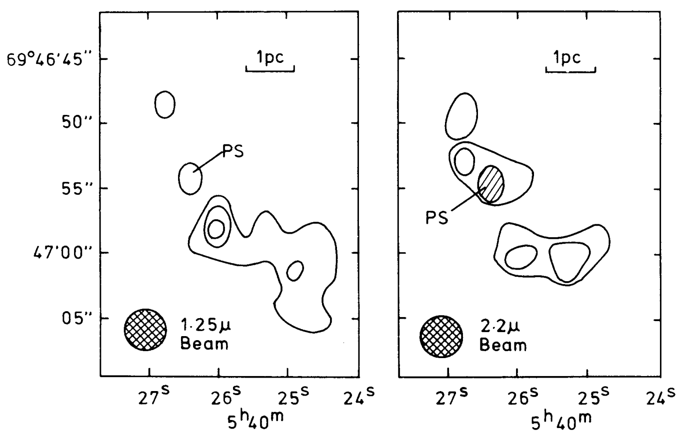

Figure 1. Maps of the vicinity of the LMC protostar at *J* (1.25 μm) and *K* (2.2 μm). The contour interval is 0.37 mJy at *J* and 0.63 mJy at *K*; the hatched area at the position of the protostar at *K* corresponds to an additional 13 contours.

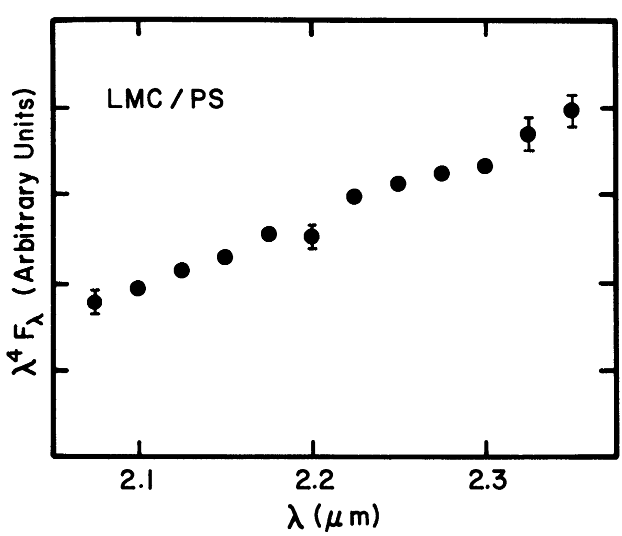

Figure 2. The 2.1–2.4 μm CVF spectrum of the LMC protostar with 2 per cent spectral resolution obtained through a 5 arcsec diaphragm.

Fig. 1 shows maps of the vicinity of the protostar at 1.2 μm (J) and 2.2 μm (K). There is conspicuous nebulosity apparent at the shorter wavelengths presumably associated with the nebula N159. Multiaperture photometry (Table 1) confirms that the extended emission is much bluer in colour than the protostar. Plate 1 is an enlargement of the central region of N159 taken from a short exposure IV N plate. The box corresponds to that covered by the maps in Fig. 1, and the + indicates the approximate location of the protostar. Fig. 2 shows the 2.1–2.4 μm spectrum of the protostar with 2 per cent resolution. The spectrum is red and featureless; in particular neither Bγ emission nor CO absorption is present.

4 Discussion

The region N159 was chosen for the present search as the most likely site of current OB star formation because it exhibits the 'signposts' of H II, molecular, maser, and far-infrared emission which characterize star formation in the Galaxy. A very limited search for protostars of an area in N159 ($\sim 12 \times 12$ pc in size at the distance of the LMC) has revealed an infrared source of the brightness, colour and spectral appearance anticipated by scaling arguments. This itself is strong evidence that the source is indeed a protostar, which is further supported by the following consideration.

There is no known population of objects in the LMC which occupy the same position in the *H, K, L* diagram as the source. The presence of extended blue emission, presumably reflection nebulosity, and the large extinction deduced for the field star, show that N159 contains a great deal of dust. The observed colour of the source (in particular the large excess at 3.8 μm(L')) is, however, not consistent with reddening of any star which does not possess a significant circumstellar shell. Furthermore, given the distance modulus of the LMC of 18.6 mag (de Vaucouleurs 1980), the absolute L' magnitude of the protostar is $M_{L'} = 9.2$, and given the fact that N159 is clearly a very young region, any reddened star hypothesis is constrained to invoke an *M* supergiant or a $> 20 M_\odot$ Be supergiant (Allen & Glass 1976) as the underlying star. The absences of CO absorption and Bγ emission in the spectrum (Fig. 2) preclude these possibilities.

The present data are therefore consistent with the identification of the LMC source as a protostar with properties similar to NGC 7538, IRS 9 and IRS 1. The observations provide only a lower limit to the bolometric luminosity of the protostar because of the large unknown contribution at longer wavelengths. A conservative extrapolation suggests $L > 2 \times 10^4 L_\odot$, which is only a small fraction of the total luminosity ($\sim 10^6 L_\odot$) of the complex (Werner *et al.* 1978) as measured in the far infrared. Further work will be required to establish the nature of the source in detail, but following the model provided by galactic studies further, we may confidently expect that the 'protostar' will in fact turn out to be a cluster of objects (Beichman *et al.* 1979; Lonsdale *et al.* 1982).

The present result shows that one LMC region (N159), whose physical characteristics are typical of galactic star formation regions, also possesses an infrared object with protostellar characteristics. The picture of star formation built up by studies within the Galaxy thus does appear to describe at least one mode of star formation within the LMC.

5 Future work

As this study has covered only a very small area ($\sim 10^{-5}$ of the surface area of the LMC), it is important to extend the studies of this and other H II regions in the LMC, to determine whether this is statistically a major mode of star formation within the LMC, or merely an isolated event within the Cloud.

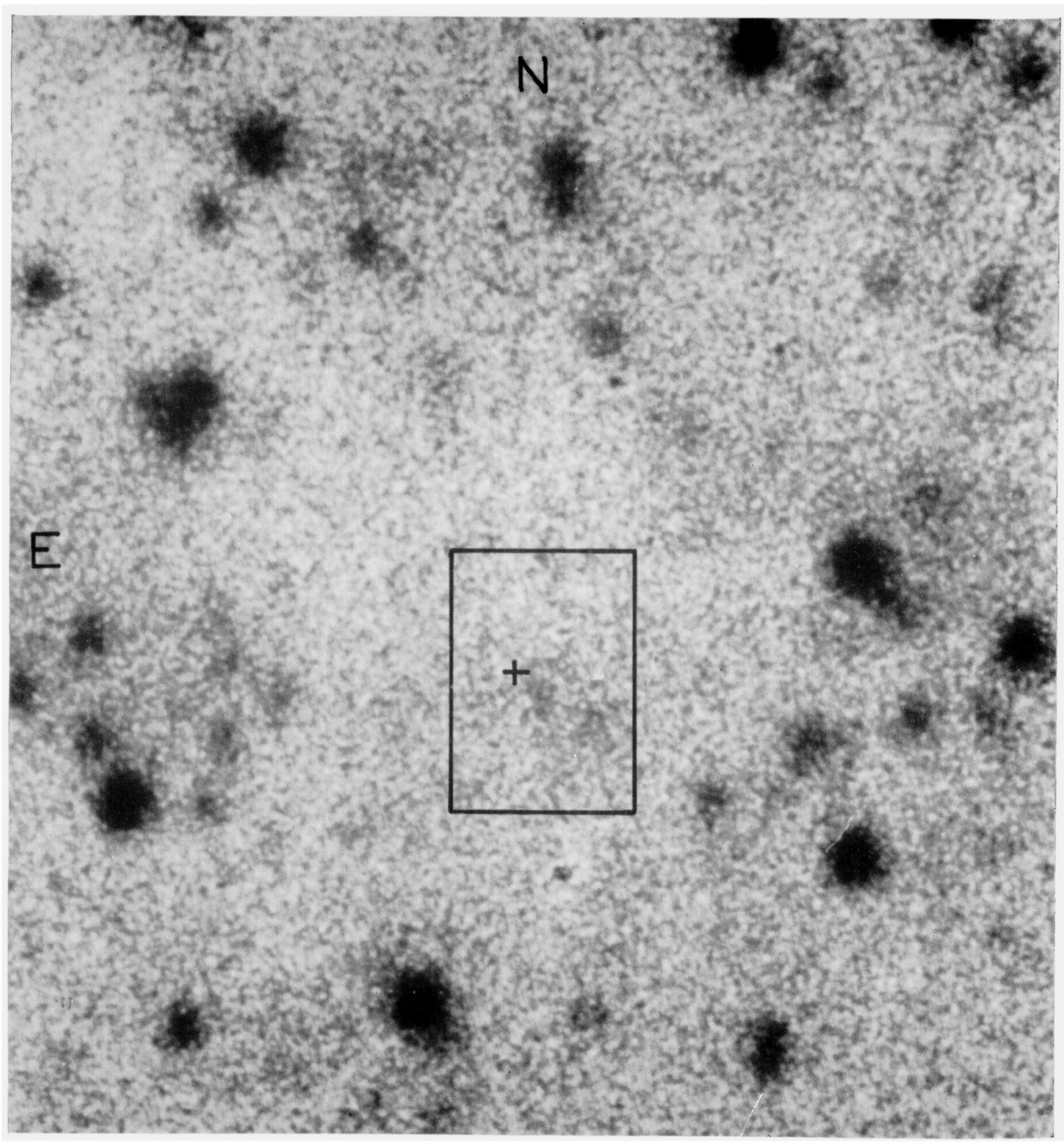

Plate 1. Enlargement of a section (centred on N159) of a short exposure IV N plate ($\lambda_0 \sim 8000$ Å). The rectangular box corresponds to the region mapped in the IR (Fig. 1). The + indicates the approximate location of the protostar, just north-east of a patch of nebulosity within the central observed area of the H II region.

[*facing page* 20P]

Several other areas for future study are suggested by the result of this work. Determination of accurate positions for the maser sources in N159 will show whether the infrared protostar is the location of the masers. Studies at longer infrared wavelengths can determine the total bolometric luminosity of the protostar, and possibly find more deeply embedded protostars. Complete searches at near- and far-infrared wavelengths offer the exciting possibility of studying the whole population of young stars in an external galaxy, and of establishing the distribution of material in the molecular clouds out of which the stars have formed.

Acknowledgments

We thank PATT and ATAC for allocation of telescope time, and the staff of the AAT, especially Dr D. A. Allen and Mr S. Lee, for help at the telescope. The manuscript was prepared by Mrs R. M. Gerke. The IV N plate was kindly supplied by the UKSTU of the ROE. This work was supported by the Royal Observatory Edinburgh, by NASA contract NASW-3159 and by Mt Stromlo and Siding Spring Observatory.

References

Allen, D. A. & Glass, I. S., 1976. *Astrophys. J.*, **210**, 666.
Beichman, C. A., Becklin, E. E. & Wynn-Williams, C. G., 1979. *Astrophys. J.*, **232**, L47.
Caswell, J. L. & Haynes, R. F., 1981. *Mon. Not. R. astr. Soc.*, **194**, 33P.
de Vaucouleurs, G., 1980. *Publs astr. Soc. Pacif.*, **92**, 579.
de Vaucoulerus, G., de Vaucouleurs, A. & Corwin, H. G., 1976. *Second Reference Catalogue of Bright Galaxies* (*RC2*), University of Texas Press, Austin.
Freeman, K. F., 1977. *The Evolution of Galaxies and Stellar Populations*, eds Tinsley, B. M. & Larson, R. B., Yale University Observatory.
Glass, I. S., 1979. *Mon. Not. R. astr. Soc.*, **186**, 317.
Habing, W. J. & Israel, F. P., 1979. *A. Rev. Astr. Astrophys.*, **17**, 345.
Hardy, E., 1978. *Astrophys. J.*, **223**, 98.
Huggins, P. J., Gillespie, A. R., Phillips, T. G., Gardner, F. & Knowles, S., 1975. *Mon. Not. R. astr. Soc.*, **173**, 69P.
Hyland, A. R., Thomas, J. A. & Robinson, G., 1978. *Astrophys. J.*, **83**, 20.
Hyland, A. R. & Jones, T. J., 1980. *Mon. Not. R. astr. Soc.*, **192**, 359.
Lonsdale, C. J., Becklin, E. E., Gatley, I., Lee, T. J. & Stewart, M. J., 1982. In preparation.
McGee, R. X., Brooks, J. W. & Batchelor, R. A., 1972. *Aust. J. Phys.*, **25**, 581.
McGregor, P. J. & Hyland, A. R., 1981. *Astrophys. J.*, submitted.
Scalise, E., Jr. & Braz, M. A., 1981. *Nature*, **290**, 36.
Straede, J. O. & Wallace, P. T., 1976. *Publs astr. Soc. Pacif.*, **83**, 792.
van den Bergh, S., 1975. *A. Rev. Astr. Astrophys.*, **13**, 2.
Werner, M. W., Becklin, E. E. & Neugebauer, G., 1977. *Science*, **197**, 723.
Werner, M. W., Becklin, E. E., Gatley, I., Ellis, M. J., Hyland, A. R., Robinson, G. & Thomas, J. A., 1978. *Mon. Not. R. astr. Soc.*, **184**, 365.
Werner, M. W., Becklin, E. E., Gatley, I., Matthews, K., Neugebauer, G. & Wynn-Williams, C. G., 1979. *Mon. Not. R. astr. Soc.*, **188**, 463.