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TWO YOUNG BRIGHT INFRARED OBJECTS

MARTIN COHEN
Cambridge University Observatory and University of Minnesota

AND

N. J. WOOLF
University of Minnesota
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ABSTRACT

Infrared photometric observations between 2μ and 22μ are reported for LkHα-101 and LkHα-190.[1] LkHα-101 is currently the brightest infrared source known at the center of a cometary nebula. The spectral distribution is a broad peak resembling a blackbody of $\sim 750°$ K but with excess emission to longer wavelengths, and depressed to shorter wavelengths.

Lick Hα-190, a recently brightened object photometrically resembling the FU Ori phenomenon, is about 4 mag fainter than LkHα-101 at 3–5 μ, but is equally bright at 20 μ. The energy distribution from 2 to 5 μ is interpreted as a reddened continuum. A double-peaked structure at 10 and 20 μ is interpreted as a moderately thick silicate shell at $\sim 110°$ K.

I. INTRODUCTION

During a systematic survey of the Caltech Infrared Catalog (Neugebauer and Leighton 1969), Cohen and Dewhirst (1970) identified the source IRC+40091 with the central region of the galactic nebula NGC 1579. At the center of this nebula is a seventeenth-magnitude emission-line star LkHα-101 (Herbig 1956). This object appears to be the only cometary nebula bright enough to occur in the 2-μ sky survey.

The star LkHα-190 occurs in the North America Nebula (Herbig 1958). It was originally sixteenth photographic magnitude, but in late 1969 it began to brighten to about tenth magnitude over 200 days (Welin 1971). Currently it is staying near this brightness and has an A1-type spectrum with Hα in emission (Herbig and Harlan 1971). Photometric observations by Brooke (Strom 1971) out to a longest wavelength of 3.5 μ showed it to be a bright infrared source.

II. LICK Hα-101

The observations of LkHα-101 were made on the 30-inch telescope of the University of Minnesota O'Brien Observatory with a ten-filter photometer with a germanium bolometer. These were made in October 1970 over three nights, with a further night to search for a possible extended source around the object.

The broad-band filters had effective wavelengths of 2.3, 3.8, 4.8, 8.6, 10.8, 12.2 and 18 μ. The beam diameter was 26″, and it was noticed that at this diaphragm size the source appeared somewhat fainter than in the CIT catalog, and therefore the source was also observed at 3.8 μ with a 90″ beam but with no significant difference in brightness compared with the smaller beam. Thus the source is apparently smaller than 26″ diameter. In this respect it differs from the Becklin-Neugebauer, Kleinmann-Low object in the Orion Nebula which has pronounced wings at wavelengths near 2 μ, and an angular diameter greater than 30″ at 20 μ.

The observations in Table 1 and Figure 1 also show a difference from the Orion object in that the 20-μ flux of LkHα-101 is very much smaller. Otherwise, from 2 to 12 μ the

[1] LkHα-190 = V1057 Cygni.

TABLE 1

OBSERVATIONS OF LICK Hα-101 WITH 26″ DIAMETER BEAM (1970 October)

λ(μ)	Magnitude	λ(μ)	Magnitude	λ(μ)	Magnitude
2.3......	+3.3	8.6......	−2.1	12.2......	−2.5
3.8......	+0.1	10.8......	−2.4	18........	−3.7
4.8......	−0.5				

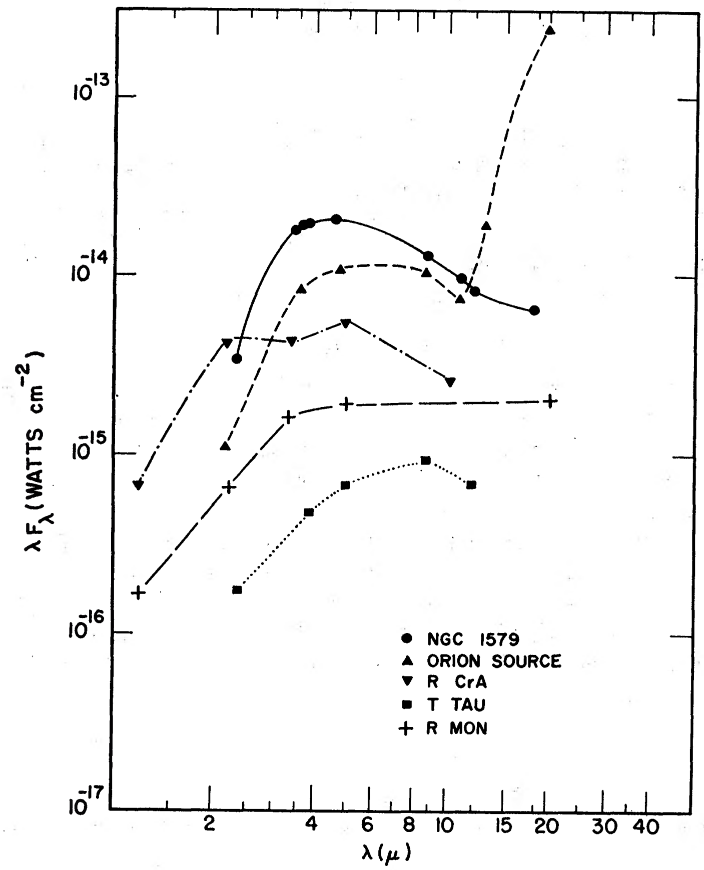

FIG. 1.—Observations of LkHα-101 compared with related objects (see text)

similarity of the energy distributions is striking. It is tempting to conclude that the similarities are due to the fact that both objects have a small optically thick dust shell. The difference would then have to be that the Kleinmann-Low extended object scatters the radiation of a basically small source, thus producing short-wavelength wings as well as producing the extra 20-μ emission. Herbig (1971) has commented on the optical spectral similarity to η Car. In the infrared these objects appear quite different, with the shell around η Car being far cooler (Westphal and Neugebauer 1969; Ney 1971).

NGC 1579 around LkHα-101 is a cometary nebula. Mendoza V. (1968) has also observed the nuclei of three cometary nebulae—R Mon, R CrA, and T Tau. Observations of these objects are also plotted in Figure 1. The observations for T Tau are our own; those for R Mon are from Low and Smith (1966); for R CrA, from Mendoza V.; and for the Orion object, they are by Ney (unpublished). The energy distributions for R Mon, R CrA, and T Tau are very much flatter than for LkHα-101. Radially extended shells or multiple shells appear necessary to explain these other objects.

The distance of LkHα-101 has been estimated by Herbig (1971) as at least 800 pc. The shell radius would be greater than 40 a.u. For this distance, the integrated luminosity so far observed corresponds to 25000 $L_\odot$; i.e., it is brighter than $M_{\rm bol} = -6$. This luminosity is far brighter than that of the comparison objects. Low *et al.* (1970) give luminosities of Becklin's object 1000 $L_\odot$, R Mon 890 $L_\odot$, and T Tau 24 $L_\odot$. The spectral behavior seems to be continuous despite the dispersion in luminosity.

Lick Hα-101 links the Orion object, where there is no visible star, to the other objects where the star is relatively bright in the optical region. This is consistent with the interpretation of the infrared energy distributions of the sources. For LkHα-101 and the Orion object the shell is optically thick in the infrared and visual, whereas for the other objects the shell is partially transparent. This variation among the objects need not necessarily be an evolutionary effect, since there should also be some aspect differences if the luminosity source is at the center of a flattened distribution of dust.

III. LICK Hα-190

Lick Hα-190 was observed on the new 60-inch telescope of University of Minnesota and University of California, San Diego, at Mount Lemmon Infrared Observatory, Arizona, with a twelve-filter photometer. Observations were made over three nights in March 1971.

The broad-band filters for these observations had effective wavelengths of 2.2, 3.7, 4.8, 8.6, 10.8, 11.3, 12.6, 18, 20, and 22 μ. The beam size was 11″.

The observations are given in Table 2 and Figure 2. In the figure they are compared with the spectral distribution of the Trapezium star θ^1C Ori obtained by Strecker (1971) and FU Ori by Mendoza V. (1968) and Geisel (1970).[2] The 10- and 20-μ emission of the Trapezium is by silicate dust, as demonstrated by the discussion of Maas, Ney, and Woolf (1970). The spectral distribution of the shell around LkHα-190 is rather similar to that of the Trapezium. It differs in that at the short wavelengths the rise toward the visual is far less pronounced in LkHα-190. And although the two peaks at 10 and 20 μ appear, they are broader in LkHα-190, as though indicating appreciable optical depth at 8.5 μ. A similar effect for shells around cool evolved M stars has been reported by Gehrz and Woolf (1971).

TABLE 2

OBSERVATIONS OF LICK Hα-190 WITH 11″ DIAMETER BEAM (1971 April)

$\lambda(\mu)$	Magnitude	$\lambda(\mu)$	Magnitude	$\lambda(\mu)$	Magnitude
2.2.......	+4.7	10.8......	−0.3	18........	−2.7
3.7.......	+3.9	11.3......	−0.5	20........	−2.5::
4.8.......	+3.2	12.6......	−0.4	22........	−3.2
8.6.......	+0.8				

[2] *Note added in proof.*—Preliminary observations of FU Ori in the 10–20-μ region show silicate double emission bands, but weaker than in LkHα-190.

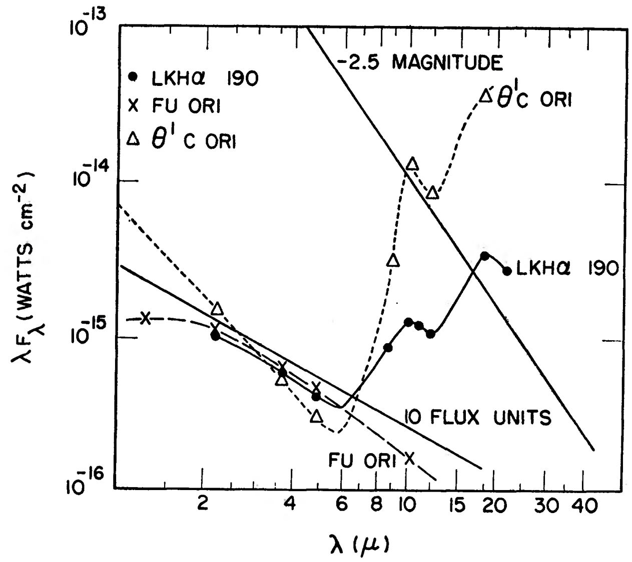

FIG. 2.—Observations of LkHα-190 compared with related objects (see text)

The interpretation of the short-wavelength continuum would be possible in terms of seeing the stellar continuum at 2–5 μ, or in seeing a free-free emission spectrum, or even perhaps a particular type and distribution of dust. The spectral appearance of Hα in emission with an A1-type absorption spectrum resembles the Be stars where Woolf, Strittmatter, and Stein (1971) showed that the near-infrared continuum was produced by free-free emission. The similar values of $F(\nu)$ from 2 to 5 μ for LkHα-190 would permit this interpretation to be applied to this object.

The infrared spectrum of FU Ori, however, has a very similar continuum from 2 to 5 μ, and so any interpretation for LkHα-190 should also be appropriate for it. If the continuum is stellar, then the absorption at V is about 6 mag. If, however, it is free-free emission, the absorption could be about half this.

The distance to LkHα-190 is unknown. Dr. W. Luyten has kindly measured the proper motion from Palomar Schmidt plates taken before the outburst. The motion is not observable to a measuring uncertainty of $\pm 0''.015$ P.A. Thus the object could be in the North American Nebula at a probable distance $\sim$500 pc (Herbig 1958). At this distance the visual magnitude, corrected for absorption, would be -2.5 to -5.5 depending on the assumptions about the origin of the 2–5-μ continuum. If we attempt to estimate the bolometric magnitude from the 10–20-μ infrared continuum, we find that a blackbody placed through the peaks of the silicate emission would have a temperature of 110° K, a diameter of 5″ corresponding to 1200 a.u., and a bolometric magnitude of -3.6. The mass of silicates in fine particles required to give the optical depth is $5 \times 10^{-5}\,\mathfrak{M}_{\odot}$, and if the ratio of gas to dust is normal, the gas in the shell would total 0.12 $\mathfrak{M}_{\odot}$. In this unusual environment, the particles might well not all be small, and the ratio of gas to dust could be abnormal, casting doubt on both these figures.

Both FU Ori and LkHα-190 seem to differ from the objects discussed with LkHα-101 in the likely absence of dust close around the star. Clearly, photometric observations of more objects are needed to substantiate this conclusion. However, the propagation of light signals to reflection nebulae at the times of outbursts are consistent with this interpretation. And then it becomes crucial to question whether the clearing of a dense inner shell has been responsible for the optical variation.

The Kelvin time scale for a change of the complete star would, for situations with hydrostatic support, be typically $\sim 10^4$ years. On the other hand, a shell such as that around R Mon or LkHα-101 has a gravitational time scale of some hundreds of days. Therefore, on a crude theoretical basis, dissipation of a shell would appear more likely.

Herbig, on the other hand, comments on the severe change of the stellar spectrum from pre- to post-outburst. He points out that this would seem to be more compatible with a change of the star. However, there are some indications of absorption features in both VY CMa and R Mon that are being produced in an extended shell, as seen by the nebular reflection spectrum having stronger absorption lines and bands. In consequence, a change of spectral appearance is not, as such, totally incompatible with the assumption that all the variation is caused by the shell. Model-atmosphere calculations could perhaps verify or explode this hypothesis. If it is accepted, it would seem to indicate that a state like LkHα-101 precedes one like LkHα-190. Or possibly the growing of a shell and the shell's then dispersing is a cyclic phenomenon.

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REFERENCES

Cohen, M., and Dewhirst, D. W. 1970, *Nature*, **228**, 1077.
Gehrz, R. D., and Woolf, N. J. 1971, *Ap. J.*, **165**, 285.
Geisel, S. L. 1970, *Ap. J.* (*Letters*), **161**, L105.
Herbig, G. H. 1956, *Pub. A.S.P.*, **68**, 353.
———. 1958, *Ap. J.*, **128**, 259.
———. 1971, *ibid.*, **169**, (in press).
Herbig, G. H., and Harlan, E. A. 1971, *Inf. Bull. Var. Stars*, No. 543.
Low, F. J., Johnson, H. L., Kleinmann, D. E., Latham, A. S., and Geisel, S. L. 1970, *Ap. J.*, **160**, 531.
Low, F. J., and Smith, B. J. 1966, *Nature*, **212**, 675.
Maas, R. W., Ney, E. P., and Woolf, N. J. 1970, *Ap. J.* (*Letters*), **160**, L101.
Mendoza V., E. E. 1968, *Ap. J.*, **151**, 977.
Neugebauer, G., and Leighton, R. B. 1969, *Two Micron Sky Survey, A Preliminary Catalog* (Washington, D.C.: NASA).
Ney, E. P. 1971, private communication.
Strecker, D. W. 1971, private communication.
Strom, S. E. 1971, private communications.
Welin, G. 1971, *Astr. and Ap.*, **12**, 312.
Westphal, J. A., and Neugebauer, G. 1969, *Ap. J.* (*Letters*), **156**, L45.
Woolf, N. J., Strittmatter, P. S., and Stein, W. A. 1970, *Astr. and Ap.*, **9**, 252.