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PHOTOGRAPHY AT 9400 Å OF INFRARED AND MOLECULAR LINE SOURCES

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ABSTRACT

Photographs with an S-1 image tube at an effective wavelength of 9400 Å have been obtained for five northern infrared sources. These photographs show objects which do not appear on the Palomar Sky Survey red plates, and which in some cases agree well in position with infrared components of OMC-2, Mon R2, Sh 269, NGC 7538, and OH 0739 − 14. The case of OH 0739 − 14 is particularly striking. We have found a bright, barlike nebulosity which agrees in position with known infrared and molecular sources. At one end of this bar is a very red stellar object.

Subject headings: infrared: sources — instruments — interstellar: molecules — nebulae: general

I. INTRODUCTION

Photography with an S-1 image tube in the 0.8–1.1 μm spectral region bridges a gap between the relatively new techniques of infrared photometry and the more classical methods of visual photometry and spectroscopy. Areas of the sky that are suspected of containing sources of infrared radiation can be surveyed rapidly and to a relatively deep level. The detection of a very red object in the 1 μm region would provide sufficient reason for detailed observations at longer wavelengths and serve as a guide to sources for which more classical observations can be obtained. For example, measurement of [S III], He, and H lines and/or the detection of continuous emission in the 0.8–1.1 μm region can indicate the presence of ionized gas and starlight. Some deep red surveys which have been reported in the literature have used I-N plates (Hansen and Blanco 1975) or extended red image tubes (Hyland 1974).

We present here the first results of our S-1 photographic survey. Three of the five sources for which we present data are believed to be associated with regions of star formation. The natures of the other two are unknown. One of these, OH 0739 − 14, is especially enigmatic and is also our most interesting observation. All five are easily accessible to Northern Hemisphere observers and are generally absent from the red Palomar Sky Survey (PSS) plates. A later paper will present results of our observations of primarily Southern Hemisphere IR/H II complexes and of OH sources.

II. OBSERVATIONS

The observations reported here were obtained with a two-stage RCA S-1 image tube sensitive up to 1.0 μm. Cooling of the tube to −40° is accomplished with alcohol flowing through dry ice. A transfer lens was used to image the output phosphor (40 mm diameter) onto baked IIIa-J plates. The tube was used with an RG 1000 filter, resulting in an effective wavelength (λ_{eff}) of about 9400 Å. Photographs at this wavelength are shown in Figure 1 (Plates 3 and 4). With the exception of NGC 7358, they are all 30 minute exposures taken at the f/7.5 focus of the Cerro Tololo Inter-American Observatory 1.5 m reflector. That of NGC 7538 was taken at the f/7.5 focus of the Kitt Peak National Observatory 0.9 m reflector and was exposed for 25 minutes. For OMC-2, we display a 15 minute exposure with the S-1 and a filter combination which yields λ_{eff} = 5500 Å, and which avoids Hα (6562 Å) and [O III] (5007 and 4959 Å). A 10 minute photograph with the S-1 at λ_{eff} = 8700 Å for NGC 7538 is also shown. For Sh 269, we show a reproduction from the blue PSS plates; for Mon R2 and OH 0739 − 14, we show reproductions from the red PSS plates.

For most of the regions in Figure 1, there are objects visible at 9400 Å which are absent from the shorter-wavelength pictures. To facilitate identification with known infrared and molecular sources, the positions of the objects marked were measured with respect to SAO catalog stars with a two-dimensional Grant machine. In some cases, for reasons of accuracy, it was better to measure positions relative to nearby stars which are themselves located on the infrared maps of the sources in the references cited below. The positions are given in Table 1. Because of spatial distortions in the S-1 tube, these positions are accurate to only ±5″. *I*-magnitudes from the S-1 plates for the objects in Table 1 were estimated through exposures of fields with photographic photometry in ω Cen (Geyer 1967; Woolley 1965) and the Orion Nebula region (Parenago 1954) by using Johnson's (1966) color-color relations. Accuracy of the *I*-magnitudes is only ±0.5 mag for the stellar objects and ±1.0 mag for the nebulous ones. We now turn our attention to the individual sources.

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TABLE 1

MAGNITUDES AND POSITIONS OF 1 μm SOURCES

SOURCE	m_{9400}	9400 Å SOURCES α(1950)	9400 Å SOURCES δ(1950)	OH/IR POSITIONS α(1950)	OH/IR POSITIONS δ(1950)	REFERENCE
OH 0739−14:*						
Star	12.0	$7^h39^m58^s.0$	−14°35′48″	$7^h39^m58^s.9$	−14°35′44″	1
Nebula	(13)	7 39 58.9	−14 35 41			
NGC 7538 No. 1	13.5	23 11 35.7	+61 12 06	23 11 36.5	+61 11 49	2
Sh 269–IRS-1	13.0	7 11 48.5	+13 50 43	6 11 47.0	+13 50 32	2
Mon R2:†						
1	11.5	0.3 W, 76 N				3
2	(15.5)	0.7 E, 5 N				
3 = IRS-3	16	1.6 E, 10 N		$1^s.7$ E, 11″ N of visible star		
4	16	1.6 E, 26 N				
5	16	0 45 N				
6 = IRS-6	16	0.3 W, 32 S		0.6 W, 28 S		
OMC-2:‡						
1 = IRS-4	13.3	0.5 W, 29 N		0.7 W, 37 N		4
2 = IRS-4	16	0.5 W, 37 N		0.7 W, 37 N		
4 = IRS-3	16	0.7 W, 6 S		1.2 W, 6 S		

* 9400 Å source $0^s.3$ W, 1″ N of visible star.

† 9400 Å source positions with respect to star B = center of IRS-1; see Fig. 1 and Beckwith *et al.* 1976.

‡ 9400 Å source positions relative to π2045 (Parenago 1954).

REFERENCES (for OH/IR positions): (1) WWBN (1974); (2) Wynn-Williams, Werner, and Wilson (1974); (3) Beckwith *et al.* (1976); (4) Gatley *et al.* (1974).

III. DISCUSSION

The most interesting of our observations is that of OH 0739−14 (OH 231.8 + 4.2). OH emission was initially detected by Turner (1971), while weak H_2O maser emission was found by Morris and Knapp (1976). A 2.2 μm source with a size of about 5″ was found to be coincident with the molecular source (Wynn-Williams, Becklin, and Neugebauer 1974, hereafter WWBN; Wynn-Williams, Werner, and Wilson 1974). Recent infrared spectrophotometric observations have been reported by Gillett and Soifer (1976). Coincident with the IR/OH position, we have found (Table 1 and Fig. 1) an extended (~20″) pencil of nebulosity which is invisible on the red PSS print. Near the southern tip of this nebulosity is a moderately bright stellar object which is also invisible on the red print. The star noted by WWBN and by Gillett and Soifer (1976) as being close to the IR position is not coincident with the stellar object in Figure 1. Note that, with the exception of these two objects, the field appears similar at the two wavelengths implying that there is no substantial reddening in this direction. This will be taken to imply that reddening and/or extinction suffered by OH 0739−14 must be due to material associated with the object itself.

We estimate that $V-I$ for the star and for the nebulosity is greater than 6. Thus, although the spectrum of OH 0739−14 from 1.65 to 20 μm is relatively flat (WWBN), shortward of 1.65 μm it falls very steeply. Within the accuracy of our present observations, it is possible to obtain several consistent fits with the data for the stellar objects in the V to 2 μm region. Examples of such fits are an unreddened blackbody with $T_e = 1000$ K, or a reddened blackbody with $T_e \approx 3000$ K and $A_v \approx 15$ mag. At a distance of 1.5 kpc (Morris and Knapp 1976), the implied size is a few AU, and the absolute visual magnitude is −5 or −6. These values are consistent with a late-type supergiant; many of them are known to possess circumstellar envelopes. This star is probably not the main contributor to the infrared radiation for $\lambda > 2$ μm, both because of a difference in position and because the infrared source is considerably extended at 2.2 μm. Also, it is unlikely that the nebula is the infrared source, since it is too big. Thus, we postulate the presence of a third component, buried in the nebula. One possibility would be a late-type star whose circumstellar shell is thick enough to absorb most of the photospheric radiation and to produce the deep 3.1 and 9.8 μm absorption features (Gillett and Soifer 1976). Such an object is not without precedent; e.g., IRC +10216. The fact that the intensity variations at 10 μm are considerably greater than those at 2.2 μm (Gillett and Soifer 1976) would then be understandable. One may then speculate that the nebulosity comprises the ejecta from this star, which in turn is illuminated by the star visible on Figure 1. Clearly, further observations are needed to unravel this complex object.

The infrared properties of Sh 269 have been discussed by WWBN. Our observations reveal a 13 mag star just to the west of the star near the center of the nebula. It is not visible on the blue PSS print (probably due to the smaller scale) but can just be seen as a 16 mag object on a V plate obtained with the S-1. This is probably the correct identification for WWBN's IRS-1 rather than the star which is visible on the blue print. A $V-I$ color of 3–4, together with the colors

given by WWBN, are consistent with this object being an unreddened late-type star. Spectroscopic observations of this star could help to determine what, if any, its association is with the nebula and the other nearby star. IRS-2 is invisible in Figure 1, implying that I is fainter than 16 mag.

There are several objects on our photograph of OMC-2 that are coincident with infrared sources noted by Gatley *et al.* (1974). Some of these are reddened stars which have been previously cataloged by Parenago (1954). The objects listed in Table 1 have not been so cataloged, however. The position of object 2 agrees with the peak of OMC-2–IRS-4, while object 1 is just south of the peak. Similarly, object 4 is close to the peak of OMC-2–IRS-3. The faintness and presumably extreme redness of objects 2 and 4 would make further observations in this wavelength region difficult. If object 1 is identified with IRS-4, then we note that the magnitude at 9400 Å (Table 1) and the data of Gatley *et al.* (1974) are consistent with a two-component model—a reddened star plus emission from a cool circumstellar shell.

Beckwith *et al.* (1976) and Downes *et al.* (1975) have discussed infrared and radio observations of the Mon R2 complex. Star B (Fig. 2 [Pl. 5]) is coincident but not associated with Mon R2–IRS-1 (Beckwith 1976). The positions given in Table 1 are with respect to this star and should be compared with the 1.65 μm map presented by Beckwith *et al.* (1976). Object 2 is coincident with some nebulosity visible on the red PSS print. Object 3 is stellar and lies on the western edge of Mon R2–IRS-3. Objects 4 and 5 are faint stellar objects lying north of the region mapped. Object 6 is coincident with Mon R2–IRS-6 and is probably to be identified with it, since IRS-6 gets brighter at the shorter infrared wavelengths. Like the objects in OMC-2, however, it would be difficult to observe. Object 1 appears to be a very red star with $V-I \gtrsim 6$. It would be interesting to obtain quantitative observations of it and investigate its connection with this molecular cloud complex.

Finally, the pictures of NGC 7538 reveal nothing extraordinary in the central region of the nebula, but do show the optical knot of nebulosity which is associated with NGC 7538–IRS-2 (WWBN). A comparison of the two photographs in Figure 1 shows the redness of this knot even over a short-wavelength baseline. Its line spectrum and optical appearance are similar to those of K3-50 (Persson and Frogel, unpublished data).

We would like to thank Fred Gillett and Steve Beckwith for useful conversations about some of these sources.

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Note added in proof.—A recent high-quality plate of OH 0739−14 taken with the KPNO 2.1 m telescope shows a striking similarity to the Egg Nebula (Ney, Merrill, Becklin, Neugebauer, and Wynn-Williams, *Ap. J.* [*Letters*], **198**, L129 [1975]). The "stellar object" noted in the text, and which on the new plate appears extended, is the southern component, while the nebulosity is the northern component. A clean gap is visible between the two, and the OH/IR position is close to this gap. Details will be presented later.

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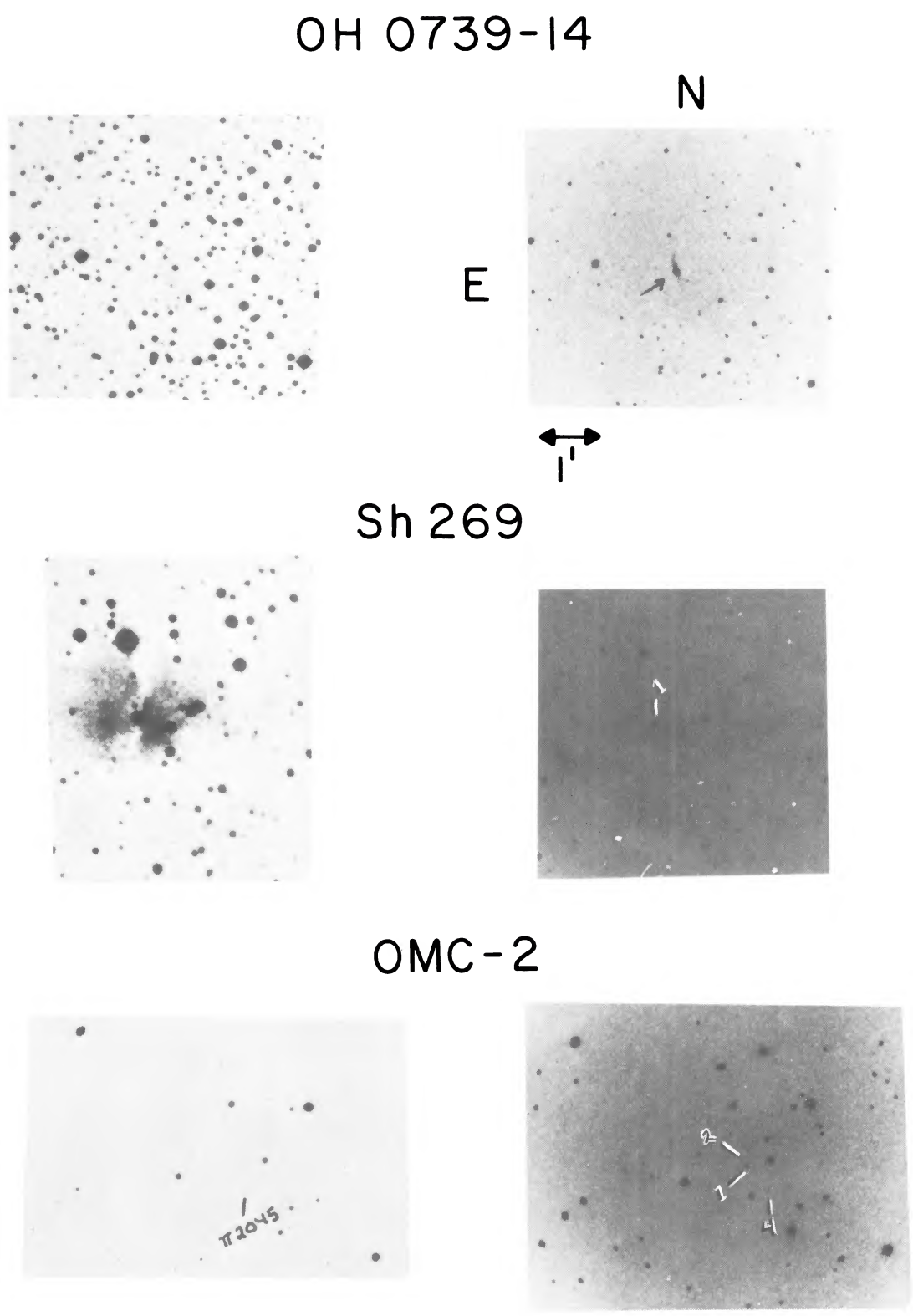

FIG. 1.—A comparison of our S-1 photographs at an effective wavelength of 9400 Å (right side of pairs) with shorter-wavelength photographs. North is to the top and east to the left.

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PLATE 4

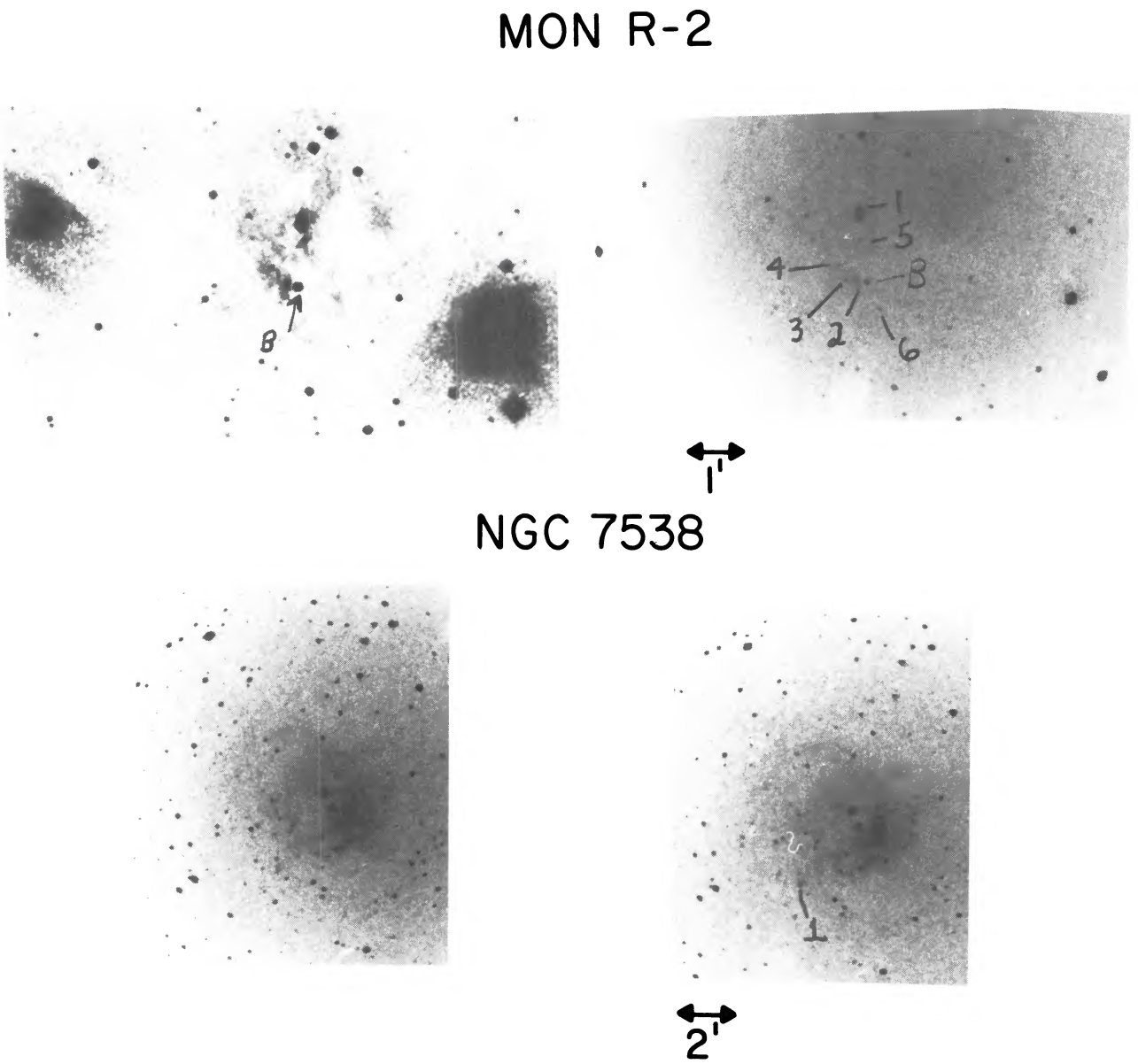

FIG 1.—*Continued*

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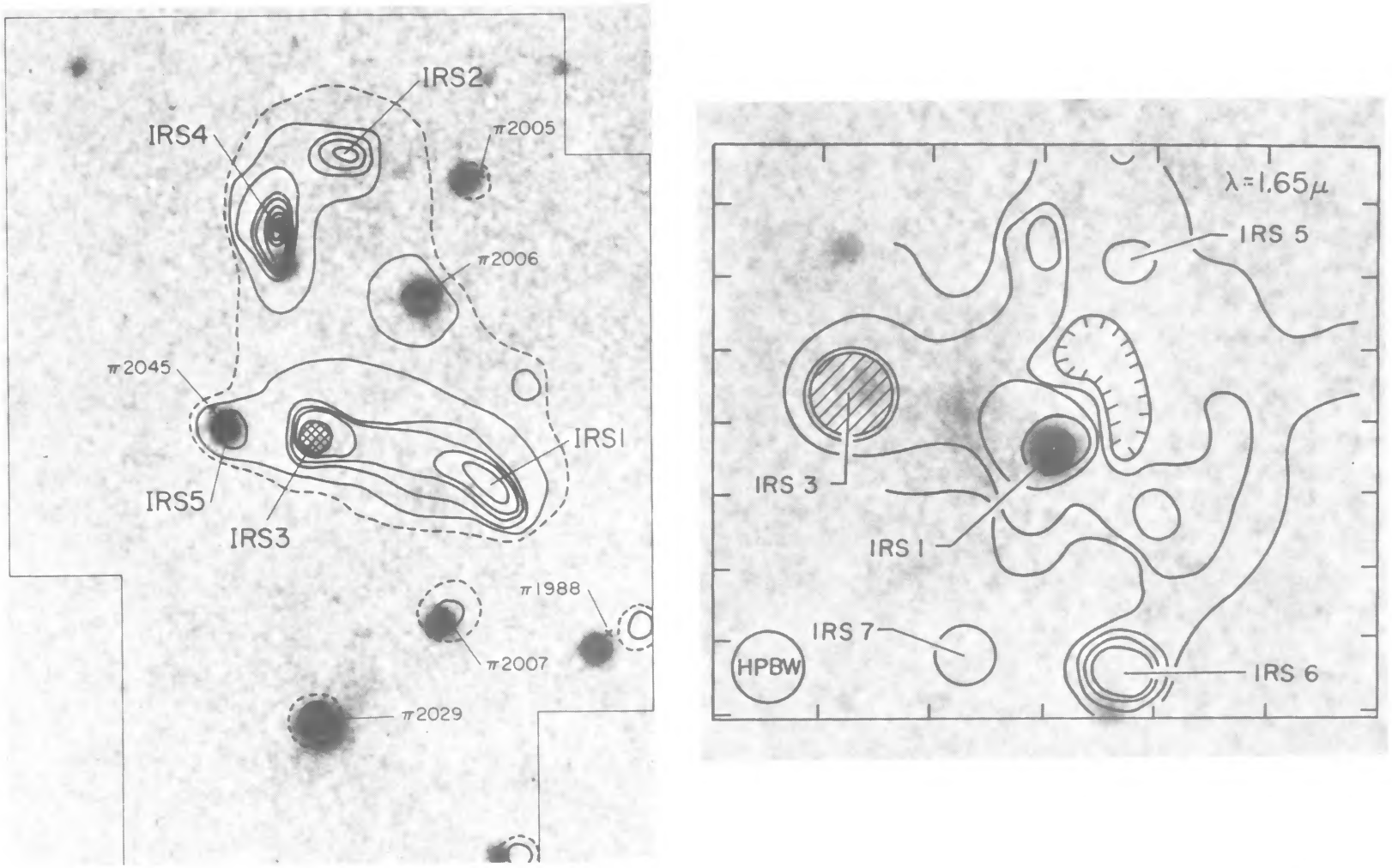

PLATE 5

FIG. 2.—The 9400 Å S-1 photograph of the region of OMC-2 is superposed on the 2.2 μm map of Gatley *et al.* (1974) on the left. On the right, the 9400 Å photograph of Mon R-2 is superposed on the 1.65 μm map of Beckwith *et al.* (1976) with a 10″ uncertainty in the relative positioning.

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