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SAGITTARIUS A* AND THE POSITIONS OF INFRARED SOURCES IN THE GALACTIC CENTER

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ABSTRACT

Observations of the central region of the Galaxy have been made with the University of Rochester 32 × 32 element InSb array camera in the 1–5 μm wavelength range. The 2.2 μm images have been used to determine positions of infrared features in comparison with that of the galactic center compact radio source Sgr A*. No infrared source lies precisely at the Sgr A* position in our images. However, the infrared source closest to the Sgr A* position is a previously little studied source directly south of IRS 7 that we have called IRS 16NW and not the often referred to IRS 16C. IRS 16NW is coincident with one of the very red objects seen in various 1 μm images of this region.

Subject headings: galaxies: Milky Way — galaxies: nuclei — infrared: sources

I. INTRODUCTION

The problem of determining absolute positions of visually unseen sources in the region of the Galactic center is a formidable one. Yet it is necessary if we are to be able to make further infrared studies of radio sources in the region. Of particular interest is the search for an infrared counterpart to the Sgr A* compact nonthermal source near, or at, the dynamical center of the Galaxy. It has been suggested that this is the site of a supermassive compact object (Lacy *et al.* 1982; Brown 1982).

A major difficulty in doing infrared astrometry in the Galactic center region has been the limitation imposed by single detector systems that require scanning over large distances to form a map. We are now entering an era in which two-dimensional imaging at infrared wavelengths is possible, and images can now be obtained while keeping a telescope pointed in a fixed direction. We have obtained such images using the University of Rochester 32 × 32 InSb array camera that has been described elsewhere (Forrest *et al.* 1985), in an attempt to specify the location of the Sgr A* radio source with respect to infrared sources in the region.

Other recent attempts to make an infrared identification of Sgr A* are the investigations of Storey and Allen (1983, hereafter SA) with a combination of CCD and single-detector infrared maps, as well as that of Henry, DePoy, and Becklin (1984) using a CCD at $\lambda \approx 1$ μm. We have obtained images at $\lambda = 1.23$ μm, 1.65 μm, 2.23 μm, 3.75 μm, and 4.67 μm and have used the 2.23 μm image for the attempt at carrying out the astrometry. Our results do not agree with those of SA and Henry, DePoy, and Becklin (1984) that the infrared source usually referred to as IRS 16C is to be identified with the position of Sgr A*. In fact, to our accuracy of $\pm 0\farcs5$, no distinct source appears at the Sgr A* position in any of our images. However, we believe that the infrared source closest to the Sgr A* position is the source directly south of IRS 7 that heretofore has not been extensively studied. We tentatively will refer to the infrared source at this position as IRS 16NW (because of its proximity to IRS 16) until further studies help resolve current uncertainties as to its nature or association with IRS 16 or Sgr A*.

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II. OBSERVATIONS

The positions that we have derived in the Galactic center region are based on the position of the visually observable star A referred to by SA. The position of this star has been redetermined independently by Dr. Burton Jones (private communication). We summarize the positions used for this star by various investigators as well as the positions of some other prominent features of the region in Table 1. We note that the positions of star A used by us and SA are in good agreement.

The 32 × 32 element InSb array camera observations were made at the NASA Infrared Telescope Facility on Mauna Kea, Hawaii in 1984 August. Plate scale and position angle orientation of the array on the sky were determined using star pairs and star streaks. Recent separations and position angles of the slowly moving star pairs γ Del, γ Ari, η Cas, and 20 Per were provided from archival data recorded by Dr. C. Worley at US Naval Observatory (private communication). The 1984.7 positions were extrapolated using these data and the earlier data of Aitken (1932). Star streaks were obtained

TABLE 1

COORDINATES (1950.0) OF GALACTIC CENTER SOURCES[a]

	STOREY AND ALLEN 1983		HENRY *ET AL.* 1984		PRESENT INVESTIGATION		BROWN *ET AL.* 1981	
SOURCE	α	δ	α	δ	α	δ	α	δ
Star A	$30^{s}.01$	$2''.0$	V & R[b] (adopted)	V & R[b] (adopted)	$30^{s}.005$[c]	$01''.86$[c]	...	...
IRS 7	29.34	12.9	...	...	29.34	13.13	...	...
IRS 16C	29.46	18.6	$29^{s}.36$	$18''.6$	29.44	18.6	...	...
IRS 1W	29.75	18.3	29.66	17.8	29.74	18.3	...	...
IRS 1E	29.93	18.4	...	...	...	...	...	...
IRS 16NW	...	...	...	...	29.33	17.6[d]	...	...
Sgr A* (radio)	29.33	18.3[e]	...	...	...	...	$29^{s}.335 \pm 0^{s}.008$	$18''.6 \pm 0''.24$
CCD 1	29.48	15.6	29.50	15.6[f]	...	...	...	...
CCD 2	29.33	17.8	29.34	17.9[f]	...	...	...	...

[a]All coordinates are $17^{h}42^{m}$ + and $-28°59'$ + .

[b]Henry *et al.* 1984 used the astrometric grid of Vanderspek and Ricker 1983 but did not specify the position of Star A or the epoch used.

[c]Burton Jones 1984.7 epoch (private communication).

[d]Coincident with CCD 2 (SA).

[e]Based on visual determination of benchmark 1730−130 (SA).

[f]IRR 1, 2 in Henry *et al.* 1984.

by shutting off the telescope drive. The results of the two methods to determine the orientation of the array were in good agreement. The resulting pixel sizes (decl. × R.A.) were: $0''.46 \times 0''.42$ (J), $0''.48 \times 0''.44$ (H and K), $0''.49 \times 0''.45$ (3.8 μm), and $0''.50 \times 0''.46$ (4.7 μm).

A crucial step in our procedure was to determine the offset from visually observable star A to IRS 7 which can only be observed at infrared wavelengths because of the large extinction of intervening dust. IRS 7 was placed in the SW corner of the array so that star A appeared in the NE corner of the array. Unambiguous identification of star A was achieved by observing at 1.23 μm, where it is relatively bright compared to the Galactic center sources. The offset between star A and IRS 7 was measured on four independent exposures which showed both objects clearly. The image of star A was shifted and blinked (as in a blink comparator) to derive the offset to IRS 7. The individual measurements were averaged to derive the position of IRS 7 quoted in Table 1. From the spread in the individual pixel offsets and our uncertainties in the plate scale, we estimate an uncertainty of $\pm 0''.2$ in our star A to IRS 7 offsets. These results are in excellent agreement with those of SA with a discrepancy of 0.00 s of time in right ascension and $0''.2$ in declination.

The positions of other prominent infrared features in a contour map (Fig. 1) derived from the 2.2 μm image of the Galactic center region (Fig. 2*a* [Pl. L8]) have also been determined from our results. In particular our positions for IRS 16C and IRS 1W as seen in the 2.23 μm image are also in excellent agreement with the results of SA.

III. INFRARED FEATURES AND THE POSITION OF SAGITTARIUS A*

We have done no new work on the absolute position of Sgr A*. The position quoted by Brown *et al.* (1981) was determined by offset from the radio source 1730−130. However, SA quote a position that is slightly different (by $0''.3$) based on the optical position of the radio position calibrator 1730−130 determined from plates taken specifically for this purpose, rather than from the Palomar sky survey plate (West and Walter 1981). Based on these arguments we adopt the position of Sgr A* quoted by SA for the purpose of our further discussion. The slight disagreement exists only in the declination coordinate, not the right ascension coordinate, and the difference is within our estimated error. We estimate the uncertainty in positioning the Sgr A* radio source on the infrared images as follows: uncertainty in the star A to IRS 7 offset $\pm 0''.2$, uncertainty in the position of star A $\pm 0''.3$, uncertainty in placing the Sgr A* radio source on our astrometric coordinate grid $\pm 0''.3$ in declination, somewhat less in right ascension. Adding these uncertainties in quadrature leads to a net uncertainty of $\pm 0''.5$.

We note that in the analysis of SA, as well as in our investigation (Table 1), the position of Sgr A* is directly south of IRS 7. This is in contrast to the position of IRS 16C at 2.23 μm that is 0.10 s of time or $1''.3$ east of Sgr A*. SA, however, suggest that IRC 16C is the infrared counterpart of Sgr A*. We disagree with this conclusion and, although we find no infrared source precisely at the Sgr A* position within our error of $\pm 0''.5$, the source directly south of IRS 7 for which we suggest the name IRS 16NW, is the closest infrared feature to the Sgr A* position in the 2.23 μm image. As a result of our analysis IRS 16NW is properly at the same right ascension as Sgr A* but $0''.7$ north.

Our derived positions of IRS 16C and IRS 1W are not in good agreement with the results of Henry, DePoy, and Becklin (1984), although their positions for CCD 1 and CCD 2 agree with SA, whose position for star A agrees with ours. This may not be attributable to any error in observation or analysis on

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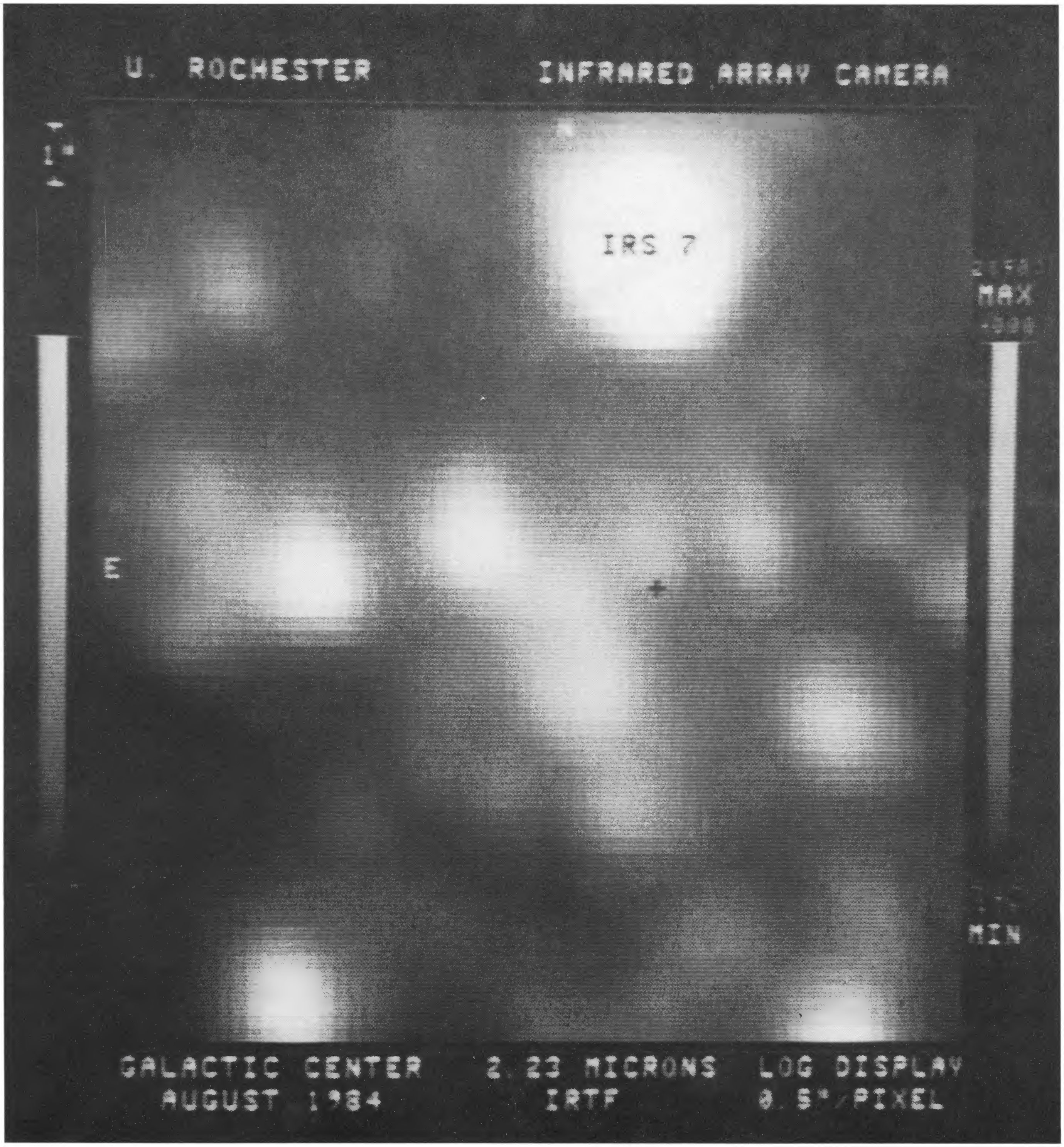

FIG. 2*a*.—A 2.23 μm image of the central region of the Galactic center. The region portrayed extends 15".1 N-S and 13".8 E-W. The scaling is logarithmic with visual brightness increasing as the log of the 2.23 μm surface brightness in order to display the wide dynamic range of this image. A "+" marks the calculated position of the Sgr A* source.

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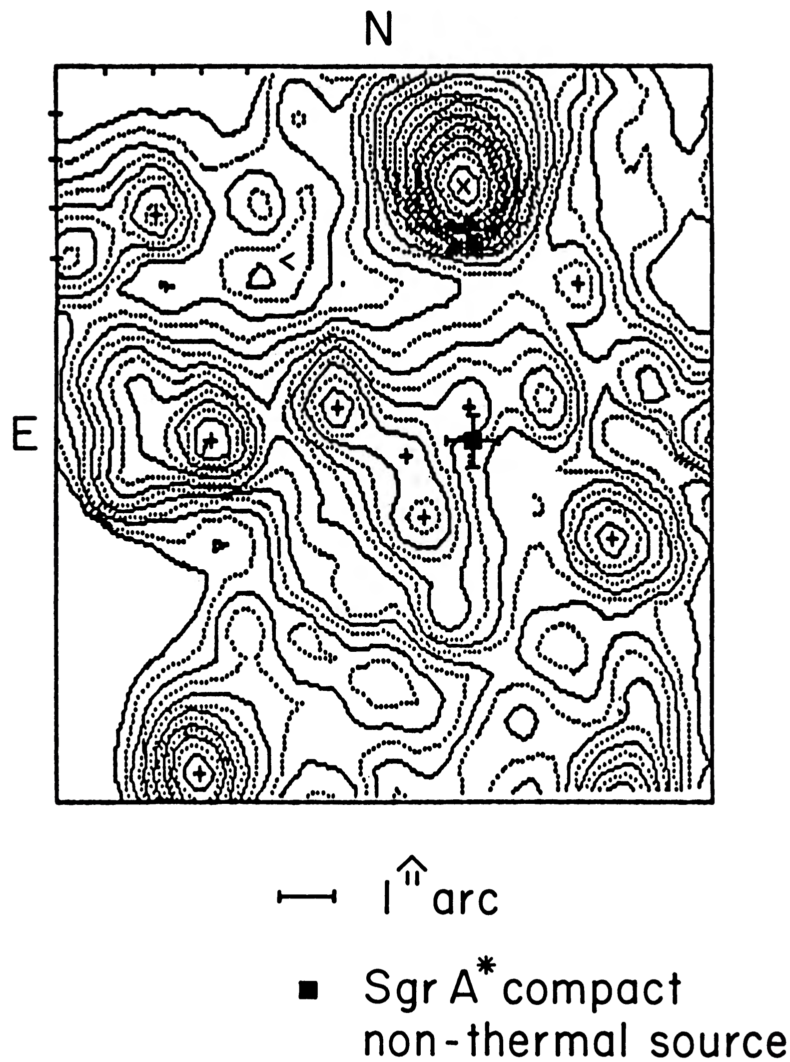

FIG. 1.—A plot of the equal surface brightness contours from the 2.23 μm image displayed in Fig. 2*a*. Contours are shown every factor of 1.20 (0.2 mag) in surface brightness with every other contour dotted. The display has been rectified to portray the true appearance on the sky with tick marks 1″ apart shown in the upper left corner. An "X" marks IRS 7 and +'s mark various 2 μm sources. The filled box represents the calculated position of the Sgr A* compact radio source; the $\pm 0''.5$ error bars are our estimate of the positional uncertainty.

the part of either investigation, but may occur because of the different wavelengths at which the observations were made. Our position for the IRS 16C complex was determined at 2.23 μm (see the cross in Fig. 1), the only wavelength at which a discrete source was seen in our images. At the other wavelengths there is diffuse emission throughout the complex (see Fig. 2*b* [Pl. L9]). We note that as the wavelength increases from 1.65 μm to 4.67 μm in our images (Fig. 2*b*), the IRS 16C, SW complex moves steadily further east of the Sgr A* position; at the same time the IRS 16NW and NE positions remain relatively fixed. On the other hand, the position of IRS 1W appears rock steady from 1.65 μm to 4.67 μm; however, our 1.23 μm image (not shown) does show a shift (westward) in the same sense as the Henry, DePoy, and Becklin (1984) 1 μm image. Such positional shifts with wavelength as these can result from nonuniform extinction in front of extended sources. Alternatively, the dust temperature, or dominant emission process at a given wavelength, may vary within an extended source, giving positional shifts. On the other hand the sources with fixed positions, i.e., IRS 16NW and NE, could be point-like objects.

IV. CONCLUSIONS

As a result of our analysis of the positions of infrared features in the region of the Galactic center, we do not believe that IRS 16C seen in the 2.23 μm images is the correct identification of the infrared counterpart to Sgr A*. Our results indicate that no infrared source lies precisely at the position of Sgr A* to within an accuracy of $\pm 0''.5$. However, if we are in error by a small amount in the declination position that we have derived, the source that is at a position closest to Sgr A* is that of the relatively unstudied IRS 16NW. The position of this object is in good agreement with one of the objects seen in far red exposures, called CCD 2 by SA. However, Biretta, Lo, and Young (1982) and Biretta *et al.* (1983) have presented evidence that this star is a foreground object that is not associated with the Galactic center. Thus

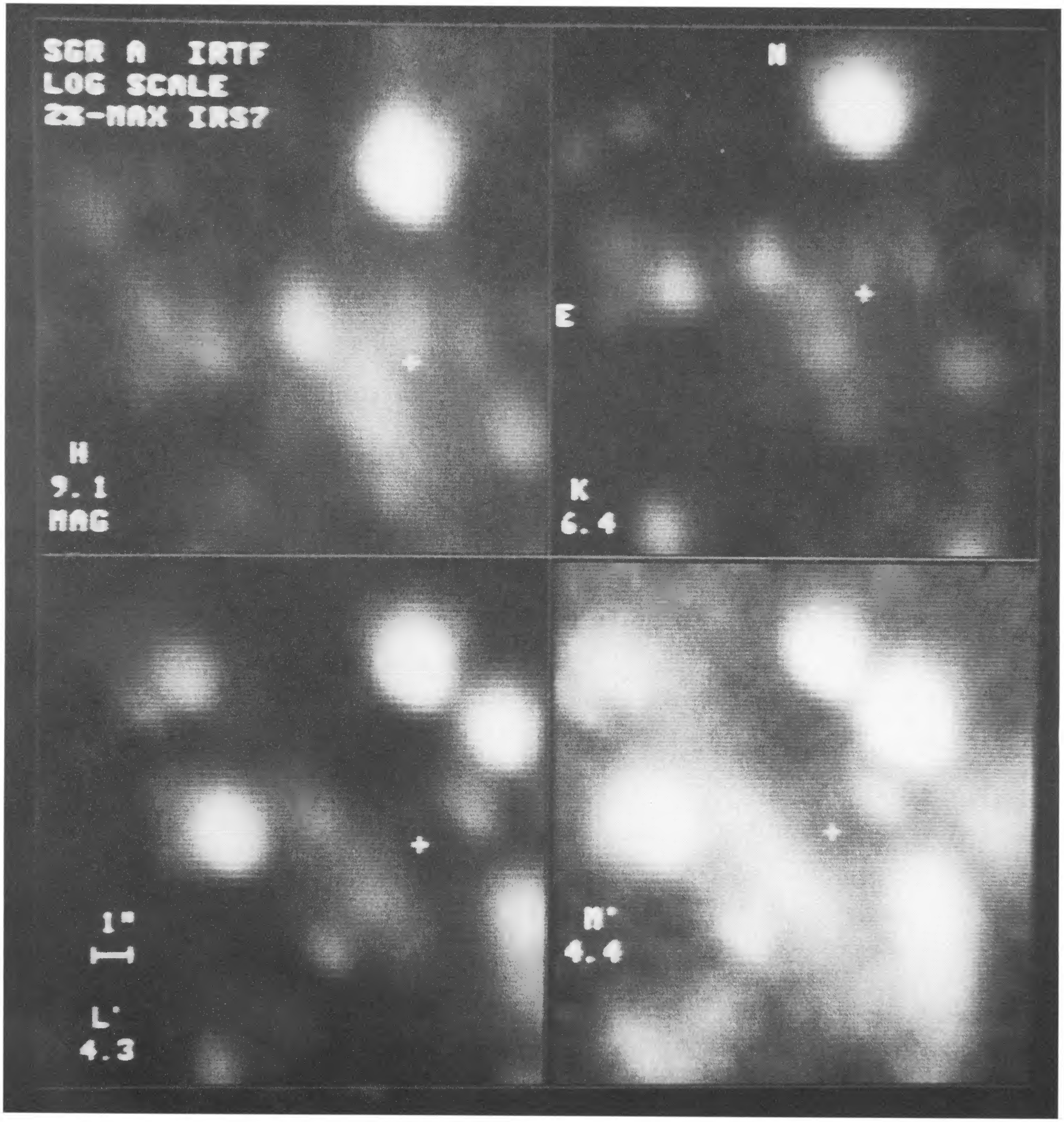

FIG. 2*b*.—Images at 1.65 (*H*), 2.23 (*K*), 3.75 (*L*′), and 4.67 (*M*′) μm of the central regions of the Galactic center. The displayed levels are scaled logarithmically from 2% to the peak IRS 7 brightness; the magnitude of IRS 7 is given for reference in each image. A "+" marks the calculated position of Sgr A*. Each image represents a slightly different size on the sky, from 15″.1 × 13″.8 for *H* and *K* to 15″.8 × 14″.5 at *M*′.

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TABLE 2

Brightness of the IRS 16NW Pointlike Object

λ(μm)	Brightness Ratio IRS 7/IRS 16NW	[λ] IRS 16NW (mag)	Dereddened[a] [λ] IRS 16NW (mag)
1.23	4 ± 1	+14.7	7.0
1.65	16 ± 4	+12.1	7.4
2.23	28 ± 5	+10.0	7.3
3.75	65 ± 15	+8.8	7.5
4.67	> 25	> 7.9 ± 0.3	> 7.1

[a]Assuming the extinction law of Becklin *et al.* 1978.

IRS 16NW may only be coincidentally positioned near CCD 2.

Photometry of IRS 16NW is difficult because of uncertainties in determining background subtraction in these complex images. Estimates of the brightness of IRS 16NW were derived by shifting and subtracting a fraction of the image of the bright point source IRS 7; subtracting too large a fraction resulted in a hole, and subtracting too small a fraction left a distinct object. The optimum fraction of subtraction gave no indication of a source at the IRS 16NW position. The resulting ratios to IRS 7 and derived magnitudes are given in Table 2. In addition, assuming the extinction law of Becklin *et al.* (1978), the dereddened magnitudes are given. We note that when dereddened, the colors of IRS 16NW are nearly neutral, consistent with a relatively hot object. If an intrinsic magnitude of 7.3 and a $\lambda^{-1.7}$ extinction law are assumed, the object would be 18–20 mag in the 1–0.9 μm region of the spectrum. Given the large uncertainties, this is consistent with the brightness of the pointlike object IRR 1 (called CCD 2 in SA) determined by Henry, DePoy, and Becklin (1984). Thus it seems plausible that IRS 16NW and IRR 1/CCD 2 are one and the same object. Spectral studies (Biretta *et al.* 1983) indicate that CCD 2 is not as red as would be expected for an object at the Galactic center unless it is intrinsically a very blue object. However, we note that the $H - K$ color of IRS 16NW is 2.1 mag. Normal stars of spectral type O5–M6 have $H - K$ colors of 0.0 to 0.3. Thus, if IRS 16NW is a star, it is reddened by at least 1.8 mag, which is just the amount of reddening to the Galactic center inferred by Becklin *et al.* (1978). We conclude that IRS 16NW is at the Galactic center. If it is associated with CCD 2, it may have an intrinsically very blue spectrum.

A blackbody object with apparent magnitude 7.3 at 2.23 μm and 30–35 × 10^3 K temperature, consistent with the low excitation conditions in the central parsec of the Galaxy, would have a luminosity of ~ 1–$1.6 \times 10^6\ L_\odot$. This would be nearly sufficient to power the central 30″ region of the source ($L \approx 2 \times 10^6\ L_\odot$; Becklin, Gatley, and Werner 1982). However, a central luminosity of ~ 1–$3 \times 10^7\ L_\odot$ is necessary to explain the general infrared emission from this region, which is considerably higher than the inferred luminosity of IRS 16NW.

Because of its proximity to Sgr A*, further studies of the nature of IRS 16NW/IRR 1/CCD 2 are warranted. The best way to make further progress in the astrometry would be to compare the infrared images directly with the radio images of this region. One possible method would be to image the Galactic center in Brγ (2.16 μm) and Brα (4.05 μm). From these images both the extinction and the emission measure could be determined independently by assuming an extinction law. The emission measure map could be compared directly to the 5 and 15 GHz radio maps (Lo and Clausen 1983; Brown and Liszt 1984) to register the infrared and radio images. Alternately, if radio emission could be detected from the bright point source IRS 7, registration could be achieved.

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