THE ASTRONOMICAL JOURNAL VOLUME 111, NUMBER 2 FEBRUARY 1996

NEAR INFRARED OBSERVATIONS OF IRAS 09104+4109[1]

B. T. SOIFER, G. NEUGEBAUER, L. ARMUS, AND D. L. SHUPE
Palomar Observatory, Caltech, Pasadena, California 91125
Received 1995 August 14; revised 1995 October 18

ABSTRACT

Near infrared imaging and grism spectroscopy of the high luminosity infrared bright galaxy IRAS 09104+4109 have been obtained with the W. M. Keck Telescope. The imaging shows 6 "knots" of emission projected against the extended stellar envelope of the cD galaxy thought to be the source of the large far infrared luminosity. The luminosities of the knots are consistent with the bulges of galaxies accreting onto the central galaxy. In addition, there are 11 companion galaxies seen at radii of 40-150 kpc from the cD nucleus. These objects have colors in the range $R-K\sim 3.5\pm 0.5$ mag, $J-H\sim 0.9\pm 0.2$ mag and H-$K\sim 0.7\pm 0.2$ mag, which are consistent with galaxies at a redshift of 0.4. The companion galaxies have luminosities comparable to or less than the characteristic luminosity (L^*) of field galaxies. While the central cD galaxy is identified with the luminous infrared source, it appears to be a quiescent, radio-quiet galaxy, showing no evidence from its near infrared colors for a highly reddened nucleus as seen in other infrared luminous galaxies. The grism spectroscopy shows forbidden lines of low ionization stages of sulfer, iron, and oxygen, as well as hydrogen recombination lines and a strong line of neutral helium. A visual extinction of $A_v\sim 2$ mag is derived to the narrow line region surrounding the galaxy nucleus, based on the line ratios [S II]1.03μm/0.407μm and Pδ/Hβ. The near infrared spectrum is consistent with the optical classification of this system being a Seyfert 2 nucleus. © *1996 American Astronomical Society.*

1. INTRODUCTION

The galaxy IRAS 09104+4109 was originally detected as a 60 μm source in the IRAS all sky survey and identified with a faint ($m_v\sim 19$ mag) galaxy at redshift z=0.442 by Kleinmann & Keel (1987). The infrared luminosity of this system is $L=6\times 10^{12}L_\odot$ for H_o=75 km/sec/Mpc and $q_o=0$ that we adopt here, making it one of the most luminous objects discovered in the *IRAS* survey. Visual imaging of IRAS 09104+4109 (Kleinmann, *et al.* 1988, hereafter referred to as K88; Hutchings & Neff, 1988, hereafter referred to as HN) has shown that the infrared source is in a cD galaxy in a rich cluster. HN show that there are many separate condensations within the large stellar envelope of the galaxy. The cD galaxy appears to be a normal, radio-quiet cD galaxy (see e.g. Tonry 1987, and references therein), *except* for its unique property of coinciding with one of the most luminous infrared sources known from the *IRAS* survey.

The identification of the cD galaxy with the infrared source (K88) is based on the combination of the agreement of the observed 10 μm flux density measured with an 8″ beam on the cD galaxy with the *IRAS* 12 μm flux density, the agreement between the radio flux density of this source with that expected based on the observed 60 μm flux density and the well estabished radio-far infrared flux density correlation (e.g. Helou *et al.* 1985, de Jong *et al.* 1985), and the close positional agreement (within 1.5″) between the radio source and the nucleus of the cD galaxy. The agreement between the radio/infrared flux ratio and that observed in IRAS 09104+4109 argues that the vast majority of the far infrared luminosity is associated with the radio source, i.e., the center of the cD galaxy rather than from the galaxies in the cluster.

K88 showed that the optical spectrum of the source was characteristic of a Seyfert 2 galaxy. The hydrogen and He II line ratios indicate a low value for the line of sight extinction, but the measured Hβ flux compared to the observed far infrared flux shows that more than 50 times the hydrogen ionizing luminosity is emerging in the far infrared. K88 suggest that IRAS 09104+4109 is a dust enshrouded quasar whose emission line spectrum is dominated by an extended narrow-line region. Hines & Wills (1993) provide additional strong evidence for this interpretation with visible spectroscopy and polarimetry that reveal a broad wing of the Mg II line at 2800 Å (rest wavelength) and a strong (20%) linear polarization of the continuum that is independent of wavelength and at a constant position angle.

The unusual nature of IRAS 09104+4109, i.e., the coincidence of a powerful infrared source associated with a Seyfert nucleus in an apparently quiescent cD galaxy, warrants further investigation. In this paper we provide new infrared imaging and spectroscopy of this system. The results are part of an ongoing program with the W. M. Keck Telescope of near infrared imaging and low resolution spectroscopy of high luminosity sources which emit predominantly in the infrared.

2. OBSERVATIONS AND DATA REDUCTION

The observations reported here were made on the nights of 20, 21 December 1994 using the near infrared camera

[1]Based on observations obtained at the W.M. Keck Observatory, which is operated jointly by the California Institute of Technology and the University of California

(NIRC) at the *f*/25 forward Cassegrain focus of the W. M. Keck Telescope. The instrument is described in detail by Matthews & Soifer (1994). It has a 256x256 InSb array with $0.15'' \times 0.15''$ pixels for a $38'' \times 38''$ field of view. Sets of four images of the central galaxy and its surrounding environment were obtained at 1.27 μm (*J*), 1.65 μm (*H*) and 2.2 μm (*K*). The images at *K* were each exposed for 40 sec, while those at *J* and *H* were exposed 80 sec each. After each image was taken, the telescope was moved along the direction of the array column in order to permit subtraction of sequential images with a separation at least 15″.

After flat fielding, the image frames were sky subtracted by differencing sequential images. These difference frames were then combined after shifting the images so that the central bright nucleus images were coincident. The resulting $38'' \times 46''$ mosaic retains the artifact of negative (black) signals created as a result of the subtraction as well as the positive (white) coadded signals. Because of the presence of a large number of sources in the field, no satisfactory uniform sky for the subtraction could be formed, so the above procedure was thought preferable to subtracting a noisy, nonuniform sky. The seeing, as determined from several images in the field was approximately 0.9″-0.7″ FWHM at 1.2, 1.6 and 2.2 μm respectively, but varied during the observations.

The photometric sensitivity was obtained by observation of the UKIRT faint standard FS 21 (Casali & Hawarden 1992). In order to directly compare the photometry obtained here with that of K88, photometry was measured using an 8″ diameter beam; the local sky was taken to be an annulus from 8.5″ to 10″. The bright nucleus of IRAS 09104+4109 yielded $J=16.45$ mag, $H=15.64$ mag and $K=14.70$ mag; the statistical uncertainties are insignificant ($<1\%$). The uncertainties due to establishing the background level in a crowded field is unknown, but is probably more significant than the statistical uncertainties. These results are in good agreement with the photometry of K88 obtained with the same beam size.

In addition to the images, low resolution grism spectra were obtained over the wavelength ranges 1.0-1.6 μm, and 1.5-2.4 μm. The bright nucleus was centered in a 0.7″ slit yielding a spectral resolution of $\lambda/\Delta\lambda \sim 70$. The slit was oriented at a position angle of 6°. Five 2 minute exposures were obtained from 1.0-1.6 μm in different settings along the slit; ten 2 minute exposures were obtained from 1.5-2.4 μm. The settings were made on centers spaced 6″ apart.

The spectra were reduced by flat fielding the spectral image, subtracting sequential frames and subtracting any residual sky 4.5″ from the central spectrum. The spectra were then combined to produce a two-dimensional spectrum from which a spectrum of the nucleus was extracted. Atmospheric features as well as any residual variations in the array were removed by dividing the central spectrum by that of the A star HD 77281. To determine the relative flux versus wavelength the spectrum of HD 77281 was assumed to follow a blackbody of temperature 10,000 K after correction for Brγ, Pα and Pβ absorption.

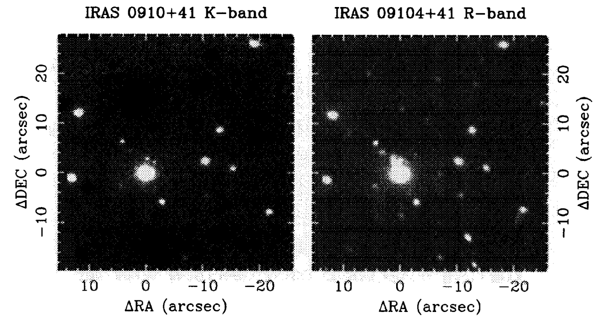

FIG. 1. Image of IRAS 09104+4109 obtained at 2.2 μm (*K*) with the near infrared camera on the W. M. Keck telescope (left). The right panel is an *R* band image from Hutchings & Neff (1988) for comparison.

3. RESULTS

The coadded image obtained at 2.2 μm is shown in Figure 1. Also presented for comparison is the *R* band image obtained by HN and originally published as a contour map. Since the *K* band image was obtained in better seeing than the *J* or *H* band images, only the former is presented here. Qualitatively, all the near infrared images show the same structure.

The appearance of the source in the *K* band (1.53 μm in the rest frame) is quite similar to that seen in the *R* band image. At 2.2 μm the source is dominated by the central nucleus, with a large extended envelope which extends approximately 8″ or 40 kpc in radius. In addition to the bright nucleus, six separate brightness peaks are clearly visible imbedded in the extended envelope of 2.2 μm emission and are explicitly identified and located in Table 1. Each of these peaks is visible in the *R* image of HN. Examination of the *R* and *K* images shows that all of the brightness peaks seen in the *R* image within the extended envelope surrounding the cD galaxy are visible in the *K* image as well. In addition to the peaks within the extended envelope of the central galaxy, a number of objects (referred to hereafter as companion objects) appear in the field. Some objects seen in the *R* image are hidden by negative artifacts in the *K* image. The *K* image clearly resolves two sources (sources 10 and 11 in Table 1) that are within 3″ of the bright nucleus and are only marginally distinguished from the nucleus in the imaging of HN. The apparent "jet" emerging to the north east in the *R* image is not seen in the *K* image. This extension may be dominated by line emission since the morphology is similar to that seen in [O III] by K88.

The crowded field of IRAS 09104+4109 made the use of a large beam for accurate photometry impractical, while the variability of the seeing during the time of the observations, made accurate photometry using a 3″ beam infeasible. Nonetheless, the photometric sensitivity in a 3″ diameter beam relative to a "sky" in an annulus extending to 4″ was transferred from FS 21 and applied directly to the companion objects lying beyond the diffuse envelope surrounding the central galaxy, and three of the brightness peaks within the diffuse envelope of the central galaxy. The magnitudes and colors of 14 such objects in the field, as well as the center of the *IRAS* source are given in Table 1. Because of the vari-

TABLE 1. Positions and photometry[a] of sources in the 09104+4109 field.

Object	X	Y	K	R-K	J-H	H-K
	″	″	mag	mag	mag	mag
1	-21.71	-7.81	17.53±0.05	3.28±0.09	0.87±0.06	0.69 ±0.07
2	-19.18	26.04	17.07±0.07	3.75±0.08	0.91±0.08	0.73±0.09
3	-15.39	0.88	17.83±0.06	3.47±0.09	1.13±0.07	0.51 ±0.08
4	-13.07	8.64	17.36±0.05	3.46±0.08	0.95±0.06	0.67 ±0.06
5	-10.52	2.38	16.95±0.03	3.49±0.05	1.04±0.04	0.72 ±0.04
6	-10.77	-4.71	19.24±0.27	3.36±0.41	1.44±0.35	0.55 ±0.33
7	-7.05	-0.38	19.47±0.36	3.45±0.61	0.85±0.33	0.52 ±0.44
8	-6.92	-17.05	18.50±0.15	3.66±0.26	0.75±0.22	0.94 ±0.23
9*	-2.89	-5.82	17.73±0.06	3.40±0.14	1.03±0.07	0.62 ±0.08
10*	-1.53	2.12	-	-	-	-
11*	-0.27	2.89	-	-	-	-
12+	0.0	0.00	15.19±0.01	2.84±0.02	0.96±0.01	0.97 ±0.01
13*	2.73	4.48	-	-	-	-
14*	4.13	6.32	18.44±0.15	3.90±1.59	0.25±0.24	1.13 ±0.27
15*	4.43	-2.53	19.45±0.35	4.98±0.35	0.85±0.67	1.18 ±0.62
16	8.97	8.17	20.01±0.85	2.50±0.89	0.95±0.39	-0.08±0.90
17	11.79	12.07	16.75±0.03	3.41±0.04	0.96±0.04	0.72 ±0.04
18	13.04	-1.04	16.79±0.03	3.55±0.05	0.87±0.03	0.78 ±0.04

[a]All photometry refers to a 3″ beam. Because of the variable seeing and crowded field, systematic uncertainties in the photometry are ~20%. The uncertainties reported in the table are statistical uncertainties only.

+central peak in cD galaxy

*falls within the diffuse emission from the central galaxy

ability in the seeing, the unknown extended emission of the objects and the crowding of the field, the uncertainties of the entries are probably on the order of 20%; statistical uncertainties are quoted. Locations with respect to the bright nucleus are given in Table 1 for 17 objects. Because of the manner in which the sky was subtracted from the infrared images, the objects found in Figure 1 and listed in Table 1 do not represent a complete sample of the sources in the field of IRAS 09104+4109.

The low resolution nuclear spectrum of IRAS 09104 +4109 from 0.95-2.45 μm (0.66-1.70 μm in the rest frame) is shown in Figure 2. The spectrum corresponds to a 1.0″ long slit centered on the nucleus, and was synthesized from the two separate spectra; there is good agreement in the wavelength region of overlap of the two spectra. No significant line or continuum flux was detected off the nucleus in the two dimensional spectrum. The spectrum shows lines of [S II] at 0.67 μm and 1.03 μm (hereafter all wavelengths will be reported in the rest frame of IRAS 09104+4109), [S III] 0.90, 0.95 μm, He I 1.083 μm, [Fe II] 1.258, 1.644 μm and P β 1.285 μm and P δ 1.005 μm. Two weak features, which we believe are residual atmospheric features, are labelled as ATM in Figure 2. All of the lines are unresolved in the spectrum, placing a limit on the full width at half maximum of the lines of Δv<3000 km/s. Equivalent widths and line fluxes have been determined for all the lines apparent in the spectrum and are presented in Table 2. The flux determination was established by first measuring the equivalent widths of the lines in the spectrum, and then converting

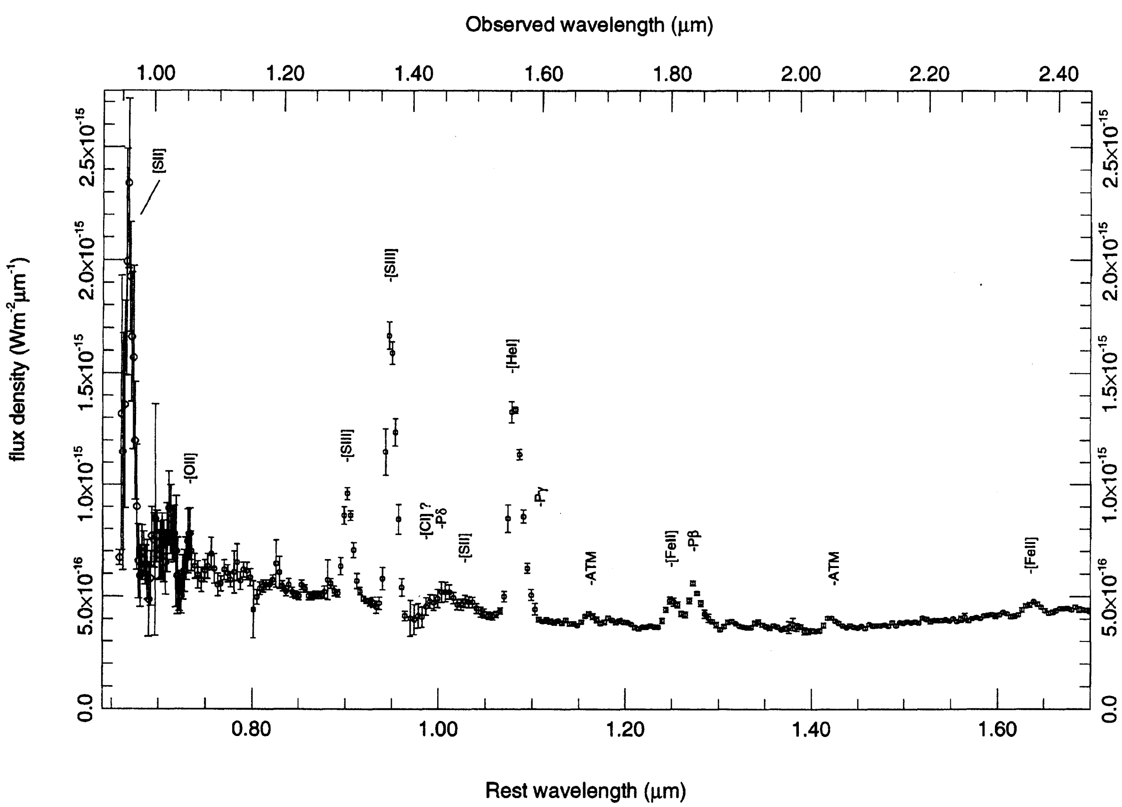

FIG. 2. The optical/near infrared spectrum of IRAS 09104+4109. The flux density is plotted vs wavelength. The rest frame wavelengths are plotted along the bottom, while the observed wavelengths are plotted on the top. The identified emission lines are indicated in the plot.

TABLE 2. Observed strengths of rest frames optical/near IR emission lines.

Rest Wavelength μm	ID	Observed Wavelength μm	Equivalent Width [a] nm	R [b]
0.668	[S II]	0.996	23.0±3.7	0.98 ±0.16
0.735	[O II]	1.057	3.1±1.4	0.12 ±0.05
0.903	[S III]	1.302	12.9±0.8	0.42 ±0.02
0.949	[S III]	1.369	34.9±1.5	1.02 ±0.04
0.988	[CI]?	1.425	2.7±0.6	0.095±0.02
1.005	Pδ	1.449	5.3±0.5	0.16 ±0.02
1.029	[S II]	1.484	3.3±0.5	0.095 ±0.01
1.080	[He I]+Pγ	1.557	34.3±1.4	1.00±0.04 [c]
1.161	?	1.674	0.8±0.3	0.02 ±0.01
1.251	[Fe II]	1.804	6.3±0.5	0.15 ±0.01
1.275	Pβ	1.839	8.8±0.5	0.21[d]±0.01
1.426	?	2.049	2.3±0.4	0.05 ±0.01
1.637	[Fe II]	2.361	2.0±0.6	0.06 ±0.02

[a]Rest frame

[b]R=F (line)/F(He 1.083μm)

[c]F(1.083μm)=2.0± 0.08 × 10^{-17} W/m^2

[d]uncertain due to atmospheric absorption

this to flux using the magnitude of the nucleus in a 3″ beam as measured in the imaging data. This procedure assumes that the line emitting region of the source is unresolved and coincident with the infrared bright nucleus. Since the spatial scale is ~ 5 kpc/″, the narrow line region should be unresolved, while the extension in [O III] (K88) contains <10% of the peak emission from the nucleus. The assumption of unresolved line emission is therefore probably accurate to the 10% level.

The detection of the Paschen lines of hydrogen and the [S II] 1.03 μm line, coupled with lines measured in the visible, permits the reddening to the line emitting region to be determined in a comparatively model independent manner over quite a broad range in wavelength. To determine the reddening to the narrow line region in IRAS 09104+4109, the observed ratio of line fluxes for the [S II] lines at 0.407 μm and 1.03 μm was used as was the Pδ to Hβ ratio assuming case B recombination (Osterbrock, 1989). The [S II] 1.03 μm and 0.407 μm lines come from the same upper level, and the intrinsic line ratios of these lines and the hydrogen recombination lines are well understood. The Pδ/Hβ ratio was chosen instead of the substantially stronger Pβ line to derive the reddening because the Pβ line is in a portion of the spectrum where the atmospheric transmission is changing rapidly, and so the line flux is unreliable. The P δ line however comes in a clean portion of the atmosphere and its flux, though comparatively small, is unaffected by significant atmospheric absorption. To compare the optical and infrared lines, we have assumed that the flux calibrations of both spectra refer to the same physical region. As mentioned above, the small extension to the northeast of the nucleus in [O III] 5007 Å presented by K88 contains <10% of the total [O III] flux, and so is consistent to within the uncertainties, with this assumption. In the case of the infrared spectrum, if the flux were emitted over an 8″ diameter disk with constant line equivalent widths, the flux in the lines would increase by at most 15% as compared to a point source.

A reddening between 0.407 μm and 1.030 μm of 1.13 ±0.15 mag is derived from the [S II] lines, while a reddening between 0.486 μm and 1.005 μm from the hydrogen lines of 1.69±0.1 mag is derived. Based on the reddening curves of Cardelli *et al.* (1989), these lead to A_v's of 1.18 mag and 2.45 mag respectively. This is consistent with the value of E(B−V) of 0.5 mag, corresponding to $A_v = 1.5$ mag, derived by K88 based on the He II 0.32 μm and 0.46 μm lines. The spread in the derived reddening between the different line ratios is consistent with the uncertainty in the comparison of the infrared and visible line fluxes, and we therefore take this spread as the appropriate uncertainty in the extinction and adopt A_v of 1.8±0.6 mag as the extinction to the narrow line region.

4. DISCUSSION

The infrared images of IRAS 09104+4109 are qualitatively quite similar to the optical imaging reported previously by K88 and HN. K88 suggest that the *IRAS* source is the cD galaxy associated with a rich cluster of galaxies while most of the companion objects are probably galaxies in the cluster surrounding the central galaxy. The infrared colors and brightnesses of the objects in the images are generally consistent with this picture. The range of colors found for the companion objects in these images, i.e., $R-K$ ~3.5±0.5 mag, $J-H$~0.9±0.2 mag and $H-K$~0.7±0.2 mag are consistent with galaxies at a redshift of 0.4, based on the models for galaxy colors given by Bruzual (1983) & Bruzual and Charlot (1993), and the observations of two clusters at z~0.4 of Stanford *et al.* (1995). Stanford *et al.* have shown that the scatter in the near infrared colors with morphology in clusters at z=0.4 is large enough that these colors cannot be used to reliably discriminate between elliptical and spiral galaxies at this redshift. Furthermore, while the apparent K band luminosity of the cD galaxy is quite large, as discussed by K88, it is typical for cD galaxies, and the surrounding galaxies have luminosities in the range $M_K \sim -22.5$ mag to −25 mag. For comparison, M_K^* (Schecter 1976) for field galaxies is ~−25.2 mag (Mobasher *et al.* 1993).

Recently it has been found that the apparently most luminous known far-infrared source, FSC 10214+4724, has a luminosity greatly magnified by gravitational lensing by a foreground galaxy (Graham & Liu 1995, Broadhurst & Lehár 1995, Eisenhardt *et al.* 1995). An immediate question arises of whether IRAS 09104+4109 could be magnified in apparent luminosity by a foreground galaxy. The coincidence of the apparently large luminosity far infrared source with a massive cD galaxy would be a natural configuration for a lens. There is no evidence for a lens morphology in the K image of IRAS 09104+4109 at 0.7″ resolution. K88 report the detection of Ca II absorption at the same redshift as the emission line redshift of z=0.442 in the spectrum of the optical counterpart. If the far infrared source corresponds to the emission line source, the cD galaxy and the far infrared source are at the same redshift and there is no evidence that lensing is a significant effect in this system. Thus we will not consider this option further, although higher resolution images such as available with the *HST* would provide a definitive resolution to this question.

The nucleus of the bright cD galaxy, the environment that is most likely to be producing the large infrared luminosity of the system, is redder in $J-K$ by only 0.2 mag than the surrounding envelope. Correcting for the strong [S II] lines in the J band increases this to 0.4 mag. The nucleus does not have the strong near infrared excess seen is many nearby high luminosity infrared bright galaxies (Sanders *et al.* 1988) where thermal emission from hot dust appears to make a significant contribution to the emission beyond 2 μm. The lack of a strong near infrared excess in IRAS 09104+4109 is most probably due to the significant redshift of this system, since the observed K band flux is centered at a rest wavelength of 1.5 μm, where thermal dust emission is not yet signficant. The contribution from the dust emission that dominates at wavelengths >3.5 μm is negligible at observed wavelengths $\leqslant$2.2 μm, since the inferred dust temperature is ~500 K. The slightly reddened core could well be simply a combination of the AGN in the nucleus of this system, coupled with the dust that is apparently slightly reddening the narrow-line region.

Based on the observed color temperature of 170 K for the far infrared emission, the bolometric luminosity of the far infrared source requires a minimum radius of ~30 pc for blackbody emission. This radius could be as large as 1 kpc if the emission arises from optically thin graphite grains. Furthermore, $\sim 10^{10} M_\odot$ of interstellar gas and dust is required to emit the infrared luminosity of the galaxy (K88). Although no red nucleus is seen, the projected scale of 5 kpc/″ implies that the "nuclear" colors may be strongly affected by the stellar population of the bulge, which could reduce the effect of such a dusty environment on the external appearance of the galaxy.

The separate brightness peaks within the diffuse (presumably stellar) envelope of the cD galaxy (source 9, 10, 11, 13, 14 and 15 in Table 1) are themselves intrinsically luminous systems having $M_K = -20$ to -24 mag. These are much brighter than globular clusters in the Milky Way which have $M_K \sim -15$ mag, but are comparable to the bulges of nearby spiral galaxies where $-22 < M_K < -18$ (Aaronson 1977), and to the nuclei of the galaxies in the cluster. This is consistent with what is known about the properties of the multiple nuclei in cD galaxies observed in the visible (e.g. Hoessel & Schneider, 1985).

The colors of the embedded peaks in the central galaxy, $R-K \sim 3.4-5.0$ mag, are also much redder than the young stellar clusters found around NGC 1275 by Holtzman *et al.* (1992). Since it is believed that cD galaxies are built up through the accretion of less massive cluster members (e.g. Ostriker & Hausman 1977, Hausman & Ostriker 1978, Tonry 1987, although alternative explanations have been put forward, e.g. Fabian *et al.* 1982), these near infrared knots may be the remnants of cluster galaxies which either have been or are in the process of being disrupted by IRAS 09104+4109. It is also possible that these remnants have supplied not only the dust which re-radiates the bolometric luminosity of IRAS 09104+4109 into the far infrared, but also the raw material

TABLE 3. Reddening corrected line strengths

	NGC1614 [a]	NGC6240 [b]	NGC 4151[c]	NGC 1068 [b]	IRAS 09104+4109
	starburst	LINER	Seyfert 1	Seyfert 2	
[OIII]5007/Hβ	0.68	1.26	13.4	12.7	11.5
[SII]6713+6730/Hα	0.19	0.97	0.56	0.33	0.33
[OII]7325/Hα	0.015	0.09	0.092	0.074	0.032
[SIII]9070+9531/Hα	0.35	0.18	0.62	0.92	0.25

[a]from Kirhakos and Phillips, 1989

[b]from Osterbrock et al. 1992

[c]from Osterbrock et al. 1990

(in the form of interstellar gas and/or stars) which fuels the central AGN. If the lifetime of the luminous infrared phase of this system is of the same order as that estimated for nearby ultraluminous infrared galaxies, i.e. a few $\times 10^8$ yrs, (Carico *et al.* 1990, Murphy *et al.* 1995) the most obvious source of the interstellar material in the cD galaxy would be one or more of the nearby infrared sources within 15 kpc of the nucleus (objects 10 or 11 in Table 1) since these appear to be the only systems that might be able to provide matter on a dynamical timescale as short as a few $\times 10^8$ yrs.

The near infrared spectroscopy reported here is consistent with the picture of this source, first deduced from optical spectroscopy, as a dust enshrouded AGN. No broad lines are seen in the spectrum of Figure 2, either in the hydrogen recombination lines or in the He I 10830 Å line. The reddening to the emission line region, derived from the near infrared and optical hydrogen recombination lines and lines of [S II], of $A_v \sim 1.8$ mag, is not extreme. The reddening is comparable to, but slightly larger than that seen in quasars where the broad line regions are directly visible (see e.g. Osterbrock, 1989, p. 362).

Indeed, it is perhaps surprising that the reddening is as small as it is given the large infrared luminosity of the galaxy. For instance, in the nearby high luminosity infrared bright galaxy Arp 220, observations of the Pβ/Brγ ratio give $A_v \sim 9-13$ mag (Larkin, et al. 1995). This suggests that the dust in IRAS 0 09104+4109 directly views the central UV source, but does not significantly obscure the narrow line region. This furthermore implies that the dust is perhaps in a disk-like geometry that directly blocks the power source from our line of sight but not from that of the narrow line gas.

In Table 3 the observed line ratios in IRAS 09104+4109 are compared with those in the prototypical IR luminous LINER (NGC 6240), starburst galaxy (NGC 1614), Seyfert 1 galaxy (NGC 4151) and Seyfert 2 galaxy (NGC 1068). The data are taken from Kirhakos & Phillips (1989), Osterbrock *et al.* (1992), K88 and the present observations. All the observed lines have been corrected for $A_v = 1.8$ mag, with the intrinsic Hα/Hβ ratio assumed to be 3.0, close to that typically found in AGNs (e.g. Osterbrock 1989).

The large [O III]/Hβ ratio which is in excess of 10 for IRAS 09104+4109 suggests an ionization source inconsistent with hot stars. Osterbrock, *et al.* (1992) have developed diagnostics for the near infrared line ratios [S II] 6713 +6730/Hα, [O II] 7325/Hα and [S II] 9069+9531/Hα that distinguish between starburst, LINER and Seyfert nuclei.

The identifications are inconclusive, IRAS 09104+4109 falls in the area of the line ratios occupied by all three classes of AGN. This is seen in Table 3, where the line ratios found in IRAS 09104+4109 are intermediate between the other systems.

The near infrared lines of [Fe II] at 1.257 and 1.644 μm are prominent in the spectrum of Figure 2. The apparent [Fe II]1.257 μm/[Fe II]1.644 μm ratio from Table 2, of 2.5$\pm$0.9 is larger than the expected value of 1.37 for no extinction (Nussbaumer & Storey 1988), but consistent with the expected value, given the uncertainties in the measurements. The non-detection of the [Fe II] 0.8617 μm line in the near infrared spectrum places a limit of T<8,000-15,000 K for electron densities less than $\sim 10^4$-10^3 cm^{-3} (Nussbaumer and Storey), again consistent with the narrow line environment seen in the optical lines and the temperature of $\sim$15,000 K inferred from the ratio of the [O III] 4363/5007 lines (K88).

The ratio of the [Fe II] 1.644 μm luminosity to bolometric luminosity is 3.5×10^{-5}, which falls in the range of values found for both AGN and starburst nuclei (Mouri *et al.* 1993). The ratio of [Fe II] to Paschen recombination lines is also consistent with that found in other AGN and starburst nuclei (e.g. Blietz *et al.* 1994), and is therefore not an effective way to determine the power source in this galaxy.

5. SUMMARY

Near infrared imaging of the environment of the highly luminous infrared source IRAS 09104+4109 shows six luminous ($M_K \sim -20$ mag to -24 mag) condensations which may be the stripped bulges of disrupted cluster galaxies within the extended envelope of the cD galaxy. The infrared sources at radaii 40-150 kpc from the cD nucleus have near infrared colors and infrared brightness expected for galaxies at the redshift of IRAS 09104+4109, i.e. z=0.442. While the nucleus of the cD galaxy is identified with the powerful far infrared source (K88), there is only a slight reddening of the nucleus over the surrounding galaxy. This suggests that the extended stellar bulge surrounding the galaxy nucleus dominates the dusty nucleus at these wavelengths. It is likely that the source of the dust that radiates the huge bolometric luminosity, and the gas which may fuel the central AGN, is one or more of the nearby companion galaxies in the process of being "devoured" by the central cD galaxy. Grism spectroscopy of the nucleus of IRAS 09104+4109 shows strong emission from low excitation lines of [S II], [S III], and [Fe II] and He I, as well as strong recombination lines of hydrogen. The [S II] 1.03 μm and Pδ lines, in combination with [S II] 0.407 μm and Hβ (K88), lead to a visual extinction A_v to the narrow line region of 1.8 mag. The relative line strengths are similar to those seen in narrow line AGN, and together with the lack of any clear permitted broad line component in the visible or near infrared, are consistent with the Seyfert 2 nuclear classification suggested by K88.

We thank W. Harrison for assistance with the observations. J. Hutchings kindly provided the *R* image of IRAS 09104+4109. It is a pleasure to thank the W. M. Keck Foundation and its President, Howard B. Keck, for the generous grant that made the W. M. Keck Observatory possible. Infrared astronomy at Caltech is supported by grants from the NSF and NASA. This research has made use of the NASA/IPAC Extragalactic Database which is operated by the Jet Propulsion Laboratory, Caltech, under contract with NASA.

REFERENCES

Aaronson, M. 1977, Ph.D. thesis, Harvard University
Blietz, M., Cameron, M., Drapatz, S., Genzel, R., Krabbe, A., van der Werf, P., Sternberg, A., and Ward, M. 1994, ApJ, 421, 92
Broadhurst, T.J., & Lehár, J. 1995, ApJ, 450, L41
Bruzual, G.A. 1983, ApJ, 273, 105
Bruzual, G. A., & Charlot, S. 1993, ApJ, 405, 538
Cardelli, J.A., Clayton, G.C., & Mathis, J.S. 1989, ApJ, 345, 245
Carico, D.P., Graham, J.R., Matthews, K., Wilson, T.D., Soifer, B.T., Neugebauer, G., & Sanders, D.B. 1990, ApJ, 349, L39
Casali, M. M., & Hawarden, T. G. 1992, UKIRT standards list (private communication)
de Jong, T., Klein, U., Wielebinski, R., & Wunderlich, E. 1985, A&A, 147, L6
Eisnehardt, P.R., Armus, L., Hogg, D.W., Soifer, B.T., Neugebauer, G., & Werner, M.W. 1995, ApJ (in press)
Fabian, A.C., Nulsen, P.E.J., & Canizares, C.R. 1982, MNRAS, 180, 479
Ferland, G.J. 1991, OSU Internal Report 91-01
Graham, J.R., & Liu, M.C. 1995, ApJ, 449, L29
Hausman, M.A., & Ostriker, J.P. 1978, ApJ, 224, 320
Helou, G., Soifer, B.T., & Rowan-Robinson, M.M. 1985, ApJ, 298, L7
Hines, D.C., Wills, B.J. 1993, ApJ, 415, 82
Hoessel, J.G., & Schneider, D.P. 1985, AJ, 90, 1648
Holtzman, J.A., etal. 1992, AJ, 103, 691
Hutchings, J.B., & Neff, S.G. (HN) 1988, AJ, 96, 1575
Kleinmann, S.G., Hamilton, D., Keel, W.C., Wynn-Williams, C.G., Eales, S.A., Becklin, E.E., & Kuntz, K.D. (K88) 1988, ApJ, 328, 161
Kleinmann, S.G. & Keel, W.C. 1987, in Star Formation in Galaxies, edited by C. Lonsdale, NASA Conf. Pub. 2466, p. 559
Kirhakos, S., & Phillips, M.M. 1989, PASP, 101, 949
Larkin, J.E., Armus, L., Knop, R.A., Matthews, K., & Soifer, B.T. 1995, ApJ 452, 559
Matthews, K., & Soifer, B.T. 1994, in Infrared Astronomy with Arrays: the Next Generation, edited by I. McLean (Kluwer Academic Publishers, Dordrecht), p. 239
Mobasher, B., Sharples, R.M. & Ellis, R.S. 1993, MNRAS, 263, 560
Mouri, H., Kawara, H., & Taniguchi, Y. 1993, ApJ, 406, 52
Murphy, T.W., Armus, L., Soifer, B.T., Matthews, K., Mazzarella, J.M., Shupe, D.L., Strauss, M., & Neugebauer, G., 1996, AJ (in press)
Nussbaumer, H., & Storey, P.J. 1988, A&A, 193, 327
Oliva, E., & Moorwood, A.F.M. 1990, ApJ 348, L5
Osterbrock, D.E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei (University Science Books, Mill Valley), p. 80
Osterbrock, D.E., Shaw, R.A., & Veilleux, S. 1990, ApJ, 352, 561
Osterbrock, D.E., Tran, H.D., & Veilleux, S. 1992, ApJ, 389, 196
Ostriker, J.P., & Hausman, M.A. 1977, ApJ, 217, L125
Sanders, D.B., Soifer, B.T., Elias, J.H., Madore, B.F., Matthews, K., Neugebauer, G., & Scoville, N.Z. 1988, ApJ, 325, 74
Schecter, P. 1976, ApJ, 203, 297
Stanford, S.A., Eisenhardt, P.R.M.E., & Dickinson, M. 1995, ApJ, 450, 512
Tonry, J.L. 1987, in Structure and Dynamics of Elliptical Galaxies, edited by T.de Zeeuw (Reidel, Dordrecht) p. 89