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NEAR-INFRARED OBSERVATIONS OF FSC 15307+3252[1]

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ABSTRACT

Near-infrared observations of the infrared luminous galaxy FSC 15307+3252 are reported. Imaging shows that there is at least one, and possibly more, companion sources within 1".5. Near-infrared spectra show the lines of a low-redshift Seyfert 2 galaxy in the visible, and the line ratios are characteristic of narrow-line AGNs. We conclude that FSC 15307+3252 represents an extension of the infrared bright systems to higher luminosities.

Subject headings: galaxies: individual (IRAS FSC 15307+3252) — galaxies: photometry — galaxies: starburst — infrared: galaxies

1. INTRODUCTION

Recently Cutrie et al. (1994, hereafter CHLBV) have identified a source, FSC 15307+3252, in the *IRAS* Faint Source Catalog (Moshir et al. 1992) with a highly luminous ($L \sim 10^{13}\ L_\odot$) galaxy at a redshift of $z = 0.93$. Besides its high luminosity the source is distinguished by its warm far-infrared color (i.e., a large ratio $f_\nu[25\ \mu m]/f_\nu[60\ \mu m] \sim 0.3$) and the presence of strong neon emission lines in its optical spectrum; the optical spectrum resembles the rest-frame ultraviolet spectrum of a Seyfert 2 galaxy. CHLBV suggest that the galaxy is powered largely by a starburst and that it is a member of a new class of galaxy.

Alternately, FSC 15307+3252 could be an extreme example of the ultraluminous galaxies discovered in the *IRAS* mission. Sanders et al. (1988) have shown that nearly all of the ultraluminous galaxies, which emit the bulk of their luminosity in the infrared, are, in fact, composed of the mergers of two galaxies. Sanders et al. have further suggested that these highly luminous galaxies may be the progenitors of active galactic nuclei (AGNs). The nature of the power source of the ultraluminous galaxies is uncertain. There is evidence that the galaxies are powered both by massive bursts of star formation and by AGNs within the nuclear region. The currently prevailing opinion is that both sources contribute to the observed luminosity.

We have obtained near-infrared images of FSC 15307+3252 and a near-infrared spectrum using the Keck Telescope. These show that FSC 15307+3252 shares many of the properties of other ultraluminous galaxies.

2. OBSERVATIONS AND DATA REDUCTION

The object FSC 15307+3252 was observed using the NIRC (Matthews & Soifer 1993) at the forward Cassegrain focus of the Keck Telescope in Hawaii. The camera uses a 256 × 256 pixel InSb array; the scale is 0".15 pixel^{-1} yielding a 38" × 38" image. Data were obtained on the night of 1994 May 1 (UT); the night was photometric and the seeing was about 1" full width at half-maximum. Nine exposures, each individually taking 60 s, were obtained at 1.25 μm (J), 1.65 μm (H), and 2.2 μm (K). An initial image was centered at the coordinates given by CHLBV, and the eight subsequent images were taken at locations offset at intervals of 5" in a box pattern. The photometric calibration was obtained by observing the UKIRT photometric standards FS24 and FS25 (Casali & Hawarden 1992) immediately after the observations of FSC 15307+3252.

In the data reduction, a sky image constructed as the median of all the nine frames was subtracted from each of the individual images. The median sky image was also used to flat-field the individual images. Subsequently the sky-subtracted and flat-fielded images were mosaiced into a single image by centroiding and collocating the star about 20" to the north and slightly east of FSC 15307+3252. Each 60 s frame was analyzed photometrically before the frames were mosaiced. The flux density of the companion nucleus was determined from the photometry of the primary nucleus.

Grism spectra with a resolution $\lambda/d\lambda \sim 100$ were also obtained with the NIRC and a 0".6 wide slit centered on the brightest peak and oriented at a position angle of 82°. Five separate spectra each of 180 s duration were obtained at steps of 5" along the slit, and neighboring spectra were used to subtract the sky. Individual spectra of the central 1".4 along the slit were extracted by subtracting the residual sky flux within about 5" of the peak spectra and the different individual spectra were averaged. The spectra were at observed wavelengths from 0.94 through 1.59 μm; atmospheric absorption effectively obliterated the wavelength region from 1.35 μm through 1.41 μm. Atmospheric features and detector efficiency variations were removed by dividing by the spectrum of the G1 V star BS 3881 obtained at a similar air mass. The rest wavelengths were calculated assuming the redshift of 0.926 (CHLBV).

3. RESULTS

The K image of FSC 15307+3252 is shown in Figure 1 (Plate L3). The image clearly shows the presence of a second nucleus at a position angle of ~130° with a separation of about 1".6. The second nucleus has, within the uncertainty of the measurement, the same colors as the primary nucleus. It is, however, a factor of ~10 fainter than the primary nucleus. The image also shows an extension to the east, not seen in the field star images, which may indicate another fainter nucleus.

[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.

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PLATE L3

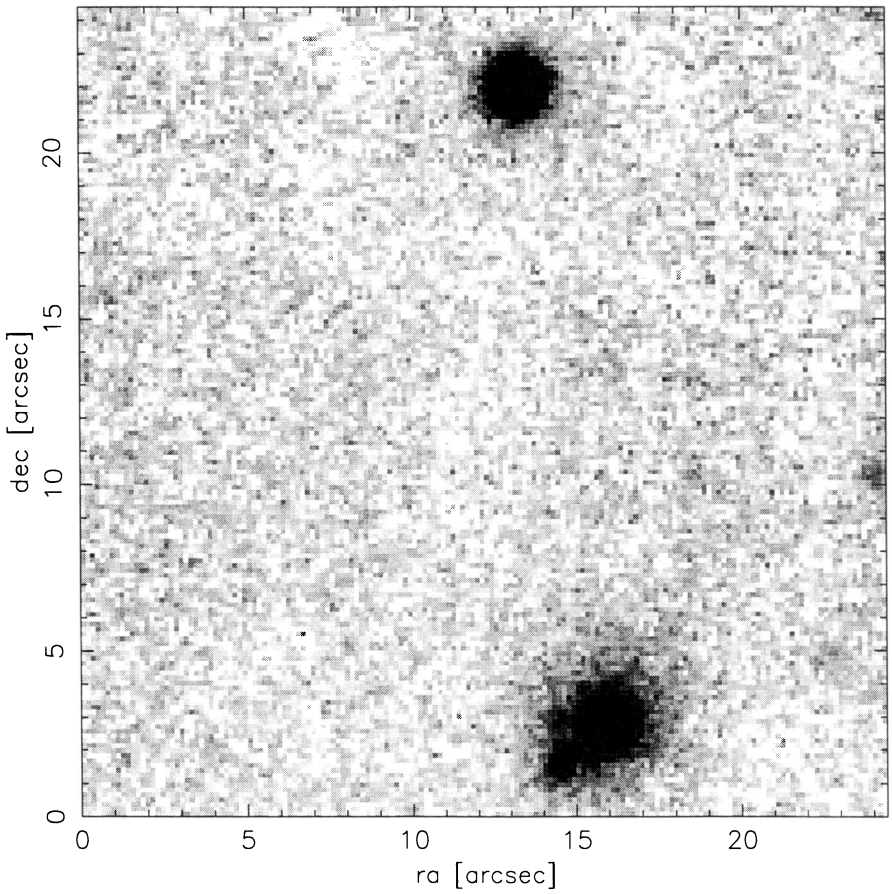

FIG. 1.—Mosaic of nine 60 s images of FSC 15307+3252 at 2.2 μm is shown at the bottom of the frame. East is to the left and north is up. The companion galaxy 1.″6 from the primary nucleus and to the south east is obvious. An extension to the east, possibly a third nucleus, is just visible. The star $\sim$20″ to the north is displayed to show the point-spread function of the seeing; the location of the object at the bottom of the frame was dictated by the desire to include this star in each image.

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TABLE 1

NEAR-INFRARED PHOTOMETRY OF FSC 15307+3252

Object	Radius	K (mag)	$J-H$ (mag)	$H-K$ (mag)
FSC 15307	0".75	16.61 ± 0.04	0.29 ± 0.09	0.98 ± 0.08
	1.50	16.33 ± 0.02	0.34 ± 0.04	0.99 ± 0.04
	2.25	16.11 ± 0.02	0.39 ± 0.03	0.97 ± 0.04
	3.00	15.98 ± 0.03	0.39 ± 0.04	0.98 ± 0.04
	3.75	15.95 ± 0.03	0.41 ± 0.03	0.94 ± 0.04
	4.50	15.93 ± 0.04	0.41 ± 0.03	0.93 ± 0.05
Star A	4.50	15.79 ± 0.02	0.58 ± 0.03	0.25 ± 0.03
CHLBV	4.50	15.79 ± 0.09	0.57 ± 0.11	1.22 ± 0.12

The near-infrared photometry of FSC 15307+3252 is shown in Table 1, along with that of CHLBV, which was done with a 9″ (diameter) beam. Curves of growth of the enclosed energy versus the beam radius were measured from the images at J, H, and K; these measurements are included in Table 1. The sky for each beam was taken to be an annulus between a diameter of 9″ and 12″, and the uncertainties in the data given in Table 1 reflect the internal dispersion between the photometry of the nine individual images. Figure 1 and Table 1 show that FSC 15307+3252 is clearly extended. Approximately 20% of the emitted energy comes from a region of radius greater than 2″; at the redshift of FSC 15307+3252 this corresponds to 11 kpc. The near-infrared magnitudes differ from those given by CHLBV by up to 0.3 mag in a manner that makes the difference in the colors of the object more extreme. The possibility of variability will have to wait for further observations.

The grism spectrum of the nucleus of FSC 15307+3252 is shown in Figure 2. The lines of Hα and [N II] are clearly present at rest-frame wavelengths $\lambda = 0.657$ μm with an equivalent width in the rest frame of 0.067 ± 0.002 μm. The width of the lines, set by the instrumental resolution, is less than 3000 km s^{-1} which is not sufficient to resolve the lines. The [S II] line at 0.672 μm and the [O I] line at 0.630 μm are also present; these equivalent widths are 0.009 ± 0.001 and 0.003 ± 0.001 μm.

4. DISCUSSION

The image of Figure 1 immediately shows that FSC 15307+3252 is, in common with most ultraluminous infrared galaxies, a composite system made up of two or more merging galaxies. At the distance of FSC 15307+3252, the separation of the nuclei is approximately 10 kpc ($H_0 = 75$ km s^{-1} Mpc^{-1}). The extent of the emission at 2.2 μm, to a diameter of ~50 kpc, shows that the nucleus is in a large galaxy. This is quite reminiscent of IRAS 09104+4109 (Kleinmann et al. 1988) which was also found to be a high-excitation system in a large galaxy. IRAS 09104+4109 was shown to be the dominant galaxy of a cluster at a redshift $z = 0.44$. The possible presence of two close companions suggests that the same might be the case in this system.

The density of galaxies with a K magnitude of $K < 18.5$ mag is ~10^{-3} (Cowie et al. 1994; Soifer et al. 1994). Thus the chance of an accidental coincidence within a radius of 1".6 is less than 1%. The number and colors of the objects seen in the ~45″ × 45″ mosaiced field are in agreement with the number

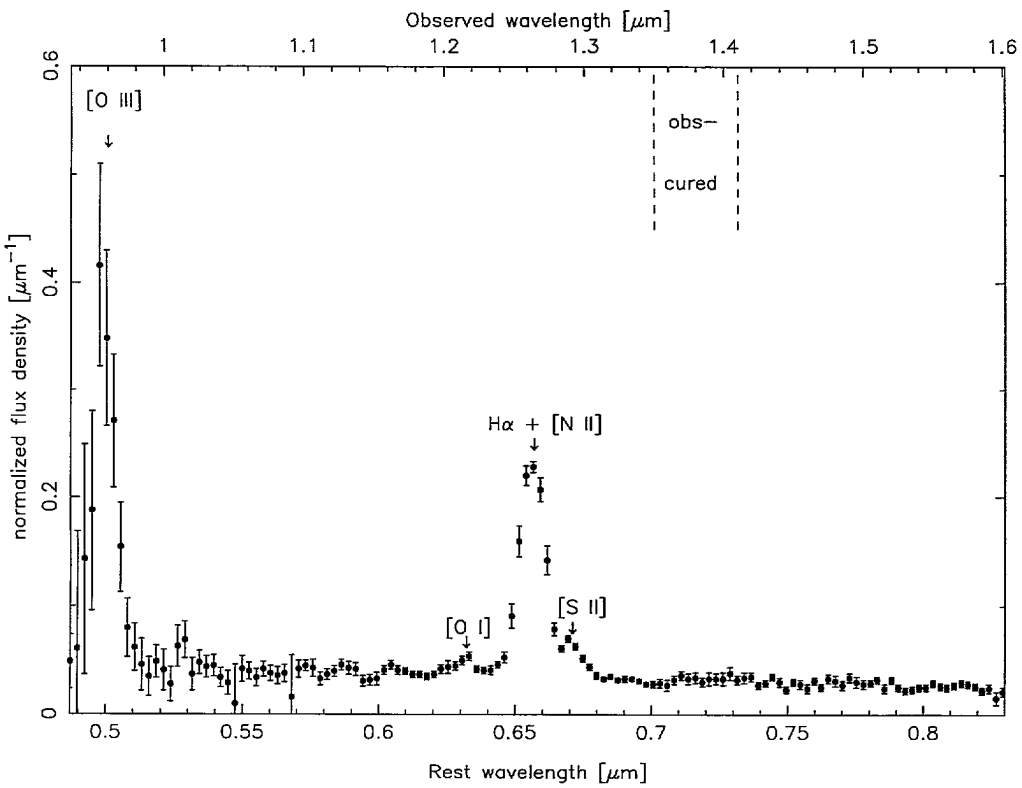

FIG. 2.—Grism spectrum of FSC 15307+3252 is shown. Lines of [O III] at 0.499 μm, [O I] at 0.630 μm, and the blend of Halp and [N II] 0.657 and [S II] at 0.672 μm are indicated. All the lines are unresolved at the resolution of the grism ($\lambda/d\lambda \sim 100$). The scale at the top of the figure represents the observed wavelengths and that at the bottom the rest-frame wavelengths at a redshift $z = 0.926$.

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of counts and colors of faint galaxies given by Cowie et al., Soifer et al., and Matthews et al. (1994).

The spectral lines detected in Figure 2 are also the strongest lines in the rest-frame visible spectra of typical narrow-line AGNs, and are comparable in strength to those found in low-redshift AGNs (Osterbrock 1989). Furthermore, it is not surprising, given the low resolution of the spectrum, that other, weaker lines are not seen. Thus the visible rest-frame spectrum, like the rest-frame ultraviolet spectra of CHLBV, resembles that of a Seyfert 2 galaxy.

From the spectrum of Figure 2 it is possible to address the origin of the luminosity of FSC 15307+3252. Osterbrock (1989) presents diagnostic diagrams of line ratios containing model calculations and observations of the ratios of the lines in question. An adaptation of the relevant figures from Osterbrock is given in Figure 3 which shows the range of line ratios for narrow-line AGNs (upper right) and H II–region galaxies (lower left). The abscissa of Figure 3 is the ratio of the line strengths of [O I] 0.630 μm and of [S II] 0.672 μm to Hα. The Hα and [N II] lines at 0.657 μm are not separated at the resolution of the grism; consequently the line at 0.657 μm was assumed to be only Hα to set a lower limit on the line ratio in FSC 15307+3252. Osterbrock shows that the ratio [N II] 0.658 μm/Hα lies in the range from about 0.01 to about 2, so that the ratio shown is truly a lower limit. Crudely speaking, the ratio [N II]/Hα < 0.5 for H II region–like objects and [N II]/Hα > 0.5 for narrow-line AGNs.

The [O III] 0.5007/Hβ line ratio shown in Figure 3 for FSC 15307+3252 was computed assuming an Hα/Hβ ratio of 2.8 (Brocklehurst 1971) and an [O III] 0.4959/0.5007 ratio of 0.33. Essentially all emission-line galaxies with significant reddening have Hα/Hβ > 2.8; for example, the extinction in the Seyfert galaxy NGC 1068, estimated to be only $E(B-V) = 0.5$ mag, results in a ratio Hα/H$\beta \sim 5.4$ (Neugebauer et al. 1980). In addition, the ratio shown for FSC 15307+3252 was again calculated on the assumption that all of the line at 0.658 μm was Hα. Thus both the quoted ratios are lower limits to the true values.

The limiting ratios from these observations, log ([O III] 0.499/Hβ) > 0.6, log ([S II] 0.672/Hα) > −0.8, and log ([O I] 0.630/Hα) > −1.3 are indicated by dashed lines in Figure 3. The permissible values of the line ratios of FSC 15307+3252 are above and to the right of the dashed lines. It is seen that for both types of lines, the ratios fall in the area occupied by narrow-line AGNs. Although the observations imply a non-thermal energy source, the lack of obvious line broadening indicates that the broad-line is not seen directly, although the limits on the line widths are not strong.

5. SUMMARY

Our observations have shown that FSC 15307+3252 shares many observational properties of other ultraluminous infrared galaxies. It is an interacting system with a bright nucleus and one or possibly two companion systems within 10 kpc. The bright nucleus has the UV and visual spectrum of a Seyfert 2 galaxy. There is no evidence for strong, broad hydrogen recombination line emission in this source, although the limits here are not strong. Its unique properties are those of a system with a luminosity ~10 times that of the closest examples of the highest luminosity infrared bright galaxies. This suggests that

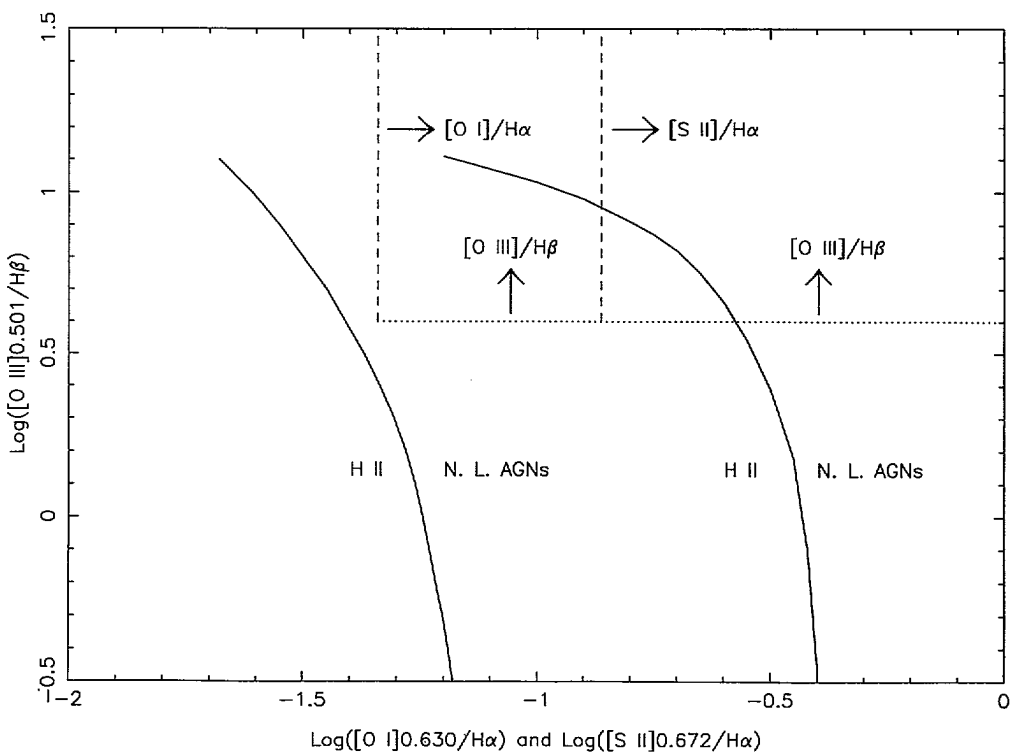

FIG. 3.—Diagnostic diagram adapted from Osterbrock (1989) is shown. Theoretically, H II region–like objects lie to the left of the solid curves and narrow line AGNs lie to the right of the solid curves for the ratio log ([O I] 0.630/Hα) (*left solid curve*) and for log ([S II] 0.672/Hα). (*right solid curve*). The measured lower limits of the line ratios in FSC 15307+3252 are shown by the left vertical dashed line for log ([O I] 0.630/Hα) and by the right dashed line for log ([S II] 0.672/Hα). The dotted horizontal line shows the lower limit to the ratio log ([O III] 0.501/Hβ) as derived from the observations.

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FSC 15307+3252 represents an extension of the infrared bright systems to higher luminosities.

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