IRAS 23060 + 0505: A HIGHLY OBSCURED $3.3 \times 10^{12} L_\odot$ ACTIVE GALAXY

G. J. Hill, 1 C. G. Wynn-Williams, 1 and E. E. Becklin 1

Institute for Astronomy, University of Hawaii
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ABSTRACT

We report ground-based observations of the high-luminosity ($3.3 \times 10^{12} L_\odot$) IRAS galaxy 23060 + 0505. It has a 0.5–100 $\mu$m energy distribution characteristic of a Seyfert 1 galaxy but very little sign of the broad Balmer lines normally seen in active galaxies. We argue that the galaxy contains a hidden active nucleus that is surrounded by dust thick enough to absorb visible light but thin enough to leave the infrared energy distribution virtually undistorted.

Subject headings: galaxies: nuclei — galaxies: Seyfert — infrared: sources

I. INTRODUCTION

As part of an IRAS followup program, we have been obtaining redshifts, CCD imagery, and infrared photometry of a number of IRAS point sources that are identified with galaxies and that have "hot" ($S_{25}/S_{60} > 0.3$) far-infrared energy distributions. These sources are drawn from the preliminary IRAS lists P11 and P16 and include 23060 + 0505, a member of the P16 list. Such galaxies often show nuclear activity and exhibit large [O III] $\lambda$5007/H$\beta$ line ratios ($\gtrsim 3$) and, in a few instances, broad Balmer lines (Carter 1984; de Grijs et al. 1985; Hill 1986).

The identification of IRAS 23060 + 0505 with a faint, compact, noticeably red object visible on the Palomar Observatory Sky Survey (POSS) prints was made at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii, in 1984 November. It was found to have unusually red J, H, K, and L' colors; subsequent spectroscopic observations at the University of Hawaii (UH) 2.2 m telescope showed it to be a galaxy at a redshift of $z = 0.1738 \pm 0.0005$, implying a large luminosity. The unusual properties of this source led us to obtain further observations as reported here.

In § II we report the observations and data reduction. In § III we discuss the properties and in § IV the nature of 23060 + 0505.

II. OBSERVATIONS

The J, H, K, L', and $N$ infrared photometry was obtained at the IRTF through a 5" aperture using standard InSb and bolometer photometer systems. The observations employed a 20" chop and were calibrated relative to nearby standard stars (Elias et al. 1982). The offset from the IRAS position (as given in the point source catalog [IRAS Explanatory Supplement 1985]) is 10" east and 6" north.

The visible wavelength spectroscopic observations of 1985 December 16 employed the UH grism spectrograph and the Galileo/Institute for Astronomy CCD camera mounted at the Cassegrain focus of the UH 2.2 m telescope. The spectrum was obtained through a 2" slit, has a resolution of 16 A, and covers the wavelength range around H$\beta$. These observations were supplemented by a higher quality 45 minute exposure centered on H$\alpha$ at a resolution of 8 A, kindly obtained by Dr. A. N. Stockton with the UH Faint Object Spectrograph (FOS) and CCD on 1986 September 6. This observation employed an image slicer with three 2" slits. The CCD processing was standard. The system response was corrected by comparison with the spectrophotometric standard stars HD 19445 for the grism observation, and BD +17°4708 for the FOS observation (Oke and Gunn 1983). A very broadband image covering approximately 4000–9000 A as defined by the system response was obtained through the FOS without a filter.

Observations were made at 2, 6, and 20 cm using the VLA 2 in "snapshot" mode, and integration times of $\sim 10$ minutes at each wavelength; to look for variability the 20 cm observations were repeated after an interval of about a year. Improved estimates of the IRAS flux densities (Table 1) were obtained by co-adding the IRAS data using the "ADDSCAN" program of the Image Processing and Calibration 3 facility at Pasadena.

III. RESULTS

The visible and infrared flux densities are presented in Table 1 and Figure 1. No visible photometry exists for this source, but pseudo-$V$ and $I$ flux densities have been calculated from the spectrophotometric observations. The luminosity of the source in the 0.5–120 $\mu$m band is $3.3 \times 10^{12} L_\odot$, based on its redshift of 0.1738 and a Hubble constant of 75 km s$^{-1}$ Mpc$^{-1}$.

A comparison of the flux density at $N$ in a 5" aperture with a simple extrapolation of the IRAS flux densities to

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10 µm reveals that 80% ± 30% of the IRAS flux density is detected in the smaller aperture. The visible image shows an unresolved (< 4″ object) with faint asymmetric emission extending 15″ (50 kpc) to the southwest. Seventy percent of the visible emission originates in the unresolved source. The extended emission may be due to a disturbed host galaxy or another closely interacting galaxy.

At centimeter wavelengths the source consists of a single unresolved component with a nonthermal spectrum (Table 1) and a diameter at 6 cm of < 0″2. Its 1950 position, 23°06′15″.5, +05°05′13″.9, is accurate to 0″1 and agrees with the optical/infrared position, as measured at the IRTF, to within 2″. No evidence was seen for variability at 20 cm. The power at 6 cm is log P = 22.5 W Hz⁻¹ sr⁻¹.

The 5200–6000 Å and 7300–8000 Å spectra are presented in Figures 2 and 3 and show lines of [O i], [O iii], [N ii], [S ii], and hydrogen. The key features are the large [O iii] λ5007 to Hβ ratio of 2.8 and the steep Balmer decrement giving Hα/Hβ = 12 ± 2. The spectrum most resembles that of a Seyfert 2 galaxy, but there are signs of a weak broad wing on the red slide of the Hα line, visible above the continuum between 7750 and 7800 Å. The feature is not visible on the blue wing due to the Fraunhofer A band atmospheric absorption, but if it is symmetrical it has a FWZI of ~ 3800
km s$^{-1}$. The FWHM of H$\alpha$, after correction for the [N II] lines, is $\sim 550$ km s$^{-1}$, typical of the narrow-line regions of active galactic nuclei.

IV. DISCUSSION

IRAS 23060 + 0505 is remarkable for its large luminosity of $3.3 \times 10^{12}$ and very steep visible to 3 $\mu$m continuum, consistent with a power law of index $\alpha = 2.8$ (where $S \propto \nu^{-\alpha}$). Figure 1 shows the visible to 100 $\mu$m energy distribution compared with those of other extragalactic objects. In this comparison, two features in the energy distribution of 23060 + 0505 are important. In most normal galaxies, the energy output at $J$, $H$, and $K$ is dominated by photospheric emission from late-type stars (see, e.g., Rieke and Lebofsky 1979), which causes a characteristic dip or inflection in the energy distribution between 2 and 3 $\mu$m. The lack of such an inflection shows that the 1–3 $\mu$m energy output is probably not dominated by starlight in 23060 + 0505. The detection of the majority of the IRAS flux density in a 5$''$5 aperture at $N$ possibly indicates a common origin for the near-infrared and far-infrared emission. The second feature is the flatness of the 25–100 $\mu$m energy distribution, indicating excess emission at 25 $\mu$m compared to typical IRAS galaxies (Carter 1984; de Grijs et al. 1985; Hill 1986). Figure 1a shows the energy distribution compared with the range observed for typical starburst and interacting galaxies (Joseph et al. 1984; Balzano 1983), and Figure 1b gives a comparison to typical Seyfert 2 galaxies (Rieke 1978). Both classes of galaxy are dominated at $J$, $H$, and $K$ by the photospheric emission from late-type stars.

A comparison to Seyfert 1 galaxies, QSOs, and BL Lac Objects (Neugebauer et al. 1979; Impey et al. 1982) is made in Figure 1c. It is striking that the energy distribution bears a marked resemblance to that of the BL Lac object with the steepest near-infrared energy distribution, 1413 + 135 (Beichman et al. 1981). However, 23060 + 0505 has a radio luminosity typical of the Seyfert galaxies studied by Ulvestad and Wilson (1984) and is much lower than typical BL Lac objects or radio-loud quasars (Neugebauer et al. 1986).

The infrared photometry therefore points to 23060 + 0505 containing a high-luminosity active nucleus. The observed luminosity of this object is comparable to those of the most luminous Seyfert 1 galaxies or to low-luminosity quasars, falling in the "hazy" region between the two classifications (Schmidt and Green 1983; Neugebauer et al. 1986). However, the visible spectrum (Fig. 2) shows only a very weak trace of the strong, broad permitted lines that would be expected from such an object. The strengths of the [O I], [N II], and [S II] lines relative to H$\alpha$ and [O III] relative to H$\beta$ are typical of active galaxies (e.g., Keel 1985) and are certainly inconsistent with the dominant energy source being a starburst (Baldwin, Phillips, and Terlevich 1981). It is therefore likely that the source contains a hidden AGN.

The weakness of the broad wing to H$\alpha$ is due either to heavy dust obscuration or to an intrinsic weakness. The broad line is not seen at H$\beta$, implying an H$\alpha$/H$\beta$ ratio of $> 5$, and a visual extinction of $> 2$ mag. The ratio of narrow H$\alpha$/H$\beta = 12 \pm 2$ implies a visual extinction of $A_{\nu} = 4.3 \pm 0.5$ mag, assuming an intrinsic case B recombination spectrum (Osterbrock 1974) and standard extinction curve (Savage and Mathis 1979). It should be noted that active galaxies selected by other means typically have visible extinctions of only a few tenths to 1 mag at most (Lacy et al. 1982). Such a large reddening in 23060 + 0505 leads one to anticipate that the extinction of the broad lines will be even greater. A similar argument has been put forward for the much lower luminosity.
narrow emission-line X-ray galaxies, which have similar properties to $23060+0505$ (Veron et al. 1980; Ward et al. 1984). If there is a heavily obscured broad-line region in $23060+0505$, then there may be a detectable broad component to the Paa line, which is redshifted into a region of good atmospheric transparency.

The steepness of the visible to near-infrared continuum is probably due to dust extinction, and it is likely that the majority of the flux density longward of 1 $\mu$m is due to thermal reradiation by this dust. The large extinction deduced for the narrow lines would tend to place some of this dust outside the narrow-line region.

The fact that this object was discovered in a survey of a relatively small number of candidates argues that there may be a significant, previously undetected, population of highly obscured AGN with luminosities approaching those of quasars. IRAS 13349+2438 is another object, selected in a similar manner, with an infrared luminosity comparable to $23060+0505$ but which exhibits strong broad lines and a much smaller extinction (Beichman et al. 1986). $23060+0505$ is an object where there is sufficient dust to almost totally obscure the nucleus in the visible and yet leave the infrared energy distribution relatively unchanged. A significantly larger amount of dust would distort the infrared emission to the extent that the $60-25$ $\mu$m flux density ratio would no longer be a useful diagnostic in the search for buried AGNs in the far-infrared. Arp 220, with its extreme infrared to blue luminosity ratio (Soifer et al. 1984) and signs of a hidden AGN from infrared spectroscopy (DePoy et al. 1987) may be such a case.

It is to be expected that infrared-selected AGN/QSOs will typically exhibit a much greater obscuration than those objects found by visible (particularly UV excess) surveys. The selection effects against even slightly reddened AGN in optical and UV surveys are well documented (see, e.g., Keel 1980; Lawrence and Elvis 1982), and Carter (1984) and de Grijp et al. (1985) have shown that there exists a significant population of (mainly Seyfert 2) active galaxies missed by other surveys. It is possible that some of these galaxies, classified as Seyfert 2 on the basis of optical spectroscopy, are similar to IRAS $23060+0505$ and are potentially hidden Seyfert 1 galaxies.

V. SUMMARY

We have demonstrated that IRAS $23060+0505$ is a highly luminous, compact extragalactic source at a redshift of 0.1738. It exhibits an infrared energy distribution characteristic of luminous Seyfert 1 galaxies or QSOs but with significantly redder colors and a highly reddened optical spectrum. These characteristics may be explained if this object contains a highly obscured AGN. It is possible that a significant population of such objects exists, which would only be recognizable with infrared observations.

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Note added in manuscript.—As pointed out by Jay Frogel, the properties of this object appear to be similar to those of 00521 – 7054 (Frogel and Elias 1987).

REFERENCES


E. E. BECKLIN, G. J. HILL, AND C. G. WYNNE-WILLIAMS: Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, HI 96822