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OPTICAL IDENTIFICATIONS OF THE ISOPHOT FIR SOURCES

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ABSTRACT

We present optical follow-up observations of the FIR sources found in our 175μm deep survey in the Lockman Hole (Kawara et al. 1998) using ISOPHOT on board *The Infrared Space Observatory* (ISO). Optical and NIR observations were made using ESI and NIRSPEC on Keck II, IRCS on Subaru, the 8k mosaic CCD camera on the UH2.2m, and VLA-B 6cm continuum observations. We have identified optical counterparts for 35 ISOPHOT FIR sources with redshifts in the range 0.03–1.6. We discuss their observational properties.

Subject headings: infrared: galaxies - galaxies: starburst - galaxies: evolution

1. INTRODUCTION

Deep surveys at far-infrared (FIR) and sub-milimeter wavelengths have been performed to investigate the nature of dust-enshrouded galaxies at high redshift. As a contribution to this field, our group made a deep FIR survey using the ISOPHOT FIR camera on board ISO (Kawara et al. 1998; Matsuhara et al. 2000). Mapping at 90μm and 170μm of two $44' \times 44'$ fields in the Lockman Hole, a region of the smallest HI column density in the sky (Lockman, Jahoda, & McCammon 1996), resulted in the detection of 36 and 45 sources brighter than 150 mJy at at 90μm and 170μm, respectively. Given the relatively large size of the ISOPHOT beam at 170μm ($\sim$90$''$), we have obtained opt/NIR images and spectra using telescopes on Mauna Kea and 6cm radio continuum maps using the VLA (Yun et al. 2002) to identify the most likely source of the 170μm emission. Here we report our initial identifications of the brightest of the ISOPHOT 170μm sources. Unless otherwise stated, we assume $H_o = 75$ km s^{-1}Mpc^{-1}, $q_o = 0$.

2. RESULTS AND DISCUSSION

Redshifts of 35 FIR source candidates were determined using optical spectra obtained with ESI on KeckII during three observing runs in 2000 March and 2001 January. To detect Balmer emission line, we also took near-infrared spectra of four sources with redshifts greater than 0.7 with NIRSPEC on KeckII in 2001 March. Infrared luminosities, $L_{\rm ir}(8-1000\mu m)$, were then estimated by using the ISOPHOT fluxes and assuming an SED similar to that of Arp220. Table 1 and Figure 1 show the distributions of redshift a and infrared luminosity of the ISOPHOT sources. We found one hyperluminous infrared galaxy (HyLIG: $L_{\rm ir} > 10^{13}L_{\odot}$) at $z = 1.6$, 11 ultraluminous infrared galaxies (ULIGs: $L_{\rm ir} > 10^{12}L_{\odot}$) at $0.3 < z < 1$, 12 luminous infrared galaxies (LIGs: $L_{\rm ir} > 10^{11}L_{\odot}$), and 11 galaxies with $L_{\rm ir} < 10^{11}L_{\odot}$. Except for one LIG at $z = 0.365$, all of the galaxies with $L_{\rm ir} < 10^{12}L_{\odot}$) are at $z < 0.3$. The mean redshift for all sources is 0.31 ± 0.31.

Optical spectra are also important for prob-

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TABLE 1
RESULTS OF SPECTROSCOPIC IDENTIFICATION

Redshift	Number
$z < 0.1$	10
$0.1 \leq z < 0.3$	12
$0.3 \leq z < 0.5$	6
$0.5 \leq z < 1$	6
$z \geq 1$	1
Infrared Luminosity (8–1000 μm)	**Number**
$L_{\rm ir} \geq 10^{13} L_\odot$	1
$10^{12} \leq L_{\rm ir} < 10^{13} L_\odot$	11
$10^{11} \leq L_{\rm ir} < 10^{12} L_\odot$	12
$L_{\rm ir} < 10^{11} L_\odot$	11
Activity	**Number**
AGN	2
LINER	10
H II galaxy	21
Early-type galaxy	2

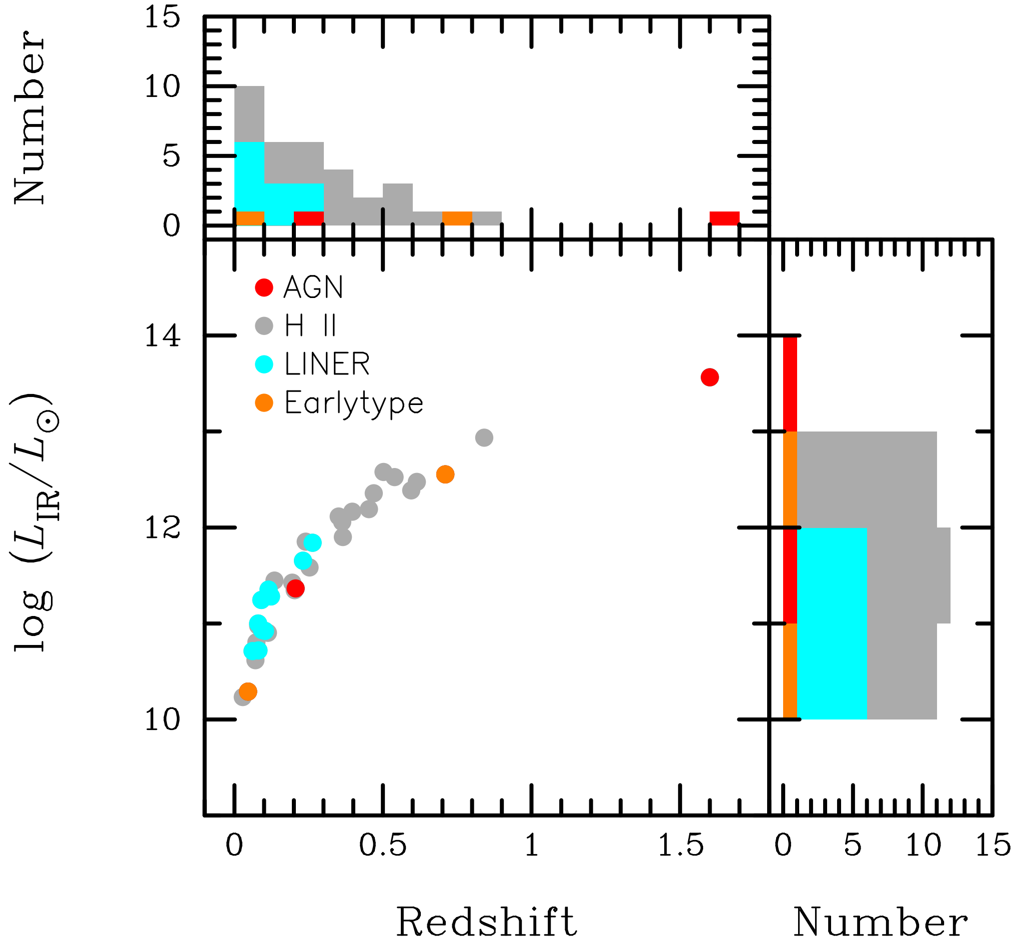

FIG. 1.— Distributions of infrared luminosity and redshift of the ISOPHOT sources.

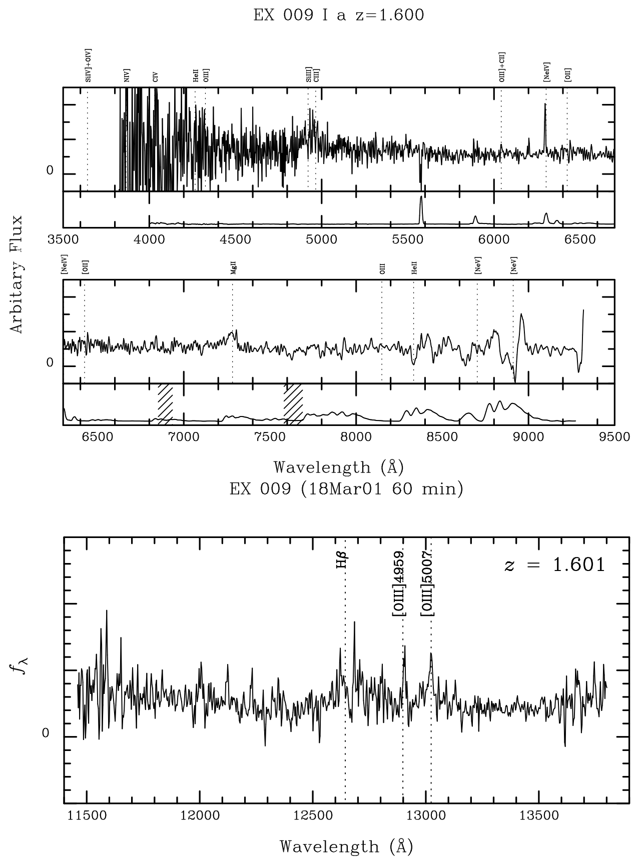

FIG. 2.— Optical (top two panels) and NIR (bottom panel) spectra of a quasar at $z = 1.6$ with infrared luminosity of $4 \times 10^{13} L_\odot$.

ing the nature of the luminosity source in these faint FIR galaxies. The low-resolution ESI spectra were used to determine the optical spectral-type of the candidate ISOPHOT sources. Following procedures used by Murayama & Taniguchi (1998), the spectra were classified into four types – AGNs, LINERs, HII-type, and early-type (without emission lines). The results are displayed in Figure 3. The HyLIG at $z = 1.6$ was found to be a quasar (Figure 2). One ULIG had an early-type spectrum and 10 ULIGs are HII galaxies. Among the remaining 23 lower-luminosity sources, there was one early-type galaxy, one AGN (Seyfert 1.5), 10 LINERs and 11 HII galaxies. Thus, based on our low-resolution ESI optical spectra most of the ISOPHOT 175μm sources appear to be powered primarily by star formation, consistent with the conclusion reached from an analysis of ISOPHOT number counts by Matsuhara et al. (2000) that most of the ISOPHOT sources are star-forming galaxies at $z < 1$.

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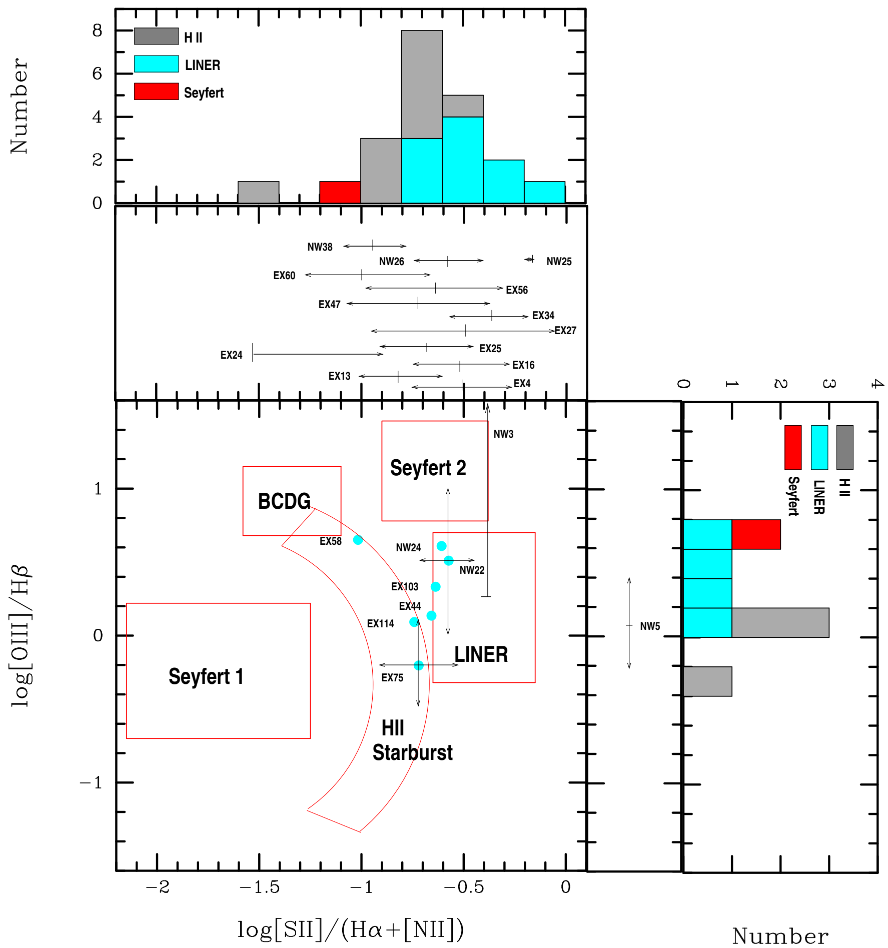

FIG. 3.— Low-resolution emission line diagnostics of ISOPHOT source candidates.