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RADIO AND FIR SOURCES IN THE LOCKMAN HOLE ISOPHOT SURVEY FIELD

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To investigate the nature and the evolution of optically faint, luminous infrared starburst galaxies, a deep survey of two $44' \times 44'$ fields in the Lockman Hole region was conducted using ISOPHOT camera on ISO at 95 and 175 μm (Kawara et al. 1998). We present the preliminary results from our multi-wavelength investigations of the identified sources in the Lockman Hole ROSAT/XMM deep field (de Ruiter et al. 1997, Hasinger et al. 2001). One or more radio sources are found at the source position in more than 80% of cases, and spectroscopic redshifts of about 50% of the sources have been obtained so far.

Sensitive observations at submm wavelengths are revealing what may be a population of active star forming galaxies at high redshift which are unseen in deep optical surveys. The differential source counts indicate a large excess of far-infrared sources by a factor of 10-50 over the no-evolution models derived from the optical deep surveys (see Matsuhara et al. 2000). Many of these faint submm sources are extremely faint and red ($R \geq 25$, $K \geq 21$), and their optical redshifts may be inaccessible even for the 10-m class telescopes. Therefore, the redshift distribution and the cosmic evolution of the dusty submm galaxy population are not well determined at the moment.

Utilizing the radio-FIR correlation (Yun & Carilli 2002), we obtained deep VLA 1.4 GHz images at $5''$ resolution in order to identify the optical counterparts within each ISOPHOT beam ($\theta \sim 1'$). The sensitivity of our VLA image is 10 μJy (1σ) in the $17' \times 17'$ field centered on the ROSAT/XMM deep survey field and 15 μJy in the remaining $34' \times 34'$ region. A total of 155 (337) radio sources have been identified to the 4σ limit of 40 (60) μJy within the deep (wide) VLA survey region. In about 80% of cases, one or more of these radio sources are found within the formal error ellipse of the ISOPHOT sources.

Optical IDs are made by comparing the deep optical images with the VLA images, and optical counterparts brighter than $I \sim 22.5$ are found in about 2/3 of the cases. Optical and NIR spectra of the optical candidates were obtained using the Keck and WIYN telescopes. Optical spectra of unrelated radio sources were also obtained for comparison. Redshifts are derived from strong emission lines and stellar absorption features. Among the 53 ISOPHOT sources brighter than 100 mJy at 175 μm, redshifts of 28 (53%) have been obtained so far. Redshifts of 7 additional sources with only the 95 μm detection have also been obtained. Bright optical emission lines are seen in 23 out of 34 (68%) sources that are detected by both the ISOPHOT and the VLA. In comparison, only about 40% of randomly selected radio sources show bright emission lines. Derived redshifts and source properties are summarized in Figure 1.

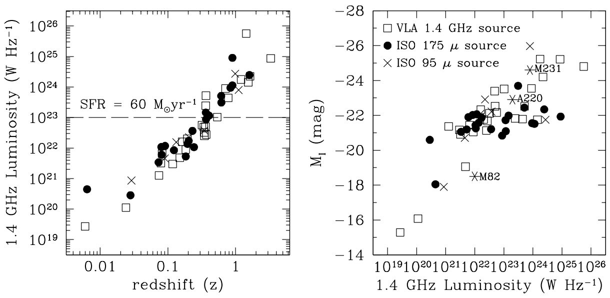

Fig. 1. **(Left)** Redshift vs. 1.4 GHz flux density for the ISOPHOT and VLA sources. The dashed horizontal line near log $L_{1.4GHz}$(W Hz^{-1}) = 23.0 ($SFR \sim 60 M_\odot$ yr^{-1}) marks the division where the AGN contribution becomes significant (see Yun et al. 2001). **(Right)** 1.4 GHz luminosity vs. I-band absolute magnitude. Well known starbursts M82, Arp 220, and Mrk 231 are shown for comparison. The ISOPHOT 175 μm sources cluster around $I \sim -22$, which is 1.0-1.5 magnitude *fainter* than the M_I^* galaxy at $z = 0$.

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