Faint Mid-Infrared Galaxies as Tracers of High Redshift Structures

Yasunori Sato

Institute of Astronomy, University of Tokyo, Japan

Abstract

A recent investigation of faint 6.7 μm galaxies detected down to 10 μJy with the *Infrared Space Observatory* shows that a significant fraction of such mid-infrared galaxies are massive galaxies at high redshift ($z > 1$). Coupled with the existing optical and near-infrared data from the ground and space, and the theoretical star/dust spectral energy distribution model GRASIL, most of their star formation histories are turned out to be early-types; characterized by a burst or a peak in the star formation rate at their early evolutionary phase. Interestingly, almost all X-ray, submillimeter and radio sources in this field are detected at the mid-infrared with such characteristics. They are likely ancestors of elliptical or early-type spiral galaxies at the local universe. As it is known that such local galaxies show significant clustering strengths, faint mid-infrared galaxies, which would become easily accessible with the coming *SIRTF* and *ASTRO-F* missions, can be used as very useful tracers to probe structures at high redshifts.

Faint 6.7 μm Galaxies

A 23 hour exposure using the Japanese Guaranteed Time on the *Infrared Space Observatory* (*ISO*) has revealed 65 mid-infrared (6.7 μm) sources with the ISOCAM LW2 filter (5–8.5 μm) in a $5' \times 5'$ area in the Hawaii Deep Field SSA 13 (Fig. 1; Sato et al. 2002b). 57 sources have been already identified with optical and near-infrared catalogs with $K < 20$, $I < 25$, and $B < 26$ (Sato et al. 2002c). Two are stars. In the ISOCAM coverage, there are four *Chandra* ($> 10^{-17}$ erg s^{-1} cm^{-2} at 2–10 keV), three SCUBA (> 2 mJy at 850 μm), and one VLT/FIRST (~ 3 mJy at 1.4 GHz) sources. All of them have counterparts at 6.7 μm (Sato et al. 2002a).

Selecting High Redshift Galaxies

Among the 55 identified galaxies, 21 have spectroscopic redshifts (Cowie et al. 1996). Photometric redshifts were derived using the GRASIL SED library (Silva et al. 1998) as fitting templates to the available photometric data from X-ray to the radio. At a flux level of 30 μJy, the 6.7 μm sample starts to have high redshift ($z > 1$) galaxies (Fig. 2).

Selecting Massive Galaxies

In the $K - z$ diagram (Fig. 3), K band selected galaxies distribute a triangular region with a boundary of model predictions for $M^*_{\rm star}$ galaxies at $z = 0$ (Cole et al. 2001), while 6.7 μm selected galaxies follow solely these massive galaxies trails. For $I - K$ colors, 6.7 μm galaxies distribute red edges of K band selected galaxies, being consistent with their maturity.

Toward High Redshift Structures

Mid-infrared observations appear to preferentially select rapidly evolved populations of galaxies, such as ancestors of E or Sa galaxies in the local universe. The reason would be that the luminous near-infrared emission of evolved stellar systems starts to shift into mid-infrared wavelengths with increasing redshift. As this 6.7 μm sample suggests, this situation will be observed with a survey limit of 10 μJy for $z > 1$ galaxies. Such massive galaxies can be used as tracers of structures at high redshifts because their descendants favor centers of clusters of galaxies in the local universe. If the target is set to larger structures than clusters of galaxies, survey area for the investigation should be as large as 1 deg $\times$ 1 deg. This size corresponds to 30 Mpc $\times$ 30 Mpc at $z \sim 2$ in a cosmology with $\Omega_{\rm m} = 0.3$, $\Omega_\Lambda = 0.7$, and $h = 0.7$. Currently, there is no survey satisfying these two criteria, 10 μJy and 1 deg $\times$ 1 deg, in the announced *SIRTF*/IRAC 8.0 μm surveys (Table 1). It would be desirable to fill in a gap between the two big *SIRTF* legacy programs, SWIRE and GOODS, with *SIRTF* itself or with the Japanese mission *ASTRO-F*.

References

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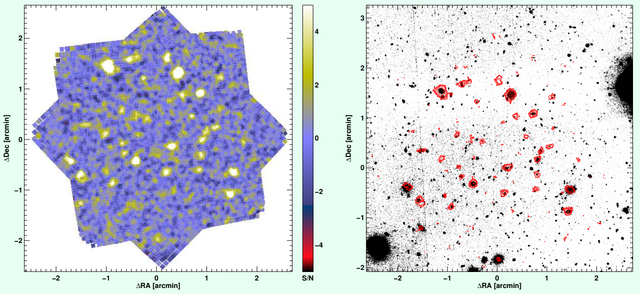

Fig. 1: A deep 6.7 μm survey in the Hawaii Deep Field SSA 13

(**Left**) The 6.7 μm map in the Hawaii Deep Field SSA 13 in a form of signal-to-noise ratio (S/N). $6''$ ISOCAM detector pixels were shrunk to their 85 % and re-sampled with $0.''6$ map pixels. (**Right**) The LW2 S/N contours are superimposed on an I band image taken from the ground.

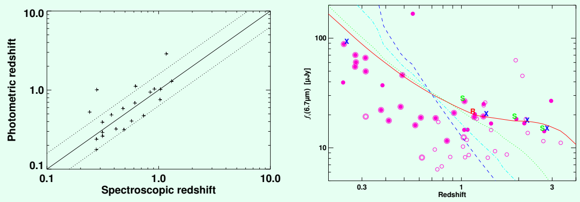

Fig. 2: Redshifts of the faint 6.7 μm galaxies

(**Left**) Photometric redshifts derived with the GRASIL SED library and their measured spectroscopic redshifts. Dotted lines show standard deviations. (**Right**) Fluxes and redshifts of the 6.7 μm selected galaxies. Solid circles are sources detected with higher significance. Double circles are plotted with their spectroscopic redshifts. Red, green, cyan, and blue lines assume star formation histories of E, Sa, Sb, and Sc galaxies, respectively, in the GRASIL model (Silva et al. 1998). They are scaled to $M^*_{\rm star}$ galaxies at $z = 0$ (Cole et al. 2001) with a formation redshift of $z_{\rm f} = 10$. X-ray, submillimeter, and radio sources are marked with letters, X, S, and R, respectively.

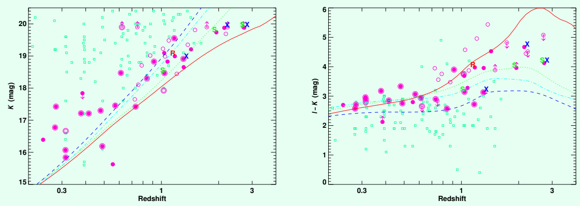

Fig. 3: A comparison with a K band selected sample

(**Left**) K magnitudes of the 6.7 μm galaxies. Symbols are the same as in Fig. 2. K band selected galaxies (Cowie et al. 1996) are marked with squares. (**Right**) $I - K$ colors of the 6.7 μm galaxies. Symbols are the same.

Table 1: *SIRTF*/IRAC 8.0 μm surveys

Project	Sensitivity (5 σ)	Coverage
SWIRE	32.5 μJy	55 deg^2
FLS-wide	58 μJy	5 deg^2
FLS-deep	18 μJy	$\sim$ 600 arcmin^2
GTO	3 μJy	10 arcmin $\times$ 2 deg
GOODS	1.2 μJy	330 arcmin^2

Apart from two legacy programs, SWIRE and GOODS, there are First Look Survey (FLS) and Guaranteed Time Observation (GTO); GS_SURVEY. FLS consists of main survey (FLS-wide) and verification survey (FLS-deep).