A systematic search for ULIRGs/HyLIRGs at intermediate redshifts with optically-faint *AKARI* FIS Bright sources

Xiaoyang Chen,[1] Masayuki Akiyama,[1] Hirofumi Noda,[2,1] Tatsuro Watanabe,[1] Abdurro'uf,[1] Yoshiki Toba,[3] and Issei Yamamura[4,5]

[1]*Astronomical Institute, Tohoku University, 6-3 Aramakiazaaoba, Aoba-ku, Sendai, Miyagi 980-8578, Japan*
[2]*Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 6-3 Aramakiazaaoba, Aoba-ku, Sendai, Miyagi 980-8578, Japan*
[3]*Institute of Astronomy and Astrophysics, Academia Sinica., AS/NTU No.1, Sec. 4, Roosevelt Rd, Taipei 10617, Taiwan, R.O.C.*
[4]*Institute of Space and Astronautical Science, JAXA, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan*
[5]*Department of Space and Astronautical Science, SOKENDAI, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan*

ABSTRACT

Ultra- and Hyper-luminous IR galaxies ($L_{\rm IR} > 10^{12}\,L_\odot$ for ULIRGs and $L_{\rm IR} > 10^{13}\,L_\odot$ for HyLIRGs) are populations of galaxies with strong IR dust emission, which is associated with a powerful AGN activity. Currently, identifications of ULIRGs and HyLIRGs are dominated by broad-line QSOs, but existence of FIR with an extremely faint optical counterpart suggests that there are significant number of obscured QSOs among the FIR sources. Utilizing the unique sample of bright FIR sources in a wide survey field from *AKARI* FIS Bright Source Catalogue, we look for luminous type-2 QSOs at $z \sim 0.5$–1 by identifying FIR sources with extremely large FIR to optical flux ratio.

In order to reveal the nature of the optically-faint FIR sources and to kick-off a systematic search for type-2 QSOs at intermediate redshifts, we observed 8 *AKARI* 90 μm FIR sources with a faint optical counterpart ($i > 20$ mag) using FOCAS on the Subaru telescope. They are identified with emission line galaxies at $z = 0.3$–0.6. Through optical–MIR–FIR SED fitting, their integrated IR luminosity are estimated to be $10^{12-12.5}\,L_\odot$. The identification of these ULIRGs at intermediate redshifts confirms the effectiveness of our selection method. One of these objects shows broad [O III] 5007Å (FWHM of 2200 km s^{-1} with blue shift of 2300 km s^{-1}) and [O II] 3726Å emission lines (FWHM of 1100 km s^{-1}). The co-existence of extreme outflow and high SFR ($\sim$1000 $M_\odot$ yr^{-1}) suggest the galaxy evolves into its most active stage when both of the AGN and star formation activities reach the peak period.

Keywords: Galaxy Evolution, Star formation, Outflows, Dust Emission

1. INTRODUCTION

Ultra- and Hyper-luminous IR galaxies ($L_{\rm IR} > 10^{12}\,L_\odot$ for ULIRGs and $L_{\rm IR} > 10^{13}\,L_\odot$ for HyLIRGs) are populations of the most IR luminous galaxies in the local universe (Sanders & Mirabel 1996; Rowan-Robinson 2000). Their large IR luminosity originats from dusts heated by UV radiation from vigorous starburst and/or AGN. Their contribution to the cosmic star formation rate density (SFRD) is low in the local universe due to their low number density, but they start to dominate the cosmic SFRD in the high redshift universe at $z > 1$ (e.g., Goto et al. 2011). They are thought to represent rapidly growing phase of massive galaxies before quenching of their star formation, and are important to understand physical interplay between AGN and star formation activities.

2. SAMPLE SELECTION

In order to construct a unique sample of ULIRGs at intermediate redshifts, we are conducting an optical follow-up program for bright 90 μm FIR sources found in the *AKARI* FIS Bright Source Catalogue (Ver.2) by utilizing the optical imaging data from the Sloan Digital Sky Survey. The cross-matched sample covers $\sim$7000 deg^2, i.e., 10 times wider survey area compared to the *Herschel*-ATLAS survey at the similar depth, and unique in constructing a sample of ULIRGs at intermediate redshifts with a selection of optically-faint FIR sources. We started spectroscopic follow-up of the targets using FOCAS on the Subaru telescope; 8 objects are observed in a service program in S17A. They are identified as emission line galaxies at $z = 0.3\sim0.6$.

Corresponding author: Xiaoyang Chen
xy.chen@astr.tohoku.ac.jp

3. RESULTS OF SED ANALYSES

Combining the photometric data from SDSS, *WISE* and *AKARI* as well as VLA FIRST Survey, we performed spectral energy distribution (SED) fitting through the Code Investigating GALaxy Emission[1] (CIGALE). The energy balance is taken into account by CIGALE that the stellar emission absorbed by dust in UV-optical will be re-emitted in IR when constructing SED templates. We chose Dale et al. (2014) model to generate dust emission and Fritz et al. (2006) model to simulate AGN characteristics including radiation from dusty torus heated by a central AGN. Physical properties such as the total IR luminosity $L_{\rm IR}$, stellar mass M_* and star formation rate (SFR) can be obtained via the SED fitting. The best fit parameters are listed in the following table. With high SFR of $10^{2-3}\,M_\odot\,{\rm yr}^{-1}$ and stellar mass of $10^{10-11}\,M_\odot$, these galaxies lie above the main-sequence in the SFR-M_* diagram. The identification of these ULIRGs ($L_{\rm IR}$ estimated to be $10^{12-12.5}\,L_\odot$) at intermediate redshifts confirms the effectiveness of the selection method. Further systematic search can be made with more than 10 *AKARI* sources with extremely large FIR / optical ratio.

Name	z	$L_{\rm IR}/10^{12}L_\odot$	$M_*/10^{10}M_\odot$	SFR/$M_\odot{\rm yr}^{-1}$	Name	z	$L_{\rm IR}/10^{12}L_\odot$	$M_*/10^{10}M_\odot$	SFR/$M_\odot{\rm yr}^{-1}$
J0818	0.31	1.78±0.10	1.69±0.38	299±15	J1219	0.55	3.68±0.28	3.34±0.89	589±29
J0916	0.49	5.95±0.49	14.86±7.40	962±78	J1227	0.61	5.86±0.92	14.13±3.41	961±150
J1010	0.56	3.55±1.42	14.13±6.23	404±226	J1348	0.55	1.07±0.51	1.81±5.31	140±82
J1034	0.52	1.14±0.58	23.14±6.44	132±88	J1402	0.33	1.81±0.12	4.94±1.53	303±19

4. DISCOVERY OF SIGNATURES OF AN EXTREME OUTFLOW

One of the ULIRGs, SDSS J0916, indicates signatures of extremely strong outflow in its emission line profiles, which is one of the most powerful outflows observed among local ULIRGs in the literature. The broad [O III] 5007Å shows FWHM of 2200 km s^{-1} and blue shift of 2300 km s^{-1} in relative to the narrow Hα line. More interestingly, the low-ionization [O II] 3726Å emission line also shows large FWHM of 1100 km s^{-1}, suggesting the outflow is extended outside of the nuclear / bulge region. In addition, SDSS J0916 also shows an evidence of an interacting system with its fainter neighbor (i = 21.43 mag, ~12 kpc away from the main galaxy). Among the optically-faint *AKARI* sources, we also found another ULIRG SDSS J1126 with similar broad [O III] 5007Å (1800 km s^{-1}) and [O II] 3726Å (670 km s^{-1}) emission lines.

Those strong outflows are thought to be driven by a strong AGN activity, based on the association with MIR excess in the SED of these galaxies. The feedback effect of the outflow would alter the star formation, however, they show large SFR as ~1000 $M_\odot\,{\rm yr}^{-1}$. The high SFR with the strong outflow can indicate that these galaxies are in the intermediate stage of evolution that the feedback just become effective and begin to sweep out the ISM with the strong AGN induced wind. We submitted proposals for further IFU as well as X-ray observation of these ULIRGs to better understand the energy source and driving mechanism of the extreme outflow, and furthermore to obtain deeper insights into the interplay between supermassive black holes and the formation and evolution of galaxies.

ACKNOWLEDGMENTS

This research is based on observations with *AKARI*, a JAXA project with the participation of ESA.

REFERENCES

Dale, D. A., Helou, G., Magdis, G. E., et al. 2014, ApJ, 784, 83
Fritz, J., Franceschini, A., & Hatziminaoglou, E. 2006, MNRAS, 366, 767
Goto, T., Arnouts, S., Inami, H., et al. 2011, MNRAS, 410, 573
Rowan-Robinson, M. 2000, MNRAS, 316, 885
Sanders, D. B., & Mirabel, I. F. 1996, ARA&A, 34, 749

[1] https://cigale.lam.fr/