A milestone to SPICA extragalactic surveys: The AKARI NEP survey

Conference or Workshop Item

How to cite:

For guidance on citations see FAQs.

© 2009 The Authors

Version: Version of Record

Link(s) to article on publisher’s website:
http://dx.doi.org/doi:10.1051/spica/200904017

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online’s data policy on reuse of materials please consult the policies page.
A MILESTONE TO SPICA EXTRAGALACTIC SURVEYS: THE AKARI NEP SURVEY

T. Takagi1, H. Matsuhara1, T. Wada1, S. Oyabu1, T. Goto2, Y. Ohyama3, H. Hanami4, C.P. Pearson5, S. Serjeant6, M. Negrello6, G. White6, M. Im7, H.M. Lee8, M. Malkan8, and the AKARI extragalactic team

1Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan
2Institute for Astronomy, University of Hawaii, USA
3Academia Sinica, Institute of Astronomy and Astrophysics, Taiwan
4Physics section, Faculty of Humanities and Social Sciences, Iwate University, Japan
5Rutherford Appleton Laboratory, UK
6Department of Physics, The Open University, UK
7Department of Physics & Astronomy, FPRD, Seoul National University, Korea
8Department of Physics and Astronomy, UCLA, USA

ABSTRACT

Large area surveys in the infrared wavelengths have revealed a significant evolution of the star formation activity of the universe in the past. The extragalactic survey we have conducted with AKARI towards the north ecliptic pole (NEP) is unique, in terms of a comprehensive wavelength coverage from 2 to 24 micron using all 9 photometric bands of the Infrared Camera (IRC). We demonstrate that this IRC all-band photometry is capable of tracing a steep rise in the flux at the blue side of the polycyclic aromatic hydrocarbon (PAH) 6.2 micron emission feature of infrared luminous galaxies at z < 1. This allows us to estimate redshifts of mid-IR sources and identify ‘ultra-luminous starburst galaxies’, based on mid-IR spectral energy distributions (SEDs). SPICA could inherit this unique capability of AKARI and extend the study to typical galaxy populations at z ~ 2, i.e. a critical period of galaxy formation.

Key words: Galaxies: formation – Galaxies:infrared – Missions: SPICA – Missions: AKARI

1. INTRODUCTION

One of the surprising results from Spitzer observations of distant ultraluminous infrared galaxies (defined with 10^{12} < L_{IR} < 10^{13}L_{⊙} – ULIRGs) is that some ULIRGs have greater PAH emission than local galaxies of similar luminosity (e.g. Rigby et al., 2008). Their mid-infrared spectra resemble that of more than 2 orders of magnitude less luminous starburst galaxies (Valiante et al., 2007; Pope et al., 2008; Farrah et al., 2008). Since these galaxies have been discovered using spectroscopic observations with Spitzer/IRS, it is difficult to assess the statistical properties of these new type of ULIRGs. This is an urgent issue to be resolved.

We are currently undertaking the study of distant infrared galaxies using AKARI’s new extragalactic survey towards the north ecliptic pole (NEP), which have comprehensive wavelength coverage at 2 – 24μm, filling the wavelength gap between Spitzer IRAC and MIPS. This survey has unique capability to identify a rough shape of PAH emission feature with photometric observations. Also, AGN identification using mid-infrared properties is more reliable than the case of Spitzer surveys. Here we describe some highlights from the AKARI NEP survey using these capabilities.

2. THE NEP-DEEP SURVEY: DESIGN AND PERFORMANCE

Owing to a strong visibility constraint of AKARI, large area surveys with pointed (hence deep) observations are possible only around the ecliptic poles. We have chosen the NEP for extragalactic surveys, given the presence of the Large Magellanic Cloud around the south ecliptic pole. The NEP area has been covered by two extragalactic surveys; the NEP-Deep and -Wide survey. This paper describes the NEP-Deep survey. All nine photometric bands in IRC have been used for both surveys to continuously cover 2 – 24μm wavelength range. Further details of the NEP-Deep survey design can be found in Wada et al. (2008).

We summarize the survey sensitivity in Table 1. The NEP-Deep survey reached a depth similar to the SWIRE survey with Spitzer (Lonsdale et al., 2004), but covers Spitzer’s band gap with 11, 15 and 18μm. Deep optical (BVRiz′ and NB711) images with the Subaru/Suprime-cam (S-cam), reaching the limiting magnitude of B = 28 and z′ = 26 AB mag, are available for a part of the NEP-Deep field with the area of 27′ × 34′, i.e. one field-of-view of S-cam. We have ground-based near-IR (JKs) images with KPNO-2.1m/FLAMINGOS for the S-cam field (Imai et al., 2007), reaching Ks = 19.5 in Vega magnitude. The ground-based near-IR images have higher spatial resolution (FWHM of 1.08′′) than that of IRC, and therefore quite useful to examine the source confusion in IRC images.

3. NUMBER COUNTS

Complicated emission features of PAHs affect the redshift distribution of flux limited samples from mid-infrared
Figure 1. Examples of the SED fitting for PAH-selected galaxies at $z \sim 1$. Data with error bars indicate the observed flux and errors adopted for the SED fitting. Solid circles are filter convolved fluxes of the best fit model.

Table 1. Summary of the NEP-Deep survey

<table>
<thead>
<tr>
<th>band</th>
<th>total area (arcmin$^2$)</th>
<th>$5 \sigma$ limit$^\dagger$ (µJy)</th>
<th>50% limit$^\ddagger$ (µJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2</td>
<td>2099</td>
<td>9.6</td>
<td>28.8</td>
</tr>
<tr>
<td>N3</td>
<td>2123</td>
<td>7.5$^*$</td>
<td>23.5$^*$</td>
</tr>
<tr>
<td>N4</td>
<td>2080</td>
<td>5.4$^*$</td>
<td>19.7</td>
</tr>
<tr>
<td>S7</td>
<td>2093</td>
<td>48.9</td>
<td>54.0</td>
</tr>
<tr>
<td>S9W</td>
<td>2078</td>
<td>58.5</td>
<td>62.6</td>
</tr>
<tr>
<td>S11</td>
<td>2102</td>
<td>70.9</td>
<td>80.7</td>
</tr>
<tr>
<td>L15</td>
<td>2220</td>
<td>117.0</td>
<td>93.3</td>
</tr>
<tr>
<td>L18W</td>
<td>2226</td>
<td>121.4</td>
<td>98.8</td>
</tr>
<tr>
<td>L24</td>
<td>1958</td>
<td>275.8</td>
<td>209.8</td>
</tr>
</tbody>
</table>

$^\dagger$ Detection limit (sky noise limit).
$^\ddagger$ Completeness limit.
$^*$ Corrected from the values in Wada et al. (2008), due to misuse of conversion factors.

surveys (Caputi et al., 2006). This has a significant effect on the MIR number counts as well. Furthermore, recent Spitzer/IRS observations of high redshift ULIRGs revealed that mid-infrared properties of high-$z$ ULIRGs are different from local ones; a significant number of ULIRGs show prominent PAH emissions (e.g. Valiante et al., 2007; Farrah et al., 2008; Pope et al., 2008). These PAH-emitting ULIRGs have a PAH feature similar to local starburst galaxies, even though they are over 2 orders of magnitude more luminous. This means that luminosity dependent SED templates of infrared galaxies based on local galaxies may not be applicable for high-$z$ galaxies, even at $z \sim 1$ (see below).

Thus, modeling the number counts can be complicated enough when applied to multiple mid-infrared wavelengths. We have obtained the number counts at 11, 15 and 18 µm from the NEP-Deep survey and compared with the model of Pearson (2005) which reproduce both ISO 15 µm and Spitzer 24 µm number counts. We found that this model overestimate the number of 18 µm sources by a factor of 2 (in differential counts). This indicates that, in the mid-infrared wavelength range, the multi-band number counts can be useful to constrain the galaxy evolution model,
even if the difference in wavelength is only \( \sim 20 \% \). We have already built a new model to remedy this discrepancy, which will be published elsewhere (Pearson et al. in prep).

### 3.1. PAH-selected galaxies

We demonstrate that PAH emission features, specifically a steep rise of flux at the blue side of PAH 6.2 \( \mu \text{m} \) feature, are recognizable in the SED of AKARI/IRC all-band photometry (Figure 1; see also Takagi et al., 2007). Such a steep rise of flux results in very red colors in IRC bands for galaxies at certain redshift ranges. In Figure 2, we show the 11-to-7 \( \mu \text{m} \) flux ratio and the 15-to-9 \( \mu \text{m} \) flux ratio as a function of redshift. These flux ratios have a prominent peak around \( z \sim 0.5 \) and 1.2, owing to the PAH emission. At these redshifts, emissions from stellar photosphere dominate the flux at shorter wavelength bands, while PAH emissions dominate at the longer wavelength bands. Thus, these flux ratios can be used as a rough indicator of mass-normalized star formation rate, i.e. specific star formation rate. Since such anomalous flux ratios can be reproduced only by the PAH emission, we select galaxies with these flux ratios greater than 8 as secure candidates of starburst dominated galaxies at \( z > \sim 0.5 \), and call them PAH-selected galaxies. In Figure 3, we show composite optical, near-infrared and mid-infrared color images of three PAH-selected galaxies at \( z \sim 0.5 \), showing red colors in the 7, 9, 11 \( \mu \text{m} \) composite image.

### 3.2. PAH-to-total IR luminosity relation

Spitzer spectroscopic observations have established the relation between PAH luminosity and total infrared luminosity for starburst galaxies (Brandl et al., 2006; Houck et al., 2007; Farrah et al., 2007). In Figure 4, we show the PAH 7.7 \( \mu \text{m} \) peak luminosity from Spitzer IRS observations (compiled in Weedman & Houck, 2008) against the total infrared luminosity. The local sample (\( z < 0.2 \)) from Spitzer IRS observations is indicated by crosses. A straight line indicates the correlation \( \log L_{7.7} = \log [\nu L_\nu (7.7 \mu \text{m})] + 0.78 \) taken from Houck et al. (2007). At the high luminosity end, \( L_{7.7} > 10^{12} L_\odot \), it is evident that the 7.7 \( \mu \text{m} \) luminosity saturates, probably because of the AGN contribution to the infrared luminosity and/or the absorption of 7.7 \( \mu \text{m} \) flux by dust.

Thanks to a good wavelength sampling of the IRC bands, we can estimate the rest-frame 8 \( \mu \text{m} \) luminosity with almost no \( K \)-correction. Using this capability, we estimate the 7.7 \( \mu \text{m} \) peak luminosity from our photometric observations. The rest-frame 8 \( \mu \text{m} \) luminosity is converted to the 7.7 \( \mu \text{m} \) peak luminosity with a correction factor of 2.0, considering the effect of filter convolutions.

We here use the sample of IRC all-band-detected sources in the Subaru/Suprime-cam field; i.e. sources detected in all 9 IRC bands. A StarBurst SED model with Radiative...
length coverage allows us to identify galaxies whose mid-infrared emission is dominated by PAHs with photometric observations. Such galaxies, PAH-selected galaxies, can be identified with single IRC colors, such as S7 − S11 and S9W − L15. They include most luminous starburst galaxies at $z \sim 1$. We estimated the PAH 7.7 $\mu$m peak luminosity from the IRC photometry and compared with the total infrared luminosity obtained with a starburst SED model. While local ULIRGs have suppressed PAH luminosity when compared with less luminous starburst galaxies, we find no such suppression for PAH-selected galaxies at $z \sim 1$. This indicates that mid-infrared properties of distant ULIRGs are different from local ones, even at $z \sim 1$.

**Acknowledgements**

We would like to thank all AKARI team members for their support on this project. This research is based on observations with AKARI, a JAXA project with the participation of ESA.

**References**