Environmental Dependence of Galaxy Properties Revealed by *AKARI* and *SPICA*

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ABSTRACT

We have investigated the dependence of galaxy properties on their surrounding environments with *AKARI*/IRC. We found less star-forming galaxies tend to be in dense region at $z = 0.8$ whereas at $z > 0.8$ universe, the star formation are more active in denser region, consistent with the previous work. As an indicator of star formation, we used 8 μm to 4.5 μm flux ratio, which is reduced by the radiation from Active Galactic Nuclei so that it can trace pure star forming galaxies. Such a useful indicator could be used by only *AKARI* which has a continuous wavelength coverage between 2–24 μm. In future work we suggest to extend this work to $z = 3.5$ universe using *SPICA* which has also continuous wavelength coverage at mid-infrared and has a great spatial resolution, which is needed to avoid source blend in dense regions.

1. UNCERTAINTIES IN ENVIRONMENTAL STUDIES

Although galaxies have been growing with their surrounding environment, we do not know the influence of the environment on the galaxy evolution. In the local universe, galaxies in dense regions tend to be massive, quiescent, and composed of old stars, which indicates they had formed a large amount of stars in the past. Recently, it is found that $z \sim 1$ galaxies in denser regions have higher star formation rates (Elbaz et al. 2007; Cooper et al. 2008), which is called reversal of environmental effect.

However, this reversal is still in debate; Popesso et al. (2011) shows that when Active Galactic Nuclei (AGNs) are excluded from the sample, the reversal disappears. Patel et al. (2009) found no reversal in a galaxy cluster at $z \sim 0.8$. The main reasons for this ambiguity are 1.) an AGN contamination influences the efficacy of standard indicators of the star formation rates, and 2.) an influence of individual galaxy cluster properties might cause systematic uncertainties.

2. ENVIRONMENTAL EFFECT USING *AKARI* NEP SURVEY

The *AKARI* NEP-deep survey (Matsuhara et al. 2006) has unique advantages to overcome these uncertainties. The *AKARI*/IRC (Onaka et al. 2007) continuous filter coverage at 2-24 μm with nine photometric bands enables us to measure the 8μm to 4.5 μm luminosity ratios, which can only be increased by star formation, not by AGN since it increases the luminosity of both bands.

The catalogue of this survey has recently been updated by Murata et al. (2013), who devised new image analysis methods and removed many of contaminations in the previous images. In the revised catalogue, the detection limits of all the mid-infrared bands were improved by ~20%, the source extraction is more than 99% reliable, and the total number of detected objects was increased by ~2000 compared to the previous version of the catalogue to 9560.

To calculate the local galaxy density, we have estimated photometric redshift with an accuracy of $\Delta z/(1+z) \sim 0.04$ at $z < 0.8$ and ~ 0.05 at $z > 0.8$ using optical to near-infrared data taken by CFHT/MegaCam($u^* g' r' i' z'$) and WIRCam($YJKs$), The calculation was performed using the LePhare code with COSMOS SED templates (Ilbert et al. 2009)

Using the photometric redshift estimated above, we calculated the local galaxy density, assuming the galaxies with the same redshift within $0.05\times(1+z)$ are at the same epoch. We found dense galaxy regions in the *AKARI* NEP-deep field at each redshift as shown in Figure 2, where galaxies at $z = 0.4$, 0.7, and 1.0 are indicated by magenta, green, and blue points. We calculated the 8 μm to 4.5 μm luminosity ratios for these galaxies, and compare them with their local over-densities. The results are shown in Figure 3. At $z = 4$, the luminosity ratio decreases with the density, consistent with trend in the local universe. The galaxies at $z = 0.7$ has a similar trend. In contrast, galaxies at $z = 1.0$ has an opposite trend; the luminosity ratio increases with the density, indicating the reversal of the environmental effect, consistent with the previous studies.

However, these results still have some difficulties. 1.) Some objects are blended with nearby galaxies, for which we cannot estimate the luminosity ratio accurately. 2.) A significant fraction of galaxies are not detected at optical to near-infrared band, preventing us from calculating the photometric redshift. 3.) The *AKARI* NEP-deep field does not contain extremely dense region, so that the galaxy properties in these region are still unknown. 4.) We cannot explore the environmental dependence of galaxy properties at higher redshifts, where galaxies are more affected by their environment.

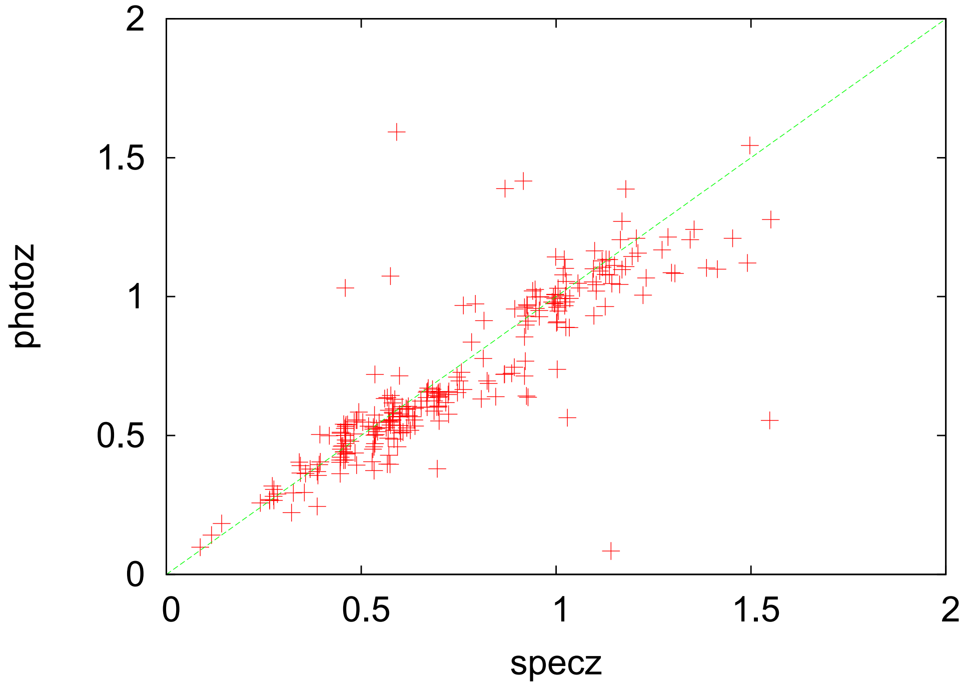

Figure 1. The photometric redshift accuracy calculated using optical to near-infrared data. The accuracy is -0.013±0.04 for $z < 0.8$ and -0.029±0.052 for $z > 0.8$.

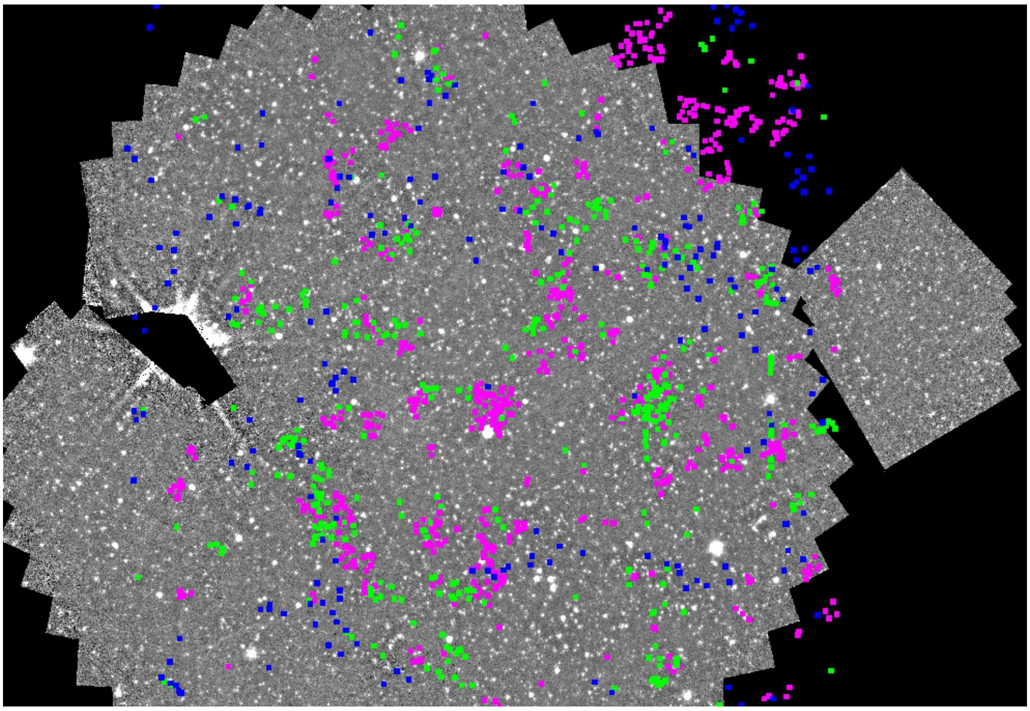

Figure 2. The galaxies identified to be in dense regions. The magenta, green, and blue points indicate the galaxies at z = 0.4, 0.7, and 1.0.

3. FUTURE STUDIES WITH *SPICA*

Making use of the *SPICA*'s advantages, we can overcome these uncertainties and explore the environmental dependence of galaxy properties in detail. This is because i.) The sharp spatial resolution can detect galaxies without blending even in the densest region. ii.) The spectral mapping with SAFARI enables us to calculate accurate density even objects without optical detection. iii.) The wide field of view will find galaxies in various kinds of environment. iv.) The high sensitivity

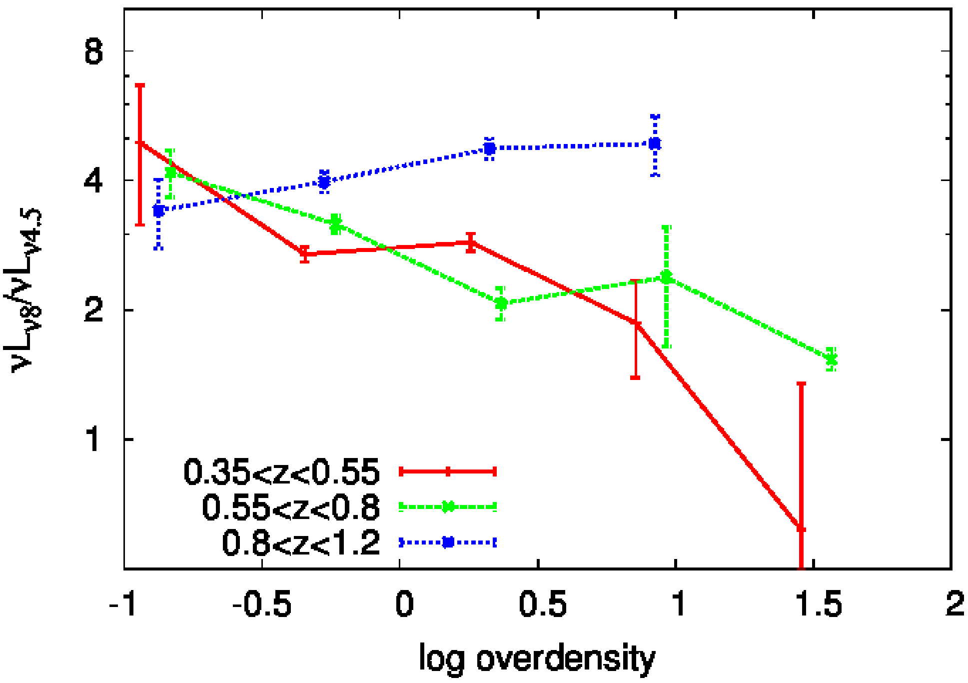

Figure 3. The environmental effects of the 8 μm to 4.5 μm luminosity ratios. At $z < 0.8$ the luminosity ratios decrease with over density, while at $z > 0.8$ the trend is reversed.

and continuous filter coverage at mid-infrared enable us to understand the environmental effect up to $z \sim 3.5$. For these purposes, deep legacy survey should be carried out with the unique advantages of the *SPICA*.

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