

STUDY OF SPECTRAL ENERGY DISTRIBUTION OF GALAXIES WITH PRINCIPAL COMPONENT ANALYSIS

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ABSTRACT

We performed Principle Component Analysis (PCA) over 264 galaxies in the *IRAS* Revised Bright Galaxy Sample (Sanders et al., 2003) using 12, 25, 60 and 100 μm flux data observed by *IRAS* and 9, 18, 65, 90 and 140 μm flux data observed by *AKARI*. We found that (i) the first principle component was largely contributed by infrared to visible flux ratio, (ii) the second principal component was largely contributed by the flux ratio between *IRAS* and *AKARI*, (iii) the third principle component was largely contributed by infrared colors.

Key words: Spectral Energy Distribution, Principal Component Analysis, starburst galaxies, Active Galactic Nuclei

1. INTRODUCTION

There are two types of energy sources in galaxies: starburst and Active Galactic Nuclei (AGN). These activities take place often in dusty areas of galaxies and thermal radiation from these areas is the main radiation of galaxies. Infrared Spectral Energy Distribution (SED) has often been used in many studies of galaxies. On the basis of *IRAS* 12/25 μm and 60/100 μm color-color diagram, Helou (1986) found that galaxies' activeness and the types of the energy sources were distinguished by their infrared radiation SED (Helou, 1986). However, the SED's wavelength coverage was not wide enough in the previous studies, and this prevented us from revealing the relation between galaxies' activities and their emission quantitatively. Hence we used *AKARI* data in addition to *IRAS* data and carried out a quantitative analysis on infrared and visible flux by the Principal Component Analysis (PCA).

2. METHOD

2.1. Sample Selection

We selected the sample for the analysis from 629 galaxies in the *IRAS* Revised Bright Galaxy Sample (RGS)(Sanders et al., 2003). The wavelengths of the flux data we used were 12, 25, 60 and 100 μm for *IRAS*, and 9, 18, 65, 90 and 140 μm for *AKARI*.

First, we executed position matching between the sample from RGS and the Point Source Catalogues of the *AKARI* Fir-Infrared Surveyor (FIS) and the Infrared Camera (IRC). The position accuracy was $1\sigma = 6$ arcsec for FIS (Yamamura et al., 2010) and $1\sigma = 3$ arcsec for IRC (Kataza et al., 2010). We set the matching radius to 20 arcsec (FIS) and 10 arcsec (IRC), each corresponding to 3σ . The number of sample galaxies with the flux data available in all the 9 bands was 369.

Next, we checked V band flux data in the sample of 369 galaxies. We referred to the *IRAS* Bright Galaxy Sample (BGS)(Soifer et al., 1987), the *IRAS* BGS Part II (Sanders et al., 1995), the New General Catalogue and the Index Catalogue. There were 323 galaxies for which V band data were collected.

Finally, we eliminated galaxies whose sizes were too

Table 1
15 parameters for PCA ¹.

F(9 μm)/F _V	F(60 μm)/F(65 μm)
F(18 μm)/F _V	F(100 μm)/F(90 μm)
F(65 μm)/F _V	F(18 μm)/F(9 μm)
F(90 μm)/F _V	F(140 μm)/F(90 μm)
F(140 μm)/F _V	F(25 μm)/F(12 μm)
F(12 μm)/F _V	F(100 μm)/F(60 μm)
F(25 μm)/F _V	
F(60 μm)/F _V	
F(100 μm)/F _V	

big to be dealt with as point sources. We used D25 from Third Reference Catalogue of Bright Galaxies (RC3) as a parameter of this selection. D25 (its unit is 0.1 arcmin) is an apparent major isophotal diameter whose surface brightness in B magnitude is $25 \text{ mag arcsec}^{-2}$. 275 out of 323 galaxies had D25 data, so we carried out our selection from the sample of 275 galaxies. We excluded galaxies having D25 larger than 100, then 264 galaxies remained. We used these 264 galaxies for the PCA.

2.2. Principal Component Analysis

The PCA is a linear analysis for the multivariate data, and it makes the property of the original data's information easy to be understood by generating new indicators (called principal components) as linear combinations of the variables. The principal components (PCs) are determined in the order. Each PC is orthogonal and we interpreted its information on the basis of variables included in each PC. We used 15 parameters for the PCA shown in Table 1.

3. RESULTS

We carried out the PCA for the 264 galaxies and found that the cumulative contribution from the first to the third PCs amounted to 89.4%. Hence we treated these three PCs as follows.

The most contributory parameter in the first PC (PC1) was F(90 μm)/F_V. In Figure 1, active galaxies such as Mrk 231 are located in the right side, and quiescent ones such as NGC 4579 are located in the left side.

The second PC (PC2) was contributed by the infrared flux ratio between *IRAS* and *AKARI* data. Figure 2 shows the correlation between the *IRAS* and *AKARI* infrared flux ratio: F(60 μm)/F(65 μm) and

F(100 μm)/F(90 μm). Large galaxies such as M 58 are located in the upper right corner and compact galaxies such as NGC 6240 are located in the lower left corner.

The most contributory parameter in the third PC (PC3) was F(18 μm)/F(9 μm). The vertical axis of Figure 1 is the distribution of this parameter. In Figure 1, starburst-dominant galaxies such as Arp 293 are located in the bottom and AGN-dominant galaxies such as Mrk 231 are located in the top.

4. DISCUSSION

In this section, we discuss what each principal component indicates.

First, we discuss what PC1 indicates. PC1 is the ratio of reprocessed radiation by dust (infrared) to the direct stellar light (visible). This ratio represents how much fraction of star-formation activity is converted into IR by dust attenuation. Hence we conclude that PC1 shows the amount of dust attenuation of galaxies.

Next, we discuss what PC2 indicates. The wavelengths of the *IRAS* and the *AKARI* bands are close to each other on the both parameters of Figure 2, so the flux ratio between *IRAS* and *AKARI* data is the difference of the aperture size of these missions. *IRAS* has larger aperture than *AKARI* (Jeong et al., 2007), so flux data measured by *AKARI* is expected to be smaller than that of *IRAS* when the galaxy is larger than the *AKARI* aperture. Thus, we conclude that PC2 shows the sizes of galaxies in the infrared.

Third, we discuss what PC3 indicates. In Figure 1 in the vertical axis, starburst galaxies are located in the bottom and AGN-dominated galaxies are located in the top of the diagram. Thus, we conclude that PC3 shows the types of energy sources of galaxies.

From these discussions, we conclude that we can characterize galaxies' dust attenuation and the types of energy sources by using PCA.

REFERENCES

- Helou, G., 1986, The *IRAS* Colors of Normal Galaxies, *ApJ*, 311,L33
- Jeong, W. -S., Nakagawa, T., Yamamura, I., et al., 2007, The Far-Infrared Properties of Spatially Resolved *AKARI* Observations, *PASJ*, 59, S429
- Kataza, H., Alfageme, C., Cassatella, A., et al., 2010, *AKARI/IRC* All-Sky Survey Point Source Catalogue Version 1.0 -Release Note (Rev.1)-
- Sanders, D. B., Egami, E., Lipari, S., et al., 1995, The *IRAS* Bright Galaxy Survey - Part II: Extension to Southern

¹F_V in the parameters is V band flux. This flux is an observed value and is not corrected for dust attenuation.

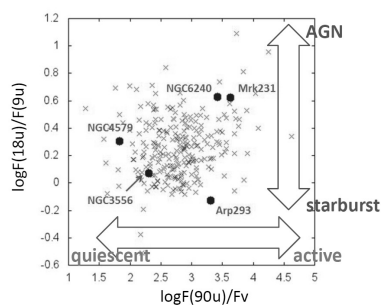


Figure 1. The scatter diagram of $F(90\ \mu\text{m})/F_V$ from PC1 and $F(18\ \mu\text{m})/F(9\ \mu\text{m})$ from PC3 with some galaxies identified individually. Both of the parameters are displayed with the common logarithm. The horizontal arrow expresses the intensity of galaxies' activity. The vertical arrow expresses the dominant activities of galaxies.

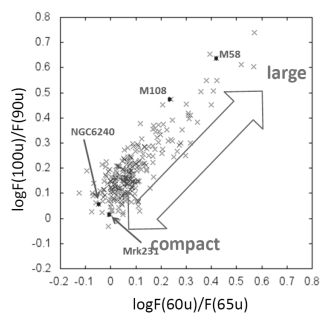


Figure 2. The correlation between $F(60\ \mu\text{m})/F(65\ \mu\text{m})$ and $F(100\ \mu\text{m})/F(90\ \mu\text{m})$, dominating parameters in the PC2, with some galaxies identified individually. Both of the parameters are displayed with the common logarithm. The arrow expresses the size tendency of galaxies.

Declinations ($\delta \lesssim -30$), and Low Galactic Latitudes ($5 < |b| \leq 30^\circ$), AJ, 110, 1993

Sanders, D. B., Mazzarella, J. M., Kim D. -C., et al., 2003, The *IRAS* Revised Bright Galaxy Sample, AJ, 126, 1607

Soifer, B. T., Sanders, D. B., Madore, B. F., et al., 1987, The *IRAS* Bright Galaxy Sample II. The Sample and Luminosity Function, ApJ, 320, 238

Yamamura, I., Makiuchi, S., Ikeda, N. et al., 2010, AKARI/FIS All-Sky Survey Bright Source Catalogue Version 1.0 Release Note