Extra-Galactic Studies with the SCI: AGNs and Nuclear Starburst Galaxies

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ABSTRACT

To reveal triggers of active galactic nucleus (AGN) and nuclear starburst generations and effects of the central activities to the circumnuclear environments, we propose the mid-infrared spectroscopic observations not only in central nuclei but also in the environments very close to central nuclei. The environments provide important information on supplying fuel to galactic nuclei, evidence for presence of materials processed by central activities and a connection between a nucleus and a host galaxy. To perform this kind of observations, we need a high contrast capability to reduce halo components of a point spread function of a bright central core. Reducing the halo components will be effective in not only obtaining the information of the faint environments around the core but also reducing the observing time. The *SPICA* Coronagraph Instrument (SCI) will provide such a high contrast capability in the mid-infrared. Using the SCI, we will obtain the circumnuclear structures and the compositions of dust, especially silicate and polycyclic aromatic carbons, in the environments very close to the bright central core in AGNs and nuclear starburst galaxies.

1. INTRODUCTION

The centers of galaxies are the sites of the two most wide-studied phenomena: active galactic nuclei (AGNs) and starburst galaxies. The AGN harbors in the center of a host galaxy. The radiation of the AGN is as luminous as or more than that of the host galaxy. The reason of the strong radiation is because mass accretion toward a super massive blackhole (SMBH) in the center releases the gravitational energy. The accretion is also important to the growth of the SMBH. A dusty torus is surrounding the SMBH and the accretion disk. The torus is an important component for infrared radiation as well as for a mass reservoir. However, for $10^{11}\,L_\odot$ AGNs, we need a mass accretion rate of $0.1\,M_\odot\,yr^{-1}$ at least. If the mass of torus is $10^7\,M_\odot$, the life time is only 10^8 yr. Thus, we need fueling to the dusty torus from the host galaxy to maintain the torus.

Starburst galaxies are also important to understand the evolution of star formation history of the Universe. Especially, dusty starburst galaxies with infrared luminosity of $10^{12}\,L_\odot$, which are identified as ultra-luminous infrared galaxies (ULIRGs), play important roles in the history. However, because the galaxies are very dusty, current observations only revealed the central part in the infrared. It is important to know the environment close to the central part, which will provide the triggers and the effects of nuclear starburst galaxies.

The SPICA Coronagraph Instrument (SCI) can reveal the phenomena and the environments of central regions of galaxies to obtain evidence for the fueling mechanism, the processing of materials, and co-evolutions of AGNs and the host galaxy. In this paper, we focus on science case for AGNs and nuclear starburst galaxies with the *SPICA*/SCI and discuss the merits of the SCI.

2. SCIENTIFIC MOTIVATIONS

2.1. Fueling mechanism of AGNs

The fueling mechanism to a dusty torus from a host galaxy is important to maintain the torus. However, there is an angular momentum problem. We have to remove large angular momentum to fuel gas to the dusty torus. Several ideas are proposed to remove angular momentum. One is galaxy mergers. The gravitational torque can be used due to galaxy-galaxy interaction to remove the angular momentum of the gas (e.g. Barnes & Hernquist 1991). The stellar bar structure is also one of the ideas. The gas in the bar structure induces shocks with which inflows toward the center are formed (e.g. Athanassoula 1992). The star formation activity in the central 100 pc region have also been considered as reasonable means of removing angular momentum of the rotating gas (e.g. Wada 2001). However, systematic observations have not shown any clear excess of bars or companions in galaxies with AGNs (Schmitt 2001). Moreover observations of the circumnuclear regions suggest no significant differences in the spatial distribution of the nuclear dust between active and inactive galaxies (Martini et al. 2003).

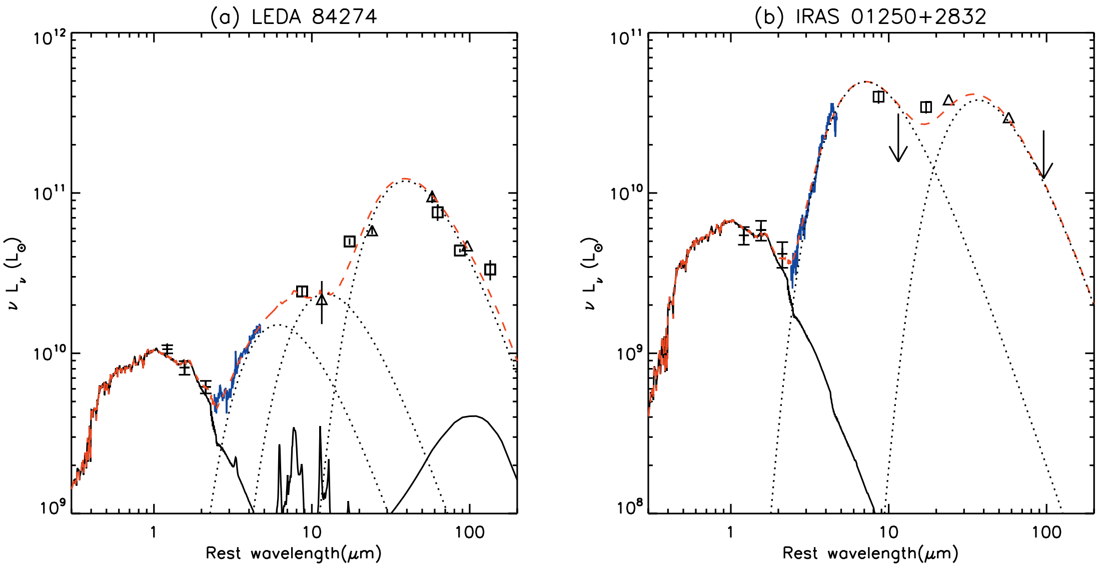

Figure 1. Spectral energy distributions of the galaxies with dusty AGNs found by the *AKARI* All-Sky Survey. (a) LEDA 84274 and (b) IRAS 01250+2832. The lines (blue) shows the *AKARI* near-infrared spectra. Squares, triangles, and crosses represent the *AKARI* All-Sky Survey, *IRAS*, and 2MASS photometry. Black solid and dotted lines represent galaxy templates and blackbody components of dust.

The observations of the circumnuclear region, especially the region where gas and dust in a host galaxy flow into a dust torus, will provide clues to the mechanism to remove the angular momentum. In particular, silicate features will have information not only at present but also in the past, e.g. the crystallization reflects the thermal history. The distributions of silicate, especially silicate heated or crystallized by galaxy-scale shocks, will be distorted and spread widely over the galaxy scale if the galaxy-galaxy interactions are a major cause. If the bar mechanism works, silicate will be heated or crystallized by the shocks induced by the flow in the bar structures. If the nuclear star formation activities are a main mechanism, the features will show variations of crystalline silicate features from inside to outside.

2.2. Processing of solid materials

Using the *Spitzer Space Telescope*, Spoon et al. (2006) reported the discovery of narrow absorption features in the mid-infrared, which is characteristic of crystalline silicates, in ULIRGs. The fact that the absorption features are seen in ULIRGs implies that the crystalline silicates are located in the cooler and outer regions of the galaxies. This would require a crystallization process for the large area of a galaxy such as shocks by a galaxy-galaxy merging process or a large-scale mechanism to transport the crystalline silicates outward and distribute it over the surrounding medium after central activities crystallize silicate.

Polycyclic aromatic carbons (PAHs) are also processed in galaxies. Using *AKARI* near-infrared spectroscopy, Yamada et al. (2013) found the decline of the ratio of PAH 3.3 μm luminosity to total infrared luminosity in the high luminosity end of star-forming galaxies after excluding galaxies with AGN signatures. The interpretation of this decline is a scarcity of PAHs relative to large grains. The merger process may cause this scarcity, because PAHs are more easily destroyed by shocks than large grains.

One of important themes for the study of AGNs is to understand the role of relativistic jets. The interaction between the radio-emitting outflows and gas/dust occurs in regions from near-nuclear to intergalactic environments. Rouan et al. (2004) observed the diffraction-limited images around the core of NGC 1068 in the *K*-, *L*-, and *M*- bands with the VLT. The observations indicated that the dust is delineating the cocoon of the radio jet and the temperature of a part of the dust components estimated from the near-infrared color reaches about 600 K which is higher than the expectation of classical large grain. It is most probably the signature of transiently heated very small dust grains, possibly nano-diamond particles. Very small grains form very efficiently in shocks induced by jets.

Processed materials provide very important information of the central activities. We need to know where the processed materials are and how they are processed.

2.3. Co-evolution of an AGN and the host galaxy

The tight correlation between a supermassive black hole (SMBH) mass and a mass of the stellar spheroid is well-known and important in the cosmological context of black hole growth and galaxy evolution (e.g. Gültekin et al. 2009). It is generally accepted that the relation $M_{\rm BH}/M_{\rm bulge} \sim 10^{-3}$ should be valid for all spheroids irrespective of the mass scale and the environment. It does not matter whether a black hole is active or not.

The tightness of the correlation suggests that some kind of feedback acts to maintain the connection between SMBH mass and the spheroid mass. Various models (Silk & Rees 1998; King 2003) are proposed to explain the mechanism to

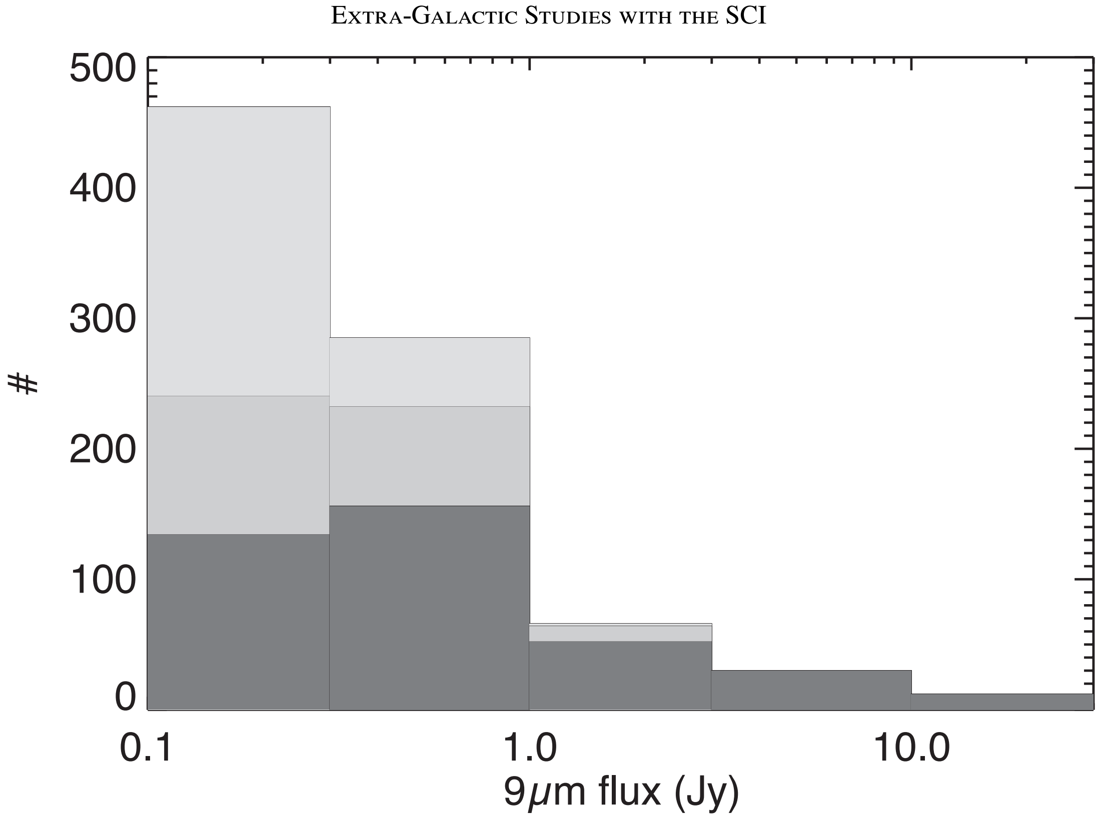

Figure 2. The number or targets whose distance is 20 Mpc (dark histogram), 40 Mpc (light dark) and 80 Mpc (bright).

maintain the correlation by using outflows from the central engine. In the mechanism, no consensus has been reached. One of the difficulties of the observations is that targets in the evolutionary stage are probably obscured by dust.

As shown in Figure 1, Oyabu et al. (2011) found galaxies with dusty AGNs in the low-redshift Universe using the *AKARI* mid-infrared all-sky survey catalog (Ishihara et al. 2010). The galaxies show the AGN signatures only in the near- and mid-infrared, not in other wavelengths. The dusty AGNs also followed the correlation between the SMBH mass and the spheroid mass even though dusty AGNs are expected to be young systems which are growing up at present. It makes sense if black holes grow at the same rate as the stellar spheroid in which they reside. It is unclear how to connect the growth of the black hole and the stellar spheroid, but we can imagine a close link between black hole growth and galaxy evolution.

To reveal how they interact, we need to obtain not only spectra of a central engine of a dusty AGN but also spectra of a host galaxy. If outflows maintain the correlation, we will find clues in both spectra. If there are AGNs which do not follow the correlation, they are probably populations before outflows occur.

3. MERITS OF THE SCI OBSERVATIONS

We are motivated to investigate the environments close to the central part of AGNs and starburst galaxies by the science cases as mentioned above. However, a very bright nucleus such as an AGN and a nuclear starburst prevents us from observing the regions close to a galaxy nucleus. Coronagraph systems can benefit the research for the regions on galaxy nuclei because they reduce halo components of a point spread function (PSF) of a bright central core. Using the capabilities of the SCI, we propose spectroscopic observations of regions near bright central cores in AGNs and nuclear starburst galaxies.

High contrast capability of the SCI can reduce the confusion of the central nuclei to the environments close to the nuclei. Without the coronagraph, a surface brightness of the PSF halo can be comparable to that of the environments and the spectra of the environment are contaminated by the halo of the central PSF. Therefore, the SCI can obtain the pure spectrum of the faint environments in the host galaxies.

In addition to the reduction of the confusion, the high contrast capability of the SCI can also dramatically reduce the noise caused by the halo of bright central core. It is very powerful to reduce observing time. When we look at 10 Jy sources at the mid-infrared with the coronagraph, the exposure time will be one hundredth of the exposure time without the coronagraph. For the 0.1 Jy sources, it is still a few times faster than the observations without the coronagraph.

Our targets are central 10–1000 pc regions of galaxies with AGNs and nuclear starbursts. If they are located at the distance of 4 Mpc, we can resolve 20 pc at 10 μm. In galaxies at 20 Mpc and 40 Mpc, 100 pc and 200 pc region can be resolved at 10 μm, respectively. Using the *AKARI* Mid-infrared All-Sky Survey catalog, we selected target candidates with a bright central core at 9 μm. We have 94 galaxies with 9 μm flux of $F_{9\,\mu\mathrm{m}} > 1$ Jy in 20 Mpc as targets. If we extend our sample to more distant or fainter targets, the number of targets increases dramatically. The observation efficiency of the SCI will be able to increase the number of observed targets and to help understanding the environments very close to galactic nuclei.

4. SUMMARY

Fueling mechanisms, processing of materials and connections between a nucleus and a host galaxy are important science topics for the study of AGNs and nuclear starburst galaxies. In order to tackle such science topics, we need to observe the environments very close to bright central cores of AGNs and nuclear starburst galaxies. However, the halo components of a PSF of a bright central core prevent us from observing the regions.

The coronagraph capabilities of the SCI overcome the obstacle. The reduction of the halo components of the PSF will distinguish the environment components from the bright central core and reduce the observation time. Therefore, we propose the spectroscopic observations of AGNs and nuclear starburst galaxies with the SCI. The SCI will be able to take mid-infrared spectra of the environment very close to bright central cores. These spectra will reveal the circumnuclear structures and the compositions of dust, especially silicate and PAHs, in the environments.

REFERENCES

Athanassoula, E. 1992, MNRAS, 259, 345
Barnes, J. E., & Hernquist, L. E. 1991, ApJL, 370, L65
Gültekin, K., Richstone, D. O., Gebhardt, K., et al. 2009, ApJ, 698, 198
Ishihara, D., Onaka, T., Kataza, H., et al. 2010, A&A, 514, A1
King, A. 2003, ApJL, 596, L27
Martini, P., Regan, M. W., Mulchaey, J. S., et al. 2003, ApJS, 146, 353
Oyabu, S., Ishihara, D., Malkan, M., et al. 2011, A&A, 529, A122
Rouan, D., Lacombe, F., Gendron, E., et al. 2004, A&A, 417, L1
Schmitt, H. R. 2001, AJ, 122, 2243
Silk, J., & Rees, M. J. 1998, A&A, 331, L1
Spoon, H. W. W., Tielens, A. G. G. M., Armus, L., et al. 2006, ApJ, 638, 759
Wada, K. 2001, ApJL, 559, L41
Yamada, R., Oyabu, S., Kaneda, H., et al. 2013, PASJ in press