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LUMINOSITY DEPENDENCE OF THE COVERING FACTOR OF THE DUST TORUS IN ACTIVE GALACTIC NUCLEI REVEALED BY AKARI

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ABSTRACT

We demonstrate the luminosity dependence of the covering factor (CF) of active galactic nuclei (AGNs), based on AKARI mid-infrared all-sky survey catalog. Combining the AKARI with Sloan Digital Sky Survey (SDSS) spectroscopic data, we selected 243 galaxies at 9 μm and 255 galaxies at 18 μm. We then identified 64 AGNs at 9 μm and 105 AGNs at 18 μm by their optical emission lines. Following that, we estimated the CF as the fraction of type 2 AGN in all AGNs. We found that the CF decreased with increasing 18 μm luminosity, regardless of the choice of type 2 AGN classification criteria.

Key words: galaxies: active — infrared: galaxies

1. THE IMPORTANCE OF THE DUST TORUS

It is well known that some galaxies have compact nuclei that radiate an energy over the entire electromagnetic spectrum from radio through gamma-rays, that is called active galactic nuclei (AGN). The activity originates from the release of gravitational energy through accretion of material on to a supermassive black hole with a typical mass in the range of 10^{6-9} $M_\odot$. A popular idea called the unified scheme (Antonucci, 1993) attempts to explain the diversity of AGN phenomena using a common framework. The basic idea of the unified scheme is that type 1 and type 2 AGNs are intrinsically the same class of objects, and their differences are due only to differences in the viewing angle relative to an obscuring medium, the so-called "dust torus". Anisotropic obscuration of the central region so that sources viewed face-on are recognized as type 1 AGNs, those observed edge-on are type 2 AGNs.

A simple, but powerful, tool to constrain torus structure is to use the number statistics of type 1 and type 2 AGNs. The covering factor (CF) can be described as the fraction of type 2 AGN (i.e., the number of type 2 AGN divided by the total number of AGN), based on an assumption that (i) the inclination angles of torus are random distributed from an observer and (ii) the central engines of type 1 and type 2 AGNs are identical. In this study, we investigate the relationship between the CF and mid-infrared (MIR) luminosity, based on the AKARI MIR all-sky survey catalog data (Ishihara et al., 2010).

2. SAMPLE SELECTION

We first narrowed our sample to AKARI sources within the Sloan Digital Sky Survey (SDSS) Data Release 7 (DR7: Abazajian et al. 2009) legacy region. We then extracted objects at 9 μm above 90 mJy or at 18 μm above

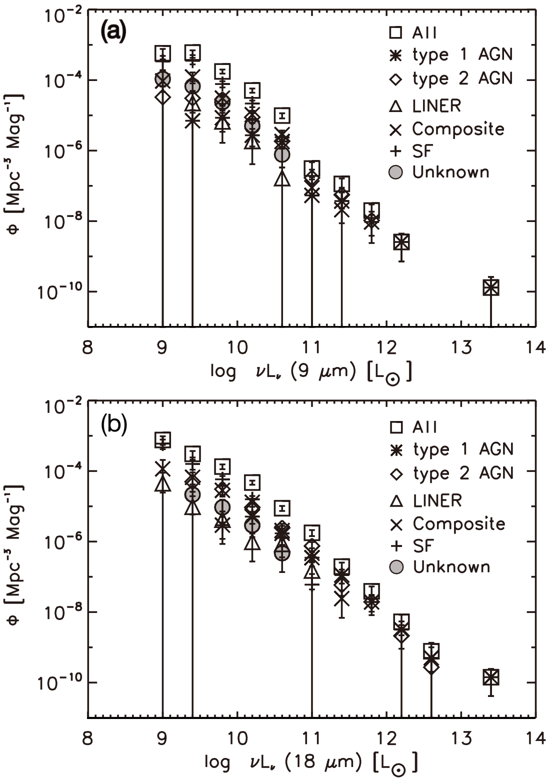

Figure 1. (a) 9 and (b) 18 μm LFs for each galaxy type plotted in terms of the space density as a function of luminosity. The error bars are calculated from the Poisson statistical uncertainty.

170 mJy, whose fluxes correspond to almost 50% completeness flux limits calculated by Kataza et al. (2010). These extracted sources were then cross-identified with the *Tycho-2* Catalog (Høg et al., 2000) to remove galactic bright stars. Following that, we conducted to cross-match with the SDSS and the Center for Astrophysics (CfA) redshift survey (ZCAT: Huchra et al. 1995). The above step yielded 243 galaxies at 9 μm and 255 galaxies at 18 μm.

Next, we spectroscopically classified the 348 galaxies into five types: type 1 AGNs including quasars and Seyfert 1 galaxies, type 2 AGNs, low-ionization narrow-emission-line region galaxies (LINER), galaxies that are likely to contain both star formation and AGN activity (composite types of galaxies, hereinafter "Composite"), and star-forming galaxies (SF). First, we separated type 1 AGNs based on the full-width-half-maximum (FWHM) of the Hα emission line. We extracted objects with FWHM (Hα) greater than 1200 km s^{-1} as type 1 AGNs in the same way as Hao et al. (2005). For the objects that have an Hα emission line with FWHM $<$ 1200 km s^{-1}, we classified the galaxies into type 2 AGNs, LINER, Composite, and SF by using

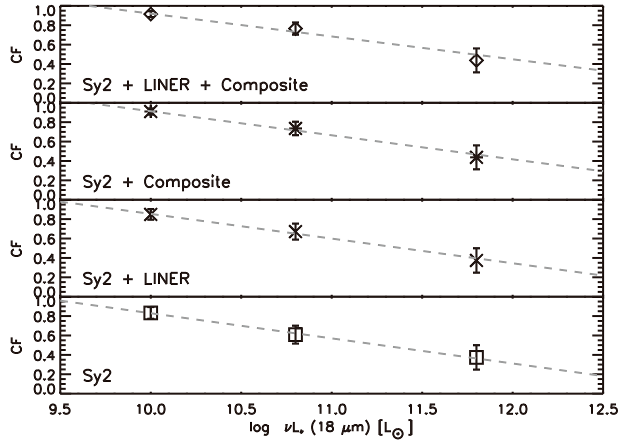

Figure 2. The CF versus 18 μm luminosity at $0.006 \leq z \leq 0.2$. Each panel represents which populations were included with type 2 AGNs. The solid line represents the best-fit linear function.

the optical flux line ratios such as [OIII]5007/Hβ versus [NII] 6583/Hα (Baldwin et al., 1981). However, the BPT diagram is not able to classify a galaxies if Hα, Hβ, [OIII], or [NII] were not detected in the emission line. These galaxies are classified as unknown types of galaxies (hereinafter, "Unknown").

3. LUMINOSITY FUNCTION OF VARIOUS TYPES OF GALAXIES AT 9 AND 18 μm

Here, we derive the Luminosity Functions (LFs) following the $1/V_{\rm max}$ method described by Schmidt (1968). Fig. 1 shows the resultant LFs for each spectroscopic type of galaxies at 9 and 18 μm. AKARI's LFs indicate that relative number of AGNs changes with increasing MIR luminosity, which means that the fraction of type 2 AGNs (i.e., the CF) varies depending on MIR luminosity.

4. LUMINOSITY DEPENDENCE OF THE COVERING FACTOR

We discuss the luminosity dependence of the CF. A point of caution here is that our flux-limited sample produces a strong artificial correlation between the redshift and luminosity. Therefore, determing whether it is the redshift or the luminosity that is the more fundamental physical variable that correlates with the CF is difficult in general. In this study, we just assume that the redshift dependence of the CF can be neglected in our low-z sample, and discuss the luminosity dependence of the CF. We also note that Seyfert 2 galaxies (Sy2) were considered as type 2 AGNs in this study. However, some LINERs and Composites would show have type 2 AGN like properties. We thus made four possible groups of type 2 AGNs: (i) Sy2, (ii) Sy2 + LINER, (iii) Sy2 + Composite, and (iv) Sy2 + LINER + Composite, and we estimated the CF for each group. Fig. 2 shows the CF as a function of 18 μm luminosity. We can see that the CF decreased with increasing 18 μm luminosity, regardless of the choice of type 2 AGNs. This trend has been confirmed by Toba et al. (2014) who investigated the dependence of the CF on 22 μm luminosity based on the Wide-field Infrared Survey Explorer (WISE) data. Fig. 2 also represents the best-fit linear function for each panel. The weighted average of the slope over the four cases shown in Fig.2 is -0.25 $\pm$ 0.03 that is good agreement with that obtained by Hasinger (2008) and Toba et al. (2014).

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