The candidate Seyfert 1-like objects found from ULIRGs in the Sloan Digital Sky Survey, 2dF Galaxy Redshift Survey and 6dF Galaxy Survey

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Abstract The infrared properties of ULIRGs in samples from the Sloan Digital Sky Survey, 2dF Galaxy Redshift Survey and 6dF Galaxy Survey (SDSS-2dF-6dF Survey) and ULIRGs in the IRAS 1 Jy sample are compared. We find that the infrared properties are quite similar in both the far infrared and the near infrared for those two samples. By using the IRAS two-color diagram and the 2MASS two-color diagram we find that 24 sources in the SDSS-2dF-6dF Survey are candidate Seyfert 1-like sources indicative of strong AGN-dominant nature.

Keywords Galaxies: AGN · Galaxies: starburst · Galaxies: ULIRG · Infrared: ULIRG

1 Introduction

An important result from the IRAS all-sky survey was the discovery of a significant population of ultraluminous infrared galaxies (ULIRGs). Their infrared luminosities are very strong, equivalent to the bolometric luminosities of optically selected quasars, e.g. $L_{\text{IR}} \geq 10^{12}L_{\odot}$ (Kim et al. 1998a and references therein). Since this discovery, the origin and the dominant energy source in the IR for ULIRGs have been interesting research topics. Sanders et al. (1988) proposed that almost all ULIRGs appear to be advanced mergers, powered by a mixture of circumnuclear starburst and active galactic nucleus (AGN) energy sources, both of which are fueled by an enormous concentration of molecular gas funneled into the merger nucleus. Lonsdale et al. (2006) pointed out that ULIRGs are mainly powered by a starburst, frequently with a significant AGN contribution. Sanders and Mirabel (1996), Farrah et al. (2001), Genzel et al. (2001) and Tacconi et al. (2002) suggested that ULIRGs may represent an important stage in the formation of quasars and powerful radio galaxies; they may also represent a primary stage in the formation of elliptical galaxy cores, the formation of globular clusters, and the metal enrichment of the intergalactic medium.

The best known samples of IRAS luminous and ultraluminous galaxies are the Bright Galaxy Sample (Soifer et al. 1987), recently significantly updated into the Revised Bright Galaxy Sample (Sanders et al. 2003), the IRAS 2 Jy sample (Strauss et al. 1990), the IRAS 1 Jy sample (Kim et al. 1998a), the FIRST/IRAS sample (Stanford et al. 2000) and the sample of the Sloan Digital Sky Survey, 2dF Galaxy Redshift Survey and 6dF Galaxy Survey (Hwang et al. 2007, hereafter the SDSS-2dF-6dF sample). Of these the IRAS 1 Jy sample and the SDSS-2dF-6dF sample are special surveys for pure ULIRGs. In the IRAS 1 Jy sample there are 118 ULIRGs in total. Kim et al. (1998b) and Veilleux et al. (1999a) made the optical spectroscopic observations for 108 ULIRGs in the range 4500–8900 Å with a resolution of 8.3 Å. Results of these spectroscopic observations show that all of the ULIRGs present emission line spectra and color excesses indicative of physical conditions of thermal gas and dust in the sample. In addition, among those spectra, about 30% present Seyfert characteristics that show the presence of a genuine AGN in the core region. It is found that ULIRGs with the Seyfert 1 spectra also have broad-line region (BLRs) similar to those of optical quasars; however, about 30% show the H II region-like features indicative of photoionization by hot stars from recent starbursts as the apparent dominant source of ionization and about 40% show the low-ionization nuclear emitting regions.
(LINERs) indicative of both hot stars and shocks as their apparent dominant sources of ionization. Therefore Veilleux et al. (1999a) concluded that AGNs are energetically important for ULIRGs with the spectral type of Seyferts in the IRAS 1 Jy sample, while the main sources of energy for ULIRGs with spectral types of H II galaxies and LINERs are starbursts rather than AGNs. In addition, Veilleux et al. (1997, 1999a, 1999b) made NIR spectroscopic observations in the range 1.9–2.5 μm of "warm" Seyfert 2 galaxies with their results show that some ULIRGs have the spectral type of H II galaxies and LINERs are starbursts rather than AGNs. In addition, Veilleux et al. (1997, 1999a, 1999b) made NIR spectroscopic observations in the range 1.9–2.5 μm with resolutions of 400–1400, for 64 ULIRGs in the 1 Jy sample selected for their lack of broad-line regions (BLRs) at optical wavelengths. Their results show that some ULIRGs have the spectral type of "warm" Seyfert 2 galaxies with F25 μm/F60 μm > 0.2, all of these ULIRGs have the hidden BLRs in the NIR indicative of an important fraction of the bolometric luminosity powered by the same mechanism as that in Seyfert 1 galaxies and optical quasars. Tacconi et al. (2002) also made NIR spectroscopic observations for some AGN-dominated ULIRGs. Their results show that those ULIRGs resemble local quasars in bolometric luminosities and in NIR spectra.

In Chen and Zhang (2006, hereafter Paper I) we made an infrared photometric study of the IRAS 1 Jy sample. We found that all Seyfert 1 sources and Seyfert 2 sources with hidden BLRs have much redder colors and steeper spectral indices in the NIR, indicative of a strong energy source from the central AGN; all Seyfert 1 sources and many Seyfert 2 sources with hidden BLRs have blue [25]–[60] colors indicative of the flatter spectral continuum and rather warm color temperature in the 25 μm to 60 μm region. In particular, in Paper I we give the criteria to select strong AGN-dominated ULIRGs having Seyfert 1 nature or Seyfert 2 nature with hidden BLRs (hereafter we call those two kinds of sources Seyfert 1-like sources) according to their locations either in the NIR two-color diagram or in the IRAS two-color diagram.

In 2007 Hwang et al. (2007) gave the largest sample so far of ULIRGs, containing 324 sources, in the SDSS-2dF-6dF Survey. In this sample 190 ULIRGs are newly discovered.

In this paper we attempt to compare infrared properties of ULIRGs between the SDSS-2dF-6dF sample and the IRAS 1 Jy sample. We also try to use the criteria found in Paper I to identify some candidate Seyfert 1-like sources from the SDSS-2dF-6dF sample.

2 Working sample and data processing

324 ULIRGs from the SDSS-2dF-6dF Survey are taken as our working sample in this paper. First of all, cross-identifications are made between the sample from the SDSS-2dF-6dF Survey and the 2MASS Point Source Catalog (hereafter 2MASS PSC). Hwang et al. (2007) gave all source positions from the IRAS Faint Source Catalog (hereafter IRAS FSC) where the positional accuracy is typically 10′′–30′′, while in the 2MASS PSC the positional accuracy is typically less than 2 arc-second, which is much smaller than the positional accuracy of IRAS. Therefore we used the IRAS positional error ellipse to restrict the cross-identifications because the IRAS error ellipse has a 95% confidence level (IRAS Explanatory Supplement 1988, hereafter IRAS ES). Hwang et al. (2007) also gave SDSS identifications for some sources in their Table 1, but over half of their sources have no SDSS counterparts. SDSS identifications and positions for some sources can be found in their Table 1.

We found 266 sources with proper 2MASS counterparts, and 249 of these sources have good quality data in all JHK bands. All identified 2MASS associations of the sample from SDSS-2dF-6dF Survey are listed in Table 1. The items in the columns of Table 1 are listed as follows: (1) IRAS FSC name; (2) redshift from Hwang et al. (2007); (3) and (4) the R.A. and Dec. in 2MASS PSC at the epoch of 2000 respectively; (5)–(7) the JHK magnitudes and their uncertainties in the bracket from 2MASS PSC respectively; (8)–(11) the IRAS flux densities (in Jy) and their uncertainties in the bracket from IRAS FSC at 12, 25, 60 and 100 μm respectively; (12) the flux quality in IRAS observations (note that "1" indicates the upper-limited value and will not be used in following discussions); (13) the spectral type given by Kim et al. (1998b) and Veilleux et al. (1999a) for the IRAS 1 Jy sample in the working sample. It should be noted that if there is a blank in the JHK magnitude uncertainty, it means the upper-limited observation from 2MASS PSC. In addition, if there are more than one 2MASS source in the IRAS positional error ellipse, the related brighter and nearer one is taken as the 2MASS counterpart.

For the corrections to interstellar extinction caused by our Galaxy, E(B − V) and interstellar extinction coefficient Av are obtained from the maps given by Schlegel et al. (1998). In fact, Av can be directly obtained through the NASA/IPAC Extragalactic Database (NED) for all sources. Then from Schlegel et al. (1998), A_{J} = 0.272A_{V}, A_{H} = 0.173A_{V} and A_{K} = 0.110A_{V} can be obtained. Actually at areas with |b| ≥ 30′′, E(B − V) is usually quite small, and as shown above, the interstellar extinction coefficients in the JHK bands are just about 1/4 to 1/10 of the value of Av. In addition, if the uncertainties of the measured magnitudes in 2MASS observation given in Table 1 are taken into account, most sources with |b| ≥ 30′′ have interstellar extinction coefficients in the JHK bands smaller than the uncertainties of the measured magnitudes. Therefore the interstellar extinction corrections are made for only a few sources. In the following discussions the magnitudes used in the JHK bands are all corrected for interstellar extinctions according to the methods mentioned above.