Publications of the Korean Astronomical Society
32: 189 ∼ 191, 2017 March

pISSN 1225-1534
eISSN 2287-6936
https://doi.org/10.5303/PKAS.2017.32.1.189

PROBING STAR FORMATION IN ULTRALUMINOUS INFRARED GALAXIES USING AKARI NEAR-INFRARED SPECTROSCOPY

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(Received June 3, 2015; Revised October 28, 2016; Accepted October 28, 2016)

ABSTRACT

We performed systematic observations of the H I Brα line (4.05 μm) in 51 nearby (z<0.3) ultraluminous infrared galaxies (ULIRGs), using AKARI near-infrared spectroscopy. The Brα line is predicted to be the brightest among the H I recombination lines in ULIRGs with visual extinction higher than 15 mag. We detected the Brα line in 33 ULIRGs. In these galaxies, the relative contribution of starburst to the total infrared luminosity ($L_{\rm IR}$) is estimated on the basis of the ratio of the Brα line luminosity ($L_{\rm Br\alpha}$) to $L_{\rm IR}$. The mean $L_{\rm Br\alpha}/L_{\rm IR}$ ratio in LINERs or Seyferts is significantly lower (∼50%) than that in H II galaxies. This result indicates that active galactic nuclei contribute significantly (∼50%) to $L_{\rm IR}$ in LINERs, as well as Seyferts. We also estimate the absolute contribution of starburst to $L_{\rm IR}$ using the ratio of star formation rates (SFRs) derived from $L_{\rm Br\alpha}$ ($\rm SFR_{Br\alpha}$) and those needed to explain $L_{\rm IR}$ ($\rm SFR_{IR}$). The mean $\rm SFR_{Br\alpha}/SFR_{IR}$ ratio is only 0.33 even in H II galaxies, where starburst is supposed to dominate the luminosity. We attribute this apparently low $\rm SFR_{Br\alpha}/SFR_{IR}$ ratio to the absorption of ionizing photons by dust within H II regions.

Key words: galaxies: active — galaxies: star formation — infrared: galaxies

1. INTRODUCTION

Ultraluminous infrared galaxies (ULIRGs) radiate most (≥90%) of their extremely large luminosities (>$10^{12} L_\odot$) as infrared (IR) dust emission (Sanders et al., 1988). The possible energy source of their enormous IR luminosity ($L_{\rm IR}$) is starburst and/or active galactic nuclei (AGN), however, it is difficult to distinguish them because of the high dust extinction.

To avoid the strong dust obscuration, we focused on the IR H I recombination line Brα ($n : 5 \rightarrow 4$, 4.05 μm). The Brα line is predicted to be the brightest among the H I recombination lines, which trace ionizing photons from OB stars and are used to estimate the starburst strength, in conditions with high dust extinction (visual extinction A_V>15 mag) expected in ULIRGs (e.g., Genzel et al., 1998). Thus the Brα line is the most suitable of the H I recombination lines for probing star formation in ULIRGs. With the unique wavelength coverage of the near-IR 2.5–5.0 μm spectroscopy of AKARI, we succeed in systematic observations of the Brα line, whose wavelength is difficult to access from ground-based telescopes, in ULIRGs.

2. OBSERVATION AND RESULTS

The observations were performed with the NG grism mode of the IRC spectrograph (Onaka et al., 2007) onboard the AKARI satellite (Murakami et al., 2007). Our targets are selected from the sources in the AKARI mission program "AGNUL" (P.I. T. Nakagawa). We se-

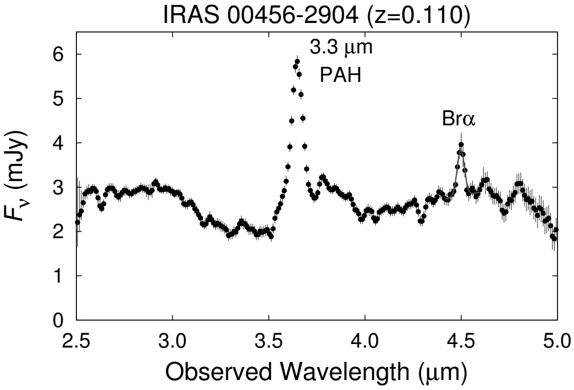

Figure 1. Typical example of AKARI 2.5–5.0 μm spectra.

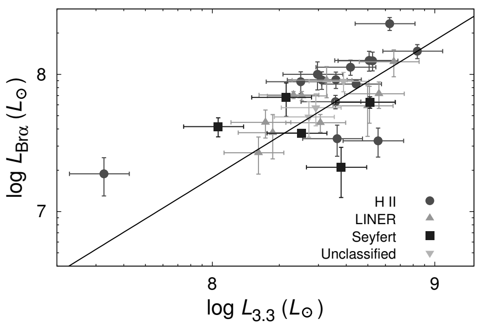

Figure 2. Comparison of $L_{\mathrm{Br}\alpha}$ with $L_{3.3}$. The symbols represent the optical classifications of the galaxy. The solid line shows the regression line $L_{\mathrm{Br}\alpha} = (0.177 \pm 0.003) L_{3.3}$.

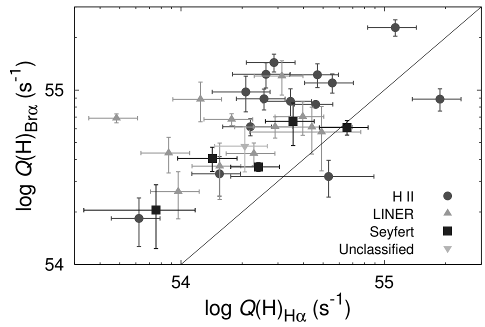

Figure 3. Comparison of $Q(\mathrm{H})_{\mathrm{Br}\alpha}$ with $Q(\mathrm{H})_{\mathrm{H}\alpha}$. The symbols represent the optical classifications of the galaxy. The solid line indicates $Q(\mathrm{H})_{\mathrm{Br}\alpha} = Q(\mathrm{H})_{\mathrm{H}\alpha}$.

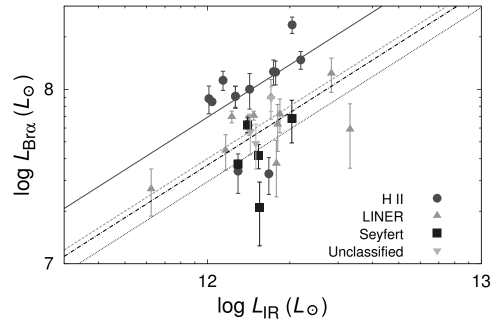

Figure 4. Comparison of $L_{\mathrm{Br}\alpha}$ with L_{IR}. The symbols represent the optical classifications of the galaxy. The solid, dashed, dotted, and dashed–dotted lines indicate the mean $L_{\mathrm{Br}\alpha}/L_{\mathrm{IR}}$ ratio for H II galaxies, LINERs, Seyferts, and the combination of LINERs and Seyferts, respectively.

lect all 51 ULIRGs observed during the liquid-He cool holding period (2006 May 8–2007 Aug. 26). All targets are nearby (z<0.3) objects. The data were processed through "IRC Spectroscopy Toolkit Version 20110114," the standard IRC-dedicated IDL toolkit. Figure 1 shows an example of 2.5–5.0 μm spectra. We detect the Brα line in 33 ULIRGs at the 2.5σ significance level. The 2.5σ upper-limit fluxes are derived in the remaining sources, although we do not use them in this paper.

Figure 2 shows that the luminosity of the Brα line ($L_{\mathrm{Br}\alpha}$) is well correlated with that of the 3.3 μm polycyclic aromatic hydrocarbon (PAH) emission ($L_{3.3}$), which is simultaneously observed in the AKARI spectra. PAH is excited by ultra-violet photons from OB stars but is destroyed by hard radiation from active galactic nuclei (AGN). Therefore, we assume that AGN contribution to the Brα line is not significant in all our sample.

3. DISCUSSION

3.1. Effectiveness of IR Observations

The most significant merit of using the IR Brα line is to reduce the effect of dust extinction. To verify this merit, we compare our Brα line results with optical Hα line results taken from the literature. Both Brα and Hα lines are extinction-corrected with the Balmer decrement and converted to the number of ionizing photons, $Q(\mathrm{H})_{\mathrm{Br}\alpha}$ and $Q(\mathrm{H})_{\mathrm{H}\alpha}$, respectively (Osterbrock & Ferland, 2006).

Figure 3 shows this comparison. We find that $Q(\mathrm{H})_{\mathrm{Br}\alpha}$ is systematically higher than $Q(\mathrm{H})_{\mathrm{H}\alpha}$ typically by a factor of 3. This means that the optical observations miss some flux originating from the heavily dust obscured regions. Using the Brα line, we succeed in reducing the effect of dust extinction.

3.2. Relative Contribution of Starburst to L_{IR}

We investigate the relative difference of the contribution of starburst to L_{IR} using the $L_{\mathrm{Br}\alpha}/L_{\mathrm{IR}}$ ratio on the assumption that L_{IR} is produced by both starburst and AGN, while $L_{\mathrm{Br}\alpha}$ reflects only the starburst strength. Figure 4 shows a comparison of $L_{\mathrm{Br}\alpha}$ with L_{IR}. We find that the $L_{\mathrm{Br}\alpha}/L_{\mathrm{IR}}$ ratio is significantly different among

Table 1
$L_{\mathrm{Br}\alpha}/L_{\mathrm{IR}}$ Ratio

Optical Class	Mean $L_{\mathrm{Br}\alpha}/L_{\mathrm{IR}}$ (10^{-5})	Relative Contribution of Starburst
H II	6.9	100%
LINERs	4.0	58%
Seyferts	3.0	43%
L+S*	3.7	54%

*Combination of LINERs and Seyferts.

the optical classifications of the galaxies (H II galaxies, LINERs, and Seyferts).

Table 1 shows that the mean $L_{\mathrm{Br}\alpha}/L_{\mathrm{IR}}$ ratio in LINERs or Seyferts is significantly lower than that in H II galaxies. If we assume that H II galaxies are 100% energized by starburst, the contribution of starburst to L_{IR} is $\sim$50% in LINERs or Seyferts. This result indicates that AGN contribute significantly ($\sim$50%) to L_{IR} in LINERs, as well as Seyferts.

3.3. Absolute Contribution of Starburst to L_{IR}

To estimate the absolute contribution of starburst to L_{IR}, we compare star formation rates (SFRs) derived from $L_{\mathrm{Br}\alpha}$ ($\mathrm{SFR}_{\mathrm{Br}\alpha}$) and those needed to explain L_{IR} ($\mathrm{SFR}_{\mathrm{IR}}$). The calibration provided by Murphy et al. (2011) is adopted: SFR ($M_\odot\,\mathrm{yr}^{-1}$) $= 1.85 \times 10^{-40} L_{\mathrm{Br}\alpha}$ (erg s^{-1}) $= 3.88 \times 10^{-44} L_{\mathrm{IR}}$ (erg s^{-1}).

The mean $\mathrm{SFR}_{\mathrm{Br}\alpha}/\mathrm{SFR}_{\mathrm{IR}}$ ratio is, however, only 0.33 even in H II galaxies. This means that starburst explains only one third of L_{IR} even in H II galaxies. We attribute this apparently low $\mathrm{SFR}_{\mathrm{Br}\alpha}/\mathrm{SFR}_{\mathrm{IR}}$ ratio to the absorption of ionizing photons by dust within H II regions. We propose that dust absorbs a significant fraction ($\sim$70%) of ionizing photons, and the Brα line underestimates SFRs by a factor of $\sim$3 in ULIRGs.

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