OBSERVING LUMINOUS INFRARED GALAXIES USING AKARI IRC NEAR-INFRARED SPECTROSCOPY

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ABSTRACT

By using ‘AKARI IRC Infrared 2.5-5 μm Spectroscopic’ data, analysis of ULIRGs (Ultra-Luminous Infrared Galaxies: Luminosity ≥ 10¹² L☉) and LIRGs (Luminous Infrared Galaxies: Luminosity, 10¹¹ - 10¹² L☉) can be conducted within the near infrared band of wavelength, 2.5-5 μm. Based on the observable PAH (Polycyclic Aromatic Hydrocarbons), Br-α and Br-β (Brackett-alpha and Brackett-beta) emission peaks, the galactic objects used in the collective datasets can be categorized into sub-groups (based on the galactic center of the respect object) isolating dust obscured starburst regions, obscured AGNs, pure AGNS and mixed dust-AGN regions.

1 INTRODUCTION

1.1 AIM

The objective is to distinguish the constituents of a sample of Luminous Infrared Galaxies (LIRGs) and Ultra-Luminous Infrared Galaxies (ULIRGs) from the spectrums they produce (in the 2.5-5 μm wavelength range). Following this, the galaxies will be categorized based on the ratio of PAH emission to near Infrared emission they exhibit.

1.2 BACKGROUND OVERVIEW

1.2.1 AKARI

February, 2006, the AKARI Infrared Satellite was launched into a sun-synchronous orbit around Earth. The mission of AKARI was aimed to survey the entire sky in the near, mid and far infrared bands of the Electro-Magnetic Spectrum; in which AKARI had succeeded following a 5 year, 9 month run before being decommissioned. The mission was operated by JAXA (Japanese Aerospace Exploration Agency) [with Co-operation with European Space Agency].

1.2.2 Investigation

For this investigation, the observed spectroscopic data obtained from AKARI Infrared Camera (IRC) for 60 LIRGs and 54 ULIRGs samples will be processed and analyzed within the 2.5-5 μm wavelength band (Near Infrared) of the Electro-Magnetic Spectrum. A galaxy is classified to be a LIRG if the luminosity (L) falls within the 10¹¹ - 10¹² L☉ range and a ULIRG if L ≥ 10¹² L☉. The samples used for the investigation are identical to those used in (Imanishi, Nakagawa, Shirahata, Ohyama, & Onaka, 2010); as such, each galaxy in the sample exhibits obscurities (caused by dust) within the spectroscopic data.

1.3 IMPORTANCE OF OBSCURED LIRG AND ULIRG ANALYSIS

Analysis of obscured LIRGs and ULIRGs will enable the compositional structure of the galactic nuclei to be identified as well as enabling a galaxy to be categorized. In particular, key features such as, the Brackett series (hydrogen emission series: Br-α and Br-β) and Polycyclic Aromatic Hydrocarbon (PAH), can be observed, if present. These features are vital in permitting obscured Active Galactic

¹ Note: In this investigation, Luminous Infrared Galaxies and Ultra-Luminous Infrared Galaxies shall be referred to as LIRGs and ULIRGs, respectively.
Nuclei (AGN) as well as Starburst regions\(^2\), to be distinguished.

It should be noted that the presence of PAH indicates obscurities around the galactic center and an absence of PAH in the continuum implies a pure AGN system. [Refer to (Imanishi, Nakagawa, Shirahata, Ohyama, & Onaka, 2010)]

# 2 PROCEDURE

## 2.1 DATA REDUCTION

The data collected from objects by the AKARI space telescope is obtained in a RAW format (all available information is collected such that there is no practical way to distinguish segments of information that are required for the investigation); as such, the RAW data is impractical for the investigation. Hence, the RAW data collected for a specific object needs to be processed further such that useful information can be extracted and model for further use.

Using the IDL software package described in (Ohyama & et al., 2007) enables relevant data to be filtered and reduced to a single spectrum as well as a single data document.\(^3\)

An example product of the stated process is presented in Figure 1.

\(^2\) Note: The terms, “Brackett – alpha”, “Bracket – beta”, “Polycyclic Aromatic Hydrocarbons” and “Active Galactic Nuclei” will be abbreviated to “Br-α”, “Br – β”, “PAH” and “AGN”, respectively, throughout this investigation.

\(^3\) Note: As well extracting the relevant data, any “bad” data points detected are removed to increase the quality and precision of the overall results. In this context, “bad” data points are referred to as data segments that are anomalous and/or are redundant due to the population of surrounding data points.
2.2.2 Validating Data

Before proceeding with further data analysis and data processing, the extracted spectra have to be validated. In this investigation, the WISE (Wide-field Infrared Survey Explorer) telescope (Wright et al., 2010) is used to verify the results obtained up to this stage\(^4\).

In order to verify the validity of the data, the apparent magnitude is calculated from both WISE and AKARI datasets for a specific object. The set of apparent magnitudes obtained are then plotted against each other with the WISE apparent magnitude on the vertical axis and the AKARI apparent magnitude on the horizontal axis. The apparent magnitude for a relative object should remain independent of the instrument/method used to obtain the data; hence, the obtained values for the apparent magnitudes for WISE and AKARI datasets respectively should be equivalent. As such, a one to one linear relationship should be observed within the generated plot.

This is observed in Figure 3 for the both datasets that are used in this investigation. Any outliers or anomalies are filtered out.

\(^4\) Note: WISE uses photometric data, as opposed to AKARI’s IRC spectroscopic data, this was corrected for in the calculation as observed in (Tanabé , et al., 2008).

2.3 Regression Fitting

With a cursory data model and the validation of the collected data, the key absorption and emission features can be isolated and observed. These features can be observed (if present) by use non-linear regression fitting.

This process is carried out for each dataset available.

There are three key features that are vital in categorizing different galaxies; these have been mentioned in Section 1.3 (Br-\(\alpha\), Br –\(\beta\), PAH).

\(^5\) Note: The values for the constants stated are used throughout the investigation.
These features correspond to emission peaks and are found at wavelengths 4.05, 2.63 and 3.30 μm, respectively. 6

In order to demonstrate the regression fitting used, the IRAS 14348-1447(ULIRG) [Object ID: 1122032.1/2/3] is used (Refer to Section 8, Table 1, 2 and 3). (Figure 4 depicts a photographic image of the object).

The following model, Figure 5, shows a clear PAH emission peak for the object observed in Figure 4. This highly suggests that the core of the galaxy is occupied by an AGN that is surrounded by a dense concentration of dust :- hence, an obscure AGN.

The result of further processing and alteration of Figure 5, produces a product that appears similar to Figure 6. In the following model, the redshift of the galaxy has also been factored in; allowing for a more accurate regression fit.

Following further processing of the model in Section 2.3, a continuous regression line can be fitted to accommodate for several other absorption/emission features (at known corresponding wavelengths) such as CO ice absorption (4.67 μm), CO2 ice absorption (4.26 μm), H2O ice absorption (3.0 μm) etc.

2.5 CATEGORIZATION
Following Section 2.4, there are regression fitted models for the object data sets at this stage. As such, the data samples can be categorised in to groups and sub-groups.
Figure 7 demonstrates the estimated classification chart that will enable LIRGs and ULIRGs to be classified into sub-groups. In this investigation, the objects will be categorised based on the amount of PAH emission that is observed from their respective processed spectra.

Obscured AGNs can be identified effectively by calculating the equivalent PAH widths observed in the spectra; the equivalent widths are evaluated by dividing the PAH emission intensity by the continuum intensity. This is possible due to the fact that AGNs exhibit stronger continuum but weaker PAH emission intensities (in comparison to the collective data spectra).

3 EXAMPLE OBJECT: NGC 3110 (LIRG)

In order to demonstrate the stages highlighted in Section 2, the object NGC 3110 (LIRG) [Object ID: 1120120.2] will be processed as an example (Refer to Section 8, Table 4). The galaxy used is a spiral arm galaxy; hence, it is probable that the galactic core contains an AGN. As such, there should be a thin PAH peak assuming dust particles are present around the galactic centre. (Refer to Figure 8, for an image of the stated galaxy)

For queries regarding to the full datasets, contact sm730@student.le.ac.uk

Figure 7. Estimated Characterisation groups based on the conclusions speculated in (Imanishi, Nakagawa, Shirahata, Ohyama, & Onaka, 2010). The boundary depicted by the line acts as an estimation for the point at which the classification of LIRGs and ULIRGs changes.

Figure 8. A photographic image of object: NGC 3110 (LIRG) [Object ID: 1120120.2]. Image Source: (Seligman, 2015)

As with Section 2.1, the data corresponding to the object in the example has been reduced to produce Figure 9.

Figure 9. Reduced spectrum for sample object, NGC 3110 (LIRG) [Object ID: 1120120.2].

The same principles of Section 2.2 have been applied; however, a second set of data has been over-plotted for comparative purposes. The resultant plot of Flux (mJy) against wavelength (μm) is portrayed in Figure 10.
Figure 10. Cursory spectroscopic model for the data corresponding to object ID, 1120120.2.

Red: (Imanishi, Nakagawa, Shirahata, Ohyama, & Onaka, 2010) Data, Green: Collected Data

From a cursory observation, there is a distinct peak at approximately 3.3 μm. This corresponds to the PAH emission stated in Section 2.3, indicating dust obscurities around the galactic centre. The peak is noticeably thin, suggesting that the centre of the galaxy contains an obscured AGN rather than a Starburst region (a region with a large population of rapid forming stars; located in the galactic centre). The spectrum exhibits minor emission peaks; however, these cannot be fully resolved without further processing. This leads to the product seen in Figure 11.

Figure 11. Refined regression model with compound annotations for the sample data used.

In order to categorize the three main features that are prominent in the cumulative datasets, it is important to note the following suggested by (Imanishi, Nakagawa, Shirahata, Ohyama, & Onaka, 2010):

- PAH emission peaks are the signature factors for implications of starburst activity (especially around AGNs), the following suggest the conditions around the galactic centre:
  - Low equivalent width of PAH emission suggests that there are possible AGNs that are surround by dust.
  - No PAH emission peak indicates no obscurities generated by dust; hence, indicating the likelihood of a “Pure” AGN.
  - PAH emission peak accompanied with a Br-α, indicates an obscured Starburst.
- Br-α and Br-β are used to verify the alignment of the data with the predicted models of the corresponding galaxies. This is only possible if both Br emission peaks are observed.
- Dust absorption is higher in ULIRGs than in LIRGs.

Note: The reference to “Collected Datasets” refers to data provided by Usui, Fumihiko (See Acknowledgements)
As the PAH emission peak is the most prominent feature in defining the galaxy categorizations for the investigation, the estimated regions in Section 2.5 has been applied to the datasets. The generated luminosity comparison (PAH Luminosity on the vertical axis and the Infrared Luminosity on the horizontal axis) plot for the datasets is shown in Figure 12.

By overlaying Figure 7 on Figure 12, it becomes easier to identify the population of galaxies that correspond to the highlighted categories, from the datasets used.

Based on the visual analysis conducted on Figure 13, there are considerably higher numbers of galaxies within the Dust Dominated Domains (directly related to Starburst Regions – indicated by high PAH luminosity but low Infrared luminosities – For LIRGs) and Obscured AGN Domains (indicated by high PAH luminosity and relatively high Infrared luminosities – For ULIRGs) than the AGN Dominated Domains (relatively low PAH Luminosity – Infrared Luminosity ratio compared to the boundary ratio).

Note: The plot has been processed using data from the Collected Datasets.
5 CONCLUSION

5.1 DISCUSSION

From this investigation, it is apparent that spectral analysis of ULIRGs and LIRGs enables the composition of galactic centers to be found (based on observations made in the 2.5-5 μm wavelength band). The information obtained is useful in the sense that it enables comparison to be drawn galaxies of different nature (comparing different compound constituents to various natures) and may provide an insight into the development of the galactic body over a period of time.

Based on the AKARI IRC 2.5-5 μm spectroscopic data that has been processed throughout this investigation, it has become ostensible that each galaxy can be divided from LIRGS and ULIRGs into smaller, more useful, sub-groups.

In conjunction with the paper, (Imanishi, Nakagawa, Shirahata, Ohyama, & Onaka, 2010), based on the observations made during the analysis, the ULIRG population suggest a larger number of buried AGNs for increasing luminosities, when compared to same observation for LIRGs.

To conclude, based on the results obtained, it is clear that luminous infrared galaxies can now be separated and grouped into different classes based on their spectroscopic data (classes based off of the speculated remnants in the galactic core).

6 REFERENCES


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