

THE RADIO-FAR INFRARED CORRELATION IN THE NEP DEEP FIELD

LAIA BARRUFET¹, GLENN J. WHITE^{1,2}, CHRIS PEARSON^{1,2}, STEPHEN SERJEANT², TANYA LIM¹, HIDEO MATSUHARA³, NAGISA OI³, MARIOS KAROUZOS⁴, AND AKARI-NEP TEAM³¹RAL Space, The Rutherford Appleton Laboratory, Chilton, UK; laia.barrufet-de-soto@stfc.ac.uk²Dept of Physical sciences, The Open University, Milton Keynes, UK³Inst of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagami-hara, Kanagawa 229-8510, Japan⁴CEOU-Astronomy Program, Department of Physics & Astronomy, Seoul National University, Gwanak-gu, Seoul, Korea*E-mail: laia.barrufet-de-soto@stfc.ac.uk**(Received September 5, 2015; Revised October 15, 2016; Accepted October 15, 2016)*

ABSTRACT

We report the results of a multi-wavelength study in the North Ecliptic Pole (NEP) deep field and examine the far infrared-radio correlation (FIRC) for high and low redshift objects. We have found a correlation between the GMRT data at 610 MHz and the Herschel data at $250\mu\text{m}$ that has been used to define a spectral index. This spectral index shows no evolution against redshift. As a result of the study, we show a radio colour-infrared diagram that can be used as a redshift indicator.

Key words: NEP— FIRC —radio continuum: galaxies — multi-wavelength survey

1. INTRODUCTION

The North Ecliptic Pole (NEP) Deep Field is in a favourable location for space telescopes. This region was observed by AKARI several times per day, allowing the study of very faint sources. It covers a 0.54 deg^2 circular area centered at RA = $17^{\text{h}} 55^{\text{m}} 24^{\text{s}}$ Dec = $66^\circ 37' 32''$ (Matsuhara et al., 2006), which has been observed at many different wavelengths. A striking relationship in far-IR astronomy has been the degree of correlation between the radio and far-infrared (FIR) flux of star-forming galaxies. It is generally believed that it is a consequence of high-mass stars heating the dust (which then re-emit in the FIR) that go on to generate supernovae that produce the relativistic electrons responsible for synchrotron radiation (e.g. Condon et al., 1992; Kóvacs et al., 2006).

Although the origins of the far-infrared-radio correlation - hereafter FIRC - seem to be understood, the linearity of the relationship is not obvious, since the synchrotron emissivity depends on both the number density of relativistic electrons and the magnetic field strength, which are not necessarily related.

Furthermore, the question about the FIRC evolution with redshift is still open: some studies have suggested that it does evolve (e.g. Seymour et al., 2009; Magnelli et al., 2015) but some others cast serious doubts (e.g. Appleton et al., 2004). Since the star formation rate (SFR) and gas density, which control in part the normalisation of the FIRC, are known to evolve with redshift, a decrease of the FIRC is expected as a consequence. The evolution of the FIRC involves the study of galaxy evolution and can allow us to understand why some high redshift galaxies lie far above Main Sequence trend, in the starburst mode with similar FIR properties to the local ULIRGs (Magnelli et al., 2014). However, other properties are different such as the size of the star forming regions or the scale heights.

In addition, the FIRC is an important tool in extragalactic astrophysics. First, in a practical sense, it is useful because it can be used to calibrate radio luminosity as a star formation indicator, using the $L_{\text{IR}} - \text{SFR}$ relation, which is especially useful for high redshift galaxies (Magnelli et al., 2015). Furthermore, it has been used to estimate the distance to and the dust temperature in starburst galaxies (Carilli et al., 1999).

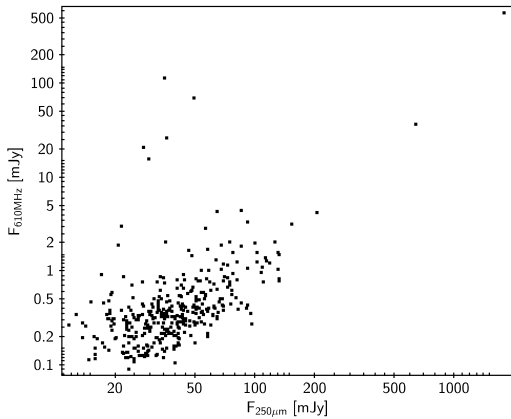


Figure 1. The figure shows the 250 μm against radio flux at 610 MHz. It is the best correlation of the radio data with the other IR and submm wavelengths.

In this proceeding we have found a correlation between the $F_{250\mu\text{m}}$ and $F_{610\text{MHz}}$ in the NEP survey field. This correlation has been used to study the FIRC correlation. After extracting the AGN contamination of our sample by using IR colour-colour diagrams, we have studied the evolution of the spectral index with the redshift. Finally we have used the correlation to select a colour redshift indicator.

2. FIR-RADIO CORRELATION

The study is based on the catalogue obtained by cross-matching the AKARI data (Murata et al., 2013) with FIR data from Herschel (Pearson, et al., in prep) and new radio data at 610 MHz from the GMRT (White et al., in preparation), in the NEP Deep field. We have cross-correlated for positional matches using an optical catalogue as a reference, and matched these with photometric redshift catalogues (Oi et al., 2014) to study the relationship between the radio and FIR luminosities. Since there is evidence for the FIR-radio correlation in other data sets (Ivison et al., 2010), we have checked this correlation for each AKARI and Herschel band. There is not a clear correlation for most of the bands, however, a correlation between the radio flux and the $F_{250\mu\text{m}}$ (see Figure 1) is found, which suggests a study focused on these data.

3. SPECTRAL INDEX

The first step in order to study the FIRC was to remove the Active Galactic Nuclei (AGN) contamination. The approach is based on IR colour-colour diagrams (C-C diagrams) since it is an effective method (Donley et al.,

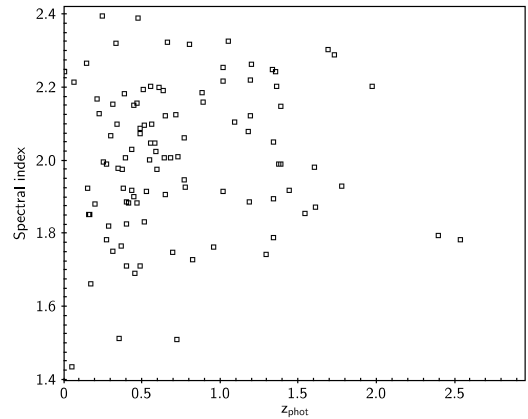


Figure 2. The spectral index against redshift shows no obvious evolution of the FIRC with redshift.

2012). We have applied different C-C criteria used in the literature (Lacy et al., 2004; Stern et al., 2012) and applied these constraints to the AKARI data obtaining a large sample of ~ 600 AGN candidates. We have cross-matched their optical position with the GMRT data with a 2 arcseconds search radius resulting in a sample of 45 AGN radio-detected candidates that we have removed from the total sample of radio sources.

To further examine the correlation, we introduce the FIR-radio spectral index $\alpha_{250\mu\text{m}}$ adapted from Vlahakis et al. 2007: $\alpha_{FIR} \propto \log \left(\frac{\text{Flux}(250\mu\text{m})}{\text{Flux}(1.4\text{GHz})} \right)$

4. RADIO FLUX - COLOUR DIAGRAMS

Combining properties at different wavelengths can be a useful method to find redshift indicators (Magnelli et al., 2015). We have used the radio properties in order to produce a flux colour diagram which could be used to discriminate between galaxies at different redshifts. The larger differences between the R-band (6258Å) and the N2 AKARI band (2.4 μm) indicate higher redshifts (see Figure 3).

5. CONCLUSIONS

A clear correlation is seen between radio and the IR fluxes in the NEP Deep Field for both low and high redshift objects. We have used this property to study the FIRC correlation against redshift by producing a spectral index. However, there is no compelling evidence of evolution of the spectral index with the redshift. We have found a radio flux colour diagram that can be used as a redshift indicator.

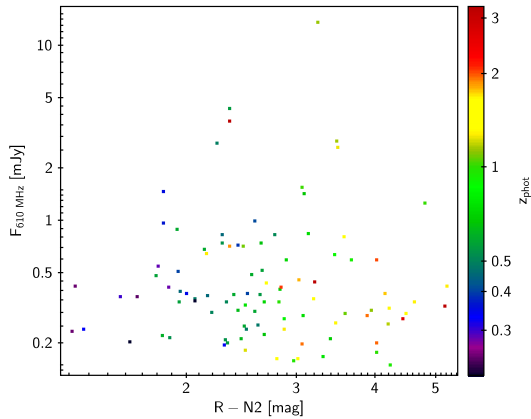


Figure 3. The plot shows the radio flux against the R-band N2-band colour (Murata et al., 2013), with redshift shown in the colour bar. The colour can split the radio-sources by redshift with a bluer colour indicating higher redshift.

REFERENCES

- Appleton, P. N., et al., 2004, The Far- and Mid-Infrared/Radio Correlations in the Spitzer Extragalactic First Look Survey, *ApJS*, 154, 147
- Carilli, C. L., et al., 1999, The Radio-to-Submillimeter Spectral Index as a Redshift Indicator, *ApJS*, 513, L13
- Condon, J. J., et al., 1992, Radio Emission from Normal Galaxies, *ARA&A*, 30, 575
- Donley, J. L., et al., 2012, Identifying Luminous Active Galactic Nuclei in Deep Surveys: Revised IRAC Selection Criteria, *AJ*, 748, 142
- Ivison, R. J., et al., 2010, The Far-Infrared/Radio Correlation as Probed by Herschel, *App*, 518, L31
- Kóvacs, A., et al., 2006, SHARC-2 350 μm Observations of Distant Submillimeter-selected Galaxies, *ApJ*, 784, 137
- Lacy, M., et al., 2004, Obscured and Unobscured Active Galactic Nuclei in the SPITZER Space Telescope First Look Survey, *AJSS*, 154, 166
- Magnelli, B., et al., 2014, The Evolution of the Dust Temperatures of Galaxies in the SFR-M Plane up to $z \sim 2$, *A&A*, 561, A86,
- Magnelli, B., et al., 2015, The Far-Infrared/Radio Correlation and Radio Spectral Index of Galaxies in the SFR-M* Plane up to $z \sim 2$, *A&A*, 573, A45
- Matsuhara, H., et al. 2006, Deep Extragalactic Surveys around the Ecliptic Poles with AKARI (ASTRO-F), *ASJ*, 58, 673
- Murata, K., et al., 2013, AKARI North Ecliptic Pole Deep Survey. Revision of the catalogue via a new image analysis, *A&A*, 559, A132
- Oi, N., et al., 2014, Optical near-infrared catalog for the AKARI north ecliptic pole Deep field, *A&A*, 566, A60
- Pearson et al. in prep., 2016, *MNRAS*
- Seymour, N., et al. 2009, Investigating the Far-IR/Radio Correlation of Star-Forming Galaxies to $z = 3$, *MNRAS*, 398, 1573
- Stern, D., et al. 2012, Mid-infrared Selection of Active Galactic Nuclei with the Wide-Field Infrared Survey Explorer, *AJ*, 753, 30
- Vlahakis et al. ,2007, The far-infrared-radio relationship at high and low redshift, *MNRAS* 379, 1042
- White, G. J., et al., in prep., *MNRAS*