THE INFRARED–GAMMA-RAY CONNECTION: A WISE VIEW OF THE EXTRAGALACTIC GAMMA-RAY SKY

F. Massaro\textsuperscript{1,2,3} and R. D’Abrusco\textsuperscript{4}
\textsuperscript{1}Dipartimento di Fisica, Università degli Studi di Torino, via Pietro Giuria 1, I-10125 Torino, Italy
\textsuperscript{2}Istituto Nazionale di Fisica Nucleare, Sezione di Torino, I-10125 Torino, Italy
\textsuperscript{3}Istituto Nazionale di Astrofisica—Osservatorio Astrofisico di Torino, via Osservatorio 20, I-10025 Pino Torinese, Italy
\textsuperscript{4}Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, MA 02138, USA

Received 2016 May 10; revised 2016 May 31; accepted 2016 May 31; published 2016 August 9

ABSTRACT

Using data from the Wide-field Infrared Survey Explorer (WISE) all-sky survey, we discovered that the nonthermal infrared (IR) emission of blazars, the largest known population of extragalactic γ-ray sources, has peculiar spectral properties. In this work, we confirm and strengthen our previous analyses using the latest available releases of both the WISE and the Fermi source catalogs. We also show that there is a tight correlation between the mid-IR colors and the γ-ray spectral index of Fermi blazars. We name this correlation the infrared–γ-ray connection. We discuss how this connection links both the emitted powers and the spectral shapes of particles accelerated in jets arising from blazars over 10 decades in energy. Based on this evidence, we argue that the infrared–γ-ray connection is stronger than the well-known radio–γ-ray connection.

Key words: BL Lacertae objects: general – galaxies: active – gamma rays: general – infrared: general – radiation mechanisms: nonthermal

1. INTRODUCTION

Blazars are one of the most extreme classes of radio-loud active galaxies whose emission extends from radio to TeV energies. They generally show extreme variability at all wavelengths along with timescales spanning from weeks to minutes, evidence of superluminal motions, high and variable polarization, flat radio spectra (see, e.g., Urry & Padovani 1995), recently observed even below \( \sim \)1 GHz (i.e., Massaro et al. 2013a, 2013d), and a characteristic double-bumped spectral energy distribution (SED; see also Massaro et al. 2009 for a recent review).

Since the launch of the Fermi satellite (Atwood et al. 2009), blazars have been identified as the dominant class of γ-ray sources, not only extragalactic. Blazars account for about one-third of the Fermi-detected objects (Acero et al. 2015) and likely for a significant fraction of the unidentified/unassociated γ-ray sources (UGSs; Massaro et al. 2012b, 2013b). Together with star-forming regions (e.g., Ackermann et al. 2012) and radio galaxies (e.g., Massaro & Ajello 2011; Di Mauro et al. 2014), blazars make a significant contribution to the extragalactic γ-ray background (Ajello et al. 2012, 2014; Massaro et al. 2016, and references therein).

At optical frequencies blazars are historically split into two subclasses: BL Lac objects and flat-spectrum radio quasars. The former, which will be indicated in this paper as BZBs following the nomenclature introduced by the Roma-BZCAT (Massaro et al. 2015a), show featureless spectra and/or weak absorption lines of equivalent width lower than 5 Å, while the latter, usually indicated as BZQs, have quasar-like optical spectra (Stickel et al. 1991; Falomo et al. 2014).

Since 2010, the NASA Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) has mapped the sky in the infrared (IR) at 3.4, 4.6, 12, and 22 μm, making possible the investigation of the mid-IR properties of a large, statistically significant sample of confirmed blazars. We discovered that Fermi blazars inhabit a region of the mid-IR color–color diagram, built with the WISE magnitudes, well separated from the location of other extragalactic sources (Massaro et al. 2011; D’Abrusco et al. 2012). This two-dimensional region in the mid-IR color–color diagram [3.4]–[4.6]–[12] μm was originally indicated as the WISE Gamma-ray Strip, and it is the projection of a three-dimensional volume in the [3.4]–[4.6]–[12]–[22] μm mid-IR color space known as the WISE locus of γ-ray blazars (D’Abrusco et al. 2013, 2014).

These findings led to the development of different procedures to search for γ-ray blazar candidates within the positional uncertainty regions of the Fermi UGSs that selected hundreds of IR sources as candidate blazars. Thanks to an extensive optical spectroscopic follow-up campaign (Paggi et al. 2014; Massaro et al. 2014, 2015b), we confirmed the nature of hundreds of new γ-ray blazars (see also Landoni et al. 2015; Massaro et al. 2015c; Ricci et al. 2015) and assessed the reliability of our association methods. Optical spectroscopy was also used to determine the nature of Fermi sources classified as active galaxies of uncertain type (AGUs; Ackermann et al. 2011b; Nolan et al. 2012) and/or blazar candidates of uncertain type (BCUs; Acero et al. 2015; Ackermann et al. 2015).

Here we present an update of the WISE Gamma-ray Strip obtained by combining the latest releases of both the WISE All-Sky catalog\textsuperscript{5} and the Fermi Large Area Telescope Third Source Catalog (3FGL; Acero et al. 2015). Additionally, for the first time, we discuss the link found between the WISE mid-IR colors and the γ-ray photon index, comparing it with the radio–γ-ray connection (e.g., Ackermann et al. 2011a).

For our numerical results, we use cgs units unless stated otherwise. Gamma-ray photon index \( \Gamma \) is defined by the usual convention on the flux density, \( N(E) \propto E^{-\Gamma} \), with \( N(E) \) being the number of γ-ray photons detected per unit of time, area, and energy. WISE magnitudes are in the Vega system and are not corrected for the Galactic extinction since, as shown in our previous analyses, such correction affects significantly only

\textsuperscript{5}http://wise2.ipac.caltech.edu/docs/release/allsky/
the magnitude at 3.4 μm for sources lying at low Galactic latitudes (see, e.g., D’Abrusco et al. 2014). WISE bands are indicated as w1, w2, w3, and w4 and correspond to the following nominal wavelengths: 3.4, 4.6, 12, and 22 μm, respectively.

2. SAMPLE SELECTION

The analysis presented hereby has been carried out using three distinct samples of sources extracted from the Roma-BZCAT catalog of confirmed blazars, the 3FGL catalog of Fermi sources, and the catalog of radio sources extracted from the NRAO VLA Sky Survey (NVSS) and the University Molonglo Sky Survey (SUMSS). Then, we searched the mid-IR counterparts in the WISE all-sky catalog for all sources in each of these samples (the fraction of objects in each sample with a WISE association is reported in Table 1). It is worth noting that the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) counterparts of the WISE sources are automatically reported in the WISE catalog.

The first sample includes all BZBs and BZQs listed in the latest version of the Roma-BZCAT (i.e., v5.0; Massaro et al. 2015a) and associated with a Fermi source belonging to the Third Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope (3LAC; Ackermann et al. 2015). This sample is the update of the sample used to build the WISE Gamma-ray Strip in D’Abrusco et al. (2012) and contains 1036 γ-ray blazars: 610 BZBs and 426 BZQs. Adopting the statistical criterion described in our previous analyses, we identified as a blazar counterpart the closest IR source within 3″ from the position reported in the Roma-BZCAT (e.g., D’Abrusco et al. 2014). This criterion was chosen because source positions of the Roma-BZCAT, even if often more precise than those reported in the 3LAC, are taken from various catalogs with different positional uncertainties. Given the high detection rate of Fermi blazars in the first three WISE filters, we only focus on the analysis in the color diagram built with the 3.4, 4.6 and 12 μm magnitudes.

The second sample is composed by BCU’s of the 3FGL with a WISE counterpart within 10″. This is the typical radio positional uncertainty used in the 3LAC, usually corresponding to that of the radio NVSS (Condon et al. 1998) and/or the SUMSS (Mauch et al. 2003) used to search for counterparts of Fermi sources.

The third sample includes all the radio sources of the NVSS and SUMSS catalog lying within the positional uncertainty region of the UGSs at 95% level of confidence and with a WISE counterpart detected at least at 3.4, 4.6, and 12 μm, within a maximum radius obtained by adding the radio to the mid-IR positional uncertainties at 1σ level of confidence.

3. GAMMA-RAY BLAZARS AT IR WAVELENGTHS

The extremely high detection rate of Fermi blazars at mid-IR frequencies (≈99%) at 3.4 and 4.6 μm (see Table 1) strongly supports the use of statistical methods combined with optical spectroscopic campaigns toward the identification of WISE-selected blazar-like sources that can be responsible for the UGSs (Acero et al. 2013; Paggi et al. 2013).

The distribution of the updated sample of Fermi blazars in the WISE color–color diagram shown in Figure 1 confirms our previous results (see, e.g., Massaro et al. 2011) with a five

---

Table 1

| Sample | w1 | w2 | w3 | w4 | J | H | K | Total |
|--------|----|----|----|----|---|---|---|-------|
| BZB    | 603| 603| 595| 497| 521| 523| 528| 610   |
| BZQ    | 419| 419| 419| 405| 207| 206| 215| 426   |
| BZB ∪ BZQ | 1022| 1022| 1014| 902| 728| 729| 743| 1036 |
| BCU    | 569| 569| 553| 433| 319| 328| 325| 571   |
| UGS    | 1546| 1465| 558| 315| 580| 607| 584| 1548 |

Note. WISE bands are indicated as w1, w2, w3, and w4, while 2MASS magnitudes are J, H, K.

---

Figure 1. Left: distribution of sources belonging to the WISE Gamma-ray Strip (see Section 2), in the w2 − w3 vs. w1 − w2 color–color diagram. BZBs and BZQs are displayed as blue circles and red squares, respectively. Approximately 3000 generic IR sources (gray circles) selected at high Galactic latitudes are also shown. The separation between the mid-IR colors of the Fermi blazars and those of other sources randomly chosen appears evident. Right: distribution of the same sample in the near-IR 2MASS H − K vs. J − H color–color diagram. The distinction between the region occupied by the Fermi blazars and other celestial objects appears clear also in this case, but there is no neat separation between BZBs and BZQs.
times larger sample. The use of WISE colors as distinct markers of the nonthermal emission of blazars is clearly supported by these findings.

For comparison, in the color–color diagram generated using the $J$, $H$, and $K$ magnitudes in the 2MASS catalog (see Figure 1), although a clear separation between generic IR sources and the region preferentially populated by Fermi blazars is visible, no peculiar color pattern is observed for BZBs and BZQs. Moreover, a large fraction of the Fermi BZQs considered do not have a 2MASS counterpart (see Table 1), strongly limiting the potential efficiency and completeness of methods for the association of UGSs based on 2MASS photometry. The region occupied by the Fermi blazars in the 2MASS color–color plot is similar to that previously indicated by Chen et al. (2005) for a different sample of BZBs and BZQs. However, about 30% of the blazars in the Chen et al. (2005) sample show near-IR colors corresponding to a blackbody spectral shape, suggesting a possible contribution from their host galaxies. Such strong contamination is not present at mid-IR wavelengths.

4. THE INFRARED–GAMMA-RAY CONNECTION

To assess the significance of the infrared–γ-ray connection, we performed a statistical analysis of the correlation between the γ-ray photon index $\Gamma$ of the Fermi blazars and the WISE mid-IR colors, since colors are a surrogate of the spectral index. We found a strong correlation between $\Gamma$ and both the WISE colors $[3.4]–[4.6]$ μm and $[4.6]–[12]$ μm as shown in Figure 2. This result constitutes the first direct evidence of the existence of the IR–γ-ray connection.

In both cases, the correlation is more statistically significant for BZBs than for BZQs. The linear correlation coefficient $\rho$ estimated for the $\Gamma$ versus $[3.4]–[4.6]$ μm correlation is 0.47 for BZBs, with negligible probability to be spurious. On the other hand, for the BZQs, we obtained $\rho = 0.15$ calculated with 419 sources and still with a negligible chance probability, given the large number of objects considered. When using the data for the whole sample of 1022 Fermi blazars, the linear correlation coefficient, unsurprisingly, increases to $\rho = 0.65$ thanks to the quite distinct distributions of both BZBs and BZQs in the $\Gamma$ versus $[3.4]–[4.6]$ μm plane.
A similar situation is observed in the $\Gamma$ versus $[3.4]–[4.6]$ $\mu$m plane, where the correlation coefficients for the 595 BZBs and the 419 BZQs separately are $\rho = 0.48$ and $\rho = 0.13$, respectively, with both negligible chance probability. The correlation coefficient for the whole Fermi blazar sample (1014 sources) is $\rho = 0.60$, lower than the previous one due to the scatter in the plane introduced by the larger uncertainties on the mid-IR magnitudes at 12 $\mu$m. The slope of the best-fit regression lines in both cases, as expected, is driven by the stronger correlations found for the BZBs.

Finally, we did not find any significant trend between the 2MASS $J$, $H$, and $K$ colors, corrected for Galactic extinction, and the Fermi $\gamma$-ray spectral index $\Gamma$.

5. COMPARISON WITH THE RADIO–GAMMA-RAY CONNECTION

Since the release of the first observations carried out with the Compton Gamma-ray Observatory, a link between radio and $\gamma$-ray emissions of blazars appeared evident (e.g., Stecker et al. 1993). This well-established radio–$\gamma$-ray connection has mostly driven the searches for counterparts associated with $\gamma$-ray sources (Mattox et al. 1997) and has been invoked to justify radio follow-up observations of the positional uncertainty regions for UGSs to date (e.g., Schinzel et al. 2015, and references therein). This connection between the blazar emission at $\sim 1$ GHz and at GeV energies is due to the correlation between their flux densities and, consequently, their powers.

Thanks to the large increase of the number of blazars detected by Fermi, it has become possible to study the presence of biases and selection effects that have to be taken into account to confirm the radio–$\gamma$-ray connection. Intrinsic variability, redshift dependence, source misidentifications, and incorrect associations (see, e.g., Mucke et al. 1997), to name a few effects that can mimic a spurious trend, were not found to affect this correlation. Based on this analysis, the existence of the radio–$\gamma$-ray connection (see also Mahony et al. 2010 and references therein) was recently confirmed by Ackermann et al. (2011a).

For the sake of comparison, it is worth stressing that the radio–$\gamma$-ray connection is based on the correlation between the radio and $\gamma$-ray flux densities. A similar trend also exists for the mid-IR emission as shown in the lower panels of Figure 2, which display the 3.4 and the 12 $\mu$m magnitudes versus $\gamma$-ray energy flux between MeV and 100 GeV for both confirmed Fermi BZBs and BZQs.

Based on the discussion in the previous section, it appears evident that the IR–$\gamma$-ray connection is stronger than the radio–$\gamma$-ray one, because it not only is a link between fluxes but also involves a tight connection between spectral shapes of the emitting particles.

6. THE UNCERTAIN GAMMA-RAY SKY

We stress the strength of the IR–$\gamma$-ray connection by showing that potential counterparts of 3FGL UGSs selected via their WISE Mid-IR colors are in good agreement with the correlation between the $[3.4]$ and $[12]$ WISE colors and the $\gamma$-ray $\Gamma$ spectral index discussed in Section 4.

We considered all the WISE sources with a radio counterpart that lie within the positional uncertainty regions of the UGSs at 95% level of confidence. By applying the Kernel Density Estimation (KDE) technique (see, e.g., D’Abrusco et al. 2009, and reference therein), as in our previous analyses (see, e.g., Massaro et al. 2011, 2013c, 2015b), we estimated the probability density function of the IR color distribution for the Fermi blazar population and selected as blazar-like candidates those located within the 95% isodensity contours drawn from the KDE probabilities in the $[3.4]–[4.6]–[12] \mu$m diagnostic diagram.

In Figure 3 we show, as an example, the eight WISE sources with a radio counterpart that lie within the positional uncertainty region at 95% level of confidence of the UGS 3FGL J1216.6-0557. The only WISE source selected by the KDE analysis is the closest to the regression line for the WISE $[3.4]–[4.6] \mu$m versus $\gamma$-ray spectral shape distribution of all the Fermi blazars (BZBs and BZQs) considered in our analysis (see Sections 2 and 4 for more details).

In general, by applying the same technique to all 987 UGSs listed in the 3FGL to date, we selected 130 blazar-like potential counterparts out of 1548 WISE sources with a radio counterpart lying within the 95% positional uncertainty regions. As shown in the $\Gamma$ versus $[3.4]–[4.6] \mu$m diagram (Figure 4, top left), these candidates are clearly located in the region occupied by the Fermi blazars, thus following the IR–$\gamma$-ray connection. It is worthwhile to stress that such consistency is not granted a priori since the WISE colors of Fermi blazars simply reflect the fact that their mid-IR emission is dominated by nonthermal radiation independently of any $\gamma$-ray information. As a consequence, the IR–$\gamma$-ray connection cannot be a consequence of the existence of the WISE Gamma-ray Strip.

To complete our investigation, we also analyzed the 3FGL BCUs. As expected, the mid-IR colors of a large fraction of them (i.e., more than 90%) are similar to the WISE colors of confirmed Fermi blazars (Massaro et al. 2012a) and follow the correlation between $\Gamma$ and $[3.4]–[4.6] \mu$m (Figure 4) that we have denominated the IR–$\gamma$-ray connection. A large fraction of
these blazar-like sources are also expected to be BZBs, in agreement with the recent results of several optical spectroscopic campaigns (see, e.g., Shaw et al. 2013; Álvarez-Crespo et al. 2016a, 2016b, for more details), which find that more than 70% of the observed sources are BZBs.

7. SUMMARY AND DISCUSSION

Five years after the discovery that the nonthermal emission of γ-ray blazars can be traced using mid-IR colors obtained from the photometry of the WISE all-sky survey, we present an updated analysis based on the latest releases of both the WISE and Fermi catalogs. Then, for the first time, we discuss the existence of an IR–γ-ray connection for the Fermi blazars that appears to be at least as strong as the well-known radio–γ-ray one.

Our results can be summarized as follows.

1. Using the largest sample of Fermi blazars available to date, we confirmed that this extreme class of active galaxies occupied a narrow and well-defined region in the mid-IR color–color plane, the so-called WISE Gamma-ray Strip.

2. Comparing mid-IR WISE and near-IR 2MASS diagnostic diagrams, we confirmed that in the latter Fermi blazars are distinct from generic 2MASS sources, even though no clear color–color trend appears as in the former. Fermi blazars have a low detection rate in the 2MASS catalog, mainly due the 2MASS higher flux limit compared to the WISE survey. These reasons advise against the use of near-IR colors to search for potential blazar-like counterparts of the UGSs.
3. We describe the statistically significant correlations between the $\gamma$-ray photon index and the mid-IR colors for both the whole sample of Fermi blazars and the BZB and BZQ spectral classes separately, the basis of the IR-$\gamma$-ray connection. This correlation appears “stronger” than the well-known radio-$\gamma$-ray connection because it involves the spectral shapes of the Fermi blazars over $\sim10$ orders of magnitude and not only their fluxes.

4. We argue that the peculiar mid-IR colors of Fermi blazars do not depend on their $\gamma$-ray photon index. In turn, the IR-$\gamma$-ray connection is unexpected. We have also highlighted its potential use to implement the search for blazar-like counterparts of the Fermi UGSs.

5. We show that a large fraction of the BCUs listed in the 3FGL whose WISE counterpart has mid-IR colors consistent with the WISE Gamma-ray Strip have Fermi spectral index values consistent with the IR-$\gamma$-ray connection.

Taking advantage of the overwhelming fraction of Fermi blazars detected in the WISE all-sky survey (i.e., $\sim99\%$) in the first two mid-IR filters, we suggest that a comprehensive investigation of their IR properties at the light of the IR-$\gamma$-ray connection described in this paper can represent a powerful tool to reveal the real fraction of Fermi blazars hidden within the sample of UGSs.

We thank the anonymous referee for useful comments that led to improvements in the paper. We also thank J. Ballet for helpful discussions. F.M. gratefully acknowledges the financial support of the Programma Giovani Ricercatori—Rientro dei Cervelli (2012) awarded by the Italian Ministry of Education, Universities and Research (MIUR). This research has made use of data obtained from the high-energy Astrophysics Science Archive Research Center (HEASARC) provided by NASA’s Goddard Space Flight Center. The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Part of this work is based on the NVSS (NRAO VLA Sky Survey). The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation and on the VLA Low-frequency Sky Survey (VLSS). The Molonglo Observatory site manager, Duncan Campbell-Wilson, and the staff, Jeff Webb, Michael White, and John Barry, are responsible for the smooth operation of the Molonglo Observatory Synthesis Telescope (MOST) and the day-to-day observing program of SUMSS. SUMSS is dedicated to Michael Large, whose expertise and vision made the project possible. The MOST is operated by the School of Physics with the support of the Australian Research Council and the Science Foundation for Physics within the University of Sydney. This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. TOPCAT6 (Taylor 2005) was used for the preparation and manipulation of the tabular data and the images.

REFERENCES

Acero, F., Ackermann, M., Ajello, M., et al. 2015, ApJS, 218, 23
Acero, F., Donato, D., Ojha, R., et al. 2013, ApJ, 779, 133
Ackermann, M., Ajello, M., Allafort, A., et al. 2011a, ApJ, 741, 30
Ackermann, M., Ajello, M., Allafort, A., et al. 2011b, ApJ, 743, 171
Ackermann, M., Ajello, M., Allafort, A., et al. 2012, ApJ, 755, 164
Ackermann, M., Ajello, M., Atwood, W. B., et al. 2015, ApJ, 810, 14
Ajello, M., Shaw, M. S., Romani, R. W., et al. 2012, ApJ, 751, 108
Ajello, M., et al. 2014, ApJ, 780, 73
Álvarez-Crespo, N., Massetti, N., Ricci, F., et al. 2016a, AJ, 151, 32
Álvarez-Crespo, N., Massaro, F., Milisavljevic, D., et al. 2016b, AJ, 151, 95
Atwood, W. B., Abdo, A. A., Ackermann, M., et al. 2009, ApJ, 697, 1071
Chen, P. S., Fu, H. W., & Gao, Y. F. 2005, NewA, 11, 27
Condon, J. J., Cotton, W. D., Greisen, E. W., et al. 1998, AJ, 115, 1693
D’Abrusco, R., Longo, G., & Walton, N. A. 2009, MNRS, 396, 223
D’Abrusco, R., Massaro, F., Ajello, M., et al. 2012, ApJ, 748, 68
D’Abrusco, R., Massaro, F., Paggi, A., et al. 2013, ApJ, 769, 12
D’Abrusco, R., Massaro, F., Paggi, A., et al. 2014, ApJ, 785, 15
Di Mauro, M., Calore, F., Donato, F., Ajello, M., & Latronico, L. 2014, ApJ, 780, 161
Falomo, R., Pan, E., & Treves, A. 2014, A&ARv, 22, 73
Landoni, M., Massaro, F., et al. 2015, AJ, 149, 63
Mahony, E. K., Sadler, E. M., Murphy, T., et al. 2010, ApJ, 718, 587
Massaro, E., Giommi, P., Leto, C., et al. 2009, A&A, 495, 691
Massaro, E., Maselli, A., Leto, C., et al. 2015a, Ap&SS, 357, 75
Massaro, F., & Ajello, M. 2011, ApJ, 729L, 2
Massaro, F., D’Abrusco, R., Ajello, M., et al. 2011, ApJ, 740L, 48
Massaro, F., D’Abrusco, R., Gioretti, M., et al. 2013a, ApJS, 207, 4
Massaro, F., D’Abrusco, R., Landoni, M., et al. 2015b, ApJS, 217, 2
Massaro, F., D’Abrusco, R., Paggi, A., et al. 2013b, ApJS, 206, 13
Massaro, F., D’Abrusco, R., Paggi, A., et al. 2013c, ApJS, 209, 10
Massaro, F., D’Abrusco, R., Tosti, G., et al. 2012a, ApJ, 750, 138
Massaro, F., D’Abrusco, R., Tosti, G., et al. 2012b, ApJ, 752, 61
Massaro, F., Gioretti, M., Paggi, A., et al. 2013d, ApJS, 208, 15
Massaro, F., Landoni, M., D’Abrusco, R., et al. 2015c, A&A, 575, 124
Massaro, F., Masetti, N., D’Abrusco, R., et al. 2014, AJ, 148, 66
Massaro, F., Thompson, D. J., & Ferrara, E. C. 2016, A&ARv, 24, 2
Mattios, J. R., Schachter, J., Molnar, L., Harman, R. C., & P接生, A. R. 1997, ApJ, 481, 95
Mauch, T., Murphy, T., Buttery, H. J., et al. 2003, MNRS, 342, 1117
Mucke, A., Pohl, M., Reich, P., et al. 1997, A&A, 320, 33
Nolan, P. L., Abdou, A. A., Ackermann, M., et al. 2012, ApJS, 199, 31
Paggi, A., Massaro, F., D’Abrusco, R., et al. 2013, ApJS, 209, 9
Paggi, A., Milisavljevic, D., Masetti, N., et al. 2014, AJ, 147, 112
Ricci, F., Massaro, F., Landoni, M., et al. 2015, AJ, 149, 160
Schinzel, F. K., Petrov, L., & Taylor, G. B. 2015, ApJS, 217, 4
Shaw, M. S., Romani, R. W., Cotter, G., et al. 2013, ApJ, 764, 135
Skrutskie, M. F., et al. 2006, AJ, 131, 1163
Stecker, F. W., Salamon, M. H., & Malkan, M. A. 1993, ApJL, 410, L71
Stickel, M., Padovani, P., Urry, C. M., & Padovani, P. 1991, ApJ, 374, 431
Taylor, M. B. 2005, in ASP Conf. Ser. 347 (San Francisco, CA: ASP), 29
Urry, C. M., & Padovani, P. 1995, PASP, 107, 803
Wright, E. L., et al. 2010, AJ, 140, 1868

6 http://www.star.bris.ac.uk/m-bt/topcat/