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Jet Physics of Accreting Super-Massive Black Holes in the Era of the *Fermi Gamma-ray Space Telescope*

Filippo D'Ammando[1,2]* on behalf of the Fermi Large Area Telescope Collaboration

[1] Dipartimento di Fisica e Astronomia, Universitá di Bologna, Bologna, Italy, [2] Istituto di Radioastronomia (INAF), Bologna, Italy

The *Fermi Gamma-ray Space Telescope* with its main instrument on-board, the Large Area Telescope (LAT), opened a new era in the study of high-energy emission from Active Galactic Nuclei (AGN). When combined with contemporaneous ground- and space-based observations, *Fermi*-LAT achieves its full capability to characterize the jet structure and the emission mechanisms at work in radio-loud AGN with different black hole mass and accretion rate, from flat spectrum radio quasars to narrow-line Seyfert 1 (NLSy1) galaxies. Here, I discuss important findings regarding the blazar population included in the third LAT catalog of AGN and the γ-ray emitting NLSy1. Moreover, the detection of blazars at redshift beyond three in γ rays allows us to constrain the growth and evolution of heavy black holes over cosmic time, suggesting that the radio-loud phase may be important for a fast black hole growth in the early Universe. Finally, results on extragalactic objects from the third catalog of hard LAT sources are presented.

Keywords: active galactic nuclei, γ-ray emission, super-massive black hole, narrow-line Seyfert 1 galaxy, blazar, relativistic jet, accretion process, cosmological evolution

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Mauro D'Onofrio, Università degli Studi di Padova, Italy

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Maria Dainotti, Jagiellonian University, Poland
Milan S. Dimitrijevic, Astronomical Observatory, Serbia

***Correspondence:**
Filippo D'Ammando
dammando@ira.inaf.it

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1. INTRODUCTION

Relativistic jets are one of the most powerful manifestations of the release of energy related to the super-massive black hole (SMBH) at the center of active galactic nuclei (AGN). In about 10% of AGN, termed radio-loud AGN, the accretion disc is at the base of a bipolar outflow of relativistic plasma, which may extend well beyond the host galaxy, forming the spectacular lobes of plasma visible in the radio band. The jet emission is observed across the entire electromagnetic spectrum, from radio to γ rays. When the jet axis is closely aligned with our line of sight, the rest-frame radiation is strongly amplified due to the Doppler boosting with a large fraction of the output observed at higher energies, and giving rise to the blazar phenomenon. Blazars are traditionally divided into flat spectrum radio quasars (FSRQ) and BL Lac objects, based on the presence or not, respectively, of broad emission lines (i.e., Equivalent Width > 5 Å) in their optical and UV spectrum (e.g., Stickel et al., 1991). Recently, a new classification based on the luminosity of the broad line region (BLR) in Eddington luminosity was proposed by Ghisellini et al. (2011): sources with L_{BLR}/L_{Edd} higher or lower than 5×10^{-4} being classified as FSRQ or BL Lacs, respectively, in agreement with a transition of the accretion regime from efficient to inefficient between these classes. The spectral energy distribution (SED) of blazars are characterized by two bumps with the lower energy peak occurring in the IR/optical band in the FSRQ and at UV/X-rays in the BL Lacs. This first peak is univocally interpreted as synchrotron radiation from highly relativistic electrons

3. NARROW-LINE SEYFERT 1 GALAXIES

The discovery of variable γ-ray emission from a few NLSy1 confirmed the presence of relativistic jets in these objects. In addition to the 5 objects reported in the 3LAC, *Fermi*-LAT has recently detected γ rays from other 3 new NLSy1: FBQS J1644+2619 (D'Ammando et al., 2015), B3 1441+476 and NVSS J124634+476 (D'Ammando et al., 2016). Luminosity, variability, and spectral properties of these NLSy1 in γ rays indicate a blazar-like behavior (e.g., D'Ammando et al., 2016). Apparent superluminal jet components were detected in SBS 0846+513 (D'Ammando et al., 2012), PMN J0948+0022, and 1H 0323+342 (Lister et al., 2016), supporting the presence of relativistic jets in this class of objects.

The detection of relativistic jets in a class of AGN thought to be hosted in spiral galaxies with a BH mass typically of 10^6-10^7 $M_\odot$ (e.g., Deo et al., 2006), challenges the theoretical scenarios of jet formation (e.g., Böttcher and Dermer, 2002), suggesting two possible interpretations: either relativistic jets in NLSy1 are produced by a different mechanism or the BH mass in NLSy1 is largely underestimated.

In the last years it has been claimed that the BH mass of NLSy1 maybe underestimated due either to the effect of radiation pressure from ionizing photons on BLR (Marconi et al., 2008) or to projection effects (Baldi et al., 2016). By considering these effects, NLSy1 have BH masses of 10^8–10^9 $M_\odot$, in agreement with the values estimated by modeling the optical-UV part of their spectra with a Shakura and Sunyaev disc spectrum (e.g., Calderone et al., 2013). This may solve the problem of the minimum BH mass predicted in different theoretical scenarios of relativistic jet formation, but leaves open the host galaxy issue.

Spiral galaxies are usually formed by minor mergers, with BH masses typically ranging between 10^6–10^7 $M_\odot$ (e.g., Woo and Urry, 2002), so it would not be clear how powerful relativistic jets could form in these galaxies. It is worth mentioning that the morphological classification has been done mainly for radio-quiet nearby NLSy1. Among the NLSy1 detected by *Fermi*-LAT up to now, the morphology of the host galaxy has been investigated only for 1H 0323+342, PKS 2004−447, and FBQS J1644+2619. Observations of 1H 0323+342 with the Hubble Space Telescope and the Nordic Optical Telescope revealed a structure that may be interpreted either as a one-armed spiral galaxy (Zhou et al., 2007) or as a circumnuclear ring produced by a recent merger (Anton et al., 2008; Leon Tavares et al., 2014). A pseudo-bulge morphology of the host galaxy of the NLSy1 PKS 2004−447 and FBQS J1644+2619 have been claimed by Kotilainen et al. (2016) and Olguin-Iglesias et al. (2017), respectively, but no conclusive results have been obtained so far. Hence, it is crucial to determine the type of galaxy hosting γ-ray emitting NLSy1 and their BH mass.

For this reason near-infrared observations in *J* band of FBQS J1644+2619 were performed using the Canarias Infrared Camera Experiment (CIRCE) at the Gran Telescopio Canaries. The 2D surface brightness profile of the source is modeled up to 5 arcsec by the combination of a nuclear component, associated with the AGN contribution, and a bulge component with a Sérsic index n = 3.7, indicative of an elliptical galaxy. The structural parameters of the host are consistent with the correlations of effective radius and surface brightness against absolute magnitude measured for elliptical galaxies. From the infrared bulge luminosity, a BH mass of $(2.1 \pm 0.2) \times 10^8$ $M_\odot$ was estimated (D'Ammando et al., 2017). All these pieces of evidence strongly indicate that the relativistic jet in the NLSy1 FBQS J1644+2619 is produced by a massive BH in an elliptical galaxy, as expected for radio-loud AGN.

4. HIGH-REDSHIFT BLAZARS

High-redshift blazars are the most powerful radio-loud AGN in the Universe and are bright targets in hard X-rays, representing a significant fraction of the extragalactic hard X-ray sky. However, they are not commonly detected in γ rays. In fact, high-redshift ($z > 2$) blazars represent <10% of the AGN population observed by *Fermi*-LAT so far. Flaring activity in the γ-ray energy range from these sources is even more uncommon, with only fourteen FSRQ at $z > 2$ detected during a γ-ray flare.

In the 3LAC there are 64 objects at $z > 2$ (∼3.7 per cent of the γ-ray sources associated with AGN) at $z > 2$, and only 2 at $z > 3$: PKS 0537−286 (z = 3.104) and TXS 0800+618 (z = 3.033). On the other hand, 13 blazars at $z > 3$ have been detected in hard X-rays by *Swift*-BAT, *INTEGRAL*-IBIS, and *NuSTAR* so far. Hard X-ray observations are more suitable for detecting blazars at $z > 3$, and this is mainly due to a spectral bias. In fact, the inverse Compton peak of high-redshift blazars is shifted toward lower energies as the bolometric luminosity increases. Only 10 sources at $z > 2$ are in both the 3LAC and the *Swift*-BAT 70-month catalog (Baumgartner et al., 2013). All high-redshift blazars listed in both 3LAC and *Swift*-BAT Catalogs have an average γ-ray luminosity $L_\gamma > 2\times10^{48}$ erg s^{-1}, indicating that only the most luminous blazars have been detected by both instruments. Furthermore, only blazars with an X-ray photon index $\Gamma_X < 1.6$ have been detected in γ rays, while no dependence on the X-ray spectral luminosity seems to be present (D'Ammando and Orienti, 2015).

As said above, high-redshift blazars at $z > 3.1$ are missing in the *Fermi* catalogs. These objects typically have large bolometric luminosities ($L_{bol} > 10^{48}$ erg s^{-1}) and harbor extremely massive BH ($M_{BH} \sim 10^9$ $M_\odot$). The new Pass 8 data set, with an improved event-level analysis, substantially enhances the sensitivity of the LAT, in particular at lower energies, increasing the capability of the LAT to detect sources with soft spectra like the high-redshift blazars. By analysing 92 months of Pass 8 data between 60 MeV and 300 GeV of a large sample of radio-loud quasars, 5 new γ-ray emitting blazars at $z > 3.1$ have been detected with high significance. Among them, NVSS J151002+570243 (z = 4.31) is now the most distant γ-ray emitting blazar so far. All the blazars discovered show steep γ-ray spectra ($\Gamma_\gamma > 2.5$), indicating an IC peak at MeV energies. These five sources lie in the region of high γ-ray luminosities ($L_\gamma > 10^{47}$ erg s^{-1}) and soft photon indices (**Figure 1**) typical of powerful blazars (Ackermann et al., 2017). Among the 5 new high-redshift blazars there are (at least) two with redshift between 3 and 4 with a $M_{BH} > 10^9$ $M_\odot$, implying the presence of $2\times2\Gamma^2$ (i.e., 675, adopting Γ = 13) similar objects but with a misaligned jet in the same range of redshift. This changes the estimate of the space density of very massive BH

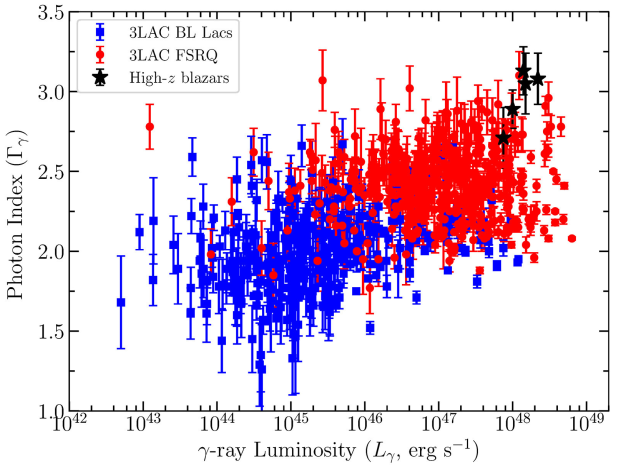

FIGURE 1 | Photon index vs. γ-ray luminosity plane for 3LAC and high-redshift blazars at $z > 3.1$ detected in γ rays. Adapted from Ackermann et al. (2017).

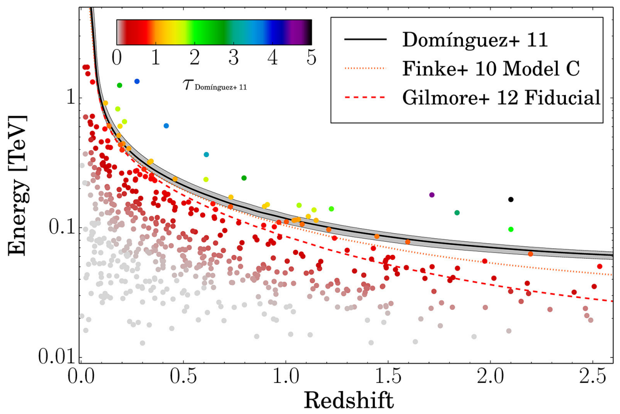

FIGURE 2 | The highest-energy photons vs. redshift for 3FHL blazars, color coded by the optical depth calculated from the model presented by Dominguez et al. (2011). The cosmic γ-ray horizon based on different EBL models is shown. Adapted from Ajello et al. (2017).

hosted in jetted sources to 68^{+36}_{-24} Gpc^{-3}. As a consequence at $z \sim 4$ we should have a similar number of SMBH hosted in radio-loud and radio-quiet sources and, given their strong evolution, above that redshift most massive BH might be hosted in radio-loud AGN. This suggests that the radio-loud phase can be a key ingredient for a rapid BH growth in the early Universe.

5. THE THIRD CATALOG OF HARD FERMI-LAT SOURCES

In addition to the *Fermi*-LAT catalogs with the standard low-energy threshold of 100 MeV, three hard source catalogs have been released: the First *Fermi*-LAT Catalog of Sources above 10 GeV (1FHL; Ackermann et al., 2013), based on the first three years of data analyzed in the 10–500 GeV energy range, the Second Catalog of Hard *Fermi*-LAT Sources (2FHL; Ackermann et al., 2016), based on 80 months of data analyzed in the 50 GeV–2 TeV energy range, and the Third Catalog of Hard *Fermi*-LAT Sources (3FHL; Ajello et al., 2017), based on 7 years of data in the 10 GeV–2 TeV energy range. The 3FHL contains 1556 objects and takes advantage of the improvement provided by Pass 8 by using the PSF-type event classification. The 3FHL includes 214 new γ-ray sources never appeared in previous *Fermi* catalogs. Three of these 214 have been detected with the Imaging Atmospheric Cherenkov Telescopes (IACT). The vast majority of detected sources (79%) are associated with extragalactic counterparts at other wavelengths, including 16 sources located at high-redshift ($z > 2$): 11 FSRQ, 3 BL Lac, and 2 BCU. BL Lacs are the most numerous extragalactic population (61%) followed by BCU (23%) and FSRQ (14%). Only 72 of the 3FHL extragalactic sources have been already detected by current IACT. In this context, the 3FHL is a resource for planning observations of the current (MAGIC, VERITAS, H.E.S.S.) and future (Cherenkov Telescope Array) IACT observatories. Interestingly, a few highest-energy photons from distant blazars included in the 3FHL Catalog are in the region around and beyond the cosmic γ-ray horizon [i.e., the energy at which the cosmic optical depth $\tau = 1$, see e.g., Dominguez et al. (2013)] as shown in **Figure 2**. These photons provide important constraints on extragalactic background light models as they may also help in the understanding of γ-ray propagation over cosmological distances.

6. CONCLUDING REMARKS

Fermi-LAT has been performing the first all-sky survey in γ rays, gathering well-sampled, continuous light curves for hundreds of AGN and compiling source catalogs for different energy ranges and time periods. These observations constitute important resources to the astronomical community for a better understanding of the jet physics, cosmological evolution, and accretion processes of SMBH. In fact, the *Fermi*-LAT observations, in conjunction with the multi-frequency data collected from radio to VHE, are key to revealing the nature of jet physics in different classes of AGN, including particle acceleration, environmental effects, and interaction processes. In addition, Pass 8 LAT data have increased the sensitivity for hard-spectrum sources, which are important targets for ground-based VHE telescopes including the planned Cherenkov Telescope Array. Moreover, the extended energy range reached by the Pass 8 data opens new opportunities for the study of blazars at high redshifts. Over the next years the *Fermi* satellite will provide a fundamental contribution in time domain astronomy and multi-messenger/multi-wavelength studies.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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REFERENCES

Abdo, A. A., Ackermann, M., Ajello, M., Baldini, L., Ballet, J., Barbiellini, G., et al. (2009). Radio-loud narrow-line seyfert 1 as a new class of gamma-ray active galactic nuclei. *Astrophys. J.* 707, L142–L147. doi: 10.1088/0004-637X/707/2/L142

Acero, F., Ackermann, M., Ajello, M., Albert, A., Atwood, W. B., Axelsson, M., et al. (2015). Fermi large area telescope third source catalog. *Astrophys. J. Suppl.* 218, 23–63. doi: 10.1088/0067-0049/218/2/23

Ackermann, M., Ajello, M., Allafort, A., Baldini, L., Ballet, J., Bastieri, D., et al. (2012). GeV observations of star-forming galaxies with the Fermi large area telescope. *Astrophys. J.* 755, 164–186. doi: 10.1088/0004-637X/755/2/164

Ackermann, M., Ajello, M., Allafort, A., Atwood, W. B., Baldini, L., Ballet, J., et al. (2013). The first Fermi-LAT catalog of sources above 10 GeV. *Astrophys. J. Suppl.* 209, 34–67. doi: 10.1088/0067-0049/209/2/34

Ackermann, M., Ajello, M., Atwood, W. B., Baldini, L., Ballet, J., Barbiellini, G., et al. (2015). The third catalog of active galactic nuclei detected by the Fermi large area telescope. *Astrophys. J.* 810, 14–47. doi: 10.1088/0004-637X/810/1/14

Ackermann, M., Ajello, M., Atwood, W. B., Baldini, L., Ballet, J., Barbiellini, G., et al. (2016). 2FHL: The second catalog of hard Fermi-LAT sources. *Astrophys. J. Suppl.* 222, 5–23. doi: 10.3847/0067-0049/222/1/5

Ackermann, M., Ajello, M., Baldini, L., Ballet, J., Barbiellini, G., Bastieri, D., et al. (2017). Gamma-ray blazars within the first 2 billion years. *Astrophys. J.* 837, L5–L12. doi: 10.3847/2041-8213/aa5fff

Ajello, M., Atwood, W. B., Baldini, L., Ballet, J., Barbiellini. G., Bastieri, D., et al. (2017). 3FHL: the third catalog of hard Fermi-LAT sources. *Astrophys. J. Suppl.* 232, 18–40. doi: 10.3847/1538-4365/aa8221

Anton, S., Browne, I. W. A., and Marcha, M. J. (2008). The colour of the narrow line Sy1-blazar 0324+3410. *Astron. Astrophys.* 490, 583–587. doi: 10.1051/0004-6361:20078926

Baldi, R., Capetti, A., Robinson, A., Laor, A. and Behar, E. (2016). Radio-loud narrow line seyfert 1 under a different perspective: a revised black hole mass estimate from optical spectropolarimetry. *Month. Notices R. Astron. Soc.* 458, L69–L73. doi: 10.1093/mnrasl/slw019

Baumgartner, W. H., Tueller, J., Markwardt, C. B., Skinner, G. K., Barthelmy, S., Mushotzky, R. F., et al. (2013). The 70 month Swift-BAT all-sky hard X-ray survey. *Astrophys. J. Suppl.* 207, 19–30. doi: 10.1088/0067-0049/207/2/19

Böttcher, M., and Dermer, C. D. (2002). An evolutionary scenario for blazar unification. *Astrophys. J.* 564, 86–91. doi: 10.1086/324134

Böttcher, M., Reimer, A., Sweeney, K., and Prakash, A. (2013). Leptonic and hadronic modeling of Fermi-detected blazars. *Astrophys. J.* 768, 54–67. doi: 10.1088/0004-637X/768/1/54

Calderone, G., Ghisellini, G., Colpi, M., and Dotti, M. (2013). Black hole mass estimate for a sample of radio-loud narrow-line Seyfert 1 galaxies. *Month. Notices R. Astron. Soc.* 431, 210–239. doi: 10.1093/mnras/stt157

D'Ammando, F., Orienti, M., Finke, J., Raiteri, C. M., Angelakis, E., Fuhrmann, L., et al. (2012). SBS 0846+513: a new gamma-ray emitting Narrow-Line Seyfert 1 galaxy. *Month. Notices R. Astron. Soc.* 426, 317–329. doi: 10.1111/j.1365-2966.2012.21707.x

D'Ammando, F., Orienti, M., Larsson, J., and Giroletti, M., (2015). The first γ-ray detection of the narrow-line Seyfert 1 FBQS J1644+2619. *Month. Notices R. Astron. Soc.* 452, 520–524. doi: 10.1093/mnras/stv1278

D'Ammando, F., and Orienti, M. (2015). High-energy properties of the high-redshift flat spectrum radio quasar PKS 2149-306. *Month. Notices R. Astron. Soc.* 455, 1881–1891. doi: 10.1093/mnras/stv2452

D'Ammando, F., Orienti, M., Finke, J., Larsson, J., Giroletti, M., and Raiteri, C. (2016). A panchromatic view of relativistic jets in narrow-line seyfert 1 galaxies. *Galaxies* 4, 11–17. doi: 10.3390/galaxies4030011

D'Ammando, F., Acosta-Pulido, J. A., Capetti, A., Raiteri, C. M., Baldi, R. D., Orienti, M., and Ramos Almeida, C. (2017). Uncovering the host galaxy of the γ-ray-emitting narrow-line Seyfert 1 galaxy FBQS J1644+2619. *Month. Notices R. Astron. Soc.* 469, L11–L15. doi: 10.1093/mnrasl/slx042

Deo, R. P., Crenshow, D. M., and Kraemer, S. B. (2006). The host galaxies of narrow-line seyfert 1 galaxies: nuclear dust morphology and starburst rings. *Astron. J.* 132, 321–346. doi: 10.1086/504894

Dominguez, A., Primack, J. R., Rosario, D. J., Prada, F., Gilmore, R. C., Faber, S. M., et al. (2011). Extragalactic background light inferred from AEGIS galaxy-SED-type fractions. *Month. Notices R. Astron. Soc.* 410, 2556–2578. doi: 10.1111/j.1365-2966.2010.17631.x

Dominguez, A., Finke, J. D., Prada, F., Primack, J. R., Kitaura, F. S., Siana, B., et al. (2013). Detection of the cosmic γ-Ray horizon from multiwavelength observations of blazars. *Astrophys. J.* 70, 77–91. doi: 10.1088/0004-637X/770/1/77

Fanaroff, B. L., and Riley, J. M. (1974). The morphology of extragalactic radio sources of high and low luminosity. *Month. Notices R. Astron. Soc.* 167, 31P–36P. doi: 10.1093/mnras/167.1.31P

Fossati, G., Maraschi, L., Celotti, A., Comastri, A., and Ghisellini, G. (1998). A unifying view of the spectral energy distributions of blazars. *Month. Notices R. Astron. Soc.* 299, 433–448. doi: 10.1046/j.1365-8711.1998.01828.x

Ghisellini, G., Celotti, A., Fossati, G., Maraschi, L., and Comastri, A. (1998). A theoretical unifying scheme for gamma-ray bright blazars. *Month. Notices R. Astron. Soc.* 301, 451–468. doi: 10.1046/j.1365-8711.1998.02032.x

Ghisellini, G., Maraschi, L., and Tavecchio, F. (2009). The Fermi blazars' divide. *Month. Notices R. Astron. Soc.* 396, L105–L109. doi: 10.1111/j.1745-3933.2009.00673.x

Ghisellini, G., Tavecchio, F., Foschini, L., and Ghirlanda, G. (2011). The transition between BL Lac objects and flat spectrum radio quasars. *Month. Notices R. Astron. Soc.* 414, 2674–2689. doi: 10.1111/j.1365-2966.2011.18578.x

Ghisellini, G., Tavecchio, F., Maraschi, L., Celotti, A., and Sbarrato, T. (2014). The power of relativistic jets is larger than the luminosity of their accretion disks. *Nature* 515, 376–378. doi: 10.1038/nature13856

Ghisellini, G., Righi, C., Costamante, L., and Tavecchio, F. (2017). The Fermi blazar sequence. *Month. Notices R. Astron. Soc.* 469, 255–266. doi: 10.1093/mnras/stx806

Kotilainen, J. K., Leon Tavares, J., Olguin-Iglesias, A., Baes, M., Anorve, C., Chavushyan, V., et al. (2016). Discovery of a pseudobulge galaxy launching powerful relativistic jets. *Astrophys. J.* 832, 157–164. doi: 10.3847/0004-637X/832/2/157

Leon Tavares, J., Kotilainen, J., Chavushyan, V., Anorve, C., Puerari, I., Cruz-Gonzalez, I., et al. (2014). The host galaxy of the gamma-ray narrow-line Seyfert 1 galaxy 1H 0323+342. *Astrophys. J.* 795, 58–70. doi: 10.1088/0004-637X/795/1/58

Lister, M. L., Aller, M. F., Aller, H. D., Homan, D. C., Kellermann, K. I., Kovalev, Y. Y., et al. (2016). MOJAVE: XIII. Parsec-scale AGN jet kinematics analysis based on 19 years of VLBA observations at 15 GHz. *Astron. J.* 152, 12–27. doi: 10.3847/0004-6256/152/1/12

Marconi, A., Axon, D. J., Maiolino, R., Nagao, T., Pastorini, G., Pietrini, P., et al. (2008). The effect of radiation pressure on virial black hole mass estimates and the case of narrow-line seyfert 1 galaxies. *Astrophys. J.* 678, 693–700. doi: 10.1086/529360

Massaro, E., Giommi, P., Leto, C., Marchegiani, P., Maselli, A., Perri, M., et al. (2009). Roma-BZCAT: a multifrequency Catalog of blazars. *Astron. Astrophys.* 495, 691–696. doi: 10.1051/0004-6361:200810161

Mattox, J. R., Bertsch, D. L., Chiang, J., Dingus, B. L., Digel, S. W., Esposito, J. A., et al. (1996). The likelihood analysis of EGRET data *Astrophys. J.* 461, 396–407. doi: 10.1086/177068

Olguin-Iglesias, A., Kotilainen, J. K., Leon Tavares, J., Chavushyan, V., and Anorve, C. (2017). Evidence of bar-driven secular evolution in the gamma-ray narrow-line Seyfert 1 galaxy FBQS J164442.5+261913. *Month. Notices R. Astron. Soc.* 467, 3712–3722. doi: 10.1093/mnras/stx022

Stickel, M., Padovani, P., Urry, C. M., Fried, J. W., and Kuehr, H. (1991). The complete sample of 1 Jansky BL Lacertae objects. I - Summary properties. *Astrophys. J.* 374, 431–439. doi: 10.1086/170133

Ulrich, M.-H., Maraschi, L., and Urry, C. M. (1997). Variability of active galactic nuclei. *Annu. Rev. Astron. Astrophys.* 35, 445–502. doi: 10.1146/annurev.astro.35.1.445

Urry, M., and Padovani, P. (1995). Unified schemes for radio-loud active galactic nuclei. *Publ. Astron. Soc. Pac.* 107, 803–845. doi: 10.1086/133630

Woo, J.-H., and Urry, C. M. (2002). Active galactic nucleus black hole masses and bolometric luminosities. *Astrophys. J.* 579, 530–544. doi: 10.1086/342878

Zhou, H., Wang, T., Yuan, W., Shan, H., Komossa, S., Lu, H., et al. (2007). A narrow-line seyfert 1-blazar composite nucleus in 2MASX J0324+3410. *Astrophys. J.* 658, L13–L16. doi: 10.1086/513604

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