IL NUOVO CIMENTO Vol. 34 C, N. 3 Maggio-Giugno 2011
DOI 10.1393/ncc/i2011-10852-7

Colloquia: Scineghe2010

Flaring Active Galactic Nuclei. The cases of 3C 279 and PMN J0948+0022 as seen by the *Fermi*-LAT

F. D'Ammando on behalf of the Fermi-LAT Collaboration
INAF-IASF Palermo - Via Ugo La Malfa 153, I-90146 Palermo, Italy

(ricevuto il 25 Febbraio 2011; pubblicato online il 26 Aprile 2011)

Summary. — Active Galactic Nuclei (AGNs) exhibit variability across the entire electromagnetic spectrum with distinct flaring episodes at different frequencies. The high sensitivity and nearly uniform sky coverage of the Large Area Telescope on board the *Fermi* satellite make it a powerful tool for monitoring a large number of AGNs over long timescales. This allowed us to detect several flaring AGNs in γ rays, triggering dedicated multifrequency campaigns on these sources from radio to TeV energies. We discuss the results for two different types of flaring AGN: the flat spectrum radio quasar 3C 279, in particular the coincidence of a γ-ray flare from this source with the drastic change of the optical polarization angle, and the first γ-ray flare from a radio-loud narrow-line Seyfert 1, PMN J0948+0022.

PACS `95.85.Pw` – Astronomical observations: γ-ray.
PACS `98.54.Cm` – Active and peculiar galaxies and related systems (including BL Lacertae objects, blazars, Seyfert galaxies, Markarian galaxies, and active galactic nuclei).

1. – Introduction

Since its launch on 2008 June 11, the *Fermi* Gamma-ray Space Telescope has opened a new era in high-energy astrophysics. The primary instrument on board *Fermi*, the Large Area Telescope (LAT), is a pair-conversion telescope covering the energy range $\sim 20\,\mathrm{MeV}$ to $300\,\mathrm{GeV}$ with unprecedented sensitivity and effective area [1]. The combination of deep and fairly uniform exposure over two orbits, very good angular resolution, and stable response of the LAT has allowed it to produce the most sensitive, best-resolved survey of the γ-ray sky, and to efficiently find episodes of flaring from γ-ray sources of different nature.

One of the major scientific goals of the *Fermi* mission is to investigate the high-energy emission in Active Galactic Nuclei (AGNs) in order to understand the mechanisms by which the particles are accelerated and the precise site of the γ-ray emission, and investigate on long timescales the AGN variability and the γ-ray duty cycle. With respect to previous γ-ray instruments, such as EGRET [2] and AGILE [3], the LAT provides opportunities to investigate more in detail the behaviour of flaring γ-ray AGNs. Best examples are the extraordinary outbursts of 3C 454.3 in December 2009 and April 2010 (see [4] for details). Together with simultaneous multiwavelength observations collected over the entire electromagnetic spectrum, LAT measurements allow us to reach a deeper insight on the jet structure and the emission mechanisms at work in AGNs. In the following we focus on two different types of AGN: the Flat Spectrum Radio Quasar (FSRQ) 3C 279, and the radio-loud Narrow-Line Seyfert 1 (RL-NLS1) PMN J0948+0022.

2. – The γ-ray flare/optical polarization change correlation in 3C 279

The FSRQ 3C 279 was one of the brightest blazar detected by EGRET with strong and rapidly variable γ-ray activity [5], and the first FSRQ detected at energies above 100 GeV by the MAGIC Cherenkov telescope on February 2006 [6]. After a quiescent phase for the first ~ 100 days of *Fermi*-LAT operations, 3C 279 entered a phase of strong γ-ray activity and a multiwavelength campaign was triggered involving a large number of observatories from radio to γ-ray bands, including also optical polarimetric observations by the Kanata telescope, as reported in detail in [7].

As shown in fig. 1, 3C 279 went into a high γ-ray state at around MJD 54780 lasting for about 120 days, a period characterized by erratic flaring events and an overall double-peak structure with variations of the flux by a factor of about 10. During the multiwavelength campaign the γ-ray emission dominated the electromagnetic output of 3C 279 with an observed γ-ray luminosity as much as $\sim 10^{48}\,\mathrm{erg\,s^{-1}}$. The most striking event occurred during the rapid, second γ-ray flare at MJD 54880, with a doubling time scale of about one day. A highly correlated behavior of the γ-ray and optical bands is evident between MJD 54880 and 54900, with the sharp γ-ray flare coincident with a significant drop of the level of optical polarization degree (PD), from about 30% down to a few percent in ~ 20 days. It suggests highly ordered magnetic fields in the γ-ray emission region. This event is associated with a dramatic change of the electric vector position angle (EVPA) that decreases by 208° with a rate of 12° per day. This behaviour is in contrast to the relatively constant value observed before of about 50°, corresponding to the jet direction of 3C 279 as observed by VLBI (see *e.g.* [8]). This clearly indicates that the sharp γ-ray flare is closely correlated with the dramatic change of optical polarization due to a single, coherent event and the optical and γ-ray emission regions are cospatial.

The X-ray observations show a relatively constant flux during the second γ-ray flare but reveal a symmetrical X-ray flare at about MJD 54950, ~ 60 days after the γ-ray peak. During the X-ray flare optical and γ-ray emission is in a lower state, even if the γ-ray emission is still dominant. That the X-ray spectrum is much harder than the optical spectrum argues against a temporary extension of the high-energy tail of the synchrotron emission. Moreover, the similarity of the X-ray shape and time scale with the γ-ray flare seems to be unfavourable to the hypothesis that the X-ray flare is just a delayed version of the γ-ray one due to, *e.g.*, particle cooling. Thus, these findings are in favour of an isolated X-ray flare produced by another mechanism that involves primary lower energy electrons, challenging the simple one-zone emission models. Compared to the higher energy emission, the radio and millimeter fluxes are less variable and no correlated or delayed radio flare was observed, suggesting that the X-ray and γ-ray flaring events take places where the radio emission is not yet fully optically thin.

The gradual rotation of the optical polarization angle requires a non-axisymmetric trajectory of the emission pattern or a swing of the jet across our line of sight, since in the case of a uniform axially symmetric jet any compression of the plasma due to a

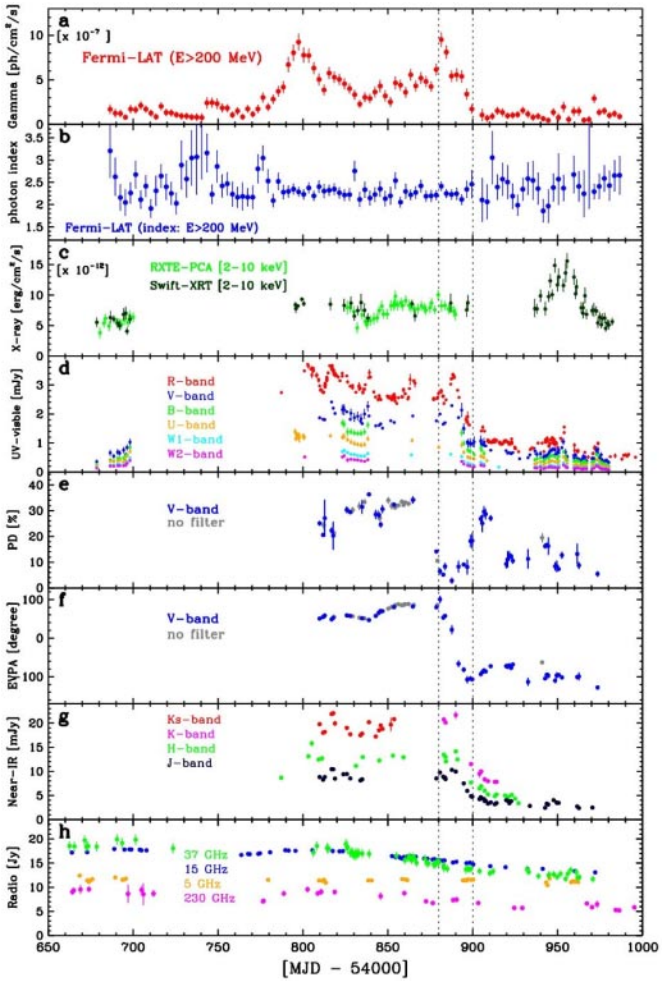

Fig. 1. – (Colour on-line) Multifrequency light curves of 3C 279 obtained between July 2008 and June 2009. (a,b) γ-ray flux above 200 MeV and photon index averaged over 3-day intervals as measured by *Fermi*-LAT. (c) X-ray flux integrated between 2 and 10 keV provided by *Swift*/XRT (dark green) and RXTE/PCA (light green). (d) Optical and UV fluxes collected by GASP-WEBT, Kanata and *Swift*/UVOT. (e,f) Polarization degree (PD) and electric vector position angle (EVPA) of the optical polarization measured by Kanata in the V-band (dark blue) and by KVA Telescope with no filter (light blue). (g) Near-infrared flux measured by Kanata and GASP-WEBT. (h) Radio fluxes measured by OVRO at 15 GHz, and GASP-WEBT at 5, 37, and 230 GHz (adapted from [7]).

perpendicular shock moving along the jet would result in a change of the PD, but not in a gradual change of the EVPA, as instead we observe. Two models have been proposed to explain the observed behavior in a non-axisymmetric/curved geometry: the propagation of an emission knot along helical magnetic field lines (see *e.g.* [9]) or along the curved trajectory of a "bent jet" (see *e.g.* [10]). In both scenarios the distance of the dissipation region from the central engine can be constrained from the ~ 20 day duration of the polarization event to $\sim 10^5$ gravitational radii away from the SMBH. This implies a jet opening angle of $< 0.2°$, smaller than typically observed with VLBI. This constraint could be relaxed in the "flow-through" scenarios, where the emission patterns may move slower than the bulk speed of the jet or not propagate at all, and thus the modulation is due to the swing of the whole jet across the line of sight. In this case the emission region could be located at $\sim 10^3$ gravitational radii, with the jet motion imposed at its base, caused by deflection due to external medium, or as consequence of dynamical instability.

The dominant source of seed photons for the inverse-Compton contribution in γ-rays depends on the distance of the dissipation region (broad-line region or accretion disk at sub-parsec scales, IR torus and synchrotron at parsec scales) so it is fundamental to discriminate between the different theoretical scenarios for understanding when the plasma blob dissipates in the jet. Long-term multiwavelength observations including *Fermi*-LAT and optical polarization measurements of 3C 279 and other sources will be fundamental for providing new insights into the structure of relativistic jets of the blazars.

3. – PMN J0948+0022 and the γ-ray radio-loud narrow-line Seyfert 1s

Relativistic jets are certainly the most extreme expression of the power than can be generated by a SMBH in the center of an AGN, with bolometric luminosity up to $10^{49-50}\,\mathrm{erg\,s^{-1}}$ (*e.g.* [11]), and a large fraction of the power emitted in γ rays. Before the launch of the *Fermi* satellite, only two classes of AGNs are known to generate these structures and thus to emit up to the γ-ray energy range: blazars and radio galaxies, both hosted in giant elliptical galaxies [12]. The first 11 months of observation by *Fermi*-LAT confirmed that the extragalactic γ-ray sky is dominated by these two classes [13], but the discovery of variable γ-ray emission from 4 RL-NLS1s revealed the presence of an emerging third class of AGNs with relativistic jets [14-16]. This finding poses intriguing questions about the knowledge of the development of relativistic jets, the origin of the radio loudness, and the Unification model for AGNs.

NLS1 is a class of AGN discovered by [17] and identified by their optical properties: narrow permitted lines (FWHM (Hβ) $< 2000\,\mathrm{km\,s^{-1}}$) emitted from the broad-line region, [OIII]/H$\beta < 3$, a bump due to FeII (see *e.g.* [18] for a review). They also exhibit strong X-ray variability, steep X-ray spectra, and substantial soft X-ray excess. These characteristics point to systems with small masses of the central black hole (10^6–10^8 $M_\odot$) and high accretion rates (up to 90% of the Eddington value) with respect to blazars and radio galaxies. NLS1s are generally radio-quiet, with only a small fraction of them ($< 7\%$, [19]) radio-loud, while generally the 10%–20% of quasars are radio-loud. In the past, several authors investigated the peculiarities of RL-NLS1s with non-simultaneous radio to X-ray data, suggesting similarities with young stage of quasars or different types of blazar [19-21]. The strong and variable radio emission, and the flat radio spectrum together with variability studies suggested the presence in some RL-NLS1s of a relativistic jet, now confirmed by the detection by *Fermi*-LAT of γ-ray emission from PMN J0948+0022 [14, 22]. After that source other 3 RL-NLS1s were detected by LAT in γ rays: 1H 0323+342, PKS 1502+036, and PKS 2004–447. The raising number of γ-ray detection suggests that they form a new class of γ-ray emitting AGNs [16]. Moreover, as in the case of blazars and radio galaxies, there should be a "parent population" with the jet viewed at large angles. The first source of this type was recently detected: PKS 0558–504 [23]. Therefore, it seems that NLS1s could be a set of low-mass systems parallel to blazars and radio galaxies. Taking into account also the high accretion rate, the RL-NLS1 is a class of extreme interest for extending the studies of the properties of relativistic jets to different mass and power scales.

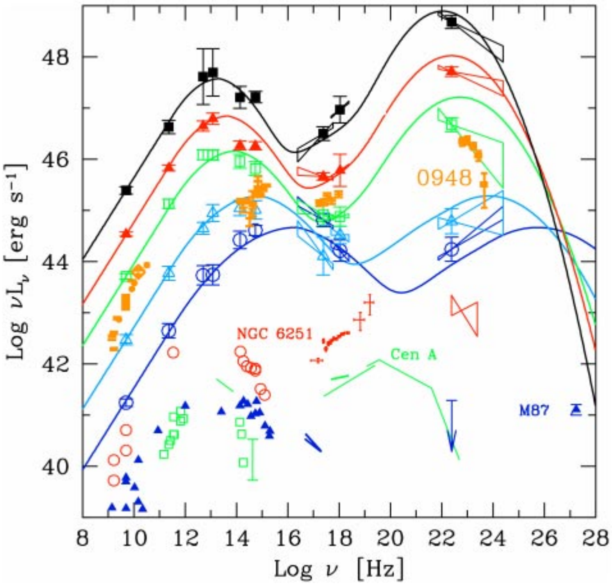

Fig. 2. – (Colour on-line) The average SED of PMN J0948+0022 as obtained during the first 5 months of *Fermi* observation together with *Swift* (XRT and UVOT), OVRO and Effelsberg data (orange squares), here shown in comparison with the blazar sequence and the SEDs of the radio galaxies NGC 6251, Cen A, and M87 (adapted from [22], see also [14, 24]).

The γ-ray detection of these RL-NLS1s was important not only for the confirmation of the presence of a relativistic jet, but also to measure its power and study the characteristics of this class of objects by modeling the broad-band spectrum. The first SEDs collected for these 4 RL-NLS1s showed clear similarities with blazars: a double-humped shape with disk component in UV (except PKS 2004–447), physical parameters blazar-like and jet power in the average range of blazars. For example, the physical parameters resulting from the modeling of the average SED of PMN J0948+0022 during the multifrequency campaign in August 2008–January 2009 (see [14]) are typical of a source midway between FSRQs and BL Lacs, with low power with respect to FSRQs (see fig. 2). A similar behaviour was observed also for the other three objects. In particular, compared with the blazars, the jet power estimated for PMN J0948+0022 and PKS 1502+036 are in the region of FSRQs, while 1H 0323+342 and PKS 2004–447 are in the range typical of BL Lac objects (see [16]). This discovery challenges the blazar sequence and more generally the AGN Unification model.

Another key question was the maximum power released by the jets of RL-NLS1s. A first answer arrived in July 2010 when PMN J0948+0022 underwent two strong γ-ray flares with peak flux of $\sim 100 \times 10^{-8}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ [25, 26], corresponding to an apparent isotropic γ-ray luminosity of $\sim 10^{48}\,\mathrm{erg\,s^{-1}}$, comparable to that of the bright FSRQs [27, 28]. The extreme power of these flaring episodes confirms that this RL-NLS1 hosts relativistic jets as powerful as those in blazars, despite the relatively low mass and the rich environment due to the high accretion rate. The continuous monitoring of the entire γ-ray sky provided by *Fermi*-LAT allows us to catch, if it happens, a new intense γ-ray flare from one of these sources. It is important to know if also other RL-NLS1s can produce similar γ-ray flares to determine if PMN J0948+0022 is an archetypical source of this new class of γ-ray AGNs or if it shows peculiar characteristics also with respect to the other RL-NLS1s. Furthermore, by considering that NLS1s are usually hosted in spiral galaxies the presence of a relativistic jet in these objects is contrary to the paradigm that the formation of relativistic jets could happen only in elliptical galaxies (see *e.g.* [29,30]). This suggests that relativistic jets can form and develop independently of their host galaxies, challenging our actual knowledge on the relativistic jet formation.

4. – Conclusions

The γ-ray all-sky monitoring by *Fermi*-LAT, combined with other simultaneous ground- and space-based observations, provide us new insights into the relativistic jets and broad emission models of AGNs. We presented the results from the multifrequency campaign of the FSRQ 3C 279, including the discovery of a γ-ray flare associated with a drastic change of the optical polarization angle as well as the detection of an "orphan" X-ray flare. In addition, the discovery by *Fermi*-LAT of γ-ray emission from 4 RL-NLS1s provided evidence for relativistic jets in these systems. The γ-ray flare of PMN J0948+0022 in July 2010 confirmed that extreme power can be produced also in this class of AGNs.

* * *

The *Fermi*-LAT Collaboration acknowledges support from a number of agencies and institutes for both the development and operation of the LAT as well as scientific data analysis. These include NASA and DOE in the United States, CEA/Irfu and IN2P3/CNRS in France, ASI and INFN in Italy, MEXT, KEK, and JAXA in Japan, and the K. A. Wallenberg Foundation, the Swedish Research Council and the National Space Board in Sweden. Additional support from INAF in Italy and CNES in France for science analysis during the operations phase is also gratefully acknowledged.

REFERENCES

[1] Atwood W. B. *et al.*, *Astrophys. J.*, **697** (2009) 1071.
[2] Thompson D. J. *et al.*, *Astrophys. J. Suppl. Ser.*, **699** (1993) 976.
[3] Tavani M. *et al.*, *Astron. Astrophys.*, **502** (2009) 295.
[4] Escande L., Lott B., Dermer C. D. and Tanaka Y., these proceedings.
[5] Hartman R. C. *et al.*, *Astrophys. J.*, **553** (2001) 683.
[6] Albert J. *et al.*, *Science*, **320** (2008) 1752.
[7] Abdo A. A. *et al.*, *Nature*, **463** (2010) 919.
[8] Jorstad S. G. *et al.*, *Astron. J.*, **130** (2005) 1418.
[9] Marscher A. P. *et al.*, *Nature*, **452** (2008) 966.
[10] Young A., *Nature*, **436** (2010) 887.
[11] Ackermann M. *et al.*, *Astrophys. J.*, **721** (2010) 1383.
[12] Blandford R. D. and Rees M. J., in *BL Lac Objects* (University of Pittsburgh Press) 1978, p. 328.
[13] Abdo A. A. *et al.*, *Astrophys. J.*, **715** (2010) 429.
[14] Abdo A. A. *et al.*, *Astrophys. J.*, **699** (2009) 976.
[15] Abdo A. A. *et al.*, *Astrophys. J.*, **707** (2009) 727.
[16] Abdo A. A. *et al.*, *Astrophys. J.*, **707** (2009) L142.
[17] Osterbrock D. E. and Pogge R. W., *Astrophys. J.*, **297** (1985) 166.
[18] Pogge R. W., *New Astron. Rev.*, **44** (2000) 381.
[19] Komossa S. *et al.*, *Astron. J.*, **132** (2006) 531.

[20] Yuan W. *et al.*, *Astrophys. J.*, **685** (2008) 801.
[21] Foschini L. *et al.*, *Adv. Space Res.*, **43** (2009) 889.
[22] Foschini L. *et al.*, in *ASP Conf. Proc.*, **427** (2009) 243 [arXiv:0908.3313].
[23] Gliozzi M. *et al.*, *Astrophys. J.*, **717** (2010) 1243.
[24] Ghisellini G., Tavecchio F. and Chiaberge M., *Astron. Astrophys.*, **432** (2005) 401.
[25] Donato D., *The Astronomer's Telegram*, 2733 (2010).
[26] Foschini L., *The Astronomer's Telegram*, 2752 (2010).
[27] Foschini L. *et al.*, *Proc. IAU Symposium 275 "Jets at all scales"* (2010) [arXiv:1009.1055].
[28] Foschini L. *et al.*, to be published in *Mon. Not. R. Astron. Soc.* [arXiv:1010.4434].
[29] Böttcher M. and Dermer C., *Astrophys. J.*, **564** (2002) 86.
[30] Marscher A. P., in *Lect. Notes Phys.*, edited by Belloni T., Vol. **794** (Springer) 2009, p. 173.