PROCEEDINGS OF SCIENCE

Global eVLBI observations of the radio loud NLS1 PMN J0948+0022

Marcello Giroletti[*a], **Z. Paragi**[b,c], **H. Bignall**[d], **A. Doi**[e], **L. Foschini**[f], **K. É. Gabányi**[g,c], **C. Reynolds**[d]

[a] *INAF Istituto di Radioastronomia, via Gobetti 101, 40129 Bologna (Italy)*
E-mail: giroletti@ira.inaf.it
[b] *Joint Institute for VLBI in Europe, Postbus 2, 7990 AA Dwingeloo, The Netherlands*
[c] *MTA Research Group for Physical Geodesy and Geodynamics, H-1585 Budapest, Hungary*
[d] *Curtin Institute for Radio Astronomy, Curtin University of Technology, Perth WA 6845, Australia*
[e] *Institute of Space and Astronautical Science, JAXA, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan*
[f] *INAF Osservatorio Astronomico di Brera, I-23807 Merate, Italy*
[g] *FOMI Satellite Geodetic Observatory, Budapest, P.O. Box 585, 1592 Hungary*

We have performed three real-time e-VLBI observations of the radio loud NLS1 PMN J0948+0022 at 22 GHz, using a global array including telescopes in Europe, East Asia, and Australia, reaching a maximum baseline length of $\sim$ 12500 km. The observations were part of a large multi-wavelength campaign carried out in 2009. We report on the results, including flux density variability, brightness temperature, jet structure, and polarization. Overall, these provide strong support for the presence of a relativistic jet in this source. We also present a new VLBI project aimed at improving our understanding of this jet, by studying proper motion and Faraday rotation.

Narrow-Line Seyfert 1 Galaxies and their place in the Universe - NLS1,
April 04-06, 2011
Milan Italy

PoS(NLS1)051

[*] Speaker.

1. Introduction

Narrow line Seyfert 1 (NLS1) are Active Galactic Nuclei (AGN) characterized by unusual optical spectra, with Hβ line FWHM < 2000 km/s, a line intensity ratio [OIII]$/$H$\beta < 3$, and a bump in FeII [19]. NLS1 are generally radio quiet, and only a small fraction of them (about 7%) is radio loud [18]. Radio loud (RL) NLS1s show the hallmarks of the presence of relativistic jets, such as flat radio spectra, high degree of compactness, and VLBI variability [21, 7]. Thanks to the advent of the *Fermi* Large Area Telescope (LAT), it has been possible to obtain a conclusive evidence for the existence of relativistic jets in these AGN. At least four RL NLS1 have been detected by *Fermi* [2, 4], and a few more are expected (and tentatively detected) as the sky exposure is increasing [10].

Among the gamma-ray detected RL NLS1, PMN J0948+0022 ($z = 0.585$) is particularly interesting, having been revealed in the *Fermi* data just a few weeks after the launch, with flux at $E > 200$ MeV of $(4.0 \pm 0.3) \times 10^{-8}$ ph cm^{-2} s^{-1} and photon index $\Gamma = 2.6 \pm 0.1$ [2]. Not only does this make PMN J0948+0022 one of the brightest gamma-ray AGNs at high latitude [1]; in the following months, the LAT has also detected bright flares from this source [9, 6], reaching a gamma-ray luminosity as high as $\sim 10^{48}$ erg s^{-1}.

Multi-wavelength (MWL) observations are essential to constrain the physical processes at work in AGNs. Soon after the discovery of gamma-ray emission from PMN J0948+0022, a MWL campaign was organized, which indeed permitted to study the variability of the broadband spectral energy distribution, estimating some basic parameters for this source, such as the size of the emitting region, the magnetic field value, and the particle energy range [3, 8]. During this campaign, which took place between March and July 2009 and covered gamma-rays, X-rays, UV, optical, we also attempted to obtain information on an essential and complementary subject: the actual structure of the source, which can only be imaged in the radio band thanks to the superior resolution provided by Very Long Baseline Interferometry (VLBI).

In the present paper, we describe the outcome of these VLBI observations, which were for the first time performed with real-time transmission and correlation of the data (e-VLBI) using telescopes in Europe, East Asia, and Australia; the experiments are dealt with in Sect. 2, while a more detailed description of the project is given by Giroletti et al. (2011, [15]). The main open points are highlighted in Sect. 3, where we also present a new Global VLBI project that could address them. Finally, in Sect. 4 we summarize the current status of our knowledge on the radio properties of NLS1, including radio quiet ones, on the basis of our existing VLBI observations.

2. e-VLBI observations

We first observed PMN J0948+0022 at 1.6 GHz with e-VLBI for about two hours using only European stations on 2009 April 21. This was a pilot experiment, which revealed a compact, well detected ~ 180 mJy radio source. On the basis of such detection, and of the inverted spectral index revealed by single dish observations [11], we organized a set of three observations at 22 GHz, exploiting the longest possible baselines achievable between Europe, East Asia, and Australia (also favoured by the 0° declination of the source). The observations took place on 2009 May 23, June 10, and July 4. While e-VLBI is routinely done on European scale [12, 13], these are the first

PoS(NLS1)051

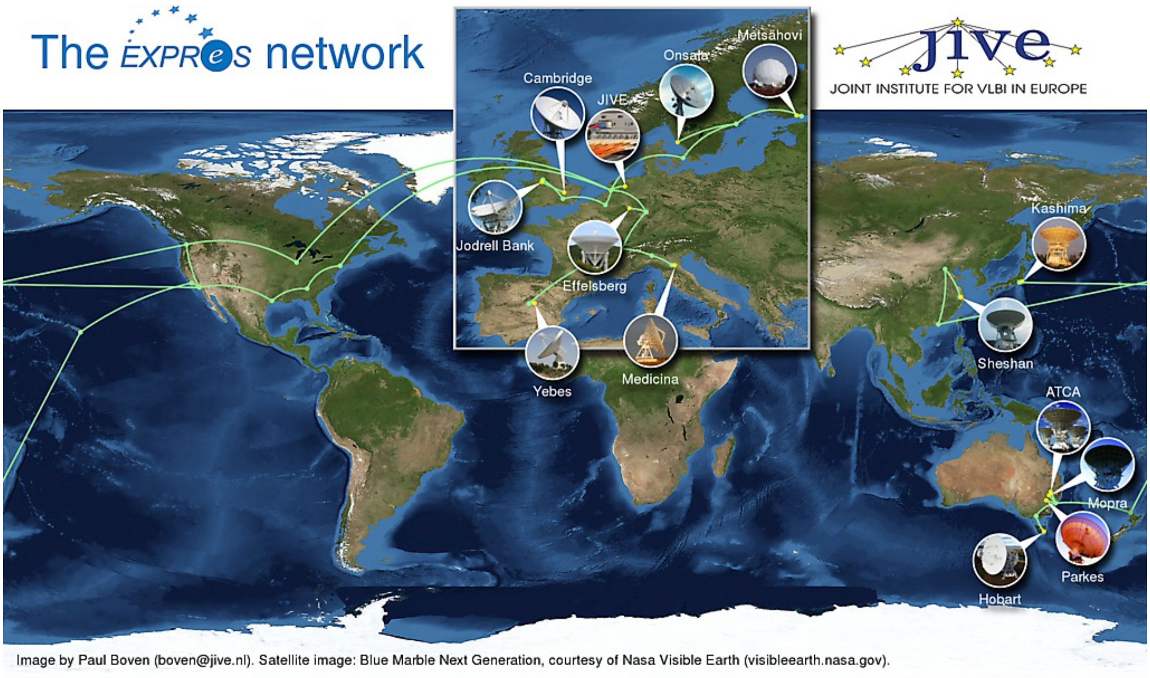

Figure 1: The network of telescopes participating in the Global e-VLBI observations of PMN J0948+0022 (courtesy of Paul Boven).

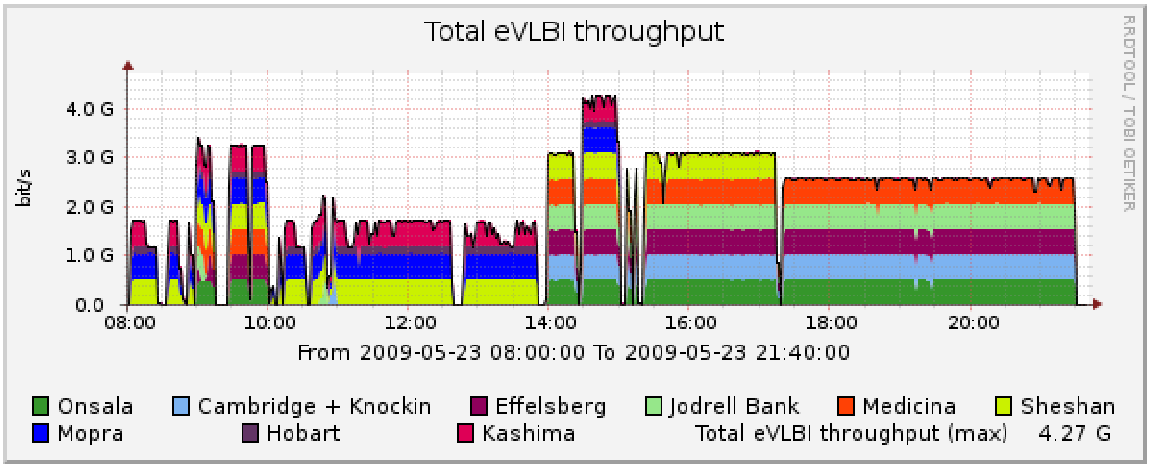

Figure 2: The aggregate data rate streamed to the JIVE correlator as a function of time, for the 2009 May 23 session of the campaign.

astronomical e-VLBI science observations on a global scale. This is facilitated by the large (and growing) number of telescopes which are now connected with optical fibers sustaining high data rates. Advantages are both scientific and practical, such as the possibility to test setups in real time and independence on the availability of storing media. Of course, a non negligible advantage lies in the much shortened time necessary to know the outcome of the observations (from weeks/months to practically zero).

In our somewhat pioneering experiments, we reached a maximum baseline of $\sim 12\,500$ km

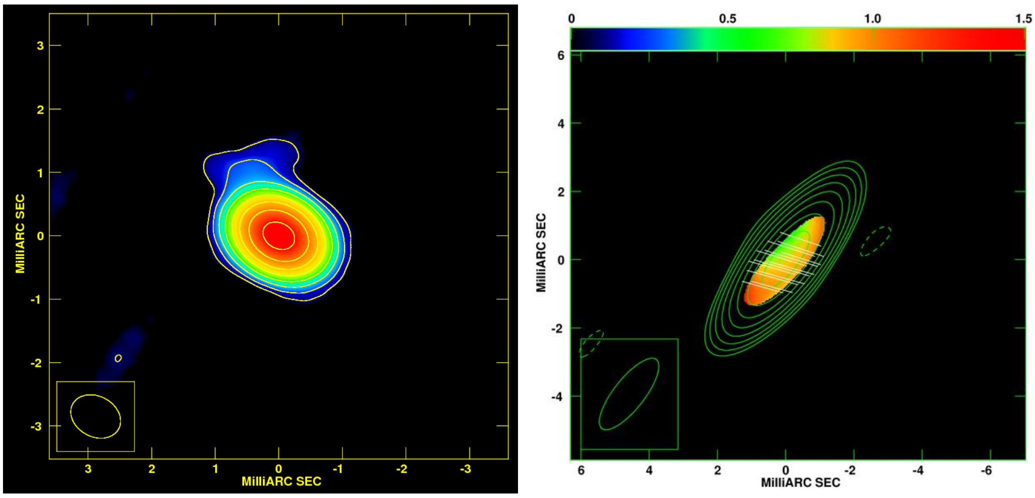

Figure 3: e-VLBI images of PMN J0948+0022 on 2009 June 10. Left: total intensity (lowest contour traced at 1.5 mJy beam^{-1}). Right: total intensity contours, overlaid to fractional polarization (in colors) and Electric vector position angle (sticks of length such that 1 mas = 1.2 mJy beam^{-1}); note that the absolute position of the EVPA is uncalibrated and that only intra-European baselines have been considered for this image.

(almost as long as the Earth's diameter), exploiting about 1 hour of mutual Europe-Australia visibility (bracketed by several hours of observations with only short/intermediate baselines). All the stations were able to transmit the data in real time, and fringes were found at all epochs. The network of telescopes participating in the observations is shown in Fig. 1, and the transmitted data rate for the May 23rd experiment is presented in Fig. 2.

The source was detected at all epochs, with a flux density varying between ~ 300 and 700 mJy. The angular resolution of the observations was typically sub-milliarcsecond, and as good as 0.15×0.38 mas. Given the unresolved nature of the core, this corresponds to a brightness temperature lower limit of $T_b > 3.4 \times 10^{11}$ K. In turn, this confirms that the source must be relativistically beamed, with Doppler factor $\delta > 1$, since the observed T_b exceeds the equipartition brightness temperature [7, 21].

Besides the bright dominant compact core, some extended emission is present in the visibility data, and a short jet-like structure in position angle $30-40^\circ$ is clearly imaged in the second epoch data, as shown in Fig. 3 (left panel). Moreover, despite the experiments were not initially conceived to address the polarization calibration, we managed to obtain a reliable detection of fractional polarization at this epoch at the level of $P \sim 0.9\%$ (Fig. 3, right panel).

These results (flux density variability, high brightness temperature, one-sided jet like structure, and detection of linear polarization) are characteristics of relativistic beamed jets, and make PMN J0948+0022 much alike the bright blazars detected by *Fermi*.

3. Open questions

The recent results obtained with VLBI in this paper and other works [7, 15, 9], as well as with MWL observations have conclusively demonstrated the presence of relativistic jets in the

RL NLS1 PMN J0948+0022. However, besides some ongoing work on other RL NLS1s [16], additional VLBI efforts are required to clarify open issues. First, if $\delta > 1$, it is natural to expect a superluminal motion of components in the jet-like structure. However, despite the growing number of observations available for this source, this issue has not been solved. Another topic that has remained somewhat obscure so far is the connection between the high energy activity and the polarization properties, not only in this source but in blazars in general. In some cases, gamma-ray flares have been concurrent to jumps in the level of fractional polarization and/or to a swinging of the EVPA in the parsec scale jets, including J0948+0022 itself [9, 5]. More generally, Fermi detected jets seem to have larger fractional polarization [17].

To shed light on the above issues, we have recently proposed a three epoch monitoring with the VLBA and EVN stations capable of doing wide bandwidth 22–24 GHz observations. The addition of the EVN baselines (including the South Africa station of Hartebeesthoek) would greatly improve the beam size (to $\sim 0.15 \times 0.12$ mas, uniform weights), permitting to further constrain the brightness temperature and to reveal possible motions in the range $\beta_{\rm app} = 10-30$. Finally, thanks to the large bandwidth, we could study the fractional polarization as well as the Faraday rotation, which could help to constrain parameters such as the magnetic field and the thermal electron content in the immediate environment of the nucleus.

4. PMN J0948+0022 and other NLS1s

The observational evidence gathered so far points to relativistic beaming in RL NLS1, i.e. the jets of these sources must be closely aligned with our line of sight. It seems that at least in these cases, the narrow FWHM of the emission lines in RL NLS1 can not be ascribed to obscuration, as these systems are viewed "pole-on".

It is natural to wonder what are the misaligned counterparts of RL NLS1, just as radio galaxies represent the parent population of blazars in the so-called unified scheme [20]. Interestingly, RL NLS1 do not possess significant radio emission on extended (kiloparsec) scales. Therefore, when the jet emission is not strongly beamed, or even in fact de-beamed, very little radio emission should be present. Indeed, one interesting case is NGC 4051, studied by Giroletti & Panessa (2009, [14]) with EVN data, in which weak radio emission is detected in an intermediate/flat spectrum central component surrounded by two fainter, symmetric steep spectrum regions about 20 pc away. The brightness temperature of the central component is $T_{\rm B} \sim 10^5$ K, and the radio luminosity at 5 GHz is $\log L = 18.8\,{\rm W\,Hz^{-1}}$. While it would be intriguing to postulate a jet base scenario in which the emission is beamed away from our line of sight, such low $T_{\rm b}$ seems much more consistent with the presence of thermal emission from an outflow, a nuclear wind, or even from a molecular disk.

Continued VLBI observations of RL and radio quiet NLS1 are therefore highly desirable, as the results obtained so far have yielded important results, but additional questions remain to be addressed.

Acknowledgments

This activity is supported by the European Community Framework Programme 7, Advanced Radio Astronomy in Europe, grant agreement No. 227290 and by the Italian Ministry of Foreign

Affairs within the Scientific and Technology Cooperation Agreement between Japan and Italy. e-VLBI developments in Europe are supported by the EC DG-INFSO funded Communication Network Developments project EXPReS, Contract No. 02662 (http://www.expres-eu.org/). KEG was supported by the Hungarian Scientific Research Fund (OTKA, grant no. K72515). We acknowledge financial contribution from the agreement ASI-INAF I/009/10/0.

References

[1] Abdo, A. A., Ackermann, M., Ajello, M., et al. *Bright Active Galactic Nuclei Source List from the First Three Months of the Fermi Large Area Telescope All-Sky Survey*, (2009) *ApJ*, 700, 597, [arXiv:0902.1559]

[2] Abdo, A. A., Ackermann, M., Ajello, M., et al. *Fermi/Large Area Telescope Discovery of Gamma-Ray Emission from a Relativistic Jet in the Narrow-Line Quasar PMN J0948+0022*, (2009) *ApJ*, 699, 976, [arXiv:0905.4558]

[3] Abdo, A. A., Ackermann, M., Ajello, M., et al. *Multiwavelength Monitoring of the Enigmatic Narrow-Line Seyfert 1 PMN J0948+0022 in 2009 March-July*, (2009) *ApJ*, 707, 727, [arXiv:0910.4540]

[4] Abdo, A. A., Ackermann, M., Ajello, M., et al. *Radio-Loud Narrow-Line Seyfert 1 as a New Class of Gamma-Ray Active Galactic Nuclei*, (2009) *ApJ*, 707, L142, [arXiv:0911.3485]

[5] Abdo, A. A., Ackermann, M., Ajello, M., et al. *PKS 1502+106: A New and Distant Gamma-ray Blazar in Outburst Discovered by the Fermi Large Area Telescope*, (2010) *ApJ*, 710, 810, [arXiv:0912.4029]

[6] D'Ammando, F. & Ciprini, F. *Fermi LAT detection of a new GeV flare from the radio-loud Narrow-Line Sy1 PMN J0948+0022*, (2011) *ATel*, 3429

[7] Doi, A., Nagai, H., Asada, K., Kameno, S., Wajima, K., & Inoue, M. *VLBI Observations of the Most Radio-Loud, Narrow-Line Quasar SDSS J094857.3+002225*, (2006) *PASJ*, 58, 829, [arXiv:astro-ph/0608507]

[8] Foschini, L., Fermi/Lat Collaboration, Ghisellini, G., Maraschi, L., Tavecchio, F., & Angelakis, E. *Fermi/LAT Discovery of Gamma-Ray Emission from a Relativistic Jet in the Narrow-Line Seyfert 1 Quasar PMN J0948+0022*, (2010) *ASPC*, 427, 243, [arXiv:0908.3313]

[9] Foschini, L., Ghisellini, G., Kovalev, Y. Y., et al. *The first gamma-ray outburst of a narrow-line Seyfert 1 galaxy: the case of PMN J0948+0022 in 2010 July*, (2011) *MNRAS*, 413, 1671, [arXiv:1010.4434]

[10] Foschini, L. *Evidence of powerful relativistic jets in narrow-line Seyfert 1 galaxies*, (2011) *arXiv*, arXiv:1105.0772, these proceedings, PoS(NLS1)024

[11] Fuhrmann, L., et al. *Gamma-ray NLSy1s and classical blazars: Are they different at radio cm/mm bands?*, (2011) these proceedings, PoS(NLS1)026

[12] Giroletti, M., Giovannini, G., Beilicke, M., Cesarini, A., & Krawczynski, H. *EVN observations of the radio galaxy M87 following a TeV flare*, (2010) *ATel*, 2437

[13] Giroletti, M., Koerding, E., Corbel, S., Sokolovsky, K., Fuhrmann, L., Schinzel, F., & C. C. Cheung, C. C. *VLBI detection of V407 Cyg*, (2010) *ATel*, 2536

[14] Giroletti, M., & Panessa, F. *The Faintest Seyfert Radio Cores Revealed by VLBI*, (2009) *ApJ*, 706, L260, [arXiv:0910.5821]

[15] Giroletti, M., Paragi, Z., Bignall, H., et al. *Global e-VLBI observations of the gamma-ray narrow line Seyfert 1 PMN J0948+0022*, (2011) *A&A*, 528, L11, [arXiv:1102.3264]

[16] Gu, M., & Chen, Y. *The Compact Radio Structure of Radio-loud Narrow Line Seyfert 1 Galaxies*, (2010) *AJ*, 139, 2612, [arXiv:1004.3058]

[17] Hovatta, T., Lister, M. L., Kovalev, Y. Y., Pushkarev, A. B., & Savolainen, T. *The Relation Between Radio Polarization and Gamma-Ray Emission in AGN Jets*, (2010) *IJMPD*, 19, 943, [arXiv:1002.1098]

[18] Komossa, S., Voges, W., Xu, D., Mathur, S., Adorf, H.-M., Lemson, G., Duschl, W. J., & Grupe, D. *Radio-loud Narrow-Line Type 1 Quasars*, (2006) *AJ*, 132, 531, [arXiv:astro-ph/0603680]

[19] Pogge, R. W. *Narrow-line Seyfert 1s: 15 years later*, (2000) *NewAR*, 44, 381, [arXiv:astro-ph/0005125]

[20] Urry, C. M., & Padovani, P. *Unified Schemes for Radio-Loud Active Galactic Nuclei*, (1995) *PASP*, 107, 803, [arXiv:astro-ph/9506063]

[21] Zhou, H.-Y., Wang, T.-G., Dong, X.-B., Zhou, Y.-Y., & Li, C. *SDSS J094857.3+002225: A Very Radio Loud, Narrow-Line Quasar with Relativistic Jets?*, (2003) *ApJ*, 584, 147