A Very Unusual γ-ray Bright Jet: The Two Sides of PMN J1603–4904

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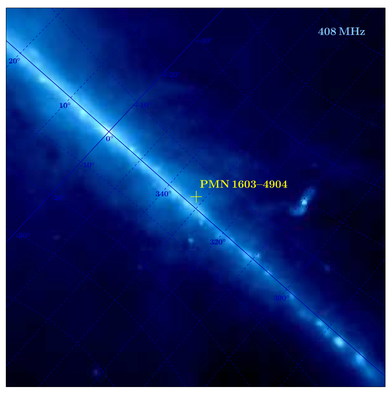
Abstract

We present our latest results on the bright, hard spectrum γ-ray source PMN J1603–4904. Our TANAMI VLBI observations reveal an unusual jet structure: a symmetric brightness distribution with the brightest, most compact component at the center of the emission region. The overall radio spectrum is flat to steep ($\alpha = -0.4$) on mas scales. Its broadband spectral energy distribution (SED) shows an excess in the infrared, which can be modeled with a black body of T$\sim$1500 K and is not expected in blazar SEDs. A classification of PMN J1603–4904 is not straightforward due to its low Galactic latitude, the lack of optical identification, and low multi-wavelength variability. We discuss different classification scenarios, which suggest that PMN J1603–4904 is either an atypical blazar or a γ-ray bright young radio galaxy, and the corresponding implications. The TANAMI VLBI monitoring program provides regular, dual-frequency (8 GHz and 22 GHz), milliarcsecond (mas) monitoring of extragalactic jets south of $-30°$ declination using the Australian Long Baseline Array (LBA) and associated telescopes in Antarctica, Chile, New Zealand and South Africa. Supporting programs provide simultaneous multiwavelength coverage of all sources.

Location of PMN J1603–4904:



408 MHz continuum survey (Haslam+2009)

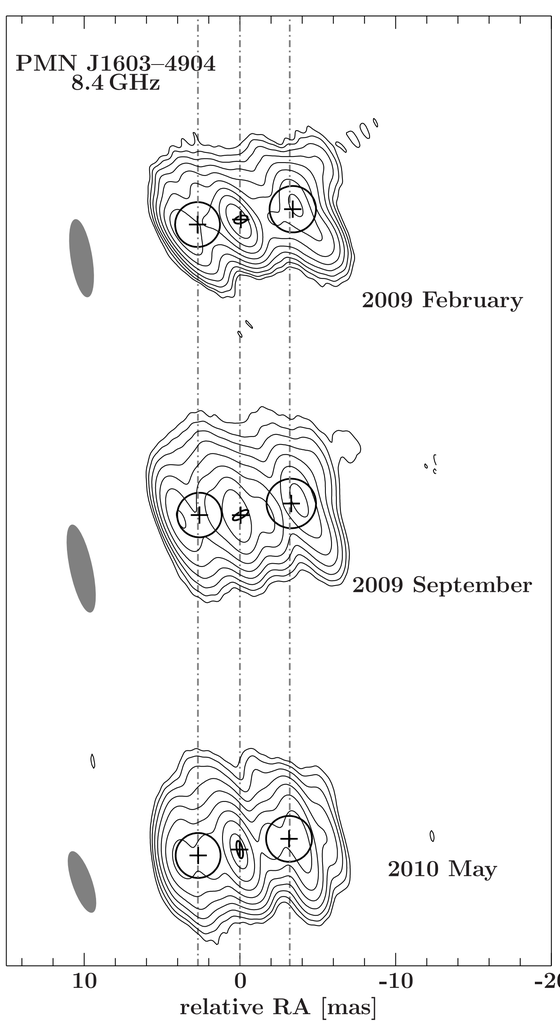


Figure 1: Time evolution of the milliarcsecond structure of PMN J1603–4904 at 8 GHz. Contours indicate the CLEAN images, while the positions and FWHMs of Gaussian modelfit components are overlaid as black ellipses. No significant apparent motion or brightness temperature variability of the individual components is detected. PMN J1603–4904 appears as a very stable source over $\sim$ 15 months of VLBI observations. The FWHM of the corresponding synthesized beam is shown as a gray ellipse at the lower left corner of each image. (for details see Table 1)

Facts on the radio source PMN J1603–4904:

- Associated with the bright, hard-spectrum γ-ray source detected by *Fermi*/LAT 2FGL J1603.8–4904 ($\Gamma_\gamma = 2.04$, $F_{1-100\mathrm{GeV}} = 1.3 \times 10^{-08}$ ph/cm^2/s)
- Classified as a low peaked BL Lac object (2FGL, Nolan+2012, Shaw+2013)
- Among the 30 γ-ray brightest 2LAC objects
- No optical counterpart and no redshift (l = 332.15, b = 2.57)
- Only very mild broadband variability, no γ-ray flares
- $\leq$1.2% polarization at 20 GHz (Murphy+2010)
- TANAMI VLBI observations: symmetric radio morphology with $\sim$15 mas extension at 8 GHz with the brightest, most compact component in the center of the emission region (Fig. 1)
- Very stable source over 15 months of TANAMI observations (Fig. 1): no superluminal motion, no flux density variability
- Spectral information with 22 GHz TANAMI data: the central region has flattest spectral index and highest brightness temperature ($T_B \sim 9 \times 10^9$ K at 8 GHz) (Fig. 1&2)
- Multifrequency ATCA spectrum (5.5 GHz to 40 GHz): total spectral index $\alpha \sim -0.4$ (with $S_\nu \sim \nu^{+\alpha}$)
- Infrared observations reveal a bright excess in SED (Fig. 3), which can be modeled with a black body (T$\sim$1500 K)
- *Swift*/XRT: very faint X-ray counterpart

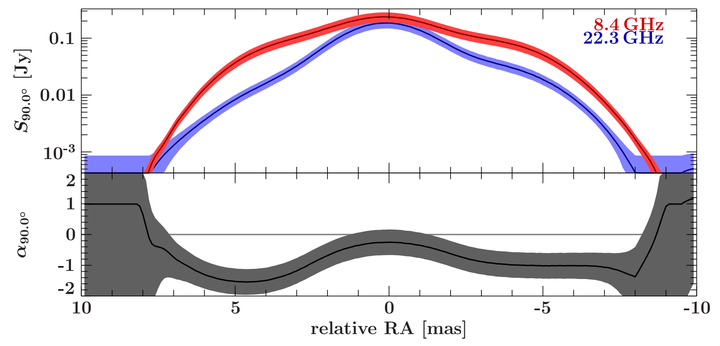


Figure 2: Top: Flux density profiles along PA= 80° at 8 GHz (red) and the 22.3 GHz (blue). Bottom: Spectral index along PA= 80°. Uncertainties corresponding to a conservative estimate of absolute calibration uncertainties and on-source errors of $\sim$20% and considering the image rms at both frequencies (with $S_\nu \sim \nu^{+\alpha}$). The central feature has flattest spectral index and highest brightness temperature.Other alignments result in unphysically steep spectral index values of $\alpha \ll -4$

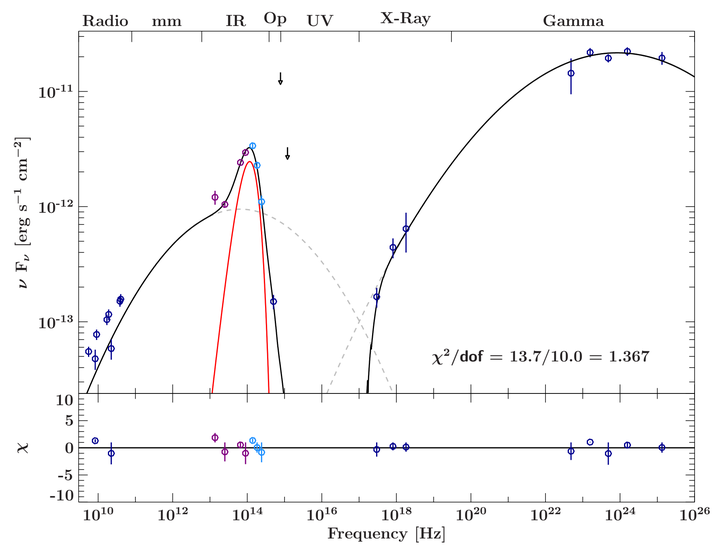


Figure 3: Broadband spectral energy distribution of PMN J1603–4904 including TANAMI, ATCA, WISE, 2MASS, optical data (Shaw+2013), *Swift*/XRT and *Fermi*/LAT data (2FGL).
The broadband data are fitted with two logarithmic parabolas (Massaro+2004), as well as the photoelectric absorption at X-ray energies (Wilms+2000), an extinction model for the optical and a black body model at infrared frequencies (Fitzpatrick1999). Most striking feature in this SED is the strong excess in the IR band, which is fitted with a black body of $T \sim 1500$ K. This could be associated with a dusty torus, the host galaxy or starburst activity.

Table 1: TANAMI imaging parameters:

Date yyyy-mm-dd	Freq. [GHz]	S_{peak} (Jy beam^{-1})	RMS (mJy beam^{-1})	S_{total} (Jy)	b_{maj} (mas)	b_{min} (mas)	P.A. (°)
2009-02-23/27	8.4	0.18	0.13	0.59	2.51	0.98	30.1
2009-09-06	8.4	0.17	0.23	0.57	3.36	1.15	19.23
2010-05-07	8.4	0.17	0.16	0.57	2.91	1.12	14.88
2010-05-05	22.3	0.14	0.35	0.29	2.09	1.16	83.91

The TANAMI Program

The Southern Hemisphere VLBI project TANAMI (Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry) aims to study the radio and γ-ray connection seen in many blazars by contemporaneous VLBI, *Fermi*/LAT and further multiwavelength observations. With the Australian Long Baseline Array (LBA) and additional telescopes in South Africa, Antarctica and Chile (see Fig. 4), we are monitoring a sample of currently 84 extragalactic jets south of $-30°$ degrees approximately every 2 months at 8.4 GHz and 22.3 GHz with milli-arcsecond resolution. The TANAMI sample consists of a combined radio and γ-ray selected subsample, with new γ-ray bright sources being added upon detections by *Fermi*/LAT. For most of these sources, TANAMI provides the first VLBI images.

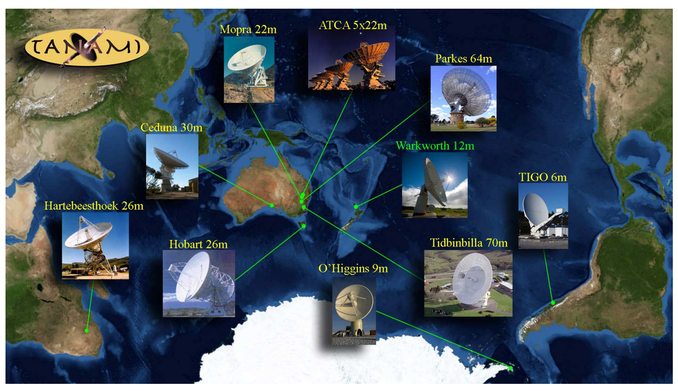


Figure 4: The TANAMI Array (Credit: J. Wilms/M. Kadler)

Current Status & First Results

- Ojha+2010, A&A, 519, 45: 8.4 GHz first epoch analysis
- 22 GHz-analysis containing spectral index maps for all sources close to submission
- first 8.4 GHz VLBI images of newly added γ-ray bright sources
- started kinematic analysis for all sources
- Catalog of quasi-simultaneous SEDs for all sources in prep.

Unusual BL Lac type object

- bright, hard-spectrum γ-ray source
- infrared colors consistent with WISE γ-ray strip parameters for BL Lacs (Massaro+2012)
- mas-scale structure at 8 GHz and spectral index distribution: brightest component (with flattest spectrum) in center of symmetric brightness distribution
- no or only mild multiwavelength variability
- low degree of polarization
- infrared excess in broadband spectrum - not expected in blazar SEDs

Alternative Classification: Compact Symmetric Object (CSO)?

- Double-sided symmetric VLBI structure $\rightarrow$ source seen edge-on, young radio galaxy/CSO
- Low variability and polarization
- Infrared excess in broadband SED: indication of starburst galaxy $\rightarrow$ starburst-CSO-connection (e.g., Tadhunter+2011)
- Size constraints by standard cosmology: 15 mas VLBI structure not larger than 125 pc
- VLBI observations miss $\sim$ 20% of total flux density compared to ATCA measurements (large scale emission?)
- caveat: no CSO in γ-rays detected so far, but theoretical predictions expect that CSOs are bright γ-emitters (e.g., Stawarz+2008, Kino+2011)

Conclusion & Outlook

- PMN J1603–4904 was initially classified as BL Lac but shows atypical multiwavelength properties
- Broadband spectrum and mas-scale structure allow alternative classification as CSO
- Prominent IR emission unusual for blazar
  - $*$ Origin of γ-ray emission to be discussed if not a blazar (possible starburst contribution?)
  - $*$ *Suzaku* & *XMM* observations approved $\rightarrow$ constrain SED
  - $*$ Optical Gemini observations approved $\rightarrow$ redshift, host galaxy
  - $*$ Further observations required to check classification: polarization, GHz spectrum, kinematics

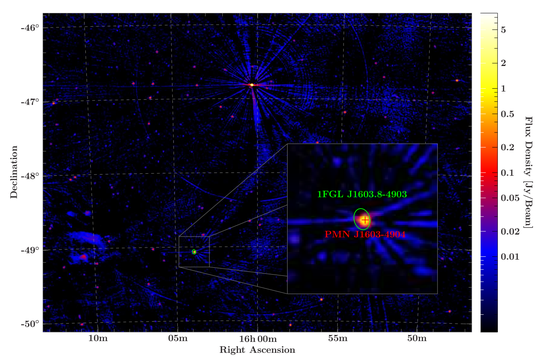


Figure 5: Radio image at 843 MHz(SUMSS, Mauch+2003).

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