Global eVLBI observations of the first gamma-ray RL NLS1

Marcello Giroletti (INAF/IRA), Akihiro Doi (ISAS/JAXA)

and Z. Paragi, H. Bignall, L. Foschini, K. Gabanyi, C. Reynolds, and many others
Outline

- This project - PMN J0948+0022
- background: detection of 1st gamma-ray RL NLS1
- support MWL campaign to assess identification and construct simultaneous, time resolved SED
- characterization of the radio jet with highest angular resolution ever
- open problems in PMN J0948+0022 and RL-NLS1 in general
- comparison to RQ-NLS1
Introduction

- Only a small fraction of NLS1s are radio loud (~7%, Komossa et al. 2006). These sources show the hallmarks of relativistic blazar-like jets (Doi et al. 2006, Zhou et al. 2003)
  - large core dominance
  - high brightness temperature
  - flat spectral index
- Blazar jets make gamma-rays... how about RL-NLS1s?
Gamma-ray discovery of PMN J0948+0022

- Just few weeks after its launch, the Large Area Telescope on board Fermi reveals gamma-ray emission positionally consistent with the NLS1 PMN J0948+0022 (Abdo et al. 2009, ApJ 699 976)

  - $z=0.58$
  
  - Flux $[E>100\text{ MeV}] = (12.1\pm2.2)\times10^{-8}\text{ ph cm}^{-2}\text{ s}^{-1}$
  
  - Photon Index = $2.60\pm0.14$
Multiwavelength archival data have initially been used to clarify the details of the emission processes at work in PMN J0948+0022.

SED parameters typical of FSRQs (bulk $\Gamma$, viewing angle, luminosity, magnetic field, $\gamma$ electrons).

However, a new observational campaign was immediately set up to obtain better, simultaneous data.
The MWL time-resolved campaign

- Other instruments involved: Fermi/LAT, Swift/BAT/XRT/UVOT, ATOM, SMARTS, VLBA, single dishes

- Variability observed at radio, optical, UV, X-ray and gamma-ray frequencies: the source is variable and powerful as a blazar; NLS1s have relativistic jets!

MWL campaign: summary

<table>
<thead>
<tr>
<th>$R_{\text{diss}}$</th>
<th>$67.5 \times 10^{15}$ cm</th>
<th>$\log L_{\text{rad}}$</th>
<th>45.32</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{\text{disk}}$</td>
<td>0.5 $L_{\text{Edd}}$</td>
<td>$\log L_p$</td>
<td>46.19</td>
</tr>
<tr>
<td>$B$</td>
<td>4.1 G</td>
<td>$\log L_e$</td>
<td>44.47</td>
</tr>
<tr>
<td>electron $\gamma_{\text{max}}$</td>
<td>2000</td>
<td>$\log L_B$</td>
<td>44.45</td>
</tr>
</tbody>
</table>
2009 MWL campaign: the radio observations

- Radio emission is generally detected somewhat out of the gamma-ray zone, but VLBI observations can still provide
  - complementary information on correlated variability
  - independent constraints on Doppler factor and viewing angle
  - highest angular resolution imaging
PMN J0948+0022 radio images on various scales

**NVSS**

**FIRST**

**VLBA 1.7 -> 15 GHz (Doi et al. 2006)**
New campaign: global e-VLBI observations

• More and more telescopes are becoming connected with optical fibers sustaining high data rates
• Advantages both scientific and practical
  • fast delivery of results
  • possibility to test setups in real time
  • no need to store data on disks
• The European VLBI Network (EVN) operates in e-VLBI mode about once per month since 2008
  • but never done before on a global scale
e-VLBI and PMN J0948+0022

- Intra-European test at 1.6 GHz succeeded in revealing the source on Apr 21
  - organization of a full-size campaign

- Known facts: inverted spectrum, Dec $\sim 0^\circ$, very compact structure

- go for maximum resolution with global high-frequency observations: **Eu+Jp+Ch+Au at 22 GHz, three epochs**
Observations: details

- 2009 May 23, Jun 10, July 3
- Maximum baseline ~12500km
- about 1 hr mutual Eu-Au visibility
- max eVLBI throughput ~4.5 Gbps
Results

- Source detected at all epochs, with a flux density varying between 300 and 700 mJy.
- Angular resolution as good as 0.15x0.38 mas, corresponding to brightness temperature $T_B > 3.4 \times 10^{11}$ K.

$$M_{BH} = 1.5 \times 10^8 \, M_{\odot} \quad \text{and} \quad 1R_s = 5 \times 10^{-5} \, \text{pc}$$

$$z = 0.585 \quad \text{and} \quad 0.1 \, \text{mas} = 0.6 \, \text{pc} = 10^4 \, R_s$$
Revealing the sub-mas jet

- The compact core dominates the structure

- However, a jet component is found at $r=0.86$ mas from the core in PA $\theta=35.4^\circ$, well aligned with the lower frequency structure, which shows a resolved jet feature in PA $\sim 30^\circ$–$40^\circ$ (Doi et al. 2006, Abdo et al. 2009, Foschini et al. 2011)
How about polarization?

- Polarization traces magnetic field structure (shocks?)
- Changes in polarization intensity and position angle often related to gamma-ray events
- On average, Fermi detected blazar jets are more polarized (Hovatta et al. 2010)
- Our result: polarization detected at epoch 2, mean 0.9% (peak of 1.3%), barely in excess of the VLBA at 15 GHz for the same epoch
The 2009 Global e-VLBI campaign: results and open problems

**Results**

- source is detected
- variable (300-600 mJy), unresolved $<10^4 \, R_\odot$ core: *relativistic jet base*
- faint one-sided jet knot
- $\sim 1\%$ fractional pol.

**Open problems**

- still not possible to trace proper motion of jet knot
- why do J0948 and other RL-NLS1 lack extended emission?
- connection between gamma-ray activity and polarization
- Even more interesting after gamma-ray flare and VLBA data reported by Foschini et al. 2011
Possible follow-ups

• We proposed a new global VLBI campaign in 2011-12: 22-24 GHz VLBA+EVN observations
  • improve angular resolution by factor ~3 over VLBA
  • 3 epochs separated by 4 months: suitable to reveal proper motions in the range $\beta \sim 10$-30
  • large bandwidth: good for polarization & RM study (clues on medium)
  • one epoch simultaneous with XMM-Newton (PI D’Ammando)

• Positive review but grades not good enough to get scheduled - a possible target for Italy+East Asia?
RL vs RQ NLS1?

- RL-NLS1 have bright compact cores
- What about RQ NLS1?
- They have compact cores too, but not as bright

NGC 4051
(Giroletti & Panessa 2009)

- \( T_B = 10^5 \) K
- linear size < 0.3 pc
- \( L_{5 \text{ GHz}} = 18.8 \text{ W Hz}^{-1} \)
- \( L_{2-10 \text{ keV}} = 40.8 \text{ erg s}^{-1} \)
- Jet base? Thermal emission from outflow/wind/molecular disk
Summary

- Global e-VLBI is a reliable technique to image AGN jets and constrain their physical properties.

- PMN J0948+0022 exhibits most features of relativistic jets - compactness, brightness, polarization.

- Future VLBI observations are fundamental for:
  - the details of this source
  - more RL NLS1
  - and RQ NLS1 too.