High resolution radio observations of gamma-ray emitting Narrow-Line Seyfert 1s

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ABSTRACT

The detection by *Fermi*-LAT of gamma-ray emission from radio-loud Narrow-Line Seyfert 1s (NLS1s) indicates that relativistic jets do not form only in blazars and radio galaxies. Despite a spectral energy distribution similar to blazars, their physical characteristics are quite different: lower black hole masses, generally higher accretion rates, and possibly hosted in spirals. Furthermore, their radio properties make the interpretation of these objects even more puzzling. The radio emission is very compact, not exceeding the parsec scales, and it is not significantly variable, as also found in the population of young radio sources. We present high resolution VLBA observations of three radio-loud NLS1s detected by *Fermi*-LAT: SBS 0846+513, PKS 1502+036, and PKS 2004-447. The information on the pc-scale morphology will be complemented with studies of flux density and spectral variability from multi-epoch and multifrequency observations, in order to unveil the nature of their radio emission.

INTRODUCTION: NLS1 is a class of AGN discovered by Osterbrock and Pogge (1985) and identified by their optical properties: narrow permitted lines (FWHM (Hβ) < 2000 km s^{-1}) emitted from the broad line region, [OIII]/Hβ < 3, a bump due to FeII (for a review see e.g. Pogge 2000). They also exhibit high X-ray variability, steep X-ray spectra and a prominent soft X-ray excess. These characteristics point to systems with smaller masses of the central black hole (10^6-10^8 $M_\odot$) and higher accretion rates (up to 90% of the Eddington value) with respect to blazars and radio galaxies. The strong radio emission and the flat radio spectrum, together with variability studies, suggested the presence in some radio-loud NLS1s of a relativistic jet, which was confirmed by the *Fermi*-LAT detection of gamma-ray emission from 5 objects optically classified as NLS1 (PMN J0948+0022, 1H 0323+342, PKS 1502+036, PKS 2004-447, and SBS 0846+513). The increasing number of gamma-ray detection of NLS1 suggests that they form a new class of gamma-ray emitting AGNs (Abdo et al. 2009). This discovery poses intriguing questions on the knowledge of the blazar sequence, the Unified model of AGNs, the development of relativistic jets, and the evolution of radio-loud AGNs.

SBS 0846+513

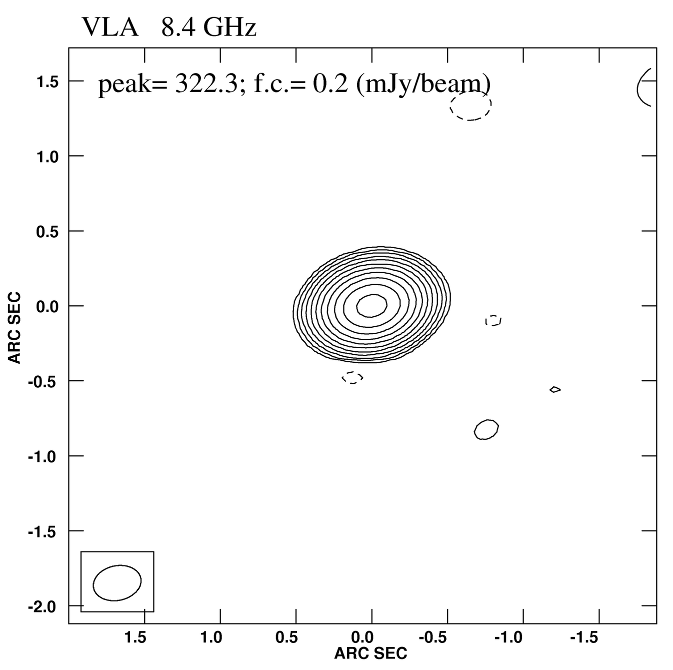

Fig. 1: VLA image at 8.4 GHz of SBS 0846+513.

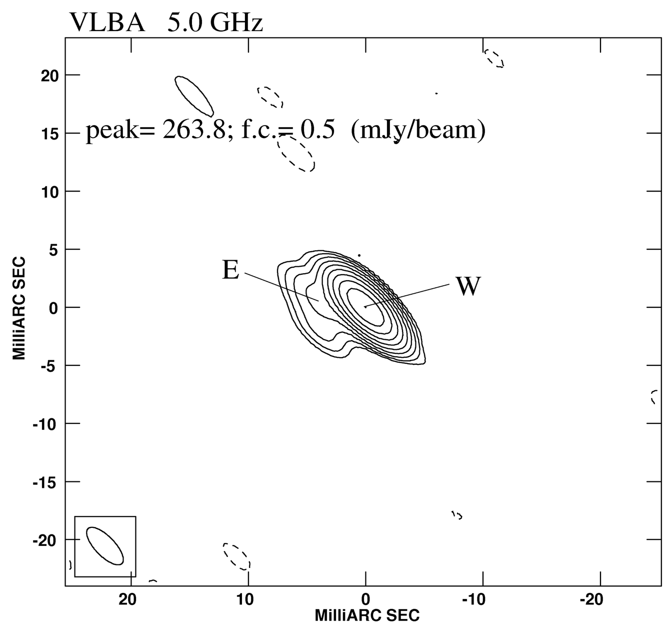

Fig. 2: VLBA image at 5.0 GHz of SBS 0846+513.

SBS 0846+513 is the most recent NLS1 detected in gamma rays by *Fermi*-LAT (Donato et al. 2011, D'Ammando et al., in prep.). Multi-epoch studies of the radio emission from the source indicate that the flux density has some degrees of variability (i.e. a variation of 55% at 4.8 GHz during 1986-2009). The resolution of the VLA is not adequate to resolve the source structure (Fig. 1). When imaged with the high spatial resolution provided by the VLBA, the source structure is resolved into two components with a core-jet structure (Fig. 2 and 3), as also pointed out in a previous work by Taylor et al. (2005). The flux density ratio between components E and W is ~19 and 14 at 5 GHz and 8.4 GHz, respectively. Their peaks are separated of about 3.5 mas (~23 pc at z = 0.5835). It is worth noting that the total flux density derived from VLBA data is smaller than the VLA flux density, even when VLA and VLBA observations were performed almost simultaneously. This could be due to the fact that extended, low-brightness features, like the jet structure, is resolved out by the VLBA array.

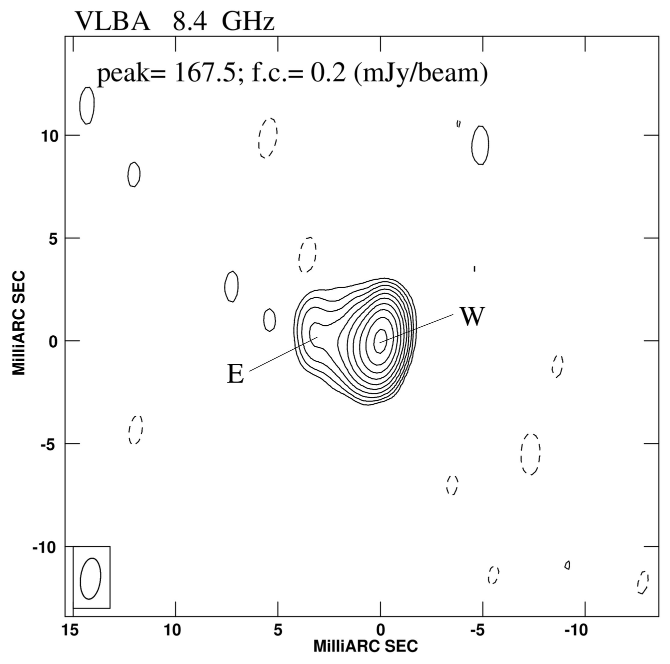

Fig. 3: VLBA image at 8.4 GHz of SBS 0846+513.

PKS 2004-447

PKS 2004-447 is a powerful ($L_{1.4\,GHz}$~1.3x10^{26} W/Hz) radio source at redshift z = 0.24 and it is one of the four radio-loud NLS1 initially detected in gamma rays (Abdo et al 2009). However its classification is still uncertain. Oshlack et al (2001) classified PKS 2004-447 as a genuine radio-loud NLS1 based on the optical definition. At radio wavelengths it is characterized by a steep (α>0.5, S(α) ∝ $\nu^{-\alpha}$) synchrotron spectrum at high frequency (above 8.4 GHz) and the absence of significant flux density variability. When imaged with arcsecond-resolution (e.g. ATCA) it is unresolved. Based on these characteristics Gallo et al. (2006) proposed this source as a genuine compact symmetric object (CSO). On the other hand, PKS 2004-447 has been included in the CRATES catalog of flat spectrum objects (Healey et al. 2007) due to its flatter spectrum (α~0.3) below 4.8 GHz, questioning the nature of the radio emission. Indeed a flat spectrum is usually an indication of a self-absorbed component as in the blazar population where the emission is dominated by the core region enhanced by projection effects. However, a flat spectrum may also be an indication of a convex spectrum as those found in CSO objects, whose spectral peak occurs between the frequencies considered.

So far the only information on the pc-scale structure of PKS 2004-447 is from archival VLBA data at 1.4 GHz (Fig. 1). The radio structure has an angular size of 45 mas (170 pc) with a position angle of -50⁰, and it is resolved into 3 main components. The lack of the spectral index information does not allow us to unambiguously classify the sub-components. For example the compact component A can be either the core of a core-jet boosted blazar, or a bright hotspot of a genuine and asymmetric CSO. Further multifrequency VLBA observations have been proposed in order to unveil the nature of this source.

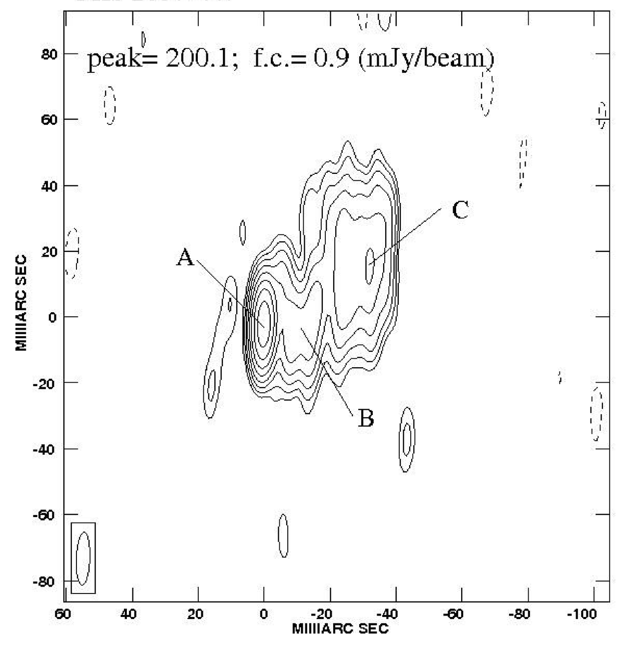

Fig. 1: VLBA image at 1.4 GHz of PKS 2004-447.

PKS 1502+036

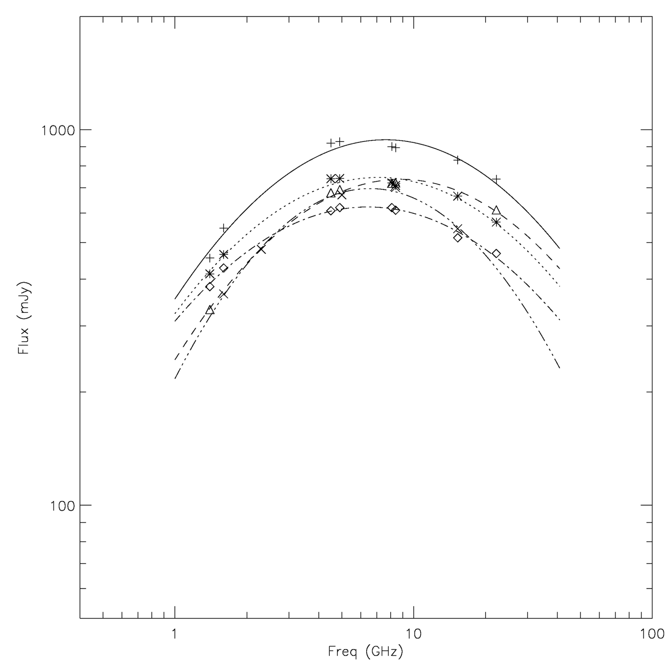

Fig. 1: Radio spectra of PKS 1502+036 observed with VLA and VLBA during 5 observing runs: + and solid line = 25 Sep 1999 (VLA); asterisk and dot line = 03 July 2002 (VLA); diamonds and dot-dash line = 13 Sep 2003 (VLA); X and dash-3dots line = 21 July 2006 (VLBA); triangles and dashed line = 14 April 2007 (VLA).

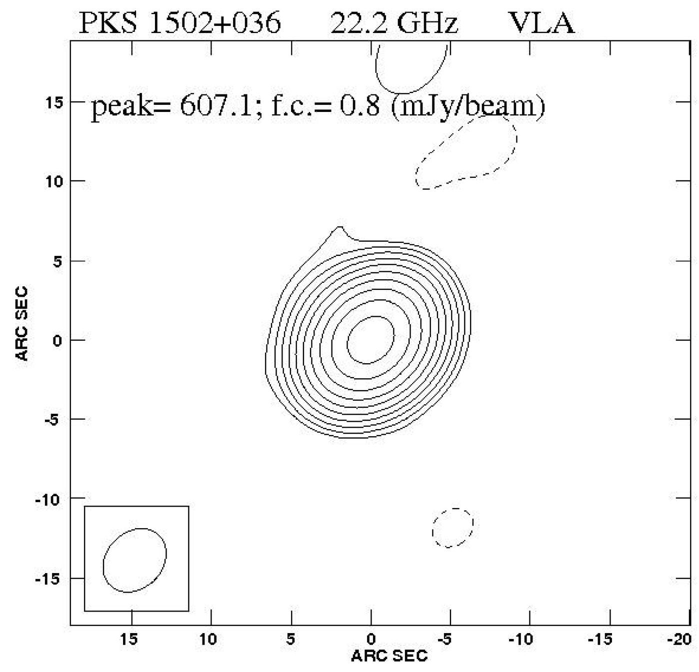

Fig. 2: VLA image at 22.2 GHz of PKS 1502+036.

With its high frequency peaking convex spectrum, PKS 1502+036 was part of the bright HFP sample (Dallacasa et al. 2000). Variability and morphological analysis suggests it is a blazar-like object. Simultaneous multi-frequency VLA observations carried out at various epochs showed that both the flux density and the peak frequency substantially change (Orienti et al. 2007). This is shown in Fig. 1 where 4-epoch VLA and 1-epoch VLBA observations carried out at various frequencies (from 1.4 to 22.2 GHz) simultaneously are plotted. During these epochs the peak occurred at 7.6, 7.1, 6.4, 6.5, and 8.8 GHz, respectively. PKS 1502+036 is unresolved on typical scales of the VLA (Fig. 2). However, when imaged with the parsec scale resolution provided by VLBA observations, its radio structure is marginally resolved and a second component seems to emerge from the core. In the VLBA images at 15 GHz the double radio structure is clearly resolved suggesting a core-jet structure. The radio emission is dominated by the core component, while the jet-like feature accounts for about 4% of the total flux density. Comparing the 15-GHz observations carried out at two different epochs (11 January 2002, and 21 July 2006, Figs. 3 and 4) it seems that in the second-epoch image there is a weak component of 4 mJy, separated by 3.05 mas (~ 16.5 pc at z=0.4088) from the core which was not detected in the previous observations. Assuming that this new component is the same knot of the jet visible in the 2002 observations, we can estimate its velocity expansion which turns out to be ~8c.

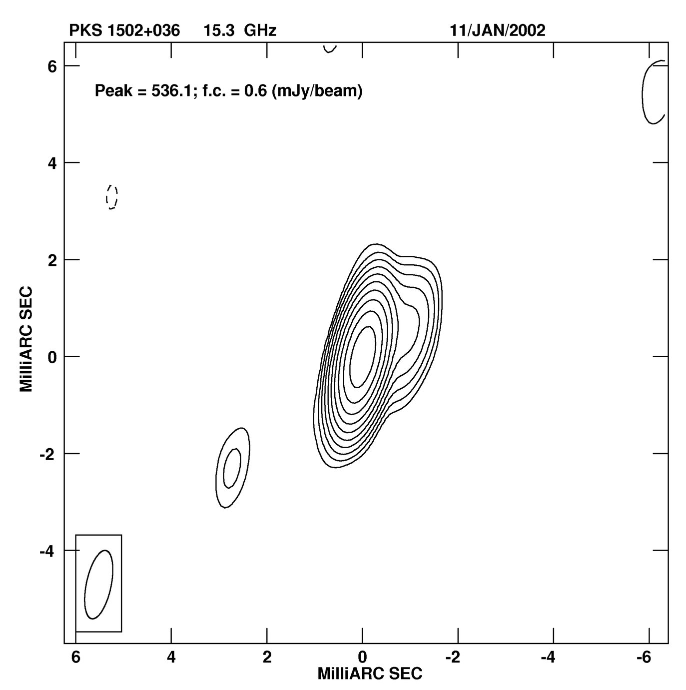

Fig. 3: VLBA image at 15.3 GHz of PKS 1502+036 collected on 11 January 2002.

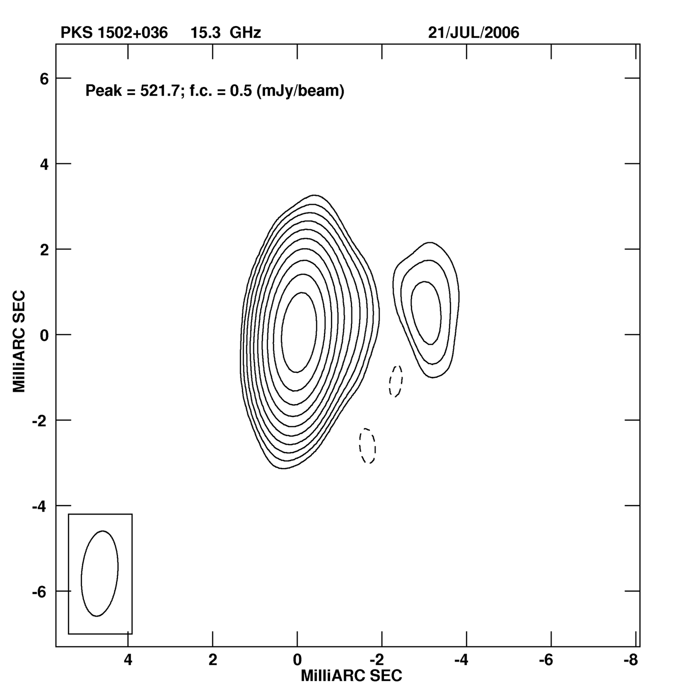

Fig. 4: VLBA image at 15.3 GHz of PKS 1502+036 collected on 21 July 2006.

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