THE GAMMA-RAY LOUD NARROW-LINE SEYFERT 1 GALAXY PKS 2004−447

The X-ray and Radio View

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Abstract

The discovery of an elusive sample of gamma-ray bright radio-loud narrow-line Seyfert 1 (γ-NLS1) galaxies revealed an intriguing new aspect of the AGN phenomenon. We study the radio-loudest γ-NLS1 galaxy, PKS 2004−447, as part of the multiwavelength monitoring program TANAMI. We show the first 8.4 GHz VLBI image, revealing a high brightness-temperature core and a prominent single-sided radio jet on parsec scales. New *Swift* and *XMM-Newton* observations reveal an unobscured flat X-ray spectrum, dominated by a single power-law component. In comparison to other γ-NLS1s, PKS 2004−447 exhibits a unique flat X-ray spectrum and persistent steep radio spectrum with moderate amplitude and spectral variability in both bands. The total radio emission is coming from a region smaller than ~ 0.5 kpc, supporting a possible classification of PKS 2004−447 as a Compact Steep Spectrum (CSS) source.

Facts on γ-NLS1

Relativistically beamed radio jets are a common feature of radio-loud active galactic nuclei (AGN), in elliptical galaxies with a central accreting supermassive black hole ($> 10^8 M_\odot$) at low accretion rates. The detection of γ-ray activity in radio-loud narrow line Seyfert 1 galaxies suggest relativistically beamed jets in spiral galaxies with low black hole masses ($\lesssim 10^8 M_\odot$), but high accretion rate. However, so far only a small number of γ-NLS1 have been detected (e.g. Foschini 2015, A&A 575, A13).

PKS 2004−447

- redshift $z = 0.24$ (Drinkwater et al 1997, MNRAS 284, 85)
- black hole mass $M_{\rm BH} \sim 10^{6.7}$ (Oshlack et al. 2001, ApJ 558, 578)
- γ-ray flux $F_{\geq 100\rm MeV} \sim 2\times10^{-8}\,\rm ph\,cm^{-2}s^{-1}$ (Abdo et al. 2009, A&A 707, L144).
- only γ-NLS1 in the Southern Hemisphere
- radio-loudest γ-NLS1

X-ray Properties

- Unobscured, flat power-law spectrum: Γ from ~ 1.6 to ~ 1.7.
- Spectral and flux variability on timescales of months

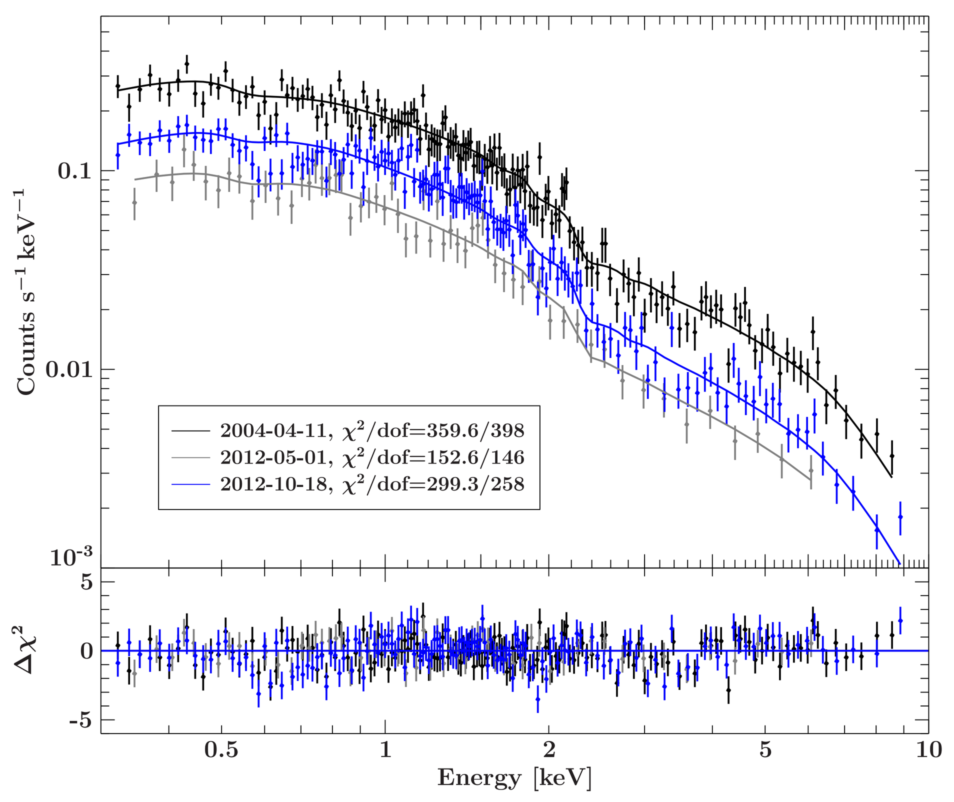

Figure 2: *XMM-Newton* EPIC PN spectra of PKS 2004−447 fit with a Galactically absorbed power law (*upper panel*) and its χ^2 residuals of the best-fit (*Lower panel*).

Parsec-scale morphology

- First 8.4 GHz VLBI image of PKS 2004−447 (Figure 5 left):
  - brightness temperature of VLBI core $\sim 4\times10^{10}$ K
  - upper limit of the jet angle to the line of sight of 24°
- Archival 1.5 GHz VLBA+VLA image of PKS 2004−447 (Figure 5 right):
  - unresolved on arcsec scales (VLA only)
  - radio source is contained within a region of projected size ~ 0.5 kpc
  - diffuse emission on scales $\gtrsim 50$ mas

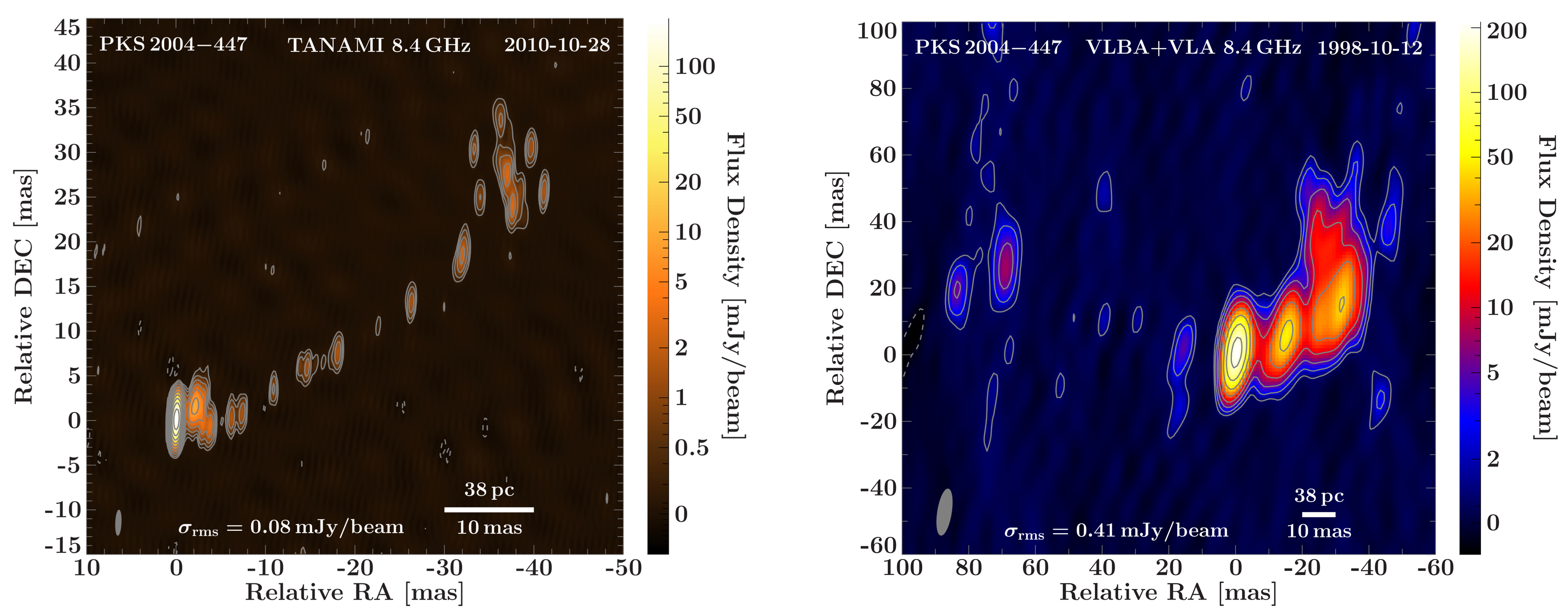

Figure 5: VLBI images of PKS 2004−447; Contour lines start at 3 times the image noise level $\sigma_{\rm rms}$ and increase logarithmically by a factor of 2; Left: TANAMI image at 8.4 GHz; Right: VLBA+VLA image at 1.5 GHz

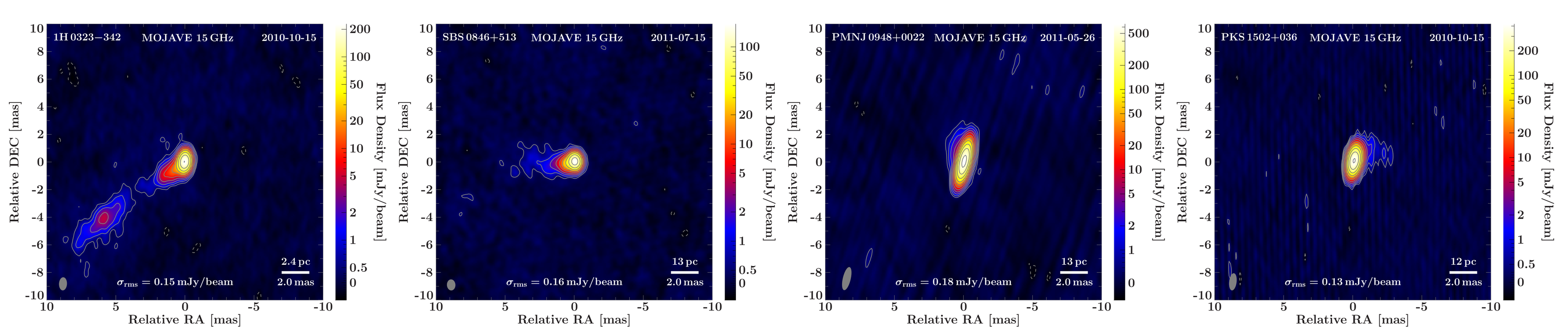

Figure 6: 15 GHz VLBI images of 1H 0323+342, SBS 0846+513, PMN J0948+0022 and PKS 1502+036 from the MOJAVE project; the contour lines start at $3\sigma_{\rm rms}$ and increase logarithmically by a factor of 2

TANAMI multiwavelength campaign of PKS 2004−447

- X-ray observations by *Swift* (from 2011 through 2014) and *XMM-Newton* (in 2004 and two in 2012)
- Radio flux density observations between 1.7 GHz and 45.0 GHz with Australian Telescope Compact Array (ATCA)
- VLBI monitoring with the Long Baseline Array and associated telescopes in the Australia, New-Zealand, Chile, South-Africa and Antarctica (Figure 1)

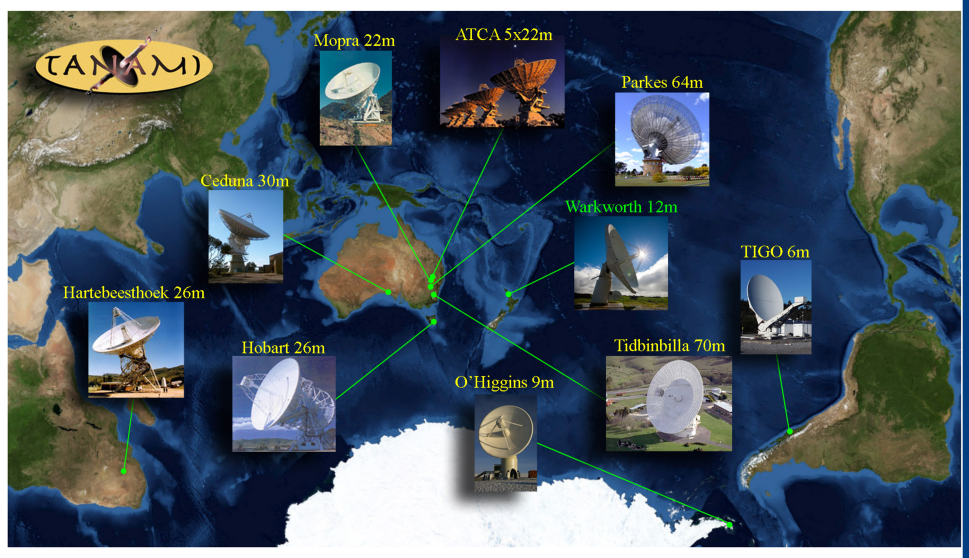

Figure 1: The TANAMI array; Credit: M. Kadler, J. Wilms; *see talk by M. Kadler on Wednesday*

Comparison with γ-ray selected MOJAVE sample

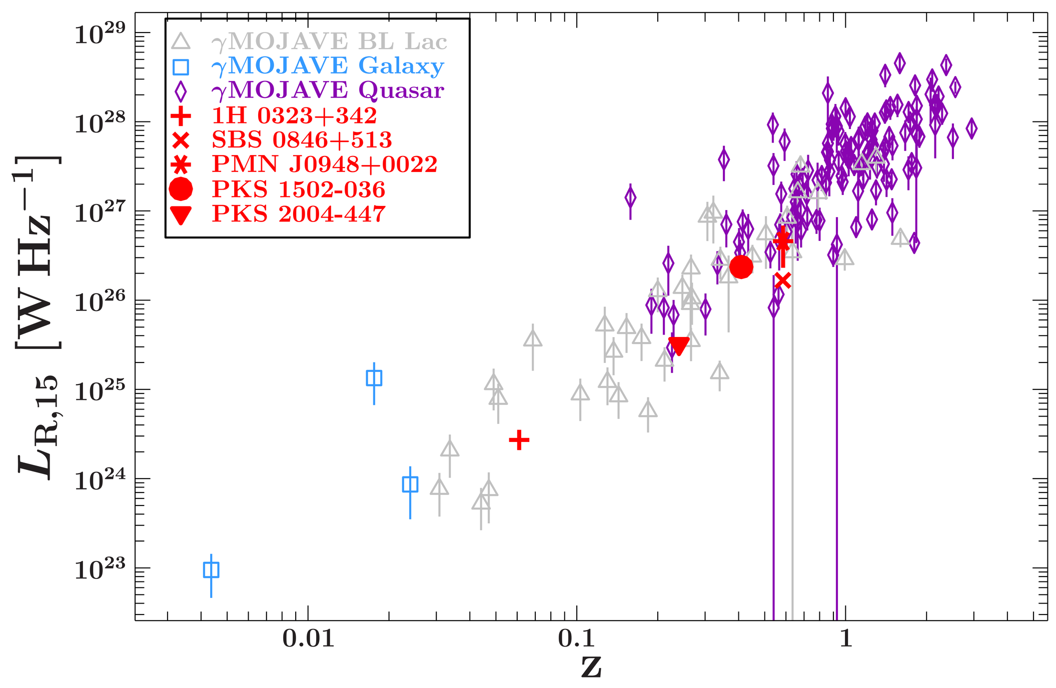

Figure 3: 15 GHz VLBI luminosity $L_{\rm R,15}$ as a function of redshift z for the γ-NLS1 sample in comparison to BL Lacs, Quasars and Galaxies of the γ-ray selected MOJAVE sample (γMOJAVE, Lister et al. 2013, AJ 146, 120)

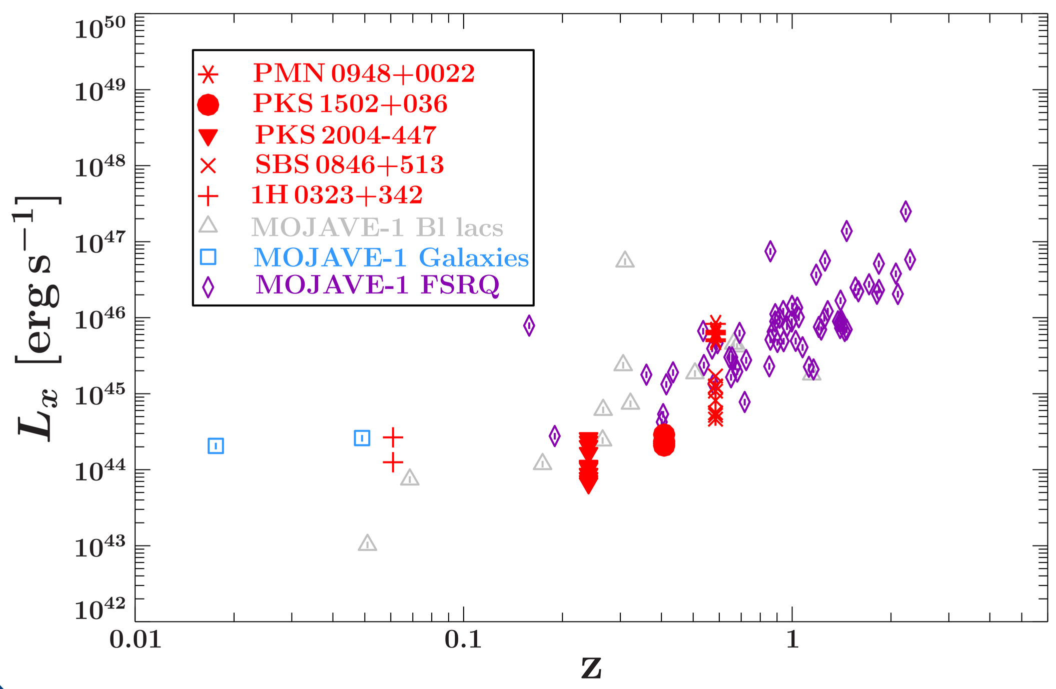

Figure 4: (0.3−10) keV X-ray luminosity L_X as a function of redshift z for the γ-NLS1 sample (black filled symbols) in comparison to X-ray snapshots of the MOJAVE-I sample (open symbols).

Conclusion and Outlook

- The flat, unobscured X-ray spectrum and linearly correlated X-ray flux variations can be explained by a single dominating, non-thermal emission component and is consistent with the interpretation of emission from the jet.
- PKS 2004−447 shows a complex single-sided jet on parsec-scales.
  → Ongoing TANAMI observation will allow us to study time evolution of pc-scale jet.
- Consistent steep radio spectrum of PKS 2004−447 unique among small sample of γ-NLS1.
  → ATCA monitoring will continue as part of the TANAMI project.
- **Intriguing resemblance of γ-NLS1s and BL Lac objects (see Fig. 4).**
- **Further detection of γ-NLS1 are necessary to test small sample properties**, such as
  → significance of different radio spectra (from steep to flat to inverted),
  → consistent ratio of γ-ray to radio luminosity contrary to the ratio of X-ray to radio luminosity.

Contact and Acknowledgement

For more information on the project please contact: akreikenbohm@astro.uni-wuerzburg.de or visit the TANAMI website http://pulsar.sternwarte.uni-erlangen.de/tanami/

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