





Jet physics of blazar-like narrow-line Seyfert 1 galaxies in the *Fermi* era

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Gamma-ray

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Gamma-ray emitting NLSy1



• In this context, the detection in y rays of a narrow-line Seyfert 1 galaxies was a great surprise that confirmed the presence of relativistic jets in this class of AGN!

NLSy1 are thought to be hosted in spiral/disc galaxies, with BH mass of $10^6 - 10^7 M_{\odot}$ and high accretion rate. The presence of a relativistic jet in some of these objects seems to be in contrast to the paradigm that the formation of relativistic jets could happen only in elliptical galaxies (e.g., Boettcher & Dermer 2002, Marscher 2010)









Narrow-line Seyfert 1 in the 3FGL



5 NLSy1 were reported in the Third *Fermi*-LAT Source catalogue (Acero et al. 2015)





New LAT detections with Pass 8 data







Re-classification of FSRQ as NLSy1?

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4C +04.12 is classified as FSRQ in the 3LAC catalogue. Its NLSy1 nature was not investigated due to the lack of a spectrum covering the H β line given its relatively high redshift (z = 0.966).

Analyzing the SDSS-BOSS the total H β line is similarly well fitted with either a Lorentzian+Gaussian profile or a double-Gaussian+Gaussian profile. In the former case, the width of the broad component is FWHM(H β broad)= (1734±104) km s⁻¹, while in the latter case FWHM(H β broad)= (2264±350) km s⁻¹.

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The *Fermi*-LAT view of NLSy1





PKS 1502+036, SBS 0846+513, PMN J0948+0022, and 1H 0323+342 showed different flaring episodes with an apparent isotropic γ -ray luminosity of ~10⁴⁸ erg s⁻¹, comparable to that of the bright FSRQ.



• On pc scale **a core-jet structure** was observed for SBS 0846+513, PKS 2004-447, 1H 0323+342, PKS 1502+036, and PMN J0948+0022

• Apparent superluminal velocity of a jet component was reported for SBS 0846+513, PMN J0948+0022 and 1H 0323+342, but not in PKS 1502+036

• An inferred variability brightness temperature of 2.5×10¹³, 1.1×10¹⁴, and 3.4×10¹¹ K was obtained for PKS 1502+036, SBS 0846+513, and PMN J0948+0022, suggesting that the radio emission is Doppler boosted

• Optical intraday variability has been reported for PMN J0948+0022, SBS 0846+513, and 1H 0323+342

• A relatively hard X-ray spectrum was detected in SBS 0846+513, PMN J0948+0022, 1H 0323+342, PKS 1502+036, and PKS 2004–447, suggesting a significant contribution of inverse Compton radiation from a relativistic jet in X-rays

• The SED of γ-ray NLSy1 showed a double-humped shape typical of blazars

D'Ammando et al. 2016 and the reference therein



SED modelling of NLSy1







Comparison with y-ray blazars





NLSy1 as VHE emitting sources?





Following the most powerful flaring activity from PMN J0948+0022, the detection of VHE emission from this NLSy1 was attempted by VERITAS, resulted in an upper limit of $F_{> 0.2 \text{ Tev}} < 4 \times 10^{-12} \text{ ph cm}^{-2} \text{ s}^{-1}$. Observations of 1H 0323+342 with Whipple during 2001-2003 resulting in an upper limit of 5.2×10⁻¹² ph cm⁻² s⁻¹

Up to now SBS 0846+513 is the only NLSy1 included in the 3FHL catalogue

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A simple power law model was insufficient to describe the data in the 0.3-10 keV energy range, with a clear soft excess and residuals in the Fe line region.

A broken power law yielded an acceptable fit with $\Gamma_1 = 2.21 \pm 0.01$, $\Gamma_2 = 1.71 \pm 0.02$, $E_{break} = 1.90 \pm 0.05$ keV. The fit improves with the addition of a weak Fe Ka line at 6.43 ± 0.06 keV (EW = 34 ± 6 eV) and Fe XXVI at 6.93 ± 0.06 keV (EW = 29 ± 6 eV)



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XMM observations of 1H 0323+342





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1H 0323+342: spiral-arm structure of the host galaxy (Zhou et al. 2007) or asymmetric ring, residual of a galaxy merger (Anton et al. 2008, Leon Tavares et al. 2014)
PKS 2004-447: pseudo-bulge morphology of the host (Kotilainen et al. 2016)



GTC observations of FBQS J1644+2619 in J band. The 2D surface brightness profile is modelled by a nuclear and a bulge component with n = 3.7. Evidence of an E1 elliptical galaxy as host galaxy. The BH mass estimated by the IR bulge luminosity is $(2.1\pm0.2)\times10^8$ M_{\odot}, consistent with the values characterizing radio-loud AGN.



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Host galaxy of PKS 1502+036



VLT-ISAAC observations of PKS 1502+036 in J and K band. The surface brightness profile, extende up to ~20 kpc, is well described by a nuclear and a bulge component with n = 3.5. Evidence of an E1 elliptical galaxy as host galaxy. The BH mass estimated by the IR bulge luminosity is ~7×10⁸ M₀. A circumnuclear structure observed near PKS 1502+036 may be the result of galaxy interactions.

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Black hole mass of NLSy1



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- The discovery of relativistic jets in radio-loud narrow-line Seyfert 1 galaxies was a great surprise. These sources behave as blazar-like objects at the low-end of the blazar BH mass distribution.
- \bullet The BH mass and mechanism for the formation of a relativistic jet in the γ -ray-emitting NLSy1 is under debate.
- If the BH mass of radio-loud NLSy1 is underestimated, this solves the problem of the minimum BH mass predicted in different scenarios of relativistic jet formation, but leaves open the host galaxy issue. Is it possible to have BH mass of $10^8-10^9 M_{\odot}$ in a spiral galaxy?
- At least two of the sources detected in γ -rays (FBQS J1644+2619 and PKS 1502+036) are hosted in an elliptical galaxy with a BH mass larger than 108 M_{\odot}
- The X-ray spectra of the γ -ray emitting NLSy1 are harder than those of the other NLSy1, the relativistic jet being the dominant emission component (at least above 2 keV) with a clear soft X-ray excess below 2 keV.
- The detection of a weak Iron line in the EPIC spectra and emission features in the RGS spectra of 1H 0323+342 confirmed that these γ -ray emitting NLSy1 are observed at relatively small angle of view, but larger than blazars (i.e., 3 < θ < 10 deg)