Gamma-ray emitting narrow-line Seyfert 1 galaxies and their place in the AGN zoo

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Narrow-Line Seyfert 1 galaxies

• Optical classification:
  - $\text{FWHM} (\text{H}\beta) < 2000 \text{ km s}^{-1} \text{ (NL)}$
  - $[\text{O III}] \lambda 5007/\text{H}\beta < 3 \text{ (Sy1)}$

• Other notable properties:
  - strong Fe II bump (Goodrich 1989)
  - relatively low BH masses ($10^6$-$10^8$ solar masses)
  - high accretion rates (up to Eddington limit)

Osterbrock & Pogge 1985
Gamma-ray emitting NLSy1

• Before the launch of the *Fermi* satellite, only blazars and a few radio galaxies were known to be γ-ray emitting AGN

• *Fermi*-LAT first 4 years of operation (1FGL, 2FGL, 3FGL) confirmed that the known extragalactic γ-ray sky is dominated by blazars but...

...the first detection of a γ-ray emitting narrow-line Seyfert 1 galaxy, PMN J0948+0022, during the first months of LAT observations was a great surprise!

Confirmation of the presence of relativistic jets also in NLSy1

NLSy1 are thought to be hosted in spiral/disc galaxies, 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)

See Foschini et al. 2012, 2014

D’Ammando, Orienti, Finke et al. 2012

See Orienti, D’Ammando, Larsson et al. 2015

Abdo et al. 2009

1H 0323+342
SBS 0846+513
PMN J0948+0022
PKS 1502+036
PKS 2004-447
Both the LAT detection of FBQS J1644+2619 in 2008 November-2009 January and in 2012 July-October correspond to periods of high optical activity, as observed in V-band by the Catalina Real-Time Transient survey.


See also Yao et al. (2015) about 4C +04.42, re-classified as a NLSy1 thanks to SDSS-BOSS.
The Fermi-LAT view of NLSy1

Adapted from Ackermann et al. (2015)
NLSy1 are flaring γ-ray sources!

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 $\sim 10^{48}$ erg s$^{-1}$, comparable to that of the bright FSRQ.


Core-jet structures in γ-ray NLSy1

Core-jet structure on parsec scale resolved with the VLBA

PMN J0948+0022

PMN J0948+0022  26/05/2011

Peak = 656.6; f.c. = 0.2 (mJy/beam)

2.4 mJy/beam

D’Ammando et al. 2014

SBS 0846+513

VLBA  15.3 GHz

peak = 172.4; f.c. = 0.2 (mJy/beam)

D’Ammando et al. 2012

PKS 1502+036

PKS 1502+036  11/JAN/2002

Peak = 535.1; f.c. = 0.6 (mJy/beam)

D’Ammando et al. 2013a
Proper motion of γ-ray NLSy1

With 6-epoch MOJAVE data for SBS 0846+513 we obtained an apparent velocity of the jet knot \((9.3 \pm 0.6)c\), suggesting the presence of boosting effect as well as in blazars. The time of ejection is \(T_0 = 24\) August 2009, likely connected with a radio flare. No significant γ-ray activity was detected in that period.


Superluminal motion was detected also in 1H 0323+342 and PMN J0948+0022 (Lister et al. 2016).

No superluminal motion was detected for the jet components of PKS 1502+036. A sub-luminal component was reported in Lister et al. (2016).

XMM observation of PMN J0948+0022

Γ = 1.88 ± 0.01 in the 0.3-10 keV energy range, $\chi^2_{\text{red}} = 1.87$ (1254)

A simple power law in 2-10 keV provides a good fit $\Gamma = 1.48\pm0.03$

A clear soft excess was observed, notwithstanding the non-thermal jet emission!

A broken power-law provides an acceptable fit, $\chi^2_{\text{red}} = 1.10$ (1252), with a break at energy $E_{\text{break}} = 1.72\pm0.10$ keV and photon indices $\Gamma_1 = 2.14\pm0.03$ and $\Gamma_2 = 1.48\pm0.04$. The emission above 2 keV is dominated by the jet component, with no detection of an Iron line in the spectrum and a 90% upper limit on the EW of 19 eV.

The soft component can be also fitted with a black body model with $kT \sim 0.18$ keV. Such a high temperature is inconsistent with the standard accretion disk theory.
Complex correlated variability

D'Ammando et al. 2013b

D'Ammando et al. 2016
Comparison with γ-ray blazars

SBS 0846+513 and PMN J0948+0022 showed a Compton dominance typical of FSRQs during both the low and high activity state.

Figures adapted from Finke 2013

In the “classical” blazar sequence plot SBS 0846+513 seems to lie in the FSRQ region.

D’Ammando et al. 2015

D’Ammando et al. 2013b
SED modelling of NLSy1

The quiescent and flaring state, modelled by EC (dust), could be fitted by changing the electron distribution parameters as well as the magnetic field.

D’Ammando et al. 2013b

The 2013 flaring state may be modelled by EC (dust) or EC (BLR). In the latter, the source is far from the equipartition favouring the EC (dust) model.

D’Ammando et al. 2015
AGN: what’s in a name – 2016 June 29


Following the most powerful flaring activity from PMN J0948+0022, the detection of VHE emission from this NLSy1 was attempted by VERITAS. Future observations with the Cherenkov Telescope Array (CTA) will constrain the level of γ-ray emission at 100 GeV or below.
Host galaxy of $\gamma$-ray NLSy1

Zhou et al. 2007: likely spiral morphology.

Leon-Tavares et al. 2015, Anton et al. 2008: residual of a merging galaxy.

These observations, together with the lack of information about the host galaxy of the other $\gamma$-ray emitting NLSy1, leave room for the hypothesis that the NLSy1 detected in $\gamma$-rays could have peculiar host galaxy respect to the other NLSy1 (e.g. non-spiral morphology, undergoing strong merger activity).
The BH mass of NLSy1 may be underestimated due either to the effect of radiation pressure (Marconi et al. 2008) or to projection effects (Baldi et al. 2016).

The BH mass of PKS 1502+036 is constrained to be $<10^8$ solar masses from the modelling of the optical/UV part of the spectrum.
Summary and Open Questions

• γ-ray emission from a few radio-loud NLSy1 was detected by Fermi-LAT, suggesting as NLSy1 are a new class of AGN with relativistic jet. Are these objects peculiar among the NLSy1?

• Radio-to-γ-ray properties, broad-band spectral energy distribution, and high-energy emission mechanisms of the NLSy1 detected in γ rays are similar to those of blazars, in particular to FSRQ.

• The discovery of relativistic jets in a class of AGN thought to be hosted by spiral galaxies was a great surprise but...BH masses of radio-loud NLSy1 are on average larger than those of the entire sample of NLSy1. This could be related to prolonged accretion episodes that can spin-up the BH leading to the relativistic jet formation. Only for a small fraction of NLSy1 the high accretion lasts sufficiently long to significantly spin-up the BH.

• These γ-ray NLSy1 may be relatively low mass version of the blazars, in which the relativistic jet formation was triggered by a major merger or the BH mass of these objects are 10^8-10^9 solar masses? In the latter case, how is it possible to have such a large BH mass in a spiral galaxy? Are γ-ray NLSy1 not in classical spiral galaxies?