Spectroscopy of extragalactic gamma-ray emitters: New identification, classification and Redshift

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Half a Century of Blazars and beyond – Torino – 12/06/2018
BLAZARs

Class of jetted AGNs with jet pointing towards the observer

- The most powerful emitters from radio up to TeV;
- Highly polarized;
- Strong variability at all wavelength.

Typical MWL double-bump SED shape

Adapted from Aleksic+2016
BLAZARs

≈ 3500 blazars in the 5th edition of BZCAT (Massaro+2015)

- sources detected at the radio frequencies
- 70% detected in the X-ray band

A significant difference is based on the optical spectrum

Two broad classes:

- **FSRQs**
  - broad emission lines
  - and thermal blue bump

- **BLLac objects**
  - weak emission lines or absent

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**FSRQs**

[Graph showing FSRQs spectrum with emission lines labeled Hβ, Hα, [OIII].]

**BLLac objects**

[Graph showing BLLac objects spectrum with weak or absent lines labeled PG 1553+113.]
Blazars represent the most abundant Extragalactic population at GeV-TeV energies

Several catalogs given by Fermi:

- $3FGL > 3FHL > 2FHL > 1FHL > 2FGL > 1FGL > 0FGL$
- $4LAC, 3LAC, 2LAC, 1LAC, 2PC, 1PC, GRBCat...$

$3FGL$ (FL8Y) catalog reports 3033 (5524) $\gamma$-ray emitters:

- $40\%$ (50\%) are blazars (the most numerous class)
- $\sim 500$ ($\sim 660$) FSRQs
- $\sim 650$ ($\sim 1050$) BLLs
- $\sim 600$ ($\sim 1235$) blazars of uncertain type (BCU)
- $30\%$ (40\%) Unassociated Fermi Objects (most of them probably blazars)

See Gasparrini’s talk of this morning!
THE TeV BAND & TeV BLAZARS

A sub-sample of the GeV blazars (mainly BL Lacs) are also emitters at the TeV (1TeV : 25GeV)

The most energetic objects of the Universe at all \( \lambda \)

To model their MWL SED to study their emission region

TeVcat: \( \rightarrow 59 +2(?) \) BLLs
\( \rightarrow 7 \) FSRQs
\( \rightarrow 4 \) blazars

Useful tool to probe the EBL

A sub-sample of the GeV blazars (mainly BL Lacs) are also emitters at the TeV (1TeV : 25GeV)

Aleksic+2016

Ahnen+2016 - MAGIC Collaboration

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Redshift
THE TeV BAND & TeV BLAZARS

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TeVcat: -> 59 +2(?) BLLs
        -> 7 FSRQs
        -> 4 blazars
ON THE REDSHIFT OF BL Lacs

The (quasi) featureless optical spectra is the main characteristic of the BL Lac class.

The determination of their redshift is extremely difficult.

≈ 50% of GeV BLLs has unknown or highly uncertain redshift.

Paiano+2016
GTC SPECTROSCOPY CAMPAIGN

It needs to have optical spectra of high S/N and spectral resolution

We are carrying out an extensive spectroscopy campaign using OSIRIS @GTC (10m) of various sub-samples of γ-ray blazars:

- more than 150 targets observed
- Spectral Range: 4000-10000 Å
- grisms: R500B, R1000 and R2500
- Spectral resolution = 600-1200
- S/N = 50 – 500
  (depending on the source mag)
GTC SPECTROSCOPY CAMPAIGN

LIST OF SUB-SAMPLES:

→ 22 TeV and TeV candidate BLLs with unknown/uncertain redshift
  → Paiano et al. (2016), Paiano et al. (2017a)
  Landoni et al. (2016), Falomo et al. (2017)

→ 10 high-z GeV BLLs
  → Paiano et al. (2017b)

→ 55 Unassociated Fermi Objects
  → Paiano et al. (2017c),
  Paiano et al. (2018b in prep)

→ 16 Optically selected high redshift BLL candidates
  → Landoni et al. (2018)

→ 20 3FHL blazars with unknown redshift
  → Paiano et al. (2018d, in prep)

→ 15 high redshift BLL candidates
  → Paiano et al. (2018e, in prep)

→ 10 neutrino BLL candidates
  → Paiano et al. (2018a),
  Paiano et al. (2018c, in prep)
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All published spectra are available at the website http://www.oapd.inaf.it/zbllac/

See Paiano’s poster about TXS0506+056

See Falomo’s poster For ZBLLAC database
Based on the properties of the optical spectra, the objects can be grouped into 4 types:

- Emission lines characteristic of low-density gas
- Absorption lines of stars from the host galaxy
- Intervening absorption lines from cold gas
- Featureless spectrum
RESULTS (Some examples...)

Emission lines characteristic of low-density gas

PKS 1424+240: TeV HBL source

**PKS, 1424+24**

![Graph showing emission lines in the spectrum of PKS 1424+240](image)
RESULTS

Emission lines characteristic of low-density gas

PKS 1424+24: TeV HBL source

\[[\text{OII}](3727) \rightarrow EW = 0.05\lambda\]
\[[\text{OIII}](5007) \rightarrow EW = 0.10\lambda\]

\(z = 0.604\)

Paiano+2017a
RESULTS

Absorption lines of stars from the host galaxy

3FGLJ0814+2943
High-z BLL of 3FGL
(literature $z = 1.08$)
RESULTS

Absorption lines of stars from the host galaxy

3FGL J0814+2943
High-z BLL of 3FGL

(literature $z = 1.08$)

CaII(3934) -> EW = 0.6A
CaII(3968) -> EW = 0.5A

$z = 0.703$

Paiano+2017b
RESULTS

Intervening absorption lines from cold gas $\rightarrow$ Redshift Lower Limits

3FGLJ0008+4713
High-z BLL of 3FGL
MgII (2008) $\rightarrow z > 1.659$

3FGLJ1450+5200
High-z BLL of 3FGL
CIV (1548) - Ly-$\alpha$(1216)
CIV (1548)

$z > 2.470 \leftarrow$
$z > 2.312 \leftarrow$

Two of the farthest BLLs known!!!
RESULTS

Featureless spectrum

RGB J0136+391
TeV HBL
S/N = 500
r = 15.80

Paiano+2017a
RESULTS

Featureless spectrum

Despite the very high S/N, no absorption/emission lines are detected

Redshift measurement likely possible only with future facilities as ELT

RGB J0136+391
TeV HBL
S/N = 500
r = 15.80

Paiano+2017a
RESULTS: Lower limit of the redshift

Featureless spectrum

Non-thermal Nucleus + Elliptical host galaxy \( [M(R) = -22.9] \) = Observed spectrum

RGB J0136+391 TeV HBL S/N = 500

Distribution of the host galaxy absolute magnitude \( M(R) \) of BLLs from HST obs.
RESULTS: Lower limit of the redshift

Featureless spectrum

Non-thermal Nucleus +
Elliptical host galaxy [M(R) = -22.9] =
Observed spectrum

RGB J0136+391
TeV HBL
S/N = 500

Mag=17, z=0.10, Diluited EW=1.6A
RESULTS: Lower limit of the redshift

Featureless spectrum

Non-thermal Nucleus + Elliptical host galaxy \([M(R) = -22.9]\) = Observed spectrum

RGB J0136+391
TeV HBL
S/N = 500

Mag=17, z=0.25, Diluited EW=0.5Å
RESULTS: Lower limit of the redshift

Featureless spectrum

Non-thermal Nucleus +
Elliptical host galaxy $[M(R) = -22.9]$ =
Observed spectrum

RGB J0136+391
TeV HBL
S/N = 500

Mag=17, $z=0.50$, Diluited EW=0.15Å
RESULTS: Lower limit of the redshift

Featureless spectrum

Non-thermal Nucleus + Elliptical host galaxy [$M(R) = -22.9$] = Observed spectrum

We can derive UL EW ...

\[ EW_{\text{obs}} = \frac{(1 + z)EW_0}{1 + \rho A(z)} \]

Paiano+2017a

RGB J0136+391
TeV HBL
S/N = 500
minEW = 0.08

\[ Z_{\text{lim}} > 0.27 \]

... and a lower limit on the redshift
For several cases, we disprove the previous published redshift. One of the first BLLs studied is 3C66A with $z = 0.444$ (Miller+78, Lanzetta+1993). The redshift of S2 0109+22 is $z = 0.26$, but this is the redshift of a close galaxy! The redshift of 3C66A is still unknown! The redshift of S2 0109+22 is still unknown!
SPECTROSCOPY OF UNASSOCIATED $\gamma$-RAY SOURCES (UGSs).

On-going spectroscopic campaign of a sample of 50 optical counterparts of UGSs selected using Swift X-ray data covering the 3FGL sky position, to find possible MWL counterparts.
SPECTROSCOPY OF UNASSOCIATED $\gamma$-RAY SOURCES (UGSs).

Examples of GTC spectra of optical counterparts of UGSs

We establish the blazar nature for >90% of our targets and find their redshift for most of them.

Paiano+2017c
CONCLUSIONS

The knowledge of the redshift of BL Lacs plays a fundamental role of the puzzle

→ High S/N GTC spectra of γ-BLLs allowed to obtain new redshift or set stringent sound lower limits
All published spectra available at
http://www.oapd.inaf.it/zbllac/

→ 25% of BLLs in the sample are at \( z > 0.5 \)
10% at \( z > 1 \)

→ We established the blazar nature of many optical counterparts of UGSs, and we found the redshift

* Search for high redshift and neutrino BLL candidates as good targets for future CTA observations

* The measure of the redshift of BLL with still featureless spectra (very high nucleus-to-host ratio) will be likely possible only in the ELT era.
THANK YOU
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