Gamma-ray emission from young radio galaxies and quasars

G. Principe[1,2,3],
L. Di Venere[4], M. Orienti[3], G. Migliori[3], F. D'Ammando[3], M. N. Mazziotta[4], and M. Giroletti[3]
[1]University of Trieste, Trieste, Italy; [2]INFN-Trieste, Trieste, Italy; [3]IRA-INAF, Bologna, Italy; [4]INFN-Bari, Bari, Italy
on behalf of the *Fermi* Large Area Telescope Collaboration

Abstract

According to radiative models, radio galaxies are predicted to produce γ-rays from the earliest stages of their evolution onwards. The study of the high-energy emission from young radio sources is crucial for providing information on the most energetic processes associated with these sources, the actual region responsible for this emission, as well as the structure of the newly born radio jets. Despite systematic searches for young radio sources at γ-ray energies, only a handful of detections have been reported so far. Taking advantage of more than 11 years of Fermi-LAT data, we investigate the γ-ray emission of 162 young radio sources (103 galaxies and 59 quasars), the largest sample of young radio sources used so far for a γ-ray study. We analyse the Fermi-LAT data of each individual source separately to search for a significant detection. In addition, we perform the first stacking analysis of this class of sources in order to investigate the γ-ray emission of the young radio sources that are undetected at high energies. We report the detection of significant γ-ray emission from 11 young radio sources, including the discovery of γ-rays from the compact radio galaxy PKS 1007+142. Although the stacking analysis of below-threshold young radio sources does not result in a significant detection, it provides stringent upper limits to constrain the γ-ray emission from these objects. We present here the results of our study and we discuss their implications for the predictions of γ-ray emission from this class of sources.

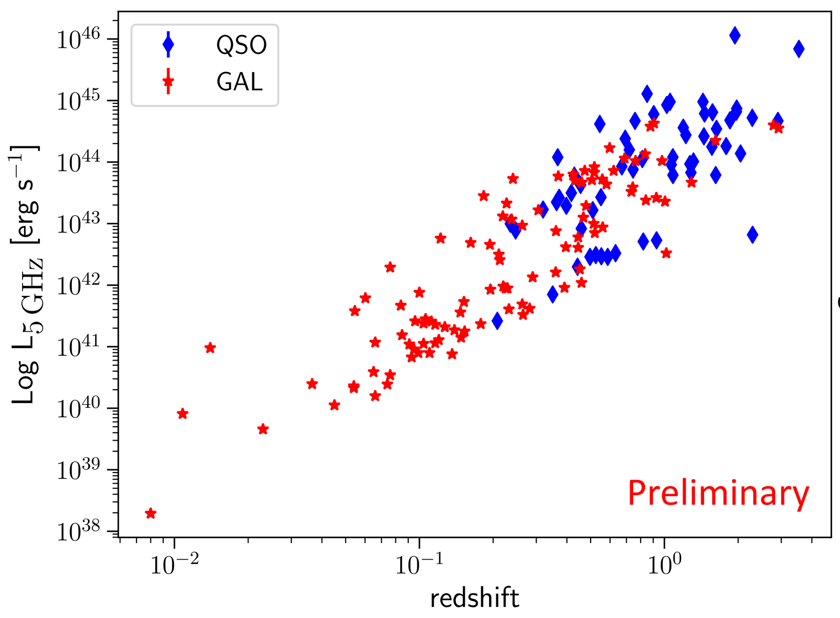
Selected sample

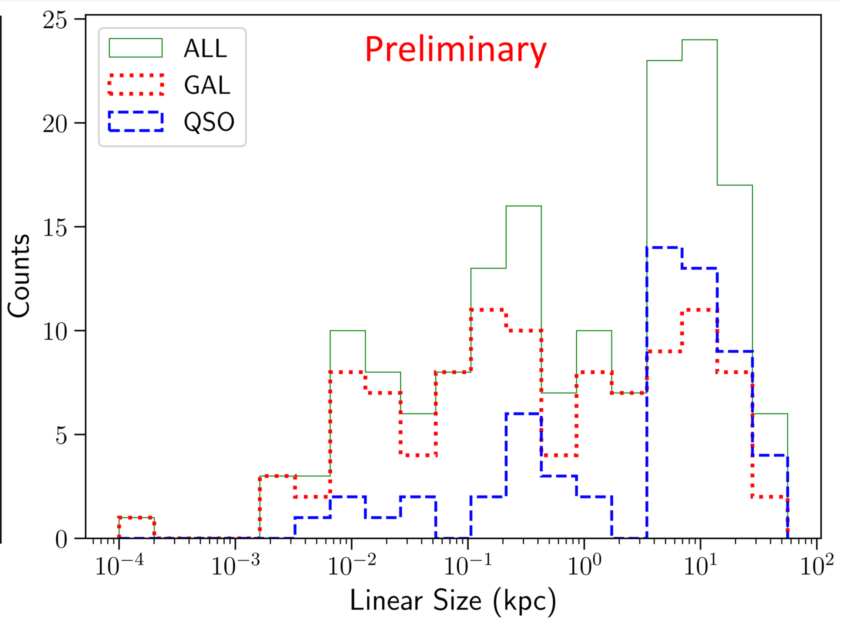
Young radio galaxies are expected to emit γ-rays due to inverse Compton of the UV photons from the disk upscattered by the lobes' electrons [1].

Systematic searches for young radio sources at γ-ray energies have so far been unsuccessful [2], while dedicated studies have reported a handful of detections: the young radio galaxies NGC 6328 [3], NGC 3894 [4] and TXS 0128+554 [5]. The 4FGL-DR2 [6] also contains 7 CSS-quasars: 3C 138, 3C 216, 3C 286, 3C 309.1, 3C 380, PKS B1413+135 and PKS 0056-00.

For this work we used <u>162 young radio sources</u>: **103 galaxies (GAL)** and **59 quasars (QSO)**, selected from [3, 4, 5, 7, 8, 9, 10]. Final sample:
<u>Linear size (LS)</u>: 79 CSO (LS < 1 kpc), 46 MSO (LS: 1-10 kpc), 37 with 10< LS <50 kpc.
<u>Radio turnover frequency</u> (f_p): 52 GPS (f_p > 0.5 GHz), 110 CSS (f_p < 0.5 GHz).

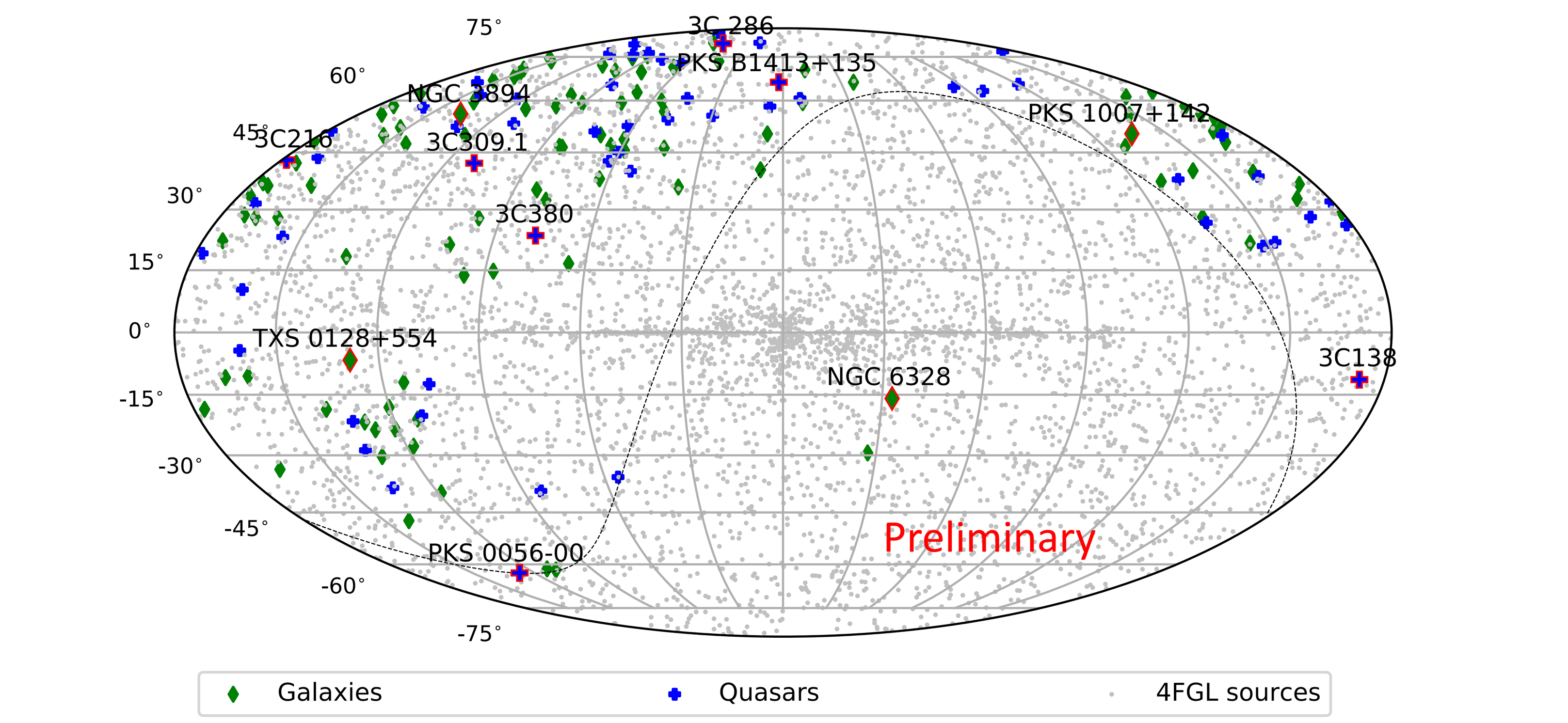
CSO: Compact Simmetric Obejects; *MSO*: Medium Size Object; *GPS*: Giga-Hertz Peaked Sources ; *CSS*:Compact Steep Spectrum





Analysis of each individual source

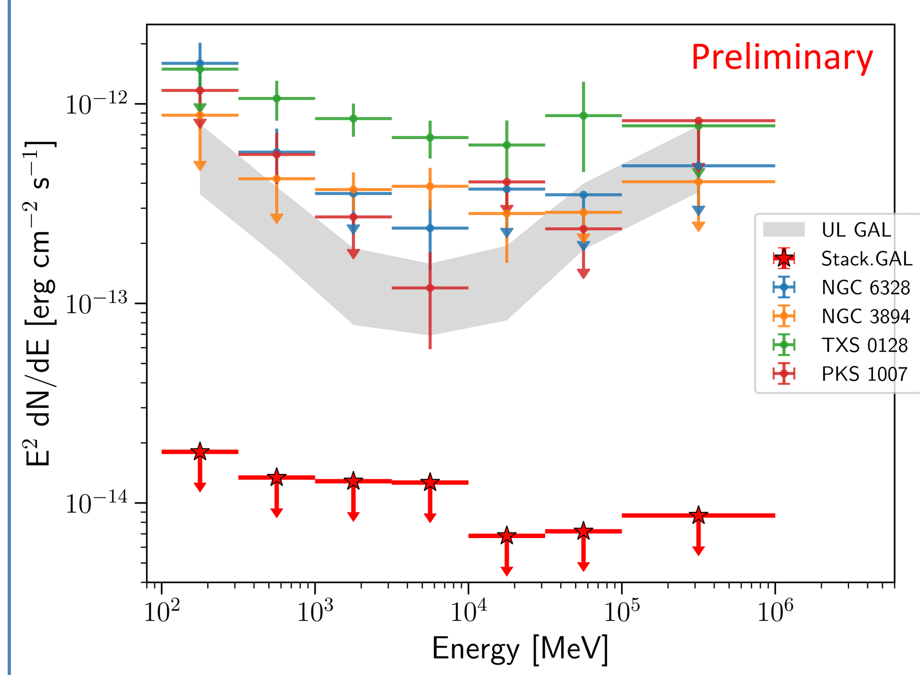
We performed <u>a likelihood analysis on each individual source</u> using 11.3 years of P8R3_v2 Fermi-LAT data between 100 MeV - 1 TeV
In our analysis we **detected 11 sources (4 galaxies, 7 quasars; labelled in the plot)**:
★ we report the <u>discovery of γ -ray emission from a compact radio galaxy: PKS 1007+142</u>
+ <u>5 quasars present significant γ-ray variability</u>.

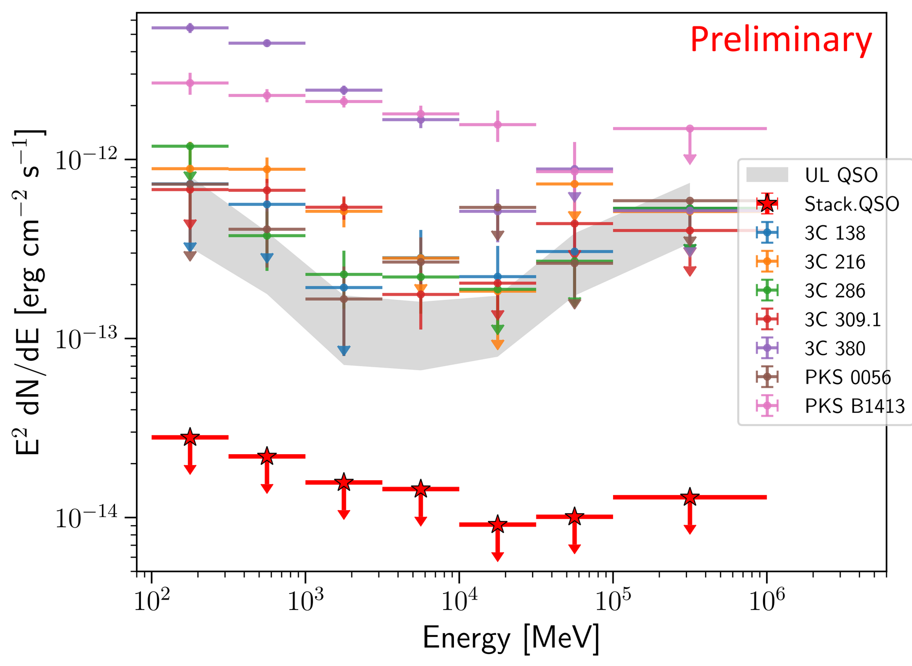


Name	type	z	LS kpc	ν_p GHz	log $L_{5\,GHz}$ W Hz^{-1}	TS	F_γ 10^{-9} cm^{-2} s^{-1}	Γ	L_γ 10^{44} erg s^{-1}	TS_{var}
Galaxies										
NGC 6328	CSO/GPS	0.014	0.002	4	24.28	36	5.30±1.45	2.60±0.14	0.011	5
NGC 3894	CSO/GPS	0.0108	0.010	5	24.60	95	2.03±0.48	2.05±0.09	0.006	11
TXS 0128+554	CSO/GPS	0.0365	0.012	0.66	23.69	178	8.03±1.46	2.20±0.07	0.19	9
PKS 1007+142★	MSO/GPS	0.213	3.3	0.5-2	25.71	31	4.65±1.55	2.55±0.18	2.8	4
Quasars										
3C 138†	MSO/CSS	0.759	5.9	0.176	27.97	34	2.09±0.89	2.05±0.12	64	68 +
3C 216†	LSO/CSS	0.6702	56	0.066	27.23	153	7.78±0.98	2.60±0.09	97	24 +
3C 286	LSO/CSS	0.85	25	<0.05	28.41	67	5.60±1.10	2.52±0.12	110	8
3C 309.1†	MSO/CSS	0.905	17	<0.076	28.08	207	6.33±0.74	2.47±0.07	180	215+
3C 380†	MSO/CSS	0.692	11	<0.05	27.68	2274	36.44±1.48	2.41±0.03	510	68 +
PKS 0056-00	MSO/CSS	0.719	15	<0.14	27.50	52	5.21±1.48	2.30±0.15	74	11
PKS B1413+135†	CSO/GPS	0.247	0.03	8.4-15	26.19	1198	14.72±1.02	2.10±0.03	28	321+

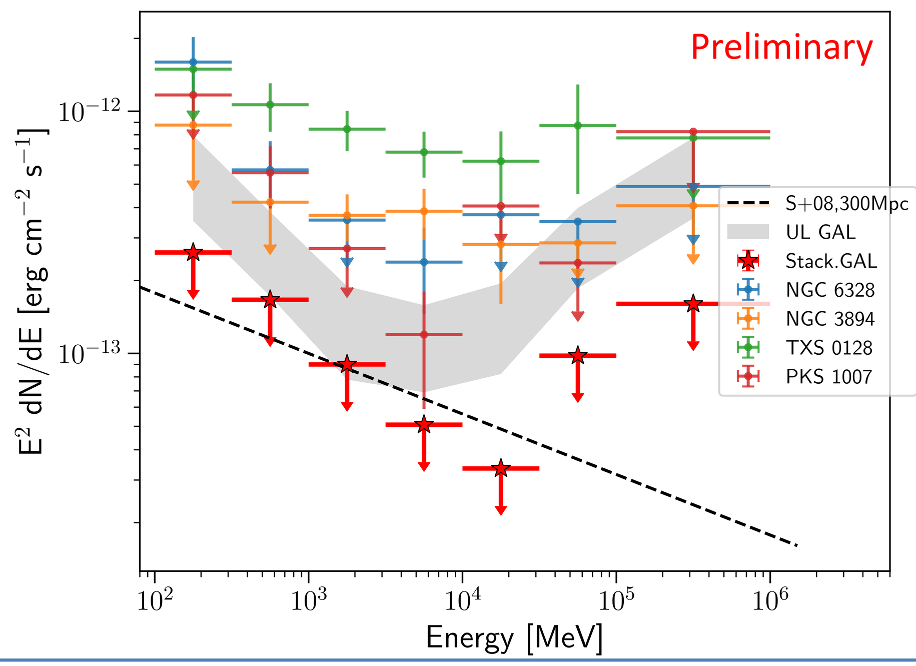
Stacking analysis

We perform the first <u>stacking analysis on the undetected (TS<25) young radio sources</u> (galaxies and quasars). **No significant emission has been detected for all the undetected sources.** We performed the stacking analysis for seven separate energy bands and we compared them with the averaged upper-limits of the undetected radio sources (grey band).





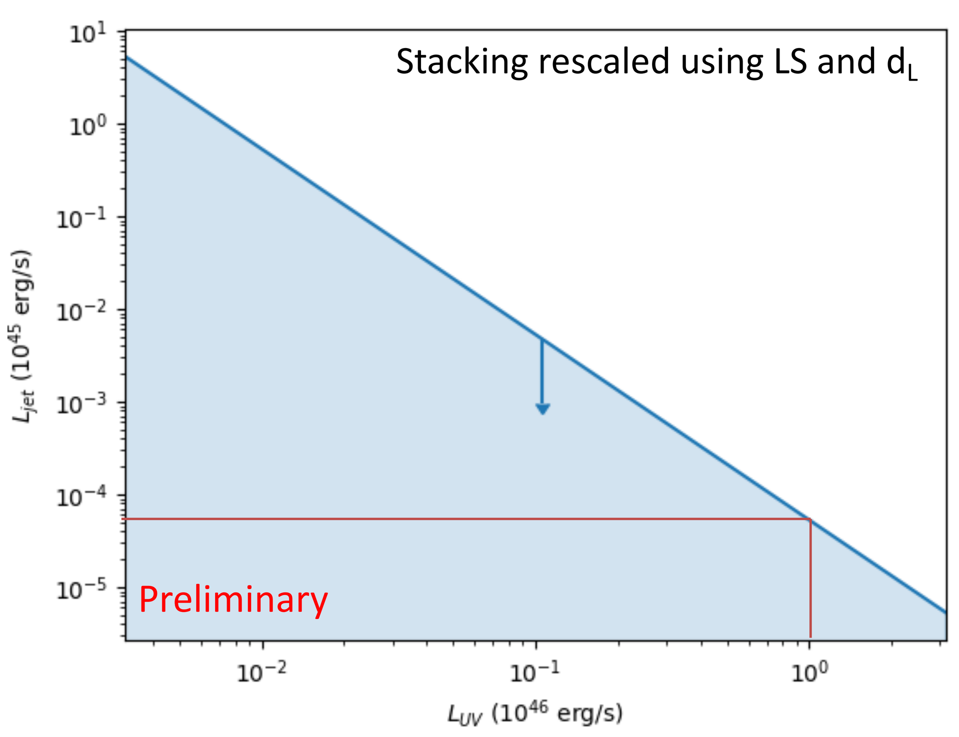
We performed the stacking analysis using different sub-samples of nearby and compact sources, indicated as most promising γ-ray candidates [1]. We found no detection.
This allows us to say that the <u>assumed model parameters are too extreme in terms of e.g. jet power and/or UV luminosity for the sources in our local Universe (d_L<300 Mpc, z<0.07).</u>



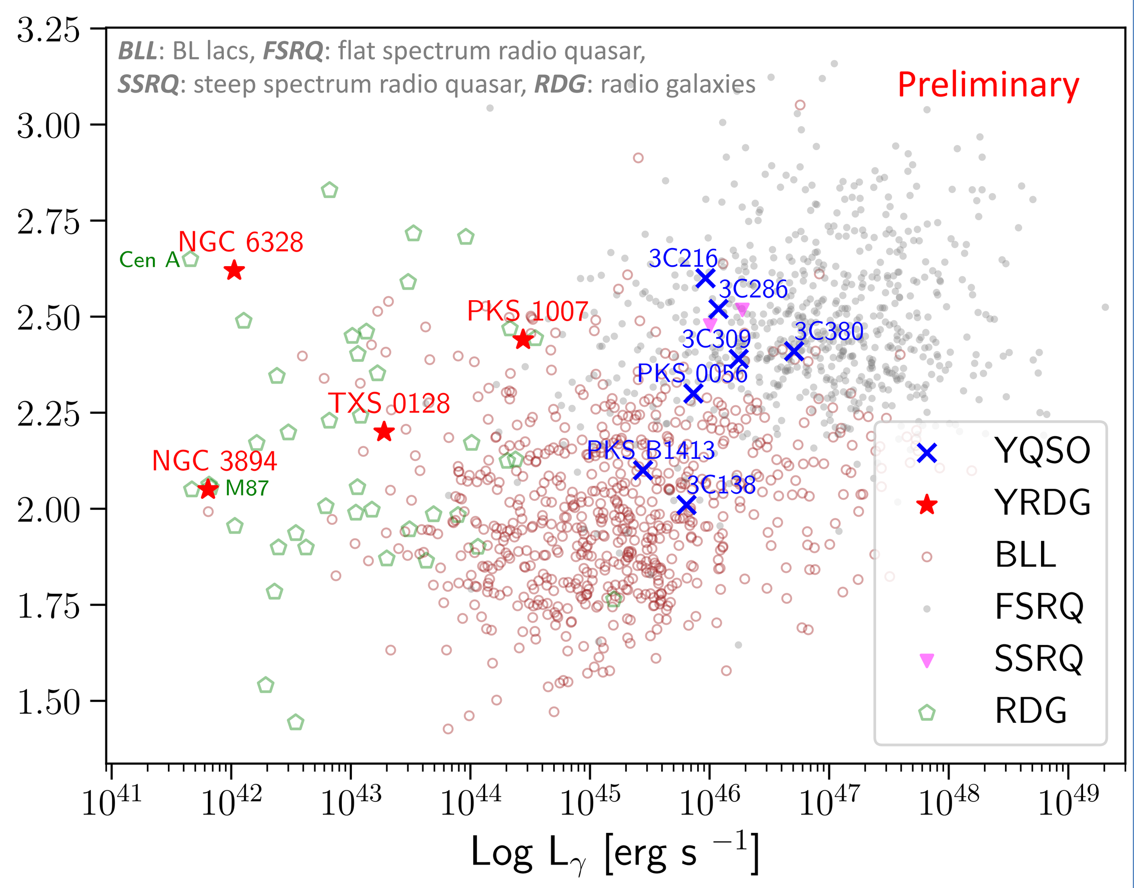
Investigating the origin of the γ-ray emission in young radio sources

We repeated the stacking procedure by converting the <u>γ-ray</u> flux UL into *<u>constraints on the UV and jet luminosity</u>* [1], using the information on LS and d_L of each individual source.

$$\frac{\epsilon L_\epsilon}{10^{42}\mathrm{erg/s}} \sim 2\frac{\eta_e}{\eta_B}\left(\frac{L_{\rm jet}}{10^{45}\mathrm{erg/s}}\right)^{0.5}\left(\frac{LS}{100\mathrm{pc}}\right)^{-1}\frac{L_{UV}}{10^{46}\mathrm{erg/s}}\left(\frac{\epsilon}{1\mathrm{Gev}}\right)^{-0.25}$$



- **Young radio galaxies (YRDG or GAL)** appear to share <u>same γ-ray properties as other misaligned AGN</u> in 4LAC
- **Young radio quasars (YQSO)** present a high γ-ray luminosity, similar to FSRQ, suggesting that <u>relativistic boosting is likely to play a role</u> in their GeV detection.
- γ-rays in **YQSO** and **YRDG** may have a different origin: **jet** vs **radio lobes**.
- **PKS 1007+142** lies between the YQSOs and other YRDGs. While the other YRDGs are very nearby (z~0.1) and compact (LS~10 pc), it presents a more evolved structure (~kpc) and it is located much further away (z~0.2).



Conclusions

We performed the largest and deepest systematic search for γ-ray emission from young radio galaxies and quasars using a sample of 162 sources and 11.3 yr Fermi-LAT data:
- we detected 11 young radio sources (4 galaxies, 7 quasars), and report the first LAT detection of the galaxy PKS 1007+128 (z=0.213; LS=3 kpc).

We performed for the first time a stacking analysis on a sample of (undetected) young radio sources:
- no significant emission found: resulting ULs are 10 times smaller than those on single sources.

Our results suggest that only the closest sources may be detected by Fermi-LAT, while considering objects at higher and higher redshift, boosting effects are necessary for their detection.

References

[1] Stawarz et al (2008), ApJ, 680, 911
[2] D'Ammando et al. 2016, MNRAS, 450, 3975
[3] MIgliori et al. (2016), ApJ, 821,L31
[4] Principe et al. (2020), A&A, 635, A185
[5] Lister et al. (2020), ApJ, 899,141
[6] Abdollahi et al. (2020), 2020, ApJS, 247, 33
[7] Orienti & Dallacasa (2014), MNRAS, 438, 463
[8] Snellen et al. (2004), MNRAS, 348, 227
[9] Liao & Gu (2020), MNRAS, 491, 92
[10] Wójtowicz et al. (2020), ApJ, 892, 116