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Duty–cycle and γ-ray activity of *EGRET* blazars

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Abstract. Active Galactic Nuclei (AGNs) show high variability in the γ-ray energy band above 30 MeV on time-scales, in some cases, as short as one day. Up to now, the sparse coverage provided by the *EGRET* instrument has made it difficult to firmly establish both *if* and especially *how often* the transient activity occurs. We report our results on the estimate of the duty–cycle of γ-ray blazars by means of a re-analysis of the *EGRET* data and their comparison with numerical simulations. We attribute a γ-ray activity index, ψ, to all *EGRET* blazars, and show that FSRQs dominate the sample with non-zero ψ. We also characterise the blazar activity, including the discovery of a region of consistency between the γ-ray flaring duty–cycle and the recurrence time between flares.

Key words. galaxies: active - galaxies: nuclei - quasar: general - BL Lacertae objects: general - gamma-rays: theory

1. Gamma-ray activity of *EGRET* AGNs

Among Active Galactic Nuclei (AGN), *blazars* show strong flux variability at almost all frequencies of the spectral energy distribution (SED). The *EGRET* instrument on-board of CGRO detected, above 30 MeV, blazars as a *class* of γ-ray sources (Hartman et al. 1999), identifying 67 objects, and detecting 27 candidates. Gamma-ray blazars are characterised by high variability on different time–scales, from one day (e.g. PKS 1622-297, Zhang et al. 2002) to one month (e.g. PKS 0208-512, von Montigny et al. 1995). This large spread in time variability and the sparse coverage obtained by *EGRET* make it difficult to quantify parameters such as the *duty–cycle* (i.e. the fraction of time spent in a flaring state) and/or the characteristic time–scale of γ-ray activity for this class of sources.

In order to investigate the blazar γ-ray duty–cycle, we analysed the Third *EGRET* Catalogue AGN sample, looking for recurrent activity (Vercellone et al. 2004). For each source we computed the exposure (EXP) accumulated during the *EGRET* lifetime and the number of times that each source was in a *high-state* (HSN), i.e. when 1) the flux of the i-th viewing period (VP) is in excess of 1.5 times the weighted mean of all the detections and upper limits, and 2) the 1-σ uncertainty of the measurement at the high state is less than the

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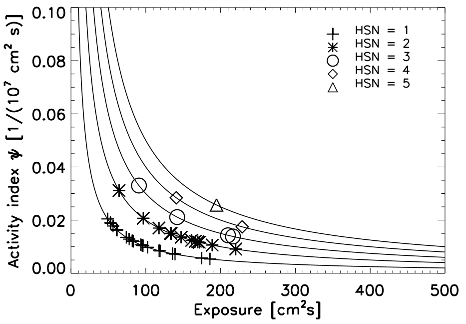

Fig. 1. Activity diagram for sources belonging to Population B. Different symbols represent sources having different number of high states.

deviation of the measurement from the mean. Given EXP and HSN, we computed an *activity index* (ψ) of each AGN as follows:

$$\psi_{\rm src} = HSN_{\rm src} \times [EXP_{\rm src}]^{-1} \ \ [{\rm cm}^{-2}{\rm s}^{-1}]\,. \qquad (1)$$

This index provides an estimate of blazar γ-ray activity, weighted by the exposure. Sources with high ψ have a γ-ray activity which is highly variable. Sources with $\psi = 0$ are sources that do not show significant flux variability. Thus, we classified sources with $\psi = 0$ as Population A and sources with $\psi \neq 0$ as Population B.

Figure 1 shows the activity diagram for sources belonging to Pop. B. Each curve represents the function $\psi(n) = n/EXP$, where n is the number of high states, and EXP is the exposure. Different symbols represent sources having different numbers of high states. Only 7 sources show a HSN greater than 2, while most of the sources have one or two high-states (the first two curves from the bottom), at the same level of exposure as those seven. This fact can be understood if we keep in mind that most *EGRET* blazars were detected only during flaring activity. If the flaring activity level does not change dramatically from one episode to another, the chance of having a high HSN is significantly reduced. Only a small subset of AGNs will then show a high HSN. Thus, we examine the possible reasons for the observed population dichotomy, taking into account instrumental biases, source luminosity and morphology. We have examined the literature and compiled (Soldi 2003) the *Multiwavelength Blazar Catalogue* (MBC)[1]. Our catalogue lists all the *EGRET* AGNs for which we have obtained radio (5 GHz), optical (5500 Å), X-ray (0.1–10 keV), COMPTEL (0.1–30 MeV), and TeV data, along with the most recent determination of the BH masses. We find a remarkable difference between the two populations when we compare the ratio between flat-spectrum radio quasars (FSRQs) and BL-Lac objects (BLs). Pop. A is almost equally divided between FSRQs and BLs (~60 and ~40 per cent, respectively), while Pop. B is dominated by FSRQs (~ 80 per cent). FSRQs are generally more variable and more luminous in the γ-ray energy band than BLs, which could explain the higher fraction of these sources in Pop. B.

Table 1 summarises the correlation between the activity index ψ and some physical properties of *EGRET* blazars. A possible correlation is found between the activity level and the black hole mass ($M_{\rm BH}$), with a probability $P_{\rm rand}$ of a randomly distributed sample of objects on the order of $\sim 10^{-2}$. The use of the ψ statistic is more robust than the use of the HSN, since the latter is not weighted by the *EGRET* coverage. Figure 2 shows our results based on ten blazars with non-zero ψ and the black hole mass estimation. The Spearman correlation parameters turn out to be $\rho = 0.76$ and $P = 0.011$. This possible correlation seems to indicate that more massive BHs can induce higher γ-ray activity, although our sample is too small to draw a firm conclusion. More reliable BH mass estimates of a larger blazar sample will be crucial in verifying the existence of this correlation.

2. The blazar γ-ray duty-cycle

A first estimate of the γ-ray blazar active fraction was given by Stecker & Salamon (1996). In order to take into account the high blazar variability in the γ-ray energy band, they introduced two parameters, the amplitude factor and the duty–cycle. A fine-tuning of the pre-

[1] http://www.mi.iasf.cnr.it/~soldi/thesis.ps.gz

Table 1. Results of the correlation between the activity level, ψ, and some physical properties of *EGRET* blazars. V_{12} is the variability index (Nolan et al. 2003).

	z	α_{ph}^{γ}	α_{ro}	α_{rx}	$L_{E>100\,MeV}^{max}$	$L_{0.1-10\,keV}$	L_{Opt}	L_{5GHz}	V_{12}	M_{BH}
C.C. ρ	0.05	-0.21	0.06	0.08	0.14	0.07	0.04	0.08	0.24	0.76
P_{rand}	0.76	0.18	0.74	0.69	0.39	0.71	0.81	0.62	0.19	0.011

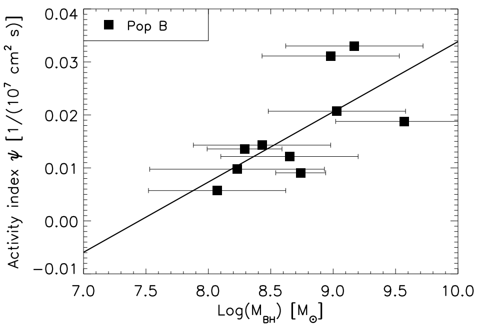

Fig. 2. Gamma-ray activity (ψ) vs. black hole mass (M_{BH}) for *EGRET* Pop. B blazars. A marginal correlation is present (ρ = 0.76 and P = 0.01, Spearman statistics). The solid line represents the best fit line, $\log(\psi) = 0.013 \times \log(M_{BH}) - 0.099$.

dicted γ-ray differential $\log N - \log S$ to the observed one could constrain the two parameters. They found that a duty–cycle $\zeta = 0.03$ was consistent with the observed data.

We use numerical simulations to develop a simplified model of *EGRET* blazar activity that yields rough, but quantifiable, estimates of physical parameters of interest. In this simplified model, we make several assumptions:

1. that all of the *EGRET* blazars exhibit the same basic behaviour;
2. that only those blazars detected by *EGRET* are part of the population of interest;
3. that the behaviour of all *EGRET* blazars can be characterised by a simple model with only two free parameters, the duty–cycle, χ, and the characteristic time–scale, T. Each blazar spends a period of time which average length is T at a low flux level (*off*) before emitting a γ-ray flare of duration τ at a high flux level (*on*), then returning to a low level. The duty–cycle is then defined as the fraction of time spent in the *on* state:

$$\chi = \frac{\tau}{\tau + T}\ . \qquad (2)$$

Note that all blazars have the same characteristic time–scale T, but the duration of each individual quiescent periods is drawn from a Poisson distribution with mean T.

We explored the parameter space of (χ, T). For each pair of χ and T under consideration, we generated 100 sets of 67 simulated light curves covering the entire time interval of *EGRET* Cycle 1 to 4 (1620 days), one for each blazar. The time sequence of *on-off* states was determined by drawing the durations of the *off* states from a Poisson distribution with mean T. The durations of the *on* states were fixed at τ. To obtain the observed fluxes, we used a bootstrap procedure. Each light curve was compared with the observation history of the corresponding AGN. If a given VP coincided with an *on* state, the observed flux was randomly drawn from the distribution of all fluxes *detected* from all *EGRET* blazars during a single VP. Otherwise, the observed flux was randomly drawn from the distribution of all *upper limits* (i.e. non-detections) at *EGRET* blazar positions during a single VP. For each AGN the flux values assigned to each VP were used to calculate its HSN (and therefore its categorisation as Pop. A or B) in the same manner as the actual *EGRET* blazar HSNs. The result is 100 sets of simulated blazar light curves, each with a ratio R_{AB} = #Pop.A/(#Pop.A + #Pop.B). Thus, for each pair of values of (χ, T), we have obtained a distribution of 100 simulated values of R_{AB}, each with a mean and variance. Therefore, we are able to define a confidence region of (χ, T) pairs whose mean values of

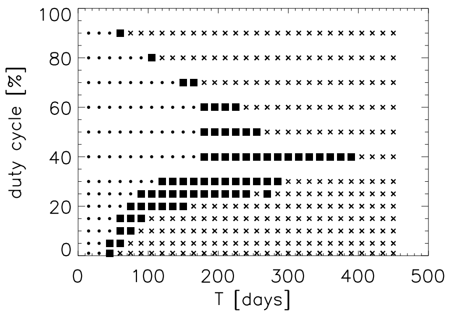

Fig. 3. Mean ratio R_{AB} from simulations of *EGRET* -detected blazars only.

R_{AB} are within one standard deviation of the observed value $R_{AB} = 24/67 = 0.36$. For values of R_{AB} close to the observed value, the simulations give a standard deviation of 0.05. Points in Figure 3 represent the mean value of R_{AB} for each value of T and χ. The filled squares represent those ratio values between $0.31 \leq R_{AB} \leq 0.41$, small filled circles represent $0.0 \leq R_{AB} < 0.31$, while crosses represent $0.41 < R_{AB} \leq 1.0$. Taking into account our simplifying assumptions, including the restriction that the observed *EGRET* blazars form the entire population of γ-ray emitting blazars, the only region consistent with the observations is the region where $0.31 \leq R_{AB} \leq 0.41$. The region with high R_{AB} produces too few flaring sources, while the region with low R_{AB} produces too many. Note that for the Stecker & Salamon duty–cycle of 0.03 the characteristic time–scale T would be on the order of 50 days.

3. Conclusions

The results presented here summarize a more detailed analysis presented in Vercellone et al. (2004) where we discuss the implications on the duty–cycle estimate of a sample of candidate γ-ray AGNs extracted from recently published radio catalogues. A firm estimate of the duty–cycle will be a scientific goal of future γ-ray missions such as *AGILE* and *GLAST* . Their wide FOV ($\sim 60°$) will allow monitoring of a large number of AGNs for each pointing on long time–scales. For the time being, an extensive black hole mass estimation by means of optical spectroscopy on FSRQs and BL Lac objects will allow us to better understand the relation between the central engine and the γ-ray activity.

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