Blazars Astroph. with BeppoSAX and other Observatories

Revisiting the Blazar Main Sequence

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ABSTRACT. A discussion of the FSRQ – BL Lac unification. All distinctive features marking these two Blazar subclasses find an unifying explanation if the sources are powered by central engines constituted by similar Kerr holes, but fueled at high and low accretion rates, respectively. The connection need not be a genetic one, but evidence toward some FSRQs switching into BL Lacs at lower \(z\) will be provided by moderately negative BL Lac evolution. Then an extrapolation will be warranted toward ultra-high energy particle accelerators operating at very low accretion rates.

1. Introduction

The BL Lac Objects may be described as minimal Blazars. This is because – unlike the FSRQs which constitute the other main Blazar subclass – they feature at the same time weak or no emission lines and blue-UV bumps, weak or moderate intrinsic power, and little or no cosmological evolution (for general descriptions and detailed references, see Urry & Padovani 1995, Padovani & Urry 2001). Being so rare, elusive, with redshifts not easily pinpointed, and hence so vulnerable to selection effects, these sources make difficult observational targets.

Yet the BL Lacs constitute the focus of keen and mounting interest, being extreme Blazars that shine by nearly pure non-thermal radiation with little or no photon reprocessing. Their spectra are exceedingly wide, in that they cover 16 frequency decades or more, from the radio band (as also the FSRQs do) up to the high energy \(\gamma\)-rays beyond 10 GeV. In fact, a number of such objects have been observed into the TeV range (see Costamante et al. 2002).

Concerning the spectral energy distribution (SED), all Blazars follow a roughly similar pattern with two bumps mainly or mostly contributed by Synchrotron and Inverse Compton emissions. But (as pointed out by Fossati et al. 1998) in the FSRQs the frequency \(\nu_p\) of the lower peak is placed in the bands from the far IR to the optical, and the upper peak is around \(10^2\) MeV. In the BL Lacs, instead, \(\nu_p\) ranges from optical to X-rays, and the upper peak (possibly modified by the Klein-Nishina limit) falls around or above 10 GeV.

In all Blazars such non-thermal emissions are sharply beamed; they arise from relativistic jets of particles with bulk Lorentz factor \(\Gamma\) around 10 (see Sikora 2001), not substantially different for BL Lacs and FSRQs. These jets are seen nearly pole on within angles of order 1/\(\Gamma\), with apparent powers enhanced by a “blazing” factor \(\Gamma^2\) relative to the emitted ones (see Sikora et al. 1997, Ghisellini 1999). What differs between the two Blazar subclasses is the total output produced; the top outputs are apparently limited to \(L \sim 10^{46}\) erg/s in the BL Lacs, but may be up to \(10^2\) times stronger in some FSRQs (see Maraschi 2001).

How and why all these BL Lac peculiarities arise together? Largely on model-independent grounds, we trace back their common origin to different fueling levels of basically similar power sources.

2. The engine

The paradigm for the energetic cores of all AGNs is of course provided by accreting black holes with masses \(M \sim 10^{8\pm1}\) \(M_\odot\). The accreting gas gathers in a disk where its
angular momentum is transferred outwards; in the process thermal, roughly isotropic emissions are generated with power \( L_{\text{th}} \sim \eta L_E \dot{m} \) in terms of the conversion efficiency \( \eta \sim 10^{-1} \), of the Eddington luminosity \( L_E \) and of the corresponding accretion rate \( \dot{m} \). Does the latter differ markedly in BL Lacs and in FSRQs?

An affirmative answer is provided evidence concerning the thermal emissions. The FSRQs, like the radioquiet Qs, emit a powerful “big blue bump” conceivably from the inner disk, in addition to strong lines from continuum reprocessed by distant gas “clouds”; the luminosities are high (Tavecchio et al. 2000) and close to the Eddington values for BH masses around \( 10^9 M_\odot \), so \( \dot{m} \sim 1 - 10 \) is to hold.

In BL Lacs, instead, the absence or weakness of both the emission lines (\( \text{EW} \lesssim 5 \AA \)) and the BBB call for conditions of low particle densities both around and in the accretion disks. Since the latter density scales as \( n \propto \dot{m}_{11}^{11/20} \) and the former as \( n \propto \dot{m} \) (see Frank, King & Raine 2002), these conditions indicate \( \dot{m} \ll 1 \). A similar conclusion holds if the BBB is due to emission from a hot corona (Sun & Malkan 1989).

On the other hand, evidence from the jets and their emission indicates the mass is not the only parameter relevant to the central BH in Blazars. Such an evidence is provided, e.g., by the strong radio emission powered by jets which has been recently shown not to be simply correlated with large host and BH masses (Ho 2002, McLure & Dunlop 2002). So a further variable must enter; we entertain the view involving the other basic parameter of the BHs, i.e., the angular momentum \( J \) (see Blandford 1990, 1993).

By its vectorial nature this is very likely to provide the sharp and steady directionality of the jets. In addition, rotating Kerr holes make closer stable orbits (approaching \( r_g \approx GM/c^2 \approx 1.5 \times 10^{14} M_9 \) cm) available to the gas particles before they plunge into the horizon; so more gravitational energy can be extracted, and the the maximal efficiency is raised from \( \eta \sim 6 \times 10^{-2} \) to nearly 0.4. Finally, the rotational energy of a Kerr hole (proportional to \( J^2 \) in a classical rendition) may contribute directly the jet-like output of BL Lacs in particular.

Part of the rotational energy of the hole can be directly extracted via hydromagnetic Poynting-like flux related to \( B \) and \( E \) fields coherent on large scales, in approximately force-free conditions \( E \cdot B \approx 0 \); this is of course the attractive but debated scheme proposed by Blandford & Znajek (1977), with the power produced \( L_K \) ultimately depending on the square of the \( B \) field rooted in the disk but threading the horizon close to \( r_g \). A similar hydromagnetic mode of energy extraction has been extended by Blandford & Payne (1982) to the contribution \( L_d \) from the accretion disk itself.

Thus two contributions to the non-thermal power \( L_K + L_d = L_{\text{nth}} \) may be envisaged from the central region surrounding the Kerr hole within radii \( r_e \gtrsim r_g \), in the presence of the poloidal field \( B \). Both components scale approximately as

\[
L_K \propto B^2 r_e^2 ,
\]

following the basic dependences provided by electrodynamics. But the pressure \( P = B^2/8\pi \) holding the magnetic field, and the specific value of the effective radius \( r_e \) are provided by the disk structure, and this depends on the accretion rate \( \dot{m} \).

### 3. Fueling rates

So both outputs \( L_{\text{nth}} \) and \( L_{th} \) are ultimately governed by the fueling regime of similar basic engines. But the latter output scales down as \( L_{th} \propto \dot{m} \) when \( \dot{m} \) is decreased, while the same may not be the case with the former.

Dependences and numerical coefficients in \( L_{\text{nth}} \) have been focused and discussed by Ghosh & Abramowicz (1997); Moderski, Sikora & Lasota (1998); Livio, Ogilvie & Pringle (1999). In the framework of standard disk models the BZ77 scheme is found to yield the maximal power

\[
L_K \approx 2 \times 10^{45} M_9 (J/J_M)^2 \text{ erg s}^{-1} ,
\]
where $J_M \approx GM^2/c$ is the maximum value for the angular momentum consistent with the Kerr metric. This value of $L_K$ is attained for accretion rates $\dot{m} \gtrsim 10^{-2}$ when the inner disk is dominated by the radiation pressure $P \propto M^{-1}$ independent of $\dot{m}$.

For lower $\dot{m}$ instead, the gas pressure $P \propto M^{-9/10} \dot{m}^{4/5}$ dominates also the inner disk; then lower powers $L_K \approx 10^{44} M_9^{11/10} \dot{m}_4^{4/5} (J/J_M)^2$ erg/s obtain. Yet the the ratio $L_K/L_{nth}$ exceeds unity and scales inversely with $\dot{m}$, as $\dot{m}^{-1/5}$. The scaling is stronger if indeed at $\dot{m} \approx 10^{-2}$ a silent ADAF regime sets in (see Narayan, Mahadevan & Quataert 1998; Frank et al. 2002); then the ions cannot share much energy with electrons before plunging into the horizon, and most radiations are suppressed sharply.

We stress two main points of interest in these results. First, the emission becomes increasingly non-thermal anyway as $\dot{m}$ decreases below some $10^{-2}$. Second, for values $\dot{m} > 10^{-2}$ the power saturates to $L_K \approx 6 \times 10^{45}$ erg/s for $M \lesssim 3 \times 10^9 M_\odot$. To this value one should add the the nonthermal disk contribution $L_d$, which in conditions of maximal $J$ and closest orbits with small $r_e \approx r_g$ may be down to the same order as, or just a few times larger than $L_K$ (Meier 2001). Then the Kerr hole and inner disk may be considered as a dynamically and magnetically coupled system, using up also energy stockpiled in previous accretion episodes of mass and associated angular momentum (Bardeen 1970).

Thus a total $L_{nth} \approx 10^{46}$ erg/s appears to provide an upper bound to outputs mainly constituted by non-thermal radiation, the defining feature of a BL Lac; the condition $L_{nth}/L_{th} \lesssim 1$ remains relevant in spite of the blazing effects of the jets that tend to swamp a comparable thermal emission. This leads us to propose that top BL Lac outputs remaining below this limit provide evidence that rotational energy is in fact extracted from the hole via the BZ77 mechanism. The existing data (Maraschi 2001, see also fig. 1) support to now this prediction.

The FSRQs, on the other hand, do have larger outputs that in some cases exceed $10^{47}$ erg/s if protons contribute more then the electrons to the beam kinetic power (Celotti, Ghisellini & Padovani 1997; Tavecchio et al. 2000). Within the above framework, such outputs require a dominant contribution $L_d \gg L_K$ from a wider disk region dominated by radiation pressure; this in turn requires conditions where $\dot{m} \sim 1$, consistent with the independent requirement posed by the high levels of $L_{th}$ discussed in §2.

The maximal power expected may now approach $10^{48}$ erg/s, exceeding the maximal $L_K$ by some $10^2$ (Livio et al. 1999). This obtains if the magnetic field in the disk is and remains a few times larger than the value threading the hole horizon out to distances $r_e \approx 5 r_g$. Here both $L_d$ and the thermal emission $L_{th}$ are directly fed by current accretion; both scale as $\dot{m}$, and $L_{nth}/L_{th} \sim 1$ is expected to hold. Now the hole contribution is subdominant, but is likely to provide a “high-velocity spine” crucial for the outward propagation of the jet (see Livio 1999, Chiaberge et al. 2000).

The detailed share between $L_d$ and $L_{th}$ depends on the balance between two scales in the power spectrum of the magnetic field inhomogeneities: the large-scale, coherent vs. the small-scale, turbulent component. A dominant share of the former, such as to yield a large $L_d$ and correspondingly an additional, large transfer of angular momentum outwards, may require modifications of the standard disk models (see Salvati 1997).

Alternatively, to account for the huge FSRQ outputs one would need very strong $B$ threading the hole, up to the values $B^2/8\pi \sim \rho c^2$ in the plunging orbit region advocated by Meier (1999). Such enhanced fields have been argued and discussed variously; they look unlikely in a thin disk, whereas in thick disks their status is still uncertain. We note they would require high levels of $\dot{m}$ anyway, the main issue here.

In sum, independently of the open if interesting questions concerning the detailed modes of power production, these considerations strongly suggest a trend toward weaker powers $L$ but higher ratios $L_{nth}/L_{th}$ as $\dot{m}$ is decreased from values 1-10 that mark the FSRQs to $10^{-2}$ that mark the BL Lacs. We (CD02) referred to this trend as the Blazar Main Sequence (BMS), with the implication that it holds independently of any genetic link between BL Lacs and FSRQs.
Fig. 1. The $L$ vs. $\nu_p$ diagram. Data from Costamante et al. (2002). Even the most powerful BL Lacs measured to now fall below $L \sim 10^{46}$ erg/s. The solid line represents the trend $L \propto \nu_p^{-2/3}$ provided by eq. (3). The dashed line represents the intrinsic scatter predicted in $\S$4a. Crosses indicate the positions of Mkn 421 and Mkn 501 at the top of their flares. The recent data by Giommi et al. (2002a) add substantial scatter particularly in the BL Lac section of the diagram.

4. The Blazar Main Sequence

The BMS may be usefully contrasted with the stellar MS. Stars were placed, even before their energy source was properly understood, on the HR diagram relating the simplest observables: luminosity and color, or black body peak $\nu_b \propto T_e$. Now the MS comprises the sources whose luminosity is powered by central nuclear burning of H. In stars, the spectra of the outgoing radiation are eventually shaped in the upper envelope under conditions still close to optically thick. All processes occur in conditions close to hydrostatic and thermal equilibrium; so the spectra are closely black body, looking like spikes at $\nu_b$ on a broad frequency span, while $L$ increases sharply (and the lifetimes decrease) with increasing $\nu_p$. The main underlying parameter is mass.

Blazars, instead, are ruled by strong gravity; in addition, the jet-like, nonthermal component of their radiation is emitted by highly relativistic particles under optically thin conditions. The lower peak at $\nu_p$ in their SEDs is broad, yet sufficiently well defined to be represented on the plane labeled by the simplest observables: $\nu_p$ itself, and the integrated steady luminosity $L$ associated with the peak. Thus a definite “spectral sequence” has been obtained by Fossati et al. (1998), with the powerful FSRQs at low $\nu_p$ and the weak BL Lacs at high $\nu_p$; the latter data have been recently extended by Costamante et al. (2002). We hold $\dot{m}$ to be the main parameter marking the BL Lacs from the FSRQs (see also Böttcher & Dermer 2002), and underlying the whole BMS.

We stress analogies and differences between the BMS and the stellar MS on representing the Blazar data first in the simplified form of fig. 1. The key difference is constituted by the decreasing trend of $L$ vs. $\nu_p$ in the BMS as compared with the increasing trend in the stellar MS; this BMS feature is resistant to selection effects and new detections presented and discussed by Giommi et al. (2002a). We trace back such a trend to conditions close to steady state (steady accretion and steady jet outflow) underlying the BMS, that replace the equilibrium conditions governing the MS.

In fact, as a condition for steady energy distribution $N(\gamma)$ of the relativistic electrons
that emit S and IC radiation, one may equate the acceleration and the radiative cooling times, taking up from Ghisellini et al. (1998) and Böttcher & Dermer (2002). So from $\gamma/E \propto 1/\gamma L$ one obtains the decreasing course $L \propto \nu_p^{-1}$, at given accelerating electric field $E$.

But we find a flatter dependence when the primary $E$ fields are stronger, due to lower densities $n \propto \dot{m}$ in the source. For example, consider the parallel fields $\mathbf{E} \cdot \mathbf{B} \neq 0$ which arise at the flow boundaries where breakdown occurs for the force-free approximation governing the bulk of the BZ77 magnetospheres; this is bound to occur in a space-inhomogeneous and also in a time-depending fashion on short scales. Then electrodynamic screening produces effective energy gains $E d \propto c/\omega_p \propto n^{-1/2}$ that scale up when the electron density in the plasma frequency $\omega_p$ is lower; so the steady state constraint $\gamma n^{1/2} \propto 1/\gamma L$ will allow larger $\gamma$ for a given $L$.

To see how the course of $L$ vs. $\nu_p$ is modified, one may iteratively relate the minimum density to emissivity to obtain $n \propto L$; matters are simplified on keeping the source volumes roughly constant. Now the course flattens to

$$L \propto \nu_p^{-2/3},$$

not a bad rendition even for the overall trend in the data, see fig. 1. To a better approximation, one may take into account (see CD02) the full dependencies of $\nu_p$, $n$, and $L/n$ on the minimal or maximal electron energies $\gamma_m$, $\gamma_M$ and on the slope of $N(\gamma)$, to obtain a sharper flattening $L \propto \nu_p^{-1/2}$ in the BL Lac range. Such flatter courses may also be viewed as “weaker” correlations.

By the same token, we expect the maximal electron energies to scale up following $\gamma_M \lesssim e B d/m_e c^2 \sim 10^8 B_4 d_{10} (M_9/r_{17})^{1.25} \propto L^{-3/4} \propto L^{-1}$; here the maximum field is expressed as $E \lesssim 10^4 B_4$ G and (following Blandford & Payne 1982) is taken to scale as $E \propto r^{-1.25}$ into the emission region at $r \sim 10^{16 \pm 1}$ cm, while the effective screening distance is $d = 10^{10} d_{10}$ cm. So we obtain values $\gamma_M \sim 10^5$ in FSRQs, and values up to $10^6$ times larger in BL Lacs; these are high enough to produce by IC radiation the observed TeV photons.

We add that $N(\gamma)$ is expected to depart from a pure power-law as the acceleration takes place in fields endowed with some degree of coherence. In fact, we expect the electrons to be accelerated on crossing a sequence of many sheets or filaments where the relativistic shocks, see Achterberg et al. 2001) to approach 10 are discussed by Massaro (2002). Then the energy distribution $N(\gamma)$ has a curved shape, actually a log-parabolic one; the emitted S or IC spectra are correspondingly curved over a wide frequency band. In fact, the data concerning a number of BL Lacs apparently show such a curvature in the O – X-ray range (Massaro 2002, Giommi et al. 2002b); so they call for energy gains of order 10, more appropriate for accelerating fields with some degree of coherence.

Having outlined the simplified picture, next we point out a number of additions yielding variance. a) The BMS has an intrinsic width related to the additional parameter $L_K/L_d$ that implies within the BL Lac subclass some asymmetric scatter toward higher $L$. This is because only $L_d$ is directly related to $\dot{m}$ and to $n$ and (inversely) to $\nu_p$ by the arguments in §3, while $L_K$ tends to be independent when relevant at low $\dot{m}$; then higher non-thermal luminosities $L_{nth} = L_d + L_K$ obtain in BL Lacs at a given $\nu_p$. b) We recall that we expect $\gamma_M \propto B n^{-1/2}$ to hold in the BL Lac range; here we add that $B$ is likely to be distributed among the objects with a bias toward low values. This will yield lower values of $\nu_p$ and $L$, contributing more asymmetric scatter. c) Additional scatter
Fig. 2. The BL Lac counts evaluated from the expression given by CD02. The short-dashed line represents the result from pure LE with time scale $\tau_L = 7$ Gyr. The solid line represents the result when negative DE with scale $\tau_D = -5$ Gyr is included. We show also the FSRQ counts from the same expression, with $\tau_L = 2$ Gyr and $\tau_D = +5$ Gyr. The dotted line represents the “Euclidean” slope. Hubble constant $H_0 = 65$ km/s Mpc. Data for BL Lacs from Giommi, Menna, & Padovani (1999).

toward low $L$ is generally contributed by misaligned sources with a given value of $\Gamma$ (see Georganopoulos 2000), and by the distribution of $\Gamma$ itself.

These different scatter components will superpose in the BL Lac range to a flattening “bare” correlation, to blur it mainly toward low values of $L$ and $\nu_p$ in a manner not unlike that observed and discussed by Giommi et al. (2002a).

Finally, episodes of violent variability are observed to occur in the form of flares from hours to weeks, particularly in BL Lacs at high photon energies (see Costamante et al. 2002). Here the steady state constraint clearly does not apply; rather, the basic transient behavior of the S and IC radiations $L \propto \gamma^2 \propto \nu_p$ provides a first approximation to the departing branches (see fig. 1) traced by flaring objects on the $L - \nu_p$ plane.

5. Cosmological evolutions

Along the BMS, we expect longer object lifetimes and slower cosmological evolution to occur. Basically this is because conditions of weak activity feeding on low levels of $\dot{m}$ can live longer than those of hyperactivity requiring high $\dot{m}$.

This may be quantified on considering that roughly similar BH masses of order $M \lesssim 3 \times 10^9 M_\odot$ found (see Treves et al. 2002) in BL Lacs and in FSRQs imply a similar limit to cumulative masses accreted during the activity of either type. As to the latter, the mass constraint bounds the cumulative activity time to a few Gyrs with a duty cycle of order $10^{-1}$ (Cavaliere & Padovani 1989).

As to the former, instead, the constraint allows a lifetime up to 10 Gyr at levels $10^{45}$ erg/s or weaker; note that a duration $E/L_K \sim 5$ Gyr can be sustained just by the rotational energy extractable from the coupled system Kerr hole - inner disk, in the absence of angular momentum replenishment (Cavaliere & Malquori 1999). Since a similar time behavior $L(t)$ is shared by these objects at various power levels, such values apply to the specific scale $\tau_L \sim 10$ Gyr for the “luminosity evolution” of their
population.

On these simple grounds we expect the space distribution of the BL Lacs to be uniform to a first approximation, out to some $z \approx 1$; so we expect from the volume test values $\langle V_c/V_a \rangle \approx 0.5$, and for the number counts a nearly Euclidean shape $N(> S) \propto S^{-1.5}$ at intermediate fluxes. This, in fact, what the data indicate to a first approximation, see Giommi, Menna & Padovani (1999).

A quantitative prediction is obtained by CD02 on using the expression for the counts at intermediate fluxes in terms of evolutionary times, in turn evaluated in more detail. The results for BL Lacs counted in the radio band are plotted in fig. 2; the short-dashed line is obtained on using only the basic time scale $\tau_L \approx 7$ Gyr that marks their slow LE.

In contrast (see the long-dashed line in fig. 2), quite steeper counts obtain for the FSRQs using the time scale $\tau_L \approx 2$ Gyr appropriate for their strong evolution, similar to that of radioquiet QSSs (Goldschmidt et al. 1999; Giommi, Menna & Padovani 1999). The latter behavior is widely traced back to exhaustion on the scale of a few Gyrs of the gas stockpiled in the host galaxy and usable for accretion; this is caused by previous accretion episodes, in addition to ongoing star formation (Cattaneo, Haehnelt & Rees 1999; Haehnelt & Kauffmann 2000; Cavaliere & Vittorini 2002). Exhaustion is bound to occur at $z < 2.5$, when the formation of cosmic structures by hierarchical clustering evolves beyond the galactic scales; then violent merging events assemble the galaxies into richer and richer groups, but rarely resuffle the galactic masses and no longer import much fresh gas supplies into the host galaxy.

In fig. 2, another time scale scale appears, namely, $\tau_D \approx \pm 5$ Gyr; this is negative for the BL Lacs (solid line), meaning negative “density evolution”, that is, birth of these objects at moderate or low $z$. In these conditions, less and less sources are found on looking out to increasing $z$; this implies $V_c/V_a < 0.5$ and flattening of the counts below the Euclidean slope at relatively high fluxes, where the low redshifts of the BL Lacs still prevent the cosmological convergence of the volumes from operating.

Negative evolution is not yet apparent in all existing the BL Lac surveys (see Caccianiga et al. 2001, Perri et al. 2002), but it will eventually provide an interesting telltale about the origin of these peculiar AGNs. To illustrate the issue, let us consider a genetic link between the Blazar subclasses such that BL Lac birthrate $\approx -$ FSRQ deathrate.

First, consider that such a link is a conceivable one, since the basic engines are similar while the fueling rates are lower for the BL Lacs. So these can constitute weaker and later stages of earlier and stronger FSRQs, provided the cosmic structures evolve so as to make less and less mass available for accretion; but this is just what has been anticipated above on the basis of the QS evolution alone.

Second, the link is supported by a closer consideration of the strong evolution shared by the FSRQs with the other QSs. For example, Cavaliere & Vittorini (2002, see also refs. therein) trace back the accretion episodes that feed the QSs to triggering interactions of the host galaxies with their companions in a group. These events destabilize the host gas and start inflow toward the nucleus; this develops over a galactic dynamical time scales of a few $10^{-1}$ Gyr, but some 5 similar cycles are expected per host galaxy since $z \approx 2.5$. The outcome is exhaustion of the host gas on a time scale of 2-3 Gyr.

Two consequences are expected. For one, the efficiency of such episodes drops on the same scale; so the average QS luminosities are bound to halve on the scale $\tau_L \approx 2$ Gyr, to be observed as strong LE in the population. Moreover, the frequency of such interactions is bound to dwindle as the groups evolve into clusters with lower galaxy densities and higher velocity dispersions; this gives rise to positive DE developing over the longer scales $\tau_D \sim$ several Gyrs set by the hierarchical clustering. These two evolutionary components are recognized in the QSO data, see Boyle et al. (2000).

Thus we expect the powerful FSRQs will fade out over times of some $10^{-1}$ Gyr after a “last interaction” and a last episode of accretion of mass with associated angular momentum. In some 1/2 of the instances this will add constructively to the pre-existing
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J, leaving behind a fast spinning hole and a long lived BL Lac.

Thus the scale for BL Lac births will be close to $-\tau_D$, i.e., the negative of that for deaths of bright FSRQs. In the formers’ counts this offsets the slow LE, to the effect of flattening them below the Euclidean slope as illustrated in fig. 2. We add that the count normalization, i.e., the object number, is bound to be at least a factor 5 below the FSRQs’ which undergo repeated activity cycles.

6. Endpoints

Note that flattening of the counts is also contributed at faint fluxes by the shape of the LF, which is itself flattened at its lower end by the beaming effects (see Urry & Padovani 1995); but this hardly could swamp a strong evolution of BL Lacs, if it were present. In fact, the similarly affected LF of the FSRQs yields counts that do show a steep bright section just corresponding to a QS-type intrinsic evolution.

In the clear absence of the latter, there is scope in focusing on the negative BL Lac evolution that is now emerging from the statistical noise in larger and deeper surveys with substantial redshift information (Perri et al. 2002). If nailed down at the quantitative levels predicted above, we stress it will provide statistical evidence that transitions FSRQs $\rightarrow$ BL Lacs do occur.

This will clearly mean a key step toward Grand-Unification of the Blazars. It will also have implications for the radio sources. If FR I and FR II constitute the parent population of the BL Lacs and of the FSRQs, respectively, then similar transitions from II to I – once a forbidden proposition, and now one more widely entertained, see Padovani & Urry (2001) and refs. therein – will be made acceptable or even likely.

The other, direct evidence toward Grand-Unification may be provided by finding at $z \lesssim 1$ the transitional Blazars implied by the genetic connection from FSRQs to BL Lacs. We expect that, when caught in the act of switching at regimes $\dot{m} \sim 10^{-1}$, such objects will show not only intermediate $L$, but also emission lines and BBB still shining; when the latter is subtracted from the continuum in the manner discussed by D’Elia & Padovani (2002), the residual non-thermal SED ought to be peaked at $\nu_p$ beyond the optical frequencies. Not many of these objects are to be expected, since by definition they will be weaker than the canonical FSRQs while the transition will take times shorter, if anything, than the lifetime at the top of $\dot{m}$. A number of these objects may have already been found, see Sambruna, Chou & Urry (2000); Perlman et al. (2001); Padovani et al. (2002).

Table 1 - The Blazar Main Sequence

| optical features | FSRQs | BL Lacs | $\rightarrow$ CR accelerators |
|------------------|-------|---------|-----------------------------|
| power evolution  | $L \lesssim 10^{48}$ erg s$^{-1}$ | $L \lesssim 10^{46}$ erg s$^{-1}$ | none |
| top energies     | $h\nu \sim 10$ GeV | $h\nu \sim 10$ TeV | $L \lesssim 10^{42}$ erg s$^{-1}$ |
| hole vs. disk    | $L_K \ll L_d$ | $L_K \ll L_d$ | negligible |
| key parameter    | $\dot{m} \sim 1$ | $\dot{m} \sim 10^{-2}$ | $E_M \sim 10^{20}$ eV |

Waiting for these two lines of evidence to consolidate, an eye should be kept open on a further connection with sources of high energy cosmic rays. This is conceivable and even likely if we carry the BMS and the genetic link to their extreme; starting from the relation $\gamma_M \propto L^{-3/4}$ one expects values of order $10^{10}$ in cases where the total output is $L \lesssim 10^{42}$ erg s$^{-1}$.

So one may envisage endpoint objects ("dead BL Lacs") with very low residual $\dot{m} < 10^{-3}$ and possibly in full ADAF conditions, which would feature very faint if any e.m.
Fig. 3. To illustrate the BMS, and the possible genetic connection from the hyperactive FSRQs at high-medium $z$ to the moderate or weak, low $z$ BL Lacs. This may be extended down to $z \approx 0$ to including as local relics the objects, e.m. silent but still effective as particle accelerators, discussed in §6.

emission. But they would still support strong, nearly unscreened electric fields under the widely entertained assumption that magnetic fields of order $B \sim 10^2 - 10^3$ G can still be held by such vestigial disks. So they can accelerate particles including protons up to limiting energies $E_M \sim 4 e B r_g (r_g/r)^{0.25} \sim 10^{20} M_g^{0.25} B_{10} r_{10}^{-0.25}$ eV. Such limiting energies, long recognized to be accessible to rotating holes, gratifyingly cover the upper range of the ultra-high energy cosmic ray spectrum.

Output levels $L \sim 10^{42}$ erg/s as envisaged above can just provide the observed UHECR flux; tens of these accelerators could lie within some 50 Mpc and evade in the simplest way the GZK cutoff (Boldt & Ghosh 1999). Intergalactic magnetic fields of nG strength would blur the geometrical memory of the sources for most except for the closest UHECR events.

We summarize in Table I the main Blazar features that the BMS can explain or predict. In fig. 3 we schematically illustrate the further steps warranted by negative evolution and transitional objects: Grand-Unification of Blazars, and the link with UHECR accelerators.

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