

Hadronic models of blazars require a change of the accretion paradigm

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ABSTRACT

We study hadronic models of broad-band emission of jets in radio-loud active galactic nuclei, and their implications for the accretion in those sources. We show that the models that account for broad-band spectra of blazars emitting in the GeV range in the sample of Böttcher et al. have highly super-Eddington jet powers. Furthermore, the ratio of the jet power to the radiative luminosity of the accretion disc is ~ 3000 on average and can be as high as $\sim 10^5$. We then show that the measurements of the radio core shift for the sample imply low magnetic fluxes threading the black hole, which rules out the Blandford–Znajek mechanism to produce powerful jets. These results require that the accretion rate necessary to power the modelled jets is extremely high, and the average radiative accretion efficiency is $\sim 4 \times 10^{-5}$. Thus, if the hadronic model is correct, the currently prevailing picture of accretion in AGNs needs to be significantly revised. Also, the obtained accretion mode cannot be dominant during the lifetimes of the sources, as the modelled very high accretion rates would result in too rapid growth of the central supermassive black holes. Finally, the extreme jet powers in the hadronic model are in conflict with the estimates of the jet power by other methods.

Key words: acceleration of particles – radiation mechanisms: non-thermal – ISM: jets and outflows – galaxies: active – galaxies: jets – quasars: general.

1 INTRODUCTION

The most commonly considered models of broad-band emission of radio-loud jets in AGNs utilize emission of relativistic electrons and positrons via synchrotron and Compton processes. These leptonic models have been highly successful in reproducing the spectra and time variability of blazars and radio galaxies, though there are some phenomena, such as their extremely short variability time-scales, in some cases down to a few minutes (Aharonian et al. 2007; Albert et al. 2007), that are not readily explained by them.

The alternative, and quite popular, model is based on hadronic (or lepto-hadronic) processes (e.g. Mannheim & Biermann 1992; Aharonian 2000; Mücke & Protheroe 2001). It utilizes emission of extremely relativistic ions, mainly due to proton-synchrotron and photopion production processes, to explain the high-energy emission from jet-dominated AGNs. The latter process gives rise to cascades of electrons and positrons, also emitting via the synchrotron and Compton processes. The peak of the high-energy emission of the broad-band spectral energy distribution (SED) of blazars, at ~ 0.1 – 10 GeV, is then due to these processes, mostly proton synchrotron.

We stress that the name ‘hadronic’ refers only to the emission processes, and the ‘leptonic’ jets in AGN models also contain ions, though with relatively low energies, preventing them from radiating efficiently. Still, those hadrons in the leptonic models usually dominate the kinetic luminosity of jets (e.g. Ghisellini et al. 2014).

Sikora et al. (2009) and Sikora (2011) have shown that the hadronic processes are very inefficient. This implies that, if the total jet power is approximately limited by the Eddington luminosity, the hadronic model can be ruled out in many cases. On the other hand, Böttcher et al. (2013, hereafter B13) have successfully applied hadronic models to a sample of radio-loud AGNs circumventing this constraint by allowing the jet power to be highly super-Eddington. Here we discuss consequences of this supposition.

2 ANALYSIS OF THE SAMPLE OF B13

We study here the sample of 12 blazars of B13. Their broad-band spectra were fitted by them by leptonic and hadronic models, and we consider here the jet powers obtained by B13 for the latter. B13 provide the redshifts, z , the apparent superluminal velocity, β_{app} , and the accretion luminosity, L_{acc} , see Table 1. Six of those objects were also present in the sample of Zamaninasab et al. (2014, hereafter ZCST14), for which those authors provide estimates of the black hole mass, M , β_{app} and L_{acc} based on literature. The values of β_{app} agree well between ZCST14 and B13, while the values of L_{acc} agree

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Table 1. The main parameters of the sample. FSRQ – flat spectrum radio quasar, LBL, IBL and HBL refer to blazars which synchrotron spectrum has the peak at low, intermediate and high frequencies, respectively; ν and νF_ν give the estimated position of the peak of the GeV spectrum approximated as a power law, and P_j is the total jet+counterjet power in the hadronic model of B13. See B13 for the remaining parameters of the sources.

Object	Type	z	L_{acc} (erg s^{-1})	M (M_\odot)	L_{acc}/L_E	$\Delta\theta$ (mas)	ν (10^{22} Hz)	νF_ν (10^{-10} erg cm^{-2} s^{-1})	γ_{min}	γ_{max} (10^9)	P_j (10^{48} erg s^{-1})
0219+428 (3C 66A)	IBL	0.3	4.80×10^{43}	4×10^8	8.1×10^{-4}	0.073	10	1	1	1.2	3.2
0235+164 (AO)	LBL	0.94	3.40×10^{44}	4×10^8	0.0057	0.006	30	7	1	4.3	27
0420–014 (PKS)	FSRQ	0.914	3.02×10^{46}	2.57×10^8	0.97	0.256	5	1	10^3	0.43	1.4
0528+134 (PKS)	FSRQ	2.07	1.70×10^{47}	1.07×10^9	1.07	0.150	5	2	1	1.1	117
0716+714 (S5)	LBL	0.31	1.80×10^{44}	1×10^8	0.012	0.125	70	1	1	2.7	0.69
0851+202 (OJ 287)	LBL	0.306	1.50×10^{44}	6.2×10^8	0.0016	0.051	5	0.5	1	1.0	0.23
1219+285 (W Comae)	IBL	0.102	1.50×10^{43}	5×10^8	2.0×10^{-4}	0.047	80	0.5	1	1.9	0.059
1226–023 (3C 273)	FSRQ	0.158	1.30×10^{47}	6.59×10^9	0.13	0.017	2	10	10^3	0.43	67
1253–055 (3C 279)	FSRQ	0.536	2.00×10^{45}	8×10^8	0.017	0.051	10	1	10^3	0.63	9.3
1510–089 (PKS)	FSRQ	0.36	1.12×10^{46}	1.58×10^8	0.48	0.151	8	5	10^3	1.1	6.7
2200+420 (BL Lac)	LBL	0.069	1.51×10^{45}	1.70×10^8	0.060	0.052	10	0.3	1	1.9	26
2251+058 (3C454.3)	FSRQ	0.859	7.24×10^{46}	4.90×10^8	1.00	0.159	10	10	10^3	1.1	96

to within a factor of ~ 2 , which is a satisfactory agreement given the necessary approximate character of those estimates. However, the exception is W Comae, for which the L_{acc} estimate used by B13 is 40 times higher than that given in ZCST14, which is the upper limit of Ghisellini et al. (2010, hereafter G10). B13 used the estimate of Xie et al. (2008), who refer in turn to two other papers, which do not seem to give that information. Thus, we use here the value of G10. B13 quote an estimate of L_{acc} of Xie et al. (2008) for OJ 287, which is seven times higher than the upper limit of G10; here we use the latter. For two objects (S5 0716+714 and 3C 66A), B13 give no estimates of L_{acc} , and we use the upper limits given by G10. In the case of 3C 66A, there is also an uncertainty of its redshift, and B13 used an estimated redshift of $z = 0.3$ based on SED modelling corrected for the extragalactic background light (Abdo et al. 2011), which is also marginally consistent with the spectroscopically determined lower limit on the redshift by Furniss et al. (2013). Since we use the estimates of the jet power from B13, we adopt their redshift value and rescale the upper limit of L_{acc} of G10, who used $z = 0.444$, by the ratio of D_L^2 , where D_L is the luminosity distance. We assume the same cosmological parameters as B13, $\Omega_\Lambda = 0.7$, $\Omega_m = 0.3$ and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

For the objects not in the sample of ZCST14, we find mass estimates from the literature, in particular from G10. In some cases, there is a considerable uncertainty. For OJ 287, we use $6.2 \times 10^8 M_\odot$ from Wang, Luo & Ho (2004). However, if the system is indeed a binary black hole system, the mass of the less and more massive component is estimated as 1.4×10^8 and $1.8 \times 10^{10} M_\odot$, respectively (Valtonen, Ciprini & Lehto 2012). Accretion would be dominated by the more massive black hole. The adopted values of L_{acc} and M for all sources studied here are given in Table 1.

B13 give the jet power¹ estimated using the energy content and for one jet only, see their equations (3)–(5). However, the jet power, P_j , is the enthalpy flux (e.g. Levinson 2006), and the counterjet should be included in the energy budget. Thus, we multiply their values by 8/3, assuming the protons are relativistic (and thus their equation of state can be described by an adiabatic index of 4/3), see Table 1. We neglect a possible contribution of cold protons, and consider only those in the power-law distribution assumed to give rise to the observed spectrum, following the fits of B13. We then compare P_j

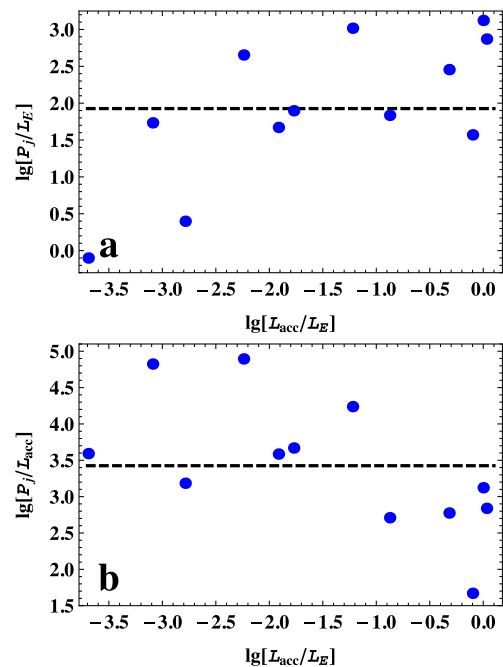


Figure 1. The ratio of the total jet power to (a) the Eddington luminosity and (b) the accretion luminosity as functions of the Eddington ratio. The dashed lines show the geometric averages.

to both L_E (calculated for an H fraction of $X = 0.7$) and L_{acc} in Fig. 1. We find $\langle P_j/L_E \rangle \simeq 85$, $\langle P_j/L_{\text{acc}} \rangle \simeq 2660$, with the standard deviations corresponding to factors of $\simeq 10$ and $\simeq 8.4$, respectively. (Hereafter, the symbol $\langle \cdot \rangle$ denotes a geometric average, i.e. average of logarithms, and the given standard deviation corresponds to a multiplicative factor.) Except for W Comae and OJ 287, the distribution of P_j/L_E is relatively uniform. As a consequence, there is an anticorrelation between P_j/L_{acc} and L_{acc}/L_E , but all the obtained values are still very high, spanning $P_j/L_{\text{acc}} \sim 50\text{--}10^5$. Furthermore, some of our values of L_{acc} are upper limits, and the corresponding true values of P_j/L_{acc} can be even higher.

In general, we can write $P_j = \epsilon_j \dot{M} c^2$, where \dot{M} is the accretion rate and $\epsilon_j \lesssim 1.5$, the ratio of the jet power to the available accretion power, which we will call here the jet formation efficiency. The approximate maximum corresponds (Tchekhovskoy, Narayan

¹ The entry for L_p (the power in protons) of OJ 287 in B13 is a typo, it should be 0.083 rather than 8.3.

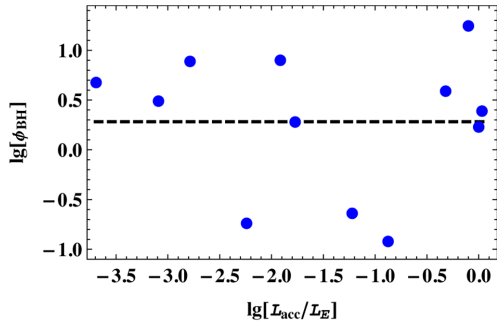


Figure 2. The dimensionless magnetic flux ϕ_{BH} as a function of the Eddington ratio. The dashed line shows the geometric average of $\phi_{\text{BH}} \simeq 1.9$. The model of efficient jet formation via black hole spin energy extraction (Blandford & Znajek 1977) predict $\phi_{\text{BH}} \gtrsim 50$ (Tchekhovskoy et al. 2011; McKinney et al. 2012), which is much higher than the obtained values.

& McKinney 2011; McKinney, Tchekhovskoy & Blandford 2012) to efficient extraction of the black hole spin energy (Blandford & Znajek 1977), in which case the jet power may exceed $\dot{M}c^2$. However, attaining such a high jet formation efficiency requires the accretion flow to possess a strong poloidal magnetic field (Tchekhovskoy et al. 2011; McKinney et al. 2012), namely to form a magnetically arrested disc (MAD; Narayan, Igumenshchev & Abramowicz 2003; see also Bisnovatyi-Kogan & Ruzmaikin 1976). The required energy density corresponds then to the magnetic flux threading a rapidly spinning black hole of $\Phi_{\text{BH}} = \phi_{\text{BH}}(\dot{M}c)^{1/2}r_g$, with $\phi_{\text{BH}} \simeq 50$, which corresponds to the magnetic field strength at the horizon of $B^2/8\pi \sim 100 \dot{m}m_p c^2/(\sigma_T r_g)$, where $\dot{m} = \dot{M}c^2/L_E$, $r_g = GM/c^2$ is the gravitational radius, m_p is the proton mass and σ_T is the Thomson cross-section. Since the magnetic flux is conserved in the jet, it can be measured at large scales e.g. through the radio-core shift effect (Lobanov 1998; Hirovani 2005). Values of $\phi_{\text{BH}} \sim 50$ were found for a large sample of blazars and radio galaxies by ZCST14 assuming $\dot{M}c^2 = L_{\text{acc}}/\epsilon_r$ for their adopted accretion radiative efficiency of $\epsilon_r = 0.4$. However, given that $P_j \gg L_{\text{acc}}$ in the hadronic model of B13, we have to estimate \dot{M} instead from the jet power, strongly dominating the energy budget, i.e. $\dot{M}c^2 \simeq P_j/\epsilon_j \gg L_{\text{acc}}/\epsilon_r$.

To calculate the values of ϕ_{BH} implied by the hadronic model, we use the radio core shift, $\Delta\theta$, measurements between 8 and 15 GHz for the sources in our sample from Pushkarev et al. (2012), which we give in Table 1. We apply a correction of Zdziarski et al. (2015) to the power of the $(1+z)$ factor in the formula for the magnetic field strength at 1 pc, B_1 , and then use the formula for the jet magnetic flux, Φ_j , of equation (5) of ZCST14. From $\Phi_j = \Phi_{\text{BH}}$ we obtain ϕ_{BH} , which we plot in Fig. 2 for $\epsilon_j = 1$ and the dimensionless black hole angular momentum of 1. We find $\langle\phi_{\text{BH}}\rangle \simeq 1.9$ with the standard deviation of a (multiplicative) factor of $\simeq 5$. These result can be compared to another formula for Φ_j of Zdziarski et al. (2015), which takes into account effects due to the small jet opening angles in the radio-emitting region (and the consequent low value of the magnetization parameter), and due to transverse averaging of the magnetic field. That formula yields values lower by approximately $\sqrt{2}$ from those above. Thus, our results appear to give robust approximate estimates of the magnetic flux (under the assumption of the hadronic jet model). Given this and that all objects in the sample have $\phi_{\text{BH}} \ll 50$, we can rule out the efficient version of the model of Blandford & Znajek (1977) for the sample. (We note that this model is likely to work for the studied sources if the leptonic model is adopted, as in ZCST14.)

In other jet formation models (e.g. Blandford & Payne 1982; Coughlin & Begelman 2014), the jet formation efficiency has to be < 1 , and it is usually $\epsilon_j \ll 1$. Thus, the accretion process is even more highly super-Eddington. For such accretion, Coughlin & Begelman (2014) make a rough estimate of $\epsilon_j = 0.1$, which we also adopt. Then, $\langle\dot{M}c^2/L_E\rangle \sim 10^3$, i.e. the accretion is indeed highly supercritical. The radiative efficiency of the accretion disc in this case is very small, $\langle L_{\text{acc}}/\dot{M}c^2\rangle \simeq 4 \times 10^{-5}$.

After the calculations presented in this Letter had been completed, Cerruti et al. (2015) presented an analysis of five high-frequency peaked BL Lac objects (HBLs), whose γ -ray peak is located around ~ 1 TeV rather than at ~ 1 GeV as typical for LBLs and IBLs considered in B13 and in this work. Cerruti et al. (2015) found that it is possible to find hadronic-model fits with sub-Eddington jet powers for those particular objects. A detailed analysis of those objects is outside the scope of this Letter, but we briefly address a few issues. Cerruti et al. (2015) took into account secondary products of hadronic processes in more detail than B13. However, they assumed steady-state primary proton and electron distributions as fixed power laws and followed the evolution of particle spectra, using the respective kinetic equations, only for the secondary particles, while B13 used the electron and proton kinetic equations for all particles, which is the self-consistent approach. It is not clear to us how this might affect the jet powers. Also, the jet powers given in Cerruti et al. (2015) are for one jet only, neglect the pressure contribution, and assume the jet Lorentz factor, Γ , to be one-half of the Doppler factor, δ , while $\Gamma = \delta$ for the inclination angle $i = 1/\Gamma$, as favoured on statistical grounds. Thus, for comparison with the results here, their jet powers need to be multiplied by a factor of 32/3. Still, we do not exclude that a sub-Eddington jet powers can be obtained for some objects, as it is e.g. the case for W Comae in our sample. Generally, due to the substantially lower total luminosities and at least equally large (if not larger) black hole masses of HBLs compared to low-frequency peaked blazars (especially FSRQs), it seems less problematic to produce hadronic-model fits with sub-Eddington jet powers for HBLs.

3 THE MINIMUM JET POWER IN THE PROTON-SYNCHROTRON MODEL

The above results are for the model fits of B13 which, due to the large number of parameters, may generally not be the only possible hadronic-model representation of the chosen SEDs. We may therefore ask whether another set of fits of the hadronic model could have lower total power. We can answer this question by finding the minimum possible power for a given proton-synchrotron flux, found to dominate the overall model spectra of the objects in the sample, see fig. 9 of B13. We use the method of Zdziarski (2014, hereafter Z14), who calculated the minimum jet power for a given electron-synchrotron flux. We can adapt those calculations to the proton-synchrotron case by replacing the electron mass, m_e , by m_p in the relevant formulae of Z14 (including physical constants). Equivalently, σ_T , the critical magnetic field, B_{cr} , the dimensionless photon energy in the jet frame, ϵ' , and the jet-frame flux, L'_e (in the notation of Z14) need to be multiplied by $(m_p/m_e)^{-2}$, $(m_p/m_e)^2$, $(m_p/m_e)^{-1}$ and m_p/m_e , respectively. Correspondingly, the constant a_e of equation (33) of Z14 needs to be multiplied by $(m_p/m_e)^{3/2}$, and the power in relativistic particles, P_e , and in the rest mass, P_i , need to be multiplied by $(m_p/m_e)^{5/2}$ and m_p/m_e , respectively. The minimum total jet power and the corresponding magnetic field strength of equation (36) in Z14 need to be multiplied by $(m_p/m_e)^{10/7}$ and $(m_p/m_e)^{5/7}$, respectively.

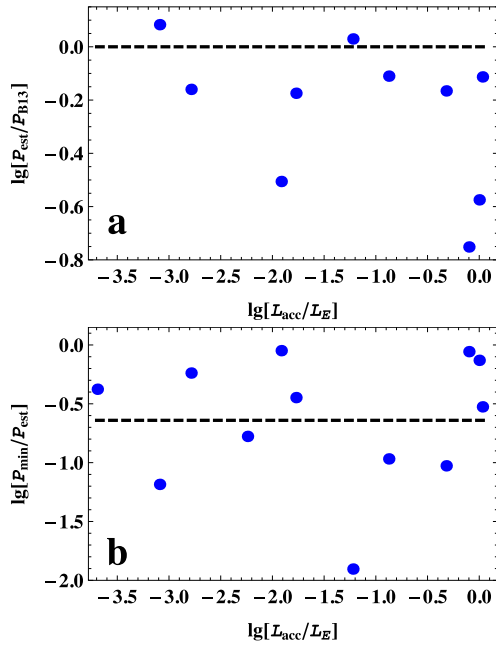


Figure 3. (a) The ratio of the total jet power estimated using the magnetic field strengths of B13 and the method of Z14 to the corresponding power given in B13, as a function of the Eddington ratio. The dashed line corresponds to equal powers. (b) The ratio of the minimum power to that calculated using the method of Z14 with the magnetic field strengths of B13. The dashed line corresponds to the geometric average.

The method of Z14 assumes a local synchrotron spectrum which can be well represented by a power law in some range of frequencies, and it uses one monochromatic measurement of the flux. Here, we use an estimate of the flux around the maximum of the νF_ν spectrum, using spectral plots in fig. 9 of B13. We list our adopted values in Table 1. This implies that the parameter e_{max} of Z14 is =1. However, we modify the method in order to take into account that γ_{min} is specified in the model of B13. In the case of ion acceleration, one would naturally expect $\gamma_{\text{min}} \sim 1$, unlike the case of electrons, which can be preheated ($\gamma_{\text{min}} \gg 1$ (with acceleration only proceeding out of this distribution)). However, B13 used $\gamma_{\text{min}} = 10^3$ for some objects, see Table 1. To account for this, we define $e_{\text{min}} = B\gamma_{\text{min}}^2/(B_{\text{cr}}m_p^2c^4)$ (cf. Z14). Since B is itself calculated by the minimization, this requires a simple iterative calculation.

We first check how well the above method reproduces the jet powers given in B13. For this, we use the values of B given in B13 instead of those corresponding to the minimum power. We show the results in Fig. 3(a). Some disagreement is expected given that in the present estimate we take into account only the proton-synchrotron emission and neglect cooling. The adiabatic cooling is, in fact, dominant in AO 0235+164 and W Comae, in which case the proton-synchrotron estimate gives values ~ 200 and 50 times too low, respectively. Apart from this, the overall agreement is good, within a factor of 2 for seven of the remaining objects, see Fig. 3(a).

We then apply the minimization method to the sample of B13. We have found the minimum powers are on average lower by a factor of few compared to the corresponding estimates above, with the geometric average being $\simeq 0.23$, see Fig. 3(b). This reduction is due to the minimum corresponding to an equipartition between the power in the relativistic ions, P_i , and in the magnetic field, P_B , which may not be able to produce a fit to the entire SED. Indeed, B13 found $P_i \gg P_B$ in most of their fits. This departure from

equipartition naturally results in higher total jet powers. Still, the overall possible reduction of the jet power due to changing the fit parameters is by at most a factor of a few.

4 ASTROPHYSICAL IMPLICATIONS

In Section 2, we found that the jet powers of the AGN sample of B13 exceed their radiative luminosities by very large factors, with $P_j/L_{\text{acc}} \sim 50\text{--}10^5$ and $\langle P_j/L_{\text{acc}} \rangle \sim 3000$. Then, we showed in Section 3 that the values of the jet power obtained by B13 in the hadronic model cannot be significantly reduced by changing the fit parameters, as they are, on average, within a factor of a few of the minimum jet powers estimated using the observed γ -ray spectra for the radiative mechanism dominant in this model, namely proton synchrotron. These findings imply that the jet formation efficiency greatly exceeds that found in leptonic models, which is already quite high (see e.g. Ghisellini et al. 2014). We have also found that the most efficient jet formation mechanism known, based on the Blandford–Znajek mechanism extracting black hole spin with a MAD (Tchekhovskoy et al. 2011; McKinney et al. 2012), is ruled out by the magnetic fields measured at the pc distance scale. Since the jet power has to be then derived entirely from accretion, the implied accretion rates are huge and the radiative efficiencies of the accretion disc must be tiny.

At the inferred accretion rates, $\langle \dot{M}c^2/L_E \rangle \sim 10^3$, accretion is supercritical (ruling out optically-thin radiatively inefficient models, which can correspond only to $\dot{M}c^2/L_E \ll 1$, see e.g. Yuan & Narayan 2014). The angle-averaged accretion-disc luminosity in this case is small, corresponding to $L \sim L_E$ and a radiative efficiency is $\sim 10^{-3}$ (Sikora 1981; Sądowski et al. 2014). However, most of that luminosity emerges through axial funnels, where the observed flux is super-Eddington, corresponding to $L \sim 10L_E$ (Sikora 1981; Sądowski et al. 2014). Our sample consists of blazars seen close to on-axis, on average at $i \sim 1/\Gamma_j$, and the accretion-disc-emission funnels have opening angles greater than that (Sądowski et al. 2014). Thus, we would expect to see super-Eddington accretion-disc luminosities, while, in fact, they are all $\lesssim L_E$, with 8 out of 12 objects having $L_{\text{acc}} \lesssim 0.1L_E$. Thus, the hadronic emission model for the jets is inconsistent with the standard accretion theory.

The inferred extreme accretion rates present also a major problem in light of results of studies of supermassive black hole growth. The e-folding time by which the black-mass would increase due to accretion, M/\dot{M} , is $\simeq 4 \times 10^5$ yr at $\langle \dot{M}c^2/L_E \rangle \simeq 10^3$ found in Section 2. This is a very short time compared to estimated lifetimes of active phases of radio sources, e.g. $\simeq 2 \times 10^8$ yr for FR IIs (Antognini, Bird & Martini 2012, and references therein). Correspondingly, the average radiative accretion efficiency we found (under the assumptions of the hadronic model) of $\langle L_{\text{acc}}/\dot{M}c^2 \rangle \simeq 4 \times 10^{-5}$ is \ll than the average accretion efficiency of $\sim 0.1\text{--}0.3$ (Soltan 1982; Marconi et al. 2004; Silverman et al. 2008; Schulze et al. 2015). Thus, blazars radiating via the hadronic emission mechanism have to represent at most a small fraction of accreting supermassive black holes and/or such extreme accretion episodes must be extremely short-lived, representing only a duty-cycle of the order of $\sim 10^{-4}$ (which is in conflict with the fact that the studied objects have quite average properties).

Finally, the obtained extreme powers are in conflict with studies of the jet power based on radio lobes and X-ray cavities (Merloni & Heinz 2007; Cavagnolo et al. 2010; Nemmen et al. 2012; Godfrey & Shabala 2013; Russell et al. 2013; Shabala & Godfrey 2013). Those studies indicate jet powers at most moderately exceeding the Eddington luminosity, and even in the most luminous sources

they exceed the accretion-disc luminosity only by a factor of $\lesssim 10$. On the other hand, those powers are in an overall agreement with the powers estimated in leptonic models, see e.g. Ghisellini et al. (2014).

Summarizing, we have found major difficulties in reconciling the jet power requirements of hadronic blazar models with (a) observed accretion-disc luminosities, (b) accretion rates inferred from super-massive black hole growth, and (c) jet powers inferred from radio lobes and X-ray cavities. While the problems (b) and (c) can be, in principle, circumvented, if we apply the hadronic model to a small number of sources and assuming a short duty-cycle, the problem (a) requires a change of the accretion paradigm for the very sources fitted by the hadronic model. We conclude that our results represent a strong argument against the applicability of hadronic models to blazars.

5 SUMMARY

We have presented an analysis of the jet powers required by hadronic-model fits to the SEDs of blazars, based both on detailed numerical modelling by B13, and on minimal jet power requirements in a proton-synchrotron interpretation of the γ -ray emission, adopting the methodology of Z14. Our main results are as follows.

We show that hadronic models of B13 that can account for broad-band spectra of blazars emitting in the GeV range, have jet powers of $P_j \sim 10^2 L_E$, approximately independent of their accretion Eddington ratio, which spans $L_{\text{acc}}/L_E \simeq 10^{-3}$ –1 for the studied sources. The ratio of the jet power to the radiative luminosity of the accretion disc can be as high as $\sim 10^5$ for the studied sample, and $\langle P_j/L_{\text{acc}} \rangle \sim 3000$.

Furthermore, we show that the available measurements of the radio core shift for the sample imply low magnetic fluxes threading the black hole, which rules out the Blandford–Znajek mechanism with efficient production of jets for hadronic blazar models.

These results require that the accretion rate necessary to power the modelled jets is very high, compared to the accretion radiative output. The average radiative accretion efficiency is $\langle L_{\text{acc}}/\dot{M}c^2 \rangle \simeq 4 \times 10^{-5}$ for the studied sample.

A major problem for the hadronic model is presented by their required highly super-Eddington jet powers. This, in turn requires highly super-Eddington accretion rates, at which the observed luminosities would be much higher than those actually seen. If the model is correct, the currently prevailing picture of accretion in AGNs needs to be revised.

The extreme jet powers obtained by B13 are in conflict with the estimates of the jet power by other methods. The obtained accretion mode cannot be dominant during the lifetimes of the sources, as the modelled very high accretion rates would result in much too rapid growth of the central supermassive black holes. Thus, if applicable, this accretion mode can only be present with a very small duty-cycle in the black hole evolution, and thus can be applied only to a very small fraction of the radio loud sources.

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