Jets in Quasars

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Abstract. In my review of jet phenomena in quasars, I focus on the following questions: How powerful are jets in radio-loud quasars? What is their composition? How are they launched? And why, in most quasars, are they so weak? I demonstrate the exceptional role that blazar studies can play in exploring the physics and structure of the innermost parts of quasar jets.

1. Introduction

The jet activity in quasars is common, but very diverse. As radio observations indicate, jet powers can differ by several orders of the magnitude within the same optical luminosity range. The most powerful jets produce hundred kiloparsec-scale double radio structures. They can be characterized as composed from a pair of edge-brightened radio lobes, with the hotspots matching their luminosity peaks. Additionally, one sided jets are often observed, connecting one of two hotspots with the radio core in the center of the host galaxy. The above structure has a good interpretation in terms of a dynamical model which involves propagation of light, relativistic jets in the IGM (Scheuer 1974; Begelman & Coffi 1989). The hotspots are located at the ends of channels drilled by the jets through the IGM. They mark the regions where material of the jet is shocked and spreads sideways, forming the radio lobe. Relativistic speeds of jets explain their one-sided appearance, while lightness (jet density lower than IGM density) is necessary to explain formation of extended radio lobe structures and the non-relativistic speeds of hotspots.

Highly polarized and relatively steep radio spectra of extended radio structures are uniquely interpreted in terms of optically thin synchrotron radiation. The synchrotron spectra extend from $\sim 10$ MHz, up to IR/optical. I discuss briefly, in §2, how these data can be used to estimate the jet power.

Quasar jets can be traced in radio down to parsec-scale central regions. There the jets are more relativistic (bulk Lorentz factor $\Gamma \sim 10$ [Padovani & Urry 1992; Ghisellini et al. 1993; Homan et al. 2000]) than on kpc-scales ($\Gamma \sim 3$ [Wardle & Aaron 1997]), and only those which are oriented close to the line of sight are bright enough to be observed in detail. Parsec-scale jets viewed “pole-on” can be decomposed into radio-cores and one-sided linear structure. The linear structure is very inhomogeneous, with some bright regions propagating with relativistic speeds and appearing to us as “superluminal” sources. Parsec-scale radio sources show spectra with a low-energy break due to synchrotron-
self-absorption. The frequency of this break is larger the closer to the center one measures, and superposition of spectra from all radio components give the characteristic flat radio spectrum, with a energy spectral index $\alpha < 0.5$. Quasars with such radio spectra are called FSRQ (flat-spectrum-radio-quasars). I discuss the energetics and composition of quasar parsec-scale jets in §3.

As high frequency VLBI observations of nearby radio galaxies show, extragalactic jets are launched much deeper than the angular-resolution and synchrotron-self-absorption limited observations can follow in quasars (Lobanov 1998; Junor, Biretta, & Livio 1999). Fortunately, sub-parsec scale jets radiate a lot at higher, non-radio frequencies: up to optical/UV by the synchrotron mechanism, and in the X-ray and $\gamma$-ray bands via Comptonization of synchrotron and external diffuse radiation fields (Sikora, Begelman, & Rees 1994; Błazejowski et al. 2000). This radiation, Doppler boosted into our direction, often dominates over thermal quasar components, such as: UV/optical radiation of the accretion disk, X-ray radiation of a disk-corona, and IR radiation of dust located in a molecular torus and heated by a disk. FSRQ which have spectra dominated by the non-thermal radiation from a jet are called blazars. Historically, this category also includes BL Lac objects, those sources with thermal signatures too weak present at all to place them in the quasar category. Hence, in order to avoid confusion while talking about “quasar-hosted” blazars, I will call them “Q-blazars”.

The broad-band spectra of Q-blazars can in general be superposed from the radiation produced over a large distance range. However, at least during short-term high amplitude flares the spectra are dominated by radiation produced co-spatially, very likely in short-lived shocks, somewhere at 0.1–1.0 pc from the center. Thus, as discussed in §4, multiwavelength studies of flares in blazars provide exceptional tools for exploring the structure and physics of jets on sub-parsec scales.

Jets are predicted to produce radiation not only by relativistic electrons (here and after the term ‘electrons’ is used for both electrons and positrons), but also by cold electrons. Streaming with a bulk Lorentz factor $\Gamma \sim 10$, the cold electrons Compton scatter the external optical/UV photons and boost them up to the soft X-ray range (Begelman & Sikora 1987; Sikora et al. 1997). It should be emphasized that cold electrons are an unavoidable constituent of jets near their base, where even mildly relativistic electrons cool faster than they propagate. And they can be present up to distances where non-thermal flares are produced, dragged by as-yet-unshocked portions of the flow. As yet, no soft X-ray excesses have been confirmed. The upper limits imposed on the number of cold electrons by observed soft X-ray fluxes exclude pure $e^+e^-$-jets and provide strong constraints on the minimum distance of jet acceleration and collimation (Sikora & Madejski 2000). These constraints, together with possible jet production scenarios, are discussed in §5.

Of course, any model of jet production should be able to explain the huge range of jet powers. Recent discoveries that many luminous radio-quiet quasars reside — like the radio-loud quasars — in giant ellipticals (Taylor et al. 1996; Kukula et al. 2000), and that the galaxy environments of the same luminosity radio-quiet and radio-loud quasars is similar (McLure & Dunlop 2000), challenge the previous claims that radio-loudness can be related to the morphology of the host galaxy or its clustering richness. Furthermore, optical/UV spectral
similarities (Francis, Hooper, & Impey 1993; Zheng et al. 1997) and recent discoveries that BAL (broad absorption line) systems exist also in radio-loud quasars (Brotherton et al. 1998; Becker et al. 2000) suggest that radio-loudness is not very dependent on the parsec-scale environment, as well. All the above strongly supports the so-called spin paradigm, according to which powerful jets, giving rise to radio-loud quasars, can be produced only with the help of rapidly rotating black holes. How the spin paradigm relates to central engine models and the evolution of quasars is discussed toward the end of §5.

2. Radio Lobes

What can we learn about jets from radio lobes? First of all, they provide very useful information about the energetics of jets, which, contrary to that derived from radio-core scales and smaller, is not biased by such uncertainties as jet bulk Lorentz factor, dissipation efficiency and variability. The procedure for deriving the jet power is simple, but not free of assumptions and approximations. The first step is to recover from the observed electromagnetic spectrum the energy distribution of electrons. This can be done using the following approximate formula:

\[ L_{\nu,\text{syn}} d\nu \simeq (N_{\gamma} d\gamma) m_e c^2 |\dot{\gamma}| \]

where

\[ |\dot{\gamma}| \simeq \frac{4 e \sigma_{\text{T}} u_B \gamma^2}{3 m_e c^2} \]

is the rate of electron synchrotron energy losses; \( u_B = B^2/8\pi \) is the magnetic energy density; and \( \nu \propto \gamma^2 B \). For power-law synchrotron spectrum \( L_{\nu} \propto \nu^{-\alpha} \), formula (1) gives \( N_{\gamma} \propto \gamma^{-s} \), where \( s = 2\alpha + 1 \). The above procedure is not sufficient to determine the normalization of the electron energy distribution, however. Additionally, one needs to know the intensity of the magnetic field, which can be estimated by assuming energy equipartition between electrons and magnetic fields. With this assumption, the electron (and magnetic) energy content of the quasar radio lobes is found to be in the range \( 10^{59} - 10^{61} \) ergs which, when divided by spectrally or dynamically determined ages of the radio lobes, \( t_{\text{lobe}} \sim 3 \times 10^7 \) years, gives jet powers \( 10^{45} - 10^{47} \) ergs s\(^{-1}\) (Rawlings and Saunders 1991).

There are several reasons why the above estimates should be considered as lower limits. First, the equipartition condition corresponds almost exactly with the minimum total energy of electrons and magnetic fields. Second, from the observed radio spectra one can deduce that most of the energy carried by electrons is contained in the low energy part of their distribution. Assuming that the electron distribution has a break at an energy corresponding with the lowest observable frequency \( \sim 10 \) MHz (limited by reflection of radio waves in ionosphere), one finds that \( \gamma_{\text{min}} \sim 500/\sqrt{B/10\mu G} \). Since there is no proof that radiation has an intrinsic cutoff at 10 MHz, the adopted value of \( \gamma_{\text{min}} \) can be greatly overestimated and the total electron energy content underestimated. Third, Rawlings & Saunders assumed no energy contribution from protons.

How much might the jet powers be underestimated due to the above assumptions? Detection of X-rays from hotspots of several nearby radio galaxies
and their interpretation in terms of the SSC (synchrotron-self-Compton) process allowed one to derive the magnetic field and electron energy densities without assuming equipartition (see Wilson, Young & Shopbell 2000 and references therein). Departure from the equipartition condition have been found to be very small. However, recent observations of X-rays produced around quasar radio lobes show that the pressure of the external gas is several times larger than the pressure in the radio lobes obtained assuming equipartition between electrons and magnetic fields and no proton contribution (Hardcastle & Worrall 2000). This inconsistency cannot be resolved, even assuming that the electron distribution extends down to $\gamma_{\text{min}} \sim 1$, if the equipartition condition is kept. There must be significant departure from equipartition between electrons and magnetic fields and/or the lobe pressure is dominated by protons. There are some observations suggesting that, indeed, the equipartition conditions can be violated in radio lobes, with particle pressure dominant over magnetic pressure (see Blundell and Rawlings 2000 and references therein). Yet another possibility is that extra pressure in radio lobes is provided by cosmic rays accelerated via the Fermi process operating in the boundary layer between a jet and the surrounding medium (Ostrowski 2000).

The rate at which energy is delivered to radio lobes can be estimated more directly, just from the bolometric luminosities of hotspots. The rate is

$$L_j = \frac{L_{HS}}{\eta_e \eta_{\text{rad}}}$$

(3)

where $\eta_e$ is the fraction of kinetic energy of a jet converted in the shock to relativistic electrons and $\eta_{\text{rad}}$ is the fraction of electron energy lost by radiation. If, in the radiative regime, the electromagnetic spectrum has a slope $\alpha \simeq 1$, then $\eta_{\text{rad}} \sim \ln(\nu_{\text{max}}/\nu_c)/\ln(\nu_{\text{max}}/\nu_{\text{min}})$, where $\nu_c$ is the “cooling” break, and $\nu_{\text{min}} \lesssim 10$ MHz. Applying this for hotspot D in Cyg A, where $\nu_c \sim 10^{10}$ Hz and $\nu_{\text{max}} \sim 10^{12}$ Hz, one can find that for $\nu_{\text{min}} = 10$ MHz, $\eta_{\text{rad}} \sim 0.4$.

Now, assuming that the energy dissipated in the hotspots is equally shared by electrons and magnetic fields, i.e., $\eta_e = 1/2$, and adopting from Meisenheimer et al. (1997) $L_{HS} \simeq 4 \times 10^{44}$ ergs s$^{-1}$, we obtain $L_j \sim 2 \times 10^{45}$ ergs s$^{-1}$. This estimate of $L_j$ is consistent with that deduced from the radio-lobe energetics (Carilli & Barthel 1996). In both cases the energy is underestimated only by a factor $3/2$, if there are protons and they equally share energy with electrons and magnetic fields. Unfortunately, hotspot spectra up to the highest synchrotron frequencies are currently available only for nearby radio galaxies and, therefore, the bolometric-luminosity method cannot be applied to distant quasars.

What about the pair content of radio-lobe plasmas? Noting that jets are approaching the hotspots with relativistic speeds, the average energy of shocked protons is expected to be of the order of the jet Lorentz factor. Thus, if the dissipated kinetic energy of a jet is initially shared equally by electrons, protons, and magnetic fields, the average electron energy should be $\gamma \sim (1/3)\Gamma(m_p/m_e)(n_p/n_e) \sim 600\Gamma(n_p/n_e)$. Since radio observations cannot follow electrons with energies lower than $\gamma \sim 500/\sqrt{(B/10\mu \text{G})}$, the pair content cannot be verified by radio lobe observations.
3. Parsec-scale Jets

In order to recover the physical parameters of radiating plasma in compact radio sources, one needs: to use the emissivity formula (like that in equation [1], but written in the source comoving frame); to transform the comoving luminosity and frequency to the observed ones; and to take advantage from two of the following:

- the value of the bulk Lorentz factor $\Gamma$ (if available from VLBI observations);
- X-ray flux, provided the X-rays are produced by the SSC process;
- synchrotron-self-absorption break;
- equipartition condition.

Such analyses have been performed for a large sample of compact radio sources by Ghisellini et al. (1992), who used (b) and (c), and for the series of compact radio components in 3C 345 and 3C 279 by Hirotani et al. (1999; 2000), who used (c) and (d). Among other aspects, they calculated electron energy distributions, $n_\gamma = C\gamma^{-s}$, assuming $\gamma_{\text{min}} = 1$, where $s = 2\alpha + 1$. This allows one to obtain electron energy densities, $u'_e \equiv n'_e(\langle \gamma \rangle m_e c^2)$, and then energy fluxes of relativistic electrons

$$L_e \sim u'_e \Gamma^2 \pi a^2 c$$

where $a$ is the cross-sectional radius of the source. For the studied sources, values of $L_e$ are in the range $10^{45} - 10^{47}$ ergs s$^{-1}$, provided $\gamma_{\text{min}} = 1$, and 2-3 times smaller, if $\gamma_{\text{min}} \gg 1$.

Hence, the energy fluxes of relativistic electrons alone come close to satisfying the energy requirements of radio lobes. However, one should note that the total energy flux also includes other forms of energy and, in general, we have:

$$L_j = \frac{L_e}{\eta_{\text{diss}} \eta_{e}(1 - \eta_{\text{rad}})}$$

where $\eta_{\text{diss}}$ is the fraction of the total jet energy which is dissipated and used to accelerate electrons, to heat protons and to amplify magnetic fields; $\eta_e$ is the fraction of the dissipated energy which is used to accelerate electrons; and $\eta_{\text{rad}}$ is the fraction of electron energy lost by radiation during the source lifetime. Thus, with the derived values of $L_e$, the total energy fluxes, $L_j$, become dangerously high, particularly if $\eta_{\text{diss}} < 0.1$ as intrinsic shock theories predict. Therefore, provided that the derived densities of relativistic electrons are not affected by systematic errors (noting their very strong dependence on the absorption-turnover frequency and the source geometry), one needs to postulate external shock models, with dissipation efficiencies $\eta_{\text{diss}} \geq 0.5$ (Dermer & Chiang 1998).

What is the pair content of the compact radio sources? Assuming that the dominant energy carriers are protons, we have

$$L_j \simeq L_{p,0} + L_{\text{diss}} = L_{p,0} + \delta L_p + L_B + L_e$$

where $L_{p,0} = n'_p m_p c^3 \pi a^2 \Gamma^2$ and $\delta L_p \simeq n'_p m_p (\langle \gamma_p \rangle - 1)c^3 \pi a^2 \Gamma^2$. Since

$$\frac{L_e}{L_{p,0}} = \frac{n'_e(\gamma)m_e}{n'_p m_p} = \frac{\eta_e \eta_{\text{diss}}(1 - \eta_{\text{rad}})}{1 - \eta_{\text{diss}}}$$

(7)
where $\eta_e = 1/(1 + L_B/L_e + \delta L_p/L_e)$, we obtain

$$\frac{n'_e}{n'_p} \simeq \frac{n_e}{2n_p} \simeq \frac{50}{\gamma_{\text{min}}}(3\eta_e)\frac{\eta_{\text{diss}}}{1 - \eta_{\text{diss}}}(1 - \eta_{\text{rad}})$$

(8)

where I used $\langle \gamma \rangle \sim 6\gamma_{\text{min}}$, which corresponds with $\alpha \simeq 0.6$.

Unfortunately, due to the synchrotron-self-absorption it is impossible to follow electrons with energies $\gamma < 50\sqrt{\nu_{\text{abs}}/1\text{GHz}}/(B/0.1\text{G})$ and determine $\gamma_{\text{min}}$ directly from the observed spectra. One can eventually try to determine the upper limits for the minimum electron energies from measurements of circular polarization provided such polarization results from the Faraday conversion mechanism. Measurements of circular polarization have been completed for several extragalactic sources (Homan & Wardle 1999) and at least in 3C 279 there are indications that circular polarization is produced by this mechanism and that $\gamma_{\text{min}} < 20$ (Wardle et al. 1998). For such $\gamma_{\text{min}}$’s the number of pairs per proton can range from a few up to tens. There are several indirect arguments in favor of rather low pair contents: (i) if pairs are produced in the central engine or its vicinity, then their flux is very limited by the annihilation process (Ghisellini et al. 1992); (ii) if pairs are created by nonthermal pair cascades operating in the jet shocks, they would produce much softer X-ray spectra than observed in Q-blazars (Ghisellini & Madau 1996); (iii) jets with a large number of cold electrons would produce soft X-ray bumps by Comptonization of UV disk radiation and BELs and such bumps have not been confirmed (Begelman & Sikora 1987; Sikora et al. 1997).

4. Q-blazars

Strong and fast variability in blazars is commonly interpreted in terms of the shock-in-jet model. Producing a flare of the observed time scale $t_f$, the shock passes a distance range

$$\Delta r_f \sim ct_f \Gamma^2 \sim 100(t_f/1\text{day})(\Gamma/10)^2 \text{ lt} - \text{days}.$$  

(9)

Sharp profiles of flares and comparable time scales of their rise and decay suggest that shocks are launched at distances $r_f \sim \Delta r_f$ (Sikora et al. 2000). The distance of flare production can be also estimated from the spectral location of the $\gamma$-ray luminosity peak, provided the peak is related to the break in the electron energy distribution caused by the cooling effect, i.e. that above the peak electrons radiate on time scales shorter than the lifetime of the shock. If $\gamma$-ray production is dominated by the ERC (external-radiation-Compton) process, and the luminosity of the ERC component is larger than the luminosity of the synchrotron component, then the spectral distance is

$$r_{sp} \sim ct_{sp} \Gamma \sim \frac{m_e c^2}{\sigma_T} \frac{1}{\nu_{\text{diff}} \sqrt{\nu_c}} \frac{1}{u_{\text{diff}}}$$

(10)

where the following relations were used: $t_{sp}' = |\gamma_c / \dot{\gamma}_c| \gamma / \Gamma \sim \Gamma^2 \gamma_c^2 \sigma_T u_{\text{diff}} / m_e c$; and $\gamma_c \simeq \sqrt{\nu_c / \nu_{\text{diff}} / \Gamma}$. It can be checked that both the variability distance, $r_f$, and
and the spectral distance, $r_{sp}$, are of the same order if $u_{diff} \sim 0.005$ ergs cm$^{-3}$, i.e., if $L_{BEL}(r_{fl}) \sim 10^{44}$ ergs s$^{-1}$, and/or covering of the central source by dust at $T = 1000$ K is $\sim 0.1$. Both quantities are consistent with our knowledge about BELR and near-IR radiation in quasars (Błażejowski et al. 2000).

Equations (9) and (10), combined with emissivity formulae for the production of X-rays via the ERC process (Błażejowski et al. 2000) and with given value of $L_{diff}(r_{fl})$, can be used to calculate the number of relativistic electrons involved in flare production and their energy flux, $L_e$. For $L_{BEL} \sim 10^{45}$ ergs s$^{-1}$ and $\Gamma$ calculated from the model, it can be found that $L_e \sim 10^{45}L_{SX,46}$ ergs s$^{-1}$, where $L_{SX}$ is the soft X-ray luminosity (Sikora et al., in preparation). Since soft X-rays are very likely dominated by the SSC process (Inoue & Takahara 1996; Kubo et al. 1998; Błażejowski et al. 2000), the above estimate should be considered only as the upper limit.

The electron energy flux, $L_e$, can be estimated also using the bolometric luminosity procedure. We have

$$L_e \sim \frac{\Omega}{4\pi} \frac{L_{QB}}{\eta_{rad}}$$

where $\Omega \sim \pi/\Gamma^2$ and $L_{QB}$ is the total apparent luminosity of a blazar. During high states $L_{QB}$ is dominated by luminosity in $\gamma$-ray bands and is of the order $10^{48-49}$ ergs s$^{-1}$ (von Montigny et al. 1995). From typical high energy spectra of Q-blazars ($\alpha \sim 1$ for $h\nu > 30$ MeV and location of $\nu_e$ in the $1-30$ MeV range), one can conclude that $\eta_{rad} \sim 1/2$ if $\gamma_{min} \sim 1$, and $\eta_{rad} \sim 1$ if $\gamma_{min} \sim 100$. With these numbers, and $\Gamma$ taken from the model calculations, we obtain $L_e \sim 1-2 \times 10^{45}(\Gamma/15)^{-2}L_{QB,48}$ ergs s$^{-1}$, which is of the same order as calculated using the X-ray flux. Noting that in Q-blazars $L_e$ is about 1-2 orders lower than $L_j$ estimated from radio lobes, and that $L_e = \eta_{diss}L_j(1-\eta_{rad})$, one can conclude that activity of the sub-parsec jets is governed by low dissipation efficiencies, very likely by intrinsic shocks. This conclusion can actually be reinforced by the fact that the high (flaring and radio active) states are not permanent, and after averaging over longer periods of time the values of $L_e$ are likely to be lower by at least a factor two.

If the main carriers of energy are cold protons, then from equation (8) the pair content is $n'_+ / n'_p \sim 5/\gamma_{min}$ for $\gamma_{min} < 5$, and is negligible for $\gamma_{min} > 5$, assuming $\alpha = 0.6$, $\eta_{diss} = 0.05$ and $\eta = 1/3$. Here, like in the radio lobes and compact radio sources, we have a sort of conspiracy regarding the value of $\gamma_{min}$. Since X-rays from blazars are presumably dominated by the SSC process, it is very difficult to follow the low energy portions of the ERC spectra to check whether there are any signatures of the low-energy cutoff in energy distribution of electrons. But at least we can say that a large pair content $n'_+ / n'_p \gg few$ can be excluded. One could speculate that there is a large number of cold pairs. However, this is excluded because such pairs, Comptonizing external UV photons, would produce a huge soft X-ray bump, which is not confirmed observationally.
5. Central Engine and Spin Paradigm

The absence of soft X-ray bumps in Q-blazar spectra provides strong constraints on the jet’s structure near its base. There, Comptonization of the disk radiation by cold electrons, dragged by the relativistic and well collimated jet, is predicted to produce a prominent X-ray bump even if number of pairs is zero. This suggests that powerful jets are wider and/or slower at their bases (Sikora & Madejski 2000). They can be launched by the innermost parts of the accretion disk, with the matter pulled from the disk surface and accelerated along the open magnetic field lines by centrifugal forces (Blandford & Payne 1982). Such proto-jets are probably collimated further away, by a disk corona or winds predicted by some models to be formed at distances $\gtrsim 100R_g$ (Rozanska & Czerny 2000; Murray & Chiang 1997; Proga, Stone & Kallman 2000). Yet in the acceleration zone, the initially proton-electron outflows can be loaded by $e^−-e^+$ pairs. This is due to boosting of the coronal hard X-rays by cold electrons in the outflow up to MeV energies and the subsequent absorption of MeV photons in the $\gamma\gamma$ pair production process. Depending on the geometry and kinematics of the proto-jet, the number of pairs per proton can reach a value ranging from a few up to a few tens.

The fact that only 10% of quasars are radio-loud implies that powerful jets are rare. It is very likely that the leading parameter which decides about the jet power is the spin of the black hole, defined as $A = J/J_{\text{max}}$ where $J_{\text{max}} = GM^2/c$ (Wilson & Colbert 1995; Moderski, Sikora & Lasota 1998). Perhaps the fast rotation of the black hole is necessary to heat the accretion disk. Due to this heating the innermost parts of the disk can be inflated and this can help to generate large scale magnetic fields, which are required both to accelerate MHD outflows and to link a disk with the rotating black hole and/or the gas plunging into the ergosphere (Meier 2000; Krolik 2000). Furthermore, extra heating of surface layers of the disk by a rotating black hole can help to put gas on magnetic field lines, if the latter are not bent enough to allow centrifugal forces to pull the gas directly from the photosphere.

Now, provided that the above scenario(s) gives a strong enough dependence of the jet power on the spin of the black hole to explain the huge range of radio-loudness, the next question which should be answered is how Nature managed to have only a small fraction of rapidly rotating black holes. Let us recall that accretion disks, acting enough long to double the black hole mass, spin up the holes to $A \sim 1$ (Bardeen 1970; Thorne 1974). On the other hand, once the black hole is spun up, it cannot be easily slowed down, certainly not during the low accretion phases during which the rate of extraction of black hole energy is very small because of its proportionality to $B^2 \propto \dot{M}$. Hence, if the spin paradigm is right and the growth of supermassive black holes is governed by the large accretion events, then the number of radio loud quasars should be larger than of radio quiet quasars, oppositely to what is observed. A solution of the problem can be that growth of the black hole in most objects is dominated by low-mass accretion events with random angular momentum orientations. This picture is supported by observations of Seyfert galaxies, which show that AGNs are randomly oriented relative to the host galaxy planes (Wilson & Tsvetanov 1994; Schmitt et al. 1996). Low-mass accretion events are also supported by analyses of the dynamics of Seyfert jet interactions with the host galactic gas which show
that the lifetime of these objects is of the order of $10^5$ years only (Capetti et al. 1999). Thus, it is tempting to speculate that only major mergers which involve at least a one gas-rich galaxy can lead to the accretion disk operating long enough to double the black hole mass and spin up the black hole to $A > 0.5$. During early phases of the process, when $A$ is still small, the quasar is predicted to show up as radio-quiet, and then slowly transform to a radio-loud one. After the fuel is off, the accretion drops, but spin of the black hole remains high and such an object can eventually be represented by FR I radio galaxies.

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