Electron positron pairs in blazar jets and $\gamma$–ray loud radio–galaxies

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1 INTRODUCTION

Relativistic extragalactic jets carry their power in the form of particles and fields. Estimating how many leptons and protons and the importance of the magnetic field flowing in the jet is not trivial, since these values depend on the model we use to explain the radiation we see, and to the presence of electron–positron pairs. The latter quantity has been a subject of investigation for a long time, with some consensus emerging about the scenario in which pairs are introduced, but not dominating the dynamics of the jet. This can be translated into a pair to proton number ratio of the order of a few tens. The arguments that have been put forward are the following.

(i) The spectra of powerful blazars are dominated by the high energy $\gamma$–ray component: the synchrotron luminosity is a factor $10^{10}–10^{11}$ erg cm$^{-2}$ s$^{-1}$ for a source at a redshift $z = 0.1$. The matter content of extragalactic relativistic jets is still an unsolved issue. There are strong arguments against pure electron–positron pair jets, but pairs could outnumber the electrons associated with protons by a factor $10–20$. This impacts on the estimate of the jet kinetic power, by reducing it by the same factor, and on the total energy delivered to leptons by the particle acceleration mechanism. Pairs cannot be created in the same jet–zone responsible for the high energy $\gamma$–ray emission we see in blazars, because the reprocessing of the created pairs would overproduce the X–ray flux. Copious pair creation could occur in the inner zone of the still accelerating jet, where the bulk Lorentz factor is small. It is found that the inner zone can produce a sufficient number of pairs to replenish the zone of the jet where most of the luminosity is emitted, but only if the $\gamma$–ray luminosity of the inner jet is above $10^{44}$ erg s$^{-1}$ at $\sim 1$ MeV. Since the beaming is modest, this emission can be observed at large viewing angles, and detected in radio–galaxies and lobe dominated quasars at the flux level of $10^{12}–10^{11}$ erg cm$^{-2}$ s$^{-1}$ for a source at a redshift $z = 0.1$.

(ii) If we have to produce enough pairs to contribute to the total lepton flux, by reducing it by the same factor, and on the total energy delivered to leptons by the particle acceleration mechanism. Pairs cannot be created in the same jet–zone responsible for the high energy $\gamma$–ray emission we see in blazars, because the reprocessing of the created pairs would overproduce the X–ray flux. Copious pair creation could occur in the inner zone of the still accelerating jet, where the bulk Lorentz factor is small. It is found that the inner zone can produce a sufficient number of pairs to replenish the zone of the jet where most of the luminosity is emitted, but only if the $\gamma$–ray luminosity of the inner jet is above $10^{44}$ erg s$^{-1}$ at $\sim 1$ MeV. Since the beaming is modest, this emission can be observed at large viewing angles, and detected in radio–galaxies and lobe dominated quasars at the flux level of $10^{12}–10^{11}$ erg cm$^{-2}$ s$^{-1}$ for a source at a redshift $z = 0.1$.

(iii) Therefore a large number of pairs must necessarily be produced in the inner jet (e.g. Blandford & Levinson 1995; Sikora & Madejski 2000). In these regions radiative cooling is severe, and pairs would quickly cool. If they are created copiously, such that their Thomson optical depth $\tau_\gamma \gg 1$, they would quickly annihilate in a dynamical time (i.e. the time needed for the region to double its size). The surviving pairs would correspond to $\tau_\gamma \ll 1$ in the inner jet (Ghisellini et al. 1992). This sets an upper limit to the number of pairs able to reach the parsec–scale, allowing Celotti & Fabian (1992) to constrain the amounts of pairs there.

(iv) Cold leptons, traveling with a bulk Lorentz factor $\Gamma$, would interact with the photons produced by the accretion disk and re–isotropized by broad line clouds and/or scattered by free electrons external to the jet (Begelman & Sikora 1987). The resulting emission would be narrowly peaked, and mainly in the soft X–rays. Observers within the $1/\Gamma$ beaming angle would see this radiation as a $\times$–ray “bump” superimposed on the continuum (Sikora & Madejski 2000; Sikora et al. 1997; Moderski et al. 2004; Celotti, Ghisellini & Fabian 2007). The absence of this feature sets constraints on the total amount of leptons, and argues against a jet dynamically dominated by e+e– pairs.

(v) If the main emission process of the $100 \text{ MeV} – 10 \text{ GeV}$ radiation we detect from blazars is the inverse Compton scattering of relativistic leptons off seed photons produced externally to the jet, then the pattern of the radiation, as seen in the comoving frame, is...
anisotropic (Dermer 1995). More power is emitted in the upward direction, and the emitting region must recoil. If the jet is “light”, only composed by e+e- pairs, the recoil would be enough to stop the bulk motion of the jet. In this way we can set an upper limit on the amount of pairs, that translates in an upper limit of 10–20 on the pair to proton number ratio (Ghisellini & Tavecchio 2010).

The presence of pairs in the region where most of the observed γ-rays are produced has important effects on at least two issues. The first is the jet power. In powerful Flat Spectrum Radio Quasars (FSRQs), if there is one cold proton per emitting lepton, then the jet is dominated by the bulk kinetic power of protons, \( P_p \). If instead there are \( \xi \equiv (n_e + n_p) / n_p \) leptons per proton, \( P_p \) can be reduced by the factor \( \xi \). The second issue concerns the acceleration mechanism. Shocks and reconnection processes are thought to accelerate both leptons and protons. If the number of proton equals the number of leptons, at least half of the available energy goes to protons. Instead, if pairs are present, most of the energy can go to leptons.

The total power budget of the jet can be reduced by the presence of pairs, and the aim of the present study is to explore the possibility to create pairs (through the \( \gamma \rightarrow e^\pm \) process) in the inner zone of the jet, where the plasma is still accelerating and the bulk Lorentz factor \( \Gamma \) is small. The pairs that survive annihilation in this compact region can then refillish the zone that produces the bulk of the radiation we see from blazars, characterized by a larger \( \Gamma \). If this mechanism is common, there is a clear observational consequence: misaligned sources, i.e. powerful radio-galaxies and lobe dominated quasars, should be strong emitters in the hard X-ray to soft \( \gamma \)-ray region. This is the diagnostic feature that provides the observational test for this scenario. The notation \( Q = 10^3 Q_X \) (in cgs units) is adopted.

2 THE INNER JET

The most likely mechanism for the acceleration of extragalactic jets is through the conversion of an initially dominant Poynting flux into kinetic power. In the inner jet, at a few Schwarzschild radii, the jet is still heavily magnetically dominated. If some dissipation occurs, accelerating electrons to relativistic energies, the resulting luminosity should be emitted by synchrotron radiation, with severe radiative losses. It is then likely that the emitting particles cannot reach high energies, and their highest emitted synchrotron frequency is well below the pair production threshold. Therefore most of the high energy emission must be produced through the inverse Compton process.

In the inner jet the bulk Lorentz factor must be relatively small, since the jet is just starting to accelerate. This implies that the radiation produced externally to the jet (in the disk, the corona, the broad line region) is not seen largely boosted in the comoving frame (see Fig. 2 of Ghisellini & Tavecchio 2009, GT09 hereafter). In turn this implies that most of the radiation of the inner jet is produced by the synchrotron process, unless it is self-absorbed. To produce a large amount of pairs we have these alternatives:

(i) The synchrotron flux itself extends up to MeV energies. This implies the presence of very energetic electrons, which is problematic because radiative cooling, in these regions, is very severe.

(ii) Most of the synchrotron flux is optically thin, produced by electrons with energies reaching \( \gamma \sim 100 \). One or two inverse Compton orders are enough to reach 1 MeV. Since the region is magnetically dominated, we expect a large ratio between the magnetic and radiation energy density, so that the synchrotron self-Compton flux is at most comparable with the synchrotron luminosity.

(iii) Most of the synchrotron flux is self absorbed, corresponding to small electron energies. In this case the high energy flux is produced by multiple scatterings. Most of the luminosity cannot be emitted through the synchrotron process, which is self-absorbed, and is emitted through the Comptonization process.

(iv) Sikora & Madejski (2000) considered yet another process to produce a significant luminosity at \( \sim \)MeV energies, through the interaction of coronal X-ray photons with cold leptons in the inner part of the jet (i.e. the “protojet”). These interactions boost the original X-ray photons to MeV energies, i.e. above threshold. The MeV photons are then absorbed and produce pairs; a fraction of these pairs can then load the protojet.

Since there are several ways to generate the required MeV luminosity, it is convenient not to specify its origin. We will therefore explore the observational consequences of the existence of a MeV luminosity large enough to produce enough pairs to feed the jet regions where most of the observed luminosity is produced.

We will then assume that in a conical jet of semi-aperture angle \( \psi \), a region located at a distance \( R_0 \) from the black hole produces an observed luminosity \( L_0 \), and that a fraction \( f \) of it is converted into electron positron pairs. We will assume that the inner jet is accelerating according to

\[ \Gamma_0 \beta_0 = \max \left[ \Gamma, \left( \frac{R_0}{3 R_S} \right)^{1/2} \right] \]

where \( R_S \) is the Schwarzschild radius and \( \Gamma \) is the final bulk Lorentz factor. The pair production process depends on the intrinsic compactness of the source, defined as

\[ \ell'_0 = \frac{\sigma_T L_0}{\psi R_0 R_S^2 m_e c^3} \]

where \( \delta_0 \equiv \psi / \Gamma (1 - \beta_0 \cos \theta_0) \) is the Doppler relativistic factor at \( R_0 \) and \( \theta_0 \) is the viewing angle.

The fraction \( f \) depends on \( \ell'_0 \) and on its spectrum. For \( \ell'_0 > 60 \) and for \( \nu L_0 \) spectra peaking in the MeV region, \( f \) reaches its maximum, which is nearly 0.1 (Svensson 1987). If the spectrum peaks at energies much larger than 1 MeV most of the absorbed energy is not transformed into rest mass of pairs, but in their kinetic energy, which is radiated away. Therefore the conversion efficiency is less. To maximize \( f \), we will assume that the spectrum indeed peaks at \( \sim \)MeV energies, but take into account the dependence of \( f \) on the compactness. Since the latter measures the optical depth for the pair production process, which becomes larger than unity for \( \ell_0 \gtrsim 60 \), we simply have (Svensson 1987):

\[ f = 0.1 \min \left[ 1, \frac{\ell'_0}{60} \right] \]

The pair production rate \( \dot{n}_\gamma (R_0) \) is then

\[ \dot{n}_\gamma (R_0) \sim 3 f L_0 \]

\[ 4 \pi (\psi R_0) \delta_0^2 m_e c^3 \]

If the optical depth of the created pairs is \( \tau_\gamma < 1 \), annihilation is negligible in one dynamical timescale (the time required for the region to expand doubling its radius) and we have

\[ n_\gamma (R_0) \sim \dot{n}_\gamma (R_0) \frac{\psi R_0}{\rho_0 c^2}, \quad \tau_\gamma (R_0) \leq 1 \]

Instead, when \( \tau_\gamma \gg 1 \), annihilation is faster than the dynamical timescale, bringing the optical depth of the surviving pairs close to unity (Ghisellini et al. 1992), giving
3 CONTRIBUTION OF PAIRS TO THE BLAZAR LUMINOSITY

Assuming number flux conservation, the density of pairs reaching the region where most of the blazar luminosity is produced is

\[ n_+(R_{\text{diss}}) = n_+(R_0) \left( \frac{R_0}{R_{\text{diss}}} \right)^2 \frac{\Gamma_0 \beta_0}{\Gamma \beta} \]  

(7)

Let us assume that all these pairs, when reaching \( R_{\text{diss}} \), are accelerated to relativistic energies, and form a particle density distribution \( N_+ (\gamma) \) as a result of continuous injection and radiative cooling. The observed luminosity produced by pairs is:

\[ L_{+\text{obs}} = V \delta \int N_+ (\gamma) \gamma^2 \sigma T \psi_R d\gamma \]  

(8)

where \( V \) is the volume of the emitting region, and \( \delta \) is the corresponding Doppler factor. If the emitting region is within the broad line region, located at a distance \( R_{\text{BLR}} \) from the black hole, the radiation density of the line photons is, as observed in the comoving frame:

\[ L_\text{BLR} = \frac{4 \pi c^2 \sigma T \psi_R}{\beta^2} \int \gamma^2 \sigma T \psi_R d\gamma \]  

(9)

This assumes that \( R_{\text{BLR}} = 10^{17} L_{1.45}^{1/2} \) cm, and that \( L_{\text{BLR}} = 0.1 L_d \) (GT09; \( L_d \) is the disk luminosity). Therefore, as long as \( R_{\text{diss}} < R_{\text{BLR}} \), the external radiation energy density is constant and independent of \( L_{\text{diss}} \). In powerful blazars this radiation energy density dominates over the energy density of internally produced synchrotron photons. Thus the contribution of pairs to the \( \gamma \)-ray luminosity, due to Inverse Compton (IC), is:

\[ \gamma_c = \frac{4 \sigma T c \gamma_0^2 \beta_{\text{IC}}^2}{9 \pi m_e c^2} = \frac{\gamma_0^2 \beta_{\text{IC}}^2}{9 \pi m_e c^2} \]  

(10)

With these assumptions \( L_{+,\gamma,\text{obs}} \) becomes:

\[ L_{+,\gamma,\text{obs}} = \frac{4 \sigma T c}{27} (\psi R_{\text{diss}}) \delta_+ \Gamma^2 \gamma_0^2 n_+(R_{\text{diss}}) \gamma^2 \]  

(11)

The factor \( \gamma^2 \) depends on the particle distribution. Since the observed high energy spectrum is peaked at a frequency \( \nu_c \), the \( N(\gamma) \) distribution must be a broken power law, with a break at

\[ \gamma_b = \left( \frac{3 \nu_c}{4 \nu_{\text{iso}} \beta_0} \right)^{1/2} \sim 300 \left( \frac{\hbar \nu_c}{100 \text{ MeV}} \right)^{1/2} \left( \frac{1}{\delta_0 \Gamma} \right)^{1/2} \]  

(12)

where we have assumed the \( \nu_{\text{iso}} \), as the typical frequency of the seed photons (that are observed blueshifted by a factor \( \sim \Gamma \) in the comoving frame).

The strong radiative cooling in powerful blazars implies that even low energy leptons cool in one light crossing time. This ensures that the low energy part of \( N(\gamma) \) cannot be flatter than \( \gamma^{-2} \). And indeed the X-ray spectrum in these sources is often characterized by a power law with a slope \( F(\nu) \propto \nu^{-\alpha_x} \), with \( \alpha_x \approx 0.5 \), corresponding to \( N(\gamma) \propto \gamma^{-2} \). As a rough estimate, we then have

\[ n_+(R_0) \sim \frac{1}{\sigma T \psi R_0} \quad \tau_+(R_0) > 1 \]  

(6)

At \( R_0 \) a density \( n_+(R_0) \) of pairs that survive annihilation is produced. These pairs, traveling along the jet, do not suffer further annihilation, because their optical depth decreases. Then they reach the region located at \( R_{\text{diss}} \gg R_0 \), where they are accelerated and produce a fraction of the flux we observed from a blazar. We want to estimate their contribution to the observed flux.

\[ L_{+,\gamma,\text{obs}} = \int \frac{\gamma^2 N(\gamma) d\gamma}{N(\gamma) d\gamma} \approx \gamma_b \]  

(13)

Then the contribution of pairs to the observed \( \gamma \)-ray luminosity is

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In principle, we can have three regimes: i) at very low values of the intrinsic \( L_0 = L_0/\delta_0^2 \), the production of pairs is not “saturated” (i.e. the \( \tau_{\gamma\gamma} \) optical depth for pair production is less than unity, and \( L_0 < 60 \)) and, furthermore, \( \tau_+ (R_0) < 1 \). In this case \( L_{+,\gamma,\text{obs}} \propto L_0^{1/2} \); ii) If \( L_0 > 60 \), but still \( \tau_+ (R_0) < 1 \), then \( L_{+,\gamma,\text{obs}} \propto L_0^{1/2} \); iii) If \( \tau_+ (R_0) > 1 \) then \( L_{+,\gamma,\text{obs}} \) reaches its maximum possible value and is therefore independent of \( L_0 \). In practice, case ii) corresponds to a very narrow range of luminosities, because when \( L_0 \) becomes larger than 60, then the pair optical depth quickly becomes larger than unity. Fig. 1 shows the amount of \( \gamma \)-ray luminosity produced by pairs at \( R_{\text{diss}} \), as a function of the \( \gamma \)-ray luminosity produced by the inner “protojet”. Different curves refer to different viewing angles. For this illustrative example, the adopted parameters are: the black hole mass \( M = 4 \times 10^9 M_\odot \); \( R_0 = 10 R_S \); \( R_{\text{diss}} = 10^3 R_0 \); \( \gamma^2 = 300 \); and \( \Gamma = 12 \). The diagonal grey line indicates \( L_{+,\gamma,\text{obs}} = L_{100,\text{X}} \). Both are observed luminosities. The flat part of these curves corresponds to saturation in the number

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(13)
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Figure 2. Example of a SED produced in the inner portion of an accelerating jet, at 10 Schwarzschild radii (solid red lines), where the bulk Lorentz factor is $\Gamma = 1.8$, and by a jet region located at $10^3 R_0$ (dot–dashed blue line), where $\Gamma = 12$. The dashed (black) lines are the contribution by the accretion disk, the IR torus and the X–ray corona. The viewing angle is $\theta_v = 3^\circ$ (top panel); $\theta_v = 10^\circ$ (mid panel) and $\theta_v = 40^\circ$ (bottom panel). The intrinsic luminosity (i.e. as measured in the comoving frame) is $L' = 10^{44}$ erg s$^{-1}$ in the outer region, and 10 times that for the inner component. The inner region dissipates more power than the outer one, but it is much less beamed. The dashed (red) line is the spectrum before the absorption due to the pair production process. The synchrotron emission of the inner jet is self absorbed (green solid line), and most of the radiation is produced by multiple inverse Compton scatterings. For reference, $\nu L_\nu = 10^{44}$ erg s$^{-1}$ corresponds to a flux of $4 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ for a $z = 0.1$ source, while $\nu L_\nu = 10^{48}$ erg s$^{-1}$ corresponds to a flux of $3.5 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ for a $z = 2$ source.

of pairs that can survive annihilation (i.e. $\tau_+ = 1$). As mentioned above, for typical parameters $L_{\gamma, \gamma} \propto L_{\gamma, X, \gamma}^{0.3}$. For this choice of $\Gamma$, the $\sim 1$ MeV luminosity of the “protojet” is larger than the luminosity produced at $R_{\text{diss}}$ for viewing angles larger than $\sim 10^\circ$.

Consider a powerful blazar emitting a $\gamma$–ray luminosity $\sim 10^{46}$ erg s$^{-1}$, observed at $\theta_v \sim 3^\circ$. If most of it is produced by pairs, the corresponding (observed) luminosity produced in the inner jet must be slightly larger than $10^{46}$ erg s$^{-1}$. If $\theta_v \sim 3^\circ$ the beamed radiation produced at $R_{\text{diss}}$ overwhelms the flux produced at $R_0$. We can ask what a misaligned observer would see. This is in part answered by the dashed line in Fig.1 if the viewing angle if $\theta_v = 40^\circ$, we see a luminosity from the inner jet close to $10^{45}$ erg s$^{-1}$. Fig.2 shows the SEDs corresponding to the two regions (located at $R_0$ and $R_{\text{diss}}$) for three different viewing angles.

The model used to construct these SEDs assumes that at $R_0$ the jet is magnetically dominated, and that the leptons there have small (albeit relativistic) energies, and produce self–absorbed synchrotron emission (solid green lines). Most of their energy is then released through multiple Compton scattering off these photons.

For the other features of the model, we refer the reader to GT09, where they are fully described. Following Eq (1) $\Gamma_0 = 1.8$ at $R_0$, and becomes 12 at $R_{\text{diss}}$. The dashed (red) lines at frequencies larger than $\sim 1$ MeV indicate the spectrum before being absorbed by the $\gamma$–$\gamma \rightarrow e^\pm$ process. The intrinsic (i.e. measured in the comoving frames) powers injected into the regions are $10^{45}$ and $10^{44}$ erg s$^{-1}$ at $R_0$ and $R_{\text{diss}}$, respectively. Due to beaming, the luminosity produced at $R_{\text{diss}}$ is dominating at all frequencies if the viewing angle is small, is comparable to the luminosity produced at $R_0$ for $\theta_v \sim 10^\circ$, and becomes unobservable for $\theta_v \sim 40^\circ$ or larger. The pair production rate at $R_0$ is sufficient to yield $\tau_+ > 1$. Therefore the surviving pairs correspond to an optical depth of unity, thus to a density $n_\gamma (R_0) = 1.2 \times 10^{16}$ cm$^{-3}$. Once arriving to $R_{\text{diss}}$, the corresponding density (see Eq.7) is $n_\gamma (R_{\text{diss}}) \sim 10^7$ cm$^{-3}$. If all these pairs are accelerated and emit, they would be enough to account for the entire radiation produced at $R_{\text{diss}}$. However, we have already discussed that a pure pair plasma would face severe difficulties (the jet would stop due to Compton drag). Thus a small fraction of protons is likely to be present.

The other parameters used to construct these models are listed in Tab.1 together with some derived quantities, such as the jet powers in the form of radiation ($P_\gamma$), of Poynting flux ($P_B$), relativistic emitting electrons ($P_e$) and cold protons ($P_p$). For the latter quantity we give two values: the first is assuming that there is one proton per lepton, while for the second there is only one proton every 20 leptons. The Poynting flux decreases from $R_0$ to $R_{\text{diss}}$, in agreement with the assumption that it is the cause for the jet acceleration. As a consequence, the kinetic power ($P_p + P_e$) increases.

We alert the reader that what shown here is only an illustrative example. There can be several factors affecting the exact values of the used parameters. As an example, both the emitting regions have been assumed to be homogeneous spheres, with a tangled magnetic field that is taken to be representative of the jet magnetic field. If the cause of the dissipation is magnetic reconnection, the listed $B$–field refers to the emitting region, and may be smaller than the magnetic field carried by the jet.

4 POWERFUL RADIO-GALAXIES AND LOBE DOMINATED QUASARS

Fig.2 shows that if the inner jet is the producer of the pairs that feed the $R_{\text{diss}}$ regions of the jet, then its luminosity must be rather large and not strongly beamed. This statement is rather general and independent of the specific adopted model.

As a consequence, misaligned blazars should be very strong hard X–ray sources (if their inner jet produce pairs copiously). If this scenario is correct, then powerful FSRQs, observed to emit $L_\gamma \sim 10^{46}$ erg s$^{-1}$, should have misaligned counterparts emitting at a level of $10^{45}$ erg s$^{-1}$ around 1 MeV. This means a flux of $\sim 4 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ for a source at $z = 0.1$. This is not far from the sensitivities of current hard X–ray instruments, such as the Burst Alert Telescope (BAT) onboard the Swift satellite (Ajello et al. 2009; 2012), and reachable (albeit at lower energies) in even short exposures by the Nu–Star satellite (Harrison et al. 2005). As a consequence, this scenario can be tested: if the inner jet regions produce pairs to feed the outer dissipation jet region, then misaligned radio loud AGNs should be strong emitters in the very hard X–ray range.

The luminosity of this $\sim$ MeV emission should be related to the $\gamma$–ray luminosity produced at $R_{\text{diss}}$, but the latter is visible
only in aligned objects, not in radio-galaxies and lobe-dominated quasars. Conversely, in aligned object we do not see the radiation produced at $R_0$. We need an isotropic component visible in both classes of objects, that is related to the jet power, hence to the $\gamma$-ray luminosity of blazars. There can be two options. The first is to compare energy of the radio lobes, assumed to be a calorimeter. The difficulty here is to estimate the lobe lifetime, to infer the measurement of the mass accretion rate, believed to be related to the jet power. The latter could be measured by the broad emission lines. Their luminosity gives a good estimate of the entire disk emission, hence of the mass accretion rate, hence of the jet power, hence of the $\gamma$-ray luminosity of an aligned source (i.e. a blazars, see e.g. Ghisellini et al. 2010; Sbarrato et al. 2012).

In other words: suppose that a radio-galaxy (or a lobe-dominated quasar) is found to emit $10^{44}$ erg s$^{-1}$ at $\sim 1$ MeV. Suppose to see broad lines in its optical spectrum, enabling to estimate a broad line region luminosity of $10^{42}$ erg s$^{-1}$. The accretion disk should then be a factor 10 more luminous, so $L_{\text{bol}} \sim 10^{44}$ erg s$^{-1}$. This is very approximately, of the order of the power $P_\gamma \sim L_{\text{bol}}/\Gamma^2$ carried by the jet in the form of radiation (Celotti & Ghisellini 2008; GT09), where $L_{\text{bol}}$ is the observed jet bolometric luminosity. If the latter is dominated by $L_\gamma$, we expect $L_\gamma \sim \Gamma^2 P_\gamma \sim \Gamma^2 L_{\text{bol}} \sim 10^{40} L_{\text{bol}}/\Gamma^2$ erg s$^{-1}$ (with an uncertainty of several). We then conclude (see Fig.1) that indeed the inner jet of the misaligned AGN could produce enough pairs to sustain the expected $\gamma$-ray luminosity of its aligned counterpart. With these (admittedly very rough) arguments, we can relate the luminosity of the inner jets of radio-galaxies and lobe-dominated quasars with the $\gamma$-ray luminosities that would be seen by an aligned observer.

## 5 CONCLUSIONS

Electron-positron pairs cannot be produced in the same region where most of the $\gamma$-ray luminosity of blazars is emitted, but there are no strong arguments against their creation in the inner part of the jet (at $\sim 10 R_0$), where the bulk Lorentz factor is small. The pairs that survive annihilation can feed larger regions of the jet (the “$\gamma$-ray zone” at $\sim 10^3 R_0$), and be re-accelerated there, to contribute significantly to the emission we see from blazars. The most efficient way to create pairs in the inner jet is through photon-photon collisions, requiring a relatively large luminosity peaked around 1 MeV. Since in these regions the bulk Lorentz factor is small, and the corresponding beaming angle is large, these large luminosities are observable in nearby misaligned sources, i.e. radio-galaxies. This is the observational test of the scenario: if a substantial number of pairs are contributing to the luminosity of powerful blazars, than powerful radio-galaxies should be strong hard X-ray emitters.

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### Table 1.

| Region | Size | $P_\gamma'$ | $B$ | $\Gamma$ | $\gamma_b$ | $\gamma_{\text{max}}$ | $s_1$ | $s_2$ | $\gamma_c$ | $\log P_1$ | $\log P_\text{B}$ | $\log P_e$ | $\log P_p$ | $\log (P_p/20)$ |
|--------|------|-------------|-----|-------|---------|-------------|-----|-----|---------|----------|----------------|-----------|-----------|-----------------|
| $R_0$  | 1.2 (10) | 1 | 4949 | 1.8 | 7 | 15 | -1 | 2 | 1 | 45.42 | 55.57 | 43.30 | 46.19 | 44.89 |
| $R_{\text{lass}}$ | 120 (1000) | 0.1 | 2 | 12 | 100 | 3e3 | -1 | 2.5 | 13 | 46.11 | 44.48 | 45.39 | 47.42 | 46.12 |