Radiation Processes in Blazars

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Abstract. We present an overview of the current theoretical models attempting to describe the structure and radiative processes operating in blazars and discuss the observational constraints that these models must confront. Many of these objects are found by CGRO to be strong high energy γ-ray sources. Their spectra consist of two broad components: the low-energy component, peaking between the infrared and soft X-ray band, and the high-energy component, peaking in the high energy γ-rays. The overall energetics is often dominated by the latter, by as much as an order of magnitude over the former. Both components show rapid large-amplitude variability, which indicates a very compact emission region.

Most current models for the structure of blazars, to avoid the problems with excessive opacity of γ-rays to pair production, invoke beaming of electromagnetic emission from the radiating matter moving in a jet pointed close to the line of sight towards the observer, in an analogy to the jet-like structure inferred from other observations. The non-thermal shape of the spectrum of the low-energy component as well as its polarization suggest synchrotron emission. For the high-energy component, most current models invoke Comptonization of the lower energy photons, either those internal to the jet, as in synchrotron self-Compton (SSC) models, or external to the jet (UV radiation from the accretion disk or from the emission-line region, or IR radiation from dust), as in External Radiation Compton (ERC) models. Comparison of the energy densities of the external radiation fields with the energy density of the synchrotron radiation field (both as measured in the jet comoving frame) suggests that while the SSC model may be adequate to explain the γ-ray emission for BL Lac objects, the ERC models are probably more applicable for flat spectrum radio-quasars (FSRQ).

1. INTRODUCTION

Blazars are extragalactic objects with core dominated, flat spectrum, variable radio sources. Radio spectra smoothly join the infrared-optical-UV spectra, and in all these bands flux is highly variable and polarized. These properties are shared by BL Lac objects as well as by most flat spectrum radio-quasars (FSRQ), and are successfully interpreted in terms of synchrotron radiation produced in relativistic jets and beamed into our direction [6,3]. This interpretation is strongly supported by direct observations of superluminal
motions observed in radio cores in VLBI data [42], and lays the grounds for
the unified scheme of radio-loud active galactic nuclei (AGN) [18].

As was recently discovered by CGRO, many blazars are strong and variable
sources of high energy $\gamma$–rays [43]; in a few sources, the spectrum extends up to
the TeV energies [32,33]. The $\gamma$–ray radiation forms a separate spectral com-
ponent, with the luminosity peak located in the MeV–TeV range. Variability
of GeV/TeV radiation itself provides evidence for relativistic speeds of radi-
ating plasma [29,14], and the lack of high energy $\gamma$–rays in AGNs other than
blazars proves that $\gamma$–rays must be at least as well collimated as synchrotron
radiation.

Production of high energy radiation was predicted many years ago by
synchrotron-self-Compton (SSC) models [19,27]. In this process, the same
electrons that produce synchrotron radiation also upscatter some of syn-
chrotron photons to $\gamma$–ray energies. However, as was recently recognized,
the SSC process is not necessarily the one which produces most of the $\gamma$–rays.
The competing process, at least in quasars, may be the Comptonization of ex-
ternal radiation. Models based on this process are called ERC (external radi-
ation Compton) and their original variants have been investigated by Dermer,
Schlickeiser, & Mastichiadis [13], Sikora, Begelman, & Rees [37], Blandford &
Levinson [4], Ghisellini & Madau [16]. Production of $\gamma$–rays is also predicted
by so-called hadronic models, where ultrarelativistic electrons/positrons are
injected by relativistic protons [25,24,1,10].

Different scenarios of $\gamma$–ray production in AGN jets are reviewed in §2.
Their predictions are confronted with multiwavelength spectral and variability
data in §3, and discussion of what we have learned already and can learn in the
nearest future about AGN jet physics from the blazar observations is presented
in §4.

2. PRODUCTION OF HIGH ENERGY $\gamma$–RAYS

The fact that the spectra of synchrotron components blazars extend up to
optical, UV, and even X–ray bands indicates that AGN jets contain highly
relativistic electrons/positrons, with Lorentz factors up to $10^4 - 10^6$. Energy
losses of such electrons are so rapid that they must be accelerated/injected in situ, i.e. at the locations where they radiate. These locations are the sites of the energy dissipation events, which propagate along the jet at moderate ($\Gamma \sim 10$) relativistic speeds. The dissipation events can result from interaction of the jet with external obstacles, annihilation of magnetic fields, and/or collisions of inhomogeneities in a jet [3]. During such events, a part of the dissipated energy is converted to relativistic electrons and protons.

Models based on the assumption that the high energy $\gamma$-rays are produced
by directly accelerated electrons are discussed in §2.1, while hadronic models
for $\gamma$–radiation production are reviewed briefly in §2.2.
2.1. ERC process vs. SSC process

Assuming that the momentum distribution of relativistic electrons is isotropic in the comoving frame of dissipative events [12] and that SSC and ERC operate in the Thomson regime, one can compare radiation production in these processes using formulae for electron cooling rates

\[
\left( \frac{d\gamma'}{dt'} \right)_{SSC} = \frac{4}{3} \frac{c \sigma_T}{m_e c^2} u'_S \gamma'^2
\]

and ( [39])

\[
\left( \frac{d\gamma'}{dt'} \right)_{ERC} \simeq \frac{16}{9} \frac{c \sigma_T}{m_e c^2} u'_{ext} \gamma'^2
\]

where \( \gamma' \) is the random Lorentz factor of relativistic electrons,

\[ u'_S = \frac{L'_S}{4 \pi a^2 c} \]

is the energy density of synchrotron radiation produced by the source with radius \( a \),

\[ u'_{ext} \simeq \Gamma^2 \xi L_{UV}/4 \pi r^2 c \]

is the energy density of the external radiation field [39], \( \xi \) is the fraction of the central radiation isotropized by reprocessing and/or rescattering at a distance scale corresponding with a distance \( \sim r \) from the central source, and all primed quantities are as measured in the source comoving frame.

Using formulae (1) - (4) one can find that

\[
\frac{L'_{ERC}}{L'_{SSC}} = \frac{(d\gamma'/dt')_{ERC}}{(d\gamma'/dt')_{SSC}} \simeq \frac{(\Gamma_j)^2 \xi L_{UV}}{L'_S}
\]

where \( \theta_j = a/r \). The above formula can be used to find the ratio of the observed SSC and ERC luminosities, provided that the angular distributions of radiation fields are known. For isotropic (tangled) magnetic field, the synchrotron radiation in the source frame is isotropic, and for jets with \( \theta_j \ll 1/\Gamma \), the observer located at \( \theta_{ob} \) sees \( L_S = D^4 L'_S \), where \( D = 1/(\Gamma(1 - \beta \cos \theta_{ob})) \) is the Doppler factor. As was pointed out by Dermer [11], this is not the case for the ERC process. Compton scattered radiation, as measured in the source comoving frame, can have quasi-isotropic distribution only for \( \Gamma \simeq \Gamma_{eq} \), where \( \Gamma_{eq} \) is the Lorentz factor at which the flux of the external radiation field is zero.

As was shown by Sikora et al. [39]

\[
\Gamma_{eq} \simeq \left( \frac{3}{16 \xi} \right)^{1/4}.
\]
At $r \ll 1$ pc, $\xi$ is provided by rescattering of central radiation by hot gas present in coronae or winds around accretion disks. Up to $r \sim 0.1 - 1.0\sqrt{L_{\text{UV}}}$ pc, this is dominated by the fraction of the central radiation converted to emission lines by optically thick clouds/filaments, and at larger distances, it is determined by the fraction of the central radiation reemitted by dust. For a typical quasar environment, $\xi$ is expected to be $\sim 0.01 - 0.1$, and, for such values, equation (6) gives $\Gamma_{\text{eq}} \leq 2$. This is much less than the Lorentz factors of AGN jets which are typically enclosed in the range $5 < \Gamma < 20$ and often reach values $> 10$ [42,30,26]. The external radiation is seen by the emitting cloud of plasma moving at $\Gamma > \Gamma_{\text{eq}}$ as coming from the front. In such a field, the Compton scattered radiation is produced with a highly anisotropic distribution, with a large deficiency of radiation scattered into the $\theta' > \pi/2$-hemisphere. As measured in the external frame, such radiation is beamed more strongly than the synchrotron radiation and the observed luminosity $L_{\text{ERC}} \propto D^6$. However, for comparable total emitted luminosities, the respective observed luminosities $L_{\text{SSC}}$ and $L_{\text{ERC}}$, if averaged over the $1/\Gamma$-cone, are also comparable. Then, for the case $\theta_j \sim 1/\Gamma$, for which the angular distribution of radiation within the $1/\Gamma$-cone is smeared out, the formula

$$L_{\text{ERC}}/L_{\text{SSC}} \sim L'_{\text{ERC}}/L'_{\text{SSC}} \sim (\Gamma \theta_j)^2 \frac{\xi L_{\text{UV}}}{L_S} \Gamma^4$$

(7)

can be used for all $\theta_{\text{obs}} \leq 1/\Gamma$-observers. Since in quasars $\Gamma \sim 10$ and $\xi L_{\text{UV}} \sim 10^{44} - 10^{45}$ erg s$^{-1}$, while $L_S$ observed in FSRQ is in the range $10^{46} - 10^{47}$ erg s$^{-1}$, the above formula seems to prove strong domination of the ERC process over the SSC process in quasar jets.

However, it should be noted here that because of the different energy distributions of the ambient radiation fields, the respective high energy components produced by a given population of electrons will not overlap entirely. As a result, a less luminous SSC component produced by far infra-red radiation can still be visible in soft/mid X-rays [20], while relativistic electrons injected at a distance $\sim 1$pc can produce in the MeV range two separate “bumps”, one due to Comptonization of external UV radiation and one due to Comptonization of external near-IR radiation.

The situation is less clear in BL Lac objects, where the radiative environment in the central region is not very well known. The lack of strong emission lines and of UV excesses (even during lowest states) suggest that in these objects $\xi L_{\text{UV}}$ can be very low. Noting also that in BL Lac objects $\Gamma$ factors are typically smaller than in quasars [30,26], domination of SSC over ERC in these objects is very likely.

One should be warned, however, that for BL Lac objects with the high energy spectra extending up to TeV energies the formula (7) cannot be applied directly; this is because the Klein-Nishina effect reduces the efficiency of the Compton process, and this reduction is different for different energy distributions of the ambient radiation fields.
2.2. Hadronic Models

In all particle acceleration processes, the injection of relativistic electrons/positrons is accompanied by injection of relativistic protons. Their energy can be converted to high energy radiation following such processes as direct synchrotron radiation of protons, proton-photon pair production, photomeson production, and nuclear collisions. The first three processes are known to be very inefficient, and in AGN jets can become important only for proton energies $\geq 10^8 - 10^{10}$ GeV. Only for such high energies can the time scales of the proton energy losses become comparable to or shorter than the propagation time scale of the source in a jet. Energy losses of such energetic protons are dominated by photomeson production, and this process was used by Mannheim and Bierman [25] to model $\gamma$–ray production in luminous blazars.

The radiation target for photomeson production is dominated by the near/mid-infrared radiation. In quasars, such radiation is provided by hot dust at distances $\sim 1 - 10$ parsecs from the central source and by synchrotron radiation in a jet, produced by directly accelerated electrons. The main output of the photomeson process are single pions. They take about 30% of the protons’ energy and convert it to photons, neutrinos, and through muons, to electrons and positrons. The photons injected by neutral pions are immediately absorbed by soft photons in the pair production process. These pairs and electrons/positrons injected by muons have Lorentz factors $\gamma' \geq 10^{11}$. For such energies, Compton scattering with the ambient radiation field takes place deeply in the Klein-Nishina regime and, therefore, their energy losses are dominated by synchrotron radiation. Most of this radiation is so energetic that it produces two more generations of photons and pairs. The final output of this synchrotron-supported pair cascade is the high energy component, enclosed within or cut off at energies above which photons are absorbed by $\gamma\gamma$-pair production process. This maximum energy can be $\sim 30$ GeV in FSRQ, as determined by external UV radiation, and $\sim 1$ TeV in low luminosity BL Lac objects, as determined by infrared radiation of dust [31].

The weakness of the “photomeson” model is that it requires fine tuning in order to avoid situations where the luminosity peak lies below MeV energies. This is because, after 3 pair generations, the location of the peak depends on the 6th power of the maximum proton energy. Also, even if a model is successful in locating the peak of the high energy component, there is still the problem of how to obtain the hard X–ray spectra after three generations of the pair cascade process [40]. To overcome this difficulty, Mannheim [24] proposed that transition from softer $\gamma$–ray spectra to harder X–ray spectra results from a break in the pair injection function. This, however, requires the ambient radiation to be transparent to $\gamma$–rays up to energies $\sim 10\sqrt{\Gamma/B'}$ TeV, while external UV and near-IR radiation fields are expected to cut the spectrum in quasars at $\sim 30$ GeV for $r < \sqrt{L_{UV}}$ pc and at $\sim 1$ TeV for larger
distances.

The photomeson scenario was also suggested to explain the production of TeV radiation in low luminosity BL Lac objects [31]. The recent discovery of variability on time scales < 1 hour seems to jeopardize this idea. This is because to get proton energy losses on such short time scales, much higher IR luminosities are required than are observed.

Much less extreme proton energies are required in models based on the assumption that proton energy losses are dominated by collisions with the ambient gas. The final output of these collisions is the same as in the photomeson process, i.e., relativistic electrons/positrons, photons and neutrinos. The process can be efficient only if the column density of the target is \( n_H \geq 10^{26} \) cm\(^{-2}\). Bednarek [1] proposed as a target the funnels formed around the black hole by a geometrically thick disk, while Dar and Laor [10] suggested interactions of jet with clouds and/or stellar winds. The shortcoming of such models is that relativistic protons, before colliding with the nuclei, may easily suffer deflections by magnetic fields; this generally results in a lack of collimation of the radiation produced following pp collisions.

3. MULTIWAVELENGTH SPECTRA

3.1. ERC and SSC luminosities vs Synchrotron Luminosity

If both high-energy and low-energy spectral components are produced by the same population of relativistic electrons, and the production of high energy radiation is dominated by the SSC process, then

\[
\frac{L_{SSC}}{L_S} \sim \frac{L'_{SSC}}{L'_S} \sim \frac{u'_S}{u'_B}
\]

(8)

where \( u'_B = (B')^2/8\pi \) is the energy density of magnetic field. Equations (3) and (8) give

\[
u'_B \simeq \frac{1}{4\pi a^2 c \Gamma^4} \frac{L_S^2}{L_{SSC}},
\]

(9)

which, in the case of steady flow with \( \theta_j \sim a/r \), determines the flux of magnetic energy

\[
L_B \simeq c u'_B a^2 \Gamma^2 = \frac{1}{4\Gamma^2} \frac{L_S^2}{L_{SSC}}.
\]

(10)

For \( \Gamma \sim 10 \), \( L_S \sim 10^{46} - 10^{47} \text{ergs}^{-1} \) this gives \( L_B \sim 10^{43} \text{ergs}^{-1} \), which is about 3 orders of magnitude less than the typical power of the quasar jets [34,8,15].
Thus, the observed high γ-ray luminosities can be explained in terms of the SSC models only if one assumes that the jets are very weakly magnetized.

In the case of ERC models we have

\[
\frac{L_{\text{ERC}}'}{L_{\text{S}}'} \sim \frac{u'_{\text{ext}}}{u'_B}, \quad (11)
\]

and provided that \( L_{\text{ERC}} \) and \( L_{\text{S}} \) are luminosities observed at \( \theta_{\text{obs}} \leq 1/\Gamma \) and that \( \theta_j \sim 1/\Gamma \), we can use the scaling \( L_{\text{ERC}}/L_{\text{S}} \sim L_{\text{ERC}}'/L_{\text{S}}' \). With this scaling equations (4) and (11) give

\[
u'_B \simeq \Gamma^2 \frac{\xi L_{\text{UV}}}{4\pi r^2c} \frac{L_{\text{S}}}{L_{\text{ERC}}}, \quad (12)
\]

This gives

\[
L_B \simeq c\nu'_B \pi a^2 \Gamma^2 = \frac{(\theta_j\Gamma)^2}{4} \Gamma^2 \xi L_{\text{UV}} \frac{L_{\text{S}}}{L_{\text{ERC}}}, \quad (13)
\]

which is 2-3 orders of magnitude greater than in the case of the SSC model.

Another interesting aspect of comparing ERC and SSC radiation components with the synchrotron component is the angular distribution of these radiation fields. As was shown by Dermer [11] and discussed in §2.1, ERC radiation is much more strongly collimated than the synchrotron and SSC radiation. Since SSC and synchrotron radiation fields have the same angular distribution (they both are produced isotropically in the source comoving frame), the predicted high-energy to low-energy luminosity ratio doesn’t depend on \( \theta_{\text{obs}} \). In contrast, the ERC model predicts this ratio to drop very rapidly with viewing angle outside the 1/Γ-cone. Dermer proposed that this can explain why a significant fraction of FSRQ do not show γ-ray activity, even though they are otherwise recognized as typical blazars on the basis of the low energy component properties.

### 3.2. Production of X-rays

X-rays in different sub-classes of blazars can have different origins. In most BL Lac objects X-ray spectra are steep (\( \alpha \sim 1 - 3 \)) and variable, and lie on an extrapolation of the UV spectrum. This indicates that X-rays in these objects represent high energy tails of the synchrotron component. In FSRQs, the X-ray spectra are usually very hard (\( \alpha \simeq 0.5 - 0.7 \)), showing weaker variability than in other spectral bands. These spectra are often interpreted as low energy tails of the γ-ray components; however, one cannot exclude the possibility that they are superposed from two or more components. And finally, there are intermediate objects where the soft X-rays are dominated (at least occasionally) by the synchrotron component, while higher energy X-rays
belong to the high-energy Compton component [23]. These differences in the
X–ray spectra seem to follow the general trend where in less luminous blazar,
the peaks of the low-energy (synchrotron) component are located at higher
energies [36,20].

The simplest interpretation of the hard X–ray spectra of FSRQs is that,
together with the γ–rays, they form a single component produced by the ERC
process. In the model, the spectral slope changes from a steeper one in the
γ–ray band to a harder one in the X–ray band, as a result of incomplete
cooling of electrons below certain energy which is determined by an equality
of the ERC cooling time scale and the propagation time scale [37]. The break
is located in the 1 – 30 MeV range if the distance of radiation production is
\(~ 0.1 – 3\) pc.

In ERC models, the X–ray spectra imprint the distribution of Lorentz fac-
tors of relativistic electrons down to \(\gamma’ \sim 10\) for the X–rays produced by
Comptonization of IR radiation, and even down to \(\gamma’ \sim 1\) for the X–rays
produced by Comptonization of UV radiation. Since for distances > 0.1 pc
the low energy electrons cool very inefficiently, to produce the observed X–ray
flux by ERC process requires such a large number of electrons that the jet
must be strongly pair dominated in order to avoid unreasonable high kinetic
energy flux.

Another possibility is that hard X–ray spectra are superposed from partial
spectra produced over a wide range of distances and having low-energy cutoffs
at energies which increase with distance [38]. In this model, the soft X–rays
are produced closely to the black hole, and therefore the production of X–rays
can be accomplished by a lower number of electrons, and thus the jet plasma
need not be pair-dominated.

Finally, the hard X–ray spectra can be produced by SSC radiation, while
production of high energy γ–rays can be dominated by ERC process [20]. In
this model, a wide range of \(n_e/n_p\) is acceptable.

### 3.3. Bulk-Compton Radiation

Very interesting constraints on the AGN jets come not only from what we \textit{do}
observe, but also from what we \textit{do not} observe. A feature that was predicted
– but not confirmed observationally – is radiation produced by cold electrons
in a jet. Such electrons, dragged by the protons and/or magnetic fields in the
jet, for \(\Gamma > \Gamma_{eq}\), should scatter external UV photons and produce a collimated
beam of bulk-Compton radiation [2,39]. The predicted observed luminosity is

\[
L_{BC} \sim \Gamma^2 n_e \pi a^2 r dE_e / dt
\]

where

\[
\frac{dE_e}{dt} = \frac{4}{3} c \sigma_T \xi u_{ext} \Gamma^2,
\]
\[ u_{\text{ext}} \sim L_{UV}/4\pi r^2c, \] and \( r \) is the distance at which this process is most efficient. The bulk-Compton spectrum should have a peak at \( h\nu_{BC} \sim \Gamma^2 n_{UV} \sim 1\text{keV} \). Since this is not observed, \( L_{BC} \) must be smaller than the luminosity \( L_{SX} \) of the nonthermal X–ray spectrum in the soft X–ray band. This gives an upper limit for the Thompson optical thickness in a jet

\[ \tau_{j,\text{max}} \equiv n_{e,\text{max}} a \sigma_T \sim \frac{3}{\Gamma^3(\theta_j \Gamma)} \frac{L_{SX}}{\xi L_{UV}} \tag{16} \]

i.e., \( \sim 0.03 \) for \( \Gamma \sim 10 \), \( L_{SX} \sim 10^{46} \text{erg s}^{-1} \), and \( \xi L_{UV} \sim 10^{45} \text{erg s}^{-1} \). With this limit, the processes scaled by \((\tau_j)^2\) (like annihilation, bremsstrahlung and Coulomb interactions) are inefficient, and play a negligible role in shaping the spectra of blazars. This is because in such thin plasmas, the time scales of these processes are much longer than the time scale of plasma propagation in a jet [9].

The upper limit for \( \tau_j \) also gives interesting constraints on the \( e^+ e^- \) pair content of a jet. If \( r_{\text{min}} \) is the radius where \( \tau_j \) is maximal and if for \( r > r_{\text{min}} \) the pair flux is conserved, then for a conical jet \( \tau_j \propto 1/r \) and, therefore, the bulk-Compton radiation is mostly contributed by the innermost parts of the jet. Assuming that the kinetic energy flux in a jet is dominated by cold protons, we have

\[ L_K \simeq n'_p m_p c^3 \pi a^2 \Gamma^2 \tag{17} \]

where \( n'_p \) is the number density of protons in the jet comoving frame. Noting that \( n_p = n'_p \Gamma \), we have

\[ n_e \simeq n_p \frac{L_K \Gamma}{n_p \pi m_p c^3 a^2 \Gamma^2}. \tag{18} \]

Substituting this into the formula for \( L_{BC} \) evaluated for \( r = r_{\text{min}} \), we obtain

\[ L_{BC} \simeq \frac{n_e}{n_p} \frac{r_g}{r_{\text{min}}} \frac{L_K}{L_{Edd}} \xi L_{UV} \Gamma^3, \tag{19} \]

where \( L_{Edd} = (4\pi m_p c^3 / \sigma_T) r_g \). Then, the condition \( L_{BC} \leq L_{SX} \) gives that for powerful \((L_K \sim L_{Edd})\) and pair-dominated \((n_e \gg n_p)\) jets, overproduction of soft X–rays can be avoided only at very large distances \((10^3 - 10^5 r_g)\) from the black hole.

### 4. SUMMARY

Discovery of strong and variable \( \gamma \)–ray radiation in blazars by CGRO provided an exceptional possibilities to explore and verify the operation of various nonthermal processes in AGN jets, and to study the structure, energetics and
matter content of these jets. The main achievements of such studies and future prospects are listed below:

- $\gamma$-ray radiation provides independent evidence that blazar radiation is produced by relativistic jets [29,14]. This is because the compactness of the source derived from the observed $\gamma$- and X-ray luminosities and variability time scales is so high that if it was intrinsic (true) compactness, all $\gamma$-rays would be absorbed by $\gamma\gamma$ pair production process. This implies that the true source compactness must be much lower than the observed one, and this is the case if the observed radiation originates from plasma propagating in our direction at relativistic speed.

- $\gamma$-rays can be also absorbed by external radiation fields, and because the compactness of such fields decreases with distance, this gives the minimum distance from which the $\gamma$-rays can escape. Of course, since the opacity for $\gamma\gamma$ interactions depends on energy and is higher for more energetic $\gamma$-rays, the minimum escape distance is smaller for less energetic $\gamma$-rays. Such stratified $\gamma$-ray production was suggested by Blandford and Levinson [4] in their inhomogeneous version of ERC model.

- Huge apparent $\gamma$-ray luminosities, reaching in some FSRQ $10^{48} - 10^{49}$ erg s$^{-1}$, provide independent evidence that AGN jets must be very powerful, with $P > (L_\gamma/\Gamma^2)/\epsilon_{rad}$, i.e., $\sim 10^{46}$ erg s$^{-1}$ for radiation efficiency $\epsilon_{rad} \sim 0.1$, $\Gamma \sim 10$ and time-averaged observed luminosity $\bar{L}_\gamma \sim 10^{47}$ erg s$^{-1}$.

- Comparison of the ERC efficiency with the SSC efficiency for typical quasar radiation fields implies that the production of $\gamma$-rays in FSRQ should be strongly dominated by Comptonization of external radiation. However, SSC can still contribute visibly to the X-ray band [20].

- The hadronic models have problems explaining hard X-ray spectra in FSRQ and very short variability time scales in TeV BL Lac objects.

- Comparing ERC and SSC spectra with the synchrotron spectra, one can attempt to derive physical parameters of radiating plasma - such as maximum electron energies, magnetic fields, electron injection function, and distance of the source from the black hole [37,17,38,41,28]. However, such analyses must be performed by taking into account that the observed spectra, especially their lower energy parts (in both the synchrotron and the Compton components) may well be superposed by two or more components.

- In the case of FSRQ, simultaneous observations in the $\gamma$-ray and X-rays bands must be used to verify various mechanisms of X-ray production. This can help to establish the pair content in AGN jets. In particular, the correlation and absence of a time lag between the $\gamma$-ray and the X-ray flares (as seen in Jan, 1996 in 3C279; [44]) may indicate co-spatial production of both, and in the case of X-rays produced by the ERC process, this would indicate a pair-dominated plasma.

- Soft X-ray limits for the bulk-Compton process prove that AGN jets are
optically thin. This implies that such processes as bremsstrahlung, annihilation and Coulomb interactions are inefficient in these jets.

- For a given $n_e/n_p$, the upper limit for the bulk-Compton radiation gives a minimum distance for jet formation. For strongly pair-dominated plasmas this distance is $0.1 - 1.0$ pc. However, jets with energy flux $P \geq 10^{46}$ erg s$^{-1}$ must be powered very near the black hole, by its rotation [7] or by the innermost parts of an accretion disk [5]. These two inferences – the large distances of formation of pair-dominated jets and the very central source of the jet energy – can be reconciled if over the first 3 decades of distance, the jet is strongly dominated by the Poynting flux. This very wide distance range of conversion of the magnetic energy to the bulk kinetic energy can result from radiation drag [22]. This transition process can be accompanied by pair production in shocks and magnetic field reconnection sites [21,35].

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