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GAMMA RAYS FROM ACTIVE GALACTIC NUCLEI

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ABSTRACT

The general properties of Active Galactic Nuclei (AGN) and quasars are reviewed with emphasis on their continuum spectral emission. Two general classes of models for the continuum emission are outlined and critically reviewed in view of the impending GRO launch and observations. The importance of GRO in distinguishing between these models and in general in furthering our understanding of AGN is discussed.

I. INTRODUCTION

In this talk I will review in very broad terms the status of our current understanding of AGN. The subject of AGN is a vast one and occupies a large number of theorists and observers working on such diverse energy bands as radio and γ-rays. The short space allocated for this review is by no means sufficient to even touch upon these very diverse subjects in a comprehensive manner. Due to the very general and broad character of this review I apologize to the many authors whose work I am unable to quote and give proper credit.

There have been over twenty five years since the discovery of quasars and despite much observational and theoretical effort we lack a fundamental understanding of the physics of these objects. The few facts that have become generally accepted after much observational effort and debate is that quasars indeed represent extremes of galactic nuclear activity. In that sense are very similar to the Seyfert I galaxies that had been known for some time, except for their much greater luminosities. In fact, as it will be soon discussed, this similarity does not pertain only to their morphology but also to the spectral distribution of their radiation. Another fact for which consensus has been reached is that quasars and Seyfert galaxies along with an additional number of classes of objects (e.g. Seyfert IIs, BL Lacs, OVVs, LINERs etc.), collectively known as Active Galactic Nuclei, derive their
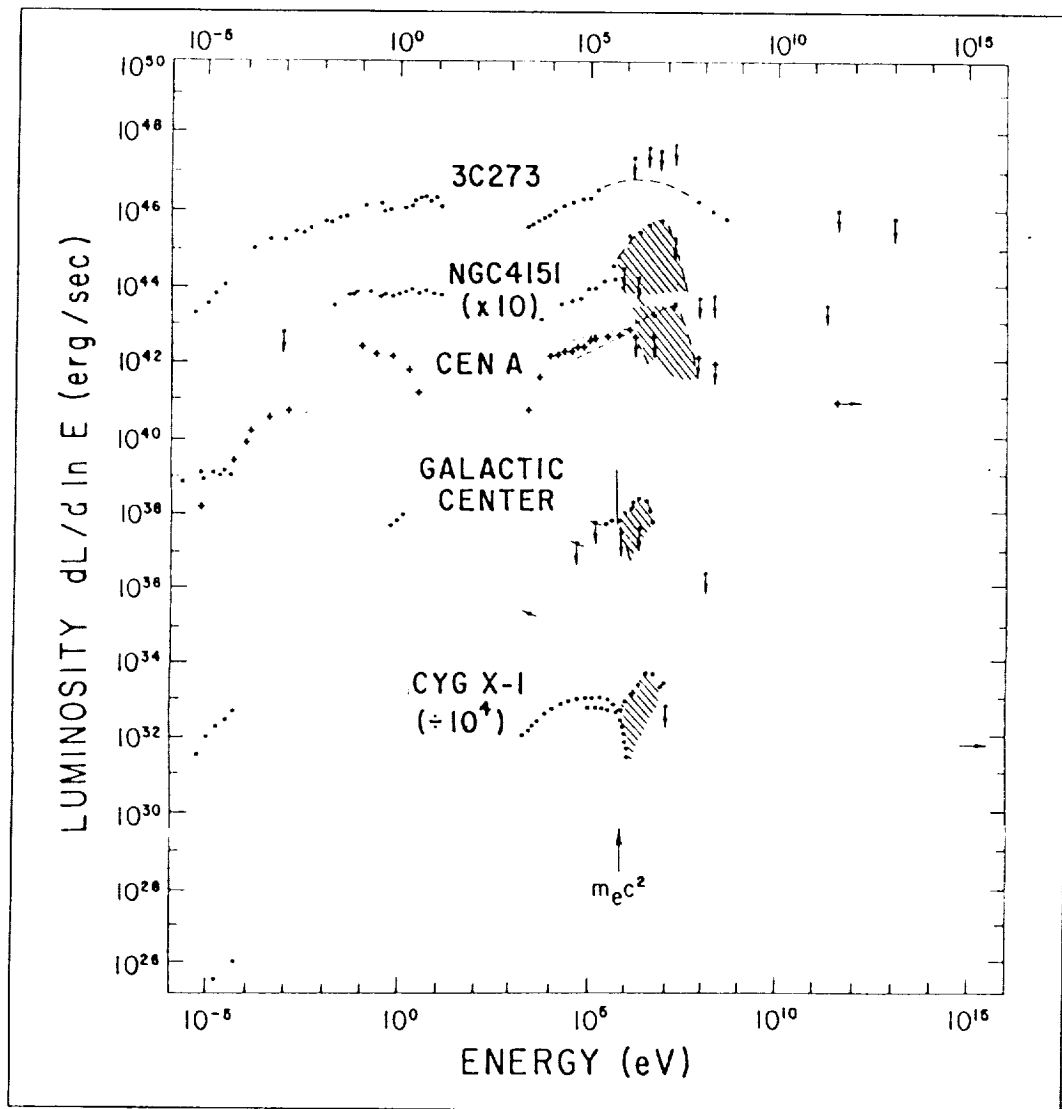
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Figure 1. The broad band spectra of five accreting compact sources plotted in energy per decade versus frequency over the whole electromagnetic spectrum. The top three belong to AGN: A quasar (3C 273), a Seyfert I galaxy (NGC 4151) and a radio galaxy (Cen A). The other two spectra correspond to galactic objects (from Lingenfelter 1987).

power from accretion of matter onto a compact object, most likely a massive black hole (Rees 1984). This conclusion has been reached mainly on the basis of the observed rapid variability and arguments concerning their efficiency of radiation emission.

This is however where the consensus ends. Beyond this point opinions tend to diverge as to the many aspects of the problem; there is very little agreement even on the source of the matter that presumably powers by its accretion these objects. The fact that every energy band (from radio to γ-rays) seems to contain a sizable fraction of the total bolometric luminosity (see e.g. figure 1) gives confidence to the respective observers that they are looking at some important feature of the puzzle of the mechanism that powers these

objects. In addition, having agreed that accretion is the ultimate energy source of these objects, the physical conditions near the black hole (where most of the energy is generated) are coupled to the physical conditions at much larger radii, where quite likely the source of accretion material resides. In addition to this dynamical coupling there is coupling of these regions through radiation transfer (e.g. by reprocessing part of the continuum radiation) which in general also changes the frequency of the transfered photons; this effect could in turn affect the local physical conditions thus changing the dynamics of accretion and so on. We are hence faced with the possibility of quite a complex system that (possibly but not necessarily) interrelates the dynamics and the radiation transfer and which spans 6-12 decades in frequency and over 4 decades in radius, and which might not even be in thermodynamic equilibrium. It should not therefore be surprising that not much progress has been achieved towards the "understanding" of these objects.

At this point one should reflect for a moment as to what is meant by "understanding", since this will determine not only when this goal has been achieved, but also strategies necessary for its achievement. It is my view that an "understanding" of these objects will have been attained when, through the dynamics of accretion, one is possible to account for their *major* spectral features and at the same time address their *major* morphological characteristics, along with the general aspects of their evolution, without the use of an inordinate number of free parameters (I personally would not allow for more than two). It is instructive to consider a class of astrophysical objects for which such an "understanding" has indeed been achieved, namely that of stars; as it is well known the general features of the spectral types of the main sequence and the general aspects of stellar evolution can be "understood" rather simply in terms of hydrostatic equilibrium, energy generation by nuclear reactions and *one* free parameter, namely their mass. Interestingly, for the stars it was their energy generation mechanism that was least understood, thus completely obscuring all the aspects of their evolution; once nuclear reactions were incorporated into the problem the right ages and the general evolutionary features of stars became apparent. In AGN, on the contrary, we think we understand the ultimate energy source (accretion), but we apparently do not understand the mechanism by which accretion energy is converted to radiation; therefore it becomes impossible to predict or understand the frequency distribution of emitted radiation. This lack of understanding of the central engine then percludes the further understanding of the other aspects of the problem (i.e. morphology and evolution).

The large number of decades in frequency over which the radiation is observed and the potentially large number of radii which could contribute to the radiation emission at a particular frequency, suggest that the problem under examination is inherently complicated and there may not necessarily exit a simple (i.e. of one or two parameters) solution to it. One can in fact easily think of a number of parameters that could in principle be relevant to the dynamics and/or radiation emission from these objects (such as the mass, the accretion rate, the specific angular momentum, the magnetic field, the angle to the line of sight). Bearing in mind the variety of features in the one parameter class of astrophysical objects we "understand", namely that of stars, one would in principle expect a much larger variation in the properties of the central engine alone. Actually, considering the above arguments, the spectra of AGN appear to be surprisingly similar in their general

outline. This is exemplified in figure 1 taken from Lingenfelter (1987), where the spectra of three morphologically different classes of AGN are presented, spanning roughly four orders of magnitude in luminosity. The apparent similarity in the spectral distribution of emitted radiation suggests that there ought to be an underlying (as yet unknown) mechanism which enforces it. It is true the that the detailed spectra do vary from object to object and trends have been suggested among classes of objects (Wilkes and Elvis 1987). However, some of this diversity must be attributable to the individual character of a particular object (or class of objects) and therefore not considered as "fundamental" when detailed modeling is attempted. Given however the roughly equal energy per decade observed and the possibility of interaction of the various energy bands through reprocessing of the radiation, as discussed above, it becomes very much a "judgement call" as to what constitutes a fundamental or an incidental feature. Nonetheless such a "choice" of the important features is quite necessary, or it is very difficult to produce any models which would provide a useful (i.e. with a small number of parameters) representation of reality.

In the following (section II) I will present two very different and general classes of models based on two different notions as to what are the "fundamental" features that should serve as the basis on which our models of these objects should be based and I will discuss the pros and cons of each class. In section III I will discuss the impact of GRO observations in distinguishing between these two classes of models. Finally, in section IV I will give an example of how a model could with a rather small number of parameters describe potentially a large number of classes of AGN and the implications of such a model on γ-ray observations.

II. THE MODELS

a. Accretion Disk - Blue Bump Models

The very fact that AGN are powered by the release of accretion energy allows some simple, straightforward estimates of the radiation characteristics (i.e. spectrum and efficiency) of this process. The mathematically and physically simplest model one can construct is that of spherical accretion and the free-free emission of radiation by the matter which is compressionally heated as it accretes on the black hole; unfortunately the efficiency of this process is very small ($\simeq 10^{-6}$), mainly because the free-free cooling time scale is much longer than the free-fall one. Thus, in the absence of a solid surface on which the radiation is released, most of the accretion energy is carried into the black hole (Shapiro 1973).

The obvious way to remedy the situation is to consider non-spherical accretion; this is not an unreasonble assumption, as even small amounts of net angular momentum could turn an almost spherically symmetric flow at large distances to a predominately azimouthal one near the horizon of the black hole; the dynamics in this case are therefore not governed by the free-fall and the efficiency of accretion can be much higher than in the spherical accretion case. In fact, since the dynamics in this case are governed by the dissipation of the azimouthal kinetic energy and its conversion into radiation, the mere assumption that the fate of accreting matter is its eventual fall into the black hole, *requires* that the efficiency of this process be high and for that reason it has served as a working hypothesis for most models of AGN. However, this additional modification of the dynamics adds
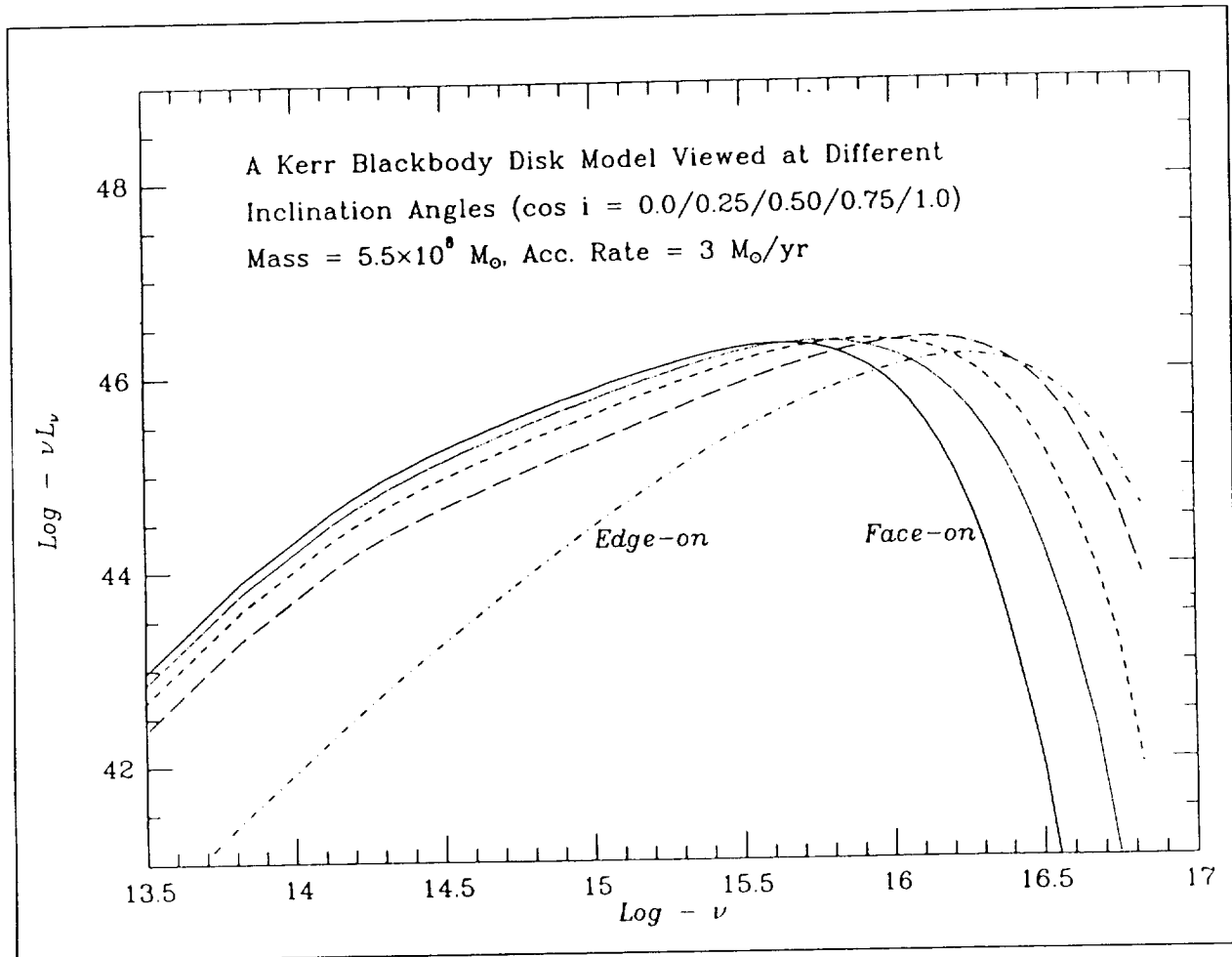
A Kerr Blackbody Disk Model Viewed at Different
Inclination Angles (cos i = 0.0/0.25/0.50/0.75/1.0)
Mass = 5.5×10⁸ M☉, Acc. Rate = 3 M☉/yr

Edge-on

Face-on

$Log - \nu L_\nu$

$Log - \nu$

Figure 2. The spectrum of an accretion disk around an extreme Kerr black hole of mass 5.5×10^8 M$_\odot$ and accretion rate of 3 M$_\odot$ per year for various values of the cosine of the inclination angle (from Sun and Malkan 1989).

considerable complication and uncertainty in the models, since the mechanism responsible for the dissipation and the eventual infall into the black hole is unknown. The general spectral characteristics of the emitted radiation can nonetheless be estimated by assuming a particular emission mechanism. The assumption of black body emission then yields the following estimate of the characteristic temperature

$$T \simeq 3 \times 10^7 F^{1/4} \left(\frac{M}{M_\odot} \right)^{-1/4} x^{-1/2} \tag{1}$$

where F is the fraction of the Eddington luminosity at which the source emits, M is the mass of the black hole, and x is the size of the inner parts of the disk measured in Schwarzschild radii (typically $x \simeq 3$ - 10).

For a black hole of the order of a solar mass, eq. (1) predicts emission in the few keV range, which has in fact been observed in the galactic black hole candidates. On the other hand for a luminous quasar (L $\simeq 10^{46}$ erg s^{-1}) which is expected to emit close to

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the Eddington limit ($F \simeq 1 - 0.1$ implying a mass $M \simeq 10^8 - 10^9 \ M_\odot$), the resulting temperature is $T \sim 10^5 \ K$, and should thus manifest itself as a rather broad quasi-thermal component in the UV part of the spectrum; moreover, this component should contain, in principle, all of the available emitted power (if one ignores the possibility of reprocessing of radiation). The existence of such a component was suggested in the late 70's by Shields (1978); however detailed fits to observed spectra were not performed until five years later. Malkan and Sargent (1983) decomposed the IR to UV quasar spectra as a power law $F_\nu \propto \nu^{-1}$ and a black body of temperature $T \sim 30,000$ K, while Malkan (1983) in a similar decomposition, fitted the broad quasi-thermal component with a superposition of black bodies appropriate to an accretion disk. The identification of this component with black body emission from an accretion disk allowed then (through modeling and data fitting) the determination of the parameters of the accretion disk (i.e. the mass of the black hole M and the accretion rate $\dot{M}$).

This quasi-thermal broad component that extends from the optical to the UV part of the spectrum of a large number of quasars became known as the "Blue Bump". The great advantage of the above interpretation of this feature is the direct way in which it associates the spectral emission in a given band to the dynamics of accretion. In addition, it suggests that, under these assumptions, this feature should be ubiquitous in AGN and should contain most of the available power. At its simplest version, this model seems to ignore the emission in the other energy bands and also the fact that the remainder constitutes a large fraction of the total power available. The emission at longer wavelengths could be accomodated by reprocessing of the UV radiation, however this model would have problems in accounting for the X-ray emission from these objects (though soft, ~ 1 keV emission could also be accomodated).

b. Non-Thermal Models

The model discussed above has as its focal point the dynamics of accretion in conjunction with the assumption of black body emission. The latter assumption, however, imposes severe constraints the particular dynamics that must take place in these objects, in order that the resulting spectrum be similar to a black body. In addition, the spectral distribution of the emitted radiation is much broader than even the most optmistic accretion disk models would imply (figure 1). An alternative approach to "understanding" AGN is by considering their spectral power distribution as their fundamental feature. Indeed, as pointed out in the introduction, this is quite different from that of normal galaxies, whose emission spanning a couple of decades in energy can be accounted of as the superposition of the emission from the constituent stars. It is of particular interest that the "Blue Bump" notwithstanding, the overall distribution of power is roughly uniform from IR to X-, and whenever present, γ-rays. It appears that the dynamics somehow provide for such a non-thermal distribution of the emitted radiation.

Unfortunately, it is difficult to construct realistic non-thermal models without building in some sense the answer into the model; the reason is that the non-thermal emission depends absolutely on the emission mechanism employed (it is easy to see that the dominant such mechanism, for the relativistic electrons responsible for the radiation, should be inverse Compton or synchrotron losses) and the non-thermal electron distribution assumed (by contrast thermal models like that outlined above are largely indepedent of the emission

mechanism provided that large optical depths are involved). Moreover, the life time of relativistic electrons, thought responsible for the non-termal emission, is much shorter than the light crossing time accross the source, a fact that in view of their steady-state emission, demands a mechanism for continuous acceleration or injection of relativistic electrons. So any non-thermal model should at its very basis address the problem of acceleration of the radiating electrons. However, the spectral distribution of energy in AGN is such an imposing feature, that non-thermal models were nontheless introduced without addressing this question (Jones O'Dell and Stein 1974; Rees 1967).

Our understanding of particle acceleration underwent a major breakthrough in the late 70's (Bell 1978; Blandford and Ostriker 1978). It was shown that upstream diffusion of particles in shocks can indeed lead to acceleration of a number of them to very high energies; in particular it was shown that this mechanism produces a power law distribution of particles, which for strong shocks (it is not difficult to imagine that shocks could be strong in AGN) results in differential particle spectra $\propto E^{-2}$ i.e. spectra with equal energy per decade, as incidentally is the power distribution of AGN. Appealing as this fact may be at first sight it is not necessarily compelling, because, on one hand the energy distribution in particles need not be the same as that of the emitted photons, and on the other hand the shock acceleration mechanism as originally proposed is operative only for protons (mainly because of their much larger gyroradii for a given upstream velocity), thus making it an unlikely mechanism to use in AGN. Protheroe and Kazanas (1983), however suggested that the radiating relativistic electrons could be secondaries resulting from the decay of π^{+}, π^{-} produced in nuclear collisions, by shock accelerated protons; thus it was made possible to relate the origin of relativistic electrons to a concrete model of the accelration mechanism. In addition, one can then easily show that if the relativistic proton spectrum is that predicted by shock acceleration (i.e. a power law $\propto E^{-2}$), the the photon spectrum resulting from the secondary electrons is also a power law, $F_\nu \propto \nu^{-1}$, i.e. of equal energy per decade. Besides the spectral characteristics which can be attributed to the presence of relativistic protons, these particles can also have significant dynamical influence on the dynamics of the accretion flow, because their energy loss time scale is in general longer that the local free-fall time scale, thus suggesting a coupling between the dynamics and the radiation emission mechanism. These notions, coupled with the dynamics of free-fall accretion can actually lead to a model that depends on only *one* free parameter, namely $\dot{m}/M$ or $\dot{m}/\dot{m}_E$, where M is the mass of the black hole and $\dot{m}_E$ is the Eddington accretion rate (Kazanas and Ellison 1985).

Despite the fact that strong shocks can indeed produce non-thermal distributions which could in principle account for the overall (i.e. $F_\nu \propto \nu^{-1}$) spectral distribution of AGN as outlined above, a single power law fit appears to be in disagreement with observations, most notably those of "hard" (> 2 keV) X-rays, whose spectra were shown to be power laws, $F_\nu \propto \nu^{-\alpha}$, $\alpha \simeq 0.75$ with a small dispersion in the values of the power law index (Rothschild et al. 1983), indicating an energy per decade spectrum which is rising with frequency ($\nu F_\nu \propto \nu^{0.25}$). Since the X-rays are affected very little by obscuration, and because their variability is the most prominent among all of the spectral bands of AGN, they are thought to provide information about the dynamics of their innermost regions. The apparent disagreement of the observed X-ray spectra with those expected from the

simplest particle acceleration models and their "universality" suggested that something was fundamentally different in the "central engine" of AGN than so far considered.

This reasoning lead to the search for an alternative scale in the problem and to the consideration of the effects of e^+e^--pair production due to photon-photon absorption within the source (Kazanas 1984, Zdziarski and Lightman 1985). The effects of this process ($\gamma\gamma \rightarrow e^+e^-$) is to remove all high energy photons and replace them with electron positron pairs which in turn are re-injected into the pool of radiating electrons to produce more high energy photons etc. Thus a cascade ensues which it was shown that, under certain conditions (*viz.* that most of the available energy is injected at energies well above the rest mass of the electron $m_e c^2$), "washes-out" all information about the original injection and produces an electron distribution $\propto E^{-3}$ down to the energy at which the opacity of the source to the above process becomes less than one. Below this energy the electron distribution is $\propto E^{-2}$ and could thus by inverse Compton produce a spectrum similar to that observed in the X-rays. This process then introduced a new scale namely the energy at which the $\gamma\gamma \rightarrow e^+e^-$ opacity is equal to one. Given that the cross section for the above process is roughly the Thomson cross section, σ_T, the (γ-ray) photon opacity to e^+e^--pair production $\tau_{\gamma\gamma}$ at energy $\simeq m_e c^2$ is given by

$$\tau_{\gamma\gamma}(E_\gamma) \simeq \frac{L\sigma_T R}{4\pi R^2 c m_e c^2} \qquad (2)$$

where L is the luminosity of the source and R its size. As it is apparent from eq. (2), the optical depth $\tau_{\gamma\gamma}(E_\gamma)$ depends only of the combination L/R of the physical parameters (called the compactness) of a source; eq. (2) then defines the natural unit of compactness $l = m_e c^3/\sigma_T \simeq 3.4 \times 10^{28}$ erg cm s^{-1}. For γ-rays of energy $E_\gamma \gg m_e c^2$ the optical depth to photon-photon depends on the spectrum of the X-rays that fulfill the threshold condition for pair production. If the L_x is the X-ray luminosity with spectral index α , the optical depth of a γ-ray of energy E_γ is given by

$$\tau_{\gamma\gamma}(E_\gamma) \simeq 1 \left(\frac{L/R}{10^{29}\ C.G.S.} \right) \left(\frac{E_\gamma}{m_e c^2} \right)^\alpha \qquad (3)$$

The energy E_γ at which $\tau_{\gamma\gamma}(E_\gamma) \simeq 1$ constitutes the additional scale sought to account for the X-ray spectra. It should be noted that if L is measured in units of the Eddington luminosity and R in units of Schwarzschild radii the compactness is independent of the mass of the black hole, a situation similar to that encountered considering the effects of relativistic protons on the dynamics of accretion.

The process of pair cascades appeared to be very appealing since it would present us with a spectrum largely independent of the initial conditions of injection, whose origin could then be sought separetely. In addition, the final spectrum was dependent of only one source related parameter namely its compactness, whose value is also largely independent of the mass of the accreting black hole, thus suggesting this mechanism to be relevant and applicable to objects of largely different masses such as quasars and galactic black holes in binary systems (White et al. 1984; Kazanas 1986). Unfortunately, more detailed calculations have indicated that the correct values of X-ray slopes are obtained only for
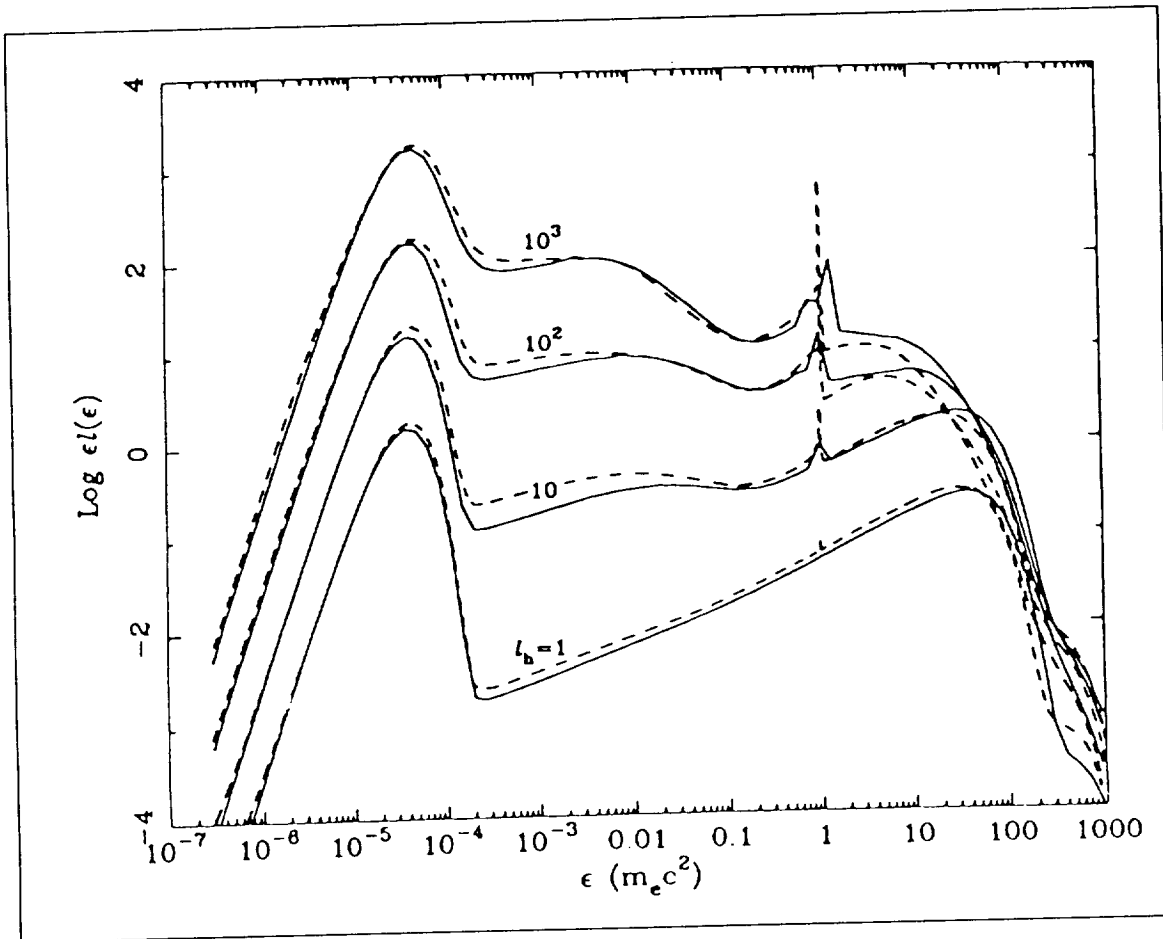
Figure 3. The pair cascade spectra for monoenergetic electron injection, for a source with compactness l_h, a black body distribution of soft photons of compactness l_s, for various values of the parameter l_h. Solid lines from Done and Fabian (1989), dashed lines from Lightman and Zdziarski (1987).

a narrow range of values of the compactness which is much too small compared with the observations (Lightman and Zdziarski 1987; Fabian et al 1987; Done and Fabian 1989). For values of the compactness appropriate to X-ray variability observations, the cascade converts most of the available power into e^+e^--pairs which render the source thick to Thomson scattering and thus modify the escaping spectrum; these detailed calculations have indicated that the down-Comptonization of the emerging radiation would introduce a break at 10-50 keV which is apparently not observed. In addition, the very large optical depth to photon-photon absorption $\tau_{\gamma\gamma}$ guarantees the virtual absence of any γ-rays of energies $E \gtrsim m_e c^2$, though a large e^+e^- annihilation feature is indeed expected at energies roughly that of the electron rest mass. Lower values of the compactness parameter could in fact lead to spectra in rough agreement with the observed ones, but the allowed range of L/R would have to be very small in order not to cause discrepancy with the AGN contribution to the extragalactic γ-ray background.

In conclusion, the introduction of pair cascades, though it can achieve what it has been invented for, it still requires AGN to lie in quite a restricted region of the available

parameter space, thus obviating the need of their introduction.

III. THE CONTRIBUTION OF GRO

Having outlined the motivation and the main features of the two most prominent recent (i.e. introduced in the 80's) ideas on the nature of AGN and their spectra, I would like to discuss their pros and cons in view of the impending GRO observations.

One of them (black body emitting, geometrically thin accretion disks), motivated by the dynamics of accretion, it can account for a particular feature, namely the "blue bump". Moreover, by detailed modeling and fitting of the data associated with this feature, this model can provide the best so far estimates of the mass and accretion rates of these objects. Unfortunately there exists within the model an *a priori* additional physical parameter which can also be adjusted to either improve the fits or introduce a degeneracy in the values of the mass, M, and accretion rate, $\dot{m}$, which are obtained from the fits to the data; this is the inclination of the disk (which is assumed to be geometrically thin) to the line of sight of the observer. I find this redundancy of free parameters rather disturbing. In addition there have been reports of several objects which do not show any evidence of the "blue bump" - accretion disk emission (McDowell et al 1989). Since this feature is of such a central importance for the dynamics and the energy generation in AGN, its absence even in a small number of objects becomes a major problem.

The "blue-bump" - accretion disk models do not attempt to address the overall distribution of radiation in AGN. Given the large amount of optical-UV-soft X-ray emission that can potentially be produced in the "blue-bump" feature, one could argue that the lower frequency (near to far infrared) radiation could be the result of reprocessing in the AGN environment, mainly by dust (Sanders at al. 1989). There remains however the question of radio ($10^9 - 10^{10}$ Hz) emission. In the majority of AGN (radio quiet), the emission in this band is but a very small fraction ($\sim 10^{-6}$) of the total luminosity, and could argueably be ignored. However, in the radio loud AGN it constitutes a substantially larger fraction ($\sim 10^{-2}$), and in certain cases the extended radio emission (which is apparently energized from the nucleus by jets) seems to be comparable to or even outshine that of the nucleus. Yet, in these two classes of objects the emission in the far IR to X-rays is quite similar, though as argued by Wilkes and Elvis (1987) the X-ray spectra of radio loud AGN are in general "flatter" than those of the radio quiet. It is generally accepted that the radio loud AGN contain large amounts of non-thermal particles, which are thought responsible for the radio emission; should one then assume that the radio quiet objects are devoid of such particles though the look quite similar (with perhaps the exception of blazars) in their IR - X-ray spectra? Should one already concede at this fundamental level two very different classes of objects despite the apparent similarities, or may the observed differences be the result of the particular environments in which these different classes reside? Such are the questions model builders are called to decide *a priori* and hopefully answer by testing their models against the observations.

However, in my view, the major problem with this class of models is its inability to deal with the emission of hard (> 2 keV) X-rays, or for that matter any radiation that is harder than that. One might argue that because of the dominance of the "blue bump" emission in a number of objects (quasars) over the (non-thermal?) harder than 2 keV

X-ray emission, that we indeed have captured the *major* features that determine the most important part of the dynamics and that the remaining constitutes but a small fraction of it. It should be born in mind that this argument may be very misleading; it suffices to remember that the energy per decade seems to be rising with frequency in the X-ray band. How far does this rise continues? It appears that extrapolating this emission to roughly 1 MeV could produce a feature whose luminosity would, in most objects, rival that of the "blue bump". It thus becomes apparent the invaluable contribution of GRO in deciding this most important question, namely the frequency band in which most luminosity is emitted. The answer to this question, along with the fastest observed variability would then set the tone for the more comprehensive models that will follow these observations. The > 2 keV radiation could be accomodated by arguing that besides the black body emitting part of the disk, there exists a hot inner region with optically thin emission and harder radiation. My feeling is that such a model would be difficult to make consistent with observations, since the present disk models have to already consider maximally rotating Kerr holes and emission from the innermost stable orbits in order to be able to account for the observed UV - soft X-ray emission.

Hybrid models of the the standard accretion disk along with an additional arbitrary non-thermal component (a corona?) could in principle account for the harder X-ray and possible γ-ray emission. I personally find models of this kind rather uninteresting since they have no way of determining the mechanism by which the availble power is apportioned between these two independent components. This argument does not by itself mean that such models are wrong; they just have much less predictive power. On the other hand it is possible that these models may indeed be the correct ones; in this case it may never be possible to improve any further our understanding of the nature of AGN, but since at present we are not aware of that, we have to keep trying (maybe in vain!). A *non-linear* combination of these components would be indeed very interesting and instructive, since it not contain any additional free parameters, but I am not aware of either models or observations suggesting such a relation.

The other general class of models (non-thermal), does in fact address the broad band energy distribution in AGN, but only at the expense of the details of the dynamics that become murkier, as one has to deal with situations (shocks, turbulence etc.) not amenable to such clean modeling as the assumption of a nice, smooth, optically thick, geometrically thin disk (of, albeit, unspecified viscosity). The non-thermal models do, of course, account for the broad band emission of AGN (once an acceleration mechanism has been assumed); however these models are at difficulty in accounting for the "blue bump", unless they resort to additional components similar to those of the previous class. Finally, they can account for the observed "hard" (> 2 keV) X-ray emission, but its detailed slope can be obtained only for a small range of the available physical parameters.

The non-thermal models, in contrast to the "blue bump" ones, do predict the emission of a significant amount of γ-rays with fluxes detectable by GRO. EGRET in particular would be instrumental in providing clues as to the highest energy particles present in these objects and therefore severely constrain the parameter freedom of available models. Thus, positive detection of a number of AGN in the EGRET energy band would strongly argue in favor of non-thermal emission as a major component in the radiative processes

of AGN. The non-thermal models also predict that for large values of the compactness parameter a large fraction of the available luminosity should be emitted at $E \sim m_e c^2$ (due to the cascade caused by the $e^+ e^- \rightarrow \gamma\gamma$ process) while suppressing the emission at the EGRET energy range. Fortunately, the other instruments aboard GRO, (i.e. OSSE and COMPTEL) will provide the necessary coverage in this energy range. The > 100 MeV γ-rays observed in 3C 273 do suggest that emission in this energy band is indeed possible (see the contribution of C. von Montigny, these proceedings). The question is whether such an emission is typical of AGN or particular to 3C 273. The positive observation of γ-rays, especially in radio quiet objects, in which the existence of relativistic particles may not be deemed necessary, would be a significant fact in determining whether these high energy particles are indeed present in the "central engine" of AGN, irrespectively of the presence or not of radio emission. The presence of γ-rays in both radio loud and radio quiet objects would suggest the possibility that the the "central engine" is quite similar among all classes objects with the observed class diversity attributed to the particular "environmental conditions" prevailing in the vicinity of the compact object, or even to a particular range of the physical parameters at which these different operate. If the latter argument were to be proven true, it would provide a unifying point around which more detailed models could be built which would account for the particular observed characteristics, in accordance with the notions of "understanding" outlined in the introduction.

IV. A MODEL

Before concluding, I would like to present a model which, in my opinion, conveys a flavor of what I have termed in the introduction "an understanding" of AGN. This model, originally conceived in order to account for the radio emission in radio loud objects, can at the same time address another major issue, namely the dichotomy of AGN in radio quiet and radio loud. The model is by no means complete and since it is mainly concerned with non-thermal emission it fails to address at all the issue of the "blue bump", as the latter is considered to be a thermal feature.

This model (developed in collaboration with P. Giovanoni of the University of Maryland) is a direct consequence of the models involving strongly interacting particles as a means of producing the radiating relativistic electrons in AGN (Protheroe and Kazanas 1983; Kazanas and Ellison 1985). One of the main channels of these reactions is that of charge exchange, which converts one of the protons to a neutron; in addition, neutrons can be the final product of photopion production reactions (Sikora et al. 1987), in which a high energy photon can produce a pion in a collision with a photon

$$pp \rightarrow nX \ , \quad p\gamma \rightarrow n\pi^+ \tag{4}$$

The neutrons resulting from these interactions can be relativistic and, not constrained by the ambient magnetic field, they escape and can transport away from the continuum source roughly half the available luminosity, which they can subsequently deposit upon their decay in the form of relativistic protons at distances $r \simeq 3 \times 10^{13} \gamma_n$ cm, where γ_n is the neutron Lorentz factor.

Relativistic neutrons thus present a mechanism for energy transport in AGN whose efffects have been previously largely ignored (see however Kazanas and Ellison 1985b for

discussion of the effects of relativistic neutrons in galactic high energy sources; see also Sikora et al. 1989). The smooth continuous way they relate the dynamics and radiation emission in the vicinity of the compact object with that at much larger radii, makes them ideal candidates for the continuum emission in radio loud AGN, which is also smooth and continuous from 10^9 to 10^{16} Hz (Landau et al. 1986). In particular, the spectra of the unresolved core (where the "central engine" resides) in radio galaxies and radio loud QSOs are "flat" i.e. $F_\nu \propto \nu^\alpha$, $\alpha \simeq 0$ from $10^9 - 10^{13}$ Hz (see e.g. Landau at al. 1986). Because synchrotron radiation (the main emission mechanism in these frequencies) from a region of size a few Schwarzschild radii would be self-absorbed at $\nu \simeq 10^{12.5} - 10^{13}$ Hz, the observed radio emission cannot be optically thin; on the other hand optically thick synchrotron emission has a much different spectral index $F_\nu \propto \nu^{2.5}$. It was then suggested that the radio flat spectra were the result of the superposition of synchrotron self-absorption edges from invreasingly larger radii extending out to $\simeq 1$ pc (Marscher 1977). This suggestion allowed the the modeling of the "flat" spectra by arbitrarily prescribing the magnetic field and the electron distribution as a function of radius and energy, i.e. $B(r) \propto B_o r^{-m}, N_e(\gamma_e) \propto r^{-n}\gamma^{-p}$ over the whole emission region (of size $\simeq 1$ pc). A suitable choice of the indices m, n, p can then set the slope of the envelope of the self-absorbed components to any value and in particular to zero as observed. The fact that the physical conditions in AGN conspire to produce a combination of m, n, p that yields a flat spectrum in the entire class of radio loud objects, when any other value is as likely, came to be known as "Cosmic Conspiracy" (Phinney 1985).

In addition to the free parameters m, n, p such models do not address at all the origin of the relativistic electrons at the large distances (~ 1 pc) from the "central engine" required to fit the spectra. This is a formidable problem considering the very short life times of these electrons. On the other hand, energy transport by neutrons does resolve the origin of relativistic electrons in a direct straightforward way, which is based on well defined physical process. Moreover, the neutron transport does not allow the arbitrary choice of the electron distribution function independently of the dynamics of the "central engine". In fact, energy transport by neutrons leads to an electron distribution function of the form $N_e(\gamma_e) \propto r^{-2}\gamma^{-2}$, in a largely model independent way (Giovanoni and Kazanas 1990). By then choosing in addition the radial dependence of the magnetic field to be $B \propto B_o r^{-1}$ (an assumption justified either on basis of equipartition with the photons or considering the magnetic field to be carried by an outflowing wind), one can obtain "flat" spectra in the $10^9 - 10^{13}$ Hz range, which then steepen to roughly $F_\nu \propto \nu^{-1}$ in very good agreement with the observations (figure 4).

The question which is immediately raised then is the following: Since the production of neutrons is inevitable once the presence of relativistic protons is considered, and given that neutrons can lead to emission at large distances from the continuum source, thereby accounting for the spectra of radio loud objects as proposed above, why are not all objects radio loud? (in fact the majority of them are radio quiet). One can simply conjecture that radio quiet objects are those in which relativistic protons are absent in their "central engine". Such an explanation however does not really improve our "understanding"; it simply reduces it to the addition of another free parameter, which quite likely we will never be able to determine. Is it possible then to account, within this model for the
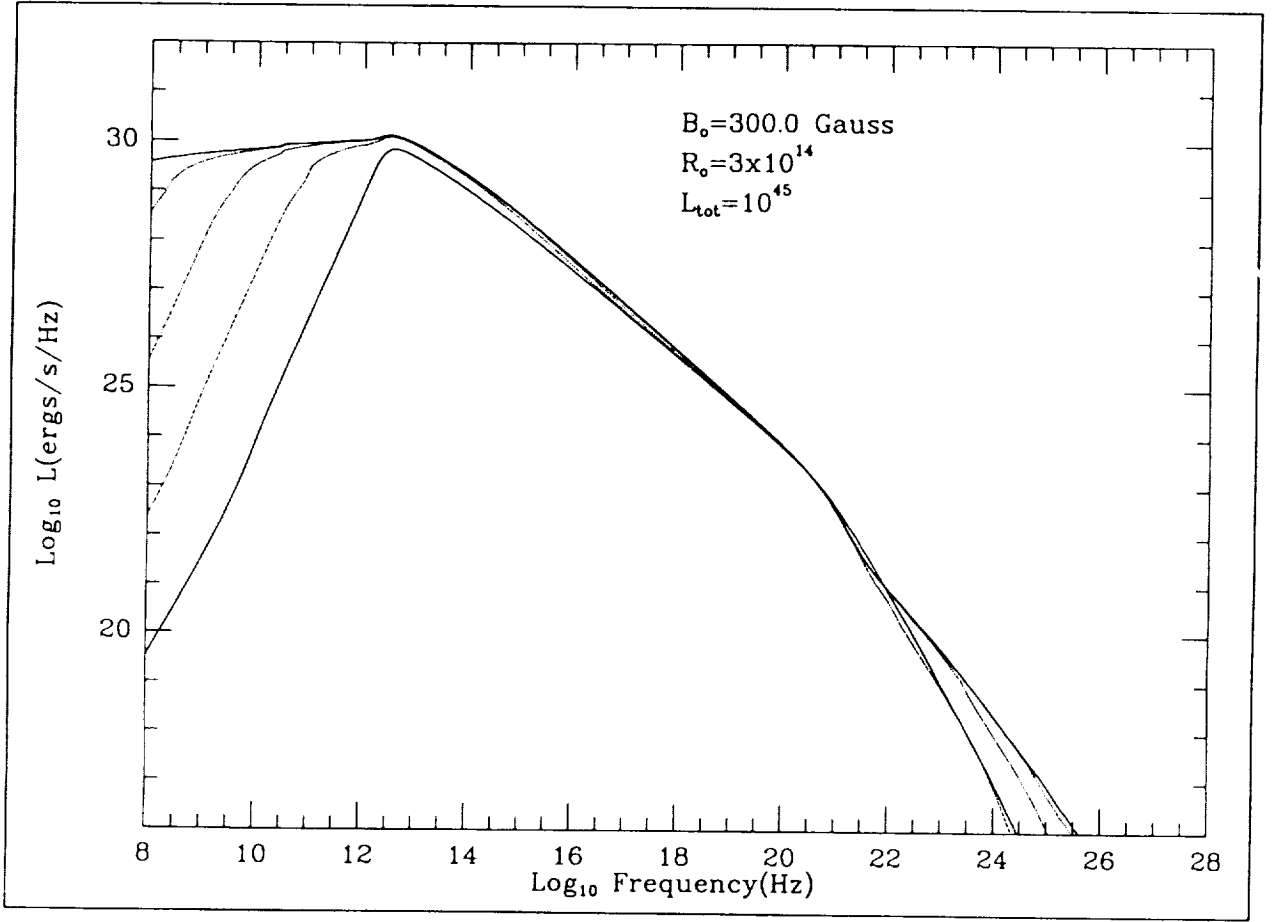
Figure 4. L_ν vs ν for a source with luminosity in neutrons (at $r = R_o$) L_{tot}, magnetic field at $r \le R_o$, B_o and central source size R_o, as indicated in the figure. The lower solid line is the spectrum of the central source, while the upper one is spectrum as observed at infinity. The dotted lines indicate the spectrum at $r = 10R_o$, $10^2 R_o$, $10^3 R_o$ respectively.

class of radio quiet objects without the introduction of an *arbitrary* free parameter? The answer is "yes". If one can simply prevent the neutrons from escaping the central source one would simply deplete emission from the larger radii, thereby leading to the absence of radio emission at frequencies $\lesssim 10^{12.5}$ Hz. Such an object would indeed qualify as a radio quiet object. The neutrons could be stopped by reactions similar to those that produce them i.e. $np \rightarrow pp\pi^-$ and $n\gamma \rightarrow p\pi^-$. Both these reactions tend to suppress preferentially the highest energy neutrons: the first one because the cross section increases (albeit logaritmically, but that is sufficient) with the neutron energy, while the second because there are more target photons at the reaction threshold for the higher energy neutrons. These processes are of roughly comparable importance for neutron Lorentz factors $\sim 10^5$, but their most important feature is that they both depend on other physical parameters of the source. For a free-fall accretion the first one depends on $\dot{m}/\dot{m}_E$, while the second depends on the compactness L/R; given however that in a dynamical model L/R itself quite likely depends on $\dot{m}/\dot{m}_E$, the classification of AGN as radio loud and radio quiet could then be understood only in terms of a *single* parameter.

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This is the best example of the notion of "understanding" as given in the introduction that I was able to come up with. Fortunately, it appears that it may be testable. As figure 4 indicates the γ-ray spectra of the central source (lower thick line; that should be similar to that of a radio quiet object) and that observed at infinity (upper thick curve; that is the emerging spectrum from a radio loud object) are different in the EGRET energy range, at least for the parameters used in this specific model. This of cource is no accident: in radio loud object, as presented in this talk, there exist high energy particles at large distances from the "central engine" whose γ-ray radiation is not absorbed by the $\gamma\gamma \rightarrow e^+e^-$ process. Radio loud ojects should then be systematically also γ-ray loud, or at least more so than the radio quiet ones. γ-rays of $E \gtrsim 100$ MeV should also be present in radio quiet objects but at lower levels, which one should in principle be able to determine from models like those of figure 3. For that however we first need to obtain the data. If I have to be consistent with my own prejudices, which I outlined in the last four sections, I would have to predict lots of positive observations and lots of excitement in this field in the next few years.

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DISCUSSION

Darryl Leiter:

Can a cool disk be compatible with a hot corona for UV & gamma production in AGN?

Demos Kazanas:

Maybe, but such a model introduces unknowable (at present) parameters at a very basic level which I do not feel are very useful, at this stage, though it may be proven correct eventually.

Richard Mushotzky:

Since the break at gamma-ray energies is related to (L/R), with R determined by gamma-ray variability, shouldn't there be a relation between the X-ray variability times scale, d t_x, and the (gamma-ray/X-ray) ratio and the gamma-ray spectrum?

Demos Kazanas:

Yes, there should be such a relation. However, one should bear in mind that d t_x is in general proportional to the mass of the black hole M while L/R may be quite insensitive to M (if L is a given fraction of the Eddington luminosity and R a few Schwarzchild radii). So though d t_x may vary by many order of magnitude, L/R and hence all aspects associated with it, may vary very little.

Dick Lamb:

I would like to ask if the possible break in the 3C273 spectrum around 3 MeV is compatible with the high energy gammas being absorbed by X-rays creating $e^{\pm}$ pairs?

Demos Kazanas:

Yes! Look at Protheroe & Kazanas Ap. J. 1983 also Kazanas & Protheroe, Nature 1983 where similar arguments have been put forward to account for the diffuse gamma-ray background.

Andy Strong:

Presumably the effect of gamma-gamma pair production will be changed by the subsequent gamma-electron cascade.

Demos Kazanas:

Yes, if the intrinsic νF_ν emission increases with energy, i.e. most of the intrinsic luminosity is produced at the highest energies. For the example given here that $\nu F_\nu \propto \nu^0 = $ constant, this feedback is not important.