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NON-THERMAL AGN MODELS

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ABSTRACT. The infrared, optical and X-ray continua from radio quiet active galactic nuclei (AGN) are explained by a compact non-thermal source surrounding a thermal ultraviolet emitter, presumably the accretion disk around a supermassive black hole. The ultraviolet source is observed as the "big blue bump." The flat ($\alpha \approx .7$) hard X-ray spectrum results from the scattering of thermal ultraviolet photons by the flat, low energy end of an electron distribution "broken" by Compton losses; the infrared through soft X-ray continuum is the synchrotron radiation of the steep, high energy end of the electron distribution. Quantitative fits to specific AGN result in models which satisfy the variability constraints but require electron (re)acceleration throughout the source.

A modified version of the non-thermal synchrotron-self-Compton (SSC) model that includes the scattering of the photons from the "big blue bump" explains the wealth of observations now available on the continuum above 10^{12} Hz for radio quiet AGN (Band & Grindlay 1986; henceforth Paper II). This model is consistent with an accretion disk around a supermassive black hole embedded in a sphere of relativistic electrons (Band 1987; henceforth Paper III). Within this model the origins of the AGN spectrum are: thermal emission, perhaps from an accretion disk, in the optical and ultraviolet; synchrotron emission from the non-thermal source in the infrared and soft X-ray bands; and inverse Compton scattering also from the non-thermal source in the hard X-ray and gamma ray energies. While this model was constructed for radio quiet AGN, it is similar to the stationary optical component proposed by Madejski (1985) for BL Lacs.

The radio and millimeter band emissions from the compact non-thermal source are synchrotron-self-absorbed. Consequently, flux in these bands must come from a more extended source and should be treated as only an upper limit on the emissions from the central source. Indeed radio emission can be resolved on various spatial scales in nearby Seyferts; this emission would be attributed to a nuclear source if the sources were further away. Thus all the distinctions between classes of radio loud and radio quiet objects may be no more than indirectly related to the fundamental source, although the correlations between radio loudness and more fundamental properties such as optical and X-ray luminosities, may be indicative of the systematics of orientation or environment.

The electron distribution within the non-thermal source consists of two components: $n \propto \gamma^{-p}$, for $\gamma < \gamma_b$ and $\propto \gamma^{-(p+1)}$ for $\gamma > \gamma_b$ with $p \sim 2.4$ (γ is the electron's Lorentz factor). Such a distribution could arise from continuous electron injection $\propto \gamma^{-p}$ with radiation losses steepening the distribution above γ_b . For both synchrotron emission and inverse Compton scattering an electron distribution $n \propto \gamma^{-p}$ produces a spectrum $L_\nu \propto \nu^{-\alpha'}$ where $\alpha' = 2\alpha + 1$. The observed spectrum reflects the component of the electron distribution that produced it.

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Thus synchrotron emission by the steep $\gamma^{-(p+1)}$ component produces the infrared and soft X-ray continua with $\alpha \sim 1 - 1.2$, $L_\nu \propto \nu^{-\alpha}$. The self-absorption turnover, with a suggestion of a flatter $\alpha \sim .7$ spectrum from the low energy electron component, is seen in the far infrared (Paper II; Edelson 1986). The synchrotron component extends into the soft X-ray band, explaining why the soft X-ray spectra are generally steeper than the hard X-ray $\alpha \sim .7$ (Elvis *et al.* 1986), and fall on the extrapolation of the infrared continuum (Malkan 1984; Elvis *et al.* 1986).

Inverse Compton scattering of ultraviolet photons by the flatter low energy electron component produces the hard X-ray through gamma ray spectra with an index $\alpha \sim .7$ (Rothschild *et al.* 1983). Since the "big blue bump" may be the dominant AGN luminosity component (Elvis & Lawrence 1985), it can easily dominate the synchrotron photons as the source of soft photons for scattering. Conversely, most of the synchrotron photons are found in the infrared. Inverse Compton scattering boosts photon energies by a factor of γ^2 . The steep high energy electron component will dominate the scattering, and thus the spectrum, for final energies more than a factor of γ_b^2 above infrared energies. Since γ_b is small in quantitative source models, the resulting X-ray and gamma ray spectrum will be steep unless there is an additional ultraviolet photon source such as the "big blue bump."

Model spectra are calculated by both analytical and numerical methods developed in Band & Grindlay (1985; henceforth Paper I) for specific radio quiet AGN (Paper II). For modeling simplicity the source is assumed to be a homogeneous sphere, although the source parameters describing more sophisticated, physically plausible, geometries (e.g., disks, clumped and radially varying spheres) are nearly the same as for the homogeneous sphere (Paper III). The assumption of homogeneity is reasonable since inhomogeneities would introduce flat spectra, which are not observed, over frequency ranges where the source is only partially optically thick (Paper I). The electron distribution and magnetic field are assumed to be isotropic within the source.

The accompanying figure shows the model and observations for the Seyfert I galaxy Mkn 509 (Paper II). In this model: $n_e = 2.78 \times 10^6 \gamma^{-2.3}$ for $1 \leq \gamma \leq 86.6$ and $= 2.4 \times 10^6 \gamma^{-3.3}$ for $86.6 \leq \gamma \leq 10^6$; $B = 418$ gauss; $R = 1.75 \times 10^{15}$ cm; and the ultraviolet source was approximated as a $\nu^{1/3}$ accretion disk spectrum with luminosity $L_T = 2.2 \times 10^{42} L_\odot$. These model parameters are uncertain due to the unobserved turnover frequency, and were taken from a model with a high turnover frequency; lowering this frequency lowers B and increases R . If a billion solar mass black hole powers Mkn 509 then the ultraviolet luminosity is .067 the Eddington luminosity, the source size is approximately ten gravitational radii, and the magnetic field is approximately in equipartition with the photon energy density.

Since the magnetic field and thermal photon energy densities are approximately equal, the luminosities of the synchrotron and scattered components are comparable; each is approximately a fifth the luminosity of the ultraviolet spectrum. As expected the electron lifetime even at the break energy is .1% of the crossing time, and (re)acceleration must occur throughout the source.

The hard X-ray $\nu^{-.7}$ spectrum steepens before $\nu_m = m_e c^2 / h$ due to the small value of γ_b . Consequently, the production of pairs by the photon-photon interaction falls short of the electron injection necessary to replace the radiative losses (Paper III). However, the flat hard X-ray spectrum below ν_m can absorb gamma rays above ν_m due to pair production, causing a break at a few MeV. A break is observed at about 3 MeV in the gamma ray background, which may be the superposition of unresolved AGN (Fichtel *et al.* 1978); observations of individual AGN also indicate a break in this energy band (Bignami *et al.* 1979). From the gamma ray background the "compactness" $\tau_0 = (L/R)(\sigma_T/4\pi m_e c^3) \sim 1/3$ (Paper III).

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Thus this model of a non-thermal source surrounding a central ultraviolet emitter explains the entire radio quiet AGN continuum above 10^{12} Hz. The various classes of AGN may then result from the relative strengths of the ultraviolet and non-thermal components, as well as the addition of more extended emission, probably from a jet.

The development of this model, and the underlying methodology, constituted a major portion of my doctoral thesis; I am grateful to my advisor, J. E. Grindlay of the Center for Astrophysics, for his guidance and insight. Recent work was supported by the U.S. Department of Energy, under contract No. W-7405-ENG-48 to the Lawrence Livermore National Laboratory.

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Figure 1. Model and observations of Mkn 509.

