LUMINOSITY TO THE EDDINGTON LUMINOSITY RATIO IN AGN

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ABSTRACT

We discuss the optical/UV/X-ray spectra of AGN within the frame of the corona model of Witt, Czerny & Žycki (1996). In this model both the disk and the corona accretes and release energy through the viscosity. The relative strength the the disk and the corona is therefore determined by the model. Translated into the spectra, this model allows to predict the spectral index $\alpha_{ox}$, measuring the relative strength of the big blue bump with respect to the hard X-ray power law. Comparison of the predicted and observed distributions of $\alpha_{ox}$ allow us to conclude that the $L/L_{\text{Edd}}$ ratio in quasars cover typically the range $\sim 0.01 - 0.1$ and it is broader in Seyferts, $0.001 - 0.3$, or even higher. We identify Narrow Line Seyfert galaxies with high $L/L_{\text{Edd}}$ ratio object although, in principle, the second branch of high big blue bump objects for $L/L_{\text{Edd}}$ below 0.001 is also predicted.

Keywords: accretion disks; accretion disk coronae; X-ray emission; active galactic nuclei.

1. INTRODUCTION

Overall similarity between the spectra and variability of active galactic nuclei (AGN) and galactic black hole candidates (BHC) indicate that the basis mechanism is the same in both kinds of objects and scales easily with the mass of the central black hole. If we restrict our study to radio quiet AGN with broad emission lines we can neglect the dependence of the observed emission on the inclination angle of an observer with respect to the symmetry axis of the nucleus since we are dealing with objects oriented 'face on', according to the generally accepted unification scheme (see e.g. Antonucci 1993). It is therefore tempting to attribute the observed diversity among the sources (well expressed as the ratio of the big blue bump to the underlying power law, e.g. Walter & Fink 1993) to the range of values of the luminosity to the Eddington luminosity ratio, $L/L_{\text{Edd}}$, with no additional parameters involved.

In order to determine $L/L_{\text{Edd}}$ one can either estimate the bolometric luminosity of an object and the mass of the central black hole separately or adopt a particular spectrum model based on these parameters and fit it to the data.

The first method was adopted for example by Barr & Mushotzky (1986) and by Wandel & Yahil (1985).

In this paper we follow the second path used for example by Sun & Malkan (1991) but we use new theoretical model. The model is a version of accretion disk with a hot corona based on the assumption that accretion proceeds both through the disk and through the corona. Both gas phases are characterized by the viscosity parameter $\alpha$ and the stratification of the flow is determined by atomic physics. The model predicts both the optical/uv/soft X-ray emission (disk component) as well as hard X-ray emission from the corona and it is parametrized by the mass of the black hole, $M$, accretion rate, $\dot{M}$, and viscosity $\alpha$. 
Since the publication of the paper of Haardt & Maraschi (1991) accretion disk models with hot optically thin thermal corona gained much attention. The model underwent significant development in several directions, like better description of the radiative transfer of X-rays and introduction of clumpiness.

The version of the model proposed by Zycki et al. (1995) and modified by Witt et al. (1996) differs qualitatively from the previous approach. At the expense of assumption that the corona itself accretes and generates energy through viscosity we are able to predict the fraction of the energy generated in the corona instead of adopting this quantity as a free parameter of the model. The model therefore has considerable predictive power. In particular, it shows systematic change of the overall spectra with the change of the accretion rate, i.e. the $L/L_{Edd}$ ratio.

The model is parametrized by the mass of the central black hole, $M$, accretion rate or $L/L_{Edd}$ ratio and the viscosity parameter $\alpha$, the same in the disk and in the corona. At each radius $r$ we calculate the fraction of energy dissipated in the main disk body and in the corona, as described in Appendix D of Witt et al. (1996). In this paper we neglect the outflow from the corona predicted by the model as it requires separate careful study so the accretion rate is assumed to be constant throughout the disk.

We calculate the radiation spectrum emitted at each radius, $r$. Optically thick disk emission is computed neglecting bound-free transitions and taking into account the effects of electron scattering in a simplified way used by Czerny & Elvis (1987). The surface density of the disk is assumed to be equal 0.1 of the mean disk density (if no corona exists at this radius) or equal the disk surface density determined by the corona pressure. This method gives results not much different from more advanced computations of Dörrer et al. (1996). Next, the local disk spectrum is Comptonized by the hot corona of the optical depth, $\tau_{es}(r)$, and electron temperature, $T_e(r)$, computed at this radius from the model. We use for that purpose the simple approximation given by Czerny & Zbyszewska (1991). We assume that the disk albedo is equal zero, i.e. we neglect the reflection component in the present study.

The final spectrum is computed by integrating over the disk surface. All the computations are done for non-rotating black hole. We show a few examples of the spectra in Fig. 1.

We see that an increase of accretion rate leads to the relative increase of the big blue bump bolometric luminosity with respect to the bolometric luminosity in X-rays. This trend is a characteristic property of the model at any single radius above certain accretion rate threshold and reflects to some extent the behaviour of the model at $\sim 10R_{Schw}$. Below the threshold value corona does not form and only disk emission is present. This threshold is an increasing function of the radius. Therefore, the extension of the disk part covered by the corona increases with increasing accretion rate and dominating part of X-ray emission comes from more and more distant parts of the disk.

3. COMPARISON WITH THE DATA

3.1. Estimation of viscosity

To fix the value of the viscosity parameter $\alpha$ we first model the mean quasar spectrum shown in Fig. 2. The data do not come from a single sample but they may nevertheless approximate well the actual distribution as the shape is not significantly different from other samples (see e.g. Elvis et. al. 1994).
The AGN spectrum predicted by the accreting corona model for parameters adopted by Zheng et al. (1996) to represent a composite HST quasar spectrum (black hole mass $1.4 \times 10^9 M_\odot$, accretion rate $2.8 M_\odot/yr$). Curves were computed assuming viscosity parameter $\alpha$ equal 0.5, 0.33, 0.2, 0.1 and 0.05. Squares represent the composite spectrum of Zheng et al. (UV data) whilst optical/UV slope and UV/X-ray slope are from Green (1996), and hard X-ray slope is put to 0.9. We use the value of the mass of the black hole and accretion rate from Fig. 10 of Zheng et al. (1996). The Comptonization effect predicted by our model is different from Comptonization required by Zheng et al. (1996) so the fit is never perfect, independently from the viscosity but the overall optical/UV/X-ray spectrum is reasonably well represented for viscosity $\alpha$ about 0.1 so we adopt this value in any further computations.

Values of the mass of the black hole and accretion rate considerably different (more than a factor 2) from the adopted above provide significantly worse representation of the UV/EUV data, independently from the viscosity.

We have to stress, however, that the corona predicted by our model is optically thin and therefore it cannot provide the mechanism to smear the Lyman edge if present in the disk emission.

3.2. Quasars

We compute the predicted values of the spectral index $\alpha_{\text{ox}}$ for a broad range of values of the masses of black holes and accretion rates. The results are expressed in term of the rest frame luminosity $\log(\nu L_\nu)$ at 2500 Å as this is the directly measurable quantity.

We compare these results against the data point taken from the sample of Green (1996). Most data point group around the median values (45.95,1.38) which correspond to central mass about $10^9 M_\odot$ and $L/L_{\text{Edd}}$ about 0.02. This mass is higher than favored by Zheng et al. (1996) since this sample contains more high luminosity objects. A few quasars have $L/L_{\text{Edd}}$ ratio higher than 0.3 but we cannot extend our computations into that parameter space. Two extreme object with the lowest luminosity may actually pose a problem to the model, other objects can be reasonably well accommodated within it.

Most of the quasars, therefore, are not actually close to the Eddington limit but occupy mostly the parameter space 0.008 - 0.1. It coincide well with the behavior of the X-ray novae: the accretion is relatively stable and the spectra are dominated by the big blue bump if the accretion rate is between $\sim 0.01$ and a fraction of the Eddington luminosity.

3.3. Seyfert galaxies

Our sample of Seyfert galaxies is taken from Walter & Fink (1993). They are shown in Fig. 4. Most data points group around the median values (43.86,1.31) which corresponds to the central mass about $10^8 M_\odot$ and $L/L_{\text{Edd}}$ ratio about 0.01.

The objects are thus, on average, much fainter but they actually cover a broad range of intrinsic luminosities. The brighter objects join smoothly the distribution of quasars mixing with them considerably without any clear systematic shift (see Fig. 4). Also the $L/L_{\text{Edd}}$ ratio obtained for Seyferts is not very much different from quasar values but it extends towards lower values of $L/L_{\text{Edd}}$, mostly covering the range 0.001 - 0.1. It is therefore difficult to say that there is a systematic difference between the quasars and Seyferts with respect to the $L/L_{\text{Edd}}$ ratios as the
absence of weak blue bump quasars might well be due to the selection effect.

On the other hand, the extension of the observed distribution of Seyferts towards \( L / L_{\text{Edd}} \) ratios below 0.01 agrees well with the behaviour of X-ray novae which are dominated by hard X-ray power law at low accretion rates and show stronger variability.

### 3.4. Narrow Line Seyfert galaxies

Steep Spectrum Seyfert galaxies, or Narrow Line Seyfert 1 galaxies constitute some 10 - 15 % of the Seyfert galaxy populations (e.g. Pounds & Brandt 1996). They are so strongly dominated by the big blue bump component that it is difficult to estimate any contribution from the standard hard X-ray power law with index \( \sim 0.9 - 1.0 \). Looking at Fig.2 we see that two types of objects are dominated by big blue bump.

The first class are objects close to the Eddington limit. Unfortunately our computations of the spectra do not extend beyond \( L / L_{\text{Edd}} \sim 0.3 \) so we cannot predict the spectral shapes quantitatively. However, we expect that independently from the luminosity the spectra should show the hard tail and this hard X-ray emission should not vary strongly since it comes from large radii and only some local instabilities within the corona (if there are any) may influence the level of emission. However, the situation may be more complex very close to the Eddington limit since the behavior of the gas may cease to be stationary (Witt et al. 1996).

The second class are objects with very small \( L / L_{\text{Edd}} \) ratio. In these object corona forms only in the innermost part of the disk or it is entirely absent, according to the present model. Small variations in accretion rate can produce enormous effect if we are close to the transitory accretion rate value.

The two classes of object differ strongly with respect to the peak frequency of the big blue bump for given luminosity. Since NL Sy1 extends well into soft X-rays the first option, i.e. large \( L / L_{\text{Edd}} \) ratio, is clearly favored.

### 4. CONCLUSIONS

The model of accreting corona well reproduces the overall optical/UV/X-ray spectra in AGN. It shows some curvature in soft X-ray bend consistent with spectra being steeper below 2 keV. The high energy extension of the spectra \( \sim 250 - 300 \) keV is independent from model parameters.

Comparison of the data with the optical/UV/X-ray spectra predicted by the this model show that quasars radiate usually at \( \sim 0.01 - 0.1 \) of the Eddington luminosity, Seyfert galaxies at \( \sim 0.001 - 0.3 \) and Narrow Line Seyfert galaxies are close to the Eddington limit.

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