# ACCRETION AND EMISSION PROCESSES IN AGN : THE UV-X CONNECTION

S. Collin<sup>1</sup>, A. Abrassart <sup>1</sup>, B. Czerny<sup>2</sup>, A.-M. Dumont <sup>1</sup> and M. Mouchet <sup>1, 3</sup>

## Abstract

The main characteristics of the average spectrum of radio quiet AGN in the UV and X-ray range are reviewed, and the emission mechanisms are discussed in the framework of accretion disk models, in particular the "irradiated cold relativistic disk". It is shown that some problems arise in confronting the predictions of the model to the observations. We propose an alternative model in terms of a hot disk surrounded by a cold Compton thick medium. Finally we mention problems with remote regions of the accretion disk.

## 1 Introduction

It is now a paradigm to say that AGN and quasars are massive black holes fueled via an accretion disk. This model is mainly based on the dominance in their energy spectrum of a thermal feature, the "Big Blue Bump" (BBB), extending from the optical to the EUV. However though much progress has been made in the last decade, thanks to a bunch of new observations, the emission mechanisms leading to the observed continuum and spectral features, as well as to their variability properties, are not easily related to the accretion disk. Moreover the physical processes taking place in the accretion disk are still not understood, neither at small nor at large distances from the black hole.

In the following we first review the main characteristics in the UV and X-ray range (Sect. 2), then the emission mechanisms (Sect. 3). In Sect. 4 we recall how to integrate these mechanisms in the framework of accretion disk models, and

<sup>3</sup> University Denis-Diderot, F-75005 Paris

<sup>&</sup>lt;sup>1</sup> DAEC, Observatoire de Paris-Meudon F-92190 Meudon ; e-mail: suzy.collin@obspm.fr

<sup>&</sup>lt;sup>2</sup> Copernicus Astronomical Center, bartycka 18, 00-716 warsaw, Poland

we discuss some problems raised in confronting the predictions of the models to the observations. We propose an alternative model to the "relativistic disk" in Sect. 5. Finally in Sect. 6 we mention the problems of the remote regions of the accretion disk. Note that some of the issues reviewed here have been discussed in more details by Collin-Souffrin & Dumont (1997).

## 2 Observations in optical-UV-soft X

We give here a very brief summary of some basic trends which are crucial for building a model of the central engine. X-ray observations are also reviewed in the same proceedings by Mouchet et al. For people interested in having more details, they can read Koratkar & Blaes' (1999) excellent review. We shall concentrate on radio quiet objects, which do not display the complications due to the presence of a non thermal component.

## 2.1 The energy spectrum

Although there is a large range of properties, general trends can be deduced from the composite optical-UV spectrum of Francis et al. (1991) and Zheng et al. (1997), and from the soft X-ray spectrum of Laor et al. (1997). From 1eV to 10 eV the continuum is relatively "flat", its spectral index  $\alpha$  defined as  $F_{\nu} \propto \nu^{-\alpha}$ being in the range -0.3 (for luminous quasars) to +0.5 (note that  $\alpha$  is generally positive for Seyfert galaxies and low luminosity guasars. The soft X-ray continuum below 1 keV seems to be simply the extension of the UV with a spectral index close to 1.5 (in  $F_{\nu}$ ). It is this part of the spectrum, from 0.1eV to 1 keV, which constitutes the Big Blue Bump. In Seyfert 1 nuclei the BBB contributes about three times less to the total power than in the previously largely used Mathews & Ferland's (1987) continuum, and its peak is located at a smaller energy, 10 eV instead of 50 eV (note that Mathews and Ferland did not have at their disposal the HST and ROSAT results). The BBB is more important in luminous quasars. A noticeable fact concerning the UV continuum is the almost complete *absence of* Lyman discontinuity (a weak absorption edge is sometimes observed but it is most probably due to the Broad Line Region or to intervening intergalactic clouds with a redshift close to the emission one). The Warm Absorber inprints a few features in the soft X-ray continuum (cf. Mouchet et al., in the same proceedings).

Above 1 keV the spectral index is 0.7 in average, so in a majority of objects the continuum below 1 keV displays an excess when compared to the extrapolation of the continuum in the 1-10 keV range. Above 1 keV the spectrum can be decomposed in an underlying power law with a spectral index ~ 0.9 and, superimposed on it, a broad emission line at 6.4 keV identified with the K $\alpha$  line of weakly ionized iron and a "hump" peaking at about 30 keV. The line shows an asymmetrical profile with an extended red wing (Nandra et al. 1997). In the two best studied objects, MCG-6-30-15 and NGC 3516, the line wing extends down to 4 keV. The continuum has a cut-off with an e-folding energy of 100 to 200 keV.

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A last important result is that the BBB luminosity is larger than the hard X–ray luminosity, or at least of the same order.

#### 2.2 Variability

The scaling of the size r in Schwarzschild radius  $R_S$  with the variability timescale in day  $t_{day}$  (assuming that the signal propagates at the speed of light) is:

$$r \sim 10^3 t_{day} M_7^{-1}$$
 (2.1)

where  $M_7$  is the black hole mass in  $10^7 \,\mathrm{M_{\odot}}$ . The same relation holds roughly for the distance between two regions and the time delay between their respective emissions (corresponding for instance to two spectral bands), provided the light curves are similar.

# 2.2.1 Correlations between continuum interbands

Variability studies are most important for understanding the mechanisms powering AGN. Unfortunately the conclusions one can draw from them are complex and sometimes controversial. A few of them are however firmly established concerning the timescales. First the characteristic time variability of the UV flux (for variations of the order of one magnitude) scales with some power of the luminosity: in Seyfert galaxies it is typically of the order of a few days, while it is several months in high luminosity quasars. Second the X-ray flux is more rapidly variable than the UV, with time scales of hours for Seyfert galaxies. Another well established result is that the optical-UV spectrum "hardens when it brightens".

From the observations of a few objects intensively monitored with optical telescopes and/or IUE, HST, EUVE, ASCA, RXTE, BeppoSAX (MCG-6-30-15, NGC 3516, 4051, 4151, 5548, 7469), one can deduce more precise conclusions. For instance NGC 7469 shows variations of the UV and X-ray flux with similar large amplitude and a time delay of the order of 2 days, the UV leading the X-rays in the flux peaks. But the X-ray flux displays in addition short term variations not seen in UV (Nandra et al. 1998). For NGC 3516 the delay between UV and X is larger than 2 days (Edelson et al. 2000). For NGC 4051 no optical variations were observed when strong X-ray variations were seen (Done et al. 1990).

The UV flux variations drive the optical flux variations with a time delay  $\leq 0.2d$  for NGC 4151 (Edelson et al. 1996),  $\leq 0.15d$  for NGC 3516 (Edelson et al. 2000), and a delay of the order a day for NGC 7469 (Wanders et al. 1997, Collier et al. 1998).

Finally soft X-ray variations are generally larger than hard X-ray ones, but this is not always the case (Nandra et al. 1997). For NGC 3516, there were strongly correlated with no measurable lag ( $\leq 0.15d$ , Edelson et al. 2000).

The fact that two light curves are very similar implies that there is a causal link between them. From these few results one can thus conclude that in Seyfert nuclei,

1. the soft and hard X-rays are emitted by the same region.

2. the size of the UV emission region is larger than that of the X-ray, itself  $\leq 10^2 M_7^{-1} R_S$ ,

3. the distance between the UV and the X-ray emission regions is  $\sim 10^3 M_7^{-1} R_S$ , 4. the distance between the optical and the UV emission regions is  $\sim 10^2 M_7^{-1} R_S$ .

For the two last results it is assumed that the causal link is functioning at the speed of light. If it would not be the case, the distance would have to be much smaller. One deduces that the optical and UV emission regions lie closer from each other than their dimension would let expect, or they simply are identical, and they both are at least one order of magnitude larger than the X-ray source.

## 2.2.2 Correlations between the continuum and the Iron K $\alpha$ line

A few objects have been intensively monitored with ASCA and RXTE, revealing a complex and surprising behaviour of the line versus the underlying continuum. Iwasawa et al. (1996) have observed rapid variations of the Iron line profile and intensity in 1 to 10 ks in MCG-6-30-15 on the basis of an ASCA study. But this result has been recently questioned by Lee et al. (1999) and Chiang et al. (2000) who have studied with RXTE the spectral variability of MCG-6-30-15 and of NGC 5548, and have shown that the Iron line flux is found constant over time scales of 50 to 500 ks, while the underlying continuum displays large flux and spectral variations. Reynolds (1999) extended the work of Lee et al. on MCG-6-30-15, excluding a time delay between the line and the continuum in the range 0.5 to 50 ks, and suggesting that the line flux remains constant on timescales between 0.5 and 500 ks.

#### 3 Emission mechanisms

## 3.1 The BBB

The shape of the BBB implies a thermal mechanism (i.e. where the bulk of the gas and not only a small fraction participates to the emission) with emission regions spanning a temperature from a few  $10^4$ K (optical emission) to  $10^6$ K (EUV emission). This can be achieved either by an optically thick medium radiating locally like a black body or a modified black body, or by a medium optically thin at frequencies smaller than the peak of the Planck curve (the emission is thus due to free-free and free-bound processes). The size of the emission region should satisfy the "black body limit":

$$r_{BBB} \ge 50 \left(\frac{\Omega}{4\pi}\right)^{-1/2} T_5^{-2} M_7^{-1/2} \left(\frac{L_{\rm UV}}{L_{\rm Edd}}\right)^{1/2}$$
 (3.1)

where  $L_{\rm UV}$  is the luminosity of the BBB,  $L_{\rm Edd}$  the Eddington luminosity,  $\Omega$  the solid angle covered by the emission region (in the case of a disk it is  $2\pi$ ),  $T_5$  the effective temperature in units of  $10^5$ K, and  $r_{BBB}$  is in  $R_S$ .

Thus  $r_{BBB}$  is marginally consistent with the dimension of the UV emission region deduced from variability studies.

# 3.2 Hard X-rays

The absence of the electron-positron annihilation line and the existence of the cut-off at about 100 keV argue strongly in favor of a thermal emission mechanism, with  $kT_{\rm e}/mc^2$  of the order of 0.1. The power law is generally believed to be due to Compton upscattering of UV photons (the BBB) by this hot medium. The hump and the Fe K line are attributed to reflection onto a Compton thick "cold" medium (by "cold" one means "not highly ionized", which, in the case of radiative ionization, corresponds to a temperature  $< 10^6$ K). This medium is commonly identified with the BBB emission region.

#### 4 Emission and accretion processes close to the black hole

One should therefore seek for models accounting for the presence of a very hot medium with a small size emitting the X-ray continuum, and of a "cold" medium with a larger size emitting the BBB. There are also compelling evidences for a radiative interaction through inverse and direct Compton scatterings between these media.

The presence of an accretion disk is attested by several facts: first the black hole must be fueled, and second there are evidences of a privileged direction (large gaseous disks, cones of ionized gas, collimated jets, Unified Scheme). So most naturally one tries to account for the emission of the BBB and of the X-ray spectrum within the framework of accretion with angular momentum. If the flow is rotationally supported it will form an accretion disk.

The main problem with accretion disks remains the outward transport of angular momentum required to transport the mass inward. It is generally assumed to be accomplished by a "turbulent viscosity" according to the  $\alpha$  prescription proposed by Shakura and Sunyaev in 1973. This prescription amounts to assuming that the viscous stress is equal to the total (gas + radiation) pressure multiplied by a parameter  $\alpha$  of the order of unity, or equivalently that:

$$V_{rad} = \alpha c_s \frac{H}{R} \tag{4.1}$$

where  $V_{rad}$ ,  $c_s$ , and H are respectively the radial velocity, the sound speed, and the scale height of the disk. For a detailed discussion of  $\alpha$ -disks one can refer for instance the book of Frank, King, and Raine (1992). Other prescriptions are under debate (cf. the paper by Huré and Richard in these proceedings).

#### 4.1 Generalities about accretion disks

There are several possible regimes according to the accretion rate  $\dot{m}$  expressed in terms of the Eddington rate,  $\dot{M}_{Edd} = L_{Edd}/\eta c^2$ , where  $\eta$  is the mass-energy conversion efficiency, generally assumed of the order of 0.1. Let us summarize briefly their characteristics.

1. for  $\dot{m} \sim 1$ 

Owing to the large accretion rate, the flow is optically thick. It is dense, so it radiates efficiently and stays cold. It is therefore radiating locally as a black body in the UV and soft X-ray range. The inner regions of these disks are *supported by radiation pressure*.

If  $\dot{m} \geq 1$  the disks are inflated and geometrically thick, their efficiency decreases with  $\dot{m}$  (cf. Paczynski and Wiita 1980, Abramowicz et al. 1980, and further works). The emission spectrum depends strongly on the viewing angle, the spectrum being harder in the direction of the pole (cf. Madau 1988). According to Eq. 4.1 the radial velocity is large, and the heat advected to the black hole is larger than the heat radiated away. As a consequence the mass-energy conversion efficiency  $\eta$  can be much smaller than the canonical value of 0.1, and the disk has a relatively small luminosity for very high accretion rate. It is one of the reasons why these disks are not considered anymore. However they could be of interest for objects radiating near their Eddington luminosity, as it is proposed for Narrow Line Seyfert 1 for instance.

If  $\dot{m} < 1$  the disks are geometrically thin (i.e. the scale height *H* is much smaller than the radius *R*), and since the radial dynamics is dominated by the gravitation of the black hole, they are in Keplerian motion. A majority of works have concentrated on these thin  $\alpha$ -disks, referred to as "standard disks". In this case the amount of heat advected to the black hole is negligible:

$$Q_{adv} = Q_{visc} - Q_{cool} \ll Q_{cool} \tag{4.2}$$

where  $Q_{visc}$  is the heat provided by gravitational release and  $Q_{cool}$  is the heat radiated away.

2. for  $\dot{m} < \alpha^2$ , i.e. typically < 0.1:

Owing to the small accretion rate, another solution can exist, where the flow has a small density and is not an efficient radiator. Moreover, if Coulomb collisions are the only process to transfer energy from the protons (to which the viscous energy is given) to the electrons which radiate it away, the protons can stay very hot, not far from the Virial temperature, while the electrons will be cooled to a lower temperature, leading to a two-temperature gas. However if efficient plasma processes couple protons to electrons, they will keep the same temperature. This solution corresponds to disks *supported by gas pressure, hot, geometrically thick, and optically thin.* They can differ by the cooling processes, for instance whether or not soft photons are present to induce inverse Compton cooling (Ichimaru 1977, Narayan & Li 1995, Abramowicz et al. 1995, Narayan et al. 1998). These disks are referred to as "Advection Dominated Accretion Flows" or ADAF. When  $\dot{m} < \alpha^2$ both solutions (i.e. the standard disk and the ADAF) exist, without an obvious prediction how to switch between them.

Much attention has been devoted these last years to ADAF. They are generally thought to be present in low luminosity objects, such as LINERs, which show a non resolved X-ray source but no optical-UV continuum. Indeed this is the kind of spectrum one expects from an ADAF. The ADAF can be surrounded by a thin cold disk located further from the black hole, where the cooling time becomes smaller

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Fig. 1. Spectrum of an ADAF with a cold disk. The 4 curves correspond to different positions of the transition between the ADAF and the cold disk : infinity (no cold disk, pure flat ADAF spectrum), 500  $R_S$ ,  $50R_S$ ,  $5R_S$ . The importance of the blue bump and its peak frequency increase when the transition radius decreases. Courtesy J.-P. Lasota

than the viscous time (cf. Fig. 1). In this case the hot medium constituting the ADAF can be cooled by inverse Compton scattering of the soft photons produced by the cold disk. If a nuclear radio source is present, the synchrotron photons can play the same role in cooling the hot gas.

It is often admitted now that the Galactic Center (Sgr A<sup>\*</sup>), the nucleus of NGC 4258, the nucleus of M87 and other nuclei of elliptical galaxies, are good examples of ADAFs (cf. Mezger et al. 1996, Lasota et al. 1996, Reynolds et al. 1996, for instance), though there are still strong debates on the subject. Since we are mostly interested by Seyfert galaxies and quasars in this review, we shall not spend more time on this vast problem, and we shall concentrate on the geometrically thin  $\alpha$ -disks, which correspond to  $\dot{m} \sim 0.1$ , as deduced for Seyfert galaxies and moderate quasars.

#### 4.2 Standard $\alpha$ -disks

Most of the time it is assumed that the disk is steady (at least locally), although this assumption is not always justified. Since the radial coupling is much weaker than in the perpendicular direction, the computation of the structure of a geometrical thin disk is more simple than that of a thick disk, as it is reduced to one dimension and a half (i.e. the radial structure can be decoupled from the vertical one). It has been shown that the inner part of  $\alpha$ -disks in AGN (< 10<sup>3</sup>R<sub>S</sub>) is dominated by radiation pressure and is viscously and thermally unstable.

It is possible to get roughly the emission spectrum of a geometrical thin disk

without computing the vertical structure and knowing the value of the viscosity parameter. The basic assumption underlying these models being that *the gravitational energy is entirely radiated locally*, to the first order the disk emits at each radius a blackbody spectrum at the effective temperature determined by the local dissipation rate:

$$\sigma T_{eff}^4 = \frac{3GM\dot{M}}{8\pi R^3} f(R) \quad \text{erg cm}^{-2} \text{ s}^{-1}$$
(4.3)

where M and  $\dot{M}$  are the mass of the black hole and the accretion rate, and f(r) is a correction factor depending on the angular momentum of the black hole. The total spectrum is given by integration on the disk surface : it is the well known spectral distribution  $F(\nu) \propto \nu^{1/3}$  with a maximum at a frequency corresponding to the maximum effective temperature. Thus the standard disk model predicts a much flatter slope than observed in the optical-UV range, cf. Sect. 2.1. This has been also stressed in Koratkar & Blaes' review (1999).

In reality things are more complex, because the disk does not radiate exactly like a black body, and many improvements should be added to this rough calculation to get detailed spectral features. Unfortunately these sophistications require to introduce some unknown physics into the model (the way viscous deposition varies with the height in the disk, for instance). In present day computations, the disk is divided into a number of rings, whose vertical structure and local emission are computed independently with a self-consistent treatment of radiative transfer. This was performed for the first time for AGN by Laor & Netzer (1989), assuming LTE. Ross, Fabian & Mineshige (1992) relaxed the LTE assumption and took into account Comptonization but kept a constant vertical density. The most sophisticated models are those of Hubeny & Hubeny (1998) who solve consistently the transfer and the vertical structure with a complete non LTE treatment, introducing all relativistic corrections, but without taking into account Compton diffusions.

One important result of these computations is that the models are not able to account for the BBB emission up to 1 keV, even in the case of maximally rotating black holes; in other words they predict a steeper slope than observed in the 0.2-2 keV range. Ross et al. (1992), found that a non negligible fraction of the disk luminosity is radiated in the soft X-ray range, as a consequence of Comptonization, but they considered low masses and large accretion rates, which correspond to high temperatures of the disk (cf. Eq. 4.3), and are probably valid only for Narrow Line Seyfert 1 Galaxies but not for the majority of Seyfert nuclei and quasars.

#### 4.3 Irradiated $\alpha$ -disks

According to the local blackbody emission, T is proportional to  $R^{-3/4}$ , so the UV emission is produced closer to the black hole than the optical emission. More precisely the mean radius  $\langle R_{\lambda} \rangle$  where the flux at a wavelength  $\lambda$  is produced

can be estimated from Eq. 4.4:

$$< R_{\lambda} > \sim 1.2 \times 10^{15} \dot{m}^{1/3} M_7^{2/3} \left(\frac{\lambda}{5000 \mathring{A}}\right)^{4/3} \text{cm} \sim 400 \dot{m}^{1/3} M_7^{-1/3} \left(\frac{\lambda}{5000 \mathring{A}}\right)^{4/3} R_S$$
(4.4)

where the numerical factor takes into account the averaging. Comparing this result with the observed time delays between UV and optical light curves we see that it is compatible with a causal link between the two emission regions propagating at the speed of light, but incompatible with the propagation of a perturbation in a viscous time, as would be expected with the standard model (the speed of propagation would then be equal to the  $c_{sound}H/R$ , which is many orders of magnitudes smaller than the speed of light). This led Courvoisier & Clavel (1991) to question the standard model, and Collin-Souffrin (1991) to propose that the disk was actually irradiated by the X-ray continuum, and emitting as a result of both viscous and external radiative heatings. The discovery of the Iron line and of the X-ray hump by Pounds et al. (1990), implying reprocessing by a cold medium, is in agreement with this model of irradiated disk.

Then began the era of "irradiated disks", consisting in an X-ray point source located at a given height  $H_X$  above the center of the disk (this model is sometimes referred to as the "lamp-post model", cf. Fig. 2) The optical-UV emission is only slightly modified with respect to the non irradiated disk: the new blackbody temperature is roughly equal to  $[(F_{visc} + F_{irr})/\sigma]^{1/4}$ . Since the external flux  $F_{irr}$  is proportional to  $1/(R^2 + H_X^2)^{3/2}$ , the temperature dependence with the radius,  $T\propto R^{-3/4},$  is not changed with respect to the viscous disk at large distances from the black hole,  $R \gg H_X$ , and the spectral distribution stays  $F_{\nu} \propto \nu^{1/3}$ . To get a steeper spectrum,  $F_{\nu} \propto \nu^{-\alpha}$  with  $\alpha \geq 0$  as observed, the height of the X-ray source should be comparable to the distance of the UV-optical emission region, which is much larger than the size of the X-ray source. Thus rapid X-ray fluctuations will be erased by the light travel time towards the disk, as observed. But the UVoptical light curves should always lag behind the X-ray one, while the opposite is sometimes observed, for instance in the case of NGC 7469. A prediction of the model is that the UV flux would be more variable than the optical, corresponding to a hardening of the spectrum correlated with a brightening, since for R > H,  $\langle R_{\lambda} \rangle$  is still given by Eq. 4.4, as observed. One should note however that in this model, to induce similar variation amplitudes in UV and X-rays,  $L_X$  should be of the order of  $L_{UV}$ , contrary to the majority of objects.

#### 4.4 The disk-corona model

In the previous model the X-ray source is given a priori without any physical background. A more physical model was proposed Haardt & Maraschi (1991 and 1993), consisting in an optically thick cold disk sandwiched within an optically thin hot corona where a large fraction of the dissipation is assumed to take place. The corona emits X-rays by inverse Compton diffusions of the soft UV photons coming from the underlying disk. The disk is heated by the X-ray photons from the corona,

and reprocesses this radiation as thermal UV (cf. Fig. 2). An advantage of this model is that it is radiatively self regulated and leads to a quasi universal spectral distribution. However it probably gives a much too strong Lyman discontinuity (Sincell & Krolik 1997), though the physics of the transition region between the disk and the corona producing the Lyman continuum is complex and still not well understood (Rozanska et al. 1999).

The ratio between the inverse Compton luminosity and the soft luminosity being of the order of unity, the model predicts a BBB/X-ray luminosity ratio smaller than observed. This is why Haardt, Maraschi & Ghisellini (1994) have proposed a variant, the "patchy corona" (cf. Fig. 2). The corona is not homogeneous, but is made of a few blobs, which could be due to the formation of magnetic loops storing energy and releasing it rapidly through reconnection like in solar flares. Below a flare, the disk is heated to a higher temperature. The rest of the disk radiates through viscous processes. One interest of the model is that the emission spectrum is independent of the fraction of gravitational power dissipated in the blobs, i.e. on the UV/X luminosity ratio, as it is observed.

Though giving a physical ground to the "lamp-post model" and being able to account for very short X-ray variation timescales, the patchy corona suffers from the same drawbacks as the lamp-post. Indeed the X-ray flares are located at only a few scale heights above the disk (Haardt et al. 1994), i.e. at a few Schwarzschild radii. This is the expected size of the variable UV emission region, assuming it is due to X-ray reprocessing; therefore it is much smaller than that given by the observations.

## 4.5 The Iron line and the irradiated disk model

So far we have discussed some problems of the irradiated disk model linked with the variations of the UV and X-ray fluxes. Let us now consider the Iron K line.

Since the discovery of the extended red wing of the Fe K line and of its short time variations, it has been proposed that the line is emitted by reprocessing of the X-ray continuum at the surface of the disk, very close to the black hole, so that the broad red wing could be accounted for by gravitational redshift: it is the well known "relativistic disk" introduced for Cyg X-1 by Fabian et al. (1989), now widely accepted for AGN, and used to model the line in data reductions. The line is assumed to be emitted at a rest energy of 6.4 keV (i.e. it is a "cold" line), the emissivity being parametrized as a power law  $R^{-a}$ . In several objects, in particular MCG-6-30-15 and NGC 3516, the index *a* is very large (up to 8 in one state) unless one assumes that the emission is produced down to a radius of the order of one  $R_S$ , which favors a Kerr geometry on a Schwarzschild one (Nandra et al. 1998).

Obviously the emission of the Iron line and of the UV continuum are correlated with each other, as they are both due to the reprocessing of the X-ray continuum in the atmosphere of the irradiated disk. Therefore the regions contributing the most to the variable fraction of the UV flux should give rise to an Iron line. On the other hand the region contributing to the Iron line should produce an UV or an EUV excess of continuum. Actually Nayakshin et al. (2000) and Nayakshin (2000) have shown that the emissivity of the line and the spectral distribution of the continuum reprocessed in the atmosphere of an irradiated disk depends strongly on a "gravitational parameter", which is a function of the ratio of the viscous to the X-ray heating of the disk. The line emissivity and the UV spectral distribution might therefore be complex functions of R and of the X-ray flux, and one must wait for progress in the computation of the vertical structure of the disk, taking into account the irradiation, to get definitive answers to this question.

However we have seen that the optical-UV variable continuum is produced at a large distance from the black hole (at  $R \sim 100$  to  $1000 R_S$ ), so whatever the details of the model, one can expect that a fraction of the Iron line should be reprocessed in this region, leading to the emission of a narrow line at 6.4 keV, constant on time scales corresponding to the UV variation time scale. It is not clear whether a narrow core is always observed, but the broad line is, and we know that it stays constant during time scales of the order of days, while the underlying X-ray continuum varies. So it is difficult to imagine that it is gravitationally broadened, and the best way to account for the red wing is then down Compton scattering in a Compton thick medium surrounding the source of line photons. We will propose this alternative model in the following section.

## 5 The Comptonisation model

Compton broadening of the Iron line has been suggested by Czerny et al. (1991). If the Iron line is intrinsically narrow because it is emitted by remote parts of the disk located at, say,  $100R_S$  from the black hole, it can be Compton broadened to the observed profile when crossing an ionized and relatively cold Compton thick medium surrounding the disk: this is *Comptonisation by transmission* (cf. Misra & Kembhavi 1998, Misra & Sutaria 1999, Abrassart & Dumont 1999). But another way to get a broad Iron line is without a cold disk, but instead a hot disk surrounded by a cold Compton thick medium, so the Iron line and the hump are emitted by the Comptonizing medium itself (cf. Collin-Souffrin et al. 1996, Abrassart & Dumont 1998): it corresponds to *Comptonisation by reflection*. In Fig. 2 the "cloud model" sketches such a possibility. In this figure a spherical symmetry has been assumed, but it is clear that the model can also correspond to an *axially symmetric thick disk geometry*.

This model is only phenomenological, and is not based on any physical ground. It is however possible to speculate on its nature. There are several observational proofs of the existence of an outflowing medium in AGN: the Broad Absorption lines, the fact that the UV lines are blueshifted with respect to the systemic velocity, the Warm Absorber which could be also in outward motion. There are also theoretical arguments for the existence of hydrodynamic winds or radiation driven flows close to the black hole. One can thus imagine that the Comptonizing medium is simply the basis of the Warm Absorber, for instance similar to the wind envisioned by Murray & Chiang (1995). One interesting aspect of such a model would be that in this case the Iron line would be easily redshifted by Doppler effect from the position of the FeXXV or FeXXVI line (6.7 keV) to 6.4 keV or less, since



Fig. 2. Models for the UV-X emission.

the observer would be seeing mainly a line coming from the illuminated side of the clouds.

Since Mouchet et al. have discussed this issue in the same proceedings we only give here a brief summary of the advantages and drawbacks of this model compared

to the disk model. A more detailed discussion will be published elsewere (Abrassart et al. 2000).

#### 5.1 The transmission model

The transmission model has been rejected since the beginning by Fabian et al. (1995) on the basis that to produce a weak (or no) Iron absorption edge (as it is observed), and at the same time to give the required amount of Compton broadening, the Comptonizing medium should be fully ionized, i.e. Iron must be stripped of all its electrons. To get such an ionization through all the Compton thick medium, the "ionization parameter"  $\xi = L_{ion}/nR^2$  (where  $L_{ion}$  is the ionizing luminosity,  $\sim L_{bol}$ , and n is the number density) should be  $\geq 10^6$ . Assuming that the Comptonizing medium is homogeneous (the most conservative case), one deduces for the distance between the Comptonizing medium and the X-ray source expressed in  $R_S$ ,  $r_{Compt} \sim 50 \dot{m} N_{25}^{-1}$ , where  $N_{25}$  is the column density expressed in  $10^{25}$  cm<sup>-2</sup>. Interestingly, this value does not depend on the mass of the black hole. We see that, provided the Eddington ratio is close to unity (and it is likely the case for MCG-6-30-15, whose mass is probably not much larger than  $10^6 M_{\odot}$ , cf. for instance Reynolds 1999), the distance of the Comptonizing region is marginally consistent with the assumption of a non relativistically broadened line which is broadened in the Comptonizing medium.

Reynolds & Wilms (1999) discussed more quantitatively this model and concluded that there is no possibility left in the parameter space when one takes into account all the constraints set by the observations. However in Abrassart et al. (2000), it is shown that the model is viable, provided that the inner source is only partially covered by the Comptonizing medium ( $\sim 90\%$ ). These computations are based on a photoionization-transfer code developed to treat Compton thick hot media (Dumont, Abrassart & Collin, 2000). Moreover the big advantage of the model is to *erase any Lyman discontinuity* which would be produced inside the Comptonizing medium, without appealing to a fine tuning of the parameters.

#### 5.2 The reflection model

The reflection model is different in that it does not require a very high degree of ionization, as the Iron line is produced in the Comptonizing medium itself. Typically  $\xi$  should be of the order of 10<sup>3</sup>, and actually a range of ionization parameters is required to fit the data (Abrassart 1998). The temperature of the medium is of a few 10<sup>5</sup>K. The Comptonizing medium is thus also emitting the BBB. This is precisely the quasi spherical model proposed by Collin-Souffrin et al. (1996) and by Czerny & Dumont (1998), to account for the UV-X spectrum of AGN. This model is made of a central X-ray source surrounded by a quasi spherical ensemble of Compton thick clouds with a large partial coverage factor. The observed X-ray continuum is a mixture of the primary continuum and of the continuum reprocessed by the illuminated side of the clouds, while the BBB is produced both by intrinsic emission of the clouds heated by the X-ray source and by reflection on the

illuminated side of the clouds (cf. Fig. 2). Like in the disk-corona model the X-ray source can be the result of Compton upscatterings of the UV photons emitted by the surrounding clouds. The radius of the Comptonizing-emitting medium is  $r_{Compt} \sim 40 \dot{m} n_{14}^{-1/2} M_7^{-1/2} \xi_3^{-1/2}$  where *n* is expressed in 10<sup>14</sup> cm<sup>-3</sup> and  $\xi$  in 10<sup>3</sup>.

This model has been applied by Abrassart (1998) to MCG-6-30-15, but it predicts an excess of highly ionized Iron emission at 6.9 keV. To get rid of this component, it is necessary to assume that the medium is made of a mixture of a mildly ionized gas with a high density ( $\xi \sim 10^2$ ) and a highly ionized gas with a low density (but in this case the gas has not to be fully ionized, since it can emit a small fraction of the Iron line,  $\xi \sim 10^4 - 10^5$  is acceptable). The Iron line and the BBB are emitted by both media, and the Iron line is Compton downscattered in the highly ionized medium.

#### 5.3 What are the advantages of the Comptonization model on the relativistic disk?

A main difference with the disk model is that the region where the Iron line is emitted is located farther from the black hole. This is in agreement with the absence of short term variations of the line correlated with variations of the continuum. Another advantage of the Compton model is to allow for the emission of the UV and of optical bands at similar distances, of the order of  $100R_S$ , contrary to the disk model, and in agreement with the relatively large time delay between the X-ray and the UV flux variations, and the small delay between the UV and the optical flux variations. It is also possible with this model to explain why in some cases the UV light curve lags behind the X-ray one, and it is the opposite in other cases. As discussed above, the UV and the X-ray spectra are due to the superposition of radiation from the central source (hard X-rays), radiation from the inner sides of the clouds further from the observer (soft X-rays and UV), and radiation from the outer side of the clouds closer to the observer (optical and UV). Moreover the photons are scattered several times in the Comptonizing medium, which complicates their travel. If the radiation emitted by the outer sides of the clouds dominates the UV (this depends on the coverage factor and on the thickness of the medium), one can well imagine that the UV photons will lead the soft X-rays which are emitted further. On the other hand, this model allows for the possibility of clouds obscuring the line of sight in a random way. This process is studied by Abrassart & Czerny (2000), and can also account for some variations. Finally a major difference with the disk model is that it gives naturally a  $L_{UV}/L_X$  ratio larger than unity since the coverage factor of the "cold" medium is large. Finally it allows to get rid of the Lyman discontinuity, a long standing and not solved problem.

## 6 What happens to the disk far from the black hole?

In an  $\alpha$ -disk the self-gravity overcomes the vertical black hole gravity beyond a few  $10^3 R_S$ , as shown by Collin & Huré (1999). Consequently the disk becomes

gravitationally unstable (Toomre 1964, Goldreich & Lynden-Bell 1965). The  $\alpha$ prescription is obviously not valid if the disk is gravitationally unstable. Moreover the viscous time for transporting the gas towards the black hole is then larger than the lifetime of the active nucleus.

What is the structure of the disk in this region, and how is the outward transport of angular momentum ensured? We know that much farther from the center, at about  $10^6 R_G$ , the disk is globally gravitationally unstable, and the supply of gas can be achieved by gravitational torques or by global non axisymmetric gravitational instabilities (cf. Combes in these proceedings). But the problem of the mass transport in the intermediate region where the disk is locally but not globally self-gravitating is still not solved.

Two solutions have been proposed. The first consists in a disk made of marginally unstable and randomly moving clouds with large bulk velocities, where the tranfer of angular momentum is provided by cloud collisions (Begelman, Frank, & Shlosman 1989). A more elaborate model is proposed for NGC 1068 by Kumar (1999) of a disk made of gas clumps undergoing gravitational interactions on one another. In this case the disk would be geometrically thick, and actually close to the picture of the torus invoked in the Unified Scheme. However the observations of the purely keplerian velocities of the maser spots lying at about  $10^5 R_G$  from the black hole in NGC 4258 (Neufeld & Maloney, 1995) argue strongly for a geometrically thin disk at this distance of the black hole, and are actually interpreted as setting on the top of a warped thin disk. Collin & Zahn (1999) have therefore adopted the opposite view that if unstable clumps begin to collapse, the collapse will continue until protostars are formed, which then accrete at a high rate and acquire masses of a few tens of  $M_{\odot}$ , leading to a "starburst" of massive stars (not comparable in size with real starbursts). In this case the disk would stay geometrically thin, and its gravity would be dominated by the gas. The mass transport would be ensured by supernovae or by outflows from stars, which at the same time would contribute to the enrichment in heavy elements observed in the BLR and in the BAL QSOs (Hamann & Ferland, 1992). A starburst at a larger scale could also be induced in the shocked gas of the supernova remnants. In this meeting were indeed reported several evidences for the existence of starbursts in the very central region of Seyfert galaxies (cf. Terlevich's talk, for instance). The intermediate case of a highly turbulent inhomogeneous thick disk made of interacting clouds and containing massive young stars is also a possible solution.

## 7 Conclusion

We have shown that besides raising several theoretical challenges, such as to assess the real state of the accretion disks close to the black hole (hot and thick, cold and thin?...) and to compute in a self-consistent way their structure and emission spectrum, the disk models are difficult to reconcile with the observations, in particular with the timing properties. We have proposed an alternative model, where the disk is hot and thick, and is surrounded by an inhomogeneous Compton thick medium, which reprocesses the X-ray continuum, emits the BBB and the broad Iron line, and satisfies at the same time the requirements of time variations. We suggest that this medium could be in outward motion and linked with the Warm Absorber. More observations on the variations of the Iron line profiles and of the UV and X-ray flux are needed to confirm or infirm these models. Finally we have also mentioned problems concerning the remote regions of the accretion disk.

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