Reflection at large distance from the central engine in Seyferts

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\begin{abstract}
We consider the possibility that most of the reflection component, observed in the hard X-ray spectra of Seyfert galaxies, could be formed on an extended medium, at large distance from the central source of primary radiation (e.g. on a torus). Then, the reflector cannot respond to the rapid fluctuations of the primary source. The observed reflected flux is controlled by the time-averaged primary spectrum rather than the instantaneous (observed) one. We show that this effect strongly influences the spectral fit parameters derived under the assumption of a reflection component consistent with the primary radiation. We find that a pivoting primary power-law spectrum with a nearly constant Comptonised luminosity may account for the reported correlation between the reflection amplitude $R$ and the spectral index $\Gamma$, and simultaneously produces an iron line $EW$ that is nearly independent of $\Gamma$. We emphasize the effects of the modelling of the primary component on the determination of the reflection amplitude, and show that in NGC 5548, when these effects are taken into account, the RXTE data are consistent with the reflection features being produced mainly from the central source.
\end{abstract}

\begin{keywords}
accretion, accretion discs -- black hole physics -- radiative transfer -- gamma-rays: theory -- galaxies: Seyfert -- X-rays: general
\end{keywords}

1 INTRODUCTION

In radio-quiet active galactic nuclei, large amounts of cold material are thought to reside at large distance from the central engine. In particular, the unified scheme (Antonucci 1993) postulates a large scale torus (with radius larger than $10^{16}$ cm). Such distant cold material (hereafter DCM) may imprint strong reflection features in the hard X-ray spectrum of Seyfert galaxies. These spectral characteristics take the form of a Compton hump in the X-ray spectrum (e.g. Lightman & White 1988; George & Fabian 1991) and a narrow iron line component at 6.4 keV. They add to similar features likely produced the primary X-ray radiation on the inner parts of the accretion disc.

In Compton thick Seyfert 2s, the observed reflection dominated spectra are generally interpreted by DCM reflection with the primary emission obscured presumably by the same outer material (e.g. Reynolds et al. 1994; Matt et al. 2000). In Compton thin Seyfert 2s, Risaliti (2002) recently present, from the analysis of a large number of BeppoSAX observations, strong evidences supporting the presence of a distant reflector in these objects. The unifications models postulate that such material is also present in Seyfert 1s but out of the line of sight. In this context, it has been argued that the reflection produced by an irradiated torus would be sufficient to account for the typical observed reflection spectra in Seyfert 1s (Ghisellini, Haardt & Matt 1994; Krolik, Madau & Zycki 1994), without need for reflecting material in the inner parts of the accretion flow.

The first evidence for remote reflection in a type 1 Seyfert came from the BeppoSAX observation of NGC 4051 in a ultra faint state where the nuclear emission had switched-off leaving only a spectrum of pure reflection from material at distance larger than $10^{17}$ cm (Guainazzi et al. 1998; Uttley et al. 1999). However, the presence of a reflecting torus in all Seyfert 1s is still a matter of debate.

This important issue motivated the search for a narrow iron emission line that would be the signature for reflection on distant cold and Compton-thick material. Recent Chandra (e.g. Kaspi et al. 2001; Yaqoob et al. 2001) and XMM-Newton (e.g. Reeves et al. 2001; Pounds et al. 2001; Pounds et al. 2001a, 2001b; Matt et al. 2001, O’Brien et al. 2001) observations indicate that a narrow line is often, if not always, present in Seyfert 1 galaxies, alone or together with a relativistic line component (Tanaka et al. 1995; Fabian et al 2000 and reference therein). An analysis of the composite ASCA spectrum of Seyfert 1s (Lubiński & Zdziarski 2001, hereafter LZ01) also suggests the presence of a narrow component confirming previous findings on individual sources.

An important complementary approach in order to locate the place of emission of the different components is the study of the variability of the reflected features. Indeed, the temporal response of the line to fluctuations of the continuum depends on the size and distance of the reflector. Reflection features formed in the disc, in

\begin{thebibliography}
\item Kaspi et al. 2001
\item Yaqoob et al. 2001
\item Reeves et al. 2001
\item Pounds et al. 2001
\item Pounds et al. 2001a, 2001b
\item Matt et al. 2001
\item O’Brien et al. 2001
\item Tanaka et al. 1995
\item Fabian et al 2000 and reference therein
\item Lubiński & Zdziarski 2001
\item LZ01
\end{thebibliography}

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the broad line region, or in a torus are expected to show little variability on time scales shorter than a few hours, a few weeks or a few months respectively. In this framework the monitoring campaigns with *RXTE* of several objects gave indications for a constant line and reflection component flux while the continuum was strongly variable (Papadakis et al. 2002).

There is thus growing evidence in favor of a significant fraction of the reflection features being formed at large distance from the central engine.

On the other hand there is an important observational and theoretical issue that is the existence of a correlation between the amplitude of the reflection component $R$ and the spectral index $\Gamma$ found by Zdziarski, Lubiniski & Smith 1999 (hereafter ZLS99) in a large sample of *Ginga* spectra. The measured $R$ tends to be larger in softer sources. This correlation is observed in sample of sources as well as in the time evolution of individual sources. The $R$-$\Gamma$ correlation is also found in the *BeppoSAX* data (Matt 2001), the *BeppoSAX* sample showing however a significantly different shape, with on average higher $R$ values at low $\Gamma$ and a flatter correlation. The usual interpretation of the correlation invokes the feedback from reprocessed radiation emitted by the reflector itself. It thus requires the main source of reflection to be present in the direct environment of the X-ray source. This thus appears inconsistent with the DCM picture.

One of the main goal of this paper is to attempt solving this paradox. We will show that under assumptions based on the present knowledge of the Seyfert 1s phenomenology, a $R$-$\Gamma$ correlation from a distant reflector is actually expected. Another possibility is that the correlation could be spurious. The $R$-$\Gamma$ correlation has been indeed widely controverted, in particular regarding the uncertainties on the measurement of $R$, but no-one could prove unambiguously that it is an artifact. In this paper we demonstrate that the determination of $R$ is sensitive to the assumed high energy cut-off and this may strongly alter the shape of the correlation.

In section 2, we recall the generic effects of the DCM reflection on the measured amplitude of the reflection features. In section 3, we investigate quantitatively the dependence of the reflection amplitude and the iron line equivalent width (EW) on the spectral index $\Gamma$ in the case where the variability of the primary component can be described as a pivoting power-law. Finally, in section 4 we attempt to test the presence of DCM reflection in NGC 5548 using *RXTE* data.

2 QUALITATIVE EFFECTS OF A DISTANT REFLECTOR

As the DCM line is spectrally distinct from the broader line emitted close to the black hole, the existence and the distance/scale of the DCM line region can, in principle, be probed using the new high resolution X-ray telescopes, as discussed above. On the other hand, the DCM Compton hump is more difficult to measure accurately and disentangle from its similar disc counterpart.

Actually, when analyzing the X-ray data, the possible contribution from DCM reflection is usually not considered a priori. The data are generally interpreted in the framework of reflection in the vicinity of the hard X-ray source. Usually, in spectral fits, the shape of the reflection component is computed assuming that the observed primary spectrum illuminates an infinite slab (e.g. *PEXRAV* model in *XSPEC*, Magdziarz & Zdziarski 1995). The normalization of the reflected spectrum is then tuned in order to fit the observed spectrum. The result of this fitting procedure provides the reflection amplitude $R$. $R$ is normalized so that $R=1$ in the case of an isotropic source above an infinite reflecting plane. $R$ is often considered as an estimate of $\Omega^{2}/2\pi$ where $\Omega$ is the solid angle subtended by the reflector as seen from the isotropic X-ray source. Obviously, any contribution from a remote structure leads to an increase of $R$ and may lead to an overestimate of the disc reflection. This may explain the very large $R$ coefficients $\sim 2$, measured in some Seyfert 1s, which are difficult to reconcile with disc reflection (see however Beloborodov 1999; Malzac, Beloborodov & Poutanen 2001).

The nuclei of Seyfert galaxies are known to harbor a significant flux and spectral variability on very short time-scales (see e.g. the recent review by Nandra 2001). Due to its extended structure, the remote reflector cannot respond to the rapid fluctuations of the primary X-ray flux. The reflected component from the DCM is thus likely to correspond to the time-averaged incident flux seen by the cold material rather than to the instantaneous (i.e. observed) one. Thus flux changes may induce a significant variation in the $R$ value derived from the spectral fits. A flux lower than the average enhances the apparent reflection, on the other hand, a larger flux may reduce $R$ down to zero. Then values of $R$ as low or large as required by the data can be easily produced. Similarly, the DCM iron line flux is expected to be constant and, consequently, its equivalent width would vary like the inverse of the primary continuum flux around the line energy.

As quoted in the introduction, a significant contribution from a remote reflector seems, at first sight, in contradiction with the reported correlation between $R$ and the spectral slope $\Gamma$. Indeed, in the context of DCM reflection, it is difficult to understand why the reflection contribution from DCM should be more important in objects with softer spectra. However, beside the simple effects of flux variability at constant spectrum discussed above, the pres-
ence of spectral variability also alters the appearance of the DCM reflection. Spectral variations with $\Delta \Gamma > 0.1$ are indeed commonly reported in Seyfert 1s. In the case of reflection on DCM, such spectral changes have a significant impact on the measured amplitude of the reflection features and the measurement of $R$. The resulting $R$ vs $\Gamma$ relation then depends on the specific spectral variability mode of the sources that may, under certain circumstances, produce a $R$-$\Gamma$ correlation (Nandra et al. 2000).

It appears indeed that the observed variability in Seyfert galaxies is generally consistent with fluctuations of the X-ray spectral slope with a nearly constant comptonised luminosity, i.e. the spectrum is mainly pivoting. This can happen for example if the UV luminosity entering the hot Comptonising plasma changes with a constant heating rate in the hot plasma (e.g. Malzac & Jourdain 2000). This kind of behaviour is widely observed in numerous sources such as NGC 5548 (Nicastro et al. 2000; Petrucci et al. 2000), 3C 120 (Zdziarski & Grandi 2001), NGC 7469 (Nandra et al. 2000; Nandra & Papadakis 2001), 1H 0419-577 (Page et al. 2002), NGC 3783 (De Rosa et al. 2002). In general, the pivot point appears to be located in the 2-10 keV range (see fig. 9 of Petrucci et al. 2000, fig. 3 of Page et al. 2002, fig. 3 of Zdziarski & Grandi 2001).

In the case of a pivoting spectrum at energies lower than 10 keV – i.e. below the energy range most of reflection is produced – when the spectrum is hard the observed primary flux in the 10–30 keV band is larger, and the relative amplitude of the DCM reflection, $R$, is reduced. On the other hand when the spectrum is soft the primary flux in this energy range is enhanced and the measured $R$ is larger. This thus produces a positive correlation between $R$ and $\Gamma$. The lower is the energy of the pivoting point, the steeper the correlation will be.

3 QUANTITATIVE EFFECTS OF A DISTANT REFLECTOR

We now attempt to investigate more quantitatively the effects of a distant reflector on the relation between the spectral index $\Gamma$ and the iron line equivalent width and reflection amplitude $R$.

As noted in the previous section, the $R$-$\Gamma$ relation depends on the variability mode. If one had a very accurate measurement of the $R$-$\Gamma$ correlation we could derive the variability mode required in order to produce the observed correlation with a DCM. However due to the large uncertainties in the measurement of $R$ and $\Gamma$ this is of little interest. We thus adopted the opposite approach: given the main observed characteristics of the variability in Seyfert 1s we test whether the presence of DCM can produce a correlation that is qualitatively similar to that observed. As discussed above, it seems that the spectral variability, in general, can be, at least roughly, described in terms of a pivoting spectrum. We will thus assume that this pivoting spectrum represents the general (or average) variability mode of the Seyfert galaxies. We caution however that the details of the variability mode in Seyferts is not known, and the single pivoting point is only a simplifying approximation.

3.1 Model with constant cut-off energy

We assume that the time average primary spectrum seen by the DCM can be represented by a power law with a photon index $\Gamma = 1.9$ – corresponding to the average $\Gamma$ in Seyferts 1 galaxies (Nandra et al. 1994; Matt 2001) – and an exponential cut-off at 400 keV. Neglecting any disc reflection, we further assume that the DCM geometry is such that the time averaged primary spectrum yield a reflection coefficient $R = 0.7$ (close to the average observed $R$ for sources with $\Gamma \sim 1.9$). As a first order approximation, the shape of the reflection spectrum is computed using the

Figure 2. The curves show the $R$-$\Gamma$ correlation obtained assuming a primary powerlaw spectrum pivoting around 2 (solid), 5 (dots) and 10 keV (dashes) with an exponential cut-off depending on $\Gamma$ according to the relation of equation 1, and a fixed reflected flux and spectrum corresponding to the reflection $R = 0.7$ and $\Gamma = 1.9$. Left panel: the simulated spectra were fitted using PEXRAV in the 2-30 keV range. The circles show the Ginga data of Zdziarski et al. (1999) and the errors have been omitted for clarity. Right panel: the simulated spectra were fitted using PEXRAV in the 2-200 keV range. The crosses show the BeppoSAX data of Perola et al. (2002).
PEXRAV procedure, i.e. assuming a slab reflector. Fixing the cut-off energy at 400 keV, we produced a set of instantaneous primary spectra for several photon indices $\Gamma$ spanning the observed range 1.4–2.2. We did this for pivot points at energies 2, 5 and 10 keV respectively.

We then added the reflection component, produced as described above, to these instantaneous spectra, and fitted the resulting spectra with PEXRAV in the 2–30 keV range. We also fitted the simulated spectra in the 2–100 keV range. In both energy ranges, the derived best fit parameters were very similar. The $R$–$\Gamma$ relations resulting from our modelling procedure are shown in Fig. 1 and compared with the correlation observed in the Ginga data.

Although the predicted correlation appears flatter than the observed one it qualitatively matches the $R$–$\Gamma$ correlation observed in the sample of Ginga data from ZLS99.

3.2 Model with variable cut-off energy

Actually the amplitude of the reflection component is difficult to measure accurately and the derived $R$ values are quite dependent on the modelling of the primary emission (see Petrucci et al. 2001). In particular, the Ginga data used by ZLS99 to demonstrate the correlation do not enable one to constrain the cut-off energy. In their analysis they thus fixed $E_c$=400 keV in all their fits. Actually the $R$ derived from spectral fits depends on this assumed $E_c$ value. The BeppoSAX data allowed better constraints on the cut-off energy. Fitting these data with PEXRAV shows that the cut-off energy differs from source to source and is also apparently correlated with the spectral slope. Fitting the $E_c$–$\Gamma$ correlation presented by Perola et al. (2002), we found that this correlation can be qualitatively represented by the following function:

$$E_c = 10^{0.73 \Gamma + 5.7} \text{ keV}. \quad (1)$$

Perola et al. (2002) also suggested that the effects of the different cut-off energies could be responsible for part of the already mentioned differences between the BeppoSAX and Ginga $R$–$\Gamma$ correlations.

In order, to check the effect of a varying cut-off on the correlation produced by a DCM reflection, we generated a set of simulated spectra in a way similar to that described in section 3.1, but instead of a constant $E_c$, we introduced a “$\Gamma$–dependent” $E_c$ as given by equation (1).

First, we mimicked the Ginga analysis of ZLS99 by fitting the set of simulated spectra in the 2-30 keV range assuming a constant cut-off at $E_c$=400 keV. As shown in the left panel of Fig. 2 this produces $R$–$\Gamma$ correlations which are steeper than in the case of the models with constant $E_c$. In particular at low $\Gamma$, the reflection amplitude is lower and reaches $R=0$ for the hardest spectra, as indeed observed by ZLS99. Thus allowing a correlation between $E_c$ and $\Gamma$ results on a better agreement of the DCM model with the observations.

We then fitted the simulated spectra in the broader (2–200 keV) energy range that is allowed by BeppoSAX. The cut-off energy $E_c$ was then let as a free parameter and we consistently recovered best fit $E_c$ close to the injected one. This procedure results in $R$–$\Gamma$ correlations which are flatter and with higher $R$ values, consistent with the BeppoSAX correlation as can be seen from the right panel of Fig. 2.

We note that the $E_c$–$\Gamma$ correlation found with PEXRAV in the BeppoSAX data does not necessarily reflect changes in the temperature of the Comptonising plasma. Indeed, although PEXRAV is useful to provide a simple and standard phenomenological description of observed spectra, this model represents only a rough approximation to real Comptonisation spectra. The physical interpretation of the fit parameters $\Gamma$ and $E_c$ in terms of Thomson optical depth and temperature is not straightforward. Moreover the use of PEXRAV in spectral fits may produce or emphasize parameter correlations that are not necessarily found with realistic Comptonisation models (Petrucci et al 2000, 2001). To see if the $\Gamma$–$E_c$ correlation obtained with PEXRAV could be produced at constant temperature, we used the COMPPS model (Poutanen & Svensson 1996) to generate a set of realistic Compton spectra that we subsequently fit with PEXRAV. In the COMPPS simulations we assumed a spherical and isotropic geometry for the comptonising plasma with temperature fixed at $kT_e$=100 keV, and varied the Thomson optical depth of the comptonising plasma. We added to all spectra the same reflected flux. We fit these spectra with PEXRAV in the 2–200 keV range and indeed obtained a correlation between the resulting $E_c$ and $\Gamma$ parameters. For $\Gamma < 1.9$, this correlation is however flatter than the observed $E_c$–$\Gamma$ relation given by equation (1). The physical significance (if any) of the $E_c$–$\Gamma$ correlation is thus unclear. From the phenomenological side however, this correlation provides the best PEXRAV representation of the data. It thus should be taken into account when simulating observed spectra with this model.

We further note that the $R$–$\Gamma$ correlation resulting from our COMPPS simulations with constant temperature, when these spectra are fit with PEXRAV in the Ginga range, is intermediate between what obtained for a constant $E_c$ (Fig. 1) and for $E_c$ given by equation (1) (left panel of Fig. 3).

* available at ftp://ftp.astro.su.se/pub/juri/XSPEC/COMPPS
3.3 The iron line equivalent width vs $\Gamma$ relation

We now discuss the effects of a pivoting spectrum on the measured Fe line equivalent width ($EW$) produced by the DCM. For a power-law spectrum pivoting at an energy $E_p$, and a pure DCM spectrum, we have:

$$EW = \frac{I_{Fe}}{F_{E_p}} \left( \frac{E_p}{E_{K\alpha}} \right)^{-\Gamma} \frac{E_{K\alpha}}{E_p},$$

with $I_{Fe}$ being the line photon intensity and $F_{E_p}$ the primary photon flux at energy $E_p$. From this relation it appears the $EW$ is positively correlated with $\Gamma$ when the pivoting point is below $E_{K\alpha} \approx 6.4$ keV, while it is anti-correlated for higher pivoting energy (the $EW$ indeed represents the amount of reflection at 6.4 keV i.e. at a lower energy than the reflection bump). Of course, the normalization depends on the geometry of the DCM reflector. For an optically thick torus with an opening angle, Ghisellini, Haardt and Matt (1994) derive an equivalent width $EW \sim 80$ eV.

This estimate depends also widely on viewing angle and elemental abundances (Życki & Cerzny 1994; George & Fabian 1991). Using a large ASCA sample, LZ01 produced 3 average spectra of Seyfert sources and/or on long time scale (i.e. longer than a few years). Although a correlation between the narrow line flux and source luminosity is reported (Nandra et al. 1997; Pound & Reeves 2002), the changes in the narrow line strength are apparently unrelated to $\Gamma$.

The resulting dependence of the measured equivalent width with $\Gamma$ is plotted on Fig. 3. We see that the trend (correlation or anti-correlation) in the $EW-\Gamma$ relation is indeed qualitatively sensitive to the pivot point energy. However, if one consider that the pivot point location is likely to fluctuate (with time or from source to source), our assumed variability mode predicts essentially no specific relation between $EW$ and $\Gamma$. Moreover, the fluctuations of $EW$ due to a pivoting spectrum are quite weak. Thus for a fixed geometry, our pivoting spectrum will produce an essentially constant $EW$, independently of $\Gamma$, as observed by LZ01.

We note that the results of the averaging procedure of ZL01 should be taken with a caution (see Yaqoob et al. 2002). On the other hand, accurate measurements of the $EW$ of the narrow line in individual sources is somewhat difficult since it requires a high resolution observations and a good determination of the continuum and the broad-line component. Actually, the present estimates have large error bars and seem to depend on the modelling of the broad-line component and in particular, on the choice of the unconstained parameters of the relativistic disc model. For instance, using XMM-Newton data of Mrk 359, O’Brien et al. (2001) find an $EW$ of the narrow line of 120 eV when assuming a disc extending down to 3 Rs, and $EW = 62$ eV when fixing the disc inner radius at 50 Rs. Despite these uncertainties, the data on individual sources suggest that the $EW$ of the narrow line changes from source to source and/or on long time scale (i.e. longer than a few years).

Actually, the observed fluctuations of the narrow line $EW$ are likely to be dominated by intrinsic differences for instance in the geometry, elemental abundances or viewing angle of the reflecting
material. Such differences are smeared out by the averaging procedure of LZ01 that shows the average $EW$-\(\Gamma\) (in)dependence.

Thus, our assumed pivoting spectrum induces only weak changes in the narrow line $EW$ that are observationally dominated by both uncertainties on the line strength measurement and a spread in the characteristics of the reflector from source to source. Simultaneously, the pivoting spectrum produces a strong dependence of $R$ on $\Gamma$ that would dominate over the intrinsic differences from source to source and may contribute significantly to the reported $R$-$\Gamma$ correlation. In this context, part of the observed spread in the $R$-$\Gamma$ plane could be due to the slightly different DCM configurations in different sources. The prediction of the absence of strong correlation between the narrow line $EW$ and $\Gamma$ (linked with our assumed variability mode) is thus consistent with the present data and will be possibly tested when better data will be available.

4 THE CASE OF NGC 5548

From the previous section we see that the effects of DCM reflection, when important, make the geometrical interpretation of $R$ extremely misleading. *Trying to disentangle the temporal and geometrical effects is extremely difficult* and requires very long observations with time resolved spectral analysis. NGC 5548 was the target of such a monitoring campaign in 1999. It was observed in the X-rays on June 15-16, June 19-24, June 29-July 2, Jul 7 and August 16-18 with RXTE, thus providing a relatively good coverage of the source evolution during nearly 2 months. The results of these observations (as well as other contemporary multi-wavelength observations) are reported in Chiang et al. (2000, hereafter C00). Interestingly, while the 2-10 keV flux changed by a factor of 2 during the campaign, C00 report a constant line flux suggestive of a DCM line. Strikingly the reflection amplitude $R$ was found to be essentially constant, with a trend for a correlation between $R$ and the 2-10 keV flux. The latter result suggests a close origin for the reflection bump and this is clearly inconsistent with DCM reflection. Then the line and the reflection bump should have a different origin, which appears difficult to explain.

In the case where the reflection component arises mainly from a distant reflector, the $R$ parameter is not very convenient to provide a physical insight. Rather the absolute reflection flux may be more relevant to probe the distant reflector since it is expected to be constant on short time scales (a few months) independently of the source flux and spectrum. On the other hand, in the case of close-by reflection, the reflected flux is expected to follow the fluctuations of the primary flux. We thus reanalyzed the C00 data, with a model of constant reflection spectrum using as fitting parameter, the absolute reflection flux $RF$ instead of the usual reflection amplitude $R$.

We used the 10 RXTE spectra taken at different epochs described in C00. Instead of using directly pexrav as did C00, our model consisted in an e-folded power-law (\textsc{cutoffpl}) plus a reflection component with a fixed shape (i.e. independent of the primary spectrum parameters). This reflection spectrum was produced by pexrav for a spectral index $\Gamma = 1.9$, a cut-off at 200 keV and standard abundances. The absolute normalization of the reflection component was a free parameter. As the reflection spectral shape is identical in all fits, this parameter is directly proportional to $RF$. The RXTE data do not enable one to constrain the high energy cut-off and we had to keep it frozen at an arbitrary value. We performed three fits of each spectrum assuming $E_c$=100, 200 and 400 keV respectively.

The dependence of $RF$ on the 2-10 keV flux is displayed on Fig.\[4\] for a fixed value of the cut-off energy the data are formally consistent with a constant value of $RF$. When the $RF$ vs 2-10 keV flux relation is fit with a constant, the reduced $\chi^2$ values are all below unity and the $\chi^2$ probability is systematically larger than 0.5. However, when a linear relation between the reflection flux and the 2-10 keV flux is assumed, we systematically get an improvement of the fit significant at better than the 95 per cent confidence level according to $F$ test. This correlation between the reflection normalization and 2–10 keV flux (in agreement with the finding of C00) is suggestive of a close reflector where the reflection flux increases almost linearly with the primary X-ray flux.

Nevertheless, as can be seen on Fig.\[4\] the measured $RF$ appears to depend on the cut-off energy. For our three fixed $E_c$ values we find 3 best fit $RF$ differing substantially. The $RF$ is systematically larger for lower $E_c$, the typical differences being about 40 per cent between $E_c = 400$ keV and $E_c = 100$ keV. Now, if we consider the uncertainties on the cut-off energy it appears that the observed $RF$ is also consistent within the error bars with a DCM reflection (i.e. constant $RF$). In particular one may consider that the actual $E_c$ might be positively correlated with the 2–10 keV flux.

Actually, the effects of the assumed $E_c$ on the $RF$ could be an artifact of our model associated with the particular e-folding cut-off shape assumed which may differ from a real thermal Comptonisation cut-off. We thus also model the primary emission using the more physical Comptonisation model \textsc{compps}. We used the Thomson optical depth as the fitting parameter. Each spectrum was fit successively with the hot cloud temperature frozen at three different test values (40, 160, and 300 keV). On average, we obtain significantly lower $RF$’s with the comptonisation model. The determination of the reflection is indeed very sensitive to the modelling of the primary continuum (see Petrucci et al. 2001). More precisely, as long as the temperature was fixed to a low value ($\lesssim 160$ keV) the best fit $RF$ appears to be independent on the assumed temperature. There is a correlation between $RF$ and 2-10 keV flux (significant at the 98 per cent confidence level) consistent with a close reflector, although the DCM can not be formally ruled out. On the other hand at higher temperature it appears that $RF$ becomes strongly dependent on the assumed $T_e$. For $T_e=300$ keV we found significantly lower values for the $RF$ and almost no-correlation with the 2-10 keV flux. The improvement of the fit between a constant and linear model is significant only at the 63 per cent confidence level. This difference with respect to the low temperature case, is due to the fact that at large temperature the best fit optical depth is in general quite low ($\tau_T \sim 0.2$). The Comptonisation spectrum then differs from a pure power-law and this affects the measured $RF$.

The main conclusion here is that whatever the fitting model used, the measured reflection amplitude is very dependent on the assumptions on the cut-off energy (or temperature) which can be constrained, together with the reflection component, only with broad band instrument such as \textsc{beppoSAX} or the future \textsc{integral}.

As shown above, when these uncertainties are considered the present data become consistent with the DCM model. In particular, our results are fully consistent with a DCM reflector in the case of a high temperature Comptonising plasma, or a cut-off energy positively correlated with the 2-10 keV flux. It is worth noting that such high temperatures of order of 300 keV are indeed deduced from spectral fits to the the \textsc{beppoSAX} data with realistic Comptonisation models (Petrucci et al. 2000) and that a correlation between the cut-off energy and spectral slope is inferred from the \textsc{beppoSAX} sample using pexrav (see Matt 2001; Perola et al. 2002).

Independently, the narrow line component detected by Chandra (Yaqoob et al. 2001), recently confirmed by XMM-Newton.
(Pounds & Reeves 2002), together with the constant line flux reported by Chiang et al. (2000) are suggestive of DCM dominated reflection in this source. Thus, although the close-by reflection model is not ruled out by the Compton bump data alone, the DCM picture appears favored when these data are considered together with the iron line information.

5 DISCUSSION

We considered the effects of reflection at large distance on the measured reflection amplitude \( R \) and equivalent width of the Fe fluorescence line. We show that the remote cold material may in principle account simultaneously for the observed correlation between \( R \) and \( \Gamma \), and the observed narrow line component which is predicted to be independent of \( \Gamma \).

We considered the \( R-\Gamma \) relation produced for different fixed pivoting point energies, with and without varying the cut-off energy, in all cases a correlation is produced. Actually, in the case of a constant comptonised flux and varying soft photon input, the pivot location is likely to fluctuate from the fact that changes in the cooling also affects the cut-off energy, and thus the energy range in which the comptonised power is released. As a consequence the pivot point may depend on \( \Gamma \). Note that if the spectral pivot shifts above 10-20 keV this produces an anti-correlation. Such an anti-correlation is reported by Larmer et al. (2000) in NGC 5506 where they find evidence for DCM reflection. However, even if the pivoting point energy changes among different sources or within the spectral evolution of an individual source we will just follow different correlations in the \( R-\Gamma \) plane and generally, a correlation will be produced. The correlation can be destroyed only if in a large fraction of the sources the pivot energy decreases very quickly with \( \Gamma \), or the pivot point is above a few 10 keV, in contrast to what is commonly observed.

Thus, despite the uncertainties a correlation between \( R \) and \( \Gamma \) is expected in individual sources and is likely to be preserved in sample of sources. In the latter case this interpretation requires that most of the Seyfert sources present a similar variability mode (i.e. pivoting primary power-law), time average properties, as well as geometry of the DCM. While a pivoting powerlaw seems to be a general characteristics of Seyfert 1s, on the other hand, the geometry of the DCM is unknown. According to the unified model, the geometry of the DCM should be similar in all sources. In this context the small differences in geometry or variability mode would explain part of the spread of the data points in the \( R-\Gamma \) plane.

Our simulated \( R-\Gamma \) correlation are qualitatively similar to the observed one, but not exactly identical. In particular it seems that many of the data points lie below the predictions in both Fig. 1 and 2. This is not a fundamental problem for the DCM interpretation. This is simply a confirmation that the simple pivoting powerlaw model is a poor approximation to the actual variability mode. For instance if the pivoting points depends on Gamma and if for some reasons the pivoting point shift toward energies below 2 keV for the hardest spectra, it can produce as many sources with low reflection as required. However if we also consider the uncertainties on the measured \( R \) this would be certainly overinterpreting the data. We thus preferred using a simple and approximative model that reproduces qualitatively the correlation, rather than a complicated and rather had hoc model.

In this study we neglected the contribution of reflection from the central part of the accretion flow. Actually the situation is probably more complex: the observed iron line profiles often present a broad component which is unlikely to be produced far away from the central engine. This broad component is probably associated with a inner reflection bump that may contribute to the \( R-\Gamma \) correlation. It is however not clear if the broad iron line component \( EW \) is correlated with \( \Gamma \) as would be expected in such case (see LZ01 and Yaqoob et al. 2002 for a critical reevaluation of their results). At least, in several sources the broad line \( EW \) appears to be unrelated to the changes in \( \Gamma \) and present complicated behavior (Nandra et al. 1999, Vaughan & Edelson 2001 and references therein).

Another interesting point is the the analogy with X-ray binaries where a similar \( R-\Gamma \) relations is observed. Due to the time-scale involved this correlation cannot be accounted for by a DCM reflector (Gilfanov, Revnitsev & Churazov, 2000). The shape of the observed correlation seems however to differ between X-ray binaries and Seyferts, in particular the DCM can naturally explain both the very large and very low reflection amplitude that are not observed in X-ray binaries. Also unlike AGNs, several X-ray binaries present a clear iron line \( EW-\Gamma \) correlation. Actually accretion onto a black hole in an X-ray binary and an AGN is expected to proceed in a very different way due to the different boundaries conditions at large distance. The correlation in both types of sources could thus have a different origin.

In any case, the observations suggest that reflection arising from the DCM is important in many Seyfert galaxies. In particular, we showed that in NGC 5548 the reflection component could be dominated by the DCM reflector in the sense that, when uncertainties on the cut-off energy are taken into account, the \( RXTE \) data of C00 are consistent with a constant reflected flux. This would solve the previously reported inconsistency between the behaviour of the reflection bump and the observed constant line flux.

Finally we stress that our results do not exclude that part or even all of the \( R-\Gamma \) correlation in Seyferts is due to some contribution from the central region, however they show that this is not required. This has important implications for the modeling of the inner part of the accretion flow. It demonstrates that in Seyfert galaxies, the \( R-\Gamma \) correlation is not a good tool to discriminate between models for the physics and geometry of the X-ray emitting region. In particular emission models that do not produce a \( R-\Gamma \) correlation are not ruled out (see e.g. Malzac & Celotti 2002).

6 CONCLUSIONS

In this paper we attempted to reconcile the numerous evidences for DCM reflection in Seyfert 1s galaxies with the presence of a correlation between the reflection amplitude \( R \) and the spectral index \( \Gamma \). We found that in the case of reflection on a DCM, the generally observed variability mode in Seyfert 1s naturally leads to a \( R-\Gamma \) correlation. We also showed that the measurement of \( R \) and the shape of the observed \( R-\Gamma \) correlation is sensitive to the value of the cut-off energy. As long as the cut-off energy cannot be constrained, this effect significantly increases the error bars on the measured \( R \) and possibly reduces the significativity of the correlation. In our case study of NGC 5548, we showed that when the effects of the cut-off energy are taken into account the data are fully consistent with the DCM picture, while in the context of close-by reflection the reported constant line flux remains a problem.

The EW of the narrow iron \( K_{\alpha} \) line produced by reflection on the DCM is predicted to be generally independent of \( \Gamma \). This appears to be consistent with the present data, although the large uncertainties on the measurement of the the narrow line prevent us from reaching a firm conclusion.
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