MULTIPLE COMPTON REFLECTIONS ON PHOTOIONIZED CLOUDS AS A MODEL FOR SEYFERTs FE K_α LINE

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ABSTRACT

We aim to assess the possible importance of multiple reflections and Compton scattering on/in a thick photoionized plasma for the interpretation of the iron K line complex observed in several unobscured AGN. We present preliminary results of calculations combining iterative 2-stream and Monte Carlo methods, in the framework of a quasi-spherical accretion model.

Assuming a high covering factor of the reprocessing plasma, so that several reflections occur, the iron line profile of Seyfert 1 galaxies might be reproduced, without invoking a gravitational shift, if clouds of different ionization parameters ($\xi = \frac{L_{ion.}}{nR^2}$) reflect a primary power-law continuum. One-ξ models are ruled out.

1. Introduction

The accretion flow onto the supermassive black holes thought to power active galactic nuclei is likely to be disk-shaped over a significant interval in radial distances. This is expected both on the theoretical requirement that the angular momentum of the accreted matter has to be dissipated somewhere, and on observationnal evidences, in many objects and on relatively large scale, of axial symetry. The question of whether a geometrically thin disk extends over the inner part of the flow, down to the radius of marginal stability, is more controversial, because of several kind of instability that could arise before.

A breakthrough occured (Tanaka et al.1995), with ASCA observations during which ultra-broad, skewed, iron fluoresent lines were resolved in the spectra of several type 1 Seyfert galaxies, the archetypical object for this feature being MCG-6-30-15, for which long exposure spectra were obtained. The skewness of the line profile, with its red tail, have been attributed to gravitational and Doppler shifts caused by relativistic orbital motion in the disk (Fabian et al.1989), and thus require that a significant part of the line emission comes from a region of the disk less than 10 R_S away from the black hole. This seems even strenghtened when one consider the very redshifted profile observed during a dip in luminosity, which, in this framework, implied emission from within the innermost stable orbit in Schwarzschild metric, thus indicating that the black hole is spinning.

This explanation of the data rules out alternative models to such a very inner disk.

2. Compton Broadening - Modelization

We report here on simulations that we made to check if this profile could be accounted for in a model where a shell of radiatively heated thick clouds reprocess the emission of a central comptonizing plasma, and cool it via the reflected radiation. It was shown to be a plausible model both from the point a view of the energy budget and because the emergent spectra were in reasonable agreement with the observed Optical/UV/soft X-ray AGN emission (Collin-Souffrin et al.1996, Czerny & Dumont 1998).

This model favors the compton broadening hypothesis for the following reasons:

First, the radiative energy density inside the clouds shell can be significantly amplified when the covering factor is high. Thus, for a given caracteristic distance of the clouds, their ionization state can be higher than one would deduce from the observed bolometric luminosity. Secondly, this amplification is energy dependant, as it is strongly dependant on the albedo of the bright side of the clouds. This naturally produces excess peaking in the UV, which helps to maintain, in these warm mirrors, a temperature that is compatible with the direct Compton effect dominating inverse Compton at 6 keV. Thirdly, as photons may be reflected several times before escaping, the minimum thickness over which the superficial reflective layers of the clouds should be significantly ionized is reduced.

The first points are illustrated on figure 1. We define the effective primary as the sum of the equilibrium multiple reflected spectrum inside the shell and the "primary" flux produced by the central inverse-comptonizing cloud. The Amplification factor is simply the ratio of these two components. Although there is no space here to describe the numerical methods we used, it should be noted that the monte carlo code, which computes the amplification due to this closed geometry, does not include free free emission (although it takes into account free free absorption). Thus we obtain a lower limit on the amplification.

High ionization is needed for multiple Compton scattering to be efficient with respect to photoabsorption. However, the peak energy of the fluorescent iron line is then higher than the observed position at 6.4 keV. This could be accounted for by an outflow velocity of the clouds, but this requires some mechanism to fine-tune this velocity so that most observed peak energies lie close to 6.4 keV. In any case, a large covering factor of highly ionized clouds leads to computed equivalent widths much larger ($\sim$ 1keV) than that observed in the time averaged spectra of unobscured Seyfert nuclei. Thus, a one-ξ model can not explain the whole line.

The proposed alternative is an additional contribution to the line from more weakly ionized material. Those could be either located further away from the black hole or have greater densities. We investigated the possibility that they lie in the same region. Time resolved spectroscopy is an important tool in disentangling these possibilities. Clumps of different densities may result from thermal instability. Alternatively, these clouds could result from other instabilities leading to a fragmentation of the disk in its inner parts.

3. First Results

Compton scattering deeply affects the multiple-reflected spectra. High ionization leads to a significantly broadened line, without producing a strong compton hump around 20 keV. The low ionization clouds seem required in order to explain the high energy tail observed in this band by RXTE, for MCG-6-30-15. The determination of the continuum is complicated on the blue side of the iron line by a smeared edge and recombination continua, and on the red side by the influence of the edges of elements lighter than iron. Figures 2 and 3 show the importance of these effects when the ionization is high. As the equivalent width associated with ionized reflection tends to be important (provided the ionization state of iron is above the critical range FE XVII-XXIII where resonnant trapping suppress line emission), these effects could be noticeable even when cold reflection dominates. Line photons in these simulations are simply defined as the escaping photons that have encountered absorption by an iron ion, irrespective of their subsequent fate. Error bars on the simulated spectrum are omitted for clarity, but have the same size as the visible wiggles. In Figure 4, we show the obtained spectrum when the cloud shell is heterogeneous. The equivalent width is still too large (480 eV) for a mean value. We emphasize that the preliminary results presented here are definitely not best fit parameters. Although work is in progress to build a table model with a not too coarse grid of the parameters $\Omega/4\pi$,ξ,Γ and reasonable photon statistic, we are not in a position to accurately fit a particular object yet. In view of our first results, however, it does not seem consistent to neglect the effect of compton scattering on the line profile, while at the same time invoking a highly ionized mirror to accomodate equivalent width higher than expected in planar reflection.

One of our assumption is that clouds of different ionization state lie in the same region. It can be relaxed. The fact that the line is a multi-component complex is strongly suggested at least for weakly absorbed (in X-ray) Seyferts 2. Indeed, it has been suggested that keeping the model of a single diskline profile implies an as low disk inclinaison angle for these objects as for type 1 Seyferts, which seems at odd with the unification scheme (Turner et al.1998). We did not include in these calculations the effect of warm absorbers on the line of sight (these should not deeply affect the spectra above 3 keV, but the possibility of a contribution to the iron edge should be investigated). Neither did we take into account dynamical effects. In the present scenario, the iron line profile should also be affected by the bulk motion of the emitting clouds, which in turn depends on the distance to a central black hole, if one assumes Keplerian cloud motion. For all these issues, the study of the variability is an extremely important tool. The EPIC camera on board XMM should permit to further test the viability of the model by providing line profiles with higher S/N ratios. In particular, the improved sensitivity will enable to study the continuum variability and response of the line profile, on shorter time-scales than has been achieved with ASCA.

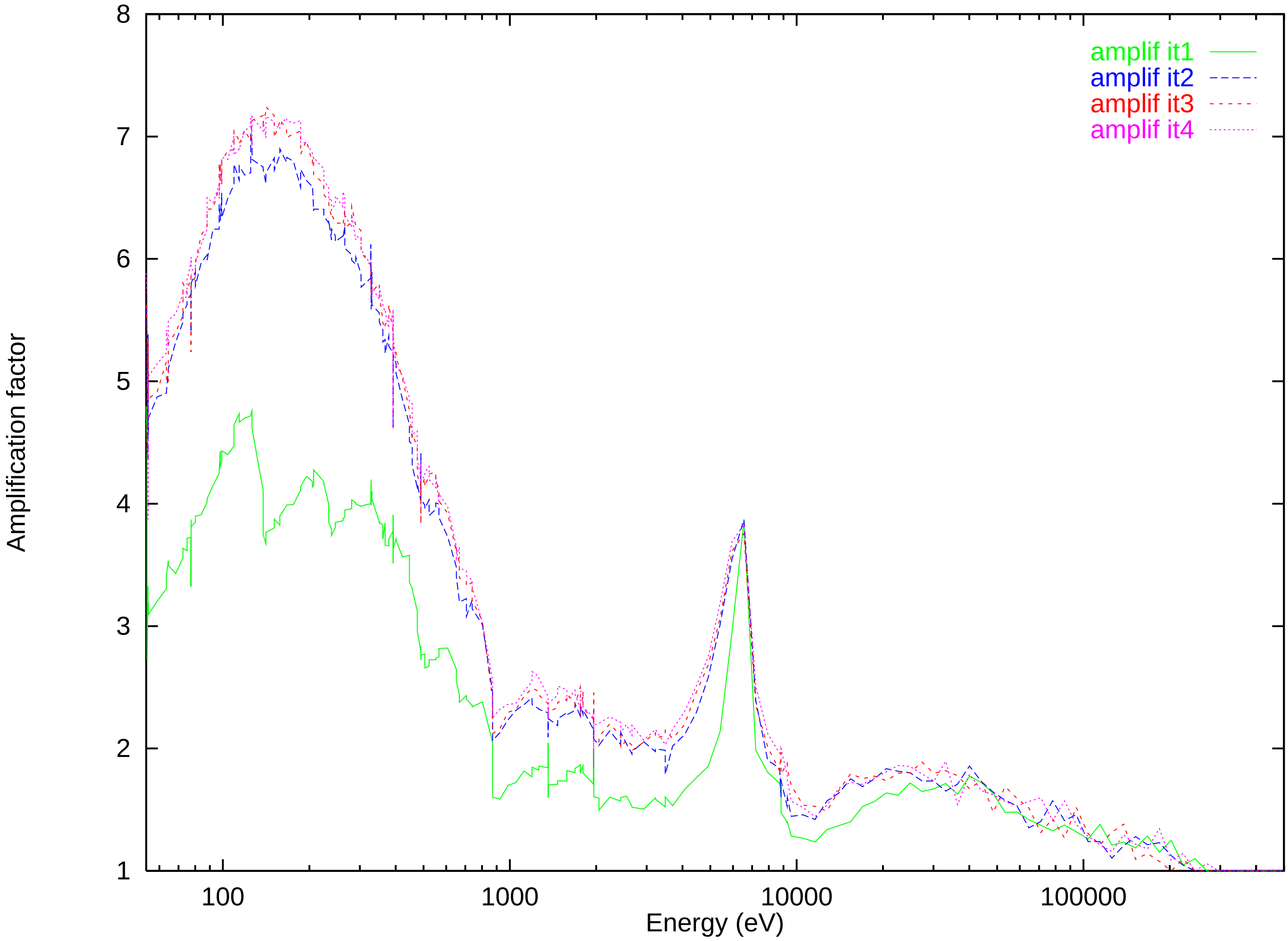

Fig. 1.— Amplification factor (see text) versus photon energy (above the He^{+} edge), showing the departure from the power law shape of the primary ionizing flux. Iterations are performed to self consistently compute the stratified physical conditions in the reprocessing clouds, photoionized by the multiple reflected primary radiation. Starting from $\xi = 3000$, the effective primary reach a value $\xi_{eff} = 10880$. Note the formation of a soft excess and the disappearance of the edges just above 100 eV. Other parameters are: covering factor $\Omega/4\pi = 0.9$, primary photon slope $\Gamma = 2$, low and high energy cutoff: 0.1 eV and 100 keV, respectively.

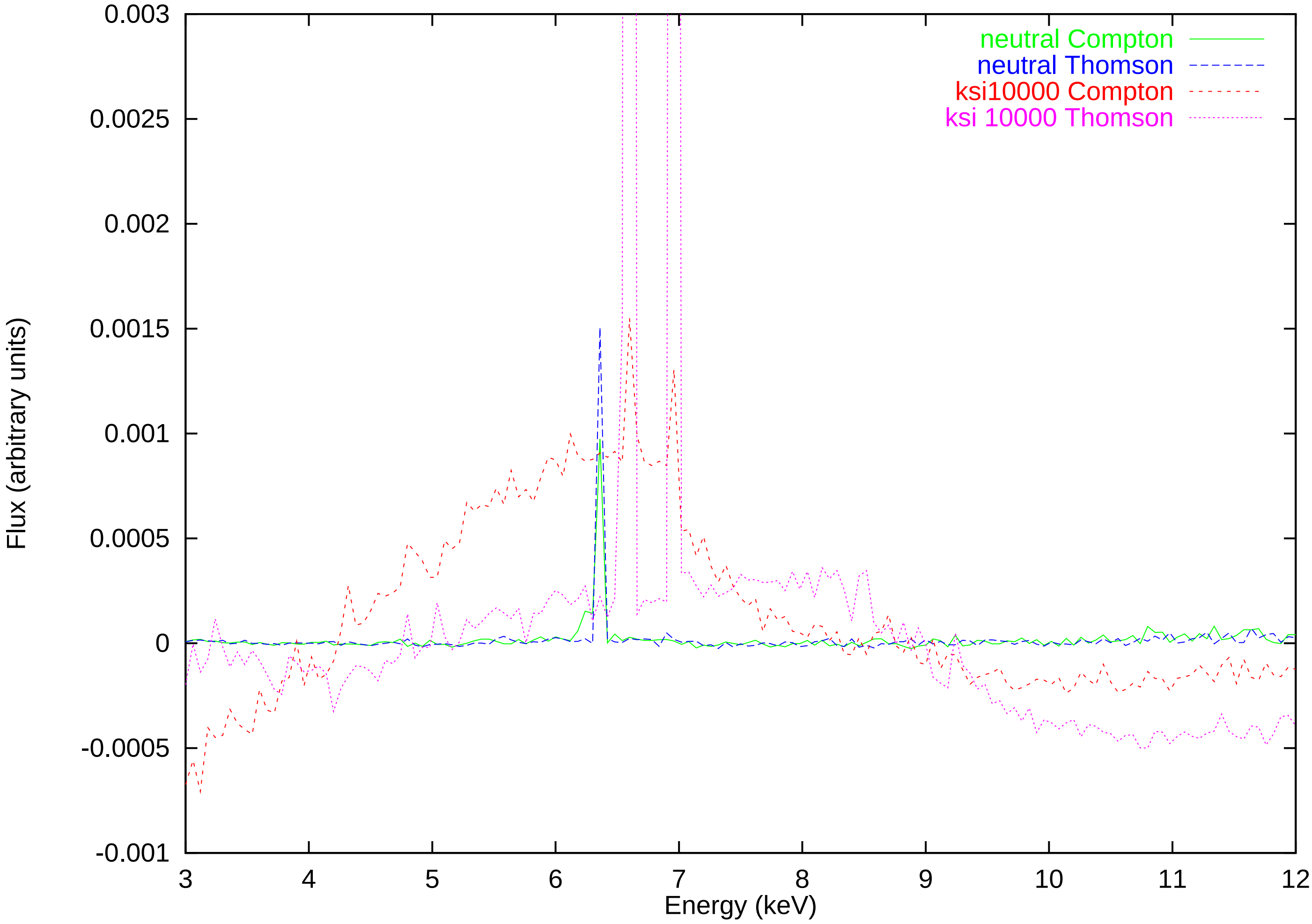

Fig. 2.— Comparison of the effect of inelastic electron scattering, for two extreme states of the reflecting clouds: $\xi = 10000$, and neutral material. The continuum is fitted on the 3-10 keV range, excluding the 5-7 keV band. Other parameters are the same as for Fig. 1. For the Compton case, the equivalent width for the $\xi = 10000$ and neutral case are 845 eV and 145 eV, respectively.

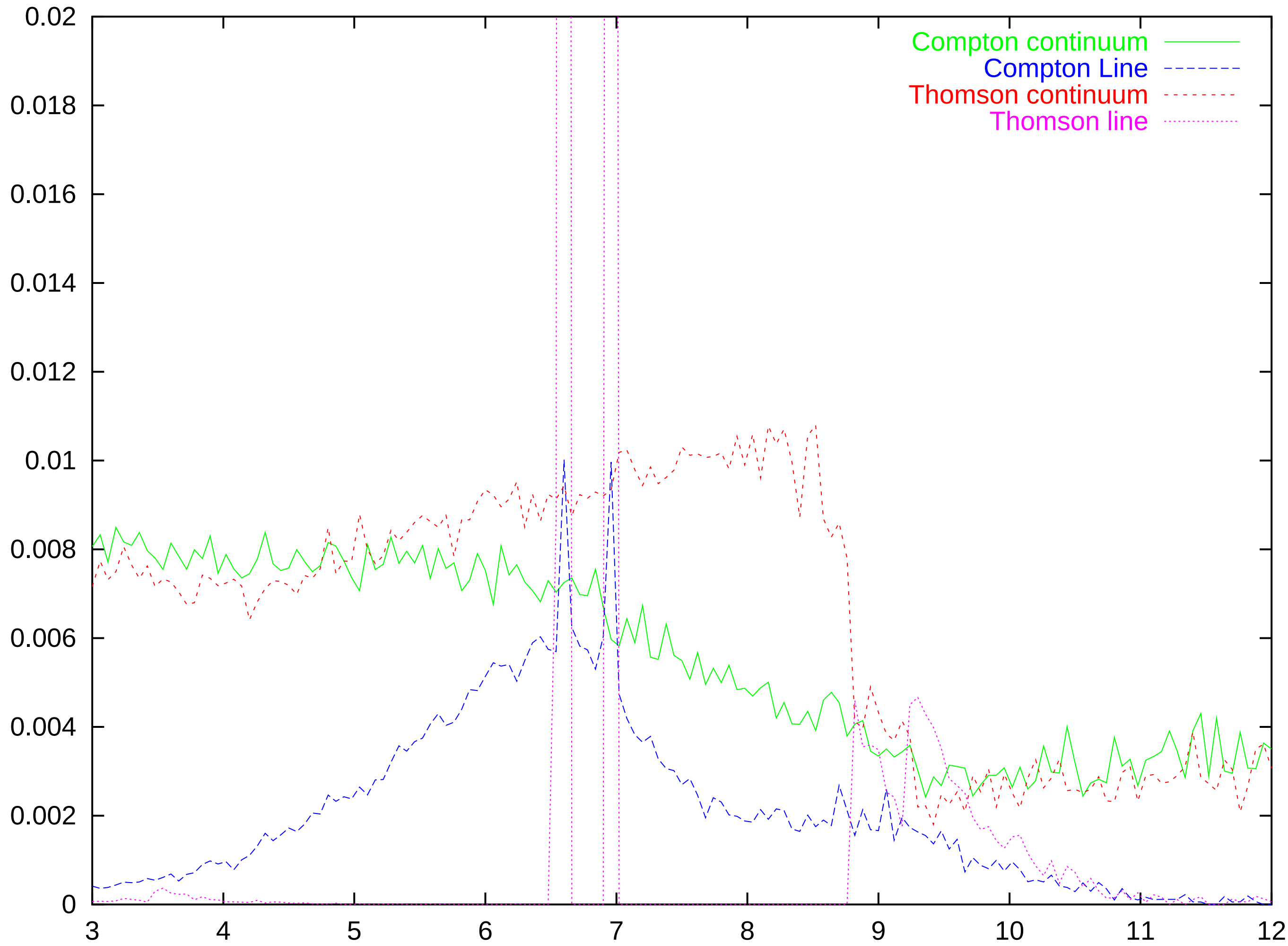

Fig. 3.— Line and "true" continuum components of the observed spectra in the iron line region, when the reprocessing clouds are highly ionized ($\xi = 10000$). This is a decomposition of the profile shown in Fig. 2. These components are also shown in the case of elastic scattering, for comparison. The smearing of the edge and the recombination continuum are clearly seen.

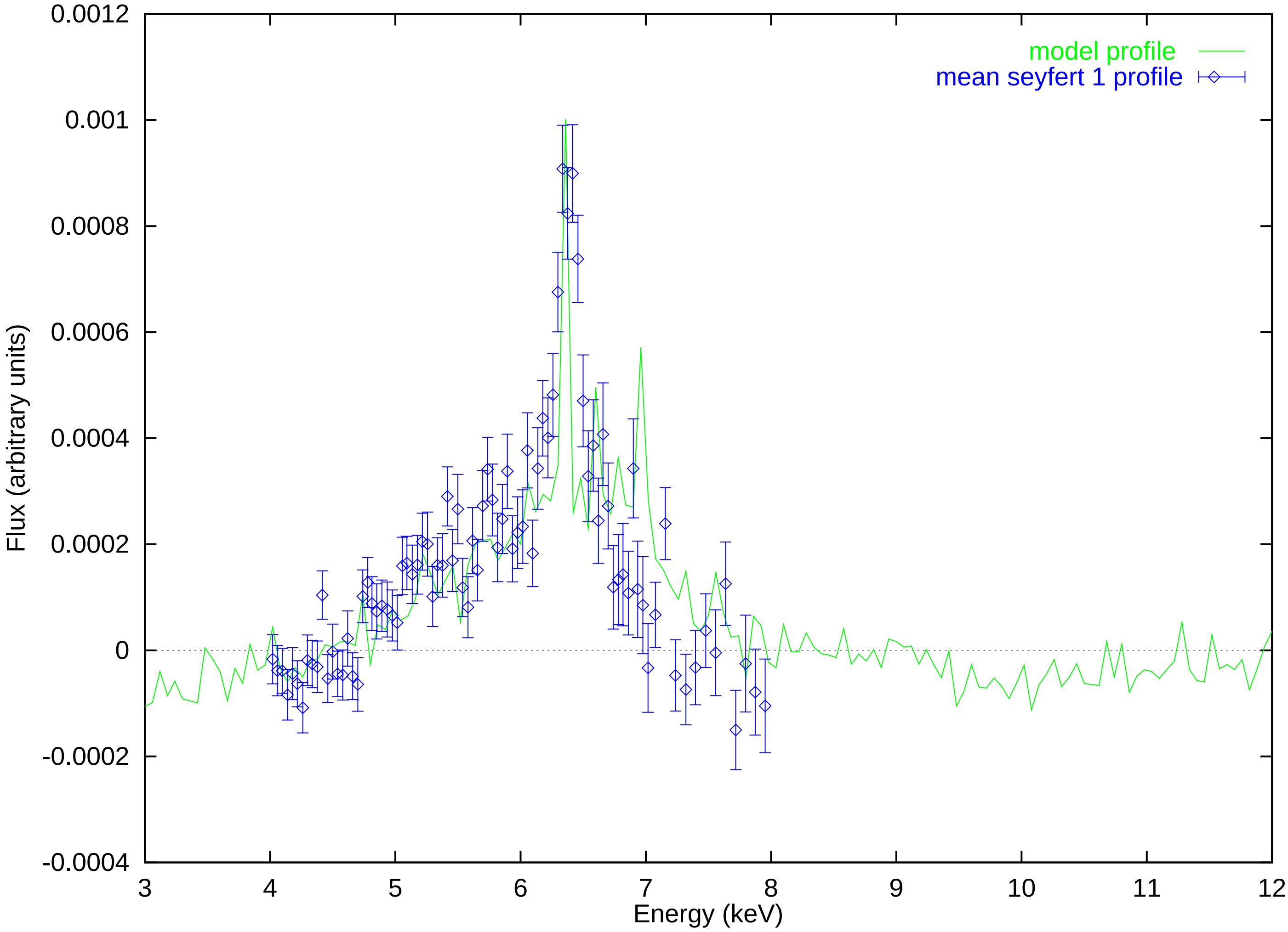

Fig. 4.— Observed profile when the reprocessing shell contains both highly ionized ($\xi = 10000$) and near-neutral clouds, in equal proportion. The radiative interaction of the two phases is self-consistently computed. Other parameters are the same as for Fig. 1. The observed mean Seyfert 1 (Nandra et al.1997) profile is shown for comparison.

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