Thermal Or Non–Thermal X–Rays From AGNs?

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Abstract. Recent data from OSSE on CGRO and SIGMA on GRANAT challenge the non-thermal interpretation of the origin of the high energy emission of AGNs, showing that the hard X-ray spectra of several Seyfert AGN are steep like those of Galactic black hole candidates. Thermal models are therefore favoured. Two-phase models, in which a hot corona is placed above a relatively cold accretion disk can account for the observed X-ray spectra and the correlated variability in the UV and X-ray bands. Cold matter, both in the vicinity of the nucleous, and located further away in the torus surrounding the nucleous, may modify substantially the spectrum with important consequences on the expected variability and spectral shape.

Key words: X–rays, Active Galactic Nuclei, Comptonization

1 Introduction

The hard X–ray and γ–ray satellites GINGA, SIGMA and CGRO have greatly changed our views on the high energy emission of Active Galactic Nuclei, deeply influencing our understanding of the main mechanisms responsible for this emission. With the improved spectral resolution of GINGA it was discovered the presence of a fluorescence K_α iron line at 6.4 keV, and that the spectra flatten above 10 keV. Both features are interpreted as the contribution of the so called Compton reflection component (Pounds et al. 1990): cold matter, possibly in an accretion disk, is illuminated by the power law X–ray spectra, and reflects part of it by scattering, degrading high energy photons by Compton recoil and absorbing low energy photons by the photoelectric effect (Guilbert & Rees 1988; Lightman & White 1988). The resulting reflected spectrum has a broad peak at an energy of 30–50 keV. Fitting the data with a power law plus the Compton reflection hump yields a steeper power law index, with $\Delta\alpha_x \sim 0.2$ with respect to a fit with a power law only.

These GINGA observations revived theoretical models in which the continuum is produced by non–thermal electron–positron pairs, because they predict $\alpha_x \sim 0.9 - 1$ in a large region of the parameter space (Zdziarski et al. 1990). However, these models are now challenged by the new observations of SIGMA on GRANAT and especially of OSSE on CGRO. The observed spectra are steep spectrum above 50 keV in several Seyfert 1 galaxies (Cameron et al. 1993). This indicates that there must be a break in the spectrum at $\sim$ 30–100 keV. In NGC 4151 the existing data (Jourdain et al. 1992; Maisack et al. 1993) seems to exclude a pure non–thermal pair plasma model (Zdziarski, Lightman & Maciolek, 1993).

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2 Thermal models and the 'universal' X–ray spectrum

Haardt and Maraschi (1991, 1993) considered the interplay between a hot, optically thin corona and a cold accretion disk. The hot plasma in the corona is thermal, and the main radiation mechanism is Comptonization. If all the power is released in the corona, it will emit half of the luminosity in the upward direction, and half down toward the disk (or more, if the Compton rocket effect makes the emission anisotropic, see Ghisellini et al. 1991 and Haardt 1993). The cold disk absorbs the incoming power, reemitting it in the UV, and thus producing the seed soft photons to be comptonized in the hot corona. Therefore, the UV and the X–ray radiation have approximately the same power, corresponding to an average spectral index of unity, and to a Comptonization parameter $y \sim 1$. Addition of the Compton reflection hump yields $\alpha_x \sim 0.7$.

In this model, luminosity balance suffices to yield the right spectral index and a relation between the optical depth τ_T and kT. Furthermore, if the hot plasma is pair dominated (for large compactnesses), kT depends only on the compactness, which becomes the only free parameter. Note that:

• The compactness of the source does not need to be large, the model works for any value of the compactness (but for low compactnesses, also τ_T must be specified).

• Pair production limits the temperature of the corona and very few γ–rays are emitted. In this model, as in all thermal steady plasma (Svensson 1984), no annihilation line should be visible.

• Since all the power is released in the corona, the UV is reprocessed radiation and should approximately have the same luminosity as the X–rays, and should follow changes of the overall X–ray power.

A major problem of thermal models concerns the thermalization mechanism able to mantain a Maxellian distribution even during the very fast variation of the luminosity we observe. It must be more efficient than electron–electron collisions. One possibility is that the thermalization is achieved through the exchange of photons (Ghisellini & Svensson 1990): in the presence of an equipartition magnetic field, all the cyclo–synchrotron radiation produced by the hot plasma is self absorbed. Self–absorption acts as a very fast thermalizing mechanism, able to produce an equilibrium quasi–maxwellian distribution (a Maxwellian plus an high energy tail) in few synchrotron cooling times, even if the primary power in injected in the source in the form of monoenergetic particles at, say, $\gamma_{max} \sim 10$.

Another possibility is that the particle distribution, albeit not perfectly Maxwellian, produce a thermal–like spectrum, as shown by Ghisellini, Haardt & Fabian (1993). What is important, in models where the X–rays are made by multiple Compton, is in fact not the shape of individual scattering orders (which indeed resemble the underlying particle distribution), but their sum, which gives indistinguishable spectra in very different cases (i.e. thermal or power law particle distributions) as long as the mean quadratic energy is similar.

3 Patchy (in space and time) coronae

There are two main objections to the two-phase model discussed above: i) it predicts that $L_{UV}/L_X \sim 1$, while observations indicate a larger ratio in many objects; ii) UV radiation should always correlate with X–rays, even at short timescales.

To overcome these problems, we (Haardt, Maraschi & Ghisellini, work in progress) suggest that the corona may not be extended, but patchy. In other words, liberation of gravitational energies is localized in small scale blobs, where accumulated energy (e.g. in magnetic fields) is suddendly released, resulting in flare activity. In this case we allow the accretion disk to emit not only reprocessed radiation, but also an important fraction of the gravitational power.

Under an X–ray blob (if the blob is sufficiently small and/or the energy dissipation time scale is short), the reprocessed radiation far exceeds the power produced locally by the disk, and this fixes the X–ray spectral shape as in the case of the extended corona discussed above.

4 The role of absorbing tori in the X–ray spectra

The popular unification scheme of Seyfert 1 and 2 galaxies assumes that an obscuring torus blocks the UV and soft X–ray radiation, hiding the Seyfert nucleous and the broad line regions at large inclination angles (e.g. Antonucci & Miller 1985). We have calculated the effects the torus has on the high energy spectrum, varying the inclination angle and the optical depth of the torus.

We were stimulated in this study by the suggestion that, if the torus is marginally Compton thick, than one can explain the X–ray background as due to Seyfert (mainly Seyfert 2) galaxies (Madau, Ghisellini & Fabian 1993). The results are presented in Fig. 1.

Compton thick tori ($N_H \gtrsim 10^{24}$ cm^{-2}) affect the overall emission even at small inclination angles, contributing to the 'reflection Compton component' and producing a fluorescence line emission at 6.4 keV, with an equivalenth width of $\sim$ 80–100 eV (Ghisellini, Haardt & Matt, 1993).

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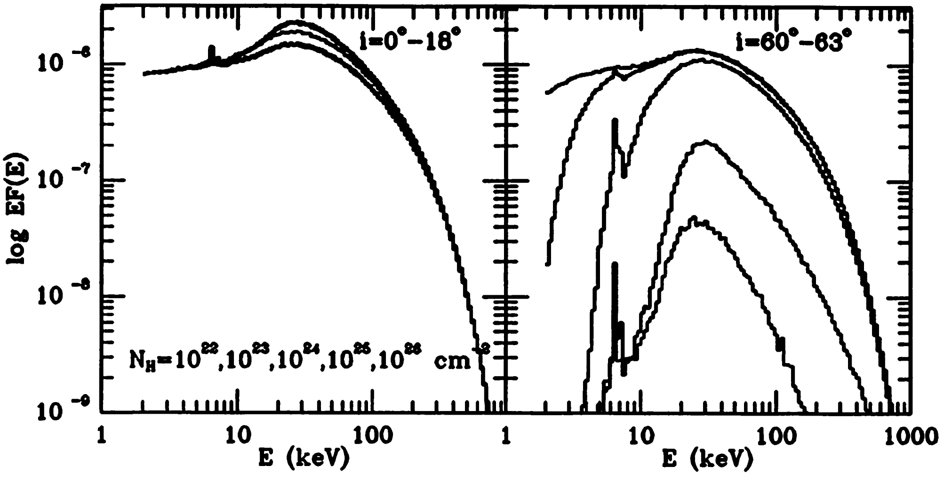

Fig. 1. The influence of the absorbing torus surrounding the nucleous of Seyfert galaxies on the X–ray spectrum. The left hand panel shows the spectra calculated for face on sources, for different values of the column density of the torus. Note that for $N_H \gtrsim 10^{24}$ cm^{-2} the funnel of the torus reflects in the line of sight some of the incident radiation, contributing to the 'reflection hump' at energies 10–50 keV. Furthermore, the funnel would produce fluorescence iron line at 6.4 keV. If the torus contributes to the observed emission, it dilutes the primary radiation, smearing fast variability at high energies. The right hand panel shows the spectrum for an inclination angle of about 60°. It shows the effects of the absorption of soft X–rays, and of the downscattering of hard X–rays as the column density of the torus increases. Not shown in the figure is the contribution of warm scattering material located above the torus, thought to contribute around 1 per cent of the primary flux. From Ghisellini, Haardt & Matt, 1993.

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