A SELF-CONSISTENT TEST OF COMPTONIZATION MODELS USING A LONG BEPPOSAX OBSERVATION OF NGC 5548

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ABSTRACT We test accurate models of Comptonization spectra over the high quality data of the BeppoSAX long look at NGC 5548. The data are well represented by a plane parallel corona with an inclination angle of 30°, a soft photon temperature of 5 eV and a hot plasma temperature and optical depth of \( kT_e \approx 360 \) keV and \( \tau \approx 0.1 \), respectively. If energy balance applies, such values suggest that a more “photon-starved” geometry (e.g. a hemispheric region) is necessary. The spectral softening detected during a flare, appears to be associated to a decrease of the heating-to-cooling ratio, indicating a geometric and/or energetic modification of the disk plus corona system. The hot plasma temperature derived with the models above is significantly higher than that obtained fitting the same data with a power law plus high energy cut off model for the continuum. This is due to the fact that in anisotropic geometries Comptonization spectra show “intrinsic” curvature which moves the fitted high energy cut-off to higher energies.

KEYWORDS: Radiation mechanisms: thermal; Methods: data analysis; BeppoSAX ; Galaxies: Seyfert; Galaxies: individual: NGC 5548

1. INTRODUCTION

The X-ray emission of Seyfert galaxies is commonly believed to be produced by Compton scattering of soft photons on a (thermal or non-thermal) population of hot electrons. The non-detection of Seyferts by Comptel and the high energy cut-offs indicated by OSSE have focused attention on thermal models (e.g. Sunyaev & Titarchuk, 1980). In this case the X-ray spectral shape is mainly determined by the temperature \( \Theta = kT_e/m_e c^2 \) and the optical depth \( \tau \) of the scattering electrons, while the cut-off energy is related essentially to \( \Theta \). Moreover, if the Comptonizing region and the source of seed photons are coupled, one can write an energy balance equation for the hot coronal plasma which determines a roughly constant value of the Compton parameter \( y \approx 4\Theta\tau(1+4\Theta)(1+\tau) \) (e.g., Svensson, 1996) and thus a one to one correspondence between \( \theta \) and \( \tau \). The required value of \( y \) depends on the fraction \( f \) of the power dissipated in the corona and on geometry. In the following
the limiting case \( f = 1 \) is considered.

In the present work (Petrucci et al., 1999, hereafter P99), we test Comptonization models over the high quality data of the (8 days) BeppoSAX long look at the Seyfert I galaxy NGC 5548, deriving constraints on the physical parameters and geometry of the source. These data have already been studied in detail by Nicastro et al. (1999), modelling the continuum with a cut-off power law.

**FIGURE 1.** (a): Comptonized models for different geometries assuming \( \theta = 0.7 \). We have also over-plotted a cut–off power law with \( E_c = 2kT_e \) in dashed line (cf. text for details). (b): BeppoSAX data set of NGC 5548 with non–simultaneous IUE and OSSE data (from Magdziark et al., 1998) with the corresponding best fits Comptonization model (in slab geometry, solid line) and simple cut–off power law model (dashed line).

2. THE COMPTONIZATION MODEL

2.1. The anisotropy break

In Fig 1a we show comptonized spectra computed for different geometries (codes of Haardt, 1994 and Poutanen and Svensson, 1996) for the same value of \( \theta \simeq 0.7 \) and for a cut–off power law spectrum (Pexrav model of xspec) with a e–folding energy \( E_c = 2kT_e = 720 \text{ keV} \), as a first order approximation to Comptonization spectral models (for \( \tau \lesssim 1 \)). For the sphere, the soft photons are supposed to be emitted isotropically at the center of the sphere, whereas they come from the bottom for the slab and the hemisphere configurations. In each case, the optical depths have been chosen so as to produce approximatively the same spectral index in the 2-10 keV X–ray range (\( \tau = 0.09, 0.16 \) and 0.33 for the slab, hemisphere and sphere geometry, respectively). We see that the spectra are quite different at medium - high energy (\( E \gtrsim 10 \text{ keV} \)). In the slab and hemisphere cases, they can be approximately described by broken power laws, the energy of the break \( E_{\text{break}} \) roughly lying between the second and the third scattering order peaks (Haardt, 1993). The slope at low energies is flat due to the deficiency of photons caused by the anisotropy of the first
2.2. Comptonization model versus cut-off power law

We show in Fig. 1b the best fit models derived using Comptonization (in slab geometry) and a cut-off power law. The two models require a different normalization for the reflection component (larger for the slab) and are roughly in agreement below 200 keV, the upper energy end of our data. However they differ by up to a factor 10 near 500 keV, since the cut-off energy required by the (harder) power law model is lower than that required by the (intrinsically curved) slab Comptonization spectrum (see Table 1).

2.3. Geometry

Both slab and hemisphere geometries give acceptable fits to the average data (cf. Table 1). The derived parameters are not far from theoretical expectations based on simple energy balance arguments (cf. Fig. 2). For the slab geometry, the data
suggest that the hot gas is *photon starved*, i.e., it is undercooled. For the hemispherical geometry the parameters are consistent with the energy balance condition but the required normalization of the reflection component is too large (cf. Table 1). This may suggest that the real geometry is intermediate and/or that the physical situation is more complex possibly involving a non uniform corona and deviations from strict energy balance (see Malzac this meeting).

2.4. Variability

Independently of geometry, the low–to–high state transition (the low/high state being the state outside/during the flare) clearly indicates a change of the Compton parameter, i.e., of the Comptonized–to–soft luminosity ratio (cf. Fig. 2). It seems to be most probably due to an increase of the cooling rate, rather than to a decrease of the heating rate, since we observe a pivoting at high energies of the continuum in the two states (cf. P99). If this interpretation is correct, then the spectral softening in the high state is very naturally explained by a drop of the corona temperature, ultimately due to an increase of the UV–EUV soft photon flux.

3. CONCLUSIONS

This *BeppoSAX* observation of NGC 5548 allowed us to show that i) the temperature $kT_e$ of the Comptonizing plasma can be largely underestimated (up to a factor of 7 here) when derived from simple power law models with high energy cut-off; ii) the data are well fitted by a plane parallel corona model with an inclination angle of $30^\circ$, a soft photon temperature of 5 eV, a hot plasma $kT_e \simeq 360$ keV and an optical depth $\tau \simeq 0.1$. The latter values suggest however that the hot Comptonizing gas, if in the shape of slab, is not in energy balance. A better agreement is obtained with an hemispherical geometry; iii) the change of state during the central part of the run clearly indicates a variation of the Compton parameter $y$, which could be due, as suggested by the data, to an increase of the cooling.

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