

# The origin of emission and absorption features in Ton S180 *Chandra* observations.

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## ABSTRACT

We present new interpretation of Ton S180 spectrum obtained by *Chandra* Spectrometer (Low Energy Transmission Grating). Several narrow absorption lines and a few emission disk lines have been successfully fitted to the data. We have not found any significant edges accompanying line emission. We propose the interpretation of narrow lines consistent with the paper recently written by Krolik (2002), where warm absorber is strongly inhomogeneous. Such situation is possible in so called multi-phase medium, where regions with different ionization states, densities and temperatures may coexist in thermal equilibrium under constant pressure. We illustrate this scenario with theoretical spectra of radiation transferred through a stratified cloud with constant pressure (instead of constant density) computed by code TITAN in plane parallel approximation. Detected spectral features are faint and their presence do not alter the broad band continuum. We model the broad band continuum of Ton S180 assuming an irradiated accretion disk with a dissipative warm skin. The set of parameters appropriate for the data cannot be determined uniquely but models with low values of the black hole mass have too hot and radially extended warm skin to explain the formation of soft X-ray disk lines seen in the data.

*Subject headings:* X-ray: galaxies - galaxies: Seyfert -galaxies: individual: Ton S180

## 1. Introduction

Narrow Line Seyfert 1 galaxies (Osterbrock & Pogge 1985) form a special class of active galactic nuclei. Narrowness of the optical lines frequently correlates with the steepness of the soft X-ray spectra (Boller, Brandt & Fink 1996) hinting for a connection of this class with soft state Galactic sources. The overall spectra are sometimes well described by a disk emission superimposed on a broad IR-X-ray power law component (Puchnarewicz et al. 2001) but in most cases the soft X-ray slope seems to be too shallow for an extension of a disk black body emission. Such a steep soft X-ray spectrum of a roughly power law shape may form either as a result of Comptonization (e.g. Czerny & Elvis 1987) by a moderately hot material (in comparison with the very hot plasma responsible for the hard X-ray component in normal Seyfert 1 galaxies) or as a result of reflection by a strongly ionized material (e.g. Czerny & Życki 1994, Czerny & Dumont 1998). The established presence of warm absorber seen in many of those objects (Collinge et al. 2001, Kastrup et al. 2002, Kaspi et al. 2002, Kinkhabwala et al. 2002, Leighly et al. 2002, Yaqoob et al. 2002) complicates the analysis. However, with the extremely good spectral resolution of *Chandra* and *XMM* the issue may be addressed through the careful analysis of the existing spectral features.

Ton S180 ( $z = 0.06198$ , corresponding to 286 Mpc for Hubble constant  $65 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ) is an extreme case of a NLS1 with its low value of the FWHM of  $H_\beta$  line ( $\sim 900 \text{ km s}^{-1}$ ; Wisotzki et al. 1995) and steep soft X-ray spectrum of photon index  $\Gamma = 2.68$  (Comastri et al. 1998). The Galactic absorption toward the object is low ( $N_H = 1.52 \times 10^{20} \text{ cm}^{-2}$ ; Stark et al. 1992). The source was extensively observed in all energy bands. The broad band spectral energy distribution (SED) determined by Turner et al. (2002) indicates that most of the energy is emitted in the band  $10 - 100 \text{ eV}$ . Furthermore, *HST* data show typical emission lines as expected for a Seyfert 1 galaxy, and the lack of absorption features. High resolution spectra obtained by *FUSE* reveal UV absorption by OVI and the absence of neutral hydrogen absorption, indicating high ionization state for the absorbing gas.

High resolution X-ray spectra of this object were recently obtained with *XMM-Newton* and *Chandra* satellites. *XMM-Newton* spectrum was steep and featureless (Vaughan et al. 2002). *Chandra* data also appeared predominantly featureless and well represented by a single power law with some soft excess (Turner et al. 2001, Turner et al. 2002). The shape of the soft excess was fitted by a DISKBB model, however plotted residua hinted for the possible presence of sharp spectral features (Fig. 1 Turner et al. 2001).

Therefore, in the present paper we reanalyze *Chandra* data in some detail (Sec. 2 and 3), using a new response matrix *acisleg1D1999-07-22rmfN0002.fits* and including any effects related to the contamination layer on ACIS-S. We note that the observation of Ton S180 was performed on day 143 of the *Chandra* mission when the effects of the contaminant were much smaller than currently observed. We detected several weak narrow absorption lines due to the material located at the line of sight to the source. Also, several individual disk lines are fitted with equivalent widths in rough agreement with the predictions of the model of illuminated accretion disk spectrum presented by Róžańska et al. (2002 a,b).

In Sec. 3.2.1 we discuss existing models (Kaastra et al. 2002, Kinkhabwala et al. 2002 and others) for fitting absorption by warm, partially ionized gas present in many AGN. We point out, after Krolik (2001), that the warm absorber may not be the slab of constant density matter, but it is rather the distribution of regions with different densities and temperatures. Such a multi-phase mixture of gas can exist under constant pressure, as a result of thermal instabilities (Krolik, McKee & Tarter 1981).

Till now, the multi-phase models of warm absorber were not constructed, because popular photoionization codes (XSTAR, CLOUDY), compute radiative transfer through the constant density matter. In Sec. 4, we present new set of models computed by the code TITAN (Dumont, Abrassart & Collin 2000), which solves radiative transfer through the matter in non-LTE approach. Introducing assumption of constant pressure (not density) of warm absorber, we obtain spectra with many absorption lines from the gas with strong temperature and density gradient. Our code is suitable for any optical thickness of the absorber, nevertheless, we consider regions with total column density of order of  $10^{23}\text{cm}^{-2}$ , as suggested by Krolik (2001) to be a typical property of warm absorber.

In Sec. 5 we construct two global disk corona models trying to predict the slope of observed continuum. The model with higher black hole mass ( $M = 10^8 M_\odot$ ) is more promising in the sense that emission lines from the disk are expected in the spectra, since hot skin does not cover disk completely.

Sec. 6 is devoted to the discussion, while conclusions are listed in Sec. 7.

## 2. *Chandra* observations and data reduction

Ton S180 was observed with the *Chandra* satellite in December 14, 1999, for about 80 ksec in Low-Energy Transmission Grating in ACIS-S/LETG configuration, as described by Turner et al. (2001) and Turner et al. (2002). The resolution of LETG corresponds to an FWHM  $\approx 1200 E_{\text{keV}} \text{ km s}^{-1}$  for the range of energies from 0.1 up to 6 keV. The source

luminosity at this epoch (2–10 keV unabsorbed flux equal  $4.6 \times 10^{-12}$  erg s<sup>-1</sup> cm<sup>-2</sup> and 0.3–10 keV unabsorbed flux equal  $2.2 \times 10^{-11}$  erg s<sup>-1</sup> cm<sup>-2</sup>) was comparable to that during the *Beppo-SAX* observation (2–10 keV:  $4.2 \times 10^{-12}$  erg s<sup>-1</sup> cm<sup>-2</sup>; Comastri et al. 1998) and *XMM-Newton* observation (0.3 - 10 keV:  $2.2 \times 10^{-11}$  erg s<sup>-1</sup> cm<sup>-2</sup>; Vaughan et al. 2002) and somewhat fainter than during the 12 days *ASCA* monitoring (2–10 keV:  $6.5 \times 10^{-12}$  erg s<sup>-1</sup> cm<sup>-2</sup>; Romano et al. 2002).

We obtained the data from the Chandra archive. The data were processed with the standard CXC data processing pipeline ASCDSVER 6.7.0. We analyzed the data using CIAO Version 2.2. and follow Grating Analysis Thread (CXC web page) to extract the spectrum and create appropriate effective area files (ARF files). We combined both sides of the first order spectrum. We used calibration data base version CALDB v.2.14, in particular we applied *acisD1997-04-17qeN0003.fits*, quantum efficiency file and *acisleg1D1999-07-22rmfN0002.fits* as response matrix. This formally allows us to study the entire energy range between 0.12 till 12.2 keV, although calibration uncertainties are higher below 0.3 keV, while the effective area drops significantly above  $\sim 4$  keV. After removing bad pixels and rebinning the data to achieve at least 20 counts per channel we examined the energy between 0.18 and 6 keV. All spectral fits have been performed with the XSPEC 9.0 fitting package.

Since the beginning of the *Chandra* mission ACIS-S detector has been accumulating a layer of a contaminant which affects any measurements at low energies (below  $\sim 0.8$  keV). Detailed effects of the contaminant are still being investigated by the Chandra X-ray Center <sup>1</sup>, however, it is clear that the overall degradation of ACIS quantum efficiency and presence of additional absorption features is time dependent. Ton S180 was observed at the day 143 of the *Chandra* mission and based on the currently available calibration data we expect that the instrument shows maximum of  $\sim 40$ -15 % degradation within 0.28-0.6 keV range (i.e. maximum  $\sim 40$  % in 0.28 keV and  $\sim 15$  % in 0.6 keV). In the following we identify the possible absorption features due to the absorber in Ton S180 using the entire available energy range. We note here that some of the features at energies close to the edges of the contaminant (C,N,O,F K-edge) may be affected. We use the available model, *acisabs*, to include the contamination effects in the analysis.

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<sup>1</sup><http://asc.harvard.edu/cal/Acis/Cal.prods/qeDeg/index.html>

### 3. Spectral analysis

#### 3.1. Continuum

In the first step, we fit the  $N_H$  value of Galactic absorption together with a broken power law continuum. Our best fit value of  $N_{H(Gal.)} = 1.83 \pm 0.15 \times 10^{20} \text{ cm}^{-2}$  is slightly larger than Galactic absorption  $N_{H(Gal.)} = 1.5 \pm 0.5 \times 10^{20} \text{ cm}^{-2}$  determined by Dickey & Lockman (1990) and used by Comastri et al. (1998) or than  $N_{H(Gal.)} = 1.52 \times 10^{20} \text{ cm}^{-2}$  determined by Stark et al. (1992) and used by Turner et al. (1998, 2001). All fitted parameters for "plain continuum" are listed in Table 1.

In the next step we fit broken power law with value of Galactic absorption fixed at  $N_{H(Gal.)} = 1.52 \times 10^{20} \text{ cm}^{-2}$  (see Table 1 second line). It results in slightly higher  $\chi^2$ , but the power law index below 2 keV is  $\Gamma_1 = 2.69 \pm 0.02$ , and agrees with the best fit slope  $\Gamma = 2.68$  presented by Comastri et al. 1998 for Beppo SAX data. Lower value obtained by Turner et al. (2001 and 2002), equal to  $2.44 \pm 0.04$  resulted from the use of additional component to model the soft X-ray excess.

The energy break obtained by us in both models (about  $1.7 \pm 0.14 \text{ keV}$ ) is somewhat lower than the value determined by Comastri et al. 1998 ( $E_{break} = 2.5$ ), but the spectral slope above this energy break,  $\Gamma_2 = 2.26 \pm 0.07$  agrees with results Comastri et al. 1998.

Since both broken power-law indices are very similar to those obtained from other satellites we adopt second model (fixed Galactic absorption) for further analysis, leaving  $\chi^2 = 1197$  per 1682 d.o.f. (reduced  $\chi^2 = 0.7105$ ).

After fitting continuum, there is still some structure in the residuals of the soft X-ray spectrum, suggesting the presence of absorbing matter along the line of sight toward the source. Therefore, we have tried to determine column density of this gas in the simplest way, by fitting OVII, OVIII, and CVI edges often seen in Seyfert galaxies (Mrk 509 Yaqoob et al. 2002, NGC 3783 Kaspi et al. 2002). Surprisingly, such edges appeared to be very weak in the data of Ton S180. We were able only to give upper limits for  $\tau_{OVII}$ ,  $\tau_{OVIII}$ , and  $\tau_{CVI}$  of order of  $10^{-4}$ , which practically indicates the lack of those edges.

#### 3.2. Spectral features

##### 3.2.1. Application of standard warm absorber

X-ray absorption lines appear to be common feature in many AGN. The widely acceptable explanation is the existence of warm, ionized gas which is illuminated by the energetic

radiation from nucleus. Trying to find properties of warm absorber we need proper tools to fit those data. Till now, models of absorption by the partially ionized plasma available in XSPEC (ABSORI, PHOTO,) do assume slab with constant density.

In ABSORI, the radiative transfer of lines is not computed at all, only photoionization cross sections are determined and absorption “on the spot” is computed  $F_{out} = F_{in} \exp(-\tau_{line})$  (Done et al. 1992). Constructed by Kinkhabawa et al. (2002) local PHOTO model (<http://xmm-astro.columbia.edu/research.html>) neglects photo-electric absorption, but allows for individual line absorption, treating each ionic column density separately with an initially unabsorbed power law. This method produces consistent results only when absorbing matter is optically thin, and transmitted spectra do not display photo-electric edges. Furthermore, they have assumed that plasma is optically thin to reemitted photons.

In the aim to find evidences for warm absorber in Ton S180, we have applied ABSORI to our data. Allowing for three parameters to be fitted in this model,  $\chi^2$  decreases by 38 (now reduced  $\chi^2 = 0.747$ ). The fit indicates that the medium has column density  $7.34^{+0.23}_{-0.22} \times 10^{21} \text{ cm}^{-2}$  and ionization parameter ( $\xi = 4178^{+2082}_{-1328}$ ) for the fixed default temperature  $T_{abs} = 3 \times 10^4 \text{ K}$ . This model, however, leaves considerable residual trends and does not allow for a deeper insight into the ionization state of the absorbing material. It is not surprising since the model is based on simple computations of photoionization cross sections without accurate transfer through the medium.

We have applied PHOTO to our analysis. The model again indicates very low column densities of each ion, about  $10^{14} \text{ cm}^{-2}$  for CVI, OVII, and OVIII. We conclude that most probably, the warm absorber in Ton S180 is more complicated than optically thin constant density slab. It may be the stratified density gas, where accurate radiative transfer, including all photoionization processes, should be calculate to model transmitted spectrum. Such models are not available for fitting the data yet, so two or three separate absorbers with different constant densities and ionization states are used together to explain spectral features in some AGN (Kaastra et al. 2002 , Kaspi et al. 2002). This motivates us to present in Sec. 4 the model of the multi-phase gas with stratified density and temperature, where the radiative transfer of incident power law is carefully computed. The model is not ready for fitting yet, but gives interesting results based on equivalent widths of various lines. Observed line properties in the Ton S180 data are determined in the section below.

More advanced modeling was done with the code XSTAR (developed by Kallman & Krolik 1999) which allows to estimate the total column densities of absorbed gas. Models are computed assuming constant density slab. Such models are very useful for reconstruction of the flat part of curve of growth (Yaqoob et al. 2002), and for subsequent estimation of turbulent velocities of the absorber. Nevertheless, at the last stage of analysis separate

Gaussian components are fitted to the data.

### 3.2.2. Absorption lines

We have successfully fitted several absorption lines using standard Gaussian model for each line separately (see Figs. 1, 2, 3, 4, 5, 6, and 7. **Gaussian fit requires three free parameters, energy of the line centroid, Gaussian width and normalizations, which has to be negative in case of absorption lines.** We include in the fit only those features which are significant. All absorption lines are presented in Table 2. For each line we list its central energy in keVs, equivalent width (EW) in eVs, the decrease of  $\chi^2$ , best identification with observed and rest frame energy, and with possible blends.

Some of those lines, especially the softest ones, may be caused by dust presented on Chandra mirrors. This should show up a common feature in all objects even those with different redshifts. To check whether lines are real or instrumental, we compare observations of Ton S180 with *Chandra* data of quasar 3c273 observed two weeks latter with the same configuration as Ton S180. Exemplary residuals (for soft range between 0.2-0.24 keV) for both objects are shown in Fig. 8. In both cases local power-law was fitted with fixed value of Galactic absorption appropriate for each object. The same features around energy 0.22 keV are present as well in 3c273 with redshift 0.156 as in Ton S180. We repeated such analysis in the whole energy range. All possible instrumental lines are labeled in Table 2.

Some of the detected features are seen only in Ton S180 spectrum and therefore seem to be real, intrinsic to the source. For example, in Fig 9 we show that line CVI with observed energy 0.4428 keV which is detected in Ton S180 data is not seen in 3c273.

Lines are very faint. They usually have equivalent width less or about 2 eVs, and several of them are just marginal detections, as clearly seen from the line EW error, given at 90% confidence level (**each error is computed for the one parameter of interest**). Only two of them are stronger, but from theoretical predictions by analysing our modeled spectra from Sec 4, they are not blends. All possible blends according of our modeled spectra obtained with spectral resolution 100 are listed in Table 2. There is therefore no major discrepancy between the *Chandra* results and the *XMM* observations (Vaughan et al. 2002) where only upper limits of order of 1 eV at energies 0.35 - 0.7 keV were provided. Most lines originate from hydrogen or helium like ions indicating that matter is highly ionized. There is an absence of lines from mildly ionized species.

Interestingly, we found two different transitions from the same element at the given ionization level, (CVI<sub>(1-2)</sub> and CVI<sub>(1-5)</sub> where i – j denotes number of levels from and to

which the transition proceeds). This is helpful in the aim to estimate the optical thickness of C VI ions and then total optical thickness of the warm absorber.

If the medium is optically thin in those lines (i.e. weak line case), we are on the linear part of the curve of growth, where equivalent width is proportional to the column density  $N_i$  of the absorbed ion:

$$EW_\nu = \frac{\pi e^2}{m_e c} N_i f_{ij}, \quad (1)$$

where  $f_{ij}$  is the oscillator strength transition and stimulated emission has been set equal to unity. Thus, for the given population of ions at the same ionization level, the ratio of equivalent widths is given by:

$$\frac{EW_{ij}}{EW_{ik}} = \frac{f_{ij}}{f_{ik}}. \quad (2)$$

Since the oscillator strengths are strictly atomic features independent from the radiation field and are calculated theoretically we use them to find the ratio

$$\frac{EW[\text{C VI}_{(1-2)}]}{EW[\text{C VI}_{(1-5)}]} = 29.86. \quad (3)$$

On the other hand, the same ratio determined for Ton S180 (see Table 2) equals  $0.62^{+3.53}_{-0.59}$ . Error is computed assuming most pessimistic case, when numerator has its maximal value  $EW + \Delta EW$ , and denominator has its minimal value  $EW - \Delta EW$ . Although the error is huge, the value of the ratio determined from observation is still far from theoretical predictions for optically thin medium (Eq. 3). Our theoretical spectra (see Sec. 4) suggest that C<sub>(1-2)</sub> line is possibly a blend with MgXII, SiXIV and most strongly with C V. We have computed that real EW of the C<sub>(1-2)</sub> line can be even up to four times lower than the EW of the whole blend. But this fact even lowers the observed ratio of EWs of two carbon lines.

The straight conclusion is that the emitting region is optically thick for those lines and the transfer in lines should be taken into account for proper modeling of the warm absorber. It is also possible that the identification of the lines is not correct or the line is a blend of the carbon line with another transition. Nevertheless, we further explore the possibility that the carbon line ratio is determined correctly.

Therefore, the Equation 1 gives only a lower limit for the ion column density, equal to  $3.6 \times 10^{16} \text{ cm}^{-2}$  from the C VI<sub>(1-2)</sub> line and  $1.7 \times 10^{18} \text{ cm}^{-2}$  from C VI<sub>(1-5)</sub>, which under assumption of all carbon being in the form of C VI ions and with solar abundances translates into the lower limit for the warm absorber column equal  $1.1 \times 10^{20} \text{ cm}^{-2}$  and  $5.1 \times 10^{21} \text{ cm}^{-2}$ , correspondingly.

Exact determination of the column density is complicated. At the flat curve of growth we need additional information about velocity dispersion  $b$  to indicate column densities.



In the case of considered data this is very difficult, because  $1\sigma$  error of full width of half maximum (FWHM) is too high to estimate  $b$  parameter. For instance for SXII line, presented in Fig. 3,  $FWHM = 5_{-1}^{+16} \times 10^3$  km/s. This fact also precludes us to integrate over fitted line profile in the aim of determining exact flux emitted in this line. So, we are unable to compute exact optical depth of the line and therefore the column density of absorbing ion. The number of lines is too small to fit full model (for instance XSTAR).

Another lower limit on column density of CVI ion can be derived knowing that the optical thickness of the CVI lines is higher than 1. In such a case we can write:

$$N_i > \frac{m_e c}{\pi e^2 f_{ij}} FWHM = \frac{1.665 m_e \nu_0}{\pi e^2 f_{ij}} \sqrt{\frac{2kT}{A_i m_H}}, \quad (4)$$

where  $T$  is the temperature of the medium and  $A_i$  is atomic mass of the ion. For the CVI<sub>(1–5)</sub> line we obtain:

$$N_{CVI} > 6.33 \times 10^{13} \sqrt{T}. \quad (5)$$

For the temperature approximately equal to  $10^6$  K this value is twice higher than the one determined by Mason et al. (2002) in case of Mrk 766. This limit is over an order of magnitude weaker than the limit obtained directly from Equation 1. FWHM estimated from the  $T \sim 10^6$  K is quite narrow and the line width is rather determined by much larger turbulent motion.

The value of reduced  $\chi^2$  was equal 0.6363 after fitting all possible absorption lines.

### 3.2.3. Disk emission lines

After absorption lines have been identified, we were able to fit a few emission lines from an accretion disk. We applied the standard DISKLINE model with fixed power law index in the radial dependence of the irradiating flux  $\beta = 2.7$ . We assumed  $r_{in} = 6R_g$  and  $r_{out} = 1000R_g$  (where  $R_g = GM/c^2$ ). We have found the best value of inclination angle  $i = 30^\circ$  for the line Cv, and we adopted it (keeping frozen) for the other lines. Results are listed in Table 3, and shown in Figs. 1, and 10.

The last column of Table 3 presents theoretical values of EWs of the same emission lines computed for accretion disk illuminated by hard X-ray flux equaled to the local disk flux (full model presented in Róžańska et al. 2002 a,b). The model takes into account harder incident radiation ( $\Gamma = 1.9$ ), than it is seen in case of Ton S180, and solar metal abundances. For moderate illumination in the model we have found for instance the equivalent width of Nex equal 11 eV, OVIII equal 18.2, MgXII equal 10.5, and FeXVII about 8 eV, or many others at the same order of magnitude in respect to the reflected continuum (factor of 2-3 smaller in

respect to the total continuum). Models do not predict lines with EWs higher than  $\sim 20$  eVs, when the disk is in the hydrostatic equilibrium (Róžańska et al. 2002 a,b; see also figures in Nayakshin, Kazanas & Kallman 2000, Ballantyne, Ross & Fabian 2001). Higher values can be only obtained from constant density medium, as discussed by Ballantyne, Ross & Fabian (2002), particularly when adopting enhanced metallicity. Emission lines also become by a factor of a few stronger when the dynamical flare model is adopted, i.e. the time-scale of the flare is shorter than the time-scale for a disk surface layer to achieve a hydrostatic equilibrium (Collin et al. 2002). However, in that case lines should be narrow and not represented well by a DISKLINE shape.

Soft disk line detection is therefore a promising tool to constrain the conditions within the cold reprocessing medium. Detection of standard broad disk lines presented in this paper, if real, suggest no strong departure from hydrostatic equilibrium and the extension of the cold disk roughly down to the marginally stable orbit.

After all lines have been fitted, we fit again broken power-law with Galactic absorption. Results presented in Table 1 last verse indicate that lines do not affect continuum very strongly. The final value of reduced  $\chi^2$  appeared to be 0.5531.

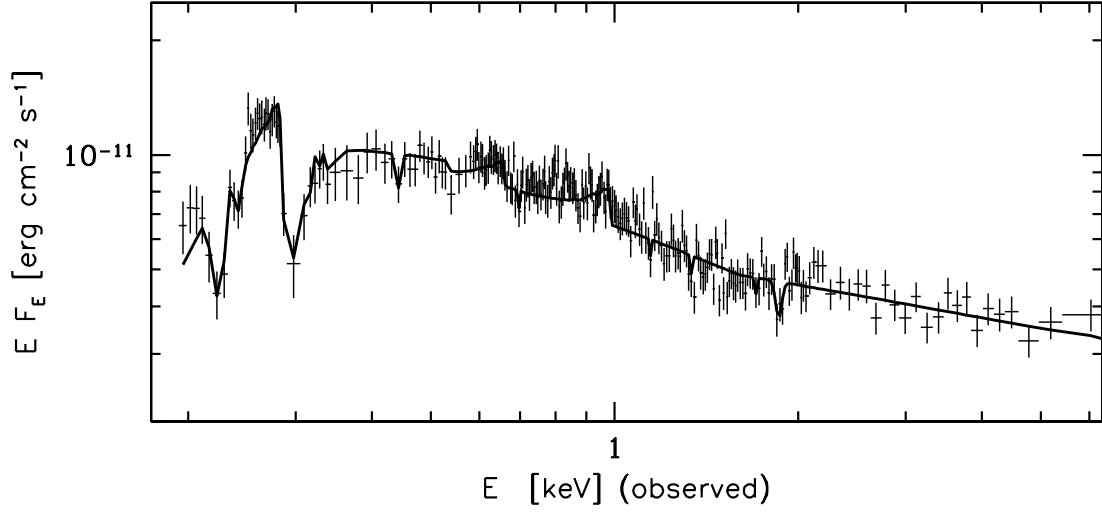


Fig. 1.— The LETG spectrum of Ton S180. Solid line denotes total model after broken power law, Galactic absorption and all lines have been fitted.

Table 1. LETG continuum fit in the 0.1– 6. keV energy range

Model	$N_{H(Gal.)} \text{ } 10^{20} \text{ cm}^{-2}$	$\Gamma_1$	$E_{break} \text{ keV}$	$\Gamma_2$	$\chi^2/\text{d.o.f.}$
Plain Cont.	$1.8277^{+0.152}_{-0.149}$	$2.755^{+0.038}_{-0.0367}$	$1.659^{+0.153}_{-0.109}$	$2.265^{+0.062}_{-0.065}$	1185/1681
Fixed $N_{H(Gal.)}$	1.52	$2.689^{+0.022}_{-0.019}$	$1.771^{+0.134}_{-0.169}$	$2.261^{+0.074}_{-0.070}$	1197/1682
With lines	$1.527^{+0.1512}_{-0.14}$	$2.682^{+0.039}_{-0.0359}$	$1.604^{+0.12}_{-0.147}$	$2.295^{+0.0549}_{-0.0564}$	932/1624

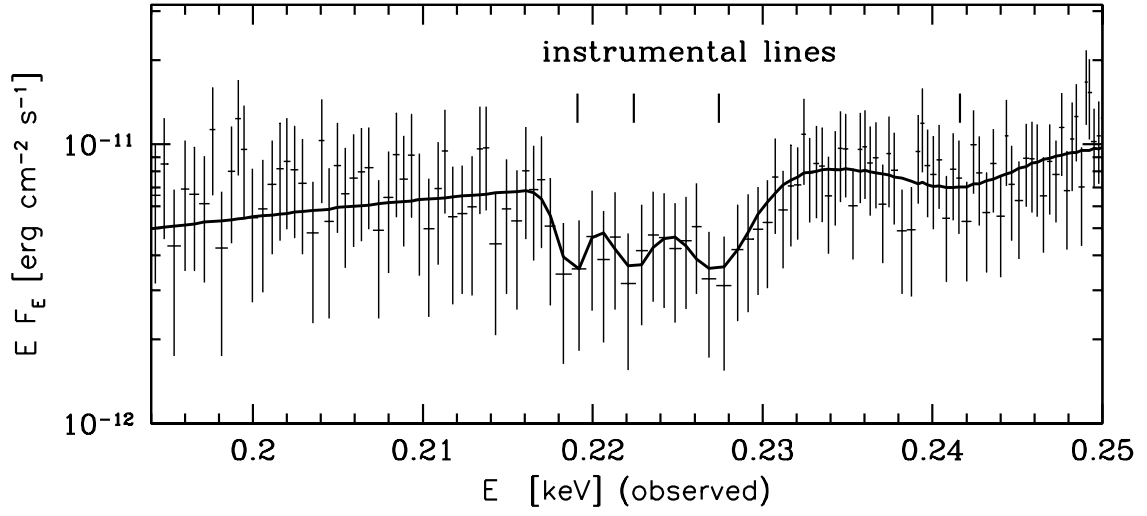


Fig. 2.— Observed spectrum with the best fit model for 0.19-0.25 keV

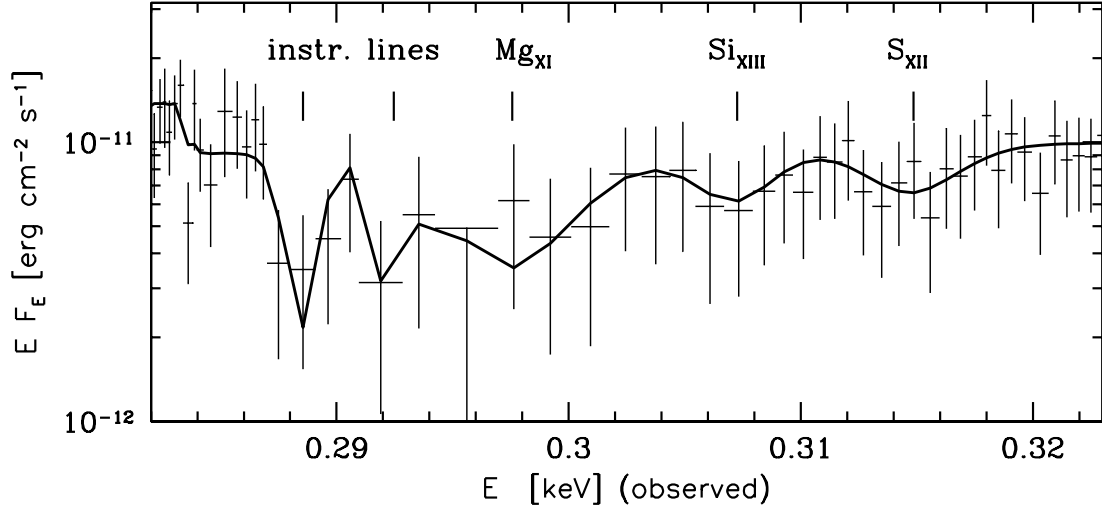


Fig. 3.— As Fig. 2, but for 0.282-0.32 keV

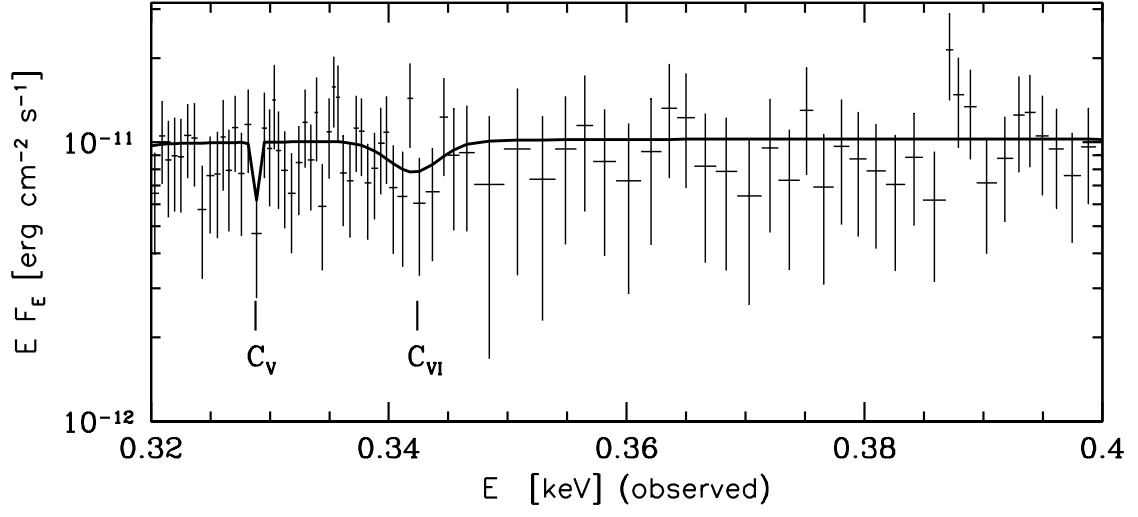


Fig. 4.— As Fig. 2, but for 0.32-0.4 keV

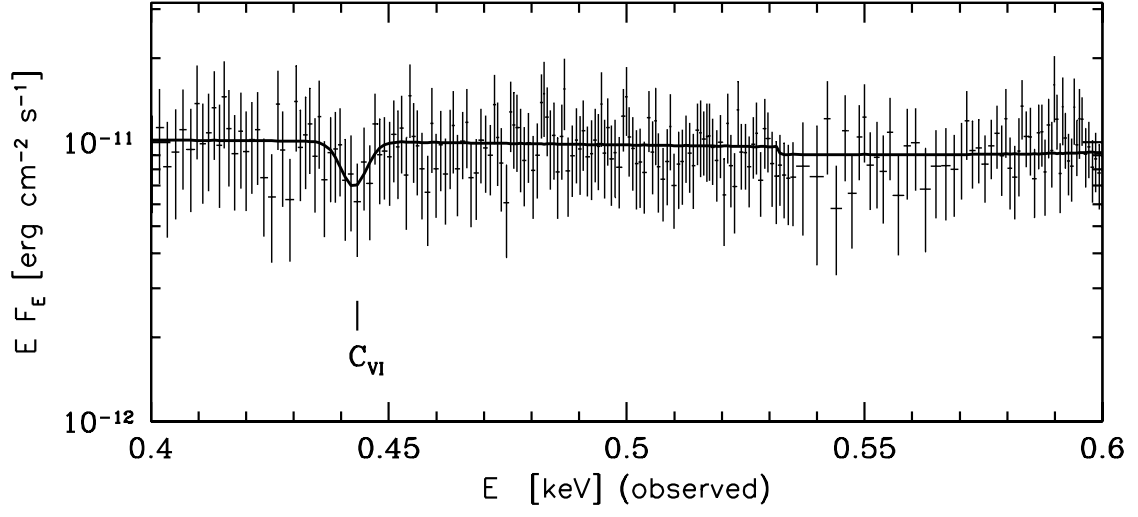


Fig. 5.— As Fig. 2, but for 0.4-0.6keV



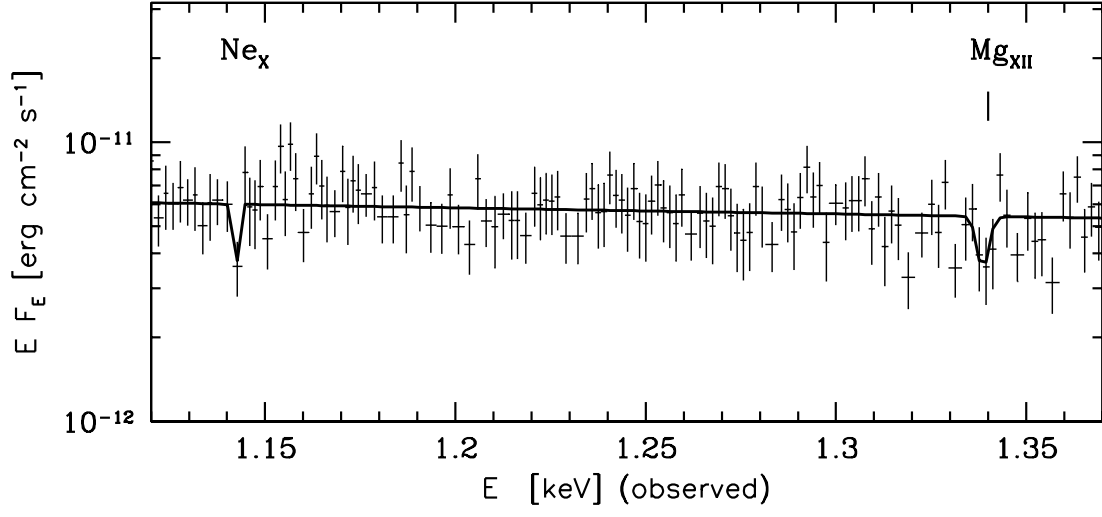


Fig. 6.— As Fig. 2, but for 1.12-1.37 keV

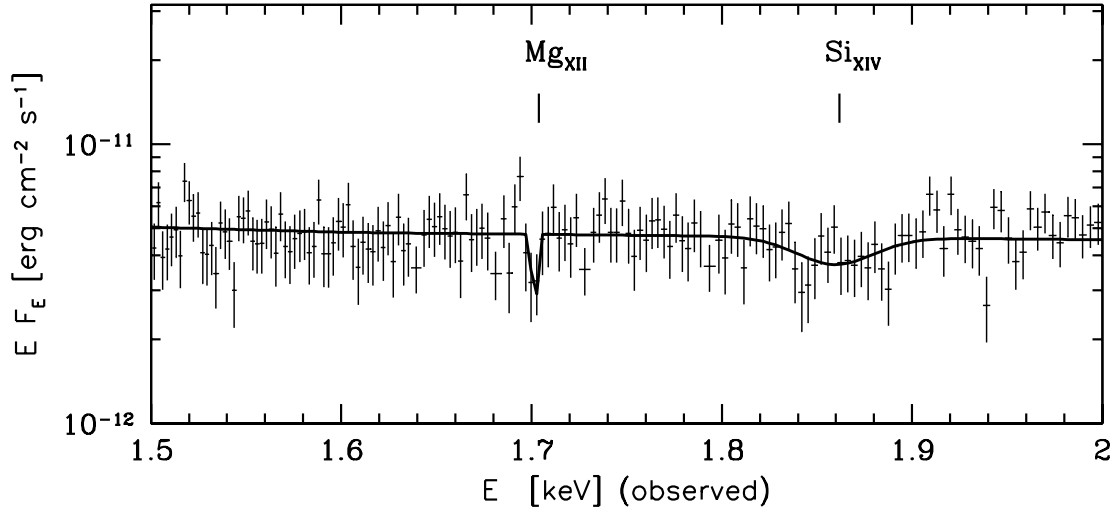


Fig. 7.— As Fig. 2, but for 1.5-2 keV

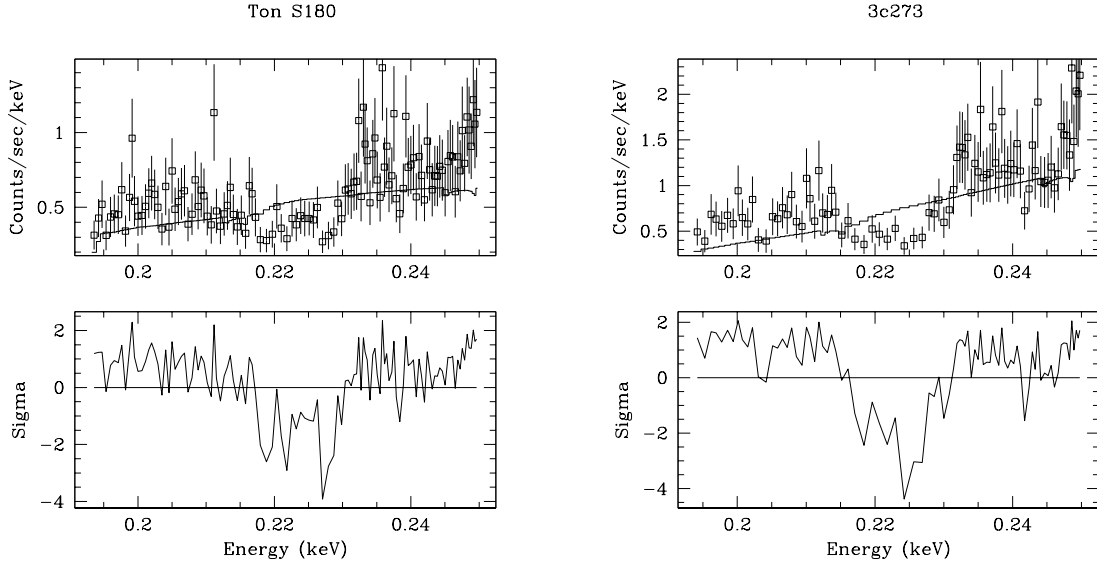


Fig. 8.— The comparison of *Chandra* data of Ton S180 to the *Chandra* data of 3c273 for energies between 0.20 to 0.24 keVs. Similar structure in residuals around 0.22 keV is present in both objects.

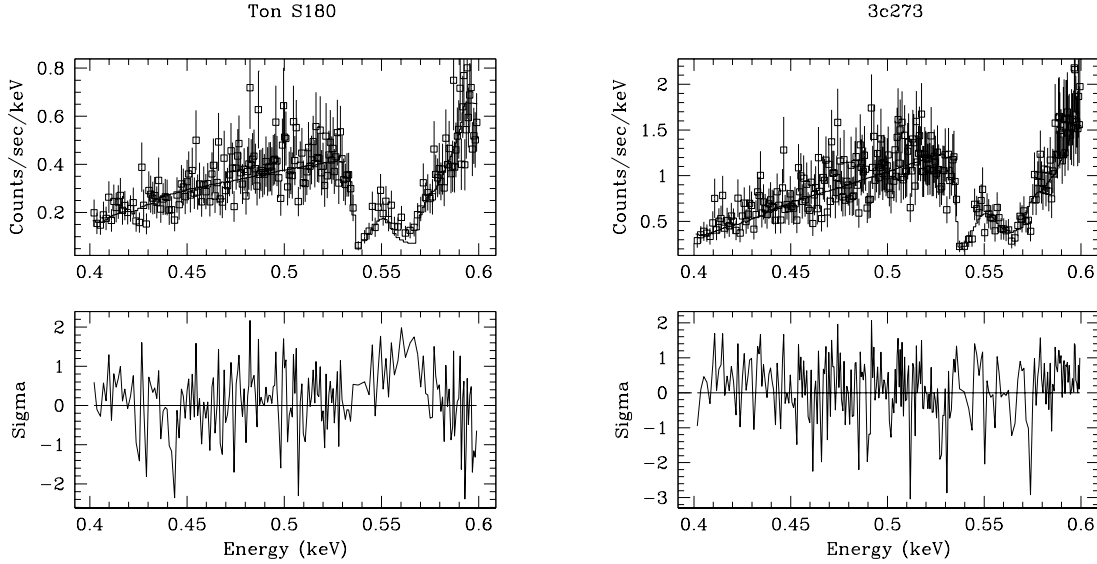


Fig. 9.— The comparison of *Chandra* data of Ton S180 to the *Chandra* data of 3c273 for energies between 0.4 to 0.6 keVs. Two sigma structure presented in Ton S180 around 0.44 keV is clearly absent in 3c273 data.

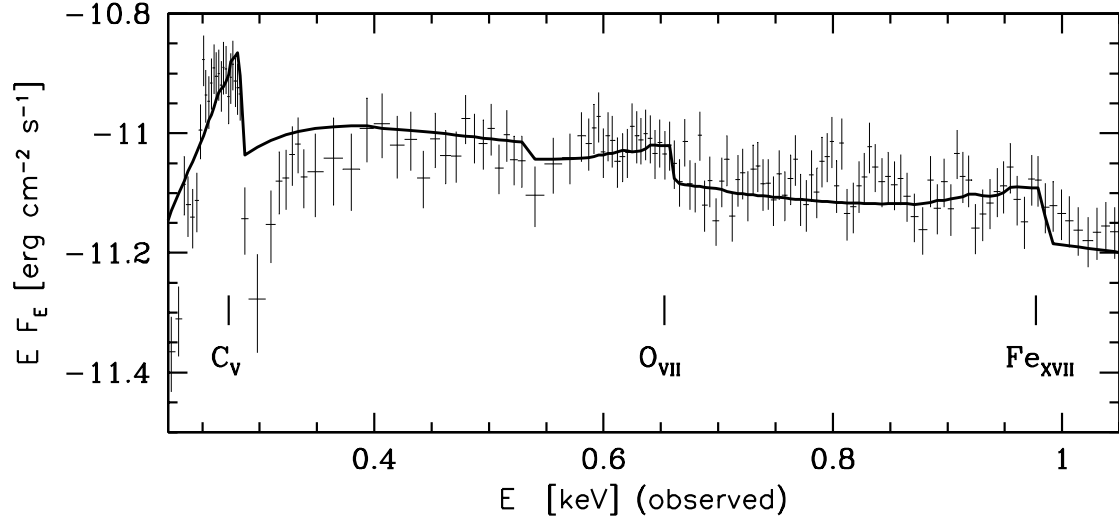


Fig. 10.— As Fig. 2, but for 0.22-1.05 keV. Three emission lines fitted to the spectrum of Ton S180 are seen.

Table 2. Absorption lines fitted to the *Chandra* data of Ton S180

Observed energy (keV)	EW (eV)	$\Delta\chi^2$	Best identification <sup>(*)</sup>
$0.2188^{+0.005}_{-0.014}$	$1.39 \pm 0.87$	7.42	<i>instrumental</i>
$0.2222^{+0.0011}_{-0.0010}$	$2.05 \pm 1.38$	6.6	<i>instrumental</i>
$0.2272^{+0.0008}_{-0.0009}$	$3.62 \pm 1.29$	22.29	<i>instrumental</i>
$0.2414^{+0.0028}_{-0.0036}$	$1.87 \pm 1.08$	6.34	<i>instrumental</i>
$0.2884^{+0.0007}_{-0.0006}$	$1.82 \pm 0.83$	15.35	<i>instrumental</i>
$0.2923^{+0.0012}_{-0.0012}$	$1.39 \pm 1.17$	6.92	<i>instrumental</i>
$0.2974^{+0.0018}_{-0.0022}$	$6.31 \pm 3.70$	14.	MgXI (0.2971; 0.3155)
$0.3071^{+0.0026}_{-0.0030}$	$2.26 \pm 1.95$	5.18	SiXIII (0.30878; 0.3279)
$0.3147^{+0.018}_{-0.030}$	$2.05 \pm 1.28$	7.55	SXII (0.31899; 0.3387)
$0.3285^{+0.0009}_{-0.0006}$	$0.39 \pm 0.50$	3.47	Cv (0.33386; 0.3545)
$0.3421^{+0.0037}_{-0.0045}$	$1.38 \pm 1.30$	4.45	CvI (0.3459; 0.3673) blend with MgXII (0.368), SiXIV (0.3703), Cv (0.3709)
$0.4426^{+0.024}_{-0.024}$	$2.22 \pm 1.58$	5.16	CvI (0.4428; 0.4702)
$0.6963^{+0.015}_{-0.032}$	$0.74 \pm 0.69$	3.47	FeXVII (0.6868; 0.72932) blend with SXVI (0.731)
$1.142^{+0.0034}_{-0.0095}$	$0.992 \pm 1.18$	3.29	NeX (1.1387; 1.209) blend with FeXXV (1.206), FeXXV (1.208), and FeXXV (1.213)

#### 4. Proposed Model of the Warm Absorber

In this section, we present models of warm absorber, allowing density, temperature and so consequently ionization state to be stratified (Krolik 2002). The only assumption which we made is the constant pressure. Such an approach is more realistic than the constant density model, since thermal instabilities can produce gas with steep ionization structure keeping all zones in pressure equilibrium.

We have used code TITAN (Dumont, Abrassart & Collin 2000) to compute temperature and density structure of the warm absorber together with radiative transfer. The code is based on two-stream approximation and works in plane-parallel geometry. Radiative transfer is computed both in lines and in continuum so the code can be used for very inhomogeneous even optically thick media. Thermal, ionization and statistical equilibrium of ions are computed in complete non-LTE for 10 elements and all corresponding ions. We consider following elemental abundances: H: 1, He: 0.085, C:  $3.3 \times 10^{-4}$ , N:  $9.1 \times 10^{-5}$ , O:  $6.6 \times 10^{-4}$ , Ne:  $8.3 \times 10^{-5}$ , Mg:  $2.6 \times 10^{-5}$ , Si:  $3.3 \times 10^{-5}$ , S:  $1.6 \times 10^{-5}$ , Fe:  $3.2 \times 10^{-5}$ ,. We transfer totally 721 lines of different ions, taking their oscillator strengths and energies from National Institute of Standards and Technology (NIST, <http://physics.nist.gov>). Photo-electric absorption is fully taken into account.

In our models, we have assumed the shape of incident radiation consistent with this fitted to the data of Ton S180. We have adopted power law photon index  $\Gamma = 2.6$  (Sec 3.1), and spectral limits from 0.012 up to 100 keV as we have concluded from broad band spectral energy distribution presented by Turner et al. (2002).

The assumption of constant pressure refers to the total: radiation and gas pressure, and its value is self consistently determined by the code. The ionization parameter on the top of the absorber  $\xi_0$  and the total column density are free parameters of our models. We have computed models for  $\xi_0 = 10^5$  and  $N_{tot} = 1.7 \times 10^{23} \text{cm}^{-2}$  named A1,  $\xi_0 = 1000$  and  $N_{tot} = 6.8 \times 10^{22} \text{cm}^{-2}$  named A2, and  $\xi_0 = 10^7$  and  $N_{tot} = 1.7 \times 10^{23} \text{cm}^{-2}$  named A3. Such values of column densities for given  $\xi_0$  are upper limits above which optical depth of cloud is large enough that strong absorption edges become present in outgoing spectra.

Even for high  $\xi_0$ , the maximum Compton temperature is low,  $T_{Compt} = 2.1 \times 10^6 \text{ K}$ , because the incident spectrum is soft ( $\Gamma = 2.6$ ).

In Fig. 11 we show the temperature structure for A1 (dashed line) (higher  $\xi_0$  does not change this structure) compared to A2 (solid line) and in Fig. 12 we show the corresponding spectra. In case of higher  $\xi_0$  (model A1) the temperature range within the medium is much broader and the effective spectrum from such region (presented in Fig. 12 dashed line) displays slightly stronger lines than for A2 (solid line spectrum). We have enlarged range of

Table 2—Continued

Observed energy (keV)	EW (eV)	$\Delta\chi^2$	Best identification <sup>(*)</sup>
$1.339^{+0.0030}_{-0.0024}$	$1.48 \pm 1.84$	2.95	MgXII (1.3861; 1.472)
$1.702^{+0.030}_{-0.032}$	$1.88 \pm 2.38$	3.7	MgXII (1.7327; 1.840)
			blend with SiXIII (1.853)
$1.860^{+0.013}_{-0.016}$	$10.6 \pm 5.24$	6.09	SiXIV (1.8831; 2.000)

<sup>(\*)</sup> Expected observed energy and the rest frame energy in keVs for identified lines are given in parenthesis, for blends only rest frame energy is listed.

Table 3. Emission disk lines fitted to the *Chandra* data of Ton S180

Observed energy (keV)	EW (eV)	$\Delta\chi^2$	Best identification	EWs from illuminated disk*
$0.2704^{+0.002}_{-0.0007}$	$15.3 \pm 2.63$	72.73	Cv (0.2899; 0.3079)	8.69
$0.6300^{+0.014}_{-0.01}$	$13.5 \pm 4.89$	21.26	OvIII (0.6149; 0.653)	19.0
$0.9403^{+0.007}_{-0.021}$	$30.7 \pm 7.41$	46.26	Nex (0.961; 1.020)	11.29

\* Theoretical EWs are computed in respect to reflected continuum

frequencies to illustrate region observed in Ton S180 data.

We have also performed comparison of A1 model to the warm absorber with constant density (Fig. 11 dotted-dashed line) assuming that both clouds have the same total column densities and they are illuminated by the equivalent fluxes. Thus, choosing the volume density for constant density cloud, the ionization parameter is determined by the value of flux the same as for stratified cloud. We have chosen volume density equal  $3 \times 10^{13} \text{cm}^{-3}$ , which implies  $\xi_0 = 300$ . Spectrum for constant density cloud presented in Fig. 12 by dotted-dashed line displays strong edges and cannot be applicable to explain our observations. Decreasing volume density we increase ionization parameter, and it may remove edges. We plan to make proper calculations in the future work to show how to distinguish between low density constant cloud and stratified cloud.

We have also calculated theoretical values of the equivalent widths of transferred lines, the same which are found in Ton S180 data. Results are presented in Table 4. EWs for high surface ionization (A1) are almost a factor of two higher than for A2 model. In our data we see slightly larger EWs and we cannot model them by increasing  $\xi_0$ , since model A3 shows the same EWs as A1.

Therefore, we have to introduce model labeled A4 in Table 4, which has exactly the same parameters as A2 i.e.  $\xi_0 = 1000$  and  $N_{tot} = 6.8 \times 10^{22} \text{cm}^{-2}$  and additionally we assume turbulent velocity  $v_{turb}/c = 3 \times 10^{-4}$ . Turbulent velocity does not change the total temperature structure, it only affects lines, making their EWs higher, as shown in Table 4. For model A4 several lines, for instance MgXI, SiXIII, SXII CVI, and SiXIV) have EWs in quite good agreement with those achieved from observations (see Table 2).

In all presented models the ratio of  $EW[\text{CVI}_{(1-2)}] / EW[\text{CVI}_{(1-5)}]$  equals 0.7, in very good agreement with observed value of 0.6.

## 5. Broad band continuum

In order to draw attention to the possible constraints resulting from detection of the broad disk lines we model the broad band spectrum of Ton S180 assuming three basic spectral components: (a) an illuminated accretion disk (b) an optically thick Comptonizing plasma (c) an optically thin (non-thermal) Comptonizing plasma. For low or moderate accretion rate we take the simplest Keplerian disk model, emitting locally as a black body and parameterized fully by the black hole mass,  $M$ , and accretion rate,  $\dot{m}$ , given in Eddington units (taking efficiency 1/12 appropriate for Newtonian model). We consider also highly supercritical accretion disk applying the model described by Kawaguchi (2002). This model includes the



Table 4. Equivalent width [eVs] of absorption lines for several models computed by TITAN

Ion	Transition	A1	A2	A3	A4
SVIII	$2s^2 2p^5 {}^2P^0 - 2s^2 2p^5 3d {}^2L$	0.522	0.293	0.506	1.431
FeXV	$3s^2 {}^1S - 3s4p {}^1P^0$	0.406	0.191	0.392	1.164
SiX	$2s^2 2p {}^2P^0 - 2s^2 3d {}^2D$	0.584	0.286	0.568	1.193
SX	$2s^2 2p^3 {}^4S^0 - 2s^2 2p^2({}^3P) 3l {}^4P$	0.585	0.305	0.567	1.549
Cv	$1s^2 {}^1S - 2p {}^1P^0$	1.112	0.587	1.079	1.849
SXI	$2s^2 2p^2 {}^3P - 2s^2 2p 3d {}^3L^0$	0.680	0.333	0.659	1.500
MgXI	$2p {}^3P^0 - 4l {}^3L$	0.834	0.468	0.809	1.995
SiXIII	$2s {}^1S - 3p {}^1P^0$	0.783	0.439	0.759	2.019
SXII	$2s^2 2p {}^2P^0 - 2s^2 3d {}^2D$	0.719	0.348	0.697	1.580
Cv	$1s^2 {}^1S - 3p {}^1P^0$	1.287	0.708	1.249	2.151
CvI	$1s {}^2S - 2l {}^2L$	1.186	0.599	1.136	1.772
CvI	$1s {}^2S - 5l {}^2L$	1.650	0.881	1.585	2.585
FeXVII	$2s^2 2p^6 {}^1S - 2s^2 2p^5 3s {}^1P^0$	1.216	0.621	1.159	4.008
Nex	$1s {}^2S - 3l {}^2L$	3.151	1.856	3.063	7.485
MgXII	$1s {}^2S - 2l {}^2L$	3.561	2.101	3.561	9.107
MgXII	$1s {}^2S - 4l {}^2L$	5.224	2.947	5.330	12.26
SiXIV	$1s {}^2S - 2l {}^2L$	4.594	2.426	4.598	11.56

<sup>a</sup> l means that the configuration is a mixture of multiplets s p d

effect of strong radial advection and the departure from the local black body emission due to electron scattering which are essential at very high accretion rates.

We assume that the energy generated in the inner disk illuminates outer disk, with the irradiating flux  $\propto r^{-2-\beta}$ , with  $\beta = 0.1$ . This irradiation effect may come from the scattering of the disk radiation back toward the disk by the warm absorber as well as from the direct interception of the radiation by the flaring outer disk. We adopted a simple parameterization and did not model this irradiation since the process is quite complex. It would require assumption about the radial and angular distribution of the density of the scattering medium (see e.g. Kurpiewski et al. 1997) and the computations of the viscosity dependent disk vertical structure, as in Róžańska et al. (1999). We did not compute the disk vertical structure in order to verify whether the outer disk is flaring strongly enough to allow for such a strong effect.

We assume that the inner disk for ( $r < r_{skin}$ ) is fully covered by the optically thick plasma. Thermal plasma parameters are: the optical depth,  $\tau$ , and the temperature,  $T$ . Only soft photons from the inner disk come through this plasma, and we compute the spectrum using the simple code based on Sunyaev & Titarchuk (1980) description (used for example by Collin-Souffrin et al. 1996). We adopt the plane parallel geometry and the generation of the photons at the bottom of the zone. This component forms a soft X-ray component of the spectrum. We next added a contribution from much hotter, or non-thermal, plasma component in order to provide the appropriate hard X-ray tail but the parameters of this component are poorly constraint and we do not address this issue in detail.

Our model provides a one-parameter family of solutions for the broad band spectrum, i.e. we can find a good model for any mass of the black hole between  $1 \times 10^7 M_\odot$  and  $1 \times 10^8 M_\odot$ , but for a fixed mass all other parameters ( $\dot{m}$ ,  $r_{skin}$ ,  $\tau$ , and  $T$ ) are uniquely determined. The appropriate accretion rate is needed to reproduce the normalization of the spectrum in the optical band, where it is mostly given by the product of  $M^2 \dot{m}$  (for illumination case). The value of  $r_{skin}$  must be chosen in order not to overproduce/underproduce far-UV flux. The slope of the soft X-ray spectrum gives one constraint on the combination of  $\tau$  and  $T$ , but for low values of  $T$  which are always derived the normalization of the soft Comptonized spectrum also depends significantly on the plasma parameters (for a number of soft photons already specified by  $r_{skin}$ ).

Examples of the solution are therefore as follows: for  $M = 10^8 M_\odot$ : we have  $\dot{m} = 0.07$ ,  $r_{skin} = 20R_g$ ,  $\tau = 17$ ,  $T = 0.65$  keV, and for high accretion rate case:  $M = 10^7 M_\odot$ : we have  $\dot{m} = 83$ ,  $r_{skin} = 140R_g$ ,  $\tau = 2.5$ ,  $T = 12$  keV; The broad band data fit for the largest mass is shown in Fig. 13 and for the smallest mass — in Fig. 14.

Those two extreme models differ considerably with the extension of the disk part covered with the hot skin. In the case of small mass, the disk model would overpredict the far-UV data points considerably if the large portion of the inner disk is not fully covered with the thermal plasma. Plasma parameters are such that they make formation of any emission lines rather difficult.

In the case of high mass the inner disk does not really have to be covered, as indicated by much smaller value of  $r_{skin}$ . Clumpy corona model would be easily applicable to this case, or even the X-ray emission could come from some shocks in outflowing material at the rotation axis. The fraction of the disk covered may be always further reduced assuming that synchrotron emission of the plasma itself provides additional soft photons. In such a case the lines from the irradiated disk are easily expected.

## 6. Discussion

### 6.1. Warm absorber

Reanalyzing *Chandra* data of Narrow Line Seyfert 1 Galaxy - Ton S180 we were able to identify several narrow absorption lines due to the warm absorber. Such lines were neither discussed by Turner et al. (2001) and Turner et al. (2002) where they presented the data for the first time nor seen in *XMM-Newton* data (Vaughna et al. 2002) because the lines are indeed very faint. We detected lines of highly ionized carbon and other elements, but we do not seem to detect any oxygen lines while in the FUSE data (Turner et al. 2002) OVI narrow absorption line components were seen.

Five of those absorption lines detected in Ton S180 (Cvi( $E = 0.3673$  keV), Nex, MgXII( $E = 1.471$  keV), MgXII( $E = 1.840$  keV), and SiXIV) are also seen in another Seyfert 1 galaxy - NGC 3783 analyzed by Kaspi et al. (2002), with similar values of EWs (0.46, 2.3, 4.3, 1.6 and 6.6 eV respectively). Also Kaastra et al. (2002) in NGC 5548 have found the same Cv, Cvi( $E = 0.3673$  keV), Nex, MgXII( $E = 1.471$  keV), and SiXIV, with following EWs - 0.26, 0.99, 0.47, 3.09, and 3.88 eV.

We found a lower limit for the warm absorber column of  $5.1 \times 10^{21} \text{ cm}^{-2}$  from the equivalent with of the one of C VI lines (see Sect. 3.2.2) and an upper limit of  $1 \times 1.7 \times 10^{23} \text{ cm}^{-2}$  from our model of the warm absorber (see Sect. 4). The upper limit is not firm since it is sensitive to the adopted turbulent velocity as well as abundances.

## 6.2. Broad-band continuum

The *Chandra* data show that the effect of the warm absorber does not modify significantly the X-ray spectrum in the case of Ton S180. Therefore our analysis do not change the overall picture of the Ton S180 continuum, as shown by Turner et al. (2002) and discussed by Vaughan et al. (2002). In particular, the huge soft X-ray excess is reasonably explained only within the frame of the Comptonization model.

Variability arguments presented by Vaughan et al. (2002) in favor of hybrid plasma model (thermal plasma being responsible for the soft X-ray slope and non-thermal plasma component leading to hard X-ray power law) are convincing. However, the data do not allow to determine all the hybrid plasma parameters uniquely, as explained by Vaughan et al. (2002), so in the present paper we have used much simpler model in order to draw attention to the possible constraints resulting from detection of the broad disk lines.

Those emission lines can be present in the broad band spectrum rather for higher black hole mass  $M = 10^8 M_\odot$  and accretion rate  $\dot{m} = 0.07$ , since with those assumptions hot skin does not cover disk completely. This conclusion is opposite to the black hole mass estimations done for Ton S180 by Wang & Lu (2001), where  $M = 1.3 \times 10^7 M_\odot$ . But our result is consistent with studies done by Siemiginowska (1997), where simple disk corona model was fitted to the *Beppo SAX* data (those presented by Comastri et al. 1998).

## 7. Conclusions

We argue, contrary to the previous papers by Turner et al. (2001) and Vaughan et al. (2002) that spectral features in absorption and even in emission are present in the *Chandra* data of Ton S180. The quality of the data does not allow us to determine column densities of individual metals, we can only put lower limit on column density of C VI.

The lack of edges in the spectrum gives upper limit on total column density, which is  $1.7 \times 10^{23} \text{ cm}^{-2}$  for the best computed model ( $\xi_0 = 10^5$ ).

A few emission lines fitted to the Ton S180 *Chandra* data have lower equivalent widths by factor of 6 than those reported by Mason et al. (2002) for Seyfert I galaxy Mrk 766, but of similar order as disk lines found by Kaastra et al. (2002) in NGC 5548.

Estimation of the mass of the black hole in Ton S180 based on FWHM of the  $H_\beta$  line and the formula of Kaspi et al. (2000) for the relation between the size of the Broad Line Region and the object luminosity at 5100 Å rather suggests small black hole mass,  $M = 1.3 \times 10^7 M_\odot$  (Wang & Lu 2001), in contradiction with our conclusion based on the detection of the soft

X-ray lines.

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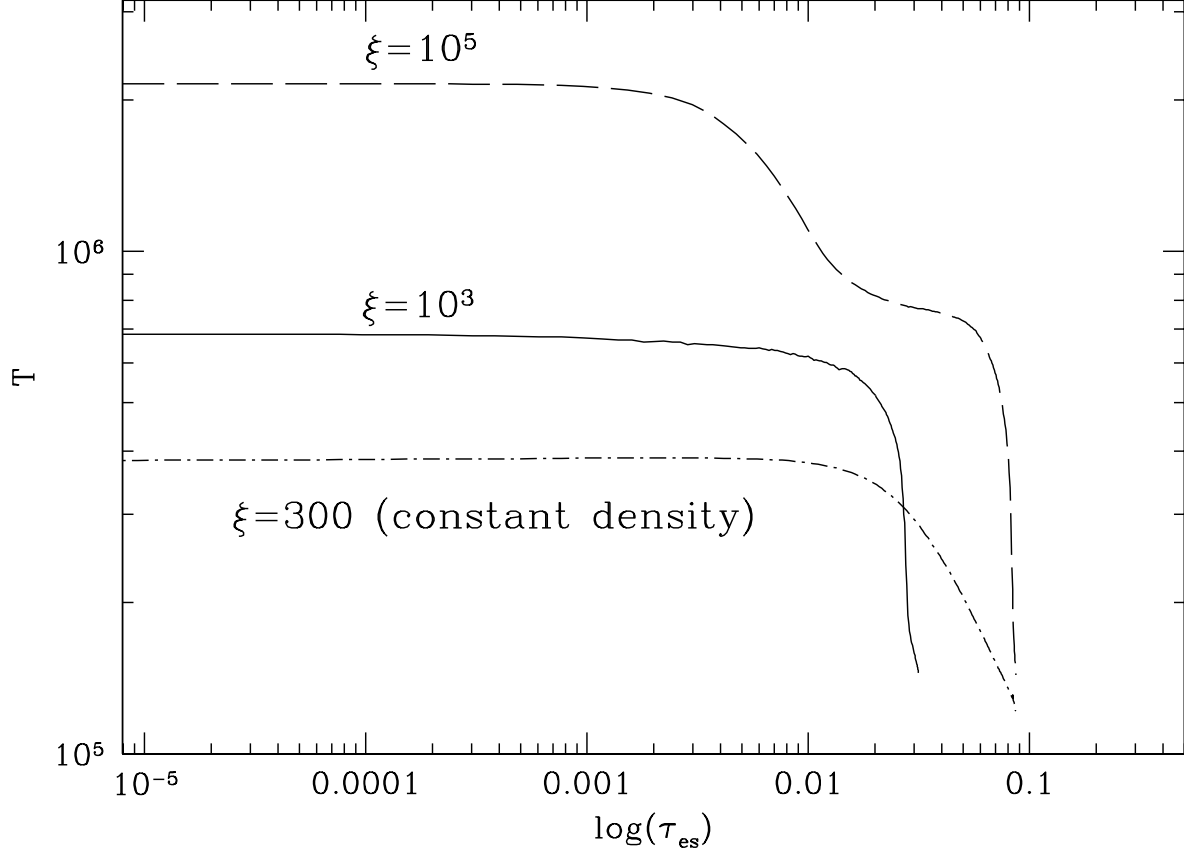


Fig. 11.— The temperature distribution for models with  $\xi = 10^5$  and  $N_{\text{tot}} = 1.7 \times 10^{23} \text{cm}^{-2}$  (dashed line),  $\xi = 10^3$  and  $N_{\text{tot}} = 6.8 \times 10^{22} \text{cm}^{-2}$  (solid line). Constant density case for  $\xi = 300$  and  $N_{\text{tot}} = 1.7 \times 10^{23} \text{cm}^{-2}$  is presented by dotted-dashed line.



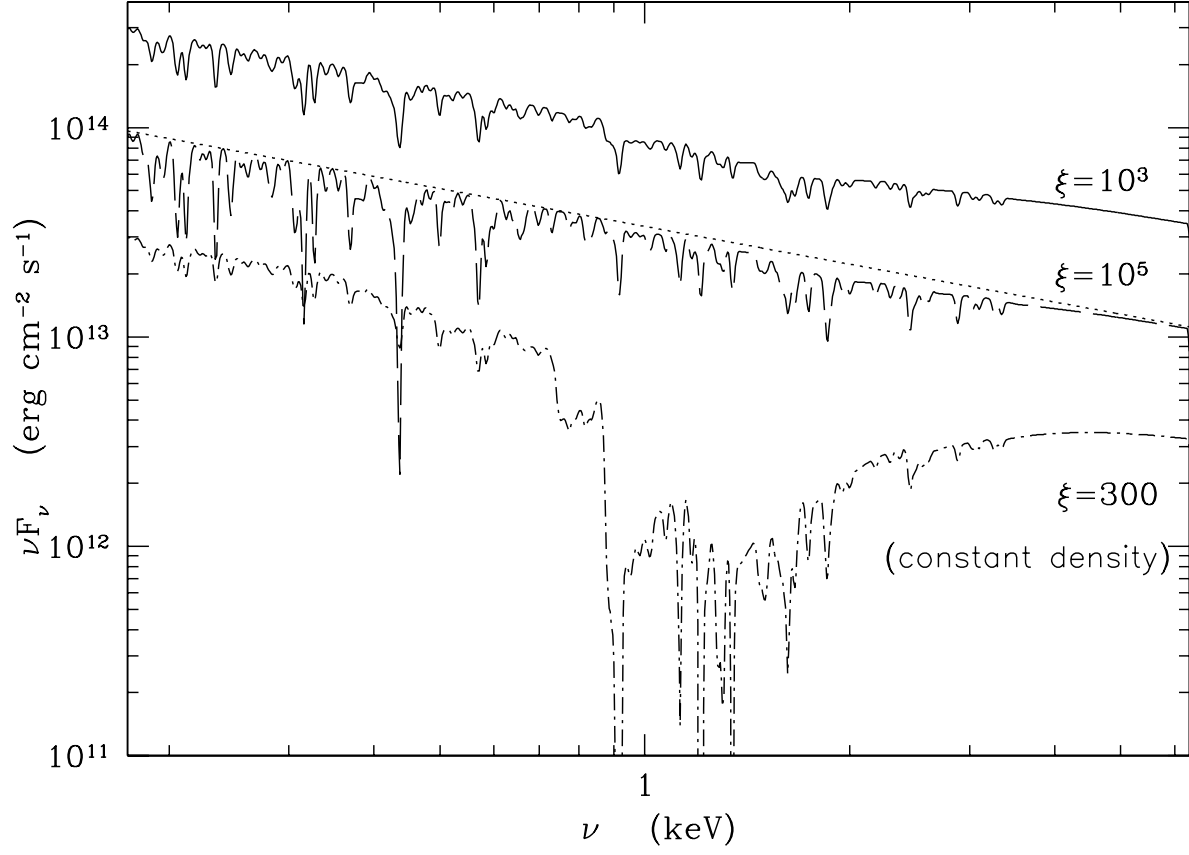


Fig. 12.— Spectral energy distribution (spectral resolution 60) for models with  $\xi = 10^5$  and  $N_{tot} = 1.7 \times 10^{23} \text{cm}^{-2}$  (dashed line),  $\xi = 10^3$  and  $N_{tot} = 6.8 \times 10^{22} \text{cm}^{-2}$  (solid line). Constant density case for  $\xi = 300$  and  $N_{tot} = 1.7 \times 10^{23} \text{cm}^{-2}$  is presented by dotted-dashed line. Both solid and dotted-dashed lines are arbitrarily moved to see differences. Dotted line indicates the slope of incident continuum.

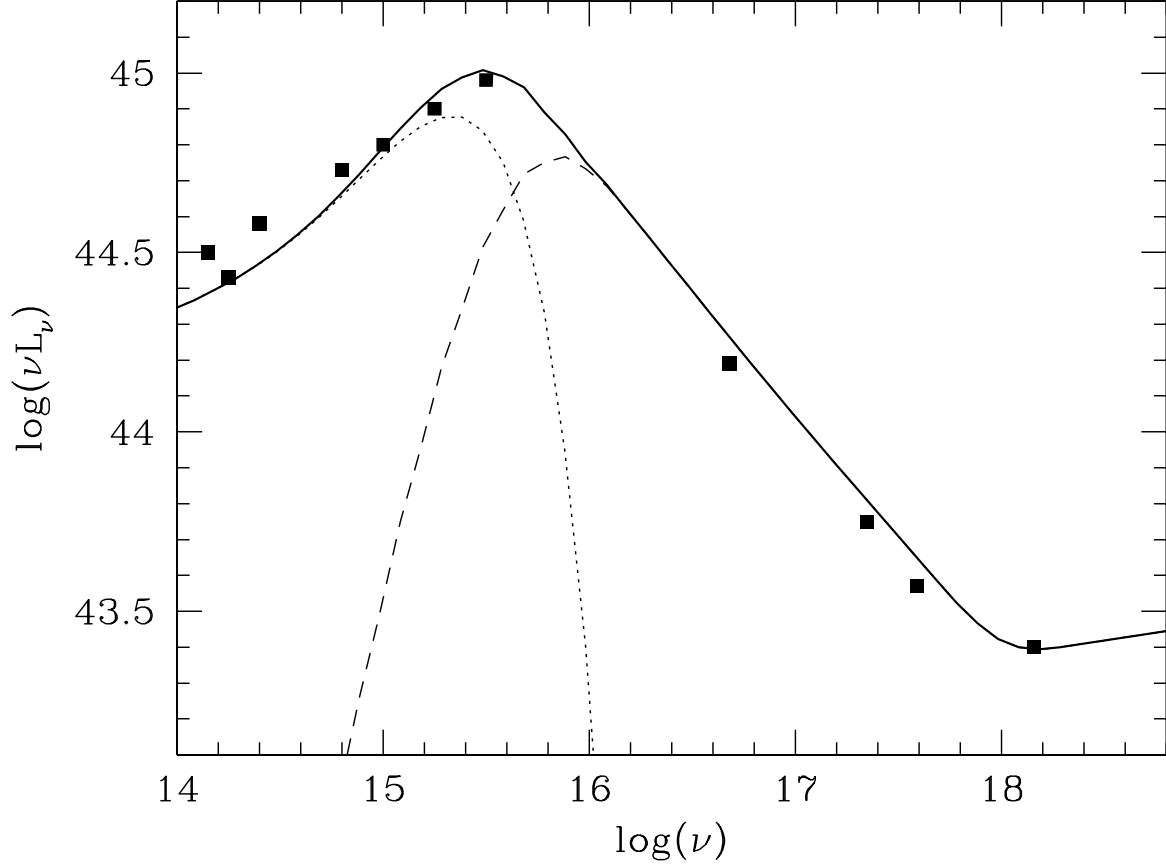


Fig. 13.— The model of the broad band spectrum of Ton S180 (solid line) for the minimum acceptable accretion rate. Dotted line gives the spectrum of the outer uncovered part of the disk and dashed line shows the radiation from the inner disk after passing through the Comptonizing medium. Model parameters:  $M = 10^8 M_\odot$ ,  $\dot{m} = 0.07$ ,  $r_{skin} = 20R_g$ ,  $\tau = 17$ ,  $T = 0.65$  keV.

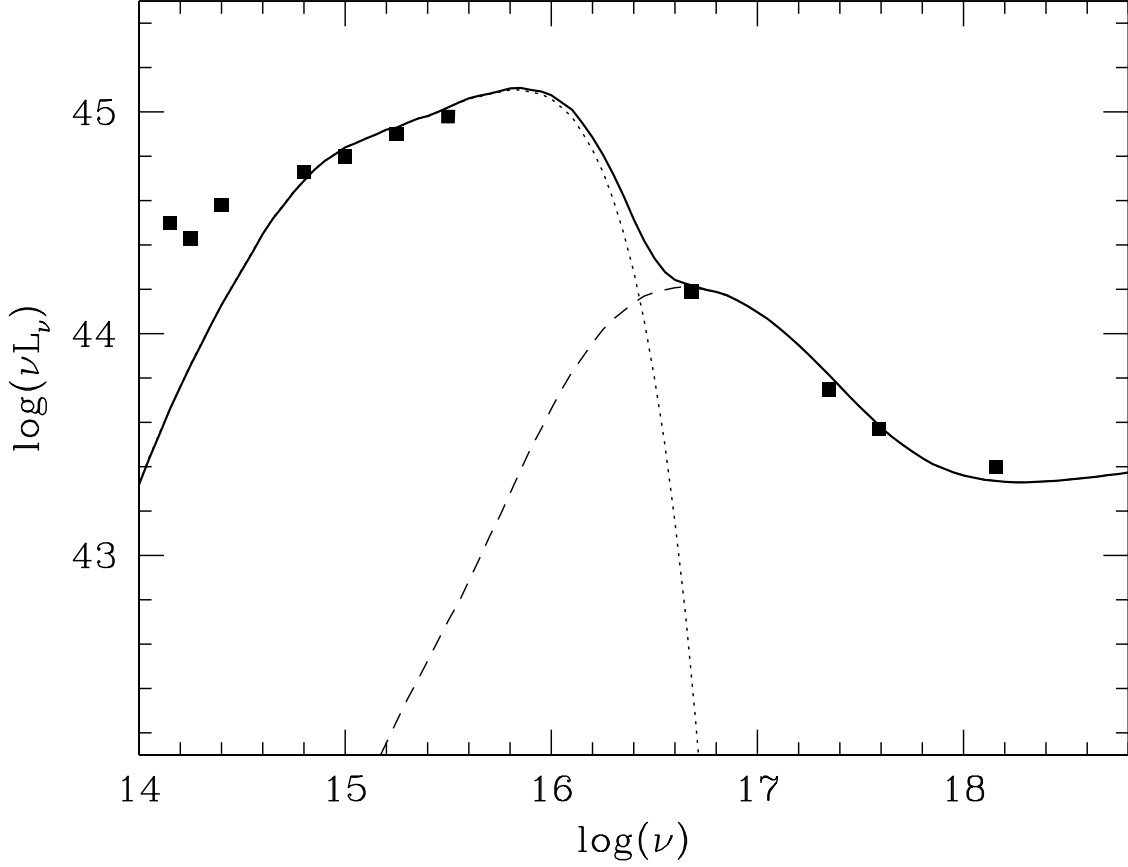


Fig. 14.— The model of the broad band spectrum of Ton S180 (solid line) for very high accretion rate (Kawaguchi 2002) . Dotted line gives the spectrum of the outer uncovered part of the disk and dashed line shows the radiation from the inner disk after passing through the Comptonizing medium. Model parameters:  $M = 10^7 M_\odot$ ,  $\dot{m} = 83$ ,  $r_{skin} = 140 R_g$ ,  $\tau = 2.5$ ,  $T = 12$  keV.