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The Ionized Gas and Nuclear Environment in NGC 3783

Hagai Netzer

School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel-Aviv University, Tel-Aviv 69978, Israel

Abstract.
The 900 ks *Chandra* spectrum of NGC 3783 was analyzed in various ways to study the properties of the absorbing gas. The main findings are: 1) On a time scale of 20–120 days, the source exhibits two very different spectral shapes with different softness ratios. The absorbing gas is not responding to these continuum variations. 2) Detailed photoionization modeling based on 10 silicon and sulphur lines near 5–7Å produces a satisfactory fit of the entire 3–25 Å spectrum of the source. The only discrepancy is in the central wavelength of the iron UTA feature. 3) A combination of three ionized absorbers, each split into two kinematic components, can explain the strengths of almost all the absorption lines and bound-free edges. The three components span a large range of ionization and have a total column of about 4×10^{22} cm^{-2}. Moreover, all three components are thermally stable and seem to have the same gas pressure.

1. Introduction

The barred-spiral galaxy NGC 3783 ($V \simeq 13.5$ mag., $z = 0.0097$) hosts a well-studied, type-I active galactic nucleus (AGN) with prominent broad emission lines and strong X-ray absorption features. The object has been observed extensively with almost all X-ray instruments, most recently by *Chandra* (Kaspi et al. 2002) and *XMM-Newton* (Blustin et al. 2002; Behar et al. 2003). The *Chandra* observations consist of a relatively short observation performed in 2000 January, and five longer observations performed in 2001 February – June, separated by various intervals from 2 to 120 days. Here we summarize the main findings of a detailed spectroscopic analysis of this spectrum. A more detailed work is presented in Netzer et al. (2003, hereafter N03).

2. The two-state X-ray spectrum of NGC 3783

The N03 study of the 900 ks *Chandra* spectrum reveals a a two-component continuum and large changes in softness ratio between "low" and "high" states of the central source. Crucial to the spectroscopic analysis is the fact that there are no obvious effects of the large continuum variations on the absorption spectrum and hence we can deduce lower limits on the distance of the absorbing gas. The present spectroscopic study is based on the low-state spectrum which is a combination of four 170 ks individual spectra (*Chandra* observations nos. 2090, 2091, 2092 and 2094).

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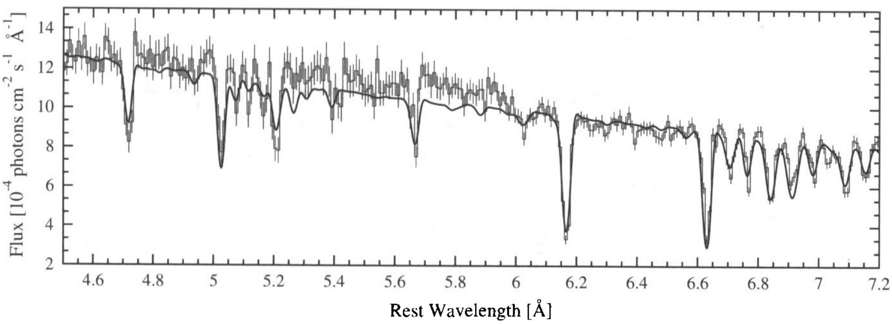

Figure 1. A comparison of the low-state NGC 3783 *Chandra* spectrum (680 ks) with the three component model described in the text.

3. Spectral analysis

The underlying idea is that the absorbing gas in NGC 3783 is photoionized by the central X-ray source and that the observed low and high-state spectra represent the physical conditions in the gas during the two phases. The principles and the ingredients of such modeling were outlined in Netzer (1996) and previous applications to the case of NGC 3783 were discussed by Kaspi et al. (2001). In the present case, the incident continuum is taken to be the broken power-law defined in Kaspi et al. (2001, Table 4) and the gas composition is "solar". The measured line profiles suggest two kinematic components per ionization component and the turbulent velocity in each is approximately 250 km s^{-1}.

3.1. The silicon and sulphur line method

We have developed a method to model the spectrum based on the EW measurements of various lines in the 5–7.1 Å band. This wavelength range contains lines from Si vii to Si xiv as well as the strongest lines of S xv and S xvi. Most of these lines are not blended. The range of ionization and excitation is very large and represents the ionization of almost all line-producing ions in the *Chandra* spectrum. The column densities of the various ions are deduced from the mesured EWs.

We searched for the best combination of photoionization models (i.e. a combination of ionization parameter, U_{OX}, and column density, N cm^2) that fit the observed 5–7Å spectrum. We found that at least three ionization components (i.e. six kinematic components) are required to fit the data to within the observational accuracy. The need for three components arise from the very large difference in ionization between the lowest (e.g. Si vii and Si viii) and the highest (e.g. S xvi) ionization lines. This requires at least one component to fit the EWs of the lowest ionization lines, one to fit the intermediate ionization lines and one for the highest ionization lines. A generic model with the required properties is the following three-component model: a low ionization component with $\log(U_{OX}) = -2.4 \pm 0.1$ and $\log(N) = 21.9 \pm 0.1$, a medium ionization component with $\log(U_{OX}) = -1.2 \pm 0.2$ and $\log(N) = 22.0 \pm 0.15$, and a high ionization component with $\log(U_{OX}) = -0.6 \pm 0.2$ and $\log(N) = 22.3 \pm 0.2$. This model is compared with the observations in Fig. 1.

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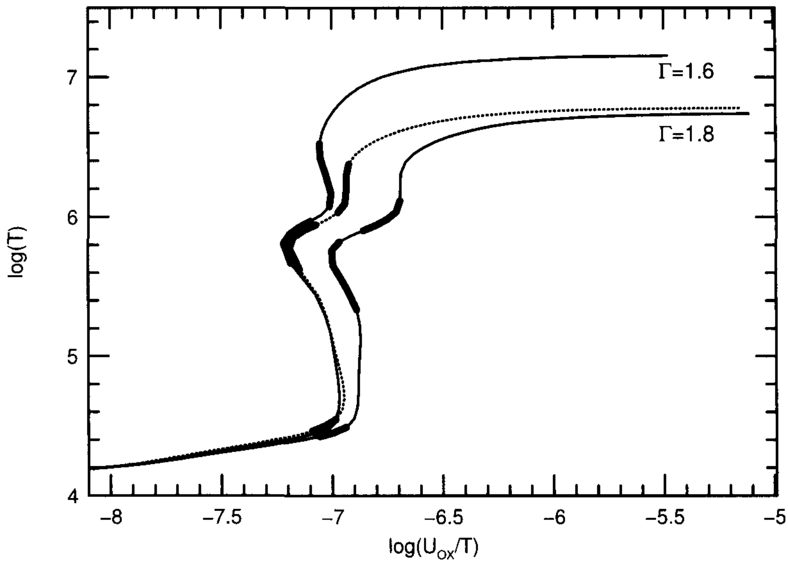

Figure 2. Thermal stability curves for a low density gas exposed to the low-state continuum of NGC 3783. The two curves marked by Γ are for a bare continuum with a 0.1–50 keV slope as marked. The dotted line is the stability curve for a gas exposed to a $\Gamma = 1.8$ continuum seen through a $\log(U_{OX}) = -2.4$ absorber. Thick sections mark the locations of the three absorbers considered in this.

The next step is to test the combination of components that fit the 5–7 Å spectrum over other wavelength bands. The results are surprisingly good and the very same combination provides a proper fit to the entire spectrum (this depends somewhat on the definition of the SED - see N03). The only significant discrepancy is in the wavelwngth of the M-shell iron UTA feature (see Behar, Sako & Kahn 2001) that indicates a lower ionization for iron compared with silicon and oxygen. We suggest that this is related to the unknown dielectronic recombination rates of M-shell iron ions (e.g. Savin et al. 2003; Gu 2003).

4. Discussion: the three component absorber

We found that three ionization components with different properties and a large range of ionization, are required to fit the spectrum of NGC 3783. Each of those components is split into two kinematic components, as implied by the observed line profiles.

A significant new aspect of our model is that the product $n_e \times T$ is similar (within a factor <2) for all three absorption components. This raises the interesting possibility that all the components are in pressure equilibrium (assuming

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gas pressure dominates the total pressure, i.e. radiation pressure and turbulent pressure are not important), and they all occupy the same volume of space. To test this idea, we have calculated a large number of thermal stability curves (log(T) vs. log(U_{OX}/T) changing the assumed SED and metalicity. Some results are plotted in Fig. 2. The interesting feature of the stability diagram is that all radiation fields considered here result in extended, almost vertical parts between $T \simeq 3 \times 10^4$ K and $T \simeq 2 \times 10^6$ K (the curve for $\Gamma = 1.6$ has a more extended vertical part since the higher mean energy of the radiation field results in a Compton temperature). All three ionization components required to explain the spectrum of NGC 3783 lie on the stable part of the curve. This suggest that the three can coexist in the same volume and provide important constraints on the location and density of the absorbing gas. More details on those models, as well as on the emission line spectrum and other physical properties of this gas are given in N03.

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