HIGH-RESOLUTION X-RAY SPECTROSCOPY OF THE ACTIVE GALACTIC NUCLEUS NGC 4051 WITH CHANDRA

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ABSTRACT

The narrow line Seyfert 1 galaxy NGC 4051 is one of the most variable Active Galactic Nuclei. During our 94 ks Chandra LETGS observation, the source was first rapidly variable at a high flux and then more quiescent when at a low flux level. The spectrum is rich in absorption and emission features some of which are significantly responding to the luminosity changes. In the high state we resolve three X-ray absorption systems of photo-ionized gas with different ionization states and outflow velocities. After the rapid ($< 3\,500$ s) transition from the high to the low flux level the emission spectrum shows Radiative Recombination Continua (RRCs). The fast observed response of the RRCs to the continuum flux change indicates that they originate very close to the central source.

Key words: NGC 4051; warm absorber; Radiative Recombination Continuum.

1. INTRODUCTION

The stupendous amount of energy emitted by an Active Galactic Nucleus (AGN) is released by gas that flows towards a super–massive black hole in the center of the galaxy. The structure and the size of the AGN environment are inferred through spectral emission features like the relativistically broadened, "classical" broad and narrow emission lines and Radiative Recombination Continua (RRCs). In addition to the accretion flow into the super–massive black hole, there is also gas flowing away from it. The mass loss rate and the accretion/mass–loss ratio play an important role in many processes (e.g. enrichment of the intergalactic medium, evolution of the host galaxy).
We present here the results of an observation of the nearby (z=0.0023) narrow line Seyfert 1 galaxy NGC 4051. The source was observed by Chandra LETGS for 94 ks.
This results will be published in Feňovčík et al. (2006).

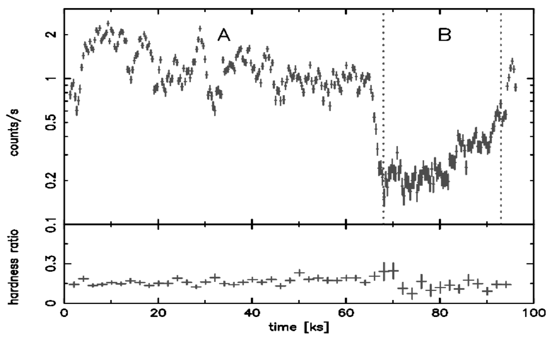

Figure 1. The light curve (upper panel) and hardness ratio (lower panel) of NGC 4051. The hardness ratio is defined as the ratio of 2—8 and 8—32 Å count rate. The upper panel has a bin size of 350 s and the bottom panel has a bin size of 2 000 s. Dotted lines denote the different flux states during the observation.

2. THE LIGHT CURVE

Looking at the light curve (Figure 1) we can distinguish two different states. At the beginning of the observation (65 ks) the source flux is characterized by a high flux level and fast variability (part A). Then the flux rapidly decreases (in $< 3\,500$ s) by a factor of ~ 5 and on short time scales stays almost constant (part B). At the end the flux rises slowly again to the previous flux level.
The hardness ratio does not vary significantly throughout the observation. This fact indicates that the soft and hard energy spectral components respond to the flux change in the same way.

3. WARM ABSORBER

Many absorption and emission lines from different elements in various ionization states are present in the spectrum (Figure 2).
In part A three absorption systems are evident: two low

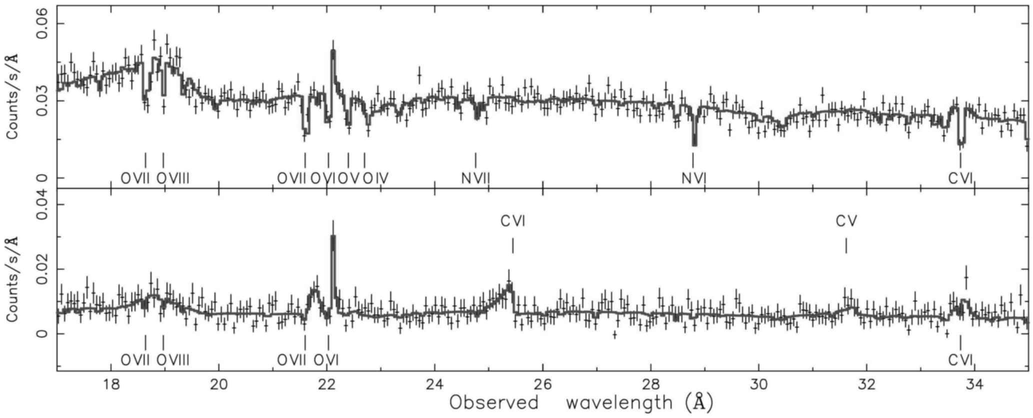

Figure 2. Chandra LETGS spectra of part A (top) and of part B (bottom). Note the strong Radiative Recombination Continuum of C VI in the spectrum of part B.

velocity components at $-400\ \mathrm{km\,s^{-1}}$ and $-800\ \mathrm{km\,s^{-1}}$ and the highest velocity outflow ever detected in a Seyfert 1 galaxy at $-4810\ \mathrm{km\,s^{-1}}$ (van der Meer et al., 2003). With increasing outflow velocity, the ionization parameter and column density of individual components are increasing as well (Table 1). In part B only one outflow component is clearly detected. It has similar physical parameters as the intermediately ionized system with outflow velocity of $-800\ \mathrm{km\,s^{-1}}$, detected in part A (Table 1), except for a lower ionization parameter.
We note that in our data the absorption system with outflow velocity $-2340\ \mathrm{km\,s^{-1}}$, observed by Collinge et al. (2001), is not significantly detected. The presence of a low velocity component was previously reported also by Collinge et al. (2001) and later by Ogle et al. (2004).

4. RADIATIVE RECOMBINATION CONTINUA

In part B (Figure 1), where the flux decreased by a factor of ~ 5, strong narrow RRCs of C VI (25.39 Å) and C V (31.64 Å) appear in the spectrum. The inferred temperature of the recombining photo–ionized gas is $\sim$ 5 eV. In addition, the RRCs show a redshift of $\sim$ 1 000 km s^{-1} with respect to the rest frame of the AGN. Interestingly, the RRCs from other abundant ions such as O VII and O VIII are not visible in the spectrum.
If we consider that the RRC is somehow linked to the warm absorber, the most natural question is, to which particular component? The best candidate is the second absorption system in part A, with outflow velocity -820 km s^{-1} and $N_{\mathrm{H}} = 1.9{\times}10^{25}\mathrm{m}^{-2}$. With a fivefold drop in the continuum, we expect a $\log\xi = 1.74$, which is close to the value observed in part B (Table1). Moreover, the gas temperature will decrease from 21 eV to 6 eV which is, within the error bars, the temperature of the gas producing the C VI and C V RRC.
By taking $\log\xi = 1.54$ we expect only a small fraction of gas recombining to O VIII. On the contrary, for this ionization parameter we expect a lot of gas producing an O VII RRC at 16.77 Å, but this feature is not clearly observed. However in this spectral region absorption from Fe IX may mask the O VII RRC emission.

Table 1. Properties of the warm absorber in the high state (part A) and in the low state (part B)

		N_{H} ($\times 10^{25}$ m^{-2})	$\log\xi$ ($\times 10^{-9}$ W m)	v$_{\mathrm{out}}$ (km s^{-1})
A	1	0.41 ± 0.04	0.74 ± 0.06	-420 ± 20
	2	1.9 ± 1.0	2.44 ± 0.08	-820 ± 40
	3	15^{+10}_{-6}	3.2 ± 0.1	-4810 ± 120
B	2	3.5 ± 1.0	1.54 ± 0.10	-790 ± 40

The fact that we see the fast response to the flux change means that the distance of the gas from the central source has to be less than 1.5×10^{12} m. As a consequence, given the mass of the black hole of NGC 4051 ($3 \times 10^5 \mathrm{M}_\odot$, McHardy et al. (2004)) we expect a keplerian velocity broadening of at least $5\,200$ km s^{-1} in the RRC, which is not observed.
From the observed C VI RRC emission measure we can derive a lower limit for the recombining gas column density: $N_{\mathrm{H}} > 10^{26}\ \mathrm{m}^{-2}$. This value is 3 – 5 times higher than the column density of the warm absorber. Therefore the hypothesis that the warm absorber and the RRC are produced by the same gas is not straightforwardly confirmed. Other effects (e.g. geometry) may play an important role in the emission/absorption process of the system.

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