The Complex X-Ray Absorbers of NGC 3516 Observed by BEPPOSAX

Citation

Costantini, E., F. Nicastro, A. Fruscione, S. Mathur, A. Comastri, M. Elvis, F. Fiore, et al. 2000. "The Complex X-Ray Absorbers of NGC 3516 Observed by BEPPOSAX." *The Astrophysical Journal* 544 (1) (November 20): 283–292. doi:10.1086/317200.

Published Version

doi:10.1086/317200

Permanent link

<http://nrs.harvard.edu/urn-3:HUL.InstRepos:30212189>

Terms of Use

This article was downloaded from Harvard University's DASH repository, and is made available under the terms and conditions applicable to Other Posted Material, as set forth at <http://nrs.harvard.edu/urn-3:HUL.InstRepos:dash.current.terms-of-use#LAA>

Share Your Story

The Harvard community has made this article openly available.
Please share how this access benefits you. [Submit a story](#).

[Accessibility](#)

THE COMPLEX X-RAY ABSORBERS OF NGC 3516 OBSERVED BY *BEPPoSAX*

E. COSTANTINI,¹ F. NICASTRO,^{1,2,3} A. FRUSCIONE,¹ S. MATHUR,⁴ A. COMASTRI,⁵ M. ELVIS,¹ F. FIORE,² C. SALVINI,⁵
 G. M. STIRPE,⁵ C. VIGNALI,^{5,6} B. WILKES,¹ P. T. O'BRIEN,⁷ AND M. R. GOAD⁷

Received 2000 March 17; accepted 2000 July 13

ABSTRACT

In this paper we present the analysis of two broadband (0.1–150 keV) *BeppoSAX* observations of the Seyfert 1 galaxy NGC 3516. The two observations were taken 4 months apart, on 1996 November 8 and 1997 March 12. We report a dramatic change in the degree of obscuration of the central source between the two observations and propose, as possible explanations, transient absorption by either a stationary-state cloud of cold gas crossing the line of sight or a varying-state, initially neutral and dense amount of expanding gas with decreasing density and therefore decreasing opacity. We also report the detection of a second highly ionized absorber/emitter, which causes deep Fe xvii–xxii K edges at ~ 7.8 keV to appear in both of the *BeppoSAX* spectra of NGC 3516 and possibly produces the soft X-ray continuum emission in the 1 keV blend of Fe L recombination lines detected during the epoch of heavy nuclear obscuration.

Subject headings: galaxies: individual (NGC 3516) — galaxies: Seyfert — X-rays: galaxies

1. INTRODUCTION

NGC 3516 is a bright ($F_{2-10\text{ keV}} = 7.8 \times 10^{-11}$ ergs $\text{cm}^{-2} \text{s}^{-1}$; Reynolds 1997) nearby ($z = 0.009$, $D = 54$ Mpc, for $H_0 = 50 \text{ km s}^{-1} \text{Mpc}^{-1}$) Seyfert 1 galaxy, which is known to host complex and variable systems of both mildly and highly ionized absorbers in the UV and in the X-ray. In the UV band *IUE* spectra of NGC 3516 taken between 1978 June and 1989 October (Ulrich & Boisson 1983; Voit, Shull, & Begelman 1987; Walter et al. 1990; Kolman et al. 1993) show the presence of at least two systems of C iv resonant-absorption lines; one is broad ($\sim 2000 \text{ km s}^{-1}$) and variable; the other is narrow ($\sim 100 \text{ km s}^{-1}$) and constant. Both are produced by ionized and outflowing gas that obscures both the continuum and at least part of the broad emission lines (BEL). Four years later the broad absorption line component was no longer detected in the spectra of NGC 3516 taken with the *IUE* (from 1993; Koratkar et al. 1996) or later with the Hopkins Ultraviolet Telescope (in 1995; Kriss et al. 1996a) and the Goddard High Resolution Spectrograph (GHRS) (in 1995; Crenshaw, Moran, & Mushotzky 1998; Goad et al. 1999, hereafter GEA99), suggesting either a change in the covering factor or in the ionization structure of the gas responsible for that feature or an increase in the emissivity of the C iv BEL. The complex X-ray absorber was observed by *ROSAT* (in 1992; Mathur, Wilkes, & Aldcroft 1997; hereafter MWA97) and *ASCA* (Kriss et al. 1996b; Reynolds 1997; George et al. 1998) through the detection of two strong absorption features at

the energies of the O vii and O viii K edges (0.74 and 0.87 keV, respectively). The optical depths measured in the *ROSAT* and *ASCA* spectra using phenomenological two-edge models are similar to one another ($\tau_{\text{O vii}} \sim 0.6$, $\tau_{\text{O viii}} \sim 0.3$).

Neutral absorption has not been unambiguously found in this source. While the 1979 *Einstein* observation (Krupe, Urry, & Canizares 1990) did not detect absorption by neutral gas, a subsequent low energy resolution *EXOSAT* observation in 1985 showed the presence of cold gas, with $N_{\text{H}} \sim 10^{22} \text{ cm}^{-2}$ affecting the low-energy spectrum (Ghosh & Soundararajaperumal 1991). A 1989 *Ginga* observation (simultaneous to *IUE*; Kolman et al. 1993) showed a low-energy cutoff of the intrinsic power law, indicating heavy absorption of the nuclear continuum along the line of sight. However, because of the limited energy coverage of *Ginga* (2–20 keV bandpass), it was not possible to establish the ionization state of that absorber, which was consistent with either a high column of neutral gas ($N_{\text{H}}^{\text{Cold}} = 4 \times 10^{22} \text{ cm}^{-2}$) or a lower column of more highly ionized gas.

In this paper we present data from two broadband *BeppoSAX* (Boella et al. 1997a) observations of NGC 3516. Preliminary results were presented by Stirpe et al. (1998). The paper is organized as follows: In §§ 2 and 3 we present our analysis of the data, while in § 4 we discuss our main results. Finally, we present our conclusions in § 5.

2. DATA REDUCTION AND ANALYSIS

NGC 3516 was detected with a good signal-to-noise ratio in the three main narrow-field instruments (NFI) on *BeppoSAX*, spanning 0.1–120 keV. In Table 1 dates and exposure times of the two *BeppoSAX* observations of NGC 3516 are presented, along with the source count rates measured by the Low-Energy Concentrator Spectrometer (LECS; Parmar et al. 1997), Medium-Energy Concentrator Spectrometer (MECS; Boella et al. 1997b), and Phoswich Detection System (PDS; Frontera et al. 1997). Data from these three instruments were screened following standard criteria, as detailed in Fiore, Guainazzi, & Grandi (1999). In particular, PDS data were screened using fixed rise-time thresholds. Data from the three MECS units were merged to improve the statistics. The scientific products for the

¹ Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.

² Osservatorio Astronomico di Monteporzio, Via Osservatorio 2, I-00040, Monteporzio, Italy.

³ Istituto di Astrofisica Spaziale-CNR, via del Fosso Cavaliere, Roma I-00133, Italy.

⁴ Ohio State University, Department of Astronomy, 174 West 18th Avenue, Columbus, OH 43210-1106.

⁵ Osservatorio Astronomico di Bologna, via Ranzani 1, I-40127, Bologna, Italy.

⁶ Dipartimento di Astronomia, Università di Bologna, via Ranzani 1, 40127 Bologna, Italy.

⁷ Department of Physics and Astronomy, University of Leicester, University Road, Leicester LE1 7RH, England, UK.

TABLE 1
OBSERVATION LOG OF THE TWO *BeppoSAX* POINTINGS OF NGC 3516

DATES	EXPOSURES			RATE (counts s ⁻¹)		
	LECS	MECS	PDS	LECS	MECS	PDS
1996 Oct 11	16,059	56,013	20,758	0.034 ± 0.001	0.36 ± 0.003	0.72 ± 0.04
1997 Dec 3	16,909	57,712	21,713	0.14 ± 0.004	0.69 ± 0.004	0.86 ± 0.04

NOTE.—Count rates are given in the bands 0.1–2 keV, 2–10 keV, and 15–150 keV, for the LECS, MECS, and PDS, respectively.

analysis are extracted from the equalized event files, using both the standard FTOOLS package (Version 4.2) and the new release (Version 1.1) of the CIAO (*Chandra* Interactive Analysis of Observation) software (M. Elvis et al. 2001, in preparation; Siemiginowska & Fruscione 2000⁸). LECS and MECS source counts were extracted from circular regions of the 6" radius centered on the source. The same extraction regions were used to extract background counts from the long-exposure “blank fields” provided by the *BeppoSAX* Science Data Center.⁹ PDS source and background counts were collected during the on- and off-source modes of the instrument, respectively. For all the instruments, spectra were binned following the instrumental resolutions and allowing a maximum of three channels per resolution element.

2.1. Model-Independent Evidence for Long-Term Spectral Variability

NGC 3516 underwent moderate (factor of 1.5–2) 0.1–10 keV flux variations during both *BeppoSAX* observations (on a timescale of hours); however, the ratios of the soft (0.1–2 keV)-to-hard (2–10 keV) light curves were consistent with being constant, indicating no significant spectral variability across these energy bands on a 1 day timescale (the duration of each observation).

A dramatically different behavior was observed on the longer 4 month timescale between the two observations, during which the source experienced strong spectral variability. The 0.1–2 keV count rate increased by a factor of ~ 4 ,

while the corresponding increase in the 2–10 keV band was only 1.9 (Table 1). Figure 1 shows the model-independent ratio between the raw LECS (0.1–2 keV), MECS (1.5–10 keV), and PDS (13–100 keV) spectra for the two *BeppoSAX* observations (1996 November and 1997 March). The amplitude of nonlinear effects in the responses of the NFIs (potentially affecting the results of such an analysis) is, at all energies, much smaller than the amplitude of the features visible in this ratio (Boella et al. 1997b; Frontera et al. 1997; Parmar et al. 1997).

In the ratio in Figure 1 the 1–5 keV energy band is a smoothly increasing function of energy. It then flattens at $E \gtrsim 5$ keV, around a value of ~ 0.6 . In the PDS band the ratio is ~ 0.8 . This implies a steepening of the ratio between 10 and 13 keV. A sharp emission feature around 1 keV is visible superimposed on these smooth changes. All this strongly suggests that some, and perhaps all, of the several components that make up the 0.1–100 keV spectrum of NGC 3516 varied independently of each other from one observation to the other. In particular, the smooth and monotonic rising of the ratio up to ~ 5 keV, along with its flattening above this energy and up to 10 keV, suggests a drastic decrease in the degree of obscuration of the central X-ray source between the two observations rather than an intrinsic variation of the slope of the primary X-ray continuum. In this case the asymptotic value of ~ 0.6 around which the ratio flattens above ~ 5 keV would be the intensity increase factor of the intrinsic X-ray power law between the two observations. The higher PDS count ratio of ~ 0.8 may suggest a higher relative intensity of a Compton-reflection component in the 1997 observation. There is no clear indication of a similar effect at the energy of the Fe K line. The emission feature at ~ 1 keV may be the signature of iron L emission, visible only during the 1996 observation, and therefore either external to the nuclear environment and detectable by the *BeppoSAX* LECS only when the soft nuclear continuum was heavily obscured or internal to the nuclear environment but only partially obscured by the amount of neutral (or mildly ionized) gas obscuring the X-ray source in 1996. Intrinsic variation of the intensity of the Fe L complex in the hot plasma is, of course, a further possibility. We use this scenario to guide the modeling and fitting of the spectra in §§ 3 and 4.

3. SPECTRAL MODELING AND FITTING

We have performed global modeling and fitting of the 0.1–150 keV spectra of both *BeppoSAX* observations of NGC 3516 using the XSPEC, Version 10.0 package. In Table 2 we summarize the results of this analysis. Errors are quoted at the 90% confidence level for one interesting parameter (i.e., $\Delta\chi^2 = 2.71$; Avni 1976). The cosmology

FIG. 1.—Ratio of the N96 and M97 spectra of NGC 3516

⁸ http://asc.harvard.edu/udocs/news_07/node5.html.

⁹ <http://www.sdc.asi.it>.

TABLE 2
BEST-FIT PARAMETERIZATIONS 96BF AND 97BF

Models	Normalization (10^{-2} photons cm^{-2} $\text{s}^{-1} \text{keV}^{-1}$ at 1 keV)	Γ	N_{H} (10^{22} cm^{-2})	kT (keV)	$\log N_{\text{H}}^{\text{WA}}$ (cm^{-2})	$\log U^{\text{WA}}$	$E_{\text{K}\alpha}$ (keV)	$\sigma_{\text{K}\alpha}$ (keV)	$\text{EW}_{\text{K}\alpha}$ (eV)	$\log N_{\text{H}}^{\text{HA}}$ (cm^{-2})	$\log U^{\text{HA}}$	R^{a}	χ^2/dof
96BF	1.43 ± 0.13	$2.03^{+0.15}_{-0.17}$	$2.31^{+0.33}_{-0.15}$	$1.78^{+0.91}_{-0.39}$	...	...	6.33 ± 0.30	<0.52	108^{+51}_{-45}	23.5 ± 0.1	2.35 ± 0.2	$1.2^{+0.6}_{-0.2}$	91/94
97BF	2.38 ± 0.05	$2.04^{+0.15}_{-0.16}$	$2.77^{+0.49}_{-0.44} \times 10^{-2}$	...	22.0 ± 0.02	0.73 ± 0.1	6.41 ± 0.15	<0.27	102^{+71}_{-56}	23.2 ± 0.2	2.36 ± 0.1	$1.4^{+0.2}_{-0.2}$	85/94

NOTE.—Both models include a cutoff power law plus Galactic absorption, a Gaussian line plus cold reflection, and a highly ionized absorber. 96BF also includes a partial covering absorber ($C_{\text{su}} \sim 0.95$) and a thermal component. 97BF instead includes a “warm absorber.” See § 3 for details.

^a Errors are calculated fixing the slope at the best-fit value.

used is $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0.5$. For all the absorption (neutral and/or ionized) models that we use in this paper, we adopt solar abundances as estimated by Grevesse & Anders (1989) and Grevesse & Noels (1993). Photoionization models for fitting purposes include photoelectric absorption but not resonant absorption and gas emission and have been built following Nicastro et al. (2000). Finally, we use pure Compton-reflection models built by running iteratively the routine PEXRAV (Magdziarz & Zdziarski 1995) for the inclination angle of 30° (consistent with the best-fit interval measured; see § 3.1.3) and a range of values of the slope Γ of the incident continuum and the e -folding energy E_c of the high-energy exponential cutoff. For fitting purposes we always combine the Compton-reflection model with a cutoff power law, linking the two Γ and E_c values to the same values and leaving the two normalizations free to vary independently.

We first fitted the 1996 November and 1997 March spectra (hereafter N96 and M97) with a model consisting of a power law plus Galactic absorption ($N_H = 3.4 \times 10^{20} \text{ cm}^{-2}$; Dickey & Lockman 1990). Both fits are very poor [$\chi^2/\text{dof}(\text{N96}) = 1147/94$, $\chi^2/\text{dof}(\text{M97}) = 600/101$], and the best-fit photon indices are different: $\Gamma \sim 1.2$ and 1.5 , respectively. The residuals clearly show the presence of several additional nonmodeled spectral features (Figs. 2a and 2b). Some are common to both spectra: (1) a linelike feature at $\sim 6.4 \text{ keV}$, (2) a deficit of counts at $\sim 8 \text{ keV}$, and (3) a systematic deviation across the PDS band. However, at low energy ($E \lesssim 4 \text{ keV}$) the shapes of the residuals are quite different from one spectrum to the other. Our best-fitting parameterizations of N96 and M97 are thus quite different and are summarized in Table 2.

The two best-fitting models (hereafter 96BF and 97BF, respectively) include several common components, which make up our “base model”: (1) a power law with a high-energy cutoff, (2) a neutral absorber (to account for Galactic absorption along the line of sight), (3) a hot photoionized absorber (HA; see Table 2) parameterized by a column density N_H and an ionization parameter U (to account for the 8 keV deficit), (4) a Gaussian emission line (to account for $K\alpha$ iron fluorescence), and (5) a pure Compton-reflection component (limited to Γ and E_c , as noted earlier). However, N96 and M97 differ from each other in requiring additional

components that are not held in common: (6) a neutral absorber only partially obscuring the direct view of the primary X-ray power law, (7) soft emission by an optically thin plasma for the N96 spectrum, and (8) a second, more mildly ionized absorber for the M97 spectrum.

3.1. The “Base Model”

Our estimates for the parameter values of our base model were consistent with each other between the 96BF and 97BF parameterizations (see Table 2). In the following discussion we describe and discuss the individual components of this model, referring to the numerical results obtained for the M97 spectrum, the one with higher statistics.

3.1.1. The Intrinsic Power Law and the High-Energy Cutoff

The 0.1 – 100 keV primary continuum of NGC 3516 is well described by a simple power law $F(E) = AE^{-\Gamma}$ [$F(E)$ in photons $\text{s}^{-1} \text{ cm}^{-2} \text{ keV}^{-1}$], with $\Gamma = 2.04^{+0.06}_{-0.07}$ (Table 2). This component varied in flux by $\sim 70\%$ between the two observations [i.e., $A(\text{N96})/A(\text{M97}) = 0.6$] without changing in shape. We then conclude that little, if any, of the dramatic spectral variability experienced by the source can be due to variation of the primary continuum, either in shape or intensity. We could only estimate a lower limit ($E > 450 \text{ keV}$) on the e -folding energy of the high-energy cutoff and were not able to measure any significant change of this parameter between the two observations.

3.1.2. Iron Line and Compton Reflection

Both the iron-line and the Compton-reflection components were required by our data at high significance. Removing each of these components, one at a time, from the 97BF model and refitting the data gives, respectively (with $\Delta\nu$ indicating the number of free parameters eliminated by the 97BF model), $\Delta\chi^2 = -25$ ($\Delta\nu = 3$) and $\Delta\chi^2 = -41$ ($\Delta\nu = 1$).

The best-fit energy of the iron emission line ($E = 6.41 \pm 0.15 \text{ keV}$) is consistent with that of Fe I–XXII $K\alpha$ transitions. When modeled with a simple Gaussian (as in our adopted best-fitting parameterization 97BF), the line is consistent with being narrow, with a 90% upper limit on its width of 0.27 keV . We note that the energy resolution of the *BeppoSAX*-MECS is only $\sim 500 \text{ eV}$ at 6.4 keV . Furthermore, an accurate determination of the exact shape of the iron-line profile is hampered by the presence in the data of the $\sim 8 \text{ keV}$ edgeline absorption feature. However, we have checked the consistency of our data with more complex scenarios, replacing the Gaussian emission line in the 97BF model with a relativistically broadened and distorted emission line from the accretion disk (the model DISKLINE in XSPEC; Fabian et al. 1989), as suggested by previous *ASCA* observations (Nandra et al. 1997b, 1999). We fixed the internal radius on the accretion disk at 6 gravitational radii, the energy of the emission-line centroid at 6.33 keV (the best-fit energy in 97BF), and the spectral index of the emissivity law at -2 and refitted the data. The result was inconclusive. We obtained the same $\chi^2/\nu = 86/95$ as in 97BF. The outer radius on the disk was only barely constrained and larger than 11.5 gravitational radii. All the other model parameters were consistent within the errors in the 97BF measurements. We also checked the extreme hypothesis that all of the negative residuals visible in Figure 2 at $\sim 8 \text{ keV}$ could be explained in terms of a very distorted blue profile of the iron line, eliminating the HA component and refitting the data. This yielded a worse χ^2 than 97BF

FIG. 2.—Residuals of a simple power law plus Galactic absorption fit for N96 (upper panel) and M97 (lower panel).

($\Delta\chi^2 = -18$ for $\Delta\nu = 3$) and accounted only partially for the absorption feature at ~ 8 keV. We then concluded that a relativistically broadened and distorted emission-line profile with no Fe xvii–xxii K absorption is not a necessary component for the description of our data.

Thanks to the broad band of *BeppoSAX*, we were able to detect a bump in the 10–30 keV data (see Figs. 2a and 2b). We model this bump as being due to Compton reflection of the primary power law off a slab of almost neutral matter reradiating the isotropic incident X-ray continuum. During both the 1996 and 1997 observations we measured relative fractions of reflection consistent with each other (Table 2) and fully consistent with the value of 1 corresponding to a solid angle of 0.5 as seen by a central isotropic source of primary radiation. Their ratio, $0.8^{+0.7}_{-0.2}$, is consistent with the value derived in § 2.1 from our model independent analysis. If the same matter were also producing the K α fluorescence iron line (but see also § 2.1), we would expect the equivalent width of this line to be ~ 100 – 150 eV (e.g., Mushotzky, Done, & Pounds 1993), consistent with the measured value (see Table 2).

3.1.3. The “Hot” Absorber

Both the N96 and M97 spectra of NGC 3516 show a clear absorption feature around 8 keV (Fig. 2). A neutral reflection component alone cannot explain the edge feature at ~ 8 keV, even allowing the inclination disk parameter to vary in a wide range (from 0° to 60°). We accounted for this feature by including a hot photoionized absorber (HA) in 96BF and 97BF, obscuring the line of sight. The same model was used for NGC 3516 to fit the absorption feature detected at the same energy ($E \sim 8$ keV) by *Ginga* (Kolman et al. 1993). We stress again that the model used to fit the data includes neither gas emission nor resonant absorption. Removing this component from both 96BF and 97BF and refitting the data gives, respectively, $\Delta\chi^2 = -13$ and $\Delta\chi^2 = -29$ for $\Delta\nu = 2$.

The best-fitting parameters U and N_H do not vary (within the errors) between the two observations (Table 2), and their values indicate that a high column density [$N_H^{\text{HA}} = (3.2^{+0.5}_{-0.6}) \times 10^{23} \text{ cm}^{-2}$, very similar to the value found by Kolman $\sim 3 \times 10^{23} \text{ cm}^{-2}$] of highly ionized ($U = 224^{+131}_{-83}$) gas, is absorbing the primary continuum of NGC 3516 in both data sets. In such an absorber elements lighter than oxygen and neon are fully ionized and therefore do not imprint any visible features on the emerging spectrum. However, iron is still not fully ionized and contributes strongly to the opacity of the absorber at the energies of the photoelectric K and L absorption edges of Fe xvii–xxii. Absorption by Fe xvii–xxii K imprints deep absorption edges at ~ 7.8 – 8.0 keV on the emerging spectrum, while L absorption by the same species affects the whole 1–5 keV band, gently flattening a low-resolution spectrum rather than producing visible sharp and resolved single absorption features on it (unless Fe L resonant-absorption lines dominate on recombination lines).¹⁰ Fitting low-resolution data with a phenomenological single-edge model, accounting for the ~ 8 keV absorption feature, would result in a wrong estimate of the slope of

the intrinsic 0.1–100 keV power law, which would appear to be flatter by $\Delta\Gamma = 0.28 \pm 0.13$. Ionized, and possibly relativistically smeared, edgeline features at energies greater than 7.1 keV have often been detected in the hard/low state of Galactic black hole candidates, where the accretion disk is supposed to be hotter than that of active galactic nuclei (AGNs) by a factor of ~ 30 (Ross, Fabian, Brandt 1996; Done & Życki 1999). In this contest to further test the uniqueness of our interpretation, we applied an ionized reflection model, which possibly also can account for an ionized edge feature to our data. The $\Delta\chi^2$ between a model with an ionized reflection (model PEXRIV in XSPEC; Magdziarz & Zdziarski 1995) and the best fit (BF) is $\Delta\chi^2/\Delta\nu = 25/1$ and $\Delta\chi^2/\Delta\nu = 23/2$ if the iron abundance parameter is left free to vary. The variation of the inclination angle of the ionized reflector ($\theta = 30^\circ, 45^\circ$, and 60°) does not influence the χ^2 test. Moreover, the expected ionized iron line at 6.7 keV, consistent with the ionization degree of the edge, is not detected even though a ionized line could have been missed because of the low-resolution instrument.

The preferred interpretation is thus in terms of a high-ionization, high column density absorber, which can simultaneously account for both the ~ 8 keV edge and the overall continuum shape at medium energies, and, most important, it provides the statistically better description of the available data.

3.2. Departure from the “Base Model”

As pointed out in § 3, the base model does not provide a fully satisfactory description of either the N96 or the M97 spectra. Additional components are present in our best-fitting parameterizations 96BF and 97BF. We describe them in the following sections.

3.2.1. The “Cold” Absorber and the Soft Thermal Emission in N96

To model the 0.1–5 keV residuals of Fig. 2b, we added to our base model a neutral absorber of column density N_H^{Cold} , which only covers a fraction C_{sou} of the nuclear X-ray source. Fitting the N96 data with this model produces a significant improvement in the χ^2 ($\Delta\chi^2/\Delta\nu = 73/2$) and gives $N_H^{\text{Cold}} = 2.31^{+0.33}_{-0.15} \times 10^{22} \text{ cm}^{-2}$ and $0.7 < C_{\text{sou}} < 1$. (We note that when using an ionized absorber model, the ionization parameter is consistently zero while the column density of the warm gas is $\sim N_H^{\text{Cold}}$, indicating absorption by neutral gas as the most likely explanation.) Nevertheless, the residuals continue to show a clear linelike, unresolved feature around 1 keV (Fig. 3, upper panel).

At this energy recombination L lines from Fe xvii–xxiv are expected to strongly contribute to the emission from either a collisionally ionized plasma (CIP) with a temperature of ~ 1 – 2 keV or from a photoionized plasma (PIP) with a high-ionization degree ($U \sim 200$) and column density ($N_H \sim 10^{23} \text{ cm}^{-2}$). Only for fitting purposes we use here a CIP model, while a more accurate discussion on the physics of this component and on its possible identification is deferred to § 4.2. We added a CIP component (the model MEKAL in XSPEC; Mewe, Gronenschild, & van den Oord 1985) to our model and refitted the data. The fit is again significantly improved by the addition of this component ($\Delta\chi^2 = 13$; for two additional parameters, see model 96BF), and the residuals are now flat over the entire 0.1–100 keV band. The best-fit temperature of this collisional plasma is $kT = 1.78^{+0.91}_{-0.39} \text{ keV}$. The covering factor of the neutral gas is now larger ($C_{\text{sou}} > 0.95$) than in the previous fit, indicat-

¹⁰ The relative contribution of Fe L resonant-absorption lines, compared to emission lines, depends critically on the geometry and dynamics: if the gas has a high microturbulence velocity and a lower or comparable bulk velocity, then Fe L resonant absorption dominates and imprints a visible “1 keV” feature on low-resolution spectra (Nicastrò, Fiore, & Matt, 1999a). See also § 4.2.

FIG. 3.—Upper panel: N96 residuals of the “base” model plus a partial covering neutral absorber; an emission feature at 1 keV is clearly present. Lower panel: M97 residuals of the “base” model; the typical warm absorber signature is visible.

ing that only a small or null fraction of the nuclear radiation escapes absorption.

3.2.2. The “Warm” Absorber in M97

Our base model did not provide a satisfactory description for the M97 spectrum either. Several features remained at $E \lesssim 2$ keV as shown by the residuals in Figure 3b (bottom panel). These strongly suggest the presence of a typical “warm” absorber obscuring the line of sight and imprinting deep O VII and O VIII K edges at 0.74 and 0.87 keV (see Reynolds 1997; George et al. 1998). For this source, the signature of a complex “warm” absorber had been previously detected by *ROSAT*-PSPC and *ASCA* (Kriss et al. 1996b; MWA97). We then added a photoionized absorber component to our base model and refitted the M97 data. The residuals are now flat over the entire *BeppoSAX* band, and the reduced χ^2 is 0.90 (Table 2, 97BF model).

4. DISCUSSION

4.1. The Variable Absorber

The 1996 November spectrum of NGC 3516 is heavily absorbed by almost neutral gas that covers most of the primary continuum source (here we choose $C_{\text{sou}} \sim 0.95$, the best-fit value obtained by fitting the soft emission with the CIP component; see § 3.2.1) and whose equivalent hydrogen column density (as derived by a fit with a neutral absorber) is as large as $N_{\text{H}}^{\text{Cold}} = 2.3 \times 10^{22} \text{ cm}^{-2}$ (exceeding the Galactic value by almost 2 orders of magnitude). This value would be even larger if the gas were mildly ionized (O II–III dominating). There is no evidence for variation of the degree of obscuration of this gas during the observation (~ 20 hr), and this component is not required by the 1997 March data (4 months later),¹¹ and the UV continuum of this source in an *HST*-FOS observation taken ~ 18 days after the 1996 November *BeppoSAX* observation (GEA99) shows no marked extinction by dust (assuming a Galactic gas-to-dust ratio, we should expect $A_v \sim 10$ mag for $N_{\text{H}} = 2.3 \times 10^{22} \text{ cm}^{-2}$; Gorenstein 1975). All this allows us to put

¹¹ We note, however, that an ionized, similar N_{H} absorber is needed in 1997; see § 4.1.2.

constraints on the geometry and the physical state of this component and to speculate on different possible scenarios.

4.1.1. Transient Cold Absorption by a Broad Emission Line Cloud?

The typical timescale of variability of the X-ray continuum (e.g., Nandra et al. 1997a) gives an upper limit on the linear size of the emitting region $D \sim c\Delta t \sim 10^{14} \text{ cm}$. In order for a homogeneous cloud of absorbing gas to cover almost the entire primary emitting region, either the cloud is at a distance R close to the central source, comparable to D , and its linear sizes l are comparable and/or larger than D or R is much larger than D , and the source appears point-like as seen by the cloud. Photoionization arguments strongly support the second picture. In fact, assuming $R \sim D$ gives an ionization parameter $U > 2500n_{10}^{-1}$, where n_{10} is the electron density of the gas in units of 10^{10} cm^{-3} . We used the ionizing luminosity of NGC 3516, derived assuming the 2200 Å flux and α_{ox} from George et al. (1998) and X-ray fluxes and spectral shape from our data. Such an ionization parameter would be associated to almost neutral gas ($U \lesssim 0.01$ —oxygen distributed between O I and O III) only for implausibly high electron densities $n_{10} > 2.5 \times 10^5$.¹² More plausible electron densities of $n_{10} = 0.1$ –100, as those estimated for the broad emission line clouds (BELCs) in AGNs (Blanford et al. 1991; Krolik et al. 1991; Ferland et al. 1992), would result in very highly ionized gas, which is inconsistent with our data. We then assume that $R \gg D$.

Reverberation mapping studies of the BELs in NGC 3516 (Wanders et al. 1993) have estimated a distance R_{BELC} of the BELCs from the source of ionizing continuum of $\sim 11 \text{ lt-days}$ ($\sim 3 \times 10^{16} \text{ cm}$), supporting the possibility that the gas obscuring the X-ray continuum of NGC 3516 in 1996 is associated with a BELC. At this distance, and assuming $n_{10}^{\text{BELC}} = 0.1$ –100, the ionization parameter measures $U(R_{\text{BELC}}) \sim 0.0003$ –0.03, and the gas is only mildly ionized and therefore compatible with the nature of the absorption seen in the X-ray band in 1996.

All this suggests that a BELC crossing our line of sight could have caused the obscuration of the X-ray primary source in 1996. As a consistency check we can calculate the time t_{cross} needed for a BELC to cross our line of sight. Assuming as transverse velocity v_{BELC} and the measured H β FWHM of 4000 km s^{-1} (Wanders et al. 1993), we obtain $t_{\text{cross}} = l/v \simeq 2500N_{\text{H}22\text{Cold}}n_{10}^{-1}v_{4000}^{-1}$ (where l is the linear size of the cloud). For the measured $N_{\text{H}}^{\text{Cold}}$, we have then $t_{\text{cross}} \sim 6000n_{10}^{-1} \text{ s}$. Since we know that t_{cross} must be longer than 20 hr (the duration of the 1996 observation) and shorter than ~ 4 months (the time elapsed between the two *BeppoSAX* observations), the above equation constrains the electron density of the gas to the range $6 \times 10^{-4} \text{ cm}^{-3} \lesssim n_{10} \lesssim 0.1$. We stress again that if the gas were mildly ionized (as is the case for the BELCs), then we would be underestimating the equivalent $N_{\text{H}}^{\text{Cold}}$ obtained by fitting the data with a neutral absorber model, and therefore the interval of densities given above would shift toward higher values. This range of densities contains the estimated BELC value. A much narrower interval could in principle be set using the time elapsed between the 1996 November observation and the last

¹² We note that this is one of the highest densities one may expect to find in the nuclear environment of a Seyfert 1, being of the order of the density of the matter in a standard Shakura-Sunyaev (1973) accretion disk around a black hole of 10^7 – $10^8 M_{\odot}$, accreting at 0.1–0.01 times the critical rate, and in proximity of the last stable orbit.

HST-FOS observation of GEA99, showing no Mg II resonant absorption nor extinction in the UV continuum in $\Delta t = 18$ days. This would give a lower limit on the density of $n_{10} \gtrsim 0.01$.

In the framework of the proposed scenario, a BELC crossing the line of sight, we estimated the probability of such an event based on an estimate of the filling factor of the BELCs. The total volume of a sphere with radius R_{BELC} is $V_{\text{tot}} \sim 8.2 \times 10^{49} \text{ cm}^3$. From the luminosity of the broad H β of NGC 3516, $L_{\text{H}\beta} \sim 2.3 \times 10^{40} \text{ ergs s}^{-1}$ (Rosenblatt et al. 1994), we can estimate the effective volume occupied by all the BELCs, given by $V_{\text{eff}} = L_{\text{H}\beta}/\alpha(T_e)n_e^2$. For an electronic temperature T_e of $\sim 10^4 \text{ K}$ at the energy of the H β emission line, the recombination coefficient $\alpha(T_e)$ is $\sim 3.4 \times 10^{-25} \text{ ergs cm}^3 \text{ s}^{-1}$ (Osterbrock 1989) and $n_e \sim 10^{10} \text{ cm}^{-3}$ (Blanford et al. 1991). We then obtain $V_{\text{eff}} \sim 6.7 \times 10^{44} \text{ cm}^3$. The probability for a cloud to find itself along a particular line of sight at any radius is then given by $P \sim V_{\text{eff}}/V_{\text{tot}} \sim 8.1 \times 10^{-6}$. This low probability supports the picture of an event that occurs very rarely, as indeed observed in AGN (Krupe et al. 1990).

4.1.2. A Variable State Absorber?

Another intriguing possibility is that the ionization state of the absorber varied between the two *BeppoSAX* observations, becoming more ionized and therefore transparent to the soft X-ray radiation. In this scenario we may speculate that the “warm” absorber seen in the 1997 March spectrum of NGC 3516 is the same gas that was obscuring the line of sight 4 months earlier but with a very different ionization degree. The same picture was drawn for this source by MWA97, who proposed a model for a variable warm absorber in NGC 3516 to reconcile the UV and the X-ray spectra within a unique scenario (see also § 4.2). In the MWA97 model the presence and subsequent disappearance of a broad C IV absorption component at 1549 Å was consistent with a variable state X-ray absorber, from mildly ionized during the 1989 *Ginga* observation to highly ionized in subsequent *ROSAT*-PSPC and *ASCA* observations.

In the framework of the scenario above described, we derived some dynamical properties of this variable state absorber. At a given ionizing flux the ionization degree of a photoionized absorber can vary because of variations of the distance of the gas from the ionizing source or of the electron density in the gas (or both). In the first of these two extreme hypotheses we assume that the absorber has a constant density in the range $n_{10} = 10^{-4}$ to 10^{-1} (typical of warm absorbers in Seyfert 1 galaxies (MWA97; Nicastro et al. 1999, 2000). The gas is almost neutral during the 1996 November observation, which gives an upper limit on its ionization parameter of $U \lesssim 0.01$; above this value, and for the ionizing continuum shape of NGC 3516, the opacity of the gas at low X-ray energies drops drastically. This gives a range of possible distances from the central source of $R \gtrsim 2 \times 10^{17} - 5 \times 10^{18} \text{ cm}$ (the larger the density the smaller the lower limit on R). If the gas were moving toward the central source with a radial velocity v_{rad} , keeping its density constant, it should have required less than $t \lesssim 4$ months to cover the distance $\Delta R = R/10$ needed for its ionization parameter to increase by a factor of ~ 100 (to reach the values observed during the 1997 November observation). The estimated radial velocity of the gas is thus $v_{\text{rad}} \sim \Delta R/t \gtrsim 0.06c$. This limit would become even higher if the cloud became denser while collapsing toward the central

source. We note that the most direct implication of this extreme hypothesis is that UV and high-resolution X-ray spectra of Seyfert 1 galaxies, during such relatively short events, should show highly redshifted resonant-absorption lines with varying strength. Such phenomenon have never been observed so far.

Alternatively, the change in the ionization state of the absorber might be a result of a change in density (as in MWA97). To change from an almost neutral state ($U \lesssim 0.01$) to a warm state ($U \sim 5.37$) would require a drop in density ($U \propto n_H^{-1}$) by a factor of $\gtrsim 500$. For example, the density of a BELC would have to change from a few times 10^{10} cm^{-3} to about $2 \times 10^7 \text{ cm}^{-3}$. A column density of 10^{22} cm^{-2} and a density of 10^{10} cm^{-3} imply a thickness of 10^{12} cm for the cold absorber. Similarly, the thickness of the warm cloud would be about $5 \times 10^{14} \text{ cm}$. Such an expansion has to occur on a timescale of $\lesssim 4$ months. If the cloud is expanding adiabatically, its velocity dispersion would then have to be about 500 km s^{-1} . Such a velocity dispersion is observed in associated absorption lines in AGN, so the derived value is completely reasonable. We conclude that a scenario based on a variable state absorber is plausible (see § 4.3 for further details). Unfortunately, no other X-ray observation was performed between the two *BeppoSAX* pointings to further constrain the variability timescale in the soft X-ray energy band.

Both cases discussed above were based on the assumption of no changes of the intensity of the photoionizing continuum. Variations of the ionizing flux could have contributed to the observed changes of the ionization degree of the gas. If, between the two observations, the continuum increased by a factor of ~ 100 and then recovered the level measured during the 1997 observation, then the gas could have been almost instantaneously ionized by this dramatic event but not yet had enough time to recombine to its equilibrium neutral state. Alternatively, the flux level seen during the 1996 observation could have been preceded by a long-duration event of very low intensity that caused the gas to recombine to an almost neutral state. The gas during the 1996 observation would then be underionized with respect to the observed ionizing continuum level. Both cases would require low electron densities of the absorber ($n_e \lesssim 10^5 \text{ cm}^{-3}$; see Nicastro et al. 1999 for details).

4.2. A Hot Ionized Absorber/Emitter Gas?

Two apparently unrelated spectral features are clearly visible in the N96 spectrum of NGC 3516: (1) soft emission (with a hump at $\sim 1 \text{ keV}$) not obscured (or only partly obscured) by the amount of neutral gas covering the primary X-ray source and (2) the signature of heavy absorption by highly ionized gas at $\sim 8 \text{ keV}$. In our spectral analysis of N96 we modeled these two features as being due to two distinct components: a collisionally ionized emitting plasma and a photoionized absorber, respectively. Extended emission by the host galaxy surrounding the AGN has frequently been observed in Seyfert galaxies, e.g., Elvis et al. (1990), Wilson et al. (1992), and Weaver et al. (1995). However, in the particular case of NGC 3516 the extended component was probably unresolved by the *ROSAT*-HRI (Morse et al. 1995). Wilson et al. (1996) found that in their sample (which includes NGC 3516) the 0.1–2.5 keV intrinsic luminosity of the extended components ranges between 10^{40} and $10^{42} \text{ ergs s}^{-1}$. In the present data we measure $L_{0.1-2.5 \text{ keV}} = 5 \times 10^{42} \text{ ergs s}^{-1}$, a value only mar-

ginally consistent with the observed range, even allowing for intrinsic variability. Based on the correlations found between far infrared (FIR) and 2 keV luminosity of bright spiral galaxies (Fabbiano, Gioia, & Trinchieri 1988), we also compared the 2 keV luminosity $L_{2\text{ keV}} = 9 \times 10^{41} \text{ ergs s}^{-1} \text{ keV}^{-1}$ measured with the mean $L_{2\text{ keV}}$ value for the 11 objects of the Fabbiano et al. (1988) sample with $L_{\text{FIR}} = 10^{42.8-10^{43.2}} \text{ ergs s}^{-1}$. This range includes the value of $10^{43} \text{ ergs s}^{-1}$ obtained for NGC 3516 (Bonatto & Pastoriza 1997). We found $L_{2\text{ keV}}^{\text{Gal}} \simeq 10^{39-10^{40}} \text{ ergs s}^{-1}$, again much lower than measured in our data. We then conclude that the soft X-ray emission visible in 1996 cannot be due entirely to an extended component in the host galaxy.

An intriguing alternative is that both the $\sim 8 \text{ keV}$ absorption edges visible in N96 and M97 and the soft emission in N96 could be self-consistently accounted for by a unique photoionized absorber/emitter in the nuclear environment of NGC 3516. If photoionized, this gas has a temperature of $T \simeq 2 \times 10^6 \text{ K}$, and iron (the lightest abundant element not yet fully ionized) is smoothly distributed between Fe xvii and Fe xxvi. Because of the high temperature, the emissivity of this gas is large and contributes to the overall spectrum in an amount that depends linearly on its covering factor around the central source. In particular, a strong contribution by Fe xvii–xxiv L recombination lines is expected at $\sim 1 \text{ keV}$, where a clear emission feature is present in the N96 spectrum. Models for photoionized gas accounting for gas emission, other than photoelectric and resonant absorption, can then be used to constrain the geometrical configuration of the observed absorber/emitter.

In the following discussion we try to test this hypothesis quantitatively. The basic assumptions of this hypothesis are that (1) the neutral absorber in 1996 covered almost entirely ($C_{\text{sou}} > 95\%$, as from the fit with the CIP component; see § 3.2.1) the nuclear source of primary X-rays but left uncovered a much larger fraction ($1 - C_{\text{env}}$) of the extended nuclear environment (i.e., the warm and hot scattering media), which is seen through scattering of the primary continuum; (2) during the 1997 observation both the primary nuclear continuum and the reprocessed components are seen directly; (3) no other component can significantly contribute to the line emission.

We proceeded to build (following Nicastro et al. 2000) two series of photoionization models, which include gas emission and resonant absorption, for the two ionized absorbers observed in NGC 3516. We used column densities and ionization parameters as measured fitting the N96 and M97 spectra with models accounting for photoelectric absorption only (Table 2). We built these models for a number of values of the covering factors f_{warm} and f_{hot} as seen by the central source, varying from 0 to 1, and for particular values of outflowing (v_{out}) and microturbulence (σ) velocities of the absorbers/emitters. In particular, we used $v_{\text{warm}}^{\text{out}} = 500 \text{ km s}^{-1}$, $\sigma_{\text{warm}} = 1100 \text{ km s}^{-1}$ (observed in the UV for the broad C iv system of NGC 3516; Kolman et al. 1993), and $v_{\text{hot}}^{\text{out}} = 500 \text{ km s}^{-1}$ and $\sigma_{\text{hot}} = 200 \text{ km s}^{-1}$. For the hot absorber, the adopted ratio $v_{\text{hot}}^{\text{out}}/\sigma_{\text{hot}}$ maximizes the contribution of line emission compared to resonant absorption (Nicastro et al. 2000). The particular choice of the absolute values of v and σ separately, however, is not critical. The warm component was not included in the models for the N96 spectrum, since we did not see it in the data (which can be either because the component was not present or because it was completely obscured by the amount of

almost neutral gas covering the line of sight during that observation). We also neglected the emission contribution from this gas. However, given the temperature and ionization degree measured in 1997 (in the photoionization hypothesis), emission of the warm component is expected to be very weak and should influence mostly the 0.5–0.6 keV portion of the spectra where weak O vii and O viii emission lines are expected. This contribution would hardly be detectable with *BeppoSAX* (Nicastro et al. 2000). The hot component instead has been included in both models. We held f_{hot} constant between the two observations. For the cold absorber in 1996, we used the best-fit column density and C_{sou} from Table 2.

We did not fit these models directly to the N96 and M97 spectra but proceeded as follows: We varied the values of the three parameters f_{hot} , f_{warm} , and C_{env} to let (1) the 0.1–2 keV flux predicted by models for N96 match the best-fitting 96BF 0.1–2 keV flux and (2) the 0.1–10 keV ratio between N96 and M97 models match the observed raw data ratio N96/M97. In this particular scenario we could put relatively strong constraints on the covering factors f_{hot} and C_{env} but not on f_{warm} , which we then fixed to the value of 0.5. We found that f_{hot} and C_{env} lie in the ranges 0.3–0.4 and 0.15–0.25, respectively. Figures 4 and 5 show two models for the N96 and M97 spectra of NGC 3516 (Figs. 4a and 4b, upper and bottom panels, respectively) and their ratio (Fig. 5) in the energy band 0.1–10 keV for $f_{\text{hot}} = 0.35$ and $C_{\text{env}} = 0.2$. The ratio between the raw 0.1–10 keV N96 and M97 data is also plotted in Figure 5c. The agreement between the models and the data is quite good. In particular, we note that the 1 keV emission feature present in the data is well reproduced by Fe L emission of the hot photoionized components, which was much more visible in 1996 because of the heavy obscuration of the primary X-rays by the cold absorber. We then conclude that a highly ionized component is present in the nuclear environment of NGC 3516 and that its emission is visible only when our view of the primary X-rays is at least partially covered by a large amount of neutral absorber.

This component could well be present in all Seyfert galaxies but has eluded detection so far. If this component is spherically distributed around the central source and if the

FIG. 4.—96BF model with no CIP component (upper panel) and 97BF model (lower panel). Photoionization models include gas emission and resonant absorption other than photoelectric absorption (see text for details).

FIG. 5.—Ratios between the two models in the upper and lower panels and the raw 0.1–10 keV N96 and M97 spectra.

covering factor f_{hot} and column density $N_{\text{H}}^{\text{hot}}$ measured in NGC 3516 are representative of the entire class, then we would expect that absorption K edges due to highly ionized iron should be observed in almost 30%–40% of all known Seyfert galaxies. Furthermore, in all heavily obscured sources (i.e., Seyfert 2 galaxies or objects with transient absorption, like NGC 3516) we should detect emission by this hot gas at energies below 1–2 keV. Soft X-ray emission indeed is observed frequently in many bright and well-studied Seyfert 2 galaxies (Turner et al. 1997; Comastri et al. 1998). High-resolution spectrometry, like that available with *Chandra* and/or *XMM*, will test this speculation unambiguously by allowing the detection of narrow emission and/or absorption lines even in objects with a low degree of nuclear obscuration with high accuracy, as already studied in NGC 5548 and NGC 3783 (Kaastra et al. 2000; Kaspi et al. 2000).

4.3. The Complex X-Ray/UV Connection

Following MWA97, we investigate whether the X-ray absorbers in NGC3516 will produce any associated UV absorption lines. If the cold absorber is mildly ionized, the maximum degree of ionization would be $U \sim 0.01$; as seen in § 4.1.2, a higher value, with the ionizing continuum shape of NGC 3516, would imply a drastic drop of opacity of the gas at low X-ray energies. In such an absorber the dominant ions would be O I–III, Mg II–III, and C II–IV. For a total column density of a few times 10^{22} cm^{-2} , the predicted column densities of Mg II and C IV are 2.5×10^{17} and $4.7 \times 10^{17} \text{ cm}^{-2}$, respectively. For the warm absorber, the C IV column density would be 5.4×10^{14} , but Mg is too highly ionized to have observable Mg II. For the cold absorber, the Mg II and C IV column densities are very large, and even for a velocity dispersion parameter, b , of 100 km s^{-1} , the resonance absorption lines would have large equivalent widths ($\text{EW} \gtrsim 3 \text{ \AA}$).

In the warm phase the C IV column density is less than that in the cold absorber. However, the predicted EW of the C IV $\lambda 1549$ absorption line would still be detectable ($\text{EW} \gtrsim 1.0 \text{ \AA}$ for $b = 100 \text{ km s}^{-1}$). The absorption line EWs would be even larger for a larger b . Therefore, for reasonable

parameters, the X-ray absorbers in NGC 3516 will contribute to the absorption in the UV. How broad the lines would be will again depend on the b parameter. The UV observations closest in time to our X-ray observations ($\Delta t = 18$ days) are presented by GEA99 (§ 4.1). With the *HST*-FOS intrinsic Mg II absorption was not detected. This constrains the cold X-ray absorber (if still along the line of sight during the UV observation) to be almost completely neutral. GEA99 found C IV $\lambda\lambda 1549, 1551$ absorption doublets with FWHM $651 \pm 16 \text{ km s}^{-1}$ and $405 \pm 9 \text{ km s}^{-1}$, respectively, and EWs $2.87 \pm 0.09 \text{ \AA}$ and $1.47 \pm 0.04 \text{ \AA}$, respectively. The lines are not resolved with the FOS and are likely to be saturated. GEA99 quote a C IV column density in the range between 6.3×10^{14} and 10^{15} cm^{-2} , very similar to our predicted value for the warm absorber. Earlier observations with GHRS have resolved the C IV absorption line into four distinct components, two of which are from the host galaxy of NGC 3516. The two nuclear components have column densities consistent with the GEA99 values. We conclude that the nuclear C IV absorption line (possibly component 1 of Crenshaw et al. 1998) is likely to arise in the warm absorber observed by *BeppoSAX*. At the least the warm absorber makes a substantial contribution to the absorption seen in the UV (based on C IV strength). The hot X-ray absorber is too ionized to contribute to the UV absorption lines, since carbon, oxygen, and magnesium are fully ionized.

X-ray and UV observations show that the system of X-ray absorbers in NGC 3516 is clearly complex and highly structured with multiple ionization stages just as in the UV absorption lines (§ 1). This complexity is enhanced by variability on many different timescales, from days to years. It is possible that on the very short timescales of a day the variability of absorption is governed by the photoionization-recombination timescales, while on the longer timescales from months to years the dynamical time may play the dominant role, via either bulk motion or adiabatic expansion. It is conceivable that the different ionization stages trace different phases in the evolution of an absorber. A neutral absorber may expand as it outflows, become a warm absorber, and eventually become hot and later completely transparent in the X-rays, or the “components” may be part of a quasi-static structure in an outflowing wind (Murray & Chiang 1995; Elvis 2000). Again high-resolution *Chandra* and *XMM* observations of this source will be crucial to disentangle the many X-ray components and clearly establish (or reject) a link with the UV components.

5. CONCLUSIONS

We presented two *BeppoSAX* observations of NGC 3516, performed in 1996 November and 1997 March.

Our main findings are the following:

1. The source underwent strong spectral variability between the two *BeppoSAX* observations, taken 4 months apart, entirely because of the drastically different degree of obscuration of the central source. During the first observation the nuclear X-ray continuum was absorbed by an equivalent column of cold hydrogen of $2.3 \times 10^{22} \text{ cm}^{-2}$, while in 1997 November the absorption was fully compatible with that from our Galaxy. This is the first time that such a change in the degree of obscuration of a Seyfert 1 has been clearly observed. We investigated several possibilities and propose as possible explanations either a BELC crossing the line of sight or a varying-state absorber.

2. We discovered the presence of a very highly ionized absorber/emitter in the nuclear environment of NGC 3516. This gas is visible in absorption (and with a stable physical state) in both *BeppoSAX* observations. Thanks to the large fraction of primary X-rays absorbed by neutral gas in 1996, we also were able to detect emission from this gas and to give an estimate of its covering factor $f_{\text{hot}} = 0.3\text{--}0.4$.

We acknowledge partial support of the Italian Space Agency under contracts ASI-ARS 98-119 and ASI-ARS 99-15, of the Italian Ministry for University and Research (MURST) under grant Cofin 98-02-32, and CXC contract NAS 8-39073. E. C. is supported by the NASA grant NAG 5-3545. S. M. acknowledges NASA grant NAG 5-3249 LTSA. F. N. acknowledges NASA grant NAG 5-9216.

REFERENCES

- Avni, Y. 1976, *ApJ*, 210, 642
 Blanford, R. D., Netzer, H., Woltjer, L., O'Brien, P. 1991, *Observatory*, 111, 328
 Boella, G., Butler, R. C., Perola, G. C., Piro, L., Scarsi, L., & Bleeker, J. A. M. 1997a, *A&AS*, 122, 299
 Boella, G., et al. 1997b, *A&AS*, 122, 327
 Bonatto, C. J. & Pastoriza, M. G. 1997, *ApJ*, 486, 132
 Comastri, A., Vignali, C., Cappi, M., Matt, G., Audano, R., Awaki, H., & Ueno, S. 1998, *MNRAS*, 295, 443
 Crenshaw, D. M., Moran, S. P., & Mushotzky, R. F. 1998, *ApJ*, 496, 797
 Dickey, J. M., & Lockmann, F. J. 1990, *ARA&A*, 28, 215
 Done, C., & Zycki, P. T. 1999, *MNRAS*, 305, 457
 Elvis, M. 2000, *NewA Rev.*, in press (astro-ph/0005161)
 Elvis, M., Fassnacht, C., Wilson, A. S., & Briel, U. G. 1990, *ApJ*, 361, 459
 Fabbiano, G., Gioia, I. M., & Trinchieri, G. 1988, *ApJ*, 324, 749
 Fabian, A. C., Rees, M. J., Stella, L., & White, N. E. 1989, *MNRAS*, 238, 729
 Ferland, G. J., Peterson, B. M., Horne, K., Welsh, W. F., & Nahar, S. N. 1992, *ApJ*, 387, 95
 Fiore, F., Guainazzi, M., & Grandi, P. 1999, *SAXabc*, Version 1.2, Cookbook for *BeppoSAX* NFI Spectral Analysis (*BeppoSAX Sci. Data Cont.*)
 Frontera, F., Costa, E., dal Fiume, D., Feroci, M., Nicastro, F., Orlandini, M., Palazzi, E., & Zavatinni, G. 1997, *A&AS*, 122, 357
 George, I. M., Turner, T. J., Netzer, H., Nandra, K., Mushotzky, R. F., & Yaqoob, T. 1998, *ApJS*, 114, 73
 Goad, M. R., Koratkar, A. P., Kim-Quirano, J., Korista, K. T., O'Brien, P. T., & Axon, D. J. 1999, *ApJ*, 524, 707 (GEA99)
 Ghosh, K. K., & Soundararajaperumal, S. 1991, *ApJ*, 383, 574
 Gorenstein, P. 1975, *ApJ*, 198, 95
 Grevesse, N., & Anders, E. 1989, in *AIP Conf. Proc.* 183, *Cosmic Abundances of Matter*, ed. C. J. Waddington (New York: AIP), 1
 Grevesse, N., & Noels, A. 1993, in *Origin and Evolution of Elements*, ed. N. Prantzos, E. Vangioni-Flam, & M. Casse (Cambridge: Cambridge Univ. Press), 15
 Kaastra, J. S., Mewe, R., Liedahl, D. A., Komossa, S., & Brinkman, A. C. 2000, *A&A*, 354, L83
 Kaspi, S., Brandt, W. N., Netzer, H., Sambruna, R., Chartas, G., Garmire, G. P., & Nousek, J. A. 2000, *ApJ*, 535, L17
 Kolman, M., Halpern, J. P., Martin, C., Awaki, H., & Koyama, K. 1993, *ApJ*, 403, 592
 Koratkar, A., et al. 1996, *ApJ*, 470, 378
 Kriss, G. A., Espey, J. H., Krolik, J. H., Tsvetanov, Z., Zheng, W., & Davidsen, A. F. 1996a, *ApJ*, 467, 622
 Kriss, G. A., Krolik, J. H., Otani, C., Espey, J. H. 1996b, *ApJ*, 467, 629
 Krolik, J. H., Horne, K., Kallman, T. R., Malkan, M. A., Edelson, R. A., & Kriss, G. A. 1991, *ApJ*, 371, 541
 Kruper, J. S., Urry, C. M., & Canizares, C. R. 1990, *ApJS*, 74, 347
 Magdziarz, P., & Zdziarski, A. A. 1995, *MNRAS*, 273, 837
 Mathur, S., Wilkes, B., & Aldcroft, T. 1997, *ApJ*, 478, 182 (MWA97)
 Mewe, R., Gronenschild, E. H. B. M., & van den Oord, G. H. J. 1985, *A&AS*, 62, 197
 Morse, J. A., Wilson, A. S., Elvis, M., & Weaver, K. A. 1995, *ApJ*, 439, 121
 Murray, N., & Chiang, J. 1995, *ApJ*, 454, L105
 Mushotzky, R. F., Done, C., & Pounds, K. A. 1993, *ARA&A*, 31, 717
 Nandra, K., George, I. M., Mushotzky, R. F., Turner, T. J., & Yaqoob, T. 1997a, *ApJ*, 476, 70
 ———. 1999, *ApJ*, 523, L17
 Nandra, K., Mushotzky, R. F., Yaqoob, T., George, I. M., & Turner, T. J. 1997b, *MNRAS*, 284, L7
 Nicastro, F., et al. 2000, *ApJ*, 536, 718
 Nicastro, F., Fiore, F., & Matt, G. 1999, *ApJ*, 517, 108
 Nicastro, F., Fiore, F., Perola, C., & Elvis, M. 1999, *ApJ*, 512, 184
 Osterbrock, D. 1989, *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei* (Mill Valley: University Science Books)
 Parmar, A. N., et al. 1997, *A&AS*, 122, 309
 Reynolds, C. S. 1997, *MNRAS*, 286, 513
 Rosenblatt, E. I., Malkan, M. A., Sargent, W. L. W., & Readhead, A. C. S. 1994, *ApJS*, 93, 73
 Ross, R. R., Fabian, A. C., & Brandt, W. N. 1996, *MNRAS*, 278, 1082
 Shakura, N. I., & Sunyaev, R. A. 1973, *A&A*, 24, 337
 Stirpe, M. G., Wilkes, B. J., Comastri, A., Mathur, S., & O'Brien, P. T. 1998, *The Active X-Ray Sky: Results from BeppoSAX and RXTE*, ed. L. Scarsi, H. Bradt, P. Giommi, & F. Fiore (Nucl. Phys. B Suppl. No. 69), 505
 Siemiginowska, A., & Fruscione, A. 2000, *Chandra Newsletters*, 7
 Turner, T. J., George, I. M., Nandra, K., & Mushotzky, R. F. 1997, *ApJS*, 113, 23
 Ulrich, M. H., & Boisson, C. 1983, *ApJ*, 267, 515
 Voit, G. M., Shull, J. M., & Begelman, M. C. 1987, *ApJ*, 316, 573
 Walter, R., Ulrich, M. H., Courvoiser, T. J. L., & Buson, L. M. 1990, *A&A*, 233, 53
 Wanders, I., et al. 1993, *A&A*, 269, 39
 Weaver, K. A., Mushotzky, R. F., Serlemitsos, P. J., Wilson, A. S., Elvis, M., & Briel, U. G. 1995, *ApJ*, 442, 597
 Wilson, A. S., Elvis, M., Lawrence, A., & Bland-Hawthorn, J. 1992, *ApJ*, 391, L75
 Wilson, A. S., Morse, J. A., Elvis, M., Mulchaey, J. S., Weaver, K. A., Cecil, G. N., & Gallimore, J. 1996, in *Proc. Röntgenstrahlung from the Universe*, ed. H. U. Zimmermann, J. Trümper, & H. Yorke (MPE Rep. 263; Garching: MPE), 529