Resolving the C IV and Mg II Absorption in NGC 4151

Gerard A. Kriss

Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, MD 21218

Abstract. Observations of the C iv and Mg ii absorption lines in the Seyfert 1 galaxy NGC 4151 obtained with the GHRS in October 1994 are presented. The data from the STScI archive show multiple broad and narrow components in both species. In addition to Galactic absorption, four narrow and four broad systems associated with NGC 4151 are identified. Two broad systems dominate the total equivalent width, and their mean blueshift and width are comparable to the broad Lyman line and continuum absorption seen in far-UV spectra from the Hopkins Ultraviolet Telescope. Narrow-line C iv emission is present on the red side of the broadest absorption trough, and narrow absorption at the systemic velocity of NGC 4151, presumably in its own ISM, absorbs the core of the narrow emission line. Strong Mg ii absorption is present in all but two velocity systems. Ratios relative to the corresponding C iv components suggest a low ionization parameter for the absorbing gas: $U \sim 1 - 3 \times 10^{-3}$. This makes none of the identified UV absorption systems a good candidate for association with the warm X-ray absorbing gas.

1. UV and X-ray Absorption in NGC 4151

A persistent problem in understanding the absorbing material in NGC 4151 has been reconciling the vastly different gas columns inferred for the X-ray absorption and for the UV absorption. The X-ray absorbing column varies between $10^{22}$ and $10^{23}$ cm$^{-2}$. Bromage et al. (1985) estimated a total column for the UV-absorbing material of no more than $\sim 10^{21}$ cm$^{-2}$. The neutral hydrogen column is variable (Kriss et al. 1995). The bulk of the absorption is in low column density gas with $N_H \sim 10^{18}$ cm$^{-2}$ and Doppler parameter $b \sim 300$ km s$^{-1}$. Any low-b component has a neutral column no greater than $5 \times 10^{20}$ cm$^{-2}$.

One possibility for reconciling these differences has been the recent success of warm absorber models for characterizing the X-ray absorption and the associated UV absorption lines in 3C 351 and NGC 5548 (Mathur et al. 1994; Mathur et al. 1995). In such models the absorption arises in gas photoionized by the central engine (e.g., Netzer 1993; Krolik & Kriss 1995). The X-ray absorption is dominated by highly ionized species of heavy ions (e.g., O vii and O viii). The total gas columns can be quite high ($10^{22} - 10^{23}$ cm$^{-2}$), with relatively low columns in the lower ionization species responsible for the UV absorption. Warm absorber models with a reflection component can fit the X-ray spectrum of NGC 4151 (Weaver et al. 1994a,b). Kriss et al. (1995) find that...
Figure 1. The C\textsc{iv} profile observed with the GHRS is shown as a gray line. The smooth solid line is the best fit to the modeled emission and absorption profile. The smooth dotted line shows the intrinsic shape of the modeled broad emission plus continuum; another dotted line shows the intrinsic profile of narrow-line emission on the red side of the absorption trough. Eight C\textsc{iv} absorption doublets are indicated as well as absorption by Si\textsc{ii} and Galactic C\textsc{i}.

Similar models can also account for the high ionization lines in NGC 4151 (e.g., O\textsc{vi}, N\textsc{v}, and C\textsc{iv}), but they cannot simultaneously match the particularly strong absorption in lower ionization species such as H\textsc{i}, C\textsc{iii}, and Si\textsc{iv}. They conclude that a single-zone warm absorber is insufficient. To search for absorption components that might possibly be identified with the X-ray absorbing gas, I examined archival high resolution GHRS spectra of the C\textsc{iv} and Mg\textsc{ii} line profiles in NGC 4151.

2. Observations and Analysis

Fig. 1 shows the spectrum of NGC 4151 in the C\textsc{iv} region with 14 km s\textsuperscript{-1} resolution obtained in 8486 s using grating G160M of the GHRS on 28 October 1994. A model consisting of an underlying power law continuum, three broad Gaussian emission lines, and 8 C\textsc{iv} absorption line doublets fits the data well and gives $\chi^2 = 1998$ for 1800 points and 50 free parameters. Although the deepest and broadest C\textsc{iv} doublet is saturated, the bottom of the line profile is not black. Either this gas only partially covers the source (at the 90\% level, both continuum and broad line), or 10\% of the continuum flux is scattered around the absorbing region back into our line of sight. Narrow-line emission is visible on the red side of the C\textsc{iv} absorption trough. This emission is apparently unabsorbed by the broad absorbing gas; a final layer of absorbing gas, however, lying at the systemic velocity of NGC 4151, absorbs the core of the narrow-line profile. This is presumably the ISM or halo of NGC 4151.

The spectrum of the Mg\textsc{ii} region at 10 km s\textsuperscript{-1} resolution obtained in a 1414 s integration with grating G270M of the GHRS on 29 October 1994 is shown in Fig. 2. The best fit to the modeled emission and absorption profile gives $\chi^2 = 1636$ for 1438 points and 22 free parameters. As with C\textsc{iv}, the Mg\textsc{ii}
emission was modeled with 3 Gaussians. Seven Mg II absorption doublets are required. Table 1 gives the velocities, equivalent widths, Doppler parameters, and column densities of each of the absorption components fit in the C IV and the Mg II spectra.

### Table 1. Absorption Line Components in NGC 4151

|    | C IV          | Mg II         |
|----|---------------|---------------|
| #  | $cz_\odot$ (km s$^{-1}$) | EW (Å) | $b$ (km s$^{-1}$) | $N_{CIV}$ (cm$^{-2}$) | $cz_\odot$ (km s$^{-1}$) | EW (Å) | $b$ (km s$^{-1}$) | $N_{MgII}$ (cm$^{-2}$) |
| 1  | -2561         | 0.514         | 294           | $1.4 \times 10^{14}$ | ...     | ...     | ...     | ...     |
| 2  | -567          | 0.120         | 20            | $4.0 \times 10^{13}$ | -577    | 0.143   | 13       | $4.6 \times 10^{12}$ |
| 3  | -128          | 0.642         | 203           | $1.8 \times 10^{14}$ | ...     | ...     | ...     | ...     |
| 4  | -4            | 0.310         | 43            | $1.1 \times 10^{14}$ | -19     | 1.259   | 34       | $4.1 \times 10^{14}$ |
| 5  | 162           | 0.083         | 19            | $2.5 \times 10^{13}$ | 154     | 0.052   | 6        | $1.5 \times 10^{12}$ |
| 6  | 187           | 1.026         | 163           | $3.4 \times 10^{14}$ | 276     | 1.116   | 235      | $2.9 \times 10^{13}$ |
| 7  | 671           | 4.018         | 234           | $5.3 \times 10^{15}$ | 685     | 0.852   | 176      | $2.3 \times 10^{13}$ |
| 8  | ...           | ...           | ...           | ...               | 799     | 0.329   | 33       | $1.0 \times 10^{13}$ |
| 9  | 1020          | 0.407         | 43            | $1.7 \times 10^{14}$ | 992     | 0.134   | 11       | $4.4 \times 10^{12}$ |

### 3. Photoionization Models of the Absorbing Gas

For the absorption components intrinsic to NGC 4151, I assume that the gas is photoionized by the active nucleus. Computing photoionization models similar to those discussed by Krolik & Kriss (1995) and Kriss et al. (1996), I search for ionization parameters and total column densities that match the Mg II and C IV columns seen in the data. Table 2 summarizes the column density ratios of...
each of the absorption components and the matching ionization parameters and total column densities. The velocities are now relative to the systemic velocity of NGC 4151 (993 km s$^{-1}$, Mundell et al. 1995).

Table 2. Photoionization Models of the Components

| # | $\Delta v$ (km s$^{-1}$) | $N_{\text{MgII}}/N_{\text{CIV}}$ | log $U$ | log $N_{\text{total}}$ (cm$^{-3}$) |
|---|-----------------|-----------------|--------|-----------------|
| 1 | −3553           | < 0.02          | > −2.6 | ...             |
| 2 | −1559           | 0.12            | −2.9   | 18.3            |
| 3 | −1120           | < 0.02          | > −2.6 | ...             |
| 4 | −992            | 3.73            | Galactic | 20.3 |
| 5 | −830            | 0.060           | −2.7   | 18.1            |
| 6 | −805            | 0.085           | −2.8   | 18.2            |
| 7 | −321            | 0.004           | −2.1   | 19.9            |
| 8 | −193            | > 5.0           | < −3.4 | 17.0–18.0       |
| 9 | −1              | 0.026           | −2.6   | 18.6            |

Note that all the absorbing systems have fairly low ionization parameters. None of the systems in which Mg II absorption is visible is a good candidate for association with the warm X-ray absorbing gas, which typically has high ionization parameters $U \sim 1$ and high total column densities log $N_{\text{total}} \sim 23$ (Weaver et al. 1994a,b). While components 1 and 3 might be possible candidates, note that component 1 is visible only at this single epoch. It is absent from all other GHRS observations at both higher and lower flux levels (Weymann et al. 1997). Observations of higher ionization species such as Si IV or N V are required to set more stringent constraints on the ionization parameters and the total column densities of components 1 and 3.

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