Abstract. We discuss new high-resolution (6.7 km/s) spectra of the associated absorption lines (AALs) in the radio-loud quasar 3C 191. The measured AALs have ionizations ranging from Mg I to N V, and multi-component profiles that are blueshifted by ~400 to ~1400 km/s relative to the quasar’s broad emission lines. Excited-state absorption lines of Si II* and C II* imply volume densities of ~300 cm$^{-3}$ and a nominal distance from the quasar of 28 kpc (assuming photoionization). The total column density is $N_H \sim 2 \times 10^{20}$ cm$^{-2}$. Surprisingly, the absorber only partially covers the quasar emission source along our line of sight. We propose a model for the absorber in which pockets of dense neutral gas are surrounded by bigger clouds of generally lower density and higher ionization. This outflowing material might be leftover from a blowout associated with a nuclear starburst, the onset of quasar activity, or a past broad absorption line (BAL) wind phase.

1. Introduction

Associated absorption lines (AALs) are important diagnostics of the gaseous environments of quasars and active galactic nuclei (AGNs). In particular, the lines can trace a variety of phenomena — from energetic outflows like the BALs
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Figure 1. Part of the 3C 191 spectrum showing its strong associated absorption lines (labeled above). The flux has units $10^{-15}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$

to relatively quiescent gas at large galactic or inter-galactic distances (Weymann et al. 1979, Hamann & Brandt 2001). We are involved in a multi-wavelength program to locate individual AAL absorbers, determine their elemental abundances, quantify their kinematic and physical properties, and understand the role of the AGNs and/or host galaxies in providing the source of material and kinetic energy to the absorbing gas.

One interesting property is that, among radio-loud quasars, AALs appear more frequently and with greater strength in sources with “steep” radio spectra and/or lobe-dominated radio morphologies (Wills et al. 1995, Richards 2001, Brotherton et al. 1998). 3C 191 (Q0802+103, emission-line redshift $z_e = 1.956$) is a radio-loud quasar having both strong AALs and a bipolar, lobe-dominated radio structure. It provides a rare opportunity to define the distance between the quasar and the absorbing gas because its AALs include excited-state lines, e.g. C II $\lambda 1336$ and Si II $\lambda\lambda 1265,1533$, which constrain the volume density and therefore the quasar–absorber distance (assuming photoionization, Bahcall et al. 1967).

2. Observations and Results

We observed 3C 191 on three occasions between 1997 and 1998 using the High Resolution Echelle Spectrograph (HIRES) on the Keck I telescope on Mauna Kea, Hawaii. On each occasion, a 0.86'' slit provided spectral resolution $\lambda/\Delta \lambda \approx 45,000$ or 6.7 km s$^{-1}$, corresponding to 3 pixels on the $2048^2$ Tektronix CCD. We reduced the data with standard techniques using the MAKEE software package. The spectra cover the observed wavelengths 3850 – 5975 Å and 6474 – 8927 Å.
Figure 2. Velocity profiles of the AALs in 3C 191. Zero velocity corresponds to the nominal emission-line redshift, $z_e = 1.956$. Dotted vertical lines mark the positions of strong features.
Figure 3. See Figure 2.
The measured AALs have ionizations ranging from Mg I to N V, and multicomponent profiles that are blueshifted by ∼400 to ∼1400 km/s relative to the quasar’s broad emission lines (see Figures 1–3). These data yield the following new results. (1) The strengths of excited-state Si II∗ AALs indicate a density of ∼300 cm−3 in the Si+ gas. (2) If the gas is photoionized, this density implies a distance of ∼28 kpc from the quasar. Several arguments suggest that all of the lines form at approximately this distance, with a range of densities determining the range of ionizations. (3) Strong Mg I AALs identify neutral gas with very low ionization parameter and high density. We estimate \( n_H > 5 \times 10^4 \) cm−3 in this region, compared to only ∼15 cm−3 where the N V lines form. (4) The total column density is \( N_H < 4 \times 10^{18} \) cm−2 in the neutral gas and \( N_H \sim 2 \times 10^{20} \) cm−2 in the moderately ionized regions (up to Al III, Si IV, etc.). There may be larger column densities in more highly ionized gas, however, the total column of \( N_H \sim 2 \times 10^{20} \) cm−2 is consistent with 3C 191’s strong soft X-ray flux and the implied absence of soft X-ray absorption. (5) The total mass in the AAL outflow is \( M \sim 2 \times 10^9 \) M⊙, assuming a global covering factor (as viewed from the quasar) of ∼10%. (6) The absorbing gas only partially covers the background light source(s) along our line(s) of sight, requiring absorption in small clouds or filaments <0.01 pc across. The ratio \( N_H/n_H \) implies that the clouds have radial (line-of-sight) thicknesses <0.2 pc. (7) The characteristic flow time of the absorbing gas away from the quasar is ∼3 × 10⁷ yr.

3. Discussion

The physical connection between the quasar 3C 191 and its AALs is established by the excited-state lines (Si II∗). However, the absorber–quasar distance is very large, ∼28 kpc. Other quasar AALs are known to form much closer to the central engines, possibly within a few pc in outflows similar to the BALs (Hamann et al. 1997, Barlow & Sargent 1997, Barlow, Hamann & Sargent 1997). 3C 191 might contain a different class of absorber (e.g. much farther from the active nucleus) than the majority of AGNs discussed at this meeting. In particular, 3C 191 does not follow the trend identified by Brandt et al (2000) for small X-ray to UV continuum flux ratios (\( \alpha_{ox} \)) accompanying large C IV absorption equivalent widths. The outflowing material in 3C 191 might be leftover from a blowout associated with a nuclear starburst, the onset of quasar activity, or a past broad absorption line (BAL) wind phase. The flow time of ∼3 × 10⁷ yr might therefore represent the time elapsed since the formation of the quasar and/or an accompanying starburst episode.

We propose a model for the 3C 191 absorber (Figure 4) in which pockets of dense neutral gas (represented by Mg I λ2853) are surrounded by a diffuse, spatially extended medium of generally higher ionization (e.g. C IV and NV). The diffuse clouds contain most of the total column density; their greater size and/or greater numbers lead to more complete coverage in both velocity and projected area. More work is needed to characterize fully this class of distant AAL absorbers (see also Hamann & Brandt 2001, Barlow et al. 1997, Tripp et al. 1996, Morris et al. 1986), and understand its relationship (if any) to other absorption phenomena in quasars/AGNs.
Figure 4. Schematic representation of the AAL environment, showing pockets of dense neutral gas (filled black circles) surrounded by a less dense and more highly ionized medium (grey circles). The more extended regions lead to smoother AAL profiles and more complete line-of-sight coverage of the background light source.

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