

Variable Interstellar Absorption toward HD 219188

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Abstract

We discuss the results of continued optical/UV monitoring of the variable intermediate-velocity (IV) absorption toward the low halo star HD 219188. Comparisons between *HST*/STIS echelle spectra obtained in 2001, 2003, and 2004 and *HST*/GHRS echelle spectra obtained in 1994–1995 indicate the following:

(1) The IV absorption from the dominant species C II, O I, Si II, and Fe II appears to be essentially constant, within the uncertainties, in all four sets of spectra — suggesting that the total hydrogen column density and the (mild) depletions have not changed significantly over a period of nearly ten years.

(2) The IV column densities of the trace species C I (both ground and excited fine-structure states) and of the excited state C II* all increased by factors of 2–5 between 1995 and 2001 — similar to the increases seen for both Na I and Ca II. The changes in C I and C II* suggest that the local hydrogen density n_{H} increased by a factor ~ 2 (from about 25 cm^{-3} to about 60 cm^{-3} , for $T = 100 \text{ K}$) and that the electron density n_e may have increased by a factor of 3–4 over that 6-year period.

(3) The IV column densities of C I and C II* have remained roughly constant (or may have decreased slightly) between 2001 and 2004, however — suggestive of roughly constant n_{H} and n_e over that interval. The relatively low (and apparently constant) total $N(\text{H})$ and the modest n_{H} suggest that the IV cloud is not a dense knot or filament. In this case, the variations appear to be due to modest differences in density and/or ionization (and not total column density), over scales of tens of AU (compared to an estimated cloud thickness along the line of sight of order 1000 AU).

Introduction

It has become evident that some clearly interstellar absorption lines can vary in strength and/or velocity. For example, changes in the profiles of Na I and/or Ca II lines have been observed toward several stars in the direction of the Vela supernova remnant (Hobbs et al. 1991; Danks & Sembach 1995; Cha & Sembach 2000) — presumably due to cloud motions in that energetic environment. High $N(\text{Ca II})/N(\text{Na I})$ ratios suggest significant shock processing of the interstellar dust grains in some of those clouds. In several other cases, however, the narrow Na I line widths ($b \sim 0.3\text{--}0.5 \text{ km s}^{-1}$) and/or low $N(\text{Ca II})/N(\text{Na I})$ ratios characterizing the variable components suggest that the gas is relatively cool and quiescent (Blades et al. 1997; Price et al. 2000; Crawford et al. 2000; Lauroesch, Meyer, & Blades 2000; Welty & Fitzpatrick 2001; Lauroesch & Meyer 2003). If these differences are due to variations in overall hydrogen column density [assuming “typical” $N(\text{Na I})/N(\text{H})$ ratios], the high implied densities (generally several thousand cm^{-3}) are difficult to reconcile with clouds in thermal pressure equilibrium at typical interstellar pressures of order $3000 \text{ cm}^{-3} \text{ K}$. The differences may reflect a population of cold, dense filaments or sheets, embedded in warmer, less dense neutral gas and containing 10–30% of the total column density of cold, neutral gas (Heiles 1997). Alternatively, the differences in these trace ions might be due to small-scale variations in density and/or ionization (e.g., Lauroesch et al. 1998).

HD 219188 is an early B supergiant located about 2800 pc from the Sun at $(l, b) \sim (83^\circ, -50^\circ)$. Sometime between 1980.75 and 1997.77, strong, narrow Na I absorption appeared at $v_{\text{LSR}} \sim -38 \text{ km s}^{-1}$ toward HD 219188; that absorption continued to strengthen, by a factor 2–3, between 1997.77 and 2000.46 (Fig. 1; Welty & Fitzpatrick 2001). The line of sight appears to be moving into/through a relatively cold, quiescent intermediate-velocity (IV) cloud, due to the 13 mas/yr proper motion of HD 219188 (ESA 1997); the variations in Na I probe length scales of 2–38 AU/yr. The high resolution (FWHM $\sim 1.2\text{--}2.0 \text{ km s}^{-1}$) achieved for most of the spectra enabled measurement of the line width $b(\text{Na I}) \sim 0.55\text{--}0.60 \text{ km s}^{-1}$ — so T must be less than 490 K. UV spectra obtained with the *HST*/GHRS in 1994–1995 suggested $N(\text{H}_{\text{tot}}) \sim 5.6 \times 10^{17} \text{ cm}^{-2}$, “halo cloud” depletions of silicon and iron, $n_{\text{H}} \sim 25 \text{ cm}^{-3}$, and $n_e \sim 0.5\text{--}5.2 \text{ cm}^{-3}$ (if $T \sim 100 \text{ K}$) for the portion of the IV cloud sampled at that time. The relatively high fractional ionization, $n_e/n_{\text{H}} \gtrsim 0.02$, implies that hydrogen must be partially ionized. In this case, the $N(\text{Na I})/N(\text{H}_{\text{tot}})$ ratio is very high (Fig. 5), and the variations in Na I do not imply large local pressures or densities.

New Optical and UV Spectra of HD 219188

We have obtained additional optical and UV spectra of HD 219188, in order to monitor the continuing variations of the column densities and physical properties of the IV gas. The new optical spectra, obtained from ESO (2000.80; 3.6m/CES; FWHM $\sim 1.3 \text{ km s}^{-1}$), KPNO (2001.80; coude feed; FWHM $\sim 4 \text{ km s}^{-1}$), and APO (2002.79–2003.99; ARC echelle; FWHM $\sim 8 \text{ km s}^{-1}$), include lines from Na I and/or Ca II. The new UV spectra, obtained at three epochs with the *HST*/STIS echelle (2001.74, 2003.43, 2004.42; FWHM $\sim 2.3 \text{ km s}^{-1}$; central wavelengths 1271, 2363, and 2812 Å), include lines from C I (for estimating the pressure and density), C II* (for determining n_e), Si II [for estimating $N(\text{H})$], and Fe II (for gauging the depletions). The IV column densities for the various species were determined via detailed fits to the line profiles, using component structures derived from the highest resolution optical and UV spectra (e.g., Welty, Hobbs, & Morton 2001).

Table 1 lists the derived column densities, several ratios, and some physical properties inferred for the IV gas. Because the C II $\lambda 1334$ line is saturated, $N(\text{Si II})$ was used to estimate the column density of carbon (C I plus C II); the resulting values for $N(\text{C I}_{\text{tot}})$ and $N(\text{C II})$ are given in parentheses. The column densities listed for Na I and Ca II (in square braces) are for the observations closest in time to the UV observations. The hydrogen density is estimated from the C I fine-structure excitation, assuming $T = 100 \text{ K}$ (Fig. 4; Jenkins & Shaya 1979; Jenkins & Tripp 2001). The electron density n_e is estimated both under the (questionable!) assumption of photoionization equilibrium ($T = 100 \text{ K}$; WJ1 radiation field) and from the C II fine-structure excitation ($T = 100 \text{ K}$); the latter (and lower) value is adopted to estimate the fractional ionization n_e/n_{H} .

REFERENCES

- Albert, C. E. 1983, *ApJ*, 272, 509
 Blades, J. C., Sahu, M. S., He, L., Crawford, I. A., Barlow, M. J., & Diego, F. 1997, *ApJ*, 478, 648
 Cha, A., & Sembach, K. R. 2000, *ApJS*, 126, 399
 Crawford, I. A. 2003, *Ap&SS*, 285, 661
 Crawford, I. A., Howarth, I. D., Ryder, S. D., & Stathakis, R. A. 2000, *MNRAS*, 319, L1
 Danks, A. C., & Sembach, K. R. 1995, *AJ*, 109, 2627
 ESA 1997, *The Hipparcos and Tycho Catalogues* (ESA SP-1200) (Noordwijk: ESA)
 Heiles, C. 1997, *ApJ*, 481, 193
 Hobbs, L. M., Ferlet, R., Welty, D. E., & Wallerstein, G. 1991, *ApJ*, 378, 586
 Jenkins, E. B., & Shaya, E. J. 1979, *ApJ*, 231, 55
 Jenkins, E. B., & Tripp, T. M. 2001, *ApJS*, 137, 297
 Lauroesch, J. T., & Meyer, D. M. 1999, *ApJ*, 519, L181
 Lauroesch, J. T., & Meyer, D. M. 2003, *ApJ*, 591, L123
 Lauroesch, J. T., Meyer, D. M., & Blades, J. C. 2000, *ApJ*, 543, L43
 Lauroesch, J. T., Meyer, D. M., Watson, J. K., & Blades, J. C. 1998, *ApJ*, 507, L89
 Meyer, D. M., & Lauroesch, J. T. 1999, *ApJ*, 520, L103
 Price, R. J., Crawford, I. A., & Barlow, M. J. 2000, *MNRAS*, 312, L43
 Wakker, B. P., & Mathis, J. S. 2000, *ApJ*, 544, L107
 Welty, D. E., & Fitzpatrick, E. L. 2001, *ApJ*, 551, L175
 Welty, D. E., Hobbs, L. M., & Morton, D. C. 2003, *ApJS*, 147, 61

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Optical Spectra of Na I and Ca II

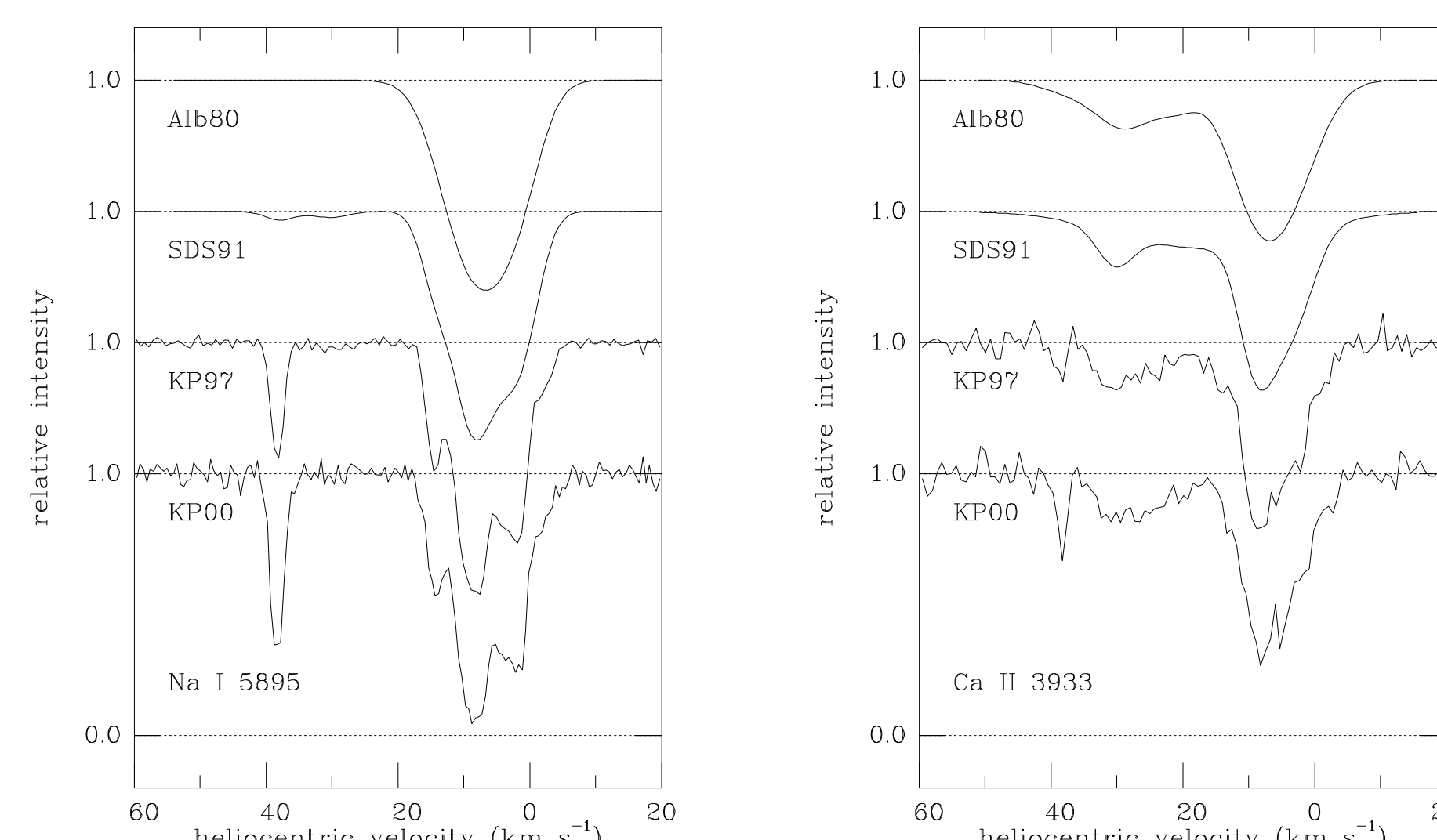


Figure 1. Selected Na I $\lambda 5895$ (left) and Ca II $\lambda 8500$ (right) spectra toward HD 219188 (Welty & Fitzpatrick 2001). The sources and dates of the spectra are indicated. The KPNO coude feed spectra were obtained at resolutions of 1.35–1.50 km s^{-1} ; the lower resolution spectra from Albert (1983; Alb80) and Sembach et al. (1993; SDS91) were generated from the component structures listed therein. The column densities in the intermediate-velocity component at $v \sim -38 \text{ km s}^{-1}$ increased by factors of 2–3 between 1995.82 and 2000.46; no Na I was detected at that velocity in 1980.

UV Spectra (GHRS, STIS)

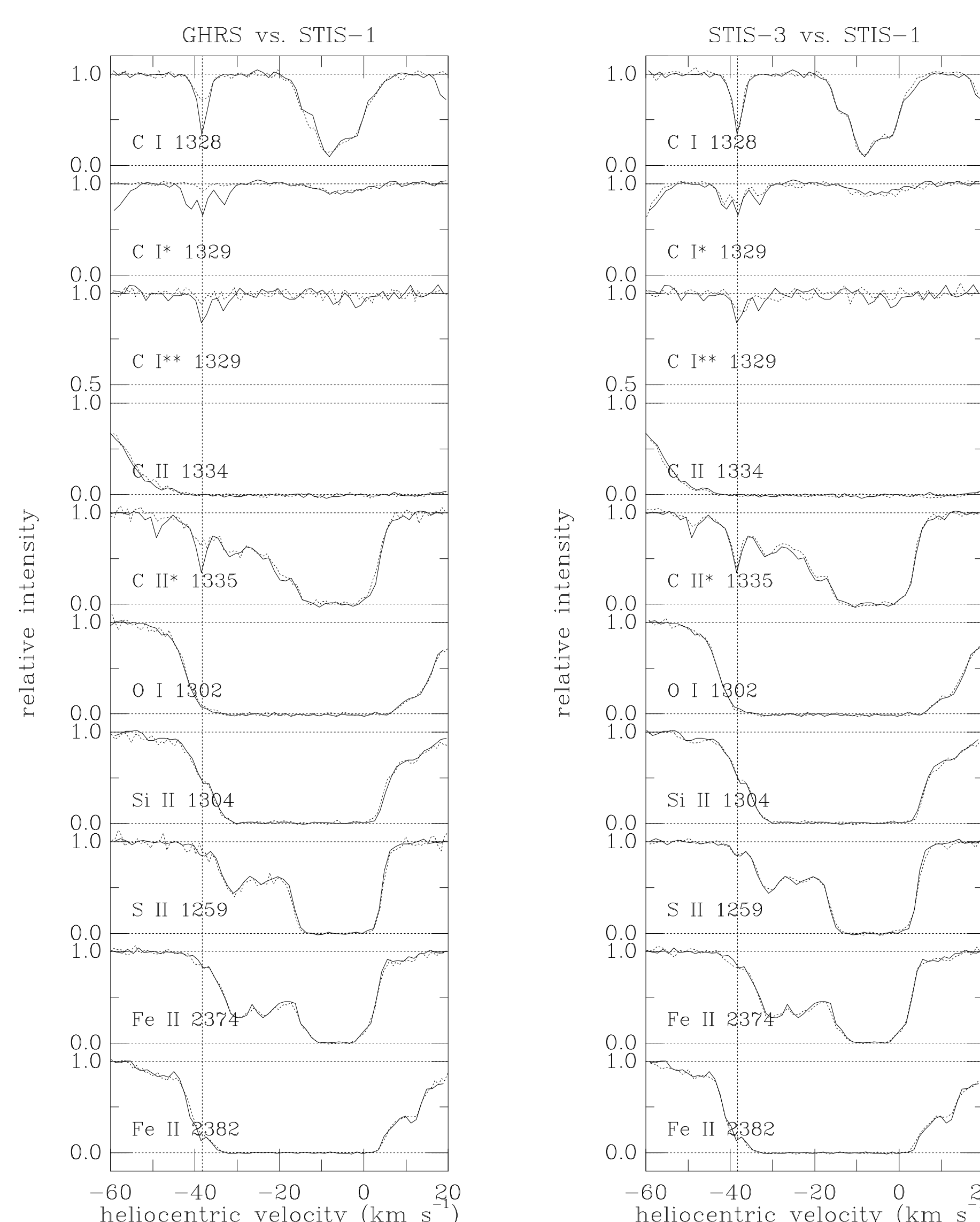


Figure 2. Profiles of selected UV lines toward HD 219188, observed with the *HST*/GHRS at resolutions of about 3.5 km s^{-1} and with the *HST*/STIS at resolutions of about 2.3 km s^{-1} . The vertical dotted line indicates the IV component at -38 km s^{-1} . The left panel compares the GHRS profiles (1994.43/1995.37; dotted lines) with the STIS-1 profiles (2001.74; solid lines). In several cases, lines observed with GHRS have been scaled in f_{λ} for comparison with the lines observed with STIS (C I $\lambda 1560$ multiplet, S II $\lambda 1253$, Fe II $\lambda 2600$). Note the clear increase in the strengths of the trace neutral species C I (both ground and excited states) and of the excited state C II*, while the strengths of the dominant species Si II, S II, and Fe II remained essentially constant. The right panel compares the STIS-3 profiles (2004.42; dashed lines) with the STIS-1 profiles (2001.74; solid lines). Both C I and C II* appear to have weakened slightly between STIS-1 and STIS-3, but the dominant species again appear to have remained essentially constant.

Column Densities and Inferred Properties

Table 1. HD 219188: -38 km s^{-1} Component

	GHRS 1994.43/1995.37	STIS-1 2001.74	STIS-2 2003.43	STIS-3 2004.42
$N(\text{C I}) (\text{cm}^{-2})$	$10.7 \pm 1.0 \text{e}12$	$24.6 \pm 2.9 \text{e}12$	$22.3 \pm 3.0 \text{e}12$	$20.2 \pm 2.6 \text{e}12$
$N(\text{C II}) (\text{cm}^{-2})$	$2.3 \pm 0.3 \text{e}12$	$11.9 \pm 0.7 \text{e}12$	$8.2 \pm 0.5 \text{e}12$	$7.8 \pm 0.5 \text{e}12$
$N(\text{C I}^*) (\text{cm}^{-2})$	$0.8 \pm 0.3 \text{e}12$	$2.8 \pm 0.3 \text{e}12$	$1.5 \pm 0.2 \text{e}12$	$1.8 \pm 0.3 \text{e}12$
$N(\text{C I}_{\text{tot}}) (\text{cm}^{-2})$	$13.8 \pm 1.1 \text{e}12$	$39.3 \pm 3.0 \text{e}12$	$32.0 \pm 3.0 \text{e}12$	$29.8 \pm 2.7 \text{e}12$
$N(\text{C II}) (\text{cm}^{-2})$	$(6.0 \pm 2.2 \text{e}13)$	$(3.7 \pm 1.1 \text{e}13)$	$(4.5 \pm 1.4 \text{e}13)$	$(4.5 \pm 1.2 \text{e}13)$
$N(\text{C II}^*) (\text{cm}^{-2})$	$0.4 \pm 0.1 \text{e}13$	$0.9 \pm 0.1 \text{e}13$	$0.8 \pm 0.1 \text{e}13$	$0.7 \pm 0.1 \text{e}13$
$N(\text{C I}_{\text{tot}}) (\text{cm}^{-2})$	$(6.4 \pm 2.2 \text{e}13)$	$(4.6 \pm 1.1 \text{e}13)$	$(5.3 \pm 1.4 \text{e}13)$	$(5.2 \pm 1.2 \text{e}13)$
$N(\text{O I}) (\text{cm}^{-2})$	$1.1 \pm 0.4 \text{e}14$	...	...	...
$N(\text{Na I}) (\text{cm}^{-2})$	...	$[3.4 \pm 0.4 \text{e}11]$	$[3.2 \pm 0.4 \text{e}11]$	$[2.9 \pm 0.3 \text{e}11]$
$N(\text{Mg I}) (\text{cm}^{-2})$	...	$9.6 \pm 1.5 \text{e}11$	...	...
$N(\text{Si II}) (\text{cm}^{-2})$	$9 \pm 1 \text{e}12$	$12 \pm 2 \text{e}12$	...	...
$N(\text{S II}) (\text{cm}^{-2})$	$8.7 \pm 2.5 \text{e}12$	$9.6 \pm 1.2 \text{e}12$	$9.5 \pm 1.6 \text{e}12$	$9.2 \pm 1.4 \text{e}12$
$N(\text{Ca II}) (\text{cm}^{-2})$	$[2.8 \pm 0.7 \text{e}10]$	...	$[6.8 \pm 1.4 \text{e}10]$	$[6.6 \pm 1.2 \text{e}10]$
$N(\text{Fe II}) (\text{cm}^{-2})$	$3.8 \pm 0.6 \text{e}12$	$2.4 \pm 0.6 \text{e}12$	$2.5 \pm 0.7 \text{e}12$	$3.3 \pm 0.6 \text{e}12$
$N(\text{C I}^*)/N(\text{C I}_{\text{tot}})$	0.17 ± 0.03	0.30 ± 0.03	0.26 ± 0.03	0.26 ± 0.03
$N(\text{C I}^*)/N(\text{C I}_{\text{tot}})$	0.06 ± 0.02	0.07 ± 0.01	0.05 ± 0.01	0.06 ± 0.01
$N(\text{C II}^*)/N(\text{C II})$	0.09 ± 0.04	...	...	...
$N(\text{Na I})/N(\text{Ca II})$	...	...	$[5.7 \pm 1.2]$	$[4.4 \pm 0.9]$
$N(\text{Si II})/N(\text{Fe II})$	2.3 ± 0.8	4.0 ± 1.1	3.8 ± 1.2	2.8 ± 0.7
$N(\text{H}) (\text{cm}^{-2})$	$5.6 \pm 1.2 \text{e}17$	$6.2 \pm 0.8 \text{e}17$	$6.1 \pm 1.0 \text{e}17$	$5.9 \pm 0.9 \text{e}17$
$\log(n_{\text{H}}/T) (\text{cm}^{-3} \text{K})$	3.4 ± 0.1	3.8 ± 0.1	3.7 ± 0.1	3.7 ± 0.1
$n_{\text{H}} (\text{cm}^{-3})$	25	60	50	50
thickness (AU)	1500	700	800	800
$n_e (\text{cm}^{-3})$	5.2	20.4	14.6	13.7
$n_e (\text{C II}) (\text{cm}^{-3})$	0.5	1.9	1.3	1.2
n_e/n_{H}	0.02	0.03	0.03	0.02

Variations in Column Densities

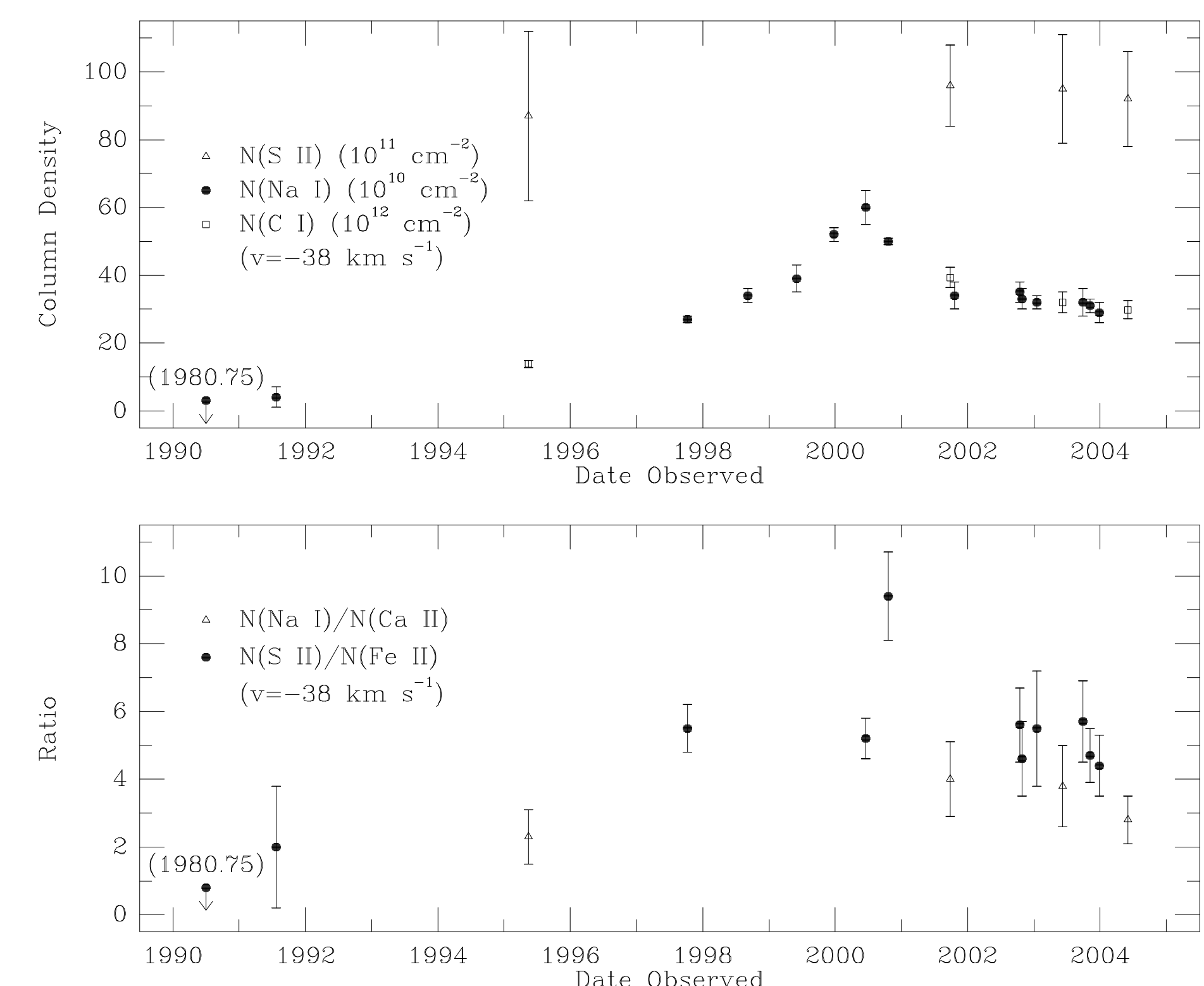


Figure 3. Variations in $N(\text{Na I})$, $N(\text{C I})$, and $N(\text{S II})$ (top) and in $N(\text{Na I})/N(\text{Ca II})$ and $N(\text{S II})/N(\text{Fe II})$ (bottom), at $v \sim -38 \text{ km s}^{-1}$ toward HD 219188. Na I was not detected, and Ca II only weakly, in 1980 (Albert 1983); a weak Na I feature may have been detected in 1991 (Sembach et al. 1993). $N(\text{Na I})$ (filled circles) increased steadily between 1997.77 and 2000.46, but then decreased between 2000.46 and 2003.99; the changes in $N(\text{C I})$ (open squares) appear to parallel those in $N(\text{Na I})$, $N(\text{S II})$ — and thus $N(\text{H})$ — has remained essentially constant between 1995.37 and 2004.42. The $N(\text{Na I})/N(\text{Ca II})$ and $N(\text{S II})/N(\text{Fe II})$ ratios — and thus the depletions — appear to have remained relatively constant since 1995 (though the former is higher than it was prior to 1992).

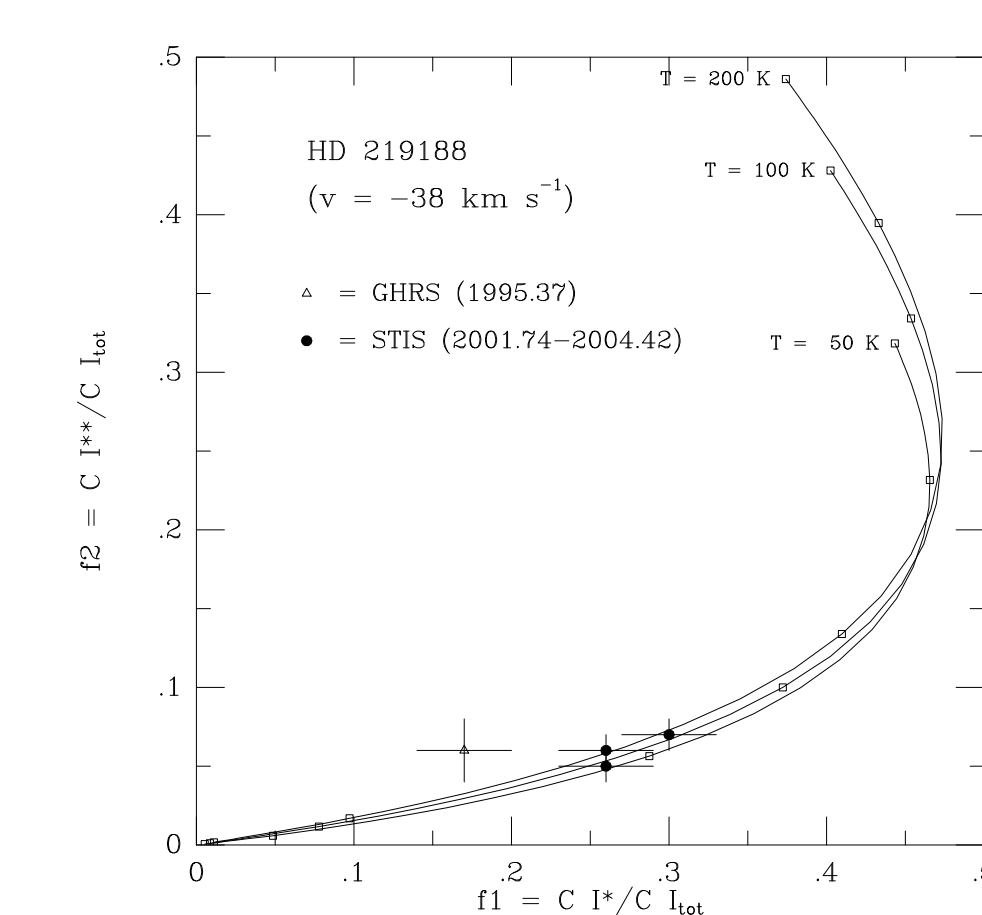


Figure 4. C I fine-structure excitation in the -38 km s^{-1} component toward HD 219188. The GHRS value (1995.37) is given by the open triangle; the three STIS values (2001.74–2004.42) are given by the filled circles. The solid lines show the predicted ratios for $T = 50, 100,$ and 200 K (Jenkins & Shaya 1979; Jenkins & Tripp 2001); the open squares along each curve denote $\log(n_{\text{H}}) = 0.4$ (the squares nearest the STIS points are for $\log(n_{\text{H}}) = 2$). The three STIS values are in good agreement with the predicted curves — suggesting that the IV gas may be characterized by uniform pressure (i.e., not a mixture of low- and high-pressure gas).

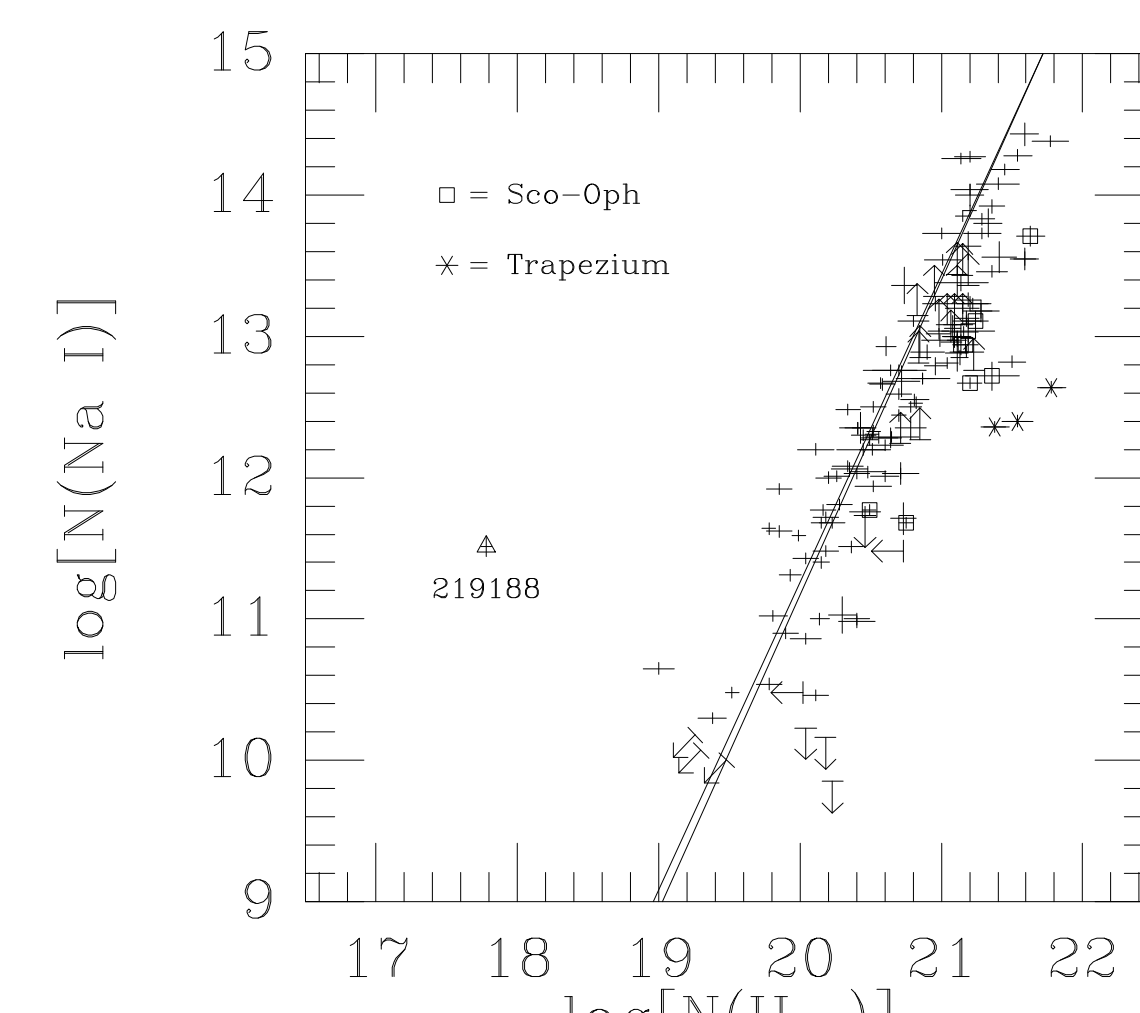


Figure 5. $N(\text{Na I})$ vs. $N(\text{H})$ for sight lines (mostly) in the local Galactic ISM (e.g., Welty & Hobbs 2001). The IV component toward HD 219188 has a much higher $N(\text{Na I})/N(\text{H})$ ratio — more similar to the values found for components in other sight lines sampling the Galactic halo (e.g., Wakker & Mathis 2000).

Variations in Column Densities and Inferred Properties

- Between 1997.77 and 2000.46, the IV $N(\text{Na I})$ increased from $\sim 3 \times 10^{11} \text{ cm}^{-2}$ (an order of magnitude higher than the limit found in 1980) to $\sim 6 \times 10^{11} \text{ cm}^{-2}$. By the end of 2003, $N(\text{Na I})$ decreased again to $\sim 3 \times 10^{11} \text{ cm}^{-2}$. If the variations are due solely to the proper motion of HD 219188, the roughly 5-year “FWHM” corresponds to a transverse linear scale of 10–200 AU for the IV cloud.
- Both the total $N(\text{C I})$ and the relative population in the excited state C I^* were higher in 2001–2004 than in 1995 — indicating pressures and densities in the IV component higher by factors ~ 2 — though n_{H} is still less than 100 cm^{-3} . The C I fine-structure populations in 2001–2004 are consistent with gas at a uniform pressure — i.e., not a mixture of low- and high-pressure gas (cf. Crawford 2003; Lauroesch & Meyer 2003). The slight decline in $N(\text{C I})$ between 2001 and 2004 is similar to that seen for $N(\text{Na I})$ (cf. Lauroesch & Meyer 2003); the ratio $N(\text{C I})/N(\text{Na I}) \sim 100$ is somewhat higher than usual, however.
- The column densities of the dominant species S II, Si II, Fe II have remained relatively constant between 1995 and 2004 — indicating roughly constant total $N(\text{H})$ and depletions over that period.
- Increased column densities for the trace neutral species and C II* [together with the roughly constant $N(\text{X II})$] suggest increased n_e (but more similar n_e/n_{H}) between 1994 and 2001–2004. While the ratio $N(\text{O I})/N(\text{S II})$ suggests that the IV gas is predominantly neutral, the relatively high n_e/n_{H} suggests that hydrogen is partially (several percent) ionized.
- The $N(\text{Na I})/N(\text{H})$ ratio is much higher than the values typically found for higher $N(\text{H})$ sight lines, but is similar to the values found for clouds in other halo sight lines (e.g., Wakker & Mathis 2000). The variations in $N(\text{Na I})$ in the HD 219188 IV component appear to be due to variations in density and/or ionization [and not overall $N(\text{H})$], on scales of tens of AU.