

HIGHLY IONIZED HIGH-VELOCITY GAS IN THE VICINITY OF THE GALAXY

K. R. SEMBACH,¹ B. P. WAKKER,² B. D. SAVAGE,² P. RICHTER,^{2,3} M. MEADE,² J. M. SHULL,⁴ E. B. JENKINS,⁵
 G. SONNEBORN,⁶ AND H. W. MOOS⁷

Received 2002 July 25; accepted 2002 November 20

ABSTRACT

We report the results of a *FUSE* study of high-velocity O VI absorption along complete sight lines through the Galactic halo in directions toward 100 extragalactic objects and two halo stars. The high-velocity O VI traces a variety of phenomena, including tidal interactions with the Magellanic Clouds, accretion of gas, outflowing material from the Galactic disk, warm/hot gas interactions in a highly extended Galactic corona, and intergalactic gas in the Local Group. We identify 84 high-velocity O VI features at $\geq 3\sigma$ confidence at velocities of $-500 < v_{\text{LSR}} < +500 \text{ km s}^{-1}$. The 84 O VI features have velocity centroids ranging from $-372 \lesssim \bar{v}_{\text{LSR}} \lesssim -90 \text{ km s}^{-1}$ to $+93 \lesssim \bar{v}_{\text{LSR}} \lesssim +385 \text{ km s}^{-1}$, line widths $b \sim 16\text{--}72 \text{ km s}^{-1}$ with an average of $\langle b \rangle = 40 \pm 13 \text{ km s}^{-1}$, and an average O VI column density $\langle \log N \rangle = 13.95 \pm 0.34$ with a median value of 13.97. Values of b greater than the 17.6 km s^{-1} thermal width expected for O VI at $T \sim 3 \times 10^5 \text{ K}$ indicate that additional nonthermal broadening mechanisms are common. The O VI $\lambda 1031.926$ absorption is detected at $\geq 3\sigma$ confidence along 59 of the 102 sight lines surveyed. The high-velocity O VI detections indicate that $\sim 60\%$ of the sky (and perhaps as much as $\sim 85\%$, depending on data quality considerations) is covered by high-velocity H⁺ associated with the O VI. We find that $N(\text{H}^+) \gtrsim 10^{18} \text{ cm}^{-2}$ if the high-velocity hot gas has a metallicity similar to that of the Magellanic Stream; this detection rate is considerably higher than that of high-velocity warm H I traced through its 21 cm emission at a comparable column density level. Some of the high-velocity O VI is associated with known H I structures (the Magellanic Stream, Complex A, Complex C, the Outer Spiral Arm, and several discrete H I HVCs). Some of the high-velocity O VI features have no counterpart in H I 21 cm emission, including discrete absorption features and positive velocity absorption wings extending from ~ 100 to $\sim 300 \text{ km s}^{-1}$ that blend with lower velocity absorption produced by the Galactic thick disk/halo. The discrete features may typify clouds located in the Local Group, while the O VI absorption wings may be tidal debris or material expelled from the Galactic disk. Most of the O VI features have velocities incompatible with those of the Galactic halo, even if the halo has decoupled from the underlying Galactic disk. The reduction in the dispersion about the mean of the high-velocity O VI centroids when the velocities are converted from the LSR to the GSR and LGSF reference frames is necessary (but not conclusive) evidence that some of the clouds are located outside the Galaxy. Most of the O VI cannot be produced by photoionization, even if the gas is irradiated by extragalactic ultraviolet background radiation. Several observational quantities indicate that collisions in hot gas are the primary ionization mechanism responsible for the production of the O VI. These include the ratios of O VI column densities to those of other highly ionized species (C IV, N V) and the strong correlation between $N(\text{O VI})$ and O VI line width. Consideration of the possible sources of collisional ionization favors production of some of the O VI at the boundaries between cool/warm clouds of gas and a highly extended ($R \gtrsim 70 \text{ kpc}$), hot ($T > 10^6 \text{ K}$), low-density ($n \lesssim 10^{-4}\text{--}10^{-5} \text{ cm}^{-3}$) Galactic corona or Local Group medium. The existence of a hot, highly extended Galactic corona or Local Group medium and the prevalence of high-velocity O VI are consistent with predictions of current galaxy formation scenarios. Distinguishing between the various phenomena producing high-velocity O VI in and near the Galaxy will require continuing studies of the distances, kinematics, elemental abundances, and physical states of the different types of high-velocity O VI found in this study. Descriptions of galaxy evolution will need to account for the highly ionized gas, and future X-ray studies of hot gas in the Local Group will need to consider carefully the relationship of the X-ray absorption/emission to the complex high-velocity absorption observed in O VI.

Subject headings: Galaxy: halo — intergalactic medium — ISM: clouds — ISM: evolution — ISM: kinematics and dynamics — ultraviolet: ISM

¹ Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218; sembach@stsci.edu.

² Department of Astronomy, University of Wisconsin, 475 North Charter Street, Madison, WI 53706.

³ Current address: Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, Florence, Italy.

⁴ Center for Astrophysics and Space Astronomy, Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO 80309.

⁵ Princeton University Observatory, Peyton Hall, Princeton, NJ 08544.

⁶ Laboratory for Astronomy and Solar Physics, Code 681, NASA Goddard Space Flight Center, Greenbelt, MD 20771.

⁷ Department of Physics and Astronomy, The Johns Hopkins University, 3400 North Charles Street, Baltimore, MD 21218.

1. INTRODUCTION

Understanding galaxy formation and evolution requires observational information about hot, highly ionized gas in and near galaxies. Numerical simulations of cosmological structure formation in the presence of cold dark matter indicate that a significant fraction of the baryonic material at low redshift should be shock-heated to temperatures of 10^5 – 10^7 K as the gas collapses and forms clusters and groups of galaxies (e.g., Cen & Ostriker 1999; Davé et al. 1999, 2001). This reservoir of hot gas is detectable through ultraviolet absorption-line measurements (Tripp, Savage, & Jenkins 2000; Savage et al. 2002a). Determining how the intergalactic medium (IGM) and the hot gas in galaxies are related will require many observations because a variety of internal and external processes affect the heating and distribution of the interstellar gas in and around galaxies. In addition to the galaxy formation process, accretion of satellite galaxies, tidal interactions, star formation, galactic winds, and galaxy-IGM interactions may all contribute to the production of hot gas. To some extent, all of these activities operate in and around our own galaxy, so studying the hot gas in the immediate environment of the Milky Way is a logical step in assessing the relevance and roles of these processes locally.

One of the primary science objectives of the *Far Ultraviolet Spectroscopic Explorer* (*FUSE*) mission is to determine the properties of hot, highly ionized gas in the low-redshift universe. A key component of this research has been the study of O VI absorption along many sight lines through the Galactic halo. Such observations were not possible until *FUSE* was launched because previous observatories lacked the spectral resolution and/or the sensitivity to study the velocity structure of the O VI absorption toward distant background sources. Among the most interesting *FUSE* results to date is the detection of O VI in high-velocity clouds (HVCs) (Sembach et al. 2000; Murphy et al. 2000). For decades astronomers have studied primarily the neutral (H I) content of the clouds and have debated the origin and location of the high-velocity gas based on this information alone. It is generally accepted that no single model can account for all of the observed properties of the neutral HVCs (see Wakker & van Woerden 1997 for a review). Observations of ionized HVCs and the reintroduction of the idea that some of the H I HVCs could be located outside of the Milky Way if they are embedded in halos of dark matter (Blitz et al. 1999) have expanded the range of locations and cloud properties that must now be considered for a complete description of the high-velocity gas. Determining the ionization and hot gas content of the high-velocity gas bears directly on the locations of the clouds and their interactions with other components of the gaseous interstellar and intergalactic media.

The O VI $\lambda\lambda 1031.926, 1037.617$ doublet lines in the far-ultraviolet spectral region are the best lines to use for kinematical investigations of hot ($T \gtrsim 10^5$ – 10^6 K) gas in the low-redshift universe. Oxygen is the most abundant element heavier than helium, and the O VI lines have large oscillator strengths ($f_{1032} = 0.133$, $f_{1038} = 0.0661$; Morton 1991). X-ray spectroscopy of higher ionization lines (e.g., O VII, O VIII) is possible with *XMM-Newton* and the *Chandra X-ray Observatory* for a small number of sources, but the spectral resolution ($R \equiv \lambda/\Delta\lambda \lesssim 500$) is modest compared to that afforded by *FUSE* ($R \sim 15,000$). Lower ionization lines observable at high spectral resolution at ultraviolet

wavelengths are generally either much weaker than the O VI lines (e.g., N V $\lambda\lambda 1238.821, 1242.804$) or are better tracers of collisionally ionized gas at temperatures $T \lesssim 10^5$ K (e.g., C IV $\lambda\lambda 1548.195, 1550.770$, C III $\lambda 977.020$, Si IV $\lambda\lambda 1393.755, 1402.770$, Si III $\lambda 1206.500$). C III–IV and Si III–IV are also considerably more susceptible to photoionization than O VI since their photoionization cross sections are large and their ionization potentials are less than the 54 eV energy of the He II ionization edge. O VI can be produced by photoionization under special conditions involving a hard radiation field and a very low gas density, but as we will show later, this does not appear to be a viable production mechanism for *most* of the O VI observed in the vicinity of the Milky Way.

This article is one in a series of three papers devoted to *FUSE* observations of O VI absorption along complete paths through the Galactic halo in the directions of quasi-stellar objects (QSOs), active galactic nuclei (AGNs), and BL Lac objects. The other two papers include a catalog with basic measurements and illustrations of all of the O VI profiles observed in the survey (Wakker et al. 2003) and a companion study of the O VI absorption associated with the thick disk/halo of the Milky Way (Savage et al. 2003). Here we concentrate on the properties of the O VI absorption at high velocities with respect to those expected for gas participating in differential Galactic rotation (generally, “high velocity” refers to $100 < |v_{\text{LSR}}| < 400$ km s $^{-1}$ in this paper). High-velocity O VI absorption associated with the Magellanic Clouds is discussed elsewhere (Friedman et al. 2000; Danforth et al. 2002; Hoopes et al. 2001, 2002; Howk et al. 2002b).

This paper is organized as follows. In § 2 we describe the observations and data reduction. We present the O VI HVC measurements in § 3 and describe the general types of high-velocity gas seen in § 4. Section 5 contains information about the column densities, sky covering fractions, velocities, and line widths of the O VI absorption. In § 6 we discuss the high-velocity O VI features associated with previously identified high-velocity clouds, and in § 7 we describe a few sight lines that show high-velocity H I 21 cm emission with no corresponding O VI absorption. Section 8 highlights new high-velocity gas detected only in O VI absorption. In § 9 we consider how the high-velocity gas is ionized. Section 10 describes the general kinematical behavior of the high-velocity gas. Section 11 contains a discussion of the high-velocity O VI features and the implications of this work for understanding hot gas in the low-redshift universe. We conclude with a summary of results in § 12.

2. OBSERVATIONS AND DATA REDUCTION

Full details of the *FUSE* observations and data reduction for the objects surveyed for high-velocity O VI are given by Wakker et al. (2003). We summarize some of the key points here. The objects included in this study form an incomplete flux-limited sample of extragalactic objects drawn primarily from the *FUSE* Science Team O VI, D/H, and AGN programs conducted in the first 2 years of the mission (1999 December–2001 November). Publicly available Guest Investigator (GI) observations have been included when it is clear that the science goals of our study and those of the GI do not conflict. Most of the objects are either QSOs or low-redshift Type 1 Seyfert galaxy nuclei, which have relatively smooth continua in the wavelength region of interest. A few

additional background sources, such as bright regions of low-redshift starburst galaxies and two high-latitude stars located >5 kpc from the Galactic disk, have been included as well. Of the more than 200 objects considered, only about half had data suitable for studies of the O VI lines. Total exposure times ranged from ~ 5 to ~ 600 ks per object, with a median of ~ 16 ks per object.

FUSE contains four coaligned spectrographs that cover the 905–1187 Å spectral region. The optics (a mirror and a holographically ruled diffraction grating) in two of the channels are coated with aluminum and lithium-fluoride (LiF) for maximum throughput above 1000 Å. The other two channels contain optics with SiC coatings for maximum throughput below 1000 Å. Each object was centered in the $30'' \times 30''$ (LWRS) aperture of the LiF1 channel, which is also the channel used for guiding. In the remaining channels, the objects sometimes drifted around in the LWRS apertures. These drifts do not affect our study since each photon event recorded by the microchannel plate detectors is time-tagged and can be corrected for these motions. Descriptions of the *FUSE* instrumentation and on-orbit performance are given by Moos et al. (2000, 2002) and Sahnou et al. (2000a, 2000b). Additional information can be found in the *FUSE Observer's Guide*.⁸

All of the data were reduced in a homogeneous fashion with the standard *FUSE* pipeline software (CALFUSE v1.8.7) available from the Johns Hopkins University.⁹ The O VI lines are covered by all four *FUSE* channels, but we have opted to use data from only the two most sensitive channels (LiF1, LiF2), which have optics coated with Al+LiF. These two channels account for roughly 76% of the *FUSE* effective area at the wavelengths of the O VI lines. For the higher signal-to-noise ratio (S/N) observations, we used only the data from the LiF1 channel and checked this result with the LiF2 data. However, we combined the two independent measurements for lower S/N observations to increase the detection confidence (see § 3 of Wakker et al. 2003). To maximize S/N, we used data obtained during both orbital day and night since the O VI lines are in spectral regions unaffected by terrestrial airglow emission. The fully sampled *FUSE* data have a FWHM velocity resolution of ~ 20 – 25 km s⁻¹ ($R \sim 12,000$ – $15,000$).

We set the zero point of the *FUSE* wavelength scale for each observation by referencing the interstellar Ar I $\lambda 1048.220$ and Si II $\lambda 1020.699$ absorption features to the H I 21 cm emission observed in each direction (see § 3.4 of Wakker et al. 2003 for a description of the method and information about the H I data used in these comparisons). This comparison was done for the low-velocity portions of the profiles. H₂ absorption features in the 1020–1040 Å spectral region provided an additional consistency check on the wavelength scales for some sight lines. We estimate a wavelength uncertainty of ~ 0.03 Å (~ 10 km s⁻¹) for the fully reduced data. None of the conclusions of this study are affected by this zero-point uncertainty. Unless otherwise

specified, all velocities in this paper are referred to the local standard of rest (LSR) reference frame, which has a standard solar motion of 19.5 km s⁻¹ in the direction $l_{\text{std}} = 56^\circ$, $b_{\text{std}} = 23^\circ$ (Mihalas & Binney 1981).

Figure 1 contains the fully reduced *FUSE* spectra between 1015 and 1040 Å for three sight lines through the Galactic halo (NGC 7469, PG 1116+215, and PG 1259+593). These sight lines exhibit varying degrees of complexity in their observed O VI absorption and in the amount of blending with other atomic and molecular lines in the bandpass. All three sight lines contain high-velocity O VI absorption that is observable in the 1031.926 Å line. Toward NGC 7469 and PG 1259+593, the high-velocity O VI $\lambda 1037.617$ absorption is blended with either C II* $\lambda 1037.018$ or with nearby molecular hydrogen lines, whose wavelengths are indicated in the top panel. Similar illustrations of high-velocity O VI absorption observed toward AGNs and QSOs by *FUSE* in this spectral region are given by Oegerle et al. (2000), Savage et al. (2000, 2002, 2003), Sembach et al. (2000, 2001b), and Heckman et al. (2001).

3. MEASUREMENTS

In our study of high-velocity O VI, we draw upon the measurements and detailed sight line comments presented in the Appendix of the *FUSE* O VI catalog paper (Wakker et al. 2003) for the 102 objects with sufficient data quality to study the absorption. The catalog contains information about line strengths (equivalent widths), velocities, and contamination by other absorption features. The catalog includes illustrations of the observed absorption profiles and some basic statistical information about the properties of the absorption and data quality. We present a complete list of the high-velocity O VI features in Table 1, sorted by Galactic longitude. The table entries include the name of the background continuum source observed, the Galactic coordinates (l, b) of the background source, a data quality factor (Q), an “identification” (ID) for the high-velocity O VI absorption based on the correspondence with Galactic structures or high-velocity gas observed in H I 21 cm emission, the velocity range spanned by the O VI ($v_{\text{min}}, v_{\text{max}}$), the average velocity and width of the O VI absorption ($\bar{v}$ and b), the logarithmic column density, and the significance of the O VI $\lambda 1031.926$ absorption-line detection (W_λ/σ_W , where σ_W is the error in the equivalent width due to statistical noise fluctuations and continuum placement uncertainties). The data quality factor is an indicator of the continuum S/N (per 20 km s⁻¹ resolution element) in the spectrum near the O VI lines as follows: $Q = 1$ (S/N = 3–5), $Q = 2$ (S/N = 5–9), $Q = 3$ (S/N = 9–14), $Q = 4$ (S/N > 14).

3.1. Identifying the High-Velocity O VI Absorption

The derived properties of the high-velocity gas depend in part upon the adopted separation of the high-velocity absorption from lower velocity absorption arising in the nearby Galactic disk and halo. In regions of the sky where there is little high-velocity gas observed in other species (e.g., H I, C II, C IV), the nearby O VI absorption is generally found at $-100 \leq v_{\text{LSR}} \leq +100$ km s⁻¹, which we adopt as the typical velocity range of the Galactic thick disk/halo O VI absorption (see Savage et al. 2003). We define absorption outside this velocity range as high-velocity gas, with a

⁸ On-line at <http://fuse.pha.jhu.edu/support/guide/guide.html>.

⁹ For a subset of the observations, we compared the CALFUSE v1.8.7 processed data to the data processed with the latest available software (v2.0.5). We found no significant differences in the reduced data sets in the spectral regions considered in this study, except for $\sim \pm 30$ km s⁻¹ differences in the velocity calibration. See § 3.4 of Wakker et al. (2003) for additional information about the zero-point velocity scale differences between the two processing versions for objects in our sample.

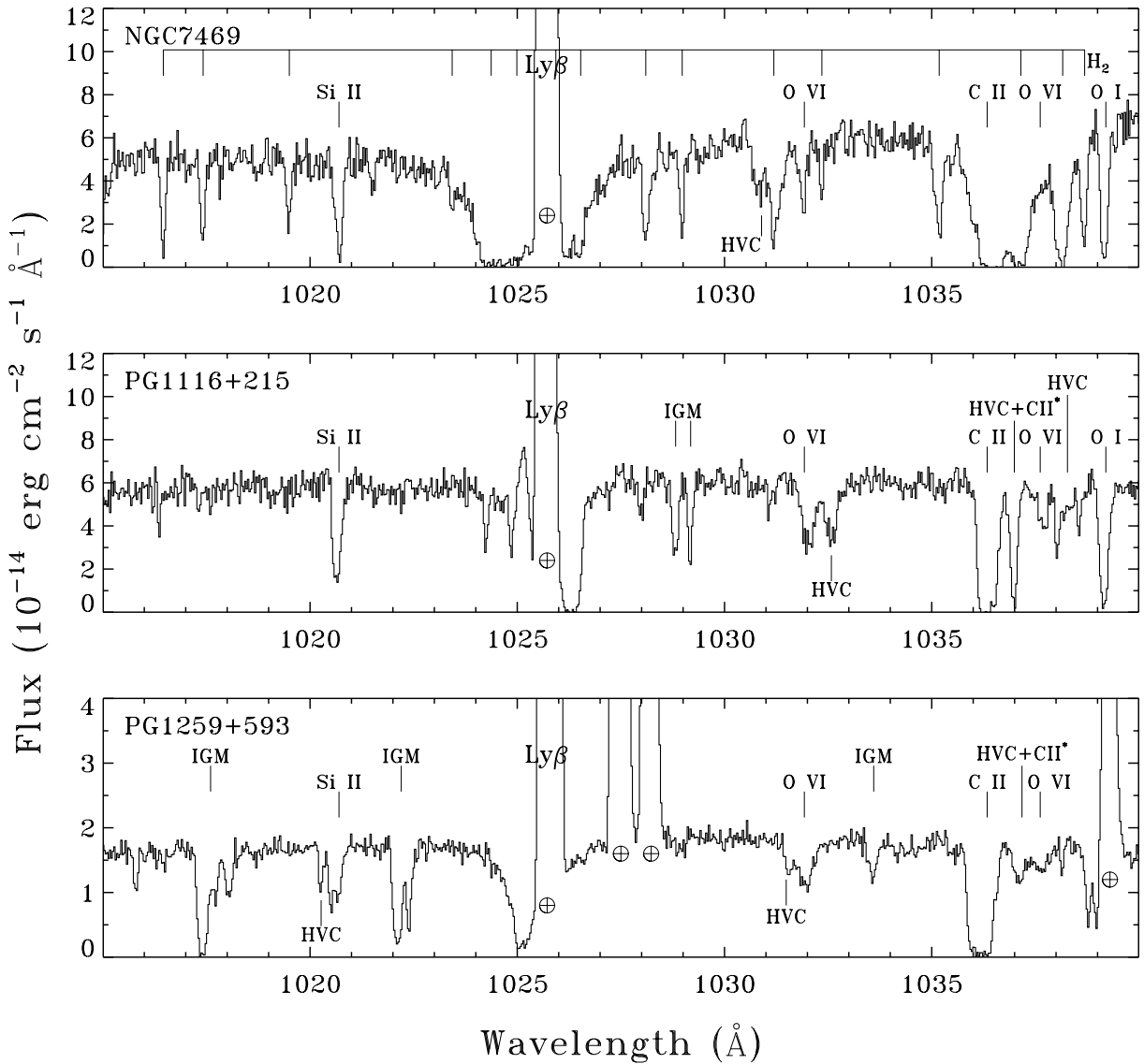


FIG. 1.—*FUSE* LiF1 observations of the 1015–1040 Å spectral region of three AGN/QSOs in the high-velocity O VI survey. The data have a velocity resolution of ~ 20 km s $^{-1}$ (FWHM) and are binned to ~ 10 km s $^{-1}$ (~ 0.033 Å) samples. Prominent interstellar lines, including the two lines of the O VI doublet at 1031.926 and 1037.617 Å, are identified above each spectrum at their rest (laboratory) wavelengths. The wavelengths of strong molecular hydrogen lines in the $J = 0-4$ rotational levels are indicated in the top panel; the H $_2$ lines decrease in strength from the top to bottom panels. Additional H I and metal lines from intervening intergalactic clouds are present in the middle and bottom panels. Crossed circles mark the locations of terrestrial airglow lines of H I and O I. High-velocity O VI $\lambda 1031.926$ absorption is present along all three sight lines.

few minor exceptions to account for directions where there is reason to believe that the thick disk absorption extends to higher velocities. For example, differential Galactic rotation may broaden the profiles in some directions, particularly low-latitude sight lines in the $l = 90^\circ$ and $l = 270^\circ$ directions and sight lines that sample the inner regions of the Galaxy. In a few cases we contracted the thick disk limits and allowed the high-velocity gas integration to extend to lower velocities by $\sim 10-20$ km s $^{-1}$ to account for absorption associated with known high-velocity features (e.g., Mrk 817, which exhibits O VI absorption in Complex C at velocities $v_{\text{LSR}} > -90$ km s $^{-1}$). For five lines of sight, the separation is based on O VI velocity structure. We list the integration limits ($v_{\text{min}}, v_{\text{max}}$) for the high-velocity gas in Table 1.

We examined the *FUSE* spectra for absorption produced by the stronger member of the O VI $\lambda\lambda 1031.926, 1037.617$ doublet because the higher velocity portions of the weaker

$\lambda 1037.617$ line are usually severely blended with other interstellar lines. We searched for absorption at velocities $-1200 < v_{\text{LSR}} < +1200$ km s $^{-1}$; with few exceptions all of the identified O VI absorption is confined to the $|v_{\text{LSR}}| < 400$ km s $^{-1}$ velocity range. The few possible cases where higher velocity features may be present are described in the Appendix of the O VI catalog paper (Wakker et al. 2003) and are not considered further here.

The identification of high-velocity O VI $\lambda 1031.926$ requires careful consideration of the absorption produced by nearby lines of other atomic and molecular species (see Sembach 1999 for model templates of the absorption in the *FUSE* bandpass). At negative velocities, the primary lines that blend with O VI $\lambda 1031.926$ are the H $_2$ (6–0) $P(3)$ line at 1031.191 Å (-214 km s $^{-1}$ with respect to the rest wavelength of the O VI line) and the Cl I lines at 1031.885 Å (-303 km s $^{-1}$) and 1031.507 Å (-122 km s $^{-1}$). At positive

TABLE 1
HIGH-VELOCITY O VI DETECTIONS

Name	l (deg)	b (deg)	Q^a	ID ^b	$v_{\min}$ (km s ⁻¹)	$v_{\max}$ (km s ⁻¹)	$\bar{v}$ (km s ⁻¹)	b^c (km s ⁻¹)	$\log N \pm \sigma_{sc} \pm \sigma_{sys}$	$(W_\lambda/\sigma_W)^d$
PKS 2155–304.....	17.73	–52.25	4	LG	–180	–85	–129	35 ± 3	13.80 ± 0.03 ± 0.11	17.5
				LG	–280	–180	–232	42 ± 4	13.57 ± 0.05 ± 0.14	8.6
Mrk 509	35.97	–29.86	4	LG	–345	–180	–247	(57 ± 4)	14.24 ± 0.02 ± 0.08	25.0
				LG	–180	–100	–143	((31 ± 3))	13.76 ± 0.04 ± 0.15	12.6
				Oth†	115	200	152	((34 ± 4))	13.55 ± 0.06 ± 0.22	7.0
MRC 2251–178.....	46.20	–61.33	3	LG	–340	–180	–258	65 ± 4	13.91 ± 0.11 ± 0.05	3.7
				LG	–145	–65	–95	31 ± 4	14.06 ± 0.06 ± 0.10	8.4
PHL 1811.....	47.46	–44.81	3	LG	–360	–295	–322	21 ± 3	13.85 ± 0.09 ± 0.09	5.2
				LG	–200	–65	–142	(42 ± 3)	14.38 ± 0.04 ± 0.08	13.0
Mrk 506	54.18	31.50	1	C	–180	–100	–144	(33 ± 4)	14.05 ± 0.11 ± 0.14	4.5
Mrk 478	59.24	65.03	3	Oth	340	435	385	35 ± 4	13.83 ± 0.10 ± 0.05	4.4
3C 382.0.....	61.31	17.45	1	OA	–130	–50	–90	((30 ± 3))	14.14 ± 0.10 ± 0.09	5.1
Mrk 501	63.60	38.86	2	C	–150	–100	–122	((22 ± 3))	13.81 ± 0.11 ± 0.19	4.3
Mrk 1513	63.67	–29.07	3	MSe	–390	–220	–293	49 ± 4	14.29 ± 0.05 ± 0.04	9.0
Mrk 926	64.09	–58.76	1	MSe	–395	–220	–295	(57 ± 5)	14.41 ± 0.12 ± 0.04	3.8
				LG	–220	–65	–125	(60 ± 5)	14.44 ± 0.12 ± 0.05	4.5
Mrk 304	75.99	–34.22	3	MSe	–355	–240	–304	40 ± 3	14.47 ± 0.06 ± 0.04	11.4
NGC 7469.....	83.10	–45.47	4	MS	–370	–235	–304	(54 ± 5)	14.18 ± 0.04 ± 0.11	11.9
				LG	–235	–120	–185	((43 ± 4))	14.22 ± 0.03 ± 0.16	14.2
PG 1626+554.....	84.51	42.19	2	C	–210	–65	–125	55 ± 8	14.22 ± 0.09 ± 0.08	5.2
NGC 7714.....	88.22	–55.56	2	MS	–310	–230	–259	(26 ± 3)	14.13 ± 0.09 ± 0.09	5.6
Mrk 290	91.49	47.95	1	C	–190	–70	–132	((52 ± 5))	14.20 ± 0.09 ± 0.07	4.7
PG 2349–014.....	91.66	–60.36	1	MS	–415	–270	–324	(43 ± 8)	14.00 ± 0.14 ± 0.11	3.0
				LG	–205	–90	–142	(51 ± 5)	14.19 ± 0.09 ± 0.09	5.5
UGC 12163.....	92.14	–25.34	2	MSe	–345	–210	–274	(41 ± 5)	14.16 ± 0.08 ± 0.05	6.0
H 1821+643.....	94.00	27.42	4	Oth	–285	–235	–258	16 ± 5	13.24 ± 0.13 ± 0.20	3.0
				Oth	–225	–160	–192	(24 ± 5)	13.72 ± 0.05 ± 0.13	8.0
				OA	–160	–100	–122	((22 ± 5))	13.87 ± 0.04 ± 0.18	12.0
Mrk 876	98.27	40.38	4	C	–200	–100	–142	((38 ± 5))	14.05 ± 0.04 ± 0.13	14.1
				Oth†	85	140	107	((20 ± 5))	13.23 ± 0.13 ± 0.31	3.0
Mrk 817	100.30	53.48	4	C	–165	–90	–116	((27 ± 4))	13.88 ± 0.03 ± 0.17	19.2
				Oth†	60	140	+93	((35 ± 5))	13.30 ± 0.08 ± 0.21	4.8
Mrk 335	108.76	–41.42	4	MSe	–375	–235	–305	(40 ± 4)	13.87 ± 0.05 ± 0.14	9.0
				LG	–225	–75	–178	((54 ± 4))	14.14 ± 0.03 ± 0.10	16.9
PG 1351+640.....	111.89	52.02	3	C	–160	–100	–124	((25 ± 3))	13.67 ± 0.08 ± 0.23	4.9
				Oth†	100	160	125	((27 ± 4))	13.44 ± 0.13 ± 0.22	3.1
Mrk 279	115.04	46.86	4	C	–210	–115	–154	(34 ± 3)	13.67 ± 0.05 ± 0.13	8.8
PG 1259+593.....	120.56	58.05	4	C	–150	–80	–110	26 ± 3	13.72 ± 0.04 ± 0.13	14.2
				Oth†	100	185	139	34 ± 7	13.06 ± 0.15 ± 0.27	2.3
Mrk 1502	123.75	–50.18	2	LG	–210	–95	–159	(38 ± 3)	14.28 ± 0.07 ± 0.06	7.0
PG 0052+251.....	123.91	–37.44	2	MSe	–415	–270	–334	(59 ± 4)	14.17 ± 0.09 ± 0.05	4.6
				LG	–240	–155	–193	((21 ± 3))	13.92 ± 0.11 ± 0.17	3.5
Mrk 352	125.03	–31.01	2	MSe	–365	–250	–300	(42 ± 5)	13.96 ± 0.14 ± 0.08	3.0
				LG	–250	–115	–185	((48 ± 6))	14.14 ± 0.10 ± 0.08	4.6
Mrk 357	132.20	–39.14	2	MSe	–340	–220	–279	((44 ± 4))	14.12 ± 0.09 ± 0.16	5.5
				LG	–220	–140	–183	((34 ± 4))	13.88 ± 0.11 ± 0.24	3.8
NGC 588	133.34	–31.39	2	MSe	–420	–310	–372	43 ± 4	14.08 ± 0.10 ± 0.07	4.5
				LG ^e	–310	–125	–212	56 ± 4	14.59 ± 0.05 ± 0.03	9.7
NGC 595	133.53	–31.31	2	MSe	–365	–215	–284	(56 ± 4)	14.28 ± 0.09 ± 0.04	4.9
				M33	–215	–80	–149	(46 ± 4)	14.35 ± 0.07 ± 0.04	7.1
Ton S180.....	139.00	–85.07	3	LG	–265	–100	–156	46 ± 6	14.18 ± 0.05 ± 0.04	8.1
				Oth	220	280	251	23 ± 6	13.64 ± 0.09 ± 0.08	4.7
NGC 3310.....	156.60	54.06	4	Oth	–195	–135	–162	(23 ± 4)	13.58 ± 0.09 ± 0.19	4.7
Mrk 106	161.14	42.88	1	A	–150	–100	–125	((22 ± 4))	13.81 ± 0.14 ± 0.17	3.0
PG 0953+414.....	179.79	51.71	4	EPn†	100	235	146	((53 ± 4))	13.83 ± 0.06 ± 0.13	6.8
Mrk 421	179.83	65.03	4	EPn†	100	185	135	((34 ± 4))	13.51 ± 0.11 ± 0.19	3.4
PG 0947+396.....	182.85	50.75	2	EPn†	100	175	136	((30 ± 4))	14.19 ± 0.10 ± 0.11	5.6
NGC 3991.....	185.68	77.20	1	EPn	145	320	229	(63 ± 5)	14.28 ± 0.13 ± 0.02	3.2
HS 1102+3441.....	188.56	66.22	1	EPn†	95	210	144	((48 ± 7))	14.30 ± 0.10 ± 0.07	4.3
PG 0844+349.....	188.56	37.97	4	EPn†	120	250	179	(48 ± 5)	13.75 ± 0.08 ± 0.14	4.8
PG 1001+291.....	200.09	53.20	1	EPn†	100	200	131	((40 ± 5))	13.97 ± 0.13 ± 0.16	3.1
PKS 0405–12.....	204.93	–41.76	4	Oth†	100	210	143	(41 ± 4)	13.75 ± 0.07 ± 0.09	6.1
NGC 4670.....	212.69	88.63	3	Oth	320	420	363	29 ± 4	13.96 ± 0.05 ± 0.04	8.1
PG 1116+215.....	223.36	68.21	4	EPn	115	230	181	42 ± 4	14.12 ± 0.03 ± 0.07	19.0

TABLE 1—*Continued*

Name	l (deg)	b (deg)	Q^a	ID ^b	$v_{\min}$ (km s ⁻¹)	$v_{\max}$ (km s ⁻¹)	$\bar{v}$ (km s ⁻¹)	b^c (km s ⁻¹)	$\log N \pm \sigma_{sc} \pm \sigma_{sys}$	$(W_\lambda/\sigma_W)^d$
Ton S210.....	224.97	-83.16	4	EPn	230	310	259	(28 ± 4)	13.28 ± 0.13 ± 0.30	3.1
Mrk 734.....	244.75	63.94	2	LG	-250	-120	-187	53 ± 4	13.97 ± 0.05 ± 0.11	8.3
HE 0226-4110.....	253.94	-65.77	4	EPn†	140	275	195	((45 ± 4))	14.10 ± 0.10 ± 0.16	4.1
PKS 0558-504.....	257.96	-28.57	3	MSe ^f	80	260	164	59 ± 4	13.98 ± 0.05 ± 0.03	8.8
NGC 1705.....	261.08	-38.74	3	MSe ^f	210	315	258	36 ± 5	13.68 ± 0.09 ± 0.07	4.5
			4	MS†	120	245	183	((53 ± 5))	13.78 ± 0.04 ± 0.41	6.8
				MS	245	405	330	55 ± 4	14.31 ± 0.02 ± 0.14	22.2
HE 1115-1735.....	273.65	39.64	1	EPn†	90	175	131	28 ± 3	14.13 ± 0.10 ± 0.06	5.0
HE 1143-1810.....	281.85	41.71	3	EPn	100	210	139	41 ± 4	14.25 ± 0.06 ± 0.12	8.9
				EPn	210	320	254	37 ± 5	13.85 ± 0.11 ± 0.08	3.6
ESO 265-G23.....	285.91	16.59	1	EPn	200	310	262	(39 ± 5)	14.44 ± 0.09 ± 0.07	6.1
ESO 572-G34.....	286.12	42.12	3	EPn†	100	275	171	((65 ± 4))	14.47 ± 0.03 ± 0.06	16.6
3C 273.0.....	289.95	64.36	4	EPn† ^g	105	160	125	(16 ± 4)	13.17 ± 0.11 ± 0.33	3.4
				EPn† ^g	160	260	210	31 ± 4	13.52 ± 0.07 ± 0.08	6.3
Fairall 9.....	295.07	-57.83	2	MS	100	275	183	(72 ± 4)	14.33 ± 0.07 ± 0.07	7.4
Tol 1247-232.....	302.60	39.30	2	EPn†	100	255	168	((66 ± 6))	14.18 ± 0.10 ± 0.07	4.4
PG 1302-102.....	308.59	52.16	4	EPn	190	340	256	51 ± 4	13.95 ± 0.06 ± 0.04	7.5
ESO 141-G55.....	338.18	-26.71	4	Oth	140	225	176	(28 ± 3)	13.45 ± 0.11 ± 0.14	3.6
Mrk 1383.....	349.22	55.12	4	Oth†	100	160	125	(23 ± 3)	13.42 ± 0.09 ± 0.18	5.0
PKS 2005-489.....	350.37	-32.60	3	Oth†	120	225	156	((42 ± 5))	13.92 ± 0.06 ± 0.17	7.9

^a Data quality (S/N per 20 km s⁻¹ resolution element): $Q = 1$ (S/N = 3–5), $Q = 2$ (S/N = 5–9), $Q = 3$ (S/N = 9–14), $Q = 4$ (S/N > 14).

^b HVC identification: (A) complex A; (C) complex C; (EPn) extreme positive (north); (LG) Local Group; (MS) Magellanic Stream; (MSe) Magellanic Stream extension; (OA) Outer Arm; (Oth) other. A dagger symbol (†) indicates that the feature is also considered a high-velocity “wing” feature, as described in § 8.1.

^c Observed line width as defined in § 3.3. These widths have not been corrected for the *FUSE* instrumental broadening ($b_{\text{inst}} \sim 12\text{--}15$ km s⁻¹). Values in parentheses are somewhat uncertain because they depend upon the integration limits adopted. Double parentheses indicate that the velocity cutoffs used for the integration are not well constrained by the data and were chosen according to the rules outlined in the text.

^d Detection significance. Equivalent widths, W_λ , and errors, σ_W , can be found in Table 2 of the O VI catalog paper (Wakker et al. 2003).

^e This NGC 588 component may contain a contribution from M33 (see Wakker et al. 2003).

^f These features toward HE 0226-4410 and PKS 0558-504 are probably closely related to the MS components (see § 6.3).

^g Sembach et al. 2001b discuss these two features toward 3C 273 as a single broad absorption feature.

velocities, the primary contaminant is the H₂ (6-0) $R(4)$ line at 1032.349 Å (+123 km s⁻¹). Of these, the H₂ lines are the most important, since even small H₂ column densities in the $J = 3$ or $J = 4$ rotational levels produce detectable absorption lines; 20 mÅ features correspond to N_J as low as $(1\text{--}2) \times 10^{14}$ cm⁻² (see, e.g., Fig. 1, *top panel*). We carefully modeled the strengths of the H₂ $J = 3$ and $J = 4$ lines in the O VI wavelength region using other H₂ lines in the same rotational levels at other wavelengths (see § 3.8 of Wakker et al. 2003 for a description of the procedure). A weak transition of Co II at 1031.542 Å (-112 km s⁻¹) produces negligible absorption along the low-density sight lines studied in this work.¹⁰ The deuterated hydrogen HD (6-0) $R(0)$ λ1031.912 line, which occurs at low velocities (-4 km s⁻¹ with respect to O VI λ1031.926), can be important for studies of the interstellar medium (ISM) in the Galactic disk and halo but has not yet been observed in absorption at high velocities. HD is detected toward only one object in our sample (NGC 7469, at low velocity) and is not important for our study of the high-velocity gas along this sight line, though it must be accounted for in our study of the halo gas in this direction (Savage et al. 2003).

Another possible source of confusion with the high-velocity O VI λ1031.926 absorption is redshifted H I and metal-line absorption in the intergalactic medium along the

sight line or in the immediate environment of the QSO/AGN. The most important lines to search for within ±500 km s⁻¹ of the O VI λ1031.926 line are H I Lyβ ($z \sim 0.0044\text{--}0.0077$) and H I Lyγ ($z \sim 0.0593\text{--}0.0628$), but we also found instances of H I Lyδ ($z \sim 0.0847\text{--}0.0883$), H I Lyε ($z \sim 0.0985\text{--}0.1022$), C III λ977.020 ($z \sim 0.054\text{--}0.0580$), Si II λ1020.699 ($z \sim 0.0093\text{--}0.0127$), and S III λ1012.502 ($z \sim 0.0175\text{--}0.0209$). Whenever possible, we have checked existing *Hubble Space Telescope* (*HST*) data for corresponding Lyα absorption or *FUSE* data for other H I Lyman series lines to confirm or refute such identifications. The middle and bottom panels of Figure 1 contain several examples of intervening absorption lines arising in the IGM. We refer the reader to the Appendix of the O VI catalog paper (Wakker et al. 2003) for comments about IGM absorption features near the O VI lines.

3.2. Column Densities

We derived the column densities listed in Table 1 from the apparent optical depths of the O VI λ1031.926 absorption lines under the assumption that there is no unresolved saturated structure in the profiles. The apparent column density as a function of velocity, v (km s⁻¹), is given by $N_a(v) = (m_e c / (\pi e^2))^{-1} \tau_a(v) (f \lambda)^{-1} = 3.768 \times 10^{14} \tau_a(v) (f \lambda)^{-1}$ [cm⁻² (km s⁻¹)⁻¹], where the wavelength λ is given in Angstroms, and the optical depth is related to the estimated continuum intensity and the observed line intensity through the relation $\tau_a(v) = \ln[I_c(v)/I(v)]$. The $N_a(v)$ profiles represent valid, instrumentally blurred versions of the actual

¹⁰ For $N(\text{H I}) = 1 \times 10^{21}$ cm⁻², a cosmic (meteoritic) abundance ratio (Co/H) = 8.13×10^{-8} (Anders & Grevesse 1989), and a typical interstellar Co depletion $\delta_{\text{Co}} \leq 0.03$ (Federman et al. 1993), we expect $W_{1032}(\text{Co II}) \leq 1$ mÅ.

column density profiles when no unresolved saturated structures are present or when the absorption is weak ($\tau_{\max} \lesssim 1$ –3). In such cases, $N = \int N(v)dv = \int N_a(v)dv$; see Savage & Sembach (1991) for a discussion of the applicability of the apparent optical depth method and uncertainties involved in calculating column densities from $N_a(v)$ profiles. At the spectral resolution afforded by *FUSE*, the O VI lines are fully resolved for gas at temperatures $T \gtrsim 1.4 \times 10^5$ K. At lower temperatures, the lines may still be resolved if the turbulent motions in the cloud are modest. For example, if $b_{\text{turb}} \approx 8$ km s⁻¹, the lines will be resolved for $T \gtrsim 8 \times 10^4$ K. At lower temperatures, the abundance of O VI in collisionally ionized gas is expected to be less than a few percent of the total oxygen abundance, even in nonequilibrium cooling situations (Shapiro & Moore 1976).

We report two errors for each of the column densities in Table 1. The first error (σ_{sc}) is a quadrature addition of the uncertainties associated with continuum placement and statistical (Poisson) noise propagated through the line profile following the procedures outlined by Sembach & Savage (1992). This error accounts for most of the uncertainty involved in making an objective estimate of the line strength. The second error (σ_{sys}) is a quadrature addition of systematic uncertainties accounting for fixed-pattern noise, choice of velocity integration limits, and removal of H₂ features. This error, which often dominates the total error, accounts for some of the more subjective decisions that must be made when measuring the line strength. To be conservative, we have made generous allowances for the various components of σ_{sys} . The fixed-pattern noise component of the systematic error accounts for an intensity uncertainty of $\sim 10\%$ integrated over the width of one resolution element. Fixed-pattern noise structures can mimic weak, high-velocity absorption lines. This pattern can vary from one observation to the next, depending upon the positions of the spectra on the microchannel plates. Whenever possible, we checked the data from multiple instrument channels (LiF1, LiF2) to determine the impact of fixed-pattern noise on the observed absorption features.¹¹ The velocity integration component of the systematic error accounts for changes of ± 15 km s⁻¹ in the values of $v_{\min}$ and $v_{\max}$. The H₂ decontamination component accounts for modest uncertainties in the profile shapes and strengths of the model H₂ lines used to deblend the absorption ($\Delta v_0 = 10$ km s⁻¹, $\Delta b = 10$ km s⁻¹, and $\Delta[I/I_c] = 0.2$). Wakker et al. (2003) describe all of these sources of error and the methods used to calculate them in § 4 of the catalog paper.

The values of $N(\text{O VI})$ listed in Table 1 should be free of saturation effects if the O VI is collisionally ionized. If the gas is photoionized, the temperature may be as low as $\sim 10^4$ K. Consider the following conservative example. A single isolated Gaussian O VI $\lambda 1031.926$ feature that arises in 10^4 K gas and has no additional broadening beyond its thermal width ($b \approx 3.2$ km s⁻¹) must have an intrinsic central optical depth $\tau_{\max}(v) \approx 1$ before a 0.10 dex saturation correction is required for a *FUSE* observation of the $\lambda 1031.926$ line (see Savage & Sembach 1991). When observed at the resolution of *FUSE*, this line has a maximum apparent optical depth $\tau_{a,\max}(v) \approx 0.21$ and a maximum apparent column density per unit velocity

$N_{a,\max}(v) \approx 6 \times 10^{11}$ cm⁻² (km s⁻¹)⁻¹. For comparison, an isolated O VI $\lambda 1031.926$ line with $\tau_{\max}(v) \approx 1$ and $b \approx 15$ km s⁻¹ observed by *FUSE* would have $\tau_{a,\max}(v) \approx 0.75$ and $N_{a,\max}(v) \approx 2 \times 10^{12}$ cm⁻² (km s⁻¹)⁻¹. Since all but a few of the observed O VI features have line widths well in excess of the instrumental width, cold narrow components can contribute only a fraction of the total observed columns, and therefore the effects of these components on the resulting $N_a(v)$ profiles are diminished by broader components (i.e., their central optical depths would have to be much greater than unity to impact the total column density by 0.1 dex).

Ideally, one would like to check explicitly whether unresolved saturated structure is present in the observed O VI absorption profiles by comparing the values of $N_a(v)$ for both lines of the doublet. In practice, this is difficult to do for the high-velocity O VI absorption since the high-velocity portions of the 1037.617 Å line are often blended with other Galactic absorption features. The comparison at high velocities is possible in two cases (ESO 572–G34 and PG 1116+215), and no unresolved saturated structure is found. For sight lines where it is possible to examine the low-velocity portions of the profiles, the $\lambda 1031.926$ and $\lambda 1037.617$ results are usually in good agreement, implying that saturation corrections for absorption in the thick disk/halo of the Galaxy are not required for most of the observations. Wakker et al. (2003) illustrate the $N_a(v)$ profiles for the two O VI lines for all of the objects surveyed. In 17 of the 22 cases where a comparison of $N_{a,\lambda 1038}/N_{a,\lambda 1038}$ can be made, the ratio is unity to within the 1σ uncertainties. In the remaining five cases, the values of $N_{a,\lambda 1037}/N_{a,\lambda 1038}$ range from ~ 1.1 to 1.6 , with four of the five cases having saturation corrections of less than 0.25 dex (see Table 2 in Savage et al. 2003). Since the high-velocity O VI absorption features are generally weaker than the Galactic thick disk/halo features, saturation corrections for the high-velocity gas are small enough that they do not affect the scientific conclusions of this study.

We show examples of the O VI apparent column density profiles for the Mrk 509, ESO 572–G34, and PG 1116+215 sight lines in Figure 2. Toward Mrk 509, the thick disk/halo O VI $\lambda 1031.926$ absorption at low velocities is several times stronger than the high-velocity absorption. The $\lambda 1037.617$ absorption is blended with other features at high velocities, so a direct comparison of the $N_a(v)$ profiles at $v_{\text{LSR}} < -100$ km s⁻¹ is not possible. However, the good agreement in the $N_a(v)$ profiles between -50 and $+100$ km s⁻¹ suggests that the weaker, high-velocity absorption seen in the $\lambda 1031.926$ line should not be affected by unresolved saturated structure. Toward both ESO 572–G34 and PG 1116+215, the high-velocity and thick disk/halo absorption features have comparable strengths and widths. The good agreement in the $N_a(v)$ profiles at velocities between -50 and $+250$ km s⁻¹ shows that the data are unaffected by unresolved saturated structure. Thus, the $N_a(v)$ profiles for these sight lines are also valid instrumentally smeared representations of the true values of $N(v)$. Since the high-velocity O VI line widths and column densities are correlated (see § 9.3), we conclude that saturation effects do not strongly influence the O VI column densities derived for the high-velocity gas.

We estimated 3σ upper limits to the column densities for the 43 sight lines for which we find no evidence of high-velocity O VI absorption. First, we scaled the equivalent width error (σ_W) obtained for the Galactic thick disk/halo component of the absorption found by Wakker et al. (2003)

¹¹ Only two of the objects considered in this study (Ton S210, HE 0226–4110) were observed with special focal-plane image motions to reduce the fixed-pattern noise in the spectra.

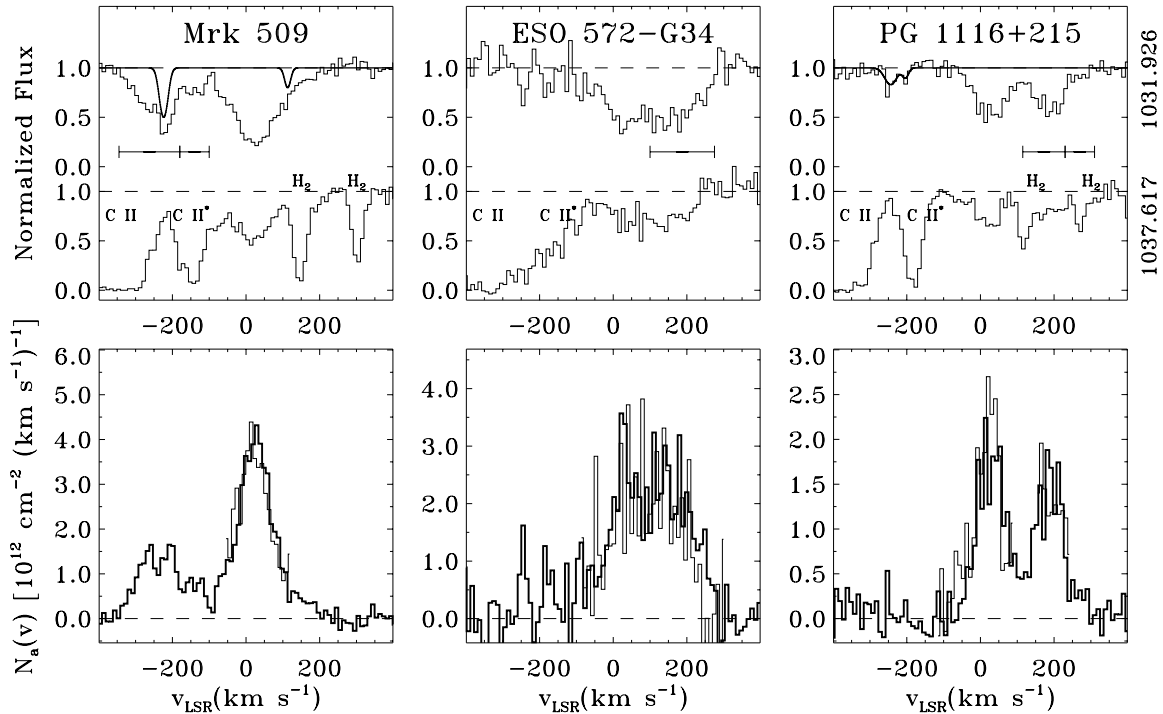


FIG. 2.—*Upper panels:* Normalized intensity profiles for the O VI $\lambda\lambda 1031.926, 1037.617$ lines toward Mrk 509, ESO 572-G34, and PG 1116+215. The O VI $\lambda 1031.926$ line is shown at the top of each panel, together with a model of the H₂ (6-0) $P(3)$ $\lambda 1031.191$ and (6-0) $R(4)$ $\lambda 1032.349$ absorption features (*thin solid line*). The O VI $\lambda 1037.617$ line is shown below the 1031.926 Å line, together with horizontal bars indicating the integration ranges of the high-velocity absorption. The high-velocity portions of the $\lambda 1037.617$ absorption are sometimes blended with other Galactic ISM features [C II $\lambda 1036.337$, C II* $\lambda 1037.018$, H₂ (5-0) $R(1)$ $\lambda 1037.149$ and $P(1)$ $\lambda 1038.157$]. *Bottom panels:* Apparent column density profiles for the O VI $\lambda 1031.926$ absorption (*heavy line*) and $\lambda 1037.617$ absorption (*light line*). The values of $N_a(v)$ for the two lines agree well when a direct comparison is possible, indicating that there are no unresolved saturated structures within the lines at these velocities.

to a value appropriate for an integration range of 100 km s^{-1} . We then calculated the corresponding 3σ column density limit assuming the linear curve-of-growth relation between W_λ and N : $W_\lambda = (\pi e^2)(m_e c^2)^{-1} N f \lambda^2$. For O VI $\lambda 1031.926$, the 3σ column density limit is $N(\text{cm}^{-2}) < 2.4 \times 10^{12} \sigma'_W(\text{mÅ})$, where σ'_W is the scaled equivalent width error. Table 2 contains the Galactic coordinates (l, b), data quality (Q), scaled equivalent width error (σ'_W), and column density limit for each of the 43 sight lines. Notes appended to the entries indicate whether the listed limits may be affected by other absorption features.

3.3. Velocity Centroids and Line Widths

For each sight line where high-velocity O VI is observed, we calculated the centroid velocity of the absorption by integrating the first moment of the apparent optical depth profiles, $\bar{v} = \int v \tau_a(v) dv / \int \tau_a(v) dv$, over the velocity range ($v_{\min}$ to $v_{\max}$) used for the column density calculation. We calculated the velocity widths by integrating the second moments of the apparent optical depth profiles, $b = [2 \int (v - \bar{v})^2 \tau_a(v) dv / \int \tau_a(v) dv]^{1/2}$, over the same velocity range. The factor of $\sqrt{2}$ in this equation scales the derived width to an approximate Doppler spread parameter; for a single Gaussian component this relationship is exact: $b = \sqrt{2}\sigma$. Most of the high-velocity O VI features observed are weak [$\tau_a(v) < 1$]. Therefore, the derived value of the line width can be sensitive to the integration limits and to noise fluctuations near the ends of the integration range. It is best to examine the values of b for the sample in a statistical sense rather than regarding these as robust measures of the

high-velocity widths for individual sight lines. We list values of $\bar{v}$ and b in Table 1.

4. GENERAL GROUPS OF HIGH-VELOCITY FEATURES

In the top panel of Figure 3, we identify the 102 sight lines in our sample. In this Hammer-Aitoff projection, the Galactic anticenter is at the center of the plot, and Galactic longitude increases from right to left. The name of each object listed in Table 1 appears next to each point. The absence of data points at low Galactic latitudes ($-15^\circ \lesssim b \lesssim 15^\circ$) is the result of selecting objects sufficiently far away from the Galactic plane to avoid significant extinction of far-ultraviolet radiation.¹² Several other regions of the figure are also sparsely populated, including the Galactic center region for $0^\circ \lesssim b \lesssim 70^\circ$ and the anticenter region for $-60^\circ \lesssim b \lesssim 0^\circ$.

Along 59 of the 102 sight lines we detect high-velocity O VI $\lambda 1031.926$ absorption with integrated (total) values of $W_\lambda/\sigma_W \geq 3.0$. Whenever possible, we have identified the high-velocity O VI absorption features listed in Table 1 with corresponding high-velocity features observed in H I 21 cm emission. H I data of varying quality exist for all of the sight lines considered here. The available single-dish radio data

¹² A reddening of $E(B-V) = 0.10$ mag corresponds to a flux reduction factor of 4 at 1032 Å (i.e., $A_\lambda = 1.5$ mag) for the standard Galactic interstellar extinction curve with a total to selective extinction ratio $R_V = 3.1$ (Cardelli, Clayton, & Mathis 1989).

TABLE 2
SIGHT LINES WITH NO HIGH-VELOCITY O VI DETECTED BY *FUSE*

Name	l (deg)	b (deg)	Q^a	$\sigma_W'^b$ (mÅ)	$\log N(\text{O vi})^c$ (3σ)	Notes ^d
PG 1352+183.....	4.37	72.87	1	51.6	<14.09	
PG 1404+226.....	21.48	72.37	1	33.6	<13.91	
NGC 5548.....	31.96	70.50	2	29.1	<13.84	
PG 1402+261.....	32.96	73.46	2	24.3	<13.76	1
vZ 1128 ^e	42.50	78.68	4	4.5	<13.04	
Mrk 829.....	58.76	63.25	2	21.1	<13.70	5
PG 1444+407.....	69.90	62.72	2	30.0	<13.86	
SBS 1415+437.....	81.96	66.20	2	25.7	<13.79	
PG 1411+442.....	83.83	66.35	2	42.4	<14.01	3
PG 1415+451.....	84.72	65.32	1	28.6	<13.84	4
Mrk 487.....	87.84	49.03	2	45.1	<14.03	
Mrk 59.....	111.54	82.12	3	9.5	<13.36	5
Mrk 205.....	125.45	41.67	1	52.2	<14.10	
3C 249.1.....	130.39	38.55	2	28.2	<13.83	1,2
Mrk 209.....	134.15	68.08	3	14.7	<13.55	4
PG 0804+761.....	138.28	31.03	4	7.1	<13.23	1,2
HS 0624+6907.....	145.71	23.35	2	19.7	<13.67	1,2
PG 0832+675 ^e	147.75	35.01	3	18.3	<13.64	1,3,4
V II Zw 118.....	151.36	25.99	4	8.4	<13.30	1,2
MS 0700.7+6338.....	152.47	25.63	1	42.0	<14.00	1
NGC 4151.....	155.08	75.06	3	11.1	<13.42	1,4
Mrk 9.....	158.36	28.75	3	16.1	<13.59	1,2
Mrk 116.....	160.53	44.84	3	19.3	<13.67	1,2
Mrk 79.....	168.60	28.38	2	21.2	<13.70	1,2
NGC 1068.....	172.10	-51.93	4	10.5	<13.40	1,4
NGC 985.....	180.84	-59.49	3	14.9	<13.55	1
Ton 1187.....	188.33	55.38	2	36.9	<13.95	
SBS 0335-052.....	191.34	-44.69	2	36.0	<13.94	
PG 0832+251.....	199.49	33.15	1	44.4	<14.03	1
HE 0238-1904.....	200.48	-63.63	1	47.3	<14.05	1,4
Mrk 1095.....	201.69	-21.13	3	9.2	<13.34	1,2
Mrk 36.....	201.76	66.49	1	57.0	<14.14	1
NGC 3504.....	204.60	66.04	1	42.2	<14.00	5
Mrk 618.....	206.72	-34.66	2	22.4	<13.73	1,2
PG 1004+130.....	225.12	49.12	3	16.3	<13.59	1,2,4
HE 0450-2958.....	231.13	-37.59	2	54.2	<14.11	
NGC 1399.....	236.72	-53.63	2	50.3	<14.08	
PG 1211+143.....	267.55	74.32	3	16.9	<13.61	1,4
Mrk 771.....	269.44	81.74	1	24.1	<13.76	
NGC 4649.....	295.88	74.34	1	47.4	<14.05	
PG 1307+085.....	316.79	70.71	3	18.6	<13.65	1
HE 1326-0516.....	320.07	56.07	1	45.2	<14.03	
Tol 1924-416.....	356.94	-24.10	2	19.3	<13.67	1

^a Data quality (S/N per 20 km s⁻¹ resolution element): $Q = 1$ (S/N = 3–5), $Q = 2$ (S/N = 5–9), $Q = 3$ (S/N = 9–14), $Q = 4$ (S/N > 14).

^b Scaled equivalent width error (1 σ). This error was derived from the equivalent width error found for the Galactic thick disk/halo O vi absorption along the sight line (Wakker et al. 2003; Savage et al. 2003) and is appropriate for a velocity integration range spanning 100 km s⁻¹. It includes statistical and continuum placement uncertainties.

^c These are 3 σ limits set by the listed value of σ_W' and the assumption of a linear curve of growth (see § 3.2).

^d (1) Sight line contains H₂ (6–0) $P(3)$ λ 1031.191 absorption. Actual limit may be higher if considering absorption near ≈ -214 km s⁻¹. (2) Sight line contains H₂ (6–0) $R(4)$ λ 1032.349 absorption. Actual limit may be higher if considering absorption near $\approx +123$ km s⁻¹. (3) Due to other absorption features, actual limit may be higher if considering absorption at high negative velocities. (4) Due to other absorption features, actual limit may be higher if considering absorption at high positive velocities. (5) Actual limit may be higher, depending on velocity range chosen because continuum placement is difficult at high velocities.

^e Stellar sight line: $z = 9.8$ kpc for vZ 1128 and $z = 4.7$ kpc for PG 0832+675.

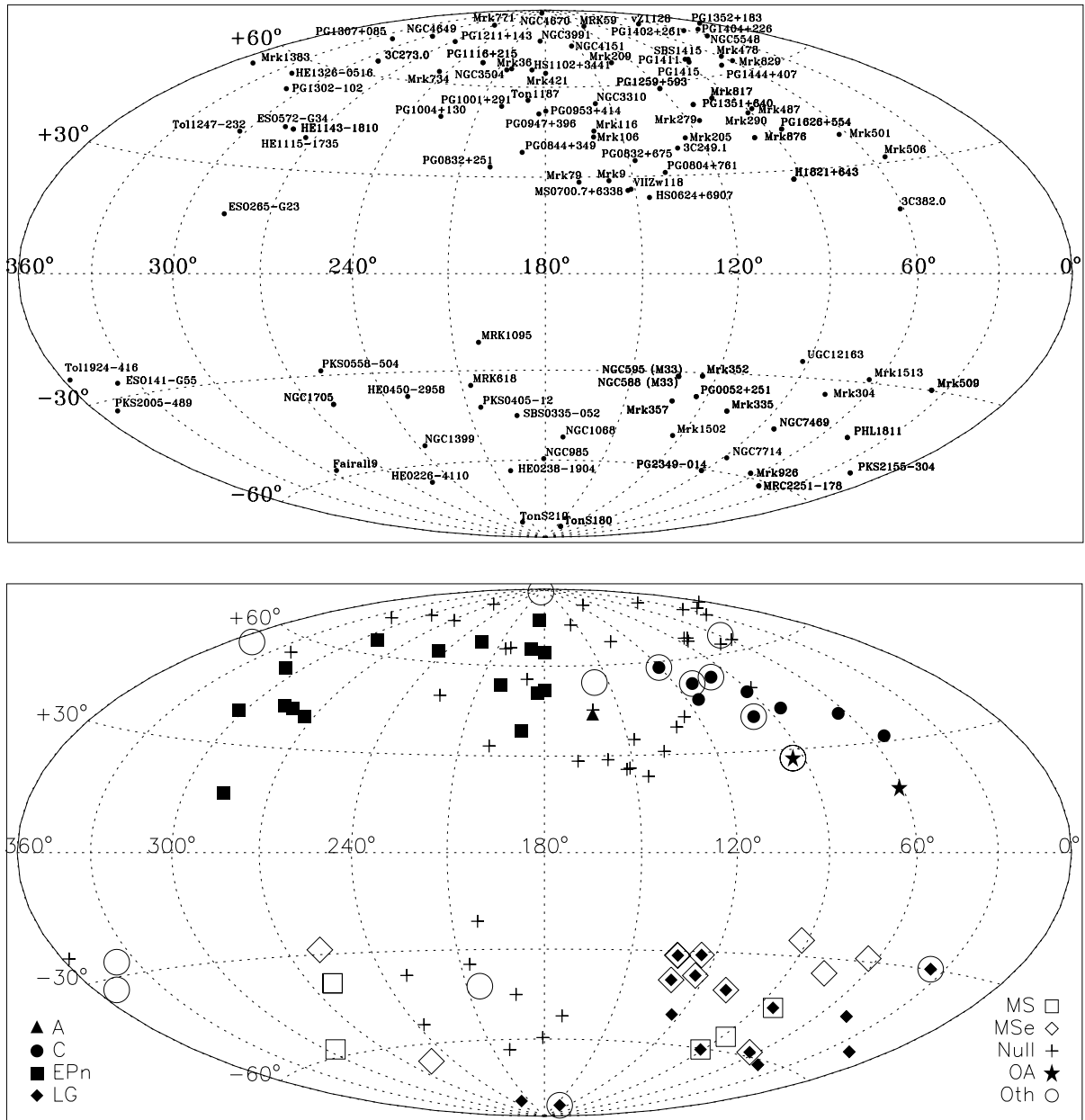


FIG. 3.—*Top panel:* All-sky Hammer-Aitoff projection of the 102 sight lines in the *FUSE* O VI survey. In this projection, the Galactic anticenter is at the center of the figure, and Galactic longitude increases to the left. The locations and names of the 100 QSOs/AGNs and two halo stars are indicated. In a few cases, the names have been abbreviated for clarity. *Bottom panel:* High-velocity O VI identifications. The “type” of high-velocity features (if any) observed along each sight line is coded according to the categories described in Table 3. For some sight lines, multiple high-velocity features are present. Plus symbols indicate the positions of the high-velocity gas nondetections listed in Table 2.

are shown by Wakker et al. (2003). The sources of H I data include the Leiden-Dwingeloo survey (Hartmann & Burton 1997), NRAO 140 foot telescope observations (Murphy et al. 1996), the Villa Elisa survey (Arnal et al. 2000; Morras et al. 2000), and Effelsberg 100 m telescope observations (see Wakker et al. 2001).

For some sight lines, the correspondence in the velocities and celestial coordinates of the O VI and H I allow for a straightforward association to be made, but for many features the association with H I emission is much less certain. Even in cases where there is obvious H I emission at the velocities of the O VI absorption, one must keep in mind that the exact relationship between the H I and O VI can be com-

plicated by ionization differences (neutral vs. ionized) and beam size effects (typically $9''$ – $36''$ for the H I emission vs. a microarcsecond beam size for the O VI absorption). With these caveats in mind, we split the sample of high-velocity O VI features into several categories, which are listed in Table 3. We summarize the number of features in each category (not necessarily the full range spanned by the H I), and the mean O VI column densities ($\langle \log N \rangle \pm \sigma_{(\log N)}$), central velocities ($\langle \bar{v} \rangle$), and velocity widths ($\langle b \rangle$). Several of these classifications contain high-velocity O VI features with relatively unambiguous H I counterparts (Complex A, Complex C, the Outer Arm, and

TABLE 3
O VI HIGH-VELOCITY CLASSIFICATIONS

Classification	ID	Number	$\langle \log N \rangle$	$\langle v \rangle$ (km s ⁻¹)	$\langle b \rangle$ (km s ⁻¹)	l (deg)	b (deg)
Complex A.....	A	1	13.81	-125	22	161.1	42.9
Complex C.....	C	9	13.92 (0.22)	-129 (14)	34 (11)	54.2 to 120.6	31.5 to 58.0
Extreme positive north.....	EPn	19	13.96 (0.37)	181 (49)	42 (13)	179.8 to 308.6	16.6 to 77.2
Magellanic Stream:							
($v_{\text{LSR}} > 0$ km s ⁻¹).....	MS	3	14.14 (0.31)	232 (84)	60 (10)	261.1 to 295.1	-57.8 to -38.7
($v_{\text{LSR}} < 0$ km s ⁻¹).....	MS	3	14.10 (0.10)	-296 (34)	40 (13)	83.1 to 91.7	-60.4 to -45.5
Magellanic Stream extension							
($v_{\text{LSR}} > 0$ km s ⁻¹).....	MSe	2	13.83 (0.21)	211 (66)	47 (16)	253.9 to 258.0	-65.8 to -28.6
($v_{\text{LSR}} < 0$ km s ⁻¹).....	MSe	10	14.18 (0.19)	-304 (29)	47 (7)	63.7 to 133.5	-58.8 to -25.3
Outer Arm	OA	2	14.01 (0.19)	-106 (22)	26 (6)	61.3 to 94.0	17.5 to 27.4
Local Group ^a	LG	20	14.09 (0.26)	-181 (53)	43 (12)	17.7 to 225.0	-85.1 to -29.9
Other:							
($v_{\text{LSR}} > 0$ km s ⁻¹).....	Oth	12	13.55 (0.28)	184 (97)	30 (6)	36.0 to 350.4	-85.1 to 88.6
($v_{\text{LSR}} < 0$ km s ⁻¹).....	Oth	3	13.51 (0.25)	-204 (49)	21 (4)	94.0 to 156.6	27.4 to 54.1

^a This grouping also includes the M33 feature toward NGC 595.

the Magellanic Stream). Other classifications contain high-velocity O VI features that do not have obvious H I counterparts, and these are labeled as either Local Group clouds or as “Other.” We discuss the above categories of features and selection criteria in more detail in §§ 6 and 8.

We show the locations and various categories of O VI features on the sky in the bottom panel of Figure 3. Each category is represented by a different symbol. We include the 43 null detections listed in Table 2 to indicate directions that have been searched for O VI but do not have any detectable high-velocity gas at a level consistent with the data quality of the observations. Most of these null detections (34/43) occur in the northern Galactic sky, and several occur within a few degrees of sight lines where high-velocity O VI is present.

5. RESULTS FOR THE SAMPLE OF HIGH-VELOCITY O VI ABSORPTION FEATURES

Eighty-four high-velocity O VI absorption features are present along 59 of the 102 complete halo sight lines having sufficient *FUSE* data quality to detect high-velocity O VI $\lambda 1031.926$ absorption at a significance of $\gtrsim 3\sigma$. Most of these detections are for absorption features with equivalent widths ≥ 30 mÅ. Six detections have $W_\lambda < 30$ mÅ. We include a weak feature toward PG 1259+593 with $W_\lambda \approx 14$ mÅ even though the formal detection confidence is only $\sim 2.3\sigma$ since the data quality is excellent and the feature is likely real. In this section, we provide information about the column densities, sky covering factors, and velocities of the O VI absorption.

5.1. Column Densities

We plot a histogram of the logarithmic column densities of the high-velocity O VI features in Figure 4, where we have binned the data into 0.10 dex intervals. The minimum and

maximum (logarithmic) column densities are 13.06 and 14.59, respectively, with an average value of $\langle \log N \rangle = 13.95 \pm 0.34$ and a median of 13.97. (The value of $\log \langle N \rangle = 14.06 \pm_{0.71}^{0.22}$ is similar.) The average high-velocity O VI column density is a factor of ~ 2.7 times (0.42 dex) lower than the value of $\langle \log N \rangle = 14.38 \pm 0.18$ reported for the Galactic thick disk/halo O VI by Savage et al. (2003). The thick disk/halo distribution of column densities, which is indicated in Figure 4 with a dashed line, is reasonably well represented as a Gaussian distribution. However, the observed velocity distribution for the high-velocity O VI is skewed and considerably broader because it is possible to

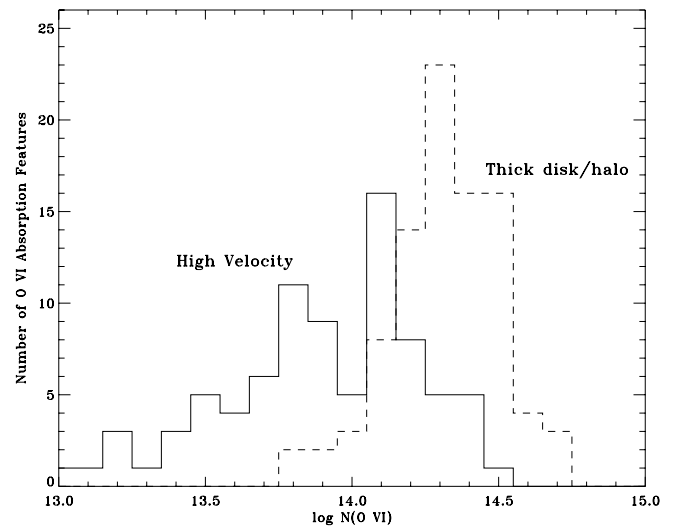


FIG. 4.—Logarithmic O VI column densities [$\log N(\text{O VI})$ (cm⁻²)] for the Milky Way thick disk/halo (dashed line) and high-velocity absorption features listed in Table 1 (solid line). The bin size for these distributions is 0.10 dex.

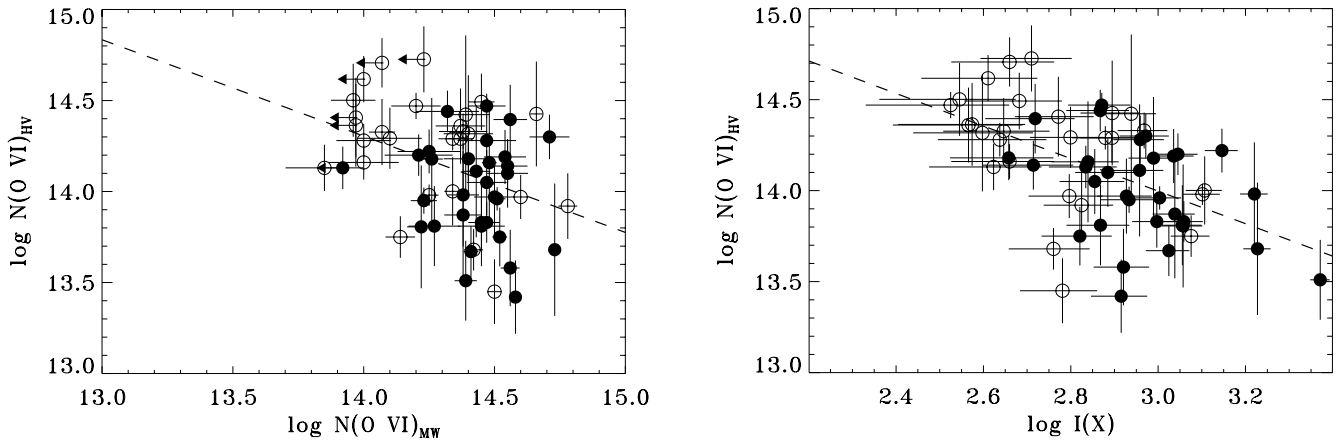


FIG. 5.—*Left panel:* Comparison of the O VI column densities of the thick disk/halo and high-velocity absorption along the 59 sight lines where high-velocity O VI absorption is observed. Open circles indicate sight lines with $b < 0^\circ$; filled circles indicate sight lines with $b > 0^\circ$. A modest anticorrelation of the two quantities exists (*dashed line*). *Right panel:* A comparison of the high-velocity O VI column densities and sight-line-averaged *ROSAT* 0.25 keV X-ray intensities ($I(X)$, in units of 10^{-6} counts s^{-1} arcmin $^{-2}$). A modest anticorrelation of the two quantities exists (*dashed line*).

trace lower column density features at velocities where blending with other O VI absorption is minimal. Low column density features exist in the thick disk/halo distribution as well (see Jenkins 1978a), but they are presumably blended with stronger O VI features at similar velocities. The lowest O VI column density observed for the Milky Way thick disk/halo ($\log N = 13.88$ toward Mrk 1095, not counting upper limits; Savage et al. 2003) is comparable to the mean of the high-velocity sample.

There are 16 sight lines for which the high-velocity gas dominates the *total* O VI absorption; these include ESO 265–G23, HE 1115–1735, MRC 2251–178, Mrk 304, Mrk 335, Mrk 926, Mrk 1502, NGC 588, NGC 595, NGC 1705, NGC 7469, NGC 7714, PG 0052+251, PG 2349–014, PHL 1811, and UGC 12163. In these directions the total O VI column densities of the high-velocity gas are $\sim 0.31 \pm 0.18$ dex higher than those of the Galactic thick disk/halo.

We plot the total high-velocity O VI column density as a function of thick disk/halo O VI column density in the top panel of Figure 5. This plot shows roughly an order of magnitude scatter in the high-velocity gas columns at all values of $N(\text{O VI})_{\text{MW}}$ encountered along these sight lines. Within this scatter there is an apparent anticorrelation of $N(\text{O VI})_{\text{HV}}$ and $N(\text{O VI})_{\text{MW}}$. For the 53/59 sight lines where good measures of both quantities are possible (excluding upper limits), we find a linear correlation coefficient of -0.26 and a slope $\Delta \log N_{\text{HV}} / \Delta \log N_{\text{MW}} \approx -0.40$ (*dashed line*). The Spearman rank correlation probability that the two populations are uncorrelated is only 5%, which indicates that the two populations are anticorrelated at about the 2σ level. If the six upper limits on $\log N_{\text{MW}}$ are included in the analysis as measured values, the significance of the all-sky anticorrelation increases to 2.8σ , with an even higher significance if the actual values are less than the measured limits. (If the actual values are a factor of 2 less than the limits, then the significance of the anticorrelation climbs to 3σ .)

A weak anticorrelation between $\log N_{\text{MW}}$ and $\log N_{\text{HV}}$ may be expected if some of the high-velocity gas is lower velocity disk/halo gas that has been displaced to high velocities by energetic processes occurring within the Galaxy (e.g., supernovae). However, selection effects likely influence the trend seen in the left panel of Figure 5. The

enhancement of thick disk/halo O VI in the northern sky (Savage et al. 2003) together with the low values of $N(\text{O VI})_{\text{MW}}$ along southern sight lines containing large columns of high-velocity O VI at longitudes $30^\circ < l < 130^\circ$ (MS, MSe, LG categories—see Table 3) results in the general trend seen. The anticorrelation is weakened if data points in the northern and southern Galactic sky are considered separately. In the north, the data points have a distribution that shows an anticorrelation at $< 1\sigma$ confidence. In the south, the anticorrelation has a significance of $\sim 1.5\sigma$ if limits are included, and $\sim 1.0\sigma$ if the limits are omitted. Thus, we conclude that much of the observed anticorrelation may simply be due to differences in the Milky Way and HVC distributions in the two hemispheres.

In the right panel of Figure 5 we plot the integrated high-velocity O VI column density against the integrated 0.25 keV X-ray intensity along the 59 sight lines where high-velocity O VI is detected. The soft X-ray data points are from the *ROSAT* all-sky survey (Snowden et al. 1997) and are R1+R2 band averages of the eight $12'$ pixels (~ 1150 arcmin 2 total) surrounding each sight line, ignoring the pixel directly along the sight line to avoid the X-ray emission from the background AGN or QSO being observed. The anticorrelation of $N(\text{O VI})_{\text{HV}}$ with $I(X)$ is slightly stronger here than in the left panel of Figure 5. The trend largely disappears if sight lines with $\log N(\text{O VI})_{\text{HV}} < 14$ are omitted from consideration. Interestingly, a similar comparison of $I(X)$ with $N(\text{O VI})_{\text{MW}}$ by Savage et al. (2003, their Fig. 19) reveals no correlation between $N(\text{O VI})_{\text{MW}}$ and $I(X)$, which if taken at face value seems to indicate that the X-ray and high-velocity O VI are coupled more strongly. This too may be the result of selection effects. The interpretation of this plot is complicated by various problems encountered when comparing infinitesimal point source absorption-line observations with low-resolution (both spatial and spectral) X-ray emission observations. Besides sampling different paths through the ISM, additional factors such as strong spectral attenuation in the X-ray band by intervening hydrogen, small-scale structure in the ISM, and strong X-ray signals from foreground ISM gas make it difficult to quantify the X-ray emission associated explicitly with the high-velocity gas. Future high-resolution X-ray

observations will be needed to determine if this trend holds up under more careful scrutiny.

5.2. Sky Distribution—Column Densities

The absorption-line measurements for the individual sight lines in our study sample gas along very small solid angles. However, it is possible to construct a rough picture of the O VI distribution on the sky when the sight lines are considered together. Figure 6 contains all-sky plots of the distribution of high-velocity O VI column densities. In the top panel, the column densities are coded for each sight line according to symbol size, with black filled circles representing detections and downward-pointing triangles indicating upper limits. In cases where multiple features are present along a sight line, the circle is split, and the values for the individual features are coded side by side. In the bottom panel of Figure 6, we plot a small filled circle, to indicate the precise location of each sight line, surrounded by a color-coded region (12° in radius) indicating the high-velocity O VI column densities of the features listed in Table 1. In some directions, the colored region is split into several colors since multiple high-velocity features are present. For sight lines where no high-velocity gas is detected (see Table 2), we color-code the column densities of the upper limits with small (2.5° radius) circles. Each sight line can be identified by cross-referencing its position with the object names in Figure 3. Large O VI column densities for the high-velocity gas occur in the southern Galactic hemisphere in directions associated with either the Magellanic Stream (e.g., Fairall 9, NGC 1705) or possible extragalactic clouds (e.g., Mrk 304, Mrk 926). In a few cases (e.g., ESO 265–G23, ESO 572–G34), large column densities also occur in the northern Galactic sky.

A comparable map of the sky distribution of Galactic thick disk/halo O VI column densities is discussed by Savage et al. (2003, see their Fig. 7). The O VI catalog paper contains maps of the high-velocity O VI column densities in narrow velocity channels. These maps allow one to examine the column densities as a function of velocity and position as well as the relationship of the high-velocity O VI to lower velocity O VI.

5.3. Sky Covering Factor

To make a meaningful estimate of the sky covering factor of the high-velocity gas, it is important to note that the data

quality varies from sight line to sight line. If we consider only the highest quality ($Q = 4$) sight lines in the O VI sample, we find that 22 of 26 sight lines have *total* high-velocity O VI equivalent widths $\Sigma W_{1032} \geq 30$ mÅ at a detection confidence $[W_{1032}/\sigma_W]_{\text{tot}} \geq 3.0$. The remaining four $Q = 4$ sight lines (NGC 1068, PG 0804+761, VII Zw 118, and vZ 1128) have equivalent width errors that would allow high confidence detections of 30 mÅ features if they were present (see Table 2). The $Q = 4$ sight lines are scattered across the sky and are not unique to one particular region. At lower data qualities ($Q = 1-3$), the percentage of sight lines with $\Sigma W_{1032} \geq 30$ mÅ detected at high confidence drops to about 50%, with few of the nondetection sight lines having sufficient data quality to rule out weak absorptions. Fifty-nine of the 102 sight lines in the sample have total high-velocity O VI equivalent widths $\Sigma W_{1032} > 30$ mÅ at a detection confidence $[W_{1032}/\sigma_W]_{\text{tot}} \geq 3.0$. Thus, a key result of our survey is that a large fraction (at least 58% and perhaps as many as 85%) of the sight lines contain high-velocity O VI with $\Sigma W_{1032} > 30$ mÅ.

At higher equivalent width thresholds, $\Sigma W_{1032} \gtrsim 100$ mÅ, the effect of data quality on the resulting detection rate is diminished considerably. We find that $\sim 42\%$ of the $Q = 4$ sight lines have $\Sigma W_{1032} \gtrsim 100$ mÅ at 3σ confidence, compared to $\sim 38\%$ for the $Q = 1-3$ sight lines. There is no significant difference in the detection rate within the individual data quality intervals at this threshold. We list the numbers and percentages of sight lines containing high-velocity O VI for various equivalent width thresholds and data qualities in Table 4. Values for equivalent width thresholds less than 100 mÅ for $Q = 1-3$ sight lines are likely incomplete and should probably be treated as lower limits. These numbers are useful for comparisons with detection rates for other O VI absorption systems, such as the weak IGM O VI absorbers (see Savage et al. 2002) or the Galactic thick disk/halo. Positive detections of O VI associated with the thick disk/halo occur for 91 of the 102 sight lines in our sample, and the 11 nondetections occur for sight lines where the data quality is marginal (Savage et al. 2003).

We provide a more detailed estimate of the sky covering fraction of high-velocity O VI in Table 5, where we list the numbers and percentages of sight lines in our sample having total high-velocity O VI column densities, $\Sigma N(\text{O VI})_{\text{HV}}$, greater than a column density threshold, N_0 . We list values for the entire sample as well as for several quadrants in Galactic longitude and latitude ($0^\circ < l < 180^\circ$,

TABLE 4
HIGH-VELOCITY O VI DETECTION SUMMARY

ΣW_λ THRESHOLD (mÅ)	NUMBER OF SIGHT LINES WITH $[W_\lambda/\sigma_W]_{\text{tot}} > 3.0$ ^{a,b}				
	All Q	$Q = 1$	$Q = 2$	$Q = 3$	$Q = 4$
30.....	59 (58%) ^c	11 (48%) ^c	14 (47%) ^c	12 (52%) ^c	22 (85%)
50.....	55 (54%) ^c	11 (48%) ^c	14 (47%) ^c	12 (52%) ^c	18 (69%)
100.....	40 (39%)	9 (39%)	13 (43%)	7 (30%)	11 (42%)
150.....	27 (26%)	6 (26%)	9 (30%)	7 (30%)	5 (19%)
200.....	18 (18%)	3 (13%)	6 (20%)	5 (22%)	4 (15%)

^a Number of sight lines (and percentages) with total integrated high-velocity O VI $\lambda 1031.926$ equivalent widths, ΣW_{1032} , greater than the listed equivalent width threshold.

^b There are 102 sight lines in the sample: 23 with $Q = 1$, 30 with $Q = 2$, 23 with $Q = 3$, and 26 with $Q = 4$.

^c These $Q = 1-3$ values should be treated with caution since the data quality is not sufficient to reliably detect weak features. These values are likely to be lower limits if the $Q = 4$ values are representative of the true detection frequency (see text).

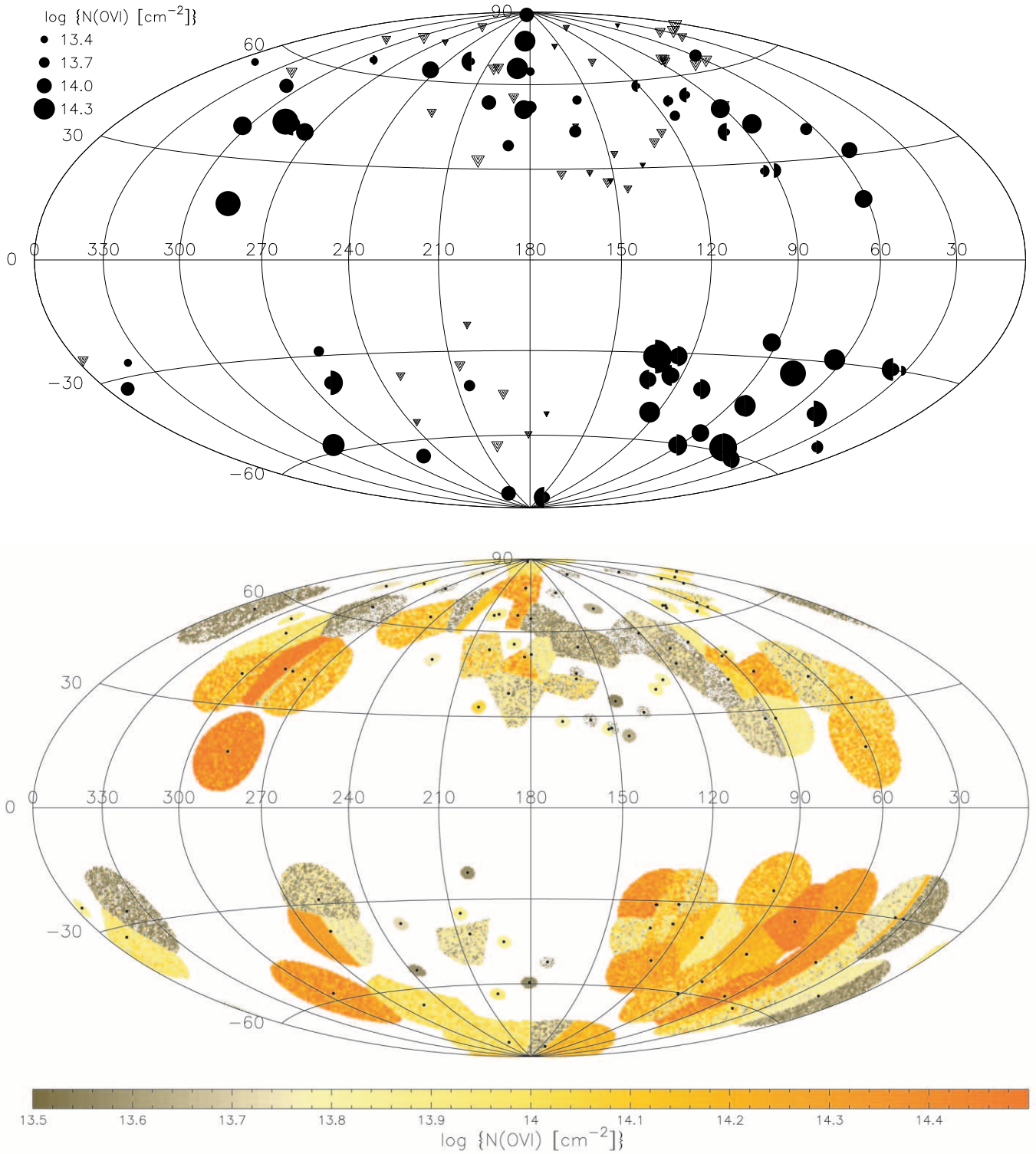


FIG. 6.—All-sky Hammer-Aitoff projections of the high-velocity O VI column densities listed in Table 1. *Top panel:* Logarithmic column density is coded according to symbol size (see legend, upper left), with the symbol split in half if two features are present. Null detections are indicated with downward-pointing triangles having a size proportional to the upper limit on the column density. *Bottom panel:* Logarithmic column density is color-coded. Detections are plotted as colored circles that are 12° in radius. When two features were detected within 12° of each other (either along the same sight line or along adjoining sight lines), the shaded area is split to allow multiple colors to be shown. The mottled appearance of some regions indicates lower reliability measurements. Null detections are indicated with small (2.5 radius) color-coded regions indicating the upper limit.

$180^\circ < l < 360^\circ$; $b < 0^\circ$, $b > 0^\circ$). Note that values of the covering fraction for $N_0 \lesssim 10^{14} \text{ cm}^{-2}$ are subject to data quality biases of the type discussed above and may underestimate the true covering fractions. For the entire sample, we

find that $\sim 60\%$ of the sight lines surveyed (and likely more if the data quality could be improved) contain high-velocity O VI with $N \geq 2.5 \times 10^{13} \text{ cm}^{-2}$, and $\sim 36\%$ have $N \geq 10^{14} \text{ cm}^{-2}$. These two O VI column density thresholds correspond

TABLE 5
HIGH-VELOCITY O VI SKY COVERING PERCENTAGES—COLUMN DENSITIES

GALACTIC REGION	SIGHT LINES IN SAMPLE	O VI COLUMN DENSITY THRESHOLD, N_0 (cm $^{-2}$)				
		2.5×10^{13}	5.0×10^{13}	7.5×10^{13}	1.0×10^{14}	2.5×10^{14}
All Sky	102	59 (58%)	52 (51%)	44 (43%)	37 (36%)	11 (11%)
$0^\circ < l < 180^\circ$						
$b < 0^\circ$	20	19 (95%)	19 (95%)	19 (95%)	19 (95%)	8 (40%)
$b > 0^\circ$	40	16 (40%)	13 (33%)	7 (18%)	6 (15%)	0 (0%)
$180^\circ < l < 360^\circ$						
$b < 0^\circ$	16	8 (50%)	6 (38%)	5 (31%)	2 (13%)	1 (6%)
$b > 0^\circ$	26	16 (62%)	14 (54%)	13 (50%)	10 (38%)	2 (8%)

NOTES.—Number (percentage) of sight lines for which $\sum N(\text{O VI})_{\text{HV}} \geq N_0$. Entries for $N_0 < 10^{14}$ cm $^{-2}$ should be treated as provisional since data quality may prevent detection of weaker features along some sight lines with data qualities $Q = 1$ –3.

roughly to $N(\text{H}^+) \gtrsim 2.3 \times 10^{17} Z^{-1}$ and $\gtrsim 9.2 \times 10^{17} Z^{-1}$, respectively, where Z is the metallicity of the hot gas (on a linear scale where $Z = 1$ is solar), and the ionized hydrogen column density of the hot gas is

$$N(\text{H}^+) = N(\text{O VI}) (\text{O}/\text{H})_{\odot}^{-1} f_{\text{O VI}}^{-1} Z^{-1}.$$

In making these estimates of H^+ in the O VI-bearing gas, we adopt a reference abundance $(\text{O}/\text{H})_{\odot} = 5.45 \times 10^{-4}$ (Holweger 2001) and an O VI ionization fraction $f_{\text{O VI}} \equiv (\text{O VI}/\text{O}) \lesssim 0.2$, which is the maximum value expected under conditions of either collisional ionization or photoionization (see § 9 and Tripp & Savage 2000).

Assuming that the high-velocity O VI covering factors listed in Table 5 provide a fair representation of the entire sky, we find that roughly 60% of the sky is covered by the hot, high-velocity H^+ at a level of $N(\text{H}^+) \gtrsim 10^{18}$ cm $^{-2}$ if the gas has a typical metallicity comparable to that of the Magellanic Stream, $Z_{\text{MS}} \sim 0.2$ –0.3 (Lu et al. 1998; Gibson et al. 2000; Sembach et al. 2001a). [The covering fraction may be higher if the sight lines for which higher quality ($Q = 4$) data are available are typical.] This $N(\text{H}^+)$ estimate would increase by a factor of ~ 2 if the metallicity is closer to the value of $Z \sim 0.1$ found for Complex C in the directions of Mrk 290 (Wakker et al. 1999) and PG 1259+593 (Richter et al. 2001). The covering factor of the hot, high-velocity H^+ inferred from the high-velocity O VI measurements is higher than the warm, high-velocity H I covering factor at a comparable column density level. In a sensitive survey of H I 21 cm emission in 860 directions, Lockman et al. (2002) find that $\sim 37\%$ of the sky is covered by high-velocity H I at a 4 σ detection threshold of $\sim 8 \times 10^{17}$ cm $^{-2}$.

We note that the detection rate of high-velocity gas in the southern Galactic hemisphere appears to be slightly higher than for northern latitudes. For the full sample, we find high-velocity detection rates of 75% (27/36) and 58% (21/36) for $b < 0^\circ$ and $N_0 = 2.5 \times 10^{13}$ and 1.0×10^{14} cm $^{-2}$, compared to 48% (32/66) and 24% (16/66) for $b > 0^\circ$. Small number statistics, data quality, and selection effects can play important roles in such comparisons. For example, the $l < 180^\circ$, $b < 0^\circ$ quadrant appears to have a high rate of occurrence of high-velocity gas, even though the sight lines sample a broad distribution of longitudes. Some of this gas is associated with the Magellanic Stream, but probably not all of it. In the north, a relatively large percentage of sight

lines (9/66) lie in the general direction of Complex C, where high-velocity O VI is prevalent (see § 6.1). Therefore, it would be desirable to diversify and increase both the sample size and data quality (preferably by factors of 2 or more) to test whether the trend we note in the current sample is a general feature of the high-velocity sky or a subtle selection effect caused by large complexes of high-velocity gas.

5.4. Velocity Centroids

The top panel of Figure 7 contains a histogram of the high-velocity O VI feature centroids in the LSR reference frame. These centroids are the profile-weighted velocities (first moments) derived by integrating the apparent optical depth profiles over the velocity ranges listed in Table 1. The most extreme velocity centroids are found for the sight lines toward NGC 588 ($v_{\text{LSR}} \approx -372$ km s $^{-1}$), NGC 4670 ($v_{\text{LSR}} \approx +363$ km s $^{-1}$), and Mrk 478 ($v_{\text{LSR}} \approx +385$ km s $^{-1}$). The average negative velocity centroid is -202 ± 77 km s $^{-1}$, and the average positive velocity centroid is 187 ± 70 km s $^{-1}$. The distribution of velocities is relatively symmetric about $v_{\text{LSR}} = 0$ km s $^{-1}$. The histogram is sampled in 20 km s $^{-1}$ velocity bins. The dashed line in the figure shows a Gaussian fit to the observed centroids. The Gaussian has a width $\sigma_{(\bar{v})} \approx 207$ km s $^{-1}$ ($b \approx 293$ km s $^{-1}$; FWHM ≈ 488 km s $^{-1}$) and is centered at ~ -33 km s $^{-1}$. Both $\langle \bar{v} \rangle$ and $\sigma_{(\bar{v})}$ are uncertain because of the absence of points at $|v_{\text{LSR}}| \lesssim 100$ km s $^{-1}$.

For comparison with the distribution of high-velocity centroids in the LSR reference frame, we also show the distributions in the Galactic standard of rest (GSR) and the Local Group standard of rest (LGSR) reference frames in the middle and bottom panels of Figure 7. Velocities in these reference frames are related to the LSR velocity through the equations $v_{\text{GSR}} = v_{\text{LSR}} + 220$ (km s $^{-1}$) $\sin(l) \cos(b)$ and $v_{\text{LGSR}} = v_{\text{GSR}} - 62$ (km s $^{-1}$) $\cos(l) \cos(b) + 40$ (km s $^{-1}$) $\sin(l) \cos(b) - 35$ (km s $^{-1}$) $\sin(b)$ (Karachentsev & Makarov 1996). In both cases the dispersion in the high-velocity gas centroids is smaller than in the LSR reference frame ($\sigma_{(\bar{v})} \approx 144$ km s $^{-1}$ in the GSR, and $\sigma_{(\bar{v})} \approx 128$ km s $^{-1}$ in the LGSR).

In Table 6 we list the means and standard deviations of the high-velocity feature centroids for the four Galactic quadrants with either $b < 0^\circ$ or $b > 0^\circ$, and $l < 180^\circ$ or $l > 180^\circ$. Values of $\langle \bar{v} \rangle \pm \sigma_{(\bar{v})}$ are given for the LSR, GSR,

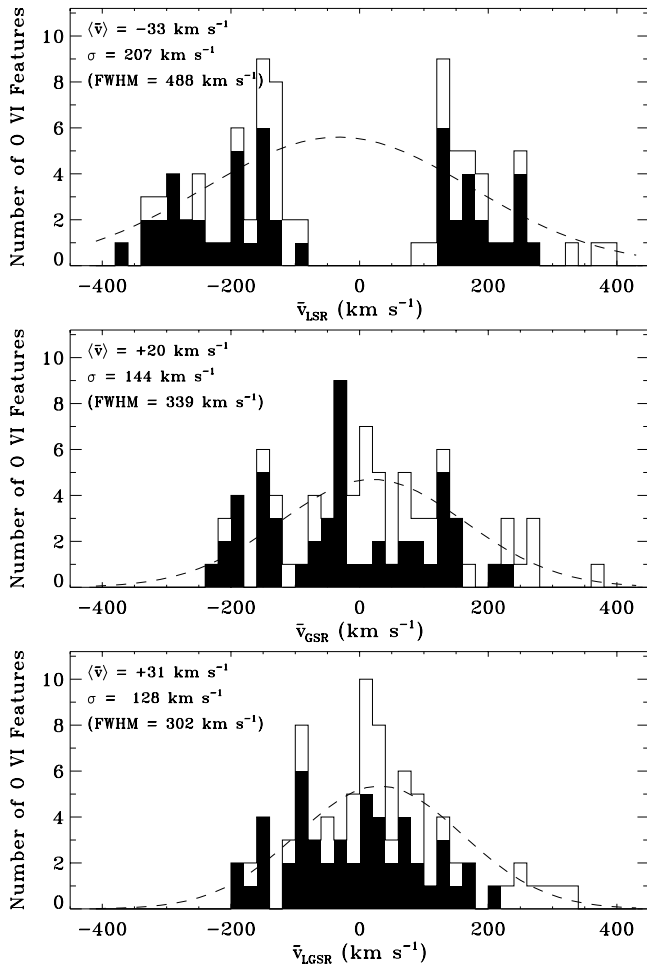


FIG. 7.—Distributions of high-velocity O VI profile centroids in the local standard of rest, Galactic standard of rest, and the Local Group standard of rest reference frames for the 84 features listed in Table 1. The distributions for the subsample of 51 LG, EPn, and MSe features considered in §§ 8.2 and 10.4 are shown as shaded regions. By definition, the absence of features at $-100 \leq v_{\text{LSR}} \leq 100 \text{ km s}^{-1}$ in the top panel occurs because of blending with the Galactic thick disk/halo O VI distribution. The bin size for these distributions is 20 km s^{-1} . The dashed Gaussian profiles are fits to the distributions containing all the high-velocity features; in the top panel, the fit is performed only for $|v_{\text{LSR}}| \geq 100 \text{ km s}^{-1}$. The ensemble velocity centroids ($\langle \bar{v} \rangle$) and widths (σ and FWHM) are given in the upper left corner for each distribution (see also Table 6).

and LGSr reference frames. The numbers of high-velocity features in each Galactic quadrant are listed at the bottom of the table. In most quadrants and in the total sample the mean centroid velocity is smaller in the GSR than in the LSR. In all but one quadrant ($l > 180^\circ$, $b > 0^\circ$) the dispersions in the centroids are also smaller in the GSR than in the LSR, suggesting that this is a better reference frame for describing the velocities. In other words, the high-velocity O VI in our sample has an observed distribution of bulk velocities that is more evenly and tightly clustered about the velocity of the Galactic center than about the velocity expected for gas participating in differential Galactic rotation at the Galactocentric radius of the Sun (with the important caveat that the HVC features were selected in a manner to avoid LSR velocities $|v_{\text{LSR}}| \lesssim 100 \text{ km s}^{-1}$). A similar result, which applies to the velocity distribution of neutral hydrogen clouds and is subject to many of the same kinds of selection effects, has been used to support

arguments for an extragalactic location for some of the H I HVCs (e.g., Blitz et al. 1999). See § 10.4 for additional discussion of this issue.

Features designated “EPn” dominate the high-velocity O VI absorption in the discrepant quadrant for which the standard deviation of the values of $\bar{v}$ is larger in the GSR than in the LSR ($l > 180^\circ$, $b > 0^\circ$). This group of clouds is not better represented in the GSR reference frame and is distinct from the other categories in this regard. As noted in the previous section, some of these features may trace thick disk/halo gas accelerated to high velocities.

We illustrate the velocities of the O VI features in the LSR reference frame in Figure 8, where we show the dependence of the velocity on both Galactic longitude (*top panel*) and Galactic latitude (*bottom panel*). The vertical bars on each point indicate the velocity widths (b -values) of the observed features, not the errors in $\bar{v}$. At $l > 180^\circ$, all but one of the features have positive LSR velocities; the exception is the LG feature toward Ton S210, which is located near the south Galactic pole. At $l < 180^\circ$, $\bar{v} > 0 \text{ km s}^{-1}$ for only eight features, while $\bar{v} < 0 \text{ km s}^{-1}$ for 43 features. This strong segregation of velocities in Galactic longitude is also apparent in the latitude plot in the bottom panel of Figure 8.

We provide a similar plot for the longitude dependence in the GSR reference frame in Figure 9. Despite showing a somewhat tighter clustering of data points about $v_{\text{GSR}} = 0 \text{ km s}^{-1}$, there is still considerable scatter in the velocity centroids as a function of longitude ($\sigma_{\langle \bar{v} \rangle} \sim 144 \text{ km s}^{-1}$ for the whole sample). The dashed lines in the figure bound the range of velocities expected for Galactic disk sight lines with $|b| < 20^\circ$ and $|v_{\text{LSR}}| \lesssim 100 \text{ km s}^{-1}$. As expected, few points fall in this zone because of sample selection effects. In the GSR reference frame, the general velocity distribution of data points clusters more tightly about zero velocity than in the LSR reference frame. The few sight lines that fall in the range of velocities expected for the thick disk/halo include Ton S210 ($l \approx 225^\circ$) and several sight lines in the general direction of Complex C ($l \sim 80\text{--}110^\circ$; Mrk 817, Mrk 876, PG 1351+640, PG 1415+451, and PG 1626+554). Both Complex C and the compact HVC toward Ton S210 are likely extragalactic clouds that will be discussed further in § 6.

5.5. Sky Distribution—Velocities

In Figure 10 we plot the distribution of O VI centroid velocities projected onto the sky for both the LSR and GSR reference frames. The projection is the same as that in Figure 6, with the Galactic anticenter at the center of the plots. In each direction we plot a small filled circle to indicate the precise location of the sight line, with a corresponding color-coded region indicating velocity if high-velocity O VI absorption is detected. In some directions, the region contains several colors since multiple high-velocity features are present within the 12° radius of the region. Each sight line can be identified by cross-referencing its position with the object names in Figure 3. The color coding of the velocities (blue/green, negative velocities; orange/red, positive velocities) is the same in both panels of Figure 10. A comparison of the two panels shows that the color shading in the GSR panel is generally lighter, indicating that the velocities are smaller in this reference frame, as discussed above.

We show a similar plot for the H I high-velocity sky observed in 21 cm emission in Figure 11a, where we have

TABLE 6
VELOCITY CENTROID MEANS AND STANDARD DEVIATIONS

Reference Frame	Longitude Range	$b < 0^\circ$	$b > 0^\circ$	All b
Local standard of rest	$0^\circ < l < 180^\circ$	-205 ± 127	-45 ± 157	-142 ± 159
	$180^\circ < l < 360^\circ$	156 ± 142	193 ± 64	181 ± 95
	All l	-129 ± 196	65 ± 172	-34 ± 208
Galactic standard of rest	$0^\circ < l < 180^\circ$	-85 ± 111	80 ± 138	-21 ± 146
	$180^\circ < l < 360^\circ$	55 ± 106	108 ± 92	91 ± 98
	All l	-56 ± 123	93 ± 118	17 ± 142
Local Group standard of rest	$0^\circ < l < 180^\circ$	-40 ± 110	86 ± 132	10 ± 133
	$180^\circ < l < 360^\circ$	56 ± 94	69 ± 108	65 ± 102
	All l	-20 ± 113	78 ± 120	28 ± 126
Number of high-velocity O VI features.....	$0^\circ < l < 180^\circ$	[34]	[23]	[56]
	$180^\circ < l < 360^\circ$	[9]	[19]	[28]
	All l	[43]	[41]	[84]

NOTES.—Velocity centroid means, $\langle \bar{v} \rangle$, and standard deviations, $\sigma_{(\bar{v})}$, of the high-velocity O VI features. All velocities are in km s^{-1} . The number of features in each longitude-latitude interval is listed in square brackets below the velocity entries.

coded the velocities in the same color system, but at the finer spatial resolution afforded by the H I data. Figures 11b and 11c display the same data in azimuthal equal-area projections looking up toward the north Galactic pole and down toward the south Galactic pole. Several large structures or

groups of H I high-velocity clouds are visible in Figure 11, including (1) the Magellanic Stream, which passes through the south Galactic pole and extends up to $b \sim -30^\circ$, with positive velocities for $l \gtrsim 180^\circ$ and negative velocities for $l \lesssim 180^\circ$; (2) high-velocity cloud Complex C, which covers a large portion of the northern Galactic sky between $l = 30^\circ$ and $l = 150^\circ$ and has velocities of roughly -100 to -170 km s^{-1} ; (3) the extreme positive velocity clouds in the northern sky (EPn), which are located in the general region $180^\circ \lesssim l \lesssim 330^\circ$, $b \approx 30^\circ$; and (4) the Galactic center negative velocity (GCN) clouds located near $l \sim 45^\circ$, $-60^\circ \lesssim b \lesssim -30^\circ$.

In Figures 11a–11c, we have indicated the positions and velocities of the high-velocity O VI features with filled circles having the same color coding scale as the H I data. If multiple high-velocity features are present, the circle is subdivided into multiple colored regions. Small open circles (or “X” marks for the two stellar sight lines) denote the directions where no high-velocity O VI is detected (see Table 2).

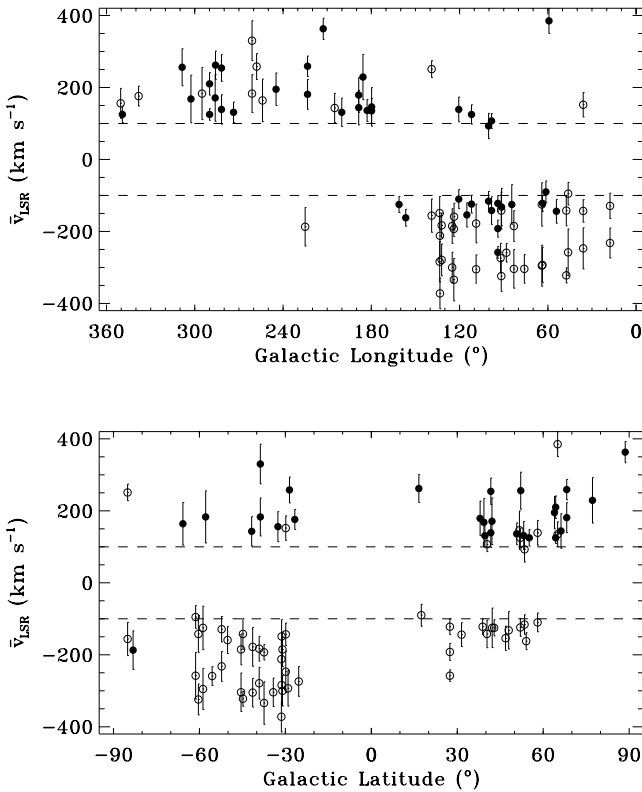


FIG. 8.—High-velocity O VI centroids in the local standard of rest reference frame. In the top panel, filled circles denote sight lines with $b > 0^\circ$, and open circles denote sight lines with $b < 0^\circ$. In the bottom panel, filled circles denote sight lines with $180^\circ < l < 360^\circ$, and open circles denote sight lines with $0^\circ < l < 180^\circ$. The vertical bar on each point is the velocity width ($\pm b$) measured for each feature. By definition, few points fall in the region with $-100 \lesssim \bar{v}_{\text{LSR}} \lesssim 100 \text{ km s}^{-1}$.

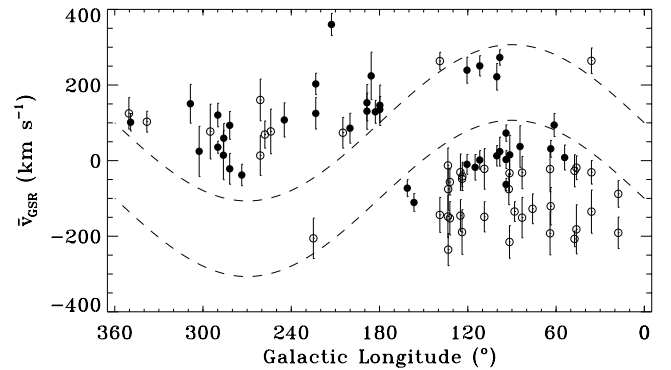


FIG. 9.—High-velocity O VI centroids in the Galactic standard of rest reference frame. Filled circles denote sight lines with $b > 0^\circ$, and open circles denote sight lines with $b < 0^\circ$. The vertical bar on each point is the velocity width ($\pm b$) measured for each feature. The dashed curves bound the region of the plot that would be occupied by gas in the Galactic disk ($|b| \leq 20^\circ$) with $|\bar{v}_{\text{LSR}}| \leq 100 \text{ km s}^{-1}$; by definition of the sample, few points fall in this region.

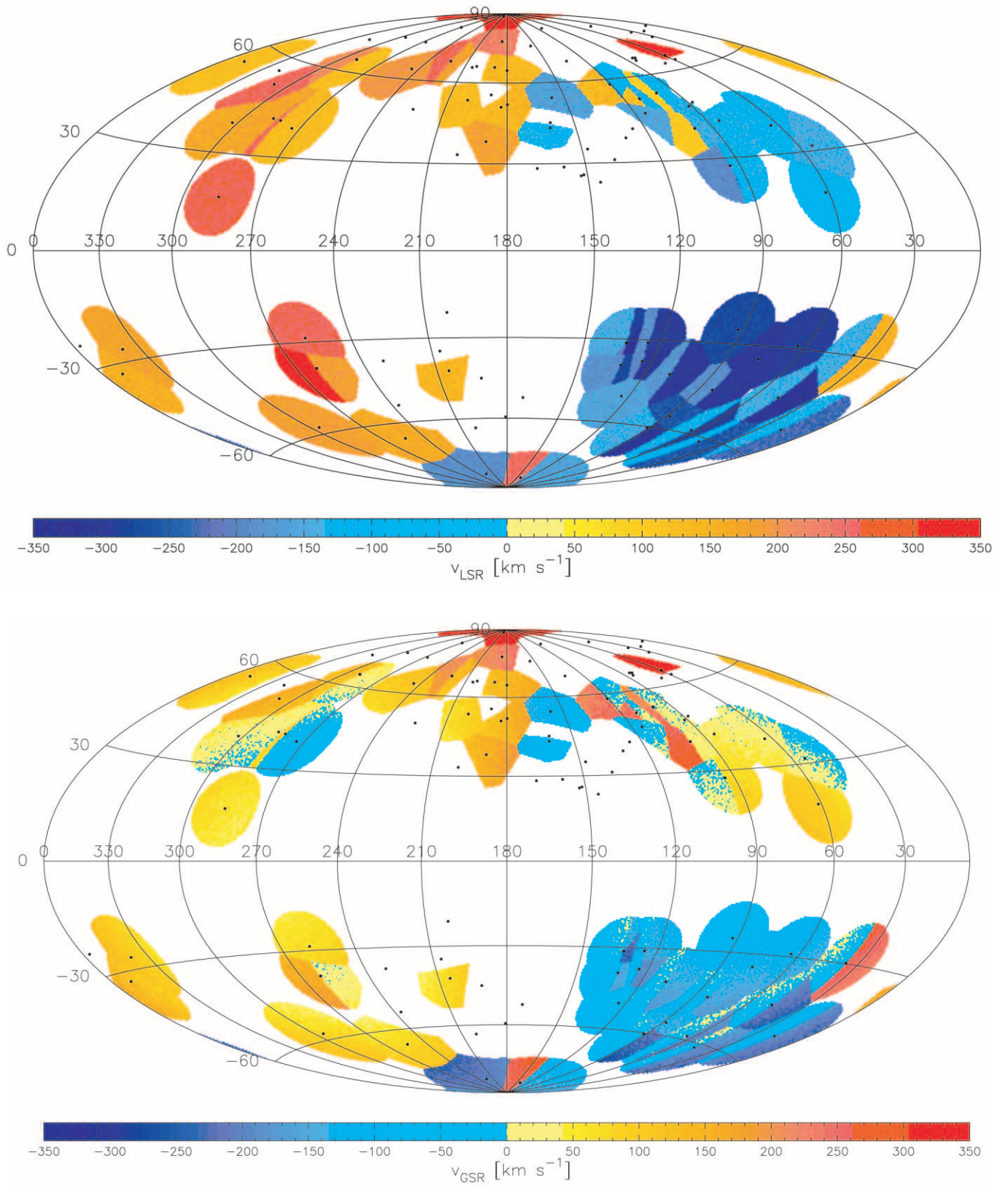


FIG. 10.—All-sky Hammer-Aitoff projections of the O VI velocities in the LSR and GSR reference frames. These maps include features listed in Table 1 and exclude gas at velocities attributed to the thick disk/halo of the Galaxy. The velocities of the O VI features are color coded and displayed as filled regions of radius 12° for each direction where high-velocity gas is detected. When two features were detected within 12° of each other (either along the same sight line or along adjoining sight lines), the shaded area size is adjusted accordingly. Points with no colors indicate null detections of high-velocity O VI.

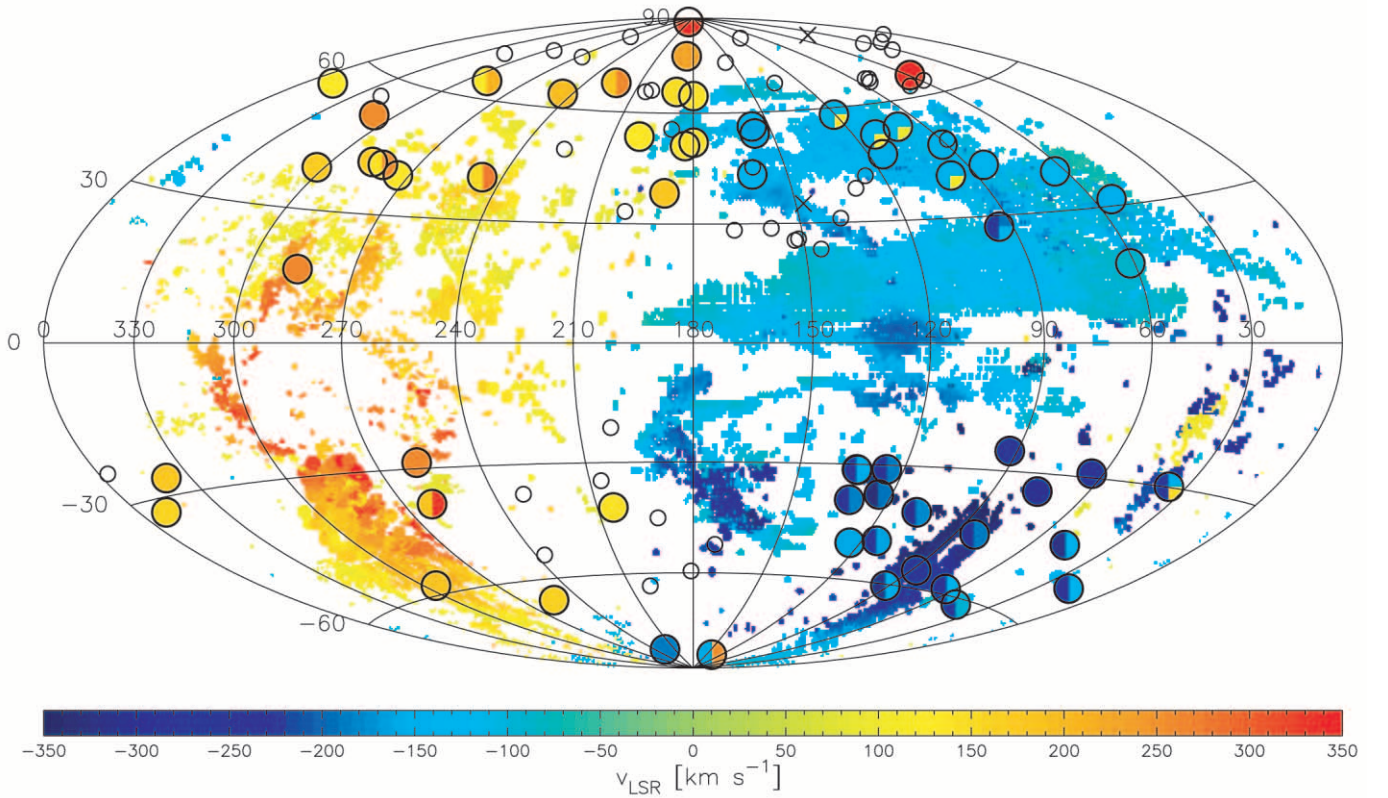


FIG. 11a

FIG. 11.—(a) Hammer-Aitoff projection of the high-velocity H I sky based on 21 cm emission measurements (adapted from Wakker et al. 2003). The H I data have a spatial resolution of approximately $36'$ and are representative of gas with $N(\text{H I}) > 2 \times 10^{18} \text{ cm}^{-2}$. Data for $|b| < 20^\circ$ have been omitted for clarity. The positions of the high-velocity O VI features listed in Table 1 are denoted by the large circles, with the fill color indicating velocity on the same color scale used for the H I emission. If more than one high-velocity O VI feature is present, the circle is split and the velocities are color-coded in each section of the circle. Small open circles indicate null detections (Table 2). “X” marks indicate the locations of the two stellar sight lines in the sample. (b) Azimuthal equal-area projection of the data shown in (a), looking up toward the north Galactic pole. (c) Azimuthal equal-area projection of the data shown in (a), looking down toward the south Galactic pole.

Several key points about these figures are worth highlighting:

1. There is excellent velocity correspondence between the H I and O VI in Complex C, with sight lines passing near to Complex C, but not through the high-velocity H I, showing no O VI absorption (see § 6.1).
2. Toward Complex A, there is a close pair of sight lines exhibiting an O VI detection (Mrk 106: $l = 161^\circ.1$, $b = 42^\circ.9$) and a nondetection (Mrk 116: $l = 160^\circ.5$, $b = 44^\circ.8$) (see § 6.2).
3. The high-velocity component toward NGC 3310 ($l = 156^\circ.6$, $b = +54^\circ.1$) has a velocity similar to that of Complexes A and C, even though there is no H I 21 cm emission detected along the sight line at these velocities.
4. The H 1821+643 sight line ($l = 94^\circ.0$, $b = 27^\circ.4$) contains O VI absorption at the velocities of the Outer Arm as well as at more negative velocities (see § 6.4). The progression of velocities between the Outer Arm and Complex C is relatively smooth.
5. In the $l < 180^\circ$, $b < 0^\circ$ quadrant of the sky there are often two negative velocity components, with the highest negative velocity components occurring in the Magellanic Stream (MS) or the extension of the Magellanic Stream (MSe) at velocities typical of the Stream (see § 6.3). Components with $\bar{v} \sim -120 \text{ km s}^{-1}$ concentrate to longitudes

less than those of the Stream, whereas components at $l \sim 120^\circ\text{--}140^\circ$ have velocities typical of the Stream.

6. There is good velocity correspondence between the H I and O VI velocities in the positive velocity portion of the Magellanic Stream at $l > 180^\circ$ (see § 6.3). The O VI features off the main axis of the Stream at these longitudes have velocities similar to those of the H I near the Stream.

7. In the $l > 180^\circ$, $b > 0^\circ$ quadrant of the sky there are positive velocity O VI and H I features, sometimes at similar velocities. These are some of the EPN features listed in Tables 1 and 3. In some cases, the O VI features have substantially higher velocities than the H I. The -262 km s^{-1} feature toward ESO 265–G23 ($l = 285^\circ.9$, $b = +16^\circ.6$) has a velocity and location close to that of H I in the leading arm of the Magellanic Stream identified by Putman et al. (1998); H I at similar velocities is seen $\sim 1^\circ$ away.

8. At $l \sim 180^\circ$, $b > 0^\circ$ there is high-velocity O VI with $\bar{v} \sim +150 \text{ km s}^{-1}$. Some of these features are broad absorption wings extending from the lower velocity absorption produced by the Galactic thick disk/halo (see § 8.1).

9. There may be high-velocity H I near the $+143 \text{ km s}^{-1}$ O VI feature toward PKS 0405–12 ($l = 204^\circ.9$, $b = -41^\circ.8$).

10. High-velocity O VI features toward Mrk 478 ($l = 59^\circ.2$, $b = +65^\circ.0$, $\bar{v} \approx +385 \text{ km s}^{-1}$), NGC 4670 ($l = 212^\circ.7$, $b = +88^\circ.6$, $\bar{v} \approx +363 \text{ km s}^{-1}$), and Ton S180 ($l = 139^\circ.0$, $b = -85^\circ.1$, $\bar{v} \approx +251 \text{ km s}^{-1}$) stand out as

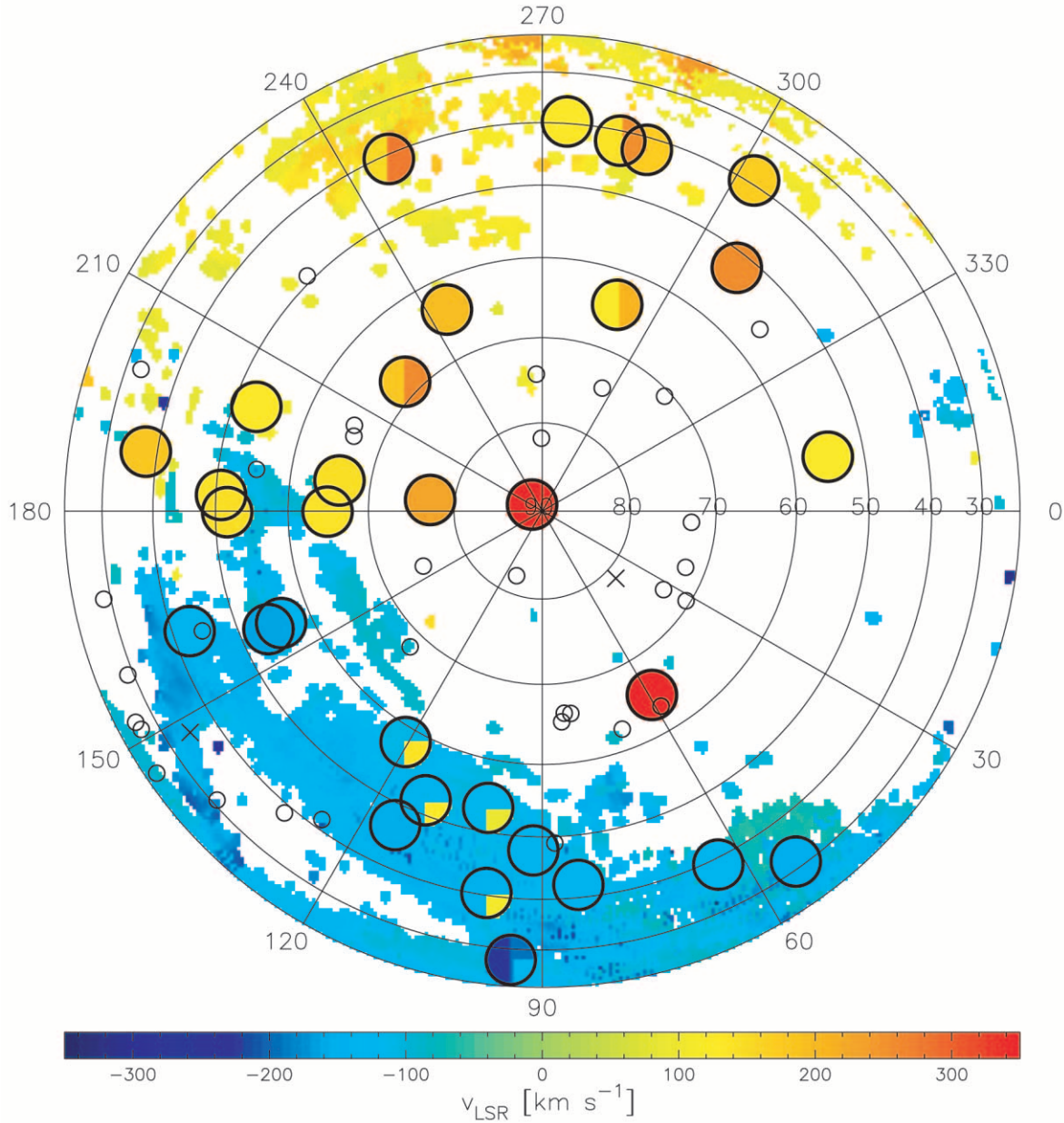


FIG. 11b

having particularly unusual velocities compared to those of other O VI features in similar regions of the sky. These features are classified as “Oth” in Table 1 and may be located outside the Local Group (i.e., in the IGM).

11. Sight lines that contain both negative and positive high-velocity features include Mrk 509 ($l = 36^\circ 0$, $b = -29^\circ 9$), Ton S180 ($l = 139^\circ 0$, $b = -85^\circ 1$), and several Complex C sight lines (Mrk 817, Mrk 876, PG 1259+593, PG 1351+640: $l \sim 85^\circ\text{--}120^\circ$, $b \sim 40^\circ\text{--}60^\circ$).

Although not shown in Figures 10 and 11, O VI and H I are also present at intermediate velocities ($|v_{\text{LSR}}| \sim 30\text{--}100$ km s $^{-1}$) along many of the sight lines considered in this work. The intermediate-velocity O VI absorption and its relationship to the intermediate-velocity H I sky are discussed briefly by Savage et al. (2003, § 7.2). The kinematics, elemental abundances, molecular content, and

locations of the intermediate-velocity clouds (IVCs) indicate that they are part of the Galactic processes that circulate and distribute interstellar material in the thick disk and halo of the Galaxy (Houck & Bregman 1990; Richter et al. 2001; Richter et al. 2003). The IVC population appears in most cases to be distinct from higher velocity phenomena traced in H I (see Wakker 2001), and it is likely that the O VI IVC population is not strongly connected with the high-velocity phenomena we observe in O VI absorption. There is no general correlation in the amount of intermediate and high-velocity H I or O VI observed along the sight lines in our sample.

Table 7 contains a general breakdown of the number of sight lines containing negative and positive high-velocity O VI features. For several cuts in Galactic longitude and latitude we list the number of sight lines containing at least one high-velocity O VI component

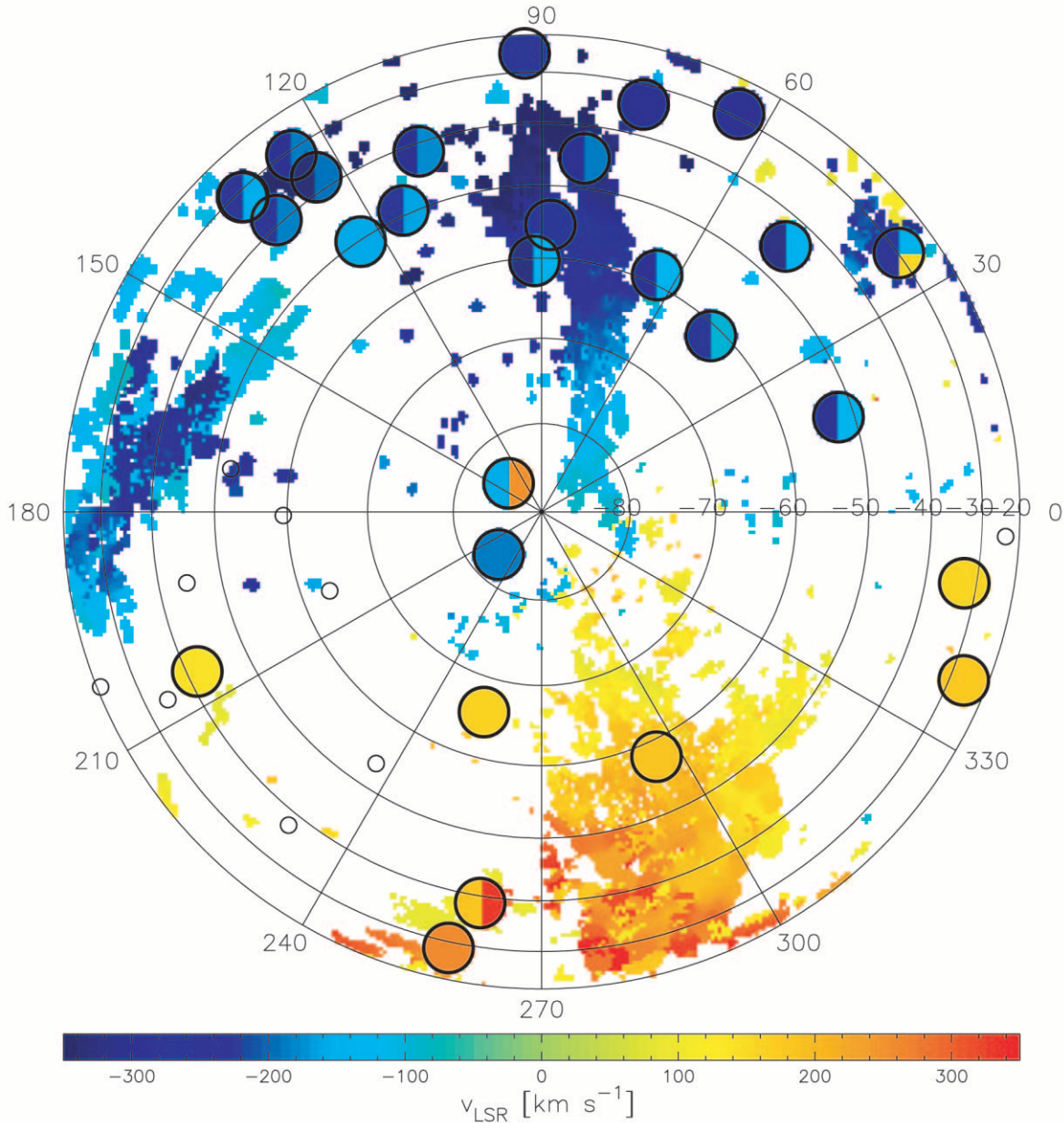


FIG. 11c

with a velocity centroid, $\bar{v}$, exceeding a threshold velocity, v_0 . The table quantifies the graphical results shown in Figures 8 and 10, namely that the $l < 180^\circ$ region of the sky contains predominantly negative velocities, while the $l > 180^\circ$ region of the sky contains predominantly positive velocities. Combined, roughly 58% (59/102) of the sight lines have O vi features with $|\bar{v}| > 90 \text{ km s}^{-1}$, and 28% (29/102) have O vi features with $|\bar{v}| > 200$. A small percentage of sight lines, 11% (11/102), has $|\bar{v}| > 300$, and of these all but three (Mrk 478, NGC 1705, and NGC 4670) are located in the southern Galactic hemisphere at $45^\circ < l < 135^\circ$. Data quality affects these percentages since weak features ($W_{1032} \lesssim 100 \text{ mÅ}$) are below the detection limit for some sight lines. Thus, the percentages enclosed within parentheses in Table 7 are best treated as lower limits. For comparison, we also tabulate the all-sky percentages for the highest quality ($Q = 4$) sight lines within square brackets in Table 7. As

expected, the $Q = 4$ sight line percentages are higher than those for the entire sample.

5.6. Line Widths

The observed line widths of the high-velocity O vi features range from $b \sim 16$ to $\sim 72 \text{ km s}^{-1}$. We show the distributions of b -values for the high-velocity gas and Galactic thick disk/halo absorption in Figure 12. These b -values have not been corrected for a small amount of instrumental broadening ($b_{\text{inst}} \sim 12\text{--}15 \text{ km s}^{-1}$). The average high-velocity feature width is $\langle b \rangle = 40 \pm 13 \text{ km s}^{-1}$ if all of the high-velocity features listed in Table 1 are considered. In some cases, the line widths are less reliable since they depend strongly on the exact choice of the velocity cutoff between thick disk/halo absorption and the high-velocity absorption used in the calculation of b . Thus, one must be careful about interpreting the meaning of the line width for some sight lines, especially when the thick disk/halo and high-velocity portions of the

TABLE 7
HIGH-VELOCITY O VI SKY COVERING PERCENTAGES—CENTROID VELOCITIES^a

VELOCITY THRESHOLD v_0 (km s ⁻¹)	ALL SKY	0° < l < 180°		180° < l < 360°	
		$b < 0^\circ$	$b > 0^\circ$	$b < 0^\circ$	$b > 0^\circ$
-300	8 (8%) [8%]	8 (40%)	0 (0%)	0 (0%)	0 (0%)
-250	16 (16%) [12%]	15 (75%)	1 (3%)	0 (0%)	0 (0%)
-200	18 (18%) [19%]	17 (85%)	1 (3%)	0 (0%)	0 (0%)
-150	23 (23%) [31%]	19 (95%)	3 (8%)	1 (6%)	0 (0%)
-90	33 (32%) [42%]	19 (95%)	13 (33%)	1 (6%)	0 (0%)
90	32 (31%) [58%]	2 (10%)	7 (18%)	7 (44%)	16 (62%)
150	20 (20%) [31%]	2 (10%)	1 (3%)	6 (38%)	11 (42%)
200	11 (11%) [15%]	1 (5%)	1 (3%)	2 (13%)	7 (27%)
250	9 (9%) [12%]	1 (5%)	1 (3%)	2 (13%)	5 (19%)
300	3 (3%) [4%]	0 (0%)	1 (3%)	1 (6%)	1 (4%)
Number of sight lines ^a	102 [26]	20	40	16	26

NOTES.—Number (percentage) of sight lines in the sample that contain at least one high-velocity O VI feature with either $\bar{v} \leq v_0$ (for $v_0 < 0$ km s⁻¹) or $\bar{v} \geq v_0$ (for $v_0 > 0$ km s⁻¹). Data quality affects these percentages since weak features are below the detection limits for some sight lines (i.e., these values should probably be treated as lower limits—see text). Values listed in square brackets are for the highest quality ($Q = 4$) sight lines only.

^a Number of sight lines in each longitude-latitude region.

absorption merge without recovery to the continuum at intermediate velocities. These less reliable values of b are enclosed in parentheses in Table 1. For the 19 features having reliable b -values, $\langle b \rangle = 42 \pm 12$ km s⁻¹, which is indistinguishable from the value for the entire sample.

The average high-velocity line width is smaller than the value of $\langle b \rangle = 60 \pm 15$ km s⁻¹ found for the low-velocity O VI (Savage et al. 2003). This is due in part to the reduced blending of the high-velocity gas as well as the multicomponent nature of the low-velocity gas, which by definition occurs between $-100 \lesssim v_{\text{LSR}} \lesssim 100$ km s⁻¹. If the broadening is purely thermal in nature, the smallest Doppler widths in the high-velocity sample ($b \sim 16$ km s⁻¹) correspond to temperatures of $\sim 3 \times 10^5$ K, the temperature at which O VI

peaks in abundance under conditions of collisional ionization equilibrium (Sutherland & Dopita 1993). These small widths are only slightly larger than the instrumental resolution, so it is possible that the temperatures may be lower in these few cases. The larger line widths are likely dominated by turbulent broadening, shear, or flows rather than thermal broadening at high temperatures since the fractional abundance of O VI decreases rapidly at $T \gtrsim 10^6$ K (i.e., $b_{\text{thermal}} \gtrsim 34$ km s⁻¹) (Shapiro & Moore 1976; Sutherland & Dopita 1993).

6. O VI ASSOCIATED WITH PREVIOUSLY IDENTIFIED HIGH-VELOCITY CLOUDS

We detect high-velocity O VI along almost every sight line in our sample for which there is a known high-velocity H I cloud observed in 21 cm emission along the sight line. These H I HVCs include large complexes of gas, such as Complex C and the Magellanic Stream, as well as smaller isolated clouds. We discuss some of these high-velocity features in this section.

6.1. Complex C

High-velocity cloud Complex C is a large assembly of high-velocity gas in the northern Galactic sky between $l \sim 30^\circ$ and $l \sim 150^\circ$. It is well-known for its substantial H I content and distance ($M > 1.2 \times 10^6 M_\odot$; $d > 5$ kpc, $z > 3.5$ kpc; van Woerden et al. 1999a; Wakker 2001), lack of molecular hydrogen (Murphy et al. 2000; Richter et al. 2001), and substantially subsolar abundances. The metallicity of Complex C is $Z \sim 0.1$ (Wakker et al. 1999; Richter et al. 2001), but may be as high as $Z \sim 0.3$ in some locations (Gibson et al. 2001a). The gas in Complex C has LSR velocities ranging from approximately -100 to -170 km s⁻¹, which is sufficient to separate the absorption from both the Milky Way thick disk/halo absorption in this direction (extending out to $v_{\text{LSR}} \sim -100$ km s⁻¹) and intermediate-velocity absorption features along the path to Complex C, such as the Intermediate Velocity Arch ($v_{\text{LSR}} \sim -55$ km s⁻¹) (see Wakker 2001). Complex C contains ionized gas as

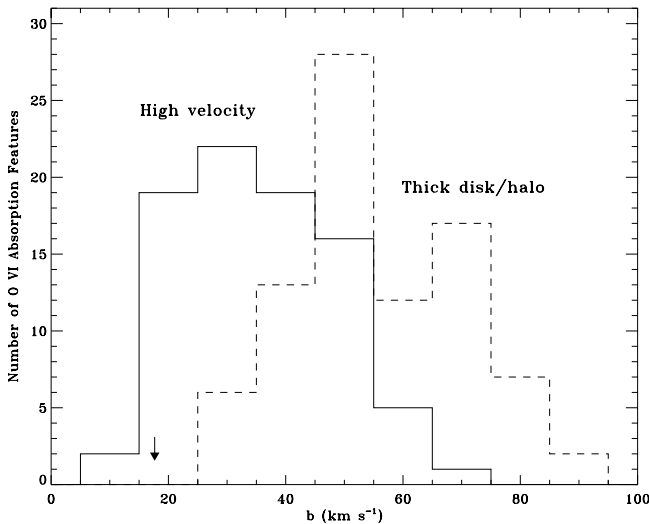


FIG. 12.—O VI profile widths for the Milky Way thick disk/halo (dashed line) and high-velocity (solid line) absorption features. These observed widths have not been corrected for the small amount of instrumental line broadening; this broadening ($b_{\text{inst}} \sim 12$ – 15 km s⁻¹) is important only for the narrowest lines observed. The bin size for these distributions is 10 km s⁻¹. The arrow indicates the thermal width ($b = 17.6$ km s⁻¹) for a single component at $T = 3 \times 10^5$ K.

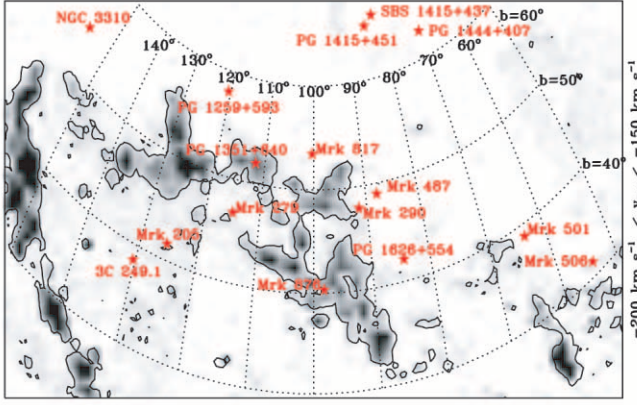


FIG. 13a

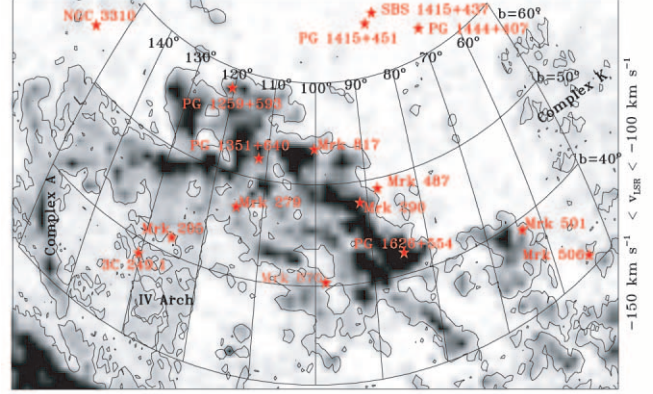


FIG. 13b

FIG. 13.—Leiden-Dwingeloo survey grey-scale map of the high-velocity H I 21 cm emission in the region of sky near Complex C. The contours denote an H I column density of $5 \times 10^{18} \text{ cm}^{-2}$. Panel (a) shows the emission over the velocity range $-200 \leq v_{\text{LSR}} \leq -150 \text{ km s}^{-1}$. Panel (b) shows the emission over the velocity range $-150 \leq v_{\text{LSR}} \leq -100 \text{ km s}^{-1}$. The FUSE sight lines are marked in red. Additional features in this region of the sky (Complex A, Complex K) are also indicated in (b).

revealed through previous observations of O VI absorption (Murphy et al. 2000; Sembach et al. 2000) and H α emission (Tuftes, Reynolds, & Haffner 1998; Wakker et al. 1999).

Nine of the sight lines in our sample pass through Complex C and contain O VI absorption at velocities characteristic of the high-velocity neutral gas. These are Mrk 279, Mrk 290, Mrk 501, Mrk 506, Mrk 817, Mrk 876, PG 1259+593, PG 1351+640, and PG 1626+554. We illustrate the H I 21 cm emission in the region of sky containing Complex C in Figure 13 to show the general morphology of the neutral gas in these directions. Two velocity ranges, $-200 < v_{\text{LSR}} < -150 \text{ km s}^{-1}$ (top panel) and $-150 < v_{\text{LSR}} < -100 \text{ km s}^{-1}$ (bottom panel), are shown to illustrate the differences in the H I structure in these velocity ranges. These H I data are from the Leiden-Dwingeloo survey (Hartmann & Burton 1997). In the more negative velocity map, the two sight lines that lie in the densest concentrations of H I are Mrk 876 and PG 1351+640. In the less negative velocity map, all of the sight lines lie in the direction of some H I emission, and additional intermediate and high-velocity features (IV Arch, Complex A, Complex K) are identified.

The O VI detections toward Complex C are clearly visible in the all-sky maps shown in Figures 10 and 11. We plot the O VI $\lambda 1031.926$ and C II $\lambda 1036.337$ absorption profiles for each of the nine Complex C sight lines in Figure 14. The O VI absorption traces highly ionized gas, while the C II absorption traces a combination of neutral and weakly ionized gases. Included for each sight line is the H I 21 cm emission profile from Murphy et al. (unpublished, see Wakker et al. 2003) for comparison with the absorption features. The single-dish NRAO 140 foot telescope 21 cm emission measurements have a beam size of $21'$ (FWHM), a channel spacing of $\sim 1\text{--}2 \text{ km s}^{-1}$, and a 3σ sensitivity of $\sim (1\text{--}2) \times 10^{18} \text{ cm}^{-2}$ for a 50 km s^{-1} integration range. The 21 cm emission provides information about the velocity structure of the primary neutral gas concentrations along the sight lines, while the C II profile reveals the total velocity extent of the neutral plus weakly ionized gas.

O VI absorption is present at the velocities of the H I 21 cm emission in Complex C. Thus, the highly ionized and neutral gases appear to be kinematically related in these different directions. Values of $\log N(\text{O VI})$ range from 13.67 to

14.35, with an average of 13.93 and a standard deviation of 0.25 dex. The O VI centroids range from a low of $\sim -110 \text{ km s}^{-1}$ (PG 1259+593) to a high of $\sim -150 \text{ km s}^{-1}$ (Mrk 279, Mrk 876). We summarize the relative velocities and column densities of the H I and O VI in Table 8. The O VI and H I velocities track each other reasonably well, with a typical scatter of $\sim 15 \text{ km s}^{-1}$. There is no obvious dependence of the O VI column density on the H I column density. For example, two sight lines (Mrk 279 and PG 1351+640) with $\log N(\text{O VI}) \approx 13.67$ have H I columns that differ by 0.46 dex, and two sight lines (Mrk 506 and Mrk 876) with $\log N(\text{O VI}) \approx 14.06$ have H I columns that differ by 0.66 dex. However, there is a weak trend for the ratio of the two species to change with position across Complex C, with higher values of $N(\text{H I})/N(\text{O VI})$ at higher longitudes.

The strong C II and O VI lines have similar negative velocity extents along each sight line. The C II traces very small amounts of H I, as well as H $^+$, so it is difficult to know if the velocity extents of the neutral and highly ionized gas are identical, but this result is at least suggestive that they are similar.

If we take the average ratio of $N(\text{H I})/N(\text{O VI}) \sim 5.6 \times 10^5$ listed in Table 8 as a typical value for all of Complex C, then we find that the mass of hot gas traced by the O VI in Complex C is

$$M_{\text{H}^+} \sim 1.8 \times 10^{-6} M_{\text{H I}} f_{\text{O VI}}^{-1} (\text{O}/\text{H})_{\odot}^{-1} Z^{-1} \\ \geq 0.18 M_{\text{H I}} > 2 \times 10^5 M_{\odot}$$

for $f_{\text{O VI}} < 0.2$ and $Z \sim 0.1$. This seems reasonable for a thin ionized gas layer at the boundary of Complex C that has its bulk motion governed by the H I kinematics.

Several sight lines in the O VI survey pass near Complex C but do not have high-velocity O VI detections associated with Complex C. We comment briefly on a few of these sight lines below.

1. Mrk 205 ($l = 125^{\circ}.4$, $b = +41^{\circ}.7$) has marginal FUSE data ($Q = 1$, $S/N \sim 4$), resulting in a 3σ upper limit of $\log N(\text{O VI}) < 13.79$ for the high-velocity gas at Complex C velocities. High-resolution Space Telescope Imaging Spectrograph (STIS) data show that the sight line intercepts neutral gas at Complex C velocities (T. M. Tripp et al. 2003,

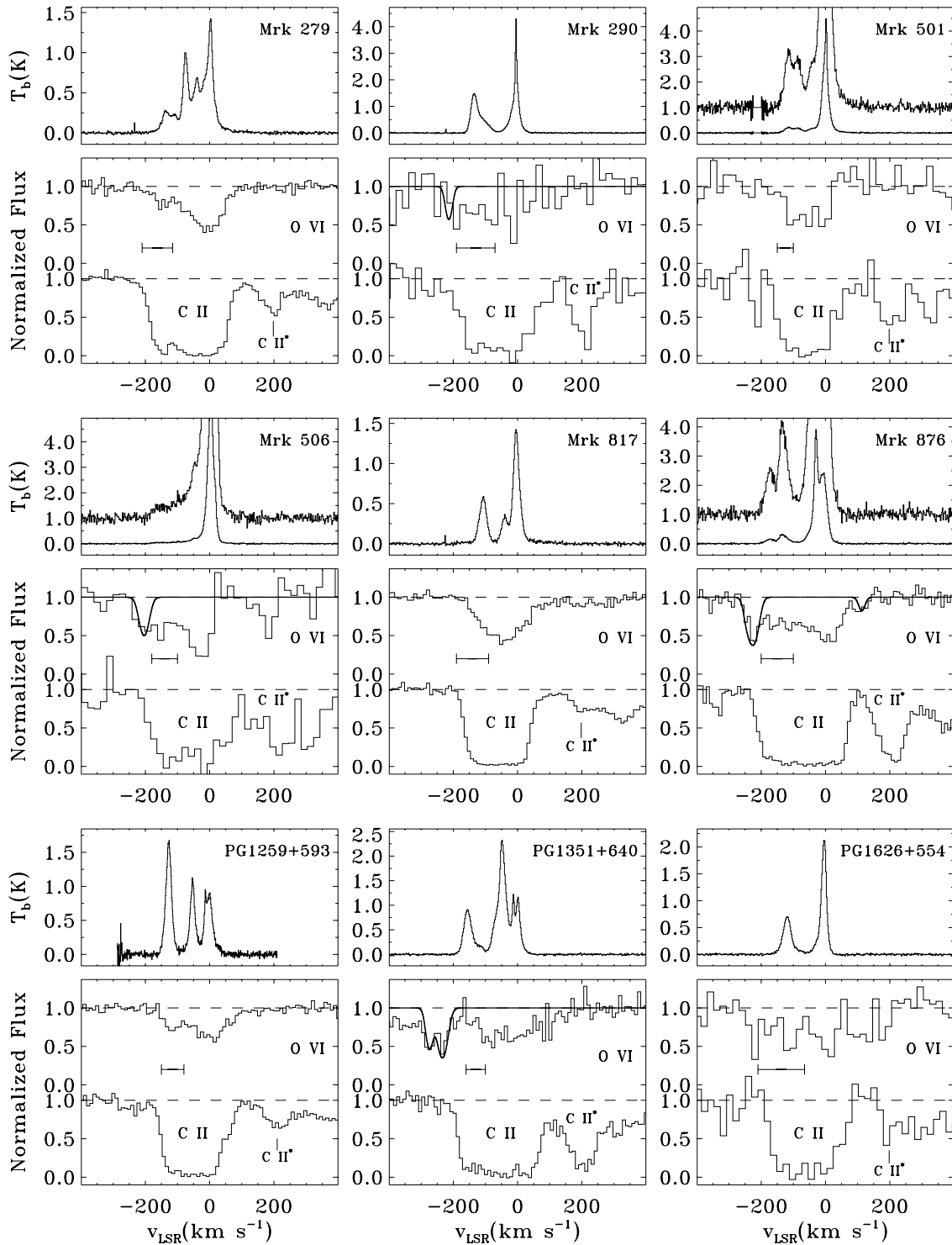


FIG. 14.—H I 21 cm emission, O VI $\lambda 1031.926$, and C II $\lambda 1036.337$ absorption profiles for nine sight lines in the general direction of Complex C. The NRAO 140 foot H I spectra have a beam size of $21'$ (FWHM). The solid line overlotted on the O VI profile is a model of the interstellar H₂ absorption in the (6–0) $P(3)$ and $R(4)$ lines. The horizontal bar below the O VI profile shows the integration range for the high-velocity O VI. C II* $\lambda 1037.018$ absorption is seen at a velocity of ~ 197 km s^{−1} relative to the C II line.

in preparation), but the *FUSE* data are insufficient for an analysis of the absorption.

2. The Mrk 487 sight line ($l = 87^\circ 8$, $b = +49^\circ 0$) has a C II $\lambda 1036.337$ absorption feature near -140 km s^{−1}. There is no detectable H I 21 cm emission at this velocity along the sight line, but nearby Complex C sight lines (e.g., Mrk 290,

PG 1626+554) show C II absorption at similar velocities. No high-velocity O VI is present at a level of $\log N < 14.03$ (3σ), even though the sight line passes only $2''.6$ from the Mrk 290 sight line, where high-velocity O VI is detected with $\log N \approx 14.20$. This separation corresponds to a linear dimension of $\sim 220(z/5)$ kpc pc.

TABLE 8
H I–O VI COMPARISON FOR COMPLEX C SIGHT LINES

Sight Line	l (deg)	b (deg)	$\bar{v}_{\text{H I}}^{\text{a}}$ (km s $^{-1}$)	$N(\text{H I})^{\text{a}}$ (10 18 cm $^{-2}$)	$\bar{v}_{\text{O VI}}$ (km s $^{-1}$)	$N(\text{O VI})$ (10 13 cm $^{-2}$)	$\bar{v}_{\text{H I}} - \bar{v}_{\text{O VI}}$ (km s $^{-1}$)	$N(\text{H I})/N(\text{O VI})$ (10 5)	Note $^{\text{b}}$
Mrk 279	115.04	46.86	−137/[−102]	20.4/[12.3]	−154	4.68	−17	4.4	1
Mrk 290	91.49	47.95	−134/[−105]	94.7/[38.5]	−132	15.8	+2	6.0	1
Mrk 501	63.60	36.86	−116	10.7	−122	6.46	−6	1.7	
Mrk 506	54.18	31.50	−155	4.4	−144	11.2	+11	0.4	
Mrk 817	100.30	53.48	−109	32.4	−116	7.59	(−7)	4.3	2
Mrk 876	98.27	40.38	[−173]/−133	[4.7]/19.9	−142	11.2	(−9)	1.8	1,2
PG 1259+593	120.56	58.05	−128	89.5	−110	5.25	+18	17.	
PG 1351+640	111.89	52.02	−154/[−115]	59.6/[7.7]	−124	5.68	(+30)	13.	1,2
PG 1626+554	84.51	42.19	−131	26.9	−125	16.6	−6	1.6	
Averages	...	...	...	...	...	...	0 $\pm$ 13	5.6 $\pm$ 5.7	3,4

^a Values derived from Effelsberg H I 21 cm spectra. Values in square brackets indicate secondary features.

^b (1) Values for $\bar{v}_{\text{H I}} - \bar{v}_{\text{O VI}}$ and $N(\text{H I})/N(\text{O VI})$ do not include the H I components listed in brackets. (2) Velocity difference is uncertain because $\bar{v}_{\text{O VI}}$ relies on integration limits that are based on something other than the O VI data (i.e., the H I velocity structure). (3) If the uncertain values listed in parentheses are included, the average of $\bar{v}_{\text{H I}} - \bar{v}_{\text{O VI}}$ becomes 2 ± 15 km s $^{-1}$. (4) The quoted uncertainties are standard deviations of the mean values.

3. 3C 249.1 ($l = 130^\circ 4$, $b = +38^\circ 5$) lies a bit further off Complex C than Mrk 205 but is still only a few degrees from the edge of moderately strong H I 21 cm emission between -150 and -100 km s $^{-1}$ (see Fig. 13). No high-velocity O VI is present at a level of $\log N < 13.83(3 \sigma)$.

4. The NGC 3310 sight line ($l = 156^\circ 6$, $b = +54^\circ 1$) has a high-velocity O VI component at velocities near those of Complex C, but no H I 21 cm emission is detected at this velocity or at lower velocities typical of Complex A. The O VI feature has a velocity of ~ -162 km s $^{-1}$ and is classified as Oth in Table 1.

5. PG 1444+407 ($l = 69^\circ 9$, $b = +62^\circ 7$), PG 1415+451 ($l = 84^\circ 7$, $b = +65^\circ 3$), and SBS 1415+437 ($l = 82^\circ 0$, $b = +66^\circ 2$) all lie to the north of Complex C, off of the main H I 21 cm emission. No high-velocity O VI is detected at Complex C velocities.

6.2. Complex A

Sight lines to two extragalactic objects in our sample (Mrk 106, Mrk 116) pass through high-velocity cloud Complex A. Complex A is located at a distance of 4–10 kpc ($z = 2.6$ – 6.8 kpc), has a mass of $\sim 2.0 \times 10^6 M_\odot$, and has H I velocities of $-210 \lesssim v_{\text{LSR}} \lesssim -140$ km s $^{-1}$ (van Woerden et al. 1999b; Wakker 2001). We detect O VI absorption with $\log N \approx 13.81$ ($W_{1032} \approx 65$ m Å) between -150 and -100 km s $^{-1}$ toward Mrk 106. This absorption strength is comparable to that of the weaker detections toward Complex C (e.g., Mrk 279, Mrk 501, Mrk 817, PG 1351+640). The centroid of the absorption (-125 km s $^{-1}$) is shifted by $+32$ km s $^{-1}$ from the centroid of the H I 21 cm Complex A feature in this direction. The O VI detection is weak, with $W_{1032}/\sigma_W = 3.0$. Thus, while it is plausible that the absorption could be due to Complex A, a higher quality *FUSE* spectrum of this object would be desirable to confirm both the strength and velocity of this feature.

We do not detect high-velocity O VI toward Mrk 116, and set a 3σ limit of $\log N < 13.49$. At the distance of Complex A, the 2° separation of Mrk 116 and Mrk 106 corresponds to a linear separation of 140–350 pc. One other object in our sample, PG 0832+675, lies in front of Complex A and does not exhibit any O VI or low-ionization species at Complex A velocities (see also Ryans et al. 1997 for a non-detection of Ca II $\lambda 3933.663$ absorption). The lack of C II absorption in the *FUSE* data sets the lower limit to the distance of Complex A.

6.3. The Magellanic Stream

The Magellanic Stream is a complex of high-velocity gas that has been tidally torn from the Magellanic Clouds as they interact with the Milky Way. The Stream is readily visible in the H I maps shown in Figure 11. It consists of gas at both positive and negative velocities, with a zero velocity crossing near the south Galactic pole. The H I 21 cm emission of the Stream covers nearly 1000 square degrees on the sky (see Putman 2000). Several sight lines in our sample either intersect the H I Stream (Fairall 9, NGC 7714, NGC 7469, PG 2349–014) or lie very near to it on the sky and have velocities similar to the Stream velocities (NGC 1705, PKS 0558–304). We classify these as MS sight lines in Table 3. An additional 12 objects lie in the general vicinity of the Magellanic Stream; we label these as possible extensions of the Magellanic Stream (MSe). The association of the MSe O VI features with the H I gas of the Magellanic Stream is less certain than for the MS sight lines since there is no detectable 21 cm emission at Stream velocities along these sight lines. Since the MSe and LG features in this region of the sky have similar velocities, it is possible that some of the MSe features may eventually be more properly identified as Local Group clouds.

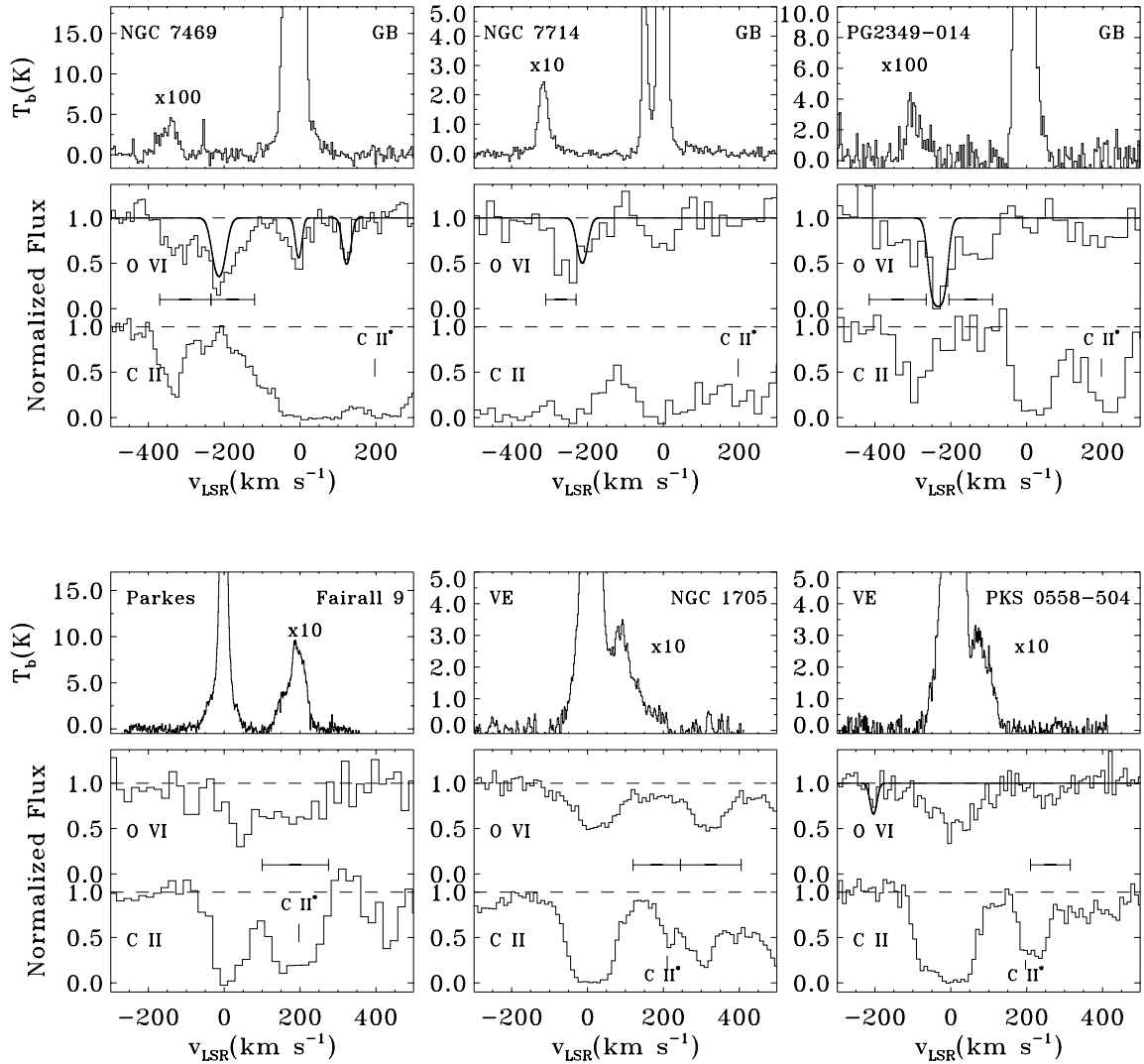


FIG. 15.—H I 21 cm emission, O VI $\lambda 1031.926$, and C II $\lambda 1036.337$ absorption profiles for six directions identified in Table 1 as Magellanic Stream (MS/MSe) sight lines. The top set of panels shows sight lines containing high negative velocity gas, and the bottom set of panels shows sight lines containing high positive velocity gas. The H I spectra come from a variety of sources (Green Bank/NRAO, Parkes, Villa-Elisa). The values of T_b have been scaled in the plots by the factors indicated to show the HVC emission. The solid line overplotted on the O VI profile is a model of the interstellar H₂ absorption in the (6–0) $P(3)$ and $R(4)$ lines. The horizontal bar above the C II profile shows the integration range for the high-velocity gas. C II* $\lambda 1037.018$ absorption is seen at a velocity of ~ 197 km s^{−1} relative to the C II line.

We show the H I 21 cm emission profiles and O VI and C II absorption profiles for six MS/MSe sight lines in Figure 15. In the four cases where both high-velocity H I and O VI are detected, the O VI absorption is broader than the H I. For the three MS sight lines with negative Stream velocities, the high-velocity O VI absorption overlaps (or nearly overlaps) in the case of NGC 7714 the velocities of the H I and extends to considerably less negative velocities. We tentatively classify the O VI feature toward NGC 7714 ($\bar{v} = -259$ km s^{−1}), as well as the higher velocity features toward NGC 7469 ($\bar{v} = -304$ km s^{−1}) and PG 2349–014 ($\bar{v} = -326$ km s^{−1}) as being associated with the Magellanic Stream, while the remaining lower velocity features for the latter two sight lines may or may not be associated with the Stream (these are designated LG in Table 1). The O VI column densities of the MS components for these three sight lines are similar: $\log N = 14.18$ (NGC 7469), 14.13 (NGC 7714), and 14.00 (PG 2349–014).

For the three primary MS/MSe sight lines with positive Stream velocities, the situation is also complex. The association of the high-velocity H I and O VI is fairly clear for Fairall 9. However, NGC 1705 and PKS 0558–304 both lie near to the Stream H I, but neither sight line intersects any obvious Stream H I emission (see Fig. 15). The velocities of the O VI absorption features are similar to those of other H I clouds cataloged by Wakker & van Woerden (1991) in the neighborhood of these two directions, but the association of these O VI clouds with the Magellanic Stream is less clear than for Fairall 9 since they lie several degrees off of the main axis of the Stream. Nevertheless, small H I clouds associated with the Stream lie in the same area of the sky as these sight lines (Putman et al. 2002). The two sight lines exhibit high-velocity C II absorption at velocities similar to those of the O VI. Given the similarity of the positive velocity O VI absorption to that seen at negative velocities in the other Stream directions, we tentatively classify the positive

velocity O VI features shown in Figure 15 as highly ionized Magellanic Stream or Magellanic Stream extension gas. These features have O VI column densities of $\log N = 14.33$ (Fairall 9), 14.31 and 13.78 (NGC 1705), and 13.68 (PKS 0558–504). We note that the only other MSe sight line in this region of the sky, HE 0226–4410, has a slightly smaller velocity ($\bar{v} = 164 \text{ km s}^{-1}$) and a similar column density ($\log N = 13.98$).

The highest velocity portions of the C II $\lambda 1036.337$ absorption along the six sight lines shown in Figure 15 occur at velocities similar to those of the high-velocity O VI absorption. At positive velocities, the C II absorption is completely confused with low-velocity C II* $\lambda 1037.018$ absorption in the ISM (at $+197 \text{ km s}^{-1}$ with respect to C II). As in the case of Complex C, the relationship between O VI and C II suggests that the C II is probably tracing ionized gas. The slight offset of the highest velocity portions of the C II absorption relative to the H I is consistent with an ionized boundary around the Stream. This finding also agrees well with higher resolution STIS data. Sembach (2002) presents a preliminary analysis of the high-velocity gas along the NGC 1705 sight line and finds that the high-velocity O VI absorption is offset slightly from the lower ionization gas. Furthermore, the O VI toward NGC 1705 has a somewhat smoother velocity structure and does not have the distinct component structure seen in the lower ionization lines with STIS.

6.4. The Outer Spiral Arm

Three low-latitude sight lines in our sample lie in the general direction of the Outer Arm seen in H I 21 cm emission in the general direction $49^\circ \leq l \leq 161^\circ$, $4^\circ \leq b \leq 31^\circ$ at a Galactocentric distance of about 15.5 kpc (Kepner 1970; Haud 1992). HS 0624+6907 ($l = 145^\circ.7$, $b = +23^\circ.4$) exhibits Outer Arm H I emission but has no associated O VI feature. H 1821+643 ($l = 94^\circ.0$, $b = +27^\circ.4$) and 3C 282 ($l = 61^\circ.3$, $b = +17^\circ.5$) exhibit O VI absorption with $\bar{v}_{\text{LSR}} \sim -119 \text{ km s}^{-1}$ and $\bar{v}_{\text{LSR}} \sim -90 \text{ km s}^{-1}$, respectively. These velocities are in excellent agreement with both the observed and expected H I velocities in the Outer Arm (-115 km s^{-1} toward H 1821+643 and -85 km s^{-1} toward 3C 282) (Hulsbosch & Wakker 1988; Haud 1992). These velocities are similar to those of some of the higher latitude Complex C sight lines at nearby longitudes, but it is unlikely that the two complexes of gas are related.

6.5. Extragalactic Clouds

Several high-velocity clouds in our sample other than Complex C and the Magellanic Stream are excellent candidates for being located outside the Milky Way. We discuss below a few of those clouds that have been studied by previous investigators at other wavelengths.

6.5.1. The C IV HVCs Toward Mrk 509 and PKS 2155–304

The Mrk 509 sight line ($l = 35^\circ.97$, $b = -29^\circ.86$) passes through two highly ionized HVCs detected in C IV absorption that have ionization properties consistent with clouds irradiated by local extragalactic background radiation (Sembach et al. 1999). The C IV absorption components are centered at -283 and -228 km s^{-1} . These clouds have little associated low-ionization absorption. There is no detectable H I 21 cm emission directly along the sight line [$\log N(\text{H I}) < 17.5$ (3σ)], although H I emission near the

velocities of the C IV HVCs is present within a few degrees of the sight line (Sembach et al. 1995b).

Sembach et al. (2000) first detected O VI absorption between -345 and -100 km s^{-1} toward Mrk 509 (see also Fig. 2). The O VI absorption is prominent at -247 and -147 km s^{-1} , with the lower velocity component shifted slightly redward of the high-velocity C IV absorption. The detection of O VI at these velocities is somewhat unexpected, since photoionization by the extragalactic background is not expected to produce the observed quantities of O VI unless the path lengths are very long and the cloud sizes very large (see § 9). At these velocities we find $\log N(\text{O VI}) \sim 14.36$, which is a factor of ~ 10 higher than predicted by the photoionization model that best fits the data for C IV and lower ionization stages (see Sembach et al. 1999). We conclude that additional ionizing sources are responsible for increasing the O VI column density above that expected for the pure photoionization case.

A similar result holds for the two highly ionized HVCs toward PKS 2155–304. These clouds are also likely ionized by the extragalactic background (Sembach et al. 1999), but they contain O VI in quantities much greater than those expected for a simple photoionization scenario. One possible explanation for the high-velocity O VI features observed along both the Mrk 509 and PKS 2155–304 sight lines is that these are photoionized extragalactic clouds that have begun to interact with the hot Galactic corona or a low-density Local Group medium (see § 11).

6.5.2. The Isolated Compact HVCs Toward Ton S210 and Mrk 205

The class of high-velocity H I clouds classified as “compact and isolated” based on their morphological properties is a difficult group of clouds to study in absorption at ultraviolet wavelengths since their sky covering factor is low ($\lesssim 1\%$ for those cataloged by Putman et al. 2002). Various authors have suggested that the compact H I HVCs may be distant (greater than a few hundred kpc) analogs of nearer H I HVCs (e.g., Braun & Burton 2000; Burton, Braun, & Chengalur 2001), but this hypothesis is not yet widely accepted. The two metallicity measurements available for these clouds suggests that the gas has $(\text{O}/\text{H}) < 0.5$ solar (Sembach et al. 2002), which is consistent with either a low-metallicity extragalactic origin or a Magellanic origin.

Two sight lines in our sample pass through or very near to isolated compact HVCs. Ton S210 ($l = 224^\circ.97$, $b = -83^\circ.16$) lies behind the outer regions of CHVC 224.0–83.4–197. The properties of this cloud are considered by Sembach et al. (2000, 2002), who find O VI absorption near the velocity of the H I 21 cm emission ($\bar{v}_{\text{LSR}} \approx -200 \text{ km s}^{-1}$). They base their upper limit of $(\text{O}/\text{H}) < 0.5$ solar (3σ confidence) on the non-detection of the O I $\lambda 1039.230$ line in the *FUSE* spectrum of this object. The H I column derived from the Lyman-series H I absorption is consistent with the H I column from the 21 cm measurements. Sembach et al. (2002) also find that the high-velocity gas in this direction contains as much hot H^+ , as inferred from the O VI absorption, as H I, suggesting that the cloud has a substantial ionized outer boundary. We discuss the production and significance of such a boundary in § 11.

The -200 km s^{-1} velocity of the CHVC 224.0–83.4–197 O VI absorption in the Ton S210 spectrum stands out in our sample since it is the only feature that has a negative LSR velocity at Galactic longitudes $l > 180^\circ$ (see § 5.4 and

Fig. 8). It also has the most extreme negative velocity in the GSR reference frame of any feature in the sample (Fig. 9). The peculiar velocity of the cloud is substantially different from that of the bulk of the Magellanic Stream in this direction ($v_{\text{LSR}} \sim -100 \text{ km s}^{-1}$), but it is not yet possible to exclude the possibility that it could be a fragment of the tidal interaction between the Magellanic Clouds and the Galaxy (see Sembach et al. 2002).

The Mrk 205 sight line ($l = 125^\circ 45'$, $b = +41^\circ 67'$) passes through CHVC 125+41–207, which is detected in H I 21 cm emission (Braun & Burton 1999) and in Mg II absorption (Bowen & Blades 1993; Bowen, Blades, & Pettini 1995). This cloud probably also has a subsolar metallicity, (Mg/H) < 0.2 solar (see Gibson et al. 2001b; Wakker 2001), but additional measurements are needed to confirm the low Mg abundance. As noted previously, the data for Mrk 205 are not optimal, and our limit of $\log N(\text{O VI}) < 13.79$ (3σ) is not terribly strict. Still, it appears that there is less O VI associated with the compact HVC along this sight line than there is with the compact HVC along the Ton S210 sight line.

6.5.3. Local Group Galaxies

Several Local Group galaxies exhibit O VI absorption occurring at high velocities with respect to the LSR. While not necessarily “high velocity” in the rest frame of the galaxies, we mention them briefly here for completeness. Basic results for the Magellanic Clouds have been described elsewhere (Hoopes et al. 2002; Howk et al. 2002b) and are not considered further here other than to note that the data for both galaxies are consistent with the idea that each is surrounded by a substantial halo of O VI. The SMC also exhibits O VI enhancements caused by local structures (e.g., supernova remnants, superbubbles, etc.). The O VI column densities in the Magellanic Cloud halos are comparable to those found for the halo of the Milky Way, despite the lower metallicities and lower masses of the Clouds.

A search for O VI in the halos of M31 and M33 in the directions of several objects yields mixed results. Wannier & Andersson (2003) detect O VI absorption toward QSO 0045+3926 (a.k.a. RX J0048.3+3941 or IO And) at an LSR velocity of -296 km s^{-1} . QSO 0045+3926 is located $1^\circ 9'$ from the center of M31, corresponding to a linear separation of $\approx 23 \text{ kpc}$ at a distance of 700 kpc . The measured velocity is within $\sim 10 \text{ km s}^{-1}$ of that expected from an extension of a flat rotation curve for M31 at the location of

the QSO. A high negative velocity O VI component is seen in many directions in this region of the sky ($l \sim 120^\circ$, $b \sim -25^\circ$), so it is difficult to know for certain whether the O VI feature toward QSO 0045+3926 is unique to M31 (see Wakker et al. 2003, Appendix). High negative velocity absorption is also seen in the direction of several H II regions in M33 (e.g., NGC 595 and probably NGC 588). However, Wakker et al. (2003) find no convincing evidence for an extended, corotating O VI halo around M33 at a level of $\log N(\text{O VI}) > 14$ based on the nondetection of *positive* velocity gas at M33 velocities along several sight lines that pass near to M33. Additional high-quality *FUSE* observations of other sight lines in the directions of M31 and M33 would be useful.

Several sight lines in our sample pass within modest impact parameters ($< 15 \text{ kpc}$) of smaller Local Group galaxies (e.g., Draco, Leo I, Ursa Minor, Carina, Sculptor). None of these show unambiguous evidence of O VI absorption (see the Appendix comments in Wakker et al. 2003 for details).

7. HIGH-VELOCITY H I 21 CENTIMETER EMISSION WITH NO CORRESPONDING O VI ABSORPTION

In general, O VI absorption is seen at velocities at which high-velocity H I 21 cm emission is detected. However, there are a few notable exceptions to this rule. We list the H I column densities and the O VI limits for these six cases in Table 9. Most of the O VI nondetections occur for sight lines with low *FUSE* data quality ($Q = 1$ – 2 in five out of six cases). However, in all cases, the nondetection is significant. One additional case not listed in Table 9 is the Complex A H I emission at -145 km s^{-1} toward PG 0832+675; since this star lies in front of Complex A, no O VI absorption is expected.

The absence of O VI along the sight lines listed in Table 9 may be due to small-scale structure within the high-velocity gas sampled by the larger H I beams. With the exception of ESO 265–G23, the absorption traced by C II $\lambda 1036.337$ at the H I velocities noted is relatively weak, which supports the idea that these sight lines pass through low-density regions of the high-velocity gas encompassed within the field of view of the H I 21 cm observations. Furthermore, in two cases (Complex A and the Outer Arm), other sight lines

TABLE 9
HIGH-VELOCITY H I 21 CENTIMETER EMISSION FEATURES WITH NO O VI

Object	l (deg)	b (deg)	$\bar{v}_{21 \text{ cm}}$ (km s^{-1})	$\log N(\text{H I})^a$ (3σ)	$\log N(\text{O VI})^b$	Q^c	Comment
PG 0052+251.....	123.91	–37.44	–121	18.60	< 13.72	2	WW 478
Mrk 205.....	125.45	41.67	–202	19.21	< 13.79	1	WW 84
HS 0624+6907.....	145.71	22.35	–100	19.32	< 13.61	2	Outer Arm
Mrk 116.....	160.53	44.84	–170	19.33	< 13.49	3	Complex A
Ton 1187.....	188.33	55.38	–104	19.23	< 13.65	2	Complex M
ESO 265–G23.....	285.91	16.59	+117	19.71	$< 13.86^d$	1	Complex WD

^a The H I 21 cm emission profiles are shown in Fig. 1 of Wakker et al. 2003.

^b O VI column density limit over an integration range of $\approx 50 \text{ km s}^{-1}$ centered on the observed velocity of the H I 21 cm emission.

^c Data quality of the *FUSE* observation.

^d A higher quality *FUSE* Guest Investigator observation obtained recently by B. K. Gibson and colleagues confirms that any O VI feature at these velocities must be weak.

in the sample show both H I 21 cm emission and O VI absorption even though the sight lines in Table 9 do not.

The Complex M sight line toward Ton 1187 ($l = 183^\circ.3$, $b = +55^\circ.4$) does not exhibit high-velocity O VI, which may be due to either lower ionization or small-scale structure. Complex M has been detected in H α emission by Tufte et al. (1998), which indicates that ionized gas is clearly present in some regions of the cloud. Complex M may contain some small-scale structure since high-velocity absorption in lower ionization lines is present toward BD +38 2182 ($l = 182^\circ.2$, $b = +62^\circ.2$, $d \sim 4.0$ kpc) but not toward HD 93521 ($l = 183^\circ.1$, $b = +62^\circ.2$, $d \sim 1.9$ kpc), which is less than $30'$ away (see Danly, Albert, & Kuntz 1993; Wakker 2001). The smaller distance of HD 93521 may also explain the absence of Complex M absorption in this direction if Complex M lies beyond $z \sim 1.5$ kpc.

Either small-scale structure or ionization may be viable explanations for the absence of O VI in the remaining H I HVCs in Table 9 (WW 478, WW 84, Complex WD). A possible alternative explanation may be that the gas has a very low metallicity, which would be very interesting since it would imply that the clouds are located at large distances. (Initial estimates indicate that Complex WD and cloud WW 84 have metallicities $Z \sim 0.1$.) This hypothesis could be tested and the metallicities refined by obtaining high angular resolution H I data in conjunction with suitable STIS observations of the three sight lines.

8. NEW HIGH-VELOCITY CLOUDS IDENTIFIED IN O VI

We observe high-velocity O VI along many sight lines for which there are no previous detections of high-velocity H I 21 cm emission. This suggests that much of the high-velocity gas in these directions is highly ionized. We discuss some of these features in this section.

8.1. High Positive Velocity O VI “Wings”

Many of the sight lines in our sample exhibit broad, weak O VI absorption features that extend asymmetrically from the Galactic thick disk/halo absorption velocities out to high positive velocities. Examples are shown in Figure 16, where we have plotted the continuum-normalized O VI $\lambda 1031.926$ absorption profiles for 21 sight lines as a function of LSR velocity. In a few cases, the extensions (or wings) comprise a significant fraction of the total O VI absorption along the sight line, but in most cases the positive velocity wings extending beyond $v_{\text{LSR}} \approx +100$ km s $^{-1}$ are much weaker than the thick disk/halo absorption along the same sight lines. Two general groupings of clouds listed in Table 1 other than the Magellanic Stream display high positive velocities. These are the extreme positive velocity clouds in the north Galactic octant between $180^\circ < l < 360^\circ$ (designated EPn in Table 1), which have properties similar to those of identified H I HVCs in the same general location (but not necessarily along the same sight lines), and the group of clouds designated Oth that lie predominantly in the northern octant containing Complex C and that have no identifiable counterpart in H I 21 cm emission.

All of the wing features carry a primary designation of EPn (11/21 sight lines), Oth (9/21 sight lines), or MS (1/21) in Table 1. These features are denoted with a dagger (†) mark attached to their HVC identification. It is important

to note that not all EPn or Oth features in Table 1 are broad absorption wings. Eighteen of the 22 sight lines with high positive velocity wings are located in the northern Galactic sky. The four sight lines in the southern sky (e.g., Mrk 509, NGC 1705, PKS 2005–489, PKS 0405–12) are widely scattered in longitude and do not appear to be associated in any obvious way with the 17 northern sight lines. The absorption wings can be seen quite clearly in the positive velocity channel maps shown by Wakker et al. (2003). We present a summary of the sky positions in Figure 17, where we indicate column density of the wing features in the same manner as in the top panel of Figure 6.

The similarities in the general locations of the northern sight lines exhibiting absorption wings and in their velocities suggest that many of the O VI wing features could have a common origin. One possibility is that the wings trace hot gas expelled from the Galactic disk. Sembach et al. (2001b) examined the absorption toward 3C 273 and found that the high positive velocity O VI in that direction has no detectable counterpart in other species, including C IV. They interpreted the high-velocity O VI absorption as an indicator of hot gas flowing out of the Galactic disk. The 3C 273 sight line passes through Radio Loops I and IV (Berkhuijsen, Haslam, & Salter 1971) and through a region of enhanced soft X-ray emission associated with the North Polar Spur (Snowden et al. 1995). The radio loops are filled with X-ray emission and were probably created by supernovae in the Galactic disk (Iwan 1980; Snowden et al. 1995). The absence of lower ionization absorption and the presence of 0.25 keV emission suggests that the O VI-bearing gas is hot ($T \sim 10^6$ K). Not all of the northern sight lines with high positive velocity wings lie in the direction of Loop I or the North Polar Spur, so it is not possible to associate all of these wings with these two large Galactic structures. However, similar physical processes may be at work along many of these sight lines, and the wider spread existence of the wings beyond the confines of Loop I may signal a larger scale production and acceleration of hot gas in the northern Galactic sky than in the south.

An additional argument in favor of the idea that some of the positive velocity wings trace gas expelled from the Galactic disk is that hot gas expelled from the Galactic disk, perhaps as part of a “Galactic fountain” (Shapiro & Field 1976; Bregman 1980; Norman & Ikeuchi 1989), would likely contain O VI. Although most Galactic fountain models start with the assumption of a much hotter flow ($T \sim 10^6$ K), entrainment of cold gas in the flow or a lower temperature fountain would result in lower temperatures compatible with the production of O VI. Lower temperature fountain models can explain the kinematics of some of the intermediate-velocity clouds (Houck & Bregman 1990). The thick disk and low halo of the Milky Way contain a substantial amount of O VI; the typical O VI column density for a sight line perpendicular to the Galactic plane is $\log N \sim 14.12$, with a ~ 0.25 dex enhancement above this value in the northern Galactic hemisphere (Savage et al. 2003). The enhancement of the thick disk O VI in the north may indicate a generally elevated level of hot gas production at these latitudes. For a few sight lines, like ESO 572–G34, Mrk 734, PG 1001+291, or HE 1143–1810, the distinction between displaced thick disk/halo absorption and high-velocity absorption is particularly nebulous.

Alternatively, some of the broad O VI absorption wings may be entirely unrelated to the thick disk of the Milky

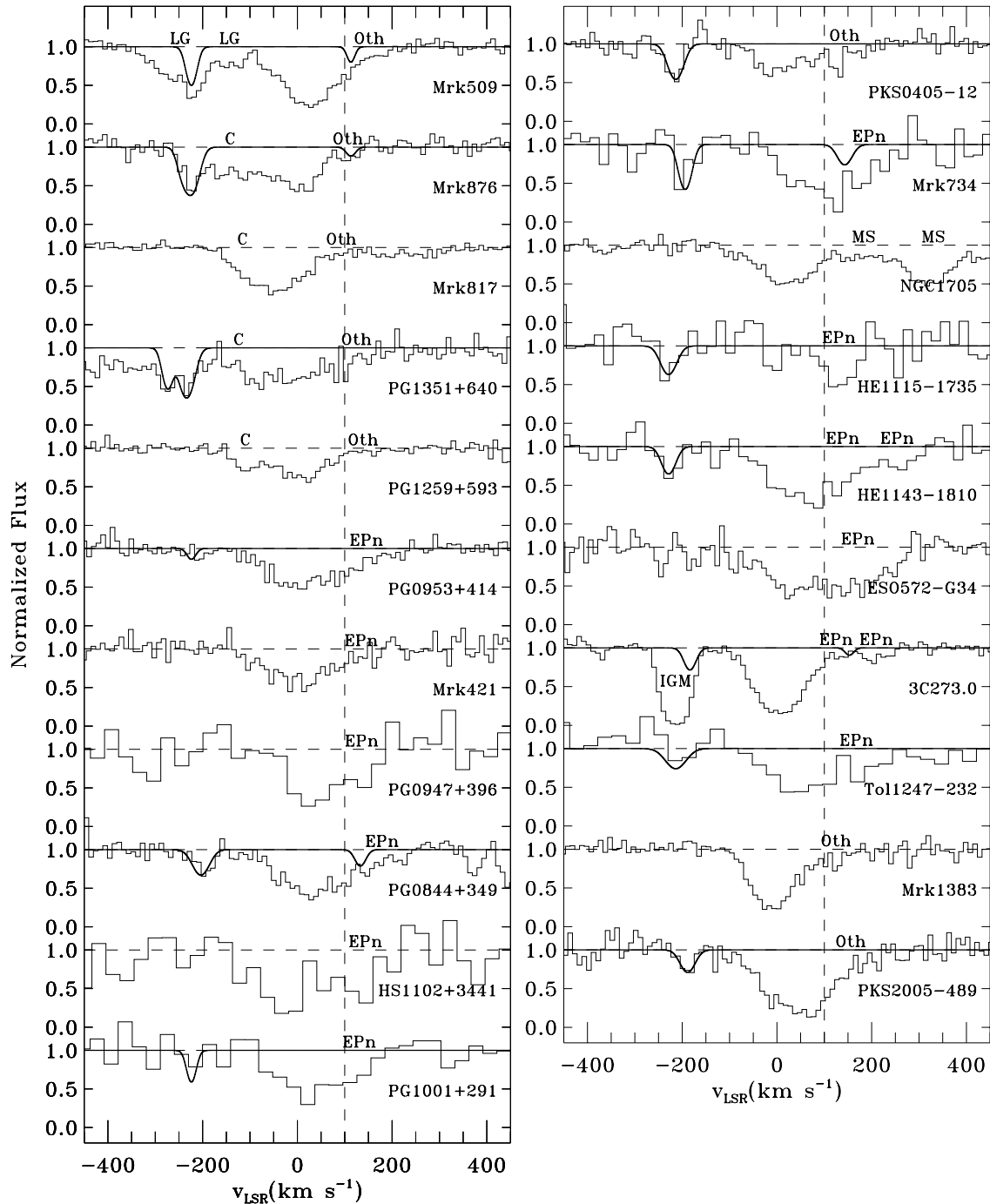


FIG. 16.—Normalized intensity vs. LSR velocity for 21 objects in our sample with high positive velocity O vi absorption wings. These components are identified in Table 1 with a dagger (†) symbol attached to the feature identification. Identifications of all high-velocity O vi features are provided above each spectrum. In many cases, the absorption wings join smoothly with the low-velocity absorption produced by the Galactic thick disk/halo. The smooth solid curves overlaid on some of the spectra are models of the H₂ (6–0) P(3) and R(4) absorption along the sight lines. The IGM absorption feature in the 3C 273 spectrum is H I Ly β at a redshift $z \approx 0.0053$ (see Sembach et al. 2001b).

Way. Some of the gas could be tidal debris remaining from encounters of the Milky Way and the Magellanic Clouds or other small galaxies. Most of the wing sight lines lie near the orbit of the Magellanic system. Another possibility might be that the wings are the positive velocity counterparts of the negative velocity LG features in the southern Galactic sky. The primary drawback to both of these hypotheses is that absorption wings are not discrete features like those associated with the Magellanic Stream (MS, MSe) or Local

Group (LG) features in the south, and at least qualitatively, they appear to be a continuation of the thick disk/halo velocity distribution. Additional observations of other species at these velocities, especially if abundances could be derived, would be particularly valuable in discriminating between the possible origins of the wings.

Finally, we call attention to the Mrk 509 sight line, which is one of the southern directions in the sample with a positive velocity wing. Unlike the 3C 273 sight line, this wing is

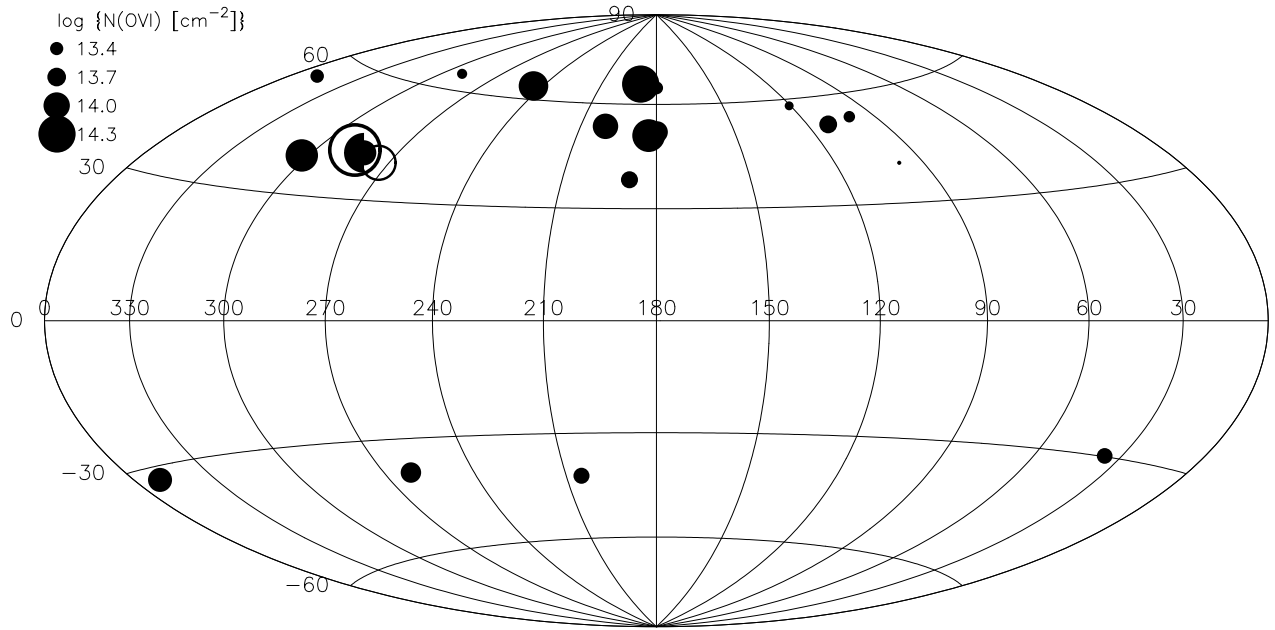


FIG. 17.—All-sky distribution of 21 sight lines containing high positive velocity O VI absorption wings. This map includes those sight lines for which a dagger (†) symbol is attached to the high-velocity feature identifications in Table 1. A split circle is shown for the two components toward HE 1143–1810 ($l = 281.8$, $b = 41.7$). The symbol size indicates the O VI column density of the absorption feature. Note that most of these sight lines are located in the northern Galactic hemisphere.

detected in other species, including Si II, Si IV, C IV, and N V (see Sembach et al. 1999). In this case, the positive velocity wing is likely related to gas in the low halo of the Galaxy. The sight line passes within 5 kpc of the Galactic center, and several other sight lines to halo stars near the Galactic center show similar features in C IV and Si IV (e.g., Savage, Massa, & Sembach 1990; Sembach, Savage, & Massa 1991; Sembach, Savage, & Lu 1995a).

8.2. High-Velocity O VI in the Local Group?

A subset of features listed in Table 1 have a category of LG (Local Group) assigned to them. This label is suggestive of an origin and location outside the Milky Way and was chosen because the absorption has some unusual properties. For most of these features, there is no obvious H I 21 cm emission at similar velocities directly along the sight lines. The most extensively studied examples include the cloud toward Ton S210 (see § 6.5.2) and the high negative velocity clouds toward Mrk 509, which have ionization properties more indicative of clouds bathed in the extragalactic ionizing background field than of clouds in the halo of the Galaxy (see § 6.5.1). All of the LG clouds are located in the southern Galactic hemisphere, mostly in the $35^\circ < l < 140^\circ$ longitude range. This is also the same general area of sky containing many of the MSe sight lines.

Various authors have considered the possibility that some of the clouds in this general region of the sky (Local Group barycenter) and in the opposite direction (Local Group antibarycenter) belong to a similar population of clouds located outside the Milky Way (e.g., Blitz et al. 1999). If we consider various standards of rest for the subsample of objects having LG, MSe, or EPn classifications in Table 1, we find the average velocities and dispersions listed in Table 10. The dispersion about the mean centroid velocity, $\sigma_{\langle v \rangle}$, is slightly smaller in the LGSr reference frame than in

the GSR reference frame, and a factor of 4 smaller than in the LSR reference frame. Restricting the sample to exclude points associated with known nearby features (e.g., Complexes A and C, the Outer Arm, the Magellanic Stream) shows the differences between the LSR and two alternate rest frames clearly. A similar result can be seen in Figure 7 for the entire ensemble of high-velocity features.

While such a reduction is a necessary consequence for a distributed population of Local Group clouds, it is not a sufficient requirement. The reduction indicates that the clouds are not located nearby (i.e., $d < 1$ kpc), but it cannot be used as the sole justification for a Local Group location for several reasons. A sample of clouds located within ~ 100 kpc of the Milky Way may have a significantly smaller dispersion in the GSR than in the LSR, but the difference between the GSR and LGSr frames would be difficult to ascertain without a very large sample because of selection biases in the directions chosen for study. An equally important bias is the strong selection against clouds with $|v_{\text{LSR}}| \lesssim 100 \text{ km s}^{-1}$ in our sample, and thus the omission of clouds with both large and small values of $|v_{\text{GSR}}|$ and $|v_{\text{LGSr}}|$. For example, a cloud with $v_{\text{LSR}} = 50 \text{ km s}^{-1}$ in the direction $b = 45^\circ$, $l = (0^\circ, 30^\circ, 60^\circ, 90^\circ, 120^\circ, 150^\circ, 180^\circ)$

TABLE 10
VELOCITY SUMMARY OF POSSIBLE LOCAL GROUP FEATURES

Reference Frame	$\langle v \rangle$ (km s ⁻¹)	$\sigma_{\langle v \rangle}$ (km s ⁻¹)
Local standard of rest	-55	212
Galactic standard of rest	-22	121
Local Group standard of rest	-7	102

NOTE.—The 51 O VI absorption features considered have classifications of EPn, MSe, or LG as defined in Table 3.

has $v_{\text{GSR}} = (50, 128, 185, 206, 185, 128, 50) \text{ km s}^{-1}$ and $v_{\text{LGR}} = (-19, 79, 163, 209, 206, 155, 69) \text{ km s}^{-1}$. Therefore, this sampling bias can cause the derived GSR and LGR velocity distributions to be narrower (or perhaps even broader) than the actual distributions, depending on the velocities of the positions of the clouds omitted in the LSR velocity range $|v_{\text{LSR}}| \lesssim 100 \text{ km s}^{-1}$.

9. PRODUCTION OF O VI

Conversion of O V into O VI requires an energy of 114 eV, which in principle can be supplied by either absorption of photons or by collisions with other species (primarily electrons). We favor collisional ionization as the primary production mechanism for most of the high-velocity O VI observed. We discuss the reasons for this preference after considering the collisional ionization and photoionization scenarios described below.

9.1. Collisional Ionization in Hot Gas

9.1.1. General Considerations and Possible Relationship to X-Ray Absorption Lines

In collisional ionization equilibrium, the ionization fractions for each element depend on the abundances and temperature of the gas. For a plasma with solar abundances, O VI has a peak ionization fraction $f_{\text{O VI}} = (\text{O VI}/\text{O}) \sim 0.22$ at $T \sim 2.8 \times 10^5 \text{ K}$ (Sutherland & Dopita 1993). Although this is often the canonical temperature quoted when referring to collisionally ionized O VI, the abundance of O VI remains high ($f_{\text{O VI}} > 0.05$) at temperatures of $(2\text{--}4) \times 10^5 \text{ K}$. In nonequilibrium, time-dependent cooling situations, the temperature of peak O VI ionization fraction does not change significantly, but at lower temperatures the ionization fractions are larger than in the equilibrium case (see Shapiro & Moore 1976; Sutherland & Dopita 1993). For example, Shapiro & Moore (1976) find that $f_{\text{O VI}} > 0.03$ down to $T \sim 2 \times 10^4 \text{ K}$ for a gas cooling isochorically from an initial temperature of 10^6 K . The peak ionization fraction diminishes to account for this increase in $f_{\text{O VI}}$ at lower temperatures, but $f_{\text{O VI}}$ at $T > T_{\text{peak}}$ remains similar to its value under conditions of collisional ionization equilibrium.

We compare the observed column densities of O VI and other well-observed high ions to the column density predictions of various collisional ionization models in the next section. Here we note that recent X-ray absorption-line observations with the *Chandra X-ray Observatory* suggest that the zero-redshift column densities of higher ionization species, such as O VII (and perhaps O VIII), may be very large: $\log N(\text{O VII}) \gtrsim 16$ (Fang, Sembach, & Canizares 2003; Nicastro et al. 2002). In collisional ionization equilibrium at $\log T(\text{K}) = (6.0, 6.2, 6.4)$, $N(\text{O VII})/N(\text{O VI}) = (255, 233, 194)$, respectively (Sutherland & Dopita 1993). For $\log N(\text{O VII}) = 16$, this implies $\log N(\text{O VI}) \sim 13.6\text{--}13.7$ if the gas has $T \sim 10^6 \text{ K}$. Thus, the amount of O VI contained in the hot gas traced by the X-ray absorption could be roughly comparable to the amounts of O VI found for the typical thick disk/halo absorption or the high-velocity gas. Even if the gas is much hotter, say $\sim 10^7 \text{ K}$, the amount of O VI predicted for such a large O VII column density [$\log N(\text{O VI}) \sim 13.3$] would still be detectable with *FUSE*. However, it is highly unlikely that all of the observed O VI in

either the Galactic disk/halo or the high-velocity gas is related exclusively to the hotter X-ray gas since lower ionization species (e.g., H I, C II, C IV) are seen at similar velocities and have miniscule ionization fractions in gas at temperatures exceeding 10^6 K . It remains to be seen whether the velocity structure of the higher temperature (O VII) gas is more consistent with disk/halo absorption or high-velocity cloud absorption since the velocity resolution of the X-ray data is currently too poor to discriminate between local Milky Way features and a more pervasive Local Group medium. Comparisons of X-ray emission and absorption-line strengths along individual sight lines may help to discriminate between these possibilities.

9.1.2. Insights from Lower Ionization Stages

Additional information about absorption by high-ionization species is available for several of the sight lines in our sample. We list the values of $N(\text{O VI})/N(\text{C IV})$ and $N(\text{O VI})/N(\text{N V})$ for several of the high-velocity O VI features in Table 11, including the Magellanic Stream, Complex C, and several Local Group clouds. The ratios are integrations over the velocity ranges covered by the high-velocity O VI features and thus are averages for the cases considered. We also list the ratios predicted by several by collisional ionization models and the photoionization model discussed below. The observed ratios of O VI/C IV and O VI/N V are typically greater than unity, with the possible exception of the highly ionized clouds toward Mrk 509.

The collisional ionization models considered in Table 11 include radiative cooling of 10^6 K gas (as in a Galactic fountain flow), thermal conduction in the presence of magnetic fields, turbulent mixing of hot ($T \sim 10^6 \text{ K}$) and warm ($T \sim 10^4 \text{ K}$) gases, and time-averaged cooling of shock-heated gas in evolved supernova remnants. The references and key assumptions for each of the models are provided in the notes at the end of the table. Spitzer (1996) summarizes these models and provides a brief discussion of the ratios for the Galactic disk and halo. Comparisons based on more extensive information for the Galactic halo have been given elsewhere (Sembach, Savage, & Tripp 1997; Savage, Sembach, & Lu 1997; Savage et al. 2003). In addition to the specific models listed in Table 11, we have also tabulated the predicted ratios if the gas is in collisional ionization equilibrium using the ionization fractions calculated by Sutherland & Dopita (1993) and the solar abundances recommended by Holweber (2001); the detailed dependences of the high ion ratios on temperature are shown in Figure 18. Incorporation of C, N, and O into dust should not affect these ratios significantly since all three elements are found predominantly in the gas phase, but the ratios may be affected if there is a nonsolar relative abundance pattern (e.g., if N/O is subsolar, as may be the case for Complex C; Richter et al. 2001).

The observed ionic ratios agree to within a factor of ~ 2 of those expected for the general turbulent mixing, thermal conduction, and radiative cooling predictions. A notable exception is the high-velocity gas toward Mrk 509. These models allow for a range of gas temperatures within the cooling regions. The simple assumption of collisional ionization equilibrium at a single temperature cannot reproduce both the observed $N(\text{O VI})/N(\text{C IV})$ and $N(\text{O VI})/N(\text{N V})$ ratios simultaneously.

TABLE 11
HIGH ION COLUMN DENSITY RATIOS

Sight Line	$\bar{v}$ (km s ⁻¹)	ID	log $N(\text{O VI})$	$N(\text{O VI})/N(\text{C IV})$	$N(\text{O VI})/N(\text{N V})$	Notes ^b
Mrk 509	-247	LG	14.24	<0.3	<0.2	1
PKS 2155-304.....	-232	LG	13.57	~1	>3	2
	-129	LG	13.80	~2	>4.6	2
NGC 1705.....	+330	MS	14.31	>3	...	3
Fairall 9	+183	MS	14.33	~7	>3	4
PG 1259+593.....	-110	C	13.72	~3.5	>3.8	5
(Galactic Halo).....	~0	...	~14.37 ± 0.18	~1.5	~5	6
Model Predictions ^a						
Turbulent mixing	...	...	...	0.1-0.8	2.5-8	7
Radiative cooling.....	...	...	...	2-10	7-14	8
Conduction.....	...	...	...	1.6-4.5	4-7	9
Supernova remnants	...	...	...	5-10	12-16	10
C.I.E. ($T < 2 \times 10^5$ K).....	...	...	...	<2.6	<0.7	11
C.I.E. ($T = 3 \times 10^5$ K).....	...	...	...	134	50	11
C.I.E. ($T = 5 \times 10^5$ K).....	...	...	...	50	47	11
Photo. ($n_{\text{H}} = 10^{-5}$ cm ⁻³).....	...	...	...	1.0	3.6	12
Photo. ($n_{\text{H}} = 10^{-4}$ cm ⁻³).....	...	...	...	0.01	0.5	12

^a Model predictions assume solar abundance ratios unless otherwise noted.

^b (1) C IV and N V from Sembach et al. 1999. The values listed are the sums for the two C IV-HVCs along the sight line at -283 and -228 km s⁻¹. An additional high-velocity O VI feature at $\bar{v} = -143$ km s⁻¹ (see Table 1) has no obvious counterpart in C IV or N V. (2) C IV and N V from Sembach et al. 1999. (3) C IV from Sembach 2002. Continuum placement for C IV is difficult. (4) C IV from Lu, Savage, & Sembach 1994. (5) C IV and N V from extant STIS data. See A. J. Fox et al. 2003, in preparation. (6) Galactic halo averages from data compiled by Sembach, Savage, & Tripp 1997, Savage, Sembach, & Lu 1997, and Savage et al. 2003. (7) Turbulent mixing layer results from Slavin, Shull, & Begelman 1993 for TMLs with postmixed temperatures $T = (1-3) \times 10^5$ K and hot gas entrainment velocities of 25-100 km s⁻¹. (8) Radiative cooling results from Edgar & Chevalier 1986 for a range of models with varying assumptions about the transition of the flow from isochoric to isobaric cooling. (9) Magnetized thermal conduction front results from Borkowski, Balbus, & Frstrom 1990 for a range of magnetic field orientations inclined between 0° to 60° to the face of the cloud at an age of 2.5×10^5 yr. (10) Evolved supernova remnant results from Slavin & Cox 1992 for isolated explosions in a medium with densities of 0.1-0.3 cm⁻³ and $B \approx 1$ μ G. Values are for remnants with ages of 4×10^5 to 5×10^6 yr. (11) Collisional ionization equilibrium ratios assuming solar abundance ratios (Sutherland & Dopita 1993; Holweber 2001). (12) Photoionization model results shown in Fig. 19. The values quoted are appropriate for models with $N(\text{H I}) = 10^{14}$ cm⁻², a metallicity of ~1/3 solar, and a solar relative abundance pattern. If the relative abundances are not in their solar proportions (e.g., if N/O is subsolar as appears to be the case for Complex C), the ratios may differ from those plotted. Higher values of $N(\text{H I})$ result in lower ratios. See § 9.2 for additional descriptions of the model.

9.2. Photoionization

9.2.1. Extragalactic Radiation

There is a considerable amount of information in the literature describing the conditions under which photoionization is relevant for highly ionized species such as O VI. Here we consider the simple case of a plane-parallel slab of gas bathed in the extragalactic background produced by the integrated light of QSOs and AGNs. Since all of the absorption features studied here occur within a few hundred km s⁻¹ of the systemic velocity of the Milky Way, we consider only the ionization of gas at zero redshift. We used the ionization code CLOUDY (v94.00; Ferland 1996) to compute the ionization fraction of O VI ($f_{\text{O VI}}$) in cases where the gas is optically thin to ionizing radiation ($\tau_{\text{H I}} < 1$; $\log N(\text{H I}) < 17.2$). We assumed the QSO spectral energy distribution given by

Madau (1992) normalized to a mean intensity at the Lyman limit $J_{\nu_0} = 1 \times 10^{-23}$ ergs cm⁻² s⁻¹ Hz⁻¹ sr⁻¹ (Donahue, Aldering, & Stocke 1995; Haardt & Madau 1996; Shull et al. 1999). This procedure followed that outlined by Sembach et al. (1999).

We summarize the results of these calculations in Figures 19 and 20, where we plot $f_{\text{O VI}}$ and $N(\text{O VI})$ as functions of ionization parameter [$U = (n_{\gamma}/n_{\text{H}}) \propto (J_{\nu}/n_{\text{H}})$] for a metallicity $\log Z = -0.5$ and neutral hydrogen column densities $\log N(\text{H I}) = 14$ to 17. The values of $f_{\text{O VI}}$ do not depend strongly on the metallicity—the curves shown are similar to those for $\log Z = -2$ to 0. These calculations show that $f_{\text{O VI}} < 0.25$ at most values of U , with the highest values occurring for values of $\log U > -1.5$. For $\log U \lesssim -2$ (i.e., $n_{\text{H}} > 3 \times 10^{-5}$ cm⁻²), $f_{\text{O VI}} \lesssim 0.01$. The values of $f_{\text{O VI}}$ do not depend strongly on $N(\text{H I})$ for $N(\text{H I}) < 10^{17}$ cm⁻².

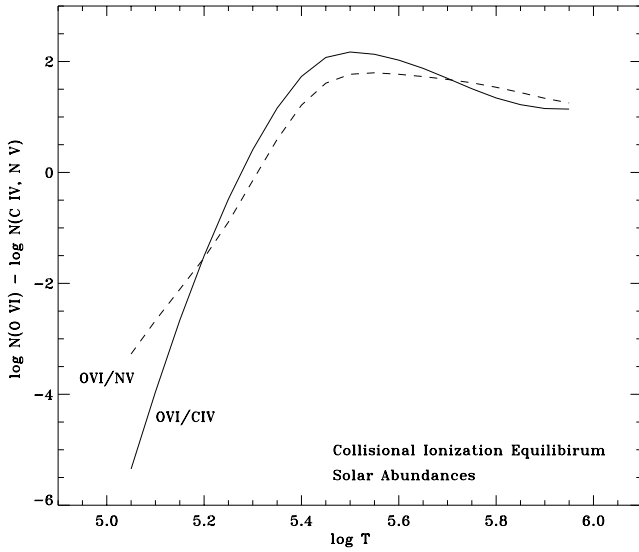


FIG. 18.—Ratios of $N(\text{O VI})/N(\text{C IV})$ and $N(\text{O VI})/N(\text{N V})$ as a function of temperature (in K) under conditions of collisional ionization equilibrium (Sutherland & Dopita 1993). The calculations assume intrinsic solar abundance ratios, $(\text{O}/\text{C}) = 1.4$ and $(\text{O}/\text{N}) = 6.4$ (Holweger 2001), and identical gas-phase depletions onto dust grains, $\delta(\text{C}) = \delta(\text{N}) = \delta(\text{O})$. Differential depletion of these elements onto dust grains will raise or lower the resulting curves by less than ~ 0.3 dex since none of these elements is strongly depleted from the gas-phase in diffuse cloud environments (see Savage & Sembach 1996).

In addition to the flux from AGNs and QSOs, the local extragalactic ionizing radiation field includes contributions from the integrated light of starburst galaxies and nearby galaxies (see Shull et al. 1999). If the high-velocity clouds are located within ~ 100 kpc of the Milky Way, the detailed ionization properties of the clouds should depend primarily upon the escape of ionizing photons from the Milky Way

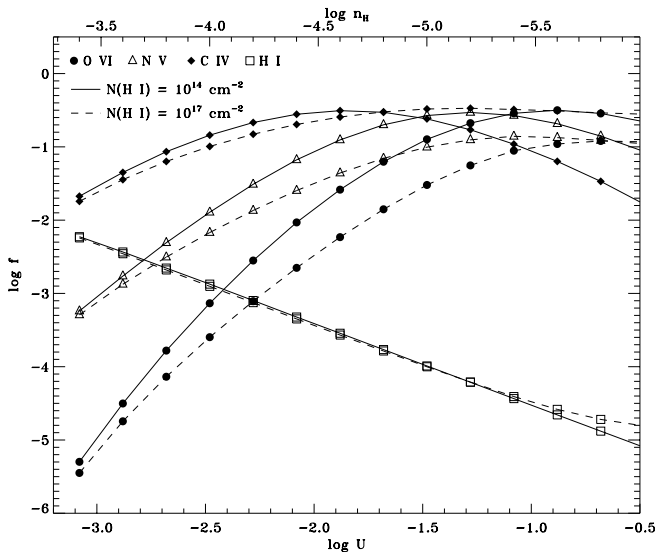


FIG. 19.—Ionization fractions of O VI, N V, C IV, and H I vs. ionization parameter, $U = \langle n_\gamma/n_{\text{H I}} \rangle$, and gas density, n_{H} , for uniform dust-free gas clouds with $1/3$ solar metallicity subjected to the extragalactic ionizing background at $z = 0$. Models for two values of total H I column density are plotted. The models assume an incident AGN/QSO spectrum with an intensity $J_{\nu_0} = 10^{-23} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Hz}^{-1} \text{ sr}^{-1}$ at the Lyman limit. The curves shown do not vary strongly as a function of metallicity for $Z = 0.01-1.0$.

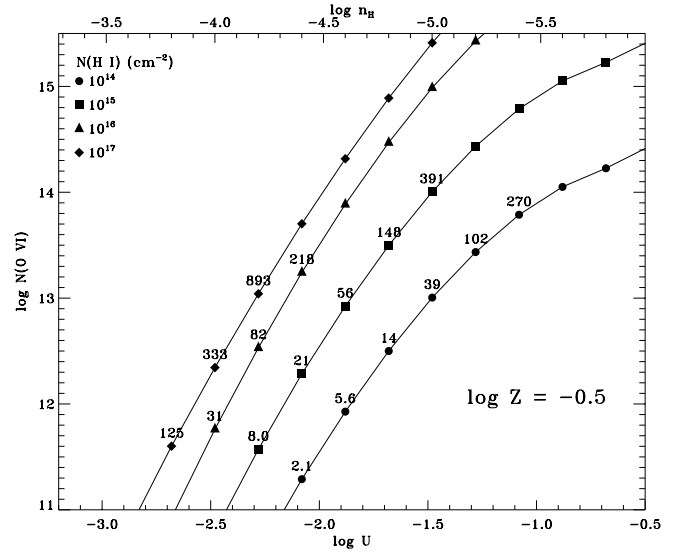


FIG. 20.—O VI column density as a function of ionization parameter and gas density for extragalactic clouds similar to those considered in Fig. 19. $N(\text{O VI})$ is shown for four values of the assumed H I column density. $N(\text{O VI})$ scales roughly linearly with metallicity for the range of $N(\text{H I})$ values shown. At a given ionization parameter (or density), the cloud size, D , increases with the H I column density; values of D (in kpc) are given immediately above several of the points.

and LMC (Bland-Hawthorn & Maloney 1999). However, starlight should not affect $f_{\text{O VI}}$ or the observed O VI column densities. Inclusion of an additional stellar spectrum in our photoionization models, like that produced by early-type OB stars, does not appreciably alter the predicted ionization fraction of O VI. Furthermore, despite intensive searches for stars associated with HVCs and the Magellanic Stream, none have yet been found (see Irwin, Demers, & Kunkel 1990; Simon & Blitz 2002), which indicates that there are few, if any, in situ stellar sources of ionizing photons. The Magellanic Bridge, a much younger portion of the Magellanic system than the Stream, contains hot stars (Irwin et al. 1990) but is generally considered to be more closely associated with the Magellanic Clouds than with the high-velocity cloud system surrounding the Milky Way. None of the sight lines in this O VI survey pass through the Magellanic Bridge (but see Lehner 2002 for an example).

In the models shown in Figure 20, $N(\text{O VI})$ increases with increasing hydrogen column density and scales approximately linearly with metallicity. The cloud size also scales roughly linearly with the total H I column density and metallicity over the column density ranges considered. A few simple scaling laws apply for fixed values of U :

$$\begin{aligned} N(\text{O VI}) &\propto Z \times N(\text{H I}), \\ n_{\text{H I}} &\propto n_{\text{H}} \times (n_{\text{H}}/J_{\nu}), \\ D &= n_{\text{H I}}^{-1} \times N(\text{H I}). \end{aligned}$$

At a given ionization parameter, smaller sizes occur for clouds with lower H I column densities or higher metallicities. To produce an O VI column density of 10^{13} cm^{-2} requires a cloud size $D \gtrsim 40$ kpc for $n_{\text{H}} \geq 10^{-5} \text{ cm}^{-3}$, $\log N(\text{H I}) > 14$, and $\log Z = -0.5$. To produce an O VI column density of 10^{14} cm^{-2} requires cloud sizes in excess of several hundred kiloparsecs, even if the metallicity is as high as solar. The assumption of a uniform, constant density

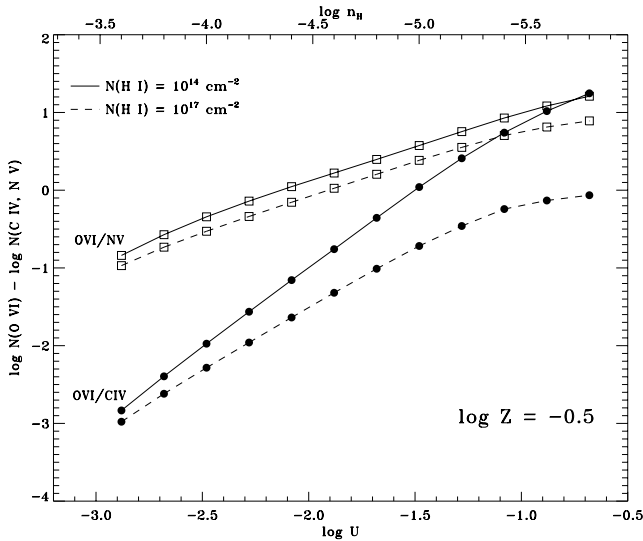


FIG. 21.—Column density ratios $N(\text{O VI})/N(\text{C IV})$ and $N(\text{O VI})/N(\text{N V})$ as a function of ionization parameter and gas density for the extragalactic cloud considered in Fig. 19, assuming solar relative abundances for C, N, and O. Models for two values of total H I column density are plotted. The ratios do not change substantially for metallicities in the range 0.01–1.0 solar.

cloud may break down as the cloud size increases beyond these sizes. Cloud sizes as large as these may be possible for pervasive media outside galaxies (e.g., a Local Group medium) but are clearly too large to be contained within the Milky Way).

We show the detailed behavior of the $\text{O VI}/\text{C IV}$ and $\text{O VI}/\text{N V}$ ratios expected for the photoionization model in Figure 21, assuming relative abundances of C, N, and O equivalent to their solar proportions. The ratios depend on the ionization parameter (or gas density for a fixed ionizing spectrum) and the H I column density, so we show ratios for values of $\log N(\text{H I}) = 14$ and 17. The ratios are not sensitive to metallicity in the range $Z = 0.01 - 1.0$; the metallicity dependence is weaker than the H I dependence. The expected column density of O VI is greater than that of C IV only for $U \gtrsim -1.5$, which corresponds to a density of $\lesssim 10^{-5} \text{ cm}^{-3}$. In Table 11 we list the high ion ratios for densities of 10^{-5} and 10^{-4} cm^{-3} . In a few cases (e.g., Mrk 509, PKS 2155–304), the photoionization models can reproduce the observed ratios of $\text{O VI}/\text{C IV}$ and $\text{O VI}/\text{N V}$ if the H I column density is very low [$N(\text{H I}) \sim 10^{14} \text{ cm}^{-2}$] and the gas density is low ($n_{\text{H}} \lesssim 10^{-4} \text{ cm}^{-3}$). However, the total observed value of $N(\text{O VI})$ is difficult to reproduce unless the clouds are very large.

9.2.2. Galactic Radiation

Much of the discussion about photoionization in the preceding section is relevant for discussions of photoionization by Galactic sources. In both the extragalactic and Galactic cases, the ionization parameter must be high for a substantial amount of O VI to be produced. The production of O VI by ionizing Galactic sources is restricted to special situations in which the interstellar gas has a very low density or lies in close proximity to the ionizing source. The dilute ultraviolet radiation that leaks out of H II regions and maintains the ionization of the warm ionized interstellar medium (WIM: $n_e \sim 0.08 \text{ cm}^{-3}$, $h_z(\text{WIM}) \sim 1 \text{ kpc}$; see Miller & Cox

1993 and Reynolds 1993) is insufficient to ionize O VI since the OB stars responsible for the WIM have strong He II absorption edges at 54 eV.

Several authors have considered the production of highly ionized atoms by radiation from hot degenerate objects, such as He-poor white dwarf stars. Dupree & Raymond (1983) calculated the O VI column densities expected in the Strömgren spheres surrounding pure hydrogen white dwarfs with surface temperatures $T \sim 60,000 \text{ K}$. They found that the column density of O VI depends upon both the size of the O VI Strömgren region and the ambient ISM density; for ambient densities of 0.01 and 0.1 cm^{-3} , the radii of the transition regions where the H I fraction is 10% are 6.8 and 2.1 pc, and the O VI columns are 1.4×10^{12} and 5.6×10^{12} , respectively. (The O VI Strömgren spheres are much smaller than the traditional H II Strömgren spheres.) Thus, the O VI produced in such a region is both confined and weak compared to the observed O VI in the high-velocity gas. Over a typical 1 kpc path through a 0.01 cm^{-3} ISM, Dupree & Raymond (1983) predict a total O VI column density of $(0.5\text{--}1.4) \times 10^{13} \text{ cm}^{-2}$ might be intercepted by a sight line given the (uncertain) space density of He-poor white dwarf stars. This O VI column density is lower than observed for all features in Table 1, often by an order of magnitude or more. Increasing the path length beyond $\sim 1 \text{ kpc}$ through the Galactic halo does not increase this prediction significantly since the space density of white dwarf stars is presumably highest near the Galactic plane.

Bregman & Harrington (1986) have also considered the production of O VI in the Galactic halo, with a radiation field that includes both Galactic sources of radiation (hot stars, planetary nebulae, the Galactic soft X-ray background) and a contribution from the extragalactic background. They find that a path length of $\sim 10 \text{ kpc}$ through a medium with $n_{\text{H}} = 0.001 \text{ cm}^{-3}$ is needed to produce an O VI column density of $\sim 1 \times 10^{13} \text{ cm}^{-2}$. In this regime, the conditions required for the production of O VI essentially revert to the situation considered in § 9.2.1, only the problem of moving such extensive regions of the Galactic halo at high enough velocities to explain the observed O VI absorption features becomes untenable, even if the entire halo decouples from the underlying disk (see § 10.2).

9.3. The Line Width–Column Density Relation

There is an interesting correlation in the column densities and velocity widths of O VI absorbers found in different astrophysical environments. This trend was first noticed by Heckman et al. (2002) for starburst systems and some of the Galactic and HVC absorption systems. In Figure 22 we plot O VI column density versus line width for O VI features in various environments, including the Galactic disk and halo, high-velocity gas, and the Magellanic Clouds. The Galactic disk points are from the *Copernicus* O VI survey (Jenkins 1978a, 1978b), which sampled gas within $\sim 1 \text{ kpc}$ of the Sun; only data points having O VI $\lambda 1031.926$ values of $b = [2\langle(v - \bar{v})^2\rangle]^{1/2}$ without substantial uncertainties due to HD contamination are illustrated. The remaining data points are based on $\lambda 1031.926$ measurements from *FUSE*. References to the sources for the data points can be found in the figure caption.

Production of O VI by photoionization should not produce the trend observed in Figure 22. Under conditions appropriate for photoionization, the line width should be

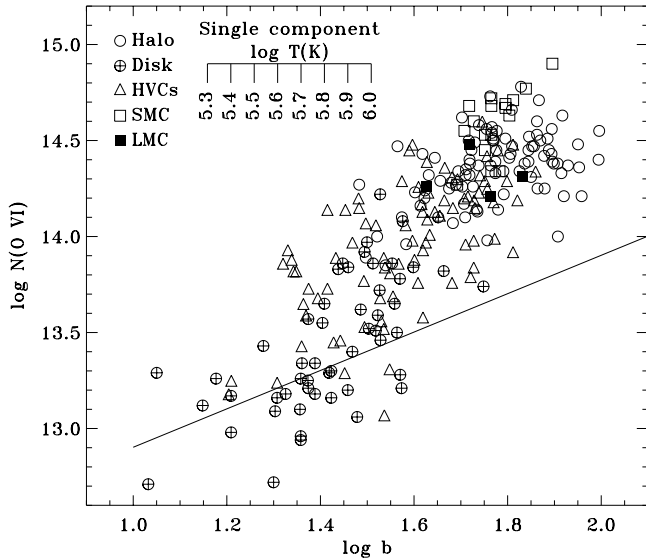


FIG. 22.—O VI column density [$N(\text{O VI}) \text{ cm}^{-2}$] vs. line width [$b \text{ (km s}^{-1}\text{)}$] for a variety of O VI absorption systems. Data points include absorption observed by *FUSE* in the Galactic halo (Savage et al. 2002, 2003), high-velocity clouds (this paper), the SMC (Hoopes et al. 2002), and the LMC (Howk et al. 2002a, 2002b). Data points for absorption in the Galactic disk are from the *Copernicus* O VI survey (Jenkins 1978a, 1978b). The straight diagonal line indicates the approximate detection limit for *FUSE* data if $W_{1032} = 30 \text{ m \AA}$. Note the good correlation between N and b . The thermal widths of single components at various temperatures are indicated at the top of the figure.

dominated primarily by the temperature of the gas and the velocity separations of the different components. Thus, one could expect to observe either very low or very high column densities at widths appropriate for photoionized gas (typically, $T \sim 10^4\text{--}10^5 \text{ K}$, or $b \sim 2\text{--}10 \text{ km s}^{-1}$). There is no reason to expect that all such components should have a similar column density, and therefore the distribution of data points would be more scattered than observed.

Collisional processes should produce a good correlation between N and b since the column density scales linearly with gas flow velocities in most collisional ionization situations. Heckman et al. (2002) have described these relationships and extend the result seen in Figure 22 to higher column density absorbers seen in starburst galaxies. They also argue that the O VI absorbers detected in the low-redshift IGM are collisionally ionized, with the exception of a few discrepant systems. Since most of the O VI IGM absorbers and the high-velocity O VI features occupy similar portions of Figure 22, understanding the ionization of one type of system in more detail may lead to a better understanding of the other.

The data points for the high-velocity O VI features follow the trend defined by the Galactic disk and halo points in Figure 22. The formal slope of the high-velocity O VI data points ($\Delta \log N / \Delta \log b$) is 1.4, which is intermediate to the values of 0.7 for the thick disk/halo and 1.7 for the nearby disk. There is some indication that the data points for the high-velocity O VI features are slightly more scattered about the best fit line than the disk or halo points: $\sigma_{\text{HV}} \sim 0.37 \text{ dex}$ compared to $\sigma_{\text{disk}} \sim 0.29 \text{ dex}$ and $\sigma_{\text{halo}} \sim 0.16 \text{ dex}$. This may result from additional bulk motions, flows, and turbulence within these clouds compared to clouds in the ISM of the Galaxy.

9.4. Ionization Synopsis

Given the above considerations, we consider it very likely that most of the high-velocity O VI we observe is created primarily by nonequilibrium collisional ionization processes. This conclusion is supported by several findings. The amount of O VI produced by photoionization is smaller than the typical column densities observed unless the gas has a very low density and the clouds are extremely large—so large in fact that the sizes are incompatible with the distances to some HVCs (e.g., the Magellanic Stream and Complex C). Second, although the observed ionic ratios for some high-velocity clouds can occur through photoionization under special circumstances, the inferred cloud sizes required are again too large to allow a cloud location within the Milky Way—Magellanic Cloud system. In other cases, the ionic ratios are more reflective of collisional processes and are similar to those found for Milky Way halo gas, which is even harder to photoionize than extragalactic clouds since the ionization sources (primarily OB stars) produce a softer radiation field than the extragalactic ultraviolet background. In the direction of Mrk 509, the ratios indicate that both photoionization and collisional ionization processes may contribute since the amount of C IV relative to O VI is higher than the standard collisional ionization models predict. The turbulent mixing layer models can reproduce the observed $N(\text{O VI})/N(\text{C IV})$ ratio toward Mrk 509 but cannot simultaneously satisfy the constraints of the $N(\text{O VI})/N(\text{N V})$ ratio. Finally, the high-velocity O VI features show a significant correlation between O VI line width and column density, which is also observed for other O VI systems that are predominantly collisionally ionized (e.g., the Milky Way disk and halo, starburst outflows).

10. KINEMATICS OF THE HIGH-VELOCITY GAS

10.1. Expectations for a Corotating Halo

By definition, the high-velocity O VI absorption features considered in this study generally have $|v_{\text{LSR}}| \gtrsim 100 \text{ km s}^{-1}$ with a few exceptions. This velocity cutoff provides isolation of the high-velocity absorption from the absorption produced by the thick disk/halo of the Galaxy. The thick disk/halo O VI absorption is roughly characterized by a patchy plane-parallel slab of hot gas with an exponential scale height of 2.3 kpc in the direction perpendicular to the Galactic plane (see Savage et al. 2003). This scale height is comparable to the scale heights derived for other highly ionized species (e.g., C IV, N V) using more limited data sets available with the *HST* (Savage et al. 1997). The thick disk high ion profiles can be modeled reasonably well assuming that the thick disk/halo gas follows essentially the same pattern of rotation around the Galactic center as the underlying disk gas for regions within 1–2 kpc of the Galactic plane (Lu, Savage, & Sembach 1994; Savage et al. 1997). In some directions toward the Galactic center, this coupling may break down at higher altitudes (Sembach et al. 1991, 1995a). It is therefore useful to quantify the magnitude of the deviations from corotation and to consider whether the high-velocity O VI features can be described within the context of various rotation models for the gaseous Galactic halo.

To test whether the high-velocity O VI we observe can be modeled as a simple extension of the thick disk/halo distribution, we have calculated the O VI column density profiles expected for each sight line in the sample assuming that the

O vi has a vertical scale height of 2.3 kpc, a typical velocity dispersion $\sigma = 42.5 \text{ km s}^{-1}$ ($b = 60 \text{ km s}^{-1}$; Savage et al. 2003), a midplane density $n_0(\text{O vi}) = 1.7 \times 10^{-8} \text{ cm}^{-3}$ (Jenkins, Bowen, & Sembach 2002), and a halo rotation speed identical to the rotation speed of the Galactic disk at the same Galactocentric radii. In this calculation we have used the Galactic rotation curve derived by Clemens (1985) with a solar orbital speed of 220 km s^{-1} around the Galactic center. We terminated the calculation for each sight line at a distance of 10 kpc from the Galactic plane (≈ 4 scale heights). (See Savage et al. 1990 for specific details about the computation of the line profiles.) After converting each column density profile into a synthetic absorption profile, we identified the extreme positive and negative velocities (v_{pos} , v_{neg}) at which each model absorption profile recovered to within 5% of the continuum. We chose the velocity interval between these cutoffs as a reasonable velocity range over which one would expect to detect weak high-velocity features that are extensions of the simple thick disk/halo distribution, considering the quality of the *FUSE* data. Broadening this interval to accommodate slightly more sensitive measures of the absorption does not change our conclusions below appreciably. Narrowing it strengthens them.

The sight lines with the most negative predicted velocities are ESO 141-G55 ($l = 338^\circ.2$, $b = -26^\circ.7$, $v_{\text{neg}} = -169 \text{ km s}^{-1}$), PKS 2005-489 ($l = 350^\circ.4$, $b = -32^\circ.6$, $v_{\text{neg}} = -164 \text{ km s}^{-1}$), and 3C 382.0 ($l = 61^\circ.3$, $b = 17^\circ.4$, $v_{\text{neg}} = -163 \text{ km s}^{-1}$). The sight lines with the most positive predicted velocities are ESO 265-G23 ($l = 285^\circ.9$, $b = 16^\circ.6$, $v_{\text{pos}} = 187 \text{ km s}^{-1}$), Mrk 509 ($l = 36^\circ.0$, $b = -29^\circ.9$, $v_{\text{pos}} = 153 \text{ km s}^{-1}$), and PKS 0558-504 ($l = 258^\circ.0$, $b = -28^\circ.6$, $v_{\text{pos}} = 150 \text{ km s}^{-1}$).

We show the results of these calculations in Figure 23, where we plot the difference between the predicted cutoffs and the observed O vi velocity centroids as functions of Galactic longitude and latitude. The figure is similar to Figure 8, where we plot v_{LSR} versus l and b , except that the deviation velocity, $\Delta v = \bar{v} - v_{\text{pred}}$, is a measure of how far beyond the expected cutoffs each O vi feature lies. Here v_{pred} is equal to v_{neg} or v_{pos} , depending upon the sign of the observed velocity $\bar{v}$. The vertical bar on each point represents the width ($\pm b$ in km s^{-1}) of the high-velocity feature (see Table 1) to give a sense of the velocity extent of the absorption. The symbols are coded according to the classifications in Table 3 and are the same as in Figure 3 to make comparisons of the figures easier. We plot horizontal dashed lines at $\Delta v = \pm 30 \text{ km s}^{-1}$ to illustrate that most of the observed velocities lie well outside those expected for corotation even after accounting for a substantial amount of additional randomness to the velocity distribution of the smooth distribution of components assumed in the model.

There are several important things to note in Figure 23. First, in the Galactic longitude plot, there is a distinct trend in the distribution of data points with longitude. At $l < 180^\circ$, the values of Δv are predominantly negative, whereas at $l > 180^\circ$ the values are predominantly positive. Second, most of the data points deviate by at least 30 km s^{-1} from the predicted extrema; only 14 of the 84 points have $|\Delta v| \leq 30 \text{ km s}^{-1}$. This clearly indicates that the deviation velocities are not described well by a corotating gas layer. (This is expected since the high-velocity sample was selected in large part to avoid velocities associated with the Galactic thick disk and low halo.) Third, in the Galactic latitude plot, the deviations in the south ($\sigma_{\Delta v} \sim 113 \text{ km s}^{-1}$) are on

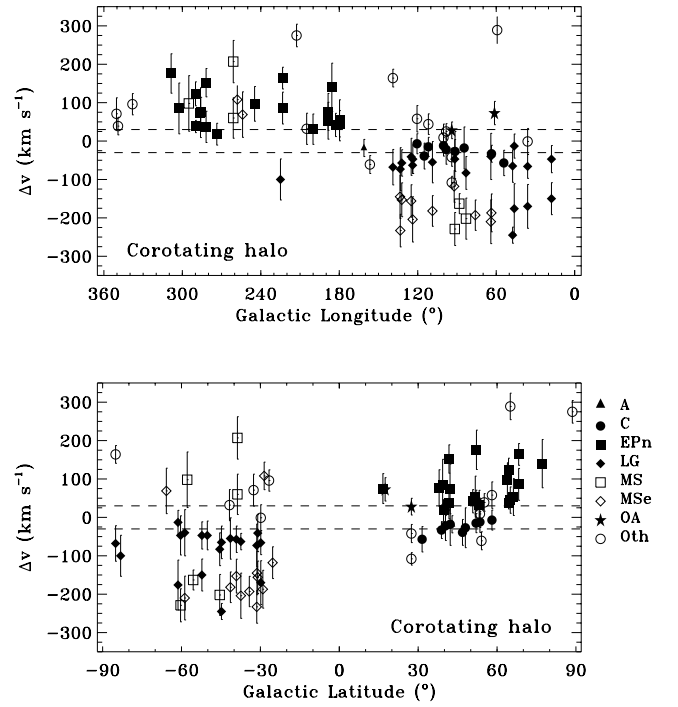


FIG. 23.—Deviations of the O vi velocities from those predicted by the corotating halo model described in the text vs. Galactic longitude (*upper panel*) and latitude (*lower panel*). The deviation velocity, $\Delta v = \bar{v} - v_{\text{pred}}$, is defined as the difference between the measured velocity centroid of the high-velocity O vi feature and the velocity extremum of the $\lambda 1031.926$ absorption expected for a smooth, corotating, exponentially stratified O vi gas layer with a scale height of 2.3 kpc, and an intrinsic gas velocity dispersion ($b = \sqrt{2}\sigma$) of 60 km s^{-1} . The different symbols denote the various high-velocity feature designations according to the code given to the right of the lower panel.

average a factor of ~ 1.4 times larger than those in the north ($\sigma_{\Delta v} \sim 83 \text{ km s}^{-1}$). A summary of the means and dispersions in Δv for different Galactic quadrants is given in Table 12.

10.2. Expectations for a Non-Corotating Halo

To see if the distribution of O vi velocities could be due to deviations from corotation in the halo gas layer, we have also calculated model O vi profiles assuming that the halo gas decouples from the disk gas. In these models, the halo gas decoupling begins at an altitude z_i and is complete at z_f ; the functional form of the decoupling is a linear decrease in rotation speed between z_i and z_f . We display the results for

TABLE 12
MEANS AND STANDARD DEVIATIONS OF Δv

Rotation Model	Longitude Range	$b < 0^\circ$	$b > 0^\circ$	All b
Corotating halo	$l < 180^\circ$	-110 ± 88	8 ± 77	-64 ± 101
	$l > 180^\circ$	71 ± 81	94 ± 65	86 ± 70
	All l	-72 ± 113	47 ± 83	-14 ± 116
Decoupled halo	$l < 180^\circ$	-27 ± 76	72 ± 72	12 ± 89
	$l > 180^\circ$	0 ± 56	33 ± 89	23 ± 80
	All l	-21 ± 73	54 ± 81	15 ± 86

NOTES.—Values listed are $\langle \Delta v \rangle \pm \sigma_{\Delta v}$. All velocities are in km s^{-1} . $\Delta v = \bar{v} - v_{\text{pred}}$. See Table 1 for values of $\bar{v}$.

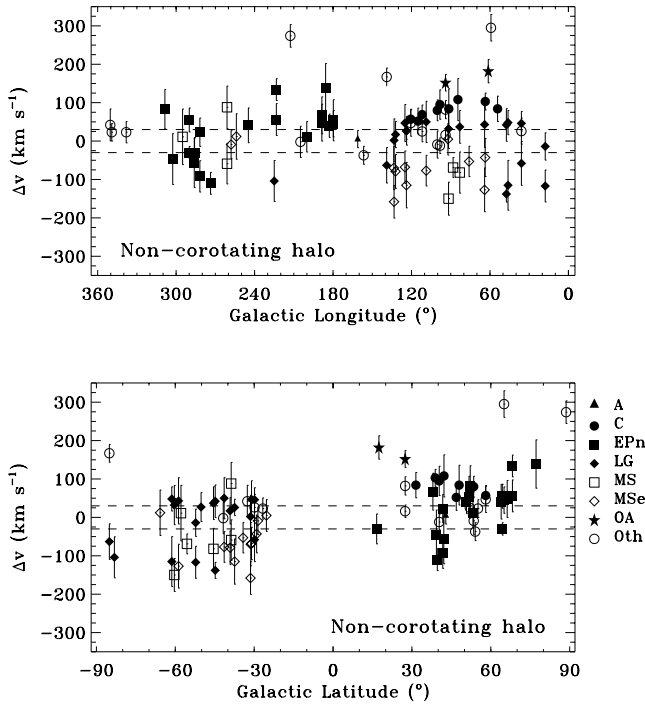


FIG. 24.—Same as Fig. 23, except for the non-corotating gas layer described in the text.

the model with $z_i = 1$ kpc and $z_f = 3$ kpc in Figure 24. This is equivalent to having a static, nonrotating halo above $z = 3$ kpc, with the predicted velocities beyond this distance simply being the projection of the Sun’s motion in each direction.

There are several key differences in the velocities predicted by this model compared to the corotation model. The trend in Δv with Galactic longitude seen in Figure 23 has largely disappeared, and the differences between north and south have decreased substantially compared to the corotation model. The slight trend for negative values of Δv in the south and positive values of Δv in the north is weaker than before but still present. Inspection of Table 12 shows that the overall dispersion of Δv for this model is 86 km s^{-1} compared to 116 km s^{-1} for the corotation model.

Twenty-two data points in the non-corotation model have $|\Delta v| \leq 30 \text{ km s}^{-1}$, considerably more than for the corotation case. Still, this is only 22 out of the 84 cataloged high-velocity features, implying that even this model does not account for most of the velocities. Of these 22 features with $|\Delta v| \leq 30 \text{ km s}^{-1}$, eight are classified as Oth. The remainder are divided roughly equally between the LG, EPn, and MSe categories. There is still a deviation well above and beyond that expected, regardless of whether or not the halo corotates (i.e., the O vi velocities do not obey any simple relation with the thick disk velocities.).

The smaller dispersion in the O vi deviation velocities in the non-corotating model suggests that much of the high-velocity O vi does not know about the rotation of the Galaxy, but it does not imply that the Galaxy has a static halo of smoothly distributed O vi. The model assumes a smooth gas distribution, but the O vi in the thick disk/halo is known to be quite patchy in nature, even on small angular scales (Howk et al. 2002a). If there were a smooth gas distribution

and the halo were not rotating, we would expect to see absorption profiles that had secondary absorption minima due to velocity crowding at the terminal velocities for some sight lines. We do not see such features.

10.3. Searching for Outflows or a Hot Galactic Wind

There is considerable interest in understanding whether galaxies have large-scale winds that are capable of altering the structure of the ISM and expelling heavy elements into the IGM. In all cases, the outflowing winds are expected to be hot, since it is typically supernovae and star formation processes that power them. As a result, the best evidence for galactic winds often comes from X-ray observations and from ultraviolet measurements of highly ionized species such as C iv, N v, and O vi (see, e.g., Heckman 2002 and Martin 2002 for current discussions of this topic and additional references). An O vi outflow in the starburst galaxy NGC 1705 has been observed by *FUSE* (Heckman et al. 2001), and lower velocity hot gas flows may also be present in the LMC (Howk et al. 2002b).

In the Milky Way, there is evidence that a wind emanating from the Galactic center has resulted in the expulsion (or ionization) of much of the neutral ISM above $z \sim 1$ kpc in the inner 3 kpc of the Galaxy (Lockman 1984). The possibility of a strong Galactic wind has been considered by Hirashita, Kamaya, & Mineshige (1997), while a review of more quiescent wind activity and Galactic “fountains” is given by Breitschwerdt & Komossa (2000). The detailed nature of a Galactic wind depends upon many factors, including the energy input at the base of the wind, the structure and density of the ISM, the gravitational potential of the Galaxy at the site of the wind flow, magnetic fields and cosmic ray support of material, and the efficiency of the entrainment of cooler material in the flow. Few of these variables are known in detail, but models of winds in rotating galaxies like our own indicate that a Galactic wind could be driven by cosmic rays and heated in part by Alfvén waves, with the gas corotating with the underlying Galactic disk up to altitudes of several kiloparsecs (Zirakashvili et al. 1996).

Consider the case of a spherically symmetric unbound wind that flows completely out of the Galaxy. The simplest directions to look for signs of an outflow would be directly toward or directly away from the Galactic center, since the effects of Galactic rotation would be minimized. Toward $l \sim 180^\circ$, we see high positive velocity O vi, as expected. Toward $l \sim 0^\circ$ we see both positive and negative velocity features. However, the number of sight lines in both directions is very limited. At high latitudes ($|b| \gtrsim 60^\circ$), positive wind velocities should dominate, which is qualitatively consistent with the O vi velocities in Figure 8. At lower latitudes, the expected wind velocity depends on Galactic longitude and the distance of the wind particles from the Sun. In the range $180^\circ < l < 270^\circ$, positive velocities are expected since the gas lies outside the solar circle. Between $l = 270^\circ$ and $l = 360^\circ$, positive velocities are expected for the wind beyond the Galactic center, while predominantly negative velocities are expected for gas within the solar circle on the near side of the Galactic center.

The altitude at which a sight line intercepts the wind influences the observed wind velocity; the projected velocity for higher z sight lines would be lower than for sight lines passing nearer the disk of the Galaxy. Furthermore, if the source of the wind was not a localized phenomenon but was instead

spread over the disk of the Galaxy (say, in spiral arm locations), then the gas motions may be dominated by regional activity. Indeed, evidence of localized outflow from the Scutum Supershell exists for several ionization stages, including O VI (Sterling et al. 2002). Some of O VI features we observe in our survey (e.g., the positive velocity absorption wings) are consistent with the presence of localized outflow from the Galactic disk. We conclude that the complexity of the high-velocity O VI sky, selection effects, and the unknown extent of a Galactic wind make it difficult to find conclusive evidence for a large-scale Galactic O VI outflow, nor can we rule out its presence without additional information. Future observations targeted at addressing this issue in specific directions in both the Milky Way and the Magellanic Clouds are needed.

10.4. Expectations for O VI in the Local Group

Several authors have argued convincingly against a distributed Local Group location for many of the H I HVCs using statistical studies of the neutral gas in other galaxy groups (e.g., Charlton, Churchill, & Rigby 2000; Zwaan & Briggs 2000). One way to escape this argument is to require that the clouds be located close to the large galaxies within the groups ($d \lesssim 100\text{--}200$ kpc). For clouds in the Local Group, this makes it difficult to distinguish between a cloud population related to the Milky Way and a truly Local Group population based on kinematical information alone (i.e., the dispersions in the cloud velocities in the GSR and LGSr reference frames are similar, and strong observational selection effects apply—see § 8.2). As a result, additional information is needed to determine if the clouds are located in the Local Group.

For the subsample of high-velocity LG, EPn, and MSe features considered in Table 10, the dispersions of the velocity distributions in the GSR and LGSr reference frames are smaller than the dispersion in the LSR reference frame. Furthermore, in the GSR and LGSr reference frames, the dispersions for this subsample are smaller than the dispersions listed in Table 6 for the entire high-velocity O VI sample (Table 6). The shaded regions of Figure 7 highlight the velocity distributions of these 51 features. Several of the sight lines classified as LG have ionization or abundance information that support an extragalactic location (§ 6.5). The MSe sight lines are included in this subsample, even though their velocities are similar to those of the Magellanic Stream, since their positions on the sky do not correspond to the locations of the bulk of the H I 21 cm emission from the Stream. Objects classified as LG, EPn, or MSe in Table 1 would be excellent candidates for concerted efforts to determine the ionized gas content, gas-phase conditions, elemental abundances, and distances of the high-velocity gas.

Increasing the number of O VI absorption-line measurements along other sight lines in the regions of the sky where the LG, EPn, and MSe features are found is highly desirable. Unfortunately, with current instrumentation, the number of additional background sources bright enough to observe in reasonable integration times is limited. An alternate approach, that of imaging the O VI in emission at very faint levels over large fields of view, may soon be possible with the NASA Small Explorer mission for *Spectroscopy and Photometry of the Intergalactic Medium's Diffuse Radiation* (SPIDR). Such measurements would help to set the context for the absorption-line measurements in this study

and perhaps reveal the association (if any) of these features with other high-velocity gas.

11. DISCUSSION

High-velocity O VI is both widespread and common along complete paths through the Galactic halo. The high-velocity O VI traces numerous phenomena, including tidal interactions with the Magellanic Clouds (via the Magellanic Stream), accretion of low-metallicity gas (e.g., Complex C), highly ionized clouds (e.g., the Mrk 509 HVCs), and the outflow of hot gas from the Galactic disk (e.g., the broad positive velocity absorption features). Distinguishing between all of the possible phenomena occurring at large distances from the Galactic plane is not easy, and clearly any attempt to treat all detections of the high-velocity O VI as a single population of clouds would be a serious mistake. That being said, considerations of subsets of the high-velocity O VI features suggest some intriguing possibilities.

Much of the high-velocity O VI probably occurs at large distances from the Galactic plane. There have not yet been any detections of high-velocity O VI at high latitudes toward halo stars out to distances of several kiloparsecs. The two stars in our sample are the most distant halo stars examined for high-velocity O VI absorption ($d \sim 8\text{--}10$ kpc) and show none. In a study of approximately two dozen halo star sight lines, Zsargó et al. (2003) find low-velocity O VI absorption associated with the Galactic thick disk/halo but no high-velocity O VI absorption at $|v_{\text{LSR}}| > 100 \text{ km s}^{-1}$. Despite the difficulties encountered in estimating the stellar continua, this result is fairly robust, especially the absence of discrete high-velocity features with modest optical depths. Broad absorption wings, like those discussed in § 8.1, would be much more difficult to detect against stellar continua with substantial curvature than against the relatively smooth spectra of QSOs and AGNs. The number of halo sight lines toward hot stars examined for high-velocity O VI absorption is small, so the absence of high-velocity O VI in halo regions within a few kiloparsecs of the Galactic disk is by no means ruled out. Some high-velocity O VI is observed toward the Magellanic Clouds at velocities intermediate to those expected for the Galactic thick disk/halo and the Magellanic Clouds (Hoopes et al. 2002; Howk et al. 2002b). The distance of the high-velocity O VI in this direction is unknown, but it is likely to be more than a few kiloparsecs from the Galactic plane.

One possible explanation for much of the high-velocity O VI is that it arises at the boundaries between cool/warm clouds of gas and a very hot ($T > 10^6$ K) Galactic corona or Local Group medium. A hot, highly extended corona much larger than the thick disk/halo region might be left over from the formation of the Milky Way or Local Group, or may be the by-product of continuous accretion of smaller galaxies over time. Interactions of this type have been proposed to explain the observed H α emission from the Magellanic Stream (Weiner & Williams 1996), the shape and confinement of some Stream concentrations (Stanimirovic et al. 2002), and the shapes of supergiant shells along the outer edge of the LMC (de Boer et al. 1998). *N*-body simulations of the tidal evolution and structure of the Magellanic Stream favor a low-density medium for imparting weak drag forces to deflect some of the Stream gas and providing a possible explanation for the absence of stars in the Stream (Gardiner & Noguchi 1996; Gardiner 1999). Moore & Davis (1994) also

postulated a hot, low-density corona to provide ram pressure stripping of some of the Magellanic Cloud gas and to explain the absence of gas in globular clusters and nearby dwarf spheroidal companions to the Milky Way (see also Blitz & Robishaw 2000). Constraints on the density of the Galactic corona from considerations of the survivability of the Magellanic Stream range from $n \lesssim 10^{-4} \text{ cm}^{-3}$ based on dynamical arguments [e.g., drag (Moore & Davis 1994)] to $n \lesssim 10^{-5} \text{ cm}^{-3}$ based on thermal considerations [e.g., heating and evaporation (Murali 2001)]. In either case, there would be little X-ray emission from the extended corona or Local Group medium at these densities, and no observational constraints on the extragalactic X-ray background observed by *ROSAT* are violated by the presence of such a medium (see Rasmussen & Pedersen 2001).

In such a scenario, one would expect the O VI to occur at the boundaries between neutral or weakly ionized gas clouds and the hotter ($T \gtrsim 10^6 \text{ K}$) medium. The data for sight lines that pass through Complex C are consistent with the idea that the Complex C is falling into and interacting with a highly extended corona. The similarity in the general velocity structure of the H I and O VI indicates that the spatial relationship is probably also close (see Fig. 14 and Table 8). The boundary between the H I and the hot corona is probably thin enough that the negative velocity extension of the O VI is essentially determined by the kinematics at the boundary (i.e., by the motion of the H I) rather than by larger scale thermal motions in hot gas or boundary layer. The distance of Complex C ($d > 5 \text{ kpc}$, $z > 3.5 \text{ kpc}$) is sufficiently large that any interactions must be occurring well above the Galactic plane, either with the Galactic corona or with the outer regions of the Galactic thick disk/halo.

Hydrodynamical simulations of clouds moving through a hot, low-density medium show that weak bow shocks develop on the leading edges of the clouds as the gas is compressed and heated (Quilis & Moore 2001). Although the simulations were motivated in an attempt to explain the “head-tail” structures seen for some HVCs as they pass through the lower halo (Brüns et al. 2000; Brüns, Kerp, & Pagels 2001), they also provide some guidance for lower density situations. The exact nature of the interaction depends on the relative speeds and densities of the two gases. The high-velocity O VI features generally have velocities comparable to the adiabatic sound speed in a medium of the type described above, and both projection effects and motion of the medium itself (e.g., a Galactic wind) would serve to increase the Mach number of the O VI clouds. However, even if the clouds are not moving at supersonic speeds relative to the ambient medium, some viscous or turbulent stripping of the cooler gas occurs (see Quilis & Moore 2001). This type of turbulent mixing of hot and warm gases has been described in detail by Slavin, Shull, & Begelman (1993). Thermal conduction may also be efficient, depending upon the orientation of the magnetic field relative to the conduction front (Borkowski, Balbus, & Fristrom 1990). Fast ionization of cold gas may also occur through the “critical velocity effect” if the coronal plasma itself is magnetized (see Konz et al. 2001). Thus, the exact details of the mixing and heating of the gas depend on the geometry of the clouds, the entrainment velocity of the gas, the presence of magnetic fields, and several other physical quantities. We would expect the observed ionic ratios in such a situation to reflect a mix of those predicted for turbulent mixing and thermal conduction, which is in general agreement with what is observed.

The presence or absence of neutral gas associated with the high-velocity O VI in the interacting corona scenario would depend on several factors, most notably the mass of the cool/warm gas cloud passing through the corona and the heating efficiency. The good correspondence of the O VI absorption velocities and the H I 21 cm emission velocities in the directions of substantial H I concentrations (e.g., Complex C, the Magellanic Stream—see Figs. 14 and 15 and Table 8) argue that the interface region between the corona and the cooler material must be relatively compact compared to the overall size of the cloud. The larger line widths seen for O VI are consistent with additional sources of turbulence expected for mixing zones in the interface region. Photoionization of O VI is very unlikely in such a region since low gas density and large path lengths are required if the photoionization is due to the extragalactic background.

Most conductive interface models and the turbulent mixing layer models predict O VI column densities of $\sim 10^{13} \text{ cm}^{-2}$ per conduction front and even less for mixing layers (if the mixing is slow—i.e., no shocks). Magnetic fields parallel to conduction fronts inhibit conduction and result in lower O VI column densities. These single-interface column densities are approximately an order of magnitude less than those observed (see Table 1). There are several possible explanations for this. First, there may be small-scale macrostructure (clumps) within the clouds that have similar enough velocities that the absorption features from the fragments blend together and cannot be distinguished. The boundary of each fragment would contribute to the total column density, and multiple ($\gtrsim 10$) boundaries would be required to explain the observed values of $N(\text{O VI})$. The O VI profiles are generally quite broad and are consistent with the presence of multiple, blended components. Second, turbulent mixing in eddy layers in the conduction zone increases the likelihood of more efficient mixing and greater O VI columns. The hydrodynamical simulations show that the transition-temperature gas layers where O VI should exist are turbulent in nature (see, e.g., Fig. 2 in Quilis & Moore 2001). Third, there may be an external source of heat that increases the depth of the mixing layer. The column densities in mixing layers depend on the temperature of the postmixed gas and on the product of the velocity of the hot gas that enters the mixing layers and the fraction of mass deposited by the hot gas in the turbulent flow (Slavin et al. 1993). In the case of a cloud moving through a low-density medium, the source of heat could be weak shocks or the ram pressure heating itself.

There are numerous examples of stellar tidal streams in the Galactic halo (see Majewski, Hawley, & Munn 1996; Martínez-Delgado et al. 2001; Newberg et al. 2002). Sources of the high-velocity material entering the Galactic corona might include infalling or tidally disturbed galaxies, such as the Sagittarius dwarf (Ibata et al. 2001). Tidal interactions of the fragments and galaxies in the Local Group could drive dynamical instabilities in some of the smaller galaxies and strip interstellar material from gas-rich irregular galaxies (Mayer et al. 2001). Since viscous processes affect the gas but not the stars in interacting systems, tracing the original source of the high-velocity gas may prove impossible. However, the fact that no pristine (zero-metallicity) HVCs have yet been identified indicates that some previous metal enrichment inside galaxies has probably occurred (see § 7 and Table 9 for some potentially low-metallicity clouds that

require further study). In the case of Complex C, the low metallicity ($Z \sim 0.1$ – 0.2) indicates a history different from that of the interstellar material in the Galactic disk.

The column density of O VI within the hot ($T > 10^6$ K) gas of the corona or Local Group gas itself is given by $N(\text{O VI}) = (\text{O}/\text{H})_{\odot} Z f_{\text{O VI}} n L$, where L is the path length through the absorbing gas. At $T \geq 10^6$ K, $f_{\text{O VI}} \leq 3.8 \times 10^{-3}$ (Sutherland & Dopita 1993). For $n = 10^{-5} \text{ cm}^{-3}$,

$$N(\text{O VI}) [\text{cm}^{-2}] \leq 6.4 \times 10^{10} Z L [\text{kpc}].$$

A hot corona with an extent of 1 Mpc and a metallicity $Z = 0.1$ would produce an O VI column density of less than 10^{13} cm^{-2} . Thus, the corona would have an O VI column density significantly less than that of the Milky Way thick disk/halo and would be difficult to detect directly through its O VI absorption. However, if the gas had a higher metallicity (e.g., $Z = 0.3$), and a higher density (e.g., $n = 10^{-4} \text{ cm}^{-3}$), then the amount of O VI expected would be substantial [$N(\text{O VI}) > 3 \times 10^{13} \text{ cm}^{-2}$] even if the corona extended only ~ 100 kpc. Such a corona should show X-ray O VII absorption features that may also be detectable (see § 9.1). A possible manifestation of the coronal gas might be very broad, shallow absorption wings like those discussed in § 8.1. Indeed, preliminary results from several authors (Fang et al. 2003; Nicastro et al. 2002) demonstrate that O VII absorption is present near zero velocity along at least two high-latitude sight lines, which is consistent with the presence of a large, nearby reservoir of hot gas.

Assuming spherical geometry, a radius $R \geq 70$ kpc, and density $n_{\text{H}} \sim 10^{-5} \text{ cm}^{-3}$, the mass of the hot tenuous gas in the corona is $M \gtrsim 4 \times 10^8 M_{\odot}$. If the hot corona is a prolate spheroid with an axial ratio $a/b = 2:1$ and a semiminor axis of $b \geq 70$ kpc, then $M \gtrsim 10^9 M_{\odot}$. If the hot medium fills the Local Group, the mass would exceed $10^{11} M_{\odot}$.

An alternative source for the high-velocity O VI may be that the clouds and any associated H I fragments are simply condensations within large remnant Local Group gas structures falling in on the Galaxy (Oort 1970). Cosmological structure formation models predict large numbers of cooling fragments embedded in dark matter, and some of these structures should be observable in X-ray absorption (e.g., Fang et al. 2002) or in O VI absorption as the gas cools through the $T = 10^5$ – 10^6 K temperature regime. Estimates of the number density of these structures are consistent with the observed IGM O VI detection rate (Fang & Bryan 2001). This situation is in many ways analogous to the coronal model developed above because only about 30% of the hot gas should be detectable in O VI absorption, while the remaining $\sim 70\%$ is too hot to observe (Davé et al. 2001). However, unlike the coronal model in which the cooler gas may be tidal fragments interacting with a Galactic corona or Local Group medium, in this scenario the O VI-bearing gas and hotter gas share a common evolution within isolated evolving structures with no external baryonic medium required (though dark matter confinement would likely be necessary—see, e.g., Kepner et al. 1999).

Distinguishing between these two models will be difficult, but there are several tests that may yield some additional insight. Metallicity determinations for a substantial number of the high-velocity H I and O VI features would help to distinguish between Magellanic debris and lower metallicity ($Z \lesssim 0.1$) gas expected for a cooling gas structure or debris from smaller Local Group galaxies. High-resolution

imaging of the H α emission from the high-velocity O VI absorbers would constrain their relationship with the H I and perhaps reveal additional signatures of interactions with an extended Galactic corona (e.g., bow shock structures or turbulently mixed layers of ionized gas between the H I and hot corona). Some high-velocity clouds have already been detected in H α emission at modest spatial resolution: the Magellanic Stream (Weiner & Williams 1996; Putman et al. 2003), Complexes A, C, and M (Tufte et al. 1998), and several compact H I HVCs in the $100^\circ < l < 160^\circ$, $-60^\circ < b < -30^\circ$ region of the sky (Tufte et al. 2002). While it is often assumed that all of the H α emission is caused by photoionization, the results of our study indicate that collisional ionization processes should not be ignored. *HST* observations of C IV and N V associated with the high-velocity O VI would help to constrain the ionization properties of the clouds. Finally, imaging of the high-velocity gas in O VI and X-ray transitions at sufficient spectral resolution to isolate individual spectral lines would provide much needed insight into the structure of the hot gas and its relationship with cooler material. This is currently difficult with existing instrumentation but should be possible with future ultraviolet and X-ray observatories (e.g., *SPIDR* and *Constellation-X*).

12. CONCLUSIONS

In this paper we report the results of an extensive *FUSE* study of high-velocity O VI absorption along complete sight lines through the Galactic halo in the directions toward 100 AGNs/QSOs and two distant halo stars. Companion studies describe the observations and data (Wakker et al. 2003) and the results for O VI absorption produced by the thick disk and halo of the Milky Way (Savage et al. 2003). In this study, the cutoff between high-velocity gas and Galactic thick disk/halo absorption was generally near $|v_{\text{LSR}}| \sim 100 \text{ km s}^{-1}$. Our main conclusions regarding the high-velocity gas are as follows:

1. We identify 84 individual high-velocity O VI features along the 102 sight lines in our sample. A critical part of this identification process involved detailed consideration of the absorption produced by O VI and other species (primarily H₂) in the thick disk and halo of the Galaxy, as well as the absorption produced by low-redshift intergalactic absorption lines of H I and ionized metal species.
2. We searched for absorption in a velocity range of $-1200 < v_{\text{LSR}} < +1200 \text{ km s}^{-1}$ around the O VI $\lambda 1031.926$ line. With few exceptions, the high-velocity O VI absorption is confined to $|v_{\text{LSR}}| < 400 \text{ km s}^{-1}$, indicating that the O VI features observed are either associated with the Milky Way or nearby clouds within the Local Group. The 84 high-velocity O VI features have velocity centroids ranging from $-372 \lesssim \bar{v}_{\text{LSR}} \lesssim -90 \text{ km s}^{-1}$ to $+93 \lesssim \bar{v}_{\text{LSR}} \lesssim +385 \text{ km s}^{-1}$. There are an additional six confirmed or very likely ($>90\%$ confidence) detections and two tentative detections of O VI between $v_{\text{LSR}} = +500$ and $+1200 \text{ km s}^{-1}$; these very high-velocity features probably trace intergalactic gas beyond the Local Group and will be discussed in a future paper.
3. The 84 high-velocity O VI features have logarithmic column densities of 13.06 to 14.59, with an average of $\langle \log N \rangle = 13.95 \pm 0.34$ and a median of 13.97. The average O VI column density is a factor of 2.7 times lower than the

typical column density for a sight line through the O vi layer in the thick disk/halo of the Galaxy.

4. The line widths of the 84 high-velocity O vi features range from ~ 16 to 72 km s^{-1} , with an average of $\langle b \rangle = 40 \pm 13 \text{ km s}^{-1}$. The lowest values of b are close to the thermal width expected for O vi at $T \sim 3 \times 10^5 \text{ K}$, while the higher values of b indicate that additional nonthermal broadening mechanisms are common.

5. We detect high-velocity O vi $\lambda 1031.926$ absorption with integrated (total) values of $W_\lambda \gtrsim 30 \text{ mÅ}$ at $\geq 3 \sigma$ confidence along 59 of the 102 sight lines surveyed. For the highest quality subsample of the data set, the high-velocity detection frequency increases to 22 of 26 sight lines. Forty of the 59 sight lines have high-velocity O vi $\lambda 1031.926$ absorption with $W_\lambda > 100 \text{ mÅ}$, and 27 have $W_\lambda > 150 \text{ mÅ}$. Converting these O vi detections into estimates of $N(\text{H}^+)$ in the hot gas indicates that $\sim 60\%$ of the sky (and perhaps as much as $\sim 85\%$) is covered by hot ionized hydrogen at a level of $N(\text{H}^+) \gtrsim 2.3 \times 10^{17} \text{ Z}^{-1}$, or $N(\text{H}^+) \gtrsim 10^{18} \text{ cm}^{-2}$ if the high-velocity gas has a metallicity similar to that of the Magellanic Stream ($Z \sim 0.2\text{--}0.3$). About 36% of the sky is covered at a level of $N(\text{H}^+) \gtrsim 5 \times 10^{18} \text{ cm}^{-2}$ given similar assumptions. The covering factor of the hot, high-velocity H^+ associated with the O vi is considerably larger than that found for warm, high-velocity H I traced by 21 cm emission at comparable column density levels.

6. High-velocity O vi absorption is observed in almost all cases where high-velocity H I 21 cm emission is observed. The six sight lines for which this is not true may contain small-scale structure within the field of view of the 21 cm observations that is not traced by the O vi absorption measures. In a few cases, ionization effects may also explain the absence of O vi. Three of the six cases are good candidates for follow-up STIS observations to determine if low metallicity may be the reason for the absence of O vi absorption.

7. Some of the high-velocity O vi is associated with well-known high-velocity structures. These include the Magellanic Stream, Complex A, Complex C, the Outer Arm, and several discrete H I HVCs.

8. Some of the high-velocity O vi features have no counterpart in H I 21 cm emission. These include discrete high-velocity features as well as broad positive velocity O vi absorption wings that blend with lower velocity absorption features produced by the Galactic thick disk/halo. The discrete features may typify clouds located in the Local Group.

9. The broad, high-velocity O vi absorption wings are concentrated mainly in the northern Galactic hemisphere (17/21 sight lines) and may trace either tidal debris or thick disk/halo gas that has been accelerated to high velocities by star formation activity in the Galactic disk. If the latter interpretation is correct, the gas may be related to the northern hemisphere thick disk/halo O vi enhancement observed by Savage et al. (2003).

10. Most of the high-velocity O vi features have velocities incompatible with those of Galactic rotation (by definition). The kinematics of the high-velocity O vi are not described adequately by models in which the Galactic halo decouples from the underlying disk. There is also no obvious signature of a hot Galactic wind emanating from the Galactic center,

but selection effects preclude a definitive statement about its existence.

11. The dispersion about the mean of the high-velocity O vi centroids decreases when the velocities are converted from the LSR to the GSR and LGSR reference frames. While this reduction is expected if the O vi is associated with gas in a highly extended Galactic corona or in the Local Group, it does not stand alone as sufficient proof of an extragalactic location. The clear separation of the various phenomena producing high-velocity O vi in and near the Galaxy will require continuing studies of the distances, kinematics, elemental abundances, and physical states of the different types of O vi HVCs.

12. We find it unlikely that many of the observed O vi features are produced by photoionization, even if the gas is irradiated by extragalactic ultraviolet background radiation. Rather, several observational constraints indicate that collisional ionization in hot ($T \sim 10^5\text{--}10^6 \text{ K}$) gas is likely the dominant ionization process for most of the O vi. The constraints include the amount of O vi observed, the ratios of O vi column densities to those of other highly ionized species (C iv, N v), and the strong correlation between $N(\text{O vi})$ and O vi line width.

13. Consideration of the possible sources of collisional ionization favors production of some of the high-velocity O vi at the turbulent boundaries between cool/warm clouds of gas and a highly extended, hot ($T > 10^6 \text{ K}$) Galactic corona or Local Group. The corona must have a low density ($n \lesssim 10^{-4}\text{--}10^{-5} \text{ cm}^{-3}$) and be very large ($R \gtrsim 70 \text{ kpc}$) to explain the O vi observed in the Magellanic Stream and other putative Local Group clouds. This corona is much more extensive than the Galactic thick disk/halo region considered in previous hot gas investigations.

14. The existence of a hot, highly extended Galactic corona or Local Group medium and the prevalence of high-velocity O vi are consistent with predictions that there should be a considerable amount of hot gas left over from the formation of the Local Group. Descriptions of galaxy evolution will need to account for highly ionized gas of the type observed in this study, and future X-ray studies of hot gas in the Local Group will need to consider carefully the relationship of the X-ray absorption/emission to the complex high-velocity absorption observed in O vi.

This work is based on data obtained for the Guaranteed Time Team by the NASA-CNES-CSA *FUSE* mission operated by the Johns Hopkins University. We thank Chris Howk for assistance with implementation of the CLOUDY ionization code, and members of the *FUSE* O vi working group for encouragement and helpful discussions. This research has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. K. R. S. acknowledges financial support through NASA contract NAS5-32985 and Long Term Space Astrophysics grant NAG5-3485. B. P. W. acknowledges financial support through NASA grants NAG5-8967, NAG5-9024, and NAG5-9179.

REFERENCES

- Anders, E., & Grevesse, N. 1989, *Geochim. Cosmochim. Acta*, 53, 197
- Arnal, E. M., Bajaja, E., Larrarte, J. J., Morras, R., & Pöppel, W. G. L. 2000, *A&AS*, 142, 35
- Berkhuijsen, E., Haslam, C. G. T., & Salter, C. J. 1971, *A&A*, 14, 252
- Bland-Hawthorn, J., & Maloney, P. R. 1999, *ApJ*, 510, L33 (erratum 550, L231 [2001])
- Blitz, L., & Robishaw, T. 2000, *ApJ*, 541, 675
- Blitz, L., Spergel, D. N., Teuben, P., Hartmann, D., & Burton, W. B. 1999, *ApJ*, 514, 818
- Borkowski, K. J., Balbus, S. A., & Fristrom, C. C. 1990, *ApJ*, 355, 501
- Bowen, D. V., & Blades, J. C. 1993, *ApJ*, 403, L55
- Bowen, D. V., Blades, J. C., & Pettini, M. 1995, *ApJ*, 448, 662
- Bregman, J. N. 1980, *ApJ*, 236, 577
- Bregman, J. N., & Harrington, J. P. 1986, *ApJ*, 309, 833
- Braun, R., & Burton, W. B. 1999, *A&A*, 341, 437
- . 2000, *A&A*, 354, 853
- Breitschwerdt, D., & Komossa, S. 2000, *Ap&SS*, 272, 3
- Brüns, C., Kerp, J., Kalberla, P. M. W., & Mebold, U. 2000, *A&A*, 357, 120
- Brüns, C., Kerp, J., & Pagels, A. 2001, *A&A*, 370, L26
- Burton, W. B., Braun, R., & Chengalur, J. N. 2001, *A&A*, 369, 616
- Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, *ApJ*, 345, 245
- Cen, R., & Ostriker, J. P. 1999, *ApJ*, 514, 1
- Charlton, J. C., Churchill, C. W., & Rigby, J. R. 2000, *ApJ*, 544, 702
- Clemens, D. P. 1985, *ApJ*, 295, 422
- Danforth, C. W., Howk, J. C., Fullerton, A. W., Blair, W. P., & Sembach, K. R. 2002, *ApJS*, 139, 81
- Danly, L., Albert, C. E., & Kuntz, K. D. 1993, *ApJ*, 416, L29
- Davé, R., et al. 2001, *ApJ*, 552, 473
- Davé, R., Hernquist, L., Katz, N., & Weinberg, D. H. 1999, *ApJ*, 511, 521
- de Boer, K. S., Braun, J. M., Vallenari, A., & Mebold, U. 1998, *A&A*, 329, L49
- Donahue, M., Aldering, G., & Stocke, J. T. 1995, *ApJ*, 450, L45
- Dupree, A. K., & Raymond, J. C. 1983, *ApJ*, 275, L71
- Edgar, R. J., & Chevalier, R. A. 1986, *ApJ*, 310, L27
- Fang, T. T., & Bryan, G. L. 2001, *ApJ*, 561, L31
- Fang, T. T., Marshall, H. L., Lee, J. C., Davis, D. S., & Canizares, C. R. 2002, *ApJ*, 572, L127
- Fang, T. T., Sembach, K. R., & Canizares, C. R. 2003, *ApJL*, in press
- Federman, S. R., Sheffer, Y., Lambert, D. L., & Gilliland, R. L. 1993, *ApJ*, 413, L51
- Ferland, G. J. 1996, *Hazy, a Brief Introduction to CLOUDY 90*, Univ. Kentucky Phys. Dept. Int. Rep.
- Friedman, S. D., et al. 2000, *ApJ*, 538, L39
- Gardiner, L. T. 1999, in *ASP Conf. Ser. 166, Stromlo Workshop on High Velocity Clouds*, ed. B. K. Gibson & M. E. Putman (San Francisco: ASP), 292
- Gardiner, L. T., & Noguchi, M. 1996, *MNRAS*, 278, 191
- Gibson, B. K., Giroux, M. L., Penton, S. V., Putman, M. E., Stocke, J. T., & Shull, J. M. 2000, *AJ*, 120, 1830
- Gibson, B. K., Giroux, M. L., Penton, S. V., Stocke, J. T., Shull, J. M., & Tumlinson, J. 2001a, *AJ*, 122, 3280
- Gibson, B. K., Giroux, M. L., Stocke, J. T., & Shull, J. M. 2001b, in *ASP Conf. Ser. 240, Gas & Galaxy Evolution*, ed. J. E. Hibbard, M. Rupen, & J. H. van Gorkom (San Francisco: ASP), 493
- Haardt, F., & Madau, P. 1996, *ApJ*, 461, 20
- Hartmann, D., & Burton, W. B. 1997, *Atlas of Galactic Neutral Hydrogen* (Cambridge: Cambridge Univ. Press)
- Haud, U. 1992, *MNRAS*, 257, 70
- Heckman, T. M. 2002, in *ASP Conf. Ser. 254, Extragalactic Gas at Low Redshift*, ed. J. S. Mulchaey & J. T. Stocke (San Francisco: ASP), 292
- Heckman, T. M., Norman, C., Strickland, D. K., & Sembach, K. R. 2002, *ApJ*, 577, 691
- Heckman, T. M., Sembach, K. R., Meurer, G. R., Strickland, D. K., Martin, C. L., Calzetti, D., & Leitherer, C. 2001, *ApJ*, 554, 1021
- Hirashita, H., Kamaya, H., & Mineshige, S. 1997, *MNRAS*, 290, L33
- Holweger, H. 2001, in *AIP Conf. Proc. 598, Solar and Galactic Composition*, ed. R. F. Wimmer-Schweingruber (New York: AIP), 23
- Hoopes, C. G., Sembach, K. R., Howk, J. C., & Blair, W. P. 2001, *ApJ*, 558, L35
- Hoopes, C. G., Sembach, K. R., Howk, J. C., Savage, B. D., & Fullerton, A. W. 2002, *ApJ*, 569, 233
- Houck, J. C., & Bregman, J. N. 1990, *ApJ*, 352, 506
- Howk, J. C., Savage, B. D., Sembach, K. R., & Hoopes, C. G. 2002a, *ApJ*, 572, 264
- Howk, J. C., Sembach, K. R., Savage, B. D., Massa, D., Friedman, S., & Fullerton, A. W. 2002b, *ApJ*, 569, 214
- Hulsbosch, A. N. M., & Wakker, B. P. 1988, *A&AS*, 75, 191
- Ibata, R. Lewis, G. F., Irwin, M., Totten, E., & Quinn, T. 2001, *ApJ*, 551, 294
- Irwin, M. J., Demers, S., & Kunkel, W. E. 1990, *AJ*, 99, 191
- Iwan, D. 1980, *ApJ*, 239, 316
- Jenkins, E. B. 1978a, *ApJ*, 219, 845
- . 1978b, *ApJ*, 220, 107
- Jenkins, E. B., Bowen, D. V., & Sembach, K. R. 2002, in *Proc. XVIIth IAP Colloq., Gaseous Matter in Galactic and Intergalactic Space*, ed. R. Ferlet, M. Lemoine, J. M. Désert, & B. Raban (Paris: Frontier Group), 99
- Karachentsev, I. D., & Makarov, D. I. 1996, *AJ*, 111, 794
- Kepner, J., Tripp, T. M., Abel, T., & Spergel, D. 1999, *AJ*, 117, 2603
- Kepner, M. E. 1970, *A&A*, 5, 44
- Konz, C., Lesch, H., Birk, G. T., & Wiechen, H. 2001, *ApJ*, 548, 249
- Lehner, N. 2002, *ApJ*, 578, 126
- Lockman, F. J. 1984, *ApJ*, 283, 90
- Lockman, F. J., Murphy, E. M., Petty-Powell, S., & Urlick, V. 2002, *ApJS*, 140, 331
- Lu, L., Savage, B. D., & Sembach, K. R. 1994, *ApJ*, 426, 563
- Lu, L., Savage, B. D., Sembach, K. R., Wakker, B. P., Sargent, W. L. W., Oosterloo, T. A. 1998, *AJ*, 115, 162
- Madau, P. 1992, *ApJ*, 389, L1
- Majewski, S. R., Hawley, S. L., & Munn, J. A. 1996, in *ASP Conf. Ser. 92, Formation of the Galactic Halo. Inside and Out*, ed. H. Morrison & A. Sarajedini (San Francisco: ASP), 119
- Martínez-Delgado, D., Aparicio, A., Gómez-Flechoso, M. A., & Carrera, R. 2001, *ApJ*, 549, L199
- Martin, C. L. 2002, in *ASP Conf. Ser. 254, Extragalactic Gas at Low Redshift*, ed. J. S. Mulchaey & J. T. Stocke (San Francisco: ASP), 305
- Mayer, L., Governato, F., Colpi, M., Moore, B., Quinn, T., Wadsley, J., Stadel, J., & Lake, G. 2001, *ApJ*, 547, L123
- Mihalas, D., & Binney, J. 1981, *Galactic Astronomy* (2d ed; San Francisco: Freeman), chap. 6
- Miller, W. W., & Cox, D. P. 1993, *ApJ*, 417, 579
- Moore, B., & Davis, M. 1994, *MNRAS*, 270, 209
- Moos, H. W., et al. 2000, *ApJ*, 538, L1
- . 2002, *ApJS*, 140, 3
- Morras, R., Bajaja, E., Arnal, E. M., & Pöppel, W. G. L. 2000, *A&AS*, 142, 25
- Morton, D. C. 1991, *ApJS*, 77, 119
- Murali, C. 2001, *ApJ*, 529, L81
- Murphy, E. M., Lockman, F. J., Laor, A., & Elvis, M. 1996, *ApJS*, 105, 369
- Murphy, E. M., et al. 2000, *ApJ*, 538, L35
- Newberg, H. J., et al. 2002, *ApJ*, 569, 245
- Nicastro, F., et al. 2002, *ApJ*, 573, 157
- Norman, C., & Ikeuchi, S. 1989, *ApJ*, 345, 372
- Oegerle, W. R., et al. 2000, *ApJ*, 538, L23
- Oort, J. H. 1970, *A&A*, 7, 381
- Putman, M. E. 2000, *Publ. Astron. Soc. Australia*, 17, 1
- Putman, M. E., Bland-Hawthorn, J., Veilleux, S., Gibson, B. K., Freeman, K. C., & Maloney, P. R. 2003, *ApJL*, submitted
- Putman, M. E., et al. 2002, *AJ*, 123, 873
- . 1998, *Nature*, 394, 752
- Quilis, V., & Moore, B. 2001, *ApJ*, 555, L95
- Rasmussen, J., & Pedersen, K. 2001, *ApJ*, 559, 892
- Reynolds, R. J. 1993, in *Back to the Galaxy*, ed. S. Holt & F. Verter (New York: AIP), 156
- Richter, P., Sembach, K. R., Wakker, B. P., Savage, B. D., Tripp, T. M., Murphy, E. M., Kalberla, P. M. W., & Jenkins, E. B. 2001, *ApJ*, 559, 318
- Richter, P., et al. 2003, *ApJ*, in press
- Ryans, R. S. I., Keenan, F. P., Sembach, K. R., & Davies, R. D. 1997, *MNRAS*, 289, 986
- Sahnow, D. S., et al. 2000a, *ApJ*, 538, L7
- . 2000b, *Proc. SPIE*, 4013, 334
- Savage, B. D., Massa, D., & Sembach, K. R. 1990, *ApJ*, 355, 114
- Savage, B. D., & Sembach, K. R. 1996, *ARA&A*, 34, 279
- . 1991, *ApJ*, 379, 245
- Savage, B. D., Sembach, K. R., & Lu, L. 1997, *AJ*, 113, 2158
- Savage, B. D., Sembach, K. R., Tripp, T. M., & Richter, P. 2002, *ApJ*, 564, 631
- Savage, B. D., et al. 2003, *ApJS*, 146, 125
- . 2000, *ApJ*, 538, L27
- Sembach, K. R. 1999, in *ASP Conf. Ser. 166, Stromlo Workshop on High Velocity Clouds*, ed. B. K. Gibson & M. E. Putman (San Francisco: ASP), 243
- Sembach, K. R. 2002, in *ASP Conf. Ser. 254, Extragalactic Gas at Low Redshift*, ed. J. S. Mulchaey & J. T. Stocke (San Francisco: ASP), 283
- Sembach, K. R., Gibson, B. K., Fenner, Y., & Putman, M. E. 2002, *ApJ*, 572, 178
- Sembach, K. R., Howk, J. C., Savage, B. D., & Shull, J. M. 2001a, *AJ*, 121, 922 (erratum 123, 3488 [2002])
- Sembach, K. R., Howk, J. C., Savage, B. D., Shull, J. M., & Oegerle, W. R. 2001b, *ApJ*, 561, 573
- Sembach, K. R., & Savage, B. D. 1992, *ApJS*, 83, 147
- Sembach, K. R., Savage, B. D., & Lu, L. 1995a, *ApJ*, 439, 672
- Sembach, K. R., Savage, B. D., Lu, L., & Murphy, E. M. 1995b, *ApJ*, 451, 616
- . 1999, *ApJ*, 515, 108
- Sembach, K. R., Savage, B. D., & Massa, D. 1991, *ApJ*, 372, 81
- Sembach, K. R., Savage, B. D., & Tripp, T. M. 1997, *ApJ*, 480, 216
- Sembach, K. R., et al. 2000, *ApJ*, 538, L31

- Shapiro, P. R., & Field, G. B. 1976, *ApJ*, 205, 762
- Shapiro, P. R., & Moore, R. T. 1976, *ApJ*, 207, 460
- Shull, J. M., Roberts, D., Giroux, M., Penton, S. V., & Fardal, M. A. 1999, *AJ*, 118, 1450
- Simon, J. D., & Blitz, L. 2002, *ApJ*, 574, 726
- Slavin, J. D., & Cox, D. P. 1992, *ApJ*, 392, 131
- Slavin, J. D., Shull, J. M., & Begelman, M. C. 1993, *ApJ*, 407, 83
- Snowden, S. L., et al. 1995, *ApJ*, 454, 643
- . 1997, *ApJ*, 485, 125
- Spitzer, L. 1996, *ApJ*, 458, L29
- Stanimirovic, S., Dickey, J. M., Krčo, M., & Brooks, A. M. 2002, *ApJ*, 576, 773
- Sterling, N. C., Savage, B. D., Richter, P., Fabian, D., & Sembach, K. R. 2002, *ApJ*, 567, 354
- Sutherland, R. S., & Dopita, M. A. 1993, *ApJS*, 88, 253
- Tripp, T. M., & Savage, B. D. 2000, *ApJ*, 542, 42
- Tripp, T. M., Savage, B. D., & Jenkins, E. B. 2000, *ApJ*, 534, L1
- Tufte, S. L., Reynolds, R. J., & Haffner, L. M. 1998, *ApJ*, 504, 773
- Tufte, S. L., Wilson, J. D., Madsen, G. J., Haffner, L. M., & Reynolds, R. J. 2002, *ApJ*, 572, L153
- van Woerden, H., Peletier, R. F., Schwarz, U. J., Wakker, B. P., & Kalberla, P. M. W. 1999a, in *ASP Conf. Ser. 166, Stromlo Workshop on High Velocity Clouds*, ed. B. K. Gibson & M. E. Putman (San Francisco: ASP), 1
- van Woerden, H., Schwarz, U. J., Peletier, R. F., Wakker, B. P., & Kalberla, P. M. W. 1999b, *Nature*, 400, 138
- Wakker, B. P. 2001, *ApJS*, 136, 463
- Wakker, B. P., Kalberla, P. M. W., van Woerden, H., de Boer, K. S., & Putman, M. E. 2001, *ApJS*, 136, 537
- Wakker, B. P., & van Woerden, H. 1991, *A&A*, 250, 509
- . 1997, *ARA&A*, 35, 217
- Wakker, B. P., et al. 1999, *Nature*, 402, 388
- . 2003, *ApJS*, 146, 1
- Wannier, P. G., & Andersson, B.-G. 2003, *ApJ*, submitted
- Weiner, B. J., & Williams, T. B. 1996, *AJ*, 111, 1156
- Zirakashvili, V. N., Breitschwerdt, D., Ptuskin, V. S., & Voelk, H. J. 1996, *A&A*, 311, 113
- Zsargó, J., Sembach, K. R., Howk, J. C., & Savage, B. D. 2003, *ApJ*, 586, 1019
- Zwaan, M. A., & Briggs, F. H. 2000, *ApJ*, 530, L61