The FUSE Survey of O VI Absorption in the Galactic Disk

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Abstract.

We outline the results from a FUSE Team program designed to characterize O VI absorption in the disk of the Milky Way. We find that O VI absorption occurs throughout most of the Galactic plane, at least out to several kpc from the Sun, and that it is distributed smoothly enough for the column density to decline with height above the disk and with distance in the plane. However, the O VI absorbing gas is clumpy, and moves at peculiar velocities relative to that expected from Galactic rotation. We conclude that the observed absorption is likely to be a direct indicator of the structures formed when violent, dynamical processes heat the ISM, such as blowout from multiple supernovae events.

The FUSE survey of O VI absorption in the Galactic disk is a PI Team program (program IDs P102 & P122) designed specifically to characterize O VI absorption in the plane of the Galaxy. In selecting suitable sightlines, we favored stars with distances $d \gtrsim 1$ kpc, with Galactic latitudes $|b| \lesssim 10^\circ$, and stellar types earlier than B3. Expending 720 ksec of PI time, and including additional data from the FUSE Archive, we recorded O VI absorption towards more than 150 stars. To understand the distribution of O VI in the Galaxy, we combined our FUSE sample with data from the Copernicus satellite (which largely sampled stars with $d \lesssim 1$ kpc; see Jenkins 1978), as well as data from distant halo stars (Zsargó et al. 2003), and nearby white dwarfs (Oegerle et al. 2004). The analysis of these data reveal the following:

1. Data from the ROSAT All-Sky Survey show that the positions of some stars coincide with regions of enhanced X-ray emission. These likely arise from hot bubbles blown out from the star or its association (Weaver et al. 1977). Many of our sightlines, however, lie at positions in the sky where there is apparently very little soft X-ray emission. For this subsample, we find that the average density along the sightline is slightly smaller than that measured towards all the stars; a simple estimate of the mid-plane density of O VI, $n_0$, for the subsample...
with no X-ray emission, derived from taking the median value of \( N_i(O \text{ VI}) / d_i \) [as measured for each sightline \( i \)], yields \( n_0 = 1.7 \times 10^{-8} \text{ cm}^{-3} \).

2. We confirm the relationship between \( N(O \text{ VI}) \sin |b| \) and height above the Galactic plane \( |z| \) found from FUSE observations of extragalactic objects (Wakker et al. 2003; Savage et al. 2003). The correlation is conventionally characterized by the relation \( N(O \text{ VI}) \sin |b| = n_0 h [1 - \exp^{-|z|/h}] \), where \( h \) is the scale height of the O VI above the plane. The value of \( n_0 \) given above and \( h \simeq 3.5 \text{ kpc} \) well fit the data, when observations towards the extragalactic sightlines are included.

3. There is a correlation between distance in the Galactic plane and \( N(O \text{ VI}) \), over distances of \( \approx 0.1 - 10 \text{ kpc} \) (Fig. 1). This shows that the processes which give rise to the existence of hot gas in the Galactic disk are ubiquitous over all the ISM between the outer spiral arms (\( l = 180^\circ \)) and the Galactic center (\( l = 0^\circ \)). The increase of \( N(O \text{ VI}) \) with distance also demonstrates that observed O VI line profiles must be comprised of (perhaps many) blended components.

4. Significantly, although O VI is distributed smoothly enough for \( N(O \text{ VI}) \) to correlate with \( d \), the dispersion in the correlation does not decrease with distance, as would be expected by simply intercepting more clouds. For example, if a single cloud gave rise to a column density \( N_0 \), and the total observed column density increased as \( n \) clouds were intercepted (\( N = N_0 n \)), then we would predict the dispersion to go as \( \pm \sqrt{n} N_0 \). In fact, the fractional dispersion at large distances is similar to that seen at small distances. This indicates that the O VI is extremely clumpy compared to the distribution expected for either a smoothly distributed intercloud medium, or for randomly distributed uniform clouds.

5. We find a correlation between \( N(O \text{ VI}) \) and the width of O VI absorption lines, as measured from their Doppler parameter, \( b \). The fraction of oxygen in the form of O VI is at its peak in collisionally ionized gas at temperatures of \( \log T = 5.5 \) (if in thermal equilibrium), when \( 1/4 \) of the oxygen exists as O VI. This corresponds to a Doppler width of \( b = 0.0321 \sqrt{T} = 17.6 \text{ km s}^{-1} \). Although the weakest lines in our sample have widths similar to this (at least within their
errors), the majority of lines have widths considerably larger. The median value of all detected lines is $b = 39.4 \text{ km s}^{-1}$, which would result in $\log T = 6.2$, and $N(\text{O VI}) \sim 1/400 N(\text{O})$, if the broadening was all thermal. The width of the lines cannot be accounted for by Galactic rotation; simulations of O VI lines along the observed sightlines, assuming a smoothly distributed hot ISM, fail to reproduce the large Doppler widths measured in most cases.

6. Since $N(\text{O VI})$ correlates with $b$ and $d$, it is of no surprise to find that $b$ correlates with $d$, although not strongly. Since there is no reason to expect the temperature of the gas to increase with distance, this again demonstrates that the width of an O VI line is determined by the velocity structure of overlapping components. The dispersion in $b$ as $d$ increases is large, which may be the result of intercepting many different regions of hot gas each with very different line-of-sight velocities.

7. We find that the velocities of the edges of O VI absorption lines and those of strong C II $\lambda 1335$ and Si III $\lambda 1206$ lines (as measured in high resolution STIS data) are very similar. This suggests that the processes which move the hot gas to high velocity also affect small amounts of lower-ionization, cooler gas, in much the same way.

Interpretation of these results must therefore explain the fact that O VI production is common throughout the local Galactic disk, that it arises in clumpy structures, and that it is dynamic. Of course, the velocity of O VI we measure need not be the true velocity of the gas; for example, material which is flowing perpendicular to the disk will have only a very small component of velocity along a line of sight. At any rate, our data apparently rule out quiescent models of the hot ISM: absorption cannot arise in a smooth, diffuse intercloud medium which rotates along with the disk of the Milky Way. Nor can O VI arise in ‘identical’ hot clouds with similar column densities, randomly distributed along a sightline—the hot ISM must be a much more complicated structure than these simple models predict. A preliminary analysis suggests that a population of clouds with sizes that follow a power-law distribution may well produce the observed dispersion in column densities. Our results are also consistent with recent hydrodynamical simulations of the ISM, which predict that hot, multiphase gas arises in turbulent, evolving structures as a result of, e.g., multiple supernovae explosions, which produce overlapping bubbles of shock-heated gas (see e.g. de Avillez & Breitschwerdt in this volume). These detailed computer simulations are themselves still evolving, and our observations will provide an important set of results which these models can aim to reproduce.

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