Abstract

We report observations of O VI resonance line emission (1032, 1038 Å) along the sight line to NGC 1068 (M77, l = 172.1, b = −11.9°), made using the Far Ultraviolet Spectroscopic Explorer's (FUSE) low resolution aperture (LWRS). The observations place tight upper limits on the O VI emission originating in our galaxy’s diffuse interstellar medium as well as tight upper limits on the emission originating in NGC 1068’s extended disk.

The Milky Way’s intensities in the O VI 1032 and 1038 Å emission lines are 150 ± 310 and 70 ± 280 photons cm⁻² s⁻¹ sr⁻¹, respectively. These values are an order of magnitude less than those reported for other unobscured, high latitude sight lines, indicating a hole in the distribution of emissive interstellar O VI ions.

Nonetheless, extensive O VI column density surveys have found large O VI column densities on almost all high S/N extragalactic sight lines, including a line of sight only 2 arcmin from our pointing direction. From the Lрыв/σLv ratio, we calculate the density, n_e. Either it is extremely low (n_e < 0.003 cm⁻³) or the O VI-rich plasma is much cooler than its collisional ionization equilibrium temperature. It’s character must differ from the emission we see toward other high latitude directions.

We also made the first search for O VI emission from the disk of a Seyfert galaxy, using NGC 1068. The intensities in the redshifted O VI emission lines (1036 and 1042 Å) are 10 ± 290 and 160 ± 330 photons cm⁻² s⁻¹ sr⁻¹, respectively. These are surprisingly tight upper limits for a galaxy known to have starburst activity in its disk and an AGN in its center. This work was supported by NASA, through grant numbers NNG04G11GQ and NNG04G07Q.

1 Introduction

O VI traces relatively hot gas (T > 3 × 10⁷ K gas, assuming collisional ionizational equilibrium.) Extensive surveys have measured O VI absorption column densities through its absorption of 1032 and 1038 Å photons (Wakker et al., 2003, Savage et al., 2003). High latitude directions are rich in O VI ions; the average column density in the Savage et al. data set is 2.1×10³ cm⁻², while the estimated scale height is 2300 pc.

Observations of O VI resonance line emission (in contrast with absorption column densities) are less numerous but provide additional information about the hot gas. The intensity is more sensitive to the plasma’s density and temperature, because the intensity is \( I \propto n_e^2 \propto n_e L(\lambda) \), where \( n_e \) and \( L(\lambda) \) are volume densities and \( L(\lambda) \) is an emission function, while the absorption column density is \( \propto n_e \). Thus, from intensity and column density information, it is possible to estimate the electron density.

Currently, there are 7 published observations of O VI emission along unobscured, high latitude directions (Dixon et al., 2001; Otte et al., 2003; Shelton 2002, 2003; Shelton et al., 2001; Welsh et al., 2002) and 183 observations in an Astro-Ph preprint (Dixon et al., 2006). The average intensity in the 1032 Å line from the published observations is 2540 photons cm⁻² s⁻¹ sr⁻¹, while the median for the Astro-Ph survey is 3300 photons cm⁻² s⁻¹ sr⁻¹. Our upper limits for both the Milky Way and for NGC 1068 are far lower.

2 Observations

FUSE observed NGC 1068 for 98 ksec between Nov. 29, 2001 and Dec. 1, 2001. Of the 98 ksec, 77 ksec were taken during the night portion of the satellite’s orbit. Our analysis uses the LIF 1A data from FUSE’s low resolution aperture (LWRS), which was directed toward NGC 1068’s disk, face-on disk ~11° from the galaxy’s center. NGC 1068’s emission is redshifted relative to the Milky Way by 3.9 Å, making it possible to search for O VI emission originating in each of the galaxies. While the LWRS observed NGC 1068’s disk, the high resolution aperture was directed at NGC 1068’s bright center. Using the AGN as a “lightbuls,” Savage et al. (2003) determined the Milky Way’s O VI column density along the line of sight to be \( N_0 \) = \( 10^{13.65} \) cm⁻².

3 Results for the Milky Way

We did not detect intensity in either of the O VI emission lines (1032, 1038 Å) as see in Figures 1 and 2 and Table 1 for the spectra and \( \sigma \) upper limits.

The 1σ upper limit in the 1032 Å line (460 photons cm⁻² s⁻¹ sr⁻¹) is far below the typical value (3300 photons cm⁻² s⁻¹ sr⁻¹, Dixon et al., 2003), suggesting that our line of sight is unusual. Our line of sight is mildly extincted, but not dramatically so more than directions on which O VI emission was observed. We found no O VI emission, suggesting that our line of sight is unusual. Our line of sight is mildly extincted, but not dramatically so more than directions on which O VI emission was observed. Table 2 lists our high latitude upper limits for the Milky Way.

4 Results for NGC 1068

NGC 1068 is a Seyfert 2 galaxy with starburst regions in its disk (Telescope et al., 1988, Le Floc’h et al., 2001). NGC 1068’s recessional velocity is \( v_r = 1.17 \times 10^3 \) km s⁻¹ (NEA, NASA/IPAC Extragalactic Database). Therefore, its spectrum is redshifted by 3.9 Å relative to the Milky Way, allowing us to search for its redshifted O VI emission at 1035.85 and 1041.56 Å. The LWRS aperture sampled a region of NGC 1068’s disk that is 2300 pc × 2300 pc in area and located approximately 9300 pc from the center, (assuming a Hubble constant of H₀ = 71 ± 1 km sec⁻¹ Mpc⁻¹). The observed region is marked with a box in Figure 3 and does not coincide with regions of known starburst activity. The observed segment would be large enough to contain a variety of region-types and not so small as to have coincidentally missed a hot region if hot regions are prevalent in or above NGC 1068’s disk. The spectra do not reveal redshifted O VI emission (see Table 2). NGC 1068’s star formation rate is comparable to that of the Milky Way (5 M_☉ yr⁻¹ versus ~1 M_☉ yr⁻¹; Smith & Wilson, 2003, Diedhi, et al., 2008). It is surprising that NGC 1068’s disk and halo do not emit more O VI photons and that a galaxy with such an enormous production of energy does not reveal hot gas at the location observed by the FUSE LWRS.