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Upper Limits on O VI Emission from *Voyager* Observations

Jayant Murthy *Indian Institute of Astrophysics, Koramangala, Bangalore 560 034, India*

Abstract. We have examined 426 *Voyager* fields distributed across the sky for O VI ($\lambda\lambda$ 1032/1038 Å) emission from the Galactic diffuse interstellar medium. No such emission was detected in any of our observed fields. Our most constraining limit was a 90% confidence upper limit of 2600 photons $\mathrm{cm}^{-2}\ \mathrm{sr}^{-1}\ \mathrm{s}^{-1}$ on the doublet emission in the direction (l, b) = (117.3, 50.6). Combining this with an absorption line measurement in nearly the same direction allows us to place an upper limit of 0.01 cm^{-3} on the electron density of the hot gas in this direction. We have placed 90% confidence upper limits of less than or equal to 10,000 photons $\mathrm{cm}^{-2}\ \mathrm{sr}^{-1}\ \mathrm{s}^{-1}$ on the O VI emission in 16 of our 426 observations.

Key words. Galaxy: halo ISM: general.

1. Introduction

There have been many detections of ultraviolet resonance line absorption by highly ionized, presumably hot, gas in the Galactic halo (e.g., Sembach & Savage 1992; Hurwitz & Bowyer 1996), but only three claimed detections of ultraviolet resonance line emission from this gas (see Murthy *et al.* 2001 for a full discussion and references). In this work, we will discuss limits, from the *Voyager* data set described by Murthy *et al.* 2001, on O VI (1032/1038 Å) line emission from the ISM. Although new instruments are now providing important results, the *Voyager* data are still the only source of information on the O VI emission over many different lines of sight.

2. Observations and data analysis

The two *Voyager* spacecrafts were launched in 1977 and have taken FUV (500–1700 Å) spectra of astronomical objects ever since. Each spacecraft includes a Wadsworth-mounted objective grating spectrometer (UVS) with a field of view of $0^{\circ}\!.1 \times 0^{\circ}\!.87$ and a spectral resolution of 38 Å for aperture filling diffuse sources. A full description of the UVS instruments and the *Voyager* mission is given by Holberg & Watkins (1992).

The data processing is described in Murthy *et al.* (1999) and resulted in 426 observations of the diffuse background which we have now examined for the presence of O VI emission. The O VI doublet ($\lambda\lambda$ 1032/1038 Å) is clearly visible in the *Voyager* spectra of bright sources such as supernovae remnants (Blair *et al.* 1995) and the Eridanus superbubble (Murthy *et al.* 1993), where the doublet is much brighter than the heliospheric hydrogen Ly β (λ 1026 Å) emission on whose wings it lies. However, the O VI emission from the diffuse halo gas is much less than the Ly β emission and we were forced to model the heliospheric emission.

Fortunately, because the Lyman lines are optically thick, the Ly β/Ly α ratio is constant throughout the heliosphere and we can use the Ly α line to scale the Ly β line. We determined the ratio between the two lines using UVS observations in which only the heliospheric lines were present and then used this empirical ratio to scale the Ly β line in each observation (see Murthy *et al.* 1999) for a full description of this procedure). We subtracted this scaled Ly β intensity from the observed spectrum and determined the O VI upper limit from the remainder.

3. Results and discussion

We detect no O VI emission in any of 426 UVS observations of the diffuse radiation field but do set upper limits on such emission in each direction. The best of these limits is 2600 photons cm^{-2} sr^{-1} s^{-1} (5.0×10^{-8} ergs cm^{-2} sr^{-1} s^{-1}) in the O VI resonance line doublet in the direction (l, b) = (117.3, 50.6). This direction is quite close to HD 121800 (l, b = 113.0, 49.8 , spectral type B1.5 V, distance = 2.2 kpc) towards which Hurwitz & Bowyer (1996) obtained a O VI column density of 1.1×10^{14} cm^{-2} using ORFEUS. Using these values and equation (5) of Shull & Slavin (1994), and confining the temperature range to that for which the fraction of oxygen atoms in the O VI state is within 10% of its maximum value in collisional ionization equilibrium plasma (T = $2.2 - 6.4 \times 10^5$ K—Shapiro & Moore 1977), we find an upper limit on the electron density of less than 0.010 cm^{-3}. Assuming that the emitting gas has a solar abundance of helium atoms and that the hydrogen and helium are fully ionized, there will be 1.9 particles per electron and thus the thermal pressure will be less than 12,000 K cm^{-3}, close to the thermal pressure of 15,000 K cm^{-3} in the Local Bubble derived by Snowden *et al.* (1998) from observations of the 1/4 keV soft X-ray flux seen by ROSAT.

The 94 locations in which we set 90% confidence upper limits of better than 5×10^{-7} ergs cm^{-2} sr^{-1} s^{-1} (25,000 photons cm^{-2} sr^{-1} s^{-1}) are plotted in Fig. 1 and those in which we set limits of better than 2×10^{-7} ergs cm^{-2} sr^{-1} s^{-1} ($\approx$ 10,000 photons cm^{-2} sr^{-1} s^{-1}) are listed in Table 1. Several of our observations are near the locations observed by Dixon *et al.* (1996) using HUT and we both set similar upper limits in those (with our *Voyager* limits in general being more constraining). Only in their Target 3 (UGC 5675; l = 218.2, b = 56.4) do we obtain inconsistent results, with Dixon *et al.* (1996) quoting a flux of 23,000 $\pm$ 6000 photons cm^{-2} sr^{-1} s^{-1} while we place a 90% upper limit of 10^4 photons cm^{-2} sr^{-1} s^{-1}at (l, b) = (216.8, 55.3) — about 1° away. Of course, it is entirely possible that there are truly spatial variations of this scale in the ISM.

We also have several observations near the four high latitude locations where Martin & Bowyer (1990) detected C IV emission but in none can we do more than say that the O VI/C IV ratio is not inconsistent with the theoretical ratios reported in the literature (eg. Shelton *et al.* 2001 and references therein).

4. Conclusion

Very recent results concerning galactic diffuse O VI emission include the *FUSE* detections by Shelton *et al.* (2001) and Dixon *et al.* (2001) at a level of 5000 photons cm^{-2} sr^{-1} s^{-1} and the *MINISAT-01* all-sky upper limit of 1200 photons cm^{-2} sr^{-1} s^{-1} by Edelstein *et al.* (1999). Combined with the present *Voyager* upper limits, it appears

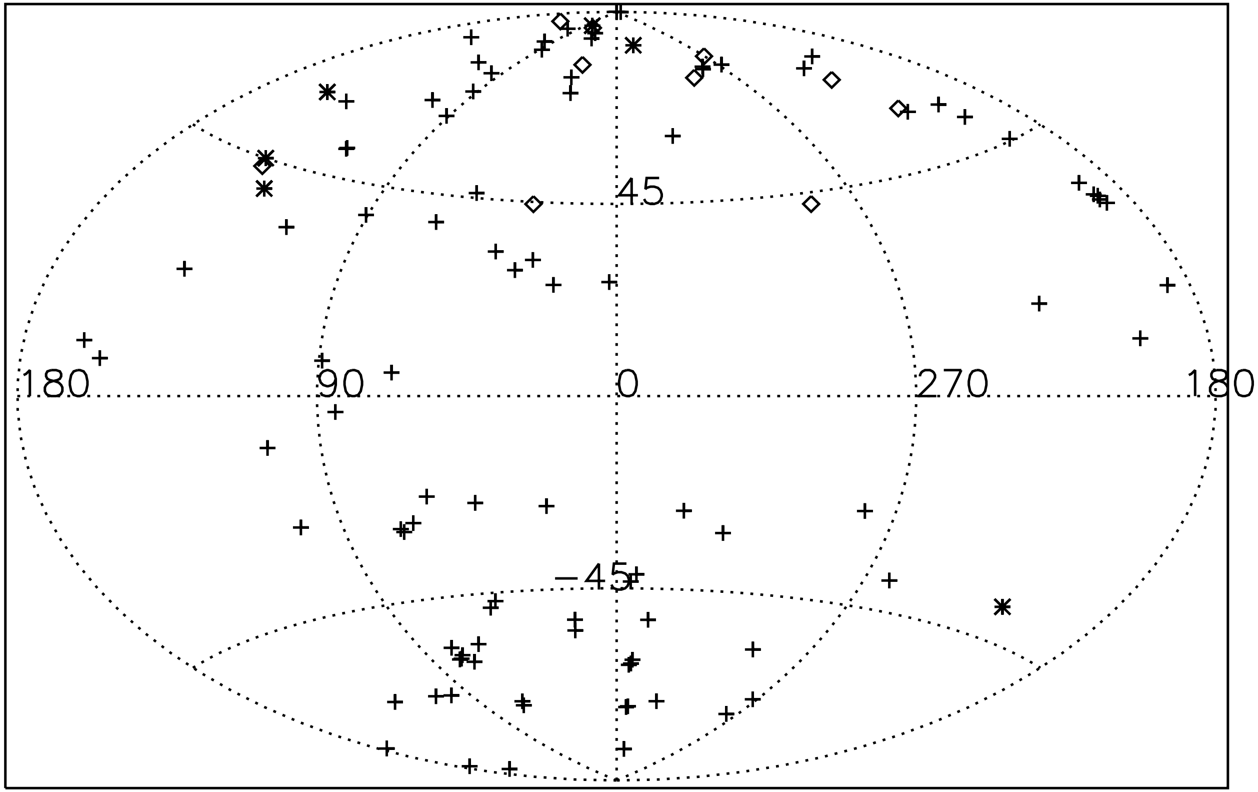

Figure 1. All of the *Voyager* observations in which we were able to set upper limits of less than 5×10^{-7} ergs cm^{-2} sr^{-1} s^{-1} (25,000 photons cm^{-2} sr^{-1} s^{-1}) are plotted as plus signs on an Aitoff map of the sky with the origin at the center and 180° at the left. The Dixon *et al.* (1996) targets are plotted as diamonds and the C IV detections of Martin & Bowyer (1990) are plotted as asterisks. In one direction in common (see text), we place a 90% confidence limit that is about half the claimed detection by Dixon *et al.*; however, given both sets of uncertainties and the different locations, we cannot rule out their claimed value.

Table 1. Best *Voyager* O VI Upper Limits: 90% Confidence Upper Limit on O VI Emission.

l degrees	b degrees	Flux photons cm^{-2} sr^{-1} s^{-1}
117.3	50.6	2,600
272.5	−67.4	4,100
67.8	5.2	5,700
60.3	−22.5	6,500
117.3	50.8	6,700
200.7	9.6	7,000
71.6	−59.6	7,400
189.6	32.3	8,600
91.1	61.4	8,700
115.7	72.6	9,000
32	70.5	9,100
331.7	60.5	9,200
99.3	80.3	9,500
225.7	68.3	9,900
190	33.3	10,000
216.8	55.3	10,000
346.6	−52.3	11,000

that much of the sky has an O VI emission of significantly less than 10,000 photons cm^{-2} sr^{-1} s^{-1}. Only the 4 HUT detections of Dixon *et al.* (1996) show higher fluxes. A mission dedicated to the observation and mapping of faint line emission from the Galactic halo would surely yield bountiful results.

References

Blair, W. P., Vancura, O., Knox, K. S. 1995, *A. J.*, **110,** 312.

Dixon, W. V., Davidsen, A. F., Ferguson, H. C. 1996, *Ap. J.*, **465,** 288.

Dixon, W. V., Sallmen, S., Hurwitz, M., Lieu, R. 2001, *Ap. J.*, **552,** L69.

Edelstein, J., Bowyer, C. S., Korpela, E., Lampton, M., Trapero, J., Gomez, J. F., Morales, C., Orozco, V. 1999, *American Astronomical Society Meeting*, **195,** 5302.

Holberg, J. B., Watkins, R. 1992, *Voyager Ultraviolet Spectrometer Guest Observer and Data Analysis Handbook*, Version 1.1

Hurwitz, M., Bowyer, S. 1996, *Ap. J.*, **465,** 296.

Martin, C., Bowyer, S. 1990, *Ap. J.*, **350,** 242.

Murthy, J., Im, M., Henry, R. C., Holberg, J. B. 1993, *Ap. J.*, **419,** 739.

Murthy, J., Hall, D. T., Earl, M., Henry, R. C., Holberg, J. B. 1999, *Ap. J.*, **522,** 904.

Murthy, J., Henry, R. C., Shelton, R. L., Holberg, J. B. 2001, *Ap. J. L.*, **557,** 47L.

Sembach, K. R., Savage, B. D. 1992, *Ap. J. S.*, **83,** 147.

Shapiro, P. R., Moore, R. T. 1977, *Ap. J.*, **217,** 621.

Shelton, R. L. *et al.* 2001, *Ap. J.*, **560,** 730.

Shull, J. M., Slavin, J. 1994, *Ap. J.*, **427,** 784.

Snowden, S. L., Egger, R., Finkbeiner, D. P., Freyberg, M. J., Plucinsky, P. P. 1998, *Ap. J.*, **493,** 715.