SPECTROSCOPIC OBSERVATIONS OF THE EXTENDED SOLAR CORONA ABOVE QUIET SUN REGIONS


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ABSTRACT

We present an analysis of ultraviolet spectra observed in regions of the extended corona (i.e., above 1.5 solar radii from Sun center) that are devoid of structure and appear to not be coronal holes or streamers. The observations were made with the Ultraviolet Coronagraph Spectrometer (UVCS) onboard the Solar and Heliospheric Observatory (SOHO). The measurements were made during several periods in 2005 and 2006. The observations were performed at 1.72 and 2.54 solar radii. We measured the intensities and line ratios of the O VI doublet (1032 and 1037 Angstroms), H I Lyα, and H I Lyβ and observed wavelength regions encompassing Fe XII, Fe X, Mg X, and Si XII spectral lines. We compared the measured spectra and derived quantities in the unstructured corona to those measured previously in streamers and coronal holes. These comparisons of the observed UVCS data over the Quiet Sun regions should help determine if the quietest extended corona consists entirely of streamers and coronal holes, or if quiet coronal regions observed at the coronal base have other manifestations in the extended corona.

Keywords: Sun: corona, Sun: spectroscopy, Sun: streamers, Sun: coronal holes, Sun: UV radiation

1. INTRODUCTION

The coronal base includes regions characterized by large scale closed magnetic structures outside coronal holes, active regions and the base of the streamers e.g., Narain and Umschneider (1990), Wilhelm (2000), Schrijver and van Ballegooijen (2005). These regions, often called “Quiet Corona”, may have extensions into the extended corona consisting of open field lines that help define the extended corona above the base (Woo and Habbal, 2000; Withbroe, 1991). Such regions might be a source of slow solar wind. Since the observed intensities of spectral lines in these regions are larger than those in coronal holes, the density is expected to be higher. As a result, it should be possible to map these regions to larger heliocentric distances than is possible for coronal holes.

In this paper we examine observations of ultraviolet spectra observed in diffuse regions of the extended corona that are devoid of structure and appear not to have any contribution from coronal holes and streamers. We compared the spectra and derived quantities to those measured previously in streamers and coronal holes. Our goal is to determine if the quiet regions observed at the base of the corona have extensions into the higher corona that form structures other than streamers and coronal holes.

In §2 we describe the observations and data reduction, calculate line ratios and derive the O/H abundance. In §3 we discuss our results as well as compare them to streamers and coronal holes and finally make concluding remarks and comment on future work.

2. OBSERVATIONS

The observations were performed on March 14 - 15, 2005 and January 30 - February 08, 2006 using the Ultraviolet Coronagraph Spectrometer (UVCS) on the SOHO spacecraft. The UVCS is described in detail by Kohl et al. (1995). Observations from the OVI channel, which is optimized to observe the O VI 1032 Å, 1037 Å doublet, also can observe H I Lyβ and H I Lyα, the former via its redundant path.

The March 2005 slit width was 50 μm (14”) for both the O VI lines and the Lyα and the spatial binning along the slit was 42”. The spectral binning was 1 pixel (0.0993 Å) for the OVI detector and 2 pixels (0.18 Å) for the redundant path. The observations were performed at position angle (PA) 180°. The January 2006 slit width was 50 μm (14”) for the redundant Lyα path and 200 μm (56”) for the O VI lines. The spectral binning is similar to that of the March 2005 observations.

The absolute radiometric calibration is accurate to ±20% (Gardner et al., 2000, 2002). Intensity ratios for closely spaced wavelengths are much more accurate.

Fig. 1 shows the EIT and LASCO images on the first day of each observation with the UVCS slit superimposed.

The line profiles presented in this paper are averaged over 55” and 70” segments of the length of the entrance slit for O VI and Lyα, respectively. The observations are corrected for geometrical distortion effects and are wavelength and radiometrically calibrated. The
corrected profiles are curve-fitted with a standard algorithm that minimizes the $\chi^2$.

The curve-fitted spectra for January 30, 2006 are given in Fig.3.

An example of the observed O VI spectrum at 1.71 $R_\odot$ is given in Fig. 2. The spectrum also shows Ly$\beta$ at 1025 Å and the 2nd order Si XII at 520.66 Å.

The intensities and $V_{1/e}$ for March 2005 and January 2006 are calculated from the curve-fitted profiles. The $V_{1/e}$ is the most probable speed derived from the 1/e half width of the observed profile. The results are shown in Table 1.

**Table 1.** The results of the UVCS observations for both March 2005 and January 2006 show the intensities and $V_{1/e}$. All results presented here are for 1.71 $R_\odot$. The intensities are in units of photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$ and the $V_{1/e}$ is in km s$^{-1}$.

<table>
<thead>
<tr>
<th>Spectral Lines</th>
<th>March 2005</th>
<th>January 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>1032 Å</td>
<td>4.19 x 10$^8$</td>
<td>71.8±3.58</td>
</tr>
<tr>
<td>1037 Å</td>
<td>1.43x10$^8$</td>
<td>75.5±2.09</td>
</tr>
<tr>
<td>Ly$\alpha$</td>
<td>2.54x10$^{10}$</td>
<td>155±3.47</td>
</tr>
<tr>
<td>Ly$\beta$</td>
<td>2.95 x 10$^7$</td>
<td>162±13.7</td>
</tr>
</tbody>
</table>

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Based on the intensities provided in Table 1, the 1032/1037 line intensity ratios are 2.93 ± 0.12 and 2.97±0.10 for March 2005 and January 2006, respectively. The uncertainties are only statistical uncertainties.

In general, the observed line intensities have contributions from resonant scattering of light from the lower solar atmosphere and collisional components (Gabriel et al. 1977, Withbroe et al. 1982)). The intensity ratio of I(1032)/I(1037) is 2:1 for collisional excitation and 4:1 for radiative scattering provided that the outflow speed is below 110 km s⁻¹. The radiative ratio (Noci, Kohl and Withbroe, 1987; Spadaro and Ventura, 1993) will be modified by the C II line at 1037.02 Å for outflow speeds close to 200 km s⁻¹. The relative intensities of Lyα, Lγ, and Lγ are 13020, 14.3, and 1.0, respectively, for the radiative component, provided that the integrals of the chromospheric emission line profiles times the coronal absorption line profiles of the Lyman lines are the same.

The O abundance relative to hydrogen is calculated following Raymond et al. (1997). Since we determined the collisional and radiative components of the line, then two estimates of the O/H ratio are obtained. The abundance for the radiative component is given by the following formula:

\[
\frac{N(O)}{N(H)} = \frac{I_{rad}(OVI)}{I_{rad}(Lβ)} \frac{C(HI)B(Lβ) f(Lβ)}{C(OVI)B(OVI) f(OVI)} \frac{I_{disk}(Lβ)}{I_{disk}(OVI)} \frac{δλ(OVI)}{δλ(HI)}
\]

where \(C\) is the ion concentration, \(B\) is the branching ratio, \(f\) is the oscillator strength, \(I_{disk}\) is the measured disk intensities, and \(δλ\) is the line width. The branching ratios are 0.88 for Lγ and 1.0 for the O VI. The oscillator strengths are 0.0791 and 0.131 for the H I Lyβ and the O VI 1032 Å, respectively, and the ratio of the measured disk intensities is 2.13. The ratio of the widths is 0.25 when the radial components of the thermal velocities of the O and H are in thermal equilibrium. \(C(HI)/C(OVI)\) depends on \(T_e\). Our calculations are based on a log \(T_e\) = 6.2.

A similar expression is obtained for the collisional component:

\[
\frac{N(O)}{N(H)} = \frac{I_{coll}(OVI)}{I_{coll}(Lβ)} \frac{C(HI)B(Lβ)}{C(OVI)B(OVI)} \frac{q(Lβ)}{q(OVI)}
\]

The abundances from the collisional contributions are a function of excitation rates, \(q\), in addition to branching ratios, ion concentrations, and the observed line intensity ratio of O VI 1032 Å to Lyβ. The calculated O abundances from both the radiative and collisional components are given in Table 2.

<table>
<thead>
<tr>
<th>March 2005</th>
<th>Radiative</th>
<th>Collisional</th>
<th>January 2006</th>
<th>Radiative</th>
<th>Collisional</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.23</td>
<td>7.97</td>
<td>8.33</td>
<td>8.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The O/H abundance values from the radiative and collisional component from the January 2006 data are similar. There is, however, a notable difference in the March 2005 data set in the abundances derived from the radiative and collisional components. This difference could be real since the radiative contribution is proportional to the density whereas the collisional contribution is proportional to the density squared. However, there is uncertainty in our separation of the radiative and collisional components of Lγ which might explain the apparent difference between the radiative and collisional abundances. There is also uncertainty in our knowledge of the Lyα/Lγ disk intensities. Although the separation of the radiative and collisional components is uncertain, the average abundance derived for the two components is believed to be more reliable.

3. DISCUSSION

We analyzed UVCS observations of the extended corona above quiet sun regions. Intensities and line ratios were calculated from data observed on March 14 - 15, 2005 and January 30 − February 8, 2006. The radiative and collisional components were separated and the abundances from both were calculated.

We compare the 1032/1037 intensity line ratios and the \(V_{lsr}\) with those of previously observed streamers and coronal holes. Our comparison is given in Table 3.

Our observations of apparently structureless coronal regions above the quiet coronal base resemble that of a streamer and not of a coronal hole. We did not find any unique characteristics that differ strongly from existing streamer observations.

In addition to the 1032/1037 line ratio and \(V_{lsr}\), we compared the O abundance from our study to those
previously observed in streamers. Our abundances comparison is shown in Table 4.

Table 3. Comparison of current observations with earlier streamer and coronal hole values for the 1032/1037 line ratio and $V_{\text{r.e.}}$.

<table>
<thead>
<tr>
<th>Heliospheric Height (R$_{\odot}$)</th>
<th>Coronal Holes Ratio</th>
<th>Streamers Ratio</th>
<th>$V_{\text{r.e.}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.59</td>
<td>2.49</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.6</td>
<td>2.96</td>
<td>213</td>
<td>-</td>
</tr>
<tr>
<td>1.72</td>
<td>2.23</td>
<td>207</td>
<td>-</td>
</tr>
<tr>
<td>1.75</td>
<td>-</td>
<td>-</td>
<td>2.86</td>
</tr>
</tbody>
</table>

- Miralles et al. 2005, 2006
- Cramer et al. 1999
- Kohl et al. 1997
- Raymond et al. 1997

Table 4. Comparison of O/H abundances for this work with photospheric and streamer values.

<table>
<thead>
<tr>
<th>Photosphere</th>
<th>This Study</th>
<th>1996 Streamer</th>
<th>1996 Streamer</th>
<th>2001 Streamer</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.66</td>
<td>8.11</td>
<td>8.40</td>
<td>8.48</td>
<td>8.51</td>
</tr>
<tr>
<td>8.93</td>
<td>8.35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Asplund et al. 2004
- Feldman et al. 1992
- March 2005 observations
- January 2006 observations
- Raymond et al. 1997
- Uzzo et al. 2003
- Uzzo et al. 2004

The data in Table 4 indicate that the abundances we derived for the observed structureless region above quiet sun regions are similar to streamer values, as were the 1032/1037 line ratio and the $V_{\text{r.e.}}$ (see Table 3).

This is a preliminary work and much is still needed to be done. Future work will perform spectral synthesis and derive $T_e$ and abundances from the ratio of Fe XII, and Fe X lines to the collisional component of H I Lyβ. We will use the resulting $T_e$ to confirm our preliminary results which assumed a value of log $T_e$ = 6.2. Finally, we will determine kinetic temperatures from the line profiles and bulk outflow speeds from a Doppler dimming analysis of the data at 2.5 R$_{\odot}$.

ACKNOWLEDGMENTS

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REFERENCES

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