J. Astrophys. Astr. (2008) **29,** 167–170

Ultraviolet Spectroscopic Observations of Coronal Streamers in the SOHO Era

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Abstract. Measurements made with the Ultraviolet Coronagraph Spectrometer (UVCS) on the Solar and Heliospheric Observatory can be used to determine physical parameters in the solar corona such as hydrogen and ion kinetic temperatures, electron densities, and absolute elemental abundances. Hydrogen and ion outflow velocities can be determined by combining the UV spectroscopic measurements with white light polarized brightness measurements. These combined measurements can be used to reveal physical characteristics of coronal streamers. To date we have studied plasma properties, such as the variation of plasma outflows in quiescent streamers, primarily in classic helmet streamers at solar minimum. Outflows have not been observed in the centers of coronal streamers suggesting that these are closed magnetic field regions. We propose to study all of the coronal streamers in the UVCS synoptic dataset in order to investigate different types of streamers and their long-term evolution.

Key words. Sun—corona—ultraviolet.

1. Introduction

Coronal streamers are bright ray-like structures extending outward from the Sun for many tens of solar radii. These structures are bright because they are more dense than the background corona. Their higher densities are due to particle trapping by the large-scale coronal magnetic field. With the Ultraviolet Coronagraph Spectrometer (UVCS) onboard the Solar and Heliospheric Observatory (SOHO), we have made considerable progress in understanding the energetics, composition, and dynamics of streamers. In this paper we describe the key results from UVCS observations of coronal streamers and the progress being made on establishing a 10-year database of streamer properties covering most of Solar Cycle 23. The database properties are derived primarily from the UVCS synoptic observations.

The goals of the UVCS streamer study are to better understand the properties (densities, temperatures, abundances and outflow speeds) of coronal streamers and to relate these properties to characteristics of the solar wind. Important questions to be answered are the following:

- From which part of the coronal streamer does the solar wind originate?
- Do the same physical processes that occur in coronal holes operate in coronal streamers?

- What is the three dimensional structure of a typical coronal streamer?
- How do coronal streamer properties vary with the solar cycle?
- How do changes in coronal streamers relate to changes in the solar wind?

2. Results from UVCS streamer studies

The UVCS program (Kohl *et al.* 1997) has made important contributions to the understanding of coronal streamers. Some of the key findings are listed below:

1. Outflow was measured at the tips of streamers at high heights and also near the edges of streamers at low heights (Strachan *et al.* 2002). The outflow speeds are consistent with LASCO 'blob' speeds at higher heights.
2. Abundances for O, Mg, Al, Si, S, and Fe in streamer cores were found to be severely depleted compared to streamer legs (e.g., flanks), irrespective of the FIP effect. In addition, the similarities between the abundances (for these same ions) in the streamer legs and the solar wind suggest that the legs are the origin of the slow solar wind (Raymond *et al.* 1997).
3. UVCS observed that the O VI 103.2 nm emission in the streamer core was considerably less intense than in the legs. This is now believed to be due to a depletion in the oxygen elemental abundance relative to photospheric values (Noci *et al.* 1997; Raymond *et al.* 1997). This may be due to gravitational settling in closed field regions.
4. Additional studies showed that not all quiescent streamers have large minor ion abundance depletions in their cores. Active region streamers have a wider range of ion abundances in their cores compared to quiescent streamers (Uzzo *et al.* 2006).
5. O^{5+} kinetic temperatures for equatorial streamers at Solar Minimum are higher than the temperatures for Solar Maximum streamers at mid-to-high latitudes. Presently there is no definitive explanation for this trend although it could be a density effect (see Frazin *et al.* 1999; Strachan *et al.* 2004).
6. Extreme ion (O^{5+}) kinetic temperatures and temperature anisotropies ($T_{\|}$ *vs.* $T_{\perp}$) exist at high heights in quiescent streamers. This similarity to coronal hole anisotropies suggest that the same mechanism for plasma heating and acceleration (ion cyclotron resonance absorption) occurs in coronal holes as well as in streamers, although at higher heights in streamers (Frazin *et al.* 2003).

3. New streamer studies using UVCS synoptic data

UVCS has made 'full corona' maps in H I Lyα and the O VI doublet (103.2 and 103.7 nm) either daily or on alternating days for almost a complete solar cycle. These data can be used to track changes in the physical parameters of coronal streamers as a function of magnetic field strength and field line orientation as derived from extrapolated photospheric magnetic fields. The synoptic maps are made from 27 individual 'full corona' plane-of-the sky maps built from spatial scans to cover heliocentric heights from 1.5 to 3 $R_{\odot}$ and 360° around the corona. Intensities and line widths at a fixed heliocentric height from each daily map are replotted on a longitude (time) *vs.* latitude grid to build Carrington rotation maps like those shown in Fig. 1. The maps in the figure are for 2 $R_{\odot}$ but other heights can be plotted as well to show streamer changes as a function of height. Carrington maps are useful for tracking the location of streamers

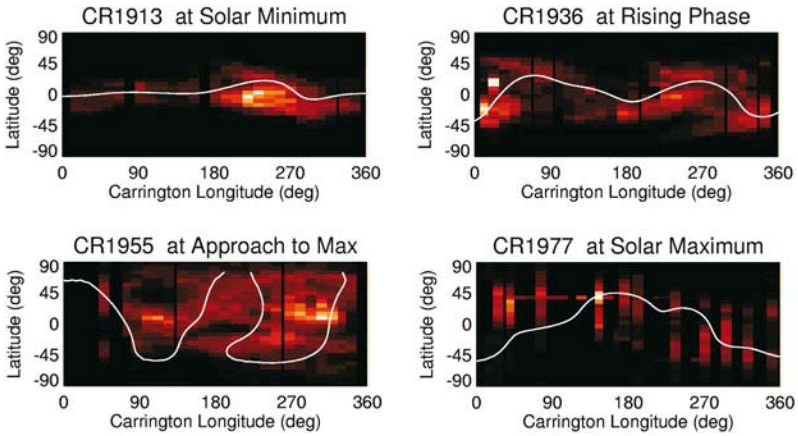

Figure 1. Representative O VI 103.2 intensity maps from different periods of solar cycle 23. White curves show the magnetic neutral line at 2.5 $R_\odot$ from WSO data.

over many solar rotations. We use the magnetic neutral line plots from the Wilcox Solar Observatory (WSO) to guide the automatic selection of the most prominent streamers. These are the ‘edge-on’ streamers that appear when the magnetic neutral line is horizontal (i.e., the current sheet is perpendicular to the plane of the sky).

Representative data from different periods of the solar cycle are shown in Fig. 1. At solar minimum, streamers are formed mainly along the magnetic neutral line (heliospheric current sheet) but as the solar cycle progresses, the neutral line becomes warped and streamers form at all latitudes. Active region streamers have the largest deviations from the neutral line. Currently these are removed from the dataset but they will be examined as a separate category once we are finished with the quiescent streamers that have well-defined helmets (along the neutral line).

We are developing software which automatically detects ‘edge-on’ streamers in the UVCS synoptic dataset. The goal is to retrieve a subset of streamers, all with similar geometric configurations, so that *intrinsic* changes in the plasma parameters for streamers can be identified. The routines are used to extract H I Lyα and the O VI doublet line intensities, line ratios, and line widths from the 10+ years of UVCS synoptic data. From these data, quantities such as kinetic temperatures and outflow velocities can be derived. We will use these data to identify long term trends in streamer properties which cannot be obtained from observations of individual streamers.

4. Summary

UVCS spectroscopic observations have revolutionized our knowledge of the plasma state in coronal streamers, and have clarified the connections between streamers and the slow speed wind. While most studies have focused on individual streamers, the UVCS synoptic database will allow the entire range of streamer variability over the solar cycle to be studied. It is desirable to continue such long range studies into the new solar cycle with coronagraph instruments capable of imaging and spectroscopy over a larger instantaneous field of view.

SOHO is a project of international collaboration between ESA and NASA. This work is supported in part by NASA grants NNG06GE99G and NNG06-GI88G to the Smithsonian Astrophysical Observatory. Wilcox Solar Observatory data used in this study were obtained via the website http://wso.stanford.edu (courtesy: J. T. Hoeksema).

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