ULTRAVIOLET OBSERVATIONS OF THE STRUCTURE AND DYNAMICS OF AN ACTIVE REGION AT THE LIMB

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Received 1994 March 14; accepted 1994 October 28

ABSTRACT

The structure and dynamics of active region NOAA 7260 at the limb has been studied using ultraviolet spectra and spectroheliograms obtained during the eighth rocket flight of the Naval Research Laboratory's High Resolution Telescope and Spectrograph (HRTS). The instrument configuration included a narrow-bandpass spectroheliograph to observe the Sun in the lines of C IV λ1550 and a tandem-Wadsworth mount spectrograph to record the profiles of chromospheric, transition region and coronal lines in the 1850–2670 Å region. The combination of high spatial resolution and high spectral purity C IV slit jaw images with ultraviolet emission-line spectra corresponding allows examination of a variety of active region phenomena. A time series of spectroheliograms show large-scale loop systems composed of fine-scale threads with some extending up to 100 Mm above the limb. The proper motion of several supersonic features, including a surge were measured. The accelerated plasmas appear in different geometries and environments. Spectrograph exposures were taken with the slit positioned at a range of altitudes above the limb and provide a direct comparison between coronal, transition region and chromospheric emission line profiles. The spectral profiles of chromospheric and transition region emission lines show line-of-sight velocities up to 70 km s⁻¹. These lower temperature, emission-line spectra show small-scale spatial and velocity variations which are correlated with the threadlike structures seen in C IV. Coronal lines of Fe xii show much lower velocities and no fine structure.

Subject headings: Sun: activity — Sun: chromosphere — Sun: corona — Sun: transition region — Sun: UV radiation

1. INTRODUCTION

The Naval Research Laboratory's (NRL) High Resolution Telescope and Spectrograph (HRTS) experiment was launched aboard a Black Brant sounding rocket on 1992 August 24. The instrument recorded ultraviolet spectra and spectroheliograms of active region NOAA 7260 at the solar limb. The combination of both ultraviolet slit jaw images and a series of ultraviolet spectra allows spatial correlation between transition region plasmas observed in the spectroheliograms and Doppler flows, plasma temperatures, and plasma densities observed in the spectra.

This set of observations presents several examples of large and small-scale proper motions with accompanying diagnostic spectra with good plasma temperature coverage. The observations allow direct comparison of the dynamics and small-scale structures at different temperature plasmas in the active region. The HRTS 8 C IV spectroheliograms are the highest resolution and spectral purity images of the solar transition region obtained to date. Although no important flare was registered during the flight, the active region was the site of frequent dynamic events such as surges and filament eruptions (Soler Geophysical Data 1993). The observations included a surge in progress in the center of the HRTS field of view. Other high-velocity phenomena were also observed during the flight. A primary conclusion derived from this data set is the great disparity between coronal structures and chromospheric/transition-region structures. The lower temperature plasmas show a great deal of highly dynamic fine-scale structure. The coronal line profiles do not contain any strong spatial variations and only minimal Doppler shifts.

2. THE HRTS-8 INSTRUMENT

For its eighth rocket flight, the HRTS rocket instrument was substantially modified from the configuration used in its previous seven rocket flights. A prime goal of the experiment was to observe the coronal forbidden lines at wavelengths above 1900 Å present above the solar limb. The lines were first observed and identified in the Skylab S082-B instrument spectra (Sandlin, Brueckner, & Tousey 1977). Beyond 1800 Å, most emission lines are masked by the intense disk continuum and are observable only above the solar limb. The ratio of emission-line radiance to solar continuum radiance is considerably larger in these ultraviolet emission lines than for comparable coronal emission lines at visible wavelengths. The emission lines provide coverage of a wide range of plasma temperatures from chromospheric to coronal. The coronal lines also provide useful diagnostics of conditions in the solar corona. In particular, a pair of Fe xii lines provide density-sensitive line intensity ratios. The relatively long wavelength increases the possibility of detecting Doppler shifts associated with the low velocities characteristic of the corona.

These different observational conditions led to some major changes in the HRTS payload. Previously, the instrument has typically been used to observe disk emission lines (1170–1710 Å) superposed over a relatively weak continuum. The groove density of the gratings in the tandem-Wadsworth ultraviolet spectrograph (Bartoe & Brueckner 1975) was changed from 24,000 lines cm⁻¹ to 15,100 lines cm⁻¹ to cover the spectral region 1850–2670 Å. Instead of a straight spectrograph slit, a curved slit with a radius of curvature equal to that of the solar image on the slit jaw was used. The slit width was set to an

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equivalent width of 0.5, corresponding to a spectral resolution of 0.075 Å. The 30 cm Cassegrain telescope was converted into a Gregorian telescope of the same focal length. To reduce the instrumentally scattered disk radiation, the telescope included a solar occultation disk at the focus of the primary mirror and a Lyot stop. These measures greatly suppressed the stray light from the disk but did not entirely eliminate it. The residual disk radiation does provide an absolute wavelength reference which is particularly useful for some of the spectra taken high above the limb.

Since its second rocket flight, the HRTS has included a double-grating, zero-dispersion ultraviolet spectroheliograph (Cook, Bracekner, & Bartoe 1983). An optical schematic of this system is shown in Figure 1. This system produces a high-quality image of the reflective spectrograph slit jaws with a narrow ultraviolet bandpass. The spectral bandpass is determined by the grating geometry and the characteristics of the spike filter. The double-grating zero-dispersion mount provides a broad geometrically defined bandpass (∼ 100 Å FWHM) with high throughput (∼ 0.16) which is essentially free of out-of-band radiation. For the HRTS 8 flight, a narrow-band spike filter (∼ 10 Å FWHM) was inserted in front of the spectroheliograph camera to isolate the C IV lines near 1500 Å. The images show that a high degree of spectral purity was achieved above the limb. Inside the limb, signatures of the 1550 Å ultraviolet continuum characterized by a distribution of small bright points remains, although at a reduced level of intensity. Previous flights have shown that scattered ultraviolet light from the disk is also a problem for experiments above the limb. To reduce the scene contrast, two different coatings were applied to the slit jaws. In those areas where would reflect the fainter, coronal portion of the image, the slit jaws were coated with AlMgF2 which has a high reflectivity at 1550 Å. The remaining portion of the slit jaws were coated with AlSiO2 which has a factor of ∼ 10 lower reflectivity in the ultraviolet.

A visible light Hα system also views the spectrograph slit jaws. A beam splitter is used to send a portion of the light to a film camera and the remainder to a video system which is transmitted to the ground. The Hα video system is used to point the instrument and to determine the best telescope focus.

HRTS 8 was launched from White Sands, New Mexico on 1992 August 24 at 1630 UT aboard a Black Brant rocket. Following target selection and telescope focusing, exposure sequences were run at each of the six slit pointing positions. Each sequence contained a range of spectrograph, spectroheliograph, and Hα exposure times to span the scene dynamic range. The curved slit was oriented nearly parallel to the limb. The first sequence placed the slit about 60° inside the limb. This set of spectra is used to absolutely calibrate the data set. Subsequent slit pointings moved outward from the solar limb. Exposure times ranged from 0.1 s to 30 s. To increase the signal-to-noise ratio of the resulting images and cover a wider dynamic range, the spectroheliograph images have been processed by combining nearly all of the images obtained at a single slit pointing into a single image.

The spectroheliograph images were combined by first coaligning each of the images at a given slit pointing position. Photographic density at each pixel is then converted to intensity by applying a film characteristic curve. The composite image is constructed from the weighted average of the intensity values where the weight is proportional to the slope of the film characteristic curve at the recorded density of each pixel. One of the disadvantages of this method is that noise spikes from each image often appear in the composite image, especially in areas well above the limb where usable film densities are found on only the longest exposure. This procedure produces a single image which is generally superior to the individual exposures in terms of dynamic range and signal-to-noise ratio.

3. ACTIVE REGION STRUCTURE AND DYNAMICS

3.1. Evolution of AR 7260 during 1992 August

NOAA active region 7260 crossed the solar central meridian on August 18 and was just inside the west solar limb at roughly north 15° (N15) on August 24 when the HRTS 8 rocket was launched. The Yohkoh SXI images showed it to be a relatively strong emitter of X-rays. On the day of the rocket flight, no major flares were reported in the region. The largest X-ray flare was a GOES class C9 at 1000 UT, 6 hr prior to the rocket flight, and a C2 class was noted at 14:40 UT. No significant X-ray activity occurred during the HRTS 8 rocket flight.

Daily full-disk Hα spectroheliograms routinely obtained at the Meudon Observatory recorded the evolution of active region AR 7260 during its passage across the disk. These observations provide a background for understanding the dynamics and structure of this active region as it appeared at the limb during the HRTS rocket flight. On August 18, the active region was strongly sheared. Clockwise spiral fibrils are visible around the sunspot located at north 17° (N17). A large filament is located to the north of the active region at N25–30. It disappeared on the next day (August 19). On August 20, a new filament formed at N20–30 and joined a dark fibril (N15–20) surrounding the sunspot in the preceding plage. This large filament extended during the following days and became denser with fine structures aligned along its axis. On August 24, it was located directly at the limb with two vertical footpoints and horizontal material joining the feet like a bridge. The two feet are located at N25 and N30 ± 2° (Fig. 2).

On August 24, the main sunspot was located slightly behind the limb. The following plage with some dark filamentary structures and active filament (clearly seen on August 22) is at the limb and appeared bright on the disk inside the limb. These bright Hα regions on the disk probably correspond to the brightest parts of the UV image inside the limb.

In Figure 2, a bright surge is clearly seen at the limb at N20. The surge was a recurrent surge, with a several hour duration;
it was detected at several observatories beginning at 16:30 UT (Solar Geophysical Data 1993). The Hz surge corresponds to the brightest C IV feature observed in the HRTS spectroheliograms. The activity registered by GOES is commensurate with an active region undergoing fast evolution as observed in the daily sequence of Hz spectroheliograms from Meudon.

3.2. The Active Region in the Ultraviolet

The HRTS 8 spectroheliograms and spectra reveal the nature of the transition zone, chromospheric and coronal plasmas comprising the active region. The data set includes a time series of six spectroheliograph images which reveal a number of dramatic apparent motions of plasmas and ejecta at the limb during an interval of about 100 s. Intense emission-line profiles of Fe II (chromosphere), Si III and C III (transition region), and Fe XII (corona) were recorded with the ultraviolet spectrograph and reveal the fine-scale variations in intensity and velocity at several slit pointings above the limb. The fiducial wires and the slit location on the spectroheliograms are used to accurately determine the slit location with respect to the C IV structures and the solar disk.

An ultraviolet spectroheliograph image taken near the end of the observing period (97.8 s elapsed time) is shown in Figure 3. Exposure times of the images used to construct this composite image ranged from 0.3 to 30 s. The position of the curved slit is noted in the figure. Just below the slit, the demarcation line from low (bottom) to high (top) reflectivity coating on the slit jaw surface is clearly visible. In addition, the position of the three slit fiducial wires, indicated by FW, are seen as the three lines that intersect the solar limb. Above the limb, the image is dominated by filamentary C IV structures that appear to be more closely related to prominences such as are commonly

Fig. 3.—Combined ultraviolet spectroheliograph exposures taken at 1634 UT, 97.8 s elapsed time, near the end of the observing period. Exposure times range from 0.3 to 30 s. ∆R denotes the location of the slit jaw reflectivity discontinuity.
seen in Hα than to coronal structures. The brightest feature is a surge directly at the west limb in the center of the image. The C IV structures to the north (left) of the surge correspond to the large Hα filament observed to the north of the sunspot and also to the active filaments embedded in the plage (Fig. 2). The various C IV structures above the limb give the appearance of a highly dynamic state, in contrast to the low level of flaring activity that characterizes this active region. This dynamic appearance is confirmed by examination of the Fe II (chromospheric), Si III and C III (transition region), and Fe XII (coronal) line profiles recorded with the ultraviolet spectrograph. The time series of spectroheliograms also shows considerable proper motion.

3.3. Dynamic Features

Several highly dynamic features are apparent in the time series of ultraviolet spectroheliograms shown in Figure 4. Each frame indicates the elapsed time in seconds from the first exposure. The image quality varies from frame to frame because it was not possible to include all of the exposures for each exposure sequence. Some were obtained during a time when the slit was being repointed, and some suffered from film defects in regions of interest. Four moving or rapidly evolving features have been indicated by arrows in the figure. The positions of the arrows are fixed to assist in gauging the motions of the different structures. The brightest feature in the center of each

Fig. 4.—A time series of the central area of the C IV spectroheliograms. Arrows indicate especially dynamic structures, including a surge, a jet, a small knot, and a loop. Each frame is labeled with the elapsed time in seconds from the first exposure.
frame is a surge which was reactivated just before the rocket was launched. Material at the tip of the surge is moving along its axis at a velocity of 70 km s\(^{-1}\). The legs of the surge are rather straight and parallel to each other. During the course of our observations, they appear to separate slightly. The main action is at the tip which moves rapidly, and in the last image seems to be breaking up into several fragments. The upper left of each figure contains a small ejecta whose size is roughly 2.5\(^{\prime}\) wide by 7\(^{\prime}\) long. It moves at a velocity of 130 km s\(^{-1}\) through an indeterminate environment. If it is following a flux tube, it is not evident in the C IV image. When its trajectory is extrapolated back to the solar surface, it passes through or near a number of clumpy emitting features to which it may be related. The upper right-hand corner of the frames in Figure 4 contains two knots. The highest knot remains stationary, but the lower knot moves upward at a velocity of 40 km s\(^{-1}\), apparently along a flux tube containing both knots. The bottom right-hand corner contains an apparently draining flux tube with a small gap in emission at the top that becomes increasingly larger during the course of the observing period. The top of the loop has an apparent altitude of about 11,000 km.

3.4. Ultraviolet Spectra of the Active Region

Figures 5, 6, and 7 display C IV spectroheliograms and portions of the ultraviolet slit spectra, including lines of Fe II near 2405 Å, Si III (1892.03 Å), and Fe XII (2405.67 Å), for three different pointings of the slit. Again, the active region was located at the west limb with solar north oriented to the left in Figures 5–7. The central fiducial wire, just to the left of the surge, intersects the solar limb at roughly 73° to the west of the north heliocentric pole. The spectra are displayed such that a redshift (motion away from the observer) is displaced toward the top of the figure (away from the spectroheliograph image). The short horizontal lines mark the rest wavelengths of the observed lines. For Fe II, the rest wavelength is referenced to the scattered photospheric spectrum where the Fe II lines appear in absorption. For Si III, the rest wavelength is estimated by comparison with similar features in the Fe II profiles. We simply assume that Fe XII is at its rest wavelength since only marginal changes in velocity can be detected.

Figure 5 was obtained at an elapsed time of 32.5 s when the slit intersected the two legs of the surge at a height of about 10 Mm (14\(^{\prime}\)). These data correspond to the third image shown in the time sequence seen in Figure 3. The longest exposure time of the spectroheliograms and spectrograms used to make up this figure was 3 s. Therefore, some of the dimmer features readily apparent in other frames are not visible in this image. In the legs of the surge, the line profiles of Fe II and Si III indicate an enhanced level of random motions on the order of \(\pm 75 \text{ km s}^{-1}\); however, the net shift of these wide profiles is less

![Figure 5](image-url)

**FIG. 5.—C IV spectroheliogram and line profiles of Fe II, Si III, and Fe XII recorded at an elapsed time of 32.4 s**
than 10 km s\(^{-1}\). Typical nonthermal velocities in solar active regions are 16–24 km s\(^{-1}\) (Dere & Mason 1993) but higher values of up to 130 km s\(^{-1}\) in C\(\text{IV}\) have previously been detected (Schmieder et al. 1983). The nonthermal velocities are on the same order as the outward motion of the tip of the surge. The surge is bright in all of the ultraviolet chromospheric and transition region lines but is not detectable in the Fe\(\text{XII}\) profiles. This confirms the result of Schmieder, Golub, & Antiochos (1994) who also found only a faint signature, near the limit of detectability, of a surge in XUV spectroheliograms in Mg\(\text{X}\) and Fe\(\text{XVI}\) at 64 Å.

In the prominence-like material to the north of the surge, several features can be noticed. First, the Fe\(\text{II}\) profiles consist of two components, a brighter component and a dimmer component which appears nearly uniformly displaced to the red by about 40 km s\(^{-1}\) from the brighter one. The origin of the two displaced components in all likelihood is due to a small, instantaneous slip of the film during the exposure. Taking this into account, most of the Fe\(\text{II}\) profiles to the north of the surge lie near the rest wavelength but approach a redshift of 30 km s\(^{-1}\) near the surge. These velocities are generally larger than horizontal velocities (\(<\)10 km s\(^{-1}\)) commonly observed in ultraviolet prominences (Schmieder 1989). A small jet with a blueshift of 40 km s\(^{-1}\) can also be seen near the end of the northernmost extent of detected emission. The Si\(\text{III}\) profiles generally show intensity and Doppler patterns essentially identical to those in Fe\(\text{II}\), once the dependence of wavelength on the observed Doppler shift is taken into account.

The C\(\text{IV}\) spectroheliogram and ultraviolet spectra for a somewhat higher pointing are shown in Figure 6 when the slit was located at a height of about 30 Mm (41") above the base of the surge. Along the slit, the Fe\(\text{XII}\) profiles show some variations in brightness but no Doppler shifts above the 30 km s\(^{-1}\) level. At the arrow, the slit passes through a bundle of three or perhaps four flux tubes. The Fe\(\text{II}\) and Si\(\text{III}\) spectra show blueshifts of 45–70 km s\(^{-1}\) in each flux tube. In the spectroheliograph image, the flux tube seems to be just resolved into two elements. The appearance of three or four spatially distinct flux tubes is quite clear in the slit spectra, but the velocities in each of the flux tubes indicates some coherence of the flow field across the bundle. Since the Doppler shift refers only to the line-of-sight component of the velocity, the motions of these plasmas along the flux tube are probably at a higher velocity. These high-speed flows might well be the high altitude counterpart of the high velocity (100–150 km s\(^{-1}\)) downdrafts commonly seen in chromospheric and transition region lines in the umbra and penumbra of sunspots in previous HRTS spectra (Dere 1982; Kjeldseth-Moe et al. 1988). Two features also
appear where the slit crosses what might be the other leg of these flux bundles. Blueshifts of 20–30 km s\(^{-1}\) are indicated by these spectra. Doppler shifts of the same sign in both legs of these loops would not be consistent with a syphon flow, if the profiles do in fact refer to the same flux tube. Since the geometry of these loops cannot be determined, the Doppler shifts could indicate either upflows or downflows. The Doppler shifts could also be caused by motion and rearrangement of the magnetic field structures themselves. To the north of these structures, the spectra in the prominence-like feature show an extended region with Fe II and Si III profiles near their rest wavelengths and two small sections with redshifts of 20–25 km s\(^{-1}\).

Figure 6 shows the C IV spectroheliogram and ultraviolet spectra when the slit was located at a height of about 72 Mm (100") above the base of the surge. The only significant Fe xii Doppler shift in the entire data set is found in these spectra where a blueshift of 9 km s\(^{-1}\) is seen in the region between the two legs of the large C IV loop near a fiducial wire. Otherwise, the Fe xii profiles show only smooth variations of intensity and Doppler shifts below the 3 km s\(^{-1}\) level. The ultraviolet lines are detectable only in the region where the slit crosses a flux bundle. The line profiles show the velocity increasing from zero velocity, at the northern edge of the flux bundle, to a redshift of 25 km s\(^{-1}\) in Fe II and 17 km s\(^{-1}\) in Si III, at the southern edge. The velocity pattern indicates that the flux bundle is undergoing a twist, an impression that is strengthened by the appearance of these loops in the C IV spectroheliogram. Just to the right of the right fiducial wire, blueshifts in what may be the opposite leg of one of these flux tubes of 17 km s\(^{-1}\) are seen. These velocities are somewhat smaller than seen at lower altitudes in Figure 6.

5. DISCUSSION AND CONCLUSIONS

The HRTS 8 observations of NOAA 7260 reveal a dynamic state of activity in plasmas at chromospheric and transition region temperatures. Examples of dynamic phenomena include a surge, a jet, a moving knot, and field line twisting, all observed in lines formed at or below 10^5 K. The level of X-ray activity observed with GOES was relatively low for the day as a whole and the only significant flare (1B/C9) occurred 7 hr prior to the flight. Similarly, the ultraviolet profiles of coronal lines show very little evidence for significant mass motions. In particular, the surge, which is extremely bright in the chromospheric and transition region lines, is not detected in the coronal lines.

One of the fundamental goals of solar physics is to understand the processes which accelerate and expel plasmas from the Sun. The HRTS 8 data set provides examples of several distinct types of motion of transition region plasmas which
further define the bulk plasma acceleration problem. These examples include a surge with two footpoints that remain tied to the photosphere, a plasmoid that is confined to a flux tube and another plasmoid that travels through the active region with little apparent awareness of its surroundings. Other previously observed forms of transient flows and ejecta include coronal jets (Brueckner & Bartoe 1983), network ejecta (Dere et al. 1986), minerruptive prominences (Hernams & Martin 1986), X-ray jets (Shibata et al. 1992a; Shibata, Nozawa, & Matsumoto 1992b), sprays, surges (Schmieder et al. 1983), eruptive prominences (Raadu et al. 1988), and coronal mass ejections. These widely varying phenomena suggest either multiple acceleration mechanisms or a single mechanism capable of assuming different manifestations. None of the currently proposed bulk acceleration process has been sufficiently developed to allow a detailed comparison with a particular event.

Mechanisms suggested for driving mass motions include a pressure pulse for coronal mass ejections (Steinolfson, Schmahl, & Wu 1979), shock waves for spicules (Uchida 1961; Parker 1964; Sterling & Hollweg 1988), magnetic reconnection for spicules (Pikelner 1969) or coronal jets (Pneuman 1983), and the destabilization of the prominence magnetic field through flux emergence and reconnection leading to an eruptive prominence (Raadu et al. 1988; van Ballegooijen & Martens 1989).

The pressure pulse mechanism has been ruled out by Schmieder et al. (1994) because the XUV radiation from the hot plasma was much weaker than expected. Shibata et al. (1992b) found the pressure pulse model incompatible with the Yohkoh observations of X-ray jets. Another drawback to the pressure pulse model is that its origin is never explained, merely assumed.

A shock could explain the movement of the plasma knot along the visible flux tube but probably not the jet which bears some resemblance to the diamagnetic plasmoids proposed by Pneuman (1983). However, when this latter scenario is considered in three dimensions, one would expect that the reconnection would produce a helical structure rather than a compact plasmoid. Any extended helix would have difficulty traversing the active region intact. The surge is also potentially explained by a shock wave because the legs appear to be rather straight and give the appearance of being stretched out, perhaps by a shock, rather than providing a tension which would spring the mass outward. The cause of the shock, or whatever accelerates the surge, probably lies with the evolving magnetic field structure at the base. The actions of these fields often produce repeated surges at the same location. Since the observations occurred at the limb, it is not possible to address the role of emerging, reconnecting flux in the destabilization of the active region.

One prominent characteristic of these spectra is the great disparity between the profiles of the cooler lines (Fe II and Si III) and the coronal line (Fe XII). Considerable fine structure at the arcsecond resolution of the instrument and large Doppler shifts on the order of tens of km s\(^{-1}\) are quite evident in the spectra of the cooler lines. The coronal line (Fe XII) shows no fine scale features; Doppler velocities in these lines are mostly below 3 km s\(^{-1}\), the limit of detectability. The coronal line widths are equivalent to their thermal broadening. Several possible explanations may be suggested for the obvious presence of the fine-scale structure in the chromosphere/transition region spectra and its lack in the coronal spectra. The obvious explanation is simply that the observations directly reveal the nature of the observed plasmas. Another possibility is that the differences in the line profiles reflect the differing sensitivities of the lines with respect to physical conditions in the solar atmosphere, such as optical depth along the line of sight. For example, the Fe II lines are allowed lines while the Si III line is an intercombination line (3\(^2\)S\(_0\)-3\(^3\)P\(_1\)) and the Fe XII line is a forbidden line due to a transition within the ground configurations (3\(^2\)S\(_1\)-3\(^2\)P\(_1\)). One would expect to find considerable optical depth in Fe II and negligible optical depth in either the Si III or Fe XII lines. The self-reversal in many of the Fe II profiles confirms the significant opacity in these lines. Because both Fe II and Si III both show the discrete structures and Doppler shifts, as opposed to Fe XII, it would seem that it is not possible to explain these differences by arguments based on opacity.

Another possibility is that the lines do not exhibit the same sensitivity to density in their source regions. Both Si III and Fe XII originate from metastable levels so the intensity of one could vary as the square of the electron density, like a typical allowed line, and the other could vary linearly with density. This effect can be studied by referring to calculations of the populations of the upper levels of the two lines as a function of electron density. These lines are formed in regions where the scaled electron pressure (n\(_e\)T) varies from 10\(^{13}\) cm\(^{-3}\) K, in quiet regions, to 10\(^{16}\) cm\(^{-3}\) K, in active regions. The population of the upper level that give rise to Si \(_{III}\) \(\lambda 1892\), formed at 5 \times 10\(^4\) K, increases by about a factor of 4 as the local electron density increases from 3 \times 10\(^{10}\) to 3 \times 10\(^{11}\) cm\(^{-3}\) (Dufon et al. 1983). For Fe XII \(\lambda 2405\), formed at 1.4 \times 10\(^6\) K, the population of the upper level increases by the same factor of 4 as the density increases from 10\(^9\) to 10\(^{10}\) cm\(^{-3}\) (Tayal et al. 1991). In conclusion, the differences between the Si III and Fe XII profiles cannot be attributed to different dependencies on the population rate of the upper levels, as a function of density.

Compared to the 10\(^4\)-10\(^5\) K plasmas, there is much more coronal plasma in the line of sight which could obscure any small-scale inhomogeneities. However, previous HRTS observations of Fe XII on the disk, where the obscurations would be reduced by about one-half, do not show any evidence for fine structure. One of the reasons that the inhomogeneities are so conspicuous in the chromosphere/transition region lines is because they are often highly Doppler-shifted, well beyond the wings of the more general profile. This is not observed in the Fe XII profiles. Fe XII \(\lambda 2405\) has a FWHM of about 0.3 \AA, corresponding to a half-width velocity of 20 km s\(^{-1}\) and a random nonthermal velocity of about 14 km s\(^{-1}\). The lack of highly shifted features in Fe XII indicates that there are no small-scale flows at velocities much above 20 km s\(^{-1}\), at a level of brightness that approaches the observed line intensity. Recent observations of Fe \(_{X}\) \(\lambda 6374\) and Fe \(_{XIV}\) \(\lambda 5303\) in an active region at the limb also show velocities of about 5 km s\(^{-1}\) or less (Ichimoto et al. 1994).

The continued success of the HRTS rocket program has depended critically upon the work of a number of individuals. We would like to thank Thomas R. Spears, James K. Smith, Donald N. Lilley, Raymond J. Stattel, Ronald J. Stattel, and Randall S. Waymire for their efforts in preparing HRTS 8 for launch. Thomas R. Spears was responsible for the mechanical design of the instrument modifications. He also assembled, aligned, and calibrated the instrument. James K. Smith was
responsible for fabricating the new telescope harness. He was also responsible for the instrument electronics bulkhead and the instrument interface to the telemetry section. The HRTS 8 instrument concepts were developed in a thesis directed by Douglas G. Currie at the University of Maryland, and his contribution to this work is gratefully acknowledged. We would also like to recognize the superb support of the SPARCS team, the Navy White Sands Missile Range team, the PSL ground support station, and the Wallops Flight Facility Sounding Rocket personnel during the HRTS 8 integration and launch. The Yohkoh team provided us with nearly real time coverage of the flight with the Soft X-Ray Telescope (SXT). These data allowed us to optimize the target selection on the day of the launch. We would like to especially thank Shinzo Enome, Marilyn E. Bruner, and James R. Lemen for their role in obtaining and analyzing the Yohkoh SXT images. We also gratefully acknowledge the contribution of the referee, R. Grant Athay, for his role in improving the quality of this paper. This work is supported by NASA contract NDR-S82091E.

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Solar Geophysical Data. 1993, No. 582, Part II (Boulder: NOAA)

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