SMM OBSERVATIONS OF THE VARIABILITY OF ACTIVE REGIONS IN THE UV: FLARES, BURSTS, AND OSCILLATIONS

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ABSTRACT

We have made extensive observations of the time-variability of solar active regions in the far-UV using the ultraviolet spectrometer on *SMM* . We describe the three different modes of solar variability (impulsive events, bursts and oscillations) that are evident in our data and discuss their physical implications.

Introduction

The Ultraviolet Spectrometer and Polarimeter (UVSP) on the ***Solar Maximum Mission*** (*SMM*) satellite has been extensively used to study the spatial morphology and time variability of solar active regions in the Far-UV. Since July 1985, the wavelength drive of UVSP has been inoperable, and all 2nd-order UVSP observations have been restricted to the wavelength region of $\lambda\,1370$ Å to $\lambda\,1400$ Å . The UVSP has a full field of view of $\sim 4' \times 4'$ and, in a standard observing mode designed to catch the UV counterparts to solar flares, this field is scanned using its slit 1 (which has an entrance slit of $10'' \times 10''$ aperture), and a step-size of $5''$. A 'sit-and-stare' experiment (typically of 13 minutes duration) with a temporal resolution of 64 milliseconds is then done at the location of the brightest pixel which yields a light curve of the ultraviolet intensity at this point on the Sun. Since November 3rd, 1987, several thousand paired experiments of this type have been made by UVSP. From July 1985 to October 1987, similar observations were made in a different slit set (slit 8) which had an entrance slit of large aperture ($30'' \times 30''$) but a much narrower (0.3 Å) exit slit which did not include O V $\lambda\,1371$.

Slit 1 has an exit slit width of 2.3 Å , and a central wavelength believed to be $\sim \lambda\,1370$ - $\lambda\,1375$ Å which probably includes some or all of the $\lambda\,1371$ line of O V. In non-flare observations, this line is weak and the dominant contribution to the count rate observed for slit 1 must be from the continuum. According to standard solar models (e.g., the VAL3 models of Vernazza, Avrett, and Loeser 1981), the Quiet Sun continuum in this spectral region is mainly formed in the lower chromosphere ($T \sim 5 \times 10^3$ K) at a height above the photosphere of 600 to 800 km (cf., the temperature minimum is at 500 km). In flare observations, the O V line is probably the main contributor to the observed count rate. This line is formed high in the transition region where $T \sim 2 - 3 \times 10^5$ K.

Modes of Variability Observed in UVSP Data

There are 3 different modes of solar variability evident in the UVSP data which we discuss below. In addition to the variability intrinsic to the Sun, we also on occasion see variability induced by fluctuations in the direction in which the spacecraft is pointing. Since the entrance aperture most commonly used is $10'' \times 10''$, only pointing drifts of more than $\sim 5 - 10''$ will (in general) produce such artifacts. Such large pointing changes are fairly rare, and usually are distinguishable from true solar variability by their peculiar temporal morphology.

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(i) Impulsive-rise type events ('flares')

Impulsive events (or 'flares') are occasionally seen in the UV light curves from solar active regions, usually those with plages of Hα intensity 4 or higher. The strongest of such UV flares generally have soft X-ray (*GOES* and/or *SMM* X-Ray Polychromator) and hard X-ray (*SMM* Hard X-ray Burst Spectrometer) counterparts, although weaker UV flares do not, presumably due to the higher thresholds and lower spatial resolution of the X-ray instruments. The UV maximum of such events precedes the ***soft*** X-ray peak by between 1 and 4 minutes, but is usually simultaneous to $\ll 1$ second with the ***hard*** X-ray peak. The implications of this last result for theories of the production of the UV continuum radiation associated with impulsive events have been discussed by Orwig and Woodagte (1986).

In Figure 1, we show an ultraviolet light curve for an M5 flare which took place in the active region AR 5047. Some gradual 'pre-heating' takes place before the impulsive-rise phase begins. The peak count rate of 17,000 counts per sampling interval of 56 millisecs. is similar to that found for an M2 flare observed in the O V line in 1980 when UVSP still had a functioning wavelength drive (See Fig. 2). The UVSP spatial raster made immediately after the end of the light curve shown in Fig. 1 indicates that the flaring region was about 30 arcsecs in size.

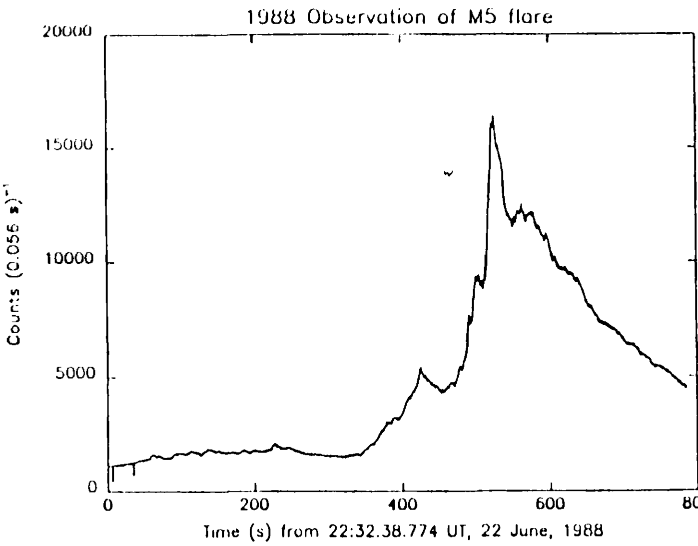

Fig. 1. UVSP Light Curve of M5 flare on 1988 June 22.

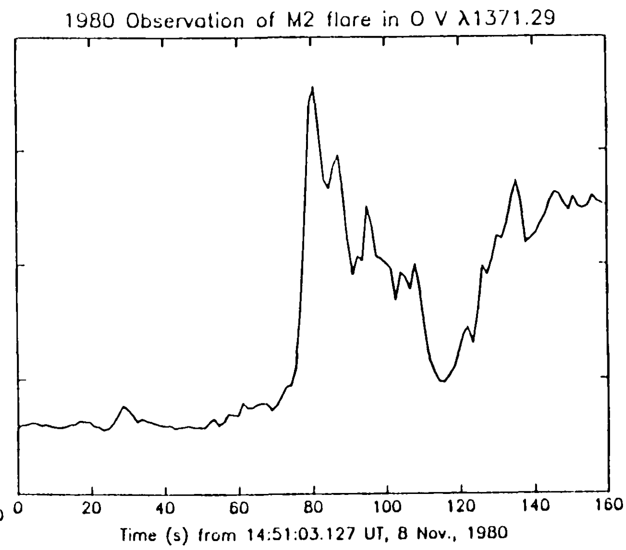

Fig. 2. UVSP Light Curve of M2 flare on 1980 November 8.

In Fig. 3, we show another example of a solar flare observed by UVSP, along with simultaneous light curves obtained by two other *SMM* instruments, the Hard X-Ray Burst Spectrometer (HXRBS) and the X-Ray Polychromator (XRP) (sensitive to soft X-rays). The GOES satellite tagged this event on April 13th, 1988 as a C1.4 flare. The UV light curve and the hard X-ray light curve show near-simultaneous impulsive rises at $\sim 00:17:00$ UT and peaks at $\sim 00:17:04$, while the soft X-ray light curve shows a more gradual rise and a later peak at $\sim 00:17:25$.

(ii) Stochastic variability ('bursts')

This type of variability is the predominant one observed in the UV light curves of active regions. The intensity is seen to vary in an irregular fashion by up to a factor of 3 to 10, with typical variability timescales from $\sim 1-10$ minutes. Rising levels of this type of irregular activity are sometimes observed shortly before a major impulsive event, suggesting a possible connection to pre-flare heating.

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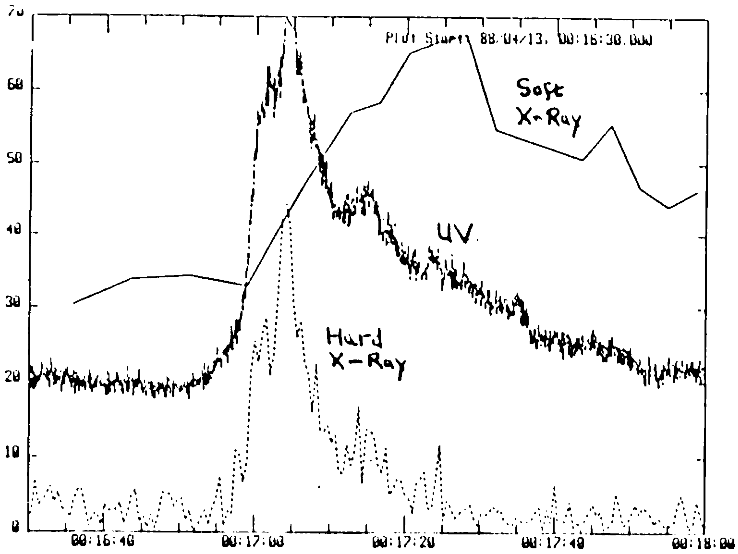

Fig 3 Light Curve of C1.4 flare on 1988 April 13 as seen by UVSP (UV), XRP (Soft X-Ray), and HXRBS (Hard X-Ray). The ordinate scale is in arbitrary intensity units, while the x-axis is Universal Time

(iii) Periodic variability ('oscillations')

In a small fraction of UV light curves the intensity is obviously varying in a periodic way. The most common type of periodic behaviour observed is a sinusoidal one with an amplitude of 10 - 50 %, and a period of 3 to 5 minutes, corresponding to frequencies of 2 to 4.5 mHz. Fourier analysis of a random sample of UV light curves reveals significant power at such frequencies in essentially all of them: these oscillations are nearly always present in the Active Sun chromosphere. [Light curves of the same format made of Quiet Sun regions show the same type of behaviour].

We show a number of examples of light curves and their derived power spectra (Figs. 4 to 6). In order to better determine the periods of these oscillations, these light curves are rather longer in duration (30 - 50 mins) than our usual ones. Periodicity in the range of 4 to 5 minutes is ubiquitous in these and similar light curves. On occasions, power at periods as short as 3 minutes is also seen. We believe that these periodic variations are probably intrinsically solar, but we are presently investigating other possibilities such as spacecraft pointing oscillations of this period. In order for the latter to produce such noticeable modulation of the intensity observed by UVSP, it would have to be of an amplitude comparable to 10″, the size of the entrance slit used. In no cases to date have we found evidence of a spacecraft pointing oscillation with such a long period and large size.

If the oscillations observed by UVSP are driven by the sub-photospheric non-radial p-mode oscillations, it appears unlikely, given the heights at which we observe them, that they are standing or propagating waves. In a quiet-Sun model such as the VAL3C, acoustic waves with frequencies below $\sim$ 5 mHz are evanescent in the temperature-minimum region. Even though the continuum at 1370 Å is believed to be formed $\sim$ 150 km above the temperature minimum, acoustic waves with the observed frequencies are still evanescent at such heights in quiet-Sun models. Active-Sun models, such as the VAL3F, condense the height range at which such waves are evanescent, and their higher values of T_{min} also reduce slightly the acoustic cutoff frequency at heights around $h(T_{min})$. Even then, only the highest-frequency oscillations we observe could be propagating waves. Since the 3 - 4.5 mHz oscillations are observed in *quiet* as well as active regions, it appears that the oscillations are evanescent, if they are caused by pressure waves. To

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prove this observationally, however, would require obtaining simultaneous velocity and pressure (intensity) measurements. (If one had an instrument capable of making such simultaneous measurements, the signature of evanescent waves would be a $\pi/2$ phase difference between pressure and velocity.)

References

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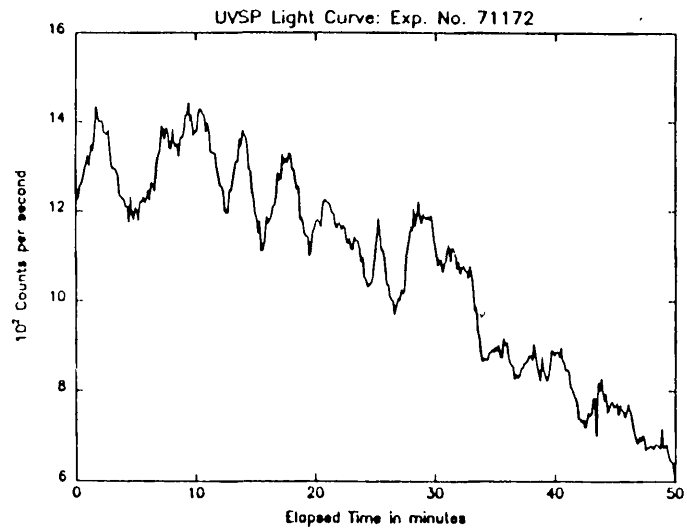

Fig. 4. UVSP Light Curve obtained on 1988 July 26 starting at 16:36 U.T. of a bright part of the chromospheric network near Disk Center.

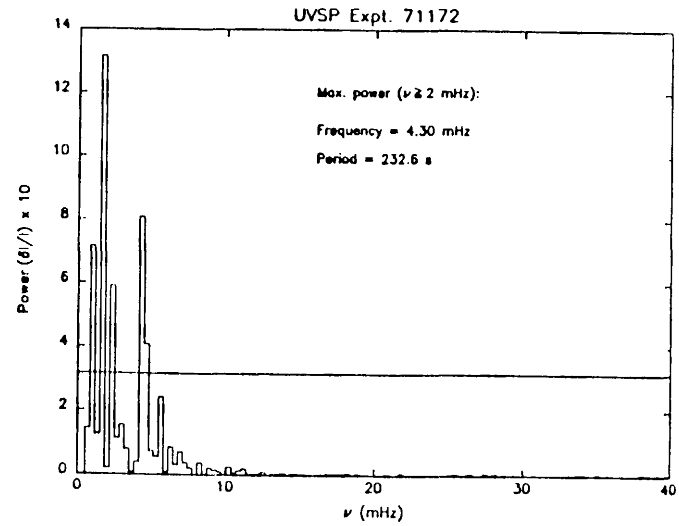

Fig. 5. Power Spectrum of Light Curve shown in *Fig.* 4. showing fractional power as a function of frequency. The horizontal line shows the 99.9% confidence level.

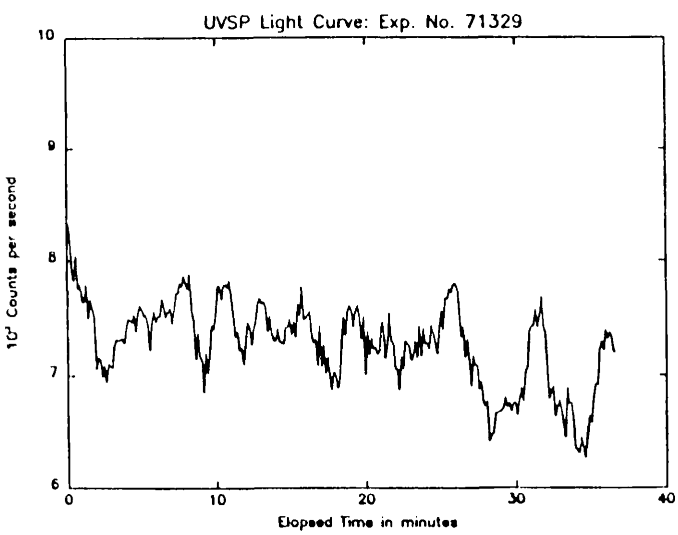

Fig. 6 UVSP Light Curve obtained on 1988 July 29 starting at 18.14 U.T. of a bright part of the chromospheric network near AR 5092.

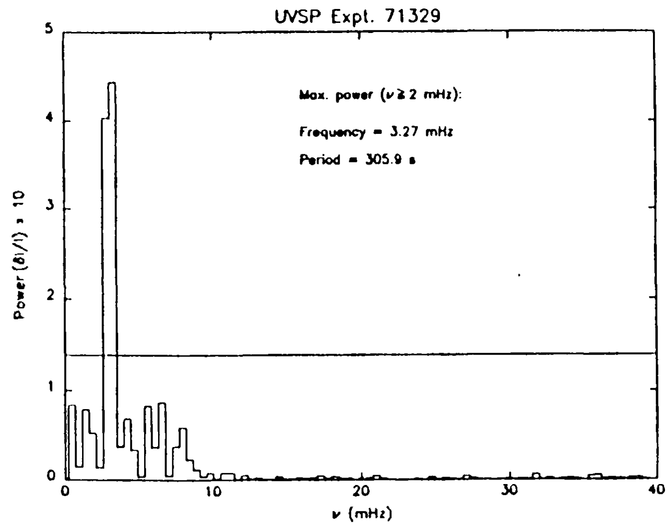

Fig. 7. Power Spectrum of Light Curve shown in *Fig.* 6.

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