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# SUMER Observations of Intensity Oscillations in the Transition Region of a Sunspot

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**Abstract.** Oscillations in the chromosphere-corona transition region above sunspots are important for investigating sunspot structure and dynamics; for instance, resonator models of magneto-atmospheric waves and their non-adiabatic behaviour can be tested. UV spectroscopic data obtained with the SUMER spectrograph aboard SOHO have been analysed to detect oscillations in the chromosphere-corona transition region (TR) above sunspots. We observed the active region NOAA 7986 in the wavelength bands around the Ne VIII line at 770.4 Å and the C IV line at 1548.1 Å on August 29, 1996, between 09:08 UT and 13:31 UT. Simultaneous observations with the Normal Incidence Spectrometer of CDS aboard SOHO have shown, that the spot had a bright EUV plume at TR temperatures. A preliminary data analysis indicates intensity oscillations in the 2-minute range (7.3 ... 7.9 mHz) in both spectral lines. The temporal variation of oscillatory power in the two spectral lines is generally in opposite directions, i.e. during an increase of oscillatory power in the Ne VIII line we find a decrease in the C IV line. A similar but smaller tendency is observed in the average intensity of the line profiles. This hints at a non-adiabatic behaviour of the oscillations and a slow cooling of the emitting sunspot plume region.

## 1. Introduction

Sharp resonance peaks of the power of oscillations of velocity and intensity observed in sunspots, particularly in the umbra, show a characteristic height dependence of frequencies and phases. This behaviour can be explained by the resonant transmission of magneto-atmospheric waves through the sunspot atmosphere. Such models of coupled resonators (Žugžda et al. 1984, 1987; Staude 1994) require regions of strong wave reflection, e.g. from the steep temperature gradient of the chromosphere-corona transition region (CCTR). Consequently, oscillations should be observed in EUV lines from the sunspot CCTR as well.

Models of intensity oscillations in optically thin EUV lines show that velocity oscillations without intensity fluctuations should be observed in the adiabatic case, while intensity oscillations would hint at a non-adiabatic behaviour such as that of almost isothermal waves (Žugžda et al. 1984; Staude et al. 1985).

Observations with the UVSP instrument aboard the Solar Maximum Mission (SMM) showed that velocity oscillations are present above most sunspots, while intensity oscillations were found only occasionally (Gurman et al. 1982; Henze et al. 1984; Thomas et al. 1984). These oscillations with resonance peaks in the 2...3 minute period band seem to be a continuation of chromospheric umbral oscillations. The CCTR oscillations have been interpreted as a signature of the resonant transmission mechanism mentioned above. The lack of significant power in intensity oscillations in some data sets of Gurman et al. (1982), on one hand, and their presence in other data, on the other hand, has been explained by our modelling of the CCTR behaviour of the waves, appearing sometimes as adiabatic, in other cases as almost isothermal oscillations.

## 2. Observations

We used UV two-dimensional spectroscopic data obtained with the SUMER spectrograph aboard SOHO to detect oscillations in the transition zone near sunspots. The SUMER instrument and first results of measurements are described by Wilhelm et al. (1997) and Lemaire et al. (1997).

Here, we look at intensity fluctuations in two EUV spectral lines in the longest time series of our observational program on August 29, 1996, between 09:08 UT and 13:31 UT. During this time, scans were made continuously over the active region NOAA 7986 which was close to the solar disk center at $l_1 = -6^\circ\!.33$, $b_1 = -10^\circ\!.94$ (August 29, 08 UT).

Observations were made in two spectral lines: the first line is emitted in the upper transition region at temperatures of about $6 \times 10^5$ K by $Ne^{7+}$ at 770.41 Å, while the 1548.1 Å line of $C^{3+}$ originates in the transition region at temperatures of about $7 \times 10^4 \ldots 1.3 \times 10^5$ K.

The spectral resolution is 21 mÅ per pixel at 770 Å in the second order, and 42 mÅ per pixel at 1548 Å in the first order. The spectral region around 1540 Å in the first order is overcrowded with weak Si I lines. Although there seems to be a blend of such a Si I line within the Ne VIII ($\lambda = 770.41$ Å) line profile, we are confident that the weak line does not influence our analysis of the strong relative intensity fluctuations of the Ne VIII line.

The slit of $1'' \times 120''$ was shifted in steps of $1.14''$ which is three times the elementary step width of the scan mode. The subsequent scan was made in the same direction, but after shifting it by half a step. Each scan consists of six spectra across the sunspot, but with intermediate slit positions as compared to the preceding scan. The maximum line intensity was extracted from spectra which correspond to identical positions on the Sun.

The integration time for each spectrum was 10 s. We did not apply the usual flatfielding procedures as residual errors were reported (see Curdt & Heinzel, 1998). For the calibration of the maximum intensity $I$ in the line center we extracted background intensity $I_0$ from an area off the spot from each image. The average background count rates are of the order of one count during the 10 s exposure off the spectral line. The peak intensity in the line center was the average of a $(6 \times 6)$–pixel area centered at the position of the highest count rate.

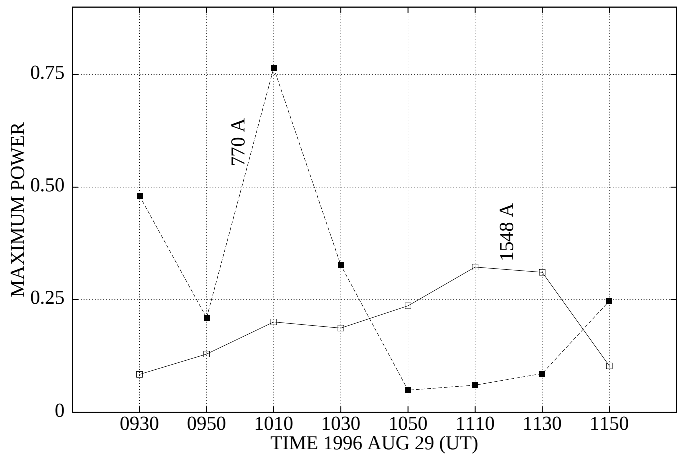


Figure 1. Maximum power found in the intensity variations observed on August 29, 1996, between 09:08 UT and 12:30 UT in 40-minute subsets, shifted by 20 minutes in the spectral lines of Ne VIII at 770 Å and of C IV at 1548 Å. The tendency for an opposite behaviour of the oscillations in the two lines formed at different temperatures can be seen.

For comparison and to avoid influences from the sampling, other areas of the image were treated the same way. We found no power at or near the frequency discussed here in the spot but off the spectral line. On the other hand, there are minor power peaks at different frequencies at locations off the spot but in the spectral line.

The power spectra were calculated for 40-minute subsets, with the sampling intervals shifted by 20 minutes. This should allow the detection of changes in oscillation patterns and to find possible artefacts. Our preliminary data analysis indicates intensity oscillations close to 7.8 mHz (near 2.15 minutes) in both spectral lines. A wavelet analysis was applied to the same data, also showing evidence of 2-minute intensity fluctuations in the same periods as derived from the power spectra.

A peak occurs in almost every of these intervals close to 7.8 mHz for the Ne VIII line at 770 Å). However, the power of the 7.8 mHz peak varies considerably during the time series. The oscillatory power in the low corona line at 770 Å (Fig. 1) is highest in the first intervals, while it increases in the later part of the series in the transition region line of C IV at 1548 Å (Fig. 1). A similar behaviour is observed in the average intensities of both lines, but the relative changes in time are much smaller than those for the oscillatory power (see section 3.).

A supplementary time series of observations of the active region NOAA 7986 is available from the EIT experiment, simultaneous to the first two hours of the SUMER time series on August 29). Furthermore, there are simultaneous data from the Normal Incidence Spectrometer of the CDS experiment aboard SOHO. These observations show that the sunspot had a bright EUV plume at CCTR temperatures (Brynildsen et al. 1997; Maltby et al. 1998), contrary to some other sunspots observed with CDS.

The EIT time series was observed in the window Fe IX/X at 171 Å. This line was expected to be still visible above a sunspot umbra as it is generated at temperatures of the order of $1 \times 10^6$ K. Indeed, the images show both the loop system above the active region NOAA 7986 and the bright plume above the sunspot.

## 3. Summary and Conclusions

There are several investigations of oscillations in the sunspot EUV region. Gurman et al. (1982) and Thomas et al. (1987) showed that time series from sunspot transition region lines obtained with the UVSP on the SMM indicate significant oscillations in the line-of-sight velocity with frequencies in the range 5.8 mHz to 7.8 mHz (periods 173 s to 129 s).

Our preliminary analysis of intensity variations above a sunspot of the active region NOAA 7986 on August 29, 1996, shows oscillations in the region 7.3 mHz to 7.9 mHz (periods 137 s to 126 s). The power of the relative intensity oscillations slowly increases in the 1548 Å line (transition region) from the interval 09:08–09:50 UT towards 11:10–11:50 UT, while it generally decreases within the same period of time at 770 Å in the upper transition region. Similar changes in time, but to a smaller extent, have been measured in the average line intensities of both lines: the intensity of the 770 Å line decreases to 0.74 in the period 11:00–12:00 UT as compared to the beginning of the observing time, while the power decreases by more than a factor of 10. The tendencies in the 1548 Å line are weaker and in opposite direction: the average intensity increases to 1.35, while the oscillatory power reaches 3.7 of the value in the first interval 09:08–09:50 UT (Fig. 1).

Despite of the preliminary character of our results a few conclusions can be drawn: The CCTR participates in the oscillation of the sunspot atmosphere, that is, the magneto-atmospheric waves reach the CCTR of the sunspot and can be reflected from there, satisfying a necessary condition for our resonance transmission model of sunspot oscillations.

The presence of intensity oscillations hints at the non-adiabatic character of the waves, resulting possibly in almost isothermal oscillations due to some, perhaps radiative, dissipation mechanism. The changes of the relative intensity oscillations as well of the mean intensities in opposite directions in both lines could result from a cooling of the emitting and oscillating volume in the CCTR. Our sunspot had a strong EUV plume, similar to most sunspots in which CCTR oscillations have been observed earlier with SMM. It remains an open question if plumes are necessary for CCTR sunspot oscillations or if they only make it easier to discover such oscillations.

The magnetic field of the sunspot derived from magnetograms obtained at the Einsteinturm Observatory at photospheric level shows a relatively complex north polarity with some weak south polarity in the immediate surrounding as well as to the eastern part of the region. The magnetic field structure above the photosphere can be obtained from a linear force-free field extrapolation to higher layers up to the lower corona.

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## References

Brynildsen N., Brekke P., Fredvik T., Haugan S.V.H., Kjeldseth-Moe O., Maltby P., Harrison R.A., Rimmele T., Wilhelm K., 1997, Proc 5th SOHO Workshop, 'The Corona and Solar Wind near Minimum Activity', Oslo, Norway, 17–20 June 1997 (ESA SP-404), 257

Curdt W., Heinzel P., 1998, ApJ 503, L95

Gurman J.B., Leibacher J.W., Shine R.A., Woodgate B.E., Henze W., 1982, ApJ 253, 939

Henze W., Tandberg-Hanssen E., Reichmann E.J., Athay R.G., 1984, Solar Physics 91, 33

Lemaire P., Wilhelm K., Curdt W., Schühle U., Marsch E., Poland A.I., Jordan S.E., Thomas R.J., Hassler J.G., Vial J.-C., Kühne M., Huber M.C.E., Siegmund O.H.W., Gabriel A., Timothy J.G., Grewing M., 1997, Solar Physics 170, 105

Maltby P., Brynildsen N., Brekke P., Haugan S.V.H., Kjeldseth-Moe O., Wikstøl Ø., Rimmele T., 1998, ApJ 496, L 117

Staude J., 1994, in: R.J. Rutten & C.J. Schrijver (eds.), 'Solar Surface Magnetism'. NATO ASI Series C 433, 189

Thomas J.H., Lites B.W., Gurman J.B., Ladd E.F., 1987, ApJ 312, 457

Wilhelm K., Lemaire P., Curdt W., Schühle U., Marsch E., Poland A.I., Jordan S.D., Thomas R.J., Hassler D.M., Huber M.C.E., Vial J.-C., Kühne M., Siegmund O.H.W., Gabriel A., Timothy J.G., Grewing M., Feldman U., Hollandt J., Brekke P., 1997, Solar Physics 170, 75

Žugžda Y.D., Locāns V., Staude J., 1987, Astron. Nachr. 308, 257

Žugžda Y.D., Staude J., Locāns V., 1984, Solar Physics 91, 219