PHASE RELATIONS BETWEEN CHROMOSPHERIC AND TRANSITION REGION OSCILLATIONS

J.M. Krijger\textsuperscript{1}, W. Curdt\textsuperscript{2}, P. Heinzel\textsuperscript{3}, and W. Schmidt\textsuperscript{4}

\textsuperscript{1}Sterrekundig Instituut, Postbus 80 000, NL–3508 TA Utrecht, The Netherlands
\textsuperscript{2}Tel: 31(0)302535225 Fax: 31(0)302535201 e-mail: krijger@astro.uu.nl
\textsuperscript{3}Max-Planck-Institut für Aeronomie, D-37191 Katlenburg-Lindau, Germany
\textsuperscript{4}Astronomical Institute, Academy of Sciences of the Czech Republic, CZ-25165 Ondřejov, Czech Republic
\textsuperscript{5}Kiepenheuer-Institut für Sonnenphysik, D-79104 Freiburg, Germany

ABSTRACT

We present results from combined TRACE and VTT observations for H\textsc{i} L\textsc{a}, Ca\textsc{ii} K and the 170, 160, 155 nm TRACE continua, showing oscillatory patterns in bright network and internetwork regions of the quiet Sun near disk centre. All data were spatially and temporally co-aligned. Temporal behaviour and phase relations of these co-spatial data are discussed.

Key words: Sun:atmosphere, oscillations.

1. INTRODUCTION

The \textit{Transition Region and Coronal Explorer} (TRACE) was launched on April 1, 1998 into Sun-synchronous orbit. It images the Sun at characteristic temperatures between 10\textsuperscript{4} K and 10\textsuperscript{7} K by sequentially selecting different spectral passbands to feed a 1024 px × 1024 CCD camera with 0.5 arcsec pixels (366 km/px on the Sun) that covers nearly 10% of the solar disk. Details are given by Handy et al. (1999a).

In this paper we use image sequences taken through the extreme-ultraviolet TRACE passbands centered at \(\lambda = 121.6\) nm, 170.0 nm, 160.0 nm, and 155.0 nm to study quiet-Sun oscillations in the atmospheric domains from which solar radiation emerges in these passbands. In standard models of the solar atmosphere such as VAL C of Vernazza, Avrett & Loeser (1973, 1976, 1981) and FALC of Fontenla et al. (1993), the disk-center intensity at 121.6 nm emerges from the "transition region", the 170.0 nm from the "upper photosphere", the 155.0 nm from the "lower chromosphere", and the 160.0 nm radiation from the "temperature minimum region", where the temperature minimum at \(h = 500\) km above continuum optical depth \(\tau_{500} = 1\) at \(\lambda = 500.0\) nm defines the transition from photosphere to chromosphere (see the formation panels in Fig. 36 of Vernazza et al. (1981)).

This and somewhat higher atmospheric regimes are accessible to ground-based observation and has been studied extensively using the cores of strong absorption lines and the Ca\textsc{ii} K\textsc{2v} and H\textsc{2v} inner-wing emission peaks.

In order to explore the relations between the oscillatory behaviour at these atmospheric levels, some studies focussed on coordinated observations with SOHO, TRACE and GBO (Ground-Based Observatories), e.g. by Steffens et al. (1997). The present contribution shows first results of a coordinated SOHO/TRACE/VTT/GCT campaign which took place in May 1999 and had similar objectives.

We carried out an observing campaign in the frame of the SOHO-TRACE-GBO programme JOP 95 with simultaneous observations in H\textsc{i} Lyman lines and continuum, the Ca\textsc{ii} K line (intensity oscillations) and a magnetically sensitive Fe\textsc{i} line (Stokes polarimetry), and, in addition TRACE H\textsc{i} L\textsc{a} images are also included. The campaign and involvement of individual instruments and some first results are described in Curdt et al. (1999). We present and discuss some more results here (TRACE and VTT data only).

2. OBSERVATIONS

Three runs of JOP 95 were performed between 4 and 9 May 1999.

The TRACE instrument took an H\textsc{i} L\textsc{a} time series during the morning observing time of the German Solar telescopes on Tenerife (VTT, GCT).

On all occasions, a quiet-Sun site near disk centre had been selected as target and the solar rotation


© European Space Agency • Provided by the NASA Astrophysics Data System
had been compensated by the instruments. Because of excellent weather conditions on Tenerife on May 8, we selected the data taken on this day for our first analysis. More details for these observations can be found in Curdt et al. (1999).

2.1. VTT TIME SERIES IN THE Ca II K LINE

At the 70 cm Vacuum Tower Telescope (VTT) on Tenerife sequences of Ca II K filtergrams were taken between 07:39–10:57 on May 8. A Lyot filter centered on the K2.0 emission peak near the core of the Ca II 393.3 nm line, with an FWHM of 0.96 nm was used. Data were recorded on a 16 bit 1024 × 1024 pixel CCD camera operated in 512 × 512 summing mode. The image scale was 0.366/pixel and the useable field of view was about 150′ × 150′. The cadence of the observations was 6 s, with an integration time of 0.25 s. Seeing conditions were good during this observation.

2.2. TRACE OBSERVATIONS

From 08:10–12:58, TRACE collected a time series of 121.6, 155.0, 160.0 and 170.0 nm band images with 0.4 s cadence. The FOV was 128 × 320′′, with 0.55 pixels (1′′) resolution. Standard procedures were employed for decompression, flatfield and dark signal correction of the data. The 121.6 nm images also contain significant leakage of UV continuum in the 150.0–170.0 nm region along with Lα emission; a subtraction technique has been developed to provide a cleaner estimate of Lα (Handy et al. (1999b)).

3. CO-ALIGNMENT

For this first analysis only the data between 08:10–08:58 was used as the TRACE FOV jumped (for, at this moment, unknown reasons) at 08:58. The 121.6 nm images however do not start before 8:20. All Ca II and TRACE data was corrected for solar/earth rotation and satellite/telescope jitter by aligning each frame to the first frame of the time series, which given the short duration of the observation (only the data during the overlapping times was used) does not introduce any errors. The different TRACE passbands were co-aligned by cross-correlating their respective average image. We converted the Ca II data to TRACE resolution and co-aligned the averaged images through cross-correlation. All alignments are accurate to within sub-pixels resolution. Finally a subfield from all overlapping data was taken.

From the aligned TRACE 121.6 nm and 160.0 nm images a Lα estimate was constructed (Handy et al. (1999b)). In this analysis we use the following naming-convention: 121.6 nm for the contaminated images and Lα for a cleaned construct.

4. PHASE RELATIONS

Having thus 5 independent (and a 6th constructed) datasets we investigated the phase relations between signals which would correspond to different atmospheric layers.

We take a x − t slice at a given X (or Y) position. For each x − t slice we determine the time-offset with the x − t slice from the same X (or Y) position from another dataset and repeat this for all X and Y positions. This gives us a scatter plot of time-offsets per dataset combination. After binning this scatter plot we fitted a curve consisting of 5 Gaussian profiles to this data. The reason for using multiple Gaussians will be explained later.

The found phase shifts were corrected for non-simultaneous sampling of the different datasets by subtracting the average difference between times of exposures.

The above process was repeated for the network and the internetwork by using adjacent (inter)network patches instead of the entire X or Y-range.

Some results are included in table 1.

5. DISCUSSION

According to table 1 the TRACE 160.0 nm passband shows the same morphology and temporal evolution as Ca II (as earlier shown by Rutten et al. (1999)): they are in phase, within the uncertainty.

In all passbands the difference between network and internetwork is small (zero within error). Other current work however shows many differences between these regions. A more detailed Fourier analysis is currently being done to confirm these results.

![Figure 1. Histogram of phase shifts (in sec) for Lα - 160.0 nm combination. Most phase shifts are around zero as a result of the 160.0 nm signal correllating with itself in the Lα construct. The sharp peaks around -80 and 120 sec are also possibly due to this effect. Note, the broad bump around 125 sec which is the most likely solar phase shift between Lα and 160.0 nm.](image-url)
Table 1. Phase relations and their 1σ - uncertainty (in sec) between different wavelength combinations for the entire field (all), network (nw) and internetwork (in) from cross-correlation of x – t data sets. The '2' in the Lα–160 set indicates the second peak. Positive shifts mean that second signal arrives later than the first signal. \(\Delta t_{\text{total}}\) is the derived phase shift between the combination of passbands (derived by adding \(\Delta t_{\text{cross}}\) and \(\Delta t_{\text{sampling}}\)) with \(\sigma_{\text{total}}\) the uncertainty in this number. \(\Delta t_{\text{cross}}\) and \(\sigma_{\text{cross}}\) give the same information derived from crosscorrelating the data (and fitting a Gaussian to the resulting histogram) and \(\Delta t_{\text{sampling}}\) and \(\sigma_{\text{sampling}}\) give the average time difference between the moments of image-taking. \(N_{\text{Gauss}}/N_{\text{total}}\) is a measure of the certainty of the fit by the Gaussian by dividing the number of counts in the fitted Gauss curve by the total number of counts.

<table>
<thead>
<tr>
<th>Passband</th>
<th>NW/IN</th>
<th>(\Delta t_{\text{total}})</th>
<th>(\sigma_{\text{total}})</th>
<th>(\Delta t_{\text{cross}})</th>
<th>(\sigma_{\text{cross}})</th>
<th>(\Delta t_{\text{sampling}})</th>
<th>(\sigma_{\text{sampling}})</th>
<th>(N_{\text{Gauss}}/N_{\text{total}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>170–160</td>
<td>all</td>
<td>2.75</td>
<td>0.92</td>
<td>5.93</td>
<td>0.80</td>
<td>-3.18</td>
<td>0.47</td>
<td>0.93</td>
</tr>
<tr>
<td>170–160</td>
<td>nw</td>
<td>2.40</td>
<td>1.29</td>
<td>5.58</td>
<td>1.21</td>
<td>-3.18</td>
<td>0.47</td>
<td>0.96</td>
</tr>
<tr>
<td>170–160</td>
<td>in</td>
<td>2.79</td>
<td>1.07</td>
<td>5.97</td>
<td>0.96</td>
<td>-3.18</td>
<td>0.47</td>
<td>0.93</td>
</tr>
<tr>
<td>160–155</td>
<td>all</td>
<td>1.16</td>
<td>1.06</td>
<td>6.22</td>
<td>0.95</td>
<td>-5.06</td>
<td>0.47</td>
<td>0.92</td>
</tr>
<tr>
<td>160–155</td>
<td>nw</td>
<td>1.06</td>
<td>1.56</td>
<td>6.12</td>
<td>0.49</td>
<td>-5.06</td>
<td>0.47</td>
<td>0.97</td>
</tr>
<tr>
<td>160–155</td>
<td>in</td>
<td>1.23</td>
<td>1.25</td>
<td>6.29</td>
<td>1.16</td>
<td>-5.06</td>
<td>0.47</td>
<td>0.94</td>
</tr>
<tr>
<td>Ca II–160</td>
<td>all</td>
<td>0.13</td>
<td>4.34</td>
<td>0.19</td>
<td>3.96</td>
<td>-0.06</td>
<td>1.77</td>
<td>0.24</td>
</tr>
<tr>
<td>Ca II–160</td>
<td>nw</td>
<td>-0.56</td>
<td>4.40</td>
<td>-0.50</td>
<td>4.03</td>
<td>-0.06</td>
<td>1.77</td>
<td>0.19</td>
</tr>
<tr>
<td>Ca II–160</td>
<td>in</td>
<td>0.86</td>
<td>5.26</td>
<td>0.92</td>
<td>4.95</td>
<td>-0.06</td>
<td>1.77</td>
<td>0.24</td>
</tr>
<tr>
<td>121.6–160</td>
<td>all</td>
<td>-3.97</td>
<td>1.84</td>
<td>4.60</td>
<td>1.82</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.92</td>
</tr>
<tr>
<td>121.6–160</td>
<td>nw</td>
<td>-4.45</td>
<td>2.88</td>
<td>4.12</td>
<td>2.86</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.96</td>
</tr>
<tr>
<td>121.6–160</td>
<td>in</td>
<td>-3.84</td>
<td>2.14</td>
<td>4.73</td>
<td>2.12</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.93</td>
</tr>
<tr>
<td>Lα–160</td>
<td>all</td>
<td>-1.50</td>
<td>2.67</td>
<td>7.07</td>
<td>2.65</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.68</td>
</tr>
<tr>
<td>Lα–160</td>
<td>2</td>
<td>111.63</td>
<td>0.31</td>
<td>120.19</td>
<td>0.04</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.02</td>
</tr>
<tr>
<td>Lα–160</td>
<td>nw</td>
<td>-2.32</td>
<td>4.10</td>
<td>6.25</td>
<td>4.09</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.66</td>
</tr>
<tr>
<td>Lα–160</td>
<td>2</td>
<td>111.63</td>
<td>0.31</td>
<td>120.20</td>
<td>0.03</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.01</td>
</tr>
<tr>
<td>Lα–160</td>
<td>in</td>
<td>-1.64</td>
<td>3.15</td>
<td>6.93</td>
<td>3.14</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.60</td>
</tr>
<tr>
<td>Lα–160</td>
<td>2</td>
<td>111.62</td>
<td>0.31</td>
<td>120.19</td>
<td>0.04</td>
<td>-8.57</td>
<td>0.31</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The Lα–160.0 nm combination is the main reason for fitting multiple Gaussians. Figure 1 shows that the spread is clearly non-uniform and cannot be fitted with a single Gaussian curve.

Two Gaussians stand out from the noise level. The large central Gaussians is the result from the construction method of the Lα channel (a linear combination of 121.6 and 160.0 nm) and is the alignment of the 160.0 nm channel with itself in the construct. More interesting is the appearance of the second Gaussian at \(\approx 112\) sec, which looks like a downward propagating wave with an average chromospheric sound speed of \(\approx 14\) km/sec (with a difference of \(\approx 1500\) km between the formation heights of Lα and 160.0 nm (Vernazza et al. (1973)). However further analysis is needed to confirm this result.

We want to emphasize that the results presented here are preliminary, and much more work has to be done. Also, the interpretation of our observation is still in its initial phase.

Future work will include fourier analysis and also different SOHO Lyman line and longer time series.

ACKNOWLEDGEMENTS

J.M. Kristjánsson would like to thank the Leiden Kerkhoven-Bosscha Fonds and the Max-Planck-Institut für Aeronomie for financial support making this analysis possible. P. Heinzel acknowledges the support of MPAE during his visit and of the grant A3003902 of GA AVČR.

6. CONCLUSIONS AND OUTLOOK

We have demonstrated here that the Lα oscillations are correlated to chromospheric (160.0 nm) oscillations. Also we have provided more proof of the strong correlation between Cαi I K and TRACE 160.0 nm channel.

REFERENCES


© European Space Agency • Provided by the NASA Astrophysics Data System
Handy B. N., Acton L. W., Kankelborg C. C., et al., 1999a, Solar Phys. 187, 229