On the Nature of Propagating MHD Waves in the Solar Atmosphere

One of the most persistent problem in solar physics is the identification of the mechanism that heats the solar corona and accelerates the fast solar wind. Many processes have been proposed for converting some fraction of the mechanical energy in sub-photospheric convective motions into heating of solar corona. Among these, Magneto-hydrodynamic (MHD) waves were proposed to play an important role in the heating of solar corona and acceleration of fast solar wind. Different types of oscillations have been now observed by various instruments. These are interpreted as due to ubiquitous presence of MHD waves. Magnetic field plays a fundamental role in the propagation and properties of these MHD waves. The topology (structure) of the magnetic fields are different in different regions of the solar atmosphere viz., active regions (high-lying closed magnetic fields), quiet Sun (low-lying closed magnetic fields) and coronal holes (open magnetic fields). In this Ph.D. project, the nature of these propagating MHD waves in the different regions of the solar atmosphere are studied.

It is believed that polar coronal holes which connects the inner corona and the solar wind, are the source regions of the fast solar wind. The on-disk part of a polar coronal hole can be divided into network and internetwork regions. We obtained long time series (*sit-and-stare*) data from the SUMER/SOHO spectrometer in N IV 765 Å and Ne VIII 770 Å spectral lines to search for the presence of waves in these two different regions from a statistical approach. The network bright regions indicated the presence of compressional waves with a dominant period of $\approx$ 25 min in both the lines. Moreover, we found that there is a difference in the nature of the wave propagation in the bright ('network'), as opposed to the dark ('internetwork') regions, with the latter sometimes showing evidence of downwardly propagating waves that are not seen in the former. These were consistent with the magnetic topology, as open field lines are rooted in network regions whereas internetwork region has low-lying closed field lines. From a measurement of propagation speeds, we found all waves are subsonic, indicating that the majority of them are slow magneto-acoustic in nature.

We found presence of propagating disturbances in off-limb coronal hole from simultaneous spectroscopic observations from SUMER/SOHO and EIS/Hinode. Based on their temperature dependent propagation speed, these disturbances were interpreted in terms of propagating slow magneto-acoustic waves. We performed further analysis in off-limb part of coronal hole which can be divided into plume and inter-plume regions. Simultaneous observations were obtained with EIS/Hinode and SUMER/SOHO spectrometer in Fe XII 195 Å and Ne VIII 770 Å spectral lines respectively. We detected the presence of accelerating waves in a polar inter-plume region with a period of 15 min to 20 min in both the spectral lines and a propagation speed increasing from 130 ± 14 km s^{-1} just above the limb, to 330 ± 140 km s^{-1} around $160''$ above the limb. These waves can be traced to originate from a bright region of the on-disk part of the coronal hole which can be visualized as the base of the coronal funnels. The adjacent plume region also showed the presence of propagating disturbance with the same range of periodicity but with propagation speeds in the range of 135 ± 18 km s^{-1} to 165 ± 43 km s^{-1} only. We found that the waves within the plumes are not observable (may be getting dissipated) far off-limb whereas this is not the case in the inter-plume region. We suggested that the waves are likely either Alfvénic or fast magneto-acoustic in the inter-plume regions and slow magneto-acoustic in the plume regions. These results indicate that the inter-plume regions are preferred channel for the acceleration of the fast solar wind over plume regions.

To detect the presence of waves in active regions, we have analysed the imaging and spectroscopic data acquired during the total solar eclipse of 2006 and 2009 respectively. We found the oscillations of periods 27 s and 20 s in imaging data obtained in green (Fe XIV 5303 Å) and red (Fe X 6374 Å) coronal emission lines respectively. Significant oscillations with high probability estimates were detected at boundary of active region and in the neighbourhood, rather than within the loops itself. From the spectroscopic observation taken during 2009 Eclipse, we reported the detection of oscillations in intensity, velocity and line width with periods in the range of 25 s to 50 s with green and red coronal emission lines. We also performed detailed line profile study and found simultaneous broadening of line profiles in red and blue wings with similar periods in both red (Fe X 6374 Å) and green (Fe XIV 5303 Å) spectral lines. These high frequency oscillations in line profiles were interpreted either in terms of fast sausage wave modes or torsional Alfvén wave mode.

Quiet–Sun can further be divided into bright magnetic (network), bright non-magnetic and dark non-magnetic (internetwork) regions. Simultaneous observations were obtained with Ca II filter-gram from SOT/Hinode, TRACE 1550 Å passband and with SUMER/SOHO spectrometer in N IV 765 Å and Ne VIII 770 Å spectral lines to study the oscillations in these different regions. We detected the presence of long period oscillations with periods between 15 min to 30 min in bright magnetic regions. The oscillations were detected from chromospheric height to low coronal heights. Fourier power maps showed that short period powers are mainly concentrated in dark regions whereas long period powers are concentrated in bright magnetic regions. We found presence of *power shadows* in high frequency ranges (period 3–6 min) and *power halos* in low frequency ranges (period 15 min and beyond) in and around magnetic network regions. We proposed that these 15 min and above periods can propagate up to the coronal heights through 'magneto-acoustic portals'. However, in this case only with the spectral imaging data, it was not possible to identify the mode of wave propagation.

Estimates of energy flux associated with these various wave modes indicate that only Alfvén waves carries sufficient energy to heat the solar corona whereas other wave modes do not contribute significantly. However, these wave modes may still provide estimates of unknown parameters such as coronal magnetic field, density scale height, transport co-efficients, fine–structuring etc upon using the technique of *solar atmospheric magneto-seismology.*