

ANNUAL REPORT TO JOSO 1998 – NORWAY

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1. Introduction

Solar research at the Institute of Theoretical Astrophysics falls into three categories: Observing on the ground, use of space data, and theoretical activities. The ground observing uses facilities in the Canary Islands and the United States. For space data the main source is ESA's and NASA's Solar and Heliospheric Observatory - SOHO, and recently we also have used data from Lockheed's and NASA's Transition Region and Coronal Explorer - TRACE. Many of the ground observing and theoretical activities are furthermore related to the use of SOHO.

2. Ground Based Observations - Bi-directional streaming in solar prominences

H α time-lapse filter-grams have been obtained of quiescent prominences at the Big Bear Observatory for up to eight hours each day for one week. The filter-grams have been analyzed in order to clarify the relation between streaming velocities and magnetic fields in prominences. The continuous mass motions seen in H α show velocities, confirmed by Doppler shifts, with vertical components of a few km s⁻¹ along narrow, steeply inclined threads. Such motions, presumed to be tracers of field aligned flows, are difficult to reconcile with the uniform, predominantly horizontal magnetic fields in prominences. The new observations are consistent with steady, bi-directional streaming everywhere in the filaments along adjacent closely-spaced threads. The pattern is observed in both wings of H α thereby confirming that the flows are mass motions and not caused by some kind of excitation wave. These observations contradict all contemporary filament models which do not allow any vertical threads containing vertical motions, let alone bi-directional streaming. (See forthcoming paper in Nature by J.B. Zirker, O. Engvold and S.F. Martin 1998.)

3. Space Activities

3.1. Coronal Observations with SOHO

The Institute of Theoretical Astrophysics has continued to use SOHO extensively, particularly the Coronal Diagnostic Spectrometer - CDS. We contributed the Ground Support Equipment for CDS, and much of the data reduction software, and we have participated in the operation of CDS at the Experiment Operations Facility at Goddard Space Flight Center since SOHO was launched. In much of our observing we have used CDS together with other instruments on SOHO, particularly Solar Ultraviolet Measurements of Emitted Radiation - SUMER, Michelson Doppler Interferometer - MDI, and EUV Imaging Telescope - EIT, in addition to TRACE and observatories on the ground. These collaborations are formalized in our 10 SOHO Joint Observing Programs (8 with Norwegian lead investigator), but additional informal collaborations have been frequent. Our degree of exploitation of CDS has remained unchanged at 10% of the observing time outside of synoptics, engineering time and dead time (f.ex. space craft maneuvers). We have also kept up our

activities with the reduced SUMER and have used about 4% of the available SUMER observing time.

We will mention some of the active fields of research in 1998:

1. *Time variable and dynamic active region loop structures.* Between 25 September 1997 and end of May 1998 we observed loop structures (mainly using CDS) above ~ 25 active regions on the solar limb. The loops, of typical height 25-100 Mm, appear isothermal along their length and loops at different temperatures are *not* necessarily co-located. High Doppler shifts are observed in parts of loops with shifts corresponding to line of sight velocities of 50-90 km s⁻¹. Finally, the loops are extremely time variable and may appear or disappear in as little as 10 min. These results apply for loops in the transition region and low corona up to 1.5 MK. Hot coronal loops have different properties. (JOP075: CDS, MDI, EIT, TRACE, see O. Kjeldseth-Moe and P. Brekke, Solar Physics 192, 73, 1998.)
2. *Sunspot structure and velocity fields - sunspot plumes, sunspot oscillations.* A comprehensive study have been made of the structure and dynamics of 17 sunspot regions. The much debated existence of sunspot plumes have been re-established, as strongly emitting regions located mainly inside the white light sunspot and existing at upper transition region temperatures, 200 000 - 600 000 K. Down-flows appear associated with the plumes. Sunspot oscillations have also been detected in both intensity and velocity, partly associated with the plumes. (JOP018: CDS, SUMER, NSO, see P. Maltby, et al., Ap.J., 496, L117, 1998; N. Brynildsen, et al., Ap.J., 502, L85, 1998; N. Brynildsen, et al., Ap.J., accepted for 1999.)
3. *Helium emission in the solar atmosphere.* The ionization of helium in the solar atmosphere has been investigated using CDS. A high spatial correlation with emission from the hot corona ($T \approx 2.7$ MK) points to strong photo-ionization of helium by coronal back radiation. However, the rate of change in the helium emission is significantly faster than the coronal line emission and red-shifted line profiles tend to be more intense than blue-shifted profiles, as is the case for transition region lines. This points to a contribution from another source (e.g. particles from the transition region) in addition to the coronal radiation. (CDS, see T. Fredvik and P. Maltby, Solar Physics, January 1999 issue.)
4. *Oscillations in the chromosphere and transition region.* Small amplitude oscillations are found in internetwork regions with periods between 120-200 s. The oscillations are seen both in C II and O VI lines. Phase relations between the velocity oscillations of the two lines show that they are a manifestation of upward propagating waves. (SUMER, see Ø. Wikstøl, et al., submitted to Ap.J.)
5. *Solar prominences.* The high-temperature iron lines Fe IX/X 171 Å, Fe XII 195 Å and Fe XV 284 Å observed in prominences have been compared with nearly simultaneous observations in He II 304 Å, H α and He I 10 830 Å. The iron lines and He II are observed with EIT on SOHO while the other two lines are from various ground observatories. In several cases the iron lines, probably emitted from a plasma between 1.3 MK and 2.0 MK, show up in absorption against a bright background, both on the disk and above the limb. Other studies suggest that the apparent absorption in the high-temperature Fe images, may partly be attributed to absorption in H and He I continua. The iron lines go into emission before the eruption of quiescent prominences. Optical depths and particle densities for the absorbing plasma and its relationship to the cool plasma of prominences is investigated, with the aim of understanding the development and disappearance of prominences. (EIT, GBO)

In addition to these 5 topics, progress is made in many other fields: The studies of high velocity events; nano-flares in the corona and transition region pertaining to distinguishing between different coronal heating mechanisms; extending the measured prevailing red-shifts in the low transition region to higher temperatures, $T \sim 1$ MK; solar EUV irradiance measurements; transition region emission and magnetic fields; studies of jets and coronal mass ejections (with TRACE and CDS).

3.2. Solar Oscillations.

Amplitude modulation of low degree p-modes in the sun are analyzed with time-frequency methods in data from the helioseismology experiments VIRGO and MDI on SOHO. Selected $\ell=0$ modes show a clear rotational modulation obviously connected to the level of solar activity. The frequency of the rotational modulation is close to the sidereal rotation frequency of the latitude of dominant activity and the strongest modulation is seen in the $\ell=0$ modes with radial orders 13, 16, 21 and 22. The modulation is nearly identical in the same modes observed when in irradiance and radiance with VIRGO and in radial velocity with MDI. No other clear and persistent peaks of similar amplitude are seen in the $\ell=1-2$ modes.

4. Theoretical Activities

There are several on-going theoretical projects at the Institute of Theoretical Astrophysics. We have selected two of these involving numerical simulation of processes in the solar atmosphere. The projects constitute the doctoral Thesis works of Drs. Roar Skartlien and Øivind Wikstøl, respectively.

4.1. The coupling between photospheric convection and chromospheric dynamics in the solar atmosphere

The dynamics of the solar chromosphere depend *i)* on its interaction with the radiation field, and *ii)* on the motion and magnetic field generated by the convection zone below. One seeks to understand the coupling between the convection zone and the chromosphere by using three dimensional numerical simulations to model the chromosphere simultaneously with the upper convection zone.

The simulations show that seismic events in the surface layers of the sun trigger wave transients in the solar atmosphere. These events are small granules in the granular layer (the cooling layer of the convection zone) that become unstable and collapse to form cool, localized down-flows within the convection zone. The instability results from the imbalance between upward energy flux by convection and radiative cooling in the cooling layer. The transients, which are wave trains with finite temporal duration, create shock waves in the chromosphere that may be linked to the observed chromospheric bright grains in the CaII spectral lines. From observations of the photosphere and chromosphere it seems that certain classes of bright grains can be used as positional markers for the seismic events. The events are also important for the excitation of the solar eigen-oscillations (p-modes), and the process is an important generator of waves in the solar atmosphere.

4.2. Dynamics and Waves in the Solar Transition Region

This project studies *i)* the propagation of acoustic and magneto-hydrodynamic waves in the solar transition region and corona, *ii)* observational signatures of such waves indicating the direction of energy flow in the solar atmosphere, and *iii)* the possibility of fine-scale structure in the transition region. It makes use of theoretical models and data from the SUMER spectrometer on SOHO.

Calculations have been made of line profiles both for downward propagating non-linear Alfvénic disturbances, which become compressive, and upward propagating acoustic waves. The relation between compression and velocity in a compressive wave leads to asymmetries in line profiles when waves run through the gas. Based on the asymmetry of the ratio of density sensitive line pairs, where the dependence of intensity on density differs for the two lines, it is possible to distinguish between up-ward and down-ward running disturbances. The numerical predictions for the two cases are then compared with line profile ratios observed with the SUMER. The result favors downward propagating disturbances and supports a picture where the corona is heated by small bursts of magnetic reconnection, i.e. nano-flares. (R. Skartlien, "3D Modeling of Solar Convection and Atmosphere Dynamics", Thesis, ITA/UiO, July 5, 1998.)

The project has also investigated the proposal by Dr. U. Feldman that the solar transition region is composed of unresolved and unconnected plasma fine structure - UFS. It is shown that a standard transition region model, that includes unresolved plasma dynamics, equally well explains the observations quoted in support of UFS. Finally, analysis of data from some relatively cool transition region lines observed by SUMER concludes that the chromosphere drives waves with periods of 120 - 200 seconds in the transition region. The oscillations are coherent over quite large spatial scales in the internetwork region and is interpreted as more evidence for the possible lack of fine-scale structure in the transition region. (See Ø. Wikstøl et al. Ap.J. 483, 972, 1997; P. G. Judge et al. Ap.J. 502, 981, 1998; Wikstøl et al. Ap.J. 501, 895, 1998.)