SUMMARY OF SESSION A: CORONAL HEATING AND SOLAR WIND ACCELERATION

TAKASHI SAKURAI
National Astronomical Observatory
Mitaka, Tokyo 181, Japan

1. Introduction

The solar corona is not easily observable from the ground; only with the coronagraphs located in high mountains or at infrequent and short occasions of total eclipses. And in any case these observations are limited to the corona beyond the solar limb. Therefore, it is natural that our understanding of the physics of the solar corona has advanced dramatically by sustained observations from space-based platforms, like Skylab in the 1970's. These several years are particularly notable in this respect, because of a wide variety of data from Yohkoh, Ulysses, and SOHO.

The three invited reviews in this session are presented by individual authors as separate papers. This report summarizes contributed and poster papers.

2. Source Regions of the Solar Wind

SOHO XUV solar images clearly showed a prominent radial structure (plumes) in the polar regions. Combined with the discovery of stable high speed wind from the polar regions, these plumes may be the site of the acceleration of the solar wind.

G. Poletto and the SOHO/UVCS team compared the physical conditions in plumes and inter-plume regions, and found the following.
(1) The profile of the plasma outflow speed vs. heliocentric distance in the altitude range between 1.5 and 3.5 $R_\odot$ has been determined via Doppler dimming effects. An outflow speed of the order of 100 km s^{-1} at an altitude of about 2 $R_\odot$ is found. There is no apparent difference between the outflow speed in plumes vs. inter-plume regions.
(2) Kinetic temperatures, far in excess of thermal temperatures, have been derived from line profiles and shown to increase with the mass of the ion. Typical values of the kinetic temperature of O VI ions at $2R_\odot$ are on the order of 8×10^7 K, vs. a value of $T_{\rm kin}$ on the order of 2×10^6 K from hydrogen Lyman alpha. Kinetic temperatures are larger in inter-plume regions and the difference between $T_{\rm kin}$ in plumes and inter-plume regions increases with increasing heliocentric distances.
(3) Radial kinetic temperatures are lower than temperatures in the direction normal to the radial. (The radial kinetic temperature $T_{\rm kin}$ for O VI ions is supposed to be less than 10^7 K at $3R_\odot$.)
(4) Electron densities in plumes and inter-plume regions have been derived from UV lines. The derived profile of electron density vs. height is in good agreement with white light determinations. It is found that densities in inter-plume regions are lower than in plumes, although by a hardly definable factor.

R. Brajsa et al. studied the coronal holes by using full-disk maps of He I 10830Å (Kitt Peak), Hα (Big Bear Solar Observatory), soft X-rays (Yohkoh), microwave at 37 GHz (Metsahovi, Finland), together with high resolution spectra of He I 10830Å obtained at the German Vacuum Tower Telescope at Tenerife. In microwave, they detected a difference in brightness temperatures between an equatorial coronal hole and the two polar coronal holes.

P. Cugnon et al. analyzed the images provided by the C2 coronagraph (through orange filter) of LASCO on board SOHO. They tried to reconstruct the large scale electron density in the corona, using a model based on the assumption of an axisymmetric corona, which allows for a separation between the angular and radial distributions. In the observed range of 2.5 – 7 $R_\odot$, the contribution

J. Andersen (ed.), Highlights of Astronomy, Volume 11B, 869–872.

from the F-corona is not negligible, so that it has to be subtracted from the raw intensity data in order to extract the signal from the K-corona. An iterative process devised by the authors has successfully been applied to the data. The authors could also trace the evolution of the global structure of the corona over one solar rotation.

B. Setiahadi et al. performed a two-dimensional MHD simulation to study the formation process of the helmet streamer in the solar corona. The simulation followed the evolution of the initially-hydrostatic corona after an arcade-type magnetic field is injected from the bottom boundary. The corona evolves to a new dynamical equilibrium and forms a helmet streamer with a cusp-shaped arcade below it. Along the helmet borders, regions of higher-speed solar wind are formed.

3. Inhomogeneity in the Solar Corona

It has long been known that two major coronal emission lines, namely the green line (Fe XIV 5303Å) and the red line (Fe X 6374Å), each representing 1×10^6K and 2×10^6K plasmas, often show different coronal structures. Different appearance of the solar corona at different temperatures is also seen by comparing the Yohkoh soft X-ray images dominated by 3×10^6K or hotter plasmas with the SOHO EIT pictures from Fe XII 192Å (1.5×10^6K). The inhomogeneity in temperature indicates that the heating rate differs from loop to loop, depending either on the physical conditions in the corona or on the conditions at the photospheric driving motions. Therefore, important clues on the heating mechanisms can be derived from the inhomogeneous structures in the solar corona.

Using the Bragg crystal spectrometer (BCS) on board the Yohkoh satellite, A.C. Sterling et al. derived the hight structure of the X-ray corona above an active region. Although BCS is a full-sun instrument and has no spatial resolution, they utilized the limb passage of an active region to differentiate the hight structure. Long integrations from times after the region had totally disappeared some days later show a substantial background in S XV. Since the background spectrum is featureless, spectral lines obtained from the time of occultation must originate from the upper corona of the active region. Their results support previous findings that the active region corona consists of two components: a cooler, steady component with electron temperature $T_e \approx 3 \times 10^6$ K, and a hotter, transient component in excess of 5×10^6 K. This hotter component is due to microflares; outside the time of microflares there is relatively little or no plasma with T_e higher than about 3.5×10^6 K. There is evidence for a decrease in T_e (down to $\approx 2 \times 10^6$ K) with height for the cool component.

B. Dwivedi et al. discussed results from a study of EUV off-limb spectra obtained with the SUMER instrument on board SOHO. A region was rastered from 40″ off the limb and outwards, and a unique, high quality set of high resolution EUV spectra was obtained. By using the Ne VI and Mg VI inter-combination lines, which also provide good diagnostics for relative high-FIP/low-FIP element abundance, the electron density in the solar atmosphere was derived. The densities derived from the two elements are discrepant by a large factor, and the reason is so far not clear.

A. Takeda derived the spatial variations of the absolute intensities of the active region corona from 1.05 to 1.5 $R_\odot$ observed at the total eclipse of 1991 July 11, in three wavelengths of two coronal emission lines (Fe XIV 5303Å and Fe X 6374Å) and the continuum around 6100Å. By examining spatial correlations among the fine structures at these three wavelengths, she found that 1.0×10^6 K (Fe X) and 2.0×10^6 K (Fe XIV) plasmas are spatially nearly exclusive with each other, and that, if they are combined, they explain about 70% of the continuum structures.

4. Coronal Activities and Magnetic Fields

Coronal activities start as a magnetic flux system emerges at the solar surface. This initial activities of magnetic regions will most probably be driven by interaction between the new emerging flux and the old pre-existing flux. As such, the interaction takes the form of magnetic reconnection between the two flux systems. As a large amount of magnetic flux is accumulated and the region matures, the relative influence of flux emergence on the activity of the region will gradually diminish, and another kind of excess magnetic energy, namely the magnetic shear, will take over.

S. Yashiro et al. studied the early-phase evolution of active regions in the corona by analyzing 56 emerging flux regions (EFRs) observed with the Yohkoh soft X-ray telescope (SXT) during the period from 1992 January to 1996 March. They found that the initial apparent velocity of the expansion of the EFRs is 0.4 – 3.6 km s^{-1}, which is much lower than that inferred from Hα

observations of arch filament systems. They also studied the thermal evolution of active regions in the corona, and found that the temperature of EFRs increase with the increasing region size.

An X-ray Bright Point (XBP) is an emission feature of small scale ($< 1'$) and short lifetime (about 2 days). XBPs can be found at practically all solar latitudes and they are associated with small magnetic bipoles whose average total magnetic flux is $2 - 3^{19}$ Mx. M. Shimojo et al. analyzed an XBP in an emerging flux region in detail, by using the Yohkoh SXT. The XBP produced 92 microflares (transient brightenings) during the observation time of SXT, whose frequency distribution as a function of the soft X-ray peak intensity shows a single power-law. This result suggests that the power-law distribution of microflares (Shimizu, PASJ 47, 251, 1995) is universal and holds even in a small emerging flux region.

H.N. Wang et al. adopted a simple analytic force-free field model to investigate the thickness expansion of magnetic loops along their lengths. The observed X-ray coronal loops apparently show an expansion which is smaller than expected from current-free field-line bundles. Their force-free field model can generate loops with little expansion if the magnetic field is strongly sheared, but only at particular locations in the model configuration.

A.H. Zhou discussed a method to infer the coronal magnetic field strength based on radio observations of gyro-synchrotron radiation. The previous study by the same author in 1984 was improved by adopting better approximation for the electromagnetic expressions describing the generation of gyro-synchrotron radiation.

5. Coupling between the Corona and the Lower Atmosphere

The relationship between the coronal phenomena and their counterparts in the lower layers is still not fully understood, although a significant amount of coordinated data sets have been obtained in recent years as described below. The ultimate obstacle is that the coronal structures may converge to a group of very small structures at the photosphere, and the ground-based optical observations cannot generally give enough spatial resolution and temporal persistency to observe such fine structures.

H. Kurokawa et al. studied the causal relation between Hα arch filament system (AFS) loops and corresponding soft X-ray features (Yohkoh). Hα observations were obtained by the 60 cm Domeless Solar Telescope (DST) of Hida Observatory, Kyoto University. The authors found the following results.
(1) A group of Hα AFS loops generally correlates in space with bright X-ray loops.
(2) Several examples show clear causal relation between a newly emerging Hα AFS loop and a soft X-ray transient brightening. In many cases it is, however, unclear because of insufficient of resolutions.
(3) Newly and actively emerging AFS with sheared structures have a tendency to cause brighter and frequent X-ray brightenings.

K. Yoshimura et al. studied the relation between arch filament system (AFS, Hα observations from Hida DST) and soft X-ray loops (Yohkoh). It had been found previously (Kawai et al., PASJ 44, L193, 1992) that the AFS was covered with the X-ray bright features. The present study shows that in some cases AFSs accompany with no particular X-ray brightenings. There were also cases in which major brightenings of X-ray loops were accompanied with Hα dark features which were not AFS but might be small filaments with sheared configuration.

T. Kudoh and K. Shibata presented the results of 1.5-dimensional MHD simulations for solar spicule formation and heating of the corona. The propagation of torsional Alfvén waves (generated by random motions on the photosphere) into an open magnetic flux tube in the solar atmosphere was calculated. In the course of propagation, a part of the Alfvén waves is reflected at the transition region and produces a slow mode MHD waves. Then, the slow mode waves lift up the transition region and produces a spicule. The remaining Alfvén waves propagate up to the corona and will contribute to heating of the corona. The simulation shows that the energy flux required for the heating of the quiet corona is transported if the rms random motion is greater than ~ 1 km s^{-1} in the photosphere. Simultaneously, the transition region is lifted up to more than ~ 7000 km.

6. Photospheric Dynamics of Magnetic Fields

In contrast to the upper atmosphere of the sun where the magnetic field is the dominant controlling factor, at the photospheric level the magnetic force is comparable to other forces. Therefore one has to consider a complex system made of several competing factors. Nevertheless, the importance in the study of the photospheric layer cannot be over-emphasized, because by disentangling complex phenomena one may gain insight into what is taking place deeper down (the dynamo process).

T.T. Ishii and H. Kurokawa studied a large active region NOAA 5395 in 1989 March, with special emphasis on the relation between sunspot motions and flare activity, by using the data from Hida DST. They demonstrated that twisted magnetic flux tubes successively emerged at the leading edge of the sunspot group and that they played an essential role in the production of strong flare and surge activities of the region.

A. Takeuchi investigated the nonlinear evolution of a convective instability within a vertical magnetic flux tube embedded in a layer extending from the solar photosphere to the convection zone. He performed one-dimensional MHD numerical simulations, adopting the thin flux-tube approximation. Furthermore, radiative energy transport was modeled by solving the transfer equation in a generalized version of the Eddington approximation. As a result it was shown that a weak flux tube evolves into an intense (1kG) flux tube in a static equilibrium, due to the convective instability. However, a comparison of the final equilibrium with semi-empirical models of flux tubes showed that the temperature and the field strength of the theoretical equilibrium are lower than the values inferred from observations.

7. Instrumentation in the Future

As was mentioned before, the next step toward deeper understanding of the solar magnetic activity will be to carry out high resolution optical observations from space. In Japan, the project for the next solar satellite (Solar-B) is in progress. Solar-B will carry a 50 cm optical telescope equipped with a video magnetograph and a Stokes polarimeter, an X-ray telescope with a resolution higher than that of Yohkoh, and an XUV spectrograph.

Q. Song et al. reported a test of CCD camera which is to be used on Beijing Observatory's balloon-borne solar telescope. The balloon experiment is a preparation for a space-borne 1 m telescope (The Space Solar Telescope) planned in China.

Besides this stream toward observations from space with the ultimately high spatial resolution, another field of solar physics is also gaining world-wide support. That is the long-term observations of the sun and study on the influence of the sun on the environment of the earth. Carefully designed instruments with deep insight into the future of the solar physics research, and an international collaboration are crucial in successfully completing such a long-range research.

As an example, B. Anwar and M. Akioka described a Sunspot Monitoring Telescope with a high resolution CCD camera of $2K \times 2K$ pixels which was recently built at Hiraiso Solar Terrestrial Research Center, Communications Research Lab, Japan. The telescope has started daily observations (10 minute cadence) in November 1996. They have also developed an algorithm for determining the positions of sunspots based on the digital images. The estimated accuracy is better than 0.1 degree in longitude and latitude for well-defined sunspots.