12 RADIATION AND STRUCTURE OF THE SOLAR ATMOSPHERE
(RADIATION ET STRUCTURE DE L'ATMOSPHERE SOLAIRE)

PRESIDENT : Y. Uchida
VICE-PRESIDENT : R. W. Noyes
ORGANIZING COMMITTEE : P. Delache, F. Deubner, A. Gabriel, S. Gopasyuk,
J. W. Harvey, R. B. Howard, P. R. Wilson, C. Zwaan, M. K. V. Bappu (Advisor, Former President)

I. INTRODUCTION

The report of Commission 12 presented here covers the parts of the field of solar physics other than those directly related to solar activities which, in our view, are the time-dependent phenomena inherent to solar active regions to be covered by Commission 10. From the sub-fields in the domain of Commission 12, the Organizing Committee selected six topics of special interest and invite six researchers to prepare reviews. Topics selected and reviewers are (1) Variations of Total Solar Irradiance (Dr. R. C. Willson, Jet Propulsion Laboratory), (2) Solar Global Oscillations (Dr. E. Fossat, University of Nice), (3) Magnetic Activity and Rotation in the Sun and Stars (Dr. R. W. Noyes, Harvard University), (4) Photospheric Magnetic Concentration and Related Problems (Dr. H. C. Spruit, Max Planck Institut fur Astrophysik), (5) Coronal Loop Structure and its Heating (Dr. E. Priest, University of St. Andrews), and (6) Coronal Transients (Dr. E. Hildner, NASA Marshall Space Flight Center). Of course it is not that there were no important contributions to the progress of sub-fields of solar physics other than those presented here. It was our consensus, however, that we should adopt this method since a complete coverage of works appearing across the entire field is no longer possible because of the rapid increase in the number of works in the expanding field of solar physics when severe page limitations exist for the IAU Reports.

II. VARIATIONS OF TOTAL SOLAR IRRADIANCE
(R. C. Willson)

Long Term Solar Variability

The only systematic long term solar variability monitoring program was conducted by the Smithsonian Institution during the first half of the 20th century (Hoyt, D. V., 1979, Rev. Geophys. Sp. Phys., 17, 427). Their measurements from mountain-top observatories, limited to a long term precision of about 1 percent by fluctuations in atmospheric transmittance, provided no clear evidence of solar variability (Frohlich, C., 1977, in "Solar Output and Its Variation" ed White). Early solar irradiance flight experiments on high altitude aircraft and balloons in the 1960's did not achieve higher accuracy or precision despite of the decreased atmospheric transmittance uncertainty. Their principal sources of uncertainty were calibration and radiation scale errors, the result of a failure to use electrically self calibrated cavity instrumentation of the type developed by the Smithsonian 50 years earlier (Kondratyev, K. Y.et al., 1970, Q. J. R. Met. Soc.96, 509 ; Murcray, D. G.et al., 1969, Air Force CRL Rep. 69 - 0070 ; Drummond, A.et al., 1968, J. Sol. En.12, 219 ; Thekaekara, M. P.et al., 1969, J. Appl. Opt., 8, 1713).

Solar monitoring with accuracy and precision higher than 1% began in the late 1960's following development of a new generation of electrically self calibrated cavity pyrheliometers (Kendall, J. M. et al., 1970, J. Appl. Opt., 9, 1082 ; Willson, R. C. , 1973, J. Appl. Opt., 12, 810 ; Brusa, R. et al. , 1975 "Sci.Discussions IPS IV" World Rad. Center; Crommelynck, D., 1973, R. Met. Inst. Belgium Publ. Ser.A, No 81 ; Frohlich, C. et al., 1973, J. Sol. En., 14, 157). The first flight observations to employ these new instruments were made by the Jet Propulsion Laboratory (JPL) in 1968 (Willson, R. C., 1971, J. G. R. 76, 4325). The most accurate of these were by Active Cavity Radiometers (ACR's) on a high altitude balloon experiment in 1969 whose 1 A.U. solar total irradiance (S) result of 1366 W/m2 was uncertain by about 0.3% in the International System of units (SI) (Willson, R. C., 1973, J. Appl. Opt., 12, 810). The first measurements by self calibrated cavity pyrheliometers outside the earth' atmosphere were made by the JPL Thermal Control Flux Monitor (TCFM) experiments on NASA's MARINER 6 and 7 Missions in 1969 (Plamondon, J. A., 1969, JPL Space Prog. Summary, 3, 162).

Radiation scale experiments conducted at the Swiss World Radiation Center (WRC) in 1975 and 1980 led to the definition of a new international scale of reference, the World Radiation Reference (WRR), based on the average performance of group of the new electrically self calibrated cavity pyrheliometers. Solar irradiance measurements reported on the WRR are believed to be uncertain by less than 0.3% relative to SI unit (Frohlich, C., 1977, in "Solar Output and Its Variation"). Through intercomparisons of flight instrumentation and the WRR-defining pyrheliometers the results of many total solar irradiance flight experiments can be related with a long term precision that exceeds their accuracy in SI units.

Total solar irradiance flight observations were made by the Earth Radiation Budget (ERB) experiment on the NIMBUS 6 satellite from mid 1975 to late 1978. The S=1389 W/m2 value quoted for ERB was 1.7% higher than the preceding 1969 ACR result, raising the possibility of systematic solar luminosity change during the intervening 6 years (Hickey, J. A.et al., 1976, in "sharing the Sun").

The first of a series of NASA solar irradiance rocket experiments was conducted in 1976 to provide an independent calibration of the NIMBUS 6 ERB solar measurements. The results clearly showed ERB's caliration to be 1.6% higher than SI units. This reconciled the ERB and 1969 ACR results to within the latter's SI uncertainty, ruling out the possibility of a detectable change in solar output between the experiments (Duncan, C. H.et al., 1977, J. Appl. Opt., 16, 2690).

The radiation scales defiend by the 1969 balloon and 1976 rocket ACR instruments were found, through comparisons with WRR-difining pyrheliometers and characterization experiments, to differ by less than the uncertainty of relating them, about 0.2% (Willson, R. C., 1981, Sol. Phys., 74, 218). The difference between their results (0.15%) is smaller than this uncertainty, indicating that 0.2% is probably the upper limit for systematic change in solar total irradiance between the maximum and minimum periods of solar cycle 20.

A 2nd ERB experiment, launched on the NIMBUS 7 satellite in late 1978, included a Hickey-Friedan (HF) electrically self calibrating cavity detector capable of greater accuracy and long term precision than the NIMBUS 6 thermopile. Although analysis of the HF science data is not yet available a preliminary result of S=1376 W/m2 has been quoted which exceeds the SI corrected NIMBUS 6 ERB result by 0.6% (Hickey, J. A.et al., 1980, Science, 208, 281). A 1978 NASA rocket experiment found the difference to be due to calibration error and not evidence for a change in solar luminosity (Willson, R. C.,1981, Sol. Phys., 74, 218). Further evidence supporting this conclusion was obtained from a balloon-borne solar total irradiance experiment conducted by the World Radiation Center in mid 1979. The result from their PMO experiment, S=1366 W/m2, is in close agreement with the ACR result for the 1978 rocket experiment (Frohlich,C. et al., 1981,Sol.Phys.in press).

The Active Cavity Radiometer Irradiance Monitor (ACRIM) experiment, launched on NASA's Solar Maximum Mission (SMM) in early 1980, was the first dedicated satellite experiment for monitoring the long term variability of solar total irradiance (Willson, R. C.et al., 1981, Ap. J., 24, 185). ACRIM employs the phased use of its three independent electrically self-calibrating ACR cavity pyrheliometers as an internal calibration procedure for sensor degradation. During the first year of flight a precision better than 0.005% was sustained using this method. A mean of S=1368 2 W/m2 and a dowmward trend at the rate of 0 . 05% per year were derived from the SMM/ACRIM measurements during 1980 (Willson, R. C.et al., 1981, Science, 211, 700).

In May, 1980 a 3rd NASA rocket flight was conducted to provide the first calibration of the SMM/ACRIM experiment and the second of the NIMBUS 7 ERB. The results of the three SMM/ACRIM ACR's and the two ACR's on the rocket were within 0.05% of their average value of 1367.7 W/m2 (Willson, R. C. 1981, in Proc. IAMAP, Hamburg). The NIMBUS 7 ERB measurement exceeded the average ACR result by 0.6%, the same difference found by the 1978 rocket experiment. A 2nd WRC/PMO balloon flight experiment in June, 1980 found S=1366.8 W/m2. Differing by less than 0.1% from the 1980 rocket/SMM average, the PMO result is an independent substantiation of the NIMBUS 7 calibration error in SI units (Frohlich, C., 1980, in Proc. IPC, V).

The ACR instruments on rocket and SMM experiments and the PMO balloon instruments were extensively intercompared with each other and with reference pyrheliometers before and after the rocket flights and in conjunction with pre-flight testing of the SMM/ACRIM instrument. The results of these comparisons, together with independent characterization experiments has demonstrated systematic performance by the ACR and PMO instruments throughout their series of flight experiments at the 0.1% level. The average of the ACR and PMO experiments from 1976 through 1980 is S=1367.7 W/m2 (std dev = 0.05%). There is a systematic difference between ACR and PMO results of 0.11% which is also equal to the largest difference between their combined average and any single observation. From this it may be concluded that 0.11% is probably the lower limit of the SI uncertainty of S and the upper limit for long term solar variability between 1976 and 1980.

Short Term Variability

The principal evidence from flight experiments for short term solar irradiance variability comes from the SMM/ACRIM, NIMBUS 7 ERB and WRC/PMO balloon experiments (Willson, R. C., 1981. Sol. Phys., 74, 218 ; Hickey, J. A.et al., 1980, Science, 208, 281 ; Frohlich, C.et al., 1981, Sol. Phys. , in press ; Willson, R. C. et al. , 1981, Ap. J., 24, 185 ; Willson, R. C.et al., 1981, Science, 211, 700 ; Willson, R. C., 1981, Proc. IAMAP, Hamburg ; Frohlch, C. , 1980, in Proc. IPC, V). The general character of the 1980 ACRIM results is that of continuous variability below the 0 . 2% level superposed on a slowly decreasing average irradiance at the rate of 0.05% per year. The timescale of variability found in the ACRIM observations ranges from seconds to the duration of the record (300 days). The NIMBUS 7 data has less precision but was able to resolve several of the major occurrences of solar variability during 1980 providing a valuable confirmation of their solar origin.

Comparison of results from the 1980 WRC/PMO balloon and SMM/ACRIM experiments over three hours of simultaneous observation has revealed a high degree of correlation between them. Solar variability on time scales of minutes to hours with amplitudes ranging from 0.005 to 0.02% were observed simultaneously by both experiments. Three filter photometers on the PMO balloon experiment detected differential irradiance variabilty at three wavelengths (360, 580 and 778 nm) with an inverse amplitude dependence on wavelength (Brusa, R.et al., 1981, in Proc. IAMAP, Hamburg).

The SMM/ACRIM detected eleven temporary solar irradiance decreases associated with solar activity maxima during 1980. Eight of nine occuring between

April and October were spaced at fairly regular intervals near 24 days (+/- 3 days). The decreases, which correlate inversely with sunspot area, 2800 MHz flux and the Zurich sunspot number, were found to result from solar active region moodulation of the average irradiance by a combination of sunspot flux deficit and facular flux excess (Willson, R. C. et al. , 1981, Science, 211, 700 ; Willson, R. C., 1981, Proc. IAMAP, Hamburg ; Hudson, H. S. et al., 1981, Sol. Phys., in press ; Willson, R. C. , 1981, in preparation ; Hudson, H. S. et al., 1981, in "Sunspots and Solar Variability"). Close correspondence of projected sunspot areas and irradiance decreases together with the prediction of the deficit by models based on sunspot area leave little doubt about the cause of the principal variations observed by ACRIM. Longer term variability such as the 0.05% per year downward trend may be related to the envelope of solar activity over the 11 year activity cycle (Mitchel, M., 1977 in "Solar Output and Its Variation").

The radiative excess of faculae are significant at the solar total irradiance level, modulating the sunspot induced decreases, causing irradiance maxima before and after most of them and reducing their amplitudes. The irradiance cycle of active regions consistent with ACRIM results begins with sunspot development and the resulting flux deficit accompanied by formation of associated facular area whose flux excess persists until regional energy balance is restored (Willson, R. C. , 1981, in Proc. IAMAP, Hamburg ; Willson, R. C. , 1981, in preparation).

The six month persistence of the 24 day periodicity in solar activity maxima and the associated irradiance decreases during 1980 is the most intriguing aspect of solar behavior detected by the ACRIM experiment. It suggests a solar assymetry in the generation of solar activity may have existed during this time. A single major locus of activity generation embedded deeply in the convection zone and rotating with a synoptic rate of 24 days or less could have spawned the many solar active regions responsible for the major short term solar irradiance variability observed by ACRIM during these six months.

The total irradiance signature of the solar five minute ocsillation phenomenon has been detected in the SMM/ACRIM results by two independent investigators. No evidence of 120 minute oscillations has been found (Hudson, H. S., 1981, private comm. ; Frohlich, C., 1981, private comm.).

III. SOLAR GLOBAL OSCILLATIONS

(E. Fossat)

In the last few years, solar global oscillations have been observed so accurately that a seismological investigatin of the solar interior has now become possible. The very large interest of the solar and stellar physics community in this new field has been demonstrated by the important participation to the very stimulating recent meeting on this topic held in Crimea in September 1981. The reader will find all references concerning the last three years of research on solar global oscillations in the proceedings of this IAU Colloquium No 66 (D. O. Gough, editor).

Discovered in 1960 by Leighton, the five-minute oscillation of the solar surface was first suggested to be a global phenomenon by Ulrich ten years later. The confirmation of this global nature by the beautiful observations of Deubner in 1975 marked the begining of a rapid progress in this field. The publication of the calculation of theoretical frequencies for the same oscillating modes by Ando and Osaki, also in 1975, made immediately the comparison possible and that year can be regarded as the birth-date of what is now called helioseismology. Indeed, it was immediately recognized that global oscillations could be used as a powerful tool to probe the theoretical models of internal structure. It happens that there was at that time a rapidly growing interest for this problem of internal structure due to the deficiency of the measured flux of neutrinos with respect to the flux predicted by models of the solar core.

The next important step came in 1980 when a 120-hour non-stop observation of full-disk Doppler velocities performed at the geographic South Pole by Grec, Fossat and Pomerantz made possible for the first time to identify many different individual frequencies of oscillations in terms of spherical and radial hormonics.

Global oscillations of the solar sphere can be classified in p-modes and g-modes, depending upon the physical nature of the prevailing restoring force, pressure or gravity. The frequencies of p-modes are determined mainly by sound speed, whereas the g-modes frequencies are governed by the density gradient in the stably stratified radiative layers.

Since the amplitudes of the oscillations are very small, a linear theory can be used. Therefore, with a spherical sun taken as a first approximation, the solutions for the normal modes are separable in time, radius, and angular coordinates. The angular structure of each mode is a spherical harmonic of degree ℓ and tesseral order m and the eigenfunctions in radius constitute a discrete sequence and can be labelled with an integer n, which is called the order of the mode. The degree ℓ determiens an effective horizontal wavenumber k. The eigen frequencies ω depend on n and ℓ, but the spherically symmetrical models are degenerate in m. In reality, the Coriolis forces arising from the rotation split the degeneracy in m.

P-modes can exist with significant amplitudes in the whole solar sphere, while g-modes cannot exist in convectively unstable layers and are then confined in stably stratified radiative layers (internal gravity modes in the radiative envelope, or atmospheric g-modes in the chromosphere). To date, only p-modes and atmospheric g-modes have been identified with a good degree of confidence.

The observations of p-modes fall in two groups : Those that detect modes with high ℓ, and those which measure modes with low ℓ. In the range of periods around five minutes, the high degree p-modes have been observed extensively by Deubner since 1975, then also by Rhodes and Ulrich and by Duvall and Harvey. An individual identification of each mode is not possible in this range of high degree, due to unachievable temporal and mostly spatial resolution. However, 12 to 15 discrete ridges are currently resolved in the diagnostic k-ω plane and can be used for a detailed comparison with theoretical predictions. These modes have a significant amplitude which penetrate only a few percent of the solar radius in the convective zone beneath the photosphere. Therefore, they give us no direct information about the deep interior. However, comparison of measured and calculated frequencies have been used by Berthomieux et al., by Gough, and by Lubow, Ulrich and Rhodes to improve the theoretical models. The information provided by the increasingly accurate observations has enabled to eliminate standard solar models with low helium abundance. It has been proved also that the best agreement between theory and measurements requires an increase of the depth of the convective zone, which is equivalent to increasing the mixing length parameter in the theory of convection. According to the best fit, this depth has to be of the order of 0.3 solar radius, instead of a value closer to 0.2 which was generally accepted before (the last number given by Rhodes at the Crimean meeting was 0.27).

Due to the different penetration of different modes in the convective zone beneath the photosphere, the measurement of their rotational splitting has made possible a use of these oscillations as tracers of radial differential rotation. This was made by Deubner, Ulrich and Rhodes. A preliminary analysis indicated an increase of average velocity with depth, but the last results shown in Crimea do not confirm this result ; the increase is within the error bars. This investigation is obviously limited also to a depth of the few percent of the solar radius.

To get some information about the deeper interior, concerning the mean structure as well as the rotation rate, the observation of normal modes of lower degree is required. Very low degree oscillations can be accessible by Doppler observations integrated over the entire solar disk (the sun observed "as a star") or a large fraction of it. The full disk measurements made in the Canaries Islands and at the Pic du Midi by the British group of Isaak and made at the geographic South Pole by the group of Nice are sensitive to modes of degree $\ell \lesssim 3$ (modes of higher degree are cancelled by averaging over the disk surface). The differential measurements (central part minus outer annulus) made in Crimea and at Stanford are sensitive to degree $3 \lesssim \ell \lesssim 6$. In both cases, the limited number of modes accessible by the observation make possible to get a discrete power spectrum, provided the length of the data set is long enough to provide the adequate resolution.

Observational evidence of this discrete spectrum was first presented by the Isaak's group at Tucson in the spring of 1979 at the meeting on non-radial and non-linear stellar pulsations (Hill and Dziembowsky, eds). The normal modes observed were still in the five-minute range and they were supposed to be radial and very low degree spherical harmonics of relatively high order (about 15 to 30). The high ω-resolution required to resolve each individual peak in this discrete power spectrum could not be achieved with the 12-hour maximum observing time under mid-latitudes. By going to observe at the geographic South Pole, Grec, Fossat and Pomerantz were able to get a non-stop observing run of 120 hours with a very high signal to noise ratio due to the unique atmospheric transparency and the removal of almost all sysmetatic data drifts in this site. At least 75 different peaks were thus resolved, corresponding to oscillations of periods between 3 and 9 minutes and amplitudes between 4 and 40 cm/s. A comparison by Grec of the measured periods with those predicted by an asymptotic approximation of the theory made possible an unambiguous complete identification of these 75 normal modes. This was confirmed by a more precise comparison making no approximation, by Christensen-Dalsgaard and Gough. Their model which provides the best fit (not quite adequate, yet) is a so-called standard model with helium and heavy elements abundances of about $Y = 0.25$ and $Z \approx 0.02$. Another comparison made by the Leige group (Gabriel, Scuflaire and Noels) confirms that a depth of about $0.3\ R_{\odot}$ is required for the convective zone, together with a normal chemical composition to get the best fit.

Also measuring Doppler shifts, the differential method used in Crimea and at Stanford has started to be used for the research of normal modes of oscillation in the five minute range. An analysis made by Scherrer during the Crimean meeting on a very limited amount of data has shown, by comparison with the Antarctic results, that three sets of frequencies could be resolved, one of them being identified as modes of degree $\ell = 3$. Two others are then presumably to be attributed to $\ell = 4$ and $\ell = 5$. Hence, we have now more than one hundred different low degree p-modes which are, or will be soon, unambiguously identified.

These low degree-high order p-modes first discoverd in Doppler shift measurements have also been looked for in brightness fluctuations. For this investigation, Deubner has used the sunlight reflected by Uranus and Neptune, whereas separately, Hudson and Frohlich are using the solar irradiance data from SMM. In both cases, a careful comparison of the Fourier spectra with those of Doppler shift indicates that the brightest peaks just get above the noise level, with amplitudes of a few ppm. The amplitudes and relative phases of velocity and white light oscillations depend on the reaction of the upper layers of the convective zone to oscillations with periods comparable with the eddy turnover time. A knowledge of this reaction is important for understanding not only the dynamics of the solar convectin zone, but also the driving and damping of certain classes of intrinsically variable stars, such as the cooler β-Cephei stars or RR Lyrae variables. Here again, a new field is open for solar physicists.

A great deal of efforts is also made in finding convincing evidence for global oscillations in the measurements of solar diameter or of the shape of the limb profile by Hill, by Stebbins and by Yerle and Rosch. Three reproducible spectral peaks around 0.42 mHz of frequency have been tentatively interpreted by Hill as low degree - low order p-modes.

In spite of the impressive amount of accurate observational data which has now become avilable, it has been shown by Gough, by means of a numerical simulation, that the solution of the inverse problem (to build a solar model, which reproduces the observed normal modes frequencies) is not accurate better than 20% in the deep interior, due to the close similarity in these regions of the contribution functions of all observed p-modes. The identification of even a very limited number of g-modes would increase this accuracy by at least one order of magnitude. This is of fundamental importance with respect to the neutrino problem. The identification of any internal gravity mode has not been possible yet ; it will be one the major goals of observers in the near future.

Another very important point concerns the lifetime and the excitation or damping mechanism of these p-modes. This is the matter of two debates which are presently still open between observers and between theoreticians. The analysis of the Antarctic data indicates a mean lifetime of about 2 days for the amplitude (measured in the mean width of the spectral peaks as well as in the time behaviour of one individual oscillation). On the other hand, Van der Raay presented in Crimea the results of the analysis of 271 hours of new data recorded during 28 days in the Canaries Islands by the British group. In spite of the problem of side bands due to the discontinuous nature of this data set, it has been shown that the splitting of individual peaks in zero, three or five components, if attributed to a rotational effect, makes possible an identification in respectively $\ell = 0$, 1 or 2. This identification is consistent with the one made with the Antarctic data. It would therefore mean that the lifetime of the mode is at least 28 days, to make possible the resolution of this splitting. The corresponding period of rotation would be of 12.2 days. Very speculative possible implications of this fast rotation have been presented by Isaak, who suggests the existence of a strong and deep magnetic rotator of about 3 Megagauss. Because the oscillations observed by the Nice group from the South Pole and by the Birmingham group from the Canareies Islands are the same solar oscillations, the debate will have to find an agreement. The consequence are very important on the driving process of these oscillations ; a lifetime of 2 days favours the interaction convection - oscillations, while a very long lifetime is more in favour of a self excitation by Kappa-mechanism. The possibility, or impossibility of measuring the rotational splitting of these modes is obviously also of great importance, even for testing the theories of gravitation because it may make possible an access to the quadrupole moment of the gravitional field J .

Regarding now the chapter of oscillations dominated by gravity, surface g-modes have been observed for the first time by Brown, as two discrete lines just emerging from noise in the lower ω-portion of the k-ω plane. This will be one more piece of information to solve the puzzle in understanding the physics of the solar atmosphere. To date, no internal g-mode has been identified. Their period is at minimum of 40 minutes and in this range of long periods, the observations are much more difficult. Most of the periodicities reported in this range (0.7 hour to a few hours) in Doppler shifts, diameter, optical brightness or radio wavelength intensity can be regarded as very suspicious and can be interpreted as spurious effects. However, a special mention must be made of the 160 minute oscillation, discovered in Crimea in 1974 and observed in quite good agreement both in Crimea and at Stanford since 1976. First suspected to be the ninth harmonic of the one-day period of data sampling, it has now proved to have a period slightly longer (the last value is 160.008 minutes) which is regarded as a strong reason to rule out this interpretation. From time to time, this period is found in another solar signal of different nature (Doppler, brightness, infrared, radio, limbshape, etc ---), but in each case the observation is too short or the signal to noise ratio too low to really provide a very strong additional piece of evidence. The combined power spectrum of the Crimean and Stanford data presented by Scherrer is now the strongest result, which display only one significant spectral peak in the range of periods between one and four hours. Presently, the solar origin of this spectral peak is its most reasonable interpretation (although a possible effect of beat between the sampling rate of the data and one of the discrete peaks in the five minute range is being investigated in detail by Delache). However, its physical nature is still totally not understood. It could be a g-mode favorably excited by non-linear coupling with other oscillations. In this case, no possibility of identification of this g-mode has been found yet. Recently, Kotov and Koutchmy have noted that this period is not only close to the ninth harmonic of a day, but it is also close to a harmonic of the period of spin of Jupiter, Saturn, Uranus and Neptune. By chance ?

The possibility of identifying global solar oscillations has open this new field of helioseismology. The result already obtained are very striking, but overall they have proved to be so promising that much more exciting and perhaps unexpected information will certainly be obtained in the near future and may give access to new elements to answer important questions such as a better knowledge of the deep solar core, of the theory of convection, the theories of gravitation and the nature of the solar cycle.

IV. MAGNETIC ACTIVITY AND ROTATION IN THE SUN AND STARS

(R. W. Noyes)

An important topic of recent work in both solar and stellar physics is the study of magnetic activity in Sun-like (ie, lower-main sequence) stars. A number of recent reviews of this and other topics concerning "the Sun as a star" are available (eg, 28 064 045 ; Linsky, J., 1981, in "Solar Phenom.in Stars and Stellar Systems" ed Bonnet and Dupree ; Rosner, R., 1980, SAO Report No 389, 79 ; Noyes, R. W. 1981 ; Zwaan, C., 1981, both in "Solar Phenom. in Stars and Stellar Systems"). Here we concentrate on the most recent research concerning the overall level and variability of magnetic activity in Sun-like stars, as it depends on stellar mass, rotation rate, and ege.

Magnetic Fields in Sun-like Stars

(A) DIRECT DETECTION OF MAGNETIC FIELDS ON LATE-TYPE DWARFS

Magnetic fields are difficult to detect on Sun-like stars by traditional Zeeman polarization analysis techniques (Brown, D. N. and Landstreet, J. D., 1981, Ap. J. 246, 899). Because fields of opposite magnetic sign nearly cancel, the spatially-integrated Zeeman shift is nearly zero. Tinbergen and Zwaan (1981, A.and Ap., submitted) suggest that intrinsic linear polarization observed on nearby lower main sequence stars is produced by transverse magnetic fields from active regions near the equatorial stellar limb. However, the most successful way to detect magnetic fields in stars with mixed surface polarities appears to be through the Zeeman broadening of lines, rather than through polarization measurements. Robinson (1980, Ap. J. 239, 961) showed that differential broadening of lines with different Zeeman sensitivity is measurable in spatially-integrated solar plage radiation, and Robinson et al.(27 116 014) applied this technique to two late-type (G8 and KO) main sequence stars, and inferred fields near two kilogauss covering 10% or more of the stellar disk. This is a much larger area than the fractional solar area covered by active regions, although the field strengths are comparable. Marcy (1981, Ap. J.248, 624) reobserved one of these stars and found the fields to have become undetectable, implying that magnetic field regions are not always present on the face of the star.

(B) LUMINOSITY VARIATIONS AS MAGNETIC FIELD INDICATORS

Magnetic fields can in principle affect the luminosity of late-type stars in at least two ways ; either through creation of dark patches (sunspots) or bright patches (stellar photospheric faculae), or by modulation of the convective efficiency of the entire convection zone.

Until recently, observational evidence of solar luminosity variations associated with sunspots was lacking ; the existence of compensatory brightening of the photosphere away from sunspots, sufficient to maintain the total solar liminosity constant, could not be ruled out. However, radiometers aboard the Solar Maximum Mission spacecraft (Willson, R. et al., 1981, Science, 211, 700 ; Hudson, H. S. et al., Sol. Phys., submitted) have revealed a clear solar irradiance variation, quantitatively consistent with expectations from the observed area and brightness of spots, assuming constant emission from the quiet photosphere. This important observation supports the interpretation that the quasi-periodic photometric modulation of both certain M dwarfs (BY Dra stars) and the K subgiant componets of RS CVn stars, is due to dark spots on the stellar surfaces, uncompensated by corresponding surface flux increases from the remainder of the photosphere ; for recent reviews of the star-spot phenomenon see Hartmann (1981, in "Solar Phenom. in Stars and Stellar Systems"), and Hall (1981, in "Solar Phenom. in Stars and Stellar Systems"). The observational evidence for dark spots with temperature deficits of up to 1200 K relative to the surrounding photosphere continues to grow, both from color determination (eg, 25 119 029) and spectroscopic indicators (22 122 050).

Foukal (1981, in "Proc. Sac. Peak Sunspot Workshop"), Foukal and Vernazza (26 080 037), and Hartmann and Rosner (25 064 077) discuss some of the physical implications of energy storage in the convection zone, associated with sunspots or starspots.

In addition to producing localized dark starspots or bright faculae which can modulate total stellar luminosity, magnetic fields could alter the overall properties of stellar convection zones and create a liminosity modulation that varies with the stellar activity cycle, as pointed out by Spiegel and Weiss (28 080 024) and Dearborn and Blake (27 080 025). Space-borne solar radiometric measurements over a solar cycle are needed to determine whether such processes occur in the Sun, and hence can be expected in other stars.

(C) CHROMOSPHERIC AND CORONAL RESPONSE TO SOLAR AND STELLAR MAGNETIC FIELDS

It is well known that emission in the Ca II K line core is quantitatively correlated with the amount of solar magnetic flux within an observed resolution element in the Sun (eg, 14 080 019). Recent observational work supports the extension of the relation to other Sun-like stars. The fields observed by Robinson et al.(27 116 014) were found on "active chromosphere" stars, whose integrated Ca II emission lies well above "quiet chromosphere" stars of the same spectral type (see, eg, 22 114 053). Furthermore, Ca II enhancements from "spotted" stars are associated with photometric minima (ie, presence of spots on the stellar disk), as on the Sun (Baliunas, S., and Dupree, A., 1982, Ap. J. submitted).

Solar coronal emission commonly occurs within magnetic loops whose footpoints are rooted in photospheric field structures, and whose temperature T, pressure P, and physical size L simply related in terms of scaling laws : $T \sim (PL)^n$ were $n \sim 1/3$ (see 21 074 007 ; Pallavicini, R. et al., 1981, Ap. J. in press ; Withbroe, G. L., 1981, in "Active Regions" ed Orrall). Not only is solar coronal emission spatially related to the field structures, but the gas pressure within coronal structures appears to vary with surface field strength approximately as $B^{1.6}$ (27 074 052).

These results readily find application to the outer atmosphere of cool stars. Holt et al. (26 120 012) and Walter et al. (27 119 001) have observed X-ray emission from Capella and interpreted in terms of a magnetically-confined corona consisting of loops, as in the Sun. From X-ray spectroscopic data Swank et al. (1981, Ap. J. 246, 208) found two regimes of temperature on RS CVn stars. The lower-temperature material ($T \sim (4-8) \times 10^6$ K) is probably confined in loops near the surface, as in the solar corona, while the hotter material ($T \sim (20-100) \times 10^6$ K) probably extends far above the surface, and is possibly associated with the binary nature of the RS CVn star pair.

The Einstein X-ray satellite has revealed strong X-ray emission from lower main sequence stars, (Vaiana, G. S. et al., 1981, Ap. J. 245, 163), with notably strong emission form late (K and M) main sequence stars for which acoustic coronal heating is thought to be totally inadequate to produce coronae ; this is further evidence for the presence of magnetic fields, and for their importance in coronal heating.

In general, as expected by analogy to the Sun, stellar coronal (X-ray) emission is correlated with Ca II chromosperic emission for lower main sequence stars (Mewe, P. et al., A. and Ap., submitted). However, the coronal emission rises more steeply with increasing activity than does chromospheric emission (Ayres, T. R.et al., 1981, Ap. J., 247, 545).

Like the solar corona, stellar coronae should give rise to significant radio emission. Gary and Linsky (1981, in "Solar Phenom. in Stars and Stellar Systems") report the detection of 6cm radio emission from two single late-type dwarf stars, and argue that the emission is due to gyroresonance emission of thermal coronal electrons in coronal magnetic fields of several hundred gauss, such as might occur above starspots ; the process is identical to that observed in the solar corona above sunspots.

The Rotation/Activity/Age Connection

(A) THE DEPENDENCE OF MAGNETIC ACTIVITY ON STELLAR AGE

It has long been realized that rotation and activity decrease with age among late-type main sequence stars with convection zones ; a recent review is given by Skumanich and Eddy (1981, in "Solar Phenom. in Stars and Stellar Systems"). Recent work confirms this trend. For example, X-ray emission from coronae of Hyades stars (age $\sim 7 \times 10^8$ years) are typically 30 times as great as that from the active solar corona (Stern, R. et al., 1981, Ap. J. in press). The general relation is significantly refined by the work of Vaughan and Preston (28 114 107) who found that although lower main sequence stars in the solar neighborhood show generally decreasing Ca II emission with increasing age, there is a "gap" in Ca II emission level at an intermediate age of 1 2 billion years. If a real physical effect, this gap implies that at a certain age the production of surface magnetism on stars precipitously decreases to a lower level. Whether the gap represents a real physical effect in stars rather than an artifact of incomplete sampling, or a non-constant stellar birthrate, is not absolutely certain at this writing. However, support of its reality is provided by Soderblom (1982, Ap. J. Suppl. in press), who derives a lithium abundance-age calibration and applies it to G2 V stars, finding that the relation between Ca II emission and age suffers a drop at age about 10^9 years. Duncan (1981, Ap. J., 248, 651) reaches a similar conclusion.

The organization of surface magnetic activity on younger stars (above the gap) appears to differ from that on older stars (below the gap). Vaughan et al.(1981, Ap. J. in press) report from rotational modulation studies that the younger stars are typically characterized by extremely assymetrical chromospheric emission distributions, giving rise to much larger rotational modulation than shown by the older stars. Furhtermore, the emission patches, presumably the stellar analogue of solar active regions, frequently survive unchanged for many months --- a time uncharacteristically long in comparison to typical solar active region chromospheric emission.

(B) THE DEPENDENCE OF MAGNETIC ACTIVITY ON ROTATION

It is widely believed that the basic parameter determining the level of magnetic activity in convecting stars is the star's rotaion rate ; the age-dependence of activity is then simply a result of the spin-down of rotation with time. Study of the rotation-activity connection requires determination of stellar rotation, which may be being carried out in three ways ; (a) measuring projected rotation velocity v sin i from line broadening (eg, smith, M. A., 1979, PASP, 91, 737 and references therein ; Soderblom, D. R., 1982, Ap. J. Suppl. in press), (b) measuring rotation period from rotational modulation of surface inhomogeneities (28 116 026 ; Middelkoop, F., 1981, A. and Ap. in press ; Vaughan, A. H. et al., 1981, Ap. J. in press ; Hallam, K. L. and Wolff, C., 1981, Ap. J., 248, L72), and (c) assuming that the rotation rate of stars in binary pairs (eg, RS CVn systems) equals the orbital period of the binary pair (see for example, Hall, D. S., in "Solar Phenom. in Stars and Stellar Systems "). Rotational velocities are now known for many stars whose activity levels are also known, thus making it possible to put the rotation-activity connection on a firm footing. Ayres and Linsky (28 114 084) showed that in the (coeval) binary system Capella, the more rapid rotation has the greater chromospheric activity. The same authors found that for a sample of 15 stars ranging from the Sun to RS CVn systems, the ratio L_X/L_{bol} of X-ray to total bolometric luminosity varies as (v sin i $)^3$. Pallavicini et al. (1981, Ap. J. in press) find from Einstein X-ray data that L_X/L_{bol} varied as (v sin i $)^2$ from G to M dwarfs ; similar results were found by Stern, R et al. (1981, Ap. J. in press). Walter and Bowyer (1981, Ap. J., 245, 671) and Walter (1981, Ap. J. 245, 677) found $L_X/L_{bol} \sim$ v sin i. Walter (1982, Ap. J. in press) tried to reconcile these conflicting results by postulating a break in slope at rotation period of 12 days for G dwarfs ; stars with longer period show a steeper decline of L_X/L_{bol} with increasing period than those with shorter period.

If the Vaughan-Preston gap represents a physical near-discontinuity in the level of magnetic activity production at particular age, the question arises whether stellar rotation rates also suffer a discontinuity at that age or whether the rotation decreases steadily with time, and that at a critical rotation rate the rotation-dependent magnetic field production sharply decreases. Support for the latter suggestion is provided (Middelkoop, F., 1981, A. and Ap., submitted) showing that, for a sample of late F and early G stars at least, the Ca II emission drops slowly with v sin i except for a narrow range of v sin i corresponding to a period about 11 days, where the Ca II emission drops very steeply.

(C) THE DEPENDENCE OF MAGNETIC ACTIVITY ON CONVECTION ZONE DEPTH

Rotation is not the only critical parameter affecting magnetic activity level ; another is the depth of a star's convection zone, or equivalently, spectral type or mass of a main sequence star. Walter (1981) found that G8-K5 main sequence stars showed a factor of 10 greater value of L_X/L_{bol} than F8-G5 stars with the same rotation rate. Vaiana et al. (1981, Ap. J., 245, 163) find that the surface flux f_X of K and M dwarfs increases steadily with advancing spectral type, even though the angular velocity decreases with advancing spectral type along the lower main sequence (Vaughan, A. H. et al., 1981, Ap. J. in press). This suggests a strong increase of surface magnetic activity with increasing depth of convection zone (see eg, Linsky, J., 1981, in "Solar Phenom in Stars and Stellar Systems"). Such an increase finds a possible explanation in terms of dynamo theories of the generation and surface eruption of magnetic fields (Durney and Robinson 1981, Ap. J. in press ; Rosner and Vaiana 1981).

(D) ACTIVITY CYCLES AND THEIR DEPENDENCE ON ROTATION AND CONVECTION ZONE DEPTH

Vaughan (28 114 108) noted that of the stars monitored for activity cycles by Wilson (22 114 053), those with smoothly varying "solar-like" cycles lay below the Vaughan-Preston gap in stellar Ca II emission level, while stars above the gap showed large irregular fluctuations, without clear signs of periodicity. Vaughan et al.(1981, Ap. J. (November)) extended this to note that clear cycles appeared only for stars with rotation period exceeding about 20 days ; all such stars lie below the gap. Aside from this result, no apparent relation was found between cycle period and either rotation period or convection zone depth (ie, spectral type).

Belvedere, Paterno, and Stix (28 065 060) carried out $\alpha - \omega$ dynamo calculations for lower main sequence stars, and predict an increase in activity cycle period toward later spectral types, which is especially sharp in the range F5 to K0. This is at odds with the observations mentioned above ; clearly such observations can provide new and useful constraints to dynamo theories.

(E) THEORETICAL IMPLICATIONS OF THE VAUGHAN-PRESTON 'GAP'

If the Vaughan-Preston gap is a true physical effect, it strongly suggests two different modes of magnetic field generation, depending principally on stellar rotation rate. Durney et al. (1981, P.A.S.P. in press) interpret the gap as *reflecting a higher mode of the* $\alpha - \omega$ *dynamo for stars whose* "dynamo number" (proportional to stellar rotation rate) exceeds a critical value. Knobloch et al. (1981, M.N.R.A.S. in press) on the other hand, argue that above a critical rotation rate convection tends to occur in rolls aligned parallel to the axis of rotation, leading to large toroidal fields but no helicity to recreate poloidal fields and produce a cyclical activity variation. Gilman (1981) reports non-linear dynamo calculations in which two classes of solution are found — one in which strong magnetic fields suppress the differential rotation and lead to strong, non-reversing surface fields, and one in which weaker fields allow differential rotation to persist, creating the normal reversing dynamo. The explicit role of rotation in determining which class of solution prevails has not been calculated.

(F) IMPLICATIONS FOR THE EVOLUTION OF SOLAR MAGNETIC ACTIVITY

It has sometimes been suggested (eg, Blanco, et al. 1974, A.and Ap. 33, 257 ; Smith, M. A., 1979, P.A.S.A., 91, 737) that the Sun has anomalously low Ca II activity and rotation rate for its age. However, Soderblom (1982, Ap. J. Suppl., in press) finds that the rotation rate of the Sun is only about 1 standard deviation below the mean observed rotation rate for similar stars, so there may be no strong evidence that the Sun is significantly anomalous compared to other lower-main sequence stars. If the Sun is typical, implications of the above results for its earlier history are (Noyes, R. W., 1982, in "Physics of the Sun" National Academy of Sci.) ; when the Sun was a younger star (age less than about $(1-2) \times 10^9$ years) it had a rapid rotation rate (period less than about 10 days), high levels of surface magnetic activity, and pronounced chromosperic and coronal emission (eg, X-ray emission perhaps 20 times the present value). The solar activity cycle was either absent or, if present, was heavily masked by large irregular outbursts of activity. When its rotation decreased (through solar wind torques) to a period longer than about 10 days, its field-production rate dropped rapidly to a lower level, presumably because of a change in character of its dynamo. Activity levels dropped, and at some later time its quasi-periodic activity cycle emerged as a dominant characteristic of its overall magnetic variability.

V. PHOTOSPHERIC MAGNETIC CONCENTRATIONS AND RELATED PROBLEMS

(H. C. Spruit)

Reviews related to this topic may be found in Livingston and Stenflo (Reports on Astronomy Vol XVIIa), Cram (26 075 009), Schmidt (26 075 010), Spruit (in "The Sun as a Star" ed S. Jordan, NASA SP-450).

New Observation

A line ratio method using 3 lines has been used by Wiehr (22 080 016) to measure the intrinsic field strengths in plages and pores. The field strenghths found agree with those found by previous authors. Tarbell (22 072 063) developed a method to deduce intrinsic line profiles from unresolved measurements. He finds field strengths around 1300 G, a reduced equivalent width, and the downdraft velocities of 0.6 - 0.9 km/s . The profiles indicate that the downdraft velocity and the field strength are positively correlated in the magnetic elements, in agreement with finding by Frazier and Stenflo (22 072 041). Livingston found that field strengths of elements in quiet areas are significantly lower than in active areas ; field strengths below 1000 G do occur. Tarbell, Title and Schoolman (25 075 010) obtained magnetograms at very high spatial resolution (0.5"). They confirm the existence of high field strengths. An upper limit of 50 G was placed on the strength of a possible weak-field component such as the 'inner network fields' observed at Kitt Peak. Semel (Astron. Astrophys. 97, 75) found a correlation between the apparent (unresolved) field strength and the equivalent width of the line. Vertical oscillations within the magnetic field were found by Giovanelli, Livingston and Harvey (22 080 047), at periods of about 5 min. They behave like the 5 min oscillation of nonmagnetic areas and are usually but not always in phase with it. Since only coherent motion in many magnetic elements is detected in this method, the oscillation seen is almost certainly due to driving by the ordinary 5 min oscillation of the photosphere. An interpretation in terms of the oscillation properties of an individual tube has, however, been given by Roberts.

Magnetograms taken in chromospheric lines have been used by Giovanelli (28 075 024) to explore the magnetic structure in the height range where the fields of individual flux tubes flare out and merge with each other. A method to interpret these magnetograms quantitatively was developed by Jones and Giovanelli (Sol. Phys. 1981). Giovanelli finds from these data that the interface between the magnetic field and the underlying nonmagnetic atmosphere lies at a rather low height, about 400 km. This would not be compatible with existing models of this interface like those by Gabriel (18 073 076), which require heights of 1000-1500 km.

High resolution pictures of faculae taken in the continuum at 470, 310, 210 and 200 nm were used by Herse (26 071 004) to derive the center-to-limb variation of the intensity contrast and the number density of facular points. The number denstiy decreases strongly towards the limb. Lifetimes and time scales of intensity fluctuations were determined by Hirayama (22 072 009) and by Komle (26 075 018), with similar results. Komle found also from magnetic measurements an rms inclination with respect to the vertical of 20° . Since the buoyancy of a magnetic flux tube is very strong (25 075 016), this cannot be a steady inclination of the tube, and more likely it represents a swaying motion of the tube. Measurements of the continuum contrast near the limb by Klabunde (thesis, 1981, Cal. State Univ., Northridge) indicate an increasing contrast down to at least $\cos\theta = 0.05$.

Interpretation, Flux Tube Models

Interpretations of contrasts in terms of plane parallel or 'hot cloud' models were given (26 071 004 ; 22 072 009). Usually however it is realized that such interpretations give widely different results depending on the type of data used. This is due to at least two complicating factors. First, the temperature structure is probably strongly dependent on the size of the magnetic element (21 072 010 ; Spruit and Zwaan, Sol. Phys 70, 207). Secondly geometrical effects are quite strong for structures of the observed sizes (200 km or less). Two-component models based on line profiles taken at the disk center are relatively unaffected by the geometrical complications. Such models were given by Chapman (26 072 006) and Koutchmy and Stellmacher (21 071 039). They can be seen as approximations to the physical situation in a magnetostatic flux tube. In the photospheric layers the interior of such a tube is predicted to be cool with respect to its surroundings for all sizes, though due to optical depth effects it will appear dark only for sizes greater than about 0"8 (18 071 100 ; 20 080 072). This agrees with continuum observations at disk center (Spruit and Zwaan, Sol. Phys. 70 207 ; Foukal, Duvall and Gillespie, 1981). At greater heights (the temperature minimum and higher) some form of heating is needed to explain the line contrasts. The continuum contrasts near the limb can be explained satisfactorily with Spruit's (18 071 100) 'bright wall' effect, down to cos θ = 0 . 1. The high contrast at the extreme limb (cos θ = 0.05) seen by Klabunde (see above) and Chapman may possibly be due to the real heating in the layers around the temperature minimum. Continuum contrasts due to a hot flux tube wall were studied by Caccin and Severino (26 072 005). The effects of two-dimensional radiative transfer in the wing of Ca K, in narrow structures like flux tubes was studied by Owocki and Auer. They find that lateral escape of photons is important, but that it has very little effect on spatially averaged line profiles.

Magnetohydrodynamics of Flux Tubes

The theory of magnetic flux tubes has undergone a healthy growth. We will make a distinction here between 'thin tube' theory which is based on an approximation in which variations in physical quantities across the tube are neglected, and cases where this assumption is not made, but where the effects of gravity are neglected instead. In the latter, tubes of arbitrary diameter can be studied. We discuss these first. Wilson (25 062 001 ; 27 062 136 ; 27 062 095), Wentzel (25 062 069 ; 25 106 001), and Roberts (1981) and Edwin and Roberts (1981) studied the wave modes of magnetic interfaces of flux tubes. The modes can have the character of surface waves or body waves. Wentzel (25 062 069) interprets the rapidly propagating wave motions seen in Hα fibrils as surface waves.

The behavior of thin flux tubes can be studied in an arbitrary stratified gravitating fluid. A general equation of motion for such flux tubes was derived by Spruit (Astron. Astrophys., 98, 155). The tubes have three modes of motion, which are analogous to the modes of an elastic wire under tension (Spruit, Sol. Phys., Vol 75). One is an Alfven wave which propagates twists along the tube. The other two modes involve fluid motions along and perpendicular to the tube. For a vertical tube there is a purely longitudinal mode and a purely transversal wave. The transversal wave in photospheric flux tubes may be important in transferring mechanical energy from the convection zone to the atmosphere (Spruit, Astron. Astrophys., 98, 155). The longitudinal mode of a vertical flux tube has been studied extensively. Defouw (18 080 013), Roberts and Webb (21 080 013) and Webb and Roberts (26 080 036) studied the case when the mode behaves as a wave. The wave has a cutoff frequency below which it is evanescent. Rae and Roberts (1982) studied the response to a longitudinal pulse in the tube. A wavefront propagates at the 'tube speed', beyond which a standing oscillation at the cutoff frequency occurs. This is analogous to the response of an isothermal atmosphere to an acoustic pulse. If the stratification is sufficiently superadiabatic, it was shown by Webb and Roberts, Spruit and Zweibel, Unno and Ando, and Parker that the mode can become unstable (22 080 054 ; 25 075 020 ; 27 075 005 ; 21 071 011). In the Sun, flux tubes are unstable if their field strength at the surface is less than 1300 G. Such unstable flux tube are transformed by the instability either into a dispersed weak field or into a stronger flux tube of about 1800 G (25 062 055).

In the studies mentioned thus far, only adiabatic motions in the flux tube were considered. If exchange of heat between the tube and its surroundings is taken into accounts, the wave modes will be damped (28 062 087 ; 28 062 088), and instability can be changed into an overstable oscillation (25 062 055).

The strong downdrafts observed in photospheric flux tubes (21 080 046) continue to pose a problem for flux tube theory. Giovanelli (20 071 033) has proposed inflow by diffusion of neutral atoms with respect to ions across the magnetic field. The effect appears to be too small, however, to explain the observed velocities. Since the downdraft measurements are not made on individual flux tubes but represent some ensemble average, it is possible that the downdraft is not a net mass flow but results from an intensity-velocity correlation in a fluctuating flow as shown by Spruit (25 062 055). The effects of a steady downflow in a flux tube were studied by Unno and Ribes (25 071 015). The downflow of fluid along field lines during the eruption of new flux has been calculated by Shibata (Sol. Phys., 66, 61).

An important connection between flux tubes and the origin of spicules was made by Hollweg et al (1981) and Hollweg (1982). Nonlinear numerical simulation of an Alfven wave generated by a pulse at the photosphere and propagating upward along an expanding tube gives results that look rather like a spicule. A quite similar result is obtained if instead of an Alfven wave an acoustic pulse (corresponding to the longitidinal tube wave) is allowed to propagate upward along an expanding rigid tube.

Distribution of Flux Tube, Connections with the Dynamo

The process of emergence of a flux tube from below and the subsequent motion of the foot points over the surface, under the action of a supergranular flow, was studied by Meyer et al (25 075 016). The effect of the buoyancy is very strong near the surface, making the tubes almost vertical in the photosphere. Small flux tubes are carried around by the flow, and are swept to the boundaries of the supergranule cell. Bigger ones resist the flow. Parker (1982) showed that around fixed flux tubes the convective flow will organize itself such that the tubes are at the cell boundaries. The aerodynamic forces acting on flux tubes moving through a fluid were studied by Parker (25 062 064 ; 25 062 077 ; 25 062 079). Neighboring flux tubes which moved together are pulled towards each other by these forces.

The distribution of sizes of flux tubes in an active region was studied by Spruit and Zwaan (Sol. Phys., 70, 207). A maximum in the surface area covered was found at a diameter of $0\overset{\prime\prime}{.}8$. The power spectrum of the surface distribution of magnetic fields was compared by Knobloch and Rosner (Ap. J., 247, 300) and Knobloch (Ap. J., 248, 1126) with theories of turbulent diffusion. They find that the turbulent motions must be three dimensional, that the effective diffusivity is large, at least of the order of 10^{12} cm/s . The depth at which the motions occur which are responsible for the observed power spectrum is found to be 15,000 km or more. Knobloch (Ap. J., 247, L93) used a simple model for the nonlinear interaction between convection and a magnetic field to derive a theoretical power spectrum that compares well with observations. The relative frequency with which unipolar and mixed-polarity areas occur during the solar cycle has been given by Giovanelli (1982).

Parker (1982) has studied the effects which the flux tube nature of a magnetic field may have on the operation of a turbulent dynamo and found no new effects. The speed of rise of horizontal flux tubes due to buoyancy has been reinvestigated by Schussler (28 062 033) and Kuznetsov and Syrovatskii (26 075 019). These authros find rather low speeds, which allow the flux to be kept within the convection zone during the cycle. Acheson (25 062 087 ; 25 075 001 ; 25 075 021) and Spruit and Van Ballegooijen (1982) have studied the breakup of horizontal flux tubes by buoyant instability. This process will destroy the toroidal field on a short time scale unless the stabilizing effect of solar rotation is strong enough. The structure of magnetic flux tubes which have emerged from deep-lying horizontal tubes was investigated by Van Ballegooijen (1982).

Piddington (1981, 1982) repeated his objections to the turbulent dynamo theory and stressed the importance of twists stored in the emerging flux for generating chromospheric and coronal activity.

VI. CORONAL LOOP STRUCTURE AND ITS HEATING MECHANISM
(E. R. Priest)

Coronal Loops

The coronal magnetic configuration consists of open flux tubes containing out-flowing solar wind plasma and closed flux tubes (ie, coronal loops) containing plasma at a higher density and higher temperature. The closed regions are inhomogeneous, so that certain flux tubes tend to stand out, possibly because of an inherent filamentation of the coronal field or a variation in the footpoint pressures. Such coronal loops were studied extensively with the Skylab satellite (28 003 011 ; 28 076 019 ; 27 074 038 ; Orrall, F. Q. 1981 ; Webb, D. F.1981, both in "Skylab Active Region Workshop" ed Orrall) and they may be classified into different types (22 074 005). Interconnecting loops joining different active regions have lengths 20-700 Mm (1Mm= 10^6 m), temperatures of about 2 x 10^6 K and densities of 7 x 10^{14} m^{-3} , while quiet-region loops are cooler ((1.5 - 2.1) x 10^6 K) and rarer ((0.2 - 1 . 0) x 10^{15} m^{-3}) and active-region loops (in X-rays) are hotter ((2.2 - 2.8) x 10^6 K) and denser ((0.5 - 5.0) x 10^{15} m^{-3}). A subclass of active-region loops known as sunspot loops have as their footpoints sunspot umbrae and contain low-temperature (10^5 K) cores. Flare loops may be divided into two classes, namely post-flare loops with L = 10 - 200 Mm, $T \sim 5 \times 10^6$ K, $n < 10^{17} m^{-3}$ and simple (or compact) flare loops 5 - 50 Mm long with $T < 4 \times 10^7$ K and $n < 10^{18} m^{-3}$.

The two main realizations of the past few years about coronal loop plasma are that it is dominated by the magnetic field and that it is extremely dynamic, showing continual activity with a wide range of flows, especially inside active region (Athay, R. G., 1981 ; Priest, E. R., 1981 ; both in "Skylab Active Region Workshop") small-scale flows of 10 - 30 km/s are suggested by nonthermal broadening, and ground-based instruments show continual surging, coronal rain and spicules, while space observations (Athay, R. G., 1981 ; Brueckner, G. E., 1981 ; both in "Skylab Active Region Workshop") reveal small transient explosions and microsurges, as well as large-scale steady upflows over sunspots, up-and-down-flows over plages and downflows over the network and filaments.

Coronal Loop Models

As a preparation for the study of loop motions, much work has been expended on setting up models for static loops. First of all, an order-of-magnitude scaling law ($T \sim (p_0 L)^{1/3}$) for the summit temperature (T) in terms of the base pressure (p_0) and loop length (L) was derived (21 074 007) by equating the radiation ($\chi n^2/T^{1/2}$) and conduction. The solutions for uniform pressure were considered in more detail by many authors (22 074 005 ; Monsignori-Fossi, B. C., 1981, in "Solar Activity" ed C. Jordan ; Withbroe, G. , 1981, in "Skylab Active Region Workshop"), by seeking analytical (28 074 079) and numerical (26 074 016 ; 27 074 060) solutions, both thermally isolated and not thermally isolated (26 074 016). It was found that the scaling laws (28 074 079 ; 26 074 016 ; Monsignori-Fossi, B. C. , 1981, in "Solar Activity") and the emission measure (22 074 035) are not very sensitive to the detailed form of the heating function.

In principle, it should be possible to deduce the form of the coronal heating from the observed lengths, pressures and temperatures of coronal loops, but in practice the observational errors are too large and the models too insensitive. For example (Chiuderi, C.et al., 1981, Astron. Astrophys , 97, 27), with a heating proportional to T^γ , 10% observational errors imply a value of γ anywhere between -2 and 7.

The above theory applies only for very low-lying loops. Its extension to loops in hydrostatic equilibrium and with non-uniform cross-section (26 074 020 ; Wragg, M. A. and Priest, E. R. , 1981, Sol. Phys. 70, 293 ; Serio, S. et al., 1981, Ap. J., 249, 288) shows how gravity lowers the pressure and density substantially and the temperature slightly, while a reasonable divergence in loop area can easily change the summit temperature by a factor 2. The thermal stability of uniform-pressure loops depends crucially on the assumed boundary conditions (21 074 032 ; 26 074 007 ; 27 074 076), but the loops appear to be unstable if the base conductive flux is low enough. In particular, thermally isolated loops, whose base flux vanishes, are unstable, which may account for the presence of continual plasma motion in the transition region and corona. However, the inclusion of gravity stabilizes loops that are long enough (Wragg, M. A. and Priest, E. R. 1982, submitted).

Two more extensions of the basic theory are to include steady siphon flows driven by a pressure difference between two footpoints (27 074 034 ; Noci, G., 1981, Sol. Phys., 73, 67 ; Glencross, W. M., 1981, Sol. Phys., 73, 67) and to model the thermal structure for a complete magnetic configuration (rather than just a single field line). Two examples of the latter are a modelling of the transverse pressure structure in a loop together with the thermal structure along it (26 074 016) ; a solution for the thermal structure along each field line of a force-free coronal arcade (26 073 073).

In future, one hopes to see more numerical simulations (25 073 083 ; 28 073 114 ; 28 074 095 ; 22 074 035 ; Craig, I., 1981, in "Solar Flare MHD" ed Priest) of time-dependent flows in loops, with an adequate treatment of the transition region and of the coupling of the coronal part of a loop to its optically thick chromospheric and photospheric base.

Magnetic Heating

The heat that is required to balance radiation and conduction in the corona is typically 300 Wm^{-2} in quiet-region loops and 5000 Wm^{-2} in active-region ones (20 073 050). It is now generally accepted on both observational (22 073 069 ; Mein, P. et al, 1981, in "Japan-France Seminar on Sol. Phys" eds Moriyama and Semel) and theoretical grounds that acoustic shocks do not heat the corona (although they may be effective for the low chromosphere (26 064 006 ; Ulmschneider, P., 1981, in "Solar Pheom. in Stars and Stellar Systems" eds Bonnet and Dupree). In particular, the OSO-8 observations show an upward propagating five-minute wave train at the temperataure minium, but by the time the transition region is reached the fluctuations have become aperiodic and the energy flux has decreased to only 10 Wm^{-2}. Presumably, this is because of scattering off spicular inhomogeneity and refraction away from the vertical. Thus, attention has been turned to some kind of magnetic mechanism (Chiuderi, C., 1981, in "Solar Phenom in Stars and Stellar Systems" ; Hollweg, J., 1981, in "Skylab Active Region Workship" ; Heyvaerts, J. and Schatzman, E., 1981, in "Proc. Japan-France Seminar on Sol. Phys."), as outlined below.

(A) MAGNETOACOUSTIC WAVES

The basic theory (Osterbrock, D. E., 1961, Ap. J., 134, 347) for magnetic wave propagation, steepening and damping in a weak uniform field needs to be reinterpreted in the light of both the field concentration to kilogauss values at supergranulation boundaries and also the inhomogeneous nature of the coronal field. Fast modes in a coronal loop whose density is larger than that of the ambient medium tend to be guided along the loop, since they are refracted away from the surrounding medium with its higher Alfven speed. A calculaton for 2s waves of the ray paths and of collisionless damping where the plasma beta exceeds 0.1 shows that a loop shape is heated preferentially (26 074 053). More details of the damping of fast modes by collisionless, viscous and conductive dissipation have been presented by Zweibel (27 074 078).

Difficulties with fast modes (Hollweg, J., 1981, in "Skylab Active Region Workshop") are the chromospheric damping of low-period waves, the reflection at the transition region and the fact that observed photospheric motions would produce vertically evanescent waves unless the horizontal wavelengths were large, which would require a non-local analysis.

(B) ALFVEN WAVES

For field strengths larger than 10G the problem is to explain how an Alfven wave can give up its energy, since the damping is so small and it doesn't steepen easily. One possibility is nonlinear interactions (11 074 052 ; 20 074 048) with another Alfven wave or a non-uniform field to produce acoustic waves which then steepen and dissipate rapidly. By this process, short-period (10s) Alfven waves may heat weak loops (10-20G).

Hollweg (26 080 007 ; Hollweg, J., 1981, Sol. Phys., 70, 25) points out that the dominant fluctuations in the solar wind at 1AU are observed to be Alfvenic, with periods of an hour or more. He models linear propagation near the axis of a vertical tube in a model atmosphere and suggests that in open regions waves with periods between 10s and 5min can heat the corona by ohmic dissipation or nonlinear coupling to magnetoacoustic modes. (However, a consideration (28 062 081) of wave reflection in a uniform vertical field shows that for a field of 1G (or 3000G) the period must be less than 1hr (or 1s) if the waves are not to be almost totally reflected at the transition region. Thus, only short-period Alfven waves can use intense tubes as ducts to reach the corona.) In closed regions, Hollweg points out that periods smaller than 10min are reflected back down at the transition region, except for resonant frequenceies at which a number of wavelengths fits along a loop and there are windows that allow a large flux to reach the corona.

(C) SURFACE WAVES

Along the boundary of a coronal loop, surface waves may propagate and provide heating (22 074 051 ; 25 062 069). They are quite distinct from the normal body waves and have profiles that decay exponentially with distance away from the boundary. The properties of such waves on an interface, a slab or a cylindrical flux tube are being investigated (27 062 136 ; Roberts, B., 1981, Sol. Phys., 69, 27 ; 69, 39 ; Spruit, H. C., 1981, in "The Sun as a Star" ed S. Jordan ; Spruit, H. C., 1981, in "Solar Phenom. in Stars and Stellar Systems"). There are two main types, corresponding to slow and fast magnetoacoustic waves, but there is no equivalent to the normal shear Alven wave. Each type in a flux tube may be either kink-like or sausage-like in nature.

When the finite thickness of the boundary is included in the analysis no steady, ideal surface modes exist, but the presence of dissipation should allow a steady solutioin, and an initial-value treatment reveals a build-up along the boundary of large motions which eventually dissipate viscously or ohmically (Rae, I. and Roberts, B., 1981, Geophys. Astrophys. Fl. Dyn , in press). If the boundary is so thin that the fluid analysis fails, a surface disturbance may feed energy into a kinetic Alfven wave which dissipates by collisionless effects (22 074 051).

This is a very lively topic, and in future one can expect much progress in understanding the properties of surface waves. A related topic that is a prime candidate for coronal heating is the resonant absorption of waves at surfaces within a magnetic arcade where the wave frequency matches the local Alfvenic or cusp frequency.

(D) DIRECT MAGNETIC DISSIPATION

When the time-scale for photospheric motions exceeds the time (L/V_A) for a disturbance to propagate along a loop (of length L), a wave description is no longer helpful. For example, this applies to a loop of length 100 Mm when $\tau > 5$ min. The problem then is how does the corona respond to such slow footpoint motions produced by, for example, mesogranulation ($\tau \sim$ hrs) or supergranulation ($\tau \sim 1$ day) ? It may evolve passively through a series of largely force-free equilibria, storing energy in the process (Uchida, Y., 1981, in "Japan-France Seminar on Sol. Phys."). At the same time, the field may dissipate the energy either continuously or sporadically in current concentrations. In this picture of magnetic (or current) dissispation the corona is in a state of ceaseless activity as it is being heated by microflarings (28 003 011 ; Priest, E. R., 1981, "Solar Flare MHD"). The actual means of dissipation is similar to that of a magnetic wave mechanism, since a region of high field gradient is formed and then the energy is released ohmically and viscously. In the previous mechanism a current sheet is propagating (a shock wave), but here it is non-propagating, and so the essential problem is how to form such a current sheet (see (E) below).

Order of magnitude estimates (10 074 109 ; 27 074 052) show that the upwards energy flux (vB^2/μ) in a field of 100G is sufficient to supply the *corona when the photospheric motions are only 100 ms . Also, in order for the* energy to dissipate fast enough, the currents need to be concentrated into sheets, sheaths or filaments. It is unlikely that the sheets are strongly turbulent, since they would decay extremely quickly and the necessary current densities are immense. A more likely alternative is the formation of sheets by resistive instability (Galeev, A., et al., 1981, Ap. J., 243, 301). Further, the energy increase by stochastic footpoint motions may be used to estimate scaling laws for loop temperature (Sturrock, P. A., and Uchida, Y., 1981, Ap. J., 246, 331).

(E) CURRENT CONCENTRATION

The formation of current sheets has long been studied in connection with solar flares (eg, Priest, E. R., 1981, in "Solar Flare MHD"). One way to create such sheets is by the interaction of topologically separate parts of the field due to photospheric motions (22 062 010). Another way is through magnetic nonequilibrium when the corona cannot find a force-free equilibrium. A small photospheric displacement from one equilibrium does in general lead to another equilibrium (Sakurai, T. and Levine, R., 1981, Ap. J. submitted), but a large displacement may produce topological dissipation (7 062 036). In particular, a large movement of the feet of a flux tube within a coronal arcade may cause the tube to become dislocated from its neighbouring field, so that in its new position it is flattened and dissipated —— "dislocation dissipation" (Parker, E. N., 1981, Ap. J., 244, 631). Furthermore, it has been shown that a continuous deformation of a force-free field in general produces current sheets (22 062 009 ; 25 062 056). It is only for particularly simple fields that such sheets do not arise.

Current filaments may be produced by resistive instability due to the gravitational, rippling, and tearing modes, whose nonlinear evolution needs to be studied in a parameter regime relevent to the solar atmosphere (Spicer, D., 1981, Sol. Phys., 70, 149 ; Van Hoven, G., 1981, in "Solar Flare MHD" ; Pellat, R., 1981, in "Solar Phenom. in Stars and Stellar Systems"). They can also be created by thermal instability (27 074 078 ; 12 062 062 ; 26 075 004), which causes a uniform current to concentrate into threads parallel to the magnetic field. The result is that the solar atmosphere is likely to have a filamentary character.

VII. CORONAL TRANSIENT

(E. Hildner)

Mass Ejections from the Solar Corona

The brisk pace of coronal transient research has resulted in a better appreciation of both the observed properties of these events and a deeper understanding of the theoretical models which might describe them. As new observations *from orbiting coronagraphs (Naval Research Laboratory's SOLWIND and High Altitude* Observatory's Coronagraph/Polarimeter) and ground based instruments (High Altitude Observatory's K-coronameter) are just now appearing in the literature, we can expect coronal transient research to continue vigorously.

Observed General Properties

The associations between coronal transients and surface activity may give clues to the mechanisms responsible for the spectacular mass ejections. During the Skylab era, three-quarters of the ejections appeared to arise in or near active regions ; eruptive prominences, with or without flares, were apparently associated with 70 percent of coronal transients, the highest association of transients with any form of activity. Flares were associated with only 40 percent of transients (25 074 023). Examining the eruptives in more detail, Trottet and MacQueen (28 074 080) found a strong correlation between regions where the filament axis was north-south and the occurrence of transients with loop-like appearance. They deduced that most loop transients were nearly coplanar with the pre-event axis of the associated filament. As yet there is no consensus whether the coronal transients appearing as arches in images from orbiting coronagraphs are better characterized as "loops" or as "bubbles", that is, as relatively thin, two-dimensional objects or as phenomena having approximately as much depth along the line of sight as extent in the plane of the sky.

Transients' forerunners, rims of enhanced density surrounding every Skylab transient for which adequate data were available, were found (22 074 073), indicating that a coronal disturbance starts not only higher but perhaps earlier than the surface activity with which a transient is associated (Jackson, 1981, Sol. Phys., 73, 133). Support for the idea that the coronal transient disturbance begins before the surface activity is found in the observation that, statistically, type III bursts emanating from regions around the sites of coronal transients tend to occur more frequently some hours before the transient event than at any other time in the 48 hours centered on the event (28 077 028 ; 28 077 039). Fisher et al. (1981, Ap. J., 246, 161) have reported one transient which was present and moving at 1.2 R ,30 minutes before the associated eruptive prominence began to ascend. It remains to be seen whether this behavior is typical when viewing transients at heights below the limits set by the occulting disks of orbiting coronagraphs.

Mass flowed up the legs - the only parts of the original loop still visible in the coronagraph field of view - of Skylab transients for several days after the passage of the transient front. This mass flow up the legs could account for up to 10 percent of the total excess mass delivered by the transient to the interplanetary medium (25 074 021).

Radio observations may be used to determine the magnetic field strength in and/or around a transient and to help discriminate between models of transients. Gergely et al. (25 074 061 ; 28 074 060) find type IV radio emission to be cospacial with a secondary loop, far beneath the primary, outer loop in a Skylab event. Under the assumption that the emission is due to gyrosynchrotron radiation, a magnetic field strength of a few gauss at 2.1 $R_\odot$ may be inferred, leading to a value to about one for the ratio of gas pressure to magnetic energy density. With Dulk et al. (28 074 129), this implies that at least some transients are magnetically controlled. Similarly, Wagner et al. (1981, Ap. J., 244, L123) found that a moving type IV burst was cospacial with the leading white light loop of a transient observed with the SMM coronagraph. Maxwell and Dryer (1981, Sol. Phys., 73, 313) suggest that the type II bursts due to shock waves should be well ahead of the white light transient loops, but this suggestion may not endure as SOLWIND and Coronagraph/Polarimeter find additional events. We note that the Jackson (1981, Sol. Phys., 73, 133) and Fisher et al. (1981, Ap. J., 246, L161) observations imply that if the type II shock starts low in the corona at the time of the flare or eruptive prominence, then it might find itself below and behind (albeit at a higher speed) than the broadband transient front.

Observations of coronal transients near solar activity maximum are just now being reported. Fisher and colleagues (1981, Ap. J., 246, 1005 ; 1981, Ap. J., 246, L161), using ground-based data, report the occurrence of dark transients, corresponding to density depletions, in the corona below 2 $R_\odot$. As a dark loop transient rises and expands, bright "horns" begin to form on each side of the dark area ; with time the leading edge of the dark feature acquires a bright sheath which joins together the bright "horns" so that the dark transient depletion is surrounded by a bright transient density enhancement. By this time, the initially dark transient has brought new excess mass into the coronagraph field of view (< 1.1 to > 2.0 $R_\odot$).

The new observations permit the characteristics of coronal transients observed above ~ 2 $R_\odot$ during the declining phase of the solar cycle to be compared with similar characteristics for transients occurring near solar activity maximum, as observed from OSO-7 and Skylab. Near-maximum SOLWIND (27 074 064 ; 27 074 044 ; 28 074 047 ; 1981, Sol. Phys. , 69, 169) and Coronagraph/Polarimeter (1981, Ap. J. , 244, L117) observations agree that transients in the two eras statistically had about the same speeds, masses, shapes, and surface activity associations. However, transients were seen at higher latitudes around activity maximum (28 074 044 ; 27 074 044 ; 27 074 023 ; 1981, Sol. Phys. , 69, 169 ; 1981, Ap. J., 244, L117) and more commonly than near activity minimum, H-alpha emitting material was seen rising to great heights in the interiors of Thomson scattering transients.

Theoretical Models

A number of workers haved analytically considered discrete structures which might become coronal transients of "loop" rather than "bubble" form. Van Tend (25 074 020) showed how destabilization might allow initial upward movement of an idealized loop carryhing current ; this would set the stage for Anzer's (21 074 053) description of a transient proceeding outward as though it were an expanding current. Pneuman (27 073 044) showed that an increase of magnetic flux under a filament will drive it outward, in turn propelling the magnetic field and material originally residing in the helmet streamer presumed to lie over the pre-eruptive filament. This increase in flux below the filament may come about due to reconnection (28 074 063 ; 28 080 039). Yeh and Dryer (1981, Ap. J., 245, 704 ; 1981, Sol. Phys., 71, 141) have shown that pressure forces within transients must be considered when calculating the movement of the mass elements making up a transient. A possible way to probe the magnetic and density structure of a loop-shaped coronal transient using Faraday rotation of a linearly polarized signal transmitted to Earth from a satellite nearly behind the Sun has been given by Bird et al.(28 074 070).

Numerical, continuum models of coronal transients become increasingly sophisticated. In these models a pre-event corona is prescribed, a perturbation is introduced at the base of the corona, and the consequences of the perturbation are followed in time. In a series of papers Wu, Nakagawa, and Han (21 062 004 ; 21 074 002 ; 1981, Ap. J., 244 331) and (22 062 037) show that a pressure pulse in an initially hydrostatic, two-dimensional atmosphere will create a rising density enhancement which looks more like an observed transient if the magnetic field is "open" to interplanetary space than if the field is "closed" back to the solar surface. A similar calculation in non-planar, two-dimensional geometry suggests that rising material should spiral upward in open field configurations and stretch closed field lines in such a way as to reduce shear (28 074 071). Steinolfson, Wu, Dryer, and Tandberg-Hanssen (22 062 018 ; 25 074 035 ; 1981, Ap. J , 243, 641) considered similar problems with similar results. Substituting an ambient corona flowing outward to make the solar wind for earlier hydrostatic background corona seemed to make little qualitative difference in their results. In one case where material outflow was permitted, a coronal streamer took about 3 hours to reform after a simulated transient occurred dur to a pulse at the base of the streamer (28 075 021).

More detailed descriptions of individual coronal transient events are available (Fisher and Poland, 1981, Ap. J., 246, 1005 ; Fisher et al., 1981, Ap. J., 246, L161 ; Gergely and Kundu, 28 074 060 ; Gergely et al., 25 074 061 ; Michels et al. , 28 074 067 ; Sheeley et al., 27 074 042 ; Wagner et al., 1981, Ap. J., 244, L123 ; Webb and Jackson, 1981, Sol. Phys., 73, 341), and reviews of the observations and theoretical models of coronal transients may be found also in Anzer (28 074 062), Dulk (27 074 063), MacQueen (1980, Phil. Trans. Roy. Soc. London A297,605), Rust et al.(28 073 133), Stewart (28 074 065), and Wu (28 104 065).

VIII. CONCLUSION

The above are brief descriptions of the advances in several sub-fields of solar physics which, among others, attracted attention in the past three years. For example, the close-up of solar type phenomena in other stars, the findings that the sun shows a light variation, although slight, and that the power spectrum of the global five-minute oscillation has very fine substructures suggesting the presence of a high-Q resonator inside the sun, are new aspects dealt with in this Commissioin report. The former two of these examples, like the investigations of coronal loops and coronal transients, have advanced through new space-oriented observations, but in comination with the ground-based observations accumulated over the last tens of years. The progress in the third example has been partly brought about by the introduction of a handy new technique, and having sought a suitable observing site available on the earth (the South Pole). These examples show that while space platforms will play more and more essential roles in solar physics, long time-spun ground-based efforts with inventive experimental formulation can continue to play indispensable roles. We believe that the increasing accumulation of knowledge to be brought about by the integral efforts of observations, ranging from pilot experments to enduring routine observations, combined with the theoretical trials of consistent interpretations, will lead us to a deeper understanding of the sun, a representative of the stars which are the fundamental constituent of the universe.

Finally I would like to express my deepest appreciation to the Vice-President and Members of the Organizing Committee for their valuable cooperation throughout the term.

Yutaka Uchida

President, Commission 12.