10. SOLAR ACTIVITY (ACTIVITÉ SOLAIRE)

PRESIDENT: K. O. Kiepenheuer (deceased).
ACTING PRESIDENT: G. Newkirk.
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ORGANIZING COMMITTEE: L. W. Acton, L. D. de Feiter (deceased), J. T. Jefferies, V. A. Krat, F. Moriyama, P. Simon.

This report summarizes research in the study of solar activity over the three-year period from December 1972 through September 1975. The expense of reproducing such a document dictates that its length be limited and that duplication be reduced to an absolute minimum. The effort to produce a comprehensive report within these restrictions is inevitably only a qualified success; and important investigations may have been inadvertently overlooked. For these oversights we apologize. The reader is also cautioned that some researches may have appeared in the literature too late to have come to the attention of the reviewers. A list of abbreviations used for references is given at the end of this Report.

It is a pleasure for the Acting President to acknowledge the fine cooperation of each of the reviewers and the Commission members who informed us of work which should be included in the report. However, it is with sadness and a profound sense of loss that we reflect upon the passing of our friends K. O. Kiepenheuer, President of the Commission, and L. D. de Feiter, Member of the Organizing Committee.

1. OPTICAL SOLAR INSTRUMENTATION
(R.B. Dunn and P. Mehltretter)

A. *New Instruments*

Kitt Peak National Observatory has constructed and put into operation a 60-cm aperture, *f*:60 vacuum tower telescope which is used with a 512-channel diode array magnetograph/spectroheliograph that has a seeing-limited resolution of 1" on full-disk magnetograms (*BAAS* 6, 291).

A 65-cm aperture Gregorian telescope, initially designed as a space-borne instrument, has been installed in a vacuum tank at Big Bear Solar Observatory. It is used with great success for observations of the photosphere in white light and with a universal filter (Beckers/Zeiss design).

At Izana (Island of Tenerife), Fraunhofer Institut is operating, since 1972, in cooperation with the Observatorio del Teide, a 40-cm aperture Newtonian vacuum telescope for photospheric and chromospheric studies (Halle Hα-filter).

The Institute for Plasma Research of Stanford University has put into operation a computer-operated telescope-magnetograph for semi-continuous observations of large-scale solar magnetic and velocity fields.

The University of Hawaii has designed, and put into operation, a multichannel coronal spectrometer that utilizes a television detector (*Astronomical Observations with Television-Type Sensors*, Univ. of British Columbia, 255).

High Altitude Observatory has constructed, in collaboration with Sacramento Peak Observatory, an emission-line polarimeter for the infrared coronal lines at λ 10 747 and 10 798 Å. The computer-controlled polarimeter uses a new gimbal-mounted 40-cm aperture, *f*:15 telescope supported by the large spar at Sacramento Peak Observatory (*Planets, Stars, and Nebulae Studies with Photopolarimetry*, Univ. Arizona Press, Tucson, 254).

A similar polarimeter, working with the line Helium 5876 Å in prominences, has been put into operation at the Pic-du-Midi (*NRO* 6, 149) in connection with a 26-cm aperture coronagraph.

At the same observatory, Leroy and Ratier (*Planets, Stars and Nebulae Studies with Photopolarimetry*, Univ. Arizona Press, Tucson, 762) have modified the existing K-polarimeter to make use of silicon diodes in the range 0.8 to 1.0 μ, thus obtaining, due to lower atmospheric scattering, a gain in accuracy by a factor 1.5 to 2, increasing with the distance to the limb.

A photoelectric Stokes polarimeter has been built by the University of Hawaii and measures photoelectrically all four Stokes parameters in the coronal or disk emission and in broad or narrow wavelengths (Mickey, *PSPIE* 28, 217; *Planets, Stars, and Nebulae Studies with Photopolarimetry*, Univ. Arizona Press, Tucson, 686).

A similar Stokes-Vector polarimeter has been built by the High Altitude Observatory and installed at the primary focus of the 40-cm coronagraph/Littrow spectrograph of the Sacramento Peak Observatory. The instrument measures simultaneously all four Stokes parameters as a function of wavelength in any line in the range λ 4000–7000 Å.

The Liège group has installed, at the Jungfraujoch Observatory, a new high resolution (<0.03 cm^{-1}) spectrometer for the near IR.

Spectro-Stratoscope, the balloon-borne telescope/spectograph of the Fraunhofer Institut (*AO* 3, 1359) (aperture 32-cm, stigmatic spectrograph with resolution >500 000, pointing stability better than 0.1" r.m.s. for 30 s) has been successfully flown in May 1975; future flights are planned to obtain high quality time series of observations of photospheric and chromospheric processes.

The Sacramento Peak Observatory has installed a Beckers/Zeiss universal filter (Beckers *et al.*, *AO* 14, 2061) at the output of the 76-cm Vacuum Telescope, and is routinely operating a 512-channel diode array system (Dunn *et al.*, *PSPIE* 44, 109) on the echelle spectrograph of this telescope.

B. *Modifications*

At a number of observatories, existing telescopes and auxiliaries have been modified or modernized: At Pic-du-Midi, a 50-cm aperture lens has replaced the 38-cm lens formerly used in the 'turret dome refractor' with a consequent increase of resolution in photospheric observations.

The Crimean Astrophysical Observatory has completely rebuilt the solar tower telescope, which has now a 100-cm aperture, 50-m focal length optical system feeding a double-channel magnetograph working in two lines simultaneously.

The horizontal spectrograph at Ondrejov has been equipped with a new guiding and scanning system, and placed under computer control, to obtain spectro-heliograms as well as magnetograms.

The Schauinsland tower telescope of Fraunhofer Institut has been equipped with an entirely new optical system (Zerodur mirrors, 45-cm objective lens, new spectrograph, and closed-circuit TV system for slit-jaw observation in Ca II-K).

A 15-cm aperture vacuum refractor has been installed at Ottawa River Observatory for white-light observations with the multiple photoheliograph.

A new computer-controlled image scanning and data collection system has been installed at the 150 ft. Tower of Mt. Wilson Observatory, and an on-line computing facility has been added to the Coudé Refractor of the Fraunhofer Institut in Anacapri.

A new subtracting double-pass spectrograph for simultaneous observations in seven wavelengths has been installed on the 60-cm Meudon solar tower. The instrument possesses some advantages over birefringent filters in that the line profiles may be restored and the lines are all photographed simultaneously (Mein and Blondel, *SP* 27, 489).

C. *Planned Modifications Include*

Installation of the 1-m path difference Fourier Transform Spectrometer, now in preliminary operation in Tucson, in a newly built Coudé room at the McMath Solar Telescope on Kitt Peak; setting up a telescope and Lyot filter system for the Helium line 10 830 Å, as well as of an improved spectrograph/spectroheliograph, at Kandilli Observatory in Istanbul; replacement of the existing optical system by a new 24-inch polar heliostat and 18-inch Cassegrain telescope for high resolution spectroscopy at the Swedish Astrophysical Station in Anacapri.

D. *Various Instruments*

Descriptions of instrumentation have been given in the literature, *e.g.*, on spectrographic techniques by Bates and McDowell (*SP* 23, 26), Petford *et al.* (*SP* 19, 264), Mein and Blondel (*SP* 27, 489), Stenflo (*AO* 12, 805), Martin *et al.* (*SP* 37, 343); on different narrow-band filter technologies by Cimino *et al.* (*SP* 11, 319), Fossat and Roddier (*SP* 18, 204), Fredga and Högbom (*SP* 20, 204), Ramsay *et al.* (*SP* 12, 492), Ramsey (*SP* 21, 54), Beckers (*AO* 9, 595), Beckers *et al.* (*AO* 14, 2061; *OE* 14, 64), and Title (*SP* 33, 521; *SP* 38, 523); on problems connected with polarimetry by Beckers and Wagner (*AO* 9, 1933), Cacciani and Fofi (*SP* 19, 270), Wiehr (*SP* 18, 226), Wiehr and Rossbach (*SP* 35, 351), Den (*SDB* 12, 91), and Jäger (*SP* 27, 481; *SP* 39, 499). Other instrumental detail has been described by Nagasawa and Chimizu (*TAOR* 16, 545), Newkirk (*PAAS* 28, 47), Obashev and Minosyants (*SDB* 2, 113), Obashev *et al.* (*TAI* 23, 3), Ta-Chun Li (*AO* 12, 2828), Pålsgård and Stenflo (*SP* 11, 155), and Tallant (*SP* 11, 263); and on semi-transparent wind shields, tower construction and instrumental vibrations by Hammerschlag (*JOSO*, 1973, p. 85; *AO* 14, 885) and Hammerschlag and Zwaan (*PASP* 85, 468; *JOSO* 1973, p. 61).

2. SKYLAB–ATM RESULTS

(R. MacQueen)

During their orbital lifetime (May 1973 to February 1974) the U.S. Skylab mission solar telescopes – collectively known as the Apollo Telescope Mount – accumulated data typified by: (a) relatively high spatial resolution; (b) modest temporal resolution; (c) high information rate; and, (d) a joint observatory concept of operation. The telescopes included two soft X-ray telescopes from American Science and Engineering (AS&E) and the Marshall Space Flight Center (MSFC)/Aerospace Corporation, an extreme ultraviolet polychromator from the Harvard College Observatory (HCO), an extreme ultraviolet spectroheliometer and an ultraviolet spectrograph, both from the Naval Research Laboratory (NRL), and a white light coronagraph from the High Altitude Observatory (HAO). Initial results are outlined below; where contributions from ATM results are summarized in the Reports of other Commissions, references to the appropriate sections are made.

A. *Flares*

The initial emphasis of flare studies has been the identification and study of profiles of high excitation emission lines present at the period of maximum flaring activity and the utilization of the high spatial resolution images in the soft X-ray and XUV to study the morphology of a number of flare events. Emission lines of Fe XVIII, XIX, XXI, XXIII and XXIV have been identified from observations by the NRL spectro heliograph and spectrograph (Widing, *ApJ* 197, L33, Widing and Cheng, *ApJ* 194, L111, Doschek *et al.*, *ApJ*, in press).

The presence of Fe XXIII and Fe XXIV emission in small ($2''$) spatial regions implies temperatures of 20×10^6 K in subflare 'kernels'. Doschek *et al.* (*ApJ*, in press), from measurements of the width of the Fe XVIII, XIX and XXI lines and under the assumption of ionization equilibrium, found random mass motions of 50 km s^{-1} present during one flare. Other lines – particularly those from transition zone ionization stages – show strong broadenings and shifts, indicating the presence of a turbulent phase in the flare development (Brueckner, *IAU* 68, 135; *PSL*, in press). Widing and Cheng (*ApJ* 194, L111) have examined the temporal behavior of the Fe XXIII and Fe XXIV emission and estimate that a density in excess of 5×10^{10} cm^{-3} was present in the small element. The latter authors have also examined the spatial distribution of XUV flare emission in five small flares – two disk and three limb events – and concluded that the high excitation Fe lines are formed at the tops of loops, with cooler lines more prevalent at lower altitudes (Cheng and Widing, *ApJ* **201**, 735). The loops apparently connect classic Hα 'ribbon' regions. They estimate temperatures between 1.0 and 1.6×10^7 K and densities in excess of 1×10^{11} cm^{-3} present in all the flares examined. A classification of all flares observed by the NRL instruments has been prepared by Scherrer and Tousey (*AIAA* **11**, 345).

The frequent soft X-ray observations of flares by the two Skylab experiments provide excellent opportunities for studies of the morphology of flare events. Kahler, Krieger and Vaiana (*ApJ* **199**, L57) have examined some dozen selected events and have identified a small (<6″) bright kernel during the rise phase in eleven of the events; the kernel evolved into loops or diffuse structures at flare maximum or during the decay phase.

On the other hand, Vorphal *et al.* (*SP*, in press) have studied the structure and evolution of 132 flare events and have identified a relatively stable 'core' throughout the duration of the flare event. This core is of a wide variety of shapes but is most commonly linear with a size 5–10″ by 5–120″ length. They conclude that small kernels are not morphologically common to the majority of events observed and that the small elements are in reality loop structures smaller than the resolution limit of the telescopes.

Petrasso *et al.* (*ApJ* **199**, L127) studied images of a simple bipolar active region subflare and found the central X-ray emitting region was confined to a small region within a pre-existing loop structure crossing the magnetic neutral line. This region increased in brightness by more than 10 times in about three minutes. Silk *et al.* (*COSP* **18**) studied spectra obtained during the decay phase of a flare and deduced that the distribution of emitting material as a function of temperature changed early in the decay phase, but later in the event the distribution became stable and the decreasing flux corresponded to an overall loss of X-ray emitting material. Vorphal *et al.* (*ApJ*, in press) have examined the flare of September 5 and concluded the region of central flare brightness is striated by individual loop structures. The striations brightened consecutively as the flare evolved, with a propagation velocity of about 200 km s^{-1}, perpendicular to the magnetic field direction (if the latter is assumed to be approximated by potential field calculations). They suggest magnetosonic wave triggered instabilities pre-existing in the structures. Pallavicini *et al.* (*SP*, in press) have examined soft X-ray emission from the 1B Hα double ribbon flare of 1973, June 15, in some detail. The flare was typified by a spatially complex system of loops crossing the magnetic neutral line; comparison between the observed system of loops before and following the event and those computed on the basis of the assumption of potential magnetic fields showed that the post flare configuration is less complex and agrees more nearly with that computed. The different regions of emission in the event had greatly different light curves and thus concepts based upon integrated X-ray measurements (e.g. 'X-ray decay time') may not be physically meaningful. Loop systems – comprised of successively higher loops (analogous to those observed in Hα) – form during the post flare phase; apparently the higher loops continued to be heated some 15 min following the end of an associated microwave burst.

Finally, preliminary analyses of flare data from the HCO experiment (Noyes *et al.*, *IAU* **68**, 3) indicate that the impulsive rise in EUV emission occurs essentially simultaneously at temperatures varying from 10^4 to 10^6 K, at least to within the 5.5-s time resolution of the instrument.

B. *Prominences*

EUV observations of prominences and filaments show emission similar to that from the quiet sun modified by the significant opacity of the hydrogen Lyman continuum (Schmahl *et al.*, *SP* **39**, 337). It is found that the transition sheath surrounding the prominence is approximately 0.4 times in density, and has a temperature gradient 2.5 times that of the quiet sun transition zone, respectively. Observations in O VI have been used to determine that the thickness of the outer transition sheath of the prominence is ~100 km.

Tousey (*IAU* **27**; *PRL*, in press) has described the EUV observations of limb eruptive events obtained with the NRL spectroheliograph, with particular emphasis on the spectacular event of 1974, January 17. Coronal changes associated with a disappearing disk filament studied by

Sheeley *et al.* (*ApJ* **196**, L129; *SP* **40**, 103) suggest a good association with a 'gradual rise and fall' X-ray signature caused when the surrounding corona was heated to about 6×10^6 K during the filament disappearance. Similar X-ray signatures associate with the occurrence of white-light transients observed by the HAO coronagraph (see Coronal Transients).

C. *Coronal Transients*

Numerous major perturbations of the outer corona have been observed with the HAO coronagraph experiment. The general characteristics of coronal transients have been surveyed by Gosling *et al.* (*JGR* **79**, 4581); their surface phenomena associations, by Munro *et al.* (*Flare Related Dynamics*, HAO/NCAR, Boulder, 1974; *U*); and their relationship to general solar activity, by Hildner *et al.* (*U*). These and additional studies (Hildner *et al.*, *SP* **42**, 163) show that the major events (more than sixty during the mission period) typically involved mass ejections of 10^{15} g over several hours, with speeds ranging from 100 km s^{-1} to in excess of 1000 km s^{-1}. Gosling *et al.* (*U*) have examined the distribution of transient event speeds and have found that faster events tend to be associated with flares; slower events with prominence eruptions. The faster events are preferentially associated with the occurrence of type II/IV metric radio events perhaps because only in the latter events are characteristic speeds in the corona exceeded. Eruptive prominences and flares are the principal causes of mass ejection transients, with the former dominant by approximately 2:1. The frequency of transient events (on average 0.4 events per day) is well correlated with solar activity as measured by conventional indices. Activity during the Skylab mission period became localized to one solar hemisphere; and the coronal transient activity become similarly localized.

That the material observed in transients is of low coronal origin was shown in two separate events by Hildner *et al.* (*SP* in press) and Poland and Munro (*U*). In the former study, the coronal transient is displaced from the prominence material observed in Hα and He 304 Å by more than 1 R_0, and the accelerations of the two components were different. The latter study compared observations of a prominence eruption in the He II 304, Hα and the polarized white light. It was found that cool material ($T \lesssim 50\,000$ K) could be responsible only for the appearance of bright elements in the inner portion of the event but that the more typical loop-like structures were comprised of material at coronal temperatures.

While the transient effect on the corona is major, the signature of events at 1 AU is apparently less so; in a preliminary search only one event, the exceptionally energetic one of 7 September, has been correlated to an interplanetary shock (Gosling *et al.*, *SP* **40**, 439).

Smith *et al.* (*U*) have computed time-dependent radial flow hydrodynamic models, including a Rayleigh dissipation function, for two transient events; one observed in Hα, soft X-rays and white light associated with an eruptive limb prominence, and another observed in X-rays and Hα, associated with a surge. The two cases modelled were best fit by pulses of density and temperature, respectively; the mechanisms responsible for such pulses are not clear. Concomitant observations of a metric continuum radio burst and a transient (1973, September 14–15) have been used to estimate the magnetic field strength in the region of radio emission (Dulk *et al.*, *SP* (submitted)) with the conclusion that the magnetic energy density is equivalent to, or in excess of, thermal or kinetic energy densities throughout the event. If this conclusion applies to transients in general, magnetic forces may be the dominant driving forces of these transient events.

D. *Magnetic Fields*

The synoptic observations obtained by the Skylab solar instruments permit study of the behavior of coronal structures outlined by emitting material. Vaiana *et al.* (*ApJ* **185**, L47) have summarized the capability of soft X-ray results in examining questions of coronal restructuring of fields, and MacQueen *et al.* (*ApJ* **187**, L85) have pointed out the wide variety of temporal variations observed in the outer corona. Sheeley *et al.* (*ApJ* **196**, L129; *SP* **40**, 103) have examined EUV heliograms in Fe XV, Mg IX and Ne VII from the NRL instrument and find evidence for the connection of magnetic flux from emerging bipolar magnetic regions to previously existing flux in neighboring areas. They also have presented observations of the disappearance of magnetic flux.

Efforts in comparing calculated low coronal magnetic fields and observed structures have been made. Smith *et al.* (*COSP* 18) have employed both potential and force-free field computations in comparisons with the pre- and post-flare soft X-ray configuration of an active region. They find the best description of the pre-flare field is that of the force-free case while post-flare the potential configuration is more appropriate. Poletto *et al.* (*SP*, in press) have examined X-ray structures in observations by rocket on March 7, 1970 and from the ASE Skylab experiment in 1973, June 15, and find qualitative agreement between the observed brightness and the density of computed field lines and also the observed and computed topology. Thus, they conclude in these cases the role of electric currents is small.

Finally MacQueen *et al.* (*RSL*, in press) have presented outer coronal observations over the mission duration which indicate a simplification of the extended coronal fields as activity decreased on one solar hemisphere. The resulting coronal density structure is similar to that described as typical of solar minimum conditions. On a smaller scale, preliminary comparison of a recurrent quasi-stable streamer with computed potential magnetic fields (Newkirk *et al.*, NCAR-TN/STR-85) showed little correlation.

E. *Active Sun Studies*

Golub *et al.* (*ApJ* 189, L93) have examined the soft X-ray appearance of bright points, their lifetimes and 'flaring' nature. The bright points are found to be much more prevalent than anticipated; more than 1500 emerge per day over the entire solar surface. They apparently carry (or are carried by) $\sim 10^{20}$ Mx of magnetic flux to the surface. Golub *et al.* (*SP* 42, 131) showed the distribution of bright points was not uniform; about half the observed points show a uniform latitude and longitude distribution, while the remainder are confined to 30° latitude, and show a distribution in longitude similar to that of active regions.

The appearance of sunspots in EUV has been examined by Foukal *et al.* (*ApJ* 193, L143) and Noyes *et al.* (*IAU* 68). Surprisingly, it is found that the umbral emission is greatly enhanced over spots in lines corresponding to temperatures $T \sim 10^5$ K. Comparison with spectra of active regions shows that the density above a spot is less than that in active regions; the enhanced emission must therefore be due to an increased thickness of the transition region above the umbrae.

The EUV observations of active regions indicate that a wide range of temperatures in loop structures are present. The hotter ($T > 10^6$ K) loops are more diffuse and stable; cooler loops are more well defined spatially, unstable, and apparently generated by material injected at the foot points. The temperature and density structure of the loops are under study by Foukal *et al.* (*SP*, in press).

The morphology of loop structures connecting different active regions has been examined by Chase *et al.* (*COSP* 18). Such loops are found to extend up to 37° in length; the number of interconnections decreases steeply with increasing distance between active regions. A search for sympathetic flares between connected regions was negative; and Chase *et al.* (*COSP* 18) question if loops of much greater extent could be responsible for storage of solar high energy particles.

'Macrospicules' (Bohlin *et al.*, *ApJ* 197, L33), whose conditions of formation are apparently associated with coronal holes, are a new solar feature observed in transition region lines. These structures, ranging in length from ~8–25″ and width ~5–15″, have lifetimes of few tens of minutes and show dynamic behavior (typically observed in He II 304). Direct visual comparison has failed to show a significant correspondence between spicules in He II and Hα images (Moe *et al.*, *SP* 40, 65). Withbroe (*BAAS*, in press) has constructed models for macrospicules and has estimated their energy content; it is large enough to question if the source is stored in the chromospheric magnetic field.

F. *Coronal Holes and Polar Regions*

In addition to the work on coronal holes summarized in the Report of Commission 12 (C. Jordan), the structure and evolution of coronal holes has been examined by Timothy *et al.* (*SP* 42, 135) utilizing AS&E soft X-ray images obtained through much of the mission. They find two types of holes – elongated features, approximately north-south, extending from one pole to a polar filament channel in the opposite hemisphere, and low-latitude isolated regions. One elongated hole has been used to determine a rotation rate close to that of a rigid rotator. Nolte *et al.* (*SP*, in press) have compiled an atlas of coronal hole boundary positions from 1973, May 28 to November 21, based upon the same data. Doschek *et al.* (*ApJ*, in press), Doschek, Feldman and Tousey (*ApJ*, in press), Feldman *et al.* (*ApJ*, in press) and Feldman, Doschek and Tousey (*ApJ*, in press) have examined emission line spectra from the NRL spectrograph taken above the limb of the quiet sun and polar regions. They have examined wavelengths of emission, relative line intensities and profiles over the spectral region 1100–1940 Å, deduced random motion velocities and compared line profiles with those synthesized from inhomogeneous models. Velocities determined both within and outside coronal hole regions show little difference.

G. *Quiet Sun Studies*

Contributions from the results of ATM in this area are summarized in the Report of Commission 12 (C. Jordan).

3. HIGH RESOLUTION OBSERVATIONS OF THE SOLAR CHROMOSPHERE WITH THE CNRS INSTRUMENT ON OSO 8

(R. M. Bonnet)

A. *Instrument Description*

The CNRS instrument (Artzner *et al.*, *SSI*, to be submitted) on OSO 8 has been continuously operating in orbit since the 24th of June 1975 as a high resolution multichannel UV and visible spectrometer to study the solar chromosphere with a spatial resolution of one arc second. Six emission lines are studied simultaneously; they are: (1) the two resonance lines of Ca II (H, K), (2) the two resonance lines of Mg II (*h*, *k*), and (3) the Ly-α and Ly-β lines of H I.

The instrument scans the spectrum in the vicinity of each line with a resolution of 0.02 Å (at Ly-β it is 0.06 Å). In addition to these, Si III (1206 Å) and O VI (1032 Å) can be studied. Spectral resolution may be reduced down to 1 Å. The telescope has the capability of rastering the disk surface over a square of one arc minute in increments of one arc second (Labeque and Vite, *SSI*, submitted). In addition the rastering capabilities of the spacecraft itself allow analysis of a field of view of $40 \times 44'$ with a resolution of $20''$ or smaller areas of $2.5 \times 2.75'$ with a resolution of $10''$. The instrument is operated in real time from the University of Colorado (LASP) together with the second pointed instrument which is under the responsibility of LASP.

In orbit, spatial and spectral resolution prove to be as designed. Line centering is the same as on the ground and to scan the distance between the two most separated lines takes only 0.48 s. A severe loss of the instrument sensitivity was encountered once in orbit due to contamination in the telescope which, combined with the high concentration of UV flux on the secondary mirror, deposited a strongly absorbing layer on the reflecting surface. The large dynamic range and very low dark counts allowed LPSP and Guest Investigators to obtain an extensive amount of data.

B. *Preliminary Results*

The chromospheric network has been extensively studied by LPSP and Guest Investigators using both the satellite and instrumental rastering capabilities and the high resolution spectrometer. The statistical properties of the network can be derived together with their variation in space (in altitude and on the disk). Comparisons between the equatorial and polar axes can also be derived as well as the variations of these properties over coronal holes. The top of the chromosphere and the transition region between the chromosphere and the corona was studied in detail in Si III and O VI.

An extensive observing program on velocity drifts and intensity fluctuations of the lines shows good evidence of periodicities. The power spectra for Ca II and Mg II show maximum power for periods ranging from 200 s for Ca II (both in velocity and intensity) to ≃180 s for Mg II. There is some evidence that longer periods are observed in Ly-α. We expect that phase correlation between the lines can be detected.

Periodic appearance and disappearance of bright points in the network have also been detected and more observations are planned of this phenomenon. Light impulses were observed in all lines and their vertical propagation can be detected. Large quantities of observations have been obtained on active regions in spite of the coincidence of the launch of OSO 8 and solar minimum. Their fine structure, time and spatial evolution will allow the elaboration of models of faculae. A group of French Guest Investigators has correlated observations made from OSO 8 with those made from the ground.

Preliminary observations of the fine structure of sunspots are by far the most exciting and promising. The vertical extension can be observed, and the observations made in each line display a different pattern. The spot, which has its 'white-light' structure in the wings of Ca II lines, becomes less defined as one rises in the atmosphere. In Ly-α the spot can barely be identified and appears as an emission feature, not necessarily located above the core of the umbra. In O VI, the spot is invisible. However, a bright filament appears between the spots of a group and we have one example of an abrupt change in the orientation of this filament in a time shorter than a day. Most surprising was the discovery of a bright ring around the spot, observed in the wings of Mg II, which does not appear in the wings of Ca II.

Observations on prominences are plentiful and spectral and spatial analyses reveal drastic velocity shifts and time and spectral variations. The shapes of the Mg II and Ly-α lines show abnormal profiles indicating the large amount of activity which develops in prominences. Large quantities of data are taken regularly on H_1, O_3, O_2 and OH in the Earth's atmosphere, at each sunset and sunrise.

To conclude, we note the excellent cooperation between the Investigators on the French and the American Experiments, as well as between the Center at Boulder and the ground-based observatories. Many of the observations briefly reported above have been made by Guest Investigators whose cooperation and enthusiasm have been very helpful in making the French program on OSO 8 a success.

4. HIGH-RESOLUTION SPECTROMETER, UNIVERSITY OF COLORADO/HAO EXPERIMENT ON OSO 8

(O. R. White)

With the launch of OSO 8 in 1975, June 21, the University of Colorado high-resolution spectrometer began taking measurements of the solar spectrum between 1200 Å and 2300 Å on a regular basis in both the active and quiet sun. This instrument has spectral resolution of 0.020 Å in second-order and spatial resolution of 2″ by 20″ as set by the exit slit of the photometer. A total of 7000 individual experiments have been conducted to measure the spectrum and its variation with both position and time.

To date the program has concentrated on the shorter wavelength lines such as H I 1216 Å, O I 1306 Å, Si IV 1393 Å, C II 1335 Å, C IV 1548 Å and He II 1640 Å. Because the instrument sensitivity is decreasing in time, faster at shorter wavelengths, the emphasis will now shift to lines such as Fe II 1702 Å and Si II 1817 Å. Although only very preliminary analyses have been conducted thus far, the following results have been obtained:

Time series of profiles of transition region lines do not show a single well-defined resonance in the upper chromosphere. The 300-s oscillation appears more strongly in the lower temperature lines, but periods of 90 s and 150 s have been observed in active regions. The identification of these as true solar effects must await further analysis because of the possibility that they may originate from oscillations in the spacecraft guiding system.

Analysis of the spatial variation of line profiles shows the strong correlation between bright solar features and downward motions. In the quiet sun this correlation presumably applies to the chromospheric network, but a strong downward flow is seen above sunspots in the Si II 1817 Å line.

At the extreme solar limb, the line profiles are shifted such that the material in the chromosphere appears to be coming toward the observer, i.e., the lines show a systematic blue shift relative to disk spectra. This puzzling effect is observed at all position angles, and its origin is not yet understood.

These are but three samples from a largely unexplored data reservoir for the chromospheric-coronal region.

5. SOLAR RADIO ASTRONOMY

(A. D. Fokker)

A. *General*

Two symposia proceedings were published and contain papers on solar radio emission which have not all been listed in the bibliography. These are: Proceedings of IAU Symposium No. 57 on 'Coronal Disturbances' (ed. by G. Newkirk, 1974) and Proceedings of the NASA Symposium on 'High Energy Phenomena on the Sun' (ed. by R. Ramaty and R. G. Stone), Goddard Space Flight Center 1973. Elements of plasma physics relevant to solar radio phenomena and contributions on solar radio astronomy are contained in the Proceedings of the Summer School on 'Plasma Physics and Solar Radio Astronomy' held at Ile de Ré (ed. by A. Mangeney, Meudon, 1973). A special issue of *Space Science Reviews* (16, Nos. 1/2, 1974) was devoted to type III bursts and related subjects. The Working Group Joint Interferometer Project of the Committee of European Solar Radio Astronomers (CESRA) published *Scientific Motivations for a High Resolution Microwave Heliograph* (ed. by E. Schanda, 1973). Several contributions on solar radio astronomy are contained in the Proceedings of the third CESRA meeting (ed. by J. Delannoy and F. Poumeyrol, Bordeaux-Floirac, 1973) and of the fourth CESRA meeting (ed. by E. Schanda, Bern, 1974).

B. *Microwave Interferometry and Heliography*

Several large radio telescopes and interferometer systems have been employed to map solar active regions at microwave frequencies. The Crimean 22-m radio telescope was used at the wavelengths 1.35, 1.76 and 8 mm (Efanov and Moiseev, 1973; *IKAO* 47, 58; Efanov *et al.*, *IKAO* 48, 93). Solar observations with the three-element interferometers of Owens Valley Radio Observatory and of National Radio Astronomy Observatory, Greenbank were made at wavelengths 3.71 and 11.1 cm. It was found that both the sources of the slowly varying component and of microwave bursts present fine structures smaller than 10″ (Hobbs *et al.*, *AL* 15, 193; *SP* 36, 369; Kundu *et al.*, *SP* 34, 185; *SP* 34, 217; Lang, *SP* 36, 351; *ApJ* 192, 777; Alissandrakis and Kundu, *SP* 41, 119). The 100-m radio telescope at Effelsberg (Bonn) was used to map the Sun at 1.7-, 2.8- and 6-cm wavelengths (Fürst *et al.*, *SP* 32, 445; Chiuderi-Drago *et al.*, *AA* 39, 429; Felli *et al.*, *SP* 42, 377). The Westerbork synthesis radio telescope was used by Kundu and Alissandrakis (*N* 257, 465) and by Felli *et al.* (to be published, 1976) to map the Sun at wavelengths 6 and 21 cm respectively. Scientific motivations for the construction of a high-resolution microwave heliograph were collected by Schanda (*Proc. 4th Meeting of Committee of European Solar Radio Astronomers*, Inst. Appl. Phys., Bern, 1974).

C. *Type I Bursts*

A review of type I bursts has been published by Bougeret (*Proc. Summer School on Plasma Physics and Solar Radio Astronomy*, Meudon, p. 341). Dulk and Nelson (*PASA* **2**, 211) reported simultaneous observations at 80 and 160 MHz and positional analyses have been produced by Bougeret (*AA* **24**, 53) and by Kerdraon (*AA* **27**, 361). Theoretical work on type I's was pursued by Sy (*PASA* **2**, 215), Vereshkov (*AZ* **51**, 261), and Melrose (*SP* **43**, 211). The origin of chains of bursts was examined by Zaitsev and Fomichev (*AZ* **51**, 252) while the generation of spike bursts was discussed by Zheleznyakov and Zaitsev (*AA* **39**, 107) and observations on spikes were reported by Chernov (*AZ* **50**, 1254).

D. *Type II Bursts*

Type II en IV bursts were reviewed by McLean (*IAU* **57**, 301). A novel hypothesis concerning the split-band structure of type II bursts was made by Smerd *et al.* (*AL* **16**, 23) who ascribe this phenomena to plasma frequency emission from ahead of and from behind a shock front. Type II bursts have been detected far out into interplanetary space (Malitson *et al.*, *AL* **14**, 111; Palmer, *SP* **37**, 443). Comparative studies were devoted to the relation of type II bursts to particle acceleration (Švestka and Fritzová-Švestkova, *SP* **36**, 417) and to the flare wave (Harvey *et al.*, *SP* **36**, 151). Krall and Smith (*ApJ* **199**, 500) dealt with the mechanism of type II radio emission in a collisionless shock wave.

E. *Type III Bursts*

Ground-based observations have been reviewed by Stewart (*IAU* **57**, 161). There is increasing evidence that single type III's radiate harmonic emission at about twice the plasma frequency (Boischot, *AA* **33**, 379; Mercier and Rosenberg, *SP* **39**, 193; Alvarez *et al.*, *SP* **31**, 493). Real harmonic pairs are hard to identify, the best evidence coming from *U*-bursts (Stewart, *SP* **39**, 451; *SP* **40**, 417). Paired bursts need not be fundamental-harmonic pairs (Caroubalos, *SP* **37**, 205; Daigne, *AA* **38**, 141; Rosenberg, *SP* **42**, 247). Much attention was devoted to the bursts that contain narrow-band features (striae) designated type IIIb bursts (Takakura and Yousef, *SP* **40**, 421; de la Noë, *AA* **43**, 201), which are frequently associated with a normal type III as a precursor at the fundamental (de la Noë, *SP* **37**, 225; Baselyan *et al.*, *SP* **39**, 213 and 223). New methods of observing linear polarization in type III bursts revealed no polarization (Grognard and McLean, *SP* **29**, 149; Boischot and Lecacheux,(*AA* **40**, 55). *U*-bursts were analysed by Akin'yan (*AZ* **50**, 806), Caroubalos *et al.* (*AA* **23**, 131) and Fomichev and Chernov (*AZ* **50**, 798). Comparative studies were devoted to the relation of type III bursts with coronal density structures (Leblanc *et al.*, *SP* **37**, 215), the impulsive phase of flares (Vorpahl, *SP* **29**, 447), prominences and coronal streamers (Mercier, *SP* **33**, 177) and Hα activity (Kuiper and Pasachoff, *SP* **28**, 187). The theory of type III emission was treated extensively by Smith (*SP* **31**, 213; *SP* **33**, 213; *SP* **34**, 393; *SSR* **16**, 91). Melrose (*SP* **38**, 205; *SP* **43**, 79), Zaitsev *et al.* (*AZ* **51**, 252), Papadopoulos *et al.* (*ApJ* **190**, 175) and Harvey (*SP* **40**, 193) dealt with the electron streams responsible for type III's and their stabilization.

F. *Type IV Bursts*

Considerable attention was devoted to fine structures in the type IV continuum (*Proc. Summer School on Plasma Physics and Solar Radio Astronomy*, Slottje, p. 245). Observations of pulsations were reported by Maxwell and Fitzwilliam (*AL* **13**, 237), McLean and Sheridan (*SP* **32**, 485), Tlamicha (*BAC* **25**, 168) and Wild (*Proc. Symp. on High Energy Phenomena on the Sun*, Greenbelt, p. 589). Gotwols (*SP* **33**, 475) contributed to the theory of pulsations. Parallel drifting bands ('zebras') and intermediate drift bursts ('fibers') were described by Elgarøy (*SP* **32**, 231). Kuijpers (*Proc. 3rd Meeting of Committee on European Solar Radio Astronomers*, Bordeaux-Floirac, p. 130; *SP* **36**, 157; *AA* **40**, 405) developed fruitful ideas on the interpretation of both zebras and fibers. Heliographic observations, simultaneously at 80 and 160 MHz, of a moving type IV burst were described by McLean (*PASA* 2, 222) and data on several moving type IV's were collected by Schmahl (*AUPA* 22). Calculations on the radiation and polarization of moving type IV sources were made by Dulk (*SP* 32, 491) and Robinson (*PASA* 2, 258).

G. *Space Solar Radio Astronomy*

A review of satellite observations of type III bursts was contributed by Fainberg and Stone (*SSR* 16, 145). Results from the 'stereo' experiment were published by Caroubalos and Steinberg (*AA* 32, 245), Caroubalos *et al.* (*AA* 32, 255) and Steinberg *et al.* (*AA* 37, 109). It was found that type I burst radiation is strongly directive. The orientation of the polar diagram changes from burst to burst. Time profiles of type III bursts are independent of the observing direction. In burst pairs interpreted as fundamental-harmonic pairs, the fundamental was found to be the more directive.

H. *Additional References*

Additional published research includes:

Akabane *et al.*, *SP* **33**, 431; Alvarez *et al.*, to appear, *SP* 1975; Alvarez and Haddock, *SP* **30**, 175; Alvarez *et al.*, *SP* **34**, 413; Aubier, *AA* 32, 141; Axisa *et al.*, *SP* 29, 163; Bell *et al.*, *SP* **28**, 123; Benz, *NPS* **242**, 39; Bhonsle and Mattoo, *AA* **30**, 301; Bocchia and Poumeyrol, *SP* **38**, 193; Böhme *et al.*, *SP* **39**, 207; Boischot, *AA* **33**, 379; Castelli *et al.*, *JGR* **79**, 889; Chernov *et al.*, to appear *SP* 1975; Chertok and Krüger, *AN* **294**, 241; Chiuderi *et al.*, *SP* 33, 225; Cole, *AL* **15**, 59; Covington, *SP* **33**, 439; Covington, *SP* **39**, 153; Dodge, *SP* **42**, 445; Dröge, *KB* **18**, 187; Dulk, *SP* **32**, 491; Dulk and Sheridan, *SP* **36**, 191; Duncan, *PASA* 2, 255; Enomé and Tanaka, in *Proc. Symp. High Energy Phenomena on the Sun*, Greenbelt (ed. by R. Ramaty and R. G. Stone), p. 78; Erjushev and Tsvetkov, *IKAO* **48**, 85; Evans *et al.*, *SP* **31**, 501; Fainberg, *IAU* **57**, 183; Felli *et al.*, *SP* **37**, 395; Fürst, *SP* **28**, 159; Fürst *et al.*, *AA* **28**, 533; Fürst *et al.*, *AA* **36**, 123; Gergely and Kundu, *SP* **34**, 433; Gergely and Kundu, *SP* **41**, 163; Gergely and Erickson, *SP* **42**, 467; Güidice and Castelli, in *Proc. Symp. High Energy Phenomena on the Sun*, Greenbelt (ed. by R. Ramaty and R. G. Stone), p. 87; Haddock and Alvarez, *SP* **29**, 183; Harvey and Aubier, *AA* **22**, 1; Heyvaerts, *AA* **38**, 45; Kai and Sakiguchi, *PASA* **2**, 217; Kai and Takayanagi, *SP* **29**, 461; Kai and Nakajima, *PASA* **36**, 379; Kai and Sheridan, *SP* **35**, 181; Kaufmann and Marques dos Santos, *AA* **34**, 197; Kawabate *et al.*, *PASJ* **26**, 387; Korolev, *AZ* **50**, 817, *SA* **17**, 518; Korolev *et al.*, *AZ* **50**, 1233, *SA* **17**, 776; Krüger and Olmr, *BAC* **24**, 202; Kuijpers, *SP* **44**, 173; Kundu and Liu, *SP* **29**, 409; Kundu and Gergely, *SP* **31**, 461; Kundu and Erickson, *SP* **36**, 179; Kurihara, *PASJ* **27**, 71; Labrum and Duncan, *IAU* **57**, 235; Leblanc, *AL* **14**, 41; Magun and Mätzler, *SP* **30**, 489; Markeev *et al.*, *SA* **19**, 207; Mattoo and Bhonsle, *SP* **38**, 217 and 223; Mätzler, *SP* **32**, 241; Melrose, *AL* **15**, 55; Melrose, *SP* **43**, 211; Melrose, *SP* **35**, 441; Melrose, *AUP* **27**, 31 and 43; Melrose, *AUP* **27**, 259; Melrose, *PASA* **2**, 261; Mercier, *SP* 1975, in press; Møller-Pedersen, *AA* **37**, 163; Mollwo, *SP* **30**, 497; Pick *et al.*, *SP* **42**, 461; Riddle, *SP* **34**, 181; Riddle, *SP* **35**, 153; Riddle, *SP* **36**, 375; Sakurai, *SP* **31**, 483; Sakurai, *SP* **36**, 171; Santin, *SP* **30**, 159; Sastry, *SP* **28**, 197; Scherrer and El-Raey, *SP* **35**, 361; Sheridan *et al.*, *AL* **15**, 139; Smith, in *Proc. Symp. on High Energy Phenomena on the Sun*, Greenbelt (ed. by R. Ramaty and R. G. Stone), p. 558; Smith and Davis, *SP* **41**, 439; Smith and Riddle, *SP* 1975, in press; Spangler and Shawhan, *SP* **37**, 189; Stepanov, *AZ* **50**, 1243; *SA* **17**, 781; Stone and Fainberg, *SP* **42**, 179; Subrahmanya Sarma, *AA* **28**, 137; Takakura and Yousef, *SP* **36**, 451; Takakura *et al.*, *SP* **41**, 153; Tanaka and Enomé, *SP* **40**, 123; Yip, *SP* **30**, 513; Zaitsev, *AZ* **51**, 801; Zheleznyakov and Zlotnik, *SP* **43**, 431; Zheleznyakov and Zlotnik, to appear *SP* 1975; Zlobec, *SP* **43**, 453.

6. SUNSPOTS

(C. Zwaan)

A. *Spectroscopic and Polarimetric Diagnostics*

Buurman (*AA* 29, 329; *AASup* 15, 35), selecting lines suitable for sunspot investigation, indicated some peculiar line profiles of V I and identified seven Ba I lines in the umbral spectrum. Blackwell and Mallia (*MN* 165, 61) concluded that strong departures from LTE exist in umbrae from anomalously strong lines of Fe II and Cr II. However, Buurman (*AA* 37, 451) questioned the identification of the spectral features. Staude (*SP* 32, 403) pointed out that peculiar V profiles in Fe I λ 5250.5 Å may be explained in a fairly homogeneous magnetic field with a temperature minimum occurring deeper than in the undisturbed photosphere. Kjeldseth Moe (*SP* 32, 393) calculated profiles of λ 5250.5 Å including effects of molecular blends, depression of the local continuum by unresolved spectral lines, and different amounts of non-thermal broadening. Zwaan (*SP* 37, 99) pointed out the effect of line-haze opacity on line profiles for $\lambda \lesssim 7000$ Å.

Kotov (*IKAO* 51, 39) confirmed the significant rotation of the transverse component of the magnetic field with the height of line formation. The sense of rotation agrees with the predicted Faraday rotation. Harvey (*SP* 28, 43) pointed out that in many molecular lines the intensity patterns of the Zeeman components are not symmetric and lead to a net polarization. Golovko (*SP* 37, 113) explained the cross-over effect observed in some penumbrae close to the solar limb as a consequence of the relative velocities and the opposite magnetic polarities in the penumbral structure.

Illing *et al.* (*AA* 35, 327; *AA* 37, 97; *AA* 41, 183) measured linear and circular polarization in broad bands 5303 ± 50 Å and 5834 ± 10 Å. Finn and Jefferies (*SP* 39, 91) attempted to explain the linear polarization in the yellow band by continuum polarization due to Rayleigh and Thomson scattering in the anisotropic radiation fields in sunspots. Calamai *et al.* (*AA*, in press) could reproduce the patterns in the linear polarization very well by line saturation *provided that* the magneto-optical effects are taken into account. Illing *et al.* found that the circular polarization consists of a rather uniform component, whose polarity agrees with the magnetic polarity, and a 'speckled' component. These authors explain the uniform component by gradients in the line-of-sight components of both the velocity and the magnetic field.

B. *Sunspot Structure, Observations and Interpretations*

I. *Thermodynamic State, Model Atmospheres*

Ekmann and Maltby (*SP* 35, 317) measured small but significant intensity differences between umbrae, which Kjeldseth Moe and Maltby (*SP* 36, 109) explained by two slightly different model atmospheres. Spots with relatively dark umbrae show slightly darker penumbrae according to Ekmann (*SP* 38, 73). Muller (*SP* 39, 55; *SP* 32, 409) made a photometric study of the penumbral fine structure. These results were used by Kjeldseth Moe and Maltby (*SP* 36, 101) to compute a two-component model which also explains the average penumbral intensities for $0.45 \lesssim \lambda \lesssim 3.8\ \mu m$ measured at Oslo Observatory. Köppen (*SP* 42, 325) compared umbral continuum intensities and line profiles measured during a partial eclipse with calculations from models. Zwaan (*SP* 37, 99; *SP*, in press) constructed a maximum- and a minimum-gradient umbral model to fit the continuum intensities over $0.5 \lesssim \lambda \lesssim 2.4\ \mu m$; it was found necessary to introduce a line-haze opacity for $\lambda < 0.8\ \mu m$. Stellmacher and Wiehr (1975, in preparation) modified their umbral model in the deep layers to fit the infrared intensities. Boyer and Sotirovski (*AA* 28, 151) determined rotation temperatures for MgH, MgO, TiO and CN bands, which turned out smaller than predicted by Henoux's model. Obridko (*AZ* 51, 1272; *SA* 18, 758) discussed bright umbral dots as convective elements penetrating from below. Prokakis, (*SP* 35, 105) found that the Wilson depression shows an east-west asymmetry and that the depression increases with the size of the spot. Mattig (*SP* 36, 275) determined the optical scale height in various spots and concluded that the majority of umbrae are in hydrostatic equilibrium but that departures may occur. Baranovsky (*IKAO* **49**, 25; *IKAO* **51**, 56) analyzed Hα and Ca II K profiles and derived a model for the photosphere and chromosphere in umbrae. Loughhead (*SP* **38**, 77) described high-resolution observations of two regular spots at seven wavelengths in Hα. EUV spectroheliograms reveal that the chromosphere-corona transition zone is brightest directly above umbrae. Foukal *et al.* (*ApJ* **193**, L143) found from density-sensitive lines a significant decrease in gas density and consequently concluded that the temperature gradient over umbrae is decreased by at least one order of magnitude.

II. *Magnetic and Velocity Fields*

Evidence that the magnetic field strength in various bright umbral structures is smaller than in dark umbral matter is given by Buurman (*AA* **29**, 329), Kneer (*SP* **28**, 361) and Gusejnov (*IKAO* **49**, 15; *IKAO* **50**, 168). The anomalous splitting of the π component in λ 6302.5 Å was investigated in many umbrae by Künzel and Staude (*AN* **296**, 171). The authors suggest this is caused by a preponderance of left-hand screws in the umbral field structure, which may be due to a mean constant quadrupole component in the general magnetic field of the Sun.

Several investigations into the vector magnetic field configuration were carried out in which the four Stokes parameters were measured and corrections for an instrumental polarization were applied. Adam (*MN* **171**, 287) found a rather untwisted structure, which she discussed in terms of magnetic forces maintaining mechanical equilibrium. Nishi and Makita (*PASJ* **25**, 51) confirmed a strong and almost horizontal penumbral field, which is parallel with the filaments. From a series of measurements in an unipolar spot during its passage across the disk Wittmann (*SP* **36**, 29) derived an expression for the field configuration across the spot as a function of depth; he found a significant azimuthal component.

Lamb (*MN* **172**, 205) analyzed Doppler shifts at various positions within a spot and derived the three velocity components assuming axial symmetry. From a three-hour sequence of high resolution photographs Muller (*SP* **29**, 55) analyzed the bright grains which constitute the bright penumbral striae. As they move *toward* the umbra, the mean velocity increased from zero at the outer boundary to 0.5 km s^{-1} at the inner boundary. The life time of the grains (40 min to about 3 h) depends on the place of origin. Maltby (*SP* **43**, 91) analyzed the chromospheric Evershed flow on high-resolution filtergrams at seven wavelengths in Hα. He discussed the results in terms of material moving into the spot along curved flux loops.

III. *Oscillations, Waves and Flashes*

Rice and Gaizauskas (*SP* **32**, 421) mapped the photospheric velocity field over and around a sunspot. Oscillations around a 300-s period in a patchy spatial pattern were found in and outside the spot. Oscillations at periods near 180 s were present in some areas in umbra and penumbra. Oscillating regions seemed to avoid the region of strongest Evershed flow. In a very strong Fraunhofer line Schultz (NCAR Thesis #32) also found oscillations at periods around 180 s and 300 s across the umbra and could not detect variations in line depth of width. From intensity and Doppler filtergrams in Hα, Phillis (*SP* **41**, 71) concluded that velocity oscillations of umbral areas of 3″ or less with characteristic periods ranging from 145 to 180 s (mean: 150 s) and which last for at least 8 cycles occur. Moore and Tang (*SP* **41**, 81) also report 150s umbral oscillations; besides the penumbral waves they observed ‘dark puffs’ which move from the edge of the umbra across the penumbra.

Giovanelli (*IAU* **56**, 137) suggested that penumbral waves seen in Hα near the line center and in Doppler filtergrams indicate the same transverse wave. Beckers (*ApJ*, in press) measured the widths of umbral spectral lines during the passage across the disk and discussed the results in terms of Alfvén waves. The upward flux of Alfvén waves may carry up to 20% of the spot flux deficit.

Schultz (NCAR. Thesis #32) investigated the Ca II umbral flashes which may be described as a quasi-periodic velocity oscillation at about a 140s period. These flashes rarely correlate with effects in Hα and do not correlate with changes in the magnetic field strength in the umbral photosphere. No rapid periodic changes in the field strength could be detected (Schultz and White, *SP* 35, 309). Kubota *et al.* (*SP* 38, 389) discussed a flare-like brightening over the core of an umbra following impact of matter from an active filament.

C. *Evolution of Sunspots, Relation to Motions*

Vrabec (*IAU* 56, 201) presented a review on streaming magnetic features near sunspots and expounded a process of growth by inflow of magnetic features (largely pores). Decaying spots are at least partly surrounded by a 'moat' across which small magnetic features of both polarities are observed to stream away from the spot. Harvey and Harvey (*SP* 28, 61) investigated the properties of these outstreaming features in a time series of magnetograms. One of their conclusions is that the *net* rate of magnetic flux carried away is about equal to the decay rate of the spot. Michalitsanov and Bhatnagar (Big Bear Solar Obs. Report #0144) showed examples of features moving coherently in ridges at a relatively low speed. Meyer *et al.* (*IAU* 56, 235; *MN* 169, 35) explained the rapid and slow decay of spots and the origin of the moat in terms of a large reversed supergranule with the spot in its center. Vazquez (*SP* 31, 377) discussed the morphology of light bridges and their role in sunspot evolution. Bumba *et al.* (*BAC* 24, 22) inferred the existence of characteristic length scales in spot diameters and distances, which these authors relate to convection.

D. *Sunspot Structure, Theoretical Aspects*

The observations of oscillations and waves have prompted several theoretical investigations. Moore (*SP* 30, 403) computed periods and growth rates for oscillatory modes in a simple two-layer umbral model. Mullan and Yun (*SP* 30, 83) investigated the depth dependence of the overstable oscillations with realistic conductivities. They concluded that both the oscillations and the penumbral waves may be excited in umbral layers at about 350 km depth. Van der Borght (*MN* 166, 191) developed a theory of overstable motions with finite amplitudes in the Boussinesq approximation. Nye and Thomas (*SP* 38, 399) argued that running penumbral waves are due to gravity-modified magneto-acoustic waves of the 'plus' type that are vertically trapped at photospheric levels. The maximum vertical velocity occurs in the chromosphere where the waves are evanescent. Mullan (*AA* 24, 103) questioned the hypothesis of penumbral convection rolls in the case of strong magnetic fields in dark penumbral filaments. A Carnot refrigerating cycle by means of the 'moat' supergranule was suggested by Wilson (*SP* 27, 354; *SP* 27, 363; *SP* 32, 435; *SP* 35, 111; *SP* 37, 488) as a mechanism to cool sunspots; the exposition was enlivened by comments from Mullan (*SP* 32, 441) and Gokhale (*IAU* 35, 323).

Parker (*SP* 36, 249) showed that Biermann's suggestion of inhibition of convection cannot be the cause of sunspots. Instead he suggested cooling by copious fluxes of hydromagnetic waves generated by overstability in the upper thousand km of umbrae. Parker (*SP* 37, 127) also investigated the properties of hydromagnetic waves and the overstability which generates them in a vertical magnetic column with sharp lateral boundaries. The calculated efficiency of the heat engine requires that the vertical convective motions are coherent over several scale heights (Parker, *SP* 40, 275). Cram and Wilson (*SP* 41, 313) investigated the behaviour of hydromagnetic waves around plane interfaces between a region with homogeneous magnetic field and regions without a field. Wilson (*SP* 42, 333) discussed Parker's explanation of the sunspot phenomenon in terms of Wilson's (*MN* 172, 535) modification of the model by Meyer *et al.* (*IAU* 56; *MN* 169, 35).

Parker (*SP* 40, 291) pointed out that the magnetic structure which follows from cooling the top parts of umbrae (Parker, *SP* 36, 249) is liable to the exchange instability. He tentatively suggested that a suitable redistribution of the cooling in the umbra may stabilize the spot. Busse (*SP* 33, 413) derived an analytical solution for a simple two-dimensional periodic magnetostatic structure in which the Lorentz forces are balanced by pressure forces induced by the magnetic inhibition of granular convection. Mullan (*SP* 30, 75) showed that it is possible to construct a magnetostatic sunspot model completely in radiative equilibrium if a convection zone model based on Öpik's theory of convection is used. Extending Öpik's model for effects of a magnetic field, Mullan (*ApJ* **187**, 621) derived sunspot models with Alfvén wave emission; these models have the property that the effective temperatures *increase* with increasing field strengths. Meyer *et al.* (*MN* **169**, 35) proposed a model for the structure and evolution of sunspots in terms of supergranular flow and small-scale convection in the sunspot below 2000 km. During the growth phase, magnetic flux is concentrated by converging supergranular flow. Thereupon, the flow is reversed to form the moat, the spot then decays very rapidly or slowly. Turbulent diffusion between 2000 and 10 000 km depth ensures a constant decay rate.

7. SOLAR ACTIVE REGIONS AND PERIODICITIES IN SOLAR ACTIVITY

(A. Bruzek)

A comprehensive review on photospheric magnetic and velocity fields in active regions and their changes was given by Harvey (*Conf. on Flare Related Magnetic Field Dynamics* Boulder, 1974). Martin (*SP* **31**, 3) published a review on the relationship of prominences in active regions. Ideas about the mechanism producing active regions are still rather controversial. Altschuler (*PIAFE*, 1973) suggested that the magnetic fields responsible for solar activity are generated in the photosphere at the boundaries of convection cells (with little or no contribution from beneath). Schoolman (*SP* **32**, 379), on the other hand, believes that the evolution of young active regions is controlled by the dynamics of the emerging flux and is independent of photospheric convection. Meyer *et al.* (*IAU* **56**, 235; *MN* **169**, 35) advocate the theory that supergranular convection concentrates (emerging) magnetic flux to form a sunspot. Mullan (*ApJ* **186**, 1059) considers large spots and spotgroups as a special type of convection cells extending down the whole convection zone.

Observational evidence on the relation between the appearance of active regions and supergranulation is not yet convincing. Born (*SP* **38**, 127) stated once more that active regions appear and develop along the borders of chromospheric network cells. Bumba *et al.* (*BAC* **24**, 22) detected the existence of a preferred spot size and deduced a stabilization of spots by supergranular convection. They believe that all active phenomena (spots, flares, prominences) are influenced by the supergranulation. Martres *et al.* (*SP* **32**, 365), on the other hand, propose a close correlation between a 'vortex type' motion at photospheric level and large changes in the magnetic field in active regions.

Recent work on the growth and development of active regions has concentrated on EUV and X-ray regions, i.e., on their coronal manifestations. Vorpahl (*BAAS* **7**, 346) found soft X-ray emission across the neutral line a few hours after magnetic field emergence. Tousey *et al.* (*SP* **33**, 265) and Sheeley *et al.* (*SP* **40**, 103; *ApJ* **196**, L129) observed the formation of bright EUV loop systems connecting opposite magnetic polarities in emerging active regions; after a few days, cooler coronal loops connected the new active region with magnetic regions previously existing in the neighborhood. Physical conditions in coronal active regions have been derived from rocket spectra by Brabban (*SP* **38**, 449), Jordan (*IAU* **68**, in press; *PTRSL*, in press), Parkinson (*SP* **28**, 137; *SP* **28**, 487; *SP*, in press), Vaiana *et al.* (*BAAS* **6**, 296), and Withbroe and Gurman (*ApJ* **183**, 279). These models contain a central hot core above the neutral line with $T_e = 5 \times 10^6$ °K, $N_e = 10^{10}$ cm^{-3} and a surrounding 'cool' loop structured region with $T_e = 2 \times 10^6$ °K and $N_e = 2 \times 10^6$ cm^{-3}. Coronal loops have been studied in detail in EUV and X-ray spectroheliograms (Tousey *et al.*, *SP* **33**, 265; Sheeley *et al.*, *SP* **40**, 103; *ApJ* **196**, L129). They are most clearly outlined in coronal lines (e.g., Fe XV 285 Å) but also appear in transition region lines, i.e., they have a cool core (Foukal, *BAAS* **7**, 346). Some regions show systematic deviations of the loops from calculated potential fields and thus must contain strong electric currents.

The decay of spot and active magnetic fields is believed to be due to the outward transport of flux by minute (2″) magnetic features at a speed of ~1 km s^{-1} (Harvey and Harvey, *SP* **28**, 61; Michalitsanos and Bhatnagar, *AL* **16**, 43; Schoolman, *SP* **32**, 379; Vrabec, *IAU* **56**, 201; Zwaan, *IAU* **56**, 234). These radially moving magnetic knots appear with both polarities but carry a net flux of the same sign as the parent spot and remove flux at a rate sufficient to account for the decay of the spot. Sheeley *et al.* (*SP* 40, 103; *ApJ* 196, L129), on the other hand, note a rather fast *in situ* disappearance of (small) magnetic regions without this fragmentation.

An extensive investigation of periodicities in solar activity was carried out by Cole (*SP* 30, 103). From the power spectral analysis of Wolf number he concluded that 10.45 yr is a basic period of solar activity which – if combined with an amplitude modulation of a period of 11.8 yr – gives the mean cycle length of 11.06 yr, the 80-year cycle, and a phase variation of about 180 yr (see also Cohen and Lintz, *N* 250, 398; Cole, CSIRO Preprint RPP 1785). Bonov (*Solar Activity and Related Interplanetary and Terrestrial Phenomena*, Springer, 1973) also detected a 180-yr cycle. Eddy (*BAAS* 7, 365, 410; *SC* submitted) has re-examined early historical observations to make a convincing case for the reality of the Maunder minimum during the late 17th century, when sunspot activity essentially ceased for seventy years. Henkel (*SP* 25, 498) and Hartmann (*MAG* 34, 116) proposed a new determination of the epochs of the maxima of the 80-yr cycle since 350 A.D. using aurora observations and Henkel (*SP* 25, 498) suggests that an ultralong cycle of about a 900-yr period is present. Ramanuja Rao (*SP* 29, 47) performed a power spectral analysis of spot activity which showed periodicities of 5.6 and 3.5 yr (see also Csada, *SP* 35, 325) which, however, appear to be harmonics of the 11-yr period (see Cole, *SP* 30, 103).

Evidence for active longitude zones continues to accumulate. Vitinskij (*BAC* 25, 222) studied the distrubution of active regions in heliographic longitude and latitude in the period 1964/70 while Trellis (*CR*, Ser. B, 277, 183) found that the active zones oscillate in longitude by about 20 deg. Stanek (*SP* 27, 89) found maximum spot occurrence in longitude intervals of 90 deg (0, 90, 180°, etc.) with secondary peaks in intervals of 30 deg.

The question of whether seasonal variations appear in indices of solar activity has been debated by a number of authors. Vassil'eva *et al.* (*SDB* 4, 96), Mahn (*SW* 13, 44), and Ambroz (*BAC* 24, 130) propose seasonal variations of spot activity which are different for even and odd cycles, while Vitinskij (*SDB* 6, 82; *SDB* 4, 111) suggests variations in strong *fluctuations* of spot activity are present. Gleissberg (*JICR* 6, 37) stated that the maxima of the 11-yr-cycles occur preferentially in the four-month period February–May. He and Mahn (*SW* 13, 44) believe that seasonal variations cannot be explained by the proper motion of the Sun in interstellar space. However, Kopecky (submitted to *BAC*, 1975) pointed out that the Wolf number is too complicated a function of the physical parameters of sunspot groups to be appropriate for such analyses of periodicities. The proposal that planetary tides (Mullan, *JFI* 298, 341) are responsible for solar activity was examined by Condon and Schmidt (*SP* 42, 529) and Okal and Anderson (*N* 253, 511) with the conclusion that neither physical nor statistical evidence support the hypothesis.

According to Gillespie *et al.* (*ApJ* 186, L85) solar cycle 21 began in 1973. Gleissberg (*SP* 30, 599; *VAIF* 42), using revised probabilty laws, calculated the probabilities for the value and epoch of R_{max} for cycle 21. Bonov (*Solar Activity and Related Interplanetary and Terrestrial Phenomena*, Springer, 1973) and Cole (*SP* 30, 103) gave a prognosis – with rather different values – for the three solar cycles to come. Dodson *et al.* (*RGEO* 12, 329) made a comprehensive comparison between solar cycles 18, 19 and 20. Cycle 20 appears to have been a typical, average cycle.

8. FACULAE AND PLAGES

(C. Durrant and U. Grossmann-Doerth)

The presence of enhanced magnetic flux distributed over fairly large areas causes the solar plasma to assume a perturbed state called 'facular' at photospheric levels and 'plage' in the chromosphere and transition region. Recent years have seen a new development which may prove to be of considerable importance for astrophysics and plasma physics, namely the phenomenon of extreme magnetic field concentrations.

To put this development in perspective the analysis of facular and plage structures must be reviewed including work published prior to 1973.

A qualitative comparison of the temperature structure in several recent models appears in

Table 1, which contains the disturbed (starred) and undisturbed temperatures as a function of continuum optical depth at 5000 Å. Even qualitatively similar models differ quantitatively one from the other. Thus, it is important to note the simplifying assumptions incorporated in each. All models except (6), which does not discuss the density structure, and (4), in which it is arbitrarily chosen, appeal to hydrostatic equilibrium (HSE) in the vertical direction. All models except (5) and (5a) are 1-dimensional (1D) with atmospheric parameters varying only in the vertical direction. All current facular models (1–6) apply LTE, whose validity is explicitly demonstrated only for the analysis of (3). All facular models assume uniqueness (U), i.e. that the facular structure changes little from point to point or from time to time – an approximation which seems to be supported by the uniformity of facular line profiles (Shine and Linksy *SP* 25, 357). However, neither of these simplifications may be made for higher layers ($\tau_{5000} < 10^{-3}$). The careful analysis by Shine and Linsky suggests that plage profiles may be understood in terms of a steepened chromospheric temperature gradient and a macro-velocity field of considerable magnitude. No model reproduces both line profiles and centre-to-limb continuum contrast variations (CLV); indeed, the models split into two classes depending on which type of observation is given most weight. The resolution of this problem proposed by several authors is that CLV alone is insufficient to define a model and that models ignoring the geometrical structure of facular elements are inadequate. In plage the geometrical structures are well known and their association with the magnetic field has been empirically demonstrated in great detail by Nakagawa *et al.* (*SP* 30, 421), Schoolman (*SP* 32, 379), and Roy and Michalitsanos (*SP* 35, 47). The network of bright dots seen in Hα – 1 Å filtergrams follows closely ± 80 G contours. Hα plages can be identified with ± 80 G contours. The evolution of a region seems to arise from the apparently random motions of discrete magnetic points. A moving rim of magnetic flux creates small surges and concentrated activity near boundaries of opposite polarity associated with this feature. Gurman *et al.* (*SP* 34, 105) compared EUV spectroheliograms with photospheric magnetograms in active and quiet regions and found a bipartite relationship between magnetic field strength and Mg X intensity averaged over square areas 35″ x 35″.

It seems that the potentialities of plane-parallel facular models have been exhausted; further progress must come from the study of models which take the highly structured geometry of real faculae and plages into account. In the last decade this structure has been investigated by a number of authors, who have observed various properties of the 'photospheric network': in active regions photospheric lines weaken in small features (~ 1″) which cluster to form a network pattern which coincides with both the enhanced network seen in chromospheric lines and the pattern of increased magnetic field strength. Since it has also been shown that the temperature in these 'line-gap'-regions is most likely several 100 K higher than in the undisturbed photosphere, a close relationship between faculae/plages and enhanced network must be expected. An ever finer network called 'filigree' has been discovered by Dunn and Zirker (*SP* 33, 281) on filtergrams in the wings of Hα (most prominent at 2Å off line-centre). The filigree is most obvious in areas of enhanced network, where it is coincident with the centres of the mottle rosettes and the photospheric network. These structures appear to consist of very small (~ 0″.3 x 1″) elongated features ('crinkles') often located in intergranular lanes. In their vicinity the granulation has an abnormal appearance. The authors suggested that the 'crinkles' are the manifestation of the photospheric footpoints of magnetic field of intermediate strength (~ 100 G).

The hypothesis that the crinkles are the footpoints of (concentrated) magnetic field was tested by Simon and Zirker (*SP* 35, 331), who measured photographically with great spatial resolution the magnetic field in and near active regions. Although no direct correlation with the filigree pattern could be established, the authors concluded from the fact that most magnetic field patches were found to be larger than 1″.5 that 'strong magnetic fields are not solely confined to the area within crinkles'. The authors confirmed however the previous suggestion that the centre of rosettes and the roots of the mottles correspond to strong magnetic fields (field strengths up to 1300 G were measured). They also found a positive correlation between magnetic field strength and the intensity of the core of a photospheric line (see also Beckers, *BAAS*, in press). Surprisingly, no relationship could be detected between magnetic field strength and brightness of the granulation pattern. Filigrees have also been studied by Mehltretter (*SP* 38, 43) by means of interference filters at λ 3934 Å with the conclusion that they are identical with faculae. His detection of 'facular points' (presumably identical with 'crinkles') in quiet regions lends support to the idea of a gradual transition from quiet region to faculae; the facular points which Mehltretter believes to be the footpoints of tubes of strong magnetic flux may be the elements of non-spot activity with their number density (found to vary from 6 to 160 per 10" x 10" area) determining both the average field and the degree of activity. This picture has been given considerable support by the analysis of photoelectric observations of solar magnetic field. Frazier and Stenflo (*SP* 27, 330) concluded from data obtained in two lines that quiet network and plages are caused by the same basic elements which are identical regarding field strength, temperature structure and velocity. Field strengths of about 2000 G at the centre of the 'network elements' and a typical size of 100–300 km have been inferred by Stenflo (*SP* 32, 41). A model of such facular element, the first which attempts to incorporate explicitly photometric, geometric and magnetic facets of the facular phenomenon, was recently put forward by Stenflo (*SP* 42, 79); its most important properties are a sub-arcsecond diameter, a temperature enhancement throughout the atmosphere, and a magnetic field strength of about 2000 G. This last property raises the dilemma that neither static nor dynamic pressure in the observable solar atmosphere appear capable of maintaining pressure equilibrium between the elements and the ambient photosphere. The author has invoked a force-free field configuration produced and maintained by a rather peculiar flow pattern. However, direct evidence for such a pattern remains to be discovered. Parker (*ApJ* **190**, 429; *ApJ* **190**, 481) proposes that hydraulic pumping by granular motions may concentrate the flux. An alternate approach has been explored by Spruit (*ECSP I*) who suggests that a Wilson depression occurs in the field elements so that the photospheric gas pressure balances the magnetic field pressure $B^2/8\pi$ at a lower level. It is quite obvious, however, that we are still far from understanding the processes which produce and maintain field concentrations of such enormous magnitude.

Table 1. Comparison of temperature structures

Facula	Author	Structure	Assumptions
1.	Schmahl, *Za* 66, 81		HSE, LTE, U, 1D
1a.	Caccin *et al.*, *SP* 35, 41	$T^* (\tau) \geq T (\tau)$	As Schmahl, 1967
2.	Stellmacher and Wiehr, *AA* 29, 13	$T^* (\tau) \geq T (\tau)$	HSE, LTE, U, 1 D
3,	Shine and Linsky, *SP* 37, 145	$T^* (\tau) \geq T (\tau)$	HSE, LTE, U, 1 D
4.	Stenflo, *SP* 42, 79	$T^* (\tau) \geq T (\tau)$	LTE, U, 1 D
5.	Chapman, *SP* 14, 315	$T^* (\tau) \leqslant T (\tau), \tau \gtrsim 0.2$	HSE, LTE, U, 2 D
5a.	Wilson, *SP* 21, 101	$T^* (\tau) \leqslant T (\tau), \tau \gtrsim 0.3$	HSE, LTE, U, 2 D
6.	Badalyan, Prudkovsky, *SP* 17, 356	$T^* (\tau) \leqslant T (\tau), \tau \gtrsim 1.0$	LTE, U, 1 D
Plage			
	Shine and Linsky, *SP* 39, 49	$(\mathrm{d}T/\mathrm{d}h)^* > \mathrm{d}T/\mathrm{d}h$	HSE, 1 D
	Kononovich and Nikulin, *SA* 18, 602	$T^* (h) > T (h)$	HSE, 1 D

HSE = hydrostatic equilibrium
LTE = local thermodynamic equilibrium
U = uniqueness
1 D, 2 D = One-, two-dimensional

9. SOLAR FLARES

(Z. Švestka)

The last few years have produced an impressive body of new information on flares. The outstanding flare activity in August 1972 was observed with high spatial resolution on the ground and with new sophisticated instrumentation on spacecraft. The Skylab mission has allowed us, for the first time, to see the development of flares in the corona on the solar disc and to relate mass-ejections in the corona to Hα sprays, radio bursts, and shocks in interplanetary space. A third highlight is the progress made in the study of heavy nuclei emitted from flares leading to an increased understanding of the nuclear processes which take place in major flares.

A. *Subflares*

The CINOF period (De Jager, *SP* **40**, 133; Švestka *et al.* paper presented at CINOF Meeting, Sao Paulo, 1974) demonstrated that many more subflares are reported when high-resolution Hα or X-ray observations are employed. Hyder *et al.* (*ApJ* **185**, 985) reported an Hα flare brightening of about 1″ in diameter, with a lifetime of 20 s while Petrasso *et al.* (*ApJ* **199**, L127) describe a soft X-ray brightening that hardly can be classified as a subflare in Hα light. Some 15% of coronal X-ray bright points (ephemeral active regions) produce flare-like brightenings (Golub *et al., ApJ* **189**, L93; AAS Meeting, Boulder, 1975).

B. *Flares in Relation to Magnetic Fields*

The outstanding flare activity in August 1972 (Lincoln and Leighton, WDC-A Report UAG-21, NOAA, Boulder, 1972 and Coffey. WDC-A Report UAG-28, NOAA, Boulder, 1973) occurred 3.7 yr after the maximum of the last solar cycle. Such late activity bursts appear to be a common characteristic of the Sun (Dodson and Hedeman, WDC-A Report UAG-28, Part 1, p. 16, 1973, NOAA, Boulder; Fritzová and Švestka, *SP* **29**, 417). The sheared magnetic fields observed in the August 1972 flares (Zirin and Tanaka, *SP* **32**, 173) stimulated studies of force-free fields (Nakagawa and Raadu, *SP*, **25**, 127) in association with flares (Tanaka and Nakagawa, *SP* **33**, 187; Rust *et al., SP* **41**, 397) and where the current-free approximation is not valid (Rust and Bar, *SP* **33**, 445). It is well known that magnetically complex active regions are more prolific in flares accompanied by impulsive bursts; however, not only magnetic, but also velocity fields determine the place at which a flare sets in (Levine and Nakagawa, *ApJ* **190**, 703; Harvey, FBS Workshop, Falmouth, 1975). Shimizu *et al.* (in preparation, 1975) observed spectographically four cases of photospheric mass motions, probably in horizontal direction, which appear to be associated with flares. Similar observations are reported by Rust (*SP* **33**, 205) and Zirin and Tanaka (*SP* **32**, 173) for the great flare of 1972, August 7. Increased random nonthermal motions above the chromospheric level (Brueckner, *IAU* **68**, 105; *IAU* **68**, 135: Brueckner *et al.*, AAS meeting, Boulder, 1975) as well as systematic downward streaming (Widing and Cheng, *ApJ* **194**, L111) were found in EUV flare spectra observed aboard Skylab.

Measurements of magnetic field changes in association with flares are still inconclusive (Rust, Meeting on the Physics of Solar Atmosphere, RSL, 1975; FBS Workshop, Falmouth, 1975). High-resolution observations confirm the earlier Meudon result that flares occur close to evolving magnetic features (Vorpahl, *SP* **28**, 115; Rust and Roy, *SPO Contr.* #221; Rust *et al.*, *SP* **41**, 397; Rust and Bridges, *SP* **43**, 129). According to Rust (*SP* **33**, 205) the likelihood of occurrence of a flare is highest when the new magnetic feature has reversed polarity. But we still have no evidence that the photospheric magnetic field changes as a *consequence* of a flare. In the major spotless flare of 1973 July 29 Michalitsanos and Kupferman (*SP* **36**, 403) find no morphological change in the Kitt Peak magnetograms. A discussion of the importance of electric currents in the flare region was presented by Altschuler (*IAU* **57**, 3) and Heyvaerts (*SP* **38**, 419) has proposed how photospheric motions may drive the currents.

It has been confirmed by direct observations from Skylab that the two Hα ribbons of a flare represent rows of foot-points of magnetic loops extending into the corona. In the flare of 1972 August 7 the Hα ribbons separated with a velocity of $\sim 50 \text{ km s}^{-1}$ in the initial phase (Křivský *et al.*, 7th RCSP, Starý Smokovec, Czechoslovakia, 1973) and were visible in white light (Rust and Hegwer, *SP* **40**, 141). Michalitsanos and Kupferman (*SP* **36**, 403), Rust *et al.* (*SP* **41**, 397) and De Jager (*SP* **40**, 133) have shown that the brightenings in Hα are not cospatial with the locations where downstreaming material hits the chromosphere as Hyder proposed in his flare theory but now recognizes is not generally applicable (Hyder, *Symp. on High Energy Pheno-*

mena on the Sun, Preprint, p. 19, 1973). Nakagawa *et al.* (*SP* 30, 111) calculated the response of the chromosphere to a shock propagating downwards as a result of the infalling material. However, Canfield and Athay (*SP* 34, 193) have shown that such a shock would give rise to flare emission line profiles different from those observed.

C. *The Chromospheric Flare*

Fisher (*BAAS*, Solar Phys. Div. Meeting, Maryland, 1973) and Rust and Bridges (*SP* 43, 129) studied the λ 10 830 Å helium line in flares and found that, contrary to the D_3 line, it is in emission even from the onset in small flares. Machado and Seibold (*SP* 29, 75) and Fontenla and Seibold (WDC-A Report UAG-28, Part I, p. 150, 1973) found an anomalously small optical thickness for the flare knots above sunspots. De Feiter (*SSR* 16, 3) found that the gas in the flare region is more dense, by a factor of ~ 10^2 above the active solar atmosphere. De Feiter and Švestka (*SP*, in press) discussed methods for deducing the hydrogen density from the Lyman spectrum and Canfield (AFCRL Env. Res. Papers #471) estimated radiative losses from a flaring chromosphere optically thick in Hα, Ly-α and H^-. Flare layers of intermediate temperature can be observed in ionized helium. Tousey *et al.* (*SP* 33, 265) observed the Lyman series of He II in a flare spectrum, and Linsky *et al.* (AAS Meeting, Boulder, 1975) found color temperature between 24 000 and 41 000°K in the Lyman continuum of He II in flares. Asymmetry in the flare EUV lines has been observed by Brueckner (*IAU* 68, 105).

It is now believed that the primary flare source is in the transition layer or in the low corona. Thus, thermal conduction should be an important mode of energy transport to the chromosphere (Shmeleva and Syrovatsky, *SP* 33, 341; Švestka, *SP* 31, 389; Rust and Roy, *SPO Contr.* #221). The layer in the chromosphere in which the energy is deposited is only a few hundred kilometers thick (Shmeleva and Syrovatsky, *SP* 33, 341; Canfield and Athay, *SP* 34, 193; Canfield, *SP* 34, 339), and may be described by a 'shell model' by Machado and Rust (*SP* 38, 499). Brown (*SP* 36, 371) has shown that the precipitation of energetic electrons, in those locations where it occurs, dominates conduction in the deeper levels. Some authors (Brown, *SP* 31, 143; Cheng, *SP* 22, 178; Biswas and Radhakrishnan, *SP* 28, 211; Petrosian, *ApJ* 186, 291; Canfield, *SP* 34, 339) even assume that streams of non-thermal particles drive *all* other flare phenomena and are the exclusive mode of energy transport in the flare. This hypothesis, however, contradicts several observed facts. Electron streams occur only in restricted flare regions and are not present in all flares (Takakura, *Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 179; Švestka, *SP* 31, 389). Canfield (*SP* 34, 339) found Brown's model unable to explain the total chromospheric flare emission. Thus, a model combining heat conduction and particle streams appears to be nearest to the truth (Somov and Syrovatsky, *SP* 39, 415; Kostjuk and Pikelner, *AZ* 51, 1002). A detailed model of the chromospheric part of a flare has been published by Machado and Linsky (*SP*, in press), who find a temperature increase ~100°K in the uppermost photospheric region, where the flare energy is not expected to penetrate. This temperature increase might be due to illumination of the photosphere by flare X-rays; however, Somov (*SP* 42, 235), concludes that the X-ray energy is deposited at higher altitudes.

D. *The White-Light Flare*

New observations of white-light flares were reported by Rust (*SP* 33, 205), Feibelman (*SP* 39, 409) and Slonim and Korobova (*SP* 40, 397) and confirm that white-light emission occurs during the impulsive phase of the flare at the feet of one or more loops which bridge the zero line. The white-light emission patches lie within the bright Hα flare ribbons (Slonim and Korobova, *SP* 40, 397), but do not move with the ribbons (Rust and Hegwer, *SP* 40, 141). Ohki and Hudson (*SP*, in press); Hudson (*SP*, in press) suggest that observations in infrared might help to determine which kind of particles produce white-light brightenings.

A completely different type of white-light emission was observed in the flare of 1972 August 7 (Rust and Hegwer, *SP* 40, 141): After the disappearance of the white-light knots, the whole edge of a fast moving flare ribbon became visible in white light. Machado and Rust (*SP* 38, 499) analyzed the spectrum of this moving white-light wave and found that the emission came from a layer between ~ 300 to 1000 km above the photosphere. In the flare of 1972 August 2 Zirin and Tanaka (*SP* 32, 173) photographed short-lived white-light (or H9) flashes along the zero line which coincided in temporal detail with hard X-ray peaks as recorded by van Beek *et al.* (*SR* 15, in press).

E. *Flare-Associated Optical Phenomena*

Quiescent filaments can be disturbed by wave motions propagating from distant flares with accompanying type II bursts (K. Harvey *et al.*, *SP* 36, 151) moving toward regions of low Alfvén speed (Uchida *et al.*, *SP* 28, 495; Uchida, *SP* 39, 431; Kassinsky and Krat, *SP* 31, 219). There is still no convincing evidence that such a wave gives rise to sympathetic flares in a distant active region. Simnett (*SP* 34, 377) and Gergely and Erickson (*SP* 42, 467) reported statistical evidence for the occurrence of sympathetic flares in physically related active regions; however, Frizová and Chase (AAS Meeting, San Diego, 1975) show that these authors underestimated the number of chance coincidences.

F. *Soft X-Rays*

According to De Feiter and De Jager (*SP* 28, 183) the highest X-ray flux and the hardest X-ray spectra are observed in those active regions which are most productive in flares. Observations in X-rays show that many active regions are interconnected with loops (Vaiana *et al.*, *SP* 32, 81; Chase *et al.*, *SR* 16, in press), which can be strongly influenced by flares in one of the regions (Švestka and Krieger, AAS Meeting, San Diego, 1975).

X-ray photographs of flares on OSO-7 were discussed by Neupert *et al.* (*SP* 34, 349), and on Skylab by Kahler *et al.* (*ApJ*, submitted), Petrasso *et al.* (*ApJ L*199, L127), Vorpahl *et al.* (*SP*, in press), Pallavicini *et al.* (*SP*, in press) and Vorpahl (*ApJ*, submitted). The basic structure of a flare is a loop, but spatial configurations vary widely from event to event. Arcades of loops appear to be the most common shape in larger flares. At flare onset the emission is often concentrated into a small bright knot (Kahler *et al.*, *ApJ*, submitted), which may survive the entire life of the flare (Vorpahl *et al.*, *SP*, in press). Prior to the flare proper one often observes a slight preheating (Petrasso *et al.*, *ApJ L*199, L127; Vorpahl *et al.*, *SP*, in press; and Pallavicini *et al.*, *SP*, in press).

From soft X-ray bursts beyond the limb, Roy and Datlowe (*SP* 40, 165) found that soft X-ray emission in flares can extend very high into the corona. Generally, however, the scale height is ~ 11 000 km (Catalano and Van Allen, *ApJ* 185, 335).

New spectra of flares were obtained by Neupert *et al.* (SP 31, 171), Doschek *et al.* (*SP* 29, 125), Beigman *et al.* (*LPI Preprint* #67, 1974) and Kastner *et al.* (*ApJ* 191, 261). A detailed analysis of the Fe complex near 1.86 Å has been presented by Grineva *et al.* (*SP* 29, 441). Measurements of emission measure and temperature in flares have been carried out by Peterson *et al.* (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 132), Catalano and Van Allen (*ApJ* 185, 335), and Datlowe *et al.* (*SP* 35, 193; *SP* 39, 155). Landini *et al.* (*SP* 29, 93) have demonstrated that we have no means of distinguishing thermal and non-thermal heating and line-excitation in the X-ray range. Temperature estimates from line spectra have been made by Landini *et al.* (*SP* 29, 93), Beigman *et al.* (*LPI Preprint* #67), Widing and Cheng (*ApJ* 194, L111), Phillips and Neupert (*SP* 32, 209) and Neupert *et al.* (*SP* 34, 349). The variation of temperature and emission measure indicates a hot X-ray core (or cores) surrounded by a larger amount of material at a lower temperature (De Feiter, IAFE Lecture, Buenos Aires, 1973). Herring and Craig (*SP* 28, 169), Craig (*SP* 31, 197) and Herring (*SP* 39, 175) have proposed a two-component model of X-ray sources while Dere *et al.* (*SP* 36, 459) prefer a multithermal analysis. The fact that the emission measure continues to rise after the temperature falls is interpreted by Datlowe *et al.* (*SP* 35, 193) as the effect of different loops successively heated to flare temperature. Švestka (*SP* 31, 389) and Zaumen and Acton (*SP* 36, 139) suppose that the flare slowly penetrates downwards to push the transition layer deeper into the chromosphere.

Electron density estimates in X-ray flares average at $\sim 3 \times 10^{10}\,\mathrm{cm}^{-3}$ (Widing and Cheng, *ApJ 194*, L111; Neupert *et al.*, *SP* 34, 349; Rust and Roy, *SPO Contr.* #221). However, these model-dependent estimates cannot exclude the existence of plasma condensations of small dimensions ($\sim 10^{26}$ cm^3) with densities up to one order of magnitude higher (Craig, *SP* 31, 197). Line ratios give only upper limits of n_e (Bonnelle *et al.*, *SP* 29, 341).

The cooling phase of flares has been discussed by Craig (*SP* 31, 197), Craig *et al.* (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 276), Neupert *et al.* (*SP* 34, 349), Zaumen and Acton (*SP* 36, 139), Rust and Roy (*SPO Contr.* #221) and Roy and Datlowe (*SP* 40, 165). These discussions confirm heat conduction as the predominant mode of cooling, but the Skylab X-ray observations indicate material loss as another mechanism of flare decay (Silk *et al.*, *SR* 16, in press). In some flares, inhibited conduction or continued heating can be suspected during the decay phase (Neupert *et al.*, *SP* 34, 349; Pallavicini *et al.*, *SP*, in press).

G. *Hard X-Ray Bursts*

The non-thermal flare component, which manifests itself through the hard X-ray bursts and microwave bursts, is only observed in about 2/3 of the flares with a flux above 10^2 photons cm^{-2} s^{-1} keV^{-1} (Švestka, *SP* 31, 389; *IAU* 68, 427; FBS Workshop, Falmouth, 1975; Takakura, *Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 179; Datlowe *et al.*, *SP* 39, 155). The impulsive burst often occurs several minutes after the onset of the thermal flare (De Feiter, IAFE Lecture, Buenos Aires, 1973; Anderson and Mahoney, *SP* 35, 419; Spangler and Shawhan, *SP* 37, 189). According to Peterson *et al.* (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 132) and Datlowe *et al.* (*SP* 39, 155) there are definitely flares in which there is insufficient energy in the non-thermal electrons to heat the thermal plasma.

Detailed analyses of a great number of hard X-ray bursts have been performed by Kane (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 55; *SSL* 14, 79), Peterson *et al.* (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC, Preprint, p. 132) and Datlowe *et al.* (*SP* 35, 193; *SP* 39, 155). Kane (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC preprint, p. 55) finds that the X-ray spectrum hardens as the flux increases and softens during the decay. This hardening was not confirmed by McKenzie *et al.* (*SP* 28, 175), while Datlowe *et al.* (*SP* 39, 155) find it only in some events. These differences may be due to unresolved fine structure in the bursts (Kane, *SSL* 14, Iss. 79) detected by Van Beek *et al.* (*SR* 15, in press) and by Anderson and Mahoney (*SP* 35, 419). Brown (*SP* 32, 227) suggested that the progressive softening of the hard X-ray bursts is due to the deeper penetration of higher energy electrons. However, the explanation of continuous acceleration is apparently more attractive (Brown, *SP* 28, 151; Kane, *Symp. on High Energy Phenomena on the Sun*, NASA GSFC, Preprint, p. 55; Petrosian, *ApJ* 186, 291; Datlowe *et al.*, *SP* 39, 155; Vorpahl and Takakura, *ApJ* 191, 563; Van Beek *et al.*, *SR* 15, in press; Roy and Datlowe, *SP* 40, 165; and McKenzie, *SP* 40, 183). The softening of the spectra of hard X-ray bursts near the solar limb (Datlowe *et al.*, *SP* 39, 155) remains unexplained.

In the thick-target model one would expect the source of hard X-rays to be situated low in the atmosphere (e.g. Van Beek *et al.*, *SR* 15, in press). However, according to McKenzie (*SP* 40, 183) a small fraction, and according to Roy and Datlowe (*SP* 40, 165) a significant fraction of the bursts must come from altitudes in excess of 10^4 km above the chromosphere. Thus, X-ray bursts appear to exhibit both kinds of emission: thick target for the electrons propagating along the magnetic field lines into the chromosphere, and thin target for electrons diffusing in the corona (Datlowe and Lin, *SP* 32, 459; Kane, *Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 55; Vorpahl and Takakura, *ApJ* 191, 562; Roy and Datlowe, *SP* 40, 165; McKenzie, *SP* 40, 183).

Confirming measurements of polarization of hard X-ray bursts have been published by Nakada *et al.* (*SP* 37, 429). Korchak (*CAPS* 6, 57) notes that the long duration of the polarization can be explained as repeated short-term injections of accelerated electrons or backscattering of thermal X-ray emission by the solar photosphere (Beigman, *LPI Preprint*, #68). Pizzichini *et al.* (*SP* 35, 431) claim that the maximum in the longitudinal distribution of the hard X-ray bursts shifts towards the disc center as one proceeds from >10 keV to >20 keV; however, Datlowe *et al.* (*SP* 39, 155) cannot confirm this result.

H. *Impulsive Microwave Bursts*

Spangler and Shawhan (*SP* 37, 189) studied 259 microwave bursts at 15.4 GHz and confirmed their similarity to the hard X-ray bursts in occurrence, duration and structure. Castelli *et al.* (*JGR* 79, 889) and Švestka *et al.* (paper presented at CINOF Mtg., Sao Paulo, 1974) have found that groups of microwave bursts with specific characteristics occur in a restricted part of an active region and that the magnetic configuration plays a dominant role in shaping the burst characteristics. Janssens *et al.* (*SP* 31, 207) and Erjushev and Tsvetkov (*IKAO* 48, 85) report quasi-periodic pulsations in microwave bursts. An estimate of the height and size of a microwave burst source behind the limb was made by Křivský and Krüger (*BAC* 24, 291);Kundu *et al.*, (*SP* 34, 217) observed a microwave burst at 3.7 cm with 40% of the energy released within a spherical volume of only 2″ diameter; Castelli *et al.* (*JGR* 79, 889) identified a series of bursts with small Hα brightenings along the zero line while Ogawa and Kawabata (*SP* 40, 159) found an Hα kernel associated with the microwave burst in 1975 August 2. Earlier studies led to discrepancies of orders of magnitude in the total number of accelerated electrons as deduced from microwave and hard X-ray bursts. This discrepancy is largely removed by considering gyrosynchrotron self-absorption, absorption by ambient plasma and the Razin effect in a non-uniform magnetic field (Takakura, *Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 179).

I. *EUV Bursts*

EUV bursts like the X-ray and microwave bursts are composed of a gradual (quasi-thermal) and an impulsive component (Noyes, *Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 231; Donnelly *et al.*, *SP* 29, 107). Thomas and Neupert (AAS Meeting, Boulder, 1975) found that multiple spikes of EUV emission during the impulsive phase may occur at different locations within the flare and that these locations are not co-spatial with the Hα flare. Widing and Cheng (*ApJ* 194, L111; Cheng and Widing, AAS Meeting, Boulder, 1975) from Skylab pictures, and Neupert *et al.* (*SP* 34, 349) from OSO-7 pictures, found a hot core centered over the zero line of the longitudinal magnetic field, while the cooler material shows the familiar two-ribbon structure co-spatial with the Hα flare. As the flare cools the hot cloud disappears and the region between the ribbons is filled gradually with emissions from ions of lower ionization temperature exhibiting loop structures.

From the ratio of line intensities Noyes (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 231) found $n_e = 5 \times 10^{11}\,\mathrm{cm}^{-3}$ in an EUV flare from O V lines, and Donnelly and Hall (*SP* 31, 411) got $n_e \gtrsim 10^{12}\,\mathrm{cm}^{-3}$ from C III lines. Noyes reports density increases by factors of 5 to 10 in the transition zone for small flares. However, in one flare Donnelly and Hall (*SP* 31, 411) found a C III intensity ratio three times larger than its maximum theoretical value. From Fe XV lines, at higher temperature, Cowan and Widing (*ApJ* 180, 285) found $n_e = 3 \times 10^{10}\,\mathrm{cm}^{-3}$. Brueckner (*IAU* 68, 105) has reported non-thermal Doppler broadening of EUV lines with characteristic velocities of ~70 km s^{-1} before the onset of the flare of 1974 January 21. However, such broadenings appear often in developing active regions and need not necessarily characterize a 'pre-flare' situation (Brueckner, paper presented at the FBS Workshop, Falmouth, 1975). Doschek *et al.* (*APJ* 196, L83) observed random velocities of 60 to 70 km s^{-1}in EUV lines of Fe XIX and XXI in the early phase of the 1973 June 15 flare. Both Brueckner and Doschek *et al.* observe asymmetries in flare EUV lines, which imply that the motions are not strictly random.

J. *Flare Theories*

Piddington (*SP* 31, 229) has proposed that flares are produced by a sudden increased flux of Alfvén waves with the pre-flare energy stored in the form of helical twists in the magnetic fields of sunspots (Piddington, *SP* 38, 465). A somewhat similar point of view was expressed by Mullan

(*ApJ* 185, 353). Uchida and Kaburaki (*SP* 35, 451) have pointed out that the Alfvén waves are expected to be generated in the convection layer and propagate significant distances in the corona without attenuation. In closed magnetic configurations, however, the Alfvén waves dissipate by non-linear interactions near the top of the magnetic loops (Wentzel, *SP* 39, 129). Several authors have suggested that the coronal flare is hot gas 'evaporated' from the chromosphere (Sturrock, *Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint., p. 3; Hudson, *Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 207; Hirayama, *SP* 34 323). These models require that streams of electrons are the primary energy source of the flare. Hirayama and Endler (AAS Meeting, Boulder, 1975) have found that, if the flare source is in the corona, the corona must be heated first.

Low (*ApJ* 181, 209) considered the resistive diffusion of force-free magnetic fields in a compressible medium and found that the force-free configuration evolves slowly for an extended period of time during the 'flare build-up' process. The flare proper occurs in a current sheet. Barnes and Sturrock (*ApJ* 174, 659; AAS Meeting, San Diego, 1975) presented a model of an open current sheet which can be built from a force-free field configuration, which can store energy exceeding the energy of the corresponding open magnetic field structure. Current sheets appear to be the most preferred flare configuration. Priest and Heyvaerts (*SP* 36, 433; Heyvaerts, FBS Workshop, Falmouth, 1975) examine the emergence of a new bipolar flux of opposite polarity on the periphery of an active region and the formation of a current sheet along the contact surface with the old field (see also Canfield *et al., Flare Related Magnetic Field Dynamics*, Boulder, 1974). Pustilnik (*AZ* 50, 211) suggested the primary source of a flare as a trough instability in an active-region filament. Syrovatsky's model has been criticized by Anzer (*SP* 30, 459) who argues that Syrovatsky's 'impulsive phase' requires too much compression of the magnetic field and an artificially low plasma density.

The idea that flares occur in current sheets has drawn attention to possible similarities between flare instabilities and magnetospheric substorms (see e.g., Schindler, FBS Workshop, Falmouth, 1975; Obayashi, *SP* 40, 217; and other papers presented at the Flare Build-up Study Workshop at Falmouth in September 1975). Theoretical current sheet models and the reconnection problems were discussed by Parker (*JPP* 9, 49; *ApJ* 180, 247), Sonnerup (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 357), Priest and Raadu (*SP* 43, 177), and Coppi (*ApJ*, in press). Priest (*ApJ* 181, 227) criticized the earlier results obtained by Yeh and Axford on the basis that the admissible maximum input velocity in their model is actually less than in the original Petschek's model. But Bratenahl and Baum (*CALR, Preprint* #74-22) believe that their laboratory experiments confirm Yeh and Axford's results.

A flare can represent a set of different instabilities which need not be present in all flares (Piddington, *SP* 38, 465: McKenna – Lawlor, *ISSTR Sao Paulo* 1, 36: Švestka, *IAU* 68, 427; FBS Workshop, Falmouth, 1975: Coppi, *ApJ*, in press). A similar situation is obtained in theories of acceleration mechanisms: the first- and second-step accelerations (and perhaps type III bursts as well) can represent vastly different physical processes (Švestka, *IAU* 68, 427). Sonnerup (*Symp. on High Frequency Phenomena on the Sun*, NASA GSFC Preprint, p. 357) and Sturrock (*IAU* 57, 437) consider the quasi-stationary reconnection process in a current sheet as the source of the first-step acceleration while the second-step acceleration appears associated with radio type II bursts (Švestka and Fritzová-Švestková, *SP* 36, 417; Frost, *IAU* 57, 421), i.e. with shock waves and stochastic processes (Sturrock, *IAU* 57, 437; Piddington, *SP* 38, 465). Melrose (*SP* 37, 353) demonstrated how the pitch-angle distribution of particles in a turbulent field can be randomized by resonant wave particle interactions. Sturrock (*IAU* 57, 437) has presented a model of stochastic accleration by post-shock turbulence which fits the demands of Cartwright and Mogro-Campero's (*Symp. on High Energy Phenomena on the Sun*, NASA GSFC Preprint, p. 393) interpretation of the enhanced abundance of heavy elements in the $\lesssim 15$ MeV nucleon^{-1} particle streams and explains the small number of relativistic electrons produced.

10. HIGH-ENERGY SOLAR PARTICLES

(L. D. de Feiter)

An important contribution to the study of high-energy solar particles has been produced by Working Group 2 of the former Interunion Commission on Solar-Terrestrial Physics (IUCSTP) by the preparation and publication of a catalogue of solar particle events for a period of 15 years, starting with the first PCA observation in 1955 (Švestka and Simon, *Catalog of Solar Particle Events 1955–1969*, Reidel, Dordrecht, 1975). A more homogeneous list of particle events for the period May 1967–December 1972 has been compiled from the IMP-IV and -V experiments (Van Hollebeke *et al.*, *A Catalogue of Solar Cosmic Ray Events IMP's IV and V, May 1967–December 1972*, NASA X-661-74-27). Using the material of the first catalogue, Švestka and Fritzová-Švestkova (*SP* **36**, 417) conclude that proton acceleration to energies above a few MeV is closely connected with the occurrence of type II radio bursts. Low energy proton events display a poor flare association (Švestka and Simon, *Catalogue of Solar Particle Events 1955–1969*, Reidel, Dordrecht, 1975). Van Hollebeke *et al.* (*SP* **41**, 189) used the second catalogue to demonstrate that flares occurring near the interplanetary magnetic-field line that connects the Earth with the Sun have softer spectra indicating energy-dependent escape during the coronal diffusion process. Reinhard and Wibberenz (*SP* **36**, 473) have shown that the rise time to maximum, t_m, of a solar particle event can be represented as the sum of a velocity dependent term, describing the velocity dispersion of the interplanetary propagation, and a constant term which describes the propagation in the solar atmosphere (see also Lanzerotti, *JGR* **78**, 3942). According to Van Hollebeke *et al.* (*SP* **41**, 189) there seems to be a small effect of coronal propagation in the proton to alpha ratio at equal energy per nucleon. Gradually more discriminating diagnostic parameters for distinguishing between coronal and interplanetary propagation are becoming available. Model calculations of the behavior of energetic particles in coronal magnetic fields lead to the conclusions that the shape of the ambient field influences the escape of particles to interplanetary space and that storage of 10-MeV particles for longer than one day and for 3-MeV particles for longer than a few hours is extremely unlikely (Newkirk, *High Energy Phenomena on the Sun*, NASA Preprint X-693-73-193, p. 453; *Coronal Disturbances, IAU* **57**, 473; Krimigis, *High Energy Phenomena on the Sun*, NASA Preprint X-693-73-193, p. 478).

The energy spectrum at high energies is discussed by Schindler and Kearney (*N* **237**, 503; *N* **242**, 56), Heristchi and Trottet (*SP* **41**, 459), Lockwood (*JGR* **79**, 4149), Duggal and Pomerantz (*JGR* **78**, 7205). The X-ray characteristics (2–12 Å flux) of proton flares (proton energy above 50 MeV) as compared to electron flares (electron energy above 50 keV) are considered by Sarris and Shawhan (*SP* **28**, 519). Biswas and Radhakrishnan (*SP* **28**, 211) attempt to derive the optical characteristics of flares from the energetic particles. Acceleration processes are discussed by Tomozov (SA **16**), Sonnerup (*High Energy Phenomena on the Sun*, NASA Preprint X-693-73-193, p. 357), Sturrock (*Coronal Disturbances, IAU* **57**, 437), Gary (*ApJ* **187**, 195), Melrose (*SP* **37**, 535), Lin (*SSR* **16**, 189).

Important progress has been made in the determination of the charge and mass composition of solar cosmic rays (Mogro-Campero and Simpson. *ApJ L* **177**, L37; Bertsch *et al.*, *SP* **31**, 247; Bertsch *et al.*, *SP* **39**, 479; Crawford *et al.*, *ApJ* **195**, 213; McDonald, *Coronal Disturbances, IAU* **57**, 415; Fan *et al.*, *IAU* **68**, 411; Pellerin, *SP* **41**, 449; Shirk, *ApJ* **190**, 695) as a result of new techniques of identifying particle species at energies well below 10 MeV. Anomalously high abundances of heavy nuclei frequently occur below 10 MeV, although Konyakina *et al.* (*KI* **11**, 162) reported enrichments of heavier elements at energies above a few hundred MeV (see also Dobrotin, *et al.*, *PCRC* **2**, 1532). The important conclusion is that the composition of the solar flare particles changes with energy and from flare to flare, in particular an enhancement of the heavy elements by an amount that increases with Z and decreases with energy has been identified. At high energies (above ~20 MeV) the composition becomes independent of energy, reflecting more or less the composition of the solar atmosphere. Data on the abundance ratios of the helium isotopes in the energy range 4-80 MeV nucleon^{-1} have been discussed by Webber *et al.* (*PCRC* **2**, 1516) and by Serlemitsos and Balasubrahmanyan (*ApJ* **198**, 195); for some flares $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ can be as high as 1.5, whereas ^{2}H and ^{3}H nuclei are virtually absent in these cases. The theoretical implications of these observations were discussed by Ramaty and Kozlovsky (*H^2, H^3, He^3 Production in Solar Flares*, GSFC, X-660-74-94), who suggest that a beaming of secondary particles originating in nuclear reactions in the flare region could account for the ^{3}He enrichment. An important test for this explanation will be the simultaneous measurement of the ^{3}He abundance and the flux of the 2.2-MeV neutron capture gamma-ray line. No further measurements of gamma-ray lines from flares, apart from the August 1972 events (Chupp *et al.*, *High Energy Phenomena on the Sun*, NASA Preprint X-693-73-193, p. 285; Talon *et al.*, *IAU* 68, 315; Forrest *et al.*, *X-rays in Space*, Univ. of Calgary, 1975) have become available; a recent review on the interpretation of these measurements has been prepared by Ramaty *et al.* (*Solar Gamma Rays, SSR*, in press). Attempts to measure the neutron flux of flares still have not given more than upper limits (Kirsch, *SP* 28, 233; Lockwood *et al.*, *SP* 30, 183; Ifedili, *SP* 39, 233; Kirsch and Münch, *SP* 39, 459).

Electron observations have been reviewed by Lin (*SSR* 16, 189) (non-relativistic electrons) and by Simnett (*SP* 34, 377) (relativistic electrons). The most important development in this area is the further investigation of simultaneous observations of non-relativistic electron streams and interplanetary type III radio bursts (Lin *et al.*, *High Energy Phenomena on the Sun*, NASA Preprint X-693-73-193, p. 439; Stone and Fainberg, *High Energy Phenomena on the Sun*, NASA Preprint X-693-73-193, p. 519).

The theory of energetic particle transport is still under extensive investigation with particular attention to the micro-scale transport theory, i.e., the relation between the statistical properties of the fluctuation spectrum of the interplanetary magnetic field and the momentum-space diffusion tensor. Apart from the original research papers included in the references (e.g., Earl, *ApJ* **193**, 231; Fisk *et al.*, *ApJ* **190**, 417; Jokipii, *ApJ* **182**, 585; *ApJ* **194**, 465; Jones *et al.*, *ApJL* **180**, L139; *PRL* 31, 485; Kaiser *et al.*, *ApJ* **180**, 239; Klimas and Sandri, *ApJ* **180**, 925; *ApJ* **184**, 955; Owens, *ApJ* **191**, 235; Völk, *ASS* **25**, 471; Völk *et al.*, *ASS* **26**, 403; Wibberenz, *JGR* **40**, 667) the interested reader should consult the report of a workshop meeting at GSFC on the main divergences of views among the investigators working in the field (Birmingham and Jones, *Cosmic-Ray Diffusion – Report of the Workshop in Cosmic-Ray Diffusion Theory*, NASA TN D-7873). In addition to resonance scattering, the effects of large scale discontinuities on particle transport have been discussed by Webb *et al.* (*SP* 29, 477) and Toptygin (*GAER* 13, 393) and those of Alfvén waves by Hollweg and Skadron (*JGR* **80**, 2701). Developments in microscopic transport theory are concentrated in the following lines: the development and testing of a new analytic solution (Lupton and Stone, *JGR* 78, 1007), numerical studies (Webb and Quenby, *PLSC* 21, 23; Palmer *et al.*, *SP* **40**, 449), the study of convective transport including the associated adiabatic energy losses and directional flux distributions (Allum *et al.*, *SP* 38, 227; Lezniak and Webber, *SP* **26**, 474; Innanen and Van Allen, *JGR* 78, 1019; Ipavich, *GRL* 1, 149; Palmer, *SP* 30, 235; see also Roelof and Krimigis, *JGR* 78, 5375) to the effects associated with interplanetary shock waves (Palmeira and Allum, *SP* 30, 243; Palmer, *SP* 27, 466: see also Kahler, *SP* 32, 477; *SP* 33, 239: Pomerantz, *JGR* 79, 913: Pomerantz and Duggal, *RGSP* 12, 343: Sarris and Van Allen, *JGR* 79, 4157), changes in the power spectrum of the interplanetary field (Hedgecock, *SP* 42, 497) and the influence of coronal transients (Newkirk, PCRC Invited Lectures, 1975) and possibly other interplanetary situations where particle acceleration might occur (Levy *et al.*, *GRL* 2, 145). Roelof and Krimigis (*Low-Energy Solar Cosmic Rays, 1971-1974: A Bibliography*, Applied Physics Laboratory, Johns Hopkins University, 1975) remind us that "although considerable success has been reported in fitting intensity histories of some events and anisotropy histories of others, both histories have not yet been simultaneously fit for the appropriate portions of a single event for which the theory should be valid".

Additional researches in the area of high-energy solar particles are reported in Anglin *et al.*, *ApJ* 186, L41; Anglin *et al.*, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 315; Axisa *et al.*, *SP* 29, 163; Axisa *et al.*, *High Energy Phenomena on the Sun* NASA preprint X-693-73-193, p. 615; Balasubrahmanyan and Serlemitsos, *N* 252, 460; Bertsch *et al.*, *SP* 31, 247; Boishot, *IAU* 57, 423; Boltenkov *et al.*, *SR* **XII**, Vol. 2, 1487; Braddy *et al.*, *PRL* 30, 669; Bukata *et al.*, *SP* 26, 229; Cartwright and Mogro-Campero, *High*

Energy Phenomena on the Sun, NASA preprint X-693-73-193, p. 393; Cheng, *SP* **22**, 178; Cherki *et al.*, *SP* **34**, 223; Crawford *et al.*, *ApJ L* **175**, L149; De Feiter, *SSR* **16**, 3: Dietrich, *ApJ* **180**, 955; Duggal and Pommerantz, *SP* **27**, 227; Elliot, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 12; Englade, *JGR* **77**, 6266; Feit, *SP* **29**, 211; Fisk, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 418; Fisk *et al.*, *ApJ L* **190**, L35; Fleischer and Hart, *PRL* **30**, 31; Frank and Gurnett, *SP* **27**, 446; Frost, *Coronal Disturbances, IAU* **57**, 421; Garrard *et al.*, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 341; Getzelev and Ikachenko, *GAER* **13**, 208; Gloecker *et al.*, *PCRC* **2**, 1492; Goldstein *et al.*, *ApJ* **195**, 801; Gregory, *JGR* **77**, 1316; Hakura, *SP* **39**, 493; Jokipii and Stone, *JGR* **78**, 3150; Kahler, *SP* **33**, 239; Kocharov, *IANS* **37**, 1228; Kuleshova, *GAER* **12**, 328; Lanzerotti, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 427; Lanzerotti and Maclennon, *JGR* **78**, 3955; Lanzerotti *et al.*, *ApJ L* **173**, L39; Lanzerotti *et al.*, *JGR* **78**, 7986; Lerche, *ApJ* **195**, 783; Lin, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 439; Low, *ApJ* **189**, 353; Mathews, *JGR* **78**, 7537; Mathews and Lanzerotti, *N* **241**, 335; Maurer *et al.*, *JGR* **78**, 29; Maccagni *et al.*, *N* **246**, 300; McDonald *et al.*, *High Energy Particles and Quanta in Astrophysics*, MIT Press, Cambridge (Mass.), London, p. 212; McDonald and Van Hollebeke, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 404; McKibben, *JGR* **78**, 7184; Miroshnichenko, *GAER* **13**, 26; Namyanovich and Nesmyanovich, *AT* **770**, 1; Nikolayev, *GAER* **13**, 917; Owens, *ApJ* **195**, 785; Price, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 377, Price *et al.*, *PCRC* **2**, 1479; Pyle, *JGR* **78**, 12; Quenby *et al.*, *JGR* **79**, 9; Ramaty and Lingenfelter, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 301; Rao *et al.*, *JGR* **78**, 8409; Roelof, *High Energy Pehnomena on the Sun*, NASA preprint X-693-73-193, p. 486; Roelof, *JGR* **79**, 2931; Rothwell *et al.*, *PRL* **31**, 407; Sakurai, *PL*[illegible]1, 793; Sakuarai, *ASS* **28**, 375; Sakurai, *Physics of Solar Cosmic Rays*, Univ. of Tokyo Press, Tokyo, 1974; Scholer *et al.*, *SP* **24**, 475; Simnett, *High Energy Phenomena on the Sun*, NASA preprint X-693-73-193, p. 503; Simnett, *SSR* **16**, 257; Teegarden *et al.*, *ApJ* **180**, 571; Van Allen *et al.*, *JGR* **79**, 1; Van Hollebeke, paper to be presented at the International Cosmic Ray Conference, Munich, 1975; Vernov *et al.*, *GAER* **13**, 164; Verzariu and Krimigis, *JGR* **77**, 3985; Wang and Ramaty, *SP* **36**, 129; Webb and Quenby, *SP* **37**, 235; Wibberenz *et al.*, *JGR* in press.

11. PROMINENCES

(E. Tandberg-Hanssen)

A. *General*

The successful Skylab mission extended our simultaneous observation of prominences to the UV, EUV and X-ray domains, and the transition region between the cooler parts of prominences and the hot corona may now be studied in greater detail than before (Tousey *et al.*, *SP* 33, 265; Schmahl *et al.*, *SP* in press; Brinkman and Shaw, *SP* 23, 120). A monograph on Solar Prominences has been published by Tandberg-Hanssen (*Solar Prominences*, D. Reidel, Dordrecht, 1974). Waldmeier (*SP* 28, 389) discovered that Cycle No. 20 showed an anomaly never observed before: The northern hemisphere contained two zones of polar prominences, the second zone followed the first at an interval of 2.5 years (see also Hansen and Hansen, SP in press). The importance of rotational, spiral or helical motions in prominences has been discussed by Rompolt (*AUW* #252) and Palus (*BAC* 23, 60).

B. *Quiescent Prominences*

Considerable work has been done on the helium line emission of prominences, and a consistent model of the cooler parts of the plasma in these objects is emerging. Observations (Hirayama and Nakagomi, *PASJ* 26, 53) indicate that the neutral and ionized helium emission both come from the same temperature regime ~6600 K. From a study of the triplet-to-singlet line intensity ratio Heasley *et al.* (*AA* **40**, 391) deduced a similar model with Te ~7000°K, η_e ~10^{10} cm^{-3} and 'turbulent velocity' ~8 km s^{-1}. In theoretical studies of the helium emission, the penetration into a filamentary-structured prominence model of UV radiation near the head of the continuum has been considered (Morozhenko, *SP* **34**, 313; *SP* **39**, 349: and Heasley and Mihalas, *ApJ* in press). The lower levels of the singlet series appear to be populated by λ = 584 Å photospheric radiation, while the upper levels may be populated by collisions from the triplet system (Morozhenko, *SP* **42**, 71; Heasley *et al., ApJ* **192**, 181). The predicted line intensities generally agree well with observations (Streete *et al., AA* **28**, 125). Kim and Nikolsky (*SP* **28**, 377) and Stellmacher (*SP* **25**, 104) have compared He I, D_3 emission with Hα and find that the intensity ratio D_3/Hα increases in the upper regions of prominences. The excitation of hydrogen has been considered by Chultem and Yakovkin (*SP* **34**, 133), who found T_e ~5000°K, η_e ~3×10^{10} cm^{-3} for one prominence and T_e ~7300 K, η_e ~5×10^{11} cm^{-3} for another in which electron impact accounted for 40% of the excitation. Models in radiative-, magneto-, hydrostatic-, and statistical equilibrium have been considered by Heasley, Mihalas and Poland (*ApJ* **192**, 181). From observations in the extreme UV, coupled with the results reported above, one confirms that prominences have cool cores, surrounded by a thin transition zone of intermediate temperature, which merges with the hot corona (Noyes *et al., ApJ* **178**, 515; Schmahl *et al., SP* in press).

A number of models of quiescent prominences have included the effects of magnetic fields on prominence stability. Raadu and Kuperus (*SP* **28**, 77) and Kuperus and Raadu (*AA* **31**, 189) considered the support of the prominence plasma in a magnetically neutral current sheet, which allows for the frequently observed prominence eruption. (See also Mercier, *SP* **33**, 177; Axisa *et al., IAU* **57**, 69). Anzer (*SP* **24**, 324) developed a method to calculate electric currents in quiescent prominences while Stellmacher and Wiehr (*AA* **24**, 321) have observed the actual propagation of an instability through a prominence and concluded that the lateral stability criterion of the Kippenhahn-Schluter model was violated. The mechanism of the disparition-brusque phase is proposed to be a stretching of the magnetic-field lines by Lyong (*AZ* **51**, 148) while Pustilnik (*AZ* **50**, 211) has examined the influence of flares on the evolution of quiescent prominences. The formation of quiescent prominences by condensation out of the corona has been considered by Hildner (*SP* **35**, 123) and Sasorov (*AZ* **52**, 106) and of eruptive prominences by Machado (*SP* **23**, 353) and Machado and Grossi-Gallegos (*SP* **23**, 340).

The role of the infall-impact mechanism to produce flare brightening was investigated by Banos and Prokakis (*AA* **39**, 245) and Michalitsanos and Kupferman (*SP* **36**, 403) with the conclusion that bright chromospheric emission may not be the result of descending prominence material.

The structure of the quiet corona near prominences has been studied by Fort and Martres (*AA* **33**, 249) and Tsubaki (*SP* 1975, in press) using optical lines, and by Kawaguchi and Kitai (*SP* **33**, 145) and Chiuderi-Drago *et al.* (*AA* **39**, 429) using radio observations, while Pick *et al.* (*SP*, in press) discuss coronal structures in relation to type III radio bursts and the role played by prominences in the burst production. Roy and Tang (*SP* **42**, 425) suggest that the X-ray emission accompanying prominence eruption may be due to compression of the overlying corona. Kundu (*SP* **25**, 108) observed prominences at 3.5 mm wavelength, as absorption features on the disk or in emission above the limb and obtained electron temperatures and densities similar to those derived from optical measures. Leroy's (*SP* **25**, 413) observation of 'cold' hydrogen emission from the corona near prominences has been supported by Alikaeva (*SP* **41**, 89). Kaufmann (*SP* **23**, 178) observed long-period oscillations in microwave emission and suggested a possible association with oscillations in quiescent prominences. Hansen and Hansen (*SP* 1975, in press) suggested that reconnection of magnetic field lines is involved in certain observed restructurings of the corona above quiescent prominences. It is noteworthy that the concept of magnetic field-line reconnection is playing an increasingly important role in discussions of several aspects of solar activity and magnetospheric physics.

C. *Active Prominences*

While numerous attempts of rather detailed modeling of quiescent prominences have been published, only scarce information still is available for many types of active prominences. However, temperature-, density-, and magnetic-field measurements, and some model-building have been reported for loops, surges and active-region filaments.

The theory of loop prominences has been treated by De (*SP* 31, 437) and Sasarov (*AZ* 51, 795), and Machado, Grossi-Gallegos and Silva (*SP* 23, 340) have discussed the formation of the loop prominence system of 1971 May 13. Fisher (*SP* 35, 401) observed a post-flare loop and deduced an electron density of 10^{11} cm^{-3} from Ca XV forbidden line data and Thomson scattering (see also McCabe, *SP* 30, 439) while Rust and Bar (*SP* 33, 445) demonstrated that only some of the loops of the 1972 August flares fit the current-free approximation. An evaporative model for post-flare prominences has been proposed by Hirayama (*SP* 34, 323).

Rakhubovsky (*AiA* 21, 70) and Yakovkin *et al.* (*AZ* 52, 112) used hydrogen-line data to conclude that for a particular active prominence on 1970 April 1, temperature and density values were close to those found for quiescent prominences. From metal-line studies Rakhubovsky (*AiA*, in press) and Yakovkin *et al.* (*AZ* 52, 332) concluded that the chemical composition of the 1970 April 1 prominence was identical to the photospheric abundances. The disruption of an active-region filament and implications concerning the magnetic-field structure were discussed by Rust *et al.* (*SP* 41, 397) using X-ray and EUV observations together with magnetic-field calculations. The velocity characteristics of different types of active prominences have been discussed extensively. Kleczek (*BAC* 23, 315) published a comprehensive study of funnel prominences, while Tandberg-Hanssen *et al.* (*SP* 1975, in press) treated fountain prominences. The fine-structure of a large active prominence was investigated by Burns (*SP* 29, 403) who found from Hβ line intensities that the fraction of length in the line of sight which contained emitting material was about 0.1.

Considerable work has been done on surges and spray prominences and their relationship to the corona. From interpretation of surge spectra, Tamenaga *et al.* (*PASJ* 25, 447) and Kubota *et al.* (*PASJ* 26, 495) discussed velocity fields, while Kubota *et al.* (*PASJ* 25, 463) deduced the existence of an He I emitting region, different from the cooler hydrogen plasma during the early phase of surges. The formation mechanism for surges and sprays has been discussed by Lyong (*AZ* 51, 148), and Roy (*SP* 28, 95; *SP* 32, 139) offered evidence that surges are composed of numerous independent filaments which originate from satellite magnetic polarity regions. Platov (*SP* 28, 477) discussed the acceleration of surges in magnetic fields while Tandberg-Hanssen and Malville (*SP* 39, 107) presented a model in which a pre-surge axi-symmetric magnetic field is established by a line-current in the corona.

With regard to coronal activity related to active prominences, DeMastus *et al.* (*SP* 31, 449) found that coronal transients were more often caused by eruptive prominences and surges than by flares. Such events appear to represent fast rearrangements of magnetic fields (Wagner *et al.*, *SP* 34, 453), (see also Hansen *et al.*, *PASP* 86, 500). Radio observations have helped greatly in the study of prominence-induced coronal transient research (McLean, *PASA* 2, 222). The role of surges and sprays in production of coronal transients was considered by Tandberg-Hanssen and Hansen (*PCRC* 13), and Riddle *et al.* (*SP* 35, 171), while Nakagawa *et al.* (*SP* 41, 387) developed a model for the coronal response to prominence ejections, (see also Wu *et al.*, *SP* 1975, in press). The analysis of the large body of observation provided by space vehicles is expected to clarify further the role of prominence ejections in coronal transient phenomena (MacQueen *et al.*, *ApJ L*187, L85; Gosling *et al.*, *JGR* 79, 4581; Hildner *et al.*, *SP* 42, 163).

12. NON-SPOT MAGNETIC FIELDS

(R. Howard)

A. *Large-Scale Fields*

Considerable empirical evidence has accumulated on the behavior of the large scale field which may suggest clues to the operation of the solar dynamo. Stenflo (*SP* 36, 495) studied the rotation rates of magnetic fields in active and quiet regions. These rates agree at the equator, but at higher latitudes the background fields deviate less from solid-body rotation. Yoshimura (*SP*, in preparation) studied the evolution of the general magnetic field covering a 16-yr interval. He found that the general field contours display a pattern similar to the butterfly diagram but with two branches in each hemisphere, one moving toward the equator with the spots and a second weaker one moving poleward. Such behavior of the large-scale field distribution is predicted by his solar cycle model (Yoshimura, *ApJ Sup.* **29**, 467). Hansen *et al.* (*TAGU* **54**, 1193) and Svalgaard *et al.* (*SP* **37**, 159) have proposed phenomenological models of the interplay between the polar magnetic fields, the low latitude sector structure, and the location of large coronal streamers. Svalgaard and Wilcox (*SP* **41**, 461) have used the inferred interplanetary magnetic field patterns to examine the long-term evolution of the solar sector structure. It appears from their analysis that a magnetic structure with four sectors per rotation persisted through the past five cycles with a synodic rotation period near 27.0 days. Superposed on this pattern was another structure with inward field polarity, a width in solar longitude of about 100° and a synodic rotation period of about 28.5 days. The latter structure is most evident during a few years near spot maximum. Scherrer and El-Raey (*SP* **35**, 361) have examined the relationship between the slowly-varying component of solar radio emission and large-scale photospheric magnetic-field patterns inferred from interplanetary magnetic-field data. An enhancement in the radio emission was found about four days before the central meridian passage of the sector boundaries.

Altschuler *et al.* (*SP* **39**, 3) have analyzed the large-scale photospheric magnetic field in terms of surface harmonics. The single harmonic which most often characterized the general solar field corresponds to a dipole lying in the plane of the equator. The north-south dipole was prominent only during quiet years. Altschuler *et al.* (*SP* **41**, 225) have tabulated the spherical harmonic coefficients for the global photospheric magnetic field distribution between 1959 and 1974, and made these results available on microfilm. Newkirk *et al.* (*NCAR* TN/STR-85) have published a microfilm atlas of calculated potential magnetic fields in the solar corona. Nakagawa (*AA* **27**, 95) has devised a practical method of representing a class of force-free magnetic fields where $\nabla \times \mathbf{B} = \alpha \mathbf{B}$.

Howard (*SP* **38**, 283; *SP* **38**, 59; *SP* **39**, 275) has examined the large-scale magnetic field distribution on the solar surface. He finds that poleward migrations of magnetic flux were responsible for the reversals of the polar field polarities – the north in mid 1971 and the south in mid 1969. About 95% of the total magnetic flux is found within 40° of the equator. The total flux is inclined so as to trail the solar rotation by a small angle at all latitudes. Gillespie *et al.* (*ApJ* L **186**, L85) confirm the mid 1971 date for reversal of the north polar field, but they report that the south polar field did not reverse polarity until mid 1972. They report the first new-cycle spot group and a preponderance of new-cycle polarity orientations among recent ephemeral regions.

Ioshpa *et al.* (*SP* **29**, 385) have examined the magnetic and velocity fields of integrated sunlight. The magnetic-field data reveals a varying oscillatory pattern with a period in the range 300–400 s while the velocity data show oscillations with periods somewhat less than this.

B. *Small Scale Fields*

A new class of solar activity named 'Ephemeral Active Regions' has been identified by Harvey and collaborators (Harvey and Martin, *SP* **32**, 389; Harvey *et al.*, *SP* **40**, 87). These minute bipolar regions have lifetimes of about 12 h, contain $\sim 10^{20}$ Mx each, are always present with several hundred distributed more or less uniformly over the Sun, and carry in total as much magnetic flux as ordinary active regions. Such regions are manifest in the low corona as small knots of elevated density and appear in X-rays as the so-called 'bright points' (Golub *et al.*, *ApJ* **189**, L93).

Gopasyuk and Tsap (*IKAO* **49**, 3) examined the properties of magnetic fields in quiet regions and found that the frequency of magnetic poles decreases exponentially with the peak field strength. The spatial distribution of field strength within a pole is the same for all poles. In a similar study Simon and Worden (*IAU* **71**, in press) investigated the magnetic fields associated with supergranulation and found that typically stationary field points slowly diffuse and dissipate. Changes in the supergranular velocity pattern can bring about sudden shifts in the positions of these magnetic points. Smithson (*SP* 29, 365), examining the same sort of fields, finds evidence for considerable random-walk type motions among the magnetic points. Livingston and Orrall (*SP* 39, 301) pointed out the existence of magnetic 'pukas', characteristic long-lived supergranular features which remain free of magnetic field for days even though surrounded by strong field. Tsap (*IKAO*, 50, 159) confirmed that brightness and magnetic fields are correlated in quiet regions. Temperature and saturation effects have been examined for many Zeeman-sensitive lines and found to be important contributors to the measured magnetic signals (Gopasyuk *et al., SP* 31, 307; Caccin *et al., SP* 35, 31).

13. THEORY OF THE SOLAR CYCLE

(M. Stix)

Recent review articles on the subject include those of Vainshtein and Zel'dovich (*USP* 106, 431), Moffat (*JFM* 57, 625), Gubbins (*RGSP* 12, 137), Weiss (*Magnetohydrodynamics*, Swiss. Soc. Astron. and Astrophys. p. 183), Krause (*IAU* 71; *NYAC* 257, 156), Soward and Roberts (*MGYR*, in press) and Stix (*IAU* 71). Soward (*JFM 69*, 145) studied the dynamo action of random waves in an electrically conducting fluid; and Roberts and Soward (*AN* 296, 49), using Fourier transform techniques, described a unified approach to mean field magneto-hydrodynamics.

The theory of the solar cycle is currently confined to the application of *dynamo theory* to the problem of large-scale fields. Usually the solar cycle is described in terms of an $\alpha\omega$-dynamo, in which non-uniform rotation and a mean electric field parallel to the mean magnetic field (caused by turbulence possessing helicity) provide the induction mechanisms. The latter of the two effects was investigated by Yoshimura (*ApJ* 178, 863) who, using the concept of global convection in the solar convection zone, found a regeneration term which enters the mean field induction equation in the same way as the α-term derived earlier by Steenbeck, Krause and Rädler. Yoshimura (*ApJ* 201, 740) also showed that in an $\alpha\omega$-dynamo the mean field locally propagates along the surfaces of isorotation and emphasized (Yoshimura, *ApJ Sup.* 29, 467) that the angular velocity in the convection zone should vary both in depth and latitude for a best solar cycle model. Köhler (*AA* 25, 467) pointed out that the coefficient α required for a solar model is much smaller that the α obtained from the original theory of Krause. Stix (*AA* 24, 275) and Deinzer *et al.* (*AA* 36, 69) found that both steady and oscillatory $\alpha\omega$-dynamos exist and that solar parameters favor oscillatory modes. Other modes were computed by Roberts (*PTRSL* A 272, 663), Roberts and Stix (*AA* 18, 453), Jepps (*JFM* 67, 625) and Ivanova and Ruzmaikin (*OLI* preprint 43). These models all have several properties in common: (1) if $\alpha\cdot\partial\omega/\partial r$ is negative in the northern and positive in the southern hemisphere the most easily excited mode has dipole-type symmetry and is oscillatory; (2) the oscillatory modes of both symmetries, dipolar and quadrupolar, propagate from higher latitudes toward the equatorial plane; (3) for the opposite sign of $\alpha\cdot\partial\omega/\partial r$, the propagation direction is reversed and the quadrupolar oscillatory mode is preferred. As a further criterion for solar dynamo models the phase lag between the poloidal and toroidal components of the mean field may be used (Stix, *IAU* 71). This and the theory of the α-effect suggest that the angular velocity should increase with depth in the convection zone contrary to current hydrodynamic models of the convection zone, which predict the opposite (e.g. Gilman, *ARAA* 12, 47).

Two interpretations of the period of the solar cycle compete at present: one is a wave period, determined by the relative strength of the two induction mechanisms (Yoshimura, *ApJ* 201, 740; *ApJ Sup.* 29, 467), the other (e.g. Krause, *IAU* 71; *NYAC* 257, 156) is a turbulent electromagnetic diffusion time. Turbulent diffusion plays, however, an important role in *all* numerical calculations, and solar models require $\sim 10^8$ m^2 s^{-1} (Stix, *AA* 37, 121).

Other mean electromotive forces in addition to the α-effect arise in mean field electrodynamics. One is proportional to $\omega \times \mathbf{j}$ and when included can yield oscillatory solutions and may be important for the theory of the solar cycle (Rädler, *IAU* 71).

The magnetic field may be amplified until the Lorentz forces are strong enough to react back upon the motion on the small scale to reduce the α-effect as described by Moffat (*JFM* 53, 385), Stix (*AA* 20, 9), Rüdiger (*AN* 294, 183), and Jepps (*JFM* 67, 625) or on the large scale, as proposed by Malkus and Proctor (*JFM* 67, 417). A general study of turbulent dynamo action has been made by Frisch *et al.* (*JFM* 68, 769), who examine inverse cascades of magnetic helicity towards small wave numbers. Parker (*ApJ* 198, 205) considered the buoyancy of magnetic flux tubes and concluded that these tubes must be generated deep in the convection zone; otherwise, they would rise to the surface before the observed field strength is reached.

The concept of turbulent diffusion of magnetic fields continues to be a controversy between Piddington (*ASS* 24, 259; *ASS* 34, 347; *ASS* 35, 269), who maintains that turbulence does not eliminate unwanted magnetic flux, and others who argue that turbulent diffusion simply describes the cascade through the magnetic spectrum from small towards large wave numbers and that ohmic dissipation and/or flux expulsion from the Sun will destroy the large wave number flux (Parker, *ASS* 22, 279; *ApJ* 180, 247; Stix, *AA* 37, 121; Krause, *IAU* 71).

The theory of large-scale fields on the Sun also includes the photospheric *sector* structure. One proposed explanation for this structure is a corresponding pattern in the large scale *velocity* field, as e.g. computed by Busse (*AA* 28, 27), Yoshimura (*PASJ* 26, 9) and Gilman (*JAS* 32, 1331). A second is that magnetic sectors are azimuthally varying modes of the turbulent solar dynamo (Stix, *AA* 37, 121); and a third, that they are a manifestation of hydromagnetic waves propagating in the azimuthal direction along a subsurface toroidal field (Suess, *AIAAJ* 13, 443). All three theories describe a wave phenomenon in which the sector boundaries tend to retain their shape as they propagate in longitude even in the presence of a mean differential rotation (Stix, *IAU* 71).

14. OBSERVATIONS OF THE ACTIVE CORONA (EXCLUDING SKYLAB)

(G. W. Pneuman)

A. *Macroscopic Properties as Deduced from Coronal Activity*

Certainly the properties of transient coronal activity depend very strongly upon the ambient characteristics of the medium and the correct interpretation of these characteristics should give us information about the temperature, density, and even velocity distribution in the solar corona. Because of their high frequency of occurrence both in space and time, type III radio bursts seem to offer the best hope for accomplishing this and, at present, are the only 'active' probe of the corona which can compete successfully with the white-light and emission-line radiations as a diagnostic tool.

The interpretation of type III burst observations, however, has become considerably clouded by increasing difficulties with the physical understanding of the observed burst properties. In particular, the harmonic structure of the bursts and the decay mechanism have been the subjects of considerable debate in the recent literature. Concerning the harmonic structure, Slottje (*AA* 32, 107), from observations using the new 60 channel solar radiospectrograph in Dwingeloo, The Netherlands, has contended from polarization profiles that the bursts observed there occurred at the fundamental plasma frequency. Riddle (*AA* 38, 153), however, argues that Slottje's observations can also be explained as a natural consequence of a fundamental-harmonic relationship. Mercier and Rosenberg (*SP* 39, 193), Rosenberg (*SP* 42, 247) and Bhonsle and Mattoo (*AA* 30, 301) suggest that the second harmonic is to be favored. Most investigators, however, support a point of view where both the fundamental and second harmonics of the plasma frequency are present (cf. Daigne and Møller-Pedersen, *AA* 37, 355; Papadopoulos *et al.*, *ApJ* 190, 175; Baselyan *et al.*, *SP* 39, 223; Melrose, *SP* 35, 441; Stewart, 'Coronal Disturbances', *IAU* 57, 161, *SP* 39, 451, *SP* 40, 417; Daigne, *AA* 37, 355; Zheleznyakov and Zaitsev, *AA* 39, 107). Haddock and Alvarez (*SP* 34, 413) and Alvarez *et al.* (*SP* 34, 413) contend that the fundamental dominates at high frequencies close to the sun but that the second harmonic becomes more important at lower frequencies. To complicate the picture even further Takakura and Yousef (*SP* 36, 451) have even reported type III bursts with a second-third harmonic structure (see also Zheleznyakov and Zlotnik, *SP* 36, 443).

The main factors which can affect the shape of the burst are velocity dispersion of the exciter stream, the damping rate of the plasma waves, and scattering by coronal inhomogeneities. The relative importance of these mechanisms is discussed by Riddle (*SP* 34, 181) and Bradford and Hughes (*AA* 31, 419). Since the decay rates for type III emission are almost always observed to be too fast to be explained by ordinary collisional damping, various non-collisional processes have been evoked (Alvarez and Haddock, *SP* 30, 175; Evans *et al.*, *SP* 31, 501) including Landau damping (Harvey and Aubier, *AA* 22, 1; Aubier, *AA* 32, 141; Zaitsev *et al.*, *SA* 18, 147). On the other hand, Takakura *et al.* (*SP* 41, 153) interprets the decay curve as a result of the time variation of the exciter alone which has nothing to do with the decay rate of the waves. Also Leblanc (*AL* 14, 41) and Riddle (*SP* 35, 153) have pointed out the importance of coronal scattering in influencing the decay curve.

B. *Streamers, Current Sheets, and Other Small-Scale Structures*

The identification and physical interpretation of coronal holes as open diverging field regions with solar wind expansion (Munro and Withbroe, *Properties of a Coronal Hole from EUV Observations*, HCO TR-31; Pneuman, *SP* 28, 247; Noci, *SP* 28, 403; Krieger *et al.*, *SP* 29, 505; Vaiana, *SP* 32, 81; *ApJ* 185, L47; Timothy *et al.*, *SP* 42, 135) in conjunction with the more classical observations of the denser regions in white light, X-ray, EUV, and green line show that the 'open-closed' nature of the coronal field is of central importance in shaping, not only the geometrical structure, but the temperature and density structure as well. Such a picture also emerges from the recent radio observations of the middle corona at 80 and 160 MHz by Dulk and Sheridan (*SP* 36, 191). Above each closed structure a neutral sheet must be present separating the opposite polarities of the field. Manifestations of large-scale neutral sheets can be seen in the sector structure. But there must be smaller scale sheets as well. Hence, we arrive at a picture of the corona as one of bright, dense, hot closed field regions in the lower corona which, at progressively greater heights evolve into thin sheets, the sum total of these sheets resembles a honeycomb-like structure around the sun defining the polarity pattern of the solar magnetic field out past the earth. Most of the coronal material resides in the closed regions and near the sheets with the solar wind expansion taking place in the spaces between.

The association of type III's with open field structures seems obvious since they have been observed out to the orbit of earth by satellites (see Fainberg and Stone, *SSR* 16, 145 for a review). Recent ground-based observations corroborate this (Caroubalos *et al.*, *SP* 30, 473; Gergely and Kundu, *SP* 41, 163). The corelation with Hα activity and Hα filaments (Kuiper and Pasachoff, *SP* 28, 187; Mercier, *SP* 33, 177) strongly associates the bursts with polarity reversals in the field. Correlations with North-South neutral sheets have been reported by Duncan (*PASA* 2, 255). Patch structure in Type II bursts have been associated with coronal irregularities (Korolev *et al.*, *SA* 17, 776) and indications of fine structure in Type III bursts have been pointed out by many authors (Takakura and Yousef, *SP* 36, 451; *SP* 40, 421; Mattoo and Bhonsle, *SP* 38, 217; Heyvaerts, *AA* 38, 45; Stewart, *SP* 40, 417). Could these be observations of turbulence in the sheet introduced by the tearing mode instability?

Difficulties with the neutral sheet hypothesis have been suggested by Kuiper (*SP* 33, 461) who, on the basis of potential magnetic field maps, associates the bursts with diverging field regions rather than streamers. Since coronal magnetic field calculations are uncertain, however, this conclusion must be regarded as questionable. Partly resulting from a previous conclusion by Smith and Pneuman (*SP* 25, 461) that the transverse magnetic field in the sheet may severely inhibit the outward flow of electrons there, Leblanc *et al.* (*SP* 37, 409) suggest that the beam exciting the bursts travels *near* a coronal streamer but not directly along the sheet. In this connection, Weber and Rosenberg (*SP* 37, 409) argue that Smith and Pneuman's conclusion may have been too severe and that the sheet's transverse field may be smaller than they estimated.

U-bursts (inverted type III) are believed to be produced by electrons travelling in closed flux tubes. Fomichev and Chernov (*SA* 17, 506) have estimated the field stiength in the loop for a particular event to be in the range 1–8 G and have concluded that the particles responsible for the U-bursts are much less energetic than those producing type III's.

The association of these bursts with the emergence of new magnetic flux has been suggested by Sheridan *et al.* (*AL* 15, 139). An apparent disagreement concerning the location of U-bursts exists between the findings of Caroubalos *et al.* (*AA* 23, 131), who associate the bursts with the dense helmet streamers, and those of Stewart (*SP* 39, 451), who claims the density is *lower* inside the flux tube than outside. This latter result is surprising and important if true – since this type of structure is not commonly seen in white light.* If U-bursts are truly excited in the same way as Type III's, then it is puzzling why the latter is so much more commonly observed. Does the exciting agent have knowledge of the overall field geometry and choose open field lines? A more plausible explanation might be that the two are excited with more-or-less the same frequency but that, due to the higher density on closed flux tubes, they are collisionally damped more efficiently and hence infrequently observed. Thus, the rarity of low density closed flux tubes such as postulated by Stewart (*SP* 39, 451) and the rarity of occurrence of U-bursts may be related and perfectly consistent. Also, the much lower electron energies mentioned above (Formichev and Chernov, *SA* 17, 506) could be consistent with the greater attenuation of the beam in the closed regions. In closing this section, it should be noted that the Type I noise storms also presumably take place in closed field regions (Kai and Sekiguchi, *PASA* 2, 217; Dulk and Nelson, *PASA* 2, 211; Kai and Sheridan, SP 35, 181; Kai and Nakajima, *PASJ* 26, 379). Further evidence for neutral sheets in the corona, however, can be inferred from the observations of Kerdraon (*AA* 27, 361) who explains the scattering of type I radiation by radially elongated inhomogeneities in the coronal density structure.

C. *Expanding Magnetic Flux Tubes*

In radio wavelengths, outward moving clouds of plasma leave their signatures by the type IV radio bursts which often occur within them. The radiation from these bursts is generally attributed to gyro-synchroton emission from relativistic electrons near the top of the loop (cf. Dulk, *SP* 32, 491). An alternative process involving coherent plasma oscillations has been proposed by Stepanov (*SA* 17, 781) in order to explain the burst without invoking the existence of too many relativistic electrons. Whether these bursts occur in flux tubes rooted in the sun or in isolated field structures which travel along larger-scale open field lines is not completely clear. Evidence for the former hypothesis is given by Krivský and Krüger (*BAC* 24, 291), Sakurai (*SP* 31, 483; *NPS* 243, 46), and Sakurai and Chao (*JGR* 79, 661) while that for the latter was argued by McLean (*PASA* 2, 222) and Stewart *et al.* (*SP* 36, 203; *SP* 36, 219). It should be noted that isolated 'plasmoids' with self contained fields have *not* been observed in white light – the most unambiguous observation to test such theories.

Velocities of the ejected material are clearly supersonic being in excess of 200 km s^{-1} (Sakurai, *SP* 31, 483; McLean, *PASA* 2, 222; Sakurai and Chao, *JGR* 79, 661; Gergely and Kundu, *SP* 34, 433). The speeds could be interpreted as being of the order of the Alfvén speed indicating that the stresses driving the transient may be magneto-hydrodynamic. The observation of 'homologous' transients of this type (Gergely and Kundu, *SP* 34, 433; Hansen *et al.*, *PASP* 86, 500; Stewart *et al.*, *SP* 36, 219), in which the original magnetic configuration is restored after the transient, suggests that either the magnetic loops can return back to the lower corona or that reconnection of previously open field lines proceeds upward from the base following the event. At present, the latter explanation should be preferred since downward moving arches were not observed by Skylab.

Evidence for an expanding shock wave traveling ahead of these ejected arches can be inferred from the well-known type II bursts which are attributed to them. These shocks move outward faster than the plasma (> 600 km s^{-1}) and have been associated with flare-associated interplanetary disturbances which produce SSC geomagnetic storms (Sakurai and Chao, *JGR* 79, 661). During this period, the first direct observation of a type II burst beyond 5 $R_\odot$ was deduced from Imp-6 data by Malitson *et al.* (*ApJ L*14, 111). Using a quiet sun density model

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* The coronal cavities in helmets surrounding the quiescent prominence could be an exception to this rule.

(Newkirk, *ARAA* 5, 213), they estimated heights of 14 to 37 $R_\odot$ from the observed frequency range. An important unanswered question regarding the relationship between type II and type IV emission is whether the shock is actually *driven* outward by the underlying plasma or whether the magnetic configuration and the shock are expelled by a common underlying disturbance and, thenceforth, the two move outward independently. Observations that the direction of movement of the magnetic bottles does *not* coincide with that of the shock wave which excites the type II burst have been reported by Sakurai (*SP* 31, 483) and Sakurai and Chao (*JGR* 79, 661).

Observations of white light coronal transients have also been made by NRL's coronagraph aboard OSO 7 and by the Coronal Activity Monitor at Mauna Loa. The results are generally consistent with those inferred from radio data. By combining data from OSO 7 and from the Mauna Loa coronagraph pertaining to a huge coronal cloud moving outward from the Sun on 1972, June 16 Koomen *et al.* (*SP* 34, 447) inferred the stretching of a closed magnetic bottle out to at least 8 $R_\odot$. Bifurcation of the underlying coronal structure was taken as evidence of the footpoints of the loop. However, it seems that such bifurcation could also be interpreted to indicate material pushed aside by the expanding bubble. Nevertheless, abrupt depletions of material from the inner corona are commonly observed during such events (Hansen *et al.*, *PASP* 86, 500) in which, for some particularly dramatic cases, an estimated 10^{39}–10^{40} electrons are expelled into interplanetary space. These numbers agree well with the increase in charged particles observed in the solar wind following interplanetary shocks (Hirshberg *et al.*, *SP* 23, 467). Three flare associated events, one on 1972, August 12 (Riddle *et al.*, *SP* 34, 181) and two homologous eruptions on 1973, January 11 (Stewart *et al.*, *SP* 36, 203; *SP* 36, 219), were reported during this period in which combined Hα, white-light, and radio observations were employed to yield a phenomenological description of the complete plasma ejection process.

Infrequently, coronal transients are also observed in the green coronal emission line, λ 5303 (Demastus *et al.*, *SP* 31, 449; Wagner *et al.*, *SP* 34, 453). In one of the few observations that may be relevant to the important problem of magnetic-field reconnection in the corona, Wagner *et al.* (*SP* 34, 453), reported the rapid opening of a coronal green line structure cospatial with the disappearance of a coronal streamer observed in white light. A subsequent doubling of the K-corona brightness in an adjacent region is interpreted as a transferral of electrons to a new streamer created by the realignment of flux tubes during the transient. In light of the wealth of expanding bubbles observed in white-light and in radio wavelengths, it remains a continuing puzzle that such events are not commonly observed in λ5303Å. Perhaps the material is usually too cool to be seen at this wavelength.

D. *Oscillations, Pulsations, and Waves*

From the ground, sporadic evidence for oscillations in the corona has been inferred from both the emission lines and from radio observations. Marshall and Henderson (*SP* 33, 153), from a study of the profiles of Fe XIV and Fe X obtained during the 1970 March 7 eclipse in Mexico, suggested the existence of a fluctuation in time in the width of these lines. The historical difficulty as to whether the broadening is thermal or due to macroscopic motions, however, complicates the interpretation of this type of measurement.

Since the magnetic energy density in the corona is certainly significant if not dominant in some regions, waves generated in the convection zone cannot remain purely acoustic in the corona. They must be hydromagnetic in nature. Pure Alfvén waves are unlikely since their interaction with the ambient corona would excite acoustic modes. Therefore, some mode-coupled combination of fast and slow mode magnetoacoustic waves should be expected. Pulsations of radio sources, attributed to magnetohydrodynamic oscillations, have been observed during stationary type IV bursts by Kai and Takayanagi (*SP* 29, 461) and by Caroubalos *et al.* (*SP* 30, 473). At decametric wavelengths, pulsations interpreted as oscillating flux tubes have been reported by Böhme and Krüger (Rept. *UAG* 28, Part 1, WDCA, *NOAA*, 260) with approximately a 5-min period and by Achong with a time scale of a few seconds. In the frequency range of 200–300 MHz, McLean and Sheridan (*SP* 32 485) have discussed a particularly simple damped wave train of regular meter-wave pulses from the Sun.

They point out, however, that despite the distinctive characteristics of this oscillation the event is yet unexplained by existing simple theories. An interesting white-light observation of wave motion was provided by Nesmyanovich *et al.* (*SA* 18, 340) from the 1968 September 22 eclipse. They reported a helical motion of a large coronal ray apparently resulting from a toroidal MHD wave traveling upward along the streamer. The spiral wave was presumably generated by the rotation of a sunspot magnetic field lower down in the corona. Also in white light, Schmidt *et al.* (AAS Meeting, Jan. 1973, Las Cruces, NM) searched for compressional waves in the corona and found *no* intensity fluctuations greater than 4%. This placed an upper limit of 15 000 km for the lateral size of the wave trains.

Although all these observations are interesting in themselves, they do not demonstrate wave heating of the corona – mainly because there is no evidence that the processes operate continuously as they must nor that such oscillations both propagate and dissipate. More observations of these types are needed to form a more complete picture of how these pulsations interact with the thermodynamics of the corona.

E. *Solar Cycle Variations*

Density variations during the solar cycle have been investigated by Leroy and Trellis (*AA* 35, 283; *AA* 35, 289) from monochromatic and K-corona observations. They found a nearly linear relationship between the integrated K-corona intensity and Wolf number at low latitudes. By comparing estimated λ 5303Å intensities from K-corona measurements with actual measured green line intensities, they were able to estimate the effects of coronal inhomogeneities and found that local densities during solar maximum were about 5 times the average whereas the temperature was about 0.4×10^6 K larger on the average. Similar increases in coronal temperature were deduced from the green line (0.7×10^6 K) and red line (0.8×10^6 K) profiles by Marshall and Henderson (*SP* 33, 153). From a study of green line transients over the past 16 years, Demastus *et al.* (*SP* 31, 449) found a good correlation between green line transients and sunspot numbers but with the onset of activity in the corona *leading* the sunspot cycle by about a year, whereas the total intensity is closely in phase with the sunspot cycle. This first result is somewhat confusing and difficult to explain. Increases in coronal density towards solar maximum have been invoked to explain the increase in the background component of solar decametric radio emission by Krüger and Olmr (*BAC* 24, 202). Finally, cyclic variations in the polarization of type III bursts have been observed (Chertok and Krüger, *AN* 294, 241), and indications are that changes of the wave propagation conditions due to density and magnetic field variations are responsible.

15. SOLAR WIND DISTURBANCES

(A. J. Hundhausen)

Correlative studies have long implied some physical influence of solar activity on such terrestrial phenomena as geomagnetic activity. Early in the spacecraft era it was demonstrated that such an influence is transmitted to the Earth by large variations in the properties of the solar wind. During the past three years our understanding of these solar wind disturbances has advanced both through consolidation of empirical and theoretical models to yield an appealing description of the interplanetary evolution of the disturbances and through rapid development of our ideas concerning their solar origins. The author of this report has reviewed this subject up to the beginning of the 1973–1975 epoch (Hundhausen, *Solar Wind*, NASA SP308). Relevant reviews from this epoch have been published by Dryer (*SSR* 15, 403), Roelof (*Solar Wind Three*, UCLA, 1974), Burlaga (*SSR* 17, 327), and Gosling (*RGSP* 13, 1053).

Solar wind disturbances have traditionally been grouped into two classes: the true transient variations presumably produced by temporal changes in the solar corona and often preceded by a shock front and long-lived spatial structures produced by slowly evolving coronal inhomogeneities and rarely involving shocks fronts. The latter structures are drawn into a spiral-like pattern by solar rotation and appear as temporal variations to a stationary observer as they rotate by. We will follow this classification scheme here, describing work on 'interplanetary shock waves' and long-lived 'solar wind streams'. However, let us immediately emphasize that this division has come to be regarded as artificial with regard to interplanetary studies due to the recognition that observed solar wind disturbances often reveal the interaction of the two types and the realization that the interplanetary propagation of the two classes is remarkably similar.

A number of simple models for the radial propagation of spherically symmetric shock waves through the solar wind were published by 1972. Recent developments have included: (1) addition of new physical processes to such models with much effort here centered on including the magnetic field and the resulting non-radial velocity components (Nakagawa and Wellck, *SP* **32**, 257; Steinolfson *et al.*, *JGR* **80**, 1223; *JGR* **80**, 1989); (2) Extension of the simple models to non-spherical waves, with efforts here following two paths, (a) the propagation of non-spherical shock waves into a spherically symmetric ambient flow (DeYoung and Hundhausen, *JGR* **78**, 3633), and (b) the propagation of shock waves into an ambient flow containing a spiral, long-lived solar wind stream (Heinemann and Siscoe, *JGR* **79**, 1349; Hirshberg *et al.*, *JGR* **79**, 3726; Burlaga and Scudder, *JGR* **80**, 4004). It appears that the last of the newly considered effects, (2b), has the most profound influence on interplanetary shock waves.

In contrast, models of long-lived solar wind streams were at a less sophisticated stage of development in 1972 with attention restricted to small perturbations. Nonetheless, the existing linear models did contribute to our basic understanding of the 'stream interaction' process, in which the faster-moving plasma in an inhomogeneous solar wind overtakes slower-moving plasma along a spiral-shaped 'interaction front'. The resulting compression of material produces a high-pressure ridge that tends to smooth out the inhomogeneity in the flow and produce non-radial deflections of the plasma (e.g., Siscoe, *JGR* **77**, 27; Siscoe and Finley, *JGR* **77**, 35). The past three years have seen the publication of several nonlinear magnetohydrodynamic treatments of this stream interaction process (Matsude and Sakurai, *CE* **3**, 97; Nakagawa and Wellck, *SP* **32**, 257) as well as a purely kinematic (i.e., every fluid element moves with unchanging speed) model used to interpret observations (Burlaga and Barouch, *JGR* 1975, in press). In addition to these theoretical models specifically applied to the spiral configuration of long-lived streams, earlier analogies with time dependent flows have been justified and extended (Hundhausen, *JGR* **78**, 1528; Suess *et al.*, *JGR* **80**, 2023) to show that the error introduced by assuming a transient, purely radial flow is of the order of the ratio of nonradial to radial velocity components. As this ratio is generally less than 10% in the solar wind, one can use models of transient and long-lived disturbances interchangeably to this degree of accuracy. This analogy has been used to study shock formation in the long-lived streams and the possible dependence of stream interactions on solar latitude.

The phenomenological study of transient solar wind disturbances has largely followed along the paths set forth in previous years with concentration on shock waves and results generally in accord with the conceptual models of this phenomenon already formulated by 1972. Bavassano *et al.* (*JGR* **78**, 4535) and Chao and Lepping (*JGR* **79**, 1799) have deduced shock front shapes at 1 AU consistent both with similar earlier studies and with theoretical models of nonspherical shock waves. Nonetheless, the theoretical models of shock propagation in a spiral stream structure already cited above suggest a complexity not previously considered; Ogilvie and Burlaga (*JGR* **79**, 2324) have presented some observations indicating that this complexity is real, while Chao (*JGR* **78**, 5411; *Solar Wind Three*, UCLA, 1974) has suggested a still more complicated, nonuniform evolution of an interplanetary shock front. The loop-like magnetic structure that might be expected in a suddenly emitted 'driver gas' has not been directly detected (Schatten and Schatten, *JGR* **77**, 4858), but Gosling *et al.* (*JGR* **78**, 2001) and Montgomery *et al.* (*JGR* **79**, 3103) have observed anomalously low proton and electron temperatures after shock passages, an effect suggestive of the expected magnetic structure.

The precise relationship between solar activity and transient solar wind disturbances remains less than clear. The traditional association of shock waves with solar flares and radio bursts was found to be plausible in 81 of 93 examples studied by Chao and Lepping (*JGR* **79**, 1799), while

Huang and Lee (*JGR* **80**, 2863) found a statistically significant elevation in solar wind speed two days after occurrence of large flares near central meridian. However, the discovery of a much more frequent class of coronal transients than those related to flares illustrates well the deficiencies in our knowledge. These numerous ejections of mass and magnetic field observed by the Skylab coronagraph (MacQueen *et al.*, *ApJ* **187**, L85; Gosling *et al.*, *JGR* **79**, 4581; *SP* **40**, 439; Hildner *et al.*, *SP* **42**, 163) would be expected to have a significant influence on the solar wind. Yet, only a minority of these coronal transients have been found to correspond to the shock waves upon which research on transient interplanetary disturbances has concentrated.

The phenomenological study of long-lived solar wind disturbances has also followed along earlier paths but with a more substantial advancement in our understanding during the years covered in this report. The general patterns of variation in plasma density, flow direction, proton temperature, and magnetic-field strength observed in such disturbances are correlated with the variation in solar wind speed (Matsuda and Sakurai, *CE* **3**, 97; Siscoe, *JGR* **77**, 27; Gosling *et al.*, *JGR* **77**, 5442; Burlaga and Ogilvie, *JGR* **78**, 2028; Pizzo *et al.*, *JGR* **78**, 6469) in the manner predicted by stream interaction models. These patterns of correlated variation emerge even in statistical studies of large blocks of unselected solar wind data (Goldstein and Siscoe, *Solar Wind*, NASA SR 308, 506) for periods longer than about 1 day. Quantitative comparison of observations with the stream interaction models (Gosling *et al.*, *JGR* **77**, 5442; Hundhausen, *JGR* **78**, 1528) indicates that the basic density and magnetic variations in long-lived streams could be produced entirely by the stream interaction process in interplanetary space but that the observed proton temperature variations are intrinsic to the solar source of the streams; i.e., high speed solar wind is hotter than normal when leaving the solar corona. Burlaga (*JGR* **79**, 3717) has identified abrupt, out-of-phase changes in density and proton temperature within streams; these 'stream interfaces' again indicate that long-lived streams of high-speed solar wind are intrinsically hot (Hundhausen and Burlaga, *JGR* **80**, 1845). Feldman *et al.* (*JGR* **80**, 481) reports the first identification of the pattern of electron temperature variations in long-lived streams. The electrons in the interaction region are about twice as hot as normal, but those in the high-speed plasma itself are abnormally cool. The relationship of those variations with those predicted by elementary models of electron temperature structure in streams (Hundhausen, *JGR* **78**, 7996) remains unclear.

Additional solar wind characteristics have been related to long-lived streams. For example, Asbridge *et al.* (*SP* **37**, 451) and Hirshberg *et al.* (*JGR* **79**, 934) found systematic changes in the helium abundance across such structures. The twofold enhancement in helium content in steady, high-speed plasma flows is important evidence for fractionization of elements in the solar corona. Feldman *et al.* (*JGR* **78**, 2017) and Asbridge *et al.* (*SP* **37**, 451) have demonstrated the existence of 'double-peaked' ion distributions in the trailing portions of streams. Goldstein and Eviatar (*ApJ* **179**, 627) and Papadopoulos (*ApJ* **179**, 931) have discussed the microscopic plasma processes responsible for the fluid-like stream interaction process in the nearly collision free interplanetary plasma.

The traditional view that long-lived solar wind disturbances are rarely preceded by shock fronts remains valid in the light of recent studies (Ogilvie, *Solar Wind*, NASA SP-308; Gosling *et al.*, *JGR* **77**, 5442), although Chao *et al.* (*JGR* **79**, 2767) reports the existence of a reverse shock within one such disturbance. This result remains somewhat puzzling in the context of the stream interaction models already described. Formisano and Chao (*Cosmic Plasma Physics*, Plenum, 1972) and Hundhausen (*JGR* **78**, 2035) have shown that the streams observed near the orbit of Earth should steepen to form shocks not far beyond 1 AU. Early reports of solar wind observations made by the Pioneer-10 space probe en route to Jupiter emphasized a decay in the amplitude of speed variations and *smoother* stream profiles (Collard and Wolfe, *Solar Wind Three*, UCLA, 1974). However, more recent examinations of the Pioneer-10 data show that shock fronts commonly bound the stream interaction region beyond 1 AU (Hundhausen and Gosling, *JGR* 1975, in press; Smith and Wolfe, *GRL* 1975, in press). The large-scale features of the observed speed variations near 4 AU agree well with predictions based on solar wind observations near 1 AU and the conventional stream interaction models (Gosling *et al.*, *JGR* 1975, in press).

Perhaps the most exciting advance in the whole area of solar wind disturbances concerns the solar origin of the long-lived streams (the long-sought M-regions). By 1972 there was considerable evidence (see the review by Hundhausen, *Solar Wind*, NASA SP-308) that the long-lived solar wind streams stemmed from a magnetic modulation of the coronal expansion with high-speed plasma emanating from the central portions of open field regions. The subsequent discovery of coronal holes and their association with high-speed solar wind streams (Krieger *et al.*, *SP* **29**, 505) has extended and given physical meaning to this concept. Noci (*SP* **28**, 403) and Pneuman (*SP* **28**, 247) have shown that the magnetically open nature of coronal holes, permitting the steady escape of the solar wind, is sufficient to produce the basic low-density, low-emission characteristics of the holes. The correlation with and mapping of high-speed streams to holes has been further explored by Nolte and Roelof (*SP* **33**, 241; *SP* **33**, 483) and by Neupert and Pizzo (*JGR* **79**, 3701). A detailed theoretical model of solar wind formation in open, diverging magnetic geometries has been developed by Durney and Pneuman (*SP* **40**, 461) and appears to explain the basic modulation of solar wind flow. Nonetheless the physical causes of the high speeds occurring in the actual solar wind streams remains obscure.

16. SUN-EARTH RELATIONS

(C. Sawyer)

New ways of looking at the corona, especially the discovery of EUV and X-ray coronal holes, have excited a lively interest in the old question of M regions, the hypothetical solar source of recurrent geomagnetic disturbance. Geomagnetic indices have been analyzed for coronal holes identified in Mg X, Fe XV (*BAAS* **5**, 269; *JGR* **79**, 3701; *CA* #271) and K-coronal (white-light) emissions (*EOS* #557 a) as well as in 9.1-cm wavelength radiation and the familiar green line of Fe XIV (*JGR* **78**, 4787). The new results confirm the old 'cone-of-avoidance' relation with a unanimity that was never attained from analysis of ground-based data alone. The relation of geomagnetic disturbance to magnetic sector boundaries has been reinvestigated (*JGR* **79**, 289) and compared to its clear dependence on high-speed streams in the solar wind (*JGR*, to be submitted).

Positive results of attempts to relate variations of climate or weather to solar activity have multiplied in recent years. The 'maximum entropy method' (MEM) of spectral analysis detects for the first time a convincing signal in global annual temperature at a period (10.5 y), near that of the solar-activity cycle (*JGR* **79**, 5657). Annual zonal averages of precipitation show a correlation with sunspot and facular activity which is strong but which strangely reverses phase at different terrestrial latitudes and in different epochs (*Proc. First European Astronomical Meeting*, Athens, September 4–9, 1972, **1**, Springer-Verlag, Berlin, 1973). On a shorter time scale, the association of a terrestrial zonal vorticity index with geomagnetic disturbance or sector-boundary crossing has been proposed (*RGSP* **11**, 731; *JAS* **30**, 135; *JAS* **31**, 581; *EOS* **56**, 364) and independently verified (*N* **258**, 313).

WORKING GROUP ON INTERNATIONAL PROGRAMS

(P. Simon)

A. *Long Duration Programs*

These are devoted to the survey of solar activity, using a great variety of techniques: white light photographs, magnetic field measurements of sunspots, spectroheliograms or filtergrams of plages and flares, optical coronal data, magnetic field of the solar photosphere, global radio flux, radiospectograms of events, radioheliograms of active centers and bursts, X-ray global flux, solar particles, magnetic field of the interplanetary medium, solar wind data, etc.

Data are reported in a variety of publications: *The Quarterly Bulletin on Solar Activity* (Zurich), *Solar-Geophysical Data* (Boulder), *Solnechnye Dannye* (Pulkovo), *The Photographic*

Journal of the Sun (Rome), *Les Cartes Synoptiques de la Chromosphere* (Meudon), the *Heliographic Maps of the Photosphere* (Zurich), *Solar Activity Charts* (Toyokawa), *Solar Terrestrial Activity Charts* (Tokyo). We note that the Fraunhofer Institute (Freiburg) discontinued its series of 'Maps of the Sun', begun with the I.G.Y. in 1956.

Several aspects of the reporting of these data are being reviewed. A new 'Instruction Manual for Monthly Reports' has been prepared by H. Tanaka (Toyokawa Obs. 1975) for radio observations. A similar work is in progress at Meudon devoted to flare and subflare survey and publication and its conclusions have been submitted to the members of Commission 10. This report recommends that the WDC-C at Meudon and the WDC-A at Boulder cooperate more closely on flare data evaluation and publication. In fact, as of the data for January 1975, the group flare reports are identical in the *Quarterly Bulletin on Solar Activity* and in *Solar-Geophysical Data*. The number of institutes contributing to the flare survey is significantly decreasing, with 29 contributors in 1974 against 40 in 1971.

The WDC-A has continued to publish in their UAG-Report series both analyses of data devoted to special events and special collections of data:

> Special events 1971 January 24 and September 1) or periods (1972 July 26–August 14; 1970 February 19–23 and November 29–December 3): Collections of data (High-Speed Streams of Solar Wind, Maps of the Sun at 3.3 mm, 1967–1969, EUV flashes of Solar Flares during Skylab, Hα Synoptic Charts during Skylab and during first year of Cycle 20, Maps of the Sun at 9.1 cm, June 1962–August 1973, Synoptic Observations of the Solar Corona for Carrington Rotations 1580–1596, Synoptic Maps of Solar Coronal Holes from He II 304 Å during Skylab, and Experimental Comprehensive Solar Flare Indices for Certain Flares (1970–1974).

B. *Temporary Projects*

I. *CINOF (Campaign for Integrated Observation of Solar Flares)*

Following the observing period (1972 June 5–29), about a dozen small events have been selected for a cooperative study by 10 of our colleagues. The relevant papers were discussed at Sao Paulo (June 1974) during the SCOSTEP *D* Symposium and a synthesis of the results has been published by the Chairman, C. de Jager (*SP* **40**, 133).

II. *Catalog of Solar Particle Events (1955–1969)*

This documents 352 particle events and reports, 394 additional weak or unconfirmed ones detected by riometer, neutron monitor, balloon and satellite detectors. Solar sources are identified for many of the events (*Catalog of Solar Particle Events, 1955–1969*, (ed. by Z. Švestka and P. Simon), D. Reidel, 1975).

ABBREVIATIONS

AA = Astronomy and Astrophysics
AA Sup. = Astronomy and Astrophysics Supplement
AiA = Astrometrija i Astrofizika
AIAA = Bulletin of the American Institute of Aeronautics and Astronautics
AIAAJ = Journal of the American Institute of Aeronautics and Astronautics
AJ = Astronomical Journal
AL = Astrophysical Letters
AN = Astronomische Nachrichten
AO = Applied Optics
ApJ = Astrophysical Journal
ApJL = Astrophysical Journal Letters
ApJ Sup. = Astrophysical Journal Supplement
ARAA = Annual Review of Astronomy and Astrophysics
ASS = Astrophysics and Space Science

AT = Astronomicheskij Tsirkular
AUP = Australian Journal of Physics
AUPA = Australian Journal of Physics, Astrophysical Supplement
AUW = Acta Universitatis Wratislaviensis
AZ = Astronomicheskij Zhurnal
BAC = Bulletin of the Astronomical Institutes of Czechoslovakia
BAAS = Bulletin of the American Astronomical Society
CA = Center for Astrophysics – preprint
CALR = Univ. of Calif. at Riverside
CAPS = Comments on Astrophysics and Space Physics
CE = Cosmic Electrodynamics
COSP = COSPAR Symposium
CR = Comptes Rendus de l'Academie des Sciences, Paris
ECSP I = First European Conference on Solar Physics, Florence
EOS = EOS, American Geophysical Union
GAER = Geomagnetizm i Aeronomiya
GRL = Geophysical Research Letters
IANS = Izv. Akad. Nauk SSSR
IAU = IAU Symposium
IKAO = Izvestiya Krymskoj Astrofizicheskoj Observatorii
ISSTR = International Symposium on Solar Terrestrial Relations
JAS = Journal of Atmospheric Sciences
JFI = Journal of Franklin Institute
JFM = Journal of Fluid Mechanics
JGR = Journal of Geophysical Research
JICR = Journal of Interdisciplinary Cycle Research
JOSO = JOSO Annual Report
JPP = Journal of Plasma Physics
KB = Kleinheubacher Berichte
KI = Kosmicheskie Issledovaniya
LPI = P.N. Lebedev Physical Institute
MAG = Mitteilungen der Astronomischen Gesellschaft
MGYR = Magnetnaya Gidrodynamika
MN = Monthly Notices of the Royal Astronomical Society
N = Nature
NCAR = National Center for Atmospheric Research Publications
NOAA = National Oceanic and Atmospheric Administration
NPS = Nature Physical Science
NRO = Nouvelle Revue d'Optique
NYAC = Ann. New York Acad. Sciences
OE = Optical Engineering
OLI = Ord. Lenin Inst. Prikl. Mat. Acad.
PAAS = Publications of the American Astronautical Society
PASA = Proceedings of the Astronomical Society of Australia
PASJ = Publications of the Astronomical Society of Japan
PASP = Publications of the Astronomical Society of the Pacific
PCRC = Proceedings of the International Cosmic Ray Conference
PIAFE = Proceedings of the IAFE Flare Conference
PLSC = Planetary and Space Science
PRL = Physical Review Letters
PSL = Proceedings of the Physical Society, London
PSPIE = Proceedings of the Society of Photo-Optical Instr. Eng.
PTRSL = Philosophical Transactions of the Royal Society, London
RCSP = Regional Consultation on Solar Physics
RGEO = Reviews of Geophysics
RGSP = Reviews of Geophysics Space Physics
RSL = Royal Society London
SA = Soviet Astronomy
SC = Science
SDB = Solnechnye Dannye Byulleten'

SP = Solar Physics
SPO = Sacramento Peak Observatory
SR = Space Research
SSI = Space Science Instrumentation
SSL = Space Science Laboratory
SSR = Space Science Reviews
SW = Sterne und Weltraum
TAI = Trudy Astrofizicheskogo Instituta
TAGU = Transactions American Geophysical Union
TAOR = Tokyo Astronomical Observatory Reports No. 62
U = Unpublished
UCR = UCAR preprint
USP = Uspekhi Fiz. Nauk
VAIF = Veroeffentlichungen Astr. Inst. Frankfurt
ZA = Zeitschrift für Astrophysik