10. SOLAR ACTIVITY (ACTIVITÉ SOLAIRE)

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This report summarizes research on solar activity over the three year period from September 1975 through September 1978. Every attempt has been made by the Organizing Committee to produce a comprehensive review of the highlights of the last three years within the limitations of available space. It is inevitable that some researches have not been described in great detail and others may have been inadvertantly omitted. For such oversights we apologize. The President wishes to acknowledge the effort of the authors who have assembled this report and our colleagues who have furnished material for inclusion in this summary of progress over the past three years.

It is our sad duty to report the death of S. F. Smerd, Member of the Organizing Committee. He served the IAU in a variety of capacities, and the loss of his astute scientific guidance and warm friendship is felt by us all.

At the 1976 General Assembly the IAU passed a resolution to encourage the Debrecen Observatory to undertake the responsibility of the continuation of the Greenwich Photoheliographic Program, which the Greenwich Observatory was forced to discontinue in January 1977. Dr. Dezsö, Director of Debrecen, reports that the 10cm telescopes at Debrecen and at Gyula (separated by about 100km) have been producing white light photographs with a solar image of 10.5cm diameter each clear day since January 1977 to continue this program. (Pub. Debrecen Obs. 1, Nos. 11-14, 1978). The Greenwich system generally operated with an aperture of 10cm with a solar image of 19 cm. Dezso has visited Drs. Graham Smith and Stickland at RGO to assure that the methods of observing and analysis used at that institution for more than a century are maintained.

Since Debrecen has been carrying out a photoheliograph program for many years and has some 40,000 plates covering the last 22 years, ample material exists for comparing the RGO and Debrecen results on the same days before 1977 to calibrate such measured parameters as sunspot area. Debrecen is developing a television scanner to automate such measurements. Debrecen has to date secured the cooperation of the Pulkovo, Kislovodsk, Kodaikanal and Royal Greenwich Observatories in supplying data of similar quality to fill in the gaps in the Debrecen series.

The solar physics community owes Dr. Dezsö and his colleagues at Debrecen and at the other collaborating stations a debt of gratitude for taking on the responsibility of maintaining continued homogeneity of these important data.

1. THEORY OF THE SOLAR CYCLE
(M. Stix)

Understanding the fundamental processes underlying the solar cycle still presents one of the principal challenges of modern astrophysics. The period of this report has been one of intense activity, some of which was undoubtedly stimulated by IAU Symposium No. 71, "Basic Mechanisms of Solar Activity," Prague, 25-29 August 1975. Most dynamo models which have been more or less successful in explaining the observed features of the solar cycle fall in the category of $\alpha\omega$-dynamos and are based on helical convection ("α"), a non-uniform mean angular velocity ("ω"), and

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turbulent diffusion of the mean magnetic field as an additional essential ingredient. Current research on each of these factors is described below.

A) The *angular velocity*, according to most of these models, should *increase* with depth in order to yield an equatorwards traveling mean field. However, most theories of the convection zone and differential rotation predict that the angular velocity should *decrease* with depth because the restraint of rotation tends to cause angular velocity to be constant on cylinders co-axial with the rotation axis. Observed differences of eastwards and westwards propagating solar p-modes indicate an increase with depth (Deubner *et al.*, *AA*, in press) in a shallow layer below the photosphere; however, the behavior of angular velocity in deeper layers is uncertain. An inwards increasing angular velocity is, however, predicted by calculations of Belvedere and Paternò (*SP* 54, 189) on the basis of a latitude dependent mean heat flow across the convection zone. This crucial question remains unresolved.

B) The α-effect employed in most models is scalar. It is, however, known that α is a tensor in general, i.e., the mean electric field arising from helical convection need not be exactly parallel to the mean magnetic field. Wälder (1978, Thesis, Univ. Göttingen) studied such an α, and Weisshaar (1978, Dipl, Univ. Göttingen) computed mean field dynamos on this basis. The behaviour of α at high electrical conductivity has been debated: Deinzer (*MAG* 40. 156) and Wälder (l.c.) find $\alpha \to 0$ in this limit, but Moffatt (*AAM* 16, 119; *Magnetic Field Generation in Electrically Conducting Fluids*, Cambridge Univ. Press) argues that a finite value is obtained if there exist contributions to the helicity spectrum at zero-frequency. Levy (*ApJ* 220, 325) finds a finite α for high conductivity, and Kraichnan's (*JFM* 75, 657; 77, 753) numerical simulation also indicates such behaviour.

C) Considering *turbulent electromagnetic diffusivity*, Knobloch (*JFM* 83, 129; *ApJ* in press) realized that the turbulent diffusion of a mean divergence-free vector field differs from that of a scalar, due to velocity correlations of higher than second order. Kraichnan (l.c.) found that helicity fluctuations influence the magnetic diffusivity, which can even be negative, while the diffusivity of a scalar remains positive. Nakano (*PASJ* 28, 451) introduced a wavenumber dependent turbulent diffusivity, and thus generalized the two-scale formalism which is normally adopted in mean field electrodynamics (e.g. Moffatt, 1978, l.c.).

MHD turbulence has been studied numerically by Pouquet *et al.* (*JFM* 77, 321) and by Pouquet and Patterson (*JFM* 85, 305). They find transfer of energy from kinetic into magnetic form together with a cascade of kinetic energy and an inverse cascade of magnetic energy. Since anisotropies, compressibility, a realistic geometry and boundary conditions are not considered in these calculations, application to the sun does not yet appear possible. But the non-linear interactions are studied in an exact fashion, even at moderately large magnetic Reynolds numbers.

Mean field models of the solar cycle predict well-defined phase relations between the toroidal and poloidal mean field components. Comparison of such models with Mt. Wilson magnetograms suggests that the rate of rotation increases with depth (Stix, *AA*, 47, 243). Yoshimura (*SP* 50, 3) argued that latitudinal shear is more important than radial shear in order to explain such observations and that the fields originate in the upper part of the convection zone. The latter result is in contrast to a conclusion of Parker that the fields would be much weaker than those observed if they were generated in the upper layers, and that, therefore, their origin must be deep. In fact, the solar dynamo seemed to be able to exist only below or at the base of convection zone. Unno and Ribes (*ApJ* 208, 222) and Schüssler (*AA* 56, 439) found that the buoyant magnetic fields could well originate from within the convection zone but only in its deeper layers. The rise of the buoyant field has been described in a linear model by Parker (*ApJ* 215, 370) as a mean upward flow with the consequence that the dynamo works with less ease. Yoshimura (*ApJ* 220, 692; *ApJ* in press) described the dynamic effects by a number of free parameters including a time delay in the build up of the field and its inhibition of the fluid motions in a non-linear model and was able to simulate numerically long term variations of the amplitude of the solar cycle. Non-linear models including an incompressible mean flow were calculated by Nelle (1977, Diplom, Univ. Göttingen); her results yield qualitatively correct butterfly diagrams, but the fields generally appear at too high latitudes. Application to the sun appears to be limited also because the Lorentz force arising from the second order correlations of the fluctuating field has been omitted. Compressible motions have been considered by Schlüsser (*AA*, in press) in a simplified geometry. Sector-type mean fields generated by the solar dynamo have been suggested to control the origin, rotation, and evolution of coronal holes (Stix, *AA* 59, 73).

The fore-mentioned models all use a mean field induction equation where the interaction of rotation with convection is described by the α-effect. More ambitious are the attempts to describe directly this interaction by a non-linear set of hydromagnetic equations. Kennet (*SAM* 55, 65) and Baker (*GAFD*, in press) used truncated modal expansions which are limited in applicability since, due to lack of convergence, they sometimes yield fallacious dynamos. Gilman has extended his spherical shell, thermal convection numerical model (*GAFD* 8, 93) to include the dynamo action of an incompressible fluid. Preliminary results indicate that convergence is obtained. These calculations reproduce oscillating fields and simulate the butterfly diagram. However, the dynamo period is too short by at least one order of magnitude. It is worth noting that this model maintains the dynamo with equatorward drift of the fields even though the mean angular velocity decreases with depth. The model appears to illustrate a basic difficulty in that the convective motions needed to drive the correct amplitude differential rotation have too much helicity to give the correct amplitude for the α-coefficient of the traditional αω-dynamo. The effect of field concentration into small flux filaments might resolve this problem; but a numerical treatment of the effect in a global dynamo has not yet been done and its complexity will surely demand that the effect can be introduced only by means of non-physical parameterization.

Recent reviews on the dynamo problem have been published by Moffatt (1976, 1.c.), Vainstein (1976, *SPU* 120, 613; *Engl.* 19, 987), Parker (*ARAA* 15, 45) and Stix (1978, *2ESM*). Moffatt (1978, 1.c.) has contributed an entire monograph to the field.

2. EMPIRICAL ASPECTS OF THE SOLAR CYCLE
(V. A. Krat)

Detailed reviews of several aspects of the solar cycle have been published by Kuklin (*IAU* 71, 147) and have appeared in, "The Sun and the Atmosphere of the Earth," by Vitinsky, Ol' and Sazonov (Gidrometeorzdat, Moscow, 1976) and "The Solar Output and Its Variation," ed. by O. R. White (Colorado Associated University Press, 1977).

Combining various data of cycle 20 including the intensity of the corona at different latitudes, Gnevyshev (*SP* 51, 175) concluded that the 11 year cycle contains two maxima. The first coincides with the maximum in sunspot number and is accompanied by high activity at all latitudes. The second occurs 2-3 years later and appears predominantly at low (about 10°) latitudes. Constructing a "butterfly diagram" from the large scale magnetic fields for the period 1959-1974, Yoshimura *SP* 47, 581) has determined that the poloidal field breaks up into two zones in each hemisphere with opposite polarity in each zone. Svalgaard and Wilcox (*SP* 49, 177) have pointed out that the borders between large scale magnetic regions on the sun which give rise to interplanetary sector boundaries have different properties depending upon whether the change in magnetic polarity with longitude is opposite to or the same as that of sunspot groups in the same hemisphere. Near the latter, designated Hale boundaries, emission in the green coronal line and the magnitude of the non-spot magnetic field are a maximum while near the non-Hale boundaries both are a minimum. The connection of this phenomenon to the presence or absence of coronal streamers above these boundaries has not yet been investigated. These Hale borders appear to coincide with the position of active longitudes as shown by the presence of photospheric faculae for the 19th and 20th solar cycle (Kramynin, *SDB* 8, 60).

Karlinsky (*BAC* 28, 200) showed statistically a dependence of the displacement of active longitudes on the level of solar activity. Tuominen (*SP* 47, 541), Kozhevnikov (*AZAN* 53, 389), Antonucci *et al* (*SP* 53, 519), found that both the latitudinal drift of sunspot groups and the variation of rotation of the chromosphere and corona with latitude vary with the phase of the cycle. Using what data exist on the variation of solar activity, solar radius, and the solar constant, Vasiliev and Kandaurova (*SDB* 10, 71) suggest that the sun may pulsate with a main period of 22 years.

Several papers have dealt with the properties of the 80 year cycle (Vitinskij, Ol' and Sazonov, *The Sun and the Atmosphere of the Earth*, 173, Gidrometeoizdat, Moscow; Berdichevskaya, *AZAN* 53, 822; *AZAN* 53, 1046; Gleissberg, *VAIF* 59, 1977; Kopecky, *7CSP*, 249; Kuklin *IAU* 71, 147; Schröter, *SP* 50, 501; Yoshimura, *SP* 47, 581), Vitinskij (*SDB* 11, 59) and Vitinskij and Miletsky, (*SDB* 5, 1977) discussed the spatial and temporal distribution of various activity indices. Trellis (*CR* 284, 453) indicated that active longitudes of sunspot areas oscillate with a period of about 20-30 revolutions. A statistically significant North-South asymmetry in the frequency of large flares, of complex magnetic class sunspots, and of large sunspots has been detected in the data covering the last two solar cycles (Roy, *SP* 52, 53). A similar asymmetry appears in the distribution of white light flares reported since 1959.

Renewed interest has emerged concerning the topic of the so-called Maunder Minimum (XVII century). Eddy (*SC* 192, 1189) and "The Solar Output and Its Variation" (l.c) presented further evidence that solar activity as revealed by sunspots essentially disappeared between 1645 and 1700. Some investigators (Gleissberg, *SW* 16, 229; Link *AA* 54, 857; Vitinskij *SP*, in press) consider that this minimum in the overall envelope of solar activity is a natural consequence of the existence of a periodicity in solar activity with a period of several hundred years. The abundance of radioactive carbon, which reflects the flux level of galactic cosmic rays at the top of the atmosphere and thus, solar activity, in the rings of trees (Dergachev and Kocharov, *IANS* 41, 422; Damon, "The Solar Output and Its Variation", 429 (l.c.)) leaves little doubt that major variations in the level of solar activity have occurred over the last 5000 years although the presence of regular periodicity remains uncertain.

A new method of solar activity forecasts using geomagnetic data was outlined by Ol' (*SDB* 9, 73; *SDB* 12, 87). Forecasts of the properties of Cycle 21 were made also by Ramaswami (*N* 265, 713) and Vitinskij (*SDB* 11, 59). In connection with this problem paper by Kopecky (l.c), Dodson, Hedeman and Mohler (U) should be mentioned.

Several authors (Pystina, Shpitalnaya, and Vasilieva, *SDB* 3, 60; Romanchuck, *Astron. Obs., Kiev*, Preprint #10, 1975; Khlystov, *SDB* 10, 78; Kozhevnikov, *AZAN* 53, 389) have attempted to prove a dependence of solar activity on such external forces as planetary tides and the galactic magnetic field. That this idea is not widely accepted can be seen in the work of Gudzenko and Chertoprud (*TAI* 90, 154) and Smythe and Eddy (*N* 266, 434).

New indices of solar activity have been proposed by Xantakis and Poulakos (U) and Kopecky and Ruzichkova-Topolova (*BAC* 29, 65).

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3. SOLAR ACTIVITY REGIONS AND PHOTOSPHERIC FACULAE
(A. Bruzek)

A. *Active Regions*

During the three-year period covered by the present report, research on solar active regions has been carried out mainly on (1) birth and development as observed at optical wavelengths; (2) photospheric faculae; and (3) the upper (mainly coronal) part of AR's employing EUV and soft X-ray observations from space.

Solar active regions were the subject of the 8th Consultation of Solar Physicists in Irkutsk 1976. There, a review on ground-based observations, physical characteristics and processes involved in the birth and development of active regions was given by Stepanyan (*8CSP* 1, 3). Jäger (*8CSP* 1, 114) gave a review on the development of AR's and its prognosis. The birth and growth of AR's in the photosphere and in the corona were studied by Baranowsky and Stepanyan (*8CSP* 1, 27), Baranowsky *et al* (*8CSP* 1, 31), and Sykora (*8CSP* 1, 42). Alikaeva (*8CSP* 1, 21) found in an extended cooperative study that the development of AR's takes place in distinct pulses. Other papers dealt with the first phases of spotgroup development (Bumba *et al*, *8 CSP* 1, 59; Romanchuk and Krivodubskij, *8CSP* 2, 91) and with magnetic and velocity field development (Deszö *et al*, *8CSP* 1, 48; Grigoryev *et al*, *8 CSP* 1, 54; Ioshpa *8CSP* 1, 70).

The third of the ATM-Skylab Workshops sponsored by NASA and operated by the High Altitude Observatory was devoted to active regions with particular emphasis on problems of energy balance, the development of refined quantitative models of the conditions above active regions, and the mechanisms responsible for energy transport. The Workshops consisted of a series of three meetings spaced over several months with F. Q. Orrall as director and R. Noyes, G. van Hoven, and R. G. Athay as advisors. Proceedings of these meetings of about 40 researchers will be available.

I. *General*

The smallest bipolar magnetic regions are associated with coronal, soft X-ray bright points. Only a small fraction of bright points lives more than a day and develops into larger active regions (Golub *et al*, *SP* 53, 111). X-ray emission is detected within three hours of the first Hα brightening of AR's. Temperatures of 2.3-4 x 10^6K and densities 1.9-10 x 10^9cm^{-3} were inferred from the analysis of soft X-ray flux in two bands (Little and Krieger *BAAS* 9, 341; Wolfson *et al*, *SP* 55, 181; Vorpahl *SP* 57, 297). Vorpahl found good agreement between the configuration of X-ray loops and the calculated potential magnetic field topology and concludes that the coronal magnetic field quickly attains a relaxed configuration. Svestka *et al*, *SP* 55, 359 detected dark gaps in the soft X-ray photographs of the later stages of AR development. These gaps are interpreted as areas of open magnetic field analogous to coronal holes. Large coronal loops or arches interconnecting neighboring AR's are commonly found on X-ray photographs and indicate a coronal connection by the magnetic field (Chase *et al*, *SR* 16, 917; Svestka *et al*, *SP* 52, 69; Howard and Svestka, *SP* 54, 65). Often several AR's are magnetically tied together to form a larger entity referred to as a "complex of activity". The speed with which these connections are established (Sheeley *et al*, *SP* 40, 103) suggests that some form of anomalous resistivity is present in the corona.

II. *Global Energy Balance*

The global energy losses of the atmosphere of an average AR above $T_e = 10^4$K were estimated by Evans *et al* (*SP* 55, 387), who found the total radiative output to be $\sim 2 \times 10^{19}$Js^{-1} with the largest loss occurring as radiation from coronal material at $T_e > 10^6$K. Conduction losses as well as mass loss to the solar wind were estimated to be negligible. Jakimiec (*8CSP* 2, 5) has reviewed models of coronal AR's and their energy supply derived from XUV and X-ray observations obtained by the

Intercosmos satellites. Temperatures T $\geq 10^7$K in flare-free active regions were inferred by Silvester (*8CSP* 2, 24). The heating of hot coronal regions by chromospheric ejections (Vasiljev *et al*, *8CSP* 2, 66) and by shock waves (Vilkovsky *8CSP* 2, 70) was also investigated. Prime candidates for the source of energy above AR's remain Alfvén waves (Wentzel, *SP* 50, 343; *SP* 52, 163) and the dissipation of magnetic fields (Nolte *et al*, *SP* 55, 401; Rosner *et al*, *ApJ* in press) although the quantitative adequacy of either mechanism remains to be established. One aspect of the latter mechanism has been explored by noting that the emergence of the magnetic fields of new AR's necessarily leads to the formation of current sheets, where magnetic field reconnection and dissipation can take place (Syrovatskii, *SAL* 2, 35; Heyvarts and Priest, *SP* 47, 223; Wolfson *et al*, *SP* 55, 181) suggest that the AR magnetic field emerges in a stressed or complex configuration ready to release energy by field reconnection. Somov and Syrovatskii (*SP* 55, 393) discuss the possibility of quasi-steady energy release in current sheets as the main source of heating of AR atmospheres. They conclude the $\sim 10^{28}$ergs s^{-1} may be released by a steady current sheet over hours or even days as EUV radiation at T $\sim 8 \times 10^4$K, which heats the chromosphere. However, in order to account for the heating of the corona and its X-rays secondary processes must be considered.

III. *Loop Structure*

The presence of magnetically confined loops of plasma has emerged as a major factor in understanding the atmosphere above AR's. Active region loops seen in EUV lines formed at temperatures 10^4-2×10^6K were studied in detail by Foukal (*ApJ* 210, 575) and Levine and Withbroe (*SP* 51, 83), who found a coaxial shell structure with a low temperature core of a few hundred km radius surrounded by an extended sheath of coronal temperature and a constant density of $\sim 7 \times 10^8$cm^{-3}. Energy loss by radiation is of the order of 10^{-4}ergs cm^{-3}s^{-1} in the hot outer shell. Observations from rockets and OSO-8 suggest downward velocities of 30-100km s^{-1} in loops over spot umbrae. Foukal assumes that the radiation losses along the loops are balanced by the thermal energy and the gravitational energy of the falling material and that magnetic fields play no role in the support of the loops. Chiuderi, Giachetti and van Hoven (*ApJ* 213, 869; *SP* 54, 107; *SP* 55, 371) on the other hand, investigating the problem of MHD stability of loops, find that in order to support the pressure gradient a large departure from the force-free Lundquist field is necessary. This is achieved by the addition of the effects of cross-field currents.

Pye *et al* (*AA* 65, 123) constructed the first detailed temperature and density map of an AR at T > 10^6K from 4-23Å observations. The resulting model of the region contains a system of loops at temperatures 2.6-3.2 x 10^6K. They assume a homogeneously filled circular cross section at densities 1-6 x 10^9cm^{-3}. They conclude that the birth, stability and disappearance of a hot loop are controlled only by the energy input, which determines not only the temperature but also the scale height and density in the loop by mass interchange with the low atmosphere. Gerassimenko *et al* (*SP* 57, 103) presented observational evidence of continual heating in X-ray emitting coronal loops.

B. *Photospheric Faculae*

Considerable progress in the interpretation of photospheric faculae has been achieved by the introduction of non-LTE models which take into account the association of facular points with small-scale magnetic flux tubes. It has been known for several years that magnetic fields in facular areas and in the photospheric network are highly concentrated in flux tubes with field strengths of 1000-2000 G and cross sections of several hundred km. The flux tubes are confined because of reduced internal gas pressure, which implies reduced opacity and also gives rise to the Wilson depression. Thus, the interior of the flux tube will be surrounded by hot walls, and radiation form the walls adds to the intensity emerging from the tube. Non-LTE multidimensional radiative transfer calculations by Stenholm and

Stenflo (*AA* 58, 273) show that radiation channeling effects in small-scale flux tubes, indeed, can give rise to locally increased line intensities, which correspond to calculated temperature enhancements in LTE models while no true temperature increase is present. Spruit (*SP* 50, 269) also concludes that the contrasts observed in continuum faculae may be caused by radiation transfer effects and do not require additional heating. The "bright wall" effect may explain the center-limb variation of facular contrast and resolve the discrepancy between the temperatures derived from the CLV of continuum intensities (ΔT = 500-1000K) and from line profiles (ΔT = 100-300K), respectively.

Frazier (*AA* 64, 35) suggests another explanation of that discrepancy: His observations show that the shape of the contrast line profile of faculae, and therefore the LTE facular temperature structure, depend largely on the total magnetic flux, i.e., the size of the faculae. The ΔT discrepancy above may then be a selection effect in that continuum contrast observations select faculae bright in the continuum, i.e., small faculae. On the other hand, line profile observations select faculae bright in the line core, i.e., large faculae.

The most elaborate LTE facular models available so far have been presented by Chapman (*ApJ Sup* 33, 35). He achieves reasonable agreement between observed and calculated line profiles by taking into account the effects of scattered photospheric light and of magnetic fields. He derives field strengths of 1500-1900 G in faculae and temperature contrasts of up to 880K. if such temperature contrasts are real, some form of non-radiative heating is required. Less refined models have been given by Müller and Hirayama. Müller (*SP* 45, 105) employed high resolution continuum photographs of photospheric faculae with the 50cm refractor at Pic-du-Midi Observatory. In his model facular granules consist of hot clouds (ΔT = 750K) 100km above a locally cooler photosphere. Hirayama (*PASJ* 30 337) infers a temperature enhancement ΔT = 1000K for 2" diameter facular granules photographed with a 10cm balloon telescope. Koutchmy, employing a restoration technique, (*AA* 61, 397) determined the contrast of filigrees in the continuum at λ6441A to be $\geq$ 100%. Stellmacher and Wiehr (*AA* in press) constructed a facula model employing the high temperature filigree model (ΔT 1000K in the deeper layers) of Koutchmy and Stellmacher (*AA* 67, 93). They consider the observed facular emission as a composite--due to limited spatial resolution--of granular, intergranular and filigree emission. This model represents satisfactorily the central intensity and the wings of the lines as well as the decrease of faculae contrast in the red. It does not describe the CLV of the continuum contrast. Physical conditions in faculae were also discussed by Mitropolskaya and Sitnik (*8CSP* 1, 64) and a heating mechanism was proposed by Vaĭnsteĭn *et al* (*8CSP* 2, 95). Their molecular spectra have been studied by Dubey and Tripathi (*BAC* 22, 161).

Important for the interpretation of plages are the observations of Giovanelli and Brown (*SP* 52, 27) and Giovanelli and Slaughter (*SP* 57, 255), who found systematic downward motions in plage elements and in small EFR's with velocities increasing with depth in the atmosphere up to 0.4 km s^{-1}. Giovanelli (*SP* 52, 315) suggests that the downflowing material is replaced by neutral gas flowing into the closed flux tube near the temperature minimum under the influence of the gas pressure gradient between the outside and the inside of the magnetic tube.

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4. SUNSPOTS
(C. Zwaan)

During 1976-78 considerable progress has been made in exploring the "sunspot problem": Why is the magnetic field concentrated in patches with large field strengths (spots, faculae, ...), and why sunspots have the structure we observe? Some problem items have been solved and remaining questions appeared in a new perspective. In this review the whole range of discrete magnetic structures is considered but we concentrate on sunspots.

A. *Magnetostatic Models*

The work by Deinzer and Yun before 1976, and by Spruit (*SP* 50, 269; 55, 3) shows that the main features of the range of magnetic structures, from sunspots down to facular points, can be explained by a set of magnetostatic flux tube models in the top of the convection zone. The underlying assumptions are that within the tubes the vertical heat flow is about one fifth of the heat flow in the normal convection zone, and that there is no heat exchange across the field except by electromagnetic radiation. In Spruit's models the transition from dark pores to bright facular points, and the center-to-limb variation of the facular contrast in continuum and line wings are explained as consequences of the Wilson depression, the cool interior and the warmer walls.

The objection that a sunspot flux tube would show up with an observable bright ring around it (Parker, *ApJ* 204, 259; Isenberg, *SP* 50, 49) is refuted by the rapid increase of the heat transport coefficient with depth (Spruit, *SP* 55, 3). The effect of an anisotropy in the heat conduction on the surface temperature distribution across an idealized sunspot was investigated by Eschrich and Kraus (*AN* 298, 1).

Staude (*BAC* 29, 71) computed magnetostatic umbral models fitting adopted magnetic field configurations and convection zone models. His analysis of the resulting thermodynamic stratifications indicated that a strong non-radiative flux is needed for heating the umbral atmosphere.

As for the dynamical stability Meyer, Schmidt and Weiss (*MN* 179, 741) put forward the argument that flux tubes in pressure equilibrium are stabilized against the exchange instability by the buoyancy of the tube overlying the denser plasma outside. They showed that vertical tubes with fluxes larger than about 10^{19}Mx are stable in the photosphere and in the very top of the convection zone. At larger depths an additional stabilizing mechanism is required.

B. *Energy Transport, Umbral Structure and Waves*

The very existence of tubes of intense magnetic field requires a reduction of the temperature inside the tube over several scale heights in the upper convection zone. Consequently, the energy flow heating the flux tube should be strongly reduced, but a consistent quantitative theory is still lacking. There is an argument about what mechanism is the most plausible: inhibition of convection by the magnetic field or cooling by emission of Alfvén waves generated by convective overstability. Parker (cf. *MN* 179, 93 P) had criticized the inhibition mechanism on the ground that whereever heat is dammed up beneath the spot the resulting pressure increase would disperse the magnetic field. Cowling (*MN* 177, 409) criticized Parker's simplification of the inhibition mechanism by adopting a thin inhibition layer beneath the spot and by treating the heat conductivity as nearly uniform and isotropic. Moreover, Cowling questioned the 80 per cent efficiency of the conversion of heat into Alfvén waves which would be required to explain the "missing flux".

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As mentioned above, in the magnetostatic models inhibition of convective transport is assumed at least near the cylindrical wall of the flux tube in the top of the convection zone, and the problem of the absence of the bright ring around spots has been solved. As to the one-fifth of the normal photospheric flux radiated by umbrae, should we ask why it is so little or should we ask why it is so much?

Besides the papers already mentioned there are several recent papers dealing with the problem of energy transport in and near flux tubes. From a detailed linear analysis of overstable Alfvén modes of a Boussinesq fluid in and around a column of uniform magnetic field, Roberts (*ApJ* 204, 268) concluded that overstable Alfvén waves may cool spots. Boruta (*ApJ* 215, 364) found from a model for the inhibition of convection and for the cooling by Alfvén waves that some initial field concentration may increase and develop into a cool spot.

Roberts and Webb (*SP* 56, 5) investigated small amplitude motions in a vertical *slender* flux tube in temperature and pressure equilibrium with the surroundings, taking into account magnetic forces, buoyancy and *compressibility*, and discussed the pressure and velocity perturbations within the tube.

From line profiles from a large spot at various positions on the disk Beckers (*ApJ* 203, 739) concluded that the Alfvén flux in the umbral photosphere may amount to 20 to 50 per cent of the "missing" flux of electromagnetic radiation, provided that the non-thermal Doppler broadening is entirely attributed to pure Alfvén waves. However, line widths in coronal arches over a sunspot indicate that the flux of Alfvén waves leaking into the corona is extremely small (Beckers and Schneeberger, *ApJ* 215, 356, see also Evans *et al*, *SP* 55, 387). Using a simple but adequate temperature model Thomas (*ApJ* 225, 275) showed that any flux of Alfvén waves generated in the umbra is almost completely reflected downwards well before reaching the corona.

From power spectrum analysis of velocity oscillations measured in several spectral lines Schröter, Soltau and Wöhl (*AA* 49, 463; 50, 367) found three ranges of periods, viz. 470-300 s, 196-164 s, and 123-110 s; the latter short period oscillations had not been reported earlier.

Bumba *et al* (*BAC* 26, 315) and Hejna (*BAC* 28, 126) show and discuss the pattern of bright umbral dots, pointing out that the distribution of the structure sizes (i.e. the distances between adjacent dots) is very similar to that of the surrounding photospheric granulation. The reader examining the plates in the first mentioned paper may find once more that the dots in small or irregular spots are much brighter than in roundish large umbrae.

The Oslo observers noticed significantly different radiation temperatures in various spots (Maltby, *SP* 55, 335). Albregtsen and Maltby (*N* 274, 41) found a dependence of the umbral intensity with the phase of the solar cycle, in the sense that the radiation flux increases during the cycle. Clearly, this intriguing result requires further investigation.

C. *The Formation of Flux Tubes; Mass Flow Along the Tube*

The effects of vigorous convection on an initially weak and uniform magnetic field have been investigated in a Boussinesq fluid by Galloway *et al* (*N* 226, 686) and by Peckover and Weiss (*MN* 182, 189). The magnetic field is concentrated in ropes or sheets in which the field strength may exceed the equipartition value for suitable combinations of parameter values characterizing the viscous, thermal and magnetic diffusivities, the initial field strength and the Rayleigh number. Galloway *et al* applied these results to the solar atmosphere by assuming that the energy balance adjusts in such a way that the internal temperature and pressure reduce in step with the increasing magnetic pressure.

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The idea that sunspots are concentrated by supergranulation from an initially dispersed field (Meyer *et al*, *MN* 169, 35) is not correct, however. Observational data indicate that in active regions magnetic field emerges in bunches of flux tubes which were already concentrated *before* penetrating in the atmosphere, and sunspots grow by coalescence of recently emerged tubes (cf. Piddington, *ASS* 34, 346; Zwaan, *SP* in press). Zwaan estimated that during the emergence the field strength amounts to several hundred gauss, which is close to the equipartition field strength in the top of the convection zone. Once the tubes have surfaced, radiative cooling sets in and then the cooled gas starts a convective downdraft carrying the cooling deeper down. New measurements in photospheric and low chromospheric lines confirmed strong downdrafts in emerging flux regions and particularly in growing pores and spots (Kawaguchi and Kitai, *SP* 46, 125; Bachmann, *BAC* 29, 180). The downdraft in spots stops when the spot ceases to grow.

Beckers (*ApJ* 213, 900) analysed line shifts in umbrae of several mature sunspots during their passage across the disk. Rotation rates from proper motions and from Doppler shifts agree within 1 per cent. The vertical flow is undetectable (< 25 m s^{-1}); there is no "convective blueshift" either. However, a systematic downdraft has been observed in the small magnetic elements in plages and network (cf. Harvey, *HA* 4 II, 223; Giovanelli and Slaughter, *SP* 57, 255).

Parker (*ApJ* 221, 368) found from calculations for slender flux tubes that a downdraft of only 100m s^{-1} would produce sufficient cooling with respect to the superadiabatic surroundings to concentrate magnetic fields up to 1500 gauss or more. Clearly, this effect may keep slender tubes concentrated as long as the downdraft lasts, and observations suggest that downdrafts are a persistent feature of thin flux tubes. This raises the question how the mass is supplied from above (cf. Giovanelli *SP* 52, 315). Spruit (*SP* in press) showed that slender flux tubes with surface field strengths less than 1300 gauss will collapse to an equilibrium state with higher field strengths ($\gtrsim$ 1700 gauss) if triggered by some downdraft. However, the collapsed tube is not in thermal equilibrium with its surroundings, and Spruit argued that in the top part an overstable oscillation will be excited. He suggested that a brightness-velocity correlation may account for the (seemingly persistent) downdraft in the magnetic plage and network structure.

In order to explain the coherent motion of parallel flux tubes during the emergence and the coalescence into spots Parker (*ApJ* 222, 357) investigated hydrodynamic attraction by the effect of the wake of a preceding tube on a following one and by the Bernoulli effect on two tubes moving side by side. These attractions vanish once the rising of tubes stops, and breakup and decay sets in. In a new series of papers Parker (*ApJ* in press) investigated the dynamical stability of long-lived spots assuming a model consisting of many separate tubes held together by the buoyancy of the top parts and by a postulated downdraft in between the separate tubes well below the visible surface. Parker suggested that the individual tubes are cooled by the convective generation of Alfvén waves which are preferentially emitted downward because of the downdraft. Parker admitted that the postulated downdraft is not easily reconciled with the upwelling in the moat supergranule. This is a pressing problem in Parker's model since the moat supergranules are frequently observed around long-lived spots.

Zwaan (*SP* in press) proposed a tentative model for the amplification, ascent and emergence of intense flux ropes, which assumes, particularly in the deep convection zone, concentration by differential rotation, containment by the external turbulent pressure, and adequately efficient lateral heat exchange by the remaining internal turbulence. The crude model describes even the largest active regions as loops from toroidal ropes of a reasonably small diameter rooted near the bottom of the convective zone. After the cooling of the top parts by electromagnetic radiation and convective downdraft the conditions are created for the magnetostatic models heated by a reduced energy flow without requiring a blocking of heat somewhere within the tubes.

D. *Penumbrae*

Galloway (*SP* 44 409) proposed a simple model for the penumbral structure, based on the well known convective rolls parallel to the magnetic field which is strongly inclined with respect to the vertical. This model predicts that the magnetic field in the dark striae is stronger and more horizontal than in the bright striae. A large radial outflow is expected in the dark striae, and a smaller inflow in the bright striae. Note that in this model the penumbra is necessarily the highly structured and dynamic fringe of the largely magnetostatic structure of the whole spot. Its structural and dynamic features are in agreement with observational data. Recently Abdussamatov (*SP* 48, 117) confirmed from 2" resolution spectrograms that the field strengths in dark penumbral matter are significantly higher than in bright matter. Müller (*SP* 48, 101) confirmed his earlier discovery of the movement of bright penumbral grains towards the umbra, reaching the maximum speed of about 0.5km s^{-1} near the umbral border.

By means of a two-layer model Nye and Thomas (*ApJ* 204, 582) concluded that the lowest "plus" eigenmode of magneto-atmospheric waves would fit the running penumbral waves observed in Hα. This result suggests that the waves are a phenomenon in the photospheric part of the penumbra. Musman *et al* (*ApJL* 206, 175) have observed oscillations in a photospheric line with periods comparable to the Hα periods, but the photospheric waves are more intermittent and the horizontal phase velocity is much larger than in the Hα waves.

This review is focused on the structure of sunspots in the deeper parts of the atmosphere and on the mechanisms causing spots and smaller patches of concentrated magnetic field. Clearly, in this way only part of relevant sunspot investigations 1976-1978 have been covered. We briefly refer to some other groups of investigations below.

E. *Chromospheric and Coronal Structure over Sunspots*

Studies in the optical, radio and particularly in the EUV and X ranges have greatly increased our knowledge of the structure of the chromosphere, transition zone and corona as influenced by the magnetic fields of spots. Several of these papers will be referred to in other sections of this report.

F. *Sunspot Spectroscopy*

Exploitation of the sunspot spectrum for solving problems in solar or stellar spectroscopy is represented by two examples: Beckers' study (*ApJ* 213, 900) of Doppler shifts in umbrae observed center-to-limb revealed a redshift which is within the accuracy of 25 m s^{-1} identical with the predicted gravitational redshift of 636 m s^{-1}. Moreover, the interpretation of the limb effect in the photospheric Doppler shifts by an average convective blueshift is in agreement with the absence of the limb effect in umbral spectra.

Wing *et al* (*ApJ* 216, 659) identified bands of the FeH molecule in the near IR spectra of spots and by comparison also in M and S type stars. The vibration-rotation spectra of CO_2, NO, SiO, and TiO expected in sunspots has been studied (Pande and Gaur, *N* 253, 104; Gaur *SP* 46, 121; Gaur *et al*, *SP* 56, 67; and Sinha, *BASI* 5, 49).

5. PROMINENCES
(T. Hirayama)

Major progress in this period has been in the spectroscopic study, Skylab and OSO-9 (Bonnet *et al*, *ApJ* 221, 1032) observations, polarimetric observations and some theoretical works on magnetohydrodynamic treatments. But theory of formation of various types of prominences is still far from complete. Even the topology of the magnetic field in quiescent prominences is still under hot discussion. The IAU Colloquium No. 44 on "Physics of Solar Prominences" was held in Oslo (1978).

A. *Quiescent Prominences*

Remarkable progress has been made in understanding the spectra of quiescent prominences; see reviews by Hirayama (*IAU* 44) and Yakovkin and Zeldina (*SP* 45, 319). The kinetic temperature and non-thermal motions of the central part of quiescents is found to be 4500-8500K and 3-9km/s while in the outer part the extended wings of emission profiles indicate values up to 22000K and 15km/s (Landman *et al*, *ApJ* 218, 888). Other authors find the same values as in the central part (Mouradian and Leroy, *SP* 51, 103). Since it seems that these are real differences, effort should be directed to finding the physical conditions producing the difference. The excitation temperature inferred from the intensity ratios of Balmer lines and triplet helium lines was found on the average, to be 7200K and 4460K, respectively (Landman *et al*, *ApJ* 220, 666). It is not known whether the former temperature is the electron temperature or the radiation temperature. Optical depths (∿ten) in the Lyman continuum were obtained from Skylab observations (Orrall and Schmahl, *SP* 50, 365).

A large amount of data of the total intensities of H, He and calcium lines has been accumulated largely by Landman and his collaborators (*SP* 45, 339; *AA* 49, 277; *SP* 50, 383; *AA* 55, 103; *ApJ* 218, 888; *ApJ* 220, 666) and by Engvold (*SP* 56, 87) together with reports at IAU Colloq 44 by Stellmacher and Kubota. These data are generally in good agreement with the theoretical predictions from isobaric and isothermal models by Heasley and Mihalas (*ApJ* 205, 273) and by Heasley and Milkey (*ApJ* 210, 827; *ApJ* 221, 689), where the transfer equations have been solved for H, He, He^+ and Ca^+ but without assuming detailed balance in the Lyman lines in some cases. The result shows that the observed excitation temperature of the helium triplet can now be well reproduced. The controlling factor is the photospheric radiation. The helium singlet to triplet ratios are interpreted as due to the varying effect of optical depth in the helium resonance lines; but an appreciable discrepancy with observations still remains when brighter prominences are treated and it is interpreted as due to the neglect of the filametary structure in the models. In faint prominences, the interpretation of the observations led to a determination of helium to hydrogen number ratio of 10% ± 2.5% (Heasley and Milkey, *ApJ* 221, 689). Hirayama *et al (IAU Colloq* 44) on the other hand found 16% ± 4%. Serious studies of resonance line profiles of HI and MgII have just begun both on the observational side from OSO-8 (Vial *et al*, *SP* submitted) and Skylab and on the theoretical side on the effect of partial frequency redistribution (Milkey *et al*, *IAU* 44).

Energy balance in the cold part of prominences has been treated by Heasley and Mihalas (*ApJ* 205, 273). This work has made considerable progress over earlier theories in that they could, for the first time, reproduce the temperature variations inside the prominence in general agreement with the observations by treating radiative equilibrium with coupled transfer solutions for hydrogen and helium. The lowest temperature in the denser part of a prominence was found to be 4500K, which can be explained as a consequence of the irradiation by a gray body photosphere at an effective temperature of 5800K. In the outer regions 7000-8000K temperatures are expected as a result of the heating from incoming UV radiations. Lerche and Low (*SP* 53, 385) have treated the mechanical equilibrium by means of simplified energy balance relations.

The study of the fine structure and its motion is becoming an important part of prominence physics: Engvold (*SP* 49, 283) found from Hα pictures that the diameter of predominantly vertical threads increases from 400km at lower heights to 1500km at larger heights while Ramsey (*SP* 51, 307) measured the length of individual threads to be about 5000km. From a spectroscopic study the thread diameter was found to be ∿200km (Hirayama *et al* *IAU* 44) in agreement with the Hα pictures. Vertical motions were detected by Engvold with photo-subtracted K-line movies; but this wave-like motion may be only apparent. Maltby (*SP* 46, 149) and others have found no systematic motions of more than a few km/s on the disk. Oscillation with a period of 20-30 minutes was discovered by Landman *et al* (*ApJ* 218, 888) from D_3 observations. Zirin (*IAU* 44) has observed large scale motions in a part of a quiescent and also found that if the height of a quiescent exceeds a certain value, the quiescent will later erupt. On active region filaments Vial *et al* (*IAU* 44) and Mein (*SP* 52, 369) found a larger velocity shift near the edges of filaments than in the middle part. The lifetime of prominence-threads was estimated by Engvold (*SP* 49, 283), Engvold and Malville (*SP* 52, 369) and Maltby (*SP* 46, 149) to be about five to ten minutes while fainter threads seem to persist much longer. Non-thermal motions in the prominence-corona-transition zone was found to be small (2-7km/s) and independent of temperature in contrast to the transition zone in the quiet region (Feldman and Doschek, *ApJL* 216, 119). Although the interpretation of these motions as deviations from a force-free-field (Malville, *SP* 50, 79), Alfvén waves (Ramsey, *SP* 51, 307) or MHD oscillations (Landman *et al*, *ApJ* 218, 888) has been discussed, no comprehensive theory has yet been presented. Mercier and Heyvaerts (*AA* 61, 685) suggested that a general slow motion downward would be expected as the result of photospheric Joule dissipation occurring in separated tiny points.

Important results have emerged on the magnetic field of quiescents: Leroy, Bommier and Sahal-Bréchot (*AA* 54, 811; *AA* 59, 223; *AA* 60, 79; *AA* 64, 237; *IAU* 44) concluded from the magnetic Hanle effect that the active region prominences show the direction of the magnetic field to be parallel to the long axis of prominences, while the polar crown prominences make an angle of 30°-40° to the axis. Other interesting results are that the average field strength (4.5 gauss) might show a systematic variation over the solar cycle and that the changes of the field direction in the polar regions as inferred from polar crowns follow the 22 year cycle when compared with earlier measurements. Further, the general increase of the magnetic field with height has been confirmed (the average value $\sim 1.1 \times 10^{-4}$ gauss/km) but a smaller value was found for young filaments. Martres *et al* (*SP* 46, 137) showed from the magnetograph observation that the stable portions of filaments are often found in regions on the magnetic neutral line where the photospheric radial velocity is small ($\lesssim$ 0.3km/s). Magnetic field strengths measured by Fabry-Perot techniques give 10-30 gauss for semi-active prominences and 80 gauss for an active prominence (Den *et al*, *SP* 52, 35) in accordance with previous results. Koval' (*IKAO* 57, 133), however, has reported values up to 1000 gauss. Further progress is being made at Sacramento Peak-High Altitude Observatories for measuring the full Stokes parameters (Smartt and House, *IAU* 44).

Information on the prominence-corona interface is being deduced from EUV spectra and radio data (see review by Schmahl, *IAU* 44): Orrall and Schmahl (*SP* 50, 365) found the gas pressure to be ∿0.03 dyne cm^{-2} at $T_e = 9 \times 10^4$K from Skylab data. Young *et al* (*SP* 45, 351) derived 0.5 dyne cm^{-2} from EUV eclipse observation. The latter value, however, is not consistent with the ground based observation by Nikolsky *et al* (*SP* 21, 332) for the same object.

Observations at radio wavelengths have been reported by Butz *et al* (*SP* 55, 161), Straka *et al* (*SP* 45, 131), Apushkinsky and Topchilo (*AZ* 53, 572), Apushkinsky *et al* (*AZ* 53, 1249) and Rao and Kundu (*SP* 55, 161; *IAU* 44) and the averaged spectra require a depression in temperature from ∿5% at 3mm to ∿40% at 6 cm compared with the quiet region (Raoult *et al*, *IAU* 44). Rao and Kundu (l.c.) found from radio spectra that little or no thermal energy is conducted into the main body of a filament. This conclusion is substantiated by EUV observations (Schmahl and also Maltby, *IAU* 44). The presence of the filament cavity is found to be important for the interpretation of radio spectra (Kundu *et al*, *AA* 62, 431).

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Anzer (*IAU* 44) has given a critical review of the various magnetic field configurations required to sustain prominences. Although the Kippenhan-Schlüter model seems to satisfy observational data, it is hardly possible to reject the neutral sheet or a combination of K-S and neutral sheet models because of the lack of stability analyses for 3-dimensional models. The MHD equilibrium for the Kippenhahn-Schlüter model has been studied by Lerche and Low (*SP* 53, 385) and Bondal and Pande (*BAC* 27, 263). Uchida and Jockers (U) have calculated quasi-three dimensional MHD solutions in a neutral sheet, where the inclusion of the field component parallel to the X-type neutral sheet may be an essential element to understanding the equilibrium and the mechanisms of formation. Malville (*IAU* 44) stressed the importance of the total electric current in classifying various prominences.

Pikel'ner's siphon mechanism for the formation of the quiescents was examined by Engvold and Jensen (*SP* 52, 37). It is, however, not as yet clear whether the assumed stationary flow exists and whether the coronal heating mechanism does not affect the energy balance. Thermal instability in a current sheet was investigated by Smith and Priest (*SP* 53, 25), who showed that a slow compression process leads to cooling if the condensing magnetic tube is long enough to limit heat conduction. This process might be combined with the Uchida-Jockers (l.c.) configuration. Glencross (*ApJL* 207, 205) considered condensation after heating in sheets sheared due to sub-photospheric motions.

B. *Active Prominences*

Internal motions ($\lesssim$ 100km/s) in active, surge and eruptive prominences were investigated by Stoyanova (*SDB* 10, 93), Jockers and Engvold (*SP* 44, 429), Engvold *et al* (*SP* 48, 137), Malville (*SP* 50, 395), Ruzdjak and Kleczek (*BAC* 28, 193), Ciurla and Rompolt (*BAC* 28, 217) (see reviews by Zirin and by Malville; *IAU* 44). Engvold *et al* (l.c.) reported that vertical structures become twisted during eruption and indicate a field aligned electric current of $\sim 10^{10}$ amps. Others have stressed the importance of spiraling motions.

Although post-flare loops should be included in the category of flares, they are partly treated here: Kureizumi *et al* (*PASJ* 29, 129) analyzed the visible spectra of a post-flare loop and found T_k = 8000-9000K, n_e = 2-3 x $10^{12}cm^{-2}$, the ionization degree of hydrogen and neutral helium to be $\sim$0.9 and $\sim$0.2, respectively. The total effective thickness of the Balmer-line emitting region is 2-10km. The high amount of mass in post-flare loops was explained as a consequence of the trapping of coronal material by reconnecting field lines following the flare (Kopp and Pneuman, *SP* 50, 85), but the total energy in the soft X-ray flare (10^7K) which later would become Hα post-flare loops does not seem to be well predicted from their theory.

On surges, Maeda *et al* (*PASJ* 30, 533) confirmed the earlier result that the material motion is wholly governed by gravity with different initial velocities. They further found that the direction of motion is the same as the direction of the type III burst and that the root of the surge had n_e = $10^{13}cm^{-3}$. Roy (*SP* 48, 149) found n_e = $10^{12}cm^{-3}$ from another surge. X-ray filtergrams have shown that most of the surges do not heat the corona (Rust *et al*, *SP* 54, 53), though in one case a coronal response was seen as a temperature pulse of short duration (Smith *et al*, *SP* 52, 379). Zirin (*SP* 50, 399) reported the formation of a short lived filament apparently triggered by an occurrence of a surge.

Sakurai (*PASJ* 28, 177) has calculated non-linear, three dimensional motions of magnetic flux tubes after the kink instability sets in using the finite element method. The result shows that the smaller the ratio of the azimuthal to axial magnetic field in the initially straight prominence, the lower the final height attained and the smaller the overall twisting motions, in accordance with observations. This work is a first great step towards full understandings of eruptive prominences, coronal transients and flares and further work should be carried out using more realistic boundary conditions. Other theoretical treatments include the work by Birm *et al* (*SP* 57, 89).

6. SOLAR FLARES AND ENERGETIC PARTICLES
(P. A. Sturrock)

A. *Activities*

The last three years have brought substantial advances in our understanding of solar flares and the clarification of key problems requiring observational and theoretical attack. The OSO-8 Spacecraft was launched on June 21, 1975 and has begun to yield new information on the X-ray emission from flares as reported in the OSO-8 Workshop held in Boulder, Colorado, 7-10 November 1977.

An international symposium on the Solar Atmosphere including a discussion of solar flares was held in London, 14-15 January 1975, and the proceedings have been published (*PTRSL, A* 281, 293). Observational data concerning the flares of August 1972 have been reviewed by Nakagawa (*SSR* 19, 459) and flare models by Somov *et al* (*SPU* 19, 813). Solar flares are also reviewed by Rust in the volume "Solar System Plasma Physics" (Kennel *et al* North-Holland, in press), based on a study commissioned by the National Academy of Sciences of the USA. Another notable compilation of information about solar flares has been provided by Svestka (*Solar Flares*, Reidel). During 1977, a Workshop on Solar Flares, based on Skylab data, was held at High Altitude Observatory, Boulder, Colorado; P. A. Sturrock served as director. The output of this Workshop will be published in 1979 by Colorado Associated University Press. This Workshop involved over 70 scientists, mainly from the US but also from Argentina, Australia, the Federal Republic of Germany, Ireland, Japan, the Netherlands, the United Kingdon, and the USSR. Participants, including not only space scientists but also optical and radio observers and theorists, organized themselves into seven teams, each attacking a specific aspect of the flare problem. The following sections are based in part on the proceedings of this Workshop.

There are several major initiatives for future research concerning solar flares. One of these is the Flare Buildup Study organized under the aegis of SCOSTEP by a steering committee chaired by C. deJager. Another is the Solar Maximum Year initiated by an IAU Commission 10 Working Group chaired by David Rust. The next major space mission to be devoted to solar flares is NASA's Solar Maximum Mission which will fly experiments built by European and United States scientists. This spacecraft, due to be launched in October 1979, will carry the following instrumentation: (a) Coronagraph/Polarimeter; (b) UV Spectrometer and Polarimeter; (c) Soft X-Ray Polychrometer; (d) Hard X-Ray Imaging Spectrometer; (e) whole sun Hard X-Ray Spectrometer; (f) whole sun Gamma Ray Spectrometer; and (g) whole sun Solar Constant Monitoring Package.

B. *Significant Problems*

I. *Preflare State and Activity*

a. *Coronal transients*. One of the major discoveries of the Skylab mission was that of coronal mass-ejection transients, seen as bright, outward moving structures above $2R_o$ (Gosling *et al*, *SP* 48, 389). For all events, the average speed within the field of view of the experiment (1.75 to 6 solar radii) was 470km s^{-1}. Typically, flare associated events (importance 1 or greater) traveled faster (775km s^{-1}) than events associated with eruptive prominences (330km s^{-1}); no flare-associated event had a speed less than 360km s^{-1}. Metric wavelength type II and IV radio bursts are associated only with events moving faster than about 400km s^{-1}; all but two events moving faster than 500km s^{-1} produced either a type II or IV radio burst or both. In another article (Gosling *et al*, *SP* 40, 439), the group described the direct observation of a flare-related coronal and solar wind disturbance. This showed a direct association of a coronagraph observed mass ejection, which followed a 2B flare, with a large interplanetary shock wave disturbance observed at 1 AU. Estimates of the mass (2.4×10^{16} grams) and energy content (1.1×10^{32} erg) of the coronal disturbance are in reasonably good agreement with estimates of the mass and energy content of the solar wind disturbance at 1 AU.

The nature of coronal transients is not yet completely understood. Photographs certainly indicate that magnetic field is essential to these structures. However, it is not yet clear whether the driving force is a pressure gradient, driving out the material as a bullet from a gun, or whether the stress is magnetic, in which case the stress would appear to be magnetic pressure rather than magnetic tension.

b. *Forerunners.* More recently, it has been found (Jackson and Hildner, *SP* in press) that these coronal transients are typically rimmed by broad halo-like regions termed "forerunners." Of over 20 transients studied, no exceptions have yet been found in the Skylab coronagraph data. Forerunners rimmed transients of all speeds and comprised from 10 to 20 percent of the underlying transient mass. They can extend the transient disturbance to heights greater than $2R_o$ above what had heretofore been considered the transient leading edge. The nature of the "forerunner" phenomenon has yet to be determined: it is not yet clear whether it is to be regarded as an outward flow of mass or a wave propagating through the corona.

c. *Preflare magnetic field geometry.* It is generally agreed that the energy released in a solar flare is the excess magnetic energy released when a stressed magnetic field relaxes to an unstressed or less stressed state with the same boundary conditions (normal component of magnetic field) at the photosphere. In the case that the plasma stresses (pressure and gravitational force) are negligible, the pre-flare field configuration will have the form of a force-free field, for which $j \times B = 0$, with the possible addition of discrete current sheets. There is therefore considerable interest in calculating force-free field configurations as well as attempting to study the stability of such configurations.

In the case of "linear" force-free fields, for which κ = constant where $j = \kappa B$, the relevant equation is a Helmholtz equation. Chiu and Hilton (*ApJ* 212, 873) and Barbosa (*SP* 56, 55) have computed solutions of this equation using Green's function methods.

The more difficult "nonlinear" force-free field problem, for which κ is not constant, has been studied by Low (*ApJ* 212, 234), and Birn *et al* (*SP* in press), using an iterative technique.

The above procedures for computing force-free fields all involve simplifying assumptions. It is important to develop a technique, for instance the development of the relaxation procedure (Barnes *et al*, *ApJ* 174, 659), with more rapid convergence properties, which could be used as a general technique for computing field configurations in active regions.

II. *Magnetic Energy Release*

It has been recognized for some time that the free energy of a stressed magnetic field can be released if "reconnection" can occur. This topic has been reviewed by Priest (*SP* 47, 41). Heyvaerts *et al* (*ApJ* 216, 123) have investigated reconnection in the context of an "emerging flux model," according to which, as more and more flux emerges, reconnection occurs, to produce some preflare heating. If the current density in the sheet should exceed a critical value, the impulsive phase of the flare is triggered.

A modification of the emerging flux model has been proposed by Uchida and Sakurai (*SP* 51, 413). They point out that a large-scale configuration including a current sheet may be unstable against the MHD interchange instability. This can develop explosively, leading to fine-scale structure which permits rapid reconnection, which they identify with the explosive phase of a flare.

In contrast to the previous model, which tends to produce a "magnetic arcade," a model has been analyzed by Spicer (*SP* 53, 305) which involves only a single twisted flux tube. The principal flare instability in this model is the resistive kink instability which plays the role of thermalizing some of the field energy in the arch and generating x-type neutral points which may be sites for particle acceleration.

Since the plasma processes involved in the release of magnetic energy are so complicated, it is important that this phenomenon should, if possible, be studied experimentally in the laboratory. Such experiments have been done by Syrovatskii (*PLI* 74, 1) and by Baum and Bratenahl (*SP* 47, 331). The difficulty is in setting up experiments for which the magnetic Reynold's number is much larger than unity. It is important that further experiments of this type be carried out, since they have much to teach us about the plasma processes involved in the release of magnetic energy in solar flares.

III. *Energetic Particles*

a. *Abundances.* The properties of energetic particles in flares can be inferred from observations made in space. Measurements made with the IMP 7 and 8 spacecraft (Armstrong *et al*, *SP* 49, 395) have shown that the Fe/0 ratio is highly variable for high-energy particles produced by a solar flare. In addition, the charged states of energetic iron were measured directly for the first time in a solar particle event of 1974 May 14-15 (Gloeckler *et al*, *ApJ L* 209, 93). The iron was not fully stripped but has a mean ionization state if 11.6, remarkably similar to the mean ionization state of iron in the quiet solar wind. The ionization states of carbon and oxygen also have been measured for a number of flare events (Sciambi, *ApJ* 214, 316). The ionization states were found to be surprisingly constant, despite great variations in other event parameters and were similar to the respective ionization states in the solar wind. This new information strongly suggests that acceleration of ions to high energies occurs in the corona sufficiently rapidly that the ionization states are not changed from those characteristic of the normal corona.

A remarkable property of particles accelerated during flares is the great variation in the abundance of ^3He (Anglin, *ApJ* 198, 733). In the range 1-20 meV/neucleon, the $^3He/^4He$ ratio varies from about 10^{-2} to more than 1. However, the enhancement in ^3He is not accompanied by a similar enhancement in either ^2H or ^3H. These large enhancements usually accompany small proton events, and they are always associated with enhancements of Fe nuclei (although the converse is not true) (Anglin *et al*, *15 ICCR* 5, 43). The ^3He problem has been addressed by Colgate *et al* (*ApJ* 213, 849). They attribute the production of ^3He to spallation of ^4He by protons and explain the comparative absence of ^2H and ^3H as the reslut of thermonuclear reactions in filaments of very hot (200 keV), very dense ($3 \times 10^{15} cm^{-3}$)plasma. Fisk (*ApJ* in press) has proposed that the enhancement of ^3He is due to selective acceleration by electrostatic ion cyclotron waves in a plasma in which $^4He/^1H \geq 0.2$.

b. *Acceleration.* The data concerning charged states and abundances of ions accelerated in solar flares provides even more stringent boundary conditions on any successful theory of acceleration. The general requirements and models have been thoroughly reviewed by Svestka (*Solar Flares*, Reidel, 1976). The current view appears to be that there are two distinct stages of acceleration. The first stage preferentially accelerates electrons to mildly relativistic energies (Hoyng, *AA* 55, 23; 55 31). Smith (*ApJ* 212, 891; 217, 644) attributes this stage to strong plasma turbulence such as might arise in the region of field-line reconnection. A method for distinguishing between alternate mechanisms of first stage acceleration has been proposed by Hoyng *et al* (*SP* 58, 139).

Second-stage acceleration, which preferentially accelerates ions, is usually attributed to shock waves on the basis of their close association with type II radio bursts. A detailed theory for the acceleration of particles in MHD turbulence, such as might develop behind a collision-free shock wave, had been developed by LaCombe (*AA* 54, 1).

c. *Reverse current.* Colgate *et al* (*ApJ* 213, 849) and others have drawn attention to a problem related to impulsive X-ray bursts, which are sometimes attributed to streams of electrons flowing from the corona down to the chromosphere (Hoyng *et al*, *SP* 48, 197). If taken at face value, the currents associated with these electron fluxes are so high that they would produce very strong magnetic fields, the energy of which would greatly exceed the total energy of the flare. This problem has been addressed by Knight *et al* (*ApJ* 218, 306) and by Hoyng *et al* (*SP* 48, 197). They find that sudden acceleration of electrons, such as would produce an electron stream, will lead to space-charge separation developing an electric field which will then drive a "reverse current," neutralizing the primary current. This mechanism may have implications for the sudden heating of the corona during the impulsive phase of a solar flare. The propagation of an electron beam in an ionized plasma has also been re-examined by Hoyng and Melrose (*ApJ* 218, 866).

IV. *Impulsive Phase*

a. *X-ray spectra.* Space scientists tend to analyze X-ray spectra in terms of simple models. The simplest are power-law spectra and thermal bremsstrahlung. The former is usually termed a "nonthermal" spectrum and may be produced by a beam of electrons with power-law spectrum. Craig *et al* (*N* 264, 340) have argued that observational data typically do not allow one to discriminate between these possibilities. However, Gabriel (*N* 267, 410) expressed a dissenting opinion. It seems clear that future observational data should be made with as high accuracy as possible over as wide a range of energy as possible if one is to attempt to discriminate between thermal and non-thermal models of the X-ray source (e.g. Boehme *et al*, *SP* 53, 139).

b. *Location and possible beaming of X-ray source.* A beam model would tend to produce X-ray emission low in the sun's atmosphere, where collisions become important. On the other hand, thermal emission must occur in a low-density region, high above the photosphere. Hence the nature of the emitting mechanism is coupled with the question of the height at which hard X-ray emission occurs. Since hard X-ray detectors have, to date, had no angular resolution, we have no direct information on this point. However, the hard X-ray detector on SMM should provide valuable information.

Roy *et al* (*SP* 40, 165) have analyzed a number of events which were attributed to flares occurring over the limb. Their data extended over the energy range 5-100keV. Their conclusion was that disk and over-the-limb bursts were similar in spectrum and they inferred that hard X-ray emission is produced by regions extending to great heights.

If hard X-rays are produced by a high-energy beam of electrons propagating towards the photosphere, the X-rays also would tend to be beamed. Brown *et al* (*AA* 41, 395) and Bai *et al* (*ApJ* 219, 705) have argued that, in this case, one could obtain information about the height of the source and the degree of beaming by observing the "albedo patch," i.e. the area of the sun's surface from which X-rays are scattered.

It has also been proposed that evidence for or against beaming could be obtained by studying the longitude distribution of impulsive X-ray bursts. Savenko *et al* (*SP*

50, 447), analyzing data from the Prognoz and Explorer satellites, found that the X-ray burst frequency (normalized to the Hα flare frequency) increases towards the solar limb. This would argue in favor of a beam model. On the other hand, Datlowe *et al* (*ApJ* 212, 561), analyzing 148 bursts observed on the OSO-7 satellites, found no center-to-limb variation. They concluded that their result rules out downward-streaming thick-target models for hard X-ray production. On the other hand, Bai *et al* (*ApJ* 219, 705) and Langer *et al* (*ApJ* 215, 666) have made detailed calculations of the angular dependence of X-rays which would be produced from a beaming source, taking into account scattering of X-rays by the sun's atmosphere, and conclude that no center-to-limb effect should be apparent.

It is clear that new data is required to help distinguish between thermal and non-thermal models for hard X-ray production during the impulsive phase of flares. Hopefully, data to be obtained from the SMM spacecraft will provide valuable new information relevant to this question.

c. *Time variation of hard X-ray emission.* The hard X-ray emission may fluctuate rapidly during the impulsive phase. Hurley *et al* (*SP* 52, 107) observed the solar flare on 1974 July 4 in hard X-rays using a balloon-borne detector. When analyzed with a time resolution of 100ms, four 2-second long spikes were observed which were correlated with decimetric emission. Crannell *et al* (*ApJ* 223, 620) have studied a number of simple impulsive solar flares in the OSO-5 hard X-ray data and in micro-wave and meter-wave radio data. They find that the emission typically has the form of a simple, fairly symmetric, spike with a duration of a fraction of a minute. It is possible that the X-ray emission from large flares comprises a sequence of such elementary spikes. These data suggest that the basic time constant for electron acceleration could be only a few seconds. (Type III radio burst data suggests that it may be less than 0.1 second.)

It has been known for some time (Svestka, *Solar Flares*, Reidel) that microwave emission from flares tends to occur in pulsations which may be quasi-periodic. There has been a hint that hard X-ray radiation from flares also contain periodic components. Lipa (*SP* 57, 191) has analyzed the hard X-ray emission from 28 large solar events and found periodicity in 26 of them with periods in the range 10-100 seconds. It is clearly an important problem to try to understand the origin and significance of these periodicities. The data analysis of Crannell *et al* and of Lipa are both suggestive of betatron-type acceleration occurring in an "electron trap," as suggested by Brown *et al* (*ApJ* 200, 734; *SP* 49, 329), but it is likely that alternative models will be proposed in the future.

V. *Energy and Mass Flow*

a. *Lower atmosphere.* Although the primary energy release is believed to be the conversion of magnetic energy into high-energy particles and/or high-temperature plasma, much of the flare energy leaves the sun in the form of electromagnetic radiation, and a large part of this energy is in the form of lines characteristic of the "lower atmosphere," i.e. the transition region and chromosphere. Hence an important problem concerning solar flares is to identify the mechanism whereby energy propagates from coronal heights to chromospheric heights where it is absorbed and radiated.

Since Hα kernels brighten in coincidence with hard X-ray emission, it appears possible that the chromosphere is heated by electron bombardment, but Roy (*SP* 48, 265), examining data for the flare of 1972 August 2, concludes that chromospheric heating cannot be attributed to the hard X-ray producing electrons.

Orrall and Zirker (*ApJ* 208, 618) and Lin and Hudson (*SP* 50, 153) have considered the possibility that the lower atmosphere may be heated by beams of non-thermal protons. It appears that the least ambiguous evidence for the presence of such non-thermal protons would be the asymmetry in the wings of Lyα predicted by Orrall and

Zirker. Canfield and Cook (*ApJ* in press) have searched for this effect without success.

Somov (*SP* 42, 235), Henoux and Nakagawa (*AA* 57, 105) and Machado (*SP* in press) have examined theoretically the possible heating of the lower atmosphere by soft X-ray flare radiation from the corona. It appears that soft X-ray heating probably plays a significant, though not dominant, role in the chromospheric flare energy budget.

Machado and Linsky (*SP* 42, 395) have taken a different approach and constructed an array of photosphere-chromosphere models designed to fit the CaII lines in a variety of flares. This model implies that the temperature may increase by about 100K during a flare in the region of temperature minimum. Machado and Noyes (*SP* in press) have also examined the SiI data of Cook and Brueckner (*ApJ* in press) and this again leads to the inference of a temperature increase near the temperature minimum. Machado and his colleagues find it difficult to assign a mechanism to heating in this region.

b. *Thermal X-ray plasma*. From the impulsive phase on, flares typically emit soft X-rays which may be attributed to bremsstrahlung from thermal plasmas at temperatures of order 10^7K. This "thermal X-ray plasma" may also provide energy to the lower atmosphere by heat transfer or by X-rays. Moore and Datlowe (*SP* 43, 189) have analyzed a number of flares using Hα and OSO-7 X-ray data. Of the possible cooling mechanisms of the thermal plasma, they find that heat conduction tends to be more important than radiation. However, Underwood *et al* (*ApJ* 224, 1017) have examined EUV and soft X-ray data of a highly compact flare in which they find that the coronal density is sufficiently high ($>10^{11}$cm^{-3}) that radiation may dominate the cooling.

The density of the thermal X-ray plasma is much higher than that of the corona in active regions. It is now generally believed that this mass "evaporates" from the chromosphere as a result of an energy flux from above. Kostyuk and Pikel'ner (*SA* 18, 590) and Kostyuk (*SA* 19, 458) have modeled the interaction of the chromosphere, transition region and corona in a hydrodynamic framework following impulsive heating by an electron beam. Craig *et al* (*SP* 50, 133) have also examined the response of a flare filament to a localized injection of energy. Antiochos *et al* (*ApJ* 220, 1137) have examined the evolution of the plasma in a closed flux tube when the primary energy release is over. They find that initially the hot plasma cools by heat conduction but this heat conduction drives a mass flux from the chromosphere into the corona. When the density is sufficiently high, radiation losses will become dominant, evaporation will cease, and mass will eventually flow back to the chromosphere.

An important question concerning large flares is whether the primary energy release is limited to the impulsive phase. Pallavacini *et al* (*SP* 45, 411) and Vorpahl (*SP* 47, 147), studying the flares of 1973 June 15 and 1973 September 5, respectively, find evidence for continued heating during the "decay" phase of these flares. If this conclusion proves correct, it will be important to understand the mechanism for this energy release and why it is slow compared with energy release during the impulsive phase.

7. RADIO PHYSICS
(S. F. Smerd and D. J. McLean)

A. *General*

A detailed summary of the observations, interpretations and theories of 'Solar Noise Storms' has been presented in book form by Elgaroy (Pergamon Press, Oxford, 1977); particular attention is paid to the type I, i.e. the high-frequency portion, of storm bursts and continua. The author concludes that before solar storms can be properly understood there is need: (i) to elucidate the relations between the metric (the type I) and the dekametric (the type III) components of storms; (ii) to obtain much more precise quantitative information, for instance, on storm spectra and source positions [the author notes "It is a sad state of affairs that most solar interferometers operate in one dimension and with inadequate resolution." The effects of this inadequacy spread, of course, right across solar radio astronomy.]; and (iii) to know much more about the complex physical conditions in the storm centres so as to allow meaningful applications of plasma physics to the generation of storm radiation. One such physical quantity is the magnetic field. However, because of the current uncertainties in a profusion of type I theories, Dulk and McLean (*SP* 57, 279) excluded type I bursts (as also fundamental type III bursts and moving type IV bursts) from the observational evidence which they used in their derivation of average 'Coronal Magnetic Fields' in active centres where solar bursts originate. These authors conclude that "observation of harmonic type III polarization promises to be one of the best ways of estimating coronal magnetic field strengths."; they suggest that the empirical formula

$$B = 0.5\ (R/R_o - 1)^{-1.5}\ G, \qquad (1.02 \lesssim R/R_o \lesssim 10)$$

fits all the data presented to about a factor of three, *provided the fields are associated with electron densities only twice those of the equatorial corona at sunspot minimum*. These densities are lower than any other derived from solar-burst observations; [see section on type III bursts].

Two specifically solar radio astronomy reviews were presented by Rosenberg (*PTRSL* 281, 461) and by Smerd (*ISSTP* ed. D. J. Williams, I, 193). Rosenberg pays special attention to a variety of fine structures in such type IV bursts as occur near the plasma level. The suggested interpretations usually involve non-linear coupling between plasma waves and other wave modes, for instance whistlers or Bernstein waves. Rosenberg also examines the radio evidence for clues on acceleration processes in flares. He concludes that during the flash phase of a flare (but also in type I sources) low-frequency plasma-turbulence is generated by m.h.d. instabilities, for instance the tearing-mode instability; the growth rate is thought to be large enough to accelerate electrons to (10-100) keV in $\sim$1 s. Further acceleration to higher energies is again attributed to Fermi acceleration.

Smerd concentrates on macroscopic radio structures and the corresponding solar disturbances. The most notable recent addition to slowly-varying structures are 'coronal holes'; co-operative studies (e.g. Dulk *et al SP* 49, 369) show that, on current solar-atmosphere modelling, the EUV-observations yield much higher electron densities than do the radio observations. An 'over abundance' of heavy elements might have to be invoked, but also explained. Smerd uses dynamic burst spectra, source positions and polarizations--in particular as observed in 2 dimensions at 43, 80 and 160 MHz with the Culgoora radioheliograph--to identify possible disturbances and radiation mechanisms. Spectra and heliograms confirm three distinct disturbance speeds, namely: $\sim 10^5$km/s for electron streams; $\sim 10^3$km/s for m.h.d. and at times shock waves; $\sim 10^2$km/s for clouds of magneto-plasma. We note that the moving disturbances can result in moving or in stationary burst sources; and that the observed circular polarization does not help to distinguish between harmonic plasma radiation and synchrotron radiation as the emission mechanism of certain stationary type IV continuum bursts.

On a far less specialized scale and seen through the eyes of a non-radio solar physicist, there is a substantial survey of solar radio astronomy included in Svestka's book 'Solar Flares', although it includes only a small part of the evidence represented.

Another, but highly-specialized, survey of USSR and of Australian radio-astronomy developments was reported at the USSR/Australia Solar Symposium at Pulkovo in September 1976; the invited papers have been published in Russian in *Izv. VUZ Radiofiz.* 20, 9 and in English in *Radiophys. Quantum Electron.* 20, 9.

B. *Type I Storms and Bursts*

The relationship of type I storms to changes of the photospheric magnetic field structures are stressed by Yurovskaya (*IKAO* 53, 139), Zanelli and Zlobec (*SP* 53, 497) and Heyvaerts *et al* (*AA* 66, 81).

A number of authors have studied fine structure in type I storms, including Dröge (*AA* 57, 285), Chernov (*AZ* 54, 1081) and Kuijpers and Slottje (*SP* 46, 247). A fairly detailed emission theory has been developed by Mangeney and Veltri (*AA* 47, 165; *AA* 47, 181) (this is well covered in Elgaroy's book). A review on continuum storms by Sakurai (*ASS* 42, 349) also includes a short theoretical section. Simultaneous observations from a space probe and earth indicate beaming of type I emission; Bougeret and Steinberg (*AA* 61, 777) have devised a fibrous model of coronal fine structure to explain these observations.

At longer wavelengths, de la Noë and Gergely (*SP* 55, 195) have found displacements between the sources of continuum, type I, type III and drift pairs.

C. *Type II Bursts*

Interesting observations of type II bursts due to "behind-the-limb" flares were reported by Gergely and Kundu (*SP* 48, 357) and McLean and Nelson (*R* 20, 359); both show similar features although the interpretations offered are different. The structure of type II burst sources and its relation to loops visible in soft X-rays is discussed by Stewart (*PASA* 3, 157).

Zaitsev and Ledenev (*SAL* 2, 172) and Ledenev (*SAL* 3, 144) have developed a theory for type II bursts which does not assume perpendicular shocks. It is interesting to contrast this theory for which emission occurs ahead of the shock with the conclusion drawn by Davis and Feynman (*JGR* 82, 4699) and Chertok and Fomichev (*PLSC* 24, 459), both of whom re-interpreted the IMP-6 observations of a type II burst at kilometric wavelengths, and concluded that the radiation is emitted from behind the interplanetary shock front. A different theoretical approach by Lampe and Papadopoulos (*ApJ* 212, 886) concentrates on the acceleration of electrons in the wake of a shock front.

D. *Type III, Type V and Inverted-U Bursts*

The Proceedings of the Workshop on Mechanisms for Solar Type III Radio Bursts held in May 1975 at Space Sciences Laboratory, Berkeley, California, were published in *Solar Phys.* 46, 433, edited by Lin. These Proceedings contain a number of observational and theoretical papers on type III bursts as well as abstracts of other papers which have since been published in full.

The theory of type III burst emission is now supported by the detection *in situ* from Helios I of Langmuir waves in the plasma at the time of a type III burst (Gurnett and Anderson, *SC* 194, 1159; *JGR* 82, 632).

There is disagreement about the electron density law appropriate to type III bursts; to interpret the observed source heights, Stewart (*SP* 50, 437) requires that type III sources lie in structures 8 to 10 times more dense than the quiet corona whereas Hoang *et al* (*AA* 56, 283) require that the sources lie in low-density parts of the corona, to explain the results of the STEREO experiment. Leblanc and de la Noë (*SP* 52, 133) compared positions and K-corona data and concluded that type

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III sources lie in low-density structures. [We note however that this last paper was criticized by Mercier (*SP* 57, 423)]. Dulk and McLean (*SP* 57, 279) found the best agreement between different estimates of the coronal magnetic fields by adopting a low-density model, more nearly consistent with those deduced from optical observations.

Further advances in the study of burst trajectories in interplanetary space were made by Baumbach *et al* (*SP* 48, 361) and Weber *et al* (*SP* 54, 431). Both experiments used simultaneous data from two spacecraft to study trajectories using fewer assumptions than in previous work.

The relative simplicity of the type III phenomenon has continued to attract the attention of the theoreticians; Bespalov (*FP* 3, 1118; *SJPP* 3, 619), Magelssen and Smith (*SP* 55, 211), and Esconde and Genouillac (*AA* 68, 405) have studied propagation of electron streams; Nicholson *et al* (*ApJ* 223, 605) and Robinson (*ApJ* 222, 696) stressed the nature of the Langmuir wave spectrum or its evolution, while Melrose *et al* (*AA* 66, 315) predicted the polarization to be expected for fundamental and harmonic components: this theory provides the key to one of the most promising indicators of coronal magnetic field strengths. Smith (*ApJL* 216, 53) discussed the theoretical consequences of the *in situ* detection of Langmuir waves quoted above. Pilipp and Benz (*AA* 56, 39) have explained type V bursts as resulting from resonant scattering of the electrons generating a type III burst, whereas Robinson (*SP* 56, 405) attributes type V bursts to long electron streams.

Suzuki (*SP* 57, 415) measured opposite polarization for the two legs of some U-burst in the range 25 to 220 MHz, but at 237 MHz Benz *et al* (*AA* 56, 123) find the same polarization for the two legs. Suzuki points out that the discrepancy may be due to different propagation effects for different observing frequencies.

E. *Type IV Bursts*

Nelson (*PASA* 3, 159) has recorded two-dimensional images at three frequencies of a moving type IV and finds new difficulties of interpretation. Kai (*SP* 56, 417) has found an unexpected relation between the observed polarization of moving type IV bursts and the polarity of the photospheric magnetic field. A metre-wave stationary type IV burst was singled out for intensive study by Dulk *et al* (*SP* 49, 369) because of the coronagraph observations of an associated white-light transient. A fairly detailed model, including magnetic field strengths, emerged from this study.

F. *Microwave*

A variety of instruments have been used to obtain high-resolution data on the emission from active regions and burst sources: the new RATAN-600 (Parijskij *et al*, *SA* 20, 577), the Stanford interferometer (Falchi *et al*, *SP* 48, 59; Falchi *et al*, *SP* 56, 355; Felli *et al*, *SP* 51, 65), Westerbork (Kundu *et al*, *ApJ* 213, 278; Allissandrakis and Kundu, *ApJ* 222, 342; Chiuderi *et al*, *AA* 61, 79), the German 100-m dish (Kundu *et al*, *AA* 62, 431) and the US NRAO interferometer (Kundu *et al*, *SP* 50, 429). Some interesting features such as very small regions with high brightness temperatures are revealed by these studies.

An interesting aspect of some microwave bursts is their association with hard X-ray bursts (Neidig, *SP* 57, 385; Mätzler *et al*, *ApJ* 223, 1058); Mätzler (*AA* 70, 181) has proposed a thermal model in which the temperature is 10^8K, which contrasts with the earlier, continuous injection model of Mätzler (*SP* 49, 117).

Also a thermal model for impulsive microwave bursts has been described by Uralov and Nefed'ev (*SA* 29, 438; *SA* 20, 590; *SA* 21, 749). In a different theoretical approach to the explanation of hard X-ray and impulsive microwave bursts, Böhme *et al* (*SP* 53, 139) use a two-component model. Neidig (*SP* 54, 165) has used optical estimates of magnetic field to test Takakura's earlier model, and found them consistent.

G. *Quiet Sun*

The quiet Sun is still the object of intensive study over a very wide range of wavelengths from dekametric to sub-millimetric. At metre and decimetre wavelengths, renewed interest arises from the recognition of coronal holes (Dulk *et al*, *SP* 52, 349; Smerd, *RQE* 20, 917; Trottet and Lantos, *AA* 70, 245; Covington, *SP* 54, 393). In the discussion of the results a discrepancy between the radio and EUV results arises, which has not yet been resolved. The arguments involved rely heavily on accurate measurements of the quiet Sun flux such as given by Kundu *et al* (*SP* 53, 489) and Erickson *et al* (*SP* 54, 57). Chambe (*AA* 70, 255) has drawn attention to the instability of some of the mathematical processes involved. At centimetre and millimetre wavelengths interest is in active regions (Righini-Cohen and Simon, *ApJ* 217, 999; see also Microwave Section), filament cavities (Kundu and Lantos, *SP* 52, 393; Rao and Kundu, *SP* 55, 161) and the centre-to-limb distribution with its information about chromospheric structure (Kislyakov and Kuznetsova, *SDB* 8, 71; Bachurin *et al*, *IKAO* 58, 40; Kuseki and Swanson, *SP* 48, 41; Labrum *et al*, *SP* in press; Labrum, *PASA* 3, #3).

8. CORONA
(J.-L. Leroy)

A. *The Slowly Variable and Active Region Corona*

I. *Coronal active regions*

a. *General structure.* The determination of accurate values of local physical parameters from observed quantities integrated along the line-of-sight is a major problem in the case of coronal active regions where the inhomogeneous structure is striking (Kahler and Krieger, *SP* 56, 351); uncertainties about coronal abundances make the problem harder (Davis *et al*, *SP* 45, 393; Withbroe *SP* 45, 301). Results are much safer if one has some knowledge of the geometrical structure of the condensation under study provided for instance by good quality X-ray images or EUV spectroheliograms (Jordan *IAU* 68, 1974; Pye *et al AA* 65, 123). In the general case, the derivation of the line-of-sight X-ray measure can lead to erroneous interpretations if there are noticeable line-of-sight temperature gradients (Underwood and McKenzie, *SP* 53, 417).

Many determinations of N_e and T_e in coronal condensations have been published (see for instance Bromboscz and Jakimiec *RZ* 51, 528; Feldman *et al*, *ApJ* 219, 304; Gelfrejkh and Korzhavin *RZ* 51, 509; Gerassimenko *SP* 48, 121). The general temperature structure of denser regions may be variable: in a condensation observed at the 1970 March 7 eclipse Gabriel and Jordan (*MN* 173, 397) have found that the density increased with increasing temperatures and that the low, central parts of the active region contained more material at high temperature than the neighbouring loop system however, even the central core must have a loop structure (Kreiger, 1977, *OSO-8 Workshop*). On the other hand, Kurokawa (*SP* 43, 385) has described a condensation observed during the 1973 June 30 eclipse as containing a cool and dense core ($T = 10^6$K; $N = 6 \times 10^9 \mathrm{cm}^{-3}$) at the lower part of the condensation. An attempt to provide a four parameter model of active regions has been published by Landini *et al* (*SP* 44, 69): the parameters are the maximum temperature ($2.2 < T_M < 2.8 \times 10^6$K), the maximum density ($2 < N_M < 9 \times 10^9 \mathrm{cm}^{-3}$), the width of the pressure distribution σ_P and the width of the temperature distribution $\sigma_T = \alpha^{\frac{1}{2}}\sigma_P$ ($2 < \alpha < 7$). The maximum temperature may be larger ($\sim 5 \times 10^6$K) according to Pye *et al* (*AA*, 65, 123). The height structure of X-ray condensations has been studied by Livshits and Bulatov *SA* 21, 1977); the height of the high temperature core can also be estimated from radio centimetric observations (Donati-Falchi *et al*, *SP* 56, 335) and has been found in the range 10000-40000Km.

b. *Energy balance.* Comprehensive reviews on this topic have been given by Withbroe (*IAU* 36, 263) and by Orrall and Kopp (*IAU* 36, 457). The need for continual energy deposition in active regions loops has been proved by Gerassimenko *et al* (*SP* 57, 103) and Levine and Withbroe (*SP* 51, 83). The evaluation of various losses shows that generally radiative losses are larger than conductive ones (up to 15 times according to Neupert *et al*, *SP* 43, 359). Solar wind losses are generally estimated to be unimportant. Teske and Mayfield (*ApJL* 210, 153) have studied the thermal energy content of a solar active region and shown that it was not in energy equilibrium at the time of observation; the time rate of change of thermal energy content was comparable to the rate of energy loss by radiation. In another global investigation of the energy balance in an active region, Evans *et al* (*SP*, in press) find that the region under study did not radiate and almost certainly did not receive more than a very small part of the "missing flux" of the spot group. Beckers and Schneeberger (*ApJ* 215, 356) reached a similar conclusion (the corona above a sunspot receives an Alfvén wave flux of less than 0.08% of the missing flux) after an analysis of the profile of the 5303Å line. In nearly all studies it is assumed that the energy deposition is of mechanical origin (Landini and Monsignori Fossi, *AA* 42, 213); Compagno (*OMOAA* 104, 74) and Jordan (*RSL* 281, 391) have provided an evaluation of the rate of change of the mechanical energy deposition as a function of height. However, Rosner *et al* (*ApJ* 222, 317) have proposed recently a process of coronal plasma heating by anomalous current dissipation which takes into account the inhomogeneous structure of the lower corona and its links with fine scale magnetic fields (Krieger *OSO-8 Workshop*).

II. *Streamers*

a. *Three-dimensional structure*. The model of a streamer as a coronal blade has been advocated again by Dollfus and Martres (*SP* 53, 449) in an analysis of K-corona measurements. On the other hand, after a study of a streamer observed over 2 months from Skylab, Poland (*SP* 57, 141) finds that the most probable structure is that of several radial cylinders of enhanced density extended in longitude and overlying both filaments and active regions.

b. *Dynamical models*. Weber (*SP* 53, 59) has developed a dynamical model of the interaction between a magnetic field emerging from the photosphere and the expanding solar atmosphere which leads to the formation of the streamer. One advantage of this model is that it does not require an extraordinary low electrical conductivity to obtain a reasonable thickness. The resulting structures are to a great extent nearly identical to those found in stationary models but there is a transverse field considerably larger than in stationary models. It will be noted that the initial magnetic configuration in this model is that of a bipolar region and it is expected that the model would fit better the so-called helmet streamers than the coronal blades which have been considered above. The long term studies of Poland (*SP* 57, 141), which depict the slow variation and mass changes of a typical coronal streamer provides us with good data for further modeling of streamers which appear to be persistent rather than stationary according to Poland.

B. *Coronal Magnetic Fields*

I. *Measurements*

a. *Optical methods*. High quality measurements of the polarization of coronal forbidden lines are now available (Arnaud, *ROL* 12, 137; Querfeld, *ROL* 12, 109) although puzzling discrepancies with eclipse measurements are still present (Sykora *et al*, *BAC* 28, 1; Picat *et al*, *AA* in press). Thus it should be possible to get good information about the orientation of the magnetic field in the lower corona; however, the difficult problem of inversion of the line-of-sight integrated measure of polarization is not yet solved.

II. *The computed coronal field*

a. *Improvement of numerical models*. Previous results have been discussed in several papers (Newkirk, *Proc. Symp. SSIMT*, GSFC, 1976; Schatten *RGSP* 13, 589; Vasilev and Kutakov, *AV* 10, 138; Roy *JRASC* 70, 292). One of the limitations of the current-free calculations has been insufficient spatial resolution by comparison with small scale arch structures, which are visible on X-ray images, in global calculations for the whole Sun. A first improvement has been to introduce as primary data the measurements obtained at Kitt Peak with a 2.5" or 1" resolution. Next an improvement of the spherical harmonics method, with a maximum index of 90 (instead of 9) has been achieved by Altschuler *et al* (*SP* 51, 345) and allows a spatial resolution of about 2^{o} heliographic. A similar result has been obtained by Adams and Pneuman (*SP* 46, 185) by a different method (fixed mesh solution to Laplace's equation using line-of-sight boundary conditions). In both cases the loop structures in the lower corona become much more conspicuous than in previous computations. Altshculer *et al* however stress that the spherical harmonic expansion technique provides essential information about the contribution of different scales of magnetic structures. Still a different approach has been chosen by Sakurai and Uchida (*SP* 52, 397) to compute the coronal field above active regions: the photospheric field is represented by an aggregate of solenoidal current loops located below the photosphere at the position of sunspots. The authors expect that discrepancies between computed lines of force and observed EUV structures will denote the presence of coronal current sheets about which they make some computations (energy stress storage). The next approximation after the current free case is that of force free fields which up to now has been treated essentially in the case of constant α ($\nabla \times B = \alpha B$) (Levine *SP* 44, 365 ; Barbosa *AA* 62, 267; Barbosa *SP* 56, 55; Nakagawa *et al*, *AA* in press). Finally the case of non-force-free solar magnetic fields in magnetohydrostatic equilibrium has been considered in an axisymmetric situation by Comfort *et al* (*ApJ* in press).

b. *Comparison with XUV structures.* While interesting comparisons can be made between coronal structures as seen on XUV images and the photospheric magnetic field (Teuber *et al*, *SP* 53, 97) the lack of measured values of the coronal magnetic field has led many authors to compare coronal structures and computed lines of force. First comparisons have shown an overall correspondence between X-ray structures and the computed potential field (Poletto *et al*, *SP* 44. 83; Sakurai and Uchida, *SP* 52, 397; Poletto *et al*, *OMOAA* 104, 175) although significant discrepancies could be found in active regions (Krieger *et al*, *SP* 47, 117). McGuire *et al* (*SP* 52, 91) and Nakagawa *et al* (*AA* in press) have found that constant α force-free lines of force gave a better agreement than potential field lines in the case of some stable arches visible either on X-ray images or on K-corona pictures. Levine (*SP* 46, 159) has found it possible to fit nearby loops above an active region by different sets of force-free computed field lines corresponding to opposite values of α, which the author interprets as being due to currents flowing in opposite directions. However, some doubt about the validity of such a procedure has been raised by Schmidt (*IAU* 36, 321) and it is not sure that the analysis of discrepancies between observed coronal structures and computed lines of force will be sure enough to provide quantitative data on coronal currents.

III. *Evolution of magnetic structures during the life of active regions*

a. *Arch structures inside active regions.* Howard and Svestka (*SP* 54, 65) have followed the evolution of the magnetic structures (identified with X-ray arches) of a coronal complex of activity. The basic components of the activity complex were permanently interconnected but the visibility of individual loops was greatly variable and typically shorter than one day. Only loops connecting active regions to the remnants of old fields could be seen with about the same shape for many days. Loop brightenings often occurred at the time of flare occurrence, triggered by the emergence of new magnetic flux, but it was also possible to observe growing and brightening of X-ray loops in old regions without flares. Although loop brightening seems, according to Howard and Svestka, to be related to a variation of the photospheric magnetic field at their foot point, it is wourth remembering (Krieger *et al*, *SP* 47, 117) that temperature and perhaps density variations are likely to explain much of the visibility change of X-ray structures.

b. *Large-scale structures.* The final decay of the complex of activity studied by Howard and Svestka (*SP* 54, 65) was accompanied by the penetration of a coronal hole into the region where the complex existed before. However, open field configurations can be found there even during the life of active regions: according to Svestka *et al* (*SP* 55, 359) X-ray observations confirm the prediction of potential field computations (Levine *et al*, *ApJ* 215, 636) that some of the dark gaps seen between interconnecting loops and inner cores of active regions may be the loci of open fields. That would occur only in a later stage of the active region development.

A long-lived coronal arch system has been followed during several rotations by McGuire *et al* (*SP* 52, 91). Svestka *et al* (*SP* 52, 69) have described the life history of a transequatorial loop system which connected a new-born active region and an older one; magnetic field variations in the young center seemed to cause striking brightenings and twisting of the loop system. Finally, the evolution of the equatorial K-corona radiance all along the Skylab mission indicates (MacQueen and Poland, *SP* 55, 143) a rapid response of equatorial outer structures to abrupt changes in the global surface field structure.

c. *Possible occurrence of reconnection of magnetic lines of force.* Examples of possible reconnections of magnetic lines of force have been pointed out by Howard and Svestka (*SP* 54, 64) but it is difficult to distinguish changes in the temperature distribution of matter and true changes in the general structure of the field (Krieger *et al*, *SP* 47, 117). This problem has been investigated in detail by Nolte *et al* (*SP* 55, 401): even if one can discard apparent configuration changes of magnetic structures due to variations of emission, it is still necessary to have observational data to decide whether reconnection has occurred or if one has observed a large-scale reconfiguration of a "frozen-in" coronal magnetic field. According to the authors, existing observations of emitting loops and magnetic fields are rarely sufficient to make the distinction.

Possible effects of reconnection are, nevertheless, considered in several publications: Sheeley (*SP* 47, 173) after a comparison between coronal spectroheliograms and photospheric magnetograms suggests that field line reconnection is a mechanism which takes place usually when coronal magnetic fields interact and prevents the building up of magnetic stresses in the lower corona. Consequences of magnetic reconnection (which would happen due to the differential rotation) for the global coronal field and for the location of quiescent prominences have been examined by Hansen and Hansen (*SP* 44, 503; *SP* 51, 169). Finally, the possible role of reconnection processes during the relaxation phase of transient events, which could lead, for instance, to the formation of loop prominences, has been studied by Kopp and Pneuman (*SP* 50, 85; see also Rust and Webb, *SP* 54, 403).

C. *Coronal transients*

I. *Frequency and relation to solar activity*

Although the structure of active regions has been described in the previous paragraphs as if it was only "slowly variable", it is well known that there exists also fast events; and one of the most spectacular results of Skylab observations has been to observe them as well in X-ray in the lower corona as in the outer K-corona thanks to the coronagraph (Mac Queen *et al*, *RSL* 281, 405; MacQueen and Poland, *SP* 55, 143).

Hildner *et al* (*SP* 48, 127) have shown that transients observed in the K-corona are not rare (110 events observed in 227 days during the Skylab mission) and that they occur more often above strong photospheric and chromospheric magnetic field regions, which is consistent with the idea that magnetic forces may play a dominant role in the expulsion of coronal material. Transients may be detected in the lower corona using ground-based observations (Fisher, *SP* 55, 135) but the association with other solar phenomena is more easily seen on the disk, with the help of X-ray images; Kahler (*ApJ* 214, 891) has shown that X-ray events with long decay times are associated either with long-lived active regions, or with Hα prominence activations or with white light outer coronal transients. Rust and Webb (*SP* 54, 403) have found that out of 156 large-scale enhancements of X-ray emission in active regions, 44% were correlated with flares and 81% with filament activity. As flare related events and prominence activations will be described in other sections of this Report, only a brief account of the low corona counterpart of these transients will be given here.

II. *Transient phenomena in the lower corona*

a. *X-ray observations of coronal brightenings in active regions.* They are in most cases associated with Hα filament activity and are observed generally as X-ray loops

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or arcades of loops which can last several hours (Rust and Webb, *SP* 54, 403). These structures can probably be identified with classical Hα loop systems and the authors suggest that loops outline magnetic lines of force which are reconnecting after filament eruptions (see also Kopp and Pneuman, *SP* 50, 85). A well observed and particularly energetic event (1973 August 13) has been described by Vorpahl *et al (ApJ* 212, 550) who derive a temperature as high as 7 x 10^6K for the top of loops and a maximum density of 3 x 10^9cm^{-3}. The correlation with a white light transient observed much higher in the corona has been established for this particular example by Rust and Hildner (*SP* 48, 381). Other examples of such associations are presented by Smith *et al (De Feiter Memorial Symposium,* in press). The life-time of the loops which have been formed can be very long (Sheeley *et al, SP* 45, 377); their decay has been studied by Krieger (*SP* 56, 107), who finds it longer than that computed for conductive cooling and thus asks for an additional energy source. In the case of the 13 August 1973 event Vorpahl *et al (ApJ* 212, 550) suggest that energy and possibly new material was added at the top of the loops as the phenomenon evolved.

b. *Coronal changes associated with disappearing filaments.* This class of transients which has been described by Webb *et al (SP* 48, 159) happens outside active regions: concomitantly with the Hα filament disappearance, X-ray emitting structures appear near the filament location; the peak temperature is of the order of 2.5 x 10^6K and the peak density of 10^9cm^{-3}, the total mass of the coronal X-ray emitting material is about 10% of the pre-existing filament. Kahler (*ApJ* 214, 891), in a study of X-ray events with a long decay time (according to the 1-8 Å flux), has suggested that these phenomena are similar to the X-ray enhancements near filament cavities. Other observations of X-ray and EUV emissions associated with the eruption of initially quiescent prominences have been described by Smith *et al. (SP* 52, 379) and Schmahl and Hildner (SP *55*, 473), who have been able to follow the phenomenon high into the corona and to study its link with the white light transient. The association of X-ray coronal transients outside active regions with disappearing filaments may be considered as a peculiar although very frequent case in the more general association of transients with neutral lines or more precisely with those which border growing equatorial coronal holes (Webb *et al, SP* in press).

III. *The "white light" transients*

a. *Kinematics* A lot of detailed data on the outward speed of mass ejections as observed in white light has been published (Hildner *et al, SP* 45, 363; Schmahl and Hildner, *SP* 55, 473). Gosling *et al (SP* 48, 389) have shown that while the overall scatter of velocities is between 100Km/s and 1200Km/s, flare associated events travel typically faster (775Km/s) than eruptive prominence associated events (360Km/s). This result is fully consistent with the long known difference (Valnicek, *BAC* 15, 207) between the kinematics of flare sprays and that of eruptive prominences. Type II and IV radio bursts (Kosugi, *SP* 48, 339) are associated only with events moving faster than 400Km/s (Gosling *et al, SP* 48, 389).

b. *Origin of ejected material.* The fact that the white light transient, although accompanying an eruptive prominence, is hot coronal material is proved by the polarimetric analysis of wide band pictures (Poland and Munro, *ApJ* 209, 927). Moreover the good coincidence between Hα and HeII images of the prominence shows that its material is not significantly heated and evaporated into the corona (Hildner *et al, SP* 45, 363). Therefore, the white light transient, which can be observed 1 $R_{\odot}$ higher than the top of ascending prominences (Hildner *et al, SP* 45, 363), must be coronal material originating from the low corona overlying the prominence. In the 1973 December 19 event studied by Schmahl and Hildner (*SP* 55, 473), the mass of the prominence material was about 2 x 10^{14}g while it reached 2 x 10^{15}g for the coronal transient. In other cases the mass of the prominence material was larger (Hildner *et al, SP* 45, 363) but the figure of 10^{15}g for the coronal transient was found in several examples (Hildner *et al, SP* 45, 363; Smith *et al, SP* 52, 379; Rust and Hildner, *SP* 48, 381). The density in the transient is roughly 10 times greater than the normal neighbouring corona (Poland and Munro, *ApJ* 209, 927; Dulk *et al*, *SP* 49, 369). An analysis of the time evolution of the kinetic and potential energy (Schmahl and Hildner, *SP* 55, 473) leads to the conclusion that in the case of the 1973 December 19 event, the total energy increased 10 times during the 4 hours of observation implying the existence of some accelerating mechanism.

c. *The role of the magnetic field.* The simultaneous observation of a white light transient from Skylab and of the associated continuum radio burst (originating above the outward-moving white light loop in a compressed medium headed by a bow wave) at Culgoora has allowed Dulk *et al* (*SP* 49, 369) to determine the magnetic energy density. It was found to be more than 10 times the thermal energy density and larger than the kinetic energy density even in the fastest moving parts of the transient. Therefore, the plasma was magnetically controlled and it is likely that magnetic forces must provide the principal mechanism for acceleration of the transient material from the Sun.

d. *Interpretations.* One important point upon which present knowledge is not sufficient is the three dimensional structure of the transient; and the theoretical explanation of the phenomenon will be different for a "loop" than for a "shell" transient (Benz, *2ESM* in press). The loop structure has been proved for one example (Munro, U) and has been investigated by Mouschovias and Poland (*ApJ* 220, 675) and by Anzer (*SP* 57, 111). The white light transient is considered as a magnetic flux tube originating from the lower corona which expands in the background corona and magnetic field. A longitudinal current is assumed to flow along the loop to produce an azimuthal magnetic field, which can account for the expansion of the loop. The velocity versus height diagram is consistent with observed data (Anzer, *SP* 57, 111).

The alternative to the expanding loop is something like a piston driven expanding structure if the transient has a shell shape (Uralov and Kasinskii, *IANS* 53, 1264; Steinolfson and Nakagawa, *ApJ* 215, 345; Smith *et al*, *SP* 52, 379). Computations of Nakagawa *et al*, (*ApJ* 219, 314), Wu *et al* (*ApJ* 219, 324), Steinolfson *et al* (*ApJ* in press) show that is is possible to reproduce the observed transient velocities. The configuration of magnetic field is important; and it is found that only radial field topologies allow the propagation of transients as observed.

It can be thought (Benz, *2ESM* in press) that both loop and shell transients exist, the first corresponding to eruptive prominences and the latter to flares.

9. SOLAR WIND – SOLAR TERRESTRIAL
(John M. Wilcox)

The Skylab Workshop on coronal holes (reviewed by Zirker, *CHHSWS; RGSP* 15, 257) established that all large near-equatorial coronal holes seen during the Skylab period were associated with high-velocity solar wind streams observed at 1 AU (Krieger *et al*, *SP* 46, 303; Bell and Noci *OMOAA* 104, 111; Watanabe, *PASJ* 27, 385; Kovalenko and Molodykh, *AZAN* 54, 859; Rickett *et al*, *JGR* 81, 3845) but it is important to note that the converse does not hold, since there are considerably more high-speed streams than there are coronal holes. Coronal holes were established as sources of recurrent geomagnetic disturbances (Sheeley *et al*, *SP* 49, 271), but observations into the rising phase of sunspot cycle 21 showed that the solar atmosphere evolved from a structure having a few, large, long-lived, low-latitude coronal holes to one having numerous small, short-lived, high-latitude holes (Sheeley and Harvey, *CHSWS*, Naval Research Laboratory Skylab/Atm. Preprint, 1978). The high-latitude holes recurred with a synodic rotation period of 28-29 days instead of the 27-day period characteristic of low-latitude holes. The high coronal structure of high velocity solar wind stream sources was examined in Nolte *et al*. (*SP* 51, 459) and coronal holes were shown to be sources of open magnetic field lines, which extend from the solar photosphere to interplanetary space, as traced in a current-free (potential field) approximation using measured photospheric fields as a boundary condition (Levine *et al*, *JGR* 82, 1061). The holes magnetically open to the interplanetary medium having "toward" field polarity tended to connect to the south polar cap and those with "away" polarity tended to connect to the north polar cap (Wagner *AJ* 206, 583) during the lase cycle. The polar holes have persisted throughout the interval of observations (Sheeley and Harvey, l.c.). The magnetic polarity of low-latitude holes agrees with the polarity of the interplanetary magnetic field in the corresponding high-speed streams of the solar wind (Sheeley *et al*, *SP* 49, 271; Sheeley and Harvey, l.c.). Theoretical discussions of the effects of coronal hole structure on the solar wind are given by Fahr *et al* (*ASS* 43, 19), Dyer and Steinolfson (*JGR* 81, 5413) Holzer (*JGR* 82, 23), and Richter and Suess (*JGR* 82, 593). The diverging magnetic field geometry is found to be of key importance.

The three-dimensional structure of the solar wind (i.e. including north-south variations) received increasing attention and stimulated a proposed Solar Polar Spacecraft Mission to investigate the interplanetary regions above the polar regions. A large-scale latitude gradient in solar wind velocity of approximately 13km/s per degree of latitude was reported (Rhodes and Smith, *JGR* 81, 2123; Rhodes and Smith, *JGR* 81, 5833), but other workers have found intermittent (Bame *et al*, *JGR* 82, 173) or no (Diodato and Moreno, *ASS* 39, 409) latitude gradients of velocity. Interplanetary scintillation observations indicate a mean solar wind speed gradient of 2km/s per degree of latitude (Coles and Rickett, *JGR* 81, 4797), while analysis of the orientations of ionic comet tails gives no support for a higher speed near the poles than at the equator (Brandt, *Proc. Symp. SSIMT*, 95). These conflicting claims may be resolved (Hundhausen, *CHHSWS*, 225) by consideration of the longitudinal average which many of these techniques impose on the latitudinal gradient away from a warped current sheet in the heliosphere (Svalgaard and Wilcox, *N* 262, 766). When Pioneer II was at heliographic latitude of 16°N near sunspot minimum, it observed for several months a nearly continuous "away" interplanetary field polarity indicating that the warp in the equatorial current sheet at the time was less than 16° (Smith *et al*, *JGR* 83, 717). The large-scale heliospheric magnetic field is, at the present phase of the sunspot cycle, directed away from the sun northward of this warped "equatorial" current sheet and directed toward the sun southward of the current sheet. A theoretical discussion of the latitude dependence of solar wind speed as influenced by the coronal magnetic field geometry was given in Pneuman (*JGR* 81, 5049) and the subject was reviewed in Dobrowolny and Moreno (*SSR* 18, 685). Evidence for a solar equatorial belt from which few protons are emitted is given in Vladimirsky and Levitsky (*N* 260, 27). Observations with a solar probe near 0.3 AU indicated that the northern boundary of the high-speed stream associated with an equatorial extension of the south polar coronal hole was quite narrow--less than about 10° in latitude thick. The local latitudinal gradient in flow speed was at least 30km/s per degree of latitude (Schwenn *et al*, *JGR* 83, 1011). These observations appear to be consistent with the considerations described by Hundhausen (*CHHSWS*, 225).

After more than a century of controversy the possible influence of solar activity on terrestrial weather may be moving toward scientific respectability (Wilcox, *SC* 192, 745). Structures related to the warped current sheet described above appear to influence the size of wintertime low-pressure troughs (Wilcox *et al*, *JAS* 34, 382). Related investigations are described in Loginov *et al*. (*TGIM* 23, 43), and Knight and Sturrock (*N* 264, 239). Atmospheric pressure at the surface of the earth was found to change in an ordered manner after geomagnetic disturbances attributed to solar flares (Mustel *et al*, *AZAN* 53, 1060; Mustel *et al*, *AZAN* 54, 682; Chertoprud, *AT* 883, 4). A solar-generated quasi-biannual geomagnetic variation was described in Sugiura and Poros (*JGR* 82, 5621), and possibly related meteorological variations were desribed in Yakoleva (*TGGO* 355, 94). Large-scale reductions in the ozone content of the middle and upper stratosphere over the polar cap regions were associated with major solar proton event (Heath *et al*, *SC* 197, 886). Stratospheric circulation at 10 mb was associated with the sun's rotation (Ebel and Batz, *T* 29, 41). An effort was made to improve regular daily observations of the magnetosphere, ionosphere and atmosphere to aid in understanding the physical mechanisms involved in sun-weather influences (Wilcox, *JATP* 39, 173). An examination of several possible physical mechanisms was given by Dickinson (*BAMS* 56, 1240) and by Schneider and Mass (*SC* 190, 741) and the energetics of such relationships was discussed by Willis (*JATP* 38, 685). Further theoretical discussions of possible mechanisms were given by Volland (*N* 269, 400), Cole (*N* 260, 229), and Schuurmans, (*Z* 3.Jaarg, 358). Possible influences of cosmic rays on the terrestrial atmosphere were discussed by Chamberlain (*JAS* 34, 737) and Schelegel (*JATP* 39, 101). A wide-ranging review of many possible climate effects of solar phenomena was given by King (*ASS* 57, 209) and some specific relationships were discussed in Gerety *et al*, (*JAS* 34, 673) and Rubashev *et al*, (*SDB* 10, 98). The Maunder minimum in solar activity may have been associated with the little ice age, and similar relationships may have occurred in earlier centuries (Eddy, *SC* 193, 1189). There is some evidence that solar activity may have a significant influence on the accuracy of weather forecasting (Larsen and Kelley, *GRL* 4, 337) but much more work on this point is needed. The Proceedings of a recent conference provide a good summary of the current state of the field (Proceedings, Symposium/Workshop on *Solar Terrestrial Influences on Weather and Climate*, Ohio State University, July 1978, in press). The overall subject remains one of considerable controversy (Pittock, *RGSP* 16, 400) and agreement on which effects are real and accepted physical mechanisms has not yet emerged.

Streams of protons with energies a few Mev observed in the solar wind near earth were attributed to an unknown solar acceleration process (Roelof and Krimigis, *STIP*, 343), but as spacecraft observations between one and five AU became available it was observed that the intensity of such proton streams was larger at a few AU than at the earth. Thus most of the acceleration is attributed to interplanetary processes which are not yet well understood (Barnes and Simpson, *ApJL* 210, 96; Smith and Wolfe, *STIP* 227; Pesses *et al*, *JGR* 83, 553; Palmer and Gosling, *JGR* 83, 2037).

The solar wind emission is highly structured in latitude and longitude by the solar magnetic field, including the effects of coronal holes discussed above. It had been thought that low speed solar wind represented the theoretical "uniform sun" conditions, but recent studies have indicated that the high-speed solar wind is more uniform and probably should be used in any comparisons with isotropic theory (Bame *et al*, *JGR* 82, 1487; Gosling, *JGR* 81, 5054). Observations from 1964-1975 showed that high- and low-speed solar wind flows originated from preferred solar longitudes, with a modulation in solar wind speed of 20% associated with the synodic rotation period of 27.025 days (Gosling, *et al*, *JGR* 82, 2371). An internal structure deep in the sun may be postulated to explain these effects, which appear to rotate rigidly, or they may be a consequence of long lived circulation patterns. Radio techniques were increasingly used to probe the solar wind near the sun and out of the ecliptic (Coles and Rickett, *JGR* 81, 4794; Rickett *et al*, *JGR* 81, 3845; Watanabe, *UK* 19, 80; Woo *et al*, *ApJ* 210, 568; Rickett, *SP* 43, 237; Fitzenreiter *et al*, *SP* 52, 477; Woo *et al*, *ApJ* 218, 557; Coles and Harmon, *JGR* 83, 1413). Most of the observers found the solar wind speed to increase at higher latitudes. Yearly averages of solar wind speed observed with spacecraft were found to be rather constant with solar cycle except for broad high-speed streams observed during about two years before solar minimum (Bame *et al*, *ApJ* 207, 977; Gosling *et al*, *JGR* 81, 5061; Feldman *et al*, *JGR* 83, 2177; Sheeley *et al*, *SP* 52, 485). A study of geomagnetic records from 1868-1975 indicated that the broad high-speed streams observed in the 1973-1975 era may have been unusually large (Gosling, *et al*, *JGR* 82, 3311). Observations just *after* sunspot minimum found solar wind streams of lower amplitude, lower maximum speed and shorter duration than those observed in the preceding years (Nolte, *et al*, *GRL* 4, 291) and that the solar wind-coronal hole relationship inferred from the Skylab period may change in other parts of the solar cycle.

In order to reduce the discrepancy between solar wind measurements at 1 AU and the corresponding predictions of the basic two-fluid model, a nonthermal heating of solar wind protons in the outer corona up to distances of about 0.1 AU has been postulated (Auer and Rosenbauer, *JGR* 82, 1503). In this connection a number of discussions have been given of the momentum and energy deposited by various wave modes in the solar wind (Wentzel, *JGR* 82, 714; Jacques, *ApJ* 215, 942; Abraham-Shrauner and Feldman, *JGR* 82, 618). Two-fluid models continue to be popular for describing solar wind flow conditions (Nerney and Barnes, *JGR* 82, 3213; Singer and Roxburgh, *JGR* 82, 2677; Summers, *PLSC* 24, 799; Benz and Gold, *AA* 55, 229). When an azimuthal velocity dependence is included in a two-region model of the solar wind, it is found that the amount of energy converted into kinetic energy in the solar wind is only a small fraction of the total expansion energy flux and has little effect upon the final radial expansion velocity (Acuna and Whang, *ApJ* 203, 720). The effects of rapidly diverging flow may produce an increased conductive energy supply to the solar wind (Holzer, *JGR* 82, 23). It was found that including the Archimedes spiral field geometry did not have a large influence on the results obtained from the two-fluid solar wind equations (Nerney and Barnes, *JGR* 83, 3729).

A sheet-current approach was introduced to describe the force balance between the magnetic field and the gas pressure in the coronal-interplanetary space (Yeh and Pneuman, *SP* 54, 419). Dynamic modeling of coronal and interplanetary responses to solar events within the contexts of hydrodynamics and magneto-hydrodynamics has received considerable attention (Dryer *et al*, *JGR* 83, 532; Steinolfson and Dryer, *JGR* 83, 1576; Wu *et al*, *STIP* 43). A review of the observations and theoretical ideas concerning the role of kinetic processes in the solar wind was given in Dobrowolny and Moreno (*SSR* 20, 577).

Analysis of the number of geomagnetic storms showed that if the component of the large-scale solar magnetic field in an active region or in a flare region is directed southward then that region and that flare produce a geomagnetic storm (Pudovkin and Chertkov, *SP* 50, 213; Pudovkin *et al*, *SP* 54, 155). A correlation of the toward polarity interplanetary magnetic field sectors with the inward polarity main body of the solar magnetic "super giant" structures was found (Bumba, *BAC* 27, 153). A study of the interplanetary magnetic field in 1969-1974 showed a clear reversal of the sense of the Rosenberg-Coleman dominant polarity effect in the 1970-71 interval and that on the average sector boundaries near the earth were inclined approximately 12° to the solar equator (Hedgecock, *SP* 44, 204). Sector boundary distortion by a possible meridional velocity gradient in the solar wind was discussed (Suess and Feynman, *JGR* 82, 2405). Coronal streamers can be followed into interplanetary space as a curved surface that is accompanied by a change of polarity of the interplanetary magnetic field (Korzhov, *SP* 55, 505). Studies of long-term interplanetary magnetic field variations in 1963-74 showed that the yearly average magnitudes of all field sectors had virtually no solar cycle variation (King, *JGR* 81, 653; Mariani *et al*, *SP* 45, 241; Kovalenko and Malyshkin, *SDB* 9, 95). Since the large-scale solar magnetic field changes considerably as a function of latitude through the sunspot cycle some compensating effects that are not well understood at the present must exist in order to produce a constant magnitude of the interplanetary magnetic field. The solar wind electric field near the earth rises sharply at each sector boundary from a pre-boundary value of approximately 1 mV/m to peak values between 3-6 mV/m, resulting in several phenomena in the polar cap ionosphere (Bahnsen and D'Angelo, *JGR* 81, 683).

10. GROUND BASED OPTICAL SOLAR INSTRUMENTATION
(R. J. Bray)

A. *New Telescopes*

A 60 cm domeless solar telescope is due for installation at the Hida Observatory of the University of Kyoto in 1978. Carried by an altazimuth mounting on a 20 m tower,

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the telescope was constructed by Carl Zeiss, Oberkochen, (Kühne, *ZI* 84). It is a modified Gregorian and most of the optical path is in vacuo.

Carl Zeiss, Jena, is also active in solar telescope design and construction. Artus (*JR* 3, 138) has described a design concept for a large, sophisticated vacuum tower telescope fed by an altazimuth coelostat and incorporating a large range of computer-controlled auxiliary instrumentation. Zeiss is currently building five horizontal telescopes with apertures of 50 cm for the Czechoslovak Academy of Sciences, equipped with 10 m Czerny-turner spectrographs.

Several member countries of the Joint Organization for Solar Observations plan to erect telescopes at sites on the Canary Islands. Details of the various instruments under construction are to be found in *JOSO*; progress in advancing the organization's aims is also described in *JOSO*.

Two vacuum telescopes of 40 cm aperture are due for completion at Kanzelhöhe over the period 1979-80 (Pettauer, private communication).

SibIZMIR (Irkutsk) is building a large telescope at Lake Baikal in Siberia. The two-lens objective has a diameter of 76 cm and a focal length of 40 m; the first images are expected by the fall of 1979. A brief description will appear in *NTA*, Nauka (in press).

There are three solar observatories currently operating in China - the Purple Mountain Observatory near Nanking, Yunnan Observatory near Kunming, and Peking Observatory. The largest solar telescope is a Chinese made Cassegrain coudè with an aperture of 60 cm located at Peking.

High Altitude Observatory is completing a new K-coronameter ('Mark III') to be installed at the Mauna Loa Observing Station during the spring of 1979. The new instrument, of 20 cm diameter aperture, features improved spatial and temporal resolution over its predecessors and is designed particularly to permit inner coronal observations of coronal changes and mass ejection events on the sun. A companion instrument to observe prominence material far from the solar limb and determine the velocity of ejecta in Hα will be brought into operation at the same site in the summer of 1979, prior to the launch of NASA's Solar Maximum Mission satellite.

B. *Filters*

There has been vigorous development of computer-controlled filters with narrow bandwidths ($\lesssim$ 0.1 Å) capable of rapid tuning to a number of Fraunhofer lines ('universal' filters). At Lockheed, Title (*AO* 15, 2871) has made a birefringent filter which, by using partial polarizers, achieves a significantly higher transmission than conventional filters. At λ5324 the bandwidth is 0.09 Å. The filter can be tuned to any wavelength in the range 4500-8500 Å by a number of stepping motors commanded by a minicomputer.

The universal birefringent filter designed several year ago by Beckers (SPO) and Zeiss (Oberkochen) is now available commercially. It may be tuned to any wavelength in the range 4200-7000 Å with a bandwidth varying from 0.09 Å to 0.28 Å, depending on the wavelength. At the Big Bear Solar Observatory such a Zeiss universal filter mounted on the 65 cm vacuum telescope operates under the control of a PDP-11 computer (Zirin, private communication).

Narrow-band birefringent filters are also being developed at SibIZMIR (Skomorovsky, *SP* 41, 254; 45, 2; Aleksandrovich *et al* , *NTA* 5, 34).

A well-recognized need exists for universal filters having much narrower bandwidths than present-day filters of the birefringent type. At SCLERA (Tucson, Arizona) Smolka and Hill (*JOSA* 66, 1089) are constructing a filter consisting of ten Michelson interferometers in series. Tuning will be carried out by means of piezo-electric transducers controlled by a minicomputer. The expected bandwidth ranges from 0.02 Å at 4000 Å to 0.09 Å at 8000 Å.

At Sydney a filter consisting of three servo- and computer-controlled Fabry-Perot interferometers is being assembled (Bray, *R* 20, 1318). To avoid parasitic images the interferometers must be tilted slightly; nevertheless, the calculated instrumental profile shows little degradation over a field 3 x 4 arcmin in extent (Loughhead *et al*, *AO* 17, 415). At Hγ (4340 Å) and Hα (6563 Å) the calculated bandwidths are 0.02 Å and 0.05 Å respectively.

A digitally controlled Fabry-perot interferometer for use in the infrared is being developed at Kanzelhöhe (Pettauer, private communication).

C. *Magnetographs*

Increasing effort is being applied to the measurement of vector magnetic fields as distinct from their purely longitudinal component. Details of performance figures and calibration procedures have been published by Baur and House (*PSPIE* 112) for the HAO/SPO Stokes Polarimeter. The instrument is mounted on the 40 cm coronagraph at Sacramento Peak and simultaneously measures all four Stokes parameters as a function of wavelength across the profile of any line in the visible spectrum. It is used to determine vector magnetic fields by means of the Zeeman and Hanle effects in both quiet and active regions on the disk and prominences beyond the limb. For longitudinal fields its sensitivity is typically 1 gauss, and for transverse fields, 20 gauss. The spatial resolution is typically 6 arcsec while the best achieved is 2 arcsec.

At Kitt Peak a Stokes polarimeter is expected to be available by the end of 1978. It will operate at the McMath telescope in conjunction with a two-dimensional diode-array detector (Harvey, private communication).

A new method of measuring vector fields which, like the Stokes polarimeter technique, is free of the saturation effects encountered in the conventional magnetograph, has been proposed by Loughhead and Bray (*SP* 50, 297; *PASP* 90, 230). Using a tunable narrow-band filter or spectroheliograph, they propose to determine the contrast profile of the point under examination in a suitable Zeeman triplet. The method is confined to strong (kilogauss) fields but is intrinsically capable of high spatial resolution (λ 1 arcsec) (see also Frazier, *AA* 64, 351).

A videomagnetograph for rapid reconnaissance of longitudinal fields built by Leighton in 1970 is now installed on the 25 cm vacuum refractor at Big Bear (Zirin, private communication). A PDP-11 is used to control this system as well as a universal birefingent filter and its associated cameras. Thus, one can carry out rapid wavelength scanning programs with the universal filter interleaved with magnetograms of the same region. The Big Bear Observatory has the capability of obtaining nearly simultaneous, real time magnetic and velocity measurements, filtergrams in a variety of spectral lines, and photographs in white light. The three vacuum telescopes employ apertures of 65, 25, and 22 cm and produce both high-resolution and patrol-type observations.

Modern methods of magnetic field measurement have recently been reviewed by Grigorev (*IKAO* 56, 166). This article is valuable for its account of vector magnetographs, the properties of various kinds of linear and two-dimensional solid-state photodetector arrays, and recent developments in the Soviet Union. A CSIRO translation is available.

Magnetographs in use in the Soviet Union have also been described by Klochek *et al*, *NTA* 5, 25) and Stepanov *et al*, (*IGAFS* 37, 147).

D. *Miscellaneous*

The intensity and linear polarization of certain coronal emission lines can be used to infer the direction, but not the strength, of coronal magnetic fields. Coronal emission line polarimeters have been placed in operation at Pic du Midi by Arnoud (*ROL* 12, 137) and at SPO by Querfeld (*PSPIE* 112, 200). The 15 cm coronameter at Pic du Midi observes the FeXIV 5303 Å line to $1.4R_o$ while the joint HAO/SPO 40 cm coronameter uses the FeXIII 10747 Å line out to $2.2R_o$.

The Haleakala Stokes polarimeter (Mickey, *ROL* 12, 81) is now equipped with a compact Czerny-Turner monochromator so that spectral profiles may be obtained with .030 Å at 6000 Å resolution in all four Stokes parameters. Since silicon diode detectors are used, the instrument has a spectral range of 3500-11000 Å. The effective spatial resolution is limited to 5 arc seconds by spar pointing stability.

A two-dimensional diode-array detector is now available for imaging and spectroscopic observations at the McMath telescope, Kitt Peak National Observatory. With the large infrared spectrometer it is now possible to build up spectroheliograms in the infrared (1 - 10 μm) using a single detector. The 1 m Fourier transform spectrometer is now in full operation (Harvey, private communication).

ABBREVIATIONS

AA = Astronomy and Astrophysics
AAM = Adv. Appl. Mech.
AASup = 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
ApJSup = Astrophysical Journal Supplement
ARAA = Annual Review of Astronomy and Astrophysics
ASS = Astrophysics and Space Science
AT = Astronomischeskij Tsirkular
AUP = Australian Journal of Physics
AUPA = Australian Journal of Physics, Astrophysical Supplement
AUW = Acta Universitatis Wratislaviennis
AV = Astro. Vestro
AZ = Astronomicheskij Zhurnal
AZAN = Astron. Zhurn. Akada. Nauk
BAC = Bulletin of the Astronomical Institutes of Czechoslovakia
BAAS = Bulletin of the American Astronomical Society
BAMS = Bulletin Amer. Meteor. Soc.
BASI = Bulletin Astron. Soc. India
CA = Center for Astrophysics
CALR = Univ. of Calif. at Riverside
CAPS = Comments on Astrophysics and Space Physics
CE = Cosmic Electrodynamics
CHHSWS = Coronal Holes and High Speed Wind Streams, Colo. Assoc. Press

CHSWS = Coronal Holes, Solar Wind Streams, and Geomagnetic Activity During the New Sunspot Cycle, Naval Research Laboratory Preprint
COSP = COSPAR Symposium
CR = Comptes Rendus de l'Academie des Sciences, Paris
CSP = Proceedings Consultation of Solar Physicists from Socialist Countries, Irkutsk 1976
ECSPI = First European Conference on Solar Physics, Florence
EOS = EOS, American Geophysical Union
ESM = 2nd European Solar Meeting
FP = Fiz. Plazmy
GAER = Geomagnetizm i Aeronomiya
GAFD = Geophys. and Astrophys. Fluid Dyn.
GRL = Geophysical Research Letters
HA = Highlights of Astronomy
IANS = Izv. Akad. Nauk SSSR
IAU = IAU Symposium
ICCR = International Cosmic Ray Conference
IGAFS = Issl po Geomagn Aer i Fiz. Solntsa
IKAO = Izvestiya Krymskoj Astrofizicheskoj Observatorii
ISSTP = International Symp. on Solar Terrestrial Physics
ISSTR = International Symposium on Solar Terrestrial Relations
JATP = Journal Atmos. Terr. Physics
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
JR = Jena Reviews
JRASC = Journal of the Royal Astron. Soc. of Canada
KB = Kleinheubacher Berichte
KI = Kosmicheskie Issledovaniya
LPI = P. N. Lebedev Physical Institute
MAG = Mittelungen der Astronomischen Gesellschaft
MGYR = Magnetnaya Gidrodynamika
MN = Monthly Notices of the Royal Astronomical Society
N = Nature
NPS = Nature Physical Science
NRO = Nouvelle Revue d'Optique
NTA = Novaya Tekhn v Astron
OE = Optical Engineering
OLI = Ord. Lenin Inst. Priki, Mat. Acad.
OMOAA = Oss. e Mem Oss Arcetri
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
PLI = Proceedings Lebedev Institute
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
R = Radiofizika
RCSP = Regional Consultation on Solar Physics

RGEO	= Reviews of Geophysics
ROL	= Reports Observatory of Lund
RQE	= Radiophysics and Quantum Electronics
RSL	= Royal Society London
RZ	= Referativnyj Zhurnal
SA	= Soviet Astronomy
SAL	= Soviet Astronomy Letters
SAM	= Studies in Appl Math.
SC	= Science
SDB	= Solnechnye Dannye Byulleten
SJPP	= Soviet Journal Plasma Physics
SP	= Solar Physics
SPO	= Sacramento Peak Observatory
SPU	= Soviet Phys. Usp
SR	= Space Research
SSI	= Space Science Instrumentation
SSIMT	= Proc. Symp. on Study of the Sun and Interplanetary Medium in 3-D
SSL	= Space Science Laboratory
STIP	= Study Travelling Interplanetary Phen.
SW	= Sterne und Weltraum
T	= Tellus
TAI	= Trudy Astrofizicheskogo Instituta
TAGU	= Transactions American Geophysical Union
TAOR	= Tokyo Astronomical Observatory Reports
TGIM	= Trudy VNII gidrometeorol inform. mirovojtsentr dannykh
TGGO	= Trudy Glav. geofiz. observ.
U	= unpublished
UCR	= UCAR preprint
UK	= Uchusen, Kenkyu
USP	= Uspekhi Fiz. Nauk
VAIF	= Veroeffentlichungen Astr. Inst. Frankfurt
Z	= Zenit
ZA	= Zeitschrift fur Astrophysik
ZI	= Zeiss Inf.

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