10. SOLAR ACTIVITY (ACTIVITÉ SOLAIRE)

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This report is intended to cover highlights in the study of solar activity over the three-year period, ending December 1972. In compliance with a request from the General Secretary, efforts have been made to reduce duplication and especially to concentrate on the more important developments over the past three years as these are judged by those preparing the different sections. Thus, if the report is less comprehensive than in previous years it is hoped that the reader will understand the reason for this whether or not he agrees with the scale of importance adopted by the contributing authors. One must also remember that some recent unpublished work will not be included because it was not brought to our attention or, as in several cases, material was received so late that it could have been included only with major rewriting and at the risk of delaying completion of the whole manuscript beyond the deadline imposed by the General Secretary.

It is a pleasure to acknowledge the excellent cooperation I have received from each of the contributors as well as from the many Commission members who reported on the progress of their work since the last report. Without this, the task of preparing the Commission 10 report covering such a vast range of subject matter, would have been almost totally impossible.

1. NEW INSTRUMENTS

Solar physicists noted with sadness and a deep sense of loss, the closing (on July 1, 1972) of the Climax Station of the High Altitude Observatory. During its thirty years of continuous service, the station played a major role in advancing the study of solar physics and of solar activity in particular. Observational programs of HAO will continue; in particular, new HAO projects are to begin at Sacramento Peak, the Mauna Loa site in Hawaii, on instrumented aircraft and on the ATM and OSO-1 spacecraft.

An important new solar observatory was dedicated in 1972 at Big Bear, California. The records obtained from the Observatory demonstrate the excellence of the seeing experienced at the site; this is undoubtedly due in large part to its location in the center of a large lake.

On April 1, 1970, solar research previously carried out at the Dominion Observatory, Ottawa, was transferred to the new Astrophysics Branch of the Canadian National Research Council. V. Gaizauskas reports that a new installation – the Ottawa River Solar Observatory – was completed in 1970 and observing equipment is under construction. In operation is a 25 cm, f/40 telescope which, under computer control, is used to obtain filtergrams across Hα in a 0·25 Å bandpass. Construction of a 15 cm vacuum solar refractor is under way.

The U.S. Naval Observatory program on observations and measures of sunspots was continued with the 40-ft photoheliograph through 1971, but was discontinued on January 1, 1972. The Observatory's sunspot data, from 1907 through 1970, is summarized by Harrington and Miranian in U.S. Naval Observatory Circular No. 133, 1971.

An equatorily mounted spar for solar observations is now operational at the Catania Astrophysical Observatory; equipment includes white light and Hα cameras for disk and prominence observations. An optical system for photography of the electron corona at Catania has been designed and built – cf. Kissel *et al.* (1970). At Locarno, the 45-cm telescope has been reconstructed as a vacuum instrument, and the observing instruments interfaced with digital control and data acqui-

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sition system. Extensive digital control systems have also been added at the Solar Tower of the Rome Astrophysical Observatory (cf. deBrase and de Gregorio, *Proc. 11th IAU Colloquium*).

Major emphasis continues to be placed on magnetometry with many groups attempting to develop satisfactory systems for recording the vector field. Tests by Deubner and Göhring (*IAU Symposium* **43**, p. 190) indicate that the basic design of the vector magnetograph of the Fraunhofer Institute appears to be adequate to carry out the intended measurements but that a multichannel capability would be highly desirable (e.g., to allow measures in lines formed at different heights). A Babcock-type magnetograph has accordingly been built for use independently or, in parallel with the vector instrument, to give data at two wavelengths. Data acquisition and control is via a digital computer.

The Heinrich Hertz Institute has also installed a vector magnetograph (of the Irkutsk type) to allow investigations of magnetic structure within active regions. Studies at Potsdam have also clarified the influence of instrumental polarization on magnetograph measures (Jager, 1972).

A polarimeter for measuring the four Stokes parameters in an incident beam has been installed and tested at the Mees Solar Observatory in Hawaii. Initial work has concentrated on the use of the system for broad wavelength band observations; a monochromator is under design to allow studies of the variation of the Stokes vector across a spectral line. The digitally controlled instrument has successfully measured the center-limb variation of polarization, the polarization of the green line corona to 0·4 $R_\odot$, and has shown the existence of linear and circular polarization (in a broad wavelength band) in an active region on the disk (Mickey *et al.*, 1972; Mickey, 1972).

The High Altitude Observatory is constructing a Stokes vector polarimeter also designed to operate at low light levels. This instrument was successfully tested at Sacramento Peak in early 1972 and it is hoped that it will be operational in the winter of 1972–1973.

At the Harvard Radio Astronomy Station Fort Davis, Texas, the frequency range of the dynamic spectrum analyzer was extended from 10–580 MHz to 10–4000 MHz (Maxwell, 1971). This has permitted, for the first time, a detailed study of the spectral characteristics of solar radio bursts in the microwave band. Aspects of bursts under consideration concern microwave pulsations (Maxwell and Fitzwilliam, 1972), and the characteristics of type III bursts throughout the whole spectral range.

An eight element interferometer at 8·6 mm wavelength has been constructed at the Department of Physics, Nagoya University, to monitor solar radio bursts and measure their locations and sizes. The instrument consists of eight 40-cm diam paraboloidal mirrors with Cassegrain feed systems and eight plane mirrors on equatorial mountings. Observations of the Sun with this instrument began in September 1970, using four of the eight antennas. Full use of the equipment started in April 1971.

2. SUNSPOTS

C. Zwaan

2.1. *Sunspot spectroscopy*

a. *Atlases*

Wöhl *et al.* (1970) have produced an atlas of the umbral and the penumbral spectra from 3900 to 8000 Å. Engvold (1972) published umbral spectrograms from 6660 to 6770 Å and tabulated the spectral lines. At Kitt Peak J. Harvey has photographed the sunspot spectrum with a Babinet compensator from 3800 to 9000 Å, and Hall has recorded the umbral spectrum in the atmospheric windows between 1 and 5·2 μ.

b. *Line identifications and abundances*

The line formation and the abundance of Li was studied by Engvold *et al.* (1970), by Maltby (1971a), by Traub and Roesler (1971), and by Stellmacher and Wiehr (1971b). Forbidden Fe I lines support the high Fe abundance (Grevesse and Swings, 1971). Lines of Eu II and La II were investigated by Bachman *et al.* (1970), and lines of Eu, Sm and La by Molnar (1972).

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Hall and Noyes (1972) identified HCl and derived the Cl abundance; the isotope ratio $^{35}Cl/^{37}Cl$ equals the terrestrial ratio. Isotope ratios compatible with terrestrial ratios were also found for Mg (Boyer *et al.*, 1971, Lambert *et al.*, 1971; but compare Branch, 1970); for C (Hall *et al.*, 1972); for Ti (Lambert and Mallia, 1972); and for Ni (Lambert and Mallia, 1971).

Some other molecules identified were CuH (Hauge, 1971), NiH (Lambert and Mallia, 1971; Wöhl, 1971) and CoH (Wöhl, 1971).

The identification of H_2O in the visual and near infrared umbral spectrum is doubtful (see Mallia *et al.*, 1971 and references cited there).

Schadee (1970) and Harvey (1972) presented evidence that the C_2 lines are greatly weakened in the umbra, as predicted by equilibrium calculations; this conflicts with Wöhl (1971, 1972).

2.2. *Sunspot structure, observations and interpretations*

a. *Thermodynamic state, model atmospheres*

The Oslo group (Staveland, 1970) perfected a method of correcting sunspot intensities for stray light using concepts derived from Makita, Zwaan and others, and published corrected umbral continuum intensities from pinhole photometer measurements and from spectrograms – Maltby (1970), Maltby and Staveland (1971), Engvold (1972), Mykland (1973). The correction method, which proved to be correct during the 1970 Mercury transit – Maltby (1971b), yields umbral intensities significantly lower than most earlier measures; Mattig (1971) arrived at the same conclusions. Sunspot intensities in the infrared have been measured by Turon and Léna (1970) and by Coupiac and Koutchmy (1972).

The measured intensities, which refer to large umbrae, are fairly consistent. Stellmacher and Wiehr (1970, 1972) constructed a model atmosphere which explains the continuum intensities, the profiles of some magnetically insensitive lines, and the NaD wings, on the basis of LTE – see also Kneer (1972a). Yun's (1971a) somewhat hotter empirical model fits earlier determinations of continuum intensities and line profiles obtained by Fay *et al.* (1972). Webber (1971), however, could not reproduce observed molecular line strengths from a reasonable model atmosphere and acceptable oscillator strengths.

The infrared spectrum, which is less contaminated by spectral lines, yields excellent criteria for the model atmosphere. It will be of interest to compare the model derived by Noyes from Hall's spectrograms, with models derived from other criteria.

The measurements mentioned above refer to fairly large umbrae; in some cases the observations refer to the darkest core in the umbra. Rossbach and Schröter (1970) concluded from photographs in two wavelength bands that the intensities in the *darkest* part of the umbra show no significant dependence on the spot's area; this conclusion seems to hold even for pores with a diameter down to 3″.

One model atmosphere ($\Delta\theta = 0{\cdot}055$) for the penumbra published earlier by Moe and Maltby was found to explain the mean intensities, averaged over the penumbral fine structure (Maltby and Staveland, 1971; Maltby, 1972) and the equivalent widths of many spectral lines (Schleicher and Schröter, 1971). The penumbral intensities show no correlation with the spot's area either (Maltby, 1972).

No new measurements of the important *Wilson effect* have been reported.

b. *Magnetic field, large-scale features and anomalous polarization*

Review papers by Schröter (1971) and Harvey (1971) refer to magnetic fields in sunspots, among other things. Several papers on sunspot magnetic fields were presented during the *IAU Symposium*, No. 43 in Paris in 1970 (Howard, ed., 1971).

For the variation of the field strength and of the inclination angle across the sunspot radius, Hale's classical model was confirmed, e.g., by Deubner and Göhring (1970) and by Adam (1971). There is still some disagreement on the strength and the inclination of the field near the outer penumbral boundary. The inclination of the field with respect to the line of sight may be overestimated because of instrumental effects (cf. Schröter, 1971).

It has been known for many years that, in umbrae, several spectral lines with a normal triplet splitting, when observed through an analyser for circular polarization, often show the π component slightly shifted in the direction opposite to the transmitted σ component. So the Stokes' parameter V shows a reversal at the line center. Probably the explanation by means of hypothetical small elements with much weaker fields of opposite polarity has to be abandoned. According to Obridko and Demkina (1972), in the regions with opposite polarity both the Doppler width and the line opacity has to be substantially smaller than in the rest of the umbra. Harvey (1971) published one more example of a spectral line without unshifted components which shows no indication for a weak field embedded in the strong field.

Magneto-optical effects may explain the anomalous behaviour of the π component. Until recently it was believed that then the direction of the magnetic field had to change drastically over a few hundred km in height – cf. Schröter (1971) and Harvey (1971) for references. An additional difficulty is that the Stokes' V profile is always inverted, with only one exception reported by Grigorjev and Katz (1972). However, Wittmann (1971), after criticizing computations in fields violating $\operatorname{div} B = 0$, calculated V curves with reversals in the line center from inclined *homogeneous* fields.

Grigorjev and Katz (1972) confirmed the 'cross-over effect' in a particular small region in one penumbra, which they claim to be no instrumental artefact.

In conclusion, proper understanding of anomalies in Zeeman patterns requires proper corrections for instrumental polarization (cf. Adam, 1971) and an adequate theory of line formation.

c. *Fine structure, Evershed flow, and magnetic field strength as functions of height and time*

Krat *et al.* (1972) published some excellent sunspot photographs, with features down to 150 km.

Zwaan and Buurman (1971) found in a dark core in a large umbra virtually no dependence of the measured magnetic field strength on the type of temperature sensitivity of the spectral lines; in an umbral region with some visible fine structure the field strength is lower, particularly in the high-temperature lines. However, Mallia and Petford (1972) recorded some Cr II and Fe II line profiles which they interpret as indications of very strong fields in hot umbral dots.

Apparently there is consensus now that the Evershed flow is stronger in the dark penumbral striae ($v \sim 5$ km s^{-1}) than in the bright striae ($v \sim 0{\cdot}5$ km s^{-1}), e.g., Stellmacher and Wiehr (1971a), Mamadazimov (1972). Sheeley and Bhatnagar (1971) showed Doppler spectroheliograms suggesting that the flow lines are appreciably curved relative to the mean solar surface.

The fact that places where the radial velocity is zero do not coincide with those where the longitudinal component of the magnetic field is zero may be explained by the inhomogeneity of the penumbra. However, both in the dark and bright striae there is a significant magnetic field (Harvey, 1971). There is no agreement on the differences in the magnetic field (in strength and in direction) between the bright and the dark features.

Several authors measured the magnetic field, supposedly at different heights in the atmosphere, by using different lines; see, e.g., Guseynov (1970), Abdussamatov (1971), Kotov (1970, 1971), Kneer (1972b). The quantitative interpretation in terms of gradients of the field strength, the vector field, or the associated electric currents should be regarded with caution for several reasons, such as the temperature fluctuations associated with fine structures – see also Schröter (1971).

Reported changes in the field strength of several hundred gauss in a few hours (Künzel, 1971) should be checked (Schröter, 1971).

Rayrole and Semel (1970) made a critical attempt to determine electric currents, in selected areas, from the tangential component of the magnetic field; the results do not fit a force-free model.

d. *Waves and oscillations*

Beckers and Schultz (1972) observed vertical velocity oscillations in a sunspot. The effect is very pronounced only over a region of 1800 km in one umbra, out of five sunspots investigated. The period changed from 180 s in the umbra to 1000 s at the outer penumbral boundary; this can be quantitatively accounted for if the oscillations are gravity waves or acoustic waves travelling along the magnetic field lines. No correlation with umbral flashes was found.

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Giovanelli (1972) observed, in Hα, vertical oscillations over the umbra. Near the umbral boundary these developed into transverse waves propagating outwards with $v \sim 20 \text{ km s}^{-1}$ and became invisible near the outer penumbral boundary. The umbral oscillations are believed to be gravity waves, and the penumbral waves to be Alfvén waves.

Rayrole (1971) found that in a penumbra the line broadening as a function of the field direction is compatible with motions due to hydro-magnetic waves.

2.3. *Sunspot structure, theoretical aspects*

a. *Quasi-stability models*

Dicke (1970) discussed quasi-steady sunspots and faculae as being due to local surface stress distributions arising in magnetic and velocity fields, which determine the thermodynamic state in the observed layers uniquely.

Yun (1970) improved Deinzer's calculations of magnetohydrostatic sunspot models on the basis of the Schlüter-Temesvary similarity assumption and a simple assumption on the non-radiative energy transport. The internal structure of the spot changes only slightly when an azimuthal component of the magnetic field is included (Yun, 1971b).

Simon and Weiss (1970) constructed magnetohydrostatic models for current-free magnetic fields in pores, neglecting the internal gas pressure. The models give fair agreement with observed fields and the transition between pore and sunspot near a critical flux follows from the models.

As a first step towards three-dimensional sunspot models Jakimiec (1970, 1971) computed the magnetic forces in the observable layers. These were found hardly to influence the vertical stratification in the penumbra.

Gokhale and Zwaan (1972) approached the construction of a three-dimensional decaying sunspot model without assumptions on the non-radiative energy transport by deriving constraints from the observational data. These constraints are consistent with an asymptotic model having a very thin current sheet below the observable layers.

b. *Energy transport and waves*

Zhugzhda (1971) investigated low-frequency convective oscillations in polytropic atmospheres with magnetic fields, and discussed the possibility for these instabilities to occur in sunspots.

Wilson (1971a, b, 1972) discussed the relation between Alfvén waves excited in sunspots, and umbral dots, heating of faculae, solar wind storms and standing waves in flux loops.

Havnes (1970) explored the suggestion that umbral flashes are caused by magneto-acoustic waves, such that Ca II emission is seen during the compressions. The observed features are in general agreement with the suggested mechanism.

2.4. *Sunspots and their surroundings*

a. *Velocity field around sunspots*

Sheeley's discovery of faculae moving away from sunspots has been confirmed (e.g., Vrabec, 1971). Sheeley (1972) also showed that the magnetic elements are carried away over 10000 to 20000 km from the sunspot boundary by a general flow with average velocities $v \sim 0{\cdot}4$ to $0{\cdot}8 \text{ km s}^{-1}$. This flow is not an extension of the Evershed effect, but more like the flow in supergranules. Elements of *both* magnetic polarities are found to be moving away from the spot.

b. *Sunspots as indicators for the magnetic field structure*

Positions of sunspots may be used to indicate the coarse large-scale structure of the magnetic field in an active region. Several authors investigated the occurrence of major flares in connection with changes in the sunspot group, either due to sunspots rapidly diminishing in area (e.g., McKenna-Lawlor, 1970) or to translations or rotations of individual sunspots relative to the group (e.g., Sakurai, 1971, 1972; Miller, 1971).

c. *Sunspots as tracers for large-scale velocity fields*

Along with faculae, sunspots are used to trace large-scale velocity fields, (Weiss (1971), and references given there, Piddington (1971a)). The motions and the development of the individual magnetic elements during the growth and decay of active regions contain information on the related problems in solar physics: the solar rotation, the convection zone and the activity cycle. Eventually the observations may discriminate between the various dynamo models (cf. Weiss, 1971), or alternative models with a magnetic field penetrating deeper than the convective zone (Piddington, 1971b, 1972).

The tilt of the magnetic axis of sunspots is also of interest in the present context. However, the east–west asymmetry in the appearance of sunspots on the disk yields no direct answer. Sawyer and Haurwitz (1972) found that the asymmetry depends strongly on the position of the spot in the plage.

3. SURFACE FIELDS – (NON-SPOT)

R. Howard

Considerable effort in the last few years has gone into the problem of understanding small-scale magnetic fields on the Sun. At the *IAU Symposium*, No. 43 in 1970, a number of contributions were in this area. Both Sawyer (1971) and Smith (1971) showed observations of very small scale magnetic fields – of the order of 1″ with an average flux per element of 3×10^{18} Mx. At times small features were clustered near a large spot of the opposite polarity. Vrabec (1971) provided spectroheliographic evidence that magnetic fields are clumped in small strong-field elements in otherwise field-free regions. Title and Andelin (1971) have observations of very small-scale magnetic fields and very high magnetic gradients on the solar surface. Grigorev and Kuklin (1971) have examined power spectra of surface magnetic fields, and they detect a smooth background which they associate with the supergranular network and a set of higher frequency spikes which they associate with the small-scale distribution of fields. Sheeley (1971a, 1971b) has used the Kitt Peak spectroheliograph to map magnetic fields in the λ3883 CN band and other lines. He finds some evidence for non-filamentary weak magnetic fields. Sheeley and Engvold (1970) have derived a relation between magnetic field strength and continuum brightness.

Studies of the magnetic fields measured in two spectrum lines have set an upper limit of 5% on the flux of weak non-filamentary magnetic fields (Howard and Stenflo, 1972; Stenflo and Frazier, 1972; Frazier and Stenflo, 1972). The lines of force outside sunspots at the photospheric level are predominantly radial to the Sun.

Observations from the Crimean Observatory of simultaneous velocity and magnetic signals in moderately strong magnetic fields have failed to show evidence for short period (< 5 min) oscillations in the magnetic field strength (Severny, 1971). Mount Wilson observations (Tanenbaum *et al.*, 1971) show a clear correlation between 5-min oscillations in magnetic and velocity fields.

Much effort has gone into the study of active region magnetic fields. Zirin (1971) has been successful in identifying magnetic field configurations from chromospheric observations, although the results have aroused some controversy (Frazier, 1972a). Nakagawa *et al.* (1971) have examined Hα filtergrams in detail and conclude that some of the observed features could be interpreted as being the lines of force of an axisymmetric force-free chromospheric magnetic field. Active region field changes in a matter of some hours are observed (Harvey *et al.*, 1971), although they are evolutionary in nature and probably not connected with any flare event. Gopasyuk and Tsap (1971) have shown that the point of maximum magnetic field strength in an active region corresponds with the minimum of vertical velocity.

On the general subject of large-scale magnetic fields on the Sun, several topics have attracted interest. The remarkable correlation of the magnetic field of the Sun, as measured in integrated light, with the interplanetary magnetic field measured at the Earth (Severny *et al.*, 1970) has been examined by Scherrer *et al.* (1972) by comparing various areas of the solar disk with the interplanetary field. For the interval studied the best correlation was for an area of one quarter of the solar disk. It appears that the interplanetary magnetic field near the Earth has its roots over a large area

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of the solar surface. The sector pattern of solar magnetic fields (Wilcox, 1971), and its relation to the more obvious solar patterns of active region magnetic fields, remain a mystery. Stenflo (1972) examined Mount Wilson digital magnetic data for the interval 1959–1970, and presented synoptic charts demonstrating the evolution of the large-scale field distribution.

The structure of the large-scale magnetic fields in the convection zone has been investigated theoretically by Yoshimura (1971), who showed that the convection is responsible for the fundamental characteristics of the complexes of activity and the unipolar magnetic regions. Yoshimura explains the different rotation rates of spots and the photosphere with phase shifts between the magnetic convective patterns.

Altschuler *et al.* (1971) expanded the digitized Mount Wilson magnetic data in surface harmonics and found that for the interval 1959–1962, the dominant harmonic was that of a dipole lying in the plane of the equator while from 1962–1964 a four-poled sector structure became dominant. Newkirk and Altschuler (1970) have calculated the current-free field distribution in the corona starting from the observed field distribution in the photosphere. An atlas of coronal magnetic maps made with this technique has been published (Newkirk *et al.*, 1972) covering the interval August 1959 to June 1970.

Stenflo (1970) examined many of the plates used by Hale's group to determine the general magnetic field of the Sun in the year 1914. He concluded that the original measurements were in error, and that if there was a general field it was less than 5 G. The polar magnetic fields of the Sun have been weak and variable for several years, but there is evidence that at last they have changed sign (Howard, 1972b). The north polar field appears to have changed in sign in the summer of 1971, and the south polar field in the spring of 1972. The fields at the poles of the Sun are still quite weak.

The form of large-scale magnetic fields in the corona has been inferred from locations of radio burst sources (Daigne *et al.*, 1971), and the expansion of a magnetic arch or loop has been followed by a study of moving type IV bursts (Smerd and Dulk, 1971).

Krause and Rädler (1971) have proposed a new dynamo theory of the solar activity cycle, utilizing a 'mean field magnetohydrodynamics', and emphasizing the induced effect of hydromagnetic turbulence. Nakagawa (1971) has constructed a non-axisymmetric model of solar activity, and suggested that the observed surface activity is secondary in nature to the cycle-type of magnetic variations that occur in the interior of the Sun.

4. SOLAR FLARES

Z. Švestka

In the past few years important progress in the study of flares has been made in the interpretation of soft X-ray flare spectra (now pretty well understood); in our knowledge of the EUV bursts and of the flare EUV spectrum variations; in our understanding of the type III radio bursts which could be safely related to electron streams directly recorded in space; and in our understanding of the flare white-light emission as being due to a flux of particles accelerated during the flare flash phase. These are the highlights; of course, many other studies have been made in other fields of flare research as well, and we shall try to pick out the most important of them in the following report.

4.1. *Flare patrol*

The monthly bulletin *Solar and Geophysical Data* (edited by NOAA, Boulder, under the supervision of J. Virginia Lincoln), has continued to expand its coverage, each year including more data on flare-associated phenomena on the Sun and in space. However, the Hα flare patrol still suffers inhomogeneity in data interpretation (Falciani and Rigutti, 1972). In order to improve it, some efforts have been made by reevaluating older observations (Dodson and Hedeman, 1972), but this certainly does not remove all the problems. One cannot escape the feeling that the center of the Hα line is not the best choice for flare patrol photographs. The much rarer observations in the wings of Hα (Janssens and White, 1970) clearly show how much more information can be obtained from wavelength sweep records than from photographs in the Hα line center. In addition, the Hα importance is not the optimum index of the whole flare phenomenon. An effort to improve this situation has been made by Dodson and Hedeman (1971) who propose a new classification, the so-called comprehensive flare index (CFI), which takes into account the Hα importance, X-ray radiation, as well as microwave and metric radio flux.

4.2. *Flares in relation to magnetic fields*

Altschuler and Newkirk's (1969) method for computing the three-dimensional magnetic field configuration from photospheric magnetic maps cannot be used for configurations leading to flares due to the existence of electric currents in the flare regions. Thus, all our knowledge of flare-associated magnetic configurations is still based on two-dimensional, and poorly resolved, photospheric magnetic data. Some efforts have been made to deduce the magnetic field topology from observations of large flares and the coronal structure on the limb (Krivsky, 1970; Bumba *et al.*, 1972), but this never yields a unique interpretation of the data – for the magnetic structure in loop prominences see Section 4.10.

Dodson and Hedeman (1970) have shown that 7% of all flares of importance $\geqslant 2$ occurred in plages with only small or no spots, mostly in old decaying regions. This indicates that flares do not need strong magnetic fields for their origin. As H. Schröter pointed out in a discussion, it may be particularly interesting to study the magnetic field changes associated with flares of this type, since a large fraction of such a weak field must disappear if the flare energy is indeed derived from the magnetic field.

The problem of magnetic field changes during flares has still not been solved. Zvereva and Severny (1970) and Mayfield (1971) found a decrease in the magnetic flux, energy, and magnetic field gradient after large flares, while in smaller flares the results are still negative (Wiehr, 1972; Janssens, 1972b). The Meudon group (Ribes, 1969; Michard, 1971) found changes in the field also in association with small flares, but only as a characteristic feature of flare-producing active regions, not as the consequence of the flare occurrence itself. Rust (1972) has found that the magnetic field changes are confined to very small areas with $\sim 10''$ diam. Thus, much better resolution is needed to clarify this difficult problem.

Zvereva and Severny (1970) have confirmed that the field pattern recovers to its preflare state fairly soon after the flare occurrence, which is important from the point of view of homologous flares. A striking example of flare homology has been demonstrated by White and Janssens (1970) who observed two large homologous flares separated by 54 hr in time.

Martres *et al.* (1971) have confirmed Severny's earlier result that flares tend to occur in places where the line-of-sight component of the photospheric velocity is zero, and intersection of null lines of field and velocity are the most likely positions for initial brightenings.

Yoshimura *et al.* (1971) claim to have observed mass motions of the order of $2\ \mathrm{km\ s^{-1}}$ in the photosphere during a flare. The size of the moving regions is of the order of 10^4 km; the velocities are larger in the weaker lines and reach their maximum value in the initial phase of the flare. K. Tanaka (unpublished) has found that a flare tends to occur when the intensity oscillations in the plage (with periods ~ 270 s in elements of 350–700 km in size) become coherent over large areas of $\geqslant 10^5$ km.

Hagen and Neidig (1971) have confirmed that flares which penetrate above sunspots are particularly strong sources of microwave radio emission, by finding that the microwave spectrum of such flares becomes harder.

4.3. *The chromospheric flare*

Little progress has been made in the interpretation of chromospheric flare spectra, the present state of our knowledge can be found in a review by Švestka (1972a). In another paper, Švestka (1972b) has discussed the influence of the filamentary structure of flares upon the analysis of the spectrum, and has pointed out several indications that the flare radiation is diluted, i.e., that the flare emission does not completely cover the area analyzed. This leads to serious errors in the interpretations of the spectrum if the flare elements are not optically thin in the spectral region studied. Semel and Soru-Escaut (1971) have shown that one can explain the hydrogen-line profiles by a set of elements with greatly different values of electron density and that the value obtained for a homogeneous set of elements need not be the actual 'mean' value of the electron density in the flare. They also give independent evidence that the Balmer lines in flares are broadened by the Stark effect.

New estimates of electron density in several flares have been made by Kurochka (1970) and his results are generally in agreement with values obtained previously by others even though he has used Minaeva's formulae for the electron damping (Kurochka, 1969) instead of those of Griem. Stepanyan (1969) obtained the interesting result that $n_e \leqslant 7 \times 10^{12}$ cm^{-3} in one rather unimportant knot of the large flare of 2 September, 1966, located above a penumbra. This indicates that the electron density in some parts of major flares (and consequently also in small flares) can be lower than 10^{13} cm^{-3} even in the low chromosphere. However, it appears that this low electron density is not due to the fact that the emitting knot was above a penumbra; Machado and Seibold (1973) have studied many cases of spot-covering flares and they get $n_e \sim 10^{13}$ cm^{-3} above spots. However, in agreement with Athay and Skumanich (1968), they find an extremely small optical thickness of the flare above spots; probably only narrow 'tongues' of the flare emission penetrate above the spots and this leads to an absurdly small thickness of the flare if it is assumed to be homogeneous.

Kurochka and Maslennikova (1970) have given the corrected Inglis-Teller formula for computing the electron densities in limb flares. When summarizing all the limb-flare measurements available, one finds a density decrease from 10^{13} cm^{-3} in the chromosphere to 10^{10}–10^{11} cm^{-3} at an altitude of about 20000 km (Švestka, 1972a). This, of course, still refers to the cold 'chromospheric' flare, i.e., to the material visible in Hα.

Cowley and Marlborough (1969) found a strengthening of the Fe I λ4063 line in a flare spectrum, which may be explained as being due to a selective excitation of the λ3969.3 line of the same multiplet by the strong Ca II H-line emission. If this is true, then the electron temperature must be substantially lower than 10000K, which is in agreement with other results. The filamentary flare structure has again been confirmed by Kurochka (1970), and Semel and Soru-Escaut (1971). A method for deducing the total number of hydrogen atoms in a flare by means of fairly simple intensity measurements in the gaps between successive Lyman lines has been suggested by De Feiter and Švestka (1972).

4.4. *The white-light flare*

The thread-like features observed in the continuum emission of some flares – but often also in plages without any flare appearance (Dolginova and Korchak, 1968) – probably have a similar origin to the moustaches (Bruzek, 1972b), or they may be interpreted as granular inhomogeneities representing small areas of rising overheated gas (Gurtovenko, 1967). The white-light flares, however, are now believed to be a clear manifestation of the acceleration process in the flare region, since they coincide in time with the hard X-ray, EUV, and impulsive microwave bursts (Švestka, 1970; Fortini and Torelli, 1970; McIntosh and Donnelly, 1972).

The first series of good photographs of a white-light flare in the central part of the disk, obtained by De Mastus and Stover on 23 May, 1967, instigated several papers on its interpretation. Švestka (1970) explained the white-light emission by >20 MeV protons accelerated simultaneously with non-relativistic electrons which produced the hard X-ray burst. Through bombardment of the photosphere by protons of this energy, the temperature in the uppermost photospheric level was increased, giving rise to the short-lived continuum enhancement. This process needs a very hard proton spectrum, with $\gamma \simeq 2$ in the power law, but this actually has been observed by Lanzerotti (1969) in the initial phase of this flare event. Najita and Orrall (1970) independently gave the same explanation, but they suppose that relativistic electrons also participate.

In contradiction to this, Hudson (1972) supposes that non-relativistic electrons deposit their energy in the chromosphere, at a height between 700 and 1500 km and that the white light emission is a direct consequence. The theory was based on the so-called thick-target theory – cf. Brown (1971) – however it is not yet clear whether the thin-target or the thick-target model better interprets the

X-ray observations. Apart from this uncertainty, according to Korchak (1972), Hudson has overestimated the ionization losses (and thus the energy output) by more than one order of magnitude and thus the number of electrons he needs does not seem to be realistic. Korchak (1972) suggests that a highly inhomogeneous structure of the flare might possibly improve the theory. In contrast with Hudson's mechanism, Machado (1971) has presented strong evidence that at least in one case (Grossi Gallegos *et al.*, 1971) the white-light emission was produced in the photosphere, since different Fraunhofer lines were influenced in a different way by the continuum, in accordance with their excitation potential and oscillator strength. This was an event close to the limb and perhaps we are dealing with a different phenomenon than for the disk.

4.5. *Soft X-rays*

Detailed correlations of soft X-ray bursts with other kinds of flare emission have been made by Thomas and Teske (1971), and by Drake (1971). Essentially all flares, and about 75% of subflares, are accompanied by soft X-ray bursts while for about 70% of X-ray bursts one can find an associated flare-like phenomenon. Some of the non-flare X-ray increases have been identified with surge-like spikes on the solar limb (Teske, 1971a); Brinkman and Shaw, 1972), or with gradual non-flare temperature variations in the active region (Krieger *et al.*, 1971).

The continuous and line spectrum in the X-ray region was computed theoretically by Culhane (1969) and, later, by Landini and Monsignori Fossi (1970), Tucker and Koren (1971), and Mewe (1972b). A simplified formula for the continuous emission has been given by Culhane and Acton (1970). For the continuum all these computations take into account the free-free and free-bound emission and Tucker and Koren also consider the two-photon decay of the $2S$ states of hydrogen-like and helium-like ions which is important below 5×10^6 K. Tomblin (1972) has drawn attention to the fact that Compton backscattering, neglected in these computations, can also contribute significantly below 2 Å. The line emission results from downward radiative transitions in highly ionized, almost completely stripped ions, following the population of an excited level either by recombination or by inelastic collisions. In some spectral lines also dielectronic recombination can contribute (Gabriel and Jordan, 1969a; Doschek *et al.*, 1971a).

After the first identifications of the X-ray lines in the flare spectra by Gabriel and Jordan (1969a, b) as the Lyman series in hydrogen-like, and transitions to the ground ($1s^2\ {}^1S$) term in helium-like ions, the vast majority of the X-ray lines could be identified by using the improved spectral resolution aboard OSO-5 (Neupert and Swartz, 1970; Neupert, 1971), OSO-6 (Doschek *et al.*, 1971a, 1972), and O V-1-17 (Walker and Rugge, 1970, 1971). Satellite lines corresponding to innershell transitions in Li-like, Be-like, and possibly less stripped ions also could be identified. However, as Tomblin (1972) has pointed out, since Compton backscattering produces a red line shift, some of these lines, being in the long-wave wing of the helium-like lines, might be misinterpreted, or at least their contribution may be overestimated.

The electron temperature in the X-ray flare can be determined from the energy distribution in the observed continuum (Meekins *et al.*, 1970), from a comparison of the X-ray flux in channels of different energies (Kahler *et al.*, 1970; Culhane *et al.*, 1970; Horan, 1971; Blocker *et al.*, 1971; Krivský *et al.*, 1972; Landini *et al.*, 1973), from the relative intensity of different lines in the X-ray spectrum (Meekins *et al.*, 1970), and from the line occurrence (Walker and Rugge, 1969; Neupert, 1971). The X-ray flare is found to be very inhomogeneous in temperature, with local temperature variations at least covering the range of 5×10^6–2×10^7 K. A filamentary structure of the X-ray region has been also directly confirmed by measurements (Beigman *et al.*, 1969b; Thomas and Neupert, 1970; Vasiljev *et al.*, 1971).

The comparison of X-ray flux in different channels also yields the time variation of temperature and emission measure. Whilst T_e peaks sharply a few minutes after the flare onset, and declines after that, the emission measure continues to grow and reaches a maximum much later in the flare development. According to Horan (1971) the time sequence of maxima always follows the order temperature, X-ray (and Hα) flux, emission measure. The peak temperature always exceeds 10^7 K

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and mostly reaches values 2 to 4 times higher. The characteristic value of the maximum (and fairly constant) emission measure is of the order of 10^{49} cm^{-3} – Kahler *et al.* (1970), Horan (1971), Blocker *et al.* (1971), and Krivský *et al.* (1972), while Culhane *et al.* (1970), and Landini *et al.* (1973) give a value one order of magnitude lower.

According to Tomblin (1972) the emission measure and temperature may be overestimated if one uses wavelengths below 2 Å and neglects the effect of Compton backscattering in this spectral region. This region is difficult to interpret also because of the extension of the impulsive non-thermal X-ray emission up to about 4 Å (Kahler and Kreplin, 1971), with a great time-variation of the Fe xxv line near 1·9 Å (Culhane *et al.*, 1969).

A new approach has been tried by Herring and Craig (1973) who have assumed that the X-ray source consists of two components, each with a characteristic temperature and emission measure. The peak values found are $T_e = 2{\cdot}4 \times 10^7$ K, $N_e^2 V = 5\text{–}8 \times 10^{48}$ cm^{-3}, and $T_e = 3 \times 10^6$ K, $n_e^2 V = 10^{51}\text{–}10^{52}$ cm^{-3}, respectively; the emission measure in the colder component is astonishingly high. Acton *et al.* (1972a) have shown that a good fit with the flux observed in O vii and Ne ix lines, and in the 5 keV continuum emission, can only be found if the temperature and emission measure are different for all three species. The cooling of the X-ray source (Culhane *et al.*, 1970) should be predominantly due to collisions with ions at lower temperature if n_e is of the order of 10^9 cm^{-3}, due to conduction if n_e is close to 10^{10} cm^{-3}, while radiative cooling should be the main process if n_e approaches or exceeds 10^{11} cm^{-3}.

Gabriel and Jordan (1969b, 1970) have shown that the relative intensities of the intercombination and forbidden lines of the helium-like ions are density dependent so that one might use them for determination of the electron density in the X-ray flare. The measurements lead to extremely high values of $10^{13}\text{–}10^{14}$ cm^{-3} (Neupert, 1971) however they are most probably not real, due to a neglected dependence on atomic number (Walker and Rugge, 1970; Rugge and Walker, 1971; Mewe, 1972a) and, especially, on temperature (Blumenthal *et al.*, 1972).

An extensive review on the soft X-ray flare emission has been prepared by Doschek (1971).

4.6. *Hard X-ray bursts*

Kane (1969) has shown that some flares do, others do not, exhibit a hard X-ray component. A detailed analysis of 13 events in which the hard burst was present, associated mostly with subflares, has been performed by Kane and Anderson (1970). The hard X-ray maximum occurs 0·5–3·0 min before the flare maximum in the Hα light, the *e*-folding rise times are 2–5 s and decay times 3–10 s at 40 keV. These times decrease with increasing X-ray energy. The best fit to the X-ray spectrum is a power-law form with $2{\cdot}4 < \gamma < 5{\cdot}5$ in the range $10 < E \leqslant 70$ keV (Kane, 1971). The hardest spectrum is obtained at the time of the peak flux. This impulsive X-ray component extends in energy downwards as far as the range between 3 and 10 keV (Kahler and Kreplin, 1971).

Using a balloon-borne X-ray collimator, Takakura *et al.* (1971) could give a limit to the size of the source of a hard X-ray burst to less than 1′. This agrees with the size of the white-light flare emission – which should have a common origin (Švestka, 1970) – as well as with interferometric measurements of impulsive microwave bursts (Enomé *et al.*, 1969). De Jager (1967) and Vorpahl and Zirin (1970) believe that they have identified the hard X-ray burst with small flare areas which brightened strikingly in Hα for the observed period of the burst.

Milkey (1971) and Chubb (1972) have pointed out that all X-ray emission from the Sun is fully interpretable as thermal plasma emission provided that one assumes sets of hot plasmas at different temperatures in the flare region. However, the non-thermal nature of hard X-ray bursts appears to have been generally accepted, mainly for the following reasons: The energy spectra follow a power law (Kane, 1969, 1971; Frost and Dennis, 1971). This is easy to explain if the non-thermal electrons also have a power-law energy distribution (Kane and Anderson, 1970; Lin and Hudson, 1971). The very rapid rise-time and the extremely short duration of the X-ray spike also favor a non-thermal origin. Further support can be found in the close correlation of the hard X-rays with impulsive microwave bursts (which are of non-thermal origin), with white-light flares (which are produced by directed streams of particles) and with the occurrence of particle fluxes in space which are believed to be produced (as non-relativistic electrons are certainly produced) during the phase when the hard X-ray burst occurs. Further arguments have been given by Kahler (1971). Finally, a thermal interpretation cannot explain the occurrence of polarization in the initial phases of several flare-associated >10 keV X-ray bursts, observed by Tindo *et al.* (1970, 1972b). According to Haug (1972) the most pronounced polarization should be observed between 10 and 50 keV.

Ohki (1969) and Pinter (1969) studied the longitudinal distribution of X-ray bursts on the solar disk. Astonishingly enough they obtained quite different results from exactly the same set of events. According to Elwert and Haug (1971) the most intense emission above 10 keV should come from flares situated between the center and the limb of the Sun, provided that the electrons move predominantly parallel to the surface and to the equator. With increasing energy the maximum should shift towards the limb. Shaw (1972) finds a maximum emission in the center of the disk for 10 keV X-rays, a broadening of the peak with increasing energy and a splitting into two peaks at about 40° for energies above 40 keV. However, as soon as the electron paths are not parallel to the surface, the maximum is brought towards the limb. A maximum near the limb has been predicted also by Brown (1972) from the thick-target model of the bremsstrahlung. Thus, as Korchak (1971) skeptically concludes, without a better knowledge about the electron trajectories we can get essentially any result we like.

Since synchrotron radiation needs many more relativistic electrons than are available in the flare region, and the Compton effect may be effective only in regions with ion density lower than 10^8 cm^{-3} (Korchak, 1971), bremsstrahlung have been generally accepted as the source of the hard X-ray bursts (Takakura, 1969; Holt and Ramaty, 1969; Kane and Anderson, 1970; Lin and Hudson, 1971; Cheng, 1972). However, as Brown (1971) has pointed out, one must bear in mind that the theory greatly simplifies the problem by ignoring the fact that the ions and electrons are spatially non-uniform in the emitting region. The non-thermal emission measure in hard X-ray bursts has been found to exceed 5×10^{46} for >10 keV (Kane and Anderson, 1970) and to be less than 6×10^{45} for >20 keV electrons (Takakura, 1969; Lin and Hudson, 1971).

Still open is the question of whether the acceleration process is accomplished at the time of the burst maximum – which implies an impulsive acceleration (Takakura, 1969; Holt and Ramaty, 1969) – or whether the acceleration mechanism continues during the whole lifetime of the burst (Kane and Anderson, 1970; Lin and Hudson, 1971; Kane and Lin, 1972). This has serious consequences for the deduced source spectrum (Brown, 1971). In the case of impulsive acceleration one can deduce the gas density (3×10^9 cm^{-3}) from the decay time as well as the total number of electrons, which is found to be $N_e(>10 \text{ keV}) \simeq 10^{35}$ (Kane and Anderson, 1970), and $N_e(>20 \text{ keV}) = 3 \times 10^{34}$–$6 \times 10^{35}$ (Takakura, 1969, and Lin and Hudson, 1971). These values are obtained if the escape of electrons is improbable; this appears to be confirmed by Lin and Hudson (1971) and by Kane and Lin (1972) who find that less than 1% of the accelerated electrons escape. On the other hand, if the model of continuous acceleration is adopted, it is found that the gas density must exceed 10^{11} cm^{-3}. Thus, in a word, impulsive acceleration implies the thin-target and the continuous acceleration the thick-target model of X-ray production (Brown, 1972). The thick-target theory seems to be gaining support; Lin (1972) has pointed out that, if the thin-traget model were correct, many more than 1% of the electrons should have to escape into space.

4.7. EUV *bursts*

Great progress has been achieved in the study of the EUV radiation (200–1350 Å) from flares. Observations in this spectral range were almost completely lacking prior to 1969, however since then many EUV bursts have been observed either directly from satellites (Hall and Hinteregger, 1969; Hinteregger and Hall, 1969; Bruns *et al.*, 1970; Hall, 1971; Wood *et al.*, 1972) or though their ionospheric effects (Sudden Frequency Deviation, Donnelly, 1969, 1971; Kane and Donnelly, 1971). Once again we find two components of bursts, as in the X-ray region, one of a quasi-thermal,

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gradual, character and the other being non-thermal and impulsive (Castelli and Richards, 1971; Wood and Noyes, 1972; Kelly and Rense, 1972).

The non-thermal burst coincides in time with the hard X-ray and impulsive microwave bursts, often even in detailed time structure (Parks and Winckler, 1971), as well as with the white-light flare emission (McIntosh and Donnelly, 1972). Its most common duration is 3–5 min, according to Donnelly, and 7 min according to Hall. The enhanced emission lines range from such highly ionized species as Si XII and Fe XVI down to neutral hydrogen and oxygen. According to Hall and Hinteregger (1969), Hall (1971) the highly ionized coronal lines peak later than the low-ionization transition-region lines, which points to the proximity of the transition region to the seat of the flare. According to Donnelly (1971) the EUV burst appears to be associated with small impulsive portions of the Hα flare that are very bright and usually located near the edge of sunspots; this coincides well with the positions of white-light flare patches in the rare events when these are observed (Švestka, 1970; McIntosh and Donnelly, 1972).

Most authors agree that the EUV burst is produced through heating of the solar atmosphere by collisional losses of the accelerated particles (Švestka, 1970; Najita and Orrall, 1970; Kane and Donnelly, 1971; Hudson, 1972). On this assumption Wood and Noyes (1972) have computed values of the emission measure between 5×10^{44} and 3×10^{47}, with the minimum values corresponding to a temperature range between 10^5 to 5×10^5 K (transition layer) and growing both with increasing and decreasing temperature.

According to Wood *et al.* (1972) there is a significant number of weak EUV events which are not accompanied by any detectable emission in any other spectral region. This suggests that EUV observations may be the most sensitive indicator of instabilities in the solar atmosphere.

4.8. *Microwave bursts*

Hudson and Ohki (1972) and Shimabukuro (1972) have confirmed the thermal bremsstrahlung origin of the gradual microwave bursts, as was proposed many years ago by Kawabata. According to Hudson and Ohki the time development of a gradual microwave burst follows that of the emission measure deduced from soft X-rays, which gives support to the thermal model of this type of radio emission. For other bursts, Shimabukuro has found the radio emission-measure of the order of 10^{49} cm^{-3}, in agreement with the X-ray values, but the temperatures found are a factor 2 to 8 lower than those deduced from the soft X-ray bursts.

On the other hand, there seems to be no doubt that the *impulsive* microwave bursts are produced by gyro-synchrotron radiation, even when one encounters the disappointing discrepancy in the number of electrons deduced from the non-thermal X-ray, and microwave bursts, respectively (Takakura, 1969). In order to explain this, Takakura supposes that the volumes and locations of these two kinds of emission are not identical, but it is then difficult to understand the great similarity between the X-ray and radio enhancements. Holt and Ramaty's (1969) explanation, that the radio emission is suppressed by gyro-synchrotron reabsorption, has been questioned by Takakura and Scalise (1970) and by Enomé (1971) so that the puzzling discrepancy remains.

In several sources of microwave bursts Tanaka and Enomé (1970) confirmed the double structure of the emission, with the magnetic polarity reversed. Several authors (Kakinuma *et al.*, 1969; Scalise, 1970; Croom and Powell, 1971) have tried to determine the center-limb variation of the microwave burst intensity, but the results are contradictory. Theoretically, according to Takakura and Scalise (1970), one should expect a limb decrease at 1 GHz and a limb increase at higher frequencies.

Croom (1971) has shown that the maximum flux of the IV μ burst shifts to higher frequencies for radio events associated with particle emission in space. A similar shift to higher frequency is found by Hagen and Neidig (1971) for events in which the Hα flare emission penetrates above sunspots. Sakurai (1972) claims that the peak flux of > 10 MeV protons statistically increases with the peak flux intensity of the IV μ bursts, which would indicate that solar protons are accelerated simultaneously with the mildly relativistic electrons producing the burst.

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4.9. *Type III bursts*

Observations of type III bursts have been extended to frequencies below 50 kHz, which corresponds to distances from the Sun close to the orbit of the Earth (Dunckel *et al.*, 1972). There is evidence for a rather constant velocity through most or all of the burst's travel in space (Fainberg and Stone, 1970). While the burst duration is a second or less at frequencies above 200 MHz, with minimum duration of $\sim 0{\cdot}2$ s (Elgaroy and Lyngstad, 1972), it increases to tens of minutes below 100 kHz. Alvarez *et al.* (1972) have succeeded in associating many of these deepspace type III bursts with direct records of >40 keV electrons in space.

This association seems to settle definitely the problem of whether type III bursts in the solar corona are produced by electrons or protons. Due to difficulties in stabilizing an electron stream, several authors – e.g., D. F. Smith (1970) – have proposed protons as the propagating agents. Since this is obviously not true, one must search for stabilizing mechanisms for the streams of electrons, which has been done by Melrose (1970) and very extensively by D. F. Smith (1972). The difficulties in the propagation along neutral sheets deep in space, suggested by McLean (1970), have been discussed by D. F. Smith and Pneuman (1972).

Kuiper and Pasachoff (1973) have studied type III bursts in a selected active region and find that more than one half of them can be associated with some sort of Hα activity. Generally, however, only strong type III bursts are associated with flares, X-rays, and microwave bursts, the associated flares being usually very small (Chin *et al.*, 1971; Kahler, 1972). In particular, essentially all type III's which produce observable streams of electrons in space, are flare-associated (Lin, 1970a, b). Most of them also produce an impulsive hard X-ray burst of short duration (Kane, 1973) and a microwave burst, but astonishingly enough, Kane and Lin (1971) did observe 19 events in which no hard X-ray component could be detected and yet electrons were recorded in space.

Some of the electron streams are bent in the solar corona, usually at frequencies corresponding to heights lower than one solar radius (Fokker, 1970), thus producing the well-known, but rather rare, U-bursts. Stone and Fainberg (1972), however, observed one event when the U-burst bent at more than 20 solar radii. They suggest that such a 'high' U-burst follows a magnetic bottle, which is to be understood as the remnant of an earlier flare, which gave rise to heated coronal plasma expanded high into space and confined by a magnetic field. Evidence for the existence of such magnetic bottles has been derived (Schatten, 1970) from Levy *et al.* (1969) measurements of Faraday rotation during the occultation of Pioneer 6 by the solar corona. However, by using the Culgoora radio-heliograph, Labrum and Stewart (1970) have observed that the two branches of a U-burst are produced in different active regions. This indicates that the U-bursts appear when there is a magnetic connection between two different centers of activity (Fokker, 1971).

4.10. *Flare-associated optical phenomena*

Bruzek and De Mastus (1970) have found that motions preceding flares, which are often observed as the pre-flare activation of a filament, can also be detected in movies taken in the green coronal line, in the form of expanding coronal arches. Other transient and probably flare-associated coronal events have been described by De Mastus and Wagner (1972) and by Hansen *et al.* (1972).

S. Smith and K. Harvey (1971) have carried out a detailed study of the visible flare-associated waves and of the post-flare filament activations produced by these waves. From filament activations, they have found wave propagation velocities between 400 and 2200 km s^{-1}, with a mean of 880 km s^{-1}, and from 440 to 1100 km s^{-1}, with a mean of 600 km s^{-1}, from the visible wave fronts. The travelling wave fronts are usually semicircular, extending across a sector of 60 to 120°. Even though the extrapolation in time is difficult, Smith and Harvey believe they have proved that the waves originate during the flash phase of the flare.

Kai (1970) has found a good time correlation of a flare wave with a type II burst, and Tousey and Brueckner (1972) have succeeded in correlating a coronal disturbance on the limb with a type II. However, a statistical correlation of type II bursts with flare waves does not give convincing results (S. Smith and K. Harvey, 1971).

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While further developing his own theory, Uchida (1971) has made an extensive ray-tracing calculation for hydromagnetic waves propagating in the corona, using realistic coronal models of density and magnetic field (Uchida *et al.*, 1973).

4.11. *Flare-associated particle events*

A catalog of Solar Events for the years 1955–1969 is being prepared by the IUCSTP Working Group 2, with participation of scientists from France, Germany, Japan, U.S.A., and U.S.S.R. The Catalogue consists of a list of particle events, a list of associated flares (when known), and a list of active regions in which these flares occurred, with a fairly detailed description of all these phenomena. The Catalogue represents an effort to provide a much needed overall picture of the energetic solar particle situation. It will make clear the existence of a large number of currently unsolved problem cases and will put into perspective the relatively small number of great (but in some ways 'easy') events that have dominated the literature.

When trying to associate a proton event with a flare, one should be aware of the fact that about 25% of all proton events should be produced by invisible flares behind the western solar limb (Fritzová and Švestka, 1971). Particle storage (Elliot, 1972) can also play a very significant role at lower energies; according to Simnett and Holt (1971) <30 MeV protons were stored in an active region in July 1968 for at least 5 days. McCracken and Rao (1970) arrived at shorter times of trapping: less than 1 hr for >10 MeV protons, and many hours for proton energies close to and below 1 MeV. Another complication may arise from anomalous propagation of accelerated particles in the solar corona, according to Fisk and Schatten (1972) along very thin current sheets separating discontinuous field structures in the corona. Palmer and Smerd (1972) have discussed the highly anomalous particle event of 30 March 1969, which gave rise to deployment of cosmic radiation over 360° long. in interplanetary space and in which low energy protons reached maximum intensity earlier than those of higher energies (McCracken and Rao, 1970). At the Culgoora radioheliograph the extent of the 80 MHz emission in this event was the largest so far recorded (Smerd, 1970).

In the cosmic-ray flare of 28 January 1967, Heristchi and Trottet (1971) have found an upper cutoff in the energy at $4{\cdot}3 \pm 0{\cdot}5$ GeV. The reality of this cutoff is supported by the fact that its value was constant during the whole duration of the GLE event.

Whilst Bertsch *et al.* (1972) confirm the earlier results that the element abundances in flare-associated particle streams are very much the same as in the photosphere, Mogro-Campero and Simpson (1971) have found increased abundances of all nuclei with $Z \geqslant 13$, which resembles the abundances deduced from galactic cosmic rays. A still puzzling problem is the increased helium content in the plasma behind flare-associated interplanetary shockwaves, this has been observed by many authors in the past and discussed in detail by Hirshberg *et al.* (1970, 1971, 1972). So far there are 12 well-identified cases of $>15\%$ helium enhancements associated with major solar flares. In discrete particle events it is difficult to deduce the helium abundance due to the striking variation of the α/P ratio with time (Lanzerotti and McLennan, 1971; Sakurai, 1971). Lanzerotti (unpublished) has found that the α/P ratio increases with decreasing energy per nucleon and a very rough extrapolation might lead to the high helium content observed for low-energy particles which travel behind the shock. By comparing the helium to medium Z nuclei ratio from particle measurements with the proton to medium Z nuclei ratio from spectroscopic data one gets a proton-to-helium ratio of 16 ± 2 (Bertsch *et al.*, 1972).

During the past three years great attention has been paid to relativistic electrons from flares (Sullivan, 1970; Datlowe, 1971; Simnett, 1972a; Dilworth *et al.*, 1972). The measurements have been reviewed by Simnett (1972b). The relativistic electrons generally accompany all strong proton events, but the flux of relativistic electrons is only 10^{-2}–10^{-5} that of protons of the same energy (Datlowe, 1971). A serious problem is raised when the time-delays of the relativistic electrons are considered (Simnett, 1971). Whilst the theoretical delay should be 4 min, the actual delay times are tens of minutes. It remains to be decided whether this increased delay is due to a later acceleration, storage near the Sun, or simply to the great reduction of the electron flux (probably a consequence of heavy synchrotron losses in the solar atmosphere).

Non-relativistic electrons have been discussed in detail by Lin (1970a, b), Anderson (1972) and Anderson *et al.* (1970). Their relation to flares and type III bursts has been already discussed in Section 4·9. The total number of >40 keV electrons in the electron stream in space can be estimated as 10^{32}–10^{33} (Lin and Hudson, 1971; Alvarez *et al.*, 1972), which does not exceed the number needed for a type III burst ($\lesssim 10^{34}$ electrons with energy >22 keV according to Kane (1973)).

4.12. *Neutron and γ-ray emission from flares*

Under the assumption that the white-light flare emission is produced by a bombardment of the photosphere by high-energy protons, Švestka (1971) has computed the neutron flux originating as a consequence of this process. He has found that the neutron flux should be observable at the Earth very early in the flare event if the proton energy spectrum is hard enough. De Feiter (1971) repeated the same consideration for γ-rays and arrived at essentially the same result.

So far all the efforts to record neutrons from the Sun have been negative (Chupp, 1971, review; Cortelessa *et al.*, 1971; Eyles *et al.*, 1972). This may be due either to the fact that the theory of neutron production is incorrect (Kirsch, 1973), or simply because the measurements have never been carried out at the proper time. However, Chupp *et al.* (1972) did succeed in recording an increased flux of γ-rays from two white-light and cosmic-ray flares early in August 1972. The preilminary data did show that the γ-ray increase was short-lived and occurred in the very initial phase of the flares, in agreement with the theoretical predictions – see also Section 4·8.

4.13. *Flare theories*

De Jager (1972) has demonstrated that the ultimate flare energy may be fully provided by the transformation of the energy of the differential solar rotation into magnetic energy, which subsequently dissipates in flares. The consequent decrease in the rotational energy of the Sun is found to lie within reasonable limits.

Piddington (1972), after pointing out the difficulties that arise if the flare energy is stored in the chromosphere or corona, has sought a subphotospheric source of the flare energy. He finds a possibility in Savage's hydromagnetic oscillations in sunspots, induced by thermal instabilities; the power for the flare would be provided when these oscillations are released upwards as a result of either supergranule motion or interaction between two spot fields.

After arguing against the magnetic source of the flare energy, Sen and White (1972) have proposed a dynamo mechanism for the production of solar flares, in which the surplus energy is stored in the Hall current caused by the crossed electric and magnetic fields; but ultimately it comes from the convective velocity field, the magnetic field acting more or less as a catalyst.

All the other contributions to the theory of flares (not many in the past three years) assume an active role of the magnetic field in the flare process, and arguments for it have been given explicitly by Syrovatsky (1972a). Syrovatsky (1972a, b) has modified his earlier mechanism into a three-phase model of flare development. In the first phase a current sheet is formed, which corresponds to the pre-flare changes in the magnetic field, manifested by filament activation. In the second phase, the current sheet becomes turbulent but still quasi-stationary, and its heating represents the thermal flare. Finally, in the third phase (not always present) the sheet is disrupted and particles are impulsively accelerated by the electric field. Another very detailed consideration about the role of a neutral sheet in the flare process was presented by Coppi and Freidland (1971). Priest (unpublished) has suggested a modification of Petschek's mechanism which removes an inconsistency in the original formulation. A model of the source of thermal X-rays in Sturrock's flare configuration has been formulated by Strauss and Papagiannis (1971).

Carlqvist (1972) has studied conditions under which electric double layers occur, in particular in the solar atmosphere, on the basis of the ideas earlier presented by Alfvén and Carlqvist. He

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finds that in the lower solar corona the electric currents must be restricted to a width around 40 km in order to reach the critical current density necessary for double layers to be developed. However, D. F. Smith and Priest (1972) have pointed out that the Alfvén-Carlqvist instability will never occur, since instead of it the ion-sound current instability will be the relevant current dissipation mechanism in the upper chromosphere and corona. They also argue against Syrovatsky's electromagnetic instability for the current sheet interruption and show that it cannot occur when the ion-sound current instability dominates the current interruption. Since instabilities seem to severely limit the possibility of accelerating particles by applying large electric fields over short distances except in near vacuum situations, Smith and Priest suggest that one should rather consider mechanisms which apply small electric fields over large distances. One such mechanism currently under investigation is nonlinear ion-cyclotron resonance (Altschuler, D. F. Smith and Priest, unpublished). On the other hand, Haurwitz (1972) has proposed a plasma evacuation-electrostatic discharge model of flares, which differs basically from that of Alfvén and Carlqvist; in particular, according to the author, it avoids disruption due to the ion-sound current instability.

Lehnert (1971) has drawn attention to the effect produced by rotating plasmas in space. He points out that rotating plasmas may be important to a greater extent than has been realized so far, since rotational motions can hardly be avoided when electric currents are flowing across a magnetic field. In this connection one should also mention Öhman's (1972a, b) observations of rotational motions in flares and prominences.

5. PROMINENCES

E. Tandberg-Hanssen

5.1. *General reviews*

Kleczek *et al.* (1972) have published a general bibliography of solar prominence research, covering the period 1880–1970. With its 1300 references it will constitute a very important source of information. A colloquium on the Physics of Prominences was organized by Kiepenheuer at Anacapri in 1971, and a summary of the proceedings has appeared (Bruzek and Kuperus, 1972). Tandberg-Hanssen (1973) has completed a monograph on Solar Prominences.

5.2. *Quiescent prominences*

The nature of quiescent prominences has been studied extensively during the past three years. As a result reasonably good models are available, and our understanding of stability of quiescent prominences has increased. However, there are still difficulties concerning the formation of prominences, and many details regarding the excitation and ionization equilibria of the prominence plasma are not well understood.

Hildner (1971) has studied the condensation process for prominence formation in a non-linear treatment and shown that the process is likely to work under existing coronal conditions. Raadu and Kuperus (1972) have considered condensation and cooling along a neutral (current) sheet. The difficulty is to account for the necessary matter. The injection of material from below to form prominences has been advocated by Pikel'ner (1971a). In this case there is enough material, but the theory is not developed in the same detail as the condensation theory.

The excitation and ionization equilibria for hydrogen has been discussed and a reasonably consistent picture has developed. Burns (1970), Morozhenko (1970) and Kostik (1971a) have considered the Lc in some detail, and Poland *et al.* (1971) conclude that at low densities the ionization of hydrogen is determined by the coronal and chromospheric radiation fields, while at the highest densities found in quiescent prominences the electron temperature and the photospheric radiation temperature in the Balmer continuum are the dominant factors.

The situation is somewhat less satisfactory for helium whose excitation and ionization conditions have been discussed in a large number of papers, but it has not been possible to treat the ionization with the same mathematical finesse as in the case of hydrogen. Yakovkin and Zel'dina

(1971) and Hirayama (1972) find that helium can be ionized by the coronal and chromospheric UV flux, and the observed line intensities, both from He I and He II, are consistent with a low-temperature plasma ($T_e \leq 10^4$ K). Studies of monochromatic images of prominences in the He I D_3 and in the He II, 4686 lines (Kubota and Leroy, 1970) show the similarity of form at both wavelengths in the prominences, and so tend to support the view of a common excitation process. However, while Kostik (1971*b*) interprets the observed populations if the triplet levels of He I in terms of recombination and requires electron densities of 10^{11} to 10^{12} cm^{-3}, Morozhenko (1971a, b) finds that for the ionizing coronal flux to penetrate and account for the He II emission, the electron density cannot be much more than 10^9 cm^{-3}. Kubota *et al.* (1972) have studied the relation between hydrogen and helium emission and find that an increased value of the intensity ratio $I(D_3)/I(H\beta)$ observed in faint parts of prominences can be explained as due to a decrease of the density in these parts to $n_e < 10^{11}$ cm^{-3}. The change in line width of Hα, Hβ and D_3, as a quiescent prominence goes into an active phase and decay, has been studied by Rakhubovsky (1972).

The best determinations of the kinetic temperature in the coolest parts of the prominence plasma indicate values of 6000 to 7000K (Orrall, 1972). Hirayama (1971a) has determined the electron density from Stark broadening of high Balmer lines and gives $n_e = 10^{10}$–5×10^{10} cm^{-3}. Hirayama (1971b) has determined the abundance of helium, and finds a helium to hydrogen number ratio of 6·5% (±1·5%). Of great importance for our understanding of excitation and ionization conditions are the recent observations of EUV emission lines made from the OSO 4 and OSO 6 spacecraft (Noyes *et al.*, 1972). Quiescent prominences appear in emission for all strong lines formed at temperatures below 3×10^5K, and it is likely that a significant fraction of the plasma is at high temperatures.

The third parameter, which has been given greater and greater importance in the last few years, is the magnetic field. The field strength is between 5 and 30 G in most quiescent prominences according to Rust (1972) and Tandberg-Hanssen (1970), while Smolkov (1970), and Shpitalnaja and Vsyalshin (1970) give much higher values. Theoretical and observational studies of prominences and their magnetic fields have been published by Godoli *et al.* (1972), Bashkirtsev (1970), Rompolt *et al.* (1971), and Wiehr (1972).

The relationship between quiescent prominences and the magnetic field of plage regions has been studied by Waldmeier (1972).

Engvold (1972) reports on persistent small-scale motions in the main body of quiescent prominences. The motions are detected in Ca II K line high resolution spectra, and merit further attention. A 'fuzzy' appearance of spectral lines from the outer parts of some quiescent prominences is interpreted by Engvold and Livingston (1971) as the result of an exchange of matter between the prominence and the corona.

The stability of quiescent prominences has been discussed from several points of view. Thermal conduction seems to be a major factor in our understanding of the stability, and Jensen (1972) has considered several consequences of this conduction. Poland and Anzer (1971) studied the balance between radiative losses from the prominence and heat conduction from the corona, and concluded that such an energy balance is possible. However, for a temperature of 6000K the required hydrogen density is about 3×10^{12} cm^{-3}, which seems too large for support by the magnetic fields generally found in quiescent prominences. A somewhat higher temperature, 7500K, would lead to a density of 5×10^{11} cm^{-3} which seems more reasonable.

The dynamic equilibrium of prominences in the presence of magnetic fields implies hopelessly non-linear equations, and drastic simplifications are necessary. Nakagawa (1970, 1971) has treated this problem at some length. There may be two magnetic fields involved in quiescent prominences, an internal and an external field (Anzer and Tandberg-Hanssen, 1970). Nakagawa uses two such fields to show that the stability depends on the angle between the fields.

5.3. *Active prominences*

We are still far from having adequate models for most types of active prominences (surges,

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sprays, loops, coronal clouds, active region filaments (sunspot filaments, arch filaments, fibrils), but it has become more and more clear that magnetic fields play an essential role in the physics of these prominences (Rust, 1972). Foukal (1971) and Frazier (1972) have studied the relation between magnetic fields and different filament and fibril structures in and near active regions.

Loops have been studied by Rust and Roy (1971) who used the Doppler-Zeeman Analyzer (Dunn, 1971) at the Sacramento Peak Observatory to measure photospheric magnetic fields and from these computed current-free field lines. The fit of such field lines to observed loop systems is excellent. Karaev (1970) has studied the possible influence of sunspot magnetic fields on coronal prominences. The excitation of helium in loops has been considered by Morozhenko (1971c), who finds that the increased UV radiation from the active corona and chromosphere above plage regions may be the source of the addtional excitation of helium observed in loops.

Of particular interest is the question of rotational motions in prominences, possibly due to helical structures of the magnetic field. Öhman has pointed out that eruptive prominences possess such structure, and it also follows from Anzer and Tandberg-Hanssen's model for quiescent prominences. From observations of a periodic asymmetry of spectral lines, which Öhman (1972a) interprets as a rotational mass motion, he deduced a rotational velocity of 13 km s^{-1} and a period of 32 min. Rompolt (1972) has derived the pitch for the helical structure in two active prominences, and from wavelike trajectories he observed in sprays he concluded that also these prominences move in a spiral motion. Malville and Tandberg-Hanssen (1973) report on possible helix structure in surges.

5.4. *Associations with flares and the coronal plasma*

Bruzek (1972b) and Martin (1972) have discussed the actions of flares on prominences. One of the most spectacular effects in the *disparition brusque* phenomenon, which occurs when a quiescent prominence is destabilized and rises in the corona to great heights. These flare-induced effects have been studied by Dodson *et al.* (1972), Godoli *et al.* (1971), McCabe (1970) and Shpitalnaja (1971). As the prominence material is accelerated through the corona, it may cause 'coronal transients', temporary changes in the intensity distribution of the white-light corona (Garcia *et al.*, 1971). It is likely that surges and sprays have similar effects on the corona (Hansen *et al.*, 1971). These and other considerations have emphasized the important link between the corona and prominences, both quiescent and active. Pneuman (1972) considers the appearance of quiescent prominences a necessary consequence of the adjustment required in the density structure of coronal helmet streamers to satisfy the energy balance as modified by the magnetic field. The association of quiescent prominences with the corona has been studied by Axisa *et al.* (1971) using radio data.

Similarly, the close connection between loops (which occur only after flares) and the corona has been emphasized by Rust and Roy (1971), Newkirk (1971) and Bruzek and DeMastus (1970). The spray-corona interaction is of great interest. Sprays are ejected from flares (McCabe, 1971). However, due to their high velocity many sprays probably go unnoticed. Also, we do not know much about their interaction with the corona. To remedy this, Öhman (1971, 1972b) has instigated an ambitious spray patrol program under IAU auspices that should provide much-needed valuable data on this prominence-corona association.

The many coronal phenomena that follow spray-producing flares, e.g., type II and IV radio bursts, coronal 'whips' – sudden changes in a previously existing arch structure seen in the green (5303 Å) coronal line (Dunn, 1970) – and coronal transients, may be considered different manifestations of the same disturbance (Smerd and Dulk, 1971; Newkirk, 1971; Stewart and Sheridan, 1970; Kopp, 1972). Sprays and moving type IV bursts have been studied by McCabe and Fisher (1970), Riddle (1970), and Dulk and Altschuler (1971).

6. CHROMOSPHERIC STRUCTURES

A. Bruzek

Major emphasis in research on chromospheric structures was placed on the study of the topology of the fine structure of the solar chromosphere and its relation to photospheric magnetic fields. A

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large number of observations of high resolution both in time and space has been secured for this purpose in recent years.

6.1. *Plages*

The appearance of *plages* in different strong lines shows a detailed correspondence, as was pointed out for Ca II K and Hα by Zirin (1972) and for Ca II K and Mg II K (2795 Å) by Fredga (1971). The coincidence of bright plages and enhanced photospheric magnetic fields was confirmed in general (Frazier, 1972; Zirin, 1972); the correlation between plage brightness and field strength, however, turned out to be rather poor. Frazier (1971) found an increase of Ca II K_{232}, plage intensity with the magnetic field strength up to about 500 G, however the scatter was so large as to make it impossible to convert plage intensity into field strength. This scatter may be due to the fact that photospheric fields are being compared with a higher level feature, and might be considerably reduced using *chromospheric* magnetic fields (which are not yet available). Nakagawa *et al.* (1972) found that the Hα plage was outlined by the ± 80 G isogauss contour, whereas Veeder and Zirin (1970), using low resolution magnetograms, considered 30 G as the limiting field strength. Zirin (1972) suggested a rough proportionality between H and $I_{H\alpha}$ while Nakagawa *et al.* (1972) and Janssens (1972a) considered the correlation as poor, and Frazier (1972a), indeed, as non-existent. This poor correlation is certainly due, in part, to the complex morphology of the Hα chromosphere in active regions where dark elements (mottles, fibrils) frequently overlie bright features. This may also explain the observation of Janssens (1972a) that Hα plages in the vicinity of the neutral line are brighter than plages at other positions with the same magnetic field strength.

A number of authors reported on the observation of periodic changes in the Hα chromosphere in plages and above spots. Zirin (1972) and Bhatnagar and Tanaka (1972) found intensity oscillations in rosette centers and in plage granules with periods of 312 ± 56 and 286 ± 49 s respectively, which are close to the period of the general 300 s oscillation. The size of the oscillating elements was 350–700 km and their mean separation 2300 km. On the other hand, Tanaka (1972) and Phillis and Ramsey (1972) detected intensity oscillations over small regions in spot umbrae at H$\alpha \pm 0{\cdot}3$ Å with a period of 145 ± 5 s, the period of the K-line umbral flashes! Stein and Zirin (1972) state that the umbral flashes are identical in K and Hα and suggest that they are the origin of the Bright Running Penumbral Waves which are observed, in the center of Hα, to be moving outward through the penumbrae of large, stable spots with a constant velocity of 8–12 km s^{-1}, and which repeat with a period of about 250 s. Stein and Zirin (1972) suggest that these are sound waves.

Giovanelli (1971) and Howard (1972a) studied velocity fields in plage regions and found steady, downward velocities which, according to Howard, may be interpreted as a real downflow of material; its nature remains unresolved.

Bruzek (1972b) presented new evidence that moustaches (bombs) are low chromospheric features which, in the center of Hα, are usually covered by dark, slightly Doppler shifted chromospheric elements and therefore are best observed at about H$\alpha \pm 1$ Å. Moustaches coincide exactly with continuous facular granules and with photospheric bright points (Vorpahl and Pope, 1972) and may be considered as extensions of faculae into the chromosphere. They may coincide with magnetic 'satellites' and form the basis of surges (Roy, 1972).

6.2. *Filamentary structures*

The various filamentary structures of the disturbed and the undisturbed Hα chromosphere (bushes, spicules, fibrils, threads, filaments) have been studied extensively by Foukal (1971a, b). He derived their physical properties and suggested that the structures inside and outside active regions are of the same nature, their morphological differences being due solely to the related magnetic fields. The strong ($H > 100$ G) and mainly horizontal active region fields constrain and bend the structures, depressing them below 4000 km. The spicules outside active regions, on the other hand, are associated with more or less vertical fields of 25–50 G (> 80 G according to Na-

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kagawa *et al.*, 1972) and reach heights of 10000 km. Foukal proposes that fibrils are produced by shocks generated by photospheric disturbances propagating along magnetic flux tubes into the chromosphere. The fibril structures found on the neutral magnetic line and near filaments were studied by Prata (1971) and Foukal (1971b).

Veeder and Zirin (1970), Foukal (1971a, b) and Zirin (1971, 1972) conclude that fibril structures which are observed to connect opposite magnetic field regions follow and outline magnetic field lines. They propose, therefore, using high resolution Hα filtergrams as 'chromospheric magnetograms' for the study of the morphology of chromospheric magnetic fields, especially horizontal fields which cannot be derived otherwise. Smith (1971), however, doubted that all fibril patterns actually connect opposite polarities. She found fibrils frequently ending in regions consisting of a complex mixture of both polarities where it was difficult, or impossible, to identify an end of an individual fibril with an area of given polarity. Frazier (1972a) argued that fibrils connecting opposite field regions do not necessarily indicate the chromospheric field direction.

On the other hand, Nakagawa *et al.* (1971), Raduu and Nakagawa (1971), Nakagawa *et al.* (1972), Meyer and Mayfield (1972) computed the configuration of magnetic field lines in the chromosphere from measured longitudinal photospheric fields, assuming a force free configuration ($\nabla \times \boldsymbol{B} = \alpha \boldsymbol{B}$) and obtained a striking topological agreement with concurrent filtergrams. There is some discrepancy in the heights of the structures which may be removed by a more refined analysis. Pikel'ner (1971b) presented a detailed model of chromospheric fibril structures.

Special types of Hα structures precede and accompany the emergence of new magnetic flux, i.e., the appearance of new active regions. According to Martres and Soru-Escaut (1972), and Harvey and Martin (1972) short-lived, dark Hα features appear hours before and with the birth of a new region. The Arch Filament Systems (AFS) are now generally believed to represent the arched field lines of new emerging flux: photospheric material is lifted by emerging and expanding field tubes and eventually flows back along the field arches which are anchored in opposite field regions (Roberts, 1970; Frazier, 1972b). Frazier observed that the formation of arch filaments follows the concentration of magnetic knots, which originate inside a supergranule and drift to opposite borders.

7. CORONAL TRANSIENTS IN THE VISIBLE

F. Q. Orrall

The slowly varying active corona (including active region enhancements and coronal condensations) is discussed in the report of Commission 12. Here we are concerned with short-lived coronal events, as they are observed in the visible.

The most dramatic coronal transients are those immediately associated with chromospheric flares. Some flares (perhaps all) produce a hot ($T > 10^7$ K) coronal plasma, an associated blast wave, energetic particles, and an ejection of relatively cold (Hα emitting) plasma into the corona. These produce dramatic events in Hα, on dynamic radio spectra, in the EUV and the soft and hard X-ray regions – manifestations that are discussed elsewhere in this Report and in the Reports of Commissions 40 and 44.

Observations of coronal transient events in the visible are remarkably rare except, of course, for the relatively cold Hα emitting (prominence) material. This is presumably a result of contrast; the intense visible photospheric radiation, scattered by the undisturbed coronal electrons as well as by the Earth's atmosphere and the observing instrument, overwhelms the transient emission. However new or improved techniques have led to a number of recent new observations and have stimulated a number of new studies.

The most frequently observed visible events are the sporadic condensations – the coronal counterpart of loop prominences which form in the aftermath of proton flares. These are easily observed photographically or visually with the coronagraph and spectrograph in the continuum and in the stronger emission lines, including λ5694 of Ca XV, or with monochromatic filters. Two quite different processes have been suggested to explain these rapidly forming condensations: one (Kiepenheuer) is that they form by condensation from the surrounding corona by thermal instability, aided perhaps by magnetic compression; the other (Jefferies and Orrall) is that they are formed from non-thermal energetic flare plasma trapped by the magnetic field and injected into the loops. New theoretical hydrodynamic studies of the condensation process have been made by Goldsmith (1971) and Hildner (1971). Teske (1971) has studied the soft X-ray emission associated with sporadic condensation and finds evidence favoring the injection process. Bruzek and DeMastus (1970) have studied monochromatic cine observations in $\lambda 5303$ of the sporadic condensation of 4 February 1962 which shows that the coronal event can be much more extensive than the Hα loop system. Fisher (1971) has used spectroscopic observations of a sporadic condensation to derive the density distribution as a function of temperature. Theoretical calculations by Newkirk of the evolution of fast particles trapped in a magnetic field may make it possible to follow the injection process more realistically. Sporadic condensations are among the most beautiful of astronomical phenomena and of especial interest because of their intimate association with proton flares. Time lapsed spectra in the visible and EUV, as well as more realistic theoretical studies are needed for deeper understanding of this phenomena.

Monochromatic photography of the inner corona in the forbidden emission lines (usually $\lambda 5303$) has provided the most frequent direct record of coronal transient events. Regular photography of the green corona is made from Mt. Haleakala, Pic-du-Midi, and Sacramento Peak. The most complete records are the cine observations from Sacramento Peak instituted by R. B. Dunn in 1956. Dunn (1971) has described the difficulties and techniques of obtaining these observations, and has given a description of the coronal structures and events recorded on them. Although about 2500 hr of usable observations have been obtained, surprisingly few events have been observed. Dunn describes three classes of events: slow; loops and arches; and fast events. The fast events he classifies as: *Oscillations* (wave-like vibration of existing structures); *Disruptions* (irregular motions of existing arch systems); *Realignments* of arch systems leaving a cavity dark in $\lambda 5303$; *Accelerated Expansions* (often whip-like) of arch systems; and *Ejections* of material from below. He finds that the disturbances are often guided by the coronal magnetic field (as outlined by observable coronal structure). De Mastus *et al.* (1972) have studied the same material and correlated (where possible) all of the observed transient fast events (30 in number) with other solar activity. They find that the number of events roughly follows the sunspot cycle (a little early in phase). Surges, eruptive prominences, and flares of class 2 or greater regularly produce transients. Type II radio bursts are associated with the *accelerated expansion* and *realignment* green line events, whereas when the coronal event appears confined to the lower corona, only centimetric bursts are observed. They remark that no blast wave has been detected on these records, although Orrall and Smith (1961) have reported what may be a shock wave preceding a flare spray through the corona and observed with this same instrument.

Observations of the inner K-corona are regularly made from Mauna Loa and Pic-du-Midi using photoelectric polarimetry to separate the K-corona from the sky background (the 'K-coronameter'). These observations normally consist of low resolution scans around the limb at several radii out to $\sim 2R_\odot$. Although the K-coronameter has been in operation for many years, few transient events have been detected. However, recent improvements in instrumentation and techniques – Hansen *et al.* (1969) and Leroy *et al.* (1972) – and more frequent observations, have resulted in the detection of a number of transients (i.e., changes taking place over a few hours or less). Hansen *et al.* (1972) have reported over a dozen such events observed since 1969 which they have classified into four basic types: Formation of a streamer or condensation, disruption of a streamer; relocation of a structure (similar to Dunn's realignment or whips); and the expansion of an arch, the latter class being most commonly observed. They suggest that some of these changes may be part of the process of evolution of coronal streamers, believed to follow the evolution of the associated magnetic field from its first appearance as a BMR in an active region, to its arrival at the polar crown.

The Culgoora 80 MHz radioheliograph has recorded a number of transient coronal events in the intermediate corona – Riddle (1970), Sheridan (1970) – some of which have been also observed visually in the inner K-corona, cf. Hansen *et al.* (1971), Sheridan *et al.* (1972). Flare spray prominences observed in Hα have been the most easily observed coronal events and their study has been stimulated by observations from Culgoora and Nançay (Daigne, 1971). An Hα coronagraph capable of observing eruptive and spray prominences, and other transient Hα events, simultaneously at all position angles to beyond 1 $R_\odot$ has been in operation at Mt. Haleakala for several years. Observations with these instruments show that major sprays (such as the event of 1 March 1969 – Riddle (1970), McCabe and Fisher (1970) – are more common than previously supposed.

Direct photography in white light is an obvious way of studying coronal transients, but until recently this has only been possible during total solar eclipse. However, the total accumulated observations (including a few coronagraph observations from balloons and rockets) has not been long enough to expect many complete observations of past events. Recently, however, the NRL externally occulted white light coronagraph (observing from 3 to 10 solar radii) on OSO 7 (Tousey and Kooman, 1971) has increased greatly the total observing time.

A very complex coronal event accompanied by the expansion and disintegration of a bright coronal streamer was observed on 14 December, 1971 (Brueckner, 1972a, b). The streamer expanded and broke up, apparently into plasma clouds which moved outward with a projected velocity of ~ 1000 km s^{-1}. Brueckner estimates that some 10^{16} g was ejected from the Sun, about the amount calculated by Hundhausen and his associates to be ejected with the shocks that produce discontinuities in the solar wind. The expansion of the streamer began prior to other observed activity and was evidently associated with a fundamental change in the magnetic structure of the underlying active region. This is the most direct and complete observation of a large scale coronal event that we possess. A total of six transient events has been observed with the NRL coronagraph (Tousey and Brueckner, 1972).

During the period of this report, considerable progress has been made on the theory of the passage of particle streams and shockwaves through the corona. A conference on Flare-produced Shock Waves in the Corona and Interplanetary Space was held at the National Center for Atmospheric Research on 11–14 September, 1972 and the proceedings are in preparation. Zirker (1971) has recently reviewed flare-associated coronal events.

Since the corona is believed to be heated by the dissipation of shock waves developing from waves generated at the top of the convection zone, one might expect some visible manifestation of these shocks to be present even in the quiet corona. Schmidt *et al.* (1972) made an intensive search for evidence of compressional waves on the white-light coronal pictures obtained at the 1970 eclipse by Newkirk and Lacey. No transients were observed, although they were able to set constraints on the size and brightness of possible fluctuations. This is clearly a difficult but important problem for future observational work.

8. SOLAR ACTIVITY – SPACE MEASUREMENTS

L. W. Acton

The return of information from space experiments has accelerated during the past three years. Improvements have been made in both the quality and quantity of new data and in more thorough analysis of earlier results. An especially encouraging trend in recent work is the increasing synthesis of observational material from a variety of space and ground-based experiments in the study of solar activity.

Reviews have been published on solar X-ray emission by Doschek (1972), Neupert (1971a), and Walker (1972). Ultraviolet and EUV studies are reviewed by Noyes (1971) and Tousey (1971); while Chupp (1971) discusses solar neutron and gamma ray emission. Wilcox (1971) has reviewed problems of interplanetary sector structure and the extension of solar magnetic fields into space.

Solar data from space experiments is available through World Data Center A for Rockets and Satellites, Code 601, Goddard Space Flight Center, Greenbelt, Md. 20771, U.S.A. An atlas of EUV spectroheliograms has been published by Reeves and Parkinson (1970) and a tabulation of EUV flares is given by Wood *et al.* (1972). Availability of solar X-ray data has been announced by Drake *et al.* (1969); Fehlau (1971); Kane and Winckler (1969); and Landini and Monsignori Fossi (1970a). Wende (1972) discusses normalization of different types of broad-band X-ray data.

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Rocket X-ray spectroscopy of non-flaring active regions reported by Batstone *et al.* (1970) and Acton *et al.* (1972a) indicate that the total emission measure in the associated coronal condensations typically falls in the range 1–2 $\times 10^{48}$ cm^{-3} but that the amount of material at temperatures above 3×10^6 K may vary by orders of magnitude. This is consistent with the OSO-4 X-ray heliogram measurements reported by Krieger *et al.* (1972) which show that the changing emission of an active region is primarily associated with temperature changes rather than variations in the emission measure. Sengupta (1971b) and Landini and Monsignori Fossi (1971) derive models for soft X-ray emitting regions on the basis of 0–2 nm X-rays and 9·1 cm spectroheliograms which indicate much higher emission measures in the 10^{49}–10^{50} cm^{-3} range.

On the basis of X-ray spectroheliographs from OSO-5, Parkinson and Pounds (1971) report a positive relation between the strength of soft X-ray regions and the strength and complexity of photospheric magnetic fields. They and Krieger *et al.* (1971) also find that soft X-ray emitting regions extend to heights of 10^5 km on the basis of limb occultation studies. These results are consistent with the high resolution X-ray photographs of the American Science and Engineering group (Krieger *et al.*, 1971; Van Speybroeck *et al.*, 1970) which, in addition, show loop-like structures linking widely separated active regions (in some cases crossing the solar equator) into solar 'complexes of activity'. The X-ray photographs also reveal hot, bright cores of emission at low levels bridging the 'neutral line' of the longitudinal magnetic field in regions of large field gradient.

Searches for predicted density dependent variations in the forbidden to intersystem line ratio (Freeman *et al.*, 1971; Gabriel and Jordan, 1972; Mewe, 1972a) of the helium-like lines of O VII yielded negative results (Rugge and Walker, 1970, 1971; Acton *et al.*, 1972b). This indicates that electron densities in the coronal region producing these lines in non-flare conditions are less than 6×10^9 cm^{-3}. Observations of X-ray satellite lines from autoionizing atomic states (Parkinson, 1971, 1972; Neupert and Swartz, 1970; Neupert, 1971; Walker and Rugge, 1971) conclusively demonstrated the importance of the dielectronic recombination process and provided a powerful new tool for measuring plasma temperatures and departures from ionization equilibrium (Gabriel, 1972; Gabriel and Paget, 1972).

The Harvard College Observatory EUV spectrometers on OSO-4 and OSO-6 have yielded important new results (Dupree and Reeves, 1971; Munro *et al.*, 1971; Noyes and Kalkofen, 1970; Noyes *et al.*, 1970; Reeves and Parkinson, 1972; Withbroe *et al.*, 1971). The chromospheric network was found to be detectable in lines formed in the transition region at 7×10^5 K but only a small residual, if any, network structure showed in coronal lines. EUV observations of active regions are in accord with a model for which the active region pressure is about 5 times the quiet Sun pressure, the temperature gradient in the transition zone is about 5 times the quiet Sun value, and the coronal temperature above active regions is enhanced by about 5×10^5 K.

Fainberg and Stone (1970a, b, 1971) report on measurements of type III solar radio burst storms with the RAE-1 satellite over the 5·4 to 0·2 MHz range. These bursts sample roughly the 10–40 solar radii region. They find storms of these radio bursts enduring for ½ solar rotation. These observations imply more or less continuous injections of burst exciters, thought to be packets of electrons, with speeds of $c/3$ and with no evidence of deceleration in their passage out through the corona. Teske *et al.* (1971) find evidence from soft X-ray burst correlations that thermal events may precede and trigger the type III instability.

For both protons and electrons, the extension of galactic cosmic ray studies to low energies has revealed a very low level quiet time component of solar origin which is always present. These solar components are observed below ~ 20 MeV for protons (Kinsey, 1970) and below ~ 100 keV for electrons (Lin *et al.*, 1972). The mechanism accelerating these particles is unknown at present.

Work on the energetic particle fluxes associated with active regions has concentrated on explaining the long lived nature (weeks) and the longitudinal extent of these fluxes. The possibilities of long term storage versus continual acceleration of the particles has been investigated, with observational and theoretical grounds for both points of view, (Simnett and Holt, 1971; Krimigis and Verzariu, 1971; Schatten, 1970). Additionally, tracing techniques from 1 AU back to the Sun have been utilized in attempts to discover the structure of the emission regions at the Sun (Lin, 1970b). Some ideas have been put forth to explain the longitudinal extent of the particle fluxes, both for active regions and impulsive solar flare events, in terms of coronal diffusion and large scale coronal structures (McKibben, 1972; Fisk and Schatten, 1972).

Study of solar thermal X-ray emission has benefitted from the theoretical spectra published by Landini and Monsignori Fossi (1972), Mewe (1972b), Tucker and Koren (1971a, b) and Culhane and Acton (1970). The interpretation of non-thermal X-ray bursts has been correspondingly facilitated by the theoretical work of Brown (1971, 1972), Elwert and Haug (1970), Hudson (1972), Kane and Anderson (1970), Korchak (1971, 1972), Strauss and Papagiannis (1971), Syrovatskii and Shmeleva (1971) and Takakura (1971).

Tindo *et al.* (1970, 1971, 1972a) report the first measurements of polarization of flare X-rays obtained from the satellites Intercosmos 1 and Intercosmos 4. They observe fractional polarization of $\sim 0{\cdot}2$ and unexpectedly long durations of polarization (5–10 min). The observations are found to be consistent with a continuous injection model of radially downward directed electrons (Brown, 1972; Tindo *et al.*, 1972b). This result is at variance with Ohki's (1969) conclusions regarding the center to limb directivity of hard X-ray bursts.

The first detection of nuclear gamma-ray lines from solar flares was reported by Chupp *et al.* (1972). Their OSO-7 instrument detected the 0·511 MeV positron annihilation line, the 2·23 MeV deuterium line, and lines at 4·4 and 6·13 MeV identified with C^{12} and O^{16}, respectively. They also observe a gamma-ray continuum up to 8 MeV which is not smooth and may contain other lines at low intensity. The flare of 2 August 1972 produced observable gamma ray emission for several thousand seconds. The observation of the deuterium line conclusively establishes the presence of substantial neutron fluxes in flares although direct measurements of solar neutrons have so far proven unfruitful (Cortellessa *et al.*, 1970; Eyles *et al.*, 1972).

Observational studies of the X-ray line emission of flares have been published by Doschek and Meekins (1970), Doschek *et al.* (1971a), Meekins *et al.* (1970) and Neupert (1971). It is found that a cooling multi-temperature plasma is required to explain the data. The heating phase of the plasma must be very fast as the highest stages of ionization are most abundant at the initiation and first rise to maximum of a flare. High resolution observations have shown that the iron line feature at 0·19 nm is predominantly due to transitions in Fe XXIV and Fe XXV (Doschek *et al.*, 1971b; Grineva *et al.*, 1972; Neupert and Swartz, 1970).

There is almost general agreement that hard X-ray bursts ($h\nu > 20$ keV) are bremsstrahlung emission from energetic non-thermal electrons and that the lifetime of the particles is short compared to the burst duration (Lin and Hudson, 1971). There is evidence for repeated, quasi-periodic particle acceleration in some flares (Parks and Winckler, 1971; Frost, 1969).

There is evidence, both from flare electromagnetic emissions and from particle observations at 1 AU (Lin, 1970; Frost and Dennis, 1971), that two separate stages of acceleration are involved: (1) the flash phase acceleration of 10–100 keV electrons, and (2) a second acceleration, occurring in flares with type II and IV radio emission of $\gtrsim 1$ MeV protons and relativistic electrons (up to $\gtrsim 30$ MeV) (Datlowe, 1971; Dilworth *et al.*, 1972).

In the acceleration of protons and nuclei two recent results point toward important future work: (1) the observation of 'micro-events' in protons which apparently arise from some small flares which also have a pronounced tendency to be accompanied by type II emission, (McDonald *et al.*, 1972) and (2) the observation of a substantial excess of Fe nuclei at low energies ($\gtrsim 1$ MeV/nucleon) in solar events (Price *et al.*, 1971). These observations give clues to the second stage particle acceleration process in solar flares.

For the first time it has been possible to relate directly the particles observed by spacecraft with phenomena seen at the Sun. Recent work shows convincingly that the various manifestations of the flash phase – hard X-ray, cm radio, EUV, type III bursts, rapid intensification of soft X-rays and Hα – are interrelated and due to 10–100 keV electrons (Kane and Anderson, 1970; Kane and Donnelly, 1971; Vorpahl, 1972; Alvarez *et al.*, 1972; Graedel, 1970; Dunckel *et al.*, 1972; Kahler

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et al., 1970; McKenzie *et al.*, 1973). Aside from the properties of this acceleration and escape, the main result has been that energy contained in these non-thermal electrons is comparable to or even dominates the thermal flare energy for many small flares in which a flash phase is observed (Lin and Hudson, 1971).

Sakurai (1972) finds that the peak flux of >10 MeV protons from west limb flares is linearly related to peak cm wave flux associated with type IV burst. This is taken to indicate that the acceleration processes of protons and electrons are closely related.

In a series of papers based on data from OSO-3, Teske has investigated the relationship of soft X-rays to other forms of solar activity (Teske, 1971a, b, c, d; Teske *et al.*, 1971; Teske and Thomas, 1969, 1972; Thomas and Teske, 1971). Several groups have reported measurements of the temperature and emission measure of the region responsible for soft X-ray bursts in flares (Culhane and Phillips, 1970a; Horan, 1971; Mandelshtam, 1971; McKenzie, 1972; Milkey, 1971). Typical temperatures are 10–30 million degrees and emission measures range up to 2×10^{50} cm^{-3}. Hudson and Ohki (1972) find that the hot material can account for both the thermal X-ray and microwave bursts and originates in the chromosphere in regions of density 10^{10}–2×10^{11} cm^{-3}. Kane and Lin (1972) evaluate satellite X-ray and electron data and conclude that electron acceleration for impulsive events occurs at levels with ion density in the 10^{9}–10^{11} cm^{-3} range while non-impulsive events may originate in lower density regions.

The flare of 4 November 1969 was observed by a rocket EUV instrument (Purcell and Tousey, 1970). Many lines in the 17–67 nm region were observed and Purcell and Widing (1972) estimated $n_e = 3 \times 10^{10}$ cm^{-3} in the flare core from this data. They identified lithium-, beryllium-, carbon-, and nitrogen-like spectra of argon and calcium on the rocket spectroheliograms. The spectrum of the bright kernel of the flare is reported to be a collision spectrum and not a recombination spectrum. Impulsive EUV enhancements have been observed by Hall (1971) to precede the Hα flare maximum by 2 min, placing them in the flash phase of the flare. Emissions of ions formed below, within, and above the chromosphere – corona transition region are enhanced at successively later times. These results are in agreement with the findings of Donnelly (1969, 1971), Kane and Donnelly (1971), Wood and Noyes (1972), and Wood *et al.* (1972) who conclude that the EUV flashes are thermally produced in transition region and upper chromospheric lines. The last authors also report the discovery of EUV microflares, in the same emission lines, which are a factor of two less intense than $-$F subflares and which do not appear to have Hα counterparts.

Observations of a surge at the limb in the 97·7 nm line of C III by Kirshner and Noyes (1971) show that the kinematic behavior of the C III and Hα regions are identical. The observations are consistent with the C III region appearing as a 100 km thick transition sheath about the Hα volume.

Beigman *et al.* (1969, 1971) and Vaiana and Giacconi (1969) report spatially resolved observations of the soft X-ray emitting volumes of flares. These regions appear in the form of filaments 1 to 2′ long and less than 20″ in width. Within these filamentary volumes are localized sources with flareups as short as 0·05 s in duration. At higher energy (30–60 keV), the location and size of an impulsive hard X-ray burst was observed by a balloon borne modulation collimator (Takakura *et al.*, 1971). The center of the X-ray source was on the line passing through the center of a large Hα flare region, but the size of the X-ray source was smaller (1′ or less) than the Hα flare (3′). Simultaneous observation of the concurrent microwave burst source was made by Tanaka and Enomé (1971). The center of the radio source was also on the line passing through the Hα flare region and the source size was less than 1·8′.

Problems associated with the emission and propagation of relativistic electrons from solar events have been discussed by Datlowe (1971), Dilworth *et al.* (1972) and Simnett (1972a). Many authors have published measurements of the energy spectra and nuclear composition of flare particles and the solar wind (Bame *et al.*, 1970; Bertsch *et al.*, 1972a; Cattaneo *et al.*, 1971; Formisano *et al.*, 1970; Geiss *et al.*, 1970; Hirschberg *et al.*, 1972; Holzer and Axford, 1970; Hsieh and Simpson, 1970; Hundhausen, 1970a; Lange and Scherb, 1970; Lanzerotti and Robbins, 1969; Mogro-Campero and Simpson, 1972; Price *et al.*, 1971; Scholer *et al.*, 1972).

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9. HIGH ENERGY SOLAR PARTICLES

C. Fichtel

In spite of the relatively modest level of solar activity during the period 1970 through 1972, several of the largest solar particle events recorded thus far occurred in these years. These include the events of January 31, 1970; March 29, 1970; August 13–18, 1970; November 5, 1970; January 24, 1971; April 6, 1971; September 1, 1971; and August 4–7, 1972. There was excellent particle coverage of many of these events by several different satellites as well as by sounding rockets. Substantial new data has been obtained on singly charged particles over a wide energy range and there are now many more experiments reporting multi-charged nuclei. On the theoretical side have been several extensive treatments on the solar particle propagation problem; however the exact means of accelerating solar particles still remains a major question.

Beginning with the singly-charged particles, proton fluxes at several energies are now being monitored on a regular basis. Daily and hourly averages of proton fluxes above several energies are reported in the U.S. Department of Commerce publication *Solar and Geophysical Data* with the data supplied by the Johns Hopkins Applied Physics Laboratory, NASA/Goddard Space Flight Center, the University of Chicago, and the University of New Hampshire from several different satellites, including the Pioneer and IMP series. The existing large body of data on energy spectra, intensities, and anisotropies is now too extensive to reference individually here.

Turning to electrons, Simnett (1972) made an extensive study of electrons of solar origin in the energy range from 0·5 to 12 MeV, and showed that the electrons generally have a differential energy spectrum of the form $E^{-\gamma}$, with γ being about 3. Values of γ exceeding 4 occurred, apparently, only if the electrons had been stored for a long time or originated in events on the back side of the Sun. Datlowe *et al.* (1970) reported measurements in the higher energy range from 10 to 200 MeV and found two events with γ equal to about 3, and one event with a much larger value of γ, but the latter event is probably one in which long term storage occurred (Simnett, 1971). At lower energies, the situation seems quite different. In the 0·02 to 1·0 MeV range Wang *et al.* (1971) have found events wherein most of the electrons appear to reach the Earth along the magnetic field lines with relatively little scattering. The energy spectra of these events are not well represented by the spectral form mentioned above, but rather have a flux which decreases more rapidly with increasing energy.

In addition to direct observations of electrons, there has been further work on deducing the spectrum of electrons in the flare region, and its time variations, from the observed X-ray spectrum (e.g., Lin, 1971). The electron spectrum is found to be consistent with a power law of the form $KE^{-\gamma}$ electrons cm^{-3} keV^{-1} for $E < 100$ keV and a similar form above 100 keV except that γ is larger.

Proceeding from singly to multiply-charged particles, attention will be given first to the He to (C, N, and O) nuclei ratio. The hydrogen to He nuclei ratio has been known to vary dramatically from one event to another as expected due to the factor of two difference in charge to mass ratio, and, hence, the very different rigidity for a given velocity. The He/(C, N, O) value has appeared to be more nearly the same; however, Armstrong *et al.* (1972) have summarized work of several groups and shown that there appears to be a real difference between the average value measured at 0·5 to 2·5 MeV/nucleon of 27 ± 9 and that measured in the range form 15 to 200 MeV/nucleon which is 58 ± 6. Teegarden *et al.* (1972) have measured He/(C, N, O) values of 46 ± 9 and $26 \pm 1{\cdot}5$ for two different events in the energy range 8 to 23 MeV/nucleon. It is not yet clear whether the differences are event to event differences or an energy effect. A combination of the two is also possible.

During the last three years, there has been a significant increase in the number of experiments which have made measurements on heavy nuclei ($Z > 2$) in the solar particle events. Although heavy nuclei were discovered in energetic solar particles over a decade ago, their small numbers made it impossible to obtain significant data from the early satellite experiments, and results were limited almost entirely to those obtained from nuclear emulsions flown on sounding rockets. Now,

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however, more sophisticated satellite experiments flown by Teegarden *et al.* (1972) and Mogro-Campero and Simpson (1972) have yielded data on the more abundant nuclei ranging from carbon to the iron group. In addition, Crawford *et al.* (1972) have obtained data ranging from O through Fe using plastic detectors recovered from sounding rockets and the Apollo mission. The relative abundance determined for C, N, O and Ne agree well with those measured in several events using nuclear emulsions recovered from sounding rockets (e.g., Bertsch *et al.*, 1972). In the region from Mg to Ca there are some differences among the various experiments. Whether these represent variations between events or disagreements between experiments is not yet clear. The abundances for nuclei above Ne measured by Mogro-Campero and Simpson (1972), generally in small events, are larger than those measured by the other groups. Teegarden *et al.* (1972) and Bertsch *et al.* (1972b) agree on Mg and S and have consistent limits on A and Ca, but disagree on Si. The abundances measured by Crawford *et al.* (1972) show the same general trend as the other groups.

The Fe abundance deserves special mention, both because many measurements now exist and because of the controversy over the abundance in the photosphere as determined by spectroscopic measurements. The presence of Fe group ($24 \leqslant Z \leqslant 28$) nuclei in the energetic solar particles was first detected by Bertsch *et al.* (1969). Fleischer *et al.* (1971) measured the energy spectrum of Fe-group nuclei from solar cosmic rays impinging for 2·6 yr on an optical filter of the Surveyor 3 Spacecraft prior to its return by the Apollo 12 astronauts on November 20, 1969. Price *et al.* (1971) used both the Surveyor-3 camera lens and a piece of the Apollo 12 Spacecraft window to deduce an Fe spectrum. Crozaz and Walker (1971) have shown that the Surveyor-3 results are consistent with lunar rock results, implying that the solar particle production rate has been the same on the average for a very long period. Bhandari *et al.* (1971) also measured Fe-group spectra in Apollo lunar samples, and Lal *et al.* (1972) deduced the long term average Fe-group energy spectrum from a meteoritic analysis.

Bertsch *et al.* (1972) measured the Fe abundance with nuclear emulsions flown on sounding rockets in both the January 24 and September 2, 1971 events and found it to be about one-twentieth of the O abundance. Crawford *et al.* (1972) measured the energy/nucleon spectra of Fe-group nuclei using plastic detectors flown aboard the second of the sounding rocket shots in the January 24, 1971 event. Teegarden *et al.* (1972) flew a low energy solid state detector telescope on IMP VI. Relative to oxygen, they measure an Fe-group abundance of about 3% in the September 1, 1971 event consistent with the other results mentioned within uncertainties. These authors also observed an iron-to-oxygen ratio of $0{\cdot}17 \pm 0{\cdot}10$ in the April 1971 event, but that was based on only 3 iron-group nuclei. On the side of high Fe abundances, Simpson and Mogro-Campero (1972) have deduced an average Fe/O value of $0{\cdot}79 \pm 0{\cdot}29$ for many events from 1968 to 1971, and Konyakhina *et al.* (1972) report several instances of enriched energetic solar particle Fe abundance.

In spite of the large body of experimental evidence which now exists not only on the particle, but also on the radio, optical, ultraviolet and X-ray emission, and in spite of extensive theoretical studies, there still is no theory of the solar flare which is able to explain all of the characteristics associated with particle acceleration. Numerous theories have continued to appear using different approaches including both one stage and multi-stage models. There now seems, however, to be general agreement that the energy source is the magnetic fields in the environment of a solar flare. The neutral sheet-plasma instability concept still seems a likely possibility for the final acceleration, but no one yet appears to have entirely satisfactory theoretical solutions for all aspects of this concept. Yeh and Axford (1970) have treated this problem well, and Sakurai (1972) has devoted a portion of a book to the general problem of solar particle acceleration.

The propagation of energetic solar particles from the Sun to the earth is now known to be a very complex problem. There appears to be good evidence to suggest a trapping region near the Sun wherein there is diffusion around the Sun, and leakage into the magnetic field lines. This picture has been developed and made more general by Lin *et al.* (1969), who also included the effect of solar rotation.

Rao *et al.* (1971) have made extensive studies on solar proton anisotropies in the energy range from 0·7 to 55 MeV with the following conclusions related to propagation. The large field aligned anisotropies which are observed during the rise time of a flare event change to an equilibrium anisotropy coming radially from the sunward direction due to the convective removal of the solar particles. At very late times during the decay ($T > 4$ days) the anisotropy is observed to be from a direction $\sim 45°$E of the satellite-Sun line which is interpreted as indicative of positive density gradient of solar cosmic ray population.

Additional results on energetic solar particles are given in the many papers presented at the XII International Cosmic Ray Conference in Tasmania in 1971 and contained in Section 5 (SOL) of the *Proceedings*, as well as the standard scientific journals.

10. SOLAR WIND DISTURBANCES

J. Wilcox

Review papers on solar wind plasma and magnetic fields were written by Hundhausen (1972a, b), Kavanagh *et al.* (1970), Burlaga (1971), Kovalevsky (1971), Schatten (1971), and Davis (1972).

A comprehensive discussion of these subjects is included in the proceedings of the Conference on the Solar Wind edited by C. P. Sonett, P. J. Coleman, Jr., and J. M. Wilcox, including reviews of Photospheric Magnetic Fields by Robert Howard, Coronal Magnetic Fields and the Solar Wind by Gordon Newkirk, Jr., Large-Scale Properties of the Interplanetary Magnetic Field by Kenneth H. Schatten, The Interplanetary Magnetic Field by Leverett Davis, Jr., Present Developments in Theory of the Solar Wind by E. N. Parker, The Large-Scale Structure of the Solar Wind by John H. Wolfe, Microstructure of the Interplanetary Medium by L. F. Burlaga, Microscale Fluctuations in the Solar Wind by Aaron Barnes, Interplanetary Shock Waves and the Structure of Solar Wind Disturbances by A. J. Hundhausen, Comparison of Deep Space and Near-Earth Observations of Plasma Turbulence at Solar Wind Discontinuities by F. L. Scarf, R. W. Fredricks, and I. M. Green, Observations of the Solar Plasma Using Radio Scattering and Scintillation Methods by A. Hewish, Spacecraft Observations of the Solar Wind composition by S. J. Bame, Elemental and Isotopic Abundances in the Solar Wind by Johannes Geiss, The Interaction of the Solar Wind with the Interstellar Medium by W. I. Axford.

Propagating interplanetary shock waves are often accompanied by energetic charged particles in the range of 1 MeV. The particles are probably accelerated in the interplanetary medium by some process involving the interplanetary shock (Armstrong *et al.*, 1970; Datlowe, 1972). In some cases the energy gain may come from successive reflection between the Earth's bow shock and the interplanetary shock (Ogilvie and Arens, 1971). Singer and Montgomery (1971) found that the proton energy spectrum does not extend beyond 5 MeV, the protons often possess unusually large streaming anisotropies, and that the peak of the intensity can occur as much as 3×10^5 km on the sunward side of the shock front. Previously proposed models such as that of Fisk (1971) cannot completely explain these observations.

Multi-spacecraft observations indicate that interplanetary shocks retain their identity over distances of at least 0·1 AU (Lazarus *et al.*, 1970) and often are highly oblique to the ecliptic (Greenstadt *et al.*, 1970). Oblique and weak reverse and forward slow shocks were found by Burlaga and Chao (1971). A forward-reverse shock ensemble was identified by Dryer *et al.* (1972). The relation of a fast shock wave in the solar wind and the corresponding geomagnetic disturbance was discussed by Ivanov and Mikerina (1970). Theoretical discussions of these phenomena were given by Dryer (1970), Eviatar and Dryer (1970), Chao and Goldstein (1972), Tam and Yousefian (1972), and Unti *et al.* (1972).

Helium rich plasma regions following several hours behind interplanetary shocks have been interpreted as a driver gas for the shocks. The ratio of the helium to hydrogen plasma velocities was strongly peaked around 1·0 (Robbins *et al.*, 1970), but at times the helium particles have an independent time history (Formisano *et al.*, 1970). The average percentage of helium increases with the solar wind velocity (Hirshberg *et al.*, 1972b).

Solar wind plasma observations within the solar latitude range of $\geqslant 7°$ that can be sampled from the ecliptic, reveal high average densities and low average flow speeds near the solar equator and

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low average densities and high average flow speeds at the largest latitudes that can be observed (Hundhausen *et al.*, 1971,; Vladimirsky and Levitsky, 1970). Gosling (1971), Gosling and Bame (1972), and Gosling *et al.* (1972a) suggest that four days is a typical time interval over which significant changes occur in the flow speed of the solar wind emanating from a particular solar region. The correlated variations of plasma and field parameters observed within interplanetary magnetic sectors earlier in the sunspot cycle were confirmed by Ness *et al.* (1971). Since magnetic sector boundaries are often observed to persist for many solar rotations, the solar wind plasma should have some properties that are stable over similar intervals of time. The yearly distributions of solar wind bulk speeds during the years 1962–1970 were found to be remarkably constant from year to year (Gosling *et al.*, 1971). Compressions and rarefactions in the solar wind were studied by Gosling *et al.* (1972b), the energy transfer at colliding streams in the solar wind was studied by Burlaga *et al.* (1971), and the energy and mass content of high-speed solar-wind streams was shown to be typically a small fraction of the total energy and mass of the normal solar-wind plasma in a typical solar rotation by Montgomery *et al.* (1972).

In a study of the magnetic field structure in flare-associated solar-wind disturbances, Schatten and Schatten (1972) found on the average a tendency for the azimuthal field component to increase. Alekseyev *et al.* (1971) found that disturbances of the interplanetary magnetic field that are small near the Sun can increase with distance. Solar wind disturbances were associated by Belcher and Davis (1971) with large amplitude, non-sinusoidal Alfvén waves propagating outward from the Sun with a broad wavelength range from 10^3 to 5×10^6 km. Coleman and Rosenberg (1971) and Rosenberg *et al.* (1971) found that between heliographic latitudes $\pm 7°$ the interplanetary magnetic field on the average is directed slightly poleward of the radial direction. Wilcox and Scherrer (1972) confirmed an earlier suggestion of Rosenberg and Coleman that there is an annual variation in the predominant polarity (toward or away from the Sun) of the interplanetary field. Severny *et al.* (1970) and Scherrer *et al.* (1972) found that changes in the sector magnetic polarity of the observed interplanetary field could be closely correlated with the large-scale photospheric magnetic field. The evolution of the interplanetary sector structure in the present sunspot cycle was discussed by Wilcox and Colburn (1970, 1972).

Solar wind disturbances have been observed through the interplanetary scintillation of natural radio sources by Houminer (1971), Houminer and Hevish (1972), Coles and Maagoe (1972), and Armstrong and Coles (1972), and by Wiseman and Dennison (1972). The results are in general agreement with spacecraft observations in the ecliptic. The radio scintillation observations offer a unique opportunity to observe the solar wind disturbances out of the ecliptic. There is some evidence for an increase of solar wind velocity at larger heliographic latitudes and for an increase in disturbances out of the ecliptic, but these results are tentative at the present time. Another radio observation of solar wind disturbances has been done by Croft (1971) using coherent phase-modulated signals at 50 and 423 MHz transmitted to specially equipped spacecraft orbiting the Sun. Extensive theoretical analyses of interplanetary scintillations have been given by Lovelace *et al.* (1970), Jokipii and Hollweg (1970), Jokipii (1970), Jokipii and Lee (1972), Hollweg (1970), Kotsarenko *et al.* (1970), Matheson and Little (1971), Buckley (1971), and Cronyn (1972).

11. SOLAR TERRESTRIAL RELATIONS (1970–1972)

Constance Sawyer

11.1. *Solar magnetic field*

Diurnal variation of the geomagnetic field at high latitudes provides a reliable daily index of the polarity of the interplanetary magnetic field over 4 solar cycles – Friis-Christensen *et al.* (1971). Svalgaard (1972a, b) describes the solar cycle evolution of sector structure derived from these data. The data show, overlying the sector structure, an annual variation of the dominant polarity, corresponding to the dominant polarity at the solar pole that is tipped earthward (Rosenburg and Coleman, 1969; Wilcox and Scherrer, 1972). The annual wave reverses phase 2 to 3yr after activity

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maximum. Russell and McPherron (1972) explain the semiannual variation of geomagnetic disturbance in terms of the southward interplanetary-field component, perpendicular to the Sun–Earth line and coplanar with it and the geomagnetic dipole axis, the same component shown by Arnoldy to be strongly correlated with the A_E index of the geomagnetic substorm, and supposed to be a measure of merging of interplanetary with geomagnetic field lines. It also gives the first explanation of the 22-yr cycle in geomagnetic disturbance discovered by Chernosky (1966). Oksman (1971) proposes that a southward component of the interplanetary field leads to contraction of the magnetosphere and plasmasphere and to systematic diurnal, annual and solar-cycle variations of the ionospheric and magnetospheric phenomena such as the location of whistler roots, geomagnetic pulsations, and F-region electron-density trough; these terrestrial manifestations thus become potential indicators of the orientation of the extended solar field.

11.2. *Solar activity and geomagnetic disturbance*

Recurrent geomagnetic disturbances are associated with inactive solar regions by Hundhausen (1972), with solar regions of open field lines by Oster *et al.* (1972), and with coronal equatorial arches by Sawyer and Hansen (1972). Dodson and Hedeman (1972a) estimate that 27% of geomagnetic disturbances belong to recurrent series, and that 58% are associated with flares with strong emission of Hα, radio frequencies, X-rays and energetic particles; 15% of the disturbances remain unexplained.

11.3. *Cosmic rays*

Forbush decreases are related to active regions, as well as to individual flares (Ballif *et al.*, 1971; Milovidova and Nefedev, 1971). Asymmetries of the world-wide pre-Forbush increase measure the tangential component of the interplanetary magnetic field at the responsible shock or discontinuity, and the solar distance of shock-wave generation (Dorman *et al.*, 1972; Kuzmicheva *et al.*, 1972). Certain Forbush decreases are associated with discontinuities in the 11-yr modulation (Stoker and Carmichael, 1971; Lockwood *et al.*, 1971). Interaction between solar cosmic-ray density or density gradient and solar-wind velocity are described, in quite different ways, by Pathak and Sarabhai (1970) and by Dorman (1970). An 80-yr variation in cosmic-ray response to solar activity is described by Neher (1971). G. C. Reid (unpubl.) compiled a list of PCA events as part of an international effort to describe particle events and solar activity (Dodson and Hedeman, 1972b).

11.4. *Ionospheric effects of flares*

Donnelly (1971) uses the sudden frequency deviation of an ionospherically transmitted high-frequency signal to measure a burst of solar EUV radiation. Amplitude and phase variation of a VLF signal depend on flux and spectrum of the X-ray burst below ~ 12 Å (Barletti and Tagliaferri, 1969; Sengupta, 1971a; Kimpara and Nishiwaki, 1971; Jones, 1971; Kaufmann and Mendes, 1970). Ohshio (1971) describes 4 cases of negative SPA occurring under conditions similar to those he predicted earlier.

11.5. *Solar–weather relations*

Objective measures of meridional circulation or of vorticity have sharpened the relation between solar-particle influx and growth of pressure troughs (Roberts and Olson, 1972a, b; Loginov and Sukhomazova (1970, 1971). Balasubrahmanyan and Venkatesan find that planetary luminosities, perhaps related to cloud cover or to atmospheric extent, vary in phase with solar activity, the amplitude being $\sim 20\%$ for the giant planets, Jupiter and Saturn. Kondratyev and Nikolsky (1970) discuss the non-linear dependence of the solar constant on solar activity, and Budyko (1969) describes the sensitivity of extent of glaciation to atmospheric transparency. Bray (1970, 1971) relates glacial advances to periods of low solar activity.

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11.6 *Data*

World Data Center A has published, in addition to regular monthly solar and geophysical data, several compilations on special events (1970–1972).

12. PRIORITIES

We believe that the major direction in which priority should be placed to facilitate the understanding of solar activity lies in the provision of space and ground based observatories specifically designed to complement each other's capabilities. Only with such a facility could we most efficiently obtain the data needed to clarify the basic phenomena underlying the different manifestations of solar activity, and so begin to understand the nature of the forces controlling the environment of the Earth in the solar system, an environment whose significance to our planet we are only now beginning to appreciate.

Major advances in space instrumentation during the past few years have increased the achievable spatial, spectral, and temporal resolution of solar satellite observations to the point where they can now match ground based equipment. Correspondingly, it is now possible to design coordinated experiments using these two approaches as equal partners in attacks on basic problems in solar activity. These facts provide at once the motivation and the force behind this recommendation.

We believe, too, that the need is immediate – unless the concept is begun soon and pursued vigorously the opportunity to study the next maximum will be lost. If that were to happen it would be 20 yr from now before an efficient, incisive, and comprehensive attack on solar activity could be launched. This would surely lead to a loss of the vigor that has characterized solar physics, especially during the past decade. We believe also that the *need* for an understanding of the basis of solar activity will become clear and, to satisfy this, hastily drafted and poorly planned expedients will be brought into being unless an adequate plan is created now and sufficient commitment given to allow it to become a reality.

As a part of such a program we believe great emphasis should be given to maximizing the achievable spatial resolution on both ground and satellite borne instrumentation since recent studies have left many workers convinced that the origin of solar activity will become clear only when we can study the Sun's atmosphere for extended periods in as fine detail as we can now achieve only rather fleetingly.

J. T. JEFFERIES
President of the Commission

WORKING GROUP ON SOLAR ACTIVITY COOPERATIVE

Although worldwide cooperation in surveying activity has had a long history, the continuation of international programs in this area is compromised by several factors, in particular by an overall decrease of financial support which has led to concentration of our limited resources and efforts on the large research instruments. In such a situation we believe it important not to lose sight of the fact that systematic data on the 'full disk' state of solar activity is still, and will remain, of great significance to students both of the Sun and of the Earth and its environment. As examples, we note that the large quantity of space data (e.g., on X-rays, EUV particles, and fields) cannot be fully studied without the supporting data obtained in classical ground-based optical and radio surveys; the same applies to magnetospheric observations.

Nor can we always know what critical future needs will be satisfied by our systematic daily surveys. An obvious example is the daily measure of sunspot area, others are provided by the Cartes de la Chromosphère and the Mount Wilson magnetograms which for years at a time have attracted little interest and quite suddenly have emerged as source data of inestimable value in quite unanticipated studies. Thus, while we should always be cautious in expanding the scope of solar activity

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