COMMISSION 10 : SOLAR ACTIVITY (ACTIVITE SOLAIRE)

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In preparing this report, which covers the period July 1, 1987, to June 30, 1990, close collaboration has taken place between the two solar commissions (10 and 12), in order to avoid duplication and to ensure that appropriate topics are treated. Further information on solar physics may be found in the report of Commission 12. It is a pleasure to thank the reviewers who wrote the different sections of this report, which demonstrate the active and lively state of our subject. Unfortunately, two topics that we had hoped to include, namely "active regions" and "solar activity from space observations", were unable to be completed in time, but they are to some extent covered in Sections 7 and 6.

1. OBSERVATIONS AND MODELLING OF SUNSPOTS

(P Maltby)

The interest in investigations of sunspots extends outside solar physics. One reason is that it involves studies of the effects of a magnetic field, a topic of general interest in astrophysics. During the period 1987-1990 few scientific meetings concentrated on sunspots or the solar cycle (Wilson, 1987,1988). However, research on sunspots was a topic at several meetings, such as, on the Sun (Hejna and Soboka, 1987) the photosphere (Stenflo, 1990), the fine-scale magnetic fields (Schröter *et al.*, 1987), secular solar and geomagnetic variations (Stephenson and Wolfendale, 1988).

1.1 SUNSPOT PROPERTIES

Studies of the Mount Wilson white-light plate collection show that the sunspot umbral areas are distributed lognormally (Bogdan *et al.*, 1988). The Greenwich photoheliographic results 1874-1976 as well as the first catalogue prepared in Debrecen (Dezso et al., 1987) are discussed by Dezso (1987). The well known Maunder's "butterfly diagram" displays the distribution of sunspots/sunspot groups in time and in heliocentric latitude. Until recently studies of the pattern in solar longitude have been given less attention. Evidence for the existence of opacity sources other than H^- in the visible umbral spectrum were given by Baranovskij and Shcherbakova (1987). Chou (1987) claimed to have detected an intensity difference between growing and stable sunspots. It should be noted that extremely good observing conditions, combined with a proper stray light correction method are required to determine with any accuracy the intensity and other physical parameters of small to medium size sunspots. Spectrophotometric analysis of small sunspots suggests higher temperatures than in cold sunspot models according to Stellmacher and Wiehr (1988). The observed fine structures of umbral dots (Garcia de la Rosa, 1987) and penumbral filaments (Shine et al., 1987; Collados et al., 1988) show dynamics in structures with dimensions comparable to the scale height. The diagnostics of sunspot regions from visible and UV observations were reviewed by Lemaire (1987). The diagnostic value of the molecular VO bands was discussed by Singh and Chaturvedi (1989).

Measurements of the umbra/penumbra area ratio and of sunspot and plage intensities have been carried out by Lawrence (1987) with the intension of clarifying the effects of sunspots on solar irradiance variations. Further discussions are given by Hudson (1988), Fröhlich and Pap (1989), Intermediate-term solar periodicities have been studied and the 155 day period is reported to be present in flare activity, the sunspot blocking function, the 10.7 cm flux, and the sunspot number (Lean and Brueckner, 1989). In addition a 216 day periodicity has been noted (Hoegy and Wolff, 1989) in the Pioneer Venus Orbiter measurements of solar EUV radiation.

1.2 MAGNETIC FIELD

Interpretation of magnetic field observations demands an understanding of the theory of spectral line formation in the presence of a magnetic field. Considerable efforts have been devoted to the solution of the Unno-Rachkovsky equations, including the magneto-optical effect (Ye and Jin, 1987; Rees *et al.*, 1989; Landi degl'Innocenti, 1987). The sunspot magnetic field is observed to be coaligned with penumbral filaments (Bachmann, 1988). New measurements of the magnetic induction and field inclination have been presented (Lites *et al.*, 1989; 1990; Lites and Skumanich, 1990), and the effects of noise on sunspot

D. McNally (ed.), Reports on Astronomy, Vol. XXIA, 53–84.

magnetic field measurements have been pointed out by Linke and Utrobin (1990). Methods giving information about the magnetic field in the corona include the use of the vertical gradient of the field (Hofmann and Rendtel 1989; Gusejnov, 1988), the deviation from a potential field (Hagyard, 1988; Linke *et al.*, 1989), and from force-free models (Lin and Wu, 1987).

Increased accuracy in the observations of the penumbral magnetic field is possible through measurements of the infrared line of MgT at 12.32μ (Deming *et al.* 1988). The magnetic splitting of the line follows the Paschen-Back pattern, with a Landé factor of unity (Lemoine *et al.*, 1988). Zirin and Bopp (1989) argued that the line was formed in the chromosphere.

Broad band polarization observations have hitherto been of limited diagnostic value (see Makita, 1988). A better theoretical calculation of the spectrum, taking into account the blends present and the magnetic intensification (Leroy, 1989; Leroy and LeBorgne, 1989) may improve this situation. Radio observations and modelling of the atmosphere above sunspots (Chiuderi Drago *et at,* 1987; Urpo *et al.*, 1987; Krüger and Hildebrandt, 1988), combined with radio-wave diagnostics (Karlicky and Krüger, 1987) may give information on the structure of the coronal magnetic field (Brosius and Hofman, 1989).

1.3 FLOWS

The motion away from the sunspot, across the surrounding moat, is of another character (Brickhouse and LaBonte, 1988; Muller and Mena, 1987; Nye *et al.*, 1988) than the Evershed flow in the penumbra, observed in various "photospheric" lines (Ichimoto, 1987; 1988). The sharp decrease in the magnitude of the Evershed velocity close to the penumbral rim is still not fully understood (Wiehr and Balthasar, 1989). Some observers confirm that the highest Evershed flow speeds occur in the dark penumbral filaments (Wiehr *et al.*, 1987; Bida *et al.*, 1990), whereas others (Wiehr and Stellmacher, 1989; Lites *et al.* 1990) question this assertion. White light observations confirm the finding that penumbral grains move in the opposite direction to the Evershed flow, ie, towards the umbra (Shine *et al.*, 1987; Zirin and Wang, 1989). Furthermore, a time variation has been reported (Shine *et al.*, 1990). One alternative to a fluid motion interpretation of the white light observations may be propagation of distortions at flux tube boundaries (Maltby, 1989).

The inverse Evershed flow, directed towards the umbra along superpenumbral filaments, has been observed in the $H\alpha$ line by Alissandrakis *et al.* (1988) and Dere *et al.* (1990). Their interpretation in terms of a subsonic siphon flow contradicts earlier findings where the driving force along individual flux tubes was regarded as being able to give subsonic solutions in some position angles, but supersonic solutions in others within the same sunspot region.

The structure of the large-scale flow field in relation to the magnetic structure of the active region has been studied (Klimchuk, 1987). With higher spatial resolution both upflows and downflows are observed (Kjeldseth-Moe *et al.*, 1988). Large disturbances in the transition region flow field may be introduced by an emerging flux region (Brueckner *et al.*, 1988). If the line shift of CIV is derived from the wavelength moment and if axial symmetry in the flow field is assumed, subsonic flow speeds are deduced (Dere *et al.*, 1990). On the other hand, line profile studies give evidence of regions with supersonic downflows (Kjeldseth-Moe *et al.*, 1988). Regions with supersonic downflow may either be of limited spatial extent, 4-6 seconds (Kjeldseth-Moe *et al.*, 1988) or more extended (Brekke *et al.* 1987). Observational evidence for a sub-resolution fine structure (Kjeldseth-Moe, 1989) and multiple flow speeds within the one arc second resolution element (Brekke *et al.*, 1987) have been presented.

The flow pattern in the sunspot area is in general agreement with the siphon flow hypothesis, but some deviations appear to be present (Kjeldseth-Moe *et al.*, 1988). Thomas (1988) and Montesinos and Thomas (1989) have presented a theoretical study of the flow in isolated flux tubes, with possible application to the Evershed flow at photospheric heights.

1.4 OSCILLATIONS

New knowledge on both the sunspot atmosphere and the interaction of a magnetic field with solar oscillations may come from the observed oscillations in the sunspot region. Oscillation periods close to 3 minutes in MgII k (Gurman, 1987) and 5 minutes in FeI (Balthasar *et al.*, 1987) are observed; see also Vial and Bellout (1987) and Lites (1988). An observed variation in the height of formation of the $H\alpha$ and Na D lines in the sunspot atmosphere with a period in the 3 minute range has been reported (Mattig and Zerfass, 1988). In the debate on the interpretation of oscillations in the sunspot atmosphere, quite sophisticated models including cavities (eg, Locans *et al.*, 1988; Campos, 1989; Abdelatif, 1988), as well as simple models (Yun and Lee, 1988; Evans and Roberts, 1990) have appeared.

Absorption by the sunspot of externally impinging p-mode waves have been detected by Braun *et al.* (1987,1988). Observations of this kind may give us knowledge about the subsurface structure of sunspots. Bogdan (1989) has reviewed the proposed wave absorption and wave scattering mechanisms (Abdelatif and Thomas, 1987; Hollweg, 1988; Grossmann and Smith, 1988; Hollweg and Yang, 1988; Poedts *et al.*, 1989; Lou, 1989; Campbell and Roberts, 1989; Bogdan, 1989a, Bogdan and Knölker, 1989; Evans and Roberts, 1990a).

1.5 SEMI EMPIRICAL AND THEORETICAL MODELS

Semi-empirical model atmospheres of the umbra containing respectively an extended temperature minimum (Lites *et al.*, 1987) and two components (Obridko and Staude, 1988; Sobotka, 1988) have appeared. Attempts to construct models for umbral light bridges (Sobotka, 1989) and penumbrae (Ding and Fang, 1989) have been published. It has been suggested (Fontenla *et al.*, 1990) that ambipolar diffusion strongly influences the energy balance in the solar atmosphere; this assumes that dynamical processes are unimportant.

Although analytical magnetostatic models (Osherovich and Garcia, 1989) are of interest, the focus has shifted to numerical solutions (Pizzo, 1987; Jahn 1989). In a study of the adiabatic instability of sunspots to convective motion, Moreno-Insertis and Spruit (1989) find a growth time of 18 minutes and note a connection between the fluting and convective instabilities. The effect of stratification on non-linear compressible magnetoconvection is to introduce a complicated oscillatory behaviour when the Boussinesq approximation is removed (eg, Hurlburt *et al.*, 1989). Weiss *et al,* (1990) studied an idealised model, whereas Stein and Nordlund (1989) have tried to simulate the sunspot atmosphere. The penumbra is very probably in a quasistatic equilibrium except with respect to motion along the field (Spruit, 1989); see Busse (1987) for an alternative view.

1.6 SUNSPOT CYCLE

The discovery by GE Williams in 1981 of layered sediments of the Elatina Formation of South Australia has attracted attention, and the periodicity has been attributed to the solar cycle (Sonett and Williams, 1987; Bracewell, 1988). New data by Williams have prompted Sonett *et al* (1988) and Williams (1988;1989) to propose a lunar-solar tidal interaction model as the source of the laminae.

A catalogue of naked eye sunspot observations from 165 BC to AD 1684 has been published (Wittmann and Xu, 1987). Further discussions of the historical records are given in Stephenson and Wolfendale (1988). Investigations of the sunspot cycle include studies of its statistical properties (eg, Wilson *et al.*, 1988), the Maunder minimum (Kopecky and Kuklin, 1987), the inclination of the bipolar axis (Ivanov, 1987), different classes of sunspots (Kuklin and Kopecky, 1988), proper motion (Marquette and Martin, 1988), decay rates of groups (Moreno-Insertis and Vázques, 1988), torsional oscillations (Snodgrass, 1987), and forecasts (eg, Wilson, 1988). Dicke (1988) has found that the phase fluctuations of the cycle is compatible with the magnetic field being carried to the surface by convection, and Weiss (1988) has discussed the solar cycle as an example of deterministic chaos.

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2. PROMINENCES

(E Tandberg-Hanssen and J M Fontenla)

2.1 INTRODUCTION

The 3-year period covered by this report (1987-1990) has seen a vigorous growth in the interest in prominence research. This interst has manifested itself in the occurrence of a number of workshops, symposia, and special meetings whose topics have included most areas of prominence physics. The publication of many important papers on prominences bears witness to the vigor of this field of solar physics research.

The major prominence-related meetings conducted in the 1987-1990 period were held at Palma de Mallorca, Spain, November 1987 (Proc. Workshop Palma de Mallorca, 1988), and at Hvar, Yugoslavia, September 1989 (Proc. IAU Symposium No 117, 1990). The book *Dynamics and Structure of Quiescent Solar Prominences* (Priest 1989), which resulted from the Workshop at Palma de Mallorca, contains a series of excellent overview articles on most areas of prominence research, viz, properties and flows (Schmieder), prominence environment (Engvold), magnetic fields (Leroy), formation (Malherbe), structure and equilibrium (Anzer), and stability and eruption (Hood). A concise review of quiescent prominences has been given by Zirker (1989).

It has been customary to divide the study of prominences into two classes, quiescent and active. It may, however, be more appropriate in the light of the recent developments to consider three types, viz. stationary (quiescent and active region), eruptive, and flare-related prominences. For example, a prominence seen in H_α in absorption against the solar disk is referred to as a filament. Some of the stationary prominences are related to active regions, and are generally low-lying and seen as active region filaments. Other staionary prominences appear out of active regions at high altitudes and are well observed as quiescent prominences above the limb.

There is strong evidence that many forms of very dynamic prominences are genuinely parts of the flare phenomenon, and should be treated in that context. For this reason we will not discuss them here, and we refer to the special symposium on eruptive flares which is held after the General Assembly. However, many eruptive prominences appear unrelated to optical flare phenomena and we will consider them below.

2.2 STATIONARY PROMINENCES

It has become increasingly clear in later years that quiescent prominences are associated to dynamic structures and often also to very dynamic features. The velocity fields associated with the prominence plasma and its surrounding have been studied by Noëns, Schmieder and Mein (1988), Schmieder (1989), Engvold (1989) and Schmieder *et al.* (1988). Periodic and quasi-periodic velocities were investigated by Balthasar, Stellmacher and Wiehr (1988) in the context of their eigenmodes. Hanaoka and Kurokawa (1989) studied mass motions in active region filaments and found flows generally along the long axis of the filament. The presence of velocity shear and microturbulence has been investigated by Mein and Schmieder (1988).

The importance of the fine structure of prominences for our understanding of their evolution as well as their equilibrium and energy balance has been studied by Démoulin *et al.* (1987), Ballester and Priest (1988, 1989), Zirker and Koutchmy (1990) and others. The height of prominences was studied by Kim *et al.* (1988a) who found a sharp decrease in the number of prominences reaching more than 30 000 km into the corona.

The role of the all-important magnetic fields in prominences has been investigated by Kim *et al.* (1988b) and Leroy (1989) from an observational point of view. These authors characterize the normal (N) and inverse (I) polarity configurations, a notation introduced by Priest (1989), who pointed out that N type polarities would apply to the Kippenhahn-Schlüter model, while the Kuperus-Raadu model would be associated with I type polarity configurations. Molodensky and Filippov (1988) studied the transverse field by using observations of H_α fibril orientation. Hood and Anzer (1990) developed a two-dimensional magnetostatic model. The interpretation of magnetic field observations and the theoretical modeling implications of the magnetic field for formation, support and stability of the magnetic field have been subject of extensive research (Amari and Aly, 1988; Aly and Amari, 1988; Bommier, Landi Degli'Innocenti and Sahal-Brechot, 1988; Démoulin and Priest, 1989; Osherovich, 1988; Rompolt, 1988; Démoulin, Priest and Anzer, 1989). Research on a three-dimensional model of prominences has been published by Wu and Low (1987) and Priest, Hood and Anzer (1989). Yeh (1989) has studied a dynamical model of prominence loops, regarded as flux ropes, and Sakai, Colin and Priest (1987) investigated a model for prominence formation in a current sheet between two regions of opposite polarity.

The prominence formation was also studied in relation to the thermal processes leading to the condensation. The proposed models include injection of chromospheric plasma into closed loops, due to surge (spicule) activity or evaporation (Démoulin and Einaudi, 1988; Wu *et al,* 1988; An *et al* . 1988; Poland and Mariska, 1988; Mok *et al.* 1990). One difficulty still to be overcome is the high value of the plasma-β required in some of these simulations, which does not seem consistent with observations. Recent simulations by Sparks, Van Hoven and Schnack (1990) show that condensational instabilities in a sheared magnetic field can generate filamentary structure.

The physical characteristics, ie, temperature and density, of the prominence plasma have been determined by different methods, including one proposed by Brickhouse and Landman (1987), where the ratio OI (7774)/NaD_2 is used to give kinetic temperatures in the range 5500-9000 K (Zhang *et al.* 1987). The electron density is found to be between 10^{10} cm^{-3} and a few times 10^{11} cm^{-3} in quiescent prominences, while erupting prominences (see Section 2.3) may have electron densities up to 10^{12} cm^{-3} and a few times 10^{12} cm^{-3} before eruption (Athay, Low and Rompolt, 1987; Foukal, Little and Gillian, 1987). Conditions in quiescent prominences and the prominence-corona transition region have also been investigated using radiative transfer methods and UV observations (Heinzel and Rompolt, 1987; Heinzel, Gouttebroze and Vial, 1988) while Rompolt (1988) and Bendlin, Stellmacher and Wiehr (1988) used optical data, and Kim (1987) studied the NaI D line, in particular arriving at values for temperature and number density of at least 5000 K and 4 x 10^{11} cm^{-3}, respectively. Wiehr, Bendlin and Stellmacher (1988) used CA II and H lines to derive optical thickness, turbulence values, and gas pressure for quiescent prominences.

Toot and Malville (1987) have studied centrally reversed Hα emission profiles in certain areas of quiescent prominences and interpret them as the result of ongoing condensation of coronal material. The relationship of a small transient, but probably not flare-related, prominence to a coronal condensation was studied by Suematsu *et al.* (1988).

While most information on the behaviour of quiescent prominences comes from the UV or optical part of the spectrum, Lang and Willson (1989) have studied radio emission from these objects at 91.6 cm wavelength, and concluded that the emission may be attributed to thermal Bremsstrahlung from a prominence-corona transition region. Landi Degl'Innocenti, Bommier and Sahal-Brechot (1987) and Bommier, Landi Degl'Innocenti and Sahal-Brechot (1988) have studied the theory of the linear polarization and Hanle effect of the Balmer lines in prominences.

Quiescent prominences are usually subject to sudden disappearances. These "disparitions brusques" (DBs) may be either dynamic in nature - the original definition, and caused by an instability in the supporting magnetic field (Raadu *et al.* 1988) which transforms a stationary into an eruptive prominence - or thermal (DBt), as studied by Mouradian *et al.* (1987), Mouradian and Soru-Escaut (1989), and Soru-Escaut and Mouradian (1990) where the plasma is heated, leading to hydrogen ionization and the apparent disappearance of the Hα prominence. A statistical study by Mouradian *et al.* (1987) found that locations where filaments rotate rigidly with respect to the mean solar rotation, "pivot points", are associated with active centers where the emergence of magnetic flux appears related to a reduced speed of filament rotation about the pivot point.

2.3 ERUPTIVE PROMINENCES

These prominences seen in cool lines (eg, Hα) display large-scale rapid motions. They often have related coronal mass ejections (CMEs) and erupting active region prominences are often associated with Hα flares. We exclude from the present review the flare-related prominences. Vizoso and Ballester (1987) made statistical study of the north-south asymmetry in the distribution of DBs for solar cycles 18-21. MacQueen and Holzer (1988) discussed the prominence-CME relationship for a well-observed event from the SKYLAB period, and Gopalswamy and Kundu (1989) reported observations of a moving type IV burst associated with a filament eruption.

Helical motions have been observed in eruptive prominences. House and Berger (1987) and Prokakis and Tsiropoula (1988) studied in detail the helicity and its evolution from prior to lift-off until the passage of the material through the outer corona. Vrsnak *et al.* (1988) and Vrsnak (1990) discussed the evolution and implications of such twisted fields, and Vrsnak *et al.* (1990) investigated oscillations of a prominence due to its eruption. Athay, Low and Rompolt (1987) studied the evolution of density and characterized the mass expansion associated with prominence eruptions. They found that the expansion cannot be described by a self-similar expansion unless one allows the expansion velocity to be a function of the direction.

Steele and Priest (1989) modeled a magnetically coupled prominence and mass ejection and suggested that this arrangement drives the reconnection below the prominence rather than the inverse. Raadu *et al.* (1987) modeled the dynamics of a filament ejection using both thermal and magnetic driving forces, finding better agreement for the latter.

A theoretical model of prominence formation and eruption, triggered by magnetic cancellation in a sheared magnetic arcade which gives rise to helical fields, was developed by van Ballegooijen and Martens (1989). Other theoretical studies by DeBruyne and Hood (1989a,b) discuss the stability of various magnetic configurations and the role of shears, based on energy principles. Priest, Hood and Anzer (1989) proposed a model where a twisted prominence with normal polarity can undergo reconnection and pass to the inverse polarity. If the flux tube becomes too long or too twisted it will loose its stability and undergo a DB. This eruption has been modeled by Priest and Forbes (1900), who found a self-consistent, ideal MHD solution in the low-β limit which describes the formation of a current sheet below the erupting filament.

There is growing evidence that magnetic energy dissipation produces localized heating and nonthermal electrons in non-flare eruptive prominences. However, these processes may be similar to those in flares. From a study of several eruptive prominences Harrison, Rompolt and Garczynska (1988) concluded that also X-ray emission appears in highly localized and compact sites. Zodi *et al.* (1988) reported on radio observations and suggested that gyrosynchrotron emission from nonthermal electrons is produced in an eruptive prominence. Fontenla and Poland (1989) found, from UV line studies, substantial heating in a section of a polar crown prominence eruption.

Measurements of Paschen-line Stark-broadening by Foukal, Little and Gillian (1987) show that 10 V cm^{-1} is an upper limit to the macroscopic electric fields in an eruption, and they conclude that the observed line shape is consistent with pressure broadening. Heinzel and Rompolt (1987) have studied theoretically the Doppler brightening and dimming effects in Balmer and Lyman lines for moving prominences.

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4. MICROSCOPIC PLASMA THEORY OF FLARES

(L Vlahos)

Microscopic plasma theory is the "kinetic" part of solar flare theory and deals with topics like (a) particle acceleration, (b) particle transport and related instabilities and (c) plasma radiation theories and plasma models of flare emission. We summarize below the progress made the last three years in these three topics.

4.1 PARTICLE ACCELERATION

One potential candidate for particle acceleration is the DC Electric fields. The source and strength of the E-field during a solar flare are not known and in most studies the E-field is treated as a free parameter. Takakura (1988) studied the acceleration of electrons by a DC Electric field in the presence of ion sound turbulence. He solved numerically the time-dependent Fokker-Planck equations and found that the electron momentum distribution became a steady state in the whole turbulent region in a short time. The steady state energy distribution has a very hard power-law like spectrum with index 0.75. The bremstrahlung emission from such a distribution shows a hard spectrum with a photon index 1.3. Takakura suggested that the spectrum index can be much greater, as observed, only if many elementary loops with a power-law distribution in the strength of the E-field accelerate the electrons. Moghaddam-Taheri and Goertz (1990) studied numerically the run-away electrons in solar flares using a relativistic quasilinear code. They estimated the synchrotron emission from the run-away electrons and concluded that in order to account for the observed synchrotron emission spectrum of a typical solar flare, the electric field acceleration phase must be accompanied or proceeded by a heating phase. Diakonov and Somov (1988) studied the behaviour of the electrons that run-away from a hot plasma; they assumed that the direct current of fast electrons is compensated by the reverse current of the thermal electrons in the hot plasma. The reverse-current E-field and the distribution function of fast electrons are found in the form of an approximate analytical solution. Winglee (1989) proposed that heavy ions during solar flares are acclerated as follows. Energetic electrons generated in the primary energy release region heat the chromospheric plasma. A portion of the heated electrons run-away, as was the case in the study of Diakonov and Somov discussed above, and set-up an E-field which accelerates the ions. This field tends to produce a differential motion between the various ion species which is unstable to an ion-ion instability. As a result of this instability, some of the light ions are declerated while some of the heavy ions are accelerated up to speeds comparable to the initial speed of the light ions. It is this transfer of energy which can lead to heavy-ion enrichment higher in the corona.

Shock wave accleration of electrons and ions is also an important candiate for particle acceleration in solar flares. Cargill, Goodrich and Vlahos (1988) studied the collisionless shock formation and the prompt acceleration in solar flares. They assumed that the primary energy release of a flare loop arises in the coronal portion of a flare loop in the form of small hot spots and studied, using a hybrid numerical code, the formation of shock waves. They found that shock waves are formed in less than a second and are able to accelerate ions, in less than a second, to energies up to 10Mev. Shock formation and shock acceleraton can account for the prompt acceleration of ions observed during the SMM.

Smith and Brecht (1989) estimated the minimum Mach number for impulsive protons by parallel collisionless shock waves in solar flares and Smith and Brecht (198) compared the shock acceleration with the stochastic acceleration in solar flares. Oshawa and Sakai (1988) studied the subject of the prompt proton and electron acceleration by collisionless fast magnetosonic shock waves.

Finally particle acceleration by MHD turbulence was discussed by Miller and Ramathy (1987), but Smith and Brecht (1989) pointed out the role of nonlinear effects in fast solar flare proton acceleration by MHD turbulence and suggested that these effects should be included in detailed models.

4.2 PARTICLE TRANSPORT AND RELATED INSTABILITIES

Energetic particles are transported from the acceleration region in serveral parts of the solar atmosphere before emitting radiation. Several articles discussed the transport of energetic particles and the related instabilites.

Cromwell, McQuillan and Brown (1988) discussed the problem of ion-acoustic wave generation and resulting anomalous Joule heating, by a return current driven unstable by an electron beam in solar flares. With a prescribed beam current evolution, and using an approximate local treatment with a two-component Maxwellian plasma, and neglecting energy losses, they demonstrate the existence of two quite distinct types of ion-accoustic unstable heating regimes. First, marginally stable heating and secondly a "catastrophic" heating regime for which marginally stable evolution is impossible. LaRosa and Emslie

(1989) analyzed again the problem of beam-return current system for astrophysical conditions claiming that in solar flares the return current is principally established by electrostatic fields. The famous problem of electron or ion beam propagation in the solar atmosphere and the related instabilities was an active research topic the last three years. LaRosa (1988) analyzed the spatial structure of a nonthermal electron beam. He developed a model, based on the theory of strong turbulence for the electron beams that are responsible for the type III bursts. LaRosa concluded that stabilization of coronal electron beams (beam velocity/thermal velocity=25) requires large beam densities, and a beam of 10^4 Km in length would lose its energy in propagating a solar radius.

Hamilton and Petrosian (1987) discussed the generation of plasma waves by thick-target electron beams. They solved the coupled kinetic equations for the plasma wave and particle distributions, using inhomogenious electron beams. They showed that the wave-particle interactions have a significant , but not dominant, effect on the overall distribution of the electrons and that is unlikely that such effects can be discerned in the observed bremstrahlung or synchrotron radiation of the nonthermal electrons.

Lu and Petrosian (1989) found analytical solutions of the time-dependent Fokker-Planck equation for accelerated electrons undergoing coulomb collisions in magnetized, full ionized plasma. Hua, Ramaty and Lingenfeter (1989) developed a Monte Carlo simulation that follows individual ions throughout a solar flare magnetic loop. They include energy losses due to Coulomb collisions and MHD pitch angle scattering.

McClements (1988) discussed also the Langmuir wave generation by electron beams and the production of short timescale hard X-ray emission in solar flares. McClements (1989) analyzed the effects of density variations and reverse current on the Langmuire wave generation by thick target electron beams in solar flares.

Melrose and Cramer (1989) use the quasi-linear theory to analyze the relaxation of electron beams, propagating inside an inhomogeneous distribution of Langmuir waves. Winglee, Pritchett and Dulk (1988a, 1988b) analyzed numerically the escape of energetic electrons from a hot plasma. In these articles Winglee, Pritchett and Dulk attempted to interpret the plasma heating and bulk plasma motions to generate the observed rapid broadening of soft X-ray lines.

An important problem discussed by Tamres, Melrose and Canfield (1989) is the stability of proton beams against resonant scattering by Alfren waves in solar flare loops. They found that streaming instabilities, previously ignored, pose serious constraints on the sustained propagation of directed proton streams in solar flare loops at energies that are only a small multiple of (mass of proton) x (alfven speed) /2.

4.3 PLASMA RADIATION THEORIES AND PLASMA MODELS OF FLARE EMISSION

The theory of electron cyclotron maser instability (Vlahos, 1987) was developed further by a number of authors.

Aschwanden and Benz (1988) studied the quasi-linear evolution of the electron cyclotron maser instability. Their computations apply to the continuum and pulsating emission observed in the decimetric radio regime of solar and stellar flares. Winglee, Dulk and Pritchett (1988) examined the cross field transport of energy associated with the electron cyclotron maser instability. McKean, Winglee and Dulk (1989) used a numerical code to study the propagation and absoption of electron cyclotron maser radiation. They found that the bulk of the cross field energy goes into heating of the ambient plasma and a few electrons are accelerated to several KeV. Gopalswamy (1987)) proposed that the pulsed electron acceleration from the release volume of a flaring magnetic trap implies that there is a possibility of interaction between a group of electrons reflected from the foot of a bipolar flux tube with the newly injected beams. It was shown that the interaction can lead to the stoppage of the electron cyclotron maser instability caused by the loss cone distribution and hence can produce millisecond microwave spikes.

The problem of radio emission from coronal shock waves was re-examined by Benz and Thejappa (1988). They proposed that the radiation originate from electrons and ions energized by the shock. Shock-accelerated electrons form velocity distributions that are unstable to electrostatic waves and the accelerated ion beams excite ion acoustic and lower hybrid waves. The non-linear interaction of these waves excites high-frequency electromagnetic radiation observed as type II bursts.

Several authors studied the trap-plus-precipitation model and applied their results to solar bursts. Hillaris, Alissandrakis and Vlahos (1988) studied the dynamics of the sub-relativistic electron beams in a magnetic trap and applied their results to the recently discovered (Caroumbalos et al. 1987) N-bursts, Spicer and Emslie (1988) studied an 'electrostatic trap model' as a quasi-thermal model for hard X-ray bursts. Their model utilizes the trapping ability of a magnetic mirror and a field-aligned electrostatic potential produced by differences in anistropies of the electron and ion distributions. One of the interesting results of their analysis is that if 50% of the flare energy needs to appear in nonthermal electrons, in order to make the pure nonthermal thick target hard X-ray hypothesis work, a combination of magnetic mirror plus electrostatic potential, together with electron and ion distributions that are anisotropic, makes the demand on the flare acceleration efficiency even more severe. McKinnon (1988) re-examined the article of Melrose and Brown (1976) and pointed out that their formalism was incomplete since they used the results of Kennel and Petschek (1966) that are not intended to apply to scattering mechanisms involving energy loss. McClements (1990) solved numerically the spatially integrated Fokker-Planck equation for a trap-plus-precipation model and applied his results to hard X-ray emission. Hulot, Vilmer and Trottet (1989) use the same model for the magnetic configuration but they solved the continuity equation to analyze the evolution of electrons and ions inside a trap and examine in particular the relative timing of the solar prompt gamma ray line and X-ray emission.

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5. OBSERVATIONS FROM THE GROUND OF SOLAR FLARES

(V Gaizauskas)

Optical observations define the properties of the cool component of flare-related plasmas in the preflare, impulsive, and gradual phases of flares. Insights to problems of the storage, release, and transport of flare energy require an understanding of the relationships between cool optically-emitting structures and the hot plasmas which emit at microwave, EUV, X-ray and γ-ray wavelengths. With ever-increasing frequency, analyses of flare observations combine results from as many of these wavelength regimes as possible in single research reports. In order to minimize overlap with Sections 6 and 7, this section selects results which depend totally or in some critical way on optical observations conducted from the ground.

A broad range of flare-related topics is found in the Proceeding of IAU Colloquium 104 edited by Haisch and Rodono (1989(I) henceforth abbreviated to HAR). A limited range of topics involving optical observations are found in the Proceedings of the Chapman Conference on Physics of Magnetic Flux Ropes (1990 Russell, Priest and Lee-RPL (II)) and of the Second Workshop on Impulsive Solar Flares (1990, III). Plans and preliminary reports of flare observations for the current solar cycle as discussed during the first two Max '91 Workshops are assembled in the documents edited by Canfield and Dennis (1988, IV) and by Winglee and Dennis (1989,V). General perspectives on ground-based flare observations are contained in the monographs published by Zirin (1988, VI), Tandberg-Hanssen and Emslie (1989, VII), and by Foukal (1990, VIII).

5.1 PREFLARE CONDITIONS

The close connection between changing magnetic fields and flares observed at high resolution is stressed by Zirin (RPL, P33) and by Zirin and Wang (1990). Zirin and Tang (III, p111) find that strong field regions close to sunspots are favoured by impulsive flares, while more gradual kinds of flare may occur in either weak or strong field regions. Livi et al. (in HAR, p197) propose cancelling magnetic fields as a necessary evolutionary condition for the initiation of flares. They observe cancelling magnetic flux as the common factor among all associations between flares and changing (developing or decaying) magnetic fields; flares cease in decayed active regions (AR) when cancellation sites disappear. Complementary to these purely local changes, dynamic global coupling of the magnetic fields between a flaring site and all the bipolar regions in an activity complex is empahsized by Gaizauskas (HAR, p135). This view is reinforced by the findings of Machado et al. (1988a) for a sample of 23 flares, and confirmed for a smaller sample of flares by Mouradian et al (1989), that the basic structure of a flare consists of an initiating magnetic bipole impacted against one or more adjacent bipoles. Such widespread connectivity increases the scope for variety among preflare phenomena (Gaizauskas in HAR, p135).

Measurements of the photospheric magnetic field with vector magnetographs are used to derive the electric current density crossing the photosphere along the line-of-sight. Hagyard (1988) finds the maximum concentration of these currents exactly at the sites of the flare initiation and where the photospheric field is sheared the most. For γ-ray flares Hagyard et al.(III, p159) find that the photospheric field is sheared over a greater length of the polarity inversion line than for flarewith no γ-ray emission. By using analytic models of non-potential fields, Wilkinson et al. (1989) predict that the effects of viewing angle on the inference of magnetic shear in preflare active regions is a significant problem. An evaluation performed by Venkatakrishnan et al (1989) of the viewing effects in an active region which produced major flares indicates no significant impact on estimates of 'critical' magnetic shear. Procedures for eliminating projection effects from vector magnetogams have been worked out by Venkatakrishanan et al. (1988) and by Gary and Hagyard (1990) who also dealt with the effects of surface curvature and of the azimuthal ambiguity of the observed transverse field. The Hα morphology at high spatial resolution of highly sheared and flare-productive regions is described in detail by Kurokawa (1989).

5.2 ENERGY TRANSPORT

The optical emissions from a flare originate in a low-temperature regime and are a by-product rather than a direct signature of the primary energy release. But the need to interpret spacecraft observations of the impulsive phase of flares has spurred theory to provide diagnostics for analyzing Hα observations obtained at high temporal, spatial, and spectral resolution during that initial phase. These new diagnostic tools have been used by Wülser and Marti (1989) to show for a medium-sized flare observed with an imaging spectograph that the combined Hα and hard X-ray (HXR) signatures of two kernels are compatible with predictions for strong nonthermal electron heating and the formation of a downward-moving chromospheric condensation. A third kernel in the same flare does not have the temporal evolution predicted by electron-beam heating. Zarro and Canfield (1989) use obervations with an imaging spectrograph of Hα redshifts as a diagnostic of the pressure excess in the evaporating region for 5 flares. Coordinated X-ray observations for the same flares enable them to show that preflare coronal pressures imply such large chromospheric densities that the chromosphere can radiate the excess flare heating energy without explosive chromospheric evaporation. Hénoux et al. (III, p303) have presented observations of Hα linear polarization in a flare as evidence for atmospheric bombardment by 200-keV protons; they propose to use impact linear polarization of chromospheric lines as diagnostics of low energy protons. Neidig (HAR, p261) shows that white-light flares are not fundamentally different from ordinary flares, yet their huge radiative losses are difficult to explain in terms of known mechanisms of energy transport.

Svestka (HAR, p399) recognizes two kinds of gradual phases in flares: one in which no energy is released and only cooling follows the impulsive phase (confined flare) and the other kind in which energy release continues (dynamic flare). The 'flaring arches' studied by Martin and Svestka (1988) and by Svestka et al. (1989) are a basic characteristic of dynamic flares with distinct consecutive phases: an early phase at the onset of an HXR burst accompanied by Hα brightening excited by particle streams at a remote footpoint; a hot conduction front producing X-rays in the least dense plasma followed by decelerating and denser plasma eventually visible in Hα; an aftermath when some ejected matter returns towards the primary site of energy release. Similar characteristics in energy transport have been deduced from combined Hα and X-ray observations by Machado et al. (1988b), Kurokawa et al (1988), and by Kitahara and Kurokawa (1990). The detection of point-like enhancements in Hα plages at the footpoints of giant post-flare coronal arches lead Martin et al. (1989) to infer a fine structure in the coronal arches which is not perceptible in low-resolution X-ray images. From the location and behaviour of these brightenings, it is deduced that the arches are either a long-lived, semi-permanent coronal structure fed by plasma from successive underlying dynamic flares, or a long-lived configuration of magnetic field lines which open and reconnect subsequent to the onset of each underlying dynamic flare. The earlier interpretation of small Hα blueshifts in flare ribbons during the gradual phase of flares as a gentle evaporation has been corroborated by Schmieder et al. (1990) from coordinated SMM observations of soft X-ray and transition zone-line emissions.

5.3 MASS MOTIONS

The many forms of mass motion related to flares have been reviewed by Martin (HAR, p215): those in the corona (erupting filaments, coronal mass ejections) which indicate a changing magnetic field within and around the flare as opposed to other coronal structures (surges, flaring arches) which indicate flows along a relatively static magnetic field configuration; and those in the chromosphere (such as moving flare ribbons) which likely result from the impact of particle beams and/or shock waves. The X-ray emission associated with Hα prominences, sprays and surges has been found to be highly localised within the active structures by Harrison et al. (1988). They call into question those models which predict that the energy release during the active phase of these structues should be evenly distributed along them. Four flare-associated erupting filaments analyzed by Kahler et al. (1988) have characteristics which indicate that the eruptions are not driven by flare plasma pressure but by a global MHD instability of the magnetic field configuration of the entire active region. They find the onset of the impulsive phase of the flares to follow the filament eruption and suggest that the eruptive motion must surpass a critical speed limit of order 100 km/s to initiate a flare. From an evolutionary study of the formation and disappearance of a flare-related filament, Gaizauskas (RPL, p331) concludes that the eruption and flare can be due to a gradual increase beyond a critical threshold of field-aligned currents generated along the separator between flux cells by the expansion, shifting, and contraction of adjacent bipolar regions. Zhang and Chupp (1989) found a solar γ-ray burst associated not with the initial impulsive phase of a flare but, about 20 min later, with an abrupt jump in velocity of an expanding post-flare loop. The late acceleration to very high energies is attributed to an efficient process of reconnection at high altitudes between existing magnetic field lines, new ones belonging to a new magnetic flux. Bai and Sturrock (1989) discuss the role of erupting filament flares in a grand scheme of flare classification.

The multi-thermal nature of a surge has been explored by Schmieder et al. (1988) using Hα, UV and X-ray data. They find that the mechanical energy of this surge exceeds its radiative energy by two orders of magnitude. They point out that this division of energy is not necessarily typical and may depend on the geometry of overlying large-scale fields in the corona. Kurokawa (1988) points to sustained surge activity on the periphery of a rapidly growing active region as the first manifestation of newly emerging flux.

5.4 FLARE RECURRENCES AND DISTRIBUTIONS

A major study of homologous flares by Martres (1989) shows that the time lapse between consecutive homologues may vary from a few minutes to some days. The term 'rafale' (a machine-gun burst) is introduced to describe rapid succesion of closely similar flares which are observed exclusively in parasitic polarities at the penumbral border of large sunspots. Periodicities in flare occurrence rates around 5 months and longer have been confirmed in studies extending over several cycles by Lean and Brueckner (1989) and by Özguc and Atac (1989). For Cycle 21 Ruzdjak et al (1989) find the rate of occurrence of two-ribbon flares to be higher in spot-group than in spotless flares; X-ray emission is systematically lower for spotless flares. A 20 yr sample of the positions of LDE flares (ie, long duration events) has been analyzed by Özguc and Düzgelen (1989) who find preferential zones for this type of activity in a latitudinal belt between 11 -20° and in longitudinal belts around 80° - 100° throughout that period. Heras et al. (1990) find sustained episodes of east-west asymmetry in the apparent longitude distribution of all sizes of flares during Cycle 21.

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Solar flare physics has thus become a truly interdisciplinary and unique field. No other branch of astronomical research encompasses so many techniques, from remote sensing by telescopes to in-situ measurements of particles and fields in the heliosphere, and has at the same time such profound bearing on the future of our civilisation at a time when humankind is ready to extend its frontiers into space. Furthermore, the Sun is used (Haish and Rodono, 1989) as a Rosetta Stone to understand many aspects of stellar activity.

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To understand flare energy release processes it is necessary to determine observationally the characteristics of its medium and high energy radiation components (keV to MeV), the dynamics of the flare plasma, the signature of processes by which energy is transported and dissipated and, last but not least, the magnetic configuration in which the energy release takes place.

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The most recent results on high-energy radiation and particles have been reviewed by Rieger (1989), Chupp (1990), Yoshimori (1990, Hinotori gamma-ray results) and Reames (1990). Rieger stresses the aforementoned directivity observed at high energies, and the good correlation between the continuum and gamma-ray line emission, which is found to be independent of flare duration and size. This suggests that the primary flare acceleration of particles may proceed under similar conditions in all flares. Evidence for a two-phase acceleration mechanism is found in some events. Particular event studies are referred to by Chupp (1990) and Yoshimori (1990), who again suggest that differences in their characterisitics may be due to those of the magnetic field in the region where they occur. In the case of solar energetic particle (SEP) events, differences in proton acceleration seem to be related to the duration of the parent flare which, in turn, is also highly dependent on the magnetic topology at its site. Evidence has also been given that coronal shocks seem to accelerate predominantly protons (Kallenrode et al. 1987). Ramaty et al. (1988), given an extensive review of gamma-ray neutron and hard X-ray studies, together with an account of the requirements for future high-energy solar physics instrumentation.

The dynamic response of the flare atmosphere has been a rather hot research topic over the past three years. Antonucci et al. (1990), Doscheck (1990) and Watanabe (1990) review results obtained from Bragg crystal spectrometers flown on SMM, P78-1 and Hinotori. There is still no absolute concensus about the interpretation of X-ray line broadening and their blue asymmetry detected during the impulsive phase. In the case of the latter, the favoured idea still is that the blue-shifted components signal the presence of upflows of heated chromospheric material into the flaring loops, the so-called chromospheric evaporation process. This interpretation is supported by combined X-ray and H-alpha observations (Zarro et al. 1988), which indicate that momentum balance exists (to within a factor of 2) between upflows inferred from X-ray lines and downflows in the underlying cool chromospheric material, shown by red asymmetries detected in the hydrogen line profiles. As noted by several authors, these observations suggest that particle beams play a dominant role in transferring energy along flaring loops, at least in large events. On the other hand, most likely because of their simplified nature, theoretical models of particle heated flare loops still fail to accurately reproduce the observed shape of X-ray line profiles, most notably the existence of a, rather strong, stationary component during the impulsive phase (Doschek, 1990; McClements and Alexander, 1989; Li, et al. 1990). Furthermore, substantial non-thermal broadening is observed in X-ray lines before and during the impulsive phase. Its origin is still unclear, but seems to be related to the production of very hot plasma ($> 30 \times 10^6$ K the so-called 'superhot' component) at these stages of the flare development (Culhane, 1988; Watanabe, 1990). Cheng (1990) has reanalyzed some Skylab XUB observations and found that turbulence is present in these data, even in cases where evaporation does not seem to play an important role in the event.

X-ray imaging observations have also provided direct and convincing evidence of the existence of thermal fronts, shocks and mass motions in large-scale flaring loops (Machado et al. 1988a; Martin and Svestka, 1988; Svestka et al. 1989). The same phenomena may occur at all size scales, but remain undetected in small loop features due to the lack of appropriate high-resolution imaging capabilities. Firm evidence of continuing evaporaton during the gradual phase of some flares and, thus, continuing energy release at this stage of flare development, has been obtained from combined analyses of X-ray, UV and H-alpha images and spectra (Schmieder et al. 1987, 1990 and references therein). Overall properties of the evolution of flaring loops, through all phases of the flare development, are reviewed by Sylwester (1988).

As noted before, much work has been carried out in trying to define the characteristic magnetic topology of flaring regions. It has become clear that single-loop flares are probably very rare (Svestka, 1989). A review of multi-wavelength observations (Gaizauskas, 1989 and references therein) shows that multiple magnetic structures are involved in the energy release process, and they cannot be considered as uncoupled from a global background. This seems to be true not just for major events but also for weak brightenings or "microflares" (Mandrini et al, 1989) and large-scale brightenings like the so-called "giant arches" (Hick et al. 1988; Svestka et al. 1989; Martin et al. 1989). New evidence shows that the giant arches are pre-existent large-scale magnetic features energized during flares (Martin et al. 1989; Poletto and Kopp, 1988: Kopp and Poletto, 1990), rather than new structures formed as a consequence of the development of two-ribbon flares (Hick, 1988 and references therein; Hick and Priest, 1989). In more general terms, Machado et al. (1988b) have reviewed a large series of X-ray imaging observations from the SMM spacecraft, and relate their characteristics to those of the magnetic configuration where the flares occurred. They show that the basic structure of a flare consists of a bipolar loop and one or more adjacent bipoles interacting with it. They conclude that although interaction between bipoles may be essential to trigger the flare energy release, most of the flare energy is derived from the stressed magnetic fields within the interacting loops. Since the energy stored in the individual loops varies from flare to flare, this naturally accounts for the large range of observed properties of flares. These conclusions, which find support from observations in H-alpha and the radio domain (Gaizauskas, 1989; Pick et al. 1990) seem at first sight to contradict the conventional wisdom derived from Skylab data analyses of the 1970's. However a re-examination of some Skylab data (Cheng and Widing, 1989), shows a flare scenario consistent with the one deduced from the more recent, lower spatial resolution SMM observations.

From all these studies it is clear that space observations have led to considerable advance, and also major revisions in some cases, in our concepts about solar flares. It is also clear that new advances will come with more sophisticated instrumentation. High-resolution soft X-ray, XUV and EUV images are a must, as well as more sensitive Bragg spectrometers, hard X-ray and gamma-ray imagers, high-resolution spectrometers in these energy ranges and, last but not least, we can also expect major breakthroughs when space optical telescopes and vector magnetographs become available. Some of these needs will be fulfilled during the present maximum, by new spacecraft and balloon programs, but others will have to wait until the first maximum of the next millenium.

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The impulsive phase of solar flares, in spite of other factors discussed below, remains the core problem in flare research. Dennis and Schwartz (1989) give the most recent review of impulsive phase phenomena, including results derived both from space and ground-based observatories. New results in this topic include the apparent lack of directivity in hard X-ray emission (Kane et al, 1988), and its obvious existence at photon energies above 10 MeV (Verstand et al. 1987). These gamma-rays are believed to be produced by ultra-relativistic electrons emitting close to their turning point at the feet of magnetic loops, thus moving parallel to the solar surface. Cheng et al (1988) confirmed previous findings about the simultaneity of hard X-ray and ultraviolet (UV) continuum bursts. These observations then place strong constraints on the energy propagation times along the flaring atmosphere (the UV continuum is emitted near the temperature minimum region), and also pose serious problems because of the very large energy deposition rate in these deep layers. However, this is true only if the continuum enhancements reflect temperature increase; instead, Machado and Mauas (1987) have proposed that the UV brightening could be fluorescence due to ionization of SiI atoms by transition zone line emission. Such a mechanism can work as fast as required and involves minimal energy transport and heating at the temperature minimum level.

Tanaka (1987) gives an extensive review of Hinotori had X-ray imaging observations, stressing the idea that flares come in three different classes, namely those that produce mainly thermal hard X-rays, those with strong non-thermal components and thick-target footpoint emission, and extended events with long-enduring energy releases at high-altitude loops. Tanaka and co-workers relate the flare characteristics to the level of departure from a potential configuration of the magnetic environment where they occur.

The most recent results on high-energy radiation and particles have been reviewed by Rieger (1989), Chupp (1990), Yoshimori (1990, Hinotori gamma-ray results) and Reames (1990). Rieger stresses the aforementoned directivity observed at high energies, and the good correlation between the continuum and gamma-ray line emission, which is found to be independent of flare duration and size. This suggests that the primary flare acceleration of particles may proceed under similar conditions in all flares. Evidence for a two-phase acceleration mechanism is found in some events. Particular event studies are referred to by Chupp (1990) and Yoshimori (1990), who again suggest that differences in their characterisitics may be due to those of the magnetic field in the region where they occur. In the case of solar energetic particle (SEP) events, differences in proton acceleration seem to be related to the duration of the parent flare which, in turn, is also highly dependent on the magnetic topology at its site. Evidence has also been given that coronal shocks seem to accelerate predominantly protons (Kallenrode et al. 1987). Ramaty et al. (1988), given an extensive review of gamma-ray neutron and hard X-ray studies, together with an account of the requirements for future high-energy solar physics instrumentation.

The dynamic response of the flare atmosphere has been a rather hot research topic over the past three years. Antonucci et al. (1990), Doscheck (1990) and Watanabe (1990) review results obtained from Bragg crystal spectrometers flown on SMM, P78-1 and Hinotori. There is still no absolute concensus about the interpretation of X-ray line broadening and their blue asymmetry detected during the impulsive phase. In the case of the latter, the favoured idea still is that the blue-shifted components signal the presence of upflows of heated chromospheric material into the flaring loops, the so-called chromospheric evaporation process. This interpretation is supported by combined X-ray and H-alpha observations (Zarro et al 1988), which indicate that momentum balance exists (to within a factor of 2) between upflows inferred from X-ray lines and downflows in the underlying cool chromospheric material, shown by red asymmetries detected in the hydrogen line profiles. As noted by several authors, these observations suggest that particle beams play a dominant role in transferring energy along flaring loops, at least in large events. On the other hand, most likely because of their simplified nature, theoretical models of particle heated flare loops still fail to accurately reproduce the observed shape of X-ray line profiles, most notably the existence of a, rather strong, stationary component during the impulsive phase (Doschek, 1990; McClements and Alexander, 1989; Li, et al. 1990). Furthermore, substantial non-thermal broadening is observed in X-ray lines before and during the impulsive phase. Its origin is still unclear, but seems to be related to the production of very hot plasma (> 30 x 10^6 K the so-called 'superhot' component) at these stages of the flare development (Culhane, 1988; Watanabe, 1990). Cheng (1990) has reanalyzed some Skylab XUB observations and found that turbulence is present in these data, even in cases where evaporation does not seem to play an important role in the event.

X-ray imaging observations have also provided direct and convincing evidence of the existence of thermal fronts, shocks and mass motions in large-scale flaring loops (Machado et al. 1988a; Martin and Svestka, 1988; Svestka et al. 1989). The same phenomena may occur at all size scales, but remain undetected in small loop features due to the lack of appropriate high-resolution imaging capabilities. Firm evidence of continuing evaporaton during the gradual phase of some flares and, thus, continuing energy release at this stage of flare development, has been obtained from combined analyses of X-ray, UV and H-alpha images and spectra (Schmieder et al. 1987, 1990 and references therein). Overall properties of the evolution of flaring loops, through all phases of the flare development, are reviewed by Sylwester (1988).

As noted before, much work has been carried out in trying to define the characteristic magnetic topology of flaring regions. It has become clear that single-loop flares are probably very rare (Svestka, 1989). A review of multi-wavelength observations (Gaizauskas, 1989 and references therein) shows that multiple magnetic structures are involved in the energy release process, and they cannot be considered as uncoupled from a global background. This seems to be true not just for major events but also for weak brightenings or "microflares" (Mandrini et al, 1989) and large-scale brightenings like the so-called "giant arches" (Hick et al. 1988; Svestka et al. 1989; Martin et al. 1989). New evidence shows that the giant arches are pre-existent large-scale magnetic features energized during flares (Martin et al. 1989; Poletto and Kopp, 1988: Kopp and Poletto, 1990), rather than new structures formed as a consequence of the development of two-ribbon flares (Hick, 1988 and references therein; Hick and Priest, 1989). In more general terms, Machado et al. (1988b) have reviewed a large series of X-ray imaging observations from the SMM spacecraft, and relate their characteristics to those of the magnetic configuration where the flares occurred. They show that the basic structure of a flare consists of a bipolar loop and one or more adjacent bipoles interacting with it. They conclude that although interaction between bipoles may be essential to trigger the flare energy release, most of the flare energy is derived from the stressed magnetic fields within the interacting loops. Since the energy stored in the individual loops varies from flare to flare, this naturally accounts for the large range of observed properties of flares. These conclusions, which find support from observations in H-alpha and the radio domain (Gaizauskas, 1989; Pick et al. 1990) seem at first sight to contradict the conventional wisdom derived from Skylab data analyses of the 1970's. However a re-examination of some Skylab data (Cheng and Widing, 1989), shows a flare scenario consistent with the one deduced from the more recent, lower spatial resolution SMM observations.

From all these studies it is clear that space observations have led to considerable advance, and also major revisions in some cases, in our concepts about solar flares. It is also clear that new advances will come with more sophisticated instrumentation. High-resolution soft X-ray, XUV and EUV images are a must, as well as more sensitive Bragg spectrometers, hard X-ray and gamma-ray imagers, high-resolution spectrometers in these energy ranges and, last but not least, we can also expect major breakthroughs when space optical telescopes and vector magnetographs become available. Some of these needs will be fulfilled during the present maximum, by new spacecraft and balloon programs, but others will have to wait until the first maximum of the next millenium.

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7. RADIO OBSERVATIONS OF FLARES AND ACTIVE REGIONS

(S. Enome)

7.1 INSTRUMENTATION

A digital multichannel spectrometer is being developed in the microwave range to study high-resolution spectral and temporal structure of radio bursts (Staehli and Fuhrer, 1987) with a performance of 32 channels in a band of 3 and 4GHz, with each channel-width of either of 0.1, 5, and 20MHz, and 350 microsec. The radioheliograph at Nancay has installed a multi-frequency capability to the north-south array (The Radioheliograph group, 1989), which enables them to make one-dimensional observations at up to five frequencies between 150 and 450 MHz with time resolution of less than 0.1 sec as well as 164-MHz two-dimensional maps. A modification of Molonglo Cross at 838 MHz for solar observations is reported by Gray et al. (1990). A non-redundant two-dimensional array is presented by Zirker (1987, 1989).

7.2 FLARES

Microwave emissions from solar flares are believed to be related to energetic electrons and coronal sunspot magnetic fields in the vicinity of the acceleration region. Those electrons are also responsible for hard X-ray emissions during flares (Kai, 1987b). There is, however, some discrepancy in the energetic electron population deduced from the gyrosynchrotron hypothesis and the hard X-ray assumption. An alternative hypothesis for both radiations is a thermal origin of emission from a very hot multi-temperature plasma. New analysis of well-defined X-ray and microwave flares leads to the conclusion that a nonthermal thick-target model with a loop length of 10^9 cm and a magnetic field of 500 G provides the best fit to the data (Lu and Petrosian, 1989). A crucial test is proposed by Kaufmann (1988) to discriminate flare models. Reviews of microwave and meterwave emission from solar flares are given by Crannell et al (1988).

The geometry of the microwave source region is also critical , being either a loop top or a foot-point (Kai, 1987a). Simultaneous X-ray and microwave observations in two dimensions are reviewed by Enome (1987). The importance of multi-frequency observations (Kundu et al, 1989b: Velusamy et al 1987) show a variety of physical source conditions, including footpoint and loop-top events at 2 and 6 cm with complex structure. At longer wavelengths of 21 and 92 cm a nonthermal model fits impulsive phase observations well, while preflare activity is explained by thermal or multi-thermal emission (Willson et al, 1990a, 1990b).

Coordinated observations in microwaves, X-rays and other energy bands have proved very effective in constraining flare models or physical parameters of flaring regions. An X4 flare on May 14, 1984 was observed with VLA and XRP of SMM by Schmahl et al (1990), which was unusually stationary during the declining phase with superhot flare plasma; the authors concluded that the flare was confined by overlying magnetic fields. Dynamic evolution of the source volumes of solar flares are compared by Bruner et al (1988) deduced from hard X-ray, microwaves, 0 VII lines. Hinotori hard X-ray events and projected microwave images show good examples of a single loop model for simple impulsive bursts and of the interaction of multiple loops for multiply impulsive bursts (Nakajima et al, 1987). A statistical study by Kosugi et al (1988) deduced physical parameters of the flare region for impulsive flares produced by electron energies of 200 keV or less and for extended flares generated by MeV electrons. A flare-associated coronal source is observed at mm and cm waves by Borovik et al (1989) with RATAN-600 and at Metsaehovi, whose spectrum is well explained by optically thin bremsstrahlung, but 10-20 % polarization indicates a possible contribution of gyroresonance and/or optically thick bremsstrahlung. A sequence of behind-the-limb events is also reported by Kosugi (1987) in microwaves and X-rays. Time-correlated bursts are observed by Lang and Willson (1989b) with the VLA at 90 cm from widely separated (6 arcmin) active regions.

An elaborate statistical analysis supports a thermal model for both hard X-ray and microwave impulsive bursts (Starr et al 1988; Batchelor, 1989). A review is given by Pick et al (1990) on radio emission associated with solar flares, in which emphasis is laid on decimeter wave millisecond spikes and thermal vs. nonthermal models. High-resolution spectral and temporal observations in decimeter wavelengths are very important to investigate plasma processes. A large sample in the decimeter range is given by Guedel and Benz (1990). Spikes are generated by plasma waves and their decay time, which is much shorter than that of type III bursts, is fell explained by collisional damping of plasma waves. Millisecond decimeter spikes have a structure of frequency ratio 1.39 and an ordinary mode of polarization (Benz and Guedel, 1987). Correlation of decimeter pulsations with hard X-ray bursts is found in 11 cases out of 56 events by Aschwanden et al (1990). They calculated X-ray emission either from collisions of trapped electrons with cold background ions or from precipitating electrons into the chromosphere. In the mm-wave range Correia and Kaufmann (1987) observed very fast pulses. A new class of microwave fine time structure at 3.1 - 5.2 GHz is found by Staehli and Benz (1987), which shows frequency drift suggesting an exciting electron beam. Harmonic radiation during solar bursts is observed by Staehli et al (1987), at 5.2 and 11.8 GHz. A frequency-agile two-element interferometer at Owens Valley gives unique observations when the source structure is simple. Gary and Hurford (1989) and Staehli et al (1989) made high-resolution spectral observations of 49 microwave bursts and found: (i) 80% of events display complex spectra; (ii) many bursts have well-defined low-side spectral index larger than a plausible theoretical value of 3; (iii) peak frequencies of the burst are remarkably constant during their life-time. A class of microwave bursts is studied by Staehli et al, (1990) with two spectral peaks, which are identified as two spectral components with the same polarization sense and time variation. The importance of spectroscopy is emphasized by Hurford and Gary (1989). Solar cycle variations of both gradual rise-and-fall (GRF) microwave burst and long duration soft X-ray events (LDEs) with duration longer than four hours are examined by Kahler and Cliver (1988). The number of GRFs correlates with the daily 10.7 cm flux density, whereas GOES LDEs do not show such relation.

Meterwave and longer wavelength observations are closedly related to coronal processes, which are produced mainly as a secondary effect of an explosive phase in the vicinity of the acceleration region. From imaging observations of the evolution of meter-decameter burst emission during a major flare, Gopalswamy and Kundu (1987a) have deduced the magnetic field structure. A review is given by Kundu (1987b) for meter-decameter wave observations with the Clark Lake multifrequency radioheliograph with emphasis on its high sensitivity. Non-flare type II/IV bursts are associated with a coronal streamer disruption and a slow coronal mass ejection (Kundu, 1987a). Observations of a coronal mass ejection at meter-decameter waves and in white light are presented by Gopalswamy and Kundu (1987b). Type IV emission is associated with an H-apha spray and a CME, and interpretated as gyrosynchrotron emission, from which the physical parameters are deduced. The relation between coronal mass ejections and metric radio emission is studied by Gopalswamy and Kundu (1989b). A slowly moving type IV burst associated with a filament eruption is analysed by Gopalswamy and Kundu (1989a). Beat structure seen in pulsating type IV radio bursts is presented by Li et al (1987) , and a possible mechanism is proposed of radial oscillation of a magnetic loop at its legs. Cane and Reames (1988) show that type IV emission is associated with long-duration soft X-ray flares and coronal mass ejections. Type II and III bursts are related primarily with impulsive soft X-ray events. Nakajima et al (1990) show a high-speed shock does not play a major role in the acceleration of the electrons or ions responsible for X-ray and gamma-ray emission in the flare of April 24, 1984.

Herringbone (HB) bursts with the Culgoora radio spectrograph, radiometer, and radioheliograph (Cairns and Robinson, 1987) are emitted at multiples of the plasma frequency. Cane and White (1989) correlate herringbone phenomena in type II burst with various flare properties, in particular type II intensity.

A study is presented by Kundu and Gopalswamy (1987) for type III bursts emitted from distant sources on the Sun. The relative timing of metric type III and microwave bursts is examined by Raoult et al (1989), who conclude that the energy of the burst exciter is much higher than the conventional value of 100 keV. A new model of type III burst souces is developed by Roelof and Pick (1989), in which inhomogeneity of coronal magnetic field and density plays a key role to determine the band width and duration of bursts. Quasi-periodicities are found in type III bursts (by Mangeney and Pick, 1989) with periods of 1 - 6 seconds. Kilometric type III bursts are observed by Reiner and Stone (1990) to have halo-like radio structure due to scattering of radiation by the solar corona. Association of kilometric type III bursts and 3He-rich events is examined by Reames et al (1988), who find an anticorrelation between

3He/4He ratio and ratio intensity. MacDowall et al (1989) has proposed a new criteria to distinguish a class of fast-drift, shock-associated, kilometric radio bursts, which are not extensions of metric type III bursts. Kahler et al (1989) shows that shock-associated kilometric radio emissions are closely correlated with type II bursts. A statistical study is made by Thejappa et al (1990) on microbursts at meter-decameter wavelengths to find low brightness of 6 x 10^5 - 6 x 10^7 and an exciter speed of 0.2 C.

Wright and Nelson (1987) find regular, narrow-band radio pulsations at 410 MHz consisting of low-amplitude 3 minute and large-amplitude 5-minute oscillations which are interpreted as sausage mode standing oscillations of coronal loops. Minute-scale pulsations in type IV burst are modeled by Aurass and Mann (1987) as standing magnetoacoustic waves. Aurass et al (1987) describe a sequence of remarkable temporal fine structures at 234 MHz during a type IV burst. It lasts nearly six hours and consists of broadband pulsations, zebra patterns, fiber bursts, and new fine structures. Temporal evolution is studied by Klein et at (1987) for coordinated observations of ten great flares in radio waves, X-rays, and gamma-rays. A new model of whistler wave packets is presented for intermediate drift bursts by Mann et al (1987). VLA observations of solar noise storms at 90 cm (Lang and Willson, 1987; Habbal et al, 1989) mostly confirm previously well-known characteristics except for the complexity of source structure and possible association with soft X-ray emission. The heliographic current sheet is mapped in synoptic plots on an assumption that noise storms are intimately related with closed magnetic field regions.

7.3 ACTIVE REGIONS

Microwave emission above a steady sunspot and a moving sunspot is modeled and compared with observations (Drago et al, 1987), agreement with a model being good for the steady spot but not for the moving spot, possibly because of synchrotron emission from non-thermal electrons . An S-component is observed at mm-waves by Urpo et al (1987) and compared with mean S-component models. Time variability of solar active regions is observed by Shevgaonkar and Kundu (1989) at 2 and 6 cm. It is interpreted as due to density (2 cm) and field (6 cm) variations.

Lantos et al (1987) shows that the S-component is not always thermal emission but is likely to be weak noice storm continua at 169 and 73.8 MHz. Emissions from a streamer are detected at all frequencies, and from a coronal hole at 169 MHz, but not from filaments. An unsuccessful search for the S-component at decameter wavelengths was made by Bazelyan (1987) with the UTR-2 radio telescope. Cyclotron lines observed with the VLA are used by Zheleznyakov and Zlotnik (1989) to estimate magnetic field inhomogeneity from the observed line width and temperature from the harmonic intensity ratio.

Outside active regions radio structures at 8.5 GHz are mapped by full-day synthesis observations with the VLA by Gary and Zirin (1990). They identified coronal loops over a decayed sunspot without longitudinal magnetic fields and identified radio chromospheric features such as network, cell interiors and filament channels. Coronal loops are mapped at multi-frequency around 1.4 GHz with the VLA and at soft X-rays with the SMM FCS by Lang et al (1987b). There are some active regions emitting neither radio waves nor soft X-rays (Lang et al, 1987a). Coronal bright points (PB) are studied at 20 cm by Nitta and Kundu (1988), Habbal and Harvey (1988), and at 6 and 20 cm by Kundu et al (1988). BPs are generally associated with bipolar structures in photospheric magnetograms, but sometimes with unipolar network. They are also correlated with dark points in HeI 10830 Angstrom maps. In general they exhibit rapid variations in intensity but this is not correlated with that of the HeI 10830 dark points. The average ratio of brightness temperatures at 6 and 20 cm is 0.09:1, suggesting a thermal origin.

Metric wave observations of a coronal hole are presented by Wang et al (1987) at 30.9, 50, 73.8 MHz (Clark Lake). Comparisons of radio maps with HeI 10830 maps and with Dulk's model are discussed. Detection of 90-cm emission is reported by Lang and Willson (1989a) possibly by a thermal mechanism associated with an H-alpha dark filament. 90-cm emission is interpreted as a streamer by Shevgaonkar et al (1988), and its time variability is discussed. A filament eruption is observed by Kundu et al (1989a) associated with 6- and 20-cm activities that appeared nearly simultaneously in two active regions separated by 200,000 km or more. The solar brightness temperature is measured by Boreiko and Clark (1987) at submillimeter wavelengths (20 - 90 cm-1) to be 4300 K, which is close to the predicted temperature minimum.

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8. CORONAL MASS EJECTIONS

(R A Harrison)

8.1 INTRODUCTION

Coronal Mass Ejections (CMEs) involve the release of up to 10^{25}J of energy from the highy stressed magnetic fields of the corona as up to 10^{13}kg of matter is expelled into interplanetary space. These events represent a significant restructuring of the solar corona and provide a large perturbation to the solar wind, undoubtedly driving several features of geomagnetic activity when passing over the Earth. The relationship between the launch of CMEs and chromospheric events such as flares, prominences, sprays and surges has been the subject of some debate for many years.

We entered the 1980's with the majority of theoretical reviews clinging to the belief that CMEs were driven by flare activity -- the blast from the explosion in the low solar atmosphere. However, the seeds had been sown for the demise of this viewpoint as several observational studies came to fruition in the mid-1980's.

To detect CMEs we make use of white-light coronagraphs. The Naval Research Laboratory's Solwind coronagraph was launched in 1979, on board the US Air Force's P78-1 satellite. It operated well, until the satellite was destroyed in 1985 as part of a demonstration of the US Strategic Defence Initiative! The High Altitude Observatory built and operated a coronagraph as part of NASA's Solar Maximum Mission (SMM). This device was only operational for the first seven months of the SMM mission in 1980, though it was repaired in 1984 and operated until SMM reentered the Earth's atmosphere at the end of 1989. The High Altitude Observatory also operates a white-light coronagraph on Mauna Loa, Hawaii -- the Mk III K-coronameter.

8.2 OBSERVATIONS

At the beginning of the reporting period (mid-1987), interdisciplinary studies of CME onsets, involving Coronagraph and "surface" observing instruments (X-rays, H-alpha etc...) were being published by Harrison and co-workers (eg. Harrison, 1986; Harrison and Sime, 1989). These studies suggested that any flare activity related to CMEs appears to occur well after the CME launch and prefers to lie away from a site under the core of the ascending CME. This appears to confirm the view that flares do not drive CMEs and indeed led to the suggestion that the flare was driven by the large-scale coronal changes which were manifested by the CME. It was clear that our understanding of the CME onset could be greatly enhanced by multi-instrument studies of this kind.

These multi-instrument studies coincided with a concerted effort to better display and advertise CME activity and related issues -- in short, there was a great resurgence of interest in the CME. Several excellent reviews were produced (eg, Hundhausen, 1988; Kahler, 1987), workshop sessions dedicated to studies of CME activity were organised (see eg. Pizzo et al, 1988, Joselyn, 1988; Harrison et al, 1989) and some excellent sets of coronagraph images published (eg. Hundhausen, 1988; St Cyr and Hundhausen, 1988).

Following the success of the multi-instrument studies which were based on relatively few data sets where compatible observations could be found, a deliberate campaign was designed to study the launch of CMEs -- the so-called CME Onset Programme. This programme was designed to make use of simultanious coronagraph, X-ray, H-alpha and radio observations through pre-planned sequences and was operated on many occasions from September 1985 to the end of 1987. The first results from this programme were published by Harrison et al (1990) and they supported the previous conclusions about the nature of the CME-flare relationship: the data suggest that all CMEs are associated with an X-ray brightening which would not always be classed as a flare. The CME launches appeared to be pre"flare" and in the average case the "flare" lies to one side of the CME span. The study highlighted the fact that the source of the CME must be larger than the active regions with which it is associated.

Several observational features of CMEs, which will provide significant constraints on models of such activity, and which provide a useful perspective of CME activity relative to other events, have emerged in the past few years.

Sime (1989) demonstrated that there was a clear relationship between the rate of CME events and the time-scale for long-term evolution of the corona. The coronal evolution was investigated by the use of a "correlation lifetime" obtained by inspecting the variations in coronal intensity over the year long periods, at 1.3 solar radii, within a 15 degree wide band above the equator. The conclusion was that long-term evolution and transient activity within the corona are closely related, ie, they are both signals of the evolution of the corona, which suggests that the CME cannot be driven from below the corona merely acting as a propagating medium.

The nature of our detection methods means that the observation of CMEs is most suited to events in or near to the plane of the sky (see Fisher and Munro, 1984). However, Howard et al. (1982) had reported the detection of a "halo" CME and suggested that it was the signal of an Earth directed event. Since this claim, several other halo events have been claimed by observers from the Solwind team. This is despite the fact that no halo events had been detected by the SMM and Mauna Loa instruments. St Cyr and Hundhausen (1988) provided a possible explanation. They identified events where CMEs were responsible for significant deflections of adjacent magnetic streamers and, in some cases, such deflections could be traced around most of the Sun. This activity certainly led to a misinterpretation of the angular spread of some events using Solwind, because of the use of subtracted images to identify transient activity. Whether this can explain all of the halo events has yet to be established.

Synoptic scans of streamers using SMM and P78-1 coronagraph data have indicated that the upper portions of a streamer will often become bloated prior to a CME eruption from below, indicating tht the coronal magnetic fields are aware of an impending event and thus not subject to a sudden, unexpected pulse from below. This is an important result in the context of the flare/CME studies mentioned above and we look forward to a report in the near future.

Another more recent finding is that for at least some CME events the origin of the CME can be traced to a previously undiscovered, huge coronal cavity which may extend to altitudes of 0.5 solar radii (Hundhausen and Sime, 1990). Previous CME-flare studies relied on the understanding that CME structures did not originate in the coronagraph fields of view because this was never observed -- therefore the source must be below 0.2 solar radii. That is not to say that the CME does not develop within the coronagraph field of view. This new discovery demands a reassessment of earlier studies; it may alter our understanding of the relative timing of the flare-CME onset but strengthens the thought that coronal magnetic activity is not driven by flare activity.

As a final comment on the observational aspects of CME activity, many studies have related CME activity to special classes of flare activity, and in particular the so-called long duration events (LDEs) (see eg. Webb and Hundhausen, 1987, and Kahler et al, 1989 for studies from this reporting period). This relationship is hotly debated and the association has been severely criticised on the grounds that the studies used artificial and varying filters to extract the longer events yet studies with all flare activity included showed no particular preference for CMEs to occur with any special type of flare.

8.3 CME MODELS

With so much activity and debate in the area of CME observation, we are finding more and more constraints to place on CME models. The models where CMEs are driven from flare activity are now generally ignored, though some do persist (see eg. Harrison and Sime, 1989b). From a theoretical viewpoint, as noted by Klimchuk (1989), we have four possibilities for CME initiation: (i) A magnetic configuration may be in a metastable equilibrium and is disrupted by a sufficiently large perturbation. (ii) A magnetic configuration might evolve from a stable to an unstable situation and be upset by a small perturbation. (iii) A configuration might evolve to the point where there is no near equilibrium (loss of equilibrium). (iv) A configuration might evolve through a sequence of stable equilibria in which a small change at the photosphere produces a rapid change in the corona.

Many models explain CME initiation by methods (iii) and (iv). Magnetic configurations are shown to evolve because of the motion of magnetic footpoints, within our reporting period, have been given by Priest (1988), Steele and Priest (1989) and Klimchuk and Sturrock (1989). Priest (1988) demonstrated a lack of equilibrium within a magnetic arcade due to changes in extension of previous work by Low (1981) and Wolfson (1982). Steele and Priest (1989) made a valuable effort to extend this work by including the three-part structure of a prominence within a cavity under a CME. Again, they found conditions which suggested a loss of equilibrium -- interpreted as the CME eruption. Klimchuck and Sturrock (1989) examined the "loss of equilibrium" approach. For one particular sequence they demonstrated that it was possible to find well-behaved solutions for a situation which, by examination through a different method, reached non-equilibrium. They discuss the results of several studies, including the work of Low and Priest.

These analytical methods have run in parallel with several numerical approaches. Within our reporting period, we note the work of Wu and co-workers (see Harrison et al, 1989) which has involved the numerical examination of an arcade under shear. This is an extension of work by Wu et al. (1983). The shear is given as a specified function of distance from the neutral line and has important consequences for CME eruption and prominence formation. However, this is at odds with the report by Klimchuk (1990) which claims that all field lines must rise in a sheared arcade. The critical review of CME models involving "non-equilibrium" was supplemented by Klimchuk (1989) who claimed that few if any published models provided an adequate explanation for CME initiation. This was claimed on the grounds that many models include "physically irrelevant effects brought about by mathematical assumptions, unrealistically high values of the plasma beta and peculiar evolutionary boundary conditions". Quite apart from including realistic temperature, density and magnetic conditions, models ought to cover the complexities of including provision for prominence eruptions under CMEs and the onset of flare activity.

8.4 COMMENTS

Although this review cannot hope to cover all work done throughout the reporting period, it is clear that we are witnessing a period of much activity, both in the examination of CME and related events but also in our approach to CME modelling. We may expect several of the observational studies to provide very clear constraints for models over the next year or so. This should result from continued analysis of the multi-instrument studies of the mid-1980's and from the completion of several studies reported above. Armed with these results and with a consideration of criticisms such as those made by Klimchuk (1989) of the model scenarios, we ought to be in a position to construct more sophisticated and realistic models. As far as new coronal observations are concerned, we have no orbiting coronagraphs at present, and are reliant on the Mk III K-coronameter as the only source of white-light coronal observatons until the launch of the Solar and Heliospheric Observatory (SOHO) in 1985. We look forward to observations from the LASCO coronagraph which will be on board SOHO.

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9. SOLAR ACTIVITY FROM THE USSR

(V.Makarov)

Regular observations of solar activity have been made at 15 observatories. A 1024-channel photodiode array was used for detection of global oscillations at Kislovodsk in the 5-minute and 160-minute ranges (Didkovsky LV and Kotov VA, 1988). At Kiev a 40-channel measuring complex gives spectra and images (Vashchenko et al 1990). At Pulkovo a new narrow-band filter with a passband of 0.10Å is used with the 40 cm telescope for observing strong magnetic fields (Kulagin, 1990). A new method for determining the surface velocity of solar rotation has been described (Grigoriev and Ilgamov, 1988)

9.1 SOLAR CYCLE

Maps of the large-scale solar magnetic field show that global solar activity commences shortly after the polar field reversal in the form of two components in each hemisphere. One is identified with polar faculae that appear at latitudes 40° - 70° and migrate polewards; the second shows up as sunspots at 40° 5-6 years later (Makarov and Sivaraman, 1989). Polar faculae and bright points in Ca II K are correlated with sunspot areas in the following solar cycle Also, the smaller the period between the ending of the polar field reversal and the beginning of a new cycle, the more intensive it is (Makarov et al. 1989). The solar cycle may be modelled as 3 waves of magnetic activity (Makarov et al. 1987).

One maximum of coronal emission in an 11-year cycle is associated with the emergence of dipole magnetic fields and another with quadrupolar fields (Mikhailutsa and Gnevyshev, 1988). It is suggested that an internal toroidal field 10^6 Gauss may be present in thin flux tubes (Dudorov et al, 1989, 1990). A cycle variation of prominence height is found (Kim et al.1988). The number of He 10830 dark points changes in antiphase with the sunspot cycle (Parfinenko and Parfinenko, 1990)

9.2 SUNSPOTS, FLUXTUBES AND LARGE-SCALE MAGNETIC FIELDS

The sunspot magnetic field increases with the ratio of sunspot area to active region area (Ermakova, 1989). Ca II lines during umbral flashes have been studied (Grigorieva et al. 1989). Torsional oscillations of sunspots permit Gopasiuk et al (1988) to determine subphotospheric rotation. A two-component model has been proposed for the atmosphere of the umbra (Obridko and Staude, 1988). The magnetic field intensity in bright regions of an umbra is by 300 Gauss smaller than in dark regions (Litvinov and Sattarov, 1989). The vertical electric current derived from vector measurements at Irkutsk and Potsdam have been compared (Hoffman et al. 1988).

Active regions that emerge near the boundaries of the background field are nearly twice as large and intense as those that do not (Ograpishvili, 1988). In polar regions the longitudinal and transverse fields are 4.2G and 7.5 G (Grigoriev, 1988). Sunspot and flocculi in activity complexes are located along cell boundaries (Sattarov, 1989).

The relationships between the large-scale solar magnetic field, coronal holes, the IMF sector structure and high-velocity streams have been found (Shelting and Obridko, 1988). The differential rotation of coronal holes is weak only near solar minimum (Obridko and Shelting, 1988).

9.3 SOLAR FLARES, OSCILLATIONS AND RADIO

Many features of flares can be explained by a model of a current sheet formed on a separator (Gorbachev and Somov, 1989). Plage with high current density increases its brightness (Abramenko et al. 1989). Vortex motions and magnetic field variations with height were studied by Abramenko et al (1989). The behaviour of thermal electrons escaping from a hot plasma has been investigated (Diakonov and Somov, 1988). Quasi-steady high-temperature current sheets are energy sources during the "main" phase of solar flares (Somov and Verneda, 1988).

Flares appear mainly on the zero line of radial velocities (Gopasiuk and Lazareva, 1988). Pitch-angle diffusion regime and turbulent propagation of energetic particles have been studied (Bespalov et al. 1987). Flares are accompanied by fluctuations of the intensity of the photospheric magnetic field (Alikaeva et al. 1989). In small volumes of prominences quasiflare processes are regularly observed (Kurochka and Kiruhina, 1989). The kinematic dynamo equations for a given distribution of sources has been solved (Ruzmaikin et al. 1988).

Radio oscillations with a period of 3 and 5 min have been observed (Tsvetkova and Tarasova, 1988). Global oscillations of flare activity have been observed (Ikhsanov et at. 1988). The results obtained indicate that the sunspot umbra are found to oscillate as a single whole (Kobanov. 1989). The cm-dm radio characteristics of coronal holes, filaments and filament cavities have been compared (Borovik et al. 1989). Cyclotron lines can serve as a diagnostic of magnetic fields and plasma in coronal active regions (Zheleznyakov and Zlotnik, 1988).

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