COMMISSION 10 : SOLAR ACTIVITY (ACTIVITÉ SOLAIRE)

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The Sun's activity may have declined in the three years since the last report, but the solar community carries on its research at a vigorous pace. During that interval there have been six IAU Symposia/Colloquia sponsored (or co-sponsored) by this commission on topics related to solar activity. Numerous activity-related conferences and workshops supported by other bodies attest to the vibrant interest in, and committement to, research on the wide range of topics which encompass this discipline. Flare research continues as the dominant topic, and is now fueled by a new generation of ground-based instruments and a highly successful solar satellite - Yohkoh (formerly Solar-A). Other recent space missions, although not devoted entirely to solar flares, are likely to have a profound bearing on our understanding of flare issues. They include, among others, the continuing series of sounding rocket flights of the Normal Incidence X-ray Telescope (NIXT), the Compton Gamma Ray Observatory (CGRO), designed to observe energetic phenomena in the Universe, and GRANAT, which is also dedicated to high-energy astronomy. The flare problem spurs research into many related subjects: active-region formation, physical proceses in prominences and filaments, coronal mass ejections, even periodicities in solar activity. This last topic is given separate attention here in order to draw attention to the still obscure link between the Sun's interior and the activity at its surface. It is a pleasure to thank the individual reviewers who took time from their busy schedules to write separate sections of this report.

As well as moments of triumph, there have been moments of anxiety, disappointment, and sadness for the solar community. Substantial numbers of solar astronomers and solar physicists in the states of the former Soviet Union live under stressful circumstances as struggles go on to form new political systems in their homelands. Elsewhere ambitious plans for new ground-based or space facilities have been delayed as a worldwide recession continues. And the community has been saddened by the loss of pioneering figures who had a major impact on shaping our discipline: Prof. Keizo Kai, former chief of the solar radio group at the Nobeyama Radio Observatory, Prof. Zenzaburo Suemoto, former director of the Tokyo Astronomical Observatory, Prof. Giuseppe Vaiana, best known in his role as principal investigator of the S054 experiment on Skylab, Dr. Mstislav N. Gnevyshev, founder and director of the Kislovodsk Solar Station of the Central Astronomical Observatory of the Russian Academy of Sciences. They will remain alive in our memory and in our work, which builds upon their considerable achievements.

1. GROUND-BASED OPTICAL INSTRUMENTS

(Guoxiang Ai)

1.1 HIGH SPATIAL RESOLUTION DEVICES

The following new devices or techniques have been introduced on the German Vacuum Tower Telescope (=VTT, Soltau 1991), on the Swedish Vacuum Solar Telescope (VST), and on the VTT of NSO/SPO (Dunn & Smartt 1991; Acton & Smithson 1992): real-time frame selection (Scharmer & Lofdahl 1991); a correlation tracker (von der Lühe 1991); adaptive optics (Dunn & Smartt 1991); and a speckle polarimeter-interferometer (Keller 1993). Dramatically improved resolution has been realized from these improvements, e.g., diffraction-limited performance of about 0.3" and successful reconstruction, using speckle polarimetry, of a narrow-band Stokes V image in which magnetic elements have a FWHM of about 200 km (Keller 1993).

New devices under construction include a continuous face-plate mirror with 218 mm clear aperture and 61 actuators (Dunn *et al.* 1991), and a coronagraph with adaptive optics using a membrane mirror with 91 actuators (Clampin *et al.* 1991).

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1.2 MAGNETOGRAPHS AND POLARIMETERS

Since April 1992 the NASA/NSO spectromagnetograph (Jones *et al.* 1992) has been measuring magnetic flux, line-of-sight velocity, continuuum intensity, equivalent widths, and line depths (spatial pixels of 1.1", spectral pixels of 30-40 mÅ). It scans the full disk in about 1 h and local regions in <5 min. The HAO/NSO Advanced Stokes Polarimeter (Lites 1993) became available to users in mid-1993 (~0.4", 12mÅ/pixel, integration time per spectrum ~4s, time resolution (for a scan 85"x85") ~16 min).

Videomagnetographs are now as popular as Hα filters were in the 1950s and 1960s. A high-resolution videomagnetograph using cross-correlation techniques to achieve 0.1"/pixel is operating in the Swedish VST (Lundstedt *et al.* 1991). A solar flare telescope (four tubes: Hα and white light (aperture 15 cm); vector magnetic field and velocities (20 cm)) is operating at Mitaka since 1991 (Ichimoto *et al.* 1993). A similar telescope is under development in the Republic of Korea. A vector videomagnetograph with a universal filter (range 4600-6600 Å; bandpass 0.05-0.125 Å) is being developed in Taiwan. Two full-disk videomagnetographs with time-resolution ~1 min have been built in tandem in Beijing and Tokyo (Ai 1993a; Sakurai 1993). Two videomagnetographs with a lithium niobate solid Fabry-Perot etalon are operational in the U.S.A.: at the Mees Solar Obs. and by JHU/APL at NSO/SPO (Rust & O'Byrne 1991); a similar unit is under development at the Udaipur Solar Observatory in India. Comparison of magnetographs built around narrow-band filters with grating instruments based on Stokes polarimetry show a high degree of consistency in the morphology of both longitudinal and transverse fields (Wang *et al.* 1992). Measurements of longitudinal fields agree better than those of transverse fields which show scatter originating in different sources for different instruments (Wang *et al.* 1992; Ronan *et al.* 1992).

Polarimetry at IR wavelengths enjoys the advantage of enhanced Zeeman splitting. The Stokes I, Q, U, and V profiles have been obtained in the lines 1.56μ FeI and 12.32μ MgI with infrared detector arrays having 640x488 pixels (1-1.5 μ), 256x256 pixels (1-5.5 μ) and 58x62 pixels (5-24 μ; Deming *et al.* 1991). Two-dimensional observations of sunspot magnetic fields have been made with a 128x128 format HgCdTl infrared array working at wavelengths from 1 to 2.5μ (McPherson & Kuhn 1992). A 0.5 Å birefringent filter at 10830 Å is being built (Ai 1993a).

An electrograph for measuring the dependance of polarization on line width in Stark-broadened Paschen lines around 8500 Å has been tested by Moran & Foukal (1991).

1.3 TWO-DIMENSIONAL IMAGING SPECTROGRAPHS

Grating-based 2-D spectrographs are gaining popularity with the improvement in quality of CCD cameras. The imaging spectrograph of the Swedish Solar Telescope (0.1"x 0.22"/pixel) is reported to have 5 s time resolution over a 25"x 25" area (Scharmer *et al.* 1991). Similar imaging spectrographs have been completed in the Solar Tower Telescope of Nanjing Univ. (Fang *et al.* 1993) and in a new 50-cm solar telescope for the Yunnan Observatory (Zhang *et al.* 1993). A 2-D spectrometer consisting of a scanning Fabry-Pérot interferometer with a universal birefringent filter as a monochromator (FWHM 0.02 Å) has been tested and will be used for THEMIS; a similar device is under way for the German VTT (Soltau 1991).

A third generation Multichannel Subtractive Double Pass (=MSDP) imaging spectrograph is presently working at the German VTT. It provide images simultaneously in many wavelengths (typically 20), covering two line profiles with spectral resolution of 0.26, 0.12, or 0.06 Å and local bandwidths 0.13, 0.04, 0.03 Å respectively (Mein & Rayrole, 1991). A multi-slit spectrograph for prominences, flares, etc. has been running at the Udaipur Solar Obs. A 2-D real-time polarizing spectrograph with 64 channels (tunable range: 4200-7000 Å, FWHM: 18-5 mÅ, wavelength coverage: 1-3.2 Å) is under development in China (Ai, 1993a).

1.4 LARGE OPTICAL SOLAR TELESCOPES

Detailed engineering design with integrated adaptive optics for LEST has been underway since 1991 (LEST Ann. Rep. 1991). Two imaging Stokes polarimeters are being prepared for it: ZIMPOL I, to obtain simultaneously I, Q, U, V with three demodulating CCD sensors (Keller *et al.* 1992); ZIMPOL II, to measure the four Stokes parameters simultaneously with a single demodulating CCD

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and a microlens array (Stenflo *et al.* 1992). THEMIS is expected to be operational 1995-1996 (Rayrole & Mein 1993).

A coronagraph with a 15-cm aperture, superpolished Zerodur mirror objective, now under development, will serve as a prototype for a meter-class research coronagraph (Dunn & Smartt 1991). An Open Tower Telescope (both the tower and the telescope have an open framework construction) with a 45 cm aperture is nearing completion (Hammerschlag & Zwaan 1992). It is an innovative concept aimed at decreasing the cost and complexity of high angular resolution telescopes.

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2. ADVANCES IN SOLAR MICROWAVE INSTRUMENTATION

(Shinzo Enome)

In preparation for the maximum of solar activity in 1991, one major new instrument was constructed and existing observing facilities were upgraded extensively. These new designs enhance the multi-dimensional character of microwave observations in the spatial, temporal, and frequency domains. A new 17-GHz T-shaped solar-dedicated array, consisting of 84 parabaloidal elements of 80-cm diameter each, was constructed at Nobeyama Radio Observatory. It began regular observations in late June, 1992. The major specifications of this unique instrument are: spatial resolution, 10"; temporal resolution 1 s with 50 ms option; 40' field of view; daily observation time of eight hours, from 2300UT-0700UT; and dynamic range of image, or quality of image, 25 dB or 300:1 for 1 s or snapshot mode (Enome 1992, Enome *et al.* 1993, Nakajima *et al.* 1993). Initial observational results have been presented for the the quiet Sun component, for active regions, and for flare sources in their impulsive and post-flare phases (Enome *et al.* 1993).

Ultra wide-band imaging systems were installed on the RATAN-600 antenna (Bogod *et al.* 1993) and on the Owens Valley Solar Array (Hurford & Gary, 1989). They take different approaches - multi-channel vs. frequency-agile systems - to cover the range 1-18 GHz in order to provide us with very rich spectral information for constraining the choice of emission mechanisms. Diagnostics and examples have been published for emission from active regions and flares (Gelfreikh *et al.* 1992, Alissandrakis *et al.* 1993, Stähli *et al.* 1990).

A five-element multi-beam system feeding a 48 GHz receiver was installed on the 13.7-m Itapetinga antenna. It produces five beams overlapping by one HPBW or 2' and covers a field of view ~2' x~4'. It is claimed to be able to track the centroid of flare sources with an angular accuracy of 5" to 19" with 1 ms time resolution (Costa *et al.* 1992; Herrmann *et al.* 1992)

Synthesis of solar images using the E-W fan-beam output of the Siberian Solar Radio Telescope has been performed for active regions (Alissandrakis *et al.* 1992). Two-dimensional maps computed from these one-dimensional observations clearly show the quiet-Sun background, sunspot- and plage-associated emission, as well as compact sources above the neutral line in some active regions.

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3. PERIODICITIES IN SOLAR ACTIVITY

(Jose Luis Ballester)

Throughout this century the existence has been claimed of periodicities in different manifestations of solar activity. Some of the reported periodicities are close to the rotation period, others lie close to that of the 11- or 22-yr cycles, while still others have been proposed with entirely different values. The interest in this topic was renewed by the discovery, in data obtained by the Solar Maximum Mission, of a periodicity between 152-158 days in the rate of flare occurrence during solar cycle 21. Since then most of the research in this field has assessed the existence of this periodicity in various forms of solar activity (flares, flare-related data, sunspots, etc). A variety of techniques have been applied to search for and characterize periodicities in time series: Rayleigh power spectrum, maximum likelihood method, Scargle periodogram, complex demodulation, etc. Also, some tentative models have been set up in order to explain their existence.

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3.1 THE NEAR 155-DAY PERIODICITY

Studies by several authors using flare and flare-related data have shown that the above periodicity has been present for some time. Dröge *et al.* (1990) examined the occurrence of energetic (>10 MeV) solar flare electron events from 1978 to 1982, finding strong evidence for a periodicity of 153 ± 2 days. Bai & Cliver (1990) studied the occurrence rate of proton flares during solar cycles 19 to 21 and identified two epochs exhibiting a 154-day periodicity. Those epochs are: a 14-year interval from January 1958 till December 1971, and a 5.5-year interval from February 1978 till August 1983. The best determined period is 154.6 (± 0.6) days. They found evidence that, between these epochs, the periodicity suffered a phase shift of 180°. Gabriel *et al.* (1990) searched for the periodicity in time-series of solar proton events during solar cycles 19 to 21. They found a prominent periodicity around 152-156 days in the occurrence of solar proton events during cycles 19 and 21, but only inconclusive evidence for it in solar cycle 20. Kile & Cliver (1991), having analysed Ottawa 2.8 GHz burst data from cycles 19, 20 and 21, concluded that the periodicity is only statistically significant during the maximum of solar cycle 21; for the other periods the evidence is contradictory. A study of flare rates during cycle 22 made by Bai (1992) shows that a periodicity around 77 days, third subharmonic of the fundamental period of ~25.5 days (the 154-day period is the sixth subharmonic), was in operation during a 15-month interval (November 1988 - February 1990) and that it reappeared in 1991. He too found a 180° phase shift of the periodicity between those epochs. The presence of a 155-day periodicity in sunspot areas during cycles 12 to 21 has been examined by several authors. Lean (1990) found that this periodicity is only present during epochs of maximum activity and that it occurs in episodes of 1 to 3 years. Carbonell & Ballester (1990, 1992) showed that a periodicity between 150-160 days seems to be significant during all solar cycles from 16 to 21; during previous cycles it is only found in some time intervals, but with high significance. They also found evidence suggesting that, in cycles characterized by a strong north-south asymmetry of solar activity, the periodicity is only present in the hemisphere most favoured by solar activity. There is also slight evidence for the intermittent presence of a 155-day periodicity in auroral data going back till the sixteenth century (Silverman 1990), which could indicate that it is a persistent feature of solar activity.

3.2 MODELS

Some explanations for the existence of a periodicity of 155 days, most of them qualitative, have been advanced. Wolff (1992) argues that some of the reported periodicities can be explained as aliases of real periodicities sampled in the 11-year window of the solar cycle. He proposes that the 155-day periodicity can be understood in terms of the normal modes of oscillation of a nearly spherical, slowly rotating star, when two r-modes (inertial modes) couple with an interior g-mode. This suggestion agrees qualitatively with the fact that the periodicity is intermittent and stronger around the maximum of solar activity; detailed calculations are needed to confirm this hypothesis. From spectrum analysis of long records of sunspot numbers, areas, and flares, Bai & Sturrock (1991) and Sturrock & Bai (1992) propose that the Sun contains a "clock", which they model by means of an oblique rotator or oscillator, with a period of 25.8 days. They suggest that the periodicity of 154 days is just a subharmonic of that fundamental period. Later, Bai & Sturrock (1993) analyzed the longitudinal distribution of major flares and found that it exhibits the largest modulation for a period 25.50 days for an oblique rotator tilted at 40°. From helioseismic evidence, however, Goode & Thompson (1992) conclude that the Sun's convective zone and at least the outer part of its radiative interior rotate on the same axis. Another explanation links the increase in flare-rate occurrence to a periodic emergence of magnetic flux through the photosphere (Lean, 1990; Brueckner & Cook, 1990; Carbonell & Ballester, 1990, 1992). In order to develop theoretical models, further studies of the 155-day periodicity are needed to focus on key points: intermittency, phase shifts, simultaneity of its presence in different primary indicators of solar activity, and the relationship to the N-S asymmetry of solar activity.

3.3 OTHER PERIODICITIES

The existence of longer periodicities has also been studied. Oliver *et al.* (1992) analyzed sunspot numbers (cycles 6-21) and sunspot areas (cycles 12-21); they found no evidence, except in solar cycle 21, for a proposed periodicity of 323 days. Another one of 540 days, first detected in flare occurrence in the northern hemisphere during cycle 19, appears clearly. It shows up in northern hemisphere data during cycles 18-19 but less prominently in cycles 12, 14 and 17. This last detection needs to be confirmed from other indicators of solar activity. A 600-day periodicity in the areas of coronal holes

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during 1977-1989 has been reported by McIntosh *et al.* 1992; this periodicity is prominent for southern coronal holes but does not appear in the data for northern coronal holes. This again suggests a relationship between periodicity and asymmetry of solar activity. However, we should remember that flares and sunspots are, in general, associated with closed magnetic fields, while coronal holes are related to open magnetic fields, which might have some bearing on the origin of both periodicities.

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4. ACTIVE REGION EVOLUTION
(Jingxiu Wang)

Studies of active-region evolution have proceeded vigorously as a result of intense interest in a wide range of topics during the last three years. This is evident in the special colloquium on active regions (Zirin *et al.* 1993, I), and in three workshops which cover most of the topics in this area (November 1991, II; Harvey, 1992, III; Thomas & Weiss, 1992, IV). Some advances in flare-associated changes in magnetic fields are found in flare meetings (Schmieder & Priest 1991, V; Svestka *et al.* 1992, VI). A colloquium on the Sun and cool stars reflects the mutual interest in solar active regions of solar and stellar astronomers (Tuominen *et al.* 1991, VII). A major impact on active-region studies from Yohkoh is evident in the initial results published in an issue of *PASJ* (1992, VIII). Relevant topics are also contained in recent monographs (Priest & Hood, 1991, IX; Cox *et al.*, 1991, X; Schmelz & Brown, 1991, XI).

4.1 FLUX EMERGENCE

The process of flux emergence has been mapped in detail by vector magnetographs, e.g. at Huairou Observatory (Zhang *et al.* VII, p. 271; Zhang & Song, 1992; Wang & Shi, 1993). Wang and Shi conclude that the emergence of new flux drives flux cancellation with pre-existing flux and is a wholly inseparable, elementary process in an active region; the observed flux cancellation is most likely a slow reconnection in the lower atmosphere. In one example this reconnection is inferred to take place below the photosphere, making an emerging flux region (EFR) show up with only one pole, but with a remarkable bundle of enhanced transverse field. High resolution Hα filtergrams have revealed EFR-surges (Kurokawa, I, p. 507). Newly discovered X-ray jets from Yohkoh's Soft X-ray Telescope (SXT) are partly associated with EFRs (Shibata *et al.*, VIII, p. L173). The first comparison between Hα and SXT images of EFRs (Kawai *et al.*, VIII, p. L193) shows bright SXT features spatially coincident with Hα arch filament systems (AFSs), indicative of fast reconnection between EFRs and overlying magnetic fields. Numerical simulations by Shibata *et al.* (1992) have reproduced the above observational features.

The unusual emergence of new flux in the sheared corridors of large, compact, δ sunspots (Wang *et al.* 1991; Tang & Wang, 1993; Wang & Tang, 1993) challenges the traditional picture of EFR

(Chou, I, p. 471). This kind of unusual emergence was first discovered in two superactive regions, March 1989 and June 1991, during this solar cycle. It is characterized by (1) penumbral motions in the direction of sheared penumbral fibrils, (2) newly emerged sunspots often with only one polarity in the midst of penumbra, (3) disordered or irregular AFSs (Kurokawa, 1991), and (4) major flares mostly with big surges. Wang *et al.* (1991) report that 80% of the flux in the March 1989 region is of following polarity. Shi & Wang (I, p. 71) find that for all δ sunspots associated with X class flares in this cycle, the average flux ratio between the two polarities is larger than 5. Kurokawa (1991) and Tanaka (1991) suggest a topology of tightly twisted or kotted flux ropes for compact δ sunspots. Zirin & Wang (1993) identify a transverse field as high as 0.4 T parallel to the magnetic neutral line within δ sunspots.

In a global sense, the injection of intense magnetic fields in bursts at a few tightly defined locations over a long period is shown to be a basic property of solar activity (Gaizauskas, I, p. 479; Zwaan, IV, p. 75). van Driel-Gesztelyi *et al.* (III, p. 89) show that more than one third of all sunspot groups between 1940-1976 appear in compact active nests. For a large sample of dipole active regions throughout cycle 21, Harvey (1993) finds that 40 - 55% of new dipole regions occur in nests, and new dipoles emerge within existing sunspot regions at a rate at least 22 times greater than they do outside. Wentzel & Seiden (1992) have reproduced the quasi-regular distributions of active regions in clusters by using percolation theory.

4.2 MAGNETIC TOPOLOGY

Solar flare research has greatly boosted the study of active regions by promoting an awareness of the coupling between flare sites and the evolving topology of global magnetic field (Gaizauskas, 1993). Basic topological structures are seen as cells of magnetic connectivity defined by separatrices and separators (Priest 1991; Hénoux *et al.*, I, p. 333). Practical 3-D representation of these structures by potential or force-free fields using distributions of charges or dipoles based on observations have been developed by Démoulin *et al.* (1992). Mandrini *et al.* (1991, 1993) find that the topological evolution corresponding to flux emergence and disappearance in NOAA 2372 is favourable to reconnection at the separator to which the Hα flare kernels are connected. In an activity complex, Schmieder *et al.* (1991), van Driel-Gesztelyi *et al.* (1993), and Démoulin *et al.* (1993) find that an old region with less magnetic shear is highly active, while a young region with strong shear is inactive. They establish that a separator is present in the old region, but not in the young one. Topologically, a complex and an active region may be equivalent. If the interaction between two regions in a complex does not create a separator, they show little similarity in activity. But if a separator is present between two regions, sympathetic activity is triggered between the two regions and is interpreted in terms of interaction between different flux loop systems. This is analogous to the interacting dipole representation for individual flares in a single region (Polletto *et al.* 1993). Loop interactions take place at various energy scales when a topological singularity appears in the evironment. They are shown to be the cause of 'active region transient brightenings' (Shimizu *et al.*, VIII, p. L147) and are, perhaps, the ultimate source of the continual expansion of the active region corona (Uchida *et al.*, VIII, p. L155).

The topology deduced by Démoulin *et al.* (1992) applies only in a global sense. Current-aligned magnetic loops may well be interwoven or twisted. Another topological concept, helicity, becomes important in the study of free energy build-up (Berger, IX, p. 241; Seehafer, I, p. 435).

4.3 MAGNETIC NON-POTENTIALITY

Greatly improved observations of vector magnetic fields during flare campaigns have given a fresh impetus to the study of magnetic non-potentiality, defined as the departure of the observed vector magnetic field from the corresponding potential configuration (Hofmann & Kalman, 1991; Gary *et al.*, II, p. 65; Canfield *et al.*, II, p. 296; Abramenko *et al.*, 1992; Wang, I, p. 323; Wang, I, p. 425). Intriguing increases of shear after major flares are reported by Wang (1992) and in other recently submitted studies. Shear increase preceding flares and relaxation following flares are shown by Hagyard *et al.* (1993) and by Wang (I, p. 425). These have revived Tanaka's old classification of shear evolutionary modes which are associated with flare activity (Tanaka, 1986). Tang & Wang (I, p. 323) find that the neutral line may not have strong magnetic shear when flare ribbons start quite far away from the neutral line. On the other hand, strong shear is not a sufficient condition for flares to occur

(Hagyard & Heyvaerts, V, p. 1). Possible non-potential features in the chromosphere are suggested by Wang and Shi (1992), Zhang (I, p. 263). These improved observations lead to a recognition of the shear evolution in both magnitude and height, in accordance with general field evolution and energy build-up.

With regard to how magnetic non-potentiality is created, three categories of evidence are reported. First, motions at the surface: shear motion of magnetic footpoints (Zhang, III, p. 124; Wang, 1992), collision of opposite polarity sunspots (Ai *et al.*, 1991; Gaizauskas and Harvey, V, p. 25), and sunspot rotation (Hofmann & Kalman, 1991; Abramenko *et al.* 1991). Second, highly non-potential features may break out from below during flux emergence (Tanaka, 1991; Kurokawa, 1991; Tang & Wang 1993; Zirin & Wang; 1993). And third, flux cancellation converts the line-of-sight magnetic field into transverse field parallel to the neutral line, favourable to filament formation (Martin & Livi, VI, p. 33). To understand these, Wang (1992) has demonstrated that the changes of the non-potential degree are caused by either the generation of local shear due to the interaction between magnetic fields and plasma motion, or the transport of shear.

4.4 SUBSURFACE DYNAMICS

Recent statistical work on the global behaviour of active regions represents an important trend in studying the subsurface dynamics of flux loops which rise to the surface to form active regions. Mount Wilson daily magnetogram data from 1967 to 1988 (in its coarse form) and digitized sunspot data from 1917 to 1985 have been used by Howard in extensive studies of global properties. Among many interesting results, the polarity separation is shown to be a property of subsurface flux loops (Howard 1992a). The relation between magnetic axial tilt and polarity separation signals the surface effect of Coriolis forces that act to twist rising flux loops (Howard 1993a). The difference between the magnetic fields of average sunspots and plages in many aspects are explored for the first time (Howard, 1991a-d; 1992b,c; 1993b). They are indicative of the different depth and nature of the connections to the subsurface flux system. Harvey selects a sample of 978 emerging bipole regions throughout cycle 21, from Kitt Peak full disc magnetograms, for her systematic analysis (I, p. 488). The shape of the characteristic distribution of active-region sizes is shown to be a fundamental invariant property of solar magnetism, in revealing the process that releases or triggers flux loops to emerge from the toroidal flux system in the solar interior (Harvey 1993). The patterns in both the bipole orientation and latitude distribution point to magnetic fields in the subsurface flux system that are strong enough to resist disordered convection and Coriolis forces.

Numerical simulation of a toroidal flux ring in a rotating spherical geometry with the inclusion of the Coriolis force has given interesting new results. D'Silva & Choudhuri (1993) are able to predict the tilt-separation relations of active regions (Howard 1993a), and to get an estimation of 6-15 kG for the initial field strength of the toroidal loops. Fan *et al.* (1993) have carried out a series of numerical simulations to study the dynamical evolution of emerging flux loops in the solar convection envelope with their innermost portions anchored beneath the base of the convection zone. They have shown nicely how the combined action of Coriolis force and the anchoring of the innermost portions to a rising loop creates the well-observed morphological asymmetry in bipolar active regions.

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5. FILAMENTS AND PROMINENCES

(Oddbjørn Engvold and Jack B. Zirker)

The past 3 years have brought a significant shift in interest, away from traditional subjects of plasma properties and magnetic fields of prominences and filaments and towards studies of their fine-structure, motions, and formation. A major IAU colloquium, "Dynamics of Quiescent Prominences" held in Hvar, Yugoslavia, Sept 25-29, 1989, attracted a large group of investigators and sparked a renewed interest in the subject.

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5.1 DYNAMICS

Schmieder (1990) and Rompolt (1990) have reviewed current understanding of the motions in and around prominences. While much information on the details of these motions has been obtained, we still do not have a convincing model of the circulation of mass to and from the corona and the photosphere.

The search for wave heating in filaments has motivated a number of studies of oscillations. Oscillations in Hα filaments (periods of 250, 200 and 150 s) were reported by Thompson & Schmieder (1991). Yi *et al.* (1991), in contrast, saw periods of 5 to 15 min in He I 10830. These oscillations occurred in fibril-like, horizontal structures that appear to be aligned with the horizontal magnetic field. Suematsu *et al.* (1990) found 240 and 830 s oscillations in prominences. Wiehr *et al.* (1990) recorded periods spread between 3 and 60 min. Mashnich & Bashkirtev (1990) also saw periods as long as an hour.

Joardar & Roberts (1992a and b) and Oliver *et al.* (1993) have studied possible MHD oscillation modes in prominences based on static, uniform (slab) models. The authors show that both slow-, fast- and Alfvén-modes can give rise to the observed short-period oscillations. Longer period oscillations may be produced by hybrid slow modes. Bakhareva *et al.* (1992) have investigated how the build up time of oscillations and their period depend on factors such as the transverse magnetic component, again in the framework of magnetostatic 'slab' models. The spatial characteristics of the short period oscillations suggest that they are due to Alfvén waves (Jensen *et al.* 1993).

Persistent flows, particularly in the vertical direction, have been studied in an attempt to clarify the geometry of prominence structures. Zirker *et al.* (1993) analyzed Dunn's (1960) Hα prominence movies using objective local correlation techniques and found consistency between the vertical velocities in prominence threads and in filament downflows. Kim (1990) found two types of downward flows in filaments: those with constant acceleration (less than gravitational) and those with uniform velocity.

Filaments undergo large-scale shearing motions. Athay (1990) showed that active-region filaments lie on long-lived shear lines. Schmieder *et al.* (1990) compared Hα and C IV spectra and found that significant shear appears in a filament before it erupts.

5.2 PROMINENCE FINE-STRUCTURE

Very little new data has been presented recently on the thermodynamic properties of the fine-structure, but Hirayama (1990) has reviewed recent determinations of mean density and temperature. Wiehr & Stellmacher (1991) have obtained magnetic measurements in structures 1" in diameter. They found field strengths between 7.5 and 18 mT in an active-region prominence. Kim *et al.* (1990) found values between 0.3 and 2.4 mT in quiet prominences and discuss statistics of the field direction. Zirker & Koutchmy (1990, 1991) obtained Hα spectra of 1"-resolution and showed that they could be modelled by random clusters of sub-arcsecond threads. Seven to twenty threads in the line of sight are typically inferred. Mein *et al.* (1990) and Mein &Mein (1991) used similar modelling to account for the observed distributions of doppler velocity and line width in well-resolved quiescent prominences.

The assumed significance of the fine-structure in the physics of prominences has led to a series of theoretical studies of its formation. Analytical solutions have been attempted by Hood & Anzer (1990), Priest *et al.* (1991), and Hood *et al.* (1992). These authors state that the conditions for Rayleigh-Taylor instabilities are not fulfilled in prominence regions. Thread structure is likely to occur as a result of radiative instability during prominence formation. Steele & Priest (1992) have modelled the prominence fine-structure as many cool slabs aligned parallel to the prominence axis in the frame of a magneto-static model. van der Linden & Goossens (1991) suggested that non-adiabatic terms in the energy equation may be applied to model the growth of prominence fine-structure. The non-static, strongly dynamic behaviour of prominence threads are not yet understood theoretically.

5.3 FORMATION AND SUPPORT

A number of authors have investigated idealized, sheared magnetic arcades in search of magnetic topologies that will provide support of prominence plasma (Fiedler & Wood 1993). Amari *et al.* (1991) found that sheared motion at the footpoints of magnetic arcades cannot produce magnetic field lines concave upwards. Ridgway & Priest (1993), on the other hand, demonstrated that converging photospheric motions acting on an already sheared force-free magnetic arcades will lead to helical fields which possibly provide the the needed support. Choe & Lee (1992) showed that quiescent prominences can be formed as the result of shearing motion at the photospheric level. Cool prominence matter collects from a combination of radiative cooling, provoking a thermal instability, and siphon upflow from photosphere and chromosphere. van Hoven *et al.* (1992) showed that rapid radiative cooling at the apex of coronal loops could give rise to siphon inflow from the chromosphere and subsequently to prominence formation. Similar results were reached by Wu *et al.* (1992).

Martin (1990) summarized several conditions for formation of prominences, as inferred from optical observations. Important new criteria include long term (hours to days) convergence of small field patches toward the neutral line and the cancellation of opposite polarity patches. Martin has proposed a conceptual model of filament formation based on her results (1992).

5.4 FILAMENT FIELDS AND THE SOLAR CYCLE

Martin *et al.* (1992) have reported a number of extremely interesting regularities of the direction of the magnetic field in quiescent filaments. Filaments are either "dextral" or "sinistral". Dextral (sinistral) filaments have their horizontal magnetic fields pointing to the right (left) as seen from the adjacent region of positive photospheric field. All northern (southern) hemisphere filaments are dextral (sinistral). The absolute direction of filament fields (ie East-West) reverses in successive cycles. The physical bases of these rules remain unknown.

5.5 PROMINENCE-CORONA TRANSITION REGION (P-CTR)

Chiuderi & Chiuderi-Drago (1991) were able to reconcile observations in EUV and at radio wavelengths. Chiuderi-Drago *et al.* (1992) modelled the P-CTR associated with individual magnetic threads. They concluded that dissipation of Alfvén-wave energy would seem able to explain the observed EUV flux radiated from the temperature layers below 100 000 K. Wiik *et al.* (1992) have performed a detailed analysis of a quiescent polar crown prominence from observations in UV and visible wavelengths.

5.6 RADIATIVE TRANSFER

Thermodynamic modelling of the prominence plasma is critically dependent on non-LTE effects in radiative transfer, where also the small-scale nature of the prominence plasma becomes important. Paletou *et al.* (1993) have studied the formation of resonance lines of H I, Mg II and Ca II in a 2-D atmospheric model. Improved codes for treatment of PRD scattering give good agreement with observed emission line profiles.

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6. CORONAL MASS EJECTIONS

(David F. Webb)

6.1 INTRODUCTION

Coronal Mass Ejections (CMEs) are ejected away from the Sun as self-contained structures of plasma and magnetic fields. CMEs apparently involve a significant restructuring of the corona on a large scale. They can significantly perturb the solar wind and disrupt the Earth's environment. The primary observations of CMEs have been obtained from orbiting white-light coronagraphs on the Skylab (1973- 74), P78-1 (1979-85), and SMM (1980 and 1984-89) spacecraft. These data have been complemented by observations of the inner corona from the K-coronameter at Mauna Loa Solar Observatory (MLSO) in Hawaii and, occasionally, in Fe emission lines. From 1975-83 white-light observations of CMEs in the inner heliosphere were obtained by the zodiacal light photometers on the Helios spacecraft.

During this reporting period, a number of Proceedings were published from meetings where important CME work was presented or reviewed. These include the Flares 22 meeting at Chantilly (Schmeider & Priest 1991, I); COSPAR at The Hague (Antonucci & Somov 1991, II); IAU Colloquium 133 in Iguazu, Argentina (Svestka *et al.* 1992, III); COSPAR in Washington, D.C. (Pick & Machado 1993, IV); Solar- Terrestrial Predictions Workshop:IV in Ottawa (Hruska *et al.* 1993, V). Review papers emphasizing CME-related observational results include Harrison (1991a, b), Kahler

(1992), Hildner (1992), Webb (1992; 1993), Dryer (1993) and Hundhausen (1993b), while those on CME modelling include Low (1990; 1993), Steinolfson (1990; 1991) and Somov (1991).

The Japanese Yohkoh satellite was launched in August 1991 and preliminary results were published (Ref. VI) with several papers discussing the coronal signatures of erupting prominences and other evidence of mass ejecta. The scope of this review does not include the considerable work done recently on interplanetary aspects of CMEs, particularly magnetic clouds, driver gas signatures, energetic particles, and shocks; some summaries appear in References III, VII-X.

6.2 OBSERVATIONAL RESULTS

Significant new results on CMEs during this period have come from analyses of the SMM, MLSO and HELIOS data. The most easily measured properties of CMEs are their occurrence rates, central latitudes, angular widths and speeds. A fundamental empirical conclusion that must be addressed by models is the large range in these parameters exhibited by CMEs. Their speeds (and accelerations), masses and energies all range over 2-3 orders of magnitude. Although difficult to determine accurately, the masses and kinetic energies of SOLWIND CMEs extended from 10^{14} - 5×10^{16} g and 10^{29} - 6×10^{31} erg, respectively (Howard *et al.* 1985), and some SMM-observed CMEs exceeded these values (Hundhausen 1993b). For the first time Gopalswamy & Kundu (1992) were able to calculate the mass of a CME from radio observations assuming only thermal emission. Parameters which vary by an order of magnitude are: CME occurrence rates over the solar cycle (Webb & Howard 1993), and CME widths, which exceed by factors of 3-10 the sizes of flares and active regions. The annual occurrence rate of CMEs is well correlated with other solar activity and tracks the sunspot cycle in both amplitude and phase (Webb & Howard 1993).

The basic structure of many CMEs consists of a bright leading arc followed by a dark cavity and a bright core of denser material, suggesting the eruption of a pre-event prominence, its overlying coronal cavity, and the ambient corona. However, there is a disparity in the fraction of loop-like CMEs reported for Skylab, SOLWIND and SMM, ranging from only 1% of the SOLWIND CMEs to nearly half of the SMM-observed CMEs, 2/3 of which contained bright cores. The leading CME structures are likely the skyplane projections of three-dimensional structures such as arcades (Steinolfson 1992a; Gopalswamy & Kundu 1993) or shells (Hundhausen 1993b).

Preliminary studies indicate that CMEs arise from large-scale, closed structures, most (~75%) from pre-existing coronal streamers. This is not consistent with the suggestion of Hewish and coworkers that CMEs arise in open field regions, i.e., coronal holes (Harrison 1990; Hundhausen 1993a). The temporal and latitudinal distributions of CMEs are similar to those of streamers and prominences, being confined to low latitudes about the current sheet near cycle minimum and becoming very broad near maximum (Hundhausen 1993a). This evolution is very different from that of active regions, flares or sunspots. Many of the most energetic CMEs are actually the disruption of a pre-existing streamer, which increases in brightness and size for days before erupting as a CME. Afterwards the streamer and CME are gone, often replaced by a thin ray, probably a current sheet. These events appear on white light synoptic charts as "bugles", portions of the streamer belt which brighten and widen then disappear (Hundhausen 1993a).

The speeds of the leading edges of SMM-observed CMEs ranged from 10 to 2100 km/s. The average speeds of SOLWIND CMEs were much higher near solar maximum than minimum, but Hundhausen emphasizes that SMM CME speeds did not vary much over the cycle. Significant progress has been made in simulating the MHD response to CMEs propagating through the corona (reviewed by Steinolfson (1992b) and by Hundhausen (1993b)). Fast MHD shocks apparently driven by fast CMEs are the most common type in the solar wind. However, in the lower corona the speeds of typical CME outer loops are supersonic but sub-Alfvénic, averaging 445 km/s for SMM. 80% of the trajectories of these CMEs were consistent with constant speed. Numerical simulations of the disruption of model streamers indicates that slow, intermediate and fast shocks should form ahead of CMEs with speeds of 200-300, 300-900, and >900 km/s, respectively. Thus, slow and intermediate shocks might be associated with most CMEs, and some CMEs have been observed that exhibit the predicted flattened fronts. Although the observation of metric type II bursts and their strong association with faster (>400 km/s) CMEs indicates that fast shocks exist in the lower corona (Kahler, 1992), it remains unclear whether they compress sufficient material to be detected optically as bow waves in front of CMEs. Some CMEs do show significant accelerations over large distances, which argues against an impulsive thermal driving force. Often such CMEs are associated with large prominence eruptions.

Statistical studies continue to show a stronger association between CMEs and erupting prominences and X-ray long duration events (LDEs) than with optical flares (reviewed by Webb 1992). But a third to a half of all CMEs cannot be associated with any near-surface activity. Previous studies have shown that CMEs are well associated with soft X-ray flares of longer duration, but Harrison (1991c) disputes this, finding that CMEs can be associated with flares of any duration. St. Cyr & Webb (1991) found that the distribution of the various forms of activity related to CMEs does not change over the solar cycle, although near minimum a lower fraction of SMM CMEs had apparent associations.

Recent results from SMM continue to indicate that, even when associated, flares are likely a by-product of the CME process rather than directly related to its origin. The departure times of flare-associated CMEs typically precede the flare onsets, even for the fastest SMM/MLSO events (Harrison 1991c; Webb 1992; Hundhausen 1993b). Some of these CMEs began their motion within the MLSO field of view before flare onset and some energetic CME/erupting prominences occurred in the absence of any GOES X-raybursts. Recent studies indicate that CME/flares can lie anywhere under the CME span, that associated active regions are offset towards the CME legs, and that even large HeI double-ribbon events have smaller spans and poor spatial overlaps with accompanying CMEs (Harrison 1991b,c; Kahler 1991; Webb 1992).

In previous years much theoretical work on CMEs was focussed on the reconnection of the magnetic fields which close after the CME has erupted. The recent models of the LDE/2-ribbon flare process describe this late phase reasonably well, but results based on CME observations have lagged. Recently, Kahler & Hundhausen (1992) found that the bright structures following many SMM CMEs are newly-formed streamers. A recent Yohkoh/MLSO observation of the reformation of a giant helmet streamer also provides strong evidence of reconnection following CMEs (Hiei *et al.* 1993). McComas *et al.* (1992) reported evidence of moving concave-outward structures which might be the upper U-shaped loops resulting from this process. They interpret these structures as the disconnection and eruption of previously open fields in streamers.

6.3 THEORETICAL MODELLING

Of the many models intended to describe the origin and propulsion of CMEs, most are over-simplified and not sufficiently developed to allow reasonable comparison with observations. The class of models which require a thermal or pressure pulse (i.e., flare) as driver no longer seem viable. Recently there has been intensive work on the origin of CMEs based on the slow evolution of particular coronal structures through metastable states or sequences of stable equilibria until the stability or equilibrium breaks down, resulting in the mass ejection and opening of the field. Low (1990; 1993), Steinolfson (1991) and Dryer (1993) have recently reviewed such analytic models and numerical simulations. Causes of the evolution of these coronal structures, especially streamer configurations, include the motion of loop or arcade footpoints (Low *et al.* 1982), the emergence of magnetic flux (Steinolfson 1992a; Guo *et al.* 1992), the dynamical evolution of arcades (Steinolfson 1991; Inhester *et al.* 1992) or the shear of field lines across neutral lines (Steinolfson 1991; Wolfson & Low 1992).

However, Kilmchuk (1990) pointed out that arcades in general must be sheared and their evolution does not readily lead to instability or loss of equilibrium. In addition, to be tractable, most of these models involve force-free equilibria which, as pointed out by Hundhausen (1993b), cannot realistically describe the complex evolution of the pressure, magnetic and gravitational forces acting on a magnetically closed coronal structure.

Another and very basic problem with both potential and force-free fields was pointed out by Aly (1991) who showed that the energy in an open field configuration always exceeds that of any closed state. Thus, there is not sufficient free magnetic energy available to open up a closed, force-free configuration to produce a mass ejection. Recently, Low & Smith (1993; reviewed by Low, 1993) found that an evolving streamer configuration can contain sufficient free energy to open the field if it contains cross- field currents in a magnetic bubble contained within the streamer core. Such a bubble is detached from the surface and probably resides in the dark cavity surrounding prominences where strong fields may exist. The internal energy of the trapped plasma is also available for the eruption and once the system becomes unstable, pressure gradients may drive the system to eruption (e.g., Wolfson & Low, 1992; Low & Smith, 1993; Low, 1993).

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7. HIGHLIGHTS FROM SPACE - YOHKOH
(Yutaka Uchida)

The Yohkoh satellite was launched on 1991 August 30. Developed under the responsibility of the Institute of Space and Astronautical Science (ISAS), Japan, with the cooperation of other Japanese institutions, and with important contributions from UK and US institutions, Yohkoh aims at studying high-energy solar phenomena (Ogawara *et al.* 1991). As the only solar-dedicated mission launched during Cycle 22, Yohkoh is the successor to previous solar observatories in space: Skylab, P78, SMM and Hinotori. It carries four scientific packages (Tsuneta *et al* 1991; Kosugi *et al* 1991; Yoshimori *et al.* 1991; Culhane *et al.* 1991): a soft X-ray telescope (SXT); a hard X-ray telescope (HXT); a set of wideband spectrometers (WBS) whose energy range spans from soft X-rays (~1 keV) to γ-rays (<100MeV); and a set of Bragg crystal spectrometers (BCS).

The following sections provide a condensed overview of the main preliminary results from Yohkoh; extended analyses are in press or submitted at the time of this report.

7.1 ACTIVE REGION BEHAVIOR

The conventional concept of the active-region corona, as a region of a hot, dense gas tied down by the magnetic field of sunspots to the photosphere by some uniform heating process, is not supported by the Yohkoh observations. Instead, the active region corona is found to be supplied with mass *already heated from below* along magnetic loops (Shimizu *et al.* 1992). These have $5x10^6$ K-type high temperatures (Hara *et al.* 1992; Watanabe *et al.* 1992). Yohkoh was able to reveal these transient brightenings in active regions because of the high cadence of its observations and its low-scattering SXT optics. The discovery may affect basic ideas about coronal heating in general.

Furthermore, the active-region corona expands intermittently and, in many cases, almost continually with a velocity ~10 km s^{-1}, showing that active regions are not in magnetohydrostatic equilibrium (Uchida *et al.* 1992). Because there is prior evidence for interplanetary magnetic clouds being ejected without any corresponding flare or dark filament disappearances on the Sun (Nakagawa et al.1989), an examination of the interrelation of these events to active-region expansion is under way. If it can be proved that active-region expansion extends into interplanetary space, concepts about solar mass loss, and especially mass loss for stars showing magnetic activity, may be significantly affected.

7.2 DYNAMISM OF THE BACKGROUND CORONA

One of the most important findings by Yohkoh is the dynamism of the background corona, a behavior recognized in its full form for the first time by viewing the high-cadence Yohkoh-SXT images as video-movies. The background corona forms an impressive dynamic system with active regions. Many examples are seen of interesting interplay between them (Uchida 1993) and of flare-related phenomena (Tsuneta & Lemen 1993).

The coronal dynamism discovered by Yohkoh is most evident in: (i) the disappearance of dark filaments far from active regions; (ii) very small changes in active regions whose effects can cover a very wide region of the corona; (iii) ejection of heated mass from the brightenings in active regions into magnetic tubes comprising the overlying magnetic structure without changing the magnetic structure appreciably. These ejecta appear jet-like when they are injected into an open flux tube (Shibata *et al.* 1992). Fast disturbances propagating with velocities greater than 1000 km s^{-1} may exist but cannot be captured effectively with the present cadence of SXT images.

Disappearing Hα dark filaments outside active regions are accompanied by the well-known, low-energy, Hα double-ribbons. Skylab captured a few examples of arcade-formation related to these events as "still" pictures. Now Yohkoh has clarified the detailed dynamic behavior of X-ray arcade-formation. New findings, such as those by McAllister *et al.* (1992), seem to contradict models proposed earlier by Sturrock (1966), by Hirayama (1974), or by Kopp & Pneuman (1976), and will contribute to the derivation of more realistic ones.

A larger version of closed-loop arcade-formation at high latitudes far removed from the active-latitude belt was seen for the first time by Yohkoh (Tsuneta *et al.* 1992b). This immense structure grew

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progressively in height (3×10^5 km) and in length (10^6 km). It formed in a dark area, seemingly a coronal hole. But it was later confirmed that a field-polarity reversal line was there in the photosphere, so that the coronal hole was not a magnetically unipolar area. The inside of the arcade appears bright in X-rays when the structure is observed on the west limb. The global structural change of the coronal magnetic field appears to take place through a non-explosive, quasi-steady magnetic reconnection.

7.3 GLOBAL AND LONG-TERM BEHAVIOR OF THE CORONA, CORONAL HOLES, AND X-RAY BRIGHT POINTS

Synoptic analyses of Yohkoh data reveal that the high latitude part of coronal holes are not rotating rigidly; the rigid rotation of a coronal hole is restricted only to that portion which is in the active-latitude zones. It is suggested (Uchida 1993) that the rigid rotation of coronal holes, noted earlier in Skylab results, merely reflects the rigidly rotating active-longitude belts.

The behavior of X-ray bright points (XBP) was examined with Yohkoh (Strong *et al.* 1992; Nitta *et al.* 1992), but their number is considerably less than found by Skylab (Golub *et al.* 1974). The number does not thus far show a marked dependence on the phase of the cycle. There is, however, a possibility that the temperature range of the Yohkoh-SXT is not suited for finding XBPs.

7.4 FLARES

By the end of June 1993, Yohkoh observed 834 flares, of which 14 are powerful GOES X-class, and 230 are M-class flares. Yohkoh observations make the detailed structure and changes in preflare structures available both in soft and hard X-rays for the first time. Knowledge of preflare-to-flare changes of magnetic structures is essential to the understanding of flare mechanisms. Results are now available from coordinated observations with ground-based optical and radio observations (Ichimoto *et al.* 1992; Sakurai *et al.* 1992; Kurokawa *et al.* 1992).

New observations with the Yohkoh-HXT in four separate high-energy bands are free of the contamination from lower energy bands in which the thermal emission from the superhot plasma could be dominant. It was found that sources in the high energy bands are from the footpoints of loops and flicker rapidly, whereas sources in the lowest energy band tend to come from the higher parts of the loops (Kosugi *et al.* 1992; Sakao *et al.* 1992).

Yohkoh-SXT results reveal several very different types of flares. One clear category is the arcade-type flare which is large, long in duration and low in energy, although the total energy yield can be large. Another clear type, which occurs only in active regions, is the simple loop flare: small, short in duration, but sometimes high in energy. There may be other categories related to the interaction of loops and emerging flux regions.

7.4.1 EVOLUTION OF ARCADE-LIKE FLARES

Arcade flares can have very large flux as measured by GOES, sometimes go up to X-class, but the emission is not necessarily contained in a high-energy range. A very instructive example is a long-enduring limb flare described by Tsuneta *et al.* (1992a) which grew steadily in a helmet-streamer arch. The development of this type of event seems at first sight to be consistent with the classical model in which a dark filament rises, and cuts open the field. The reclosing of the severed field lines through magnetic reconnection is supposed to release energy, to evaporate chromospheric plasma which fills the structure, thus causing the Hα double-ribbon flare. The preflare magnetic structure revealed by Yohkoh in both of two well-observed limb flares, however, turn out to have configurations suggesting a quadrupolar field, not a dipolar one as expected in the conventional (classical) model. A quadrupole model was proposed for the magnetic configurations of dark filaments and applied to related flares by Uchida *et al.* (1980), but the idea was not received too well that time because it lacked experimental connfirmation. Investigations are now being pursued along this line.

7.4.2 ENERGETIC FLARE WITH HARD X-RAY EVENTS

The large explosive flare of 1991 November 15 is one of the most comprehensively studied events captured by Yohkoh. This single event enables some far-reaching conclusions to be drawn

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(Acton *et al.*1992; Canfield *et al.*1992). The morphology of X-ray and Hα emissions from the flare provide supporting evidence that energy release takes place through driven rather than spontaneous reconnection. High-velocity upflows were observed (Culhane *et al.*1993) as soon as brightenings began in SXT images. But strong hard X-ray bursts did not begin until more than 2 min later (Sakao *et al.*1992). This creates a problem for supplying mass to the soft X-ray emitting loops by electron bombardment leading to chromospheric evaporation. It supports the view that in some flares a thermal conduction front is responsible for evaporation. Nevertheless, the simultaneous occurrence of a white-light flare with the hard X-ray sources during this event seems to support the electron bombardment model (Hudson *et al.*1992). In a study of X-ray emission with height for nearly 100 flares, Matsushita K, *et al.* (1992) found no evidence to support thin-target emission from flaring coronal loops.

The evolution of the hard X-ray source from a single to a double source, with separation increasing with time (Sakao *et al.*1992), is evidence for a multiple loop system in which particle acceleration proceeds on successively higher and higher field lines. The changing shapes of the HXT images in different energy bands indicate a preferential loss of higher energy electrons from the source region as the flare progresses.

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8. HIGHLIGHTS FROM SPACE - COMPTON GAMMA-RAY OBSERVATORY

(James Ryan and Richard A. Schwartz)

The instruments on-board the Compton Gamma Ray Observatory (CGRO) are far larger and more sensitive than any flown previously. The measurements of solar flare high energy fluxes have, as expected, yielded new insights (or questions) regarding X- and gamma-ray emissions from flares. The progress brought about by the CGRO measurements are in the following areas: (1) long-duration, high-energy flares, (2) neutron measurements, (3) microflares, (4) bremsstrahlung-dominated, gamma-ray flares, and (5) good statistics in smaller hard X-ray flares. The four instruments on the CGRO are BATSE, COMPTEL, OSSE, and EGRET. They are briefly described elsewhere (Gehrels *et al.* 1993). BATSE and OSSE are spectrometers operating in the 100 keV to 10 MeV range, while COMPTEL and EGRET are gamma-ray telescopes that can resolve the Sun in gamma rays as a point source in the 1 - 30 MeV and 30 - 30 000 MeV ranges, respectively.

8.1 LONG-DURATION, HIGH-ENERGY FLARES

The active region 6659 during the month of 1991 June produced a series of enormous flares during its transit across the disk, at least four of which one can classify as long duration high-energy flares. Each of these flares (1991 June 4, 9, 11 and 15) was measurable for at least two spacecraft orbits and each exhibited pion-related gamma-ray emission. The flares on 11 (Kanbach *et al.* 1993) and 15 (Leikov *et al.* 1993) June both produced gamma-ray emission with energies on the order of 1 GeV. The 11 June flare emitted gamma rays for a period of over 8 hours. The flare of 1991 June 9 (Ryan *et al.*, 1993) was of much lower intensity than the others but by virtue of the sensitivity of the instruments on CGRO, the measurements reveal that it too was a long-duration, high-energy event. This phenomenon of pion- related high-energy gamma-ray emission was observed earlier on SMM (Dunphy & Chupp, 1993), but the new measurements push theoretical models to the limit. There is a consensus that energetic protons must be stored for long periods of time (Mandzhavidze & Ramaty, 1992), but it is not clear whether there is continued acceleration in the traps high in the solar corona (Ramaty & Mandzhavidze, 1993).

8.2 NEUTRON MEASUREMENTS

The COMPTEL instrument brings a new aspect to solar studies - neutron spectroscopic capabilities. Being able to measure the energy of individual neutrons means that neutron emission can be studied in the same manner as gamma-ray emission, i.e., measuring the neutron spectrum at the time of emission. The neutron emission from the 1991 June 9 event (Ryan *et al.* 1993) primarily occurs after the impulsive phase. This clearly identifies the long-duration emission as having a proton rather than an electron origin.

8.3 MICROFLARES

The BATSE instrument's ability to detect weak cosmic gamma-ray bursts makes it an ideal instrument for measuring solar microflares. Flares three times smaller than those detected by HXRBS are being recorded by data inspection, while an automated search (Biesacker *et al.* 1993) has a sensitivity a factor of ten below the published HXRBS results. The sensitivity translates into a database of good statistics for microflare studies. Although the HXRBS results for flare-size distribution break down into one at solar maximum and another at solar minimum one, the BATSE data can be broken down to time scales as short as one solar rotation. Early results indicate no striking change in the flare-size distribution other than total frequency as a function of solar activity.

8.4 BREMSSTRAHLUNG-DOMINATED GAMMA-RAY FLARES

One of the many surprises from the Solar Maximum Mission was the discovery of gamma-ray flares which exhibited no nuclear line features. Typically, in the MeV range, proton- (ion-) produced nuclear lines from carbon, nitrogen, etc. dominate the photon energy spectrum. The spectra of these flares, however, are consistent with an emission process dominated by the bremsstrahlung of primary solar flare electrons up to energies of tens of MeV (Rieger and Marschhäuser, 1991). The CGRO has been able to observe several more of these events in an attempt to understand why the population of accelerated particles can change its composition so dramatically.

8.5 GOOD COUNT RATE STATISTICS FOR SMALL X-RAY FLARES

With the new sensitive measurements by CGRO come opportunities to correlate these data with those from other spacecraft and ground-based observatories. A graphic example is the correlation of the BATSE data with those of the BCS instrument on the YOHKOH spacecraft. One of the first observable quantities of soft X-ray observations of flares is the non-thermal broadening of the Ca XIX line. In the SMM data, the line width is large (doppler widths corresponding to ~100 km/s) as soon as the line is measurable. The BCS instrument on YOHKOH is much more sensitive than that on SMM, so it is of great interest to combine the sensitive hard X-ray data of BATSE and those of the YOHKHO/BCS instrument, possibly revealing the nature of the interplay in lower coronal mass motions with the energy deposited by fast electrons. Similarly, the cross comparison of metric and decimetric radiation with high time resolution X-ray data of BATSE can be more productive now that the sensitivity of the X-ray measurements is closer to that of the radio (Aschwanden *et al.*, 1993). The analysis of these data will improve our understanding of how the energetic electron population evolves, preferentially being transported upwards to produce Type III bursts or being transported downwards to produce the hard X-ray bursts.

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ADVANCES IN FLARE PHYSICS

The final four sections of this report bring together the significant results in solar flare research, from theory as well as from observations, achieved in the past 3 years. Because the subject of flares permeates many aspects of solar activity, it is unavoidable for some overlap to occur between the following and preceding sections. Overlaps have been eliminated except in those cases where different reviewers bring an entirely different perspective to the significance of any single publication.

9. PREFLARE ENERGY STORAGE

(Jean-Claude Hénoux and Boris V. Somov)

It is widely believed that flare energy is stored in electric current systems. Two possible origins of these currents have been advocated: 1) stressed magnetic fields, carrying currents, emerge through the photosphere; 2) currents are formed through motions of the photosphere that displace field line footpoints. In the latter case we can distinguish localised electric currents formed by twisting motions from extended current sheets due to shear motions. Vector magnetic field measurements show unneutralized electric current islands. As discussed by Melrose (1991), such observations support a subphotospheric origin of the currents. However the ambiguity in the sign of the transverse field may prevent a detection of the neutralizing currents.

9.1 THEORY OF ELECTRIC CURRENT GENERATION

Theoretical investigations of the formation of current sheets have been pursued. Low (1991) and Vekstein *et al.* (1991) showed analytically that shearing motions can produce current sheets along separatrices with or even without neutral points of magnetic field. Numerical computations of Karpen *et al.* (1991) confirmed the formation of currents in the line-tying hypothesis. However, applying a force to photospheric field lines not strictly line-tied, these authors found more distributed currents that cannot be considered as sheets. In these numerical computations time-dependent MHD equations were solved. They showed that currents are continuously evolving and are due to variations in plasma response time, with the line-tying condition corresponding to an infinite response time.

Other numerical studies of the dynamics of solar coronal magnetic fields resulting from footpoint motions at the photosphere have been made. Dahlburg *et al.* (1991) twisted the field of an arcade and followed the evolution of the field after stopping the photospheric motions. No instability and no current-sheet formation were observed; the stresses were minimized by an extension of the magnetic field. In an attempt to understand coronal mass ejection rather than to study current-sheet formation, Steinolfsen (1991) sheared an initial dipole configuration by azimuthal motions in opposite directions on each side of the equatorial plane. Resistive slippage was prevented, leading to an eruptive behavior; rapid expansion of the coronal magnetic field at velocities exceeding the Alfvén speed was obtained.

9.2 FREE MAGNETIC ENERGY STORAGE

Demonstrations that a force-free configuration with a completely open field has lower magnetic energy than a closed-field state were given by Aly (1991) and by Sturrock (1991). This property indicates either that the coronal mass ejection (CME) phenomenon cannot be strictly driven by force-free magnetic fields or that the final configuration associated with a CME is not in the open state; it gives the maximum value of the energy that can be released by current dissipation. Then using a Clebsch-variables representation of the magnetic field, Klimchuk & Sturrock (1992) and Porter *et al.* (1992) computed numerically the amount of free magnetic energy built up by photospheric shearing or twisting motions. The computations were done for magnetic configurations either of arcade type or cylindrically symmetric around a vertical axis. They suggest that a completly open-field configuration corresponds to the maximum of energy storage and indicate that the energy buildup can satisfy the energy requirements of solar flares. Wolfson & Low (1992) show that, by shearing, a closed force-free field can become partially open. LaRosa (1992) has found, in contrast to the previous studies, that a laminar reconnecting current sheet cannot be responsible for the activity associated with emerging flux. This result comes from a study of the resistivity in a neutral current sheet and seems to agree with a conclusion by Somov (1992) that there is no thermal equilibrium for such a sheet with classical heat conduction along and across the magnetic field.

9.3 THE OBSERVED ROLE OF PHOTOSPHERIC MOTIONS IN FLARE OCCURENCE

Observations of shear motions, and of head-on collision of bipoles, leading to flares have been reported by Wang *et al.* (1991), Wang (1992) and Tang & Wang (1993). Generally the shear derived from the shape of Hα fibrils is reduced after a flare. However some observational results contradict this simple behavior. Simaravan *et al.* (1992) relate flare occurence to the change in the shear, decrease or increase, a day prior to the flare. Using a vector magnetograph, Wang (1993) measured the change in shear angle (angle between the observed transverse field and the direction of an extrapolated transverse potential field) after a flare and observed an increase of this shear angle. Then Forbes (1993) pointed out that rotations of the transverse photospheric magnetic field are not sufficient by themselves to determine the change in the stored energy.

9.4 OBSERVATIONAL EVIDENCE OF THE ROLE OF ELECTRIC CURRENTS IN SOLAR FLARES

Calculations of the longitudinal component of electric currents in active regions rely on the measurement of transverse fields; one has then to solve the 180° ambiguity to determine the direction of the transverse fields (Wang 1993; Linxiang 1993). The development of vector magnetographs (Wang *et al.* 1992) leads to new observational results on the association between electric currents and solar flares. The morphological relationship between vertical electric currents in the photosphere and flare kernels has been confirmed. Abramenko et al. (1991) suggest that the direction of the current affects the Hα brightness. Using not exactly simultaneous observations of currents and flares, Lin *et al.* (1993) suggested that Hα kernels were located near the peaks of the vertical currents. On the other hand, Canfield *et al.* (1991) in four flares found that the non-thermal precipitation sites were at the edges of the major vertical currents, whereas the sites of high coronal pressure were within them. In a class X Flare, the hard X-ray emission (23-33 keV) was found to be located at the edges of sites of high vertical current density (Canfield *et al.* 1992), a result confirmed in more recent work by the same group (Leka et al, 1993; de la Beaujardière et al. 1993). All these observations suggest that flares begin at the edges of current systems and spread towards their interiors.

Comparison of the location of Hα kernels with the location of separatrices of magnetic flux in active regions has been pursued and developed (Mandrini *et al.* 1991, 1993; Démoulin *et al.* 1993; Hénoux *et al.* 1993). In the ten flares that have been studied, the Hα kernels were located on the separatrices. For all events for which longitudinal current densities were measured, two of the four Hα kernels partially overlapped the current-density kernels. Then two stages are possible. In the first, currents are produced by photospheric shear motions; magnetic energy is stored in field aligned currents on separatrices. In the second, flare-energy release takes place when a strong current system approaches the separator and is disrupted by field line reconnection in the region of the separator.

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10. THE 'COOL' PLASMA IN FLARES
(Petr Heinzel)

The relationship between the cool flare plasma observed at optical and UV wavelengths and the hotter plasma 'seen' in EUV, X-ray and radio wavebands has become clearer in studies based on SMM

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and ground-based data. Now we are entering a new phase of flare research where more complex questions can be addressed with high-resolution YOHKOH observations. Substantial research effort has been reported in the proceedings of several workshops and colloquia, in monographs, and in extensive reviews (see Refs. I-XI).

10.1 CHROMOSPHERIC FLARE MODELS

Several important papers have appeared which deal with non-LTE aspects of flares. Their discussion in this section is organized around three categories: (i) semi-empirical models, (ii) synthetic models, and (iii) general line-formation problems related to flares.

New semi-empirical flare models have been constructed by Mauas *et al.* (1990) for an observed case of a white-light flare (WLF) in which two bright kernels had the same level of continuum emission, but different line spectra in which the line-formation depths spanned from the photosphere to the chromosphere. They found the origin of the continuum emission to be photospheric, not chromospheric, for both observed kernels. The observations and the models derived from them show that continuum emission can occur in the absence of Hα emission, thus leading the authors to suggest that some WLFs are inconsistent with the conventional picture for WLFs: energy released in the corona and transported downward by some mechanism. On the other hand, Sotirovski *et al.* (1992) found from another WLF spectrum that the Paschen continuum is responsible for WLF emission. A combination of both possibilities for WLF emission is suggested by Baranovsky (1990) on the basis of semi-empirical modelling. A drawback of semi-empirical models is that they do not take into account non-thermal excitation and ionization of atoms by beamed particles; this naturally leads to an overestimation of empirically derived temperatures. Also, soft X-ray irradiation from the overlying coronal loop is also neglected in these models. The models are static while, in fact, asymmetries in the observed line profiles may indicate departures from hydrostatic equilibrium. The effect of non-thermal excitation and ionization by electron resp. proton beams on Hα and CaII K lines was recently investigated by Fang *et al.* (1993) and by Hénoux *et al.* (1993) for two earlier semi-empirical models. Hydrogen lines are greatly strengthened and broadened, showing an obvious central reversal. The effects are weaker for the CaII K line. Similar calculations have been performed by Zharkova & Kobylinsky (1993).

Synthetic models (class (ii)) of physically self-consistent coronal loops which cover a wide range of physically relevant conditions, have been presented for the case of giant flares on M dwarf stars by Hawley & Fisher (1992). This work has recently been extended to the case of the Sun (Hawley & Fisher, submitted 1993). These models are also static, but the energy balance problem is solved consistently by taking into account electron-beam heating, coronal X-ray heating and thermal conduction. In contrast to previous non-LTE models of this kind, e.g. Falchi *et al.*(1990), the electron flux, conductive flux and the coronal pressure are mutually connected which clearly shows that certain combinations of these parameters used in previous work are not physically allowed. For example, high coronal pressure occurs in tandem with high conductive flux thus forming a deep transition region with reduced chromospheric heating. High coronal pressure is not consistent with very bright Hα, as previously assumed; typically observed Hα fluxes can only be produced under conditions of a low pressure corona with strong beam heating. Surprisingly, the computed ratio of total Hα flux to the flux of non-thermal electrons with energies > 20 Kev (F_{20}), differs strongly from that derived for well observed flares by Canfield et al. (1991). Therefore, the authors suggest that the pressure is a more relevant physical parameter than the beam flux F_{20}.

The third class of non-LTE computations is represented by the work of Gayley (1991) and Gayley & Canfield (1991). They studied semi-analytically the conditions under which hydrogen Lyman and Balmer lines are formed in chromospheric flares, taking into account the effects of partial redistribution. A rough proportionality was found between Stark wing-intensity and the total energy deposited in the partially ionized layers. Therefore, under favourable conditions (i.e. without additional masking opacity effects), one can infer the magnitude of the nonthermal heating in the chromosphere from enhancements in the Stark wings of Lyman and Balmer lines. The blue wing is suggested for such a diagnostic. However, intense electron beams produce impulsive Lα emission which is much brighter than that so far detected (Gayley & Canfield 1991). This will be a challenging application for the SUMER experiment on the SOHO satellite mission.

10.2 RADIATIVE-HYDRODYNAMICAL MODELS OF CHROMOSPHERIC HEATING

Time-dependent simulations of pulsed beam heating of the solar atmosphere have been done by Karlicky (1990) and by Karlicky & Hénoux (1991). A new particle-representation of an electron beam enabled these authors to take into account the finite travel time of non-thermal electrons and to simulate the general form of the beam distribution function. A chromospheric response is treated by solving the standard set of hydrodynamical equations. As shown by Heinzel & Karlicky (1992a), for a series of subsecond beam pulses, one gets a correlation between computed hard X-ray spikes and Hα variations. However, it was found that subsecond Hα pulses exhibit an intensity decrease rather than the expected increase. Relevant HXR observations for testing such models are now being made on GRO (BATSE instrument) and on YOHKOH. High temporal resolution Hα data come from new CCD cameras in Boulder (Kiplinger *et al.* 1990) and in Ondrejov (Kotrc *et al.* 1993). More consistent radiation-hydrodynamical simulations have been presented by Heinzel & Karlicky (1992b), who demonstrated the importance of hydrogen recombination relaxation for modelling subsecond heating pulses. Using time-dependent numerical simulations and SMM observations of a soft X-ray line of CaXIX, Mariska (1992) examined the ability of electron-beam heating to reproduce the rise phase of flares.

The correspondence between coronal upflows (CaXIX from YOHKOH) and chromospheric downflows (Hα) are under extensive discussion. For the hydrodynamical model of a flare loop Gan *et al.* (1991) and Gan *et al.* (1992) have evaluated synthetic CaXIX spectra as well as Hα and CaII K line profiles. The conclusion of these authors is that a thermal hydrodynamical model can describe the behaviour of these lines rather well. In another paper, Gan *et al.* (1990) computed hydrodynamical models of the impulsive phase. Efficiency of chromospheric heating by soft X-rays is stressed; the authors propose a method for evaluating X-ray irradiation of the chromosphere by a flaring loop.

10.3 FLARE DYNAMICS FROM SPECTRAL DIAGNOSTICS

All semiempirical models (based on spectral data) published so-far are static. The most sophisticated synthetic models (like those of Hawley & Fisher 1992) are also treated in hydrostatic equilibrium. On the other hand, the above-mentioned hydrodynamical simulations naturally predict the macroscopic velocity fields (evaporation, downward moving chromospheric condensation), but only rather limited effort has been devoted to a direct comparison with asymmetrical optical or UV line profiles. Using the bisector method for Hα, Wülser *et al.* (1992, 1993) have deduced the downflow velocities of the chromospheric condensation from typical red asymmetryies of this line. The velocities, of the order of 40-50 km s^{-1}, give the plasma momentum which seems to be consistent with that derived from soft X-ray data (SMM, YOHKOH). This would confirm the idea of explosive evaporation during thick-target heating.

Heinzel *et al.* (1993) analyzed a blue asymmetry in the Balmer and CaII lines which was clearly detected with the Ondrejov multichannel flare spectrograph. An upflow of cool material cannot be excluded (Canfield *et al.* 1990; Karlicky & Hénoux 1992). However, an attractive explanation for the blue asymmetry at flare-onset is that the downward moving plasma with a certain velocity gradient produces an excess of blue-wing emission, simply due to non-LTE transfer effects. In such a case the bisector method, indicating an upflow, fails. A velocity gradient was also deduced from SPO spectral observations by Falchi *et al.* (1992). These authors derived downward velocities ~30 km s^{-1} from Balmer lines, ~20 km s^{-1} from the CaII K line, and ~10 km s^{-1} from the Na D2 line. Simultaneous upflows were detected for this flare on SMM. The line asymmetries were also studied by Fang *et al.* (1991) using CaII line observations and by Fang *et al.* (1992) with an approximate non-LTE model which incorporates an ad hoc velocity field around the temperature minimum region. However, the velocities considered by these authors are too large for models in hydrostatic equilibrium. New dynamical non-LTE models are thus required.

10.4 Hα POLARIZATION

Linear polarization of the hydrogen Hα line has been suggested as an indicator of the precipitation of downward-directed electron and/or proton beams. This diagnostic can give us an idea about the ratio of the particle number densities in the proton and electron beams and about their energy distribution, both clues to understanding the acceleration mechanisms. Impact linear polarization was

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studied by Hénoux *et al.* (1990) as a diagnostic of 100 keV proton beams, using new Hα polarization observations made at Meudon. A polarization degree as high as 2.5 % was detected in some Hα kernels. Preference is made for non-local proton acceleration which leads to a bombardment of the chromosphere. It was shown that transport processes in the chromosphere strengthen the anisotropic velocity distribution of protons, which is the cause of the collisional polarization of the Hα line. When Hα polarization is observed, X-ray emission appears to be more thermal (soft) than impulsive (hard). For example, polarization above 2 % correlates well with the Hα mean intensity during 20-30 min. (Aboudarham *et al.* 1992a). It resembles the temporal variation of soft X-ray emission, while no hard X-ray bursts were detected during this period by the HXRBS instrument on SMM. Another plausible explanation for the Hα linear polarization is the existence of neutral beams with the same speed for both protons and electrons (Aboudarham *et al.* 1992a). Similar Hα polarization characteristics have also been deduced from measurements made with the Hawaii Stokes Polarimeter (Metcalf *et al.* 1991). A new CCD Hα polarimeter is currently being completed at Meudon (Aboudarham *et al.* 1992a).

Further investigation of the electron impact excitation of Hα by Aboudarham *et al.* (1992b) shows that, while the anisotropy of a proton beam can be caused or maintained by transport effects, in the case of electrons the anisotropy may result from large temperature gradients or from acceleration within electric fields. Although the electrons may be equally responsible for the observed Hα linear polarization, their anisotropy due to heat conduction has to be treated with caution. New detailed computations for this case are required. Another possibility is acceleration by an ambipolar electric field (Aboudarham *et al.* 1992b). A general quantum-mechanical scheme of electron impact polarization was given by Fineschi & Landi Degl'Innocenti (1992).

10.5 COOL FLARE LOOPS

The term 'cool' flare loops was introduced instead of 'post'-flare loops because these loops form a natural part of a developing flare complex and appear during the flare. Moreover, they are obviously cool (10^4 K) relative to hot flare loops. The morphology, physical and evolutionary characteristics of cool flare loops have been reviewed by Simnett & Forbes (1991), Svestka (1991) and by Schmieder (1992). Heinzel *et al.* (1992) have made rather complex non-LTE and hydrodynamical analysis of the loops observed in Hα by the MSDP instrument at Meudon and derived the values of several plasma parameters. The basic conclusion is that the downward motions along both legs have lower velocities than a free-fall motion. Inspired by this finding, Karlicky & Simnett (1992) performed radiation-hydrodynamical simulations of a cool plasma blob moving inside the hot loop and showed that the blob can indeed be decelerated by pressure gradients. The evolution of cool flare loops system was studied by Gu *et al.* (1992), who found the whole system rising with a velocity of about 5-10 km s^{-1}. Effects of heating cool loops by Alfvén waves were considered by Lin and Zhang (1991). Finally, we mention an interesting observation by Hiei *et al.* (1992) of a loop system on the limb in white light, indicating electron densities of 10^{12}-10^{13} cm^{-3}.

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11. THE HOT PLASMA COMPONENT IN FLARES

(Giannina Poletto)

11.1 GENERAL OVERVIEW

An overall description of the flare phenomenon can be found in chapters of recently published textbooks on solar physics (e.g. Refs. I, II). Theoretical aspects have been dealt with in some detail in more advanced texts (Refs. III, IV). Additional material apears in reviews on solar flares by Phillips (1991), Sakurai (1991), and Rust (1992). But the wide interest in solar flare research is best documented in the numerous meetings dedicated to flares held in the past three years (e.g. the proceedings in Refs. V-IX). All include papers which focus on the hot plasma component of flares.

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When we speak of the hot plasma component of flares, we refer to plasma at temperatures $\sim 10^7$ K or higher and densities $\sim 10^{10}$ cm^{-3}. In spite of extensive work, we still have not arrived at an unambiguous solution to the problem of how such high densities and temperatures are attained. The primary energy release site has not yet been observed - although the sudden energy release is generally ascribed to some sort of magnetic reconnection process - and there is no consensus on how energy is transported from the energy release site to other places within the flaring flux tube (see, e.g., Zarro 1992). The controversy about the origin of high densities is still very much alive: see, e.g. Feldman 1990; Bornmann & Lemen, 1992; Wülser *et al.* 1992; Seely & Feldman 1992.

11.2 MORPHOLOGY OF THE HOT PLASMA COMPONENT

From an analysis of 10 large non-impulsive flares observed by the SXT instrument on Yohkoh, Acton *et al.* (1992) showed that these events usually consist of a single or, at most, a few loops where plasma at $\sim 2 \times 10^7$ K is concentrated in a small volume (2-3 " diameter) at loop tops. As the flare decays, this hot region stays bright and concentrated in a fairly small volume, while the legs of the loops do not appear to contain any significant amount of hot plasma ablated from the chromosphere. Analogously, Doschek *et al.* (1992), from an analysis of ~60 events (most of X-ray class M1) observed by the BCS experiment on Yohkoh, conclude that most flares have weak blue-shifted signatures which are not consistent with the standard evaporation scenario. These observations support the suggestion that plasma is heated *in situ* and compressed via the pinch effect of a large electric current or via a "sweeping pinch effect" (Uchida & Shibata 1988). However, large plasma motions indicative of chromospheric evaporation have been observed by BCS as well (Culhane *et al.* 1992) while other flares do not present conclusive evidence in favor of one mechanism or the other (Ichimoto *et al.* 1992). It certainly looks like the transport of energy in flares is more complicated than previously assumed; further BCS spectra, taken during the initial phase of a flare, may help discriminate between different scenarios.

11.3 MODELLING

Flare modelling progressed along two main lines: by numerical modelling as pursued by Gan *et al.* (1991), and by using the Palermo-Harvard hydrodynamic code (Jakimiec *et al.* 1992; Sylwester *et al.* 1993). A simplified analytical treatment has been developed by Serio *et al.* (1991). These models provide a good description of flares where standard evaporation occurs. Takakura (1992) has made numerical simulations of impulsive flares caused by transient heat conduction along a loop with an applied axial electric current. His model predicts X-ray emission from the two footpoints and a coronal source expanding along the loop. A different approach has been used by Zaitsev & Stepanov (1992) who, while further developing the circuit theory of solar flares, point out that a powerful energy release at chromospheric levels should accompany the energy release in the coronal section of the loop. It is difficult to establish how realistic these predictions are and what percentage of flares are represented by them. Further analysis of Yohkoh data will possibly allow us to define the most representative characteristics of flares, thus allowing modelers to focus on these aspects of flare events.

The model of Melrose (1992) takes into account a feature which is usually overlooked, i.e. the propagation of energy from the photosphere into the corona that is required prior to or during the flare. However, his model pertains to the class of *current models*; hence it favors energy dissipation through double layers rather than through reconnection. This may occur only in a minority of flares, since many Yohkoh observations support magnetic reconnection in a neutral sheet at loop tops as the source of the flare energy (Tsuneta *et al.* 1992a; Ichimoto *et al.* 1992). In addition, Yohkoh showed that magnetic reconnection plays a role also in non-flaring conditions: the global solar corona continually undergoes a process of global and local restructuring which is ascribed to quasi-steady magnetic reconnection (Tsuneta *et al.* 1992b). Larger spatial dimensions and a smaller energy release seem to be the only differences between flare events and this large-scale non-explosive restructuring of the corona. This new result from Yohkoh points towards a unified view of flares and low-level large-scale coronal activity; it was anticipated over the past few years by a number of works which tried to establish a link between flares and large scale events.

In fact, careful analysis of SMM and Skylab flares has shown that secondary excitation of large-scale structures - X-ray giant arches and flaring X-ray arches - may develop after the primary energy release (Svestka 1991). The latter features - with lengths extending up to 300 Mm - may give us the unique opportunity of observing the effect of coronal heating, as through a magnifying lens, by following the progressive X-ray brightening along the arch. A remote and delayed brightening with respect to the impulsive phase of the flare has been detected also by Martens *et al.* (1990) in NIXT flare data and ascribed to sudden topological changes occurring when one of the flare ribbons, in its motion away from the neutral line, crosses a magnetic separatrix. Analogously, an analysis of Yohkoh X-ray bright points revealed the presence of many bright point flares associated with the enhancement of larger scale structures (Strong *et al.* 1992). Reconnection of emerging flux with ambient fields is invoked to explain this unexpected phenomena. Topological models in which flares are ascribed to reconnection of large-scale magnetic structures have been developed by Mandrini *et al.* (1991. All these studies show that the flare community starts considering the hot flaring plasma no longer as a local event, but as the outcome of the energy released by the interaction of an ensemble of large-scale loops, in a scenario which couples flare activity to a global background.

11.4 MICROFLARES

A unified view of the flare phenomenon may result also from studies of coronal heating. The possibility that microflares are the high-energy tail of a hidden distribution of events (nanoflares) possibly responsible for the hot solar corona, has become popular lately (see Parker 1993 and references therein; Chouduri *et al.* 1993; Kopp & Poletto, 1993). Although individual nanoflares supposedly release too little energy to be detectable by present instrumentation, Yohkoh's observations of repeated, transient brightenings of compact loops (Shimizu *et al.* 1992) are consistent with the view of the solar corona as a swarm of nanoflares. Thus the corona, rather than being interpreted as a medium where impulsive energy release occurs at the time of flares, will itself be the outcome of a myriad of these events.

We may say that emphasis is shifting from individual powerful events to the overall effect of multitudes of tiny events. Traditionally, flares occur because of some instability causing the release of magnetic energy stored in a large-scale structure. Lately, however, the suggestion has been advanced that flares occur because of a chain reaction which involves many small-scale sites (see, for instance, Lu & Hamilton 1991; Zirker & Cleveland 1993). In the so-called "avalanche model" of flares, a small-scale event creates a disturbance that propagates close-by, triggering additional energy release events. The traditional and the avalanche scenarios are not necessarily in conflict, but stress different aspects of the same phenomenon.

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12. PARTICLE ACCELERATION IN FLARES
(Arnold O. Benz)

The 3-year period covered by this report has seen major conferences devoted entirely to acceleration phenomena in astronomy. The Bartol conference (Zank & Gaisser 1992) and the IAU Colloquium 142 (Chupp & Benz 1993) on this general topic had substantial sessions on particle acceleration in solar flares. Solar flares have become a laboratory for acceleration processes in the Universe. New solar observing facilities put into operation during the period include the Yohkoh satellite (Kosugi *et al.* 1991) with an imaging hard X-ray telescope, the X-ray and γ-ray spectrometers on board the Compton Gamma Ray Observatory (Fishman *et al.* 1992), and Granat (Talon *et al.* 1993). New imaging solar radio interferometers in Nobeyama (Enome *et al.* 1993) and Siberia (Alissandrakis *et al.* 1992) have seen 'first light', and the BIMA (Kundu *et al.* 1990) and Itapetinga (Herrmann *et al.* 1992) millimeter telescopes have become operational. A broadband radio spectrometer, Phoenix (Benz *et al.* 1991), has been finished near Zürich.

A general overview on acceleration processes in coronal plasmas has appeared in Benz (1993); more detailed reviews on specific theoretical ideas have e.g. been published by Melrose (1990) on bulk energisation of electrons, by Reames (1990) on heavy ion acceleration, and in the proceedings of the above conferences.

12.1 ROLE OF ACCELERATION IN FLARES

The role of acceleration in the energy release during flares has been studied in emissions of energetic (high temperature or non-thermal) particles and thermal particles, respectively. The correlation observed in some solar flares between hard X-rays (bremsstrahlung of energetic electrons) and the time-integrated soft X-rays (thermal) has been called the Neupert effect (Hudson 1991). It supports a flare model in which the primary energy is initially released into energetic electrons at a high (or at least constant) efficiency. The electrons lose their energy in the lower corona and chromosphere emitting hard X-rays and heating the plasma to radiate enhanced thermal soft X-rays. Feldman (1990) has questioned a causal relationship in view of non-impulsive flares where the hard X-ray emission varies more gradually and the Neupert effect is often absent. Dennis & Zarro (1993) have used the large data base of X-ray flares observed on board the SMM (Dennis *et al.* 1991) and GOES (Speich *et al.* 1991) satellites to determine the fraction of flares that show the Neupert effect. They find that 80% of the large flares (peak count rate > 1000 counts s^{-1}) show good correlation.

12.2 FRAGMENTATION OF ACCELERATION

Hamilton *et al.* (1994) have shown that the peak intensity distribution of hard X-ray events associated with a type III radio burst is significantly different from the distribution of all hard X-ray events. This is inconsistent with the statistical independence of the two emissions and suggests that they are caused by electrons drawn from the same population. Aschwanden *et al.* (1990) presented observations of a flare that shows a linear correlation between the type III burst rate and the hard X-ray flux. The occurrence of up to ten type III bursts per second, each representing an independent electron beam, suggests a high degree of fragmentation in the acceleration region and an approximately constant rate of electrons per type III burst. Sawant *et al.* (1990) find a one-to-one correlation in some reverse drifting type III bursts (corresponding to downward moving beams) and hard X-ray peaks. Narrowband radio spikes of a few tens of millisecond duration occur during some flares and show an order of magnitude higher fragmentation than type III bursts. Spikes in the 0.3-3 GHz range have been found to be well associated with an enhanced hard X-ray flux and are usually correlated with a peak in hard X-rays (Güdel *et al.* 1991). Aschwanden & Güdel (1992) find an average delay of the radio emission of the order of 1s, decreasing with increasing flare importance. The spikes have been a target of intensive study during the period (Güdel, 1990, Bruggmann *et al.*, 1990, Güdel & Zlobec, 1991, Benz *et al.* 1992, Csillaghy & Benz 1993), and have inspired new interpretations of the emission process by Melrose (1991), Tajima *et al.* (1991) and Wentzel (1993). Yet, the nature of narrowband spikes remains controversial and is an interesting field for future research.

12.3 ACCELERATION SITE

Matsushita *et al.* (1992) observed a decrease of the average height of hard X-ray sources with increasing photon energy. At higher energies, the sources become more compact and patchy. These observations are compatible with an acceleration height near the top of the loop. Chupp *et al.* (1993) examined the evolution of electron acceleration (as observed by the Nançay Radioheliograph at meter waves) and ion acceleration (GRS on SMM in γ-ray lines). Gamma-rays have been detected before the main peak of the flare. As new radio sources appear at different locations, the spectra of hard X-rays and γ-ray lines change, reflecting changes in the electron and ion acceleration process.

12.4 THEORY AND MODELS

The ideas on particle acceleration in solar flares may be divided into three groups, each having many variants: (i) acceleration by constant or slowly varying electric fields parallel to the magnetic field, (ii) interaction of particles with waves may stochastically increase the particles' energy, (iii) acceleration by shock waves. The period of this report has seen the first attempts at modelling specific observations, although the controversy over the energisation of the hard X-ray emitting electrons continues.

Schindler *et al.* (1991) have related magnetic field-aligned electric potentials in non-ideal plasma flows to magnetic field properties. Holman & Benka (1992) have explored the consequences of electric field acceleration and heating in current channels. For electrons, Joule heating by the current and the acceleration of runaway particles are both crucially important. The radiative consequences are seen in microwave gyrosynchrotron radiation and the hard X-ray emissions from flares. In hard X-rays, the presence of a superhot thermal component at low photon energies, together with nonthermal emission at higher energies, is a natural consequence of the presence of currents. Tajima *et al.* (1991) have simulated acceleration by electric fields using a particle code. They find that the acceleration process is accompanied by strong, narrowband radio emission. Karlicky (1993) simulated the propagation of an electron beam in a loop and finds acceleration of back-scattered electrons by the electric field of the return current.

An alternative acceleration process for hard X-ray emitting electrons has been modelled by LaRosa & Moore (1993). They suggest the dissipation of MHD turbulence in solar flares in order to accelerate electrons by the second-order Fermi process. Each energy-release fragment (possibly visible as a radio spike) can be produced by an MHD turbulent cascade. Smith & Brecht (1993) have modelled proton acceleration by MHD waves in a loop geometry and, including the related proton transport, find it possible to reach the observed short duration of γ-ray bursts.

The observed fragmentation of the energy release has been taken up by Kliem (1990) who modelled particles acceleration by a multitude of current sheets. He has also found that a perpendicular electric field can accelerate electrons efficiently. Alternatively, Anastasiadis and Vlahos (1993) have studied the effect of a large number of randomly propagating shocks on the evolution of the energy distribution of electrons.

With only a small fraction of the observations of the passed maximum analyzed, it is clear that progress in the field of particle acceleration will continue. High resolution imaging and spectral hard X-ray telescopes and dedicated solar radio instruments will be needed to make further progress, but will have to wait for the next maximum.

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