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VII. RESULTS FROM RADIO OBSERVATIONS
(C. Alissandrakis)

This section does not mention some results reported in sections V and VI. Other papers can be found in proceedings of CESRA Workshops (Benz 1985 (I), Pick and Trottet 1986 (II)).

A. INSTRUMENTATION

During the last three years important developments in instrumentation have taken place. A new antenna has been added to the Nobeyama solar radio interferometer increasing its one-dimensional resolution to 25" at 17 GHz (Nakajima et al, 1984). A frequency-agile receiver system has been added to the Owens Valley 2-element interferometer, operating at up to 86 frequencies in the 1-18 GHz range (Hurford et al, 1984), while a new digital, high time resolution spectrometer is in operation at Bern. The VLA and the RATAN-600 have continued to give high spatial resolution data at cm wavelengths, while the E-W branch of the Siberian Solar Radio Telescope is fully operational, giving one-dimensional scans at 5.2 cm with a resolution up to 17" (Smolkov et al, 1986). In the long wavelength range the Nançay Radioheliograph has been used as an earth rotation aperture synthesis instrument (Allissandrakis et al, 1985), while the Clark Lake Radioheliograph is operating regularly at decametric wavelengths providing instantaneous maps. A multi-frequency system has been installed in the N-S branch of the Nançay Radioheliograph. In spite of these developments the community has suffered greatly from the loss of the Culgoora Radioheliograph.

B. QUIET SUN

Just after the solar maximum, few publications refer to the quiet sun, Kosugi et al (1986) detected polar cap emission of 3-7% at 36 GHz apparently associated with coronal holes. Alissandrakis et al (1985) presented maps of the corona at 169 MHz. The maps show coronal holes with $T_b \sim 10^5$ K and apparent height of .03 R_o ; the distribution of brightness at 1.15 R_o shows a gross similarity with the coronal green line. Bright features are sources of noise storm continua, while weaker emission regions are associated with neutral lines of the magnetic field. Limb synoptic charts (Lantos and Alissandrakis, 1986) are very similar to K-coronameter charts and show very well the base of the heliosheet. Kundu et al (1987a) presented coronal maps at 30.9, 50 and 73.8 MHz for one rotation. A coronal hole shows an eastward displacement at the lower frequencies. Elongated features at the limb correspond well to white light streamers. Radio synoptic charts show overall similarities with K-coronameter charts. The solar diameter at decameter wavelengths was measured by Gergely et al (1985). Observations of bright points with a lifetime of a few minutes have been reported by Habbal et al (1986) at 20 cm and Fu et al (1987) at 6 cm. Benz and Furst (1987) found little

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correlation in simultaneous observations of solar fluctuations at 4.75 GHz from Arecibo and Effelsberg. New observations of filaments at 6 and 20 cm with the VLA have been reported by Kundu et al (1986a).

C. ACTIVE REGIONS

The emission of μ-λ sunspot associated sources in terms of the gyroresonance process is well understood. Alissandrakis and Kundu (1984) observed a simple, sunspot associated source over 6 days ; they identified the region where the magnetic field is parallel to the line of sight and they mapped the B vector. Kundu and Alissandrakis (1984) detected islands of o-mode polarisation inside sunspot associated sources and interpreted them in terms of hotter than average regions at the height of the second harmonic. A detailed study of the inversion of circular polarisation gave a height of 0.16–0.19 R_o and a magnetic field of 10–20 G for the depolarisation region. The polarisation inversion was also studied by Gelfreikh et al (1987) who found similar values for the depolarisation region. Kruger et al (1986) computed model parameters from spectral observations of 36 sources ; they found values of $(7.4 \pm 2.3) \times 10^8$ cm for the scale height of the magnetic field and a value of $B \sim 1750$ G at a height of 2000 km. Model computations for sunspot-associated sources were given by Kruger at al (1985), while Siarkowsky (1984) pointed out that the steep temperature gradient in the transition region results in a non-Maxwellian distribution which may increase the observed brightness of a sunspot-associated source. Computations of gyroresonance emission from a hot coronal loop were made by Holman and Kundu (1985). Strong sources associated with neutral lines were studied by Kundu and Alissandrakis (1984) and Akhmedov et al (1986a, 1986b) ; Kundu and Alissandrakis pointed out their association with soft X-ray loops and arch filament systems and their persistence for at least 6 days ; Akhmedov et al pointed out their very steep spectra which cannot be interpreted in terms of traditional models of thermal emission. The emission mechanism of this type of sources is still uncertain.

Multi-λ observations of active regions were reported by Schevgaonkar and Kundu (1984, 1985a, 1985b) and Gary and Hurford (1987). Using the VLA and the Owens Valley frequency agile interferometer in the range of 1.4 to 8 GHz during an eclipse, the latter found a transition from sunspot associated sources at short wavelengths to a source associated with a large loop at long wavelengths. Maps of active regions at closely spaced frequencies were obtained by Schmahl et al (1984) at 3 frequencies near 6 cm and by Willson (1985) at 10 frequencies near 20 cm ; Schmahl et al found a source with a spectral slope of 6 and they proposed interpretations in terms of neutral current sheets and cyclotron lines ; Willson found a spectral peak with a bandwidth of ~100 MHz which he interpreted as a cyclotron line due to a hot region located at the 4^{th} harmonic of the gyrofrequency. Willson and Lang (1986) observed compact, variable sources inside active regions at 2 cm.

D. MICROWAVE BURSTS

Observations with the VLA have provided additional evidence for pre-burst changes in the active region (Willson, 1984 ; Melozzi et al, 1985 ; Kundu and Shevgaonkar, 1985) ; these include heating of the burst region, sudden change of polarisation, change of the zero polarisation line and appearence of new sources (Kundu, 1986). Nakajima et al (1985) found sympathetic μ-λ and X-ray bursts separated by up to 10^6 km, implying exciter speeds of 10^4–10^5 km/sec. Kundu et al (1987b) presented the time evolution of a complex unipolar burst at 6 cm. Multi-frequency observations as well as simultaneous imaging observations in the microwave and X-ray range have given the opportunity to compare the structure of bursts at different frequencies. Melozzi et al (1985) found the 6 cm emission near the legs of flaring loops, while the 20 cm emission was complex and displaced with respect to the 6 cm sources. Shevgoankar and Kundu (1985b) found that in some impulsive peaks the 2 cm sources occured at the same location as the maximum of the 6 cm source, while in others they were located at the footpoints of the 6 cm loop. Dulk et al (1986a) observed an event near the limb, in which the 6 cm source spanned the Hα emission patches, while the 2 cm source was located at the edge of the 6 cm source. Takakura et al, (1985) observed a burst, apparently associated with an active region behind the limb, at 6 cm and 20–30 keV ; the centroid of both sources was above the limb but the 6 cm source located 3×10^4km further out than the X-ray source, Schmahl et al, (1985) observed a limb event with the 6 cm emission in the form of a loop with peaks at the footpoints and the 20-30 keV emission close to one of the footpoints. The ensemble of these observations does not give a very clear picture, however it appears that quite often the long wavelength μ-λ emission comes from the entire flaring loop, while the short wavelength μ-λ emission and the hard X-ray (HXR) emission comes from the footpoints. This is in agreement with the models of Alissandrakis ans Preka-Papadema (1984) and Klein and Trottet (1984) ; the former also pointed out the importance of propagation effects in the observed sense of circular polarisation.

By comparing the rate of increase of 17 GHz and HXR bursts, Nitta and Kosugi (1986) concluded that the former are due to electrons with energy less than a few hundred keV. Mac Kinnon et al, (1986) reported a μ-λ burst with two peaks, of which only one showed HXR emission (see also section VI, C). In a study of gradual μ-λ and soft X-ray (SXR)-events Schmahl et al (1986) found that the thermal plasma parameters deduced from SXR cannot account for the μ-λ emission and proposed a non-isothermal model. The question of the number of electrons required for the μ-λ and HXR emission was studied by Gary and Tang (1985), Gary (1985), Klein et al, (1986) and Kai (1986) who concluded that the numbers can be reconciled, while Schmahl et al (1985) found differences of a factor of 10^3. The interpretation of the impulsive phase in terms of thermal emission was studied by Batchelor et al, (1985) and Wiehl et al, (1985a).

E. SHORT SCALE TIME VARIATIONS IN BURST SOURCES

There is a growing interest in fast structures from the mm to the m range. Loran et al, (1985) presented an interpretation of the ripple structure in μ-λ events in terms of the elementary burst concept. Kaufmann et al (1985) analysed observations of 17 simple microbursts at 22 GHz ; their peak fluxes were 0.9 to 8.8 sfu, their time scales $0.05 < t \ll 1s$ and $0.5 < t < 2s$ and they were 7-67% polarised.

Wiehl et al, (1985b) studied 664 decimetric pulsation events, classified them in short (<1s) and long (5-300s) and interpreted them in terms of transient and trapped electrons respectively. Benz (1985) studied events rich in spikes with relative bandwidth down to 1.5 % ; he estimated an upper limit to their size of 200 km. Aschwanden and Benz (1986) found that pulsations exhibit three times higher drift rates at 650 MHz than type III's. Stahli and Magun (1986) found that msec spikes observed in the long μ-λ range extend up to 5.2 MHz. They occur during μ-λ continuum emission, mostly in the rise and maximum phase ; they are polarised from -100% to 100%, with no correlation with the continuum polarisation. In the 3570-3370 MHz range their bandwidth can be < 0.5 MHz. Jin et al (1986) analysed 250 spike events at 2.84 GHz ; they have shorter duration and higher flux than previously known and many were not resolved at 1 ms. Enome and Orwig (1986) found that events with a very spiky structure had relatively high associated HXR emission (see also section VI, D). Stahli and Benz (1987) observed drifting structures in the 3100-5205 MHz range with a duration of 25-200 ms, bandwidth > 150 MHz, slightly circularly polarised ; they had reverse frequency drifts with an average of 8100±4300 MHz/s and were interpreted as signatures of electron beams.

Electron cyclotron masering (ECM) is the favorite candidate for the interpretation of high brightness temperature fast structures. The growth rates have been studied by Sharma and Vlahos (1984), Winglee (1985a), Li (1986) and Zhao and Shi (1986). The effects of finite plasma temperature and superthermal tails have been studied by Sharma and Vlahos (1984), Winglee (1985b) and Vlahos and Sharma (1985). The non-linear evolution of the instability in a ring distribution was studied by Sprangle and Vlahos (1986), while White et al, (1986a) studied the formation of a loss cone in a free steaming approximation, Although ECM can produce the required T_b, its applicability is still uncertain due to the sensitivity of the growth rates to ω_p/Ω_e and the problems of possible gyroresonance absorption.

At longer wavelengths Bakunin and Chernov (1985) have studied broad-band spike bursts in the 175-235 MHz range ; they are rare in noise storms, while in type IV's series of non-periodic spikes predominate. Elgaroy (1986) studied 1552 pulses in a type IV event and found an average period of 0.09s at 300 and 500 MHz. The polarisation of type IV associated spikes varies widely, but it is almost constant for the same group (Nonino et al, 1986), while their decay phase is similar to that of type III's

(Abrami et al, 1986). Zaitsev et al, (1984) and Rozenraukh and Stepanov (1986) proposed an interpretation in terms of MHD pulsations for type IV pulse trains, while Zaitsev and Zlotnik (1986) suggested that ms time structure at m-λ is similar to Jovian s-bursts.

F. METRIC BURST EMISSION

Stewart (1985) found that storm sources occur in large unipolar cells, which after the solar maximum form a longitudinal sector pattern. Stewart etal (1986) found a close association between changes of the large scale photospheric magnetic field and the onset and cessation of noise storms ; the new flux diffuses slowly in the corona, producing storms 1-2 days later. Concerning the theoretical interpretation of the emission, Malara et al (1984) proposed that the non-linear coupling of ion acoustic waves and high frequency waves might explain the o-mode polarisation. Levin and Rapoport (1985) considered the streaming of diffusely distributed super-thermal electrons along inhomogeneous magnetic field. Wentzel (1985) interpreted the type I continuum in terms of a non relativistic electron gap distribution. Wentzel et al (1986) suggested that all type I bursts are emitted fully polarised and depolarisation occurs due to large angle scattering. Wentzel (1986) suggested that type I continuum may arise from the combination of 2 electrostatic waves, nearly normal to the magnetic field.

Robinson (1985) measured type II velocities from dynamic spectra and found a distribution which peaks at 500-700 km/s. Robinson and Stewart (1985) found that type II's can occur at the leading edge of a coronal mass ejection (CME), well behind the leading edge, or in the absence of a CME ; the first kind is probably generated by the CME, the last by a blast wave. Gergely (1986) made a statistical analysis of CME's and moving type IV's and found that 1/3-1/2 of the latter are associated with CME's but only 5% of CME's show the inverse association; the mean speed of the type IV is smaller than that of the CME. Lengyel-Frey et al (1985) gave observations of interplanetary (IP) type II's ; the fundamental was more intense and variable, had a larger size and a smaller bandwidth. In a model of type II emission, Krasnosel'skikh et al (1985) suggest that nonmaxwellian electron tails can form from low frequency waves driven by unstable ion beams produced in a collisionless shock wave. In a different approach, Wu et al (1986) considered the formation of a hollow beam electron distribution in the shock wave, which attains larger pitch angles as it propagates to low altitudes ; the result is a maser instability which amplifies unpolarised or weakly polarised radiation. Lakhina and Buti (1985) suggested that type IV radiation is emitted from the interaction of slow whistler solitons with upper hybrid waves in a region with a transient density increase. Cane and Stone (1984) investigated the relationship between interplanetary and metric type II bursts, interplanetary shocks and energetic particles.

Two-dimensional maps of microbursts (weak type III) at decametric wavelengths have been given by Kundu et al (1986b), White et al (1986b) and Gopalswamy et al (1987) ; they are short duration events (2-10s) with a peak T_b sometimes less than 10^6K and a size of ~ 15' at 50 MHz. Their brightness is too low to be interpreted in terms of current type III theories ; their size increases at lower frequencies.

Poquerusse et al (1984) studied the decay of U bursts and concluded that the process is beam dependent. Leblanc and Hoyos (1985) found a close relation between type U groups and type II's. Eremin (1985) presented examples of radio echos observed during a type III storm. Pick and Ji (1987) studied the relative position of spatial components of type III's at 169 MHz and concluded that the angular extent of the electron injection region was ~35°. Mein and Avignon (1985) and Chiuderi-Drago et al (1986) found an association of type III's with ascending Hα features. Raoult et al (1985) studied 55 type III groups associated with HXR bursts ; they found that those accompanied with type V continuum longer than 30s were associated with much more intense HXR bursts, with spectra extending to ≥100 keV. They also found that comparative hard x-ray and metric radio observations indicate interaction of magnetic structures and subsequent magnetic reconnection in the vicinity of the electron acceleration/ injection region giving rise to the impulsive phase of a flare. In a study of IP type III's Dulk et al (1984) found that the emission begins at the same time as the Langmuir waves and it is at the fundamental. Steinberg et al (1984) concluded that propagation effects, group delays, ducting and scattering are important in IP type III's. Steinberg et al (1985) attributed the large size of IP type III's to scattering ; scattering makes them visible even if they originate behind the sun (Dulk et al, 1985). Dulk et. al, (1986b) traced the lines of force of the IP magnetic field using type III trajectories. Reiner and Stone (1986) reconstructed type III trajectories using the frequency drift, in addition to the position of the source. Fokker (1984) examined the deviation of electron stream trajectories from a smooth path due to irregularities in the magnetic field lines and pitch angle variations. Lin et al (1986) gave evidence of non-linear wave-wave interactions in IP type III's ; they observed spiky Langmuir waves to be driven by electron beams associated to type III's ; low frequency, apparently ion-acoustic wave were often observed, coincident in time with the more intense Langmuir spikes. Grognard (1984) proposed a simple test of the quasilinear theory and estimated the initial temperature of the associated distributions. Levin (1985) suggested that plasma turbulence behind the leading edge of an electron stream leads to quasilinear relaxation ; Melrose et al (1986) presented a model of IP type III emission, in which Langmuir wave growth is suppressed by refraction in density irregularities except near density minima where clumps of waves form. A two component model for the generation of type III fundamental was proposed by Eremin and Zaitsev (1985).

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VIII. Theory of Solar Flares
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A. INTRODUCTION

By far the most significant event for Solar Flares as a whole over the past 3 years has been the operation of the Solar Maximum Mission Satellite, together with the accompanying data analysis, ground-based support and theoretical modelling. This has culminated in the series of SMM Flare Workshops, whose proceedings have now appeared (Kundu and Woodgate 1986 (I)), with chapters on a wide variety of topics which indicate the enormity and complexity of the flare problem.

Here we shall review only one aspect, namely the MHD theory of a flare (Priest 1986a), focussing on two topics. These are the instability or nonequilibrium process which initiates a large flare and the magnetic reconnection process whereby the stored magnetic energy is released. However, one should bear in mind the subtle interaction between the MHD and the microscopic plasma physics of the flare : the MHD provides the environment (the current sheets, shock waves and turbulent medium) where particles can be accelerated, whereas microscopic processes will determine the turbulent transport coefficients. Furthermore, the MHD coupling between a plasma and a magnetic field is much more complex and represents quite different physics from simply the electromagnetism of circuits, so it can often be misleading and dangerous to use circuit theory analogues.