40. RADIO ASTRONOMY (RADIO ASTRONOMIE)

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A. SOLAR RADIO EMISSION

M. Pick

1. *Introduction*

Many fields of interest have been covered in the past three years. Owing to space limitations, the bibliography presented here is not complete, and the references of some contributions will have to be found in general review papers or the proceedings of meetings in which the exact reference is given.

Attempts have been made to detect millimetric or centimetric radio lines without success **(1)** **(2)**. – Both radioheliographic and high time resolution observations have revealed very many new phenomena (see Sections 6 to 11). – Coronal magnetic fields have been deduced from the known photospheric magnetic fields computation: the rôle played by coronal structure in transient radio events was widely discussed (Newkirk **3**, **4**). – New insights relative to the high corona have been obtained from space radio exploration. In particular systematic information of the burst source positions has been obtained for the first time. It was also demonstrated that the only way to provide reliable information on the directivity of short lived events is to observe them simultaneously from the Earth and a remote space probe **(5)**. – Observations of the interplanetary scintillations has proved a fruitful technique for investigating several problems, such as solar wind measurements outside of the ecliptic plane, and the relationship between solar activity and corotating structures of the interplanetary medium **(6)** **(7)** **(8)**. Characteristics and implications of radar echoes have been investigated **(9)** **(10)**.

Much effort has been devoted to the comparison of impulsive X-ray bursts, microwave bursts and the occurrence of type-III bursts [for precise references see **(11)**, **(12)**, **(13)**]; two components of impulsive Hard X-ray bursts have been distinguished **(11)** **(14)**. In particular, evidence for two stage particle acceleration in solar flares has been found **(13)**. The connection between microwave pulsations and the characteristics of type-III bursts have been considered **(15)** **(96)**.

2. *Reviews*

Lists of U.S. Radio and Radar Astronomy Observatories and of U.S.S.R. stations have been published **(16)** **(17)**.

New proceedings giving a summary of the European solar radio work are published each year (**18**a, b). A review paper has summarized observational and theoretical aspects of the radiobursts **(19)**. Three books including several aspects of the solar radio emission have been published **(3)** **(4)** **(20)**.

3. *The quiet Sun*

Brightness temperature has been measured at 6 mm **(21)**. Brightness distribution of the quiet Sun has been obtained in the mm range around 1·2 mm, 3·5 mm and 9 mm. Center-limb variations

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have also been deduced from eclipse measurements at 1·2 cm (**22**). The distribution around 9 mm shows definite limb brightening (**23**) (**24**) (**25**); at 3 mm according to different observers, either a slight limb brightening (**23**) (**26**) or, on the contrary, darkening (**24**) was observed. The distribution at 1·2 mm exhibits a possible (**27**) or a definite limb darkening (**28**). These distributions have been interpreted in terms of chromospheric structure (**24**) (**29**).

Two dimensional maps have been obtained both at 6 cm and 11 cm (**30**). Radio models of the transition region have been proposed (Chiuderi *et al.* **18**b) (**31**). The latter (**31**) takes into account the hydrodynamical conservation equations and an expansion velocity.

The quiet Sun distribution has been observed and interpreted in the decametric wavelength range (**32**).

4. *Oscillatory components*

The solar oscillatory components have been observed at 3 mm with the most evident period near 180 s (**33**). Correlation spectral analysis at 3·3 cm led to periods of 150–900 s. Oscillations with periods longer than 600 s originate in the active regions (**34**). Longer periods were detected in the *S* component intensity (**35**).

Microwave 23 s period pulse trains were observed for many minutes preceeding a flare (**36**).

5. *Slowly varying component*

Solar active regions have been intensively studied at wavelengths between 1 mm and 9 mm (**37**) (**38**) (**39**) (**40**) (**41**) (**28**). They show excellent correspondence with plage regions as well as with regions of longitudinal magnetic fields on Mt. Wilson magnetograms. Studies of circular polarisation structure at 9 mm indicate that all important active regions are bipolar in nature (**41**).

Absorption features at 3 mm and 9 mm were observed to correspond with Hα dark filaments on the disk. Beyond the limb the prominences correspond to emission regions (**42**).

Eclipse observations of filaments at 3 mm and 9 mm have indicated a multicomponent structure (**43**). Eclipse observations also include 1966 November 12 at 3 cm and 21 cm (**44**), 1968 September 22 in the 2–3 cm range (**45**) and 1970 March 7 (**46**).

In the centimetric range the large variety of the spectra of the *S* component has been recognized and interpreted in terms of non-thermal emission (**47**). Theoretical models have been proposed (**44**) (**48**) (**49**).

At 169 MHz, the *S* component has been at first associated with coronal enhancements leading to a model of these regions (**50**). However a new association predominantly with filaments leads to an alternative interpretation in term of streamers (**51**).

6. *Microwave bursts*

Statistical studies of radio bursts observed at 71 GHz and 19 GHz have been presented (**52**) (**53**). For bursts associated with proton events, the major part of the radio energy is emitted in the millimetric band (Croom – **54**).

Several observations of the time changes in the polarization during a burst have been made and different interpretations of this effect have been given (**55**) (**56**).

Homologous events from different active centers (**57**) and also largely spaced in time (**58**) were observed.

Existence of double sources with similar evolution was deduced from microwave high-resolution observations (**59**). Expansion of a radioburst source was interpreted in terms of diffusion of energetic electrons in a turbulent magnetic field (Tanaka *et al.* **4**).

Decay times of impulsive microwave bursts were explained through a model electron distribution (Fluckiger **18**b). The theory of synchrotron radiation was reviewed (**60**) (**61**) in order to interpret the center to limb variation of spectrum polarisation of impulsive bursts (**62**) and structure of the sources. Effects on the spectrum of self absorption (**63**) and of the free-free absorption (**60**) have been considered. Due to high intensities of the radio radiation, a non-linear coupling of various wave bands leading to a redistribution of the intensity within the radio spectrum has been considered as probable (**64**).

7. *Type-III bursts and type U bursts*

Polarization characteristics on decametric wavelengths were investigated (**65**) (**66**) and analysed in terms of effects of Faraday rotation dispersion (**67**). High spectral resolution observations have given characteristics of the emission (**68**). A precursor of the decametric type-III burst was discovered (**69**). Quasi oscillatory decay in type-III burst groups has been observed (**70**).

A large scatter in type-III burst positions can be observed in agreement with a distribution of sources along a neutral plane (McLean **19**). Existence of an asymetrical halo implies the influence of coronal scattering (**71**).

Relative positions of fundamental and second harmonic emissions were consistent with a backward emission of the second harmonic (**72**). These two emissions were also observed for emissions near the limb (**73**) and the results disagree with a simple refraction theory so scattering must be considered.

The effects of coronal scattering on the source observation have been studied at metric wavelengths (**74**) (**75**) (**76**) and hectometric wavelengths (**77**) [(**74**), (**75**) correspond to isotropic inhomogeneities and (**76**) (**77**) to anisotropic conditions]. On hectometric wavelengths, type-III burst storms have been observed (**78**), in association with metric and decametric activity (**79**). These observations were extended down to 30 KHz (**80**) (**81**). Physical conditions and evidence for spiral structure were deduced (**82**).

Type-III bursts are systematically observed at a different position (Kai – **19**) from type-I bursts and have their origin in weak magnetic field regions. Type-III bursts occur in association with motions of absorbing chromospheric material which appear as the basic perturbation in the absence or presence of a flare (**83**).

Theories

Studies of the stabilization of the two stream instability have undergone an intensive but inconclusive development. After a critical treatment neglecting all anisotropies in the spectrum of the excited plasma waves (**84**) (**85**), a treatment which took them into account in a somewhat rough way has shown that stabilization was effective only for an ion beam (**86**) (**87**). Neutralization of particle streams may occur as a consequence of the development of a large amplitude wave at the head of the stream and leads to new difficulties (**88**) (**89**).

Any possible stream stabilization has been rejected in coronal conditions by other authors; they support a strong quasilinear relaxation of the beam (**90**a) (**91**) and the continuous existence of the stream is obtained in considering a spatially limited beam with inhomogeneous front. Energy conversion of the plasma waves generated in the preceeding theory has been presented (**90**b).

The energy dissipation of plasma waves for the low frequency type-III bursts cannot be due only to collisions (**92**). Landau damping has to be considered (**93**) (**94**).

Classical theories have to be reconsidered in the presence of a transverse magnetic field inside the streamers (**95**). Both the modulation of X-ray or microwave emissions and the occurrence of type-III bursts in pulse trains might be a consequence of bouncing whistlers scattered on coherent plasma waves (**96**).

Coherent synchrotron deceleration of 100 keV electrons has been proposed as the mechanism by which type-II and -III bursts are generated (**97**).

Radioheliographic observations of type-U bursts have been consistent with a guiding of fast electron streams along coronal magnetic loops (**98**).

From radio spectrographic observations, trajectories followed by U like radio bursts were computed (**99**). Several attempts have been made to explain the fact that the second branch of U like bursts is less developed than the first branch (**99**) (**100**) (**101**).

A U type burst having a reversing frequency of 700 kHz has been reported (**102**).

8. *Type-II bursts*

The majority of the recent observational results have been obtained from the Culgoora radio-heliograph. The front of the shock wave may be extremely large, as large as 200°; multiple sources can appear for the same type-II burst, around a large arc roughly centered on the flare site (Smerd 1970 – **19**), (Dulk 1970 – **19**), (**103**), (**104**).

Observations have shown that the source of the two components of a split band are spatially separated (Dulk 1970 – **19**). This result is consistent with an interpretation based on simple geometrical considerations proposed by McLean in 1967, and contrary to theories invoking magnetic field origin as well as theories invoking Doppler effects.

Comparison of computed coronal magnetic-field structure and some type-II positions strongly suggests that the shocks are propagating more parallel to the magnetic field than perpendicular to it; in some cases, sources of emission have been observed when the field is directed radially out from the flare region (Newkirk 1971 **3, 4**) (**105**). Type-II solar bursts have been observed at frequencies below 9 MHz (Malitson, unpub.). Observations of fundamental and harmonic emission are in agreement with the excitation of a forward fundamental radiation and a preferential backward harmonic radiation (**103**).

Fine structure of type-II bursts have been interpreted in term of coronal turbulence (**106**). Spontaneous processes of Rayleigh and Raman scattering of the plasma waves in the collisionless shock wave front have been considered and the scattering coefficients have been determined and shown to be less than in a uniform plasma (**107**).

A new theory in which the plane of the shock wave is allowed to form a slight angle with respect to the direction of the ambient field has been proposed. In this theory, the radiation is generated at the head of the shock front by electrons escaping from the shock layer along the ambient field (**108**a). The emission mechanism involves the beam plasma instability caused by these escaping electrons, and the plasma waves are subsequently transformed by induced Rayleigh and Raman scattering in a relatively large region ahead of the shock (**108**b). This recent theory has been applied to observations (**108**c).

The interaction of a shock wave and a stream of particles in the upper solar corona has corresponded to enhancements of decametric type-III bursts; it was supposed that the ion acoustic waves excited in the shock wave lead to a modification of the non-linear stabilisation of the stream instability (**109**).

9. *Type-IV bursts*

According to radioheliographic observations at least three varieties of moving type-IV bursts have been recognized (**110**): – (I) the advancing shock front, giving type-II burst emission at the plasma level and, later, synchrotron radiation from *in situ* accelerated electrons (Kai 1970, **110**), (Stevard *et al.* 1970, **110**), (Stewart and Sheridan 1970, **110**). – (II) The expanding magnetic arch, within which energetic trapped electrons generate synchrotron radiation near the top of the arch, and plasma radiation near the foot of the arch (**110**). – (III) the ejected plasma blob (Riddle 1970, **110**), (Sheridan 1970, **110**) for which both intensity and polarization behaviour have been explained in terms of radiation from mildly relativistic electrons in an ordered and gradually expanding magnetic field (Dulk 1970, **110**), (Schmalh 1972, **19**).

Velocities as large as 5000 km were observed (Kundu, **3**). The decametric stationary continuum has been found to be much higher than at meter wavelengths, and it is consistent with the plasma origin of the decametric continuum (**111**). Spectral features and classifications of type-IV bursts were reviewed (**20**). Account is taken of the distinction of observed continua at metric wavelengths (**112**).

For the first time, a coronal disturbance was observed simultaneously with a white light coronometer and with the 80 MHz radioheliograph (**113**).

10. *Fine structures in association with type-IV bursts*

Very peculiar phenomena have been observed on several occasions in the emission of type-IV events. These structures are in particular clearly visible on spectrographic observations (**114**). The pulsating structure corresponds to broad-band quasi-periodic intensity fluctuations (**115**) (**116**) occurring practically instantaneously over a considerable frequency range. The source extent was found to be very limited with the Nancay radioheliograph (Caroubalos *et al.*).

Pulsating structure has been interpreted as due to M.H.D. pulsations in coronal flux tubes (**117**), Rosenberg (**4**). This theory has been incorporated in different models (McLean *et al.*, **19**, **118**).

Zebra patterns or 'parallel drifting bursts' (Elgaroy, Slottje, **18**a) might be due to coupling of Bernstein waves and upper hybrid waves (**119**) (**120**); on this basis, it is possible to derive the local magnetic field. A new type of metric bursts, so called 'Tadpole' structure, has been discovered (Slottje **18**a).

11. *Type-I bursts and noise storm activity*

From eclipse measurements, the structure of a noise storm source has been investigated, leading to the determination of the size of a type-I burst source and continuum source (**121**). High-resolution space time structure at 169 MHz was studied (**122**).

Characteristic properties of small chains of type-I bursts were determined (**123**).

An appropriate magnetic-field configuration explains the correlations of separated widely spaced bursts (Newkirk, **3**, **4**). Location of type-I burst activity has been used to infer large scale magnetic arches (**124**) (Daigne *et al.* **4**). Hectometric continuum radiation has been detected (**125**).

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B. CONTINUUM RADIATION FROM THE GALAXY

F. D. Drake

The breadth of studies of the galactic continuum radiation has greatly expanded since the last reporting period due to the discovery of new types of emitting objects, and new interest in aspects of previously known phenomena. The number of papers published has been of the order of a thousand, and it is possible here only to give a representative collection and to indicate some of the important papers.

A most important development was the discovery of radio emission from a number of stellar galactic objects of various types. These included novae (**59, 62, 177**) which were seen to change their intensity and spectra in accordance with the theoretically predicted evolution of radio emission

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