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INTRODUCTION

Le contenu de ce rapport est basé essentiellement sur les données qui ont été fournies par les membres de la Commission 40. Mais, contrairement au rapport de 1961, celui-ci n'a pas été rédigé par un seul auteur, mais par différents spécialistes: la partie consacrée au Soleil est due à J. P. Wild, celle sur les Planètes (qui a été séparée du rapport de la Commission 16) à C. H. Mayer. G. Westerhout a réuni les informations concernant l'émission radioélectrique de la Galaxie, et R. N. Bracewell les données sur les instruments nouveaux. En raison de la connexion de plus en plus étroite entre l'étude optique et radioélectrique des galaxies, il a été décidé par les Présidents des Commissions 28 et 40 d'inclure l'émission radioélectrique des galaxies dans le rapport de la Commission 28. J. Lequeux a été chargé de la rédaction de ce travail.

V. V. Bazykin a fait parvenir au Président de la Commission 40 un exposé complet des travaux soviétiques en Radioastronomie, qui a été séparé en différentes parties selon le sujet traité; on trouvera chacune de ces parties à la suite des rapports généraux. On lira en outre un bref rapport sur la recherche spatiale radioastronomique en U.S.S.R.

A. SOLAR RADIO EMISSION

(prepared by J. P. Wild)

Introduction

The literature on solar radio astronomy during the last three years has been so extensive that it is not possible in this kind of report to give more than an annotated bibliography on recent events. For recent reviews on the subject reference may be made to papers by Christiansen (1) and Swarup (2) on the quiet and slowly-varying components of the solar radio emissions and by Wild, Smerd and Weiss (3) on the bursts and high intensity emissions. Radio phenomena also figure significantly in rather less recent reviews on *The Sun as a source of interplanetary gas* by de Jager (4) and on *Fast phenomena in the solar corona* by Wild (5).

The three years have seen steady progress in various directions. One may cite in particular: (1) the extensive work on the slowly-varying component, in which observations in the lower centimetre and millimetre wavelength band have revealed distinctive differences from what was previously known in the lower decimetre band and which have revealed the necessity of invoking gyro-synchrotron process to account for part at least of the radiation: (2) the considerable increase in understanding of the detailed relationships between the nature and timing of radio bursts on the one hand and the optical, X-ray and corpuscular emissions from solar flares on the other; (3) the discovery of complex structure and transverse motions in the sources responsible for the slow-drift metre-wave bursts of spectral type II, phenomena which must surely lead eventually to an understanding of the propagation in the solar corona of shock waves from flares and of the magnetic configurations in which the propagation occurs; (4) the systematic series of observations at El Campo of radar reflections from the Sun, which already seem to reveal direct measurements of the solar wind and of the mass internal motions of the corona. Published work on the various recognized components of solar radio emission will now be considered in their respective categories.

The Quiet Sun

The most significent advance in radio studies of the quiet Sun has been the extension of observations into the millimetre range of wavelengths. Observations have been made at wavelengths of 3-7 mm (**6**), 4·3 mm (**7, 8**), 2·15 mm (**7**), 2 mm (**9**) and 1·8 mm (**10**) and values of temperature close to the photospheric temperature have been found in all cases. A minimum near 6 mm wavelength has been suggested (**6**). Special measurements of the disk temperature have also been made at wavelengths of 8 cm (**11**) and 3·1 and 20 cm (**12**). High resolution investigations at longer wavelengths—in the decimetre (**13**) and metre (**14**) ranges—have generally substantiated earlier results that the quiet Sun retains its elliptical shape throughout the sunspot cycle and the limb brightening at decimetre wavelengths is confined to the equatorial regions even near the maximum phase (**13**). At 169 Mc/s (**14**) an appreciable reduction in the dimensions of the Sun has been found since 1960, especially in the equatorial plane; between 1960 and 1961 the ellipticity of the Sun was found to be 0·8.

Radio data have been combined with optical and ultra-violet data to derive or test several models of the chromosphere (**15**), the lower corona (**16**), and the transition region between them (**17, 18, 19**).

Observations of the outer corona by means of its occultation of the Crab Nebula were made, in June 1961 and 1962, at wavelengths of 11·4 metres (**20**) and 9·4 metres (**21, 22**) using interferometers, and in 1962, at 10 and 25 cm (**23**) using an 85-ft parabolic mirror. A detailed analysis of the high resolution 11·4 metre observations by Erickson (**20**) revealed scattering effects (changes in apparent angular size) out to a radius of 60 R_0, the degree of scattering appearing to fall as the $-2·0$ power of the angular separation between the Sun and source; the evidence favoured a model in which the irregularities and hence magnetic fields were largely isotropic, though a slight tendency for preferential radial fields were evident. These results may be compared with the earlier (1960) results of Slee (**24**), who observed a number of occulted sources and formed a scattering law of index $-2·3$. It is believed that the scattering law may well be proportional to the true variation of electron density.

A 1963 observation of the occultation at a wavelength of 6 cm has been reported (**25**); no perceptible variation in source diameter occurred, a result consistent with the extrapolation of longer wave observations.

The Slowly Varying Component

Considerable observational data have become available to elucidate the nature of the slowly varying component thermally emitted mainly at millimetre, centimetre and decimetre wavelengths from active regions: direct high-resolution observations, notably in the Soviet Union, at wavelengths of between 1·8 mm and 8·7 cm (**26, 27, 28, 29, 30, 31**), high resolution studies with interferometers at wavelengths between 3 and 21 cm (**13, 32, 33, 34**) and longer wave observations at 327 Mc/s (**35**) and 169 Mc/s (**36**). To these should be added eclipse observations: some final analyses on the spectrum (**37**) and polarization (**38**) of the radiation observed at the eclipse of 1958, April 19; and observations of the eclipse of 1961, February 15, from the Soviet Union (**39, 40, 41**) (including the extensive chain of observations at the Main Observatory, summarized by Mochanov (**39**)) and from Italy (**42, 43, 44**).

Recent observations have revealed or confirmed earlier indications of new features of the slowly varying component, particularly as regards the shorter wavelengths ($\lesssim$ 10 cm) and the distinction between the 'centimetre' and 'decimetre' waves. The conclusion (**34, 37, 45, 46**) is now quite clear not only that the brightness temperature shows a maximum near 10 cm wavelength but that in many cases the flux density also shows a maximum typically in the vicinity of 6 cm. Furthermore as the wavelength is reduced from 20 cm to 3 cm there is a steady increase in the degree of circular polarization from $\sim 0\%$ to $\sim 30\%$, a decrease in the height of the source above the photosphere from some 5×10^4 to 10^4 km, while the order of dimensions of the source tends to decrease from that of the plage ($\sim 3'$ arc) to that of the individual sunspots ($\lesssim 1'$ arc). There is sometimes evidence of a highly polarized, spot-sized 'core' superposed on two largely unpolarized plage-sized 'halo'.

From these observed characteristics there has emerged the important result that the slowly-varying component, especially at wavelengths below 10 cm, cannot be accounted for only in terms of thermal Bremsstrahlung emission, in which the emissive and absorptive processes are ascribed to the Coulomb interaction of electrons and ions; rather it is necessary to invoke resonances at the harmonics of the gyro frequencies, in which case the gyro-synchrotron process is responsible for emission and absorption. The new theory was advanced by Zheleznyakov (**47**) to explain the intensity and polarization observations, by Kakinuma and Swarup (**45**) and subsequently Zheleznyakov (**48**) to explain the 'turn-over' in the flux-density spectrum as well as the observed polarization. Kakinuma and Swarup proceeded to develop a model of the source region which accounts for the observed properties. Magnetic fields are required of about 600 gauss at a height of 2×10^4 km and 250 gauss at a height of 4×10^4 km. Other works relating to various aspects of the slowly varying component deal with: the limiting polarization to be expected from a source region on the basis of normal magneto-ionic theory (**49**); the relationship of the radio emission with loop prominence activity (**50**) and with E-layer ionization (**51**); a model of the coronal condensation from optical and radio data, emphasizing the 'core-halo' structure (**52, 52 bis**) the statistical properties of flux measurements over a broad range of wavelengths (**53**); and the predicted effects of the slowly varying component at millimetre wavelengths (**54**).

Bursts

Microwave and Decimetre bursts

In our present state of knowledge solar bursts in the microwave spectrum may be broadly classified into three main groups:

(i) Gradual, low intensity, phenomena (*the gradual rise and fall* and *post-burst increase*) which are believed to be thermal in origin (**55**) and originate in localized areas within centres of activity (**56**).

(ii) *Impulsive bursts* which exhibit their sudden rise near the flash phase or explosive phase of flares (**57**) and which also coincide in time of start and sometimes in detailed temporal structure with the burst of hard X-rays (**58, 59, 60**) and their associated geophysical effects (**61, 62**); Kundu (**58**) has concluded that both X-rays and microwaves are likely to originate in the same (chromospheric) region. Investigations of the spectrum of these bursts between 500 and 25 000

Mc/s by Hachenberg and Wallis (**63**) have shown that the spectrum often corresponds to that of an optically thin thermal source, and indeed thermal models have been explored (**63, 64**); their interpretation in terms of thermal Bremsstrahlung present difficulties which are overcome by Takakura's gyro-synchrotron theory, or at least a mixture of the two mechanisms (**65, 66**). In any case the flux density tends statistically to decrease with frequency near 10 000 Mc/s (**67**), and so, as with the slowly varying component, it is essential to invoke the magnetic field in the majority of cases.

(iii) Large outbursts of microwave radiation which are now classified as components of *type IV bursts* and which are discussed separately below.

Observational and statistical studies of microwave and decimetre bursts in general have been made: on statistics of bursts in the ranges 1500–9400 Mc/s (**68**) and 200–9400 Mc/s (**46**); on the position, angular size, brightness temperature and movement of bursts at a wavelength of 21 cm (**69**); on magnetic fields in the burst source region deduced from polarization measurements (**70**); on the bursts' relation to flare importance (**71**); on their association with flares which persist in the same region and belong to 'families' with common characteristics (**72**); on the configuration of flares in respect to the sunspot groups, which produce microwave bursts (**73**); on the occasional simultaneous occurrence of bursts on different parts of the disk (**74**); on their time distribution through the solar cycle and their tendency to be relatively infrequent at the maximum phase (**75**); on their statistical relationship with bursts on metre wavelengths (**65**); and on the emission accompanying certain outstanding events (**76**).

Reports of observations of bursts at *millimetre wavelengths* remain very scarce in the literature. The most recent examples appear to be those reported by Salomonovich (**77**) at a wavelength 8 mm, and by Edelson (**78**) at 4·3 mm; the latter author favours an origin of the emission in gyro-synchrotron radiation of 10^4 keV electrons in magnetic fields exceeding 10^4 gauss.

Type III (fast drift) and type V bursts

Comprehensive investigations of the characteristics of type III bursts using wide-band spectral data have provided detailed information on the observed duration, band-width, frequency drift, starting frequencies, etc. of the bursts, the derived dimensions, velocity, and acceleration, of the sources of the bursts, and the derived temperature of the surrounding corona (**79, 80,** see also **81, 82**). High resolution observations have given measures of the heights of the sources, and in some cases the source size and directivity, at wavelengths of 1·5 m (**83, 84**) and 11·4 m (**85**). In a small percentage of the bursts linear polarization was detected, in the presence of Faraday rotation, using a narrow-band polarimeter (**86**). The statistical distribution of amplitudes of all bursts (not specified by their spectral type) at 209 Mc/s has been derived (**87**).

The association of type III (**79**) and type V bursts (**88**) with flares has been discussed, and it has been confirmed that the type III bursts occur at the time of the flash phase (**89**). An association has also been reported with eruptive prominences (**90**). The bursts have been found to occur preferentially in the '*R* regions' of storm activity (**91**).

The theory of Ginzburg and Zheleznyakov by which the type III and type II (**3**) bursts are explained in terms of scattered plasma waves, has been extended for the incoherent case, by Cohen (**92**) to take account of the finite band-width of plasma waves. However the coherent case appears to be more relevant (**3**).

Type II bursts

New features have been found on the structure and movements of the sources (presumed to be shock fronts) responsible for type II bursts in an extensive analysis by Weiss (**93**) of observations of intensity and position as a function of frequency and time. In particular it has been found that the fronts are fragmentary in form and that different parts propagate through the corona along widely diverse paths; also there is clear evidence that the direction of motion is not always radial but may at times be essentially parallel to the Sun's surface.

A comprehensive analysis (**94**) of the spectral properties of type II bursts revealed by the Fort Davis radio spectrograph has been made. The Fort Davis, Dapto (**93**) and other (**95**) analyses all give results consistent with source velocities of some 1000–2000 km/sec, the sources travelling through the corona along dense paths compatible with those within coronal streamers. Further data has been given (**84**) on the directivity of the burst radiation.

The increasing quantity, quality and detail of the data becoming available about these phenomena, may be expected to give firm clues on the nature of the shock fronts, their propagation through the corona, and their generation of radio waves. Three recent discussions (**96, 97, 98**) have been given on possible means by which the shock fronts give rise to the fast electrons required to generate the radio waves. Suggestions have also been made to explain the less-than-two-to-one harmonic ratios and the phenomenon of band splitting (**99**).

Catalogues of major outbursts with type II or type IV events have been published for the years 1952–1960 (Dapto data) (**100**) and 1957–1962 (Fort Davis data) (**101**).

Type IV bursts

It has been known for some time that the long-duration broad-band continuum radiation which follows certain large flares and type II bursts constitute several physically different components which are nowadays grouped together under the heading of 'type IV'. Resolution of the separate components is often difficult; universal agreement on the general structure of a typical fully-developed type IV event has not been reached, but events differ so much one from another that the problem is at present rather intangible. Further evidence has confirmed: the occasional existence of the early, outward-moving component at metre wavelengths (**102**); the distinction between moving and stationary parts at metre wavelengths (**103**); and the distinction between the early part at metre waves and that at decimetre waves (**103, 104, 105**). The main point of disagreement lies in the existence of a separate decimetre continuum intermediate between the stationary metre component and the microwave or centimetre component. Some models, such as that summarized at the Kyoto conference (**106**) describe the decimetre component as a separate entity, and further Japanese evidence has supported this view (**107, 108**); in others (**109**) it is implied that the decimetre waves are so closely linked with the microwaves (**105**) or metre waves (**110**) that any distinction is an artificial one. The same remarks are not true of the fine structure or short bursts in the decimetre wave spectrum which are undoubtedly characteristic. The various models have been reviewed by Fokker (**111**).

Descriptions of the spectral characteristics, including fine structure, have been given (**105, 110, 103**), and in some cases the spectral data have been compared with events revealed at 4·3 mm wavelengths (**110**). Positions on the disk have been found to be very different from those of the accompanying type II bursts (**103**). Linear polarization has been detected in type IV emissions (**112**).

Part of the type IV emission is believed to be gyro-synchrotron radiation from fast electrons. Takakura (**113**) has suggested that the electrons may be accelerated according to the Fermi process by Alfvén waves provided that adequate redistribution of pitch angles occurs between reflections. Further statistical treatments have been given on the well known relationships of type IV bursts and type II bursts with cosmic ray and P.C.A. events (**114, 115, 116**) and geomagnetic storms (**114, 115, 116, 117, 118**). Evidence has been given (**115**) that the proton events with short Sun-Earth time delays are especially closely related to the microwave component. All cosmic-rays flares and most flares producing a P.C.A. event have been found to be preceeded by another flare with a type IV burst occurring in the same sunspot group (**119**). The question as to whether type IV bursts have a statistical influence on the diurnal variation of cosmic ray intensity has been investigated in two analyses, yielding a positive result in one case (**120**) a negative in the other (**121**). All type IV bursts have been found to be accompanied by appreciable X-ray emission (**122**).

Detailed optical studies of flares associated with type IV bursts have shown (i) that the flares tend to cover the umbra of sunspots (**123, 124**), (ii) that certain flare configurations relative to spots and filaments are favoured (**125**), (iii) that loop-type prominences (seen in projection on the disk) are present (**126**), and (iv) that the active region tends to be surrounded by a dark halo ('flare nimbus') during the burst (**127**).

It has been found that large microwave outbursts, like cosmic-ray events, tend to have an unexpectedly low probability during the maximum phase of the solar cycle (**128**).

Type I bursts and storms

Very thorough investigations of type I storms have been made using the interferometer at Nançay (**129**) and the combined interferometer and polarimeter at Mitaka, (**84, 130, 131, 132**). These investigations have given a great amount of data on the height, dimensions, directivity and polarization of the burst and continuum sources and their variation across the disk. Bursts occurring near the limb have been found to have a lower intensity, longer duration, weaker polarization, and greater height than those occurring near the centre of the disk.

The association between the onset of storms and flares is confused by many factors, notably the great duration of storms. A statistical study (**133**) has shown the association to be rather loose, while Le Squeren (**129**) has concluded that the start of all storms can essentially be attributed to flares seen on the disk or to the passage of previously emitting regions round the eastern limb.

Descriptions have been given of a number of unusual or outstanding noise storms (**134, 135, 136, 137, 138**); in some cases anomalous fluctuations are attributed to scintillation phenomena (**135, 138**), in others to absorption effects near the active centre (**136**). A statistical study has been made of storms which occurred during the IGY (**46**).

Peaks of very short duration and narrow bandwidth have again been identified as the limiting case of type I bursts and their possible origin in mode-coupled plasma oscillations has been discussed (**139**). Another plasma-wave interpretation (**156**) of type I bursts invokes relatively slow electron streams which are accelerated in the storm region; this allows us to estimate the magnetic fields in the coronal regions where the storms originate ($\sim$40 gauss at a height of 0·3 R_0).

Radar Observations

Following the pioneering radar observations at Stanford, a systematic study of the Sun by radar has been conducted at El Campo, Texas, by Abel, Chisholm, Fleck and James (**140**) of the M.I.T. Lincoln Laboratory. The observations, which were begun in April 1961 and have continued since, were made at 38·26 Mc/s using an array of 1016 dipoles. The results have shown both a large Doppler shift, compatible with the motion of the solar wind, and a large Doppler spread suggesting internal mass motions of the corona. The results emphasize the danger of interpreting optical line-width data in terms of very high coronal temperatures.

Instrumental Developments

Apart from special high resolution techniques which are considered elsewhere (see the report by R. N. Bracewell on instruments (page 675)), descriptions of a number of spectrographs (**141, 142, 143, 144, 145, 146, 147, 148, 149**) and swept-lobe or equivalent interferometers (**130, 150, 151, 152**) and radiometers (**153, 154**) have been given during the last three years. Recent developments (**142, 146, 148**) have seen the increasing use of voltage-tuning rather than mechanical tuning, in low-frequency spectrographs. An entirely new technique for covering very wide frequency ranges ($\sim$10:1) using the principle of the parametric upconverter has been developed by Suzuki, Attwood and Sheridan (**149**) for the range 200–2000 Mc/s. The parabolic mirror with log-periodic focal feed provides a satisfactory aerial for such broad frequency coverage (**155, 149**).

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A. (APPENDIX) REPORT OF WORK DONE IN U.S.S.R. ON SOLAR RADIO-EMISSION

(prepared by V. V. Bazykin)

In 1960–62 the solar radio-emission was studied by the following institutions: Main Astronomical Observatory, Academy of Sciences of U.S.S.R., Lebedev Physical Institute, Academy of Sciences of U.S.S.R., Institute of Terrestrial Magnetism, Ionosphere and Propagation of Radiowaves, Academy of Sciences of U.S.S.R., Astrophysical Laboratory, Academy of Sciences of Latvian S.S.R., Siberian Institute of Terrestrial Magnetism, Ionosphere and

Propagation of Radiowaves, Academy of Sciences, U.S.S.R., Radio-astronomical Laboratory of the Institute of Radio Physics and Electronics, Academy of Sciences of Ukrainian S.S.R., Radio Physics Research Institute and Leningrad University.

Occultations of the Crab Nebula by the solar corona on wavelength 6·3 cm were observed, and it was found that the Sun general magnetic field does not exceed $8 \cdot 10^{-3}$ gauss at a distance of 5 to 6 Sun radii (**1**). By scanning with a small pencil beam, an attempt was made to measure the ellipticity of the Sun radio disk on centimeter wavelengths (**2**).

After new series of observations using the large Pulkovo radio telescope of which the east-west resolution is about one minute of arc on 3 cm and three minutes on 8·7 cm, it was established that the angular dimensions of the sources in the 2 to 10 cm band do not exceed the dimensions of the connected groups of spots and in a number of cases are near one minute of arc. On 8·7 cm the brightness temperature reaches 2 to 3 10^6 degrees. Observations in various bearings allowed to determine both co-ordinates of the sources with respect to the spots. Besides the displacement of the source relative to the spot which depends on the height of the source over the photosphere, the source appears to be displaced towards the equator, the value of the displacement reaching sometimes one minute of arc. The lifetime of the local source on 8·7 cm was found to be much longer than that on 3 cm and can exceed the lifetime of the group of spots by a full month.

The observations of the solar eclipse on 1961, February 15, in the 2 to 21 cm range showed that dimensions of the emitting zone over a spot depend on the wavelength. From 9 to 21 cm the linear dimensions become about three times larger. The source spectrum has its maximum on 6 to 8 cm. The nature of the spectrum reveals strong influence of the magnetic field on the emission process. The flux spectrum from the bright flocculi which were in the eclipse zone in the disc centre does not materially differ from the decelerating thermal radiation spectrum of an optically thin layer (**3, 7, 10, 11, 12, 13, 14, 15**). In some cases, dark areas related to the solar prominences were observed on 3 and 21 cm (**4, 9, 10**).

The observations of the solar eclipse on 1962, July 31, allowed to determine accurately the solar radio diameter on 3·2 and 4·5 cm. A marked increase of diameter compared to measurements of 1958 was noticed (**29**).

Using a three-component spectrograph the inclination and the residual intensity at the frequency of hydrogen excitation (3·04 cm) were measured in the 3 cm band for more than 100 radio bursts; 18% of them show a residual intensity that noticeably differs from 1 and is within 0·9 to 1·1. The most typical is expressed as $\nu^{-0\cdot75}$, where ν is the frequency. In individual cases the power value reaches as much as -8 to -3. Near the maximum of the flux, characteristic changes have been observed (**16, 17, 18**).

The observations included detailed analysis of the burst polarization on 2·2 and 4·9 cm. In most of the cases the polarization was practically circular while the degree of polarization is about 12% of excess of ordinary wave. A decrease in the polarization degree was often observed near the maximum of intensity. A thermal model, which explains the variations of flux and the polarization degree by expansion of a hot condensation of matter in the corona, was considered. After processing the data of observations made on 1961, July 19, the variations in temperature, density and dimensions of the emitting zone were determined. The measured temperature gradient brings about the change in the polarization sign to a longer wave (**19**).

A statistical method of determining the magnetic field by measuring the ellipticity of the burst polarization has been proposed. The application of this method to the observations made by Akabane (Japan) on 3·15 cm gives average field of about 500 gauss (**20**).

The radio bursts were studied in the 10 to 26 Mc/s band. The structure of the observed bursts was a complicated one, each one consisting in a large number of comparatively narrow-pole outbursts which continuously changed their shape and position on each frequency (**21**).

From the observations made during the total solar eclipse on 1961, February 15, the Sun radio dimensions were determined in the range of 20 cm to 4 m (41′·5 on 1·45 m, 46′·5 on 2·5 m, 51′.5 on 4 m). The values of residual intensity at the totality were: 23·8% on 22 cm, 24% on 83 cm, 34% on 1·45 m, 52% on 2·6 m and 66% on 4 m. The shape of the radio brightness distribution over the Sun disk is similar for the whole range. Co-ordinates, dimensions and brightness temperatures of Sun 'radio spots' for the eclipse day were also determined (this gives $2\cdot10^5$ °K for 22 cm and $4\cdot10^7$ °K for 83 cm) (**22, 23**).

In the external corona, plasmoids (at distances of $4\,R_0$) and plasma inhomogeneities which cause variations of radio emission in the decimetre range, were found. The possibility of plasma cloud movements as satellites of the Sun was considered.

Possible cause of distortion in the regular structure of the solar super-corona magnetic fields were also considered (**24, 25**).

The influence of the super-corona on radio emissions of several solar active zones was calculated at the case of radial distribution of irregularities, taking into account the limited distance from the emission source to diffusing areas of the super-corona. Among other data obtained were: the values of attenuation factor due to this limited distance from the source to the diffusing zones; the estimates for the attenuation of the diffusion effect depending on the source position (3 to 10^2 times); the observed angular dimensions of the solar active zones on 3·5, 5·8 and 12 m (13′·37 and 155′ respectively) (**26**).

On 8 m, series of studies of distribution of Sun radio-brightness and radio-emission bursts were carried out with the use of the PT-22 radio telescope (Physical Institute, Academy of Sciences). Two-dimensional Sun 'radio images' were obtained, and it was shown that the enhanced radio emission comes from areas which are usually located over the flocculae fields. The angular dimensions of the active zones were determined (1′–2′, sometimes 4′–5′) and also the increase in the brightness temperature over the quiet Sun level ($2\cdot5 - 6\cdot10^3$ °K). The 'radio bright spots' have been identified with zones optically active on the Sun disk and dynamic changes of 10 zones were observed. The comparison of the 'radio images' on 8 m and 3·2 cm showed that the discrete source are of thermal nature, and are optically thin on millimetric and the centimetric wavelengths (**27**).

The radio bursts which begin at the same time as chromospheric flares have been localized, their angular dimensions and maximum brightness temperatures (10^4–10^6 °K) estimated (**40**).

The spectrum of the Sun radio-emission was studied on 1·8 mm, and from 3 to 7 millimeter and theoretical research of the Sun radio-emission mechanism continued.

On 8 to 9 Mc/s and 25·13 Mc/s simultaneous observations of sporadic Sun radiation were carried out (**30**).

Study of the radio-emission mechanism of the sources over groups of Sun spots is beginning. It has been established that the sources have strong magnetic fields exceeding 1000 oersteds which can hardly be explained by decelerating radiation only.

Theoretical Research on Solar Radio-emission

The propagation of electro-magnetic waves in the solar corona were studied.

Among the problems considered were:

(1) characteristic interaction of waves in the zone of quasi-transversal magnetic field and its relation to the peculiarities of the microwave bursts polarization (**31**);

(2) transversal transformation of longitudinal waves in conditions of non-homogeneous coronal plasma and its role in the solution of problems of radio-emission from the corona (**32**);

(3) conditions for amplification and instability of electromagnetic waves at anisotropy of temperatures in plasma (**33, 36**).

The study of Sun sporadic radio-emission mechanism was continued (non-coherent radio-emission mechanism for the metric band (37) and synchrotron mechanism for generating the slowly varying component (38, 39)). It was shown in particular, that combined action of Bremsstrahlung and synchrotron radiation provides an explanation for basic characteristics of this component.

The possibility of determining the intensity of magnetic field in the external solar corona by observation of the polarization of the occulted discrete sources, was studied.

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B. RADIOASTRONOMICAL STUDIES OF THE PLANETS AND THE MOON

(prepared by C. H. Mayer)

Radio-emission of the planets and the Moon

Mercury

Howard, *et al.* (1962) reported the first observations of radio emission of Mercury which were made at wavelengths of 3·45 and 3·75 cm. The observations gave an apparent blackbody disk temperature near maximum elongation of Mercury of 400°K. Assuming a smooth, non-rotating, bare planet with negligible emission from the dark side, the observations are consistent with a temperature at the sub-solar point of 1100 ± 300°K.

Venus

A number of recent observations of the radio radiation received from Venus at near inferior conjunction have been made over a range of wavelengths with the following results given as the apparent blackbody disk temperature calculated using the solid angle of the optical disk: at 0·40 cm, 390 ± 120°K (Kislyakov *et al.*, 1962); 0·43 cm, 350°K (from 320° to 400°) (Grant *et al.*, 1963); 0·80 cm, 374 ± 75°K (Kuzmin and Salomonovich, 1962*a*); 0·85 cm, 380 ± 55°K (Lynn *et al.*, 1963); 0·86 cm, 410°K(from 390° to 440°) (Gibson, 1963); 1·18 cm, 395°K (from 340° to 470°) (Staelin *et al.*, 1963); 1·35 cm, 520 ± 40°K (Gibson and Corbett, 1963); 2·07 cm, 500 ± 70°K (McCullough and Boland, in press); 3·15 cm, 548 ± 60°K (Mayer *et al.*, 1962); 3·30 cm, 542 ± 85°K (Bibinova *et al.*, 1963); 9·6 cm, 690 ± 100°K (Kuzmin and Salomonovich, 1961, Bibinova *et al.*, 1962); 10·0 cm, 583 ± 48°K (Drake, 1962); 10·7 cm, 580 ± 70°K (Clark and Spencer, 1963); 18·0 cm, 596 ± 100°K (Clark and Spencer, 1963); 21 cm, 616 ± 100°K (Clark and Spencer, 1963); 21 cm, 600°K (Lilley, 1961).

These new observations further delineate the features of the radio spectrum of the dark side of Venus and it now appears that the apparent blackbody disk temperature lies between 350 and 400°K at wavelengths from 0·40 cm to 1·18 cm, increases rapidly to about 500°K at wavelengths of 1·35 and 2·07 cm, and gradually rises with increasing wavelength to about 600°K at wavelengths near 10 and 21 cm.

The 1·35 cm wavelength of Gibson and Corbett (1963) was chosen to coincide with the water vapor absorption line. They point out that the measured spectrum when compared with the spectra calculated by Barrett (1961) for different model atmospheres shows no evidence for a water vapor absorption in the atmosphere of Venus. In fact, the measured spectrum is more nearly in accord with Barrett's calculations for atmospheres containing 75% carbon dioxide and 25% nitrogen and with surface pressures of 20 or 30 atmospheres.

In addition to the observations made near inferior conjunction, several investigations were carried out over a range of phase angles to clarify the indications of a variation of the radio emission with the phase of solar illumination which were suggested by the earlier observations.

The 0·40 cm radiation was observed by Kislyakov *et al.* (1962) over a period covering about one month before and 1½ months after inferior conjunction and the difference in brightness temperature between the extreme phases was less than 230°K. An apparent minimum occurred slightly before conjunction, but the authors state that this may have been caused by changes in the antenna.

The radiation at 0·43 cm was measured over a period including 1½ months either side of inferior conjunction by Grant *et al.* (1963) who observed no trend toward variation with phase within the scatter of the daily measurements of 70°K standard deviation.

Kuzmin and Salomonovich (1962*a*) observed at 0·80 cm from about two weeks before to about 1½ months after inferior conjunction and found a tendency for the brightness temperature to increase as the phase angle decreased, and reached an average value of brightness temperature of 483 ± 100°K for the fraction of the illuminated disk between 0·3 and 0·4 as compared with 374 ± 75°K at inferior conjunction. As with the 0·40 cm observations the apparent minimum occurred before conjunction but the authors consider that instrumental effects may have influenced the position.

A long series of observations at 3·15 cm which covered a period of from one month before to $4\frac{1}{2}$ months after inferior conjunction was made by Mayer, *et al.* (1962). A definite phase variation with a minimum brightness temperature of 548°K and an extrapolated maximum of 694°K was found at this wavelength with the minimum at a phase angle of 12° after inferior conjunction. These results are consistent with the other measurements made with the same reflector in 1956 and 1958 at about the same wavelength indicating little change in the emission characteristics of Venus from one inferior conjunction to another.

Another long series of observations at 10·0 cm which covered a similar period of time was made by Drake (1962*a*) who found evidence for a small phase variation at this wavelength. The minimum brightness temperature of 583°K occurred at a phase angle 17° after inferior conjunction and the extrapolated maximum was found to be 660°K. Drake (1962*b*) later made further observations near superior conjunction at a phase angle of about 25° and found a brightness temperature of 610°K with a statistical uncertainty of 55 (m.e.)°K and the same systematic error of the previous 10 cm measurements (8%). This value is consistent with the previous extrapolated maximum of 660°K to within the uncertainties.

These observations verify a slightly higher level of emission of the sunlit hemisphere over the dark hemisphere of Venus. A smaller phase effect at 10 cm than at 3·15 cm is consistent with the emission of the longer wavelengths at a deeper level which is expected in the absence of ionospheric effects. The lag of the minimum of the observed level of emission after inferior conjunction suggests that the rotation period of Venus is not the same as the orbital period and that the sense of the rotation is retrograde.

High resolution interferometer observations of Venus made at 9·4 cm wavelength by Clark and Spencer (1963) gave a small part of the amplitude-spacing spectrum which might be interpreted as a uniform disk 15% larger than the visible planet or as a thin ring containing $\frac{1}{4}$ the flux from the planet at the limb of a uniform disk the size of the visible disk.

High resolution observations of Venus at 3·02 cm using the large variable profile antenna at Pulkovo with a beamwidth of 1·2′ in the narrow dimension of the fan beam were made by Korol'kov *et al.* (1963). From the broadening of the observed drift curve for Venus they found that radio-emission is nearly absent at a radius of 1·07 Venus radii, and therefore cannot be from extensive radiation belts as is the case for Jupiter. The amount of observed broadening is not consistent with limb brightening for Venus as might be found if the main source of radiation were atmospheric or ionospheric, and limb darkening is favored. They also determine that the amplitude of the phase variation of the brightness temperature at 3·02 cm must be less than 170°K which is in agreement with the phase measurements.

A third high resolution radio measurement was made by means of the Mariner II space craft which carried radiometers at 1·35 and 1·9 cm to within 36 000 km of Venus. Preliminary results have been reported (Barath, *et al.* 1963; Barrett and Lilley 1963) for the three scans of the antenna beam over the disk of Venus which were obtained at 1·9 cm. The antenna beamwidth was 1/18 the diameter of Venus and the scans indicate less emission near the limb of Venus. The results are interpreted as evidence against an atmospheric or ionospheric origin for the radiation, and the observed limb darkening is consistent with the origin at or near the hot surface of Venus. Lilley and Barrett (1963) have attempted to find the real temperature at the surface of Venus by applying corrections for the absorption of the radiation in the atmosphere of Venus and for the assumed emissivity of 90% estimated from radar data. The resulting preliminary value of approximately 700°K is reasonably consistent with the radio brightness temperatures found from the Earth which have not been corrected upward.

Of the three high resolution measurements, the interferometer measurement at 9·6 cm suggests limb brightening or an enlarged uniform radio disk, while the narrow fan beam scans at 3·02 and the close up pencil beam scans from Mariner II at 1·9 cm suggest limb darkening. At this time all three measurements appear marginal, although it may be that when a full analysis of the Mariner II data is made available a more reliable evaluation of the results can be made.

The results of the new observations of the radio emission of Venus, with the exception of the interferometer measurements, support the hypothesis that the radiation at wavelengths longer than about 1 cm originates as thermal emission of a hot solid surface rather than as thermal or non-thermal emission of atmospheric, ionospheric, or magnetospheric origin as tentatively suggested by Jones (1961), Sagan, *et al.* (1961), Mintz, (1962), Tolbert and Straiton (1962), Kuzmin and Salomonovich (1962), Scarf (1963). The possibility of an ionospheric origin is also difficult to reconcile with the results of the radar observations of Venus (Pettengill, *et al.* 1962; Muhleman 1963). The problem of maintaining such a high temperature at the surface of Venus has been discussed by Jastrow and Rasool (1963), Kaplan (1962), Kellogg and Sagan (1961), Mintz (1961), Opik (1961, 1962*a*), Rasool (1963), and Sagan (1961, 1962). It has been argued for example by Drake (1962*a*), that the dependence of the observed intensity of the radio radiation on the phase of solar illumination argues against the more indirect heating process of the aeolosphere model proposed by E. J. Öpik. However, Öpik (1962*b*) has pointed out that the small phase effect indicated by the recent measurements may be an effect of opacity and emission level and need not necessarily contradict the aeolospheric model. A. H. Barrett (1961) has made a quantitative investigation of the effect of various model atmospheres of Venus on the observed spectrum of the radio emission.

Moon

The recent work has concentrated on observations with high resolution and the measurement and interpretation of the variations of the radio emission caused by the interruptions of solar heating during the monthly phase cycle and during eclipses.

Observations made at 0·43 cm by Coates (1961) with the relatively high resolution of 6·7′ showed variations of radio brightness over the disk which correlate with surface features and which indicate that the lunar maria heat up and cool off more rapidly than surrounding regions. Mare Imbrium was an exception which always remained cooler than its surroundings. These measurements showed that the radio emission characteristics are different for different parts of the Moon, and that interpretations based on averages over large portions of the lunar disk may be misleading.

The 22 meter reflector of the Lebedev Institute has been used for high resolution observations of the Moon at 0·8, 2·0, and 3·2 cm where the beamwidth of the radio telescope was 2′, 4′, and 6·3′ respectively (Salomonovich, 1962*a*, *b*; Salomonovich and Losovskii, 1962). These observations were used to derive the latitude and longitude distributions of radio brightness temperature which were found to be consistent with the calculated distributions for a one-layered model of porous, low-density material.

The Moon was observed with high resolution in one plane using a portion of the Pulkovo variable profile antenna at 2·3 cm where the beamwidths were 2′ in the horizontal plane and from 20′ to 1° in the vertical plane (Kaydanovsky, *et al.*, 1962). The displacement of the center of gravity of the radio disk was measured and from this the amplitude of the phase variation of the 2·3 cm brightness temperature at the center of the disk was determined to be 13·5 ± 4°K.

The high resolution of the Pulkovo antenna was also used at 3·2 cm by Soboleva (1962) with beamwidths of 1′ and 40′ in orthogonal planes to detect the preferential polarization of the radiation emitted by the Moon's surface as predicted by Troitskiy. A small degree of polarization was measured and the results have been interpreted as indicating a surface dielectric constant of between 1·5 and 1·7 with the normals to the surface elements contained within an 80° cone angle.

Additional observations have been made with lower resolution, where the beamwidth of the radio telescope is more nearly equal to or greater than the angular diameter of the Moon. Kislyakov (1961, 1962) has reported measurements at 0·40 cm made from a location at 3150 meters above sea level which gave $T = 230°\text{K} + 73°\text{K} \cos (\Omega t - 24°)$ for the brightness temperature over a lunation. Observations at 3·2 cm gave $T = 245°\text{K} + 15{\cdot}5°\text{K} \cos (\Omega t - 50°)$ (Strezneva and Troitskiy, 1962) for the variation at the center part of the Moon. Krotikov, Porfir'yev, and Troitskiy (1961) report the variation of the average brightness temperature over the disk to be $T = 210°\text{K} + 13{\cdot}5°\text{K} \cos (\Omega t - 55°) + 1{\cdot}7°\text{K} \cos (2\Omega t + 44°) + 0{\cdot}5°\text{K} \cos (3\Omega t + 11°)$. Medd and Broten (1961) measured an average equatorial temperature of 220°K at 9·4 cm and estimate that the phase variation is less than 5%. Krotikov (1962*a*) reports a variation of the radio disk temperature at 9·6 cm of $T = 218°\text{K} + 7°\text{K} \cos (\Omega t - 40°)$. Observations at 10 cm were made by Koshchenko *et al.* (1962) who found an average disk brightness temperature of 230°K which did not vary by more than 4·5°K with lunar phase. Observations by Waak (1961) over 3 lunations at 21 cm indicated a phase variation of 5°K around a mean temperature of 205°K. Baldwin (1961) has observed lunar radiation at 178 Mc/s and found a mean disk temperature of 233 ± 8°K which indicates no detectable steady temperature gradient and gives an upper limit to the heat flow from the interior.

The radio emission of the Moon during lunar eclipses was studied by Castelli and Ferioli (1962) who observed two different eclipses and found no change in the measured radiation greater than 2·5% at 3100 Mc/s and 5% at 1200 Mc/s; Gibson (1961) who found less than 1°K change at 0·86 cm; Tyler and Copeland (1961); Tyler (1962) who observed an apparent decrease of 20°K at 0·86 cm during the first part of an eclipse; and Tolbert *et al.* (1961) who reported a change of approximately 10°C at 4·3 mm during an eclipse. The apparent disagreement of the results and the difficulty of finding consistent interpretations suggest that more observations are desirable.

The interpretation of the observations of the radio emission of the Moon has been discussed in a number of papers and in the general reviews by Mayer (1961) and Sinton (1962).

Baldwin (1962) interprets the lack of phase variation at 22 cm as evidence that a gravelly material extends to a depth of at least 20 meters, and finds his upper limit of $2{\cdot}5 \times 10^{-7}$ to $2{\cdot}5 \times 10^{-8}$ cal cm^{-2} sec^{-1} close to that expected for a Moon of chondritic composition.

Gibson (1961) interprets the very small apparent effect of an eclipse on the observed radiation along with the observed variation during a lunation as requiring at least two and possibly three layers; the outer 0·5 cm like sand in vacuum, the intermediate several centimeters of material having high electrical conductivity, and a base of rocklike material.

Giraud (1962) finds from his analysis that the radio-emission and radar results favor a model for the Moon with a low dielectric constant between 1 and 1·5, thermal conductivity of order 5×10^{-6} to 10^{-5} cal sec^{-1} cm^{-1} deg^{-1}, and volumetric specific heat about 0·1 or 0·2 cal deg^{-1} cm^{-3}.

Krotikov (1962*b*) observes that the loss tangent of earth rocks is found experimentally to be independent of wavelength from 0·8 to 10 cm and extrapolates values of the dielectric constant and density for earth rocks which have the same ratio of loss tangent to density as observed for the Moon to estimate the density of the lunar material as between 0·2 and 0·7 g cm^{-3}.

Krotikov and Troitskiy (1962, 1963) compare the measured value of the time average disk temperature at 3·2 cm of 210 ± 5°K with a calculated value for a 'black' Moon, and interpret the resultant high emissivity as being due to a low dielectric constant of the surface rather than to surface roughness. They use the observed time average disk brightness temperature in conjunction with the density of the lunar surface material derived from radio observations of

0·5 g cm^{-3} to estimate the quantity $(k\rho c)^{-1/2}$ to be between 250 and 450, and the thermal conductivity k to be (1 ± 0·5) × 10^{-4} cal cm^{-1} sec^{-1} deg^{-1}.

Salomonovich (1962*a*, *b*) uses the observations made with the relatively high resolution of the 22 meter reflector at 0·8, 2·0, and 3·2 cm to estimate the dielectric constant of lunar material as between 1 and 2, the surface heating function as $\cos^{1/2}\Phi$, and that a single homogeneous surface layer with $(k\rho c)^{-1/2} = 300$ to 750, $\rho = 0{\cdot}5$ g cm^{-3} is consistent with the measurements, with some evidence for decreasing density and thermal conductivity at very near the surface.

Troitskiy (1962*a*, *b*, *c*, *d*) interprets the wavelength dependence of lunar radio emission as evidence for a quasi-homogeneous surface material at least to a depth of 1 meter. From the measured values of the time average disk brightness temperatures of 211°K at 3·2 cm and 218°K at 9·6 cm he estimates the heat flow from the interior of the Moon as less than 4 × 10^{-6} cal cm^{-2} sec^{-1}. The density of the lunar surface material is estimated as between 0·4 and 0·9 g cm^{-3} by a new method based on the dependence of the heat conductivity on density, the similarities of specific heats for different silicates, and the value for $(k\rho c)^{-1/2}$ of 350 deduced from radio measurements.

Jupiter

Three types of radio radiation are observed from Jupiter: thermal radiation which is dominant at centimeter wavelengths, steady and partially linearly polarized non-thermal radiation at decimeter wavelengths thought to be synchrotron radiation from radiation belts of Jupiter as proposed by Drake, and intense bursts of elliptically polarized radiation at decameter wavelengths.

Observations at wavelengths near 3 cm spread over a period of nine months (Alsop and Giordmaine, 1961) gave a blackbody disk temperature of 177 ± 22°K at 3·16 cm and indicated a frequency dependence of $-1{\cdot}2 \times 10^{-2}$ °K $(Mc/s)^{-1}$. An anomolously high planetary radiation level of 268 ± 14°K was observed on one day. No evidence was found for a dependence of the radiation on the rotation of Jupiter for periods between $9^h\,40^m$ and $10^h\,10^m$, a correlation with solar activity, or linear polarization of the radiation.

The 3·3 cm radiation from Jupiter was measured in 1961 (Bibinova *et al.*, 1962) and an average brightness temperature of 193°K was found with possible day to day variations of 30°K.

The 10 cm radiation of Jupiter was observed in two successive years with blackbody disk temperatures of 640 ± 85°K in 1958 and 315 ± 65°K in 1959 by Sloanaker and Boland (1961).

Morris and Berge (1962) have shown that the radio source at 31 and 22 cm is elliptical (or double) with the polar diameter nearly that of the visible planet, that the degree of linear polarization is about the same at the two wavelengths, and that the plane of polarization wobbles as Jupiter rotates from which they inferred that the magnetic axis is tilted by about 9° from the axis of rotation. More recently, Morris and Bartlett (1962) have found similar results at 10·6 cm as have Miller and Gary (1962) at 21 cm and Rose *et al.* (1963*a*) at 9·4 cm.

These remarkable observations have stimulated theoretical studies of the decimeter radiation as synchrotron radiation (Davis and Chang, 1961; Chang, 1962; Chang and Davis, 1962), and apparently rule out the explanation as cyclotron radiation which has been considered by Field (1961).

The tilt of the magnetic axis can also explain some of the variations of the observed intensity with time (McClain *et al.*, 1962), and Morris and Berge (1962) from their observations suggested that the received radiation is more intense when the radiation belts appear edge on. This beaming of the synchrotron radiation has now been observed by Gary (in press) and J. A. Roberts and Komesaroff at near 20 cm.

M. S. Roberts and Huguenin (1962) present evidence for a correlation of the polarized decimeter radiation with solar activity and attempt to explain the polarized decimeter radiation as synchrotron radiation, and the unpolarized, excess decimeter radiation as thermal emission from an ionosphere, or non-thermal radiation from an inner radiation belt.

The spectrum of the steady non-thermal radiation of Jupiter has recently been extended through measurements by Barber and Moule (1963) at 49 cm, and Gower (1963) at 1·78 meters which show the flux density to be nearly independent of wavelength between 10 and 178 cm.

The demonstration of radiation belts of Jupiter by their decimeter radiation provides a link with the strong bursts of radiation at decameter wavelengths. The tendency for the decameter radiation to occur when preferred longitude ranges on Jupiter face the Earth is well confirmed over a long time period (Burke, 1961; Carr *et al.*, 1961; Douglas, 1962; Douglas and H. J. Smith, 1962, 1963*a*; Gallet, 1961; A. G. Smith *et al.*, 1962), and Burke *et al.* (1962) have proposed a new longitude system based on the rotation period of the decameter sources. However, Douglas and H. J. Smith (1963*b*) have recently presented evidence that the period of rotation of the decameter source regions has gradually lengthened by about 0·8 seconds in the two year interval 1960–1962.

It is likely that the decameter radiation which is elliptically polarized (Barrow, 1962*a*, *b*; Carr *et al.*, 1961; Douglas and H. J. Smith, 1962; Dowden, 1963; Sherrill and Castles, 1963) is connected with the magnetic field of Jupiter, and Morris and Berge (1962) have pointed out the near coincidence of the longitude of the principal source of decameter activity and the magnetic pole deduced from the polarization of the decimeter radiation.

It was previously thought that the decameter radiation was limited to a narrow range of frequencies around 18 Mc/s, but recent observations indicate that the occurrence of noise storms does not fall off rapidly at the lower frequencies and occasional bursts have been detected at frequencies as high as 38 Mc/s (Barrow, 1963; Carr *et al.*, 1961; Ellis, 1962*a*; A. G. Smith, 1961; A. G. Smith *et al.*, 1962; Warwick, 1963*a*).

The swept frequency observations of Warwick (1961, 1963*a*, *c*) show that the bandwidth of a noise storm is narrow and that the band drifts in frequency with time with a negative drift for the main source and a positive drift for the secondary source, and that the dynamic spectra show reproducible features from one year to the next.

Simultaneous observations, made at widely separated points, indicate that the radiation has a burstlike nature which is sometimes modified by passage through the ionosphere (Carr *et al.*, 1961; Douglas and H. J. Smith, 1961, 1962; Gallet, 1961; A. G. Smith *et al.*, 1962; Warwick, 1963*a*).

Inverse correlation of the decameter radiation with solar activity indices seem established (A. G. Smith *et al.*, 1962; Douglas and H. J. Smith, 1963*a*), but correlations with individual events do not seem conclusive (Barrow, 1962; Carr *et al.*, 1961; Warwick, 1963*a*).

Several mechanisms have been proposed recently to explain the decameter radiation. Warwick (1961, 1963 *a*,*b*) has proposed that many of the observed characteristics of the radiation can be accounted for by Cerenkov radiation produced by high energy electrons precipitated into the auroral zones and reflected toward the Earth under certain geometrical circumstances requiring that the magnetic dipole be offset drastically. Strom and Strom (1962) suggest that the decameter bursts are really due to focussing by an ionosphere of Jupiter of the radiation of weak radio sources occulted by Jupiter, but serious objections to this idea have been raised by Jelley (1963), and by A. G. Smith *et al.* (1963). Field (1962) proposes that the radiation is amplified by interaction with fast trapped electrons. Amplification by maser-like action in the ionosphere or magnetosphere of Jupiter has been proposed by Landovitz and Marshall (1962), and by Hirshfield and Befeki (1963). Ellis (1962*b*, 1963) and Ellis and McCulloch (1963) propose that many of the observed characteristics of the decimeter radiation can be accounted for by cyclotron radiation from bunches of electrons trapped in the magnetic field of Jupiter provided that an extensive ionized exosphere exists.

Saturn

Drake (1962*c*) recently observed Saturn at 10 cm and found a blackbody disk temperature of 196°K, about twice that found at 3·4 cm and at infra-red, which he interpreted as possibly indicating non-thermal radiation. Later, Rose *et al.* (1963*b*) observed Saturn at 9·4 cm using an antenna with a variable plane of polarization, and they found blackbody disk temperatures of 140°K with the electric vector oriented parallel to the equator of Saturn and 213°K for the orthogonal polarization. This surprising result suggests that the 9·4 cm radiation is strongly linearly polarized with the plane of polarization aligned with the rotational axis of Saturn. However, very recent observations by Cooper, Beard, and Davies suggest that the polarization of the 10 cm radiation is not greater than 6%.

Radar Observations of the Planets and Moon

There has been much activity in the radar observations of the planets and Moon over the past few years, and the use of improved techniques and higher powered equipment has made it possible to greatly improve the previous observations of Venus and the Moon and to extend the observations to Mercury and Mars.

Mercury

Radar echoes from Mercury were detected using a wavelength of 43 cm by Kotelnikov (1962) who found a reflectivity of approximately 6%, similar to that of the Moon, although the signals were too weak for accurate measurement.

Venus

Observations using a radar at 68 cm wavelength (Pettengill *et al.*, 1962; W. B. Smith, 1963) gave a value for the astronomical unit of 149 597 850 ± 400 km. A distinct surface smoother than that of the Moon was inferred from the range dispersion of the signals and the echo intensity was consistent with a hard rocky surface with a reflectivity of 11% corresponding to a dielectric constant of 4·1. The frequency broadening of the signal was compatible with a rotation period of 225 (+275, −110) days which suggests slow, possibly retrograde rotation.

Radar measurements at a wavelength of 12·5 cm (Muhleman *et al.*, 1962; Victor and Stevens, 1963) gave a value for the astronomical unit of 149 598 500 ± 500 km, a value for the radar cross section of 11 ± 2% of geometric, and indicate small scale surface roughness similar to the Moon and a rotation rate of 200 to 400 days. More recent measurements (Goldstein and Carpenter, 1963) indicate that Venus may rotate in the retrograde sense with a period of approximately 240 days.

Measurements at 43 cm wavelength (Kotelnikov *et al.*, 1962) gave a value for the astronomical unit of 149 599 300 ± 570 km. The spectra of the returned signal from Venus showed in addition to the narrow band echo a wide band component which was not found by the other groups of observers. If the broad band component is interpreted as due to Venus, a rotation period of 10 days is implied, while if interpreted as not due to Venus a rotation period greater than 100 days is consistent with the measurements.

A radar measurement at 74 cm was reported by Thomson *et al.* (1961) which gave a value for the solar parallax of 8·7943 ± 0·0003 sec of arc. Another measurement giving a value for the astronomical unit of 149 596 000 ± 200 km was reported by Maron *et al.* (1961).

Priester *et al.* (1962) found a correlation between the systematic variations in the 68 cm radar distance to Venus and the intensity of the 20 cm radiation from the Sun, a good indicator of solar activity, in the opposite sense to explain by increased electron density in the path, and they advance a possible explanation based on a variable reflecting level in the ionosphere of Venus. Muhleman (1963) also notes this correlation using the 10·7 cm solar flux and interprets it in terms of either a sweeping out of electrons or an increase of recombinations due to increased solar activity. Muhleman (1963) discusses the results of the 12·5 and 68 cm radar measurements and concludes that the effects of plasma phenomena are small, and that the echo power indicates an average dielectric constant of the surface between 3 and 7, interpreted as evidence against large bodies of water on Venus.

Moon

The mean radar distance to the Moon has been refined by Yaplee *et al.* (1963) and the final value is 384 400·2 km ± 1·1 km. The accuracy of this value is limited primarily by the uncertainties of the lunar radius and the velocity of radio wave propagation at 10·4 cm wavelength.

The scattering properties of the Moon at 10 cm wavelength were investigated by Hughes (1961) who found the Moon to scatter as a rough surface with an angular scattering law consistent with that found at longer wavelengths.

Pettengill and Henry (1962) using high transmitter power find diffuse reflection over the surface of the Moon which is very much weaker than the sharp specular component with an angular scattering law between the Lommel-Seeliger and the Lambert Laws. The reflectivity at this wavelength is 6·4% which corresponds to a dielectric constant of 2·8.

Evans and Pettengill (1963*a*) have investigated the scattering behavior of the Moon at 3·6, 68, and 784 cm, and find that at 3·6 cm, 14% of the surface has structure of the order of a wavelength, while at 68 cm the figure is only 8%. The mean surface gradient is about 1 in 11 for points spaced by 68 cm and 1 in 7 for points spaced by 3·6 cm. The best estimate of the reflection coefficient of the surface is 6% at 68 cm corresponding to a dielectric constant of 2·8. Evans and Pettengill (1963*b*) have presented a revised list of values of the radar cross section of the Moon for wavelengths from 8 mm to 7·84 meters which shows little dependence on wavelength.

Daniels (1963) has formulated a theory of radar reflection from planetary surfaces and applies it to lunar observations at 440, 151, and 38·25 Mc/s to find a value of 14° for the rms slope of the lunar surface.

Senior, Siegel, and Giraud (1962) interpret Moon radar data corrected by them to correspond to short pulse length measurements on the assumption of a quasi smooth surface for the Moon, and get a very low reflection coefficient of 5×10^{-4} and a very small dielectric constant of 1·1 which are not in agreement with the results of other investigators.

Mars

Goldstein and Gillmore (1963) observed Mars over a month near a favorable opposition with a radar at 12·5 cm, and report that Mars is a somewhat smoother reflector than Venus, with an average reflectance of 3·2% and find that differences in reflectance between different areas could be detected, for example, Syrtis Major appears light to radar but dark to visual observations.

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B. (APPENDIX) REPORT OF WORK DONE IN U.S.S.R. ON RADIO-ASTRONOMICAL STUDY OF MOON AND PLANETS

(prepared by V. V. Bazykin)

The radio-astronomical studies of the Moon and of the Solar System Planets were carried out at P. N. Lebedev Physical Institute, Academy of Sciences, U.S.S.R., Main Astronomical Observatory, Academy of Sciences, U.S.S.R., Institute of Terrestrial Magnetism, Ionosphere and Propagation of Radiowaves, Academy of Sciences, U.S.S.R., Institute of Applied Geophysics, Academy of Sciences, U.S.S.R., as well as at Gorky Radio Physics Research Institute, Ministry of Higher and Secondary Special Education, R.S.F.S.R.

1. *Study of Moon Radio-emission and Nature of its Surface*

From 1960 to 1963 Radio Physics Research Institute as well as Physical Institute, U.S.S.R., and Main Astronomical Observatory, Academy of Sciences, U.S.S.R., measured the Moon radio-emission in the millimeter, centimeter and decimeter frequency range. The analysis of the results gives the possibility to obtain new data on the physical nature of Moon surface layer.

A method of accurate measurement of radio emission by Moon and other sources (error within 1 to 2 per cent) has been worked out and successfully employed. The method is based on the comparison of the emission measured with the thermal radiation of an absolutely black disk of known angular dimensions (the 'artificial Moon' method, (**1**)). With the use of this method precision measurements of integrated radio emission by Moon were carried out on many wavelengths in the millimeter, centimeter and decimeter range (0·4, 1·62, 3·2, 10, 35, 36 and 50 cm) (**2, 3, 4, 5, 6**).

Besides, the Pamir alpine expedition at 3860 m, in addition to measurements on wavelength 0·4 cm has measured the radio-emission by the Moon on wavelengths 0·13 and 0.18 cm (**7, 8**). Together with the measurements made previously on wavelength 0·4 cm (**9**) and with those on wavelength 3·2 cm, which helped to discover the phase dependence (**10**), these new data were analyzed in a number of studies (**11, 12, 13, 14, 15**). As a result, the two-layer model of Moon surface was proved to be false and quasi-homogeneity of the surface layer represented by a hard foamy matter was established, first, to a depth of 1 m, and later, to a depth of 20 m. Among other values determined were the average spherical emissive capacity of Moon surface (0·96) and the average dielectric constant of Moon rock ($\epsilon = 1{\cdot}5$). The analysis of the precision data on the Moon effective temperature allows to determine the density of its rock ($\rho = 0{\cdot}5$ gr/cm^3) and the parameter $(k\rho c)^{-1/2} = 350 \pm 75$.

The theoretical study and the analysis of the precision measurements resulted in the conclusion, which looks very probable, that there exists a considerable thermal flux coming from the Moon interior (**16, 17**). The thermal flux density was found to be $1{\cdot}3 \times 10^{-6}$ cal/cm^2 sec, the specific thermal generation per gram of Moon matter $= 2.2 \times 10^{-7}$ cal/year which is five to six times higher than the specific thermal generation of chondrites and that of the Earth. New methods for direct measurements of the dielectric constant of the Moon rock were proposed (**18, 19**).

A series of measurements of brightness temperature distribution over the Moon disk were done with a 22-metre telescope on a number of wavelengths (0·8, 2, 3·2 cm). According to the measurements, 'radio images' of the Moon were constructed for the first time. The images show a systematic decrease of the brightness temperature on the limb and towards the poles, as well as a shift of maximum radio brightness area on the Moon disk. The analysis of the Moon 'radio images' allows to establish a law of the distribution of temperatures on Moon surface with the latitude ($\sqrt{\cos\psi}$), to determine independently the effective dielectric constant ($\epsilon = 1{\cdot}5$), and to derive the effective density of the material (near $\rho = 0{\cdot}5$). The analysis of the temperature phase dependence obtained supported the surface one-layer model theory (**20, 21, 22**). Detailed measurements of the brightness temperature distribution in the equatorial and the meridional areas made on wavelengths 0·8 cm and 0·4 cm (the latter in co-operation with Radio Physics Research Institute) revealed some difference in the radio emission intensity by the seas and the mainland areas of the Moon disk (**23, 24**).

Using the large Pulkovo radio telescope, one-dimension distribution of radio brightness over the Moon disk was obtained on 2·3 cm and an estimate made of the variable component amplitude in the disk centre (± 13·5°K). On wavelengths 3·2 and 6·4 cm, linear polarization of Moon proper emission was detected and studied and data on the dielectric constant ($\epsilon = 1{\cdot}6 \pm 0{\cdot}1$) and on the nature of Moon surface emissivity (for the frequencies mentioned) obtained (emission cone ± 20°) (**25, 26, 27**).

2. *Study of Venus Radio-emission*

Venus emission was measured close to the time of its inferior conjunction in 1959 on wavelength 0·8 cm (**28**); in 1961, similar measurements were taken again in wavelengths 0·4, 0·8, 3·3 and 9·6 cm (**29, 30**). The temperature of the planet dark side averaged on the observed disk was found to be close to 400°K. It was shown for the first time that the Venus brightness temperature varies with the phase. The average temperature for the observation period near the dichotomia, measured on wavelength 3·3 cm, was equal to 542°K with a tendency to increase with the increase of the illuminated portion of the disk. On wavelength 9·6 cm the averaged brightness temperature for the observation period was close to 690°K. The difference in the temperature measured at millimeter wavelength and centimeter wavelength was explained by absorption of the surface radiation in the planet colder atmosphere. Some people believe that a Venus ionosphere accounts for the higher brightness temperature near 10 cm. The presence of the brightness temperature phase effect on wavelengths 0·4 cm and 0·8 cm is an evidence of the planet slow rotation and of the existence of mainland areas on its surface. Possible shifting of brightness temperature minimum after the inferior conjunction in the direction of the east elongations suggests a direct rotation (**31**).

The spectrum of Venus emission was measured in the centimeter range, close to the time of the inferior conjunction (**32**). Water content in the Venus atmosphere has been estimated (**33**) and the problem of its ionospheric model studied. The parameters of the ionospheric model that would fit the radioastronomical and radar data have also been determined and the possibility of detecting an emitting layer in the Venus low atmosphere demonstrated (**34**).

Venus observations between August and November 1962 on 3·02 cm with resolving power of about 1′ allow an estimate of the upper limit of the emission by the radiation zones (less than 6 per cent) and of the boundaries of the emission area ($< 1{\cdot}7\,R_{♀}$). The nature of the brightness distribution suggests some darkening at the disk edges on this wavelength. The absence of displacement of the radio emission center allows to determine the upper limit of the variable component of the Venus radio-temperature (less than 170°K).

On the basic of the study of recombination and ionization processes, similar to those observed in the Earth atmosphere, a model of the Venus ionosphere has been constructed (**35**) and the possibility of high electron concentrations in the Venus high atmosphere considered (**36**) since such concentrations are necessary to support the 'ionospheric' theory of its radio emission.

3. *Study of Jupiter Radio-emission*

From measurements of Jupiter radio-emission on 3·3 cm it was found that its average brightness temperature is about 193°K (**29**). The radio-emission of Jupiter on 8 mm (**31**) was detected for the first time.

Among other work performed were the calculations of the polarization, the intensity and the positional angle of the synchrotron emission in the dipole magnetic field (37). The Stokes parameters of synchrotron radio-emission in the dipolar magnetic field were calculated. It was shown that the intensity, the polarization degree and the position angle are functions of the energy spectrum index of the electrons and of their angular distribution. The problem of detecting the planetary radiation zones with the use of radio-astronomical methods was also considered.

4. *Radar Study of Planets*

The value of the Astronomical Unit determined during the radar experiment on Venus in 1961 has been confirmed by echoes on Mercury and some data on the surface reflexion coefficient of Mercury have been obtained (39).

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C. RADIO-EMISSION FROM THE GALAXY

(prepared by C. Westerhout)

Polarization

Undoubtedly the most outstanding development in the last three years is the discovery of the background emission and the Faraday rotation of the polarized component of the radiation from discrete sources. Measurements of the polarization of the galactic background emission were started in 1957 and seemed to be partially successful, but so uncertain that not much weight was attached to them. Since late 1960, 408 Mc/s measurements of the polarization provided full sky surveys down to about 0·5 °K in the linearly polarized components (**7, 46, 53**). Recently, the first series of observations at 610 Mc/s were obtained (**1a, 35**). The degree of polarization in most parts of the sky is a few per cent or less, whereas we expect 50% or more if the interstellar Faraday rotation is small and the magnetic fields are aligned. In one region of high polarization (up to 10%) there is some correlation with the polarization of starlight, the Faraday rotation seems to be rather small, and there are indications that the line of sight is at right angles to the direction of the magnetic field (**35**). It seems likely that the small degree of polarization is due to the fact that the galactic magnetic fields are rather tangled, particularly in the galactic halo. Higher resolving powers and observations at several different frequencies are planned in the near future. The linearly polarized component of the radiation from discrete sources, both galactic and extragalactic, suffers little Faraday rotation at high galactic latitudes, much at lower latitudes, indicating that the product of electron density and magnetic field strength NH increases towards the galactic plane, given the same path lengths (**1a**).

Unpolarized Continuum

One of the most important data needed for the interpretation of the galactic background emission is its spectrum. Accurate measurements of the absolute intensity up to 400 Mc/s have been made by the Cambridge group (**43, 47, 49**). At this frequency, where the background intensity goes down to 20°K or less, background radiation in sidelobes makes a determination of the zero level very difficult. We may hope that with great effort and specialized antennas, eventually the background intensity down to 21 cm might be determined; it is only a few degrees K at that wavelength. The spectral index between 38 and 400 Mc/s is in the neighbourhood of 0·5 or 0·6. At the low-frequency end, measurements of the background emission, averaged over a large part of the visible sky, were made with ground-based (**12, 21**) and rocket-borne receivers (Haddock), down to 1·25 Mc/s. They indicate that the spectral index decreases to zero at the lower frequencies and possibly becomes negative at the low-frequency end. It may be shown that at least part of this is due to absorption by the ionized interstellar medium.

Several high-resolution maps have been produced recently such as those at 19 Mc/s (beamwidth 1·4 × 1·4 square degrees) (**26, 45**), at 38 Mc/s (1 × 1) (**23**), at 178 Mc/s (4·5 × 0·2) (**48**), at 408 Mc/s (0·8 × 0·8) (**28**), at 960 Mc/s (0·9 × 0·9) (**55, 56**), at 1400 Mc/s (0·9 × 0·9) (**31**) for the southern hemisphere, completing the earlier northern hemisphere map, and 2700 Mc/s (0·3 × 0·4) (**3**). The mapping with high resolution is now really underway, and many details become visible. The question of whether the spiral arms are really visible as humps in the distribution of the non-thermal and the thermal emission along the plane, seems to be answered in the affirmative. The interpretation is less certain: is the thermal, and for that matter the non-thermal background also, entirely broken up into sources concentrated along the arms, or is there a continuous source medium of ionized hydrogen and non-thermal emitters as well (**1b, 11**)? The situation of the continuous emission from the galactic centre does not seem to be cleared up yet. There are clearly several bright sources at or very close to the centre, but not enough data with high resolution at various frequencies are available to accurately determine the spectrum of the various components (**1c, 30, 41**). There is clearly a mixture of ionized gas and non-thermal emitters.

The thermal sources in the Galaxy are now well understood, in particular the bright emission nebulae (see Commission 34). Recent high-resolution observations at 21 and 10 cm in Australia show that many of the unidentified thermal and non-thermal extended sources along the galactic plane are breaking up into several smaller sources (**1d**). There are now about 15 super-nova remnants known and both their spectra and their structure have been studied in detail (**18**). Most apparently are in the form of shells or parts of shells (**1e, 29**).

21-*cm Line*

An almost complete low resolution ($2^\circ{\cdot}5$) survey of the whole sky is now available (**13, 32, 33**). The velocity pattern in the solar neighbourhood derived from this shows that most of the hydrogen at higher galactic latitudes is moving towards the plane (**19, 33**). The galactic rotation curve in the southern hemisphere has been compared with the older northern hemisphere curve and shows lower velocities (**25**). This was tentatively explained as due to radial motion of the local standard of rest, and a velocity model was proposed which included an expansion term going as $1/R^2$. Recent observations have shown this latter assumption to be invalid (**1f, 6**): general expansion, if present at all, does not seem to be larger than 5 to 10 km/sec throughout the Galaxy. Further work on the central regions of the Galaxy indicates that the very central part can be described as a rapidly rotating disk (solid-body rotation) with a diameter of 600 pc, and a ring with a diameter of 1200 pc (**1g**; Oort, in **2, 44**). The 3-kpc arm is shown to break up into various parts at greater angular distances from the centre (**1h**). Further away from the centre, between 3 and 6 kpc, it appears that the spiral structure might be described as a condensation in a rather smooth layer of neutral hydrogen (Oort in **2**). The far outer arm, at about $R = 12$ kpc, is shown to extend up to several kpc above the galactic plane (Blaauw, in **2**). In several regions both near the Perseus arm and in the more central regions of the Galaxy neutral hydrogen concentrations have been found at many hundreds of parsecs from the galactic plane (Blaauw, in **2**). Recently, hydrogen clouds at high galactic latitudes with radial velocities larger than 100 km/sec have been found (**36**). It seems likely that they are situated in the galactic halo. Investigations of hydrogen in various restricted areas of sky are underway. These include studies of associations, such as Orion, Sco II, Per I (Groningen), I and II Mon (**15**, Leiden); IC 443, the anticentre region (Penticton), and many others. These studies lead to dynamical models of the hydrogen in some of the associations, and to detailed density distributions. The anticentre observations are aimed at a study of the large-scale motions beyond the Sun (**20**). Individual hydrogen clouds have been studied by resolving the line profiles into Gaussian components (**50**, Takakubo, **54**). The observations may be reproduced by uniform spherical clouds with 3 pc radius, a density of 14 cm^{-3}, a number density in the galactic plane of 3×10^5 clouds per kpc, and a mass of 55 $M_\odot$. Reconsideration of the original Leiden catalogue of line profiles in combination with new observations, has led van Woerden to calculate a total neutral hydrogen mass of between 3 and 4×10^9 $M_\odot$. Changing $R_\odot$ from 8·2 to 10 kpc will increase the hydrogen mass to 5 to 7×10^9 $M_\odot$. The largest amount of hydrogen is found in the Perseus arm, enhancing the similarity with the Andromeda nebula. Several studies of the 21-cm line absorption have been made or are in progress, confirming the earlier conclusions that these absorption lines are, in general, very much narrower than the emission lines (**10**). Of several attempts to measure the Zeeman splitting in the 21-cm line, only one has yielded positive results, indicating a field of the order of 2×10^{-5} gauss in one cloud, and a general field of the order of 5×10^{-6} gauss (**11**). The upper limits of the investigations giving negative results are about 5×10^{-6} gauss (**51**).

Theoretical

A number of theoretical papers on the non-thermal emission from the Galaxy discuss the emission mechanism (**14, 42**), the distribution of the magnetic field (**57**) and the galactic 'spur' (**37, 38**). A review of the theoretical work on magnetic fields and spiral structure is given in (**52**). The expansion of hydrogen near the galactic centre and the existence of a galactic halo suggest phenomena similar to those in the very bright radio galaxies, but on a much smaller scale (**8**). The thermal emission mechanism is now well understood and formulated in various papers (for example **39**). Measurement of the gravitational redshift in the 21-cm line due to the mass of the Galaxy was shown to be impossible due to the large random and systematic motions of the hydrogen (**24, 27**).

Attempts at measuring the deuterium and OH lines were unsuccessful. Several other lines, notably those of H_2^+, are discussed (**9, 22, 34**).

Galactic Pole and Scale of the Galaxy

The evidence on which the choice of a new galactic co-ordinate system was based (21-cm line, radio continuum, galactic centre, and optical determinations) was published (**4, 5, 16, 17, 40**). The new galactic co-ordinates are now being used in most recent publications. For the reductions of 21-cm line data, a value for the distance Sun-centre of 8·2 kpc was used up until 1963. It is recommended that, in view of present evidence, the values $R_0 = 10$ kpc, $\theta_0 = 250$ km sec^{-1}, $A = 15$ km sec^{-1} kpc^{-1} and $B = -10$ km sec^{-1} kpc^{-1} be used for 21-cm line work (**58**).

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C. (APPENDIX) REPORT OF WORK DONE IN U.S.S.R. ABOUT GALACTIC AND EXTRAGALACTIC RADIO-EMISSION

(prepared by V. V. Bazykin)

Radio-astronomical investigations of Galaxy and Metagalaxy were carried out by the Institute of Radio Physics and Electronics, Academy of Sciences of Armenian SSR; Institute of Radio Physics and Electronics, Academy of Sciences of Ukrainian SSR; Radio Physics Research Institute, Ministry of Higher and Secondary Special Education; Sternberg Astronomical Institute; Lebedev Physical Institute, Academy of Sciences of U.S.S.R. and Main Astronomical Observatory, Academy of Sciences U.S.S.R. The purpose of the investigation was to measure the absolute fluxes of sources Cassiopeia-A, Virgo-A, Cygnus-A and Taurus-A, in the frequency range 12 to 40 Mc/s. It was shown that below 20 to 25 Mc/s the intensity of all the sources (with exception of Taurus-A) decreases (**1–5**).

With the use of the artificial Moon method fluxes from discrete source Cassiopeia-A on 3·2 and 9·8 cm were calibrated. The values obtained are respectively:
$(5{\cdot}2 \pm 0{\cdot}15) \times 10^{-24}$ W m^{-2} hz^{-1}, $(14{\cdot}6 \pm 0{\cdot}5) \times 10^{-24}$ W m^{-2} hz^{-1} (**6**).

The spectral index measured $\alpha = -0{\cdot}87$ which differs from the one obtained before for the entire frequency range ($\alpha = -0{\cdot}8$).

Taurus and Orion nebulae fluxes were calibrated on $\lambda = 3{\cdot}2$ cm, the fluxes measured are $(5{\cdot}6 \pm 0{\cdot}3) \times 10^{-24}$ W m^{-2} hz^{-1} and $(4{\cdot}5 \pm 0{\cdot}3) \times 10^{-24}$ W m^{-2} hz^{-1} for the central part of Orion nebula, diameter 6′ (**7**).

On wavelength 3·2 and 10·25 cm, measurements were done again to check the data obtained in 1961 for the centimetre wavelengths during the calibration of Cassiopeia-A flux, and to draw out the effect of the diameter on the precision of flux calibration using the artificial Moon method. The fluxes measured are:
$(5{\cdot}14 \pm 0{\cdot}30) \times 10^{-24}$ W m^{-2}hz^{-1} and $(15{\cdot}26 \pm 0{\cdot}30) \times 10^{-24}$ W m^{-2}hz^{-1} respectively, which support the spectral index of Cassiopeia-A $\alpha = -0{\cdot}87$ obtained before.

Cygnus-A flux, calibrated on $\lambda = 10{\cdot}26$ cm, is $(7{\cdot}5 \pm 0{\cdot}5) \times 10^{-24}$ W m^{-2}hz^{-1} (**9**). The spectral indexes calculated with the use of these data are: $\alpha = -0{\cdot}81$ for Cassiopeia-A, $\alpha = -0{\cdot}24$ for Taurus-A and $\alpha = -0{\cdot}85$ for Cygnus-A.

Several diffusion nebulae were observed and the data obtained were theoretically interpreted (**11, 12**).

Paper (**13**) contains theoretical grounds for a secular variation in radio emission for young envelopes of super-novae; the paper shows, in particular, that a good accuracy in observation would allow the detection of the effect of this variation in the flux of Cassiopeia-A. Some years later this effect was actually observed by Soviet, American and British scientists.

Papers (**14, 15**), based on the studies of Cygnus-A radio galaxy spectrum, provide grounds for the conclusion that the age of this source is $(0{\cdot}1 \text{ to } 1) \times 10^{6}$ years and that the sources of radio emission are moving off from their native galaxy near the light velocity.

Papers (**16, 17**) show dependence of spectral index of radio galaxies and of super-nova envelopes on their absolute radio magnitudes and contain a possible theoretical interpretation of this effect.

Papers (**18–22**) are devoted to the theory of discrete galactic and extragalactic sources of synchrotron emission.

Papers (**22–24**) contain information on the observations of the Galaxy periphery in the 21-cm line. A considerable thickening of the Galaxy gas disk has been detected in the periphery. A model of the gas disk for the whole Galaxy has been constructed, the curvature and thickening of the gas disk resulting from its interaction with the intergalactic medium were theoretically interpreted.

Paper (**25**) contains information on observations in the 21-cm line of association Tau T2.

Paper (**26**) describes an attempt to detect emission in the 21-cm line from two Galaxy clusters; the upper estimate of the hydrogen mass in the clusters has been made.

Paper (**18**) is devoted to a model of neutral hydrogen distribution within the Galaxy with a clearly expressed spiral structure; the model was constructed on the basis of introduction of systematic K-effect in the Galaxy rotation laws and on the observations in the 21-cm line.

The boundary limit of the longitudinal component of the regular magnetic field in the plane of Galaxy in the direction of the anticentre was assessed to be $H = 0{\cdot}3 \times 10^{-7}$ gauss (**28**).

On the basis of observations on the 21-cm wavelength the spatial distribution of neutral hydrogen in the central part of the Cygnus constellation has been obtained within the limits in α: $20^{h}\ 04^{m}$-$20^{h}\ 44^{m}$ and in δ: $38^{\circ}-46^{\circ}$.

It has been found that the Cygnus-X radio source located there lies inside our nearest galactic spiral arm and comprises at least two parts located at different distances (**29-31**).

Co-ordinates, angular dimensions, radio flux density of 80 discrete sources have been measured on 10 cm. The measurements allowed to obtain independent data on electron density, mass and dimensions of the diffusion nebulae (**32, 33**).

Polarization of the Crab nebula radio-emission has been measured at 20 cm: the amount of polarization is $\rho = 0{\cdot}5\%$ in position angle $\psi = 82^{\circ}$ (**28**).

Angular dimensions and radio-emission flux densities of discrete sources Cassiopeia-A, Cygnus-A, Omega and Orion on 3·2 cm have been measured.

Theoretical studies of Galaxy and Metagalaxy radio-emission were carried out in conjunction with the problem of mutual concentration of cosmic rays, and in particular, of their electron component in the Metagalaxy space. As results from the analysis, the conclusion that the cosmic rays concentration in the Metagalaxy space is considerably lower than in Galaxy appears now as the most probable one (**47**).

The problem of general Galaxy radio-emission spectrum was considered assuming that the emitting electrons are due to nuclear collisions in the interstellar medium. The energy spectrum of the secondary electrons and positrons, the radio-emission spectrum as observed from the Earth with due allowance for synchrotron losses and Compton losses, as well as the diffusion, are calculated. It has been shown that one may account for a considerable reduction of radio-emission spectral index at low frequencies and for the observed intensity.

The calculated and observed data are compared and are in good agreement. However, the final conclusion as to the nature of radio-emitting electrons in Galaxy will become possible only after more precise observations (**48**).

The investigations of the central parts of the galaxy was continued on wavelengths 3·2, 8·7, 9·4, 21 and 33 cm (**34, 35, 36, 37, 38, 39, 40**). On wavelength 21 cm Sagittarius-A source components were separated. The central bright source is not purely thermal, while the spectra of parts of the Drake ring are different (**39, 40, 41**). An attempt to interpret the phenomena in the central part of Galaxy was undertaken (**34**).

Radio brightness distribution of Orion nebula (NGC1976), Omega (NGC6618), NGC6523, NGC6514 was obtained. Detailed comparisons to the optical data were done and models of Orion and Omega sources constructed (**42, 43**). The distribution of radio brightness in Crab nebula obtained on wavelength 3·2 and 6·4 cm reveals strict boundaries in the radio-emission source which coincide with the filamentary shell of the nebula. Distribution of radio brightness on wavelength 21 cm has been obtained (**45**) and distribution of Crab nebula polarized radio-emission on wavelengths 3·2 and 6·4 cm studied. It was found that the polarized radio-emission zone is much smaller than the non-polarized one while the polarization percentage on 3·2 cm is close to the optical one (**44, 46**). Right ascensions of radio sources Cygnus-A, Sagittarius-A (the central part), Omega, Orion, Crab nebula were measured with an accuracy of ± 1′ and their integrated fluxes were determined on wavelengths 3·2 and 21 cm (**38**).

21-cm line absorption on source Sagittarius-A was studied on two frequencies of line profile ($V = 0$ and $V = -53$ km/sec). The neutral hydrogen from the 3 kpc arm does not absorb the emission of the south-western part of Drake ring (**39, 40, 41**).

Distribution of brightness for Cygnus-A was obtained on wavelength 3·2 cm. The distribution reveals two sources with dimensions 25″ and 40″ and relative intensity of 1:1·2. The distance between them is 102″; the emission between the sources is practically absent. A model of the source based on the comparison with the observations by other observers is proposed (**38**).

It has been found that over 80 per cent of emission on wavelength 8·7 cm in radio galaxy Virgo-A originates in a point source whose diameter is less than 1′. The co-ordinates carefully measured reveal a displacement of the source $3^s \pm 1^s$ in the direction of escape from the centre of Galaxy (**35**). Distribution of radio brightness on wavelength 21 cm was obtained (**45**). Observations of radio sources Sagittarius-A and Omega (NGC6618) on wavelength 32·5 cm have been completed. It was shown that the Sagittarius-A contains three components. The spectrum of component 1 is either a thermal one or a combination of a thermal spectrum with a non-thermal one. Component 2 is symmetrical relative to component 1 and is connected with the galactic nucleus. Component 3 is identified with gas nebulae located between them and the galactic centre (**49**).

Identification of radio sources with galaxies in clusters was carried out. On the basis of the identification, a dependence of the binary galaxy radio emission power on the relative distance between the components of the galaxy was assessed (**50**).

In co-operation with the British astronomers the neutral hydrogen was studied on wavelength 21 cm in five galactic clusters: Pleiades, NGC1502, Trapezium, Orion, NGC2244 and NGC6910 (**51**).

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D. RADIOASTRONOMICAL INSTRUMENTS

(prepared by R. N. Bracewell)

New radio telescopes in several categories have come into use, new receivers have been developed, and techniques of data processing have developed further.

Reflectors

A large altazimuth reflector of 64-m aperture has come into operation in Australia (**1**). In the U.S.A., a meridian mounted reflector of 91 m aperture (**2**), and the fixed parabolic cylinder of 121 × 183 m aperture (**3**) have come into use, and the 305 m fixed spherical reflector has undergone preliminary tests (**4**). Portions of the fixed-tiltable reflectors of Ohio (**5, 6**) and Nançay (**7**) have been used for observations. A fixed spherical reflector 24 m in diameter for operation at 21 cm has been constructed at Mitaka. Construction has begun on a 46 m steerable reflector for 3 cm operation at Algonquin Park.

Interferometers

An interferometer comprising two 27-m reflectors has been constructed in California (**8**).

In the United Kingdom new instruments include a pair of mobile, steerable 25-m reflectors (**9**), a phase-coherent interferometer using microwave links to operate over baselines up to 120 km at a wavelength of 1·89 m (62 100 λ) (**10, 11, 12**), and three 18 m reflectors on rails for generating an equivalent collecting area of 40 000 m^2 by two-dimensional synthesis (**13**). The large meridian interferometers at 7·9 m (**14**) and 1·7 m (**15**) have continued in use for sky surveys, and elements of the latter have been used to map a polar cap by using a computer to reconstruct the brightness distribution automatically from data observed over a range of position angles (**16**).

Compound Interferometers

At Toyokawa, a compound interferometer at 3·2 cm with a resolution of 0·7 minutes of arc was put into operation for measuring the intensity and polarization of solar emission (**17**), and a similar system was assembled at Stanford at 9 cm for solar and also non-solar studies (**18**). A multi-element array with a phase-switched end-aerial was assembled at Fleurs to give a beamwidth of 1·5 minutes of arc (**19**). A 210-m array of 32 reflectors combined with a 1-km array of 6 reflectors on polar mounts is under construction at Algonquin Park for high-resolution solar studies.

Crosses

The 1-km cross at Serpukhov (**20**) is nearing completion. Construction has started on the 1·6-km cross for Sydney University (**21**); the original Christiansen solar crossed grating-interferometer (**22**) is being converted to a pair of north-south and east-west compound interferometers by the addition of two 13-m reflectors to each arm; and a cross with a 1 degree beam at 10 m wavelength is being constructed from the original Shain cross. The 1-km cross in Italy is under construction (**23**). A solar-mapping system, related to the cross, using 100 13-m antennas arranged in a ring 3 km in diameter is under construction (**24**). The 3-minute-of-arc cross at Stanford (**25**) now automatically types out the daily survey of the Sun's disk in a form suitable for publication.

Solar System Radars

Special instruments constructed for radar observations of the solar system, especially of the solar corona, include a 305-m square of 1800 dipoles in Peru (**26**), a 31 × 533 - m array of 1024 dipoles in Texas (**27**), and an array of 48 tiltable logperiodic antennas in California (**28**). In addition, various reflectors (**29, 30, 31**) have been applied to radar studies of the Moon, Mercury, Venus and Mars.

Data Processing

Digital computers have been used to process observational data recorded on punched tape, magnetic tape or punched cards (**32, 15**) and most large installations now being planned depend on automatic processing of observational data. Pictorial presentation is also a feature of several display systems. Processing within the antenna and receiver for the production of multiple beams, multiple channels, or other properties is also important (**33, 34, 35, 36**), and in many cases could in principle be handled by a computer. The design of the antenna, receiver and data analysis have become a fully integrated whole (**33**).

Large Antennas

Deliberations on the design of antennas with beamwidths of a minute of arc or less have been published (**37**), including designs (**38**) for the Benelux cross. Guiding principles have been proposed (**39**) leading to echelon and lattice arrangements within various outlines. The suppression of grating responses, which are inseparable from repetitive arrangements, has been investigated experimentally (**39**) and suppression by suitable data handling has been investigated (**40**). Polarizable line feeds, such as will be required for echelon arrangements, have been studied (**41**).

Satellite- and Rocket-borne Instruments

The Canadian satellite, Alouette, launched 1962 September 29, contains a sweep-frequency receiver with which galactic and solar noise has been observed. Rocket observations of the cosmic radiation at 1·225 and 2·0 Mc/s up to an altitude of 1700 km have been made (**42**) with a short dipole; confirmation of theoretically predicted behavior of radiation resistance in a magneto-ionic plasma (**43**) was found. Several techniques have been proposed (**44, 45**) for using the focusing properties of the ionosphere to perform spatial surveys of the radio sky at frequencies that are not observable at ground level (**46, 47, 48**). At the University of Michigan a 2–4 Mc/s receiver for solar and Jovian bursts has been developed for the Eccentric Orbit Geophysical (EOGO) satellite and a cosmic noise mapping system at 2·5 Mc/s for the Polar Orbit Geophysical (POGO) satellite. Observations of the planet Venus were made by radiometers fired into the vicinity (**49, 50**).

Spectrometers

Several solar spectrometers for the range 7–14 cm were developed (**51, 52, 53**). Reflectors with very wide-band feeds were constructed (**54, 55, 56**). An interference spectrometer (**57**) was applied to observations of Jupiter.

Hydrogen Line Polarimeters

A number of combinations of sensitive receivers with polarimeters have been developed (**58, 59, 60, 61**) at Jodrell Bank.

Low-noise Receivers

A great deal of effort has been devoted to the technology of low-noise amplification by means of traveling-wave tubes, masers, and parametric amplifiers using electron beams, varactor diodes and tunnel diodes. Extensive bibliographies (**62, 63**) have been published that deal with astronomical applications.

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D. (APPENDIX) REPORT OF WORK DONE IN U.S.S.R. IN IMPROVING EQUIPMENT AND METHODS IN USE FOR RADIOASTRONOMICAL STUDIES

(prepared by V. V. Bazykin)

In 1960–1963, work on new radio-astronomical equipment and radio-telescopes was carried out at Lebedev Physical Institute, Academy of Sciences of U.S.S.R., Main Astronomical Observatory, Academy of Sciences of U.S.S.R., Institute of Radio Physics and Electronics, Academy of Sciences of Ukr. S.S.R., Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation of Academy of Sciences, U.S.S.R.

1. *Radio Telescopes*

Work on theory and design of radio telescopes for the decimetric and metric range was carried out. The theoretical work included the study of the pattern of an electrically controlled multi-dipole antenna located near the Earth surface. Necessary formulas for calculating directive gain of such systems were obtained.

Two large radio interferometers have been built and are now in operation. The first one, for the 10 to 20 Mc/s range, comprises two 24-dipole antennae which are 332 m apart along East-West line. The antenna of the telescope can be controlled in elevation within ±90° by introducing time delays, which ensures independent position of the pattern main lobe with the frequency. The second interferometer (for 20 to 40 Mc/s) has two 128-dipole broadband antennae also controlled in elevation within ±90°. The antennae are so built that one has high resolution in right ascension and the other in declination. The separation of the centres of the antennae is about 650 m, the effective area of each antenna about 4000 m^2, the width of the lobe about 3°.

Theoretical studies of the reception pattern of electrically controlled multi-dipole antennae on the decimetric band located near the Earth surface were carried out. Formulae for calculating directive gain of such systems have been obtained (**1–6**).

Theoretical and experimental work was continued to study possibilities and properties of antenna with a reflector of varying shape, of which the large Pulkovo telescope built in 1956 is a prototype (**7, 8, 9**). The antenna of this type has marked advantages for radio astronomy since, due to its large area and broadband, it has high resolving power (both in right ascension and declination) and is free from saturation caused by weak sources (**10, 11**). Studies of electrical characteristics and spectrum of the space frequencies (**12, 13, 14**) have given the beam shape; it was shown that the vertical beam depends on the elevation, but not the effective area. The problem of turning main cross-section of the beam pattern and that of the space harmonic sensitivity were studied, and also the random error influence on the electrical characteristics of the varying shape antenna; the noise properties of the large Pulkovo radio telescope were measured (**15, 16**). The latter study supports the idea that a varying shape antenna could have an effective area 50 times larger than the tiltable paraboloid, which would give the same noise level.

Paper (**17**) is devoted to the polarization observations with a varying shape antenna, and describes methods of compensating parasitic polarization.

Further development of methods of tuning and adjusting varying shape antenna with nearby measurements of electrical characteristics were continued.

The influence of fluctuations in the atmospheric refraction on the electrical characteristics of large antenna was analyzed (**20**). It was shown that the first factor to be influenced is the effective area but not the beam shape.

The possibility of using effectively a varying shape antenna in the system of compound interferometer was studied theoretically and experimentally (**21, 22**).

A simplified varying shape antenna for studying the solar radio-emission was constructed (**23**).

The exploration of possibility of using conical scanning for radio-astronomical observations was continued (**16**).

Paper (**24**) is devoted to automatization of calculations and reduction of radio-astronomical observation data.

Papers (**25, 26**) deal with the influence of the solar heat on the telescope reflecting surface.

Papers (**27, 28**) contain new proposals for hydration of radiotelescopes.

2. *Radioastronomical Equipment*

A correlation receiver for polarization exploration of discrete sources ($T = 0{\cdot}3^\circ$K with $f = 4$ Mc/s, $t = 20$ sec) and interferometer with radio link on a 5 km base have been designed.

In 1961, a 21-cm receiver for observation of interstellar neutral hydrogen at the large Pulkovo radiotelescope was completed. The receiver uses the principle of direct comparison radiometer, its sensitivity is about 1°K, with a 19 kHz bandwidth and a 8 sec time constant (**30**).

In 1961–1963, a number of instruments were manufactured for the investigation of the Sun on the centimetre wavelength. Among them are two polarimeters for 2 and 5 cm with an accuracy of about 0·5% in the circular polarization channel and of 1% to 3% in the linear polarization channel. These polarimeters were used for observation of the solar radio bursts.

The work on the radiometer polarization theory was continued (**31**). To study the relation between the spectral density of flux and the frequency a spectrometer was constructed. The spectrometer measures three spectral components with separation of several hundreds Mc/s near 3·04 cm. Its output registers sums of all components and their differences averaged for a period of 1 sec (**32**).

Highly sensitive radiometers were designed and used for observations. One of these radiometers uses direct amplification with travelling wave tubes on 3 cm, and gives a sensitivity of 0·3°K with 1 sec time constant and the other uses direct amplification with a parametric amplifier at the input (wavelength 3 cm, sensitivity 0·07°K with 1·6 sec time constant). Some individual units of the receivers as well as theoretical problems were worked out (**31, 33, 34, 35**).

A spectrograph for observation of the solar enhanced radio emission in 45 to 90 Mc/s band has been constructed. Continuous sweeping in the receiver frequency is ensured by magnetic variometer. The spectrograph operates with wide band cophase array antenna, tiltable in both co-ordinates (**36**).

Theoretical analysis of broadband phase modulators for radiometers was carried out. The radiometers were employed in the condition of considerable monochromatic interference, characteristic of the decimetre band (**37**).

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E. RADIO-ASTRONOMICAL EXPLORATION MADE IN U.S.S.R. USING ARTIFICIAL SATELLITES AND SPATIAL ROCKETS

The Earth surface radio-astronomy is limited to the frequency band from 1 cm to 20–40 m because of the Earth atmosphere. The only chance for considerable widening of this band lies in the use of artificial Earth satellites and of space rockets for the radio astronomical exploration.

E. A. Benediktov, G. G. Getmantsev and V. L. Ginzburg showed (1) that the radio-astronomical explorations with the use of artificial satellites and rockets may give new valuable data for radio astronomy.

Exploration on submillimetre, millimetre and short centimetre wavelengths may supply new data on the solar radio emission, the distribution of temperatures on the surface of the planets, the structure and electrical properties of their soils as well as on chemical composition of their atmosphere.

Exploration in the 20 to 40 m range of the spectral characteristics of the solar radio-emission bursts and the nature of temporary changes in the intensity is of the greatest importance for working out the detailed theory of the solar sporadic radio emission and for the physical study of the external solar corona. New possibility of interpreting data on the solar sporadic radio-emission is very important for the prediction of geophysical perturbations.

The above mentioned methods allow to find the cause of Jupiter sporadic radio-emission.

Measurements of the spatial radio emissions on several hundred meters allow to determine the concentration of electrons in the interstellar medium.

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F. ÉPHÉMÉRIDES D'INTÉRÊT RADIOASTRONOMIQUE

Deux organismes diffusent des éphémérides qui intéressent plus particulièrement les radio-astronomes: le Nautical Almanac Office (Royal Greenwich Observatory) calcule les prédictions d'occultations pour 25 stations d'observation, sur une liste de 160 radiosources, et assiste les observateurs pour la détermination des positions des sources dont l'occultation a été observée. D'autre part, le Nautical Almanac Office de l'U. S. Naval Observatory continue le calcul de l'éphéméride de la longitude radio (système III) du méridien central de Jupiter pour la période 1964–1967. La Commission 40 tient à remercier ici ces organismes et leurs responsables, notamment Mrs Flora McBain Sadler et le Dr R. L. Duncombe, pour leur importante contribution à la recherche radioastronomique.

G. NOTES BIBLIOGRAPHIQUES

Les revues bibliographiques publiées par l'Université de Cornell, d'une part, et par le CSIRO, à Sydney, d'autre part, se sont enrichies:

1. pour la première, de deux volumes couvrant la littérature publiée en 1961 et 1957 respectivement; le volume donnant les références pour 1962 est en cours de publication.

2. pour la seconde, d'un volume couvrant la littérature de 1957 à 1960 inclus.

Tous les détails concernant ces bibliographies peuvent étre demandés à:

1. Martha Stahr Carpenter, editor, Bibliography of Extra-terrestrial Radio Noise, Service of Radiophysics and Space Research, Phillips Hall, Cornell University, Ithaca, N.Y., U.S.A.

2. Chief, Division of Radiophysics, CSIRO, University Grounds, Sydney, Australia.

Parmi les livres publiés sur la Radioastronomie depuis le dernier Symposium de l'UAI, citons:

I. S. Shklovsky, *Cosmic Radio Waves*, traduit par R. B. Rodman et C. M. Varsavsky. Cambridge Harvard University Press, 1960.

J. Budějický, Z. Plavcová, M. Plavec, *Radioastronomie*, Nakladatelství Československ. Academie Vĕd, Praha, 1962 (en tchèque).

L'ouvrage de F. G. Smith a été traduit en russe, de même que celui de J. Lequeux et J.-L. Steinberg. Ce dernier ouvrage a également fait l'objet d'une édition américaine révisée, traduite par R. N. Bracewell (McGraw Hill, 1963).

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