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

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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 polariza-

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tion 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 $T = 230°\mathrm{K} + 73°\mathrm{K} \cos(\Omega t - 24°)$ for the brightness temperature over a lunation. Observations at 3·2 cm gave $T = 245°\mathrm{K} + 15{\cdot}5°\mathrm{K} \cos(\Omega t - 50°)$ (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 $T = 210°\mathrm{K} + 13{\cdot}5°\mathrm{K} \cos(\Omega t - 55°) + 1{\cdot}7°\mathrm{K} \cos(2\Omega t + 44°) + 0{\cdot}5°\mathrm{K} \cos(3\Omega t + 11°)$. 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 $T = 218°\mathrm{K} + 7°\mathrm{K} \cos(\Omega t - 40°)$. 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 $(1 \pm 0{\cdot}5) \times 10^{-4}$ 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 $\pm$ 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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