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SOLAR SYSTEM RADIO ASTRONOMY

Dave Buhl

I. MOON (Diameter = 30')

The radio emission from the Moon has a mean temperature of ~ 200° K plus a 29.5 day sinusoidal variation whose amplitude decreases with greater depth into the lunar surface. The depth of penetration is proportional to the radio wavelength and therefore, by comparing the phase and amplitude of the diurnal variation at different wavelengths, some information about the bulk properties of the lunar surface layer can be obtained.

Infra red observations of a Lunar Eclipse have revealed a rapid temperature decrease for most regions (400° K → 200° K). This indicates a very porous insulating surface. Numerous bright rayed craters have enhanced thermal emission during the eclipse, being as much as 50° K warmer than their surroundings. Several of the Lunar Maria also exhibit an elevated temperature of ~ 5° K.

Radio observations of the Moon at λ = 2 cm (depth ~ 1/2 m) have revealed departures from the diurnal temperature variation of ~ 5° K for several of the Maria. However, no signficant departures were observed for the bright rayed craters. These results suggest that the origin of the thermal anomalies in the craters is the large boulders and surface roughness of these relatively young craters. The Mare anomalies are the result of a relatively dense surface material probably due to lava flows. Presumably this Mare filling followed the gigantic impact which left behind the Mascons buried in the Mare basins.

Radar observations (λ = 3.8 cm and 68 cm) show strong reflections from the very young crater Tycho and smaller returns from the other craters and

and Maria. This fits into the general picture of a rough rocky surface for the bright rayed craters and large areas of dense material filling the Mare basins.

II. VENUS (Maximum Diameter 1')

Because of the cloud layers on the planet Venus, the lower atmosphere and surface are only accessable to radio and radar observations or satellite probes. Radio observations at λ = 6 cm give a maximum temperature of 650 ° K with a decrease at longer and shorter wavelengths. This value of 650° K is assumed to be the surface temperature. The decrease at shorter wavelengths is due to the increasing optical thickness of the atmosphere. At the water vapor line wavelength of 1.35 cm the main emission is coming from an altitude of 50 km, still well below the cloud layer. Accurate measurements of radio temperature of Venus around this wavelength would settle the question of how much water vapor there is in the Venus atmosphere.

Interferometer observations of Venus at λ = 11 cm have been used to determine the diurnal temperature variation of the surface of the planet. This variation is only 18° K between the day and night sides. Since the day on Venus is 243 Earth days, there must be considerable heat transport in the lower atmosphere of Venus to allow this small a temperature difference. In addition, very little cooling of the poles is observed. Since the surface pressure is 100 atmospheres, these conditions are quite reasonable.

Radar observations of Venus have determined that the rotation of the planet Venus is retrograde with a possible lock to the Earth's orbit. A number of features have been identified on the surface, but a map of the surface will probably require a bistatic radar experiment using a satellite orbiting about the planet. A combined radar satellite experiment has already yielded a very accurate radius for Venus of 6053 km.

III. MERCURY (Maximum Diameter 12")

A very hot Moon-like planet, Mercury has been shown by radar measurements to have a synchronous rotation period equal to 2/3 its orbital period. Radio measurements at various wavelengths and infra-red observations indicate a very porous surface with some radiation conductivity in the upper layers.

IV. MARS (Maximum Diameter 6")

Mars appears to have seasons like the Earth with developing and receding polar caps of CO_2 frost. Surface temperature is between 200° K and 300° K with a rotation period about the same as the Earth's.

Surface pressure is 1/100 atmosphere providing little heat transport or protection from solar UV. As a result it is unlikely that the seasonal variation in the color of the light and dark areas is due to some form of plant life. Altitude variations as determined from CO_2 densitites are rather large ($\sim$ 10 km.). There appears to be no volcanic activity at present and a large number of crater basins can be seen in the Mariner photographs.

V. JUPITER (Maximum Diameter 40")

Low frequency radio emission from Jupiter (10 - 100 MHz) contains very large bursts apparently associated with the satellite Io. When the satellite is 90° to the Earth-Jupiter line the maximum number of bursts occurs. This is thought to be the result of Io pulling a section of the magnetic field of Jupiter through the plasma in the Van Allen belts, and creating a dynamo which dumps large currents at the planets surface near the poles.

Radio emission at λ = 11 cm is primarily synchrotron from the high energy particles in the Van Allen belts. This appears as a dumbell centered on the planet and extending $\sim$ 2' on either side perpendicular to the magnetic axis. The belts rock back and forth in the 10 hour rotation period indicating a tilt of 10° between the magnetic axis and the rotation axis. There is also apparently an assymetry in the belts which rotates with the planet. Further interferometer and polarization measurements of Jupiter will help clarify the geometry of the magnetic field and high energy particles.

Short wavelength radiation from Jupiter is primarily thermal emission from the 150° K planet. Emission in the range 20 - 30 GHz exhibits the shape of the ammonia bands, which is a major constituent of the atmosphere.

VI. SATURN AND THE OUTER PLANETS (Diameter less than 20")

No radiation belts have been detected for Saturn. Recent infra-red measurements of Saturn's rings have shown a spectral band which could be ammonia or water frost.

Uranus and Neptune have been detected in the 3 mm to 10 cm range but very little is known about these planets.

VII. SUN (Diameter = 30)

Solar burst emission at long wavelengths can be classified into various types depending on the duration, direction of frequency drift, polarization and intensity. Bursts are apparently related to flares in active regions. It is thought that shock waves in the lower solar atmosphere propagate upward and cause plasma bursts in the upper atmosphere. Large bursts are usually accompanied by particle emission in the solar wind along the magnetic field lines which probably extend at least as far as Jupiter, 5 AU from the Sun.

Short wavelength emission is slowly varying and associated with bright plage regions seen in H α. Occassional flaring can be seen over a period of several minutes to hours. At $\lambda = 3$ mm the emission originates from $\sim$ 5,000 km above the photosphere and in active regions is 100° K to 700° K hotter than the quiet Sun. Cool regions are observed which appear to be coincident with filaments in Hα. They are sometimes observed several days before the appearance of a filament because the optical depth is greater at 3 mm than in Hα. The general structure is stable over several days and probably over several 27 day rotation periods of the Sun.

The radio spectrum of the quiet Sun has a constant temperature of 6000° k up to a wavelength of 3 mm and then increases slowly to 9000° k at λ = 2 cm and then sharply upward to 10^{5}° k at 30 cm. Since the altitude of emission from the atmosphere increases with increasing wavelength, these radio wavelength measurements help to define the models of the solar chromosphere.

VIII. REFERENCES:

Thermal Radio Emission from the Major Planets, Kenneth I. Kellermann, Radio Science, 5, 487, 1970.

Preliminary Results of Interferometric Observations of Venus at 11.1 cm Wavelength, A. C. E. Sinclair, John Basart, David Buhl, W. A. G le, and M. Liwshitz, Radio Science, 5, 347, 1970.

The Microwave Spectrum of Mercury, David Morrison and Michael J. Klein, Ap. J., 160, 325, 1970.

An Interferometric Study of Jupiter's Decimeter Radio Emission, Glen L. Berge, Ap. J., 146, 767, 1966.

The Mapping of the Sun at 3.5 mm, David Buhl and Antonin Tlamicha, Astron. and Astrophys., 5, 102, 1970.

Radar Observations of the Planets, Irwin I. Shapiro, Scientific American, 219, 28, July, 1968.