III. RADIO ASTRONOMY*

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A. MEASUREMENTS OF THE WATER-VAPOR LINE IN THE TERRESTIAL ATMOSPHERE

Measurements of atmospheric absorption have been made recently in the spectral region 21.0-32.4 Gc/sec. These were made at Lincoln Laboratory, M.I.T., with the 28 ft paraboloid and the Research Laboratory of Electronics 5-channel k-band microwave radiometer. The absorption was measured by observing the atmospheric

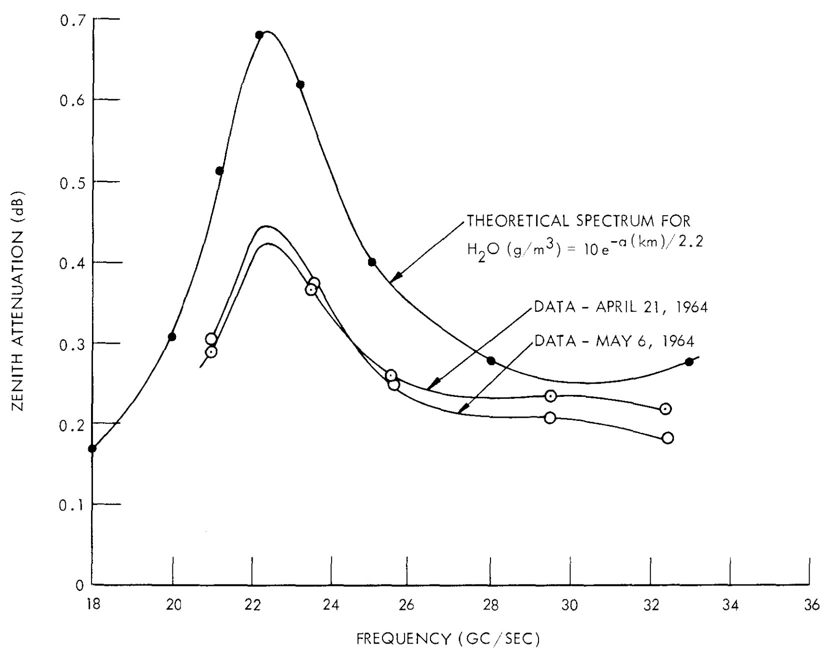

Fig. III-1. Experimental and theoretical atmospheric absorption spectra in the 18-33 Gc/sec regions.

extinction of the sun during several sunsets.

Figure III-1 shows one theoretical and two experimental spectra. At the beginning

*This work was supported in part by the National Aeronautics and Space Administration (Grants NsG-250-62 and NsG-419); and in part by Purchase Order DDL BB-107 with Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, with the support of the U.S. Air Force under Contract AF 19(628)-500.

of the experiment, on April 21, 1964, the temperature was 50° F and the relative humidity was 35%; on May 6, 1964, the temperature was 66° F, and the relative humidity was 43%. These results are preliminary, and the measurements will be continued.

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B. THEORETICAL WATER VAPOR SPECTRA FROM AN EARTH-ORBITING SATELLITE

Theoretical atmospheric emission spectra have been computed for the range 5-40 Gc. These computations indicate that satellite-based measurements of the atmospheric water-vapor content may be quite feasible if microwave radiometers are used. These calculations include the effects of water vapor and oxygen,[1,2] and also the radiation reflected and emitted from the earth's surface and the effects of the earth's curvature.

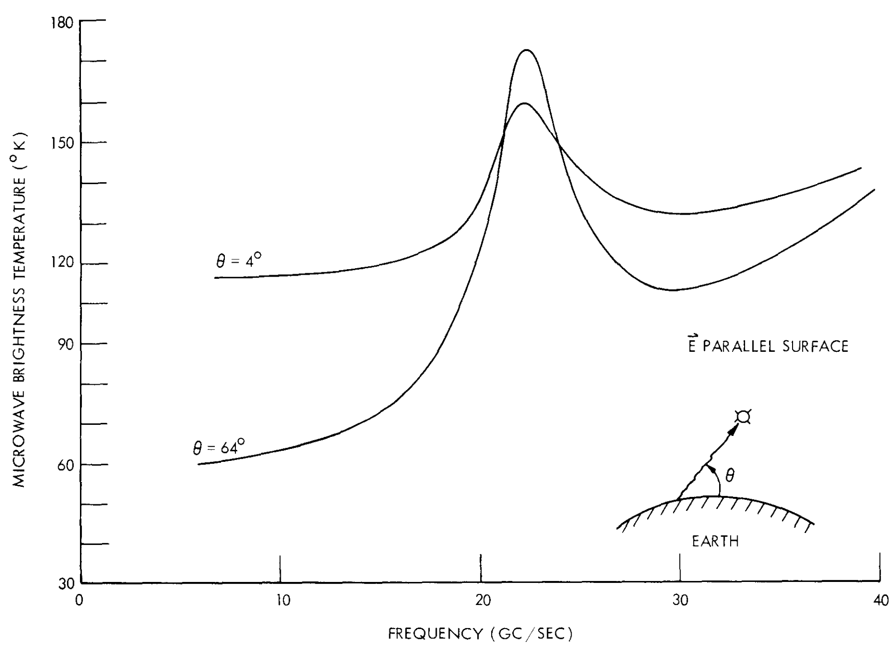

Fig. III-2. Atmospheric spectra as seen from space when the satellite is over a body of water.

In the computations an atmosphere containing a typical exponential distribution of water vapor was assumed: $H_2O = 10\ e^{-a/2.2}\ g/m^3$, where a represents altitude in kilometers. The temperature and pressure distribution were approximately those of the ARDC standard atmosphere.[3]

Figure III-2 shows spectra that would be observed by a satellite receiving horizontally polarized radiation from a smooth body of water. These spectra show that the effect of water vapor is quite large, producing a microwave brightness temperature difference of 30-100° K between the center of the emission line and the wings. Since microwave radiometers can be built with noise fluctuations less than 2° K for 1-second averaging, such an emission line could readily be measured. Although more typical water-vapor densities are perhaps half the values assumed here, the signal is still large.

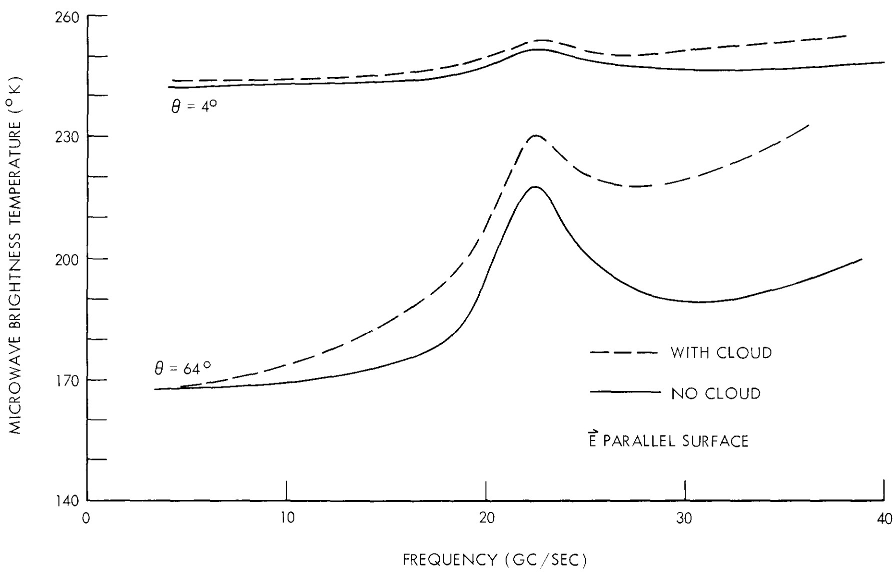

Fig. III-3. Atmospheric spectra as seen from space when the satellite is over a smooth surface of dielectric constant $\epsilon = 5$. The cloud layer is assumed to be uniform at 2-3 km with 1 g/m^3 condensed water.

Over land such measurements would be more difficult because the ground is often approximately a black body with almost the same microwave brightness temperature as the air above, and thus yields almost no spectral line. This fact is shown in Fig. III-3, which presents spectra for a smooth planetary surface with dielectric constant $\epsilon = 5$. The spectral line is large at O = 64° because of the assumption of a smooth surface — which is rarely true.

Also shown in Fig. III-3 is the effect of cloud on the spectral line. The cloud was assumed to be 1 km thick and to contain 1 g/m^3 condensed water, which is a moderately large amount. Although the cloud reduces the line intensity, it does not conceal it. Over bodies of water the line could be even more distinct.

Of course, the exact amounts of atmospheric water vapor and cloud cover are not simply related to the spectra. The spectra are also affected by temperature, pressure, and water-vapor distributions in the atmosphere, and these have to be carefully considered in accurately interpreting any data.

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References

1. M. L. Meeks, Atmospheric emission and opacity at millimeter wavelengths due to oxygen, J. Geophys. Res. 66, 3749-3757 (1961).

2. A. H. Barrett and V. K. Chung, A method for the determination of high altitude water-vapor abundance from ground-based microwave observations, J. Geophys. Res. 67, 4259-4266 (1962).

3. U. S. Air Force, Handbook of Geophysics (Macmillan Company, New York, revised edition, 1960).

C. EXCITATION TEMPERATURE OF INTERSTELLAR OH LINES

The recent detection of the 18-cm absorption lines of OH in the radio spectrum of the interstellar medium[1] has forced consideration of the excitation temperature of the OH Λ-doublet energy levels to provide proper interpretation of the observations in terms of OH abundance. If n_1 and n_o are the densities of OH molecules in the upper and lower energy levels of the transition, respectively, the excitation temperature T_s is defined by

$$\frac{n_1}{n_o} = \frac{g_1}{g_o} e^{-h\nu/kT_s}, \tag{1}$$

where g_i is the statistical weight of the level, and ν is the frequency of the transition. The excitation temperature is related to the optical depth, or total absorption, τ_ν, as

$$\tau_\nu = \frac{hc^2AN}{8\pi kT_s\nu(\Delta\nu)} \frac{g_1}{\Sigma\, g_i}, \tag{2}$$

where A is the transition probability for the line, N is the total integrated number of OH radicals per unit area, and $\Delta\nu$ is the linewidth.

At the present time, OH has been observed only in absorption. The observations allow a determination of the optical depth τ_ν, but this does not enable a determination of N without a knowledge of the excitation temperature T_s. Observations of OH emission and absorption in adjacent regions of the sky would greatly aid our knowledge of both N and T_s.

It is apparent from Eq. 1 that a theoretical estimate of T_s can be made by considering the various physical mechanisms by which the OH energy levels can be populated.

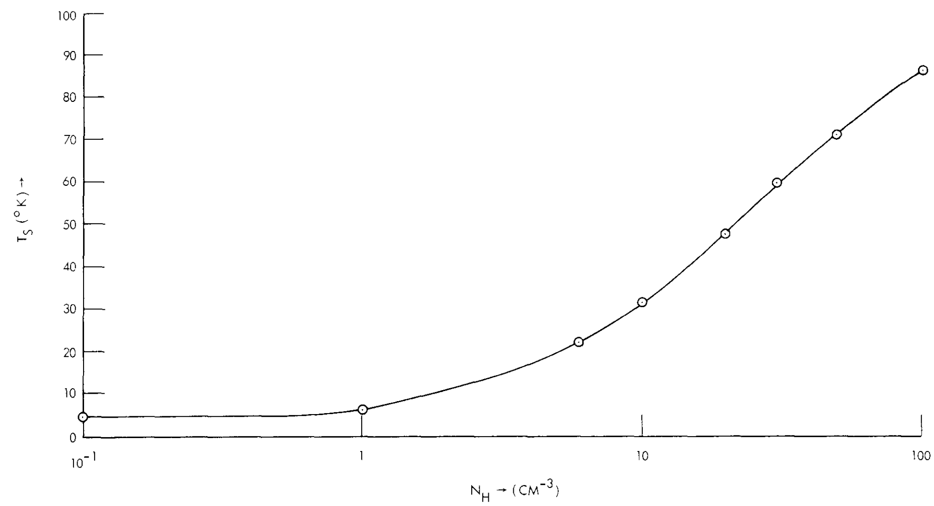

Fig. III-4. Excitation temperature T_s of the 18-cm lines of OH, under the assumption that $T_R = 5°$ K.

Two general processes must be considered: collisional and radiative. Collisional processes involve the interaction of an OH molecule with another particle whose kinetic energy is distributed according to the Maxwell-Boltzmann law; radiative processes are those in which the OH molecule interacts with the interstellar radiation field. Radiative processes can be conveniently subdivided into two types: those involving direct transitions between the Λ-doublet levels and governed by the interstellar radiation field at 18-cm wavelength, and those involving transitions to higher OH levels and subsequent decay to other Λ-doublet levels of the ground state. In the steady-state case, the excitation temperature[2] is given by

$$T_s = \frac{T_R + y_k T_k + y_L T_L}{1 + y_k + y_L},$$

where T_R is the characteristic radiation temperature of the interstellar 18-cm radiation field, T_k is the kinetic temperature of the colliding particles, and T_L is the characteristic temperature of the particular radiation required for an indirect transition. The y_i are the "efficiencies" of the various processes for establishing the steady-state population distribution.

Calculations of the efficiencies from present knowledge of the environment of the interstellar medium[3] show that the collisions of OH with the heavy ions, especially C^+, is the most important process. This process has a large collision cross-section because the heavy ions produce a large 18-cm component in the frequency spectrum of the pulse of electric field experienced by the OH molecule during the passage of an ion. If the relative abundance of ions in relation to hydrogen atoms is assumed to be constant, typically $\sim 10^{-4}$, then the excitation temperature is obtained as a function of hydrogen density as shown in Fig. III-4. Taking the average hydrogen cloud density to be 10 atoms cm^{-3} the excitation temperature is estimated to be $\sim 30°$ K. On the other hand, observations set an upper limit of 10° K on the excitation temperature. The apparent disagreement with the upper limits set by observations is being investigated and may be due to a high abundance of OH in regions of low hydrogen density. Another possible explanation is the existence of a radiation pumping effect tending to reduce the excitation temperature due to a larger radiation density of appropriate profile in the infra-red region than that used in estimating the light temperature and "efficiencies." Further observation will help to resolve the difficulty and lead the way to other possible explanations.

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References

1. S. Weinreb, A. H. Barrett, M. L. Meeks, and J. C. Henry, Nature 200, 829 (1963).

2. G. B. Field, Proc. IRE 46, 240 (1958).

3. M. J. Seaton, Ann. Astrophysik 18, 188 (1955).