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MICROWAVE, MM, AND SUB-MM MEASUREMENT CAPABILITY

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J.W. Waters, Jet Propulsion Laboratory

The microwave, millimeter, and sub-millimeter spectral range covers wavelengths between about 10 mm and 0.1 mm and contains spectral lines due to rotational transitions of many molecules of interest to upper atmospheric research. These spectral lines can be measured, either in thermal emission or in absorption, to remotely determine the abundances of certain molecules. Temperature and pressure can also be determined. Measurements in this spectral region have been performed from ground, aircraft, balloon, and are now being developed for Earth orbit. Most measurements have been made of thermal emission due to the sensitivity of the technique and the desire to obtain data over all portions of the diurnal cycle.

At wavelengths longer than about 1 mm measurements are generally performed using coherent microwave (superheterodyne) techniques. At wavelengths shorter than about 1mm measurements are generally performed using incoherent (filter, interferometric) techniques, although coherent techniques are rapidly being pushed to the shorter wavelengths. Coherent techniques have the advantage of greater sensitivity and spectral resolution than incoherent techniques; this spectral resolution can be used to infer vertical profiles from the measured line shape of pressure-broadened lines. Incoherent techniques have the advantage of more easily covering a wider spectral range than coherent techniques and, because they now operate at shorter wavelengths, can measure the important species of OH and atomic O which do not have measurable lines at longer wavelengths. However, the sensitivity to other radicals such as ClO, HO2, and NO2 appears to be about 10x worse for incoherent techniques than for coherent techniques even though the incoherent techniques operate in a region of larger line strengths.

The spectroscopy in this spectral region is relatively well-known and spectroscopic uncertainties appear not to be a limitation in either planning or interpreting measurements. Line strengths in this region can be reliably calculated from the molecular dipole moment which is measured very accurately from Stark or Zeeman effects.

Figure 1 shows the calculated stratospheric spectrum for balloon measurements of a layer around 30 km using expected stratospheric abundances. This figure, which covers a wavelength range of only 1.5mm to 1.0mm, illustrates the many lines which are available for measurement; it also illustrates the care which must be taken to avoid interference from unwanted lines. The vertical scale in the figure is the logarithm of the optical depth (for weak lines the optical depth is proportional to the strength of the emission). The heavy horizontal line represents rms noise for a liquid nitrogen cooled radiometer with a few minutes integration; anticipated technological developments, e.g. SIS-based radiometers, could improve sensitivity 10x. Many of the lines in Figure 1 can be measured from ground; Figure 2 compares vertical resolution of balloon-based and ground-based measurements.

Our program at JPL has involved measurements with a balloon-borne microwave limb sounder which is tuned to lines of CLO, O3, and H2O2 near 205 GHz and is now operational. A similar instrument is now being developed for the Upper Atmosphere Research Satellite, which has additional measurements of H2O and pressure. W. Wilson at JPL and collaborators have recently performed ground-based measurements of mesospheric H2O using a borrowed radiometer which is no longer available; there is interest in continuing these measurements, but an instrument needs to be constructed. Wilson and D.Muhlemann at Caltech now have a developmental model of a 233 GHz radiometer for a Mars mission; tentative plans are to test that instrument with ground-based measurements of stratospheric and mesospheric O3 and mesospheric CO. H.Pickett and collaborators at JPL are also developing an incoherent balloon instrument operating at 0.1mm wavelength for measurements of OH and possibly other species.

Table 1 indicates the general capability of measurements which could be performed from balloon at millimeter wavelengths where heterodyne radiometers can be constructed using existing technology.

Table 1. Some millimeter-wavelength spectral lines of stratospheric molecules and approximate measurement sensitivities for balloon-based measurements. The lines given here are expected to be substantially free from other interfering lines based on the JPL catalog. The approximate sensitivity is the volume mixing ratio required to produce an emission brightness temperature of approximately 0.05 Kelvin for a balloon-based measurement of a 3 km thick layer at 30 km height; this signal corresponds to the rms noise for a liquid-nitrogen cooled radiometer (system noise temperature of 1500 Kelvin) with square-wave switching, spectral resolution of 30 MHz (approximate width of the lines at 30 km), and integration time of 2 minutes. Many of these lines can also be measured from the ground.

Molecule	Line Frequency (GHz)	Approximate Sensitivity (vmr)	Note
O3	206.13	3 E-09	1
O3(16-17-16)	283.42	2 E-10	
O3(16-16-17)	266.92	6 E-10	
O3(16-18-16)	278.45	3 E-10	
O3(16-16-18)	277.93	4 E-10	
H2O	183.31	2 E-10	2,3
HDO	255.05	8 E-11	
H2O2	204.57	1 E-10	
HO2	265.77	3 E-11	3
N2O	276.33	2 E-10	
NO	250.44	1 E-09	3
NO2	265.56	3 E-09	3
HNO3	269.2	2 E-11	
CL-35-O	204.35	2 E-11	4
CL-37-O	237.42	1 E-11	
HOCL-35	227.60	5 E-11	
HOCL-37	297.01	3 E-11	
BR-79-O	320.48	3 E-12	
BR-81-O	395.65	2 E-12	
CO	230.54	6 E-10	3
HCN	265.89	5 E-13	
H2CO	225.70	8 E-12	
SO2	221.97	4 E-11	
OCS	267.53	2 E-11	

Notes:

1. This line is given because of the insensitivity of its emission strength to stratospheric temperature variations. Other O3 lines exist which are ten times stronger.

2. Not observable from ground, but the 22.23 GHz H2O line can be used from ground to measure mesospheric H2O with a sensitivity of approximately 5 E-07 volume mixing ratio.

3. An additional mesospheric contribution must be accounted for

4. CLO line at 278.63 GHz is approximately 3x stronger.

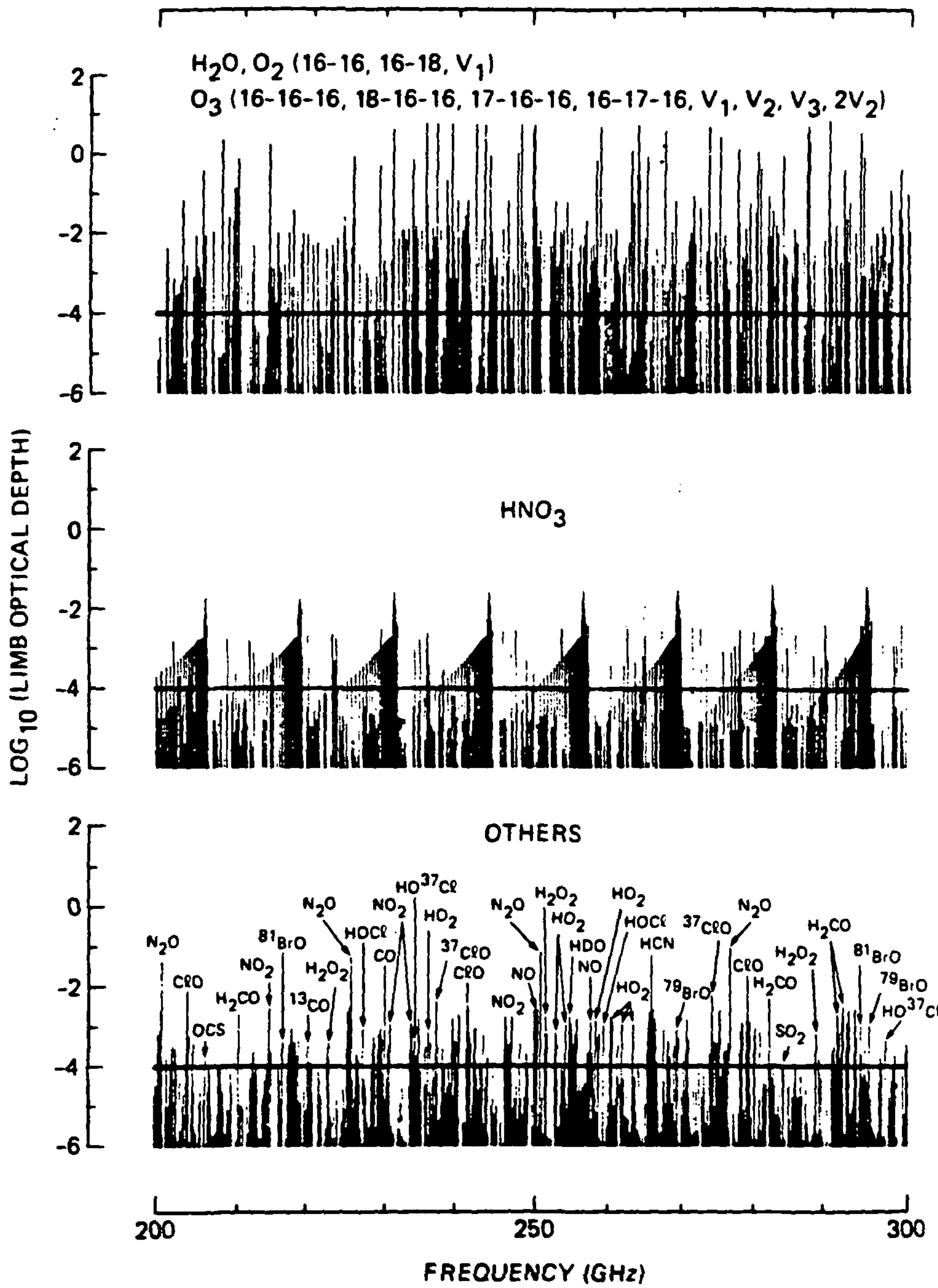

Fig. 1. Atmospheric spectral lines in the 200–300 GHz range. The vertical scale is the logarithm of the calculated optical depth for a limb sounding path through the middle stratosphere. The calculations are for a temperature of 225 K and the species abundances in Table Ia. The heavy horizontal line is the approximate noise level for emission measurements using a state-of-the-art radiometer with a few minutes integration and spectral resolution to resolve the stratospheric lines.

Table 1. The stratospheric species abundances used for calculations shown in Fig. 1. Abundances here are relative to the total number density by volume. Species are listed in order of increasing mass.

SPECIES	LOG (ABUNDANCE)	SPECIES	LOG (ABUNDANCE)
H_2O	-5.3	$^{16}O^{17}O^{18}O$	-8.7
HDO	-9.1	$^{16}O^{16}O^{17}O$	-8.3
HCN	-9.8	$^{16}O^{18}O^{16}O$	-7.8
CO	-7.0	$^{16}O^{16}O^{18}O$	-7.5
H_2CO	-10.0	ClO	-9.4
NO	-8.0	HOCl	-9.8
O_2	-0.7	^{37}ClO	-9.9
HO_2	-9.7	$HO^{37}Cl$	-10.3
$^{16}O^{18}O$	-3.1	OCS	-10.7
H_2O_2	-9.5	HNO_3	-8.7
N_2O	-7.0	SO_2	-11.0
NO_2	-8.0	^{79}BrO	-11.1
O_3	-5.2	^{81}BrO	-11.1

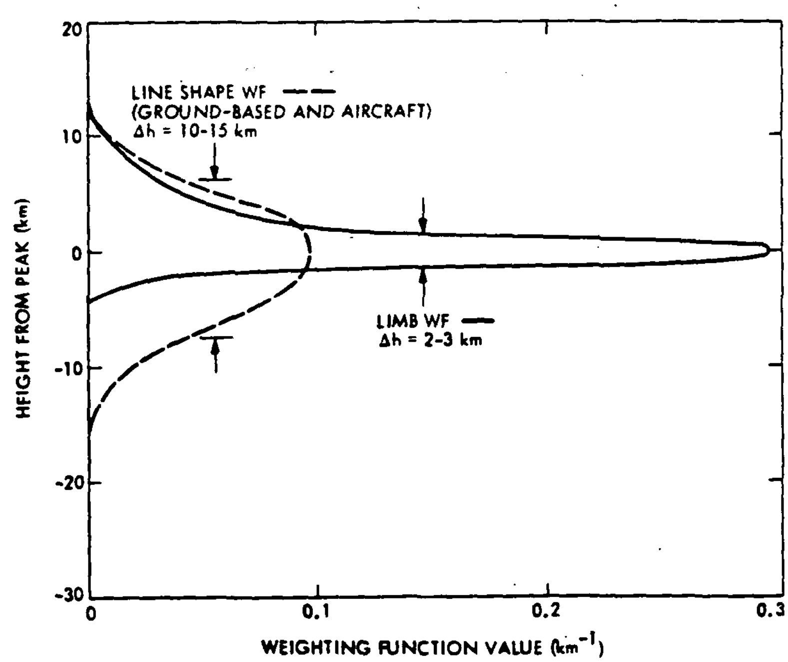

Fig. 2. Weighting functions for limb and spectral line shape microwave measurements. These functions describe the vertical resolution of the technique; the measured signal is proportional to the integral, through the observed atmospheric path, of the product of this function and the mixing ratio of the species being measured. The curves shown here have been normalized to unity area. The limb curve includes smearing by the BMLS antenna when pointed at 15 km tangent height from a float height of 40 km; for higher tangent heights this curve is narrower. The line shape curve is calculated for infinitesimally spaced spectral channels with infinitesimal resolution.