II. RADIO ASTRONOMY[*]

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A. MILLIMETER-WAVE INTERFEROMETER

Construction has started on a phase-stable interferometer that comprises three 18-ft dishes, one movable, on a 1000-ft baseline. The paraboloids have been delivered, and the surface tolerances are much better than specified, leading us to expect operation at 3-mm wavelength. The interferometer will be directly coupled to a small computer that will perform the crosscorrelation, and in turn will be directly coupled to the large CDC-3300 computer of the Haystack Observatory. The first observations will be performed at K-band and Ku-band to calibrate the instrument which will have absolute phase stability and be capable of performing complete aperture synthesis measurements of sources. The site is now being prepared at the Haystack Observatory and test observations are expected to start before the end of 1972.

G. D. Papadopoulos, B. F. Burke

B. H_2O LINE OBSERVATION

The Haystack-Westford interferometer has been adopted for operation at K-band, and observations of several of the brighter H_2O line sources have been completed. Our aim has been to build a phase-stable system that will yield accurate positions for the H_2O line sources of precision which will be comparable to optical observations. The data are now in the reduction process.

K-Y. Lo, B. F. Burke

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C. APERTURE SYNTHESIS OF EXTRAGALACTIC NEBULAE

The program of mapping the distribution of H II regions in nearby galaxies has proceeded, with the use of the 3-element interferometer of NRAO at 11-cm and 3-cm wavelengths. Originally, M31 and M33 were the principal objects of study, but we have now added M51 to the program. The first results show that M31, though it has many H II regions, is fundamentally different from our own galaxy, since it lacks giant H II regions comparable to M17, Eta Carinae, or W49. The bright H II regions of M33 can be detected easily, and some are large enough to show structure despite the great distance. M51 is particularly interesting, since our results can be directly compared with the 21-cm continuum observation of the Westerbork instrument in the Netherlands. We have discovered structure in the nuclear regions of M51 that indicates that its nucleus is similar to the nucleus of our galaxy.

J. H. Spencer, B. F. Burke

D. AIRCRAFT FLIGHTS WITH THE NIMBUS E MICROWAVE SPECTROMETER

During March and April, 1972, the engineering model of the Nimbus E Microwave Spectrometer (NEMS) was flown on the National Aeronautics and Space Administration Convair 990 Microwave Earth Observations expedition. This expedition, which was similar to that of 1970,[1] included 18 flights over the continental United States, the Northwestern Atlantic Ocean and Northeastern Pacific Ocean, Alaska, and the Arctic Ocean. Each flight lasted approximately 6 hours, at altitudes between 200 ft and 40,000 ft.

NEMS data from the flights are now being reduced at the Jet Propulsion Laboratory of California Institute of Technology. Ground truth data from special surface sites are being reduced at NASA, Goddard Space Flight Center, and will be available to us. Conventional and special radiosonde soundings for the flights have been obtained. NEMS brightness temperatures calculated for selected soundings indicate a calibration error in some preliminary reduced data, and the instrument will be recalibrated before further data reduction, as had been originally planned. After data reduction is complete we shall compare the NEMS measurements with values calculated from the surface and radiosonde data. These data will also be used to test the software package now being developed for reducing the NEMS satellite data and to test NEMS accuracy in determining atmospheric parameters. The results will be reported in detail in NEMS Memoranda and summarized in future reports.

J. Blinn, K. Ishikawa, and P. Rosenkranz, of the Jet Propulsion Laboratory, participated in these experiments. We are grateful to E. Petersen and the Convair 990 team for excellent support during the flights, to Northeast Weather Services for supplying supporting meteorological data, and to T. Schmugge of NASA for supplying data from special radiosondes.

B. G. Anderson, K. F. Kunzi, D. H. Staelin, J. W. Waters

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E. RADIOMETER SYSTEM FOR GROUND-BASED MEASUREMENT OF STRATOSPHERIC TEMPERATURES

The radiometer system for ground-based measurement of stratospheric temperatures is nearly completed, and atmospheric thermal emission has been observed from the 27_ O_2 line at 53 GHz. A sample of the real-time output from O_2 line observations is given in Fig. II-1. Column 1 in this figure gives channel numbers. The nominal center frequencies and bandwidths of Channels 1-23 have been given in a

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CH  TSYS      S-C      1
01  2918  +00020.4281  1                                               *
02  2770  +00012.6613  1                *
03  2710  +00011.6829  1            *
04  2769  +00011.5592  1           *
05  2823  +00012.1086  1              *
06  2848  +00012.8642  1                 *
07  2832  +00013.7271  1                    *
08  2869  +00014.8781  1                         *
09  3000  +00016.3847  1                               *
10  3027  +00017.1209  1                                  *
11  3104  +00017.7386  1                                    *
12  3105  +00017.8182  1                                    *
13  3049  +00017.6524  1                                    *
14  3147  +00017.0145  1                                 *
15  3079  +00016.1601  1                              *
16  2975  +00014.4855  1                       *
17  2977  +00012.6186  1                *
18  3008  +00011.7823  1            *
19  3004  +00010.5936  1       *
20  2983  +00009.2677  1  *
21  3012  +00008.6009  1*
22  2994  +00009.4665  1   *
23  3484  +00017.1630  1                                  *
24  2860  +00016.9315  1
                       ----------------------------------------------
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Fig. II-1. Real-time output of the oxygen line receiver system showing the measured emission from the 27_ line.

previous report[1] and Channel 24 is a broadband channel covering the entire 40-80 MHz range of the filter bank. Column 2 gives the system temperature (in degrees Kelvin) computed independently for each channel, and Column 3 gives the synchronously detected differences (in degrees Kelvin) between signals and comparisons with the Dicke switches. The synchronously detected difference is plotted at the right of the column, and the 27_- O_2 centered in Channel 12 is evident. Broadband Channel 24 is not plotted. Because of the 40-MHZ harmonics generated in the klystron local-oscillator frequency stabilizing system and leaking into the radiometer via the klystron reflector leads, Channels 1 and 23 indicate a large output. These harmonics have since been eliminated by filtering the reflector leads. We are now investigating the unexpected baseline slope which has been observed. The O_2 emission measurements will be discussed in a future report.

R. M. Paroskie, J. W. Waters, J. W. Barrett,
D. C. Papa, D. H. Staelin

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F. REMOTE SENSING OF ATMOSPHERIC O_3 AND H_2O TO 70 km FROM AIRCRAFT MEASUREMENTS OF RADIATION AT 1.64 mm WAVELENGTH

Ozone (O_3) has many relatively strong spectral lines in the millimeter wavelength region,[1] and as millimeter receiver technology advances it becomes feasible to sense ozone remotely by measurements of thermal emission from these lines. The purpose of this report is to point out that a strong O_3 line is predicted at 184.375 GHz (1.6 mm wavelength), conveniently near the 183.310 GHz water-vapor line, and that a single radiometer can sense both O_3 and H_2O up to altitudes of ~70 km from aircraft measurements of thermal emission. An aircraft (or other) platform at ~10 km or higher altitudes is required because of strong water-vapor absorption at lower altitudes. Remote sensing of stratospheric water vapor by balloon and satellite measurements of 183-GHz emission has been theoretically considered.[2] Remote sensing of ozone with the 184-GHz line has not been considered before, although lower frequency O_3 lines for remote-sensing purposes have been examined theoretically[3] and experimentally.[4,5]

We used a nominal atmospheric O_3 distribution up to 60-km altitude and a water-vapor mixing ratio of $2 \cdot 10^{-6} \frac{\text{gm } H_2O}{\text{gm air}}$[3] to compute the atmospheric emission spectrum

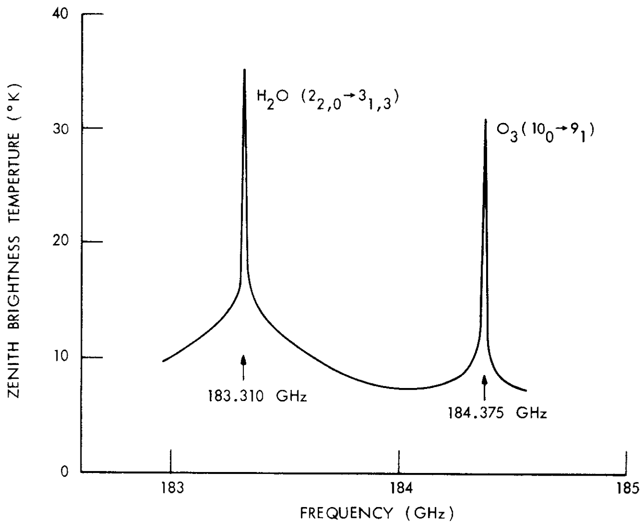

Fig. II-2. Computed atmospheric emission spectrum for nominal distribution of H_2O and O_3 up to 60 km, and 1962 U.S. Standard Atmosphere temperature profile. Calculations are for zenith observations made from 12-km altitude.

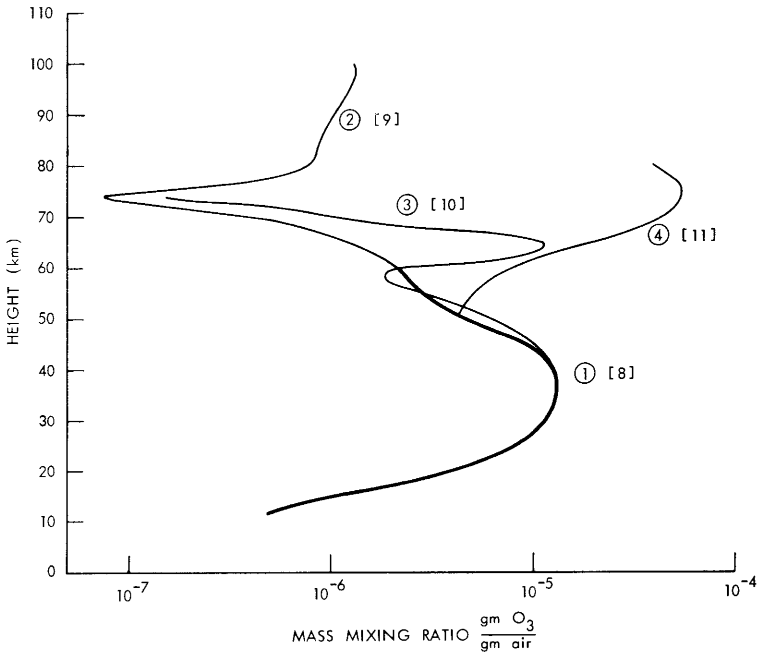

Fig. II-3. Ozone profiles used for computations. Numbers in brackets refer to references. The original data from the references were converted to mixing ratios by use of densities from the 1962 U.S. Standard Atmosphere.

as observed at 12-km altitude (see Fig. II-2). For these distributions the 183-GHz H_2O line and 184 GHz O_3 line were computed to be of approximately equal intensity. A matrix element $\phi^2 = 5.7$, inferred from Gora,[1] and lower state energy $E_\ell = 0.81 \cdot 10^{-14}$ erg, calculated from the slightly asymmetric prolate rotor energy level formula[6] (appropriate for O_3) was used to calculate the $J_K = 10_0 \rightarrow 9_1$ 184-GHz O_3 rotational transition. Other parameters in the expression for the O_3 absorption coefficient have been discussed elsewhere.[3] The expression of Gaut and Reifenstein[7] was used for the H_2O absorption coefficient. Oxygen absorption at these frequencies was computed to be negligible. The O_3 distribution used for the calculation of Fig. II-2 is indicated by a heavy line in Fig. II-3. Atmospheric ozone below ~30 km has been studied routinely and measurements of ozone up to ~50 km, with few exceptions, are in substantial agreement. Most recent stratospheric water-vapor measurements give mixing ratios of $\sim 2 \cdot 10^{-6} \, \frac{\text{gm } H_2O}{\text{gm air}}$ up to ~30 km altitude. Above ~30 km, water-vapor concentrations

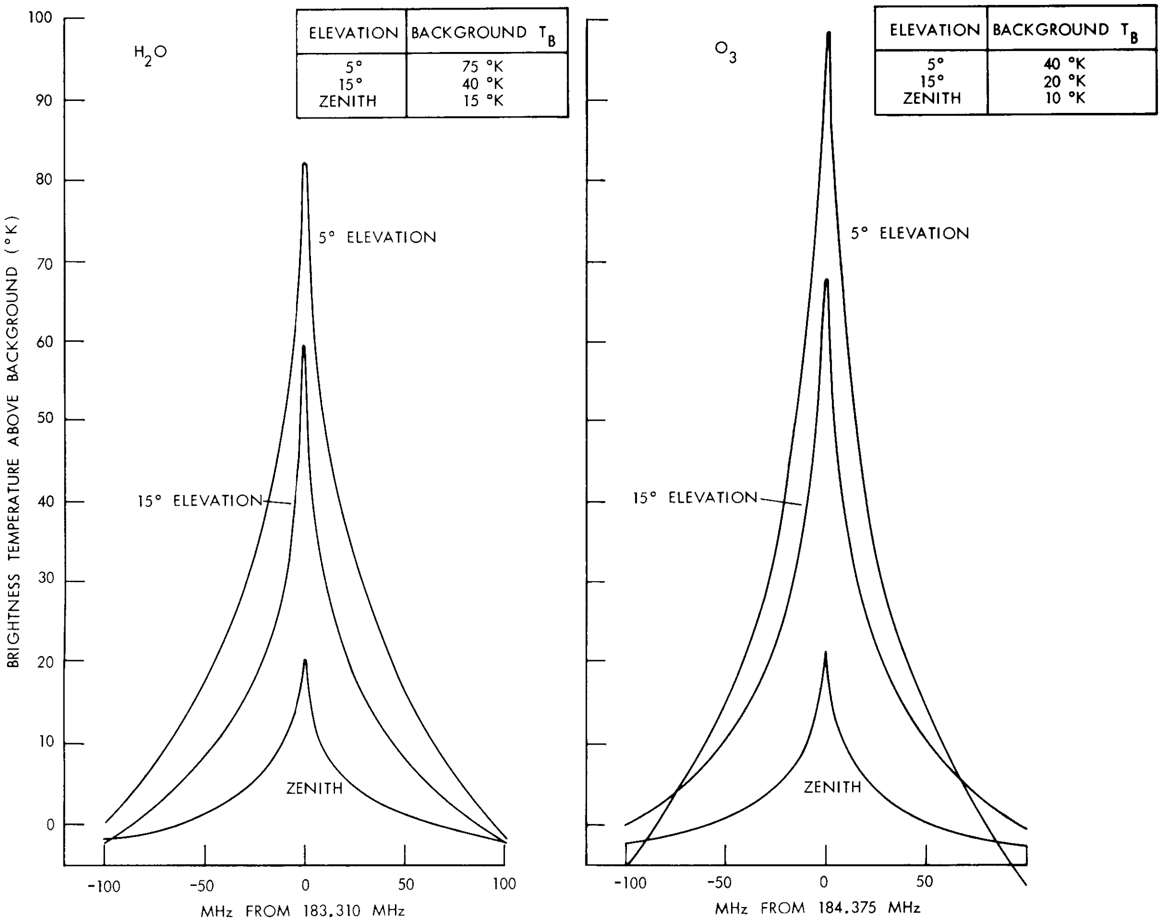

Fig. II-4. Spectral lines of Fig. II-2 on expanded scale and for different elevation angles of observation.

have not been accurately measured, but observations of atmospheric emission at the 22-GHz H_2O line[3] indicate that the average H_2O mixing ratio in the 30-60 km region does not exceed $2 \cdot 10^{-6}$. It is interesting to note that if the water-vapor mixing ratio at this altitude range is significantly less, the stratospheric emission spectrum at $\lambda \cong 1.6$ mm is dominated by the O_3 line, not the H_2O line, as is usually believed. The spectral lines in Fig. II-2 are shown in Fig. II-4 on an expanded frequency scale for 3 elevation angles of observation.

Measurements of emission from these lines allow remote sensing of O_3 and H_2O with ~16-km altitude resolution up to the altitude at which Doppler broadening dominates the linewidth.[3] This occurs at altitude ~70 km for both lines. Above 50 km only a few measurements of O_3 distribution have been made, and these measurements are not in general agreement. This altitude region is also marked by photochemical reactions involving ozone which predict a nocturnal increase, and the O_3 distribution can be calculated if certain assumptions are made about reaction rates. Certain reported O_3 profiles above 50 km are shown in Fig. II-2, and Fig. II-5 gives the spectra computed for

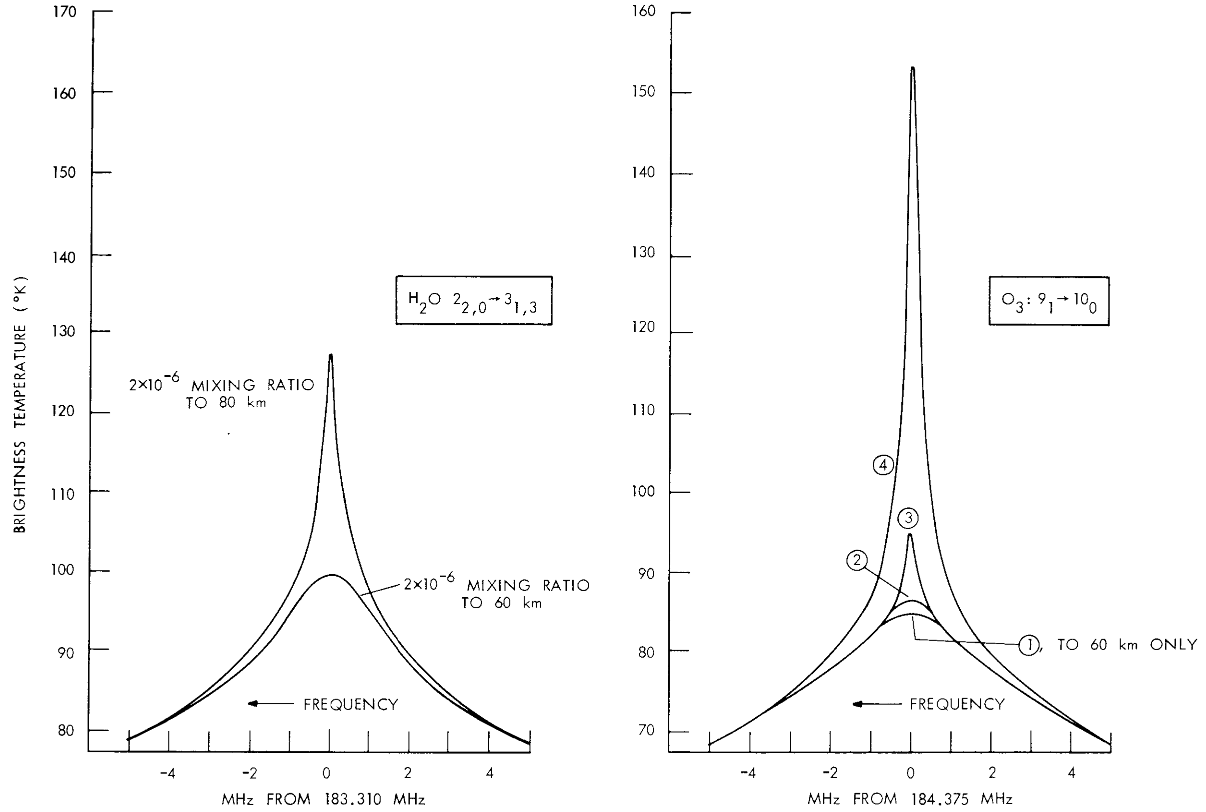

Fig. II-5. Calculations of spectral line emission for different profiles above 60 km. The frequency scale has again been expanded. Observation altitude, 12 km. Elevation angle, 15°.

them. Also shown is the water-vapor line computed for $2 \cdot 10^{-6}$ H_2O mixing ratios extending to 60-km and 80-km altitudes. Note that the frequency scale has again been expanded for Fig. II-5 and that the center of the lines for 15° elevation in Fig. II-4 is shown again in Fig. II-5.

The radiometer sensitivity required for use of these lines as meaningful atmospheric remote sensing tools is ~1°K rms. (Less sensitivity is required, of course, for simply detecting the lines.) A frequency resolution of 1 MHz is required for sensing to 50 km and 0.1 MHz for sensing to 70 km. A maximum reasonable integration time is 20 min which, with the resolution and sensitivity just mentioned, dictates maximum single sideband receiver noise temperatures of 15,000°K and 5,000°K for meaningful remote sensing to 50 km and 70 km, respectively. These receiver noise temperatures are well within state-of-the-art technology. Room-temperature 170-GHz mixer-receivers with ~2,000°K noise temperatures have recently been constructed at Bell Telephone Laboratories, and experiments have indicated that significantly lower noise temperatures can be obtained by cryogenically cooling the mixer. Both lines can be observed simultaneously with the same radiometer simply by making the bandwidth sufficiently large (1.1 GHz) that both lines are covered and by arranging the frequency down-conversion so that the two lines appear in the output at different IF frequencies.

It should be pointed out that temperature to ~50 km can also be inferred from radiometric measurements of 5-mm wavelength thermal emission of high angular momentum O_2 transitions, as has been discussed for ground-based measurements.[3] The strongest O_2 line appropriate for stratospheric temperature sensing from 12-km zenith observations is calculated to be the 25_- line at 53.596 GHz with 128°K amplitude (for the 1962 U.S. Standard Atmosphere) over ±100 MHz, although less intense lines are more sensitive to atmospheric temperature variations. One can envision developing radiometers at 1.6 mm and 5 mm wavelengths for aircraft which can sense temperature, water vapor, and ozone in the stratosphere and mesosphere. Such an instrument can be built compactly and automated so that measurements of these quantities would be routine. Mounting this instrument as a permanently installed sensing device on an atmospheric research aircraft would supply, as a matter of routine, stratospheric and mesospheric data for scientists studying upper atmospheric processes. Global coverage would be quite limited, of course, but the measurements would be valuable in designing a similar experiment for a satellite platform.

I am grateful to N. E. Gaut and E. C. Reifenstein III for supplying the FORTRAN subroutine for the H_2O absorption coefficient.

J. W. Waters

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