VII. RADIO ASTRONOMY*

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RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

1. Development of long-baseline interferometry techniques and studies of small angular diameter sources. The use of highly stable atomic-frequency standards for frequency and time control has made possible the construction of radio interferometers of arbitrarily long baseline. Separate stations have been operated simultaneously at the Haystack facility of Lincoln Laboratory, M. I. T., the National Radio Astronomy Observatory at Green Bank, West Virginia, and the Hat Creek Observatory of the University of California at Berkeley, and the Onsala Observatory of Chalmers University, Sweden. The maximum spacing used, thus far, has been 43, 000, 000 wavelengths at OH frequencies, which gives 0. 004 second of arc fringe spacing. A map of the OH emission region in the radio source W3 has been constructed, and shows an assemblage of discrete sources, the smallest of which has an angular size of 0. 0045 second of arc. The observations continue, both at OH and higher frequencies. Observations have been made to check the validity of general relativity and to apply the technique to geophysical problems.

2. Observations of interstellar OH. Single-antenna studies of the 18-cm lines of OH have continued with the antennas of Lincoln Laboratory, M. I. T., or the National Radio Astronomy Observatory, Green Bank, West Virginia, used. Strong OH emission from infrared stars was discovered in July 1968, and a survey of such stars is now under way. Further studies of $O^{18}H$ continue in an attempt to shed light on maser theories and the O^{16}/O^{18} interstellar abundance ratio.

3. Study of the microwave continuum from galactic and extragalactic radio sources at short centimeter wavelengths. The variable quasi-stellar radio sources are observed at 3. 75 cm and 2. 0 cm wavelengths to determine their time-variant spectra and polarization properties.

4. Study of microwave emission and absorption by the terrestrial atmosphere, with particular emphasis on meteorologcial satellite application. This work has included ground-based observations of atmospheric water vapor and ozone, and balloon observations of microwave emission by molecular oxygen. Up-looking balloon observations have been conducted to determine the line absorption coefficient, and down-looking flights have been carried out to test inversion techniques for recovering the temperature profile.

5. Aperture synthesis. A 2-cm interferometer is nearly complete and will be used to make high-resolution studies of the bright radio sources. The interferometer will

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make use of an on-line computer for real-time data reduction, and is intended to serve as a prototype for further high-resolution instruments for continuum studies.

6. Pulsar antenna. An antenna is being constructed for use at low frequencies (300 MHz and lower). The principal use ot the antenna will be to study pulsars at a variety of frequencies, and to search for new pulsars. The antenna is equivalent in aperture to a 200-ft dish.

A. H. Barrett, B. F. Burke

A. PULSAR FACILITY

The design and testing of a prototype 143-MHz feed for the 16-50 ft dishes is now complete. Each feed consists of two orthogonal end-fire antennas. Each end-fire antenna consists of 4 half-wave folded dipoles spaced by a quarter wavelength and with a phase shift of 90° provided by the transmission line between the elements. The resulting power reception pattern for each feed antenna has a front-to-back ratio of approximately 20 dB and a 28 dB minimum toward the horizon to reduce reception of local interference. The feed will provide approximately a cosine squared distribution of field across the aperture of the 50 ft dishes. The illumination at the edge of the reflector is -10 dB.

Open wire transmission lines to the dishes are being installed. Each column of 4 dishes in the North-South direction is connected to a central point via the equal length transmission lines. At the central point the 4 signals thus obtained can be combined to give a multibeam response for the entire array.

A ten-channel receiver has been designed and is being built. It employs a 100-kHz bandwidth for each channel and covers a 1-MHz band at 143 MHz, the selected observing frequency.

B. F. Burke, R. M. Price, M. S. Ewing

B. MILLIMETER-WAVE ABSORPTION BY ATMOSPHERIC OXYGEN

The atmospheric oxygen program[1-5] has been continued during the past year. There have been four flights of the previously described balloon-borne radiometer.[2] See Table VII-1 for general information on the flights. Two flights were made with the antenna axes pointing upward at zenith angles of 60° and 75° to measure the absorption line shape. Two other flights were made with the antennas pointing downward at nadir angles of 0° and 60° in an attempt to obtain data that could be used to infer the atmospheric temperature profile. In all flights the local-oscillator frequency was 64.681 GHz, corresponding to the 21+ oxygen resonance (64.687 GHz). Three intermediate frequencies were used, 20, 60, and 275 MHz. Only the first of these flights has been analyzed

Table VII-1. General flight information.

Flight #	Date	L.O. Frequency	Float Altitude	Descent	Purpose	Comments
380-P	Feb 12 1968	64.681 GHz	30 km	valve (slow)	To investigate atmospheric absorptions near 21^+ O_2 line	Good flight 5 hours
381-P	Feb 24 1968	64.681 GHz	30 km	valve (slow)	same	Good flight 5 hours
406-P	Jun 27 1968	64.681 GHz	36 km	parachute (fast)	To measure atmospheric temperature profile below balloon	Interference problem on 20 mc otherwise good 9 hours
408-P	Jul 5 1968	64.681 GHz	35 km	parachute (fast)	same	lost local oscillator after 2 hours

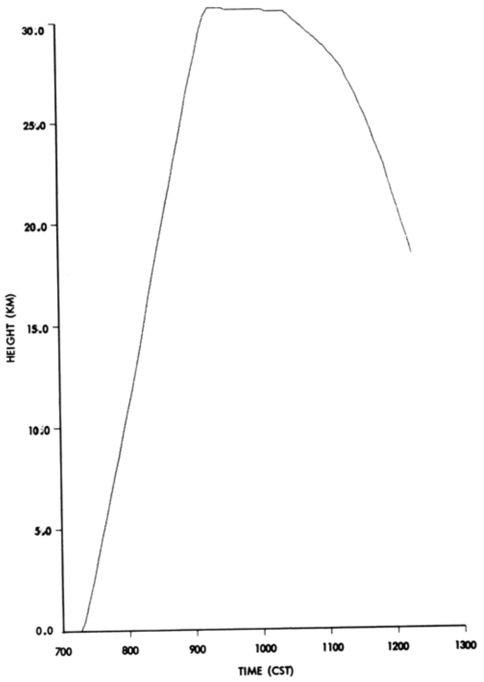

Fig. VII-1. Height vs time, Balloon Flight 380-P.

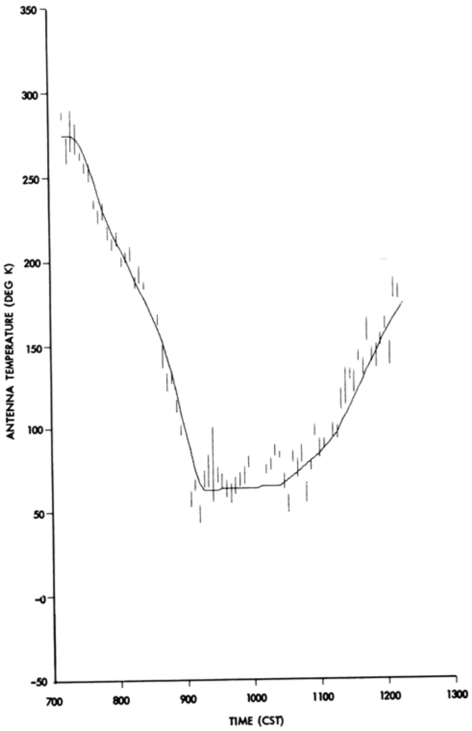

Fig. VII-2. Antenna temperature vs time 20-cm channel, 60° Antenna Flight 380-P.

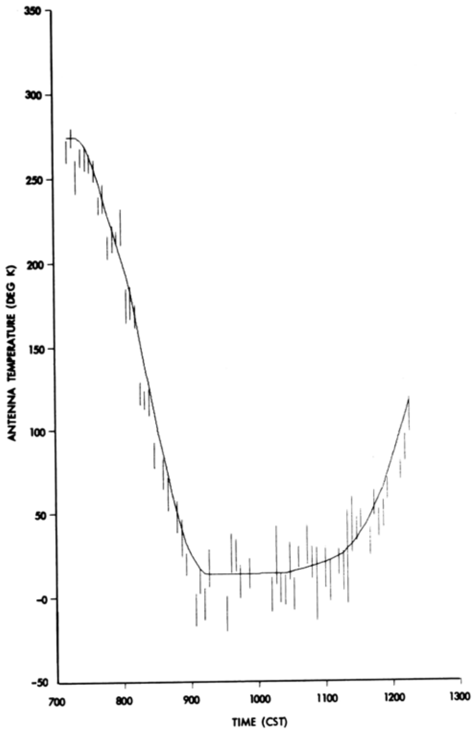

Fig. VII-3. Antenna temperature vs time 60-MHz channel, 60° Antenna Flight 380-P.

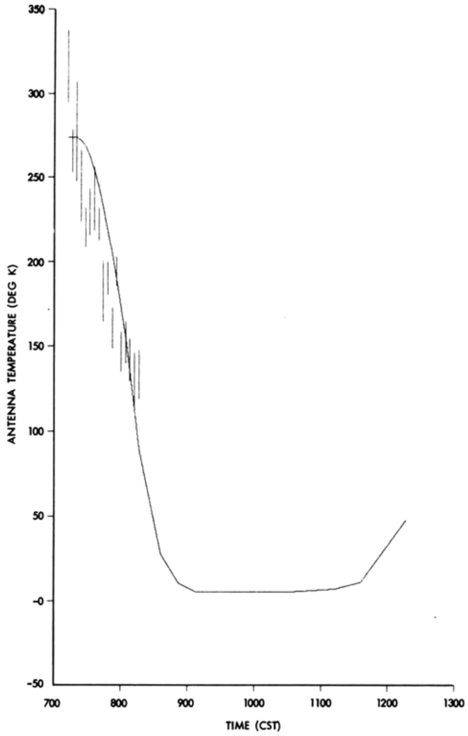

Fig. VII-4. Antenna temperature vs time 275-MHz channel, 60° Antenna Flight 380-P.

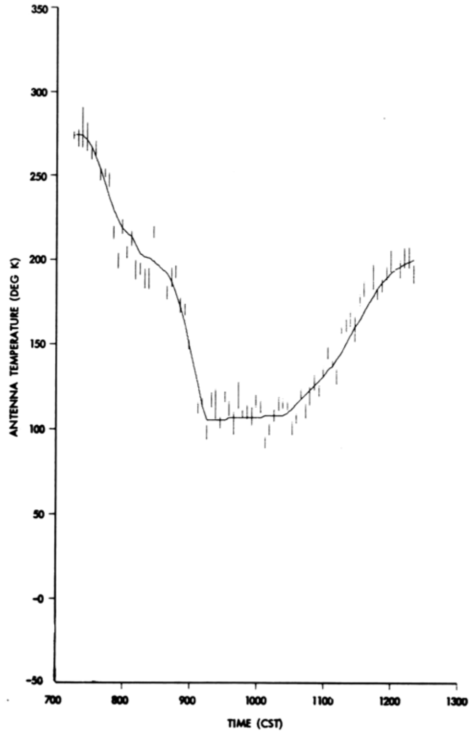

Fig. VII-5. Antenna temperature vs time 20-MHz channel, 75° Antenna Flight 380-P.

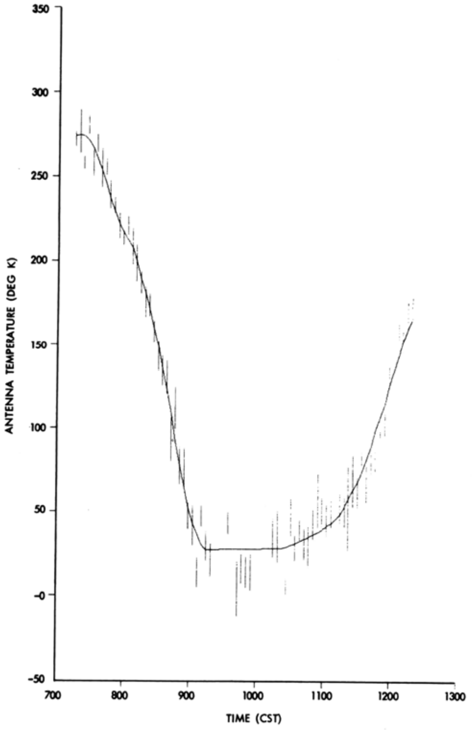

Fig. VII-6. Antenna temperature vs time 60-MHz channel, 75° Antenna Flight 380-P.

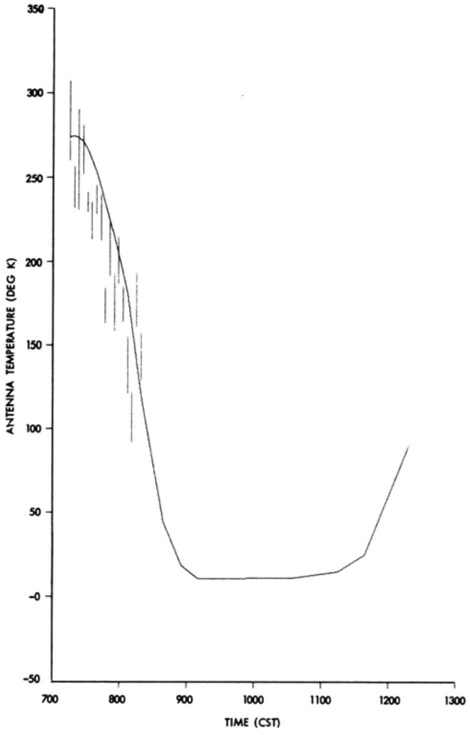

Fig. VII-7. Antenna temperature vs time 275-MHz channel, 75° Antenna Flight 380-P.

enough to be worth discussing now.

Meeks and Lilley[6] compared the absorption data then available (1962) with the Van Vleck-Weisskopf[7] theory and found that agreement required a pressure-broadened linewidth, δ, not quite proportional to the pressure, P. Rather, they found it depended on altitude, h, in the following way.

$$\delta = \alpha g(h)\, p\left(\frac{300}{T}\right)^{.85}$$

$$g(h) = a \qquad h \leqslant H_1$$

$$g(h) = a + (1-a)(h-H_1)(H_2-H_1) \qquad H_1 \geqslant h \geqslant H_2$$

$$g(h) = 1 \qquad h \geqslant H_2$$

where T is the temperature in degrees Kelvin.

The values that Meeks and Lilley found to agree with the data are

$a = 0.51$

$H_1 = 8$ km

$H_2 = 25$ km

$\alpha = 1.55$ MHz/Torr.

Carter, Mitchell, and Reber[8] have done an extensive series of solar extinction measurements between 53.4 GHz and 56.4 GHz from various altitudes 0 to 14.75 km. They find results similar to those of Meeks and Lilley. They find good fit with the values

$a = 0.476$

$H_1 = 8$ km

$H_2 = 25$ km

$\alpha = 1.86$ MHz/Torr.

Their value for α is considerably larger than the Meeks and Lilley value.

In the present experiment, we measure the thermal radiation from the Earth's atmosphere as a function of height from 0 to 30 km at frequencies approximately 20, 60, and 275 MHz removed from the center frequency of the 21+ oxygen line (64.687 GHz), and at antenna zenith angles of 60° and 75°. The radiometer was continuously calibrated throughout the flight by cyclically switching the radiometer input in the order: 60° antenna, hot calibration load, cold calibration load, 75° antenna, with a 4-min period. The effective temperatures of these loads differ from their physical temperatures because of losses and reflections in the waveguides and the switches, and are, in general, different for the two antennas. The radiometer was calibrated on the ground to determine these effective temperatures, but the uncertainty in the cold-load temperature was still large. During Flight 380-P some 5 hours of data was obtained. On account of malfunctions of the equipment, some of these data had to be rejected.

The data were edited for self-consistency and the points inconsistent with the bulk of the data were rejected. The 20-MHz channel worked extremely well, and 93.5% of its data was retained. The 60-MHz channel was noisy, but 83.8% of its data was useful. The 275-MHz channel was extremely noisy and degenerated into complete nonsense after approximately an hour and a half into the flight. Only the first 22.1% of its data was kept.

Coincidentally with the flight, radiosondes were launched from the N.C.A.R. Balloon Base in Palestine, Texas, and from 3 downrange sites, Shreveport, Louisiana, Lake Charles, Louisiana, and Jackson, Mississippi. By using the atmospheric temperature profiles thus obtained and the measured antenna patterns, it was possible to calculate, on the IBM System 360, antenna temperatures as a function of height for various models. Thus far, they have been calculated for $a = 1$ and $a = 0.51$ (the Meeks and Lilley value), for a range of values of α.

Since the cold-calibration temperatures were uncertain, they had to be determined by comparing the data with each theory. The calibration temperatures were chosen to minimize the ratio of the mean-square error to the mean-square signal noise. We shall call the square root of this quantity the "normalized error." The best fit for the $a = 1$ model was obtained for $\alpha = 1.60$ GHz/Torr and gave a normalized error of 1.91408 (12.7°K). The $a = 0.51$ (Meeks and Lilley) model gave a best fit of 1.853 (12.2°K) for $\alpha = 1.65$ MHz/Torr. For the Meeks and Lilley value of 1.55 MHz/Torr we obtain a normalized error of 1.8577. No calculations have been done for the $a = 0.468$ (Carter-Mitchell-Reber) model, but it is not expected to be significantly different. For their value of (1.86 MHz/Torr) and $a = 0.51$, however, the relative error is 1.8664.

The statistical error analysis for this experiment is not trivial and has not been done yet. At any rate, it appears that the Meeks and Lilley model is substantially correct. The value of α may be slightly larger than theirs, but probably not as large as the Carter-Mitchell-Reber value.

The experimental data, fitted to the $\alpha = 1.65$ MHz/Torr, $a = 0.51$ theory, are shown in Figs. VII-1 through VII-7.

T. T. Wilheit, Jr., A. H. Barrett

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