FINAL REPORT TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NSG-615

by:

W. C. Erickson

UNIVERSITY OF MARYLAND

DEPARTMENT OF PHYSICS AND ASTRONOMY

COLLEGE PARK, MARYLAND

This grant reimburses expenses incurred by the University of Maryland in carrying out a cooperative program of long wavelength radio astronomy research with staff members of the Goddard Space Flight Center. The grant has also enabled the University of Maryland to employ Professor M. M. Komesaroff who is on leave from the Commonwealth Scientific and Industrial Research Organization in Sydney, Australia. As a Visiting Professor on the University of Maryland faculty, Mr. Komesaroff has participated in the program. During the first half of the year, Professor Komesaroff completed the reduction of a 408 Mc sky survey which he obtained in Australia with the 210' Parkes radio telescope. A pre-print of the paper which he is publishing concerning this work was submitted as a part of the last semi-annual progress report. Among other things, he has also engaged in a study of the theory of Jupiter's decimetric radiation. In particular, he has been exploring certain ideas to explain the spectrum of Jupiter's emission by means of the synchrotron theory. He has also carried out a study of supernova remnants at decameter wavelengths using the Clark Lake Radio Telescope. Most of the data for this study have been obtained, but the reduction of these data is not yet complete.

On the instrumental side he has been studying the response pattern of the Clark Lake antenna in considerable detail, both from the theoretical and from the experimental point of view. The purpose of this work is to understand in detail to what extent the predicted response pattern of large arrays can be obtained in practice. Of course, we also hope that it may be possible to reduce the sidelobe levels of the Clark Lake antenna through this detailed study.

Recently, Professor Komesaroff has designed and built a test element for a new type of steerable antenna. In this antenna the radiating elements are illuminated by a traveling wave feed line. In order to steer the response pattern of such an antenna it is necessary to produce a uniform phase gradient along all of the elements. This can be done by modifying the phase velocity of the exciting wave on the feed line. Professor Komesaroff's method of modifying a phase velocity is to load the line with varactor diodes. The capacitance of these diodes can be modified by applying a DC potential to the feed line. Thus, the pattern of the antenna can be shifted in position by simply controlling the DC potential applied to the feed line. Of course, the capacitance of the varactors also effects the impedence of the line to a small extent. The modification of the impedence in not violent, however, since an array of elements placed at half-wave intervals along the feed line can be made to sweep from horizon to horizon by only a modification in feed line impedence by $\sqrt{2}$. Professor Komesaroff has constructed such an antenna at Clark Lake. Through radio star observations he has demonstrated the ability to sweep the response pattern of this element through large angles, and the element appears to operate almost exactly as he predicts theoretically. We next plan to construct a small Mill's Cross antenna with arms steerable in each direction in order to produce a fully steerable array. This small Mill's Cross will be a prototype for a large fully steerable array which we hope to build in the future.

During this year, Professor Komesaroff attended conferences on planetary radio astronomy at Arecibo, Puerto Rico, and at the California Institute of Technology, and he attended the meeting of the American Astronomical Society at Ann Arbor, Michigan.

During this year Professor Erickson has been engaged primarily in observational work with the Clark Lake Radio Telescope. However, he has also studied some of the questions of interest in the design of space radio telescopes for radio source observation. In particular, he has studied the question of the maximum resolution of a radio telescope imposed by coronal scattering. A paper concerning this work is in publication, and a preprint was submitted with the last semi-annual progress report. He has also been studying various questions concerning the spectra of radio sources at very long wavelengths. The fact that radio source spectra may be expected to turn down at long wavelengths may limit greatly the usefullness of radio telescopes in the megacycle range of frequency. Finally, he has been studying the possibility of solar interferometric work at very long wavelengths, either from space or from the surface of the moon.

On the instrumental side we have been cooperating with the Goddard Space Flight Center in the construction of an array of 16 fully steerable log periodic antennas. This array is under construction at Clark Lake. When completed, it should provide an excellent picture of the spectral and angular structure of solar bursts in the frequency range of 20 to 60 Mc.

In order to explore the possibilities of ground based observations at long wavelengths we have extended the baseline of the Clark Lake antenna to four miles by placing extra elements off its eastern end. When we phase switch between these extensions and the main array we produce a fan beam of 4' resolution. This 4' resolution system operates very satisfactorily, and we will use it in the near future to observe a number of radio sources. We have been pleased to find that ionospheric scintillations disturb the observations with the 4' antenna no more than they disturb observations with 14' beamwidth system. Apparently, if an antenna is sufficiently large it averages over the variations in the wave front which are imposed by the ionospheric irregularities, and the resulting scintillation level is as low as that found with a smaller antenna. There appears to be no particular limitation on the resolution which can be obtained at our wavelength of 11.4 m. The only limitations are those of the topography of the earth, and our ability to extend antennas over exceedingly large baselines. Tracings of the observed and predicted response pattern of the 4' array are shown in Appendix III.

This grant also supported one graduate research assistant, Mr. Bruce Gotwols. A large fraction of Mr. Gotwols' time during this year was devoted to the reduction of lunar occultation observations obtained by Professor Erickson and Professor Owren of the University of Alaska. These observations were obtained with a special 26 Mc array which was constructed at College, Alaska, and with interferometers which are normally used for radio star scintillation studies at the University of Alaska. A paper reporting the results of these observations is included as Appendix I of this report.

We have continued our cooperative program of Jupiter observations with the Goddard staff. Since Jupiter and the radio source Tau A are in conjunction this year, we have been particularly interested in obtaining accurate positional information on Jupiter bursts by comparing their positions with the position of Tau A. We have also been attempting to find the decametric tail of the decimeter spectrum of Jupiter. Unfortunately, the Tau A sidelobes have interferred with this program, and it will probably be necessary to repeat the observations at some later date. Finally, we are cooperating in studies of interplanetary scintillations with the Clark Lake antenna, and in studies of solar radio emission. The solar emission studies have resulted in the paper enclosed as Appendix II. This paper is largely a result of Mrs. Malitson's work in the reduction of Clark Lake observations obtained during the summer of 1963.

Since the Astronomy Program at the University of Maryland is only a few years old, we have not yet granted our first Ph.D. Several students are involved in the work at Clark Lake, but none have completed all course work and Ph.D. qualifying examinations. Mr. Gotwols expects to complete his Master's degree requirements shortly. He then plans to join the Goddard staff and continue his Ph.D. studies on a part-time basis.

The normal operating expenses of the Clark Lake Radio Observatory are covered by a grant from the National Science Foundation. However, this grant from the National Aeronautics and Space Administration has allowed us to undertake programs which would have otherwise been impossible, and to cooperate with the Goddard staff in mutually beneficial studies of long wavelength radio astronomy.

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TWO LUNAR OCCULTATIONS OF THE CRAB NEBULA

N66-22168

B. L. Gotwols and W. C. Erickson

Department of Physics and Astronomy
University of Maryland
College Park, Maryland

E. Fremouw and L. Owren†

Geophysical Institute of the University of Alaska
College, Alaska

† Presently at Dartmouth College, Hanover, New Hampshire

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

Introduction

Due to the precession of the moon's orbit it is possible to observe a series of lunar occultations of Taurus A at intervals of approximately nine years. The first series of occultations to be observed at radio wavelengths was observed from November 1955 through January 1956.[1,2,3] Owing to the high resolution attainable by this technique it was possible to obtain brightness distributions at several frequencies. The main conclusions which were drawn from this series of occultations were that there was an increase of the source size with decreasing frequency and a progressive westward shift of the radio center with decreasing frequency.

More complete observations[4,5] have been carried out during the most recent occultation series, with the intention of increasing the frequency range and especially testing the conclusions drawn from the 1955-56 observations.

Observations

Two lunar occultations of the Crab Nebula were observed from College, Alaska. One occurred on May 14, 1964, and the other on July 7, 1964. Interferometer observations were attempted on four frequencies during each occultation. In May, the observing frequencies were 26,68, 223, and 456 MHz. In July, the 68 MHz instrument was replaced with one operating at 136 MHz because of solar contamination in the beam of the 68 MHz antenna. Transmission lines were not available for observation on all five frequencies simultaneously.

Unfortunately an ionospheric disturbance began shortly before the May 14th occultation, seriously impairing the quality of the lower frequency data. During the July 7th event, the 26 MHz antenna did not function properly.

The circumstances of the occultations are exhibited in Fig. 1.

Apparatus

Instrument characteristics are summarized in Table I.

TABLE I

ANTENNA AND RECEIVER DESCRIPTION

Frequency	Basic Antenna	Interferometer Spacing
26.3 MHz	11 dipoles 1λ long with $\lambda/2$ spacing Dipoles polarized E-W Array axis N-S	18.9λ E-W
68 MHz	Four-Bay Yagi, equatorially mounted	49.8λ E-W
136.5 MHz	Four-Bay Yagi, equatorially mounted	150.2λ E-W
223 MHz	28 ft. parabolic reflector, equatorially mounted	68.0λ E-W
456 MHz	Same as 223 MHz	138.9λ E-W

OCCULTATION OF MAY 14, 1964

Data Reduction

The frequencies monitored on the May occultation were 26.3, 68, 223, and 456 MHz. Facsimilies of the original records are shown in Fig. 2. On the 26.3 and 68 MHz receivers, the relative phases of the antennas were shifted by 90° at 30^s intervals to provide information concerning both the sine and cosine components of the correlated signal. These two independent sets of data were filled in by linear interpolation and slightly smoothed by eye. For the 223 and 456 MHz records only one component of the signal was recorded, and there was no need to smooth the records.

Observations were made of the Crab Nebula on the day following the occultation in order to have a comparison record without the presence of the moon. At 26 MHz a useable record could not be obtained until May 19, 1964, due to scintillations. The flux densities (in arbitrary units) as derived from the interferometer records are shown in Fig. 3. The flux densities at 26.3 and 68 MHz were obtained by the following technique:

$$F(t) = [(Y_c(t) - B_c(t))^2 + (Y_s(t) - B_s(t))^2]^{\frac{1}{2}}$$

where $Y_c(t)$ = recorder deflection for the cosine signal

$Y_s(t)$ = recorder deflection for the sine signal

$B_c(t)$ = center-line for cosine signal determined by least square fitting

$B_s(t)$ = center-line for sine signal determined by least square fitting.

Values of $F(t)$ were determined every 30 seconds, and the average of $F(t)$ over a standard 20^m interval outside the occultation was set equal to unity.

Due to the absence of sine component records on 223 and 456 MHz, the flux density was extracted from the data through measurement of only the positive and negative peak deflections. The following method was employed:

$$F(\bar{t}_n) = Y(t_n) - Y(t_{n+1})$$

where $Y(t_n)$ = recorder deflection at the extremum time t_n

$Y(t_{n+1})$ = recorder deflection at the extremum time t_{n+1}

t_n = time of the n^{th} extremum

$\bar{t}_n = (t_{n+1} - t_n)/2$.

Thus the time resolution of the flux density at the two higher frequencies is two points per cycle of the interferometer signal. Finally, the average of $F(\bar{t}_n)$ over the standard interval was set equal to unity.

Because of the limited time resolution of the equipment the angular resolution obtainable from the data is only $\sim 0.3'$ to $0.7'$. Thus diffraction effects are negligible, and it is possible to analyze the flux density curve in the geometrical optics limit. A reasonable approximation to the strip brightness distribution is obtained simply by differentiating the occultation curve. Fig. 4 shows the result of a least squares determination of $|\frac{dF}{dt}|$ at

223 and 456 MHz. The 26 and 68 MHz curves displayed too much scintillation for this technique to be employed.

Interesting Features

One startling feature which is clearly evident at both 26 and 68 MHz is that the flux does not decrease to zero at any time during the occultation. Two possible explanations are (1) other sources were simultaneously present in the antenna beam, and (2) the Crab is so large that an appreciable part of it protruded from behind the moon even during optical totality.

Examination of the 68 MHz comparison curve (Fig. 3) reveals a distinct oscillation of variable period. The pattern may be explained easily as being the beat between the signals from the Sun and Tau A. Thus, explanation (1) seems to be entirely adequate in explaining the high residual flux during the central portion of the occultation.

The 26 MHz record does not permit such a simple explanation. Three possible sources of interference were considered: IC 443, 3C 123, and the Sun. The position of each of these sources was plotted with respect to the antenna response pattern. Inspection of the resulting graph showed that interference might be expected from IC 443 and 3C 123. The interference from the Sun appeared to be negligible. The suspicion that IC 443 and 3C 123 caused the interference was confirmed when a simulated occultation was computed. As shown in Fig. 5, a pattern which is a reasonable approximation of the observed record was predicted by removal of the Tau A flux during the occultation period. Thus, explanation (1) again appears to explain the apparently incomplete occultation.

The approximate strip brightness distributions shown in Fig. 4 indicate no appreciable difference in the angular size of the source at 223 and 456 MHz. The radio centers are approximately coincident with the optical center. The apparent scatter of the centers is on the order of the resolution imposed by the interferometer patterns.

OCCULTATION OF JULY 7, 1964

Data Reduction

The reduction of the 136, 223, and 456 MHz records proceeded in exactly the same fashion as for the 223 and 456 MHz records obtained in May. Unfortunately the 136 MHz observation was hindered by the presence of a satellite which was broadcasting during the critical portion of egress. Another problem was that a useable 456 MHz comparison record could not be obtained because of a source of continuing interference.

Fig. 6 presents a facsimilie of the original interferometer records; Fig. 7 shows the flux as deduced from the interferometer records; and Fig. 8 exhibits the strip brightness distribution.

Interesting Features

The angular size of Tau A at 136, 223, and 456 MHz are all comparable. Furthermore, to within the uncertainties imposed by our data reduction techniques, the radio centers are coincident with the optical center.

CONCLUSIONS

Our observations for the frequencies above 100 MHz indicate that the angular size of Tau A is approximately constant with increasing frequency. This is in agreement with Andrew et al[4] and in contradiction to the conclusions drawn from the 1955-56 occultation series.[1,2,3] We also find no shift of the radio centers from the optical center greater than $\sim 0.4'$, which is approximately the uncertainty of our observations.

The observation at 68 MHz was spoiled by solar contamination, and the 26 MHz observation was spoiled by ionospheric scintillation and by interference from IC 443 and 3C 123. Therefore, we are unable to comment upon the possible existence of a compact decametric source[4,6] in Tau A. Since lunar occultations of Tau A are rare but potentially very useful, it is emphasized that future observations at decameter wavelengths must avoid contamination from IC 443 and 3C 123.

We wish to thank W. Nicholson of H. M. Nautical Almanac Office for calculating the circumstances of the occultation. This work was supported by the National Science Foundation under grants NSF-GP-3393 and NSF-GP-169, and by the National Aeronautics and Space Administration under grant NsG-615.

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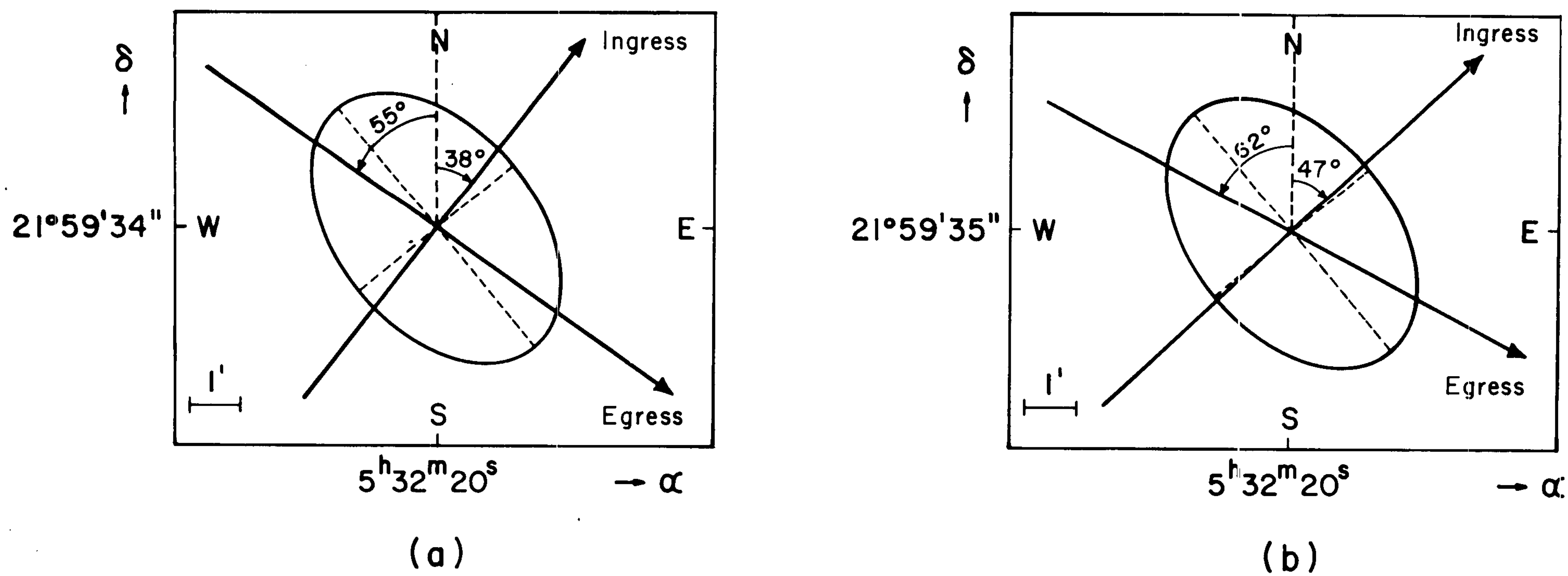


FIG. 1 Velocity of the moon's limb relative to the Crab Nebula,
(a) May 14, 1964 (b) July 7, 1964.

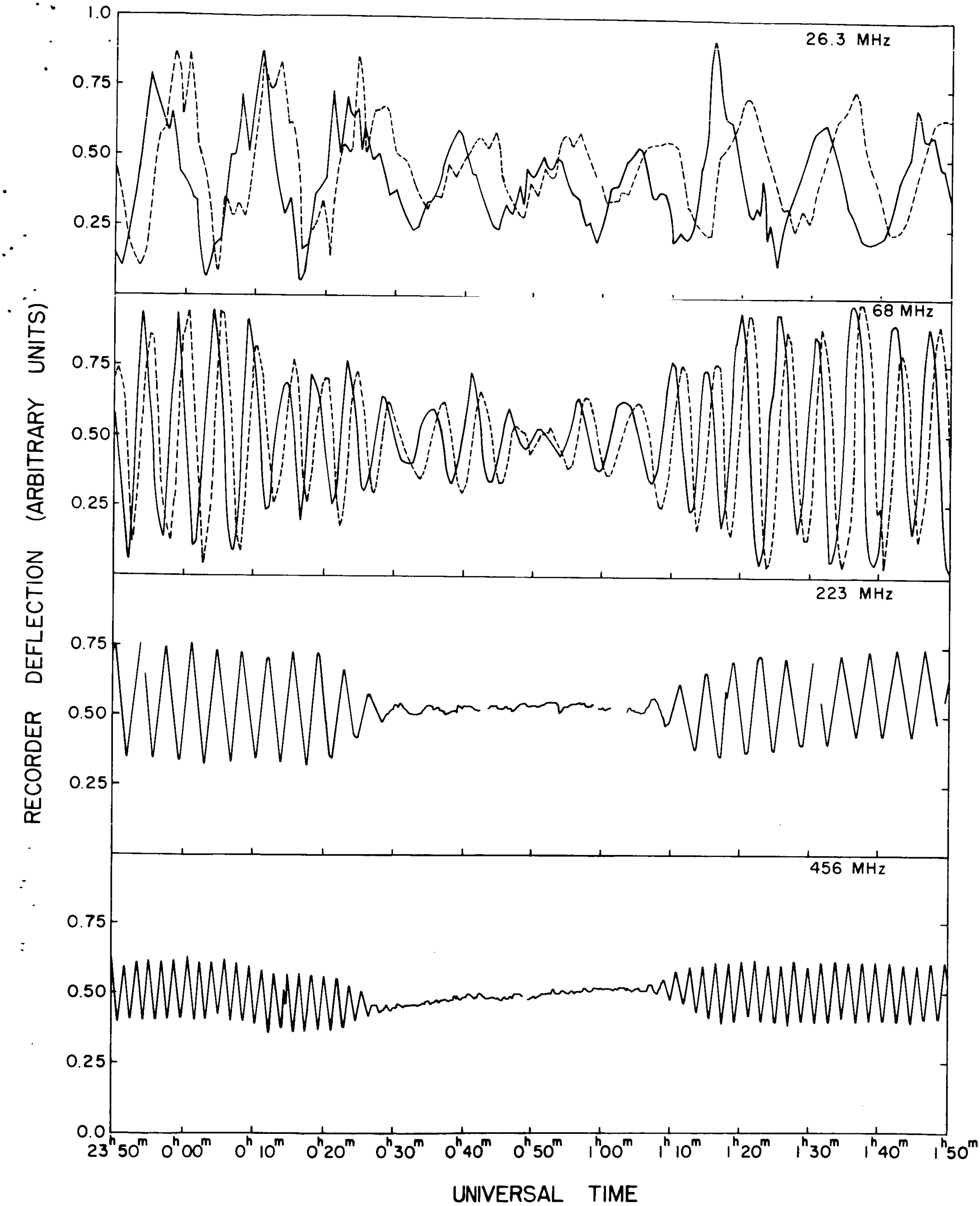


FIG. 2 Fascimilies of the original interferometer records for May 14, 1964.

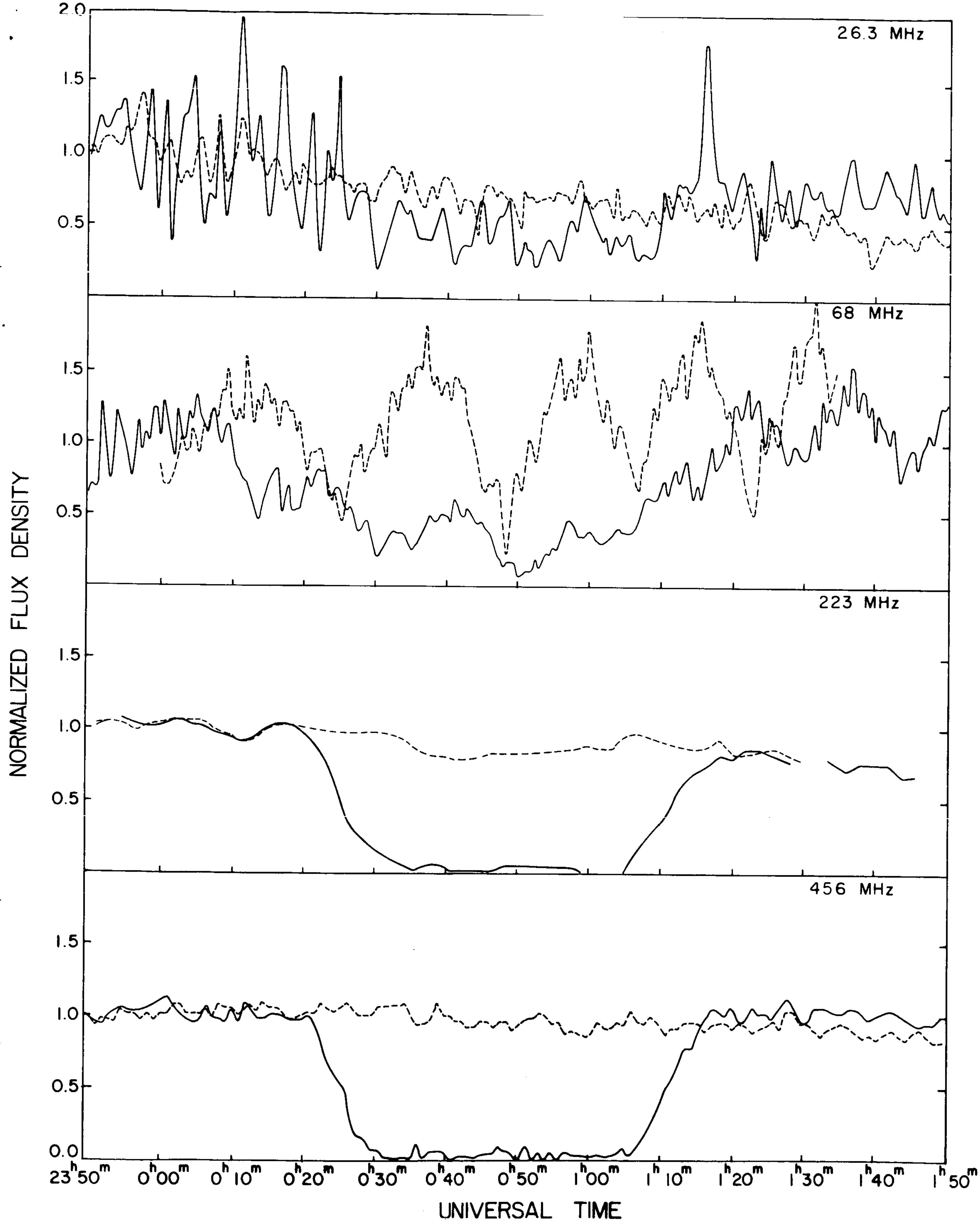


FIG. 3 Normalized flux densities calculated from the May occultation and comparison records. ———, occultation; -----, comparison.

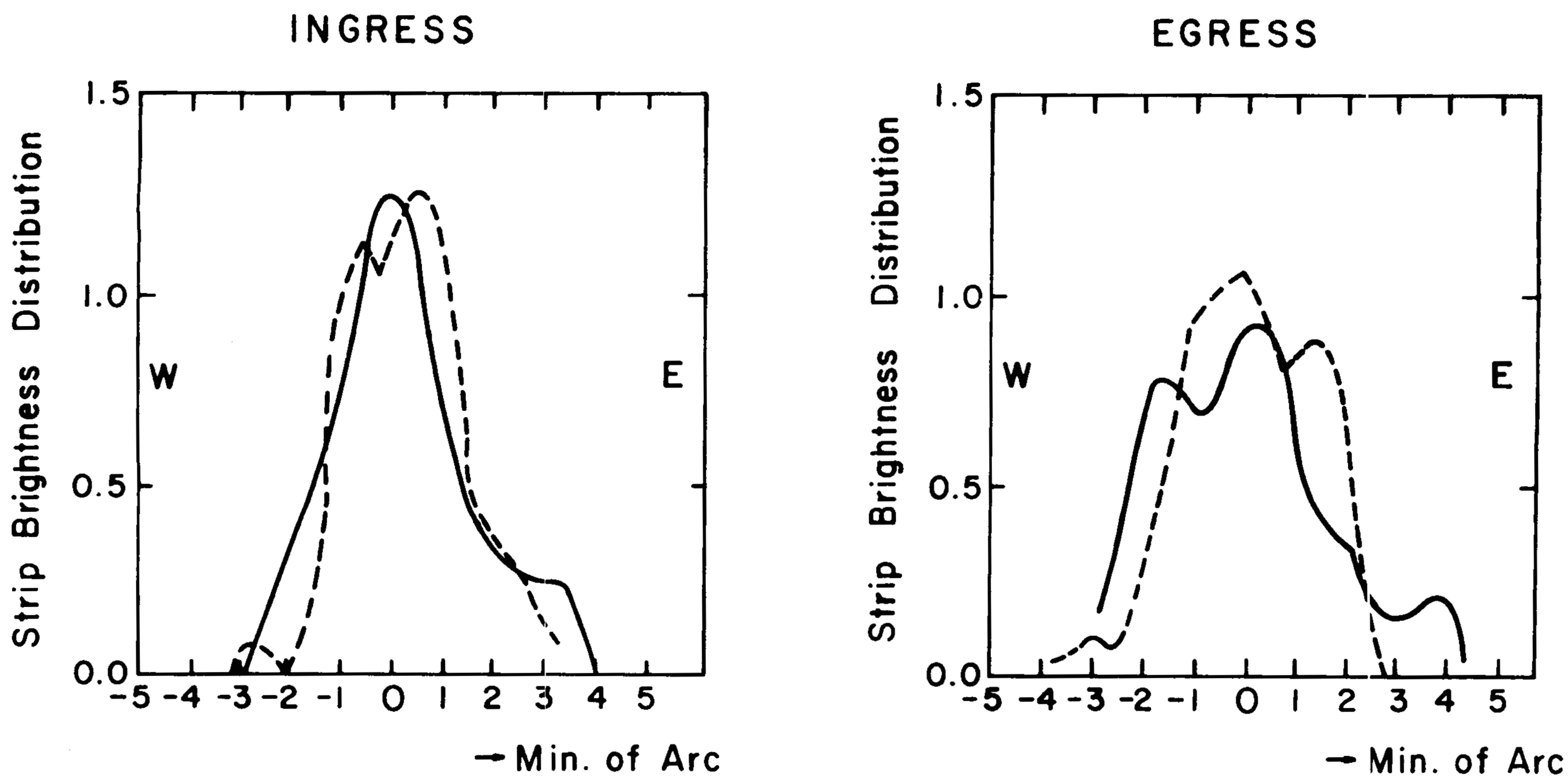


FIG. 4 Approximate strip brightness distribution from the occultation of May 14, 1964.
———, 223 MHz; -----, 456 MHz.

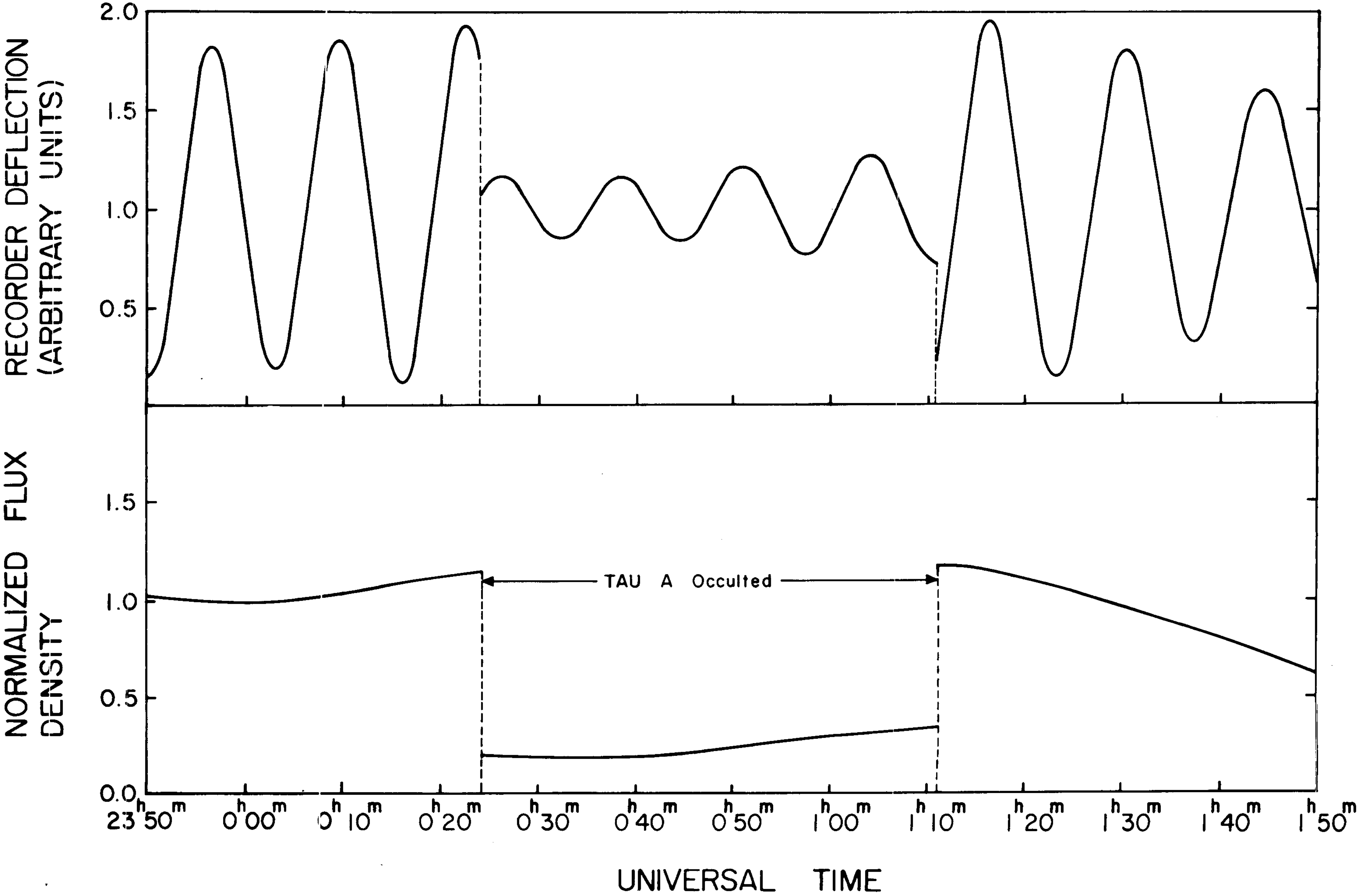


FIG. 5 Simulated occultation of Tau A for May 14, 1965 at 26.3 MHz. Top - Interferometer record (cosine component) produced by combination of Tau A, IC 443 and 3C 123. Compare with Fig. 2. Bottom - Normalized flux density. Compare with Fig. 3.

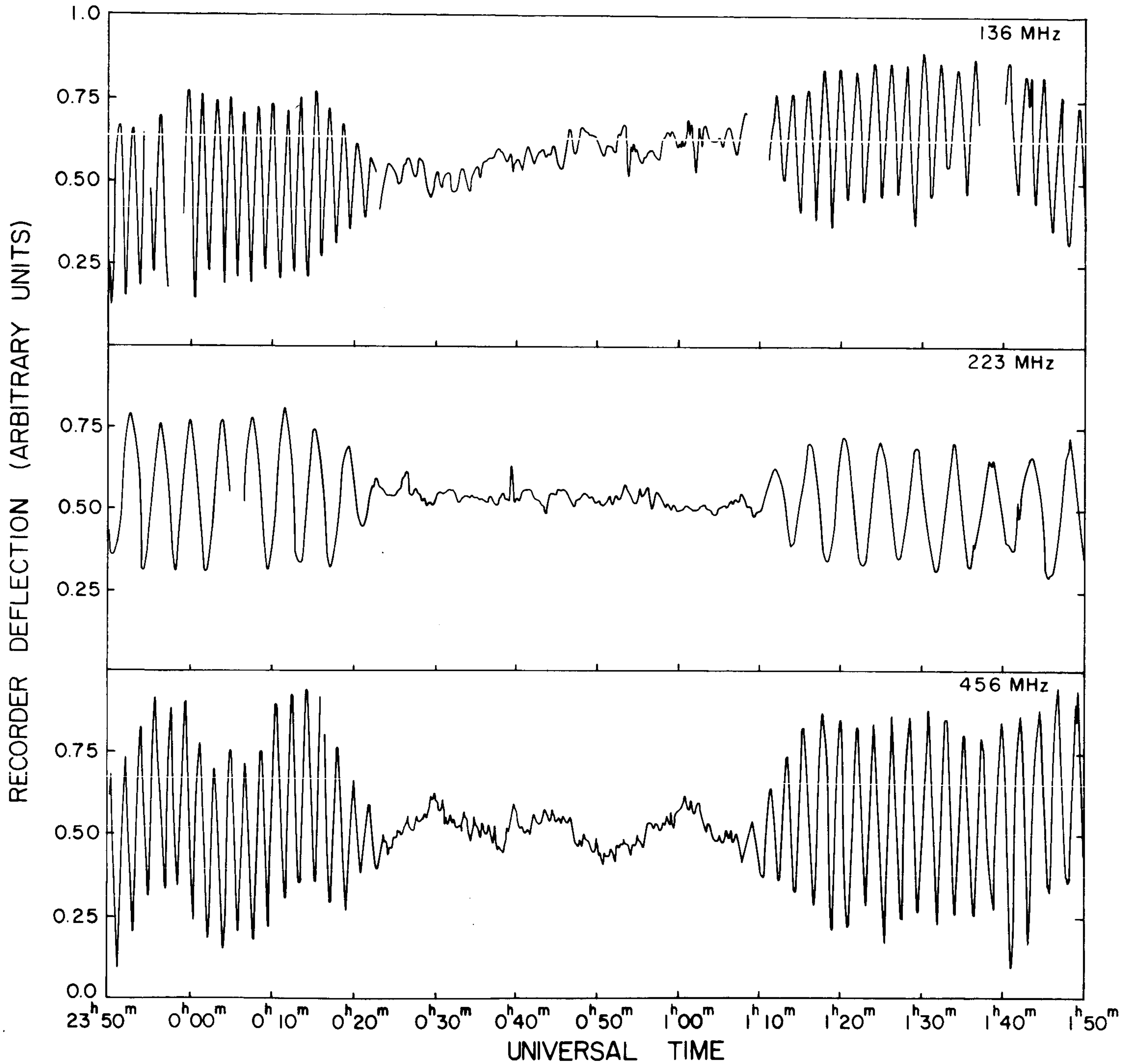


FIG. 6 Fascimilie of the original interferometer records for July 7, 1964.

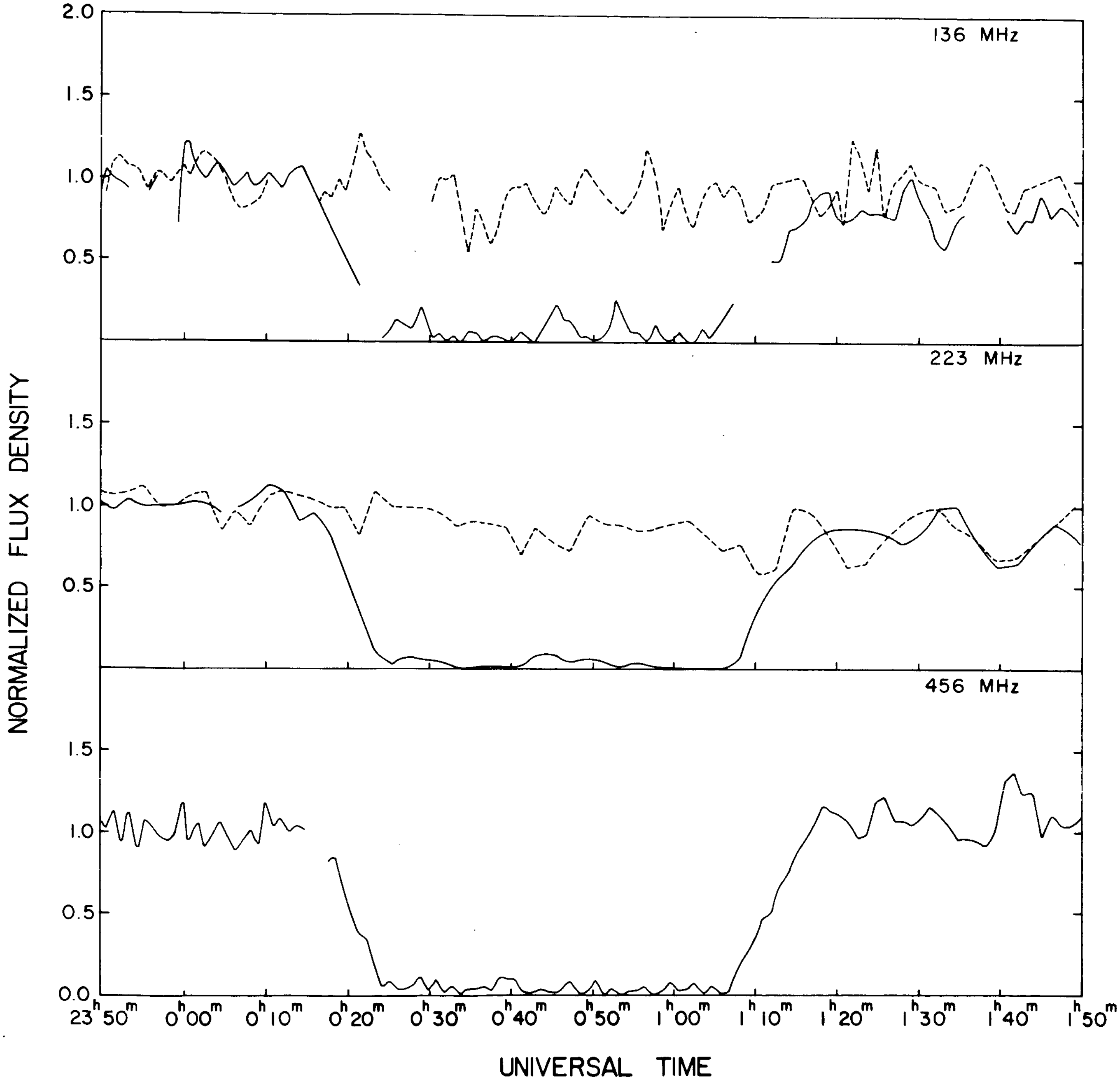


FIG. 7 Normalized flux densities calculated from the July occultation and comparison records. ———, occultation; -----, comparison.

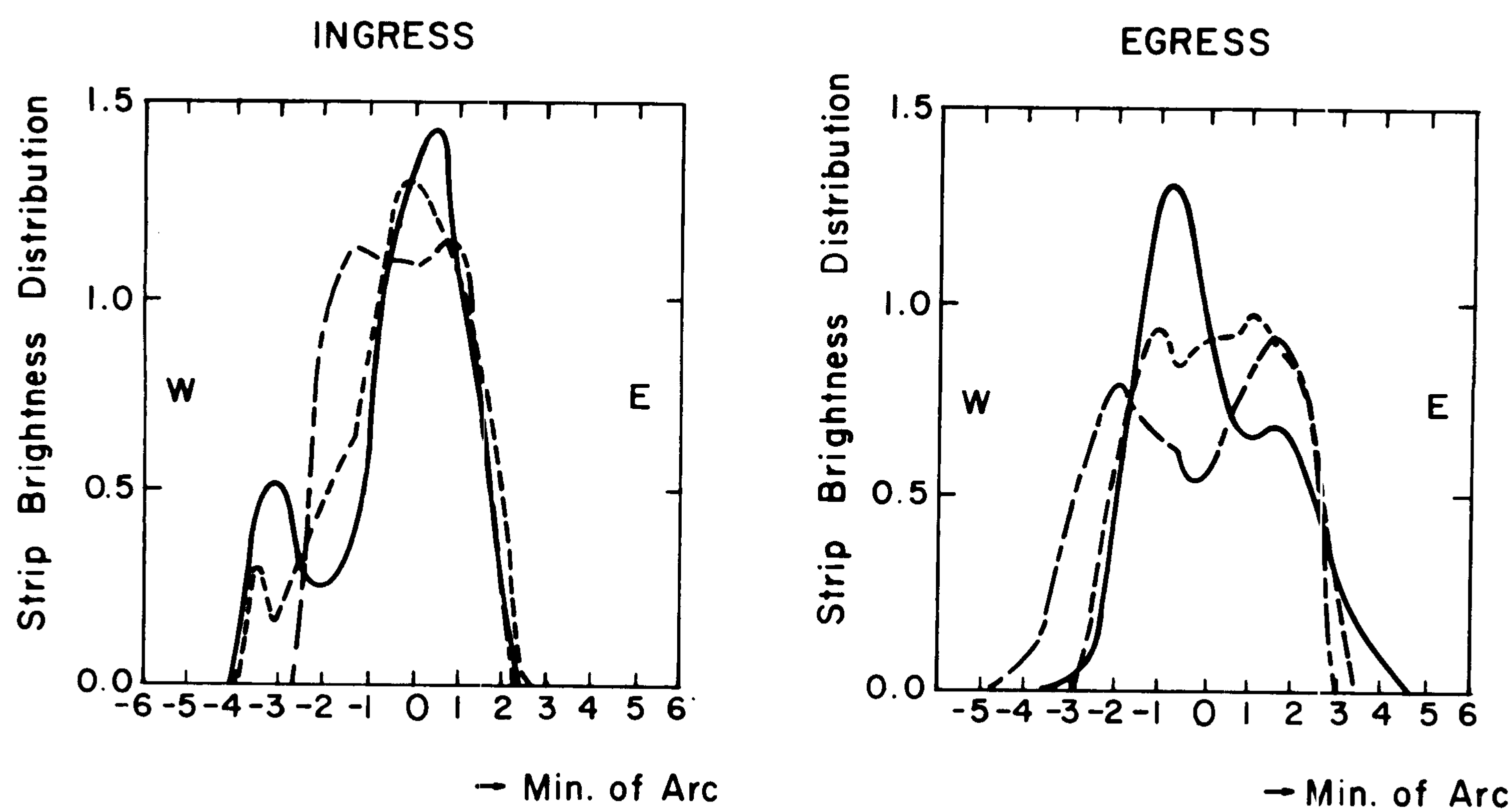


FIG. 8 Approximate strip brightness distributions from the occultation of July 7, 1964.
, 136 MHz; ———, 223 MHz; -----, 456 MHz.

N66-22169

11.4 METER WAVELENGTH OBSERVATIONS
WITH 4 ARC MINUTE RESOLUTION

W. C. Erickson

The two-mile E-W grating array of the Clark Lake Antenna (Erickson, 1964) has been extended to approximately four miles by installing extra elements off its eastern end. The extended array consists of a pair of colinear elements just east of the grating array, and another pair two miles further east. When the signals from the extended array and the grating array are correlated, we predict a response in the E-W direction proportional to

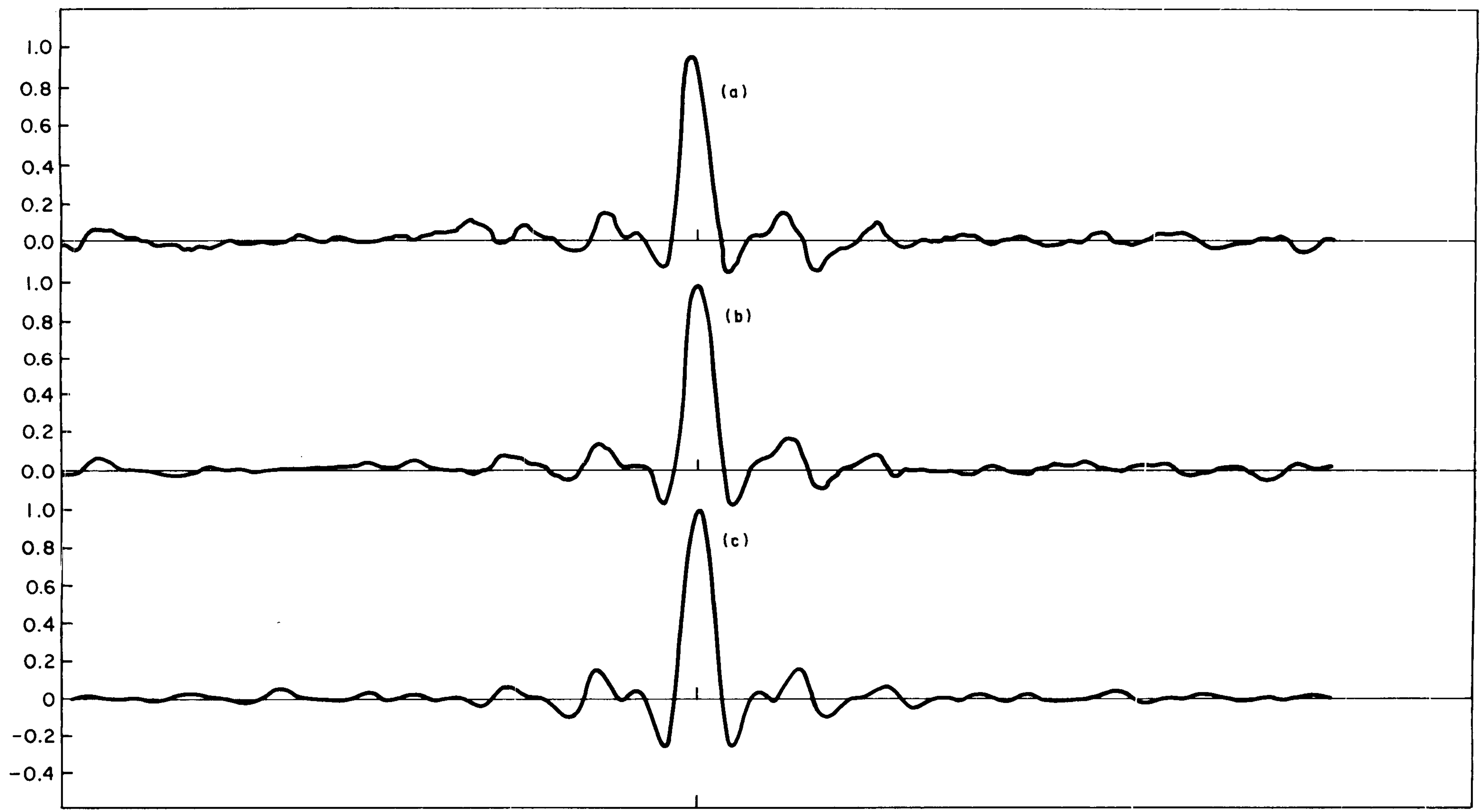
$$V = \frac{[\sin(2n + 16\theta) - \sin(2n\theta) + \sin(16\theta)]}{64 \sin \frac{\theta}{2}} \qquad (1)$$

where n is a parameter proportional to the separation between the pairs of elements of the extended array. Originally, we had hoped to make $n = 8.0$ which would have yielded a $\frac{\sin(64x)}{64 \sin x}$ pattern of 3'.5 halfwidth. However, because of the terrain at the site, this was impossible and we were forced to make $n = 5.85$. This yields a fan-beam pattern of 4'.0 halfwidth E-W and 3° halfwidth N-S.

On the afternoons of November 11, 1965 and November 13, 1965, transits of Cyg A through this pattern were observed. They are shown in Figs. (a) and (b). For comparison, a graph of Eqn. (1) with $n = 5.85$ is shown in Fig. (c). The curves are seen to be almost identical. Analysis of a number of such transits yields an average observed half-width of 4'.5. Assuming Cyg A to be 2' wide, this observed broadening from 4'.0 to 4.5' is precisely what we should expect if the antenna operated according to theory.

Ionospheric scintillations appear to disturb observations with the four mile antenna no more severely than they disturb work with smaller antennas. Since rays traversing the ionosphere at four mile spacings encounter nearly uncorrelated ionospheric irregularities, there appears to be no particular limit to the resolution obtainable with arrays at this wavelength. The signals appear to maintain good phase correlation over long baselines, and beamwidths considerably less than 4'.0 should be entirely feasible.

Erickson, W. C., 1965, I.E.E.E. Trans. on Ant. and Prop., AP-13, 422.



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-0.2
-0.4
(a)
(b)
(c)