05863-12-T

# THE UNIVERSITY OF MICHIGAN


COLLEGE OF ENGINEERING
DEPARTMENT OF AEROSPACE ENGINEERING
HIGH ALTITUDE ENGINEERING LABORATORY


*Technical Report*

# *A Fourier Transform Spectrometer for the Measurement of Atmospheric Thermal Radiation*


L. W. CHANEY, L. T. LOH, M. T. SURH





*Under contract with:*

National Aeronautics and Space Administration
Contract No. NASr-54(03)
Washington, D. C.

*Administered through:* *May 1967*

OFFICE OF RESEARCH ADMINISTRATION · ANN ARBOR

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# A FOURIER TRANSFORM SPECTROMETER FOR THE MEASUREMENT OF ATMOSPHERIC THERMAL RADIATION

L. W. Chaney, L. T. Loh, M. T. Surh

ORA Project 05863

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## ACKNOWLEDGEMENTS

The work described in this report was successfully completed as a result of the dedicated help of the other members of the laboratory staff. Many thanks go to Fred Bartman who has directed the atmospheric radiation studies as well as being responsible for the balloon flights.

The authors are particularly grateful to the following staff members who participated directly in the instrument development. Douglas Robinson carefully performed the many optical and electrical tests of the components as well as assembling and testing the completed instrument. Donald Bandkau designed many of the mechanical parts and prepared all the required drawings. Gunar Liepins designed the mirror drive magnetic circuit. Wan Lee wrote many of the computer programs and carried out the numerous computations.

Thanks also go to the members of the Goddard Space Flight Center staff who under the direction of Dr. R. A. Hanel designed most of the electronic circuits for the IRIS instrument. Others who contributed to the success of the effort were the balloon flight crew and the Weather Bureau personnel at the National Center for Atmospheric Research Balloon Base in Palestine, Texas.

The work described in this report has been supported by the National Aeronautics and Space Administration Contract NASr-54(03).

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# A FOURIER TRANSFORM SPECTROMETER FOR THE MEASUREMENT OF ATMOSPHERIC THERMAL RADIATION

## I. Introduction

The High Altitude Engineering Laboratory has been engaged for the past few years in developing Fourier transform spectroscopy* for meteorological measurements. The eventual application will be the measurement of the earth's thermal radiation from a satellite and the determination of the temperature structure of the atmosphere. This report is a tabulation of the measurements obtained on a balloon flight at 7 mb altitude May 8, 1966 from Palestine, Texas and a collection of four papers which document the instrument development.

Nine sets of radiation data are presented covering the time from 8:30 EST to 15:11 EST at intervals of approximately 50 minutes. Each data set covers the spectral range from 500 $cm^{-1}$ to 2000 $cm^{-1}$ in 2 $cm^{-1}$ steps. The standard deviation of the measurements is approximately 0.5 ergs $sec^{-1}$ $cm^{-1}$ $sr^{-1}$. This uncertainty is exceeded in the range from 500 $cm^{-1}$ to 550 $cm^{-1}$ due to a drop in instrument sensitivity and in the region from 725 $cm^{-1}$ to 750 $cm^{-1}$ due to external vibration.

The aerial photographs which follow the data tabulation correspond to each data set. The instrument field of view is outlined on each photograph from which an estimate of cloud cover can be made.

* A bibliography at the end of the report lists many of the contributions to the development of Fourier spectroscopy.

The papers reproduced are as follows:

(1) Earth Radiation Measurements by Interferometer from a High Altitude Balloon - presented to the Third Symposium on Remote Sensing of Environment - October 14, 1964, Ann Arbor, Michigan. The paper describes measurements made June 26, 1963 from a high altitude balloon using a Block I-4 interferometer ($5\mu$ to $15\mu$) 50 $cm^{-1}$.

(2) An Infrared Interferometer Spectrometer (IRIS) for Meteorological Studies - presented to the 13th Infrared Information Symposium - October 26, 1965, Pasadena, California. A description is given of the interferometer which was developed in conjunction with Goddard Space Flight Center. The development of this instrument was a direct result of the successful measurements described in the first paper.

(3) The Measurement of the Earth's Thermal Radiation by a Fourier Transform Spectrometer - presented to the American Meteorology Society Symposium on physical processes in the lower atmosphere March 21, 1967, Ann Arbor, Michigan. The installation of the IRIS instrument (described in the second paper) aboard a high altitude balloon is described. Some of the data obtained from the May 8, 1966 flight is presented. The errors both in wavelength and amplitude are discussed and finally a temperature inversion is presented.

(4) Fourier Transform Spectrometer - Radiative Measurements and Temperature Inversion, by L. W. Chaney, S. R. Drayson, and C. Young - published in Applied Optics, February 1967. This paper presents the first data reduced from the May 8, 1966 balloon flight and compares the temperature profile measured by radiosonde with that obtained by an inversion of the Fourier transform spectrometer data.

A paper entitled, "The Determination of Meteorological Variables from Atmospheric Thermal Radiation Measurements," by S. Roland Drayson and Charles Young which presents additional details on the inversion technique was presented to the American Meteorology Symposium March 21, 1965. A paper which expands on the technique is currently being prepared for publication.

## II. Radiation Data Obtained on May 8, 1966 Balloon Flight

The data listed on the next fifteen pages was obtained on May 8, 1966 from a high altitude balloon flight over Palestine, Texas. The balloon float altitude was 110,000 feet and the flight path followed is shown in Figure 6 of Appendix 3.

The time at which the data was taken is listed across the top of each page and the wavenumber in inverse centimeters is listed in the left hand column. The radiation is given in ergs per second per square centimeter per steradian per inverse centimeter and has been written ergs/sec cm str.

Following the data are three pages of photographs which correspond to the data. Although the photographs and the data are listed for the same time, this is not precisely correct. The data for each listed time was recorded over a period of 45 seconds and the photographs were taken once each minute, but not synchronized with the data recording. Hence, there can be up to one minute time displacement between the data recording and the photograph.

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 500 | 105.0 | 107.3 | 105.8 | 105.9 | 106.3 | 102.9 | 106.9 | 102.8 | 106.0 |
| 502 | 100.8 | 103.3 | 102.8 | 102.2 | 104.3 | 100.9 | 103.5 | 102.7 | 103.2 |
| 504 | 100.8 | 102.9 | 101.4 | 102.0 | 104.1 | 99.6 | 103.1 | 102.0 | 101.9 |
| 506 | 101.2 | 103.0 | 101.5 | 102.9 | 102.9 | 99.9 | 103.9 | 101.3 | 101.2 |
| 508 | 101.7 | 103.6 | 103.4 | 103.6 | 103.6 | 101.7 | 104.8 | 99.8 | 102.3 |
| 510 | 104.3 | 107.1 | 106.5 | 104.9 | 106.3 | 103.5 | 106.5 | 99.8 | 105.8 |
| 512 | 106.1 | 109.4 | 107.2 | 105.6 | 111.8 | 104.0 | 107.6 | 100.6 | 107.6 |
| 514 | 105.3 | 108.1 | 106.2 | 104.2 | 111.1 | 104.2 | 107.4 | 102.0 | 107.0 |
| 516 | 101.9 | 102.9 | 101.8 | 100.3 | 106.2 | 101.8 | 104.5 | 101.7 | 103.8 |
| 518 | 99.7 | 99.7 | 98.9 | 97.8 | 103.1 | 99.6 | 103.0 | 100.3 | 101.0 |
| 520 | 103.7 | 103.8 | 102.7 | 100.7 | 106.3 | 102.8 | 106.7 | 102.3 | 104.2 |
| 522 | 107.6 | 108.2 | 106.4 | 104.2 | 110.0 | 105.8 | 109.0 | 103.7 | 107.4 |
| 524 | 105.4 | 107.0 | 106.6 | 104.5 | 109.0 | 105.6 | 108.9 | 104.3 | 107.2 |
| 526 | 104.0 | 105.9 | 106.2 | 104.2 | 107.3 | 104.4 | 108.2 | 104.5 | 105.4 |
| 528 | 108.3 | 109.8 | 109.4 | 107.9 | 109.7 | 105.8 | 109.6 | 105.6 | 107.2 |
| 530 | 113.1 | 115.2 | 117.8 | 114.9 | 118.5 | 114.7 | 111.5 | 114.2 | 112.8 |
| 532 | 113.5 | 117.5 | 118.1 | 115.8 | 119.9 | 115.1 | 114.1 | 114.9 | 114.0 |
| 534 | 110.9 | 112.3 | 111.4 | 114.0 | 117.4 | 113.0 | 111.4 | 113.2 | 111.3 |
| 536 | 109.2 | 110.8 | 109.1 | 110.0 | 114.0 | 107.2 | 110.9 | 109.3 | 107.9 |
| 538 | 110.8 | 112.2 | 110.5 | 113.5 | 114.7 | 111.0 | 111.1 | 109.8 | 109.6 |
| 540 | 111.4 | 112.8 | 113.3 | 113.7 | 117.9 | 113.9 | 117.2 | 110.7 | 110.1 |
| 542 | 110.6 | 111.9 | 110.9 | 109.8 | 113.4 | 113.7 | 112.6 | 110.6 | 108.7 |
| 544 | 107.3 | 109.3 | 109.1 | 108.3 | 109.7 | 108.8 | 110.8 | 107.6 | 107.3 |
| 546 | 103.9 | 105.9 | 105.5 | 105.5 | 107.1 | 106.9 | 108.5 | 105.7 | 105.5 |
| 548 | 104.1 | 107.1 | 105.9 | 106.0 | 108.2 | 107.0 | 108.6 | 106.5 | 106.4 |
| 550 | 107.4 | 110.9 | 108.5 | 109.2 | 111.4 | 109.1 | 110.2 | 107.8 | 108.7 |
| 552 | 108.9 | 113.2 | 114.6 | 113.0 | 117.3 | 114.2 | 111.8 | 114.3 | 111.0 |
| 554 | 110.2 | 114.1 | 113.7 | 113.2 | 114.6 | 114.4 | 111.0 | 114.4 | 110.4 |
| 556 | 112.3 | 115.3 | 115.0 | 114.5 | 118.2 | 114.9 | 113.4 | 114.6 | 109.9 |
| 558 | 114.0 | 119.8 | 120.2 | 120.8 | 121.1 | 119.9 | 118.3 | 119.8 | 113.9 |
| 560 | 114.9 | 120.1 | 121.3 | 121.5 | 121.6 | 120.8 | 119.2 | 119.9 | 114.9 |
| 562 | 114.4 | 114.8 | 118.0 | 114.9 | 119.2 | 118.5 | 116.8 | 115.0 | 114.4 |
| 564 | 111.7 | 112.0 | 111.9 | 110.2 | 114.6 | 114.1 | 110.8 | 110.6 | 109.9 |
| 566 | 108.7 | 109.0 | 108.6 | 108.5 | 110.7 | 109.8 | 109.9 | 107.7 | 109.5 |
| 568 | 105.5 | 105.0 | 105.4 | 105.7 | 107.6 | 107.4 | 107.6 | 106.5 | 106.2 |
| 570 | 107.0 | 106.8 | 106.8 | 107.3 | 109.2 | 108.8 | 107.9 | 107.9 | 106.5 |
| 572 | 109.7 | 110.3 | 109.3 | 109.8 | 111.2 | 110.9 | 110.0 | 111.5 | 108.8 |
| 574 | 109.2 | 109.9 | 108.8 | 110.0 | 111.9 | 110.5 | 110.2 | 109.6 | 109.4 |
| 576 | 106.5 | 107.7 | 107.7 | 107.7 | 110.0 | 108.4 | 108.9 | 108.6 | 108.3 |
| 578 | 104.8 | 107.0 | 107.5 | 105.9 | 109.1 | 107.6 | 108.2 | 107.9 | 107.5 |
| 580 | 103.4 | 106.2 | 106.1 | 104.8 | 108.4 | 106.9 | 107.2 | 107.4 | 106.2 |
| 582 | 103.0 | 105.7 | 104.7 | 104.9 | 108.1 | 106.3 | 106.2 | 107.4 | 105.6 |
| 584 | 104.5 | 106.6 | 105.8 | 106.0 | 108.4 | 107.0 | 106.1 | 108.0 | 105.8 |
| 586 | 104.8 | 105.8 | 105.9 | 105.8 | 107.0 | 107.1 | 104.4 | 106.7 | 104.7 |
| 588 | 100.6 | 101.5 | 100.8 | 101.3 | 101.8 | 102.1 | 99.8 | 102.0 | 100.6 |
| 590 | 95.2 | 96.8 | 95.9 | 95.4 | 96.3 | 96.5 | 95.9 | 97.2 | 96.1 |
| 592 | 93.7 | 95.1 | 95.2 | 93.5 | 95.1 | 95.3 | 95.2 | 95.6 | 95.1 |
| 594 | 93.7 | 93.9 | 95.1 | 93.4 | 95.4 | 94.6 | 94.5 | 95.0 | 94.5 |
| 596 | 92.0 | 91.9 | 93.2 | 92.5 | 94.7 | 92.5 | 92.6 | 93.3 | 92.9 |
| 598 | 91.3 | 91.8 | 92.5 | 92.6 | 94.4 | 92.3 | 92.2 | 92.9 | 92.7 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 600 | 92.0 | 93.4 | 93.7 | 93.2 | 94.4 | 93.5 | 93.3 | 93.9 | 93.2 |
| 602 | 91.7 | 93.0 | 93.7 | 92.5 | 93.4 | 93.1 | 93.0 | 93.5 | 92.0 |
| 604 | 90.6 | 90.7 | 92.2 | 90.9 | 92.5 | 91.5 | 91.2 | 91.6 | 89.9 |
| 606 | 89.2 | 89.1 | 90.9 | 89.3 | 91.5 | 90.0 | 89.6 | 89.8 | 88.9 |
| 608 | 87.7 | 88.4 | 89.9 | 88.2 | 89.7 | 88.7 | 88.3 | 88.4 | 88.1 |
| 610 | 87.1 | 87.0 | 89.0 | 87.9 | 87.9 | 87.8 | 87.8 | 87.9 | 87.5 |
| 612 | 85.8 | 84.9 | 88.0 | 86.7 | 86.3 | 86.7 | 87.1 | 86.9 | 87.2 |
| 614 | 79.8 | 79.8 | 82.5 | 81.2 | 81.7 | 81.1 | 81.3 | 81.7 | 82.5 |
| 616 | 72.1 | 72.4 | 74.1 | 73.5 | 74.3 | 72.6 | 73.1 | 74.1 | 74.1 |
| 618 | 72.7 | 72.3 | 73.7 | 73.2 | 73.2 | 72.5 | 73.5 | 73.4 | 73.8 |
| 620 | 79.4 | 78.3 | 80.7 | 78.7 | 78.9 | 79.1 | 79.8 | 79.3 | 79.9 |
| 622 | 79.3 | 78.1 | 81.4 | 78.3 | 79.3 | 78.8 | 78.8 | 80.5 | 78.4 |
| 624 | 72.5 | 71.9 | 75.1 | 71.8 | 72.6 | 72.4 | 71.8 | 74.9 | 71.4 |
| 626 | 66.6 | 66.5 | 69.4 | 65.7 | 65.7 | 66.4 | 66.1 | 67.7 | 66.5 |
| 628 | 62.5 | 62.4 | 65.2 | 61.4 | 62.3 | 61.4 | 62.4 | 62.3 | 63.3 |
| 630 | 58.2 | 58.3 | 60.0 | 57.2 | 60.6 | 57.0 | 58.2 | 58.0 | 59.9 |
| 632 | 54.1 | 54.5 | 55.4 | 53.4 | 58.2 | 53.9 | 54.1 | 54.2 | 56.2 |
| 634 | 51.9 | 52.2 | 54.0 | 51.9 | 55.8 | 51.9 | 52.3 | 51.6 | 53.4 |
| 636 | 50.8 | 51.3 | 53.6 | 51.2 | 54.1 | 50.7 | 51.4 | 50.6 | 52.0 |
| 638 | 49.9 | 50.3 | 51.6 | 50.1 | 52.4 | 49.9 | 50.2 | 50.0 | 51.1 |
| 640 | 48.8 | 48.5 | 48.7 | 48.5 | 49.5 | 48.4 | 48.6 | 48.4 | 49.2 |
| 642 | 48.2 | 48.0 | 48.4 | 48.1 | 48.3 | 47.6 | 48.3 | 47.5 | 47.9 |
| 644 | 46.9 | 47.7 | 48.6 | 47.4 | 48.2 | 46.9 | 47.9 | 47.0 | 47.3 |
| 646 | 46.4 | 47.5 | 48.2 | 47.0 | 48.0 | 46.6 | 47.5 | 47.0 | 47.7 |
| 648 | 48.4 | 48.8 | 49.2 | 48.4 | 48.9 | 48.0 | 48.7 | 48.3 | 49.2 |
| 650 | 49.6 | 49.7 | 50.4 | 49.8 | 49.8 | 49.1 | 49.9 | 49.1 | 50.0 |
| 652 | 47.6 | 48.5 | 49.5 | 48.7 | 48.7 | 47.6 | 49.1 | 47.9 | 49.0 |
| 654 | 46.2 | 48.0 | 48.9 | 47.9 | 48.1 | 46.7 | 48.6 | 47.5 | 48.3 |
| 656 | 45.9 | 47.6 | 48.5 | 47.7 | 48.0 | 46.2 | 48.5 | 47.4 | 47.6 |
| 658 | 46.4 | 47.0 | 48.1 | 47.9 | 48.0 | 45.8 | 48.2 | 47.1 | 47.6 |
| 660 | 47.4 | 47.1 | 48.7 | 47.9 | 48.4 | 46.0 | 48.0 | 47.4 | 48.3 |
| 662 | 47.8 | 48.0 | 50.1 | 48.1 | 49.0 | 46.6 | 48.3 | 48.2 | 48.8 |
| 664 | 47.9 | 48.6 | 50.4 | 48.7 | 48.7 | 47.3 | 48.6 | 48.7 | 49.1 |
| 666 | 50.5 | 50.4 | 51.7 | 50.5 | 50.0 | 49.6 | 50.6 | 51.0 | 51.4 |
| 668 | 53.0 | 51.9 | 53.3 | 51.9 | 52.0 | 51.6 | 52.2 | 53.3 | 53.7 |
| 670 | 51.2 | 50.2 | 51.7 | 50.4 | 50.9 | 50.0 | 50.4 | 51.4 | 51.9 |
| 672 | 47.5 | 47.1 | 48.7 | 47.7 | 47.8 | 46.8 | 47.5 | 48.0 | 48.2 |
| 674 | 46.5 | 46.2 | 47.6 | 46.5 | 46.5 | 45.6 | 46.7 | 46.9 | 46.7 |
| 676 | 46.9 | 46.1 | 47.3 | 46.1 | 46.4 | 45.0 | 46.8 | 46.5 | 46.7 |
| 678 | 45.9 | 45.5 | 46.3 | 45.5 | 46.1 | 44.1 | 46.2 | 46.0 | 46.2 |
| 680 | 44.8 | 45.5 | 45.8 | 45.1 | 46.3 | 44.7 | 45.8 | 46.2 | 46.2 |
| 682 | 44.2 | 45.1 | 45.5 | 44.3 | 46.3 | 45.4 | 45.7 | 46.0 | 46.0 |
| 684 | 43.3 | 43.8 | 44.8 | 43.3 | 45.5 | 44.7 | 45.0 | 44.9 | 45.1 |
| 686 | 42.1 | 42.8 | 43.7 | 42.9 | 44.3 | 43.5 | 43.7 | 43.8 | 43.9 |
| 688 | 41.8 | 42.8 | 43.7 | 43.4 | 43.5 | 43.0 | 43.2 | 43.6 | 43.4 |
| 690 | 42.0 | 43.1 | 44.6 | 43.6 | 43.4 | 43.0 | 43.7 | 43.6 | 43.5 |
| 692 | 42.3 | 43.0 | 44.7 | 42.8 | 43.5 | 42.5 | 43.8 | 43.1 | 43.5 |
| 694 | 42.4 | 42.8 | 44.6 | 42.2 | 43.4 | 42.2 | 43.7 | 42.6 | 43.7 |
| 696 | 42.8 | 43.1 | 45.4 | 43.2 | 44.0 | 43.0 | 43.9 | 43.1 | 44.2 |
| 698 | 44.1 | 44.5 | 46.6 | 45.0 | 45.0 | 44.8 | 45.1 | 44.7 | 45.5 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 700 | 46.2 | 46.9 | 48.3 | 46.9 | 46.5 | 46.8 | 47.2 | 46.7 | 47.3 |
| 702 | 48.2 | 49.3 | 50.4 | 49.2 | 48.6 | 48.7 | 49.6 | 48.7 | 49.4 |
| 704 | 50.6 | 52.0 | 52.5 | 52.1 | 51.8 | 51.4 | 52.7 | 51.7 | 52.2 |
| 706 | 53.9 | 55.0 | 55.0 | 54.8 | 55.0 | 54.4 | 56.0 | 55.4 | 55.3 |
| 708 | 57.8 | 58.3 | 58.6 | 57.8 | 58.4 | 57.9 | 59.2 | 59.0 | 58.3 |
| 710 | 60.6 | 61.5 | 62.2 | 61.5 | 61.6 | 61.4 | 62.4 | 61.9 | 61.3 |
| 712 | 64.2 | 65.1 | 66.0 | 65.4 | 64.7 | 64.5 | 65.9 | 65.4 | 64.9 |
| 714 | 68.6 | 69.0 | 69.7 | 69.1 | 68.5 | 68.1 | 69.3 | 69.4 | 68.7 |
| 716 | 68.4 | 69.4 | 69.5 | 69.1 | 69.4 | 68.9 | 69.2 | 69.4 | 68.9 |
| 718 | 62.8 | 64.4 | 64.2 | 63.2 | 64.4 | 63.9 | 63.7 | 63.6 | 63.5 |
| 720 | 62.8 | 63.4 | 64.3 | 62.8 | 64.1 | 64.1 | 63.5 | 63.2 | 63.2 |
| 722 | 72.6 | 73.8 | 75.3 | 73.9 | 74.4 | 74.7 | 73.9 | 73.3 | 73.7 |
| 724 | 81.9 | 84.0 | 85.2 | 83.7 | 84.1 | 84.3 | 83.1 | 82.6 | 83.4 |
| 726 | 82.8 | 84.9 | 86.0 | 84.8 | 85.8 | 85.5 | 84.3 | 84.1 | 84.5 |
| 728 | 79.3 | 81.3 | 82.9 | 82.2 | 82.9 | 82.6 | 82.0 | 81.6 | 81.7 |
| 730 | 78.4 | 79.7 | 80.7 | 80.3 | 80.7 | 81.2 | 80.7 | 80.5 | 80.2 |
| 732 | 79.5 | 78.6 | 81.1 | 80.7 | 81.2 | 81.7 | 80.9 | 81.6 | 80.9 |
| 734 | 80.1 | 78.6 | 83.9 | 82.9 | 83.0 | 82.9 | 81.9 | 83.1 | 82.4 |
| 736 | 80.6 | 80.9 | 84.8 | 83.6 | 84.2 | 84.0 | 82.8 | 84.3 | 82.9 |
| 738 | 81.7 | 82.2 | 82.6 | 82.8 | 83.5 | 83.4 | 82.4 | 83.9 | 82.0 |
| 740 | 82.4 | 80.4 | 81.6 | 82.3 | 81.2 | 81.9 | 80.8 | 82.1 | 80.8 |
| 742 | 82.8 | 81.7 | 85.0 | 83.3 | 82.8 | 83.9 | 82.2 | 84.5 | 82.1 |
| 744 | 87.1 | 87.7 | 90.5 | 87.2 | 89.3 | 89.4 | 88.0 | 90.4 | 86.7 |
| 746 | 93.3 | 92.9 | 94.0 | 93.4 | 94.7 | 95.7 | 93.3 | 95.1 | 92.6 |
| 748 | 97.4 | 96.4 | 96.1 | 100.6 | 99.0 | 101.8 | 96.6 | 97.1 | 98.2 |
| 750 | 96.5 | 99.2 | 100.8 | 103.7 | 103.1 | 103.1 | 99.5 | 100.4 | 101.2 |
| 752 | 97.1 | 100.9 | 102.4 | 101.9 | 106.1 | 101.8 | 100.5 | 104.1 | 101.1 |
| 754 | 100.4 | 102.6 | 102.0 | 100.0 | 107.3 | 104.8 | 100.3 | 105.7 | 99.7 |
| 756 | 104.1 | 106.5 | 105.2 | 103.8 | 109.7 | 112.9 | 103.6 | 108.2 | 98.0 |
| 758 | 108.0 | 110.8 | 112.0 | 110.7 | 114.5 | 119.8 | 109.8 | 112.9 | 101.1 |
| 760 | 110.8 | 113.7 | 117.4 | 114.7 | 117.3 | 122.1 | 113.6 | 117.0 | 108.5 |
| 762 | 113.2 | 115.4 | 119.4 | 116.8 | 116.7 | 122.3 | 113.5 | 117.6 | 114.0 |
| 764 | 114.5 | 116.7 | 119.7 | 120.0 | 118.5 | 122.2 | 113.5 | 118.3 | 115.6 |
| 766 | 114.4 | 117.2 | 119.5 | 122.1 | 122.7 | 121.0 | 114.0 | 120.2 | 115.6 |
| 768 | 114.0 | 116.2 | 119.1 | 121.6 | 123.9 | 120.4 | 114.0 | 120.1 | 115.2 |
| 770 | 114.3 | 116.1 | 119.7 | 121.5 | 123.9 | 123.0 | 115.2 | 119.6 | 115.2 |
| 772 | 114.6 | 117.1 | 120.7 | 122.4 | 124.9 | 126.2 | 116.9 | 120.5 | 115.8 |
| 774 | 113.9 | 116.3 | 119.4 | 121.0 | 123.4 | 125.2 | 116.1 | 119.6 | 114.6 |
| 776 | 113.1 | 114.3 | 117.1 | 118.5 | 120.4 | 122.0 | 114.3 | 117.5 | 112.9 |
| 778 | 113.6 | 114.3 | 117.2 | 118.9 | 120.6 | 122.1 | 114.2 | 118.0 | 114.0 |
| 780 | 114.2 | 115.9 | 119.0 | 121.4 | 123.6 | 125.0 | 115.7 | 120.4 | 116.3 |
| 782 | 113.6 | 115.7 | 119.2 | 121.6 | 124.2 | 125.3 | 115.9 | 120.6 | 116.0 |
| 784 | 113.1 | 114.4 | 118.2 | 120.1 | 122.5 | 123.1 | 114.9 | 119.1 | 114.4 |
| 786 | 114.1 | 115.5 | 119.6 | 121.1 | 124.1 | 123.9 | 115.8 | 120.0 | 115.5 |
| 788 | 114.7 | 116.6 | 121.3 | 123.1 | 127.0 | 126.2 | 117.0 | 121.8 | 116.8 |
| 790 | 112.6 | 114.6 | 118.7 | 121.0 | 124.7 | 123.7 | 114.7 | 119.8 | 114.3 |
| 792 | 110.1 | 111.6 | 114.4 | 117.2 | 119.8 | 119.0 | 111.6 | 116.1 | 111.1 |
| 794 | 108.9 | 109.8 | 112.4 | 114.5 | 116.4 | 116.1 | 110.0 | 113.7 | 109.3 |
| 796 | 107.4 | 108.1 | 111.2 | 112.1 | 114.3 | 113.8 | 108.5 | 112.0 | 107.4 |
| 798 | 107.0 | 108.2 | 111.4 | 112.0 | 114.8 | 114.5 | 108.8 | 112.3 | 107.4 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 800 | 109.4 | 110.3 | 113.7 | 115.3 | 117.9 | 118.7 | 111.1 | 115.2 | 110.0 |
| 802 | 111.1 | 112.0 | 115.4 | 117.6 | 120.1 | 121.0 | 112.2 | 117.5 | 111.6 |
| 804 | 111.1 | 112.7 | 116.0 | 117.9 | 121.0 | 121.2 | 112.3 | 118.4 | 112.2 |
| 806 | 111.5 | 113.7 | 117.2 | 118.8 | 122.1 | 122.6 | 112.8 | 119.2 | 113.4 |
| 808 | 112.3 | 114.6 | 118.1 | 120.2 | 122.8 | 124.1 | 113.7 | 119.8 | 114.1 |
| 810 | 112.8 | 115.3 | 118.7 | 121.3 | 123.7 | 125.1 | 114.8 | 120.6 | 114.4 |
| 812 | 112.5 | 115.0 | 118.9 | 121.7 | 123.9 | 124.6 | 114.7 | 120.5 | 114.2 |
| 814 | 111.8 | 114.2 | 118.2 | 121.5 | 123.3 | 123.4 | 113.2 | 120.0 | 113.4 |
| 816 | 112.3 | 114.9 | 118.3 | 122.0 | 124.4 | 124.5 | 113.5 | 121.3 | 114.0 |
| 818 | 113.3 | 115.8 | 119.6 | 123.0 | 126.8 | 127.3 | 115.6 | 123.2 | 115.9 |
| 820 | 113.2 | 116.0 | 120.0 | 122.8 | 127.6 | 127.9 | 116.4 | 123.2 | 116.1 |
| 822 | 112.4 | 115.5 | 119.8 | 121.9 | 126.9 | 127.2 | 115.8 | 122.0 | 115.1 |
| 824 | 111.4 | 114.5 | 118.5 | 121.0 | 125.3 | 125.8 | 115.0 | 120.6 | 113.9 |
| 826 | 110.9 | 113.5 | 116.6 | 120.4 | 123.9 | 123.5 | 113.9 | 119.4 | 112.7 |
| 828 | 111.3 | 113.4 | 116.6 | 121.0 | 124.5 | 123.2 | 113.7 | 119.8 | 113.0 |
| 830 | 111.5 | 114.3 | 118.0 | 121.9 | 125.8 | 125.2 | 114.2 | 121.4 | 114.6 |
| 832 | 111.1 | 114.8 | 118.4 | 122.1 | 125.7 | 126.5 | 114.5 | 122.3 | 115.1 |
| 834 | 110.9 | 114.4 | 117.4 | 121.7 | 125.2 | 126.0 | 114.4 | 121.6 | 114.2 |
| 836 | 110.8 | 113.7 | 116.6 | 120.9 | 125.2 | 125.2 | 113.9 | 120.6 | 113.7 |
| 838 | 109.9 | 112.5 | 115.9 | 119.3 | 123.7 | 123.7 | 112.7 | 119.2 | 112.7 |
| 840 | 108.9 | 111.6 | 115.4 | 118.3 | 122.1 | 122.3 | 112.2 | 118.0 | 111.8 |
| 842 | 108.6 | 111.5 | 115.6 | 118.7 | 122.4 | 122.1 | 112.4 | 118.1 | 112.5 |
| 844 | 108.4 | 111.5 | 115.8 | 118.9 | 122.8 | 122.4 | 112.5 | 118.6 | 112.8 |
| 846 | 108.0 | 111.2 | 115.2 | 118.4 | 122.0 | 121.9 | 111.9 | 118.0 | 111.5 |
| 848 | 107.1 | 110.1 | 113.8 | 117.0 | 120.2 | 119.7 | 110.4 | 116.2 | 109.9 |
| 850 | 105.6 | 108.5 | 111.5 | 114.7 | 117.3 | 116.7 | 108.3 | 113.8 | 108.1 |
| 852 | 104.3 | 106.7 | 109.7 | 112.9 | 114.4 | 114.6 | 106.9 | 111.5 | 106.2 |
| 854 | 104.6 | 106.9 | 110.0 | 113.4 | 114.8 | 115.4 | 107.1 | 111.6 | 106.5 |
| 856 | 106.1 | 108.8 | 112.3 | 115.7 | 118.0 | 118.7 | 108.6 | 114.2 | 108.5 |
| 858 | 106.9 | 109.8 | 113.9 | 117.3 | 120.2 | 120.9 | 110.3 | 116.5 | 109.9 |
| 860 | 106.4 | 109.5 | 114.0 | 117.5 | 120.4 | 120.7 | 110.6 | 117.1 | 110.2 |
| 862 | 105.5 | 108.9 | 113.5 | 116.9 | 120.0 | 119.9 | 109.5 | 116.4 | 110.0 |
| 864 | 105.1 | 108.3 | 112.4 | 116.0 | 119.0 | 119.2 | 108.0 | 115.1 | 109.4 |
| 866 | 104.9 | 107.9 | 111.5 | 115.3 | 118.6 | 118.8 | 107.9 | 114.7 | 109.0 |
| 868 | 104.7 | 107.7 | 111.4 | 114.8 | 119.0 | 118.3 | 108.5 | 115.2 | 108.7 |
| 870 | 104.8 | 107.2 | 110.9 | 113.8 | 118.0 | 117.2 | 107.9 | 114.7 | 107.8 |
| 872 | 105.1 | 106.7 | 110.7 | 113.5 | 117.1 | 117.4 | 107.6 | 114.2 | 107.0 |
| 874 | 105.3 | 107.0 | 111.3 | 114.2 | 117.7 | 118.7 | 108.1 | 114.6 | 107.4 |
| 876 | 104.6 | 107.1 | 110.8 | 114.0 | 117.8 | 118.1 | 107.4 | 113.9 | 107.7 |
| 878 | 103.7 | 106.3 | 109.7 | 113.1 | 117.2 | 116.2 | 106.2 | 112.7 | 107.1 |
| 880 | 103.3 | 105.7 | 109.3 | 112.6 | 116.5 | 115.3 | 105.7 | 112.4 | 106.2 |
| 882 | 103.2 | 105.2 | 108.8 | 112.1 | 115.5 | 115.8 | 105.8 | 112.6 | 105.4 |
| 884 | 102.5 | 104.4 | 108.1 | 111.3 | 114.1 | 115.9 | 105.6 | 112.3 | 105.1 |
| 886 | 101.5 | 103.7 | 107.6 | 110.4 | 112.8 | 114.6 | 104.5 | 111.2 | 105.5 |
| 888 | 101.2 | 103.7 | 107.7 | 110.2 | 112.6 | 113.6 | 103.8 | 110.7 | 105.7 |
| 890 | 101.8 | 104.0 | 108.6 | 110.9 | 113.6 | 114.1 | 104.3 | 111.5 | 105.5 |
| 892 | 102.6 | 104.2 | 108.9 | 111.9 | 114.4 | 114.7 | 104.4 | 112.1 | 105.4 |
| 894 | 103.0 | 104.2 | 108.3 | 112.4 | 114.8 | 115.4 | 104.4 | 112.0 | 105.6 |
| 896 | 102.6 | 104.0 | 108.2 | 112.1 | 115.4 | 116.7 | 105.2 | 112.0 | 105.9 |
| 898 | 101.7 | 104.0 | 108.5 | 111.6 | 116.0 | 117.2 | 105.4 | 112.2 | 105.8 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 900 | 100.8 | 103.9 | 108.1 | 111.7 | 115.9 | 116.8 | 104.5 | 111.5 | 104.5 |
| 902 | 100.6 | 103.4 | 107.6 | 111.8 | 115.8 | 116.7 | 104.2 | 110.5 | 103.5 |
| 904 | 100.5 | 102.8 | 107.2 | 110.5 | 115.3 | 115.6 | 104.3 | 110.2 | 103.5 |
| 906 | 99.7 | 101.9 | 105.7 | 108.4 | 113.6 | 112.9 | 103.4 | 109.7 | 102.3 |
| 908 | 98.3 | 101.1 | 104.0 | 106.8 | 111.3 | 110.8 | 102.2 | 108.3 | 100.0 |
| 910 | 97.8 | 101.0 | 103.9 | 106.7 | 110.6 | 111.2 | 102.2 | 107.4 | 100.1 |
| 912 | 98.7 | 101.2 | 104.5 | 107.4 | 111.9 | 112.4 | 102.6 | 107.8 | 102.2 |
| 914 | 99.3 | 101.2 | 104.6 | 108.4 | 112.7 | 112.5 | 102.6 | 108.6 | 103.2 |
| 916 | 99.0 | 101.2 | 104.8 | 108.6 | 112.1 | 112.2 | 102.7 | 108.8 | 102.8 |
| 918 | 98.4 | 100.9 | 104.1 | 107.3 | 110.9 | 111.6 | 102.3 | 108.0 | 101.8 |
| 920 | 97.8 | 100.2 | 102.9 | 106.1 | 110.5 | 110.9 | 101.4 | 106.9 | 100.8 |
| 922 | 97.2 | 99.3 | 102.1 | 105.7 | 109.8 | 109.6 | 100.8 | 105.8 | 99.9 |
| 924 | 97.0 | 98.9 | 102.3 | 105.7 | 109.6 | 109.0 | 100.9 | 105.4 | 100.2 |
| 926 | 97.3 | 99.0 | 102.5 | 105.4 | 109.6 | 109.9 | 100.9 | 105.9 | 101.0 |
| 928 | 97.2 | 99.2 | 102.4 | 104.8 | 109.1 | 111.0 | 100.7 | 106.0 | 101.0 |
| 930 | 96.5 | 99.1 | 102.5 | 104.7 | 108.8 | 111.1 | 100.7 | 106.1 | 100.6 |
| 932 | 95.9 | 98.9 | 102.2 | 105.0 | 108.8 | 110.5 | 100.3 | 106.2 | 100.6 |
| 934 | 96.1 | 98.6 | 102.0 | 105.5 | 109.4 | 110.4 | 100.3 | 106.3 | 100.9 |
| 936 | 95.9 | 98.0 | 101.6 | 105.6 | 109.2 | 110.1 | 100.5 | 105.9 | 100.4 |
| 938 | 95.1 | 97.1 | 101.4 | 105.5 | 108.7 | 109.6 | 100.3 | 105.6 | 99.7 |
| 940 | 94.4 | 96.7 | 100.9 | 104.3 | 107.9 | 108.5 | 99.6 | 105.0 | 98.8 |
| 942 | 94.3 | 96.3 | 100.6 | 103.2 | 107.9 | 108.2 | 99.5 | 104.8 | 98.4 |
| 944 | 93.7 | 95.9 | 99.8 | 101.9 | 106.5 | 107.6 | 98.7 | 103.5 | 97.8 |
| 946 | 92.8 | 95.0 | 98.3 | 100.3 | 104.5 | 106.4 | 97.3 | 101.6 | 96.8 |
| 948 | 92.3 | 94.1 | 97.2 | 99.2 | 103.6 | 105.5 | 96.3 | 100.8 | 96.1 |
| 950 | 92.6 | 94.3 | 97.4 | 99.9 | 104.4 | 105.6 | 96.0 | 101.4 | 96.2 |
| 952 | 92.1 | 94.2 | 97.3 | 100.6 | 104.4 | 105.3 | 95.6 | 101.3 | 95.6 |
| 954 | 91.1 | 93.6 | 96.8 | 100.4 | 103.6 | 104.7 | 95.4 | 100.8 | 95.0 |
| 956 | 91.1 | 93.4 | 97.2 | 100.5 | 103.5 | 105.1 | 95.8 | 101.3 | 95.7 |
| 958 | 91.6 | 93.6 | 97.6 | 100.3 | 103.9 | 105.6 | 96.5 | 102.1 | 96.3 |
| 960 | 91.3 | 93.3 | 97.1 | 99.8 | 103.7 | 105.2 | 96.5 | 102.0 | 95.9 |
| 962 | 91.2 | 92.5 | 97.1 | 99.6 | 103.7 | 104.7 | 95.9 | 101.7 | 95.4 |
| 964 | 90.9 | 92.0 | 96.4 | 99.1 | 103.0 | 104.2 | 95.0 | 100.9 | 94.8 |
| 966 | 90.3 | 91.8 | 95.3 | 98.5 | 102.1 | 103.5 | 94.4 | 100.1 | 93.8 |
| 968 | 89.9 | 91.4 | 95.8 | 98.2 | 101.7 | 103.1 | 94.3 | 99.8 | 93.4 |
| 970 | 89.1 | 90.7 | 95.6 | 96.9 | 100.8 | 102.1 | 93.4 | 98.4 | 92.9 |
| 972 | 88.1 | 90.1 | 93.7 | 95.3 | 99.5 | 101.0 | 92.1 | 96.7 | 92.1 |
| 974 | 87.3 | 89.3 | 92.8 | 94.7 | 98.5 | 100.4 | 91.1 | 96.1 | 91.4 |
| 976 | 86.7 | 88.6 | 92.7 | 94.5 | 97.9 | 99.8 | 90.7 | 96.0 | 90.7 |
| 978 | 86.8 | 88.7 | 92.2 | 94.7 | 98.5 | 100.1 | 91.2 | 96.6 | 90.9 |
| 980 | 86.9 | 88.7 | 92.2 | 94.5 | 98.8 | 100.7 | 91.5 | 96.9 | 91.5 |
| 982 | 86.2 | 88.4 | 92.9 | 94.0 | 98.4 | 100.4 | 91.3 | 96.2 | 91.3 |
| 984 | 85.1 | 87.5 | 93.0 | 93.5 | 97.8 | 99.5 | 90.5 | 95.2 | 90.6 |
| 986 | 84.4 | 86.9 | 92.4 | 93.2 | 97.4 | 99.1 | 89.5 | 94.5 | 90.2 |
| 988 | 83.9 | 86.0 | 91.2 | 92.5 | 96.4 | 98.4 | 88.7 | 93.4 | 89.1 |
| 990 | 82.9 | 85.1 | 89.7 | 91.5 | 95.2 | 97.1 | 88.1 | 92.4 | 87.8 |
| 992 | 81.6 | 84.1 | 88.1 | 90.4 | 93.8 | 95.4 | 87.0 | 90.9 | 86.9 |
| 994 | 80.3 | 82.9 | 86.7 | 88.8 | 92.5 | 93.7 | 85.6 | 89.1 | 85.9 |
| 996 | 78.7 | 81.2 | 84.8 | 86.6 | 90.4 | 91.9 | 84.2 | 87.7 | 84.1 |
| 998 | 76.8 | 79.2 | 82.3 | 84.1 | 87.4 | 89.4 | 81.9 | 86.1 | 81.4 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1000 | 75.0 | 77.3 | 79.9 | 81.7 | 84.6 | 86.6 | 79.3 | 84.0 | 79.0 |
| 1002 | 72.9 | 75.4 | 77.5 | 79.2 | 82.0 | 83.3 | 76.6 | 81.4 | 76.8 |
| 1004 | 70.6 | 73.0 | 74.6 | 76.3 | 79.4 | 80.0 | 73.9 | 78.5 | 74.2 |
| 1006 | 67.7 | 70.2 | 71.7 | 73.1 | 76.2 | 77.3 | 71.4 | 75.3 | 71.5 |
| 1008 | 64.5 | 67.3 | 69.0 | 70.1 | 72.7 | 74.5 | 68.7 | 71.9 | 68.9 |
| 1010 | 62.0 | 64.0 | 66.0 | 67.1 | 69.3 | 71.1 | 65.2 | 68.7 | 66.3 |
| 1012 | 59.2 | 60.8 | 62.7 | 64.1 | 66.1 | 67.6 | 61.9 | 66.3 | 63.7 |
| 1014 | 56.5 | 58.3 | 59.7 | 61.4 | 63.1 | 64.6 | 59.2 | 63.6 | 61.1 |
| 1016 | 53.7 | 55.9 | 57.3 | 58.4 | 60.6 | 62.0 | 57.1 | 60.5 | 57.8 |
| 1018 | 51.7 | 53.6 | 55.3 | 55.9 | 57.6 | 59.5 | 54.7 | 57.9 | 55.6 |
| 1020 | 50.6 | 51.7 | 53.6 | 53.8 | 55.3 | 56.7 | 53.2 | 56.0 | 54.0 |
| 1022 | 49.2 | 49.9 | 51.8 | 51.8 | 53.8 | 55.0 | 51.8 | 53.8 | 52.0 |
| 1024 | 47.7 | 48.6 | 50.2 | 50.5 | 53.0 | 53.7 | 50.4 | 52.1 | 50.2 |
| 1026 | 46.7 | 47.8 | 48.9 | 49.7 | 51.8 | 52.5 | 49.2 | 51.2 | 49.5 |
| 1028 | 46.4 | 47.1 | 48.6 | 48.8 | 50.5 | 51.1 | 48.4 | 50.2 | 49.0 |
| 1030 | 46.0 | 46.6 | 48.9 | 48.2 | 49.6 | 50.3 | 48.0 | 49.6 | 48.5 |
| 1032 | 44.9 | 45.9 | 48.0 | 47.6 | 48.6 | 49.7 | 47.1 | 49.1 | 47.5 |
| 1034 | 43.2 | 44.2 | 45.7 | 45.9 | 47.0 | 48.7 | 45.9 | 47.5 | 45.7 |
| 1036 | 41.2 | 41.8 | 43.4 | 43.2 | 44.9 | 46.8 | 44.2 | 45.0 | 43.4 |
| 1038 | 39.6 | 40.1 | 41.6 | 41.5 | 43.3 | 44.7 | 41.8 | 42.9 | 41.7 |
| 1040 | 42.5 | 42.8 | 44.1 | 44.6 | 46.1 | 46.9 | 43.5 | 45.7 | 44.3 |
| 1042 | 49.5 | 50.1 | 51.7 | 52.7 | 54.4 | 55.9 | 50.7 | 54.2 | 51.9 |
| 1044 | 52.0 | 53.3 | 55.6 | 56.9 | 59.1 | 60.8 | 54.4 | 58.7 | 55.7 |
| 1046 | 46.8 | 48.2 | 50.8 | 51.6 | 53.6 | 55.3 | 49.7 | 53.1 | 50.5 |
| 1048 | 40.4 | 41.2 | 43.2 | 43.7 | 44.8 | 45.9 | 42.7 | 44.9 | 43.1 |
| 1050 | 37.1 | 37.2 | 38.8 | 39.1 | 39.6 | 40.6 | 38.6 | 40.3 | 38.9 |
| 1052 | 35.7 | 35.6 | 37.6 | 37.2 | 38.0 | 38.8 | 36.8 | 38.6 | 37.2 |
| 1054 | 35.7 | 36.3 | 38.2 | 37.4 | 38.5 | 39.4 | 36.9 | 38.9 | 37.1 |
| 1056 | 37.1 | 37.9 | 39.4 | 39.4 | 40.6 | 41.5 | 38.6 | 40.8 | 38.6 |
| 1058 | 39.1 | 40.0 | 41.3 | 42.3 | 43.3 | 44.2 | 41.2 | 43.5 | 41.3 |
| 1060 | 42.7 | 43.5 | 45.0 | 46.2 | 47.0 | 48.3 | 44.6 | 47.4 | 45.2 |
| 1062 | 47.9 | 48.6 | 50.6 | 51.4 | 52.9 | 55.0 | 49.3 | 53.1 | 50.3 |
| 1064 | 53.5 | 54.4 | 57.0 | 57.6 | 59.6 | 61.4 | 55.5 | 59.3 | 56.0 |
| 1066 | 58.4 | 59.3 | 62.3 | 63.6 | 65.7 | 67.6 | 61.7 | 65.0 | 61.5 |
| 1068 | 62.7 | 63.9 | 66.9 | 68.8 | 71.0 | 73.5 | 66.7 | 70.3 | 66.8 |
| 1070 | 66.1 | 67.2 | 70.3 | 72.7 | 75.4 | 77.9 | 70.0 | 74.5 | 70.8 |
| 1072 | 67.2 | 68.4 | 71.2 | 73.6 | 76.3 | 78.8 | 70.5 | 75.4 | 71.6 |
| 1074 | 66.9 | 68.2 | 71.0 | 73.2 | 75.5 | 78.2 | 70.2 | 74.8 | 71.2 |
| 1076 | 67.0 | 68.1 | 71.2 | 73.4 | 76.1 | 78.9 | 70.6 | 75.1 | 71.5 |
| 1078 | 67.1 | 68.5 | 71.7 | 74.0 | 77.2 | 79.8 | 71.2 | 76.0 | 72.0 |
| 1080 | 66.8 | 68.5 | 71.9 | 74.3 | 77.5 | 79.9 | 71.3 | 76.4 | 72.2 |
| 1082 | 66.8 | 68.3 | 72.0 | 74.5 | 77.6 | 79.9 | 71.4 | 76.5 | 72.6 |
| 1084 | 67.0 | 68.4 | 71.8 | 74.2 | 77.5 | 79.8 | 71.5 | 76.3 | 72.7 |
| 1086 | 67.0 | 68.3 | 71.9 | 74.1 | 77.5 | 79.8 | 71.7 | 76.2 | 72.3 |
| 1088 | 66.6 | 67.5 | 71.5 | 73.9 | 77.0 | 79.2 | 71.5 | 75.7 | 71.6 |
| 1090 | 66.1 | 66.9 | 70.5 | 73.3 | 76.0 | 78.1 | 70.9 | 74.6 | 70.9 |
| 1092 | 66.0 | 66.9 | 70.4 | 73.1 | 75.8 | 77.9 | 70.9 | 74.2 | 71.2 |
| 1094 | 66.1 | 67.3 | 71.4 | 73.9 | 76.5 | 78.5 | 71.3 | 74.7 | 72.2 |
| 1096 | 66.5 | 67.5 | 71.7 | 74.1 | 76.4 | 78.6 | 71.1 | 75.0 | 72.5 |
| 1098 | 65.9 | 66.7 | 70.4 | 72.8 | 74.8 | 77.3 | 69.9 | 73.8 | 71.0 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1100 | 64.7 | 65.2 | 68.7 | 71.3 | 73.3 | 75.6 | 68.7 | 72.2 | 68.9 |
| 1102 | 64.3 | 64.7 | 68.0 | 71.0 | 73.2 | 75.2 | 68.3 | 71.8 | 68.3 |
| 1104 | 64.2 | 64.7 | 67.7 | 70.6 | 73.2 | 74.9 | 67.9 | 71.5 | 68.4 |
| 1106 | 63.5 | 64.0 | 67.5 | 69.5 | 72.6 | 73.9 | 67.2 | 70.9 | 67.7 |
| 1108 | 63.0 | 63.6 | 67.5 | 69.0 | 72.3 | 73.9 | 67.1 | 71.1 | 67.3 |
| 1110 | 62.9 | 63.7 | 67.3 | 69.4 | 72.6 | 74.3 | 67.5 | 71.7 | 67.7 |
| 1112 | 62.9 | 63.5 | 66.5 | 69.4 | 72.5 | 73.8 | 67.2 | 71.4 | 67.3 |
| 1114 | 63.0 | 63.8 | 66.4 | 69.6 | 72.7 | 74.1 | 66.9 | 71.3 | 67.0 |
| 1116 | 62.6 | 64.1 | 66.6 | 69.4 | 72.5 | 74.3 | 66.9 | 71.4 | 67.2 |
| 1118 | 61.1 | 62.9 | 65.7 | 67.7 | 70.6 | 72.3 | 65.8 | 69.6 | 66.0 |
| 1120 | 60.4 | 61.6 | 64.4 | 66.6 | 68.9 | 70.9 | 64.3 | 67.8 | 64.5 |
| 1122 | 60.8 | 61.5 | 63.8 | 66.9 | 69.0 | 71.4 | 64.1 | 67.7 | 64.4 |
| 1124 | 61.6 | 62.1 | 64.5 | 67.7 | 70.6 | 72.7 | 65.4 | 69.0 | 65.5 |
| 1126 | 61.4 | 62.2 | 65.2 | 68.3 | 71.4 | 73.3 | 66.4 | 69.6 | 65.7 |
| 1128 | 60.7 | 61.2 | 64.8 | 67.8 | 70.8 | 73.0 | 66.0 | 69.1 | 65.0 |
| 1130 | 60.3 | 61.2 | 63.8 | 67.1 | 69.9 | 72.3 | 64.7 | 68.5 | 64.7 |
| 1132 | 59.4 | 60.0 | 62.8 | 66.1 | 68.0 | 70.1 | 62.9 | 66.9 | 63.6 |
| 1134 | 57.3 | 58.1 | 60.9 | 63.7 | 64.5 | 66.0 | 60.3 | 63.8 | 60.5 |
| 1136 | 56.2 | 57.0 | 59.6 | 62.2 | 62.7 | 64.0 | 58.9 | 62.2 | 58.8 |
| 1138 | 57.1 | 57.9 | 60.4 | 63.5 | 64.4 | 66.3 | 60.2 | 63.6 | 60.4 |
| 1140 | 58.2 | 59.2 | 62.1 | 65.5 | 67.5 | 69.4 | 62.5 | 65.6 | 62.6 |
| 1142 | 58.1 | 59.4 | 62.8 | 66.1 | 68.8 | 70.1 | 63.2 | 66.0 | 63.1 |
| 1144 | 57.7 | 59.2 | 62.7 | 65.6 | 68.3 | 69.9 | 62.9 | 65.7 | 63.0 |
| 1146 | 57.2 | 58.3 | 62.2 | 64.1 | 67.1 | 69.1 | 61.8 | 64.7 | 62.2 |
| 1148 | 56.1 | 57.2 | 60.5 | 61.8 | 64.7 | 65.9 | 59.8 | 62.4 | 60.0 |
| 1150 | 55.4 | 56.3 | 59.0 | 60.4 | 62.6 | 63.0 | 58.5 | 60.8 | 58.5 |
| 1152 | 55.4 | 56.5 | 58.8 | 60.4 | 62.0 | 63.1 | 58.5 | 60.9 | 58.7 |
| 1154 | 55.7 | 57.1 | 59.8 | 61.6 | 63.3 | 65.5 | 59.7 | 62.3 | 60.1 |
| 1156 | 55.9 | 57.2 | 60.4 | 62.6 | 64.7 | 67.1 | 60.4 | 63.1 | 61.0 |
| 1158 | 55.9 | 57.1 | 60.2 | 62.6 | 64.7 | 66.5 | 59.9 | 62.9 | 60.8 |
| 1160 | 55.4 | 56.8 | 59.7 | 62.2 | 64.0 | 65.3 | 59.1 | 62.7 | 60.1 |
| 1162 | 54.3 | 55.7 | 58.6 | 60.9 | 62.8 | 64.0 | 58.2 | 61.9 | 58.6 |
| 1164 | 53.2 | 54.4 | 57.0 | 58.9 | 60.5 | 62.2 | 56.8 | 60.0 | 56.7 |
| 1166 | 53.2 | 54.3 | 56.7 | 58.5 | 59.6 | 61.7 | 56.3 | 59.3 | 56.3 |
| 1168 | 53.6 | 55.1 | 57.5 | 59.4 | 60.7 | 62.7 | 56.8 | 60.1 | 57.3 |
| 1170 | 53.1 | 54.4 | 57.0 | 59.1 | 60.7 | 62.5 | 56.6 | 59.6 | 57.3 |
| 1172 | 51.1 | 52.1 | 54.2 | 56.2 | 57.4 | 59.2 | 54.4 | 56.6 | 54.7 |
| 1174 | 49.5 | 50.6 | 51.9 | 53.8 | 54.5 | 56.2 | 52.2 | 54.3 | 51.9 |
| 1176 | 50.5 | 51.5 | 53.1 | 55.0 | 55.9 | 57.4 | 53.3 | 55.5 | 52.8 |
| 1178 | 52.4 | 53.2 | 55.7 | 57.5 | 58.8 | 60.2 | 55.8 | 57.8 | 55.6 |
| 1180 | 52.9 | 53.8 | 56.8 | 58.6 | 59.8 | 61.1 | 56.4 | 58.4 | 56.4 |
| 1182 | 52.2 | 53.3 | 56.3 | 58.1 | 59.2 | 60.5 | 55.7 | 57.7 | 55.4 |
| 1184 | 50.8 | 51.9 | 54.5 | 56.2 | 57.5 | 58.6 | 54.3 | 55.9 | 53.6 |
| 1186 | 49.5 | 50.5 | 52.7 | 54.1 | 55.2 | 56.2 | 52.6 | 53.8 | 51.7 |
| 1188 | 49.7 | 50.9 | 52.8 | 54.2 | 55.0 | 56.3 | 52.6 | 53.9 | 52.0 |
| 1190 | 51.0 | 52.0 | 54.2 | 56.0 | 56.7 | 58.7 | 53.8 | 55.9 | 54.1 |
| 1192 | 51.6 | 52.5 | 54.8 | 56.6 | 57.9 | 60.0 | 54.5 | 57.0 | 55.2 |
| 1194 | 51.4 | 52.1 | 54.4 | 56.2 | 57.8 | 59.5 | 54.2 | 56.6 | 54.6 |
| 1196 | 50.4 | 51.0 | 53.0 | 54.9 | 55.8 | 57.8 | 53.1 | 54.9 | 52.9 |
| 1198 | 49.5 | 50.0 | 52.0 | 54.0 | 54.0 | 56.6 | 52.4 | 53.6 | 51.9 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1200 | 49.9 | 50.6 | 52.7 | 54.8 | 55.0 | 57.5 | 53.1 | 54.5 | 53.0 |
| 1202 | 50.5 | 51.6 | 53.8 | 55.8 | 56.6 | 58.6 | 53.9 | 55.7 | 53.9 |
| 1204 | 50.6 | 51.3 | 53.4 | 55.3 | 56.4 | 58.5 | 53.9 | 55.4 | 53.6 |
| 1206 | 50.1 | 50.4 | 52.2 | 54.1 | 55.4 | 57.4 | 53.3 | 54.3 | 52.7 |
| 1208 | 48.6 | 48.8 | 50.5 | 52.2 | 53.7 | 55.2 | 51.7 | 52.3 | 50.8 |
| 1210 | 46.4 | 46.2 | 47.7 | 49.2 | 50.0 | 51.3 | 48.8 | 48.9 | 47.9 |
| 1212 | 45.2 | 44.9 | 46.2 | 47.5 | 47.5 | 48.7 | 46.7 | 46.9 | 46.6 |
| 1214 | 45.8 | 45.9 | 47.1 | 48.6 | 48.7 | 49.8 | 47.3 | 48.1 | 47.8 |
| 1216 | 46.1 | 46.5 | 47.6 | 49.2 | 49.8 | 50.7 | 48.0 | 49.1 | 48.2 |
| 1218 | 45.5 | 45.5 | 47.0 | 48.2 | 48.5 | 49.6 | 47.1 | 48.3 | 47.2 |
| 1220 | 45.0 | 44.8 | 46.7 | 47.5 | 47.6 | 48.7 | 46.4 | 47.8 | 46.6 |
| 1222 | 44.7 | 44.3 | 46.2 | 47.1 | 47.4 | 48.7 | 46.3 | 47.5 | 46.0 |
| 1224 | 43.9 | 43.6 | 45.1 | 45.9 | 46.1 | 47.6 | 45.5 | 46.2 | 44.7 |
| 1226 | 44.0 | 44.0 | 45.4 | 46.4 | 46.6 | 48.0 | 45.5 | 46.2 | 45.2 |
| 1228 | 45.2 | 45.3 | 47.0 | 48.4 | 49.1 | 50.5 | 46.7 | 48.0 | 47.2 |
| 1230 | 46.1 | 46.1 | 48.2 | 49.8 | 50.7 | 52.2 | 47.6 | 49.4 | 48.3 |
| 1232 | 46.0 | 46.1 | 48.4 | 50.1 | 50.7 | 52.4 | 48.1 | 49.7 | 48.5 |
| 1234 | 44.8 | 45.3 | 47.1 | 48.9 | 49.6 | 51.2 | 47.3 | 48.5 | 47.0 |
| 1236 | 43.4 | 43.7 | 45.0 | 46.7 | 47.5 | 49.0 | 45.2 | 46.4 | 44.6 |
| 1238 | 42.3 | 42.4 | 43.2 | 44.7 | 45.3 | 46.6 | 43.4 | 44.5 | 43.0 |
| 1240 | 41.2 | 41.0 | 41.8 | 43.0 | 43.5 | 44.6 | 42.2 | 42.8 | 41.8 |
| 1242 | 39.2 | 38.9 | 39.6 | 40.6 | 41.2 | 42.2 | 40.2 | 40.6 | 39.6 |
| 1244 | 37.4 | 37.3 | 37.9 | 38.8 | 39.2 | 40.3 | 38.4 | 39.2 | 38.1 |
| 1246 | 37.5 | 37.5 | 38.5 | 39.2 | 39.3 | 40.6 | 38.5 | 39.5 | 38.5 |
| 1248 | 38.4 | 38.3 | 39.6 | 40.4 | 40.4 | 41.6 | 39.6 | 40.5 | 39.4 |
| 1250 | 38.1 | 38.1 | 39.4 | 40.4 | 40.6 | 41.6 | 39.4 | 40.4 | 39.3 |
| 1252 | 36.7 | 36.6 | 37.9 | 38.8 | 38.8 | 39.8 | 37.8 | 38.7 | 37.6 |
| 1254 | 35.4 | 35.2 | 36.2 | 36.7 | 36.5 | 37.7 | 36.1 | 36.5 | 36.0 |
| 1256 | 34.1 | 33.7 | 34.3 | 34.7 | 34.6 | 36.0 | 34.6 | 34.6 | 34.5 |
| 1258 | 31.6 | 31.0 | 31.1 | 31.2 | 31.6 | 33.0 | 31.8 | 31.4 | 31.7 |
| 1260 | 28.0 | 28.3 | 28.6 | 28.3 | 29.0 | 29.3 | 29.0 | 29.2 | 28.5 |
| 1262 | 27.2 | 27.5 | 27.7 | 27.4 | 28.0 | 27.8 | 28.0 | 28.1 | 27.5 |
| 1264 | 27.2 | 27.2 | 27.8 | 27.4 | 27.8 | 27.5 | 27.7 | 27.7 | 27.5 |
| 1266 | 25.9 | 25.7 | 26.6 | 25.9 | 26.2 | 26.3 | 26.7 | 26.3 | 26.3 |
| 1268 | 23.8 | 23.8 | 24.6 | 23.9 | 24.0 | 24.6 | 25.3 | 24.6 | 24.6 |
| 1270 | 22.8 | 23.0 | 23.4 | 23.2 | 23.0 | 23.5 | 24.2 | 23.7 | 23.8 |
| 1272 | 23.7 | 24.0 | 24.3 | 24.5 | 24.0 | 24.4 | 24.5 | 24.9 | 24.5 |
| 1274 | 25.6 | 25.6 | 26.2 | 26.6 | 26.1 | 26.6 | 25.9 | 26.8 | 26.0 |
| 1276 | 27.0 | 26.9 | 27.6 | 27.9 | 27.5 | 28.2 | 27.2 | 27.7 | 27.4 |
| 1278 | 27.4 | 27.4 | 28.2 | 28.2 | 27.8 | 29.0 | 27.6 | 27.8 | 28.0 |
| 1280 | 27.1 | 27.1 | 28.0 | 27.6 | 27.5 | 28.3 | 27.3 | 27.7 | 27.6 |
| 1282 | 26.6 | 26.7 | 27.4 | 27.1 | 27.0 | 27.4 | 26.9 | 27.3 | 27.0 |
| 1284 | 26.6 | 26.7 | 27.3 | 27.1 | 27.0 | 27.4 | 27.0 | 27.3 | 27.4 |
| 1286 | 26.2 | 26.0 | 26.5 | 26.3 | 26.2 | 27.1 | 26.5 | 26.5 | 26.9 |
| 1288 | 24.9 | 24.6 | 25.0 | 24.9 | 24.9 | 25.7 | 25.1 | 24.9 | 25.2 |
| 1290 | 24.4 | 24.4 | 24.6 | 24.6 | 24.8 | 25.2 | 24.7 | 24.4 | 24.8 |
| 1292 | 24.3 | 24.3 | 25.0 | 24.7 | 24.9 | 25.3 | 24.5 | 24.8 | 24.9 |
| 1294 | 23.4 | 23.1 | 24.1 | 23.4 | 23.5 | 24.0 | 23.1 | 23.9 | 23.5 |
| 1296 | 22.2 | 21.7 | 22.5 | 21.8 | 21.8 | 22.1 | 21.6 | 22.5 | 21.9 |
| 1298 | 21.2 | 20.9 | 21.4 | 21.0 | 21.1 | 21.2 | 21.0 | 21.5 | 21.2 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1300 | 19.8 | 19.5 | 20.2 | 19.8 | 20.1 | 20.2 | 19.8 | 20.1 | 19.9 |
| 1302 | 17.8 | 17.3 | 17.9 | 17.6 | 17.7 | 17.6 | 17.6 | 17.9 | 17.6 |
| 1304 | 16.5 | 16.1 | 16.5 | 16.1 | 15.9 | 15.6 | 16.6 | 16.5 | 16.4 |
| 1306 | 17.9 | 17.9 | 18.2 | 17.5 | 17.3 | 17.2 | 18.5 | 18.2 | 18.3 |
| 1308 | 21.1 | 21.2 | 21.7 | 20.9 | 20.6 | 20.9 | 22.0 | 21.7 | 21.8 |
| 1310 | 22.7 | 22.5 | 23.5 | 22.7 | 22.3 | 23.0 | 23.8 | 23.7 | 23.5 |
| 1312 | 22.1 | 21.8 | 22.9 | 21.9 | 21.7 | 23.0 | 23.7 | 23.4 | 23.1 |
| 1314 | 21.5 | 21.3 | 22.0 | 21.1 | 21.0 | 22.7 | 23.2 | 23.0 | 22.7 |
| 1316 | 21.1 | 21.1 | 21.8 | 21.0 | 21.0 | 22.6 | 23.0 | 22.9 | 22.8 |
| 1318 | 20.8 | 20.9 | 21.7 | 21.0 | 20.8 | 22.4 | 22.7 | 22.7 | 22.5 |
| 1320 | 21.6 | 21.6 | 22.4 | 21.7 | 21.4 | 22.6 | 22.9 | 23.3 | 22.8 |
| 1322 | 23.0 | 23.4 | 24.4 | 23.4 | 23.3 | 24.0 | 24.3 | 25.1 | 24.9 |
| 1324 | 25.4 | 25.0 | 26.7 | 26.0 | 26.4 | 26.7 | 26.2 | 26.8 | 26.2 |
| 1326 | 25.7 | 25.3 | 26.4 | 26.0 | 26.3 | 27.1 | 26.0 | 26.7 | 26.3 |
| 1328 | 25.3 | 25.1 | 25.7 | 25.6 | 25.7 | 26.7 | 25.3 | 26.3 | 25.4 |
| 1330 | 24.9 | 24.7 | 25.2 | 25.3 | 24.7 | 25.9 | 25.1 | 25.8 | 25.1 |
| 1332 | 23.9 | 23.8 | 24.0 | 23.4 | 23.5 | 24.9 | 24.3 | 24.6 | 24.3 |
| 1334 | 21.7 | 21.9 | 22.4 | 21.8 | 21.7 | 22.4 | 22.9 | 22.8 | 22.5 |
| 1336 | 19.5 | 19.3 | 20.1 | 19.6 | 19.6 | 20.2 | 21.0 | 21.1 | 20.7 |
| 1338 | 17.6 | 17.1 | 18.1 | 17.4 | 17.6 | 18.1 | 18.7 | 19.2 | 18.7 |
| 1340 | 17.1 | 16.9 | 17.8 | 16.9 | 17.2 | 17.6 | 17.9 | 18.5 | 18.1 |
| 1342 | 18.5 | 18.5 | 19.2 | 18.7 | 18.7 | 19.1 | 19.3 | 19.8 | 19.4 |
| 1344 | 20.5 | 20.5 | 21.1 | 20.8 | 20.5 | 21.0 | 21.2 | 21.7 | 21.2 |
| 1346 | 20.8 | 21.0 | 21.5 | 21.2 | 20.9 | 21.2 | 21.4 | 22.1 | 21.3 |
| 1348 | 19.9 | 20.3 | 20.7 | 20.3 | 20.4 | 20.4 | 20.8 | 21.4 | 20.6 |
| 1350 | 19.9 | 19.8 | 20.2 | 19.9 | 20.1 | 20.2 | 20.7 | 21.2 | 20.7 |
| 1352 | 20.3 | 19.8 | 20.3 | 20.0 | 20.1 | 20.5 | 20.7 | 21.5 | 21.0 |
| 1354 | 19.8 | 19.4 | 20.1 | 19.6 | 19.7 | 20.2 | 20.3 | 21.3 | 20.7 |
| 1356 | 19.1 | 19.1 | 19.6 | 19.3 | 19.3 | 20.0 | 20.3 | 20.9 | 20.4 |
| 1358 | 18.7 | 18.8 | 19.2 | 19.1 | 18.7 | 20.0 | 20.0 | 20.3 | 19.9 |
| 1360 | 17.4 | 17.6 | 18.1 | 18.0 | 17.5 | 19.2 | 18.6 | 19.0 | 18.5 |
| 1362 | 16.3 | 16.6 | 17.1 | 16.8 | 16.3 | 18.2 | 17.5 | 18.1 | 17.7 |
| 1364 | 16.8 | 17.0 | 17.5 | 17.1 | 16.8 | 18.5 | 18.1 | 18.6 | 18.6 |
| 1366 | 17.8 | 17.8 | 18.5 | 18.1 | 18.0 | 19.3 | 19.0 | 19.4 | 19.6 |
| 1368 | 17.8 | 17.7 | 18.3 | 18.3 | 18.1 | 19.4 | 19.0 | 19.6 | 19.3 |
| 1370 | 17.4 | 17.2 | 17.5 | 17.5 | 17.2 | 19.0 | 18.4 | 19.0 | 18.9 |
| 1372 | 16.4 | 16.4 | 16.7 | 16.3 | 16.2 | 17.8 | 17.3 | 17.9 | 18.1 |
| 1374 | 15.3 | 15.7 | 15.8 | 15.4 | 15.6 | 16.6 | 16.2 | 17.1 | 17.0 |
| 1376 | 15.6 | 16.0 | 16.2 | 15.9 | 16.1 | 17.0 | 16.8 | 17.7 | 17.4 |
| 1378 | 16.9 | 17.1 | 17.6 | 17.2 | 17.3 | 18.2 | 18.3 | 18.9 | 18.6 |
| 1380 | 17.6 | 17.9 | 18.7 | 17.9 | 18.0 | 18.9 | 19.3 | 20.6 | 19.3 |
| 1382 | 17.8 | 18.1 | 18.8 | 17.9 | 18.0 | 19.2 | 19.6 | 21.0 | 19.6 |
| 1384 | 17.1 | 17.5 | 17.9 | 17.2 | 17.2 | 18.5 | 18.9 | 20.2 | 19.1 |
| 1386 | 15.4 | 16.1 | 16.6 | 16.1 | 15.7 | 17.0 | 17.4 | 18.0 | 17.5 |
| 1388 | 14.3 | 15.4 | 15.9 | 15.4 | 15.0 | 16.5 | 16.6 | 17.2 | 16.4 |
| 1390 | 14.5 | 15.2 | 15.5 | 15.3 | 15.3 | 16.6 | 16.5 | 17.3 | 16.4 |
| 1392 | 14.2 | 14.5 | 14.8 | 15.2 | 15.1 | 15.9 | 16.0 | 16.9 | 15.9 |
| 1394 | 12.9 | 13.4 | 13.7 | 14.5 | 13.7 | 14.5 | 14.9 | 15.6 | 14.5 |
| 1396 | 11.8 | 12.7 | 13.1 | 13.7 | 13.0 | 13.5 | 14.3 | 14.8 | 13.8 |
| 1398 | 12.0 | 12.7 | 13.4 | 13.8 | 13.6 | 13.6 | 14.5 | 15.0 | 14.4 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1400 | 13.1 | 13.5 | 14.4 | 14.8 | 14.7 | 14.7 | 15.2 | 15.9 | 15.2 |
| 1402 | 13.8 | 14.2 | 15.3 | 15.4 | 15.4 | 15.5 | 15.7 | 16.5 | 15.7 |
| 1404 | 13.9 | 14.5 | 15.3 | 15.3 | 15.6 | 15.7 | 15.7 | 16.6 | 16.0 |
| 1406 | 14.2 | 14.8 | 15.1 | 15.2 | 15.5 | 16.2 | 16.0 | 17.1 | 16.5 |
| 1408 | 14.8 | 15.3 | 15.3 | 15.6 | 15.5 | 16.8 | 16.8 | 17.8 | 16.9 |
| 1410 | 14.8 | 15.1 | 15.3 | 15.5 | 15.1 | 16.7 | 16.9 | 17.4 | 16.7 |
| 1412 | 14.2 | 14.5 | 14.9 | 15.0 | 14.6 | 16.2 | 16.1 | 16.6 | 16.3 |
| 1414 | 13.3 | 13.8 | 14.2 | 14.5 | 14.0 | 15.3 | 14.9 | 15.8 | 15.6 |
| 1416 | 11.7 | 12.3 | 12.7 | 13.2 | 12.9 | 13.8 | 12.8 | 14.1 | 13.9 |
| 1418 | 10.4 | 10.9 | 11.0 | 11.6 | 11.5 | 12.1 | 10.9 | 12.5 | 12.3 |
| 1420 | 10.3 | 10.6 | 10.7 | 11.4 | 11.0 | 11.4 | 10.6 | 12.2 | 12.1 |
| 1422 | 10.7 | 11.2 | 11.2 | 11.9 | 11.2 | 12.0 | 11.4 | 12.7 | 12.7 |
| 1424 | 11.2 | 11.8 | 12.0 | 12.5 | 11.6 | 12.9 | 12.5 | 13.4 | 13.4 |
| 1426 | 11.7 | 12.0 | 12.4 | 12.8 | 11.9 | 12.9 | 13.2 | 13.8 | 13.6 |
| 1428 | 11.6 | 11.9 | 12.3 | 12.6 | 11.7 | 12.3 | 13.0 | 13.6 | 13.2 |
| 1430 | 10.9 | 11.4 | 11.8 | 11.8 | 11.3 | 11.9 | 12.2 | 13.0 | 12.5 |
| 1432 | 10.4 | 11.0 | 11.6 | 11.4 | 11.4 | 11.6 | 11.8 | 12.6 | 12.3 |
| 1434 | 10.1 | 10.6 | 11.1 | 11.2 | 11.2 | 11.0 | 11.3 | 12.1 | 11.8 |
| 1436 | 9.9 | 10.4 | 10.7 | 10.8 | 10.6 | 10.9 | 10.9 | 11.7 | 11.4 |
| 1438 | 10.1 | 11.0 | 11.0 | 11.3 | 10.9 | 11.7 | 11.6 | 12.3 | 11.9 |
| 1440 | 10.9 | 12.2 | 12.1 | 12.7 | 12.3 | 13.1 | 12.8 | 13.5 | 13.1 |
| 1442 | 11.4 | 12.4 | 12.6 | 13.3 | 13.0 | 13.8 | 13.2 | 13.9 | 13.7 |
| 1444 | 11.2 | 11.8 | 12.3 | 12.7 | 12.4 | 13.5 | 12.8 | 13.3 | 13.4 |
| 1446 | 10.3 | 11.0 | 11.4 | 11.6 | 11.3 | 12.4 | 11.7 | 12.1 | 12.1 |
| 1448 | 9.5 | 10.3 | 10.4 | 10.7 | 10.7 | 11.2 | 10.8 | 11.1 | 10.8 |
| 1450 | 9.1 | 9.6 | 9.4 | 10.2 | 10.2 | 10.7 | 10.5 | 10.5 | 10.4 |
| 1452 | 8.7 | 9.1 | 8.9 | 9.7 | 9.4 | 10.3 | 10.2 | 9.9 | 10.1 |
| 1454 | 7.5 | 8.3 | 8.2 | 8.8 | 8.2 | 9.2 | 8.8 | 8.8 | 8.9 |
| 1456 | 6.2 | 6.9 | 6.9 | 7.6 | 6.8 | 7.8 | 6.8 | 7.1 | 7.5 |
| 1458 | 6.2 | 6.4 | 6.8 | 7.2 | 6.6 | 7.6 | 6.4 | 6.9 | 7.0 |
| 1460 | 7.2 | 7.2 | 8.0 | 8.3 | 7.9 | 8.5 | 7.7 | 8.2 | 7.9 |
| 1462 | 7.7 | 7.8 | 8.9 | 9.2 | 8.9 | 9.2 | 8.8 | 8.9 | 8.7 |
| 1464 | 7.3 | 7.5 | 8.7 | 8.9 | 8.6 | 8.9 | 8.6 | 8.8 | 8.6 |
| 1466 | 7.2 | 7.6 | 8.4 | 8.7 | 8.5 | 8.8 | 8.3 | 9.1 | 8.8 |
| 1468 | 7.5 | 8.1 | 8.4 | 9.0 | 8.8 | 9.1 | 8.6 | 9.4 | 9.1 |
| 1470 | 7.0 | 7.6 | 7.9 | 8.3 | 8.0 | 8.7 | 8.1 | 8.5 | 8.2 |
| 1472 | 6.4 | 6.7 | 7.1 | 7.2 | 7.0 | 7.9 | 7.1 | 7.4 | 7.2 |
| 1474 | 6.2 | 6.3 | 6.8 | 6.9 | 6.7 | 7.5 | 6.8 | 6.9 | 6.8 |
| 1476 | 6.6 | 6.9 | 7.6 | 7.8 | 7.4 | 8.1 | 7.7 | 7.8 | 7.4 |
| 1478 | 7.4 | 8.1 | 8.7 | 8.5 | 8.6 | 9.0 | 8.9 | 9.1 | 9.0 |
| 1480 | 7.8 | 8.6 | 8.8 | 8.5 | 8.9 | 9.2 | 9.5 | 9.6 | 9.8 |
| 1482 | 7.7 | 8.6 | 8.5 | 8.5 | 8.5 | 8.9 | 9.3 | 9.2 | 9.4 |
| 1484 | 7.2 | 8.1 | 7.9 | 8.2 | 7.7 | 8.2 | 8.5 | 8.4 | 8.6 |
| 1486 | 6.1 | 6.9 | 7.1 | 7.3 | 6.6 | 7.1 | 7.6 | 7.5 | 7.6 |
| 1488 | 4.9 | 5.8 | 6.1 | 6.3 | 5.5 | 6.0 | 6.7 | 6.2 | 6.2 |
| 1490 | 4.9 | 5.8 | 6.0 | 6.3 | 5.7 | 5.9 | 6.3 | 5.7 | 5.8 |
| 1492 | 5.2 | 6.4 | 6.3 | 6.6 | 6.3 | 6.1 | 6.6 | 6.3 | 6.3 |
| 1494 | 4.8 | 6.3 | 6.3 | 6.5 | 6.2 | 5.8 | 6.7 | 6.6 | 6.4 |
| 1496 | 3.9 | 5.6 | 6.0 | 5.6 | 5.5 | 5.0 | 5.4 | 5.7 | 5.9 |
| 1498 | 3.9 | 5.2 | 6.1 | 5.2 | 5.3 | 4.8 | 4.7 | 4.7 | 5.5 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1500 | 4.4 | 5.5 | 6.0 | 5.6 | 5.6 | 5.0 | 5.3 | 4.6 | 5.5 |
| 1502 | 4.5 | 5.3 | 5.5 | 5.6 | 5.3 | 4.8 | 6.0 | 4.7 | 5.2 |
| 1504 | 4.0 | 4.5 | 4.7 | 4.9 | 4.6 | 4.0 | 5.2 | 4.3 | 4.6 |
| 1506 | 3.3 | 3.7 | 4.0 | 3.9 | 3.8 | 3.4 | 3.7 | 3.5 | 3.8 |
| 1508 | 3.3 | 3.7 | 4.3 | 3.4 | 3.8 | 3.8 | 3.3 | 3.2 | 3.5 |
| 1510 | 4.0 | 4.5 | 5.0 | 3.7 | 4.4 | 4.5 | 4.3 | 3.8 | 3.9 |
| 1512 | 4.4 | 5.0 | 5.1 | 4.0 | 4.2 | 4.3 | 5.3 | 4.1 | 4.4 |
| 1514 | 4.0 | 4.9 | 5.0 | 3.7 | 3.3 | 3.6 | 5.6 | 3.4 | 4.2 |
| 1516 | 3.2 | 4.3 | 4.6 | 3.4 | 2.5 | 2.7 | 5.4 | 2.7 | 3.2 |
| 1518 | 2.6 | 3.6 | 3.9 | 3.3 | 2.2 | 2.6 | 4.7 | 2.4 | 2.9 |
| 1520 | 2.6 | 3.3 | 3.0 | 3.4 | 2.2 | 2.9 | 3.6 | 1.9 | 3.0 |
| 1522 | 2.8 | 3.3 | 2.7 | 3.4 | 2.7 | 2.7 | 3.4 | 2.1 | 2.7 |
| 1524 | 2.8 | 3.5 | 3.1 | 3.5 | 2.9 | 2.5 | 3.9 | 2.8 | 3.0 |
| 1526 | 2.8 | 3.9 | 3.7 | 3.6 | 3.0 | 3.0 | 4.4 | 2.8 | 3.8 |
| 1528 | 3.1 | 4.3 | 3.9 | 3.6 | 3.3 | 4.0 | 4.6 | 2.8 | 4.4 |
| 1530 | 3.2 | 4.3 | 4.1 | 3.3 | 3.6 | 4.0 | 4.7 | 3.1 | 4.3 |
| 1532 | 3.2 | 3.9 | 3.8 | 2.8 | 3.5 | 3.0 | 4.2 | 3.1 | 3.8 |
| 1534 | 3.1 | 3.3 | 3.1 | 2.6 | 3.3 | 2.2 | 3.6 | 2.7 | 3.0 |
| 1536 | 2.8 | 2.9 | 2.4 | 2.4 | 3.4 | 2.0 | 3.2 | 2.4 | 2.6 |
| 1538 | 2.4 | 2.3 | 2.0 | 1.8 | 2.8 | 1.7 | 2.6 | 1.9 | 2.1 |
| 1540 | 2.1 | 1.9 | 2.1 | 1.4 | 1.8 | 1.3 | 2.2 | 1.4 | 1.6 |
| 1542 | 2.1 | 2.3 | 2.6 | 1.9 | 2.1 | 1.5 | 2.8 | 1.6 | 2.1 |
| 1544 | 2.2 | 3.0 | 3.2 | 2.7 | 2.8 | 1.8 | 3.9 | 2.4 | 2.9 |
| 1546 | 2.7 | 3.6 | 4.1 | 3.5 | 3.6 | 2.6 | 4.9 | 3.4 | 3.6 |
| 1548 | 3.0 | 3.9 | 4.3 | 3.8 | 4.0 | 3.1 | 5.0 | 3.7 | 3.8 |
| 1550 | 2.9 | 3.8 | 3.8 | 3.6 | 4.0 | 3.1 | 4.6 | 3.2 | 3.5 |
| 1552 | 2.7 | 3.4 | 3.3 | 3.3 | 3.7 | 2.9 | 4.3 | 2.6 | 3.2 |
| 1554 | 2.5 | 3.0 | 2.7 | 2.8 | 3.3 | 2.6 | 3.8 | 2.0 | 2.9 |
| 1556 | 1.7 | 2.3 | 2.1 | 2.1 | 2.5 | 2.2 | 3.0 | 1.3 | 2.2 |
| 1558 | 1.2 | 1.9 | 2.1 | 1.8 | 2.1 | 1.8 | 2.7 | .8 | 1.5 |
| 1560 | 1.6 | 2.4 | 2.6 | 2.1 | 2.5 | 1.9 | 3.4 | 1.5 | 1.8 |
| 1562 | 2.6 | 3.3 | 3.3 | 2.8 | 3.4 | 2.5 | 4.4 | 2.8 | 3.0 |
| 1564 | 3.4 | 3.9 | 3.9 | 3.4 | 3.9 | 3.2 | 5.1 | 3.6 | 4.1 |
| 1566 | 3.5 | 4.1 | 4.0 | 3.6 | 3.8 | 3.6 | 5.0 | 3.6 | 4.5 |
| 1568 | 3.1 | 4.1 | 3.7 | 3.3 | 3.5 | 3.4 | 4.4 | 3.3 | 4.0 |
| 1570 | 2.9 | 4.1 | 3.7 | 3.1 | 3.7 | 3.5 | 4.1 | 3.3 | 3.6 |
| 1572 | 2.9 | 4.1 | 3.7 | 3.2 | 3.9 | 3.7 | 4.3 | 3.4 | 3.7 |
| 1574 | 2.7 | 3.7 | 3.3 | 3.4 | 3.6 | 3.5 | 4.5 | 3.2 | 3.6 |
| 1576 | 2.8 | 3.5 | 3.3 | 3.5 | 3.4 | 3.4 | 4.5 | 3.2 | 3.5 |
| 1578 | 3.6 | 4.1 | 3.8 | 3.9 | 4.0 | 4.0 | 5.0 | 4.0 | 4.3 |
| 1580 | 4.2 | 5.0 | 4.6 | 4.5 | 5.0 | 5.0 | 5.9 | 5.1 | 5.5 |
| 1582 | 4.4 | 5.4 | 5.2 | 4.9 | 5.5 | 5.9 | 6.5 | 5.7 | 6.0 |
| 1584 | 4.7 | 5.5 | 5.4 | 4.9 | 5.6 | 6.0 | 6.9 | 6.0 | 6.0 |
| 1586 | 5.1 | 5.7 | 5.8 | 4.9 | 5.9 | 5.8 | 7.3 | 6.3 | 6.2 |
| 1588 | 5.2 | 5.9 | 5.8 | 4.9 | 6.0 | 5.9 | 7.4 | 6.3 | 6.3 |
| 1590 | 4.9 | 5.7 | 5.5 | 4.8 | 5.7 | 6.0 | 7.1 | 6.0 | 6.3 |
| 1592 | 4.6 | 5.5 | 5.5 | 4.6 | 5.4 | 5.9 | 6.6 | 5.8 | 6.0 |
| 1594 | 4.5 | 5.1 | 5.6 | 4.7 | 5.3 | 5.6 | 6.4 | 5.7 | 5.7 |
| 1596 | 4.5 | 4.9 | 5.3 | 4.8 | 5.2 | 5.6 | 6.6 | 5.6 | 5.6 |
| 1598 | 4.5 | 5.0 | 5.1 | 4.9 | 5.1 | 5.8 | 6.7 | 5.7 | 5.4 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1600 | 4.5 | 5.1 | 5.3 | 4.9 | 5.3 | 6.0 | 6.6 | 5.8 | 5.5 |
| 1602 | 4.4 | 5.0 | 5.3 | 4.8 | 5.3 | 5.9 | 6.3 | 5.6 | 5.7 |
| 1604 | 4.2 | 4.7 | 5.3 | 4.6 | 5.1 | 5.6 | 6.1 | 5.1 | 5.6 |
| 1606 | 4.0 | 4.6 | 4.9 | 4.3 | 4.9 | 5.3 | 6.0 | 4.4 | 5.1 |
| 1608 | 3.9 | 4.6 | 4.3 | 3.8 | 4.8 | 5.0 | 5.7 | 4.1 | 4.6 |
| 1610 | 4.0 | 4.5 | 4.1 | 3.5 | 4.6 | 4.6 | 5.4 | 4.5 | 4.4 |
| 1612 | 3.8 | 4.4 | 4.2 | 3.4 | 4.3 | 4.6 | 5.5 | 4.7 | 4.4 |
| 1614 | 3.3 | 4.0 | 3.8 | 3.3 | 4.0 | 4.5 | 5.2 | 4.4 | 4.0 |
| 1616 | 3.0 | 3.5 | 3.4 | 3.0 | 3.7 | 3.8 | 4.2 | 4.0 | 3.6 |
| 1618 | 2.8 | 3.4 | 3.2 | 2.6 | 3.6 | 3.6 | 4.0 | 3.9 | 3.5 |
| 1620 | 2.6 | 3.5 | 3.4 | 2.8 | 3.7 | 4.0 | 4.8 | 3.7 | 3.8 |
| 1622 | 2.3 | 3.6 | 3.4 | 3.0 | 3.7 | 3.9 | 5.1 | 3.3 | 3.8 |
| 1624 | 2.6 | 3.7 | 3.7 | 2.9 | 3.6 | 3.5 | 4.6 | 3.5 | 3.8 |
| 1626 | 3.1 | 3.9 | 3.9 | 3.2 | 3.7 | 3.9 | 4.5 | 4.4 | 3.8 |
| 1628 | 3.2 | 4.0 | 3.7 | 3.4 | 3.9 | 4.6 | 4.8 | 4.8 | 3.8 |
| 1630 | 3.2 | 3.9 | 3.8 | 3.0 | 4.0 | 4.6 | 4.9 | 4.7 | 4.0 |
| 1632 | 3.1 | 3.8 | 4.0 | 2.8 | 4.2 | 4.4 | 4.5 | 4.3 | 4.1 |
| 1634 | 2.8 | 3.4 | 3.4 | 2.8 | 3.8 | 4.0 | 3.8 | 3.7 | 3.7 |
| 1636 | 2.3 | 2.7 | 2.6 | 2.4 | 3.1 | 3.4 | 3.3 | 3.3 | 3.0 |
| 1638 | 2.3 | 2.7 | 2.8 | 2.1 | 3.1 | 3.0 | 3.5 | 3.7 | 3.1 |
| 1640 | 2.8 | 3.1 | 3.3 | 2.6 | 3.7 | 3.4 | 4.4 | 4.5 | 3.8 |
| 1642 | 2.8 | 3.2 | 3.6 | 2.6 | 3.7 | 4.0 | 4.9 | 4.6 | 4.0 |
| 1644 | 2.5 | 2.9 | 3.4 | 1.9 | 3.1 | 4.1 | 4.4 | 4.2 | 3.8 |
| 1646 | 2.2 | 2.6 | 3.0 | 1.8 | 2.7 | 3.8 | 3.6 | 3.6 | 3.4 |
| 1648 | 2.1 | 2.4 | 2.9 | 2.1 | 2.7 | 3.6 | 3.1 | 3.2 | 3.1 |
| 1650 | 2.1 | 2.3 | 2.8 | 2.3 | 3.0 | 3.3 | 3.0 | 3.3 | 3.0 |
| 1652 | 2.1 | 2.0 | 2.5 | 2.6 | 3.0 | 3.2 | 3.0 | 3.6 | 2.9 |
| 1654 | 2.0 | 2.2 | 2.6 | 3.0 | 3.0 | 3.4 | 3.1 | 3.7 | 2.8 |
| 1656 | 2.3 | 2.9 | 3.2 | 3.4 | 3.4 | 4.0 | 3.6 | 4.2 | 3.1 |
| 1658 | 2.8 | 3.6 | 3.9 | 3.8 | 3.7 | 4.9 | 4.3 | 4.8 | 3.6 |
| 1660 | 2.9 | 3.6 | 4.1 | 3.7 | 3.6 | 5.1 | 4.7 | 4.6 | 3.9 |
| 1662 | 2.8 | 3.6 | 4.0 | 3.3 | 3.4 | 4.6 | 4.6 | 4.1 | 3.9 |
| 1664 | 3.0 | 3.6 | 4.0 | 3.2 | 3.7 | 4.5 | 4.7 | 4.1 | 4.0 |
| 1666 | 3.1 | 3.5 | 4.1 | 3.2 | 3.9 | 4.8 | 4.6 | 4.4 | 3.9 |
| 1668 | 2.7 | 3.1 | 3.9 | 3.0 | 3.7 | 4.5 | 3.9 | 4.0 | 3.4 |
| 1670 | 1.9 | 2.7 | 3.3 | 2.7 | 3.5 | 3.8 | 3.3 | 3.6 | 3.0 |
| 1672 | 1.7 | 2.7 | 2.9 | 2.4 | 3.5 | 3.7 | 3.5 | 3.8 | 3.0 |
| 1674 | 2.2 | 2.9 | 3.0 | 2.3 | 3.5 | 4.2 | 3.9 | 4.1 | 3.0 |
| 1676 | 2.4 | 2.9 | 3.5 | 2.6 | 3.7 | 4.7 | 4.2 | 4.3 | 3.3 |
| 1678 | 2.6 | 3.0 | 3.7 | 3.0 | 4.0 | 4.9 | 4.3 | 4.5 | 3.9 |
| 1680 | 2.6 | 3.1 | 3.4 | 2.9 | 3.9 | 4.7 | 4.0 | 4.4 | 4.0 |
| 1682 | 2.3 | 2.7 | 3.1 | 2.5 | 3.4 | 4.2 | 3.5 | 3.9 | 3.2 |
| 1684 | 1.9 | 2.4 | 2.9 | 2.0 | 3.2 | 3.8 | 3.4 | 3.7 | 2.6 |
| 1686 | 2.1 | 2.5 | 3.0 | 2.3 | 3.6 | 4.0 | 3.6 | 4.2 | 3.1 |
| 1688 | 2.6 | 2.9 | 3.4 | 3.0 | 3.7 | 4.4 | 3.9 | 4.5 | 3.5 |
| 1690 | 2.8 | 3.0 | 3.9 | 3.2 | 3.9 | 4.6 | 4.0 | 4.4 | 3.5 |
| 1692 | 2.6 | 3.0 | 3.9 | 3.2 | 4.2 | 5.6 | 4.0 | 4.3 | 3.5 |
| 1694 | 2.3 | 2.6 | 3.3 | 2.8 | 4.1 | 4.2 | 3.6 | 4.1 | 3.2 |
| 1696 | 1.9 | 2.3 | 2.9 | 2.3 | 3.5 | 3.6 | 2.7 | 3.4 | 2.7 |
| 1698 | 1.6 | 2.2 | 2.8 | 2.3 | 3.2 | 3.3 | 2.4 | 2.9 | 2.8 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1700 | 1.7 | 2.1 | 2.6 | 2.4 | 3.3 | 3.2 | 2.8 | 3.0 | 2.9 |
| 1702 | 1.8 | 2.0 | 2.7 | 2.5 | 3.6 | 3.3 | 3.1 | 3.5 | 2.8 |
| 1704 | 1.8 | 2.3 | 2.9 | 2.8 | 3.7 | 3.5 | 3.1 | 3.9 | 2.8 |
| 1706 | 2.1 | 2.6 | 3.1 | 2.8 | 3.7 | 3.8 | 3.4 | 4.1 | 3.1 |
| 1708 | 2.2 | 2.8 | 3.5 | 2.6 | 3.7 | 4.3 | 3.8 | 4.3 | 3.4 |
| 1710 | 2.3 | 2.9 | 3.9 | 3.0 | 4.9 | 5.5 | 4.1 | 4.7 | 3.5 |
| 1712 | 2.6 | 2.9 | 3.8 | 3.4 | 4.7 | 5.8 | 4.0 | 4.8 | 3.7 |
| 1714 | 2.6 | 2.6 | 3.3 | 3.2 | 3.6 | 5.9 | 3.7 | 4.5 | 3.5 |
| 1716 | 2.3 | 2.4 | 3.0 | 2.7 | 3.7 | 5.4 | 3.3 | 4.2 | 3.1 |
| 1718 | 2.3 | 2.7 | 3.2 | 2.8 | 5.1 | 4.9 | 3.5 | 4.3 | 3.2 |
| 1720 | 2.6 | 3.0 | 3.7 | 3.2 | 6.0 | 5.9 | 3.9 | 4.7 | 3.7 |
| 1722 | 2.5 | 3.2 | 4.1 | 3.4 | 6.1 | 6.4 | 4.5 | 5.8 | 4.1 |
| 1724 | 2.5 | 3.4 | 4.1 | 3.8 | 6.1 | 6.6 | 4.8 | 6.2 | 4.6 |
| 1726 | 2.6 | 3.5 | 3.8 | 4.0 | 5.2 | 6.6 | 5.6 | 5.9 | 4.7 |
| 1728 | 2.5 | 3.3 | 3.4 | 3.8 | 5.0 | 6.5 | 5.3 | 5.6 | 4.1 |
| 1730 | 2.5 | 3.0 | 3.4 | 3.4 | 4.7 | 6.2 | 5.0 | 5.4 | 4.4 |
| 1732 | 2.5 | 2.8 | 3.2 | 3.0 | 3.5 | 5.2 | 3.5 | 5.1 | 4.1 |
| 1734 | 2.3 | 2.4 | 3.0 | 2.7 | 3.4 | 3.5 | 2.9 | 4.1 | 4.0 |
| 1736 | 2.0 | 2.2 | 3.3 | 2.6 | 3.6 | 3.7 | 2.5 | 5.0 | 2.7 |
| 1738 | 1.9 | 2.2 | 3.7 | 2.8 | 3.4 | 5.6 | 2.9 | 4.9 | 2.5 |
| 1740 | 1.9 | 2.4 | 3.5 | 3.0 | 4.3 | 4.4 | 3.2 | 3.9 | 2.6 |
| 1742 | 2.0 | 2.5 | 3.5 | 2.8 | 4.3 | 5.6 | 3.2 | 3.9 | 2.8 |
| 1744 | 2.0 | 2.7 | 3.7 | 2.8 | 5.1 | 5.8 | 3.3 | 4.3 | 3.0 |
| 1746 | 1.9 | 2.6 | 3.4 | 2.7 | 4.1 | 5.7 | 3.3 | 4.2 | 3.1 |
| 1748 | 1.7 | 2.3 | 2.8 | 2.3 | 3.8 | 5.4 | 3.1 | 3.4 | 2.9 |
| 1750 | 1.9 | 2.3 | 2.5 | 2.4 | 3.5 | 5.3 | 3.3 | 3.1 | 2.8 |
| 1752 | 2.3 | 2.9 | 3.0 | 2.8 | 3.7 | 5.5 | 3.7 | 3.6 | 3.0 |
| 1754 | 2.5 | 3.2 | 3.4 | 2.8 | 4.5 | 4.8 | 4.7 | 3.9 | 3.3 |
| 1756 | 2.6 | 2.9 | 3.2 | 2.7 | 3.8 | 4.8 | 4.5 | 4.4 | 3.4 |
| 1758 | 2.7 | 2.9 | 3.0 | 2.7 | 3.6 | 5.0 | 3.1 | 4.6 | 3.4 |
| 1760 | 2.7 | 3.1 | 3.2 | 2.8 | 4.3 | 5.0 | 3.1 | 4.5 | 3.0 |
| 1762 | 2.5 | 3.1 | 3.4 | 3.0 | 4.8 | 4.8 | 3.4 | 3.9 | 3.0 |
| 1764 | 2.7 | 2.9 | 3.4 | 3.1 | 4.9 | 4.7 | 4.0 | 4.8 | 3.4 |
| 1766 | 2.8 | 3.2 | 3.0 | 2.9 | 4.5 | 4.6 | 2.9 | 4.9 | 3.4 |
| 1768 | 2.3 | 3.0 | 2.7 | 2.6 | 3.4 | 3.6 | 2.6 | 4.0 | 2.8 |
| 1770 | 1.9 | 2.7 | 2.5 | 2.3 | 3.0 | 3.2 | 2.3 | 3.4 | 2.3 |
| 1772 | 1.8 | 2.7 | 2.4 | 2.4 | 2.9 | 3.2 | 2.1 | 3.2 | 2.5 |
| 1774 | 2.1 | 2.6 | 2.6 | 2.7 | 3.1 | 3.7 | 2.4 | 3.4 | 3.0 |
| 1776 | 2.6 | 2.9 | 3.2 | 3.1 | 3.4 | 3.9 | 3.2 | 4.0 | 3.3 |
| 1778 | 2.7 | 2.9 | 3.5 | 3.3 | 3.3 | 4.2 | 3.7 | 3.9 | 3.3 |
| 1780 | 2.6 | 2.8 | 3.4 | 3.2 | 3.3 | 4.4 | 3.6 | 4.0 | 4.2 |
| 1782 | 2.6 | 3.1 | 3.2 | 3.0 | 4.1 | 4.5 | 3.5 | 3.6 | 3.3 |
| 1784 | 2.6 | 3.4 | 3.3 | 2.9 | 5.2 | 4.5 | 3.7 | 3.7 | 3.1 |
| 1786 | 2.7 | 3.4 | 3.4 | 3.2 | 4.7 | 5.0 | 4.4 | 3.5 | 3.3 |
| 1788 | 2.8 | 3.0 | 3.3 | 3.4 | 4.6 | 5.2 | 3.7 | 3.3 | 3.4 |
| 1790 | 2.4 | 2.5 | 2.5 | 3.2 | 3.2 | 4.6 | 2.9 | 3.1 | 3.0 |
| 1792 | 1.9 | 2.0 | 2.0 | 2.8 | 2.5 | 3.8 | 2.3 | 2.6 | 2.5 |
| 1794 | 1.9 | 2.2 | 2.4 | 3.0 | 2.6 | 2.7 | 2.5 | 2.4 | 3.4 |
| 1796 | 2.1 | 2.6 | 2.9 | 3.3 | 3.3 | 3.0 | 2.7 | 2.7 | 2.5 |
| 1798 | 2.1 | 2.7 | 2.8 | 3.1 | 3.5 | 3.9 | 3.6 | 2.8 | 2.4 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

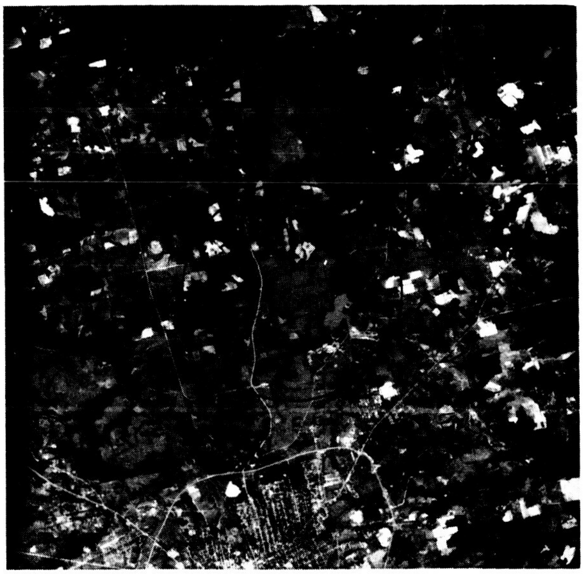
| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1800 | 2.0 | 2.6 | 2.7 | 3.1 | 3.3 | 4.1 | 3.4 | 2.5 | 2.7 |
| 1802 | 2.1 | 2.6 | 2.7 | 3.4 | 3.2 | 3.7 | 3.0 | 2.5 | 2.8 |
| 1804 | 2.5 | 2.9 | 2.9 | 3.5 | 3.3 | 3.7 | 3.2 | 2.8 | 2.9 |
| 1806 | 3.0 | 3.0 | 3.2 | 3.2 | 3.5 | 4.3 | 3.4 | 3.8 | 3.2 |
| 1808 | 3.1 | 3.2 | 4.1 | 3.0 | 3.4 | 4.0 | 3.5 | 2.8 | 3.2 |
| 1810 | 3.5 | 2.7 | 4.2 | 2.8 | 3.2 | 3.5 | 3.2 | 2.7 | 3.3 |
| 1812 | 2.9 | 3.2 | 4.3 | 3.2 | 3.2 | 3.4 | 3.3 | 3.7 | 3.7 |
| 1814 | 3.1 | 3.4 | 3.5 | 3.7 | 3.4 | 3.8 | 3.6 | 3.2 | 4.3 |
| 1816 | 3.1 | 3.7 | 3.5 | 3.8 | 3.3 | 4.0 | 3.6 | 3.0 | 3.8 |
| 1818 | 2.8 | 3.3 | 3.3 | 3.5 | 3.0 | 3.9 | 3.6 | 2.8 | 3.4 |
| 1820 | 2.7 | 2.7 | 3.2 | 3.1 | 2.6 | 4.0 | 3.4 | 2.7 | 3.2 |
| 1822 | 2.4 | 2.4 | 3.1 | 2.8 | 2.4 | 3.5 | 2.7 | 2.5 | 3.1 |
| 1824 | 2.1 | 2.4 | 2.9 | 2.9 | 2.4 | 3.2 | 2.3 | 2.3 | 2.9 |
| 1826 | 2.0 | 2.2 | 2.7 | 2.9 | 2.5 | 3.3 | 2.3 | 2.3 | 2.7 |
| 1828 | 1.9 | 2.0 | 2.7 | 2.6 | 2.3 | 3.3 | 2.6 | 2.4 | 2.4 |
| 1830 | 1.9 | 2.0 | 2.6 | 2.4 | 2.1 | 3.4 | 2.9 | 2.6 | 2.3 |
| 1832 | 2.1 | 2.3 | 2.6 | 2.3 | 3.0 | 2.8 | 2.8 | 3.3 | 2.4 |
| 1834 | 2.1 | 2.8 | 2.5 | 2.3 | 4.1 | 3.6 | 2.8 | 3.3 | 2.7 |
| 1836 | 1.8 | 2.3 | 2.2 | 2.2 | 4.2 | 4.0 | 3.0 | 2.8 | 2.5 |
| 1838 | 2.0 | 2.0 | 2.1 | 2.1 | 3.5 | 2.8 | 3.0 | 1.8 | 2.2 |
| 1840 | 2.0 | 1.7 | 2.1 | 2.0 | 3.1 | 3.0 | 2.5 | 1.8 | 2.4 |
| 1842 | 1.6 | 1.4 | 1.9 | 1.6 | 2.8 | 3.1 | 2.0 | 1.6 | 2.1 |
| 1844 | 1.4 | 1.4 | 1.9 | 1.3 | 2.9 | 3.0 | 2.1 | 1.2 | 1.9 |
| 1846 | 1.6 | 2.1 | 2.3 | 1.4 | 3.3 | 2.0 | 2.5 | 1.3 | 1.9 |
| 1848 | 2.1 | 2.4 | 2.5 | 1.7 | 3.6 | 2.5 | 2.8 | 1.9 | 2.2 |
| 1850 | 2.6 | 2.4 | 2.7 | 2.2 | 4.5 | 2.9 | 3.1 | 2.3 | 2.7 |
| 1852 | 2.8 | 2.8 | 3.0 | 2.5 | 3.9 | 2.8 | 3.1 | 2.5 | 3.4 |
| 1854 | 2.7 | 2.6 | 3.2 | 2.2 | 3.2 | 2.5 | 3.0 | 2.5 | 3.4 |
| 1856 | 2.8 | 2.4 | 3.2 | 2.1 | 3.0 | 2.5 | 3.0 | 2.1 | 3.2 |
| 1858 | 2.7 | 2.6 | 3.2 | 2.8 | 3.4 | 2.6 | 3.1 | 1.9 | 3.1 |
| 1860 | 1.9 | 2.7 | 3.2 | 3.0 | 3.7 | 3.3 | 2.8 | 2.0 | 3.1 |
| 1862 | 1.8 | 2.7 | 3.1 | 2.5 | 4.1 | 3.3 | 2.6 | 2.0 | 2.8 |
| 1864 | 1.8 | 2.2 | 3.2 | 2.2 | 3.1 | 3.1 | 2.6 | 1.7 | 2.2 |
| 1866 | 1.5 | 1.7 | 3.1 | 1.5 | 2.5 | 3.4 | 2.3 | 1.5 | 1.5 |
| 1868 | 1.9 | 2.0 | 3.1 | .9 | 1.7 | 2.6 | 1.7 | 1.5 | 1.6 |
| 1870 | 1.9 | 2.1 | 3.2 | 1.1 | 2.2 | 2.9 | 2.2 | 1.4 | 2.1 |
| 1872 | 1.8 | 2.9 | 3.2 | 2.6 | 3.8 | 3.5 | 2.9 | 1.8 | 2.4 |
| 1874 | 2.1 | 3.2 | 3.4 | 2.6 | 4.7 | 4.2 | 3.0 | 2.8 | 2.6 |
| 1876 | 3.6 | 3.2 | 4.0 | 2.8 | 4.6 | 4.4 | 3.1 | 2.6 | 3.0 |
| 1878 | 3.6 | 3.2 | 3.9 | 3.1 | 4.5 | 4.1 | 3.4 | 2.9 | 3.2 |
| 1880 | 3.7 | 3.2 | 3.3 | 2.8 | 4.5 | 3.8 | 3.8 | 3.7 | 3.3 |
| 1882 | 2.3 | 3.0 | 3.2 | 2.7 | 4.5 | 4.0 | 3.5 | 3.6 | 3.2 |
| 1884 | 1.9 | 2.8 | 2.9 | 2.2 | 4.1 | 4.2 | 3.2 | 2.7 | 2.9 |
| 1886 | 1.8 | 2.8 | 2.8 | 2.3 | 4.1 | 3.9 | 3.3 | 2.8 | 2.7 |
| 1888 | 1.6 | 2.4 | 2.7 | 2.3 | 3.3 | 3.5 | 2.7 | 2.2 | 2.8 |
| 1890 | 1.6 | 2.3 | 3.2 | 2.1 | 3.5 | 3.5 | 2.4 | 2.0 | 2.8 |
| 1892 | 2.1 | 2.2 | 3.3 | 2.3 | 3.8 | 3.9 | 2.5 | 2.2 | 2.4 |
| 1894 | 2.1 | 2.5 | 3.6 | 3.7 | 4.4 | 4.0 | 3.0 | 2.4 | 2.8 |
| 1896 | 2.5 | 3.2 | 3.3 | 4.2 | 3.8 | 3.5 | 3.5 | 2.3 | 2.9 |
| 1898 | 2.6 | 3.4 | 3.2 | 3.8 | 3.8 | 3.2 | 3.7 | 2.5 | 3.8 |

SPECTRAL RADIANCE IN ERGS/SEC CM STR

TIME --IN EASTERN STANDARD TIME-- MAY 8, 1966

| WAVE NO | 08 30 | 09 10 | 10 06 | 11 09 | 12 34 | 13 31 | 14 12 | 14 48 | 15 11 |
|---|---|---|---|---|---|---|---|---|---|
| 1900 | 3.7 | 3.4 | 3.3 | 3.1 | 4.2 | 3.7 | 3.5 | 2.4 | 3.8 |
| 1902 | 3.3 | 3.2 | 2.8 | 2.8 | 4.2 | 4.2 | 2.9 | 3.3 | 3.3 |
| 1904 | 3.3 | 3.0 | 3.0 | 3.2 | 4.4 | 4.4 | 3.3 | 2.8 | 3.0 |
| 1906 | 3.1 | 2.9 | 2.8 | 3.2 | 4.4 | 4.5 | 3.7 | 2.3 | 2.8 |
| 1908 | 1.8 | 2.7 | 2.7 | 2.8 | 3.9 | 4.3 | 4.1 | 2.7 | 2.9 |
| 1910 | 1.6 | 2.4 | 2.7 | 3.0 | 3.7 | 4.0 | 3.8 | 3.8 | 3.0 |
| 1912 | 1.5 | 2.4 | 2.9 | 2.8 | 3.9 | 3.7 | 3.4 | 3.9 | 3.0 |
| 1914 | 1.6 | 2.5 | 2.6 | 2.8 | 3.5 | 3.9 | 3.3 | 3.8 | 3.0 |
| 1916 | 1.4 | 2.5 | 2.4 | 2.3 | 3.0 | 4.0 | 3.3 | 3.9 | 3.1 |
| 1918 | 1.3 | 2.3 | 2.5 | 1.9 | 3.0 | 3.3 | 2.9 | 3.9 | 3.0 |
| 1920 | 1.5 | 2.6 | 2.6 | 2.0 | 3.9 | 2.9 | 2.5 | 3.9 | 2.7 |
| 1922 | 3.1 | 3.0 | 2.9 | 2.0 | 4.3 | 3.9 | 2.7 | 4.0 | 2.9 |
| 1924 | 3.2 | 3.3 | 3.1 | 2.1 | 4.4 | 4.4 | 3.0 | 4.3 | 3.8 |
| 1926 | 4.0 | 3.7 | 3.4 | 3.0 | 4.4 | 4.4 | 3.7 | 4.4 | 3.9 |
| 1928 | 4.0 | 3.7 | 3.7 | 3.4 | 4.3 | 4.5 | 4.0 | 4.3 | 3.7 |
| 1930 | 3.8 | 3.6 | 3.9 | 3.4 | 4.3 | 4.7 | 4.1 | 4.3 | 3.7 |
| 1932 | 3.8 | 3.4 | 3.9 | 3.7 | 4.6 | 4.6 | 4.1 | 4.5 | 3.8 |
| 1934 | 4.1 | 3.2 | 3.2 | 4.0 | 4.8 | 4.6 | 4.1 | 4.5 | 3.8 |
| 1936 | 4.1 | 3.3 | 3.8 | 4.3 | 4.5 | 4.8 | 4.3 | 4.3 | 3.6 |
| 1938 | 3.7 | 3.4 | 3.8 | 4.1 | 4.1 | 4.6 | 4.3 | 4.0 | 3.5 |
| 1940 | 3.6 | 3.4 | 2.9 | 3.7 | 4.0 | 4.3 | 4.0 | 3.9 | 3.3 |
| 1942 | 3.7 | 3.1 | 3.0 | 3.7 | 4.1 | 4.3 | 3.7 | 4.0 | 3.1 |
| 1944 | 3.7 | 3.1 | 3.1 | 4.0 | 4.1 | 4.7 | 3.6 | 4.5 | 3.0 |
| 1946 | 3.8 | 3.3 | 2.9 | 4.1 | 4.2 | 4.9 | 3.9 | 5.0 | 3.0 |
| 1948 | 4.0 | 3.7 | 3.1 | 4.1 | 4.4 | 4.8 | 4.0 | 5.3 | 3.3 |
| 1950 | 4.2 | 3.9 | 3.6 | 4.3 | 4.4 | 5.0 | 4.0 | 5.5 | 3.7 |
| 1952 | 4.3 | 3.6 | 3.7 | 4.4 | 4.5 | 5.4 | 4.1 | 5.5 | 3.8 |
| 1954 | 4.2 | 3.5 | 3.5 | 4.2 | 4.8 | 5.4 | 4.3 | 5.3 | 4.1 |
| 1956 | 4.3 | 3.9 | 3.6 | 4.1 | 4.9 | 5.4 | 4.4 | 5.3 | 4.4 |
| 1958 | 4.5 | 4.1 | 3.6 | 4.1 | 4.5 | 5.3 | 4.3 | 5.5 | 4.6 |
| 1960 | 4.4 | 3.8 | 3.6 | 4.0 | 4.2 | 4.8 | 4.0 | 5.4 | 4.3 |
| 1962 | 4.2 | 3.5 | 3.9 | 3.9 | 4.3 | 4.7 | 4.0 | 5.4 | 4.1 |
| 1964 | 4.1 | 3.7 | 4.1 | 3.7 | 4.5 | 4.9 | 4.2 | 5.6 | 4.3 |
| 1966 | 3.8 | 3.7 | 4.0 | 3.8 | 4.5 | 4.8 | 4.0 | 5.2 | 4.5 |
| 1968 | 4.2 | 3.8 | 3.8 | 4.0 | 4.7 | 4.8 | 4.0 | 4.9 | 4.3 |
| 1970 | 4.5 | 3.9 | 3.8 | 4.4 | 4.9 | 5.3 | 4.5 | 5.2 | 4.4 |
| 1972 | 4.6 | 4.0 | 4.1 | 4.6 | 5.0 | 5.7 | 5.0 | 5.6 | 4.7 |
| 1974 | 4.9 | 4.1 | 4.5 | 4.8 | 5.1 | 5.8 | 4.9 | 5.6 | 4.9 |
| 1976 | 5.1 | 4.1 | 4.8 | 5.1 | 5.1 | 5.9 | 4.7 | 5.6 | 5.1 |
| 1978 | 5.1 | 3.8 | 4.6 | 5.1 | 4.8 | 6.2 | 4.8 | 5.7 | 5.3 |
| 1980 | 4.6 | 3.5 | 4.2 | 4.6 | 4.5 | 6.1 | 4.8 | 5.4 | 5.2 |
| 1982 | 4.5 | 3.3 | 4.4 | 4.6 | 4.5 | 5.9 | 4.7 | 5.2 | 5.0 |
| 1984 | 4.5 | 3.8 | 4.4 | 4.8 | 4.4 | 5.8 | 4.7 | 5.4 | 4.7 |
| 1986 | 4.2 | 3.6 | 4.0 | 4.4 | 4.2 | 5.8 | 4.7 | 5.5 | 4.5 |
| 1988 | 3.9 | 3.2 | 3.8 | 3.7 | 4.0 | 5.5 | 4.5 | 5.1 | 4.4 |
| 1990 | 3.9 | 3.2 | 3.4 | 3.3 | 3.9 | 5.2 | 4.4 | 4.9 | 4.3 |
| 1992 | 4.0 | 3.3 | 3.3 | 4.1 | 4.0 | 5.1 | 4.3 | 5.0 | 4.3 |
| 1994 | 4.2 | 3.4 | 3.8 | 4.5 | 3.9 | 5.4 | 4.4 | 5.4 | 4.3 |
| 1996 | 4.3 | 3.5 | 4.2 | 4.3 | 3.9 | 5.5 | 4.7 | 5.4 | 4.1 |
| 1998 | 4.3 | 3.6 | 4.1 | 4.1 | 4.1 | 5.4 | 4.7 | 5.2 | 4.1 |

08:30 E.S.T.



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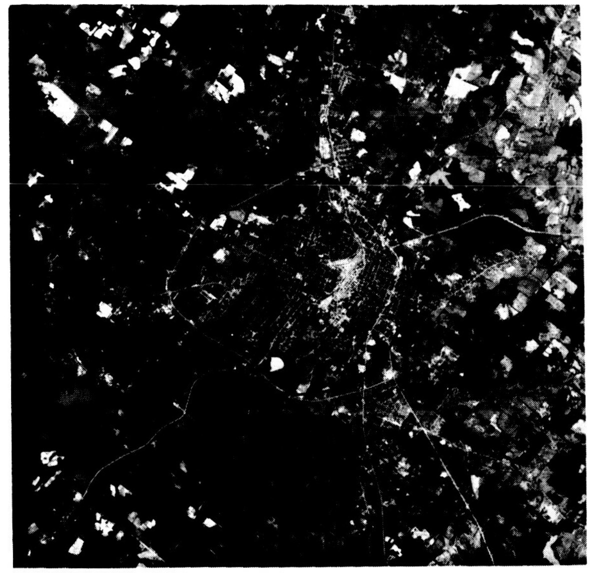

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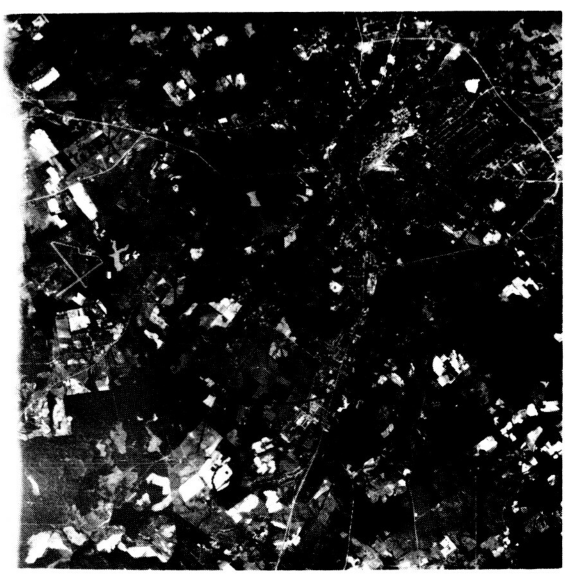
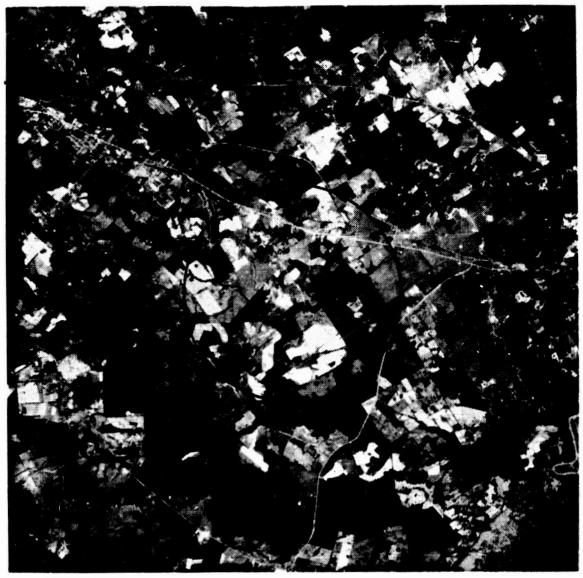


The nine scene photographs reproduced here and on the following two pages correspond to the data given on the preceding fifteen pages. The photographs were taken with a Maurer 220 camera from a float altitude of 110, 000 feet. The black circle shown in the center of each photograph outlines the $8^{\circ}$ interferometer field of view.

The camera developed a light leak during the later portion of the flight and four of the later photographs are streaked along one side.

Figure 1. - SCENE PHOTOGRAPHS

11:09 E.S.T.



12:34 E.S.T.

13:31 E.S.T.

Figure 2. - SCENE PHOTOGRAPHS

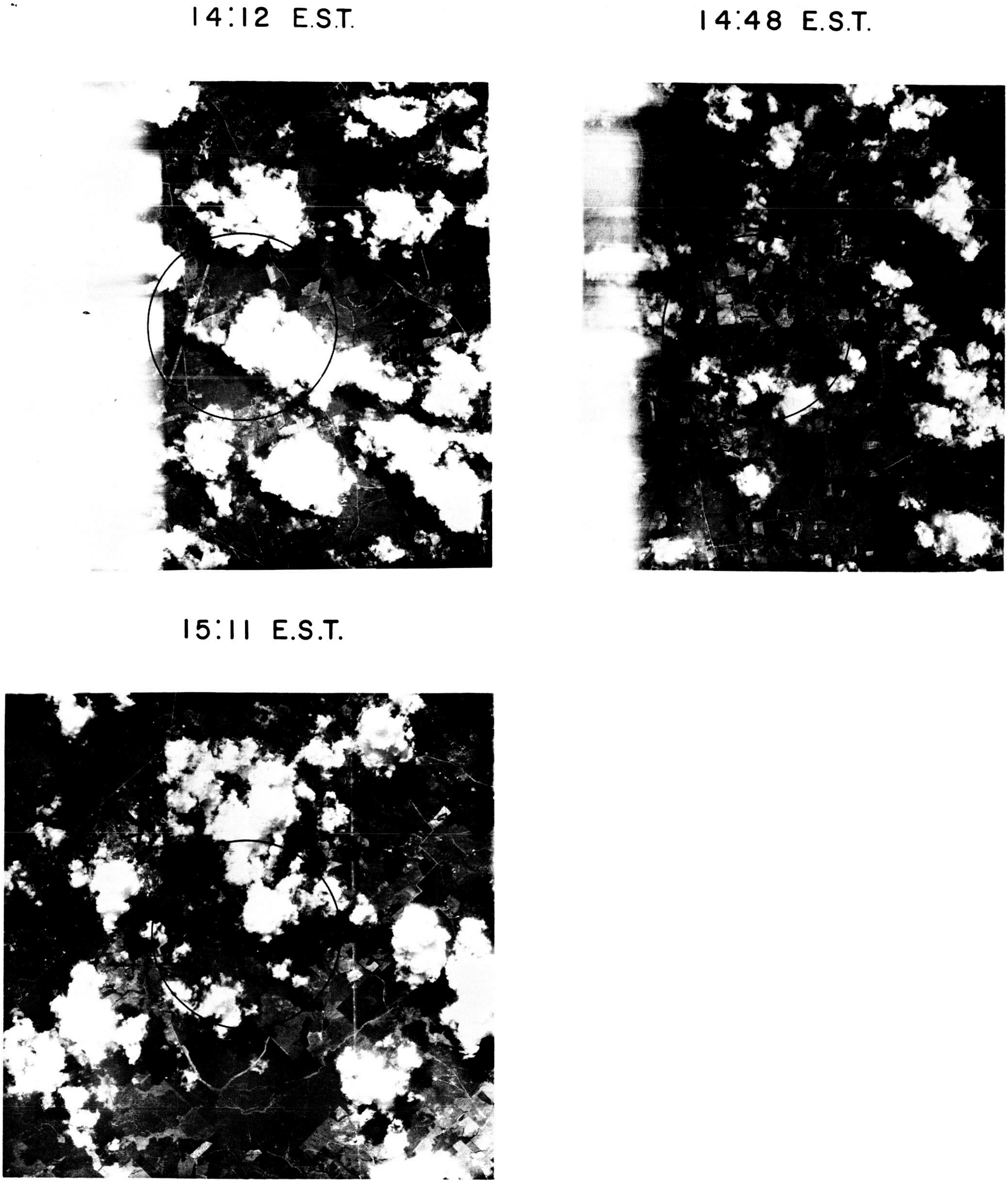



Figure 3. - SCENE PHOTOGRAPHS

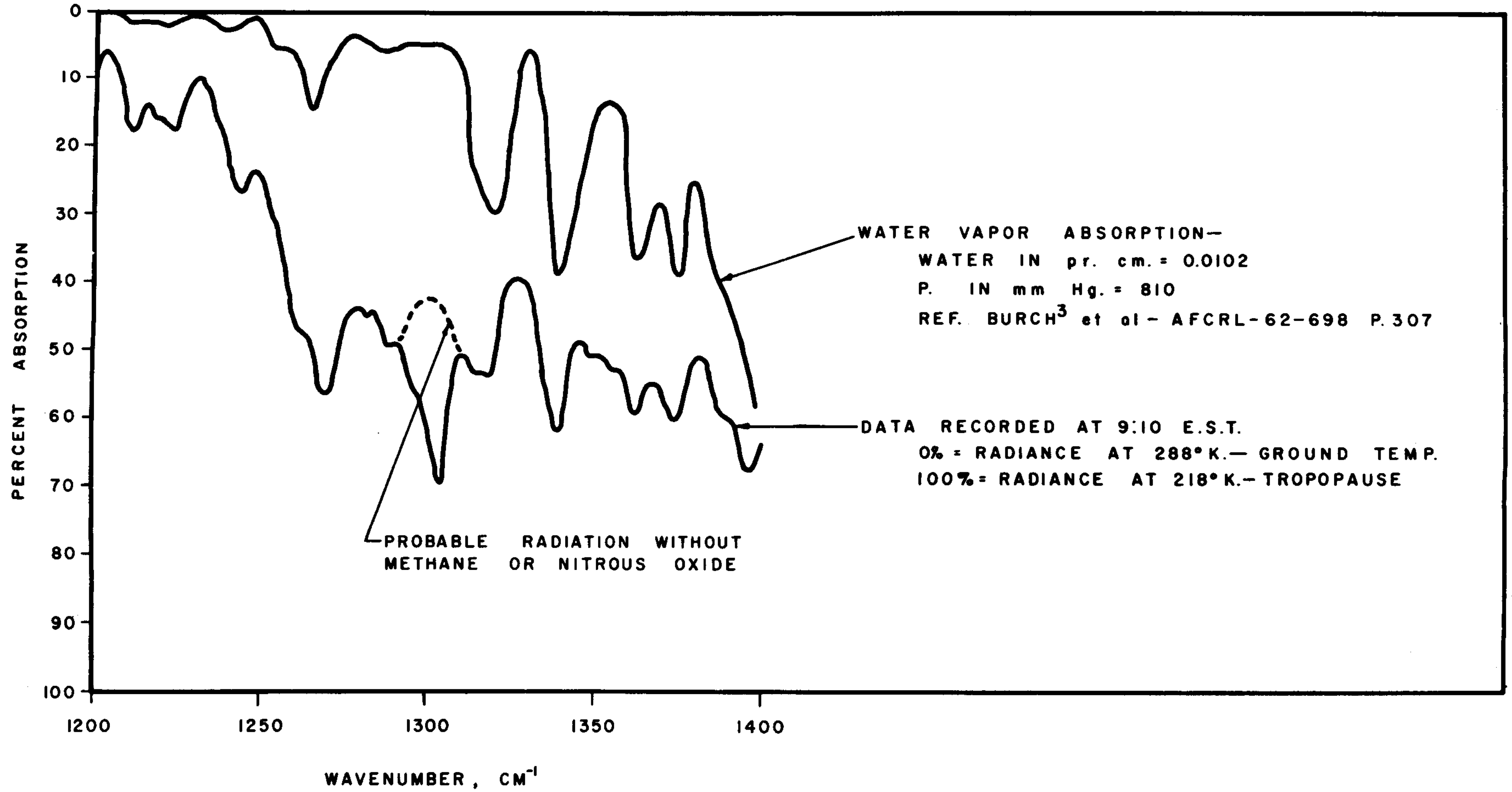



FIG. 4. COMPARISON OF WATER VAPOR ABSORPTION AND MEASURED SPECTRAL RADIANCE TO DEMONSTRATE ABSORPTION DUE TO METHANE AND NITROUS OXIDE.

## III. Conclusion and Plans for Further Work

The data presented in this report meets the accuracy requirements originally specified (0.5 ergs $sec^{-1}$ $cm^{-1}$ $sr^{-1}$) in order to make reasonable temperature inversions. Furthermore, the results obtained justify the effort expended to develop Fourier transform spectroscopy for this application and represent a demonstration of the power of the technique.

The specified minimum noise is based on the use of seven independent frequencies in the $CO_2$ band to compute the temperature profile. If more frequencies are used, the allowable noise could be increased or the number of spectral scans required decreased. An advantage of the interferometer is that more frequency measurements are available and an investigation of this point is now being made.

Although measurement of the spectrum of the $15\mu$ band was a primary purpose of the development, additional data in other spectral bands is available and may prove valuable in the future. There is the possibility of using the $9.6\mu$ data to determine the ozone profile. A water vapor profile can be calculated, even though the data in the $6.3\mu$ region is accurate to only about 20%. In fact, the data has been used by Smith[1] to infer the water vapor structure. Also the data in the "window" region can be used to determine the ground temperature under a cloudless condition or make an estimate of the cloud height for the case of complete cloud cover. Whenever the cloud cover is partial any analysis is difficult.

In the case of the data presented here, the photographs were not synchronized with the data which was collected from three scans over a period of 45 seconds. Hence, when clouds appear near the edges of the field of view there can be considerable error in estimating the percentage of cloud cover. There is, however, a definite correspondence between the "window" measurements and the cloud cover. By observing the radiance measured at 900 $cm^{-1}$ the steady increase in radiance during the morning can be observed as well as the effect of clouds at 14:12 EST and 15:11 EST. The following assumptions were made relative to the data at 14:12 EST, (1) the cloud cover is 33%, (2) the radiance in the clear area is the same as that at 13:31 EST, and (3) the lapse rate is -2°C/1000 feet. Under these conditions the calculated cloud height is 14, 000 feet. Considering the crudeness of the estimates, the agreement with Colorado State University[2] aircraft flight observation of 16, 000 feet maximum is quite good.

The absorption band at 1304 $cm^{-1}$ is thought to be due primarily to the $CH_4$ 1306 $cm^{-1}$ line with some contribution from the $NO_2$ 1285 $cm^{-1}$ line. The conclusion was reached by comparing the flight spectra in this region with laboratory water vapor spectra[3] and noting the variation in structure (fig. 4).

The present plans for further development of the instrument call for an increase in resolution to 3 $cm^{-1}$ and an extension of the wavelength span to 200 $cm^{-1}$ to include the rotational bands of water vapor. If these goals are realized, the determination of a water vapor profile by radiation measurements will be more readily accomplished.

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# Appendix I

## EARTH RADIATION MEASUREMENTS BY INTERFEROMETER FROM A HIGH ALTITUDE BALLOON

(a paper presented at the 3rd Symposium on Remote Sensing of Environment, 14 October, 1964, Ann Arbor, Michigan)

ABSTRACT

The earth's thermal radiation was measured with an infrared interferometer (5μ to 15μ), 50 $cm^{-1}$. The platform used was a high altitude balloon which maintained a float altitude of 112,000 feet for eleven hours. The data obtained are discussed.

### 1. INTRODUCTION

The High Altitude Engineering Laboratory of The University of Michigan has conducted a series of tests in support of the Meteorological Satellite Program. As a part of this program, an interference spectrometer was flown on a high altitude balloon. The results of this test are the subject of this paper.

The current satellite radiation instruments are radiometers having various spectral characteristics. The need for higher resolution radiation data is becoming more apparent. This is particularly true if we are to measure temperature as a function of altitude from a remote position in space. Success in this effort will require the measurement of small differences in radiation in adjacent spectral channels. The interference spectrometer offers an attractive possibility for performing this function. The advantages of this instrument over a diffraction grating instrument have been discussed elsewhere.[1,2,3]

The instrument which was flown in the evaluation test was a Block Associates I-4 Interferometer. The instrument as it was purchased was not designed for a balloon flight. Hence, several modifications were required, but the basic instrument remained unchanged. The modifications and laboratory calibrations have been discussed in a separate report.[4]

### 2. INSTRUMENT SPECIFICATIONS

The instrument as it was modified for flight had a theoretical resolution of 50 $cm^{-1}$. The useful spectral response covered the region from 600 to 1600 $cm^{-1}$. This just nicely included the 15μ $CO_2$, 9.6μ $O_3$, and the 6.3μ $H_2O$ bands. The instrument field of view was a circular $15^{\circ}$ which covered an area five miles in diameter on the ground.

The data reduction scheme selected required the measurement of the amplitude of coefficients of the Fourier Series. This was accomplished with a loop tape recorder, wave analyzer, and x-y plotter, The instrument was then calibrated as though it were a 31 channel radiometer. The scanning time for one complete spectrum was 0.5 seconds. However, in the data reduction process a total of 34 spectra were integrated for a total of 17 seconds.

The instrumentation package (Figure 1) as flown measured 7 1/2 in. × 10 in. × 15 in. and weighed 34 pounds including the calibrating blackbody and a 24 hour battery supply. A copper shield can (not shown) covered the entire package during flight.

3. INSTRUMENT INSTALLATION

The instrument inside its copper shield can was mounted in the gondola which is shown ready for launching (Figure 2). The instrument was completely self-contained, but external lines to the telemetry were required. In addition, a command signal from the gondola master timer actuated the calibration blackbody. The blackbody was mounted on a track and moved in front of the interferometer for 50 seconds every 15 minutes.

The instrument looked down at a zenith angle of $30^{o}$. This was done so that the interferometer data could be compared with the Tiros 5-channel radiometer. The radiometer had to be mounted at a $30^{o}$ angle in order for the space side of the instrument to look past the balloon.

4. CALIBRATIONS

Extensive calibrations of the instrument were carried out in the laboratory prior to the flight. Several tests were made by using the instrument to observe the atmosphere from the earth side. The procedure in calibrating the instrument was to hold the bolometer at a fixed temperature while varying the target temperature over the calibrating range. The bolometer would then be changed to another fixed value and a similar calibration performed. In this way, a table was composed from which it was possible to interpolate to find the measured temperature. The complete data reduction scheme and the method of presenting the data have been described previously.[4]

The in-flight calibrations were checked post-flight by adjusting the interferometer temperature and the blackbody temperature to those measured during the flight, and recording the instrument output. The correspondence between the in-flight and the post-flight calibrations is shown in Figure 3. The discrepancy through the specified spectral range is less than $3^{o}$C and the average variation is less than $1^{o}$C.

5. MEASUREMENT CONDITIONS

The meteorological conditions which existed on the day of the flight were ideal. The balloon was launched from Sioux Falls, South Dakota on 26 June 1963 at 457 CST and terminated south of Wall, South Dakota at 1815 CST. Until 1130 CST, the balloon flew over completely cloudless skies at a height of 112,000 ft.

The sky gradually became cloudy and at 1350 CST the balloon flew over very high storm clouds and emerged on the western side of the storm two hours later. Scattered clouds were again observed until cut-down.

To summarize: 1) observations were made through clear sky as the earth heated, 2) broken clouds were observed on both sides of the storm, and 3) storm clouds were observed directly.

## 6. DATA

A complete set of reduced data is given in the data table (Figure 4). The data is given in equivalent blackbody temperatures in degrees centigrade as a function of both wavelength and time. Equivalent blackbody temperatures rather than spectral radiance is used since this is the manner in which the instrument was calibrated.

The data have been reduced for five minute intervals during the first half of the ascent and at ten minute intervals during the last half. While at float altitude, a reduction was made once each hour except for three selected periods when a reduction once each minute for four minutes was made.

The temperatures are reduced for 31 discrete wavelengths. In essence, the instrument might be considered a 31 channel radiometer.

Some of the data have been plotted for fixed time as a function of wavelength, and some at fixed wavelength as a function of time.

The Tiros and Nimbus radiometers flown on the same balloon were compared as follows. The equivalent blackbody temperatures were converted to spectral radiance and multiplied by the appropriate filter function. The resulting function was integrated to obtain radiance. The equivalent blackbody temperature was then obtained from the radiometer calibration curve. The temperature comparison chart (Figure 8) compares the temperatures obtained by this method, the temperatures measured by the Tiros radiometer, temperatures measured by the $10.3\mu$ interferometer channel, and the actual surface temperatures measured by W. E. Marlatt from Colorado State University.[5]

## 7. DISCUSSION

The temperature comparison chart (Figure 8) indicates excellent agreement between the Tiros radiometer measurements and the adjusted interferometer measurements. The average variation is less than one degree and the maximum is three degrees centigrade. This comparison was a great aid in establishing confidence in the interferometer.

The comparison between the Nimbus filter function and the 10.3$\mu$ interferometer channel shows that both read closer to ground temperatures than the Tiros. The 10.3$\mu$ channel is slightly closer to ground temperatures. The Nimbus temperatures are 3.5$^{o}$C below the average ground temperatures measured by Marlatt. It should be noted that the measured ground temperatures varied by ±2.5$^{o}$C from point to point in the field.

Spectra of the clear sky (Figure 9) are plotted for the maximum measured difference in surface temperatures. The points to be noted are: 1) increase in $CO_2$ absorption, 2) increase in water vapor absorption, 3) deterioration of the edges of the window, and 4) constant ozone absorption. These changes can be accounted for by the upward movement of the tropopause and the increase in water vapor.

The spectra of clear sky and that of a high cloud area are compared (Figure 10). The most interesting point to note is that in the case of the high cloud, the coldest temperatures appear in the window and that the former absorption bands now appear as emission spectra. Since these temperatures are very low, there is an average scatter of about ±3$^{o}$C at 10.3$\mu$ and ±5$^{o}$C at 6.3$\mu$.

A pair of spectra for opposite sides of the storm cloud are given in Figure 11. In this case the window temperatures are identical. It should be noted that the latter spectrum indicates a colder tropopause and warmer water vapor temperatures. This should be expected after passing over a frontal storm.

Temperature variations as a function of time have been plotted. The best window at 10.3$\mu$ (Figure 12) appears at the top of the graph. You will note that except for relatively minor fluctuations there is a steady rise in temperature due to the earth's heating. The drop in temperature at 1300 and 1400 CST is due to scattered clouds in the field of view. The sudden drop in temperature at 1500 and 1600 CST is due to the passage over a large high storm cloud.

The ozone at 9.6$\mu$ exhibits a different character. The first few data points on ascent follow the "window." This is followed by a slight drop as the balloon reaches the tropopause and then a sudden drop around 52,000 ft. The drop continues somewhat past the tropopause and a minimum was recorded at 82,000 ft followed by a slight rise to float altitude. A relatively constant temperature near -2$^{o}$C was recorded during the clear sky portion of the flight. The effect of clouds is clearly seen in this channel.

The $CO_2$ at 14.5$\mu$ exhibits a very smooth rapid drop in temperature at 50,000 ft followed by a rise as the balloon moved from 70,000 to 112,000 ft. Throughout the day there is a steady decline in temperature indicating a slow rise in the height of the tropopause. The high clouds have very little effect on this channel.

Referring to Figure 13, the 8.5$\mu$ "window" exhibits the same tendencies as the 10.3$\mu$ except that the temperatures are lower indicating a poorer "window."

The 7.6$\mu$ channel is in the wings of the water vapor bands and clearly shows the dip in temperature as the balloon passed through the tropopause and a steady decline in temperature caused by the gradual increase in water vapor. Again the effect of high clouds is clearly seen.

The 6.4$\mu$ water vapor channel follows much the same pattern as the $CO_2$. The minimum temperature occurs at the tropopause followed by a rise and another drop after reaching float altitude. This could possibly be explained by trapped moisture in the gondola which disappeared after being at float altitude for a short time. The random error in this data is approximately $\pm 2 \times 10^{-7}$ watts/cm$^2$/cm$^{-1}$. This represents a temperature fluctuation of 0.5$^\circ$C in the warm "window" to 20$^\circ$C for the coldest water vapor readings.

## 8. CONCLUSIONS

This instrument has two inherent shortcomings: poor resolution, and systematic errors due to unstable wavelength calibration and secondary spectra. The data gathered indicate that the interferometer is a fruitful technique for studying the earth's atmosphere.

The conclusions to be drawn from this data are:

1) The 14.5$\mu$ channel is essentially unaffected by high clouds and is reasonably indicative of the tropopause temperature.
2) The best window is located as close to the ozone absorption band at 9.6$\mu$ as possible
3) More information can be obtained regarding water vapor by a channel located in the wings of the water vapor band than at 6.4$\mu$.

A new instrument which we hope to test in the next year is now being developed.

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## ACKNOWLEDGMENTS


The author wishes to thank F. L. Bartman and many other members of the High Altitude Engineering Laboratory of The University of Michigan for their assistance in carrying out the instrument modification and calibration, the balloon flight operation, and data processing. Others who made the work possible are personnel of Raven Industries for balloon flight operations, and the United States Weather Bureau personnel at Sioux Falls for weather forecasting assistance.

The work described in this paper has been supported by the National Aeronautics and Space Administration under contract NaSr-54(03).

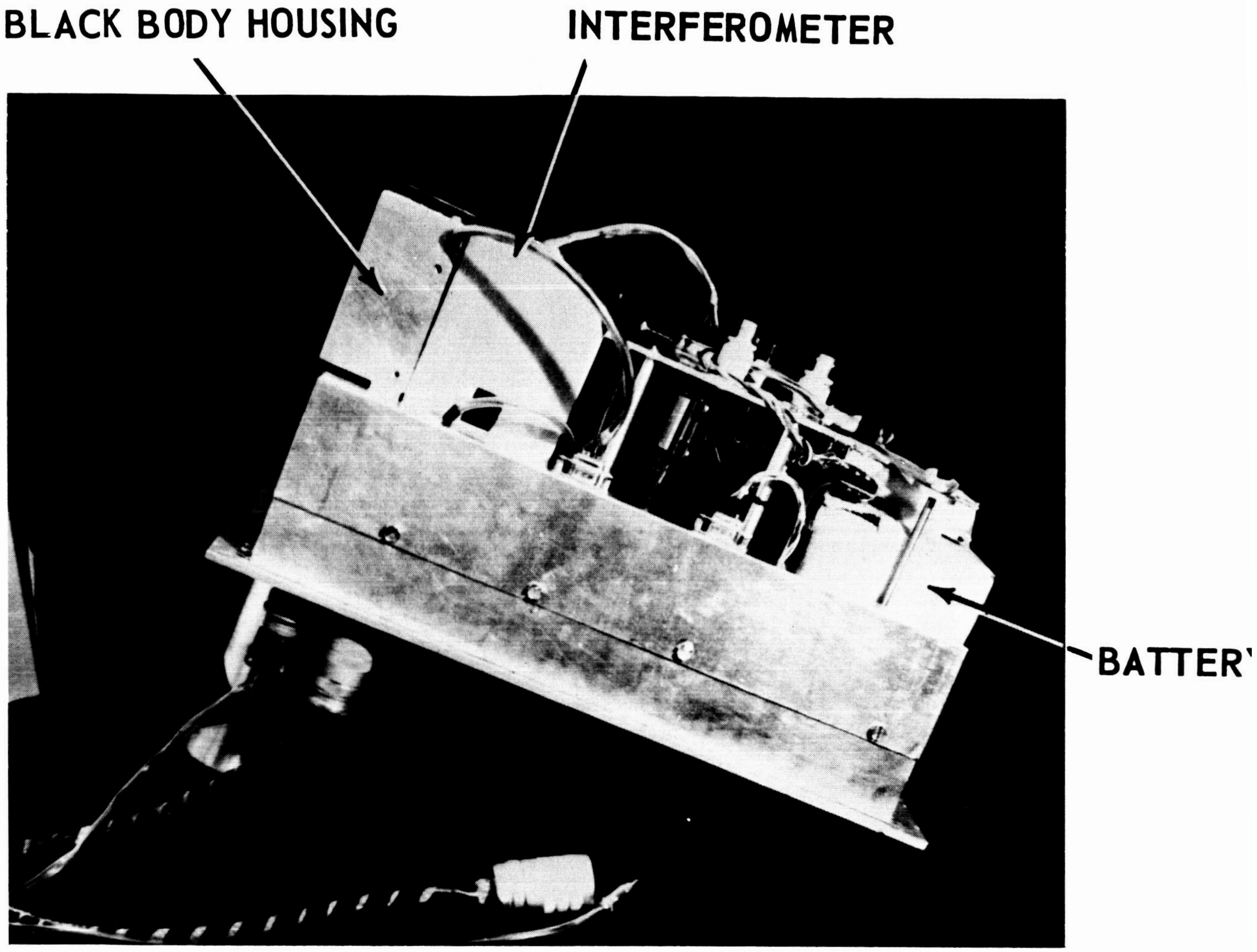



FIGURE 1

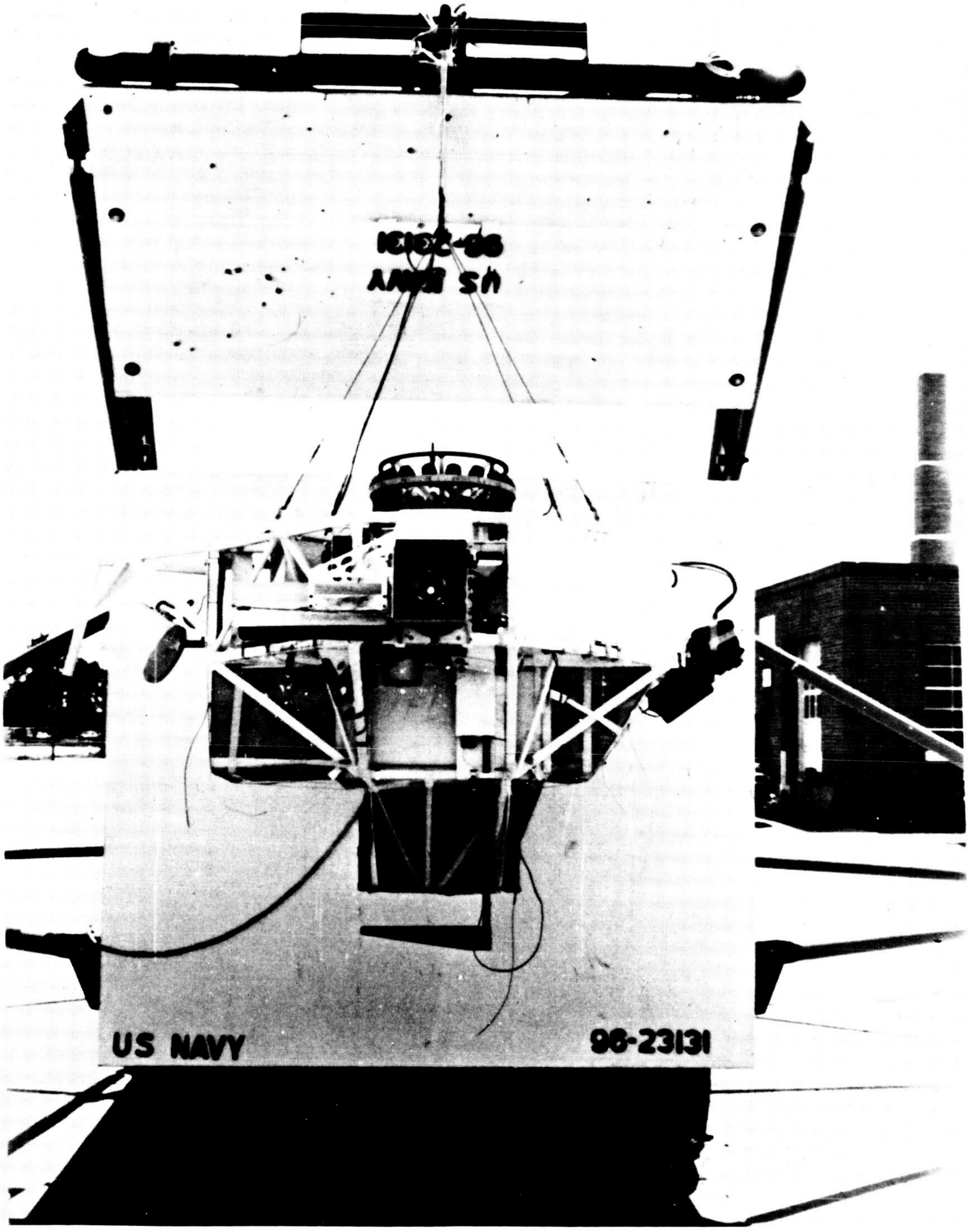



FIGURE 2

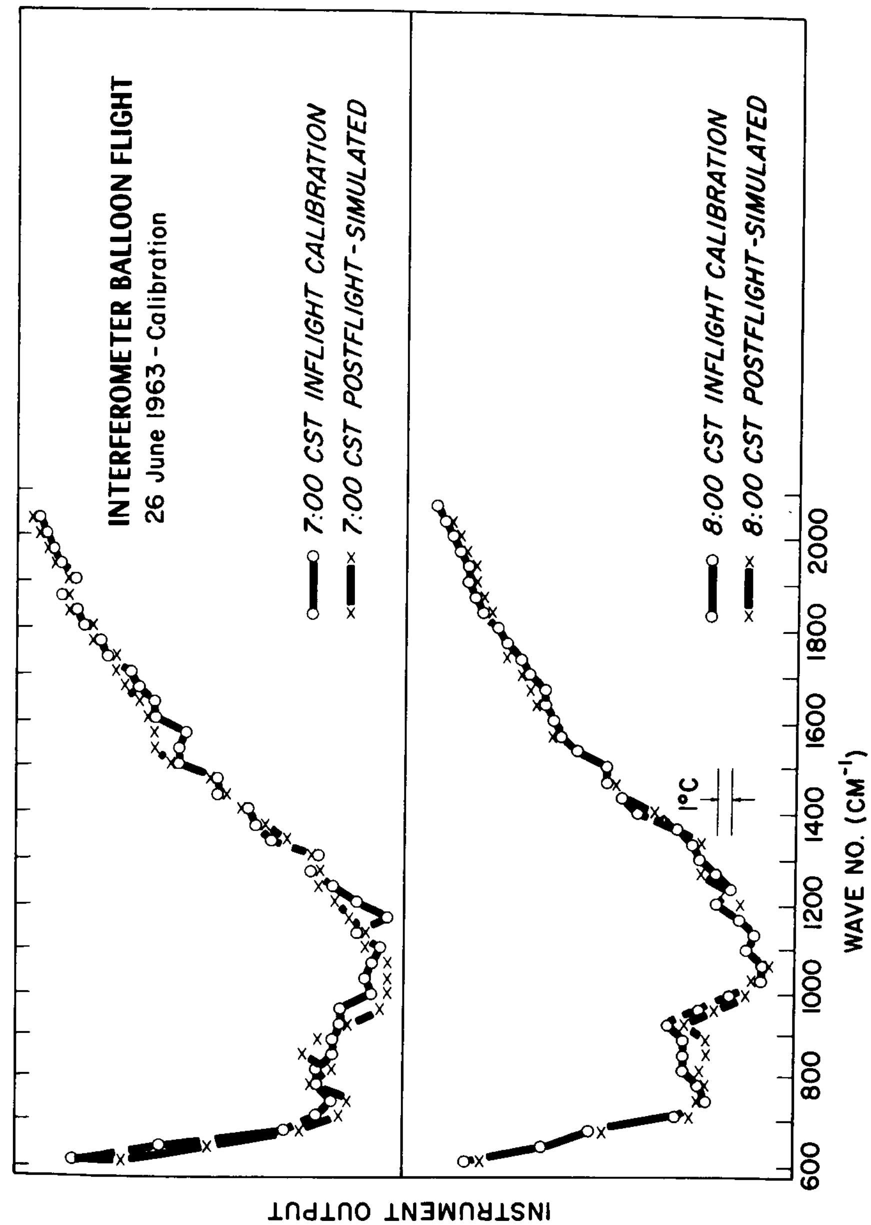

INTERFEROMETER BALLOON FLIGHT
26 June 1963 - Calibration
7:00 CST INFLIGHT CALIBRATION
7:00 CST POSTFLIGHT-SIMULATED
8:00 CST INFLIGHT CALIBRATION
8:00 CST POSTFLIGHT-SIMULATED
1°C
600
800
1000
1200
1400
1600
1800
2000
WAVE NO. (CM⁻¹)
INSTRUMENT OUTPUT

FIGURE 3

INTERFEROMETER DATA

Equivalent Black Body Temperatures, °C

| CST | Wave No. $(cm^{-1})$: | 620 | 655 | 690 | 725 | 760 | 795 | 830 | 865 | 900 | 935 | 970 | 1005 | 1040 | 1075 | 1110 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wavelength ($\mu$): | 16.15 | 15.3 | 14.5 | 13.8 | 13.2 | 12.6 | 12.1 | 11.6 | 11.1 | 10.7 | 10.3 | 10.0 | 9.63 | 9.32 | 9.03 |
| 5:00:00 | | | | | 19 | 19 | 16 | 14 | 13 | 11 | 10.5 | 12 | 12 | 14 | 13 | 13.5 |
| 5:04:55 | | 5.3 | 11.5 | 11.7 | 13.7 | 16.7 | 14 | 15.5 | 14.5 | 13.5 | 13 | 13 | 15 | 13 | 13.5 | 13.5 |
| 5:09:55 | | 3.7 | - .03 | 2.5 | 7.0 | 12.0 | 12.3 | 13 | 14 | 12.3 | 11.8 | 13.2 | 14.3 | 13.7 | 12.2 | 12 |
| 5:14:54 | | - 6.5 | - 7. | - 7.5 | 1.3 | 11 | 12 | 13.5 | 13.3 | 13.3 | 13.3 | 12.7 | 14.2 | 12.7 | 11.8 | 12.5 |
| 5:19:54 | | -11.0 | -20.7 | -21.7 | - 5.7 | 9.8 | 12.7 | 14.5 | 13.7 | 13.5 | 13.5 | 13.5 | 14.5 | 13.3 | 12 | 13.7 |
| 5:24:54 | | -21.3 | -33.3 | -35 | -14.7 | 8.0 | 13.5 | 14 | 12.7 | 12 | 11 | 12.7 | 13.5 | 11.5 | 11.7 | 12 |
| 5:29:54 | | -25 | -49.3 | -41.5 | -17.7 | 7.5 | 14 | 13.5 | 13.5 | 11.7 | 11.5 | 12.7 | 13.3 | 8.7 | 9.8 | 12.5 |
| 5:34:54 | | -34.5 | -55.2 | -58.8 | -20.7 | 6.7 | 11.5 | 13.6 | 13.6 | 13.8 | 15.5 | 14 | 12 | 8.7 | 10.5 | 12 |
| 5:39:55 | | -33 | -63.2 | -61.5 | -27 | 7.0 | 11.5 | 13.0 | 13.4 | 13 | 13 | 13 | 12.7 | 8.0 | 9.5 | 12.0 |
| 5:44:54 | | -34.5 | -61.5 | -67.2 | -21.7 | 7.5 | 14 | 14.5 | 13.8 | 13.8 | 14.3 | 13.6 | 13.5 | 7.5 | 9.0 | 13.8 |
| 5:49:54 | | -32.8 | -64 | -62 | -27.5 | 7.2 | 13.5 | 15 | 16 | 15.2 | 14.3 | 14.8 | 15.0 | 6.5 | 10. | 14.7 |
| 5:54:54 | | -33.5 | -61.3 | -67.2 | -27.7 | 7.0 | 14.3 | 15.2 | 16.2 | 14.5 | 15.3 | 15.3 | 14.5 | 2.8 | 7.3 | 15 |
| 5:59:54 | | -36.2 | -55 | -58.3 | -29.5 | 7.3 | 15.5 | 16.5 | 15.7 | 16 | 16 | 16.5 | 15.7 | - 2.0 | 4.0 | 16.2 |
| 6:09:54 | | -38.3 | -55.5 | -62.3 | -32.3 | 6.7 | 16 | 17 | 15.8 | 16.5 | 16.7 | 17 | 14.5 | - 6.2 | 0.0 | 16.3 |
| 6:19:54 | | -35 | -55 | -57 | -30.2 | 6.3 | 16.5 | 17.5 | 16.0 | 17 | 17 | 17 | 14.8 | - 7.7 | - 1.0 | 16.3 |
| 6:29:54 | | -31 | -45.7 | -50.2 | -26.2 | 6.8 | 17.5 | 18.5 | 19 | 18.3 | 19 | 20.3 | 17.5 | - 4.5 | 0.02 | 17 |
| 6:39:54 | | -33 | -44 | -48.2 | -26.5 | 6.0 | 16.8 | 18.8 | 19 | 18.2 | 20 | 18.5 | 17 | - 4.0 | 0.03 | 17.7 |
| 6:49:54 | | -32.5 | -42.5 | -46 | -26 | 6.8 | 17 | 18 | 19.2 | 20 | 20.7 | 19.3 | 17 | - 2.0 | 0.03 | 18 |
| 8:00:00 | | -37 | -50 | -55 | -35 | 5 | 21 | 22 | 24 | 24 | 24.5 | 24 | 23 | - 3 | - 1 | 22 |
| 8:36:00 | | -35 | -47 | -54 | -34.3 | 5.0 | 23 | 25.3 | 26 | 26.5 | 26.3 | 26 | 25 | - 1.0 | 3 | 26 |
| 8:37:00 | | -30 | -46 | -54 | -34.3 | 4.0 | 23 | 25.3 | 27.5 | 27.5 | 27.5 | 27.0 | 25.5 | - 0.5 | 3 | 26 |
| 8:38:00 | | -35 | -47 | -55 | -34.3 | 0.5 | 23 | 26.5 | 26.5 | 26.5 | 27.5 | 27.5 | 25 | 0.0 | 3 | 26 |
| 8:41:00 | | -35 | -44 | -49 | -33 | 5.5 | 22 | 25.3 | 25.5 | 25.5 | 26.8 | 26. | 24.3 | - 0.5 | 2 | 25 |
| 9:00:00 | | -45 | -46 | -53 | -31 | 7 | 19 | 23 | 25 | 25 | 26 | 25 | 22 | - 3 | 1 | 22 |
| 10:00:00 | | -41 | -49.7 | -57.5 | -34 | 8.0 | 21 | 26.3 | 26 | 26.8 | 26.5 | 28.7 | 24.3 | - 2.2 | 8.3 | 27 |
| 10:01:00 | | -29.7 | -49.2 | -56 | -31.2 | 9. | 21 | 23.3 | 23. | 23.2 | 24 | 25.8 | 25.3 | - .3 | 9.0 | 28.3 |
| 10:02:00 | | -31.8 | -49 | -55.5 | -30.8 | 9.5 | 22.3 | 28.2 | 27.2 | 28.8 | 29.2 | 31. | 26.7 | 1.4 | 1.5 | 29.1 |
| 10:02:30 | | -38.2 | -51.2 | -58.8 | -36.6 | 8.2 | 21.4 | 27.5 | 27.4 | 29.5 | 28.2 | 30.4 | 26 | - .2 | 7.5 | 28.6 |
| 11:00:00 | | -40 | -56 | -58 | -33 | 8 | 20 | 27 | 26 | 28 | 29 | 30 | 26 | - 2 | 7 | 28 |
| 12:00:00 | | -50 | -56 | -58 | -33 | 9 | 22 | 27 | 27 | 31 | 32 | 34 | 29 | - 1 | 13 | 34 |
| 13:00:00 | | -56 | -60 | -60 | -32 | 8 | 15 | 20 | 20 | 5 | 24 | 26 | 18 | -18 | 8 | 26 |
| 13:59:15 | | -58 | -60 | -65 | -37 | - 6 | 2 | 6 | 6 | 11 | 7 | 14 | 6 | -20 | - 3 | 14 |
| 14:00:00 | | -56 | -60 | -60 | -33 | 2 | 8 | 14 | 11 | 15 | 17 | 17 | 11 | -14 | 5 | 21 |
| 15:00:00 | | -56 | -52 | -60 | -69 | -69 | -69 | -74 | -72 | -74 | -74 | -69 | -69 | -69 | -69 | -58 |
| 15:58:20 | | -74.5 | -64 | -77.4 | -64.2 | -68.4 | -70.3 | -75.2 | -75 | -89.6 | -87.2 | -81 | -71 | -73.5 | -76.2 | -69.5 |
| 16:00:20 | | -64.5 | -62 | -73.5 | -61 | -61.6 | -67.5 | -71.2 | -64.8 | -82 | -84.4 | -76 | -70.2 | -69.2 | -75.8 | -64.5 |
| 16:01:20 | | -77.5 | -65.5 | -76.2 | -62.7 | -67.2 | -67.5 | -75.7 | -76.4 | -91.9 | -90.5 | -81.4 | -71.4 | -70 | -78.8 | -68.3 |
| 17:00:00 | | -55 | -70 | -60 | -13 | 20 | 21 | 26.5 | 27 | 27 | 27 | 30 | 10 | - 9 | 23 | 30 |

FIGURE 4a

INTERFEROMETER DATA (Concluded)

| CST | Wave No. ($cm^{-1}$): | 1145 | 1180 | 1215 | 1250 | 1285 | 1320 | 1355 | 1390 | 1425 | 1460 | 1495 | 1530 | 1565 | 1600 | 1635 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wavelength ($\mu$): | 8.75 | 8.49 | 8.24 | 8.01 | 7.8 | 7.58 | 7.39 | 7.2 | 7.03 | 6.86 | 6.7 | 6.55 | 6.4 | 6.26 | 6.12 |
| 5:00:00 | | 13.5 | 15 | 13.5 | 14 | 16 | 19 | 19 | 15.5 | 21 | 19 | 17.5 | | | | |
| 5:04:55 | | 14.8 | 15 | 15 | 14.2 | 14.2 | 13.5 | 13 | 11 | 12 | 12 | 13 | 14.5 | 15.5 | 12.5 | 13.8 |
| 5:09:55 | | 15 | 13.3 | 13 | 10.5 | 12 | 10.7 | 6.8 | 5.0 | 2.5 | 4.5 | 3.7 | 7 | 6 | - 2.5 | 5.0 |
| 5:14:54 | | 14 | 13.5 | 12.5 | 10.5 | 8.5 | 7.2 | 4.5 | 1.3 | - 2.5 | 0.0 | - 6.0 | 1.0 | - 4.2 | -11.5 | - 8.5 |
| 5:19:54 | | 14.7 | 14.3 | 14 | 12.6 | 6 | 5 | - 3.2 | - 3.2 | - 7 | -15.2 | -14.2 | - 9.5 | -22.5 | -25.5 | -18.2 |
| 5:24:54 | | 13 | 13 | 12 | 10 | 2.5 | - 1.5 | - 5. | - 8.8 | -10 | -18.5 | -28.5 | -32 | -38.8 | -26.2 | -29 |
| 5:29:54 | | 13.5 | 13 | 12.5 | 11.7 | 8.2 | - 3.2 | - 5.5 | -10.5 | - 9.0 | -19 | -34.3 | -22.5 | -40.3 | -20 | -49. |
| 5:34:54 | | 13.5 | 14.5 | 13 | 10. | - 1.0 | - 5.5 | - 0.8 | - 7.7 | -14 | -21 | -31.5 | -42.7 | -47 | -35. | -26.8 |
| 5:39:55 | | 13.6 | 13.9 | 12.6 | 9.0 | - 2.5 | - 6.3 | - 2.7 | - 9.6 | -13.9 | -22 | -31.5 | -49.2 | -52.2 | -29.5 | -31.5 |
| 5:44:54 | | 14.0 | 14.3 | 13.7 | 11.8 | - 3.0 | - 6 | - 2.4 | - 9.0 | -11 | -17.7 | -31.8 | -58.7 | -56.0 | -31.5 | -25.5 |
| 5:49:54 | | 14.3 | 15.3 | 14.3 | 12.3 | - 1.8 | - 6.5 | - 1.4 | - 5.5 | -10 | -15.3 | -33.3 | -41 | -70.7 | -12 | -26.5 |
| 5:54:54 | | 14.3 | 14.5 | 14 | 12.5 | - 1.5 | - 6.5 | - 1.0 | - 6.3 | -13.7 | -15.5 | -25 | -43 | -57 | -28 | -32.2 |
| 5:59:54 | | 15 | 15.3 | 15 | 12.5 | 0.05 | - 4.7 | - 0.7 | - 3.7 | -12.5 | -18.5 | -32.8 | -38.3 | -44.7 | -17.5 | -17.5 |
| 6:09:54 | | 14.5 | 14.5 | 15.5 | 9.0 | 1.0 | - 6.7 | 0.03 | - 6.0 | -12.5 | -19.2 | -35 | -34.3 | -48.3 | -24.2 | -21.8 |
| 6:19:54 | | 16.3 | 15.7 | 16 | 13.5 | 4.0 | - 5.5 | 1.2 | - 3.5 | - 7.0 | -11.5 | -25 | -33.7 | -43.2 | -24.2 | -13.5 |
| 6:29:54 | | 17.5 | 17.7 | 16.8 | 14.5 | 13.5 | - 2.7 | 4.0 | - 1.3 | - 9.0 | -12 | -27.5 | -44 | -39.5 | -23 | -20 |
| 6:39:54 | | 16.8 | 17 | 17.3 | 14.8 | 7.0 | - 3.0 | 2.5 | - 3.7 | -14.5 | -10.2 | -28.5 | -27 | -47.3 | -24.5 | -13 |
| 6:49:54 | | 17.5 | 17.5 | 17.7 | 16 | 8.0 | - 2.0 | 2.7 | - 1.3 | -10.5 | -12.5 | -24.5 | -31.5 | -42.3 | -47 | -46.5 |
| 8:00:00 | | 22 | 20 | 22 | 16 | 4 | -10 | - 3 | - 7 | -14 | -14 | -35 | -55 | -75 ? | -35 | -20 |
| 8:36:00 | | 25 | 23.5 | 23.3 | 19 | 1.0 | -11 | - 4 | -12 | -18 | -20 | -34 | -55 | -65 | -45 | -25 |
| 8:37:00 | | 26 | 23.5 | 23.3 | 19 | 1.0 | -12 | - 4 | -12 | -17 | -19 | -34 | -55 | -70 | -40 | -23 |
| 8:38:00 | | 25 | 23.5 | 23.3 | 19 | 2.0 | -12 | - 3 | -13 | -13 | -20 | -34 | -55 | -75 | -35 | -23 |
| 8:41:00 | | 25 | 23.5 | 22.3 | 19 | 1.0 | -10 | - 4 | -10 | -15 | -17 | -30 | -40 | -75 | -35 | -19 |
| 9:00:00 | | 22 | 21 | 21 | 17 | 2 | -12 | - 5 | -14 | -16 | -23 | -32 | -50 | -66 | -35 | -23 |
| 10:00:00 | | 26 | 23.4 | 23.4 | 18 | - 0.07 | -15.7 | 11.5 | -23.3 | -27 | -26.3 | -49 | -55.5 | -70.7 | -50 | -53 |
| 10:01:00 | | 25.6 | 24.7 | 24.7 | 19 | .4 | - 9.5 | - 9.7 | -16.5 | -23.6 | -20.8 | -40.6 | -54.6 | -65.7 | -17.2 | -83.2 |
| 10:02:00 | | 26.2 | 25.6 | 24.6 | 19.7 | - 2.2 | - 7.7 | - 6.7 | -18.3 | -25.8 | -30.5 | -41.6 | -41 | -64 | -39.8 | -46 |
| 10:02:30 | | 25.6 | 25.3 | 24.2 | 19.4 | - 3.9 | -14.5 | -13 | -24.8 | -32 | -41.3 | -52.3 | -52.5 | -73.2 | -49.5 | -58 |
| 11:00:00 | | 28 | 26 | 25 | 18 | - 3 | -15 | -13 | -21 | -28 | -33 | -60 | -60 | -75 ? | -58 | -50 |
| 12:00:00 | | 32 | 29 | 26 | 17 | - 4 | -22 | -13 | -21 | -21 | -35 | -45 | -70 | -75 ? | -75 | -58 |
| 13:00:00 | | 23 | 23 | 20 | 10 | -12 | -22 | -15 | -28 | -33 | -56 | -56 | -75 ? | -75 ? | -75 | -70 |
| 13:59:15 | | 8 | 9 | 6 | - 2 | -28 | -31 | -28 | -36 | -60 | -68 | -75 | -75 | -75 | -75 | -75 |
| 14:00:00 | | 16 | 17 | 14 | 2 | -19 | -26 | -23 | -40 | -45 | -69 | -75 ? | -75 | -75 | -75 | -75 |
| 15:00:00 | | -65 | -65 | -65 | -65 | -65 | -55 | -60 | -65 | -52 | -60 | -50 | -40 | -40 | -40 | -40 |
| 15:58:20 | | -77 | -81.5 | -71 | -73 | -86.5 | -74 | -65.6 | -68.8 | -59 | -71 | -47.6 | -78.5 | -73.2 | -66 | -81 |
| 16:00:20 | | -70.2 | -80.8 | -73.5 | -68.5 | -77.0 | -68.5 | -57.7 | -67.7 | -52.8 | -63.2 | -48. | -53.5 | -61.7 | -56.4 | -91.8 |
| 16:01:20 | | -76.4 | -85.6 | -82.5 | -74 | -86.5 | -74.8 | -73.5 | -70.6 | -57 | -70.5 | -50 | -65.5 | -69.8 | -65.2 | -91.8 |
| 17:00:00 | | 27 | 26 | 24 | 7 | -10 | - 9 | - 4 | - 5 | -15 | -25 | -35 | -40 | -50 | -35 | -75 |

FIGURE 4b

FIGURE 5

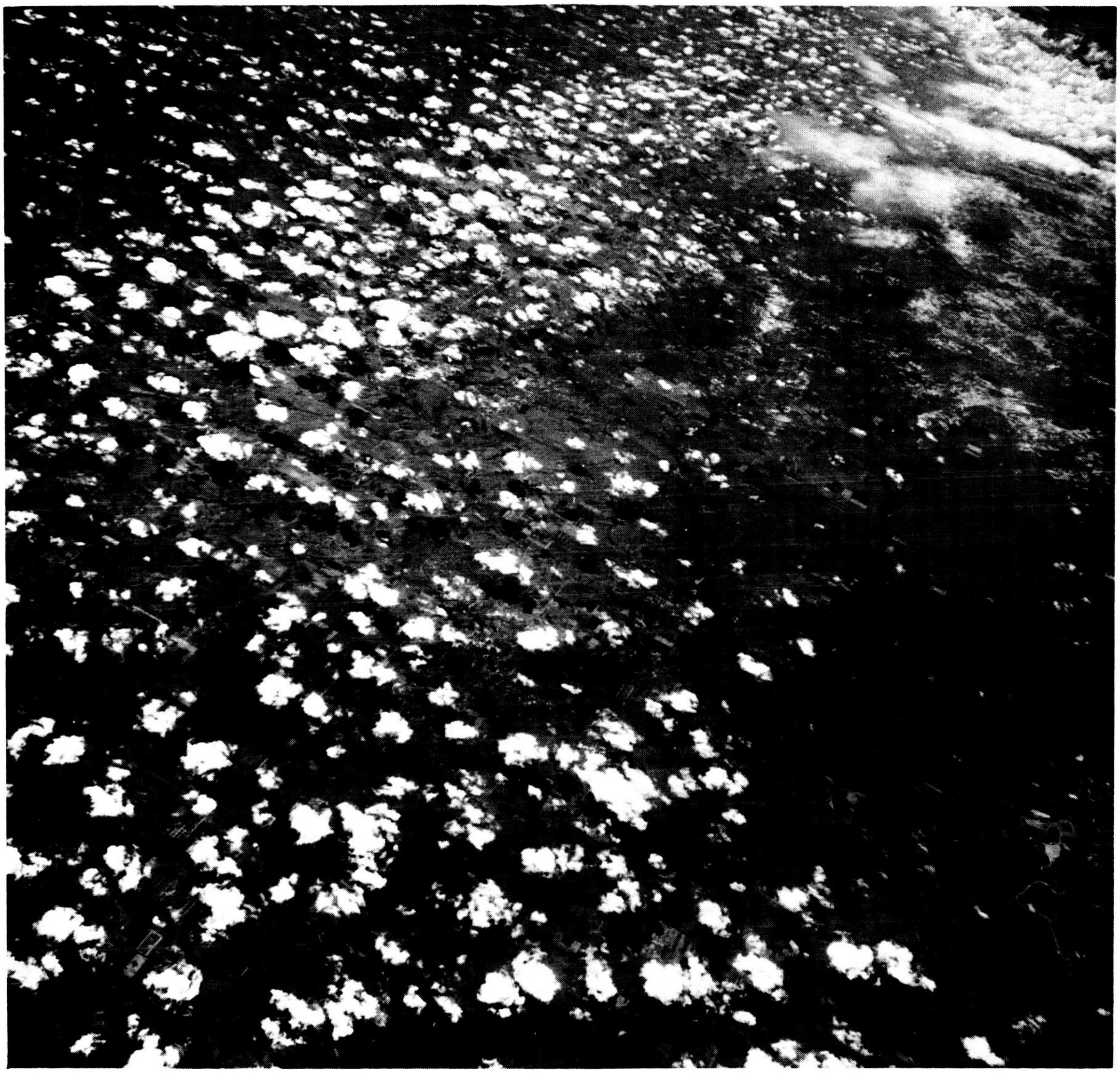


FIGURE 6

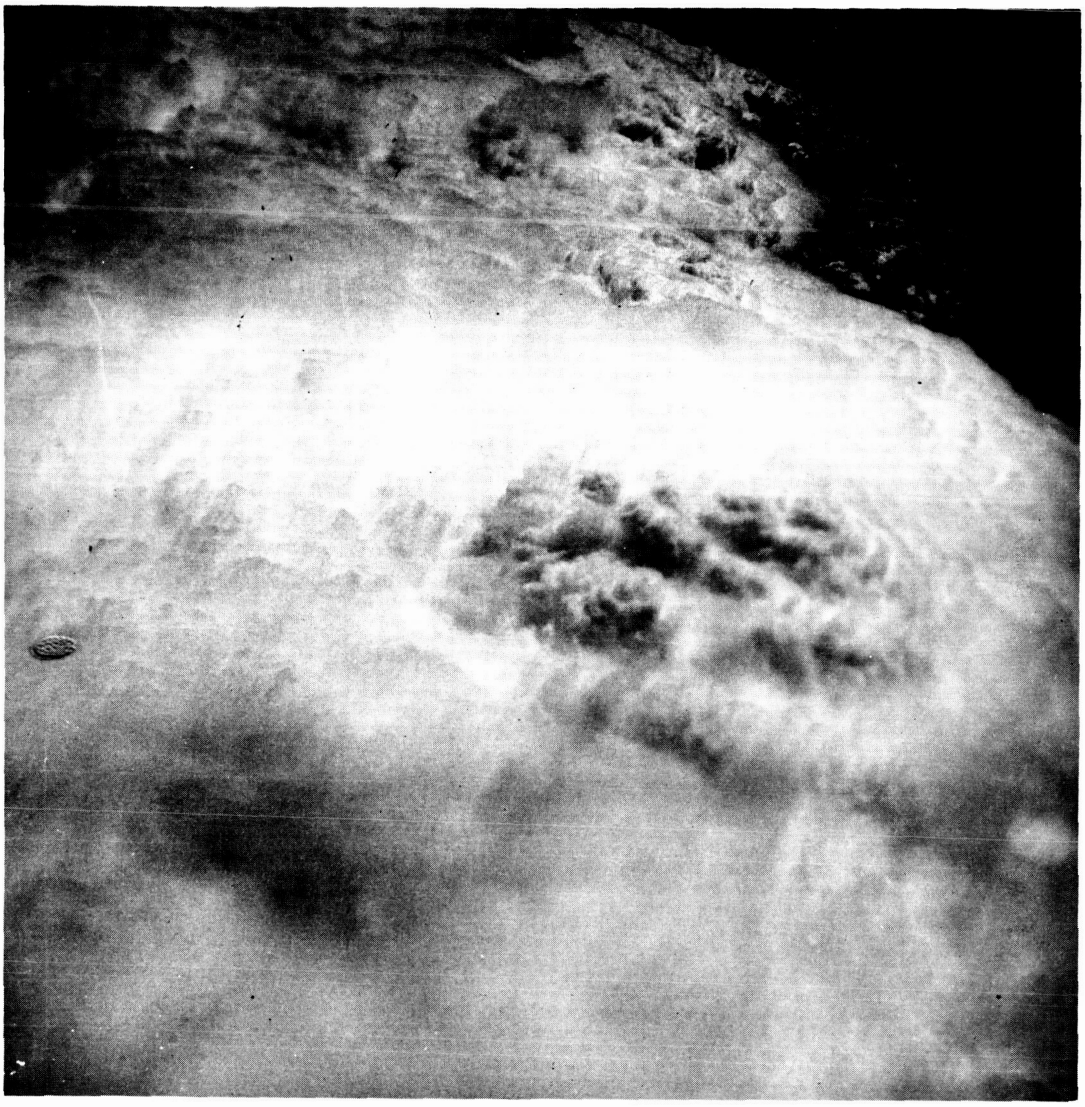


FIGURE 7

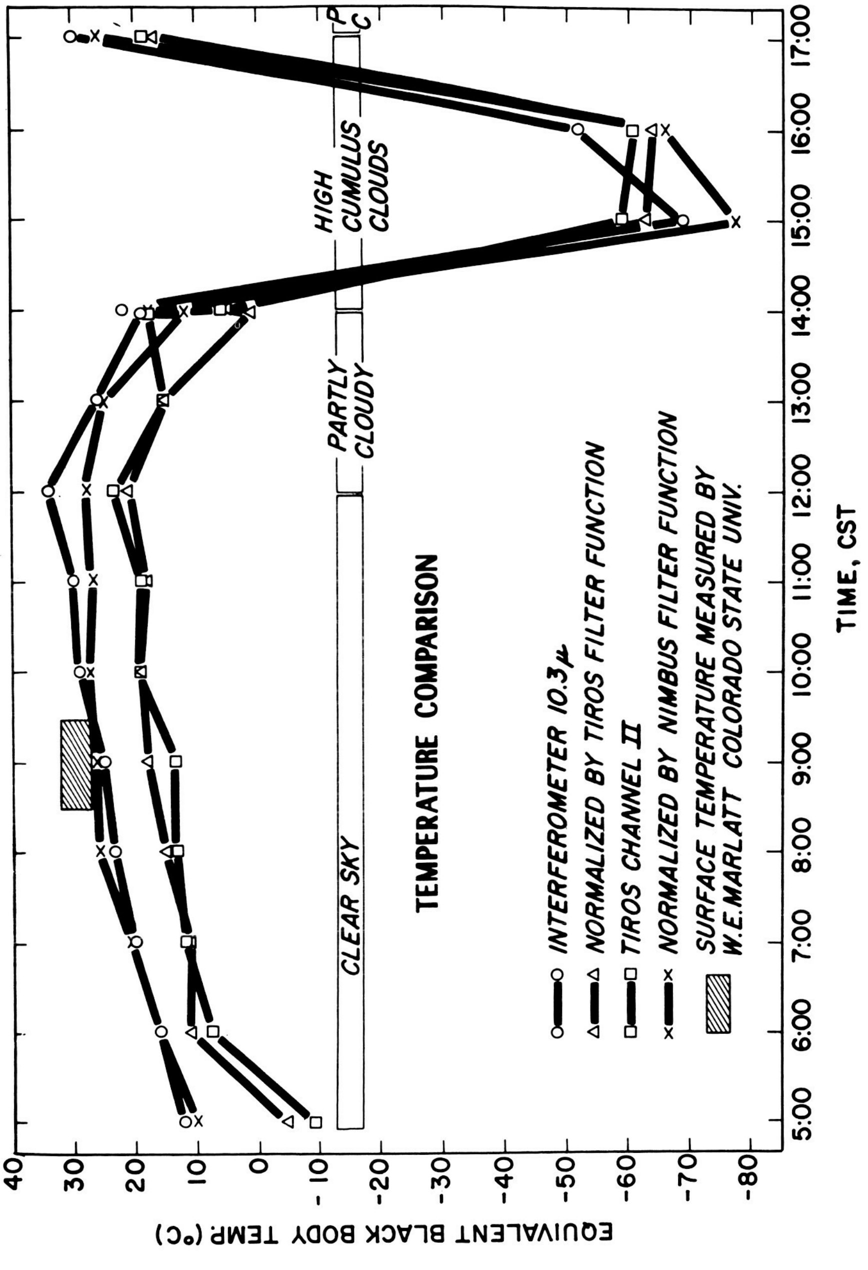

TEMPERATURE COMPARISON
INTERFEROMETER 10.3μ
NORMALIZED BY TIROS FILTER FUNCTION
TIROS CHANNEL II
NORMALIZED BY NIMBUS FILTER FUNCTION
SURFACE TEMPERATURE MEASURED BY W.E.MARLATT COLORADO STATE UNIV.
CLEAR SKY
PARTLY CLOUDY
HIGH CUMULUS CLOUDS
P C
TIME, CST
EQUIVALENT BLACK BODY TEMP (°C)

Figure 8

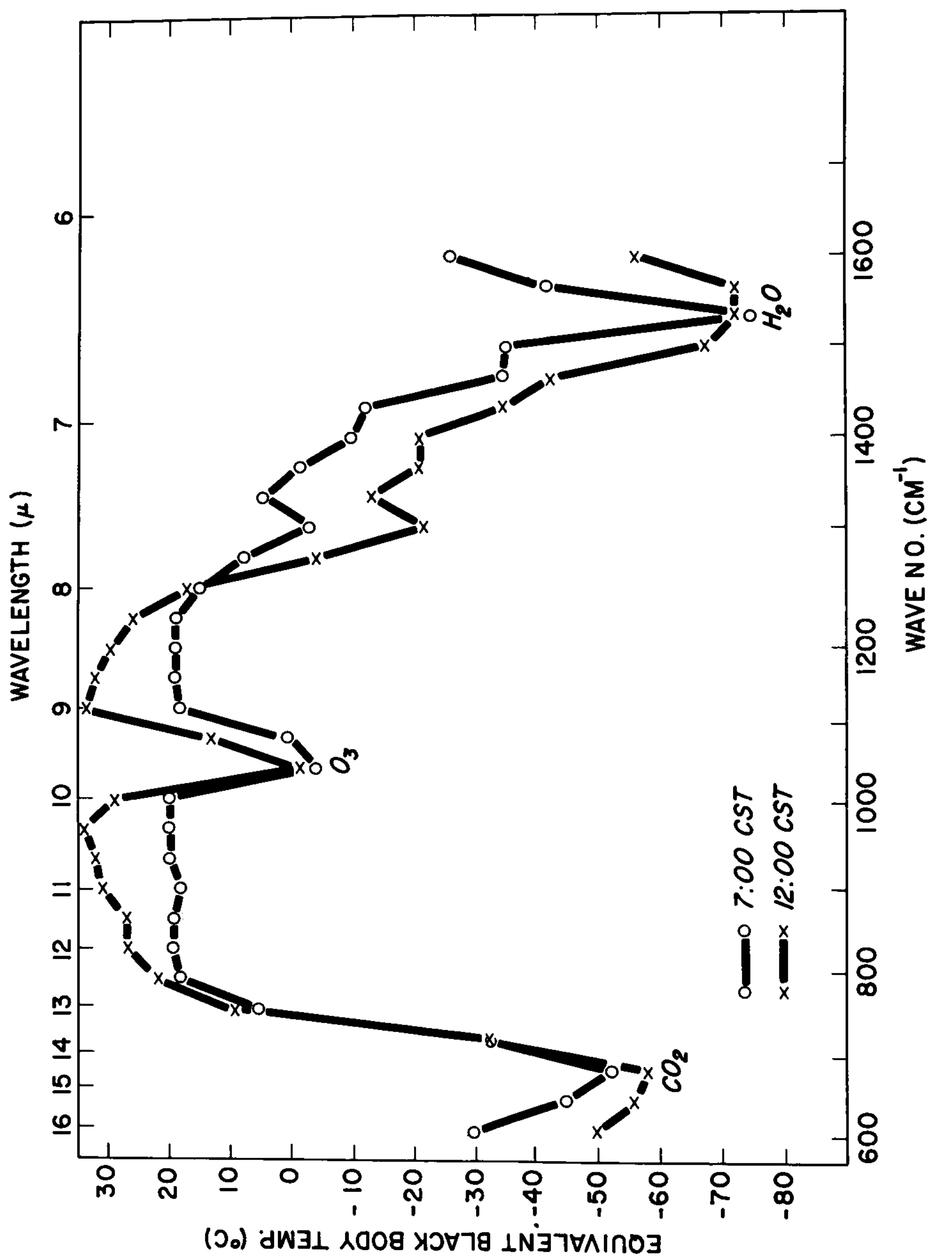
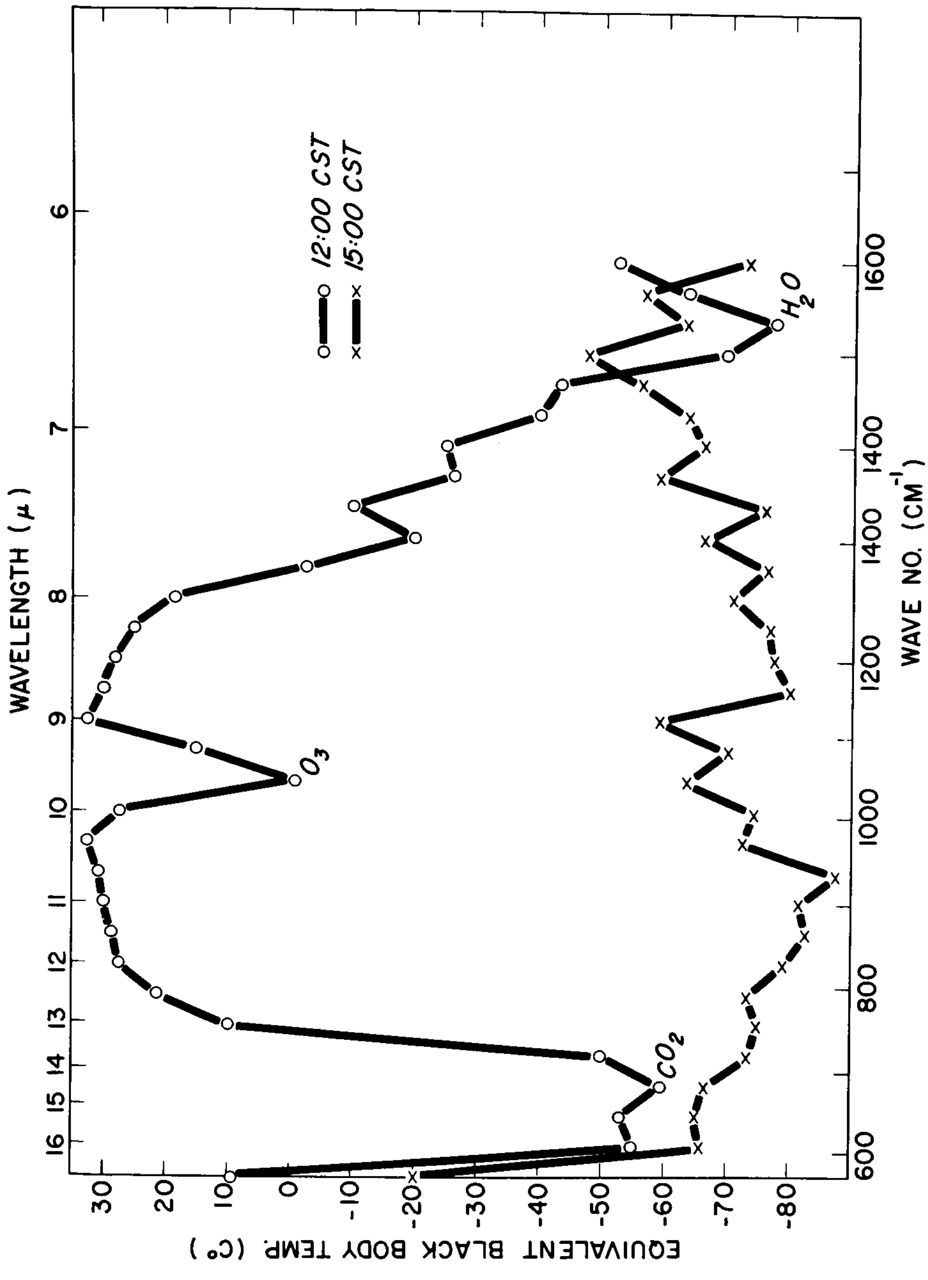

WAVELENGTH (μ)
16 15 14 13 12 11 10 9 8 7 6
WAVE NO. (CM$^{-1}$)
600 800 1000 1200 1400 1600
EQUIVALENT BLACK BODY TEMP. (°C)
30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80
$CO_2$
$O_3$
$H_2O$
7:00 CST
12:00 CST

FIGURE 9



WAVELENGTH (μ)
6
7
8
9
10
11
12
13
14
15
16
12:00 CST
15:00 CST
$O_3$
$CO_2$
$H_2O$
EQUIVALENT BLACK BODY TEMP. (C°)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
WAVE NO. (CM$^{-1}$)
600
800
1000
1200
1400
1400
1600


FIGURE 10

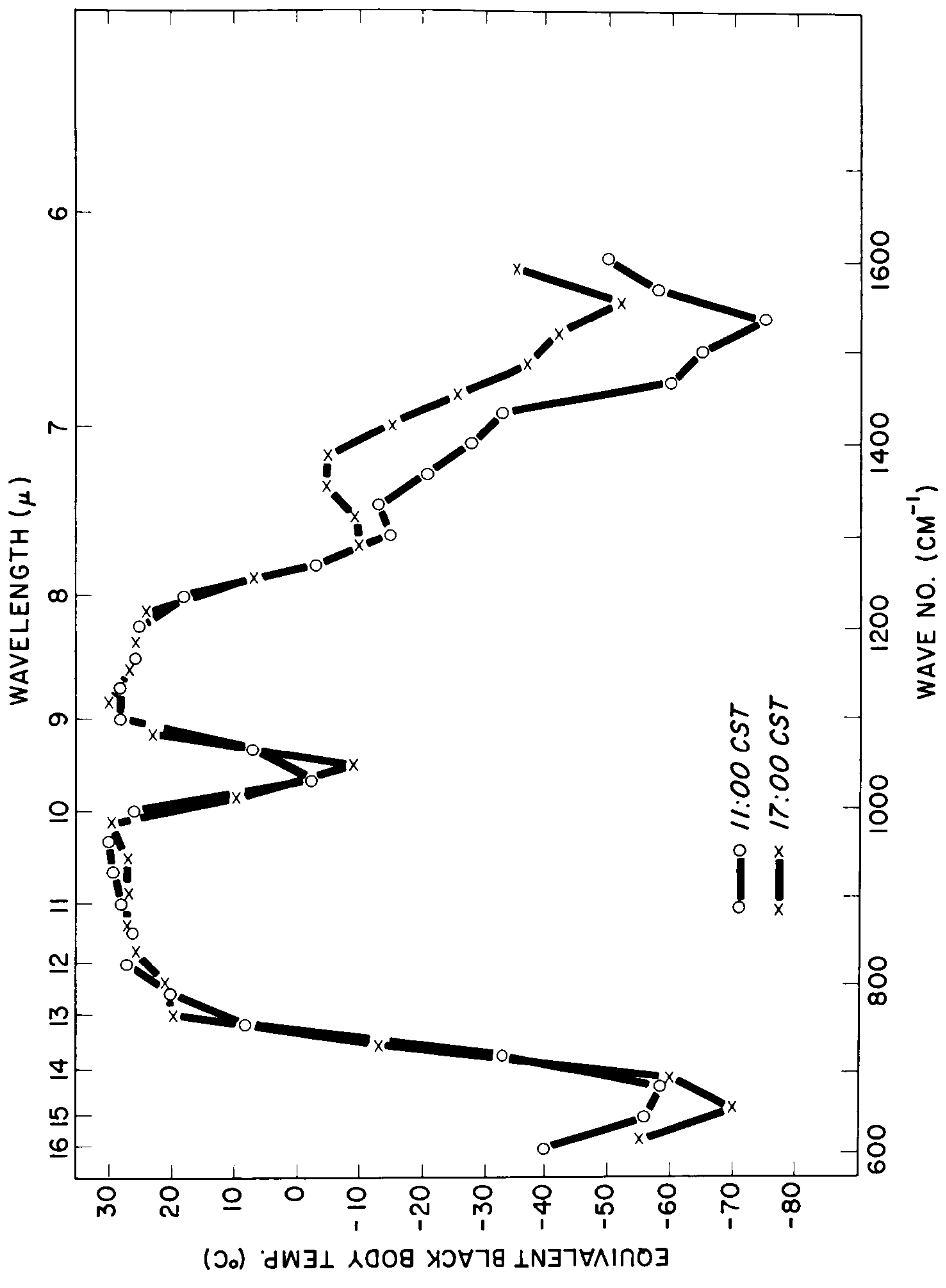

WAVELENGTH (μ)
16 15 14 13 12 11 10 9 8 7 6
WAVE NO. (CM⁻¹)
600 800 1000 1200 1400 1600
EQUIVALENT BLACK BODY TEMP. (°C)
30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80
11:00 CST
17:00 CST

FIGURE 11

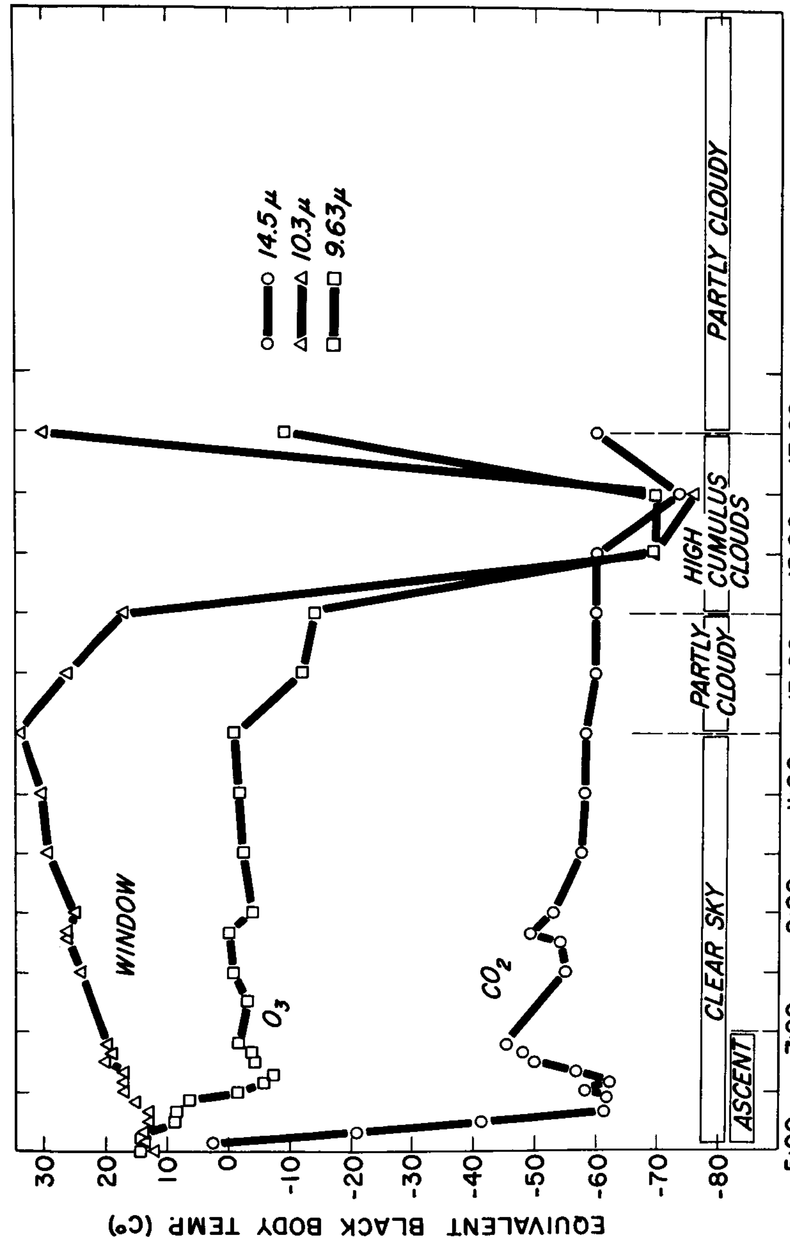
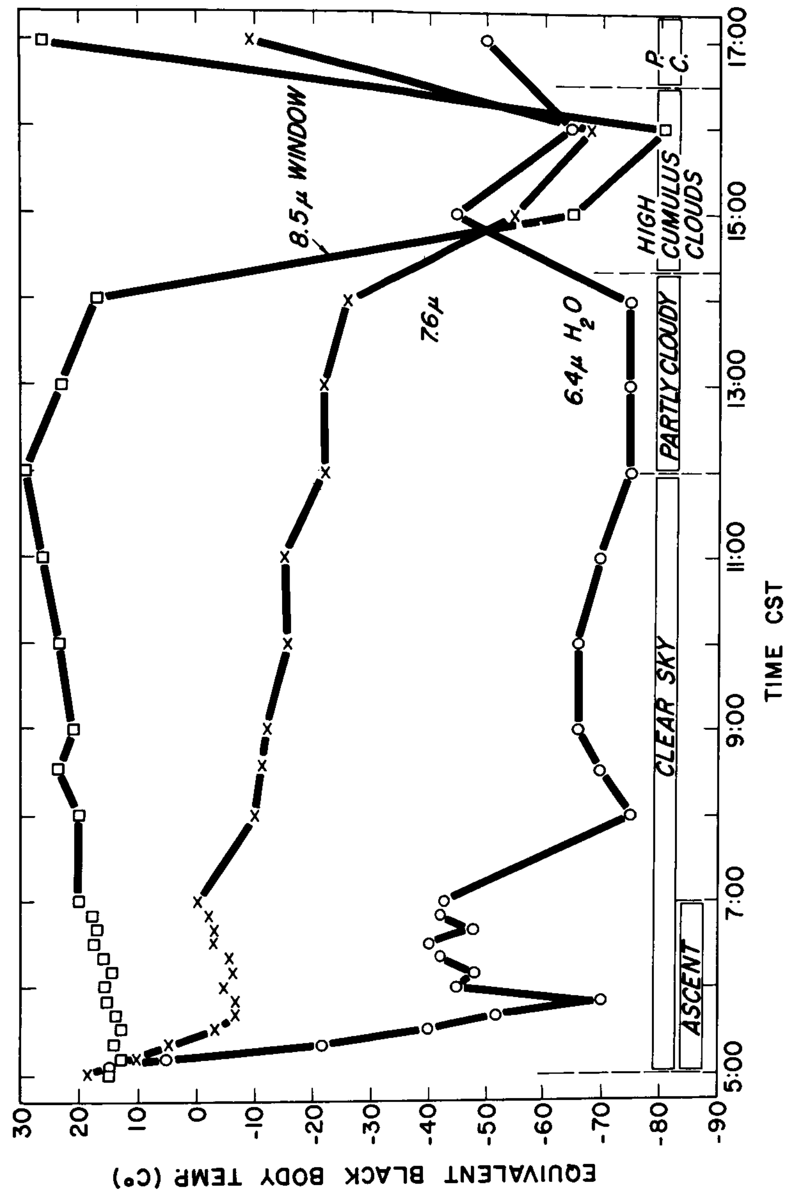

14.5 μ
10.3 μ
9.63 μ
WINDOW
$O_3$
$CO_2$
CLEAR SKY
ASCENT
PARTLY CLOUDY
HIGH CUMULUS CLOUDS
PARTLY CLOUDY
EQUIVALENT BLACK BODY TEMP (C°)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
5:00
7:00
9:00
11:00
13:00
15:00
17:00
TIME (CST)

FIGURE 12



8.5μ WINDOW
7.6μ
6.4μ $H_2O$
CLEAR SKY
PARTLY CLOUDY
HIGH CUMULUS CLOUDS
P. C.
ASCENT
TIME CST
5:00
7:00
9:00
11:00
13:00
15:00
17:00
EQUIVALENT BLACK BODY TEMP (C°)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90


FIGURE 13

## APPENDIX II

# AN INFRARED INTERFEROMETER SPECTROMETER (IRIS) FOR METEOROLOGICAL STUDIES

(a paper presented to 13th Infrared Information Symposium
October 26, 1965, Pasadena, California)

ABSTRACT: The instrument discussed is the breadboard of a satellite interferometer spectrometer (5 - 20$\mu$ ), 5 $cm^{-1}$ resolution. This instrument will be used to measure the earth's thermal radiation from a balloon floating at more than 100, 000 feet.

INTRODUCTION: The development of improved meteorological satellite instrumentation is of continuing interest to Goddard Space Flight Center. As a result of this interest, they have supported the University of Michigan, High Altitude Engineering Laboratory in the development of interferometry for radiation measurements.

Our first measurements were made from a high altitude balloon in June 1963. The instrument used for these measurements was a Block I-4, which has been modified and calibrated for balloon flight.[1] The spectral range was from 5$\mu$ to 15$\mu$ with a resolution of 50 $cm^{-1}$. This represented a significant increase in spectral information compared to present meteorological radiometers.

The data from this flight[2] were extremely encouraging and served to indicate that an interferometer has good possibilities as a meteorological instrument. As a result of this work and the work of Kaplan[3] (1959), Wark[4] (1961) and Drayson[5] (1963) on $CO_2$ emission, we became interested in the possibilities of designing an interferometer for relatively high resolution measurements in the 15$\mu$ band. The purpose of these measurements would be the determination of the vertical temperature structure of the atmosphere. The individual lines in the P and R branches of the 15$\mu$ $CO_2$ band have a line separation of about 1.6 $cm^{-1}$. To identify individual lines a resolution of about 0.1 $cm^{-1}$ would be required. This is not presently possible in a satellite borne instrument. The next best choice is to resolve the band contour as well as possible, Kaplan and Wark have shown that 5 $cm^{-1}$ is sufficient for this purpose. As a consequence, 5 $cm^{-1}$ became a design goal for a new interferometer.

While we were in the process of considering the design of a 5 $cm^{-1}$ interferometer, we made a joint proposal with Goddard Space Flight Center to fly an interferometer on a Mars mission. This instrument would have had a broad spectral range 5$\mu$ - 33$\mu$ and a relatively low resolution. However, we later decided that one instrument could be designed having both the resolution required and a wide spectral range that would include both the rotational bands of water vapor and the vibrational bands at 6.3$\mu$ .

DESCRIPTION: The project was initiated as a joint effort of the University of Michigan and Goddard Space Flight Center. The objectives and a complete desciption of the proposed instrument are completely described in GSFC[6] report #X650-65-75. A brief resume of the instrument specifications is as follows:

Spectral range: 2000 - 500 $cm^{-1}$ (5-20$\mu$ )

Spectral resolution: 5 $cm^{-1}$ over entire range (Rayleigh Criteria)

Travel of drive mirror: 0.2 cm.

Diameter of effective aperture: 3.6 cm.

Detector: Thermistor Bolometer in conical light pipe

Detector time constant: 1.2 mil-sec.

Duration of interferogram: 10.5 sec.

Electrical frequencies at detector: 20-80 cps.

Sampling: every second fringe of 5852 $A^o$ monochromatic source

Sampling rate: 312 words per second

Output: Serial Bi-phase words

Words per interferogram: 3472

Bits per word: 12

Field of view: $1.57 \times 10^{-2}$ ster (appr. $8^o$)

Peak signal/noise: 1500

Minimum detectable signal: $8 \times 10^{-8}$ watts/cm$^2$ sr cm$^{-1}$

Mirror drive velocity: $\pm$ 1%

Reference temperature: $250^oK$

The general features of the optical design can be best explained by referring to the optical head layout (Fig. 1).

Spectral range: The long wavelength end of the range is set by the cut-off of the KBr used in the beam splitter, window and lens. The short wavelength end is set by the germanium beam splitting surface.

Moving mirror: The mirror is attached to a scan platform which is driven by a coil in a closed magnetic field. The scan distance is 0.2 cm which sets the resolution at 5 cm$^{-1}$. The magnetic circuit is specially designed to eliminate stray flux.

Field of view: The field of view is $8^{o}$. The 3.6 cm diameter Michelson mirror forms the front stop and the 3.5 mm cone opening forms the back stop.

Detector optics: The optics consist of an F-1 KBr lens and a gold coated conical light pipe. In theory this combination should produce an ideal F-0.5 system. The detector is a thermistor balometer having a flake 3.8 mm square. This is masked by the gold cone to a circle 3.5 mm diameter.

Monochromatic: The neon lamp source is mounted in the position shown. The energy is reflected on to the beam splitter through a right angle prism and the energy is focused on a silicon photodiode.

Electronics: The electronic system will be explained with the aid of the block diagram (Fig. 2).

The IR signals are first amplified in a 40 db preamplifier before passing to the band pass filter. The switched attenuator automatically changes the gain 20 db when the signal level exceeds $\pm$ 3.2 volts. When the attenuator is switched this information is stored as the third bit in the A-D converter. The signal to be digitized appears at the A-D converter input.

The digitizing encode pulses are derived from the monochromatic signal and hence one pulse occurs after the mirror moves exactly $1.1704\mu$ . The monochromatic signal is amplified in a pre-amplifier, passed through the filter and formed into pulses by the trigger circuit. The sequence and timing circuit serves the following functions: provides an input to the mirror drive amplifier for the duration of the drive, furnished encode pulses to the A-D converter, provides pulses to operate the commutator.

The project was planned to be carried out in several stages: scientific breadboard, engineering breadboard, prototype, and flight model. At this time we have demonstrated the scientific breadboard in the laboratory, and have now completed the packaging of this breadboard for a balloon flight. Figure 3 is a photograph of the optical head of the balloon flight instrument and Figure 4 shows the electronics package. Spectra obtained with this instrument are shown in Figures 5 and 6.

SPECIFICATION MODIFICATIONS: This instrument deviates in several ways from the original specification.

Resolution: The achieved resolution is approximately 8 $cm^{-1}$. This is almost twice the planned resolution, but we believe that 5 $cm^{-1}$ resolution can be achieved with more careful adjustment of the zero retardation and the elimination of variation in the mirror drive velocity.

Signal/noise: The peak signal to noise is approximately 1000. The specification is 1500 and this should be achievable with a more carefully designed detector optic.

Mirror velocity: The specification calls for a mirror velocity of $\pm$ 1%. The actual variation is $\pm$ 5% in one unit and $\pm$ 10% in another unit. This can be greatly improved by using a much longer feedback coil. A better solution would be to use the monochromatic light frequency in a feedback circuit. This was attempted in the original design, but had to be abandoned due to insufficient time to develop the circuitry.

Reference temperature: The planned reference was 250°K which is approximately equal to the average earth temperature. This would be best in a satellite instrument since there would be no net exchange of energy between the instrument and the target. We were, however, beset with many practical problems in trying to achieve this reference temperature. The main problem is that the interferometer is extremely temperature sensitive. In this design, gradients in excess of $1^{\circ}$ C produce significant changes in sensitivity. In fact, temperature stability on the order of $0.1^{\circ}$ C is required for accurate measurements.

The reference temperature was changed to $273^{\circ}$K to take advantage of the thermal stability of the melting ice temperature. This technique works very well and a hollow aluminum base plate was designed for this purpose. The plate holds 1725 cc of water which after freezing will hold the instrument at $1^{\circ}$ C for 20 hours. The temperature stability of a given point is better than $0.1^{\circ}$C.

ENGINEERING PROBLEMS: In the course of any development such as this, engineering problems arise which must be solved or disposed of in some way. The areas to be discussed are as follows: 1) Mirror drive, 2) Beam splitter, 3) Fixed mirror, 4) Detector optics, 5) Neon reference channel, 6) Electronics, 7) Thermal control.

Mirror drive: (see Figure 1) Initially, the design of the mirror drive was considered to be the most difficult part of the development. The rotation of the moving mirror relative to the fixed mirror should be held to $\pm$ 2 arc seconds throughout the 2 mm travel. This specification has been achieved in the breadboard, but at a sacrifice in versatility. It was our original concept that the instrument should operate in any position. The present design is restricted to a single plane due to gravitational effects on the drive system. The final design configuration is a most elementary parallelogram.

The drive coil is mounted in the center of the scanning platform. The motivation behind this particular design was to provide a closed magnetic circuit in order to reduce stray magnetic fields, but this has an additional advantage. By driving the scanning platform near its center of mass, the angular rotation is appreciably reduced (by a factor of approximately 3).

Beam splitter: At the outset of the project the design and construction of a satisfactory beam splitter was considered a major problem. This has not been satisfactorily solved and is the major problem to be dealt with in the development of interferometry in this spectral region.

The basic problem is that there is no satisfactory material available for a substrate. We investigated various materials and of these, only KBr and IRTRAN-4 offered reasonable possibilities. The initial effort was concentrated on IRTRAN-4 because KBr was considered too fragile and too easily contaminated to be useful.

IRTRAN-4 has the basic advantage that it is impervious to water and has good dimensional stability. The disadvantages are that it is nonhomogeneous and scatters an appreciable proportion of the incident radiation. Also, the high index of refraction results in large reflective losses. The large unwanted reflections made it very difficult to make the original visual alignments. These disadvantages made it extremely difficult for us to use IRTRAN-4 and we turned all of our attention to KBr.

It was demonstrated that KBr cut in the 111 plane and suitably mounted would withstand the satellite vibration specification. The positive result from this test allowed us to go ahead with the development of KBr beam splitters.

However, a successful beam splitter mounting has not yet been developed. In order to demonstrate the scientific breadboard, the substrate was glued at three points near the edge using rubber cement. This is the only mounting that we have been able to use which does not distort the substrate. New mounting techniques are currently under development.

Fixed mirror: No difficulties were expected with the fixed mirror, but five separate models were made in an attempt to obtain a satisfactory design. The present design uses a pair of differential screws for adjustment and a spring pivot for the third point. The differential screws are driven through slotted couplings in order to eliminate unwanted torques. The basic problem is that screws, no matter how well made, are too crude for such a close adjustment. We hope to develop a better adjustment in the future by using either magneto-strictive or piezo-electric devices.

Detector optics: The detector is a standard design and had the predicted detectivity. However, the complete optic was low in sensitivity by approximately 30%. This was due to the optical design which did not properly account for all the off axis rays. The F-1 KBr lens has been satisfactory; but for any future design, completely reflective optics would be more satisfactory.

Monochromatic reference: The neon 5852 $A^{o}$ line was originally picked because of its good visibility. Good visibility greatly simplifies the initial line-up of the optics. However, a signal to noise ratio in excess of 10 is required for accurate digitizing. This requirement is only marginally satisfied at the end of the sweep. Further investigation has revealed that another neon line at 7032 $A^{o}$ is stronger and the silicon detector is more sensitive to this line. The available signal is more than doubled but we decided not to change because our data reduction scheme had already been keyed to the 5852 $A^{o}$ line.

Electronics: (see Figure 2) All of the electronics met the original specifications. However, the analog filters are the source of electrical phase shift which is non-linear with frequency. The effect of the phase shifting is to make the interferogram asymmetric which complicates the data reduction process. It is no longer sufficient to take the cosine transform, but it is now necessary to take the power spectrum and from the sign of the sine and cosine terms determine if the radiation is positive or negative.

Thermal control: The development of an adequate thermal control was a major unanticipated project. In addition to developing a vacuum-tight hollow aluminum mounting plate for cooling the interferometer, a means of providing a dry nitrogen atmosphere had to be designed. A shroud completely surrounds the instrument and liquid nitrogen is boiled into the instrument. The gas leaks out across the windows to keep them moisture free. One liter of nitrogen will be sufficient for a 10-hour balloon flight.

DATA REDUCTION: The data reduction or data processing from an interferometer is rather elaborate compared to other instruments. For each interferogram reduced to spectra, 41, 664 bits must be processed. This can also be an advantage in that it is easy to do additional processing of the data since it is already on the computer.

The output of the instrument is serial Bi-phase words 12 bits long. Each word consists of 8 bits from the A-D converter, a gain bit to indicate the position of the automatic attenuator, a parity bit, and two synch bits. This information is recorded on a tape recorder at 60 ips and reproduced at 7 1/2 ips. A CDC-160 A computer is programmed to translate this information into IBM compatible format. The IBM compatible tape is used with an appropriate program to apodize the interferogram, compute the transform, apply phase corrections, apply calibration factors, and compute spectral radiance.

The spectra presented (Figure 6) represents the results obtained thus far. In this case, the interferogram was apodized and the transform computed without applying any calibration factors. The data indicate that the wavelength calibration is very good. This should be expected since the wavelength calibration is determined by the 5852 $A^{o}$ neon line. The actual resolution can only be estimated from this data. The reduction in resolution by apodizing can easily be seen by comparing Figure 5 and Figure 6.

Now that a working instrument is available, a very complete calibration and evaluation must be performed before measurements can be made. It is also necessary to determine the best apodizing function and the instrument profile.

Once the instrument has been properly calibrated, it will be flown on a high altitude balloon to further evaluate the instrument performance.

SUMMARY: The continuing central problem with the interferometer is the obtaining of an adequate beam splitter.

Temperature sensitivity is also a difficult problem and a possible solution is to servo control the fixed mirror so that it lines up with the moving mirror. It is our intention to continue to work on these problems until an adequate instrument for meteorological studies is produced.

## LIST OF FIGURES

## REFERENCES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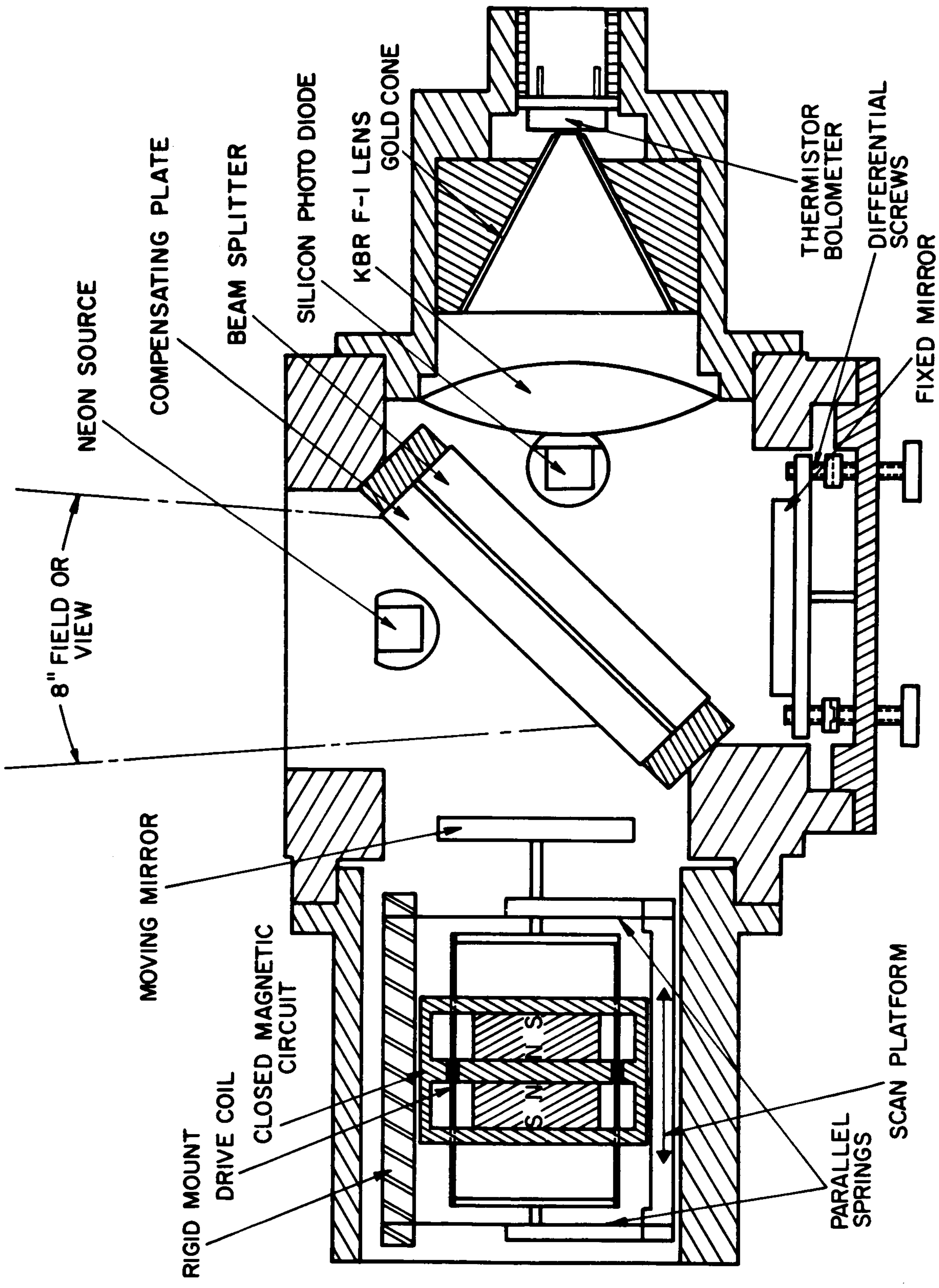
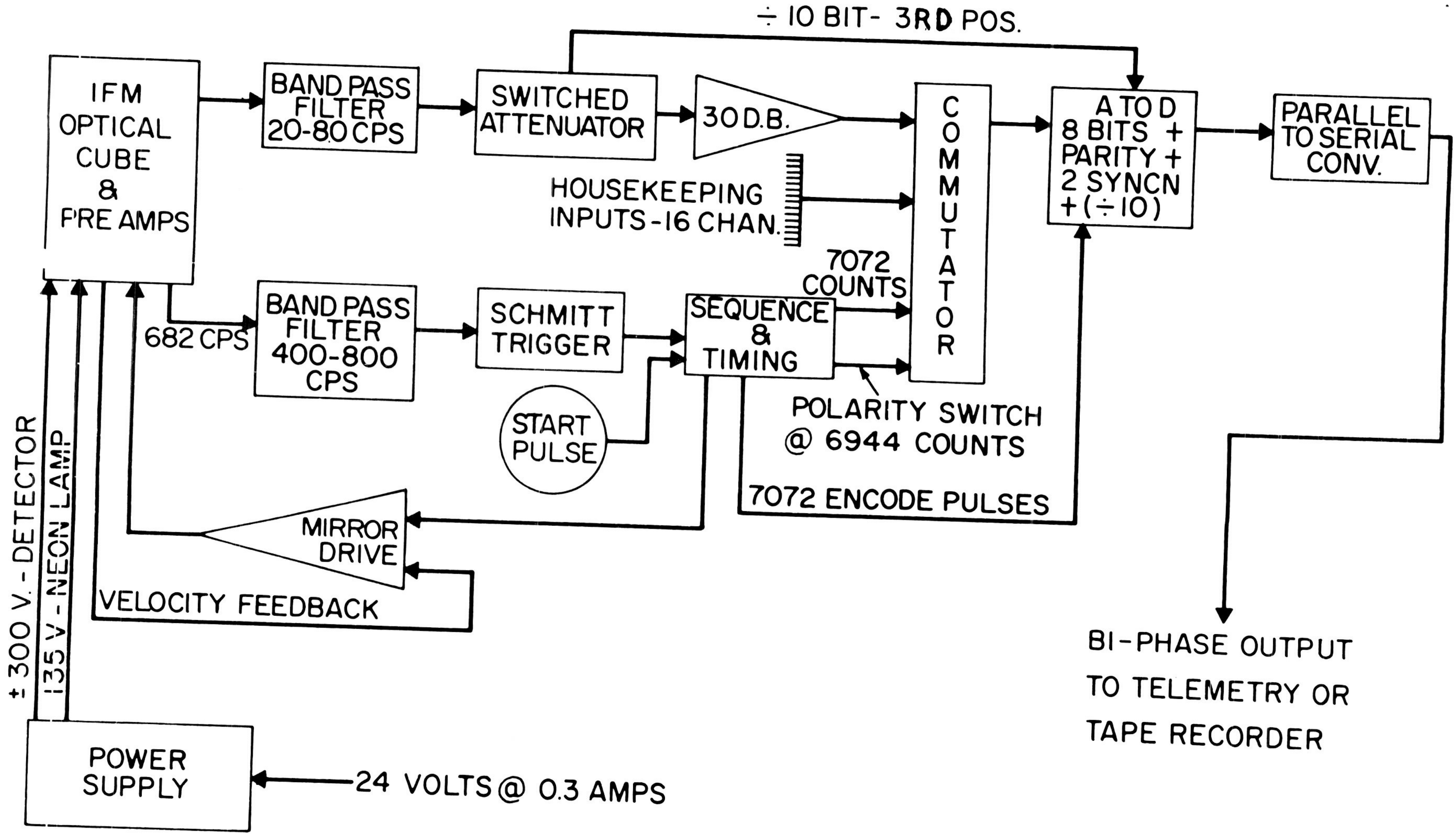
6. Hanel, R. A., and Chaney, L. W., 1965, The Infrared Interferometer Spectrometer Experiment (IRIS) Vol. II, Meteorological Mission, Goddard Space Flight Center Report X-650-65-75.




**OPTICAL HEAD LAYOUT**

Figure 1




**BALLOON INTERFEROMETER ELECTRONICS BLOCK DIAGRAM**

Figure 2

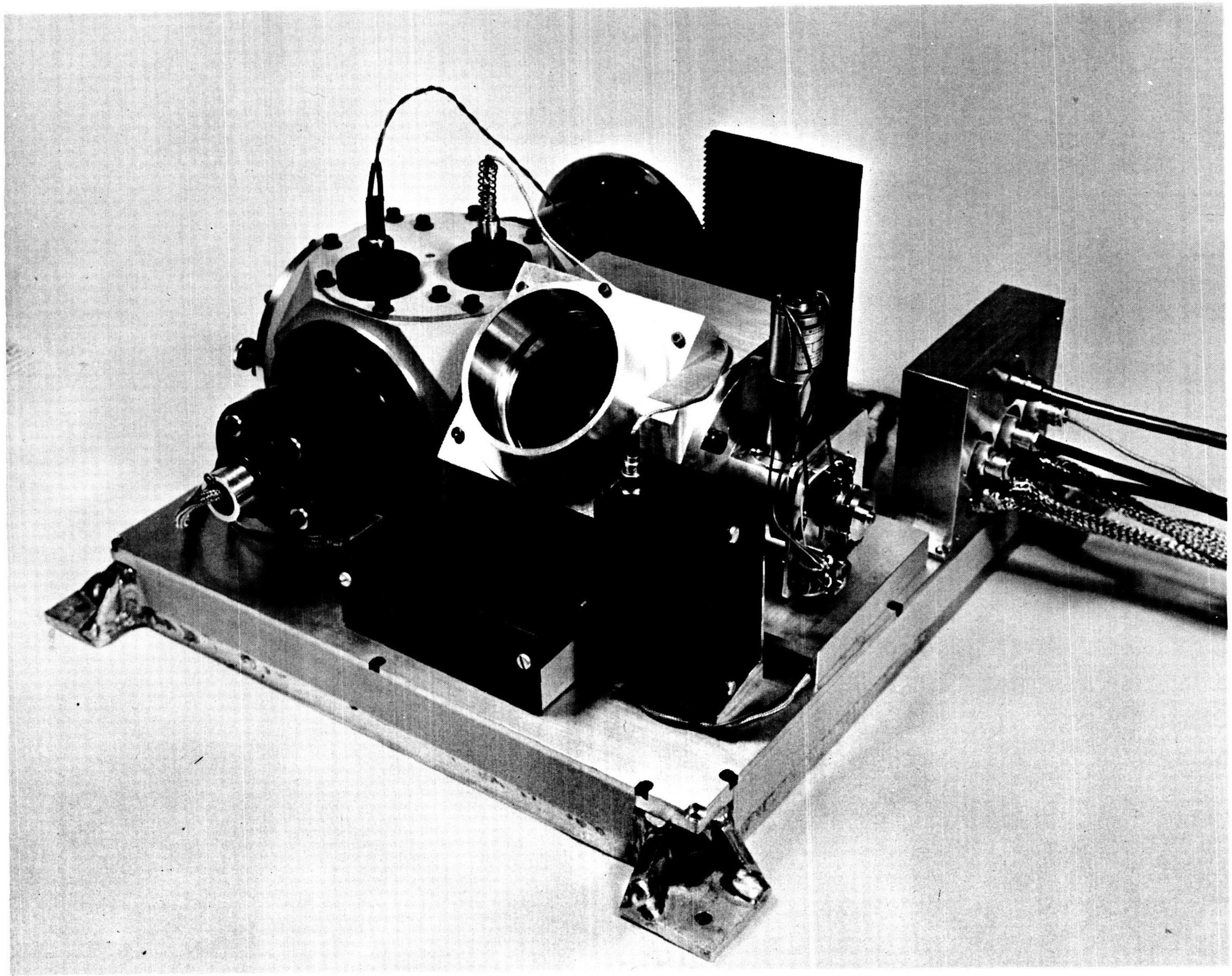


Figure 3. - Balloon Flight Optics

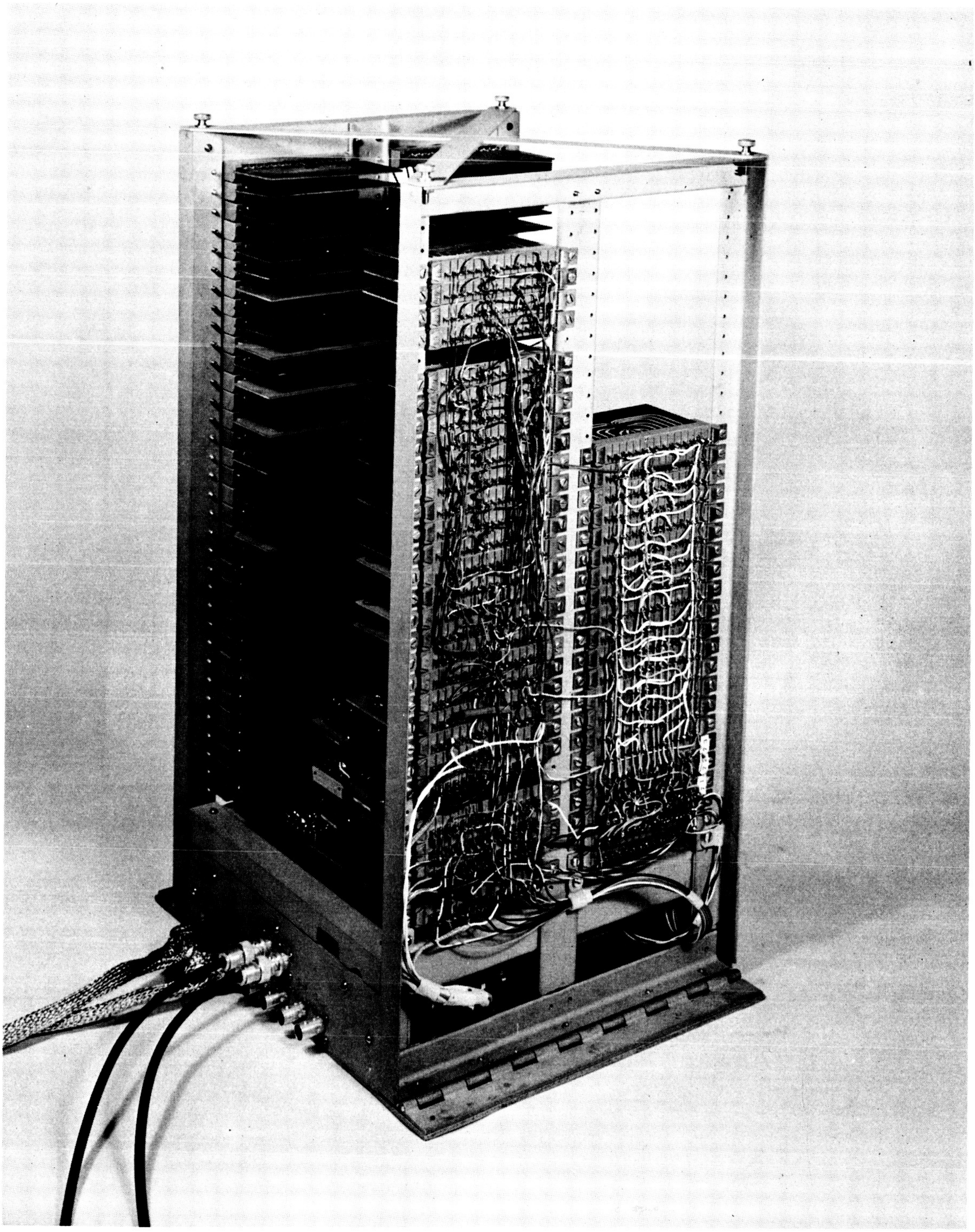
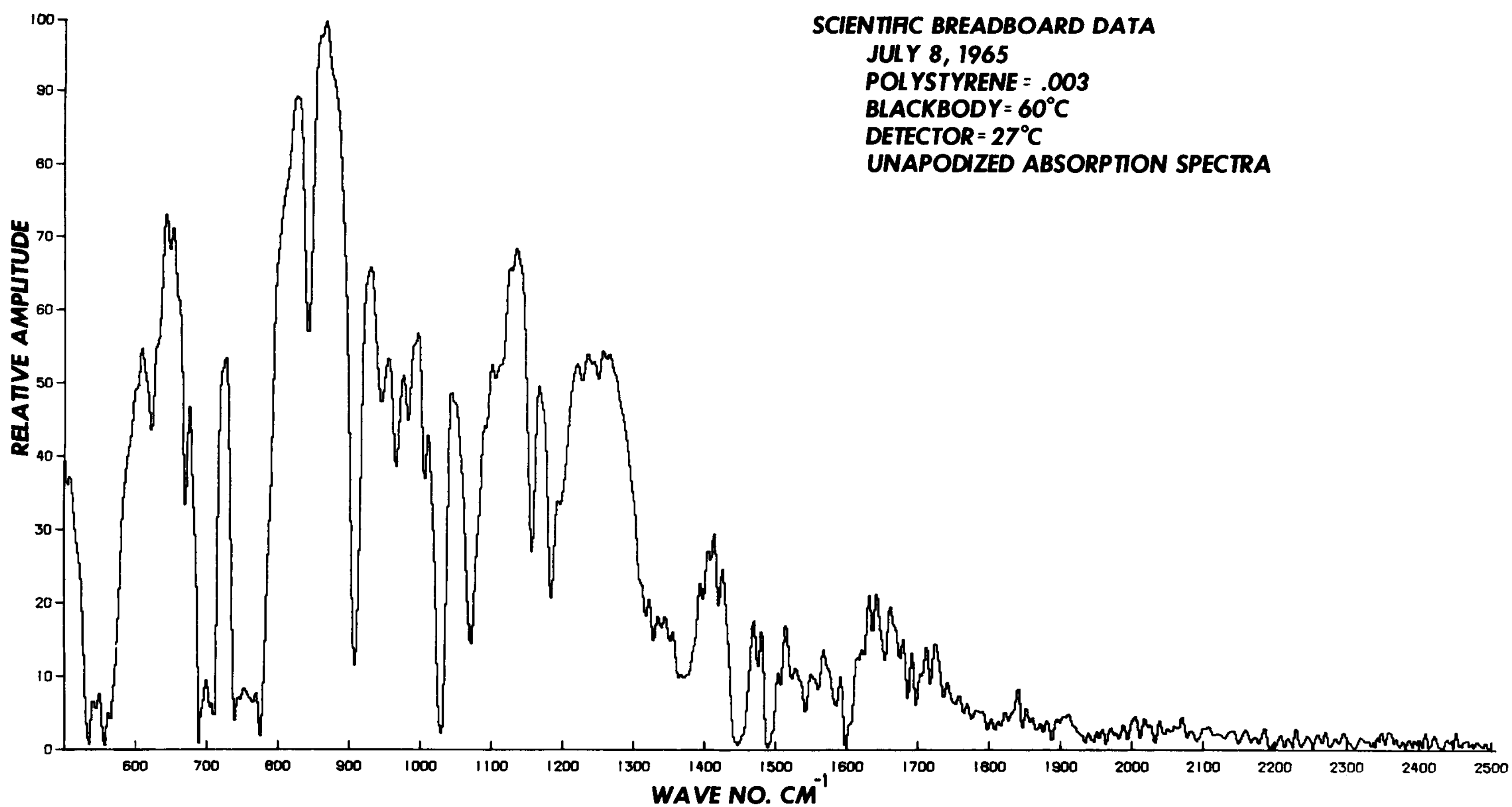


Figure 4 - Balloon Flight Electronics


SCIENTIFIC BREADBOARD DATA
JULY 8, 1965
POLYSTYRENE = .003
BLACKBODY = 60°C
DETECTOR = 27°C
UNAPODIZED ABSORPTION SPECTRA
RELATIVE AMPLITUDE
WAVE NO. CM$^{-1}$
0
10
20
30
40
50
60
70
80
90
100
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
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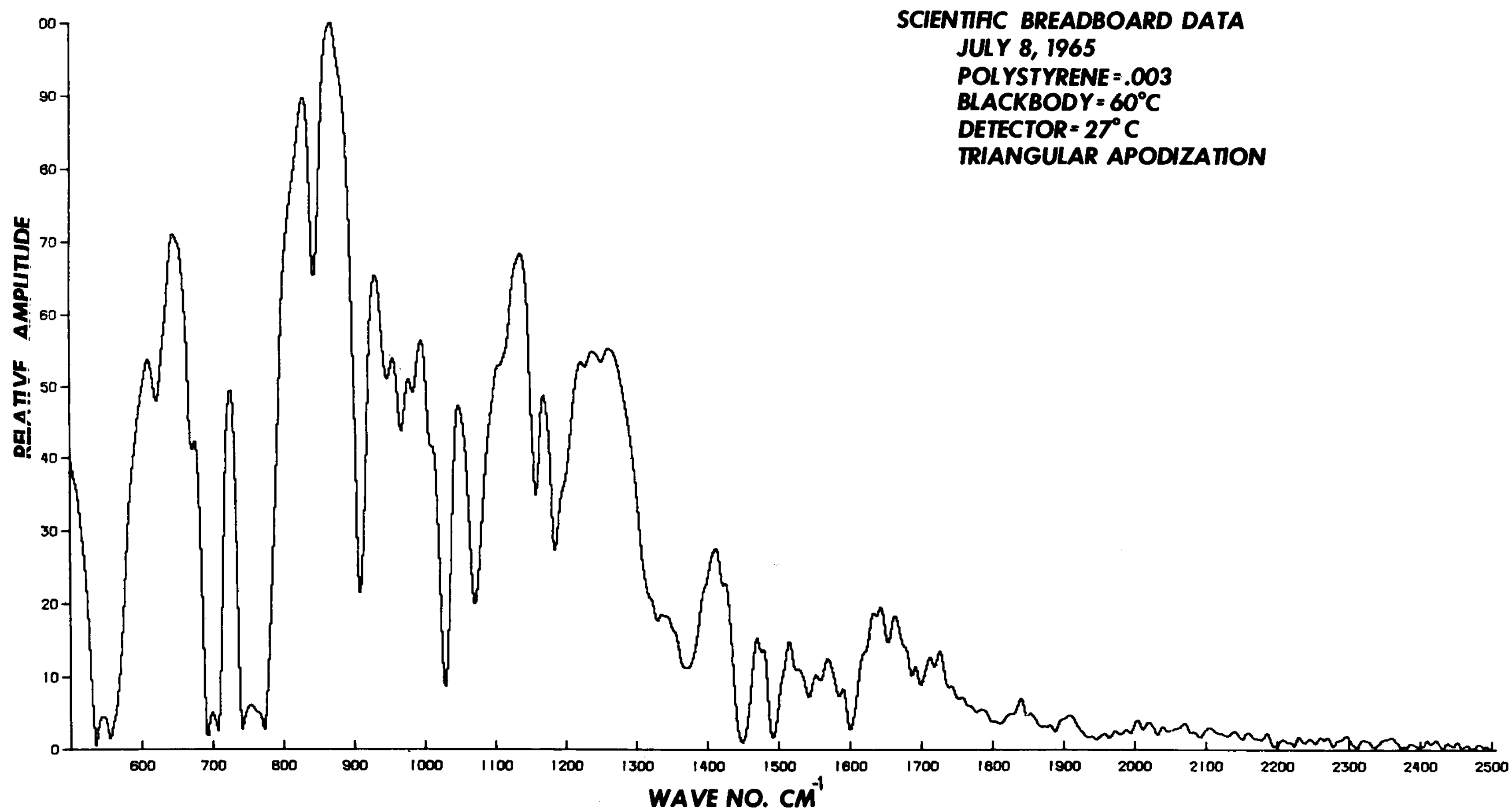
1900
2000
2100
2200
2300
2400
2500

Figure 5



SCIENTIFIC BREADBOARD DATA
JULY 8, 1965
POLYSTYRENE=.003
BLACKBODY=60°C
DETECTOR=27°C
TRIANGULAR APODIZATION
RELATIVE AMPLITUDE
00
90
80
70
60
50
40
30
20
10
0
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
WAVE NO. CM⁻¹


Figure 6

Appendix III

# THE MEASUREMENT OF THE EARTH'S TERMAL RADIATION BY A FOURIER TRANSFORM SPECTROMETER

(presented to American Meteorological Society Symposium March 21, 1967, Ann Arbor, Michigan)

## 1. Introduction

The High Altitude Engineering Laboratory under the sponsorship of Goddard Space Flight Center began an investigation of Fourier transform spectroscopy [1] in the spring of 1961.

During the course of the original literature survey it was discovered that Block Associates was manufacturing an infrared interferometer. The Block instrument covered the spectral range from 15$\mu$ to 5$\mu$ with a resolution of 40 cm$^{-1}$. The instrument was purchased, modified and calibrated for a high altitude balloon flight and flown from Sioux Falls, South Dakota, June 26, 1963.

Following the successful flight, a study was made to determine the feasibility of designing a higher resolution instrument. The primary objective in building the instrument was to carry out the temperature inversion experiment proposed by Kaplan. [2] The experiment required measurements in the 15$\mu$ $CO_2$ band with a radiation accuracy of 0.5% and a resolution of 5 cm.$^{-1}$

The study was in its early stages when the laboratory was approached by Dr. R. A. Hanel of Goddard Space Flight Center to make a joint proposal to fly an interferometer on the Mars 1966 mission. The original proposal[3] to fly such an instrument was made in February 1964 and the basic design was accepted for the mission in May 1964.

The Mars 66 mission was subsequently cancelled but G. S. F. C. continued to support the instrument development for the Nimbus satellite program. The objective of the development was to produce an instrument the output of which could be used to make a temperature inversion. The instrument development was completed for use in the laboratory by October 1965.

The instrument is basically a Michelson interferometer whose design features and operation have previously been described. The purpose of this report is to describe the balloon flight preparations, the data reduction and the data analysis.

## 2. Balloon Flight Environmental Problems and Testing.

The principal problems associated with flying the instrument on a high altitude balloon arise as a result of the enviroment. The environmental conditions which influence the instrument operation are as follows:

1. Pressure - 1000 mb to 7 mb
2. Temperature - $+25^{\circ}C$ to $-65^{\circ}C$
3. Humidity - to 100%
4. Vibration - induced from other equipment.

In addition to making provisions to overcome the adverse environmental conditions, calibration of the instrument had to be provided.

2.1 Pressure

The principle problem associated with the decrease in pressure is the corresponding decrease in the spark breakdown voltage. Except for the detector, all the voltage breakdown points were eliminated. Unfortunately we were unable to seal the detector and had to operate with an open flake. This created two problems: one, the "swish" noise created by air passing over the flake made the instrument "noisy" in the standard atmosphere; and two, the spark breakdown point was approached rather closely at "float" altitude. For example, if the pressure dropped below 3 mm a detector burn out could be expected, but at a pressure of 4.5 mm there was no problem. We actually had several detector failures before we realized that one of the atmospheric test chambers would momentarily reduce the pressure below 3 mm.

2.2 Temperature and Humidity

In order to measure radiance it is necessary to know the reference temperature quite accurately. Also the optical alignment of the interferometer is disturbed by any change in temperature differentials across the cube. The temperature control problem was solved in the following way (Fig. 1): The optical base plate is a vacuum tight container in which 1500 cc of water has been sealed. The water is frozen by circulating cold alcohol through an aluminum coil attached to the base. After the water has been completely frozen the alcohol is removed and cold nitrogen gas is circulated through the coils. The instrument is insulated with two inches of urethane foam completely surrounding the package. The temperature of the instrument under these conditions will remain constant at or near $0^{\circ}C$ for a period of 15 hours. The detector, due to self heating, will assume a temperature of $0.8^{\circ}C$.

The nitrogen in addition to cooling the base plate serves two other purposes. First, the liquid nitrogen is forced up to the input of the cold black body. The nitrogen boils, passes through the black body and lowers the temperature to $240^{\circ}K$. The gas is then fed into the base plate cooling coil from which it emerges at $273^{\circ}K$. From here it is fed directly into the optics and leaks out through the exit door. The purpose in the latter case is to maintain a purge of the optical head. The purge is necessary because both the beam splitter and the lens are made of potassium bromide which is very hygroscopic. Any "fogging" of these pieces will attenuate the monochromatic digitizing signal with disastrous results. Whenever the instrument is outside of the laboratory, it is necessary to maintain a nitrogen purge of the optics.

The multiple use of the liquid nitrogen created conflicting requirements. In the final package the cooling of the black body placed the greatest demand on the system. The final specifications were as follows:

Liquid Nitrogen Storage Capacity = 3 liters liquid

Flow Rate = 2.8 liters gas per minute

Flow Duration = 11.4 hours

The usual procedure was to freeze the sealed water, fill the liquid nitrogen flask, connect the nitrogen purge and turn the heat on the warm black body. When the black bodies reached their operating temperature a final adjustment of the fixed mirror was made while observing the output of the monochromatic detector. The instrument then operated in the flight mode. The flight mode signifies that the programmer is in operation, the drive mirror is triggered every 15 seconds, and the view mirror is rotated in front of the black bodies and the earth viewing port.

A polythylene bag was taped on the under side of the gondola over the view window and purged with dry nitrogen. This kept moisture off of the instrument during the checkouts and permitted the opening of the view window. In the actual flight the view window opened after reaching the float altitude.

The electronic system was arranged so that the digitized output, the monochromatic signal, and the infrared interferogram could be checked and monitored at the gondola. The monochromatic signal was used to monitor the final alignment of the fixed mirror. The infrared signal was used to check the operation of the view mirror. By observing the form of the interferogram (Fig. 4), it is possible to determine the position of the view mirror. An observation of the digital output on an oscilloscope was sufficient to determine the data encode rate and the output bit rate. However, to determine that the encoding was correct and that the gain switching was operative a more elaborate check was required.

## 2.3 Vibration

Interfering vibrations were produced by other equipment on the gondola. The aerial cameras' film advance mechanism created a large impulse. The basic programmer was a matrix of Ledex switches that periodically produced a series of pulses. Finally, another radiation instrument produced a steady vibration.

When the instrument was originally placed on the gondola with all the equipment in operation, the mirror drive vibrated so badly that it was impossible to make any measurements.

Several steps were taken to correct the situation. The entire programmer was shock mounted. The aerial cameras were shock mounted and the interferometer itself was placed on vibration isolators. The instrument as it was flown on the gondola is shown in Fig. 2. The gondola ready for flight, hanging on the launching truck, is shown in Fig. 3.

## 2.4 Calibration and Altitude Chamber Tests

Prior to the balloon flight the instrument was tested several times in altitude chambers to simulate the balloon flight environment. A series of five tests were carried out in the Bendix Systems environmental chamber in Ann Arbor and three tests were performed in a Chrysler Corporation chamber in Warren, Michigan. The first tests were required to perfect the liquid nitrogen cooling-purge system and the later tests checked the spark breakdown conditions. The last test was used for making calibrations. These tests were very valuable in that they uncovered instrumental difficulties which were corrected before the balloon flight. The corrected problems were:

(1) formation of moisture on some of the integrated circuit boards

(2) motor arcing noise due to the reduced atmospheric pressure

(3) faulty microswitch action due to the cold temperature.

During the final test the instrument was held at the simulated float altitude for calibration. The basic procedure was to use an external target which was first cooled to -100°C by means of liquid nitrogen. The target temperature was monitored at four places by means of platinum resistance thermometers. The thermometer voltages were measured with a Dymec data logging system. The temperature of the black body corresponding to a given interferogram was established to within 0.1°C.

A study of the data showed that the Fourier transform of the interferogram and the actual radiance were linearly related such that $\beta(\nu) = c+k(\beta'(\nu))$ where $\beta'(\nu)$ is the Fourier transform of the recorded interferogram. The instrument was calibrated at every two wave numbers from 500 to 2000 $cm^{-1}$.

3. Field Preparations

After the series of tests and calibrations were completed in the Chrysler chamber the instrument was transported to Palestine, Texas, the site of the National Atmospheric Research Center balloon facility. Several complete checkouts of all the gondola equipment were carried out in order to determine that all the equipment was working properly. Because of the uncertainty of the weather it was necessary to hold extensive count downs prior to each intended launch. The instrument was prepared for launching four times prior to the actual launching. Therefore, by the day of the actual launching the procedure was almost routine.

After checking the instrument output at the gondola, the telemetry system was turned on and the same outputs were checked at the mobile telemetry station (Fig. 5). The data was recorded for at least 15 minutes to fill one magnetic tape. As a final check the tape was played back at ($7\frac{1}{2}$ ips), 1/8 of the record speed, and recorded on a galvanometer recorder operating at 64 ips. This combination allowed the visual recording of the individual bits. Using the bit information available, the peak of interferograms were plotted as analog signals. If a plotted curve was a reasonable representation of an interferogram and made a smooth transition across all gain change values, the instrument was assumed to be in proper adjustment.

4. The Flight

On the day of the flight the same procedure was followed as described for the check out with the following additions. A secondary $1\frac{1}{2}$ liter liquid nitrogen container was placed on top of the gondola to keep the primary 3 liter bottle filled during the flight preparations. The flight preparations started at midnight for a 6 am launch. About 15 minutes prior to launch, when the gondola was hanging from the launch truck, the secondary $1\frac{1}{2}$ liter bottle and the plastic bag over the view window were removed. The gondola program was set so that the command to open the view window occurred just as the balloon reached the float altitude. The balloon was launched at 0653 EST and impacted at 1711 EST. Data was recorded throughout the entire flight at the rate of three tapes per hour.

As the balloon rose, the background noise decreased just as it had done during the altitude chamber tests. There were bursts of noise throughout the flight and a large amount of noise was generated as the view door opened. Furthermore, noise was generated as the view mirror scanned to a new position. Later analysis determined that most of the noise was due to arcing brushes in several D. C. motors. In addition to the two motors used in the interferometer, several were employed by the other equipment. Fortunately the motors were not in continuous operation and there were periods of relative quiet.

The flight path of the balloon is shown in Fig. 6 and it can be seen that for most of the early part of the flight the balloon circled the Palestine area and later drifted in a southwesterly direction. The impact point was 63 miles from the launch site.

The interferometer functioned properly throughout the flight and interferograms were recorded until shortly before impact. However, the monitor channels failed at 1528 EST and the aerial cameras ceased to take photographs just prior to this time. These failures were the result of a problem with the programmer and it was realized prior to impact that the view door would also fail to close. This information was relayed to the ground crew who were at the impact site as the gondola came down and closed the door almost immediately. This was extremely fortunate since nitrogen was still being exhausted, although the liquid nitrogen container was empty. Post flight checks of the instrument have indicated that the sensitivity remained unchanged from the time of the flight.

## 5. Post Flight Data Reduction

Immediately after the flight a few interferograms were converted from digital to analog form by hand to see that good data had been recorded. Once this fact was established the equipment was packed and returned to Ann Arbor.

### 5.1 Formatting

The data recorded in the field was in the form of serial bits recorded on an analog tape (Fig. 7). It was necessary to translate this presentation into a parallel 6 x 6 format understandable to the 7090 IBM computer.

We were extremely fortunate in being able to use the Meteorology Department's computer facility which was ideal for the job. Their equipment consists of an analog computer which we used for shaping the signals, a CDC-160A digital computer, digital tape recorders, and a Cal-Comp plotter. The computer was programmed to decode each 8-bit word plus gain bit and store the result as a new 12-bit word in the memory. Each interferogram consists of 3472 words. When the correct number of words have been stored the contents of the memory is automatically plotted in analog form. By examining the plot any irregularities such as noise, gain change, or housekeeping commutator errors can be detected. If the interferogram is satisfactory, it is stored on magnetic tape and the computer can accept another interferogram. The playback and formatting was done at 1/8 the speed of the original recording. This allowed 80 seconds to store the interferogram and 40 seconds for plotting and examining the results. As long as everything was satisfactory the decoding proceeded automatically.

## 5.2 Computer Calculations

There was a great deal more data available than could possibly be processed and since there were intermittent noise bursts throughout the flight, the analog plots from the CDC-160A were carefully examined and samples from each tape were selected for processing on the IBM 7090 computer. The sequence of interferograms selected from each tape was as follows: one cold black body, one warm black body, three successive scenes, followed by one cold black body and one warm black body.

The selected information from each tape was presented on a single sheet as three separate plots.

The first interferograms to be reduced to spectra occurred immediately before and immediately after the window opened. The characteristic $14\mu$ absorption line due to the polyethylene window was observed in the before spectrum (Fig. 8) and was absent in the following spectrum (Fig. 9).

These spectra have a rather strange appearance because they are relative spectra. The measured radiation is both negative and positive with respect to the detector reference of $0.8^{\circ}C$. We encountered a slight problem in originally reducing the data because of the need to know the polarity of the radiation. Referring again to Fig. 4 it can be seen that both the cold and the warm black bodies have well defined peaks which define the zero retardation point whereas the scene zero retardation point falls on a signal minimum. If the calculation is started away from zero retardation by one sample, the phase error will be from $22^{\circ}$ to $90^{\circ}$. We originally used the maximum peak as the starting point which produced phase errors from $154^{\circ}$ to $560^{0}$.

The originally calculated spectra were used to identify many spectral lines. In fact, almost all the lines appearing in the spectra could be identified. This was the first positive indication that the instrument performed as expected and was a source of great encouragement.

5.3 Calibrations

The instrument had been calibrated before the flight in the vacuum chamber and the first procedure was to apply these calibrations to the in-flight black body data. The result was quite a disappointment. The cold black body appeared to be colder than it should have been and the error became larger at the shorter wavelengths. The conclusion was reached that the altitude chamber was severly contaminated by water vapor. This proved to be the case and calibrations were applied to the data using the in-flight calibrations. A linear relation between the radiance and the relative amplitude had to be assumed since there were only two calibrating temperatures.

The measurement results were compared in the region between 600 $cm^{-1}$ and 750 $cm^{-1}$ with theoretical calculations of the spectral radiance (Fig. 10). The theoretical radiance was calculated by Young and Drayson using the average temperature profile obtained from radiosondes flown on the same day as the flight from several surrounding weather stations. The comparison is extremely good and was a source of encouragement to all concerned with the project.

## 6. Data Analysis

Three successive scans were averaged for each tape and the results are tabulated in the appendix. Two plots were made of the data from each tape. One plot extended from 500 $cm^{-1}$ to 900 $cm^{-1}$. The other plot extended from 500 to 2000 $cm^{-1}$. The scene data is the average of three scans, but the black bodies are single scans taken just before and just after the scene. Two examples of the plots are given in Figs. 11 and 12. These two plots represent the maximum difference in cloud cover during the flight. The corresponding photographs are shown in Figs. 13 and 14.

### 6.1 Noise Study

The excellent comparison between the measured and the theoretical radiance was extremely gratifying, but in order to establish the accuracy of the measurements a noise analysis of the data was made.

The first step in the noise study was to fit a fourth order curve to a single scan black body spectrum (Fig. 15) and calculate the standard deviation (Fig. 16) of the data from this curve. The standard deviations are averaged over 20 $cm^{-1}$ intervals. Therefore, the values obtained are equivalent to a four scan average computed over a 5 $cm^{-1}$ interval.

The black body standard deviation plot shows that the noise is a sensitive function of wavelength. A false line appeared in the flight data at 740 $cm^{-1}$ and is very apparent in the standard deviation plot. It is also apparent that the signal to noise ratio decreases from 600 $cm^{-1}$ to 500 $cm^{-1}$ due to signal attenuation through the potassium bromide. Except for the two areas noted, the average noise is less than 0.5 ergs $sec^{-1} cm^{-1} sr^{-1}$ which was the original goal for the instrument.

Another technique for evaluating the noise is to calculate the signal in the non-signal area of the spectrum and assume that anything measured is noise. The electronic filter attenuates the signal sharply beyond 2500 $cm^{-1}$ and the fold over point is at 4272 $cm^{-1}$ (Fig. 17). Hence, in the region between these two limits the only signal should be noise. The standard deviation of the signal in this area was calculated for several interferograms and all were found to be less than 0.5 ergs $sec^{-1}cm^{-1}sr^{-1}$.

When the instrument was originally proposed, a noise study indicated that a signal to noise ratio of 2000:1 in the interferogram would result in spectral noise of less than 0.5 ergs $sec^{-1}cm^{-1}sr^{-1}$. The measured signal to noise ratio of the instrument for a single scan is 1000:1 or 2000:1 for a four scan average which is in agreement with the original calculations.

6.2 Wavelength Calibration

The wavelength accuracy of the instrument was checked by comparing the percent transmission measurements made using the interferometer with those made using a Perkin-Elmer 13U spectrometer (Fig. 18). The agreement is excellent, and the deviations in percent transmission can be attributed to the difference in source temperature.

It is always desirable to know the instrument scanning function, but thus far we have not had the equipment required to make the measurement. A laser would be an excellent tool for this purpose or a high resolution monochromator.

## 7. Conclusion

The final results (Figs. 11 and 12) are measurements which met the proposed accuracy requirements of the temperature inversion experiment. The data has been used by Drayson and Young[4, 5] to perform the temperature inversion. An example of their results is reproduced here (Fig. 19). There is, of course, a great deal more information available in the data, and we hope to make use of this in studying the distribution of ozone and water vapor.

# LIST OF FIGURES

## LIST OF REFERENCES


1. Chaney, L. W. and L. T. Loh, An Infrared Interference Spectrometer - Its Evaluation Test and Calibration, NASA Contractor Report CR-61, June 1964.

2. Kaplan, L. D., J. Opt. Soc. Am 49, 1004, 1959.

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4. Drayson, S. R. and C. Young, The Determination of Meteorological Variables from Atmospheric Thermal Radiation Measurements, Am. Met. Symposium, March 21, 1967.

5. Chaney, L. W., S. R. Drayson, and C. Young, Appl. Opt. 6, 347, 1967.

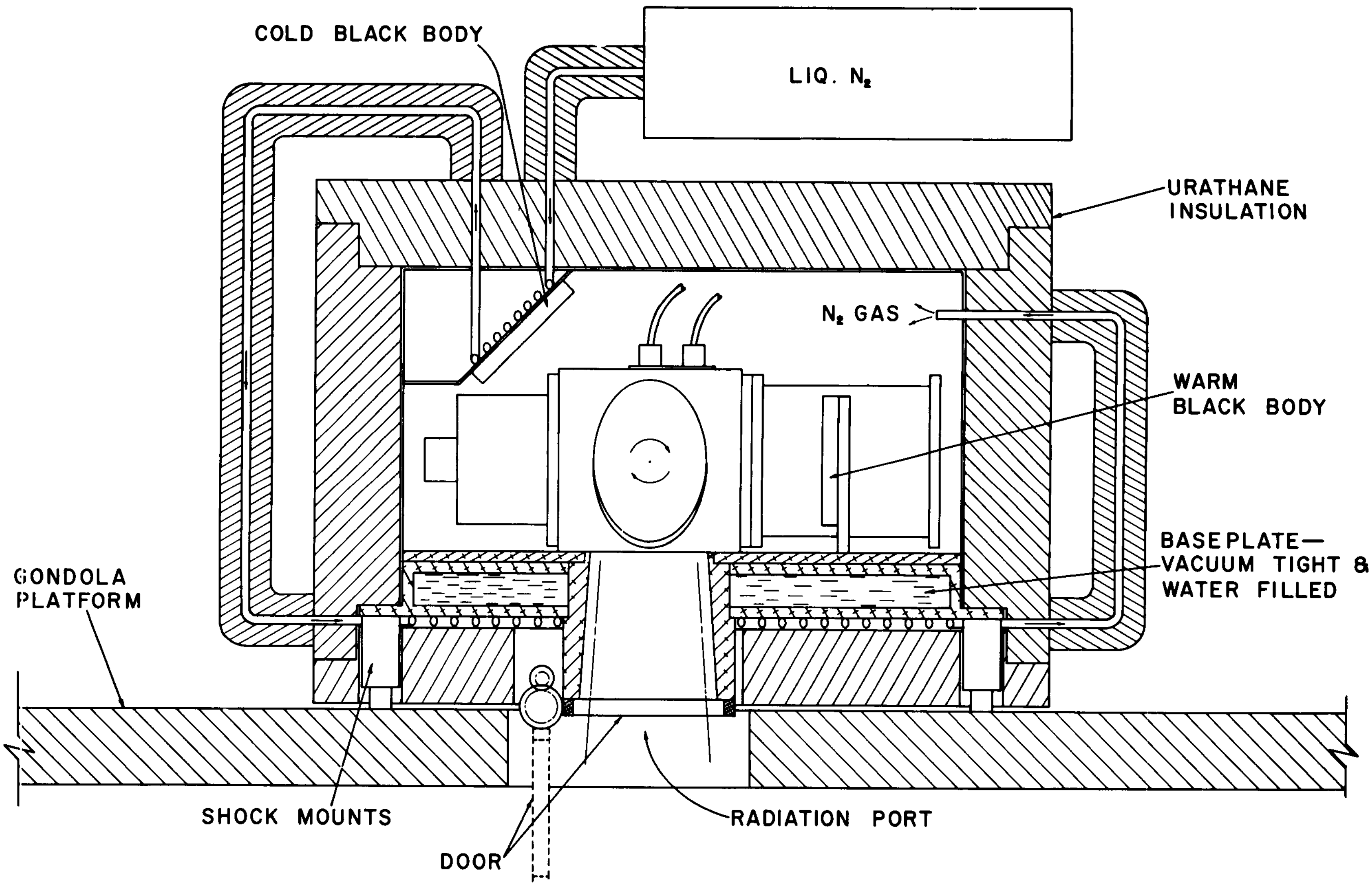



Figure 1 - Gondola Interferometer installation outline

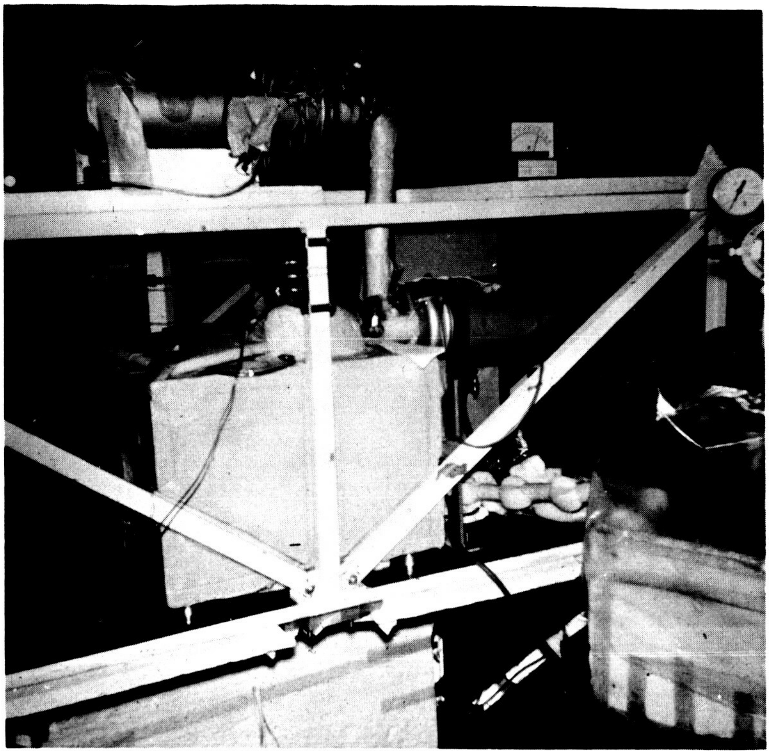


Figure 2. - Gondola installation

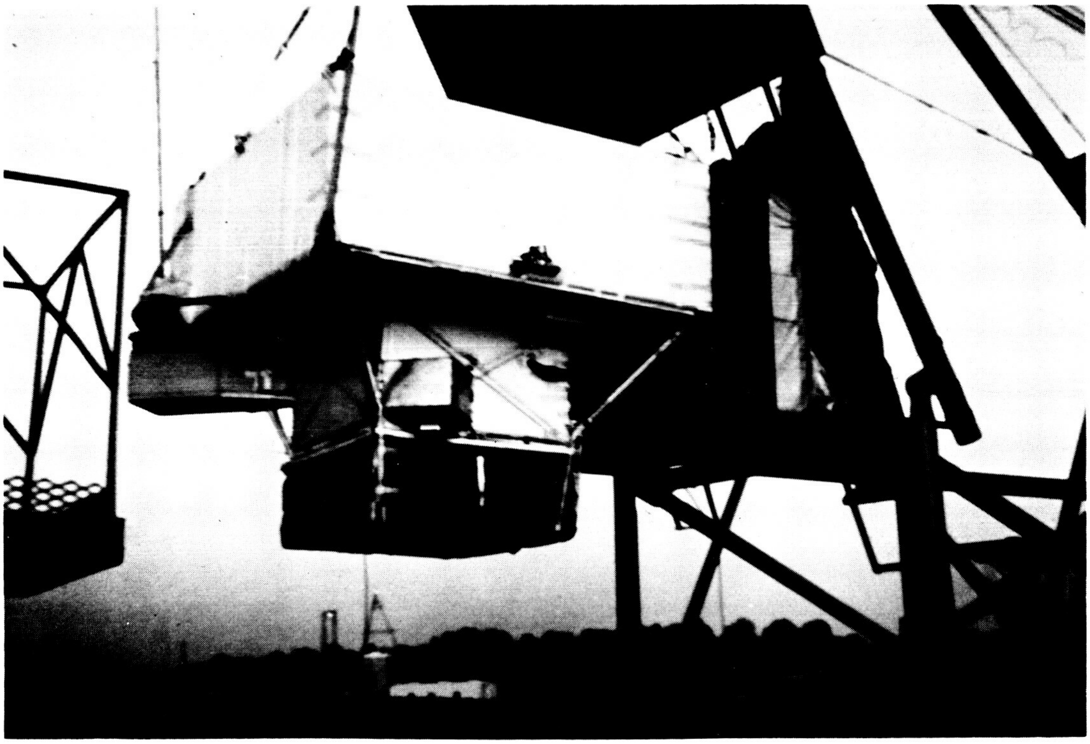


Figure 3. - Gondola on launching truck

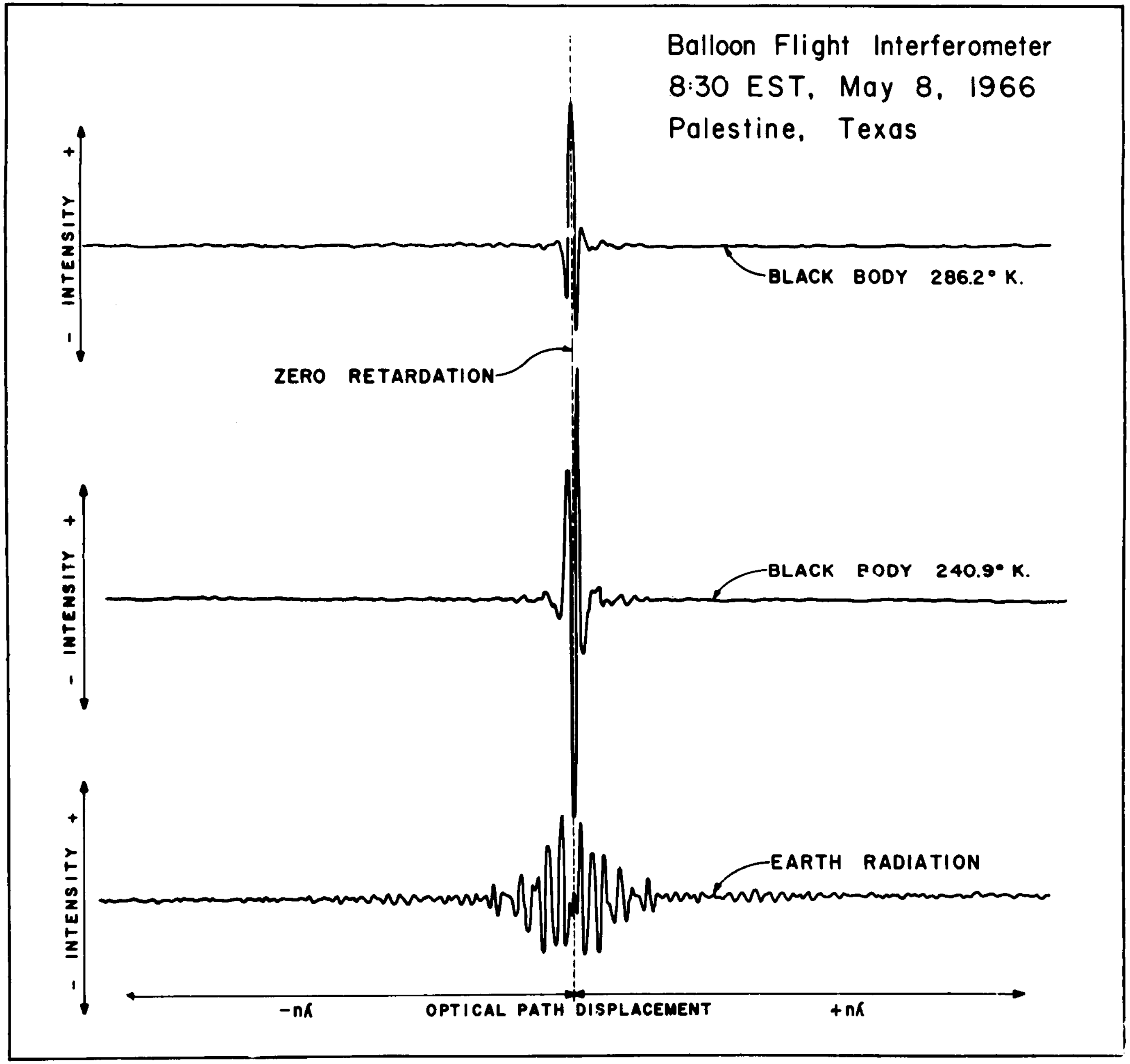



Figure 4 - Interferogram Comparison

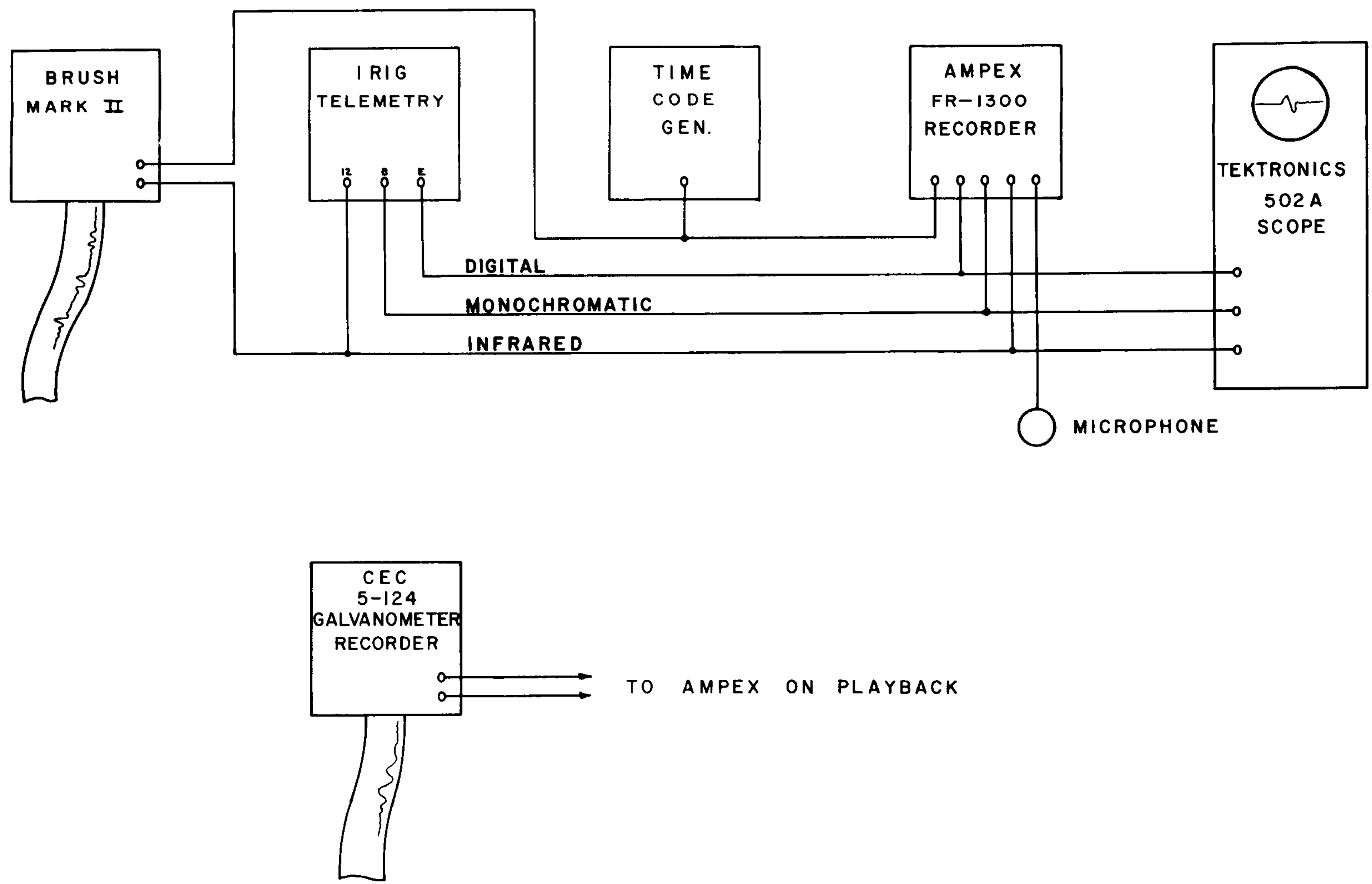
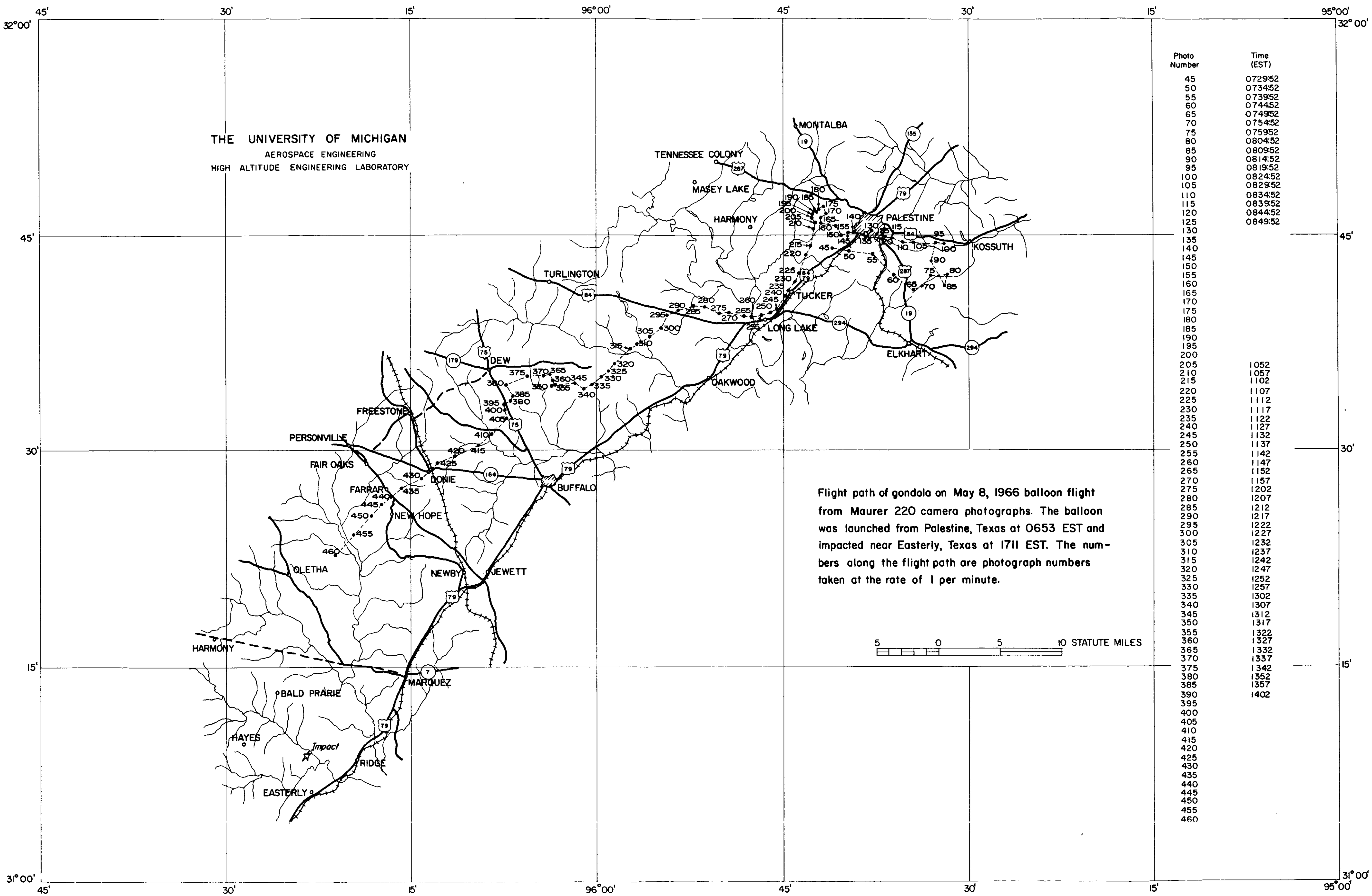



Figure 5. - Telemetry station block diagram

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| 50 | 0734:52 |
| 55 | 0739:52 |
| 60 | 0744:52 |
| 65 | 0749:52 |
| 70 | 0754:52 |
| 75 | 0759:52 |
| 80 | 0804:52 |
| 85 | 0809:52 |
| 90 | 0814:52 |
| 95 | 0819:52 |
| 100 | 0824:52 |
| 105 | 0829:52 |
| 110 | 0834:52 |
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Figure 6 - Gondola Flight Path

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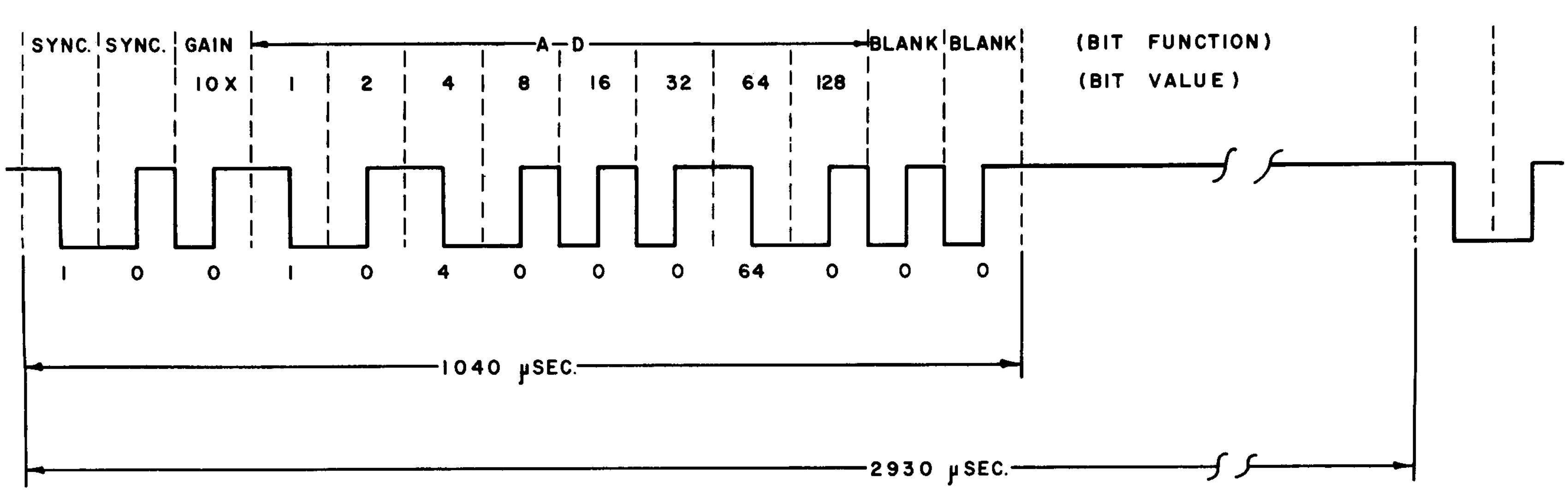



Figure 7 - Digital data format

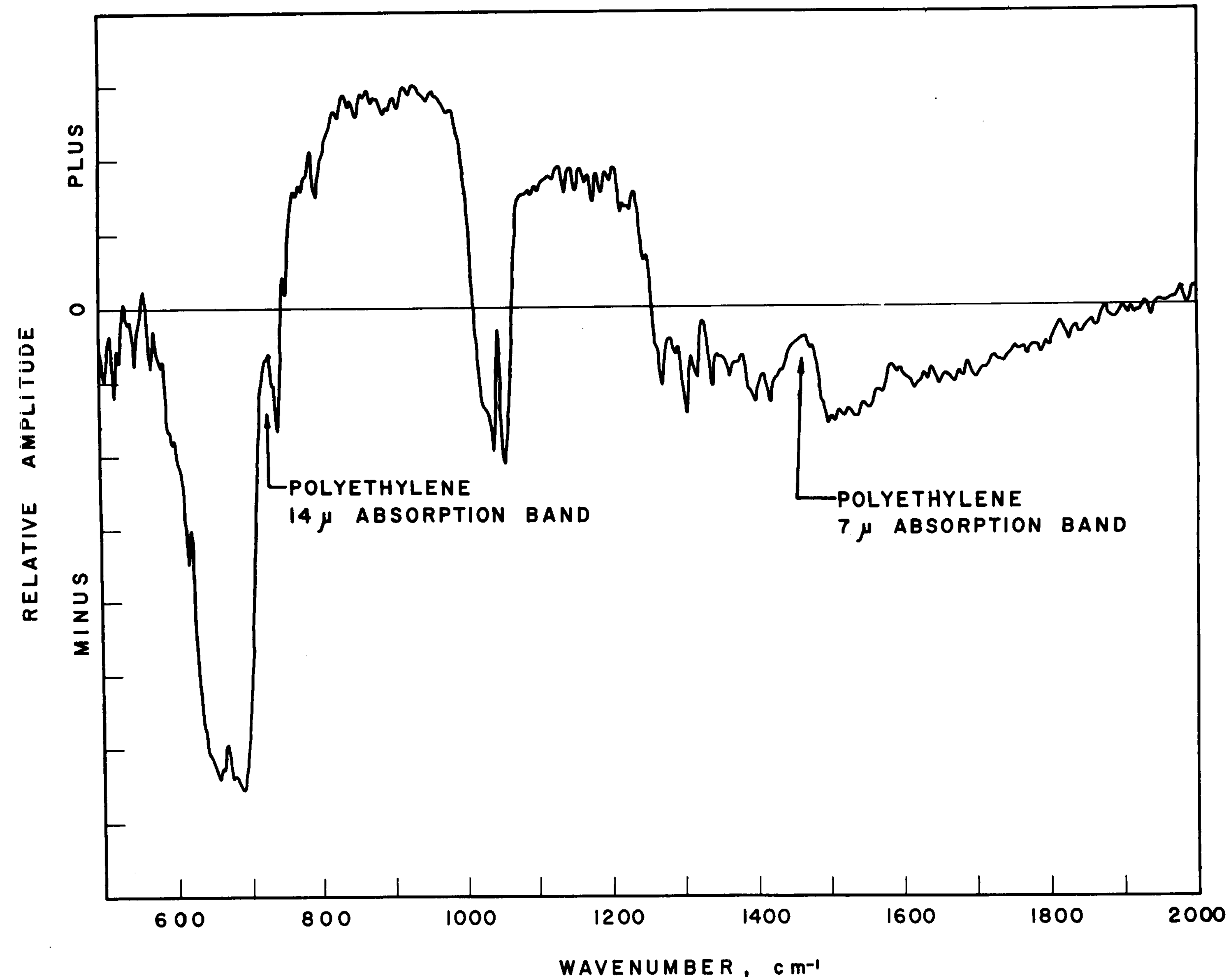



Figure 8 - Relative spectrum through poly~~styrene~~ ethylene window

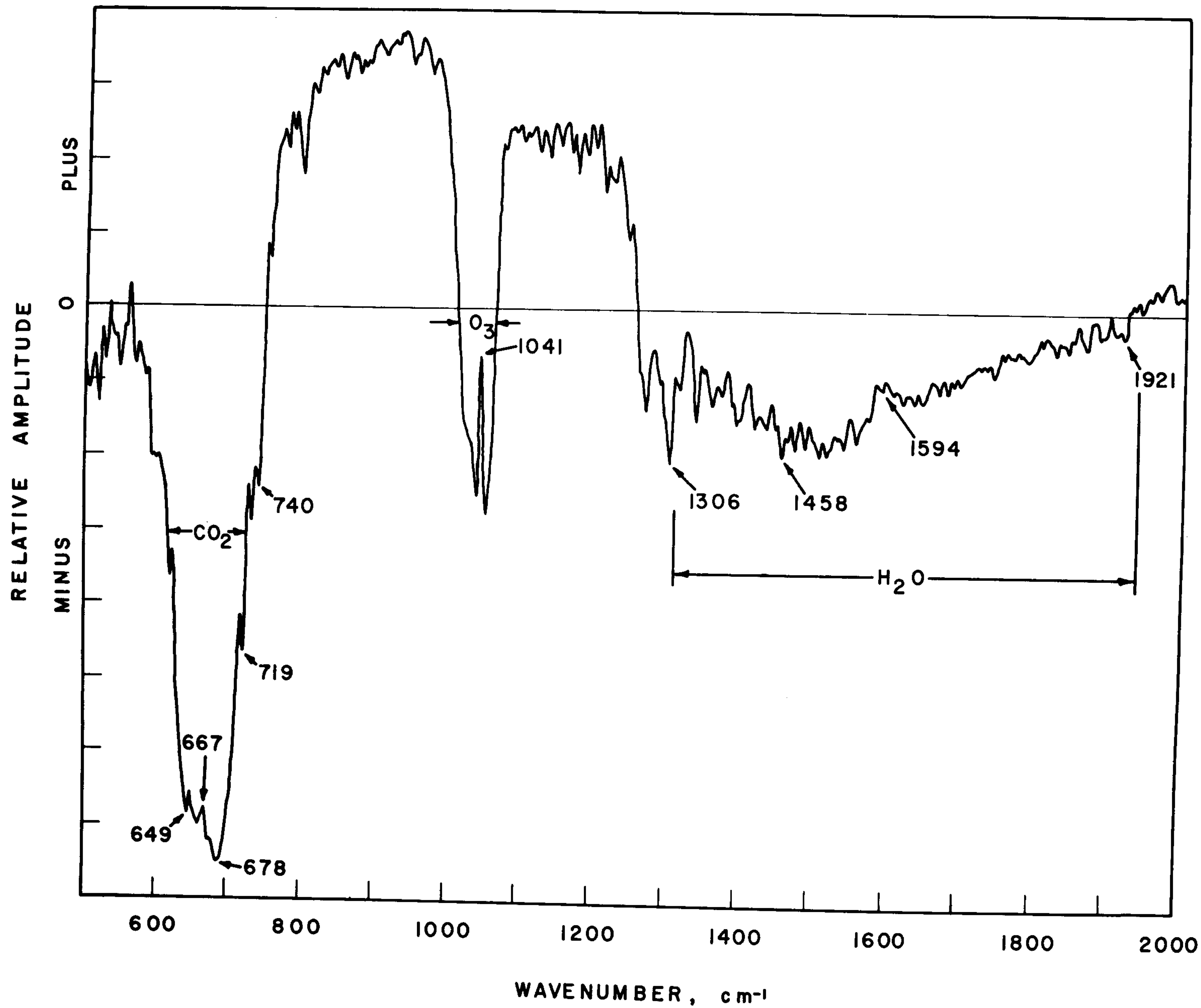



Figure 9 - Relative spectrum at 8:30 EST and line identification

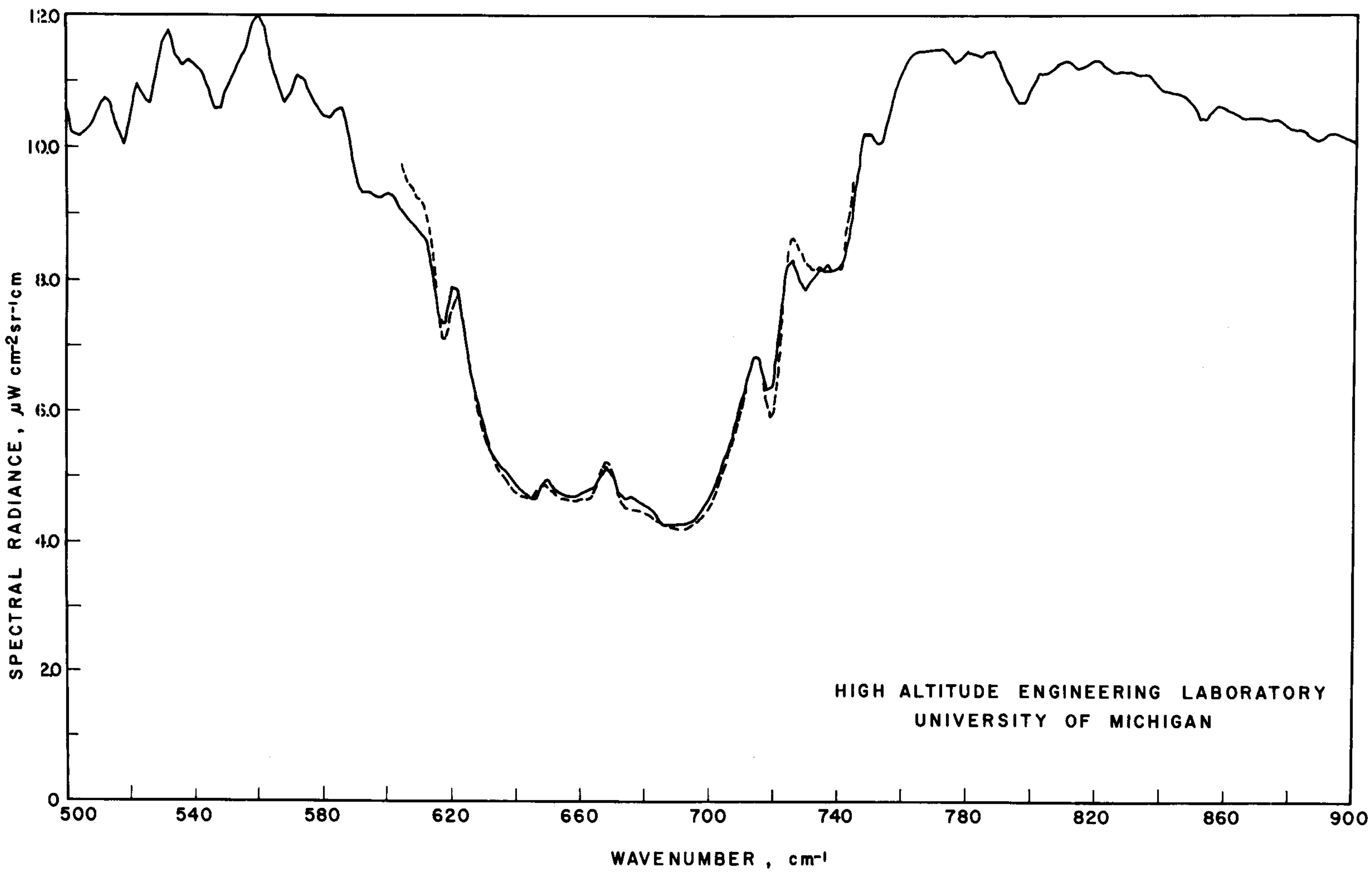



Fig. 2. Theoretical radiances calculated using transmissivities of Drayson & Young[4] (600–750 $cm^{-1}$), and an average radiosonde temperature profile for Eastern Texas on May 8, 1966 (----).

Balloon flight Fourier Transform Spectrometer radiance measurements May 8, 1966-07:30 CST Palestine, Texas. A three scan average (500–900 $cm^{-1}$) (——).

Figure 10 - Comparison of calculated and measured radiance

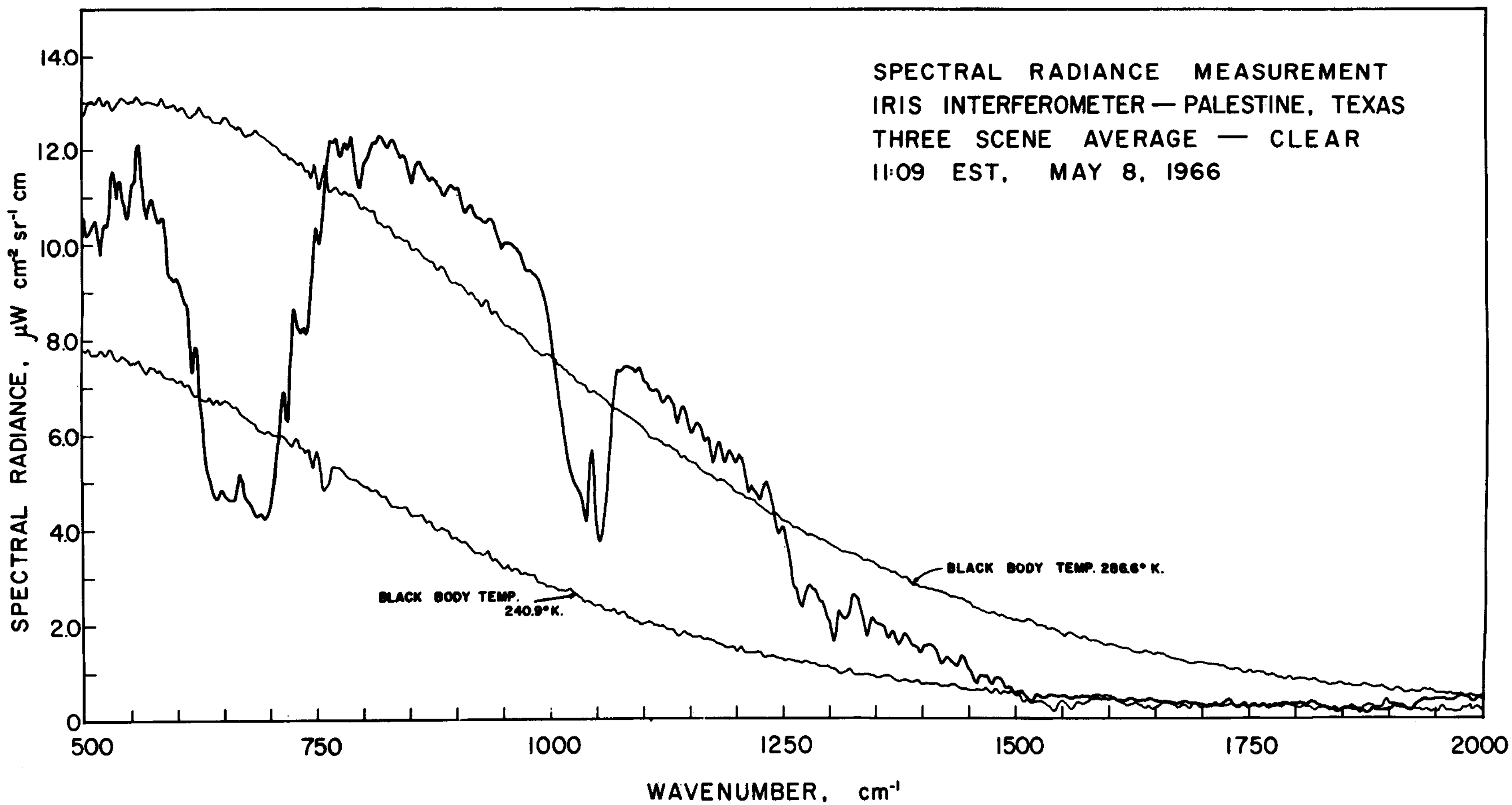



Figure 11 - Spectral data at 11:09 EST

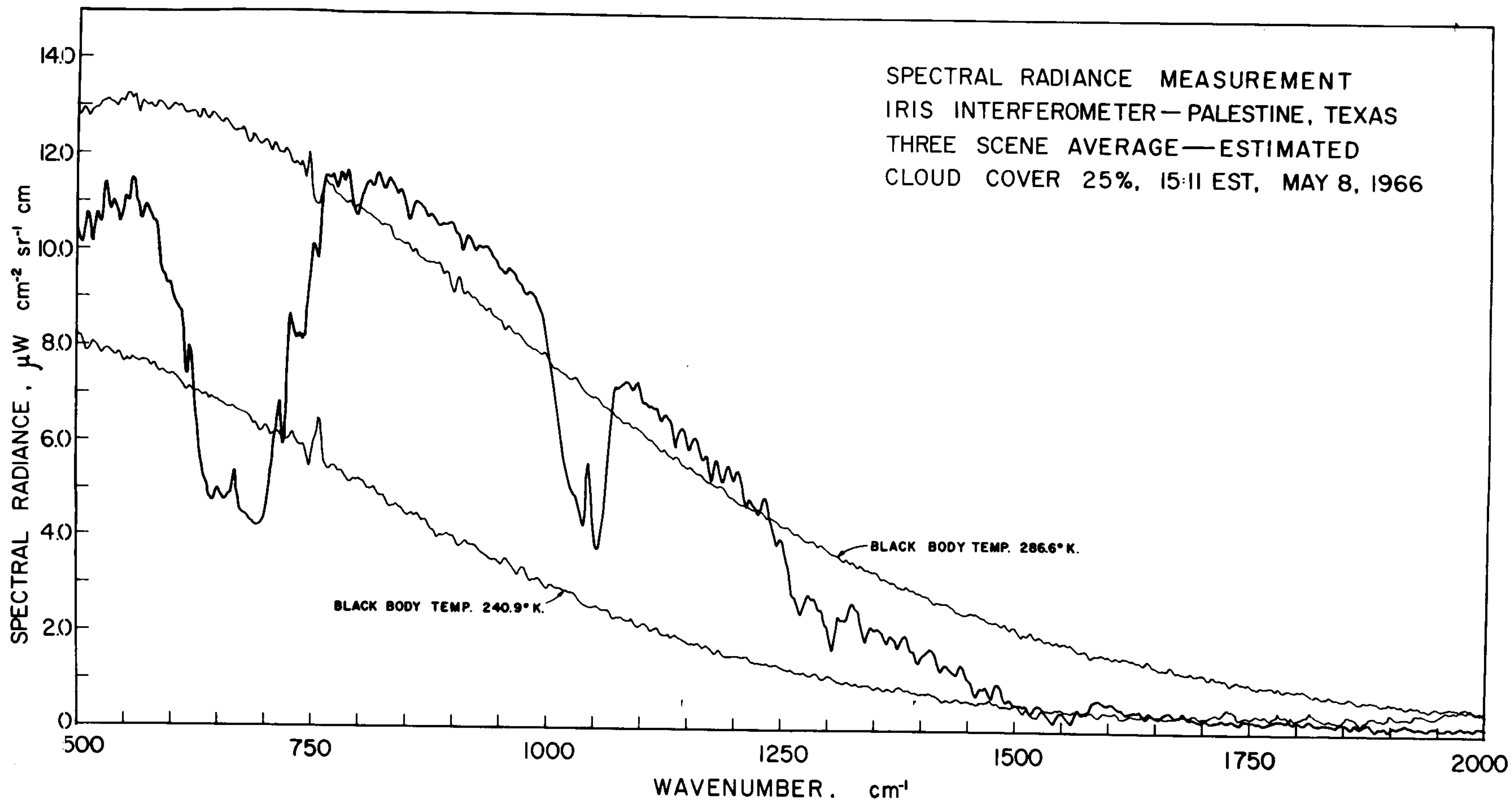



Figure 12 - Spectral data at 15:11 EST

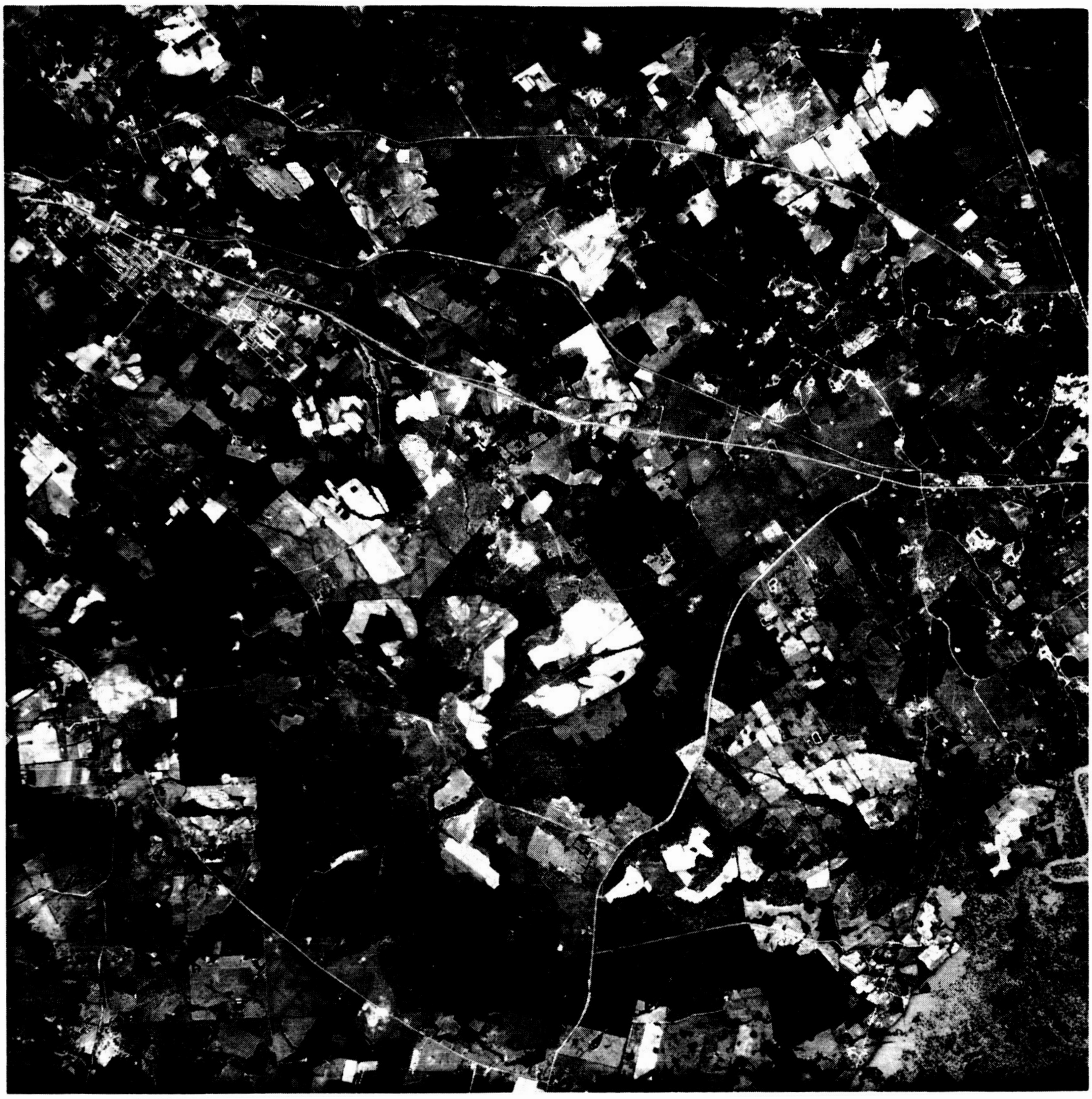


Figure 13 - Photograph of scene at 11:09 EST

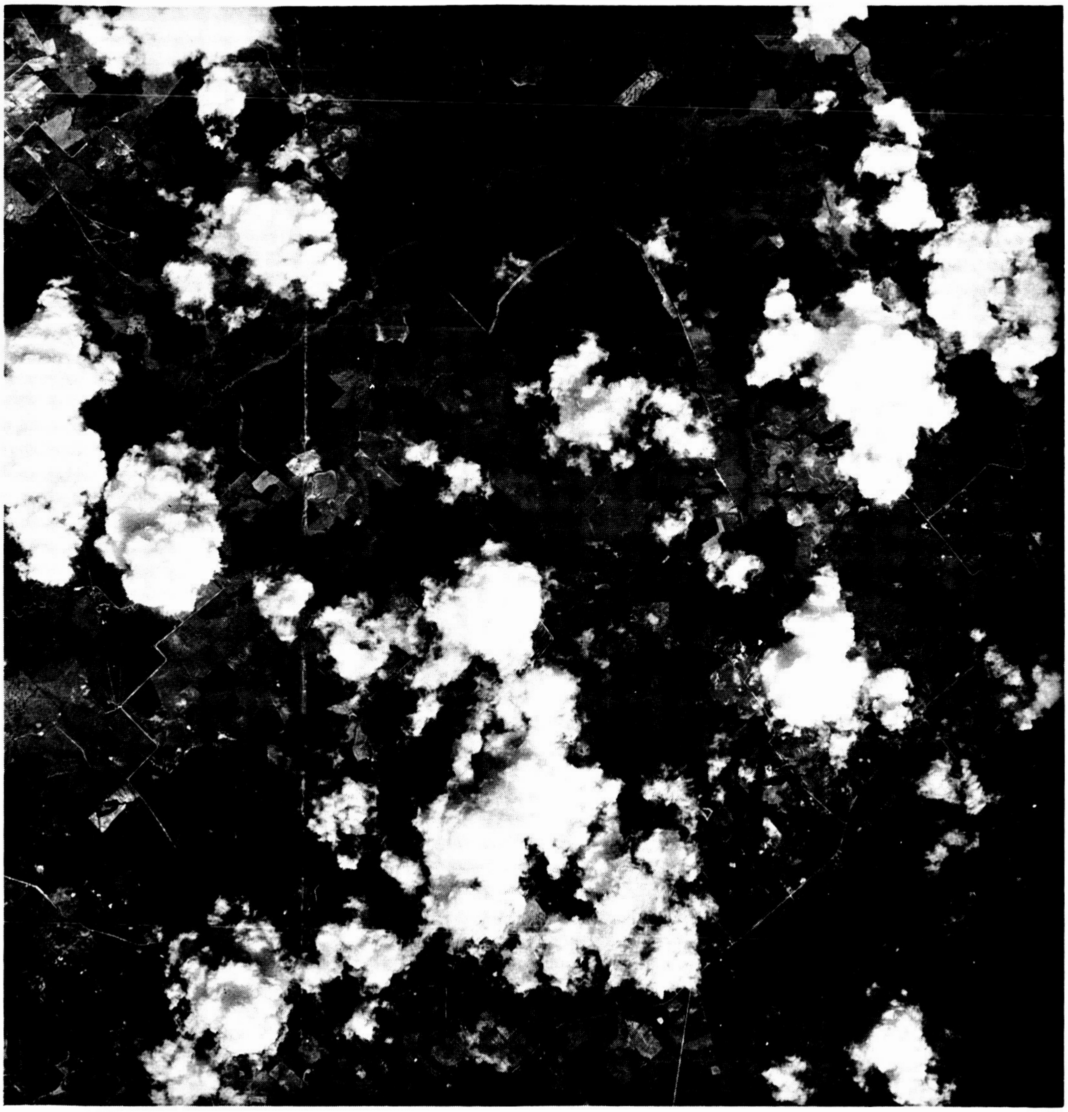
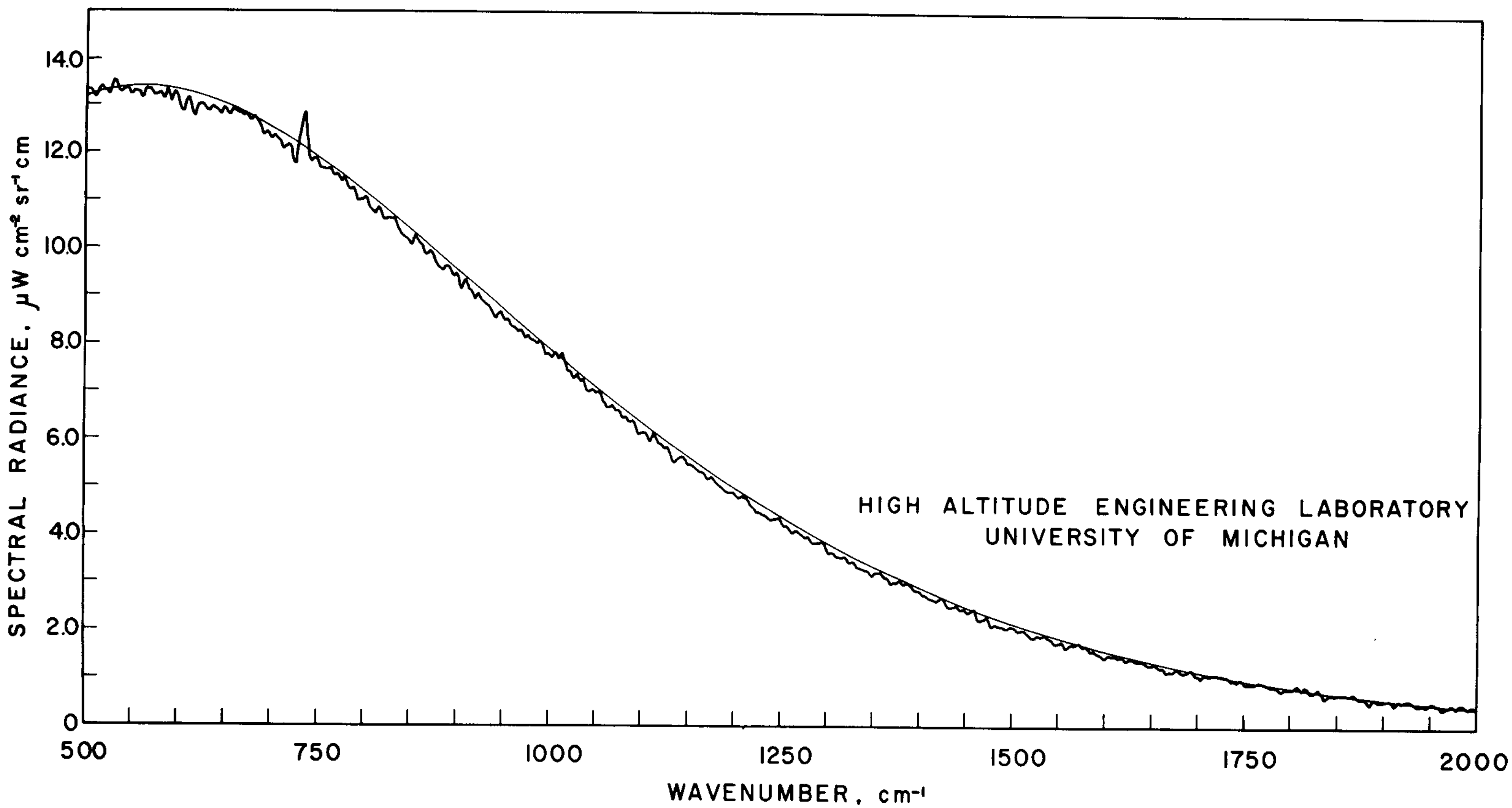


Figure 14 - Photograph of scene at 15:11 EST




Comparison of Fourier transform spectrometer single scan radiance measurement of 286.2°K calibration black body and theoretical radiance of 286.2°K black body.

Figure 15 - Black body spectrum

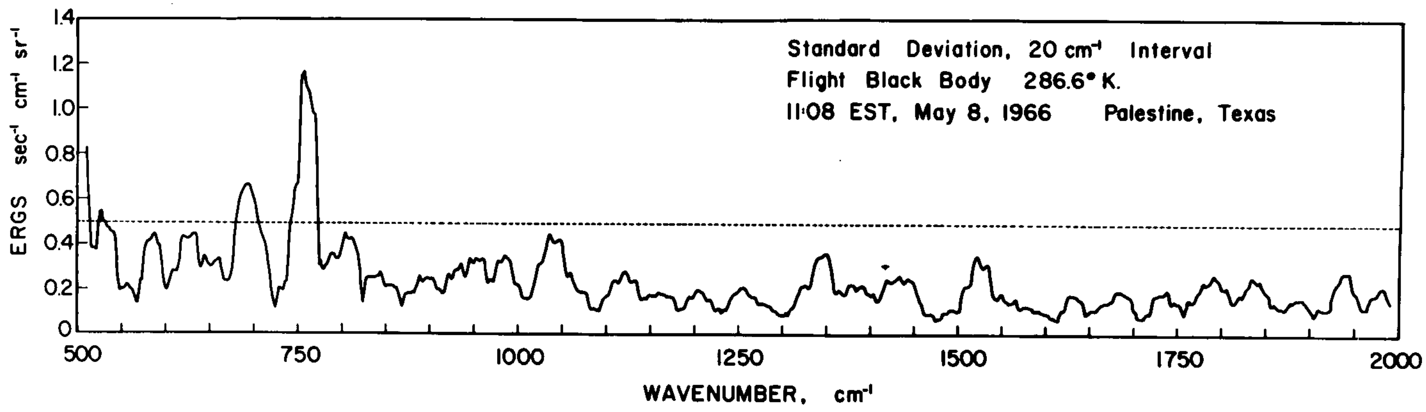



Figure 16 - Standard Deviation of black body data

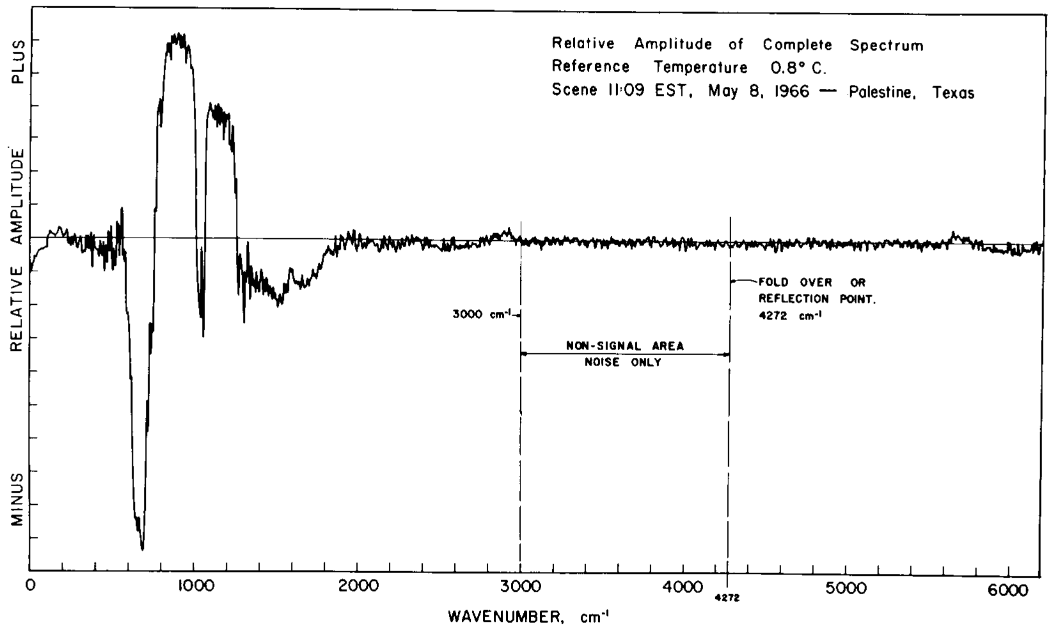
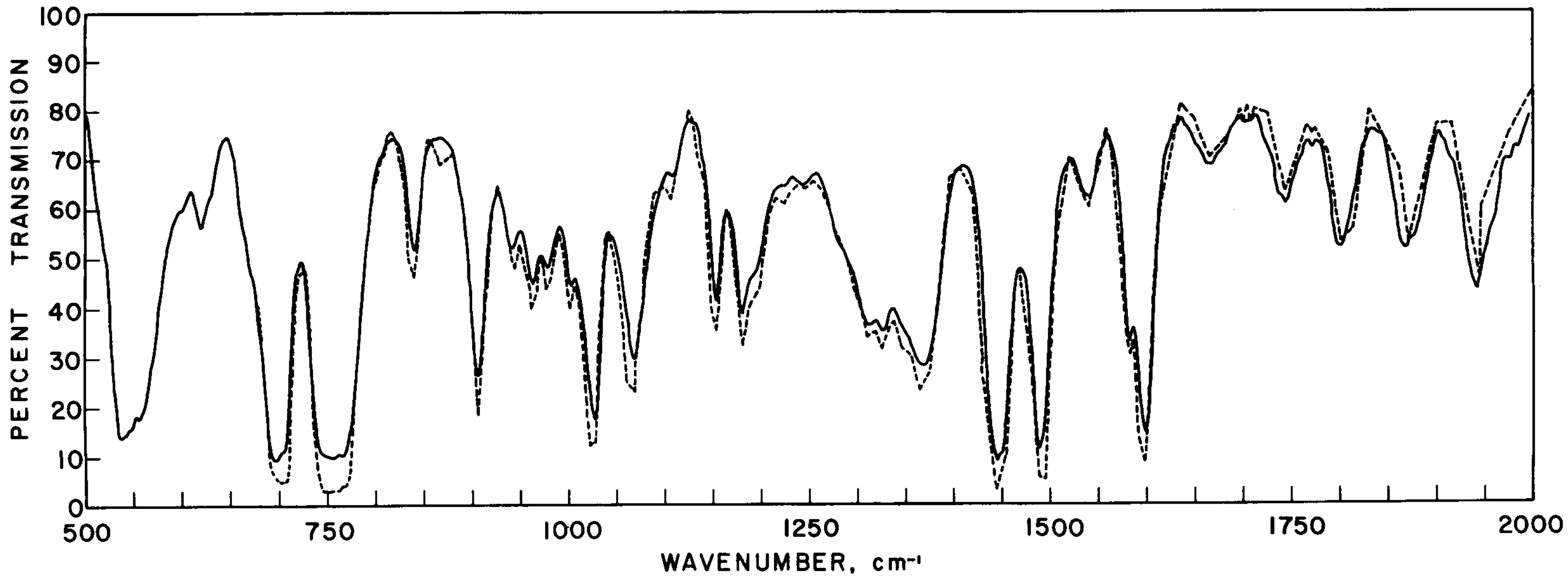
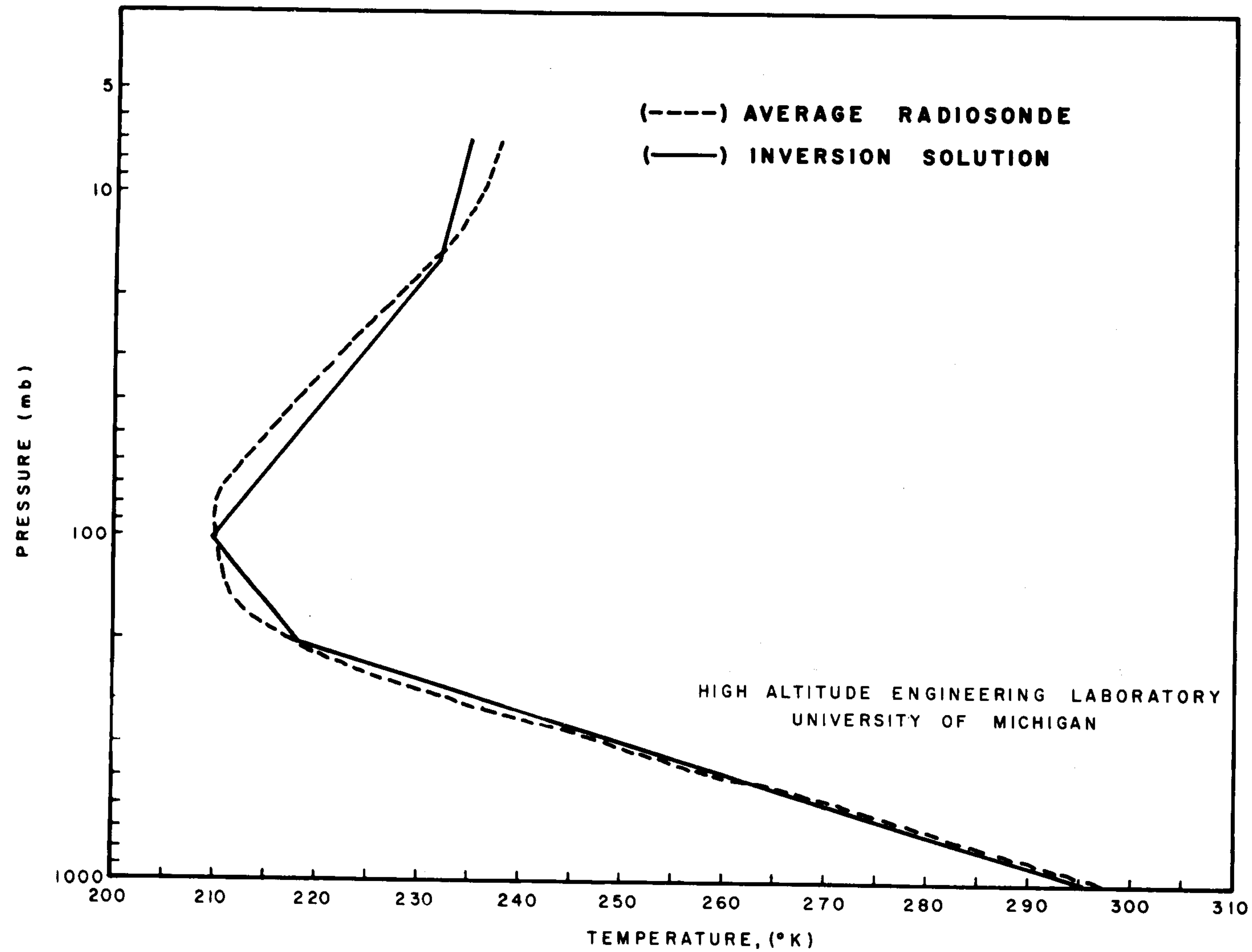



Figure 17 - Spectral data through the fold over region




Polystyrene percent transmission measurements. Perkin-Elmer model 13U at approx. 2 $cm^{-1}$ resolution and with Nernst glower (----). I.R.I.S. scientific breadboard with approx. 5 $cm^{-1}$ resolution and a blackbody source at 333° K. (——)

Figure 18 - Wavelength Calibration




Comparison of temperature profile by radiosonde measurements in Eastern Texas on May 8, 1966 and temperature profile obtained by the inversion of Fourier Transform Spectrometer data.

Figure 19 - Temperature inversion typical

APPENDIX IV

# FOURIER TRANSFORM SPECTROMETER — RADIATIVE MEASUREMENTS AND TEMPERATURE INVERSION

L. W. Chaney, S. R. Drayson, and C. Young

(a paper published in Applied Optics, February 1967)

As part of a program to develop improved meteorological satellite instrumentation, a Fourier transform spectrometer for radiation measurements has been developed in cooperation with Goddard Space Flight Center (Hanel and Chaney, 1964 and 1965). The purpose of the instrument is to measure the earth's thermal radiation in the spectral band from 500 to 2000 $cm^{-1}$ with a resolution of 5 $cm^{-1}$ and a radiance error not exceeding 0.5%.

The final version of the instrument is planned for a Nimbus satellite to be launched late in 1967. The breadboard version was flown on a high altitude balloon from Palestine, Texas, on May 8, 1966. The balloon was launched at 0553 CST and rose to a stable float altitude of 7 mb or 110,000 feet, which was reached at 0736 CST. The sky was perfectly clear at the time of launch and throughout most of the day. Scattered clouds appeared during the latter part of the afternoon. The balloon gradually drifted southwest and impacted 63 miles from the launch site near Easterly, Texas, at 1611 CST. The dry bulb air temperature at the time of launch was approximately 19$^{\circ}$C and increased to 29$^{\circ}$C by 1400 CST. The data from the initial portions of the balloon flight have been reduced to radiation measurements and are reported here.

The complete radiance spectrum is plotted in Figure 1. These are, to our knowledge, the highest resolution thermal radiation measurements in the 5 to 20$\mu$ spectral region which have been made from a high altitude balloon. Starting from 500 $cm^{-1}$ the following features of the spectrum can be observed:

| | |
|---|---|
| 500 - 600 $cm^{-1}$ | rotation water vapor |
| 600 - 750 $cm^{-1}$ | $CO_2$ |
| 800 - 950 $cm^{-1}$ | thermal window |
| 950 - 1050 $cm^{-1}$ | ozone |
| 1100 - 1250 $cm^{-1}$ | thermal window plus wings of water vapor |
| 1300 - 2000 $cm^{-1}$ | water vapor |

An absorption band is noted at 1306 $cm^{-1}$ which has tentatively been identified as $CH_4$.

In addition to developing the instrumentation for making the measurements, an extensive theoretical study of the carbon dioxide molecule to determine the transmissivity of the atmosphere in the 600-750 $cm^{-1}$ spectral region was carried out. By using the calculated $CO_2$ transmissivities and a temperature profile obtained by radiosonde data on the day of the flight, a calculated radiance curve extending from 600 to 750 $cm^{-1}$ was obtained. The effects of water vapor and ozone were neglected in the theoretical calculations.

The measured and calculated radiances are compared in Figure 2. The measured values are the average of three spectrometer scans of 10 seconds each, taken 15 seconds apart at 0730 CST just as the balloon reached float altitude. The agreement shown demonstrates the capability of the Fourier transform spectrometer to make the required radiance measurements as well as the reliability of the theoretical calculations.

The first application of the data has been to invert to an atmospheric temperature profile. The inversion method employed was to calculate the deviations from an initial guessed profile expressing the solution as a matrix equation (cf. Kaplan, 1961). The instabilities in the matrix inversion were suppressed using a truncated eigenvector expansion (Mateer, 1965). The results of a temperature inversion using the measured radiation and a monthly average profile as an initial guess is shown in Figure 3. The inversion profile is compared with a measured profile obtained from the average of the radiosondes flown in eastern Texas on the day of the flight. The agreement through the tropopause is very good, and the deviation above the tropopause is probably due to the higher radiance measured from 670 $cm^{-1}$ to 720 $cm^{-1}$ combined with the smaller radiance at the peak of the Q-branch. Although the results are still tentative, the agreement between theory and measurement is very encouraging. In fact, our confidence in the reliability of the data is based on the excellent agreement.

Thus far, the examination of the errors in the data have been confined to observing the deviations of measured black body spectra from the calculated radiation using Plank's equation and the measured black body temperature. A comparison for the two black bodies incorporated in the instrument was made. In each case the measured spectra represented the average of three 10-second scans. The least square error was calculated for each black body data set, and through most of the spectral range it is less than $0.3 \times 10^{-7}$ watt $cm^{-2}$ $sr^{-1}/cm^{-1}$. There is one bad spot in the data at 740 $cm^{-1}$ which can be atrributed to external vibration arising from some auxiliary instrumentation. The systematic error is probably due to inaccuracies in measuring the temperatures of the black bodies. The total error is less than 1 x $10^{-7}$ watt $cm^{-2}$ $sr^{-1}/cm^{-1}$.

The results obtained thus far indicate that the breadboard instrument matches the theoretical instrument performance within a factor of 2.

It is planned to continue development of both the instrument and the techniques for obtaining temperature profiles as well as the investigation of the ozone band.

This research was supported under contracts with the Laboratory for Atmospheric and Biological Sciences, NASA Goddard Space Flight Center and the National Environmental Satellite Center, ESSA.

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4. Drayson, S. R. and C. Young, Intensities of the Carbon Dioxide Bands in the 12 to 18-Micron Spectral Region, paper presented at Symposium on Molecular Structure and Spectroscopy, The Ohio State University, September 1966.

## LIST OF FIGURES

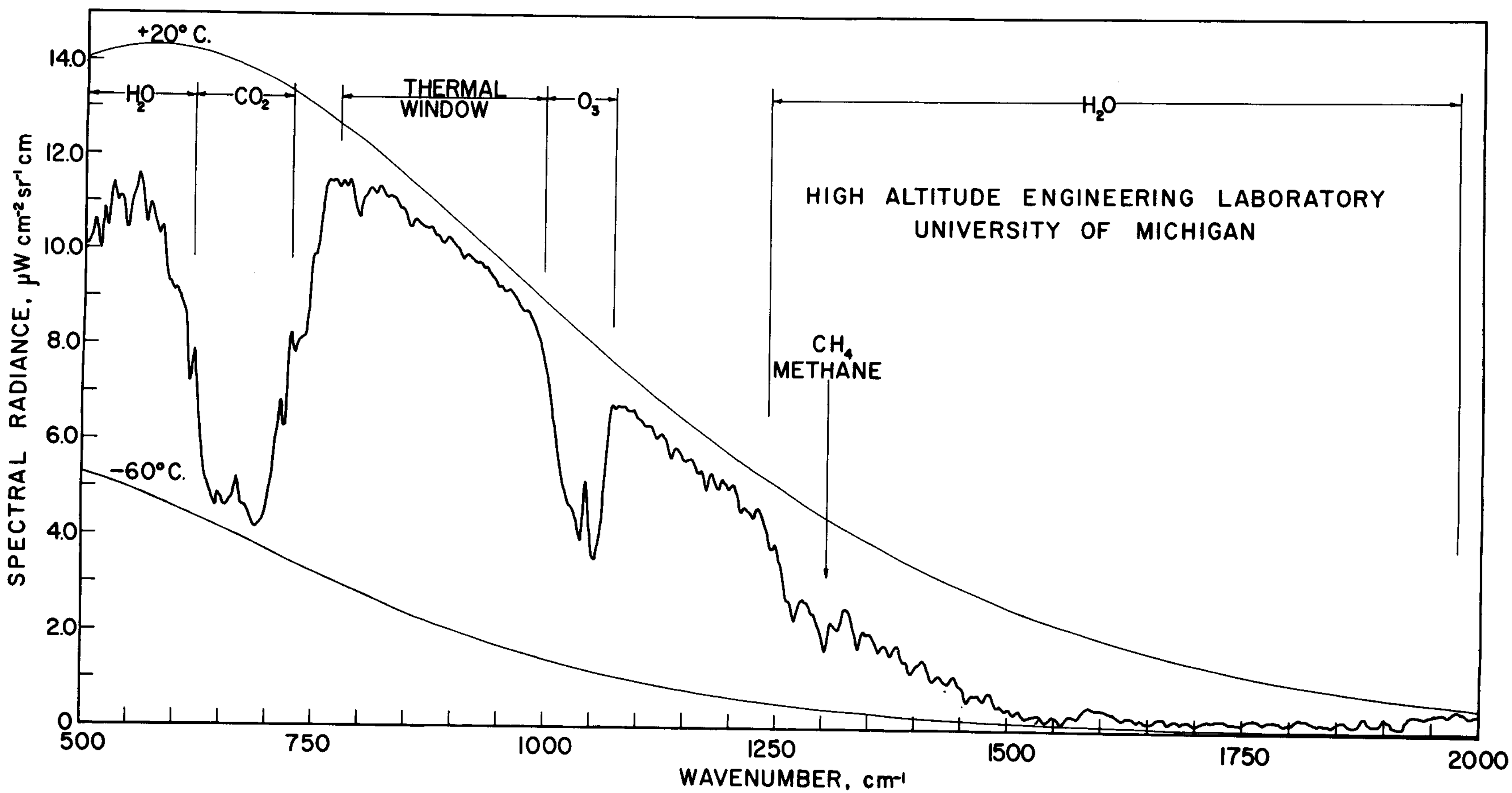
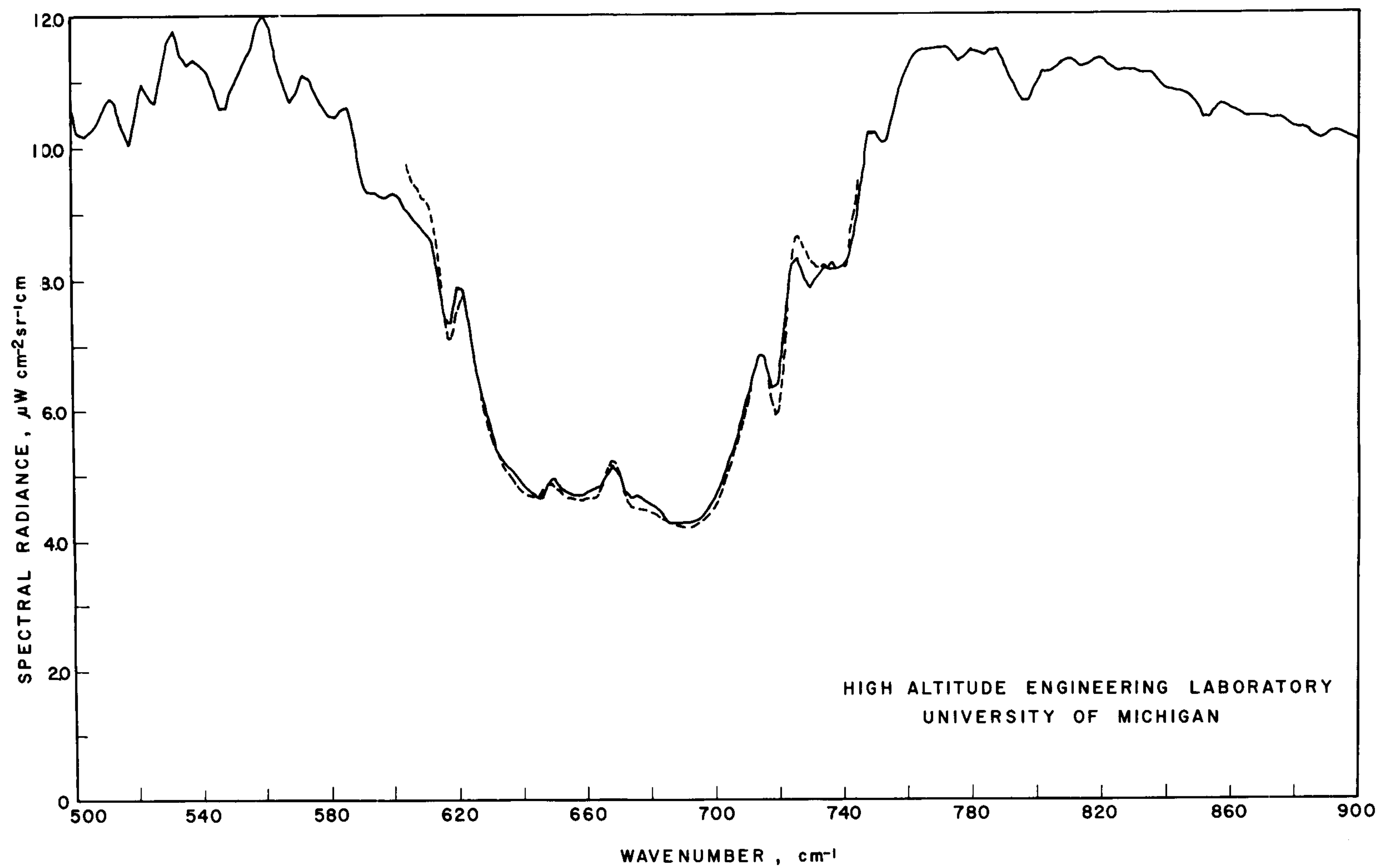



Fig. I. Balloon flight Fourier Transform Spectrometer radiance measurements May 8, 1966 07:30 CST Palestine, Texas. Altitude 33.5 KM. A four scan average.




Theoretical radiances calculated using transmissivities of Drayson & Young[3] (600–750 $cm^{-1}$), and an average radiosonde temperature profile for Eastern Texas on May 8, 1966 (----).

Balloon flight Fourier Transform Spectrometer radiance measurements May 8, 1966-07:30 CST Palestine, Texas. A three scan average (500–900 $cm^{-1}$) (——).

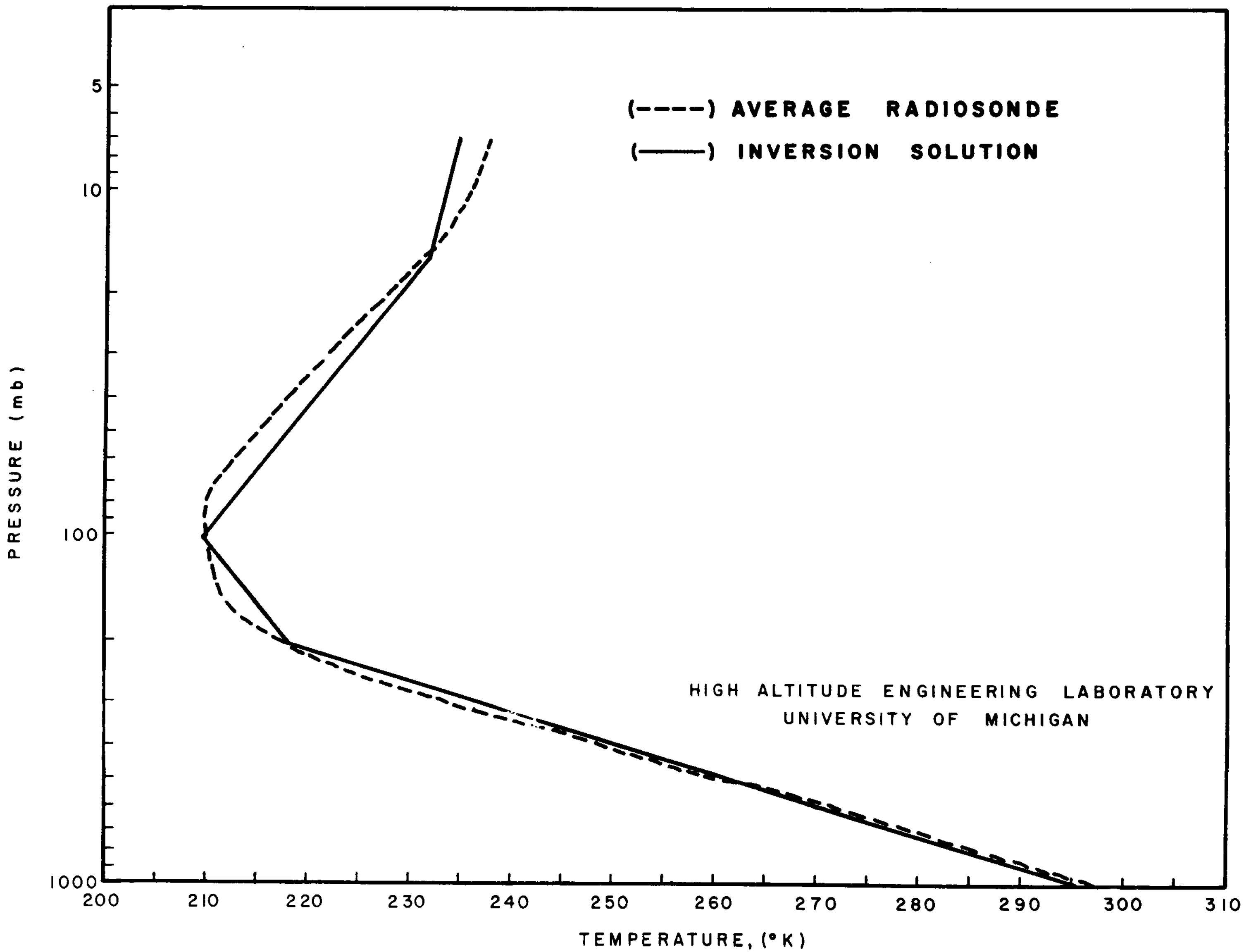



Fig. 3 Comparison of temperature profile by radiosonde measurements in Eastern Texas on May 8, 1966 and temperature profile obtained by the inversion of Fourier Transform Spectrometer data.