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

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ACKNOWLEDGEMENTS

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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 measure-

ment of the earth's thermal radiation from a satellite and the determination

of the temperature structure of the atmosphere. This report is a tabu-

lation 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.

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* 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) <u>Earth Radiation Measurements by Interferometer from a High Altitude Balloon</u> - 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 (5μ to 15μ) 50 cm^{-1}.

(2) <u>An Infrared Interferometer Spectrometer (IRIS) for Meteorological Studies</u> - 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) <u>The Measurement of the Earth's Thermal Radiation by a Fourier Transform Spectrometer</u> - 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) <u>Fourier Transform Spectrometer - Radiative Measurements and Temperature Inversion,</u> 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.

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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	110.5	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	105.9	105.5	107.1	106.9	108.5	105.7	105.5
548	104.1	107.1	108.5	106.0	108.2	107.0	108.6	106.5	106.4
550	107.4	110.0	114.6	109.2	111.4	109.1	110.2	107.8	108.7
552	108.9	113.2	113.7	113.0	117.3	114.2	111.8	114.3	111.0
554	110.2	114.1	115.0	113.2	114.6	114.4	111.0	114.4	110.4
556	112.3	115.3	120.2	114.5	118.2	114.9	113.4	114.6	109.9
558	114.0	119.8	121.3	120.8	121.1	119.9	118.3	119.8	113.9
560	114.9	120.1	118.0	121.5	121.6	120.8	119.2	119.9	114.9
562	114.4	114.9	111.9	114.9	119.2	118.5	116.8	115.0	114.4
564	111.7	112.0	108.6	110.2	114.6	114.1	110.8	110.6	109.9
566	108.7	109.0	105.4	108.5	110.7	109.8	109.9	107.7	109.5
568	105.5	105.0	106.8	105.7	107.6	107.4	107.6	106.5	106.2
570	107.0	106.8	109.3	107.3	109.2	108.8	107.9	107.9	106.5
572	109.7	110.3	108.8	109.8	111.2	110.9	110.0	111.5	108.8
574	109.2	109.9	107.7	110.0	111.9	110.5	110.2	109.6	109.4
576	106.5	107.7	107.5	107.7	110.0	108.4	108.9	108.6	108.3
578	104.8	107.0	106.1	105.9	109.1	107.6	108.2	107.9	107.5
580	103.4	106.2	104.7	104.8	108.4	106.3	108.2	107.4	106.2
582	103.0	105.7	105.8	104.9	108.1	106.3	106.2	107.4	105.6
584	104.5	106.6	105.9	106.0	108.4	107.0	106.1	108.0	105.8
586	104.8	105.8	100.8	105.8	107.0	107.1	104.4	106.7	104.7
588	100.6	101.5	95.9	101.3	101.8	102.1	99.8	102.0	100.6
590	95.2	96.8	95.2	95.4	96.3	96.5	95.9	97.2	96.1
592	93.7	95.1	95.1	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

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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	91.6	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	78.1	78.9	79.1	79.8	79.3	79.9
622	79.3	78.1	81.4	78.7	79.3	78.8	78.8	80.5	79.3
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	48.0	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	45.5	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	44.8	44.3	46.3	45.4	45.7	46.0	46.0
684	43.3	43.8	43.7	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	44.6	43.4	43.5	43.0	43.2	43.6	43.4
690	42.0	43.0	44.7	43.6	43.4	43.0	43.7	43.6	43.5
692	42.3	43.0	44.6	42.8	43.5	42.5	43.8	43.1	43.5
694	42.4	42.8	45.4	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	102.4	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	112.7	114.7	117.3	122.1	113.6	117.0	108.5
762	113.2	115.4	117.4	116.8	116.7	122.3	113.5	117.6	114.0
764	114.5	116.7	119.4	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	114.3	116.2	119.1	121.6	123.9	120.4	114.0	120.1	115.2
770	114.6	116.1	119.7	121.5	123.9	123.0	115.2	119.6	115.8
772	113.9	117.1	120.7	122.4	124.9	126.2	116.9	120.5	114.6
774	113.6	116.3	119.4	121.0	123.4	125.2	116.1	119.6	112.9
776	113.6	114.3	117.1	118.5	120.4	122.0	114.3	117.5	114.0
778	114.2	114.3	117.2	118.9	120.6	122.1	114.2	118.0	116.3
780	113.6	115.9	119.0	121.4	123.6	125.0	115.7	120.4	116.0
782	113.1	115.7	119.2	121.6	124.2	125.3	115.9	120.6	114.4
784	114.1	114.4	118.2	120.1	122.5	123.1	114.9	119.1	115.5
786	114.7	115.5	119.6	121.1	124.1	123.9	115.8	120.0	116.8
788	112.6	116.6	121.3	123.1	127.0	126.2	117.0	121.8	114.3
790	110.1	114.6	118.7	121.0	124.7	123.7	114.7	119.8	111.1
792	108.9	111.6	114.4	117.2	119.8	119.0	111.6	116.1	109.3
794	107.4	109.8	112.4	114.5	116.4	116.1	110.0	113.7	107.4
796	107.0	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

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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	108.0	111.2	115.8	118.9	122.8	122.4	112.5	118.6	112.8
846	108.0	111.1	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	119.2	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	107.7	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	107.4	110.6	111.2	102.2	107.4	100.1
912	98.7	101.2	104.5	108.4	111.9	112.4	102.6	107.8	102.2
914	99.3	101.2	104.6	108.6	112.7	112.5	102.6	108.6	103.2
916	99.0	101.2	104.8	107.3	112.1	112.2	102.7	108.8	102.8
918	98.4	100.9	104.1	106.1	110.9	111.6	102.3	108.0	101.8
920	97.8	100.2	102.9	105.7	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	105.4	109.6	109.0	100.9	105.4	100.2
926	97.3	99.0	102.5	104.8	109.6	109.9	100.0	105.9	101.0
928	97.2	99.2	102.4	104.7	109.1	111.0	100.0	106.0	101.0
930	96.5	99.1	102.5	105.0	108.8	111.1	100.7	106.1	100.6
932	95.9	98.9	102.2	105.5	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	105.5	109.2	110.1	100.5	105.9	100.4
938	95.1	97.1	101.4	104.3	108.7	109.6	100.3	105.6	99.7
940	94.4	96.7	100.9	103.2	107.9	108.5	99.6	105.0	98.8
942	94.3	96.3	100.6	101.9	107.9	108.2	99.5	104.8	98.4
944	93.7	95.9	99.8	100.3	106.5	107.6	98.7	103.5	97.8
946	92.8	95.0	98.3	99.2	104.5	106.4	97.3	101.6	96.8
948	92.3	94.1	97.2	99.9	103.6	105.5	96.3	100.8	96.1
950	92.6	94.3	97.4	100.0	104.4	105.6	96.0	101.4	96.2
952	92.1	94.2	97.3	100.4	104.4	105.3	95.6	101.3	95.6
954	91.1	93.6	96.8	100.5	103.6	104.7	95.4	100.8	95.0
956	91.1	93.4	97.2	100.3	103.5	105.1	95.8	101.3	95.7
958	91.6	93.6	97.6	99.8	103.9	105.6	96.5	102.1	96.3
960	91.3	93.3	97.1	99.6	103.7	105.2	96.5	102.0	95.9
962	91.2	92.5	97.1	99.1	103.7	104.7	95.9	101.7	95.4
964	90.9	92.0	96.4	98.5	103.0	104.2	95.0	100.9	94.8
966	90.3	91.8	95.3	98.2	102.1	103.5	94.4	100.1	93.8
968	89.9	91.4	95.8	96.9	101.7	103.1	94.3	99.8	93.4
970	89.1	90.7	95.6	95.3	100.8	102.1	93.4	98.4	92.9
972	88.1	90.1	93.7	94.7	99.5	101.0	92.1	96.7	92.1
974	87.3	89.3	92.8	94.5	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	94.0	98.5	100.1	91.2	96.6	90.9
980	86.9	88.4	92.2	93.5	98.8	100.7	91.5	96.9	91.5
982	86.2	88.4	92.9	93.2	98.4	100.4	91.3	96.2	91.3
984	85.1	87.5	93.0	92.5	97.8	99.5	90.5	95.2	90.6
986	84.4	86.9	92.4	91.5	97.4	99.1	89.5	94.5	90.2
988	83.9	86.0	91.2	90.4	96.4	98.4	88.7	93.4	89.1
990	82.9	85.1	89.7	88.8	95.2	97.1	88.1	92.4	87.8
992	81.6	84.1	88.1	86.6	93.8	95.4	87.0	90.9	86.9
994	80.3	82.9	86.7	84.1	92.5	93.7	85.6	89.1	85.9
996	78.7	81.2	84.8	82.6	90.4	91.9	84.2	87.7	84.1
998	76.8	79.2	82.3	80.1	87.4	89.4	81.9	86.1	81.4

SPECTRAL RADIANCE IN ERGS/SEC CM STR

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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	48.2	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	66.0	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	78.1	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

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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	64.0	67.7	70.6	73.2	74.9	67.9	71.5	68.4
1106	63.5	63.6	67.5	69.5	72.6	73.9	67.2	70.9	67.7
1108	63.0	63.7	67.3	69.0	72.3	73.9	67.1	71.1	67.3
1110	62.9	63.5	67.3	69.4	72.6	74.3	67.5	71.7	67.7
1112	62.9	63.8	66.5	69.4	72.7	73.8	67.2	71.4	67.3
1114	63.0	64.1	66.6	69.6	72.7	74.1	66.9	71.3	67.0
1116	62.6	62.9	66.6	69.4	72.5	74.3	66.9	71.4	67.2
1118	61.1	61.6	65.7	67.7	70.6	72.3	65.8	69.6	66.0
1120	60.4	61.5	64.4	66.6	68.9	70.9	64.3	67.8	64.5
1122	60.8	62.1	63.8	66.9	69.0	71.4	64.1	67.7	64.4
1124	61.6	62.2	64.5	67.7	70.6	72.7	65.4	69.0	65.5
1126	61.4	61.2	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	60.0	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	59.4	62.1	65.5	67.5	69.4	62.5	65.6	62.6
1142	58.1	59.2	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	55.4	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	58.5	60.5	62.2	56.8	60.0	56.7
1166	53.2	54.3	56.8	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	54.2	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

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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	38.1	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	23.8
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	23.7	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

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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	19.6	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	18.1	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	16.4	15.9	15.4	15.0	16.5	16.6	17.2	16.4
1390	14.5	15.4	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

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	15.1	15.3	15.6	15.7	15.7	16.6	16.0
1406	14.2	14.8	15.3	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	14.9	15.5	15.1	16.7	16.9	17.4	16.7
1412	14.2	14.5	14.2	15.0	14.0	16.2	16.1	16.6	16.3
1414	13.3	13.8	12.7	14.5	12.9	15.3	14.9	15.8	15.6
1416	11.7	12.3	11.0	13.2	11.5	13.8	12.8	14.1	13.9
1418	10.4	10.9	10.7	11.6	11.0	12.1	10.9	12.5	12.3
1420	10.3	10.6	11.2	11.4	11.2	11.4	10.6	12.2	12.1
1422	10.7	11.2	12.0	11.9	11.6	12.0	11.4	12.7	12.7
1424	11.2	11.8	12.4	12.5	11.9	12.9	12.5	13.4	13.4
1426	11.7	12.0	12.3	12.8	11.9	12.9	13.2	13.8	13.6
1428	11.6	11.9	11.8	12.6	11.7	12.3	13.0	13.6	13.2
1430	10.9	11.4	11.6	11.8	11.3	11.9	12.2	13.0	12.5
1432	10.4	11.0	11.1	11.4	11.4	11.6	11.8	12.6	12.3
1434	10.1	10.6	10.7	11.2	11.2	11.0	11.3	12.1	11.8
1436	9.9	10.4	11.0	10.8	10.6	11.0	10.9	11.7	11.4
1438	10.1	11.0	12.1	11.3	10.9	11.7	11.6	12.3	11.9
1440	10.9	12.2	12.6	12.7	12.3	13.1	12.8	13.5	13.1
1442	11.4	12.4	12.3	13.3	13.0	13.8	13.2	13.9	13.7
1444	11.2	11.8	11.4	12.7	12.4	13.5	12.8	13.3	13.4
1446	10.3	11.0	10.4	11.6	11.3	12.4	11.7	12.1	12.1
1448	9.5	10.3	9.4	10.7	10.7	11.2	10.8	11.1	10.8
1450	9.1	9.6	8.9	10.2	10.2	10.7	10.5	10.5	10.4
1452	8.7	9.1	8.2	9.7	9.4	10.3	10.2	9.9	10.1
1454	7.5	8.3	6.8	8.8	8.2	9.2	8.8	8.8	8.9
1456	6.2	6.9	6.8	7.6	6.8	7.8	6.8	7.1	7.5
1458	6.2	6.4	8.0	7.2	6.6	7.6	6.4	6.9	7.0
1460	7.2	7.2	8.9	8.3	7.9	8.5	7.7	8.2	7.9
1462	7.7	7.8	8.7	9.2	8.9	9.2	8.8	8.9	8.7
1464	7.3	7.5	8.4	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	7.9	9.0	8.8	9.1	8.6	9.4	9.1
1470	7.0	7.6	7.1	8.3	8.0	8.7	8.1	8.5	8.2
1472	6.4	6.7	6.8	7.2	7.0	7.9	7.1	7.4	7.2
1474	6.2	6.3	7.6	6.9	6.7	7.5	6.8	6.9	6.8
1476	6.6	6.9	8.7	7.8	7.4	8.1	7.7	7.8	7.4
1478	7.4	8.1	8.8	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	6.6	5.7	5.9	6.3	5.7	5.8
1492	5.2	6.4	6.3	6.5	6.2	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	4.3	3.9	3.8	3.4	3.7	3.5	3.8
1508	3.3	3.7	5.0	3.4	3.8	3.8	3.3	3.2	3.5
1510	4.0	4.5	5.1	3.7	4.4	4.5	4.3	3.8	3.9
1512	4.4	5.0	5.0	4.0	4.2	4.3	5.3	4.1	4.4
1514	4.0	4.9	4.6	3.7	3.3	3.6	5.6	3.4	4.2
1516	3.2	4.3	3.9	3.4	2.5	2.7	4.7	2.7	3.2
1518	2.6	3.6	3.0	3.3	2.2	2.6	3.6	2.4	2.9
1520	2.6	3.3	2.7	3.4	2.2	2.9	3.4	1.9	3.0
1522	2.8	3.5	3.1	3.5	2.7	2.5	3.9	2.1	2.7
1524	2.8	3.9	3.7	3.6	2.9	3.0	4.4	2.8	3.0
1526	2.8	3.9	3.9	3.6	3.0	4.0	4.6	2.8	3.8
1528	3.1	4.3	4.1	3.3	3.3	3.0	4.7	3.1	4.4
1530	3.2	4.3	4.1	2.8	3.6	2.2	4.2	3.1	4.3
1532	3.2	4.3	3.1	2.6	3.5	3.0	3.6	2.7	3.8
1534	3.1	3.3	2.4	2.4	3.4	2.2	3.2	2.4	3.0
1536	2.8	2.9	2.1	1.8	2.8	2.0	2.6	1.9	2.6
1538	2.4	2.3	2.1	1.4	1.8	1.7	2.2	1.4	2.1
1540	2.1	2.3	2.6	1.9	2.1	1.3	2.8	1.6	1.6
1542	2.1	2.3	3.2	2.7	2.8	1.5	2.9	2.4	2.1
1544	2.2	3.0	4.1	3.5	3.6	1.8	4.9	3.4	2.9
1546	2.7	3.6	4.4	3.8	4.0	2.6	5.0	3.7	3.6
1548	3.0	3.6	3.8	3.6	4.0	3.1	4.6	3.2	3.8
1550	2.9	3.8	3.7	3.3	3.7	3.1	4.3	2.6	3.5
1552	2.7	3.4	3.7	2.8	3.3	2.9	3.8	2.0	3.2
1554	2.5	3.0	3.3	2.1	2.5	2.6	3.0	1.3	2.9
1556	1.7	2.3	2.7	1.8	2.1	2.2	2.7	.8	2.2
1558	1.2	1.9	2.1	2.1	2.1	1.8	3.4	1.5	1.5
1560	1.6	2.4	2.6	2.1	2.5	1.9	4.4	2.8	1.8
1562	2.6	3.3	3.3	2.8	3.4	2.5	5.1	3.6	3.0
1564	3.4	3.9	3.9	3.4	3.9	3.2	5.0	3.6	4.1
1566	3.5	4.1	3.7	3.6	3.8	3.6	4.4	3.3	4.5
1568	3.1	4.1	3.7	3.3	3.5	3.4	4.1	3.3	4.0
1570	2.9	4.1	3.7	3.1	3.7	3.5	4.3	3.4	3.6
1572	2.9	3.5	3.3	3.2	3.9	3.7	4.5	3.2	3.7
1574	2.7	4.1	3.3	3.4	3.4	3.5	4.5	3.2	3.6
1576	2.8	3.5	3.3	3.5	3.4	3.4	5.0	4.0	3.5
1578	3.6	4.1	3.8	3.9	4.0	4.0	5.9	5.1	4.3
1580	4.2	5.0	4.6	4.5	5.0	5.0	6.5	5.7	5.5
1582	4.4	5.4	5.2	4.9	5.5	5.9	7.3	6.3	6.0
1584	4.7	5.5	5.4	4.9	5.6	6.0	7.4	6.3	6.2
1586	5.1	5.7	5.8	4.8	5.9	5.8	7.1	6.0	6.3
1588	5.2	5.9	5.8	4.6	6.0	5.9	6.6	5.7	6.0
1590	4.9	5.7	5.5	4.7	5.7	6.0	6.4	5.6	5.7
1592	4.6	5.1	5.6	4.8	5.4	5.6	6.6	5.6	5.6
1594	4.5	4.9	5.3	4.9	5.2	5.6	6.4	5.7	5.4
1596	4.5	5.0	5.1	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

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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	4.5	5.5	4.7	4.4
1614	3.3	4.0	3.8	3.0	4.0	3.8	5.2	4.0	4.0
1616	3.0	3.5	3.2	2.6	3.7	3.6	4.2	3.9	3.6
1618	2.8	3.4	3.4	2.8	3.6	4.0	4.0	3.7	3.5
1620	2.6	3.5	3.4	2.9	3.7	3.5	4.8	3.5	3.8
1622	2.3	3.6	3.7	3.2	3.7	3.9	5.1	3.3	3.8
1624	2.6	3.7	3.9	3.4	3.7	4.6	4.6	3.5	3.8
1626	3.1	3.9	3.7	3.0	3.9	4.6	4.8	4.4	3.8
1628	3.2	4.0	3.8	2.8	4.0	4.6	4.9	4.8	4.0
1630	3.2	3.9	3.6	2.9	4.0	4.4	4.5	4.7	4.1
1632	3.1	3.8	4.0	3.4	4.2	4.4	3.8	3.7	3.7
1634	2.8	3.4	3.4	2.8	3.8	4.0	3.3	3.3	3.0
1636	2.3	2.7	2.6	2.4	3.1	3.4	3.5	3.7	3.1
1638	2.3	2.7	2.8	2.1	3.7	3.0	4.4	4.6	3.8
1640	2.8	3.1	3.6	2.6	3.1	3.4	4.9	4.2	4.0
1642	2.5	3.2	3.4	2.6	3.7	4.0	4.4	3.6	3.8
1644	2.2	2.9	3.0	1.9	3.1	4.1	3.6	3.2	3.4
1646	2.1	2.6	2.9	1.8	2.7	3.8	3.1	3.6	3.1
1648	2.1	2.4	2.8	2.1	2.7	3.6	3.0	3.2	3.0
1650	2.1	2.3	2.5	2.3	3.0	3.3	3.1	3.6	3.0
1652	2.0	2.0	2.6	2.6	3.0	3.2	3.6	3.7	2.9
1654	2.3	2.2	2.6	3.0	3.0	3.4	4.3	4.2	2.8
1656	2.8	2.9	3.2	3.4	3.7	4.0	4.7	4.8	3.1
1658	2.9	3.6	3.9	3.8	3.6	4.9	4.6	4.6	3.6
1660	2.8	3.6	4.1	3.7	3.4	5.1	4.7	4.1	3.9
1662	3.0	3.6	4.0	3.3	3.7	4.6	4.6	4.4	3.9
1664	3.1	3.5	4.1	3.2	3.9	4.5	4.7	4.1	4.0
1666	2.7	3.1	3.9	3.0	3.7	4.8	4.6	4.0	3.9
1668	1.9	2.7	3.3	2.7	3.5	4.5	3.9	3.6	3.4
1670	1.7	2.7	2.9	2.4	3.5	3.8	3.3	3.8	3.0
1672	2.2	2.9	3.0	2.3	3.7	3.7	3.5	4.1	3.0
1674	2.4	3.0	3.5	2.6	3.7	4.2	4.2	4.5	3.3
1676	2.6	3.1	3.7	3.0	4.0	4.7	4.3	4.4	3.9
1678	2.6	2.7	3.4	2.9	3.9	4.9	4.0	3.9	4.0
1680	2.3	2.4	3.1	2.5	3.4	4.7	3.5	3.7	2.6
1682	2.1	2.5	3.0	2.0	3.2	3.8	3.4	4.2	3.1
1684	1.9	2.9	2.9	2.3	3.6	4.0	3.6	4.5	3.5
1686	2.6	3.0	3.4	3.0	3.7	4.4	3.9	4.4	3.5
1688	2.8	3.1	3.9	3.2	3.9	4.6	4.0	3.9	3.2
1690	2.6	2.7	3.3	3.2	4.2	5.6	3.6	4.2	2.7
1692	2.3	2.6	3.3	2.8	4.1	4.2	3.4	4.5	3.1
1694	2.3	2.3	3.3	2.3	3.5	4.2	3.6	4.3	3.5
1696	1.9	2.2	2.9	2.3	3.2	3.6	2.7	4.1	3.2
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	2.7	5.1	5.8	3.3	4.3	3.0
1746	1.7	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	2.7	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	3.4	4.7	5.2	4.4	3.5	3.3
1788	2.8	3.0	3.3	3.2	4.6	4.6	3.7	3.3	3.4
1790	2.4	2.5	2.5	2.8	3.2	3.8	2.9	3.1	3.0
1792	1.9	2.0	2.0	2.8	2.5	2.7	2.3	2.6	2.5
1794	1.9	2.2	2.4	3.0	2.6	3.0	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	10 10	11 09	12 34	13 31	14 12	14 48	15 11
1800	2.0	2.6	2.7	2.6	3.1	3.3	4.1	3.4	2.5	2.7
1802	2.1	2.6	2.7	2.6	3.4	3.2	3.7	3.0	2.5	2.8
1804	2.5	2.9	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	3.2	3.5	4.3	3.4	3.8	3.2
1808	3.1	3.2	4.1	2.8	3.0	3.4	4.0	3.5	2.7	3.2
1810	3.5	2.7	4.2	3.5	3.2	3.2	3.5	3.2	3.7	3.2
1812	2.9	3.2	4.3	3.5	3.7	3.4	3.4	3.3	3.2	3.7
1814	3.1	3.4	3.5	3.4	3.8	3.3	3.8	3.6	3.2	4.3
1816	3.1	3.7	3.5	3.3	3.5	3.0	4.0	3.6	3.0	3.8
1818	2.8	3.3	3.3	3.3	3.1	2.6	3.9	3.4	2.8	3.4
1820	2.7	2.7	3.2	2.7	2.8	2.4	4.0	3.4	2.7	3.2
1822	2.4	2.4	3.1	2.4	2.9	2.4	3.5	2.7	2.5	3.1
1824	2.1	2.4	2.9	2.4	2.6	2.5	3.2	2.3	2.3	2.9
1826	2.0	2.2	2.7	2.2	2.4	2.3	3.3	2.6	2.4	2.7
1828	1.9	2.0	2.7	2.0	2.3	2.1	3.4	2.9	2.6	2.4
1830	1.9	2.0	2.6	2.3	2.2	3.0	2.8	2.8	3.3	2.3
1832	2.1	2.3	2.6	2.8	2.2	4.1	3.6	2.8	3.3	2.4
1834	1.8	2.8	2.5	2.3	2.1	4.2	4.0	3.0	2.8	2.7
1836	2.0	2.3	2.2	2.0	2.0	3.5	2.8	2.5	1.8	2.2
1838	2.0	2.0	2.1	1.7	1.6	3.1	3.0	2.1	1.8	2.4
1840	1.6	1.7	2.1	1.4	1.4	2.8	3.1	2.5	1.6	2.1
1842	1.4	1.4	1.9	2.1	1.7	2.9	3.0	2.8	1.3	1.9
1844	1.6	1.4	1.9	2.4	2.2	3.3	2.5	3.1	1.9	2.2
1846	2.1	2.1	2.3	2.8	2.2	3.6	2.9	3.1	2.3	2.7
1848	2.6	2.4	2.5	2.6	2.1	4.5	2.8	3.0	2.5	3.4
1850	2.8	2.4	2.7	2.4	2.8	3.9	2.5	3.1	2.1	3.2
1852	2.7	2.8	3.0	2.6	3.0	3.2	2.9	3.0	1.9	3.1
1854	2.8	2.6	3.2	2.6	3.1	3.0	2.8	3.1	2.0	3.1
1856	2.7	2.4	3.2	2.7	2.8	3.4	2.5	2.8	1.7	2.2
1858	1.9	2.6	3.2	2.2	2.5	3.7	2.6	2.6	1.5	2.1
1860	1.8	2.7	3.1	2.9	2.2	4.1	2.3	2.8	2.0	2.8
1862	1.8	2.7	3.2	3.1	2.5	3.1	3.4	2.6	1.7	2.2
1864	1.5	2.2	3.1	3.1	2.2	2.5	2.6	2.3	1.5	1.5
1866	1.9	1.7	3.1	2.6	1.5	1.7	2.9	2.6	1.5	1.6
1868	1.9	2.0	3.2	2.6	.9	2.2	2.9	1.7	1.4	2.1
1870	1.8	2.1	3.4	3.1	1.1	2.2	3.5	2.9	1.8	2.4
1872	2.1	2.9	4.0	2.8	2.6	3.8	4.2	3.0	2.8	2.6
1874	3.6	3.2	3.9	3.2	2.6	4.7	4.4	3.1	2.6	3.0
1876	3.6	3.2	3.3	3.0	3.1	4.6	4.1	3.4	2.9	3.2
1878	3.7	3.2	3.2	2.8	2.8	4.5	3.8	3.8	3.7	3.3
1880	2.3	3.0	2.9	2.4	2.7	4.5	4.2	3.6	3.6	3.2
1882	1.9	2.8	2.8	2.3	2.2	4.1	3.9	3.2	2.7	2.9
1884	1.8	2.8	2.7	2.2	2.3	3.3	3.5	3.3	2.8	2.7
1886	1.6	2.4	3.2	2.5	2.3	3.5	3.5	2.7	2.2	2.8
1888	1.6	2.3	3.3	2.2	2.1	3.8	3.9	2.4	2.0	2.4
1890	2.1	2.2	3.6	2.3	2.3	4.4	4.0	2.5	2.2	2.9
1892	2.1	2.5	3.6	2.5	3.7	4.8	3.5	3.0	2.0	2.8
1894	2.5	3.2	3.3	3.3	4.2	4.8	3.9	3.5	2.4	2.9
1896	2.6	3.4	3.2	3.6	3.8	3.8	4.0	3.7	2.3	2.9
1898	2.6	3.4	3.2	3.2	3.8	3.8	3.2	3.7	2.5	3.8

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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	2.5	2.6	2.8	3.9	3.7	3.3	3.8	3.0
1914	1.6	2.5	2.6	2.8	3.5	3.9	3.3	3.9	3.0
1916	1.4	2.3	2.4	2.3	3.0	4.0	3.3	3.9	3.1
1918	1.3	2.6	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	4.4	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	4.3	4.5	3.7	4.4	3.9
1928	4.0	3.7	3.7	3.4	4.3	4.7	4.0	4.3	3.7
1930	3.8	3.6	3.9	3.4	4.6	4.6	4.1	4.5	3.7
1932	3.8	3.4	3.9	3.7	4.8	4.6	4.1	4.5	3.8
1934	4.1	3.2	3.2	4.0	4.5	4.8	4.3	4.0	3.8
1936	4.1	3.3	3.8	4.3	4.1	4.6	4.3	3.9	3.6
1938	3.7	3.4	3.8	4.1	4.0	4.3	4.0	4.0	3.5
1940	3.6	3.4	2.9	3.7	4.1	4.3	3.7	4.5	3.3
1942	3.7	3.1	3.0	3.7	4.2	4.7	3.6	5.0	3.1
1944	3.7	3.1	3.1	4.0	4.4	4.8	3.9	5.3	3.0
1946	3.8	3.3	2.9	4.1	4.4	5.0	4.0	5.5	3.0
1948	4.0	3.7	3.1	4.1	4.5	5.4	4.0	5.5	3.3
1950	4.2	3.9	3.6	4.3	4.8	5.4	4.1	5.3	3.7
1952	4.3	3.6	3.7	4.4	4.9	5.4	4.4	5.3	3.8
1954	4.2	3.5	3.5	4.2	4.5	5.3	4.3	5.5	4.1
1956	4.3	3.9	3.6	4.1	4.2	4.8	4.0	5.4	4.6
1958	4.5	4.1	3.6	4.1	4.3	4.7	4.2	5.6	4.3
1960	4.4	3.8	3.6	4.0	4.5	4.9	4.0	5.2	4.1
1962	4.2	3.5	3.9	3.9	4.7	4.8	4.0	4.9	4.5
1964	4.1	3.7	4.1	3.7	4.9	4.8	4.5	5.2	4.3
1966	3.8	3.7	4.0	3.8	5.0	5.3	4.9	5.6	4.4
1968	4.2	3.8	3.8	4.0	5.1	5.7	4.7	5.6	4.7
1970	4.5	3.9	3.8	4.6	5.1	5.8	4.8	5.7	4.9
1972	4.6	4.0	4.1	4.6	4.8	5.9	4.7	5.2	5.1
1974	4.9	4.1	4.5	4.8	4.5	6.2	4.7	5.4	5.3
1976	5.1	4.1	4.8	5.1	4.4	5.9	4.5	5.5	5.2
1978	5.1	3.8	4.6	5.1	4.2	5.8	4.9	5.1	5.0
1980	4.6	3.5	4.2	4.6	4.0	5.8	4.7	4.9	4.7
1982	4.5	3.3	4.4	4.6	3.9	5.5	4.8	5.0	4.5
1984	4.5	3.8	4.4	4.8	4.0	5.2	4.7	5.6	4.4
1986	4.2	3.6	4.0	4.7	3.9	5.1	4.7	5.6	4.3
1988	3.9	3.2	3.8	3.7	3.9	5.4	4.5	5.7	4.3
1990	3.9	3.3	3.4	3.3	4.1	5.5	4.4	5.1	4.3
1992	4.0	3.4	3.3	4.1	4.0	5.2	4.3	5.0	4.1
1994	4.2	3.5	3.8	4.5	3.9	5.1	4.4	5.4	4.3
1996	4.3	3.6	4.2	4.3	3.9	5.4	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.
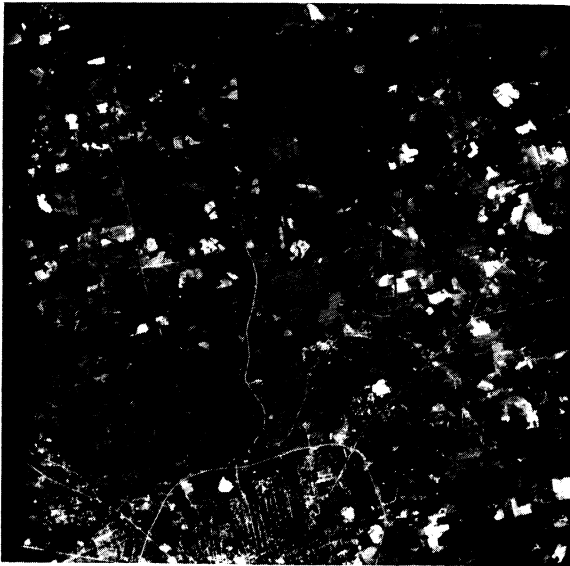
09:10 E.S.T.
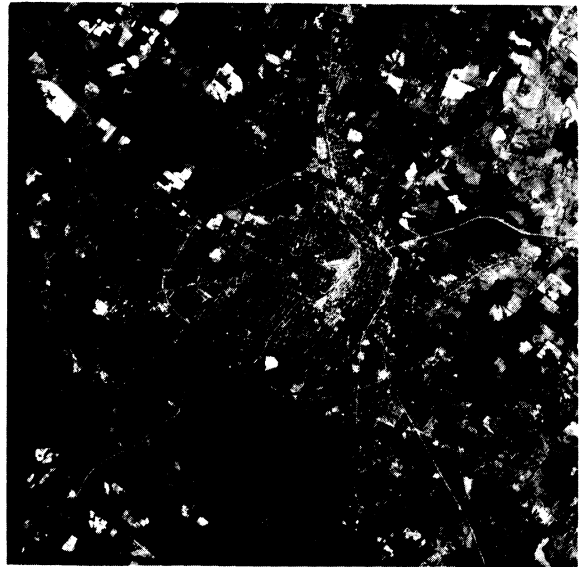
10:06 E.S.T.

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° 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
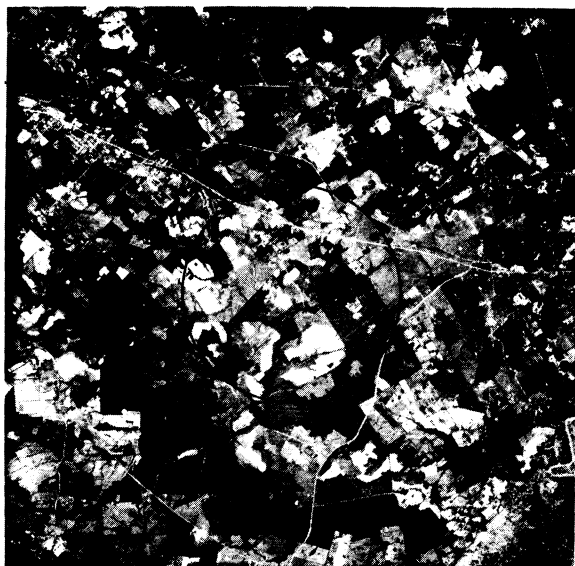
11:09 E.S.T.   12:34 E.S.T.

13:31 E.S.T.

Figure 2. - SCENE PHOTOGRAPHS

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14:12 E.S.T.　　　　　　　14:48 E.S.T.
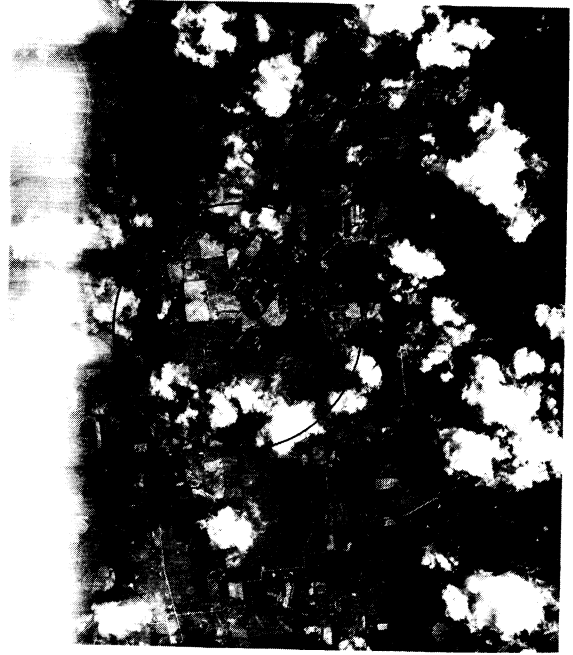
15:11 E.S.T.
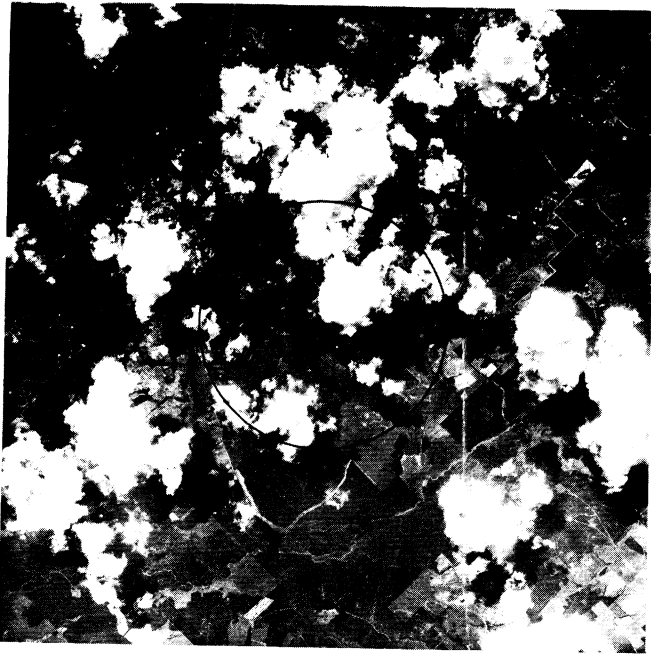
Figure 3. - SCENE PHOTOGRAPHS

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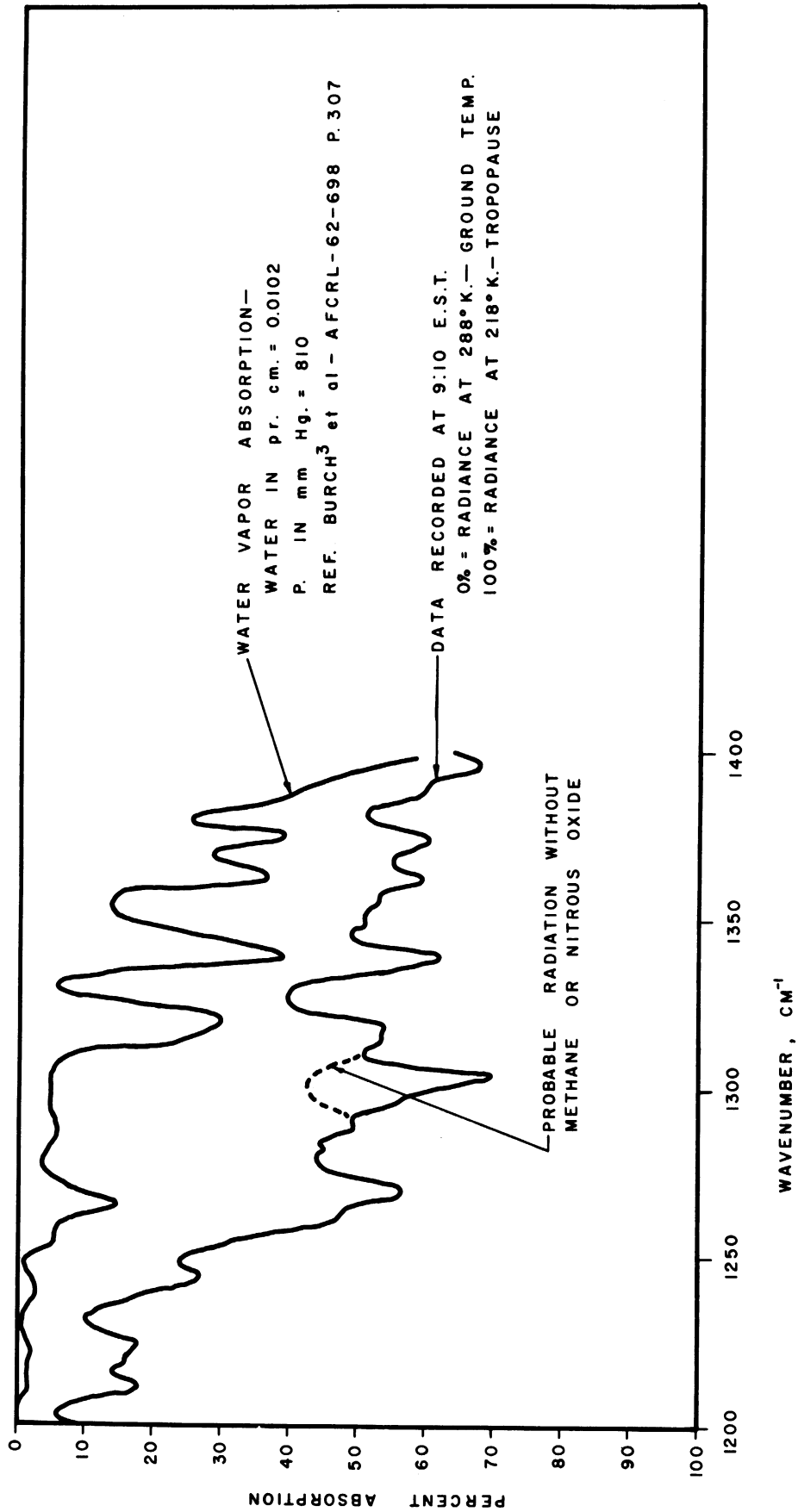
FIG. 4. COMPARISON OF WATER VAPOR ABSORPTION AND MEASURED SPECTRAL RADIANCE TO DEMONSTRATE ABSORPTION DUE TO METHANE AND NITROUS OXIDE.

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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 15μ 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 9.6μ data to determine the ozone profile. A water vapor profile can be calculated, even though the data in the 6.3μ 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

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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 $-2^{\circ}C/1000$ 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 inter-
ferometer (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 char-
acteristics. 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 Inter-
ferometer. 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° which covered an area five miles in diameter on the ground.

The data reduction scheme selected required the measurement of the amplitude of co-
efficients 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°. This was done so that the interferom-eter data could be compared with the Tiros 5-channel radiometer. The radiometer had to be mounted at a 30° 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 tem-perature 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° C and the average variation is less than 1°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 10.3μ 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 com-

parison was a great aid in establishing confidence in the interferometer.

The comparison between the Nimbus filter function and the 10.3μ interferometer channel shows that both read closer to ground temperatures than the Tiros. The 10.3μ channel is slightly closer to ground temperatures. The Nimbus temperatures are $3.5^{\circ}C$ below the average ground temperatures measured by Marlatt. It should be noted that the measured ground temperatures varied by $\pm 2.5^{\circ}C$ 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 $\pm 3^{\circ}C$ at 10.3μ and $\pm 5^{\circ}C$ at 6.3μ.

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 10.3μ (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 9.6μ 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 $-2^{\circ}C$ was recorded during the clear sky portion of the flight. The effect of clouds is clearly seen in this channel.

The CO_2 at 14.5μ 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

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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 8.5μ "window" exhibits the same tendencies as the 10.3μ except that the temperatures are lower indicating a poorer "window."

The 7.6μ 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 6.4μ 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°C in the warm "window" to 20°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 14.5μ 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 9.6μ 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 6.4μ.

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

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ACKNOWLEDGMENTS

BLACK BODY HOUSING   INTERFEROMETER

FIGURE 1

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FIGURE 2

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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
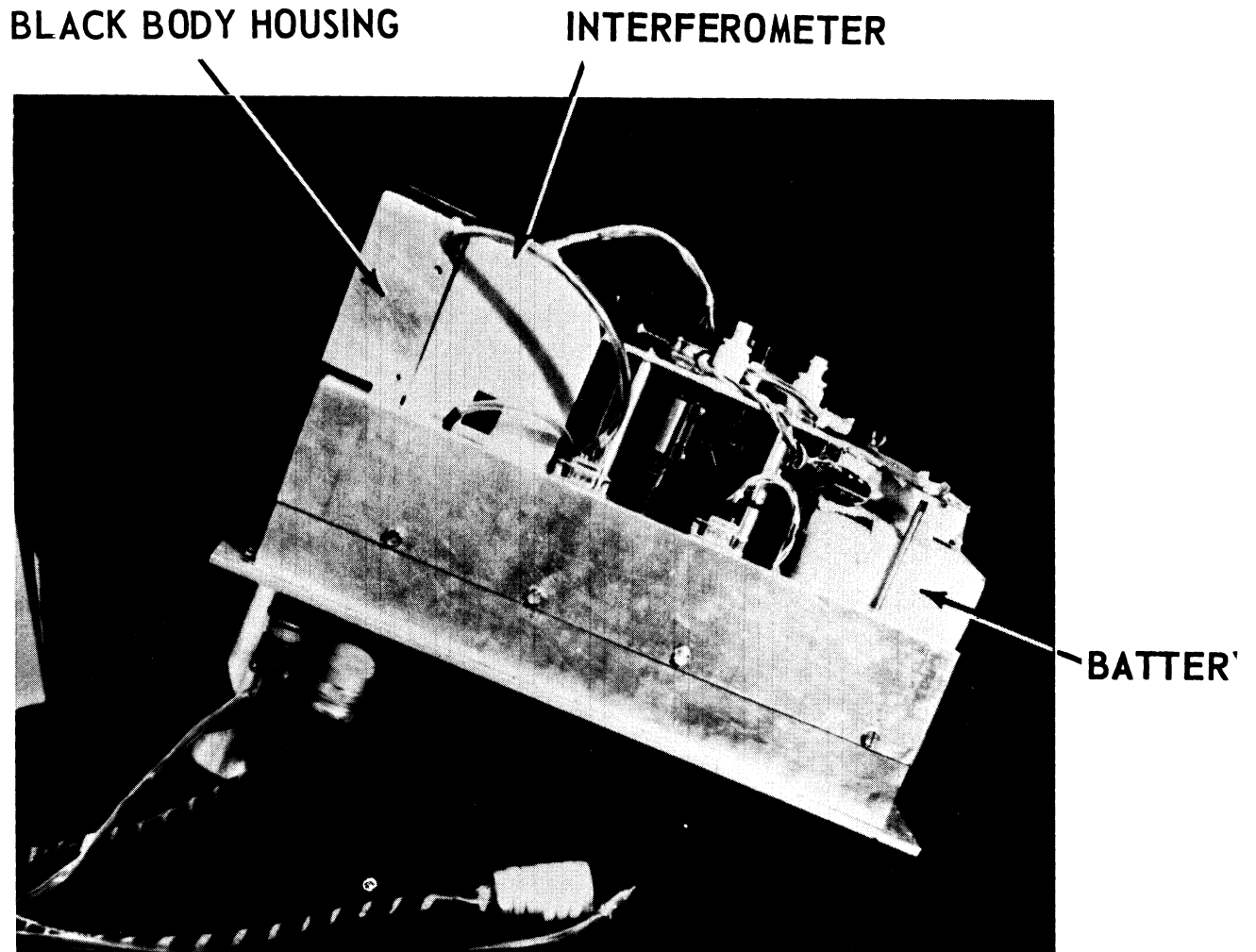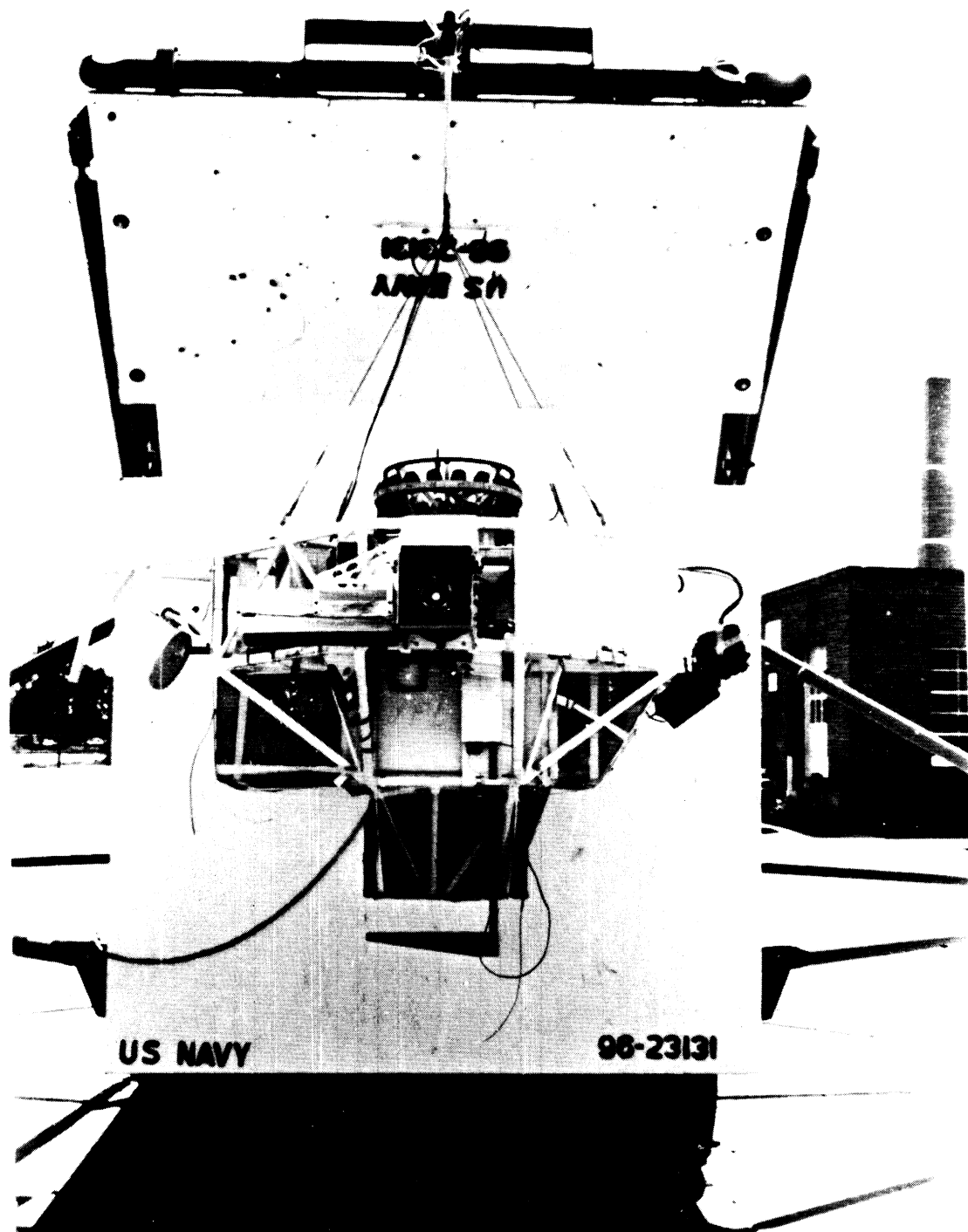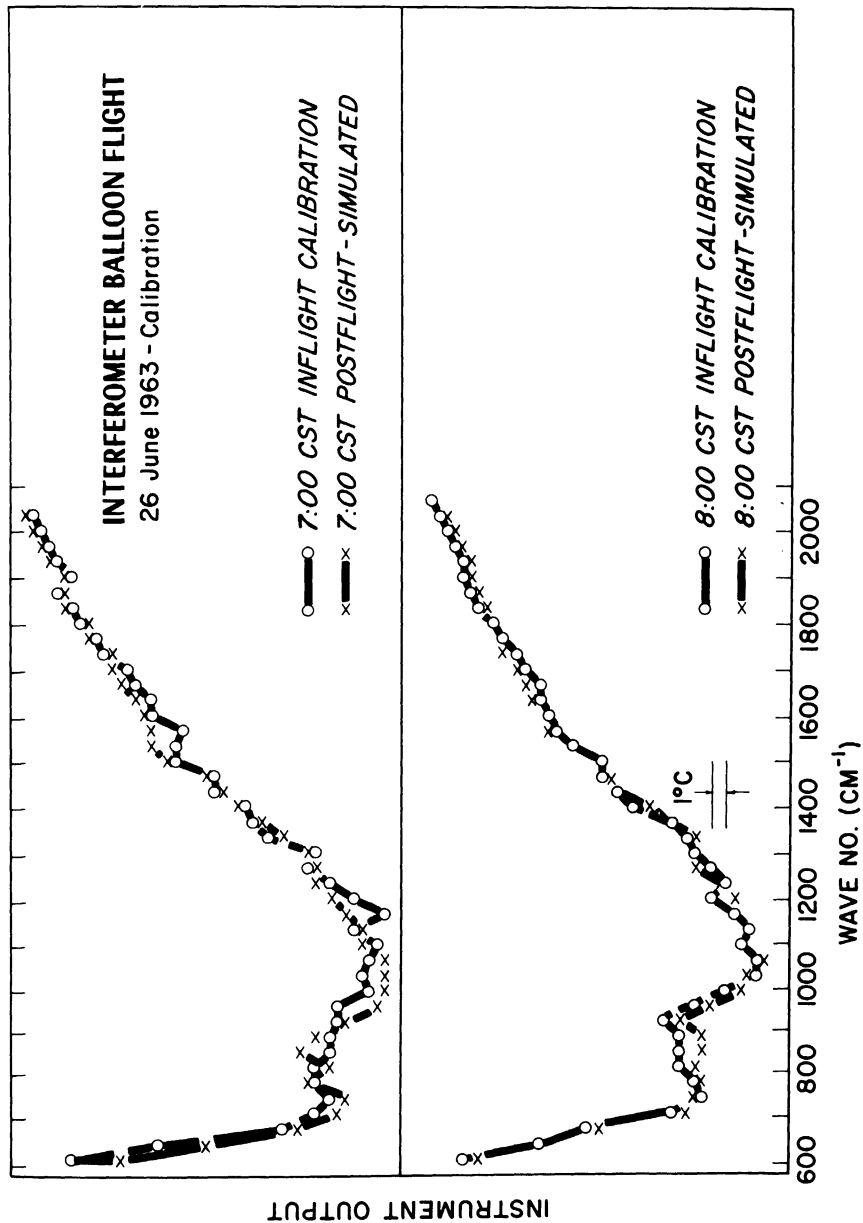
FIGURE 3

INTERFEROMETER DATA

Equivalent Black Body Temperatures, °C

CST	Wave No. (cm⁻¹):	620	655	690	725	760	795	830	865	900	925	970	1005	1040	1075	1110
	Wavelength (μ):	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		5.3	11.5	11.7	19	19	16	14	13	11	10.5	12	12	14	13	13.5
5:04:55		3.7	.03	2.5	13.7	16.7	14	15.5	14.5	13.5	13	13	15	13	13.5	13.5
5:09:55		-6.5	-7.	-7.5	7.0	12.0	12.3	13	14	12.3	11.8	13.2	14.3	13.7	12.2	12
5:14:54		-11.0	-20.7	-21.7	1.3	11	12	13.5	13.5	13.5	13.5	12.7	14.2	12.7	11.8	12.5
5:19:54		-21.3	-33.3	-35	-5.7	9.8	12.7	14.5	13.7	13.5	13.5	13.5	14.5	13.5	12	13.7
5:24:54		-25	-49.3	-41.5	-14.7	8.0	13.5	14	12.7	12	11	12.7	13.5	11.5	11.7	12
5:29:54		-34.5	-55.2	-58.8	-17.7	7.5	14	13.5	13.5	11.7	11.5	14	13.3	8.7	9.8	12.5
5:34:54		-33	-63.2	-61.5	-20.7	6.7	11.5	13.6	13.6	13.8	15.5	13	12	8.7	10.5	12
5:39:55		-34.5	-61.5	-67.2	-27	7.0	11.5	13.0	13.4	13	14.3	13.6	13.5	8.0	9.5	12.0
5:44:54		-32.8	-64	-62	-21.7	7.5	14	14.5	13.8	15.2	14.3	14.8	15.0	7.5	9.0	13.8
5:49:54		-33.5	-61.3	-67.2	-27.5	7.2	13.5	15	16	14.5	15.3	15.3	14.3	6.5	10.	14.7
5:54:54		-36.2	-55	-58.3	-27.7	7.0	14.3	15.2	16.2	16	16	15.3	15.7	2.8	7.3	15
5:59:54		-38.3	-55.5	-62.3	-29.5	7.3	15.5	16.5	15.7	16.5	16.7	16.5	14.5	-2.0	4.0	16.2
6:09:54		-35	-55	-57	-32.3	6.7	16	17	15.8	17	17	17	14.8	-6.2	0.0	16.3
6:19:54		-31	-45.7	-50.2	-30.2	6.5	16.5	17.5	16.0	18.3	19	20.3	17.5	-7.7	-1.0	16.3
6:29:54		-33	-44	-48.2	-26.2	6.8	17.5	18.5	19	18.2	20	18.5	17	-4.5	0.02	17
6:39:54		-32.5	-42.5	-46	-26	6.0	16.8	18.8	19	20	20.7	19.3	17	-4.0	0.03	17.7
6:49:54		-37	-50	-55	-35	5.	17	18	19.2	24	24.5	24	23	-2.0	0.03	18
8:00:00		-33	-47	-54	-34.3	4.0	21	22	24	26.5	26.3	26	25	-3	-1	22
8:36:00		-30	-46	-54	-34.3	0.5	23	25.3	26	27.5	27.5	26	25	-1.0	3	26
8:37:00		-35	-47	-55	-34.5	4.5	23	25.3	27.5	26.5	27.5	27.0	25.5	0.5	3	26
8:58:00		-35	-44	-49	-33	7	23	26.5	26.5	25.5	27.5	27.5	25	0.0	3	26
8:41:00		-45	-46	-53	-31	8.0	22	25.3	25	25.5	26.8	26.	24.3	0.	2	25
9:00:00		-41	-49.7	-57.5	-34	9.	19	23	26	26.8	26	25	22	-1.2	1	22
10:00:00		-29.7	-49.2	-56	-31	9.5	21	26.3	26	26.3	26.5	28.7	24.3	-2.2	8.3	27
10:01:00		-31.8	-49	-55.5	-30.8	8.2	22.3	23.3	23.	23.2	24	25.8	25.5	.3	9.0	28.3
10:02:00		-38.2	-51.2	-58.8	-36.6	8	21.4	28.2	27.2	28.8	29.2	31.	26.7	1.4	1.5	29.1
10:02:30		-40	-56	-58	-33	9	20	27.5	27.4	29.5	28.2	30.4	26	.2	7.5	28.6
11:00:00		-50	-56	-58	-33	8	22	27	26	28	29	30	26	2	7	28
12:00:00		-56	-60	-60	-32	9	15	27	27	31	32	34	29	-1	13	34
13:00:00		-58	-60	-65	-57	8	2	20	20	5	24	26	18	-18	8	26
13:59:15		-56	-60	-60	-33	-6	8	6	6	11	7	14	6	-20	-3	14
14:00:00		-56	-32	-65	-69	2	-69	-74	11	15	17	17	11	-14	3	21
25:00:00		-74.5	-64	-77.4	-64.2	-68.4	-70.3	-75.2	-72	-74	-74	-69	-69	-69	-69	-58
15:58:20		-64.5	-62	-73.5	-61	-61.6	-67.5	-71.2	-75	-89.6	-87.2	-81	-71	-73.5	-76.2	-69.5
16:00:20		-77.5	-65.5	-76.2	-62.7	-67.2	-67.5	-75.7	-64.8	-82	-84.4	-76	-70.2	-69.2	-75.8	-64.5
16:01:20		-55	-70	-60	-13	20	21	26.5	-76.4	-91.9	-90.5	-81.4	-71.4	-70	-78.8	-68.5
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	1330	1355	1390	1425	1460	1495	1520	1565	1600	1625
---	Wavelength (μ):	8.73	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	14.5	15.5	12.5	13.8
5:04:55		14.8	15	15	14.2	14.2	13.5	13	11	12	12	13	7	6	-2.5	5.0
5:09:55		15	13.3	13	10.5	12	10.7	6.8	5.0	2.5	4.5	3.7	1.0	-4.2	-11.5	-8.5
5:14:54		14	13.5	12.5	10.5	8.5	7.2	4.5	1.3	-2.5	0.0	-6.0	-9.5	-22.5	-25.5	-18.2
5:19:54		14.7	14.3	14	12.6	6	5	-3.2	-3.2	-7	-15.2	-14.2	-32	-38.8	-26.2	-29
5:24:54		13	13	12	10	2.5	-1.5	-5.	-8.8	-10	-18.5	-28.5	-22.5	-40.5	-20	-49.
5:29:54		13.5	13	12.5	11.7	8.2	-3.2	-5.5	-10.5	-9.0	-19	-34.3	-42.7	-47	-35.	-26.8
5:34:54		13.5	14.5	13	10.	-1.0	-5.5	-0.8	-7.7	-14	-21	-31.5	-49.2	-52.2	-29.5	-31.5
5:39:55		13.6	13.9	12.6	9.0	-2.5	-6.5	2.7	-9.6	-13.9	-22	-31.5	-58.7	-56.0	-31.5	-25.5
5:44:54		14.0	14.3	13.7	11.8	-3.0	-6	2.4	-9.0	-11	-17.7	-31.8	-41	-70.7	-12	-26.5
5:49:54		14.3	15.3	14.3	12.3	-1.8	-6.5	1.4	-5.5	-10	-15.3	-33.3	-43	-57	-28	-32.2
5:54:54		14.3	14.5	14	12.5	-1.5	-6.5	1.0	-6.5	-13.7	-15.5	-25	-38.3	-44.7	-17.5	-17.5
5:59:54		15	15.3	15	12.5	0.05	-4.7	0.7	-3.7	-12.5	-18.5	-32.8	-34.3	-48.3	-24.2	-21.8
6:09:54		14.5	14.5	15.5	9.0	1.0	-6.7	0.03	-6.0	-12.5	-19.2	-35.	-33.7	-43.2	-24.2	-13.5
6:19:54		16.3	15.7	16	13.5	4.0	-5.5	1.2	-3.5	-7.0	-11.5	-25	-44	-39.5	-23	-20
6:29:54		17.5	17.7	16.8	14.5	13.5	-2.7	4.0	-1.3	-9.0	-12	-27.5	-27	-47.3	-24.5	-13
6:39:54		16.8	17	17.3	14.8	7.0	-3.0	2.5	-3.7	-14.5	-10.2	-28.5	-31.5	-42.3	-47	-46.5
6:49:54		17.5	17.5	17.7	16	8.0	-2.0	2.7	-1.3	-10.5	-12.5	-24.5	-55	-75	-35	-20
8:00:00		22	20	22	16	4	-10	-3	-7	-14	-14	-35	-55	-65	-45	-25
8:36:00		26	23.5	23.3	19	1.0	-11	-4	-12	-18	-20	-34	-55	-70	-40	-23
8:37:00		25	23.5	23.3	19	1.0	-12	-3	-13	-17	-19	-34	-55	-75	-35	-23
8:38:00		25	23.5	23.3	19	2.0	-12	-4	-10	-13	-20	-34	-40	-75	-35	-19
8:41:00		22	21	22.3	17	1.0	-10	-5	-14	-15	-17	-30	-50	-66	-35	-23
9:00:00		26	23.4	21	18	2	-12	-11.5	-23.3	-16	-23	-32	-55.5	-70.7	-50	-55
10:00:00		26.6	24.7	23.4	19	-0.07	-15.7	-9.7	-16.5	-27	-26.5	-49	-34.6	-65.7	-17.2	-93.2
10:01:00		26.2	25.6	24.7	19.7	0.4	-9.5	-6.7	-18.3	-23.6	-20.8	-40.6	-41	-64	-39.8	-46
10:02:00		25.6	25.3	24.6	19.4	-2.2	-7.7	-13	-24.8	-25.8	-30.5	-41.6	-52.5	-73.2	-49.5	-58
10:02:30		28	26	24.2	18	-3.9	-14.5	-13	-21	-32	-41.3	-52.3	-60	-75	-98	-50
11:00:00		32	29	25	17	-3	-15	-15	-21	-28	-33	-60	-70	-75	-75	-58
12:00:00		23	23	26	10	-4	-22	-28	-28	-21	-35	-45	-70	-75	-75	-70
13:00:00		8	9	20	-2	-12	-22	-25	-36	-33	-56	-56	-75	-75	-75	-75
13:59:15		16	17	6	2	-28	-31	-60	-40	-60	-68	-75	-75	-40	-40	-75
14:00:00		-65	-65	14	-65	-19	-26	-65.6	-65	-45	-69	-75	-40	-73.2	-66	-40
15:00:00		-77	-81.5	-65	-73	-65	-55	-77.7	-68.8	-52	-60	-50	-78.5	-61.7	-56.4	-81
15:58:20		-70.2	-80.8	-71	-68.5	-86.5	-74	-75.5	-67.7	-59	-71	-47.6	-53.5	-69.8	-65.2	-91.8
16:00:20		-76.4	-85.6	-73.5	-74	-77.0	-68.5	-4	-70.6	-52.8	-65.2	-48.	-65.5	-50	-35	-91.8
16:01:20		27	26	-82.5	7	-86.5	-74.8		-5	-57	-70.5	-50	-40			-75
17:00:00				24		-10	-9			-15	-25	-35				

FIGURE 4b

FIGURE 5

FIGURE 6
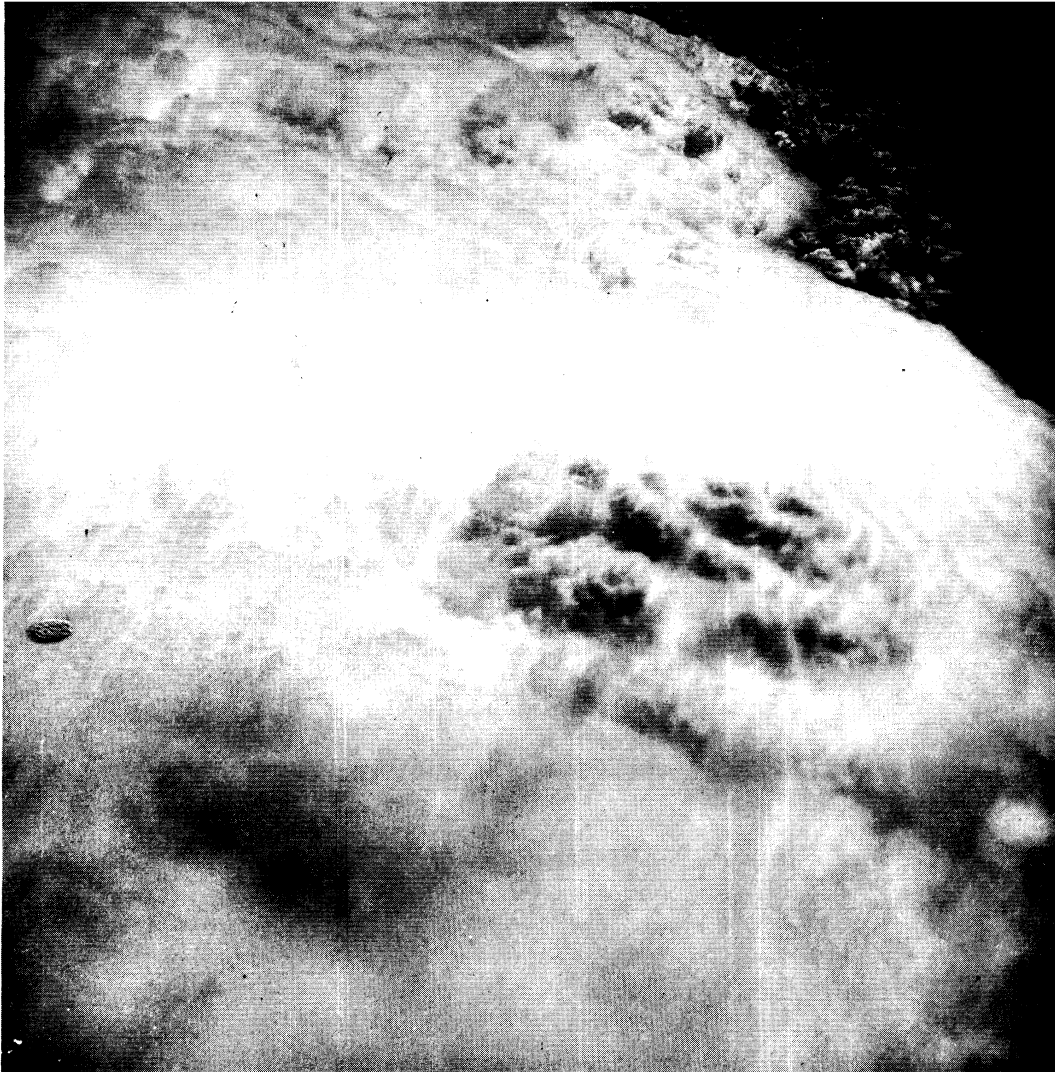
FIGURE 7
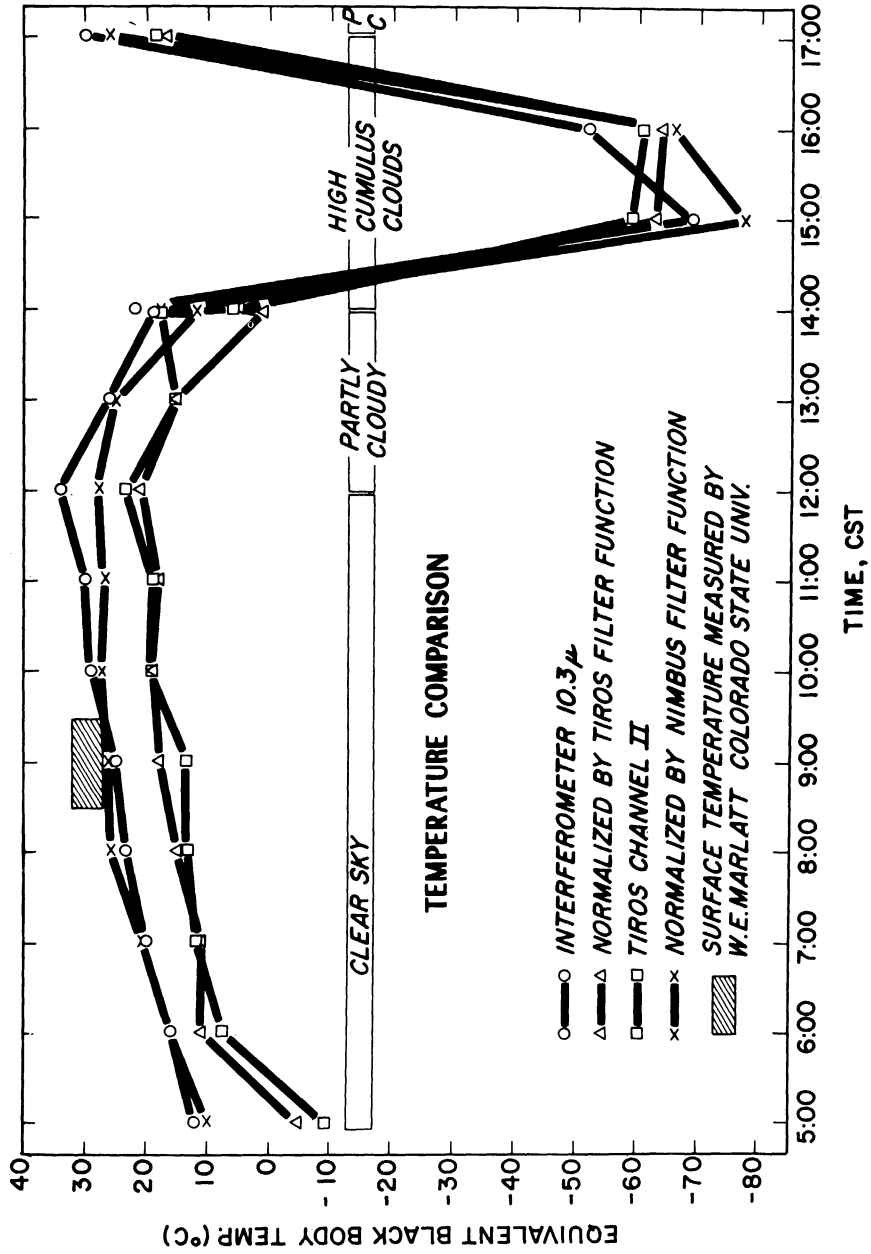
Figure 8
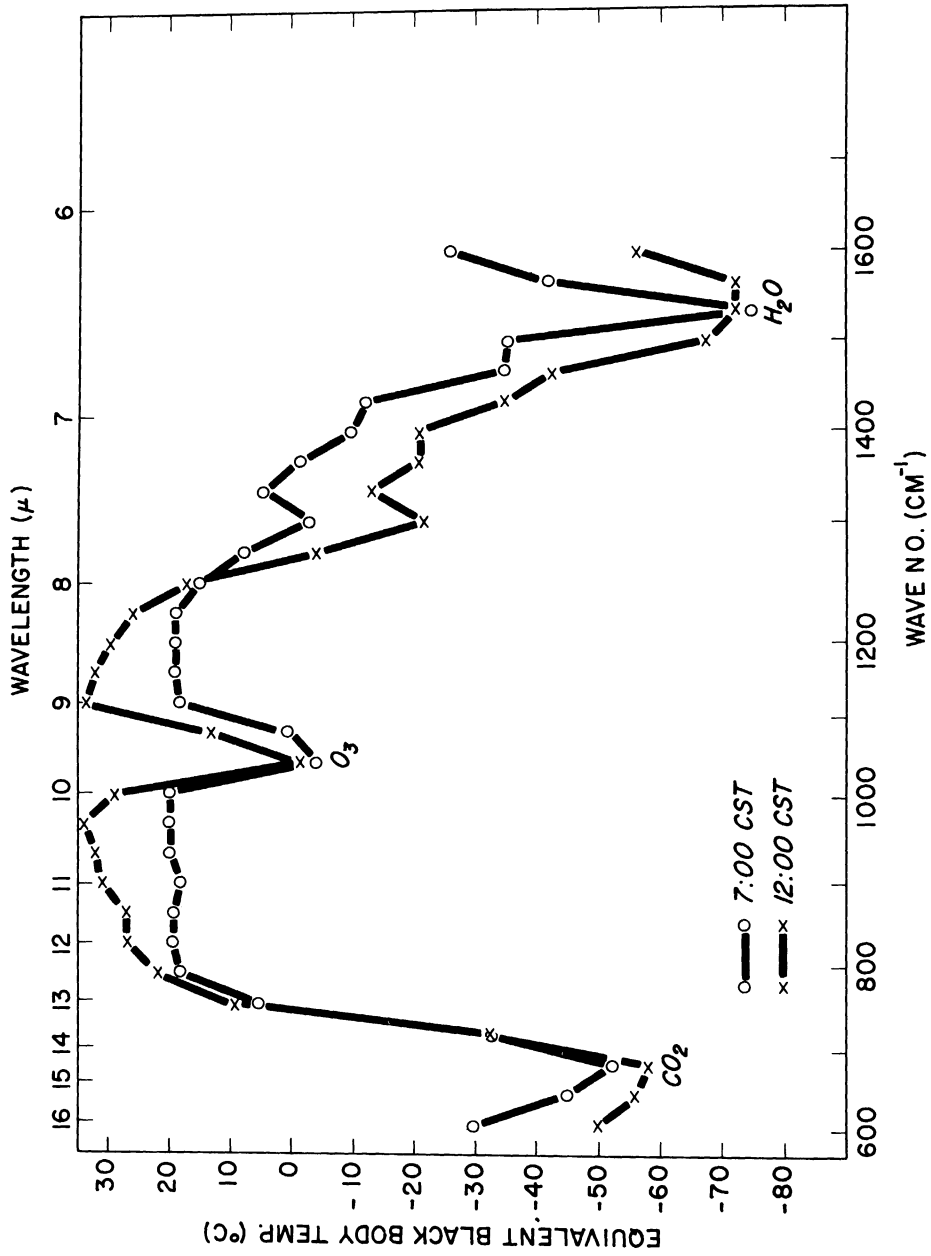
FIGURE 9
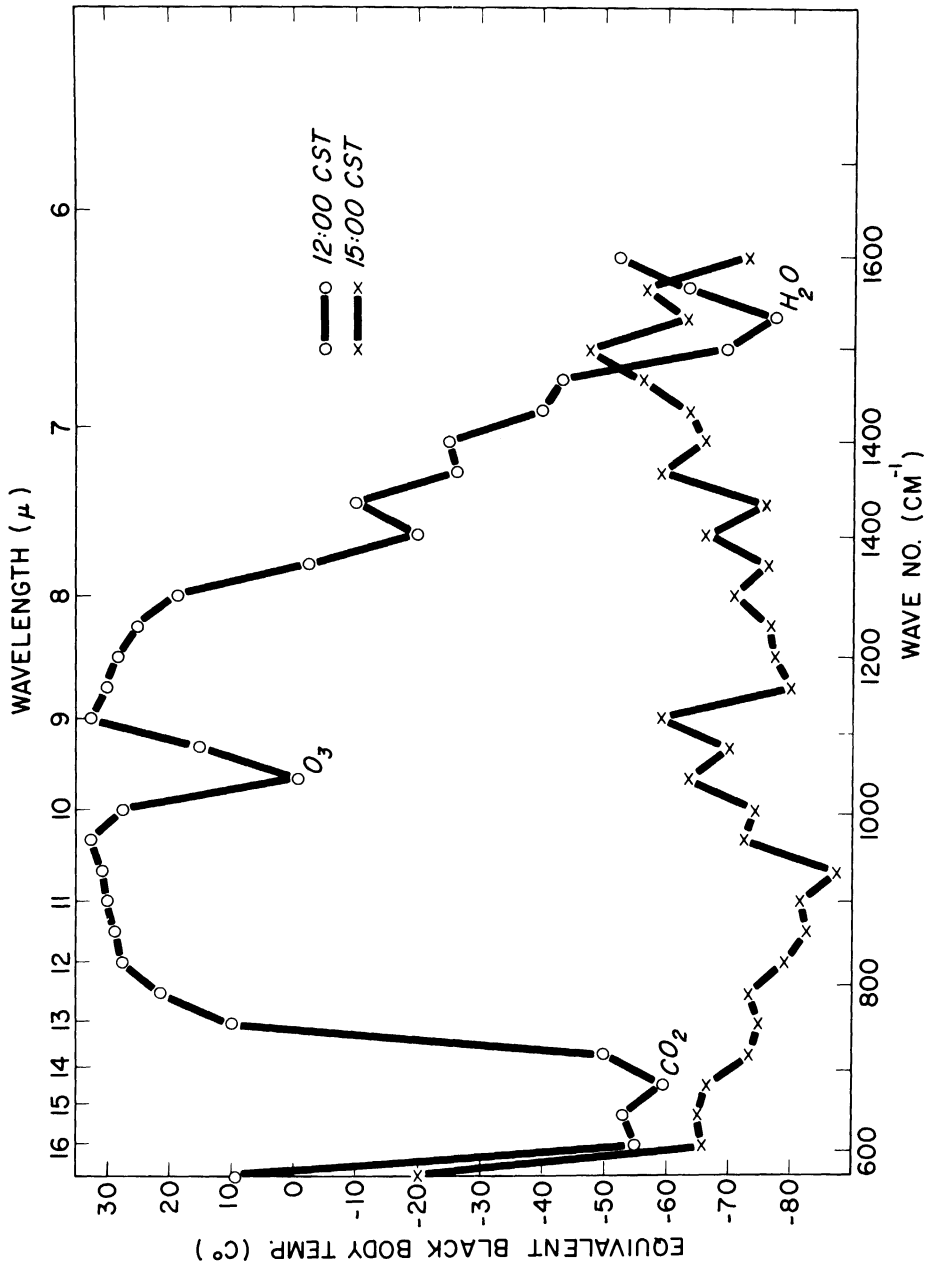
FIGURE 10
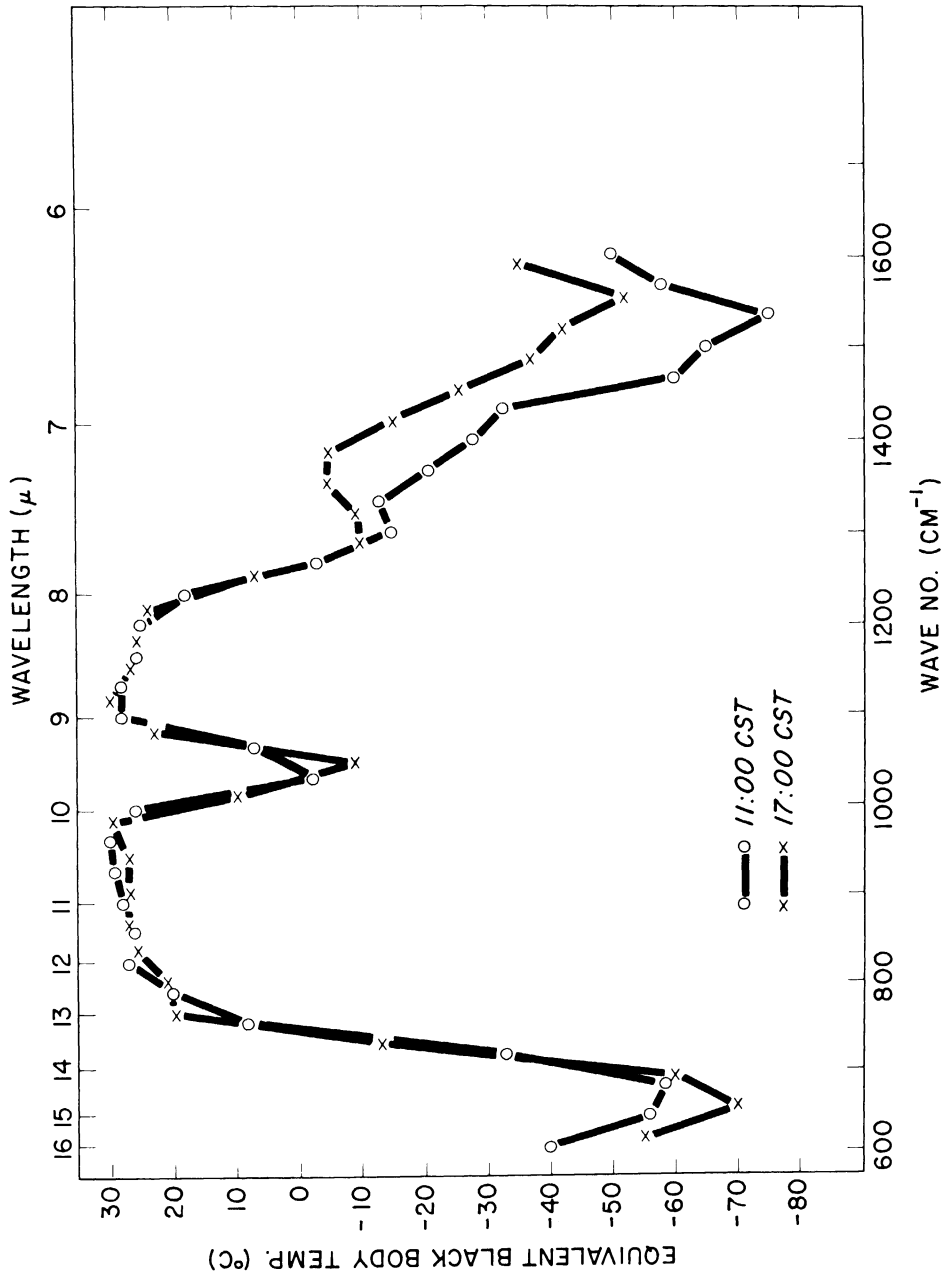
FIGURE 11

FIGURE 12

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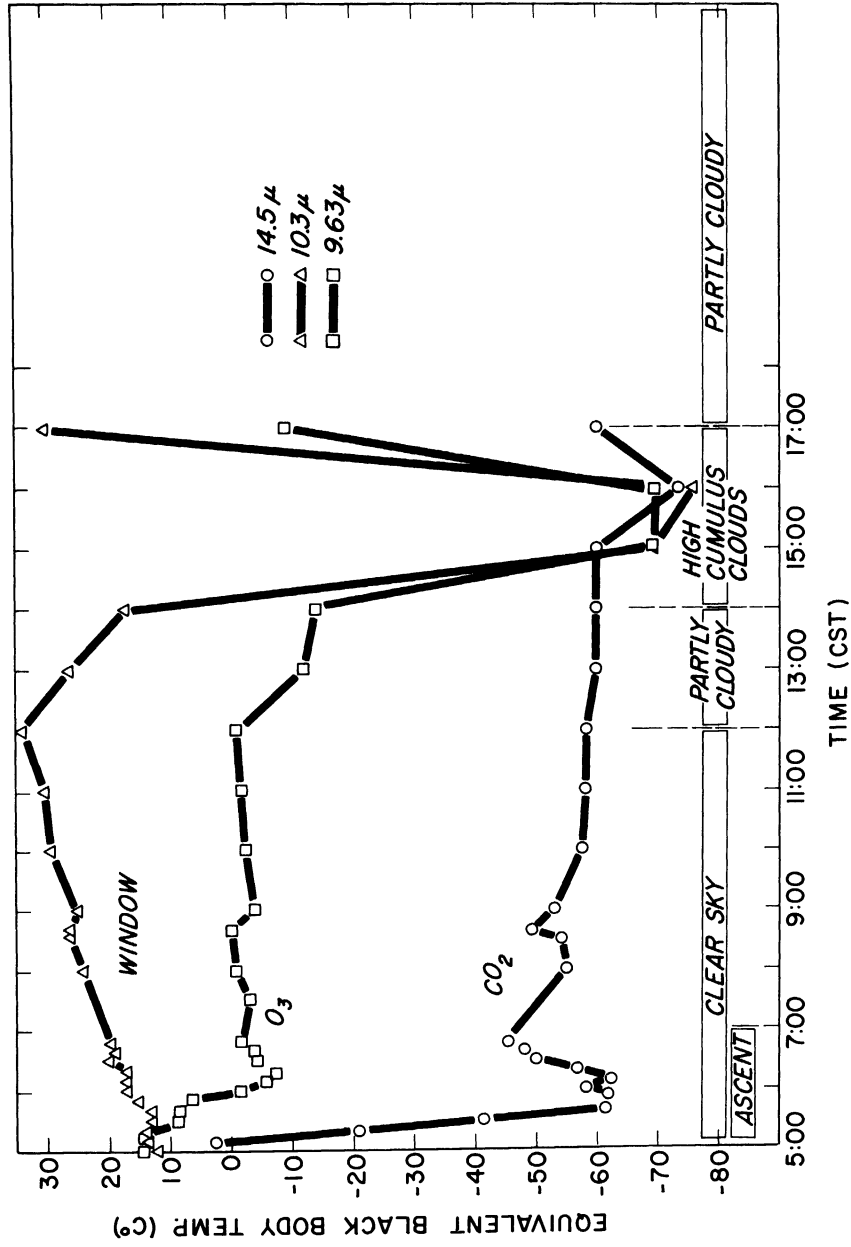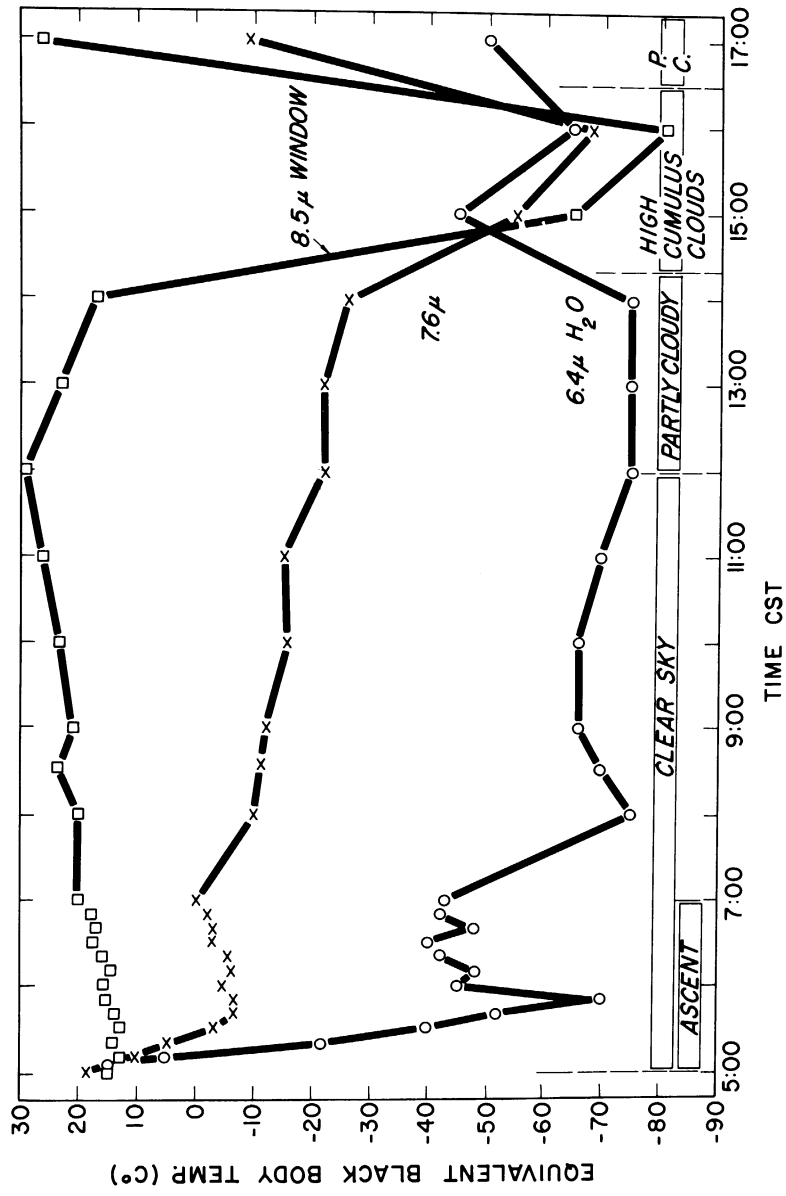
FIGURE 13

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 inter-
ferometer spectrometer (5 - 20μ), 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 radi-
ation 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 5μ to 15μ with a resolution of 50 cm^{-1}. This represented a signifi-
cant 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

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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 15μ 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 15μ 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 5μ - 33μ 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 6.3μ .

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} (5-20μ)

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° monochromatic source

Sampling rate: 312 words per second

Output: Serial Bi-phase words

Words per interferogram: 3472

Bits per word: 12

Field of view: 1.57×10^{-2} ster (appr. 8°)

Peak signal/noise: 1500

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

Mirror drive velocity: $\pm$ 1%

Reference temperature: $250^{\circ}K$

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°. 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 1.1704μ . 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° C produce significant changes in sensitivity. In fact, temperature stability on the order of 0.1° C is required for accurate measurements.

The reference temperature was changed to 273°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° C for 20 hours. The temperature stability of a given point is better than 0.1°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

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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 pre-dicted 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 $\underline{10}$ is required for accurate digitizing. This requirement is only marginally satis-fied 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.

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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 interfero- meter is rather elaborate compared to other instruments. For each interfero- gram 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

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5. Drayson, S. R., 1963, Errors in Atmospheric Temperature Structure Solutions From Remote Radiometric Measurements. Univ. of Mich. Tech. Report.

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

NEON SOURCE

COMPENSATING PLATE

BEAM SPLITTER

SILICON PHOTO DIODE

KBR F-1 LENS

GOLD CONE

8" FIELD OR VIEW

THERMISTOR BOLOMETER

DIFFERENTIAL SCREWS

FIXED MIRROR

MOVING MIRROR

RIGID MOUNT

DRIVE COIL

CLOSED MAGNETIC CIRCUIT

PARALLEL SPRINGS

SCAN PLATFORM

S N N S

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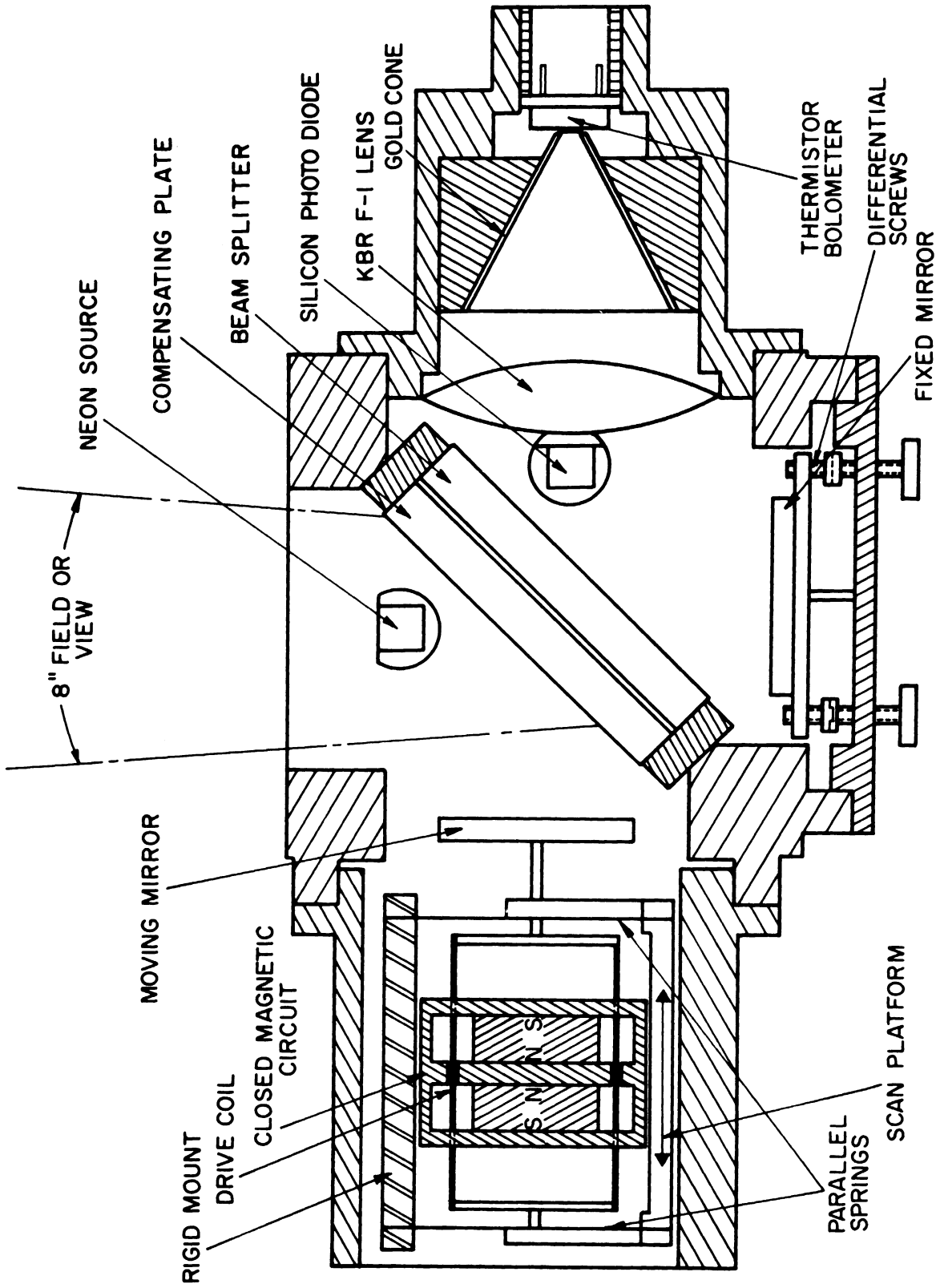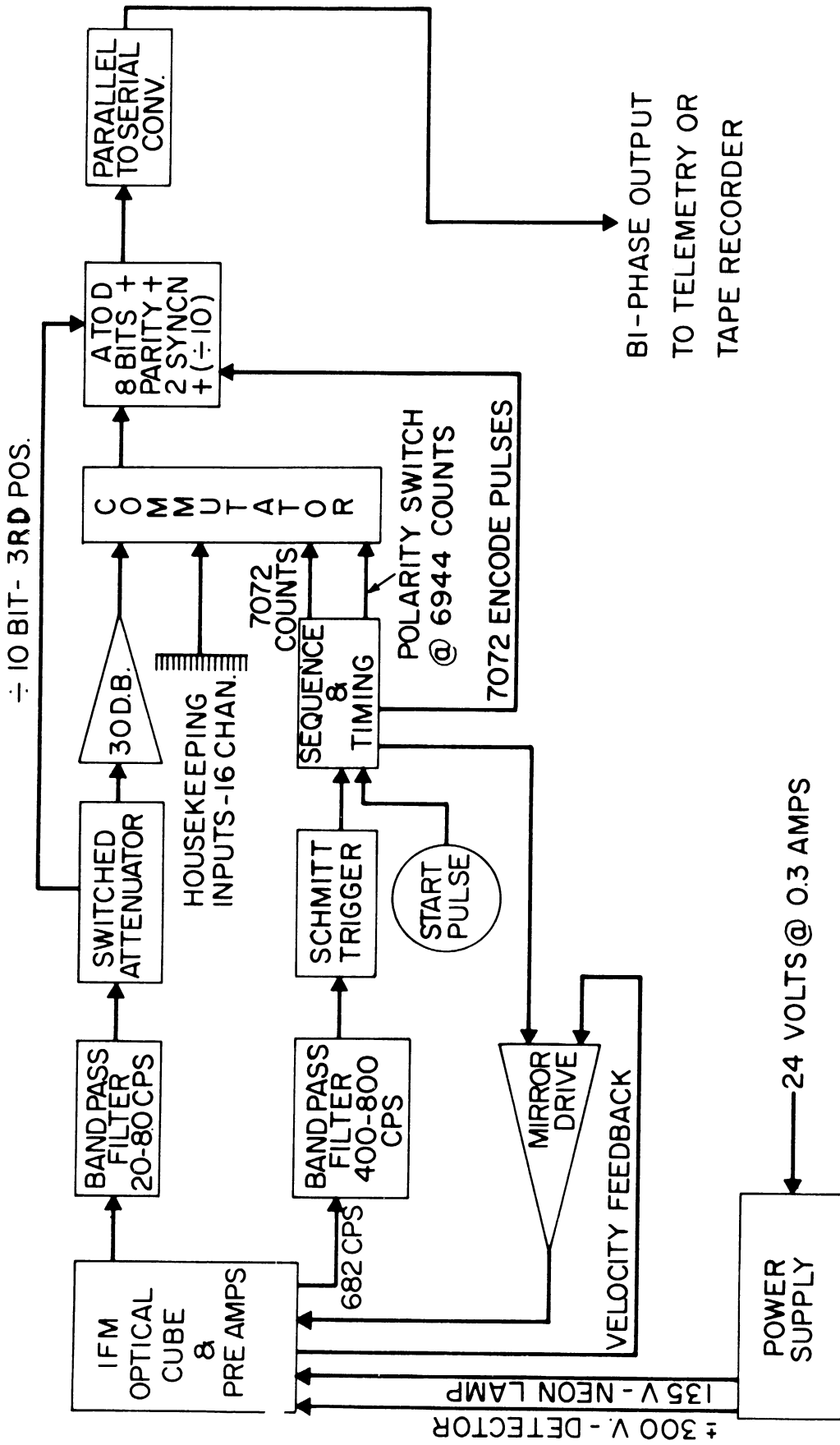
BALLOON INTERFEROMETER ELECTRONICS BLOCK DIAGRAM

Figure 2
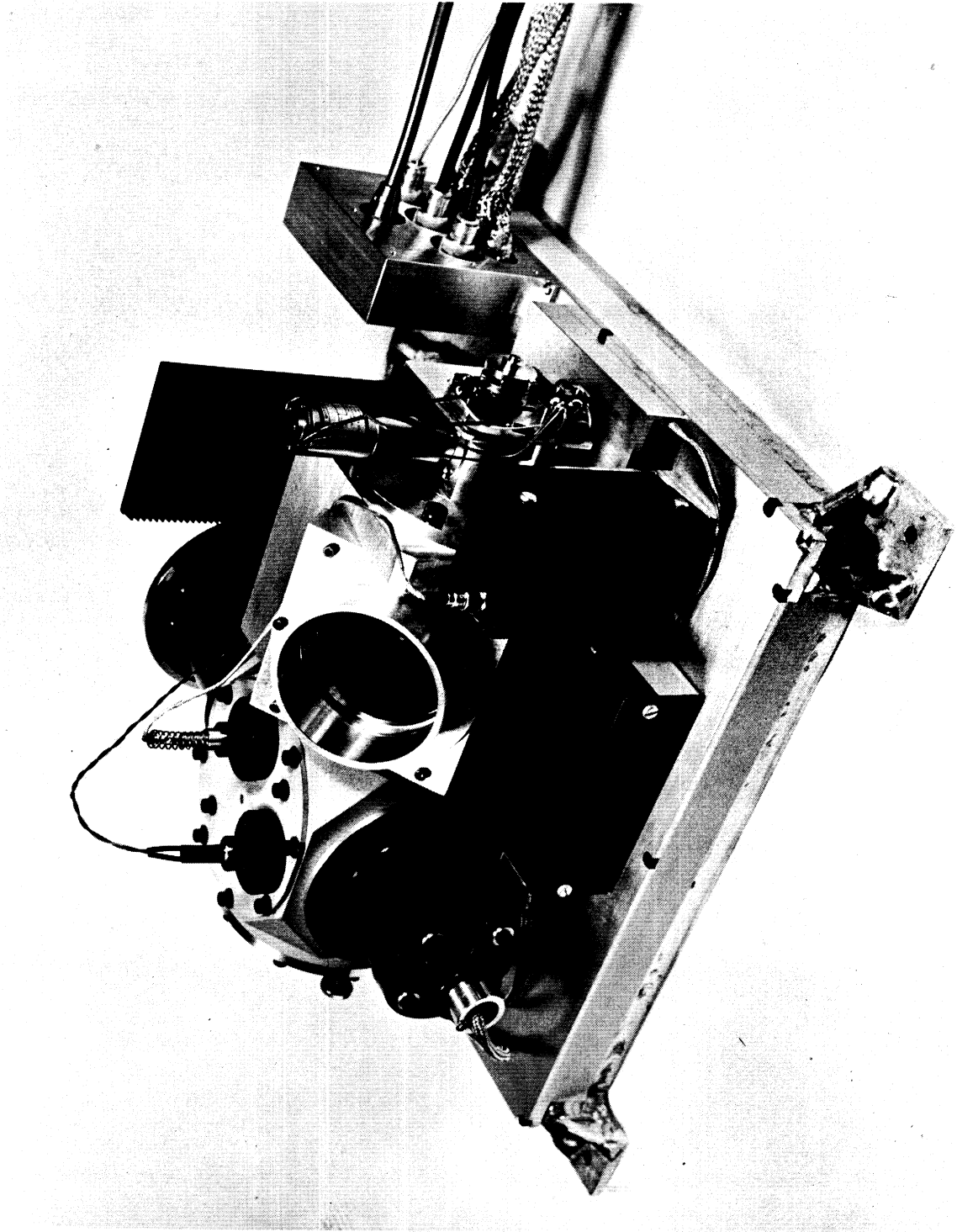
Figure 3. – Balloon Flight Optics
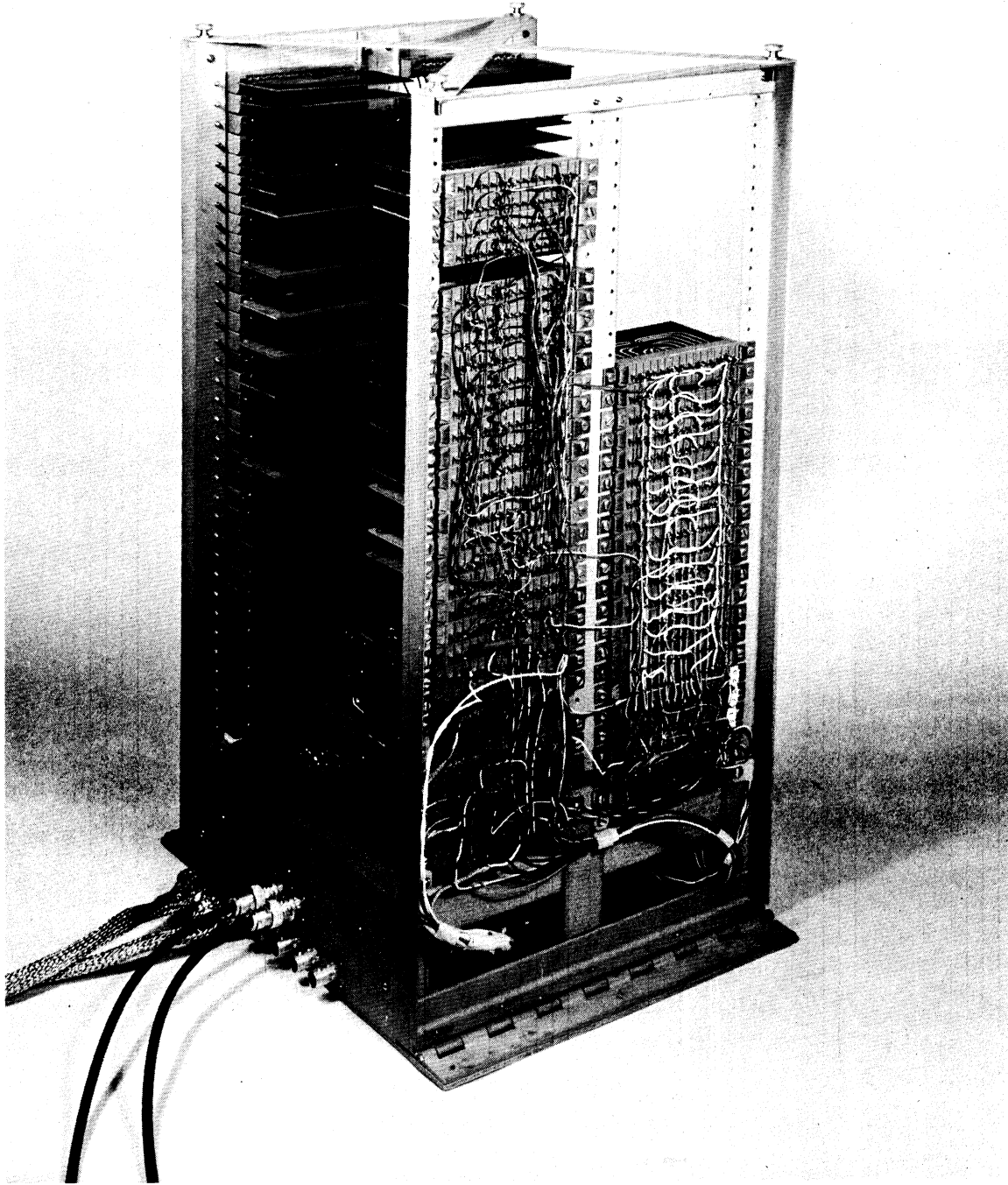
Figure 4 - Balloon Flight Electronics
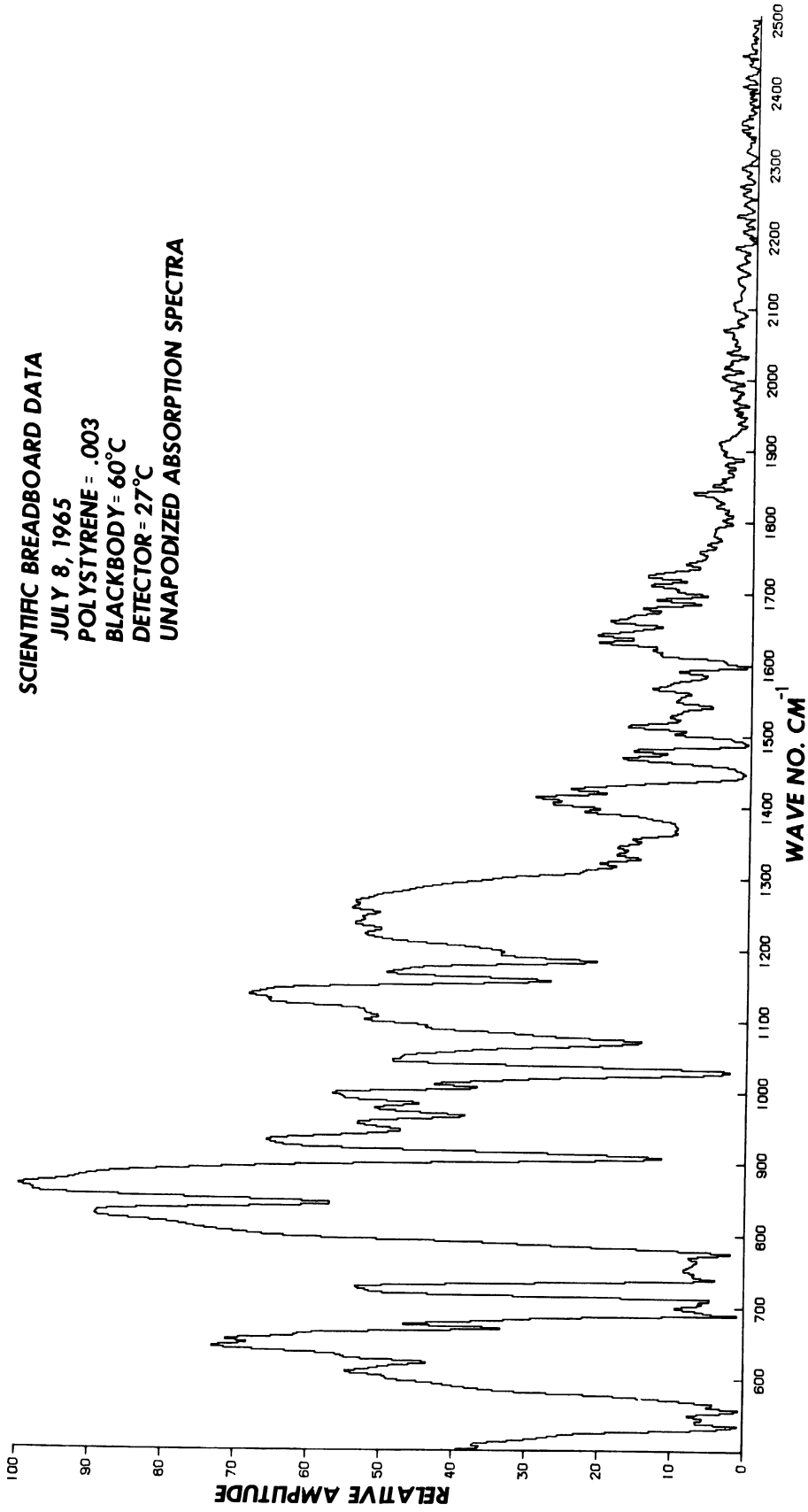
Figure 5

SCIENTIFIC BREADBOARD DATA
JULY 8, 1965
POLYSTYRENE = .003
BLACKBODY = 60°C
DETECTOR = 27°C
UNAPODIZED ABSORPTION SPECTRA

WAVE NO. CM^{-1}

RELATIVE AMPLITUDE

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Figure 6

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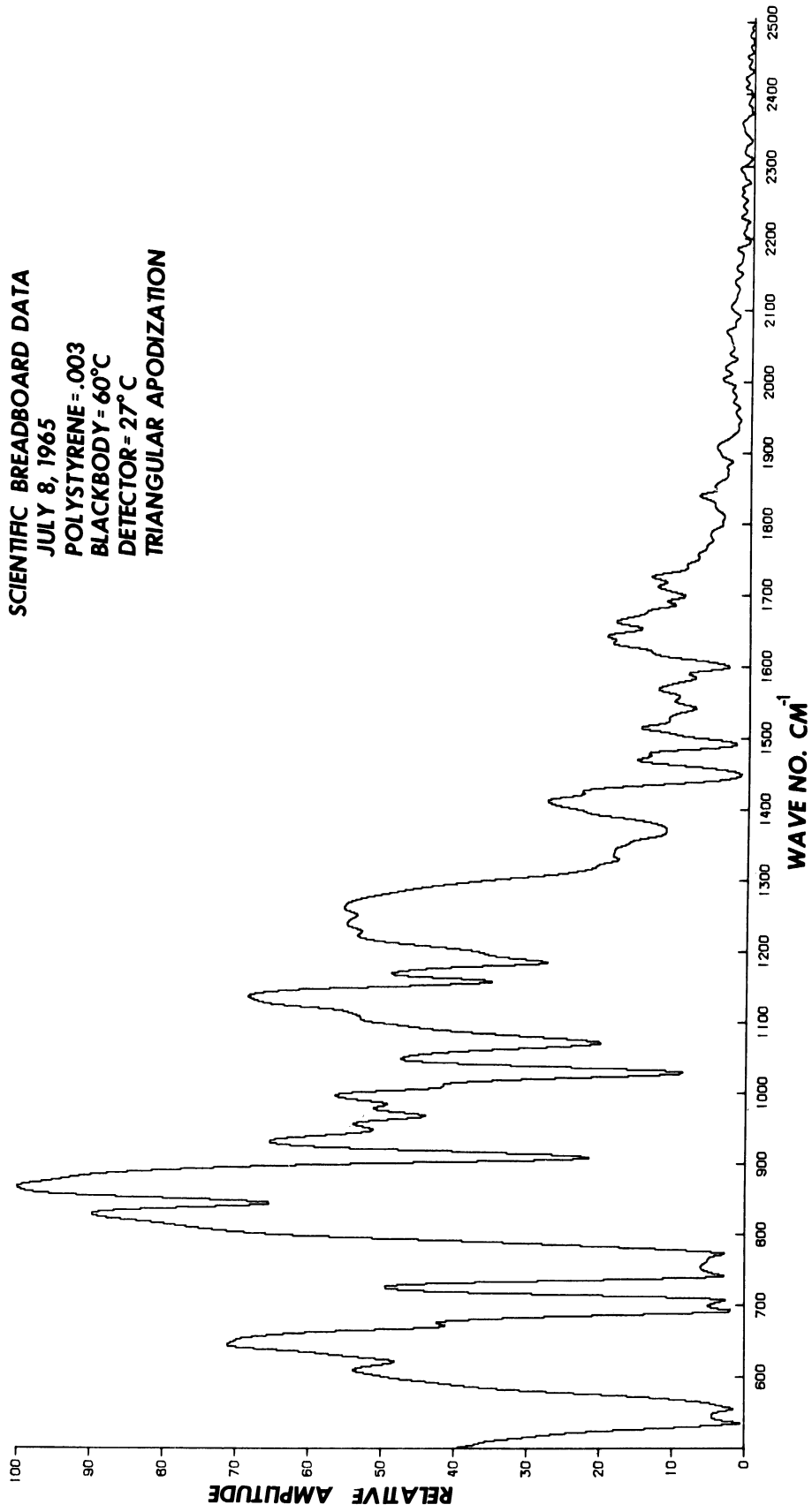
Appendix III

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 15μ to 5μ 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 15μ 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.

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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°C for a period of 15 hours. The detector, due to self heating, will assume a temperature of 0.8°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°K. The gas is then fed into the base plate cooling coil from which it emerges at 273°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.

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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:

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(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 $-100^{\circ}C$ 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 $0.1^{\circ}C$.

A study of the data showed that the Fourier transform of the inter-ferogram 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 interfero-gram. 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 un-certainty 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.

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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.

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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 14μ 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° to 90°. We originally used the maximum peak as the starting point which produced phase errors from 154° 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.

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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.

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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

Page

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.

3. Hanel, R. A. and L. W. Chaney, The Infrared Interferometer Spectrometer Experiment (IRIS), Goddard Space Flight Center Report X-650-64-204 and X-650-65-75, July 1964 and March 1965.

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.
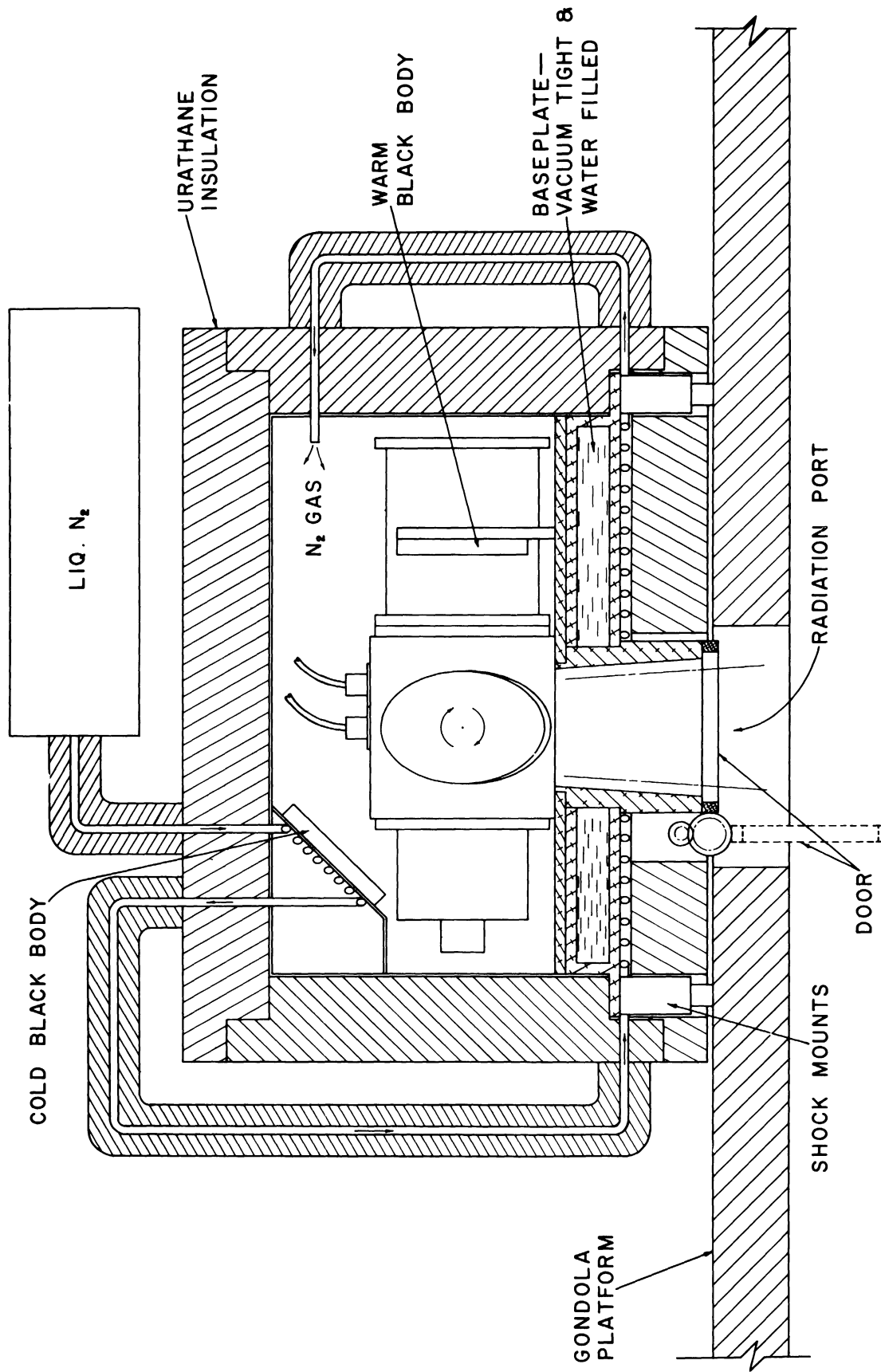
Figure 1 - Gondola Interferometer installation outline

COLD BLACK BODY

LIQ. N$_2$

URATHANE INSULATION

WARM BLACK BODY

N$_2$ GAS

BASEPLATE— VACUUM TIGHT & WATER FILLED

RADIATION PORT

DOOR

SHOCK MOUNTS

GONDOLA PLATFORM

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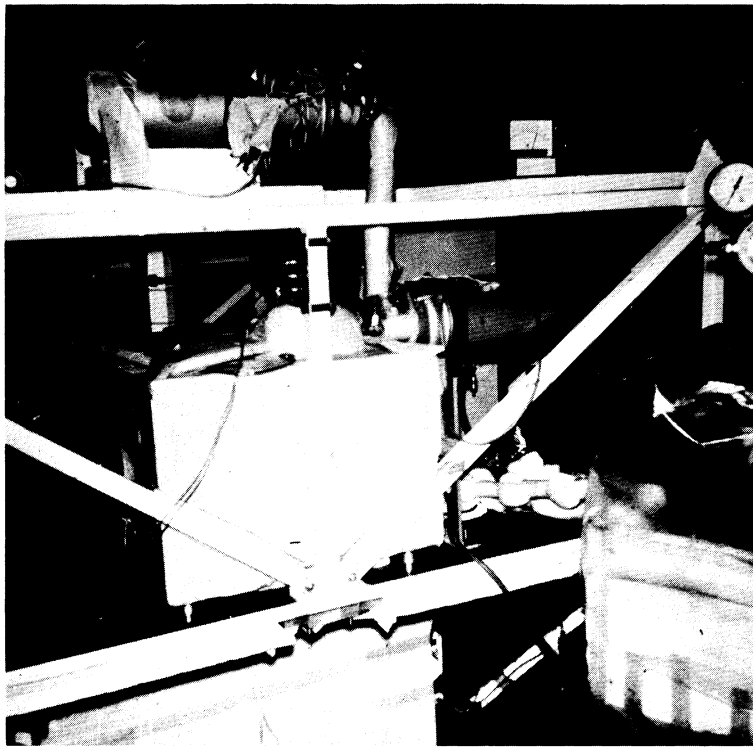
Figure 2. - Gondola installation

Figure 3. - Gondola on launching truck
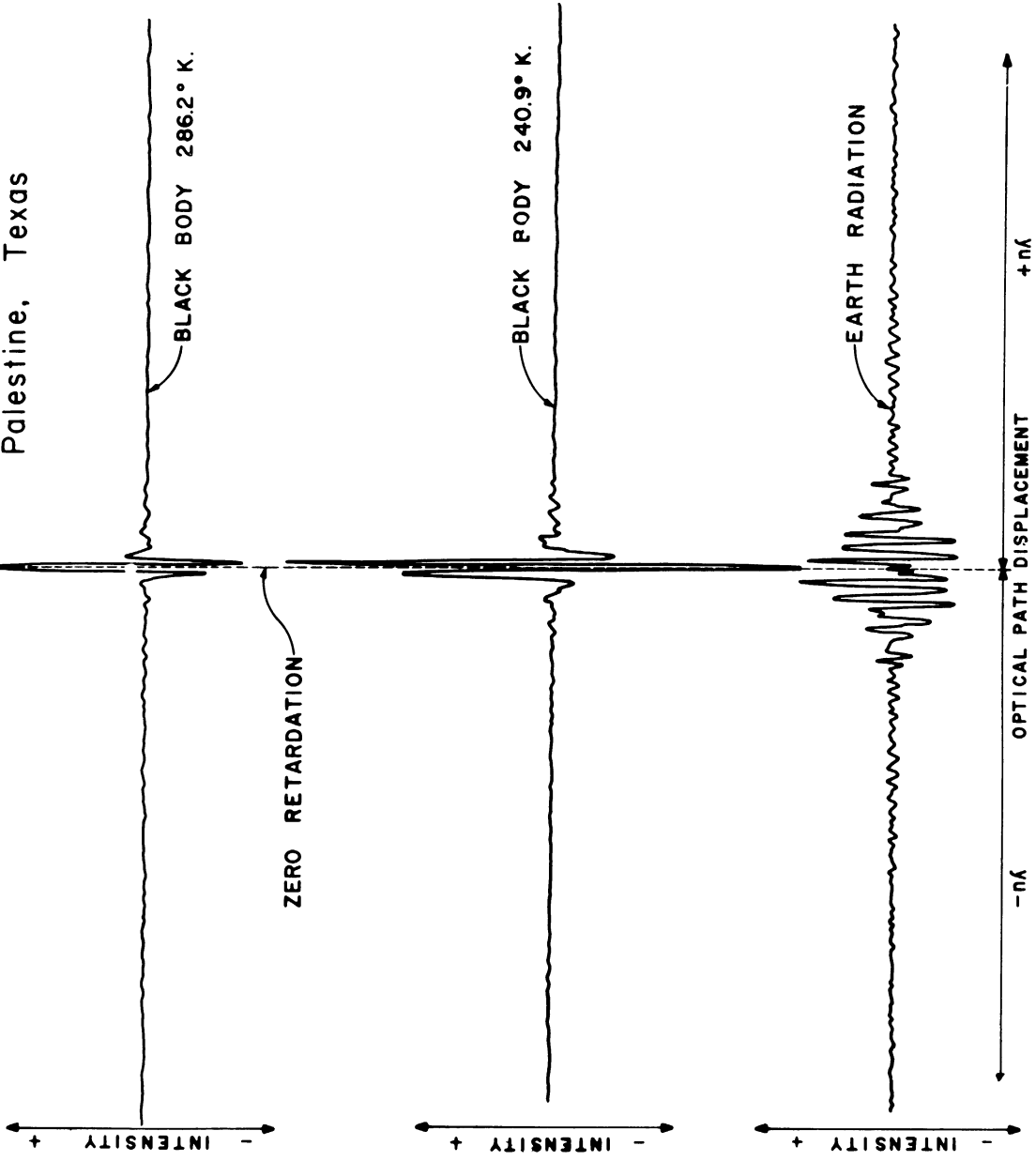
Figure 4 - Interferogram Comparison

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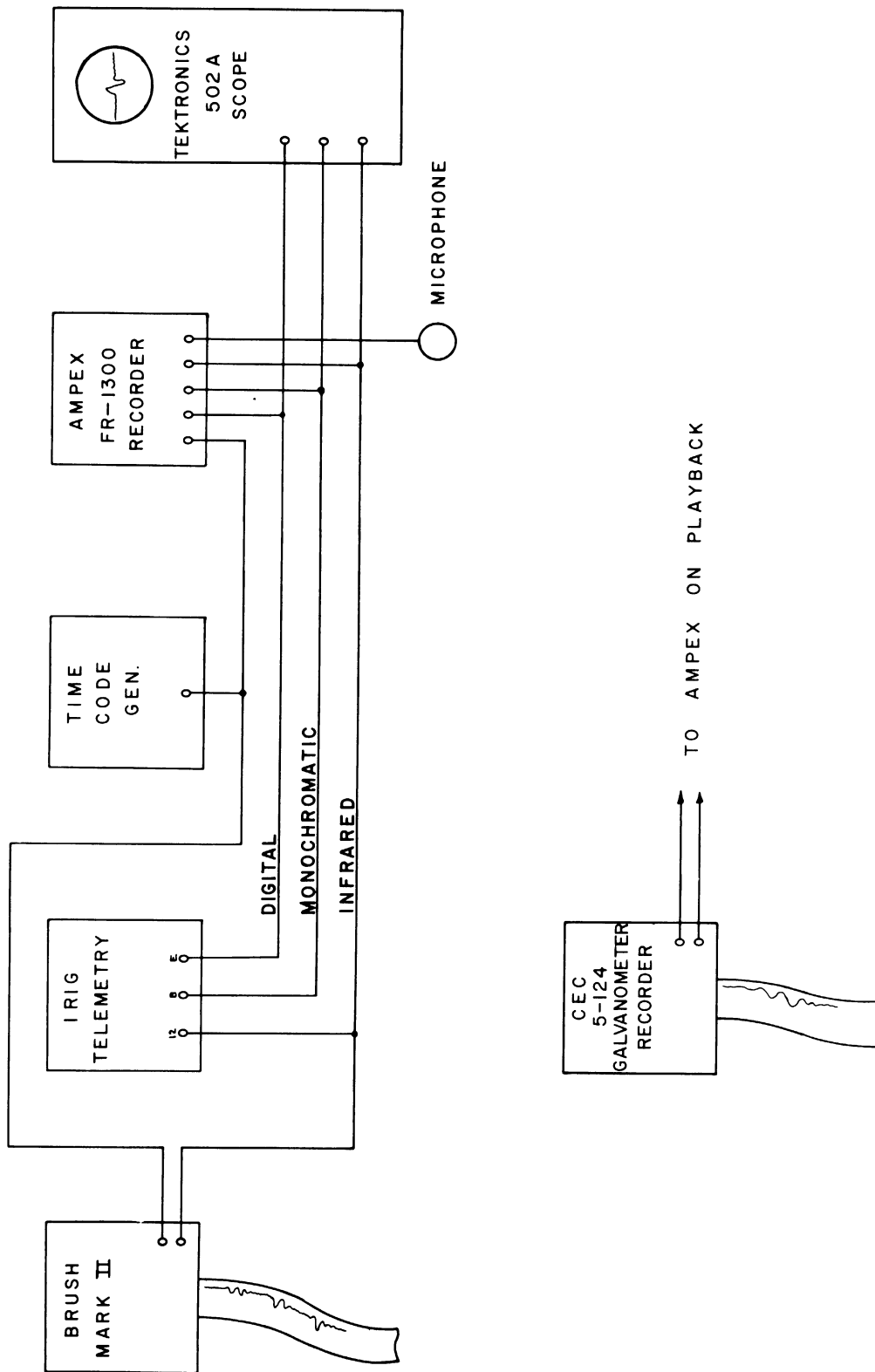
Figure 5. - Telemetry station block diagram
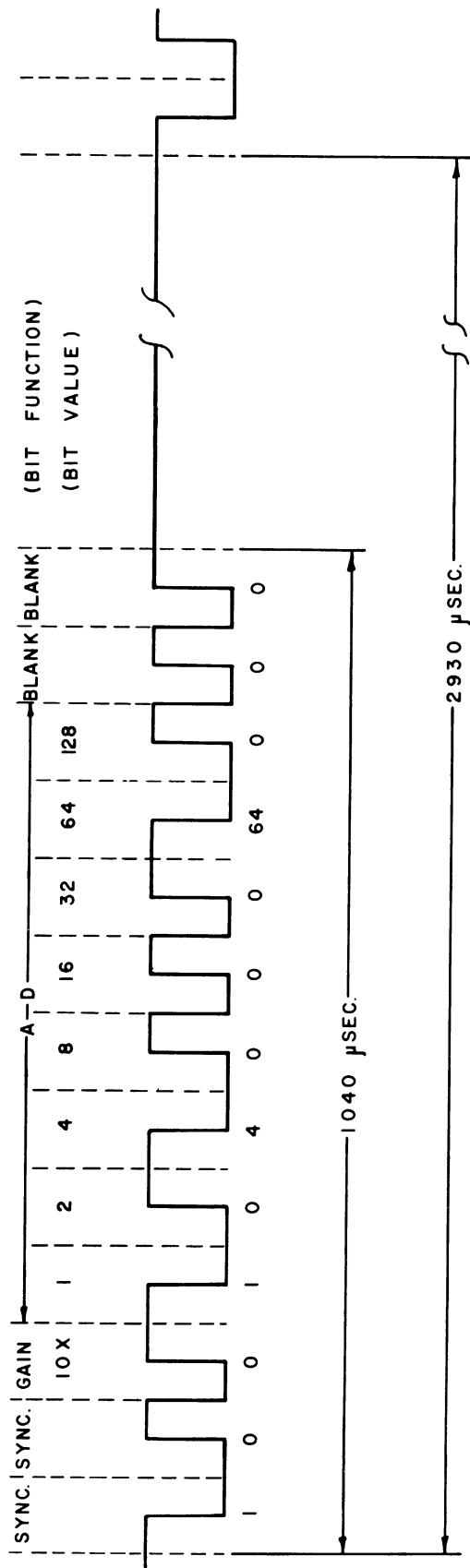
Figure 7 - Digital data format

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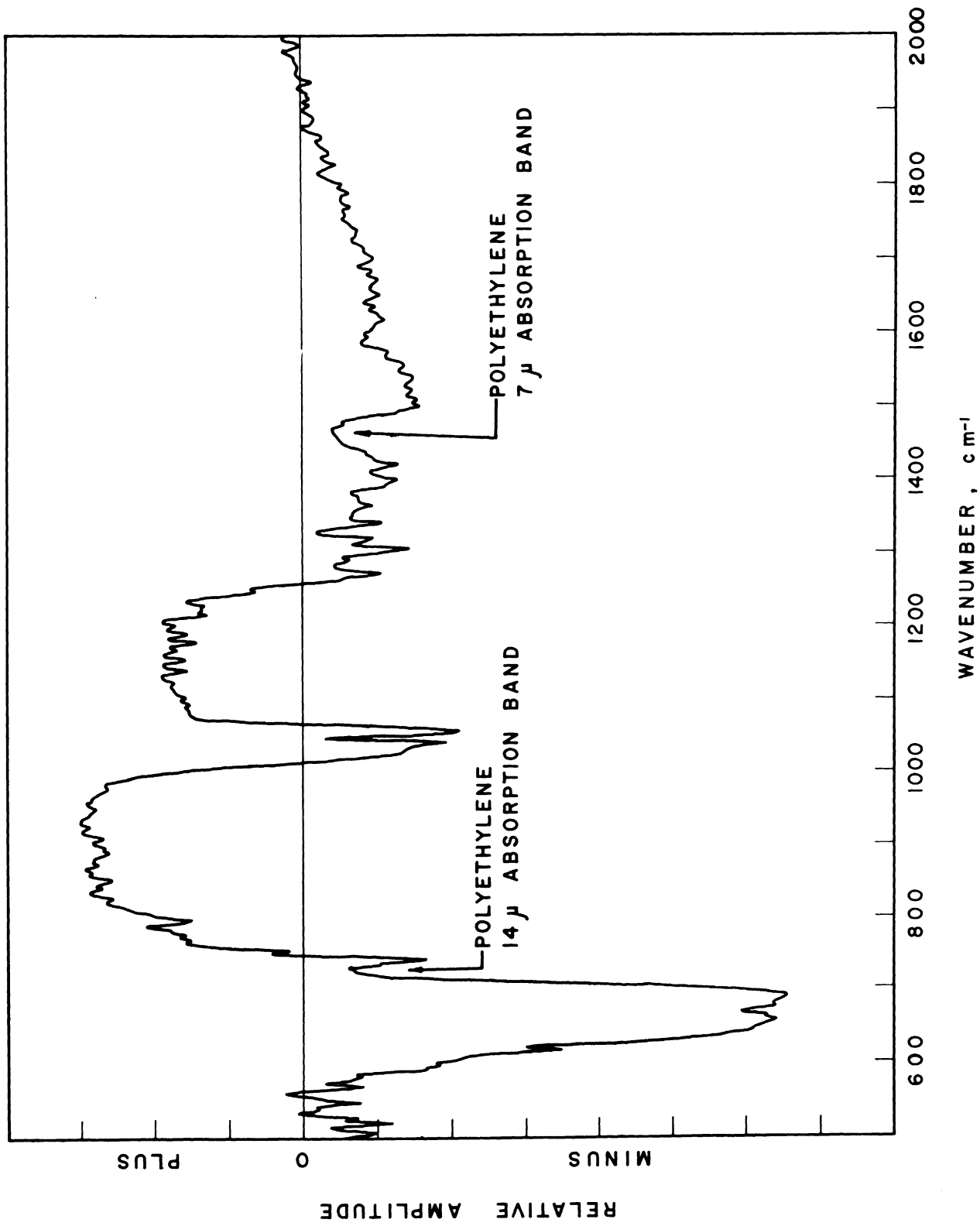
Figure 8 - Relative spectrum through polystyrene window

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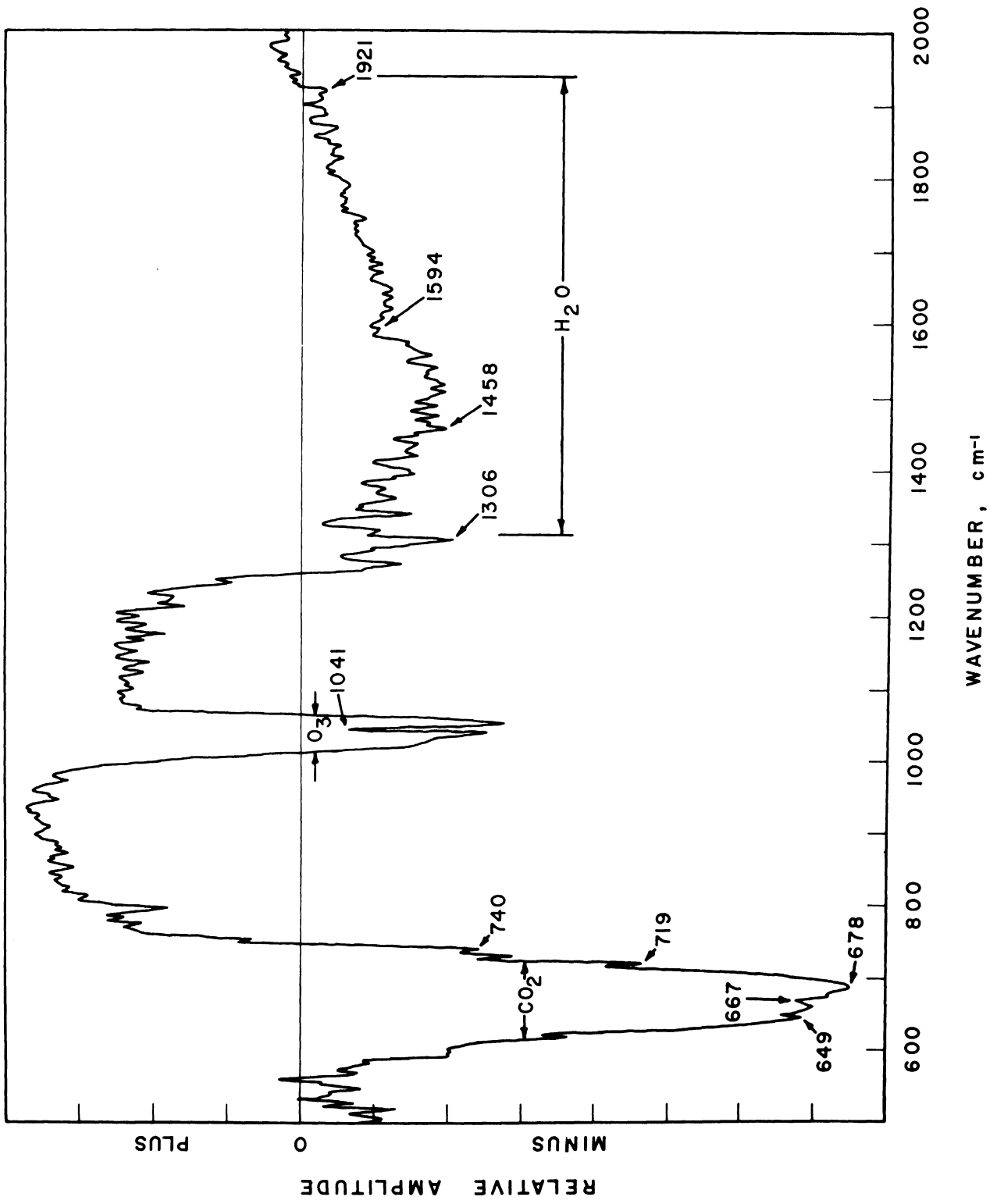
Figure 9 - Relative spectrum at 8:30 EST and live identification
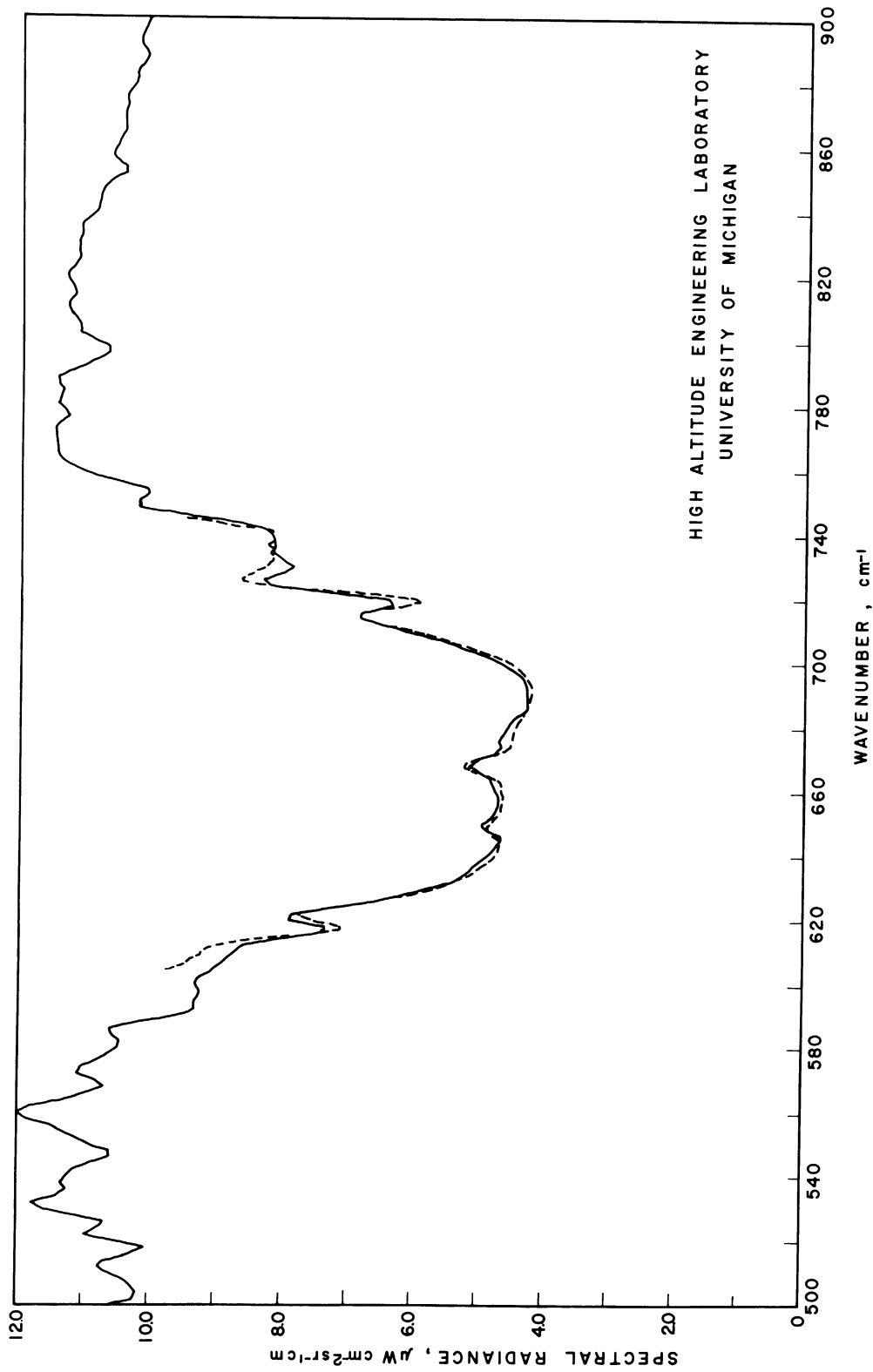
Fig.2. Theoretical radiances calculated using transmissivities of Drayson & Young[4] (600-750 cm^{-1}), and an average radiosonde temperature profile for Eastern Texas on May 8, 1966 (-----).

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
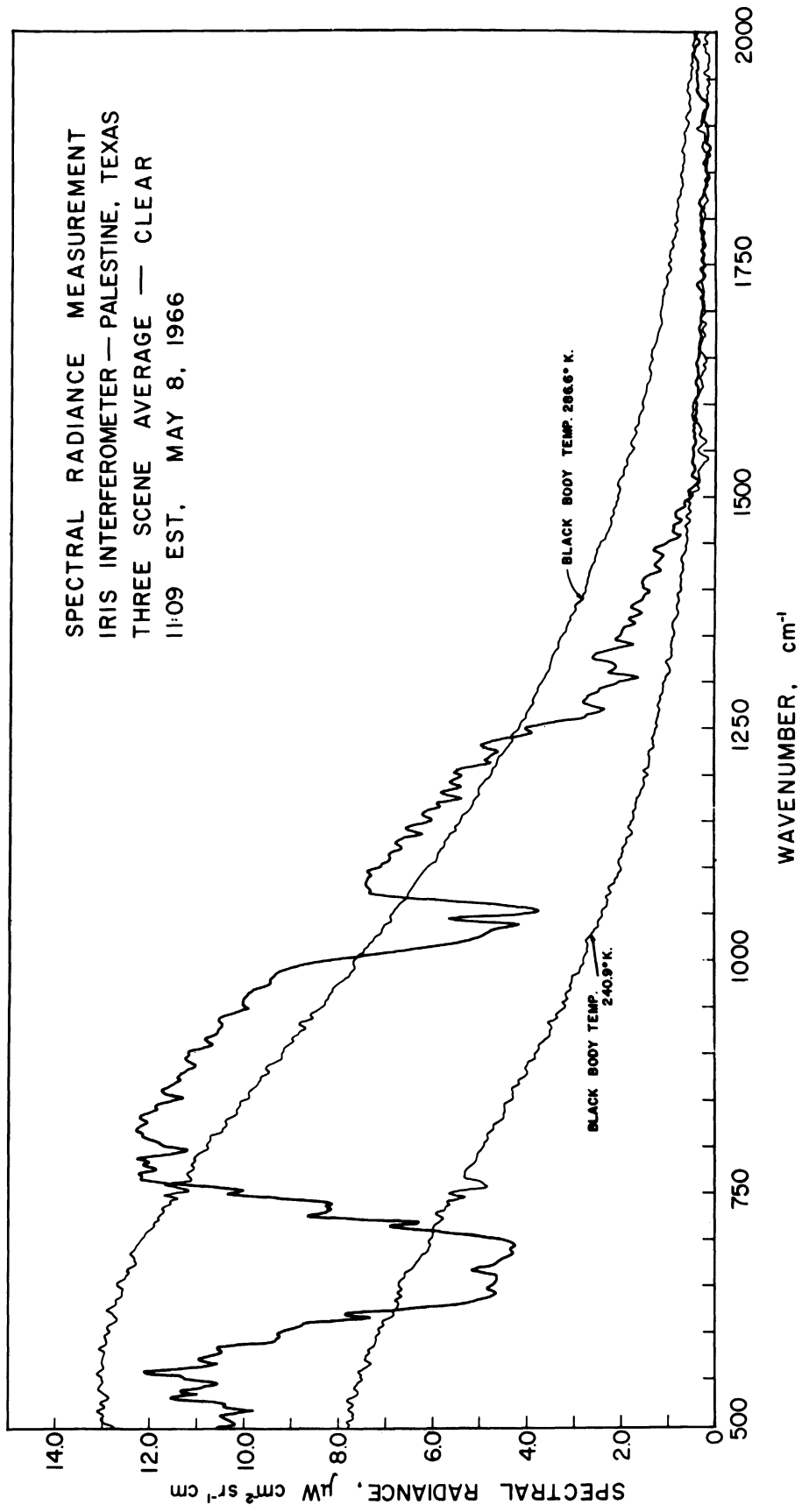
Figure 11 - Spectral data at 11:09 EST

SPECTRAL RADIANCE MEASUREMENT
IRIS INTERFEROMETER — PALESTINE, TEXAS
THREE SCENE AVERAGE — ESTIMATED
CLOUD COVER 25%, 15:11 EST, MAY 8, 1966

BLACK BODY TEMP. 286.6° K.

BLACK BODY TEMP. 240.9° K.
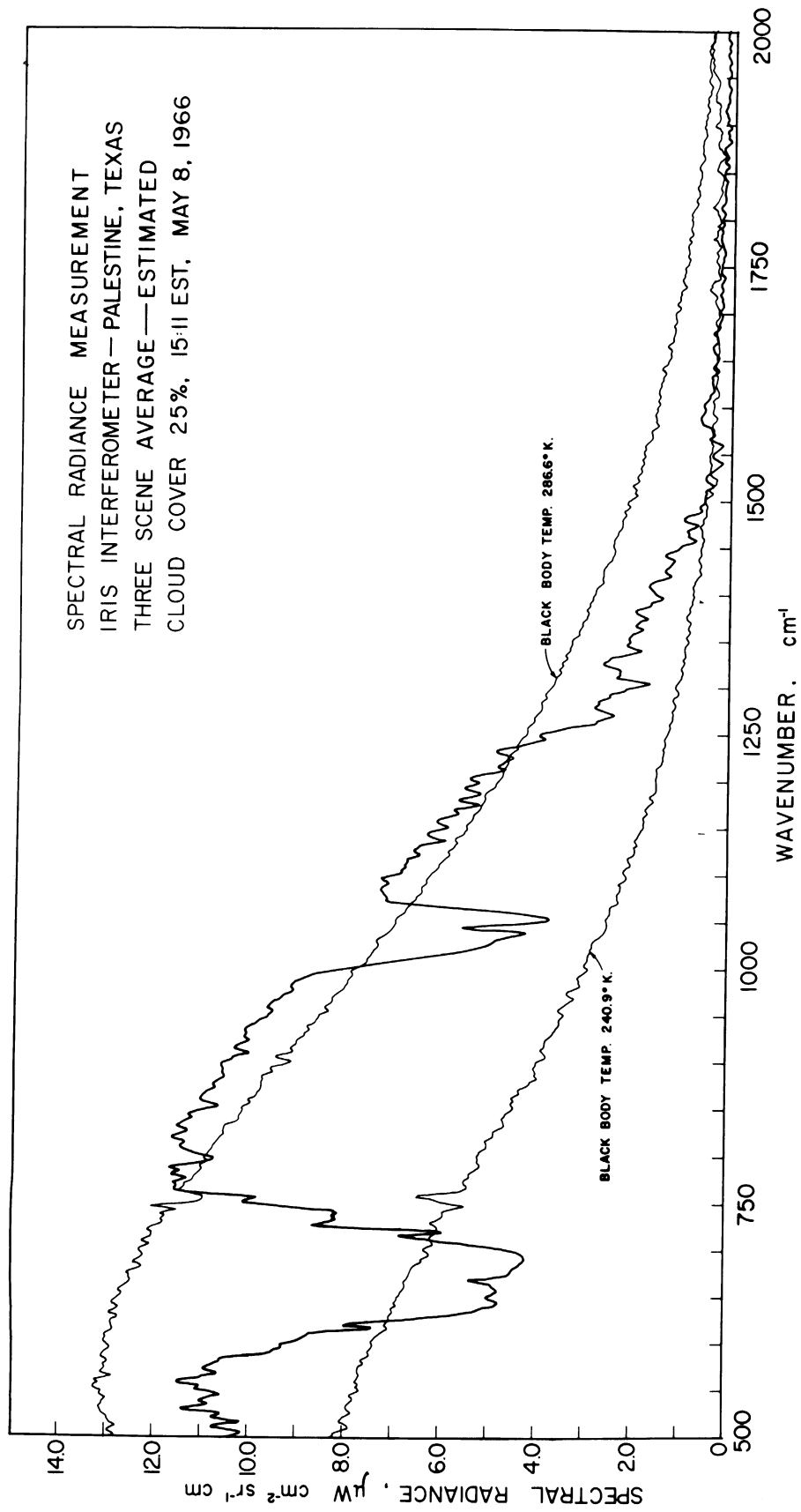
Figure 12 - Spectral data at 15:11 EST
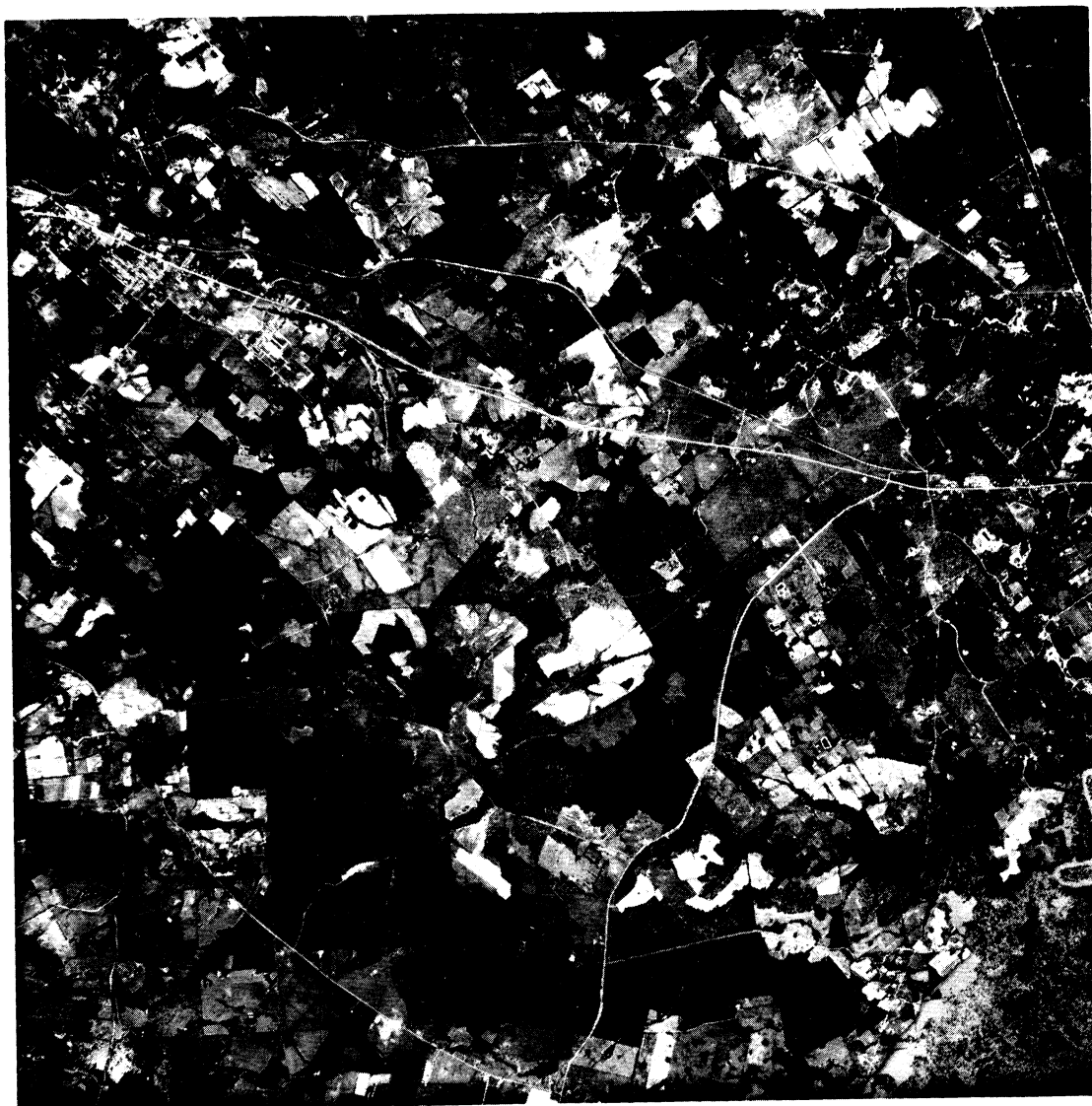
Figure 13 - Photograph of scene at 11:09 EST
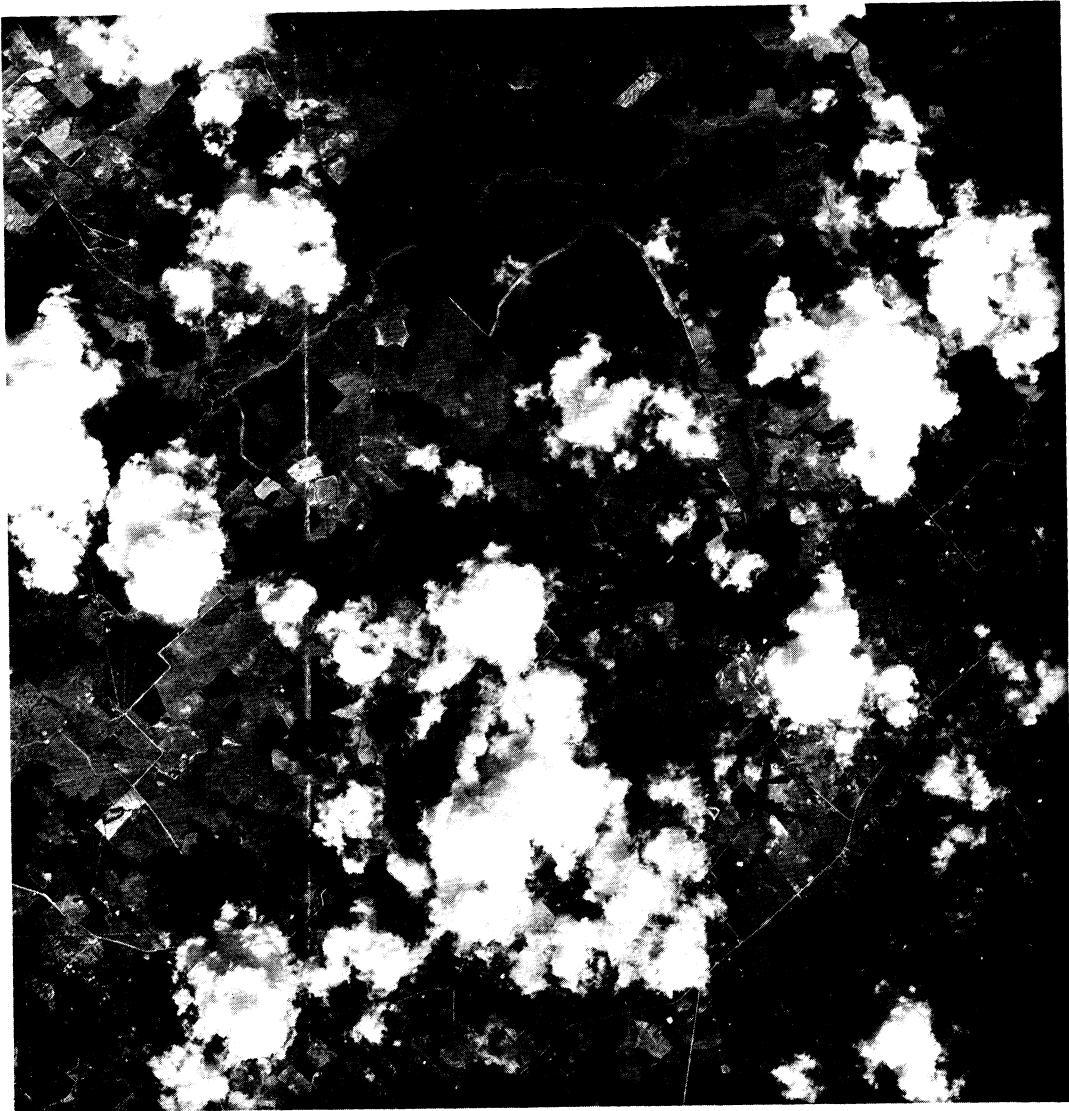
Figure 14 - Photograph of scene at 15:11 EST
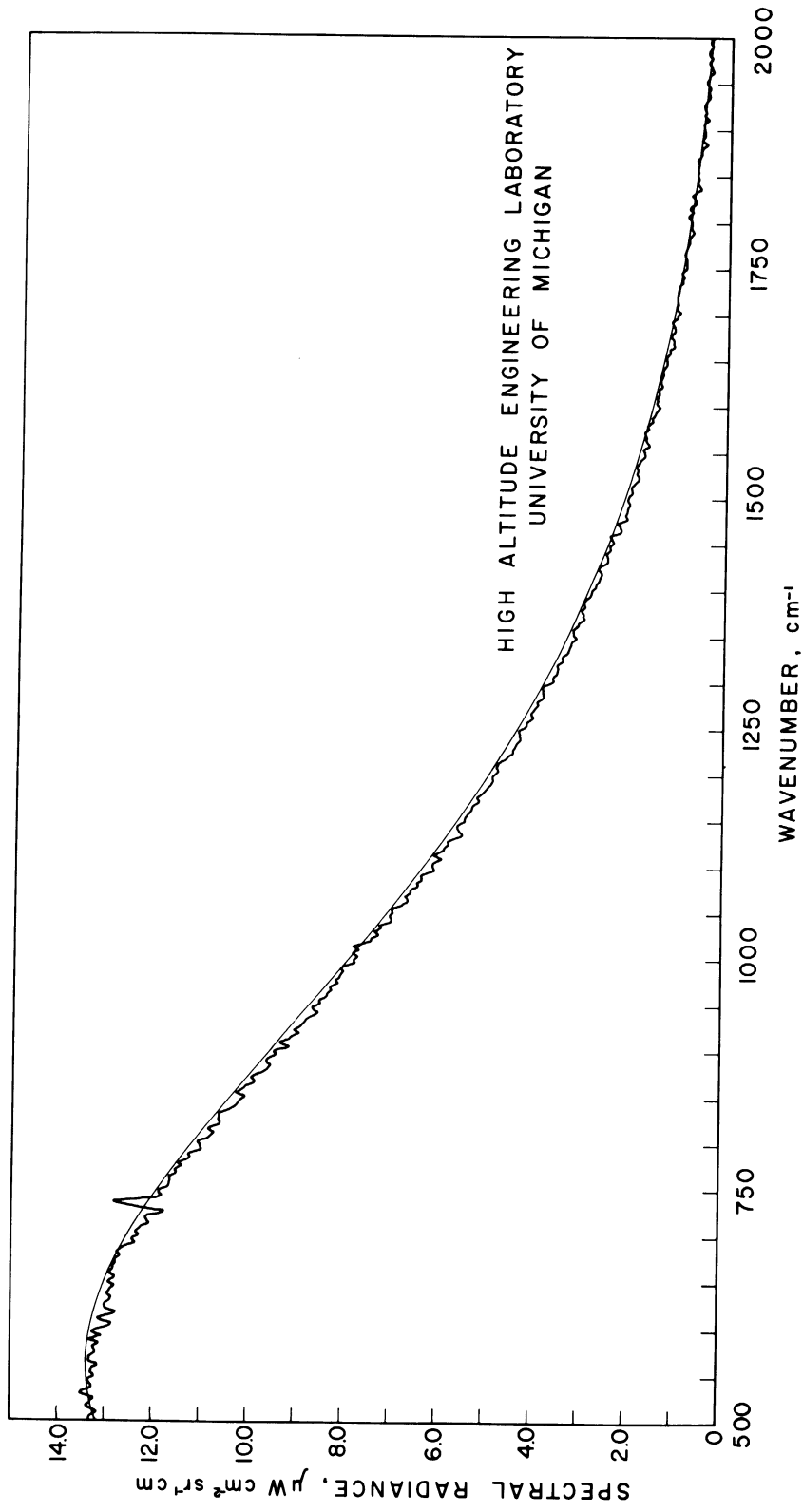
Figure 15 – Black body spectrum
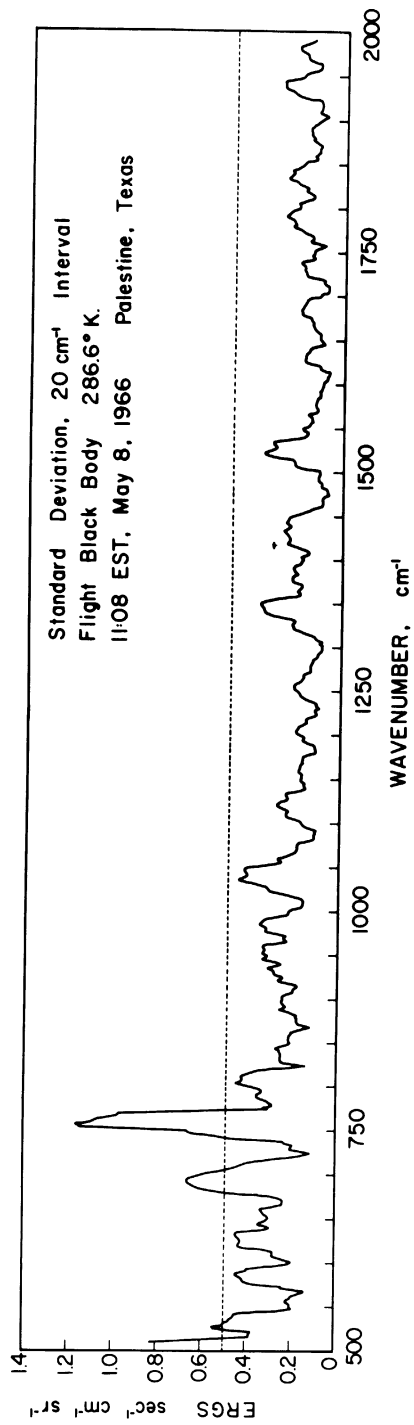
Figure 16 - Standard Deviation of black body data
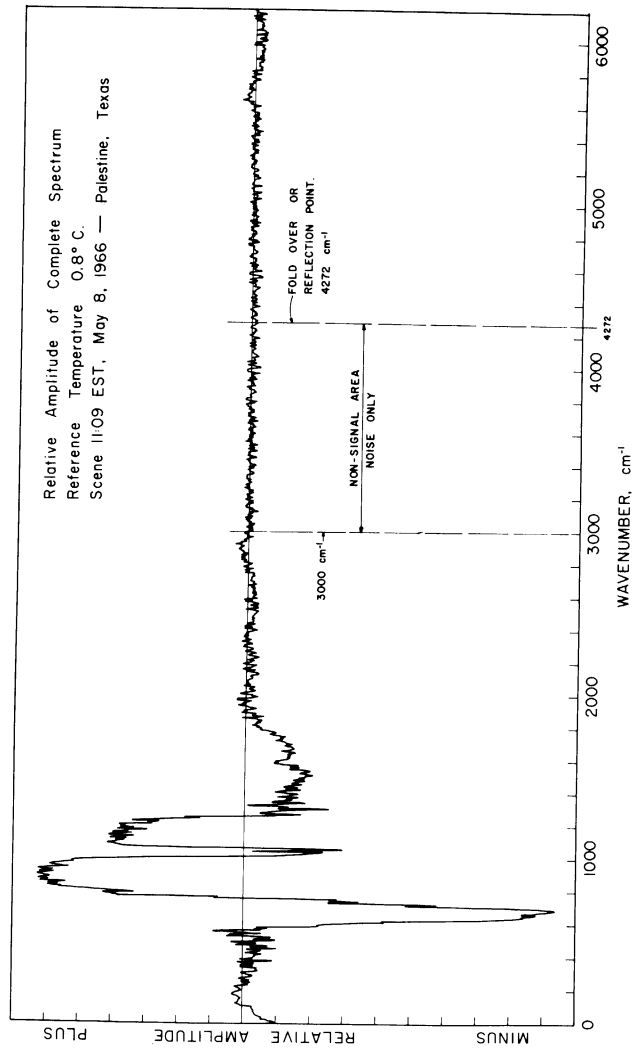
Figure 17 - Spectral data through the fold over region

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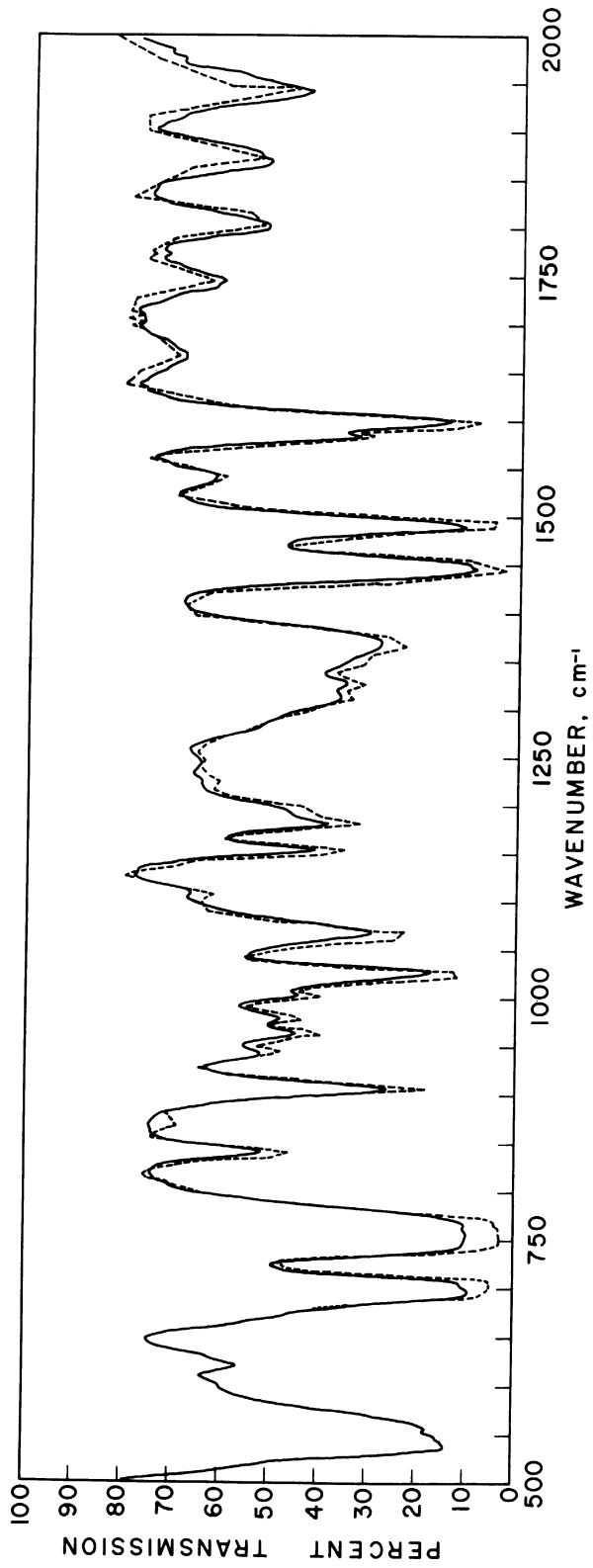
Polystyrene percent transmission measurements. Perkin-Elmer model 13U at approx. 2 cm⁻¹ resolution and with Nernst glower (----). I.R.I.S. scientific breadboard with approx. 5 cm⁻¹ resolution and a blackbody source at 333° K. (——)

Figure 18 - Wavelength Calibration
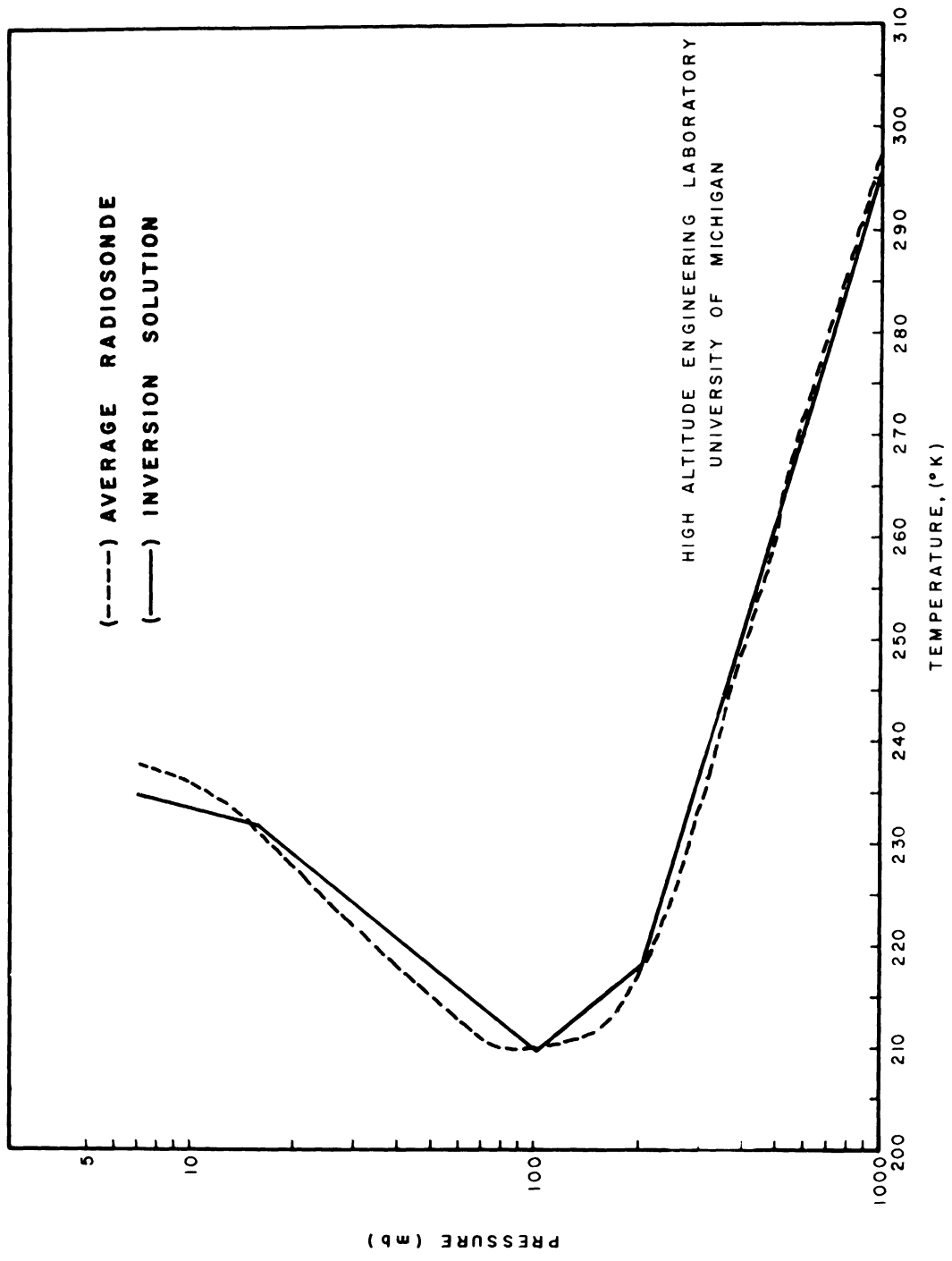
Figure 19 – Temperature inversion typical

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.

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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 20μ 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 0.3×10^{-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 1×10^{-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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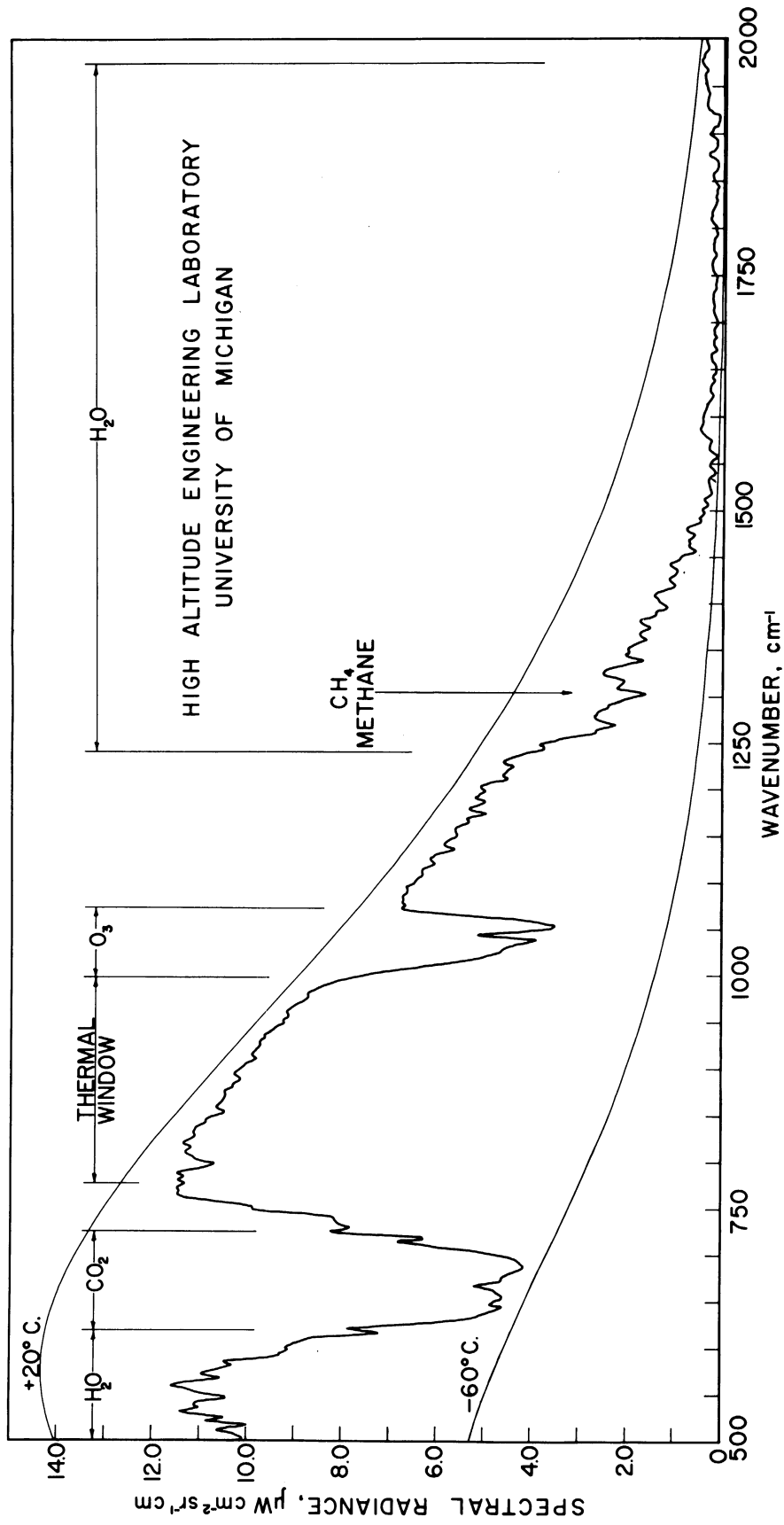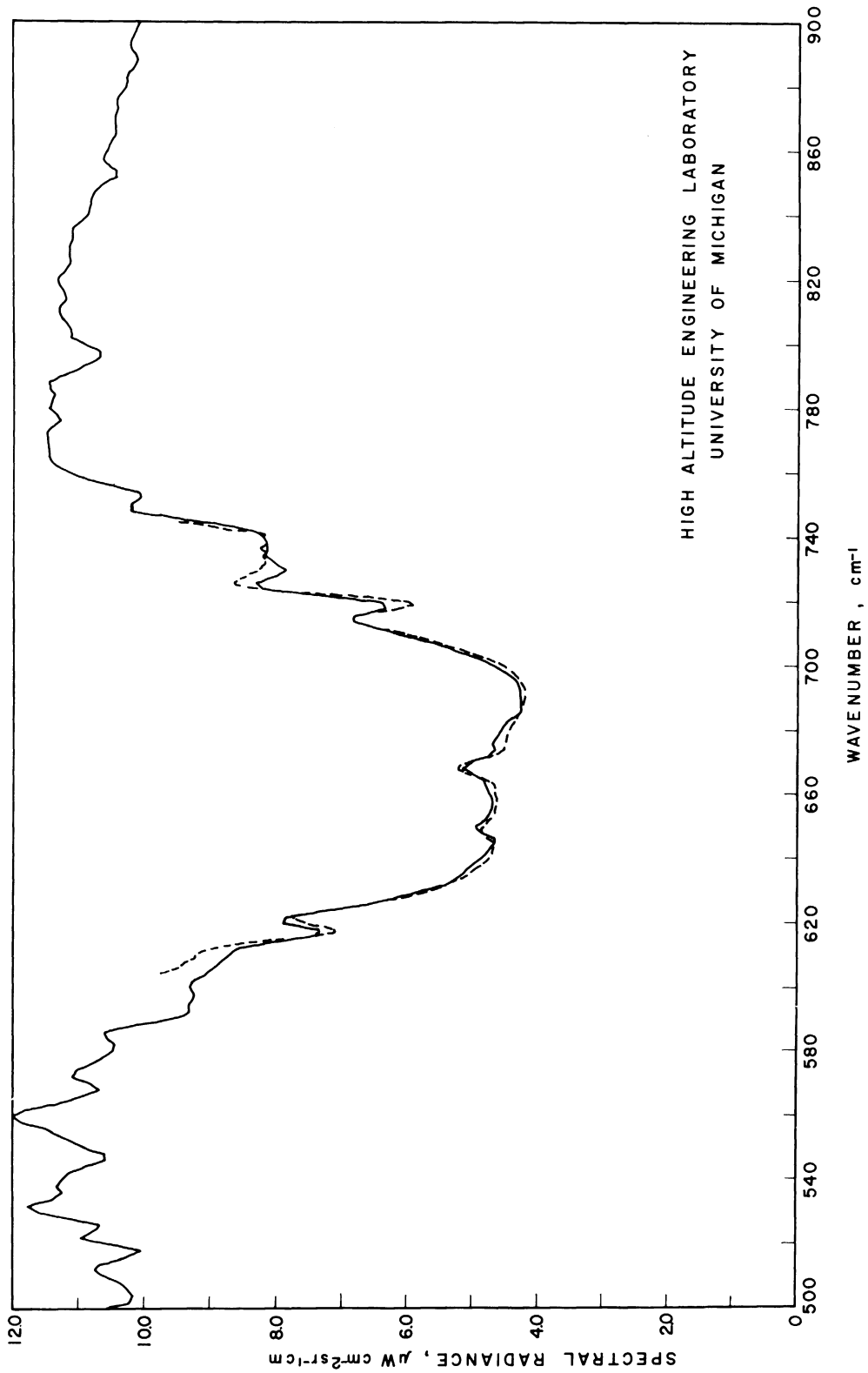
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Fig.1. Balloon flight Fourier Transform Spectrometer radiance measurements May 8, 1966 07:30 CST Palestine, Texas. Altitude 33.5 KM. A four scan average.

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
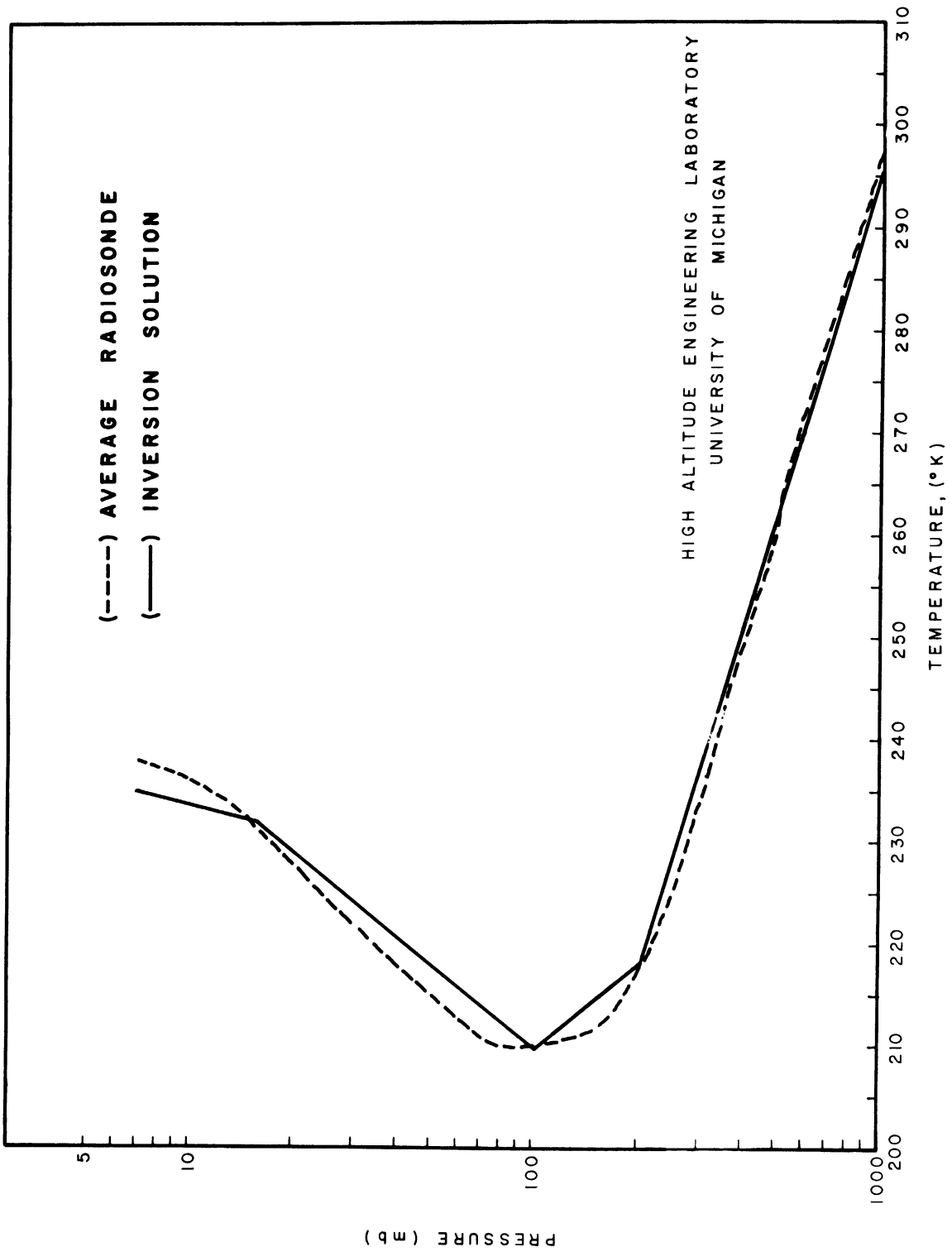May 8, 1966–07:30 CST Palestine, Texas. A three scan average (500–900 cm⁻¹) (——).

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.

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