NO. 23. INFRARED SPECTRA OF STARS AND PLANETS, II. WATER VAPOR IN OMICRON CETI

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1. Introduction

Infrared spectra of the variable star Omicron Ceti, particularly those taken at light minimum during the winter 1961/62, showed a peculiar shape of the energy curve. Normally the water vapor bands at 1.13, 1.38, and 1.87μ appear V-shaped on low dispersion spectra, and the maxima near 1.25, 1.6, and 2.1μ appear broad and rounded. For Omicron Ceti the maxima were found pointed instead, like inverted V's, while the H_2O minima were deep, broad, and U-shaped.

Because of the large widths of the water vapor bands, low-resolution spectra suffice to make quantitative comparisons with suitable standard stars. Such comparisons were made with the PbS spectrometer that was described in *Communications No. 15,* attached to the 82-inch telescope of the McDonald Observatory. The date was January 15, 1963, when the star was very nearly at minimum, about $9^{m}_{\cdot}0$ visually. This night followed an extensive invasion of arctic air over the central USA, with freezing temperatures and low humidities resulting over the region of the McDonald Observatory.

2. The Spectra

The series of spectra relevant here is listed in Table 1. After 5^h U.T. other stars were recorded besides those listed, but the spectra of α Aur and α Boo are characteristic of the conditions encountered during the remainder of the night. Clearly, the atmospheric conditions were quite uniform and the spectrophotometric comparisons valid, with the computed air masses a sufficient indication of the total atmospheric water content.

The stars were observed under as nearly as possible identical conditions: (1) slitless; (2) guiding by the reflected image from a microscope cover glass placed over the slit; (3) the same scan and chart rates used for all stars; (4) comparable air masses; (5) an interlacing comparison sequence: star, star, standard, standard, star, standard, etc.

The principal standards observed were α Ori and β And, M1 and M0 stars respectively. In order to check whether they themselves might contain observable quantities of water vapor, a further comparison was made with β Orionis which showed convincingly that these early M stars had no observable H_2O content. The abundance of atmospheric water vapor was estimated at 0.5-1.0 mm precipitable water in a vertical column, and the content of the early M stars is therefore probably well below 0.1 mm.

For Omicron Ceti, however, the H_2O bands are strikingly different. Figures 1 and 2 indicate by dotted lines the expected profile in the absence of stellar H_2O. The observed stellar bands in o Ceti are not merely deeper; they are much *wider,* causing the peculiar shape of the continuum already referred to. Presumably this extra width is due to "hot" bands, not appreciably excited in the telluric spectrum and therefore not present even for large telluric H_2O contents. Spectra of o Ceti with resolutions up to 2000 have been obtained on several occasions. These will be published later with similar records for other stars.

For ready reference, the dispersion curve of the quartz prism used is given in Figure 12. The resolution of the spectra $\lambda/\Delta\lambda$ is about 50-60.

Several other M stars have been observed with the same resolution as well as with resolutions up to 2000-3500. Among these are ρ Persei, μ Geminorum (both M4), χ Cygni (near maximum, 6th mag., M6) and R Leonis (near minimum, $8\overset{\mathrm{m}}{.}2$, M7). None of these stars have shown any appreciable excess strength in their H_2O bands. Only o Ceti has consistently shown the remarkable profiles of the infrared H_2O bands.

The possible presence of H_2O in very cool stars was predicted many years ago by H. N. Russell (1934). A quantitative laboratory calibration of the water vapor content observed in o Ceti will be attempted at a later time.

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Further comments on interferometer vs. spectrometer. — On page 116 the statement was made that "the total information content of each element must be constant and not dependent on *n* which is arbitrary." This statement applied to the case where a constant spectral interval was observed and *n* was varied. If, instead, the spectral interval were increased with *n*, the total energy received would increase roughly proportionally, and with it the signal-to-noise ratio and thus, in principle, the information content.

My earlier comments on the efficiency of the spectral interferometer related to an instrument of the type used by Gebbie *et al.*, where a single interferogram was recorded with a time constant comparable to that used in the spectrometer. If the considerations given by Kahn (1959) could be realized in practice, it should be possible to scan the Venus spectrum with the interferometer in about one second (with an uncooled PbS cell, which has a short response time).

However, a further complication in the astronomical use of the interferometer must be mentioned. It is caused by *stellar scintillation.* It has been my experience with the 82-inch telescope that even on bright stars the records obtained with a spectrometer are often noisy if a time constant as short as one second is used. This noise is not electronic but due to stellar scintillation. It usually becomes inappreciable for time constants of a few seconds unless the scintillation is excessive and/or the seeing very bad. For smaller telescopes the scintillation effects would be worse. At a given instant, different wavelengths will be affected differently by scintillation (owing to atmospheric dispersion and phase delays), and the effect on the spectral interferometer will be complex. Scintillation effects (i.e., fluctuations of $\simeq 1\%$) will probably limit the number of spectral elements that can be deduced from a single stellar interferogram to $n < 100$ unless a very slow scan is used (intensity fluctuations $< < 1\%$) or, better (because of the variable water vapor content of the atmosphere), the interferogram itself is the average of a *large* number of scans.

For planets the case will be more favorable as will be the application to stars observed in very large mirrors (which may have optically imperfect images).

I am indebted to Dr. H. L. Johnson for clarifying discussions on this subject.

REFERENCES

Kahn, F. D. 1959, *Ap. J.*, *129*, 518.
Russell, H. N. 1934, *Ap. J.*, *79*, 317.

TABLE 1
DATA FOR SPECTRAL RECORDS

Fig. No.	Star	Vis. Mag.	Type	U.T.		Hour Angle		Gain*	Time Const.	Air Mass
				Begin	End	Begin	End			
1	*o* Ceti	9.0	M8	2:34	2:45	0:57W	1:07	4-5	1 sec	1:26
2	*o* Ceti	9.0	M8	2:47	3:00	1:09W	1:22	4-5	1	1:28
3	α Ori	0.9	M1	3:10	3:20	2:03E	1:53	3-6	1	1:24
4	α Ori	0.9	M1	3:22	3:36	1:52E	1:38	3-6	1	1:20
5	*o* Ceti	9.0	M8	3:43	3:55	2:06W	2:18	4-5	1	1:45
6	β And	2.4	M0	4:04	4:15	3:36W	3:48	4-5	1	1:45
7	β And	2.4	M0	4:17	4:26	3:49W	3:58	4-5	1	1:52
8	β Ori	0.3	B8	4:58	5:09	0:26W	0:37	5-3	2	1:22
9	β Ori	0.3	B8	4:40	4:47	0:08W	0:15	5-5	2	1:21
10	α Aur	0.1	G0	7:17	7:31	2:44W	2:58	4-5	2	1:25
11	α Boo	0.2	K2	12:18	12:31	1:15E	1:02	4-4	2	1:06

*First digit step is 10x or 2.5 mag.; second digit step is 0.5 mag.; 3-6 = 4-1, etc.

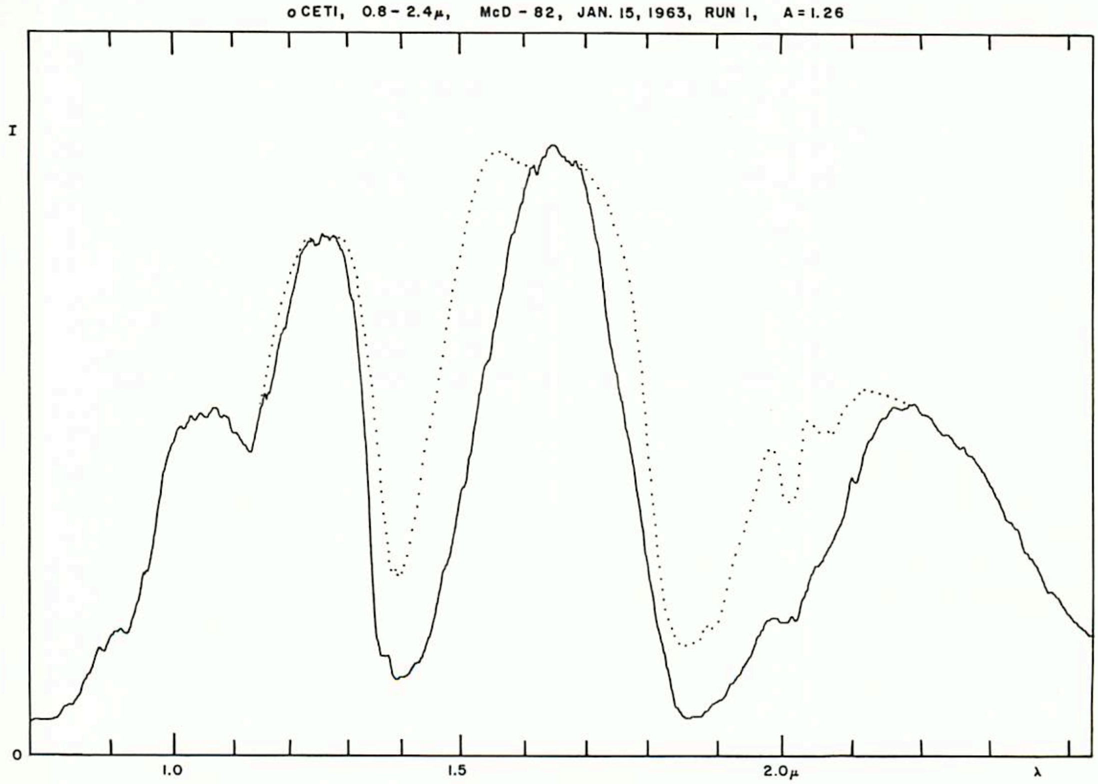

Fig. 1.

Erratum: The colons in the last column of Table 1 should be decimal points.

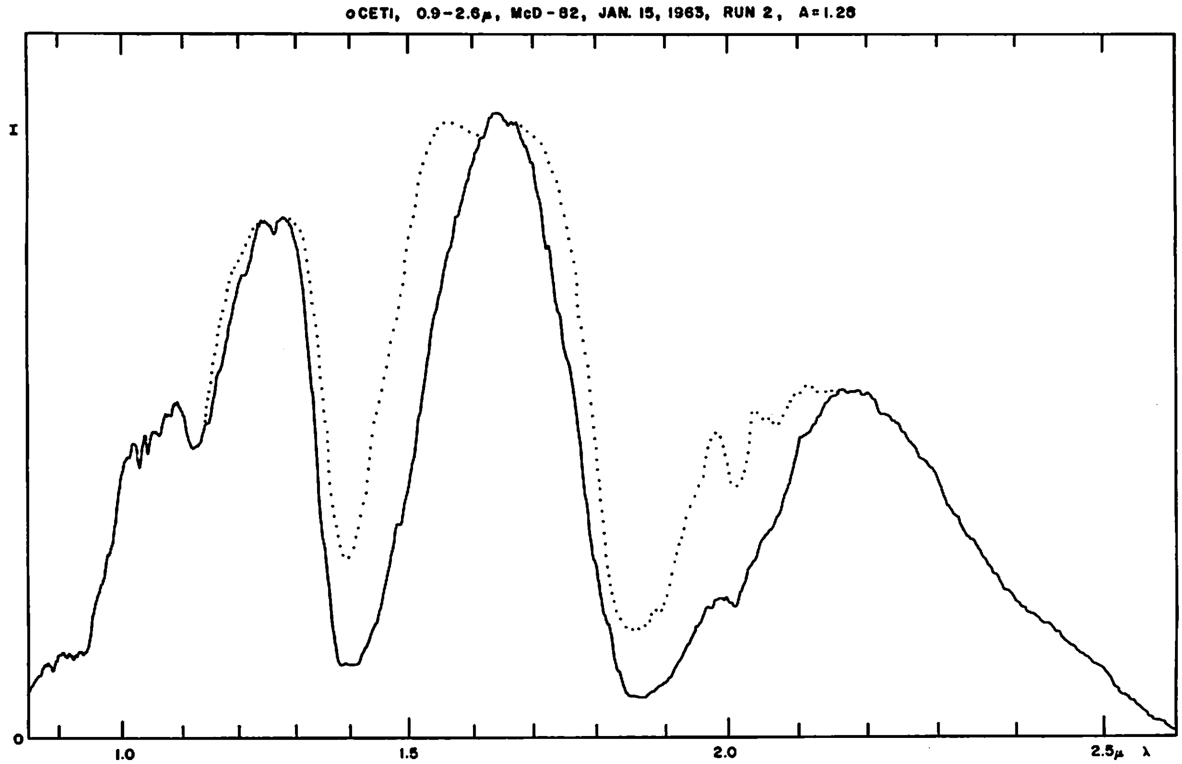
o CETI, 0.9–2.6μ, McD – 82, JAN. 15, 1963, RUN 2, A=1.26
I
0
1.0
1.5
2.0
2.5μ
λ

Fig. 2.

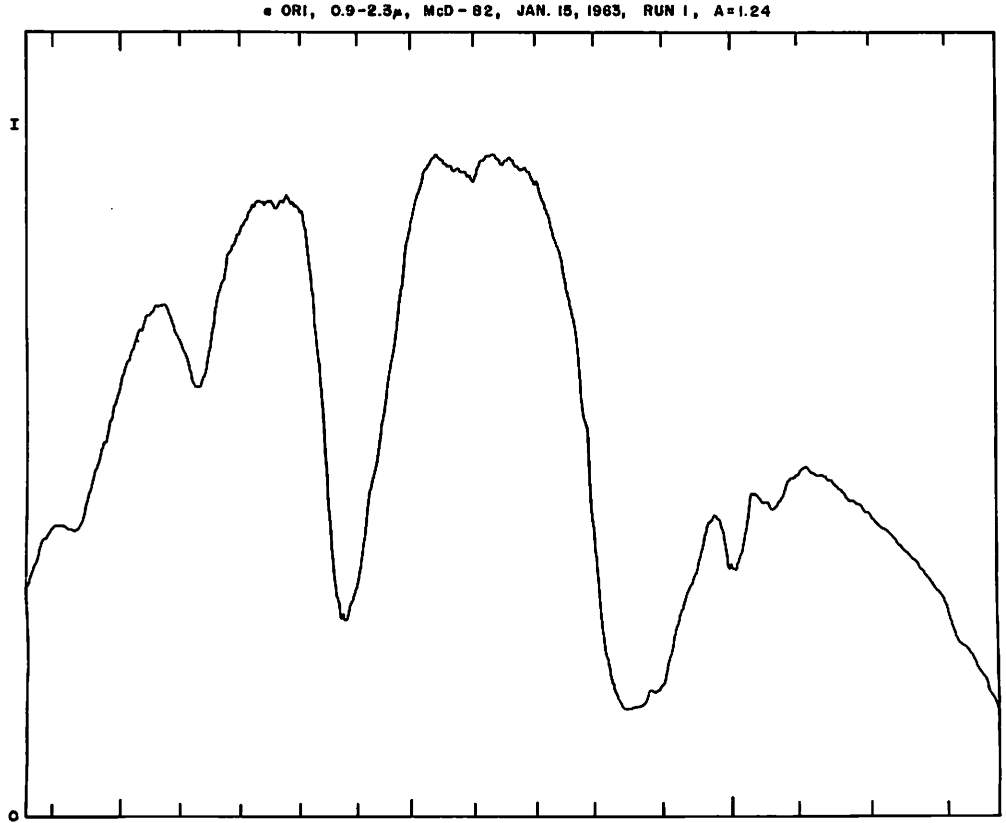
ε ORI, 0.9–2.3μ, McD – 82, JAN. 15, 1963, RUN 1, A=1.24
I
0
1.0
1.5
2.0μ
λ

Fig. 3.

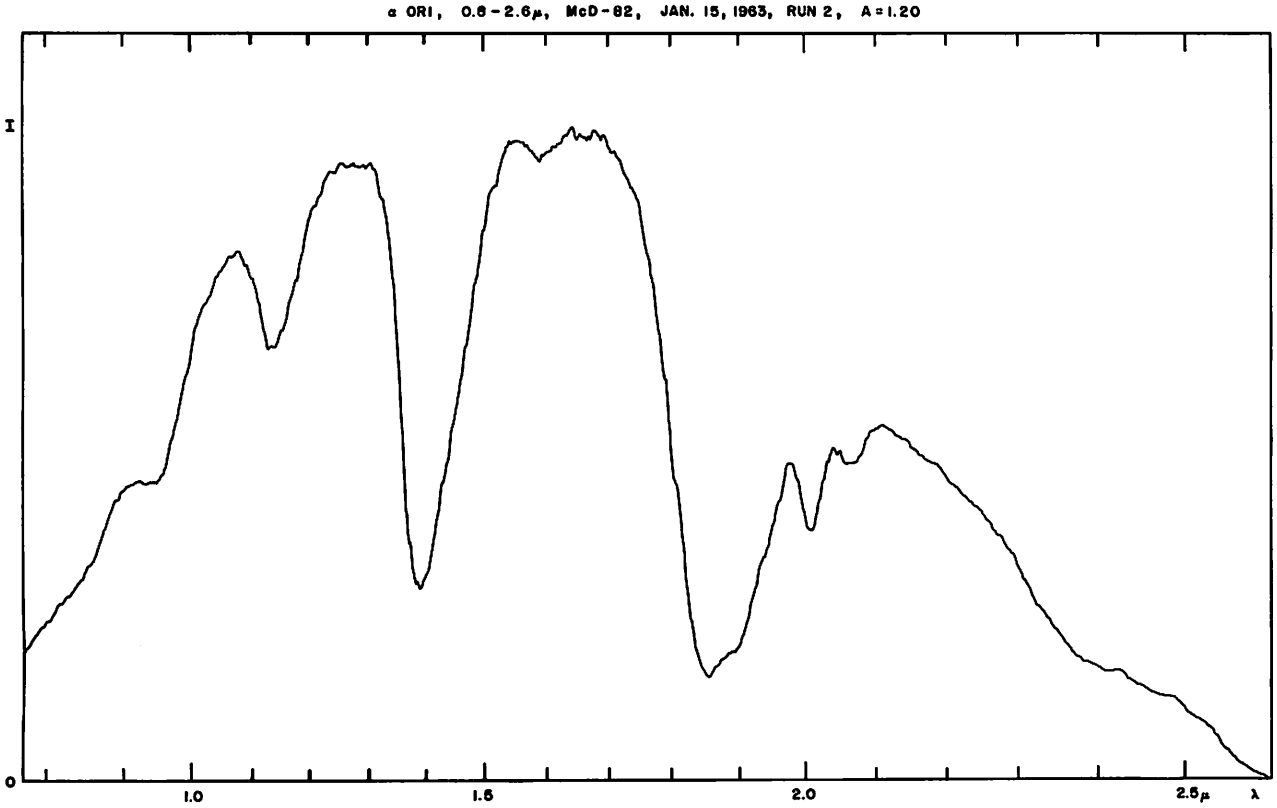
α ORI, 0.8 – 2.6μ, McD – 82, JAN. 15, 1963, RUN 2, A = 1.20
I
0
1.0
1.5
2.0
2.5μ
λ

Fig. 4.

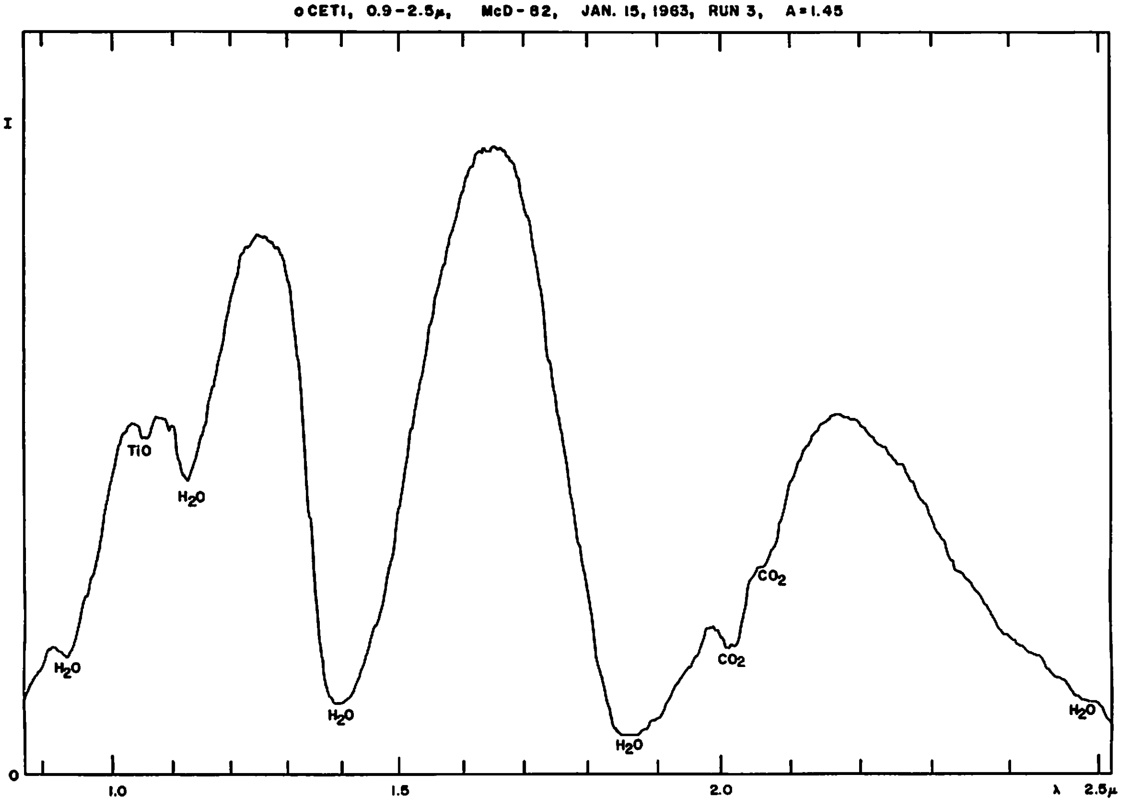
o CETI, 0.9 – 2.5μ, McD – 82, JAN. 15, 1963, RUN 3, A = 1.45
I
0
TiO
H_2O
H_2O
H_2O
H_2O
CO_2
CO_2
H_2O
1.0
1.5
2.0
λ
2.5μ

Fig. 5.

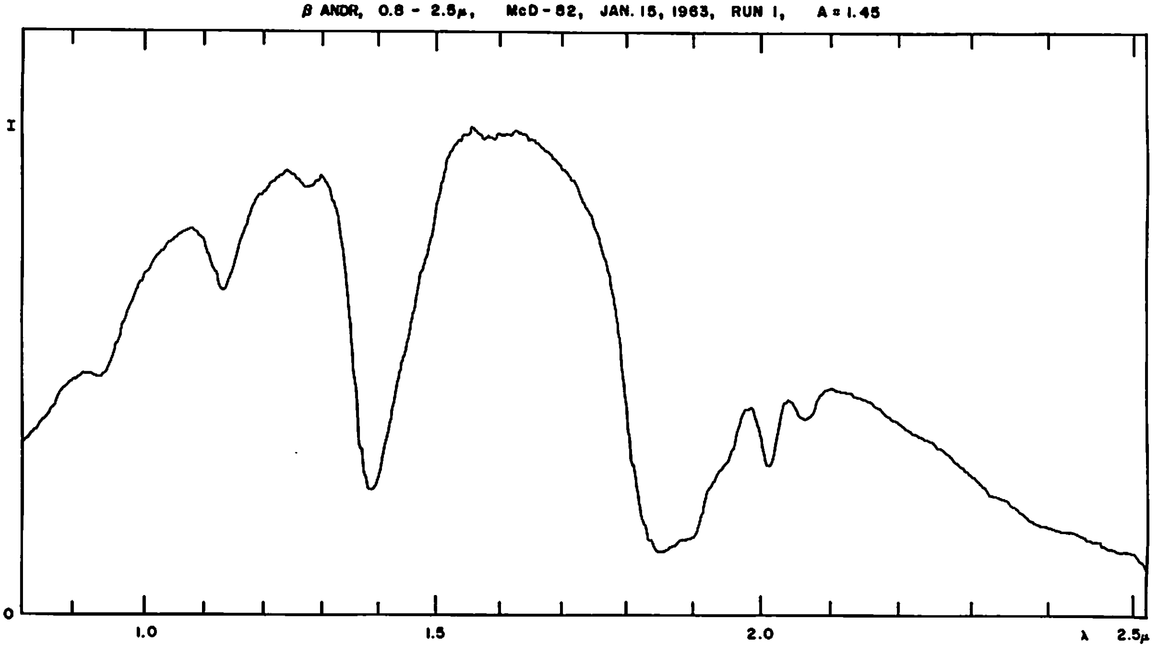
β ANDR, 0.8 - 2.5μ, McD-82, JAN. 15, 1963, RUN 1, A = 1.45
I
0
1.0
1.5
2.0
λ 2.5μ

Fig. 6.

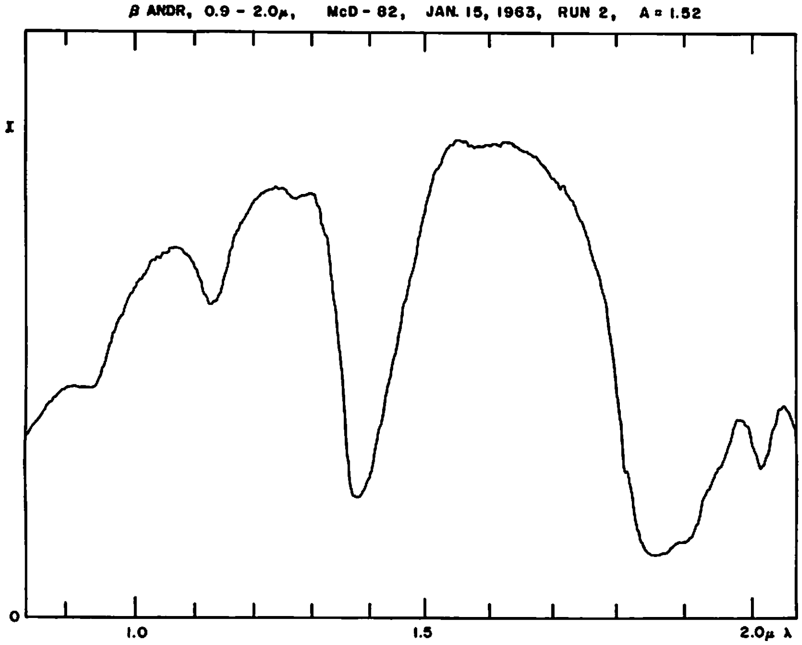
β ANDR, 0.9 - 2.0μ, McD-82, JAN. 15, 1963, RUN 2, A = 1.52
I
0
1.0
1.5
2.0μ λ

Fig. 7.

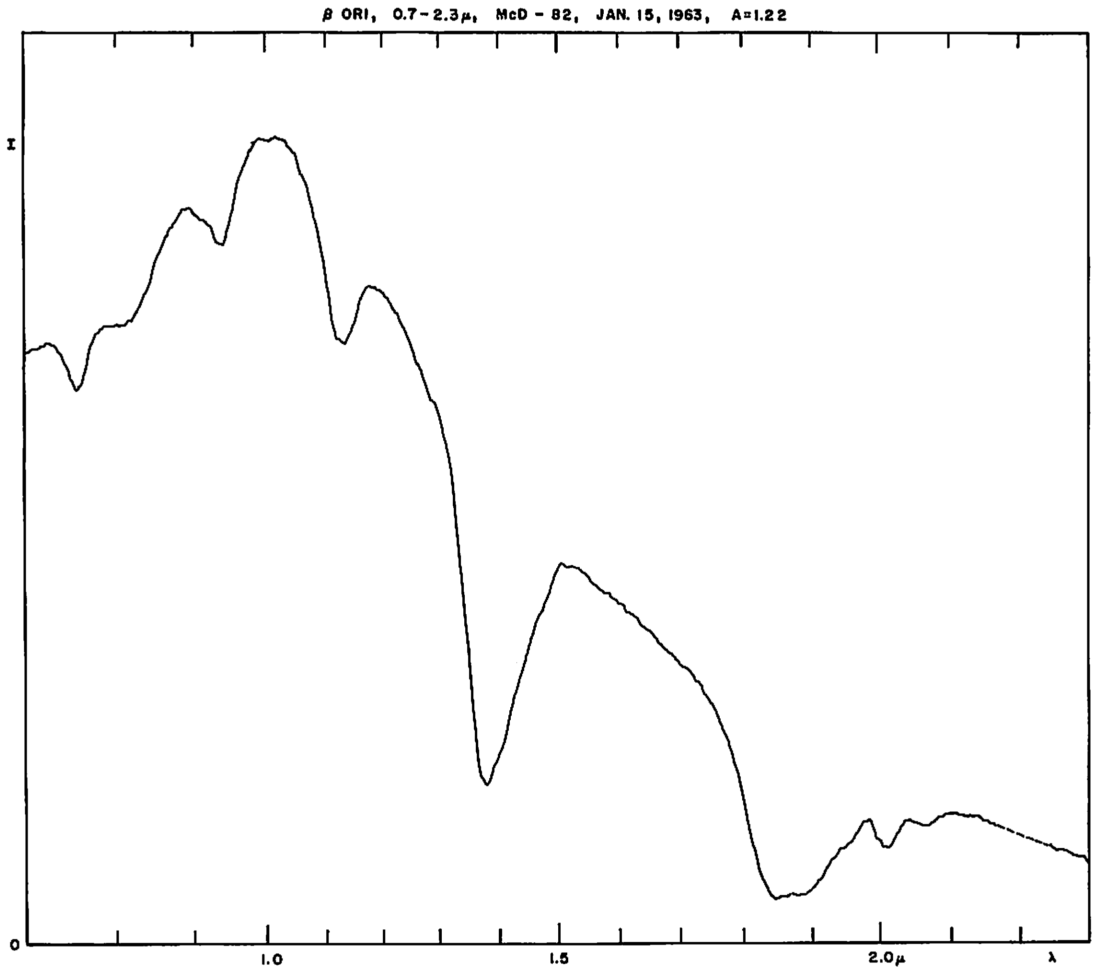

Fig. 8.

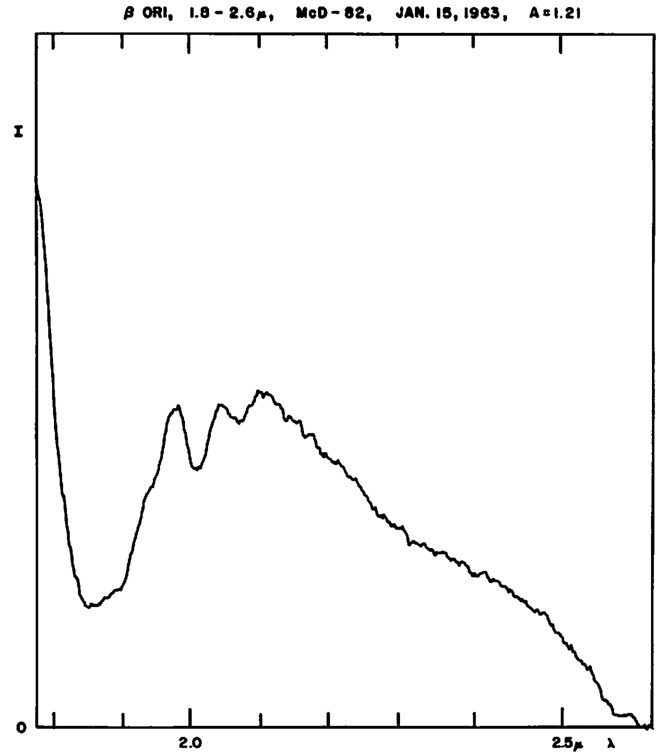
β ORI, 1.8 - 2.6μ, McD-82, JAN. 15, 1963, A=1.21
I
0
2.0
2.5μ
λ

Fig. 9.

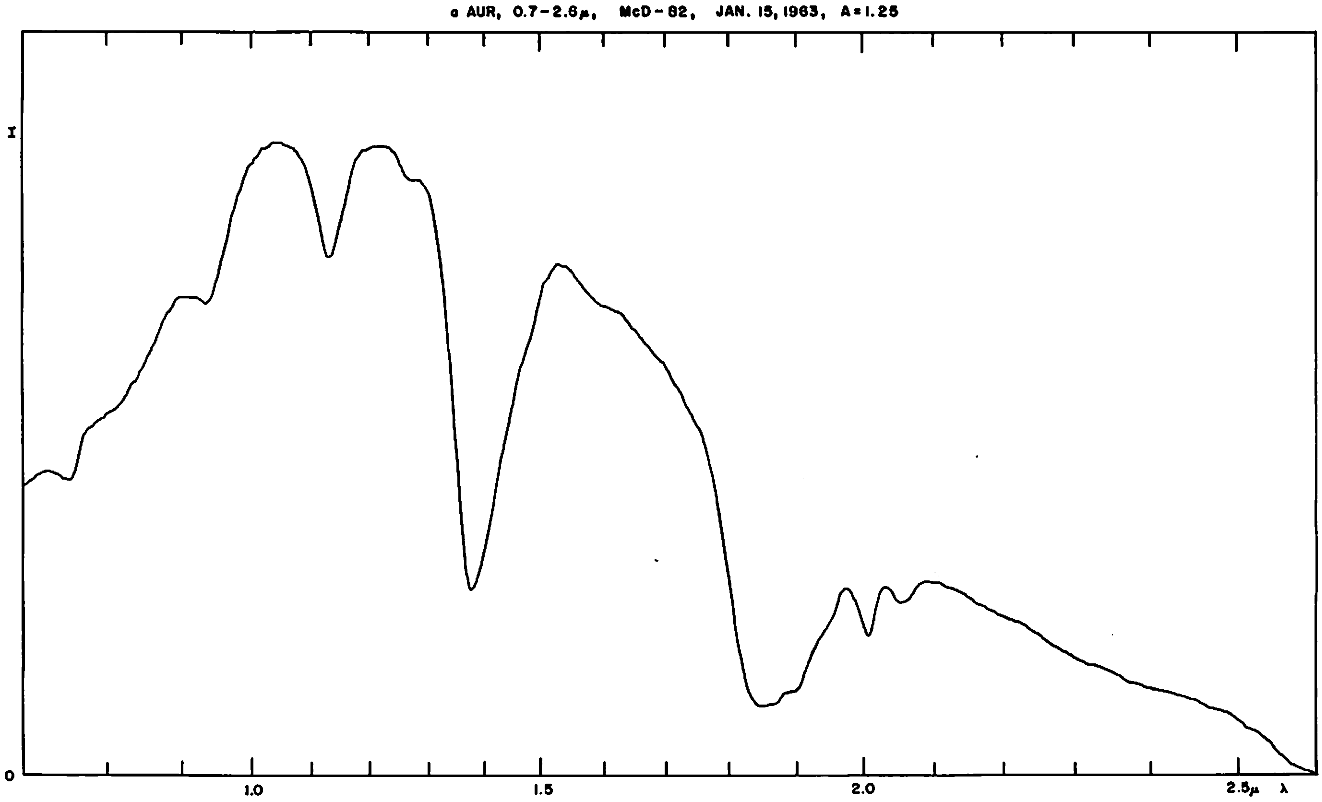
α AUR, 0.7-2.6μ, McD-82, JAN. 15, 1963, A=1.25
I
0
1.0
1.5
2.0
2.5μ
λ

Fig. 10.

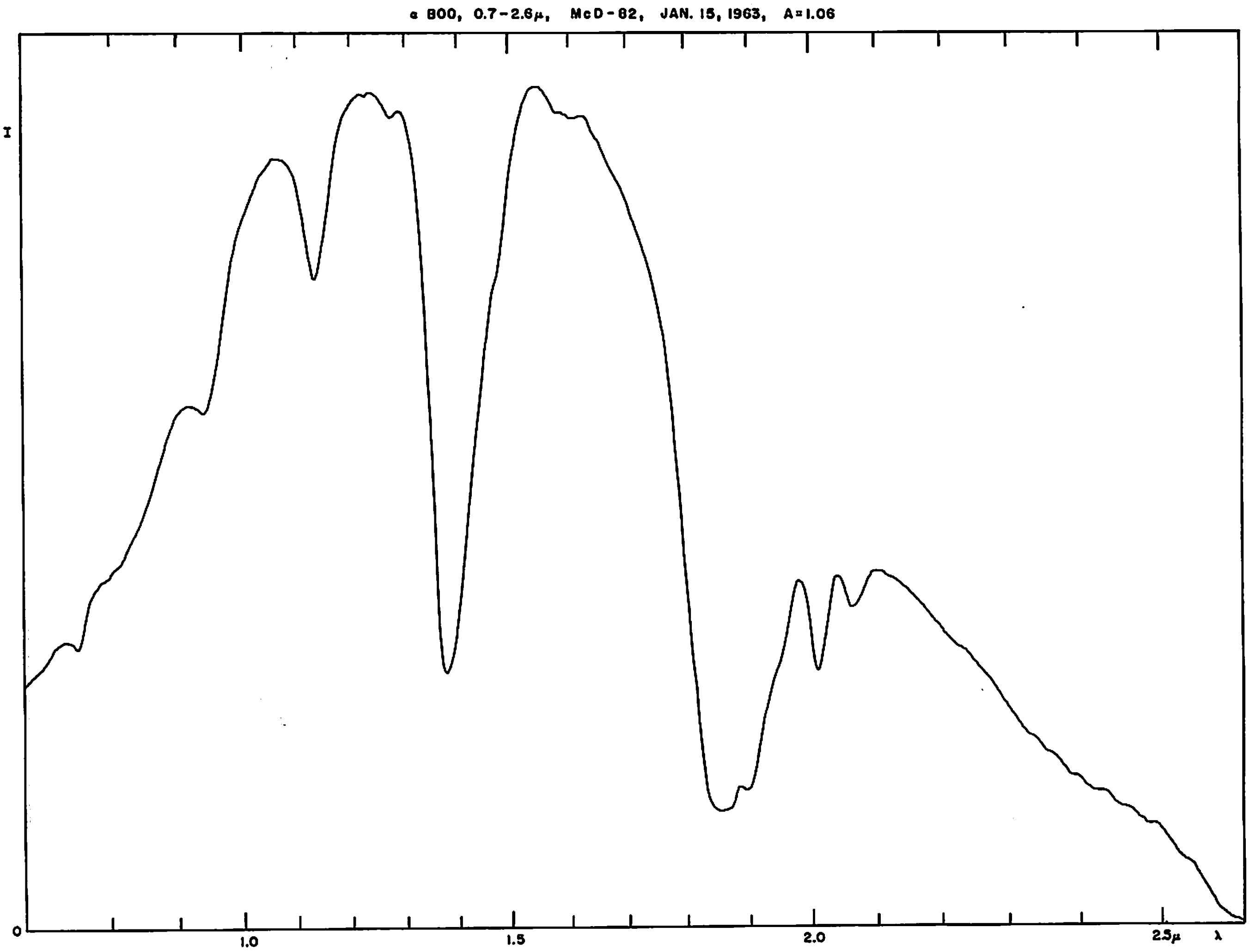

Fig. 11.

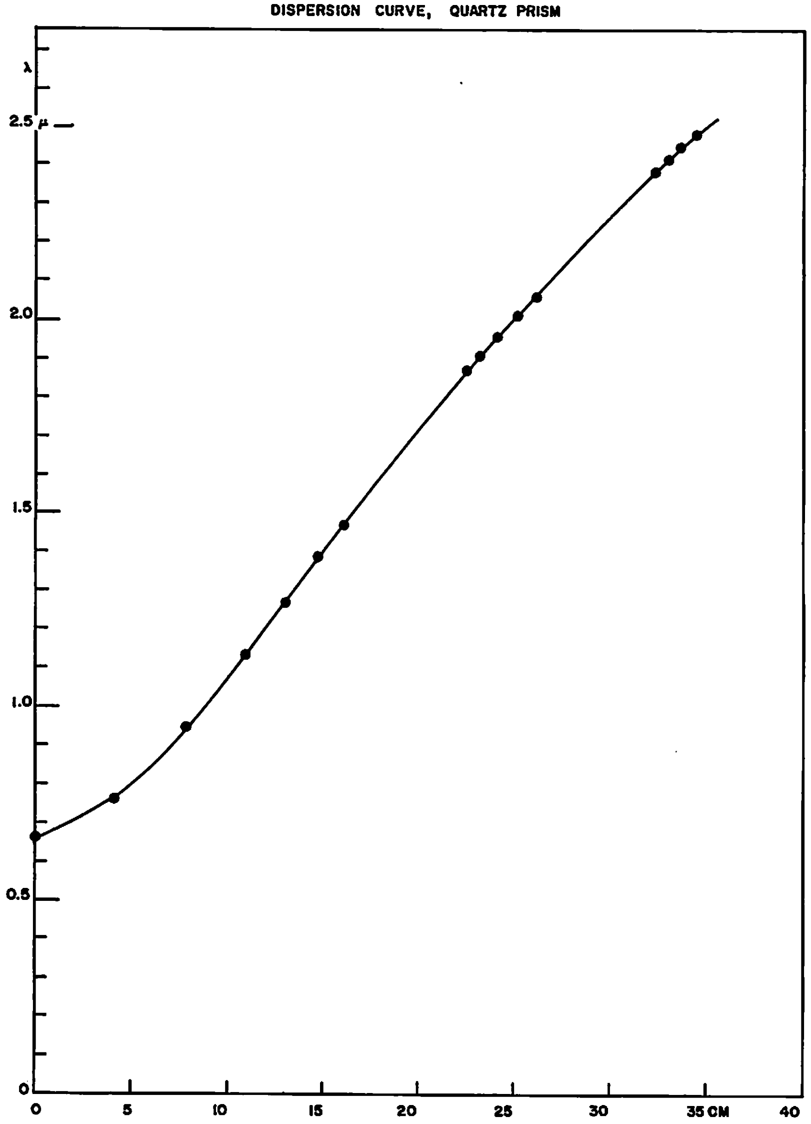
DISPERSION CURVE, QUARTZ PRISM
λ
2.5 μ
2.0
1.5
1.0
0.5
0
0
5
10
15
20
25
30
35 CM
40

Fig. 12.

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