No. 113 STELLAR SPECTROSCOPY, 1.2μ TO 2.6μ

by H. L. JOHNSON, I. COLEMAN, R. I. MITCHELL
AND D. L. STEINMETZ

Aug. 8, 1968

ABSTRACT

We have made infrared spectroscopic observations of 21 stars, using a rapid-scanning Michelson interferometer. The range of wavelength is from 1.2 μ (8200 cm^{-1}) to 2.6 μ (3900 cm^{-1}), and the resolution is 8 cm^{-1}. All spectra have been corrected for atmospheric extinction, mostly by the method of equal-altitude photometric transfers from standard objects. The atmospheric transmission corrections are based upon a Lunar spectrum obtained from the NASA Convair 990 Jet Aircraft, at an altitude of 41,500 feet. The corrected ground-obtained spectrum of α Ori was checked by an aircraft spectrum of the same star, showing that the extinction corrections are valid.

Only four stars, all Mira variable stars, showed significant amounts of steam absorption in their spectra. There exists a correlation of this absorption with long-wavelength (9–14 μ) infrared excess for giant stars, but not for supergiants.

1. *Introduction*

Observation of infrared stellar and planetary spectra has been one of the major programs at the Lunar and Planetary Laboratory. Up to this time, most of these spectroscopic observations were made by Kuiper (1962a, 1962b, 1963, 1964), who used a single channel spectrometer.

It is possible, however, to make the observational procedure much more efficient by observing all of the spectral elements simultaneously, as is done in the visual spectral region where photographic plates record an entire spectrum. A similar procedure could, perhaps, be used in the infrared spectral region but it would require several hundred, or a thousand, separate detectors to be placed in the focal plane of a spectrograph. A different method was suggested by Felgett (1951), who showed that, under the special condition that the detector noise output is not signal-dependent, a Michelson interferometer has the ability to make very efficient simultaneous observations of all the individual spectral elements. The special condition, above, is met in the infrared spectral region.

2. *The Instrumentation*

All of the spectra that are discussed and presented in this article were made using a Michelson interferometer constructed for us by Block Associates of Cambridge, Massachusetts. This interferometer is similar to the one described by Mertz (1965a); it differs in that it contains two interferometer "cubes" whose moving mirrors are coupled mechanically. The "signal cube" is used for the stellar spectra and has two unrefrigerated PbS detectors arranged as described by Mertz. The "reference cube" has two optical inputs: one, a broad-band white light whose interferogram is used to establish the zero-point of the signal interferogram from the other cube; the other, a nearly monochromatic helium line at 1.0833 μ. The monochromatic line produces a sine-wave interferogram whose amplitude is nearly independent of the positions of the moving mirrors, but whose "zero-crossings" are used to determine the scale of the signal interferogram. Thus, in this interferometer design, the mirror motion need not be exactly uniform or linear, since the mirror position is at all times known from the helium reference line. Furthermore, all frequencies (or wavelengths) in the final spectrum are directly related to that of the helium line.

The interferometer uses the rapid scan technique of Mertz; the scan time is 2 seconds, so that all electrical signal frequencies are between 200 and 500 Hz. It is, of course, necessary to add together many scans (interferograms) of the fainter objects in order to obtain spectra with a satisfactory signal-to-noise ratio. This summation is performed by a "co-adder," also supplied by Block Associates.

The interferometer mirrors move a distance of approximately 0.6 mm, thus causing a change in path length of about 1.2 mm. The final spectra have a resolution of approximately 8 cm^{-1}.

Unfortunately, the reference cube drifts slightly with respect to the signal cube, making it impossible to "co-add" interferograms for more than 10 or 15 minutes. We overcame this problem by sending a relatively broad-band "green light" (at about 0.55 μ) through the signal cube; comparison of the resulting interferogram with those from the reference cube allows us to compensate for the drift. Thus, the interferometer has four outputs: The stellar signal interferogram, the "green light" fringe, the "white light" fringe from the reference cube, and the monochromatic signal from the 1.0833 μ helium reference line. These four outputs must be combined to produce the corrected signal interferogram, with known zero-point and scale.

At the telescope, the data consisting of the four outputs of the interferometer are recorded on a Consolidated Electrodynamics Model 5-752-7 seven-track tape recorder. In order to increase the signal-to-noise ratio of the tape recorder, the signal interferogram is recorded on three tracks, connected in parallel. These recordings are subsequently played back by a similar machine in the laboratory, and co-added. The tapes are played back at eight times the recording speed, so as to reduce the time spent co-adding.

3. *Data Reduction*

The Fourier transformation of the co-added interferograms, and the subsequent phase correction, follow the procedures outlined by Mertz (1965b, 1967), with minor modifications. Since the sample points are controlled by the zero-crossings of the interferogram of the helium reference line, no corrections for non-uniform sampling are needed. We found it necessary to correct the interferograms for non-linearity of the electronics (actually, the non-linearity of the magnetic tape) before the computation of the spectra. All computations were made by an IBM 1130 computer system; this machine includes a plotter which drew the spectra we publish here.

The fact that the sample points are controlled by the zeroes of the helium reference line's interferogram means that we know the wavelength (or frequency) of each point in the computed spectrum. It is, therefore, quite convenient to combine spectra or to take the ratio of one spectrum (point by point) to another. We can, therefore, treat our data as multicolor photometry (2000-filter photometry!) and make corrections for atmospheric extinction and reductions to a standard system by the usual photometric procedures. We have not yet established a standard photometric system based upon the interferometer data (although we do plan to do so), but all of the spectra we publish here have been corrected for atmospheric extinction.

Our correction of the computed spectra for atmospheric extinction was made possible by lunar observations that were made from an altitude of 41,500 feet. These observations were made with a 12-inch telescope in the NASA Convair 990 Flying Observatory. The same interferometer was used, so that the airplane data are strictly comparable with the data obtained from the ground. The airplane setup and procedures have been described by Kuiper and Forbes (1968) and Kuiper, Forbes and Mitchell (1968). Since our atmospheric extinction corrections are based upon a lunar spectrum obtained at an altitude of 41,500 feet, our corrected spectra still contain the atmospheric absorption features due to the atmosphere above this altitude. We have not yet worked out the corrections from the airplane altitude to outside the atmosphere; all of the corrected spectra published herein are, therefore, corrected to 41,500 feet. As will be seen, this incomplete correction removes most of the atmospheric absorptions; it even makes possible significant observations through the water vapor absorption bands near 1.4 μ and 1.8 μ.

4. *Atmospheric Extinction*

The first spectrum we exhibit is that of the Moon from 41,500 feet; this spectrum is shown in Figure

1. Figures 2 and 3 show ground-based lunar spectra on a relatively dry night at the Catalina Observatory; the air-masses are 1.2 and 1.9, respectively. Division of the spectra of Figures 2 and 3 by that of Figure 1 yielded the atmospheric-transmission spectra shown in Figures 4 and 5. A stellar observation taken at the same air mass as the ground-based lunar observations may be corrected for atmospheric extinction by dividing the stellar spectrum by the atmospheric-transmission spectrum. Alternatively, standard photometric procedure, which involves the computation of an extinction coefficient at each wavelength, can be used to correct stellar data that have no equal-altitude lunar comparison.

It is our plan to set up on a satisfactory basis the photometric correction of our spectra. This must involve, of course, the taking of observations by standard photometric procedures, so that the data needed for the corrections are available. On only one of the nights (March 14, 1968) upon which our present data were taken were good photometric procedures of observation used. The corrected spectra from this night show what the technique is capable of doing; the data from other nights have been corrected as well as possible, using equal-altitude transfers from either the Moon, or stars calibrated from data taken on the good photometric night.

The quality of our correction for atmospheric extinction may be assessed by comparison of Figures 6, 7 and 8. Figure 6 shows the spectrum of α Ori, as observed from the ground on the night (March 14) on which satisfactory photometric data were obtained; Figure 7 shows the spectrum of α Ori, corrected for atmospheric extinction, (the computer program lifts the pen when the atmospheric transmission is less than 20%; this explains the discontinuous line in Figure 7). Figure 8 shows the spectrum of α Ori as actually observed from the airplane by Kuiper, Forbes, and Mitchell.

Since the aircraft observatory has only a 12-inch telescope (compared to a 60-inch on the ground), the signal-to-noise ratio of the high-altitude α Ori spectrum is comparatively poor. Nevertheless, it serves to confirm our correction of the ground-obtained spectrum; compare the spectra of Figures 7 and 8.

5. The Stellar Spectra

The spectra of Figures 7 and 8 indicate that the amount of water-vapor absorption in the α Ori spectrum is very small. Note, especially, that the aircraft spectrum (Figure 8) shows no lines stronger than

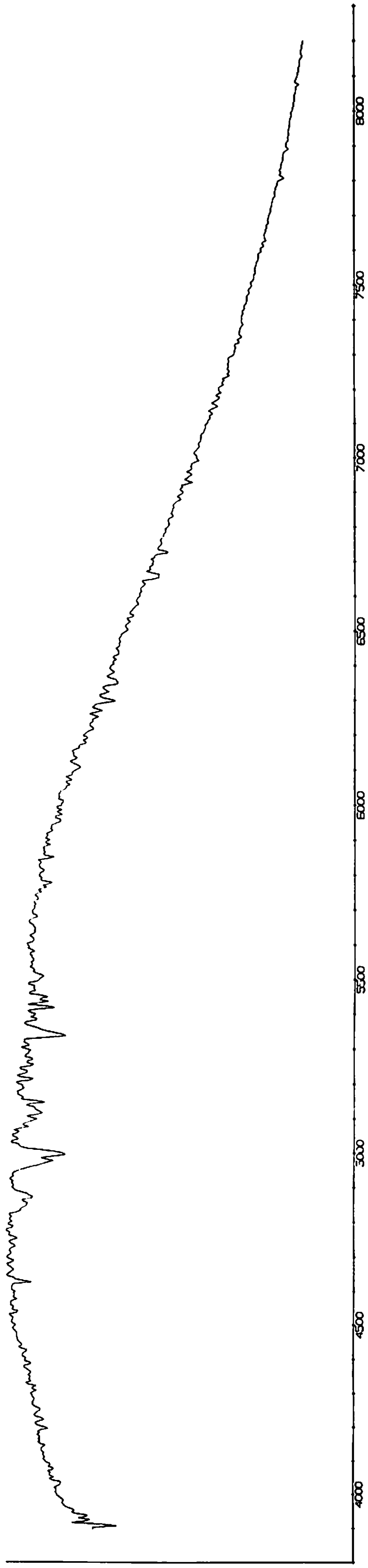

Fig. 1 The spectrum of the Moon from the NASA Convair 990 Jet Aircraft, at 41,500 feet.

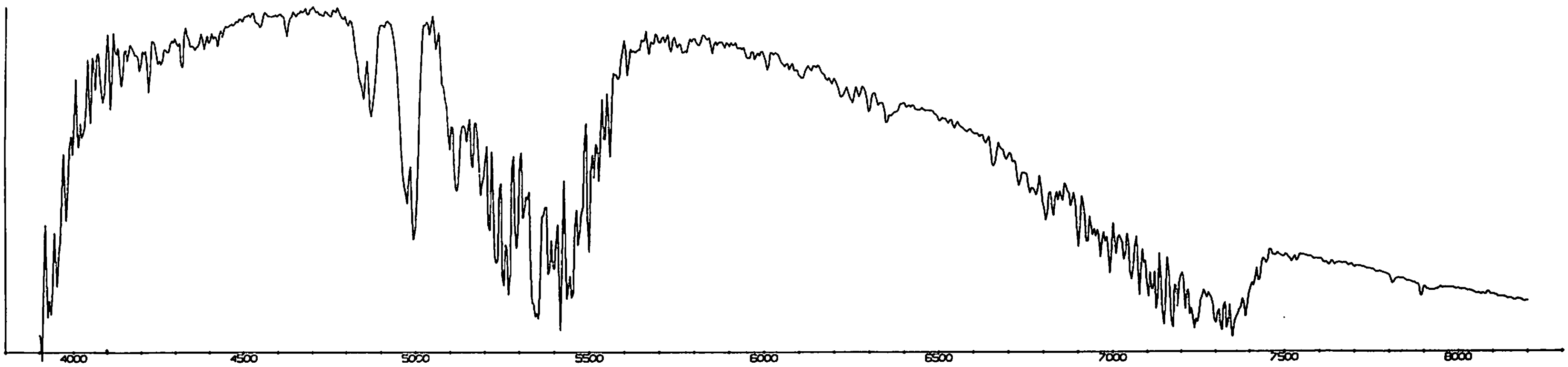

Fig. 2 The spectrum of the Moon from the Catalina Observatory. The air mass is 1. 2.

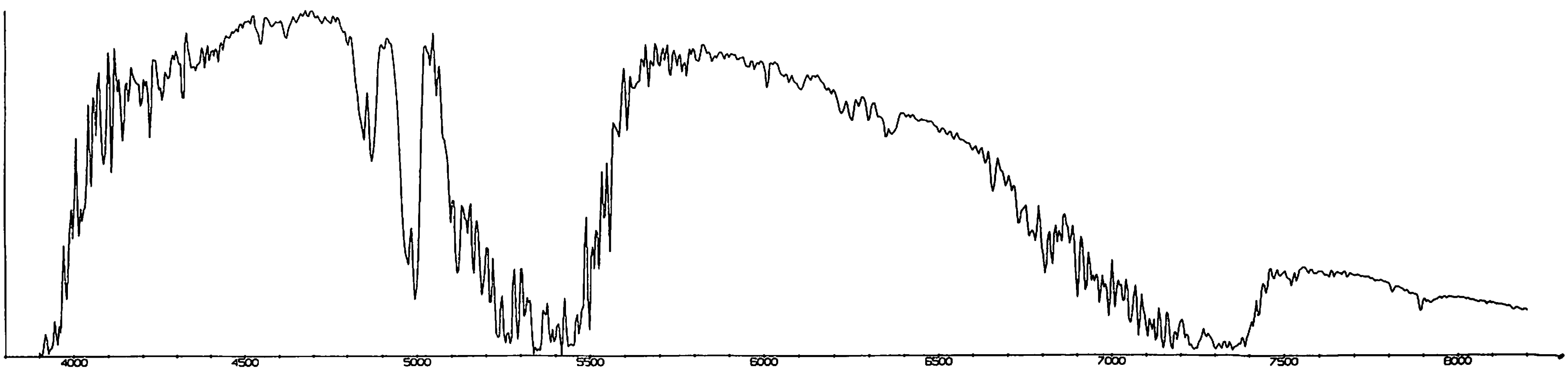

Fig. 3 The spectrum of the Moon from the Catalina Observatory. The air mass is 1.9.

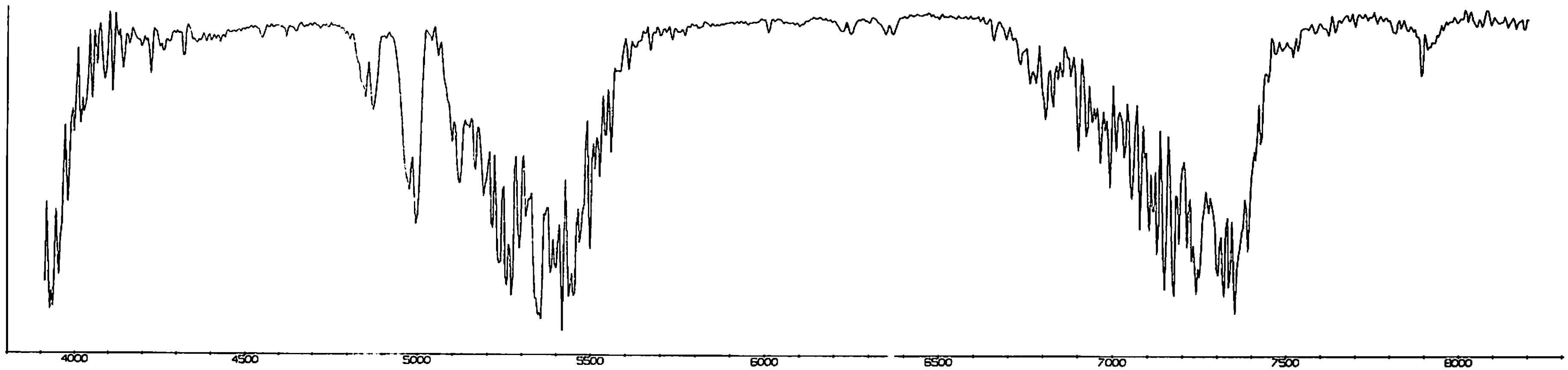

Fig. 4 The atmospheric transmission from the spectra of Figures 1 and 2.

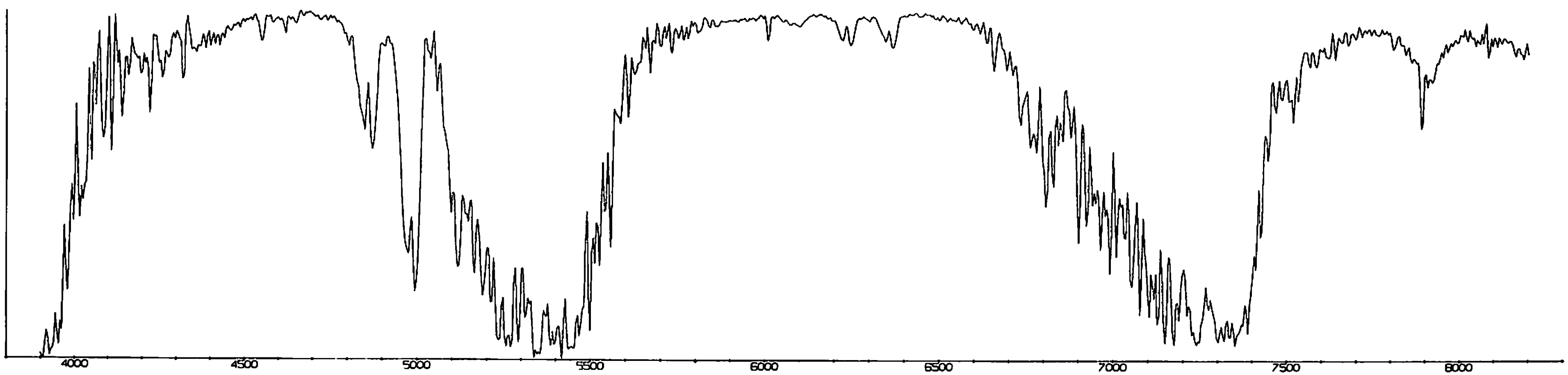

Fig. 5 The atmospheric transmission from the spectra of Figures 1 and 3.

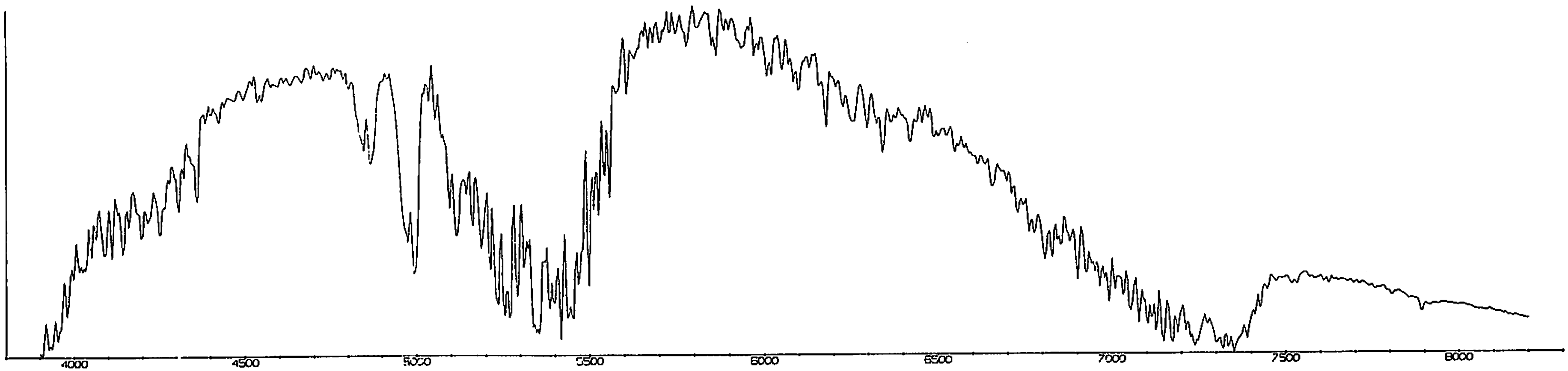

Fig. 6 The spectrum of α Ori from the Catalina Observatory, without correction for atmospheric extinction.

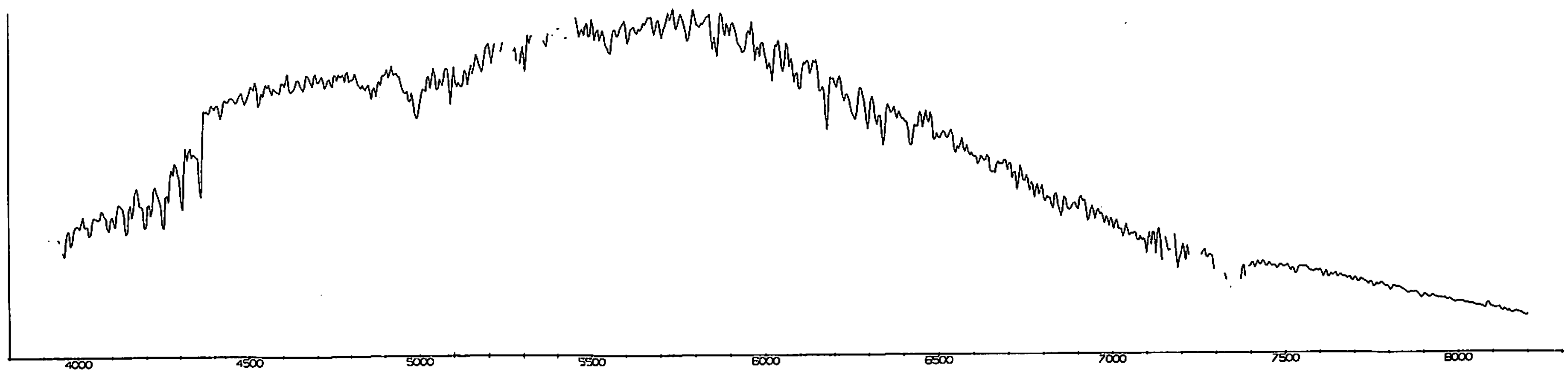

Fig. 7 The corrected spectrum of α Ori; M2 Iab. Dry night. Good equal-altitude transfer on March 14.

the noise level, in the regions of the 1.4 μ (7000 cm^{-1}) and 1.9 μ (5300 cm^{-1} bands.

As shown by Auman (1967), the opacity of steam (hot water-vapor) in the 3850 cm^{-1} (2.6 μ) region is several times as great as at 5300 cm^{-1} and 7000 cm^{-1}. Therefore, the use of the 3850 cm^{-1} band results in a more sensitive test for stellar steam. Although Figure 8 does not so indicate, our interferometer operates down to, and below, 3300 cm^{-1}, the practical limit of the present unrefrigerated PbS detectors. The aircraft spectra do cover this important spectral region; the spectrum of α Ori and the comparison lunar spectrum taken from the same altitude are shown in Figures 9 and 10, for the range from 3500 cm^{-1} to 4300 cm^{-1}. This lunar spectrum is not the one shown in Figure 1, but is another one taken during the flights when α Ori was observed; the two objects were separated in the sky by only a few degrees at the time of observation and the absorption due to the atmosphere above the aircraft should be very nearly equal in the spectra of Figures 9 and 10.

It is evident that the amount of water-vapor absorption at 3850 cm^{-1} in the α Ori spectrum is practically identical to that in the comparison lunar spectrum. These spectra show conclusively that there is no appreciable steam absorption in the spectrum of α Ori, a result contrary to that obtained by Woolf, Schwarzschild and Rose (1964) from the balloon observatory, Stratoscope II, but in agreement with that of Kuiper (1962b). (Could a water-vapor atmosphere carried up by the balloon be the cause of the Stratoscope II results?)

The CO bands in the spectral range from 3900 cm^{-1} to 4300 cm^{-1} show clearly in Figures 6, 7 and 8, although the higher noise level in Figure 8 obscures the weaker details and distorts the line shapes. Note that the correction for atmospheric extinction that is contained in the spectrum of Figure 7 removes the interfering water-vapor bands and allows a clearer picture to be obtained of these CO bands. These bands were observed by Kuiper (1964, Fig. 22) with a resolution of about 5000 showing the rotational structure. They also show in the α Ori spectrum given by McCammon, Münch and Neugebauer (1967). Their spectra, however, have lower resolution and are not corrected for atmospheric extinction.

We have observed 21 stars, including α Ori, whose infrared spectra have been corrected for atmospheric extinction. These stars are listed in Table 1, along with their spectral types and the numbers

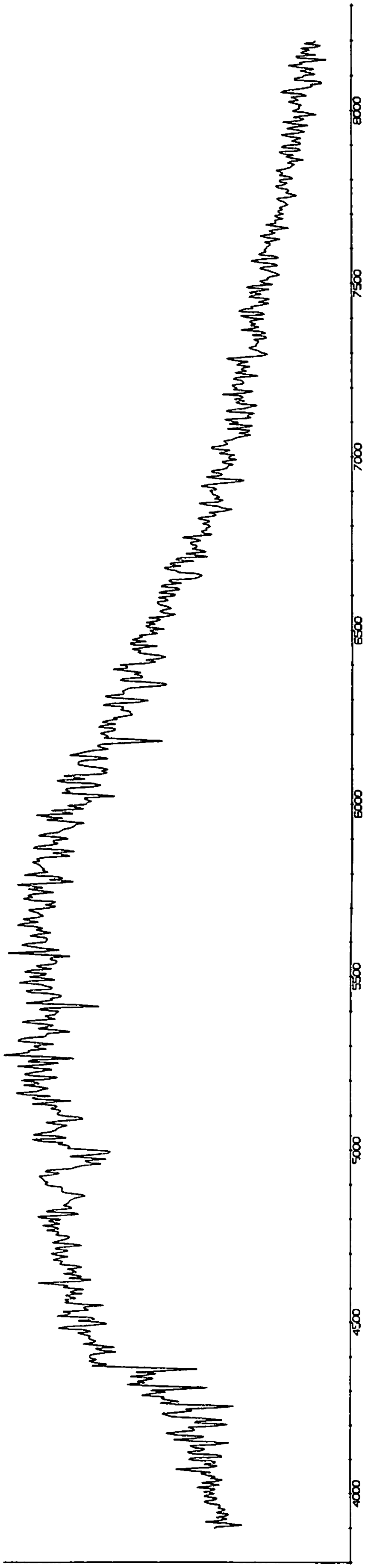

Fig. 8 The spectrum of α Ori from the NASA Convair 990 Jet Aircraft.

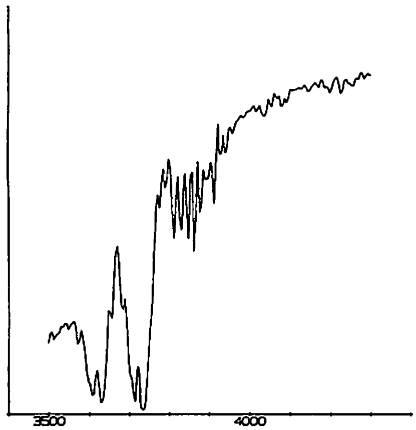

Fig. 9 The spectrum, 3500 cm^{-1} to 4300 cm^{-1}, of the Moon from the NASA Convair 990.

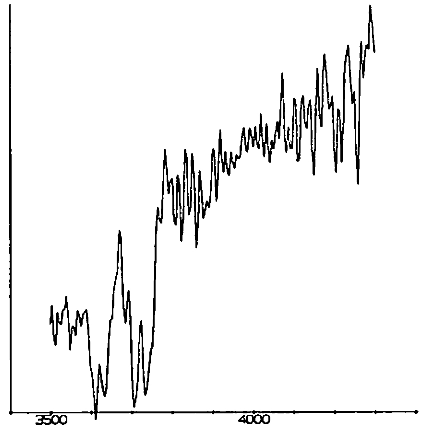

Fig. 10 The spectrum, 3500 cm^{-1} to 4300 cm^{-1}, of α Ori from the NASA Convair 990.

of the Figures in which their spectra appear. In addition, the lunar spectrum of Figure 1 (except for the general trend of the continuum) may also be considered to represent that of the Sun, whose spectral type is G2 V. Most of these spectra have been corrected for atmospheric transmission by the method of photometric equal-altitude transfers. Some, however, had no satisfactory equal-altitude comparisons; these were corrected for atmospheric extinction as well as possible, using transmission curves derived for other nights. This compensation cannot be expected to be satisfactory except in spectral regions where the water-vapor absorption is always relatively small; we have, therefore, blanked out regions where the water-vapor absorption is high. The captions for the Figures describe the method of extinction correction (equal-altitude, or not) and indicate the quality of the night.

Two spectra of α Boo are shown in Figures 11 and 12; the first is uncorrected, while the second is corrected for atmospheric extinction. Note that in Figure 12, as in Figure 7, the spectrum is discontinuous in the regions of strong atmospheric water-vapor absorption; this is caused by the fact that the computer program lifts the pen when the atmospheric transmission is less than 20 percent. Note the clarity with which the CO bands around 3900-4300 cm^{-1} can be seen in the corrected spectrum. The CO bands in the α Boo spectrum are weaker than those in α Ori, but there are more of them, extending toward smaller wave-numbers. This fact is not readily apparent in the uncorrected spectra.

The strengths of these CO bands increase with advancing spectral type; among the giant stars, they are strongest in the Mira stars. Their strengths also increase with stellar luminosity; compare δ Oph (M1 III), α Ori (M2 Iab) and μ Cep (M2 Ia). The CO bands in the spectrum of μ Cep are fully as strong as those in the Mira spectra. Numerous other features show changes with spectral type. For example, there are band structures at about 6380 and 6470 cm^{-1} which become stronger in the later spectral types, but do not become stronger with higher luminosity (at M2). There is an emission feature at about 4616 cm^{-1}, which appears in some spectra, but not in others. In most cases, the presence or absence of this feature has been confirmed by other spectra taken on other nights; for example, we have several spectra of R Hya, all of which show this

TABLE 1
CATALOGUE OF OBSERVATIONS

STAR	SPECTRAL TYPE	FIGURE
Sun (Moon)	G2 V	1
α Boo	K2 IIIp	11, 12
α Hya	K4 III	13
α Tau	K5 III	14
γ Dra	K5 III	15
β And	M0 III	16
δ Oph	M1 III	17
η Gem	M3 III	18
δ^2 Lyr	M4 II	19
ρ Per	M4 II-III	20
R Lyr	M5 III	21
α Her	M5 Ib-II	22
o Cet	M5e (max)	23
R Hya	M6e	24
R Leo	M8e	25
χ Cyg	Mpe, S	26
α Ori	M1-M2 Iab	6, 7, 8
α Sco	M1-M2 Iab	27
μ Cep	M2 Ia	28
U U Aur	C5, 3	29
Y CVn	C5, 4	30
U Hya	C7, 3	31

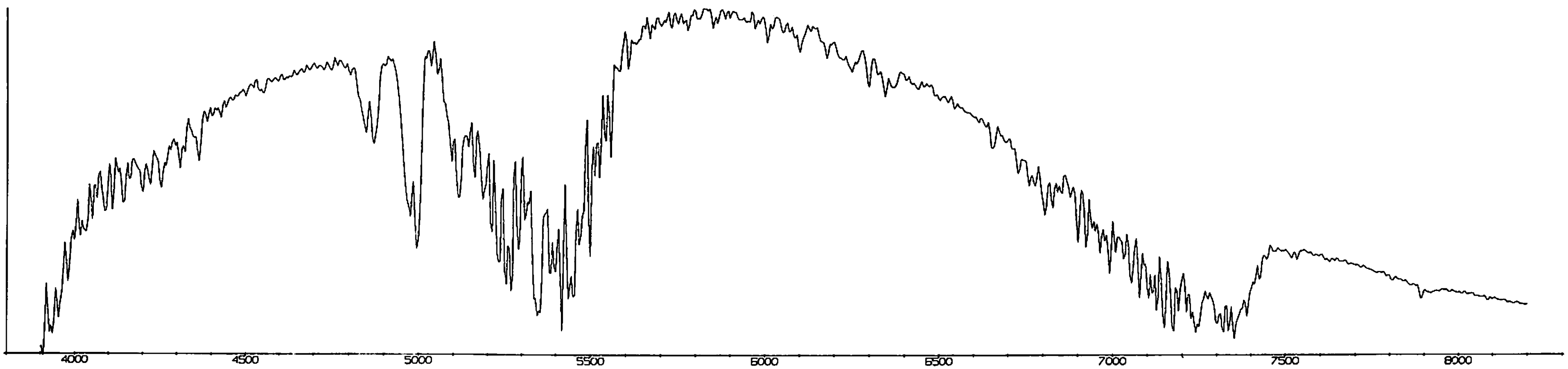

Fig. 11 The spectrum of α Boo from the Catalina Observatory, without correction for atmospheric extinction.

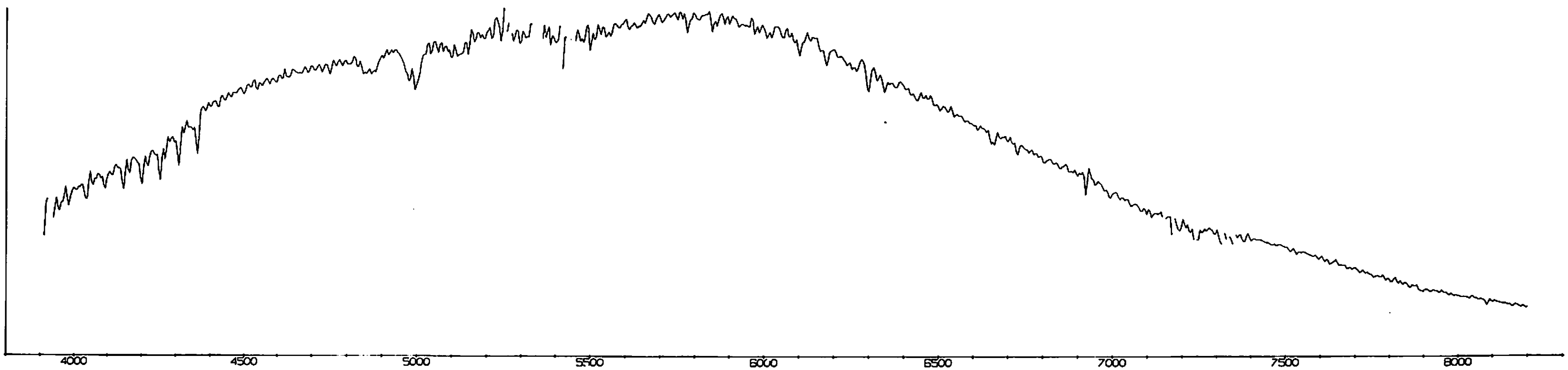

Fig. 12 The corrected spectrum of α Boo; K2 IIIp. Dry night. Good equal-altitude transfer on March 14.

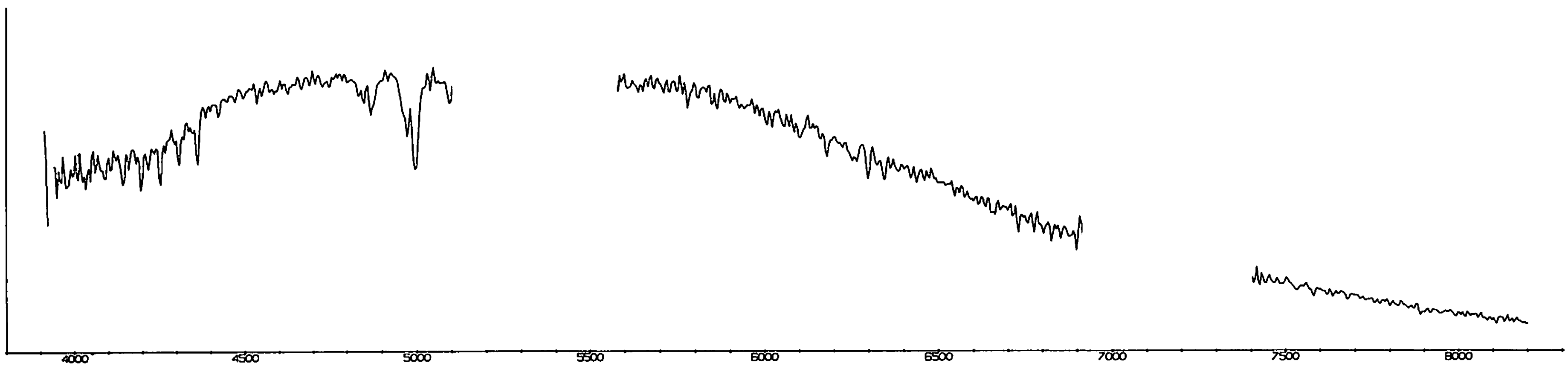

Fig. 13 The corrected spectrum of α Hya, K4 III. Not equal-altitude transfer. CO_2 seems somewhat undercorrected, but water-vapor satisfactory. No. 4616 cm^{-1} peak is evident.

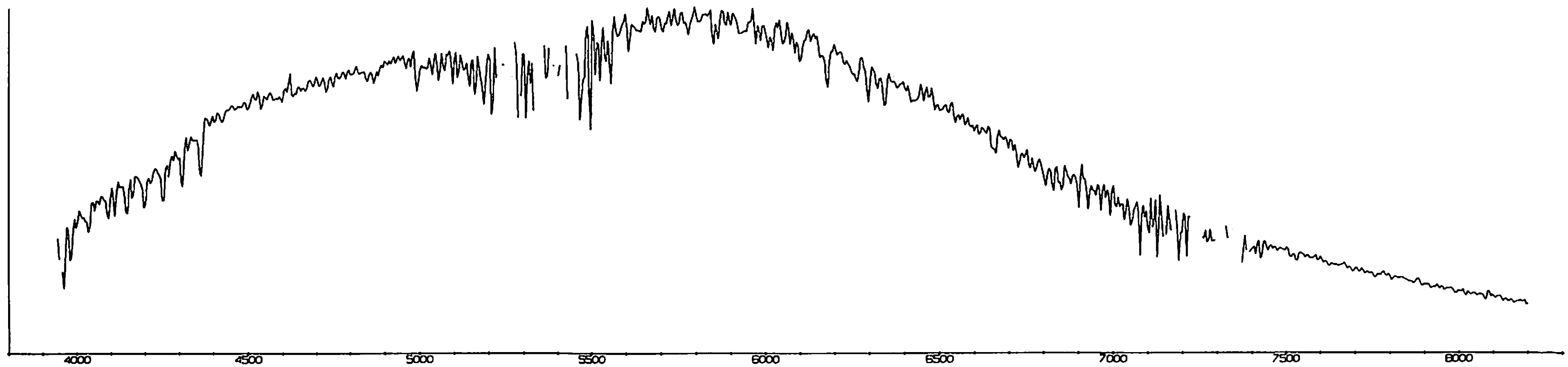

Fig. 14 The corrected spectrum of α Tau, K5 III. Dry night, good equal-altitude transfer on March 14. CO_2 is somewhat overcorrected, but H_2O is nevertheless undercorrected, with line structure present. The spectrum was taken on the same night as those of α Ori and α Boo (Figure 7 and 12) and the correction should be of similar quality.

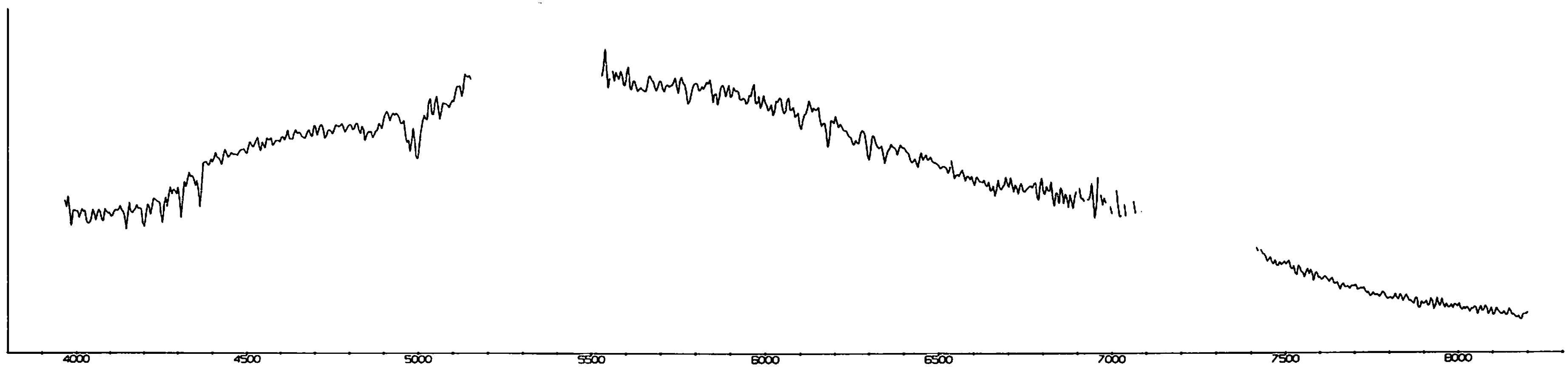

Fig. 15 The corrected spectrum of γ Dra, K5 III. Damp night, but good equal-altitude transfer. Even though this night was much damper than March 14, the line structure showing in α Tau (Figure 14) around 5100, 5500 and 7000 cm^{-1} is not evident.

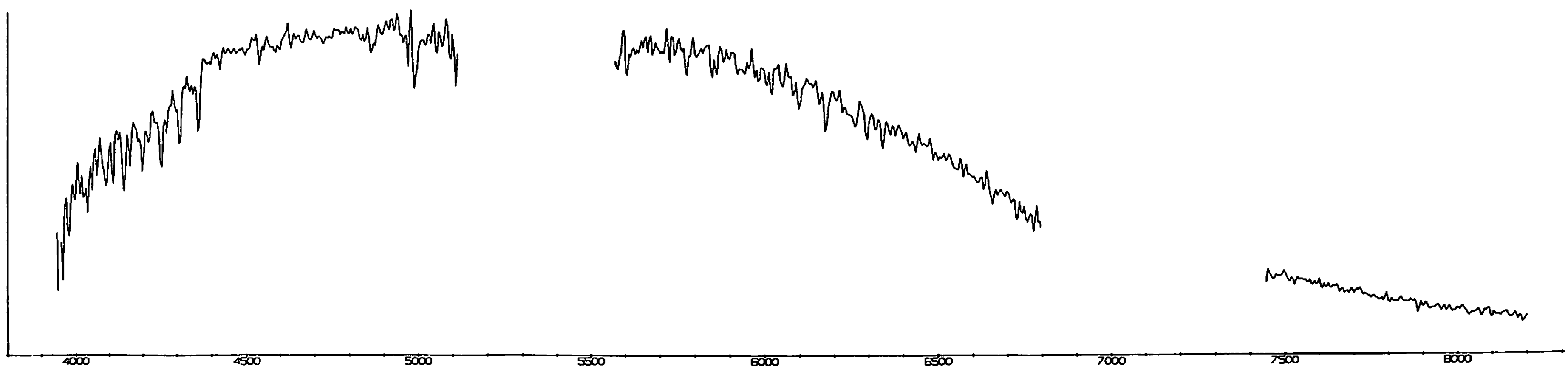

Fig. 16 The corrected spectrum of β And, MO III. Not equal-altitude transfer.

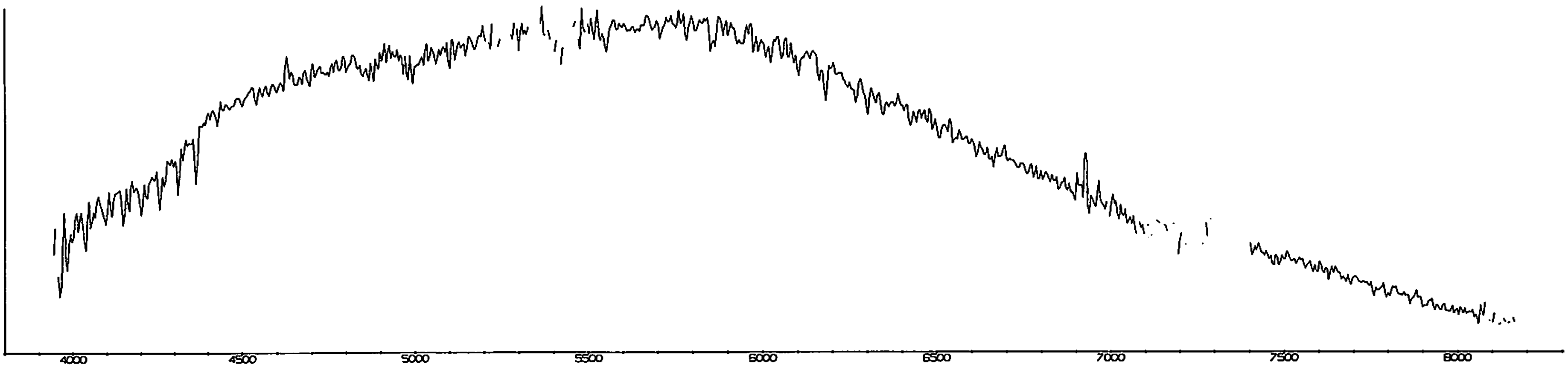

Fig. 17 The corrected spectrum of δ Oph, M1 III. Dry night, good equal-altitude transfer.

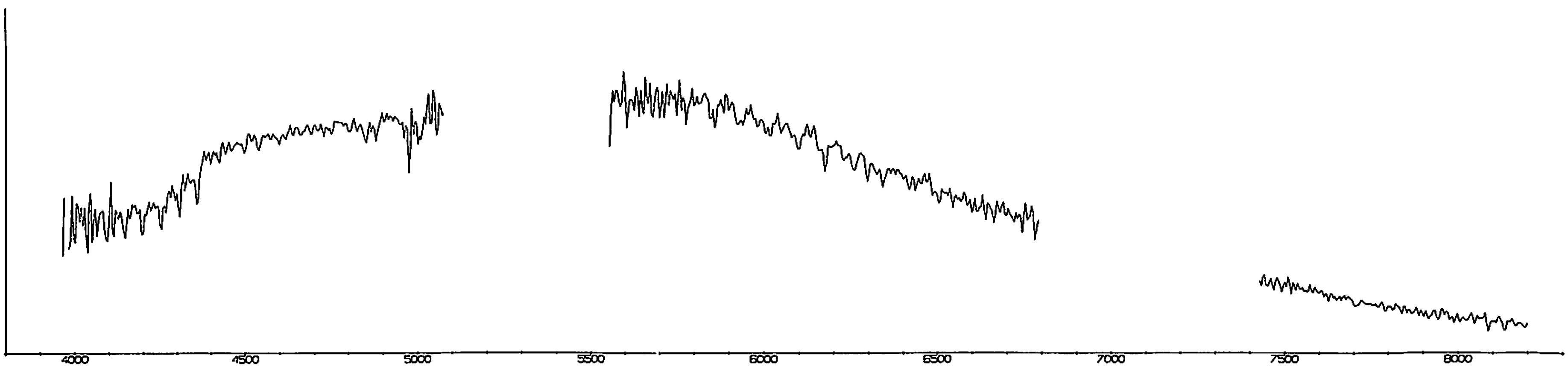

Fig. 18 The corrected spectrum of η Gem, M3 III. Not equal-altitude transfer. CO_2 and, probably, H_2O are overcorrected.

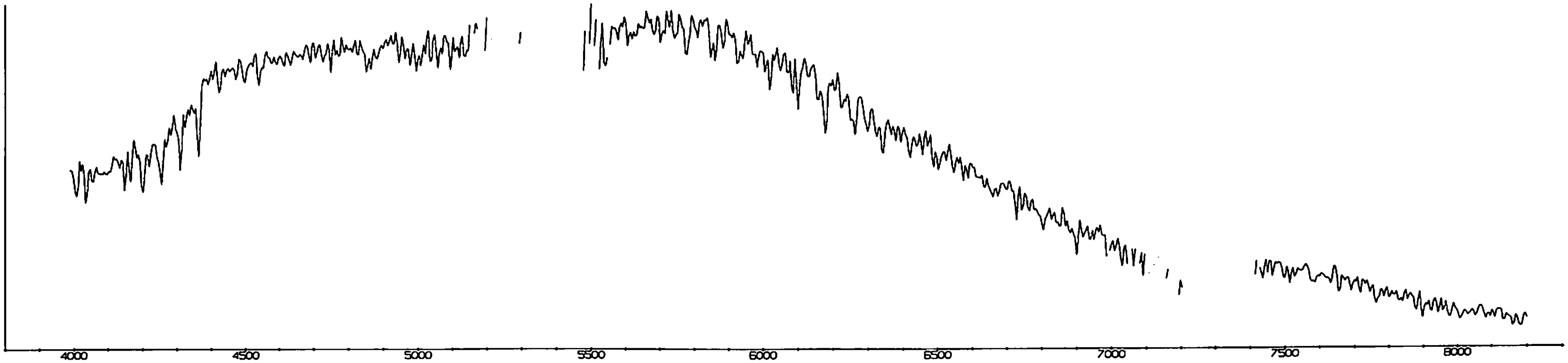

Fig. 19 The corrected spectrum of δ^2 Lyr, M4 II. Good equal-altitude transfers on two nights. No 4616 peak on either spectrum.

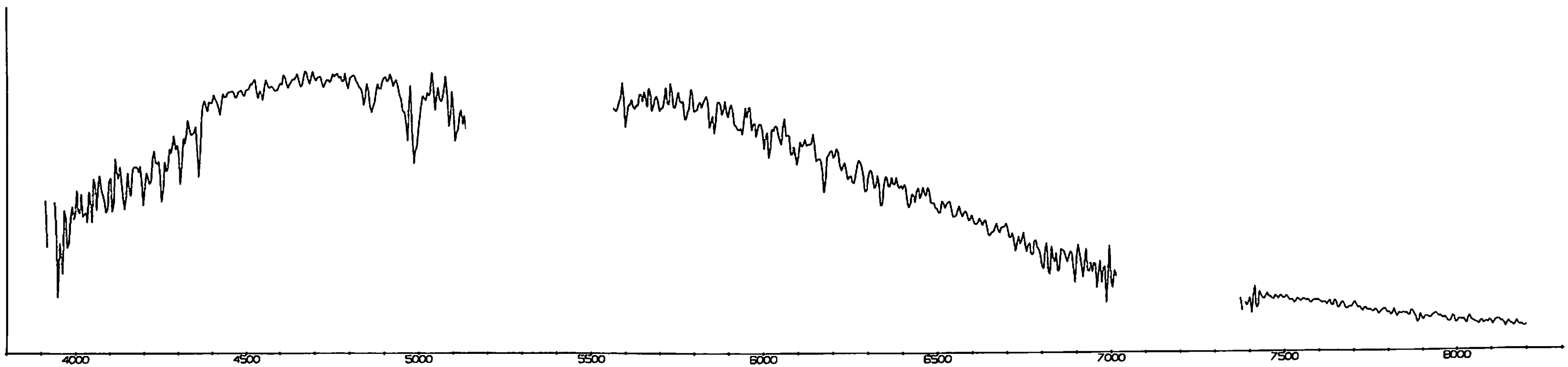

Fig. 20 The corrected spectrum of ρ Per, M4 II-III. Not equal-altitude transfer. CO_2 slightly undercorrected, possibly also H_2O.

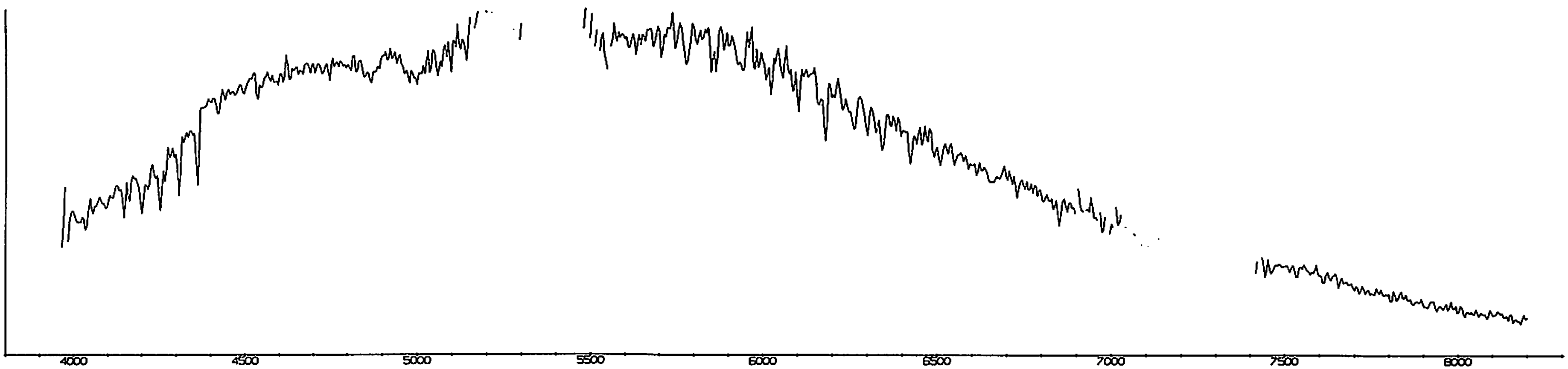

Fig. 21 The corrected spectrum of R Lyr, M5 III. Good equal-altitude transfers on two nights. CO_2 a little overcorrected. 4616 peak on both spectra.

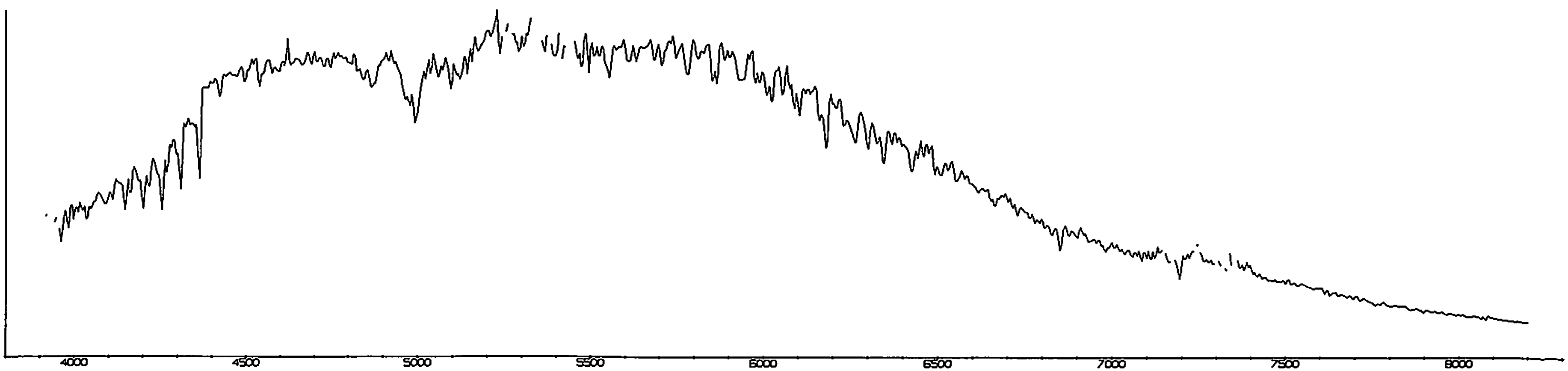

Fig. 22 The corrected spectrum of α Her, M5 Ib-II. Dry night, good equal-altitude transfer on March 14.

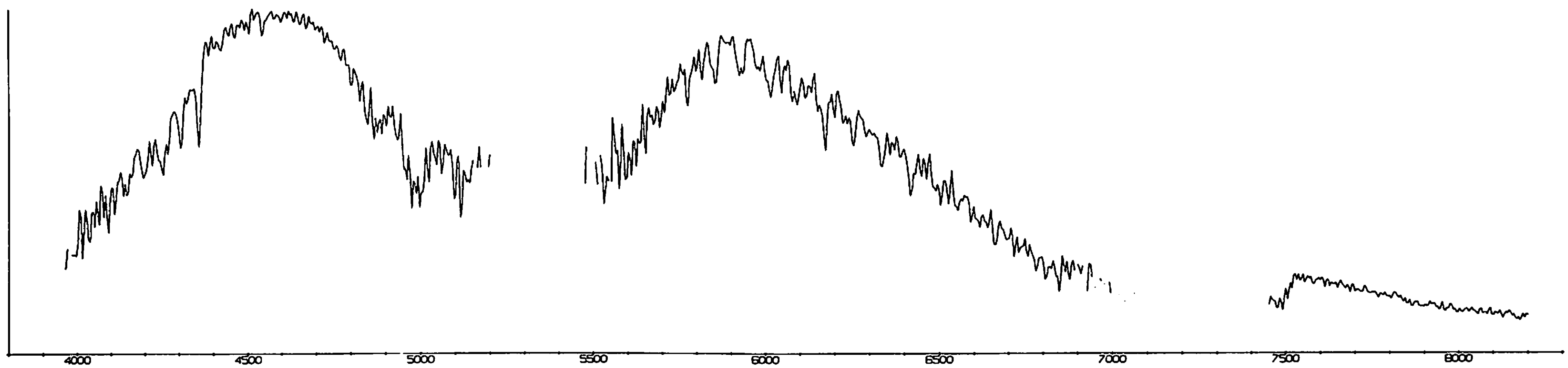

Fig. 23 The corrected spectrum of *o* Cet, M5e (max). Equal-altitude transfer on damp night. The presence of large stellar steam absorptions is evident.

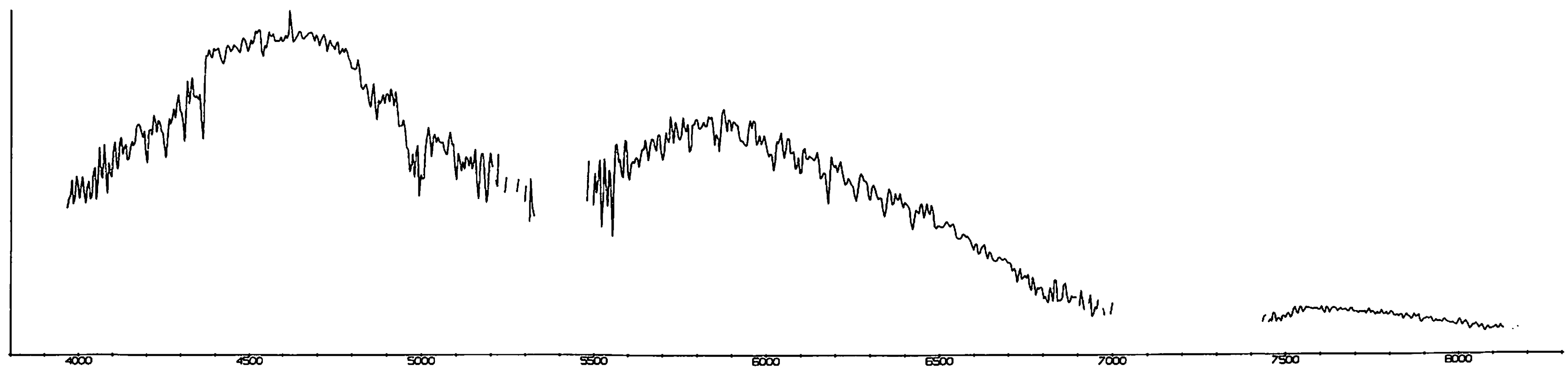

Fig. 24 The corrected spectrum of R Hya, M6e. Equal-altitude transfer on dry night. Steam absorption less than in *o* Cet. The 4616 cm^{-1} emission peak (Brackett γ) appears in all our spectra of this star.

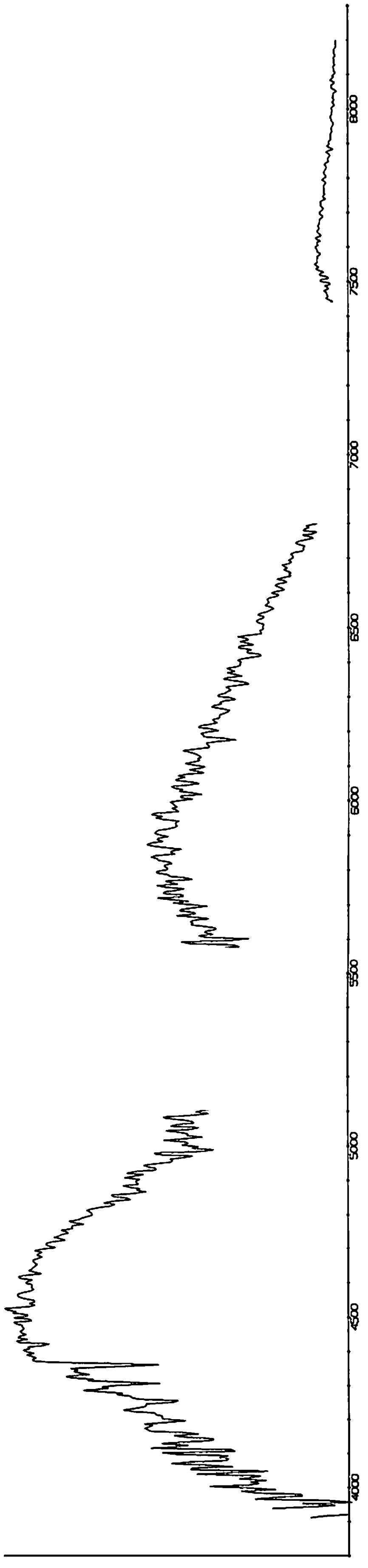

Fig. 25 The corrected spectrum of R Leo, M8e. Not equal-altitude transfer. Steam absorption is like in *o* Cet, stronger than in R Hya. The 4616 cm^{-1} emission appears in another spectrum of this star.

emission feature, while the duplicate spectra of *o* Cet do not show it. One spectrum of R Leo shows this emission feature, the other (Figure 25) does not. An absorption feature appears at this point in the lunar spectra, Figures 1, 2 and 3. This feature is apparently Brackett γ.

There is another series of CO bands beginning at 6420 cm^{-1} and extending downward to 5700 cm^{-1}. Altogether, ten bands of this series are clearly visible in the spectrum of χ Cyg (Fig. 21); they are less clearly visible in the spectra of the M4-M5 stars and the other Mira stars.

As we would expect from the spectral type of α Boo, Figure 12 shows no significant steam absorption in the spectrum of this star. Unexpected was the virtual absence of steam from all of the observed stars, except for the four Mira stars, χ Cyg, *o* Cet, R Hya and R Leo. α Tau exhibits lines around 5300 and 7000 cm^{-1} which could be attributed to steam, unless the correction for atmospheric extinction is faulty; α Sco shows some evidence of absorption at these wavelengths, but the star was observed at an air mass of 2.0, and the extinction correction probably is imperfect. A second specrum of α Sco was obtained on another night, when another equal-altitude transfer to the Moon was made. This spectrum is deficient at the high-frequency end, probably because of a mal-adjustment of the interferometer, but it serves to confirm the spectrum of Figure 27. We see no reason to believe that α Sco has a higher steam content than does α Ori. The 4616 cm^{-1} peak is confirmed by this spectrum.

The spectra of the four Mira stars show large absorptions due to stellar steam, a fact that was first shown for Mira (*o* Cet) by Kuiper (1962b, 1964). The infrared spectra of *o* Cet, R Hya and R Leo appear to be quite similar, except for the amount of steam absorption. χ Cyg not only has less steam absorption than do the other three Miras, but its spectrum differs in other respects. Note particularly that the steam absorptions in the Mira-star spectra differ greatly in character from the water-vapor absorptions in our atmosphere (Figure 4 and 5); this was first pointed out by Kuiper (1962b), who attributed the extra width to "hot" (steam) bands that are not appreciably excited at the temperature of the Earth's atmosphere. The wings of the steam bands extend well into the atmospheric transmission "windows" where the extinction corrections are small. Thus, determinations of the amount of stellar steam absorption from our spectra should be accurate. The difference between the o Cet spectrum and those of R Lyr and α Her cannot be due to the extinction correction.

This segregation of the Mira stars from other stars, on the basis of their large steam absorptions, was previously unknown, although Kuiper's (1962b, 1964) data suggested it. It has generally been assumed that steam absorption would increase with advancing spectral type and that stars at M5, such as R Lyr and α Her, would surely exhibit the effects. The difference between these two M5 giants and o Cet (which was observed near maximum light when its spectral type is about M5) is spectacular.

Our findings that the M4-M5 giants and the supergiants α Ori, α Sco and μ Cep have little or no stellar steam absorption is contrary to those of Woolf, Schwarzschild and Rose (1964) and Danielson, Woolf and Gaustad (1965), who observed from the balloon observatory, Stratoscope II. Their low-resolution spectra were interpreted as indicating steam absorptions in α Ori 10 to 20 percent of those in o Cet, while the μ Cep absorptions were 33 percent of those o Cet. Clearly, such absorptions in α Ori and μ Cep are not indicated by our spectra; as we discussed in the second paragraph of this section, the aircraft spectrum of α Ori offers no evidence for significant stellar steam absorptions.

The spectra of the three carbon stars, U U Aur, Y CVn and U Hya (Figures 29, 30 and 31), show, as expected, that the steam absorption bands in these stars are weak. These late carbon stars show no evidence of steam absorptions like those of the Mira stars (Figures 23, 24 and 25). Note the peaked appearance of the carbon-star spectra at about 5700 cm^{-1}; steam absorption in Miras shifts their peak to 5900–6000 cm^{-1}. These differences are not due to the atmospheric extinction correction, since the corrections are small in these regions (see Figures 4 and 5). McCammon, Münch and Neugebauer (1967) have already commented upon other features of the spectrum of Y CVn, including the sharp drop at 5660 cm^{-1}. This feature also appears in the spectra of U U Aur and U Hya. We suggest that the absorption is due to C_2, in accord with the laboratory spectra of Ballik and Ramsey (1963). Note the inverse correlation of this feature with the strength of the CO bands at 3900–4300 cm^{-1}. These stars show many features that do not appear in the K and M stars; furthermore, they differ rather strongly among themselves.

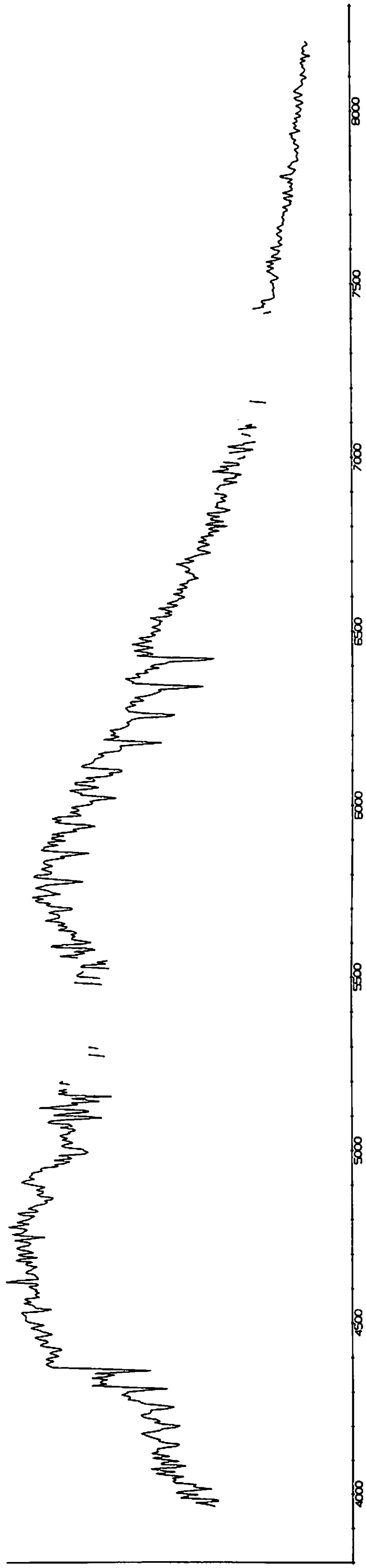

Fig. 26 The corrected spectrum of χ Cyg, Mpe, S. Good equal-altitude transfers on two nights. Steam absorption smaller than in R Hya, but quite definite. The 4616 cm^{-1} emission appears here, and also in another spectrum.

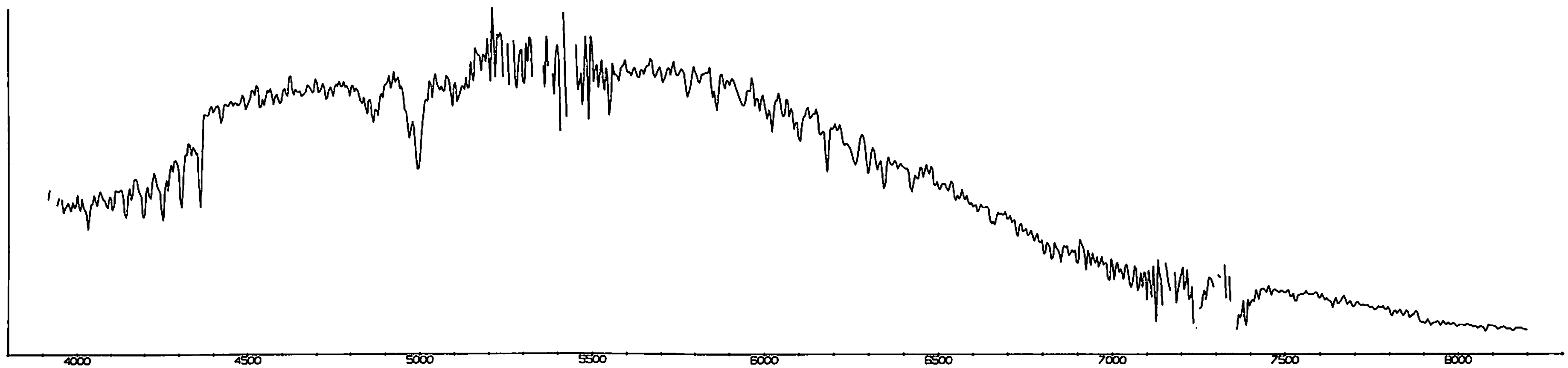

Fig. 27 The corrected spectrum of α Sco, M2 Iab. Dry night, equal-altitude transfer on March 14. CO_2 is undercorrected, probably also H_2O. Air mass = 2.0. Another spectrum, also from equal-altitude transfer, confirms low steam absorption.

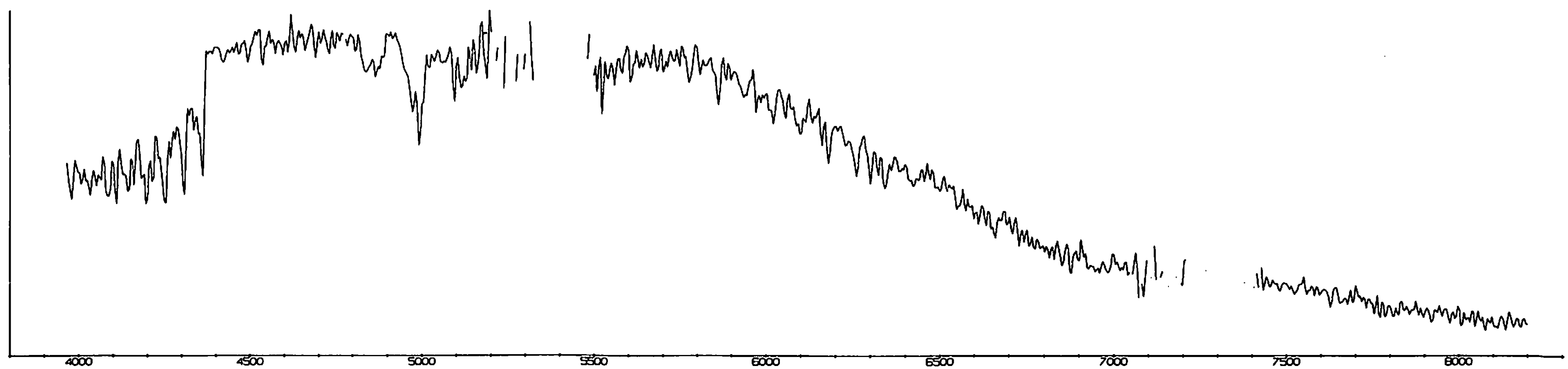

Fig. 28 The corrected spectrum of μ Cep, M2 Ia. Equal-altitude transfer on night of moderate water-vapor absorption. The spectrum shows no steam absorption, even though the CO_2 band strengths suggest undercorrection. A second spectrum confirms this one.

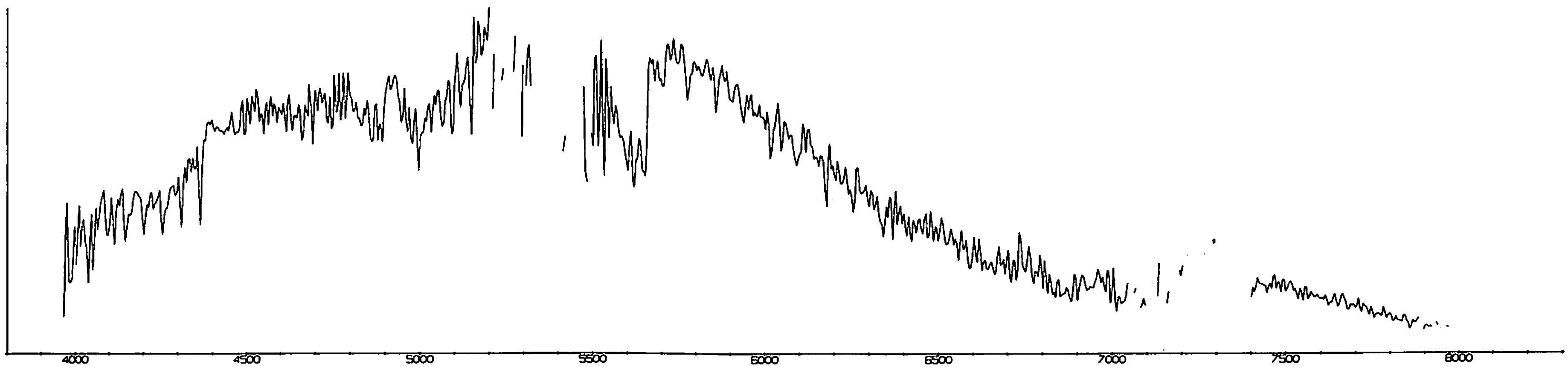

Fig. 29 The corrected spectrum of UU Aur, C5, 3. Equal-altitude transfer on moderately damp night.

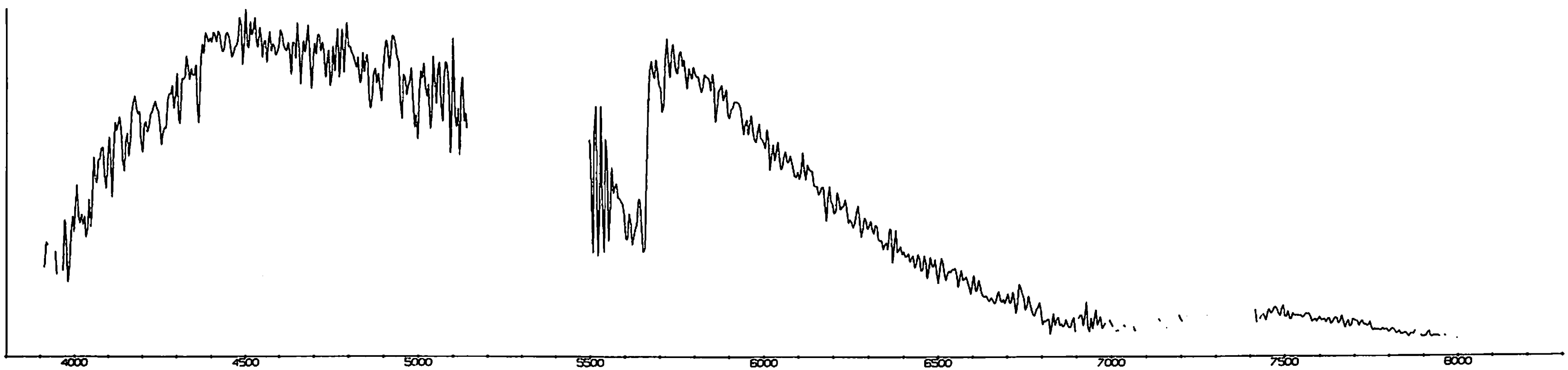

Fig. 30 The corrected spectrum of Y CVn, C5, 4. Dry night, but not equal-altitude transfer.

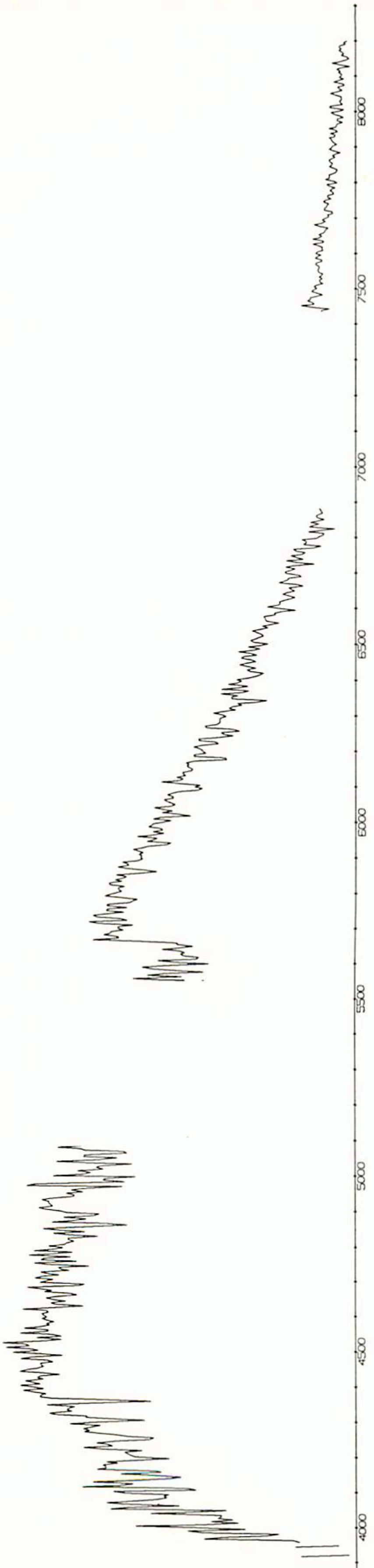

Fig. 31 The corrected spectrum of U Hya, C7, 3. Not equal-altitude transfer.

6. Conclusion

We have given here infrared spectra of 21 stars, corrected for atmospheric extinction to 41,500 feet. All spectra were derived from data taken with a rapid-scanning Michelson interferometer. Some stars show evidence of stellar steam absorption in their spectra; others do not. There is no evidence of steam in the spectra of α Her or R Lyr, even though their spectral type is M5; o Cet near maximum light, with a spectral type also about M5, has strong steam absorption. We also note that χ Cyg has smaller steam absorptions than does o Cet (and R Hya and R Leo).

There is some correlation between the strength of the steam bands in our spectra and the strength of the 9–12 μ excess emission found by Gillett, Low and Stein (1968). For example, α Her has no steam, and has no 9–12 μ excess; o Cet has strong steam absorptions, and strong 9–12 μ emission. χ Cyg is intermediate in both attributes. The same point can be made by reference to the K-N (2.2 μ–10.2 μ) colors, as shown in Table 2. The first group of stars in the table has K-N averaging around zero; the second group (the Mira stars) has K-N $\sim +1.0$. On the other hand, the third group of stars shows that the correlation does not exist for the early-M supergiants, which also have large excesses both in K-N (Johnson 1967) and from the data of Gillette, Low and Stein.

It seems quite possible to explain the observed infrared excesses exhibited by both the supergiants and the Mira stars as radiation from large circumstellar clouds surrounding the stars. Such clouds are already known to exist for some of these stars (Deutsch 1960). Why the steam is associated only with the Mira stars, remains to be explained.

TABLE 2
K-N COLORS OF STARS

STAR	SPECTRAL TYPE	K-N	H_2O PRESENT
α Boo	K2 IIIp	−0.10	No
α Tau	K5 III	+0.15	?
γ Dra	K5 III	+0.10	No
δ^2 Lyr	M4 II	−0.05	No
R Lyr	M5 III	+0.06	No
α Her	M5 Ib-II	−0.08	No
χ Cyg	S7, 1e	+1.2:	Yes
o Cet	MSe (max)	+0.9	Yes
R Hya	M6e	+0.9	Yes
α Ori	M2 Iab	+0.77	No
α Sco	M2 Iab	+0.42	No
μ Cep	M2 Ia	+1.62	No

Acknowledgments. The Block interferometer and co-adder were acquired by the Laboratory through support from the NASA Institutional Grant to the University of Arizona which made possible both the program on the NASA 990 Jet based at NASA-Ames, and the interferometer observations at the Catalina Observatory. We are much indebted to the Department of Mathematics of the University of Arizona for making available to us computer time on the IBM 1130 which was well suited to the data reductions, Fourier Transform computations, and the plotting of the data. Mr. Alan Wittbecker carried out most of the co-adding, and most of the data processing with the IBM 1130. This research was supported by the National Aeronautics and Space Administration and the National Science Foundation.

REFERENCES

Auman, J., Jr., 1967, *Ap. J. Suppl.,* **14**, 171.

Ballik, E. A. and Ramsey, D. A. 1963, *Ap. J.,* **137**, 61.

Danielson, R. E., Woolf, N. J., and Gaustad, J. E. 1965, *Ap. J.,* **141**, 116.

Deutsch, A. J. 1960, *Stars and Stellar Systems,* **6** (*Stellar Atmospheres,* Ed. J. L. Greenstein; Univ. of Chicago Press, Chicago), 543.

Felgett, P. 1951, Cambridge University thesis.

Gillette, F. C., Low, F. J., and Stein, W. A. 1968, *Ap. J.,* in press.

Johnson, H. L. 1967, *Ap. J.,* **149**, 345.

Kuiper, G. P. 1962a, *Comm. LPL,* **1**, 83.

Kuiper, G. P. 1962b, *Comm. LPL,* **1**, 179.

Kuiper, G. P. 1963, *Comm. LPL,* **2**, 17.

Kuiper, G. P. 1964, *Mém. Soc. R. Sci. Liège,* Ser. 5, **9**, 365.

Kuiper, G. P. and Forbes, F. F. 1968, *Comm. LPL,* in press.

Kuiper, G. P., Forbes, F. F., and Mitchell, R. I. 1968, *Comm. LPL,* in press.

McCammon, D., Münch, G., and Neugebauer, G. 1967, *Ap. J.,* **147**, 575.

Mertz, L. 1965a, *A. J.,* **70**, 548.

Mertz, L. 1965b, *Transformations in Optics* (John Wiley and Sons, Inc., New York).

Mertz, L. 1967, Infrared Physics, **7**, 17.

Woolf, N. J., Schwarzschild, M., and Rose, W. K. 1964, *Ap. J.,* **140**, 833.

TABLE OF CONTENTS