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High-Resolution Spectroscopy

C. A. Beck
J. H. Campbell
Naval Research Laboratory
Washington, DC



1 March 1955

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OPERATION CASTLE

Project 18.3

HIGH-RESOLUTION SPECTROSCOPY

**C. A. Beck
J. H. Campbell**

**Radiometry I Branch
Optics Division**

March 1955

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ABSTRACT

The high resolution work undertaken at CASTLE with three spectrographs of relatively high dispersion is described and analyzed. Profitable results are obtained from the spectra taken with the JACO 21-inch Wadsworth-mount spectrograph, mainly the highest violet cutoff to date and a very predominant NO_2 spectrum in absorption.

PREFACE

This report covers one of two phases of work done under the project titled "Spectroscopy." The report on the second phase concerning low-resolution spectroscopy will appear separately under the title "Operation CASTLE, Project 18.3, Low-Resolution Spectroscopy - Color Temperature."

The experimental work with the JACO 21-ft Wadsworth-mount spectrograph described here was carried out by John H. Campbell.

The final analysis of the JACO plates, the subsidiary experiments on NO_2 , and the conclusions given in this report were made by Carl A. Beck.

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HIGH RESOLUTION SPECTROSCOPY

1. OBJECTIVE

The high resolution spectroscopy performed at the operations prior to CASTLE consisted mainly of taking exposures over a relatively long interval of time and encompassing the whole surface of the luminous sphere.

It was considered important to try to observe time variations in the spectra of all or of part of the fireball at rather high dispersion; and also, if enough light were available, to record the manner in which spectral variations over the area of the fireball behave with time.

Since spectra of previous shots contained much very close structure, it was decided to try to photograph some spectra with a somewhat higher resolving power than that previously used; hence the utilization of an Echelle grating.

The attempt was also to be made to correlate results from these data on bombs of higher order of effective kilotonnage with those of lower kilotonnage.

2. BACKGROUND

The plates of high resolution spectra taken at previous operations yielded information in the wavelength region from about 3000 to 9000 Å.

These showed a continuous emission spectrum of the fireball with superimposed absorption lines and bands. In some cases, emission lines and bands were evident. Most of these lines and bands have already been identified.^{1,2,3,4,5,6} In addition, from the intensities of absorption, some rough calculations on the amounts of absorbing material present have been made.

Many atomic lines have been observed both in emission and in absorption, some originate in the casing materials (e.g., Fe, Ba) and others in the earth's atmosphere (O, N).

The molecules which can be seen spectroscopically in absorption belong to two classes: First, those which already exist in the normal atmosphere of the earth - namely, water vapor and oxygen. Secondly, those which are affected by the bomb: some merely experiencing excitation (e.g., N_2^+ or the Schumann-Runge bands of O_2), others being manufactured in the space surrounding the fireball (e.g., NO_2 - due to the result of some action of the bomb).

An interesting feature of all these spectra is the cutoff on the short wavelength side. This can be produced by any material whose spectral absorption curve trails off toward higher wavelengths in the region concerned. This cutoff has been observed to lie as low as about 2900A. (This is the approximate value for ' of Operation UPSHOT.) The spectrum of ozone (O_3) can be responsible for a cutoff around the 3000A region. Of course, more than one

type of molecule could be responsible. Nitrogen dioxide (NO_2) (with a maximum absorption at about 4000A at room temperature) can contribute, especially above this value.

3. EXPERIMENTAL CONDITIONS

Table 1 gives pertinent data on some general experimental conditions under which the shots of Operation CASTLE were carried out. These data (other than atmospheric transmission) were supplied by the Los Alamos Scientific Laboratory.

Table 1 - COMPILATION OF DATA ON THE CASTLE SHOTS

Shot	Location	Yield, MT	Temp., °C	Relative humidity, percent	Distance from shot to Sta. 70, km	Trans- mission- from shot, percent
	Bikini-Charlie	15.0 $\pm$ 0.5	26.7	77	37	12 (to Tare)
	Bikini-Barge	11.0 $\pm$ 0.5	26.7	77	37	22 (to Tare)
	Bikini-Tare	0.11 $\pm$ 0.02	27.2	82	21	rain
	Bikini-Barge	7.0 $\pm$ 0.5	27.2	86	26	26 (to Sta. 70)
	Bikini-Barge	13.5 $\pm$ 1.0	27.1	84	26	1 (to Sta. 70)
	Eniwetok-Barge	1.7 $\pm$ 0.3	26.7	93	35 (to Parry)	rain

4. INSTRUMENTATION

To accomplish the above objectives, three high resolution spectrographs were set up in the NRL experimental room of Station 70 on Enyu. These were the JACO 21-ft Wadsworth-mount, the 2-m Baird-Hulcher, and the Hilger-Echelle.

For each instrument, the light was brought into the room by being reflected from a plane mirror mounted on the 200 ft level of the adjacent tower and then transmitted through a Vycor window mounted in the roof (see Fig. 1). It was then reflected by a plane mirror onto a concave mirror which focussed the image of the fireball on the slit of the spectrograph. In the case of the Baird instrument, in order to increase the field of view, it was necessary to use a concave mirror as well as a plane mirror on the 200 ft level to form a pre-image.

4.1 JACO 21-ft Wadsworth-Mount Spectrograph

The JACO 21-ft Wadsworth-mount spectrograph was used for five shots. Pertinent data for the spectrograph are given in Table 2. It includes travel time of plates, slit height, types of plates used in each deck, also a notation of those plates yielding some measurable results and those which were microphotometered.

This double-deck Jarrell-Ash 21-ft fixed-position grating (15,000 lines to the inch) spectrograph is actually two complete Wadsworth-type grating spectrographs, incorporated in a single cover. The horizontal aperture ratio is 33:1 while the vertical value is 66:1. Each deck has a plate holder which can accommodate three 10 in. plates. The positions of the grating, slit, and plate holder are set so that the lower wavelength limit in the first order is about 3500Å for each deck. The dispersion in the first order is about 5Å/mm, so the range of each plate is about 1250Å in the first order. The upper

Table 2 - COMPILATION OF DATA FOR THE JACO 21-ft WADSWORTH-MOUNT SPECTROGRAPH

UPPER DECK				LOWER DECK			
Time for sweep of 4 in., sec	Slit height, ^a mm	Plate used	Exposure time, sec	Time for sweep of 4 in., sec	Slit height, mm	Plate used	Exposure time, sec
3	0.1	O-F-O ^b	3/1000	0.3	0.1	O-F-O	3/10,000
4	1.0	O-F-O Mc R	1/25	static	20	O-F-N M M M R (uv filter)	0 - 0.3
4	0.4	O-F-N (uv filter) ^d	4/250	0.4	0.4	O-F-N (uv filter)	4/2500
5	1.0	O-F-N M' M M R (uv filter)	1/20	0.5	1.0	O-F-N (uv filter)	1/200
4	1.0	O-F-N M' M M (uv filter)	1/25	static	20	O-F-N (uv filter)	0 - 0.3

^aA 50 μ slit width was used in all cases.

^bO, F, N signify Kodak spectroscopic plate sensitizing classes. Type 103 emulsion was used with the O and F classes, and Type I with the N. The lower wavelength region is covered by the plate designated on the left.

^cM below the plate type means the plate has some measurable results, M' means some spectral blackening;

^dR below the plate type means the plate was microphotometered.

uv filter - ultraviolet filter used over entrance slit.

wavelength limit is therefore about 7250A. The second order spectrum can be eliminated by the use of an ultraviolet filter. On the other hand, by the use of the proper plates (O emulsion), the first order spectrum above 5000A can be eliminated; the second order spectrum from 2500 to 3600A is now present; and it is possible to photograph on either deck from 2500 to 5000A. Slit-height is controlled by the use of mounted razor edges separated by the desired distance.

The plate-moving mechanism for this instrument is a hydro-mechanical servo system. The whole system operates from timing signals. The position of the photographic plate is programmed on a cam. This cam is rotated by a variable-speed dc motor through a one-turn clutch. The motion of the plate is started by an electrical pulse obtained by delaying the -1 sec signal an appropriate amount by a phantastron circuit. The speed control provides various plate speeds over a range of approximately 5 to 1. Further changes in speed are made by gearing. The cam is linked to a hydraulic valve which controls the flow of fluid to a cylinder which moves the plate. A lever is attached to the plate carriage and is linked to the hydraulic valve in such a way that the plate must move ten times the change in radius of the cam to keep the valve in a neutral position. This arrangement forces the plate to follow the cam contour very accurately. The upper and lower decks are alike except for cam contour and speeds. The maximum speeds attainable are 30 in./sec on the lower deck and 3 in./sec on the upper deck.

The external optical system used at CASTLE is schematically represented in Fig. 1. This same system is used for each deck. In this figure, M_1 represents a 16 x 23 in. flat mirror mounted on the tower at an elevation of 200 ft; M_2 , a 12 x 16 in. flat mirror mounted inside the shelter; P, a 15 ft focal length, concave parabolic mirror placed alongside the spectrograph; and M_3 , a small 6 x 6 in. flat mirror situated on the optical axis of the spectrograph, for directing the light into it. A plan view of the rays inside the spectrograph is included in Fig. 1.

4.2 Baird Two-Meter Spectrograph with Hulcher Camera

The Baird two-meter spectrograph has a numerical aperture of about $1/30$ and a dispersion of about $8\text{\AA}/\text{mm}$ (1st order), thereby giving a spectral response range of $1000\text{\AA}$ over 5 in. The regular plate-holder assembly for this instrument was dismantled and a holder for a high speed camera attached. This camera was a Hulcher "70" high-speed sequence camera. It was altered so that the 70 mm film could pass through the transport mechanism along a curve made to agree in curvature with that of the Rowland circle proper to the grating, namely a circle of 1 m radius. A vacuum arrangement insured that the film adhered to this curve. The film traveled intermittently through the film gate so that 25 exposures of 5 in. lengths were taken per sec. The camera was equipped with two shutters rotating in the same direction, one at four times the speed of the other. The slow shutter blanked

out the fast shutter for three out of four revolutions. The fast shutter had a fixed opening of 60 deg. There is a dead-to-live-time ratio of 23 to 1. Therefore, the exposure time for this case was $1/600$ sec. In experiments after the second shot, the speed was slowed down to about $1/10$ of the above value.

For the first three shots the spectral range covered was 3500 to 4500A and afterward, 5000 to 6000A. A concave mirror (15 ft focal length) was used on the 200 ft level of the Enyu tower to obtain a sufficient field of view for the instrument. This formed a pre-image of the fireball which, in turn, through the optical system shown in Fig. 1, was imaged by a 10 ft mirror on the slit of the spectrograph. For the first two shots, this provided an image length on the slit of about 0.6 in. for 4000 ft of fireball. Eastman Super XX and Tri X films were used in order to insure maximum sensitivity.

4.3 Hilger Spectrograph with Echelle Grating

A large E-1 Hilger spectrograph with a numerical aperture of about $1/25$ was adjusted so that the range from 3000A upwards could be photographed. An echelle grating with 200 lines/in., ruled by Bausch and Lomb, was placed in back of the prism so that light after reflection from it was returned in Littrow fashion through the prism. The dispersion in the vertical echelle orders was roughly 1A/mm, and a resolving power of more than 100,000 was available. Since it was decided not to use a large field of view in this case, this instrument

was used as indicated in Fig. 1, where P is now a 10 ft focal length concave mirror. This focussed the center of the image of the fireball on the slit.

To check the behavior of the instrument, a spectrum of the sun was taken, the Fraunhofer lines appearing with good resolution. A negative print of this is shown in Fig. 2.

For the first shot a Type 103-O plate, sensitive up to 5000A, was used and for succeeding shots a Type 103-F plate, sensitive to 7000A.

4.4 Other Instruments Used

For the last shot the IVY spectroscopy room on the Parry Island tower was used. The Hilger-Echelle was moved there. Also, a JACO 1 1/2-m Wadsworth-mount grating spectrograph without collimator lens was set up to take a 0.3 sec exposure over two-thirds of its slit and an 8 sec exposure over the remaining one-third. This was used with two strips of O and N film running from 3000A up to 7800A.

A Hilger small quartz-spectrograph that was used for in connection with Project 18.5 was also used for this shot. It was set for a total time exposure of about 8 sec. The slit width was 0.025 mm, and a Type 103-F plate was used.

5. RESULTS

5.1 JACO 21-ft Wadsworth-Mount Spectrograph

There was no apparent blackening on most of the plates exposed in this spectrograph. In Table 2 there are notations designating which plates were measurable (M) and which were microphotometered (R).

For the first shot, both decks were moved during exposure; there was no measurable blackening on the plate.

The strongest spectra observed at CASTLE were obtained for in the lower deck. A static exposure from detonation to +0.3 sec was used here. These three plates are labeled C2(CASTLE, second shot) L(lower deck) A, C2LB, and C2LC; A, B, and C indicating the regions of low, medium and high wavelengths, respectively. C2LA shows the end of the cutoff from approximately 4600 to 4800Å but the exposure was weak and was not microphotometered; C2LB and C2LC were microphotometered. These three plates provided most of the information obtained from the operation. Negative prints of them are given in Figs. 3, 4, and 5. It was not thought feasible to try to measure these plates on a comparator because it was not practicable to place a comparison spectrum on the moving plates.

A spectrum was obtained on the F plate of the upper, moving deck. This plate was run on the microphotometer. It was very faint and not suitable for wavelength determination.

There were no recorded spectra for

For there were spectra on the F and N plates of the upper, moving deck; the O plate shows some faint blackening. The N plate was microphotometered. There was an accident in photographic development on half of the F(C4UB) plate. There were no results for the lower deck.

On there were no results for the lower static deck, which might have resulted from error of alignment. On the upper moving deck, the F and N plates show a weak exposure and the O plate very weak, but measurement on them was thought not to be practicable.

This instrument was not used for

In almost all cases where no measurable blackening was observed, it is believed that the lack can be attributed to the lowness of the light level. Setting of exposure time was too optimistic, so that no moving plate recorded any blackening, except when the plate was moved at a relatively low speed of about 1 in./sec. Even then, the blackening was not sufficient for good measurement.

For the sake of completeness, all other plates from the JACO which gave some results, no matter how scanty, are reproduced in this report; these are C2UB(Fig. 6), C4UA (Fig. 7), C4UB (Fig. 8), C4UC (Fig. 9), and C5UC (Fig. 10). However no definite measurements were made on these plates.

5.2 Two-Meter Baird-Hulcher Spectrograph

This instrument produced no measurable results. The exposure time for the first two shots was $1/600$ sec. The setting of 3500-4500A was first chosen because in the past this region provided more information than any other. However, the lack of light in this region for the shots of this operation prevented any positive results.

For () the region was changed to include 5000 to 6000A, and the camera run at the lowest adjustable speed of the motor, namely about $1/10$ of the previous value. This gave an exposure of about $1/60$ sec. This still proved to be too short an exposure. A decided disadvantage proved to be the large amount of dead time required to move the next piece of 5 in. film into position. (The ratio of dead to live time is 23 to 1.) Hence, nothing positive can be reported from this instrument.

5.3 Hilger-Echelle Spectrograph

This instrument, with an exposure of about one minute, had produced plates of fair intensity for the spectrum of the sun (see Fig. 2). But again the light level from the shots was too low. Even though the instrument was set to take long exposures (8 sec) there was no measurable blackening in any exposure.

5.4 Shot ()

There was rainfall over the optical path at the time of detonation of (), but in spite of this a faint exposure in the interval of 5000-7000A was obtained on the 8 sec portion of the small Wadsworth spectrograph. It was not possible to obtain any definite structural information from it.

No blackening was observed on the plate of the Echelle instrument. A plate with good blackening was obtained on the small Hilger instrument, this representing an integrated exposure of 8 sec.

6. ANALYSIS

6.1 Cutoff Values

From an examination of the spectra taken, the violet cutoff can be set roughly at 4600A for the shots in this series for which spectra were obtained. Blackening conditions do not permit obtaining a quantitative value for this. Below this value, however, nothing can be observed in any of the spectra. While it is faintly noted for C2LA (Fig. 3) and C4UA (Fig. 7), it is best seen in the static exposures on the JACO for the second shot (Figs. 4 and 5). It is roughly 1000A higher than any value given in the IVY report or for any shot before this operation.

It is not possible to say with certainty what absorption spectrum or spectra are responsible for the cutoff and to what quantitative extent. To do this one needs to know the intensity distribution of the background continuous spectrum, and this is not known. (It can be deduced from a so-called "chord experiment" in which an auxiliary continuous source is sighted along a line which is intersected by the later stages of the expanding fireball.) There is the possibility of certain continuous spectra underlying this region and they could

easily escape detection. However, we are inclined to say that the observed cutoff at CASTLE is essentially due to NO_2 . It possesses the proper shape of absorption curve for this, namely a maximum at around 4000A and a diminishing tail extending upward several thousands of Angstroms.⁷ N_2O_4 has an almost constant absorption in the region above 4000A and cannot be responsible. Of course the absorption of ozone around 3000A and of the Schumann-Runge bands of oxygen up to about 4000A is no doubt present, probably constituting the greater part of the absorption in those regions.

The probability of some sort of scaling of the cutoff frequency with effective kilotonnage of explosion was mentioned in the IVY report⁶ and it seems now that a trend is well substantiated.

6.2 Observed Materials

There is scarcely a line or band in C2LB (Fig. 4) and C2LC (Fig. 5), except for those due to oxygen and water vapor, which cannot be made to agree with the comparison spectrum of NO_2 (see Sec. 6.3). However, all regions are not favorable for this comparison. The low wavelength ends of C2LB and C2LC have a considerable takeout and some peaks might easily escape notice. There may be a few peaks that do not agree, like the one at 5409A which we were not able to identify. The amount of NO_2 will be discussed under Sec. 6.3.

The plates C2UB (Fig. 6) and C4UB (Fig. 8) show NO_2 to a smaller extent. It is present in the weak bands around 6100A. However, the

other regions are difficult for detection because of underexposure. Only the water vapor spectrum shows with prominence and it was not thought worthwhile to reproduce these prints. The small amount of NO_2 present here in the moving plate cases may point to the smaller production of NO_2 at later times than during the earlier stages, as illustrated by the integrated 0 - 0.3 sec exposure of the lower deck for the second shot (C2LB and C2LC - Figs. 4 and 5).

The plate of the 'little Hilger taken for() shows NO_2 very markedly, but because of the low dispersion, it was felt that no productive analysis could result from its measurement.

Other materials were not definitely observed, but from past experience other molecules should be excited or produced. Molecules producing continuous spectra would easily escape notice. Also, the region which was observed is too high in wavelength for showing the strong bands of the expected molecules: N_2 , O_3 and the Schumann-Runge band of O_2 .

6.3 Excitation State of NO_2

The extensive structure on the plates run on the lower deck of the JACO for (C2LB and C2LC) looked very similar to that of NO_2 which has often been observed spectroscopically in atomic explosions but in a lower wavelength region. Hence, for the purpose of identification and comparison, absorption spectra of NO_2 were prepared.

A tungsten strip filament taking 6 amp afforded the background continuum. Two quartz absorption cells of 5 and 50 cm length were used. In each case, about 22 cm of Hg (pressure) of NO₂ taken from a cylinder supplied by the Matheson Co. was admitted. Air was added to bring the whole to atmospheric pressure. Spectra were taken on a large JACO Ebert-mount spectrograph set for 4750 to 7250A. The dispersion was about 5.0A/mm which, incidently, agrees with that of the JACO 21-ft instrument in the first order.

These NO₂ plates were measured on a Leeds and Northrup Recording Microphotometer with a scanning slit width of about 0.02 mm. They were also measured on a Mann comparator. The values of the NO₂ wavelengths were used for the marked values of the bands of C2LB and C2LC on the microphotometer traces. Prints of the spectra of NO₂ are shown in Figs. 11 and 12. The high wavelength region on the right in Fig. 12, is not blackened because of the F plate cutoff at about 6600A. Comparison of a portion of the microphotometer traces of NO₂ and C2LB is shown in Fig. 13. All the microphotometer traces will be reproduced in a separate atlas.

While the frequency match mentioned in Sec. 6.2 is excellent, the relative intensities of all the peaks do not agree with the peaks of the spectra taken in the laboratory at room temperature. It should be noted that two factors make the accurate determination of absolute absorption intensities impossible. First, the lack of knowledge of the continuous emission background which is present in atomic explosions

and secondly, the lack of certainty of the amount of the absorptive background of the NO_2 spectrum in this case. One can then only work with extrapolation of peak to shoulder distances. There is good general agreement of these distances between the spectrum of the 5 cm cell (Fig. 11) and that of C2LB (Fig. 4). The former appears to be about twice as strong in some instances.

It is also true that there is good agreement between the spectrum or the long, 50 cm cell (Fig. 12) and that of C2LC (Fig. 5). For example, the peak to shoulder height of bands around 6738Å agree well as do the bands around 6691Å. The long-cell NO_2 spectrum shows a complete absorption takeout in the lower wavelength region (this is illustrated in C2LB - Fig. 4) while the NO_2 bands obtained with the short-cell give peak to shoulder distances which are about one-tenth too small to match the upper wavelength region (as shown in C2LC - Fig. 5). All of this points to a decided difference between the excitation state of NO_2 produced by the explosion and that observed at room temperature. Whether this can be due to excited vibrational states or to an excited electronic state cannot at present be determined. From the experiments with the two cells, it is seen that about one cm of NO_2 at STP is necessary to produce the same appearance of spectrum as seen in C2LB and also that roughly 14 cm of NO_2 at STP are required to give the same appearance of the spectrum as seen in the higher wavelength region (C2LC). Values of less than one mm have been obtained for certain shots of

Operation UPSHOT by Curcio of NRL. A precise value of excitation temperature cannot now be given but a very rough estimate would be about 1000°C.

The continuous background may be due merely to the overlapping of very many bands in a rich and complicated electronic spectrum. The bands have apparent structures of quite varying degrees of sharpness, some very diffuse with widths up to about 5Å and more. The spectrum should be taken at higher resolving power to show to what extent there is additional structure.

The work on the theoretical analysis of the NO₂ spectrum in this region (about 2500-9000Å) is very meagre. A thorough classification of the observed structure has not been done. Charles Petty is at present investigating the nature of this spectrum in the Physics Department at Johns Hopkins University.

6.4 Diffuse Bands

On the plate C2LC (Fig. 5), diffuse band at about 6630Å and about 40Å wide is very prominent among other diffuse bands in the general region. It does not appear in our spectrum of NO₂ taken at room temperature and may be a band due to a photodissociation at high temperature. Although this can be observed only in C2LC, it is not likely that this is due to an imperfection in the plate or to the development technique.

6.5 Time Variation

Not much can be said about the results of time variation. There was a great deal of uncertainty about the smoothness and time-of-start of travel in the experiments. The slow velocity used caused a periodic sticking in the plate travel. The only plate which shows the time variation well is C5UB (Fig. 14) which was a 4 sec sweep. It shows the first maximum as a narrow, relatively intense portion of the strip-spectrum and the presence of the minimum very well. The minimum condition shows no blackening at all on this plate. This is in agreement with the high-speed frame-spectra taken by Fussell of NRL, where, at minimum, no blackening shows below about 6000A. It is not possible to detect with certainty any differences in the spectrum with time. The NO₂ bands are not easily detected but at the long wavelength end of the plate the intensity of a few NO₂ bands agree well with about 1 cm of NO₂ at room temperature.

The plate C5UC (Fig. 10) shows only a strip corresponding to the first maximum and this only at the upper half of its wavelength range. Here, in the region where the structure is mainly that of the normal earth's atmosphere, it agrees with the C2LC plate (Fig. 5).

7. CONCLUSIONS AND RECOMMENDATIONS

While much of the objective of the experiment was not attained, information has been gathered on the value of the cutoff and on the order of magnitude of NO₂ production. There is a definite indication

that the NO_2 exists in a state of excitation above that observed at ordinary room temperature. Thus a further study of NO_2 is very important from the point of view of both analyzing structure and determining the method of formation in the nuclear explosion. The observation as a function of time of the formation of NO_2 , which conceivably can be formed in different ways during different intervals of the explosion, would also be of great interest.

It is proposed to take spectra of NO_2 at elevated temperatures of excitation and degrees at NRL. To measure the amount of NO_2 present in a bomb spectrum, one can determine the shoulder to peak ratios (since the background absorption is present) of the absorption spectra of known amounts of NO_2 for various temperature and pressures. One hopes to find the bomb spectrum agreeing with one of these spectra, and hence the amount of NO_2 present can be judged.

The obtaining of spectral information as a function of space is still considered important, even though results were negative for this operation. The ratio of dead to live time must be considerably reduced in the Baird-Hulcher spectrograph. Also, simple filter photography should be very fruitful for spatial studies. This could be done with narrow band-pass filters to give information about diffuse bands, like HNO_2 .

Of the moving-JACO exposures attempted, blackening was obtained for time exposures of about $1/25$ sec - even in one case where there was an extremely low value of transmission (1 percent).

With clearer weather and a closer station, one could expect that an exposure of $1/1000$ sec would produce enough blackening, except at the minimum. Conservatively, one deck of the JACO might be set to sweep through the first maximum with an exposure time of $1/100$ sec and the other deck to sweep the time after the first maximum with $1/10$ sec exposure.

REFERENCES

7. T. C. Hall and F. E. Blacet, Separation of the Absorption Spectra of NO_2 and N_2O_4 in the Range of 2400-5000A, J. Chem. Phys., 20:1745 (1952)

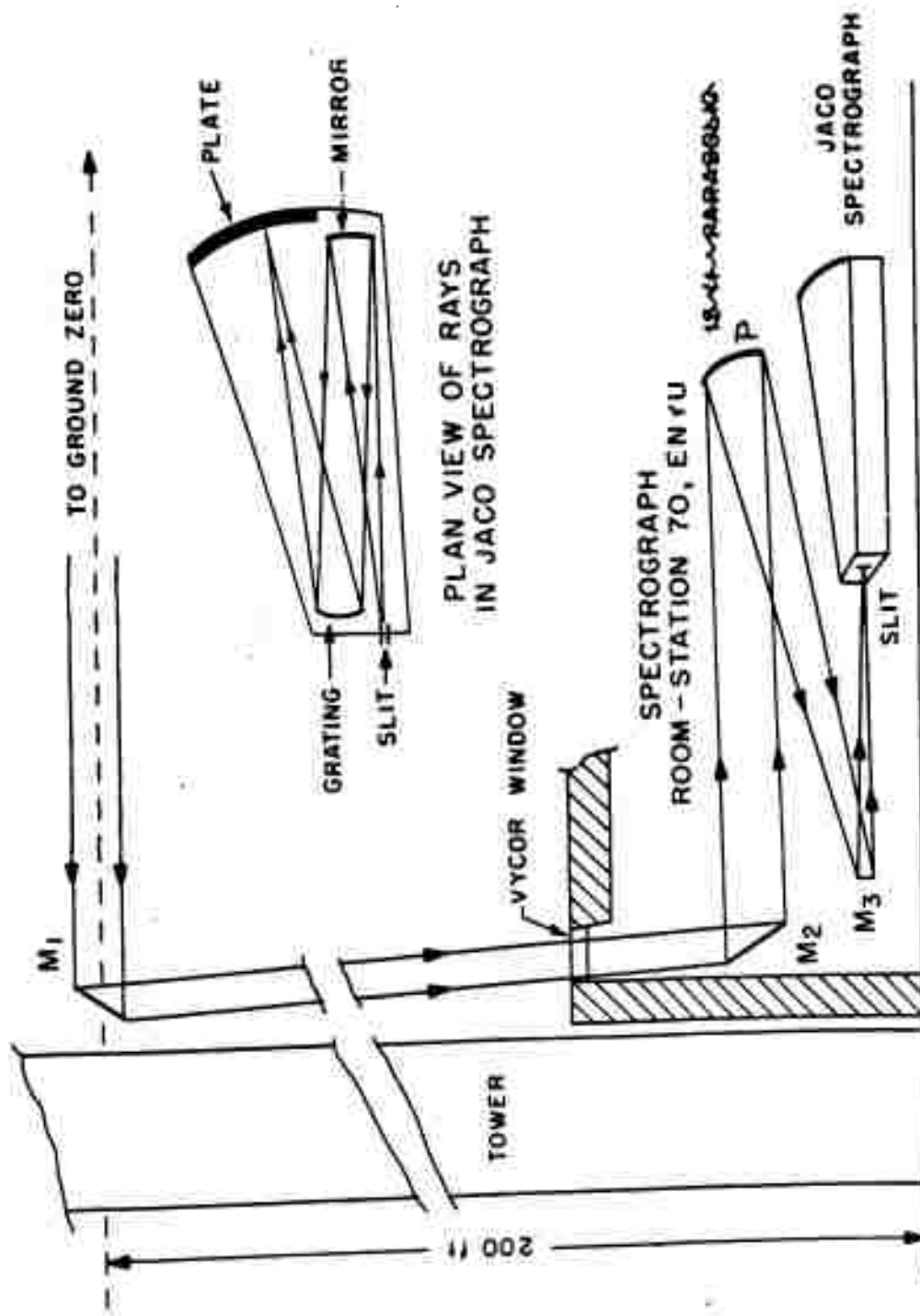


Figure 1 - External Optical System for Spectrographs used in Station 70 on Enyu. (The JACO 21-ft Wadsworth-Mount Spectrograph is Illustrated.)

Al { 3944 A
3961 A

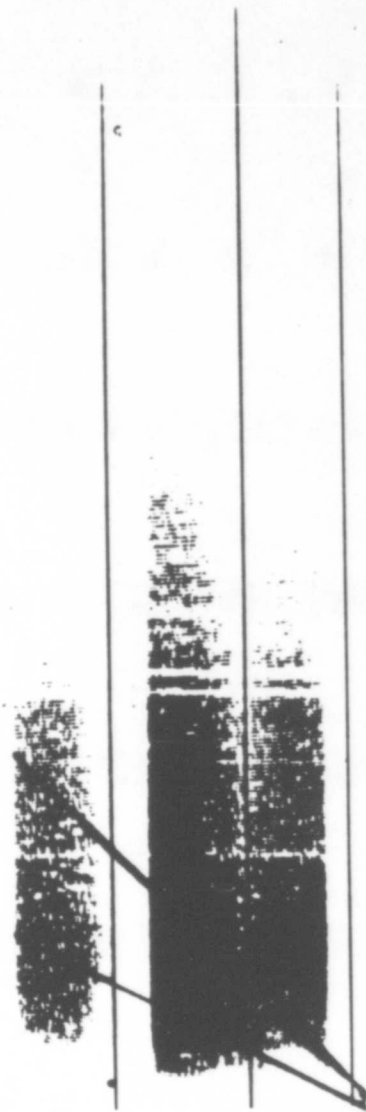
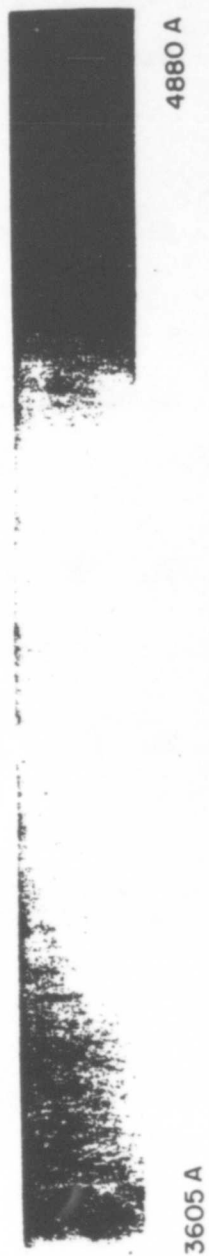


Figure 2 - Spectrum of the Sun Taken with the
Hilger-Echelle Spectrograph



EXPOSURE - 0-0.3 SEC PLATE TYPE 103-0

Figure 3 - Reproduction of the Static JACO Plate C2LA for Shot, .

5380
5450
SELECTED
NO₂ BANDS

H₂O BAND
(~ 5725)
H₂O BAND
(~ 5950)



4880 A

6150 A

EXPOSURE - 0 - 0.3 SEC PLATE TYPE 103-F

Figure 4 - Reproduction of the Static JACO Plate C2LB for Shot

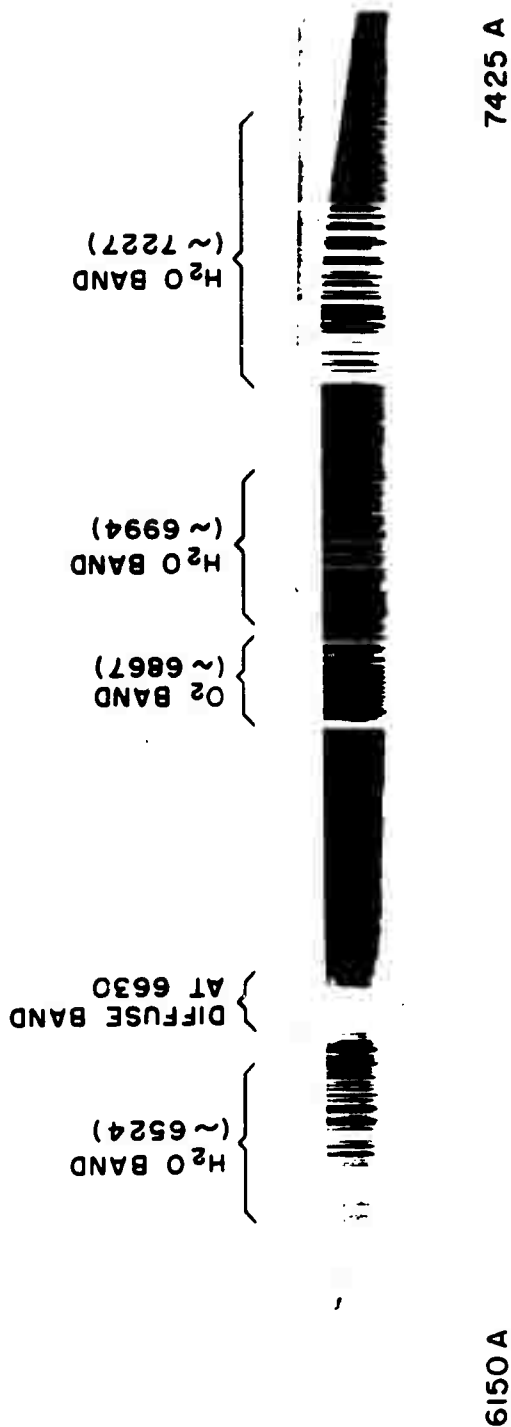
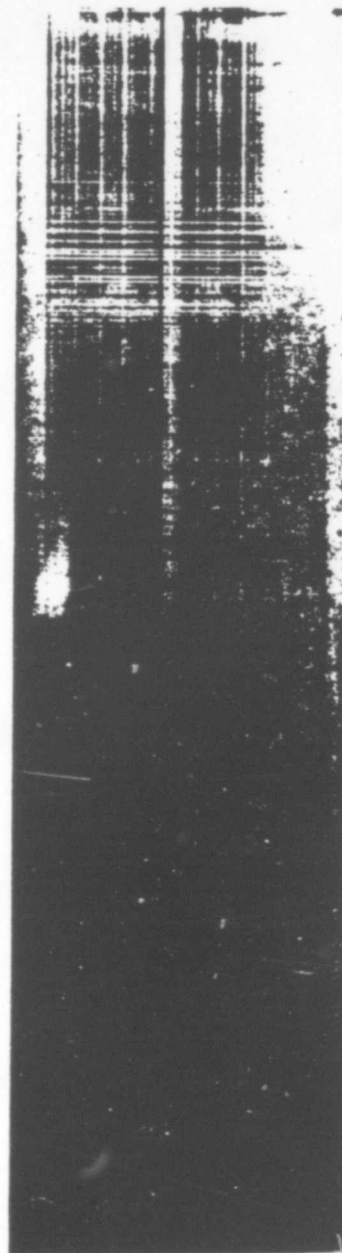


Figure 5 - Reproduction of the Static JACO Plate C2LC for Shot



4880 A

6150 A

EXPOSURE - 1/25 SEC PLATE TYPE 103 - F

Figure 6 - Reproduction of JACO Plate C2UB for



3605 A

4880 A

EXPOSURE - 1/20 SEC PLATE TYPE 103 - O

Figure 7 - Reproduction of JACO Plate C4UA for

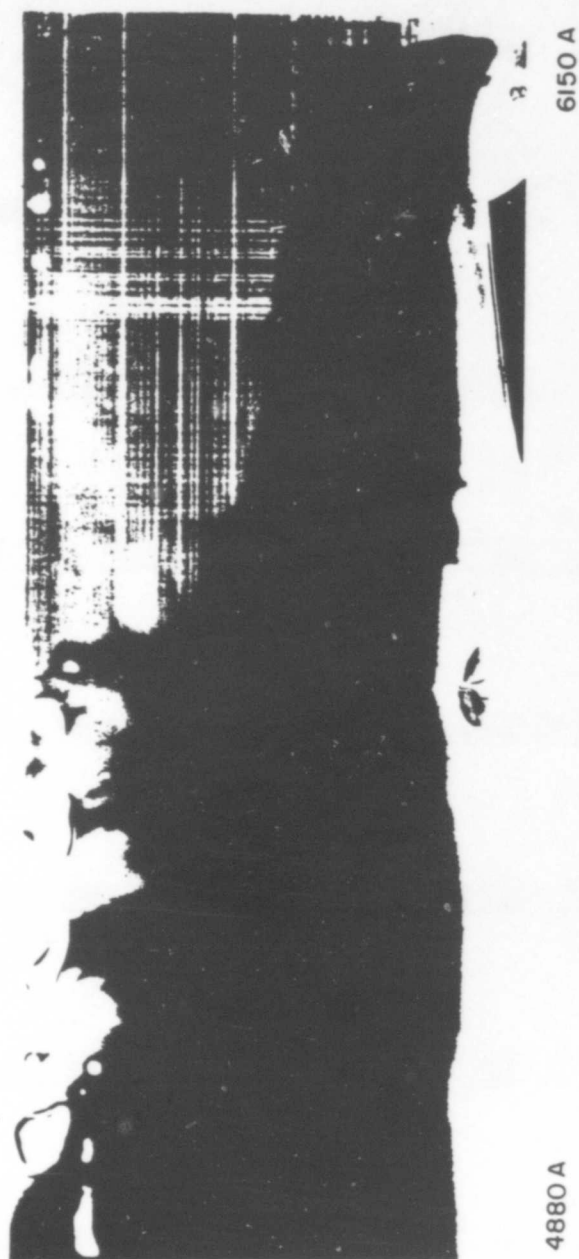


Figure 8 - Reproduction of JACO Plate C4UB for

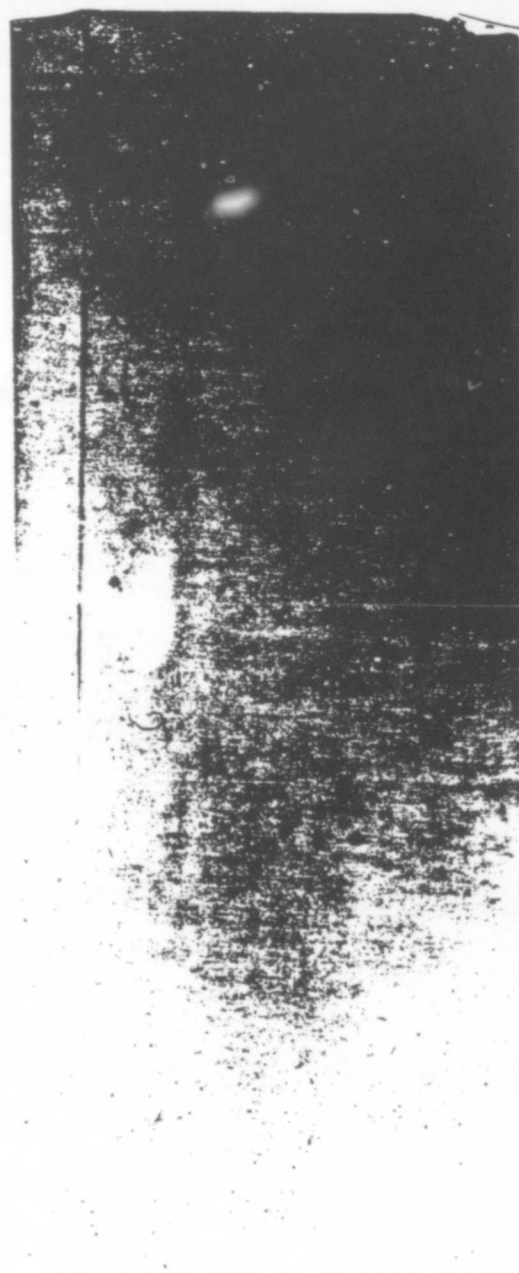


6150A

7425A

EXPOSURE - 1/20 SEC PLATE TYPE I - N

Figure 9 - Reproduction of JACO Plate C4UC for



6150 A

EXPOSURE - 1/25 SEC PLATE TYPE I-N

7425 A

Figure 10 - Reproduction of JACO Plate C5UC for

- 5900 Å

- 4957 Å

(Fe) →

Figure 11 - Reproduction of Spectrum of NO₂: 5 cm Path Length
22 cm Mercury Pressure

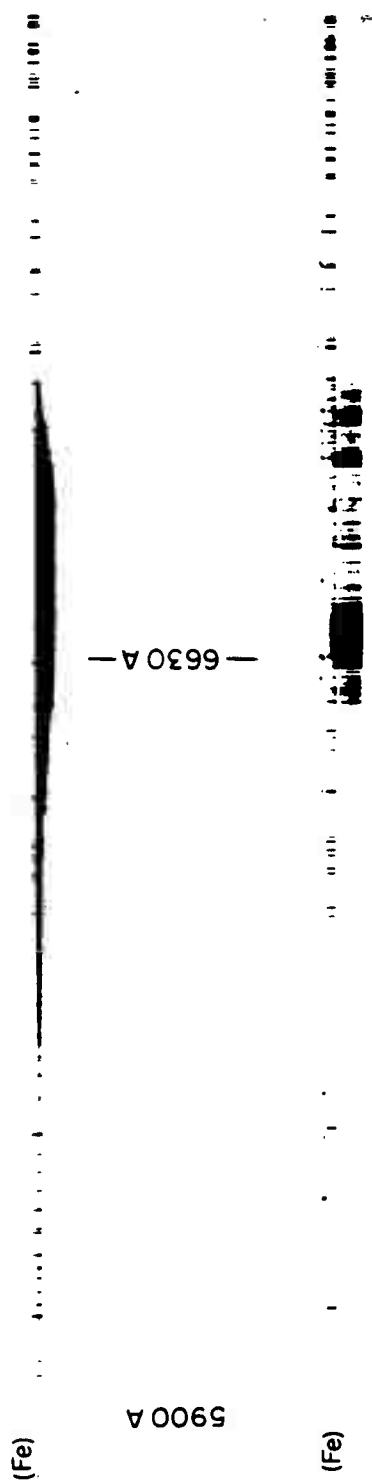


Figure 12 - Reproduction of Spectrum of NO_2 (a) 2.5 cm Path Length, and
(b) 50 cm Path Length; 22 cm Mercury Pressure

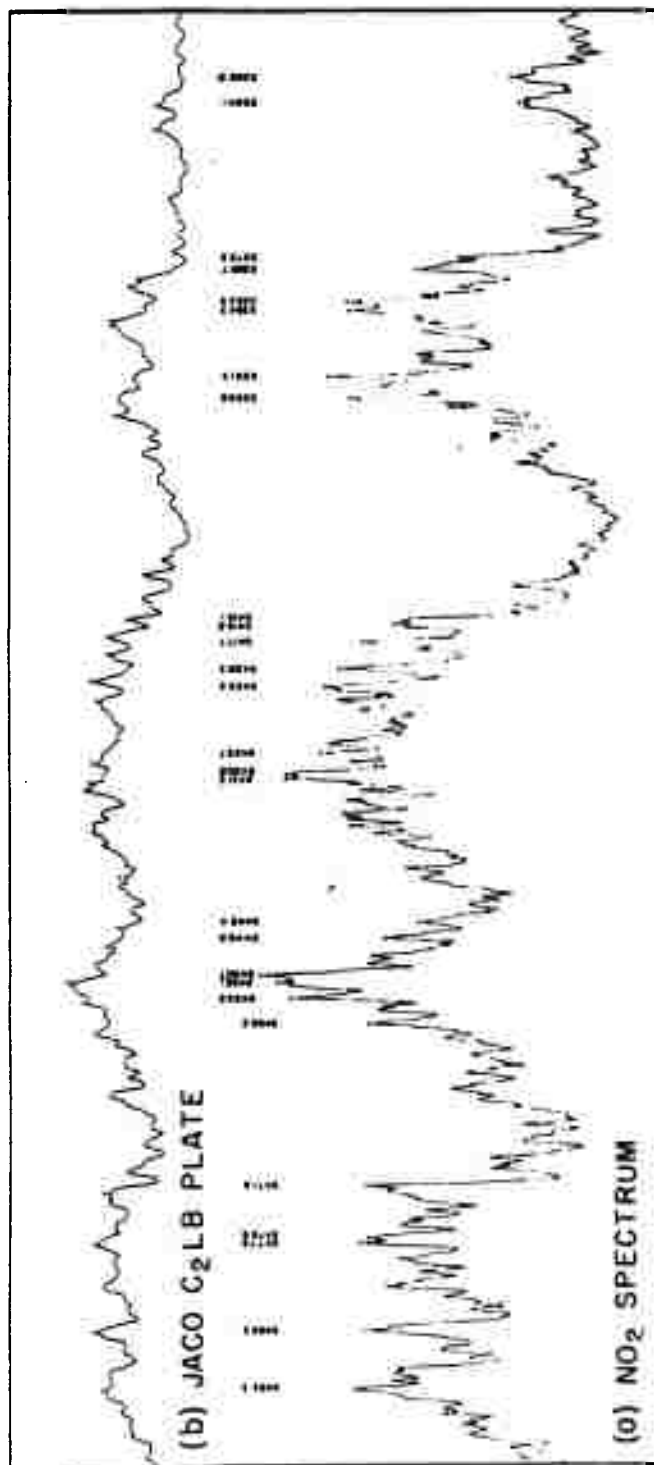


Figure 13 - Comparison of Microphotometer Traces of Portions of (a) NO₂ Spectrum, (b) JACO C₂LB Plate

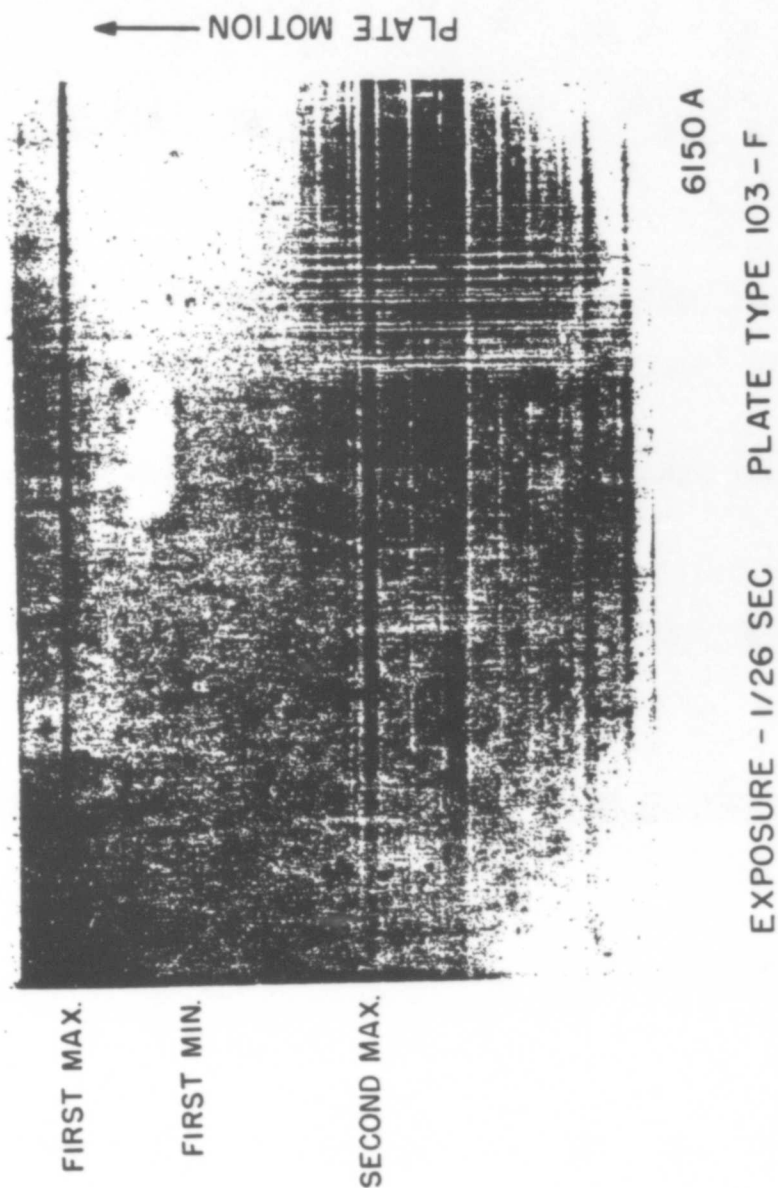


Figure 14 - Time Variation of Spectrum on JACO Plate C5UB
(4 sec Sweep) for Shot