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ROCKET SPECTROHELIOGRAPH FOR THE Mg II LINE AT 2802.7 Å

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GREENBELT, MARYLAND

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FOR THE

Mg II LINE AT 2802.7 Å

By

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Greenbelt, Maryland

May 1966

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ROCKET SPECTROHELIOGRAPH

FOR THE

Mg II LINE AT 2802.7 Å

CONTENTS

INTRODUCTION

Two of the most interesting absorption lines in the near ultraviolet part of the solar spectrum are the Mg II lines at 2795.5 Å and 2802.7 Å. Monochromatic pictures of the sun in these lines may reveal new features in the chromospheric structure and contribute to our knowledge of the formation and development of the active regions on the sun. This paper describes a spectroheliograph designed to obtain monochromatic pictures of the sun in 2802.7 Å line. A Šolc-type birefringent filter, with a spectral bandpass of approximately 3.5 Å was used to select the proper wavelength. The instrument also carried four photoelectric radiometers for absolute measurements of the solar flux in the regions 2200 Å, 2600 Å and 2800 Å respectively.

The spectroheliograph was flown with a Ball Brothers Research Corporation biaxial solar pointing control aboard an Aerobee 150 rocket launched from White Sands Missile Range, New Mexico. The experiment has been launched three times, namely 12 April 1965 (NASA 4:49), 26 October 1965 (NASA 4:53) and 2 December 1965 (NASA 4:145). All three times the payload was successfully recovered. Due to a malfunctioning of the pointing control no data were obtained from the October flight. Preliminary results from the first and the third flights are given by Fredga (1966).

GENERAL DESCRIPTION OF THE INSTRUMENT

The photographic system consists of a Cassegrain-Maksutov telescope behind which is placed a Šolc-type birefringent filter surrounded by a temperature control unit, and an automatic 35 mm camera with a 30-foot film magazine. The components are mounted on a 14-pound aluminum base-plate. Figure 1 shows a top view of the instrument. A boresight consisting of a small lens mounted in the instrument front plate with an eyepiece and a reticle in the back plate is used for coarse alignment.

The instrument front plate carries the four radiometers and the pointing sensors. In Figure 2 the instrument is mounted on the pointing control. The four radiometers and pointing sensors surround the telescope entrance aperture. A light-tight aluminum cover encloses the whole instrument which is shaped to fit into that half of the space in a regular ogive nose-cone of the Aerobee 150 rocket not occupied by the pointing control. The overall length of the instrument is 22 inches, with a total weight of 40 pounds.

The entire instrument unit has been tested according to the Aerobee 150 vibration specifications: 10 G, 5-2000 cps, sine and random on all three axes. The same instrument was flown all three times and survived both the launch and recovery with the optics still aligned and in focus after each flight.

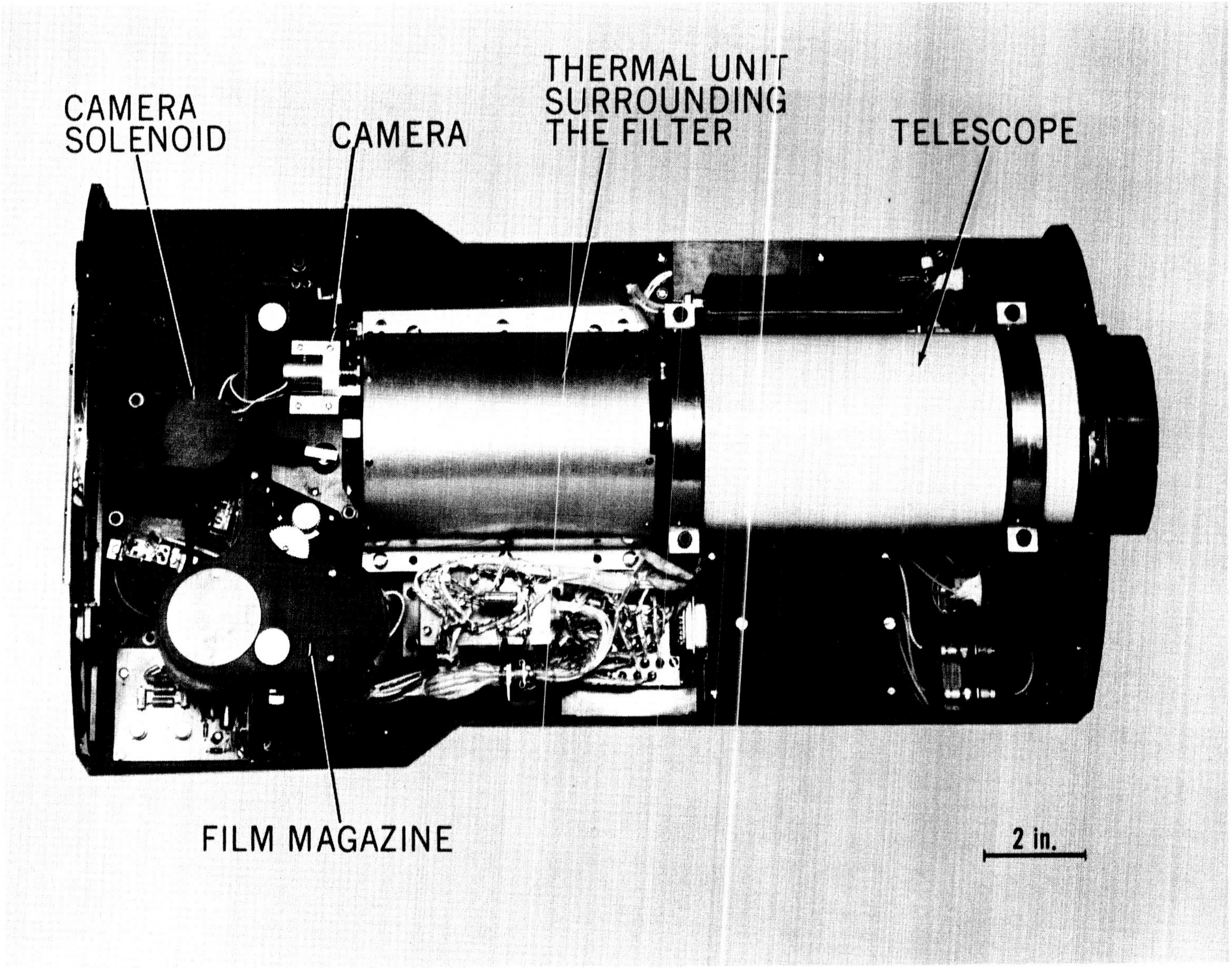

Fig 1 - Top view of the instrument with the covers removed.

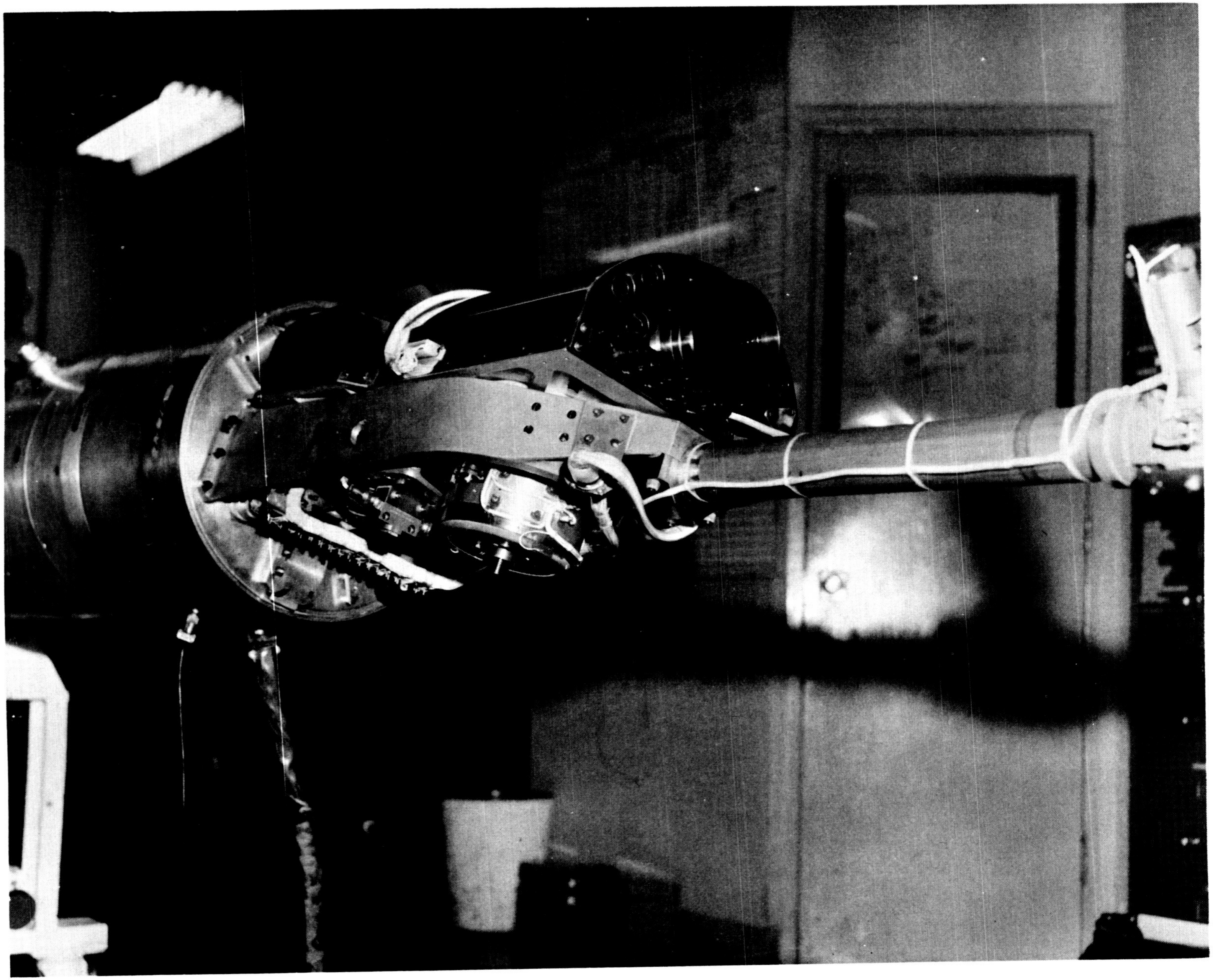

Fig 2 - Instrument mounted on the pointing control for the horizontal test at White Sands Missile Range.

TELESCOPE

The telescope is a modified Questar (Questar Corporation, New Hope, Penn.) The Maksutov-type telescope was chosen because it combines a very compact, closed construction with high resolution, a long effective focal length and excellent imaging qualities.

The primary and secondary mirrors are both spherical mirrors with a focal length of approximately 192 mm and 50 mm respectively. The secondary mirror is integral with the corrector plate, mounted in the front end of the tube. All optics were made of fused silica, with mirror surfaces of evaporated aluminum without any protective over-coating. The f/19 system has an aperture of 8.9 cm and an effective focal length of 169 cm. Figure 3 shows the light path through the optical system.

Some modifications to the commercially available model were necessary to adapt the telescope for rocket use. In order for the telescope to withstand the launch vibration, the primary mirror had to be supported by three stainless steel rods. These also are used to lock the telescope focus.

The telescope is extremely sensitive to changes in the distance separating the two mirrors. With the focal length used in the experiment, the focal plane position will change 70 times the change that may take place in the separation of the mirrors. With a 20 cm aluminum telescope tube, a 10°C

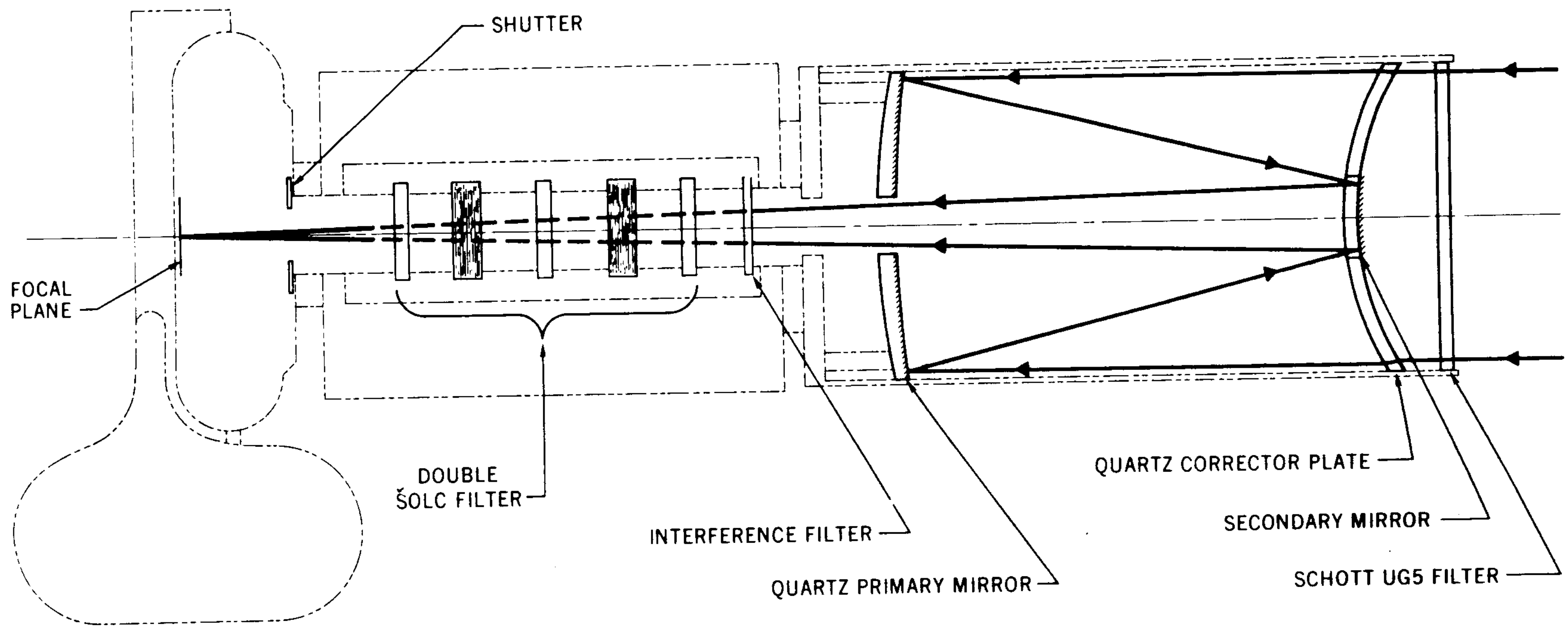

Fig 3 - Light path through the optical system.

change in temperature causes a 3.5 mm change in the position of the focal plane. This would usually not cause any problem on the ground where the focus can be reset until the telescope has adopted the ambient temperature, but for a rocket flight the focus must remain fixed over a wide temperature range. To overcome this problem the mount of the two mirrors was made of a 20 cm Invar tube, the thermal expansion of which was compensated by the three 2 cm stainless steel rods supporting the primary mirror. The resulting thermal expansion for the mounting system comes very close to the thermal expansion for the quartz optics, giving a satisfactorily small change in the focal plane position of less than 0.002 mm per degree C.

A 4 mm Schott UG 5 color filter was placed in front of the telescope. This filter transmits approximately 70% of the light around 2800 Å but less than 1% of the visible light between 4200 and 6800 Å. The filter was hand polished to a parallellism of $\lambda/4$ measured at 5461 Å. Because the telescope is pointed directly at the sun above the atmosphere for about 5 minutes, this filter is needed for several reasons. It prevents uneven heating of the telescope mirrors. Specifically the full heat impinging on the secondary mirror would cause far worse image distortion than the uniform heating of the UG 5 filter. It prevents heating of the temperature sensitive birefringent filter placed in the convergent beam behind the telescope. Also, it further improves the spectral discrimination of the system.

ŠOLC FILTER

Principle of Šolc Filter

The birefringent filter developed by Šolc [Šolc (1953, 1959, 1960, 1965), and Evans (1958)] is similar to the well known Lyot-Öhman type filter [Lyot (1933, 1944), Öhman (1938), Evans (1949)]. In the Lyot-Öhman filter, birefringent retardation plates of diminishing thicknesses are alternated with properly oriented linear polarizers. The Šolc filter employs a pile of uniformly thick retardation plates, but only two linear polarizers - one at each end of the filter. The Šolc filter is particularly useful in the ultraviolet region of the spectrum where the Lyot-Öhman type filter fails to function, because of the difficulty in obtaining satisfactory polarizers with high transmission.

The retardation plates in the Šolc filter are cut with the crystal optic axes parallel to the surface. Šolc (1959, 1960, 1965) describes several different arrangements of the orientation of the axes of the plates and the polarizers.

The filter used in the spectroheliograph is of the type that works between crossed polarizers. In the simplest filter of this type all retardation plates make equal angles ω with the plane of polarization of the first polarizer, but alternate between plus and minus ω. This particular arrangement of the plates and the polarizers is called Type I by Šolc, the folded filter by Evans (1958) and Type A by Beckers and Dunn (1965).

The angle ω is determined by

$$\omega = \frac{45°}{N} \quad , \tag{1}$$

where N is the total number of plates. The thickness d of a single plate is determined by

$$\gamma = \frac{\pi \, d \, (n_e - n_o)}{\lambda} + \frac{\pi}{2} \quad , \tag{2}$$

where γ represents the retardation of a single plate. At the wavelength of peak transmission $\gamma = k\pi$, where k is any integer. λ is the wavelength of the light and n_e and n_o the refractive indices for the extraordinary and ordinary rays respectively.

As Evans (1958) states in his paper "It is difficult to see intuitively how the Šolc filter accomplishes its purpose." To obtain an analytical expression for the transmission of the filter Evans made use of matrix calculus developed by Jones (1941). He finds the on-axis transmission of initially unpolarized light for the simplest type of the Šolc filter to be

$$T = A \left[\frac{\sin N\chi}{\sin\chi} \; \cos \gamma \; \sin\alpha \right]^2 \quad , \tag{3}$$

where

$$\alpha = 2\omega \quad , \tag{4}$$

and the parameter χ is related to the retardation γ by:

$$\cos \chi = \cos \gamma \cos \alpha \quad . \tag{5}$$

A is a constant representing absorption and reflection losses in the filter.

This type of filter gives a sharp main transmission peak but has adjacent secondary maxima with peaks transmitting about 11 % that of the main peak. Šolc (1960, 1965) describes how these secondary maxima can be successfully suppressed by a small change in the orientation of the optic axes of the birefringent plates. This tuning results in a small increase in the width of the main transmission peak.

The angle ω is made smaller for the end plates of the filter than for the central plates, but the condition that

$$\sum_{i=1}^{N} |\omega_i| = 45^\circ \quad , \tag{6}$$

must be fulfilled. For equal angles ω, this is the same condition as given in equation (1). One possible arrangement is the following, where ω is increasing in an arithmetic series from both ends towards the center.

TABLE 1

Element	Orientation
Polarizer	$P_1 = 0°$
Plate 1	$\omega_1 = + \rho$
Plate 2	$\omega_2 = -(\rho + \delta)$
Plate 3	$\omega_3 = +(\rho + 2\delta)$
Plate 4	$\omega_4 = -(\rho + 3\delta)$
:	:
Plate N-1	$\omega_{N-1} = \pm(\rho + \delta)$
Plate N	$\omega_N = \pm \rho$
Polarizer	$P_2 = 90°$

This arrangement of the plates and the polarizers is called Modified type I by Šolc (1960, 1965) and Type C by Beckers and Dunn (1965). The thickness d of a single plate is determined as before by equation (2). No attempt has been made to obtain a general analytical expression for the transmission in this case.

All types of birefringent filters give rise to several transmission peaks throughout the spectrum (as k takes on different integer values). The spacing of the transmission peaks depends on the thickness of each retardation plate. The bandwidth of the filter depends on the thickness of the whole pile of retardation plates. The bandwidth $\Delta\lambda$ (full width at half intensity) of the Šolc filter can be approximated by:

$$\Delta\lambda = C \frac{\lambda^2}{2\, d(n_e - n_o)\, N} \quad , \tag{7}$$

where C is a correction factor which varies with wavelength and also depends on how the secondary maxima are suppressed. In a Type A filter C is 0.8 at 2000 Å, 1.2 at 2800 Å and 1.5 between 6000 and 10000 Å. In a Type C filter C varies usually between 0.9 and 1.7.

For all calculations the birefringence $(n_e - n_o)$ for quartz has been derived from the following expression given by Macé de Lépinary (1892)

$$n_e - n_o = 8.8641 \times 10^{-3} + \frac{1.07057 \times 10^{-4}}{\lambda^2} + \frac{1.9893 \times 10^{-6}}{\lambda^4} -$$

$$- 1.7175 \times 10^{-4} \times \lambda^2 - t \times 10^{-6} \left(1 + \frac{t}{900}\right) (1.01 + 0.2\, \lambda^2) \tag{8}$$

where λ is expressed in microns and the temperature t in degrees C.

<u>Experimental and Theoretical Transmission Curves</u>

The actual filter used in the rocket instrument was built by the Dioptra Company in Turnov, Czechoslovakia for Y. Öhman of the Stockholm Observatory in Sweden. The filter is a combination of two Šolc filters as shown in Figure 4. Table 2 describes the two filter units F_1 and F_2.

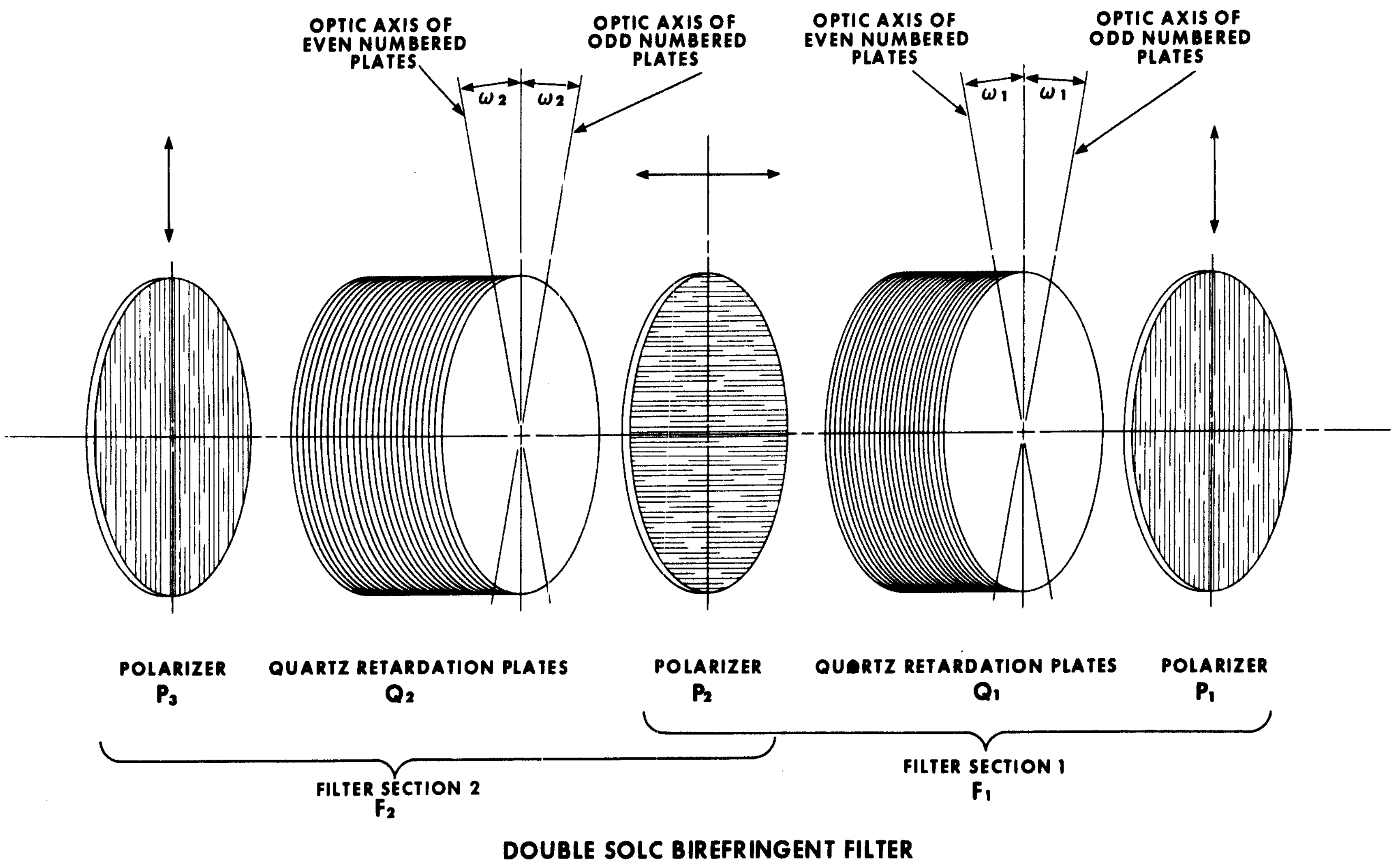

Fig 4 - Double Solc birefringent filter.

TABLE 2

	$\underline{F_1}$	$\underline{F_2}$
Birefringent plates	Quartz	Quartz
Number of plates	24	24
Thickness of plates in mm	0.359604	0.412878
Orientation of optic axes ω	Unknown	Unknown

Each unit gives rise to a set of transmission peaks throughout the spectrum. By making the thicknesses of the single plates a little different in the two units, all but the desired peak at 2802.7 Å will occur at different wavelengths in the two sets.

Table 3 gives calculated positions and bandwidths for the transmission peaks in F_1 and F_2 in the wavelength interval 2000-12000 Å. The bandwidths are calculated for a Type A filter according to equation (3). Also listed in Table 2 are the positions of the peaks measured with a Cary 14 monochromator in the 2200-6000 Å interval. Except in the ultraviolet, the measured values are accurate to only ±5 Å but show good agreement with the theoretical values. In Figure 5 the transmission peaks are plotted for the 2200 - 6000 Å interval. Note the coincidence of the two sets at 2800 Å. By chance there is another close coincidence of peaks near 5100 Å. This green transmittance has been most valuable for visual alignment and focusing. In the flight configuration, the green peak was blocked by an interference filter.

TABLE 3

	F_1				F_2		
	Calculated		Measured		Calculated		Measured
k	λ_{max}	$\Delta\lambda$	λ_{max}	k	λ_{max}	$\Delta\lambda$	λ_{max}
				26	2036.8	1.5	
23	2022.0	1.6		25	2083.6	1.6	
22	2074.6	1.8		24	2134.6	1.7	
21	2132.7	2.0		23	2190.4	1.9	
20	2197.0	2.2	2202	22	2251.8	2.1	2259
19	2268.8	2.4	2271	21	2319.6	2.3	2325
18	2349.4	2.8	2354	20	2394.9	2.6	2395
17	2440.5	3.2	2442	19	2479.0	2.9	2480
16	2544.4	3.7	2546	18	2573.6	3.3	2575
15	2663.9	4.2	2663	17	2680.6	3.8	2680
14	2802.7	5.0	2803	16	2802.7	4.4	2803
13	2965.8	5.9	2966	15	2943.2	5.0	2938
12	3159.7	7.0	3159	14	3106.2	5.8	3103
11	3393.8	8.6	3393	13	3297.6	6.9	3293
10	3681.1	10.6	3683	12	3525.2	8.3	3524
9	4041.0	13.5	4039	11	3799.2	10.1	3799
8	4502.8	17.6	4499	10	4135.0	12.4	4134
7	5113.5	23.4	5110	9	4554.4	15.6	4550
6	5953.8	33.2	5946	8	5090.8	20.3	5085
5	7172.8	49.5		7	5797.7	27.2	5791
4	9081.4	81.2		6	6766.3	38.1	
				5	8164.6	56.8	
				4	10340.0	92.2	

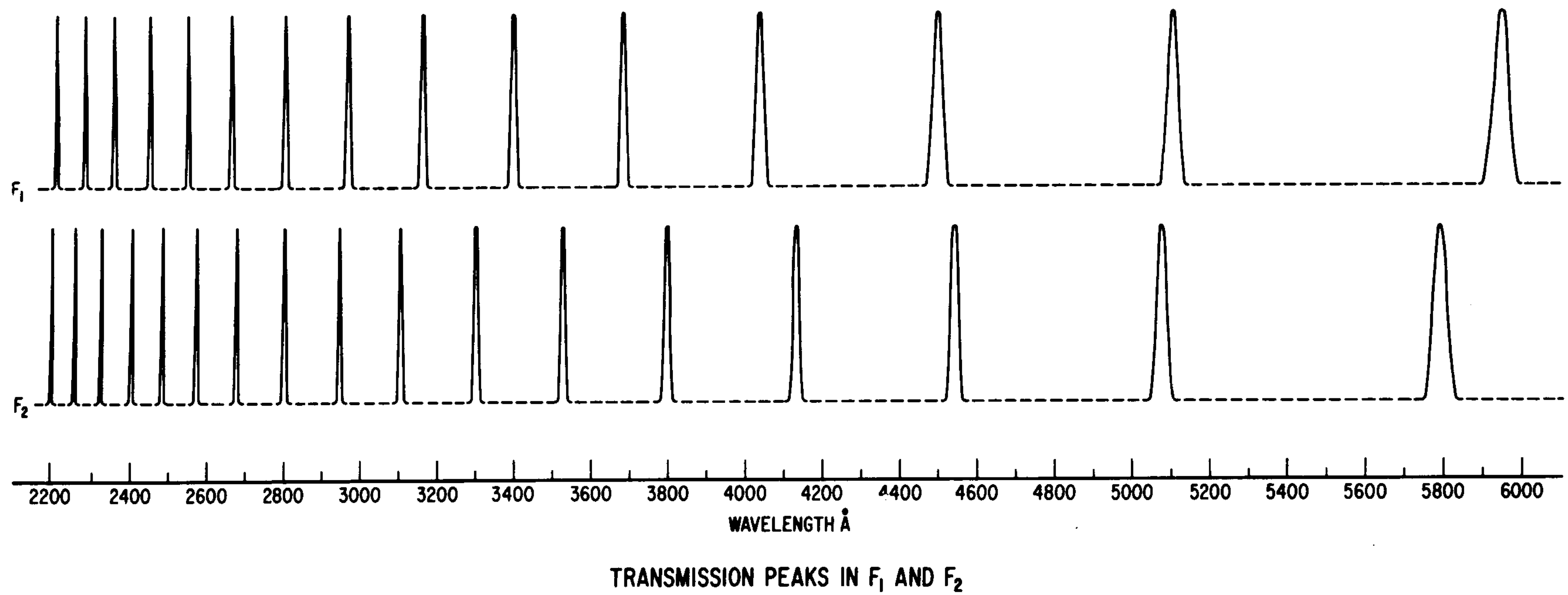

Fig 5 - Transmission peaks in filter units F1 and F2.

The exact orientation of the optic axes of the birefringent plates in the two filter units was never disclosed by the manufacturer. Figure 6 and 7 show the transmission curves of F_1 and F_2 measured with a one meter McPherson 225 monochromator as the units were tuned for the 2 December 1965 flight. Judging from the shape of the experimentally determined curves it seems most likely that some arrangement of the plates has been used to suppress the secondary maxima. For comparison two theoretical curves are plotted for each unit. The dashed curves represent an A type filter with equal angles $\omega = \pm 1.875°$ calculated according to equation (3). The dotted curves represent one probable arrangement for a C type filter where I have chosen $\rho = 1.3°$ and $\delta = 0.1°$. These two curves were kindly calculated by Dr. Beckers with his ray-tracing program.

The F_1 unit has a wider transmission peak than either of the theoretical curves. The main peak of the F_2 unit fits the Type A curve very closely. For both units the transmission in the secondary maxima resembles most the Type C filter. Strangely, the position in wavelength of the secondary maxima does not fit either of the theoretical curves. Table 4 gives bandwidths of the main peaks and transmissions of the first adjacent maxima.

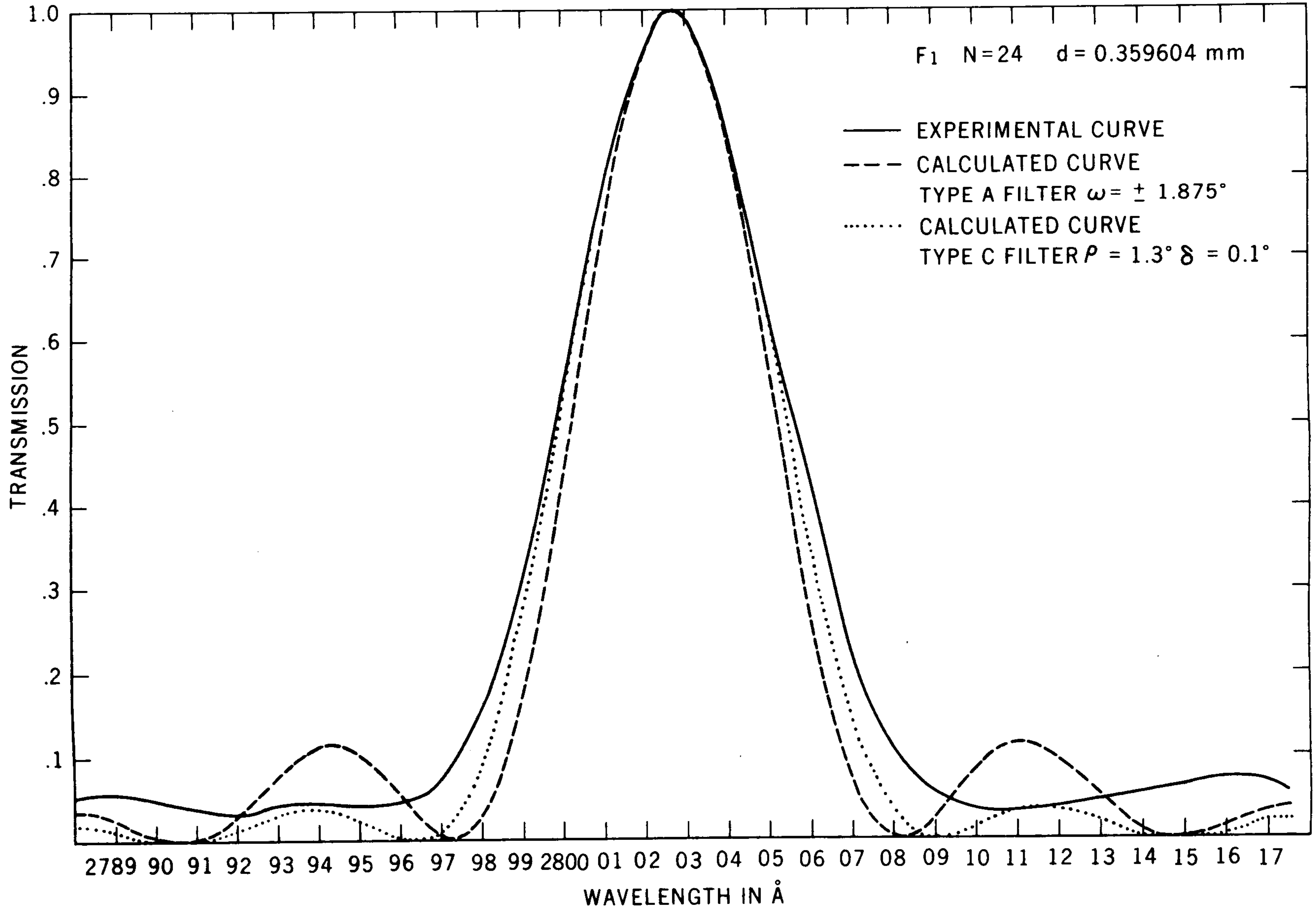

Fig 6 - Experimental and theoretical transmission curves for filter unit F_1.

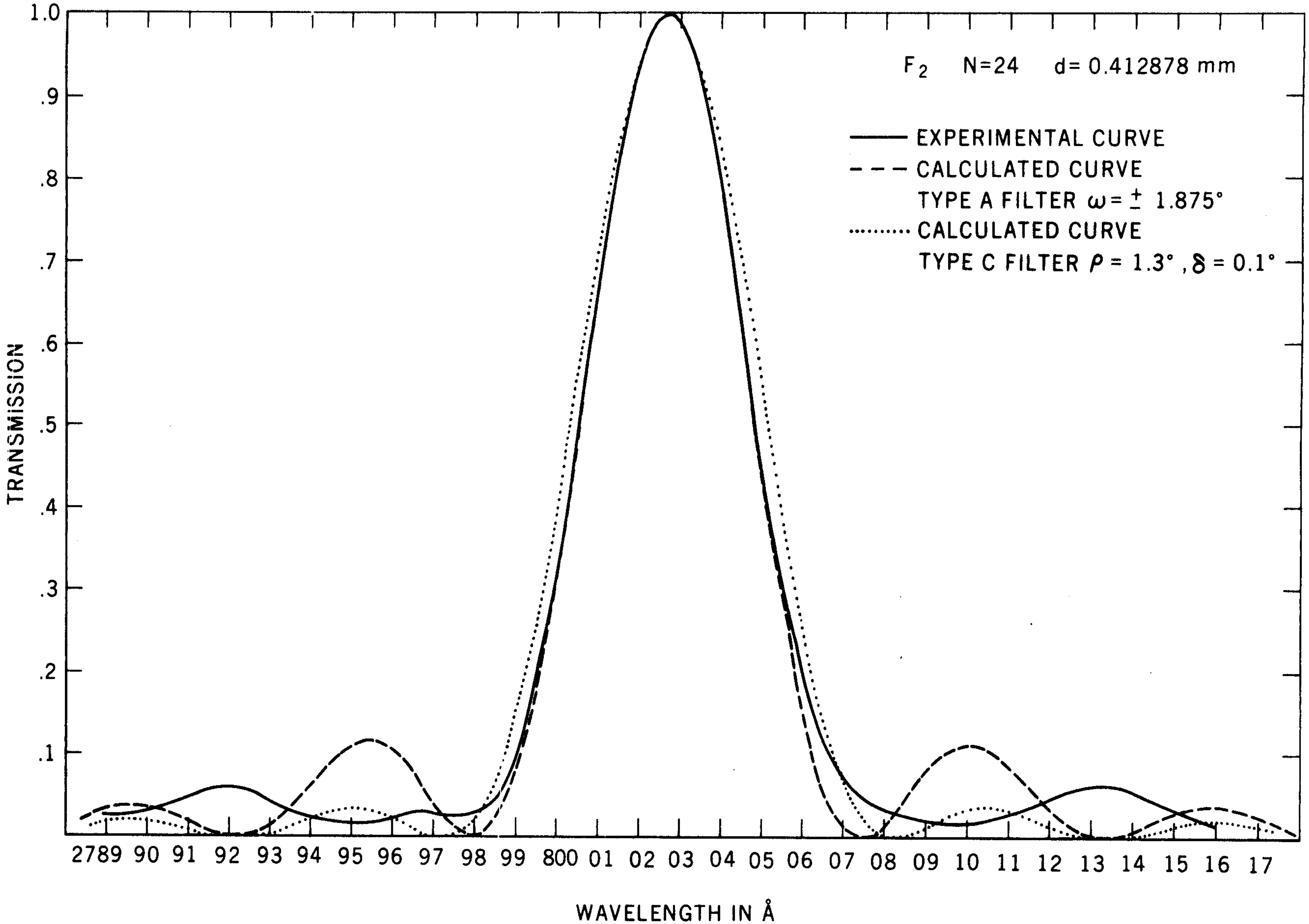

Fig 7 - Experimental and theoretical transmission curves for filter unit F_2.

TABLE 4

Bandwidth $\Delta\lambda$ in Å	F_1	F_2
(full width at half intensity)		
Experimental	5.9	4.5
Calculated Type A	5.0	4.4
Calculated Type C	5.6	4.8
Transmission in First Adjacent Maximum		
(in % of peak transmission)		
Experimental	4.2	4.7
Calculated Type A	11.4	11.4
Calculated Type C	3.7	3.7

Considering the great difficulties involved in manufacturing Šolc filters, the actual transmission curves must be considered very satisfactory. Considerable deviations from the theoretical curve are usually to be expected. Beckers and Dunn (1965) have numerically verified an observation made by Evans (1963) that the tolerances in plate orientations and plate thicknesses in Solc filters must be kept very small, much smaller than those for the Lyot-Öhman filter. The plate thicknesses are especially critical. In a filter working around 2800 Å, with about 24 quartz plates, it is desirable to control the optical thickness of a single plate to ±0.002 orders which correspond to material thickness variations of ±0.2 λ. The thickness control becomes ever more critical for filters with larger number of plates.

Polarizers

The filter was originally delivered with polarizing prisms of calcite of the Foucault type. In this type, no cement is used to join the two halves, in order to prevent absorption of the ultraviolet. These prisms did not have satisfactory imaging qualities, due to interference occurring at the interface, and it was found necessary to replace them.

Linear film polarizers working in the ultraviolet have recently been developed [McDermott and Novick (1961), Makas (1962)]. I tested two different types: 105UV manufactured by the Polacoat Incorp. of Blue Ash, Ohio and HNP'B manufactured by Polaroid Corporation of Cambridge, Mass Figure 8 shows transmittance measurements of the both types. Two single films were measured in crossed and parallel positions. From these measurements the principal transmission t_y for light polarized along the pass axis and the transmission t_z for light polarized at right angle to the pass axis can be determined, as well as the degree of polarization P which is defined as

$$P = \frac{t_y - t_z}{t_y + t_z} \quad . \tag{9}$$

As can be seen in Figure 8, the polarizing properties of the Polaroid HNP'B are highly superior to the Polacoat 105UV for wavelengths greater than 3000 Å. On the other hand, HNP'B loses nearly all polarizing properties at wavelengths shorter than 2600 Å. At 2800 Å the two types show very much the same dichroism (approximately 1.0 density unit) but the 105UV is somewhat more transparent.

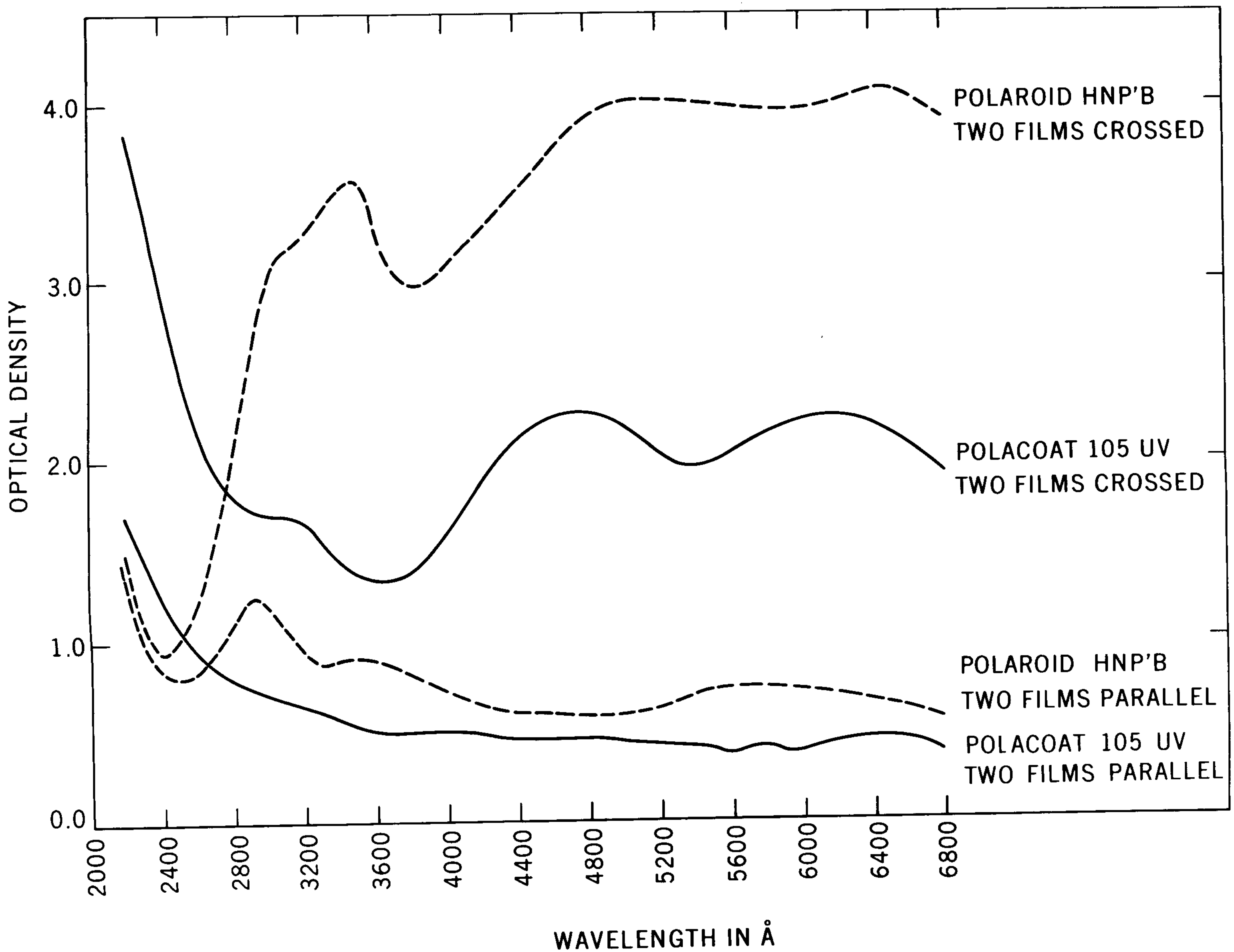

Fig 8 - Transmission curves for two types of linear film polarizers.
Two single films measured in crossed and parallel positions.

Transmission and dichroism vary considerably for different samples, and these curves merely show the typical behavior of the two types. No single film gives adequate polarization, therefore different combinations of films were tried. Because of the different polarizing properties of the two types for wavelengths shorter than and greater than 2800 Å, a combination of one HNP'B and one 105UV film could be expected to give a satisfactory result. Table 5 gives typical values of principal transmission t_y and degree of polarization P at 2800 Å.

TABLE 5

Type of Polarizer	t_y %	P %
Single Polacoat 105UV	36	90
Single Polaroid HNP'B	31	93
105UV + HNP'B parallel	12	99.2
Two 105UV parallel	14	97.8

The first modification of the filter (used in 12 April 1965 flight) was built with a combination of one HNP'B and one 105UV mounted parallel in each polarizer P_1, P_2 and P_3. This modification gave a useful behavior of the filter throughout the spectrum although the transmission was fairly low. The transmission for each of the filter units F_1 and F_2 was 1.4 %. The peak transmission through the entire filter was only 0.13 %.

Although the HNP'B film has superior polarizing properties in a large part of the spectrum it has some disadvantages. It is obtained as a 0.002" thick unsupported film which very easily splits along the oriented molecular chains, and makes it very difficult to handle. It also bleaches and loses polarizing properties under intense ultraviolet radiation [McDermott and Novick (1961)]. This could be hazardous to the filter when it has to undergo repeated useage with ultraviolet light.

In the second modification of the filter, the main goal was to increase the transmission, and if possible avoid the HNP'B type of polarizer. A new set of 105UV polarizers were obtained from Polacoat, having better properties than the first set. Table 6 gives t_y and P around 2800 Å for the second set of 105UV.

TABLE 6

Type of Polarizer	t_y %	P %
Single Polacoat 105UV	39	93
Two 105UV parallel	16	99.4
Rochon calcite prism	32	99.9

A calcite Rochon prism was used as first polarizer P_1 in the second modification of the filter (used in 2 December 1965 flight). The other two polarizers P_2 and P_3 consisted of two films of the second set of 105UV mounted parallel.

Because of space limitations only P_1 could be substituted with a Rochon prism. The Rochon prism is a double image device requiring a minimum distance to the focal plane in order to separate the two images. The resultant transmission is 7.7 % in the filter unit F_1 and 2.2 % in unit F_2 giving a transmission of 1.1 % for the entire filter.

Transmission Curves for the Flight Filters

Table 7 summerizes the characteristics of the two modifications of the double Solc filter used in the two flights. The transmission of the second modification was increased 8 times over that of the first modification. Contrast, the ratio between the peak transmission and the transmission at the first minimum to the long wavelength side, depends mainly on the excellence of the polarizers. The contrast is nearly increased twice in the second modification of the filter. Figure 9 shows the transmission curves for the double Solc filters used in the 12 April 1965 and 2 December 1965 flights.

An interference filter* with a bandwidth of 110 Å and 13 % peak transmission was used in combination with the Solc filter to secure adequate blocking of the visible part of the solar spectrum. Figure 10 gives the transmission curve for this interference filter.

*(manufactured by Thin Film Products Incorp. of Cambridge, Mass.)

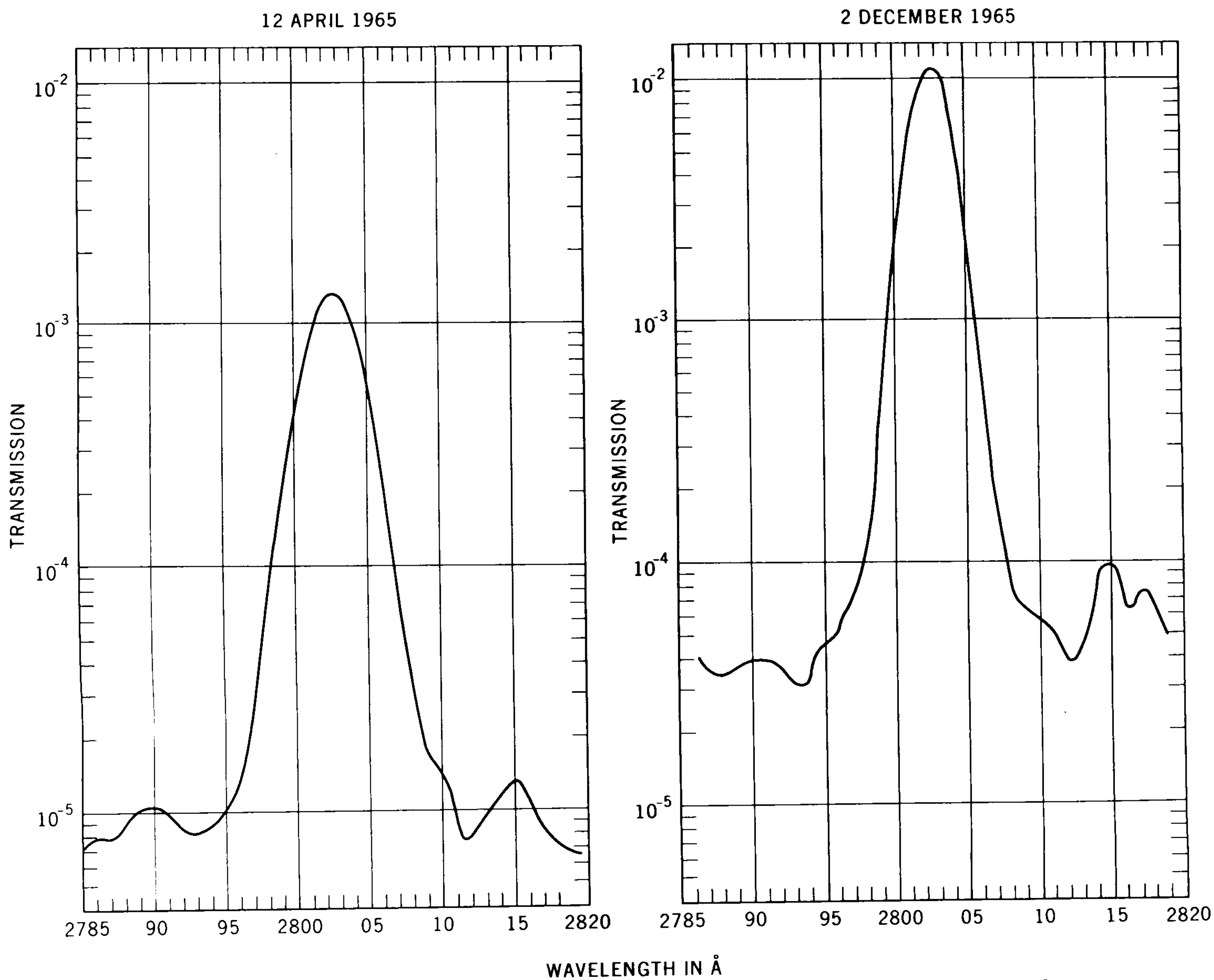

Fig 9 - Transmission curves for the double Solc filter used in the 12 April 1965 and 2 December 1965 flights.

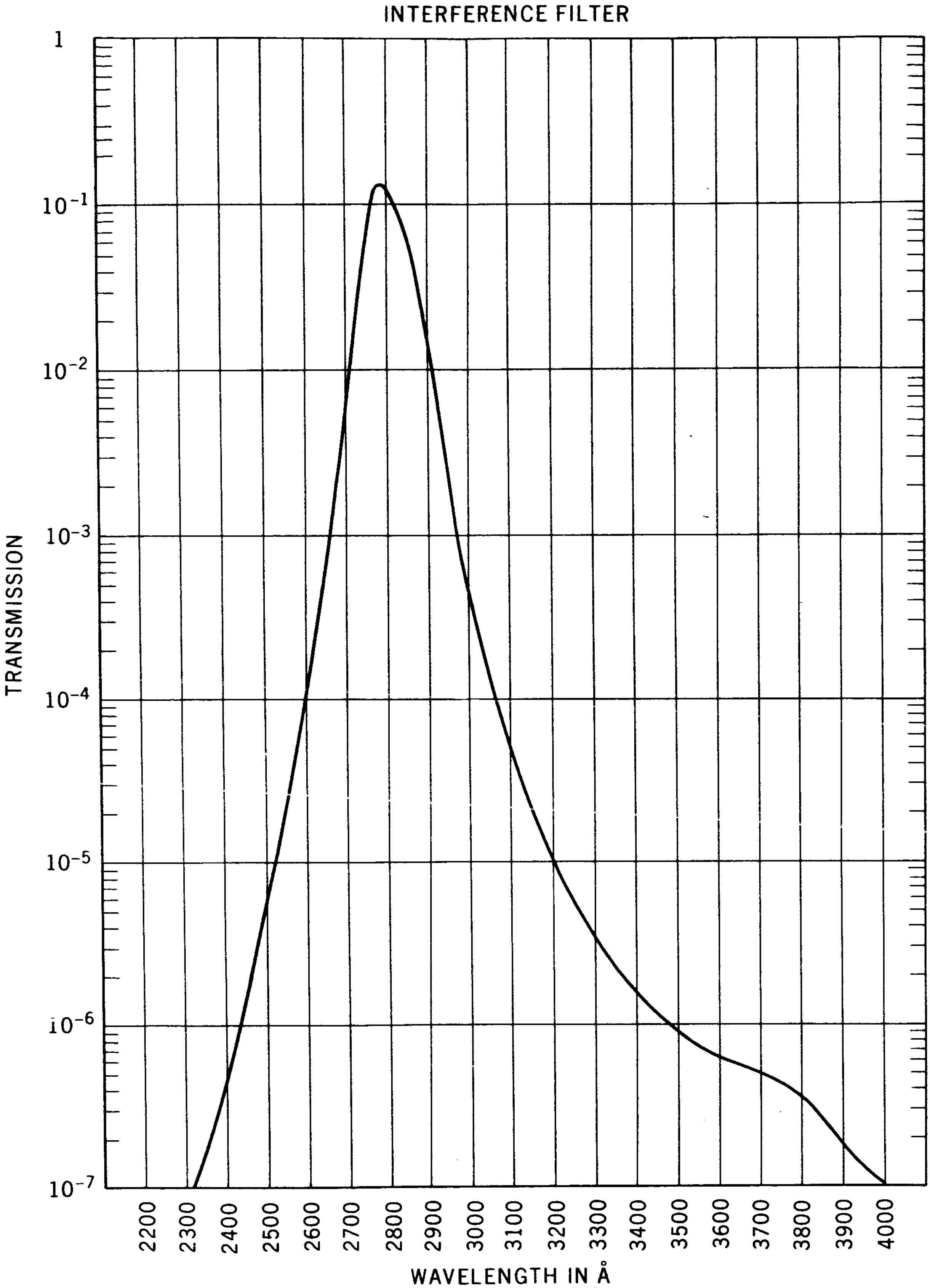

Fig 10 - Transmission curve for the interference filter.

TABLE 7

CHARACTERISTICS OF THE DOUBLE SOLC FILTER

	12 April 1965	2 December 1965
Polarizers	Linear film polarizers: One Polacoat 105UV and One Polaroid HNP'B oriented parallel in each polarizer	P_1: Calcite Rochon prism P_2 and P_3: Linear film polarizers: Double Polacoat 105UV in each polarizer
Peak wavelength	2802.7 Å	2802.7 Å
Bandpass (full width at half intensity)	4.0 Å	3.5 Å
Peak transmission	0.13 %	1.1 %
Contrast = $\frac{T\ max}{T\ first\ min.}$	165	275
Operating temperature	11.0 °C	13.7 °C
Shift of wavelength with temperature	- 0.17 Å/°C	- 0.17 Å/°C

Temperature Dependence

In all birefringent materials the retardation γ depends on the temperature. Both the geometrical thickness d and the birefringence $(n_e - n_o)$ are functions of temperature. The result is a small shift in the wavelength of the transmission peaks with changes in temperature. In Figure 11 the peak wavelength

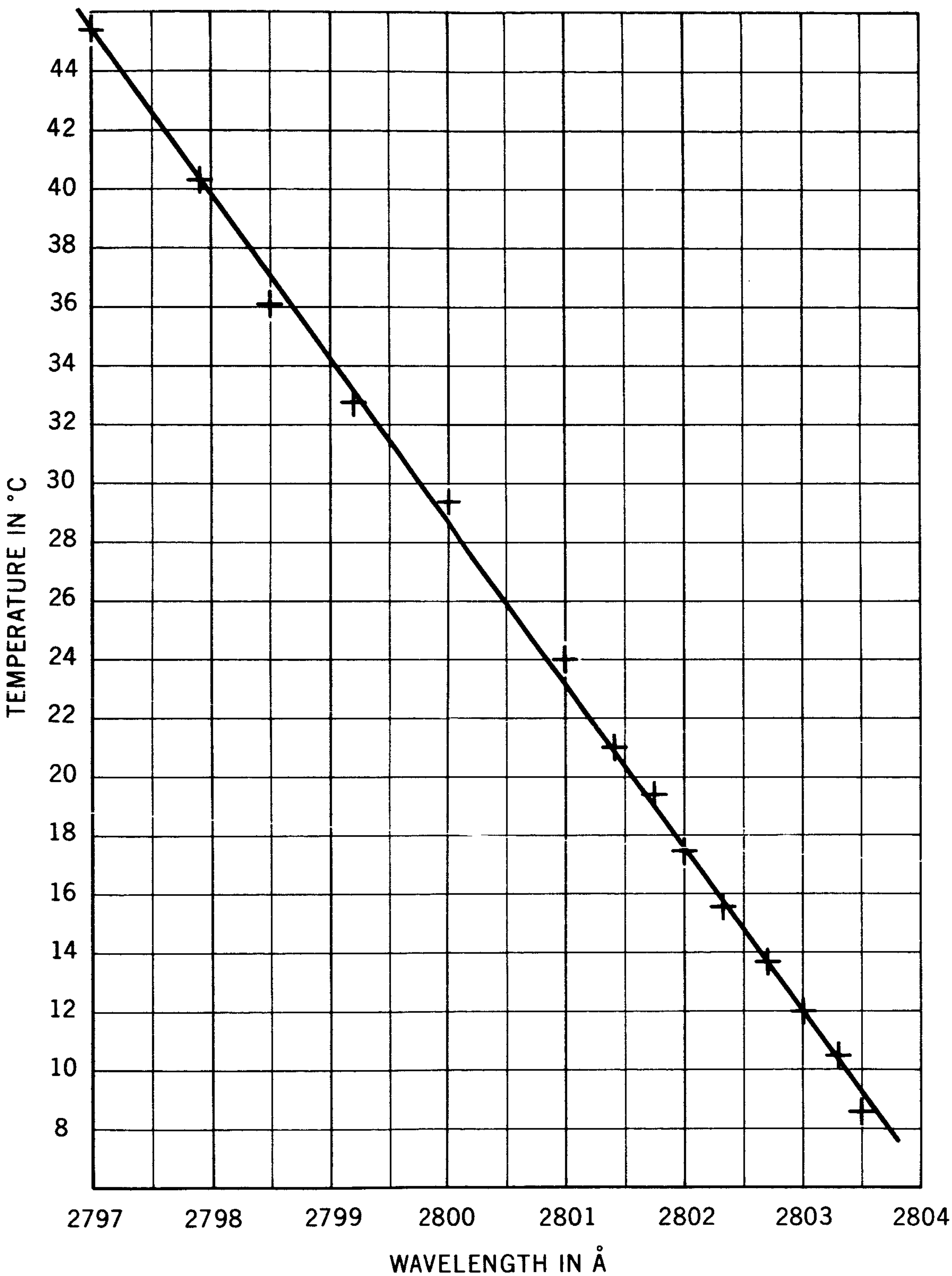

Fig 11 - Shift of wavelength of main transmission peak with temperature for the filter used in 2 December 1965 flight.

is plotted versus temperature for the filter used in 2 December flight. For a temperature of 13.7°C the filter peaks at 2802.7 Å. Only the 2802.7 Å line of the Mg II doublet could be isolated, if the filter were to operate at a reasonable temperature. The experimentally determined wavelength shift amounts to -0.17 Å per degree C rise in temperature. This value is compared with a calculated value obtained by differentiating equation (2), which gives

$$\frac{\Delta\lambda}{\Delta t} = \frac{\Delta d}{\Delta t} \cdot \frac{\lambda}{d} + \frac{\Delta(n_e - n_o)}{\Delta t} \cdot \frac{\lambda}{(n_e - n_o)} \quad . \tag{10}$$

The thermal expansion coefficient for cyrstal quartz in the direction perpendicular to the optic axis was taken to be

$$\frac{\Delta d}{\Delta t} = 13.37 \times 10^{-6} \times d \tag{11}$$

The change in birefringence with temperature is obtained from equation (8), which becomes for values near 20°C and 2800 Å

$$\frac{\Delta(n_e - n_o)}{\Delta t} = - 1.048 \times 10^{-6} \quad . \tag{12}$$

In (11) and (12) Δt is expressed in degrees C. The result of this calculation is a wavelength shift of -0.24 Å per degree C rise in temperature, a somewhat greater value than that found experimentally.

Thus, in order to maintain the wavelength of the main transmission peak to within ±0.2 Å (which corresponds to a total excursion of approximately one-tenth of the bandwidth) the temperature must be controlled to within ±1°C.

TEMPERATURE CONTROL UNIT

A thermal control unit was developed to control the temperature of the filter and keep the main transmission peak at the desired value of 2802.7 Å. The unit utilizes solid state circuitry with Peltier thermoelectric heat pumps as temperature-controlling elements. Heat can be transferred from either surface of the heat pumps to the other by controlling the direction of the current flow. Consequently, the system may be used for both heating and cooling.

In the laboratory, the control unit could stabilize the temperature of the filter to within ±0.015°C. For extreme changes in the ambient temperature, the unit kept the filter temperature well within the prescribed limits. The controlled temperature changed 1°C when the ambient temperature changed from -11°C to +29°C.

During the 12 April 1965 flight, the instrument pointed at the sun for approximately 260 seconds, and the temperature of the front portion of the Šolc filter showed a gradual rise of 0.5°C above the set temperature. This temperature rise was due to solar radiation absorbed by the interference filter mounted in front of the Solc filter. The crystal quartz plates were most likely not affected by this temperature rise. A detailed description of the mechanical and electronic design of the temperature control unit, as well as results from the laboratory tests and the in-flight performance is given by Fredga and Lee (1966). Figure 12 shows the filter in place behind the telescope, and the lower parts of the temperature control unit. Two of the Peltier heat pumps are partly visible under the bottom shell in which the filter is fitted. Temperature sensors for monitoring the filter temperature are attached at the front and rear ends of the filter.

CAMERA, FILM AND EXPOSURE TIMES

The spectroheliograph employs a modified 35 mm electric driven Robot camera with a 30-foot film magazine. A pulse-train generator [described by Lee (1966)] activates a solenoid, which in turn operates the camera shutter. The camera is equipped with two coplanar, behind-the-lens shutters. With the camera on the bulb setting the guillotine-type shutter determines the exposure time, which is controlled by the solenoid. The reaction time of the solenoid precludes bulb exposures shorter than 1/20 second. The behavior of the shutters, the exact time when the exposure took place with reference to the solenoid action and the exact length of the

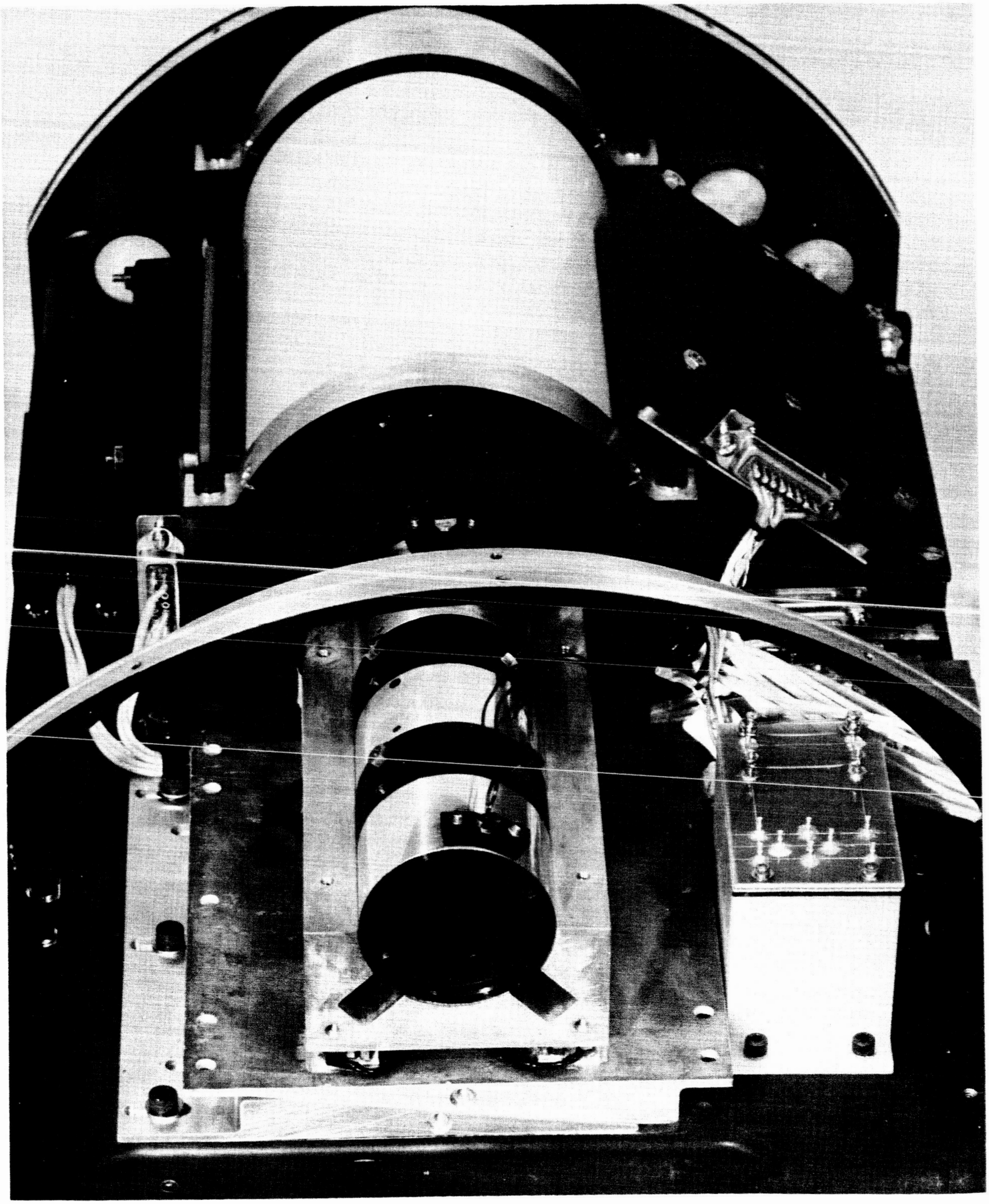

Fig 12 - The filter in place behind the telescope and parts of the temperatur control unit.

exposure was determined with three small photodiodes fit immediately behind the shutters. It was found that the guillotine shutter gives a somewhat longer (approximately 7 ms) exposure time for the central part of the picture than for the top and bottom parts.

In the first flight the camera was operated on the bulb setting the whole time, and the following series of exposure times were repeated throughout the flight 1/15, 1/8, 1/3, 1/3, 1, 1, 3 and 10 seconds. A time of 1 second was allowed between each exposure for advancing the film. With a frame size of 35 x 24 mm this arrangement allowed 90 pictures to be taken during the 260 seconds long pointing time.

In the second and third flights the camera was programmed to operate with the following series of exposure times: 1/20, 1/10, 1/3 and 1 second with a spacing of 2/3 seconds between each exposure. After 200 seconds of pointing time the camera exposure control was switched from bulb to 1/60 second by means of a second solenoid actuation. This condition was maintained for the rest of the flight. With a frame size of 24 x 24 mm this arrangement allowed for approximately 240 pictures to be taken during normal pointing time. Unfortunately the pointing control did not work properly in the two last flights, giving zero pointing time in the October flight and only 23 seconds of pointing time in the beginning of the December flight. During this 23 seconds five sets of exposures (20 pictures) were obtained.

Some moficiations had to be undertaken to make the camera and film magazine suitable for use in the space environment.

The camera is equipped with a DC motor for advancing the film. This motor had to be furnished with an electrical noise-filter; in vacuum the motor generates noise of sufficient amplitude to reset the timer in the pulse-train generator every time film is advanced.

In the first flight some frames of the film were fogged by extraneous light. It was found that an internal switch in the camera regulating the film advance was arcing in a random manner when the environmental pressure was between 0.15 and 200 mm Hg. This problem was solved for the two last flights by reducing the voltage and current to the internal switch.

Light-tight air release holes were put in the film magazine to avoid differential pressure across the shutter.

The film was 35 mm Eastman Kodak 103-0. For low temperatures ($< + 5°C$) the film transport did not operate relaibly in vacuum, probably due to film stiffness. An insulated heater wire was wrapped around the film magazine to heat it to approximately room temperature before launch.

ULTRAVIOLET RADIOMETERS

In cooperation with J. P. Hennes, the absolute solar flux in the ultraviolet was also measured with four radiometers. These were small sensitive photoemissive diodes with ultraviolet bandpass filters. The selected wavelength regions were 2200 Å, 2600 Å and 2800 Å. In the 2800 Å region, two radiometers were used, one with a narrow bandpass and one with a broader bandpass. Table 8 gives effective wavelengths and effective bandwidths for the four radiometers. On the first rocket all four radiometers were flown. In the two last flights only the measurements in the 2800 Å region were repeated.

TABLE 8

Radiometer	Effective Wavelength Å	Effective Bandwidth Å
2200	2202	111
2600	2608	99
2300B	2817	142
2800N	2807	45

The radiometer calibrations were carried out in two steps. First, a relative response curve of the spectral sensitivity was obtained. This is a product of the measured filter transmittance and the spectral response of the photocathode. Figure 13 shows the relative spectral sensitivity of the four radiometers. Second, an absolute measurement using a calibrated lamp was obtained. For this a calibrated low pressure Hg arc, a Zn spectral source of 2139 Å radiation which was in turn calibrated with respect to the Hg lamp,

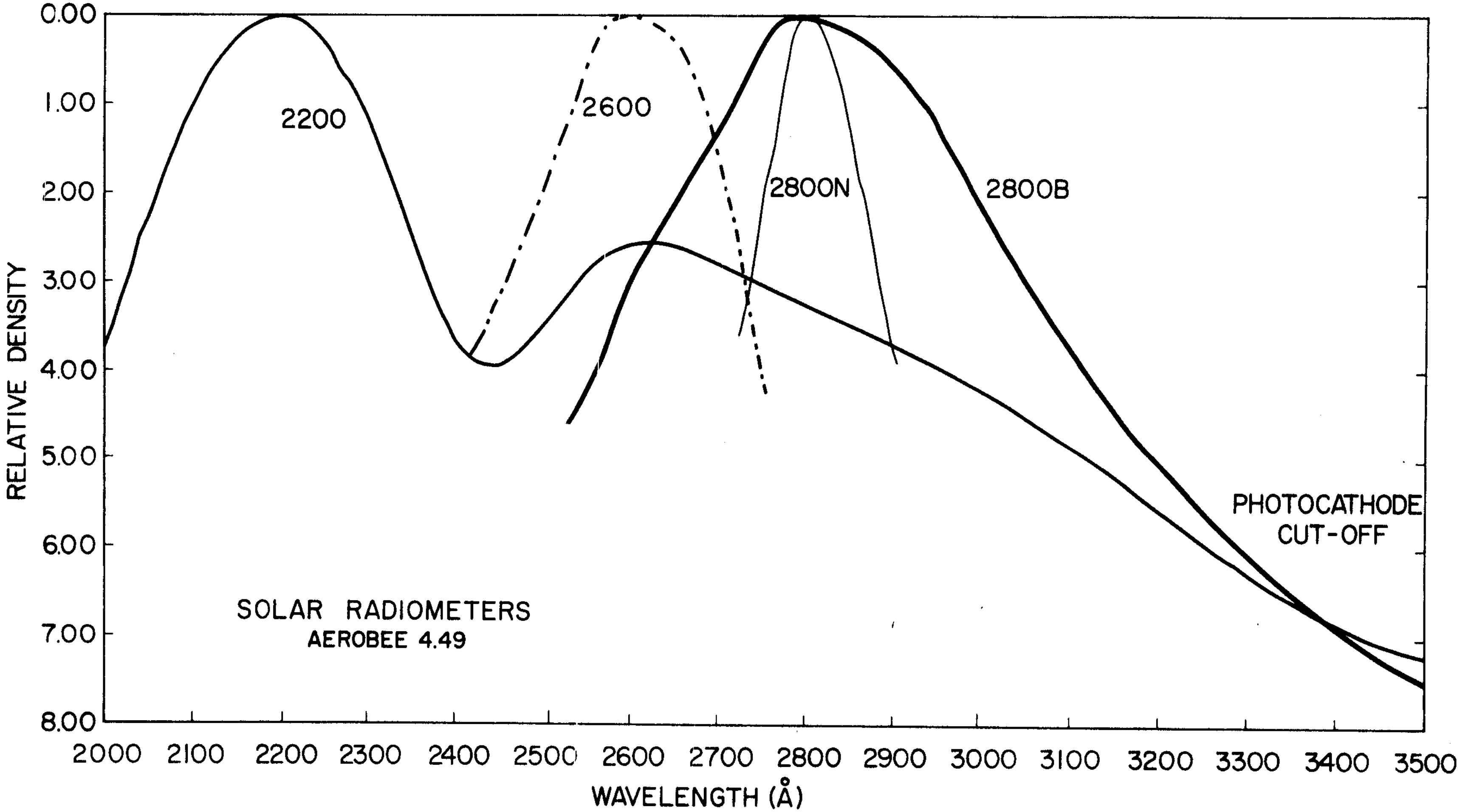

Fig 13 - Relative spectral sensitivity curves for the radiometers.

and an NBS calibrated tungsten-iodine lamp were used. The maximum error in the absolute calibration is estimated to be 12%. Results from the first flight have been presented by Hennes (1965).

TELEMETRY DATA

Several functions were monitored during the flights to aid the interpretation of the scientific data. Two full time telemetry channels recorded the output signals from the fine pointing sensors, one in elevation and one in azimuth. One full time channel recorded the camera solenoid action and the camera motor operation. These three channels indicate the exact time for each exposure and make it possible to exactly determine the smearing of each picture due to pointing errors.

The output from the four radiometers were recorded on two full time channels each commutated into two sections. On one commutated telemetry channel of 28 points with a read out every 2.5 seconds, 5 points were used to record four temperature sensors and the voltage of the experiment battery. The temperature sensors were monitored before and during the flight and showed the temperature of the filter front, the filter back, the film magazine and the baseplate.

An indicator showing that the film was actually advancing was added in the two last flights. In the last flight an additional temperature sensor was mounted on the rear portion of the filter and the analog output of this sensor was read out by a 10-bit analog-to-digital converter [Lee (1966)] in order to give higher accuracy in the temperature data.

SUMMARY

A rocket-borne spectroheliograph designed to take monochromatic pictures of the sun in the Mg II line at 2802.7 Å is described in detail. The photographic system consists of a Questar telescope, a Šolc-type birefringent filter and an automatic Robot camera. The telescope and the camera are commercially available models which have been considerably modified for rocket application.

The double Šolc birefringent filter had a spectral bandwidth of 4.0 and 3.5 Å respectively in the first and the two last flights. The two units in the double filter have been thouroughly tested and are compared with theoretically calculated transmission curves which they fit reasonably well. Two new types of linear film polarizers for the ultraviolet region have been tested and used in the filter. The temperature dependence of the filter has been determined, and a temperature control unit was developed which stabilized the filter temperature in flight to within ±0.2°C.

The instrument has been tested in vacuum and to the Aerobee 150 vibration specifications. It has been flown and successfully recovered three times during 1965 and performed excellently during each flight.

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