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FUNCTIONAL CHARACTERISTICS OF THE OGO MAIN BODY AIRGLOW PHOTOMETER

by

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ABSTRACT

The OGO-4 main body airglow photometer used a trialkali cathode photomultiplier to sense light at selected wavelengths between 2500 and 6300Å corresponding to important emissions in the aurora and night airglow at emission rates ranging from a few rayleighs to about 200 kilorayleighs. The optical, electronic, and mechanical systems are described in terms of their functional characteristics.

INTRODUCTION

The main body airglow photometer was flown on OGO-2 and OGO-4 in order to measure important airglow and auroral lines at wavelengths as given in Table 1. It was designed to measure integrated vertical emission and was mounted on the spacecraft as indicated in Figure 1. A cutaway view of the instrument is given in Figure 2 and an overall diagram of functional units is given in Figure 3.

1. Emission was measured in 6 different wavelength regions below the spacecraft and in one (6300Å) above the spacecraft.

2. Spectral bandpass for visual wavelengths was a nominal 50Å and for the uv(2630Å) was about 250Å. The filters had shape and temperature characteristics as given in Tables 1 through 3.

3. Minimum detectable signal (for 5577Å) was less than 5 rayleighs. Details of responsivity are given for line and continuum emissions in Table 2, and its change with respect to time are given in Figure 4.

4. Photometer output was measured with an accuracy ranging from 4 to 10% between the minimum detectable signal and the upper limit of about 200 kilorayleighs. Absolute accuracy of radiance was about 15%. Further details of the calibration are discussed in Reed, Fowler, and Blamont 1972.

TABLE 1. Spectral characteristics of each channel.

Channel	Wavelength (Å) at stated relative responsivity							Effective bandpass
	0.01	0.1	0.5	1.0	0.5	0.1	0.01	
1	2250	2436	2554	2652	2778	2920	3118	258
2	6240.5	6267	6284.5	6303	6319.5	6336.2	6364	40
3	6238.5	6262.3	6279.0	6298.5	6319.5	6334.5	6360.5	44
4	6139.5	6179.7	6201.7	6229.5	6257.0	6279.7	6320.7	59
5	5818.8	5846.0	5864.0	5885.0	5905.5	5921.7	5951.7	45
6	5487	5526.8	5549.0	5574.0	5600.2	5625.5	5670	57
7	3847.5	3881.0	3900.2	3924.5	3946.2	3965.0	3997	49

TABLE 2

Mirror Position	Nominal Wavelength	Conversion factor continuum	Conversion factor line	Temperature coeff. continuum	Temperature coeff. line	Background coefficient	Field of view Half-angle	Field of view area
1	2630 Å	61.75		9.6×10^{-3}			$4^\circ 51'$	0.0220
2	6300 Å	474	195.4	1.6×10^{-2}	1.04×10^{-2}		$3^\circ 23'$	0.0109
3	6300 Å	226	99	3.6×10^{-3}	1.04×10^{-2}	0.7	$4^\circ 27'$	0.0190
4	6225 Å	162.6		3.6×10^{-3}			$4^\circ 42'$	0.0211
5	5892 Å	160.8	75.8	3.6×10^{-3}	6.0×10^{-3}	1.2	$4^\circ 54'$	0.0229
6	5577 Å	89.3	51.3	3.6×10^{-3}	8.8×10^{-3}	1.5	$4^\circ 41'$	0.0210
7	3914 Å	85.4	49.3	3.6×10^{-3}	1.4×10^{-2}		$4^\circ 52'$	0.0227

Response and field of view of the airglow photometer. The conversion factors are in Rayleighs per 100 A per volt for continuum and in ayleighs per volt for line emissions. The temperature coefficient is the change of the responsivity per degree centigrade divided by the responsivity at 25° C. The background coefficient multiplies the continuum observation in volts in mirror position 4 for the corresponding background measurement that would be estimated for another mirror position. The area of the field of view is in steradians.

TABLE 3

Relative response to light in the passband of the stated mirror position

	1	2	3	4	5	6	7
1	1.0	$2.5x10^{-4}$	0	$2.5x10^{-5}$	$1.5x10^{-5}$	$5. x10^{-6}$	0
2	0	1.0	0	$2.7x10^{-5}$	$5. x10^{-6}$	$1.3x10^{-6}$	0
3	0	$1.6x10^{-4}$	1.0	0	$5. x10^{-4}$	$6.6x10^{-4}$	$3. x10^{-4}$
4	0	$1.0x10^{-5}$	$2.5x10^{-2}$	1.0	$8. 10^{-3}$	$8.6x10^{-4}$	$4.2x10^{-4}$
5	0	0	$9. x10^{-4}$	$2.8x10^{-3}$	1.0	$5.7x10^{-4}$	$1.9x10^{-3}$
6	0	$1.6x10^{-6}$	$1.6x10^{-5}$	$2.7x10^{-4}$	$2.3x10^{-2}$	1.0	$4.4x10^{-4}$
7	0	$1.6x10^{-6}$	0	0	$3. x10^{-6}$	$3.3x10^{-5}$	1.0

Crosstalk coefficients: the relative response of the photometer to near-monochromatic light corresponding to each of the stated mirror positions. The light scattered into mirror position 0 due to a continuum source was taken to be 5×10^{-5} times the response in channel 7.

5. The field of view had a half angle slightly less than 5 degrees. See Table 2.

6. A complete set of measurements was made in 8 seconds, corresponding to a movement of the spacecraft along the orbit of about 1/2 degree of latitude.

7. Appropriate protection was provided to avoid photocathode and dynode fatigue and damage from direct or earth reflected solar illumination.

8. Although the instrument was designed primarily for use with the spacecraft in the earth's shadow, baffling was sufficient for some low brightness measurements when the spacecraft was sunlit; skyward measurements could be made when the sun was more than 60^{o} from zenith.

A general description of the instrument was given in Reed and Blamont 1967. Details of mechanical devices are found in Bauernschub 1965. A discussion of operational characteristics such as data rates, time and spatial coverage, and methods of data reduction is found in Reed, Fowler, and Blamont 1972.

OPTICAL

The sensor was an EMR Model 541E, an end-window photomultiplier with a tri-alkali photocathode, sapphire window, and 14 venetian blind dynode stages. A diagram of the earth directed optics is given in Figure 5.

Light entering the earthward side of the spacecraft passed through a shutter assembly, which included a low-fluorescence quartz window, and then through a quartz objective lens, 5.1 cm in diameter with a focal length of 31.1 cm for yellow light. Lightpaths, each with an interference filter, were selected by two flat rotating mirrors inclined 45° to the optical axis and mounted on a common shaft (Bauernschub 1965). To take into account the chromatic aberration of the objective lens, whose focal length decreased to 28.5 cm for 2537 Å, the assemblies of the filter and the two fixed mirrors were designed to obtain a light path of appropriate length for each filter wavelength.

A 5.1 cm diameter quartz field lens (F/1.6) set at the focal plane of the objective lens, focused the entrance aperture (objective lens) on the photocathode. The 2.5 cm diameter cathode was slightly larger than the largest area of illumination.

For the skyward light path, Figure 6, selected by the inner shaft mirror, physical restrictions of the spacecraft required an additional 5.1 cm quartz lens (F/2.0) to create a virtual aperture image at the correct distance from the field lens.

Tube-like ribbed light baffles were used to reduce scattered sunlight. The earthward baffle was 7.6 cm long, sufficient to protect against the sun which should never be closer than 60° off axis. The skyward baffle was 28 cm long, which gave protection when the sun was more than 30° off axis.

In addition, a conical sunshade was mounted in the skyward side of the spacecraft. When the spacecraft was properly oriented with respect to the sun, the lower aperture was further shaded by the horizon scanner appendage.

The outer windows were protected against dirt during handling and launch by sliding panels (Bauernschub, 1965) which were retracted by command after the spacecraft was in orbit. Every effort was made to avoid the use of paints and other organic materials in the vicinity of the optics to avoid coatings which might reduce sensitivity or even fluoresce. Protection of the photomultiplier was accomplished by small photodiodes which sensed the sun or sunlit earth and closed shutters in either the up or down aperture.

The sapphire window of the photomultiplier was the part most sensitive to fluorescence due to energetic particles ($\sim$ 2.6 MeV electrons), of the inner and outer radiation belts. It was shielded in front by the suprasil plate, 2.2 mm thick.

Surrounding the tube were cylindrical shields of 1.02 mm thick tungsten inside 6.0 mm aluminum. This shielding, not flown on the OGO-2 instrument, reduced theresponse to energetic particles in the South Atlantic magnetic anomaly by about two orders of magnitude. Further information concerning related laboratory studies and dark current observations in flight may be found in Reed, Fowler, Aitken, and Brun, 1967, and Fowler, Reed, and Blamont, 1968. As the satellite passed through the

South Atlantic anomaly, the signal due to energetic particles overwhelmed that due to airglow. The response to cosmic rays at magnetic latitudes greater than about 45^{o} was noticeable and was equivalent to a few rayleighs of airglow.

ELECTRONICS

The functions of amplifying the photomultiplier current, controlling the high voltage supply, and buffering the outputs to telemetry were related as indicated in Figure 3. The dc electrometer was a hybrid vacuum-tube-semiconductor amplifier (using Raytheon CK-587 tubes and a 10^{8} ohm feedback resistor) capable of measuring currents from about 10^{-10} amperes to 5×10^{-7} amperes. This was followed by three field-effect transistor amplifiers to give the 3 decades (linear to better than 1%) appropriately buffered for telemetry.

In addition, the system included a high voltage control amplifier connected in a closed loop system which served to reduce the high voltage as the photomultiplier anode current became greater than 4×10^{-7} amperes. Since the gain of the photomultiplier was a nearly logarithmic function of the high voltage applied, the monitor of the high voltage served also as the fourth range for measurements of the photocathode current, extending the range by a factor of 40.

The system was carefully designed to minimize dc drifts due to temperature changes, aging, etc. In fact, the dc zero level, which was measured every 200 seconds by disconnecting the photomultiplier from the electrometer, varied in flight by less than 35 millivolts. The photomultiplier anode current was drained to ground before reconnecting to the electrometer to avoid surges.

The high voltage power supply and control were designed to have a short term stability of less than 0.1% of output voltage and a long term variation of less than 0.5% with a voltage ripple of less than 1 V peak to peak. During the first six months in flight, the high voltage for anode currents under 4×10^{-7} amperes increased slowly by 2.3%, due probably to radiation damage, and corresponding to an increase in photomultiplier gain of 19%.

AUXILIARY FUNCTIONS

Every 200 seconds the normal measurement of radiance above and below the spacecraft was interrupted by a calibration cycle. Both shutters (Bauernschub, 1965) were closed and the three calibration lamps were turned on. One was located just inside each shutter, but outside the objective lens, and the third was located on the filter assembly plate in the "dark current" position. The lamps were grain-of-wheat sized tungsten filament incandescent lamps. During the first 9 seconds of the cycle, the mirrors stepped through each of the 8 positions, starting and ending on the dark current mirror position. During the tenth second, the photomultiplier was disconnected from the electrometer for 1.5 seconds for the measurement of the zero level of the several outputs. The lamps were turned off, the shutters were opened (as ambient light conditions permitted), and normal operation resumed.

By ground command it was possible to cause the photometer mirror to step to any of the 7 filter positions and to remain there until given a further command. This permitted continuous observations for the chosen color. In this mode a modified calibration sequence was used: the shutter closed, the dark current was measured for one second, the calibration lamps were turned on for one second, and finally the photomultiplier was disconnected for 2 seconds for the zero level measurement.

The two shutters were controlled independently of each other. Each opened whenever the associated photodiode indicated that ambient light levels were below the predetermined levels. The signals from the photodiodes were overriden by those from the calibration cycle sequencer. When the photodiodes indicated high light levels both above and below the spacecraft (daytime conditions) the photometer went into a standby condition in which parts of the photometer circuitry were turned down or off to conserve power.

In addition to the four dc analog outputs indicated on Figure 3, a fifth was used to measure the temperature of the electrometer. Two other telemetry words were used to transmit digital information regarding mirror position, shutter positions, photodiode signal, calibration and electrometer zero measurements, and receipt of commands.

The telemetry system handled the data in the form of 9-bit words and could accept digital words directly from registers in the photometers. This was done for housekeeping information. Each of the analog photometer outputs was converted by the spacecraft data handling system to a 9-bit word with a leading bit of 0; that is, the signals in the acceptable range of 0 to 5.10 volts were converted to numbers ranging from 0 to 255 with an accuracy of $\pm$ 1. The data were generally stored in on-board tape recorders for playback and transmission when the satellite came into view of a tracking and data ground station, of which there were 8 located in various parts of the world. The data could also be transmitted directly to the ground station in real time.

The number of times per second that the photometer outputs were sampled depended on which of several different telemetry formats were in use, whether the data were going to the tape recorder or directly to a ground station, and for direct real time transmission, the bit rate which had been commanded by the ground station. Two of the photometer outputs, the temperature and the digital word containing command and some shutter information, were on a subcommutator, with a substantially slower sample rate. A summary of the various rates are given in Table 4.

Commands from the ground could be used for several purposes: one group of commands were used to instruct the

TABLE 4

Bit Rate	Main Commutator			Sub-Commutator
	Format 00	Format 12	Format 15	
4 kbs	3.47	41.7	27.8	0.027
16 kbs	13.9	167	111	0.108
64 kbs	55.6	667	444	0.434

Data rate in samples per second. The four analog outputs and one digital output from each photometer were on the Main Commutator. The remaining words were on the Sub-Commutator.

stepping mirror to either go to a stated mirror position and stay there, or to resume stepping operation. Another set of commands could be used to change the dc level of the electrometer. Drift was not the problem that was anticipated, and it was not necessary to use this capability in orbit. Another command was used to ensure that the shutters were closed prior to opening the sliding protective doors.

PERFORMANCE IN ORBIT

The OGO-2 instrument performed as designed during the 24 months of OGO-2 operation, except that the response to energetic particles was greater than expected. For a few orbits during the first few days after launch, the down-looking shutter did not close in response to the sunlit earth, and the responsivity decreased due to fatigue. When proper operation resumed, the responsivity climbed back to its normal value. However, the failure of attitude control on the OGO-2 spacecraft made the data of little value.

The OGO-4 instrument performed as designed during the 18 months of OGO-4 operation except that about six months after launch, the photodiodes apparently developed a leakage current, probably due to radiation damage, that was comparable to that from the sunlit earth, and no longer directed the down-looking shutter to open. The characteristics of the calibration lamps tended to wander over a period of months, and hence were useful primarily for noting short term variations (over hours or a few days) of sensitivity.

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FIGURES

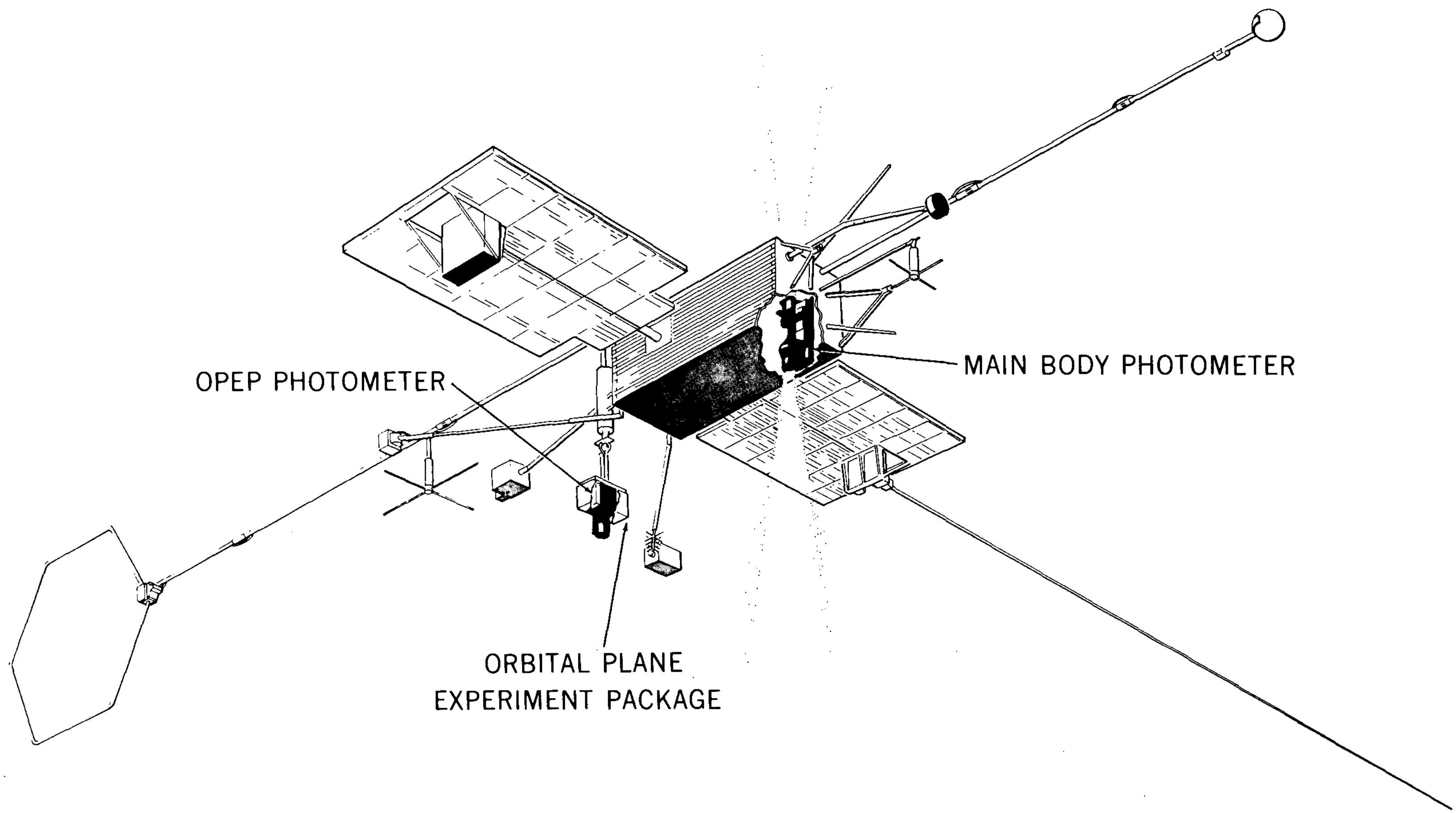

MAIN BODY PHOTOMETER
OPEP PHOTOMETER
ORBITAL PLANE
EXPERIMENT PACKAGE

Fig. 1

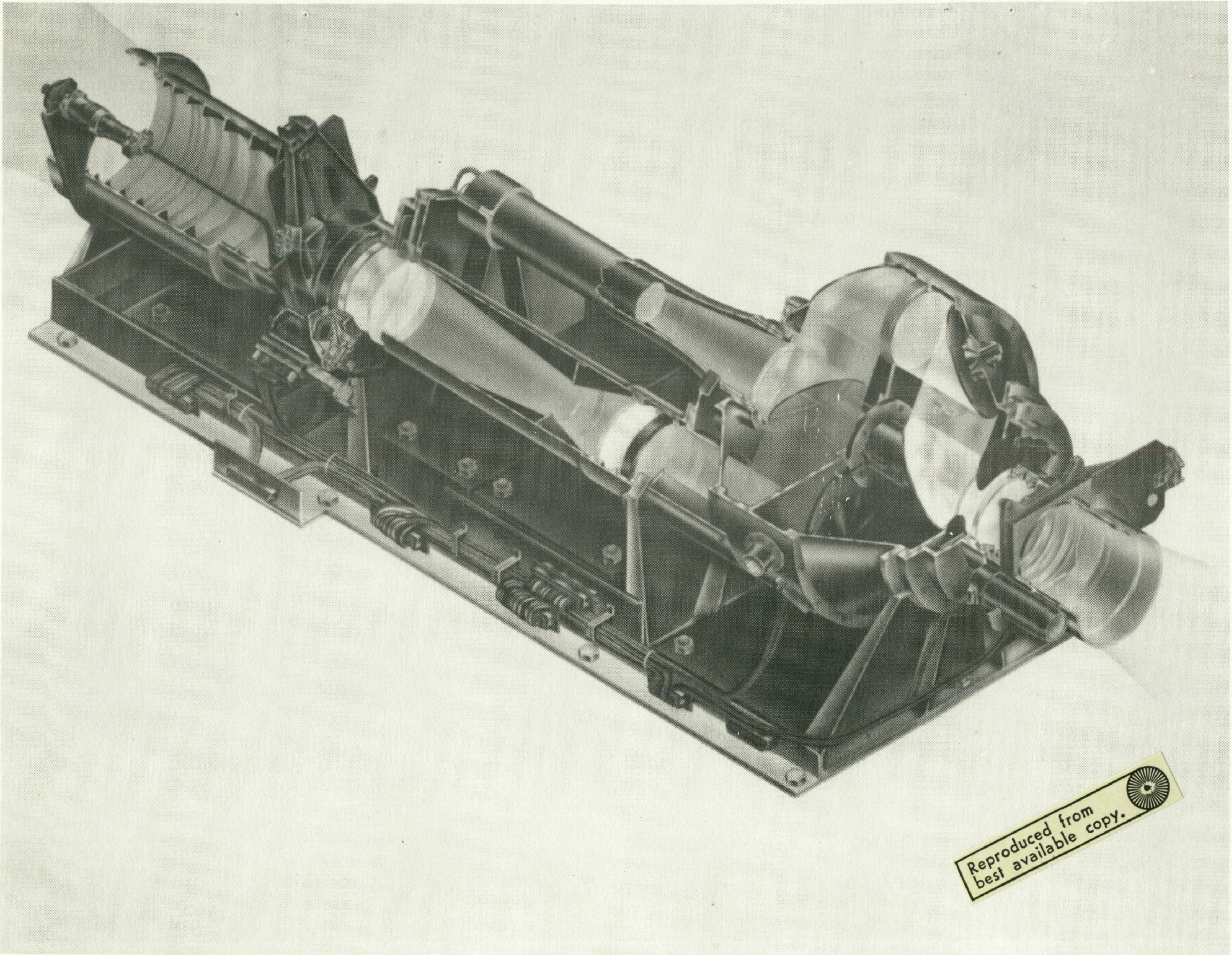
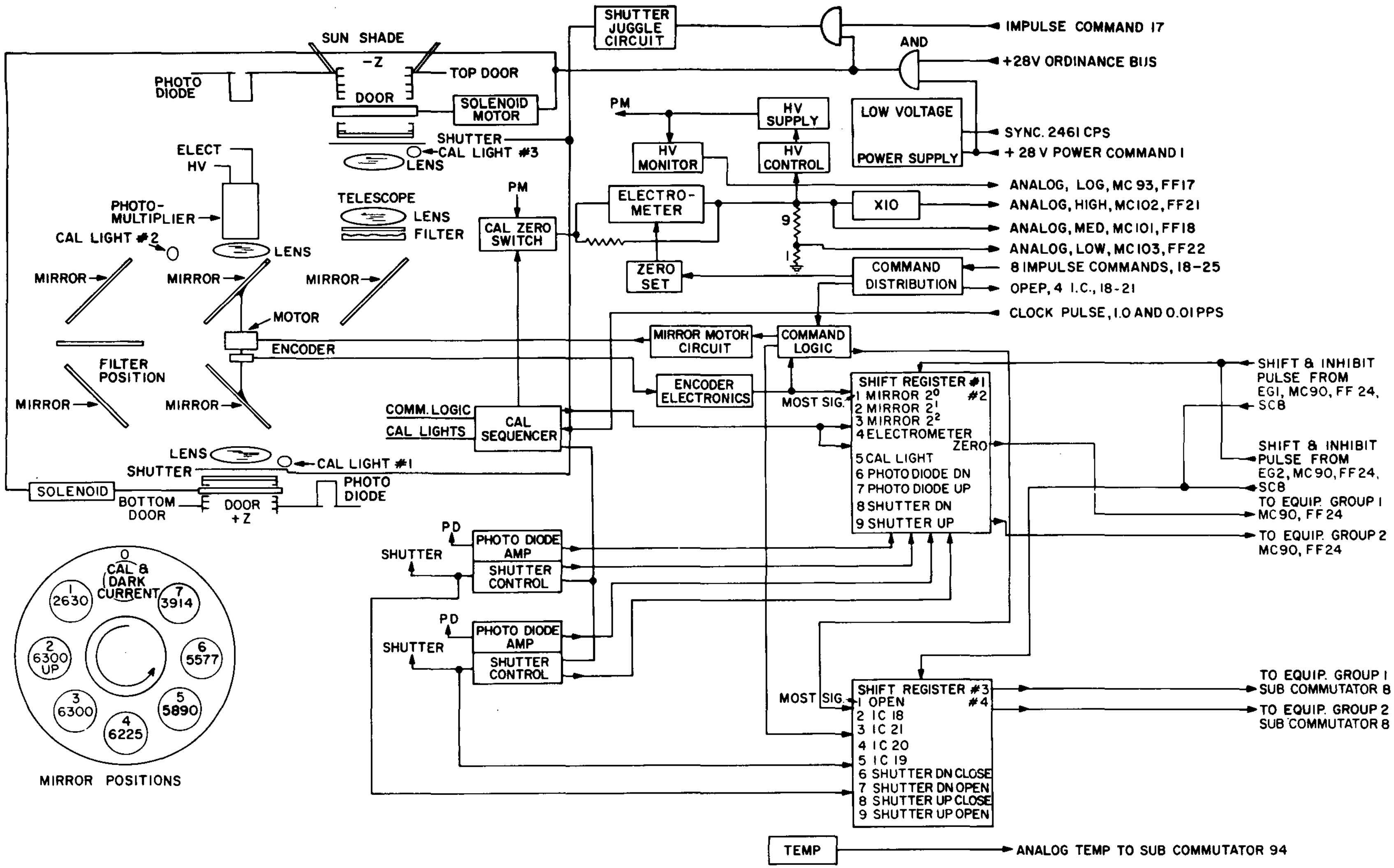


Fig. 2

NASA G-64-6489



MAIN BODY PHOTOMETER

(EXP NO. D-12)

JUNE 1967

Fig. 3

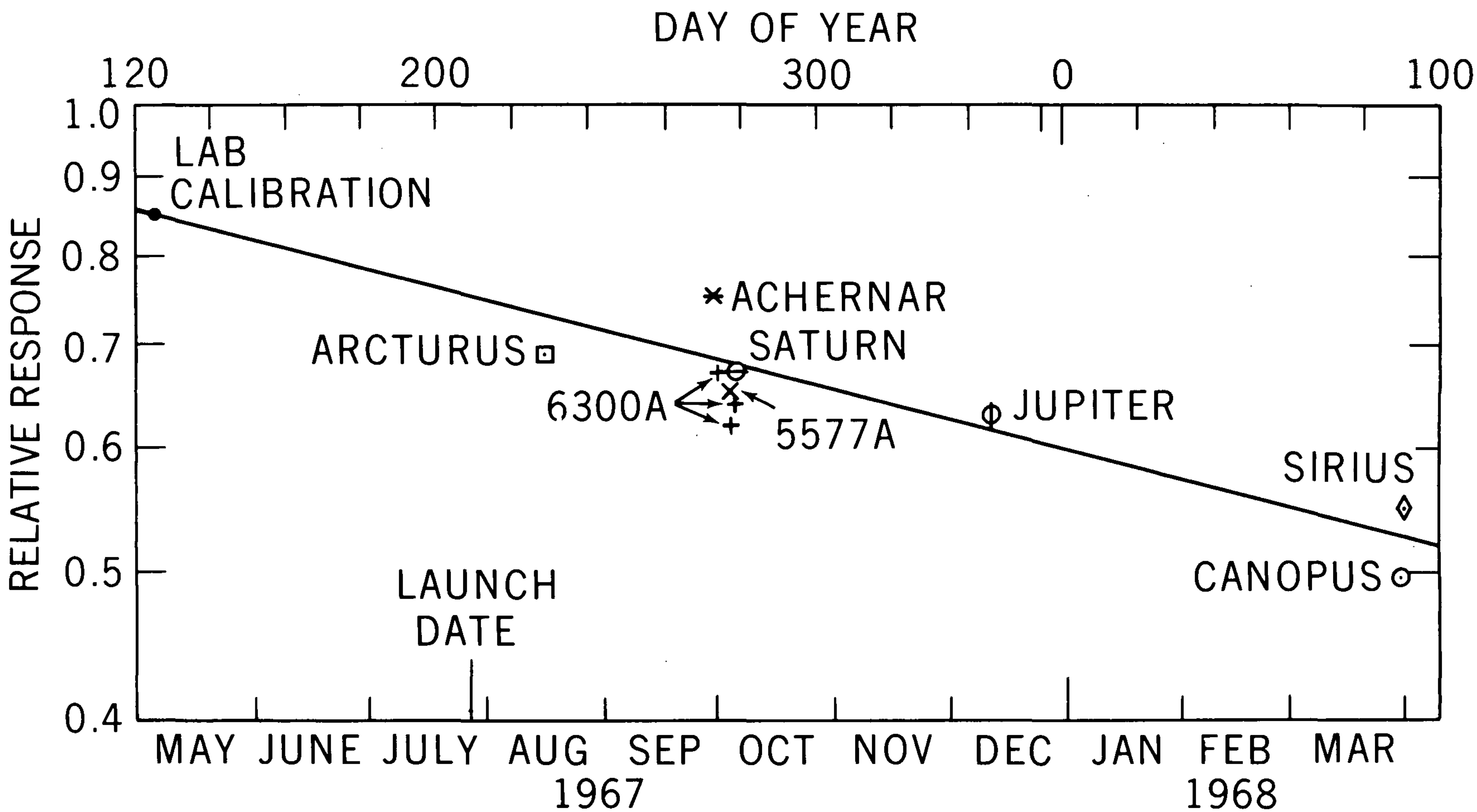

DAY OF YEAR
120
200
300
0
100
1.0
0.9
0.8
0.7
0.6
0.5
0.4
RELATIVE RESPONSE
LAB
CALIBRATION
ARCTURUS
ACHERNAR
SATURN
6300A
5577A
JUPITER
SIRIUS
CANOPUS
LAUNCH
DATE
MAY
JUNE
JULY
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
1967
1968

Fig. 4

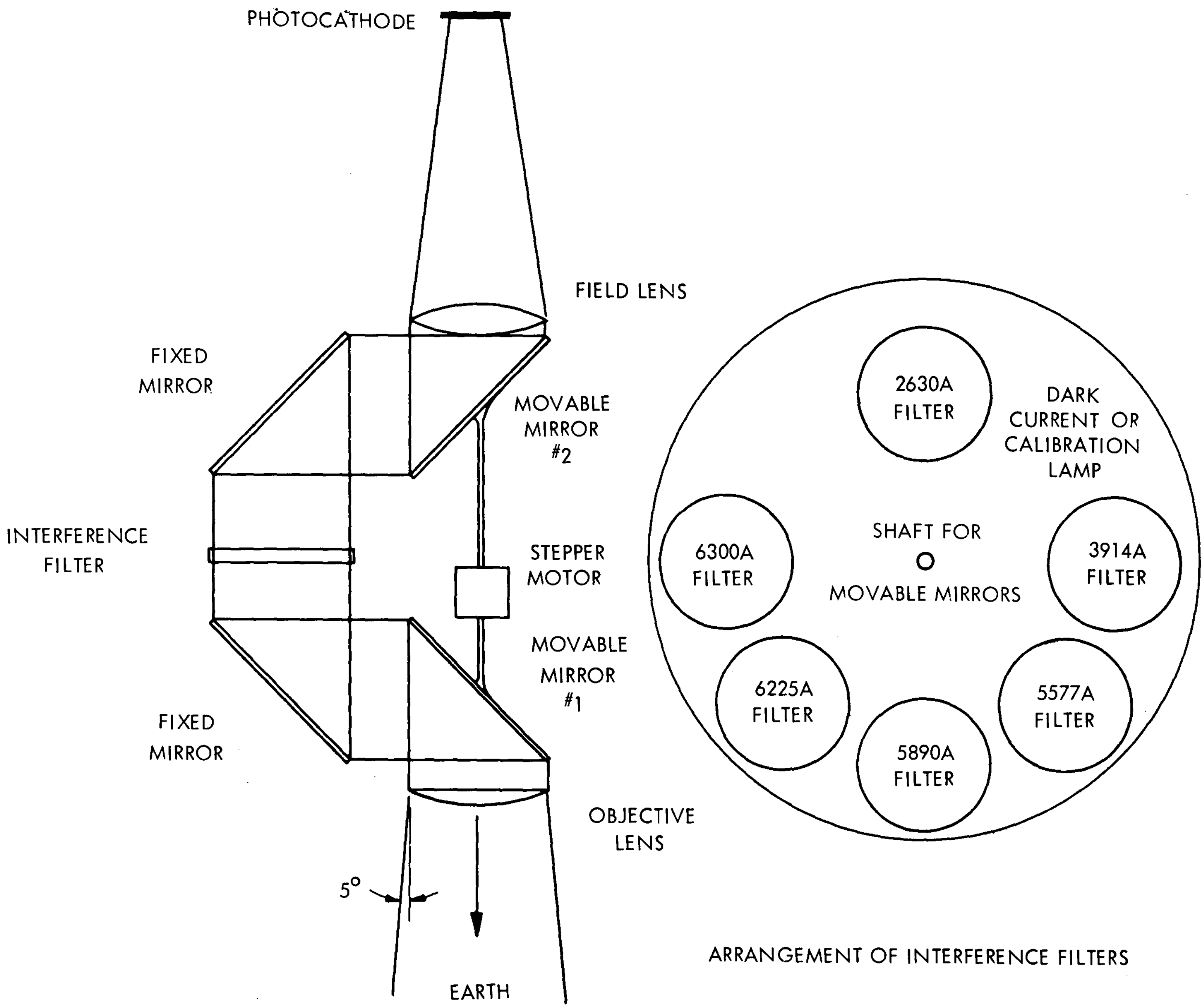

PHOTOCATHODE
FIELD LENS
FIXED MIRROR
MOVABLE MIRROR #2
INTERFERENCE FILTER
STEPPER MOTOR
MOVABLE MIRROR #1
FIXED MIRROR
OBJECTIVE LENS
5°
EARTH
2630A FILTER
DARK CURRENT OR CALIBRATION LAMP
6300A FILTER
SHAFT FOR
MOVABLE MIRRORS
3914A FILTER
6225A FILTER
5577A FILTER
5890A FILTER
ARRANGEMENT OF INTERFERENCE FILTERS

Fig. 5

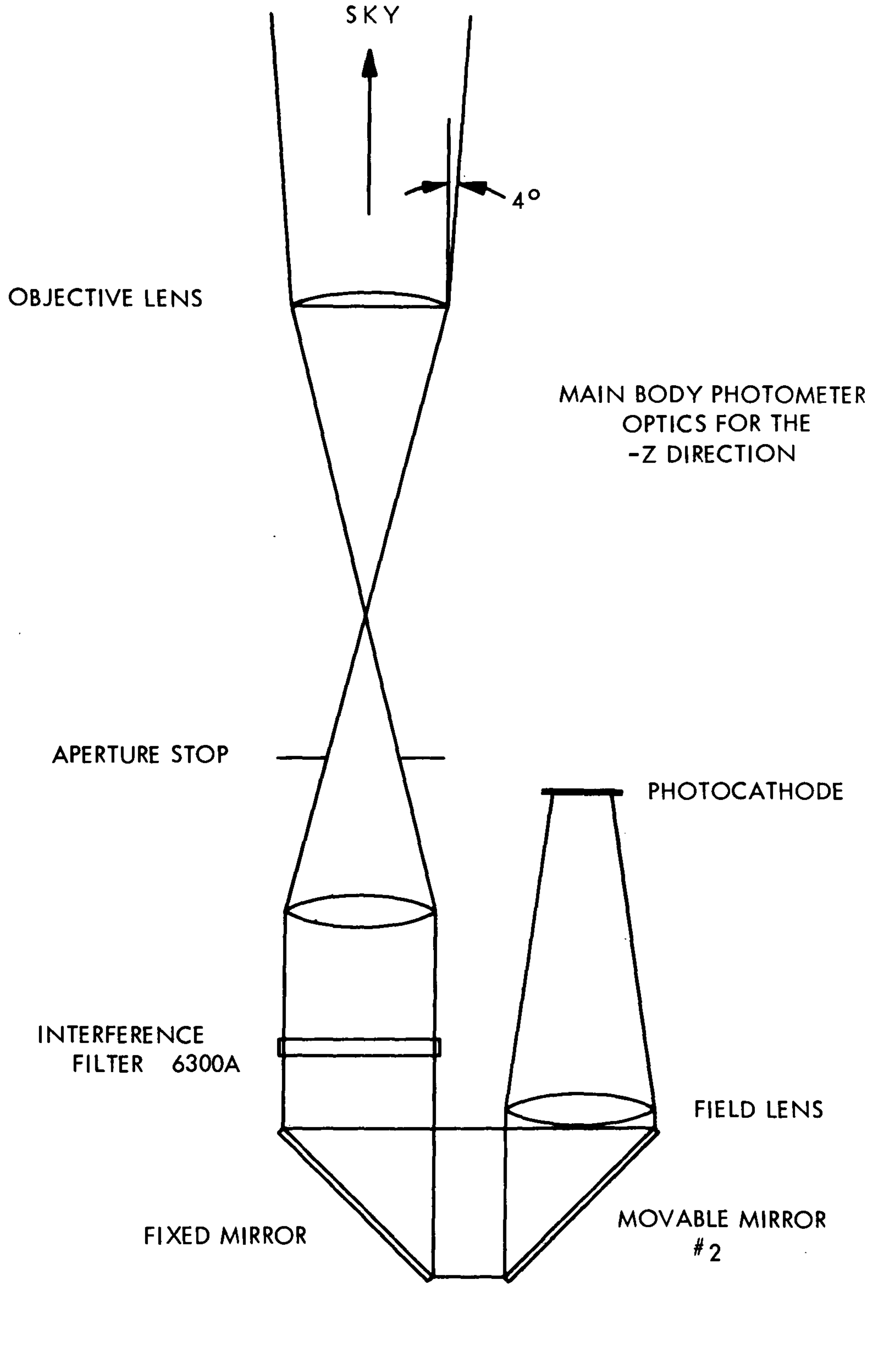

SKY
4°
OBJECTIVE LENS
MAIN BODY PHOTOMETER
OPTICS FOR THE
-Z DIRECTION
APERTURE STOP
PHOTOCATHODE
INTERFERENCE
FILTER 6300A
FIELD LENS
FIXED MIRROR
MOVABLE MIRROR
#2

Fig. 6