THE DETECTOR PACKAGE

for the

Laser Ranging Experiment at McDonald Observatory:

ITS DESIGN, PERFORMANCE AND OPERATION

14 August 1969

Technical Report #957

S. K. Poultney

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

Department of Physics and Astronomy
University of Maryland
College Park, Maryland

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Much of the detailed design and most of the machining on the package was done by Faust Meraldi. Morris Baldwin helped with the machining at times. John Mullendore did the detailed design of the heated window and its installation. He also installed the shutter attenuator. Cal Rossey and the Goddard Space Flight Center machine shop adjusted the package baseplate so that the package fit correctly on the Goddard Space Flight Center mount. Douglas Currie initiated the purchase of the Perkin-Elmer filter and Henry Plotkin followed up the many details of the purchase. Harvey Richardson was instrumental in the measurement of laser and filter wavelengths. He also was a great help in the Great Efficiency Chase as were Douglas Currie and Eric Silverberg. The various measurements of background required the McDonald 107" and the guiding of Douglas Currie and McDonald Personnel.

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I. INTRODUCTION

The Detector Package performs spectral and spatial filtering on the lunar return. Spectral filters with passbands of 3 Å and 0.7 Å and with transmissions of 55% and 35% are available. Their center wavelength at 6943 Å can be adjusted by temperature control devices. Spatial filters with fields of view from one arc second to 15 arc seconds are available. The spatial filters can be quickly changed without optical realignment. A prism beam-splitter directs the lunar return to two or more photomultipliers so that discriminator deadtimes can be circumvented when the return is greater than a single photoelectron. It also enables one of the common geometric methods of enhancing quantum efficiency to be employed. The latter provision was not used during acquisition; the former only a few times. An insulated chamber with a heated window contains the PMT so that its photocathode may be cooled to reduce dark current. Cooling is required during lunar night-earth night with the RCA C31000F PMT used during acquisition. The PMT base and discriminator, Ortec 270, is housed in a separate chamber. The base is electrostatically shielded and the PMT is both electrostatically and magnetically shielded. An air driven shutter is provided which remains closed during the time of laser output and opens at the time the lunar return is expected. Opening and closing times are each about 100 milliseconds at 60psi. When closed, the shutter allows a very small portion of the output laser beam to be directed into the package so that the matching of laser and filter wavelengths can be checked during operation. PMT safety features include an inner light-tight compartment and an auxiliary shutter directly in front of the

PMT which closes whenever the cover to the filter compartment is opened. Figure 1 gives a schematic diagram of the detector package.

Daily alignment of the detector package is quite easy. Provision is made to retroreflect a HeNe beam that is previously aligned to the outgoing ruby laser beam. The alignment is checked prior to and after ranging by observing one of several bright stars. Spectral alignment was first done by separately measuring ruby laser wavelength and spectral filter wavelength using the large spectrograph of the McDonald 107-inch and suitably controlling both laser and filter temperatures during operation. Provisions for a portion of the ruby beam to be sent back into the detector package so the spectral filter/ruby laser wavelengths could be matched during operation were added later. Total receiver efficiency for single photoelectron counting has been optimized at about 1/2% with a PMT of 5% quantum efficiency and 90% counting efficiency. This efficiency corresponds to a counting rate using Alpha Lyra and the 3 Å filter of about 720KHZ. A summary of dark current and background measurements for Site 2 on the moon and selected stars is given for each night of operation. The star counts are a direct indication of the atmospheric conditions at McDonald on those nights. PMT quantum efficiency measurements and single photoelectron counting level determinations are discussed in a separate report. Contacts with the lunar array and surface have been made with both spectral filters and the returns are about the magnitude expected.

II. The Basic Package

The outer dimensions of the basic detector package were frozen at 10" by 10" by 30" in early February. Fig 2 (GC-121-1128570) shows these dimensions as well as the beam entrance hole, the isolator plate, and tapped holes in the bottom of the baseplate. The baseplate is made of 1/2 inch aluminum jigplate. The sides and covers are made of 1/4 inch aluminum. The frontplate and backplate are made of 3/8 inch aluminum. Figure 1 gives a schematic diagram of the detector package. The detector package is divided into two compartments by a 1/2 inch aluminum centerplate. The forward compartment contains the shutter, spectral filter, spatial filter, and heated window. The rear compartment is divided into two parts by a 1/4 inch aluminum plate. This plate holds the PMT base which is located in the rear compartment. The middle compartment is insulated and contains the PMT's and beam-splitting prism. The prism is mounted on the back side of the centerplate. The heated window and auxiliary safety shutter are mounted on the forward side of the centerplate. All electrical connections to the detector package are made using cables to the connectors mounted on the backplate. Feed-through connectors bring the cables through each compartment plate. The spatial filter and spectral filter are mounted on a small optical bench in the forward compartment mounted directly to the baseplate. The shutter is mounted to the backside of the frontplate with its solenoid and airlines attached to the left side (when looking from the front). Access to the package is gained by lift-off covers or by unscrewing the two segments of the right side. The forward cover opens the forward compartment while the rear cover opens the two other compartments. An auxiliary cover must be lifted to gain access to the PMT compartment.

Efforts were made to provide all mating portions of the package sides, covers, etc. with recessed shoulders in order to make the package light-tight. In a few places, this provision was not made due to time constraints and the priority necessarily placed on the innards of the package. At those few places, the joints were backed with felt so that The package was light-tight in practice. All metal parts of the detector package were anodized black.

The package is mounted on the GSFC mount with some difficulty due to the blind mounting holes, but there is almost no need to remove the package once mounted. All tests of the detector package components can be made with the package in position.

Figure 3 shows a view of the detector package in position on the GSFC mount. Figure 4 gives a schematic diagram of the GSFC mount with all the components on it. Figure 5 shows a view of the detector package from the top with all three covers off. Detailed descriptions and views of the compartments are given below.

Descriptions of the GSFC mount, the GSFC optics, and the University of Texas optics are contained in separate reports.

III. The Spatial Filter

The spatial filter serves to limit the field of view of the detector package and to reduce the size of the light bundle for the beam-splitting prism. The beam entering the spatial filter is a near-parallel bundle of 0.8 inches in diameter. This beam is focused to a point on -axis by an Edmund Scientific Better Grade Double Convex Lens with a diameter of 35mm and a focal length of 101mm. The light is re-collimated by a second Edmund Scientific Better Grade Double Convex Lens with a diameter of 22mm and a focal length of 51mm. The lenses are centered on the optical axis of the detector package and can be moved longitudinally $\pm$ 1cm from their nominal position. The nominal 0.4 inch diameter output beam of the spatial filter then passes on to the spectral filter and beam-splitting prism. The spatial filter is aligned by placing it in the HeNe alignment beam of the GSFC package. This alignment beam is normally adjusted to be 0.8 inches in diameter and to have a beam divergence of less than 0.6 milliradians. The two lenses are then adjusted to yield a near-parallel beam out of the spatial filter. Typical beam divergences are about 0.6 milliradians. Both lenses were anti-reflection coated by Muffeletto Optical Co. Since the lenses used were inexpensive, an inexpensive MnF_2 hard coating was used with a quoted reflectivity of 1.2% per surface. The light loss in each lens was measured before and after coating by means of 30milliwatt HeNe laser. The two lenses used in the spatial filter were measured to have transmissions of 97% each.

The field of view limitation is done by placing the proper diameter pinhole at the proper position in the focal plane of the 101mm lens. The proper size pinhole is determined knowing the field of view desired, ϕ

the diameter of the telescope objective, D, the diameter of the beam entering the spatial filter, d, and the focal length of the spatial filter lens, f. The diameter of the pinhole, b, is given by (1).

$$b = \varphi \frac{D}{d} f \qquad (1)$$

The field of view desired will be no smaller than the beam divergence of the laser beam out of the telescope (i.e. θ D/d) and will usually be larger due to atmospheric seeing. The acquisition laser has a measured beam divergence, θ, of about 2.5 milliradians full-width at full energy at the normal operating point (See Appendix I). With an 0.8 inch beam and a 107 inch telescope, the smallest field of view for the acquisition laser is 19 microradians or 3.7 seconds of arc. The corresponding pinhole would have a diameter of 250 microns. A particularly convenient set of pinholes is manufactured by Ealing and these were purchased. Pinholes with diameters of 50, 100, 200, 400, 600, and 800 microns were mounted for use as described below. When seeing was good ,the 400 micron pinhole (i.e. 6 seconds) was used. At other times, the 600 micron pinhole (i.e. 9 seconds) was used. Section IX discusses star observations made with these pinholes.

The pinhole was placed at the proper position in the focal plane by means of an adequate xyz mount. Each dimension can be separately adjusted and locked. Figure 6 shows a view of the spatial filter with the xyz mount in place. The major constraint on the xyz mount was the requirement of mounting the pinhole wafers in such a manner that the pinholes could be easily aligned as well as interchanged without realignment. The movement along the axis (i.e. z-axis) is made by a micrometer head which moves the xy platform. The horizontal transverse motion is made by a fine screw and moves the y platform. The vertical transverse motion (i.e. y axis) is made by a fine screw and it is on this piece that the interchangeable pinholes are mounted. Each movement is backed by a spring and is constrained to move in the correct direction to a sufficient degree of accuracy. The pinhole wafers were each mounted in the front of hollow, conical brass pieces which were machined to close tolerance and which could be slipped finger-tight into a conical hole in the y-movement brass piece. A view of the pinhole wafer mounting and the xy mount is shown in Figure 7.

Alignment of the pinhole is done using the retro-reflected HeNe beam. A rough longitudinal adjustment is first made to place the pinhole approximately in the focal plane of the 101mm lens for red light. The X and Y adjustments are then made and locked. The fine longitudinal adjustment is then made. These adjustments are easily made and easily checked. The spatial filter is normally placed after the shutter and before the spectral filter. Therefore, one can at any time retroreflect the HeNe beam using the GSFC device or a good quality corner reflector. One should also check at the same time that the GSFC flip mirror assumes the same position when it is fixed open as when it is flipped open and that it does this consistently from shot to shot (See Figure 4). Interchange of pinholes may also be checked although Section X indicates that the 400 and 600 micron pinholes can be interchanged without alignment.

The pinhole alignment discussed above assumes that the detector package axis and hence the spatial filter axis is correctly aligned with the HeNe beam. The detector package has no internal adjustments for this purpose and is fixed in position on the GSFC mount. The necessary adjustments of the HeNe beam must be done inside the GSFC optics box either at the flip mirror which switches the lunar return to the detector package or at the fixed 1% mirror which makes the final deflection of the return into the detector package. None of these adjustments are particularly easy to make since they are all coupled. The HeNe laser is a great help. One plays with the position of the fixed mirror in three dimensions until the HeNe beam axis coincides with the detector package axis. The stops on the flip mirror can also be changed to gain more rotation of the beam in the horizontal plane. During this major and infrequent adjustment, one should also check for vignetting in the GSFC optics box and in the detector package as discussed below in Section VI. One should also check to see that a parallel beam of starlight does enter the GSFC optics and detector package correctly. A beam from a bright star can be seen in a darkened room at might. One can check that the beam falls on the PMT if the spectral filter is removed, but must realize that the spatial filter is adjusted optimally only for red light.

IV. The Spectral Filter: Its Performance and Control

A. Introduction

Once the field of view has been limited to the laser spot size on the moon, the high backgrounds during earth night/lunar day and earth day/lunar day can only be reduced by using narrow spectral filters (and laser sources). The expected background noise rate from the bright moon was 1.6×10^{11} photons/steradian cm^2 Å sec. The origin of this number is discussed in Appendix II. The earth day background was expected to be no more than the bright moon background. The above bright moon rate does not take into account any possible decrease due to a lower albedo of the landing site. The receiver geometry includes a diameter of 270 cm, a field of view of at least 19 microradians, an estimated optical train of 30%, and a PMT quantum efficiency of 10%. The bright moon background noise rate is expected to be

$$1.3 \times 10^5 \; T_F \; \text{photoelectrons/ Å sec} \qquad (2)$$

where T_F is the transmission of the particular spectral filter used and where (2) must be multiplied by the filter width to obtain the PMT counting rate at the single photoelectron level. The absolute PMT counting rate is important with regard to possible PMT overload. The RCA 31000F has a maximum average anode current rating of 1 milliampere which corresponds to 6×10^6 photoelectrons per second at the normal tube operating point. All the spectral filters used have bandwidths narrow enough so that overload is not a problem. The PMT is additionally protected by being exposed to the noise background for only one second out of every six.

The signal to noise ratio, however, is what will primarily determine the filter used at a particular time. This ratio is influenced by the time of operation, date of operation, range uncertainty, and lunar array behaviour. Some of these considerations are discussed in Appendix III. The expected signal return from the lunar array of the original proposal is about one photoelectron per laser firing during the laser pulsewidth. Since the lunar range could have had a systematic error up to about a microsecond in range time, one must initially use a range gate of the order of 5 microseconds or larger. For a gate of 5 microseconds and a 10 Å filter with 50% transmission, a total of 3 noise counts would be recorded along with the single signal count on each laser firing. A 3 Å or narrower filter is therefore needed during these high noise conditions when the range is so uncertain. Note that one would not normally try to acquire the array under such adverse conditions. However, certain decisions at MSFC on the array and the press of publicity gave us no choice. Detailed discussion of the signal to noise problem appears in the report on Acquisition at McDonald (Science, In Press). The basic data on observed lunar noise rates appears in Section VIII and are discussed in Section IX.

Spectral filters with 3 Å and 10 Å fullwidths at half-maximum were purchased from Thin Film Products. Their specifications are given in Appendix IV. Note the requirements on minimum peak transmission, special blocking, and peak-wavelength temperature coefficient. The 3 Å filter is the only one used with any regularity in the detector package. The 10 Å filter is used in the laser monitor photodiode. The performance and control of the 3 Å filter is discussed below.

A spectral filter with a 0.7 Å fullwidth at half-maximum and a complete built-in temperature control and monitor system was purchased from Perkin-Elmer. Its specifications are given in Appendix V. This filter was used extensively during acquisition at high background operating times. Its performance and control is discussed below.

B. Laser Wavelength Measurement and Control

The narrower one makes the filter bandwidth, the lower the noise background becomes, but the more difficult the problems of matching the laser output wavelength to the filter passband and of keeping the laser wavelength narrower than the filter bandwidth. Both the Spacerays laser used for acquisition and the Korad laser to be used for precise ranging were required by contract to have full linewidths of 0.1 Å or less. The author and Richard L. Smith made measurements of the linewidth of the Spacerays laser at GSFC before shipment to McDonald using a Fabry Perot interferometer. A glass plate was used at the output of the GSFC box to deflect a small portion of the laser beam at right angles to the main beam in the horizontal plane. The laser is polarized in the same plane. Both the calorimeter and monitor photodiode remained in plane and in operation. The beam sample was then diffusely reflected into the interferometer by means of an MgO block. A Hilger interferometer with a spacer of 2.01mm and silver coated plates was used. A Speed View Graphic camera with a 203mm focal length lens was placed in back of the interferometer to form the rings. Calibration interferograms were taken using the HeNe laser beam from a Spectra Physics 130B and using Polaroid Type 47 film. A red gelatin filter was used in front of the camera lens to eliminate stray light. The laser linewidth was measured using Polaroid Type 413 film. (Type 47 film has an extremely sharp cutoff just after the HeNe wavelength). A neutral density 1.0 filter was needed in front of the camera lens and a frosted glass plate placed in front of the interferometer. A run of thirty laser shots was made with the diagnostics done on the tenth, twentieth, and thirtieth pulses. The laser pulse was a nominal ten joules and 20 nanoseconds. The HeNe interferogram showed that the plates had an equivalent finesse of about 5 and that the linewidth could be measured to about 0.25 Å. The first ruby interferogram showed a central bright ring with a width of 0.25 Å surrounded on both sides by faint coterminous rings with widths of 0.25 Å each. The second and third interferograms were similar with an inner bright ring and a coterminous faint ring with the same widths as above. The laser cooling water during this period had a temperature of $62^{o}F \pm 2^{o}F$. The reproducibility of laser line center was required by contract to be repeatable at each shot to ± 0.5 Å. A check of this reproducibility can be read from the same interferograms by noting the fractional change in ring diameter from one interferogram to the next. A change of ± 0.13 Å was observed in the three shot sequence.

The laser output wavelength must be known to an accuracy better than the width of the spectral filter used in order that the filter passband and laser wavelength can be matched to each other. Such a measurement is not possible with a Fabry Perot interferometer since neither the plate spacing nor lens focal length is known to better than 0.1% which corresponds to about 7 Å or more uncertainty in the wavelength. A direct measurement of laser wavelength and filter wavelength as functions of temperature can be made using a high dispersion spectrograph. An indirect measurement of laser wavelength could be made by calibrating the filter wavelength as a function of temperature using a set of standard lamps and then sample the passing of laser light by the filter as a function of laser water temperature for the several calibration points of the filter. This indirect measurement is useful because the atmosphere and normal laser operating conditions restrict the laser wavelength to values close to 6943.0 Å as discussed below and because there is a potassium line at 6939 Å and a thorium line at 6943.6 Å. The indirect method was tried at Maryland before shipment to McDonald, but the low intensity of the thorium lamp prevented its use. The equipment for the indirect measurement was therefore left at Maryland. The idea of the indirect measurement will be used, however, to continously monitor the laser-filter wavelength matching as discussed in F. below.

Fortunately, the McDonald observatory has a high dispersion grating spectrograph for use with the 107" in the Coudé configuration. The corner reflectors used by D. Currie on the 107" spider to point the laser beam send a sufficient amount of laser light directly back to the slit of the spectrograph. The spectrograph can also be used with white light to calibrate the filter wavelengths as a function of temperature and to check to see if the atmosphere above the summit of Mt. Locke had water absorption bands as has been observed at lower altitudes[1]. The latter check was made while viewing a planet one clear night and little absorption was seen. Using the B grating at 42.6°, no filters, 0.5 to 1mm slits, and the 14 foot camera, dispersions of about 1.9 Å/mm were obtained. Iron and neon calibration spectra were used and the camera focus checked with a Hartmann mask. The laser wavelengths made on 11 July were done by D. Currie and H. Richardson. The measurements on 19 July were done by S. Poultney and H. Richardson. H. Richardson did the detail analysis of all the plates. Table I lists the results of the measurements. The temperature given is that of the laser cooling water and is accurate to about ± 1°F. The laser was operated at its normal 10 joule level. Some of the weak lines observed on 19 July are not listed. Immediately apparent is the lack of a single wavelength as the contract stipulated. In particular, operation at 71.5°F causes the laser output to be equally divded between two spectral lines. The choice of operating temperature depends

[1]R. K. Long, Proc. I. E. E. E. 51., 859 (1963)

upon the wavelength of the filter used, its degree of adjustability, and the possibility of absorption by water vapor lines in the atmosphere.

According to Long[1], atmospheric absorption lines can appear at 6942.37 and 6943.80. A laser wavelength of about 6943.2 Å will be in the window between these two lines. The various filters were selected to have passbands in the vicinity of this wavelength while maintaining sufficient range of adjustment as discussed in C and D below. The temperature coefficient of the laser output wavelength was expected to be 1 Å per 27°C at room temperature. The measurements in Table I indicate that the coefficient is about 1 Å per 11°C, but the resonant reflector in the cavity may modify the temperature coefficient that is expected from the behaviour of the center of the ruby fluorescent line. The resonant reflector temperature was not controlled and was at about room temperature of 70°F. The initial reason for measuring the laser wavelength was to determine its absolute value as a function of temperature near the operating point. Although rough estimates of the wavelength at a given water temperature can be made (Appendix VI), heating of the laser rod during a flash lamp cycle and a change in the time of Pockel cell firing can cause the laser light to be emitted at a rod temperature 4°C or higher than the water temperature. It was estimated that the laser would have to be operated at 21°C or 68°F to obtain an output at 6943.2. The measurements of Table I indicate that the water temperature should be somewhat higher than 71°F. However, the laser gain drops fairly rapidly as the temperature is raised so 71°F was chosen as a compromise for flash lamp life. The Spacerays laser is supplied with a temperature control unit that maintains the cooling water temperature to ± 2°F. Table I indicates that this control is sufficient to maintain a

[1] R.K. Long, Proc. I. E. E. E. 51., 859 (1963)

stable output after a few warm-up shots. In spite of these absolute measurements, the laser/filter matching monitor system discussed in F. below for use with the narrow bandpass filters was installed.

A complete set of laser diagnostic equipment was purchased with the help of GSFC. A list of the equipment appears in Appendix VII. A continuous monitor of laser pulsewidth, pulse energy, and beam divergence was available with this equipment. The beam divergence equipment shown in Figure 4 was built at Maryland and installed at McDonald.

C. The 3 Å Filter: Its Calibration, Performance, and Control

This section will deal mainly with the 3 Å filter although the mount, temperature monitor, and temperature control units built for the 3 Å filter will work just as well with the 10 Å filter because the filters have the same diameters. The 3 Å filter specifications appear in Appendix IV. The requirement that the peak wavelength be at 6944 +2 -0 Å for a temperature of 40°C was made for two reasons. First, good temperature regulation using only a heater requires that the filter operating point be above ambient. Room temperature at McDonald is kept close to 70°F or 22°C. The filter specifications allow a temperature range of 25°C to 35°C for 6943 Å operation as long as no filter rotation is made. Second, the manufacturer stated that filters of this type often age during the first year so as to drop about 2 Å in peak wavelength. This drop has been independently confirmed by J. Alishouse at ESSA. In the case that the initial wavelength of the filter is too high, it may be tuned by rotation as well as by temperature. Both of these tuning behaviours for similar filters have been discussed in detail by Blifford[2] and a summary appears in Appendix VI.

Figure 8 gives an exploded view of the filter mount which includes

[2] Blifford, Appl Optics 5, 105 (Jan 1966)

provision for rotating the filter at an angle to the axis and provision for heating the filter. The filter drops into a cylindrical box of aluminum and is held in by a threaded wall. The optical axis is along the cylinder axis; the wall perpendicular to it. Both wall and box have a one inch diameter hole for the beam to pass through. The box is made into an oven by fixing a heating band to the outside of the cylinder. Contact between the walls and the filter is just surface to surface along the area of the filter outside the one-inch wall-hole. The heating band was made by looping nichrome wire onto a flat strip of Scotch #27 Glass Cloth Electrical Tape and bonding a second piece of tape to the first. The heater resistance was about 4 ohms. The heating band could be slid onto the cylinder and held in place by the filter retaining wall. The cylindrical oven was mounted inside an open rectangular box by means of a threaded shoulder on the oven. The oven and box were separated by an O-ring. The air insulation on all but the open side of the rectangular box (where the filter retaining wall was) proved adequate in practice as discussed below. An insulating wall can be provided for the shallow rectangular box if it becomes necessary. The shallow rectangular box is mounted on its side on a square cross-section optical bench mount so as to pivot about a vertical axis. Movement of the filter about the vertical axis is done by a micrometer head adjustment backed by a spring. The tilting mechanism was designed so that a motor-driven cam could be added later for rapid tuning in angle if that feature were ever needed. Rotation of $\pm 4^{\circ}$ is available with a precision of about 0.2°. The filter mount is placed on the detector package optical bench after the spatial filter. The bench has a milled shoulder which allows the mating bench mounts to slide longitudinally along the axis of the package. The mounts are held to the bench with a single knurled-head bolt.

The temperature of the filter is monitored with a YSI 3000 ohm precision thermistor probe buried in the oven close to the filter. The electronic sensor circuits and the heater control circuits were designed by C. Whitted and are described in a separate report (Dept. P & A Electronics Shop W.O. #68/69-5363). The Thermal Monitor and Control contains ten identical channels. The maximum total power for all ten heaters is 400 watts. Temperature stability and sensitivity of each channel is better than 0.1°C. The sensitivity and heater power should be adjusted in conjunction with the insulation of the heated object so that the proportional heater design is effective. Figure 9 gives a view of the front panel of the Thermal Monitor. The channel on the far left of the Thermal Monitor is used for the 3 Å filter. It is permanently connected to a meter panel and a chart recorder (1 ma full scale) BNC for temperature readout. The two meters on the far right are the temperature readouts for channel one and all channels respectively right to left. A 10 position rotary switch selects the channel to be read on this last meter. The meters at each channel position read the percentage of the available heater power which is being used in that channel at any particular time. Directly below these heater meters are dials which provide a temperature range from 25°C to 50°C to be individually set for each channel. A temperature calibration chart is taped to the Thermal Monitor and included in W.O. #68/69 - 5363. There is a small toggle switch mounted between meter number one and meter number two. This switch allows temperature controller number one to be controlled by its 10-turn dial or slaved to controller number two. In this manner, the filter and laser water temperatures may be slaved together at a given offset if so desired. The same functions are true of channels number three and four. The other channels were meant to regulate the temperatures of certain critical electronic components of the ranging system. (University of Maryland Tech Report #   ). A fine potentiometer and thermocouple wire were purchased so that the absolute temperature of the filter could be measured to $\pm$ 0.1^{o}C.

The 3 Å and 10 Å filters were ordered through GSFC. They doubled the order for their own use. All filters were calibrated at the factory before shipment. The 3 Å filter that we received (i.e. 6942/2#1) was quoted to have its passband center at 6942.2 Å at a temperature of 25^{o}C, a peak transmission of 52%, and a full width at half maximum of 3.1 Å. No temperature coefficient or rotation coefficients were given. The work on the filter at Maryland focused on measuring these coefficients for this filter and studying its behaviour under a sudden change in temperature. The spectral filter was mounted in the detector package along with the spatial filter and an EMI 9558 PMT. One of the calibration lamps was placed outside the package with a crude chopper to chop the light beam. The light source was placed at least 60cm from the package aperture of 2cm so that the beam of light entering would not be too divergent and spoil the measurement. The spatial filter was used backwards to reduce the divergence further. To test the thermal response of the 3 Å filter, the filter was tilted to accept the 6939 potassium line and its temperature varied. The signal was maximized at 25^{o}C on a Tektronix 564 oscilloscope after the filter had reached equilibrium. The temperature dial was then raised to 30^{o}C. The heater temperature reached equilibrium in about 2 minutes. The light signal, however, took 10 to 15 minutes to reach a steady new value which means that it took the filter this long to reach the new temperature. These changes were repeated up to 40^{o}C and back to 25^{o}C with essentially the same results. The hunting at each equilibrium point was minimized by the addition of a fixed resistance in series with the heater and indicated that the filter temperature was stable to at least $\pm$ 0.25^{o}C. The cover of the detector package was removed during one of these equilibrium periods with no effect on the filter.

The above measurement of transmission as a function of temperature also served to measure the temperature coefficient of the filter. A plot of transmission as a function of temperature should have the same shape as the factory calibration curve of transmission as a function of wavelength as long as transmission is a linear function of temperature. The fullwidth at half-maximum of the temperature curve which was 20°C should then be directly related to the 3 Å width of the filter. This relation yields a coefficient of 0.15 Å per °C. The sign was determined to be positive by rotating the filter so as to decrease the wavelength and by adjusting the filter temperature to maximize transmission at the new angle. The rotation coefficient and its sign was determined by maximizing the transmission of the filter for spectral lines of 6939 Å (K), 6929 Å (Ne), and 6911 Å (Ne). The wavelength shift as a function of rotation angle from the normal for this particular filter is given by

$$\Delta\lambda = -2.3\ \alpha^2$$

where the angle α is in degrees.

The filter tests with the spectral lamps also indicated that the hope of using the 6943.6 Å line of thorium for calibration purposes during operation was not to be realized. That particular line was very weak. Synchronous detection with a Princeton Applied Research JB-5 and chopping wheel did not work even at highest sensitivities. Furthermore, the 6929 Å line of Ne which was in the hollow cathode thorium lamp could easily be mistaken for the 6943.6 Å line of Th by an uncareful worker. The calibration lamps were not used at McDonald for those reasons.

The 3 Å filter was examined at McDonald using the spectrograph as described above for the laser and a white light source. During alignment of the filter inside the spectrograph room, it was noticed that the filter had a wedge which resulted in a refraction of about 0.1°. This refraction means a displacement in the focal plane of the spatial filter of 100 microns. The 3 Å filter should never be placed before the spatial filter unless a large pinhole is being used. The width of the filter passband on the photographic plates appeared to be about 3 Å, but no detailed measurements were made. Measurements of the filter wavelength were made at 40°C and 25°C and gave 6945.7 Å and 6942.4 Å respectively. Since the filter was relatively wide, no great care was taken to average out the effect of the wedge as was done later for the Perkin Elmer Filter. The temperature coefficient of the 3 Å filter was calculated to be +0.22 Å/°C which is close to the value found above. If the filter is to be set so that its center is at the center of the laser doublet at 71°C, then its temperature must be 27.6°C. This temperature corresponds to a setting of 287 on the Thermal Monitor dial as long as room temperature is not drastically different from 70°F.

D. The Perkin Elmer 0.7 Å Spectral Filter

The specifications for the Fabry Perot portion of the 0.7 Å filter appear in Appendix V. Note that the free spectral range of the etalon is 10 Å or more and the temperature coefficient is + 0.042 Å/°C. The peak wavelength must be specified at a given temperature. This temperature was chosen as in C. for the 3 Å filter and the choice is discussed in Appendix IV. The etalon itself has a whole series of passbands so that an auxiliary narrow band filter must be added to select the passband of interest. The auxiliary filter must then be temperature controlled and at the proper angle. The discussion of the 3 Å filter in C. above gives a good idea as to how the rest of the 0.7 Å filter works. In fact, if there had been a little more time, only the etalon needed to have been purchased. As it was, a complete filter package was purchased from Perkin Elmer including oven and temperature monitoring devices similar to those discussed for the 3 Å filter. An insertable thermocouple was also supplied to make occasional absolute temperature readings.

The filter was delivered at McDonald with a passband at 6943.2 Å at 44°C, a bandwidth of 0.7 Å, and a peak transmission of 35%. The calibration at McDonald was worked on by D. Currie, H. Plotkin, and H. Richardson with Dr. Richardson doing most of the analysis. The filter was examined using the spectrograph and a white light source. In summary, it was found that the filter had a cylinder divergence (or convergence) of 12 seconds of arc and a refraction of 37 seconds of arc. The refraction was toward 9 o'clock when the auxiliary filter screw was at 12 o'clock. These findings show that the Perkin Elmer calibration was only approximately correct. The peak average wavelength was measured to be 6942.88 Å at 41°C. A second measurement at 37.5°C gave 6942.695 which indicates a temperature coefficient of +0.0529 Å/°C. The McDonald measurements mean that the filter temperature must be 47°C for 6943.2 operation rather than 44°C. The discrepancy is only 0.16 Å which is less than the filter width. The filter transmission was not directly measured but is consistent with the transmission of the 3 Å filter and the star measurements in Section IX and X. The filter transmission is maximized by rotating the auxiliary filter slightly by means of the external screw. Care should be taken in changing both etalon wavelength and auxiliary filter angle that one does not jump to another etalon pass band. Details of filter operation can be found in the instruction book supplied with the filter.

The temperature of the Perkin Elmer filter now used is chosen to put the filter center midway between the strong laser doublet seen at a laser temperature of 71°F. The filter temperature is 44°C. It slightly favors the 6943.2 Å laser line. The laser operating point was chosen before the filter operating point was and with an eye to possible atmospheric absorption. Since the laser temperature cannot be raised as one would like to do to solve the problem,one should probably lower it to where only the 6942.7 Å line is strong. That laser temperature is probably around 66°F, but a measurement should be made. The temperature of the filter for this lower line should be 39.9°C. If the temperatures are changed, the auxiliary filter must be retuned in angle. In any case, the filter width corresponds to 13°C and a complete mismatch of laser and Perkin Elmer is not expected.

It was fortunate that the Perkin Elmer filter did fit inside the detector package for the package dimensions were frozen in December and the Perkin Elmer filter dimensions were not known until June. The Perkin Elmer filter is so big that it must go in place of the spatial filter. The spatial filter must then go after the spectral filter which has the disadvantages that the spatial filter alignment cannot be checked without removing the spectral filter and that the refraction and cylinder on the wedge limits the size pinhole that can be used in the spatial filter. The refraction amounts to 20 microns in the focal plane of the spatial filter and so is not serious for the 6 second pinhole. The Perkin Elmer filter can only be put in the proper place if portions of the air shutter mounted on the far wall of the package are relocated.

The temperature of the Perkin Elmer filter is monitored and controlled by an external box with meter. Two wires run from this box to the filter inside the package. In order that both the 3 Å and the Perkin Elmer filter be available at anytime, both sets of wires are kept hooked up. This procedure allows the 3 Å filter to be kept inside the package either in line or to the side. Since all cable feedthroughs were used before the arrival of the Perkin Elmer filter, access to it is made through the side of the box. The opening is backed by felt on both sides to maintain light tightness. In this manner, the Perkin Elmer filter is easily removed from the package when not in use without disrupting the temperature control. If the temperature of the Perkin Elmer should need changing, one should recall that the heater and monitor indicate the change in a matter of minutes while the filter takes hours to reach the new equilibrium point.

E. Alignment of the Spectral Filter

Alignment of the spectral filters is done by autocollimation using the HeNe retroreflected beam. The spectral filter is always the last item of the detector package to be put in place and adjusted. When the spatial filter is placed before the spectral filter as is normally done, it is convenient to remove the pinhole temporarily. In both cases the "silver" face of the filter is made perpendicular to the HeNe beam. For the Perkin Elmer filter, this face is the one opposite the one with the adjustment screw. A card with a millimeter hole in it is placed as far forward in the GSFC optical train as is possible (typically 70 cm). The reflected dot is aligned with this hole by rotating the filter either about a vertical or horizontal axis. The former rotation is rather easy to make using the micrometer head on the 3 Å filter or a simple twist on the Perkin Elmer filter mount. The latter rotation should be aided by the use of a shim under one edge of the filter mounts. In this manner alignment to better than 0.1 degrees can be made. Vignetting by the Perkin Elmer filter should also be checked.

F. Continuous Monitoring of Laser/Filter Wavelength Matching

The problems that arise in matching separately-measured laser wavelengths and narrow band filter wavelengths make it highly desirable that a continuous monitoring of the matching of the wavelengths is made. Such a monitor is especially needed for filters narrower than the Perkin Elmer 0.7 Å filter. Single wavelength lasers are also needed. One method of monitoring the matching is to sample a portion of the outgoing beam. The sample may be made by any light sensitive detector as long as it is behind the spectral filter and the sampled beam is perpendicular to the filter. Provision was made in the detector package and in the GSFC optics to do this sampling. Figure 4 shows the sampling path. From the pickoff plate which doubles as the HeNe entrance to the optics a 1% beam sample passes through an ND3.0 filter, is reflected at right angles toward the detector package, passes through a partially silvered ($\tau \doteq 1\%$) mirror, and enters the detector package. At the time of sampling, the shutter is closed, but an ND9.0 filter is mounted in the shutter so that a sample may be taken at the time of laser firing. The sample then passes through the spatial filter, spectral filter, and back to the timing PMT. The PMT has a linear output which is monitored for the degree of laser/filter matching. Thermal tuning of the laser can be done to optimize the linear signal. The PMT also can be used for the start timing pulse in an identical channel to the stop timing pulse and so cancel out discriminator and cable delays. The main problem in making the system work is to suitably attenuate the beam sample.

Previous experience with providing pickoff signals from laser beams has shown that the amount of light obtained is more than enough to degrade PMT performance drastically. In order to operate the PMT near the single photoelectron level both at start and stop and use it as a matching monitor, an attenuation of at least 10^{16} must be provided. By agreement with GSFC, they supplied about a factor of 10^7 with their 'wrong' polarization reflection (1%), the ND3.0 filter, and the 1% transmitting mirror. More was not asked of them because the amount of extraneous laser scatter is difficult to predict. The remaining attenuation (or more) had to be in the detector package itself. The ND9.0 filter mounted in the airshutter raised the attenuation to the 10^{16} factor which corresponds to about 10^4 photons. One wants to sample the cross section of the spectral filter and so can use no other geometric attenuation inside the detector package. PMT efficiency of 5% and typical filter transmission of 50% reduces this sample signal to an estimated 200 photoelectrons. The linear output scale was calibrated by observing noise photoelectrons at high gain across a 50 ohm load into a Tektronix 564 oscilloscope. A typical noise pulse gave a 20 millivolt signal at 3400 volts on the PMT. During initial testing, the PMT gain was lowered drastically (10^{-2}) and then raised as the sample path attenuation was increased. The attenuation required for safe operation of PMT 1 is 10^{16} as described above. The linear output signal increased from 6 millivolts at a laser temperature of 60°F to 16 millivolts at 65°F to 30 millivolts at 72°F. Above 72°F, there was an indication that the linear output decreased. This matching scheme is a relative one so that the additional spectrograph measurements discussed above are still needed.

Alignment of the sample path is critical and is done by adjusting the sample mirror to direct the HeNe beam into the spatial filter so as to be centered on the 101mm lens and to pass through the pinhole. When the Perkin Elmer filter is used, it must then be added as discussed in E. After the initial installation and testing, it proved necessary to add an extra ND1.0 to the GSFC ND3.0. Provision to tilt the GSFC ND3.0 had to be added due to damage to the HeNe expanding telescope.

V. Beam Splitting and Quantum Efficiency Enhancement

After passing through the spatial and spectral filters, the lunar return has to be processed in two ways. First, the light should strike the photocathode of the PMT at an angle such that one of the many current schemes of quantum efficiency enhancement by geometric means can be used. Second, the beam should be split in amplitude between two or more photomultipliers if the return signal approaches one photoelectron per laser firing in order to make use of all the information in the return pulse. Not only are large fluctuations expected due to the nature of the radiation and the lunar array, but the laser pulse will be several nanoseconds wide for the forseeable operation period. In such a case, a single discriminator would see only the first pulse of a doublet in time. By splitting the return, one makes the probability of using all the information in the return pulse much higher. Additional constraints on the processing after the filters appears in Appendix VIII.

Figure 5 shows the design chosen. A reflecting prism is used to split the beam and send it into an angle to the photocathodes of two PMT's. The prism can be slid horizontally along an axis perpendicular to the optical axis of the detector package. Two PMT's were used at times during acquisition. However, a single PMT was most commonly used. The prism movement allows either configuration to be easily used. No quantum efficiency enhancement device appears for several reasons. The primary reason is that the PMT comes with its curved face unpolished. One could have cemented a pancake to the face and used the common enhancement method, but RCA advised that the quantum efficiency probably could not be increased in this manner. The design shown in Figure 5 was therefore chosen until further work can be done at Maryland on this question. The author did notice while measuring the quantum efficiencies of these tubes that there did appear to be about a 10% increase in quantum efficiency for light striking the photocathodes at angles comparable to those in the detector package.

The prism used was an Edmund Scientific 60-Degree Spectroscope Prism. Again, a low cost coating was applied by Muffoletto Optical Company. The apex surfaces were given a durable 97% reflecting coating. A triangular prism was designed and ordered with similar coatings for use in case a three PMT detector package was required later in the project. Its specifications appear in Appendix VIII. If a large return signal is observed, one is more likely to reduce the laser output than to add a third PMT. Alignment of the prism is quite straightforward with either a HeNe beam or a starlight beam. In either case, the alignment should be done with the spectral filter out. One checks to see that the beam falls as desired on the prism apex surfaces. At the same time, one should check to see that the beam falls on the photocathode(s) correctly. This latter adjustment is made by sliding the PMT base in its holder along the axis of the package.

VI. Light and Heat Baffles

A. Light-Tightness of Detector Package

Care was taken in the construction of the detector package to provide recessed shoulders on most mating pieces of the package. Not all pieces were recessed due to the short schedule and the attention that had to be paid to the innards of the package. At McDonald, felt strips were added as backing to all pieces not so recessed and at other critical edges and corners. To protect the PMT from accidental movement of the slipon covers, an inner PMT chamber was provided. The detector package was then tested in a darkened room with the PMT at working voltage by directing a bright flashlight at each outside seam. No excess dark current was seen; not even with full room lights on. It is worth noting that a counter is always on to monitor the PMT dark current at all times the PMT is on. The insulation added to allow dry ice to be added to the PMT chamber degraded the light-tightness somewhat as discussed below and so care must be exercised to replace all sealing tapes and cloth whenever the package has to be opened.

B. Light Baffles

The light baffles used at the present time to restrict unwanted light from traveling along the package axis to the PMT after a number of reflections consist of those baffles in the GSFC optics, the detector package frontplate, the pinhole and its mount, and the centerplate. These are at present quite sufficient because no dark current increase is observed with room lights on either with the package shutter open or closed. In fact, the GSFC light baffles were too good and had to be opened up so that the return beam was not vignetted in the GSFC optics. With the filter/laser matching monitor installed, one may have to add baffles in both the GSFC optics and the detector package to prevent scattered laser light from reaching the PMT. Only trial and error will settle this question.

C. The Detector Package Shutter

In normal operation, the flip mirror in the GSFC optics will be out of the beam path and so serve as a shutter for the detector package. However, if one wants to monitor the laser/filter wavelength matching by sampling the output laser beam and to use this pulse to start the ranging electronics, one must insert a large attenuation in the sample path. Large amounts of light may be scattered in the GSFC optics so that attenuation placed only in the sample path may endanger the PMT. The attenuation is best placed at the entrance to the detector package in both sample and return beams. It must then be moved out of the beam to allow the lunar return to reach the PMT unattenuated. Such a shutter will also serve to protect the PMT whenever necessary. The shutter must be fast and controlled electrically to open and close at the proper time during the ranging cycle.

Severe space limitations at the frontplate made it mandatory that a flat, rotating shutter be used. Figure 10 gives a detailed view of the shutter. The front face has one concentric ridge that mates with a groove in the frontplate to make the shutter quite light-tight. The shutter is rotated by an air piston driven by a solenoid-controlled valve. The air piston is a Tiny Tim TF-RC-3/8 with positioner valves at both ends. The open and close air lines run to it inside the package from the solenoid assumbly. The solenoid assembly is an AirServ 22-001-001., 115 volt Double Solenoid Actuator and a 4-Way Valve Body Assembly. It is supplied with air from a compressed air line through a fitting in the left side of the detector package. There are two exhaust filter plugs at the same location. A REGO MINI-LINE filter, regulator, and lubricator is placed in the supply line right after the room tie-off. The pressure in the line is 60psi.

The shutter is switched on and off in synchronism with the GSFC flip mirror by signals from the Maryland interface logic. The logic is described in Maryland Technical Report #70-049. Drivers and power supplies were independently designed by Maryland and GSFC for the shutter and flip mirror respectively. At McDonald, it turned out to be more convenient to use one of the two drivers built by GSFC in conjunction with a 15 volt power supply built by Maryland to actuate the shutter solenoid. These devices are shown in Figure 9 below the Thermal Monitor Unit. Figure 11 is a schematic of the Maryland Driven Power Supply and certain detector package wiring details.

At present, the shutter and flip mirror operate on the six second cycle used with the Spacerays laser. Both are moved to the receive positions at about 1.75 seconds after laser firing for about one second. The Maryland shutter takes somewhat less than 100 milliseconds to respond to these commands as measured at 60 psi at Maryland before shipment. The performance of the GSFC flip mirror is described in a GSFC report and should be considered at such time as three second cycle operation is to begin. Maintenance of the Maryland shutter consists mainly in disassembly once a month for lubrication with MOLYKOTE dry lubricant. The air line filter should also be checked periodically and refilled with clean oil. There do remain some noise pickup problems from the laser which occasionally cause multiple openings of the shutter during a cycle. More careful grounding and shielding of the circuits involved should eliminate this minor problem.

The shutter attenuator used in the laser sampling system consisted of two ND4.0 neutral density filters mounted together in glass by Eastman Kodak. The filter was held to the back of the shutter by a suitable metal piece backed by gaskets. An ND1.0 gelatin filter was later added.

D. Heat Baffles

The heat baffles consist of insulation in the PMT chamber to keep the cold in and a heated window at the centerplate to prevent frosting of the optical components on either side of the centerplate. The PMT chamber was lined with 1/2 inch styrofoam except for the cutouts for PMT and beam-splitting prism. The chamber was sprayed with black paint and supplied with a styrofoam cover. To cool, pieces of dry ice were added to the chamber without direct contact with the PMT. Each charge was effective for about four hours and reduced PMT dark current by about a factor of ten. Closer contact to the PMT will probably reduce the dark current further, but care must be taken not to put stresses on the PMT envelope and pins. Some moisture did collect inside the chamber, but did so as ice adhering to the dry ice.

The heated window can be seen on the front side of the centerplate in Figure 5. Attached to it is the safety shutter which automatically closes whenever the front cover is removed. The window design is based on the 3 Å filter design. The piece of glass used is one that had been used in place of the 3 Å filter during initial temperature control tests. An aluminum disk wound with nichrome wire is used as the heater and holds the window against the centerplate. Insulating rings are used both between window and centerplate and between oven and the piece holding it to the centerplate. A thermistor is mounted in next to the glass in the same manner as is done with the filter. Channel 5 of the Thermal monitor is used for temperature monitor and control. The window temperature is kept at about 30°C. The connecting wires are brought out at the same point the wires to the Perkin Elmer filter are brought out. The window has been in operation for a month now and no sign of frosting has ever been seen.

VII PMT Mounts and Shielding

The PMT used in this experiment is an RCA 31000F. An evaluation of its sensitivity and single photoelectron counting properties are summarized in Section VIII. Its fast timing capabilities and details of the sensitivity and specific counting measurements appear in University of Maryland, Department of Physics and Astronomy Technical Report 958. The dark current in these tubes is a sensitive function of the cleanliness of the glass envelope and photocathode. RCA will apply a light and dirt shield to the back end of the tube on request. They claim that any ordinary treatment of this surface will only serve to increase the dark current. One PMT which came untreated was coated with Denkote Red Insulating Enamel #2X727 before electrostatic shielding, but RCA later advised against this procedure although the enamel was the second best enamel they had ever seen. It is extremely important to provide an electrostatic shield for the PMT to keep the dark current down and prolong the life of the tube. The tubes used in this experiment were shielded by wrapping the tube as it arrived with a double layer of aluminum foil. Connection was made between this shield and the cathode (which rides at the HV potential) by means of stranded hook-up wire which was frayed at the foil end and wrapped about the cathode pin at the other. The latter connection is not the best way to proceed (e.g. soldering the wire to a point inside the PMT base), but it is a very practical way if the PMT is to be removed frequently. One PMT has been in use for two months now with no degradation in performance.

The gain and counting efficiency also depends on stray magnetic fields in the vicinity of the PMT. Magnetic shielding of both soft and hard types was purchased and formed into a cylinder surrounding the tube.

A check of counting efficiency as a function of PMT orientation inside this shield was made and the shielding appeared entirely adequate. The magnetic shield was supported by annular felt strips glued to the outside of the PMT. Care was taken that the electrostatic shield had been well insulated with outer layers of 3M black electrical tape.

The PMT base used was an Ortec 270 suitably modified so that the required first dynode voltage was supplied. This base was held in a circular hole in the rear divider plate and projected back into the rear compartment. The electrostatic shield supplied with the PMT base was replaced with a shield made from fine copper screening to aid in keeping the base cool. It is most unfortunate that the Spacerays laser produces a very noisy trigger pulse on its ground and hence on the grounds of the whole system in spite of the insulation provisions on the GSFC mount. This noise thus rides on all shields that are grounded as well as on all cable grounds leaving the detector package. The PMT fits only into Ortec base and so is free to rotate about its axis as well as to translate along the optical axis of the detector package. During alignment, one should use the retro-reflected HeNe beam to adjust the PMT base so that the beam hits the photocathode in the right area.

VIII. Dark Current, Lunar Background, and Star Measurements

A. Dark Current

During the acquisition phase, background rates from the moon of up to 1 MHZ were expected and so high dark current rates were not particularly worrisome. PMT 1 (RCA 08132) had a typical dark current of 90 KHZ at its operating point and at room temperature. This dark current stayed relatively constant during the whole span of Table II and so it was inferred that the operating level of the PMT likewise stayed constant. The operating level of the PMT was determined by two methods which agreed with each other. First, provision was made to mount a light-emitting diode in the GSFC optics box so that light signals could be introduced into the detector package. The diode is an Electro Nuclear Laboratories Model 498 GalliumPhosphide diode with a peak emission wavelength of 6950 Å. The diode was easily driven by the Rutherford B16 pulser used to test the system ranging electronics. The driving pulse amplitude was adjusted so that about one light pulse in every ten was counted. Light could be sent through both spectral filters. It was often advisable to remove the spatial filter to shorten the alignment time of diode with PMT. The next adjustments were made on the Ortec 403A and 270 as described in their instruction manuals. Finally, the PMT high voltage was adjusted to yield a plateau in the count rate. Such a plateau was found for all PMT's, but at a rather high voltage (i.e. 3400 volts for PMT 1). Particular care must be taken in raising the PMT voltage to such a level; at least initially. The voltage should be raised from 2500 volts slowly over a period of days with a continuous check made on the dark current for any tube breakdowns which may start to occur. A high voltage breakdown will probably destroy the photocathode. PMT 1 behaved well during the whole period of

Table II up to the present. In fact, RCA had initially tested this particular tube at about 2900 volts. The pulser method of determining the single photoelectron level is in fact a prototype of one of the aids to calibrating the ranging electronics. More study of the light emission process in the diode is necessary, however, before it can be relied upon. The second method of determining the single photoelectron level is the conventional plateau determination using a steady light source which may be either a star or a light leak. Once again the PMT voltage is varied after base and discriminator optimization. PMT 1 has a plateau in the region of 3300 volts with 3400 volts selected as the working voltage. With the light leak method, high dark currents are often a hindrance. The pulsed light diode can be operated in a coincidence mode and so circumvents dark current problems (e.g. with the Ortec 437A TPHC). It should be noted that the low relative quantum efficiency of PMT 2 was first noted with the pulsed light source by substituting PMT's at a fixed light pulse level.

As lunar night approached, preparations were begun to cool the PMT. The PMT compartment was insulated and a heated window added as described above. A good charge of dry ice would last for about four hours and maintain a dark current of about 10KHZ in the situation where no direct contact was made between PMT and dry ice. Table III indicates that a further reduction in dark current is in order to about the 1KHZ level. Such a reduction can probably be made by making suitable contact between PMT and dry ice. However, before this contact is made, careful consideration must be given to possible stresses placed on the PMT envelope.

The PMT chosen for this experiment must satisfy the timing requirements of the ranging system as well as high quantum efficiency, high gain, and low noise. The RCA 31000F is the only PMT that presently approaches the requirements of this experiment. Evaluation of new PMT's and of different discrimination schemes with the 31000F's is now under way at Maryland. Detailed discussion of fast timing measurements as well as single photoelectron level determination and quantum efficiency measurements appear in University of Maryland Department of Physics and Astronomy Technical Report #958.

B. Lunar Background Measurements

The peak observed lunar rates obtained during lunar ranging runs are given in Table III. The rates are adjusted for the case of a 3 Å filter and a 6 second pinhole. The expected rate for this geometry according to IV A. above is about 1 MHZ. (Note that the rate in IV A was calculated for 3.8 seconds rather than the 6 actually used). The adjusted rates can be compared to the expected rate by dividing the adjusted rate by the receiver efficiency difference from that expected (i.e. about 0.25). Each entry in Table III is consistent with this expected rate except 28 July. The rate on this day may be an inadvertent entry of a background rate measured during earth day. All earth day measurements were omitted from Table III. Most earth day readings in the above geometry were about 600KHZ, but highly dependent on cloud conditions. It is very interesting to note that, at one sunrise, the atmosphere was so free of dust that the background rate remained surprisingly low until only a short time before the sun rose.

C. Star Measurements

Star photometry was done on every partially clear night to check the alignment of the system as described in IX. Table II lists those measurements. All rates are adjusted for operation with PMT1 at the single photoelectron level and the 3 Å filter. All star values were adjusted to that for Vega using the extensive star photometry data of Iriarte et al[4]. The interpretation of these star measurements as well as the lunar background measurements in terms of atmospheric conditions is given below in IX.

IX. Receiver Efficiency

Total receiver efficiency was optimized at about 0.4% for single photoelectron counting on 19 July. At that time, a counting rate of 714 KHZ was obtained using the 3 Å filter, the 9" aperture, PMT 1, and Alpha Lyra. PMT 1 was measured at McDonald to have a quantum efficiency of 5% at 6943 Å and was operated at about 90% counting efficiency. The 3 Å filter had a peak transmission of 55%. Code[3] quotes an absolute spectral intensity from Alpha Lyra at 5560 Å of 3.8×10^{-9} erg/cm^{2}sec Å. Using the measurements of Iriarte et al[4], this spectral intensity corresponds to one of 1.2×10^3 quanta/cm^2 sec Å at about 7000 Å. If one chooses 4.6×10^4 cm^2 as the collecting area of the 107", then one expects 5.5×10^7 quanta/sec Å in the star image for the no-loss case. The total receiver efficiency must then be the 0.4% quoted above. The losses are due to the 90% PMT collection efficiency, the 5% quantum efficiency, the 55% filter transmission, the 97% prism reflectivity, the 94% transmission in the spatial filter, and the resultant 18% transmission of the 107" telescope, the special injection optics, and the GSFC optics. This latter transmission will be discussed in a separate report by D. Currie. The assumption of 90% transmission each for the four telescope elements, the three elements of the injection optics, and the three GSFC optics elements yields a resultant transmission of 35% which is a factor of two greater than the number quoted above.

The period of 10 July to 18 July was the time of the great efficiency chase. Table II indicates that the initial peak observed counting rate was only 36 KHZ. During the chase almost every element in the system was

[3] Code, A.D., Stars and Stellar Systems, Vol. VI, P. 50, J. Greenstein (edit) University of Chicago Press, Chicago, (1960).

[4] Iriarte, Johnson, Mitchell, and Wisniewski, Sky and Telescope, p21 (July 65)

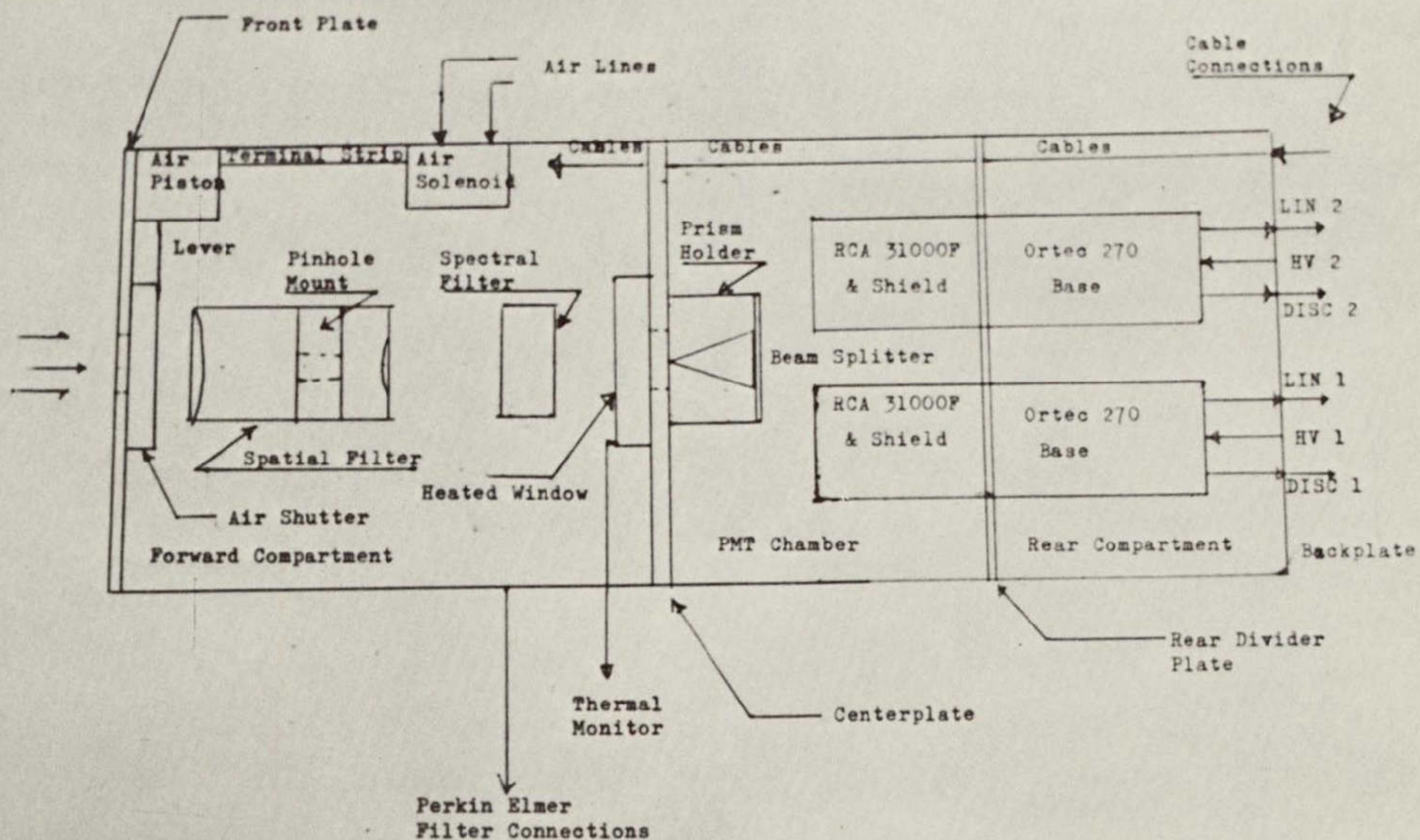
checked and adjusted. PMT 2 was found to have 1/2 the efficiency of PMT 1. PMT 1 was found to have an efficiency 1/2 of that quoted by RCA. Transmissions of each element were measured and will be described by D. Currie in a separate report. H. Richardson and the author checked the entire receiving system for vignetting and misalignment. The position of the concave lens that matches the laser into the telescope was adjusted to produce a parallel return beam from a star. This adjustment reduced the vignetting in the GSFC optics which was then eliminated by enlarging several apertures in that box of optics. The concave lens was then located with its mount base in the first bench hole, its mount at 57.84 along the beam axis, 22.20 in height, and 29.6 along the horizontal perpendicular to the beam axis. The telescope focal length was 0170360. It was also at this time that a 6" aperture was chosen for use in the detector package. Finally, the GSFC flip mirror appeared at times to have a different rest position in manual open than in automatic open. This happening is the reason why the detector package alignment should be checked each time with the mirror flipping.

Table II gives the star photometry record for every partially clear night of operation from 10 July to 4 September. These were taken as a check on system alignment. The peak observed rates quoted are the peak rates observed as the star image is moved over the detector aperture. Such movements check the coincidence of the HeNe spot, the ruby spot, and the pinhole. These spots were always within a few seconds of each other. Changes in the absolute rates above that expected because of filter changes are not expected to be due to detector package misalignment. Detector package alignment was quite stable and reproducible using the HeNe laser. The adjusted rates in Table II are a direct indication of the atmospheric transmission and seeing on the nights of the measurements. The adjusted rates are the peak observed rates adjusted for change of filter, change of PMT, and change of star. The data in Iriarte[4] was used to adjust for changes in star selections. The PMT counting level was monitored each night by recording the dark current rate and each month observing the count rate from a star as a function of PMT gain. Slight changes in level were noted by both methods and were traced to discriminator level changes. Table II indicates that the adjusted rates did recover to near their values at the beginning of July and therefore that the rate changes were not due to a monotonic decrease in any element efficiency. However, changes in element alignment were made as discussed by D. Currie. Although these changes are not expected to cause loss of receiver efficiency, the observed lunar rates presented in Table III are somewhat perplexing. They indicate that a large part of the loss of efficiency for certain days is due to poor atmospheric transmission since poor seeing is not expected to reduce the observed lunar rate. Drifting clouds and halo phenomena were observed on a number of these nights. Direct evidence for poor seeing does exist on the nights of 28 July and 18, 20, and 22 August when the apertures were changed. A 40% loss in efficiency due to seeing was observed on 28 July.

Figure Captions

Table Captions

FIGURE 1 : Schematic Diagram of Detector Package (not to scale)



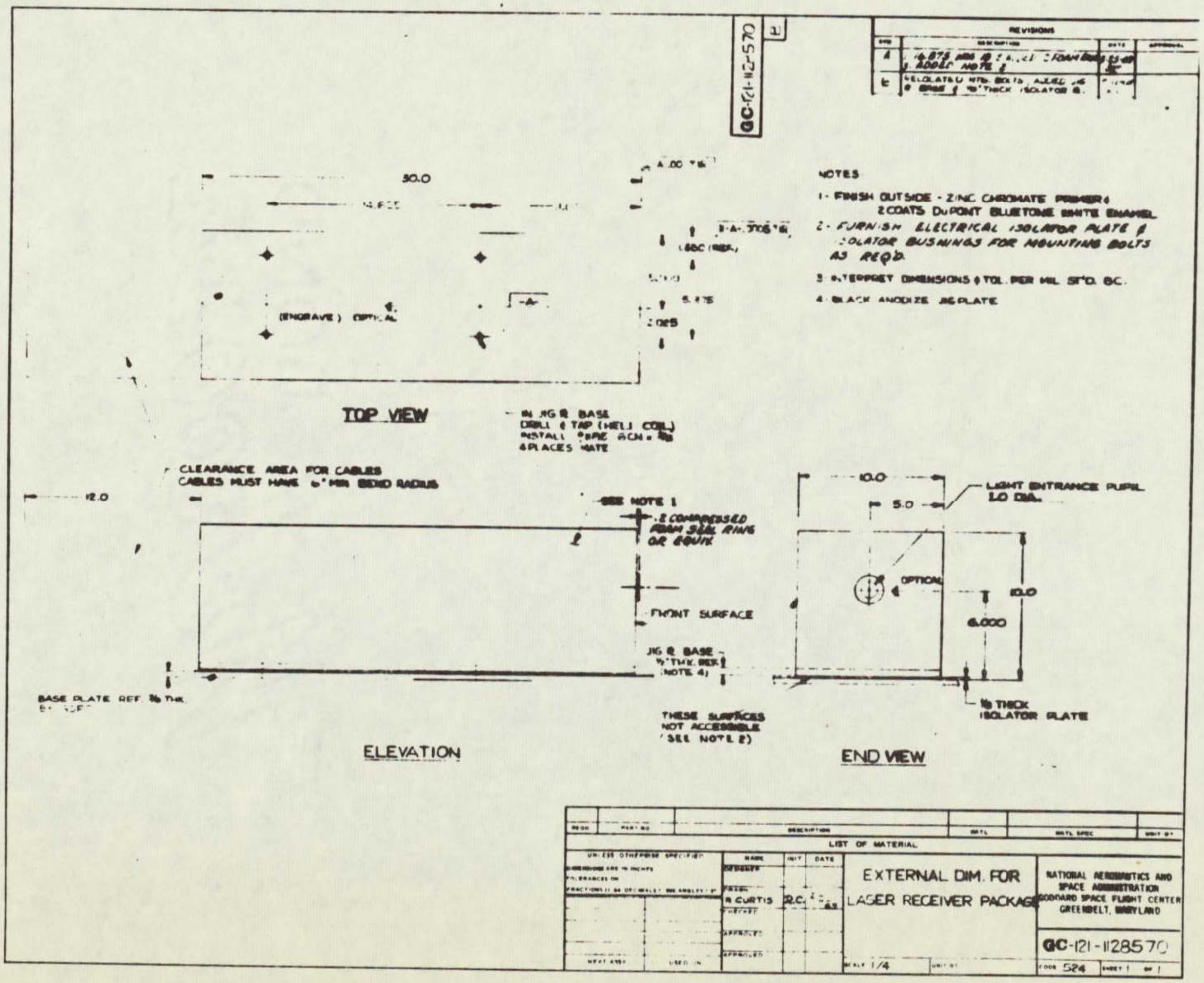

REVISIONS
GC-121-1128570
NOTES
1- FINISH OUTSIDE - ZINC CHROMATE PRIMER & 2COATS DuPONT BLUETONE WHITE ENAMEL
2- FURNISH ELECTRICAL ISOLATOR PLATE & ISOLATOR BUSHINGS FOR MOUNTING BOLTS AS REQ'D.
3- INTERPRET DIMENSIONS & TOL. PER MIL STD. 8C.
4- BLACK ANODIZE JIG PLATE
30.0
(ENGRAVE) OPTICAL
TOP VIEW
CLEARANCE AREA FOR CABLES
CABLES MUST HAVE 6" MIN BEND RADIUS
12.0
SEE NOTE 1
.2 COMPRESSED FOAM SEAL RING OR EQUIV.
FRONT SURFACE
JIG PL BASE
(NOTE 4)
BASE PLATE REF
THESE SURFACES NOT ACCESSIBLE (SEE NOTE 2)
ELEVATION
10.0
5.0
LIGHT ENTRANCE PUPIL 1.0 DIA.
OPTICAL
10.0
6.000
1/8 THICK ISOLATOR PLATE
END VIEW
LIST OF MATERIAL
R CURTIS
EXTERNAL DIM. FOR LASER RECEIVER PACKAGE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND
GC-121-1128570
SCALE 1/4
CODE 524

FIGURE 2

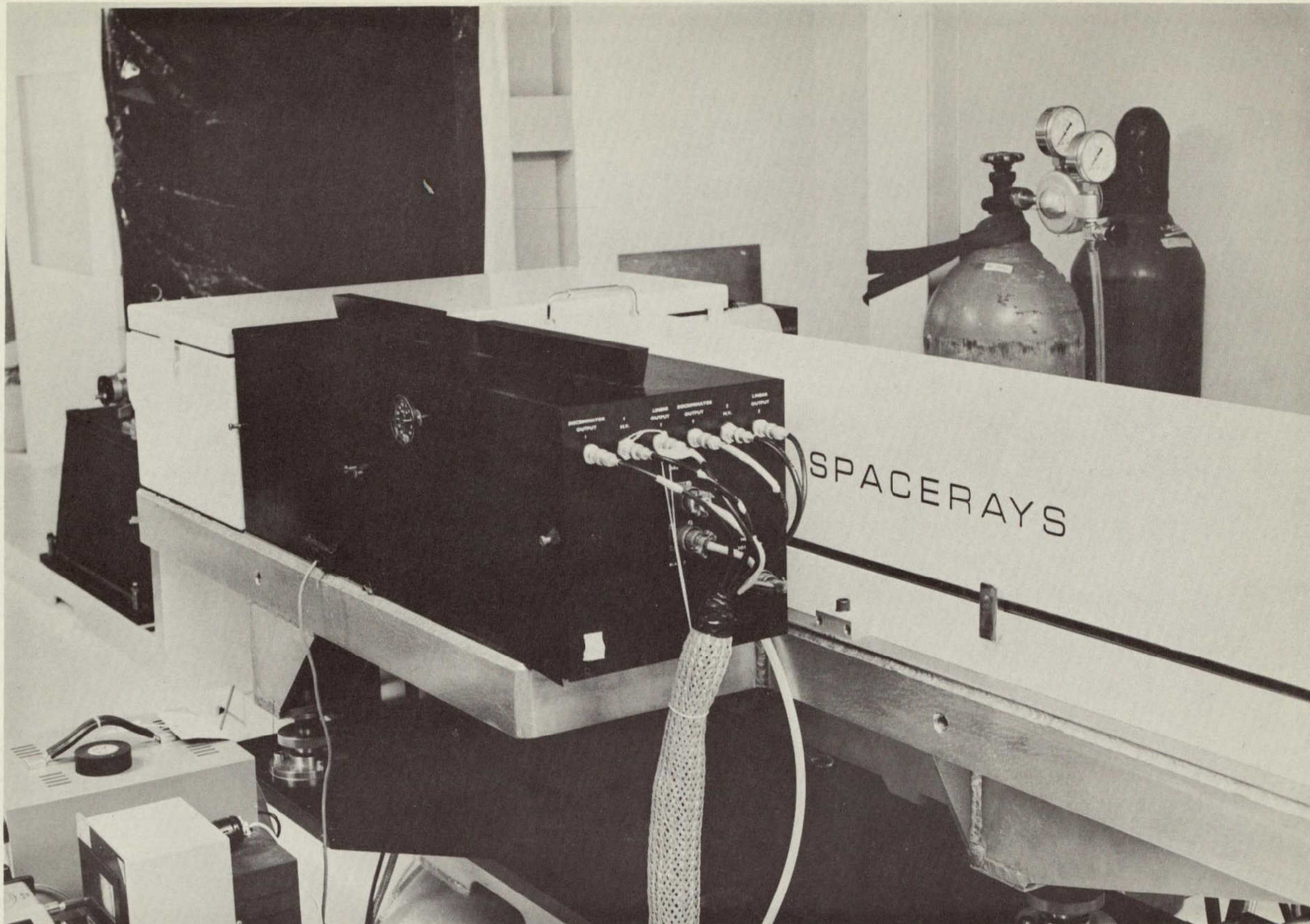
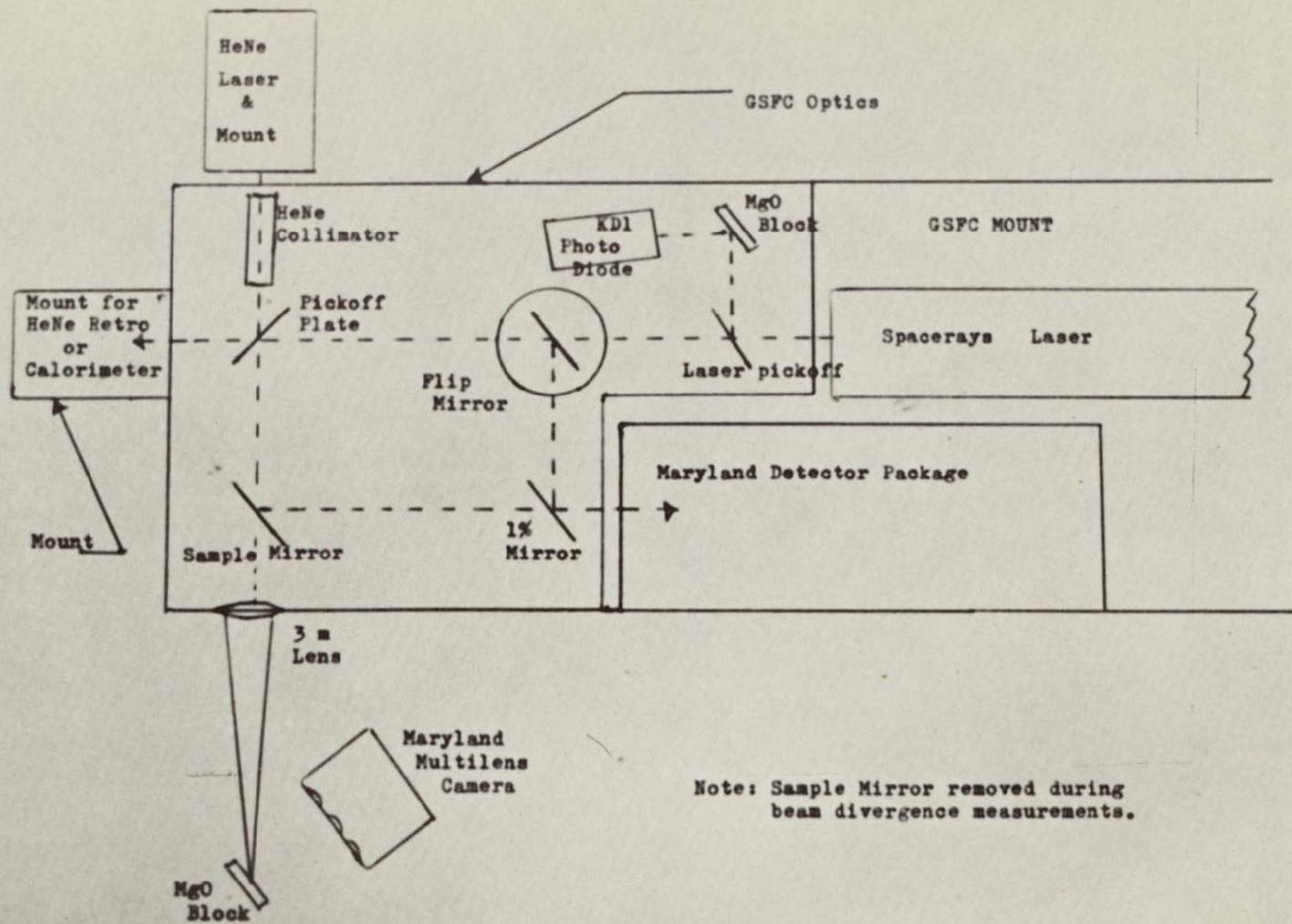


FIGURE 3

FIGURE 4 : GSFC Mount With GSFC Optics, Spacerays Laser, and Maryland Detector Package With Maryland Beam Divergence Modification (not to scale)



Note: Sample Mirror removed during beam divergence measurements.

9

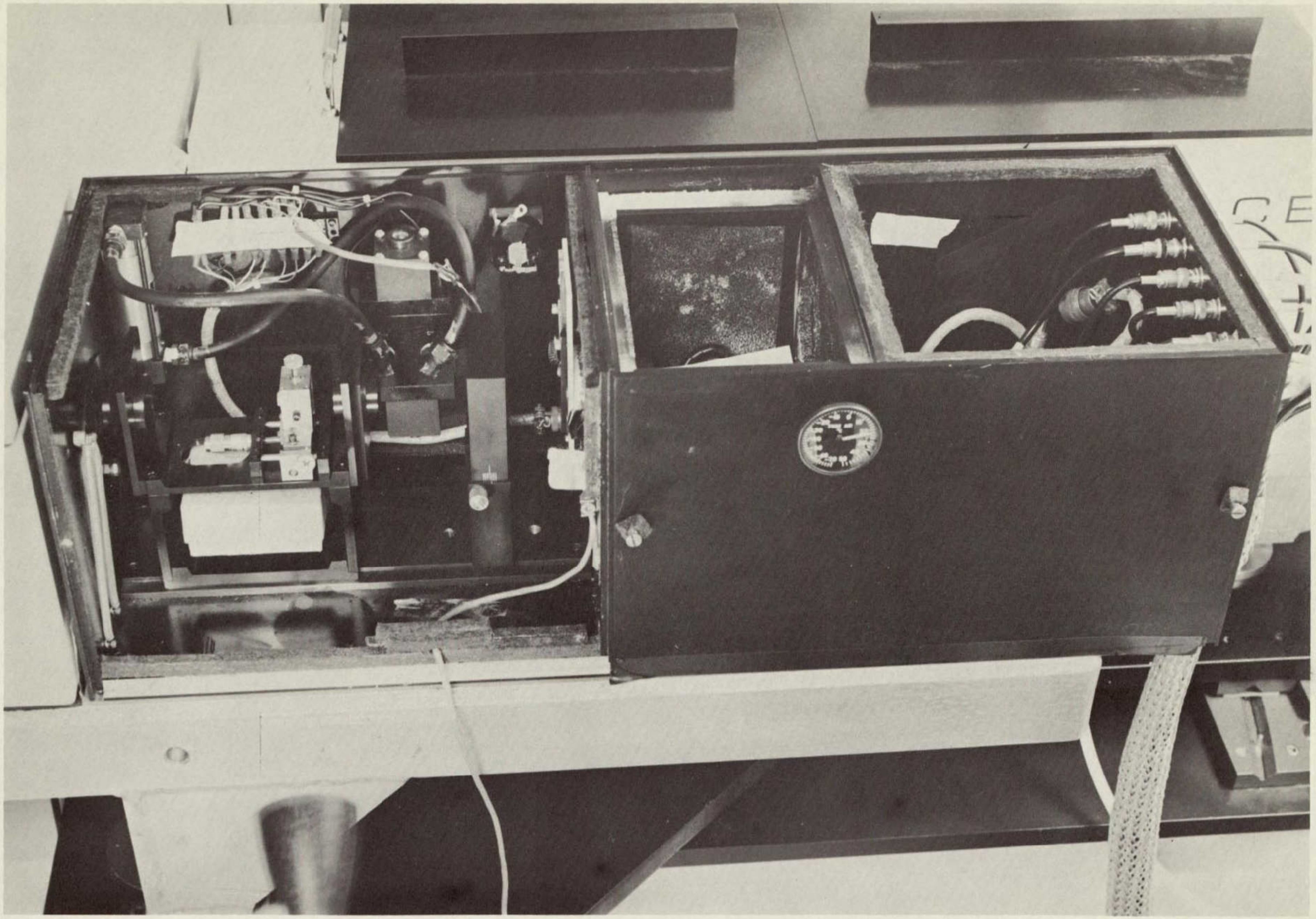


FIGURE 5

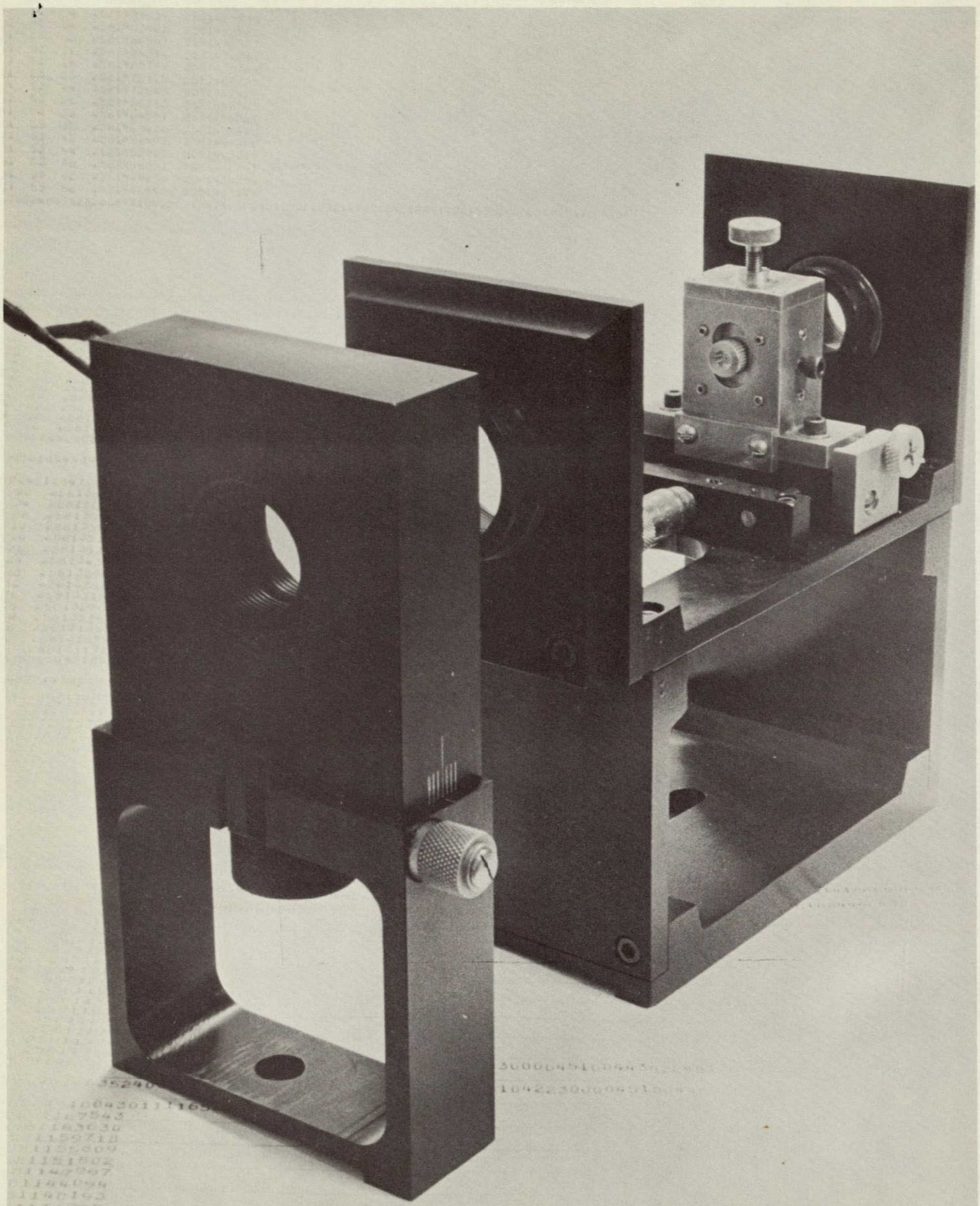


FIGURE 6

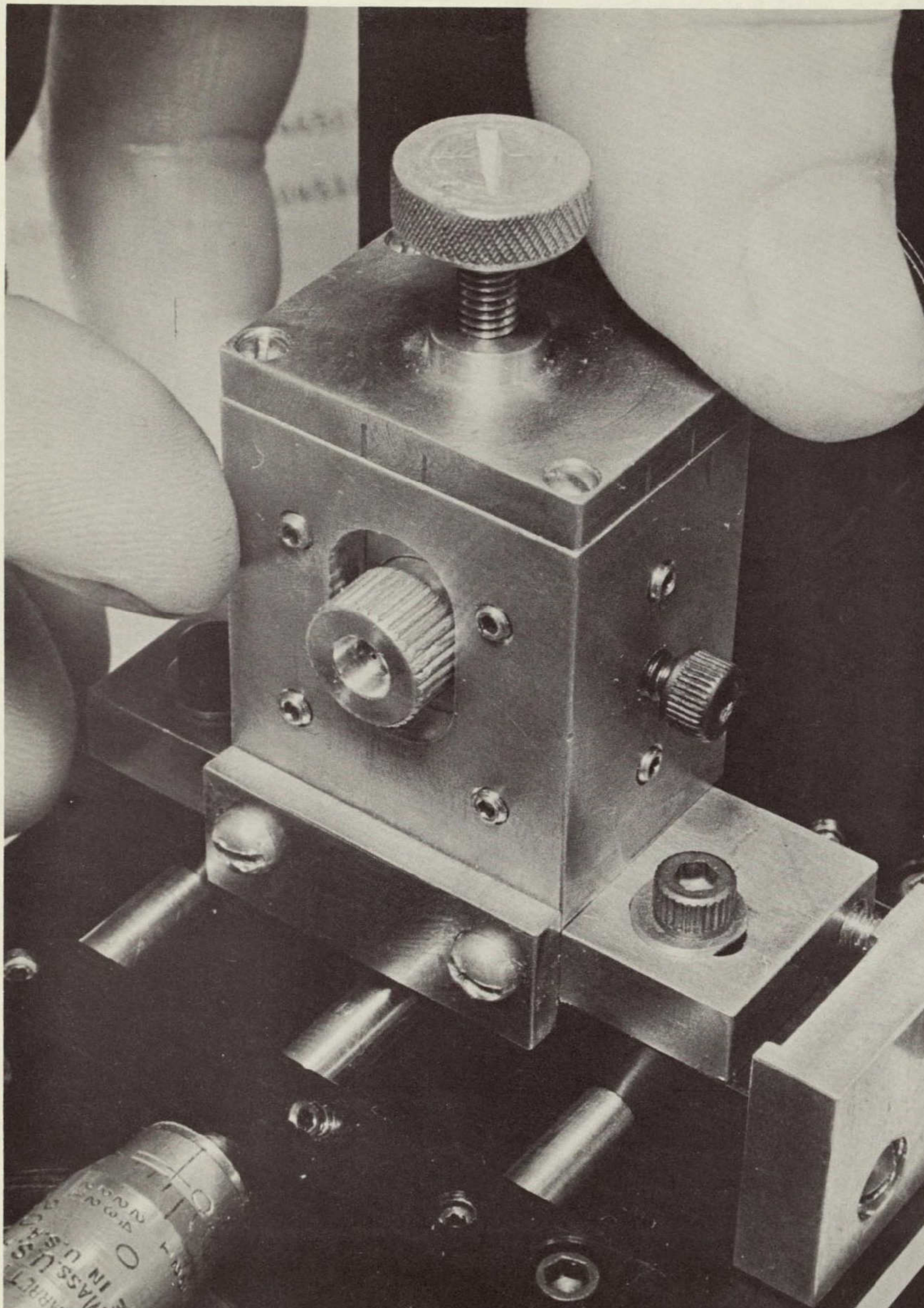


FIGURE 7

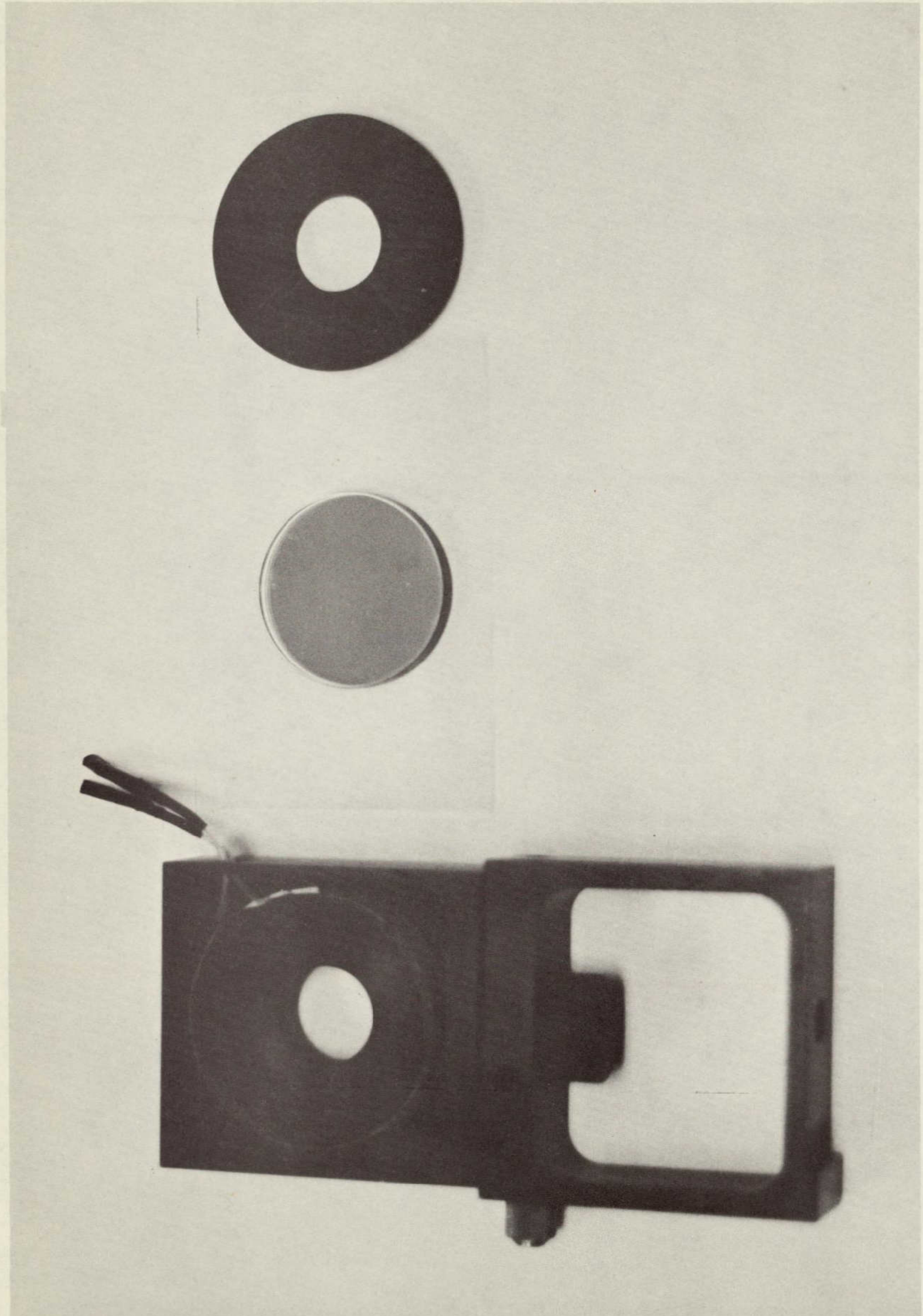
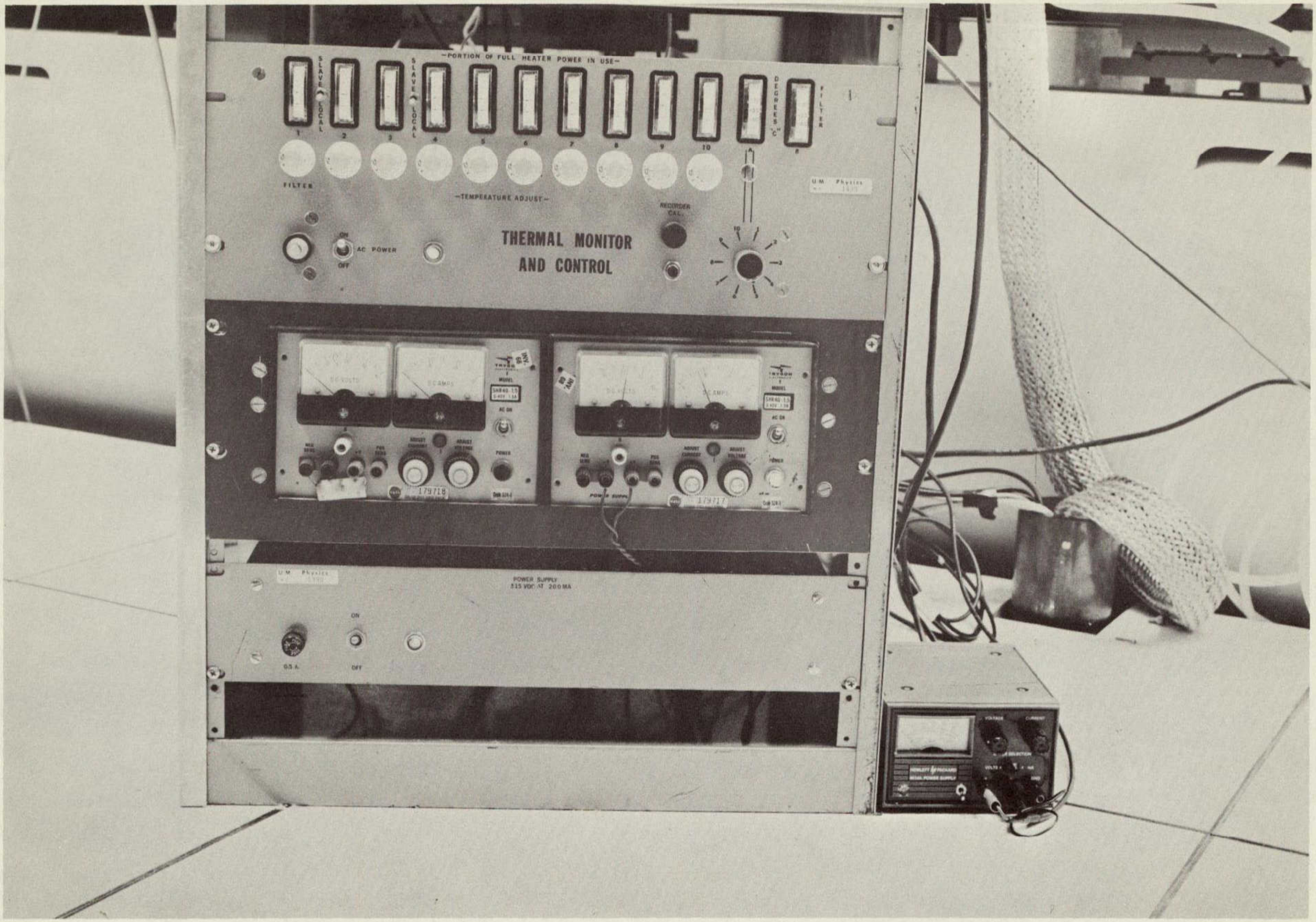


FIGURE 8



PORTION OF FULL HEATER POWER IN USE
FILTER
TEMPERATURE ADJUST
RECORDER CAL.
THERMAL MONITOR
AND CONTROL
ON
AC POWER
OFF
POWER SUPPLY
315 VDC AT 200 MA

FIGURE 9

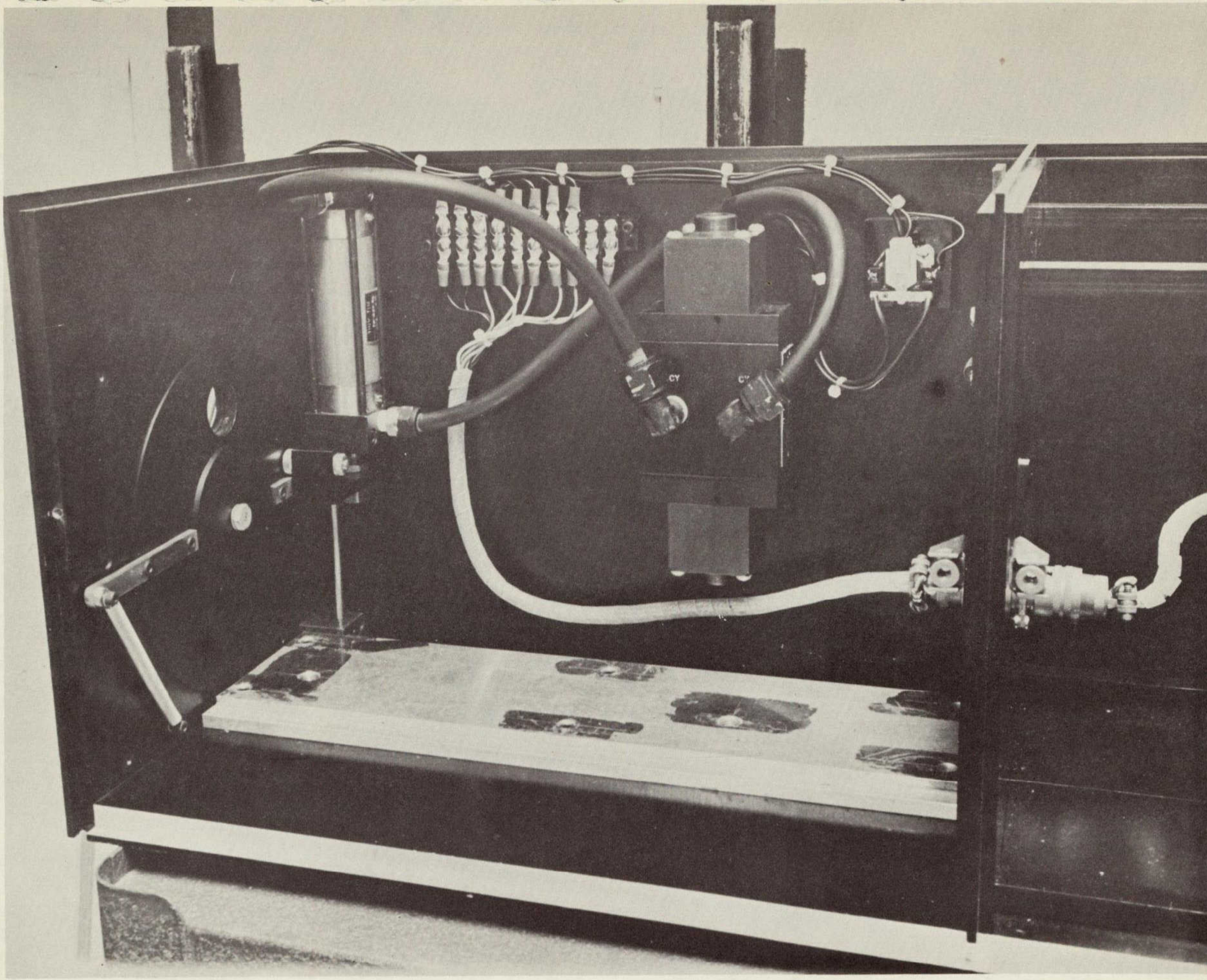


FIGURE 10

TABLE: I : Laser Wavelength Measurements

Date	Temperature	Wavelength	Strength	Plate #	Remarks
11 July	61.5°F	6942.89	weak	9	single shot
		6942.82	weak		
		6942.73	medium		
		6942.39	strong		
		6942.08	very weak		
11 July	62.5°F	6943.21	very weak	9	10 shots
		6942.89	strong		
		6942.72	medium		
		6942.42	very strong		
11 July	60.5	6942.89	medium strong	9	20th through 30th shots
		6942.71	medium strong		
		6942.40	strong		
11 July	58°F	6942.39	strong	10	single shot
**		6942.11	weak		
11 July	59	6942.87	medium	10	ten shots
		6942.70	weak		
		6942.39	strong		
		6942.10	very weak		
11 July	59.5	6942.88	medium	10	10 shots
		6942.80	very weak		
		6942.69	weak		
		6942.39	strong		
11 July	59.5	6942.87	medium weak	10	20th through 30th shots
		6942.69	weak		
		6942.39	strong		
		6942.09	weak		

TABLE I : Laser Wavelength Measurements (cont)

Date	Temperature	Wavelength	Strength	Plate #	Remarks
19 July	70° F	6943.2 6942.7 6942.3	weak strong very weak		single shot
19 July	71.5	6943.2 6942.7	strong strong		15th shot
19 July	71.5	6943.2 6942.7	strong strong		16th through 20th shot

TABLE II : Star Photometry Record

Date	Config	Star	ObsRate	Corr Fact	Adj Rate	Remarks
10 July	3A, 6", PMT2	A LYR	36 KHZ	2 x 1/1	72 KHZ	
13 July	3A, 6", PMT2	A LYR	190 KHZ	2 x 1/1	380 KHZ	
15 July	3A, 6", PMT2	A LYR	300 KHZ	2 x 1/1	600 KHZ	
16 July	10A, 6", PMT2	A LYR	1.2 KHZ	2 x 1/4 /1	600 KHZ	T10A = 4 x T3A
16 July	3A, 9", PMT2	A BOO	700 KHZ	2 x 1/2.7	520 KHZ	A BOO = 2.7 x A LYR
18 July	3A, 9", PMT2	A LYR	360 KHZ	2 x 1/1	720 KHZ	Best tele + optics align
19 July	3A, 9", PMT1	A LYR	714 KHZ	1 x 1/1	714 KHZ	PMT 1 = 2 x PMT 2
20 July	.7A, 9", PMT1	A BOO	300 KHZ	1 x 4/2.7	445 KHZ	
21 July	.7A, 9", PMT1	A BOO	340 KHZ	1 x 4/2.7	500 KHZ	T3A = 4 x T .7A
23 July	.7A, 9", PMT1	A BOO	340 KHZ	1 x 4/2.7	500 KHZ	
23 July	3A, 6", PMT1	A SCO	340 KHZ	1 x 1/1.8	190 KHZ	A SCO = 1.8 A LYR
24 July	3A, 6", PMT1,2	A SCO	430 KHZ	1 x 1/1.8	240 KHZ	
25 July	3A, 6", PMT1	A SCO	340 to 530	1 x 1/1.8	295 KHZ	
26 July	3A, 6", PMT1	A LYR	250 KHZ	1 x 1/1	250 KHZ	
28 July	3A, 6", PMT1	A LYR	230 to 290	1 x 1/1	290 KHZ	made within 15 min
28 July	3A, 9", PMT1	A LYR	500 KHZ	1 x 1/1	500 KHZ	
29 July	.7A, 6", PMT1	A LYR	45 KHZ	1 x 4/1	185 KHZ	
30 July	.7A, 6", PMT1	A LYR	35 KHZ	1 x 4/1	140 KHZ	
31 July	.7A, 6", PMT1	A LYR	56 to 64	1 x 4/1	256 KHZ	
2 Aug	.7A, 6", PMT1	A LYR	50 KHZ	1 x 4/1	200 KHZ	

TABLE II. (cont)

6 Aug						
7 Aug						
16 Aug	.7A, 6", PMT1	A LYR	65 KHZ	1 x 4/1	260 KHZ	
17 Aug	.7A, 6", PMT1	A LYR	107 KHZ	1 x 4/1	428 KHZ	best seeing, same align as 16 Aug
18 Aug	.7A, 6", PMT1	A LYR	100 KHZ	1 x 4/1	400 KHZ	
18 Aug	.7A, 9", PMT1	A LYR	109 KHZ	1 x 4/1	436 KHZ	exchange done within 10 min
18 Aug	.7A, 6", PMT1	A LYR	93 KHZ	1 x 4/1	372 KHZ	some hi ci
19 Aug	.7A, 6", PMT1	A LYR	115 KHZ	1 x 4/1	460 KHZ	same align as 16 Aug
20 Aug	3A, 6", PMT1	A LYR	564 KHZ	1 x 1/1	564 KHZ	
20 Aug	3A, 6", PMT1	A SCO	690 KHZ	1 x 1/1.8	380 KHZ	
20 Aug	3A, 6", PMT1	A SCO	774 KHZ	1 x 1/1.8	430 KHZ	made within 15 min (1 sec integration)
20 Aug	3A, 6", PMT1	A SCO	800 KHZ	1 x 1/1.8	445 KHZ	
22 Aug	3A, 6", PMT1	A LYR	410 KHZ	1 x 1/1	410 KHZ	after seeing got bad
22 Aug	3A, 9", PMT1	A LYR	510 KHZ	1 x 1/1	510 KHZ	sec. int.
24 Aug	.7A, 6", PMT1	A AQL	65 KHZ	1 x 4/0.45	580 KHZ	
3 Sept	3A, 6", PMT1	A TAU	680 KHZ	1 x 1/1.5	460 KHZ	at run end, sun coming up
4 Sept	3A, 6", PMT1	B AND	340 KHZ	1 x 1/05	680 KHZ	at begin run 3 A.M.
11 Sept	.7A, 6", PMT1	109 Herc	180 KHZ ?	1 x 4/0.67	1,080 KHZ	count uncertain

Notes: No air mass correct. 1% system #3A on A LYR = 1.5 MHZ. T3A = 4xT.7A checks int and ext.
Star red ratios from Johnson, Sky and Telescope July 1965

TABLE III: Lunar Background Measurements in the Vicinity of Site 2

Date	Config	Peak Obs Rate	Corr Fact	Adj Rate	Remarks
18 July	3A, 9", PMT1	3 KHZ	1x0.45	1.3 KHZ	Site 2 Dark
19 July	3A, 9", PMT1	30 KHZ	1x0.45	9.0 KHZ	Drifting clouds, Low
20 July	.7A, 9", PMT1	70 KHZ	4x0.45	126 KHZ	Clouds
21 July	.7A, 9", PMT1	80 KHZ	4x0.45	144 KHZ	Trans. Fluct.
23 July	.7A, 9", PMT1	110 KHZ	4x0.45	198 KHZ	
23 July	3A, 6", PMT1	70 KHZ	1 x 1	70 KHZ	Low
24 July	3A, 6", PMT1&2	100 KHZ	1 x 1	100 KHZ	Cirrus
25 July	3A, 6", PMT1	109 KHZ	1 x 1	109 KHZ	35 KHZ low
28 July	3A, 9", PMT1	1.8 MHZ	1x0.45	810 KHZ	
29 July	.7A, 6", PMT1	30 KHZ	4 x 1	120 KHZ	
31 July	.7A, 6", PMT1	36 KHZ	4 x 1	144 KHZ	
2 Aug	.7A, 6", PMT1	44 KHZ	4 x 1	156 KHZ	40 KHZ low
17 Aug	.7A, 6", PMT1	2 KHZ	4 x 1	8 KHZ	
19 Aug	.7A, 6", PMT1	30 KHZ	4 x 1	120 KHZ	
20 Aug	3A, 6", PMT1	200 KHZ	1 x 1	200 KHZ	
22 Aug	3A, 6", PMT1	300 KHZ	1 x 1	300 KHZ	
24 Aug	.7A, 6", PMT1	90 KHZ	4 x 1	360 KHZ	

TABLE III. (cont)

3 Sept	3A, 6", PMT1	1.5 KHZ	1 x 1	1.5 KHZ
4 Sept	3A, 6", PMT1	---	---	---

Appendices

APPENDIX I.

BEAM DIVERGENCE MEASUREMENTS OF THE SPACERAYS LASER

Appendix I.

Beam Divergence Measurements of the Spacerays Laser

Beam divergence measurements were made on the Spacerays laser at three different locations. At Spacerays at the end of May, at Goddard Space Flight Center on June 24 (oscillator only), and at McDonald Observatory on and after August 4. The measurements were made as described by Winer[1] using beam pickoff, focusing lens, MgO diffusing block, multilens camera, and Polaroid 55B film. GSFC had been requested to supply these components mounted (or mountable) on the GSFC mount for convenient measurements of the Spacerays beam divergence. These components had not arrived as of August 4 so the beam divergence modifications to the GSFC optics shown in Figure 4 were made. The fixed mirror was moved aside so that the laser light picked off for laser/filter matching passed through a hole punched in the GSFC optics box. A long focal length (2.8m) spectacle lens was mounted at the hole opening with the convex side towards the laser. The back side of a Polaroid print was used as the diffuser in the lens focal plane. The multilens camera was placed at 45^{o} to the laser beam and focused on the diffuser. The diffuser-plane normal split the 45^{o}. The multilens camera was assembled from a multilens plate built at Maryland and a Speed Graphic Press Camera.

Measurements at all three locations were made by the author with equipment similar to that described above. The Maryland multilens board was designed and built at Maryland immediately after discussions with I. Winer about his idea and before his publication. It was designed for use with a Speed View Graphic Studio Camera and has been used extensively for the last three years. The only addition to the design was a red filter which aided measurements in rooms with stray light. The multilens camera is shutterless. The Maryland design allowed one to use the expensive camera for all its regular applications as well as the beam divergence measurements.

The 55B negatives were analyzed as described by Winer. At Spacerays, measurements at 12 joule Q-switched indicated a beam divergence of 2.5 milliradians full-width, 90% energy. An extended-run evaluation could not then be made due to breakdown in the laser equipment. The laser was then shipped to GSFC for their acceptance tests. The author did not approve of the tests as proposed and executed at GSFC and so did not attend the tests. However, time was kindly made available for some independent study. The spectral behaviour and beam divergence of the laser were studied at that time. The beam divergence measurements were made on only the oscillator/beam expander part of the laser due to amplifier breakdown and time priorities. Measurements at the 2.8 joule Q-switched level indicated a beam divergence of 3.4 milliradians full-angle, 90% energy. At McDonald, measurements at the 7 joule Q-switched level typical of daily operations there indicated a beam divergence of 2.4 milliradians full-width, 90% energy. It should be noted that the beam expanding telescope was set for minimum beam divergence on the first and last measurements by J. Griffin of Spacerays and was set in a less favorable position at GSFC. Measurements at GSFC and at McDonald were done after the laser temperature had reached an equilibrium value.

[1] Winer, Appl. Optics. 5, 1437. (Sept 1966)

APPENDIX II.

BRIGHT MOON SPECTRAL RADIANCE AT 6943 Å

UNIVERSITY OF MARYLAND

Department of Physics and Astronomy

INTRAMURAL

To: C. O. Alley

From: Sherman K. Poultney

Subject: Moon Radiometry -- 20 January 1967 (about half moon) $N_{BM}=1.6\text{x}10^{12}\ \frac{\text{photons}}{\text{ster cm}^2\ 10\text{Å sec}}$

Date: January 23, 1967

1. Attempted to calibrate system on the point source Polaris, but could not find it in the twilight and high cirrus.
   Dark Noise = 180 counts/second
   Sky Noise = 77 counts/second - $2\text{x}10^{8}\ \frac{\text{photons}}{\text{ster cm}^2\ 10\text{Å sec}}$

2. System constants

Amplifier Gain	= 64
Tube Voltage	= 1500v
Discriminator	= 100 millivolts
Field of view (1/2)	= 1.4 milliradians
Receiving Area (20")	= 2020 cm^2
Filter	10Å wide at 6943Å

3. Moon Rates
   Neutral Density Filter (10^{-3})
   Dark Noise = 128 counts/second
   Sky Noise Not seen
   Counting Units 256
   Counting Period 10 seconds
   Read-out Interval 3 seconds
   Time 7:36 p.m.

Counting Rates
5,5,6,6,7,116,121,131,95,64,30,9,6,5,5

Multiplication factor = $2.52\text{x}10^{9}\ \frac{\text{photons}}{\text{counts ster cm}^2\ 10\text{Å sec}}$
(assuming tube and telescope efficiency 0.01)

Peak Moon Rate = $3.3\text{x}10^{11}\ \frac{\text{photons}}{\text{ster cm}^2\ 10\text{Å sec}}$

4. Expected Moon Rate

   Ackerman (measured center crescent) - 3.8 to $34\text{x}10^{10}\ \frac{\text{photons}}{\text{ster cm}^2\ 10\text{Å sec}}$

   Orszag (quoted for dernier quartier) = $1.6\text{x}10^{12}\ \frac{\text{photons}}{\text{ster cm}^2\ 10\text{Å sec}}$

Allen (Astrophysical Quantities) =

Our Quote (Moon Proposal) = 1.5×10^{13} $\frac{\text{photons}}{\text{ster cm}^2 \ 10\text{Å sec}}$

5. Cloud Scatter or Telescope Scatter
Counting Rates without ND 3.0 after Moon Had Passed
694,652,656,546,450,372,306,253,208,
170,138,116,97,83,74,66,60,54,
48,44,40,38,34,32,29,27,
25,-,20,20,19,19,28,72,105,
110,98,61,24,13,15,34,30,
23,15,11,11,10,10

Initial Night Sky Rate (again achieved) = 77 counts/sec

6. Expected Night Sky Noise

Allen (Astrophysical Quantities) = 6.5×10^{6} $\frac{\text{photons}}{\text{cm}^2 \text{ ster sec } 10\text{Å}}$

7. We must conclude that the high cirrus scattered much of the moonlight because dark shy noise is up by a factor of thirty. The atmospheric transmission is not known although it is unlikely that it is below about 50%.

February 28, 1967

8. Calibration on Polaris and subsequent quantum efficiency measurements on photomultiplier tube show that system efficiency is four to five lower than quoted above. Thus

Peak Moon Rate = 1.6×10^{12} $\frac{\text{photon}}{\text{ster cm}^2 \ 10\text{Å sec}}$

9. Eric quotes $\alpha\ \varepsilon\ T = 5\times10^{-4} \pm 0.2\times10^{-4}$ (9 March 1967)

6×10^{12}

January 1, 1969

10. Silverberg

One day before full

6.6×10^{10} $\frac{\text{photon}}{\text{ster cm}^2 \ 10\text{Å sec}}$

$\pm$ 3.0

APPENDIX III.

CONSIDERATIONS OF ACQUISITION DURING LUNAR DAY

UNIVERSITY OF MARYLAND
Department of Physics and Astronomy

INTRAMURAL

To: C. O. Alley

From: S.K. Poultney

Subject: Interim "Interim Station"

Date: January 27, 1969

Here follow some suggestions for the interim "interim station" if we are forced to it. The simplest means which use present equipment are sought.

1. Range Prediction

Let us assume that the range of the reflector can be predicted to ±1 Km. If one observes the moon near minimum range (i.e. at zenith meridian), a pre-calculated print-out with ranges listed every three minutes is sufficient to allow manual pre-setting of the range-gate counter. Acquisition in telescope field of view and laser priming can be accomplished ahead of time. At one hour before or after minimum range, the range rate is 0.1 Km/sec. Such a rate begins to make it difficult to fire the laser manually at the right time.

One method would be to have the range dialer crank in the range for the next second in time and then open a gate which allows that next second pulse from a 60 Hz audio generator fire the Pockel cell of the ready laser. The dialer would work modulo three seconds to correspond to the laser firing rate (20 pps). If the dialer cannot crank in the entire range in this time period, the process of determining the certainty of detection is increased.

2. Time of Firing

Near range minimum, the time of firing need be known only to a second or two which can be obtained from synchronized wall clocks. The pre-calculated printout will also list the time of each range prediction. Away from range minimum, the 1 pps gated clock would be needed to fire correctly.

3. Range-Gate and Data Display

A range uncertainty of ±1 Km requires a range gate of about 10 μsec. A preset counter with microsecond accuracy and total count of 3 seconds would be adequate to trigger an oscilloscope at the correct time. Our HP 5245L counter with our HP5264A preset unit is capable of 100 microsecond accuracy with a preset range of three seconds. An additional auxiliary oscillator giving a 33 KHz output would increase the accuracy to 30 microseconds.

The oscilloscope trace would be 10 microseconds per cm and the trace would be recorded on film. The TEK 564 storage oscilloscope would be quite useful. One would choose the load resistor to be such as to maximize the signal voltage and width to make it observable on the oscilloscope limited only by background noise and an upper limit of about 1 microsecond.

High background noise would force a narrower range gate than would otherwise be chosen. Assuming that the geometry of the receiver and the sensitivity of the detector (10 Å filter and 10% efficiency) is the same as in the original proposals and supplements, noise rates of 15 x 10^6 photoelectrons per second can be expected at bright moon (worse case). This rate means 15 noise photoelectrons per microsecond. If the return signal is not greater than 15 photoelectrons per shot, the range gate must be shortened and hence a better preset counter (or delay generator) will be needed. The best our present equipment could do is to cut the noise to about 5 photoelectrons per 0.3 microsecond resolution element on the oscilloscope. However, if the range cannot be predicted to better than ±1 Km, a better preset counter will not help.

Narrower filters would help cut the noise also, but at the cost of controlling their temperature so that their pass-band would coincide with the laser line. A filter with a 3 Å pass-band at the correct wavelength might just get by without such control, but we would have to buy it.

Ranging at a rate faster than 3 pps will require the use of several oscilloscopes if a Polaroid film readout is desired of each firing. One additional oscilloscope will be assumed to have an electronic film - advance.

4. Detector Package

A detector package must be made that will fit on the receiving telescope. A flip mirror will serve to protect the PMT from the a laser burst. Standard Ortec bases (that we have) can be used with an RCA 8575 to do the detection. The analog PMT signal would be displayed. Dead-time is not a problem.

5. Laser and Transmitter

The laser must be mounted so as to fire through a telescope transmitter. A coude', or other fixed image system is highly desirable. Let us assume the laser puts out 30 joule in 70 nanoseconds and 3 milliradians. The geometry in our original proposal means that the return signal expected is about one photoelectron. A 100" telescope would mean 2.5 photoelectrons (and 1.6 x the noise). The laser pulse width sets a lower limit on PMT pulse width and oscilloscope sweep time.

6. Pointing and Tracking

This aspect is probably the most time-consuming (reticle construction), most preparation-demanding (laser cannot be focused) aspect of the interim "interim station". Currie's variation of the Kitt Peak method is called for.

7. Confidence of Acquisition

If the dialer can keep the range cranked in correctly (an automatic reader of each setting used might be a good idea along with its time to the nearest second), and the signal to noise is 1:1 or better in the resolution unit of time forced on one, acquisition will readily become certain after a few shots (one photoelectron average return).

8. Prognosis and Discussion

If the present range prediction can only be done to ±1 μsec, the requirement to range to a bright moon with present lasers and telescopes makes the chances for success quite small. However, there is evidence that the bright moon noise is about an order of magnitude lower than quoted above; especially at the phase we will observe it at. In such a case, one would expect 0.5 photoelectrons of noise per 0.3 microseconds and a signal of 1 photoelectron. For a 3 Å filter, the numbers are 0.15 and 1 respectively.

If the range can be predicted to ±0.1 Km, the noise could be cut the same factor of ten. However, a better preset counter must be purchased. All the other equipment would remain the same. An oscilloscope trace of 100 nanoseconds approaches the laser pulse limit. In the worst noise case, the experiment is just double. In the best noise case with ±0.1 Km range, the noise would be 0.05 photoelectrons in 0.03 microseconds and 1 photoelectron.

Other cases can be scaled from the above figures.

APPENDIX IV.

10 Å and 3 Å SPECTRAL FILTER SPECIFICATIONS

2 April 1969

Mr. Peter Minott
Code 524
Goddard Space Flight Center
Greenbelt, Md 20771

Dear Pete;

In view of the higher dome temperatures (i.e. 27°C) and later information from Infrared Industries, let me confirm my telephone transmittal of specification modification. This letter also incorporates my letter of 1 April.

1. General Specifications

Change in peak with temperature ≈ +0.2 Å/°C

Special blocking to achieve 0.0001% outside passband from X-ray to 1 micron

Transmission curve to be supplied

Filter diameter 2 inches

Filter must withstand control temperature variations +30°C -30°C from 25 °C nominal

2. Filter #1

Peak wavelength 6944 +2 -0 Å at 40 °C

Full-width at half intensity 10 +1 -1 Å

60% Minimum peak transmission a must (as per E. Barr)

3. Filter #2

Peak wavelenghh 6944 +1 -0 Å at 40 °C

Full-width at half intensity 2 +1 -1 Å

45% Minimum peak transmission a must (as per E. Barr)

You should probably also order

4. Filter #3

Peak wavelength 6944 +2 -0 Å at 40 °C

Full-width at half intensity 5 +1 -1 Å

52% Minimum peak transmission a must (as per E. Barr)

Yours truly,

Sherman K Poultney
Assistant Professor in Physics

CC; Alley, Currie,
Carrion

APPENDIX V.

0.7 Å PERKIN ELMER FILTER SPECIFICATIONS

31 March 1969

Mr. Walter Carrion
Code 524
Goddard Space Flight Center
Greenbelt, Maryland

Dear Walt:

1. Enclosed find a copy of the quotation and specifications from Perkin Elmer for the 0.5Å filters. Please order at once (three) in the most expeditious manner. You will recall that the original budget showed that GSFC would purchase these items. We have no provision for them in our detailed budget with Strickland. We also have to generate paper work to get him to approve a change of this magnitude in our detailed budget.

2. Note that Perkin Elmer management quotes a twelve week delivery whereas the Perkin Elmer fabricator estimated six weeks. Please indicate that we are willing to accept partial delivery of one at the earliest possible date with the other two following as quoted.

3. In regard to the other filters, please tell Pete Minott that Infrared Industries bought Thin Film Products. Unless the best Thin Film people left and started a new company, Infrared Industries is probably the best supplier. OCLI and PE are also good as is Laser Optics.

Yours truly,

Sherman K Poultney
Assistant Professor in Physics

March 27, 1969

UNIVERSITY OF MARYLAND

WORK STATEMENT

THIS WORK STATEMENT APPLIES TO SOLID ETALONS ONLY

The prices agreed in this quotation are for solid etalons having the following performance specification when operated in collimated radiation with semi field angle not exceeding 30 minutes of arc.

Peak Wavelength	6943Å
Bandwidth	0.5Å
Free Spectral Range	≥10Å
Peak Transmission	≥45% of unpolarized light.
Peak Wavelength Location	Will be between λ_0 and λ_0-2 where λ_0 is the specified wavelength in angstroms.
Tolerance on Bandwidth	Will be minus 0.1 angstroms, plus 0.2 angstroms of the requested bandwidth.
Peak Wavelength Variation	This will be no greater than plus or minus 0.2 angstroms of the nominal peak when measured with a beam area not less than 1/16 of the area of the clear aperture.
Temperature Stability	The etalons have a positive temperature coefficient of wavelength shift, of 0.042Å/°C.

June 23, 1969

Dr. Henry H. Plotkin
Assistant Dir. - Adv. Dep. Div.
Goddard Space Flight Center
Greenbelt, Maryland 20771

Dear Henry:

SUBJECT: PERKIN ELMER FILTER

1. Peak Wavelength Location

Based on data of Long (IEEE p. 859, May, 1963), the center of the atmosphere passband for ruby light at room temperature is 6943.2 Å. I recommend that the Perkin Elmer filter be centered at 6943.2 Å at an internal temperature of 10 to 20°C above the highest room temperature at McDonald. The temperature coefficient of the filter is +0.042 Å/°C. This coefficient will allow adjustment of the center wavelength throughout the atmosphere passband (if needed) for a ±10°C change in internal temperature. In all probability, the filter will be fixed at the temperature of 6943.2 operation for normal incidence.

2. Laser Wavelength Determination and Adjustment

The wavelength of the laser output is best determined by a spectrograph with dispersion of better than 2 Å/mm or by superimposing a known wavelength on a Fabry Perot interferogram. I recommend that the Perkin Elmer filter be prealigned at the factory as discussed above. On site the temperature of the laser water can be varied until the laser wavelength matches the filter. Since most short term laser heating depends on the flash lamps, the laser can be operated at lower output power to conserve rod life. The coefficient of laser wavelength temperature change is about the same as that of the filter. My recent measurements were adequate for laser spectral width and line center variations, but not for absolute line center. My guess is that the laser water must be held at about 17 to 22°C ±2°C to match the filter center. My measurements of linewidth indicate that the linewidth and lineshift are stable to better than ±0.2 Å during a 30 shot sequence at 1 pulse every six seconds.

3. Filter Fine Tuning

If the PE filter must be fine-tuned, we must build a transmission sensor and feedback tilt mechanism. To ease our task, please see that the 5 Å blocking filter has its tilt adjustment axis in the horizontal plane (i.e. vertical tilt). It would also be preferable to use small blocking-filter tilt angles. At the moment I can say no more than to call Doug Currie about fine tuning. I do not know the tilt sensitivity of the Fabry-Perot filter.

4. Enclosed find more information on Wavelength matching.

Yours truly,

Sherman K. Poultney
Assistant Professor of Physics

SKP/fm
cc: C. O. Alley
D. G. Currie

APPENDIX VI.

WAVELENGTH MATCHING OF RECEIVER FILTER AND LASER TRANSMITTER

UNIVERSITY OF MARYLAND

Department of Physics and Astronomy

INTRAMURAL

To: C. O. Alley, D. Currie

From: S. K. Poultney

Subject: Wavelength Matching of Receiver Filter and Laser Transmitter

Date: December 20, 1967

A. References

1. Blifford, "Factors Affecting the Performance of Commercial Interference Filters," Appl Optics 5, 105 (Jan. 1966).

2. A. Vaughan, "Astronomical Fabry-Perot Interference Spectroscopy" Ann. Rev. of Astronomy and Astrophysics 5, 139 (1967).

3. M. Hercher, "The Optical Characteristics of Ruby Laser Emission," Ph.D. Thesis, 1963.

4. Md. Technical Report #695, S. K. Poultney.

5. C. N. Stickley, Private Communication.

6. Korad Bulletin KWC3.

B. Filter Performance[1]

Blifford's evaluation of available narrow-band interference filters (down to widths of about 12 Å) shows that the temperature coefficient for the change in center wavelength of a typical filter is approximately +0.1Å/°C to +0.3 Å/°C. The transmittance and bandwidth showed coefficients of <0.01%/°C and <0.01 Å/°C respectively. The change in center wavelength with angle of incidence can be taken to equal

$$\frac{\delta\lambda_\phi}{\lambda_{\phi=0}} = -0.35\,\frac{\phi^2}{2} \qquad (1)$$

for a good first approximation in the case of a parallel beam. ϕ is the angle from the normal in radians. This means, for example, that a filter rotation corresponding to 1°C temperature change for a 6943 Å center wavelength will be 1.6×10^{-2} rad or 0.9°. With a passband of 3Å, one must therefore hold the filter at about ± 1°C and align it to ±0.9° to have the center wavelength definitely within the 3Å at 6943Å. A gross adjustment of the filter's actual center wavelength to the desired one is probably best done by working at the necessary temperature above or below room temperature.

Blifford found the decrease in the transmittance to be less than 10% for filter rotations of up to 5°, but states that narrow bandwidth filters show a sharper fall-off. The bandwidth change with angle of incidence is quite small for angles below about 4°.

$$\frac{(\Delta\lambda)_\phi}{(\Delta\lambda)_{\phi=0}} = \left\{1 + \left[\frac{0.35\ \phi^2}{(\Delta\lambda)_{\phi=0}\ /\ \lambda_{\phi=0}}\right]^2\right\}^{1/2} \qquad (2)$$

In general, one must measure the behaviour of the filter under consideration; especially since the very narrow-band filters are quite new and unevaluated.

Narrow filters may be achieved by means of Fabry-Perot interferometer techniques.[2] These filters will be examined later.

C. Laser Transmitter Performance[3]

The change in wavelength of a single-mode ruby oscillator with a change in temperature is about 1 Å per 27°C near 300°C where the wavelength is 6943.0 Å.[3] This dependence means that the laser temperature need only be kept constant to ±4.5°C to be sure the transmitter is held within the filter passband to the same accuracy as the filter center wavelength is held in B. Typical laser rod temperature increases on the short term (during one shot) due to pumping range from 2°C per 100 μsec[4] to 4°C per 1000 μsec[5]. Typical times of Q-pulse extraction are 500 μsec to 1000 μsec. It is assumed that the long term temperature changes (shot to shot) are reduced by suitable cooling. Korad uses a regulated heat-exchanger which maintains the long term temperature to ±1°C.[6] The shot-to-shot reproducibility of the laser output wavelength will thus depend primarily on the time of extraction of the output pulse during the pumping period. Any dependence on the rate of firing (i.e. gradual rise in ambient temperature) is not considered here. Assuming that the pulse can be extracted at a given time in the pumping cycle to ±50 μsec (smaller uncertainties could probably be achieved), one sees that the match between the 3Å filter and the laser oscillator is quite good.

In the above, it has been assumed that the laser amplifiers can be kept to the same temperature as the oscillator. The ruby oscillating linewidth is about 5.5 Å.[3]

Finally, the operating temperature will be chosen to place the laser wavelength in the region between two water absorption lines near 6943 Å. This restriction means 25°C ±5°C.

D. Filter-Transmitter Matching Control System

With the present system parameters no matching control above ambient temperatures appears necessary. However, to have the capability to account for unforseen variations in temperature of the laser system, one would like to monitor the laser output wavelength and to be able to adjust the filter so as to place its center wavelength at the laser wavelength. One thinks first of adjusting the filter temperature to the laser temperature at the time of firing (if it can be determined) since the filter is temperature-controlled already. However, the necessary adjustment could be required on a time scale shorter than the filter equilibrium time. The filter temperature control must be supplemented by other means. D. Currie has suggested making the adjustment by a small rotation of the filter. Rotations of the magnitude necessary (see B) should certainly be possible. D. Currie has also suggested adding two or more PMT-filter channels to the one proposed for determining the departure time of the laser pulse. Each filter would be at the same temperature, but at different angles to the incident beam (e.g. +3° - 0° - -3° for 3Å filter). The magnitude of the signals in the monitor PMT's would yield a measure of the amount the center filter (in the receiving channel) must be rotated to pass the return pulse. This control system becomes a necessity if one wishes to work with filters which have narrower passbands than 3Å.

E. Extremely-Narrow Passband Filters[2]

The high noise rate expected during daytime location of the retro-reflector in range-time forces one to look for filters with passbands even narrower than 3 Å. While these are available, the sensitivity of adjustment may rule against their use; if for no other reason than that the filter adjustment to the output wavelength may be much too complicated.

APPENDIX VII.

LASER TEST AND MONITOR EQUIPMENT

December 10, 1968

Mr. Walter Carrion
Code 524
Goddard Space Flight Center
Greenbelt, Maryland 20771

Dear Walt:

Subject: <u>Laser Test and Monitor Equipment</u>

1. Fast Detector for Monitoring Laser Pulse Shape and Energy

Rise Time:	≤ 0.2 nsec.
Sensitivity:	Must be sensitive to 6943 Å
Output:	20 volts nominal into 125 Ω load
Power Range:	Up to and including 0.2 GW (working level ≈ 0.1 GW)
Energy Range:	10^{-3} j to 100 j (Range adjustable using self-contained ND filters)
A Accuracy:	± 3%
Bias Supply:	Should be self-contained
Aperture:	2 cm diameter
Dimensions:	Nominal 4 x 5 x 8 inches

2. Pickoff Pellicle (3)

Reflectivity:	Nominal 4%
Coating:	None, Fresnel Reflection
Durability:	Must withstand 5j, 5 nsec ruby laser pulses on area of ≈ 4 cm^2 in clear atmosphere
Size:	Pellicle: 2.5 cm diameter clear area Mount: 2" diameter nominal

NOTE: Detector and Pellicle must mount on laser rail in normal laser operation.

3. Fast Oscilloscope

Rise Time:	0.2 nsec
Sensitivity:	10 v/cm
Shortest Sweep:	1 nsec/cm
External Trigger Provision	
Trace Intensity:	Bright enough on 1 nsec/cm trace for recording on film using camera which should also be supplied.

4. Fast Oscilloscope Camera (See above)

   Should have an electronic shutter and film advance.

5. Calorimeter

Absolute Accuracy:	$\pm$ 3%
Aperture Size:	2.5 cm diameter
Energy Range (Joules):	0.05 to 100
Sensitivity (Joules/ microvolt):	20
Spectral Range:	5300 Å to 10,600 Å
Power Range:	Up to 1×10^9 watts/cm^2
Size:	Nominal 4 x 5 x 8 inches

NOTE: Room must be allowed on laser rail (or optical package) to insert calorimeter when needed.

6. Microvoltmeter

   Keithley 150 A or equivalent

7. Chart Recorder

   Compatible with Keithley 150 A. For example Bausch & Lomb VOM5

8. Beam Divergence Camera

   Camera must have adjustable focus (bellows range about 10") removable lens-board not smaller than 3" x 3", all-purpose tripod, Polaroid and cut-film (4 x 5") plate-holders, and Graflock back (or reflex viewer). Example: Speed View Graphic II.

NOTE: Provision must be allowed on laser rail (or optical package) to extract laser beam for farfield tests. A farfield test will consist of photographing the laser spot in the focal plane of a long focal length lens (e.g. 2m) using the above multi-lens camera in conjunction with a H_2O block. The pellicle pick-off would probably be used to extract laser beam from laser rail.

9. H_2O Block

For far-field laser beam evaluation. Must withstand 50 GW/cm^2.

10. Laser Supplier Optical Package for Laser Cavity Alignment

Should consist of a small (4 x 4 x 12 inches), reliable He-Ne laser of nominal 1 milliwatt and collimated pencil beam, and an auto-collimator with 2 cm diameter beam and ± 2.5 second accuracy.

Both components should clip on laser rail in a standard position for laser cavity alignment.

11. General Purpose Illuminator for Surface Inspection and Pockel Cell Alignment.

American Optical 651 (or equivalent)

12. Supply of Polaroid 55B Film for Far Field Camera.

Yours truly,

S. K. Poultney
Assistant Professor of Physics

SKP:mm

cc: D. Currie
C. Alley
T. Johnson
P. Minott

APPENDIX VIII.

DESIGN OF A BEAM SPLITTER/QUANTUM EFFICIENCY ENHANCEMENT DEVICE.

March 14, 1969

Dr. James Faller
Dept. of Physics
Wesleyan University
Middleton, Connecticut 06457

Dear Jim,

Having finally obtained a few seconds to think rather than do menial tasks, I designed the following basic beam splitter/quantum-efficiency enhancement device for the Haleakala station detector. I drew upon both my and Eric Silverberg's experimental experience in this area. The constraining requirements were:

1. PMT must be parallel to axis of detector box and beam (facing forward <u>or</u> backward.
2. Quantum efficiency must be enhanced. Expected enhancement from our prior experience is 2X or more starting with 4 or 5% at 6943 Å. An oblique path through photocathode gains 50% or so. The higher enhancement requires an enhancement device, to provide one or more bounces inside photocathode. Two bounces appear to be the maximum number of bounces that are useful.
3. Beam must be split into two or more beams to eliminate discriminator dead-time effects of a one-channel system. Splitter must be easily replaced by a single device to split beam to three, four, or more PMT's.
4. Splitter and enhancer device should be one solid piece (i.e. no alignment should be needed.).
5. Area of light incidence at photocathode may have to be restricted to eliminate transit time spread between cathode and first dynode.
6. Difference in optical path lengths in splitter and enhancer and total path in enhancer must be less than one inch for 0.1 nsec. Thus, two bounces are probably all that can be expected in the enhancer.

Two sketches are enclosed for a two beam device. The first sketch shows a single pass splitter-enhancer arrangement. The second shows a two bounce splitter-enhancer. Obviously, a tetrohedron may be put in place of the prism if three PMT's are necessary (etc., etc.).

Yours truly,

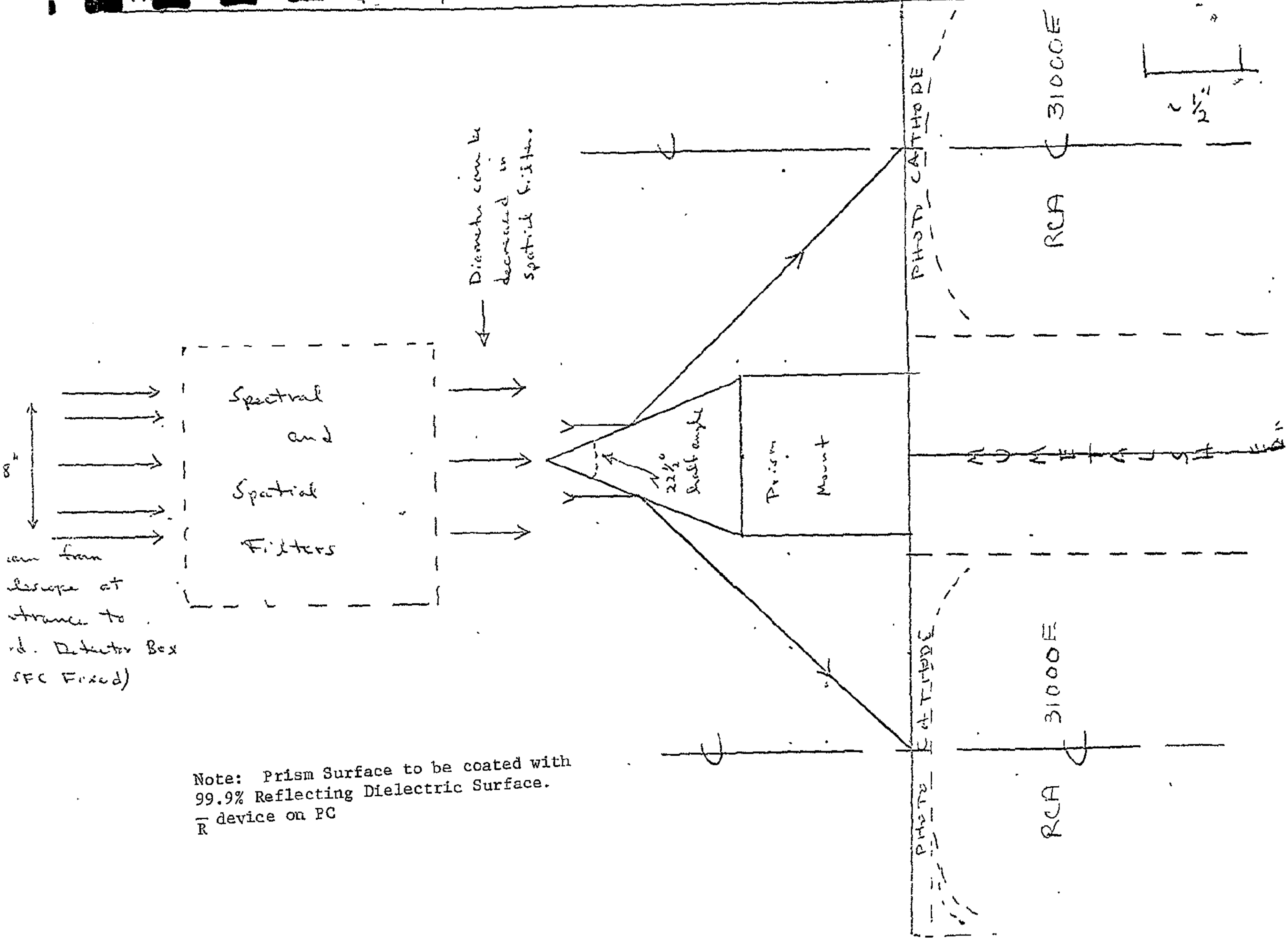
Sherman K. Poultney
Assistant Professor of Physics

SKP:mm

Encls. (3)
cc: E. Silverberg, C. O. Alley, D. Currie, W. Carrion

[redacted] Sin[redacted] - [redacted] [redacted] S[redacted] H[redacted] Entrance [redacted] fo[redacted]. [redacted] Detector [redacted] [redacted] [redacted]

14 March 1969

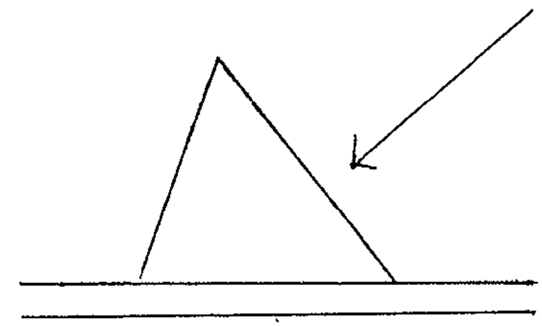


Note: Prism Surface to be coated with 99.9% Reflecting Dielectric Surface.
$\overline{R}$ device on PC

S. K. Poultney
14 March 1969

SINGLE - BOUNCE SPLITTER/ENHANCER FOR HALEAKALA DETECTOR

1) Use prism with half-angle $\geq 24^{\circ}$



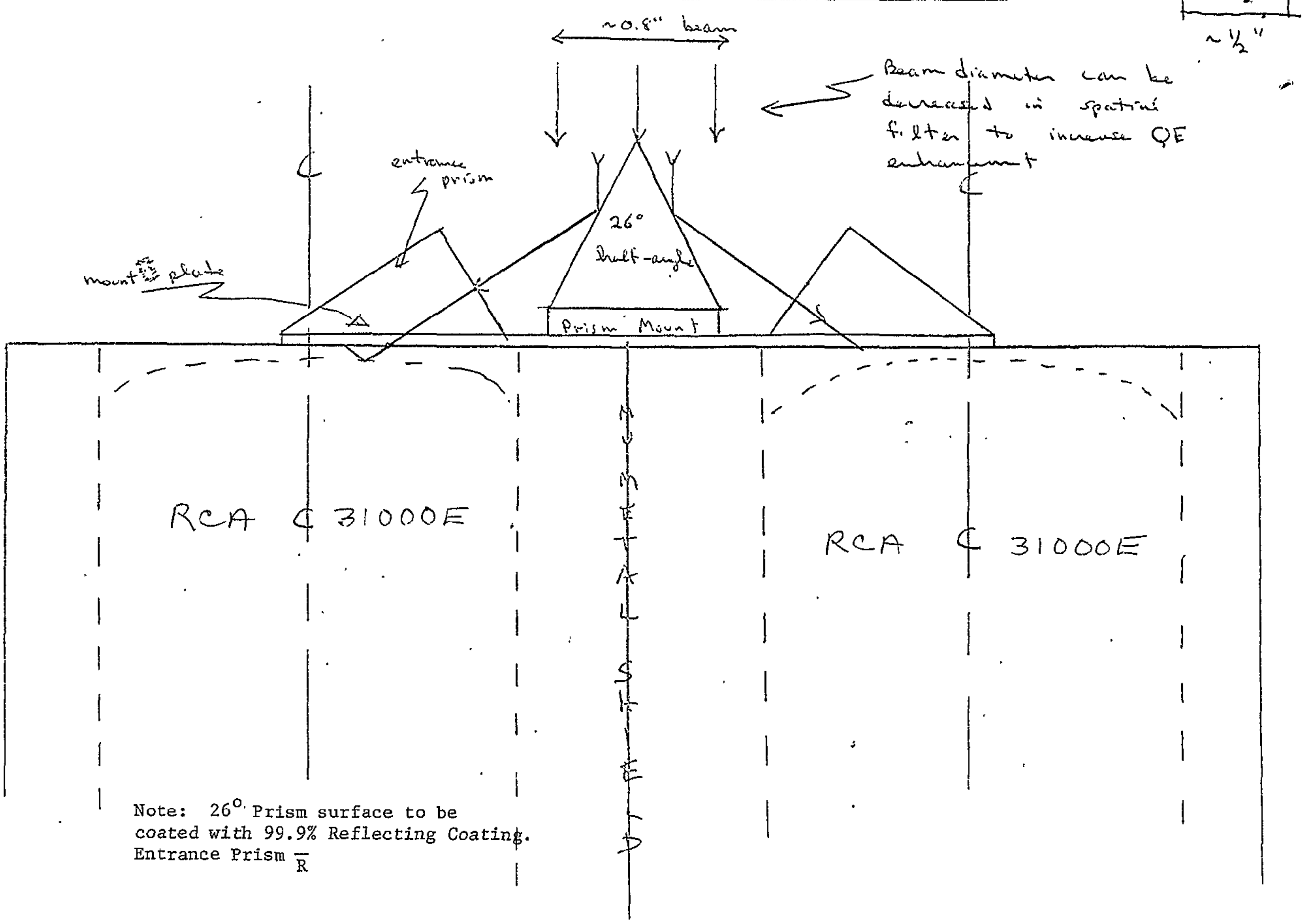
2) Use $\overline{R}$ device on photocathode (PC)

a) auxiliary prism

3) In all cases on p1,2,3 one may wish to reduce the diameter of the 0.8" beam (GSFC Fixed) in the spatial filter in order to maximize quantum efficiency enhancement.

[redacted] 90

Double-Pass Splitter / Enhancer for Haleakala Detector



Note: 26° Prism surface to be coated with 99.9% Reflecting Coating. Entrance Prism $\overline{R}$

TRIANGULAR PYRAMID BEAM SPLITTER

S. K. Poultney, University of Maryland

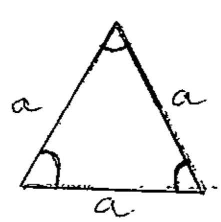
28 April 1969

Purpose: A parallel beam incident on the apex of a triangular pyramid is split into three equal beams deviated 60° from direction of incidence. Initial beam diameter less than or equal to 0.8". Apex surfaces shall be coated with Ag and SiO for durable 97^{+}% reflection. Surfaces flat to 1/2λ. Angles to 5 minutes of arc.

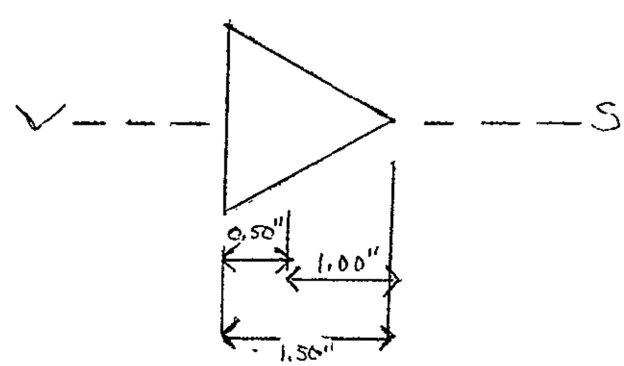
Bottom View

Equilateral Triangle

Side a = $\sqrt{3}$ = 1.732"

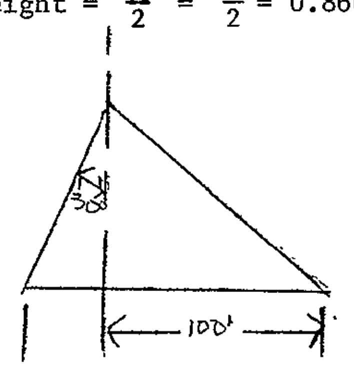


Top View



Section View (V----S)

Height = $\frac{a}{2}$ = $\frac{\sqrt{3}}{2}$ = 0.866"



APPENDIX IX.

DAILY DETECTOR CHECK SHEET

Date____________________

Appendix IX.

Daily Detector Check Sheet

HeNe Aligned with Ruby	______________	
Pinhole Size	______________	microns
HeNe gets through pinhole when mirror flipping	______________	
HeNe OK at Beamsplitter	______________	
HeNe OK at PMT face	______________	
Spectral Filter	______________	
0.7A Filter Remp (44°C)	______________	
3A Filter Temp 287	______________	
Filter Autocollimated	______________	
Light Seal On	______________	
Dark Current (Hot) HV 3400 volts 403A Disc 6	______________	KHZ
HV Off	______________	
Dry Ice Added	______________	
Light Seal On	______________	
Dark Current (Cold, HV 3400)	______________	KHZ
Star Check (beginning)	______________	KHZ
Star and Air Mass	______________	
Shutter on Auto	______________	
Monitor ed Dark Current During Run	______________	
Monitored Lunar Noise During Run	______________	
Star Check (at run end)	______________	KHZ
Star and Air Mass	______________	
Shutter--Auto and Off	______________	

Use a new sheet if a new pinhole or filter is added during a run.

Make sure flip mirror and shutter are on <u>Auto and OFF</u> whenever laser has any chance of being fired.