

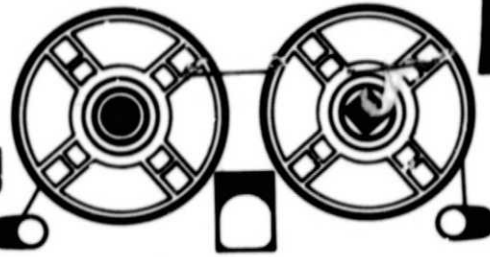
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Image Processing and Data Reduction
of Apollo Low Light Level Photographs

by

Gregory C. Alvord

MATHPACK/GPSS/SIMULA/ALGOL/FORTRAN/COBOL/SNOBOL/APL/GRAPHICS

1110



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Type III Report

29 July 1974 to December 1975

Contract # NAS5-20683

Agency: State University of New York at Albany
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Preface

This Type III Report covers the contract period from 29 July 1974 to 31 December 1974 and fulfills the requirements as outlined in Article II item 4 and Article IV, for NASA contract NAS5-20683, "Image Processing and Data Reduction of Apollo Low Light Level Photographs". The contents of the report include the technical details pursuant to contract NAS9-14413 "Apollo Experiment S-211 Low Brightness, Astronomical Photography."

Abstract

The objective of this study was to remove the lens induced vignetting from a selected sample of the Apollo Low Light Level photographs. The methods used were developed under an earlier contract. A study of the effect of noise on vignetting removal and the comparability of the Apollo 35mm Nikon lens vignetting was also undertaken.

The vignetting removal was successful to about 10% photometry. Noise has a severe effect on the useful photometric output data. Separate vignetting functions must be used for different flights since the vignetting function varies from camera to camera in size and shape.

List of Figures and Tables

Figure 1	Flow chart for vignetting removal	3-5
Figure 2	Scaled Density vs. Scaled Log Intensity	3-7
Figure 3	Step wedge and Histogram	3-8
Figure 4	Step wedge profile	3-8
Figure 5	Contoured vignetting function	4-3
Figure 6a	Vignetting function	4-3
Figure 6b	Difference function for two vignetting functions 60 sec exposure	4-3
Figure 7a	Difference function for two vignetting functions 30 sec minus 60 sec	4-3
Figure 7b	Difference function for two vignetting functions 15 sec minus 60 sec	4-4
Figure 8	Difference function for two vignetting functions 120 sec blue minus 30 sec	4-4
Figure 9a	Difference functions for two vignetting functions 30 sec minus 30 sec	4-4
Figure 9b	Difference functions for two vignetting functions Apollo 17 minus Apollo 15	4-4
Figure 10a	Contoured Average Apollo 15 vignetting	4-5
Figure 10b	Contoured Average Apollo 16 vignetting	4-5
Figure 10c	Contoured average Apollo 17 vignetting	4-5
Figure 11a	L4 Point Density Image	5-3
Figure 11b	L4 Point Log Intensity	5-3
Figure 11c	L4 Point Log Intensity Contoured	5-3
Figure 11d	L4 Point Vignetting Removed	5-3
Figure 11e	L4 Point offset Log Intensity contoured vignetting removed	5-4
Figure 11f	L4 Point offset Log Intensity	5-4
Figure 11g	L4 Point Vignetting Removed contrast enhanced 2:1	5-4
Figure 11h	L4 point vignetting removed contrast enhanced 4:1	5-4

List of Figures and Tables (continued)

Figure 12a	A15-100-13531-ZL-30sec Density	5-5
Figure 12b	A15-100-13531-ZL-30 sec Log I offset	5-5
Figure 12c	A15-100-13531-ZL-30 sec Log I contoured offset	5-5
Figure 12d	A15-100-13531-ZL-30 sec vignetting removed	5-5
Figure 12e	A15-100-13531-ZL-30 sec vignetting removed offset contoured	5-6
Figure 12f	A15-100-13531-ZL-30 sec vignetting removed noisy	5-6
Figure 13a	A15-100-13529-ZL-20 sec Density	5-6
Figure 13b	A15-100-13529-ZL-20 sec Adjusted Log I	5-6
Figure 13c	A15-100-13529-ZL-20 sec vignetting removed average	5-7
Figure 13d	A15-100-13529-ZL-20 sec vignetting removed old	5-7
Figure 13e	A15-100-13529-ZL-20 sec vignetting removed offset	5-7
Figure 13f	A15-100-13529-ZL-20 sec vignetting removed offset contoured	5-7
Figure 14a	A15-100-13528-ZL-60 sec Density	5-8
Figure 14b	A15-100-13528-ZL-60 sec Log I	5-8
Figure 14c	A15-100-13528-ZL-60 sec Log I offset	5-8
Figure 14d	A15-100-13528-ZL-60 sec vignetting removed	5-8
Figure 15a	A15-100-13513-ZL-120 sec Density	5-9
Figure 15b	A15-100-13513-ZL-120 sec Adjusted Log Intensity	5-9
Figure 15c	A15-100-13513-ZL-120 sec vignetting removed	5-9

Table of Contents

Preface	ii
Abstract	iii
List of Figures and Tables	iv
1 Statement of Problem	1-1
2 Algorithm for Solution	2-1
3 Implementation of Algorithm	3-1
4 Comparison of Vignetting	4-1
5 Examples of Results	5-1

List of Figures and tables (continued)

Figure 16a	A15-13515-ZL-120 sec	Density	5-10
Figure 16b	A15-13515-ZL-120 sec	Log I	5-10
Figure 16c	A15-13515-ZL-120 sec	Log I adjusted	5-10
Figure 16d	A15-13515-ZL-120 sec vignetting removed, adjusted, contoured		5-10
Figure 17a	A15-13517-ZL-90 sec.	Density	5-11
Figure 17b	A15-13517-ZL-90 sec	Log I adjusted	5-11
Figure 17c	A15-13517-ZL-90 sec vignetting removed contoured		5-11

Statement of the Problem

In the collection of certain scientific data, it is convenient to use readily available film, lenses and cameras. When the Phenomena is of such a light level as to require that the lens be wide open, an effect known as vignetting is observed. The effect changes the relative photometry at different points on the film. This effect is unacceptable for photometric studies.

If after taking all the appropriate precautions to avoid getting vignetting (i.e., faster film, faster optics, longer exposure times), one still must use a lens wide open, then there is no recourse but to try to remove the effect. This is exactly the problem with the low light level astronomical photographs taken during Apollos 15, 16 and 17 under S211 and S158.

Pictures were taken while in lunar orbit, and during trans-lunar flight with a 35mm Nikon camera with a f1.2 lens. The camera was mounted on a clamp in front of the window and exposed for from 15 to 240 sec., depending upon the phenomena. The camera was loaded with Kodak 2485 film with an estimated equivalent ASA rating of 8000.

A Nikon f1.2 lens is about as fast a lens as can be found. 2485 film is also a very fast film. Due to film reciprocity failure and space craft movement, extending the exposure time beyond 240 was not manageable. The phenomena which was to be recorded was estimated to be of a brightness between 6.5×10^{-11} and 1.02×10^{-9} solar units. These facts indicated the need to try to remove the photometric effects of vignetting after the film was brought home.

Added to these photographic reasons for the need to remove vignetting was the fact that these images contained data about phenomena which we will not have an opportunity to view again for the foreseeable future. Contained on these frames were images of the Zodial light at long and short elongation, and attempts to photograph both the gegenshein and L4 points.

Our attempt to solve this problem was by way of an image process system called VICAR (Video Image Communication and

Retrieval). This system of programs was originally designed at Jet Propulsion Laboratory (JPL). The version we used was implemented on the Science and Application Computing Center IBM 360/75 and 360/91 at Goddard Space Flight Center.

We sought, then, an algorithm for removing vignetting which could be brought to fruition on the VICAR system. It is the intent of this report to present that algorithm. We also shall present the properties of vignetting in general, and the properties which specifically relate to our test data.

The Algorithm for Solution

Prior to our presentation of the digital images to the computer, a digitization process is undergone. The process takes a smoothly varying analog image and converts it to a matrix of values, each element of which is an approximation of the density of the film at some X,Y. Equation 1) shows how this approximation is obtained from:

$$S_{i,j} = h(x-id_x, y-jdy) s(x,y) \quad (1)$$

where dx, dy are the scanning step size
for x and y respectively

$h(x,y)$ is the scanner aperture
envelop assumed to be zero
outside some finite area.

Vignetting behaves as if it were a neutral density filter with a positional dependence upon its density. We write $V_{i,j}$ as the matrix which represents this process.

$$V_{i,j} \begin{cases} \approx 1.0 & \text{near the center} \\ \approx 0.0 & \text{near the edge at the image} \end{cases}$$

$V_{i,j}$ is normalized to show percent of transmissivity when multiplied by 100. The density of the filter $F_{i,j}$ which would simulate the effect is given by

$$F_{i,j} = \text{Log} \frac{1}{V_{i,j}} \quad (2)$$

The image $I_{i,j}$ of the scene $S_{i,j}$ is attenuated by passing through this filter $V_{i,j}$. Equation 3 represents this process

$$I_{i,j} = V_{i,j} \cdot S_{i,j} \quad (3)$$

where this multiplication is element by element.

As a first approximation at an algorithm for removing vignetting, we could merely divide the image by an approximation of the vignetting to reconstruct the scene (Equation 4)

$$S_{ij} = \frac{I_{ij}}{V_{ij}} \quad (4)$$

When the image is captured on film, it is done so as a density representation D_{ij} . Photographic film reacts in a non-linear manner to light intensity. The shape of this non-linear process is represented by the function H_I

$$I_{ij} = H_I (D_{ij}) \quad (5)$$

Our reconstruction algorithm is then

$$S_{ij} = \frac{H_I (D_{ij})}{V_{ij}} \quad (6)$$

If we have the lens which created the images, we can observe the effect of the lens upon a uniform flat field of light. We can photograph this field and have a density representation of the effect at the lens.

We can approximate V_{ij} with one minus the difference between the known intensity K_{ij} of the flat field and the received Intensity R_{ij}

$$\begin{aligned} V_{ij} &\approx 1 - (K_{ij} - R_{ij}) \\ &\approx 1 + R_{ij} - K_{ij} \end{aligned} \quad (7)$$

Since we are again collecting data via photograph. R_{ij} is effected by film non-linearity. Let $D(v)_{ij}$ be the density image of the flat field. Then equation (8) provides R_{ij}

$$R_{ij} = H_V (D(v)_{ij}) \quad (8)$$

where H_V is the characteristic function of the film used to capture the flat field image

We set $1 - K_{ij}$ equal to some constant which is independent of position C and our vignetting function approximation becomes.

$$V_{ij} \approx C + H_V (D(v)_{ij}) \quad (9)$$

We place equation (9) into equation (6) and obtain

$$S_{ij} = \frac{H_I(D_{ij})}{C+H_v(D(v)_{ij})} \quad (10)$$

One of the conditions for a good algorithm is that it be easily implemented on the VICAR System. Equation (10) shows element by element division of one image $H_I(D_{ij})$ by another $C+H_v(D(v)_{ij})$. The VICAR system did not have a division function for images. The drawback to implementation one is that the images within VICAR are 8 bit integers. Using integer arithmetic would cause too much of a loss of significant digits. We put equation 10 into this form

$$\text{Log}(S_{ij}) = \text{Log}(H_I(D_{ij})) - \text{Log}(C+H_v(D(v)_{ij})) \quad (11)$$

This allowed us to use the available subtractions routine, for vignetting removal. Within the VICAR system, the integers 0 thru 255 were assigned to represent certain log intensity values so that a change of one data number was a change of known log intensity. We called this form of the data scaled Log intensity.

Implementation of Algorithm

In this section, we follow the flow of fig. 1 and discuss each step and our attempts to fulfill its requirements. Tables and graphs are presented to show the actual data used. Although data was collected during Apollo 15, 16 and 17, we shall present just the details associated with the Apollo 15 data frames.

Step 1.a obtain data frames

Seven data frames were obtained by the Apollo 15 crew - Al Warden, Dave Scott, Jim Erwin - which were deemed worth investigation by the Apollo project S-211 principle investigator R. D. Mercer. These included one 240 sec. exposure of the L_4 point for the earth-moon system, and a series of six exposures of the solar outer corona and zodiacal light. The film upon which these exposures was made was exposed to a calibrating sensitometer at the High Altitude Observatory at Boulder, Colorado prior to flight. This was to insure that the calibration received the same background radiation as did the data frames.

Step 1.b Obtain Vignetting Frames

After the flight lenses were returned to earth with the crew, they were brought to GSFC to determine their vignetting function. A set of film was calibrated at HAO in a manner similar to that for the data frames. The same film type was used for the vignetting exposures as was used on the flights. (Kodak 2485), although this is not a requirement of the algorithm.¹

An optical arrangement was set up by Walter Fowler of GSFC to present to the lens a uniformly illuminated field of light. Due to the high speed of 2485, great care was needed to insure uniformity tolerances greater than those observable by the film. The film containing these exposures and the calibrations were developed under controlled conditions by Al Stober of GSFC.

¹Some of the smoothing done to the vignetting frame may not have been needed had a finer grain film been used for the vignetting exposures.

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Step 2 Digitize and Scale

The data images and their calibration wedges were scanned on a high speed microdensitometer made by Boller and Chivens. The scanning process makes a linear transform from photometric density to the range 0,255. The density average is found within some aperture. That average is used as the density value for that point (pixel). The film was scanned from sprocket hole to sprocket hole so as to provide registration information.

A complication occurred that caused the aperture size to be different between the data and vignetting frames. The data was scanned with 35 micron circular pixel size. The vignetting frames were scanned with a 40 micron square aperture. This is not a severe problem. The vignetting effect is a slowly varying function. A 10% change in the vignetting value occurs over many pixels even with a 40 micron spot size. We have not lost any detail by scanning the vignetting with a larger spot size.

Step 3 Remove Fog

On all of the density images, including the calibration wedges, an area of unexposed film was histogrammed to yield the mean grey level. This value was subtracted from the density pictures. This zeroed the density scale so that no light meant 0 on the scaled density image.

There is, of course, a problem that the matrix, which represents the image for the data, will have a different number of rows and columns than will the vignetting frame. This problem is met by stretching the vignetting image to a size which it would have had if it had been scanned at 35 microns. In this technique, linear interpolation is used to fill in the missing pixels. This is completely adequate because of the smooth nature of the vignetting function.

Step 4 Determine film characteristics

The calibration step wedges were scanned with the same

aperture setting as the frames to which they correspond. The wedges were made by a known amount of light falling on the film. By scanning these wedges, we were able to build a table which related density to intensity. Fig 2 is the calibration curves for the Apollo 15 vignetting frames in terms of scaled density versus scaled Log Intensity.

The techniques used to determine the values for this graph were fairly straight forward. First a histogram was taken of the entire wedge and is shown in fig. 3. From this histogram, we can see count peaks at each of the wedge levels. In the figure (3) is a picture of an example test wedge with the region for the histogram shown. The next step was to simulate a slit averaging technique. Figure 4 shows a slit average as a function of position for a test wedge. This provides us with a detailed position of the steps and ramps. The last pass at the wedge is to histogram just the step regions of the wedge image. From this pass we get mean and standard deviations of the wedge steps. The mean is used as the scaled density created by a known intensity. The standard deviation is our measure of error bars. The error ranges from 9 to 12 counts. Figure 2 was drawn with the points on tables 1 and 2.

Step 5 Rescaling to Log I

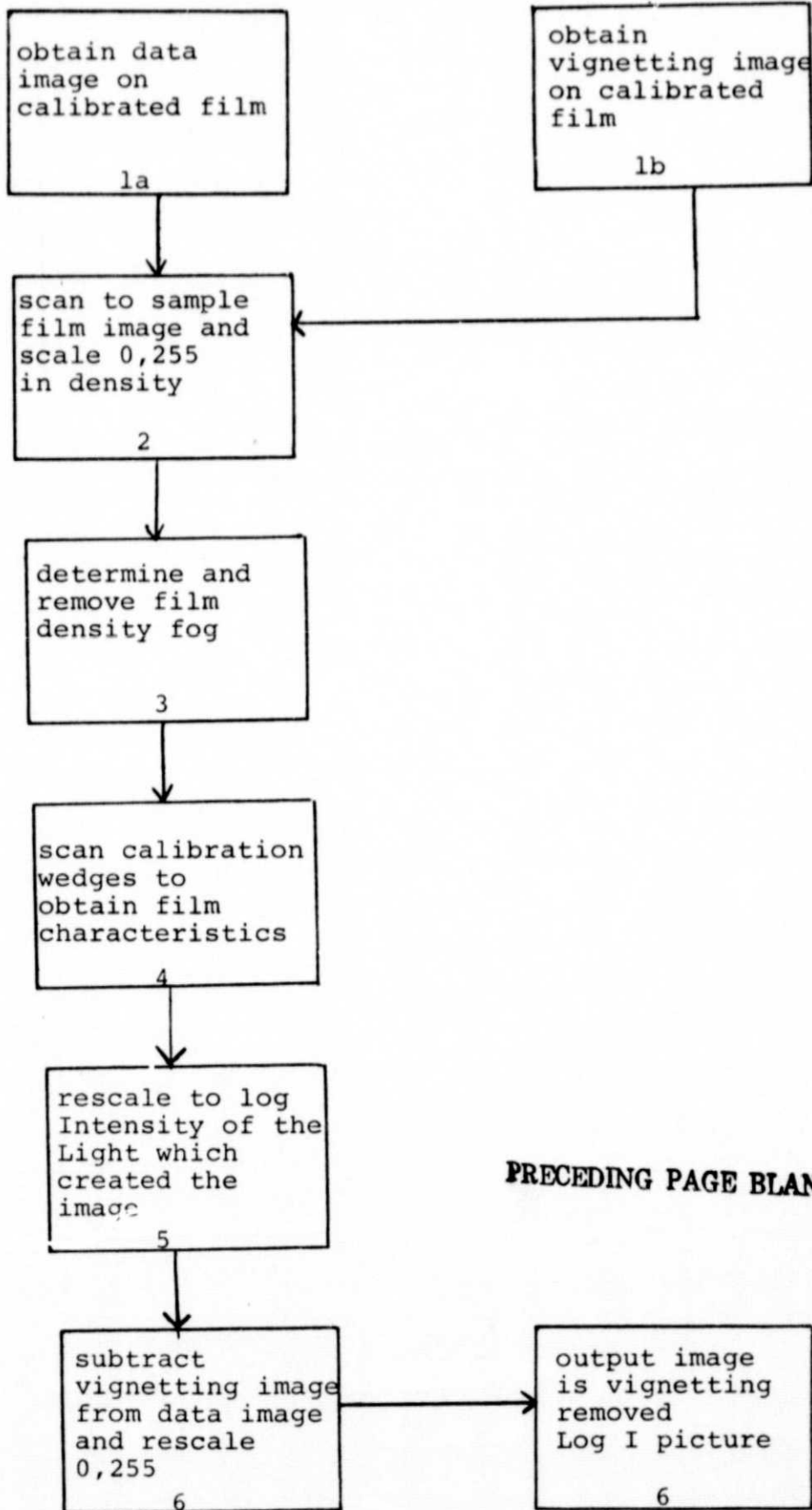
The tables created in step 4 were used to change for scaled density to scaled Log intensity. A 256 entry table was built to map each input number to an output number. Linear interpolation was used to add conversion table values between calibration table values.

Step 6 Remove vignetting

The data and vignetting frames were measured to locate the pixel position for alignment. Figure 4 shows how the sprocket holes were used to register the pictures. Each of the four corner sprocket holes were used as fiducial marks. We made the assumption that between frames on the same strip of film and with the same

camera body the position of the optical axis is fixed with respect to the sprocket holes. This assumption was later reinforced by observing frame to frame discrepancy on the two pixels. That is the relative distance between the sprocket hole and the corner of exposed film varied by not more than two pixels in X and Y.

When the subtraction is performed, results between -255 and 255 may be obtained. We rescale these values to 0,255 by a linear shift so the minimum difference is set to zero. This causes a slight offset of the Log Intensity scales from one data frame to the next. It prevents, however, loss of data off the low contrast or high contrast end of the scale. We have also preserved the equality of data number and log intensity.



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figure 1

Table 1
Neutral Density 2
Scaled Density

Scaled Log I	240sec.	180sec.	120sec.	90sec.	60sec.	30sec.	15sec.
157.7	99	95	91	86	66	67	48
137.5	92	87	81	75	47	48	30
119.6	86	75	67	59	29	29	13
101.1	63	59	48	41	13	14	4
82.9	50	41	29	23	4.5	4.2	1.2
63.9	31	23	14	10	1.2	1.1	.6
47.9	16	11.2	3.1	3.4	.4	.3	0
30.0	7	4.5	1.4	1.5	0	0	
15.6	3	4.9	.5	.03			
0	1	1.0	0				

Table 2
Neutral Density 1
30 sec

Scaled Log I	Scaled Density
255.0	107
233.9	103
216.9	98
198.6	90
180.4	81
161.2	69
145.1	54
127.6	38
113.2	24
97.7	13
82.1	4
68.1	2
52.4	.2

SCALED DENSITY

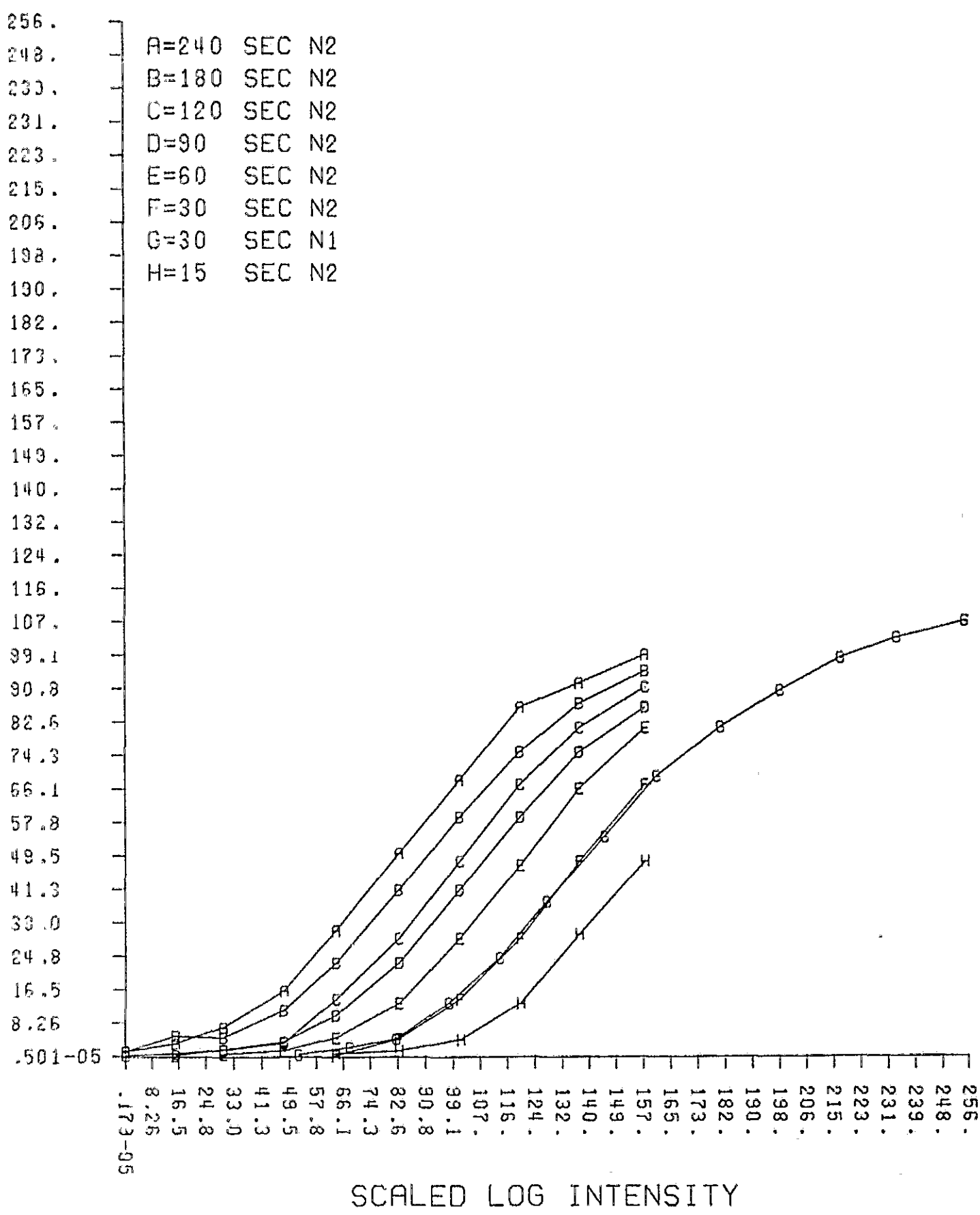


Figure 2

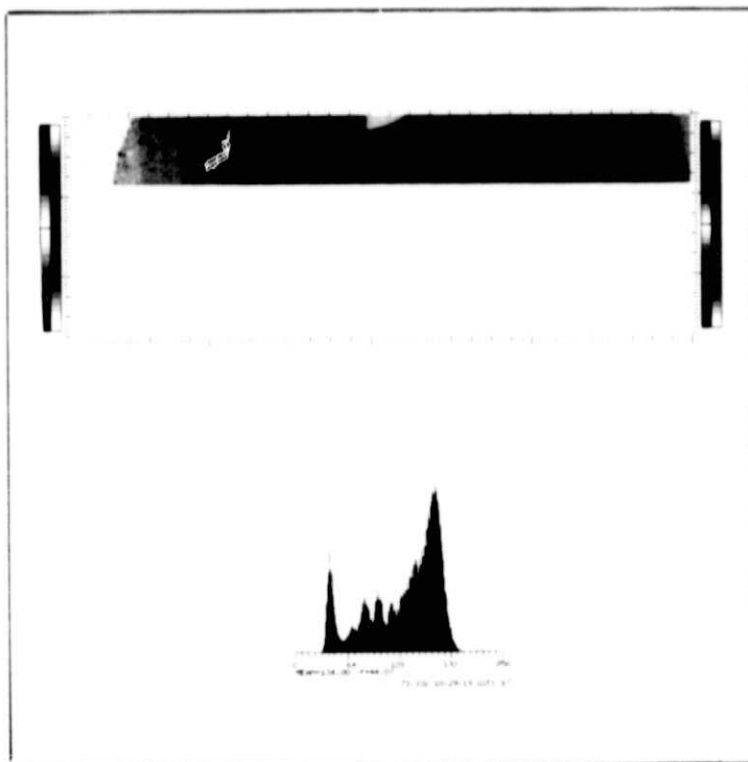


Fig. 3

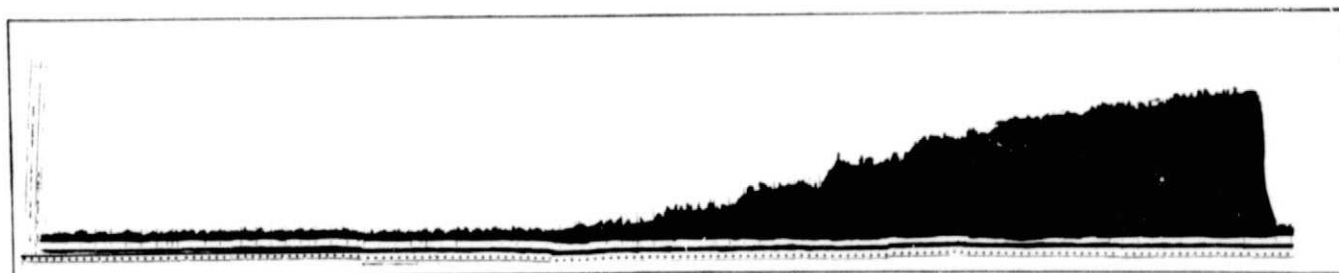


Fig. 4

Comparison of Vignetting

The algorithm presented under sections 2 and 3 was developed during the S211 project. It was felt that further work was needed to obtain a better approximation of the vignetting function. Figure 5 shows the noise on the 60 sec. A15 vignetting frame used in our first attempt to remove vignetting. In this display, every 8th grey level has been set to 255 (white). We can see the shape of the function clearly in this display. The contour lines are wide and diffuse.

Noise in the approximation to the vignetting has had an adverse affect upon the output image. We could have used averaging to remove some of this noise. If we were to have averaged several exposures together, the film grain noise would have been removed. Unfortunately, we did not have multiple exposures of the vignetting function at each exposure time.

Another approach would have been to convolve some smoothing function within a small non-zero window over the vignetting image. This would have had a smoothing effect. As long as the non-zero region of the convolution mask was small compared to the region of high gradient on the vignetting image, no adverse effect would have been produced.

VICAR did not provide an easy means by which to experiment with convolution masks. We therefore chose to average vignetting frames of different exposure time. To insure that this was a legitimate operation, we had to measure the shape of the vignetting function between cameras, exposure times and color filters.

By subtracting two vignetting frames, we could measure their similarity. Figures 6a and 6b show the results of three subtractions. Fig 6a is the 60 A15 frame. Fig 6b is the rescaled difference image, where the 60 sec A15 frame has been subtracted from another A15 60 sec. image. The rescaled histogram shows a large symetric peak at 128 (zero before rescaling).

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Figure 7 a,b shows A15 60 sec. subtracted from A15 - 30 sec. A15 - 15 sec. respectively. This difference shows the same properties as fig. 6b and are therefore the same basic shape. We can use the six Apollo 15 frames to form an average Apollo 15 frame without distorting the vignetting shape. Figure 10a is that average image with every eighth grey level enhanced to show contours. The Log intensity difference between contours is 0.17. The averaging has had the desired result of lowering the noise as evidenced in the less diffuse contours. We conclude that, as predicted by the geometrical optics explanation of¹ vignetting, shape is independent of exposure time.

Figure 8 shows the difference between the Apollo 16 30 no filter and blue filter vignetting frame. The histogram is shifted because of different incident intensity levels with the red filter in place. The histogram is still symmetric and no banding is evident. It is our conclusion that the various filters used did not effect the basic shape of the vignetting function.

The next comparison is that between lenses. If the lens for the three flights were to be the same, a single average vignetting function can be produced and used independent of the flight upon which the data were taken. Grain noise removal would have also been better with a higher number of images to average. Figure 9a,b shows the Apollo 16 - 15 30 sec. and Apollo 17-15 30 sec. There appears to be no banding. However, the histograms have become more asymmetric. Figure 10 a, b,c are the average contoured A15, A16 and A17. The contours show the difference in the vignetting shape between lens. We conclude from this that the three lens used are different enough in their vignetting functions to advise against using a single average vignetting in removal attempts.

¹Fundamentals of Optics, Jenkin and White, P. 115 McGraw Hill, 1957

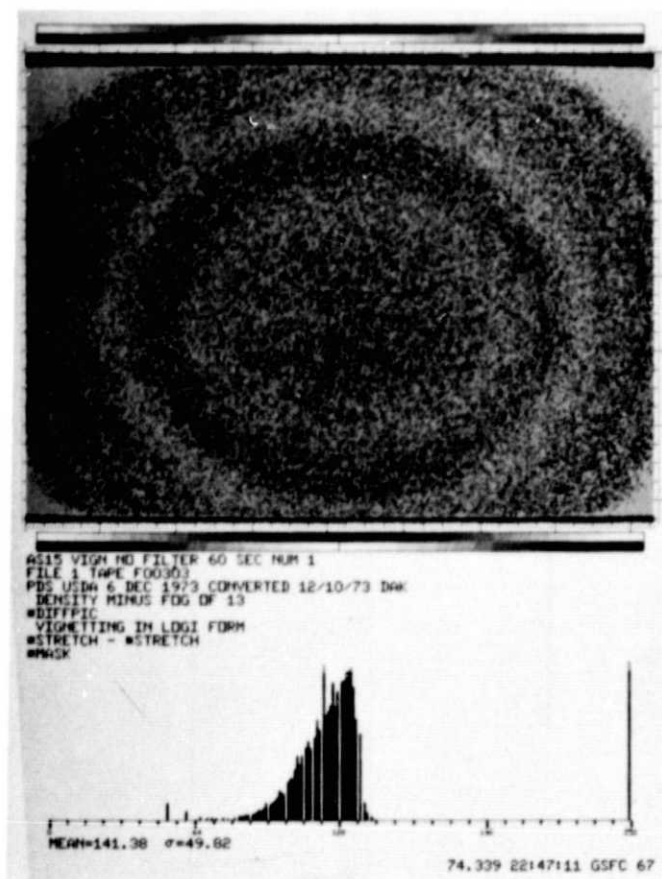


Fig. 5

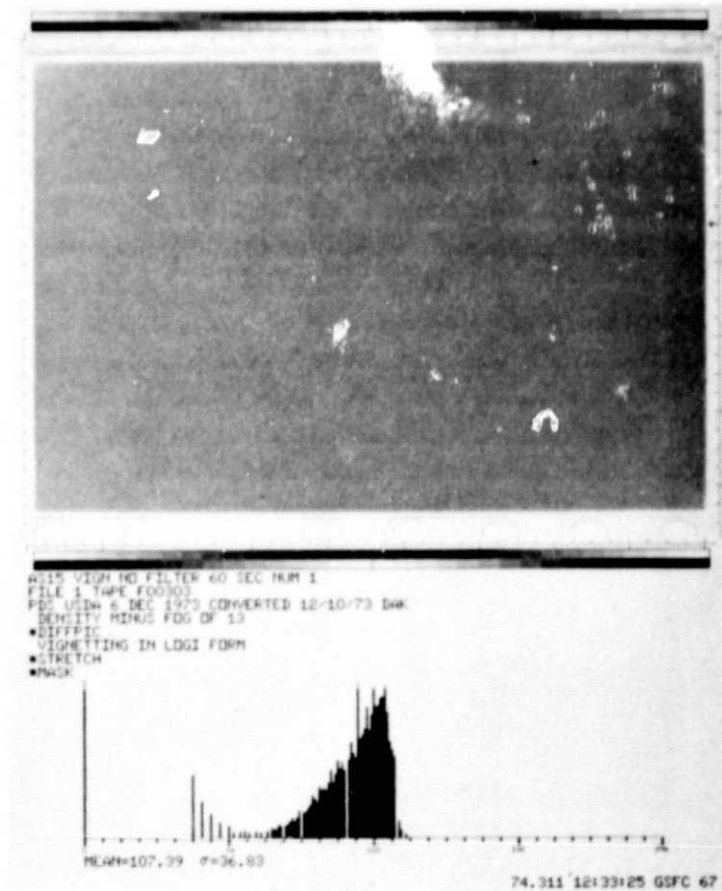


Fig. 6a

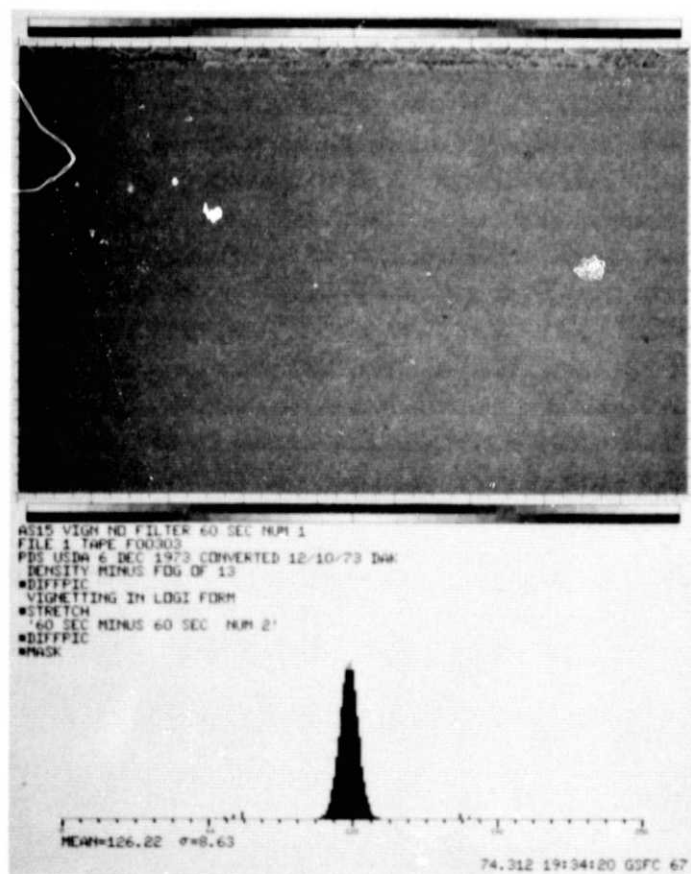


Fig 6b

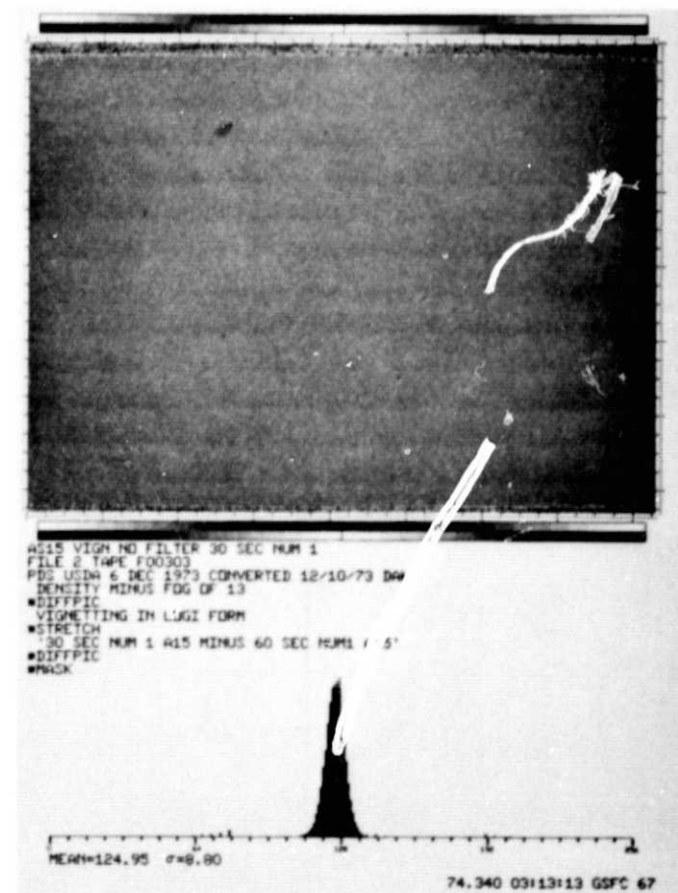


Fig. 7a

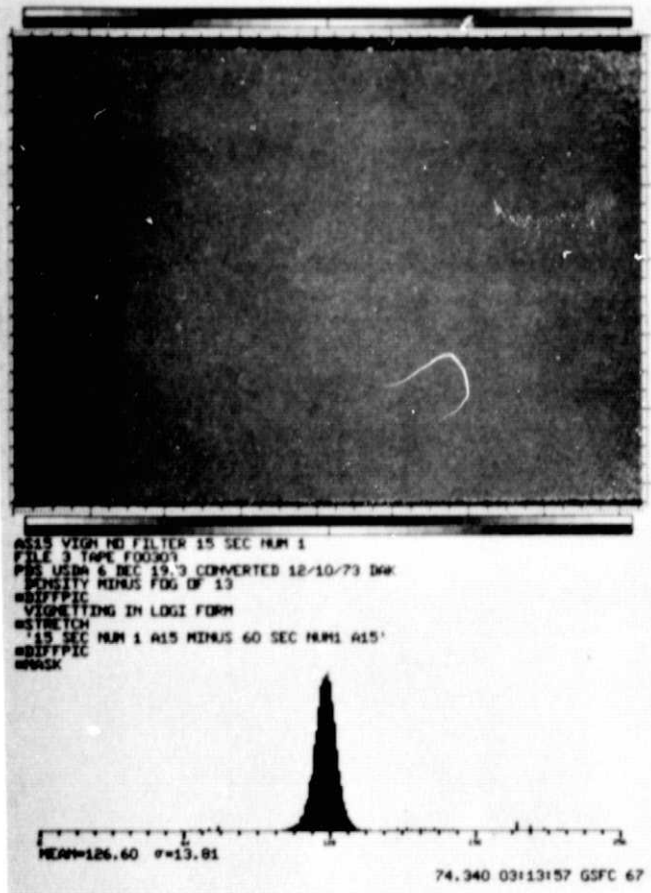


Fig. 7b

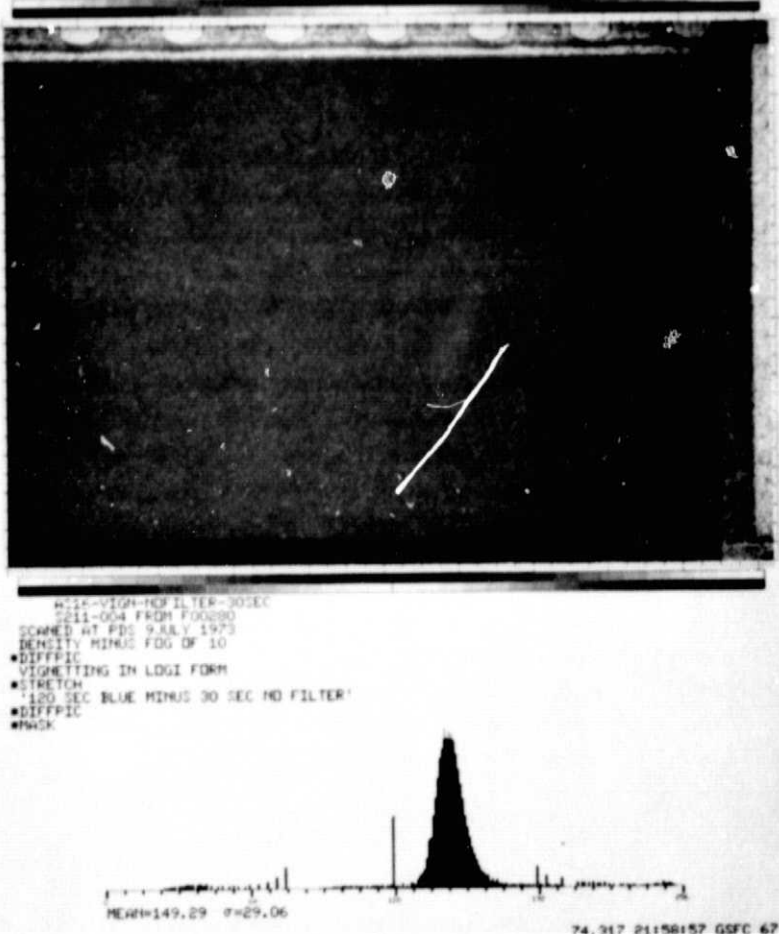


Fig. 8

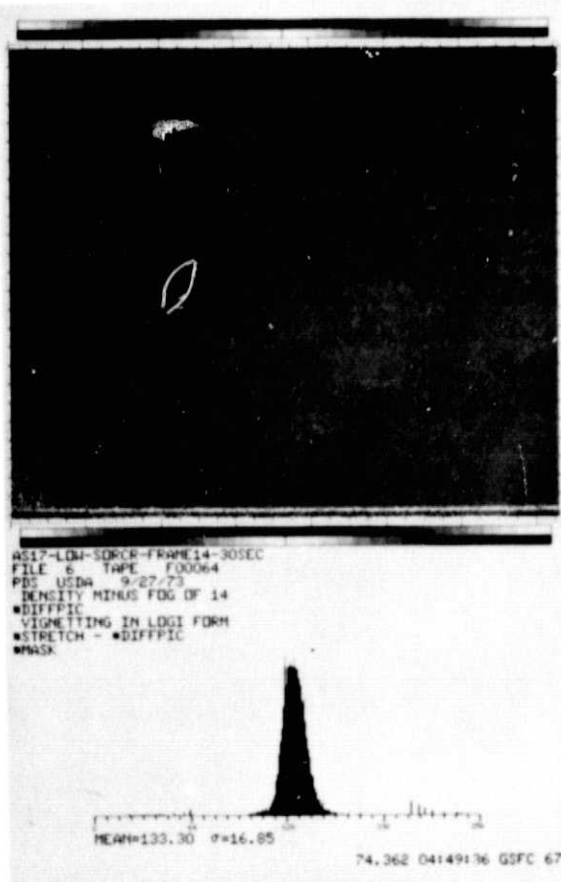


Fig. 9a

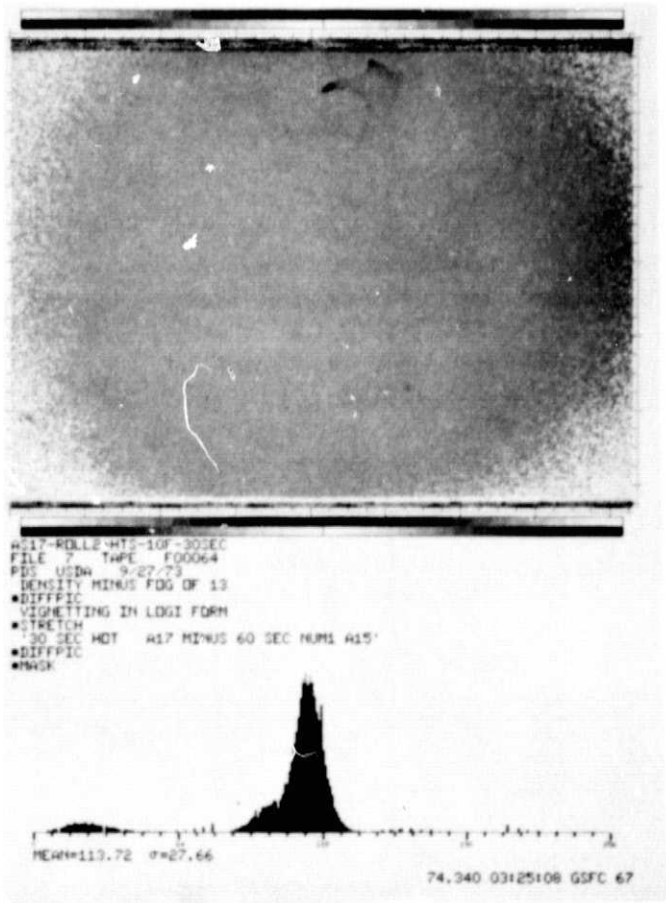
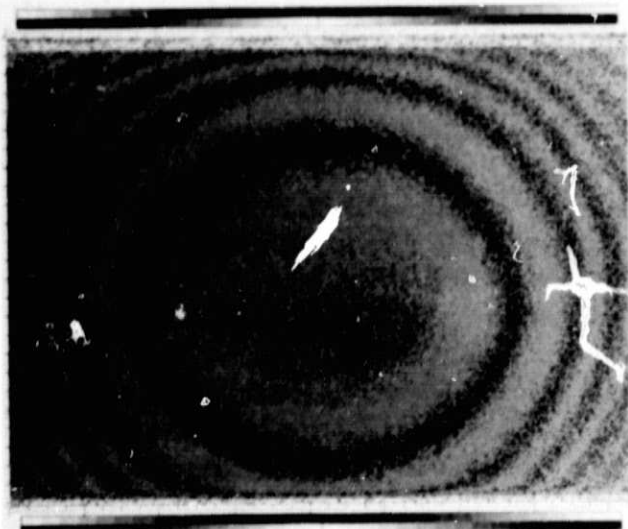
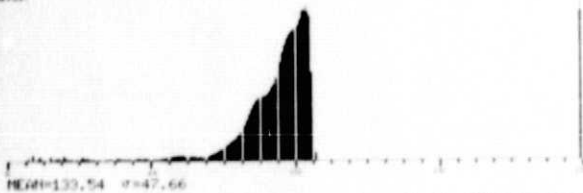


Fig. 9b

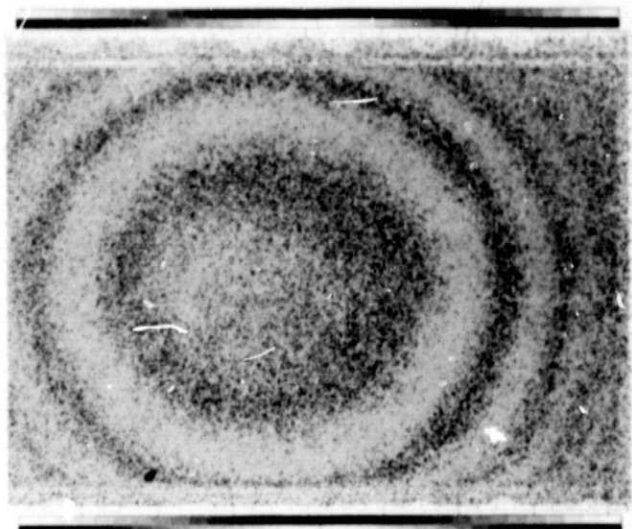


W15 VIGN NO FILTER 60 SEC NIM 1
 FILE 1 TAPE F00303
 PDS UTM 6 DEC 1973 CONVERTED 12/10/73 DW
 DENSITY MINUS FOG DF 10
 *DIFFIC
 *VIGNETTING IN LOGI FORM
 *STRETCH - *PICAVE - *STRETCH
 *MASK



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Fig. 10a

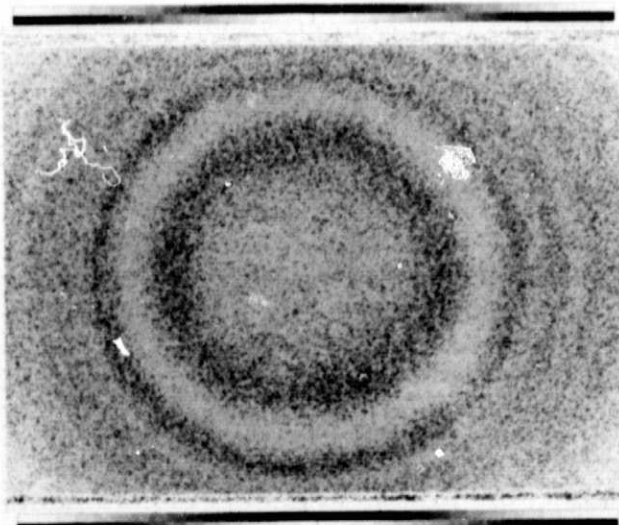


W16 VIGN NO FILTER 30 SEC
 S11-004 FROM F00280
 SCANNED AT PDS 9.55.7 1973
 DENSITY MINUS FOG DF 10
 *DIFFIC
 *VIGNETTING IN LOGI FORM
 *STRETCH - *GEOM - *PICAVE - *STRETCH
 *MASK

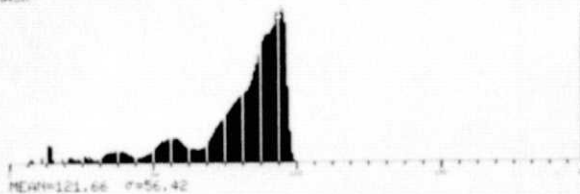


74.341 13153128 GSFC 67

Fig. 10b



W17 VIGN BLUE FILTER S-N 1006 180SEC 1
 FILE 5 TAPE F00301
 PDS UTM 5 DEC 1973
 DENSITY MINUS FOG DF 10
 *DIFFIC
 *VIGNETTING IN LOGI FORM
 *STRETCH - *PICAVE - *STRETCH
 *MASK



74.341 13154109 GSFC 67

Fig. 10c

ORIGINAL PAGE IS
OF POOR QUALITY

Examples of Results

Figures 11a through 11h are results of processing frame AS15-101-13566-LL4-240SEC, a photograph of the fourth lagrange libration point for the earth moon system. The photograph was taken on 31 July 1971 at 13:37 GMT. The 240 second exposure was centered at $23^{\text{h}} 15^{\text{m}}$ Right Asension -3 declination taken from lunar orbit in double umbra shadow. Figure 11a is the density image. 11b is 11a after converting to Log Intensity. Note the circular shape to the 'bright' (dark) region in 11b. This is the same shape one sees in figure 10a (the A15 vignetting function). There is a spacecraft oscuration in the upper left side of all these images. Figure 11c is an attempt to contour the Log I image by setting to black every 4th grey level. Figure 11d is a vignetting removed image. Comparison of the background between 11b and 11d along a horizontal line Y4 of the way up the image shows the background flatter in 11d than in 11b. The pronounced circular edge of 11b is gone from 11d. A bright spot appears to still exist at center in the upper portion at 11d. This region is asymeric and off axis so thus may well be the L4 dust cloud.

Figure 11f is another Log I image which has been shifted to avoid scale trucation when vignetting is removed. The DN/4 Log I factor is left constant but dn of 64 on all such offset images does not imply the same intensity light created the image. Figure 11e is a contoured vignetting removed version. There seems to be some residual vignetting as evidenced by the short arc in the lower righthand corner of 11e. Figures 11g and 11h are contrast enhanced versions of 11d (vignetting removed). These two images show the L4 cloud to be quite asymeric and off axis.

Figure 12 through 17 are images taken of the rising sun to show outer corona and inner zodiacal light. Table 3 gives the data on when and how these images were taken. Figure

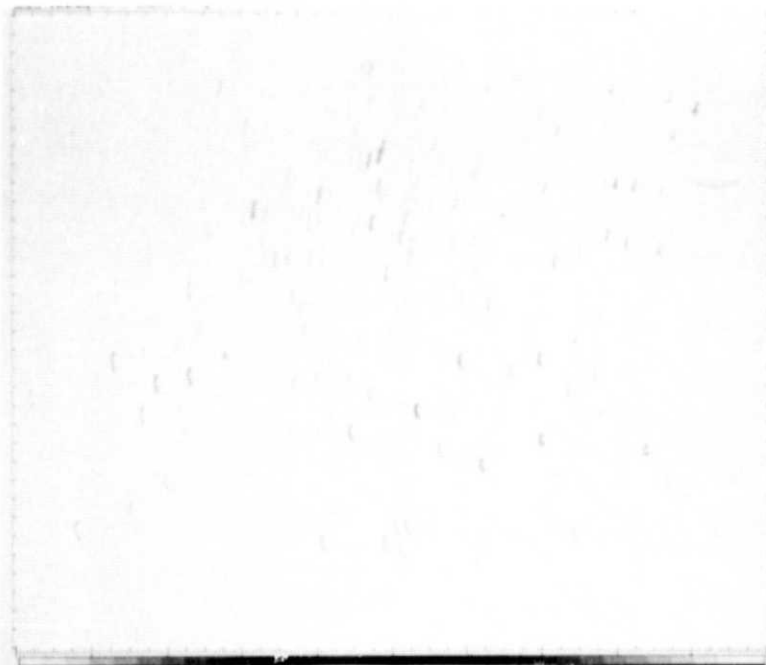
12a, b, c and d are density, Log I, contoured Log I and Vignetting removed respectively. Figure 12e is a contoured vignetting removed image with offset log scale.

Figure 13a is a density image while 13b is an offset Log I image. Figures 13c and 13d are both vignetting removed images with different vignetting functions used. 13d was done with the 60 sec A15 function while 13c was done with the Average A15 function. Figure 13e and 13f are contoured offset images. 13e has vignetting still in it and 13f has it removed. Figure 13f has visible circular bands. It appears that in this case we over-corrected for vignetting. Figure 13 is a short exposure time image. Although we have seen the exposure time has no effect upon vignetting shape, the light levels of a 20 sec exposure are sufficiently different from those of a 60 sec one as to lose normalization when we subtract.

Figures 14a, b, c and d are density Log I, offset Log I vignetting removed series of a zodiacal light image. Figure 15a, b, and c represent another zodiacal light series of density, offset Log Intensity and vignetting removed offset contoured image.

Figure 16a is a density image. Figure 16b is a Log I image that has had the contrast deminished by an attempt to contour it by setting every eight grey levels to 256. 15c is the offset Log I image and 16d has had the vignetting removed. Here there seems to be a small residual vignetting not apparent in the upper lefthand corner (where there was spacecraft obscuration).

Figure 17a, b and c is a series similar to that of figure 15 density, offset Log I, and contoured vignetting removed, offset image respectively.



W15-101-17566-LL4-240SEC
 2211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 DENSITY MINUS FOG (DN=48=0.98D)
 *DIFFPIC
 *THICK

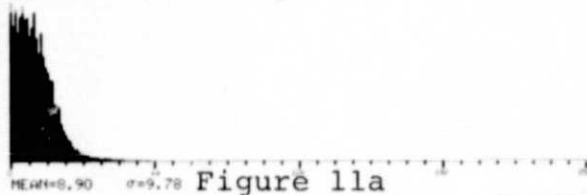
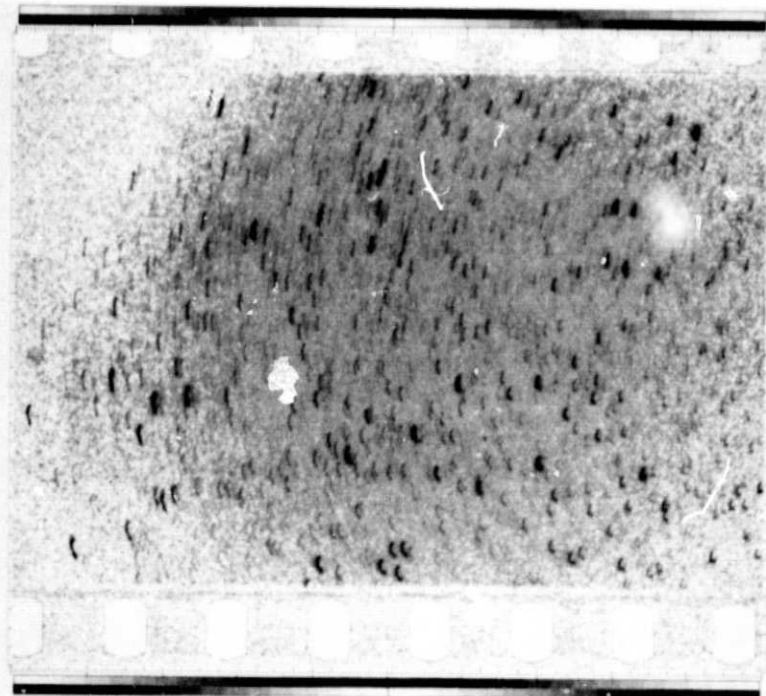
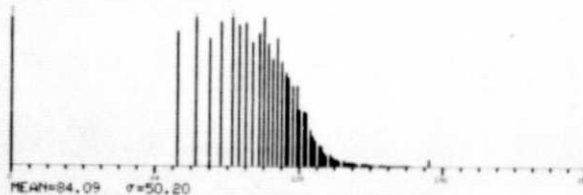


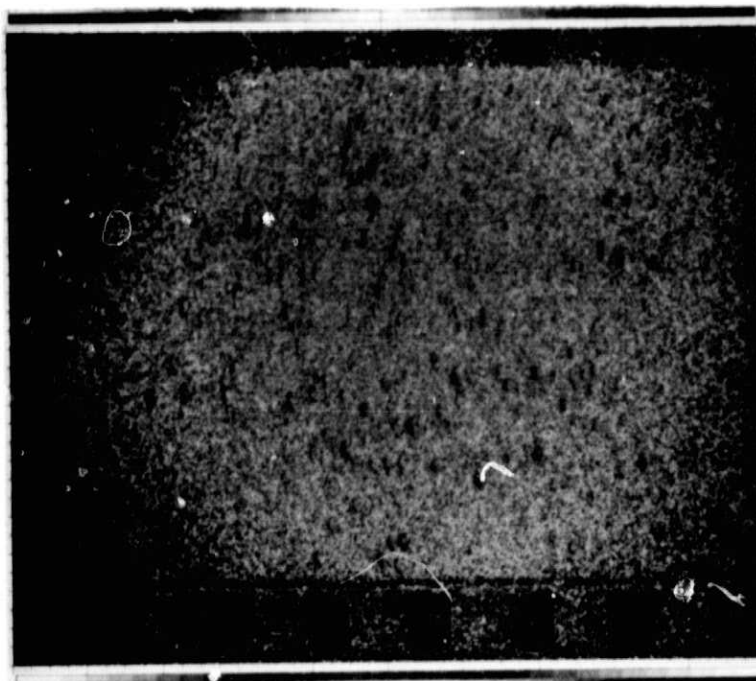
Figure 11a

74.311 12:50:53 GSFC 67

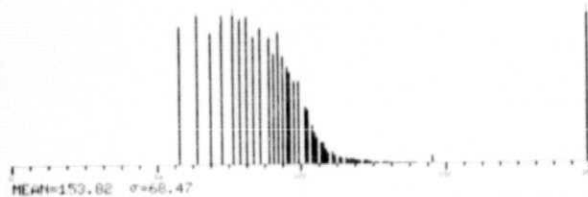


W15-101-17566-LL4-240SEC
 2211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 DENSITY MINUS FOG (DN=48=0.98D)
 *DIFFPIC
 LOG OF INTENSITY
 *STRETCH
 *THICK





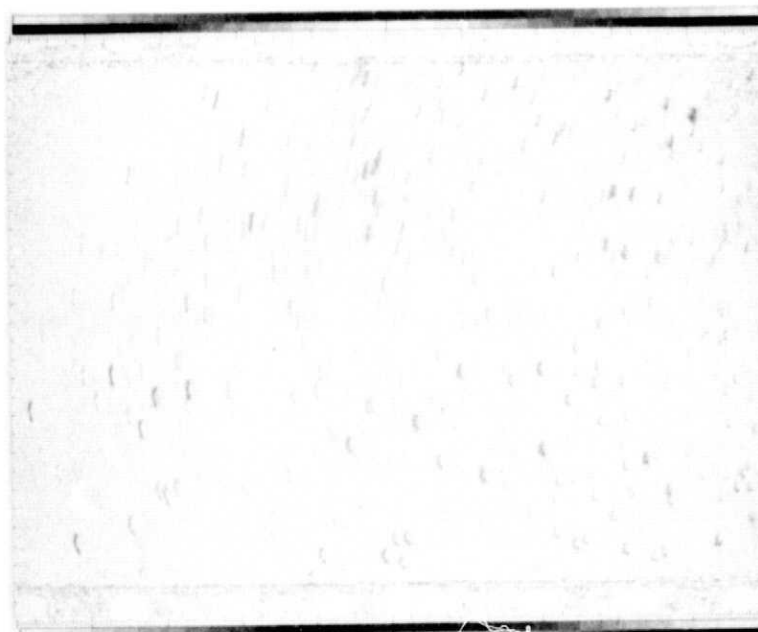
W15-101-1756-LL4-2405C
 S211-004 FROM F00280
 SCANNED AT PDS 9.88LY 1973
 'DENSITY MINUS FOG (Dm=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH - *STRETCH
 *MASK



MEAN=153.82 σ =68.47

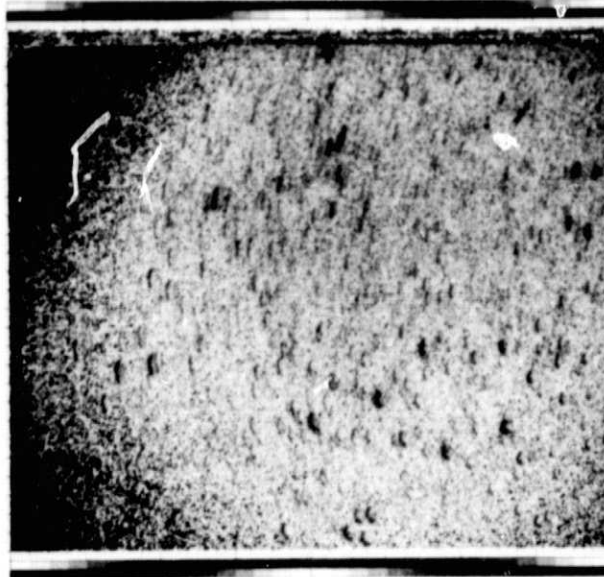
74.351 05:21:29 G5FC 67

Figure 11c



W15-101-1756-LL4-2405C
 S211-004 FROM F00280
 SCANNED AT PDS 9.88LY 1973
 'DENSITY MINUS FOG (Dm=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 'VIGNETTING REMOVED'
 *DIFFPIC
 *MASK





H15-101-1756-LL4-240SEC
 S211-004 FROM F00290
 SCANNED AT FDS JULY 1973
 'DENSITY MINUS FDG (Dm=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFPIC - *DIFFPIC - *STRETCH
 *MASK

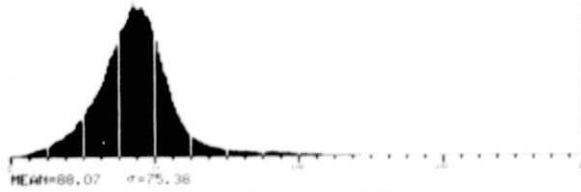
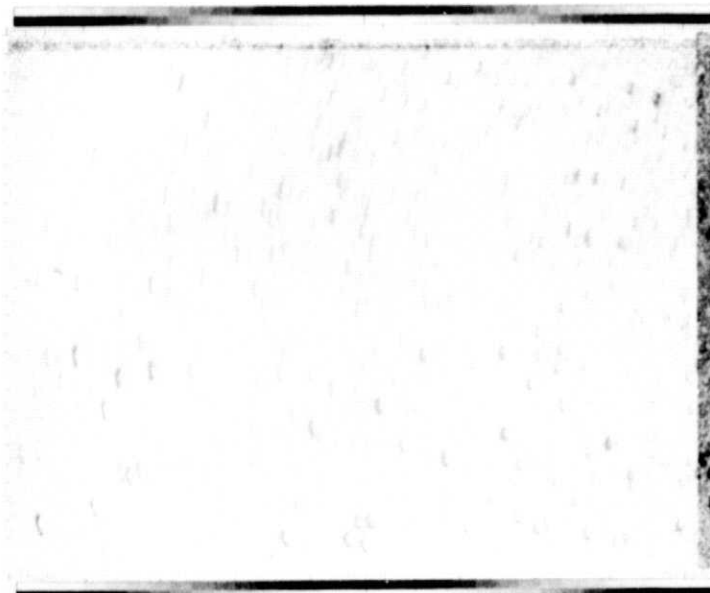


Figure 11e



H15-101-1756-LL4-240SEC
 S211-004 FROM F00290
 SCANNED AT FDS JULY 1973
 'DENSITY MINUS FDG (Dm=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFPIC
 *MASK

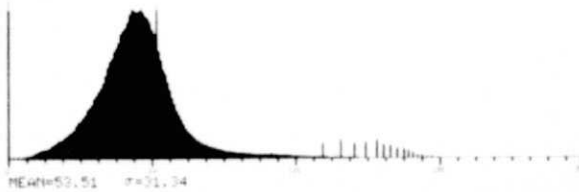


Figure 11f



W15-101-10566-LL4-2405C
 2211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 DENSITY MINUS FDG (Dn=48=0.98D)
 *DIFFPIC
 LOG OF INTENSITY
 *STRETCH
 LOGI MINUS LOGV
 *DIFFPIC
 ---STRETCH=0.128---
 *MASK

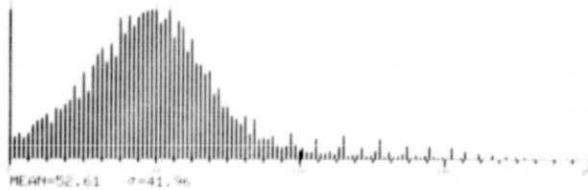


Figure 11g



W15-101-10566-LL4-2405C
 2211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 DENSITY MINUS FDG (Dn=48=0.98D)
 *DIFFPIC
 LOG OF INTENSITY
 *STRETCH
 LOGI MINUS LOGV
 *DIFFPIC
 ---STRETCH=0.64---
 *MASK

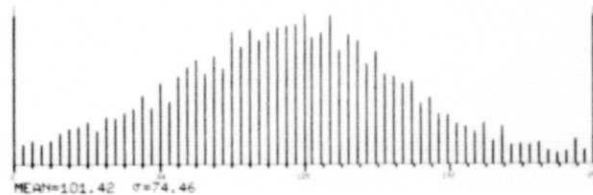


Figure 11h



W15-100-17531-2L-30SEC
 2211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 *DENSITY MINUS FDG (DN=48=0.98D)
 *DIFFIC
 *PBACK

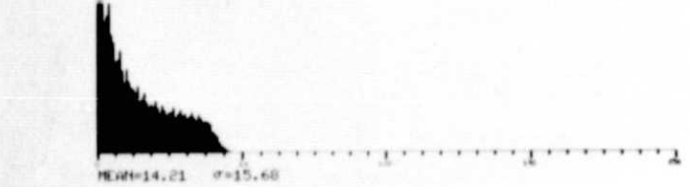
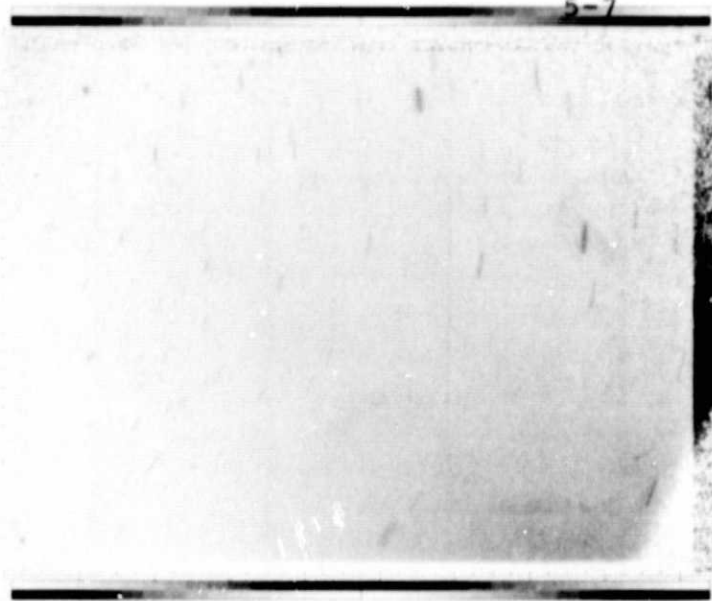


Figure 12a



W15-100-17531-2L-30SEC
 2211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 *DENSITY MINUS FDG (DN=48=0.98D)
 *DIFFIC
 LOG OF INTENSITY
 *STRETCH
 *ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFIC
 *PBACK

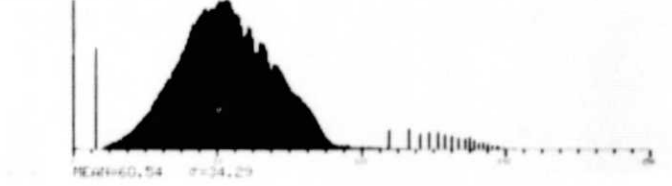
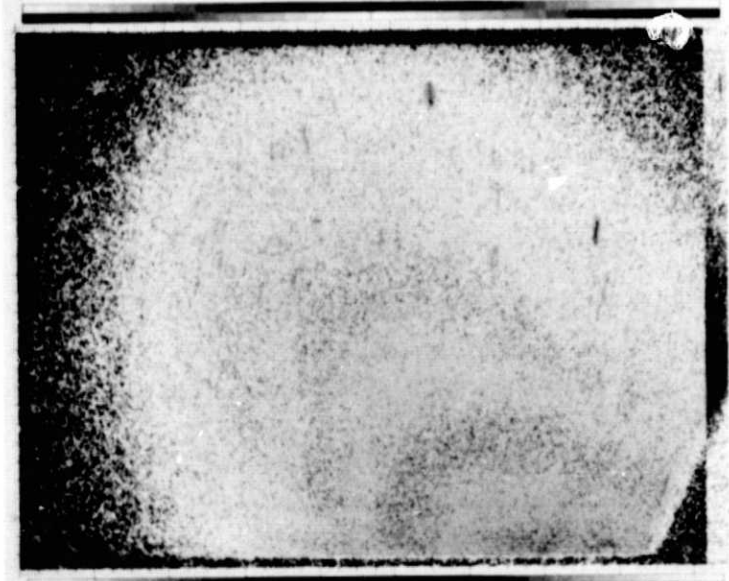
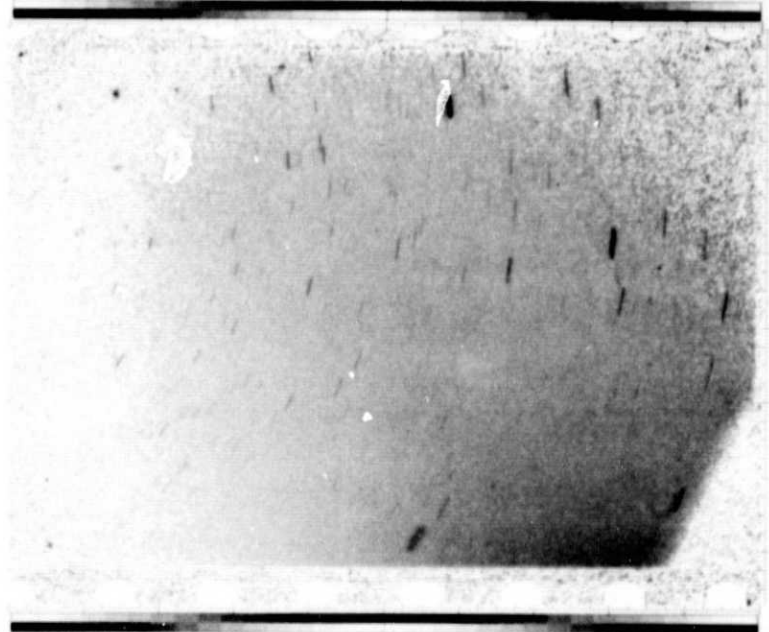
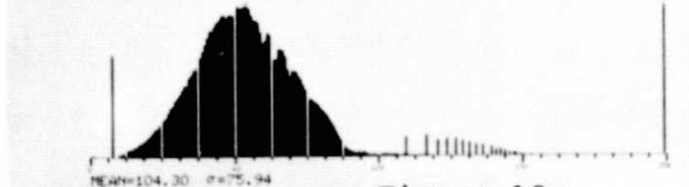


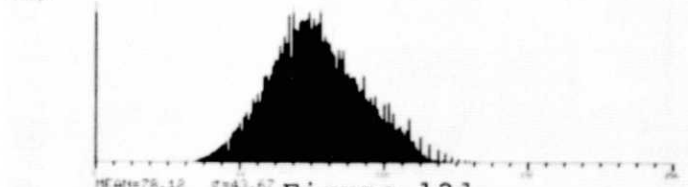
Figure 12b



W15-100-17531-2L-30SEC
 2211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 *DENSITY MINUS FDG (DN=48=0.98D)
 *DIFFIC
 LOG OF INTENSITY
 *STRETCH
 *ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFIC - *STRETCH
 *PBACK



W15-100-17531-2L-30SEC
 2211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 *DENSITY MINUS FDG (DN=48=0.98D)
 *DIFFIC
 LOG OF INTENSITY
 *STRETCH
 VIGNETTING REMOVED
 *DIFFIC
 *PBACK





AS15-100-13531-2L-20SEC
 S211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFPIC - *DIFFPIC - *STRETCH
 *MASK

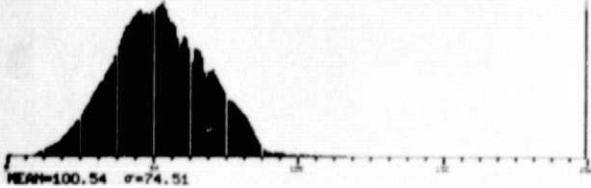
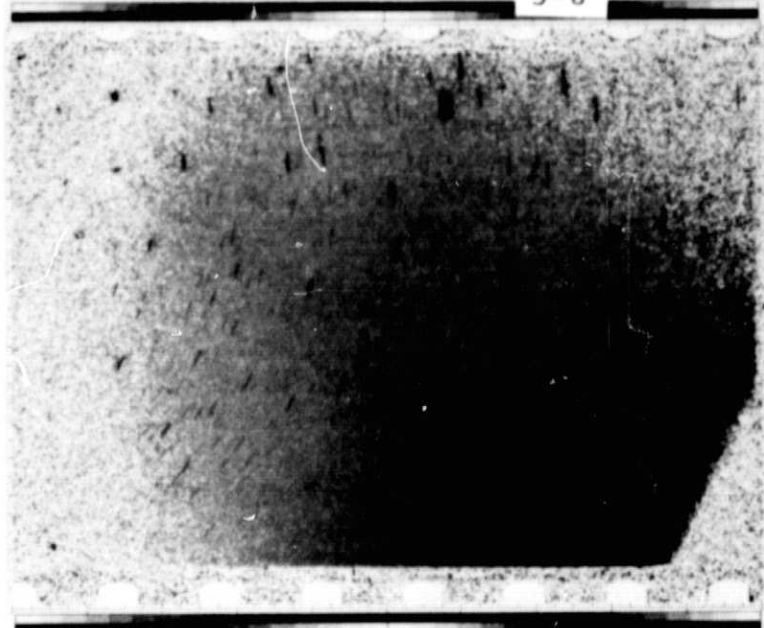


Figure 12e



AS15-100-13531-2L-20SEC
 S211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 'VIGNETTING REMOVED'
 *DIFFPIC
 *MASK

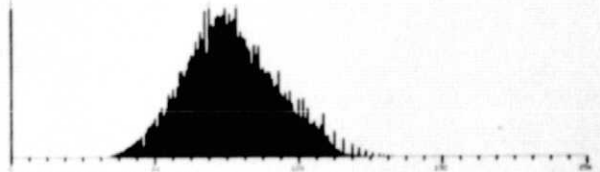
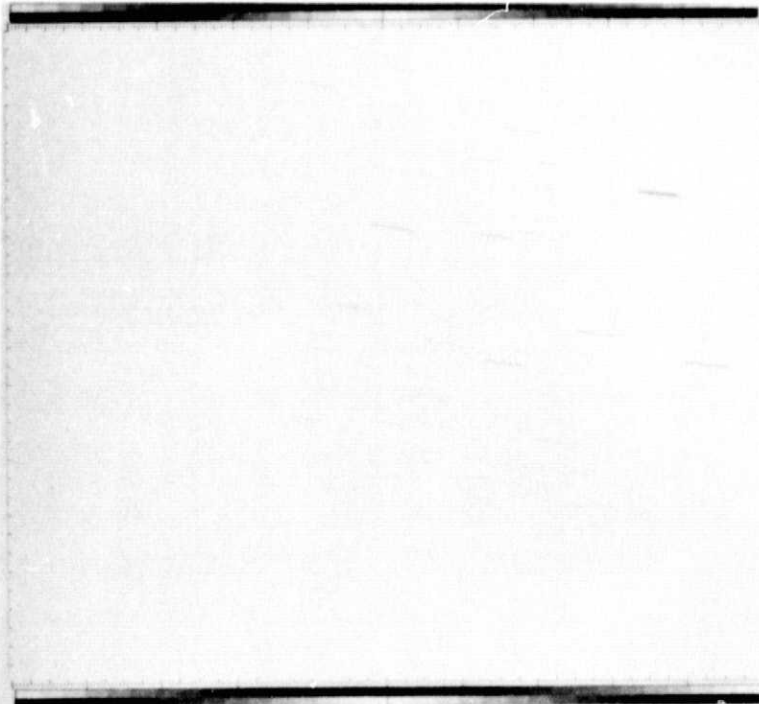


Figure 12f



AS15-100-13529-2L-20SEC
 S211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 *MASK

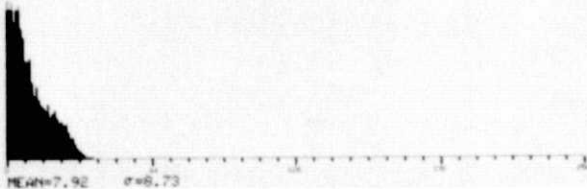


Figure 13a



AS15-100-13529-2L-20SEC
 S211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFPIC
 *MASK

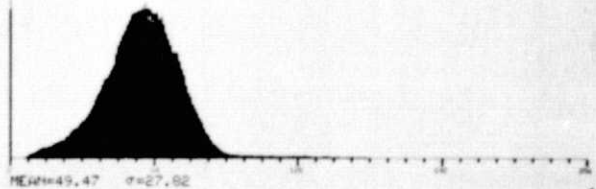
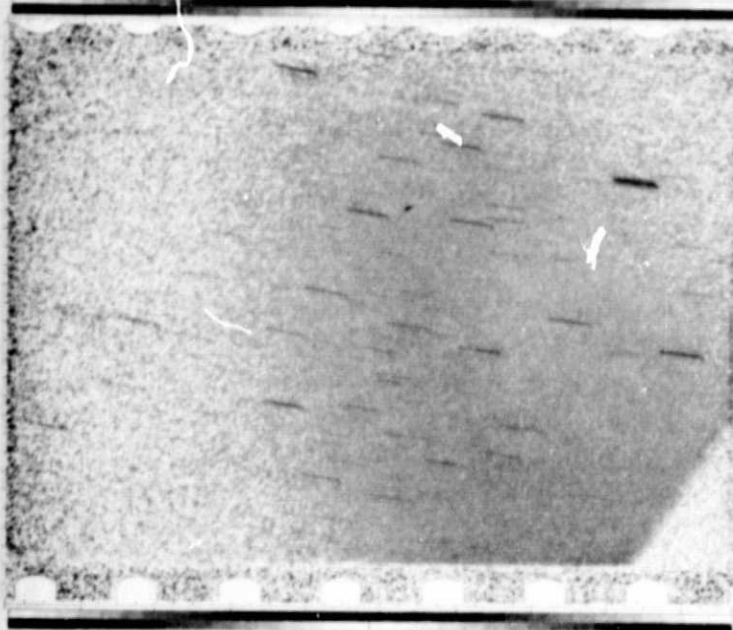


Figure 13b



A515-100-17529-2L-20SEC
 S211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 *DENSITY MINUS FDG (DN=48=0.98D)
 *DIFFPIC
 *LOG OF INTENSITY
 *STRETCH
 *VIGNETTING REMOVED
 *DIFFPIC
 *MASK

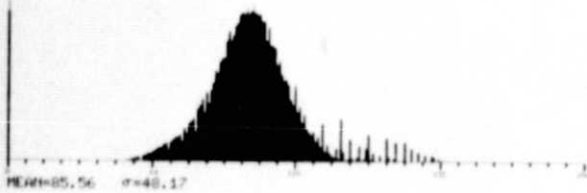
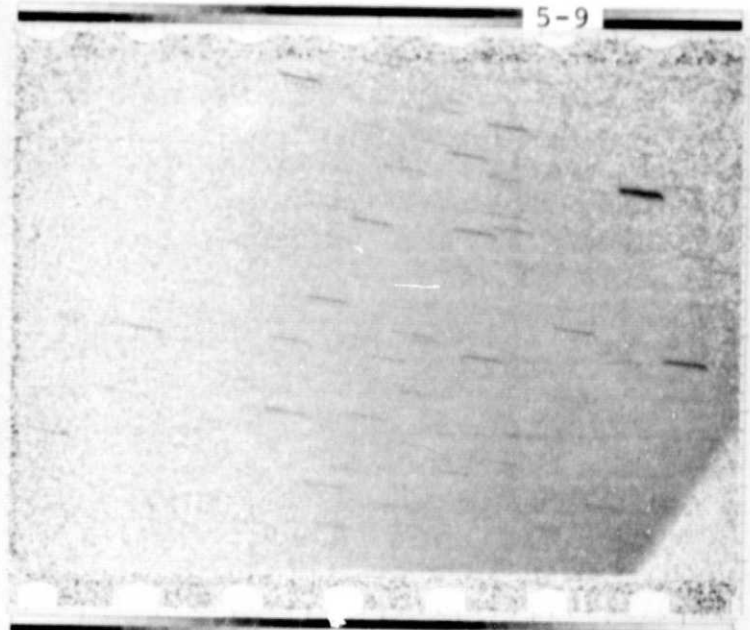


Figure 13c



A515-100-17529-2L-20SEC
 S211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 *DENSITY MINUS FDG (DN=48=0.98D)
 *DIFFPIC
 *LOG OF INTENSITY
 *STRETCH
 *VIGNETTING REMOVED
 *DIFFPIC
 *MASK

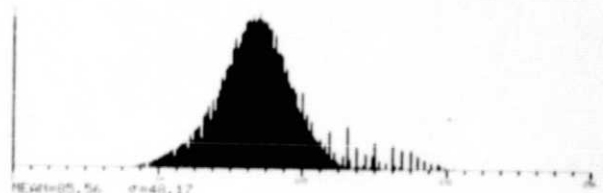
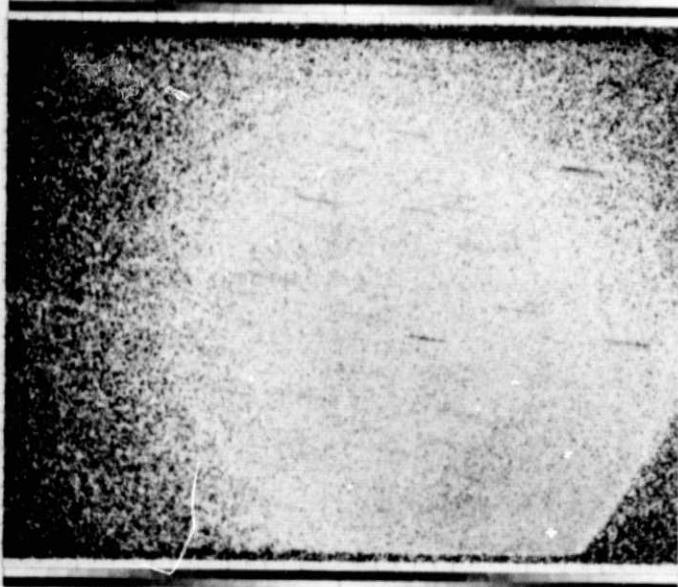
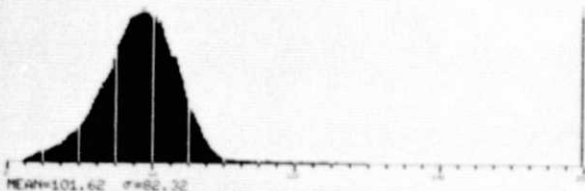


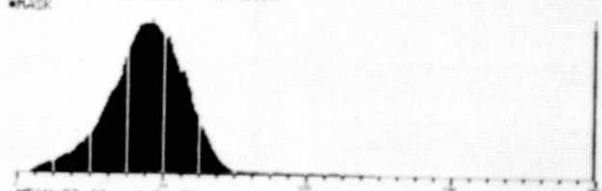
Figure 13d



A515-100-17529-2L-20SEC
 S211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 *DENSITY MINUS FDG (DN=48=0.98D)
 *DIFFPIC
 *LOG OF INTENSITY
 *STRETCH
 *ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFPIC - *STRETCH
 *MASK



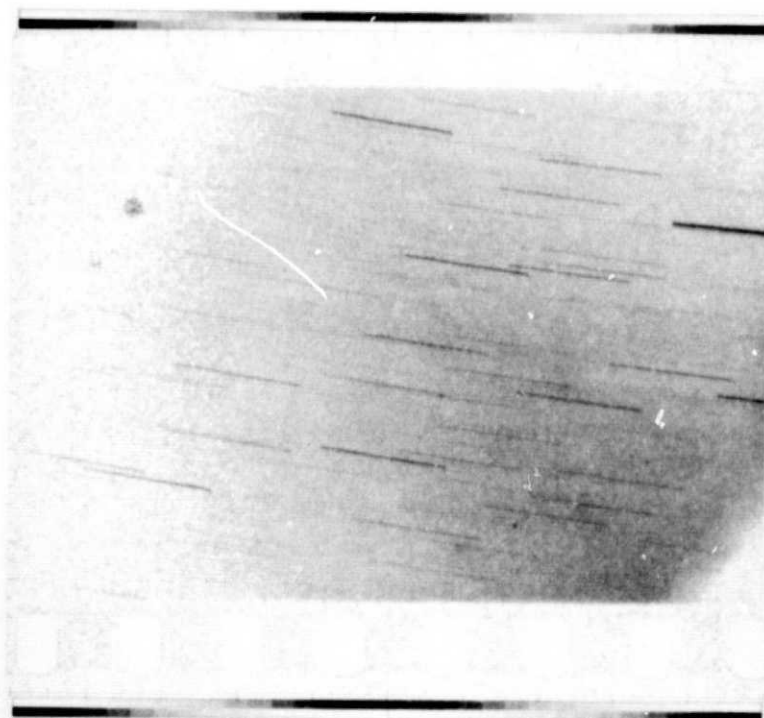
A515-100-17529-2L-20SEC
 S211-005 FROM F00281
 SCANNED AT PDS 9 JULY 1973
 *DENSITY MINUS FDG (DN=48=0.98D)
 *DIFFPIC
 *LOG OF INTENSITY
 *STRETCH
 *ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFPIC - *STRETCH
 *MASK





W15-100-13528-2L-60SEC
S211-005 FROM F00281
SCANNED AT PDS 9 JULY 1973
'DENSITY MINUS FDG (DN=48=0.98D)'
*DIFFPIC
*MASK

Figure 14a



W15-100-13528-2L-60SEC
S211-005 FROM F00281
SCANNED AT PDS 9 JULY 1973
'DENSITY MINUS FDG (DN=48=0.98D)'
*DIFFPIC
'LOG OF INTENSITY'
*STRETCH
*MASK

Figure 14b

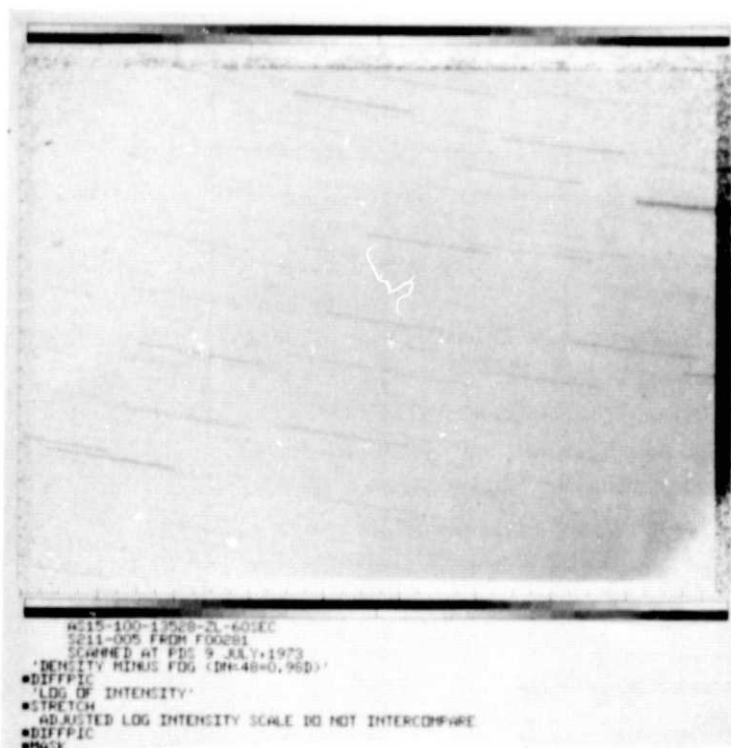


Figure 14c

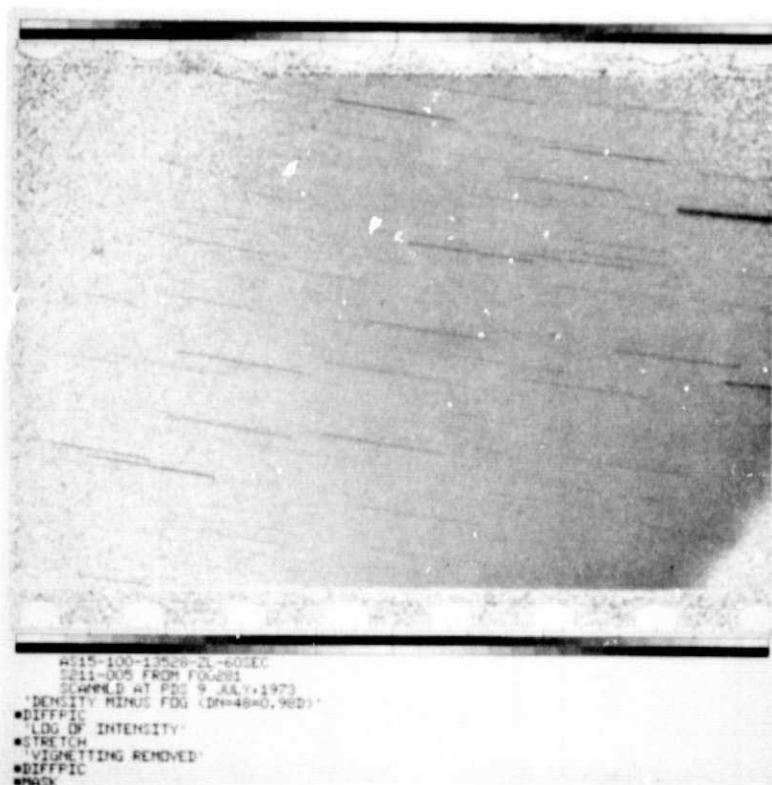


Figure 14d



W15-10012513-ZL-120SEC
 S211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 *MASK

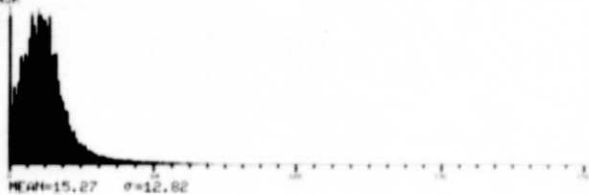
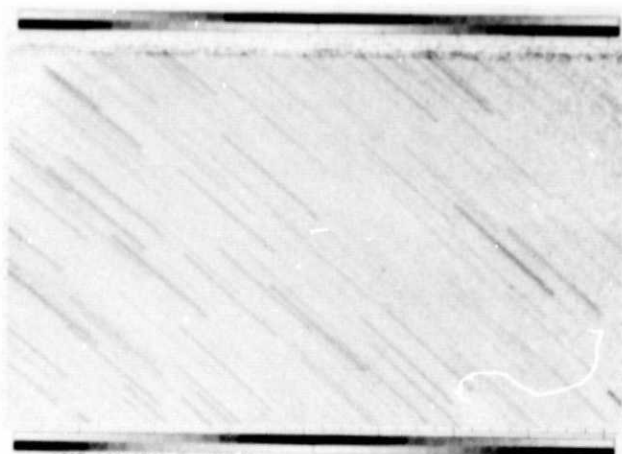


Figure 15a



W15-10012513-ZL-120SEC
 S211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 'ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE'
 *DIFFPIC
 *MASK

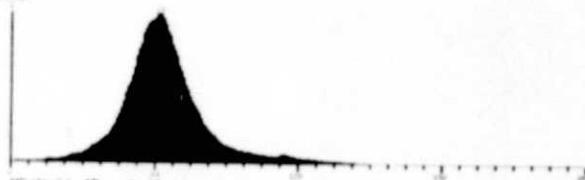
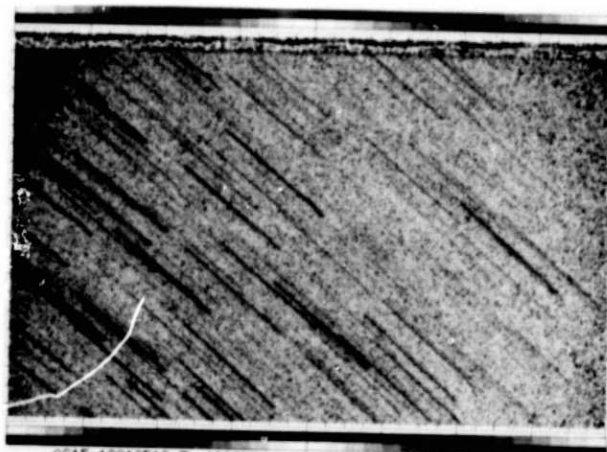


Figure 15b



W15-10012513-ZL-120SEC
 S211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 'ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE'
 *DIFFPIC - *DIFFPIC - *STRETCH
 *MASK

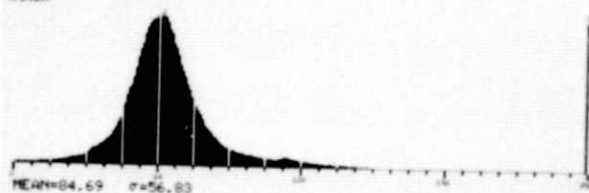
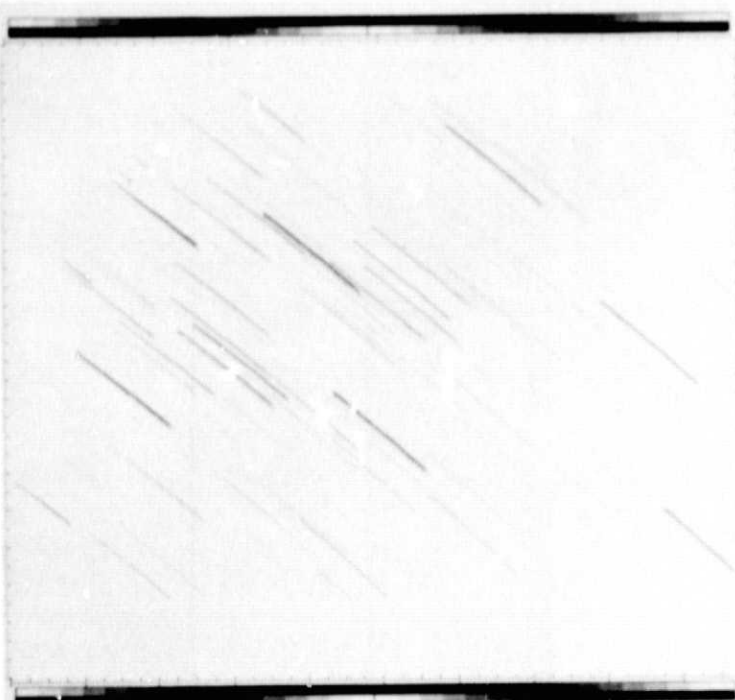


Figure 15c



AS15-100-13515-2L-1205EC
 S211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 #NASK

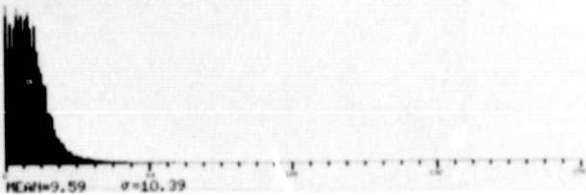


Figure 16a



AS15-100-13515-2L-1205EC
 S211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH - *STRETCH
 #NASK

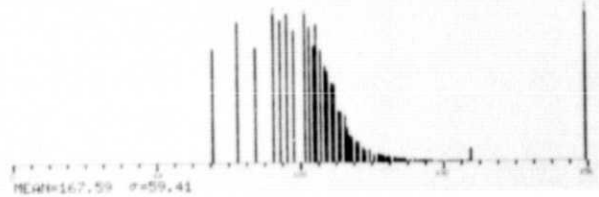
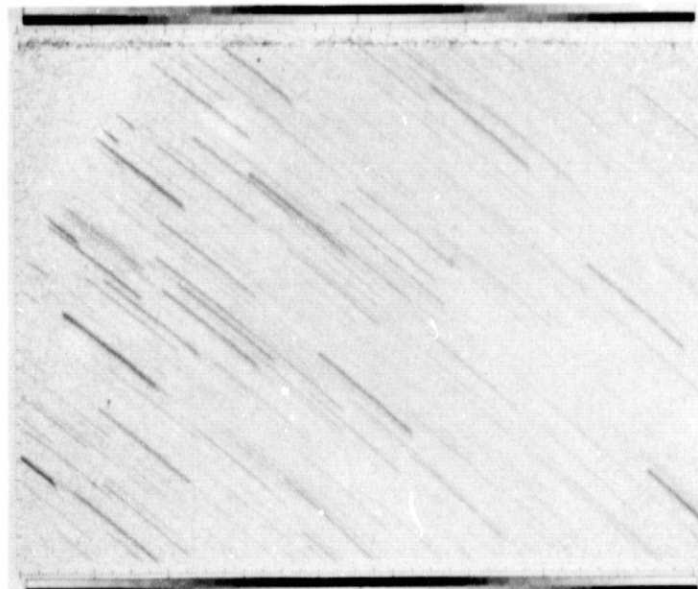


Figure 16b



AS15-100-13515-2L-1205EC
 S211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFPIC
 #NASK

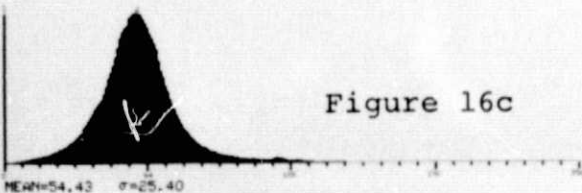
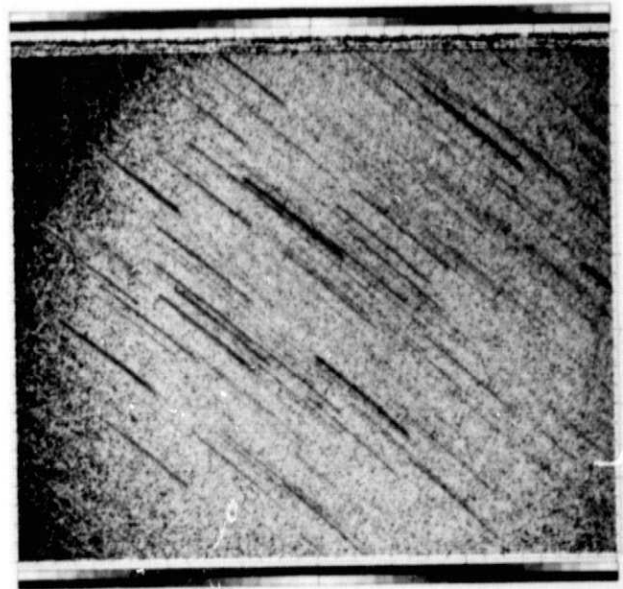


Figure 16c



AS15-100-13515-2L-1205EC
 S211-004 FROM F00280
 SCANNED AT PDS 9 JULY 1973
 'DENSITY MINUS FDG (DN=48=0.98D)'
 *DIFFPIC
 'LOG OF INTENSITY'
 *STRETCH
 ADJUSTED LOG INTENSITY SCALE DO NOT INTERCOMPARE
 *DIFFPIC - *DIFFPIC - *STRETCH
 #NASK

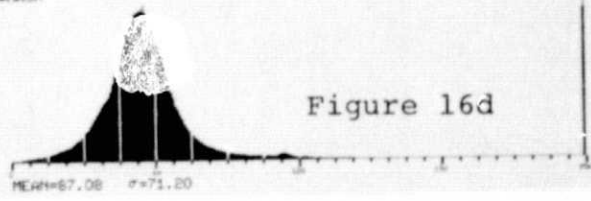


Figure 16d

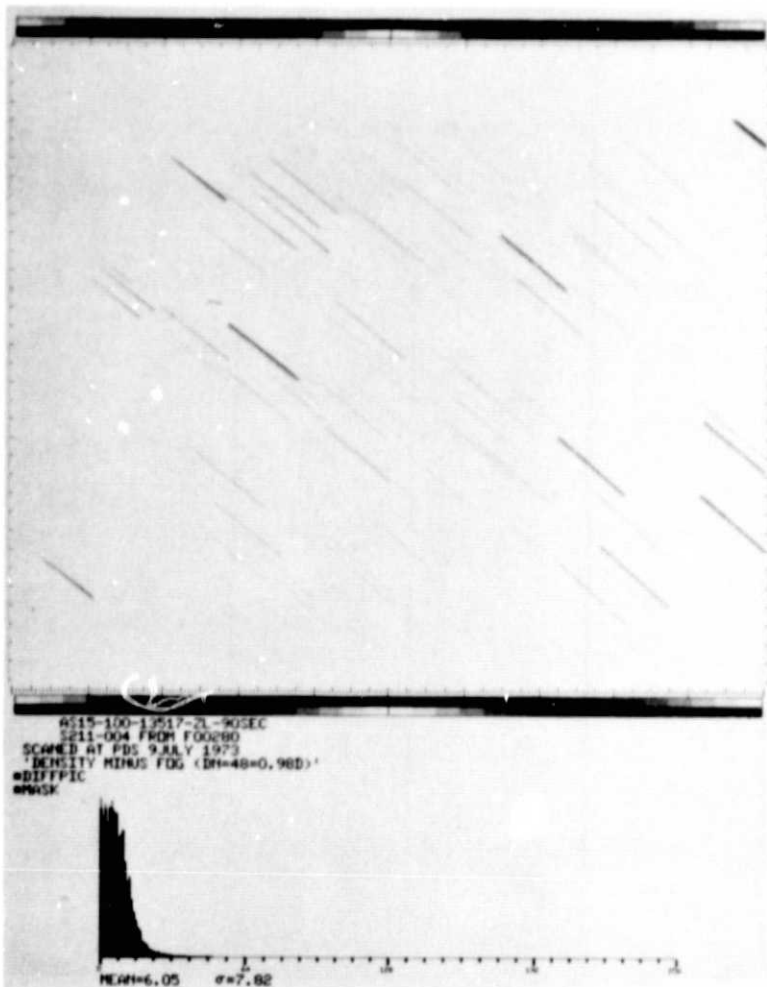


Figure 17a

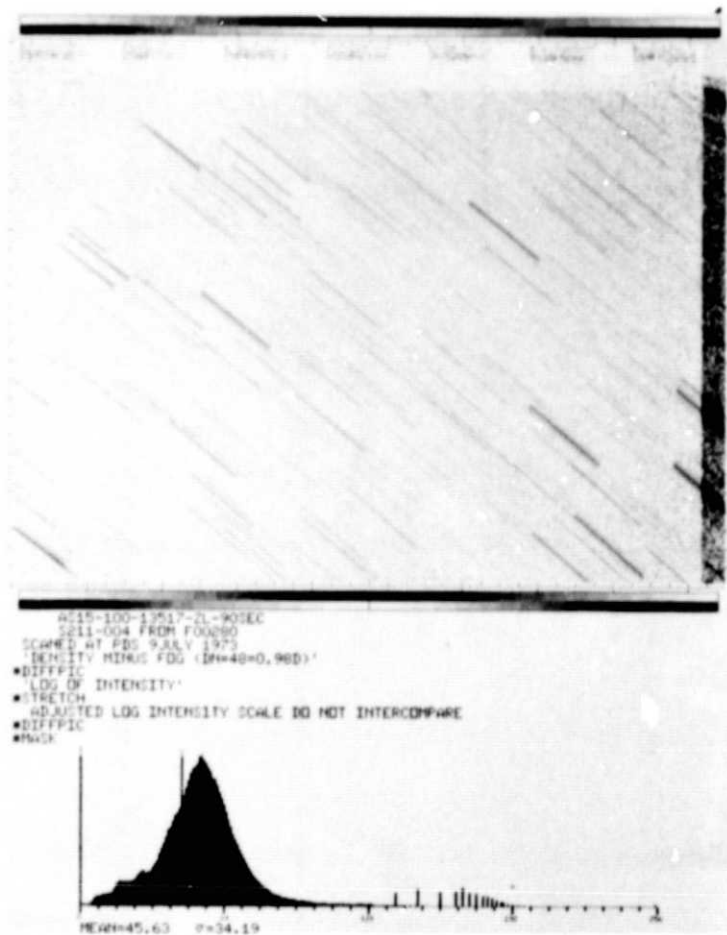


Figure 17b

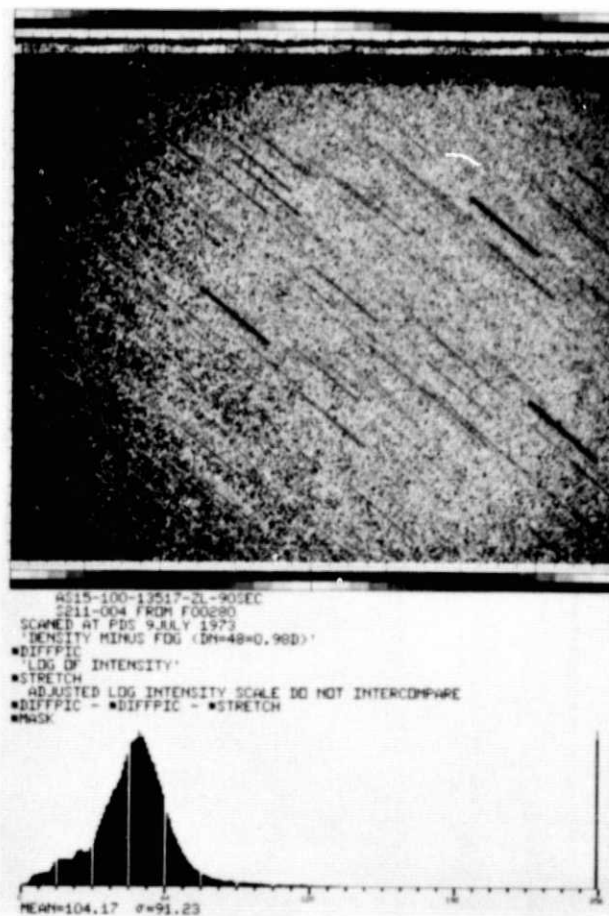


Figure 17c