CR-1999-208190

IN-34

046 ...

UAH Propulsion Research Center

Final Report

Injector Mixing Efficiency Experiments

Contract Number NAS8-38609 D.O. 159

Prepared by

Dr. Marlow D. Moser
Principal Investigator

August 31, 1998

Submitted to:

Mr. John Cramer EP13
Marshall Space Flight Center, AL 35812

Dr. Clark W. Hawk
Program Director
Propulsion Research Center
The University of Alabama in Huntsville

Injector Mixing Efficiency Experiments

Final Report

Submitted by
Marlow D. Moser

1. Summary

Various optical diagnostic techniques such as laser induce fluorescence, Raman spectroscopy, laser Doppler velocimetry, and laser light scattering have been employed to study the flowfield downstream of a single injector element in a optically accessible rocket chamber at Penn State for a number o years. These techniques have been used with both liquid and gaseous oxygen at pressures up to 1000 psia which is the limit of the facility. The purpose of the test programs at Penn State were to develop the techniques and to study the flow field from various injector designs. To extend these studies to higher pressure and ultimately to multiple injectors require the capabilities of the Marshall Space Flight Center. These studies will extend the data base available for the various injector designs to higher pressure as well as to determine the interaction between multiple injectors.

During this effort the Princeton Instruments ICCD camera was set up and checked out. The functionality of the system has been thoroughly checked and the shutter compensation time was found to be not working. The controller was returned to the manufacturer for warranty repair. The sensitivity has been measured and found to be approximately 60 counts per photon at maximum gain which agrees with the test data supplied by the manufacturer. The actual value depends on wavelength. The Princeton Instruments camera was been installed in a explosion proof tube for use with the rocket combustor. A 35mm camera was also made ready for taking still photos inside the combustor. A fiber optic was used to transmit the laser light from an argon-

ion laser to the rocket combustor for the light scattering images. These images were obtained for a LOX-hydrogen swirl coax injector. Several still photos were also obtained with the 35mm camera for these firings.

2.0 Objectives

The objective of this research was to determine the mixing efficiency of the various injector configurations by measuring the species concentrations, temperature and velocity across the combustor downstream of the injector face.

3.0 Scope

A Princeton Instruments Cooled Array Intensified CCD camera was checked out and characterized. The camera was used to image UV emission from a LOX/hydrogen single element rocket engine. The same camera was used to image light scattered from the liquid oxygen spray. Visual images were also obtained with a 35 mm camera.

4.0 Results

4.1 Intensified camera characterization

Advance diagnostics such as Raman spectroscopy and absorption measurements will be used to measure the major species concentration (H_2, O_2, and H_2O) and temperature at various axial locations downstream of the injector face. Raman spectroscopy yields a spatially resolved instantaneous or averaged profile of major species. The Raman signal is very weak and therefore the strength of the laser, the sensitivity of the detector and the background emission from the flame determine whether instantaneous or averaged measurements can be obtained.

A Princeton Instruments Intensified CCD array camera will be used for the Raman spectroscopy and other measurements in this and other efforts. The system was assembled and checked out for functionality and detectability limits. The results are reported here.

The various controls on the FG-100 pulse generator and the camera are all multi-turn potentiometers. The dial indicates number of turns only. The dial settings and the resulting effect were measured and are reported in the following tables. These copies of these tables were place on the camera controller and pulser controller so the operator can readily set the camera to the desired values.

The FG-100 has a frequency generator built in that produces pulses at a fixed rate. These pulses can be used to drive an experiment. The period and frequency of the pulse as a function of dial position are shown in Table 1.

Table 1 Frequency Generator Output, FG-100 Pulse Generator

Dial Setting	Period (msec)	Frequency (Hz)
0.0	34.0	29.4
1.0	30.6	32.7
2.0	37.2	26.9
3.0	23.9	41.8
4.0	20.5	48.8
5.0	17.1	58.5
6.0	13.7	73.0
7.0	10.3	96.9
8.0	7.0	142.8
9.0	3.6	227.8
10.0	2.5	400.0

The gate width and timing with respect to a trigger of the intensified camera are controlled by the gate width and gate delay dials respectively. The gate width has two ranges selected with a toggle switch while the delay has three ranges selected with a knob. The gate width and delay were measured by observing the pulse monitor and trigger signals on a digital oscilloscope. The results are reported in Tables 2 and 3.

Table 2 Gate Width, FG-100 Pulse Generator

	Pulse Width (nsec)	
Dial Setting	Range 1	Range 2
0.0	20	32
1.0	21	33
2.0	22	37
3.0	23	42
4.0	24	48
5.0	25	60
6.0	28	73
7.0	31	96
8.0	37	142
9.0	63	278
9.5	106	520
9.7	151	789
9.8	199	1060
9.9	288	1600
10.0	567	3300

Table 3 Gate Delay, FG-100 Pulse Generator

	Pulse Delay (nsec)		
Dial Setting	Range A	Range B	Range C
0.0	56.7	85	90
1.0	-	103	246
2.0	-	121	410
3.0	58	140	565
4.0	-	161	730
5.0	58	181	900
6.0	60	200	1006
7.0	60	220	1230
8.0	64	245	1390
9.0	69	263	1550
10.0	86	285	1700

A series of tests were conducted to determine the linearity of the camera and the absolute response (counts/photelectron) over a wide range of gate widths, light intensity, and wavelengths. The light source was an integrating sphere with a calibrated light intensity meter. At the exit aperture of the sphere, the light intensity was constant over an area of one inch in diameter. The aperture was imaged on to the intensified camera through a standard camera lens. An iris was placed in front of the lens to the $f^{\#}$ could be accurately determined. The images were recorded on the computer and then a region of approximately 100 pixels in the center of the light source aperture image was averaged. The results of ten frames were then average together. A background image with no light was acquired and processed in the same manner. this result was subtracted from each of the other images.

The data from these series of tests are in the appendix. some of the pertinent conclusions derived from these data will be discussed below and when appropriate compared with test data supplied by Princeton Instruments which is also included in the appendix.

The minimum gate width was found by reducing the gate width while observing the image for evidence of iris effects. Iris effects are a result of the outer edges of the intensifier tube turning on and off at different rates than the center of the tube resulting is different intensities recorded on the edges as compared to the center. The minimum FWHM gate was found to be 100 ns which compared well with the results for Princeton Instruments.

The linearity of the detector is very good for both short and long gates (5ms and 100 ns respectively). This will need to be checked again with a pulsed laser since it may not hold with the high fluxes resulting from very short pulsed light sources.

The maximum sensitivity was measured to be approximately 60 counts per photon at a gain setting of 10. This was lower than the 90 count per photon reported by Princeton Instruments but within the uncertainty of the measurement. In any case it is well within the limit for single photon counting as advertised by the manufacturer and desired for the Raman measurements.

Table 4 shows the relative gain four several dial settings on the camera. The relative gain has been normalized such that a dial setting of 10 is 1.24 so that it can be compared with the data supplied by Princeton Instruments. This table can be used to determine approximately how much change to dial setting to get the desired change in gain. These results are the average of both long and short gate tests with white light and filter light.

Table 4 Relative Gain

Dial Setting	Relative Gain
10	1.24
9.5	1.01
9	0.68
8	0.41
7	0.20
6	0.098

4.1 Flow imaging

Several imaging techniques were used in the initial checkout tests of the window rocket combustor at MSFC. They were photography of visible light using a 35mm camera and video and imaging UV light and laser light scattered from the liquid oxygen spray.

4.2.1 Visible light imaging

An Olympus 35mm camera with a remote shutter control and automatic film advance was mounted such that it could photograph the flame in the region immediately downstream from the injector face. The shutter speed was 1/1000 of a second and the iris was set to f8. This provied adequate lighting for the 400 ASA color film used. The images were not very satisfactory because of the lens combinations available for this camera. The area of interest occupied a small portion of the frame. It was decided that a new camera system would be purchased for future tests. A Nikon camera was selected since it had been used with success at Penn State plus the lens could be used with the Princeton Instruments ICCD camera as well. The photographs negatives reside at MSFC.

Video of each of the check out tests were recorded on standard VHS video tape. The video lack any interesting detail but help monitor the tests and provide a permanent record of the tests. These tape also reside at MSFC.

4.2.2 Princeton Instruments ICCD camera set up

The Princeton Instruments Intensified CCD (ICCD) camera consists of an ST-138 camera controller and a FG-100 Pulser. These pieces of equipment had to be near the camera. An environmental box equipped with a cooled purge was built on the test stand to house this equipment. The shutter monitor BNC connector on the back of the ST-138 was connected to the PULSE IN BNC connector on the front of the FG-100 as well as a cable in the instrumentation trailer so that the signal could be monitors on an oscilloscope. The NOTSCAN BNC connector on the back of the ST-138 was connected to the ENABLE BNC connector on the back of the FG-100. This signal was also monitored on the instrumentation trailer. The gate monitor on the front of the FG-100 was also monitored. The NOTSCAN signal was recorded by the data system in the block house. This signal indicated when the in firing sequence the images were obtained so they could be correlated to the sequence of the firing.

A UV bandpass filter was placed in front of the camera lens for UV emission imaging and a narrow bandpass filter centered around the Argon-Ion laser wavelength was used when imaging the scattered light from the LOX drops.

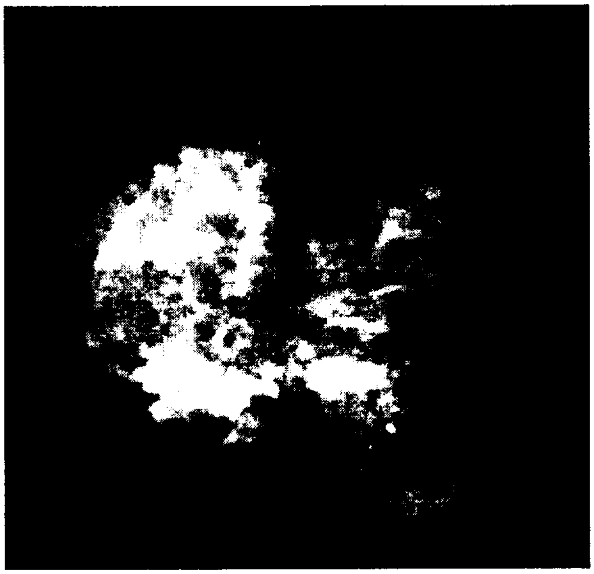
4.2.3 UV Images

UV images were obtained for several of the initial checkout tests. The camera gate time was set to 3 μsec and 30 frames were obtained at a rate of approximately 5 Hz. Figure 5 shows a series of the instantaneous images followed by an averaged image. The averaged image is an average of 30 frames. The flow is from left to right and the injector face can be seen at the left side of the images. The area viewed is approximately 1 inch square.

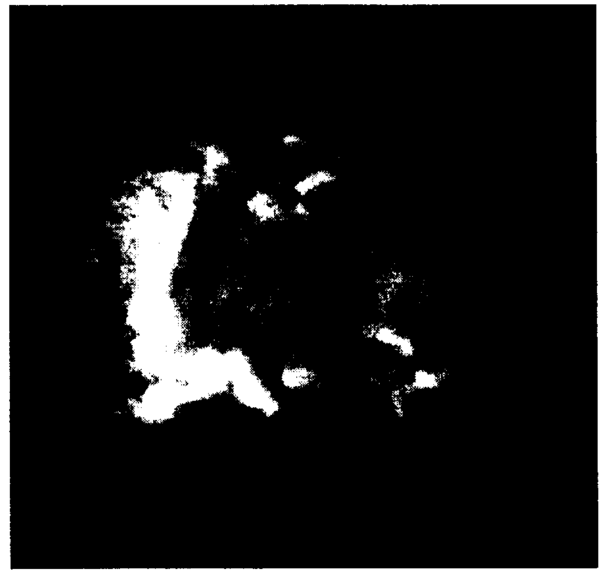
The UV light is an indication of the reaction location. From the instantaneous images it can be seen that the flame is very turbulent. The averaged image indicate that the bulk of the reactions take place just downstream of the injector. It was later determined that the nitrogen flowing around the injector had a strong recirculating flow at the injector face that cause the rapid mixing and reaction at this location. All UV raw images reside at MSFC.

4.2.4 Light scattering images

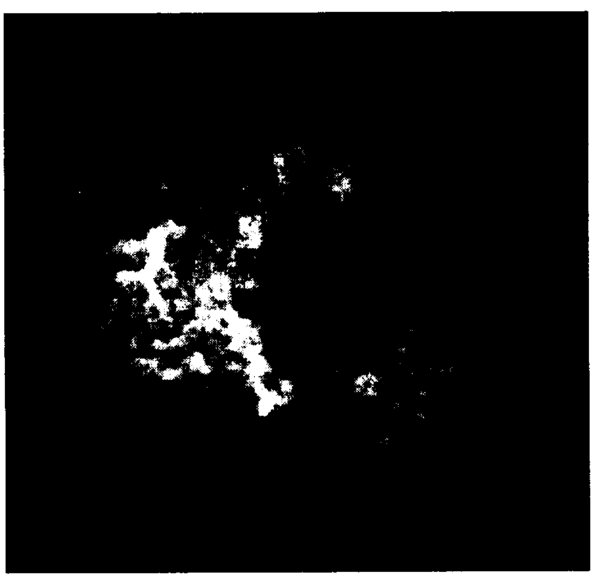
Laser light from an Argon-Ion laser at 514 nm was delivered to a window of the rocket chamber via a polarization preserving fiber optic. The beam emitting from the fiber was formed into a sheet with cylindrical optics and directed through the windows of the rocket chamber. The sheet centered on the injector and illuminated a cross-section of the chamber from the injector face toward the aft end of the chamber. About a 1 inch square area was observable.



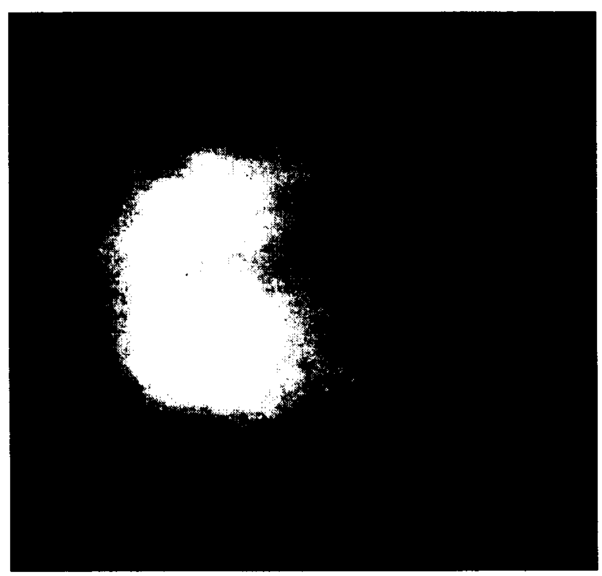
a.



b.



c.



d.

Figure 1 UV images of LOX hydrogen firing. Instantaneous images are a. through c. Image d. is an averaged image.

It was discovered that the polarization of the beam was not very well maintained by the fiber and seemed to oscillate with time. The cause of this was not known but seemed to be effected by the changing temperature through out the day. It was postulated that the length of the fiber was changing and had some sort of an effect on the polarization.

The camera was setup to record the light scattered from the LOX drops normal to the plane of the laser sheet. The narrow bandpass filter effectively reduced the flame luminosity so that the light recorded was from the LOX drops only.

Figure 2 shows a sample of the instantaneous images and an averaged image from the light scattered from the LOX drops. The laser light passes from top to bottom on these images. The top half of the image is much brighter than the bottom half because of attenuation as the laser light passes through the spray. The quality of these images is poor due to the poor light transmission of the fiber optic. These images were not corrected for variation of laser intensity across the sheet.

It can be seen that the LOX seems to be broken up into relatively large clumps along the edge of the spray. The injector used in these tests is an swirl coaxial injector and the majority of the spray is expected to be in a cone along the outside of the spray. This is consistent with the images although a significant amount of spay appears inside the cone. This is most likely due to the strong recirculating flow induced by the nitrogen flow around the injector.

a.
b.
c.
d.

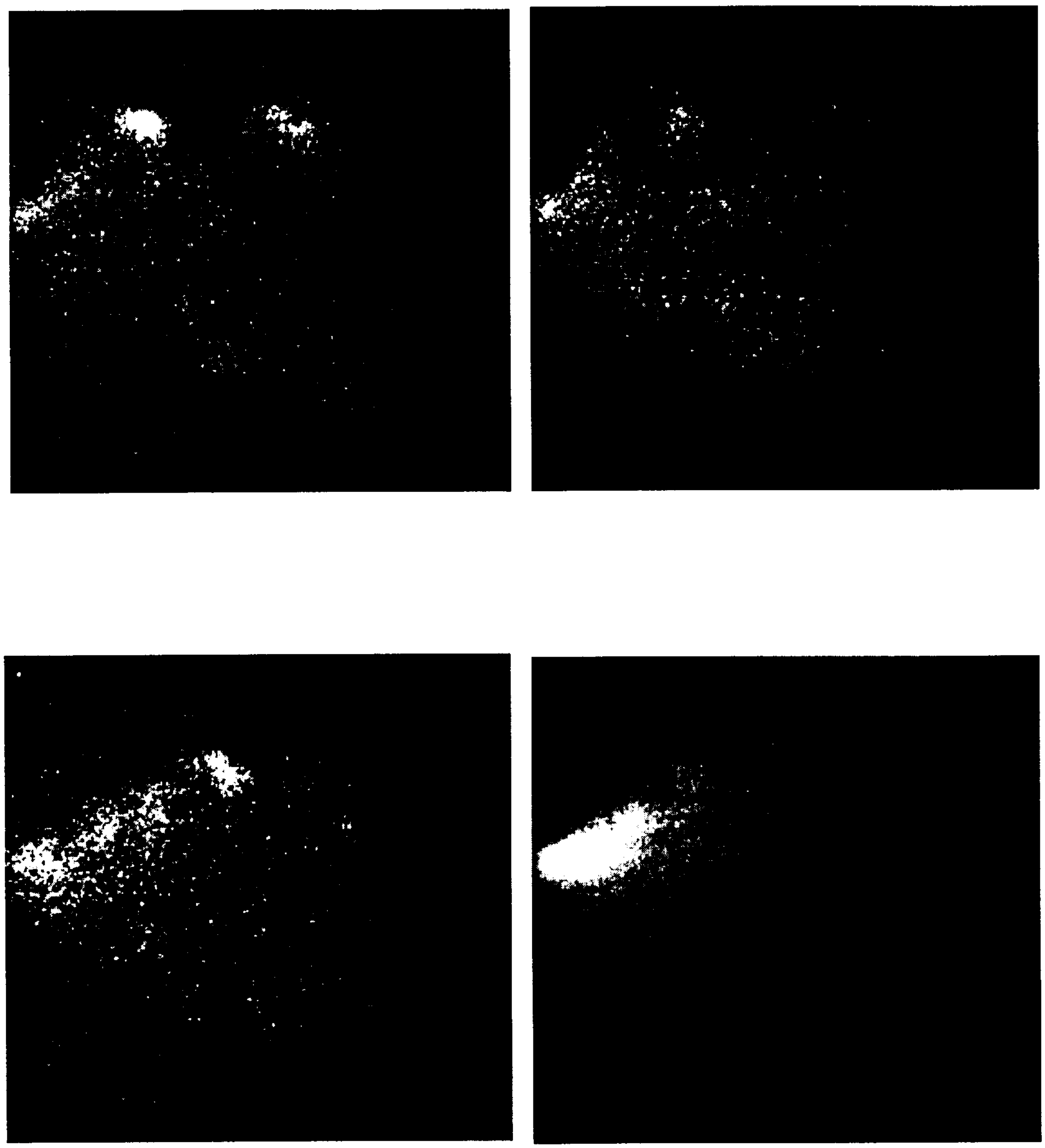


Figure 2 Light scattering images of LOX hydrogen firing. Instantaneous images are a. through c. Image d. is an averaged image.

Appendix

The data sheets on the following pages a the results of the check out tests performed on the Princeton Instruments intensified CCD camera. The information at the top of each sheet give information on the imaging lens used, aperture size, distance from light source to the lens, the area of the images averaged and the resulting solid angle and light source area image on each pixel. The columns are the file name, average counts, standard deviation, gain as indicated on the camera dial, light intensity as indicated by the integrating sphere light meter, the micrometer setting which operates an iris on the integrating sphere, shutter setting on integrating sphere which changes the light level and the gate time. The rest of the columns contain data derived from the first columns including light intensity in Joules/s-str-m^2, average raw - background, noise ((raw-background)/Sigma), and counts/photon.

The remaining information is the ICCD System Test Results supplied by Princeton Instruments. It contains their test results on this camera before it was shipped to MSFC.

Long gate

135 mm lens, 1:3.5, Limiting aperature 0.945" 63.5" from source						Averaged ROI (82,64) (106,91) 600 Pixels					Solid Angle	0.000174		3.58E-19
FILE	Ave. Counts	Sigma	Gain	Intensity	Micrometei	Shutter	Gate time	Comments			Pix area	5.64E-08	107 Pix/in.	
07MR96XX.spe			(turns)	Ft. Lamberts			(msec)		J/s-str-m^2	counts-bad	Noise	Counts/photon		
1	352.8	1.178	0	0			5	Backgroun	0.00E+00	0	#DIV/0!			
2	9247	408	0	832.2	0.8	5	5		1.31E+01	8894.2	0.045873	0.004944		
3	1570	53.8	0	100.7	0.8	4	5		1.59E+00	1217.2	0.0442	0.005591		
4	456.3	5.42	0	8.7	0.8	3	5		1.37E-01	103.5	0.052367	0.005503		
5	8130	354	0	699.7	0.449	3	5		1.11E+01	7777.2	0.045518	0.005141		
6	7182	310.7	0	595.4	0.4	3	5		9.41E+00	6829.2	0.045496	0.005306		
7	6066	258.5	0	483.5	0.35	3	5		7.64E+00	5713.2	0.045246	0.005466		
8	4742	197	0	363.9	0.3	3	5		5.75E+00	4389.2	0.044883	0.005579		
9	3461	138.3	0	256	0.25	3	5		4.04E+00	3108.2	0.044495	0.005616		
10	2310	85.6	0	161.9	0.2	3	5		2.56E+00	1957.2	0.043736	0.005592		
11	53921	2267	1.8	832.2	0.8	3	5		1.31E+01	53568.2	0.04232	0.029775		
12	47442	1901	1.8	697.7	0.45	3	5		1.10E+01	47089.2	0.04037	0.031219		
13	42803	1683	1.8	596.4	0.4	3	5		9.42E+00	42450.2	0.039646	0.032924		
14	37809	1463	1.8	486	0.35	3	5		7.68E+00	37456.2	0.039059	0.03565		
15	32008	1214	1.8	365.7	0.3	3	5		5.78E+00	31655.2	0.038351	0.04004		
16	26053	992	1.8	256.2	0.25	3	5		4.05E+00	25700.2	0.038599	0.046401		
17	13198	527	1.8	100.7	0.8	4	5		1.59E+00	12845.2	0.041027	0.059004		
18	55088	1942	3.75	100.7	0.8	4	5		1.59E+00	54735.2	0.03548	0.251424		
19	39425	1487	3.75	51.42	0.325	4	5		8.12E-01	39072.2	0.038058	0.351484		
20	22679	901	3.75	25.21	0.225	4	5		3.98E-01	22326.2	0.040356	0.409649		
21	7131	285	3.75	7.54	0.125	4	5		1.19E-01	6778.2	0.042047	0.415828		
22	2251	81.9	3.75	2.13	0.225	3	5		3.37E-02	1898.2	0.043146	0.412223		
23	54905	2239	8.1	2.131	0.225	3	5		3.37E-02	54552.2	0.041043	11.84129		
24	33426	1431	8.1	1.265	0.175	3	5		2.00E-02	33073.2	0.043268	12.09361		
25	17725	789	8.1	0.665	0.125	3	5		1.05E-02	17372.2	0.045417	12.0838		
26	10462	453	8.1	0.385	0.1	3	5		6.08E-03	10109.2	0.044811	12.1458		
27	6301	307	8.1	0.228	0.075	3	5		3.60E-03	5948.2	0.051612	12.0676		
28	2950	150.7	8.1	0.099	0.05	3	5		1.56E-03	2597.2	0.058024	12.13502		
29	941	59.5	8.1	0.022	0.025	3	5		3.48E-04	588.2	0.101156	12.36723		
										average	0.045557			

Short gate

50 mm lens, 1:1.8, Limiting aperature 0.984" 26" from source						Averaged ROI (64,59) (87,84) 624 Pixels					Solid Angle	0.001124		3.58E-19
FILE	Ave. Coun	Sigma	Gain	Intensity	Micromete	Shutter	Gate time	Comments			Pix area	7.62E-08	92 Pix/in.	
07MR96XX.spe			(turns)	Ft Lamberts			(ns)		J/s-str-m^2	counts-bac	Noise	Counts/ph	0	
30	62710	1778	10	832.6	0.8	5	707		1.32E+01	62357.2	0.028513		0	
31	54931	2241	10	832.6	0.8	5	604		1.32E+01	54578.2	0.04106	28.6924	0.047504	
32	45944	1741	10	832.6	0.8	5	503		1.32E+01	45591.2	0.038187	28.78045	0.057218	
33	36633	1542	10	832.6	0.8	5	405		1.32E+01	36280.2	0.042503	28.44456	0.070233	
34	26565	1500	10	832.6	0.8	5	303		1.32E+01	26212.2	0.057225	27.46916	0.090657	
35	16511	749.5	10	832.6	0.8	5	204		1.32E+01	16158.2	0.046385	25.15055	0.123287	
36	11128	536	10	832.6	0.8	5	152		1.32E+01	10775.2	0.049744	22.50953	0.148089	
37	5600.5	275	10	832.6	0.8	5	101		1.32E+01	5247.7	0.052404	16.49804	0.163347	
38	4795	266.5	10	701.8	0.45	5	101		1.11E+01	4442.2	0.059993	16.56855	0.164045	
39	4135	241.8	10	602.6	0.4	5	101		9.52E+00	3782.2	0.063931	16.42915	0.162665	
40	3422	223	10	485	0.35	5	101		7.66E+00	3069.2	0.072657	16.56468	0.164007	
41	2644	167.8	10	366.4	0.3	5	101		5.79E+00	2291.2	0.073237	16.36844	0.162064	
42	1975	127	10	256	0.25	5	101		4.04E+00	1622.2	0.078289	16.58686	0.164226	
43	1372	105.6	10	163.3	0.2	5	101		2.58E+00	1019.2	0.103611	16.33702	0.161753	
44	922.9	75.1	10	89.7	0.15	5	101		1.42E+00	570.1	0.131731	16.63636	0.164716	
45	737.2	70.4	10	8.85	0.05	5	408		1.40E-01	384.4	0.183143	28.14498	0.068983	
46	1976	149.7	10	36.41	0.1	5	408		5.75E-01	1623.2	0.092225	28.88765	0.070803	
47	4211	270	10	86.22	0.15	5	408		1.36E+00	3858.2	0.069981	28.99596	0.071069	
48	7440	412	10	151.3	0.2	5	408		2.39E+00	7087.2	0.058133	30.35265	0.074394	
49	11611	593.8	10	248.7	0.25	5	408		3.93E+00	11258.2	0.052744	29.33283	0.071894	
50	16484	713.3	10	357.1	0.3	5	408		5.64E+00	16131.2	0.044219	29.27101	0.071743	
51	21781	919.9	10	475.7	0.35	5	408		7.52E+00	21428.2	0.042929	29.18861	0.071541	
52	27097	1135	10	593.4	0.4	5	408		9.38E+00	26744.2	0.042439	29.20404	0.071579	
53	31230	1256	10	694.3	0.45	5	408		1.10E+01	30877.2	0.040677	28.81719	0.07063	
54	53731	2115	10	694.3	0.45	5	702		1.10E+01	53378.2	0.039623	28.95347	0.041244	
55	38542	1582	10	485.4	0.35	5	704		7.67E+00	38189.2	0.041425	29.54535	0.041968	
56	20708	944.9	10	255.9	0.25	5	704		4.04E+00	20355.2	0.046421	29.87125	0.042431	
57	7559	409.5	10	90.3	0.15	5	704		1.43E+00	7206.2	0.056826	29.96863	0.042569	
58	1067	101.2	10	8.9	0.05	5	704		1.41E-01	714.2	0.141697	30.13548	0.042806	
59	37307	1445	9	831.5	0.8	5	704		1.31E+01	36954.2	0.039102	16.68975	0.023707	
60	20809	840	8	831.9	0.8	5	705		1.31E+01	20456.2	0.041063	9.221164	0.01308	
61	11016	440.2	7	831.9	0.8	5	705		1.31E+01	10663.2	0.041282	4.806714	0.006818	
62	5564	219.4	6	831.9	0.8	5	705		1.31E+01	5211.2	0.042102	2.349084	0.003332	
63	2456	107	5	831.9	0.8	5	705		1.31E+01	2103.2	0.050875	0.948072	0.001345	
64	1371	43.8	4	831.9	0.8	5	705		1.31E+01	1018.2	0.043017	0.45898	0.000651	

135 mm lens, 1:3.5, Limiting aperature 0.945" 63.5" from source						Averaged ROI (64,59) (87,84) 624 Pixels						Solid angl	0.000174			
FILE	Ave. Coun	Sigma	Gain	Intensity	Micromete	Shutter	Gate time	Comments				Pix area	5.43E-08			
29FB96XX.spe			(turns)	Ft Lamberts			(microsecs)		J/s-str-m^	counts-ba	Noise		Counts/J	Counts/photon		
0	358.7	1.29	0	0	0.8	5	5000		0.00E+00	0					J/photon	
1	10027	438	0	832	0.8	5	5000		1.31E+01	9668.3	0.045303	735.478	1.56E+16	0.005577	3.58E-19	
2	1739	73	0	100.8	0.8	4	5000		1.59E+00	1380.3	0.052887	866.6742	1.84E+16	0.006572		
3	474	7	0	8.7	0.8	3	5000		1.37E-01	115.3	0.060711	838.7895	1.78E+16	0.00636		
4	365.6	1.55	0	0.7	0.8	2	5000		1.11E-02	6.9	0.224638	623.8698	1.32E+16	0.004731		
5	363.7	1.56	0	830.2	0.8	5	3.25		1.31E+01	5	0.312	0.38118	1.24E+16	0.004447		
6	443.4	4.83	2	830.2	0.8	5	3.25		1.31E+01	84.7	0.057025	6.45719	2.1E+17	0.075327		
7	1024	30.1	4	830.2	0.8	5	3.25		1.31E+01	665.3	0.045243	50.71982	1.65E+18	0.591676		
8	3802	148	6	830.2	0.8	5	3.25		1.31E+01	3443.3	0.042982	262.5035	8.56E+18	3.062256		
9	13888	573	8	830.2	0.8	5	3.25		1.31E+01	13529.3	0.042353	1031.42	3.36E+19	12.03211		
10	43153	1743	10	830.2	0.8	5	3.25		1.31E+01	42794.3	0.04073	3262.467	1.06E+20	38.05858		
11	5693	33	10	100.6	0.8	4	3.25		1.59E+00	5334.3	0.006186	3356.003	1.09E+20	39.14973		
12	453.3	612	0	8.7	0.8	3	5000		1.37E-01	94.6	6.469345	688.2002	1.46E+16	0.005218		
13	1792	45.95	2	8.7	0.8	3	5000		1.37E-01	1433.3	0.032059	10427.03	2.21E+17	0.079064		
14	11016	337.7	4	8.7	0.8	3	5000		1.37E-01	10657.3	0.031687	77530.19	1.64E+18	0.587883		
15	53103	1562	6	8.7	0.8	3	5000		1.37E-01	52744.3	0.029615	383706.5	8.13E+18	2.909504		
16	5331	162	6	0.772	0.8	2	5000		1.22E-02	4972.3	0.03258	407645.8	8.64E+18	3.091027		
17	20569	653	8	0.772	0.8	2	5000		1.22E-02	20210.3	0.03231	1656908	3.51E+19	12.56372		
18	50249	1558	9.5	0.772	0.8	2	5000		1.22E-02	49890.3	0.031229	4090173	8.67E+19	31.01427		
19	2103	55.98	2	830.5	0.8	5	5000	1.23E-05	1.23E-01	1744.3	0.032093	14169.78	3E+17	0.122196	4.07E-19	488 nm Filter
20	13155	392.3	4	830.5	0.8	5	5000	W/str-cm^	1.23E-01	12796.3	0.030657	103950.4	2.2E+18	0.896436		488 nm Filter
21	60660	1802	6	830.5	0.8	5	5000	Filter Funti	1.23E-01	60301.3	0.029883	489856.2	1.04E+19	4.224367		488 nm Filter
22	8648	272.5	6	100.5	0.8	4	5000	at 830 Ft-l	1.49E-02	8289.3	0.032874	556459.3	1.18E+19	4.79873		488 nm Filter
23	33683	1097	8	100.5	0.8	4	5000		1.49E-02	33324.3	0.032919	2237054	4.74E+19	19.29166		488 nm Filter
24	61250	1798	9	100.5	0.8	4	5000		1.49E-02	60891.3	0.029528	4087622	8.66E+19	35.25037		488 nm Filter
25	636.1	46.77	9	830.2	0.8	5	3.25		1.23E-01	277.4	0.168601	2254.267	7.35E+19	29.90783		488 nm Filter
26	383.1	13.78	9	830.2	0.8	5	3.25	8.81E-06	8.81E-03	24.4	0.564754	2769.58	9.03E+19	34.88592	3.86E-19	514 nm
27	403.7	24.38	10	830.2	0.8	5	3.25	W/str-cm^	8.81E-03	45	0.541778	5107.832	1.66E+20	64.3388		514 nm
28	526.2	6.56	2	830.2	0.8	5	5000	Filter Funti	8.81E-03	167.5	0.039164	19012.49	4.03E+17	0.155664		514 nm
29	1609.8	42.5	4	830.2	0.8	5	5000	at 830 Ft-l	8.81E-03	1251.1	0.03397	142009.1	3.01E+18	1.162695		514 nm
30	7140	219	6	830.2	0.8	5	5000		8.81E-03	6781.3	0.032295	769727.6	1.63E+19	6.302121		514 nm
31	27714	947	8	830.2	0.8	5	5000		8.81E-03	27355.3	0.034619	3105028	6.58E+19	25.42232		514 nm
32	50806	1616	9	830.2	0.8	5	5000		8.81E-03	50447.3	0.032033	5726141	1.21E+20	46.8826		514 nm

50 mm lens, 1:1.8, Limiting aperature 0.984" 26" from source						Averaged ROI (54,81) (81,85) 756 Pixels					Solid Angle	0.001124	
FILE	Ave. Count	Sigma	Gain	Intensity	Micrometer	Shutter	Gate time	Comments			Pix area	7.62E-08	
19MR96XX.spe			(turns)	Ft Lamberts			(ns)		J/s-str-m^2	counts-bac	Noise	Counts/photon	
1	354	1.2	10	832.6	0.8	5	3.28			1.2	1		
2	822	78.9	10	832.6	0.8	5	3.28	514 nm	8.81E-03	468	0.16859	73.03165	3.86E-19
3	5186	302.7	10	832.6	0.8	5	3.28	488 nm	1.23E-01	4832	0.062645	56.88611	4.07E-19
4	1385	120	10	832.6	0.8	5	0.698	488 nm	1.23E-01	1031	0.116392	57.03697	4.07E-19
5	436	27.3	10	832.6	0.8	5	0.1	488 nm	1.23E-01	82	0.332927	31.66409	4.07E-19
6	919	83.7	10	832.6	0.8	5	0.403	488 nm	1.23E-01	565	0.148142	54.1373	4.07E-19
7	1741	56.9	0	832.6	0.8	5	5000	488 nm	1.23E-01	1387	0.041024	0.010712	4.07E-19
8	17934	644.5	2	832.6	0.8	5	5000	488 nm	1.23E-01	17580	0.036661	0.135769	4.07E-19
9	63669	1606	4	832.6	0.8	5	5000	488 nm	1.23E-01	63315	0.025365	0.488979	4.07E-19
10	12816	481.6	4	832.6	0.8	5	5000	514 nm	8.81E-03	12462	0.038645	1.275724	3.86E-19
11	59200	2076.8	6	832.6	0.8	5	5000	514 nm	8.81E-03	58846	0.035292	6.024015	3.86E-19

ICCD System Test Results

General System Information

Order ID	ID	Customer	PO No.	Tested	Approved
5072		NASA	NAS8-40442	8/12/95	8/17/95

Detector	7098-0002	ICCD-576-S/RB-EM DETECTOR	A0895262
Controller	7152-0008	ST-138S CONTROLLER,12 BIT 1MHZ-16BIT 200,SERIAL	A0895519

Array #	Array Description	Array S/N
4814-0022	CCD-02-06-1-656 MPP 576X384, W/3MM FIB OPTIC, EEV	A2959-24

Intesifier #	Intesifier Description	Intesifier S/N
5701-0004	PMCP,18MM,I,S,SPECIFY WINDOW AT TIME OF ORDER	BT926209

Noise Test Results

Noise Units: CTS/SEC

Speed	200 KHz	1 MHz				
Noise	0.97	1.71				

CCD Test Results

Unif - Top	Unif - Center	Unif - Bottom
7.80	7.50	7.90

Avg. Signal	Avg. Unifom
12,236	7.77

DC (e-/pix)	Time	Temp (Deg. C)	Air Cooled Temp	Full Well Cap.(Ke-)
0.25	Sec.	35 C		

Dark Spots	Dark Clusters	Dark Columns	Hot Spots
2	0	0	0

White Clusters	White Columns	White Spots
0	0	0

☒ Full Lite
☒ Full Dark
☒ Target

Bias Level (cts)	Speed(KHz)	Calibration (e/cts) Hi	Mid	Low
100	200		14	

Vrd or Vod (Volts)	Vss or Vlg (Volts)	Burn In (Hrs)
18.0	7.89	48

Intesifier Test Results

Phosphor	Delta MCP	PCathode	Pos. Bias	Sensitivity	Avg. Sig	EBI	Scintllation	QE270	QE520	QE810
5610	670	6450	39	72	4750	0.1	0	70.9	57	1

Sbt Res.	Other Res	Other Res	Term Res	ABC	Gating	FWHM	Resolution
2.2	400 M	400 M	50	SET	142	100	39

Notes

White 33@150
All data taken at 14 bits>

By: D.T./JV

Post-it® Fax Note 7671

Date	# of pages ▶ 10
To Marlow Moser	From Rob Allen
Co./Dept.	Co. 7787
Phone # 205 890 7201	Phone # 605 587 ~~[illegible]~~
Fax # 205 890 7205	Fax # 605 587 1970

DARK DEFECT REPORT

Customer Name	: NASA
Date	: 08/07/95 14:22:30
Detector Type	: EEV 576x384 [6 ph] / TE COOLED
Chip Size	: 576 x 384
Exposure	: 1
Number Head Cleans	: 0
Async/Sync Mode	: Asynchronous
Timing Mode	: Free run
ADC Bits	: 16
Readout Rate	: 200 kHz
Output Image File Name	: fulluni.SPE
Output Text File Name	: thrshuni.txt
Threshold Image Name	: thrshuni.SPE
Number Of Defects	: 2
Threshold Value	: 0.464053
Low Defect Value	: 0.270705
High Defect Value	: 0.451969
Average Defect	: 0.361337

X, Y Coordinates	Intensity
569 , 153	0.270705
89 , 247	0.451969

Bad Rows	Row Intensity

WHITE DEFECT REPORT

Customer Name	:	NASA
Date	:	08/07/95 15:50:43
Detector Type	:	EEV 576x384 [6 ph] / TE COOLED
Chip Size	:	576 x 384
Exposure	:	100
Number Head Cleans	:	0
Async/Sync Mode	:	Asynchronous
Timing Mode	:	Free run
ADC Bits	:	16
Readout Rate	:	200 kHz
Temperature	:	-35C
Input File Name	:	dcfull.SPE
Output Image File Name	:	dcfull.SPE
Output Text File Name	:	dcthresh.txt
Threshold Image Name	:	dcthresh.SPE
Number Of Defects	:	33
Threshold Value	:	150
Average Dark Charge	:	0.00930415 ADU/pixel/sec
Low Defect Value	:	157
High Defect Value	:	2348
Average Defect	:	352.364

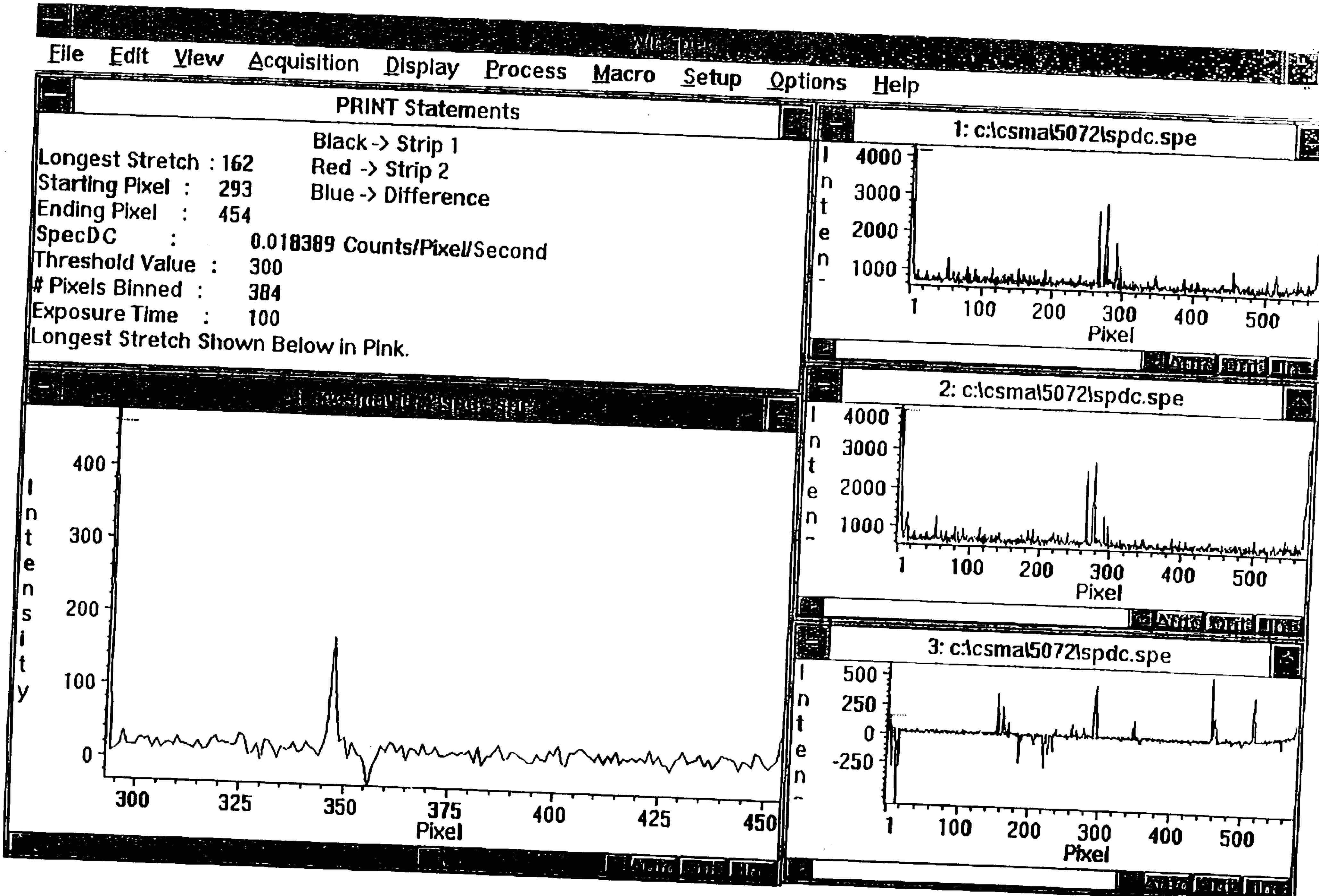
White Defect Data For NASA

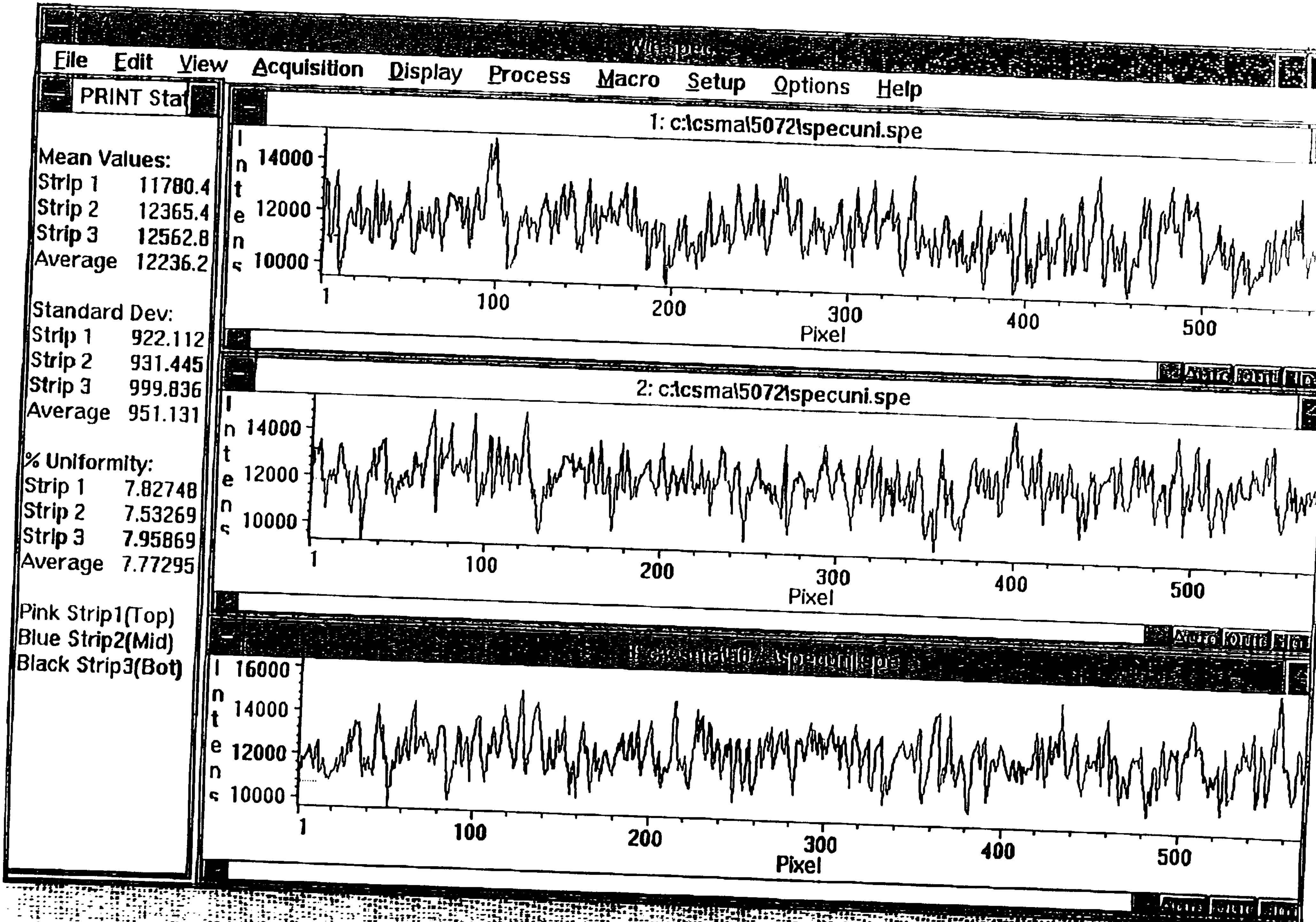
X, Y Coordinates	Intensity
283 , 20	262
439 , 29	162
559 , 35	244
398 , 45	218

501 , 45	355
115 , 50	459
53 , 66	256
387 , 66	295
176 , 93	189
561 , 98	203
568 , 103	165
92 , 107	401
337 , 108	203
80 , 112	180
440 , 113	189
144 , 140	229
297 , 162	530
69 , 166	198
191 , 173	184
347 , 178	248
406 , 183	206
572 , 204	1378
76 , 211	218
40 , 239	220
266 , 248	2348
61 , 254	299
545 , 275	337
142 , 282	204
85 , 314	218
476 , 314	171
240 , 324	236
53 , 337	466
67 , 375	157

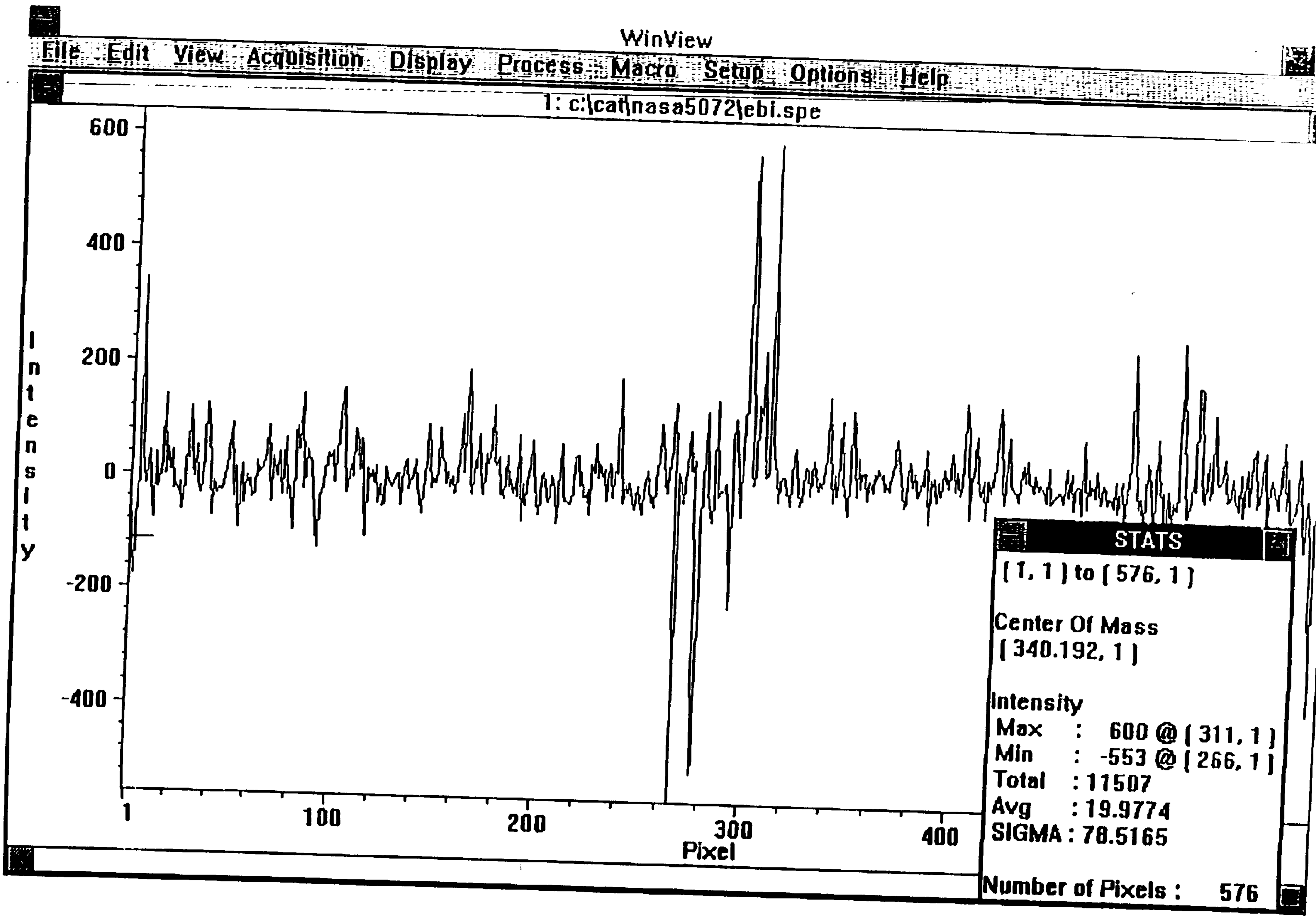
Bad Rows	Row Intensity

Bad Columns	Column Intensity


File Edit View Acquisition Display Process Macro Setup Options Help
PRINT Statements
Longest Stretch : 162
Starting Pixel : 293
Ending Pixel : 454
SpecDC : 0.018389 Counts/Pixel/Second
Threshold Value : 300
Pixels Binned : 384
Exposure Time : 100
Longest Stretch Shown Below in Pink.
Black -> Strip 1
Red -> Strip 2
Blue -> Difference
Intensity
Pixel
1: c:\csma\5072\spdc.spe
2: c:\csma\5072\spdc.spe
3: c:\csma\5072\spdc.spe
Inten-
Pixel



File Edit View Acquisition Display Process Macro Setup Options Help
PRINT Stat
Mean Values:
Strip 1 11780.4
Strip 2 12365.4
Strip 3 12562.8
Average 12236.2
Standard Dev:
Strip 1 922.112
Strip 2 931.445
Strip 3 999.836
Average 951.131
% Uniformity:
Strip 1 7.82748
Strip 2 7.53269
Strip 3 7.95869
Average 7.77295
Pink Strip1(Top)
Blue Strip2(Mid)
Black Strip3(Bot)
1: c:\csma\5072\specuni.spe
Intens
14000
12000
10000
1
100
200
300
400
500
Pixel
2: c:\csma\5072\specuni.spe
Intens
14000
12000
10000
1
100
200
300
400
500
Pixel
Intens
16000
14000
12000
10000
1
100
200
300
400
500
Pixel


WinView
File Edit View Acquisition Display Process Macro Setup Options Help
1: c:\cat\nasa5072\ebi.spe
600
400
200
0
-200
-400
Intensity
1
100
200
300
400
Pixel
STATS
[1, 1] to [576, 1]
Center Of Mass
[340.192, 1]
Intensity
Max : 600 @ [311, 1]
Min : -553 @ [266, 1]
Total : 11507
Avg : 19.9774
SIGMA : 78.5165
Number of Pixels : 576

etector : EEV 576x384 [6 ph] / TE COOLED
hip Size : 576 x 384
ontroller : ST138
eadout Rate : 200 kHz
CD Serial Number : A2959-24
umber Grouped In X : 1
umber Grouped In Y : 1
ackground Mean : 874.447

xpos	H	Net ADU	ADU/Exp Norm	% Non-Linear	e/CTS
1	1503.52	-----	-----	-----	10.4469
2	3007.96	1504.44	15044.4	-0.0426613	11.9639
3	4512.4	3008.89	15044.4	-0.04271	14.3215
4	6018.53	4515.01	15050	-0.00540701	14.3316
5	* 7524.85	6021.33	15053.3	0.0163833	13.7173
6	9029.44	7525.92	15051.8	0.00657925	14.4996
7	10533.1	9029.53	15049.2	-0.0108573	15.37
8	12043	10539.5	15056.4	0.0366132	15.9751
9	13552.7	12049.2	15061.5	0.0707643	16.2052
	15029	13525.5	15028.3	-0.149854	20.9516

age % Non-Linear (Absolute Values Used): 0.0230302

age e/CTS : 14.3113

Relative Gain Chart

INV#	Customer Name:	PO NO.	Image Intensifier No.
5072	NASA-MARSHALL	NAS8-40442	BT926209

Dial:	Cts/pe:	Relative Gain:
10.0	93	1.24
9.9	86	1.15
9.8	79	1.05
9.7	75	1.00
9.6	67	.89
9.5	63	.84
9.4	59	.78
9.3	55	.73
9.2	51	.68
9.1	48	.64
9.0	45	.60
8.5	31	.41
8.0	24	.32
7.5	17	.22

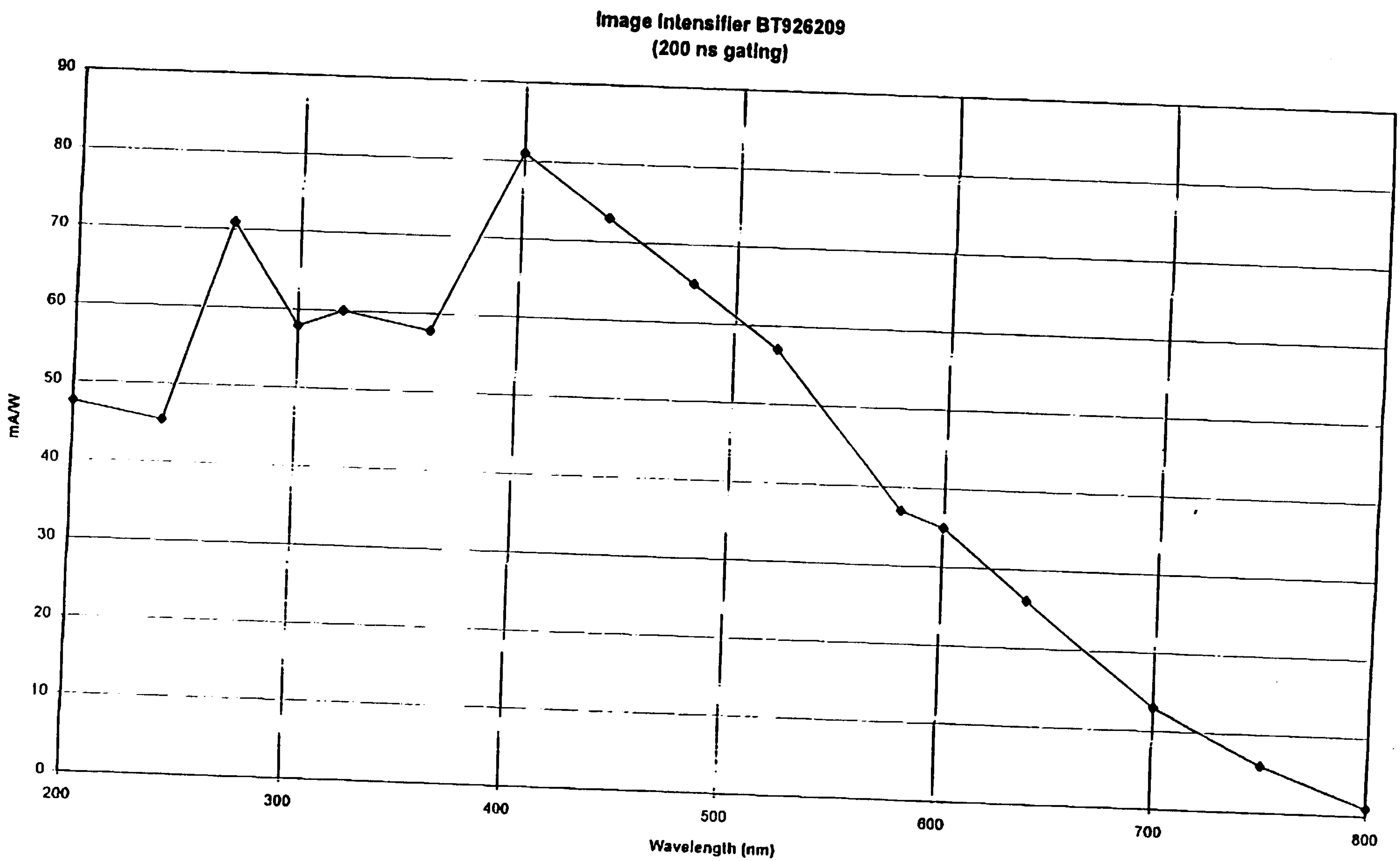


Image Intensifier BT926209
(200 ns gating)
mA/W
90
80
70
60
50
40
30
20
10
0
200
300
400
500
600
700
800
Wavelength (nm)