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LA-UR -86-2868

CONF-860820--26

Received by OSTI

SEP 08 1986

LA-UR--86-2868

DE86 015301

TITLE CHARACTERIZATION RESULTS FROM SEVERAL COMMERCIAL SOFT X-RAY STREAK CAMERAS

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SUBMITTED TO SPIE's 30th Annual International Technical Symposium on Optical and Optoelectronic Applied Sciences and Engineering
Town & Country Hotel
San Diego, California

August 17-22, 1986

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MASTER

FORM NO. 836 R4
ST. NO. 2629 5/81

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Characterization Results From Several Commercial Soft X-Ray Streak Cameras

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Summary

We have characterized the spatio-temporal performance of four soft x-ray streak cameras. Our objective in evaluating the performance capability of these instruments is to enable us to optimize experiment designs, to encourage quantitative analysis of streak data and to educate the ultra high speed photography and photonics community about the x-ray detector performance which is available.

These measurements have been made collaboratively over the space of two years at the Forge pulsed x-ray source at Los Alamos and at the Ketjak laser facility an CEA Limeil-Valenton. The x-ray pulse lengths used for these measurements at these facilities were 150 psec and 50 psec respectively.

The results are presented as dynamically-measured modulation transfer functions. We also calculate limiting temporal resolution values.

Emphasis is placed upon shot noise statistical limitations in the analysis of the data. Space charge repulsion in the streak tube limits the peak flux at ultra short experiment duration times. This limit results in a reduction of total signal and a decrease in signal to noise ratio in the streak image.

The four cameras perform well with 20 lp/mm resolution discernable in data from the French C650X, the Hadland X-Chron 540 and the Hamamatsu C1936X streak cameras. The Kentech x-ray streak camera has lower modulation and does not resolve below 10 lp/mm but has a longer photocathode. The C650X bi-lamellar design shows uniform high fidelity recording across both spatial and temporal dimensions. The other three streak cameras show resolution degradation off axis. This must be weighed against a 10X lower streak tube throughput for the C650X.

Introduction

We are presenting test results which compare spatio-temporal resolution characteristics of three commercially manufactured soft x-ray streak cameras and a prototype of the C650X soft x-ray streak camera made at CEA Limeil-Valenton using an RTC P650X streak tube (ref3) and now commercially available from the Thomson CSF company.

These tests have been done with ultra short x-ray pulses both at the Forge(ref1) pulsed x-ray source facility at Los Alamos National Laboratory in the United States and at the Ketjak(ref2) laser facility at CEA Limeil-Valenton in France.

The purpose of this research is to evaluate the relative performance of the C650X, the Hadland X-Chron 540, the Hamamatsu C1936, and the Kentech soft x-ray streak cameras. Experimenters in the ultra-high-speed community need this information to make knowledgeable choices of instrumentation for time resolved x-ray experiments in the subnanosecond and nanosecond range. Often experiments require many time resolved detection channels which are both contiguous and synchronous in a single measurement. Time resolved x-ray spectroscopy or x-ray imaging experiments which use streak cameras as ultra-high-speed position sensitive x-ray detectors are frequently constrained by limited information density.

Optimization of the experiments and quantitative understanding of the data require knowledge of both the modulation transfer function (MTF) in the spatial axis of the instrument during the streak and the temporal resolution . This is the spatio-temporal performance character of the instrument.

Complete studies of these dynamic performance features have not previously been done. Particular care must be taken to measure performance under relevant conditions and to make complete measurement sets (ref4standards). We have found that there can be significant differences in the static MTF and the MTF measured in the streaked mode. The MTF is not usually constant across the streaked image. These characteristics obviously vary between instruments.

This set of tests is directed toward the class of instruments which use a large electron extraction field at the photocathode in order to obtain temporal resolution limits of a few picoseconds at the fastest sweep speeds. Compared to low extraction field designs, this high extraction field configuration can result in degraded MTF for some streak tubes.(ref5 550RCA)

We have not performed detailed MTF characterizations on the two picosecond range x-ray streak cameras which use the RCA C73435 and the similar RTC P501 tubes respectively. Our extensive experience with these instruments (ref6 SXRSC,550) has shown them to have limiting dynamic spatial resolutions of about 5 lp/mm when used with high extraction fields in the picosecond regime.

The Soft X-ray Streak Cameras

For the purpose of an informed comparison, we have listed important features of the four instruments in Table 1. More complete descriptions may be obtained in the literature and from the manufacturers. We will try to include relevant observations on subjective operational differences as well as quantitative performance measurements. All of the instruments use avalanche transistor sweep drivers. All of the data have been obtained on Kodak negative film after the intensification of the streak tube signal by channel plate image intensifiers (ITT type F4113, F4112). The Kentech and Hadland data were taken with Royal X Pan film. The C650X and Hamamatsu data were taken with type 2485 film.

Table 1. Soft x-ray streak camera features.

	C650X	Hadland X-Chron 540	Hamamatsu C1936	Kentech
Streak tube	RTC P650	Photochron II	N2019	Kentech
Tube type	Bilamellar focus	conventional	conventional	conventional
Astigmatism correction	Yes	Yes Each Speed	Yes	No
Cathode voltage (kV)	15	17.0	6.5	14.78
Extraction field (kV/cm)	60	20	7.5	20
Photocathode to extraction grid space (mm)	2.5	0.5	2.0	2.0
Useful photocathode length (mm)	12	17	10	25
Photocathode slit width (microns)	100	80	80	200
Photocathode configuration	$2X15mm^2$ area separate from slit	on slit	on slit	$5X30mm^2$ area separate from slit
Tube magnification	2X	1.6X	1.6X	1.2X
Tube length (cm)	40	30	15	34
Sweep speeds (ps/mm)	40 50 80	20 500 50 1000 100 2000 200 5000	66 133 333 666	12.5 83 28.6 250 50 1000
Photocathode accessability	requires instrument demounting for access	remotely demountable for inspection and replacement	remotely demountable for inspection and replacement	requires instrument demounting for access
Phosphor screen size (mm)	63	50	25	50
Relative camera sensitivity	0.1	1	1	1
Image intensifier used	ITT F4113 40 mm	ITT F4113 40 mm	ITT F4112 25 mm	ITT F4113 40 mm
Vacuum pumping	small turbo pump	small turbo pump	8 l/s ion pump	pumped by experiment vacuum system
Tube construction	glass, Kovar	ceramic, stainless steel epoxy casting	glass, Kovar	Aluminum, plastic standoff Open to chamber vacuum in re-entrant design

C650X (Figures 1 and 2)

This instrument has been designed for optimum spatio-temporal resolution. The concept of the bi-lamellar P650X tube is based mainly on two technological advances. The first is an intense accelerating field applied to the photocathode (60kV/cm) (ref3). The second is the use of two focusing electron lenses designed to work independantly. A quadrapole lens is used for spatial focusing and a separate cylindrical electrostatic lens focuses in the temporal direction.

The C650X streak camera is conveniently self contained with the control settings on the camera chassis; sweep window durations and differential variations of the sweep speed along the screen are supplied with the camera. The soft x-ray tube is actively vacuum pumped with a small 40 l/s turbo pump. The instrument slides away from the chamber on a rail for photocathode access and replacment. This operation can be performed several times a day if necessary. The photocathode slit is 12 mm. Thin film photocathodes (300 A gold on 3000 A parylene) have been used for these tests.

Hadland X-Chron 540 (Figure 3)

This instrument was engineered to meet a stringent Los Alamos specification. The design constraints focus on spatial resolution, on user convenience and on reliability and flexability under laboratory conditions. This streak camera is compact in a single chassis. A wide variety of sweep speeds and sweep options are switch controllable at the chassis. Astigmitism focus corrections for the various sweep speeds are separately controlled. The photocathode can be extended remotely for viewing through a vacuum window without breaking vacuum. The photocathode can be replaced by removing the vacuum window without moving the streak camera. The useable photocathode slit length is 17 mm. A 40 l/s turbo pump provides active vacuum pumping of the streak tube. A 4x5 cut film back is provided for image recording as well as a Polaroid film back. A durable ceramic, stainless steel, and cast epoxy streak tube construction is used.

Hamamatsu C1936 (Figure 4)

The Hamamatsu soft x-ray streak camera was also engineered to meet the same Los Alamos specification as the Hadland X-Chron 540. The streak camera is also compact with all of the adjustments on the camera chassis. A small external power supply is part of the system. Four sweep speeds are used. The photocathode may be remotely extracted for external viewing through a vacuum window. Photocathode replacement is executed without moving the streak camera. An 8 l/s ion pump actively pumps the streak tube. An astigmatic focus correction is integrated into this streak camera. A 35 mm motor drive film back is available; however, a standard 4x5 Polaroid film back is not offered. The photocathode is relatively small, 10 mm.

The Kentech

This instrument was engineered for re-entrant positioning of the photocathode close to the source inside of the experimental chamber. It fits in a 10 inch port and extends 20 cm into the chamber. The sweep control chassis, the EHV power supply chassis, and the user supplied intensifier controls and supplies are separate from the camera. The mechanical engineering is inferior to the other three instruments tested but appears to be adequate for many applications. The photocathode and cathode slit mask are supplied as separate items. A Polaroid film back is available but a negative film back is not offered. The streak tube, which resides in the experiment chamber and depends on the experiment vacuum system, is assembled of plastic and aluminum parts. The useable photocathode length is a relatively long 25 mm.

Experimental facilities

The Forge

The Forge pulsed x-ray source facility at Los Alamos National Laboratory uses a high power ND:glass laser to focus 1.5 J of 1.06 micron light onto a 100 micron spot on a target in 100ps. The laser pulsewidth can be varied up to 1 ns with a comparable increase in pulse energy. The Forge x-ray source is viewed by the streak cameras through a vacuum. An aluminized 50 microg/cm^2 CH filter is used for these measurements as a UV and charged particle shield. The target to streak camera photocathode distance is 56 cm for the Hadland and Kentech cameras and 66 cm for the Hamamatsu camera.

The laser irradiation conditions in these measurements were held to 0.18 J at 2x10^{13}W/cm^2 onto a gold slab target. Higher energy laser pulses resulted in saturation level exposures in the streak cameras.

The photocathodes on the Hadland, Hamamatsu, and Kentech cameras consist of thin films [300 A Al on 1000 A paraiyene(CH)] which are directly mounted onto the cathode slit aperatures of the streak tubes.

The Ketjak Laser Facility

The Ketjak laser facility at CEA Limeil-Valenton uses a high-power ND:glass laser to focus 35-50 psec pulses of 1.06 micron light in a 100 micron spot onto a metallic target. Under these conditions the laser produced plasma delivers one or more x-ray pulses of approximately 50psec duration. The C650X streak camera is coupled to the experiment vacuum chamber and views the target through an aluminized CH filter used as a UV and charged particle shield. The target to streak camera photocathode distance is 130 cm.

Measurement technique

Resolution in both the temporal and the spatial directions of the streak cameras are measured. We have observed that the temporal and spatial resolution characterictics of some streak cameras are mutually dependant and that to optimize resolution in one axis requires a compromise in the resolution in the other axis. Thus both features must be evaluated under the same focus conditions.

Spatial resolution

A variety of resolution masks were used to map out the modulation transfer character of the four instruments. In all cases, the resolution masks discussed in this comparison consist of free standing gold bars separated by spaces nominally equal to the bar width. The 18 micron thick gold bars are completely opaque to the incident x-radiation. This produces total shadowing of the photocathode at the spatial frequency of the mask. We used shadow masks with spatial frequencies of 5, 8, 10, 12.5, 16, or 20 lp/mm.

The mask is positioned 1 to 2 mm from the photocathode. Penumbral blurring of the shadow by the source size and by the experiment geometry is less than 0.2 micron and is negligible.

The spatial frequency values in this comparison refer to that of the shadow mask at the streak camera photocathode instead of that in the streak image. The various streak tubes have different values of photocathode-to-screen image magnification.

Temporal resolution

X-ray pulses with pulselengths less than the temporal resolution of these instruments were not readily available. In order to estimate the temporal resolution, we evaluate the imaging fidility in the temporal direction and calculate the expected temporal response. Where the pulse shapes and energy distributions may be taken to be gaussian, the temporal resolution is approximated by: (ref7)

$$Tau = (t_v^2 + t_d^2)^{1/2}$$

The minimum time resolved element, t_v, for a given sweep speed V^{-1} (psec/mm) and the experimental (unswept) width, X_e, of the slit image in the temporal direction is given by:

$$t_v = X_e V^{-1}$$

The transit time dispersion (ref7) t_d resulting from the photoelectron energy spread (delta epsilon)(eV) and field E(V/cm) on the photocathode is given by:

$$t_d = 2.3 \times 10^{-8} \text{ (delta epsilon)}^{1/2}/E$$

The energy spread, delta epsilon, of 6.5 eV or 4.6 eV for incident 1487eV x-ray photons on gold or aluminum respectively may be had from Henke[ref8] .

Data processing and analysis

Film digitization

The data was recorded on negative film with a density calibration wedge. The image was then scanned with a microdensitometer at aperature sizes approrriate to the spatial frequency of the data in the image. The digitized data was then converted to relative intensity values through the D-vs-logE calibration data.

Digitization of the data was performed with a Joyce-Lobell microdensitometer at CEA Limeil-Valenton and with a PDS computer controlled microdensitometer at Los Alamos. Image processing was accomplished using a Recognition Concepts image processor.

Image analysis

High fidelity recording of temporal or spatial detail in an ultra-fast signal is limited by the signal-to-noise ratio in the image as well as by the streak system imaging capability. The signal-to-noise ratio becomes a more important issue as the recording time becomes shorter because the instantaneous charge current in the streak tube is limited by Coulomb repulsion effects. When this limit is exceeded, temporal and spatial fidelity of the system is degraded and saturation becomes apparent. Thus the integrated electron signal through the streak tube, which must make up the streak image, is limited by the product of the tube saturation current and the signal pulse width. The image may be intensified to obtain adequate signal levels for film recording but this does not improve the shot-noise-limited statistical character of the data. Because of this signal level limitation, the full temporal and spatial fidelity of the streak system may not both be simultaneously available.

When we wish to analyze the streak image with empahsis on spatial fidelity, we may need to integrate signal in the temporal direction for a number of resolution times to obtain adequate statistics for the full spatial resolution of the streak tube to be apparent. Similarly, if we wish to obtain the limiting spatial resolution of the instrument, it may be necessary to sum over a number of spatial resolution lengths for adequate statistical character in the temporal profile.

The contrast modulation in the data is defined here as the ratio of the intensity modulation to the peak intensity with an adjustment for the background level of the film.

$$\text{Contrast} = \frac{L_{max} - L_{min}}{L_{max} - \text{background}}$$

The modulation was observed to vary in the streak image. The uncertainty in modulation is tabulated in Table 2. In these characterization tests, we have used flux levels as high as possible without going into saturation. However, it has been necessary to use the integration techniques described here to evaluate the full temporal and spatial capabilities of the instruments. Substantial signal averaging in the temporal direction was necessary to reduce the error in modulation level to the few percent level. The area of integration used in each measurement is listed with the value in Table 2.

Characterization results

C650X

The measurements on this instrument used the 50-psec x-ray pulse from the Ketjak facility. The static image of the slit, X_{w}, has an average width of 100 microns across the screen. With a sweep rate of V^{-1} of 50psec/mm, we would obtain a temporal resolution value, tau, of 5 psec anywhere on the screen at the fastest sweep.

At this sweep speed the dynamic temporal resolution extends to 20 lp/mm at the limit of visually discernable modulation. The modulation transfer function, a more meaningful representation of the instrument performance, is given in figure (T1). Signal averaging of 50psec in the time direction was used determine the modulation depth at the 5, 8, 10, 12.5 and 16 lp/mm resolution values respectively. A plot of signal amplitude vs position for the 10 lp/mm data is given in figure(T2). The streaked image of a 10 lp/mm resolution chart is shown in figure(T3). The modulation at 10 lp/mm is 85%.

This instrument has demonstrated uniform high fidelity recording capability across both spatial and temporal dimensions of the sweep. This advantage must be weighed against the tube throughput which is a factor of 10X lower in this streak camera than in the other three discussed here.

Hadland X-Chron 540

The measurements presented for this instrument were performed with 150 psec duration x-ray pulses at the Forge x-ray source . The static image of the slit, X_* , has an average width of 170 microns at the screen center. At midpoint between the screen center and the end of the sweep the width of the static image degrades to 220 microns. With a sweep rate of V^{-1} of 50 psec/mm, we obtain a temporal resolution value, tau, of 9.2 psec at the center of the screen at the fastest sweep.

At this sweep speed the dynamic temporal resolution extends to 20 lp/mm. The modulation transfer function is given in figure (Had 1). Signal averaging of 50, 50, 50, 100, 50 and 50 psec in the time direction was necessary to unambigously determine the modulation depth at the 5, 8, 10, 12.5, 16, and 20 lp/mm resolution values respectively. A plot of signal amplitude versus position for the 10 lp/mm data is given in figure(Had 2). The streaked image of a 10 lp/mm resolution chart is shown in figure(Had 3). The modulation in this data is 70%. This modulation degrades to XX% at the edge of the screen.

Hamamatsu C1936

The measurements presented for this instrument were performed with 150 psec duration x-ray pulses at the Forge x-ray source. The static image of the slit, X_*, has an average width of 130 microns at the screen center. At midpoint between the screen center and the end of the sweep the width of the static image degrades to 190 microns. With a sweep rate of V^{-1} of 66 psec/mm, we obtain a temporal resolution value, tau, of 13 psec at the center of the screen at the fastest sweep.

At this sweep speed the dynamic temporal resolution extends to 20 lp/mm. The modulation transfer function is given in figure (Ham 1). Signal averaging of 15, 15, 33, 66, 100, and 130 psec in the time direction was necessary to unambigously determine the modulation depth at the 5, 8, 10, 12.5, 16, and 20 lp/mm resolution values respectively. A plot of signal amplitude vs position for the 10 lp/mm data is given in figure(Ham 2). The streaked image of a 10 lp/mm resolution chart is shown in figure(Ham 3). The modulation in this data is 54%. This modulation degrades to XX% at the edge of the screen.

Kentech

The measurements presented for this instrument were performed with 150 psec duration x-ray pulses at the Forge x-ray source. The static image of the slit, X_*, has an average width of 215 microns at the screen center. At midpoint between the screen center and the end of the sweep the width of the static image improves to 200 microns. With a sweep rate of V^{-1} of 50 psec/mm, we obtain a temporal resolution value, tau, of 11 psec at the center of the screen at the fastest sweep.

At this sweep speed the dyramic temporal resolution extends to 10 lp/mm. The modulation transfer function is given in figure (K1). Signal averaging of 15, 25, and 50 psec in the time direction was necessary to unambigously determine the modulation depth at the 5, 8, and 10 lp/mm resolution values respectively. A plot of signal amplitude vs position for the 10 lp/mm data is given in figure(K2). The streaked image of a 10 lp/mm resolution chart is shown in figure(K3). The modulation in this data is 24%. This modulation degrades to XX% at the edge of the screen.

Summary of results

The contrast modulation results from the four soft x-ray streak cameras evaluated are summerized in table 2.

TABLE 2-Modulation results averaged over time for unambiguous determination of streak camera capability.

Spatial Frequency	C650X	Hadland X-Chron 540	Hamamatsu C1936	Kentech
5 lp/mm	92±4% at 50ps	82±10% at 50ps	80± 5% at 15ps	40± 7% at 15ps
8 lp/mm	91± 4% at 50ps	82± 5% at 50ps	57± 5% at 15ps	18± 6% at 25ps
10 lp/mm	85± 8% at 50ps	70± 6% at 50ps	54± 5% at 33ps	24± 6% at 50ps
12.5 lp/mm	73±12% at 50ps	45± 7% at 50ps	43± 5% at 66ps	--
16 lp/mm	52±16% at 50ps	18± 6% at 100ps	20± 7% at 100ps	--
20 lp/mm		21± 4% at 50ps	12± 4% at 130ps	--

The effective temporal resolutions of the four instruments, at the fastest sweep speed available with the individual instrument, are tabulated in Table 3. This coupled with the useful photocathode size, the output screen size and the spatial resolution at 30% modulation results in a quantity: the information capacity of the streak system. Calculation of this quantity is slightly complicated by pragmatic constraints. The modulation transfer function is not uniform across instrument in space or in time. The entire 50mm screen cannot be used with a 40mm diameter image intensifier. Thus we use average values to compute the information capacity of the streak system which is taken to include a standard image intensifier size. In addition to the imaging limits of the streak system, statistical noise will constrain the achievable information capacity to well below this optimum value.

$$\text{Information capacity} = (R_{ave}\, L_{pc})(D_{II}/X_{ave})$$

TABLE 3

	C650X	Hadland X-Chron 540	Hamamatsu C1936	Kentech
Tau_{a}	1.4psec	3.6psec	9.6psec	3.6psec
Fastest Speep Speed	40psec/mm	20psec/mm	66psec/mm	12.5psec/mm
Static Slit Image Width X_{ave}	100microns	195microns	160microns	182microns
Tau_{x}	4.0psec	3.9psec	10.6psec	2.3psec
Temporal Resolution	4.3psec	5.3psec	14psec	4.3psec
Sweep Length w/ II D_{II}	40mm	40mm	25mm	40mm
Temporal window at fastest sweep	1.6nsec	0.8nsec	1.6nsec	0.5nsec
Average Resolution at 30% R_{ave}	17 lp/mm	12 lp/mm	10 lp/mm	8 lp/mm
Useful PC Length L_{pc}	12mm	17mm	10mm	25mm
Information Capacity	16×10^{4}pixels	8.3×10^{4}pixels	3.1×10^{4}pixels	8.8×10^{4}pixels

!These information capacity numbers do not yet include MTF nonuniformity across the screen.!

Conclusions

The four soft x-ray streak cameras evaluated have shown good spatio-temporal fidelity. Each instrument was shown to have both strengths and weaknesses. The C650X has particularly high fidelity and uniformity of spatio-temporal resolution across the output screen. Users must weigh the relative advantages to their applications of spatial and temporal resolution, of resolution uniformity, photocathode length, user convenience, and instrument cost.

It is important that shot noise degradation of the signal to noise ratio in the streak image be taken into account in experiment design and data analysis.

Acknowledgments

We appreciate the extensive support of our **management** and technical staff both at Los Alamos and at CEA Limeil-Valenton. We particularly thank Robert Day Jean Coutant and M. Coudville for their funding and encouragement through the span of this two year project. We appreciate the flexability and responsiveness of Jack Clifford in film processing, Becky Gomez-Lujan in image digitization and George Jordan in software development.

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CHARACTERIZATION RESULTS FROM SEVERAL COMMERCIAL SOFT X-RAY STREAK CAMERAS

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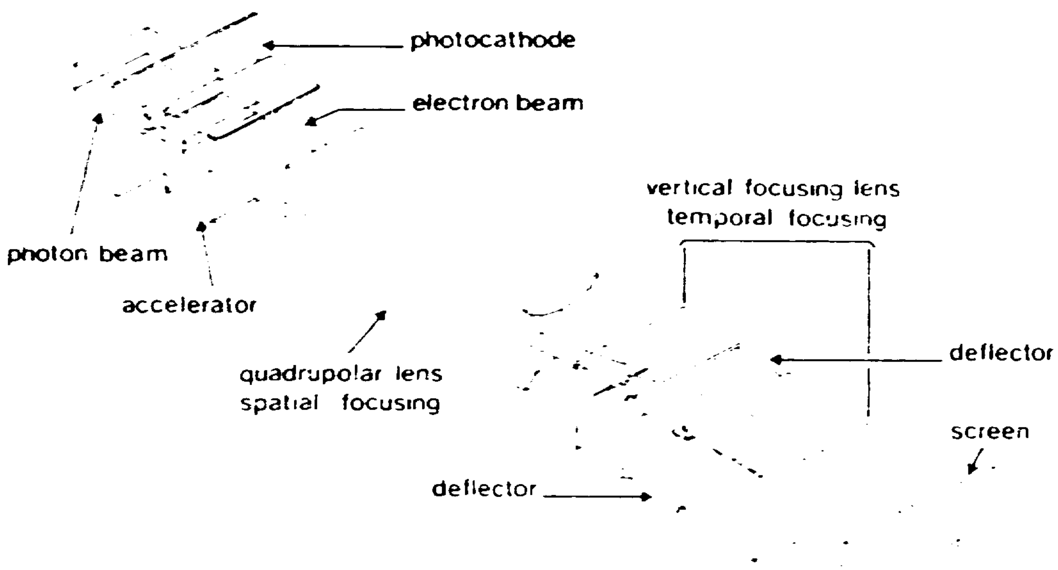
Los Alamos National Laboratory/Operated by University of California

MOTIVATION OF CHARACTERIZATION WORK

- DATA IS CRITICAL FOR OPTIMIZATION OF QUANTITATIVE STREAK EXPERIMENTS AND FOR INTERPRETATION OF THE RESULTS
- COMPLETE STUDIES HAVE NOT BEEN AVAILABLE IN THE LITERATURE
- MISCONCEPTIONS AND PREJUDICE THRIVE IN THE DARK
- THE INSTRUMENTS ARE COSTLY - DETAILED PERFORMANCE RESULTS HELP SELECTION

OBJECTIVES OF CHARACTERIZATION MEASUREMENTS OF SOFT X-RAY STREAK CAMERAS

- MEASURE <u>DYNAMIC</u> MODULATION TRANSFER FUNCTION (<u>MTF</u>)
- EVALUATE <u>TEMPORAL</u> <u>RESOLUTION</u>
- EVALUATE <u>INTERDEPENDENCE</u> OF SPATIAL AND TEMPORAL IMAGING CAPABILITIES
- EVALUATE LIMITATION OF <u>SHOT</u> <u>NOISE</u> ON OVERALL INFORMATION DENSITY
- PROVIDE TO ULTRA-FAST STREAK COMMUNITY A GENERAL COMPARISON BETWEEN AVAILABLE INSTRUMENTS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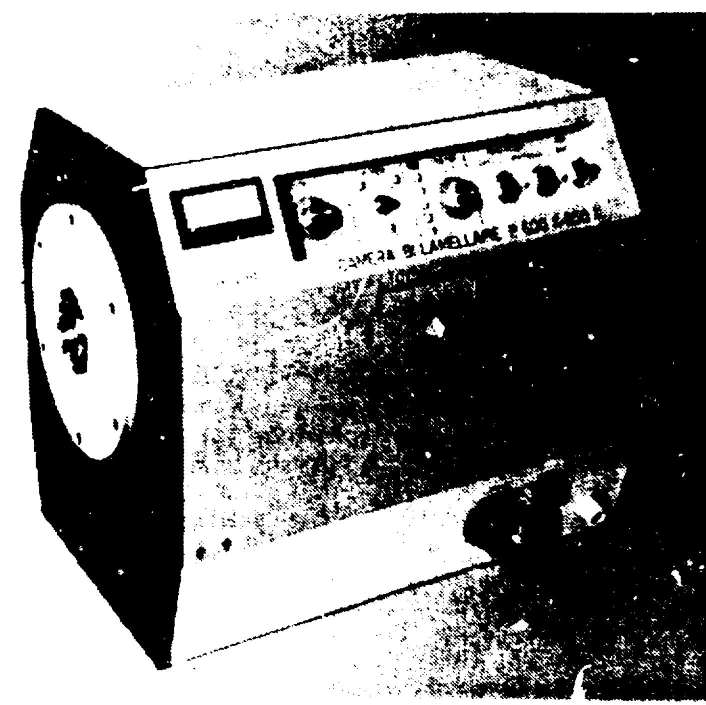

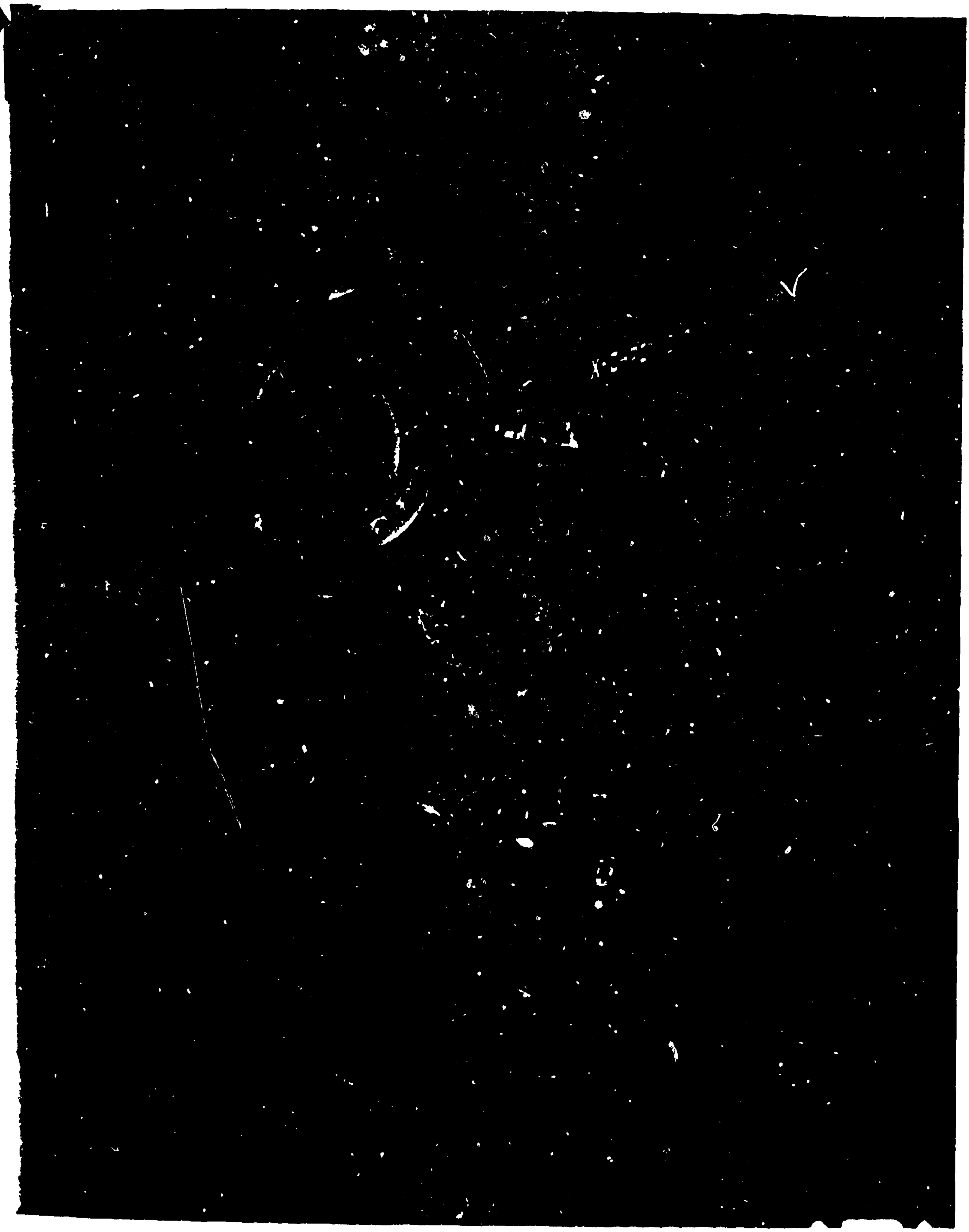

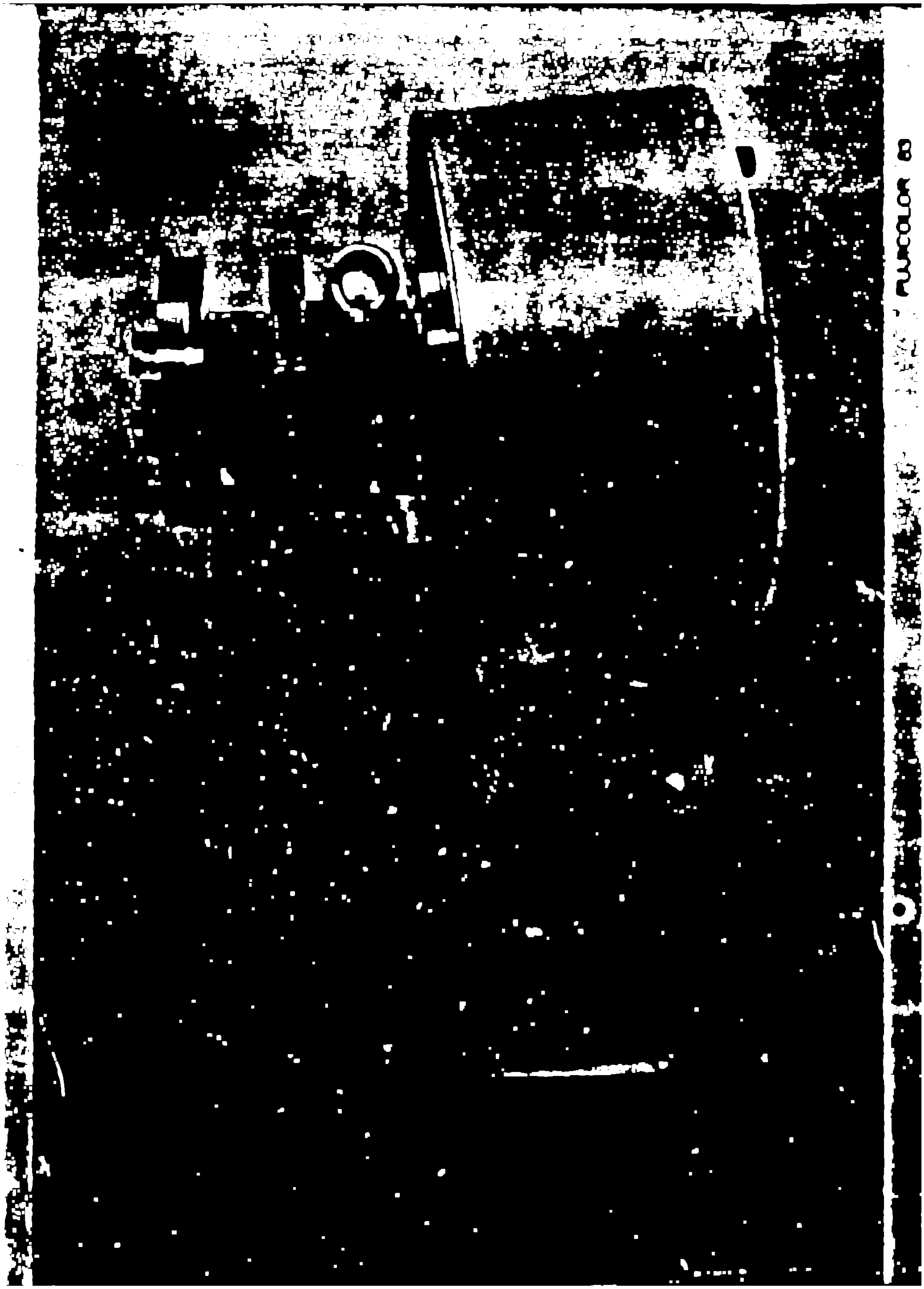
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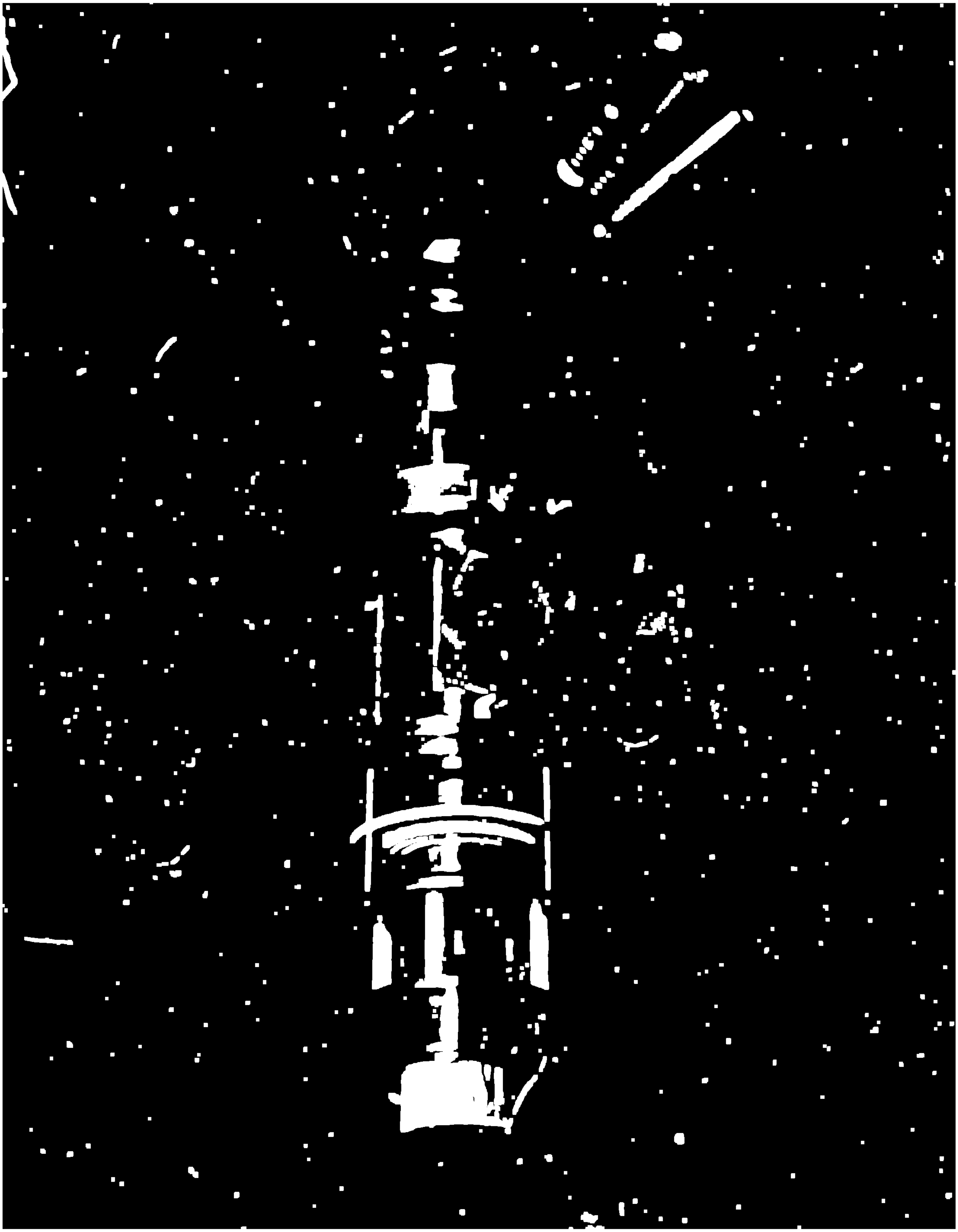


DATA ANALYSIS

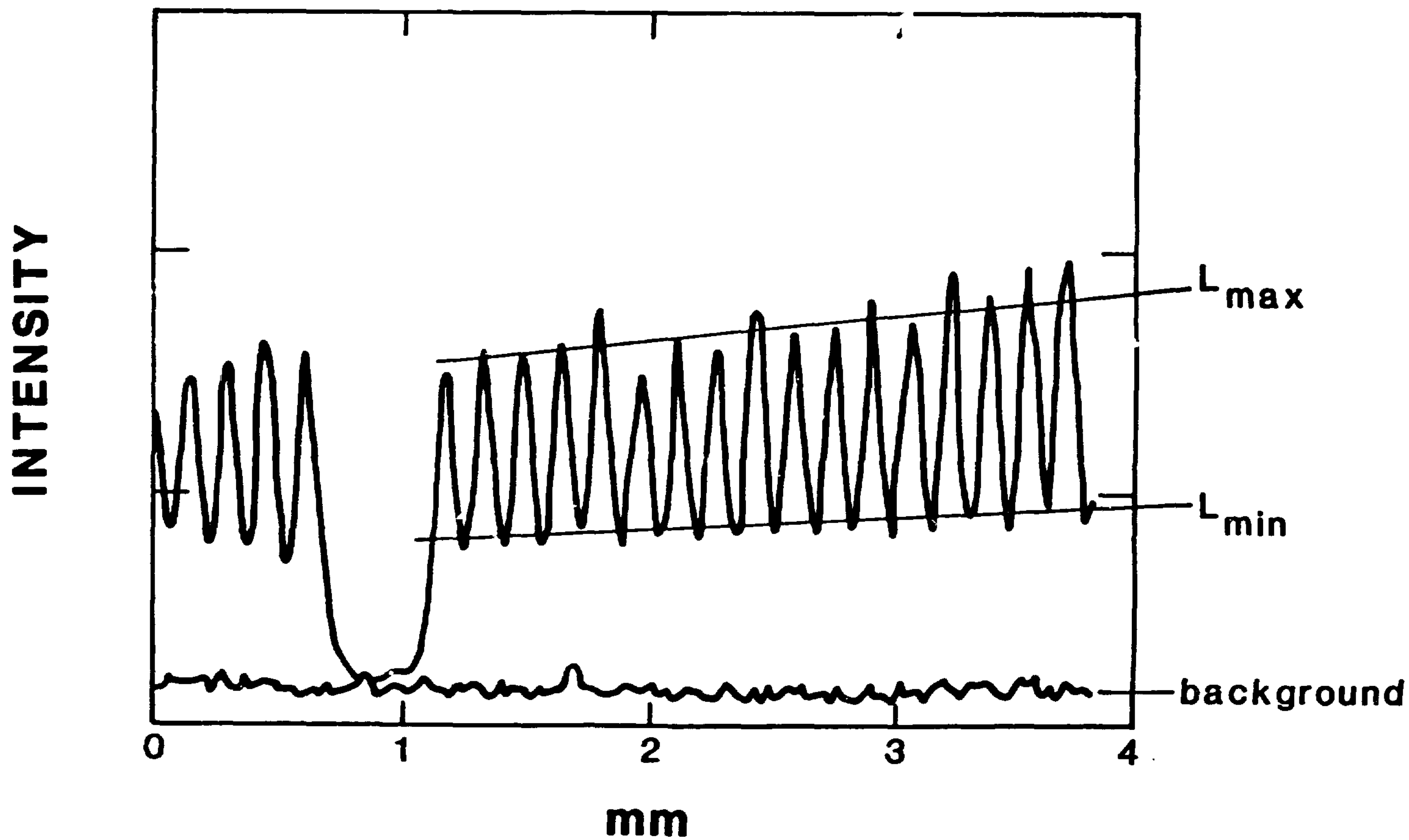
- FILM RECORDING - KODAK RXP, 2485
- MICRODENSITOMETRY - PDS COMPUTER CONTROLLED, JOYCE LOBELL
- D vs log E CORRECTION TO INTENSITY

SHOT NOISE LIMITED INFORMATION DENSITY

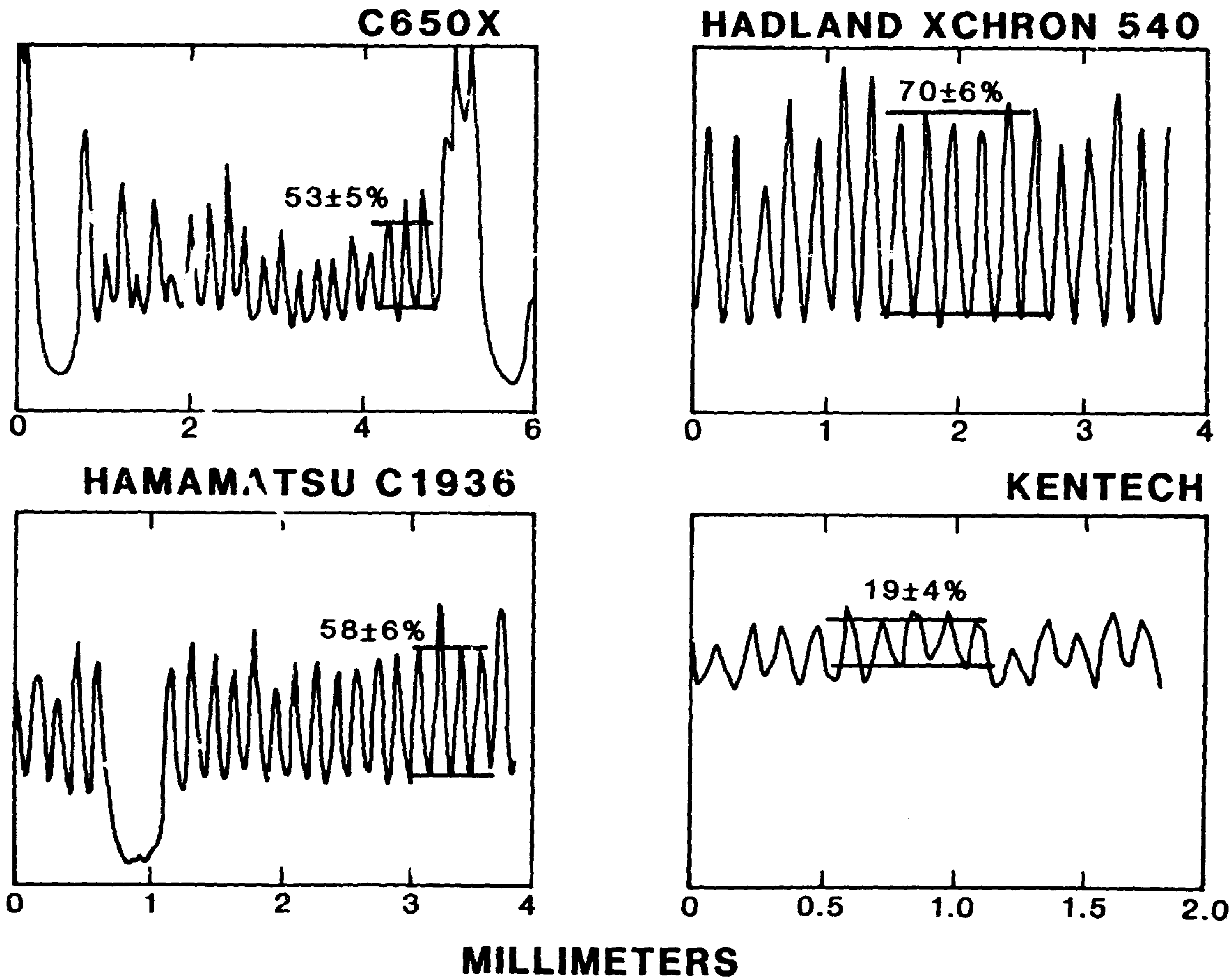
- COULOMB REPULSION IN TUBE LIMITS RESOLUTION AT HIGH CURRENT
- IMAGE IS MADE UP OF ELECTRONS, Q_{col}
- $A_{max} \sim Q_{col}/\Delta t$ TOTAL CHARGE COLLECTED IS RESTRICTED IN SHORTER EVENTS
- WHERE INSTRUMENT SPATIO-TEMPORAL RESOLUTION CAPABILITY IS GOOD, SHOT NOISE LIMITATIONS OF SHORT PULSES MAY STILL LIMIT INFORMATION DENSITY IN THE STREAKED IMAGE
- TO DETERMINE INSTRUMENT RESOLUTION CAPABILITY IN TIME OR SPACE, WE INTEGRATE THE IMAGE IN THE PERPENDICULAR DIRECTION FOR ACCEPTABLE STATISTICS

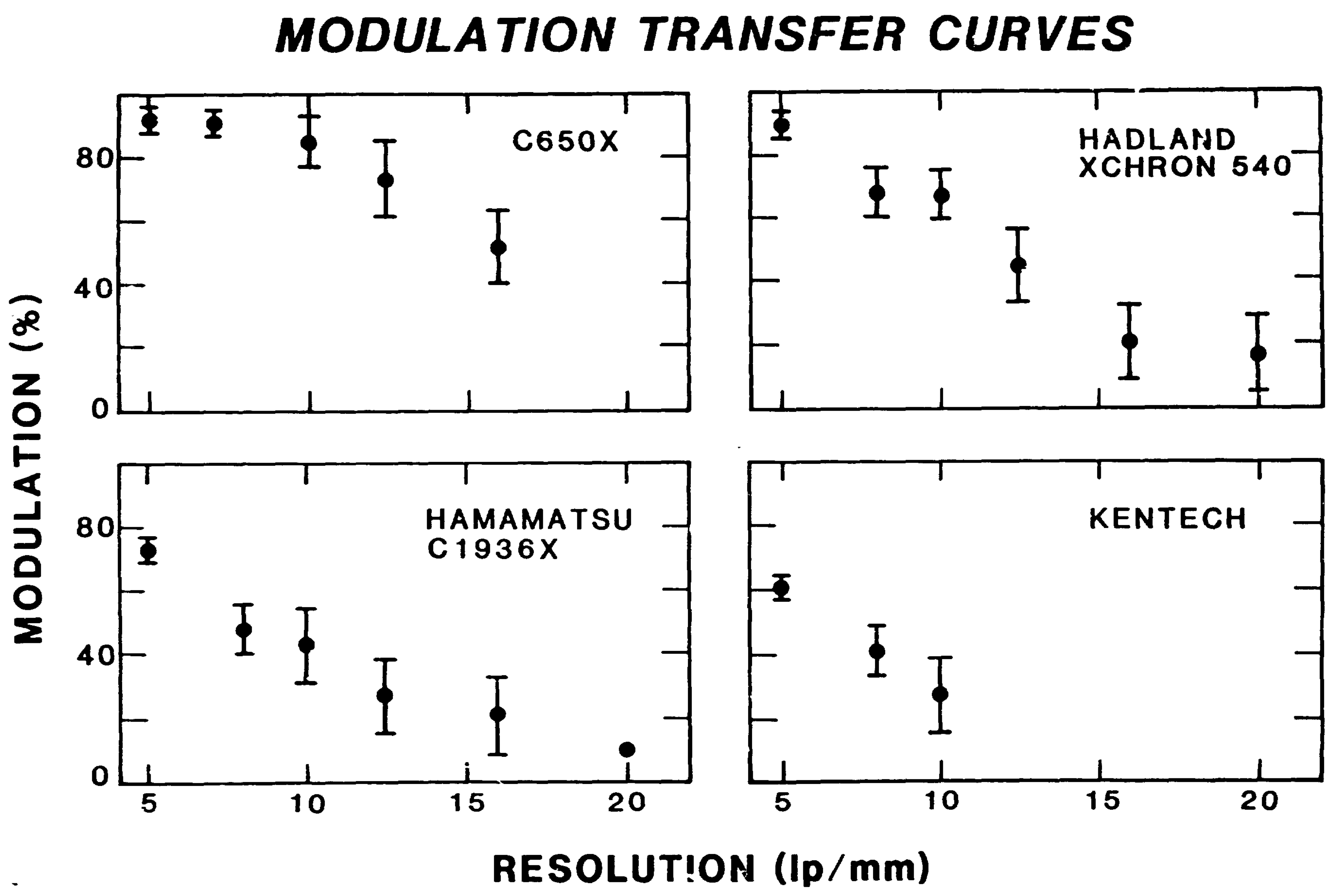
MODULATION CONTRAST CALCULATION

$$C = \frac{L_{max} - L_{min}}{L_{max} - \text{background}}$$



MODULATION CURVES AT 10 lp/mm




MODULATION TRANSFER CURVES
C650X
HADLAND
XCHRON 540
HAMAMATSU
C1936X
KENTECH
MODULATION (%)
80
40
0
5
10
15
20
RESOLUTION (lp/mm)

TEMPORAL RESOLUTION

TRANSIT TIME DISPERSION $T_{d(ps)} = 2.3 \times 10^{-8} \left(\frac{\Delta\Sigma}{E}\right)^{1/2}$

IMAGING CONTRIBUTION TO TEMPORAL RESOLUTION

$$T_v = X_s V{-1}$$

X_s = IMAGE OF SLIT ON PHOSPHOR (mm)

V^{-1} = SWEEP SPEED (ps/mm)

E = EXTRACTION FIELD STRENGTH (V/cm)

$\Delta\Sigma$ = ELECTRON ENERGY SPREAD (eV)

$\Delta\Sigma_{Au} = 6.5$ eV, $\Delta\Sigma_{Al} = 4.6$ eV at 1487 eV X-RAY ENERGY

FOR GAUSSIAN DISTRIBUTIONS AND PULSE SHAPES

$$\tau \simeq (T_v^2 + T_d^2)^{1/2}$$

CONCLUSIONS

- ALL FOUR INSTRUMENTS OFFER QUALITY PERFORMANCE

- THE USER MUST SELECT BETWEEN VARIOUS TRADE-OFFS OF INFORMATION CAPACITY, RESOLUTION, RESOLUTION UNIFORMITY, PHOTOCATHODE LENGTH, USER CONVENIENCE AND COST

- USERS SHOULD BE CAUTIOUS OF THE EFFECT OF SHOT NOISE IN SINGLE-SHOT ULTRA-FAST APPLICATIONS. ADEQUATE SIGNAL MAY NOT BE AVAILABLE TO UTILIZE THE FULL CAPABILITY OF THE STREAK CAMERA.