XMM Optical Monitor

MULLARD SPACE SCIENCE LABORATORY
UNIVERSITY COLLEGE LONDON
Authors: H. Kawakami and Frank Thurlow

Throughputs of OM optical components

Document Number: XMM-OM/MSSL/TC/0055.01 10-September-99

Distribution:

XMM-OM Project Office	A Dibbens	Orig.
Mullard Space Science Laboratory	K Mason	
	A Smith	
	A Breeveld	
	M Cropper	
	J Lapington	
	J Tandy	
	H Kawakami	
ESTEC	R Much	

8 September 1999

<< Throughputs of OM optical components >>

XMM-OM/MSSL/TC/0055.01

Hajime Kawakami and Frank Thurlow

Mullard Space Science Laboratory, University College London

1. Measurement

Throughputs of spare optical accessaries, 6 filters, 2 grisms and 1 magnifier, were measured to estimate those of FM components. Barr Associates Inc. already provided transparency curves for the 5 filters with high wavelength resolution (March 1998). But, there is no data for UVW2 filter (shortest wavelength), the 2 grisms and the magnifier. It is also important to check the transparency curve redundantly even for the 5 filters .

The vacuum monochrometer (ref. XMM-OM/TC/0053) was used for these measurements from 1900A to 5800A. A MIC photon counting detector, fed to the port-A of the monochrometer, counted input photons with and without the optical components (see Fig. 1). Throughput of a optical component was determined from the ratio between the two fluxes. Since the filters, magnifier and grisms are too large to be fitted in the 0"5 filter wheel at the monochrometer, they were held in front of the MIC intensifier. In this consequence, the input fluxes without the optical component had to be measured for all wavelengths in a day, then those with the optical components were followed in the other days. The intensities of the light source had to be monitored all the time by a photomultiplier, fed to the port-B of the monochrometer. Aluminium slots were placed in front of the two detectors at the same distances from the light source to insure the constant ratio of input flux. The size and position of the slots used for individual measurement are summarized in table-1

Deuterium lamp was used for the light source for all wavelengths. It has strong intensity in short wavelengths and weak in longer wavelengths (150:1 @2000A v.s. @5500A). This is ideal spectral pattern if combined with long pass filters, which produces quasi narrow band light. Order sort filters used in this measurements are tabulated in table-2

The primary problem of the measurements was difference of the sensitivities between the 2 detectors, though both detectors were operated in photon counting mode. The dynamic range of the photomultiplier is high (> 100,000 counts/sec for small size light source), but its D.Q.E. is only 1/17 of MIC's at 2000A (though it was 1/6.5 in Oct. 1992). The noise current (not dark current) caused by charge up of the photomultiplier is extraordinary high, and it increases with elapsed time of the operation exponentially. It is

typically 400 counts/sec in the beginning, but reaches 4,000 counts/sec after 3-4 hours operation. It takes more than 24 hours to discharge the photomultiplier.
The D.Q.E. of the MIC intensifier is reasonably high and dark current is extremely low (<10 counts/sec). But, its dynamic range is not excellent (10% coincidence loss at 2 count/sec/CCD_pixel).
As a consequence, the maximum input flux is limited by the small dynamic range of the MIC. With the 2.5x3mm slot, 2,500 c/s is practically maximum for MIC, but it can create only 150 c/s in the photomultiplier at 2000A against the noise events of a few 1000s counts/sec. This was essential problem for the measurements of the Grisms, which required the narrow slots. To overcome this problem, the wider 2mm slot was used for the photomultiplier assuming illumination is uniform in the scale of 2mm.

The secondary problem was fading intensity of the light source (1/10? of 1992). It is still bright below 3000A, but not in the longer wavelengths. If opening the entrance/exit slits to provide more photons, non-uniformity of the illumination appears on the detector in the scale of 10mm due to the narrow beam of the Deuterium lamp. This is the reason why the slot for the photomultiplier could not be wider than 2mm for grism measurement.
Input photon flux for the photomultiplier must be relatively high to overcome its low Q.E. and high noise. This, however, causes too high count rate for MIC, hence non-linearity correction is required to keep accuracy. The correction should be successful if the illumination is uniform, but systematic error remains if non-uniform.
Compromisations were required between photon statistics and illumination uniformity in the wavelengths above 3000A because of the wider slit.
Other impact of the wide slit is poor wavelength resolution. The exit slit had to be opened to 2500um above 4000A to provide sufficient photons to the photomultiplier. Since the linear dispersion at exit slit is about 33A/mm, the band width of the monochromatic light is about 80A in the longer wavelengths.

The non-linearity correction of the MIC detector was carried out following the procedure described in XMM-OM/TC/0050 ("Flat Field coincidence loss in the MIC detector"). From the equation A-2, the true incoming photon "**n**" is calculated by the equation,

$$n = -a \times \ln\left(1 - \frac{n\_det}{a}\right)$$

where, "**n_det**" denotes detected photon number and "**a**" scale frequency. The scale frequency depends on CCD frame rate, illumination area and event width captured by the CCD. It is typically 10 c/s/CCD_pix when CCD frame rate is 100Hz. Since the event width could be different after mount/dismount of CCD camera from the MIC intensifier, the non-linearity data were obtained for every set of measurements. The schedule of the measurements is summarized in table 3.

Table 1. Mask pattern

MIC	Photomultiplier	Position	component
10x10mm	10x10mm	in front of detector	filters
2.5x 3mm	2.5x 3mm	in front of magnifier	magnifier
1x10mm	2x10mm	in front of grism	grism

Table 2. Order sorting filters

Filter	cutoff (0%)	Transition(10%-50%)	90%	
Fused Silica	1600A	1600-1700A	1700A	
UL-30.5 (short)	1800A	1900-2100A	2100A	band-
UL-30.5 (long)	---	3800-6000A	3700A	pass
Pyrex	2600A	2900-3100A	3300A	
OG515	4900A	4900-5100A	5300A	

Table 3. Schedule of measurement

	CCD Format	Time	Date	Remark
10x1mm slot	84(H)x180(V)	15:04-18:26	1999/07/19/	Reference
Linearity	84(H)x180(V)	18:38-19:13	1999/07/19/	a=0.030MHz
UV-Grism	84(H)x180(V)	16:05-20:27	1999/07/20/	1st order
Linearity	84(H)x180(V)	20:39-21:07	1999/07/20/	a=0.023MHz
Optical Grism	70(H)x180(V)	16:15-18:45	1999/07/22/	1st order
Linearity	70(H)x180(V)	18:56-19:27	1999/07/22/	
Optical Grism	52(H)x180(V)	15:24-18:14	1999/07/27/	0-th Order
UV_Grism	64(H)x180(V)	16:36-18:47	1999/07/31/	0-th Order
Linearity	64(H)x180(V)	14:43-15:30	1999/08/02/	
//////////////////				
10x10mm slot	176(H)x196(V)	13:24-15:46	1999/08/16/	Reference
Linearity	176(H)x196(V)	15:51-16:20	1999/08/16/	a=0.24MHz
V-Filter	176(H)x196(V)	13:46-17:19	1999/08/17/	
Linearity	176(H)x196(V)	17:25-17:55	1999/08/17/	a=0.16MHz

B-Filter	176(H)x196(V)	12:26-17:31	1999/08/19/	
Linearity	176(H)x196(V)	17:37-18:08	1999/08/19/	a=0.28MHz
U-Filter	176(H)x196(V)	14:35-16:24	1999/08/20/	
Linearity	176(H)x196(V)	17:14-17:42	1999/08/20/	a=0.21MHz
UVW1	176(H)x196(V)	15:50-20:20	1999/08/23/	
Linearity	176(H)x196(V)	15:14-15:44	1999/08/23/	a=0.24MHz
UVM-2	176(H)x196(V)	19:50-20:08	1999/08/24/	
		10:48-15:11	1999/08/26/	
Linearity	176(H)x196(V)	11:59-12:28	1999/08/26/	a=0.22MHz
UVW-2	176(H)x196(V)	19:05-20:55	1999/08/26/	
Linearity	176(H)x196(V)	14:15-14:44	1999/08/27/	a=0.21MHz

//

Magnifier	200(H)x180(V)	19:08-19:39	1999/08/31/	
		10:31-14:15	1999/09/01/	
Linearity	200(H)x180(V)	14:50-15:21	1999/09/01/	a=0.27MHz
2.5x3mm slot	70(H)x 60(V)	18:57-19:29	1999/09/03/	Reference
Linearity	70(H)x 60(V)	18:57-19:29	1999/09/03/	a=0.044MHz

2. Filters

The transparencies of V, B, U, UVW1, UVM2 and UVW2 are shown in Figs. 2 - 7 individually. The composite curves are in Fig. 8. The U, B, V filters show sharp cutoff and excellent transparencies (> 90%) in the appropriate wavelengths. The ripples in the plateau region showed same features as those in Barr's measurements for V- and B-filters. The ripple of the U-filter, which is shown in Barr's measurement with a large amplitude, is not significant in our measurement. This difference may be due to the higher wavelength resolution of Barr's spectrometer. A small peak of 25% at 4800A seen in Barr's data was detected in our measurement with the peak of 11%.
The spectrum of UVW1-filter looks more like UVW1-30 than UVW1-32 in Barr's data. The asymmetric shape with gentle ripple at red wind looks similar to UVW1-30. The peak transparency at 2400A is higher in our measurement by 5%.
The spectrum of UVM2-filter looks more like UVM2-30 than UVM2-32 in Barr's data. The peak transparency at 2100A is again higher in our measurement by 5%.

One of our concern is leakage in blocked wavelengths even if very low transparency, such that cannot be seen in a diagram (e.g. <1%). The leakage may look negligible at one wavelength, but it could be significant after integrating wide wavelength range. The detailed data are available in table 4. The fundamental problem of the measurement associated with the grating monochrometer is scattered light, which can be suppressed by the excellent combination of an order sorting filter and D2 lamp spectrum, but it is still difficult to achieve lower than 0.1%. Therefore, it is recommended not to trust much if the value is smaller than 0.1% in the table.

Table 4. Throughputs of 6 filters

Wavelength	V	B	U	UVW1	UVM2	UVW2
1900A	.005%	.020%	.053%	1.333%	5.169%	26.609%
2000	.002	.016	.045	2.232	22.949	25.947
2100		.017	.049	5.171	42.969	23.865
2200	.005	.017	.054	14.363	42.363	17.409
2300		.022	.065	40.664	39.320	10.118
2400	.005	.025	.080	56.623	32.323	5.268
2500		.033	.105	52.545	22.374	2.873
2600	.008	.041	.126	48.211	11.581	1.633
2700	.009	.042	.138	44.440	4.910	1.019
2800	.009	.049	.157	40.445	2.175	.740
2900		.055	.198	33.481	1.231	.530
3000	.015	.076	3.909	27.147	.673	.367
3100		.083	72.868	20.017	.545	.334
3200	.020	.095	87.662	12.884	.522	.325
3300		.103	97.560	7.403	.060	.084
3400	.023	.113	94.532	4.082	.038	.061
3500		.159	94.139	2.299	.028	.046
3600	.036	.278	94.354	1.654	.017	.040
3700	.060	1.100	90.625	1.163	.013	.032
3800	.146^^^	9.930	96.727	.556	.013	.028
3900	.036	58.446	32.202	.358	.005	.021
4000	.043	96.474	1.605	.229	.006	.017
4100		95.248	1.016	.201	.006	.022
4200	.070	93.725	.942	.170	.007	.020
4300		91.211	.933	.135	.007	.007
4400	.101	92.311	1.034	.127	.007	.034
4500		93.420	1.076	.156	.012	.004
4600	.106	89.854	1.245	.115	.004	.016
4700	.386	91.489	2.450	.164	.013	.008
4800	.541	91.506	11.047^^^	.151	.013	.013
4900	1.441	27.971	1.770	.158	.009	.021
5000	15.204	1.486	1.860	.180	.008	.013
5100	69.984	.270 (OG5)	.351 (OG5)	.004 (OG5)	.041 (OG5)	.004
5200	96.647	.236	.213	.057	.019	.004
5300	96.353	.217	.239	.055	.018	.000
5400	96.002	.210	.183	.017	-.010	.003
5500	95.724	.238	.175	.013	-.028	-.003
5600	92.649	.195	.198	.016	.008	-.005
5700	96.204	.148	.175	.021	.004	.002
5800	84.814	.207	.015	.003	.010	.004

3. Grisms

Photon counting images were acquired with the UV_Grism through 1mm slot at 1900-3000A with 100A step and at 3500-5500A with 500A step (see Figs. 9-12). Since the grating was not blazed, diffracted light was distributed into many orders. The tilt derived from Fig. 9 is +6.4 degrees.

The photon fluxes in the first order, in the 0-th order and without the grism were measured. The input light intensities were monitored simultaneously by the photomultiplier. The throughputs in the both orders were derived from the ratios to the flux without the grism. Then, the throughput for the -1st, 2nd and 3rd orders were determined relative to the 1st order brightness in the photon counting images (1900-3000A). The results are shown in Fig. 13 and table 5.

Since the UV_Grism contains 6 surfaces including the grating, the 4% loss /surface makes transparency of 78%. While, adding the 0-th, the +/-1st, the +/-2nd (assuming the -2nd order is similar to the +2nd and +/-3rd orders are zero) makes only 69% at 2500A, for instance. This discrepancy of 9% may be due to absorption by the material and due to dirts on the surfaces.

Ghost is visible at longer wavelengths (>5000A), which seems to be from 0-th order because the position is constant. The intensities are 0.76% at 5000A and 0.7% at 5500A.

Photon counting images were acquired with the Optical_Grism at 3100-4500A with 100A step and at 5000-5500A with 500A step (see Figs. 14-16). Since the grating is blazed brilliantly, most of diffracted light go into the 1st order. The blazed wavelength seems to be around 3600A from 0-th order throughput spectrum. The tilt derived from Fig. 14 is -1.2 degrees.

The photon fluxes in the first order, in the 0-th order and without the grism were measured. The throughputs in the both orders were derived from the ratios to the flux without the grism. Then, the throughputs for the -1st, 2nd and 3rd orders were determined relative to the 1st order brightness in the photon counting images (3100-4500A). The results are shown in Fig. 17 and table 6.

Since the ~~UV~~ Optical_Grism contains 6 surfaces including the grating, the 4% loss /surface makes transparency of 78%. While, adding the 0-th, the +/-1st, the +/-2nd (assuming the -2nd and +/-3rd orders are zero) makes 74% at 4500A. This is reasonable matching.

Ghost is visible at 4000A. Its intensity is 0.8%.

Colour aberrations at 0th order image were investigated with the both grisms (see Fig. 18). The position shift versus wavelength is relatively small above 3000A for the both grisms, while the shift below 3000A is significant in the UV_Grism. It, however, should be noted the grisms were placed 7mm forward from the designed position in this test, and input light beam is collimated (unlike XMM-OM's F/11). The position shift could be much smaller if the grisms were placed in the right position.

Table 5. Throughput of UV-Grism

Wavelength (A)	Efficiency (%) 1st	0-th	2nd	3rd	-1 st
1900A	12.826%	12.262%	7.428%	2.862%	16.808%
2000	13.296	13.599	6.777	2.409	17.475
2100	14.787	16.182	6.557	2.419	19.258
2200	15.539	18.949	6.360		19.608
2300	15.885	21.117	5.787		19.893
2400	15.052	22.896	5.218		18.473
2500	15.216	24.917	5.058		18.558
2600	15.740	29.151	4.709		18.530
2700	14.666	30.411	3.970		17.070
2800	14.598	33.838	3.892		16.537
2900	13.820	35.397	3.586		15.360
3000	14.969	39.163	3.736		16.277
3100	14.097	40.608			
3200	13.311	40.285			
3300	13.372	42.591			
3400	13.135	45.257			
3500	12.688	45.904			
3600	11.681	45.767			
3700	11.391	47.283			
3800	10.456	47.228			
3900	10.535	50.877			
4000	10.058	50.679			
4100	9.949	53.220			
4200	9.347	52.995			
4300	8.684	53.497			
4400	8.933	57.910			
4500	8.598	56.291			
4600	8.041	57.294			
4700	7.855	58.263			
4800	7.511	58.747			
4900	7.238	61.162			
5000	6.949	61.607			
5100		61.251			
5200		60.495			
5300		63.747			
5400		63.344			
5500	5.451	63.985	(0-th Order)		
5600		63.683			
5700		62.972			

Table 6. Throughput of Optical-Grism

Wavelength (A)	Efficiency (%) 1st	0-th	2nd	3rd	-1 st
2900A	.077	.006			
3000	.604	.166			
3100	20.812	1.173	5.492	0.806	0.402
3200	24.779	1.052	3.884	0.689	0.261
3300	29.865	.755	2.913	0.630	0.136
3400	32.484	.587	1.992	0.413	0.062
3500	39.020	.449	1.374		0.072
3600	40.040	.419	0.872		0.130
3700	45.083	.417	0.510		0.212
3800	53.123	.635	0.234		0.407
3900	63.508	1.237	0.089		0.753
4000	63.077	1.828	0.072		1.076
4100	69.080	2.720	0.086		1.418
4200	63.887	3.663	0.180		1.727
4300	61.291	4.566	0.232		2.045
4400	61.222	5.782	0.390		2.447
4500	63.430	7.*058	0.601		2.804
4600	60.483	8.796			
4700	58.514	9.564			
4800	56.219	10.917			
4900	56.995	12.428			
5000	51.888	14.156			
5100	53.030	15.652			
5200	50.066	17.155			
5300	49.204	18.439			
5400	48.953	19.381			
5500	44.270	19.863			
5600	40.952	21.439			
5700	40.267	22.274			

4. Throughputs of magnifier

A 2.5 x3mm slot was placed in front of the magnifier, which created 10x12mm image on the MIC detector. The photon fluxes with and without the magnifier were measured. The throughput was determined from the ratio of both measurements. The results are shown in Fig. 19 and table 7. The cutoff at 3200A seems to be due to the optical material. The throughput is constantly ~53% above 3500A.
Since the magnifier contains 10 surfaces, the 4% loss /surface makes transparency of 66%. The discrepancy of 13% may be due to absorption by the material and due to dirts on the surfaces.

Acknowledgement:
Mr. Jon Lapington and Mr. Jason Tandy repaired grating rotation units of the monochrometer, which burnt out disastrously in the very beginning of this measurement. Thanks also go to Dr. Alice Bleeveld and Prof. Keith Mason for their advices and encouragements.

Table 7. Throughput of magnifier

Wavelength	Efficiency
1900	.030%
2000	.029
2100	.028
2200	.036
2300	.045
2400	.050
2500	.066
2600	.083
2700	.105
2800	.108
2900	.112
3000	.154
3100	2.066
3200	20.127
3300	40.938
3400	50.520
3500	54.083
3600	53.120
3700	51.987
3800	52.427
3900	52.591
4000	52.439
4100	52.105
4200	54.091
4300	51.654
4400	52.543
4500	53.323
4600	52.736
4700	52.035
4800	53.140
4900	53.143
5000	52.604
5100	52.890
5200	52.398
5300	54.084
5400	55.365
5500	54.946
5600	52.845
5700	53.631
5800	55.449

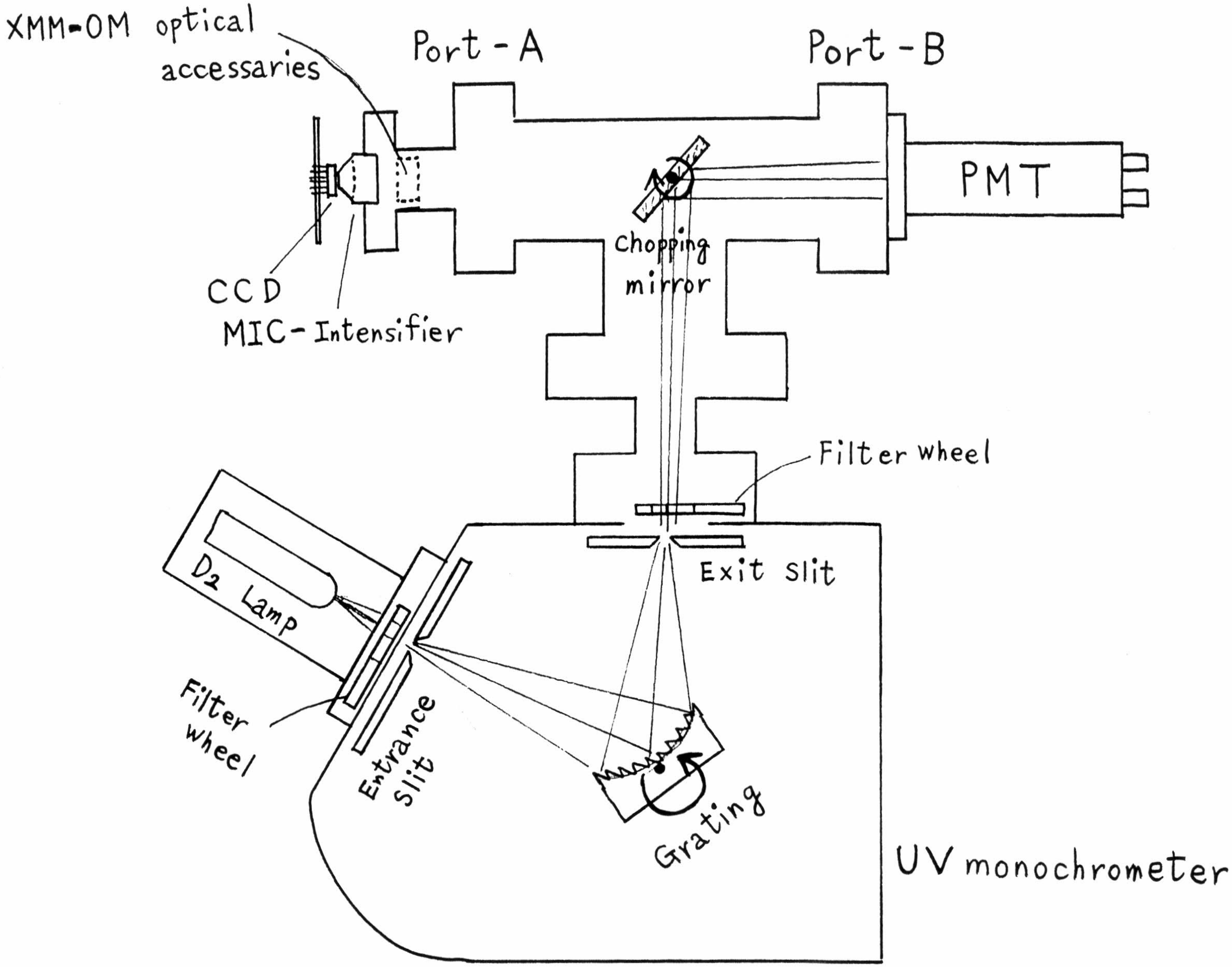


Fig. 1 Optical Set-up of measurements

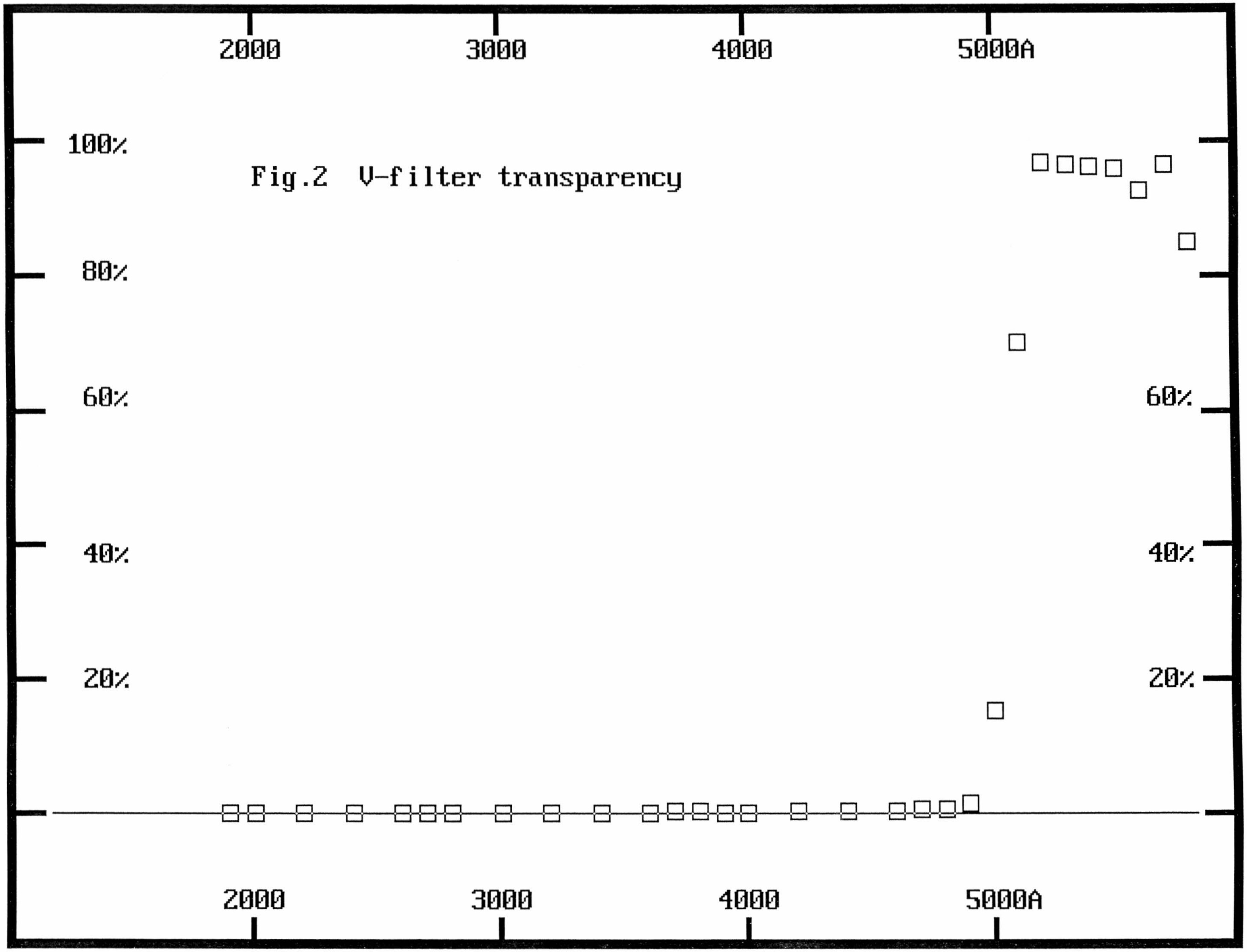


Fig.2 V-filter transparency

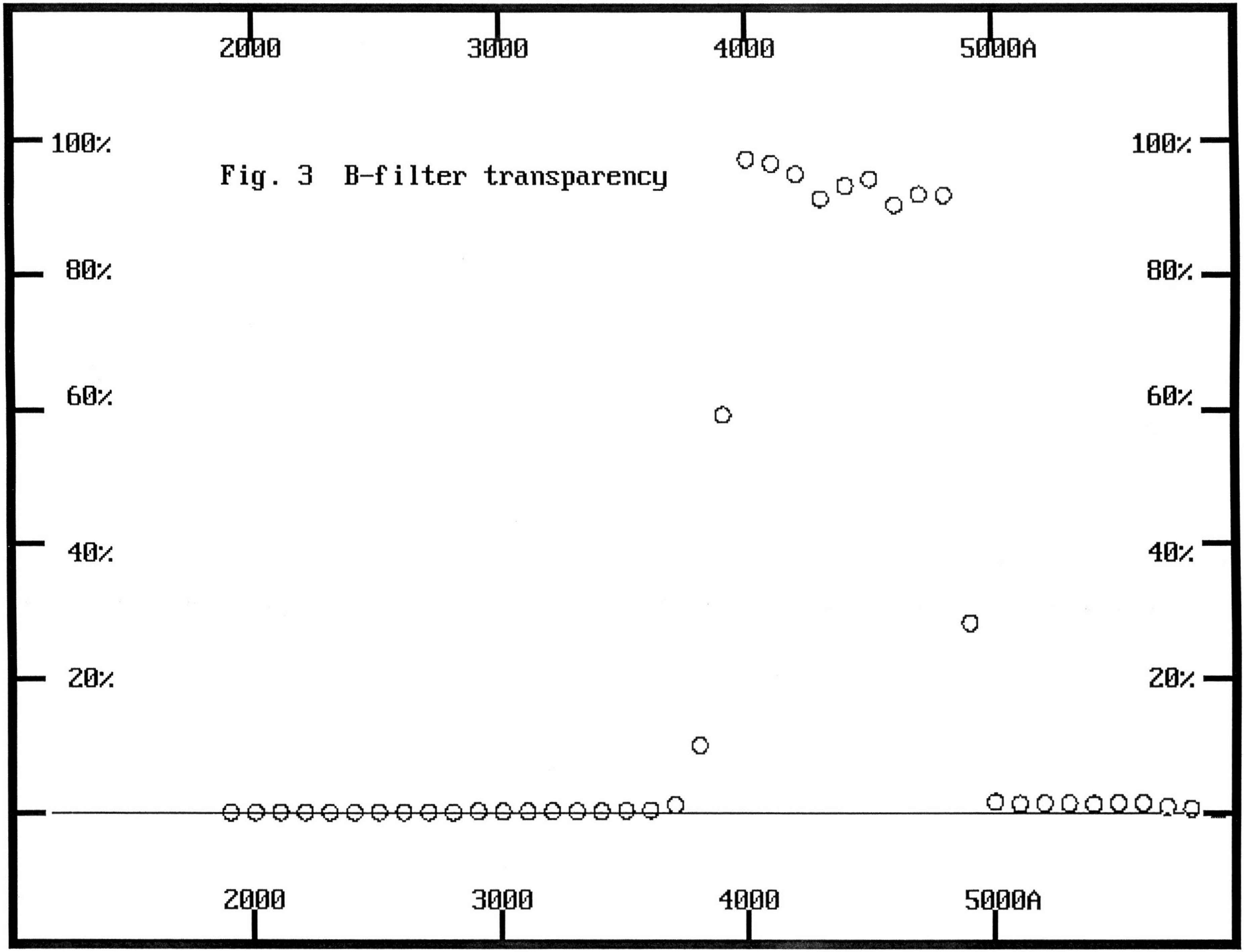


Fig. 3 B-filter transparency

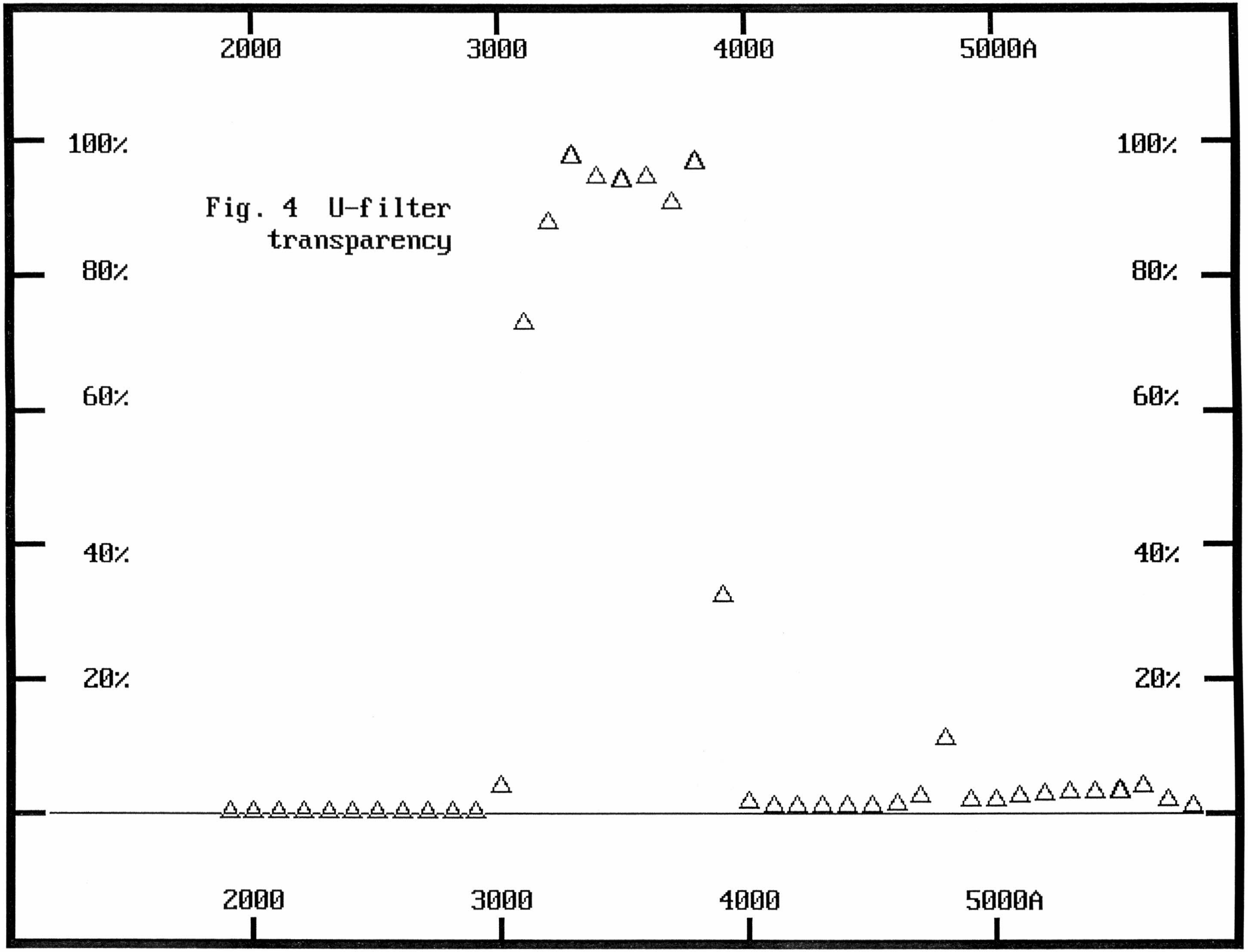


Fig. 4 U-filter transparency

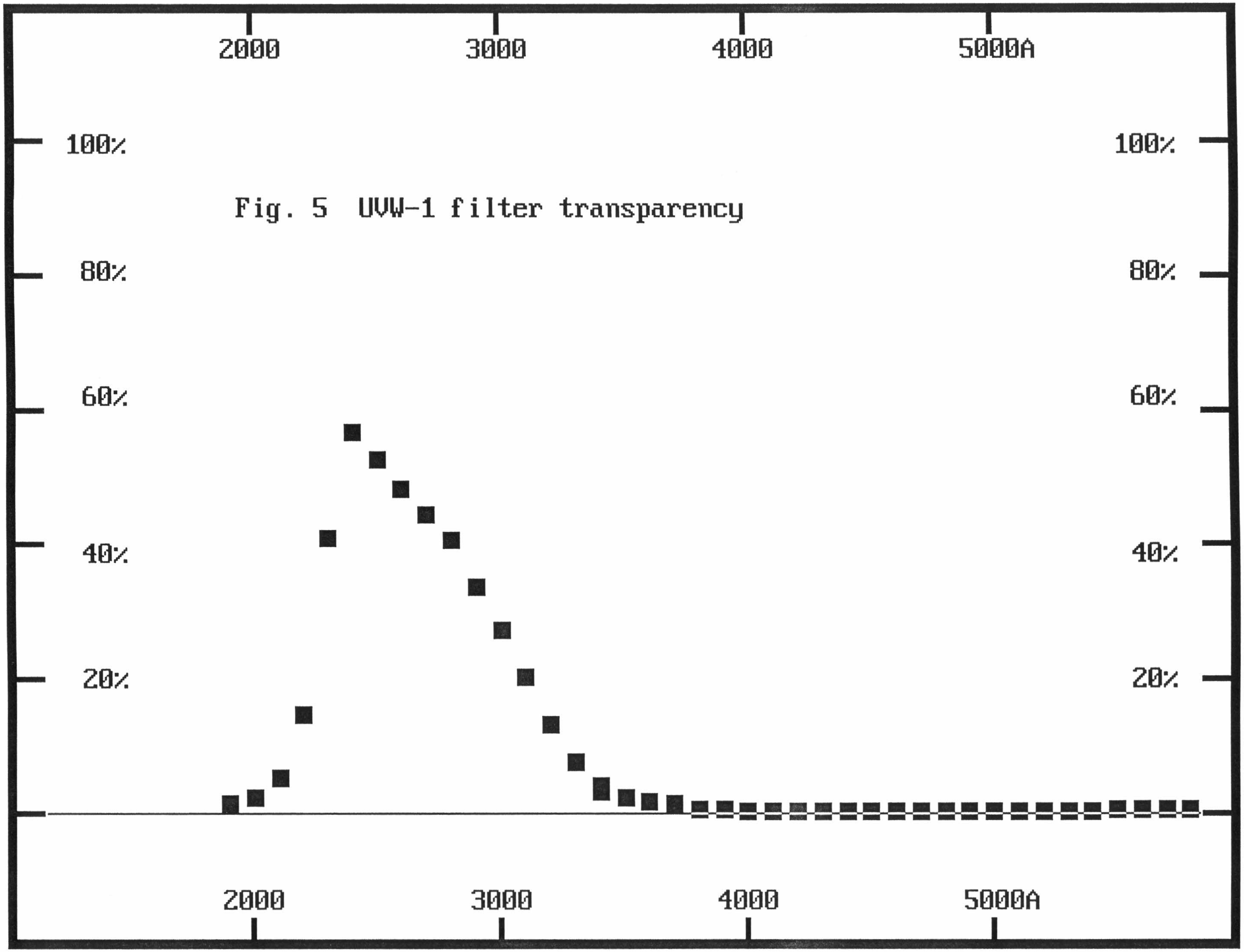
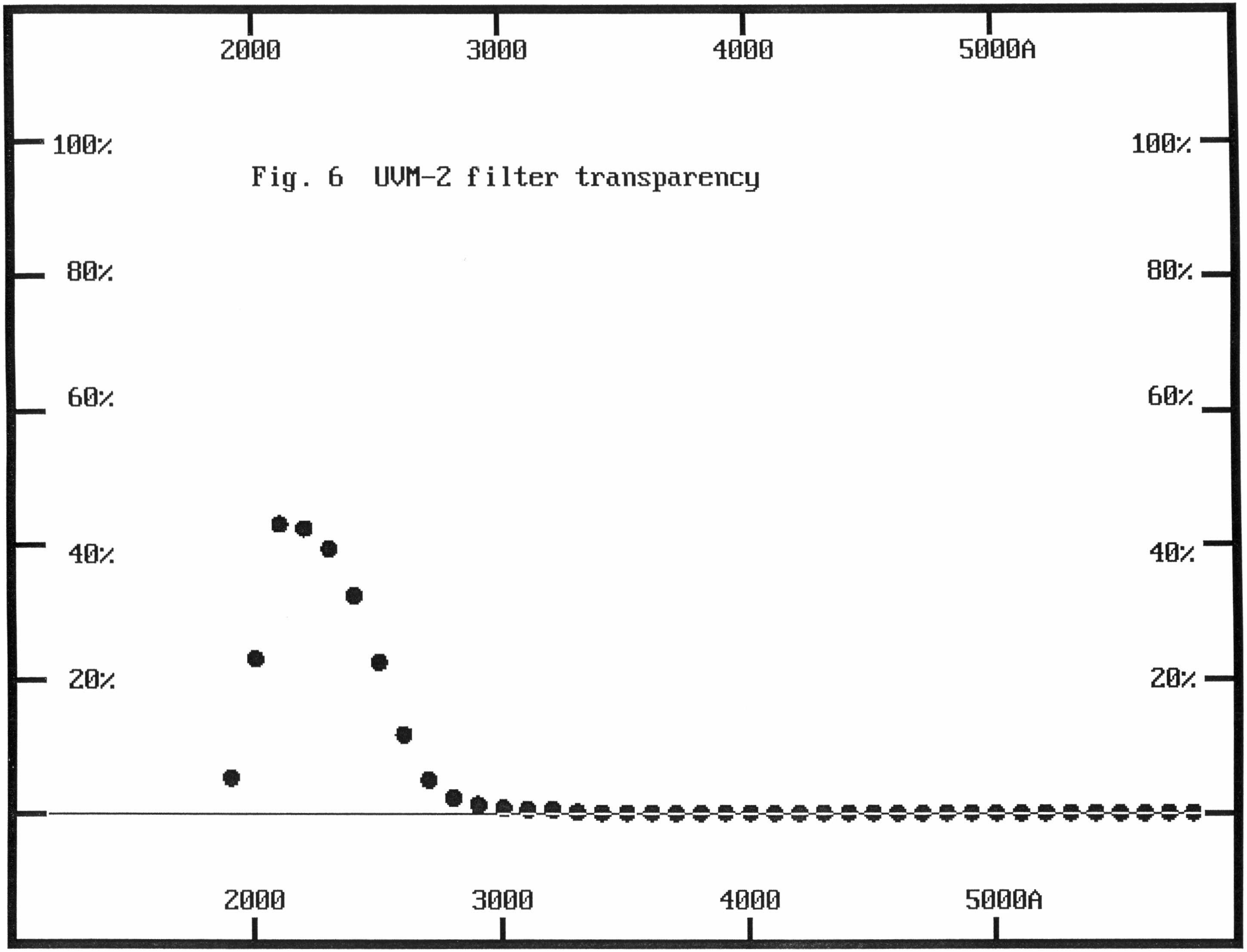


Fig. 5 UVW-1 filter transparency



2000
3000
4000
5000A
100%
80%
60%
40%
20%
Fig. 6 UVM-2 filter transparency

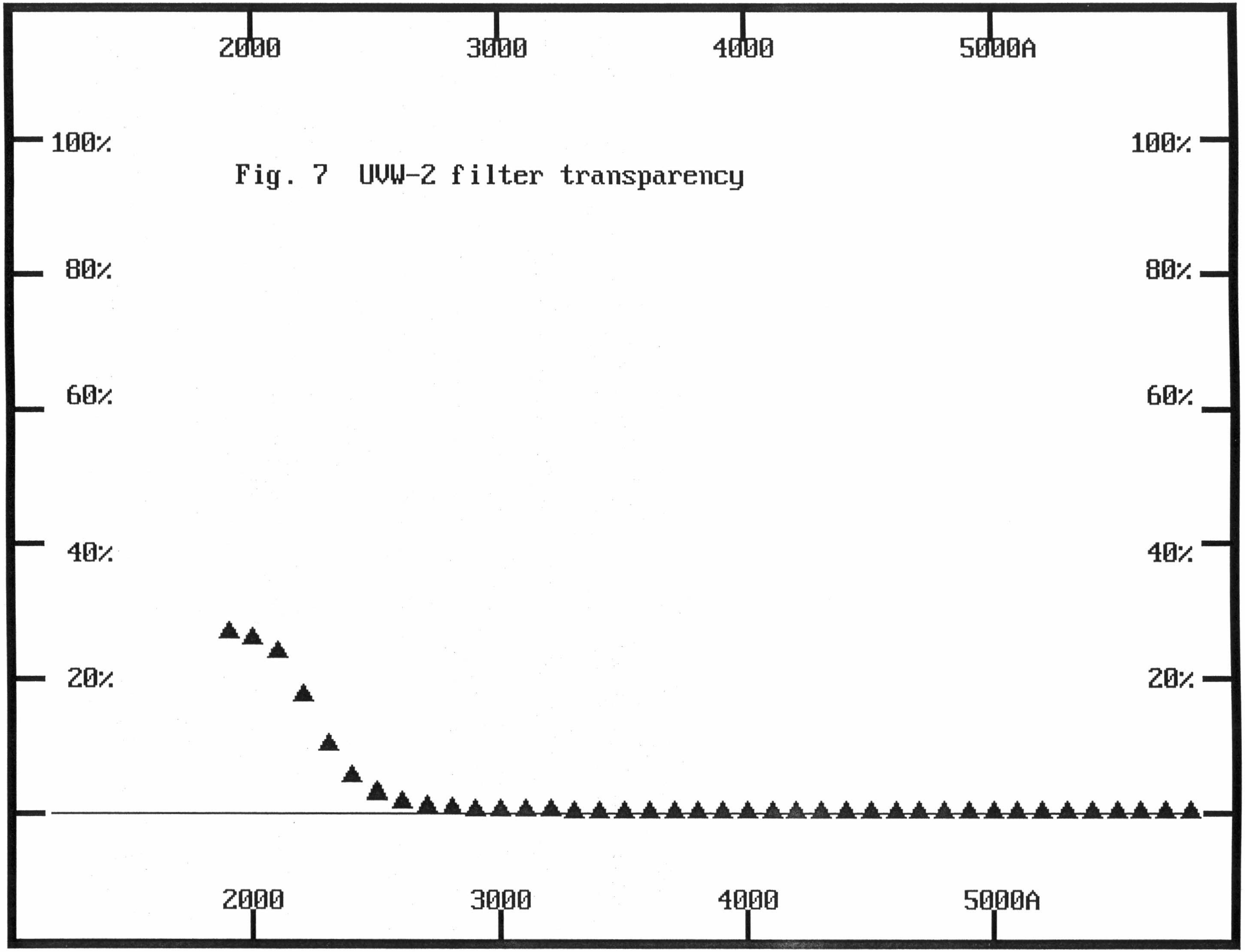


Fig. 7 UVW-2 filter transparency

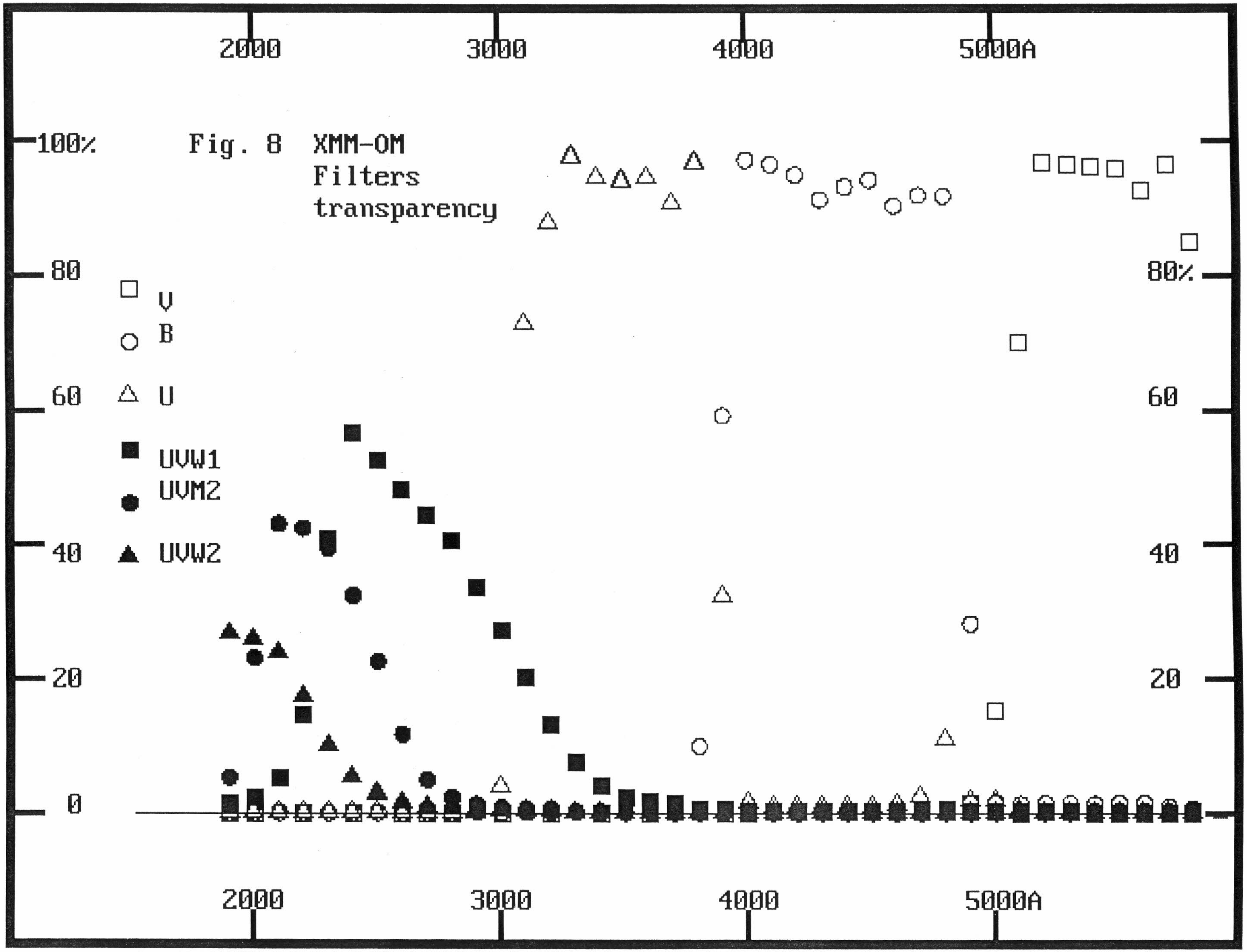
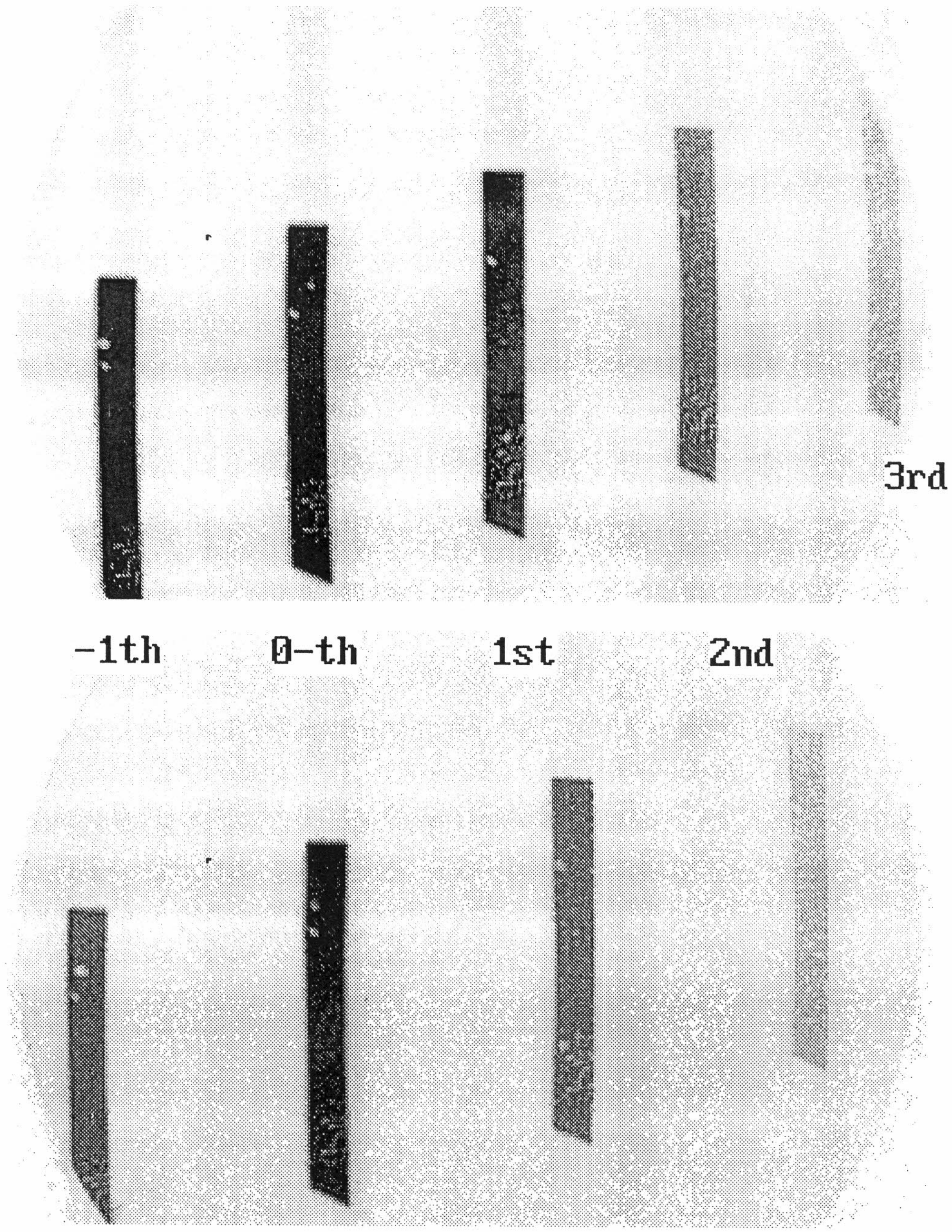
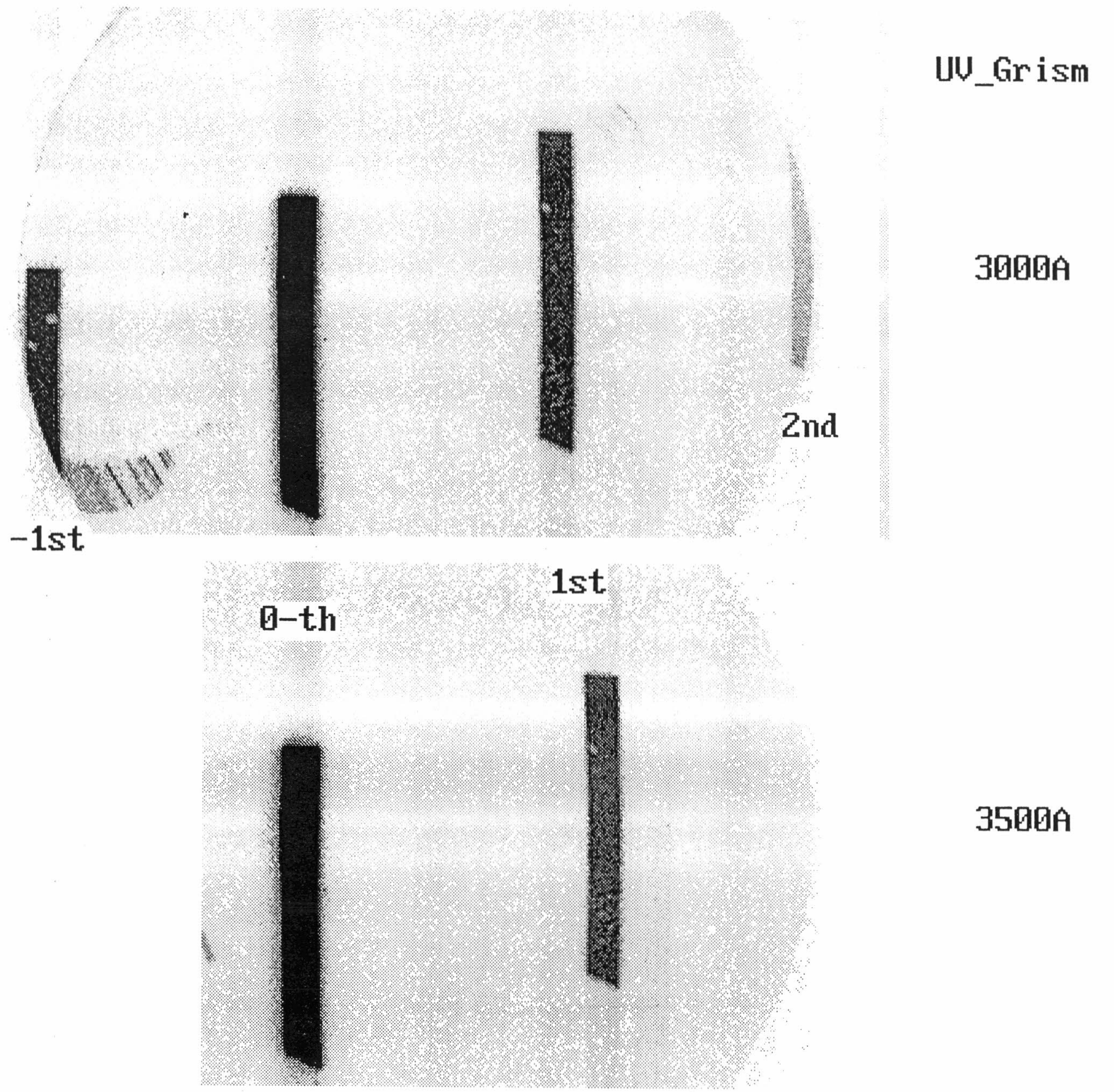


Fig. 8 XMM-OM
Filters
transparency
100%
80
60
40
20
0
80%
60
40
20
2000
3000
4000
5000A
V
B
U
UVW1
UVM2
UVW2



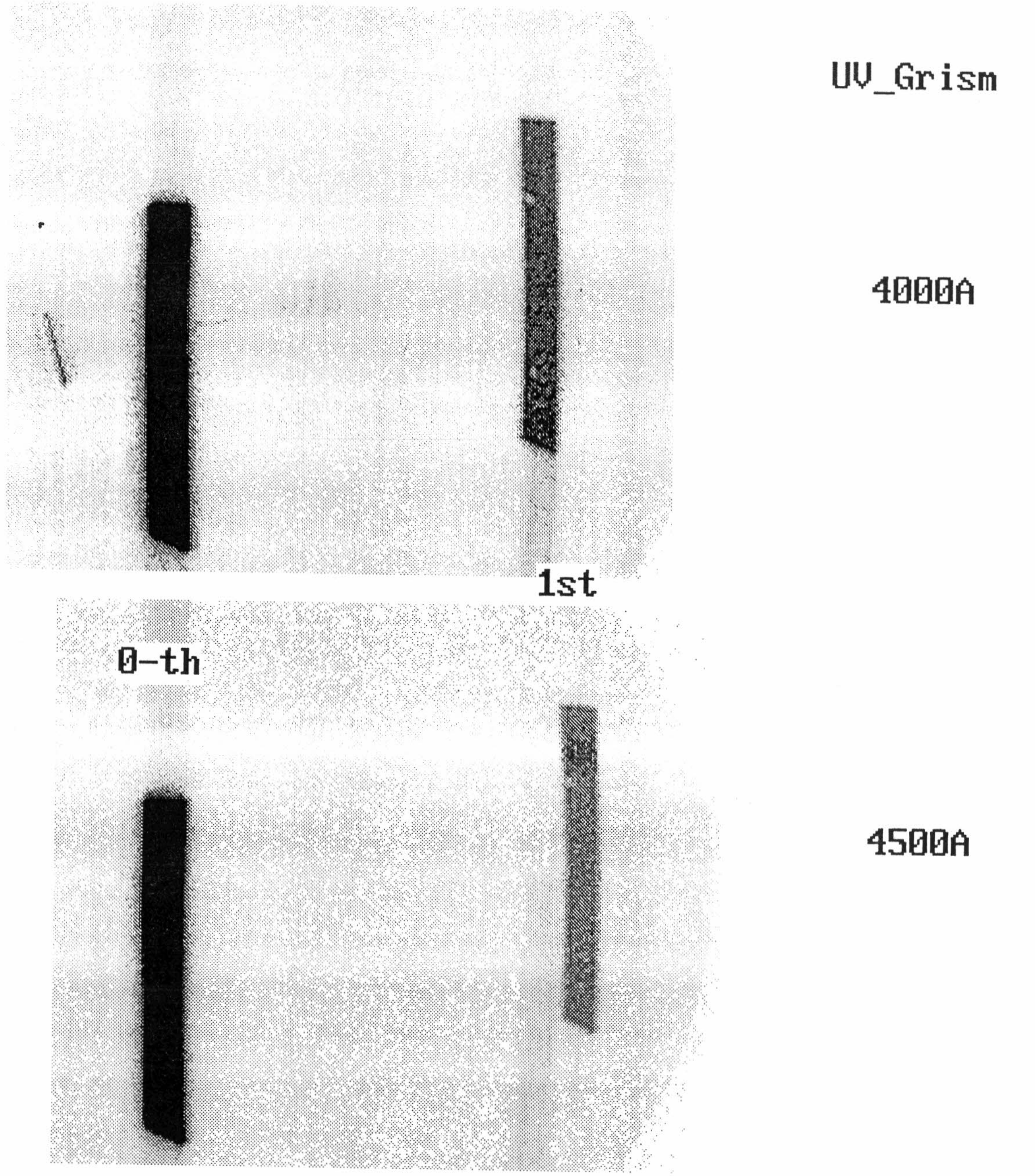
11H 23M 20S   11H 40M 00S   1999/07/20/

Fig. 9 Composit 0300S 200nm & 250nm UV_Grism 8x8 Bin DEP#5



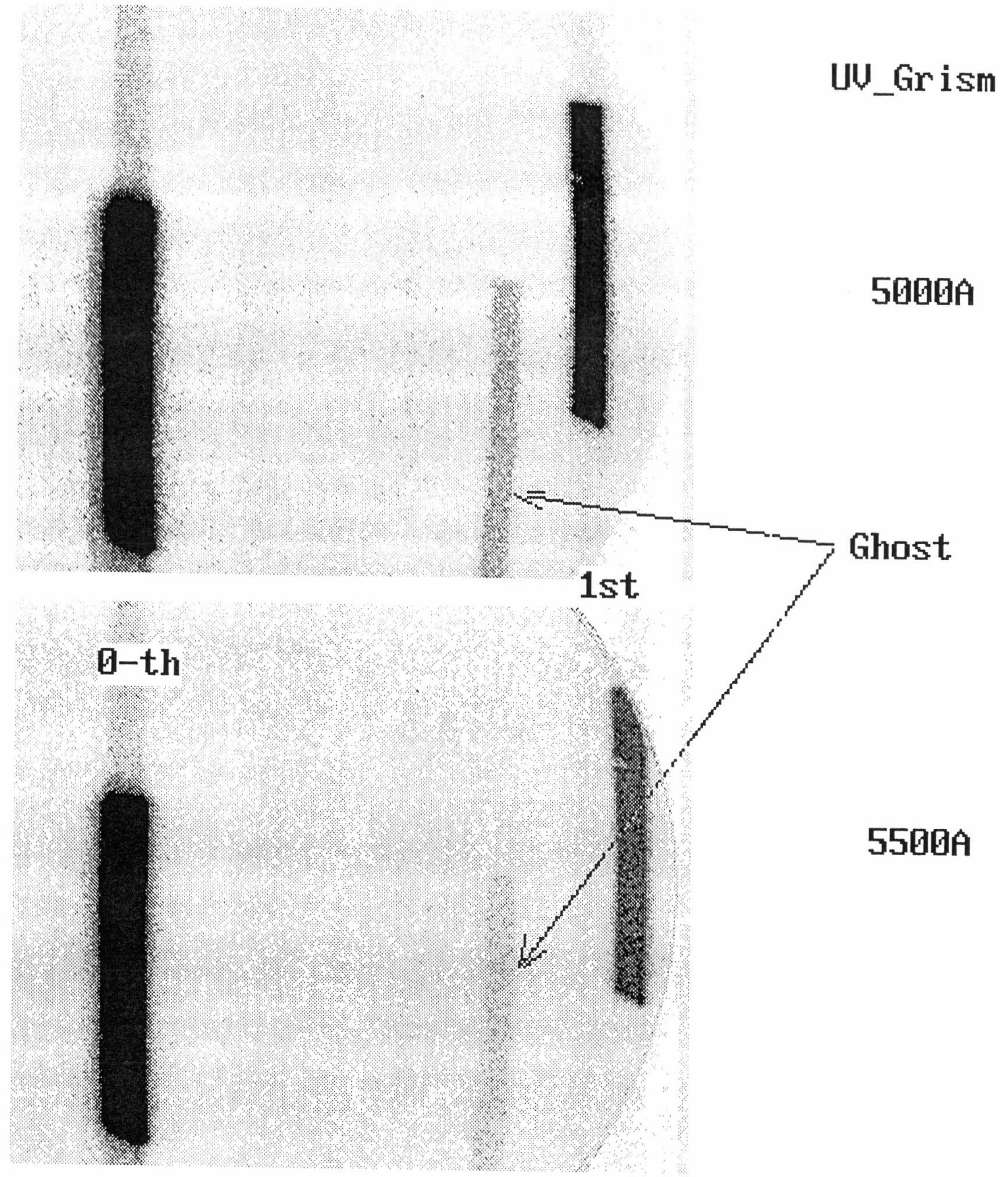
12H 12M 22S 12H 17M 22S 1999/07/20/

Fig.10 Composit 0300S 300nm & 350nm UV_Grism 8x8 Bin DEP_#5



12H 33M 57S 12H 38M 57S 1999/07/20/

Fig.11 Composit 0300S 400nm & 450nm UV_Grism 8x8 Bin DEP_#5



12H 44M 47S 12H 49M 47S 1999/07/20/
Fig.12 Composit 0300S 500nm & 550nm UV_Grism 8x8 Bin DEP_#5

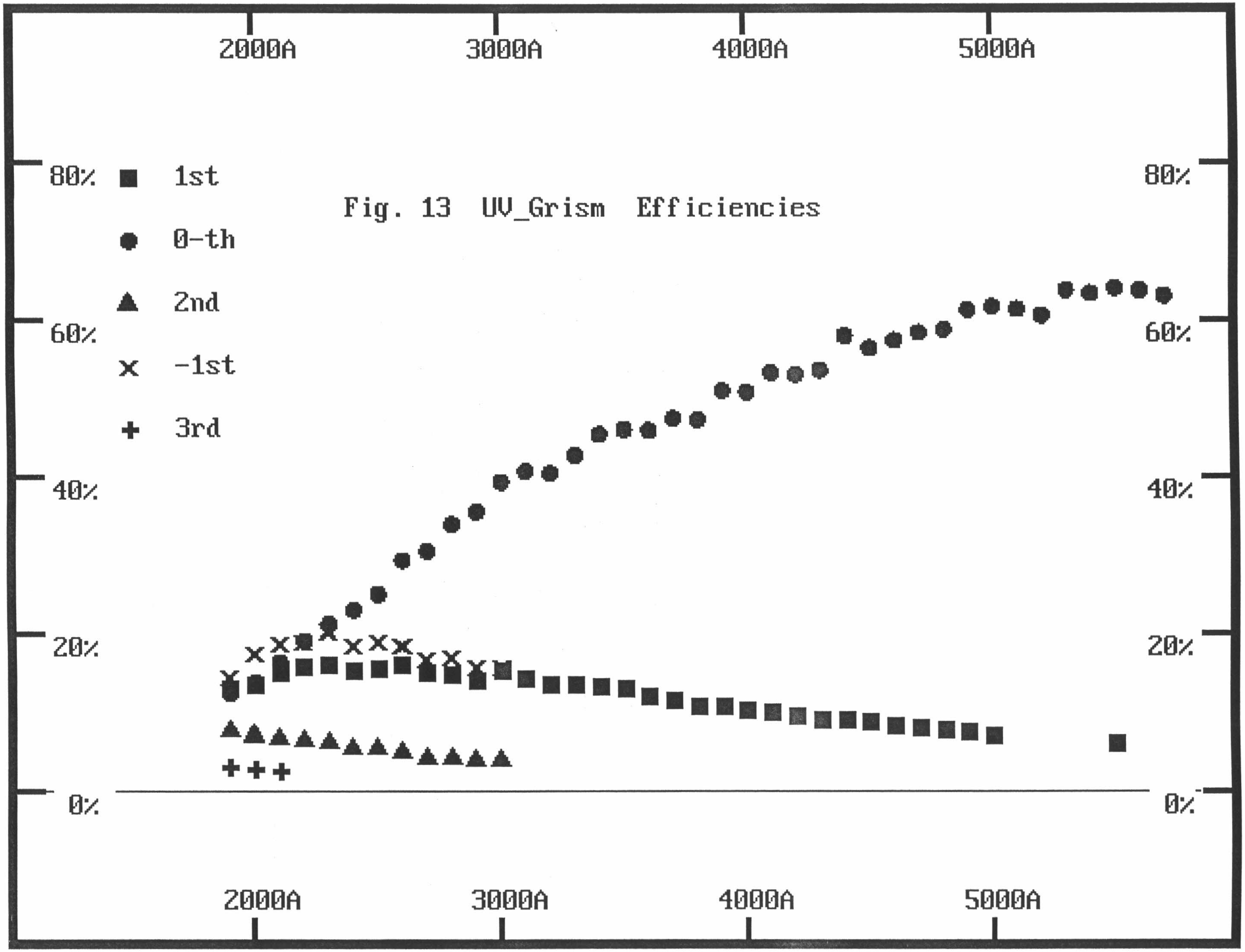
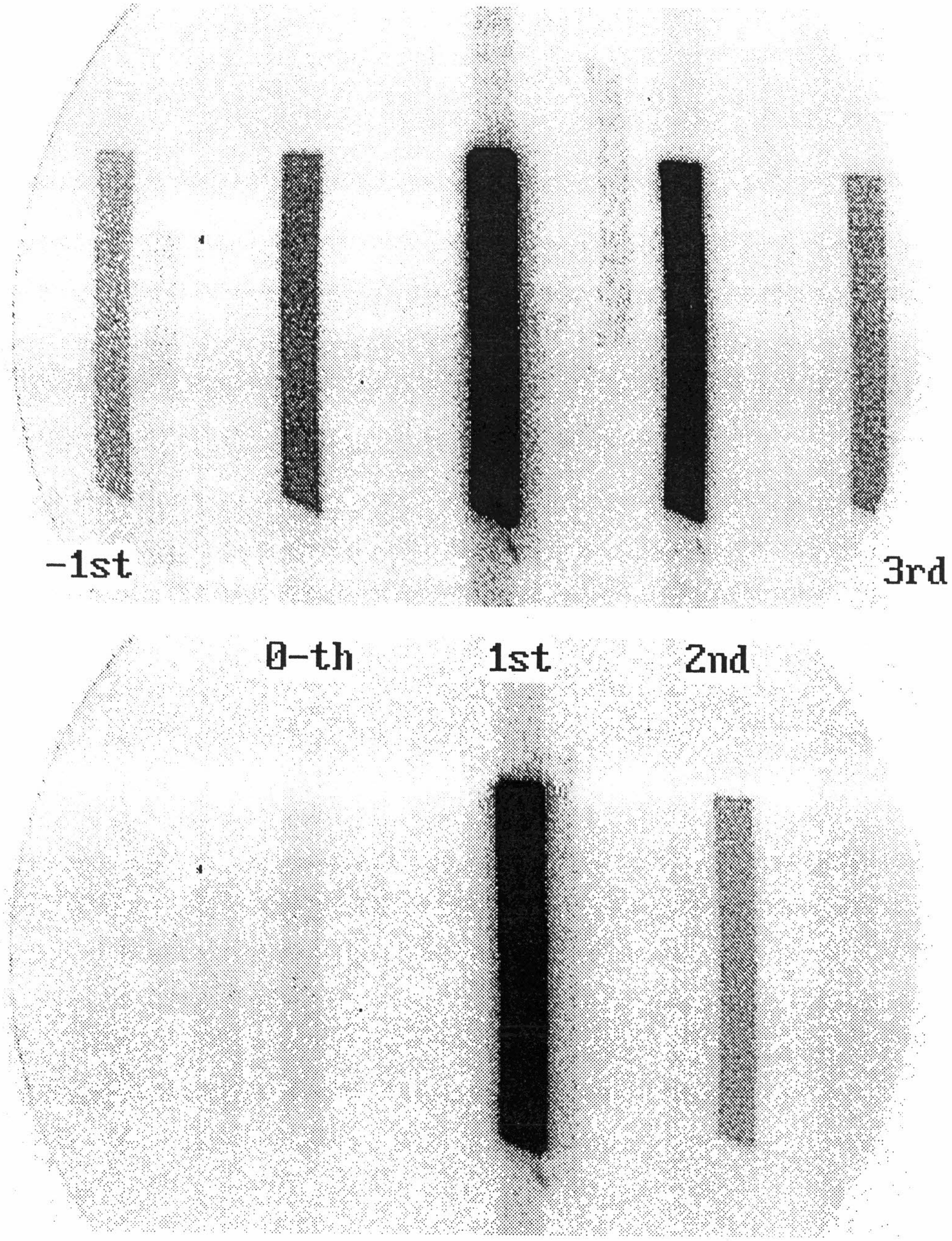


Fig. 13 UV_Grism Efficiencies

Optical Grism



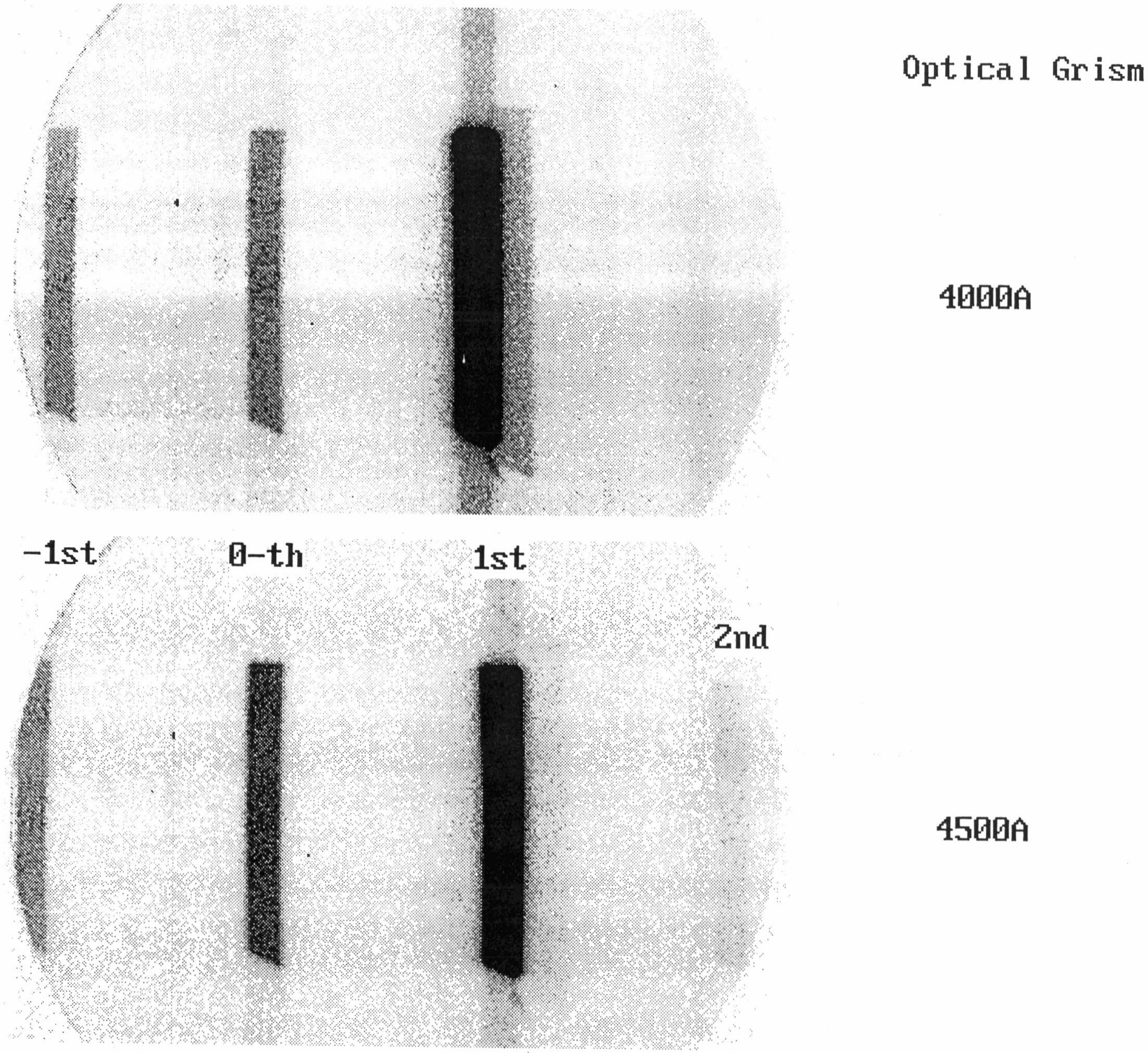
3100A

3500A

splendid blaze !!

18H 48M 09S　　18H 53M 09S　　1999/07/21/

Fig.14　Composit 0300S　310nm & 350nm　Op_Grism　8x8 Bin　DEP_#5



19H 01M 15S 19H 06M 15S 1999/07/21/

Fig.15 Composit 0300S 400nm & 450nm Op_Grism 8x8 Bin DEP_#5

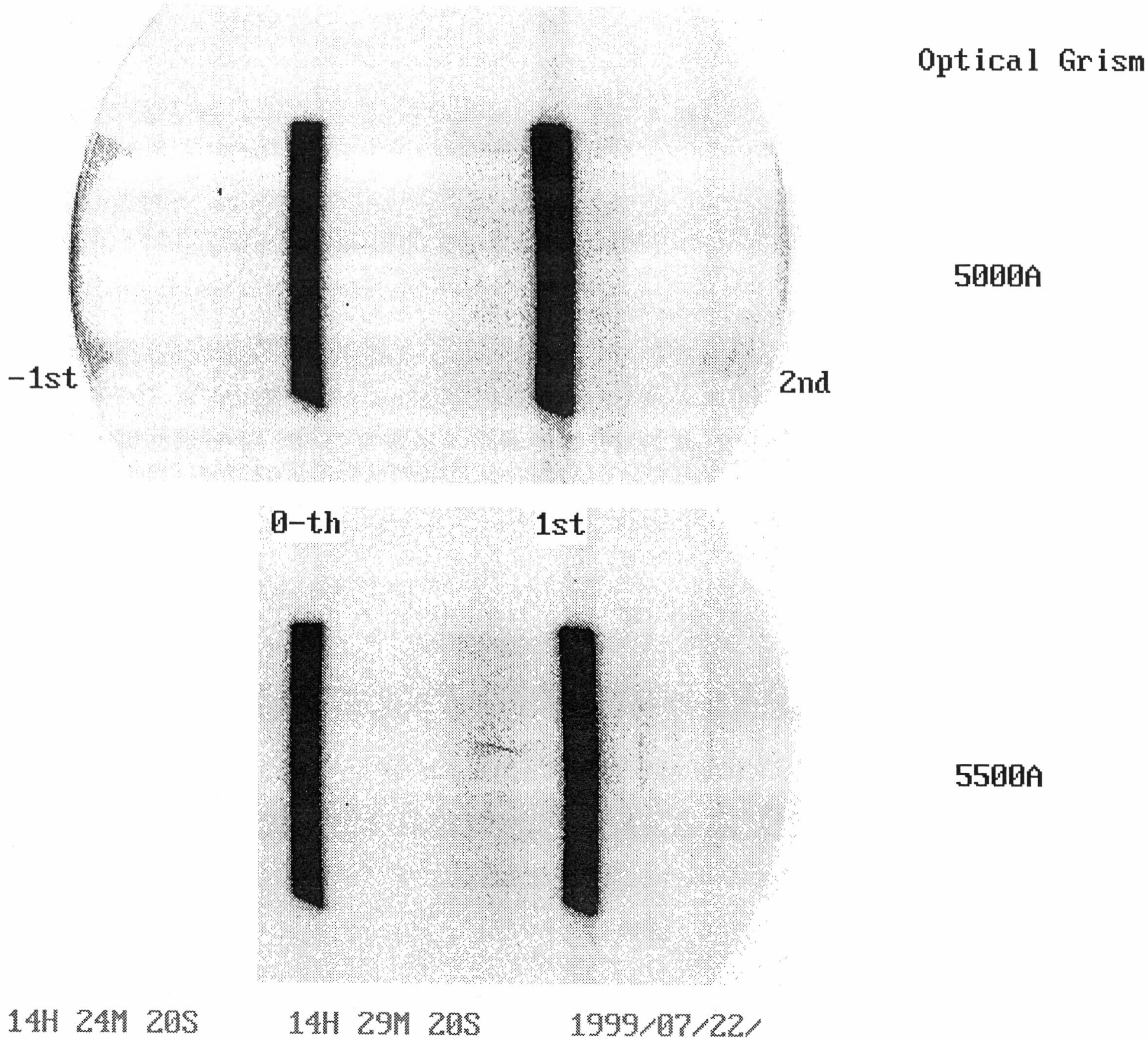
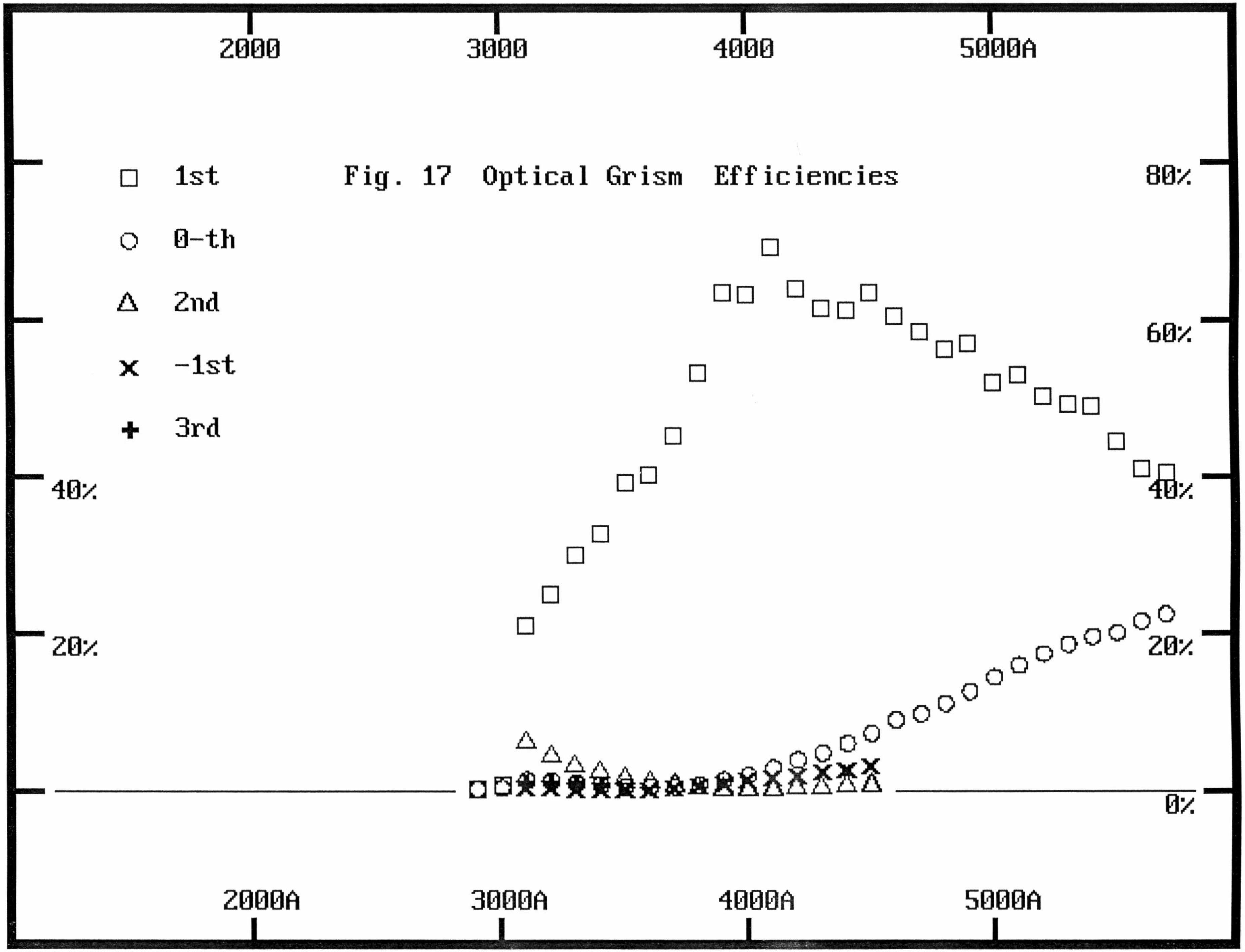


Fig.16 Composit 0300S 500nm & 550nm Op_Grism 8x8 Bin DEP_#5


1st
0-th
2nd
-1st
3rd
Fig. 17 Optical Grism Efficiencies
2000
3000
4000
5000A
80%
60%
40%
20%
0%
40%
20%
2000A
3000A
4000A
5000A

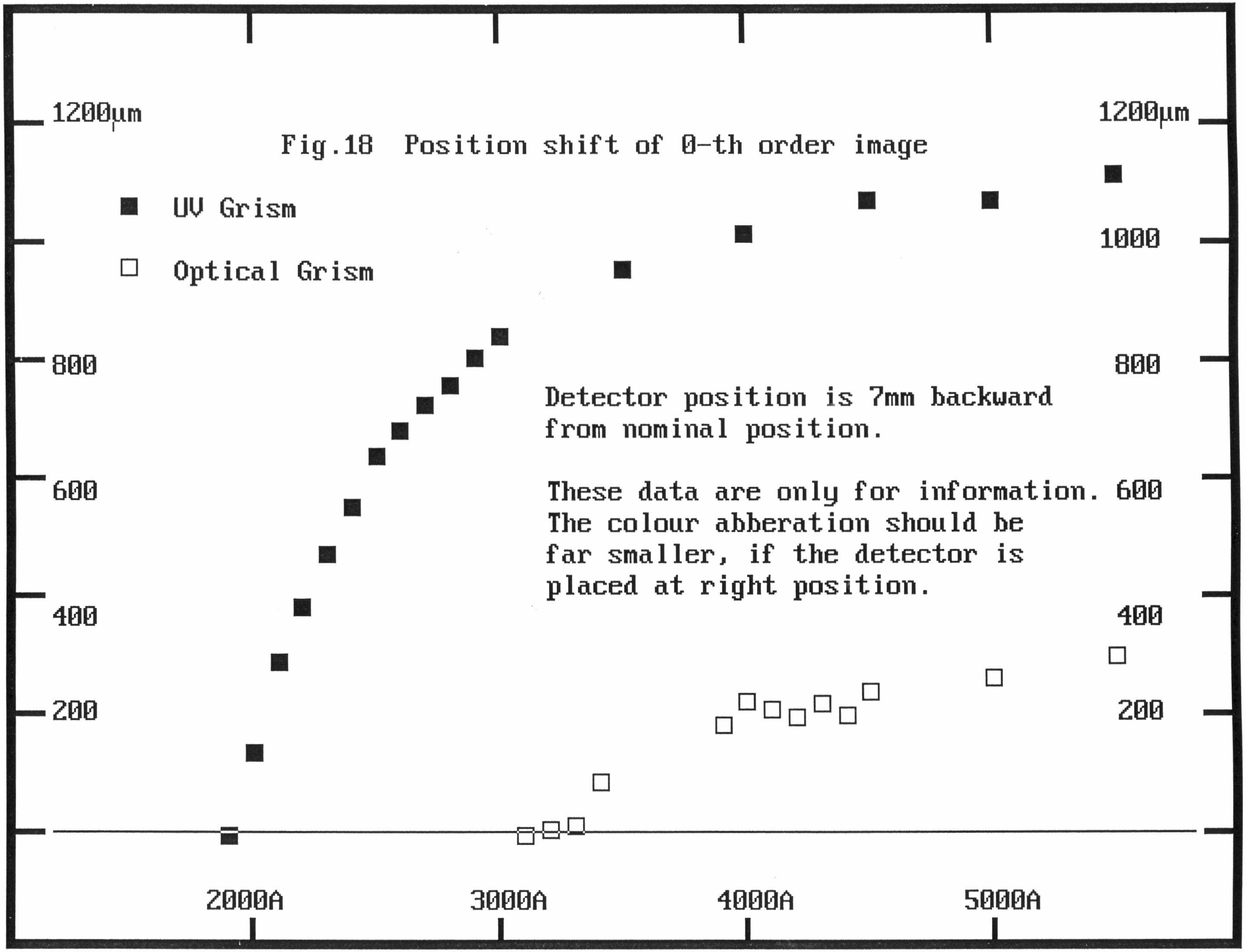


Fig.18 Position shift of 0-th order image
UV Grism
Optical Grism
Detector position is 7mm backward
from nominal position.
These data are only for information.
The colour abberation should be
far smaller, if the detector is
placed at right position.
1200µm
1000
800
600
400
200
1200µm
800
600
400
200
2000A
3000A
4000A
5000A

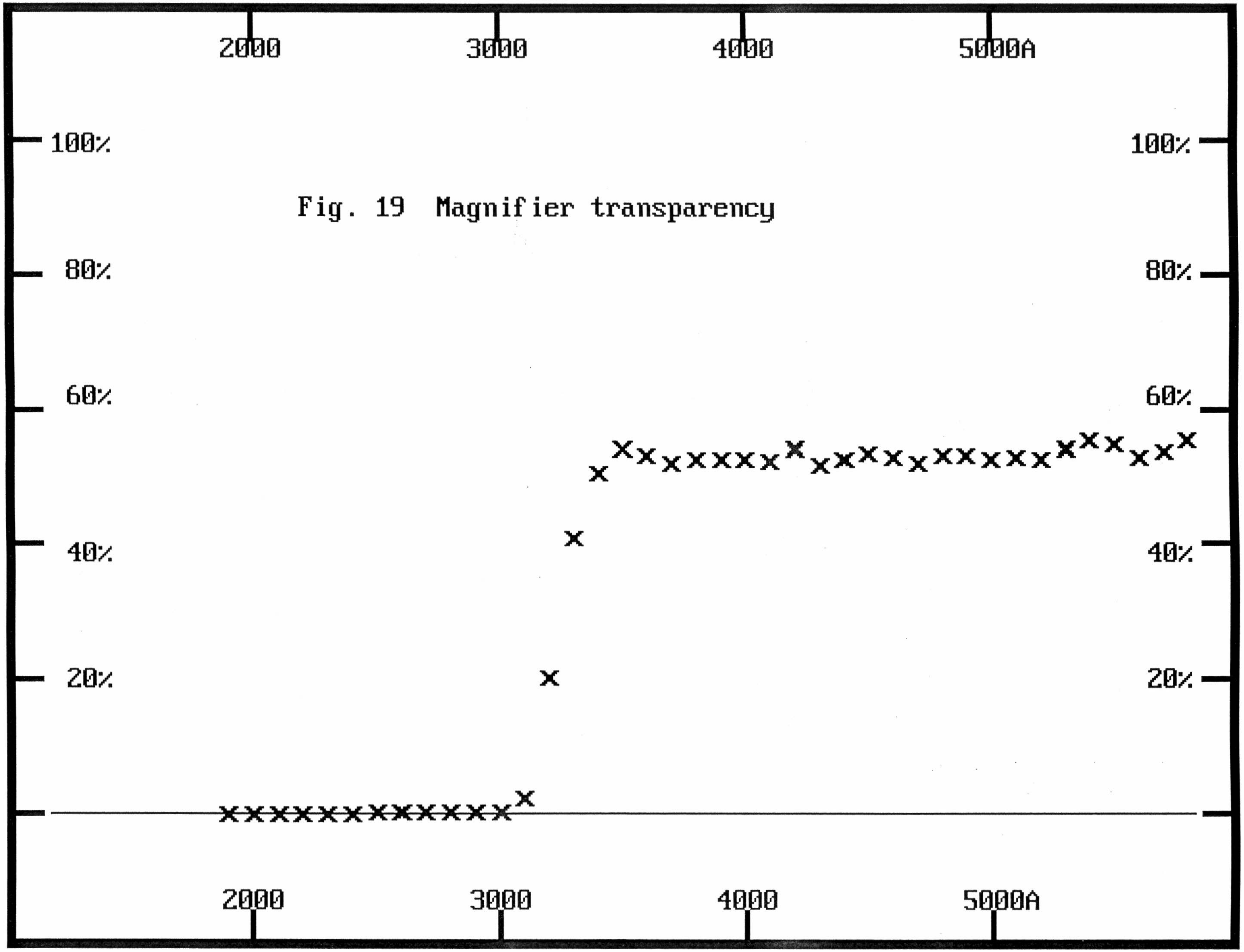


Fig. 19 Magnifier transparency