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SUBKILOVOLT RESPONSE OF KODAK T max XUV FILM

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Introduction:

A calibration of Kodak T max 100 XUV film at six x-ray energies ranging from 0.27 keV to 1.49 keV has been concluded. The primary purpose was to compare the sensitivity of this film to that of Kodak type 101-07 XUV film in order to appraise the feasibility of replacing the type 101-07 film with the type T max 100 film. In addition to being considerably less expensive, the T max 100 film is less disposed to abrasion from handling. A secondary objective was to provide a base for further response measurements should the T max 100 film prove to be an acceptable substitute for the type 101-07 film.

Instrumentation:

An x-ray source and spectrometer facility at the LBL Center for X-ray Optics in Berkeley provided the means for recording all x-ray exposures used for these measurements. The x-ray source is a water cooled Henke tube using interchangeable anodes selected to produce the desired characteristic emission. The anode is illuminated by electrons electrostatically focused onto each face of the V shaped emission surface. These electrons are produced by a tungsten filament hidden behind the anode to prevent contamination from tungsten evaporation on the emission faces of the anode. Under normal conditions, a period of about 1 hour is required to bring the system to atmosphere, change the anode, and return to a stable vacuum environment.

The x-ray source housing is directly coupled to a vacuum pipe leading to an experimental chamber containing the spectrometer, camera and proportional counter. This chamber is also equipped with an x-ray shutter to block off the x-ray beam while changing film position between exposures. All movable components within the chamber are remotely controlled from outside the vacuum system. The spectometer is described in detail in Reference 1[1]. It features a removable elliptically curved crystal which can be precisely aligned to Bragg reflect line radiation from the source and focus the reflected beam at the aperture adjacent to the camera window slit. This slit is at the center of an arc which forms a circular tray holding the film. Thus, the Bragg reflected beam, focused at the slit produces a normal incident spectrum along the circular film channel. All measurements for this experiment were made using a lead stearate crystal (2d=100Å). The camera box is a light-tight structure containing supply and take-up reels to move the 35mm film along the circular track. Depending on the film thickness, the camera will easily accommodate from 5 to 10 exposures.

Before or following a set of exposures, the camera was remotely translated out of the Bragg reflected beam to allow a proportional counter to view and record the spectrum by scanning along the circle at a pre-set rate. The exposure intensity in units of photons per square micrometer related to a film recorded spectral line is calculated from the measured peak count rate, counter efficiency and exposure time. Pre-measured geometry factors, (ratio of the proportional counter to film radii and slit dimensions) are entered as constants. Both camera and proportional counter are fitted with identical window material to eliminate the need for window attenuation corrections. X-ray tube and proportional counter parameters used in this experiment are given in Table 1.

All exposed film was taken to the L-division "Technical Photography Laboratory" at LLNL in Livermore for processing and analysis. The films were developed 8 minutes at 68°F in Kodak "T max developer" using agitation intervals of 5 seconds every 30 seconds. Following development, the film was sequentially transferred to a "Kodak Indicator" stop bath for 30

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[1]B.L. Henke, H.T. Tamada, and T.J. Tanaka, Pulsed plasma source spectrometry in the 80-800-eV x-ray region; Rev. Sci. Instrum. 54,10,1983.

seconds, then 5 minutes in Kodak "Rapid fix" ending the process with a 10 minute wash before drying.

Specular density measurements were obtained by scanning the Bragg reflected line spectra and background for each exposure. The instrument used was a Photometric Data System Model 1010A microdensitometer with a $100\mu M^2$ aperture. A numerical aperture (NA) of 0.1 was used for both the illumination and objective lenses of the microdensitometer. The microdensitometer outputs were digitized and filed in appropriate format for computer analysis.

Results:

A constant film-fog background, determined by examination of the total exposure set, was subtracted from the measured densities to yield a net specular density. These net densities and the corresponding exposures are tabulated in Table 2. For the iron and copper L emission lines, sub-level emissions are also noted. These data were grouped into a single file since the differences in emission energy are too small to produce density deviations of any significance.

Examples of the measured data are shown in Figures 1 and 2. Figure 1 illustrates the spectral measurements of the Cu L emission by the scanning proportional counter. For this measurement, the scan rate was 0.05°/step with a net counting time of 1.7 seconds per step. Two film exposures, 90 minutes and 15 minutes, of the corresponding digitized film data are shown in Figures 2a and 2b. The low angular position (~58°) of the proportional counter place the measurement of the 4^{th} order Bragg reflected Cu Lα line in this example under suspicion. Therefore, all data related to this spectral line were rejected.

The densities and exposure intensities (photons per square micrometer) measured at each of the 6 energies are individually plotted in Figures 3 to 8. The solid curve plotted along with the measured points in each figure is a least square fit to the data using a 2^{nd} order polynomial. Figure 9 shows the polynomial fits plotted collectively. These plots indicate a decrease in sensitivity as the energy is lowered from 1487 eV to 705 eV and further suggest a flat sensitivity dependence for energies lower than the iron emission at 705 eV. In order to substantiate this argument however, more data is needed for Oxygen and Carbon.

Figure 10 compares the Kodak 101-07 XUV measurement of Henke et al[2] at 1487 eV (Aℓ (Kα)) to our measurement of the Kodak T max 100 XUV at the same energy. These measurements illustrate a similar response of the two films at this energy. The two measurements also imply that the sensitivities of the two films remain comparable in the sub-kilovolt region.

Acknowledgement:
We wish to thank Eric Frerking for furnishing and demonstrating the software used in making the plots for this report.

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[2] B. L. Henke, F.G. Fujiwara, M.A. Tester, C.H. Dittmore, and M.A. Palmer, Low energy x-ray response of photographic films II Experimental characterization, J. Opt. Soc. Am 1,6, 1984.

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TABLE 1

ANODE					PROPORTIONAL COUNTER				
Material	Potential (kV)	Current (mA)	Fluorescent Radiation (Line)	Fluorescent Radiation Energy	Gas	Pressure (mm)	Volts	Window Material	Efficiency
Carbon	5.0	42	C (Kα)	277 eV	C_3H_8	200	1760	40μgm/cm^2 Al + 50μgm /cm^2 Polypropylene	0.8843
AL_2O_3	7.0	"	O (Kα)	525 eV	"	50	1050	"	0.9343
Fe	"	"	Fe (L)	705 eV	"	100	1250	"	0.9215
Cu	"	40	Cu (L)	930 eV	"	200	1650	"	0.9081
Mg	8.0	38	Mg (Kα)	1254 eV	"	400	2200	1500μgm/cm^2 Aℓ	0.8732
"	"	39	"	"	"	760	2900	"	0.9802
Al	"	40	Aℓ (Kα)	1487 eV	P10	"	1700	"	0.9807
"	"	"	"	"	"	"	"	"	0.9807

Note: Analyizing Crystal - Lead Stearate, 2d=100Å

Pb-sta 2d spacing=100Å

Polypropylene ($CH_2 = CH\,CH_3$) x

TABLE 2

		Photons	Speculer			Photons	Speculer			Photons	Speculer			Photons	Speculer
Line	N	μM	Density	Line	N	μM	Density	Line	N	μM	Density	Line	N	μM	Density
AL (Kα)	10	0.06	0.10	AL (Kα)	10	0.63	0.56	Cu L ( )	β6	1.40	0.33	Fe L( )	ℓ4	2.34	0.42
1487 eV	9	0.09	0.19	1487 eV	7	1.29	0.54	930 eV	β5	1.84	0.44	705 eV	α4	3.64	0.60
	8	0.10	0.10		8	1.53	0.62	4/6/89	α6	2.10	0.52	5/23/89	α3	4.21	0.55
1/23/89	9	0.14	0.12	1/23/89	9	1.64	0.79		ℓ5	2.20	0.37		ℓ3	5.81	0.73
	10	0.15	0.14		10	2.71	1.03		α5	2.33	0.37		α5	6.65	0.64
	8	0.15	0.18		7	5.41	1.19		β6	2.81	0.49		α3	8.42	0.76
	7	0.20	0.17		8	6.56	1.35		β5	3.68	0.62		α4	9.11	0.81
	9	0.21	0.25		9	7.03	1.52		α6	4.19	0.74		α5	16.61	1.00
	8	0.25	0.14		7	23.2	2.00		β6	4.21	0.89		α3	16.85	1.03
	10	0.30	0.18		7	1.48	0.59		α5	6.98	0.92		α3	42.12	1.27
	9	0.36	0.27	Mg (Kα)	6	1.52	0.61		β5	7.35	0.83	O (Kα)	3	1.64	0.42
	7	0.40	0.21	1254 eV		4.45	1.16		α6	8.39	0.96	525 eV	3	9.84	0.79
	10	0.45	0.26	2/6/89	6	4.57	1.29		β5	11.03	1.05	5/9/89	3	27.1	1.13
	8	0.51	0.29		7	8.89	1.34		α6	12.58	1.18	C (Kα)	2	0.63	0.28
	9	0.71	0.42		6	9.13	1.48		α5	13.97	1.10	277 eV	2	1.26	0.29
	8	0.76	0.49		7	13.3	1.56		α5	27.94	1.38	5/4/89	2	2.52	0.51
	10	0.89	0.41		6	13.7	1.64		α5	41.90	1.58		2	3.78	0.62
	7	0.99	0.39		5	0.67	0.25		ℓ4	0.08	0.02				
	9	1.07	0.57		8	0.71	0.25	Fe L ( )	ℓ3	0.19	0.05				
	10	1.19	0.58		7	1.10	0.55	705 eV	ℓ4	0.23	0.05				
	8	1.52	0.64		6	1.12	0.57		α4	0.30	0.08				
	7	1.98	0.71		5	1.33	0.46	5/23/81	ℓ4	0.47	0.09				
	8	2.02	0.81		7	2.19	0.81		α5	0.55	0.11				
	9	2.14	0.87		8	2.25	0.89		ℓ3	0.58	0.12				
	9	2.85	1.07		5	10.7	1.39		α4	0.91	0.19				
	7	2.97	0.88		7	17.6	1.80		α4	0.93	0.16				
	7	5.93	1.27		6	18.0	1.93		ℓ3	1.16	0.25				
	7	7.91	1.46	Cu L ( )	ℓ5	0.55	0.14		α3	1.40	0.25				
	10	0.15	0.30	930 eV	β5	0.61	0.21		α5	1.66	0.27				
2/17/89	8	0.36	0.37	4/6/89	β6	0.70	0.19		α4	1.82	0.35				
	9	0.39	0.38		ℓ5	1.10	0.36		ℓ3	2.33	0.53				

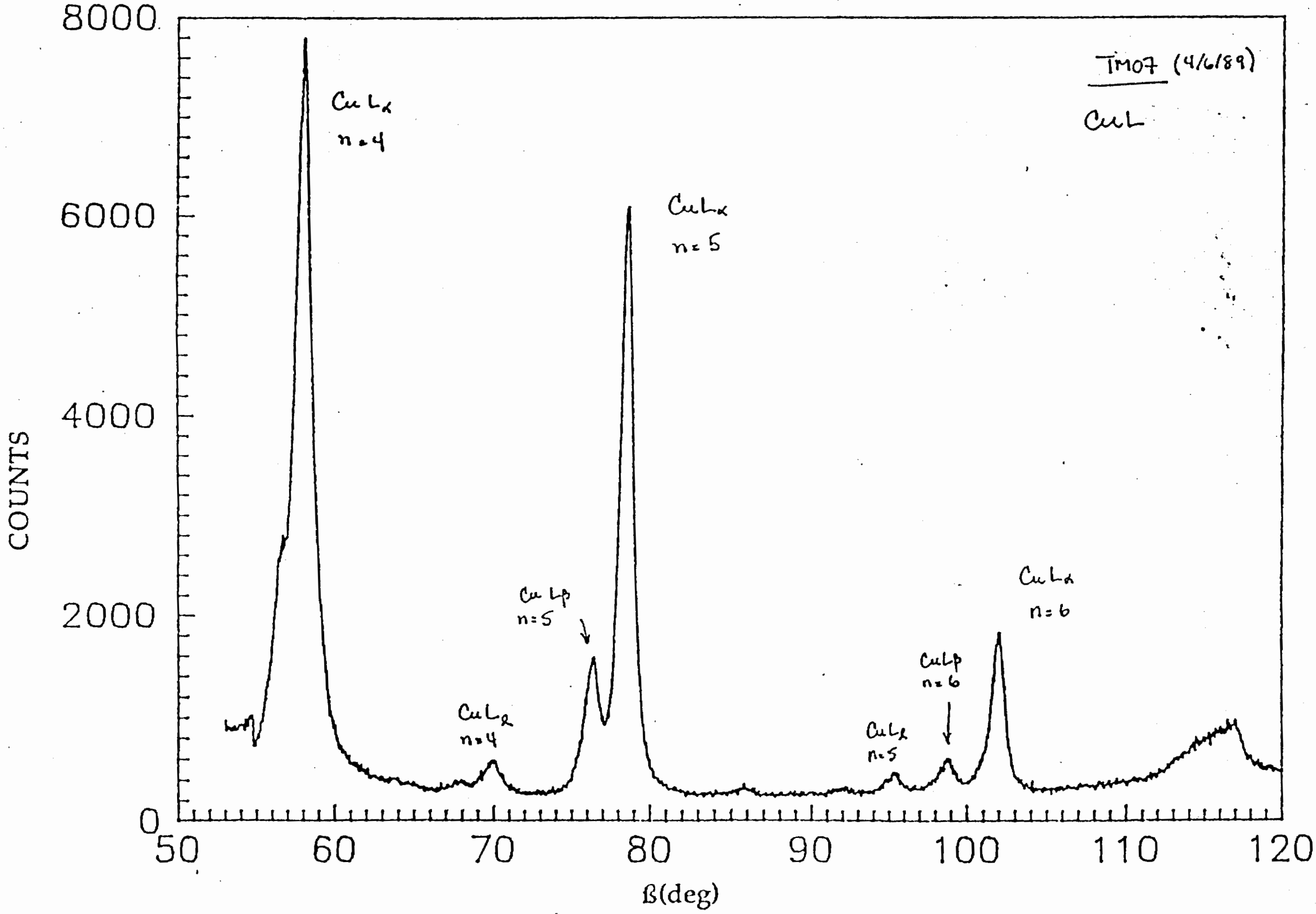

Figure 1
Spectral emission of Cu(L) line, measured by the proportional counter scan.

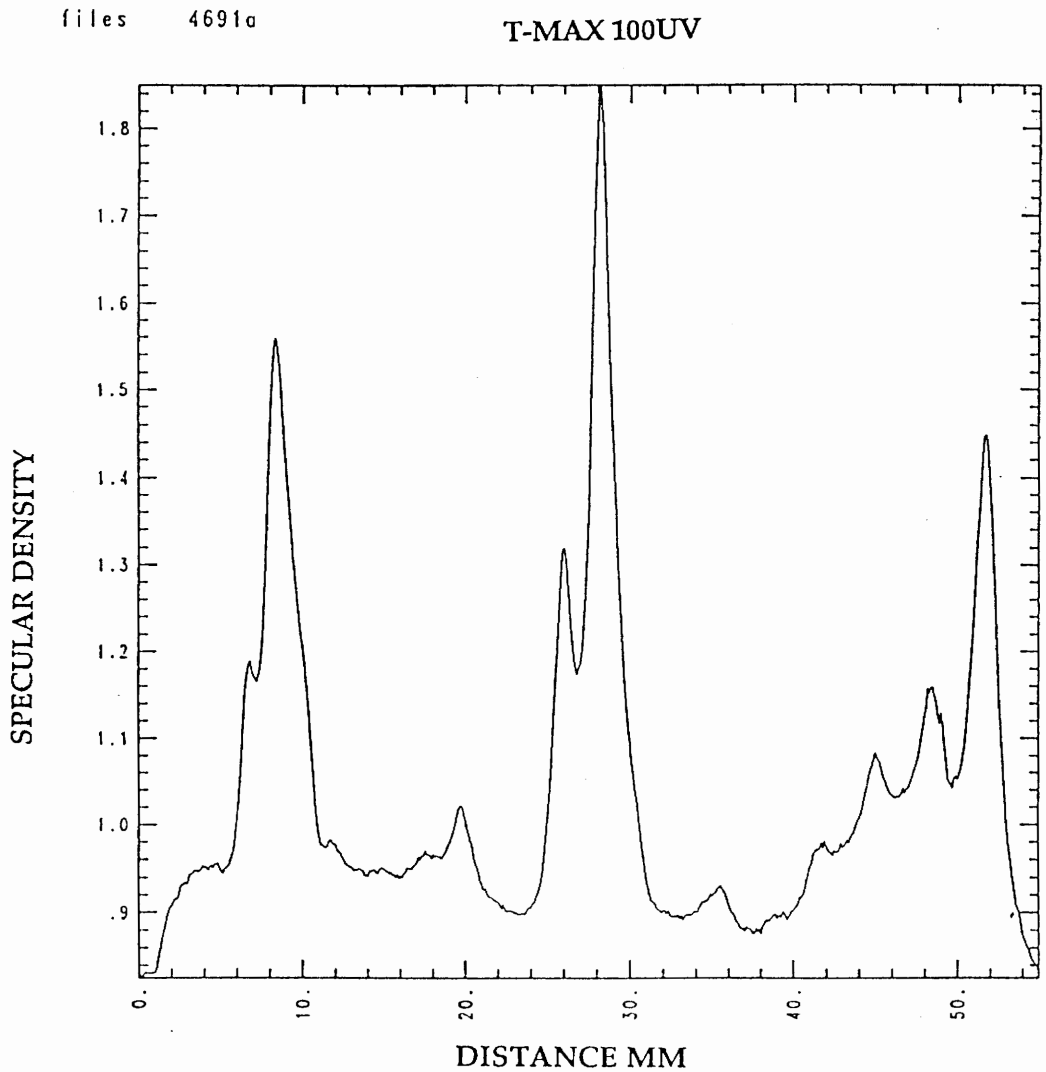

Figure 2a
Microdensitometer record of Bragg reflected emission of Cu(L) line.
(90 minute exposure)

files 4694a

T-MAX 100UV

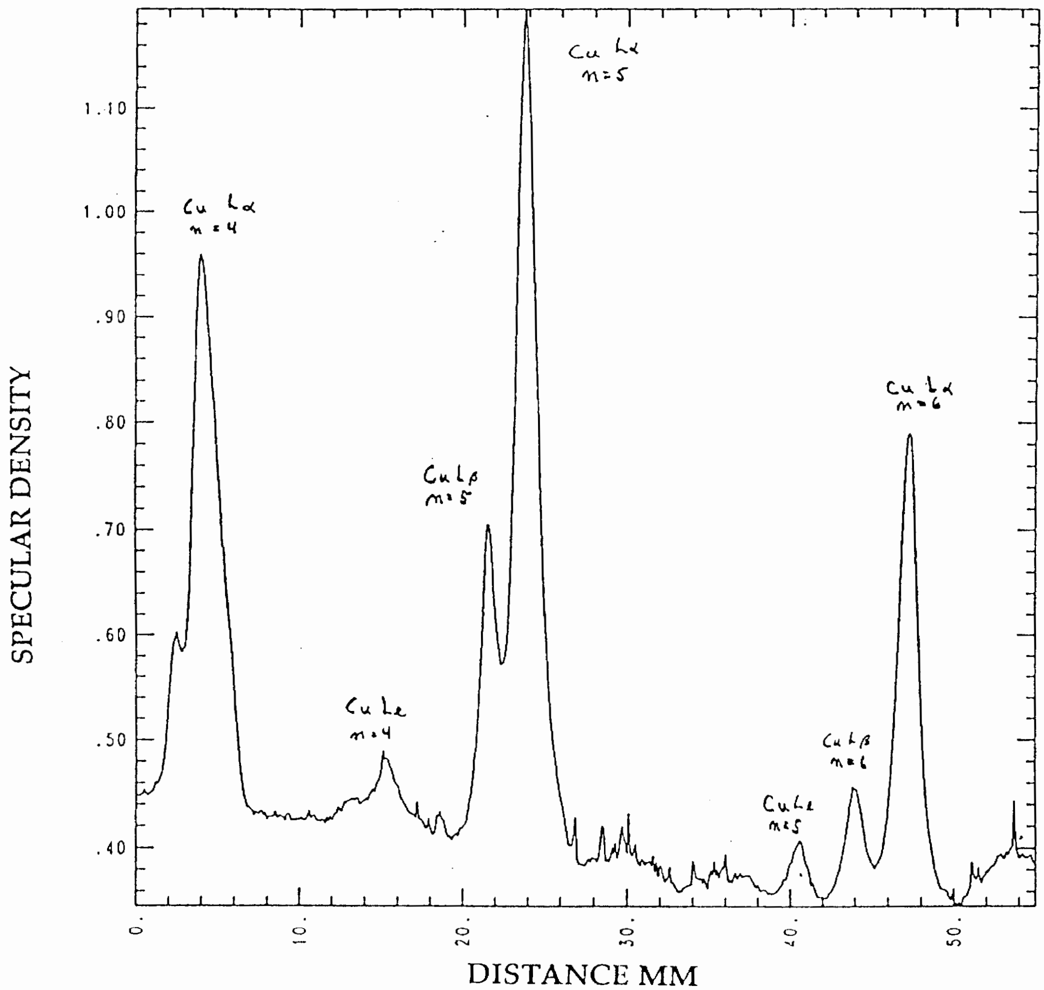

Figure 2b
Microdensitometer record of Bragg reflected emission of Cu(L) line. (15 minute exposure)

foreground: al0123p background: al0123pfit

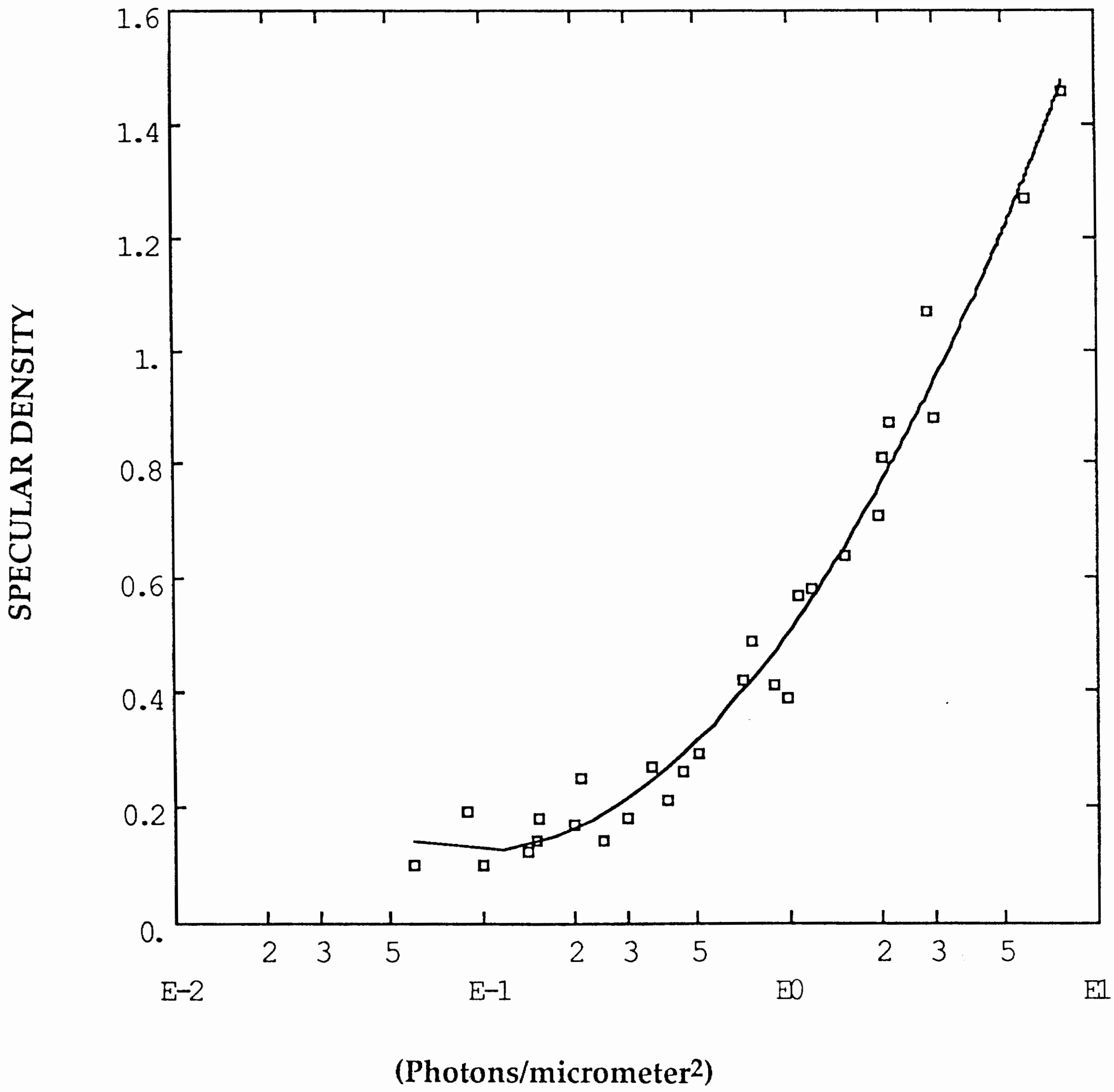

Figure 3
Aℓ (Kα); 1487 eV

foreground: mg0209a background: mg0209afit

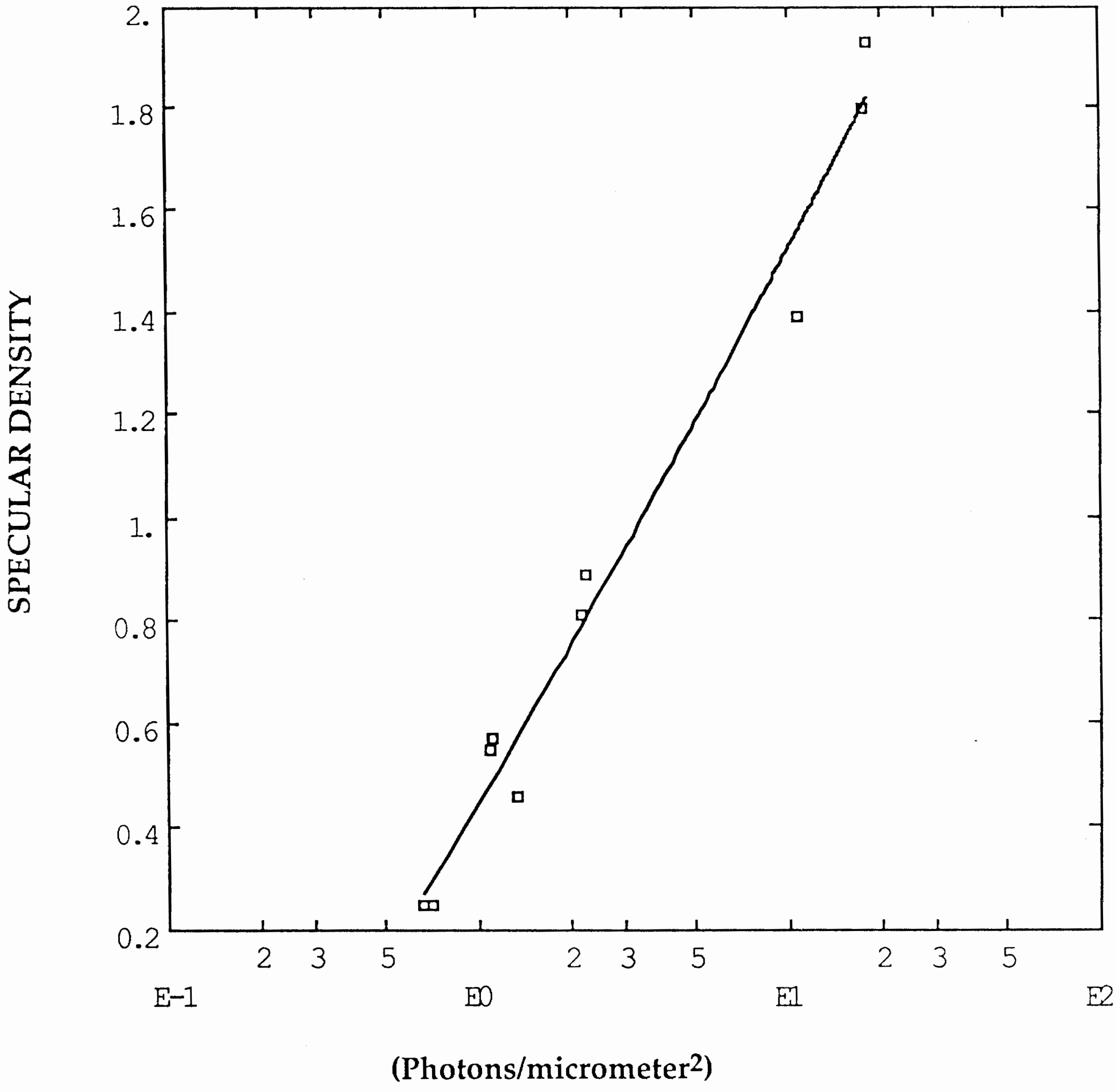

Figure 4
Mg (Kα); 1254 eV

foreground: cu0406b background: cu0406fit

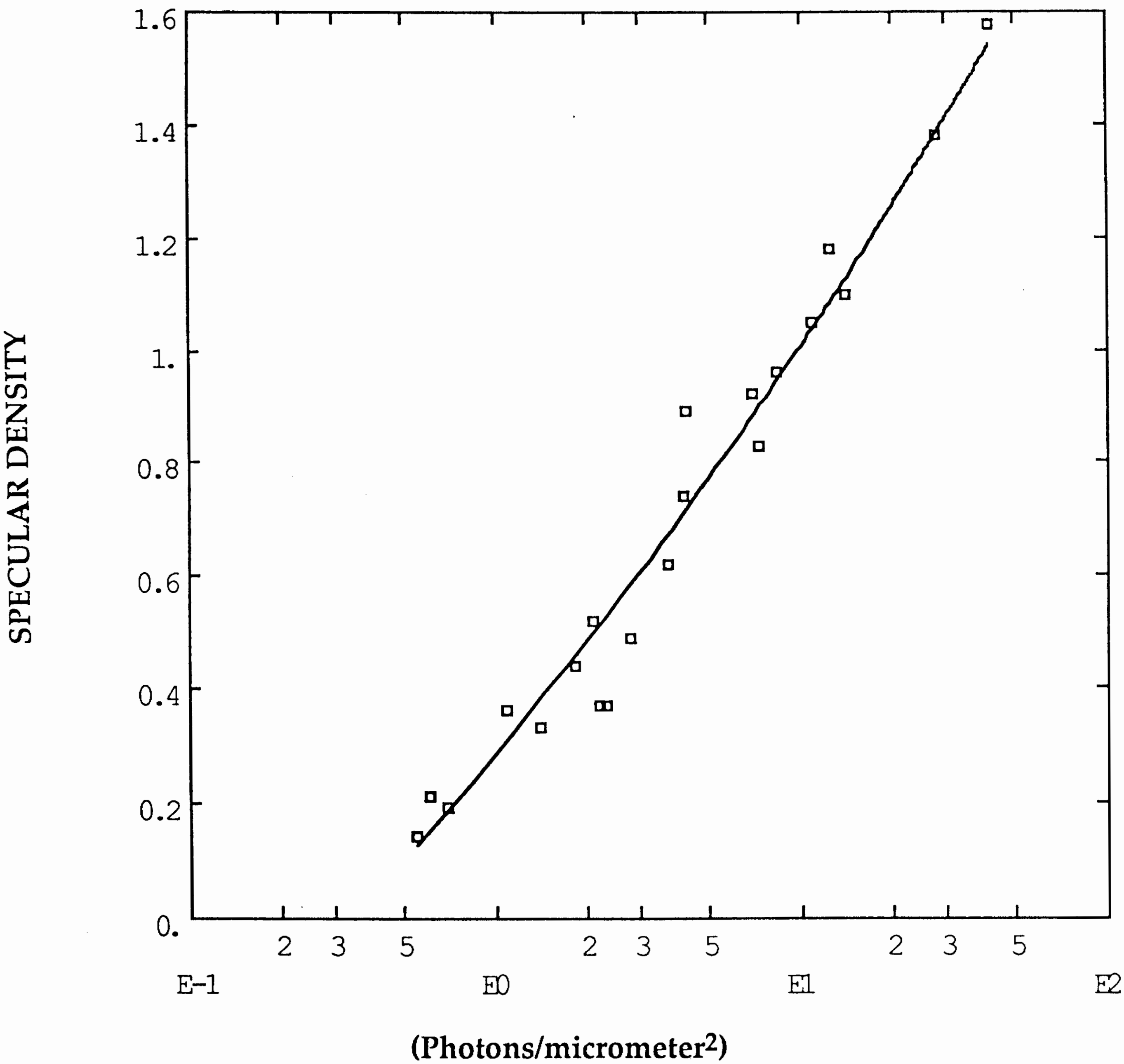

Figure 5
Cu (L); 930 eV

foreground: fe0523a background: fe0523afit

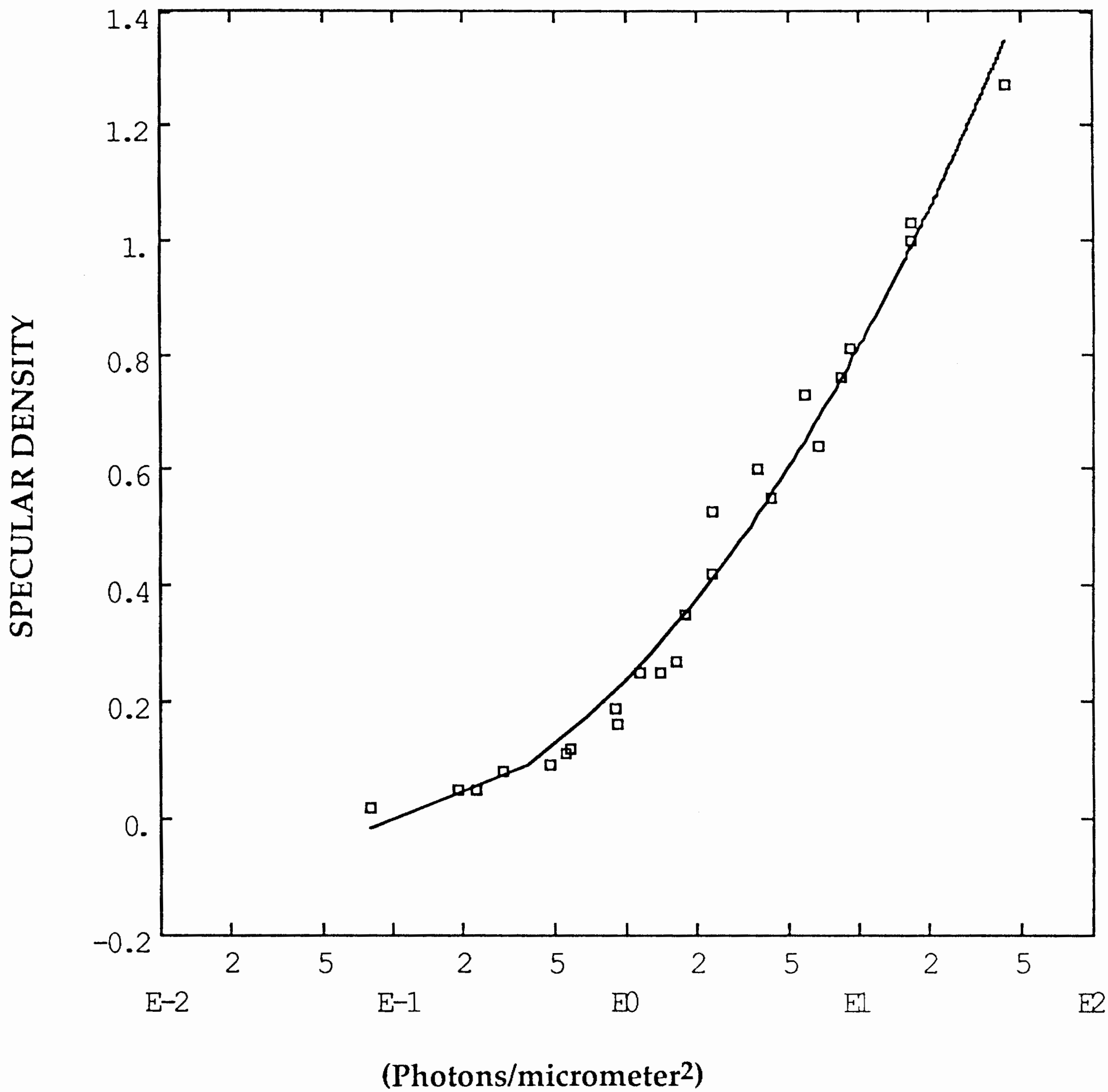

Figure 6
Fe (L); 705 eV

foreground: oo0509b　　　　　　background: oo0509bfit

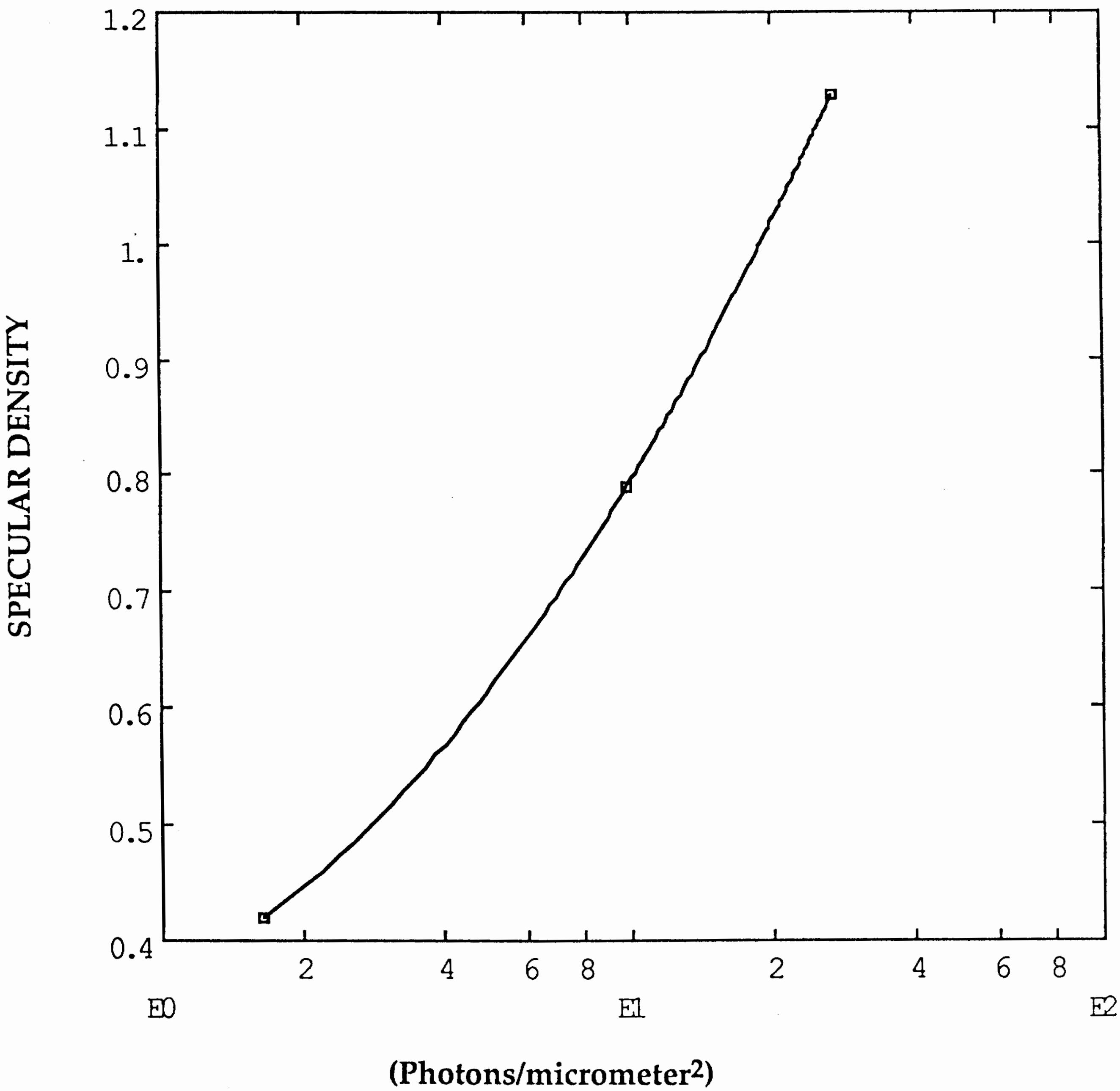

Figure 7
O (Kα); 525 eV

foreground: cc0504a background: cc0504afit

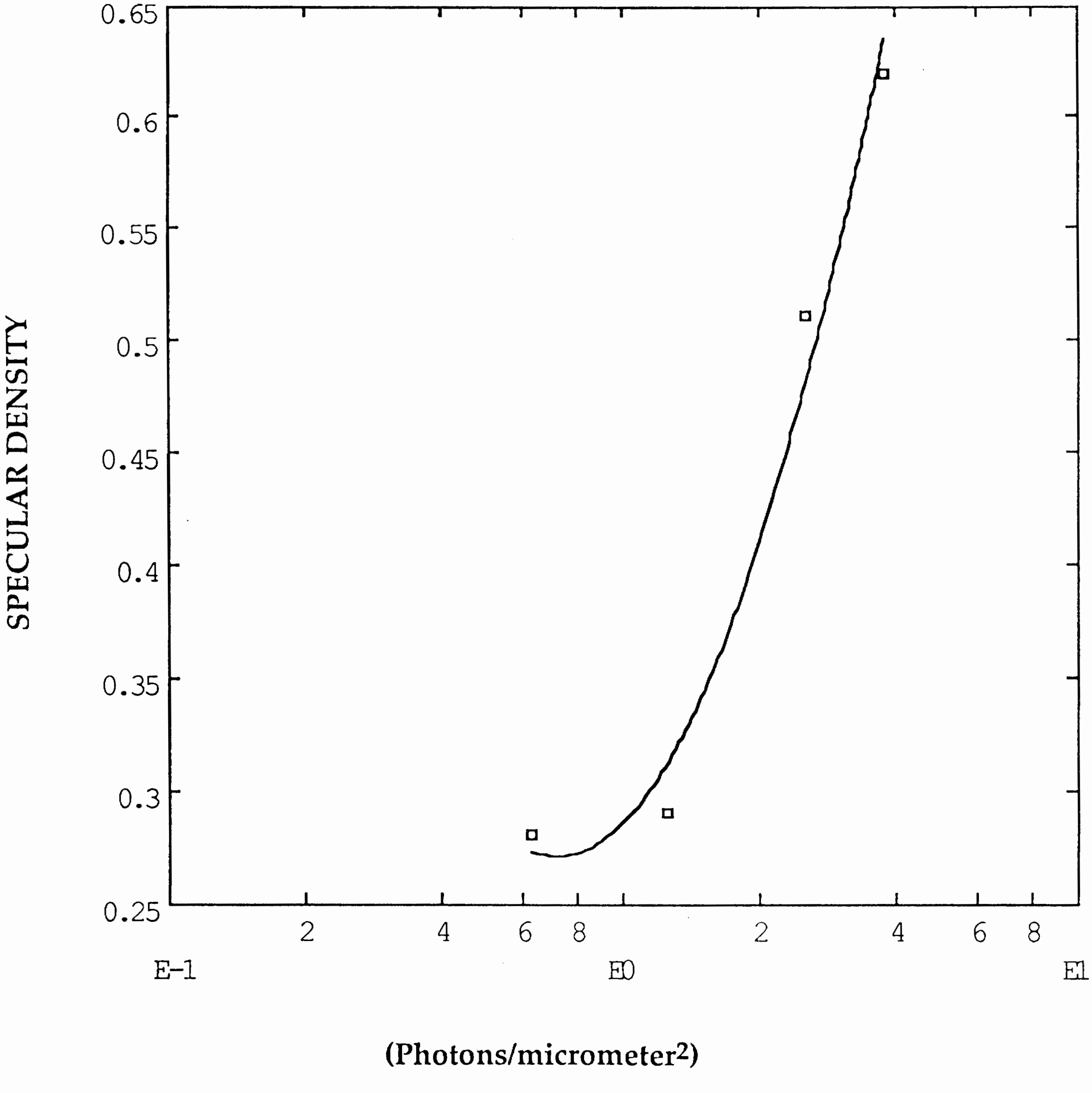

Figure 8
C (Kα); 277 eV

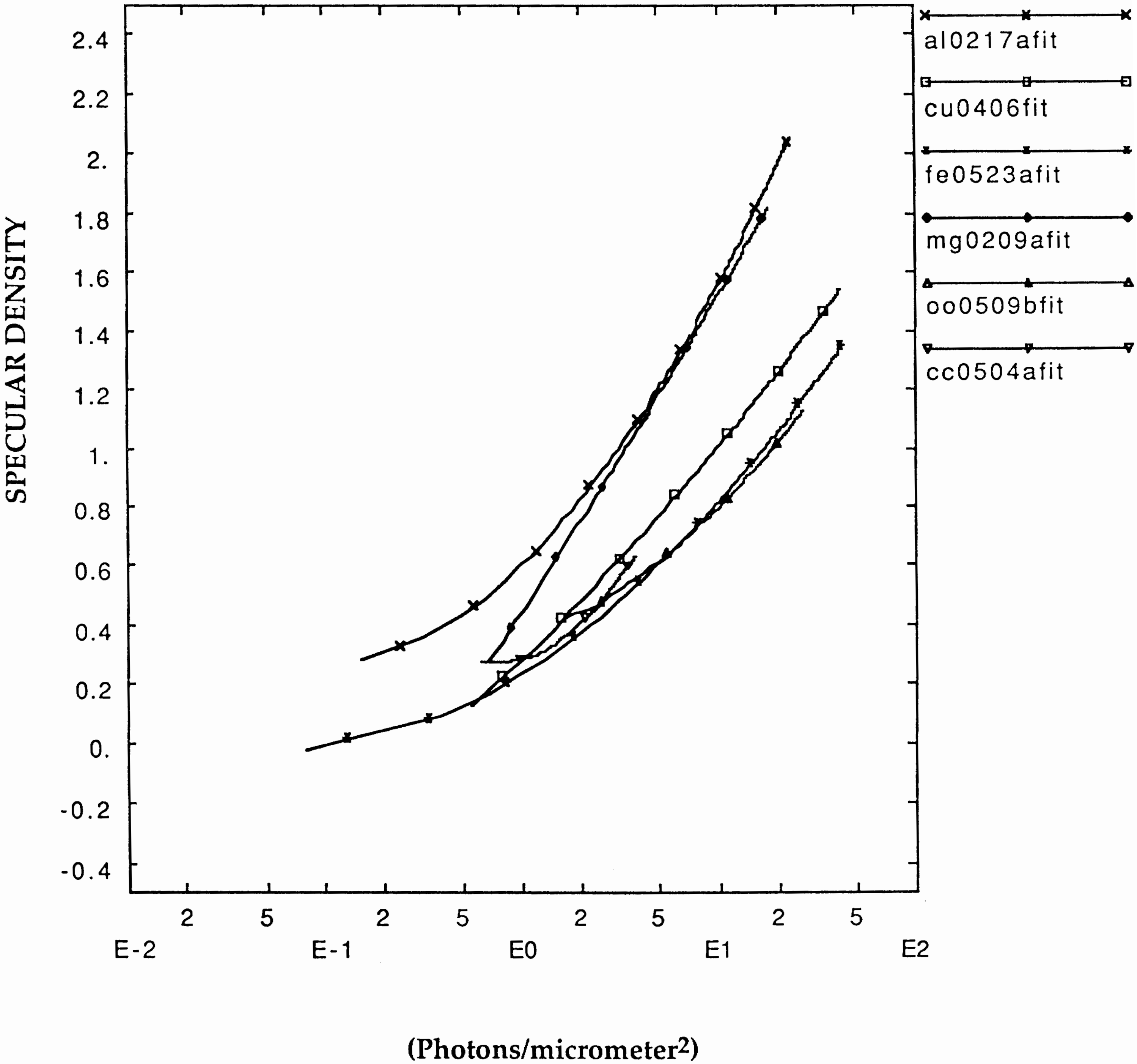

Figure 9
Polynomial fits to measured data

foreground: al101-07 background: al0123pfit

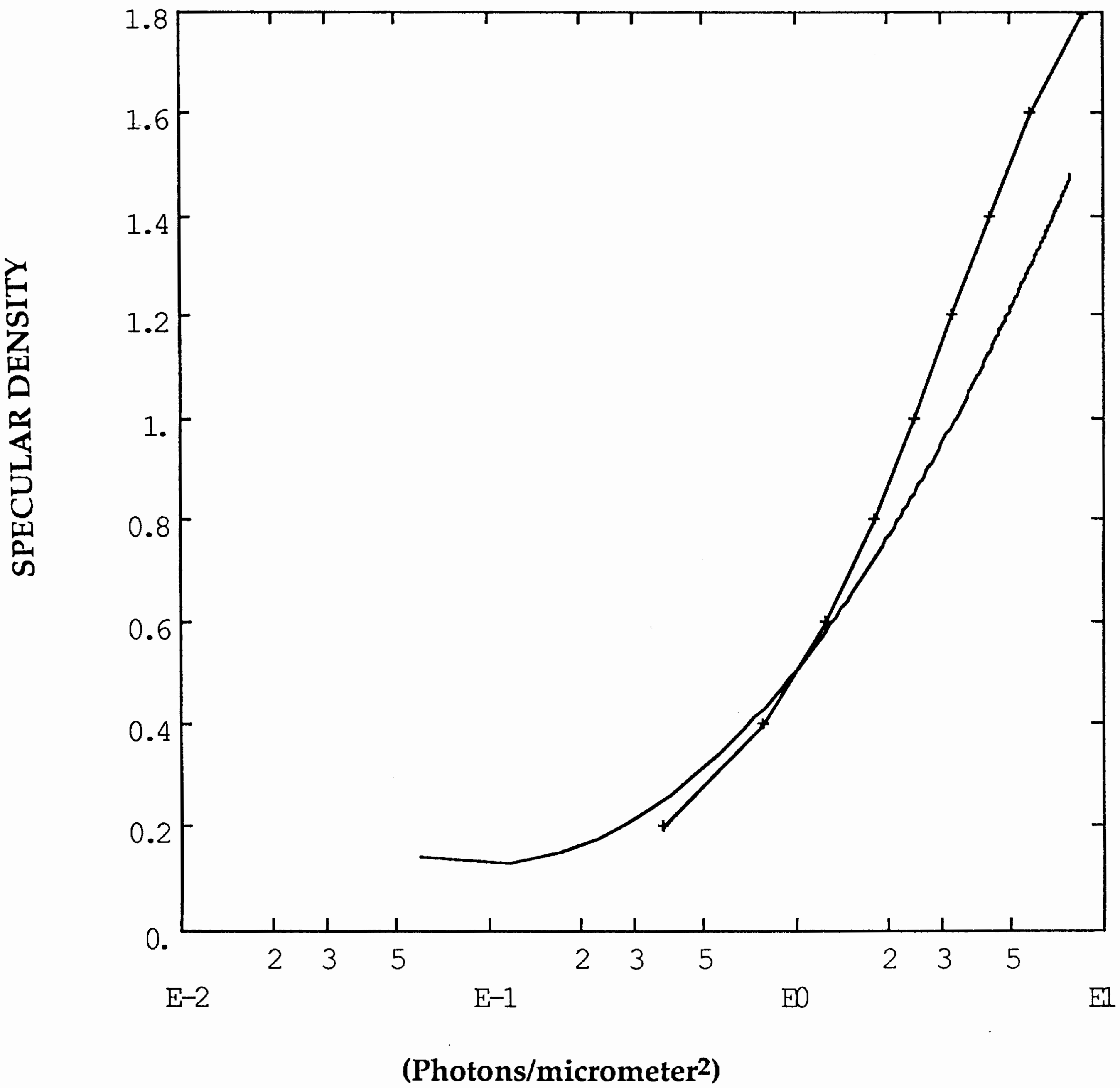

Figure 10
101-07 (+) compared to T max 100 at 1487 eV (Aℓ (Kα))

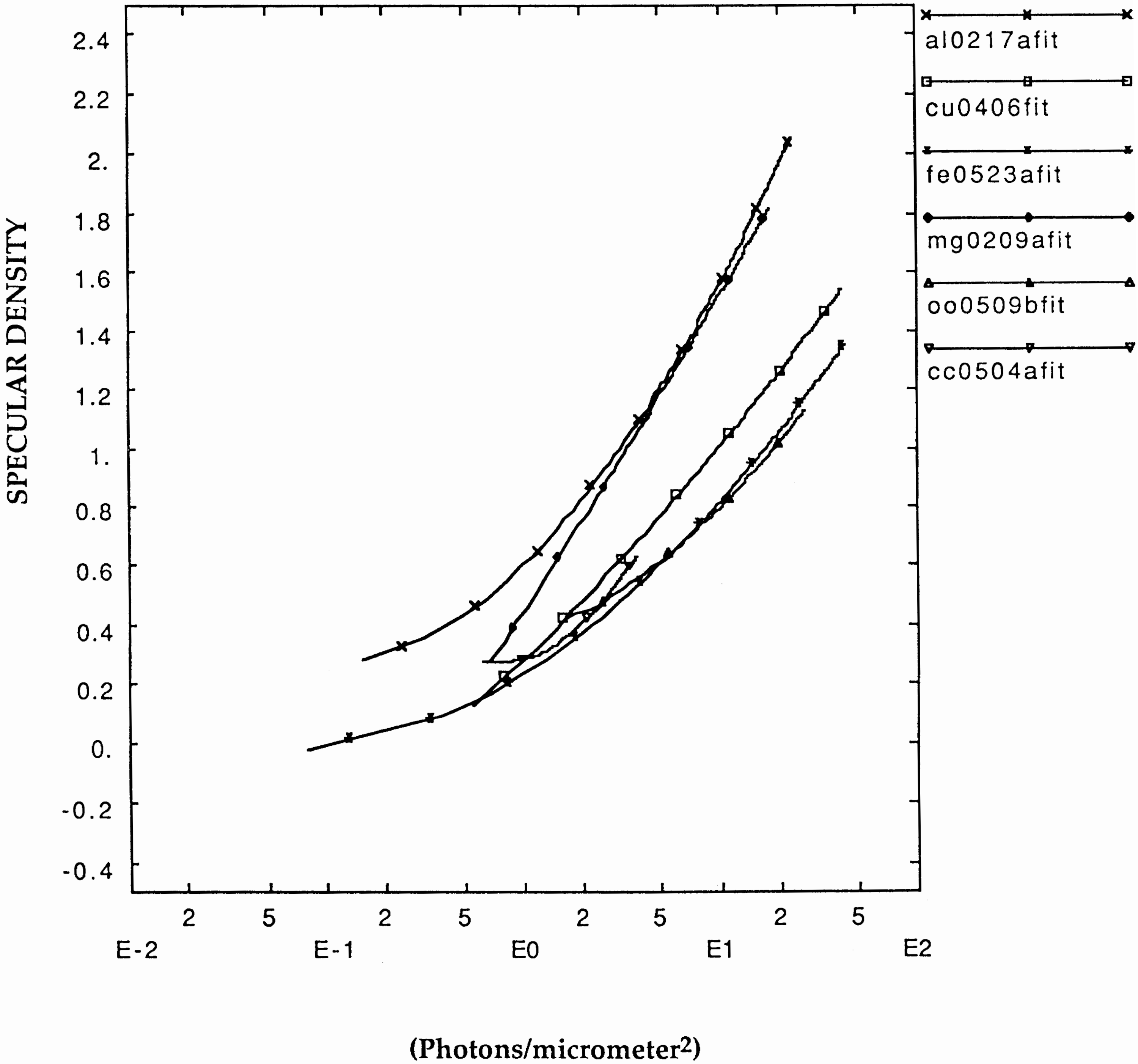

Figure 9
Polynomial fits to measured data

foreground: al101-07 background: al0123pfit

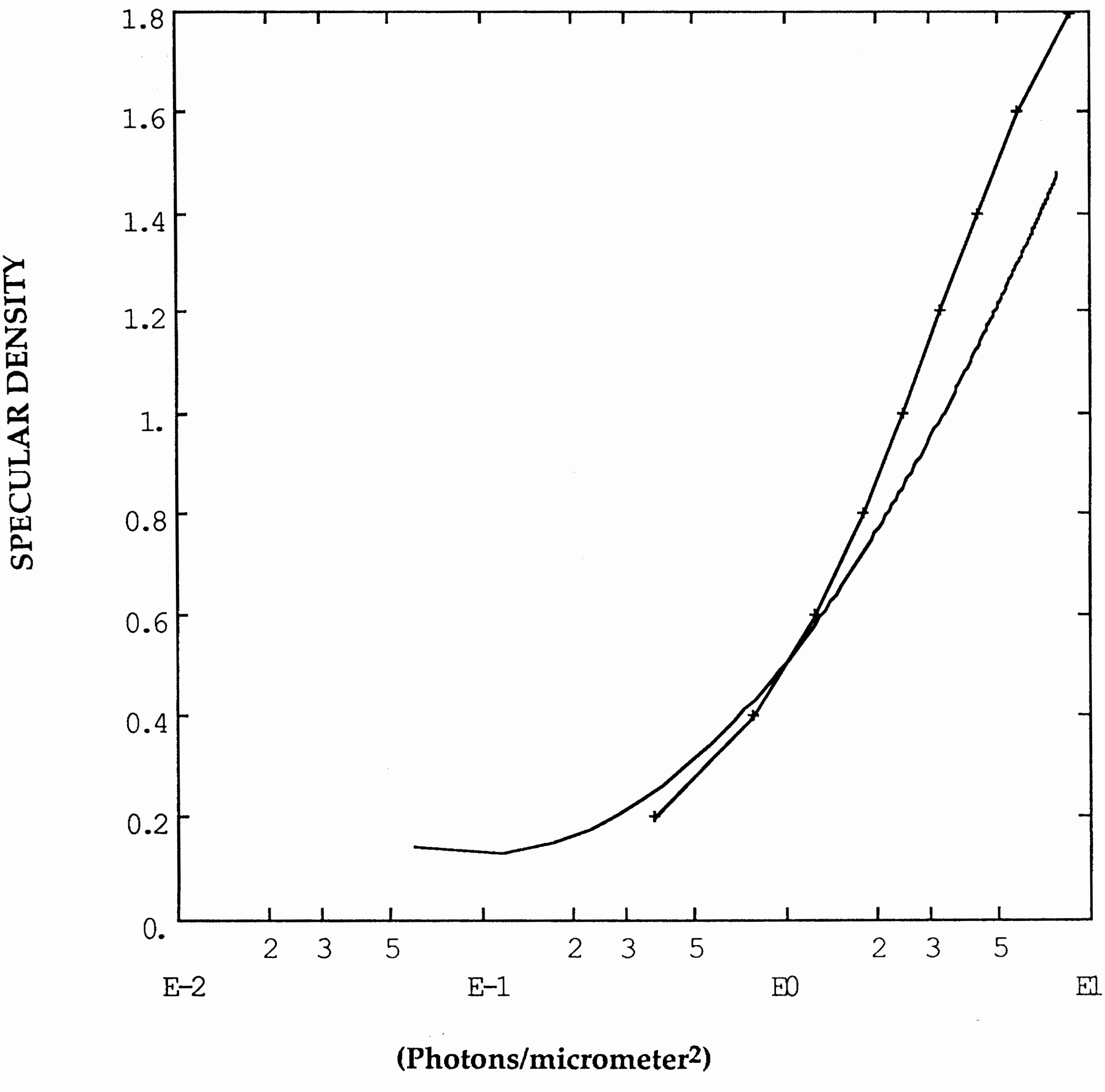

Figure 10
101-07 (+) compared to T max 100 at 1487 eV (Aℓ (Kα))